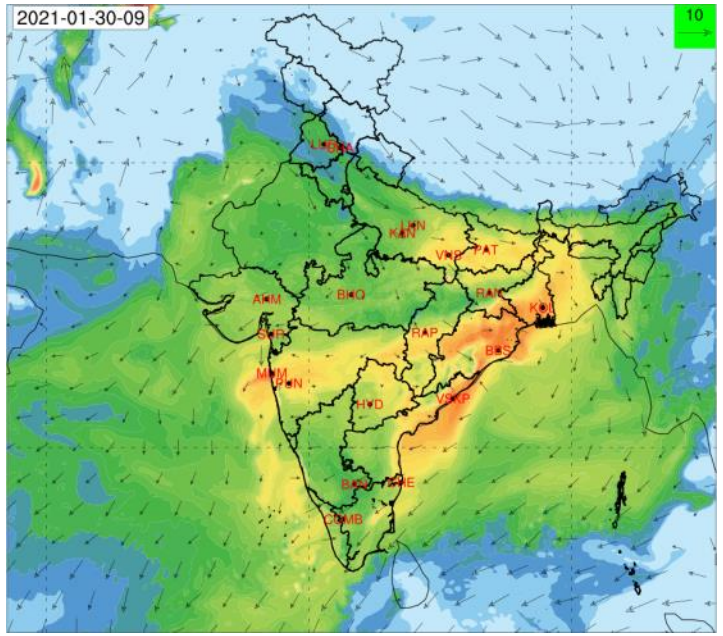
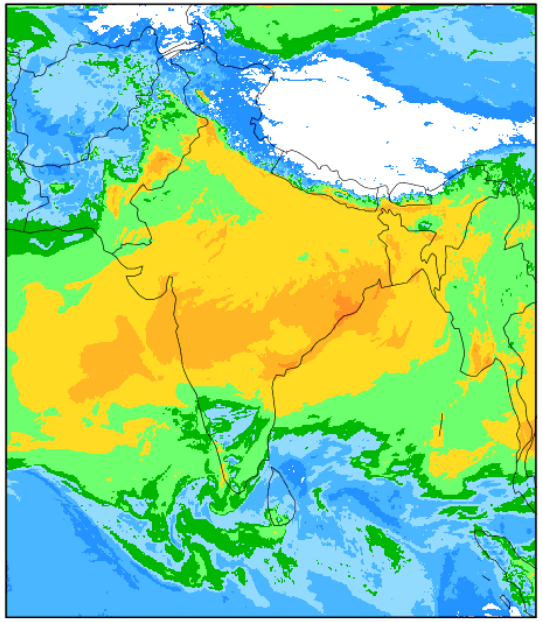
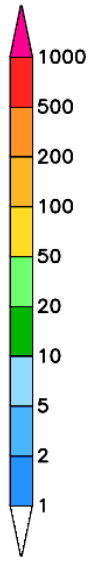
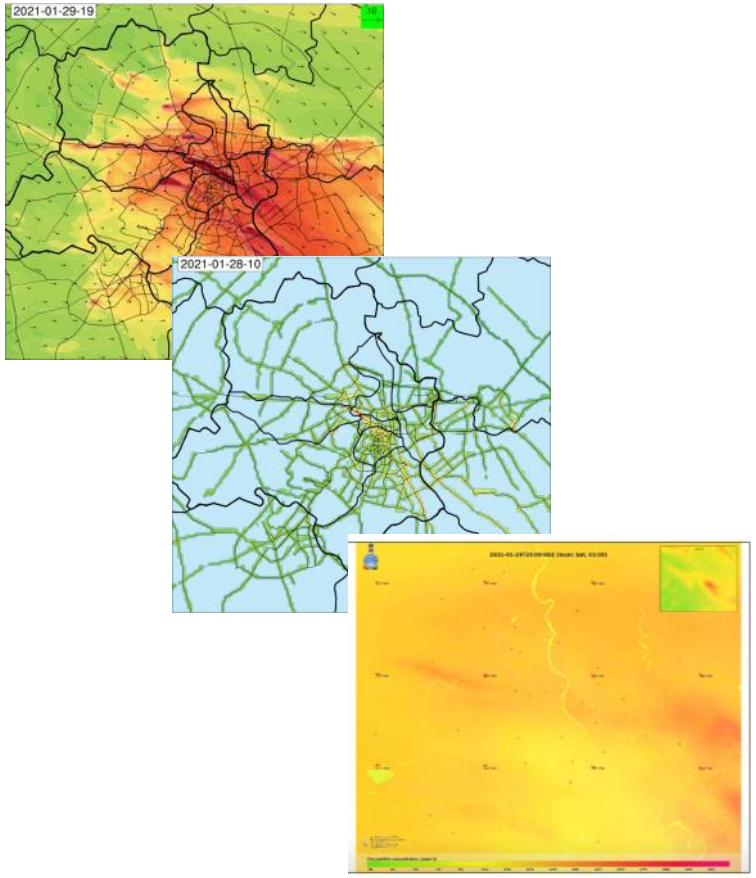
Recent Advance in Air Quality Forecasting over India







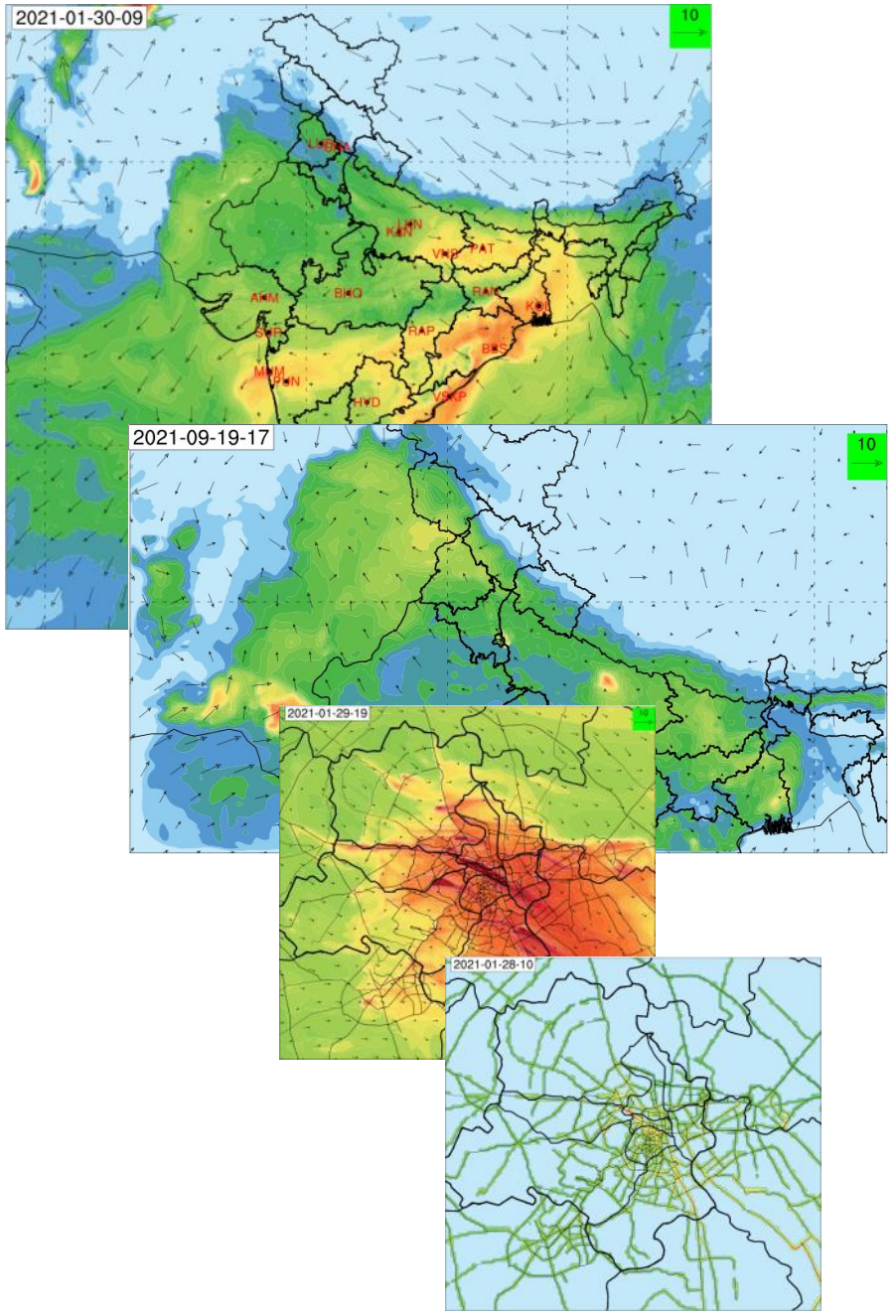


Chinmay Kumar Jena, V. K. Soni, A.K. Das, A. Kumar, Sachin Ghude and Team

India Meteorology Department, New Delhi
India Institute of Tropical Meteorology, Pune
Ministry of Earth Sciences (MoES)

What Are We Forecasting

- **Scales**
  - Regional or mesoscale (10 km)
  - Urban or sub-regional (10 km to 400m)
  - Neighborhood or single site (400 m and less)
  - Forecast scale needs to match local air quality scale
- **Metrics**
  - Extremes of all sites in forecast zone
  - Multi-site average
  - Others
- **Pollutants of concern**
  - Major (PM10, PM2.5, O3, CO, SO2, and NOx)
  - Dust
  - Contribution from Dust, Fire
- **Critical forecast issues**
  - Timeliness (when do users need it)
  - Localized forecasts
  - Multi-day (three-to-ten day) forecasts are useful
  - Easy-to-understand format (AQ Index)



National Ambient Air Quality Standards

Environment (Protection) Seventh Amendment Rules, 2009

Sensitive Areas: Hill stations, health resorts, sancturies, national parks, national monuments and other areas where the nation conserves its clean environment even if that implies some curb on economic activity

Pollutant	Time Weighted Average	Concentration in Ambient Air		
		Industrial, Residential, Rural and other area	Ecologically sensitive areas (notified by Central Govt.)	Methods of Measurement
SO_2 (μgm^{-3})	Annual* 24 hours**	50 80	20 80	- Improved West and Goeke - UV - fluorescence
NO_2 (μgm^{-3})	Annual* 24 hours**	40 80	30 80	- Modified Jacob & Hochheiser (Na-Arsenic) - Chemiluminescence
PM_{10}, (μgm^{-3})	Annual* 24 hours**	60 100	60 100	- Gravimetric - TEOM - Beta Attenuation
$PM_{2.5}$, (μgm^{-3})	Annual* 24 hours**	40 60	40 60	- Gravimetric - TEOM - Beta Attenuation
Ozone (μgm^{-3})	8 hours 1 hour	100 180	100 180	- UV photometric - Chemiluminescence - Chemical Method
Lead (μgm^{-3})	Annual* 24 hours**	0.5 1.0	0.5 1.0	- AAS/ICP method after sampling on EPM2000 or equivalent filter paper - ED-XRF using Teflon filter
CO (mgm^{-3})	8 hours 1 hour	2000 4000	2000 4000	- Non-dispersive Infra Red (NDIR) spectroscopy
NH3 (μgm^{-3})	Annual* 24 hours**	100 400	100 400	-Chemiluminescence -Indophenol Blue Method
Benzene (μgm^{-3})	Annual*	5	5	- Gas Chromatography based continuous analyzer - Absorption and Desorption followed by GC analysis
Benzo(a)Pyrene - particulate phase only (ngm^{-3})	Annual*	1	1	- Solvent extraction byHPLC/GC analysis
Arsenic (ngm^{-3})	Annual*	6	6	- AAS/ICP method after sampling on EPM2000 or equivalent filter paper
Nickel (ngm^{-3})	Annual	20	20	- AAS/ICP method after sampling on EPM2000 or equivalent filter paper

How do we know if Air Quality is poor?

AQI is an overall scheme that transforms individual air pollutant (e.g. SO_2, CO, PM_{10}) levels into a single number, which is a simple and lucid description of air quality for the citizens.

AQI relates to health impacts and citizens can avoid the unnecessary exposure to air pollutants;

AQI indicates compliance with National Air Quality Standards;

AQI prompts local authorities to take quick actions to improve air quality;

AQI guides policy makers to take broad decisions; and

AQI encourages citizens to participate in air quality management.

AIR QUALITY INDEX (AQI)	CATEGORY
0-50	Good
51-100	Satisfactory
101-200	Moderate
201-300	Poor
301-400	Very Poor
401-500	Severe

Equation for Calculating an Air Pollutant AQI Index Value

$$I_P = \left(\frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} \right) [Cp - BP_{Lo}] + I_{Lo}$$

Ip = Index magnitude for air pollutant P

Cp = concentration for pollutant P

I_{Hi} = AQI value corresponding to BP_{Hi}

I_{Lo} = AQI value corresponding to BP_{Lo}

BP_{Hi} = breakpoint that is greater than Cp

BP_{Lo} = breakpoint that is less than Cp

AQI categories and breakpoint concentrations with averaging times

(units: µg/m³ unless mentioned otherwise)

AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m³)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.6 –1.0
Moderate (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10.1-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17.1-34	801-1600	1201-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

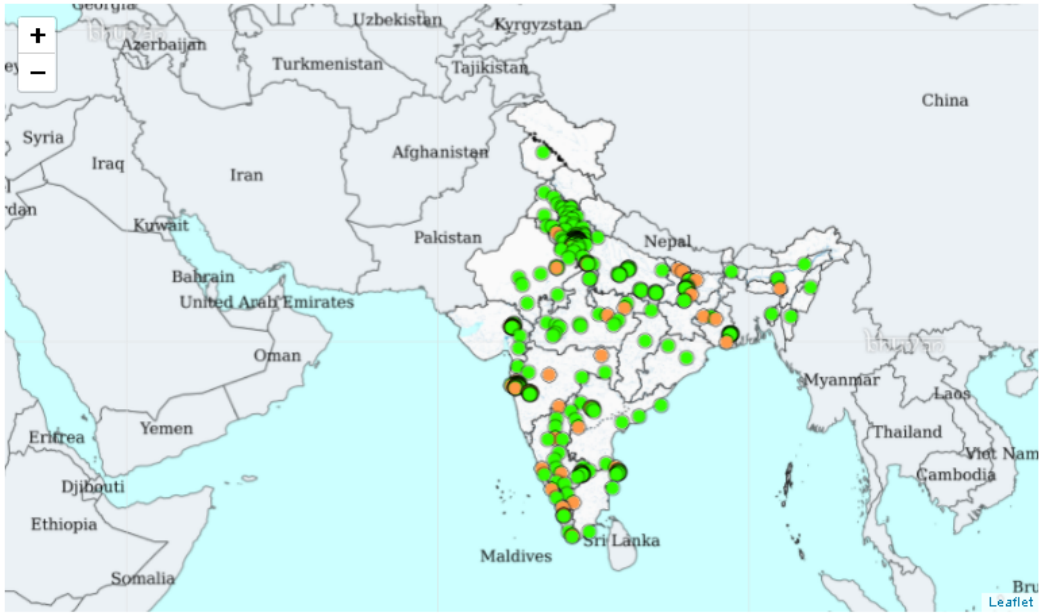
AQI	Possible Health Impacts
Good	minimal impact
Satisfactory	minor breathing discomfort to sensitive people
Moderate	breathing discomfort to the people with lung disease such as asthma and discomfort to people with heart disease, children and older adults
Poor	breathing discomfort to people on prolonged exposure and discomfort to people with heart disease with short exposure
Very Poor	respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases
Severe	respiratory effects even on healthy people and serious health impacts on people with lung/heart diseases

Web-based AQI dissemination

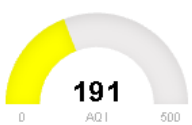
National Air Quality Index

Central Pollution Control Board,
Ministry of Environment, Forests and Climate Change

State: Delhi | City: Delhi | Station: Lodhi Road, Delhi - IITM | 28/10/2021 | 11:00



Moderate

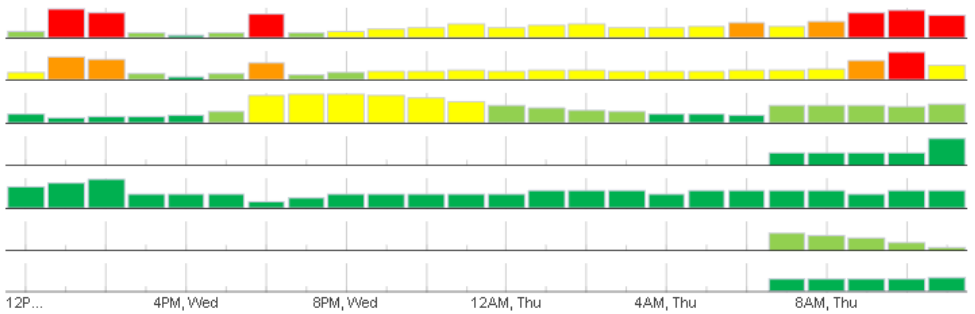


Lodhi Road, Delhi - IITM

Prominent Pollutant is PM2.5

On Thursday, 28 Oct 2021 11:00 AM

Pollutant	Timeline	Avg	Min	Max
PM2.5		191	48	389
PM10		143	49	338
NO2		75	29	135
NH3			-	-
SO2		5	2	8
CO		65	62	68
OZONE		16	15	17



List of AQI Stations with Data of above selected Date & Time

AQI	Remark	Color Code	Possible Health Impacts
0-50	Good		Minimal impact
51-100	Satisfactory		Minor breathing discomfort to sensitive people
101-200	Moderate		Breathing discomfort to the people with lungs, asthma and heart diseases
201-300	Poor		Breathing discomfort to most people on prolonged exposure
301-400	Very Poor		Respiratory illness on prolonged exposure
401-500	Severe		Affects healthy people and seriously impacts those with existing diseases

Air Quality Early Warning System

1. **Integrated AQEWS system based on IITM WRF-Chem**
   a) 10 Km regional air quality forecast (10-days in advance)
   b) 400 m forecast for NCR-Delhi (3-days in Advance)

2. **Air Quality forecasting system based on IMD-SILAM**
   a) 5 Km regional air quality forecast (3-days in advance)
   b) ENFUSER street level forecast for NCR-Delhi (3-days in advance)

Salient Features:

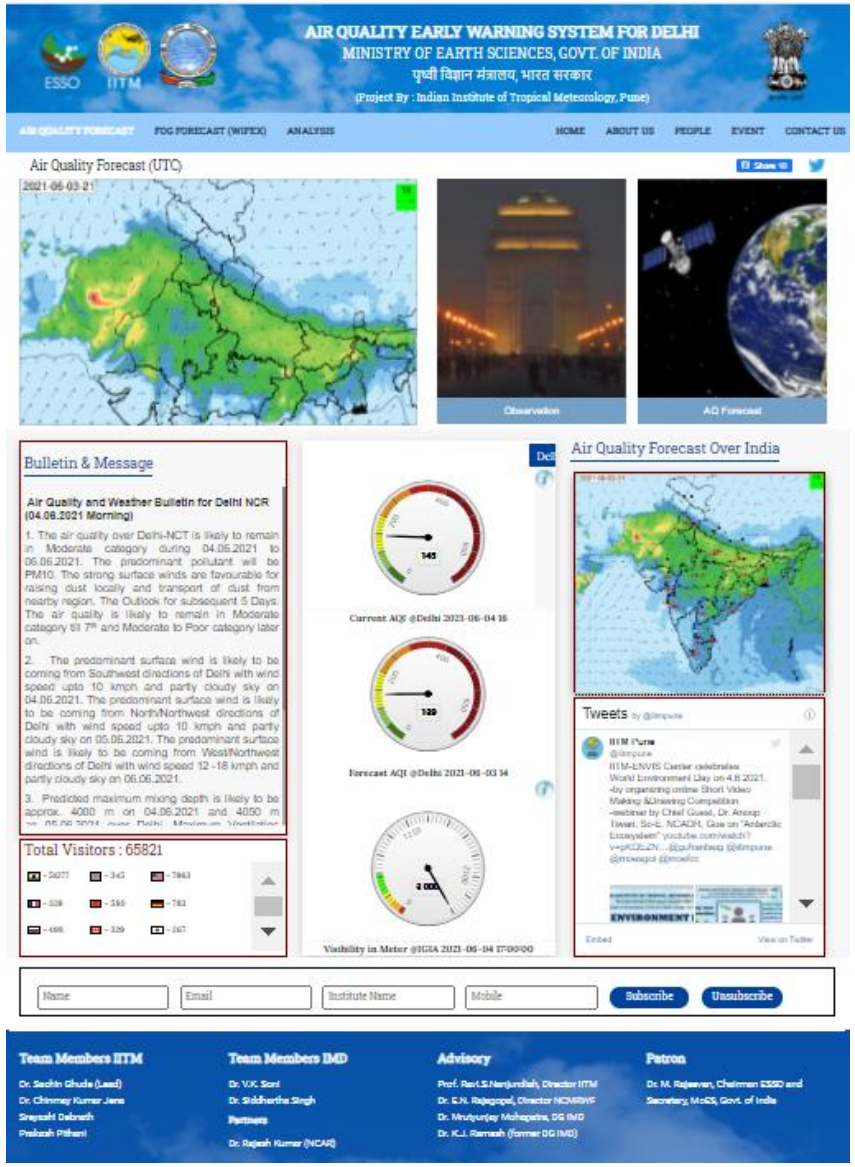
The advanced warning system provides:

a) air quality forecast at 400 meters for Delhi region for 3-days and outlook for next 7-days
b) air quality forecast for entire India and specifically for several non-attainment cities (Pune, Mumbai, Bangalore, Kolkata, Varanasi, Lucknow, Hyderabad, Patna ……)
c) real time observations of air quality over Delhi region, fire counts, AOD
d) details about natural aerosols like dust (from satellite and model forecast)
e) Near real-time fire information over India
f) forecast of the contribution of non-local fire emissions,
g) Weather Information
h) Day to day verification of forecast product.

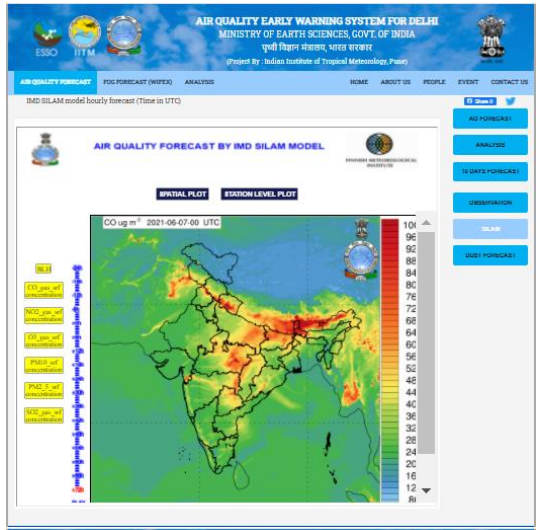
i) Public Dissimilation system: Dedicated website launched for Public for air quality forecast: https://ews.tropmet.res.in/.

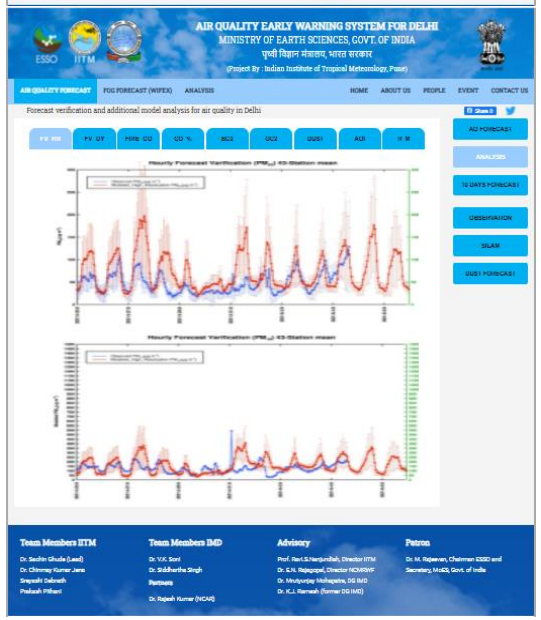
Public dissemination system (ews.tropmet.res.in)

For general public



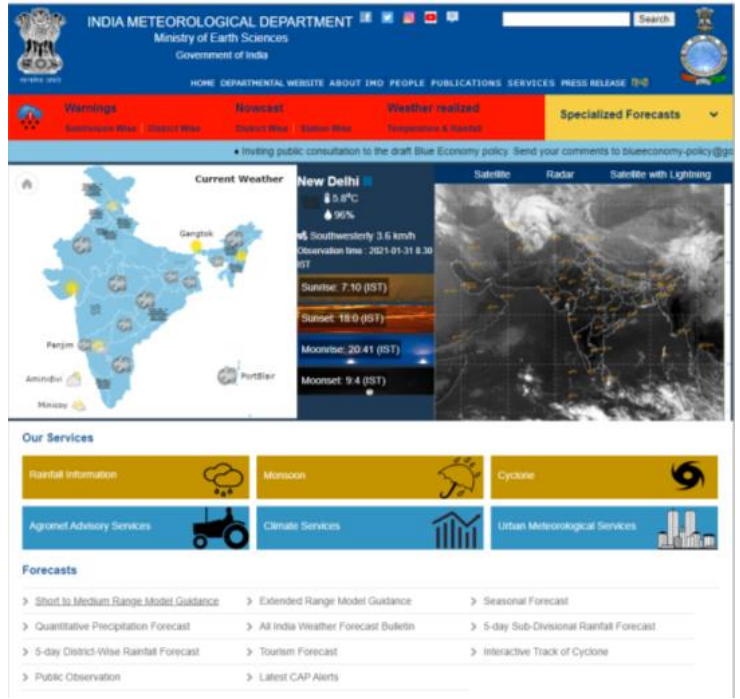
For advanced user





Weather

https://mausam.imd.gov.in/



Apps

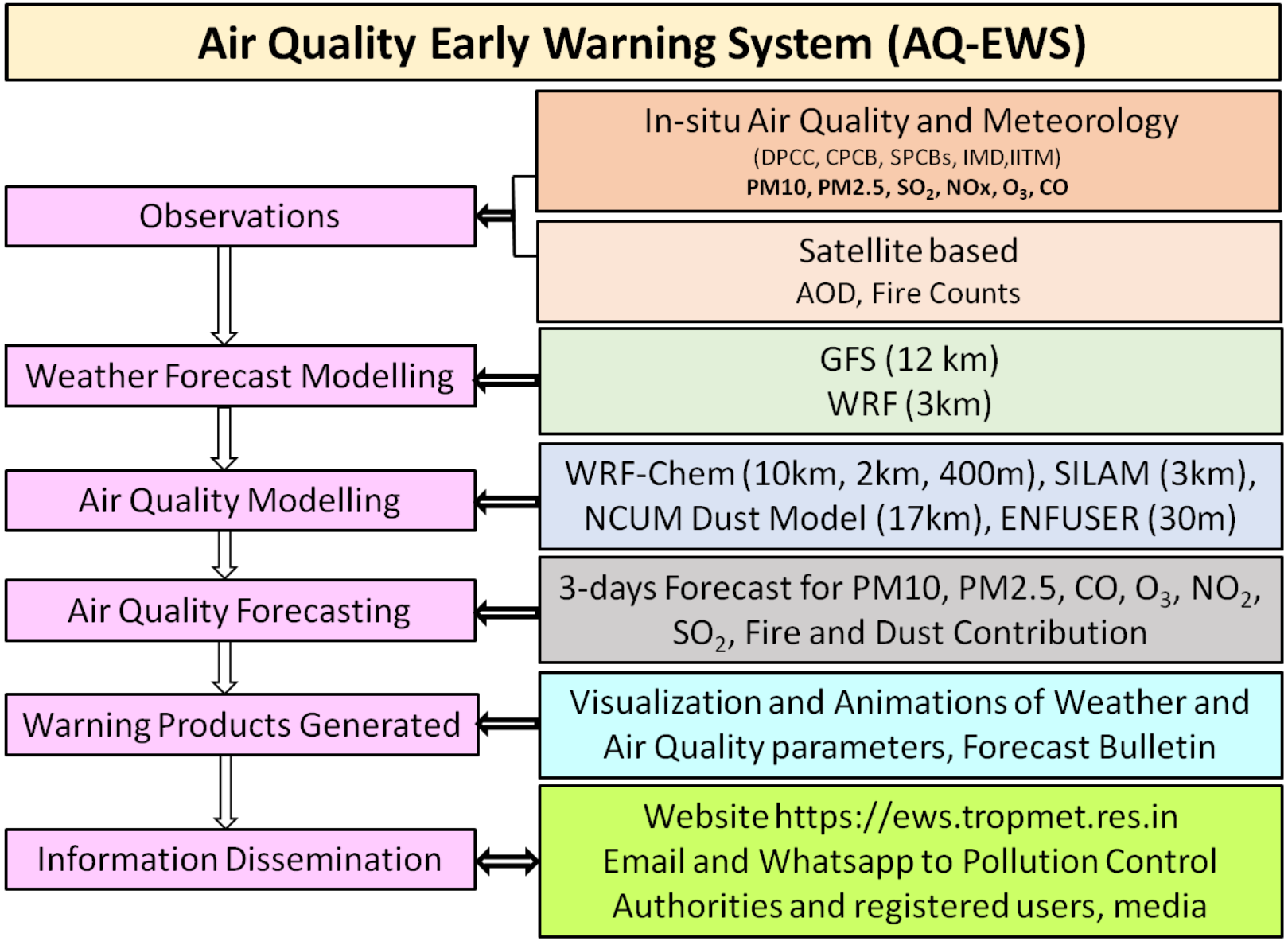
MAUSAM

Damini Lightning

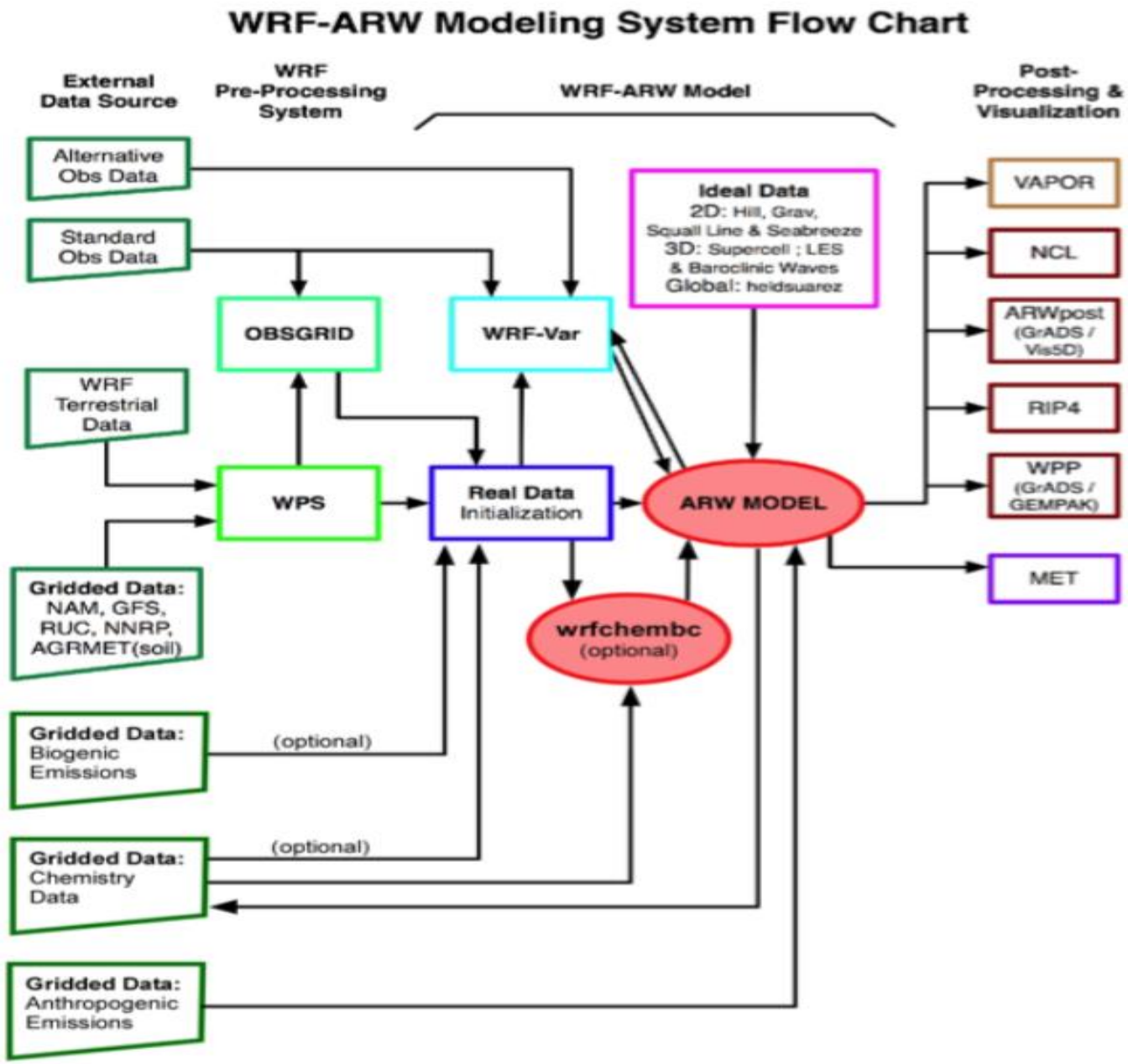
Meghdoot Agro

Social Media

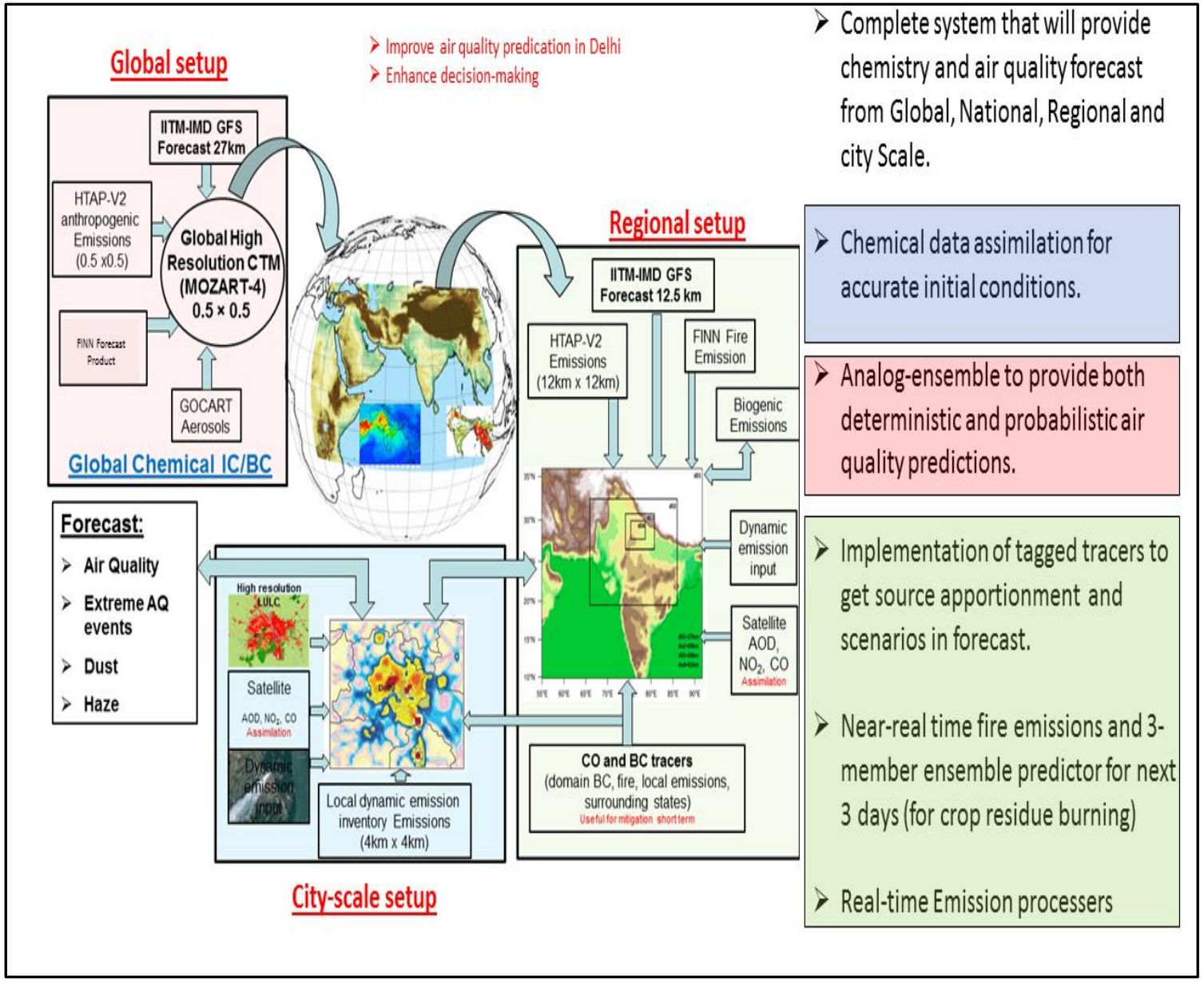
https://city.imd.gov.in/citywx/crowd/enter_th_datag.php


Air Quality Early Warning System (AQ-EWS)
In-situ Air Quality and Meteorology
(DPCC, CPCB, SPCBs, IMD,IITM)
PM10, PM2.5, SO2, NOx, O3, CO
Satellite based
AOD, Fire Counts
Observations
Weather Forecast Modelling
GFS (12 km)
WRF (3km)
Air Quality Modelling
WRF-Chem (10km, 2km, 400m), SILAM (3km),
NCUM Dust Model (17km), ENFUSER (30m)
Air Quality Forecasting
3-days Forecast for PM10, PM2.5, CO, O3, NO2,
SO2, Fire and Dust Contribution
Warning Products Generated
Visualization and Animations of Weather and
Air Quality parameters, Forecast Bulletin
Information Dissemination
Website https://ews.tropmet.res.in
Email and Whatsapp to Pollution Control
Authorities and registered users, media

WRF/Chem Flow Chart



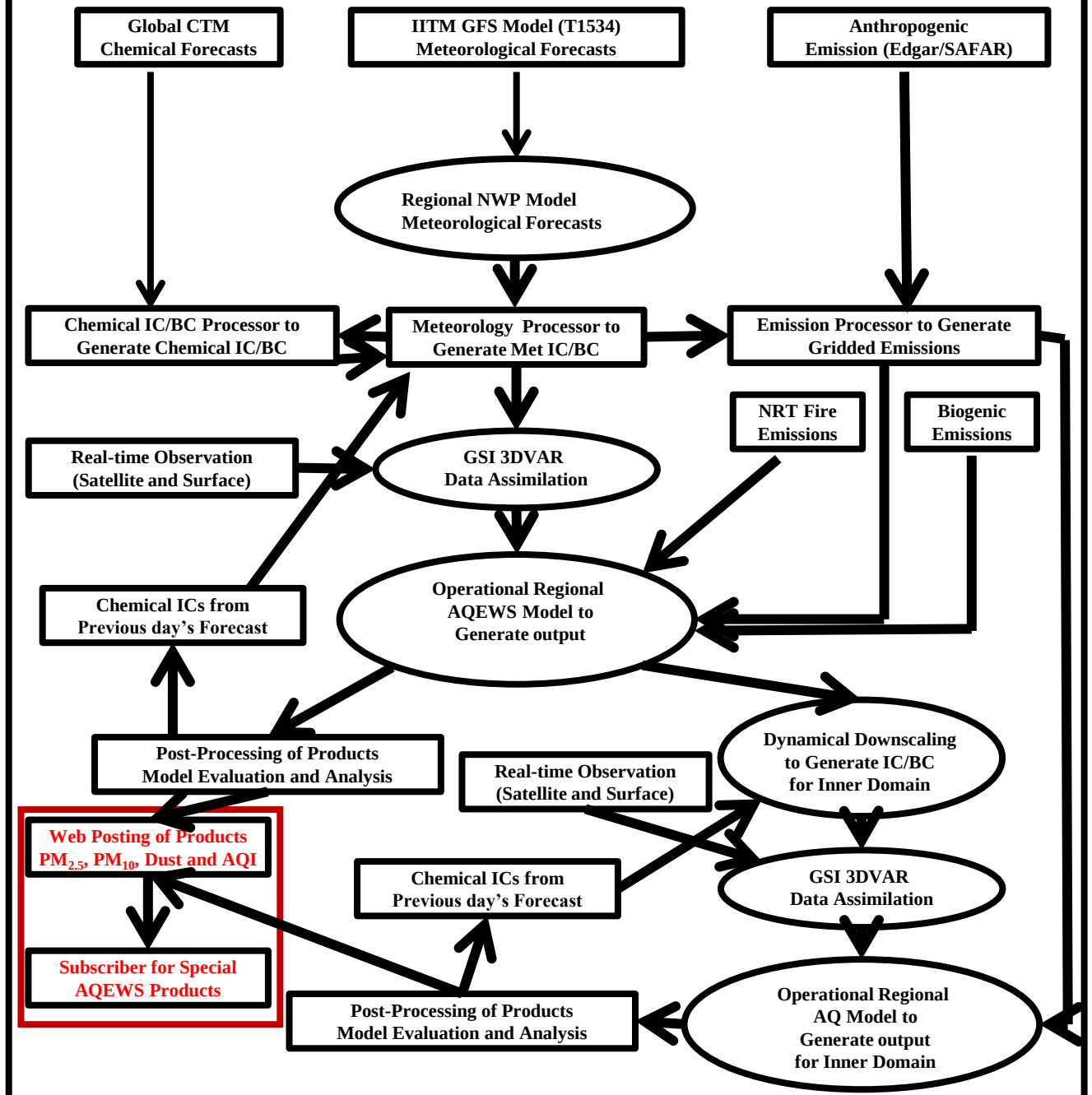
WRF-Chem System Architecture



Technological integration of the EWS system:

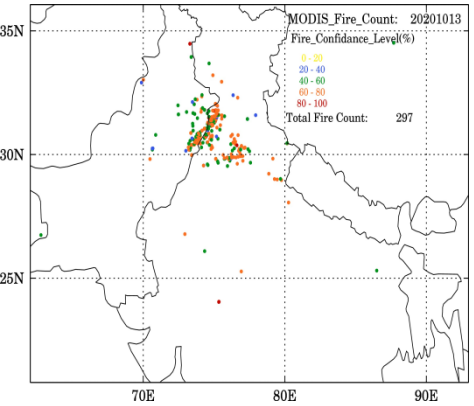
- Integrated chemical data assimilation system (3D-VAR -GSI).
  - MODIS AOD at 06 UTC and at 09 UTC AOD is assimilated at 09 UTC.
  - Surface PM2.5 data assimilation from dense monitoring network
- Near-real time stubble fire emission from MODIS fire count at assimilation cycle
  - Fires data from MODIS (1km) +VIRS (370 m)
- On-line WRF-Chem Chemistry Transport Mdoel
- EDGAR emissions and MoES 400 meter emission inventory.
- Updated LULC maps with more category for urban buildup
- High resolution land surface data assimilation (HRDAS).
- System is driven by analysis and forecast product (Ensemble-Kalman filtering) produced by the Indian Institute of Tropical Meteorology-Global Forecasting System (IITM-GFS, T1534) spectral model initial and boundary conditions at 12.5 km grid resolution available at every three hours

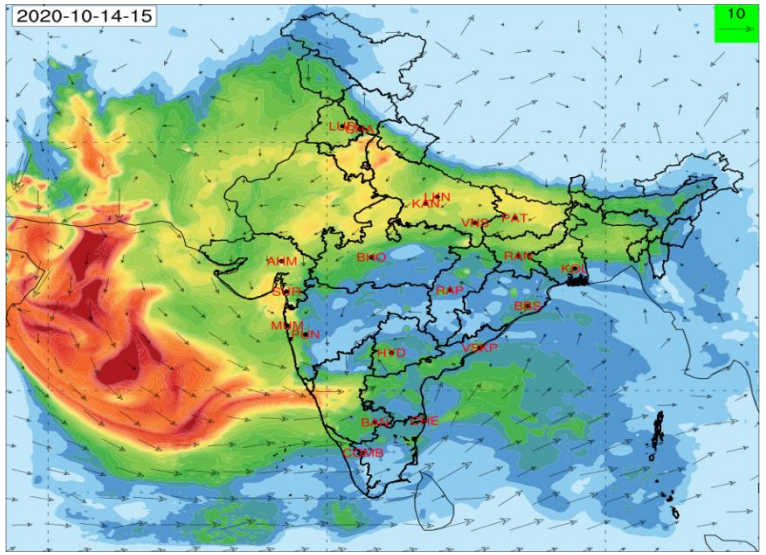
Air Quality Early Warning System



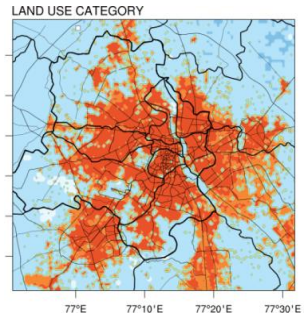
Quick Overview of operational air quality forecasting setup:

Hourly $PM_{2.5}$ forecast at 10 km based on WRF-Chem

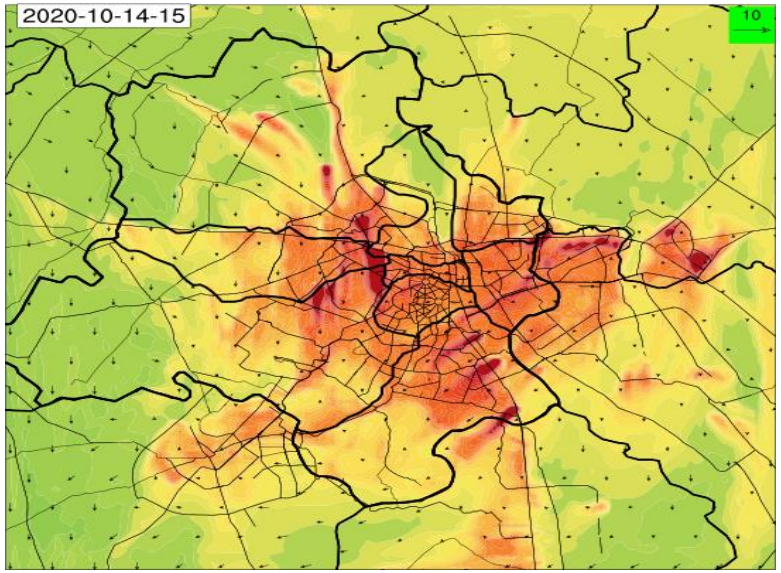




Dynamical downscaling frame-work

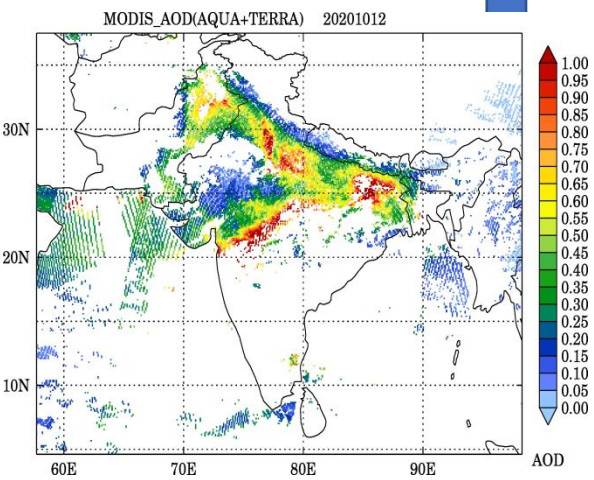


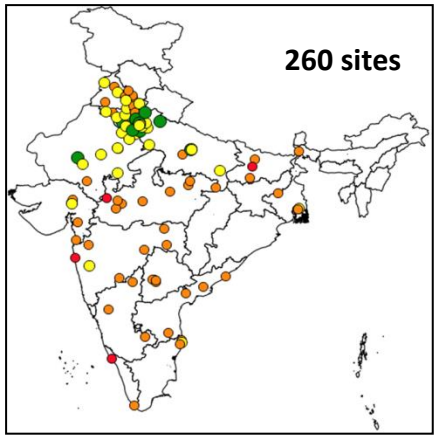
forecast at 400 m



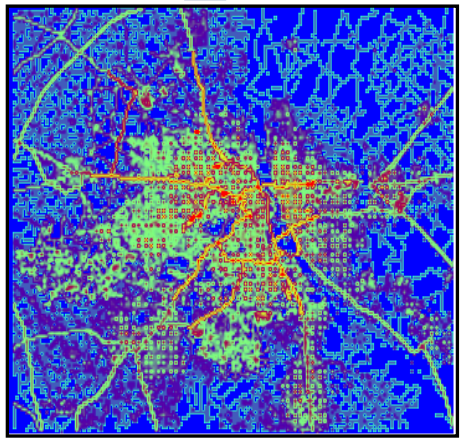
Assimilation at 9 UTC and 18 UTC

Assimilation at 9 UTC

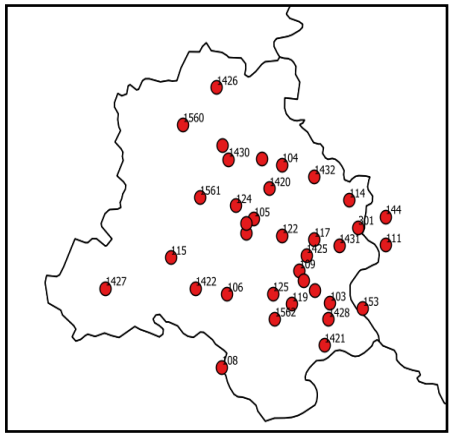




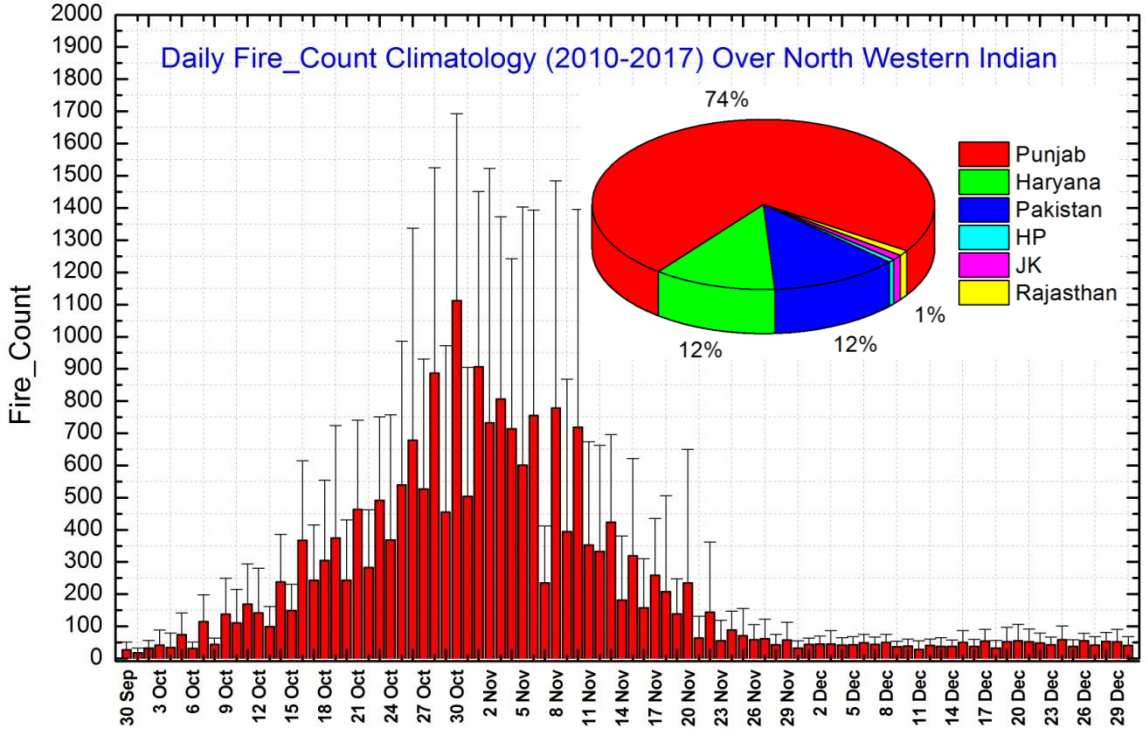
Driving meteorological IITM-Global Forecasting System (IITM-GFS, T1534, Ensemble-Kalman filtering) spectral model at 12.5 km grid resolution available at every three hours

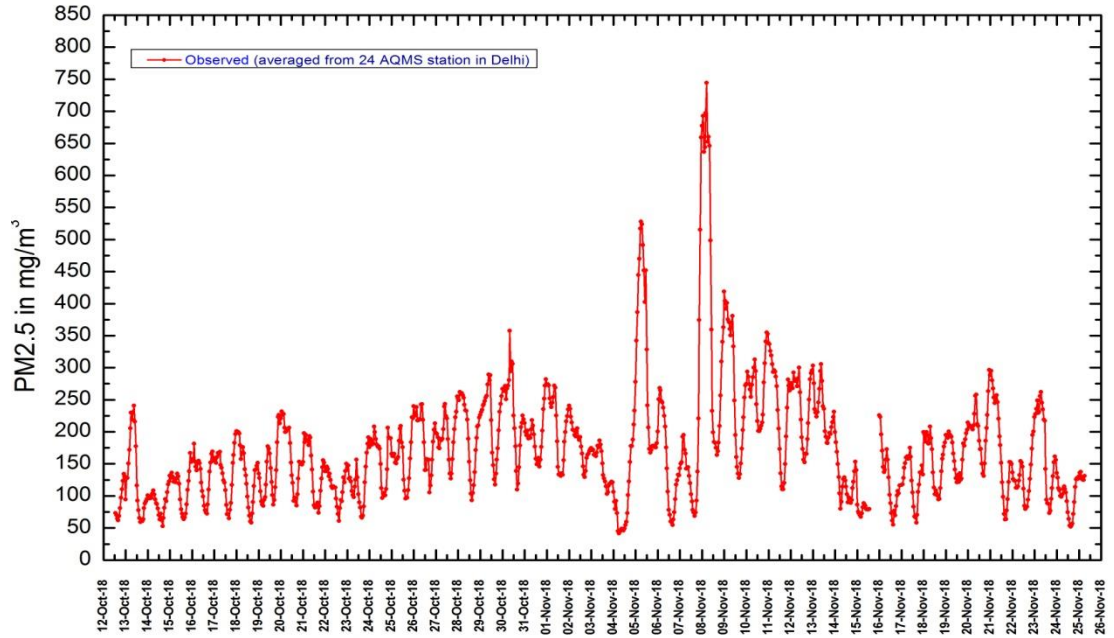


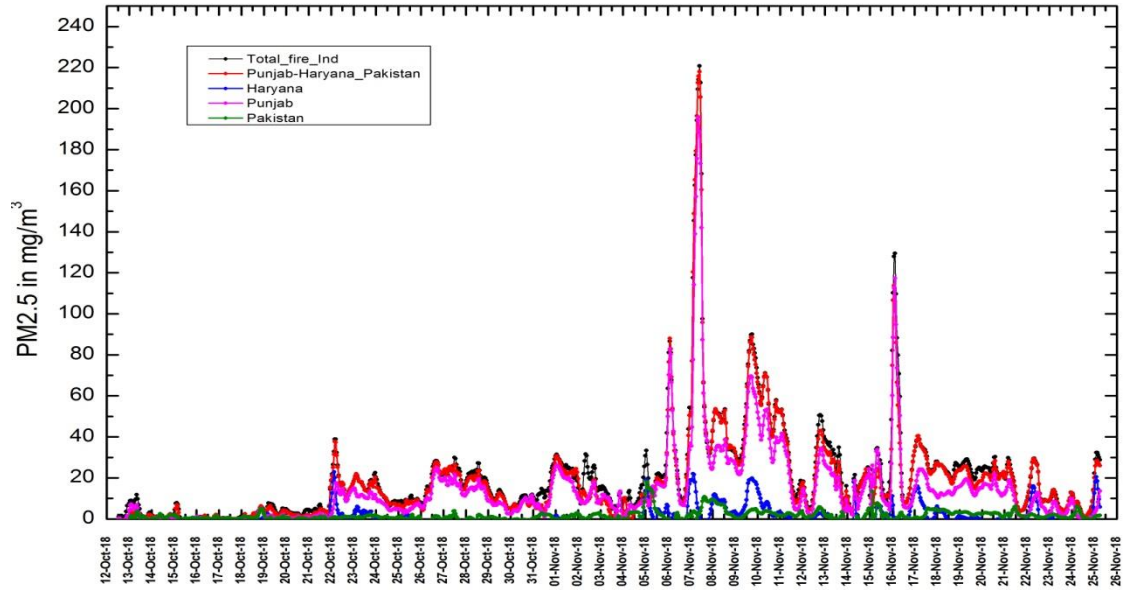
Emission inventory @ 400 m



Contribution of Fire emissions to $PM_{2.5}$ in Delhi

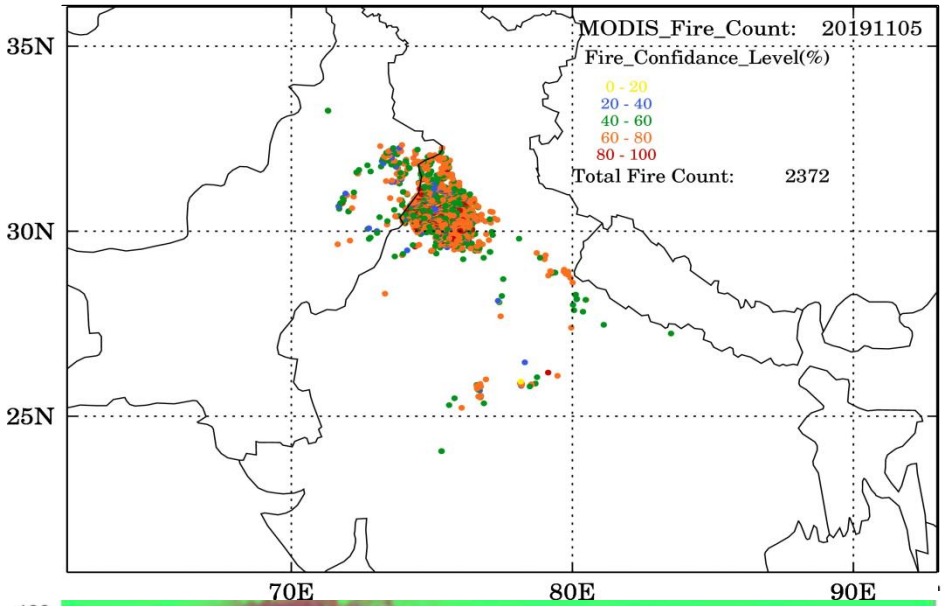


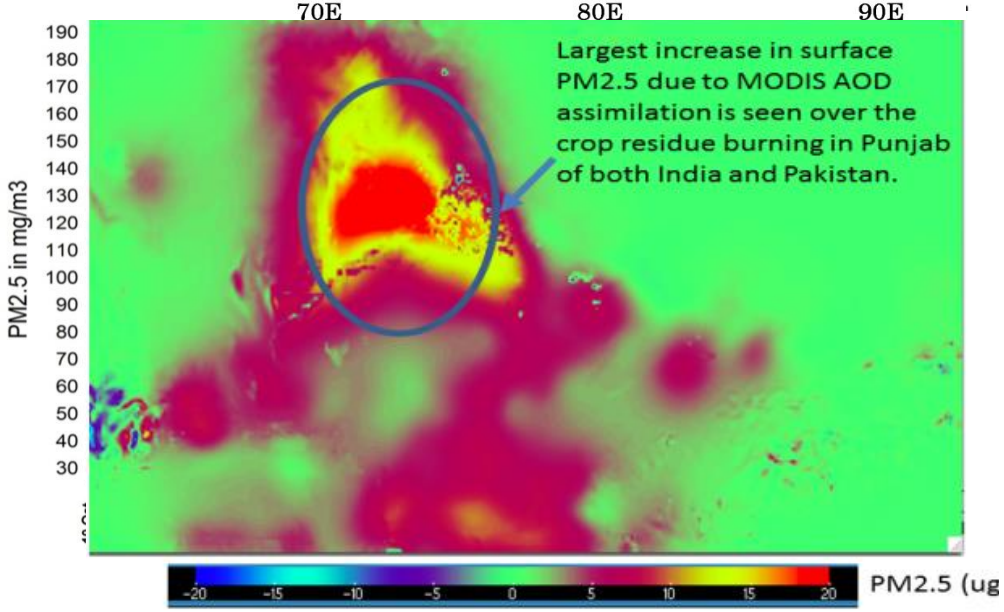


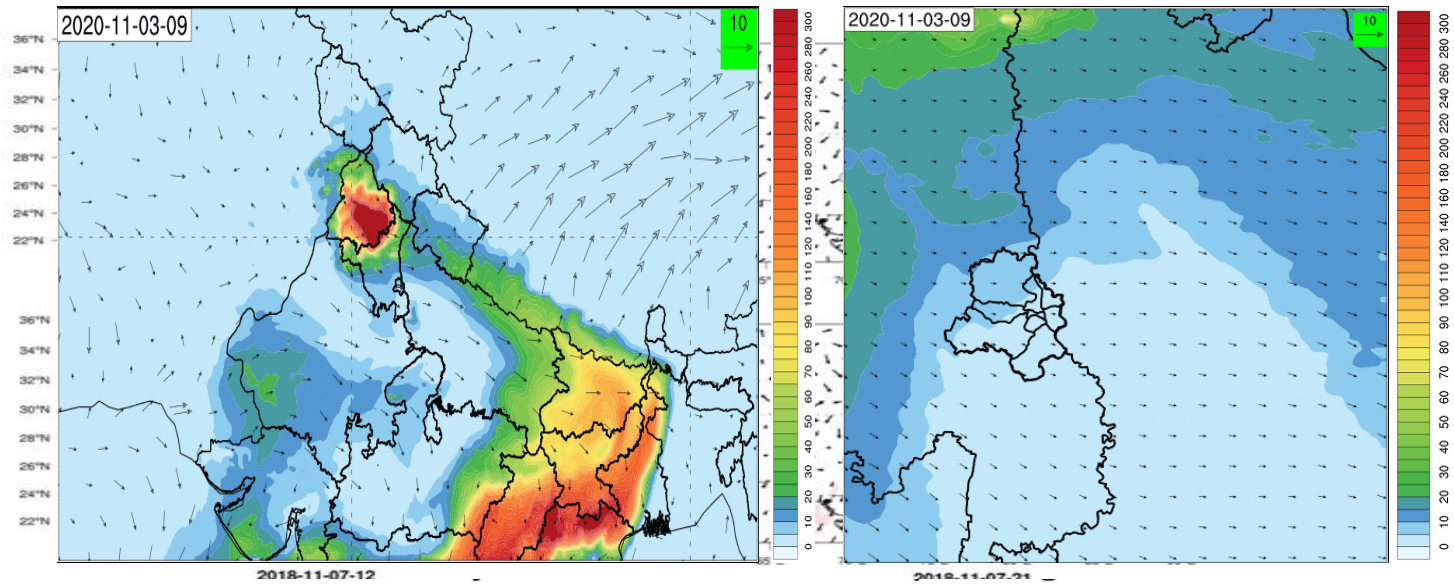


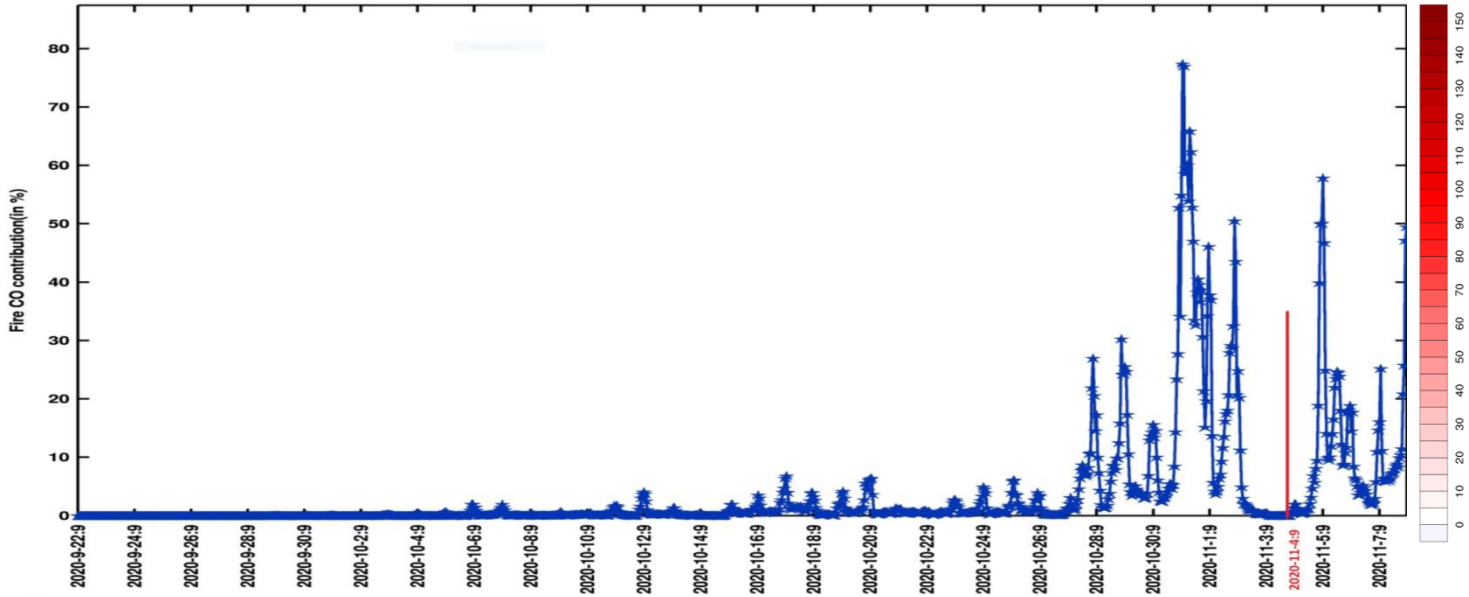
Kulkarni, Ghude, Jena et al., (EST, 2020)

Improvement in $PM_{2.5}$ Prediction after inclusion of satellite data on crop-fire



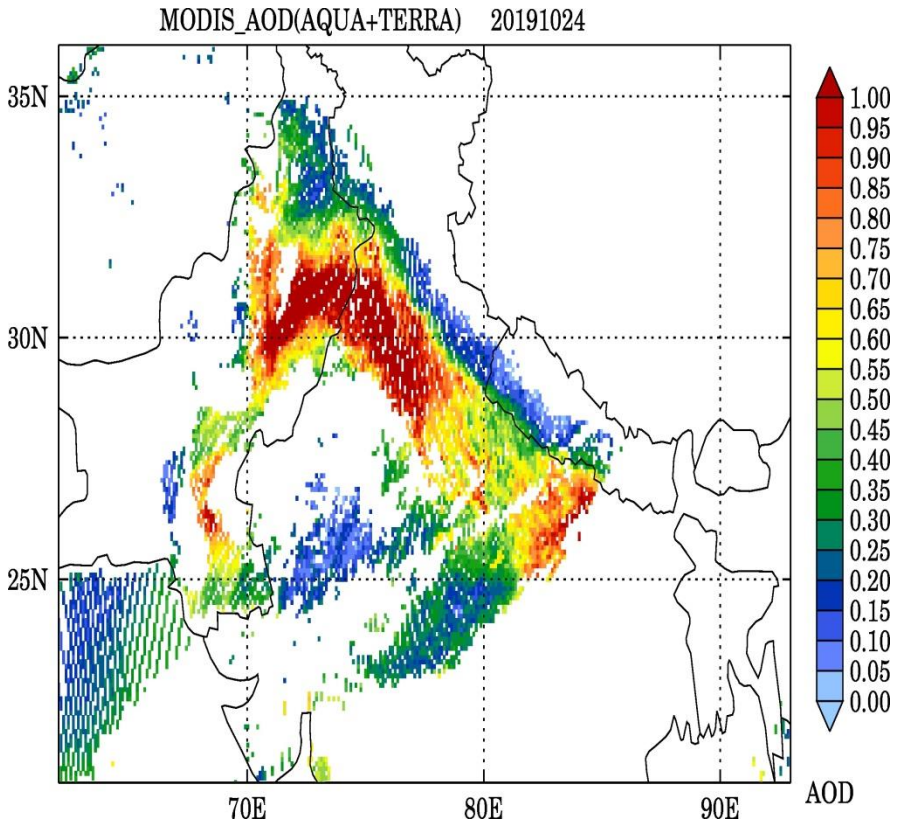


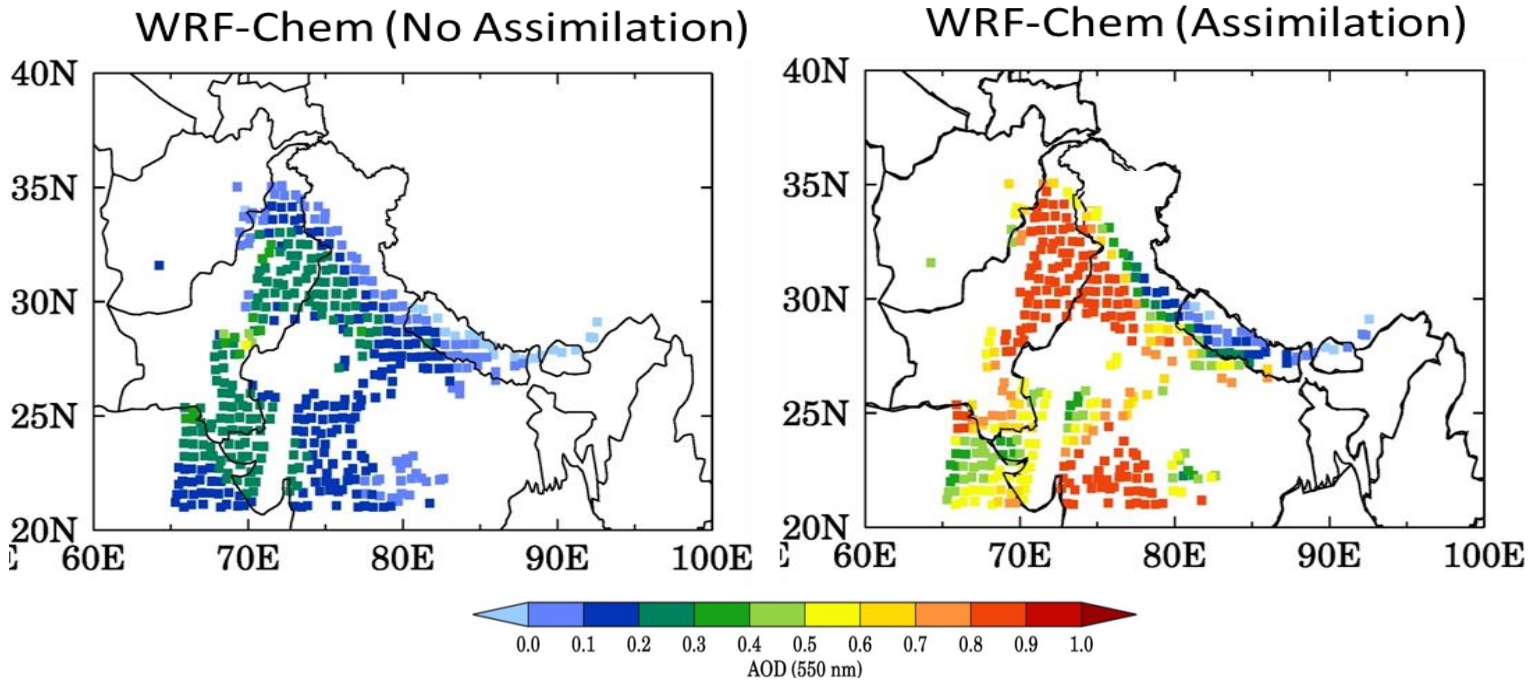


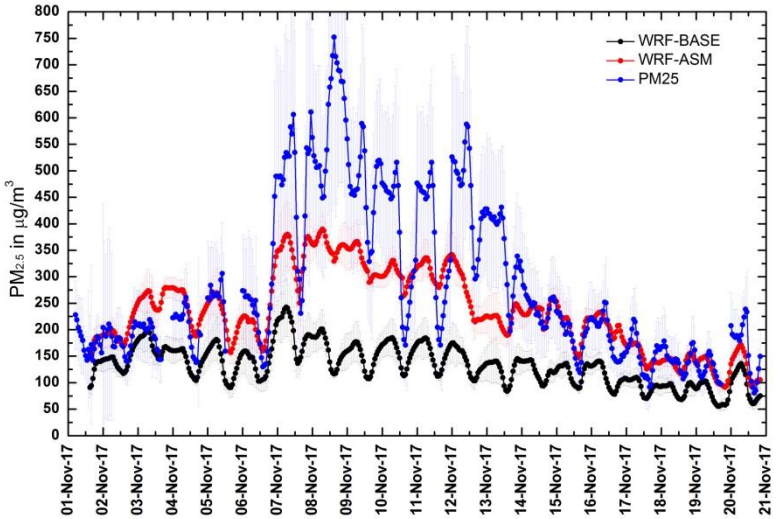


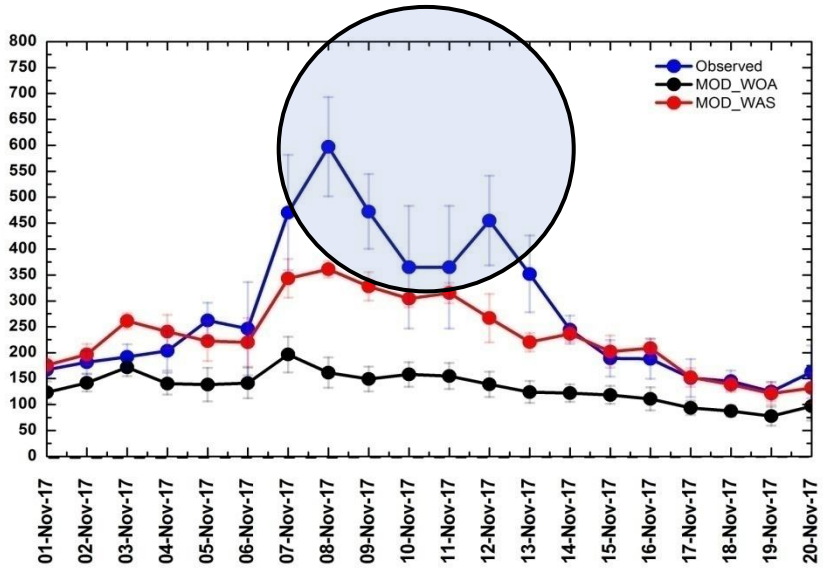
Kulkarni, Ghude , Jena et al., (EST, 2020)

MODIS AOD (TERA+AQUA)



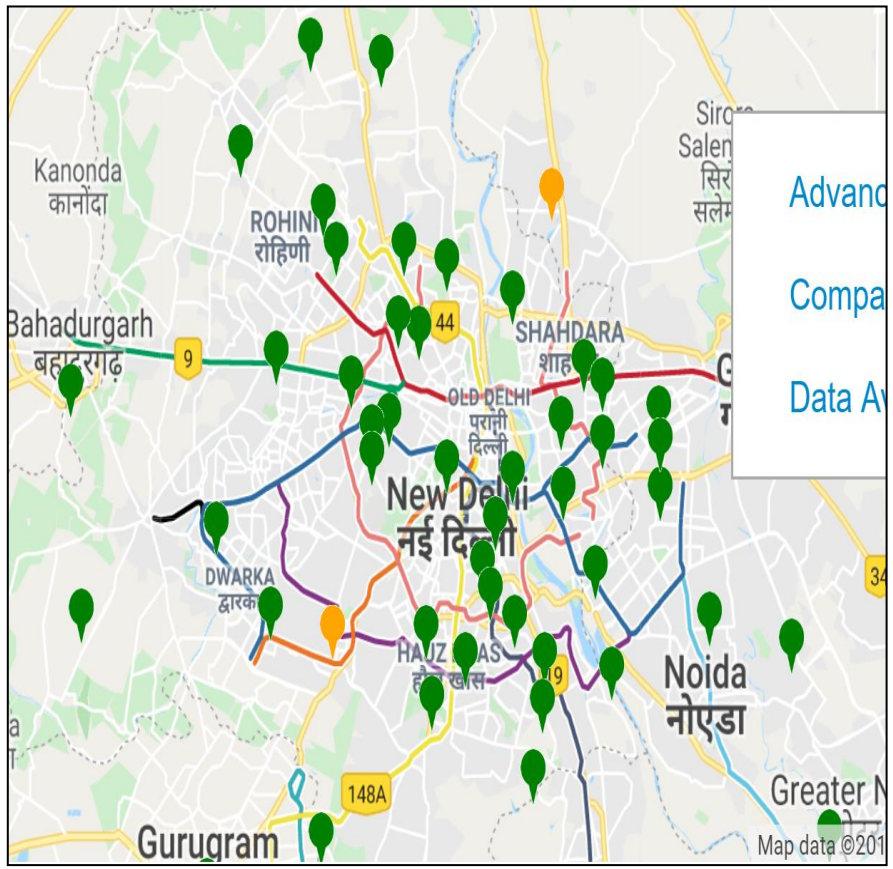


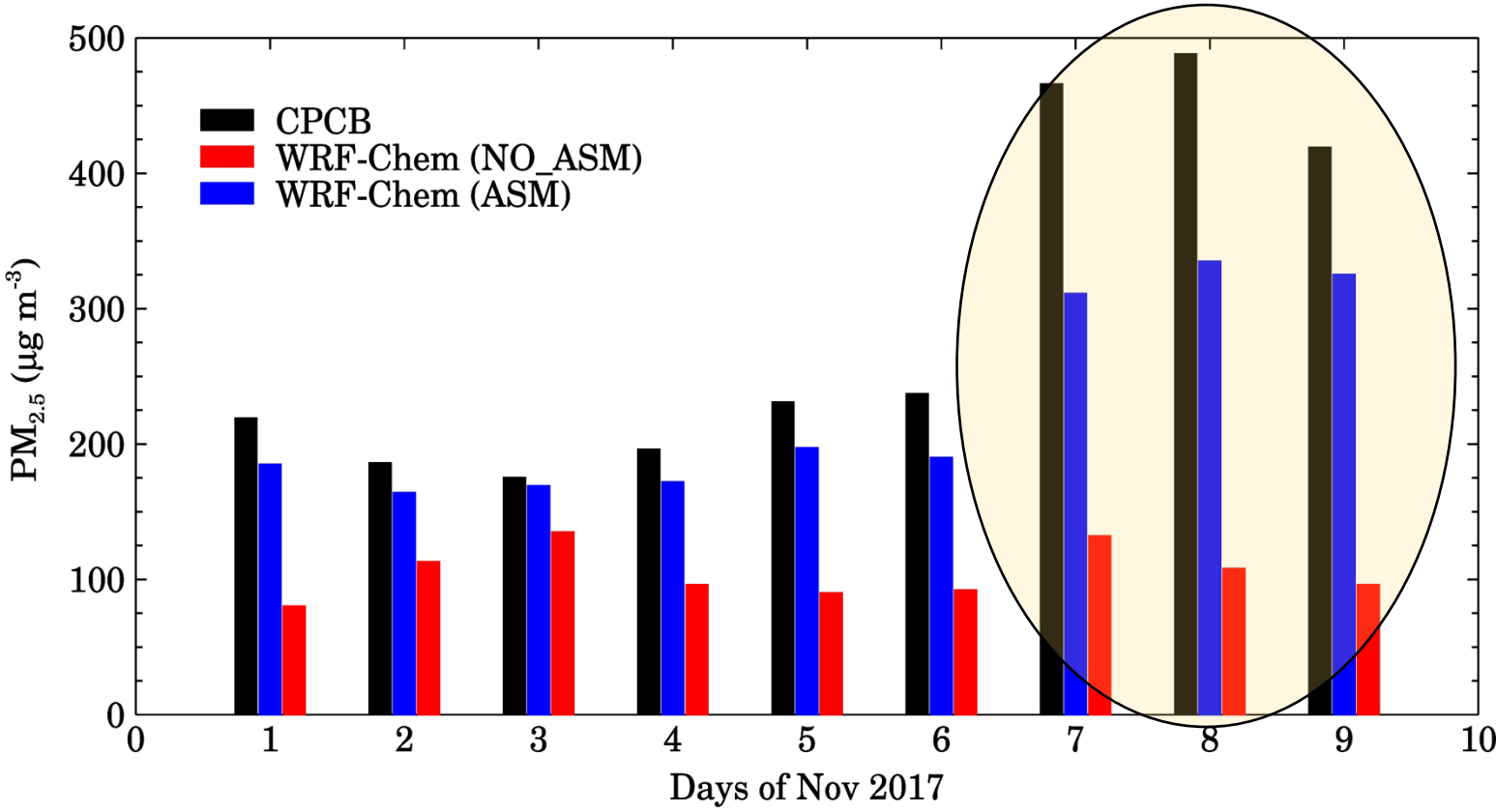




Ghude, Kumar , Jena et al., (CS, 2020) Kumar, Ghude , Jena et al., (JGR, 2020)

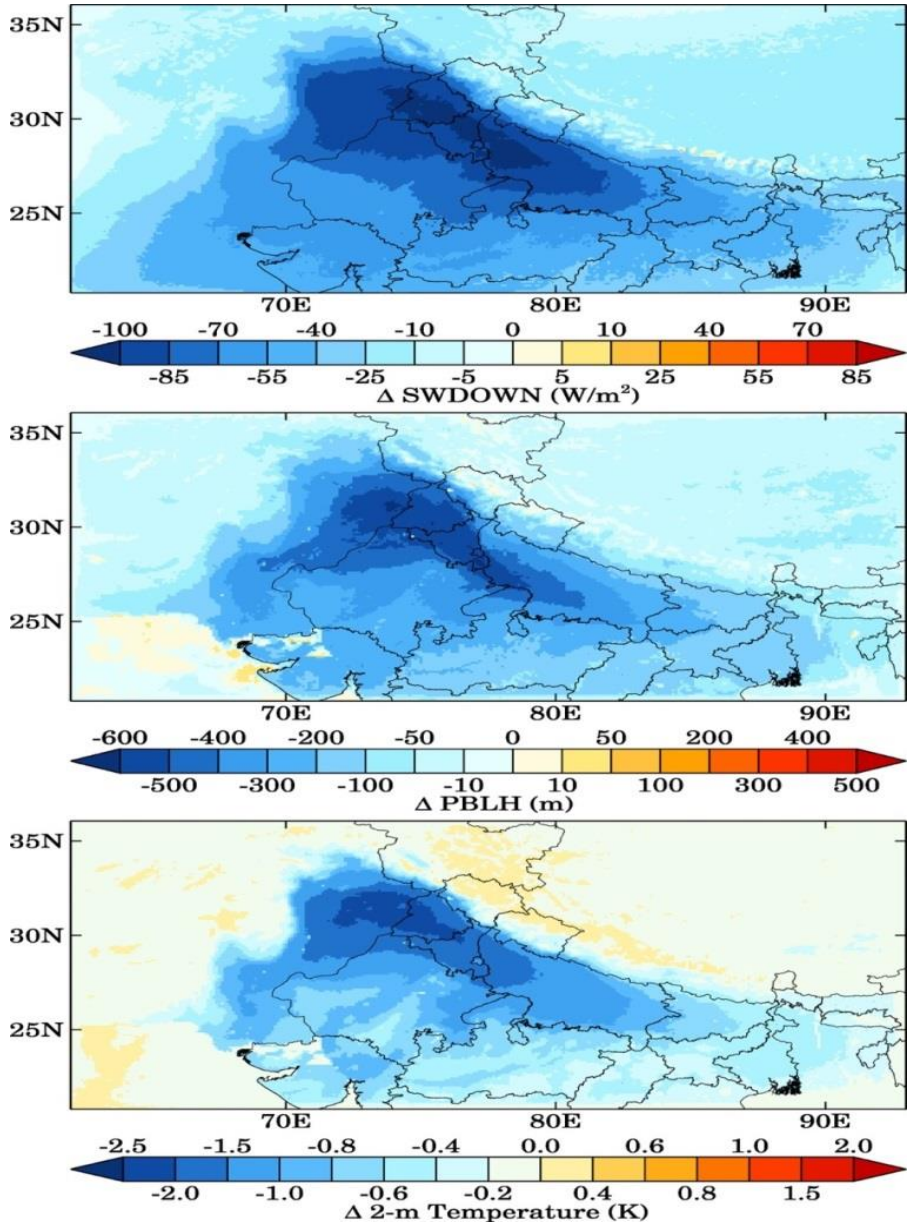
Surface $PM_{2.5}$ assimilation

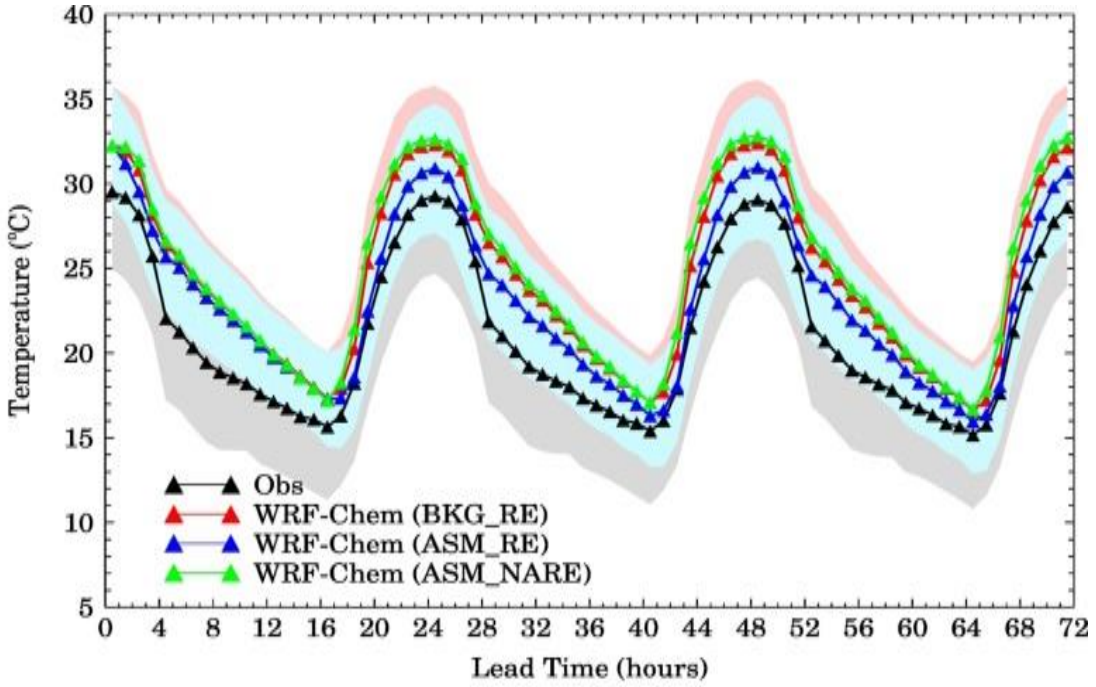




43 AQMS (CPCB,DPCC, IITM/IMD)

Changes in PBL, radiation and 2m temperature due to chemical data assimilation



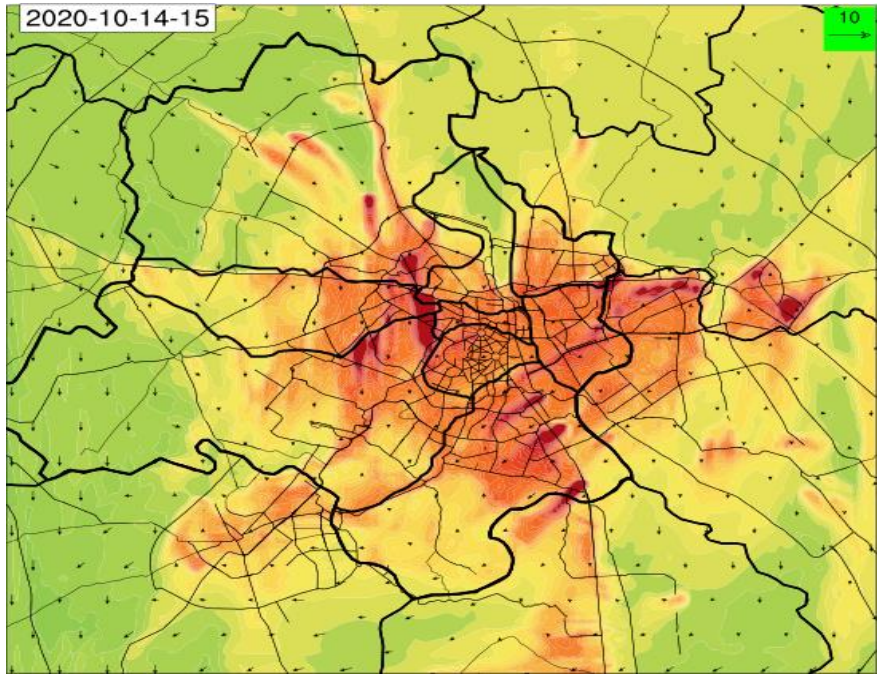


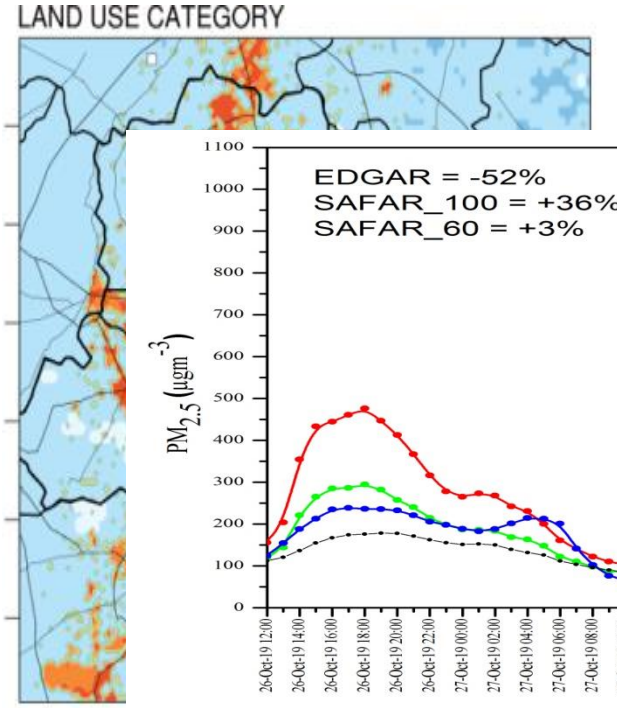
Improvement in 2m temperature and 2nd and 3rd day of forecast due to chemical data assimilation

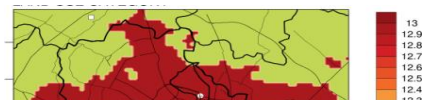
Average changes in downward solar radiation reaching at the surface (SWDOWN), planetary boundary layer height (PBLH), and 2-m temperature between the ASM_RE and BKG_RE experiments

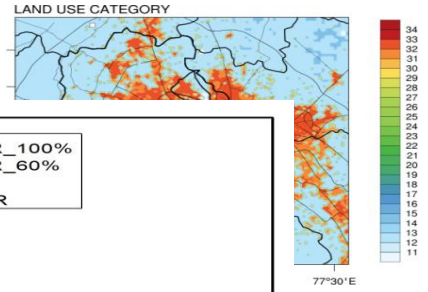
Kumar, Ghude, Jena et al, 2020, JGR

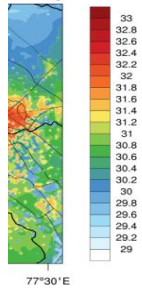
forecast at 400 m

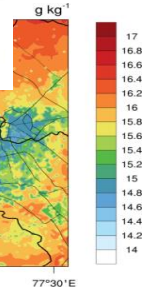


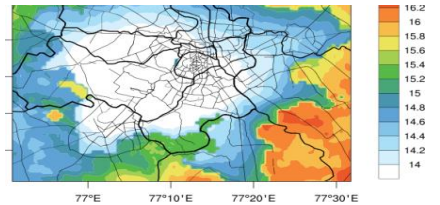


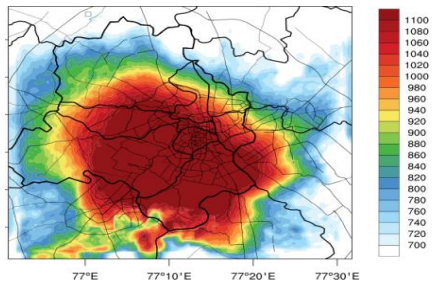


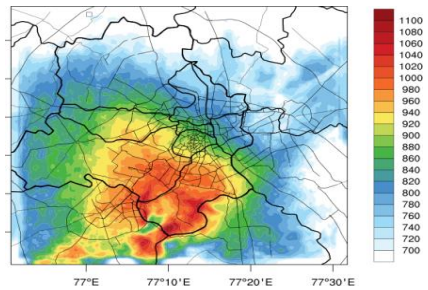


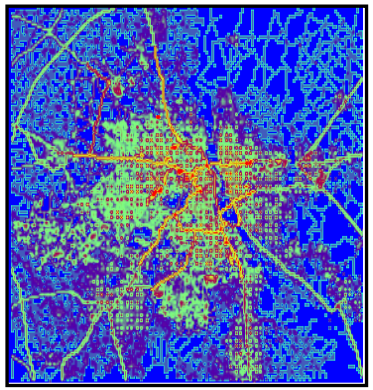




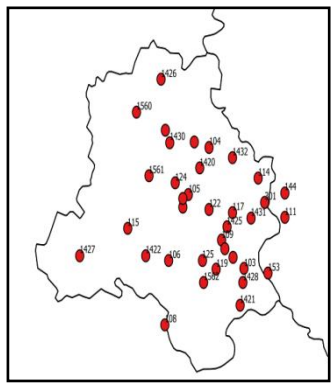


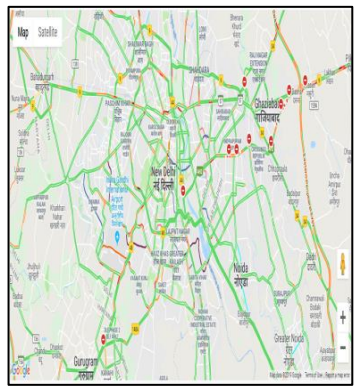




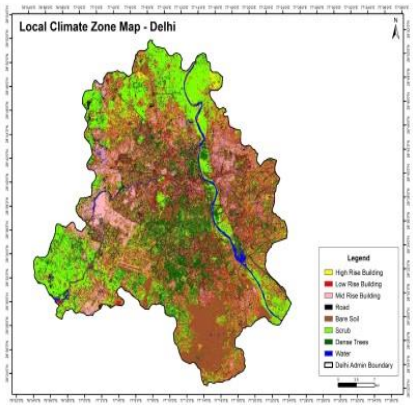


Emission inventory @ 400 m





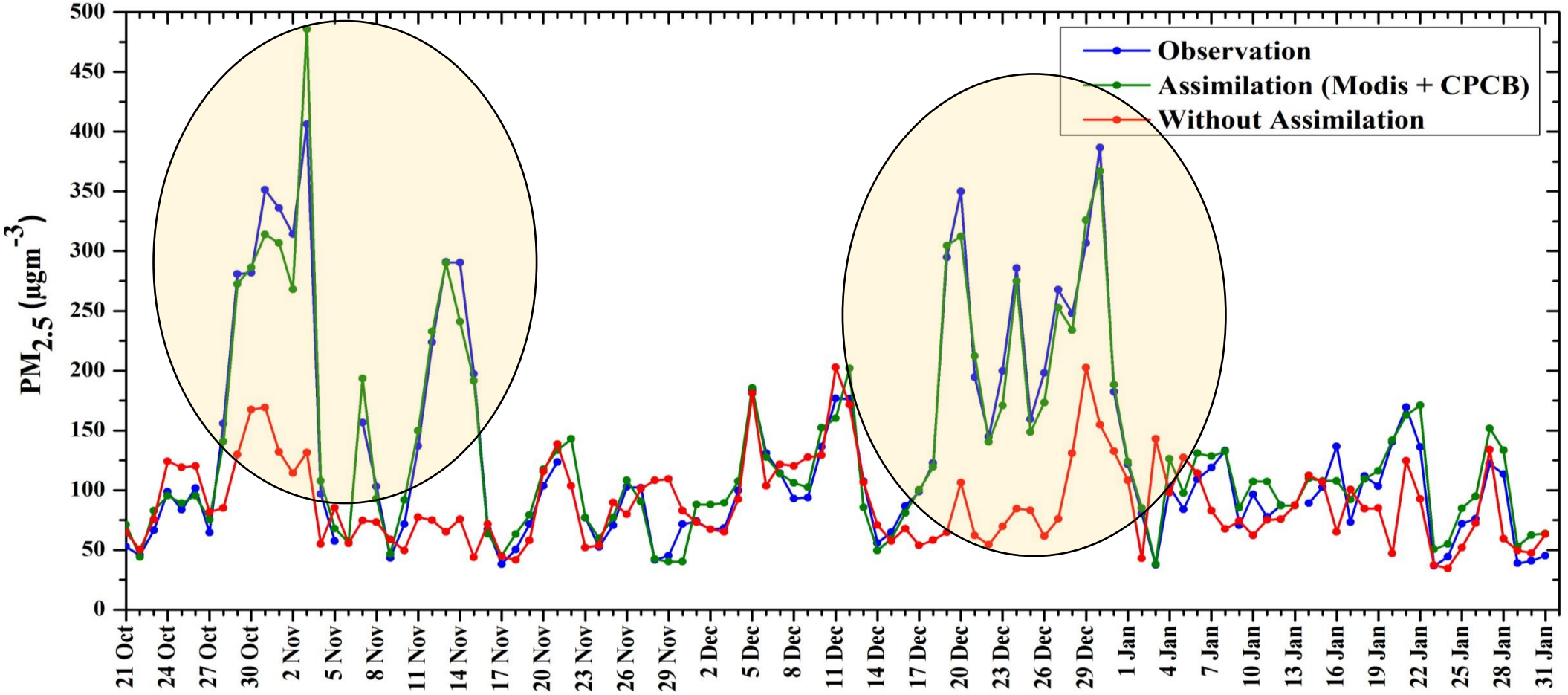
Diurnal variation from traffic



Sentinel-2 Satellite

Urban area reclassified in to low, medium and high intensity areas and updated in the MODIS LULC

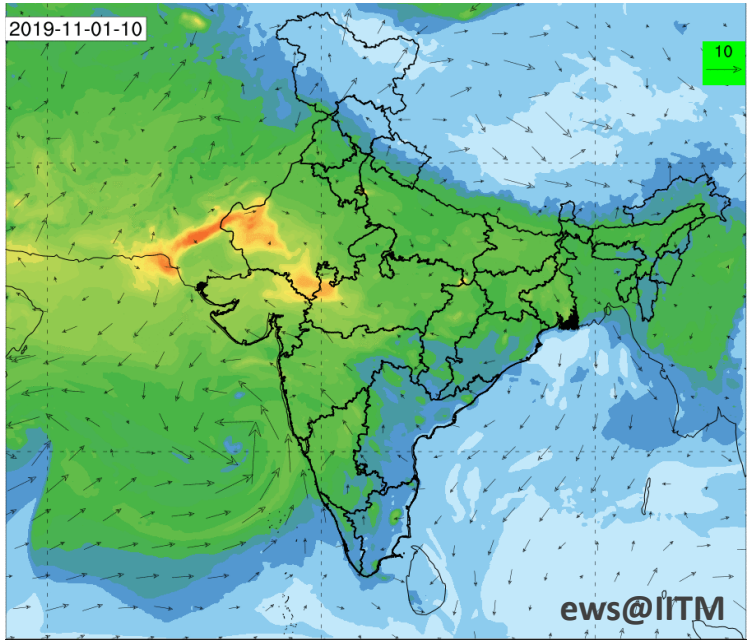
Improvement in $PM_{2.5}$ initial conditions due to satellite (MODIS) and Surface $PM_{2.5}$ (43-Stations) at assimilation Cycle (T=0)



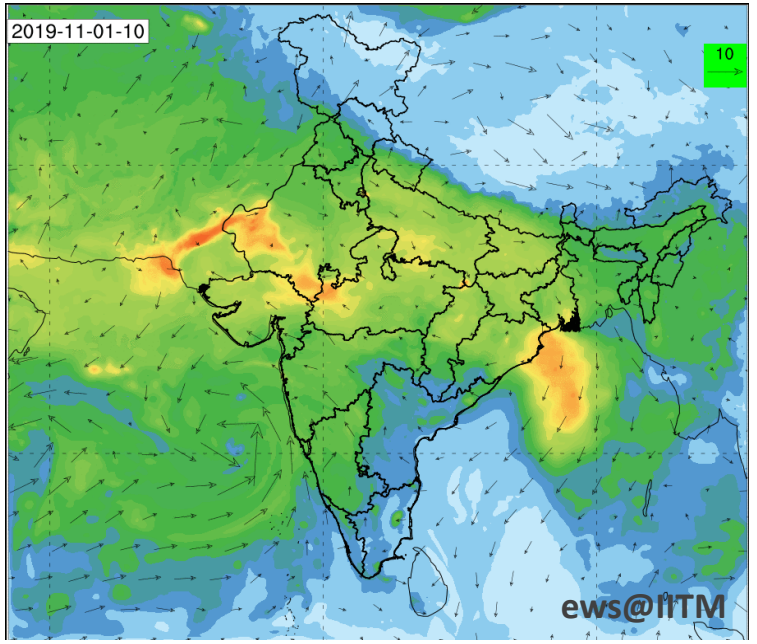
Scientific Report, 2020 (under review)

Satellite (MODIS) and surface data (230 stations) assimilation for improving short term air quality forecast over South Asia @10 KM

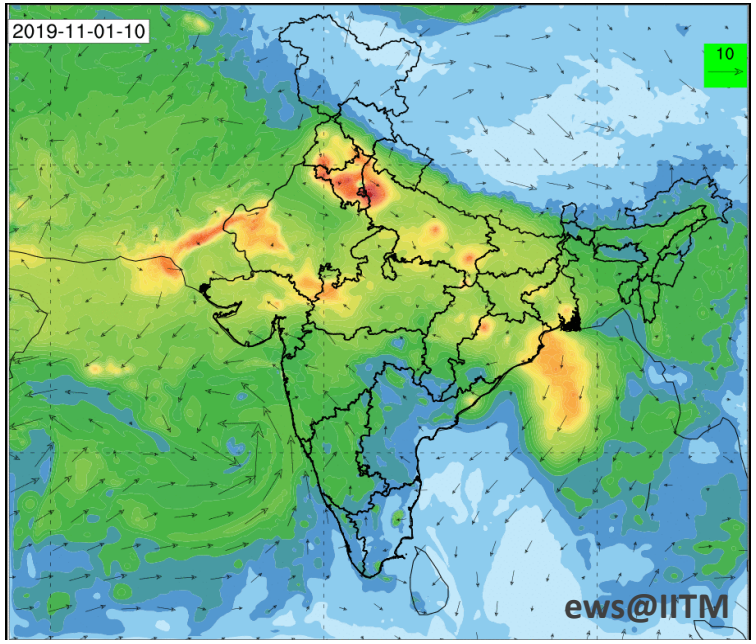
MODEL



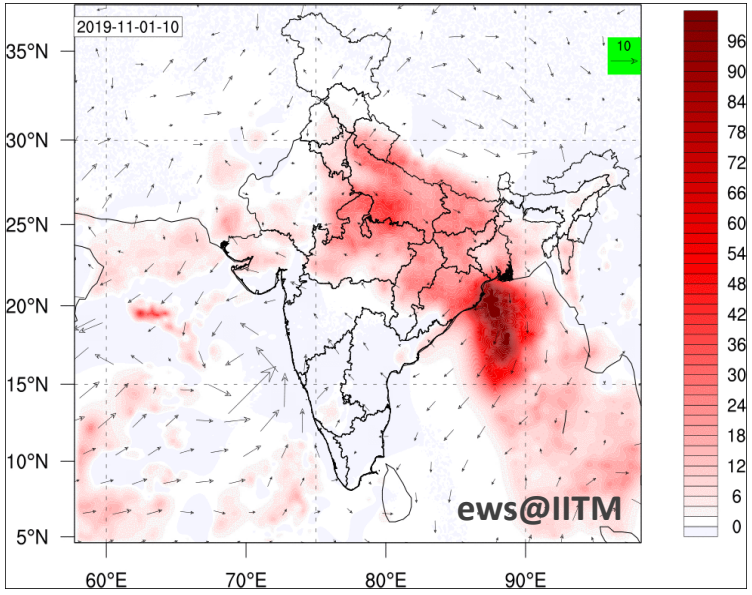
MODEL+MODIS



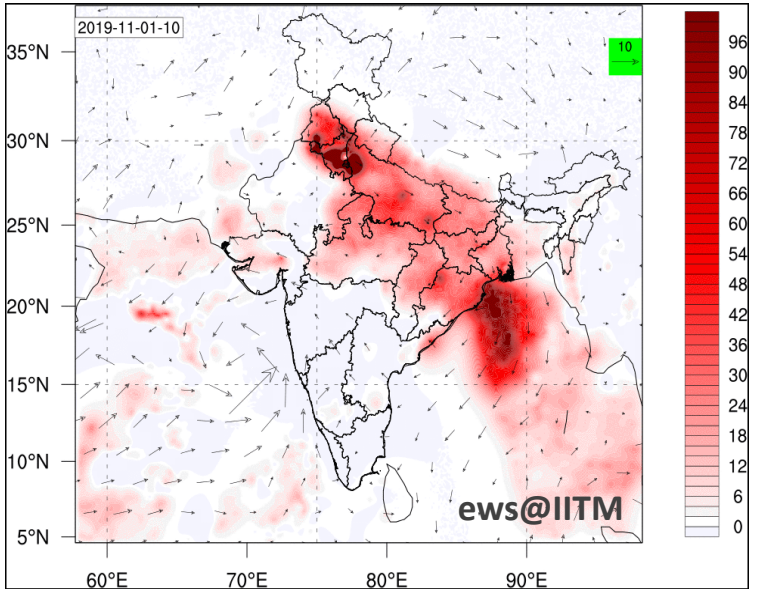
MODEL+MODIS+CPCB



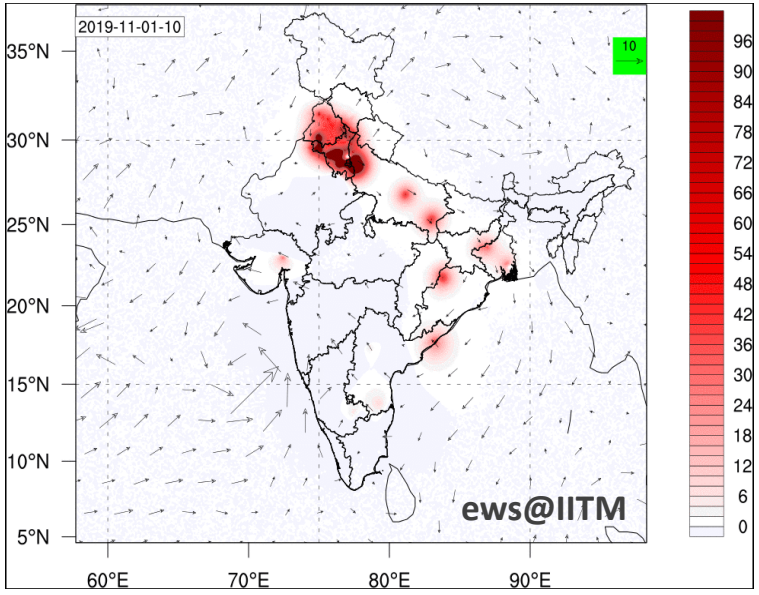
Improvement due to MODIS



Improvement due to MODIS +CPCB

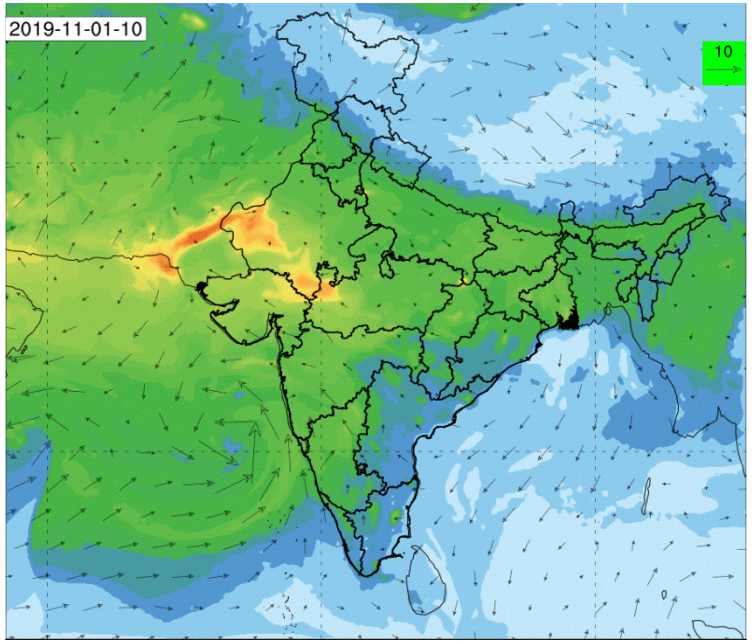


Improvement only due to CPCB

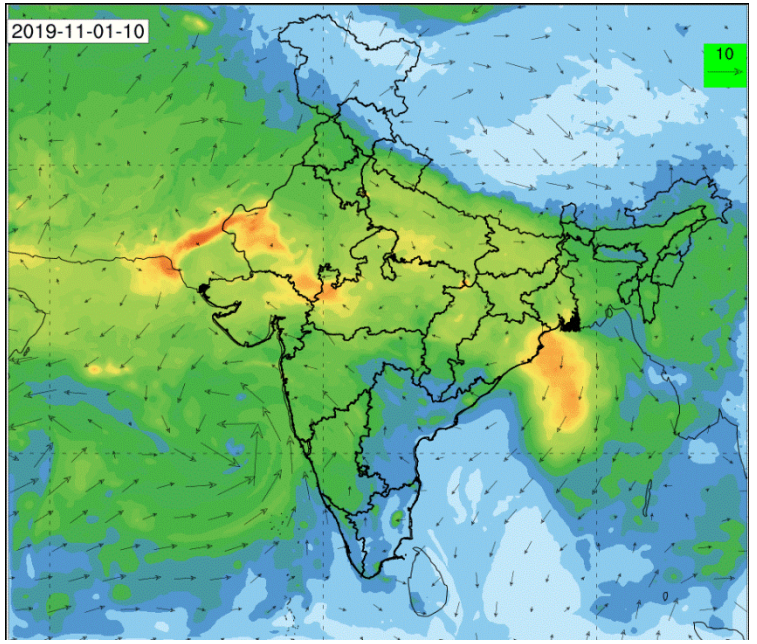


Satellite (MODIS) and surface data (300 stations) assimilation for improving short term air quality forecast over South Asia @10 KM

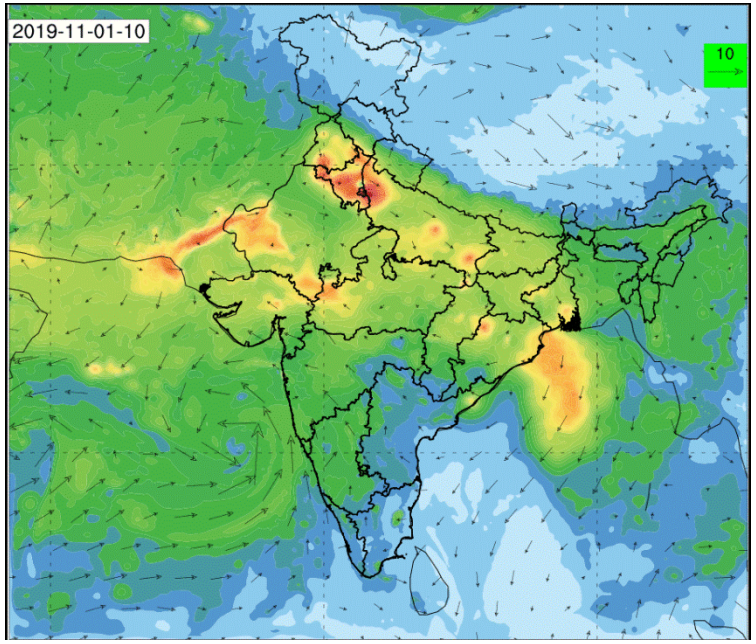
MODEL



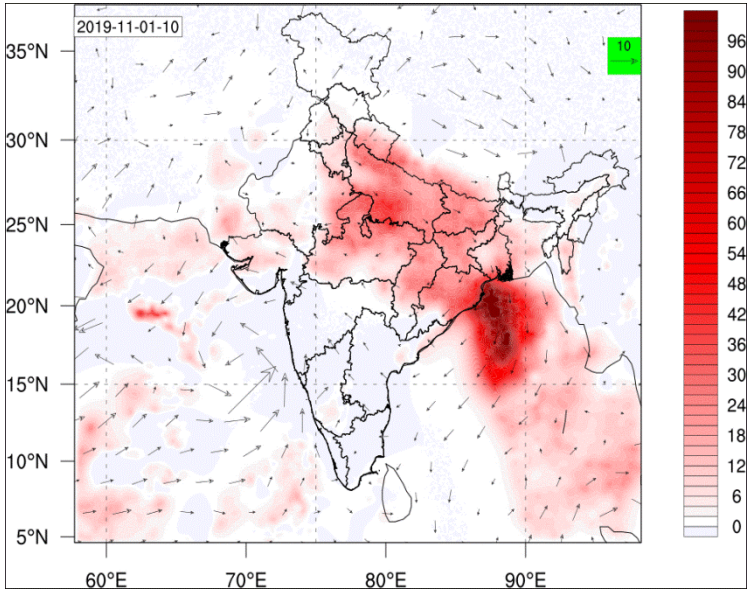
MODEL+MODIS



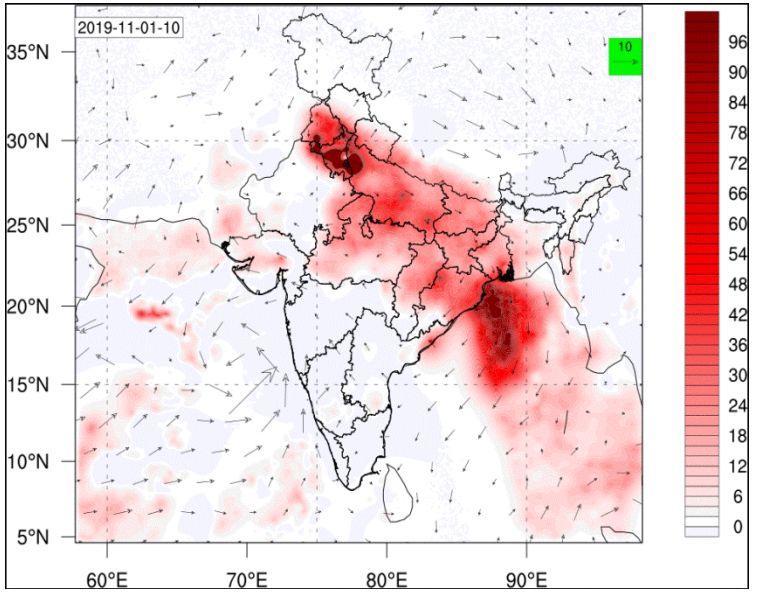
MODEL+MODIS+CPCB



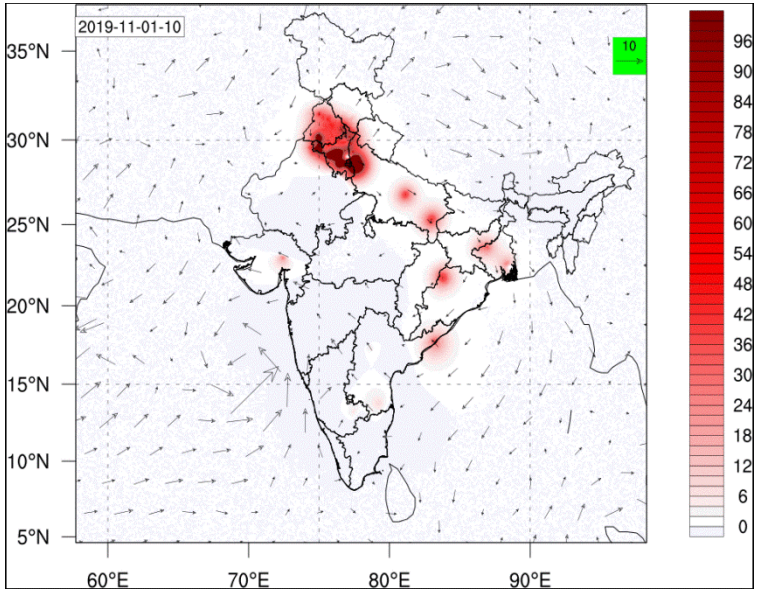
Improvement due to MODIS



Improvement due to MODIS +CPCB

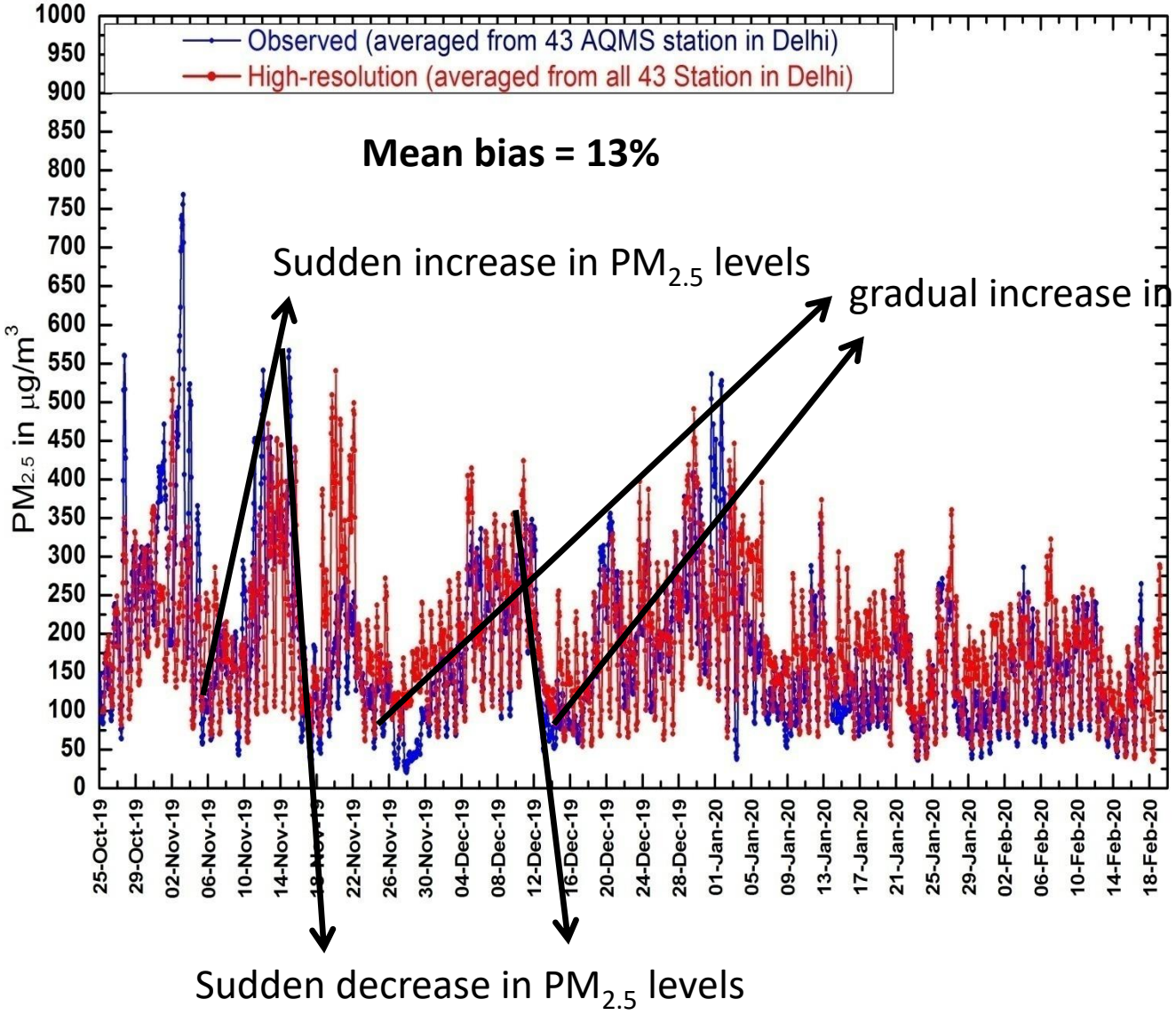


Improvement only due to CPCB

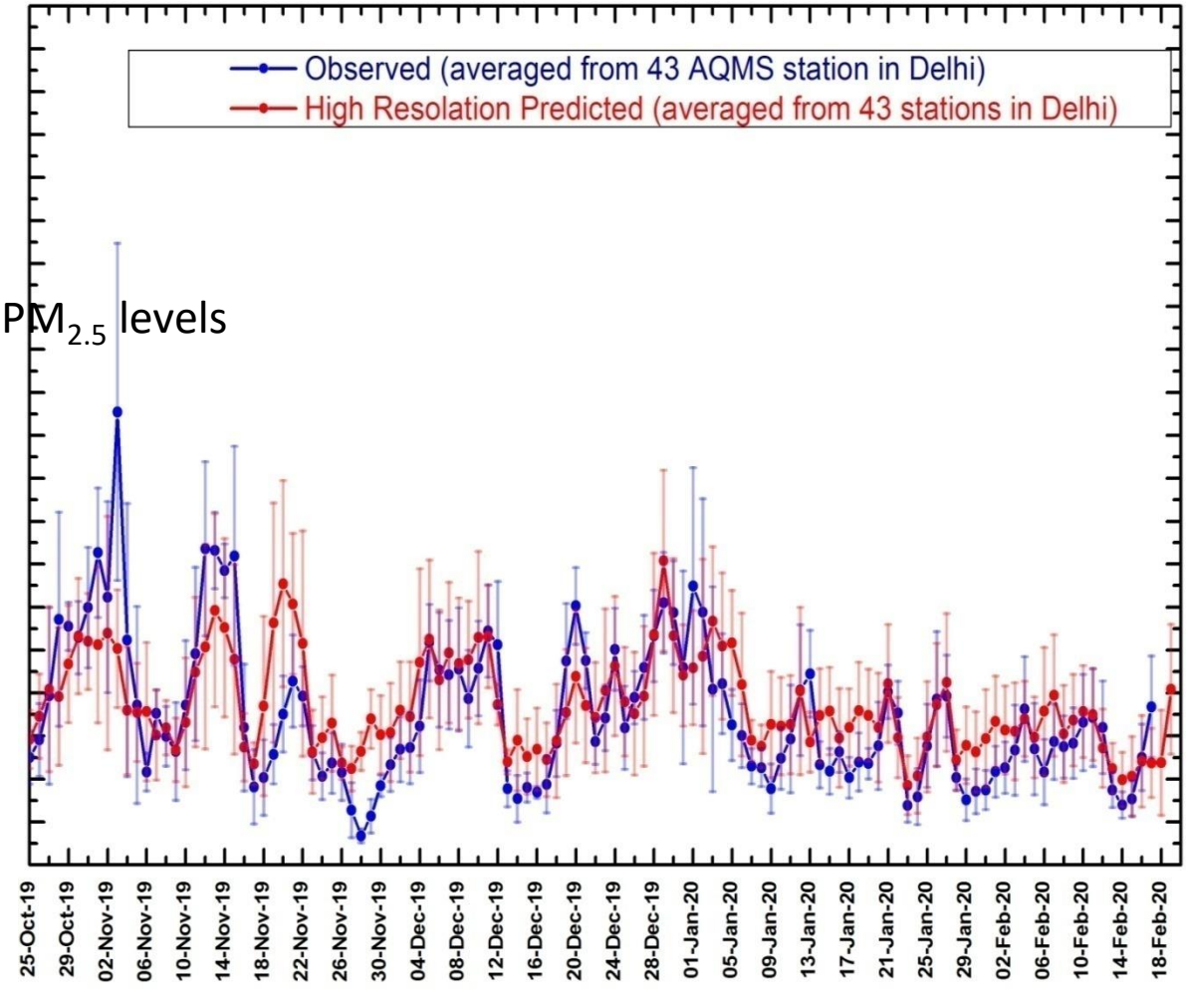


Forecast Evaluation @ 400 meter resolution (Winter 2019-2020)

Hourly mean $PM_{2.5}$ concentration



Daily mean $PM_{2.5}$ concentration



Forecast Evaluation (US-EPA Metrics)

How good is good?

Fractional Bias	Fractional error	Comment
≤ ± 15%	≤ 35%	A level of model performance that would be considered excellent
≤ ± 30%	≤ 50%	A level of model performance that would be considered good
≤± 60%	≤ 75%	A level of model performance that would be considered Average and hope each PM species could meet for regulatory modeling
>± 60%	> 75%	At or exceeding this level of performance indicates fundamental problems with modeling system

Moris et al.,2005

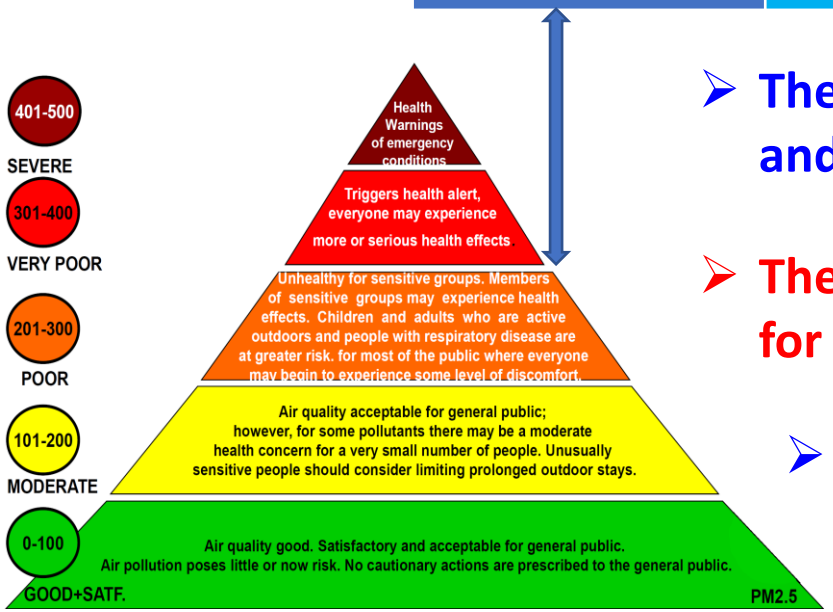
How good is forecast for absolute PM2.5 concentration?

Variables	Variables	10km		400 meter	
		NMFB (%)	NMFE (%)	NMFB (%)	NMFE(%)
PM_{25}_hourly	1st day	-0.1	33.0	13	36.3
	2nd day	-14.5	38.9	-4.8	38.1
	3rd day	-19.9	42.2	-9.8	40.5
PM_{25}_daily	1st day	-0.5	23.2	1.0	25.6
	2nd day	-14.8	29.5	-5.0	26.7
	3rd day	-20.2	33.7	-10.1	29.5
PM_{25}_AQI	1st day	5.2	15.0	6.5	16.5
	2nd day	-2.6	17.7	3.1	16.5
	3rd day	-6.7	20.0	0.1	17.8

- **Performance is good for hourly $PM_{2.5}$ prediction**
- **Performance is excellent daily mean $PM_{2.5}$, hourly AQI**
- **Performance of the forecast is not significantly going down from day 1 to day 3 of forecast.**

How good is forecast for absolute AQI index?

AIR QUALITY INDEX (AQI)		10km		400 meter	
		NMFB (%)	NMFE (%)	NMFB (%)	NMFE (%)
Very Poor (301-400)	1st day	1.2	6.4	2.3	6.8
	2nd day	- 5.3	9.1	- 0.8	6.9
	3rd day	- 8.3	11.4	- 3.9	8.7
Severe (401-Above)	1st day	- 11.1	15.6	- 13.9	16.3
	2nd day	- 22.1	22.2	- 17.2	17.8
	3rd day	- 26.7	26.7	- 20.7	20.9



- The Performance for very poor AQI category is excellent for day 1 day 2 and day 3.
- The performance is excellent for severe AQI category for day 1 and good for day 2 & 3.
- The mean bias for severe category is more indicating severe events are underestimated by about 14% on day 1 and 20% on day 3

Forecast Evaluation (Skill score 2019-2020 Winter)

Statistic name	What it measures	Equation %
Accuracy (A)	Percent of forecasts that correctly predicted the event or non-event.	A=(a+d)/(a+b+c+d) *100
False Alarm Rate (FAR)	The percent of times a forecast of high pollution did not actually occur.	FAR = (b/(a+b)) *100
POD or HE (Hit Rate)	Ability to predict high pollution events (i.e., the percentage of forecasted high pollution events that actually occurred).	POD = (a/(a+c)) * 100
CIS Threat schore	How well the high-pollution events were predicted. Useful for evaluating rarer events like high-pollution days. It is not affected by a large number of correctly forecasted, low pollution events.	CSI = (a/(a+b+c)) * 100

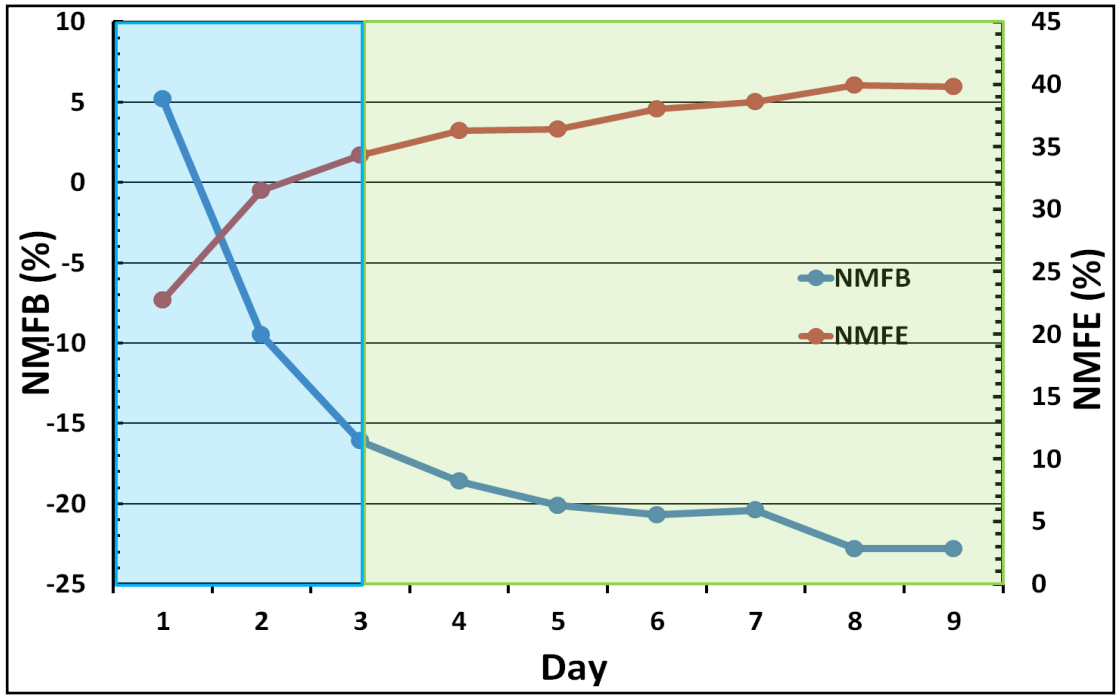
PM_{25} AQI Category	Variables	400 meter			
		FAR	POD	CSI	Accuracy
Unhealthy (200-above)	1st day	0.11	1.00	0.88	0.88
	2nd day	0.09	0.99	0.90	0.90
	3rd day	0.09	0.98	0.88	0.88
Very-Unh (300-above)	1st day	0.28	0.98	0.70	0.72
	2nd day	0.25	0.94	0.71	0.75
	3rd day	0.23	0.89	0.70	0.74
Severe (400-above)	1st day	0.35	0.34	0.29	0.82
	2nd day	0.15	0.35	0.33	0.85
	3rd day	0.25	0.21	0.19	0.82

- For unhealthy category HR is above 90%, CSI is above 80% and FAR is less than 10%.
- For very-unhealthy category HR is 85-90%, CSI is about 70% and FAR is less than 20-30%.
- For sever category although the accuracy is excellent, POD & CSI is moderate, but no much increase is seen in FAR.
- FAR show decrease on day 2 & day 3 of forecast

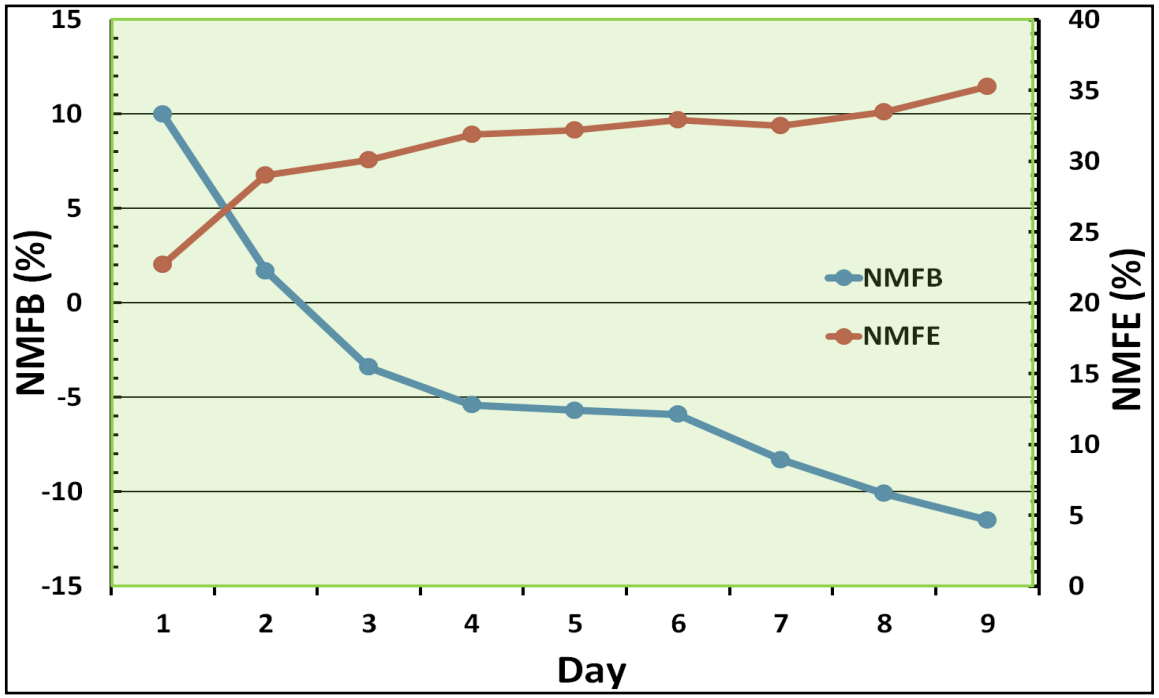
Forecast \ Observation	YES	NO
YES	a	b
NO	c	d

Skill of the 10-day forecast from AQEWS

10 days skill @ 10 km

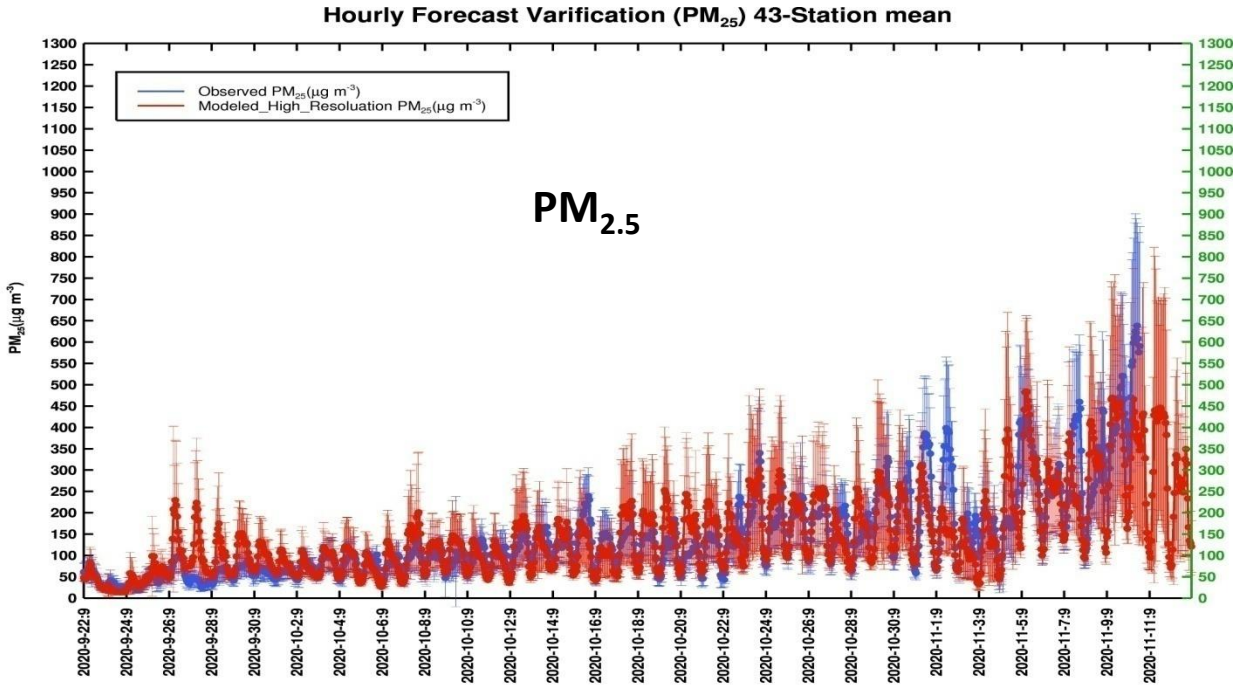


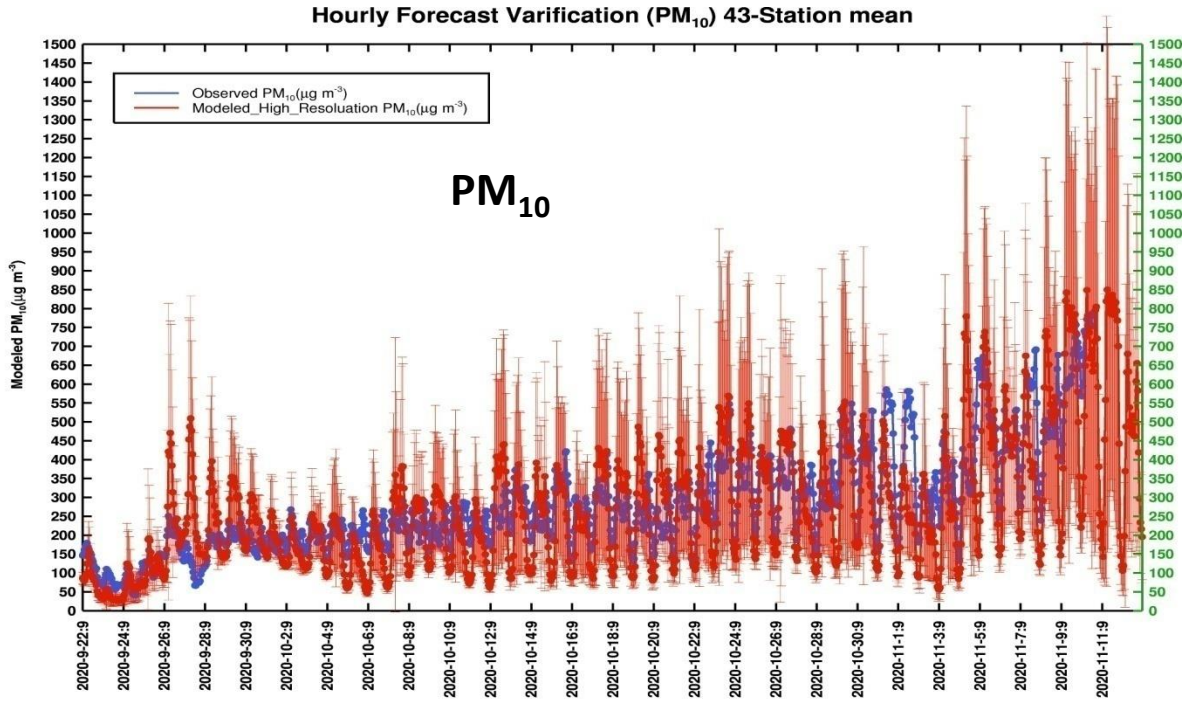
10 days skill @ 2km

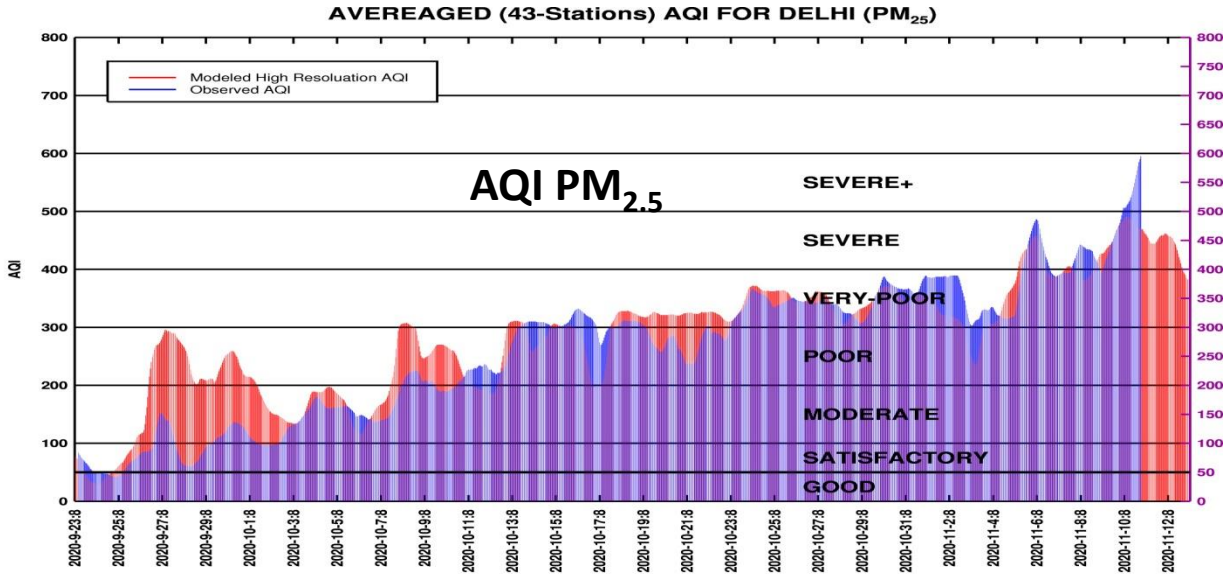


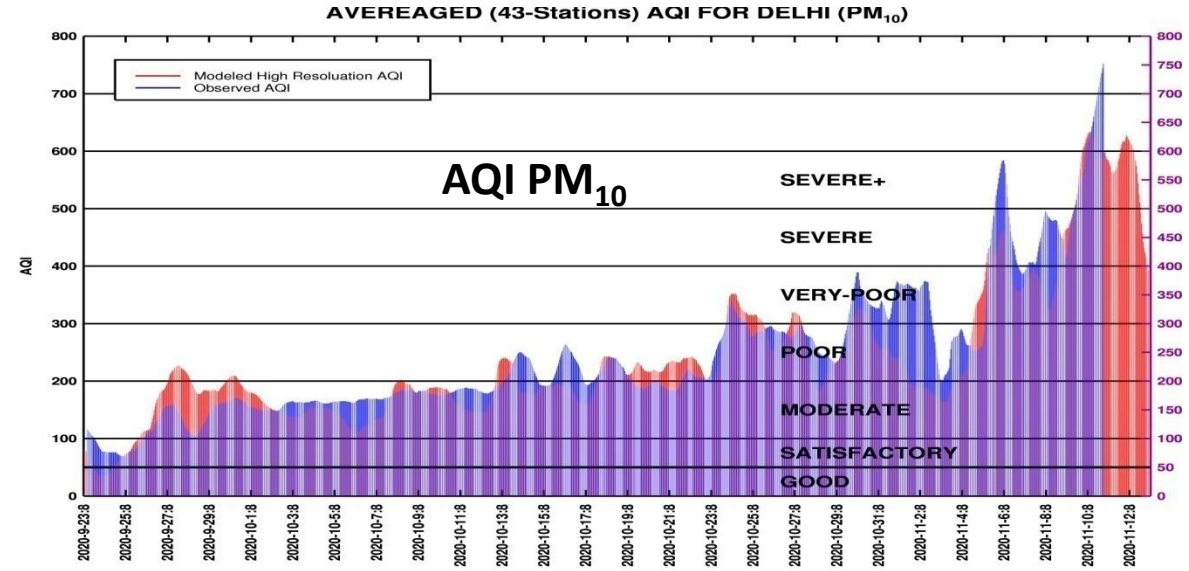
- The overall Performance of forecast is excellent for 3 days lead time and good for next 7 days at 10 km resolution
- The overall Performance of forecast is excellent for 9 days lead time at 2 km resolution

Real-time Forecast Evaluation @ 400 meter resolution

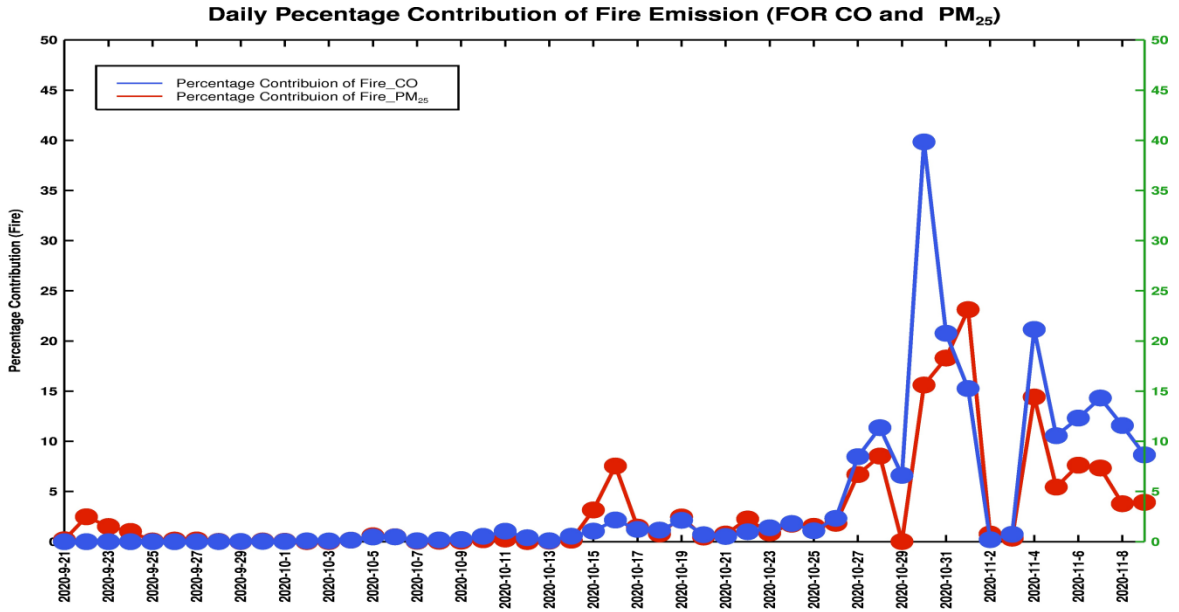


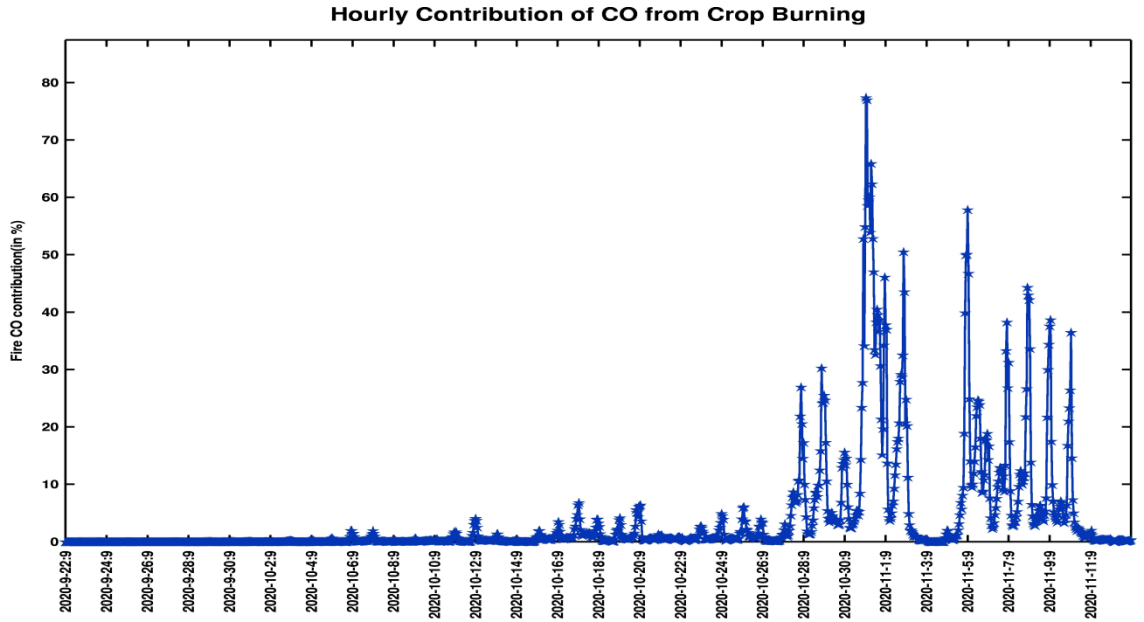


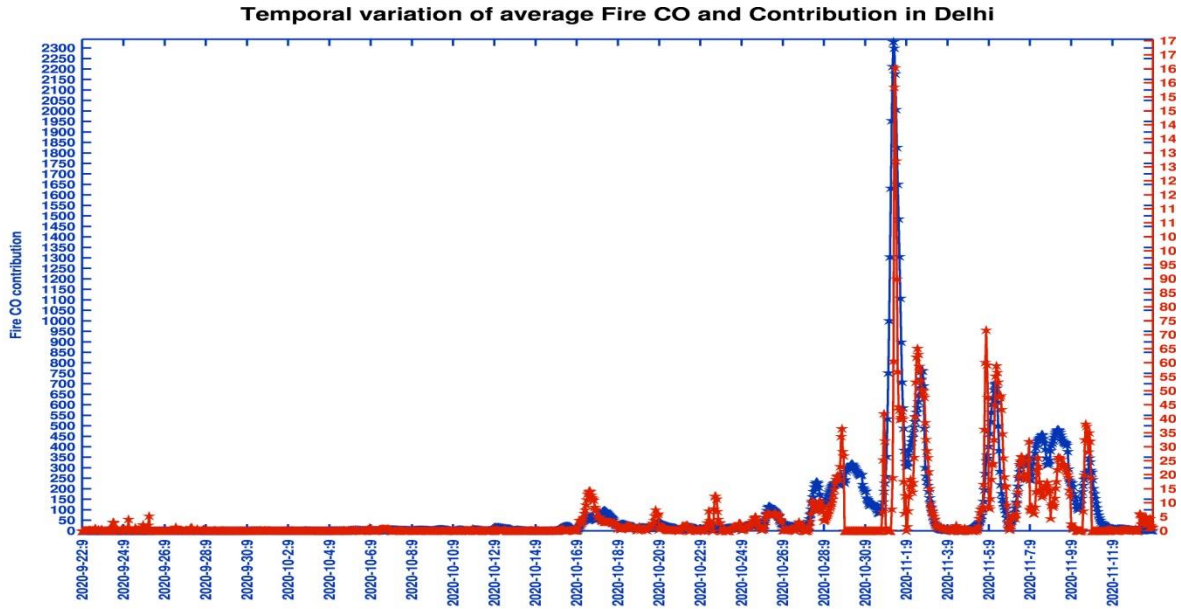


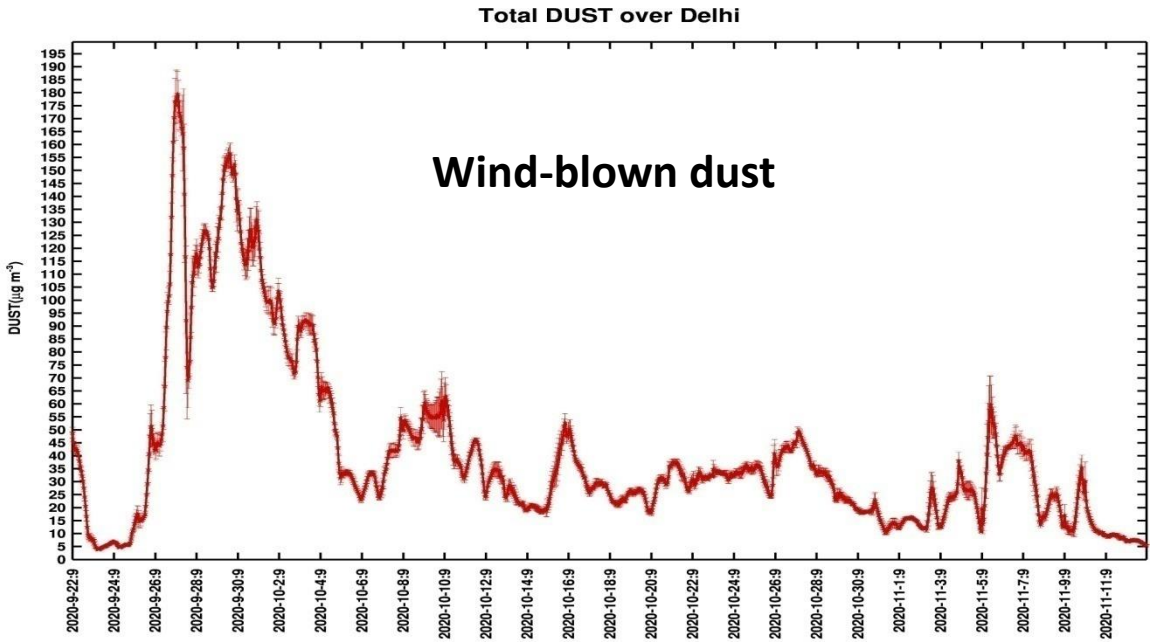


Stubble burning contribution

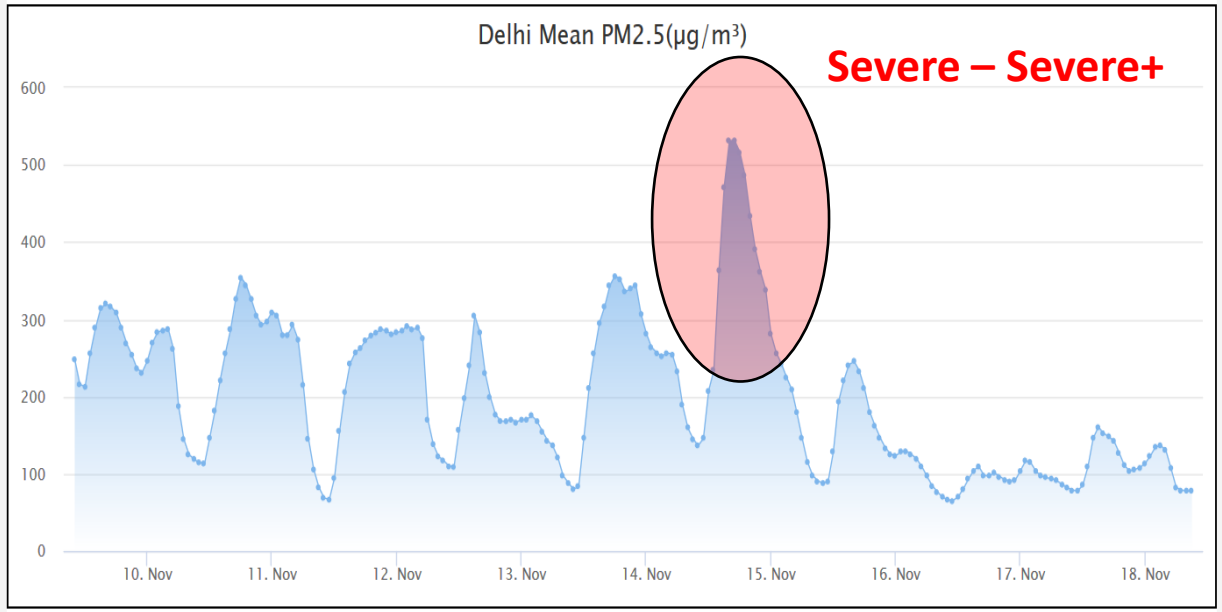


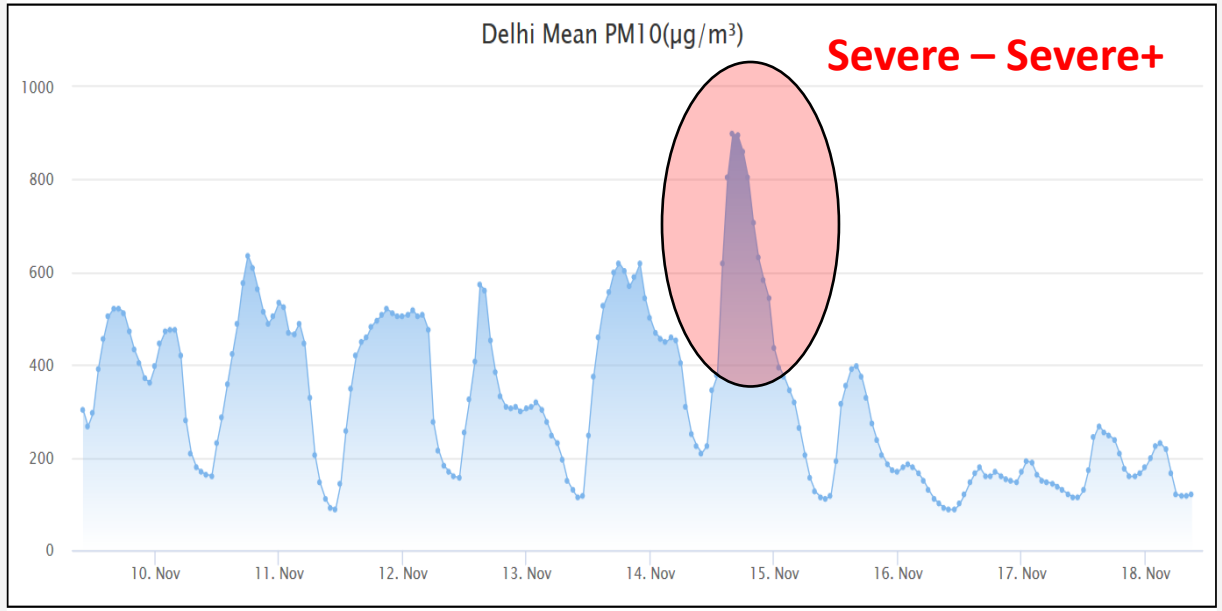


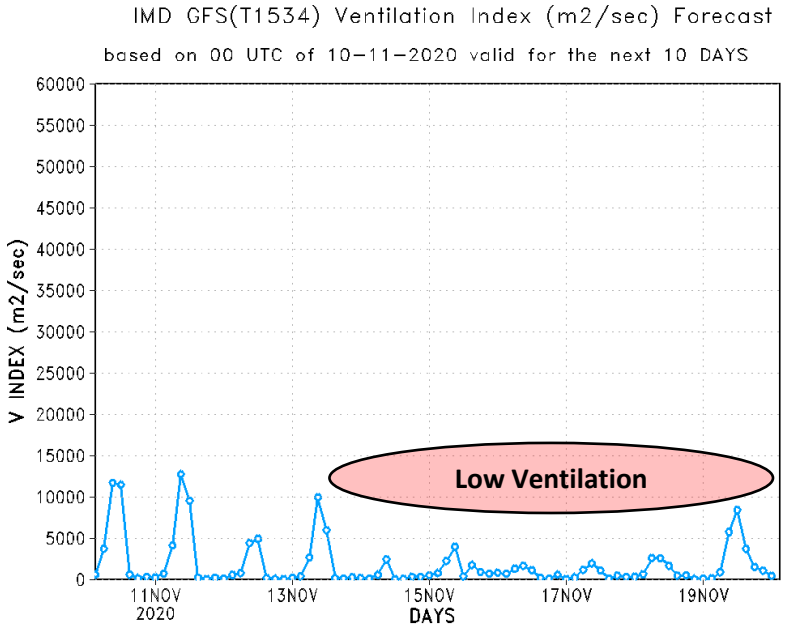


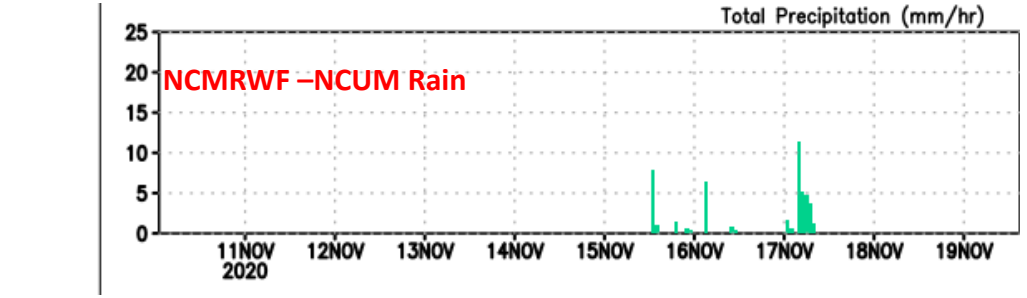


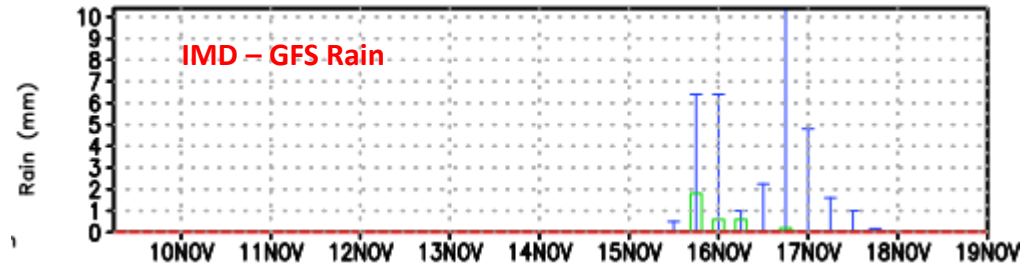
Air Quality Forecast for Diwali, 14-15 November, 2020 (no restriction)



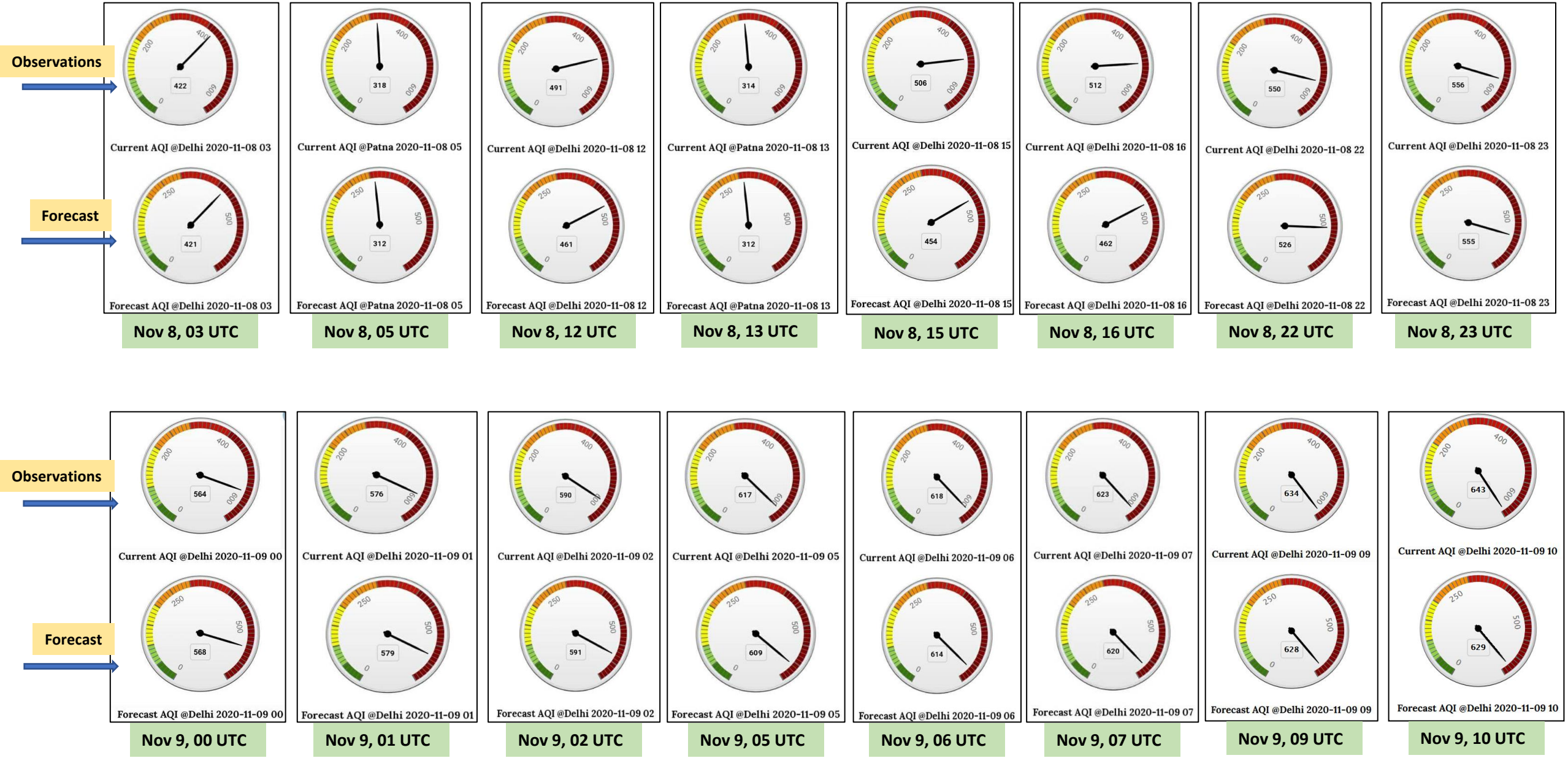






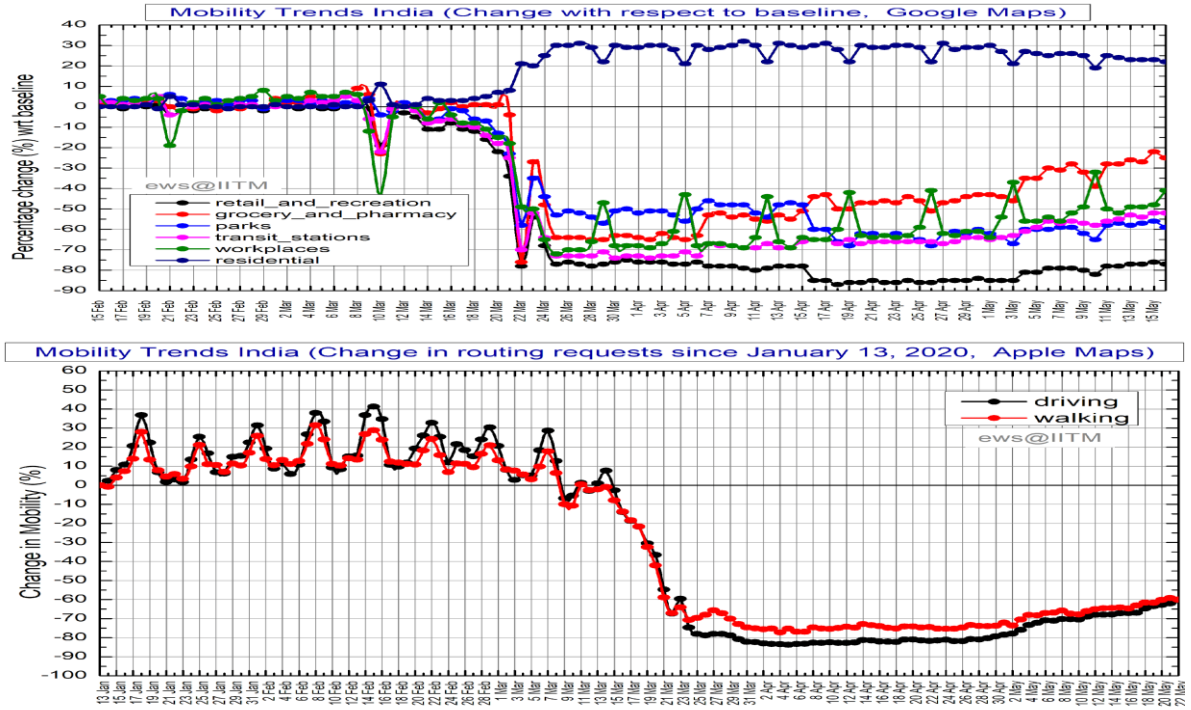


IITM WRF-Chem Air Quality Forecast for Delhi (400 m resolution) on 8-9 November 2020

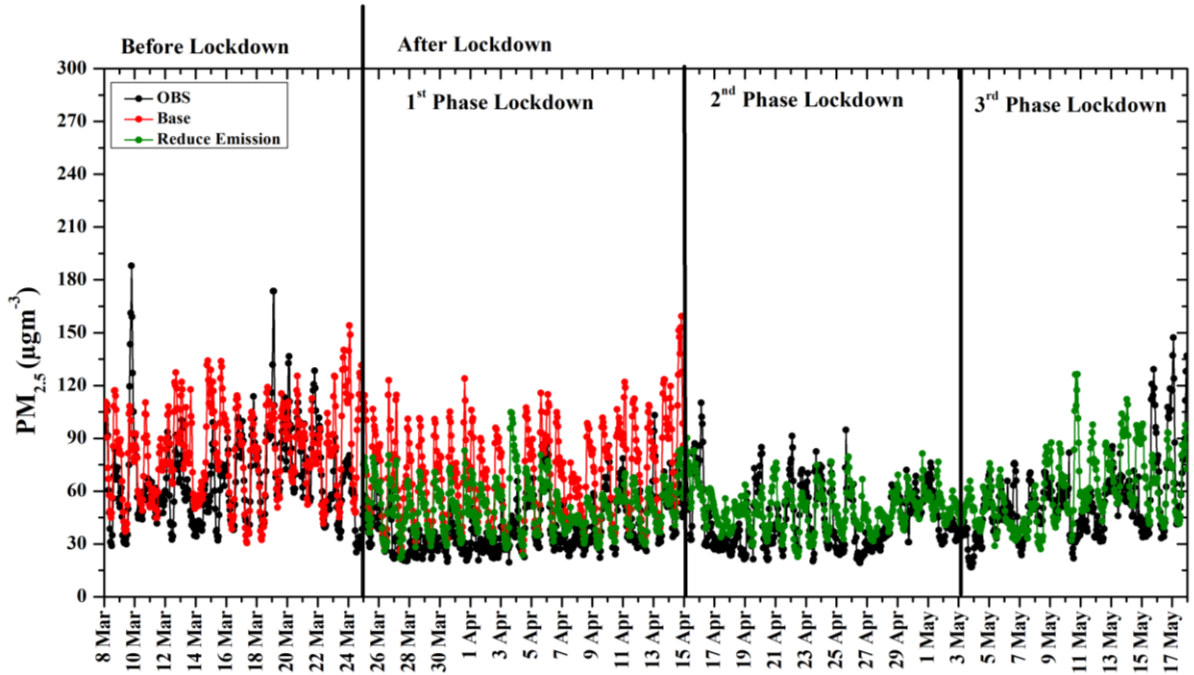


@ews.tropmet.res.in (IITM, Pune, IMD, Delhi)

Forecast Performance during COVID-19 lockdown phases



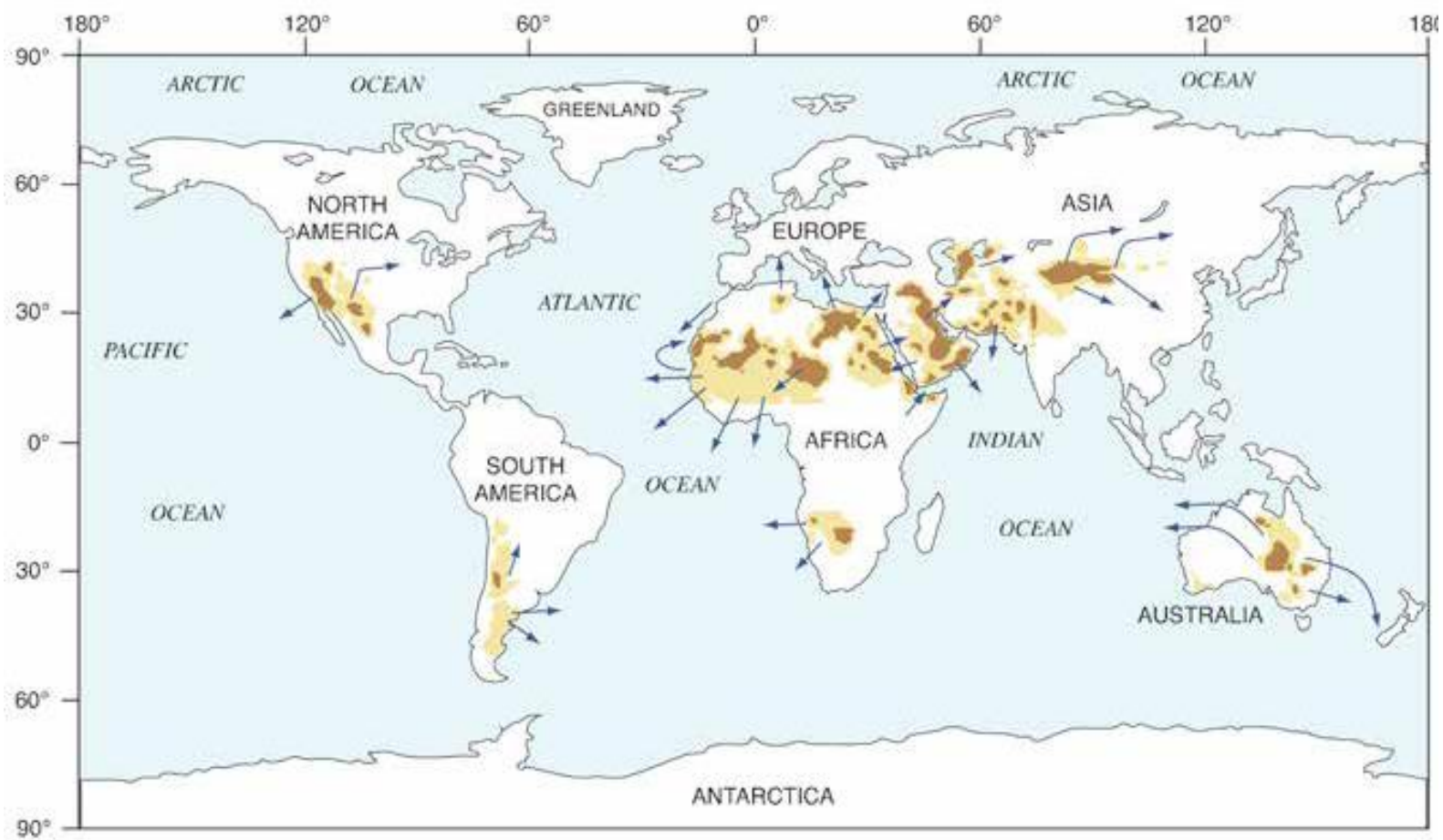
Change is community mobility before and during the nationwide COVID-19 lockdown in India (a) recorded by Google maps (https://www.google.com/covid19/mobility/) and (b) Apple maps (https://covid19.apple.com/mobility)



Comparisons between hourly mean $PM_{2.5}$ forecast without emission reduction (red), hourly mean $PM_{2.5}$ forecast with emission reduction (green) and hourly mean $PM_{2.5}$ observations (black) on day one forecast at 2km horizontal grid spacing over Delhi during 8 March to 17 May 2020.

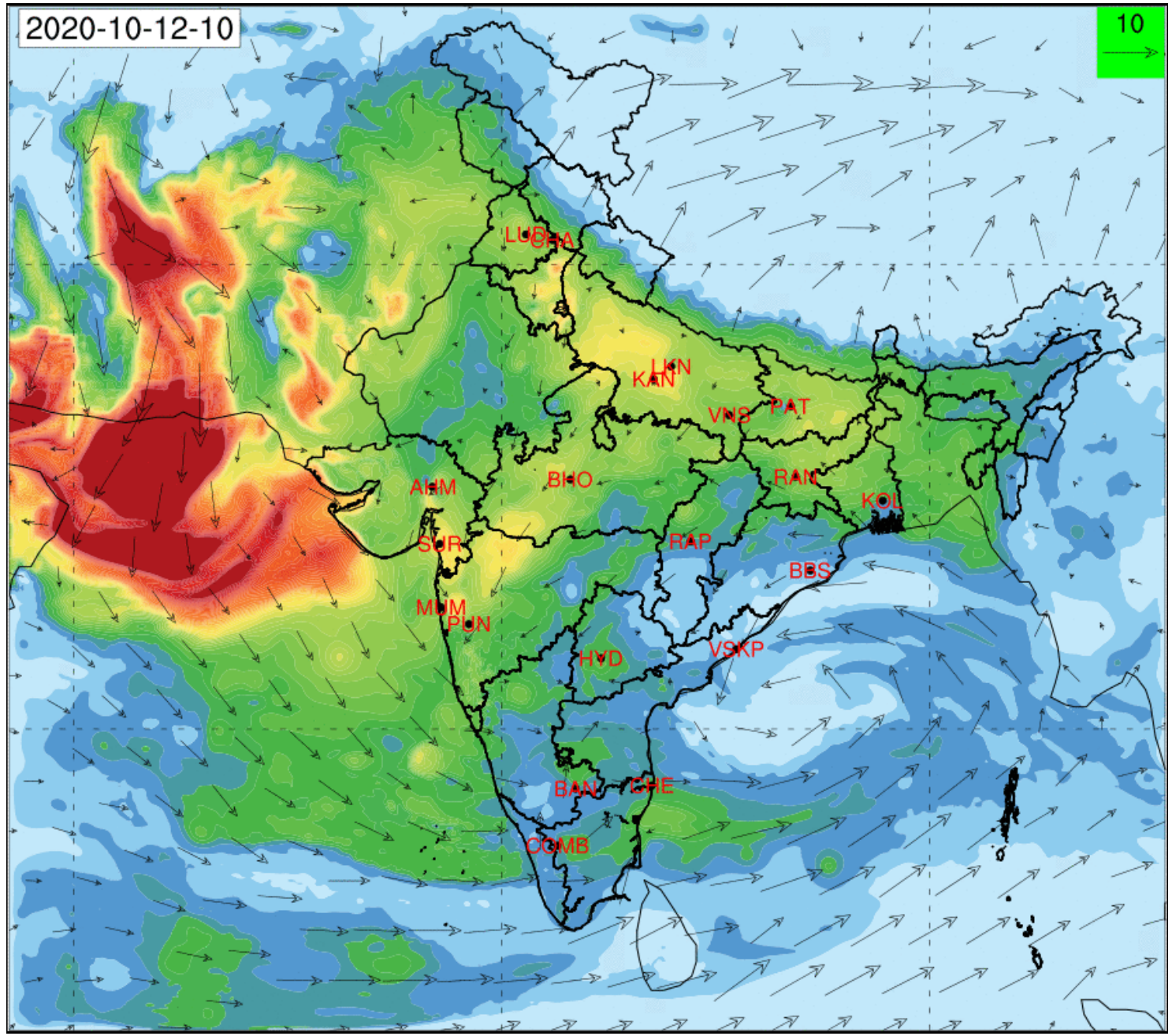
MAUSAM journal under review paper 2021

Global Dust sources and Dust Transport Pathways



The main routes of desert dust transport and location of the major dust sources are: (i) Sahara Desert; (ii) Arabian Peninsula; (iii) Asia; (iv) North America; (v) South America; and (vi) Southern Africa. *Source: Muhs et al, 2014*

151 UNCCD country Parties are affected directly by SDS and 45 country Parties are classified as SDS source areas. Most locations are in the low-latitude drylands, but dust sources can develop in almost any environment, often through human influence. Unsustainable use or agricultural land, deforestation, overgrazing, high latitudes, depletion of water sources and industrial activities can all trigger SDS.

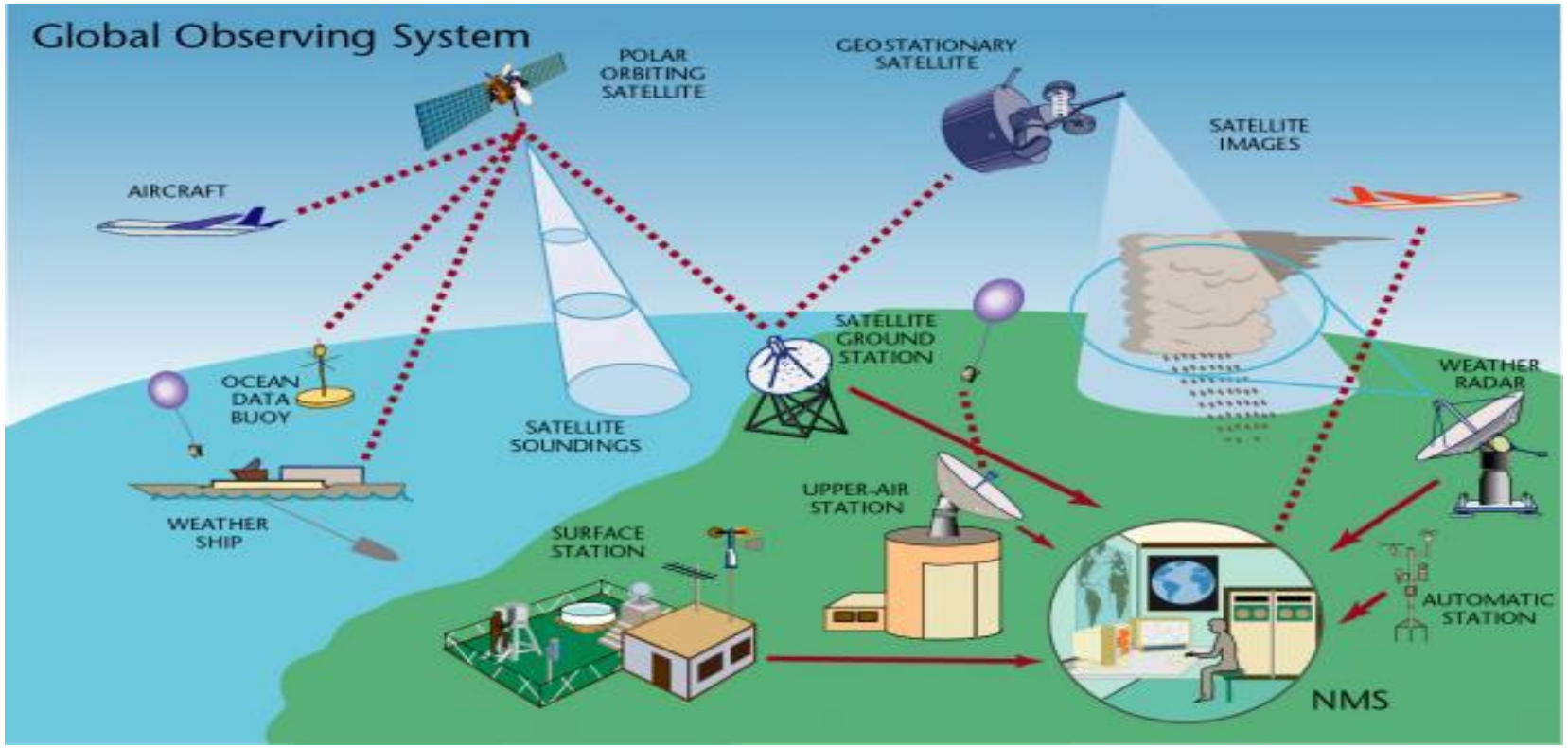

2020-10-12-10
10
LUDHA
KAN
LKN
VNS
PAT
BHO
AHM
RAN
KOL
SUR
RAP
BBS
MUM
PUN
HYD
VSKP
BAN
CHE
COMB

Environmental monitoring

Environmental monitoring can be defined as the systematic sampling of air, water, soil, and biota in order to observe and study the environment, as well as to derive knowledge from this process

Ambient Environment Monitoring

Ambient air quality, Air pollution emissions
Water Resources Monitoring
Sediment, Soil and Biological Monitoring



SILAM (System for Integrated Modeling of Atmospheric Composition)

IMD Setup

Running:

- Hourly AQ Forecast
- 3 KM WRF forecast (IMD)

Boundary conditions:

- SILAM Global Suit

Emissions:

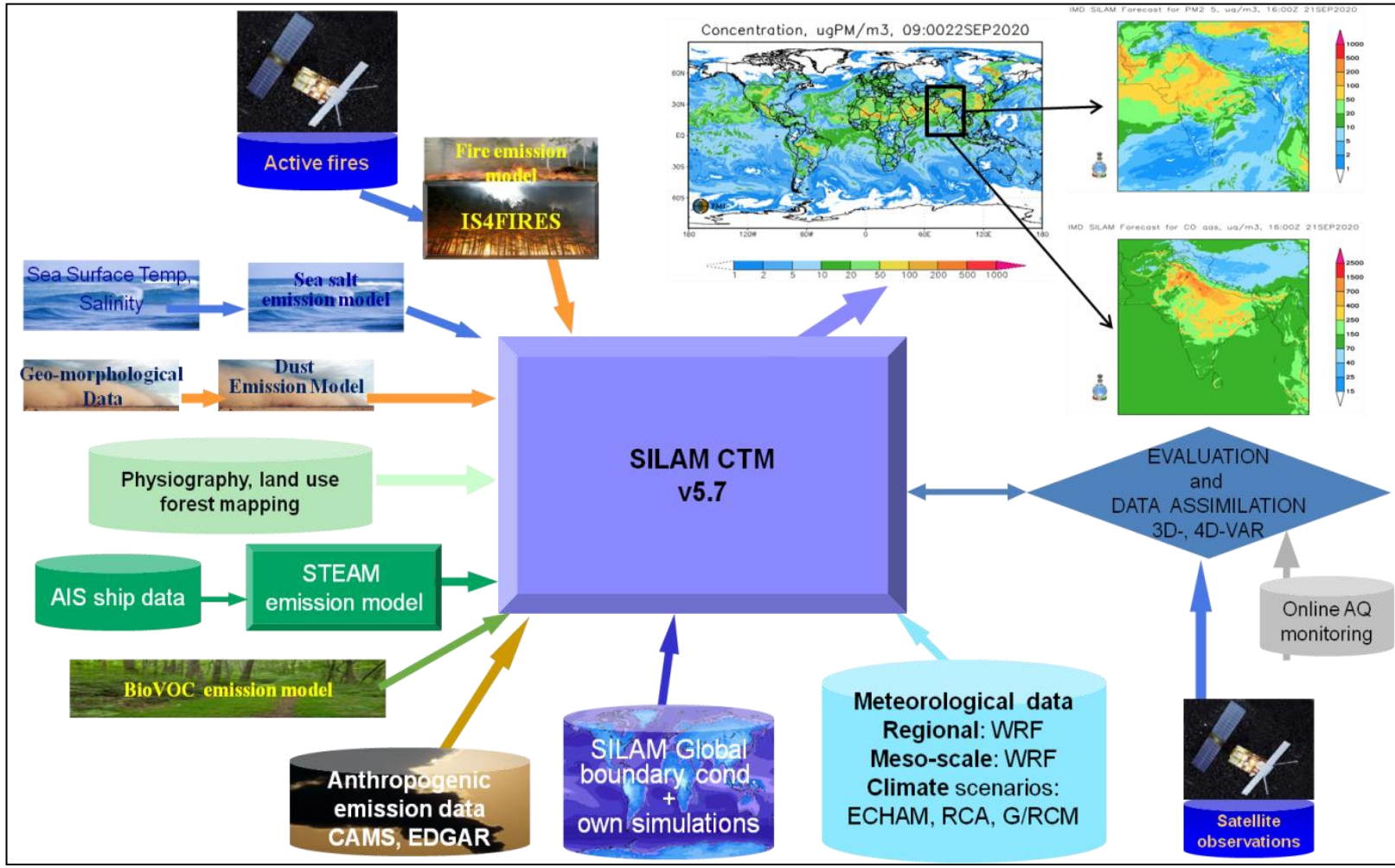
- CAMS-GLOB v2.1, 0.1-deg supplemented with EDGAR v4.3.2 for coarse and mineral-fine anthropogenic PM.
- GEIA v1 lightning climatology
- MEGAN-MACC biogenic climatology for isoprene and monoterpene.
- Natural (dynamic): Silam desert dust, Silam sea salt, Silam marine DMS.
- MoES-SAFAR Emission Inventories

Aerosol Process:

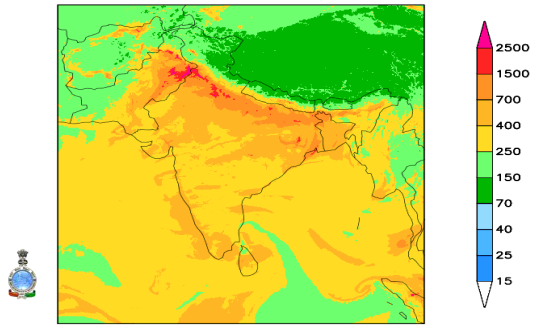
- Simple equilibrium scheme for secondary inorganic aerosols, VBS for secondary organics
- CBM5 chemistry supplemented with secondary organics, DMAT_SULPHUR sulphur oxidation.

Validation

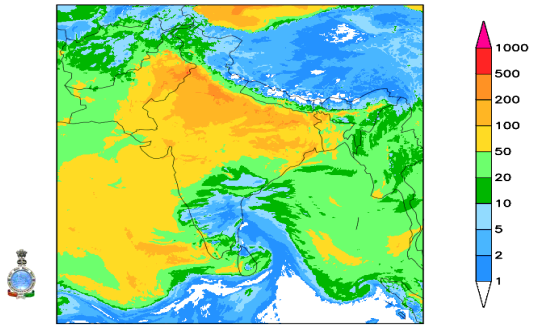
- In-situ data



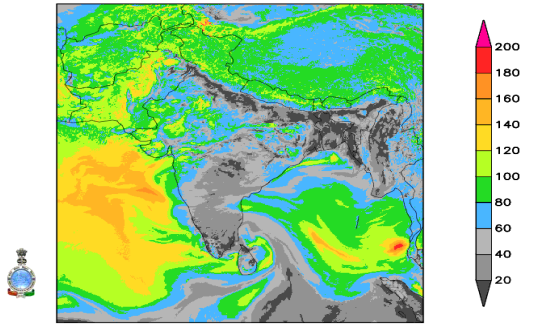
IMD SILAM Forecast for CO gas, ug/m3, 00:00Z 12NOV2020



IMD SILAM Forecast for PM2 5, ug/m3, 00:00Z 12NOV2020



IMD SILAM Forecast for O3 gas, ug/m3, 00:00Z 12NOV2020



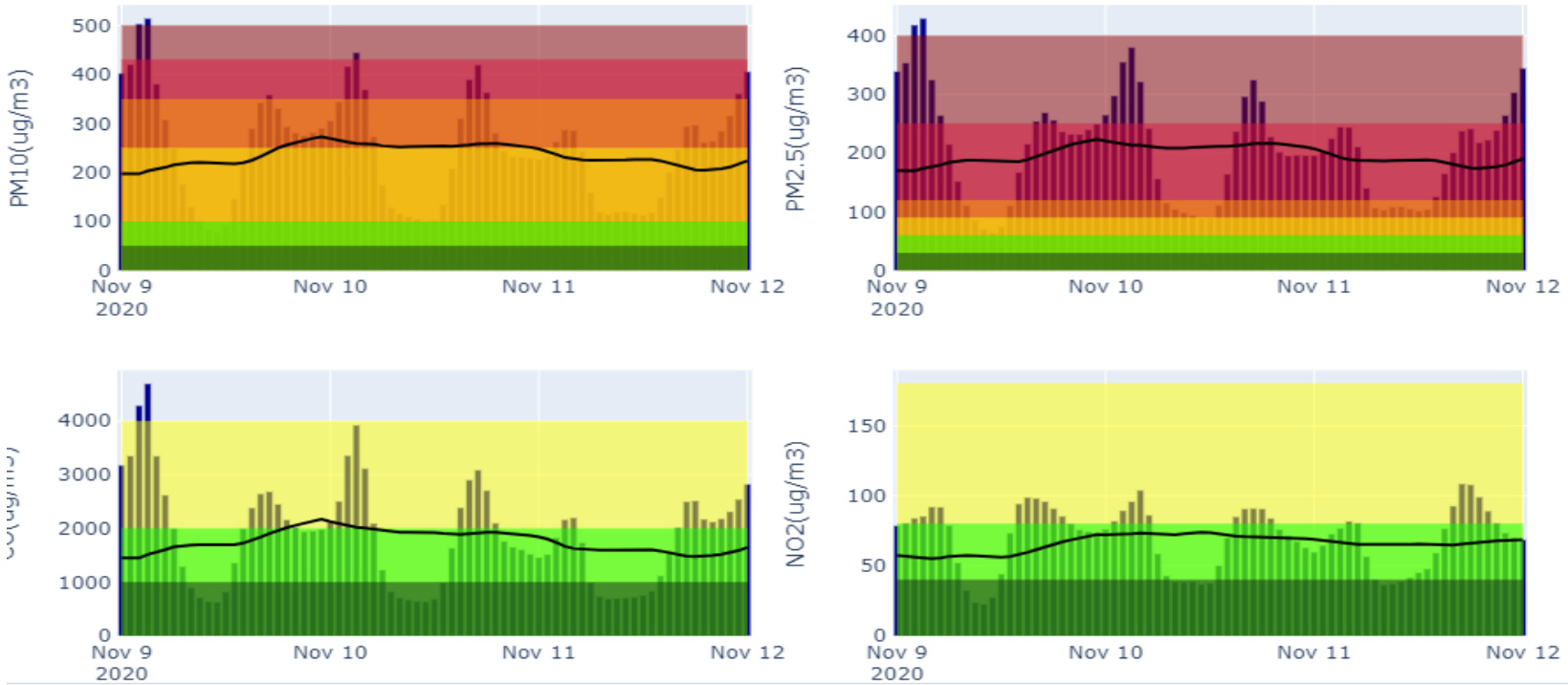
AIR QUALITY FORECAST BY IMD SILAM MODEL

FINNISH METEOROLOGICAL INSTITUTE

SPATIAL PLOT | STATION LEVEL PLOT

SELECT CITY: Delhi SUBMIT

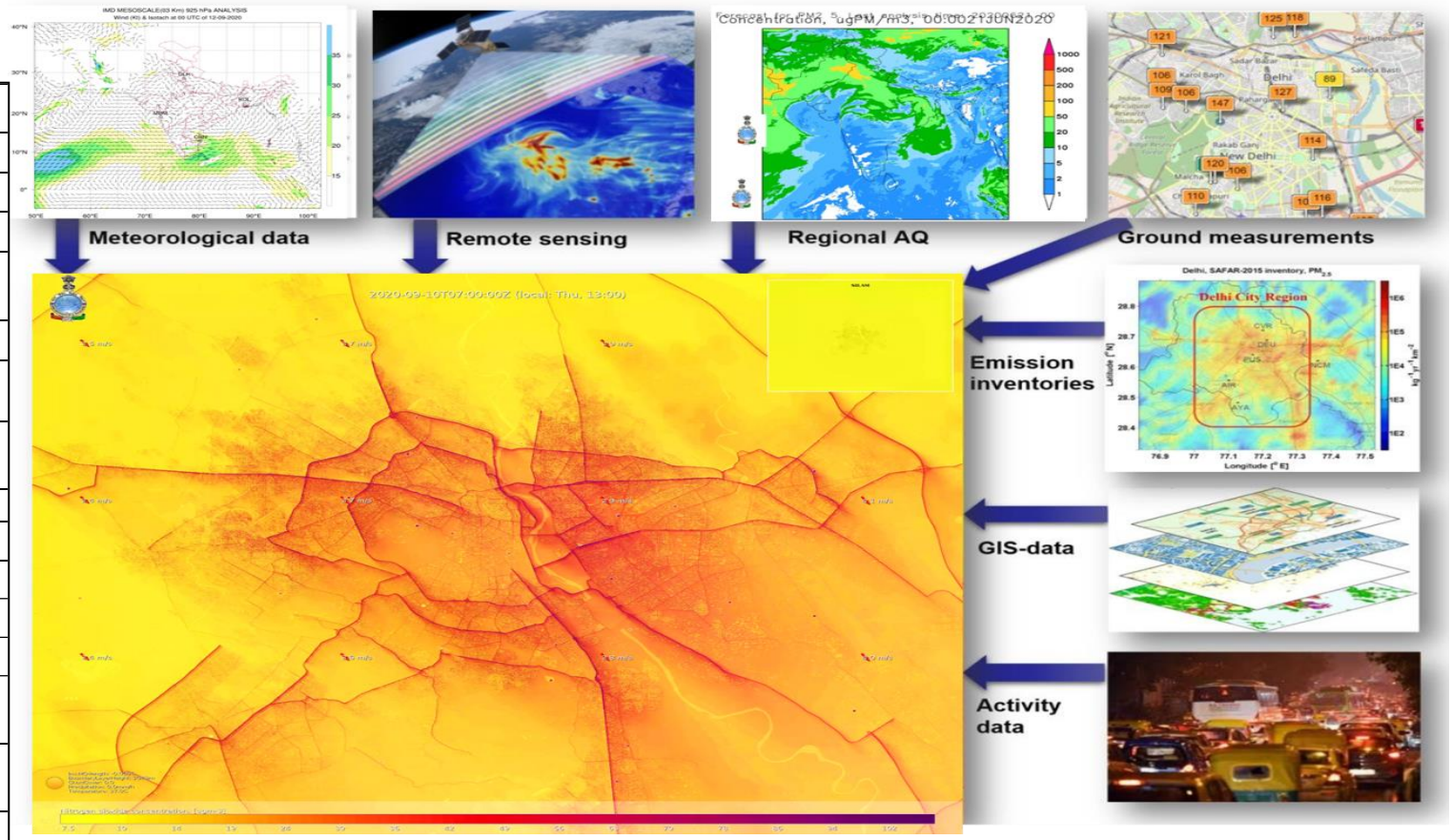
IMD SILAM Air Quality Forecast over Delhi



FMI-IMD ENFUSER

https://nwp.imd.gov.in/enfuser_imd.php

Name	Resolution [m]	Source
OSM land-use, surface*	5	OpenStreetMap
OSM land-use, functional	10	OpenStreetMap
Satellite image	10	Sentinel 2 MSI (TCI)
Satellite image, near-infrared	10	Sentinel 2 MSI (B08 band)
Elevation	30	NASA SRTM
Population	300	Global Human Settlement
Built land-use	30	Global Human Settlement
Road network	5	Several
Elevation gradient	30	Several
Vegetation index	10	Several
Enhanced population	50	Several
Building height	5	Several
Population density at radius X	200	
Property X density at radius Y	200	
Household emission inventory proxy	20	Many
Traffic flow estimates for roads	5	Many

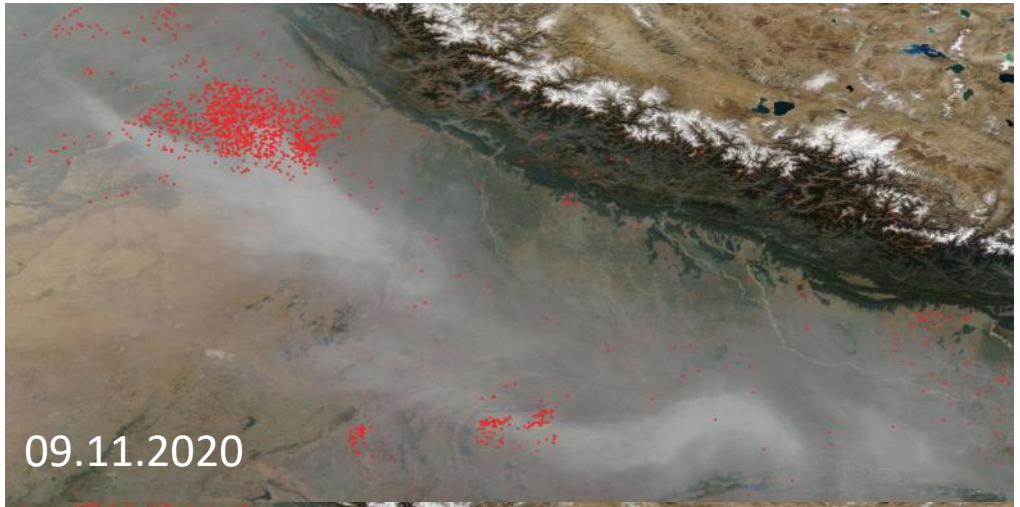


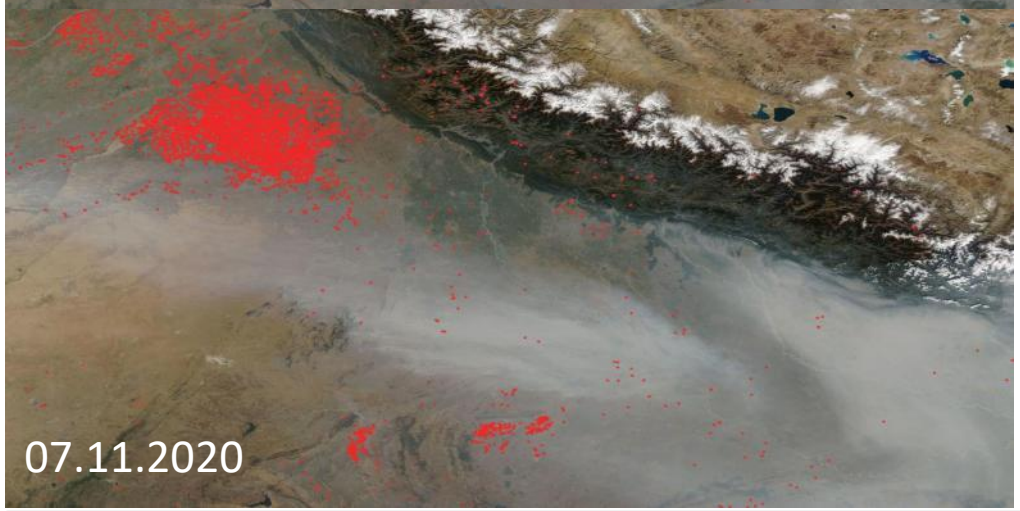
Domain range, Latitude	28.362N - 28.86N
Domain range, Longitude	76.901E - 77.56E
Spatial resolution	27m (inner areas with higher resolution can be added)
Temporal resolution	1h averages
Modelled species	NO2, PM2.5, PM10, O3, coarse PM, SO2, CO
Modelling time span	>48h per model run, updated several times a day
Main output formats	netCDF, statistics as CSV
Secondary output formats	animations (avi), gif, Figures (PNG)
Output storage	Local (compressed) and optionally AWS S3 cloud storing

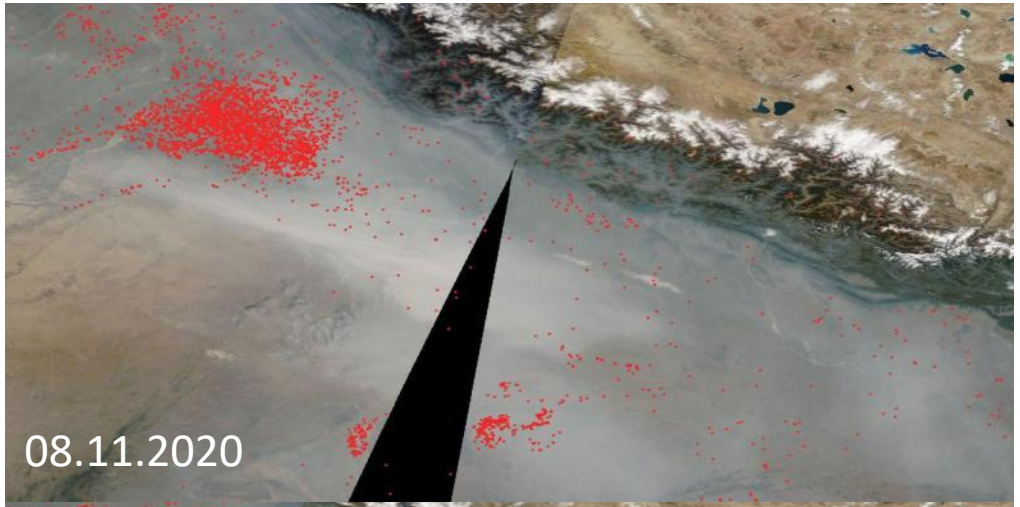
https://nwp.imd.gov.in/silam/SO2_gas_srf.php

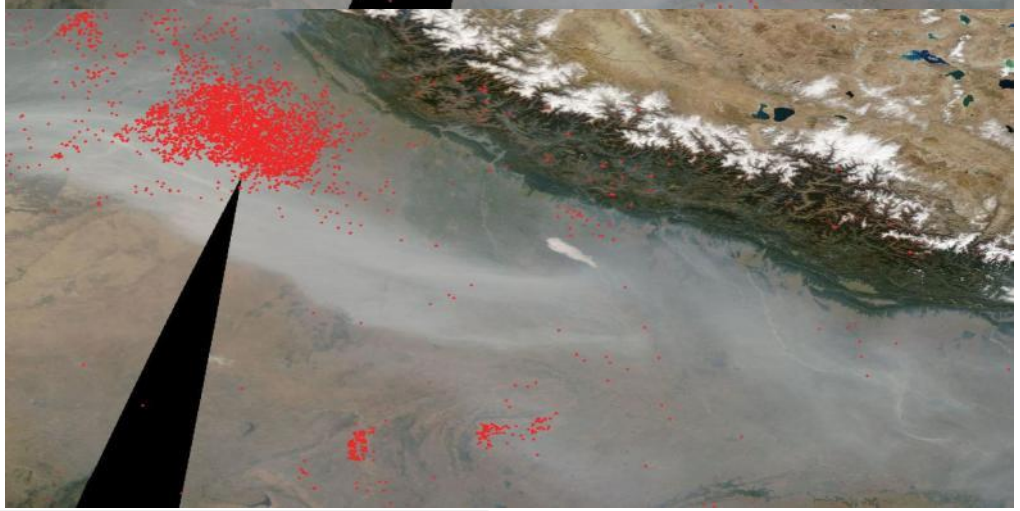
Satellite based Environment Monitoring

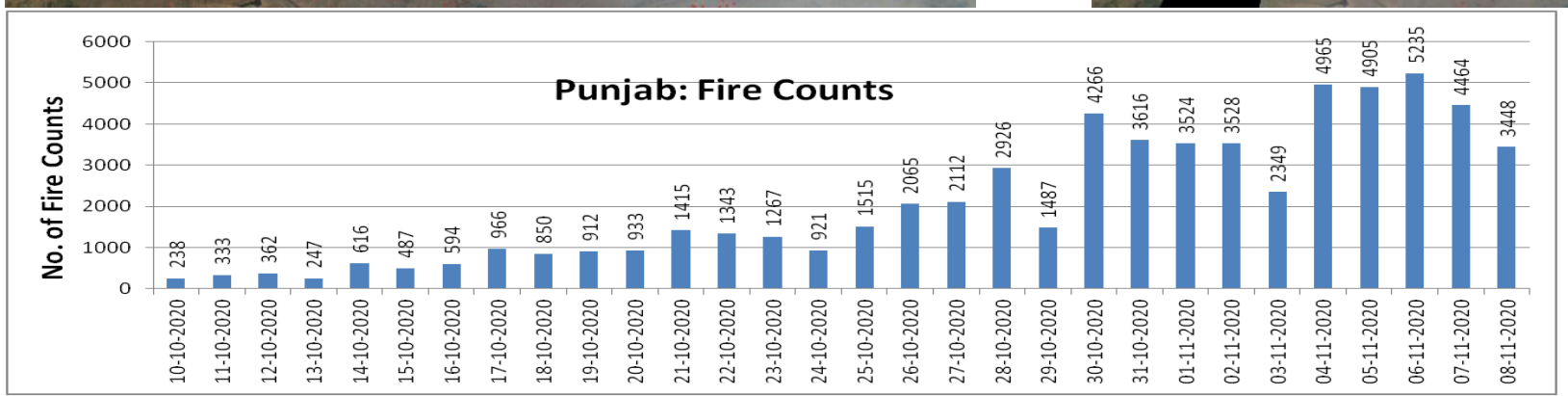
- Satellite data can help forecasters
  - Estimate aerosol concentrations in areas without continuous $PM_{2.5}$ monitors
  - Track aerosols from
    - Regional haze episodes
    - Wildfires
  - Estimate upwind $PM_{2.5}$ concentrations or aerosol loading
- Aerosol optical depth (AOD) provides this information
  - A satellite-derived measure of light extinction through the atmosphere
  - Proportional to the number of particle in the atmospheric column


09.11.2020


07.11.2020

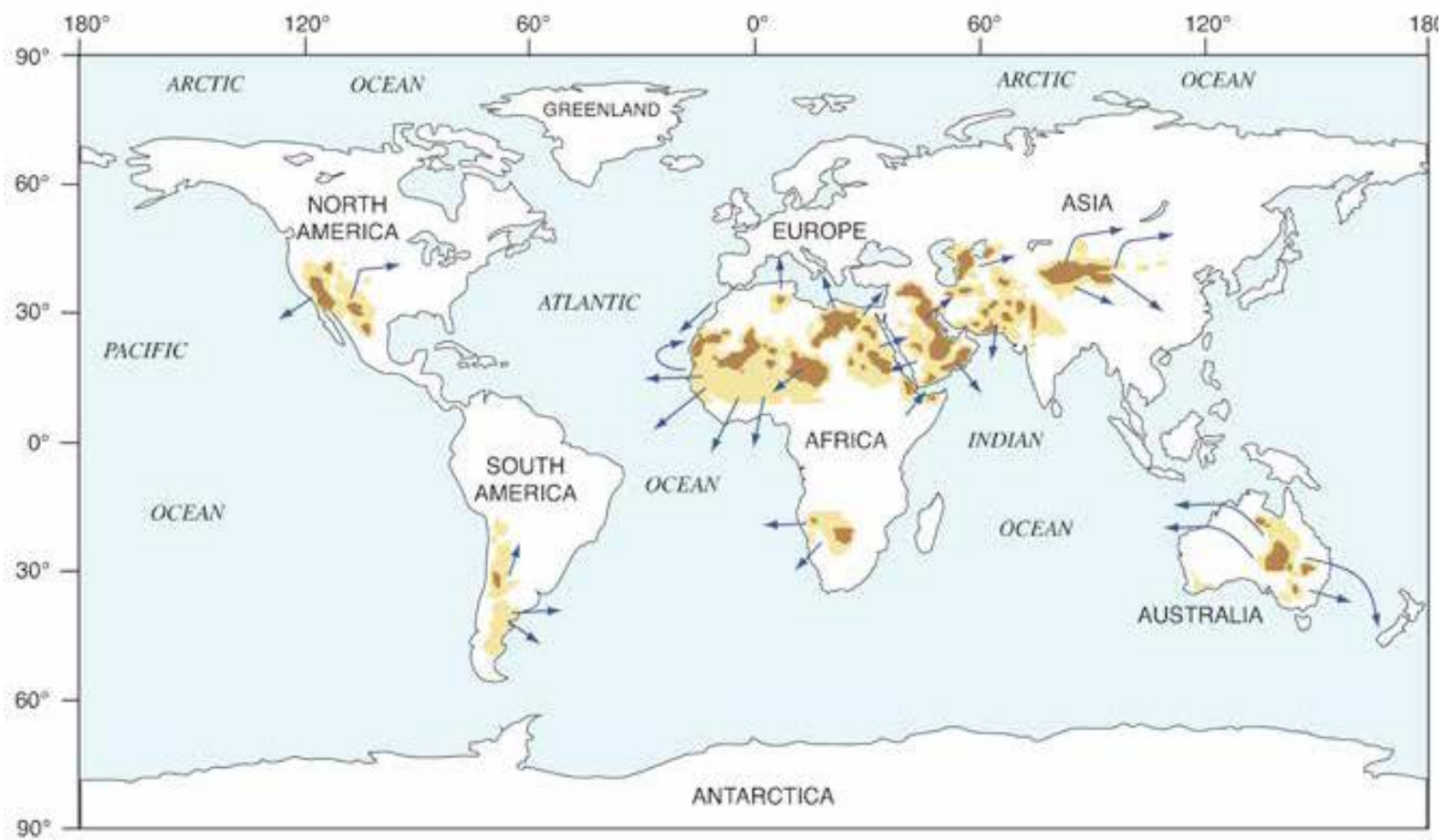

08.11.2020




Punjab: Fire Counts
No. of Fire Counts
6000
5000
4000
3000
2000
1000
0
238
333
362
247
616
487
594
966
850
912
933
1415
1343
1267
921
1515
2065
2112
2926
1487
4266
3616
3524
3528
2349
4965
4905
5235
4464
3448
10-10-2020
11-10-2020
12-10-2020
13-10-2020
14-10-2020
15-10-2020
16-10-2020
17-10-2020
18-10-2020
19-10-2020
20-10-2020
21-10-2020
22-10-2020
23-10-2020
24-10-2020
25-10-2020
26-10-2020
27-10-2020
28-10-2020
29-10-2020
30-10-2020
31-10-2020
01-11-2020
02-11-2020
03-11-2020
04-11-2020
05-11-2020
06-11-2020
07-11-2020
08-11-2020


Year wise Fire event counts
Fire Event Counts
75k
50k
25k
0
70208
40510
39973
47484
61139
2016
2017
2018
2019
2020
Year

Global Dust sources and Dust Transport Pathways



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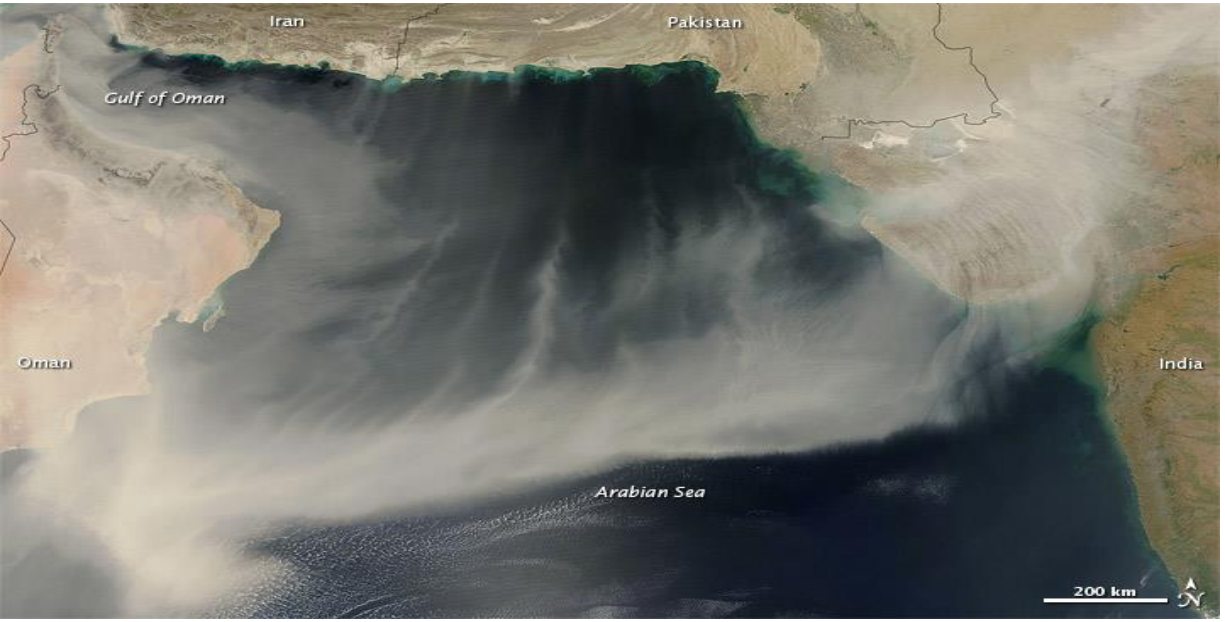
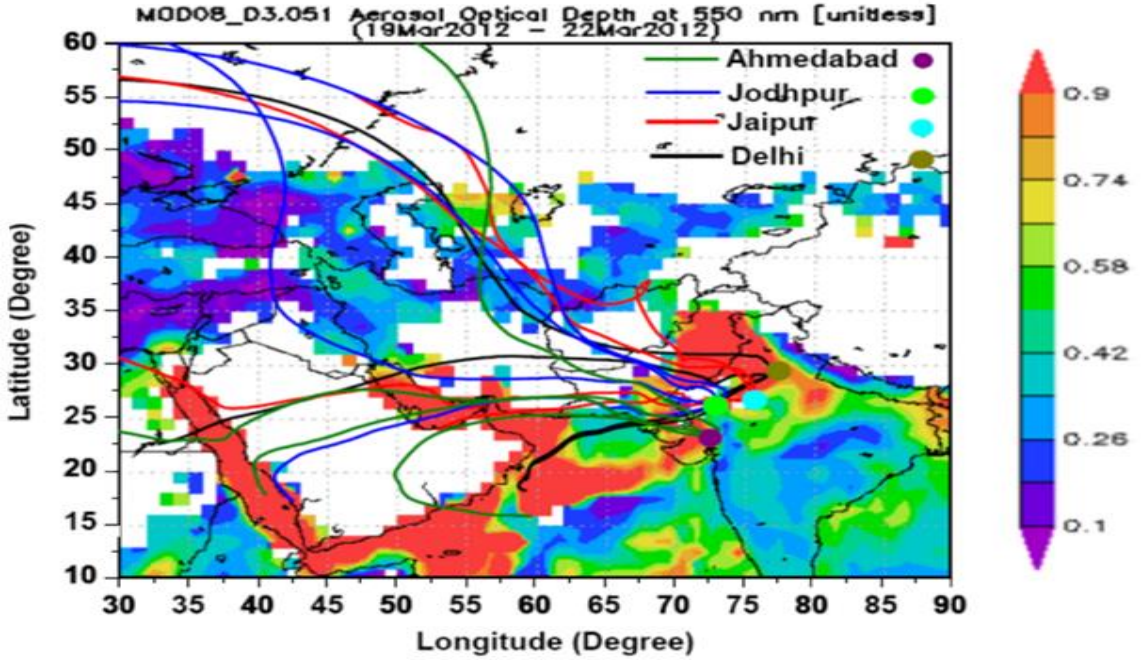
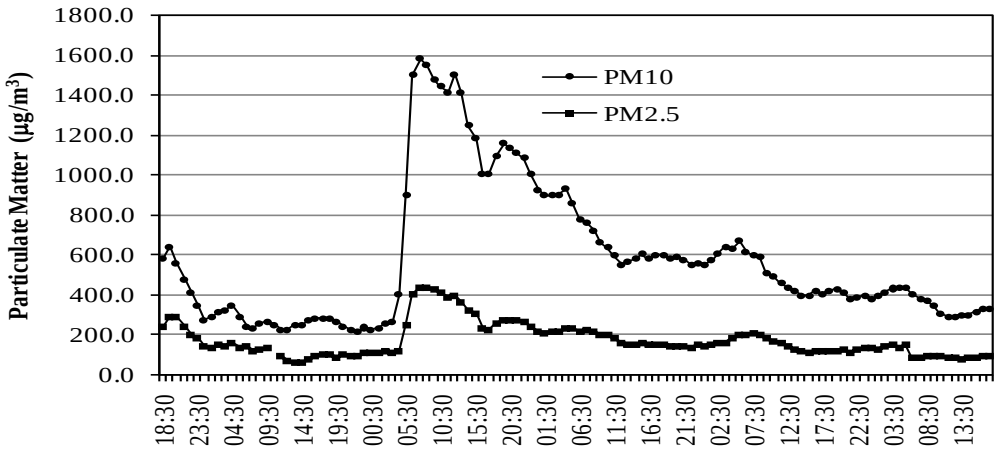
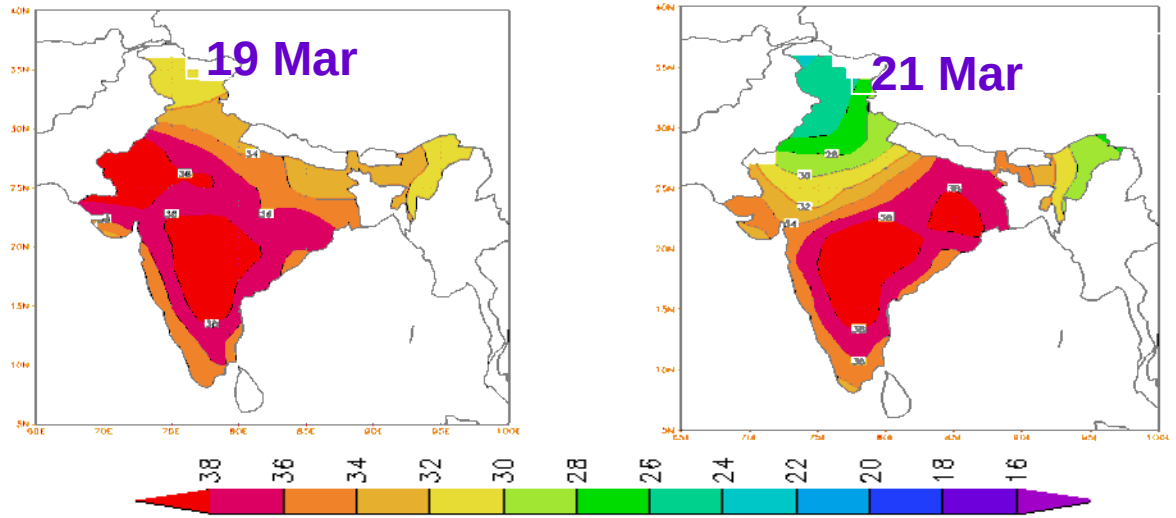


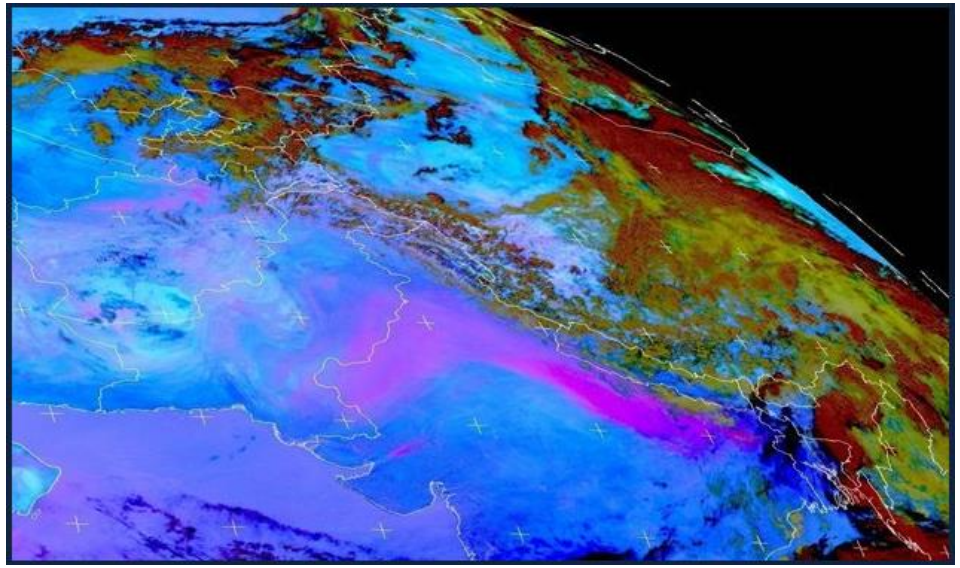


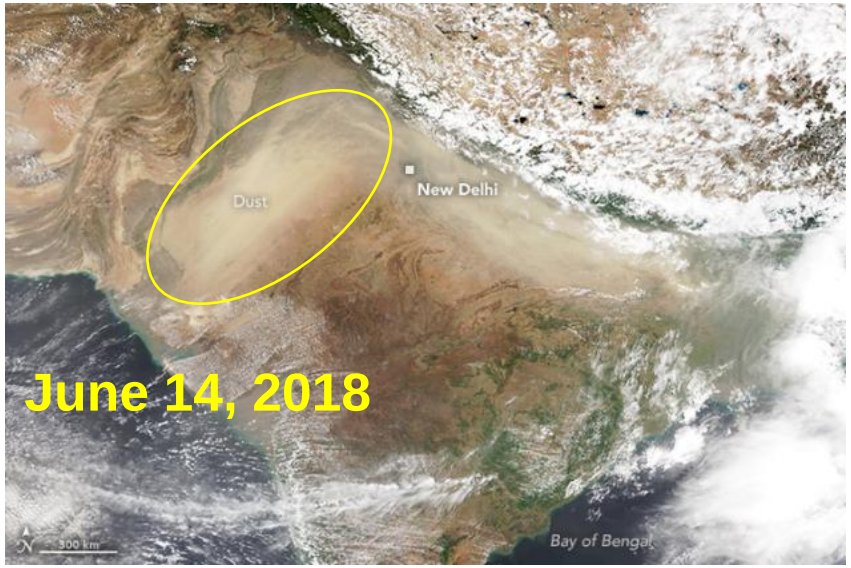


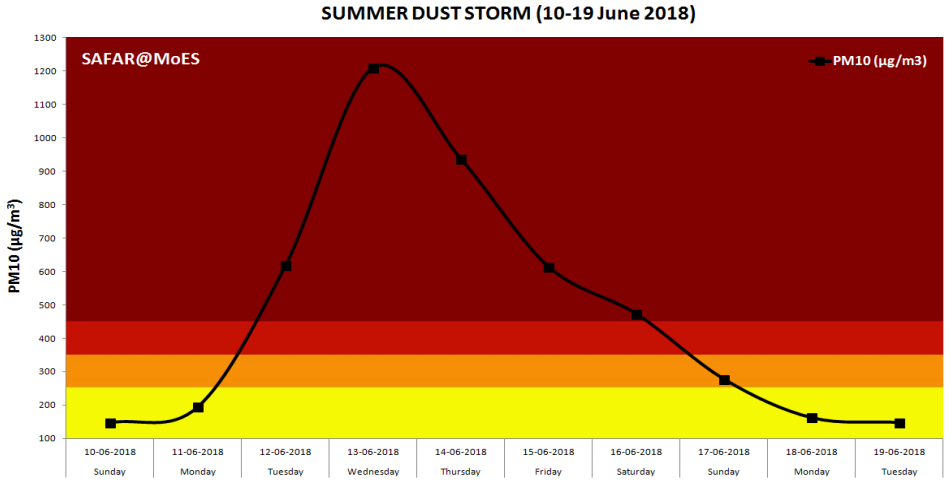


Soni et al (2014), Science of Total Environment
Soni et al (2018), Mausam

Dust Transport in 11-14 June 2018







Surface PM10 Concentration at Delhi

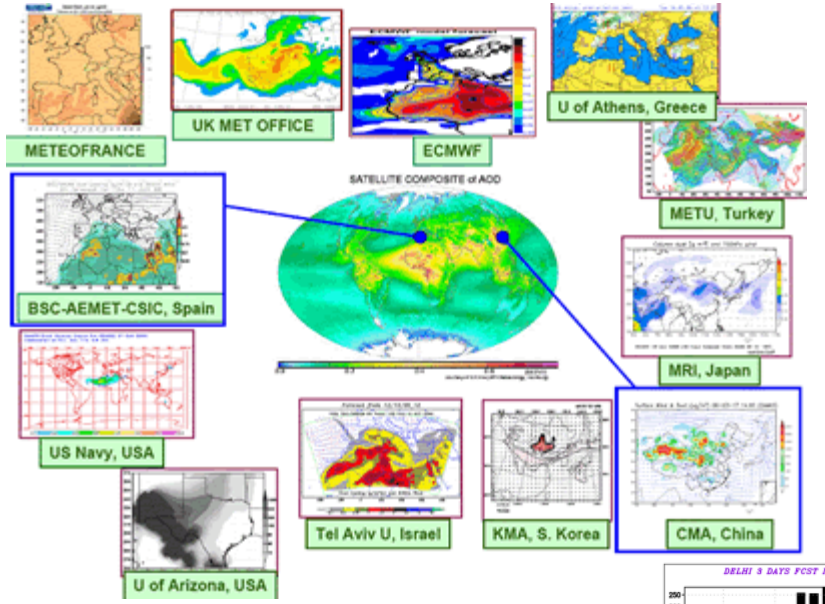
Sand and Dust Storm Warnings

The WMO Sand and Dust Storm Project was initiated in 2004 and its Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) was launched by the Fifteenth World Meteorological Congress in 2007.

WMO SDS-WAS Regional Centre for Northern Africa, Middle East and Europe, coordinated by a Regional Centre in Barcelona, Spain,

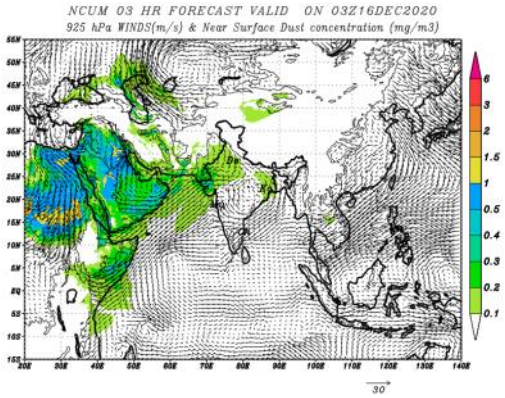
WMO SDS-WAS Regional Centre for Asia, coordinated by a Regional Centre in Beijing, China, hosted by the CMA

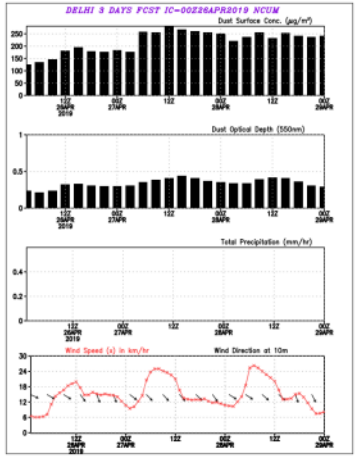
WMO SDS-WAS Regional Centre for the Americas, hosted by the Caribbean Institute for Meteorology and Hydrology (CIMH) in Barbados, will focus on the health implications of airborne dust.



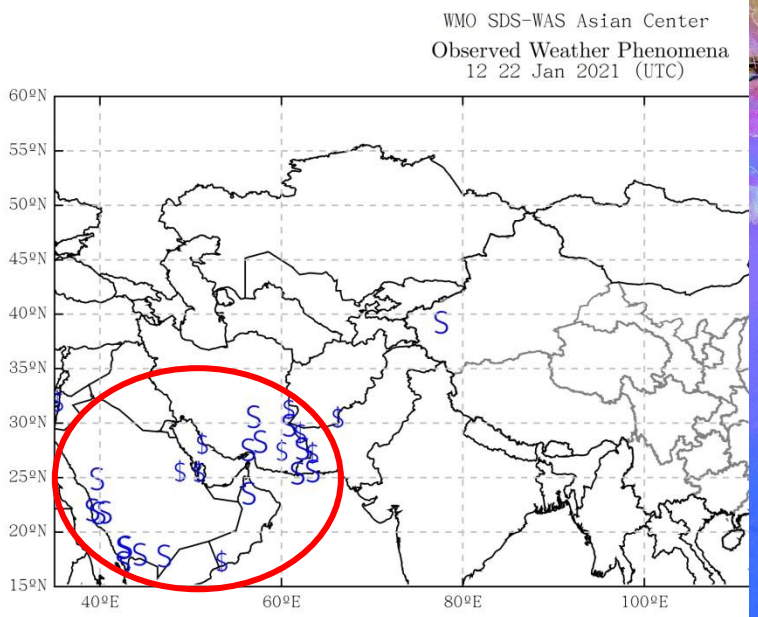
Data Shared with IMD (Dust Conc., Dust AOD, Obsns)

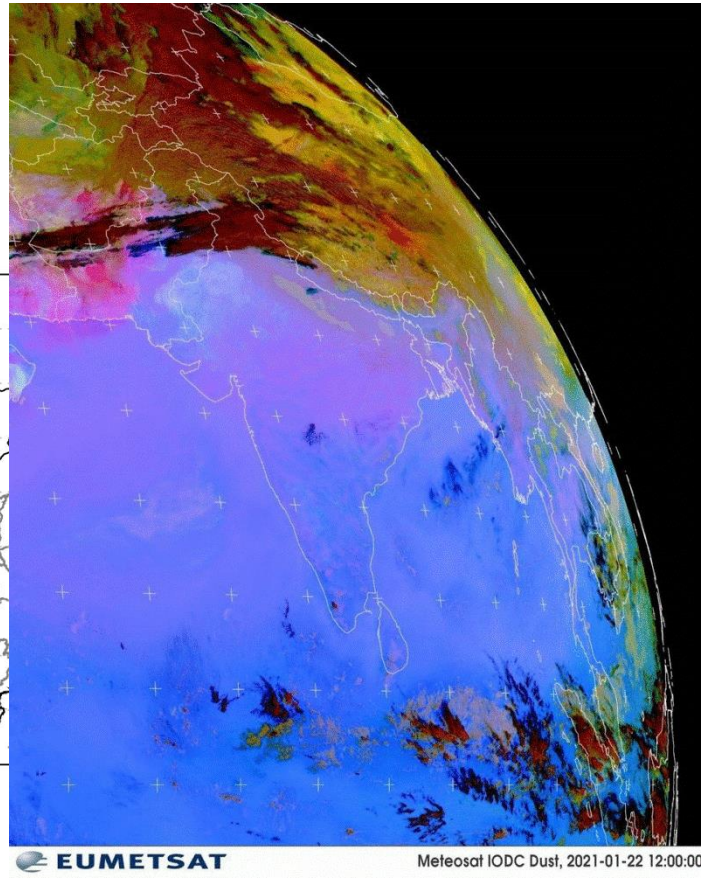
CMA	**ECMWF**
FMI	**NCEP**
KMA	**ENSEMBLE**
JMA	
HKO	





https://ews.tropmet.res.in/ncmrwf.php


WMO SDS-WAS Asian Center
Observed Weather Phenomena
12 22 Jan 2021 (UTC)
60ºN
55ºN
50ºN
45ºN
40ºN
35ºN
30ºN
25ºN
20ºN
15ºN
40ºE
60ºE
80ºE
100ºE


EUMETSAT
Meteosat IODC Dust, 2021-01-22 12:00:00

SILAM Forecast for PM10, ug/m3, 00:00Z 22JAN2021
3000
1500
600
300
150
60
30
15
6
3

Air Quality/ Atmospheric Chemistry: Definition and Importance

- **Air Quality** is the state of the atmospheric chemical substances at a given time and place.

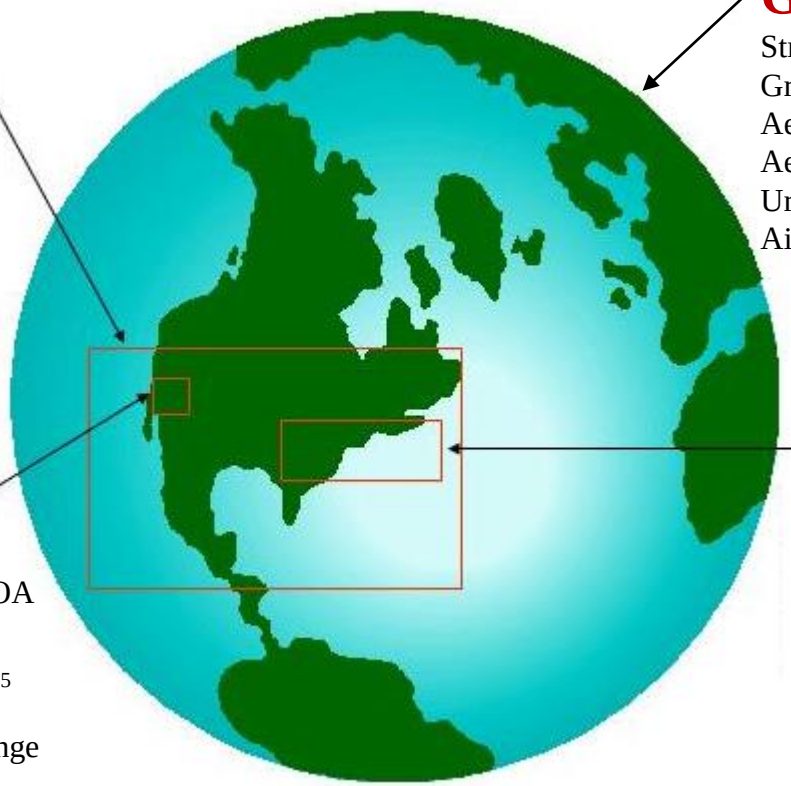
- **Atmospheric Chemistry** deals with all materials of the globe and the changes they undergo chemically, from polluted to clean, remote regions and from the region closest to the earth's surface into the upper atmosphere.

- **Air pollution** is the significant adverse effects on humans, animals, vegetation or materials caused by chemical substances present at concentrations higher than their normal ambient levels.

- **National Ambient Air Quality Standards**: primary standards provide public health protection, including protecting the health of sensitive populations such as asthmatics, children and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation and buildings.

- **Relationship of Air Quality with Environment, Health, Economy and Weather.**

One Atmosphere
Multiscale Multi-pollutant Air Quality Problems



Continental

Intercontinental transport (SO_2, NO_X,O_3),
Regional climate change,
Urban/regional impact,
Air Toxics (e.g., Hg)

Global

Stratospheric O3 hole
Greenhouse effect (CO/CH4/O3)
Aerosol direct forcing
Aerosol indirect forcing
Urban/regional impact,
Air Toxics (e.g., Hg)

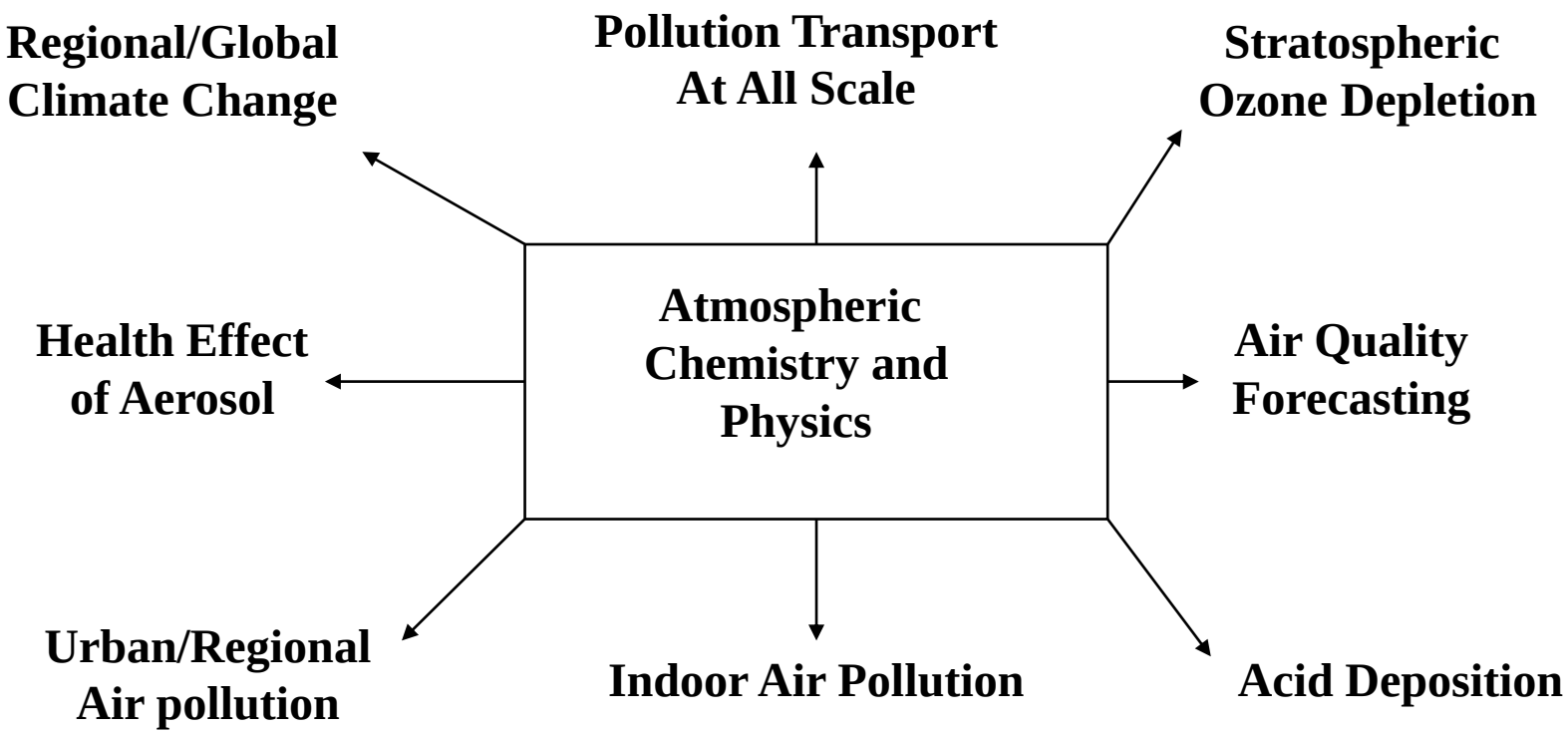
Urban

Smog: O3, VOCs, SOA
Visibility reduction
Health effect of $PM_{2.5}$
Air Toxics (Hg, As)
Impact of global change

Regional

Transport of (SO_2/NO_X/O_3)
Acid deposition (SO_X/NO_X)
Regional haze (SO_4^+)
Ecosystem damage (Hg)
Regional climate change
Impact of global change

Roles of Atmospheric Chemistry/Physics



Six Principal Air Pollutants

- **Nitrogen Dioxide (NO_2)**
- **Ozone (O_3) – formed by volitile organic compounds (VOCs) and nitrogen oxides (NO_X)**
- **Sulfur Dioxide (SO_2)**
- **Particulate Matter (PM) – formed by SO_2, NO_X, ammonia, VOCs, and direct particle emissions**
- **Carbon Monoxide (CO)**
- **Lead (Pb)**

Source Categories of Air Pollutants

- **Types of Sources**
  - **Anthropogenic Emissions**
  - **Natural Emissions**
    - Biogenic Emissions
    - Oceanic Emissions
    - Earth Emissions
    - Volcanic Emissions
- **Types of Processes**
  - **Fuel Combustion**
  - **Industrial process**
  - **Transportation**
- **State of Plumes**
  - **Stationary Source**
    - Point Emissions
    - Area Emissions
  - **Mobile Source**

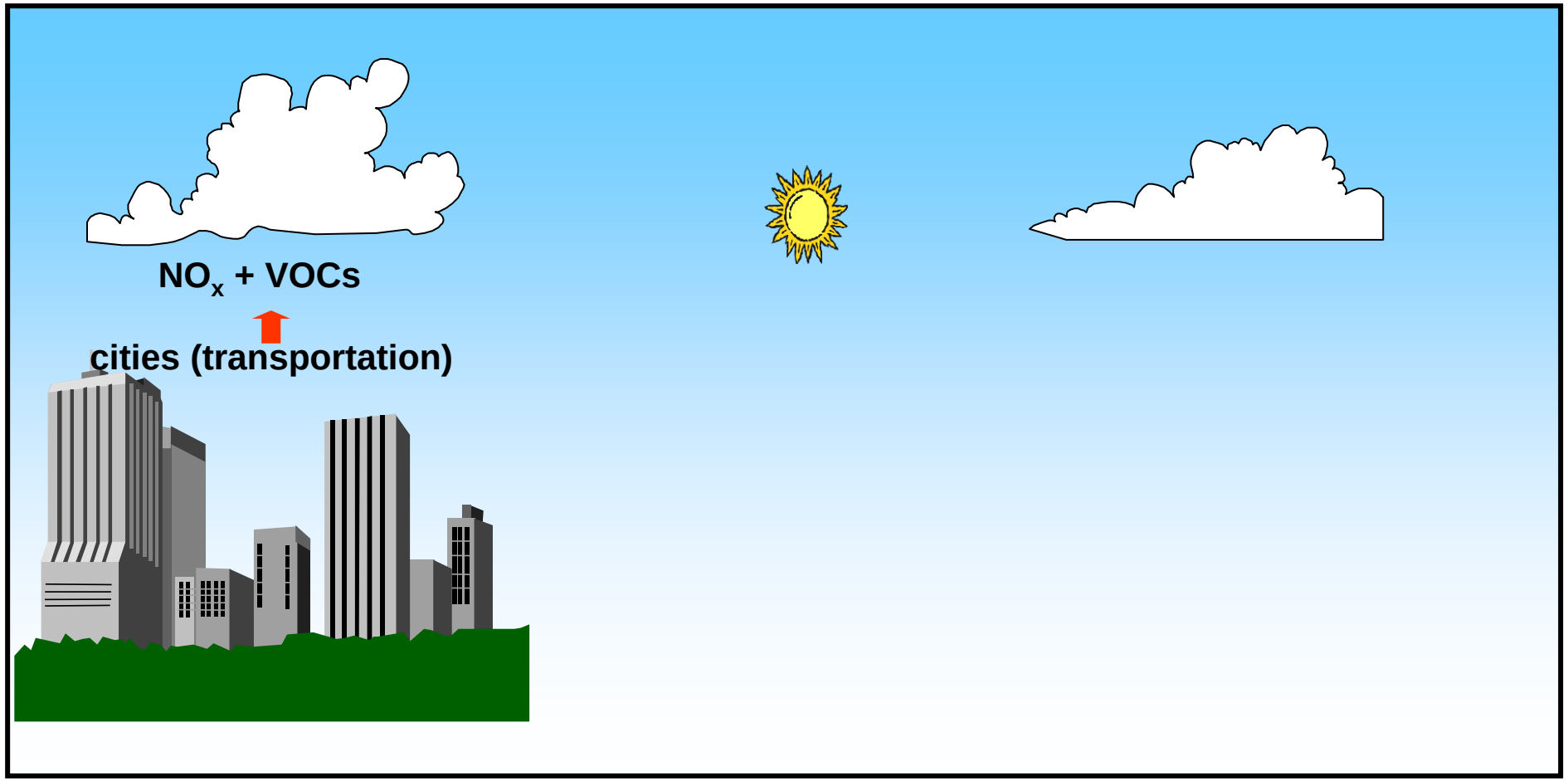
National Ambient Air Quality Standards

Environment (Protection) Seventh Amendment Rules, 2009

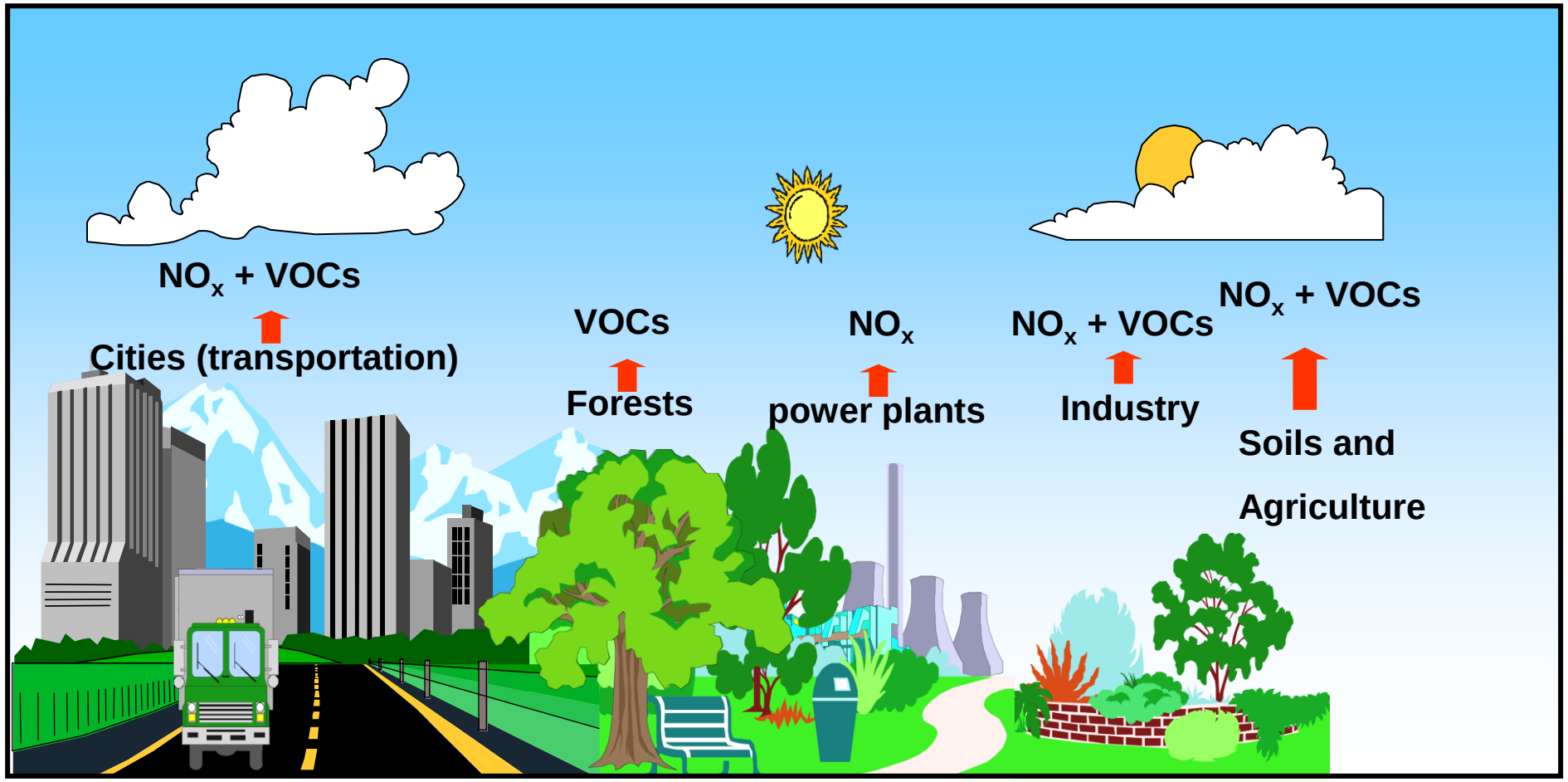
Sensitive Areas: Hill stations, health resorts, sancturies, national parks, national monuments and other areas where the nation conserves its clean environment even if that implies some curb on economic activity

Pollutant	Time Weighted Average	Concentration in Ambient Air		
		Industrial, Residential, Rural and other area	Ecologically sensitive areas (notified by Central Govt.)	Methods of Measurement
SO_2 (μgm^{-3})	Annual* 24 hours**	50 80	20 80	- Improved West and Goeke - UV - fluorescence
NO_2 (μgm^{-3})	Annual* 24 hours**	40 80	30 80	- Modified Jacob & Hochheiser (Na-Arsenic) - Chemiluminescence
PM_{10}, (μgm^{-3})	Annual* 24 hours**	60 100	60 100	- Gravimetric - TEOM - Beta Attenuation
$PM_{2.5}$, (μgm^{-3})	Annual* 24 hours**	40 60	40 60	- Gravimetric - TEOM - Beta Attenuation
Ozone (μgm^{-3})	8 hours 1 hour	100 180	100 180	- UV photometric - Chemiluminescence - Chemical Method
Lead (μgm^{-3})	Annual* 24 hours**	0.5 1.0	0.5 1.0	- AAS/ICP method after sampling on EPM2000 or equivalent filter paper - ED-XRF using Teflon filter
CO (mgm^{-3})	8 hours 1 hour	2000 4000	2000 4000	- Non-dispersive Infra Red (NDIR) spectroscopy
NH3 (μgm^{-3})	Annual* 24 hours**	100 400	100 400	-Chemiluminescence -Indophenol Blue Method
Benzene (μgm^{-3})	Annual*	5	5	- Gas Chromatography based continuous analyzer - Absorption and Desorption followed by GC analysis
Benzo(a)Pyrene - particulate phase only (ngm^{-3})	Annual*	1	1	- Solvent extraction byHPLC/GC analysis
Arsenic (ngm^{-3})	Annual*	6	6	- AAS/ICP method after sampling on EPM2000 or equivalent filter paper
Nickel (ngm^{-3})	Annual	20	20	- AAS/ICP method after sampling on EPM2000 or equivalent filter paper

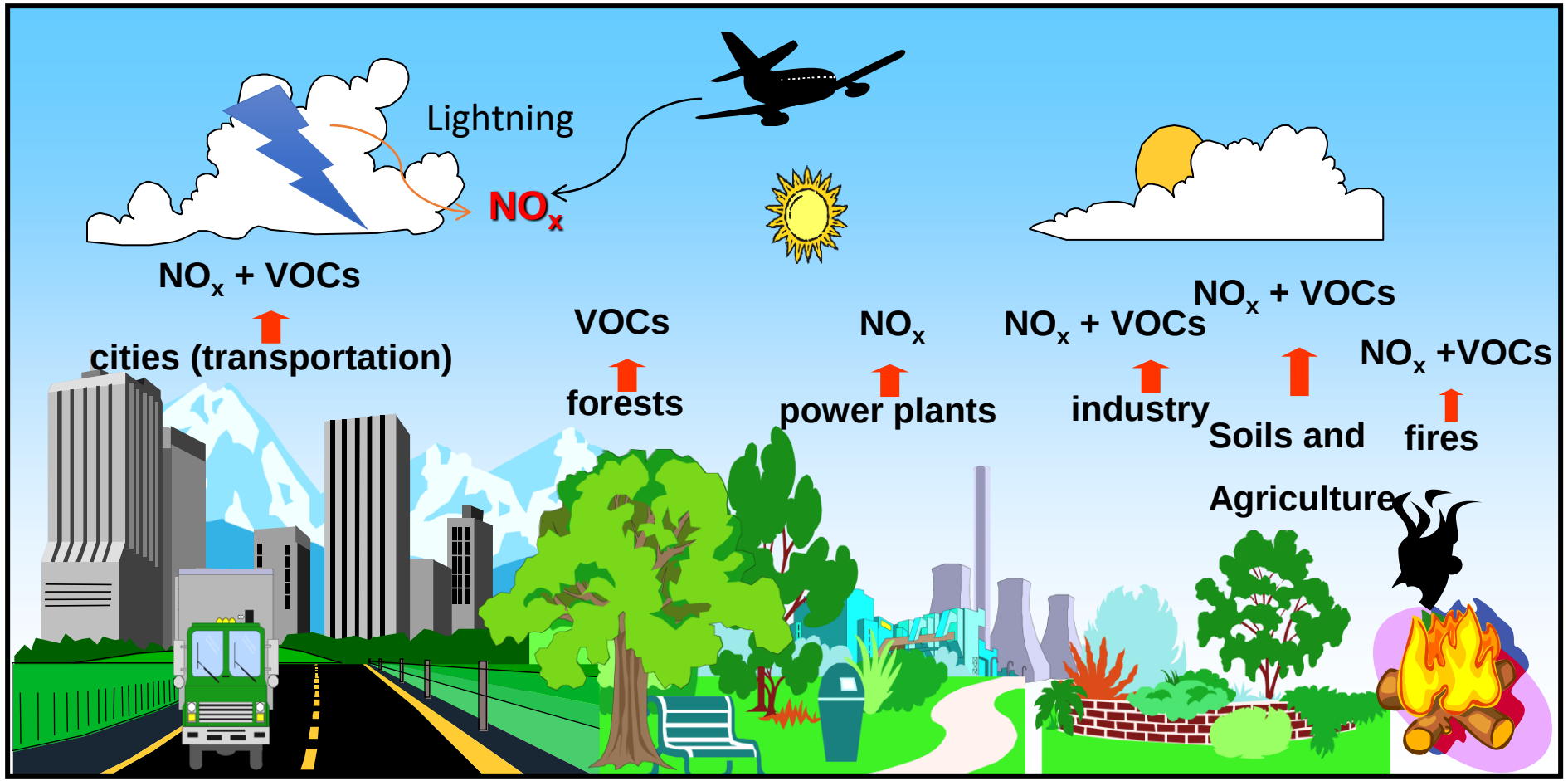
NO_x emission sources



NO_x emission sources



NO_x emission sources

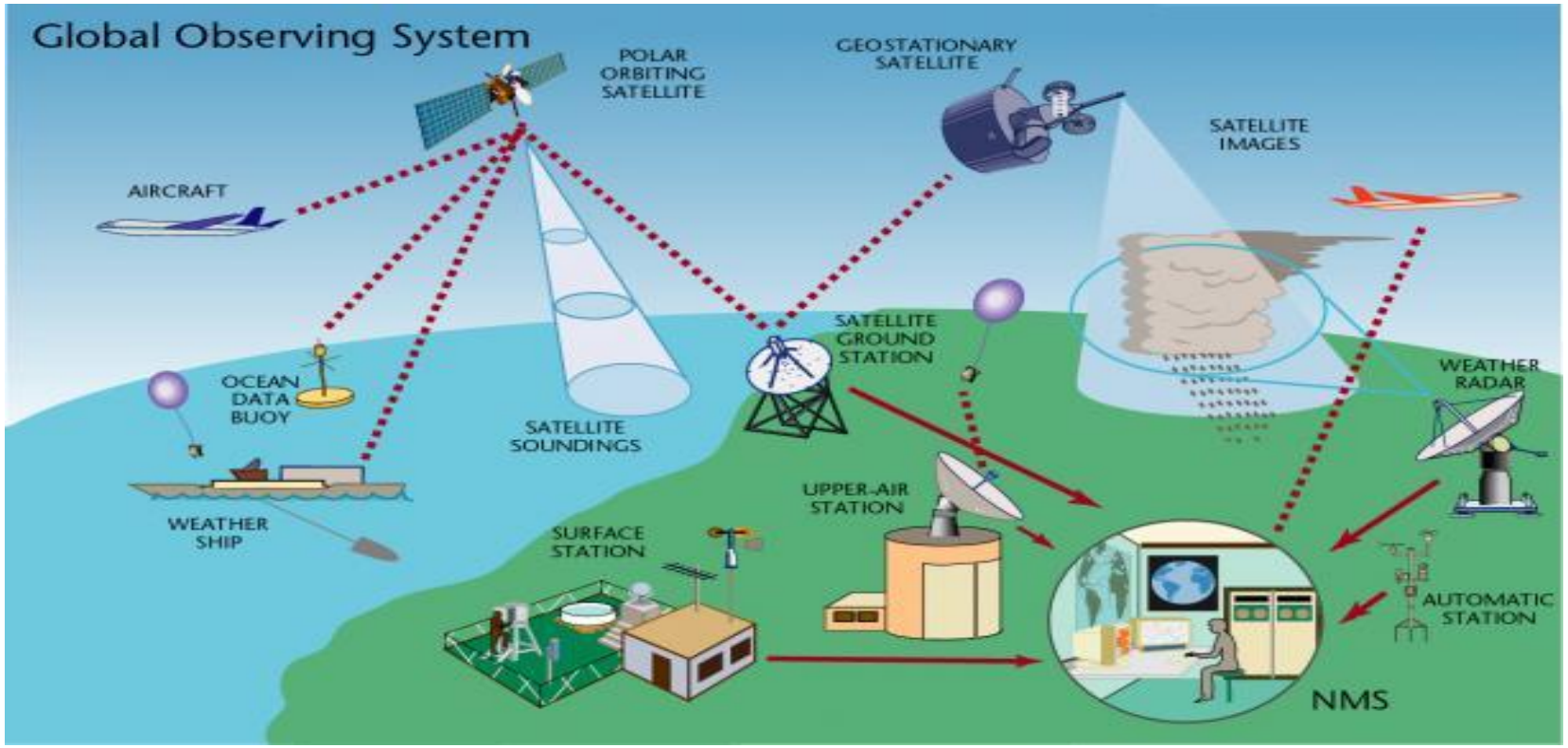


Environmental monitoring

Environmental monitoring can be defined as the systematic sampling of air, water, soil, and biota in order to observe and study the environment, as well as to derive knowledge from this process

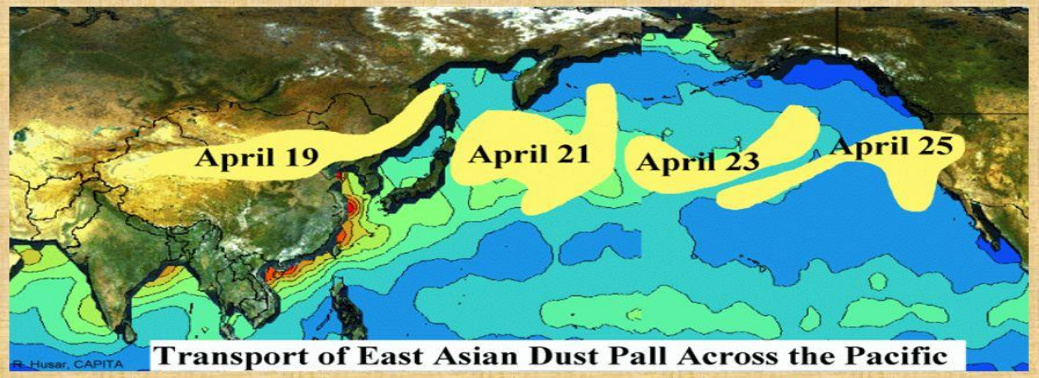
Ambient Environment Monitoring

Ambient air quality, Air pollution emissions
Water Resources Monitoring
Sediment, Soil and Biological Monitoring



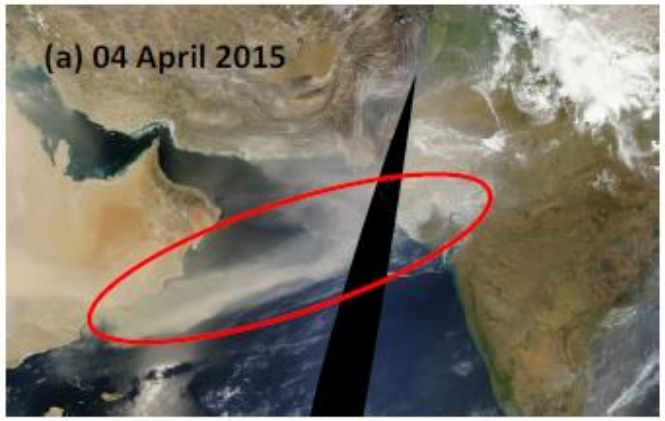
Dust Event

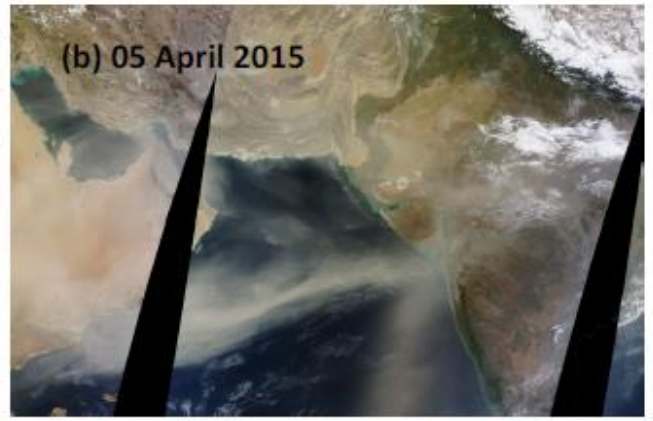
Asian dust event

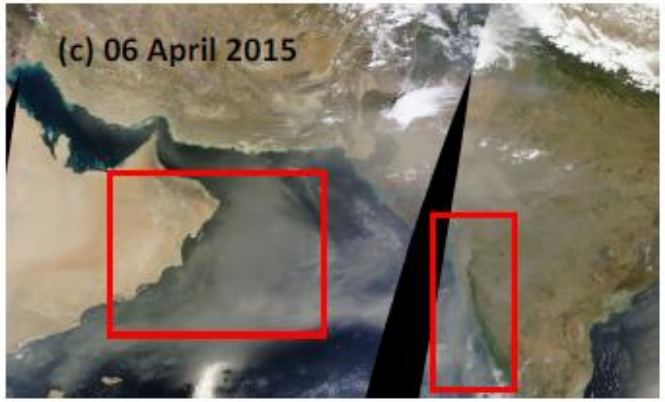


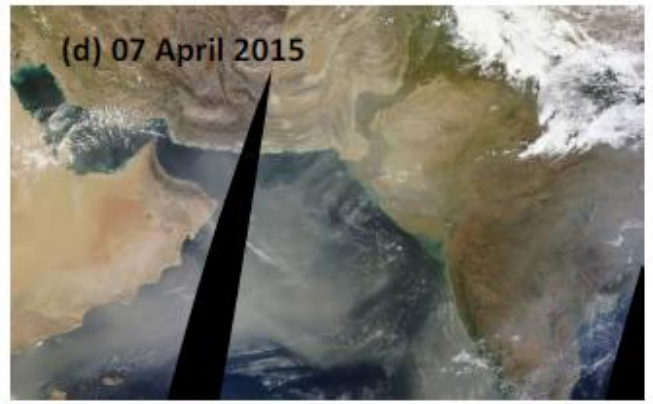
Transport of East Asian Dust Pall Across the Pacific

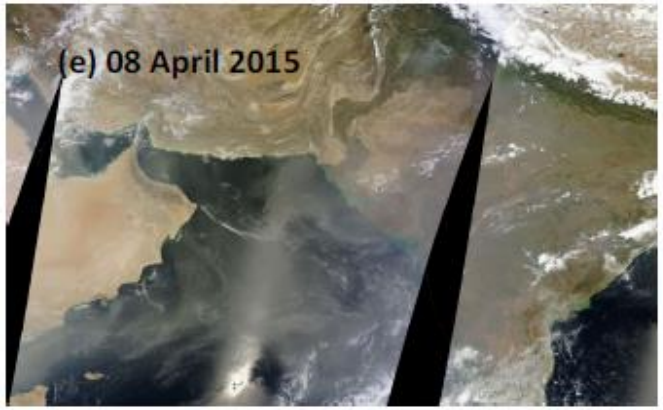
"On April 15th, 1998, a dust storm in Western China has produced a huge atmospheric dust cloud that was transported across the Pacific Ocean and caused elevated aerosol concentrations over much of the Pacific Coast of North America." *http://capita.wustl.edu/Asia-FarEast/*

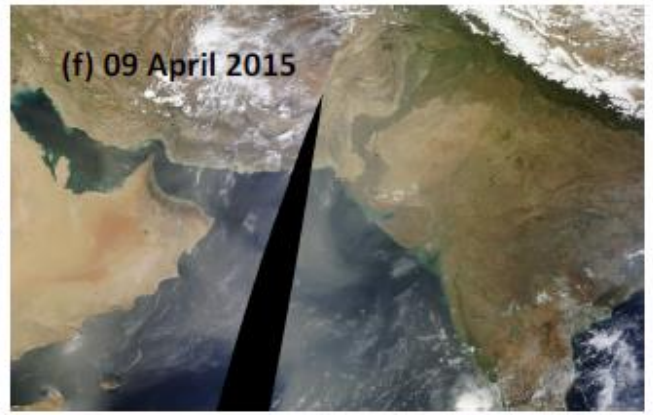






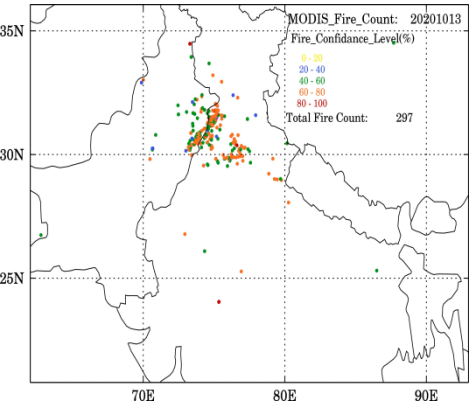


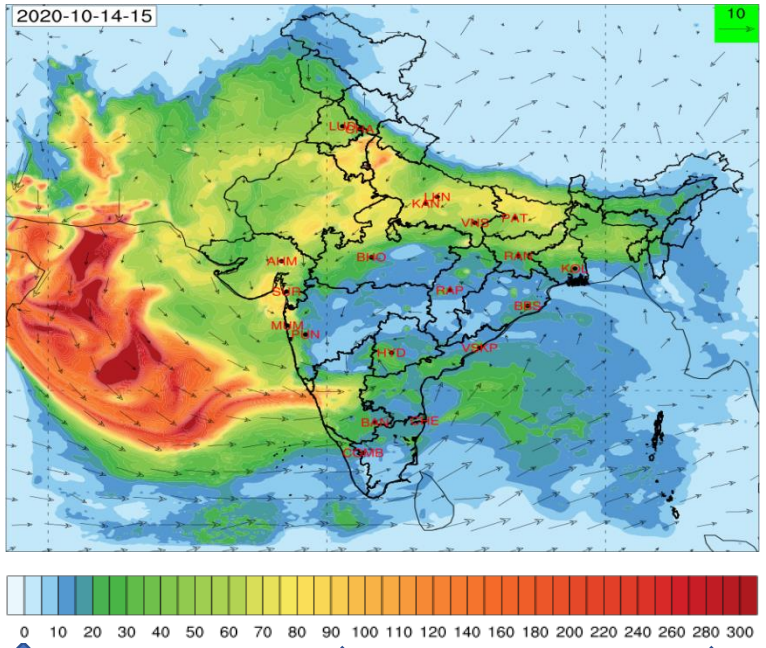




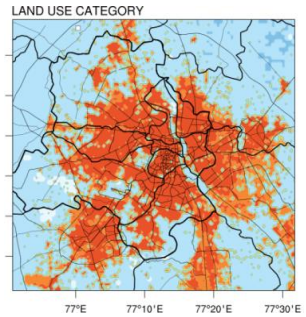
Quick Overview of operational air quality forecasting setup:

Hourly $PM_{2.5}$ forecast at 10 km based on WRF-Chem

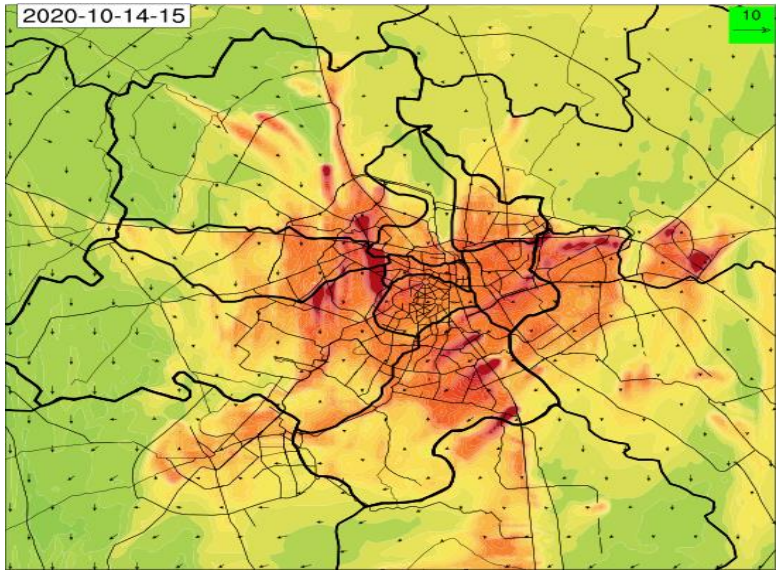


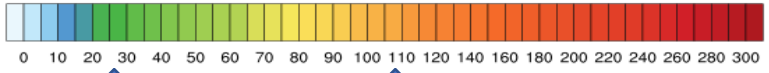


Dynamical downscaling frame-work



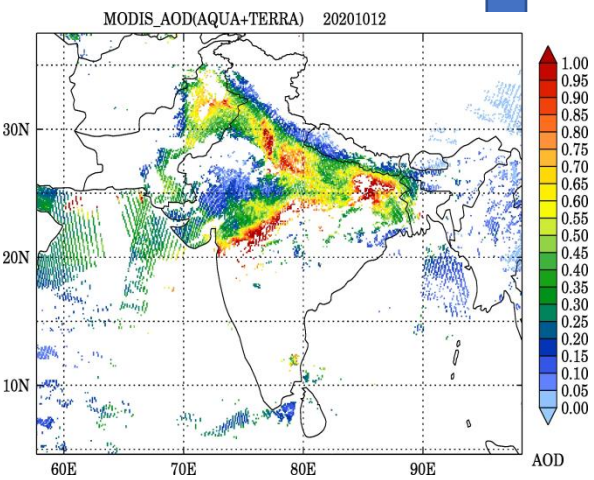
forecast at 400 m

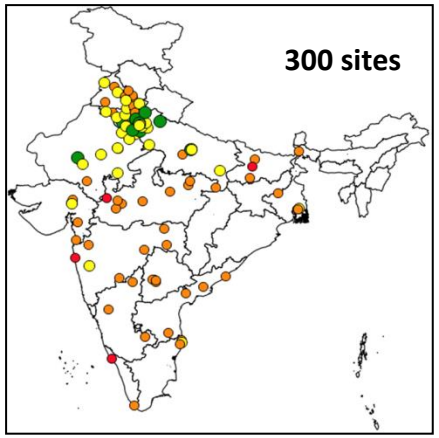




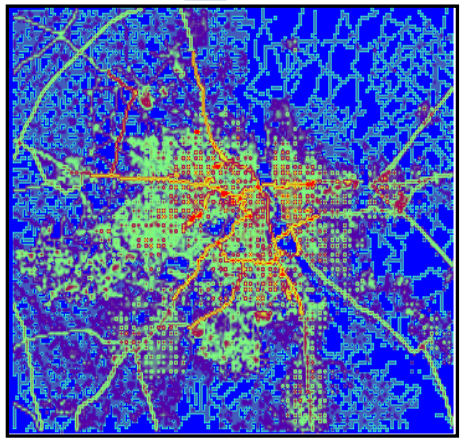
Assimilation at 9 UTC and 18 UTC

Assimilation at 9 UTC

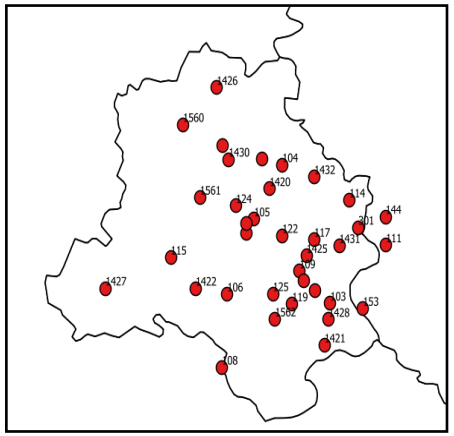




Driving meteorological IMD-IITM-Global Forecasting System (IMD-IITM-GFS, T1534, Ensemble-Kalman filtering) spectral model at 12.5 km grid resolution available at every three hours

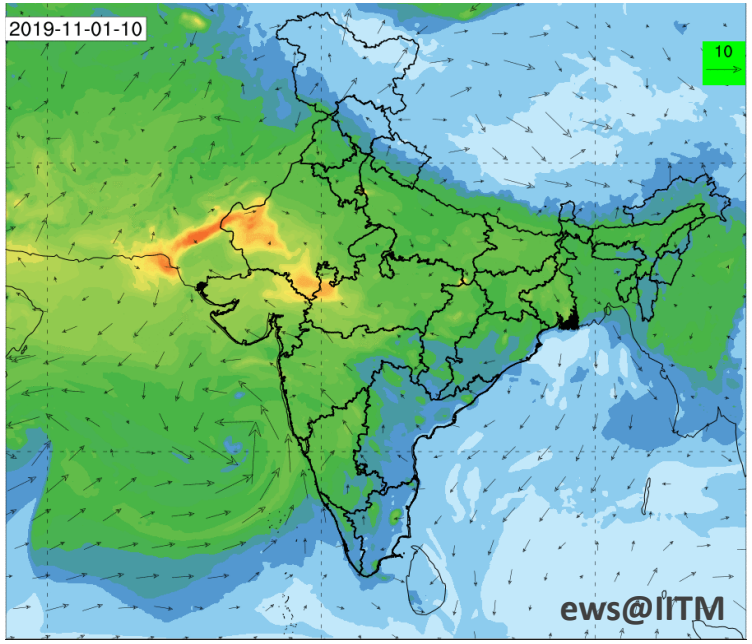


Emission inventory @ 400 m

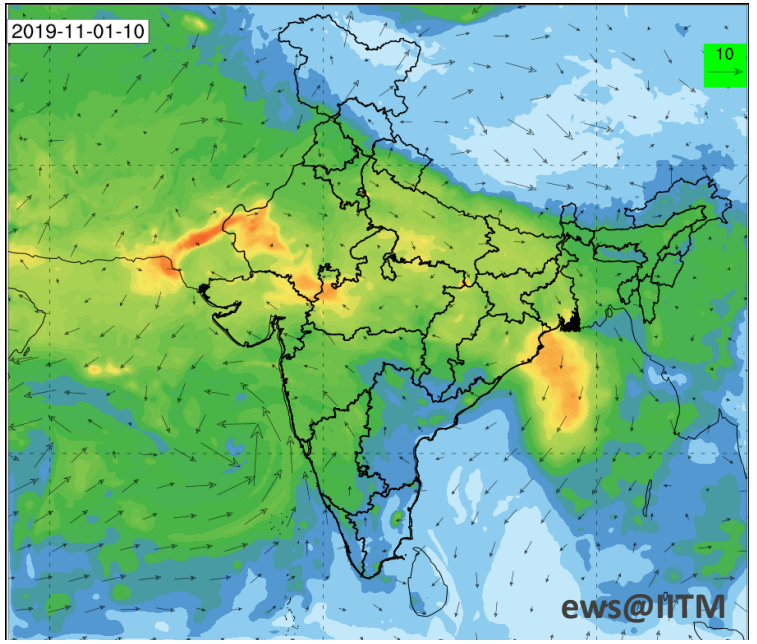


Satellite (MODIS) and surface data (230 stations) assimilation for improving short term air quality forecast over South Asia @10 KM

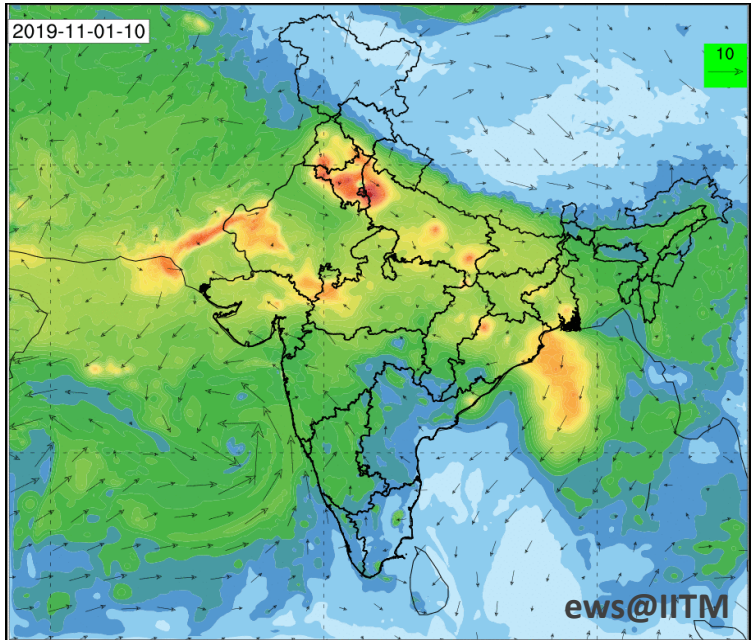
MODEL



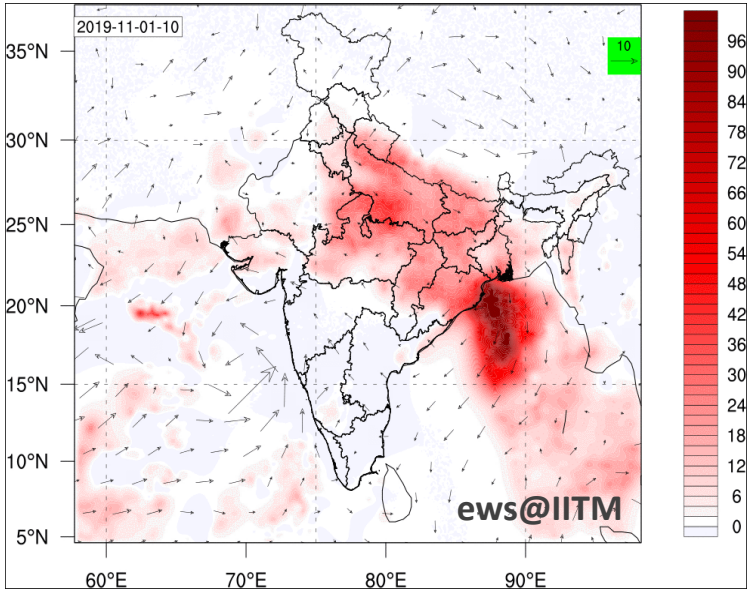
MODEL+MODIS



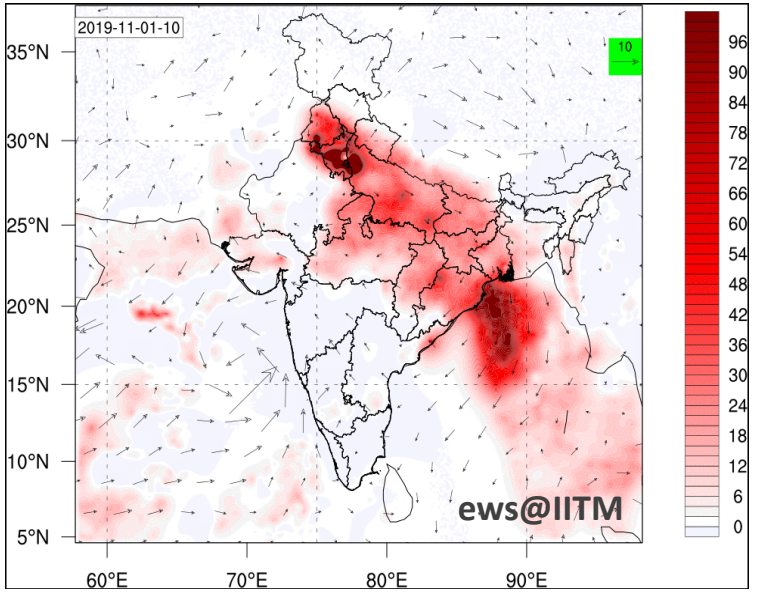
MODEL+MODIS+CPCB



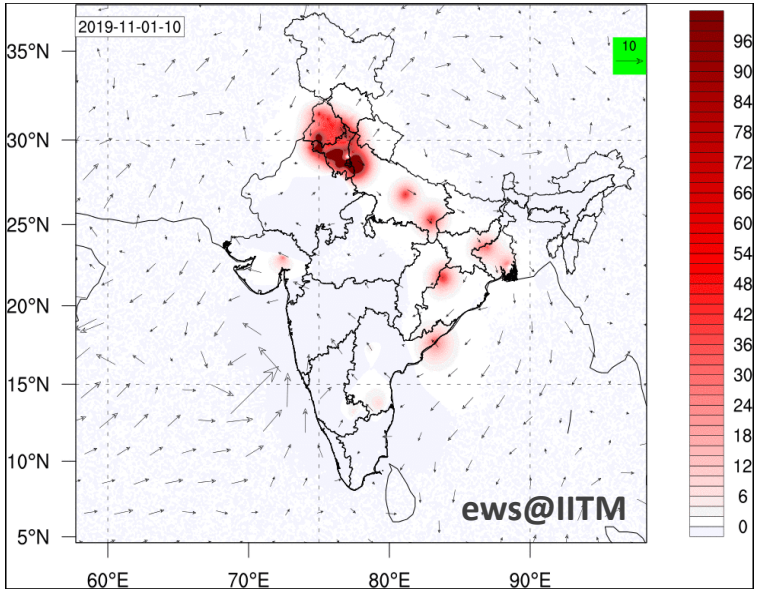
Improvement due to MODIS



Improvement due to MODIS +CPCB



Improvement only due to CPCB



SILAM (System for Integrated Modeling of Atmospheric Composition)

IMD Setup

Running:

- Hourly AQ Forecast
- 3 KM WRF forecast (IMD)

Boundary conditions:

- SILAM Global Suit

Emissions:

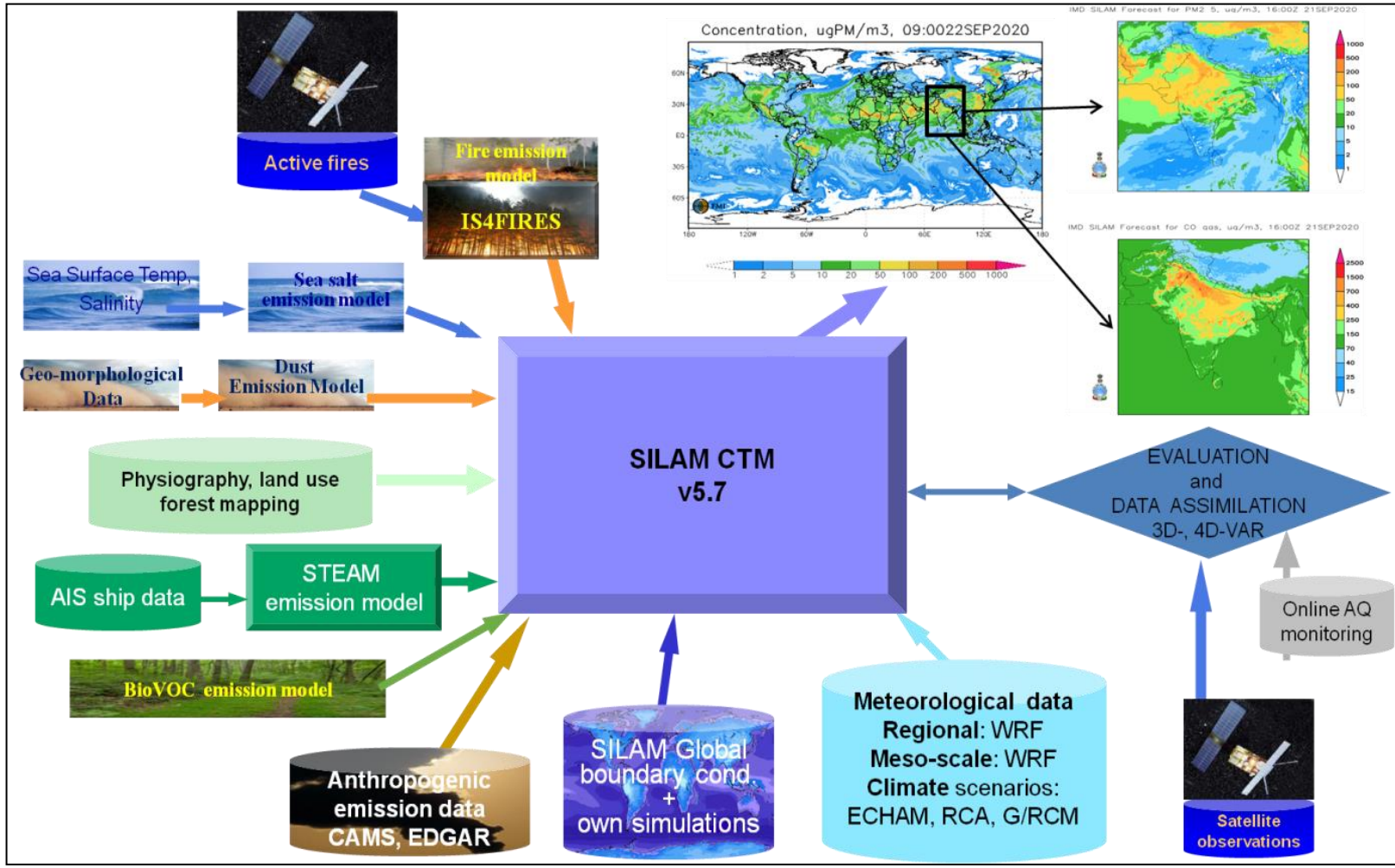
- CAMS-GLOB v2.1, 0.1-deg supplemented with EDGAR v4.3.2 for coarse and mineral-fine anthropogenic PM.
- GEIA v1 lightning climatology
- MEGAN-MACC biogenic climatology for isoprene and monoterpene.
- Natural (dynamic): Silam desert dust, Silam sea salt, Silam marine DMS.
- MoES-SAFAR Emission Inventories

Aerosol Process:

- Simple equilibrium scheme for secondary inorganic aerosols, VBS for secondary organics
- CBM5 chemistry supplemented with secondary organics, DMAT_SULPHUR sulphur oxidation.

Validation

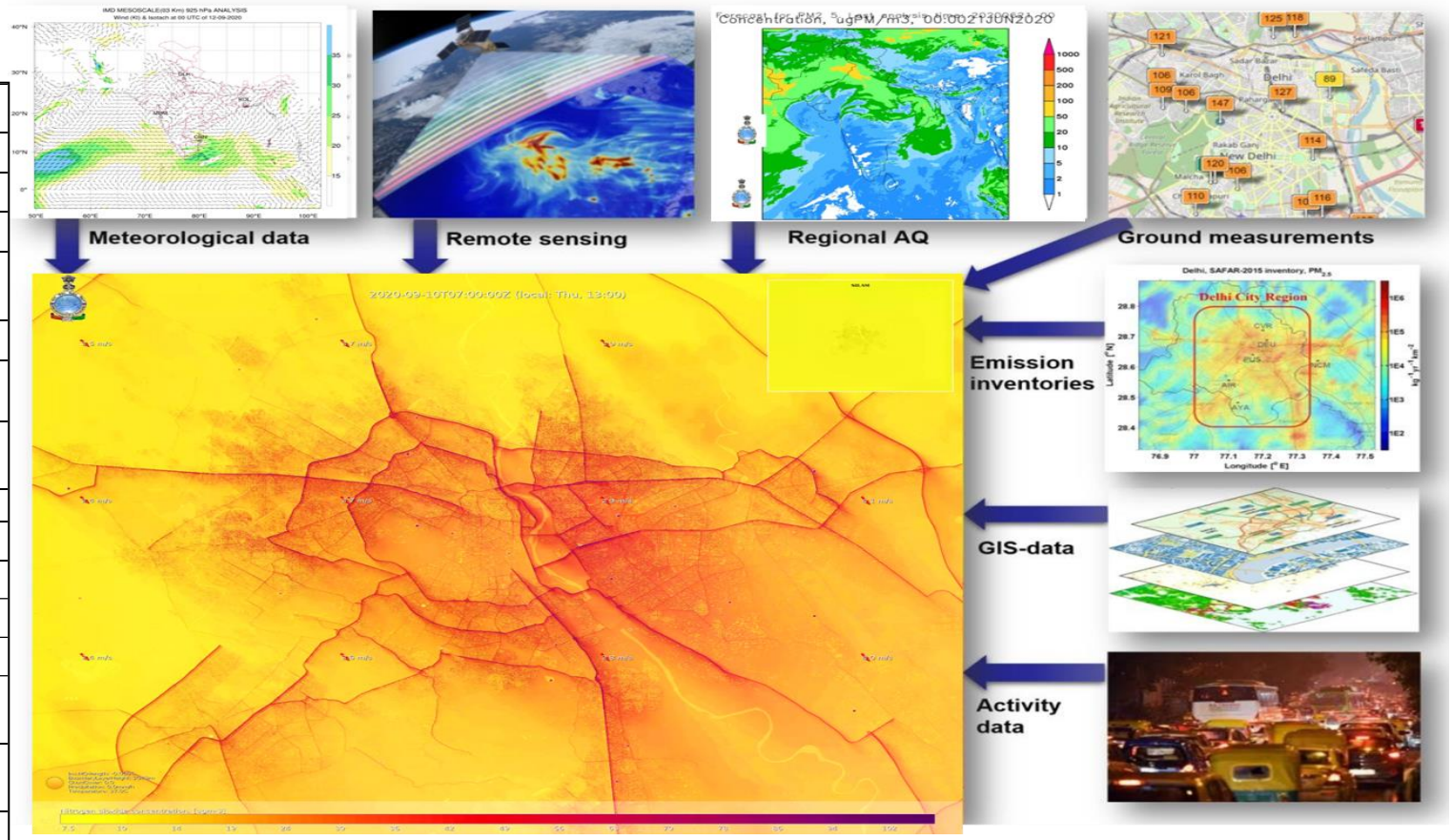
- In-situ data



FMI-IMD ENFUSER

https://nwp.imd.gov.in/enfuser_imd.php

Name	Resolution [m]	Source
OSM land-use, surface*	5	OpenStreetMap
OSM land-use, functional	10	OpenStreetMap
Satellite image	10	Sentinel 2 MSI (TCI)
Satellite image, near-infrared	10	Sentinel 2 MSI (B08 band)
Elevation	30	NASA SRTM
Population	300	Global Human Settlement
Built land-use	30	Global Human Settlement
Road network	5	Several
Elevation gradient	30	Several
Vegetation index	10	Several
Enhanced population	50	Several
Building height	5	Several
Population density at radius X	200	
Property X density at radius Y	200	
Household emission inventory proxy	20	Many
Traffic flow estimates for roads	5	Many



Domain range, Latitude	28.362N - 28.86N
Domain range, Longitude	76.901E - 77.56E
Spatial resolution	27m (inner areas with higher resolution can be added)
Temporal resolution	1h averages
Modelled species	NO2, PM2.5, PM10, O3, coarse PM, SO2, CO
Modelling time span	>48h per model run, updated several times a day
Main output formats	netCDF, statistics as CSV
Secondary output formats	animations (avi), gif, Figures (PNG)
Output storage	Local (compressed) and optionally AWS S3 cloud storing

https://nwp.imd.gov.in/silam/SO2_gas_srf.php

Integrated system of Urban Meteorological Services

MINISTRY OF EARTH SCIENCES

INDIA METEOROLOGICAL DEPARTMENT

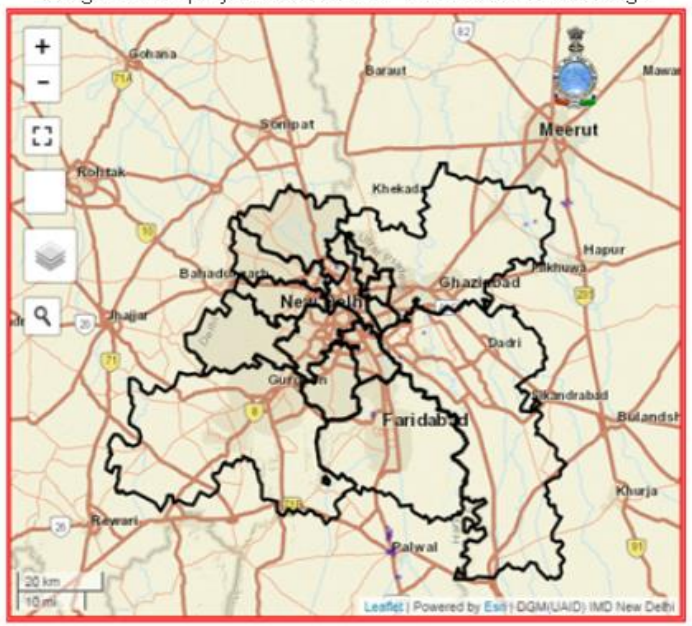
URBAN METEOROLOGICAL SERVICES FOR DELHI/NCR

ABOUT US | OBSERVATIONS | WEATHER/AIR QUALITY FORECAST | WARNING | BULLETIN

October 28, 2021 | October 29, 2021 | October 30, 2021 | October 31, 2021 | November

No warning | Watch | Alert | Warning

Integrated Display of weather and Thunderstorm Warnings



Current Weather across Delhi/NCR

New Delhi

New Delhi	Palam	Ayanagar	Jafarpur	Najafgarh	Pitampura
18.4°	19°	18°	14.91°	17.71°	18.41°
South-southwesterly 11.1km/h	Westerly 5.4km/h	Calm 0km/h	Southerly 1.8km/h	1.8km/h	Westerly 0km/h

THANKS

QUESTIONS?

chinmay.jena@imd.gov.in