Observations of aerosol-induced fog thickening over North India

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Synopsis

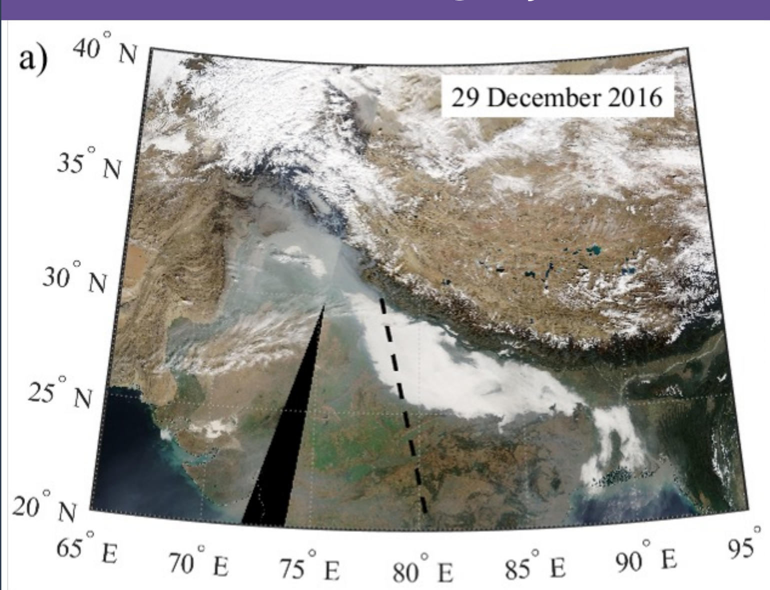
Fog events can cause widespread day-to-day disruptions to the public sectors leading to substantial economic losses over India and their frequency is increasing in recent decade. These fog events form in a heavy aerosol-laden environment over the Indian Gangetic Plains, one of the major global hotspots of aerosol pollution.

However, our understanding of aerosol-fog associations are very limited, mainly due to lack of co-located aerosol and fog samples. Here, we developed a novel detection algorithm for simultaneous fog and aerosol properties retrieval from 15 years of active remote sensing observations.

Results indicate a distinct linear relationship between the fog's top height (and hence thickness) and aerosol loading. Fog top height increased by ~42% from low aerosol loading to high aerosol loading scenario.

Although, meteorology can also play a role in the observed association but preliminary simulations using WRF-Chem conducted over the same region reveal a substantial influence of aerosol microphysical effect on fog occurrence and lifetime coverage over the central IGP.

CALIPSO based fog layer detection



Fog detection algorithm was developed and applied on 15 years (2006-2021) of CALIPSO profiles.

Around 1500 profiles of daytime fog layers coupled with surface (base height less than 75m) were identified.

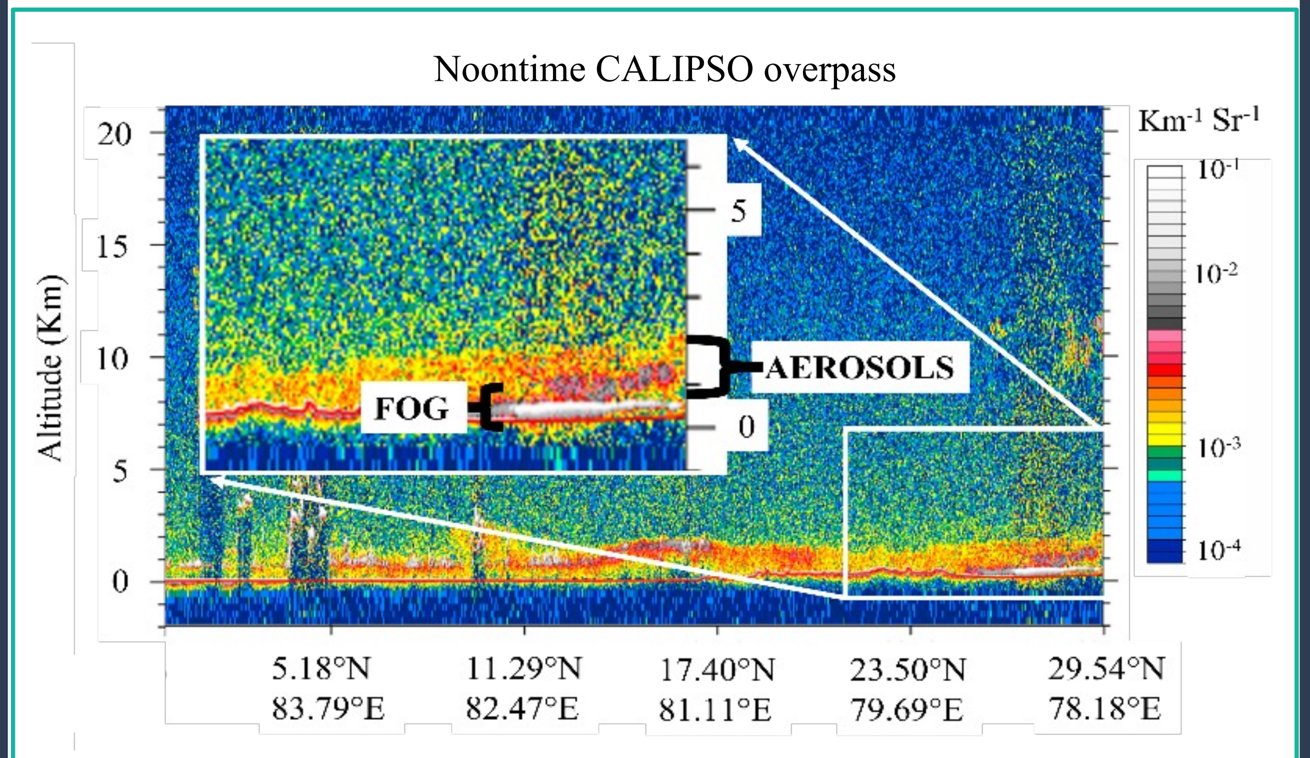


Figure 1a. True color snapshot of a fog event on 29 December 2016 by MODIS.
Figure 1b. Attenuated backscatter from CALIPSO profile corresponding date.

Results

1. Aerosol-associated fog thickening

Strong vertical linkages between the fog layer and the aerosol above the fog (AOD_{FOG}). We assume this aerosol to be the proxy for the whole columns AOD as this could be the remanent aerosol loading from the previous night's residual layer.

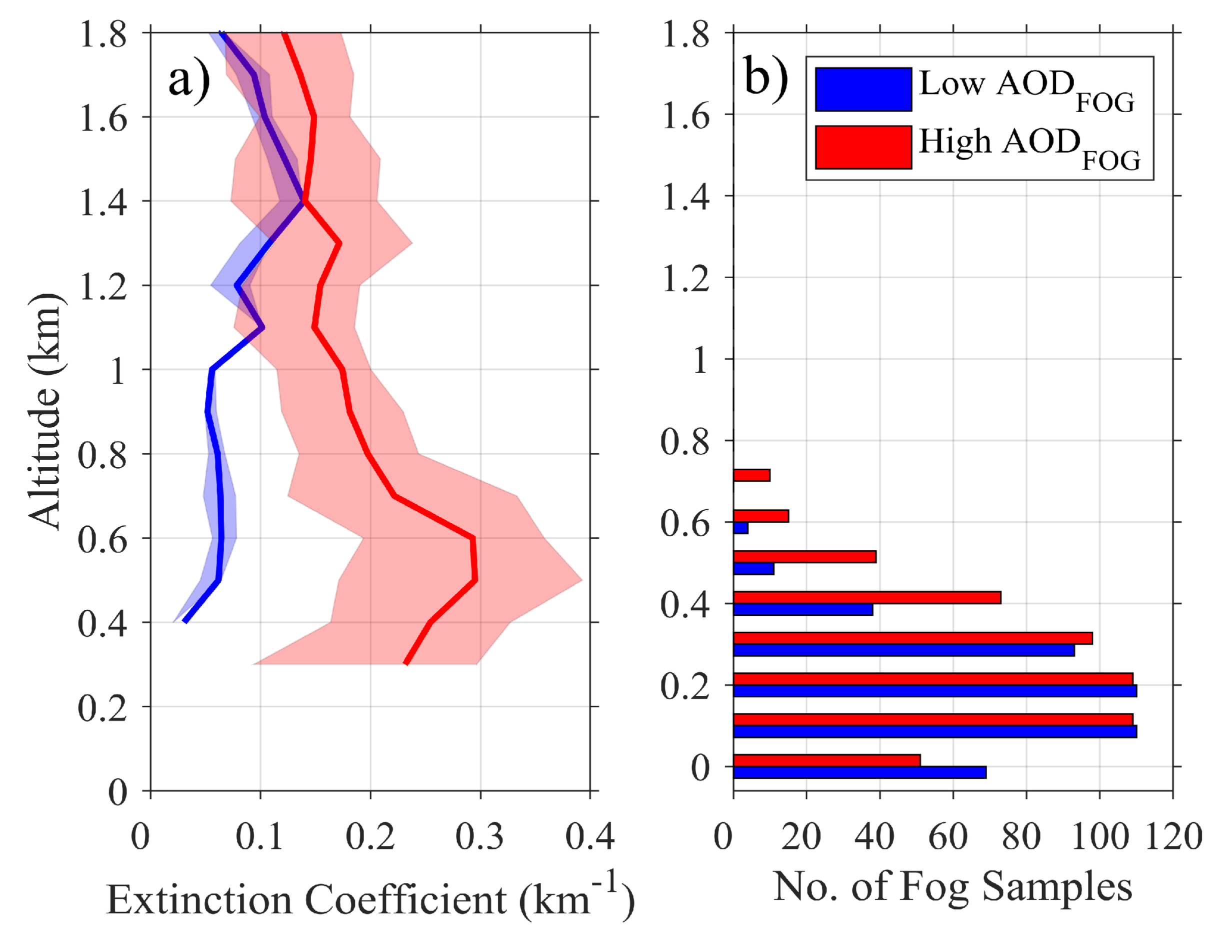


Figure 2. Vertical distribution of aerosol extinction and fog layers over IGP. (a) Vertical profiles of extinction coefficient (altitude above ground) and (b) number of fog samples (altitude above ground) over IGP corresponding to low AOD_{FOG} (0 – 0.02; 110 profiles) and high AOD_{FOG} (0.06 – 0.28; 109 profiles) scenarios.

The top height increases by ~42% from 0.32 km to 0.49 km as the AOD_{FOG} increases from ~ 0.02 to 0.2, eventually leading to a thickening from 0.31 km to 0.46 km at higher AOD_{FOG}.

Low aerosol-above-fog often promotes the growth of fog top height up to only 0.4 km, while on the other hand, the fog can grow/mature further above 4 km and up to 8 km under more significant aerosol loading above.

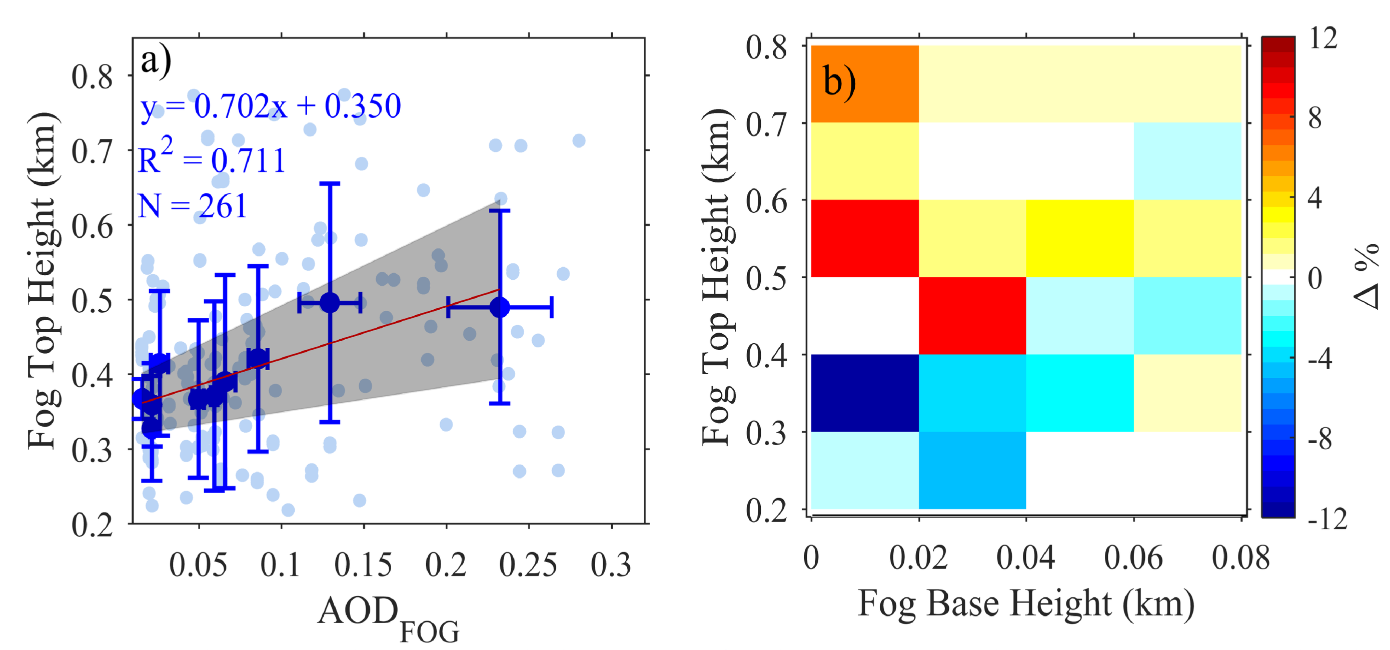


Figure 3. The aerosol associated changes to fog layer macro-physics. (a) Scatter plot (total number of profiles = 261) between fog top height-AOD_{FOG} (blue color). The error bars denote the standard deviation. (b) The percentage occurrence changes in the fog top height-base height distribution (high AOD_{FOG} minus low AOD_{FOG}).

2. MODIS observed CTH composites based on high vs low AOD

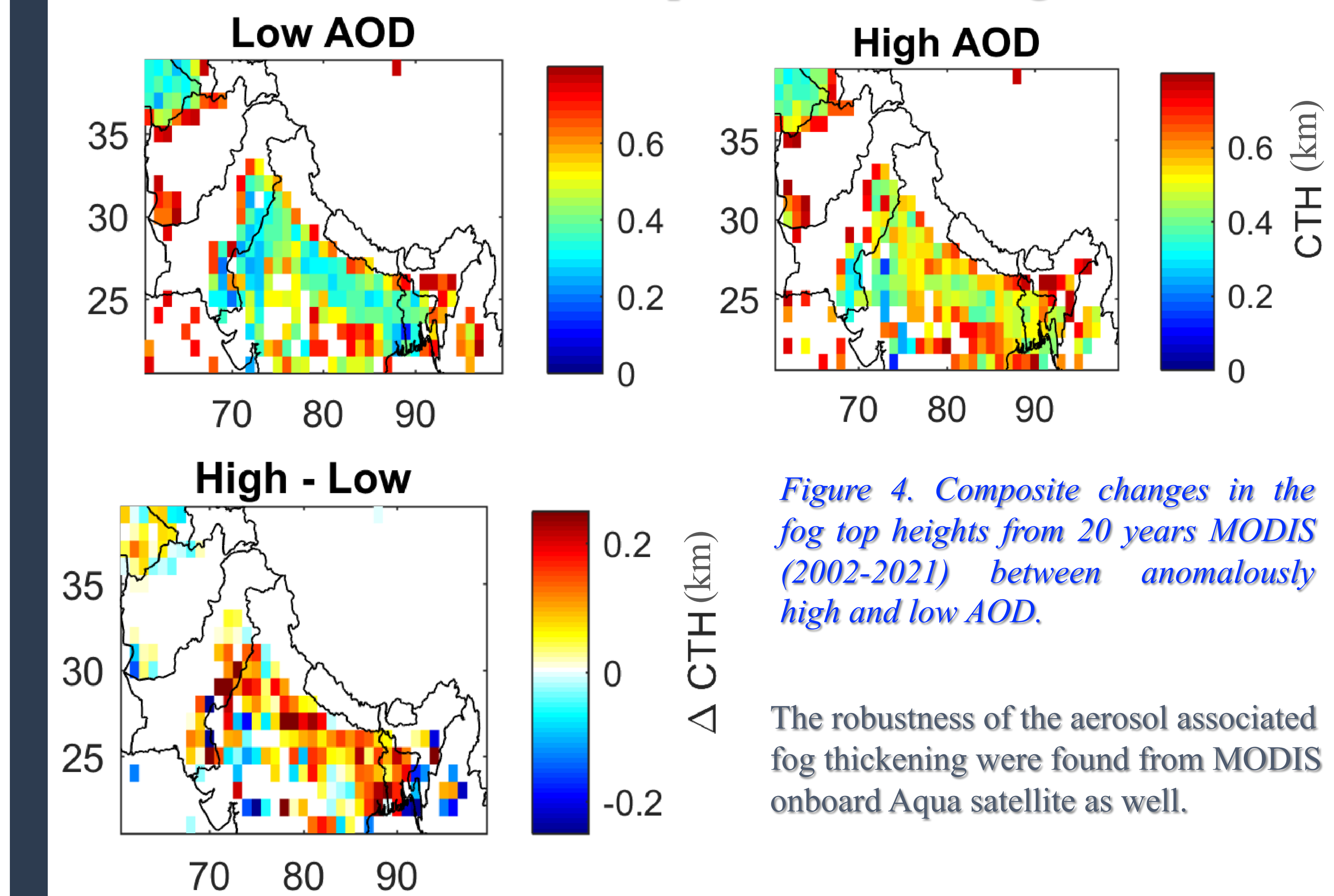


Figure 4. Composite changes in the fog top heights from 20 years MODIS (2002-2021) between anomalously high and low AOD.

The robustness of the aerosol associated fog thickening were found from MODIS onboard Aqua satellite as well.

3. High aerosol loading preceding longer fog days

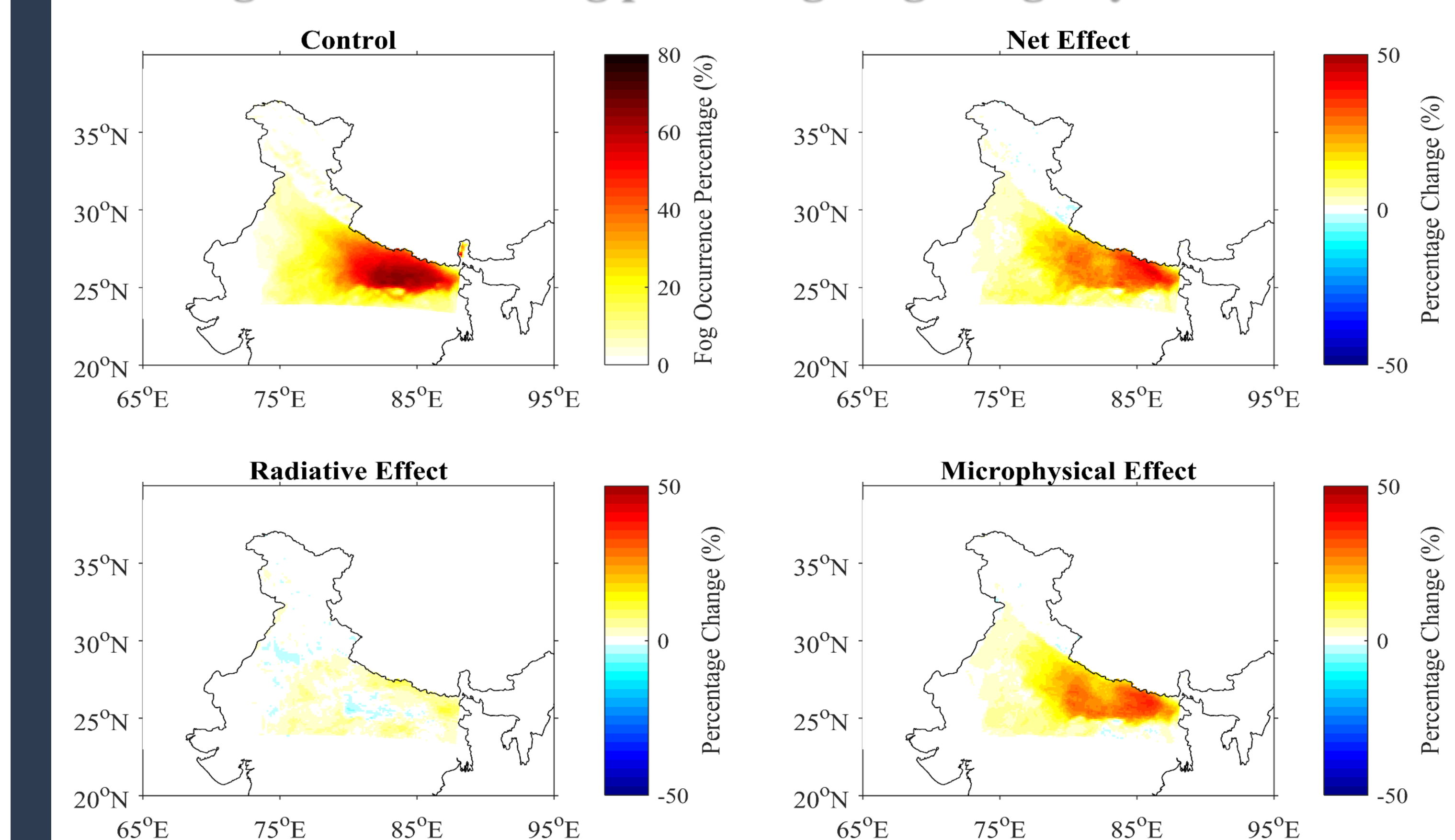


Figure 5. Fog occurrence percentage for a) Control run. The changes in the fog occurrence percentage for b) net effect, c) radiative effect and d) microphysical effect.

The aerosol loading is causing ~50% increase in the fog occurrence over the central IGP. Mainly the aerosol microphysical effect is the dominant pathway than aerosol radiative effect.

The radiative effect seem to be promoting fog over northern and southern periphery of the IGP.

Conclusion

- A robust fog identification and isolation algorithm is developed from 15 years of active lidar remote sensing satellite CALIPSO.
- The simultaneous retrieval of fog layer's macro properties and aerosol above fog enabled us to isolate the fog aerosol interaction over North India.
- A significant thickening due to aerosols is evident from observation which was also corroborated from MODIS observations
- Meteorology may be a cofactor in the observed association , therefore regional modelling was used for further analysis
- WRF-Chem model was able to simulate fog events over the Indo-Gangetic Plains, India.
- We exploit this ability to perform multiple aerosol sensitivity runs and found that aerosol indirect effect to be a dominating factor in fog occurrence.
- Nonetheless, an emerging trend in the fog expansion over the IGP suggests the complex role of fog-aerosol-meteorology.

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