Two decades of aerosol trends over India: Seasonal characteristics and urban-rural dynamics - Supplementary Materials

Tables

The table given below shows all the CAAQMS sensor locations with coordinates from where the ground $PM_{2.5}$ concentration data is gathered.

Table S1 Monitoring stations' location and data availability

Location Name	Latitude	Longitude	Data Availability
ITO, Delhi	28.62	77.24	Nov 16' – Active
Lodhi Road, Delhi	28.59	77.22	Nov 17' – Active
Chandni Chowk, Delhi	28.65	77.22	Dec 20' – Jun 22' (Data not available after)
Powai, Mumbai	19.13	72.91	Nov 19' – Active
Chhatrapati Shivaji Intl. Airport (T2), Mumbai	19.10	72.87	Oct 19' – Active
Bandra, Mumbai	19.06	72.84	Sep 18' – Oct 20' (Data not available after)
FTI Kidwai Nagar, Kanpur	26.42	80.32	Oct 21' – Active
IITK, Kanpur	26.51	80.23	Jan 21' – Active
Nehru Nagar, Kanpur	26.47	80.32	Sep 15' – Active
NSI Kalyanpur, Kanpur	26.50	80.25	Oct 21' – Active

Table S2 Percentage area (sq m) of urban regions across Indian states used in the classification and analysis of urban, peri-urban, and rural areas

State Name	State Area (in m2)	Urban Area	Peri Urban Area	Rural Area	Percentage (Urban)
Andaman & Nicobar	7.34E+09	5.40E+07	2.88E+07	7.26E+09	0.74
Andhra Pradesh	1.64E+11	3.10E+09	4.16E+09	1.56E+11	1.9
Arunachal Pradesh	8.21E+10	0	0	8.21E+10	0
Assam	7.86E+10	1.02E+09	1.50E+09	7.61E+10	1.3
Bihar	9.44E+10	5.85E+09	8.30E+09	8.02E+10	6.19
Chandigarh	1.15E+08	1.08E+08	8783143	0.00E+00	93.9
Chhattishgarh	1.36E+11	1.81E+09	2.41E+09	1.31E+11	1.34
Daman and Diu and Dadra and Nagar Haveli	5.83E+08	1.07E+08	1.03E+08	3.73E+08	18.35
Delhi	1.49E+09	1.14E+09	3.71E+08	0.00E+00	76.61
Goa	3.71E+09	2.65E+08	2.86E+08	3.16E+09	7.13
Gujarat	1.88E+11	4.05E+09	5.25E+09	1.79E+11	2.15
Haryana	4.42E+10	2.17E+09	3.42E+09	3.87E+10	4.91
Himachal Pradesh	5.57E+10	3.36E+08	4.75E+08	5.49E+10	0.6
Jammu and Kashmir	5.76E+10	9.80E+08	1.33E+09	5.53E+10	1.7
Jharkhand	8.00E+10	2.52E+09	3.31E+09	7.42E+10	3.15
Karnataka	1.92E+11	4.36E+09	5.49E+09	1.83E+11	2.27
Kerala	3.90E+10	6.09E+09	5.68E+09	2.72E+10	15.64
Ladakh	1.67E+11	0	0	1.67E+11	0
Lakshadweep	3.34E+07	0	0	3.34E+07	0
Madhya Pradesh	3.09E+11	3.64E+09	5.03E+09	3.00E+11	1.18
Maharashtra	3.08E+11	7.30E+09	8.91E+09	2.92E+11	2.37
Manipur	2.24E+10	2.42E+08	3.42E+08	2.18E+10	1.08
Meghalaya	2.25E+10	7.38E+07	1.27E+08	2.23E+10	0.33
Mizoram	2.11E+10	2.85E+07	4.43E+07	2.11E+10	0.14
Nagaland	1.66E+10	6.06E+07	7.40E+07	1.65E+10	0.36
Odisha	1.56E+11	2.05E+09	2.91E+09	1.51E+11	1.31
Puducherry	3.61E+08	1.23E+08	8.63E+07	1.51E+08	34.18
Puducherry	3.79E+07	0	0	3.79E+07	0
Punjab	5.04E+10	2.02E+09	2.71E+09	4.57E+10	4.01
Rajasthan	3.43E+11	4.24E+09	5.78E+09	3.33E+11	1.24
Sikkim	7.12E+09	0	0	7.12E+09	0
Tamilnadu	1.31E+11	6.50E+09	7.98E+09	1.16E+11	4.98
Telengana	1.12E+11	2.25E+09	2.77E+09	1.07E+11	2
Tripura	1.05E+10	2.01E+08	2.54E+08	1.00E+10	1.92
Uttar Pradesh	2.41E+11	1.00E+10	1.35E+10	2.18E+11	4.15
Uttarakhand	5.35E+10	8.10E+08	1.03E+09	5.16E+10	1.51
West Bengal	8.38E+10	9.49E+09	1.08E+10	6.35E+10	11.33
Total (India)	3.28E+12	8.30E+10	1.04E+11	3.09E+12	2.53

Table S3 This table presents the Mann-Kendall Trend Test results for Aerosol Optical Depth (AOD) data across various states from 2001 to 2019. The test identifies whether a trend exists in the time series data for each state. We consider a threshold of 0.05 to determine statistical significance in this study.

State	Trend	p-value	Tau
Andaman & Nicobar	increasing	$p < 0.05$	0.684
Andhra Pradesh	increasing	$p < 0.05$	0.789
Arunachal Pradesh	increasing	$p < 0.05$	0.474
Assam	increasing	$p < 0.05$	0.637
Bihar	increasing	$p < 0.05$	0.778
Chandigarh	increasing	$p < 0.05$	0.427
Chhattisgarh	increasing	$p < 0.05$	0.836
Daman and Diu and Dadra and Nagar Haveli	increasing	$p < 0.05$	0.684
Delhi	no trend	0.36	0.158
Goa	increasing	$p < 0.05$	0.661
Gujarat	no trend	0.48	0.123
Haryana	no trend	0.05	0.333
Himachal Pradesh	no trend	0.23	0.205
Jammu and Kashmir	increasing	$p < 0.05$	0.357
Jharkhand	increasing	$p < 0.05$	0.731
Karnataka	increasing	$p < 0.05$	0.766
Kerala	increasing	$p < 0.05$	0.684
Ladakh	increasing	$p < 0.05$	0.345
Lakshadweep	increasing	$p < 0.05$	0.544
Madhya Pradesh	increasing	$p < 0.05$	0.766
Maharashtra	increasing	$p < 0.05$	0.825
Manipur	increasing	$p < 0.05$	0.450
Meghalaya	increasing	$p < 0.05$	0.637
Mizoram	increasing	$p < 0.05$	0.556
Nagaland	increasing	$p < 0.05$	0.497
Odisha	increasing	$p < 0.05$	0.778
Puducherry	increasing	$p < 0.05$	0.567
Puducherry	increasing	$p < 0.05$	0.614
Punjab	increasing	$p < 0.05$	0.520
Rajasthan	no trend	0.09	0.287
Sikkim	no trend	0.2	0.216
Tamil Nadu	increasing	$p < 0.05$	0.708
Telangana	increasing	$p < 0.05$	0.778
Tripura	increasing	$p < 0.05$	0.661
Uttar Pradesh	increasing	$p < 0.05$	0.661
Uttarakhand	no trend	0.23	0.205
West Bengal	increasing	$p < 0.05$	0.871

Figures

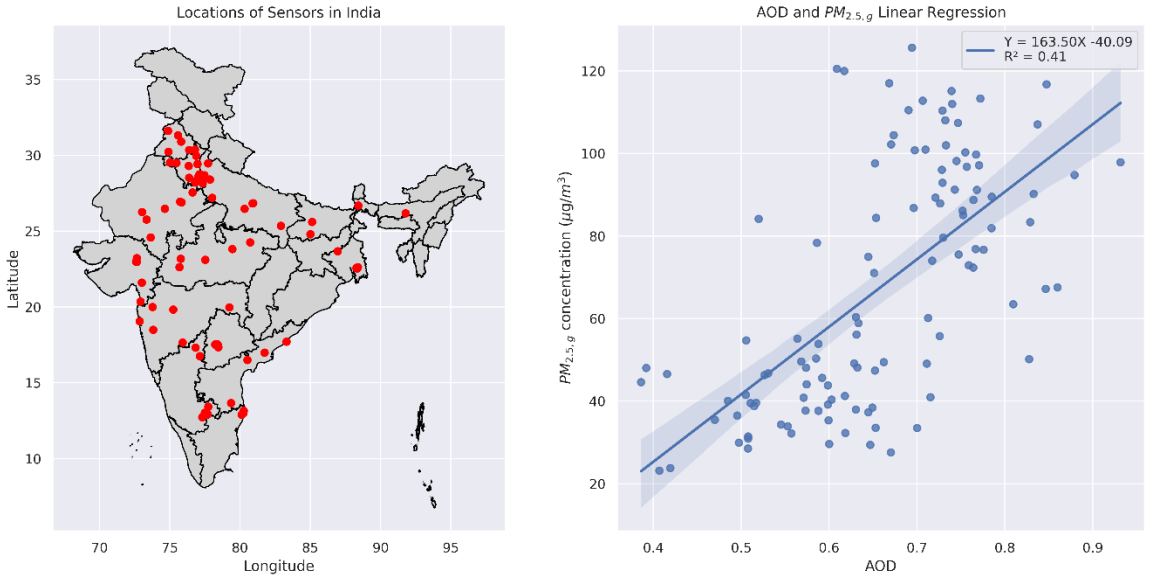

Figure S1 Association between $PM_{2.5,g}$ measured by CPCB sensors (n=114) within India and the overlaying satellite-derived AOD for the year 2019. The line of best fit and coefficient of determination are noted

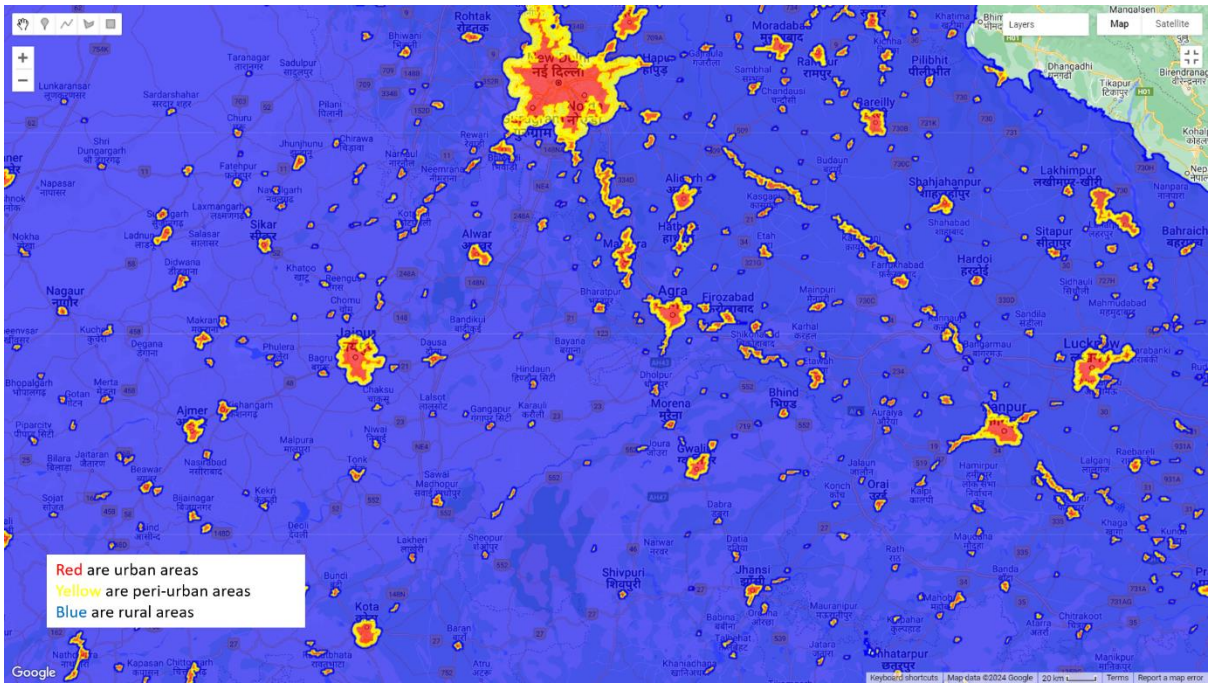

Figure S2 Snapshot over Delhi and surrounding regions marking the Urban (in Red), Peri-Urban (in Yellow) and Rural (in Blue) regions

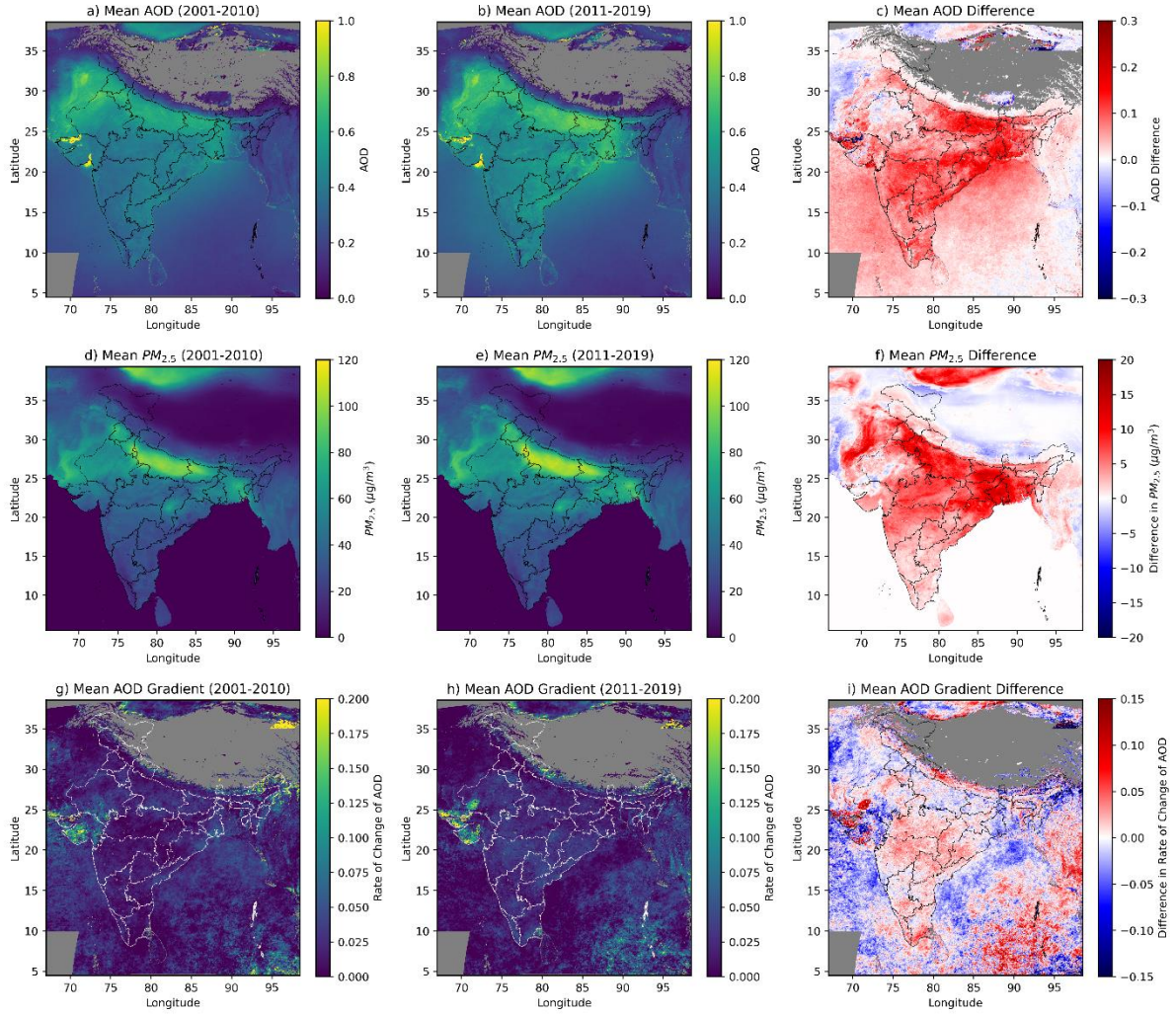

Figure S3 Geographical plots illustrate the mean AOD levels for the first decade (2001-2010) in (a) and the second decade (2011-2019) in (b), along with the difference between these two periods in (c). Additionally, satellite-derived mean $PM_{2.5}$ levels for the first decade and second decade (from (Van Donkelaar et al., 2021)) are shown in (d) and (e), with their difference presented in (f). The mean rate of change of AOD for the first and second decades is displayed in (g) and (h), and the difference between these rates is depicted in (i) (Grey color represents missing data)

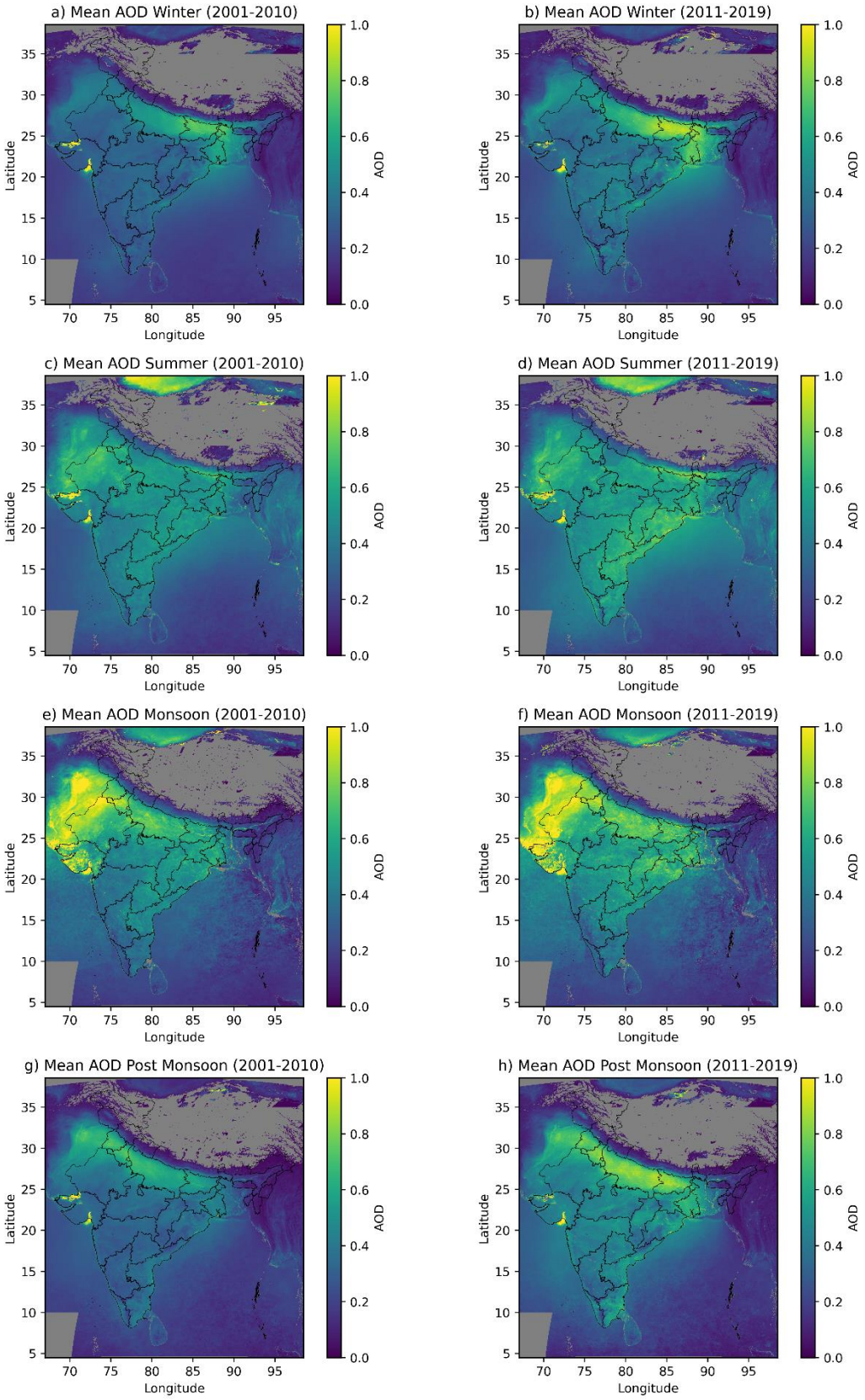

Figure S4 Geographical plots of mean AOD levels for each season over two decades. (a) and (b) show winter AOD for 2001-2010 and 2011-2019, (c) and (d) display summer AOD for the two decades, (e) and (f) present monsoon AOD, (g) and (h) show post-monsoon AOD. (Grey color represents missing data)

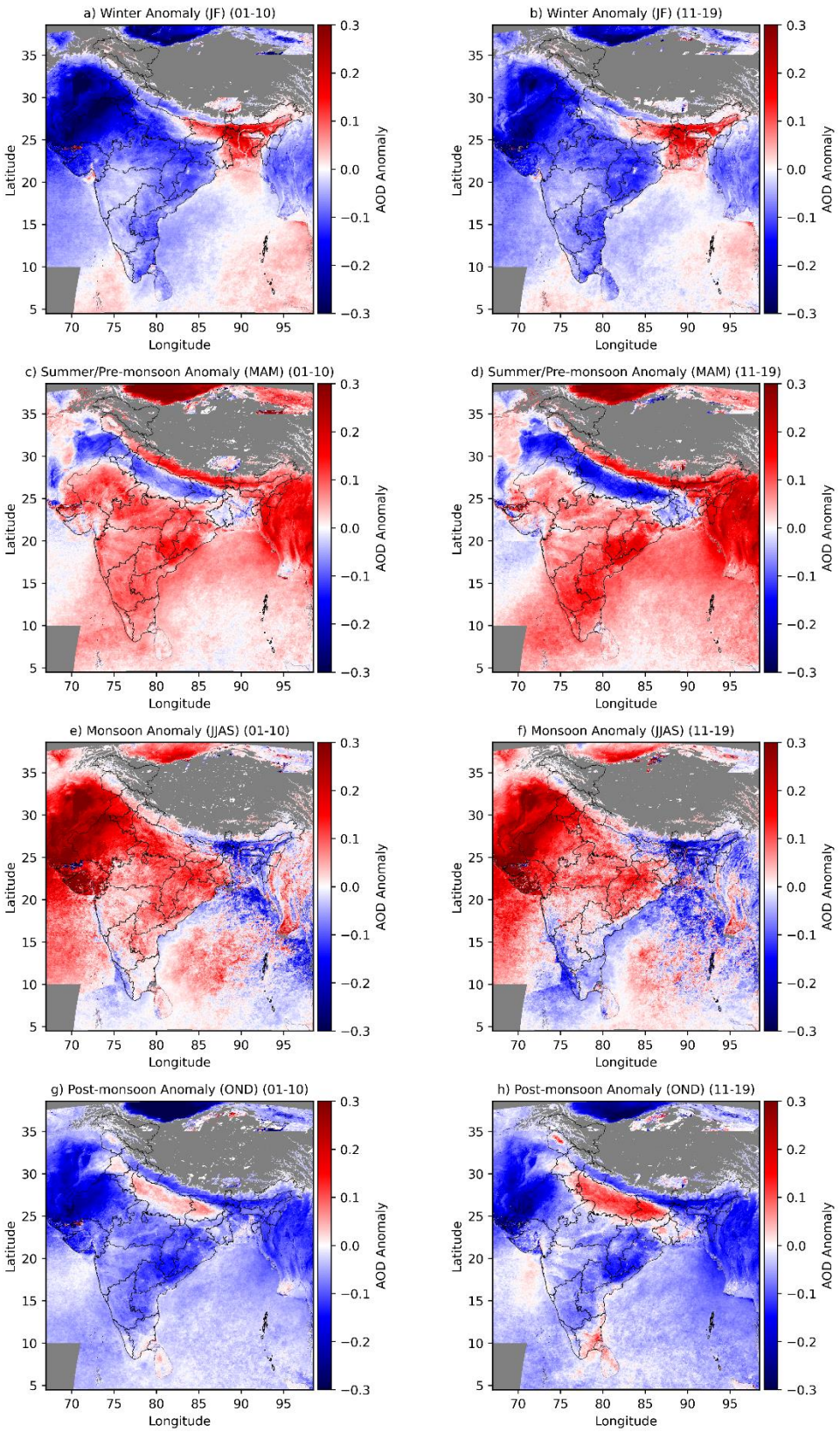

Figure S5 Geographical plots of seasonal AOD anomalies (difference in seasonal and annual AOD, averaged for the same time period) over two decades (a) show winter anomaly (01-10), (b) for (11-19), (c) depict summer anomaly (01-10), (d) for (11-19), (e) presents monsoon anomaly (01-10), (f) for (11-19), (g) shows post-monsoon anomaly for (01-10), (h) for (11-19) (Grey color represents missing data)

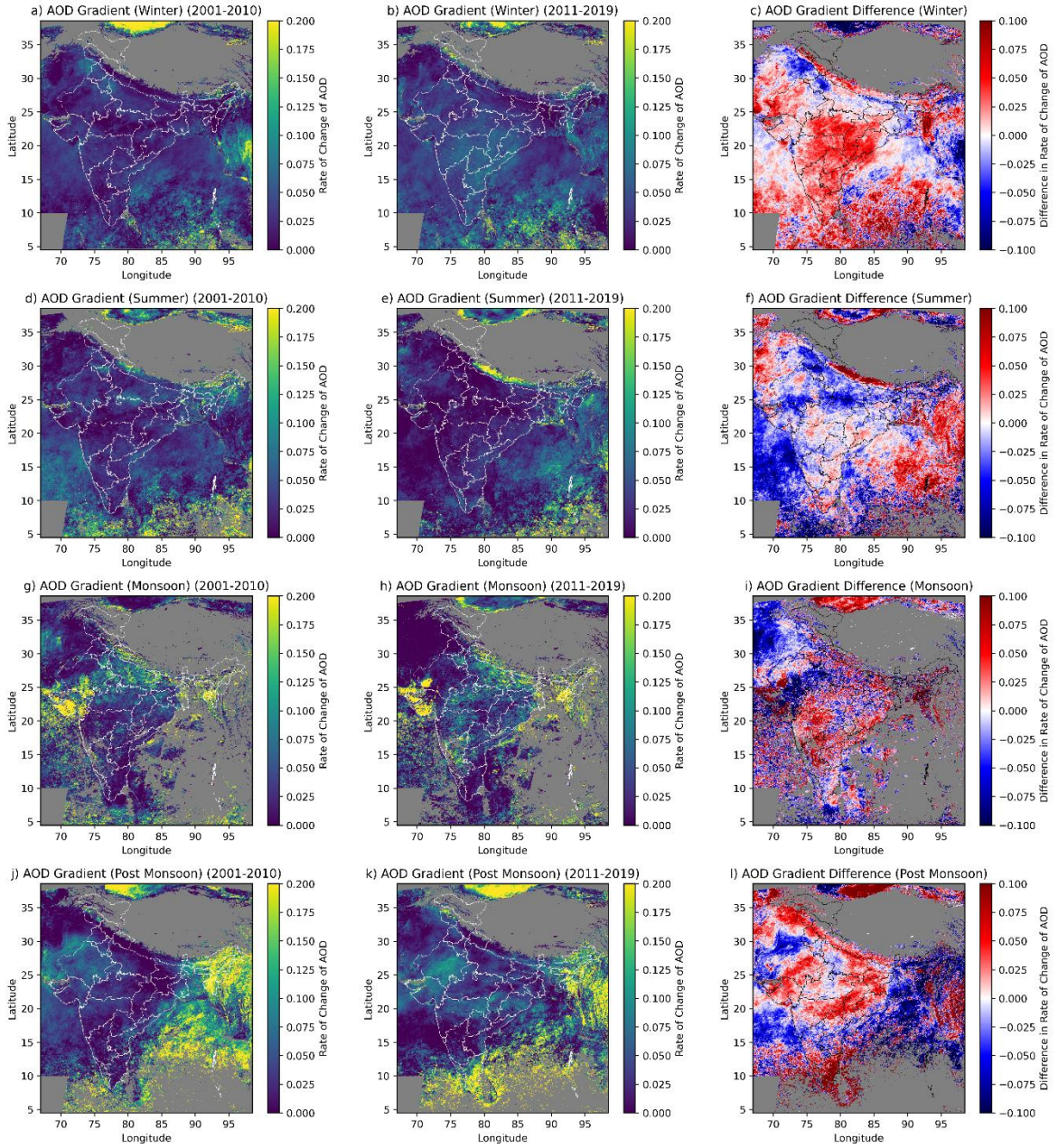

Figure S6 Geographical plots of mean AOD gradient for each season over two decades. (a) and (b) shows the winter AOD gradient for 2001-2010 and 2011-2019, with (c) showing the difference. (d) and (e) displays the summer AOD gradient for the two decades, with (f) showing the difference. (g) and (h) presents the monsoon AOD gradient, with (i) illustrating the difference. (j) and (k) show post-monsoon AOD gradient, with (l) depicting the difference (Grey color represents missing data)

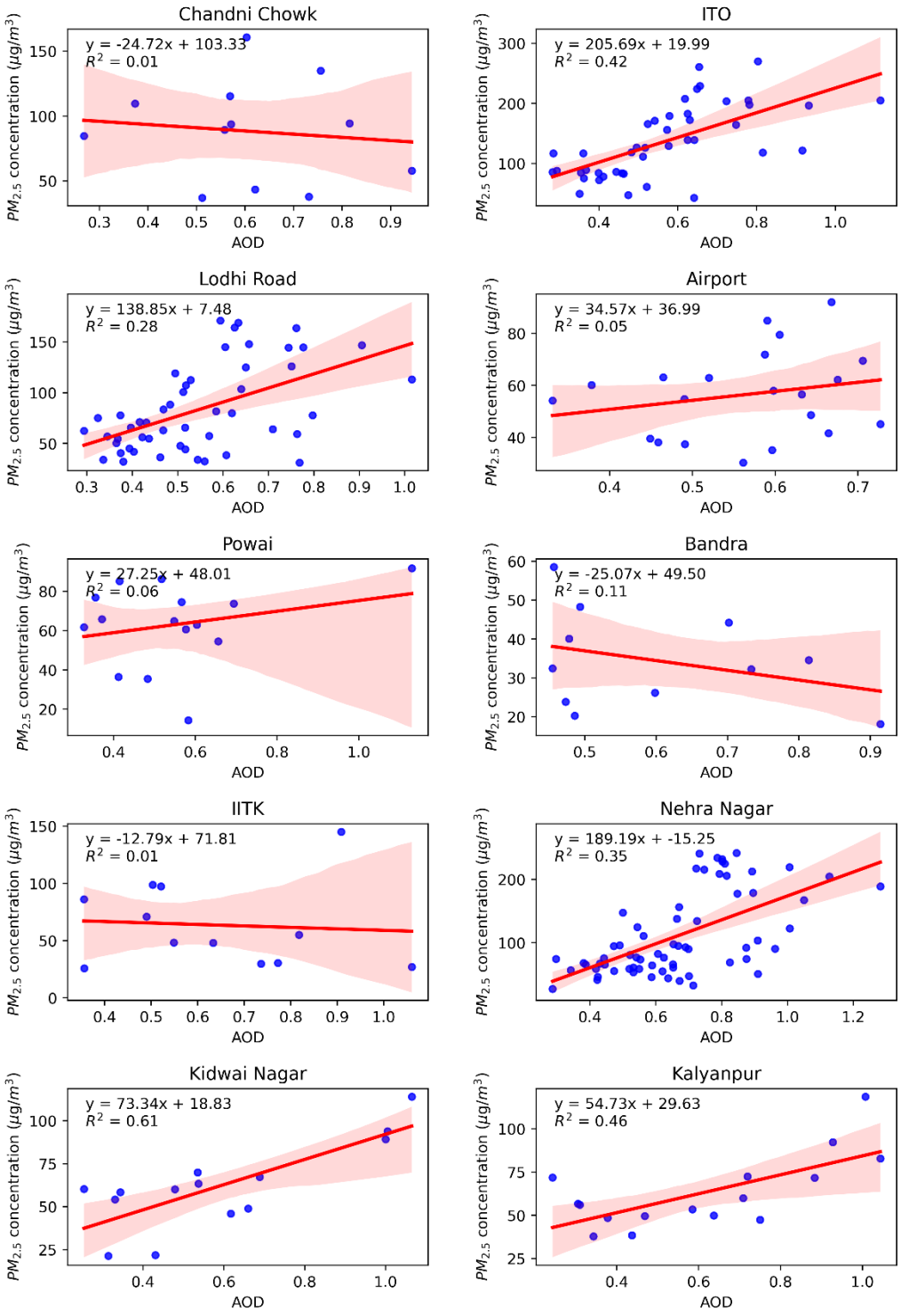

Figure S7 AOD and Ground-based $PM_{2.5}$ correlation plots for all 10 locations

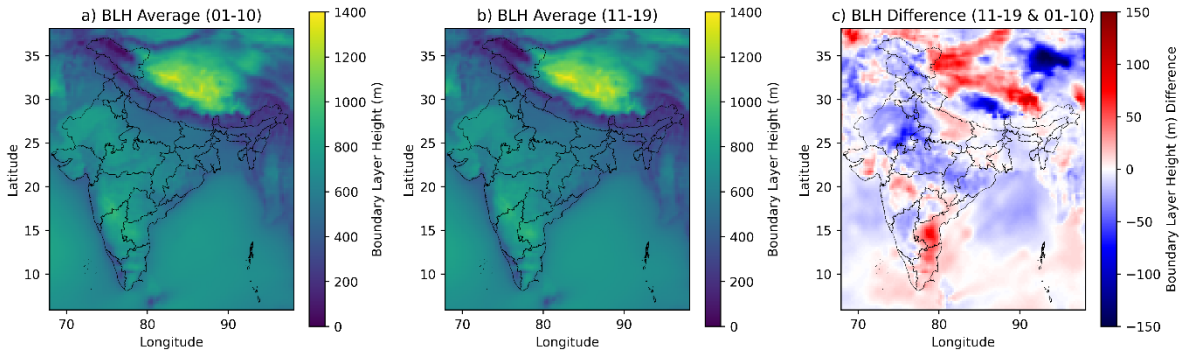

Figure S8 Boundary Layer Height (BLH) averages for India during the periods 2001-2010 (a) and 2011-2019 (b), and the difference in BLH between these two periods (c)

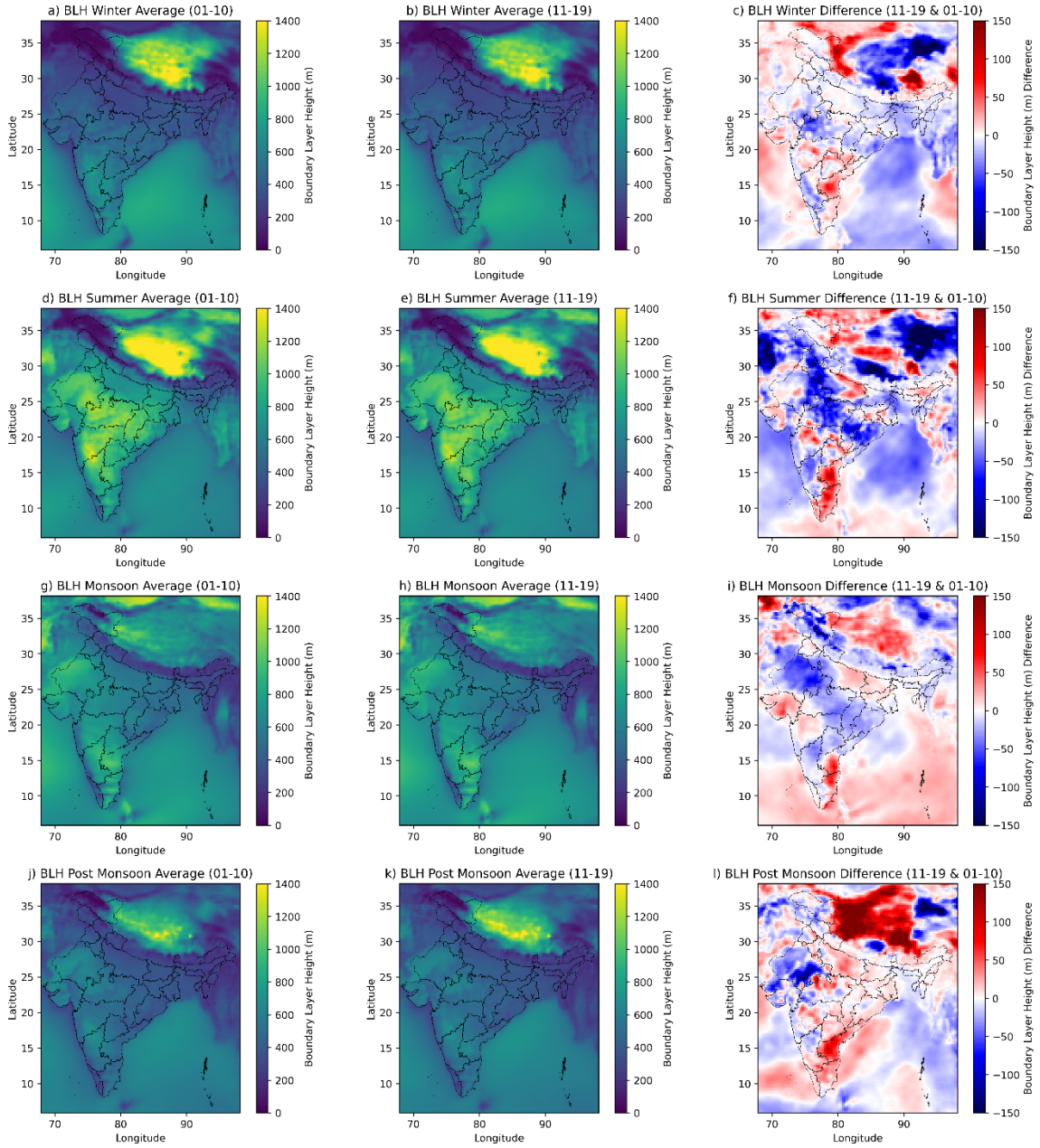

Figure S9 Boundary layer height averages for winter (2001-2010) in (a), winter (2011-2019) in (b), and the difference between the two periods in (c); summer (2001-2010) in (d), summer (2011-2019) in (e), and the difference between the two periods in (f); monsoon (2001-2010) in (g), monsoon (2011-2019) in (h), and the difference between the two periods in (i); post-monsoon (2001-2010) in (j), post-monsoon (2011-2019) in (k), and the difference between the two periods in (l)

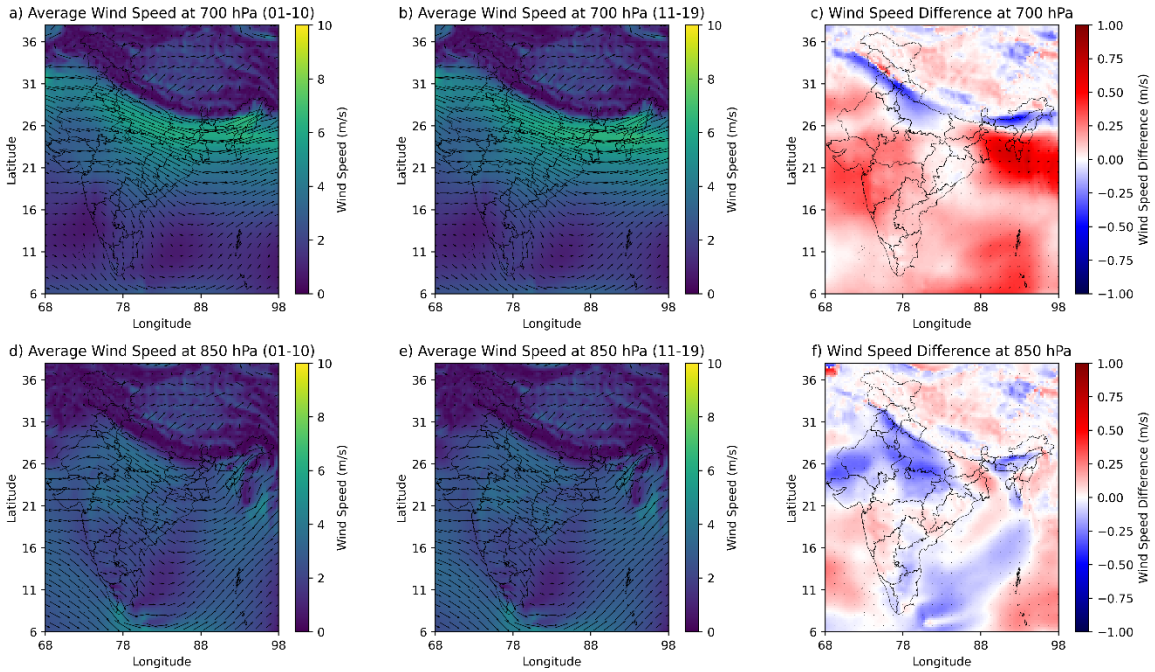

Figure S10 Wind Speed averages at 700 hPa for 2001-2010 (a), 2011-2019 (b), and the difference between the two periods (c); and similar plots at 850 hPa in (d), (e) and (f)

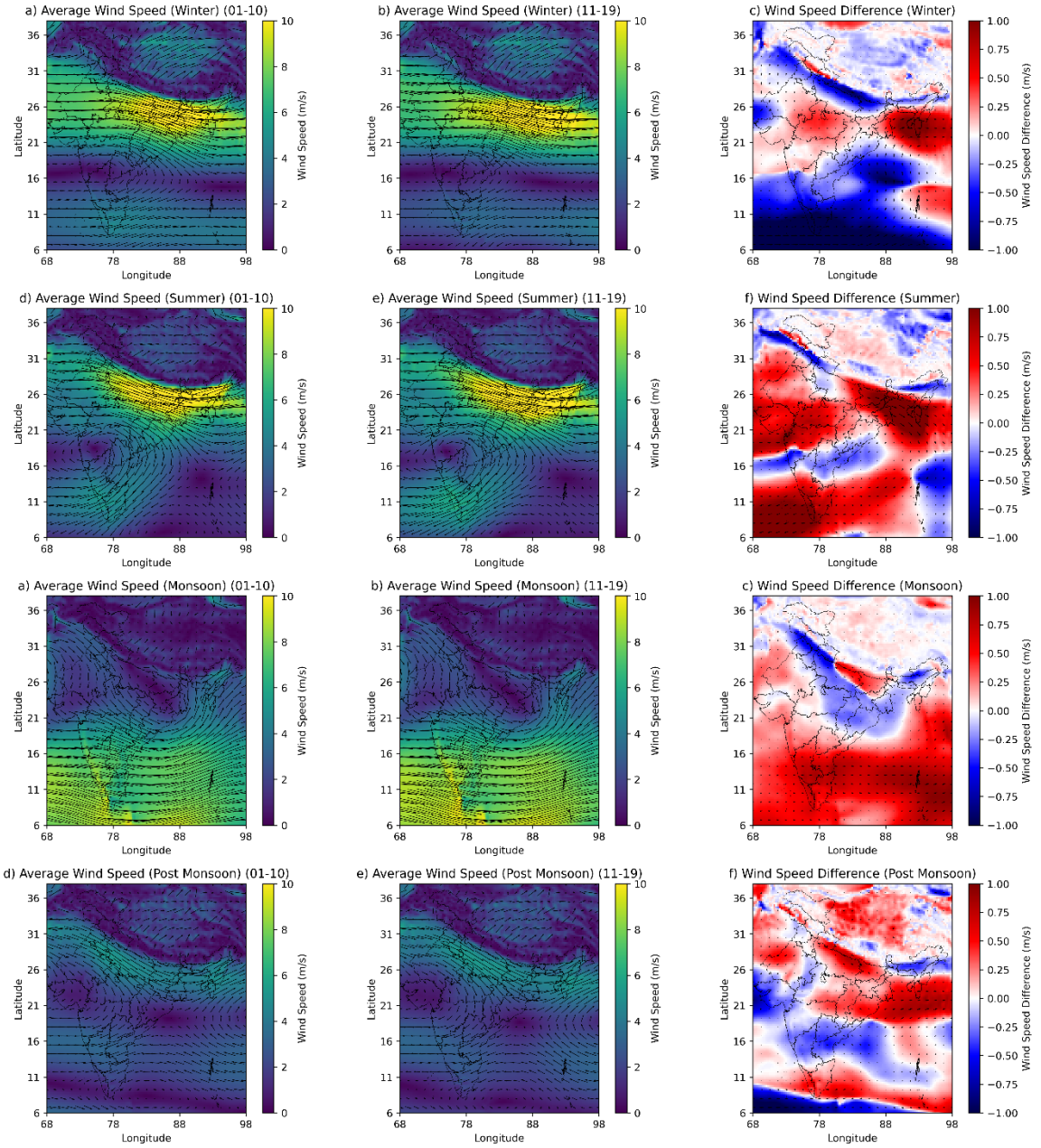

Figure S11 Wind Speed averages at the 700 hPa pressure level for winter (2001-2010) in (a), winter (2011-2019) in (b), and the difference between the two periods in (c); summer (2001-2010) in (d), summer (2011-2019) in (e), and the difference between the two periods in (f); monsoon (2001-2010) in (g), monsoon (2011-2019) in (h), and the difference between the two periods in (i); post-monsoon (2001-2010) in (j), post-monsoon (2011-2019) in (k), and the difference between the two periods in (l)

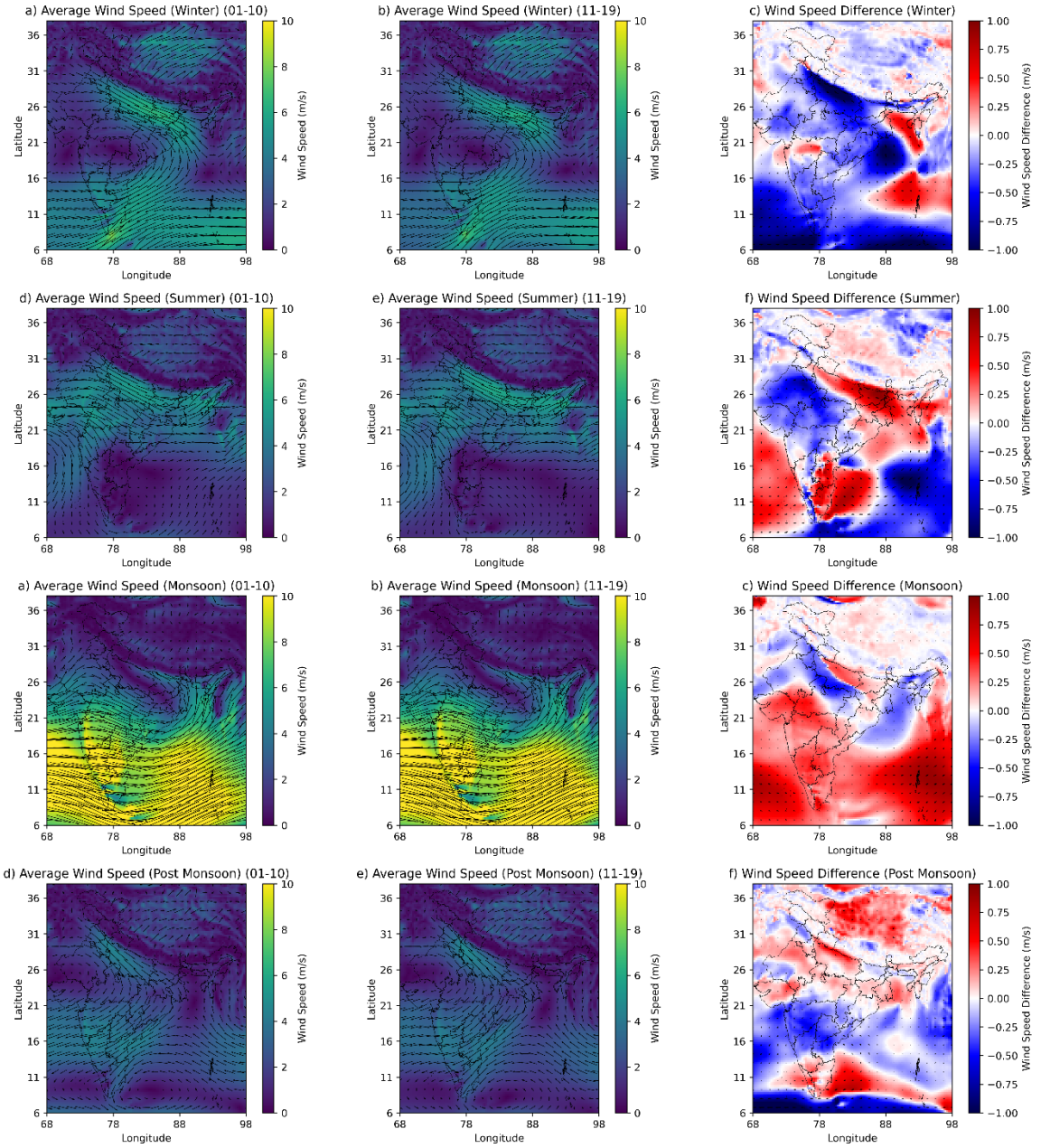

Figure S12 Wind Speed averages at the 850 hPa pressure level for winter (2001-2010) in (a), winter (2011-2019) in (b), and the difference between the two periods in (c); summer (2001-2010) in (d), summer (2011-2019) in (e), and the difference between the two periods in (f); monsoon (2001-2010) in (g), monsoon (2011-2019) in (h), and the difference between the two periods in (i); post-monsoon (2001-2010) in (j), post-monsoon (2011-2019) in (k), and the difference between the two periods in (l)