Study of the Extent of Contribution of Regional Stubble Burning to the Air Pollution in Delhi-National Capital Region

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ABSTRACT

The issue of extreme episodic air pollution events in the Delhi-National Capital Region (NCR), India, during the month of November has been of concern for the last few years. Recent studies have used satellite observations and transport models, which indicate movement of smoke from stubble burning regions in Punjab and Haryana towards Delhi. Quantification of contribution of these emissions to the air pollution in Delhi, however, remains uncertain. In the present study, a similar attempt was made, and measurements are reported from 16 ground-based continuous air quality monitoring stations (CAAQMS) in the Delhi-NCR for the years 2016 and 2017. Time series $PM_{2.5}$ ground measurements were compared with the total Fire Radiative Power (FRP) from Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Terra and Aqua satellites for the airshed for Delhi-NCR. To quantify the smoke contribution from the fire pixels to the Delhi-NCR, the Navy Aerosol Analysis Prediction System (NAAPS) smoke data were used. NAAPS simulations show that the smoke aerosol contribution to Delhi-NCR from stubble burning was ~5-10 μg/m^3 during the pollution episodic days in 2016. NAAPS results along with the $PM_{2.5}$ measurements at Ludhiana, Punjab, indicate that the stubble burning emissions may contribute 33-66 μg/m^3 to the $PM_{2.5}$ at Delhi depending on wind conditions and emission levels at the source. The predominant aerosols over the study area during the episodic period were verified to be

absorbing in nature. Limited meteorological data indicated low temperatures and high relative humidity conditions during the episodic events.

Keywords: MODIS FRP, Airshed, CAAQMS, NAAPS, Stubble Burning, Regional transport

INTRODUCTION

Identification and quantification of contribution from regional air pollution sources is a major concern for many cities. Bergin et al., 2005 have reviewed the regional air pollutants, their impacts on air quality and management. Agricultural biomass burning, forest fires, dust storms and volcanic eruptions were identified as some of the regional sources of pollution. To study regional transport, studies have reported use of satellite data, transport models and ground based observations.

During October-November a thick layer of smoke was observed over the Northern India and Kaskaoutis et al., 2014 found that the back trajectories at 500 m levels originated from the stubble burning regions in Punjab showing the potential influence of transport of aerosols (Kaskaoutis et al., 2014). More recently, Liu et al., 2018, Jethva et al., 2018 and Cusworth et al., 2018 have focused more specifically on the episodic events in the Delhi-NCR. Their approach uses covariation, and the contribution of the regional source is likely to be overestimated as the entire episodic enhancement is attributed to stubble burning activity, while the possibility of some local sources specific to the season may not have been given adequate consideration.

In the present study, Navy Aerosol Analysis and Prediction System (NAAPS) smoke data was used to study and quantify the contribution of stubble burning emissions to the air pollution in the Delhi-NCR. NAAPS has been reported previously for studying the transport of smoke (Xian et al., 2013; Hyer and Chew 2010; Reid et al., 2004). NAAPS is a 6-day forecast model, which gives global distribution of sulphate, dust, smoke and sea salt aerosols (Xian et al., 2013). Ground based air quality measurements from CAAQMS were used to assess the correlation between the $PM_{2.5}$ pollution levels in Delhi, with the FRP in the airshed for Delhi-NCR (Liu et al., 2018).

MATERIALS AND METHODS

The near real time MODIS collection 6 fire product (Giglio et al., 2015; Justice et al., 2006) data were collected for the Post Monsoon (October-November) stubble burning period from 2003-2017 within the bounding box 25°N, 70°E; 35°N, 80°E (Figure 1) from Fire Information for Resource Management System (FIRMS) (URL 1). The historical variation in FRP within Delhi airshed (Figure 1 (b)) was studied. Variation of daily FRP in the airshed was compared with that of daily $PM_{2.5}$ levels in Delhi for 2016 and 2017 to assess the correlation. The fire pixels with confidence (Justice et al., 2002) greater than or equal to 80% were considered for the study.

(a) (b)

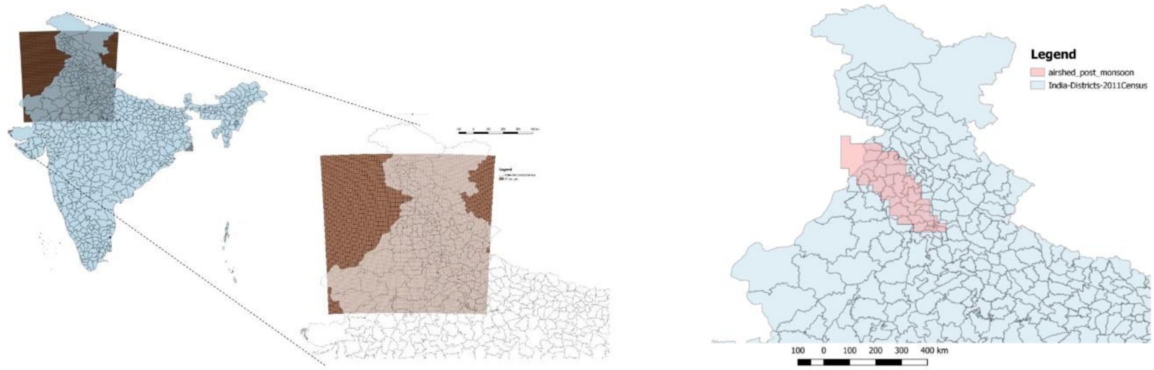


Figure 1: (a) The bounding box selected for the present study covering Punjab, Haryana, Rajasthan and Delhi; (b) Post-monsoon airshed for Delhi NCR (adapted from Liu et al., 2018) based on HYSPLIT analysis for the October-November period.

The spatial and temporal variation of aerosols during October-November were studied using MODIS Aerosol Optical Depth (AOD) and the Ozone Monitoring Instrument Aerosol Index (OMI-AI) for the type of aerosols during October-November using DataFed (Husar and Poirot, 2005; Husar and Hoijarvi, 2007; Husar et al., 2008).

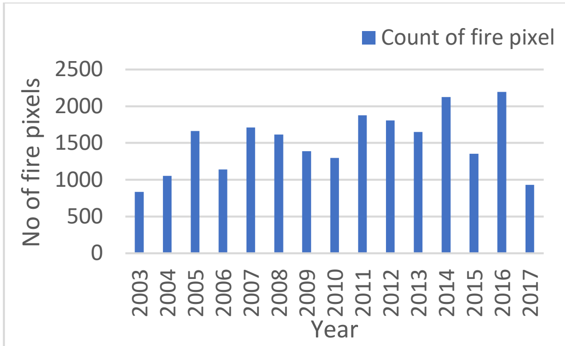
There are mainly two harvesting seasons in Punjab and Haryana Kharif (June-September) and Rabi (December-March). Crop area data from 2003-2016 over Punjab and Haryana were studied for the Kharif Season. The data were collected from the statistical reports available from DACNET portal, an initiative by Department of Agriculture and Cooperation (DAC) Ministry of Agriculture (URL 2), and the Department of Agriculture and Farmers Welfare, Haryana (URL 3).

PM_{10}, $PM_{2.5}$ and NO_2 data from CAAQMS were studied over Punjab Haryana and Delhi. The time series of total FRP within Delhi airshed for October-November were compared with that of the $PM_{2.5}$ levels at 16 stations over Delhi.

NAAPS smoke product was used in the present study to estimate the contribution of stubble burning in the Haryana and Punjab region to the air pollution in Delhi. NAAPS uses near real time fire location details from FLAMBE (Reid et al., 2009) and MODIS AOD assimilation as an input for the simulations. The analyses were carried out using DataFed.

RESULTS AND DISCUSSION

The assessment of fire pixels within the airshed were carried out in terms of the total number of fire pixels (count) and the total Fire Radiative Power (FRP) value - of the fire pixels (Figure 2 a and b). It was observed that these both are highly correlated, and since FRP value is directly proportional to the amount of stubble burnt, the analysis in terms of total FRP was used for further analysis instead of the number of fire pixels. Further assessment were carried out for the years 2016 and 2017 on the basis of data availability.

a) 

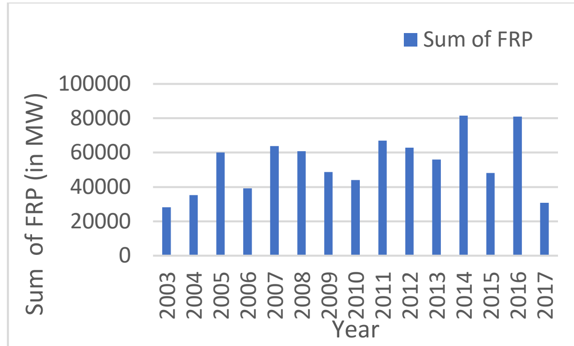
b) 

Figure 2: Historical trend of fire pixels within airshed for October-November Season from 2003 to 2017 a) fire count; and b) total FRP

High pollution levels in Delhi have been observed since past few years during the first half of November. CAAQMS data available from Central Pollution Control Board portal (URL 4) were used for assessing the trend of air pollution in Delhi. Figure 3 shows the distribution of these ground monitoring stations.

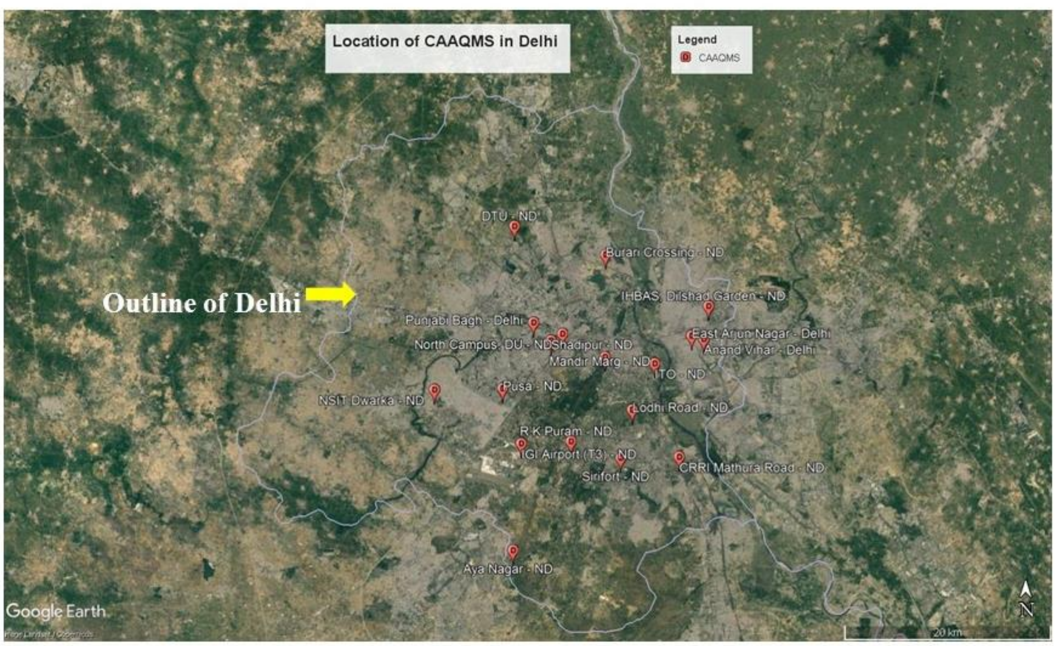
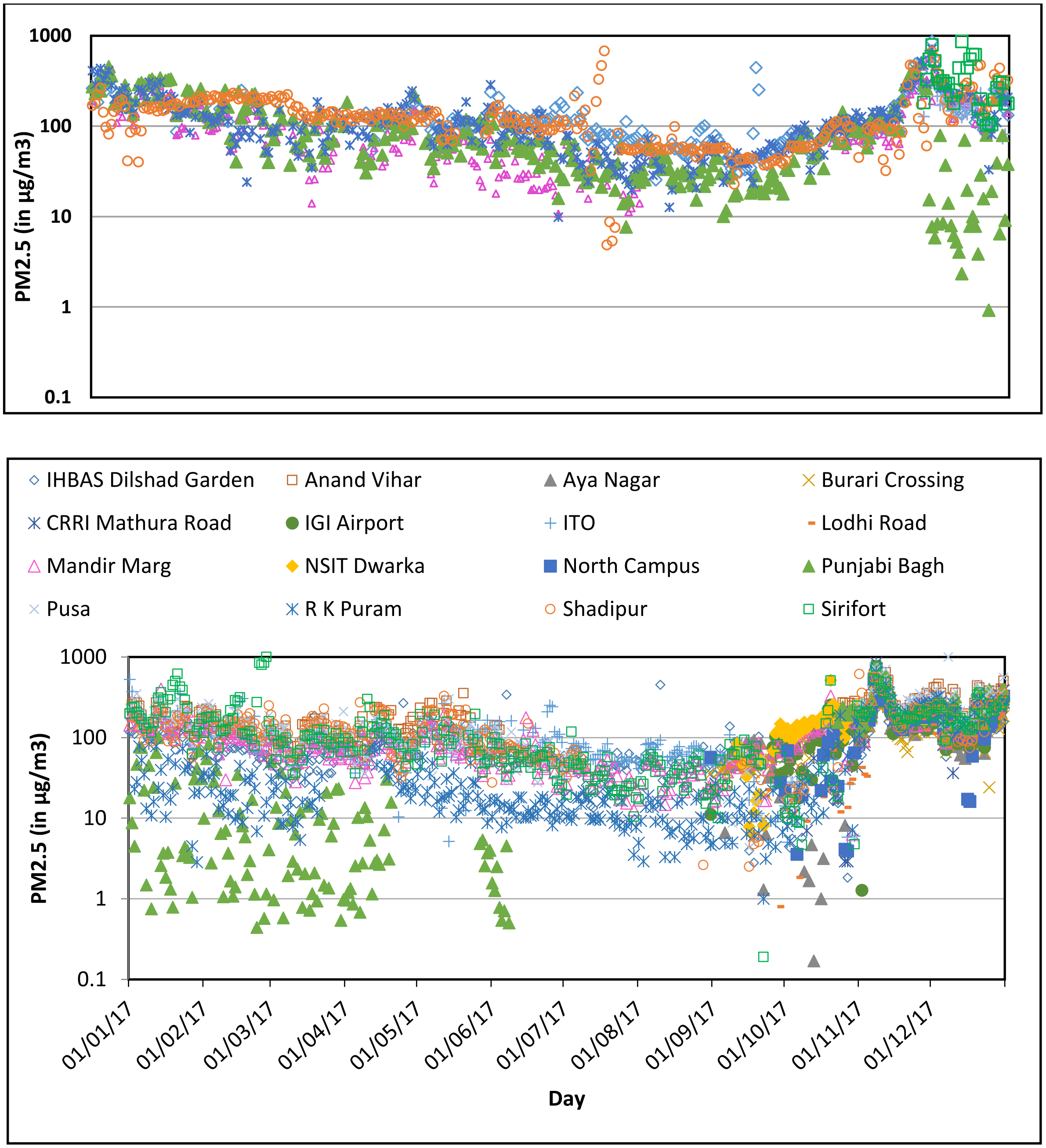


Figure 3 : Location of f CAAQMS stations in Delhi-NCR

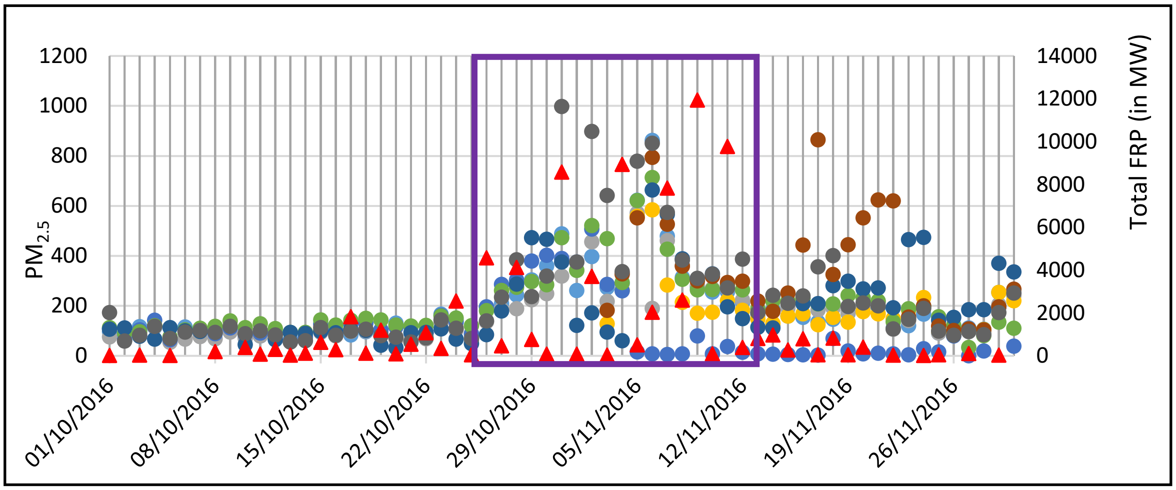
The $PM_{2.5}$ levels in Delhi range from 200 to 1000 $\mu g/m^3$ in both 2016 and 2017 (Figure 4(a) and (b)). Comparing broadly, the episodic $PM_{2.5}$ levels in Delhi during 2016 and 2017 are similar. The reduced FRP in 2017 compared to 2016 (Figure 2) does not seem to have affected the episodic levels of $PM_{2.5}$ observed in Delhi.



(a) (b)

Figure 4: Time series of $PM_{2.5}$ data (unprocessed) from CAAQMS in Delhi a) at 7 stations in 2016: b) at 16 stations in 2017

The $PM_{2.5}$ data for the period October 1 to November 30 for 2016 and 2017 from CAAQMS are plotted against the corresponding FRP in the Delhi airshed (Figure 5 (a) and (b) respectively. The increased PM levels were observed in the first half of November. It was observed that there is an occasional time delayed correlation between FRP peaks and the $PM_{2.5}$ peaks in Delhi during 2016 and there is little correlation during 2017 (Figure 5).

(a) 

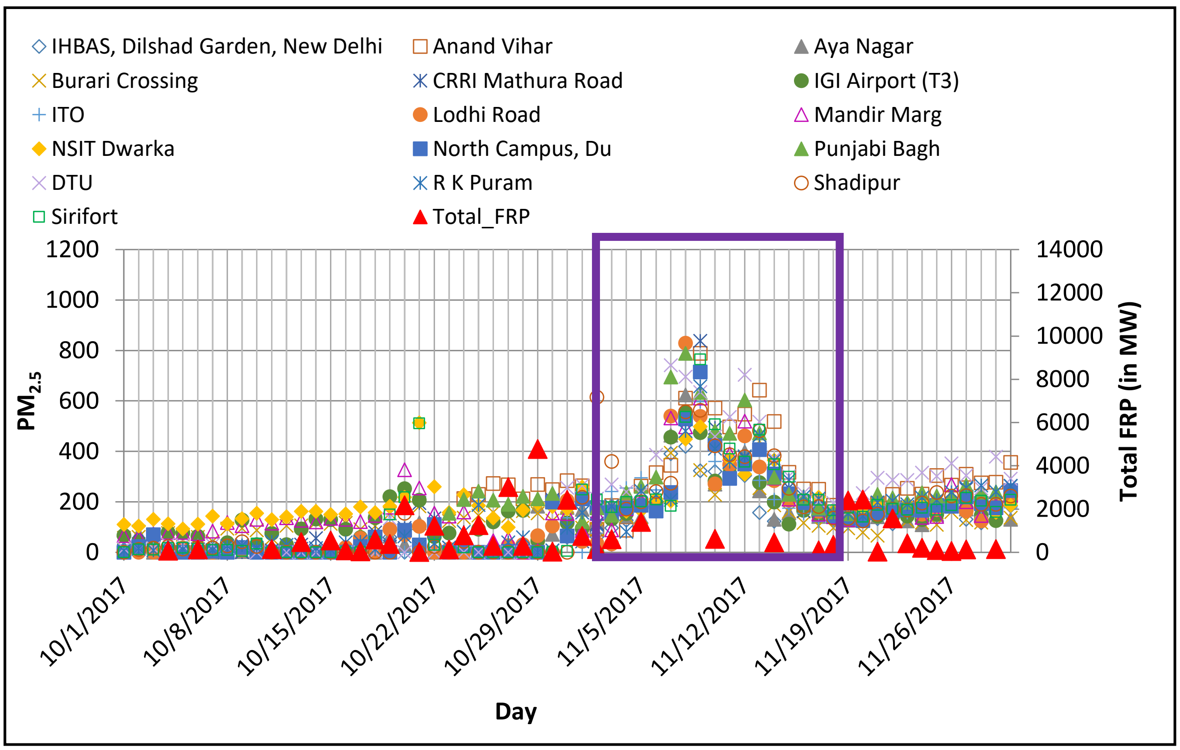
(b) 

Figure 5: Time series of $PM_{2.5}$ over Delhi as per CAAQMS data for episodic days along with FRP within Delhi airshed (a) in 2016 and (b) in 2017 The inset box indicates the period of the episodic events for the two years.

The temporal variation of PM levels at Punjab (Amrutsar and Ludhiana) and Delhi were studied for the year 2017 (Figure 6) using local CAAQMS data. It was observed that while the $PM_{2.5}$ levels at Punjab for the October-November, 2017 season is about 200-400 μg/m^3 the same at Delhi were around ~300-600 μg/m^3.

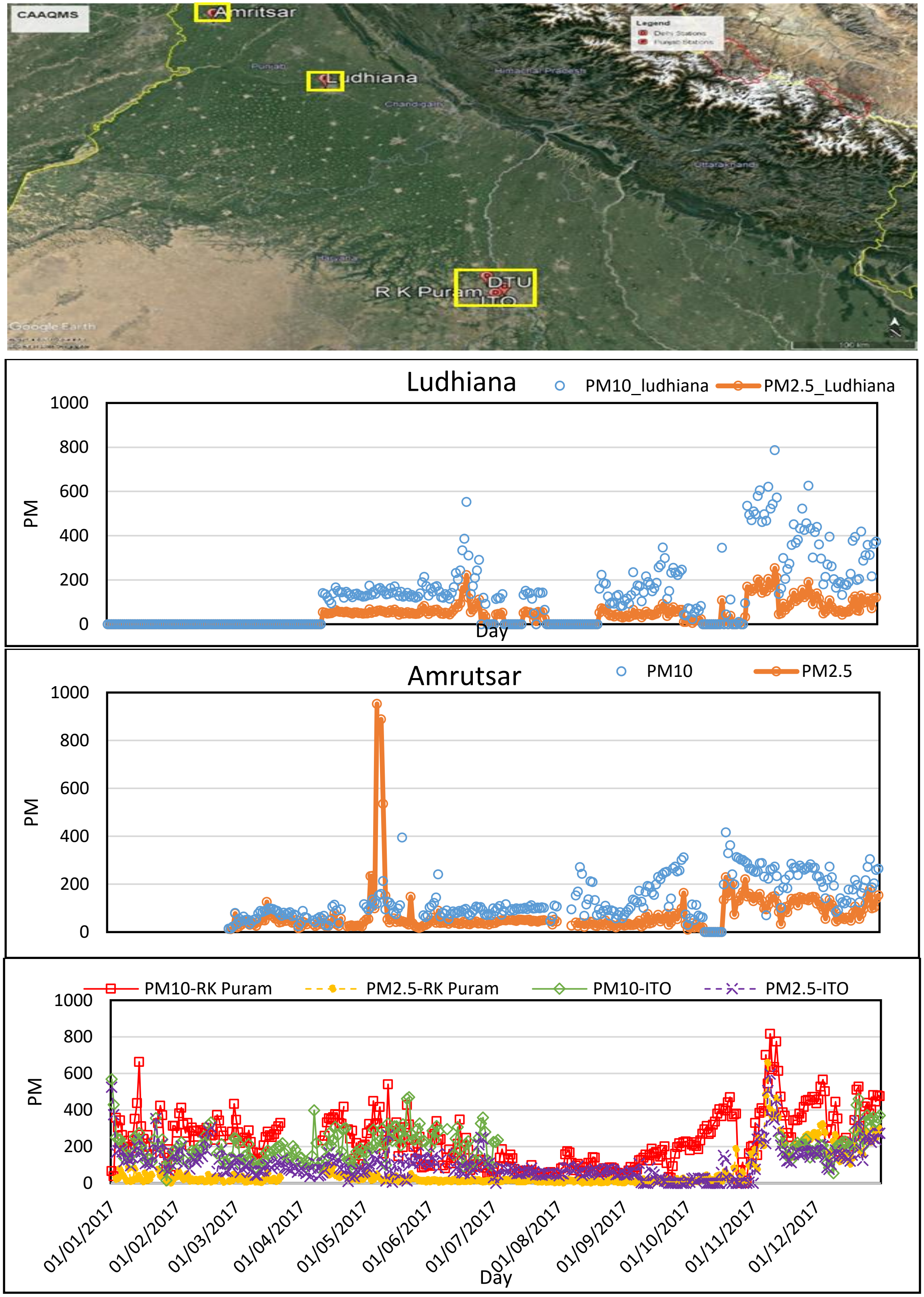


Figure 6: Comparison of PM_{10} and $PM_{2.5}$ (in $\mu g/m^3$) concentrations from CAAQMS (unprocessed) at two locations in Punjab (Ludhiana and Amrutsar) and two locations in Delhi-NCR (R K Puram and ITO) for the year 2017

The spatial distribution of OMI absorption aerosol index (90th percentile values) over the study region were aggregated for the period 2012 to 2016 with data for Oct-Nov season (Figure 7). The 90th percentile values indicate the extreme values of AAI, and could be an indicator of the fire events. The assessment of UV aerosol index (Figure 7) shows that absorbing aerosol is predominant over this region (with UV Aerosol Index values of about 1.8).

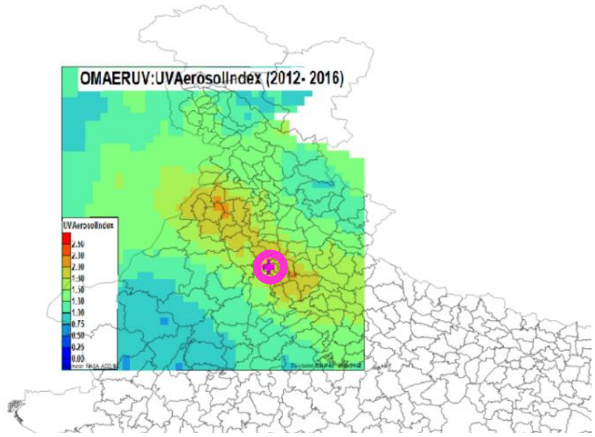


Figure 7: Spatial distribution of OMI Absorbing Aerosol Index over the region during 2012-2016 (Delhi NCR is marked with a circle)

More specifically, over Delhi-NCR, the seasonal variation of MODIS AOD and OMI Aerosol Index are shown in Figure 8. The data was averaged for the period of 2012-2016. It is clearly visible that there is an increase in MODIS AOD in October-November months over Delhi NCR, and relatively high Aerosol Absorption Index indicates that the nature of the aerosols over Delhi NCR during this period is largely that of an absorbing type.

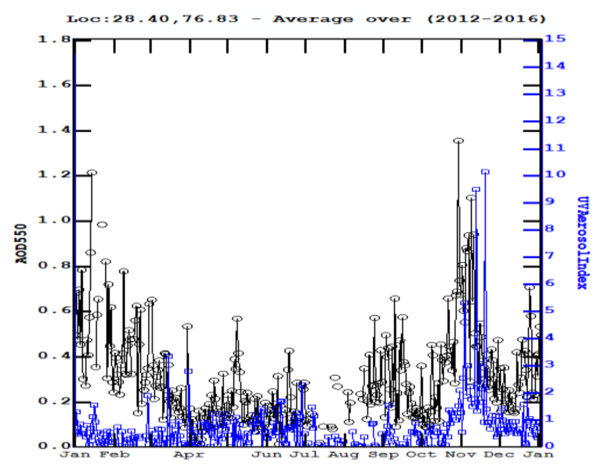


Figure 8: Seasonal variation of MODIS AOD and OMI Aerosol Index specifically over the Delhi-NCR (2012-16)

The temporal variation of smoke concentration at Delhi during 2012-16 are plotted as Figure 9, and it was observed that during October-November and April-May seasons there is increased contribution of smoke from fire pixels in the airshed that is contributing to the air pollution in the Delhi-NCR.

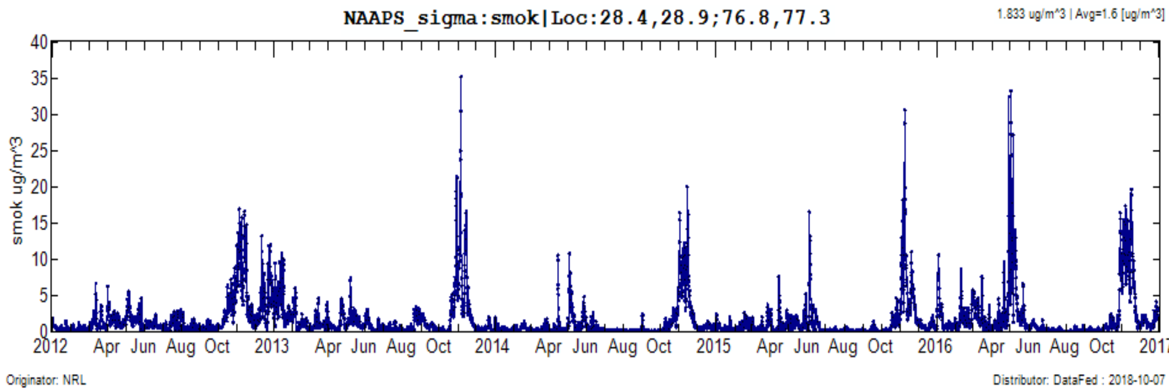


Figure 9: Temporal variation of NAAPS simulated surface level smoke concentration averaged over Delhi NCR for 2012-016

November 11, 2016 was identified as one of the days on which there were high fire activities in the airshed for Delhi. NAAPS data were analyzed for November 10-12, 2016 at 6-hour resolution and are presented in Figure 10. It was observed that on November 10 and 11 smoke plumes from Punjab region reached Delhi-NCR, while on November 12 the direction of dispersion changed and the smoke does not affect the Delhi-NCR. For November 11, the model estimates a contribution of ~25 µg/m^3 of smoke to the Delhi-NCR. The high fire activity within the airshed does not lead to the extreme pollution events at Delhi. $PM_{2.5}$ levels at Delhi during these days were 200-300 µg/m^3 range. An analysis of NAAPS smoke product for every 6-hour from October 20-November 20, 2016 were analyzed, and indicate that smoke plumes start to appear from late October. On November 11, 2016 with the extreme fire event, about 5-15 µg/m^3 of the smoke from source pixels were found to reach the Delhi-NCR. The extreme pollution events were observed to be on November 6-8, 2016 in Delhi, and during these days, ~5-10 µg/m^3 of the smoke from stubble burning region reaches Delhi. As per the NAAPS results the smoke concentration over the burning region during this period was around 30-60 µg/m^3, whereas the ground based measurements show a concentration of 200-400 µg/m^3. On the basis of ground measurements and NAAPS simulation results the pollution contribution reaching Delhi would be expected to be in the range of 33-66 µg/m^3.

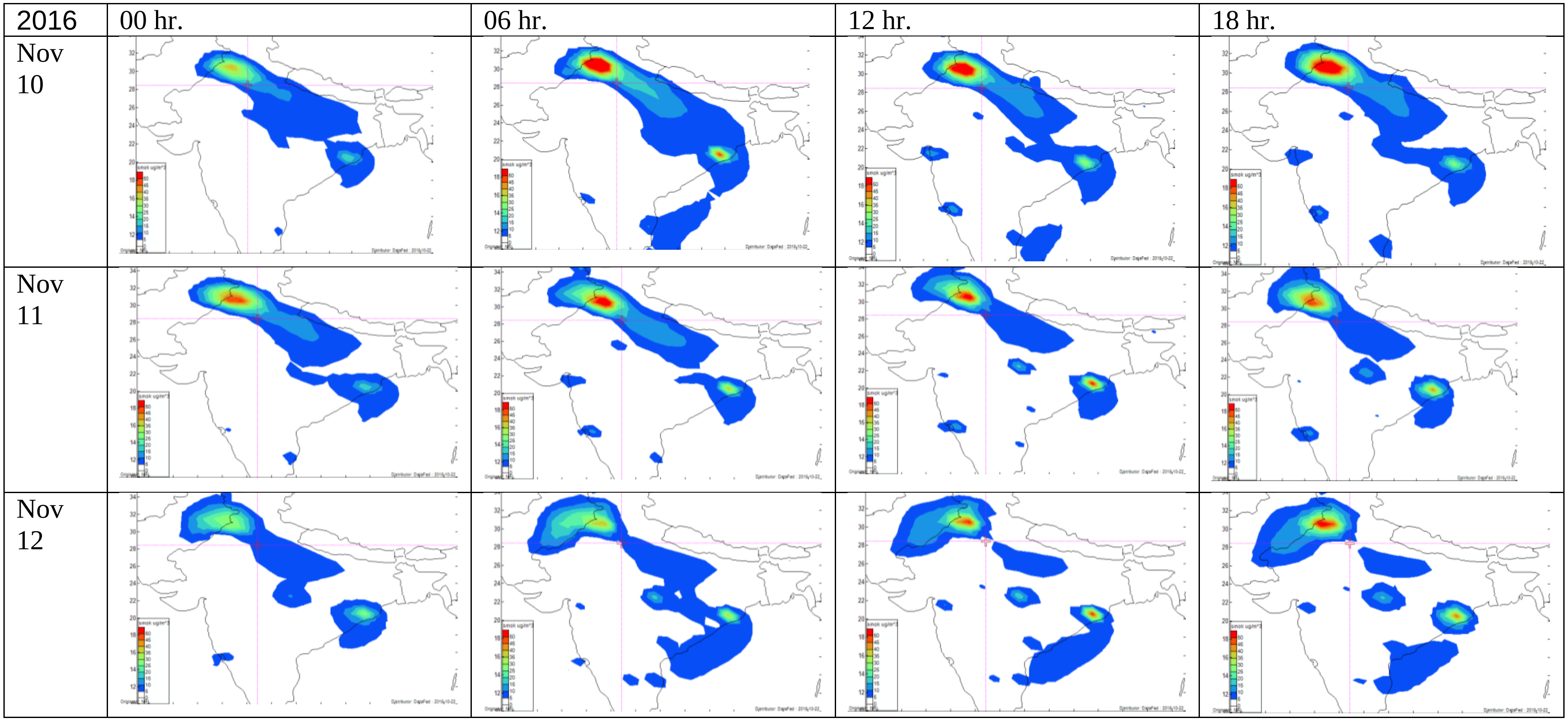


Figure 10: The spatial and distribution of NAAPS smoke over the study area for November 11, 2016 (the peak activity date as per total FRP)

SUMMARY

Estimation of contribution of stubble burning in Punjab and Haryana to the air pollution in Delhi-NCR during October-November was made using NAAPS smoke product. Smoke concentrations over the source region were estimated by NAAPS model as 30-60 μg/m^3, and that contributed to Delhi-NCR was 5-15 μg/m^3. Assessment of CAAQMS data indicates possible presence of local aerosol sources. The prevailing aerosol over the study area during October-November were observed to be of absorbing type. Comparison of time series of total fire pixels within the airshed with that of the $PM_{2.5}$ levels at Delhi for the year 2016 indicate only occasional time delayed correlation, and even lesser so for 2017. There were many days with high fire events within the airshed for which corresponding (time delayed) pollution episodes were not observed at Delhi. The percentage of particle transport was observed to vary with meteorology, and the highest percentage contribution at Delhi did not coincide with the highest fire activity. The CAAQMS measurements in the airshed show that during October-November the $PM_{2.5}$ concentrations over Delhi (300-600 μg/m^3) is much higher than that observed in the CAAQMS in Punjab (about 200-400 μg/m^3). On the basis of NAAPS model results and the ground based $PM_{2.5}$ concentrations at Ludhiana site in Punjab the possible contribution of stubble burning to the $PM_{2.5}$ at Delhi-NCR could be of the order of 33 to 66 μg/m^3.

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