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Growth in mid-monsoon dry phases over the Indian region: prevailing influence of anthropogenic aerosols

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Supplementary Text 1

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. As a result, AOD datasets were expected to be completely of different magnitude before after the year 1999. But, fortunately it was also observed from Randle et al. (2017) that a prominent overlapping is observed between AOD datasets before and after 1999 globally between June – October. Since, the present study is also focussed during the month of July- August, hence they 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 have been depicted in Table S3 which reveal 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 implies the fact that mean AOD values did not undergo a massive scale change in magnitude after 1999; hence it will not exert any significant impact on the aerosol clustering analysis presented in the manuscript.

Supplementary Text 2

The last 20 years data has been utilized for this analysis (as aerosol datasets after 1999 are considered more reliable than the first half) and in these case they have taken two equal clusters of SDP' and LDP'. The boxplot analysis results for Region 1a,is depicted in Table S4. The BC and OC AOT values depict an increase 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. 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.

Table S1 List of Abbreviations

Slno	Short Form	Full Form	Slno	Short Form	Full Form
1	**PET**	Potential EvapoTranspiration	24	**CER**	Cloud Effective Radius
2	**DDF**	Dry Day Frequency	25	**SDP**	Short Dry Phase
3	**DI**	Drought Index	26	**MDP**	Medium Dry Phase
4	**IGP**	Indo-Gangetic Plain	27	**LDP**	Long Dry Phase
5	**RCP**	Representative Concentration Pathway	28	**SSN**	Sun Spot Number
6	**WMO**	World Meteorological Organization	**29**	**PCT/A**	Principle Component Analysis/Test
7	**SPEI**	Standardized Precipitation Evapotranspiration Index	**30**	**PM**	Particulate Matter
8	**ENSO**	El Niño–Southern Oscillation	**31**	**SHUM**	Specific Humidity
9	**IOD**	Indian Ocean Dipole	**32**	**CMIP**	Coupled Model Intercomparison Project
10	**BC**	Black Carbon	**33**	**AOD**	Aerosol Optical Depth
11	**PDSI**	Palmer Drought Severity Index	**34**	**MISR**	Multi-angle Imaging SpectroRadiometer
12	**SPI**	Standardized Precipitation Index	**35**	**MLR**	Multi Linear Regression
13	**CRU**	Climatic Research Unit	**36**	**BOB**	Bay of Bengal
14	**P**	Precipitation	**37**	**UP**	Uttar Pradesh
15	**D**	Difference of P and PET	**38**	**CCN**	Cloud Condensation Nuclei
16	**IMD**	India Meteorology Department	**39**	**TCC**	Total Cloud Cover
17	**OC**	Organic Carbon	**40**	**HCC**	High Cloud Cover
18	**AOT**	Aerosol Optical Thickness	**41**	**MCC**	Medium Cloud Cover
19	**MERRA**	Modern Era Retrospective-Analysis for Research and Applications	**42**	**LCC**	Low Cloud Cover
20	**SEDAC**	SocioEconomic Data and Applications Centre	**43**	**ACF**	Autocorrelation Function
21	**ERA**	European Re-analysis	**44**	**GCM**	General Circulation Model
22	**NEO**	NASA Earth Observations	**45**	**R1/R1A**	Region 1/1a
23	**MODIS**	Moderate Resolution Imaging Spectroradiometer	**46**	**M6/7/8/9**	Month 6/7/8/9

Mon	Threshold	r1	r2	r3	avg
6	1	-0.421	-0.266	-0.389	-0.359
6	2	-0.429	-0.292	-0.392	-0.371
6	3	-0.433	-0.298	-0.396	-0.376
7	1	-0.403	-0.376	-0.425	-0.401
7	2	-0.405	-0.39	-0.422	-0.406
7	3	-0.406	-0.397	-0.421	-0.408
8	1	-0.413	-0.407	-0.433	-0.417
8	2	-0.412	-0.411	-0.431	-0.418
8	3	-0.414	-0.411	-0.436	-0.42
9	1	-0.418	-0.411	-0.442	-0.424
9	2	-0.422	-0.417	-0.444	-0.427
9	3	-0.424	-0.419	-0.449	-0.431

Table S2. Selection of thresholds for DDF analysis

	Region 1a						Lucknow						Region 3					
	BC	Dust	OC	SeaSa	Sulph	TotAer	BC	Dust	OC	SeaSa	Sulph	TotAer	BC	Dust	OC	SeaSa	Sulph	TotAer
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 S3. Statistical analysis of MERRA2 aerosol datasets post EOS period

	Region 1a					Lucknow					Region 3				
	BC	Dust	OC	SeaSa	Sulph	BC	Dust	OC	SeaSa	Sulph	BC	Dust	OC	SeaSa	Sulph
SDP' Mean	0.021	0.032	0.050	0.018	0.199	0.022	0.055	0.051	0.027	0.192	0.014	0.112	0.031	0.049	0.126
LDP' Mean	0.024	0.038	0.053	0.020	0.215	0.025	0.062	0.054	0.028	0.207	0.017	0.150	0.036	0.058	0.138
Total Mean	0.022	0.035	0.052	0.019	0.207	0.024	0.059	0.053	0.027	0.200	0.017	0.131	0.031	0.053	0.126
Difference	0.003	0.006	0.004	0.002	0.016	0.003	0.007	0.003	0.001	0.015	0.002	0.037	0.004	0.009	0.012
Total STD	0.002	0.017	0.003	0.009	0.050	0.002	0.021	0.003	0.012	0.040	0.002	0.030	0.007	0.017	0.021
Overlapping	***1.431***	0.349	**1.086**	0.258	**0.329**	***1.465***	0.341	**1.143**	0.074	**0.368**	**1.151**	***1.262***	0.643	0.529	**0.566**
MLR value	0.414	0.098	0.281	0.114	0.105	0.731	0.184	0.398	0.070	0.160	0.251	0.406	0.160	0.066	0.105

Table S4. Statistical analysis of MERRA2 aerosol AOTs for overlap tests

Sl No.	**Model Name**	**Correlation**	**Normalized STD**
1	ACCESS 1.3	0.20398	0.417101
2	CAN ESM 2	0.3534	0.291455
3	CMCC CESM	0.27519	0.376355
4	CNRM CM5	0.51646	0.254338
5	CSIRO MK 3	0.02852	0.564645
6	GFDL ESM 2M	-0.01922	0.649957
7	HADGEM2 -CC	-0.23064	0.410529
8	INMCM4	-0.05084	0.558969
9	IPSL CM5 LR	0.27714	0.41382
10	MIROC 5	0.26838	0.362948
11	NOR ESM 1M	0.39618	0.283413

Table S5 Performance details of all 11 GCMs used

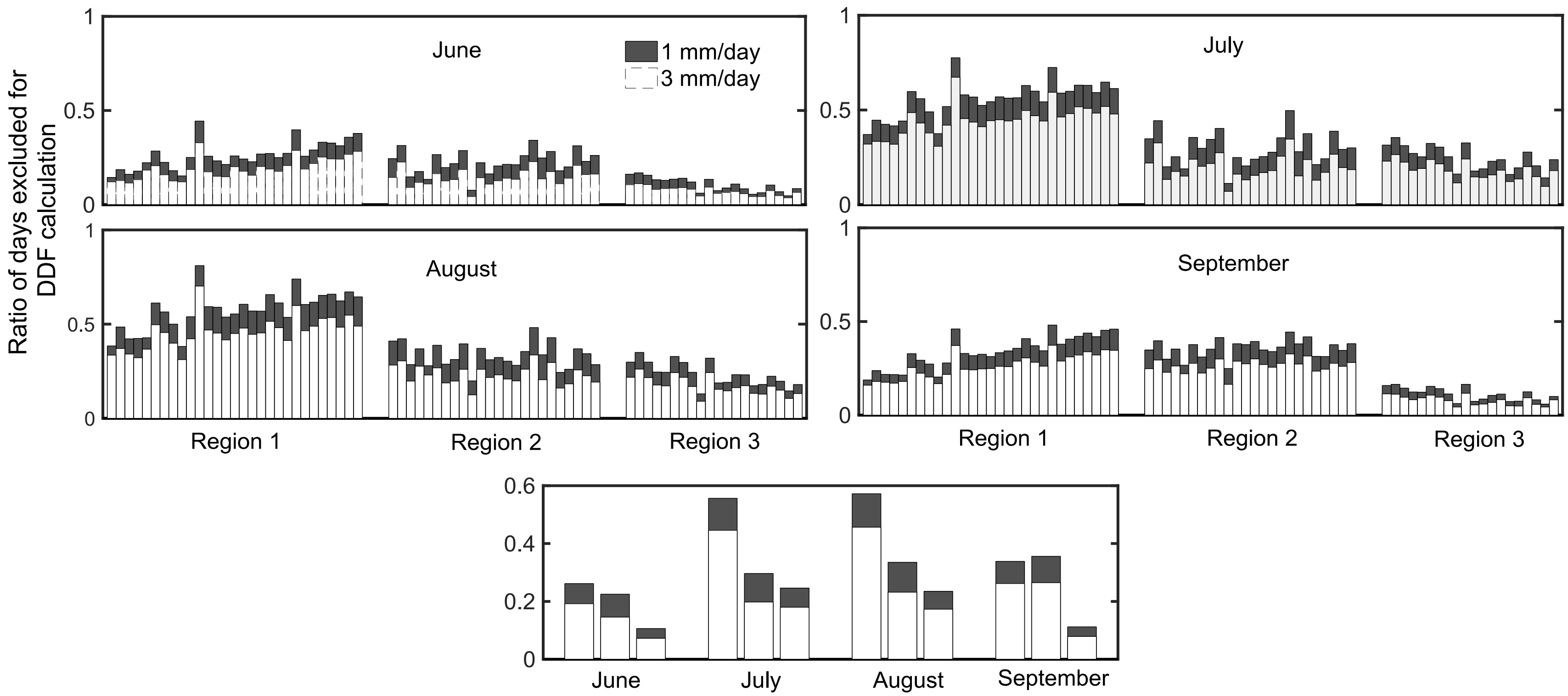

Figure S1. Estimation of the optimum threshold for DDF selection using dry day exclusion method

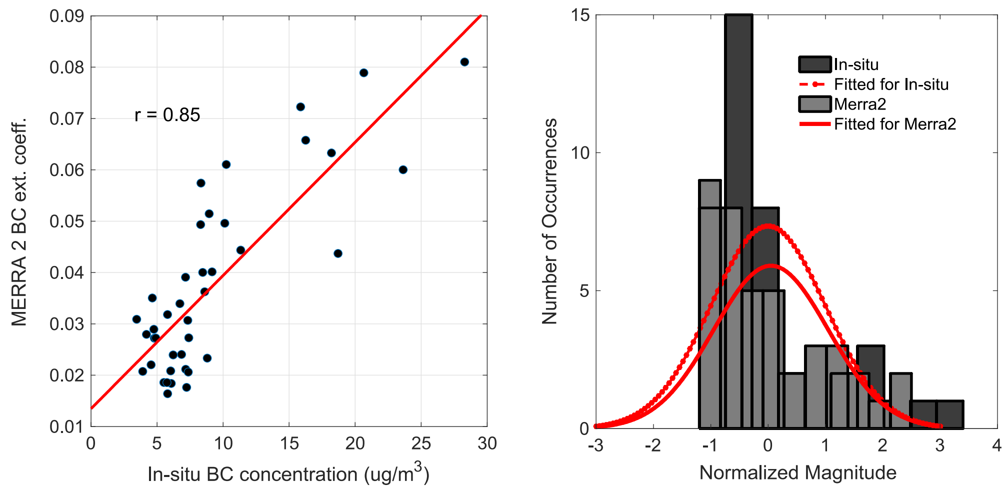

Figure S2. Validation of MERRA 2 BC AOT.

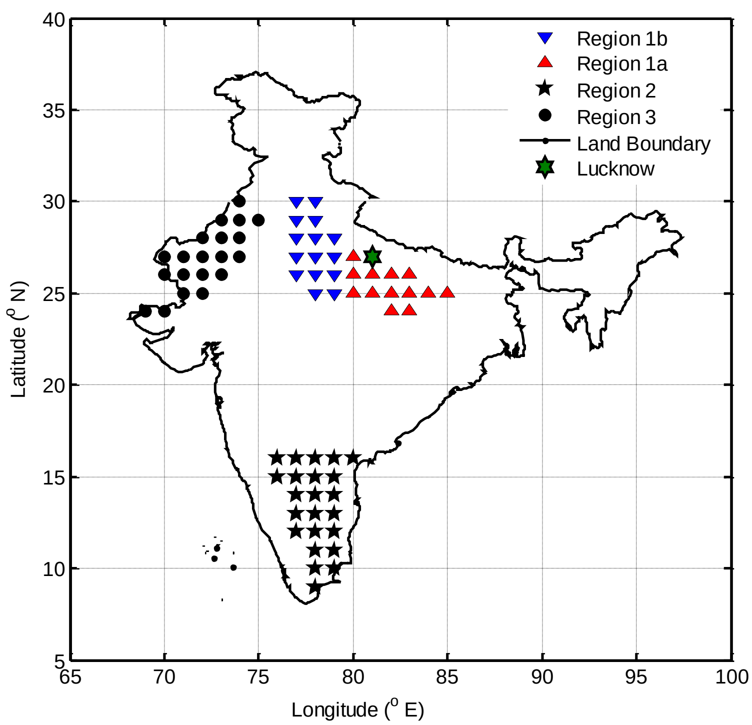

Figure S3. Division of the study area into 3 broad regions.

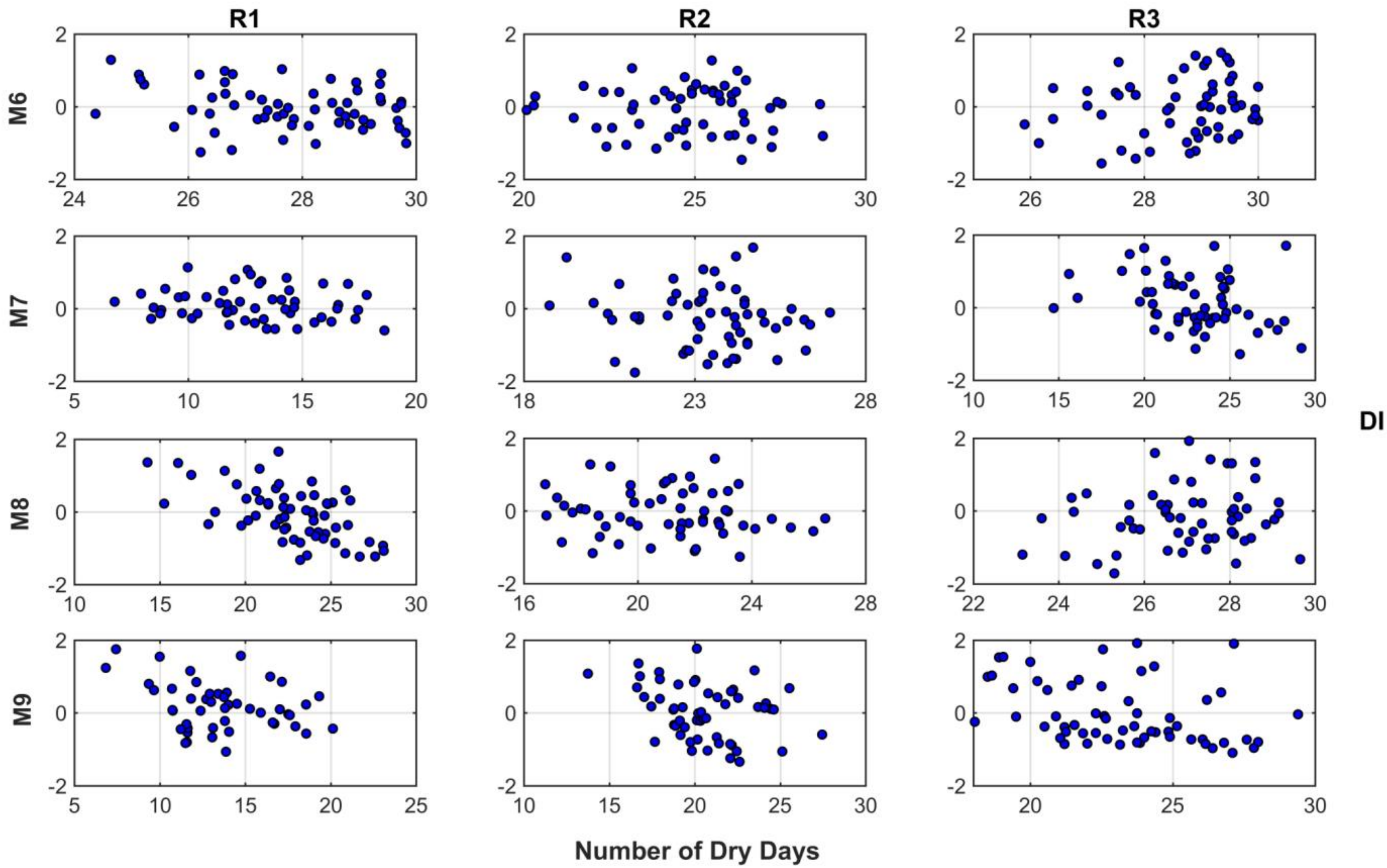

Figure S4. Relationship between DDF and DI for different months across three broad regions.

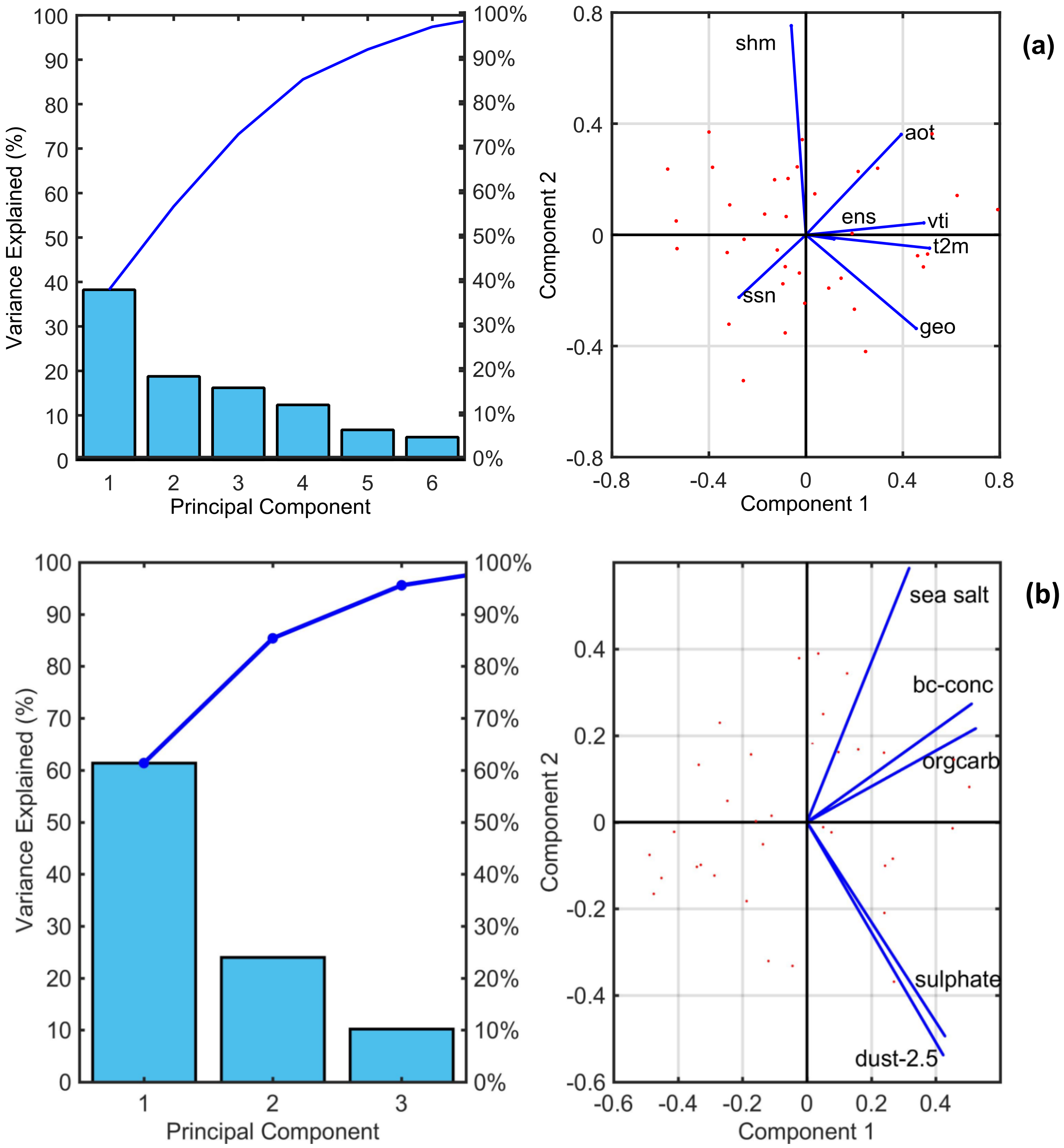

Figure S5. Principle Component Analysis results for various controlling factors on DDF for region 1a, (a) using general parameters like total aerosols, SSN, ENSO and humidity (b) Variation of DDF corresponding to 5 aerosol components such as BC, Dust PM 2.5, OC, Sea Salt and Sulphates.

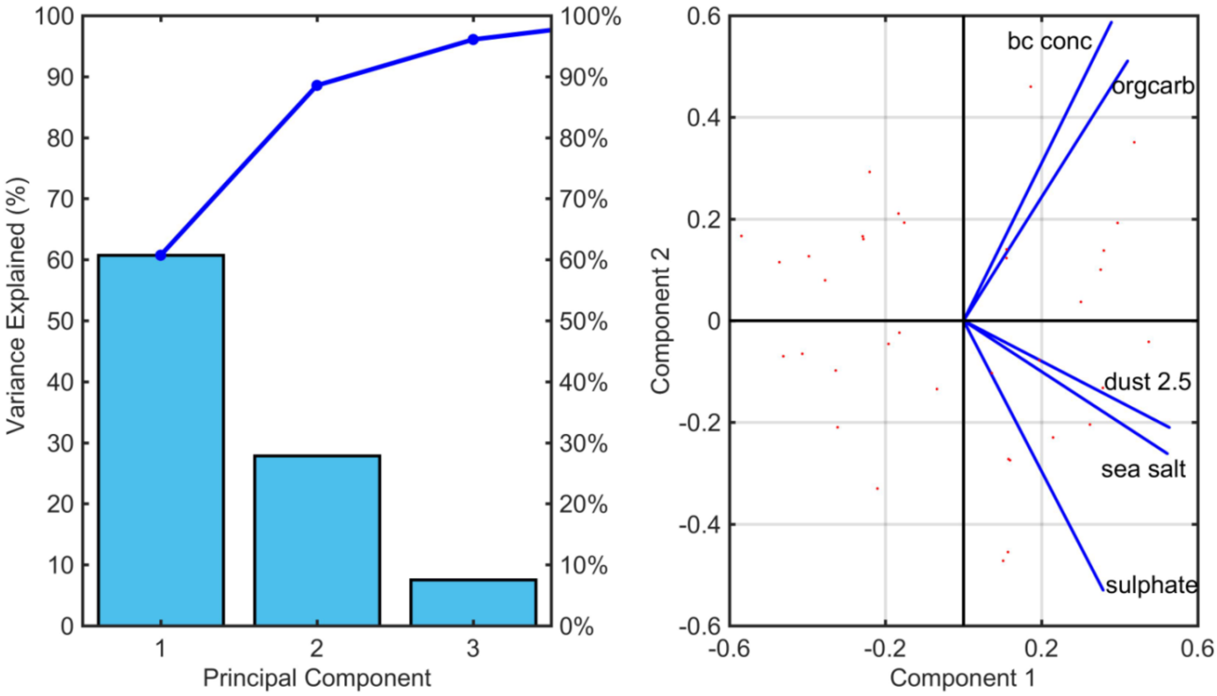

Figure S6. Principle Component Analysis results for various controlling factors on DDF for Lucknow corresponding to 5 aerosol components such as BC, Dust PM 2.5, OC, Sea Salt and Sulphates.

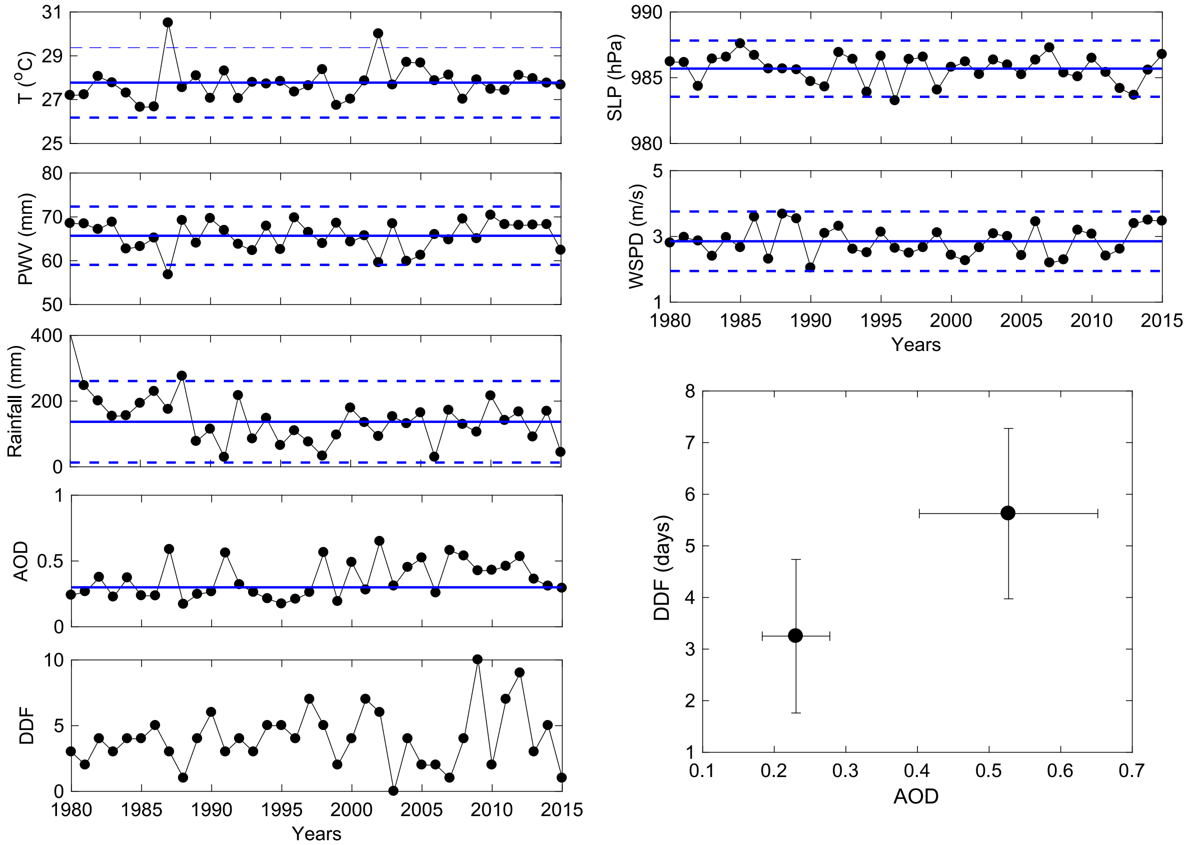

Figure S7. Effect of various meteorological parameters such as surface temperature, pressure, PWV, winds and rainfall along with average AOD during 16-31 July with DDF during 1-15 August.

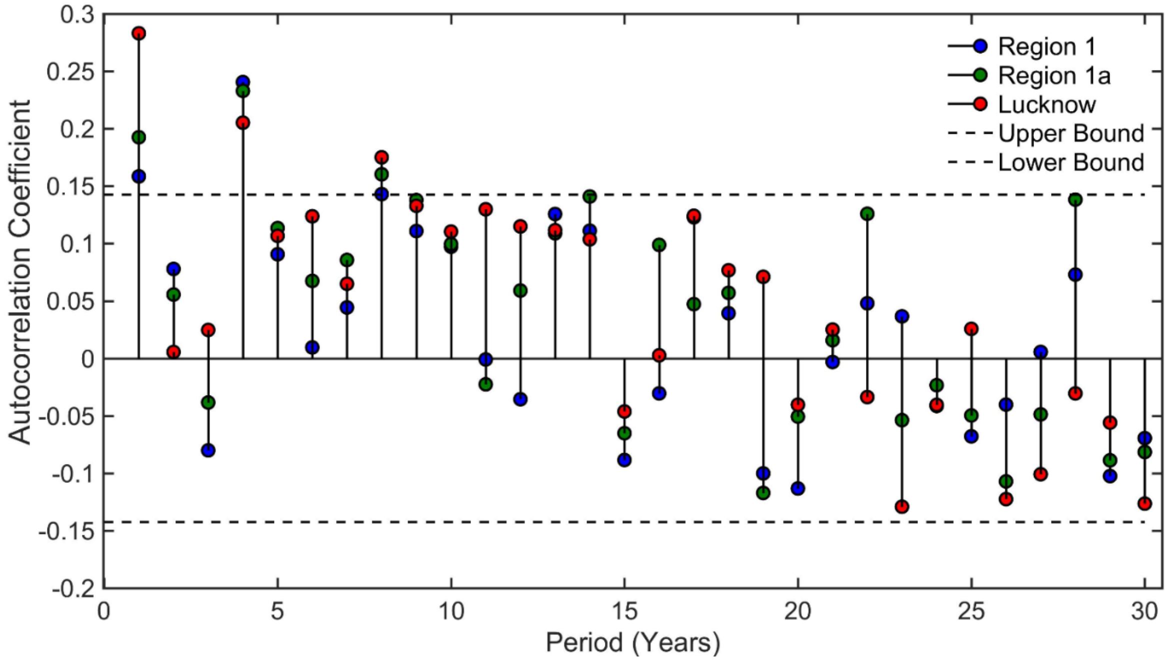

Figure S8. Demonstrating the effect of various periodicities in the trends of DDF in August for Region 1, 1a and Lucknow along with 1 sigma confidence bounds.

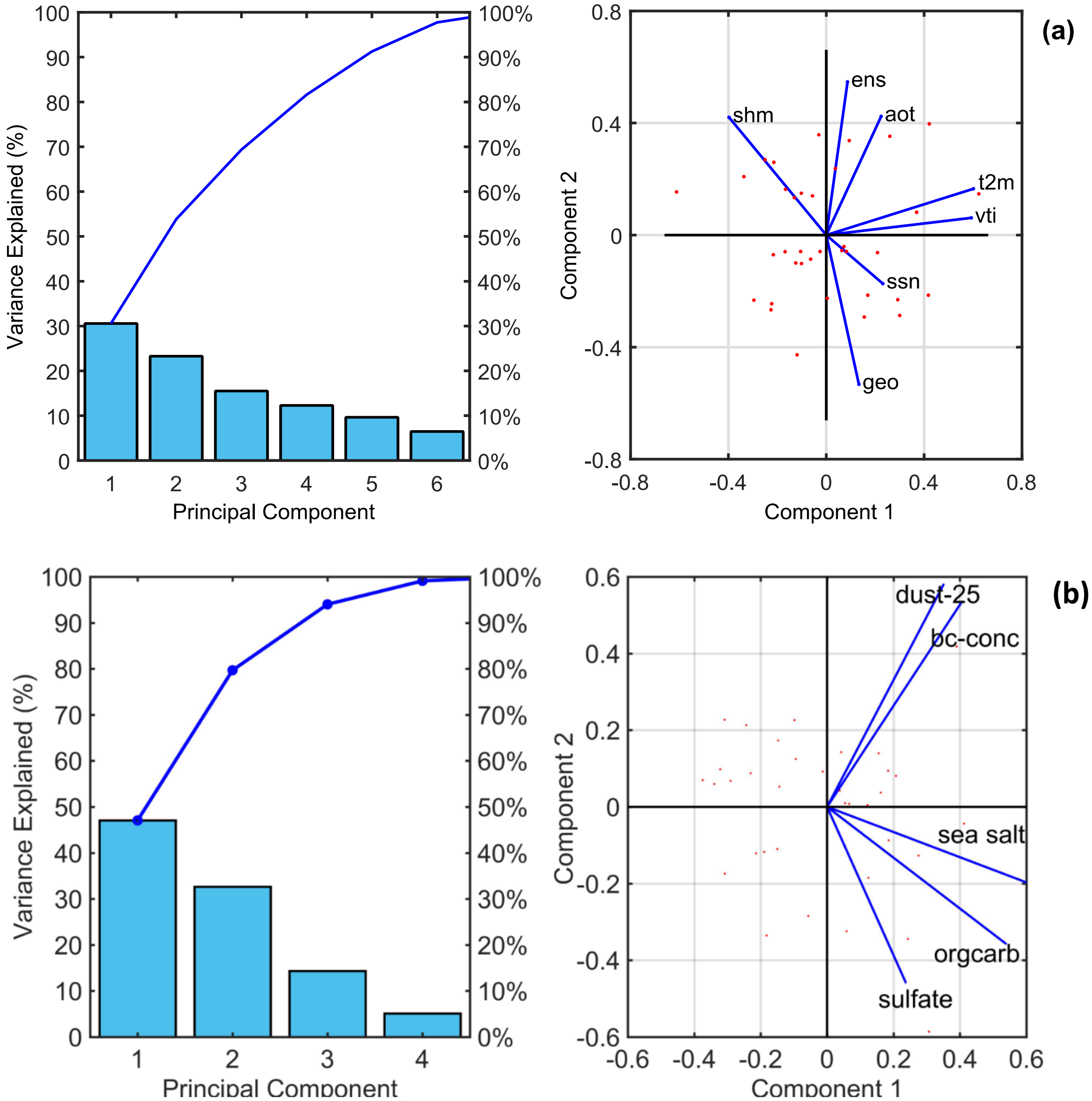

Figure S9. Principle Component Analysis results for various controlling factors on DDF for region 3, (a) using general parameters like total aerosols, SSN, ENSO and humidity (b) Variation of DDF corresponding to 5 aerosol components such as BC, Dust PM 2.5, OC, Sea Salt and Sulphates.

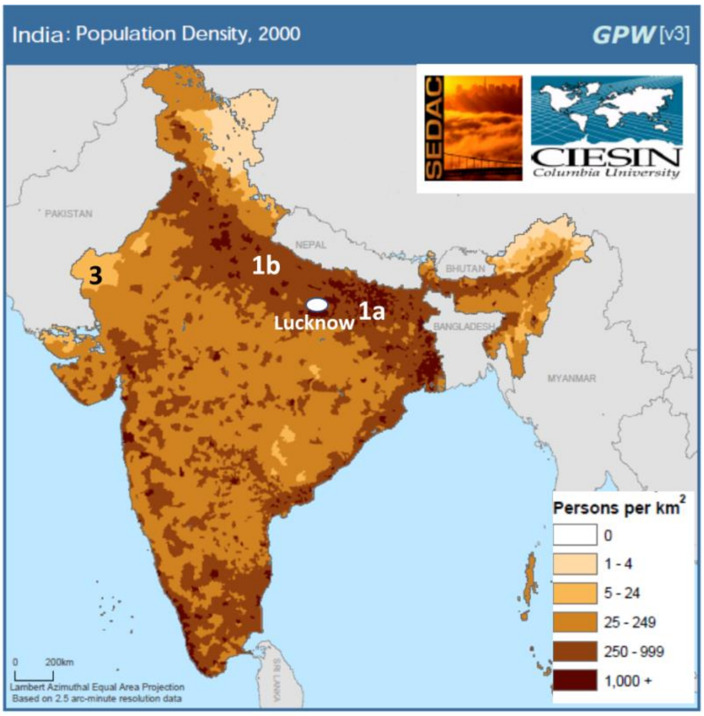

Figure S10. District-wise average population densities according to SEDAC in 2000.

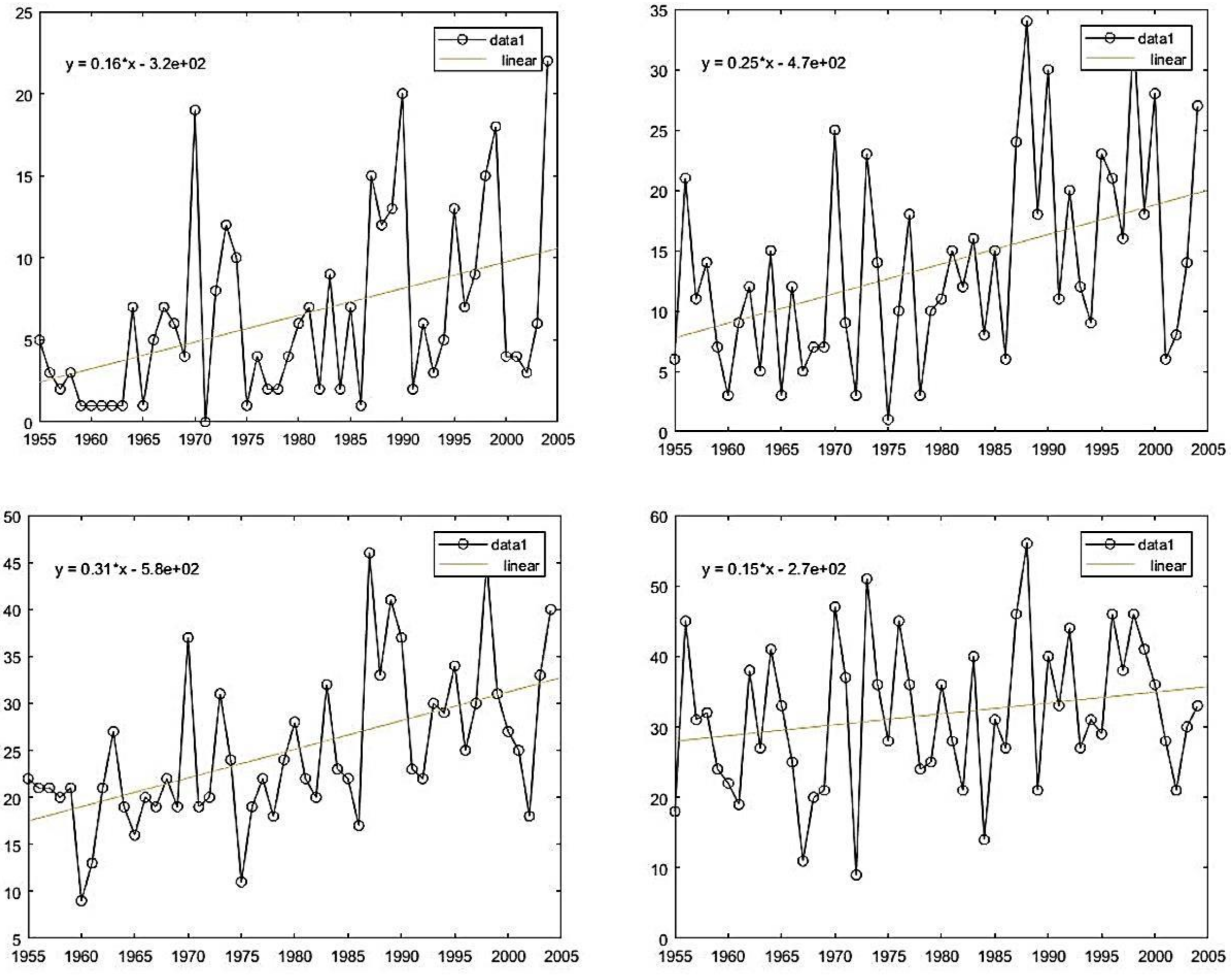

Figure S11. Demonstration of trends in DDF from multi model mean historical datasets of 3 GCMs during 1955-2005.

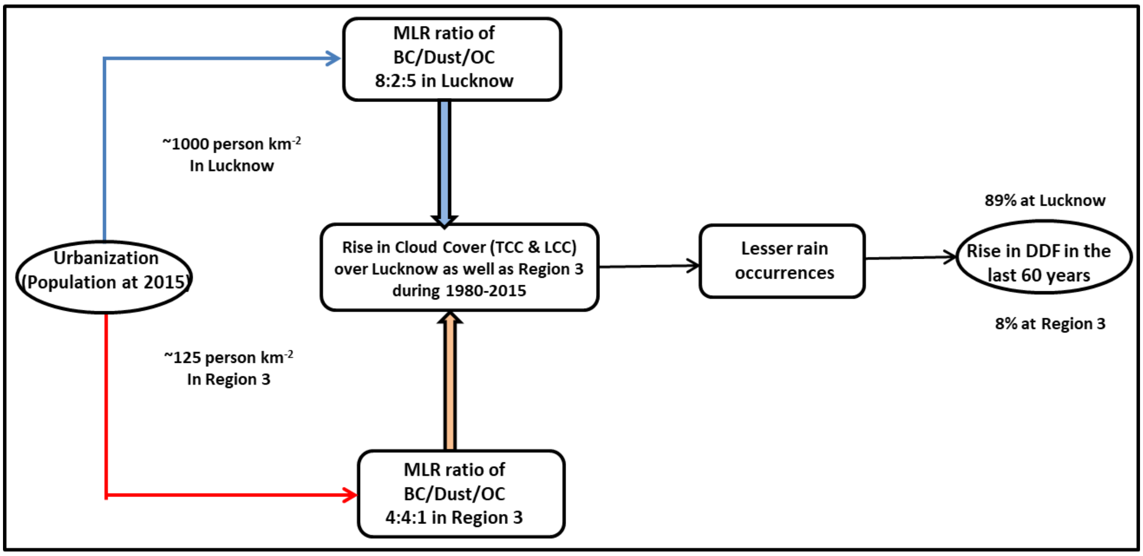

Figure S12. Possible mechanism behind the extension of drying phases in Lucknow and region 3 during the mid-monsoon period.