Review “Influence of covariance of aerosol and meteorology on co-located precipitating and non-precipitating clouds over INdo-Gangetic Plains” Gulistan et al.

We are very thankful to the anonymous referee for his/her expert opinion on our work which leads to the improvement of the manuscript. Below are the replies to the reviewer's comments, and indications of additions, modifications, or subtractions to the text under discussion. We report the reviewer's comments in italic red, our responses in italic black, and the text added to the manuscript in roman green.

General overview,

The article studies the aerosol-cloud-precipitation interaction at six stations in the Indo-Gangetic Plains. The authors use the synergy of satellite observations and reanalyses to collocate information on cloud, aerosol, precipitation, and meteorological properties in winter and summer. Their analysis is based on the distinction between precipitating and non-precipitating clouds. Several plots show differences between different stations, seasons, and cloud types with different conclusions, e.g. that the lower tropospheric stability is higher for non-precipitating clouds in winter and lower for precipitating clouds. Another interesting result is that the precipitation rate maximum does not occur for the same cloud type when the cloud droplet number concentration is high or low. The study is comprehensive and it is appreciated that the authors analyzed their data set in different ways.

- *Thank you very much for the positive comments and appreciation.*

Nevertheless, the current study lacks a lot of information on the methodology, uncertainties and I am particularly concerned about a part of the study where the authors retrieve an indirect effect parameter with dependent datasets, therefore it is difficult to give credit to some result as it is now. I have detailed my various concerns below.

From page 14 on, there are no more line numbers, which makes it difficult to refer to the questions I want to ask. From page 14 on, I will refer to the page number, not the line number.

Major revisions:

- *Methodology section: The satellite observations are associated with uncertainty, but it does not appear (except briefly mentioned on page 24). The results should be associated with the potential uncertainty. A detailed analysis of the propagation of uncertainty in the results should appear with a discussion of the implications.*

Reply: Thank you for your thoughtful and kind suggestion. We comply with the reviewer's suggestion and include a discussion about the uncertainty in satellite retrievals and its propagation in our results. Further, in this regard the following passage is inserted (pls see also our response to referee 1) as last passage in section 3.4.1:

Recent advances in remote sensing led to cost-effective solutions and an increase in available data at various temporal and spatial resolution to bridge scientific gaps among different disciplines. While satellite-based retrievals have many advantages over in-situ and ground-based measurement such as broader regional coverage and enhanced spatial resolution, they are still prone to considerable uncertainties owing to the indirect nature of remote-sensing, retrieval algorithms, thermal radiance, infrequency of satellite overpasses, and cloud top reflectance (Hong et al., 2006;Tian et al., 2010; Hossain et al., 2006). In our study, apart from the aforementioned factors contributing to the uncertainty, any residual cloud contamination could also lead to biased retrieval of AOD. Likewise, satellite-based retrievals for cloud properties are crucial to understanding the pivotal role of clouds in climate and the role of clouds is still a dominant source of uncertainty in prediction of climate change. These, uncertainties in AOD and retrievals of cloud properties also propagate through the modeling process, potentially leading to less accurate climate predictions. Likewise, these uncertainties appeared to influence the findings in the current investigation. For instance, a limited correlation between AOD and CER is observed over Lahore, particularly in cloudier regimes as depicted in Fig. (5-6). This contrasts with robust impacted documented in the earlier studies (Michibata et al., 2014). However, high sensitivity of SIE is observed for PCs particularly in winter season indicating the delay in onset of precipitation and more retention of clouds.

- *Related to uncertainty, there is no mention of the number of points used in the statistics. For example, Figure 6, there are a lot of regimes and I have some doubt that each regime has a large enough number of pixels to provide significant statistics. Figure 6 is an example,* *but I have the same concern for all the other results. This is mentioned on page 29, but I would like to see the numbers.*

Reply: Thank you for the good suggestions and your concern about the significance of our results. For the sake of large number of data points, we have analyzed daily averages for a period of 2 decades, data points less than 15 are not considered in further analysis.

Details of the data points for each regime are given below.

Table 1. Number of data points / observations for each CTP-COT joint histogram for both NPCs and PCs in both summer and winter over each area.

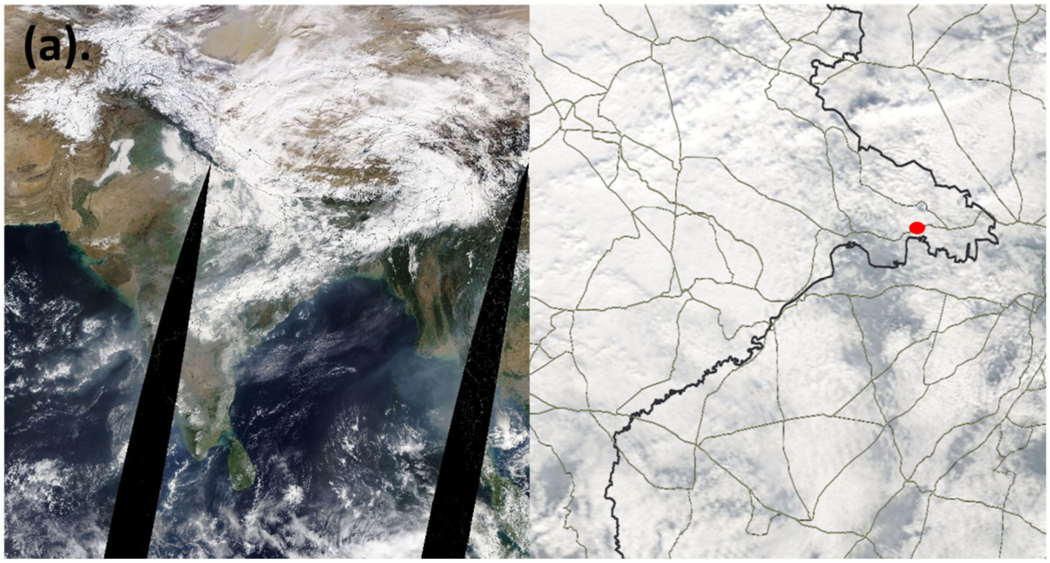
		Karachi Winter (NPCs)			*Lahore Winter (NPCs)*			*Delhi Winter (NPCs)*			*Kanpur Winter (NPCs)*			*Jaipur Winter (NPCs)*			*Gandhi College Winter (NPCs)*		
CTP (hPa)	*440 to <180*	*35*	*29*	*11*	*27*	*19*		*19*	*17*		*22*	*16*		*29*	*19*		*16*	*19*	
	680-440	*60*	*63*	*19*	*79*	*34*		*66*	*42*	*16*	*50*	*31*	*15*	*74*	*35*	*20*	*29*	*18*	
	<800 to 680	*570*	*107*	*18*	*293*	*183*	*21*	*357*	*258*	*22*	*438*	*228*	*20*	*376*	*173*	*48*	*380*	*92*	*17*
		Karachi Winter (PCs)			*Lahore Winter (PCs)*			*Delhi Winter (PCs)*			*Kanpur Winter (PCs)*			*Jaipur Winter (PCs)*			*Gandhi College Winter (PCs)*		
CTP (hPa)	*440 to <180*	*17*	*15*		*17*	*16*	*18*	*19*	*16*	*15*	*17*	*16*			*19*		*20*	*17*	
	680-440	*23*	*22*	*16*	*23*	*43*	*22*	*20*	*21*	*18*	*17*	*15*	*20*	*17*	*15*	*18*	*19*	*15*	*19*
	<800 to 680	*27*	*23*		*60*	*53*	*27*	*26*	*34*	*22*	*27*	*16*		*33*	*26*	*22*	*33*	*35*	*16*
		Karachi Summer (NPCs)			*Lahore Summer (NPCs)*			*Delhi Summer (NPCs)*			*Kanpur Summer (NPCs)*			*Jaipur Summer (NPCs)*			*Gandhi College Summer (NPCs)*		
CTP (hPa)	*440 to <180*	*52*	*76*		*38*	*99*	*19*	*43*	*69*	*15*	*43*	*43*	*15*	*81*	*122*	*20*	*44*	*49*	*16*
	680-440	*29*	*133*		*55*	*136*	*21*	*54*	*80*	*18*	*52*	*51*	*18*	*38*	*90*	*15*	*24*	*40*	*20*
	>800 to 680	*162*	*400*		*155*	*164*		*110*	*66*	*41*	*91*	*64*	*27*	*27*	*82*	*17*	*44*	*34*	
		Karachi Summer (PCs)			*Lahore Summer (PCs)*			*Delhi Summer (PCs)*			*Kanpur Summer (PCs)*			*Jaipur Summer (PCs)*			*Gandhi College Summer (PCs)*		
CTP (hPa)	*440 to <180*	*24*	*19*		*26*	*63*	*16*	*24*	*68*	*21*	*18*	*50*	*16*	*16*	*25*	*15*	*35*	*76*	*20*
	680-440		*21*		*31*	*88*	*20*	*39*	*71*	*34*	*17*	*54*	*22*	*19*	*24*	*20*	*23*	*47*	*17*
	<800 to 680	*31*	*33*		*62*	*86*		*42*	*45*		*26*	*23*		*15*	*22*	*16*	*29*	*40*	
		0-3.6	*3.6-23*	*23 to >60*	*0-3.6*	*3.6-23*	*23 to >60*	*0-3.6*	*3.6-23*	*23 to >60*	*0-3.6*	*3.6-23*	*23 to >60*	*0-3.6*	*3.6-23*	*23 to >60*	*0-3.6*	*3.6-23*	*23 to >60*
		COT			*COT*			*COT*			*COT*			*COT*			*COT*		

- *Methodology: There is no discussion of the collocation of the various products. How are CER and AOD collocated? MODIS does not retrieve AOD when a cloud is detected, did the authors look at the nearest pixel? If so, did they consider the potential 3D effect of clouds? How are MODIS and TRMM data collocated? Same questions with reanalysis (temporal and spatial resolution are not the same).*

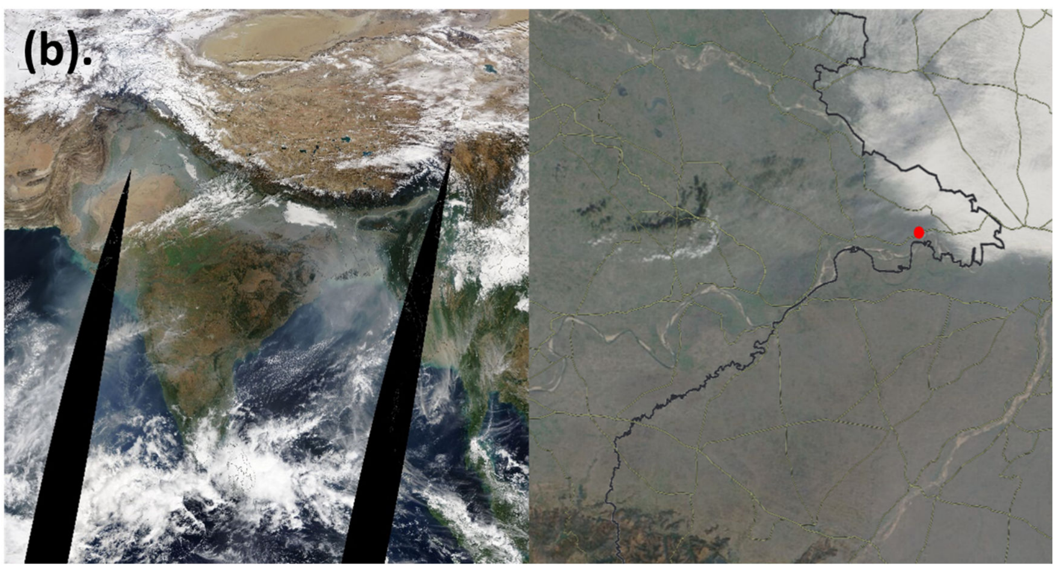
Reply: We are thankful to the reviewer his/her good suggestion and thoughtful comments. Following is the explanation/clarification regarding concerns of data collocation.

- *Daily averages of AOD and CER are obtained from aerosol-cloud data product MOD08 of 1 ° X °1 spatial resolution from MODIS TERRA with fraction of pixels that satisfy some conditions e.g., cloudy and clear (*MODIS Web (nasa.gov)*). Then statistical function is applied to align the data for both parameters on corresponding dates.*
- *Similar to the previous studies (Cheng et al 2017; Remer et al.,2005; Anwar et al., 2022), the AOD data are obtained from MODIS TERRA data product MOD08 using combined Dark target and deep blue algorithms. Further, following Anwar et al. (2022), data with AOD > 1.5 are excluded to avoid potential misidentification between aerosols and clouds.*

  The potential 3D effect is not considered. However, the filtered data are tallied with MODIS-TERRA that use, true color images with corrected reflectance for both AOD > 1.5 and AOD < 1.5. For example, the true color image for AOD> 1.5 over Gandhi College, dated January 09, 2020 is given below in Fig (a).



And the true color image for AOD <1.5 on same location dated December 22, 2020 is given below Fig (b).



From the images it is clearly observed that for AOD> 1.5 (shown in Fig (a)) the cloud occurred over Gandhi college and for A0D< 1.5 (shown in Fig (b)) it is cloud free.

- *Amin et al. (2009) validated and verified that the daily mean of PR from TRMM were coincident with the available ground-based records and confirmed its suitability for PR monitoring. The authors also concluded that MODIS-TERRA and TRMM data with their short retrieve time (daily) permit establishing a monitoring approach between both. Therefore, TRMM data retrievals are utilized to observe and analyze the PR.*
- *In this study the data retrievals from MODIS, TRMM and reanalysis are aligned through point-to-point collocation. In this type of collocation, the spatial coordinates*

(latitude and longitude) are matched for the common points of datasets. And then align the temporal information of the observation at each point.

- *Methodology: The authors consider temperature, LTS, RH, vertical velocity as meteorological parameters. It is not clear why they considered these parameters and not others.*

Reply: We are grateful to reviewer 2 for his/her/their thorough reading of our manuscript. In this regard the following text is inserted on line 219 in the revised manuscript:

Generally, LTS has relationships to factors such as temperature, humidity, wind patterns, and atmospheric pressure over extended periods. It is also widely acknowledged that atmospheric stability, temperature, RH and wind speed and direction play a significant role in cloud formation (Yang et al., 2015; Tao et al., 2012). Therefore, the influence of long-term variations in the said meteorological parameters are considered in the current study.

I suspect that the authors considered only liquid clouds for their analysis, but this is not mentioned in the manuscript. Did the authors filter their data set, and if so, how?

Reply: Many thanks to the reviewer for constructive and insightful comments. Yes, in the current study only liquid clouds are considered and it is mentioned on line 93 that the analysis is done for low level clouds which means liquid clouds over IGP. Fortunately, aerosol-cloud data product, MOD03 version 6.1 of MODIS-TERRA allows the retrieval of data for liquid and ice clouds as separate variable in the search tabs, available on https://giovanni.gsfc.nasa.gov/giovanni/ .

- *The authors based their study on 6 stations, but they only use satellite and reanalysis datasets, so I wonder why they only focus on 6 stations and not do a full analysis of the region. The eastern part of the region is not considered, and this is unfortunate if satellite observations are considered. I expected a comparison with ground observations to explain why the sites were chosen, but there is none. Therefore, I would suggest explaining why the full map of the region is not considered.*

Reply: Thanks for the excellent comment. The study is extended to the eastern part by including Kolkata, Dhaka and Patna as study sites. For detailed analysis please see our response to a similar comment of referee 1.

- *FIE, SIE, and TIE parameters are based on dependent records. CDNC is derived from CER and CLWP, and CLWP is derived from CER and COT. Therefore, it is not possible to infer the different parameters. To study these effects, we should consider only independent datasets. Therefore, Figures 8, 9, 10 and the related discussions and conclusions, I have doubts about them.*

Reply: Thank you for the nice comment. Of particular importance is the fact that aerosols may serve as cloud condensation nuclei (CCN). Increased aerosol concentrations may thus increase cloud droplet number concentration (CDNC), enhancing the cloud albedo (Twomey, 1974), and enhancing cloud lifetime and liquid water content by lowering the collision/coalescence rate (Albrecht, 1989). These so-called "indirect effects" of aerosols on liquid water clouds are referred to as the cloud albedo or first indirect effect and the cloud lifetime or second indirect effect. Therefore, according to the valuable comment of the respected reviewer, CDNC is dependent parameters. However, it has a pivotal role in the indirect effects.

- *The article lacks quantification in most of the paragraphs, which makes the analysis difficult to follow because I sometimes do not know what is being referred to.*

Reply: Thank you for the kind suggestion. We have taken the suggestion and added quantitative discussion in the revision. For example, the following lines are revised in section 3.3.1:

- Most of the identified PCs are formed in the two bins of CTP (180< CTP < 440 hPa) and (440< CTP < 680 hPa) with CF values ranging from 0.8 to 1.0. The results suggest low values of CF for the low-lying thick NPCs over all study areas.
- Similarly, the type of PCs in both summer and winter season that occurred with CF ~1.0 include cirrus and cirr-stratus.
- In addition, among all the estimated low-level PCs, cumulus and strato-cumulus exhibit good CF values (0.7) over Kanpur and Gandhi College.

The following text is revised in section 3.4.3:

- The results illustrate high PR (0.0007 mm/day) values for clouds with COT ranging from 3 to 28 with CDNC < ~ 50 cm^{-3} and intermediate for optically thick clouds and CDNC > ~ 50 cm^{-3} in both seasons.
- However, sensitivity analysis for COT > 23 could not be performed due to less number (0 to 04) of available samples. In the sensitivity equation the minus sign shows the suppression of precipitation formation due to the increase in CDNC. Further, when S_o is positive, correlation between PR and CDNC is negative; however, for negative S_o, PR and CDNC are positively correlated. The results show peak values of S_o i.e., 0.7 ± 0.3, 0.6 ± 0.3, 0.5 ± 0.3, and 0.4 ± 0.4 over Jaipur, Delhi, Gandhi College and Karachi respectively at intermediate values of COT in winter, indicating the occurrence of lightly precipitating clouds. Referable to Fig. 13b, the low magnitude of S_o 0.2 ± 0.3 and 0.08 ± 0.2 over Kanpur and Lahore respectively is due to coagulation, in which precipitations are less sensitive to CDNC.

Minor revisions:

- *l.11, "different physical mechanisms", can the authors specify the different physical mechanisms?*

Reply: Thank you for the comment. Yes, the different physical mechanisms are mentioned in revision of manuscript on line 93 as follows: (condensation/droplet growth and precipitation rate).

- *l.11 "systematically analyze", what does systematically mean?*

Reply: Here 'systematically analyze' means an organized approach of investigation or set of procedure to gather, organize , analyze and interpret information.

- *keywords, "Aerosol option depth" -> "aerosol optical depth"*

Reply: Corrected. Thank you.

- *Figure from the abstract, I am not sure if the figure helps to understand the abstract, it is rather a lot of information with parameters not yet defined (LTS, CER, AOD), I suggest removing it.*

Reply: We comply with the good suggestion of respected reviewer and removed the figure.

- *Introduction: citations are missing, I suggest adding citations. For example, the first two sentences should have citations.*

Reply: Thank you for suggesting the addition of citations. In the revised manuscript the following citation is inserted for the first two lines: (Romero et al., 2021)

- *l. 66, aerosols can also act as ice nucleating particles but this is never mentioned in the article. Did the authors consider this? I think it should at least be mentioned in the introduction and emphasize that only liquid clouds are relevant for the analysis.*

Reply: The good suggestion of the reviewer is implemented.

- *l. 67, "The decrease in CDNC and increase in CER increases the probability of precipitation rate (PR)". Stevens and Feingold (2009) have shown that you can actually have the opposite effect: An initial inhibition of precipitation from aerosols can lead to increased precipitation later. The region is affected by large precipitation and this may be an effect that the authors did not consider. I suggest adding a discussion about it.*

Stevens, B., & Feingold, G. (2009). Untangling aerosol effects on clouds and precipitation in a buffered system, Nature, 461(7264), 607-613.

Reply: We are thankful to the reviewer for pointing out a very useful research work by Stevens, B., & Feingold, G. (2009). Relevant to our study, the following text is added on line no. 67:

Conversely, Stevens and Feingold (2009) have shown that initially, more sea salt carried by high wind speed inhibit the precipitation formation. However, the same sea spray tends to seed the coalescence by producing larger CER that led to enhanced precipitation.

- *l. 82: "Twomey effect", I think it would be best to describe the effect before mentioning it.*

Reply: The good suggestion is implemented by adding the following text on line 82:

decrease (increase) in CER with aerosol loading Twomey effect (anti-Twomey effect) over the monsoon (weak and moderately intensive monsoon) regions.

- *l. 83: "anti-Twomey effect", I do not know this effect, can the authors describe it?*

Reply: The increased aerosols can reverse the Twomey effect in water clouds. In the anti-Twomey effect, with a potential decrease in CDNC, droplets of larger size are formed with the increased aerosol loading leading to the decreased cloud albedo (Khatri et al., 2022).

- *l.87: "FIE", the acronym is not defined before.*

Reply: Your good suggestion is implemented.

- *l. 87, the Twomey effect refers to the change in cloud radiative properties and not to the cloud droplet size. Also McCoy et al., (2018) may not be the best and the citation from Twomey may be more relevant*

  Twomey, S. (1977). The influence of pollution on the shortwave albedo of clouds. Journal of the atmospheric sciences, 34(7), 1149-1152.

Reply: In the Twomey effect a large number of smaller cloud droplets are formed. Smaller droplets scatter sunlight more effectively than larger droplets which can result in a cloud that appears brighter and reflects more solar radiation back into space. Therefore, the authors agree with the reviewer that Twomey effect refers to the change in cloud radiative properties. Further, the reference is updated to insert the suggested reference.

- *l. 111, I suggest including the names of the cities on the map.*

Reply: Thank you. Good suggestion of the reviewer is implemented as follows.

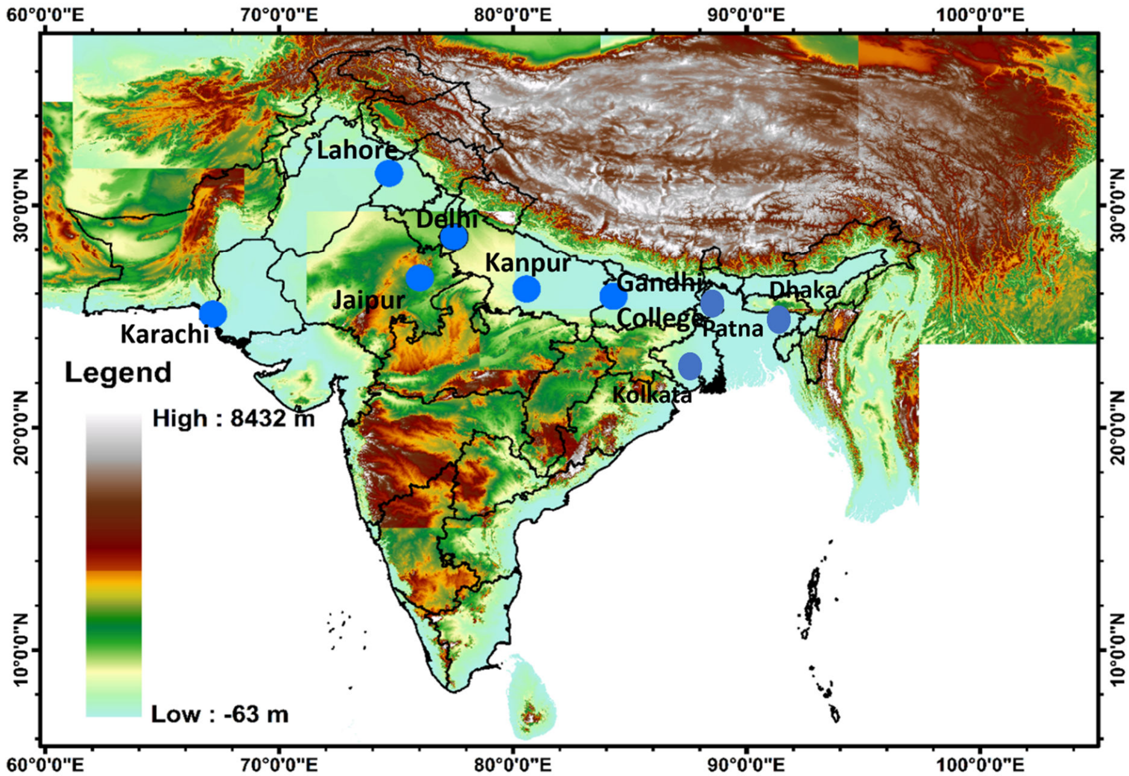


Fig. 1. Topography of the study area.

- *Figure 1 caption: "Geographical map" -> "topography".*

Reply: Thank you. The good suggestion is implemented as shown figure caption in reply to previous comment.

- *Figure 1: What is the data for topography? Some regions are covered and some are not. I suggest removing Figure 1 and adding the points on Figure 2 (with the names of the stations) since there is no mention of topography in the article.*

Reply: In response to the good suggestion of the reviewer instead of removing Fig.1, the following explanation is added about the topography at line 179:

IGP characteristically exhibits a diverse and massive pool of aerosols due to its unique topography. The western part of IGP is the coastal location and inlet for the westerly winds. Therefore, dry regions and Arabian sea in the west contribute dust, sea salt and water vapors to the region. The Himalayas in the north act as barriers to the winds, leading to the trapping of aerosols over the central part of IGP. Therefore, this region exhibits a high concentration of anthropogenic aerosols. The Bay of Bengal in the east allows southeasterly winds to enter passing across Dhaka, Kolkata, Patna to Delhi and Lahore (Hassan et al., 2002; Anwar et al., 2022). The westerly and easterly winds traverse forested hilly terrain, rivers and lakes elevating humidity level and initiate the cloud formation by activation of the newly originated small aerosol particles as CCNs and cloud formation affecting the local microclimate.

- *l. 122, "resolution of x to study atmospheric…", change x to the correct value.*

Reply: Thank you for your correction. Changed to (1°) at line 122.

- *l.125, CDNC and CLWP are not direct products of MODIS. They are defined later but should not appear here.*

Reply: Thank you. your kind suggestion is implemented.

- *l. 126 "Data with AOD>1.5", with the threshold the authors avoid misidentification of clouds as aerosols and not the reverse as stated in the article. Is there a threshold to avoid misidentification of clouds as aerosols?*

Reply: Thank you for the nice comment. Although a detailed reply is given to such comment in the major revisions. However, it is further explained as follows.

The following table shows the threshold values AOD for classification aerosols into different types (B AL-Taie et al., 2020).

Aerosol type	*Aerosol optical depth (AOD)*	*Angstrom exponent(AE)*
Maritime	*< 0.3*	*0.5-1.7*
Dust	*> 0.4*	*< 1.0*
Urban	*0.2-0.4*	*> 1.0*
Desert dust	*> 0.45*	*0.4-2.0*
Biomass burning	*> 0.7*	*> 1.0*

Generally, the value of AOD ranges from 0.05 to 1 over the remote ocean and 2.0 to 5.0 during the time of heavy pollution smoke and dust (Petal et al., 2016).

Therefore, idea of excluding AOD > 1.5 to avoid clouds as aerosols is taken from a recent study (Anwar et al., 2022), which may not be the threshold value for this purpose.

- *Equation 1, square root does not go all the way.*

Reply: Thank you. Equation 1 is corrected as follows:

$$\mathrm{CDNC} = \left(\frac{\mathrm{B}}{\mathrm{CER}}\right)^{3} * \sqrt{(2 * \mathrm{CLWP} * \gamma_{\mathrm{eff}})}$$

- *LTS equation (line 144), is not numbered.*

Reply: Thank you. LTS equation is numbered as (3)

- *l. 144, \theta_{0} -> \theta_{1000}*

Reply: Thank you. The correction is done as follows.

$$\mathrm{LTS} = \theta_{700} - \theta_{1000}$$

- *l. 150, PR is defined for precipitation rate but is not an instrument and for Precipitation Radar it is not mentioned.*

Reply: Thank you. Corrected.

- *l. 150, TMI is not defined.*

Reply: Thank you. TMI is defined as follows:

TRMM Microwave Imager (TMI).

- *Methodology section: is both Aqua and Terra for MODIS used?*

*Reply: Thank you for the detailed and thorough reading of the manuscript. In the methodology section it is already mentioned that "*level 3 aerosol-cloud data product MOD08*" which means MODIS-TERRA. While the same data product of MODIS AQUA is named MYD08.*

- *l. 187, "is similar", the authors state the opposite afterwards so I would remove the "similar"*

Reply: Thank you. The good suggestion is implemented.

- *lines 195 and 196, citations are missing.*

Reply: Thank you. The following citation is added.

(Sun & Ariya, 2006).

- *l. 199, Why does Karachi have lower values?*

Reply: Thank you for the insightful comment. Reason for lower AOD values is inserted on line 199 as follows.:

Ali et al., 2020 associated the low AOD values over Karachi to the westerly and southwesterly winds currents at tropospheric level. However, the decreasing trend in AOD over the coastal city may also be attributed to the variations in other meteorological parameters like T and RH.

- *l. 201, "illustrate pristine atmosphere", I suggest adding "comparatively".*

Reply: Thank you. Nice suggestion of the reviewer is implemented.

- *lines 200-206, it would be better to quantify with the median to compare different regimes.*

Reply: Thank you for your advice. This has been very useful. Per your good suggestion lines 200-206 are revised as follows.

As compared to summer season, the pattern of PDF in winter is significantly different as shown in Fig. 3b. The low value of PDF (0.5) for the high value of AOD (0.9) over Karachi illustrates a comparatively pristine atmosphere. Similarly, the PDF peaks for Lahore, Delhi and Jaipur (0.7, 0.7 and 0.8) indicate comparatively high AOD over Delhi. Likewise, the distribution over Kanpur and Gandhi College is similar illustrating similar values of AOD (1.1and 1.2 respectively).

- *l. 204, before the new sentence, the authors compare with the other PDF, I think it should be a new paragraph with the description.*

Reply: Thank you for useful suggestion. The correction is made per your insightful suggestion. on line 204, the new sentence is revised as new paragraph as follows:

Few authors attributed the reduced values of AOD in winter season to the wet scavenging and suppressed emission of aerosols from earth surface (Alam et al., 2010; Zeb et al., 2019). However, in our case, the low (high) values in winter (summer) are associated to dispersion of fine (course) mode particles due to the variations in meteorological conditions.

- *l. 204, "winter season is the wet scavenging", it contradicts with Fig 5 and Fig. 11 for which summer as more precipitation. Can the author explain?*

Reply: Thank you for your good remarks. The reason is explained as follows:

However, in our case, the low (high) values in winter (summer) are associated to dispersion of fine (course) mode particles due to the variations in meteorological conditions.

- *From Fig 3, AOD in winter is not smaller for Jaipur and Kanpur (it does not look like it). Any reason for this difference?*

Reply: We comply with the useful suggestion of the reviewer and explained the same with quantification of AOD values and reason for high values AOD over Kanpur and Jiapur as follows:

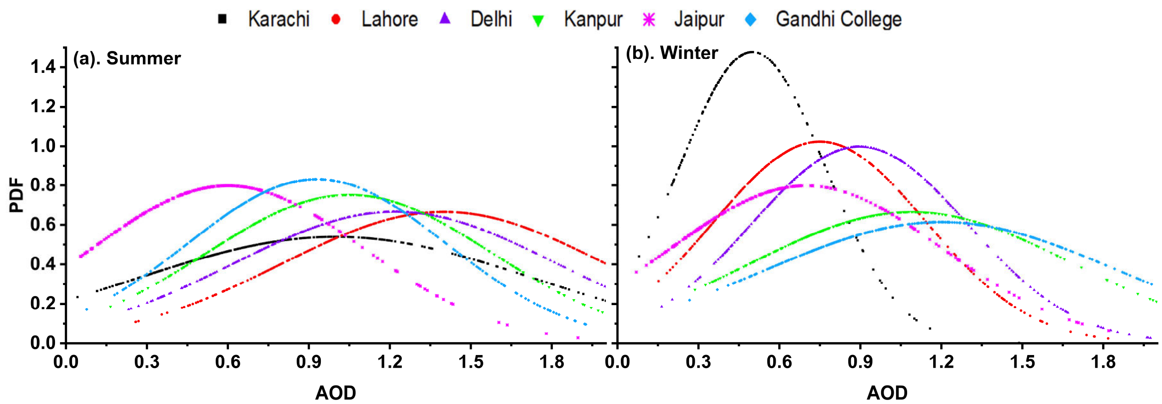
Similarly, the PDF peaks for Lahore, Delhi and Jaipur (0.7, 0.7 and 0.8) indicate comparatively high AOD over Delhi. Likewise, the distribution over Kanpur and Gandhi College is similar illustrating similar values of AOD (1.1and 1.2 respectively). These high values of AOD are attributed to the high emission of anthropogenic aerosols at local and regional level over the central part of IGP (Delhi, Jaipur, Kanpur and Gandhi College).

- *Table 1 "Total number of counts", "counts", is it pixels?*

Reply: This is not pixels but the number of observation/ days.

- *Figure 3, it is difficult to distinguish the different points and colors especially between Karachi and Gandhi College,*

Reply: Thank you for your good suggestion. Fig.3 is revised as follows:



- *l. 219, "estimation of", I think should be removed.*

Reply: Thank you so much. The correction is made per good suggestion of the reviewer.

- *l. 221-222, "the potential for vertical convection… precipitation formation", I do not understand this part, can the author rephrase?*

Reply: Thank you for the very useful remark. The good suggestion is implemented by rephrasing line 221-222 as follows:

LTS to determine the lower atmospheric stability and instability that influence the process of cloud and precipitation formation through its significant implications on evaporation and convection of the air parcel,

- *l. 235, "is relatively high", is it compared to PCs or to summer?*

Reply. Thank you for your time and thorough reading of our manuscript. This is compared to NPCs in summer season.

- *l.236 "The increase", which increase? I am not sure what it refers to. (same for line 242)*

Reply: Thank you for the useful and detailed comments. Per your comment line 236 is revised as follows:

The increase in RH% for PCs during winter ranged from (60±5)% to (72±5)%.

Similarly, line 242 is revised as follows:

Also, the increase in RH% during summer ranged between 25-45 %.

- *l. 236 "33-57%", I do not find these values in the Table.*

Reply: Thank you for your comment. Line 236 is already corrected and revised. Please refer to previous comment.

- *Sometimes RH is referred to as RH% and sometimes RH.*

Reply: Thank you so much for your useful remarks and suggestions. The correctio is made per your good suggestion.

- *l. 242, "suitable thermodynamical conditions" can the authors say more about this and add a citation?*

Reply: To comply with the useful suggestion of the respected reviewer the following passage is inserted on line 242:

The reason for the high values of wv and RH% is mainly the suitable thermodynamical conditions such as evaporation and convection due to the high temperature of earth surface and air (Sherwood et al., 2010). The results show high values of RH% 72 ± 5 (71.6 ± 3) in winter (summer) season for PCs over Gandhi College. Conversely, notable fluctuations in RH% are observed over the coastal city, Karachi, with values of 70 ± 13.9 (68.4 ± 6.7) in winter (summer).

- *l 244, Gandhi's college has a higher value of RH. I was expecting Karachi because it is closer to the coast. Can the author add a discussion about this?*

Reply: Thank you. Line 244 is revised per useful remark of the reviewer as follows:

The results show high values of RH% 72 ± 5 (71.6 ± 3) in winter (summer) season for PCs over Gandhi College. However, high values of standard deviation show notable fluctuations in RH% over the coastal city, Karachi, with values of 70 ± 13.9 (68.4 ± 6.7) in winter (summer).

- *Table 2, did the author consider the mean? I would suggest considering the median since we do not expect Gaussian distributions.*

Reply: Thank you for the kind suggestion. We considered (mean ± SD) so that the fluctuated values can also be examined.

- *page 14 "the frequency of occurrence of precipitable clouds" is it the frequency of occurrence relative to the total or to cloudy pixels?*

Reply: This is the frequency of occurrence relative to total clouds (both precipitable and nonprecipitable).

- *page 14, the authors apply filters to avoid overestimation (COT and CF> 5), but I wonder if this does not lead to underestimation.*

Reply: Thank you giving useful suggestions to improve our manuscript. The correction is made per your good suggestion. This is not (COT and CF> 5) but (COT ~ > 5) for PCs only. Thank you.

- *page 14, some discussion of the results is missing.*

Reply: Thank you for your good suggestion. To comply with your useful suggestion the following lines are added in the discussion on page 14:

Chen et al. (2018) suggested the COT to be the effective measure for assessing the clouds and potential for precipitation. In our case, to avoid any overestimation, the COT data are aligned with PR data on corresponding dates and then filtered to include COT ~ > 5 for PCs.

- *Fig. 6, I think the authors are not showing a joint histogram as stated in the article but rather the CF for different regimes of COT and CTP, can it be explained in more detail what is shown here? Is CF averaged?*

Reply: Mean values of CF were calculated for all regimes. However, in response to one of the following comments, median of CF is calculated and therefore, fig. 6 is revised in the revised manuscript.

- *Page 16: Is CF>0.7 a threshold used for the entire paragraph to state that it is "high CF"? if so, it should not be in parentheses but rather explicitly explained.*

Reply: Thank you for the useful suggestion. No CF> 0.7 is not the threshold value. Further, the quantification of CF and related discussion is revised as Fig. 6 is revised in response to one of the following comments for median values of CF. The suggestion is also implemented, and CF value is explicitly mentioned as follows:

The results exhibit noticeable differences in the pattern of cloud regimes over all study areas. The diverse CF values are observed in winter and summer seasons for NPCs and PCs over Karachi. In winter season, only stratus NPCs (23 < COT <60, 800 > CTP > 680 hPa) are dominant with CF ~ 0.9. While, in summers, high value of CF ~ 0.9 for low and intermediate thickness of high-level clouds such as Cirr-Stratus NPCs (3.6 < COT < 23, 180< CTP < 440 hPa) are observed. Similarly, the type of PCs in both summer and winter season that occurred with CF ~1.0 include cirrus and cirr-stratus. The relatively reduced value of CF for thick NPCs in winters and PCs in summers is attributed to the low values of AOD and high values of LTS. The results depicted slight differences and similarities in CF values for thick and thin NPCs respectively in winter season for all areas except Karachi. Besides, the high-level PCs are identified in the two bins of CTP (180< CTP < 440 hPa) and (440< CTP < 680 hPa) over all study areas. The formation of these similar types of PCs in winters are associated with the similarities in Ω, LTS values and aerosols concentration.

- *Page 16, (23<COT<60, CTP>680), should read (23<COT<60, 800>CTP>680).*

Reply: Thank you for your useful feedback on our manuscript which improved our manuscript. The correction is made on page 16 as follows:

(23<COT<60, 800>CTP>680).

- Page 16, "Similarly, in winter season the type of PCs…" why cirrus & cirro-stratus not included with CF>=0.9.

Reply: Thank you for useful advice. The discussion is revised in response to one of the following comments after revision of figure, and cirrus and cirro-stratus are included with median value of CF ~1.0 . Please refer to one of the following comments explained with figure.

- *Page 16, "less significant values", do the authors mean "lower"?*

Reply: Thank you the valuable comment. Yes, here, "less significant values", means low values of CF.

- *Page 16: The paragraph starting with "Also, in summer…" it is difficult to follow this paragraph, I suggest changing the presentation of the paragraph.*

Reply: Thank you for the valuable feedback on our manuscript. The said paragraph is revised per your good suggestion as follows:

Likewise, in summer season, the matrices of PCs and NPCs exhibit a wide range of cloud types. However, the CF values are comparatively high for PCs. Most of the identified PCs are formed in the two bins of CTP (180< CTP < 440 hPa) and (440< CTP < 680 hPa) with CF values ranging from 0.8 to 1.0. The results suggest low values of CF for the low-lying thick NPCs over all study areas. Moreover, the results illustrate a more frequent occurrence of all the three types of thick NPCs in one bin of COT (23 < COT< 60) and all the three types of high-level NPCs for CTP (180 < CTP < 440 hPa) over Delhi, Kanpur, and Gandhi College. Therefore, these are considered the cloudiest regimes. Besides, contrasting regional variations are also observed in PCs. The maximum CF values for all types of PCs are observed over Kanpur and Gandhi College. Similarly, relatively good values of CF in a bin of COT (23 < COT< 60) and a bin of CTP (180 < CTP < 440 hPa) over Lahore, Delhi, and Jaipur depict the frequent occurrence of thick and high-level PCs respectively. In addition, among all the estimated low-level PCs, cumulus and strato-cumulus exhibit good CF values (0.7) over Kanpur and Gandhi College. The formation of thick clouds can be attributed to the enhanced convection process due to the atmospheric instability.

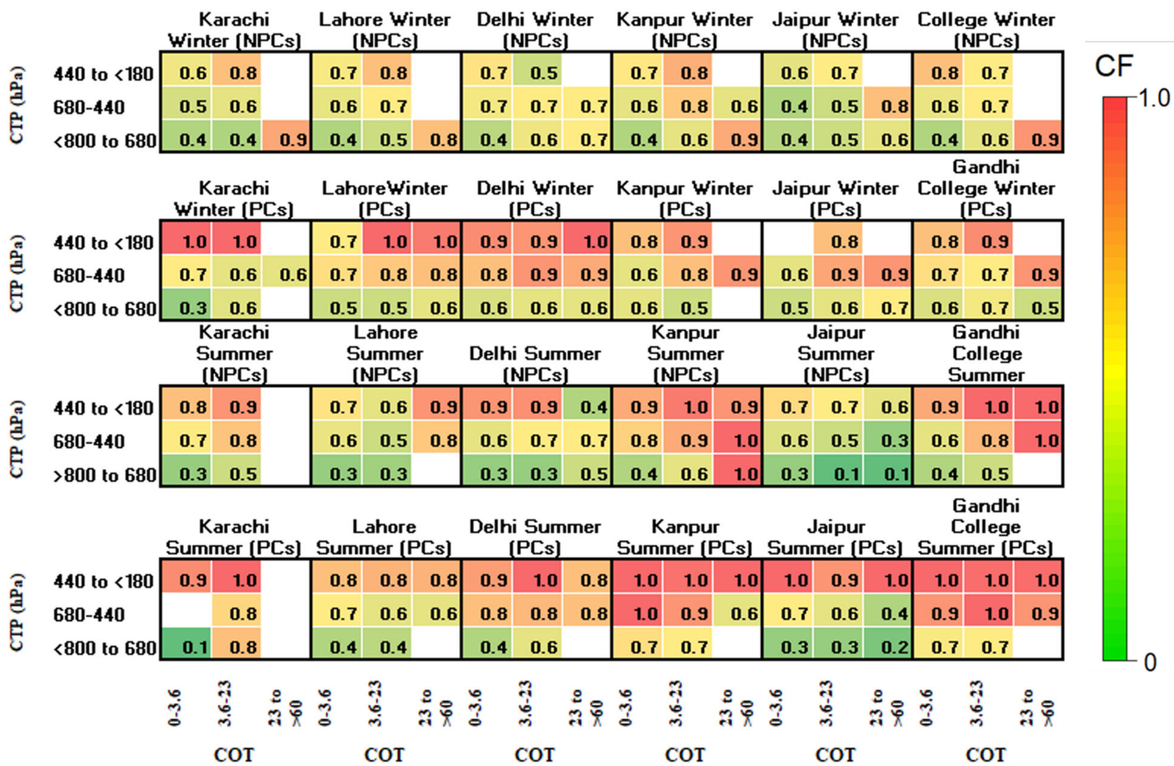
- *Table 3, ">800 to 680" should it be "<800 to 680"?*

Reply: The correction is made in Table 3 per good suggestion as follows:

<800 to 680

- *Figure 6, Is the mean CF shown? If so, the number of points and the SD should also be shown. I would also suggest showing the median instead of the mean.*

Reply: Thank you for the valuable suggestion. Median instead of mean is calculated and Fig 6 is revised as follows:



- *Page 19 "depicted an approximately similar values", did the authors perform a statistical test to infer this conclusion?*

Reply: We are thankful and appreciate the thorough reading of our manuscript. Yes, the statistical analysis is done by applying the 'probability distribution function' (PDF). Then the conclusion is made on the basis of quantification of PDF obtained.

- *Page 19 "The low number of CDNC", there is no information on CDNC in Figure 6*

Reply: Thank you for your valuable time and suggestions. The correction is made on page 19 for the said sentence. Actually, this sentence is for the results shown in figure 7 not 6. Thank you again.

- *page 21 "detailed linear regressed slopes", what is meant by "detailed".*

Reply: Here 'detailed' means the slope with the trend line equation, along with values of regression and correlation coefficient.

- *page 21 "correlation is good for PCs and weak for NPC", what is the criteria and threshold to determine if it is good or not? In both cases, r2 looks low.*

Reply: Thank you for detailed feedback on our manuscript. It is observed in winters that the value of correlation coefficient 'R' is higher for PCs than that for NPCs. Further, it is good correlation if R >~ 0.5, either positive or negative.

- *page 21 the positive AOD-CER correlation, what exactly does it mean physically ? Why should droplets be larger in the presence of aerosols?*

Reply: Thank you for you useful and valuable remarks. The AOD-CER correlation can either be positive or negative. Positive AOD-CER means increasing CER with increasing aerosol loading. Few authors associated the positive (negative) AOD-CER correlation to the unstable (stable) meteorology and moist (dry) regions (Yuan et al., 2008).

- *Figure 10 "the error bars show the standard deviation" the plot represents sensitivities, so I am not sure to understand what standard deviation is being retrieved here.*

Reply: Thank you for the nice comments. Due to the variations in local and regional meteorology, the mean value of sensitivity fluctuates between maximum and minimum. For this reason, the standard deviation is retrieved here.

- *Page 27, I am not sure what the authors mean by "approximation", is it uncertainty ?*

Reply: Since satellite-based retrievals are prone to considerable uncertainties owing to the indirect nature of remote sensing. These uncertainties in retrievals also propagate through the modeling process, potentially leading to less accurate climate predictions. Therefore, the word "approximation", is used in the discussion .

- *Page 27 "Fig. 12 shows scatter plots of…" the paragraph lacks quantifications,*

Reply: Thank you. Quantification is added per your useful feedback and suggestion as follows:

Fig. 12 shows scatter plots of PR verses CDNC. The plot is colored with COT to examine the impact of CDNC on PR for similar macrophysics. When CDNC are few, then the COT are sparse that grow larger, form less reflective clouds and precipitate faster (Kump & Pollard, 2008). The same phenomenon seems true in our case. The results illustrate high PR (0.0007 mm/day) values for clouds with COT ranging from 3 to 28 with CDNC < ~ 50 cm^{-3} and intermediate for optically thick clouds and CDNC > ~ 50 cm^{-3} in both seasons.

- *Fig. 11 caption, is the mean shown ?*

Reply: Thank you. Yes, the bars show the mean values of PR. Caption of Fig. 11 is revised in the revised Manuscript as follows.

Fig. 1. Mean Precipitation rate (PR) for the PCs in winter and summer season and SD values with 95% confidence interval

- *l. 30 "Also the frequently occurred…" it should be rephrased.*

Reply: sorry "Also the frequently occurred ….." could not be found on line 30 or page 30.

- *page 31, the ladsweb website does not work,*

Reply: Thank you for useful comment. The URL is corrected as follows:

https://giovanni.gsfc.nasa.gov.giovanni/

- *Bibliography: multiple references are not correctly written in the bibliography (some doi are underlined, some are not),*

Reply: Thank you for the valuable remarks and suggestion. For implementation of your suggestion refer to the next comment please.

- *Bibliography: some names are not outputed correctly, for example: "Thomas, A., Kanawade, V. P., Sarangi, C., & Srivastava, A. K. J. S. o. t. T. E"*

Reply: Thank you for detailed and useful feedback which helped to improve our revised manuscript. Your good suggestions about bibliography are implemented in references as follows:

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- *I suggest removing words that are unnecessary (meaningful (179), completely (l. 225), evidently (l. 228)...)*

Reply: Thank you. Your useful and valuable suggestions are implemented and the unnecessary words such as meaningful (line 179), completely (line. 225), evidently (line 228,…) are removed in revision.

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