## Replies to Co-Editor

We thank the Co-Editor for his comments/suggestions which significantly improved the content of the manuscript. We have addressed all the comments and have incorporated all corrections in the revised manuscript.

### Major Comments

**1.** The analysis in the paper does not establish clearly that the increase in the dry day frequency (DDF) is due to aerosols which is the principal claim of the paper. The increase in DDF could also have resulted in increase in aerosols. Thus there could be a mutual dependence of these two factors.

**Reply:** In the previous version of the manuscript, we have done a sequential association analysis where we selected a set of years having almost normal meteorological conditions and rainfall accumulation between 16 – 30 July for Lucknow (an urban case study location). Accordingly, a set of 16 years were obtained which were uniformly divided into two non-overlapping clusters based on their AOD values (during the same period). After that the DDF values for the next 15 days (1 -15 August) were calculated and their cluster mean and variance were plotted with AOD values. The analysis revealed that years having higher AOD in second half of July also experience higher DDF in the first half of August which proves the impact of aerosols on DDF growth. However, the same analysis was not done for other regions in the study. Hence to clear the confusion of the reviewer, the same is also done for Region 1 and 1a along with Lucknow. The analysis has showed almost similar results with slightly higher overlapping conditions for region 1. On the other hand, as the DDF growth of region 3 could not be completely explained by aerosol growth, hence the corresponding cluster analysis in that region has also provided slightly higher overlap. But leaving these minor issues overall, it seems that aerosol growth by itself triggers the dry phase growth. A figure depicting the AOD-DDF relation is shown here (Figure R1) and these figures has also been placed now in the required portions of the revised manuscript as per suggestions from the reviewer.

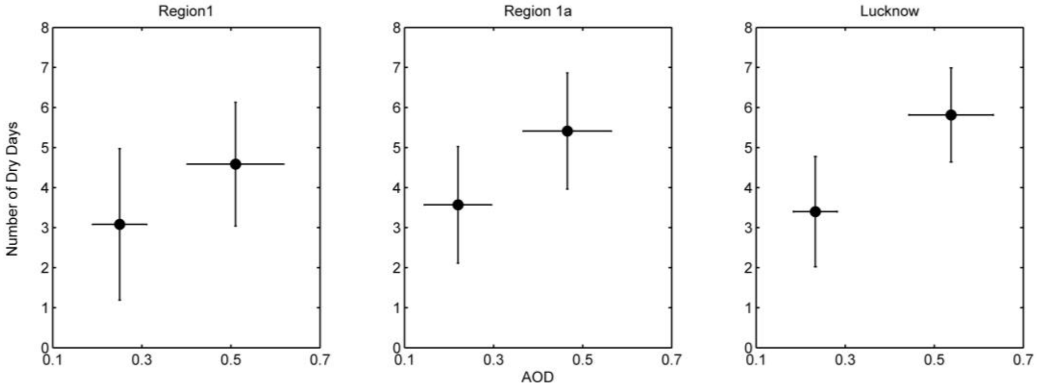


**Figure R1:** Sequential association between AOD cluster (16-30 July) and DDF (1- 15 August) for Region 1, 1a and Lucknow

We once again would like to thank the editor for providing potential suggestions throughout the paper. This review experience was indispensable in pushing us forward to improve our work.

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## Replies to Reviewer's Comments/Suggestions

First of all we wish to thank the reviewer for his comments/suggestions which significantly improved the content of the manuscript. We have addressed all the comments raised by the reviewer and incorporated in the revised manuscript.

**Major Comments**

**1.** The primary data on aerosol characteristics (aerosol optical depth (AOD) and contributions to AOD by black carbon (BC), organics, PM2.5 dust, sulphates, and sea salt) are taken from MERRA-2. Several papers published earlier have shown the overall usefulness of MERRA-2 AOD. However, accuracy of the contributions from the individual aerosol components at different geographical regions is not clear, though this product has been compared against observations at a few locations. In order to address this issue, in the present study, the monthly mean near-surface level BC concentration at Kolkata (a polluted region in the Indian subcontinent) has been compared with that of the BC contribution to AOD obtained from MERRA-2 at the same location (Fig.S2). (Here I assume that the contribution of BC to total AOD is the Y-axis of Fig.S2; it is not clear from the text or figure caption). How to validate the columnar contribution of BC to AOD by comparing with the surface values of BC concentration? The inference from Fig.S2 is that the two values are well correlated (which is also expected), but it does not validate the BC contribution to AOD or provide information on the absolute accuracies (bias, slope, uncertainty). Further, the monthly mean values of MERRA-2-derived BC themselves show scatter of +/-0.01 to +/-0.02 (about +/-33% of the mean BC AOD) for the same surface concentration of BC (Fig.S2). Hence, Fig.S2 does not provide information on the absolute accuracies or reliability of the individual aerosol species in MERRA-2. Also, as seen from Fig.S2, the variation of surface BC concentration (varying in the range of 4 to 25 microgram/m3) with columnar BC AOD is linear. What about the non-linear effects due to large variations in effective aerosol single scattering albedo and large changes in multiple scattering contributions for such wide range of BC concentration?

**Reply:** In Fig S2 of the manuscript, the BC component of AOD (shown in Y-axis) has been validated against the surface BC concentrations (in X-axis) over Kolkata. The validation has been progressed with AOD data and not surface concentrations as AOD datasets from MERRA2 have been more explicitly validated with various observational sources over different locations and time frames as pointed out in several previous studies like Randle et al. (2017). We are aware that AOD is calculated as a columnar integral and hence bears information to various phenomena (such as non-linear effects from large variations in effective aerosol single scattering albedo and changes in multiple scattering contributions) at different heights. This possibility is further supported from the deviation in data points from the linear fit line as shown in the figure. However, due to dearth of enough data volume, we cannot verify whether the relation between AOT and surface level concentration is strictly non-linear. We have also sought to access the possibility of using vertical profile-based aerosol extinction/ concentration data. But due to absence of balloon borne measurements or LIDAR observations, this cannot be done either. A dedicated attempt can be taken to examine the absolute accuracy of aerosols from MERRA2 against observational datasets wherever available over India, but it would be out of scope of this study.

On the other hand, we wanted to show the feasibility and not the absolute accuracy of the data which is also supported from the congruence between the frequency distributions of AOT and BC concentrations. Further, we have never talked about any absolute thresholds or values but rather have always talked about certain well separated groups of data after which we have tried to explain the physical mechanisms driving the association (and not direct relationship) between aerosols and mid-monsoon drying.

**2.** It may be noted that MERRA-2 assimilates AOD estimated from MODIS, AVHRR and MISR satellite data and insitu AOD observations from AERONET network. While MERRA-2 globally compares well with the AOD observations (especially over the marine regions), it cannot correct for the deficiencies existing in terms of the missing emissions (e.g., Buchard et al., 2017). More importantly, the satellite-derived AOD used in MERRA-2 was only from AVHRR till 1999, while the subsequent period has seen a major increase in the assimilated satellite data, including MODIS and MISR (see Fig.3 of Buchard et al., 2017). This will enhance the quality of MERRA-2 AOD data during the post-1999 period compared to the period before. The present study focuses on the period between 1980-2015 (Line no. 353). What is the bias or accuracies in MERRA-2 AOD during the periods before and after 1999? This is especially important when the AOD is apportioned into different chemical components.

**Reply:** We accept that satellite-derived AOD of MERRA2 was mainly obtained from AVHRR data till 1999 after which MODIS and MISR is being utilized with ground-based observations from AERONET which has enhanced the quality of MERRA-2 AOD data. In this context, we have found out from MERRA2 Technical Manual by Randle et al. (2017) that the global mean standard deviation between MERRA2 AOD and observations is as small as ±0.013 in case of total AOD and ±0.001 in case of BC and these indicate the feasibility of using the data. However, no such absolute uncertainness values before and after the year 1999 have been quoted in any of the previous attempts especially over the Indian region.

On the other hand, we observed from Randle et al. (2017) that though the magnitudes of AOD and its various components are quite different before and after 1999, yet a prominent overlapping is observed globally between June – October. Since, the present study is also focussed during the month of July-August, hence we have reanalysed the aerosol monthly mean AODs in two clusters of before and after year 1999 respectively. An in-depth statistical analysis of the cluster means show that in most of the cases the cluster mean difference is very small compared to the net variance in the data. Even in case of BC and OC the net rise in mean AOD after 1999 was hardly 60% of the total standard deviation (while it should have been at least >= 150% to be considered significant). This indicates that the mean AOD values remained almost similar over the entire time span of 40 years; thereby addressing the data quality related issues faced in the manuscript. A table showing the extent of overlapping between the aerosol datasets before and after the year 1999 is shown below (Table R2).

| | Region 1a | | | | | | | Lucknow | | | | | | | Region 3 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BC | Dust | OC | Sea Sa | Sulph | Tot Aer | | BC | Dust | OC | Sea Sa | Sulph | Tot Aer | | BC | Dust | OC | Sea Sa | Sulph | Tot Aer |
| | | | | | | | | | | | | | | | | | | | | |
| 1980-1997 Mean | 0.015 | 0.032 | 0.038 | 0.015 | 0.143 | 0.265 | | 0.018 | 0.036 | 0.040 | 0.016 | 0.148 | 0.286 | | 0.010 | 0.080 | 0.024 | 0.048 | 0.082 | 0.519 |
| 1998-2015 Mean | 0.023 | 0.036 | 0.051 | 0.018 | 0.203 | 0.372 | | 0.023 | 0.056 | 0.052 | 0.028 | 0.210 | 0.415 | | 0.015 | 0.139 | 0.035 | 0.053 | 0.124 | 0.625 |
| Total Mean | 0.019 | 0.034 | 0.045 | 0.017 | 0.173 | 0.319 | | 0.021 | 0.046 | 0.046 | 0.022 | 0.179 | 0.350 | | 0.013 | 0.110 | 0.029 | 0.051 | 0.103 | 0.572 |
| Difference | 0.008 | 0.004 | 0.013 | 0.003 | 0.060 | 0.107 | | 0.005 | 0.020 | 0.012 | 0.012 | 0.062 | 0.129 | | 0.005 | 0.059 | 0.011 | 0.005 | 0.042 | 0.106 |
| Total STD | 0.013 | 0.061 | 0.023 | 0.029 | 0.231 | 0.199 | | 0.007 | 0.049 | 0.018 | 0.019 | 0.120 | 0.231 | | 0.010 | 0.144 | 0.021 | 0.077 | 0.178 | 0.238 |
| Overlapping | 0.612 | 0.069 | 0.565 | 0.092 | 0.259 | 0.537 | | 0.684 | 0.417 | 0.634 | 0.625 | 0.517 | 0.558 | | 0.433 | 0.409 | 0.550 | 0.064 | 0.234 | 0.356 |

Table R2 The table and related text has been incorporated for the ease of understanding for readers in the supplementary section of the revised version of the manuscript.

**3.** Even if the reliability of the individual chemical compositions from MERRA-2 is acceptable and the comments-1 and 2 given above are ignored, the analysis carried out in the present analysis does not show that the observed increase in dry day frequency (DDF) is caused by aerosols. There is a clear association between the increase in DDF and AOD in several cases (and the individual contributions by some of the species). But this increase in AOD and individual chemical species can (and most probably) be due to increase in dryness, which increases the aerosol production as well as their residence time in the atmosphere, both of which contribute to increased accumulation of aerosols in the atmosphere.

**Reply:** We have already investigated the sequential association between the atmospheric residence of aerosols and development of dry phases over a case study location Lucknow in the previous version of the manuscript. However, to clarify the doubt raised by the reviewer, now this analysis has also been progressed over all the regions mentioned in this study. In this analysis, the first step is to screen out all years during 1980-2015 which depict abnormal meteorological variations. In the next step, a set of years having comparatively lower rainfall accumulation during 16-31 July are identified and the average AOD values of those years produced two very well separated clusters. To study the effect of these two AOD clusters on rainfall, their corresponding DDF values are examined for the next 15 days (1-15 August) over Region 1, 1a and Lucknow. The analysis shows almost similar clustering in DDF with respect to aerosols but the effect of AOD is seen to become more diffused as one shifts from a small urban region Lucknow (having more localised anthropogenic dominance) to Region 1 (having lower urbanization density), which is also well reflected from slightly higher DDF values over Lucknow. After this, the same study is also repeated over Region 3, but in this case the AOD values are observed during 16-30 June while DDF values are taken from 1-15 July. The results from this analysis indicate that the DDF values are much higher over this region due to prevalence of arid climate and not primarily due to aerosols which is also understood from the widespread overlapping between the two clusters. These explanations have been provided in the revised portion of the manuscript.

**4.** For argument, let us assume that the increase in DDF is due to aerosols, as they can cause changes in clouds, radiation balance of the Earth's surface and atmosphere as well as make atmospheric thermodynamical changes. In Region-1, during the long dry phase (LDP), about 67% of AOD is contributed by sulphates, while the organics, BC, dust and sea salt contribute ~14%, ~6%, ~8% and 5% respectively (this is a rough calculation made from the median values shown in Fig.3). On the contrary, during the short dry phase (SDP), the AOD contribution by sulphates reduces to ~53%, while the organics, BC, dust and sea salt contribute ~21%, ~7%, ~12% and 7% respectively. Overall, the BC contribution remains ~6-7% of the AOD. How does this compare with the aerosol chemical measurements carried out over this region, reported in the literature? The sulphate AOD increased by ~0.15 between the SDP and LDP in Region-1. How such major contribution of sulphates prevails and can contribute to long dry phases? How such a small fraction and weak increase (in terms of magnitude) of BC (with BC AOD of 0.014-0.025) can cause the atmospheric heating or radiation budget changes required for LDP (spanning for 2-3 weeks)? Note that such values of BC (often more, typically 10% by BC mass fraction) prevail over most of the Indian landmass (including southwest India).

**Reply:** In accordance with the reviewer's comment we would like to clarify the following points. First, due to the absence of suitable aerosol particle size distributions measurements and also due to the poor spatial resolution of CALIPSO aerosol profiles, there have been very sparse research attempts which validated the relative contribution of BC to total aerosols especially over the current location. Secondly, it is very difficult to comment on the impact of sulphate aerosols on DDF separately due to inadequate number of previous attempts in this field. Thirdly, an detailed quantitative investigation to understand the specific impact of BC or any other aerosol particles in causing radiative budget changes requires the use of exhaustive in-situ database and strenuous numerical modelling which is not available in this study. Another very important point is that the reviewer has calculated the relative contribution of aerosol components based on the median values and they have made certain % based assumptions. We would humbly like to remind the reviewer that the individual distributions of these aerosol AOTs are not squewed perfectly and they have quite large interquartile ranges and, these component datasets are mutually independent of each other. Hence, it may be possible that yeas having high BC may have either high or low OC or sulphates. In this case the median alone gives a completely biased idea about the % contribution of these aerosols' components over total AOD during the SDP/MDP/LDP period. This is the main reason we have utilized the boxplots rather than showing the mean values with error bars in most of the analysis. A rough idea about the contribution of components can only be authenticated after using intensive observation datasets which is not available in the current scope.

However, in this pretext confusion remains regarding how such small changes in BC have a dominant influence on DDF while Sulphates have relatively no effect on it. As already mentioned before, we do not have real-time observation data or sufficient literature to support this fact theoretically. But, to have a double check on this fact statistically, we have only taken the last 20 years data (as aerosol datasets after 1999 are considered more reliable than the first half) and we have redone the analysis. We have taken all the components of AOD and separated it into two equal clusters of SDP' and LDP'.

Next we have done the boxplot analysis of the AOD values for all the study regions Region 1a, Lucknow and Region 3. Like the previous figure, here also BC and OC has shown clearly increased values in LDP' clusters with very less overlapping. But in the case of Sulphates, despite having larger magnitudes of AOD and showing an increase in mean and median AOD values, it shows a huge overlapping which makes the significance of the cluster separation negligible. Here it may be noted that such overlapping was not observed previously due to presence of MDP which the reviewer may have overlooked in the analysis. To prove that the net increase in Sulphate AOD is negligible with respect to BC, the cluster means of SDP' and LDP' are calculated and the net increase is obtained from their difference. Next the total deviation in the values is calculated and the ratio between the cluster mean increment and the standard deviation (std) are examined. In case of BC the actual growth in cluster mean is ~ 1.45 times of the std while in sulphate it is ~0.5. This implies that though sulphate values show much higher absolute change in LDP but its affect is completely overpowered by the variance or uncertainness in the cluster; but on the other hand, the increase in AOT of BC component is seen with marginal overlapping. This to an extent explains how the sulphate AOD median value increase cannot influence DDF as strong as in the case of BC. A figure depicting the frequency distribution analysis of all aerosol components during the modified SDP' and LDP' classes is shown for reference (Figure R3). This figure will not be added in the revised manuscript to remove additional confusion but a pertinent table in support of this will be provided with some discussion in the appendix section of the manuscript.

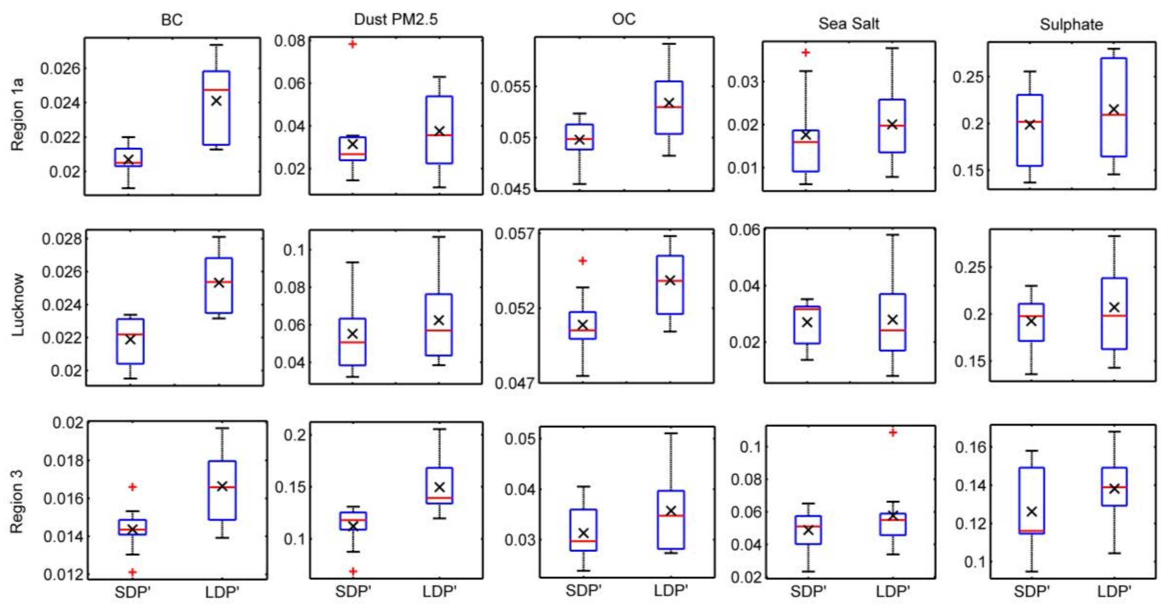


**Figure R3:** Frequency distribution of all aerosol components (BC, Dust PM 2.5, OC, Sea salt and Sulphate) for modified SDP' and LDP' classes in Region 1a, Lucknow and Region 3

**5.** Similar scenario prevails over Lucknow (Fig.4). The BC AOD fraction is ~6-7% for SDP and LDP. The increase in BC from SDP to LDP is only ~0.007 (here comes the accuracy of MERRA-2; is this outside the uncertainty limit?), while the AOD increase is ~0.11, of which the contribution of BC is only ~6-7%. Unlike in Region-1a, Lucknow (which is a city located in Region-1a) does not show an appreciable increase in sulphate AOD. Why is this feature distinctly different, when the aerosol residence time can be 3-7 days (during dry phases it can be even more). Observations reported in the literature suggest that the day-to-day variability or variations within a few days in AOD over most of the Indian region can be significantly more than ~0.1. Further, AODs in the range of 0.3 to 0.8 often prevails over Region-1 and at several other regions in the Indian subcontinent. The median value of AOD prevailing over Lucknow during SDP is ~0.27, which is rather clean. The important question is, can such a relatively small AOD or such small variations (reported here) in AOD or BC AOD cause short or long dry phases? If so, what are the thermodynamical changes or radiative impact produced by such variations? This is not studied in the present work. On the contrary, it is very much possible that dry spells can cause accumulation of aerosols to produce the observed variations.

**Reply:** We would like to bring forward certain important observations. First, the Technical manual of Merra2 by Randle et al. (2017) depicts that the net standard deviation of aerosol components from Merra2 with respect to observation data globally ranges from 0.001 in case of BC to 0.013 in Total AOD. Thus, the issue about small change in BC AOT of 0.007 seems to be addressed. Secondly, here we have talked about a phenomenon of 15 days and 30 days scale, with respect to number of dry days over regions; hence it is important to see the total variability in aerosols rather than the day to day availability. And this mechanism has also been supported in all regions by the sequential effect of aerosols on DDF (with an aerosol residence time of 15 days) as already discussed in previous replies to comments. Third, the reviewer has expressed a concern that if the AOD values are less over SDP then it should not bear any signature towards DDF. We accept this comment, but we want to clarify that the SDP cluster is only shown to draw a contrast with LDP and certain MDP cases where atmospheric aerosols can have some impact on DDF (note that AOD values during LDP are almost double of SDP). Fourth, we have already supported our claim statistically in the previous reply where we showed that BC values exhibit a distinct change with lesser overlapping while the uncertainties in cluster formation in case of sulphates clearly indicate that they do not have any deterministic effect on DDF. Finally, we agree that we have not considered the thermodynamic or circulation-based aspect in previous versions of the manuscript, but now we have added them also in DDF sensitivity analysis which is described in detail in later replies.

**6.** Long-term trends in cloud occurrences shown here are very interesting. However, most of the aerosols being limited to the lower atmosphere, the increase in AOD (which is proposed to have produced the dry spells) should have first affected the low level clouds. In contrast, Fig.5 does not show any increase in low level clouds in Region-1 or 1a, but produced significant increase in high level and total clouds. However, the low level clouds did show a weak increase over Lucknow. Why only at Lucknow? Overall, the increase in middle, high and total clouds is much larger than that in the low level clouds. How does this happen? Is it possible that the increase in high level clouds and consequent increase in greenhouse warming has also contributed to the dryness occurrence? (The variations between low level clouds and aerosols itself can be an interesting study).

**Reply:** Thanks for the comment and appreciation. We wanted to show the impact of aerosols on all types of cloud cover in the previous version of the manuscript. However it is a fact that aerosols are mainly limited to the lower atmosphere; hence the increase in AOD should have mainly affected the low-level clouds. Consequently, this time we have only considered the low cloud cover for analysis. Further, we do not have much idea about which the probable mechanism leading to this increase in high and total cloud cover over the mentioned regions; hence we have been removed in the revised manuscript. After readjusting the scales of low cloud cover data to obtain best fit for region 1, 1a and Lucknow, we have found an increase of cloudiness magnitude in almost all three cases. But then again, the growth in LCC is most prominent over Lucknow. The reason for this is the fact that Lucknow and its surrounding regions have higher anthropogenic emissions due to more urbanization background which has depicted a prominent impact on DDF growth compared to other regions of more spatial extent like region 1, 1a where the anthropogenic emission dominance on cloud processes is expected to be diffused due to many other factors. This hypothesis can be explained much better by looking at Figure 8 of the old manuscript.

A brief discussion of low cloud cover and deletion of unwanted text is now been done in the revised manuscript in accordance with the reviewer's comment.

**7.** In Region-3, AOD is quite high (median values ~0.55) and comparable for SDP, MDP and LDP. However, based on the average or median values, the total contribution from the individual species (BC, dust, OC, sea salt, sulphate) contributes only ~60% of the total AOD. What are the other components that contribute ~40%? The increase in BC AOD (median) between SDP and LDP is ~0.004 while that of dust AOD is ~0.04. In contrast, sulphate (and OC by a negligible magnitude) has decreased by ~0.03 between SDP and LDP. Why is this contrasting behaviour and how does it compare with the Region-1 (though the precipitation mechanisms at these two places are different, why the role of aerosols is contrasting?).

**Reply:** In general, all the five aerosol components given by Merra2 (BC, Dust PM 2.5, OC, Sea Salt and Sulphates) account for >90% of total AOD in average over Region 1a. But in case of region 3 these parameters account for only ~77% on an average. This large deficit is only prevalent over Region 3 (experiencing arid climate) due to the omission of dust AOT (not Dust PM 2.5). These particles were already represented by the Dust PM 2.5 values in the manuscript hence were obliterated to remove further confusion. However, after incorporation of Dust component, the sum of all AODs now account for more than 95% of the total AOT (not shown here as it is out of the present scope).

Though OC does not show much of this decreasing nature, but the median values of Sulphates have really shown a decrease in the frequency distribution plot over Region 3 only. This has come as an exception to the entire analysis and we do not have any pertinent explanation for it. Moreover, this exception does not affect the main contention of the study, hence may be neglected.

**8.** I presume that the data on aerosol characteristics presented in Figs. 3, 4 and 6 are for the respective days of different dry phases (SDP, MDP and LDP). On the contrary, the analysis on AOD versus DDF shown in Fig.S7 (which is interesting) considers AOD during 16-31 July and DDF during 1-15 August. This may have a basis: aerosols may cause the atmospheric thermodynamical and circulation changes, which may result in dry spells subsequently. In that case, why the analysis shown in Figs.3,4, and 6 used simultaneous data for AOD and DDF?

**Reply:** We have shown the overall association between DDF and aerosol concentrations in a simultaneous time scale for region 1a, Lucknow and Region 3 in the main figures only to depict the relative dominance of anthropogenic aerosols over all other components. However to additionally explain the sequential impact of aerosols on DDF we have made the sequential AOD- DDF clustering analysis for all the regions in the study and we have now added these figures just below those main figure in revised manuscript to remove any confusion.

**9.** In summary, this study shows that there is an association between the increase in dry day frequency and AOD (including some of the individual species) in some regions. As stated earlier, the increase in AOD can be a result of increased dry day frequency as well. This paper does not provide any evidence to show that the increase in dry day frequency is caused by aerosols. Even if it is so, the important question remaining is whether the observed magnitude of increase in aerosols (and individual components) is sufficient to produce SDP, LDP, etc.

**Reply:** This has already been addressed by us using sequential analysis and also by analysing AOD contribution overlapping over all regions using better quality-controlled aerosol data after 1999.

**10.** On the contrary, the manuscript does not present the role of changes in atmospheric circulation pattern, atmospheric thermodynamics, radiation balance or surface temperature variations among SDP, MDP and LDP, all of which are expected to be important (all of which can be also produced by aerosols and other climate forcing mechanisms) in producing dryness and increase in its occurrence (Example, Raman and Rao (1981) on the relationship between blocking highs and droughts; Krishnamurti et al. 2010, etc).

**Reply:** As already mentioned before, an investigation of radiation balance over these regions cannot be done due to dearth of in situ aerosol profiles. But apart from it, as the reviewer suggested, now meteorological parameters such as surface temperature, thermodynamics such as instability parameters (namely vertical index) and circulation patterns such as 850 hPa geopotential height has been added into all the three analysis levels like Distribution analysis, PCA and multi-linear regression test. The analysis of these parameters is not done over Lucknow as it falls inside Region 1a. The investigation reveals that surface temperature and atmospheric instability exhibit an increase (~ 0.5 K) from SDP to LDP in Region 1a but it cannot be considered significant due to prominent overlapping among the clusters. However, this association becomes more diffused in Region 3 and thus it follows that these parameters do not have much impact on dry phases in various regions. A sample of the meteorological parameter variation for region 1 and 3 is shown with total AOT for reference. The same is also supported from the PCA and MLR analysis in Figure R4 thereby addressing the comment.

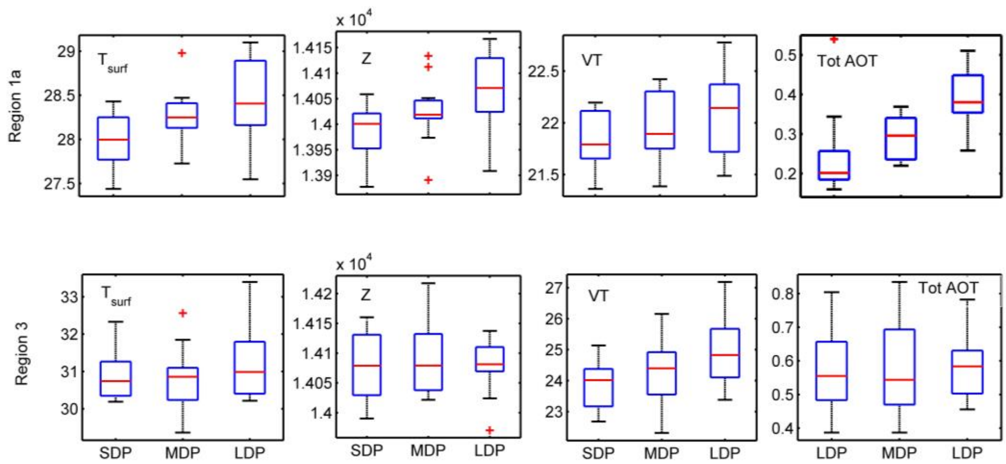


**Figure R4:** Yearly variation of Surface temperature, Geopotential height at 850 hPa, Vertical Totals Instability index with total AOT for various classes of dry phase length during August for region 1nd July for Region 3.

The updated figures, tables and text have been readjusted in the manuscript wherever needed.

**11.** Overall, the manuscript (text) is too lengthy for conveying the message presented in it. At the same time, some of the very important information are not provided: e.g., the individual species contributions (like BC, dust PM2.5, OC, etc) are the contributions to AOD, proper, incomplete Fig/Table captions (e.g., Fig.S1, S2,S4, S11 (even axes titles are missing), Table-S2, Table-S3, Tables 1,2 and 3). Readability of the manuscript has to be significantly improved.

**Reply:** In the previous review, one of the reviewers have particularly quoted that the manuscript length suits the ACP standards and that it is able to explain its statistical association properly. Species contribution of the aerosol components to AOD is also not done due to its random year to year variability of each component which is mutually independent of each other. The overlapping natures of the clusters have already been explained in replies to previous comments which explain why cluster analysis is used instead of absolute value-based thresholding in majority of this manuscript. Finally, we have done a double check to add axes title and figure description wherever applicable.

**Other comments**

**1.** Table-1: Why is the range of dry days for short dry phase (SDP) different for different regions? Same is the case with MDP and LDP.

**Reply:** It may be noted that Region 1 and 3 fall under two different climatic regimes. Region 3 experiences arid climate as a result of which the number of dry days is almost double of Region 1a and Lucknow in case of SDP and MDP. Keeping a fixed threshold of DDF would have created a biased picture, namely: Region 1 would have always shown SDP and MDP while Region 3 would have always shown LDP. To preserve the relevance of boxplots, the size of all three clusters were required to be kept almost equal, hence this uneven classification.

**2.** In Fig.2(a), correlation coefficients between DI and DDF are positive. Then, why there is a decreasing trend in Fig.S4 (R1, M9; R2, M9; R3, M9; R1, M8; R3, M7, etc)?

**Reply:** In this analysis, long dry period (LDP) conditions have more probability to create droughts with negative DI. Hence, DDF and DI are inversely proportional to each other. We forgot to mention that the absolute values of the correlation coefficients have been plotted in Figure 2. This has now been added in the relevant text of the revised manuscript.

**3.** Lines 245-250: What is the validity of this assumption when the region experiences intra seasonal oscillations and active and break spells?

**Reply:** This study investigates the formation of prolonged dry phases which can also be considered as a type of break spells in monsoon. Hence in these cases the rainfall would be marginal while PET would increase. On the other hand, the impact of prolonged wet spells or active phases in this study has been obliterated as we have taken only those years for sequential analysis where the total rainfall accumulation was between 25-50 percentile of the total rainfall climatology (to maintain uniformity in the hypothesis).

**4.** Fig.S4: DI has both positive and negative values even when the number of dry days in a month is 29-30 (e.g., R3, M6; R3, M8; R1,M6). What could be the mechanism?

**Reply:** It may be noted that the temporal extent of the study was limited to August (M8) for Region 1 and July (M7) for Region 3 for which such exceptions were not observed. However, Region 3 has shown a cluster of few years where DI was abnormally positive even in the presence of extremely high DDF. As already shown in the manuscript, these anomalies may be due to the dominance of natural aerosols (Dust) over anthropogenic aerosols (BC, OC) which could not be explained in the study. On the other hand, certain exceptions were also seen in Region 1, but number of such cases is relatively small. The physical mechanisms behind the occurrence of such anomalies cannot be approximated at present without a separate analysis which does not fit with the current scope of the study.

**5.** Lines 412-414: Regarding sulphate AOD - This is incorrect and against what is seen in Fig.3. It showed a distinct increase from 0.1 to 0.25 between SDP and LDP.

**Reply:** We accept that it is a mistake in explaining the figure. The sulphates were not taken in to analysis in spite of a prominent increase owing to the widespread overlapping between MDP and LDP. This correction has been done in the text of the revised manuscript.

**6.** Lines 450-452: "The distribution analysis on total aerosol AOT shows much larger values over Lucknow than in region 1a and also the variability of the median values with the quartiles and whiskers are also far more deterministic here …". This statement is incorrect as is evident in the AOD variations shown in Figs. 3 and 4. In fact, distinct increase in AOD (median and distribution) between SDP and LDP is better seen in Fig.3 (Region 1a).

**Reply:** We partly disagree with the reviewer. The median and upper quartile values are much higher in Lucknow than Region 1a. But as per as the distinctness of the distribution is concerned, Region 1a looks slightly better especially between MDP and LDP. This line has now been suitably modified in the revised manuscript.

**7.** Line-470: "hence the dependence of dry days can be primarily associated with urbanization". This statement is not supported by the facts at this stage. Or refer to Fig.8 here while making this statement.

**Reply:** This line has now been suitably modified by adding reference to Fig.8 in the revised manuscript.

**8.** Lines 503-504: "Figure 5 reveals that region 1 has a weak but discernible increase from 5 to 15 days in last 60 years". Is this correct? The mean trend line shows an increase from 9 to 13 days only. Similarly, the trend line for Lucknow shows an increase from 9 to 17 (and not 4 to 25 days as given in Line 511). The mean long-term trend over the 60 years and the scatter in the values (year to year variability) should be stated unambiguously.

**Reply:** The authors accept the suggestion of the reviewer. These changes have now been done so that the actual trend fit and not the observation points are presented to clear the confusion of the readers.

**9.** Line 529: "… reduction in cloud particle size …". This is not shown in the manuscript.

**Reply:** This line has now been suitably modified in the revised manuscript.

10. Lines 548-550: “Another periodicity is expected to lie at ~1-2 years which represents the year-year varying component of urbanization.” What is the year-to-year varying component of urbanization; how urbanization can have a periodicity of 1-2 years?

**Reply:** We accept that it is a typographic error presented in the manuscript. Actually, a primary peak (of 1-year periodicity) is observed in addition to the 4-year ENSO periodicity due to the presence of various anthropogenic elements such as BC and OC in the ACF analysis. These lines have now been rewritten to remove the confusion of the readers.

**11.** Unnecessary words may be avoided (words like ‘now’, ‘next’’, etc are used unnecessarily at several places; Also see usages like ‘methodically introduce’ (line-13), ‘crucial concern’ (line 28), ‘third and final’ (Line-171), ‘considerable conditions’ (line-225), ‘whether daily’ (line-257), ‘a set of various components’ (line 275), ‘over mentioned regions’(subtitle, Line 290), ‘all throughout in 1a’ (line -335), ‘which demand primary importance throughout the study’ (lines-339-340), ’ENSO oscillations’ (line 355), ‘previous attempts taken’ (line-357), ‘the distribution of total aerosols start increasing‘ (Lines 368-369), ‘rain cloud’ (Line 399; avoid ‘rain’ here, as the cloud burning effect due to aerosol absorption is possible for non-precipitating clouds as well), ‘an attempt has been progressed over Lucknow… ‘ (Line 477), ‘slant rise in dry days’ (Line 621), ‘rlilpl’(Line 675), ‘A series of investigations are progressed which infer …”(Lines 722-723). This is not a complete list.

**Reply:** All these issues and similar ones have now been addressed in the revised manuscript.

**12.** Missing reference: Tyalagadi et al. 2015.

**Reply:** This reference is now added in the revised manuscript.

**13.** Lines 329-331: What does this mean?

**Reply:** We primarily meant to say that the DDF trends are very weak (< 5%) in most of the 15-day time slots for Region 3. However, the month of July has shown a weak increase in DDF (~10%) which is probably due to alternating precipitation phases in June and August. On the other hand, the DDF trends are much stronger over Region 1. Hence this region will be examined with more emphasis throughout the majority of the study compared to region 3 which is being given secondary importance. These lines have now been simplified and inserted into the revised version of the manuscript.

**14.** Line 430: Modify as : “… 0.542, 0.129, … and 0.124 for BC, dust … and sulphates respectively”. Similar is the case in all places where MLR coefficients are given in this manuscript.

**Reply:** These changes have now been done in the revised manuscript.

We once again thank the reviewer for providing potential suggestions throughout the paper. This review experience was indispensable in pushing us forward to improve our work.

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