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Regional transport of aerosols from northern India and its impact on boundary layer height and air quality over Chennai, a coastal megacity in southern India

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Supplementary Table

Table S1. Details of the sample available for the present study from various instruments between December and March during 2015-2024. The RTE and clear days are segregated between 2015-2024; however, CALIPSO products are available between 2015-2023, and MPL is during 2018 and 2023

Instrument	**Data Availability (Days)**	
	RTE	**Clear**
MODIS	119	70
CALIPSO	61 (Day Passes) 51 (Night Passes)	41 (Day Passes) 30 (Night Passes)
MPL	10 Days	6 Days
Radiosonde	59 (Kolkata) 59 (Bhubaneswar) 103 (Vizag) 111 (Chennai) 66 (Karaikal)	30 (Kolkata) 25 (Bhubaneswar) 40 (Vizag) 55 (Chennai) 27 (Karaikal)
$PM_{2.5}$	117	54
AWS	72 (Chennai)	40 (Chennai)
MERRA2	119	70

Supplementary Figures

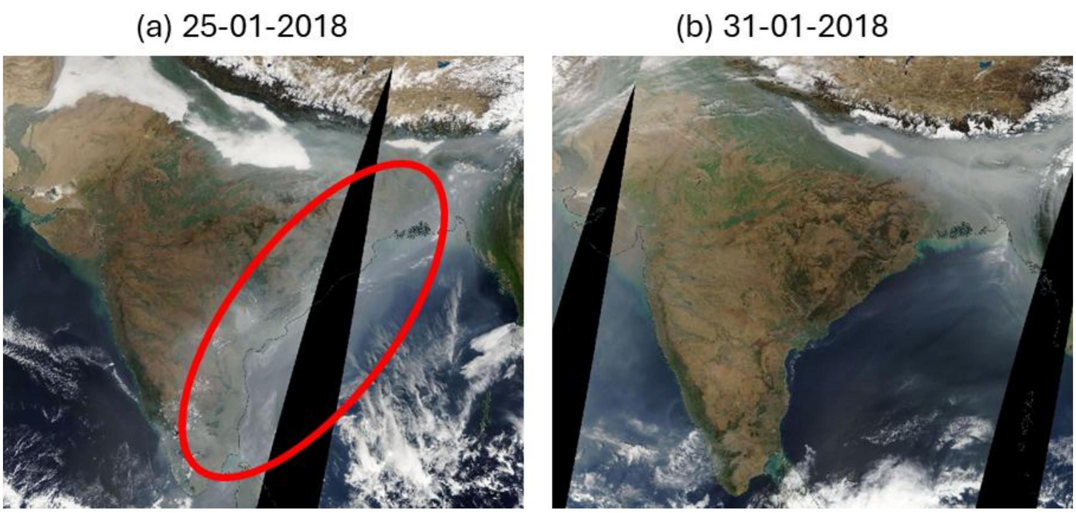

Figure S1. (a) A typical example of the aerosol transport occurrence from north India towards south observed from MODIS corrected reflectance (True Color) on 25-01-2018. The red circle denotes the transport and region of interest of RTE events. (b) A typical clear sky observation (31-01-2018).

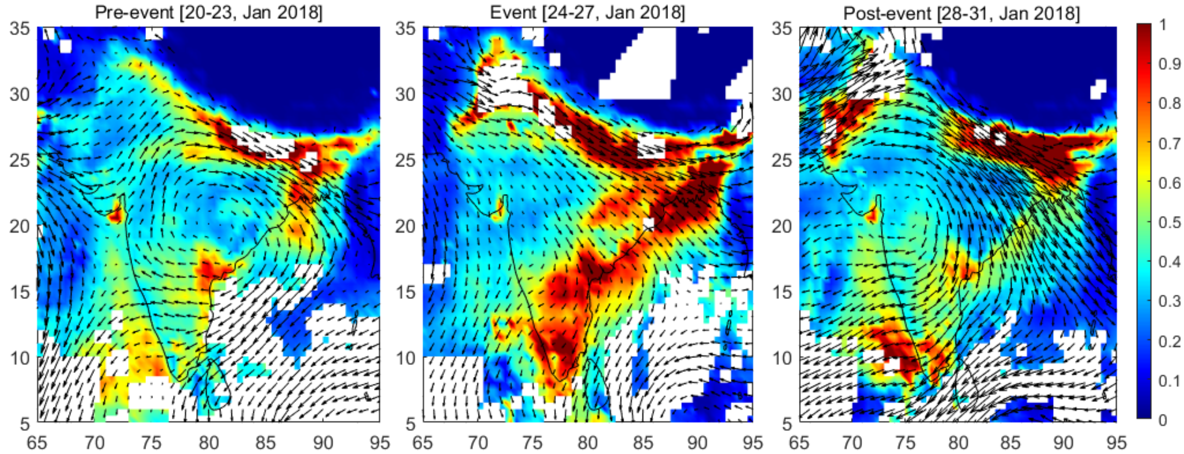

Figure S2. Spatial distribution of MODIS-AOD observations during (a)20-23 Jan 2018- before the RTE event occurs, (b) 24-27 Jan 2018 – during the RTE event, and (c) 28-31, after the RTE event

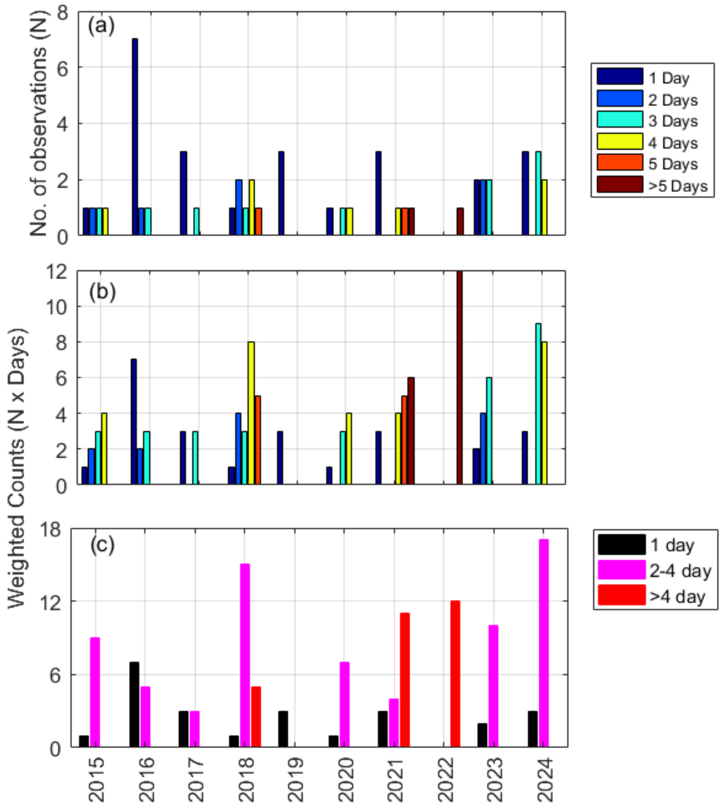

Figure S3. Annual variation of RTE occurrence duration. (a) Total number of observations (N) obtained for 1 day, 2 day, 3 day, 4 day, 5 day, and more than 5 day (colour coded separately). (b) The number of observations (N) weighted by the day bins, shown separately for different day bins. (c) Same as (b) but shown the cumulative counts for 1 day (black), 2-4 day (magenta), and more than 4 day (red)

The endurance of RTE days is estimated based on the prevalence of mean AOD obtained from MODIS observation, exceeding 0.7 over the eastern-coastal box, as shown in Fig.1a. Figure S2a shows the composite of the RTE days estimated between 2015 and 2024. The available RTE and clear days used in this study are provided in the supplementary table ST1. The RTE characterization are based on a day, as MODIS AOD products (Terra+ Aqua combined) are available for 1 day period only; hence diurnal variation of such aspects is not attempted using MODIS. The endurance of RTE events is estimated by taking the initial occurrence as day 1, till the eastern coastal box became a clear day. There are multiple times an RTE occurs in a year, and their duration can be from 1 day to 12 days. These multiple occurrences are termed as counts (N). The weighted counts are estimated by multiplying N by the respective days. For instance, the total observation of RTE endurance during 2015 for 1 day to 4 day is equal (Fig.S2a), but Fig.S2b signifies the duration of such episodes by adding weights to the day bins. Figure S2c shows a similar weighted observation as shown in Fig.R3b; however, it is shown for 1 day, and the cumulative weighted observation is between 2-4 days and more than 4 days. Note that, although a day between consecutive days is absent, e.g., the second day of three consecutive days of an event, it is counted in this statistic to overcome the instrument limitation.

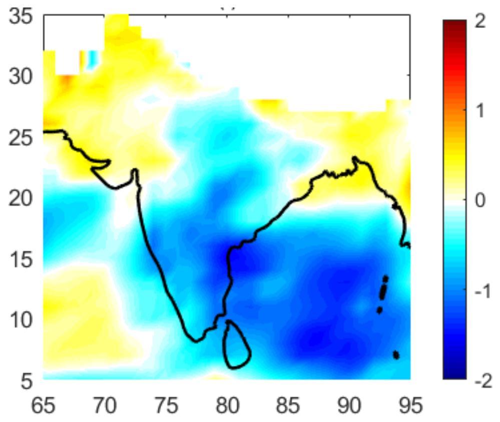

Figure S4. Composite of the difference in the wind speed between RTE and Clear days

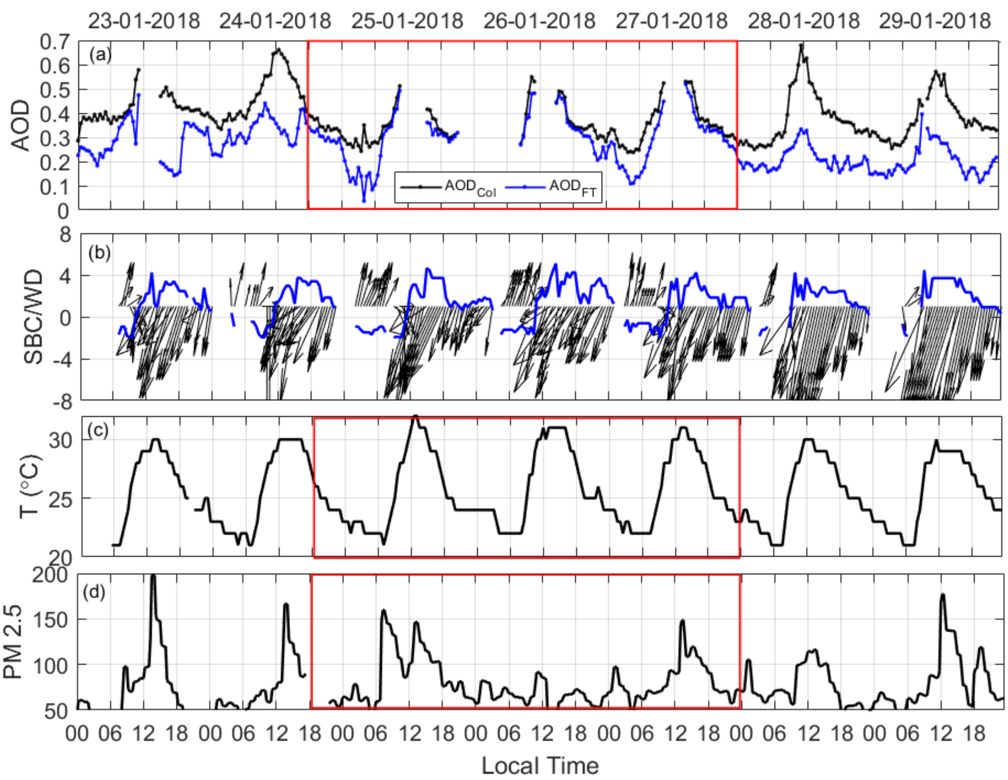

Fig. S5 Temporal variation of (a) AOD derived from MPL shown separately for the column (black) and above the ABL (blue), (b) wind parameters and sea breeze component, (c) surface temperature, and (d) PM 2.5 variation during 23-29 January 2018.

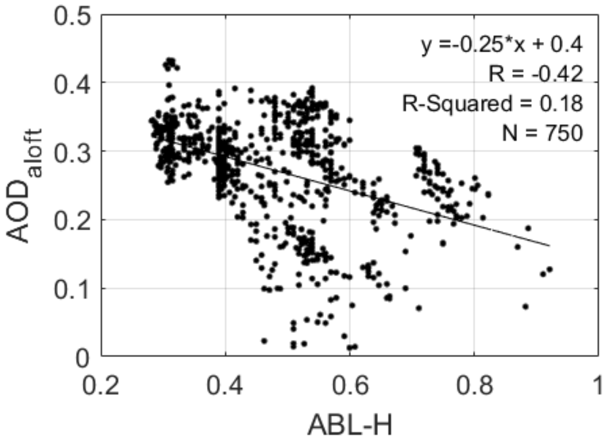

Figure S6. Scatter plot between ABL-H and AOD_{aloft} (integrated extinction above ABL-H).

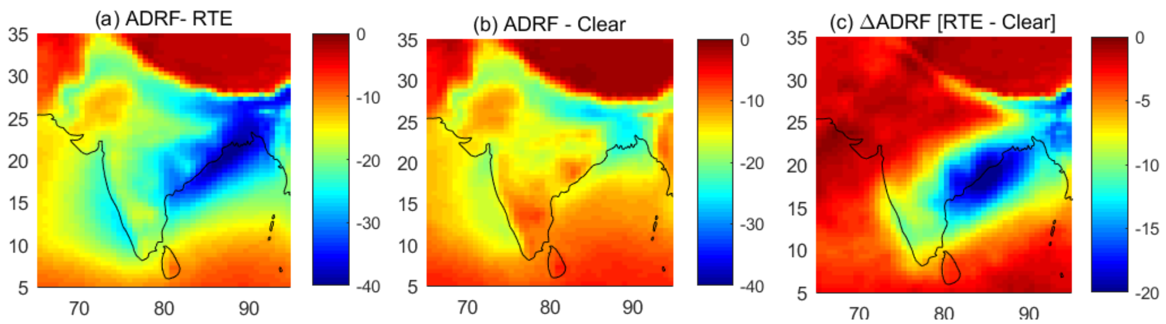

Figure S7. Aerosol Direct Radiative Forcing observed during the(a) RTE and (b) Clear days. (c) Difference between the ADRF of RTE and clear days

ST1. Uncertainties associated with the land and ocean swaths in the composite of aerosol extinction coefficients from CALIPSO observations

Figure. 2a and 2b show a rapid decrease in the extinction coefficient during the clear days compared to the RTE based on the CALIOP observation. The extinction coefficient shown for both the RTE and Clear day is averaged within a ±5 ° longitude box encompassing the eastern coast, and it covers both the land and ocean parts. There exists a difference in the extinction coefficient due to the contrast between the land and ocean swaths of the CALIPSO. To understand the land-sea contrast and ABL variation of the lat-lon box along the east coast of India, we have estimated the mean extinction coefficient for the RTE days as depicted in Figures S7 and S8.

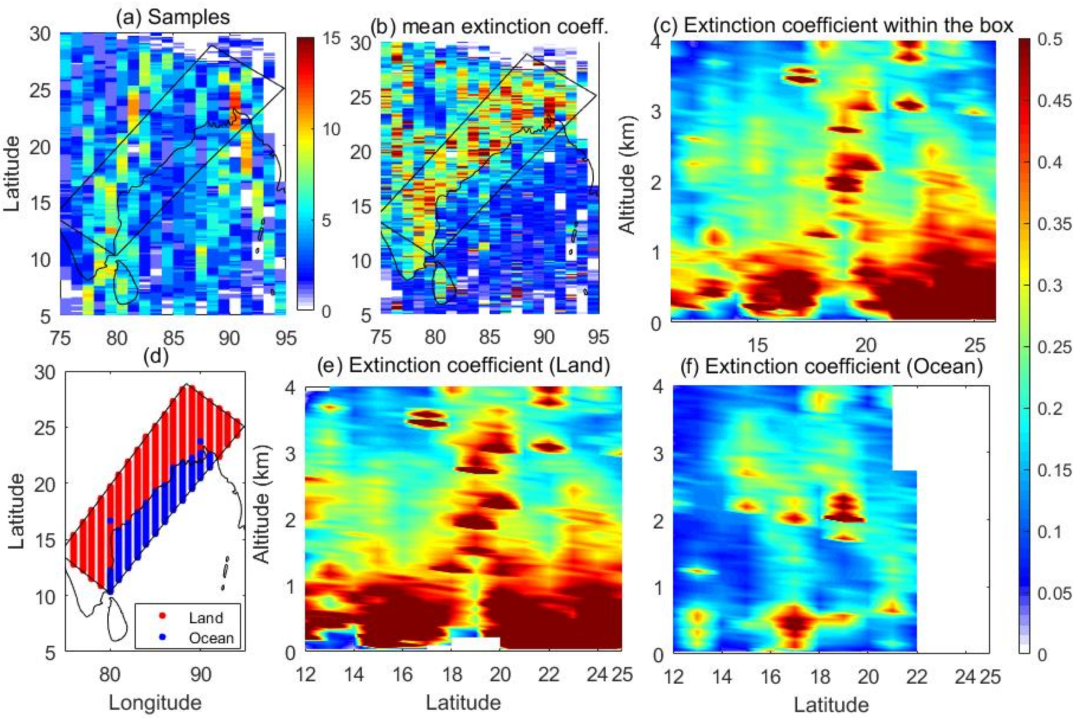

Figure S8. Spatial distribution of aerosol obtained from CALIOP along the eastern coast during the RTE days. (a) Number of valid aerosol data samples available in a 1 degree x 0.1 degree (lon x lat) grid box. (b) mean extinction coefficient and (c) vertical variation of aerosol extinction coefficient within the eastern coastal box portrayed in (a) and (b) for the RTE composites. (d) The land and ocean separation within the eastern coastal box. Latitude-altitude cross-section of the aerosol extinction coefficient over (e) land and (f) ocean.

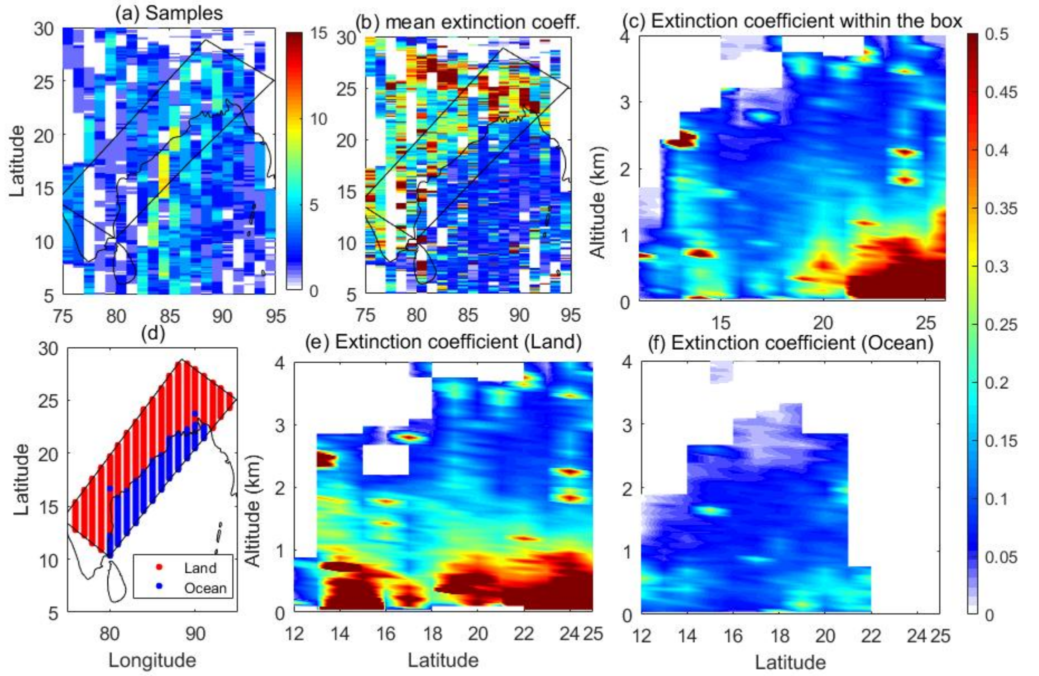

Figure S9. Same as Fig.S8 but for clear days

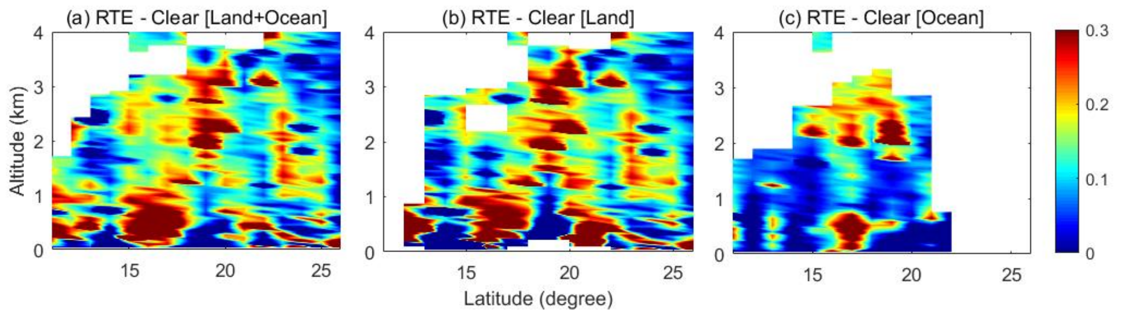

Figure S10. Difference in the extinction coefficient between RTE and clear days obtained separately for (a) Land and Ocean composites, (b) Land composites alone, and (c) Ocean composites alone

Fig.S7 and S8 show the spatial distribution of aerosol across the eastern coastal box during the RTE and clear days, respectively. It also shows that the number of valid aerosol data samples available is ~10-15 for the entire period December and March 2015 to 2023 to obtain the mean extinction coefficient over the box. The composite domain-mean and column-averaged aerosol extinction coefficient over land and sea was observed to be ~0.45 and 0.2, respectively, during the RTE days. In comparison, the composite mean aerosol extinction coefficient over land and sea during clear day was observed to be ~0.25 and 0.1, respectively, during the clear days. However, it observes more than 0.45 over the IGP regions during both the RTE and clear days. It is also interesting to observe that the extinction gradient is higher near the coast compared to away from it.

Fig. S7c shows the vertical variation of the aerosol extinction, indicating the higher aerosol concentration below the 2 km, which features the stronger concentrations with increasing latitude in the selected box, where the strong aerosol accumulation rises till 2.5-3.5 km. However, the aerosols are mostly concentrated below 1 km during clear days (Fig.S8c), confined to the higher latitudes only. Fig.S7e suggests that the overall gradient present in the extinction coefficient is mainly contributed by the land part. Since the marine boundary layer is often formed below 500 m, CALIOP observations are limited and have a large bias (Ananthavel et al., 2021) to fully resolve the distinction in the gradient over the ocean. However, the aerosol extinctions over the ocean during the RTE days (Fig.S7f) are observed to be higher (~0.2) than on clear days (Fig.S8f). It can also be noted an enhancement in the aerosol extinction coefficient at elevated heights (~1-3 km). Such enhancements can be attributed to the aerosol loading due to the transport. On the other hand, enhancement in the aerosol extinction coefficients is due to the aerosol loading within the boundary layer (<1 km) and also due to the TAL presence (~1-3 km)

The differences in the aerosol extinction coefficient between RTE and clear day composites are shown in Fig. S9, separately shown for the land and aerosol composites. It also suggests that the TAL enhances overall aerosol loading over the eastern coast, contributing to an enhancement of 0.2-0.3 compared to clear days, mostly confined over the land. On the other hand, it observes above the ABL (>1.5 km) over the oceanic region.