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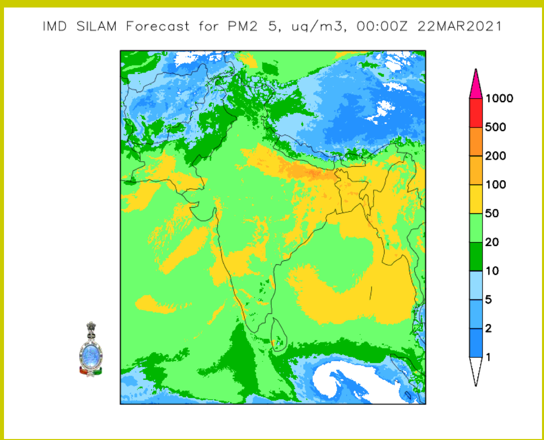
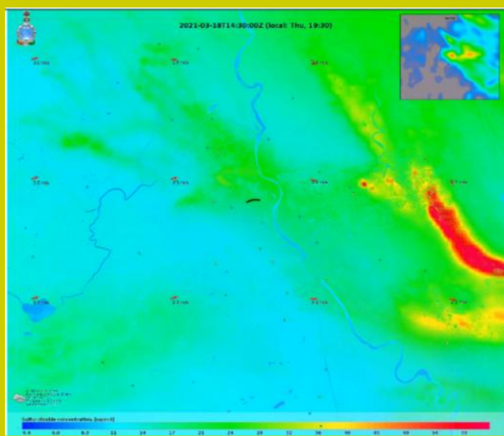
Ministry of Earth Sciences

STANDARD OPERATING PROCEDURE (SOP)

Air Quality Monitoring and Forecasting Services

(Air Quality Early Warning System)





INDIA METEOROLOGICAL DEPARTMENT

Ministry of Earth Sciences

Government of India

2021

STANDARD OPERATING PROCEDURE (SOP)

Air Quality Monitoring and Forecasting Services

(Air Quality Early Warning System)

ENVIRONMENT MONITORING AND RESEARCH CENTRE,
INDIA METEOROLOGICAL DEPARTMENT, NEW DELHI
2021

PREFACE

India Meteorological Department (IMD) is perhaps the first institution in India to start systematic long term environment monitoring of atmospheric aerosol properties, ozone and precipitation chemistry. The technical coordination and overseeing of the functions of the operational air quality forecasting services in India has been entrusted to Environment Monitoring and Research Center (EMRC), a division of IMD. EMRC conducts monitoring and research related to atmospheric constituents that are capable of forcing change in the climate of the Earth, and may cause depletion of the global ozone layer, and play key roles in air quality from local to global scales. EMRC also provides specific services to Ministry of Environment and Forest & Climate Change and other Government Agencies in the assessment of air pollution impacts. IMD contributes in the field of atmospheric environment to the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) programme. The main objective of GAW is to provide data and other information on the chemical composition and related physical characteristics of the atmosphere and their trends, required to improve understanding of the behavior of the atmosphere and its interactions with the oceans and the biosphere.

India Meteorological Department in collaboration with Indian Institute of Tropical Meteorology (IITM) and National Centre for Medium Range Weather Forecasting (NCMRWF) has implemented Air Quality Early Warning System to predict extreme air pollution events and give alerts to take necessary steps as per Graded Response Action Plan of the Government of India. The high-level objective of this system is to enable and provide air quality forecasting and information services in a globally harmonized and standardized way tailored to the needs of society and policy makers. The warning system consists of (1) near real-time observations of air quality and visibility and details about natural aerosols like dust, biomass fire information, satellite aerosol optical depth (AOD) and PBL height, (2) Predictions of air pollutants based on state-of-the-science atmospheric chemistry transport models, (3) Warning Messages, Alerts and Bulletins issued by IMD and (4) forecast of the contribution of non-local fire emissions to the air quality in Delhi and other cities. The warning system also provides an air quality forecast for several non-attainment cities. IMD has operationalized two air quality forecast models (1) System for Integrated modelLing of Atmospheric coMposition (SILAM) for India (2) ENvironmental information FUsion SERvice (ENFUSER) a very high resolution City Scale air quality model for Delhi. The operational modelling system provides both real-time and forecasted, high resolution information on the urban air quality.

The role of air quality forecasts is growing as an Air Quality Management tool. In order to meet demands of operational forecasters and officials working in field of air quality management, the first edition of Standard Operational Procedure (SOP) on air quality monitoring and forecast services is being released. The topics of this SOP are restricted to procedural aspects of air quality forecast services. It is hoped that the information contained in SOP will be very useful to the officials working in operational field.

Dr. M. Mohapatra
Director General of Meteorology

ACKNOWLEDGEMENT

The entire work of the publication has been made by a group of officers and other members associated with Environment Monitoring and Research Center of IMD. I am thankful to the authors for their tireless effort towards formulation of the document—Standard operational procedure of air quality monitoring and forecast services. I would like to place on record the significant contributions and guidance made by Dr V. K. Soni, Scientist-F & Head, EMRC as Chairman of the committee towards preparation, compilation and edition of the publication. I express my sincere thanks to Dr Siddhartha Singh, Scientist-E and Mr Sanjay Bist, Scientist-E & Member Secretary for their significant contribution as resource persons in preparation of the SOP. I express my appreciation to Dr Chinmay Jena, Scientist-C and Dr Anikender Kumar, Scientist-C for editing the SOP. I am also thankful to Dr D. R. Pattanaik, Scientist-F and Dr Anand Das, Scientist-E, NWP for contributing and reviewing the SOP.

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1. Introduction

Air Quality Forecasts, if they are reliable and sufficiently accurate, can play an important role as part of an air quality management system The air quality (AQ) Forecast lets the public know expected air quality conditions for next 72 hours so that Government authorities can take action to manage the air quality and issue health advisories. Local air quality affects how you live and breathe. Like the weather, it can change from day to day or even hour to hour.

The Graded Response Action Plan (GRAP) ensures that air pollution control actions are taken in Delhi-National Capital Region (NCR) based on the different air quality index categories namely, Moderate & Poor, Very Poor, and Severe as per National Air Quality Index. A new category of “Severe+ or Emergency” has also been added. The details of GRAP can be found at http://cpcbenvis.nic.in/pdf/final_graded_table.pdf. The meeting of task force is convened by CPCB periodically and more frequently during Severe and Severe+ AQI category. The task force, which includes officials from the different pollution control boards and experts, discusses the current air quality, the prediction ahead and the need for more proactive measures. The Air Quality forecast is highly important so that pollution control authorities can initiate action in advance. Head, EMRC attends the meeting as a representative of Director General of Meteorology. Generally, the meeting starts with the inputs presented by Head, EMRC and the discussion on weather and air quality prediction is considered of very high importance.

The Air Quality Early Warning System (AQ-EWS) has been developed under the aegis of Ministry of Earth Sciences, jointly by Indian Institute of Tropical Meteorology (IITM), Pune, India Meteorological Department, and National Centre for Medium-Range Weather Forecasting (NCMRWF). The System is designed to predict air pollution events and give alerts to take necessary steps for air pollution control. India Meteorological Department has been entrusted with issuing Air Quality and Weather Forecast Bulletin and operationally run the AQ model SILAM for this purpose.

2. Ambient Air Pollutants and their Concentration Measurement

Under the provisions of the Air (Prevention & Control of Pollution) Act, 1981, the CPCB has notified fourth version of National Ambient Air Quality Standards (NAAQS) in 2009. The national standard aims to provide uniform air quality criteria for all, irrespective of land use pattern, across the country.

Table-2.1: National Ambient Air Quality Standards and Measurement Methods

	Pollutant	Time Weighted Average	Concentration in Ambient Air		Methods of Measurement
			Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area	
1.	**Sulphur Dioxide (SO_2), µg/m^3**	Annual * 24 Hours **	50 80	20 80	-Improved West and Gaeke Method -Ultraviolet Fluorescence
2.	**Nitrogendioxide (NO_2), µg/m^3**	Annual * 24 Hours **	40 80	30 80	-Jacob &Hochheiser modified ($NaOH-NaAsO_2$) Method -Gas Phase Chemiluminescence
3.	**Particulate Matter (Size less than 10µm) or PM_{10}, µg/m^3**	Annual * 24 Hours **	60 100	60 100	-Gravimetric -TEOM -Beta attenuation
4.	**Particulate Matter (Size less than 2.5µm) or $PM_{2.5}$, µg/m^3**	Annual * 24 Hours **	40 60	40 60	-Gravimetric -TEOM -Beta attenuation
5.	**Ozone (O_3) , µg/m^3**	8 Hours * 1 Hour **	100 180	100 180	-UV Photometric -Chemiluminescence -Chemical Method
6.	**Lead (Pb) , µg/m^3**	Annual * 24 Hours **	0.50 1.0	0.50 1.0	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper -ED-XRF using Teflon filter
7.	**Carbon Monoxide (CO), mg/m^3**	8 Hours ** 1 Hour **	02 04	02 04	-Non dispersive Infrared (NDIR) Spectroscopy
8.	**Ammonia (NH_3), µg/m^3**	Annual * 24 Hours **	100 400	100 400	-Chemiluminescence -Indophenol blue method
9.	**Benzene (C_6H_6), µg/m^3**	Annual *	05	05	-Gas Chromatography (GC) based continuous analyzer -Adsorption and desorption followed by GC analysis
10.	**Benzo(a)Pyrene (BaP) Particulate phase only, ng/m^3**	Annual *	01	01	-Solvent extraction followed byHPLC/GC analysis
11.	**Arsenic (As), ng/m^3**	Annual *	06	06	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper
12.	**Nickel (Ni), ng/m^3**	Annual *	20	20	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper

***** Annual Arithmetic mean of minimum 104 measurements in a year twice a week 24 hourly at uniform interval. ** 24 hourly/8 hourly values should be met 98% of the time in a year. However, 2% of the time, it may exceed but not on two consecutive days.

3. Air Quality Index

Air Quality Index (AQI) is a tool for effective communication of air quality status to people can easily understand and take action. The AQI is used by agencies to communicate to the public how polluted the air currently is or how polluted it is forecast to become. Public health risks increase as the AQI rises. AQI is intended to enhance public awareness and involvement in efforts to improve air quality. It transforms complex air quality data of various pollutants into a single number (index value), nomenclature and colour.

(i) There are six AQI categories, namely Good, Satisfactory, Moderate, Poor, Very Poor, and Severe. Each of these categories is decided based on ambient concentration values of air pollutants and their likely health impacts (known as health breakpoints). AQ sub-index and health breakpoints are evolved for eight pollutants (PM10, PM2.5, NO2, SO2, CO, O3, NH3, and Pb) for which short-term (upto 24-hours) National Ambient Air Quality Standards are prescribed.

(ii) Based on the measured ambient concentrations of a pollutant, sub-index is calculated, which is a linear function of concentration. The worst sub-index determines the overall AQI.

(iii) All the criteria pollutants may not be monitored at all the locations. Overall AQI is calculated only if data are available for minimum three pollutants out of which one should necessarily be either PM2.5 or PM10. Else, data are considered insufficient for calculating AQI. Similarly, a minimum of 16 hours' data is considered necessary for calculating subindex.

(iv) Note that AQI is based on 24 hour or 8 hour average pollutant concentration and not on hourly concentration.

(v) The web-based system designed to provide AQI on real time basis is an automated system that captures data from monitoring stations on a continuous basis without human intervention, and displays AQI based on running average values. The near real time AQI based on monitoring data can be found at https://app.cpcbccr.com.

(vi) AQI categories and health breakpoints for the eight pollutants are as follow:

Table-3.1: Breakpoints for AQI Scale 0-500 (units: µg/m3 unless mentioned otherwise)

AQI Category	PM_{10}	$PM_{2.5}$	NO_2	O_3	CO	SO_2	NH_3	Pb
(Range)	24-hr	24-hr	24-hr	8-hr	8-hr (mg/m^3)	24-hr	24-hr	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)	431-500	251-350	400+	748+*	34+	1600+	1800+	3.5+

Table-3.2: Colour Coding for different AQ Index categories

AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m^3)	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+

Table-3.3: AQI and Associated Health Impacts

AQI	Associated Health Impacts
Good	Minimal Impact
Satisfactory	May cause minor breathing discomfort to sensitive people.
Moderate	May cause breathing discomfort to people with lung disease such as asthma, and discomfort to people with heart disease, children and older adults.
Poor	May cause breathing discomfort to people on prolonged exposure
Very Poor	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases.
Severe	May cause respiratory impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.

4. Air Quality Monitoring

The methods of measurement prescribed by CPCB for respective parameters are the combination of physical method, wet-chemical method and continuous online method. The continuous online ambient air quality monitoring systems are equipped with analyzers for measurement of PM10, PM2.5, SO2, CO, NO2, O3, NH3 and Benzene. The metallic parameters Pb, Ni, As are measured offline using filter based air samplers. The ambient air quality monitoring station (AQMS) consists of following systems:

- **PM10 & PM2.5:** Operates on the principle of Beta Ray Attenuation and measures Particle Mass concentration ranging from 0 to 5 mg/m^3 with Minimum detection limit 1 µg/m^3. The equipment includes a PM10 inlet and PM2.5 inlet.
- **NOx and NH3:** Operates on the principle of Chemiluminescence method, ranging from 0 to 2000µg/m^3 with minimum detection limit 0.5µg/m^3.
- **SO2 Analyser:** Operates on the principle of UV Fluorescence method, ranging from 0 to 2000 µg/m3 with minimum detection limit 0.5 µg/m^3
- **CO Analyser:** Operates on the principle of Non-Dispersive Infrared Spectrometry (NDIR) method, ranging from 0 to 100 mg/m^3 with minimum detection limit 0.03 µg/m^3
- **O3 Analyser:** Operates on the principle of UV Photometry method, range : 0 to 2500µg/m3 with minimum detection limit 0.5 µg/m^3
- **Benzene, Toluene, Ethylbenzene, Xylene (BTEX):** GC/PID for automatic monitoring of BTEX in air with minimum detection level as low as 10 ppt in ambient air
- **Multigas Calibrator:** to calibrate gas analyzers manually, remotely controlled or automatically, for quality assurance. Multi Calibration upto 20 points.
- **Automatic Weather Station (AWS):** Ultrasonic Wind Sensor, Barometric Pressure, Temperature, Relative Humidity, Rainfall, Solar Radiation etc.

All these instruments except AWS are housed in a room or walk-way shelter with proper sampling system for gaseous and particulate matter parameters. AQMS should have the calibration facility for onsite calibration with zero and standard gases. Beta Ray Attenuation for the measurement of PM10 and PM2.5 should be calibrated with standard filters. The detailed guideline for site selection, measurement frequency, reporting etc has been notified by CPCB. Each AQMS should also have a PC for recording and transmission of the data via internet.

Table-4.1: Details of SAFAR Ambient Air Quality Monitoring Stations in Delhi

S. No.	Name of monitoring station	No. & name of monitored parameters notified under NAAQS	Additional parameters monitored
1.	NPL, Delhi (Pusa Road)	PM (10 & 2.5), NO, NO2, CO, O3, Benzene	CO2, BC, Toluene, Ethyl Benzene, Xylene
2.	IMD, Lodhi Road	PM (10 & 2.5), NO, NO2, CO, O3,	CO2, BC
3.	NCMRWF, NOIDA	PM (10 & 2.5), NO, NO2, CO, O3	CO2
4.	CRRI, Mathura Road	PM (10 & 2.5), NO, NO2, CO, O3, Benzene	CO2, BC, Toluene, Ethyl Benzene, Xylene
5.	IMD Ayanagar	PM (10 & 2.5), NO, NO2, CO, O3, Benzene	CO2, BC, Toluene, Ethyl Benzene, Xylene
6.	CV Raman Institute, Dheerpur	PM (10 & 2.5), NO, NO2, CO, O3	CO2
7.	Delhi University	PM (10 & 2.5), NO, NO2, CO, O3, Benzene	CO2, BC, Toluene, Ethyl Benzene, Xylene
8.	IGI Palam Airport	PM (10 & 2.5), NO, NO2, CO, O3	CO2
9.	NISE, Gurgaon	PM (10 & 2.5), NO, NO2, CO, O3	CO2
10.	IIT New Delhi	PM (10 & 2.5), NO, NO2, CO, O3	CO2

The Air Quality Monitoring System is under Comprehensive Operation and Maintenance Contract (COMC). EMRC, IMD monitors the functioning of all the AQMS daily. If any instrument is found not working, it should be brought to the notice of the COMC engineer.

Air Quality and Meteorological Data collected from monitoring stations are transmitted to the control room in each city. From Control rooms, data are transmitted to the Central Control Room installed at IITM, Pune. Central Control Room, Pune converts the AQMS data to AQI and transmits AQI with meteorological data and Air Quality forecast to FTP server of each city. FTP server then transmits the data to control server of DDS system which further transmits data to Digital Display Boards installed in each city. Entire system has following three components for all four SAFAR-Cities:

(i) Air Quality Monitoring System (AQMS): This system consists the Air Quality Walkway Shelters with different air quality analyzers, Calibration System, Zero Air Generator, Sampling System, UPS, ACs and control computer installed in the Shelter. The main control room computer receives data from all AQMS control computers in a particular city, Central Control Room Server at IITM, Pune and FTP server at each stations control room.

(ii) Digital Display System (DDS): It consists of LED and LCD digital display boards along with a control computer to receive data from FTP server and to transmit the same to display boards.

(iii) Automatic Weather Stations (AWS): AWSs have been installed in some cities adjacent to Air Quality Walkway Shelters with a computer in control room of respective city to receive data from different stations in a particular city and to transmit the received data to Central Control Server at IITM, Pune.

4.1 Maintenance and Calibration

- Maintenance of the all the equipment including Air quality Walkway Shelters, ACs, Furniture, PCs and control rooms is the responsibility of COMC service provider. All the spares and consumables are to be provided by the COMC service provider.
- Calibration: As per the SOP of instruments / analyser and guidelines provided by CPCB, a periodic calibration is the responsibility of COMC service provider. The calibration should be done (i) after any repairs or service or relocation that might affect its calibration, (ii) when there is prolonged interruption in operation, (iii) at some routine interval as specified by original manufacturer to identify early evidence of sensor drift. In addition, as and when IMD demands for calibration of any analyzer, vendor should provide the same without any extra cost. The method and frequency of calibration, indicated by CPCB, should be adhered to. Field calibration should be performed by a qualified calibration engineer on site.

Table-4.2: Details of the AQMS installed in Delhi

	Description / Model No	**Make**	**Quantity**
1	NOX Analyzer (Model 42i-B-Z-M-S-D-C-A)	ThermoFisher Scientific (TFS)	10
2	O3 Analyzer (Model49i-B-3-N-C-A)	TFS	10
3	CO Analyzer (Model 48i-Z-S-C-A)	TFS	10
4	PM 10 Continuous Ambient Particulate Monitor (SPM) with PM 10 Head (Model FH 62 C14 Series)	TFS	10
5	PM 2.5 Continuous Ambient Particulate Monitor (RSPM) with PM2.5 Head (Model FH 62 C14 Series)	TFS	10
6	Multipoint Calibrator for calibration (Model146i-B N-3-B-E-A-A)	TFS	10
7	Thermo Make CO2 Analyzer (Model 410i-B-Z-P-E-C-A)	TFS	10
8.	BTX-Analyser		05
8	Black Carbon Analyzer Model : AE31	Magee Scientific	05
9	Gas & Dust Sampling System	TFS	10
10	Zero Air Unit	TFS	10
11	(1) Cal. Gas cylinders with regulators; (2) 10 ltr. Water Capacity Aluminum Cylinder; (3) 47 ltr. water capacity CS Cylinder	TFS	10 10

	Description / Model No	Make	Quantity
12	Rack for Analyzers	TFS	10
13	Data Acquisition system for individual AQMS (PC)		10
14	GSM Modem with accessories		10
15	Spilt AC 2 Ton/ Hr Capacity		20
16	UPS 5 KVA Online UPS 4 hours back up for all analyzers		10
17	Central Data Acquisitions System (PC)	TFS	01
18	Data Acquisition software for individual AQMS	TFS	10
19	Data Acquisition software for central stations	TFS	02
18	High –Definition Multimedia Interface Movie Plus, Smart frame plus. Wide color enhancer software		02 01
19	Walkway Shelter (Environnement SA)		10

5. Relation between weather and pollutant concentration

The weather is one of the main factors affecting the air quality. Weather can help to clear away pollutants from atmosphere to improve air quality, or it can make air pollution extremely worse by helping to form highly polluted regions. The concentration of air pollutants in ambient air is governed by the meteorological parameters such as atmospheric wind speed, wind direction, relative humidity, and temperature.

- The stubble burning is common across northwestern India and neighbouring Pakistan during the October and November. The stubble burning also takes place during summer months of May and June but comparatively very small extent. The number of fire counts and prevailing wind direction influence the air quality over Delhi NCR.
- The mixing height and ventilation coefficient are important parameters to assess the dispersion of pollutant. Ventilation coefficient defined as the product of the mixing height (m) and the transport wind speed (m/s) is used as a tool for air quality forecasters to determine the potential of the atmosphere to disperse pollutants. There exist a negative correlation between PM concentrations and mixing boundary layer depth. The ventilation index lower than 6000 m^2/s with average wind speed less than 10 kmph is unfavourable for dispersion of pollutants.
- In summer, with an average PM2.5 of 40–100 $\mu g/m^3$, in addition to the road dust already present on Delhi roads, dust storms from the Thar Desert, to the southwest, contribute to increased fugitive dust. This is aggravated by the low moisture content

in the air, leading to higher resuspension (40-50% of PM in summer, compared to less than 10% in winter).

- In the winter months, with an average PM2.5 of ~100 - 200 μg/m^3, the use of biomass primarily for heating contributes to ~10-30% with most of the burning taking place at night, when the "mixing layer height" is low and further worsening the ambient concentrations. This emission source is difficult to incorporate in inventories which lead to under-estimation of model forecast concentration. When night temperature is low this should be taken into account while preparing bulletin.
- Stagnant weather conditions (eg, low wind speeds, descending air, and low boundary layer) favour accumulation of pollutants. On the other hand, in the presence of a strong pressure gradient, prevailing wind speeds increase and, as a result, dust resuspension occurs and PM10 concentration increases.
- Higher air pollution is known to be associated with anticyclonic conditions, and conversely, cyclonic conditions are associated with lower air pollution. Anticyclones are characterized by surface-air flow outward from the high-pressure center and subsiding air from an overlying atmosphere. Due to this subsidence, the skies are typically clear, with minimal precipitation and increased stability. These factors inhibit dispersion and promote accumulation of air pollutants. Stagnation episodes, often associated with anticyclones, tend to favour pollutant accumulation.
- On the other hand, low-pressure cyclonic systems exhibit ascending air flows, frequently accompanied by cloudy skies and precipitation, associated with strong winds and are fast moving. All these weather conditions result in lower concentration of pollutants.
- Rainfall can effectively remove atmospheric particulate pollutants, and the removal rate of PM10 is greater than the removal rate of PM2.5.
- The reactions that create harmful ozone in our atmosphere require sunlight. In the summers and especially during extreme heat waves, ozone often reaches dangerous levels in cities or nearby rural areas. The photochemical reactions for ozone formation or destruction decline rapidly at night-time resulting in lower levels of ozone at night. Ozone can accumulate when there are high temperatures, which enhance the rate of ozone formation and stagnant air. The often cloudless and warm conditions associated with large high-pressure systems also are favorable for the photochemical production of ozone. Heat waves often lead to poor air quality. The extreme heat and

stagnant air during a heat wave increases the amount of ozone pollution and particulate pollution.

- Western disturbance particularly in winter season significantly impact the air quality. The approach of WD is characterized by rise in minimum temperature and occurrence of rainfall. Once the WD crosses a place then minimum temperature starts dropping.The formation of fog starts and slowly the cold wave occurs spreading to southwards in the country.
- Wind-blown dust: In general windspeed more than 7 m/s can lift dust. Heavier particles will settle near the source area, with the smaller ones settling farther away.

6. Air Quality Early Warning System

Short-term air quality forecasts can provide timely information about forthcoming air pollution episodes that the decision-makers can use to reduce public exposure to extreme air pollution events. In this perspective, the Air Quality Early Warning System (AQ-EWS) has been developed under the aegis of Ministry of Earth Sciences, jointly by Indian Institute of Tropical Meteorology (IITM), Pune, India Meteorological Department, and National Centre for Medium-Range Weather Forecasting (NCMRWF). The System is designed to predict air pollution events and give alerts to take necessary steps for air pollution control. The Early Warning System consists of:

a) Air Quality forecast for Delhi region for 3-days and outlook for next 7-days from different air quality prediction systems based on state-of-the-art atmospheric chemistry transport models
b) Air Quality Forecast for entire India and specifically for several non-attainment cities
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) Generation of Warning Messages, Alerts and Bulletins for Air Quality and Weather.
g) Forecast of the contribution of non-local fire emissions,
h) Weather Information
i) Day to day verification of forecast product.
j) The Air Quality information is disseminated through website https://ews.tropmet.res.in. The link of the website is provided on IMD website also.

6.1 Air Quality Prediction Models

There are different Air Quality Prediction Models operationally run under the air quality early warning system (AQ-EWS)

(i) Weather Research and Forecasting model coupled with chemistry (WRF-Chem)

(ii) System for Integrated modeLling of Atmospheric composition (SILAM)

(iii) High resolution model ENvironmental information FUsion SERvice (ENFUSER)

(iv) NCMRWF Unified Model (NCUM) Dust-Forecast

(v) HYSPLIT Backward and Forward Trajectories

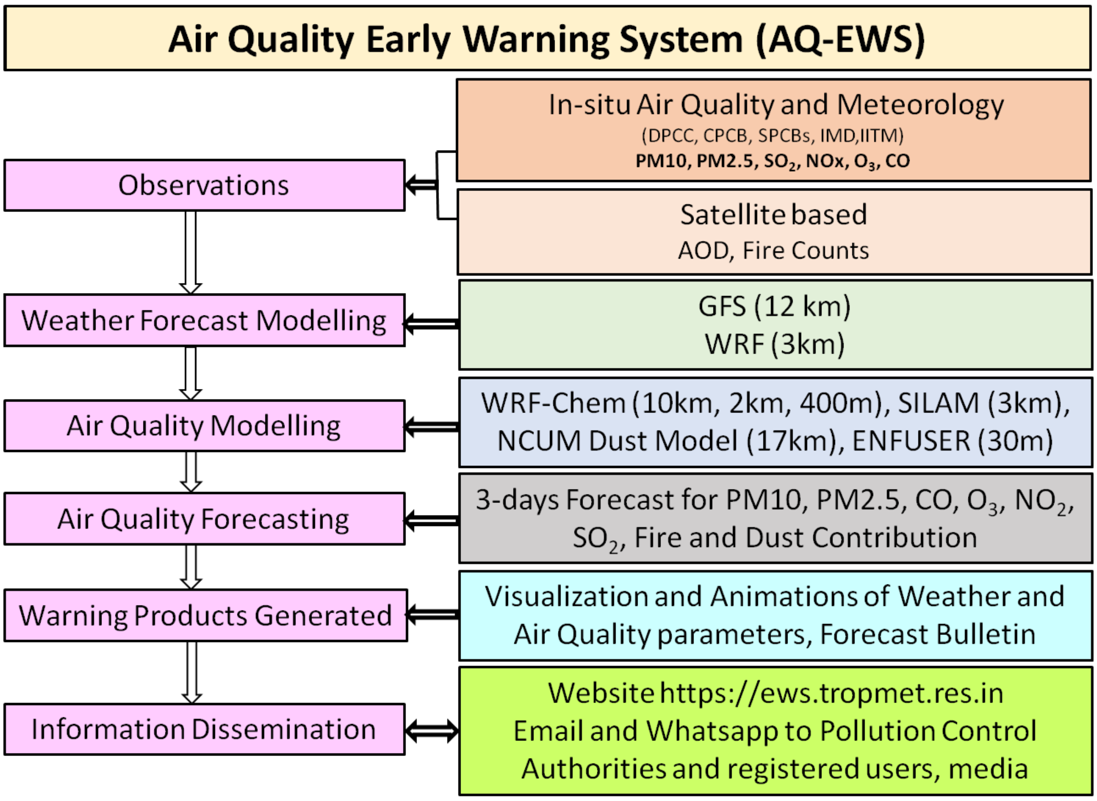

Figure-6.1: General Schematic of the Air Quality Early Warning System

6.1.1 System for Integrated modeLling of Atmospheric coMposition (IMD SILAM)

System for Integrated modeLling of Atmospheric coMposition (SILAM) is a global-to-meso-scale dispersion model developed for atmospheric composition, air quality, and emergency decision support applications, as well as for inverse dispersion problem solution.

The model incorporates both Eulerian and Lagrangian transport routines, 8 chemico-physical transformation modules (basic acid chemistry and secondary aerosol formation, ozone formation in the troposphere and the stratosphere, radioactive decay, aerosol dynamics in the air, pollen transformations), 3- and 4-dimensional variational data assimilation modules. SILAM source terms include point- and area- source inventories, sea salt, wind-blown dust, natural pollen, natural volatile organic compounds, nuclear explosion, as well as interfaces to ship emission system STEAM and fire information system IS4FRIES.

The regional SILAM model generates 3 days forecasts over a domain covering whole India at 3 km horizontal resolution. The meteorological forcing is provided from the operational 3 km WRF model. The initial condition is derived from the forecast of the previous cycle of regional SILAM model and boundary condition is supplied from global version of the model. The SILAM model setup for India is as follows:

Running:

- Hourly AQ Forecast of all criteria pollutants (PM10, PM2.5, O3, CO, NOx, SO2 and other species) for 72 hours.
- Domain: 60-100E, 0-40N, 3km x3km grid, 15 hybrid layers up to ~10km (~270hpa).

Driving Meteorology:

- Hourly 3-km WRF forecasts (IMD)

AQ Boundary conditions:

- 3 hourly SILAM Global Suit forecasts

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 mono-terpene.
- Natural (dynamic): Silam desert dust, Silam sea salt, Silam marine DMS.
- Delhi 400m emissions

Aerosol Process:

- Simple equilibrium scheme for secondary inorganic aerosols, Volatile Basis-Set (VBS) for secondary organic aerosol module
- CBM5 chemistry supplemented with secondary organics, DMAT_SULPHUR sulphur oxidation.

Validation

- In-situ air quality data from SAFAR, CPCB, DPCC and SPCBs

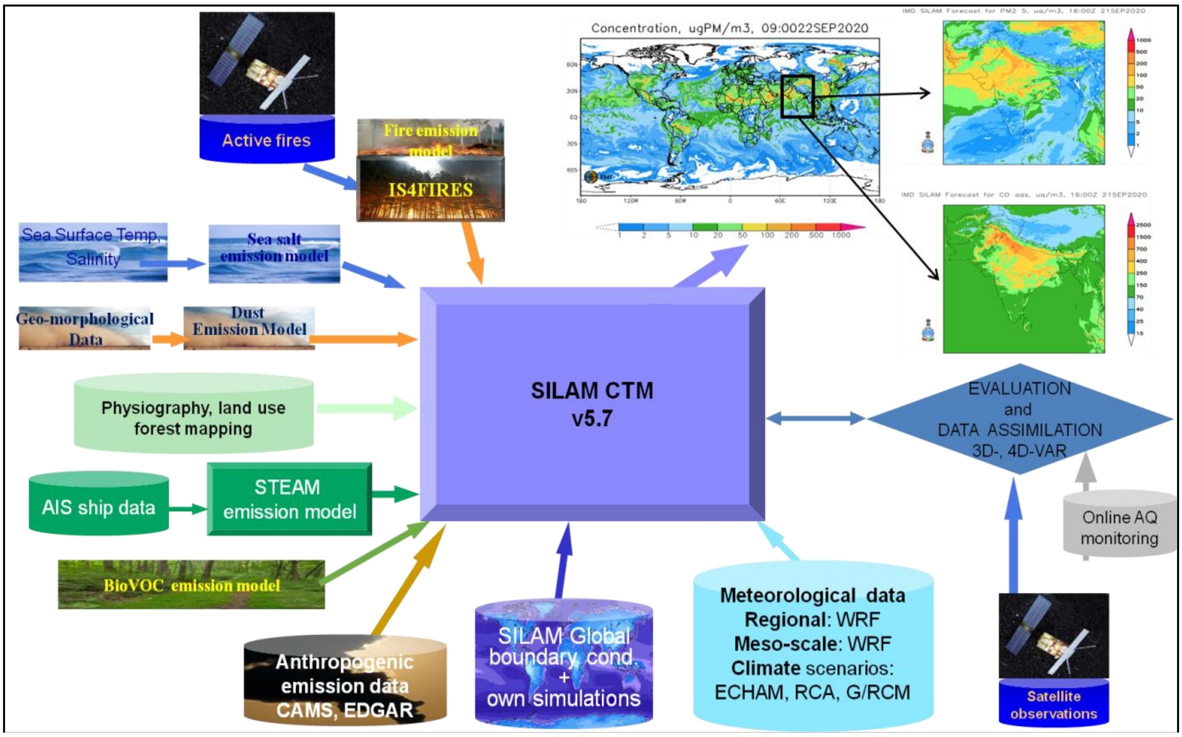

Figure-6.2: Schematic diagram of IMD SILAM

6.1.2 WRF-Chem (MoES-UCAR joint activity)

This modeling framework consists of a high-resolution fully coupled state-of-the-science Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) and three-dimensional Variational (3DVAR) framework of the community Gridpoint Statistical Interpolation (GSI) system, which assimilate data from satellites at 3 km resolution on aerosol optical depth, surface data from more than 260 air quality monitoring stations in India and high-resolution emissions from various anthropogenic and natural sources including dust and stubble burning. Forecast of the contribution of non-local fire emissions to the air quality in Delhi is also generated. The warning system also provides an air quality forecast for a few more cities in the northern region of India at 10 km resolution. The website also shows forecast verification for Delhi on a daily basis.

- The model is being run by IITM
- The chemical data assimilation system is based on Gridpoint Statistical Interpolation (GSI) system.
- Aerosol Optical Depth (AOD) retrieved from Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Tera and Aqua are assimilated.

- Terra AOD is assimilated at 06 UTC and Aqua AOD is assimilated at 09 UTC.

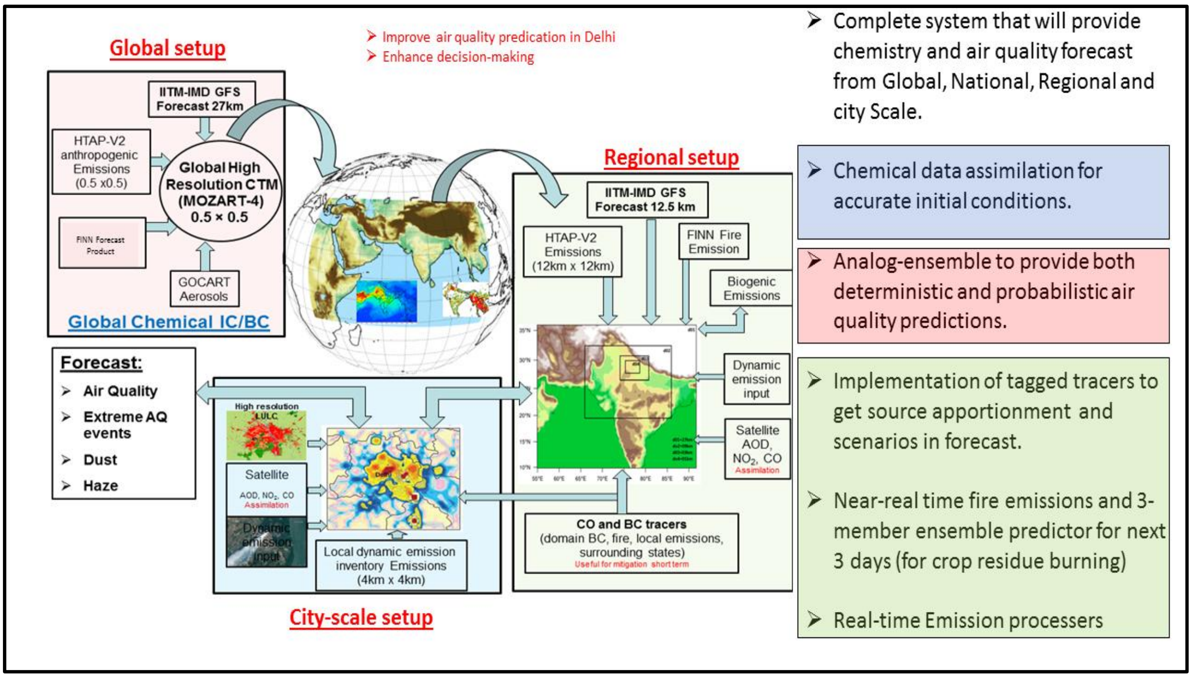

Figure-6.3: Schematic diagram of WRF-Chem

- 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)
- High resolution land surface data assimilation (HRDAS)
- A background error covariance matrix incorporating uncertainties in both anthropogenic and biomass burning emissions is generated.
- 100% uncertainty is assumed in anthropogenic and biomass burning emission sources following the literature.
- An observations preprocessor for MODIS collection 6.1 is developed.
- 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

6.1.3 Description of FMI-IMD ENFUSER

ENvironmental information FUsion SERvice (ENFUSER) is an operational, adaptive local-scale dispersion model. Technically, the model is a combination of Gaussian Puff and Gaussian Plume –style of dispersion modelling that utilizes measurement data to perform data fusion. The long-range transportation of pollutants are handled in the model by nesting the local-scale modelling on a regional-scale mode concentration fields. The aim of the data fusion is to adapt the dispersion modelling on an hourly basis to gain higher level of agreement with measurements; technically this is done by modifying emission factors for known sources and adjusting background concentrations, while simultaneously benchmarking measurement reliability. Further, on a longer term analysis period more realistic parametrization for emission sources can be obtained via the data fusion process, which after a while begins to show distinguishable trends and patterns for emission factors.

In addition to traditional dispersion model inputs, the ENFUSER uses and assimilates a large amount of Geographic Information System data (GIS) to describe the modelling area on a high resolution. This includes detailed description of the road network, buildings, land-use information, high-resolution satellite images, ground elevation and population data.

6.1.3.1 ENFUSER setup at IMD

FMI-IMD ENFUSER is set to model the Delhi as defined in Table-6.1 below and the overall configuration has been illustrated in the Figure-6.4 below.

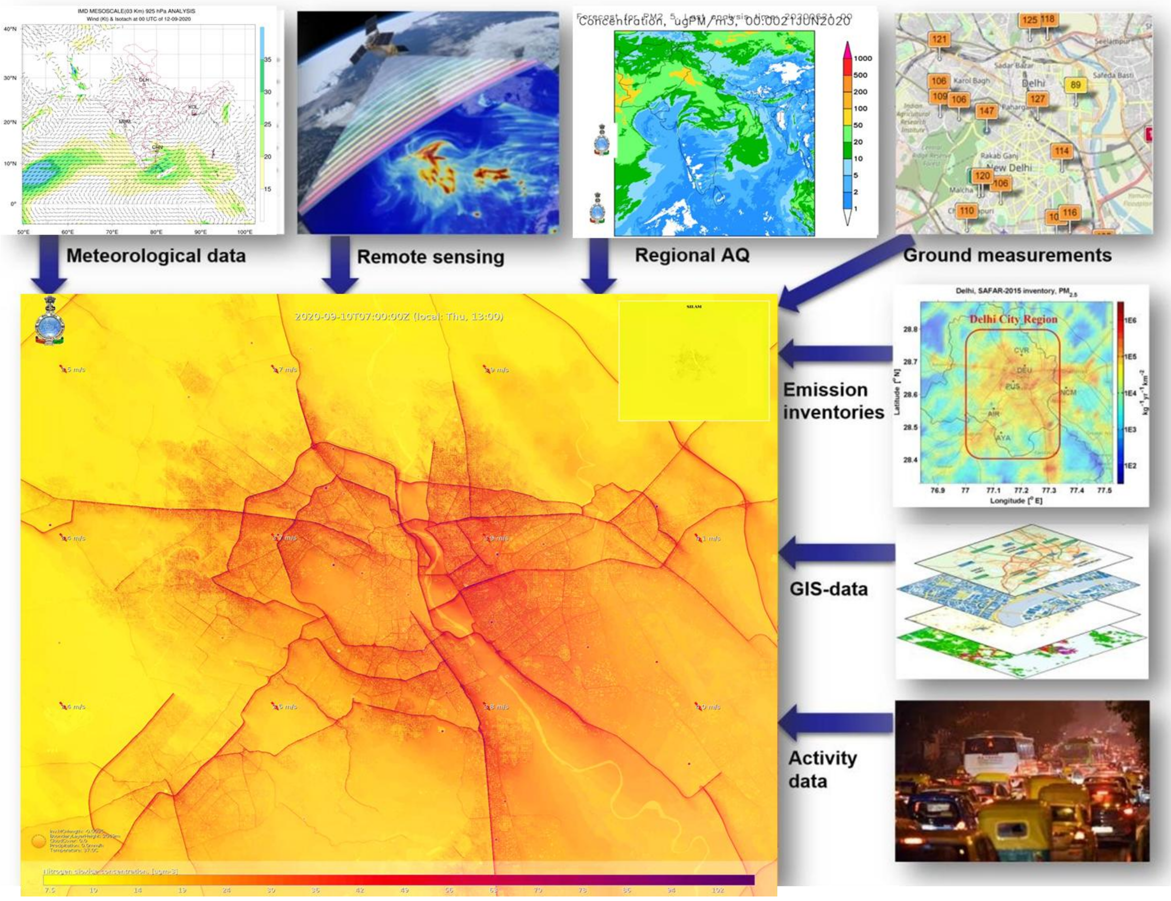

Figure-6.4: The ENFUSER modelling concept

Table-6.1: The main details of the installed ENFUSER configuration at IMD.

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

6.1.3.2 Static Data - GIS

ENFUSER operates with a static model of the area as a basis for the modelling, i.e. data from various sources about terrain, population, infrastructure and land-use. For automatic processing and extraction of such information ENFUSER uses a built-in tool called the “mapFUSER” shown in Figure-6.5. The basic principle of the mapFUSER is to collect core (“Level 1”) GIS data for the target area (Delhi) and combine the information to create derivative datasets (Level 2 and 3) also to be used in the modelling. Examples of these datasets and their processing levels are presented in Table-6.2.

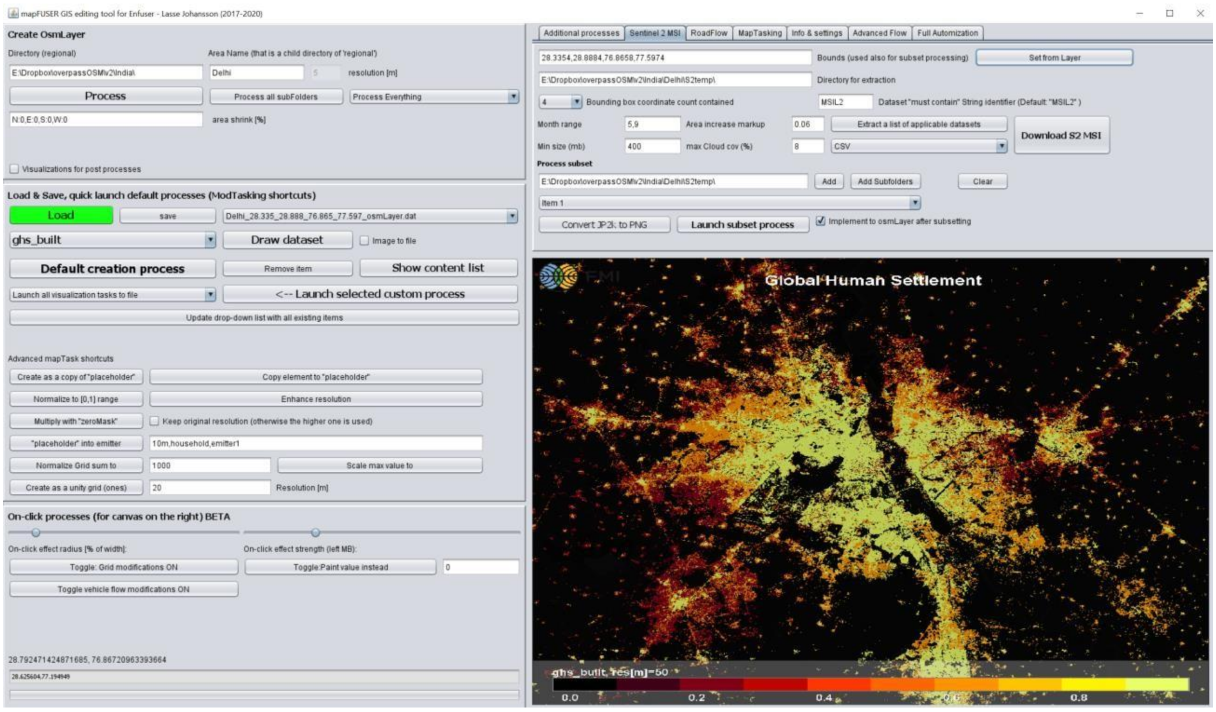

Figure-6.5: The mapFUSER program for the creation and editing of GIS-data

Table-6.2: mapFUSER datasets, default resolutions, sources of information and processing levels. A higher processing level means that the creation of the dataset relies on lower level datasets.

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

6.1.3.3 Static Data – Emissions

The key emission inventory used in the modelling is the SAFAR emission inventory provided by IMD as a text file (400x400m data). For ENFUSER this information has been converted into netCDF format. However, since the model requires some specific emission sources to be presented in greater detail than can be derived from the inventory, there are some exceptions:

(i) ENFUSER has its own traffic emission model that uses OpenStreetMap road network for Delhi and an associated traffic flow model to the roads

(ii) Thermal power plants are treated as elevated point sources (and not as gridded inventory) and the base source for information is the Global Energy Observatory.

(iii) Brick kiln –industry has been preliminarily mapped in higher detail[1] than it is available in the SAFAR-inventory and is modelled as a separate source of interest.

(iv) Aviation, based on OpenSky-activity data, processed into line-sources.

(v) Some notable dump-yards in Delhi are modelled as point sources.

6.1.3.4 Dynamic Data

To facilitate the modelling, a separate instance of ENFUSER is running in the background, continuously extracting online information (i.e, "DataMiner"). The DataMiner has a number of data "feeds" which download dynamic data for the model from different online sources and stores local files for the model to access.

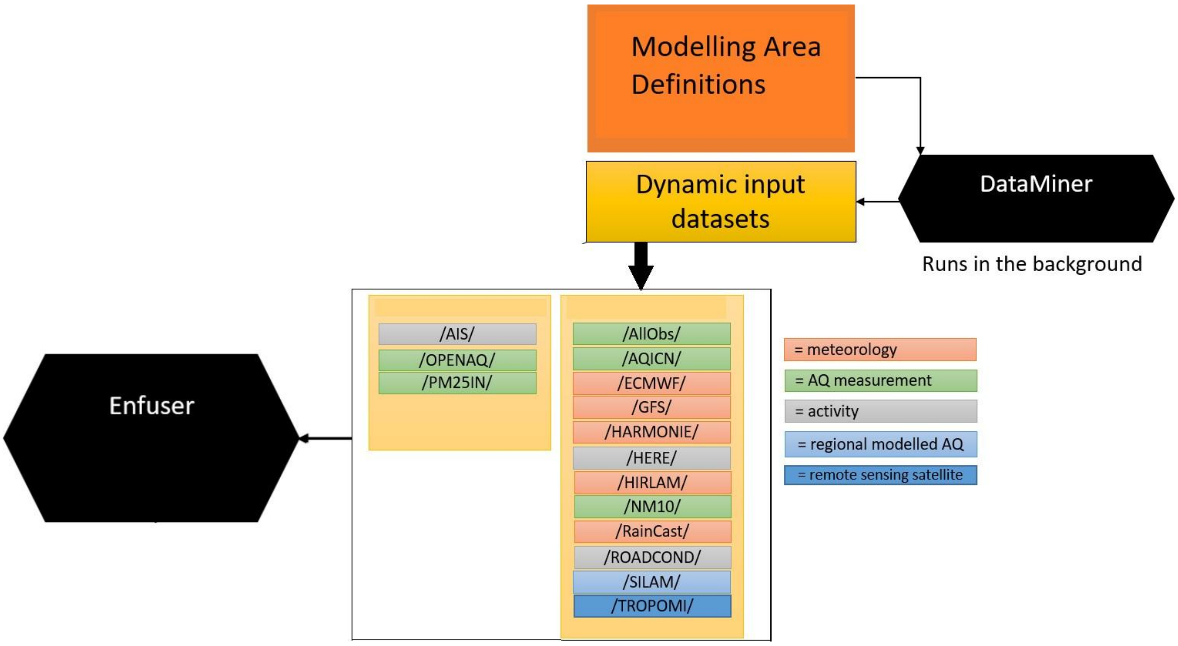

Figure-6.6: The basic principle of mining dynamic input data for the mode

The precise setup of the DataMiner varies from installation to installation, depending on the geographical area. Most ENFUSER installations still share many of the information feeds regardless of the modelling area, however.

Currently the feeds in the ENFUSER installation at IMD are as follows:

- **WRF/GFS:**

  At the moment this feed with WRF data (3km x 3km resolution) is in use but can also be substituted with GFS data of IMD.

- **SILAM:**

  ENFUSER natively tap in to the operative IMD regional SILAM access point.

- **Traffic Congestion Data**

This feed obtains real-time traffic congestion data from https://www.here.com for Delhi. These data can be used to modify traffic flow speeds in Delhi in real time, thereby affecting the modelled traffic emissions. It can also be used to characterize traffic patterns in Delhi when properly analysed over a longer period of time.

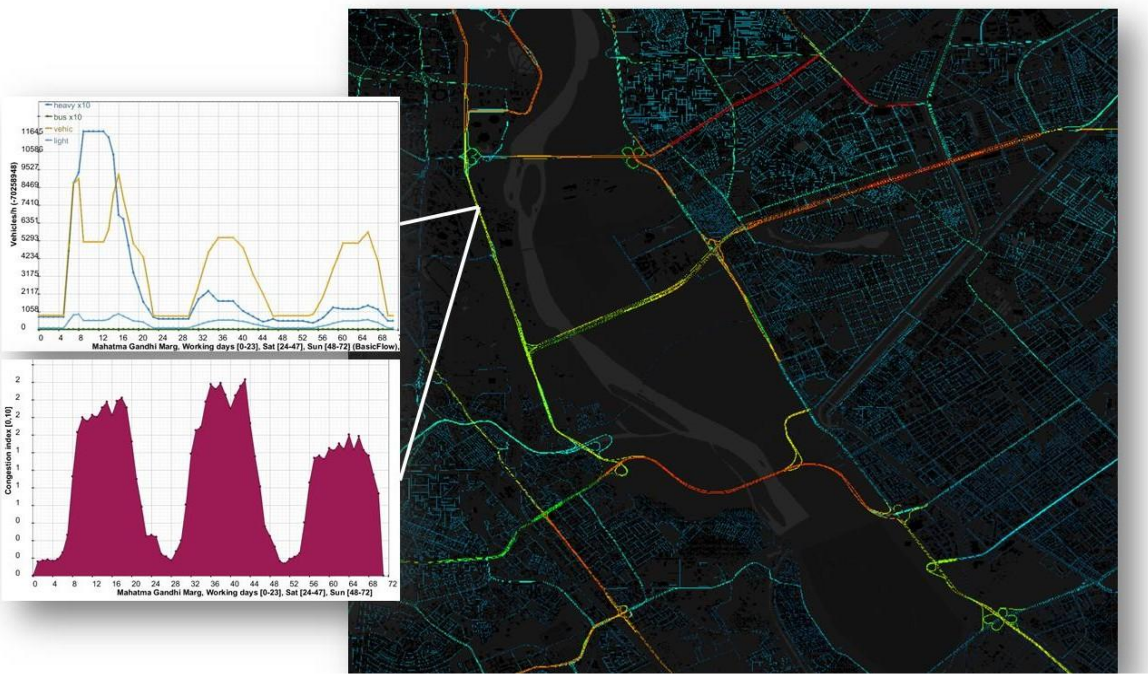

Figure-6.7: HERE-congestion profile (visualized by mapFUSER) for a selected road in Delhi (Mahatma Gandi Marg). Traffic congestion data such as this can be used for a) emission factor adjustments and b) as input for deep learning –estimated traffic flow patterns.

- **TROPOMI:**

This feed downloads data from Copernicus ESA SENTINEL 5P Tropomi satellite pollutant total column concentration data: https://sentinel.esa.int/web/sentinel/missions/sentinel-5p/data-products/. TROPOMI-data does not currently contribute to the operational use of the model due to it nature (total column concentration), resolution (7x4km) and data availability (once per day). However, it makes setting up the model easier since it is possible to see the pollution hotspots in the area.

- **OPENSKY:** This feed downloads air traffic data from https://opensky-network.org/
- **DELHIAQ:** This is a custom feed for downloading data from AQMSs in Delhi via EMRC FTP server. For Delhi, this source of information is able to provide measurements from approx. 40 reference stations.
- **OPENAQ:** This feed extracts measurement data from a global, open access source of information. This is to be used only when DELHIAQ are unable to provide measurement data.
- **BLview/Ceilometer:** Boundary layer height (BLH) information can be optionally fed to the modelling system, however, the local access for this kind of data needs to be provided in proper format.

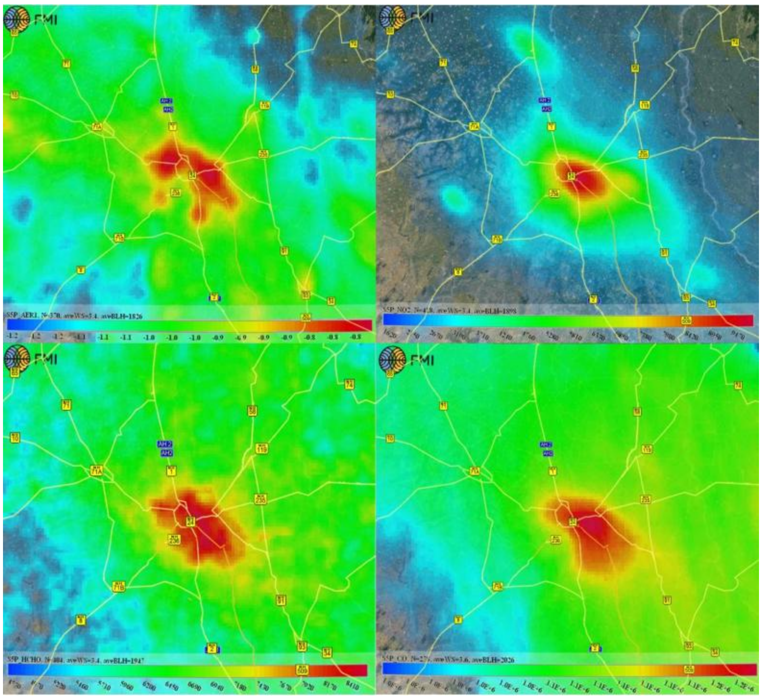

Figure-6.8: Assimilated S5P TROPOMI total column -concentrations for a) Aerosol index (up, left), NO2 (up, right), HCHO (down, left) and CO (down, right). ENFUSER was used to assimilate the data, using 300 to 400 daily S5P snapshots.

6.1.3.5 Technical details

An AOT (ahead-of-time) compiled binary of the Java application has been installed on a Workstation PC at EMRC, IMD. The system uses Linux OS, has a twelve core Intel(R) Xeon(R) Silver 4214 CPU @ 2.20GHz and 96 GB of RAM.

The installation has been set for several modelling runs per day (run as “cron jobs”), currently three times, however, the frequency of model runs can be easily modified by system manager as well as the overall modelling time span can be modified freely. Currently, each modelling task run has been seen to take approx. 2 hours (including the creation of visualizations). Each model run creates a log-file that describes detailed information on the health and events occurred during the modelling run task. Each model run will archive the modelling output on an hourly basis in a compact and permanent local file storage. In addition, each model run optionally creates larger netCDF-files (whole modelling time span), animation videos and figures for all pollutant species modelled. Regarding the measurements that were used during the modelling task (data fusion) a thorough statistical summary (as CSV) is also stored in a permanent archive for later reference and longer-term statistical analysis works.

6.1.3.6 Backward and Forward Trajectories

HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) transport model can be used to estimate the forward or backward trajectory of an air mass. The model has been developed by National Oceanic and Atmospheric Administration (NOAA), Air Resources Laboratory (ARL). Back trajectory analysis is helpful for ascertaining the origins and sources of pollutants, which makes is most useful for air quality forecasting. Forward trajectory analysis is helpful for determining the dispersion of pollutants. Trajectories are applied in various fields such as climatology, meteorology, transport of pollutants, residence time analysis, air quality, source apportionment, aerosol measurements, precipitation chemistry etc.

In meteorological terms, a trajectory is the time-integration of the change in position of an air parcel as it is transported by the wind. Air mass trajectories are typically calculated in a backward mode (path of air movement arriving at a receptor location) or forward mode (path of air movement leaving from a source location). Backward trajectories have been used to explore predominant source regions of particulate matter and regional haze for various receptor locations and time periods and to establish typical flow patterns and transportation ranges. When calculating trajectories, computational methods use (1) IMD WRF model-derived wind data to compute horizontal components, and (2) either isobaric, kinematic or isentropic methods to determine the vertical components of the trajectory. The isobaric and isentropic approaches assume that the trajectory remains on surfaces of constant pressure and constant potential temperature, respectively, whereas the kinematic approach assumes that the trajectory moves with the vertical wind fields generated by a diagnostic or prognostic meteorological model. The kinematic approach has been found to be preferable for trajectory modelling over Asian region. The model calculation method is a hybrid methodology between the Lagrangian approach (using a moving frame of reference as the air parcels move from their initial location) and the Eulerian approach (using a fixed three-dimensional grid as a reference frame). In the model, advection and diffusion calculations are made on a Lagrangian framework to describe the transport of the air parcel and trajectories, while a fixed grid is used to calculate pollutant concentrations.

The model uses previously gridded meteorological data. The meteorological data used by HYSPLIT is gridded four-dimensional (x, y, z, t) meteorological fields output as analysis or forecast wind fields from the IMD WRF (3 km resolution). The HYSPLIT model has been installed on a computer and run locally. HYSPLIT backtrajectories from multiple heights are often run to capture the effects of vertical variation of horizontal winds within the mixed layer depth. Sample backward trajectories of New Delhi station with multiple start height obtained from HYSPLIT system are shown in Figure-6.9.

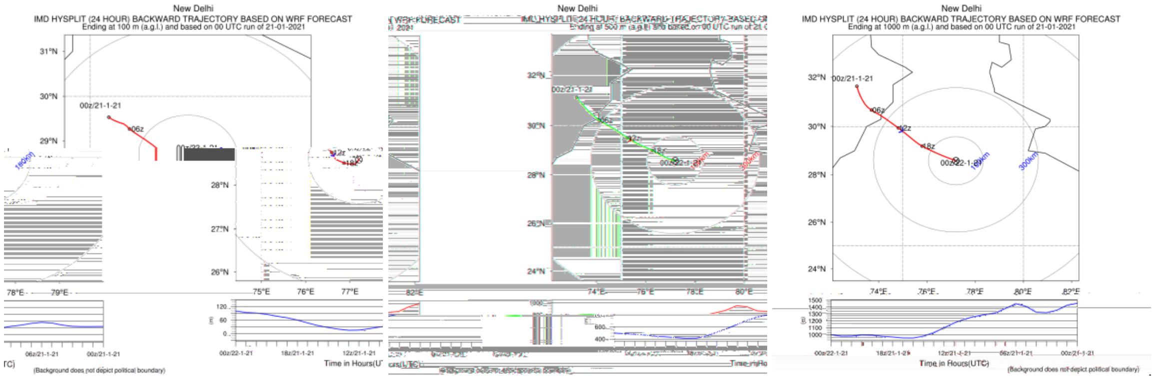

Figure-6.9: IMD HYSPLIT Backward Trajectories at 100m, 500m and 1000m above ground level based on WRF Forecast

6.1.4 System of Air Quality and Weather Forecasting and Research (SAFAR)

System of Air Quality and Weather Forecasting and Research (SAFAR) was introduced by MoES to provide location specific information on air quality in near real time and its forecast upto 3 days in India. The SAFAR system is developed by Indian Institute of Tropical Meteorology (IITM), Pune, along with India Meteorological Department (IMD) and National Centre for Medium Range Weather Forecasting (NCMRWF). The implementation of SAFAR is made possible with an active collaboration with local municipal corporations and various local educational institutions and governmental agencies in Delhi, Pune, Mumbai and Ahmedabad. The objective of the project is to increase awareness among general public regarding the air quality changes in their city well in advance so that appropriate mitigation measures and systematic action can be taken up for betterment of air quality and related health issues.

The SAFAR project involves four components to facilitate the current and advance forecasting, namely:

(i) Development of the high-resolution emission inventory of air pollutants for NCT and in cities of Pune, Mumbai and Ahmedabad.

(ii) Establishment of a network of Air Quality Monitoring Stations (AQMS) equipped with Automatic Weather Stations (AWS) to monitor and provide air pollutant information and weather parameters 24x7 over Delhi. The continuous data monitoring has a vital role in validation of model output and its incorporation in forecast model.

(iii)The 3-D atmospheric chemistry transport forecasting model coupled with weather forecasting model to provide air quality forecasts. Weather plays a major role in the transport of pollutants from the sources and to the ambient concentrations.

(iv)Dissemination of the information and reaching the general public. The data are translated into a public friendly format in the form of AQI for India and then displayed via LED and LCD screens located at different locations in Delhi.

The data collected from the monitoring network is a major input for the forecasting model along with the emission inventory. After running the 3D atmospheric chemistry transport model, results are transferred to the IITM Data server. Once the near real-time and forecasted data are checked for quality assurance, it is transferred to the display server after converting to AQI.

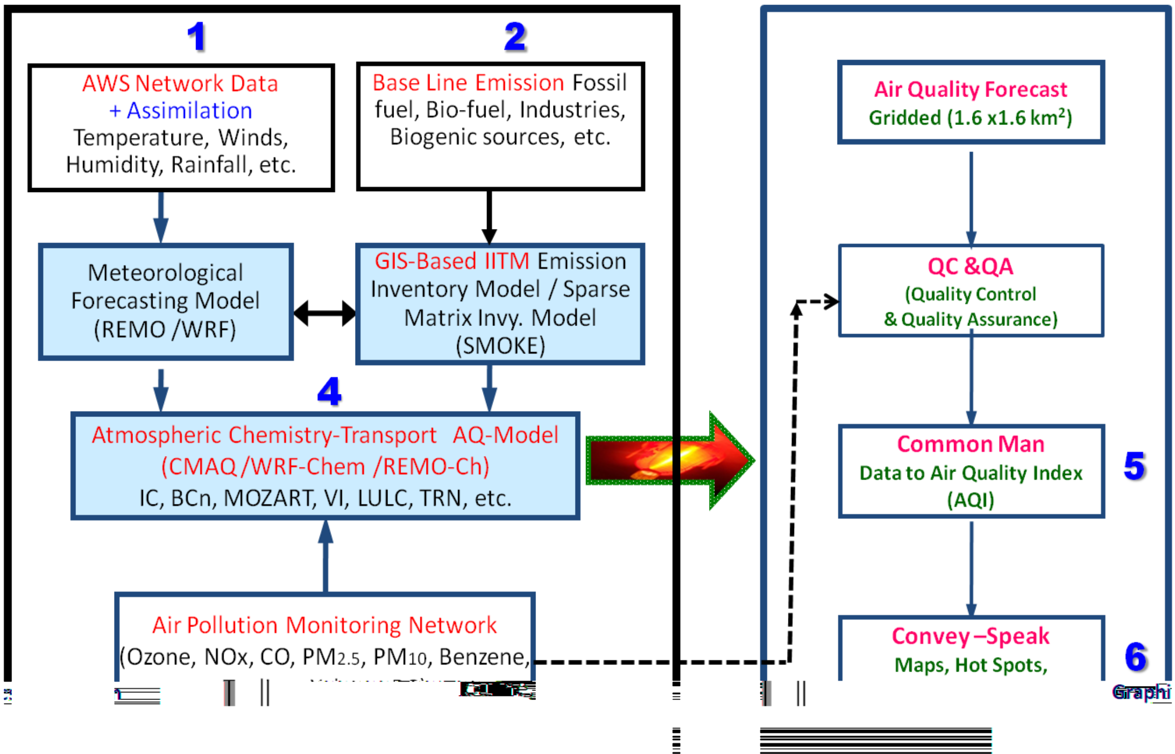

Figure-6.10: System of Air Quality Forecasting And Research (SAFAR) setup

7. Preparation of Daily Air Quality and Weather Bulletin

The daily Air Quality and Weather Bulletin is prepared, once in the morning and another in afternoon.

a) Air Quality and Weather Prediction for 3 Days and outlook for weather and air quality event for next seven days.
b) Meteorological Forecast for next 7 days: Wind direction and windspeed, Temperature, Relative Humidity, Rainfall and Weather events
c) Diagnostic Products:
   (i) Mixing Height and Ventilation Forecast from GFS model (10 Days)
   (ii) Airmass Trajectories: Forward and Backward using HYSPLIT model
d) Satellite Images:
   (i) Dust Transport (During summer or when dust transport is expected)
e) Meteogram/EPSgram (10 Days) Wind, RH, Rainfall
f) Fire Counts during Post-monsoon, Winter and Summer

7.1 Source of Forecasting Products and Information

a) Weather Forecast (Wind direction and windspeed, Temperature, Relative Humidity, Rainfall and Weather events):
   The forecast is available on http://rmcnewdelhi.imd.gov.in

b) The current AQ information is available at CPCB website
   https://app.cpcbccr.com/ccr/#/dashboard-emergency-stats
   The current AQ is also available on https://ews.tropmet.res.in. The near real time air quality data are being received at EMRC ftp server for use in AQ models.

c) Following products are available on https://ews.tropmet.res.in under the Tab 10 Days Forecast

   (i) Mixing Height and Ventilation Forecast from GFS model (10 Days)

   (ii) Air Quality Forecast:- Under the Tab Analysis, see AQI for PM2.5 and PM10

   (iii) Meteogram/EPSgram (10 Days)

d) The Backward and Forward Trajectories are available at http://nwp.imd.gov.in/hysplitproducts.php

e) Fire Counts from MODIS and VIIRS https://firms.modaps.eosdis.nasa.gov/map/
Fire counts are also available on EWS website.

7.2 Air Quality Forecast Dissemination

The Air Quality information is disseminated through website https://ews.tropmet.res.in
The link of the website is provided on IMD website also.
The Air Quality Bulletin is sent to following officials daily:

(i) Commission for Air Quality Management (C-AQM)
(ii) Central Pollution Control Board (CPCB)
(iii) Ministry of Environment, Forest & Climate Change (MoEFCC)
(iv) Delhi Pollution Control Committee (DPCC)
(v) State Pollution Control Board in Delhi NCR region (Regional Office: Noida, Ghaziabad, Faridabad, Gurugram, Ajmer, Jaipur, Punjab)
(vi) NWFC, RMC, New Delhi
(vii) Registered Users

Also, the forecast bulletin is sent to PMO and other higher officials only on instruction of Secretary, MoES and DGM.

8. Contact Details of EMRC/NWP Officers:

Dr. Vijay Kumar Soni, Head, Environment Monitoring and Research Center (EMRC), Room No. 609, SatMet Building India Meteorological Department Ministry of Earth Sciences, Mausam Bhawan, Lodi Road, New Delhi-110003	vijay.soni@imd.gov.in soni_vk@yahoo.com 01143824440 (O) 01124646339 (O)
Dr Anand Kumar Das Scientist-E, NWP	akuda.imd@gmail.com 01143824266(O)
Dr. Chinmay Jena Scientist-C, EMRC	Chinmay.jena@imd.gov.in
Mr. Sanjay Bist Scientist-E, EMRC	sanjay.bist@imd.gov.in

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Annexure-I

Example

Air Quality and Weather Bulletin for Delhi NCR (Date DD.MM.YYYY Morning/Afternoon)

1. As per AQ-EWS models the air quality over Delhi NCR is likely to remain in Poor category on 29.06.2020. The PM10 is the predominant pollutant due to dust raising winds. The air quality is likely to improve marginally but remain in Moderate category on 30.06.2020. The air quality is likely to improve further but remain in Moderate to Satisfactory category on 01.07.2020.

2. The predominant surface wind is likely to be coming from Northwest direction of Delhi having wind speed up to 15 kmph with partly cloudy sky and light rain/thundershowers towards evening/night on 29.06.2020. The predominant surface wind is likely to be coming from East direction of Delhi having wind speed up to 15 kmph with partly cloudy sky and very light rain/thundershowers on 30.06.2020. The predominant surface wind is likely to be coming from Southeast direction of Delhi having wind speed up to 15 kmph with partly cloudy sky and possibility of thundery development on 01.07.2020.

3. Predicted maximum mixing depth is likely to remain from 3900 m on 29.06.2020, 3800 m on 30.06.2020 and 4300 m on 01.07.2020 over Delhi. Ventilation index is likely to be 23000 m^2/s on 29.06.2020, 17000 m^2/s on 30.06.2020 & 29000 m^2/s on 01.07.2020. The ventilation index lower than 6000 m^2/s with average wind speed less than 10 kmph is unfavourable for dispersion of pollutants.

4. Strong surface winds are likely to impact dust concentration over Delhi NCR. Dust transport from Rajasthan and adjoining Pakistan is also likely to impact air quality on 29.06.2020.

5. Location specific AQ forecast can be seen at safar.tropmet.res.in. Detailed forecast analysis and verification can be seen at https://ews.tropmet.res.in.

6. Air mass inflow in Delhi along with ventilation index is attached.

Dated: 17 November 2019 **Time of Issue 1100 IST**

DELHI WEATHER FORECAST FOR NEXT SEVEN DAYS

DATE	Temp (°C)		Direction/ Wind Speed (Kmph)			WEATHER FORECAST
	MAX	MIN	0530-1130 (IST)	1130-1730 (IST)	1730-2330 (IST)	
17.11.2019	28	16.2	NW/12	NW/25	WNW/15	Mainly clear sky. Strong surface winds during the day (speed 25-30 kmph).
18.11.2019	27	15	WNW/12	WNW/20	W/10	Partly cloudy sky. Strong surface winds during the day (speed 15-20 kmph).
19.11.2019	27	13	WNW/10	NW/12	NNE/08	Mainly clear sky. Shallow fog in the morning.
20.11.2019	27	12	CALM/00	NE/06	E/10	Partly cloudy sky. Moderate fog in the morning.
21.11.2019	28	13	E/08	ESE/10	E/10	Partly cloudy sky. Shallow to moderate fog in the morning.
22.11.2019	28	14	E/08	WNW/08	CALM/00	Partly cloudy sky. Shallow fog in the morning.
23.11.2019	27	15	NW/08	NW/10	NW/12	Partly cloudy sky. Shallow fog in the morning.

TEMPERATURE NORMALS		
DATE	MAX	MIN
17TH NOV TO 21ST NOV	27.8	12.4
22ND NOV TO 26TH NOV	26.5	12.4

LEGEND

RAINFALL INTENSITY

Terminology	Rainfall Range in mm	Terminology	Rainfall Range in mm
Very Light Rainfall	Trace – 2.4	Heavy Rainfall	64.5 – 115.5
Light rainfall	2.5 – 15.5	Very Heavy Rainfall	115.6 – 204.4
Moderate Rainfall	15.6 – 64.4	Extremely Heavy Rainfall	>= 204.5

CLOUD AMOUNT

Terminology	Amount of Cloud in Octa
Clear Sky	0
Mainly clear sky	1 - 2
Partly cloudy sky	3 - 4
Generally cloudy sky	5 - 7
Overcast	8

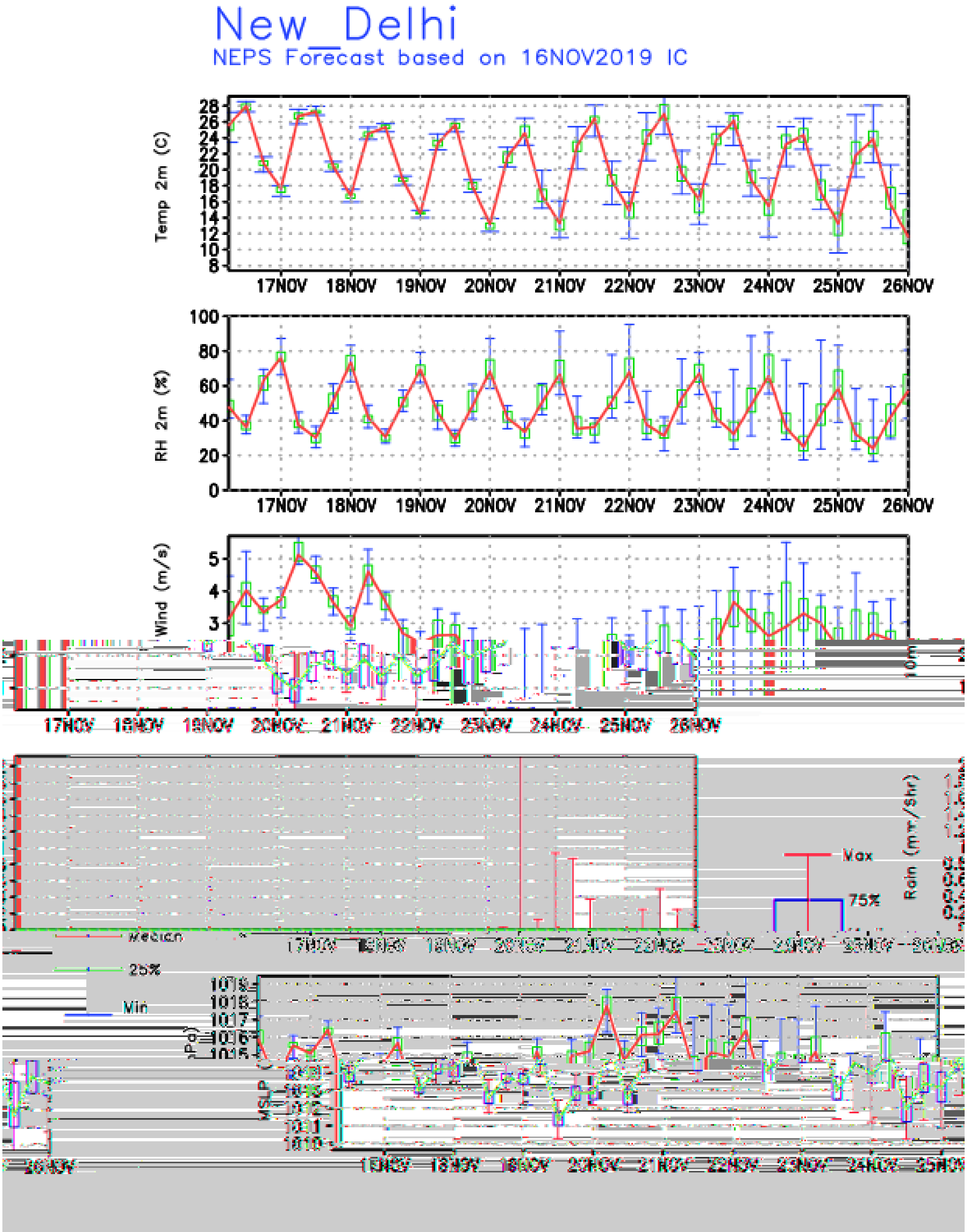
PROBABILISTIC FORECAST

Terms	Probability of Occurrence (%)
Unlikely	<25
Likely	25 - 50
Very Likely	50 – 75
Most Likely	>75

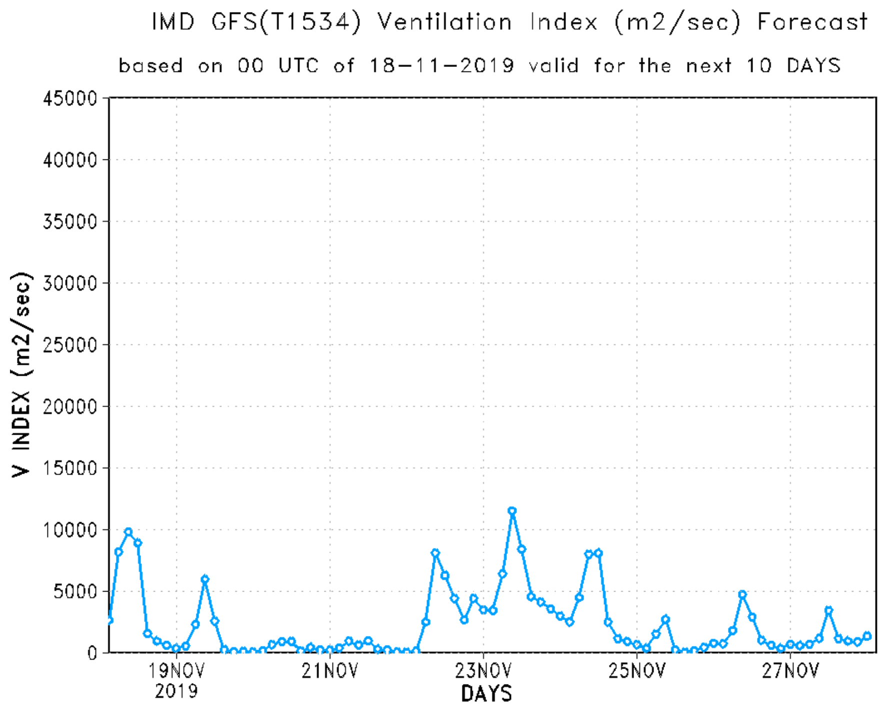
WIND DIRECTION (WIND COMING FROM)

CALM	No Wind is Blowing		VRB	Variable wind (direction cannot be determined)
NNE	North-North Easterly wind		SSW	South-South Westerly Wind
NE	North Easterly wind		SW	South Westerly Wind
ENE	East-North Easterly wind		WSW	West-South Westerly Wind
E	Easterly wind		W	Westerly Wind
ESE	East-South Easterly wind		WNW	West-North Westerly Wind
SE	South Easterly wind		NW	North Westerly Wind
SSE	South-South Easterly wind		NNW	North-North Westerly Wind
S	Southerly wind		N	Northerly wind

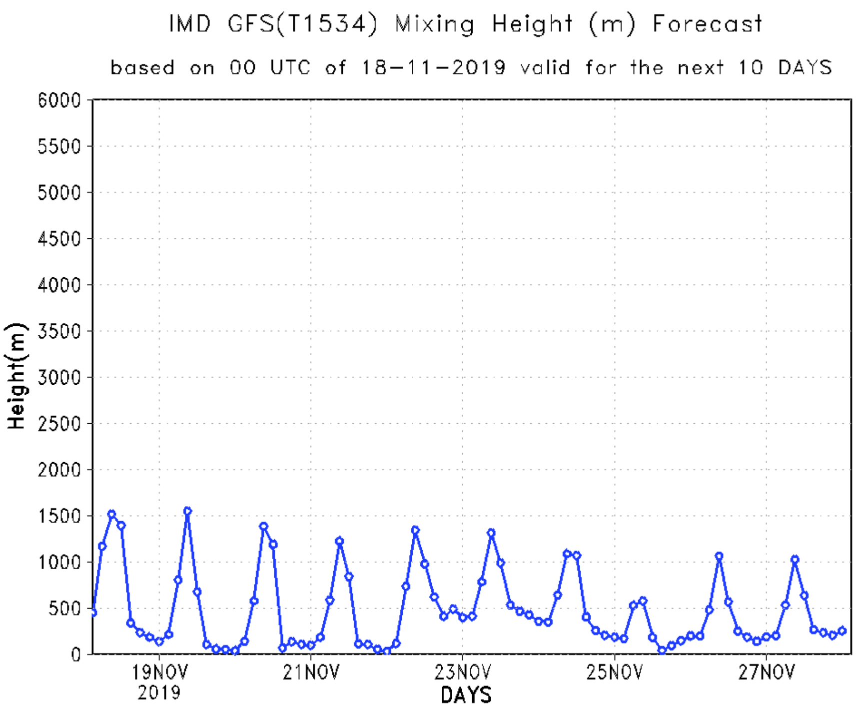
10 Days Forecast of Wind, RH and Rainfall for Delhi



10 Days Forecast of Ventilation Index

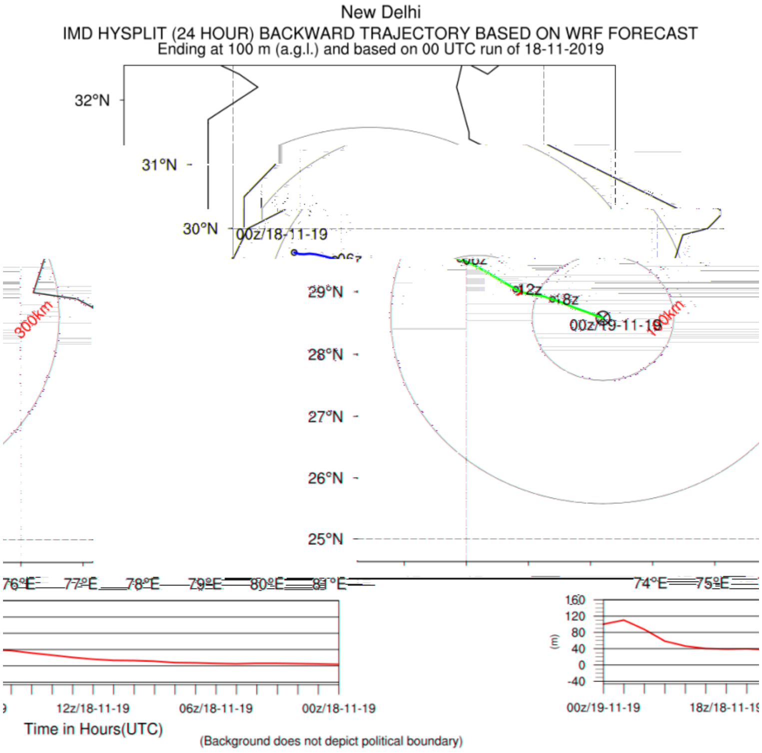


10 Days Forecast of Mixing Height

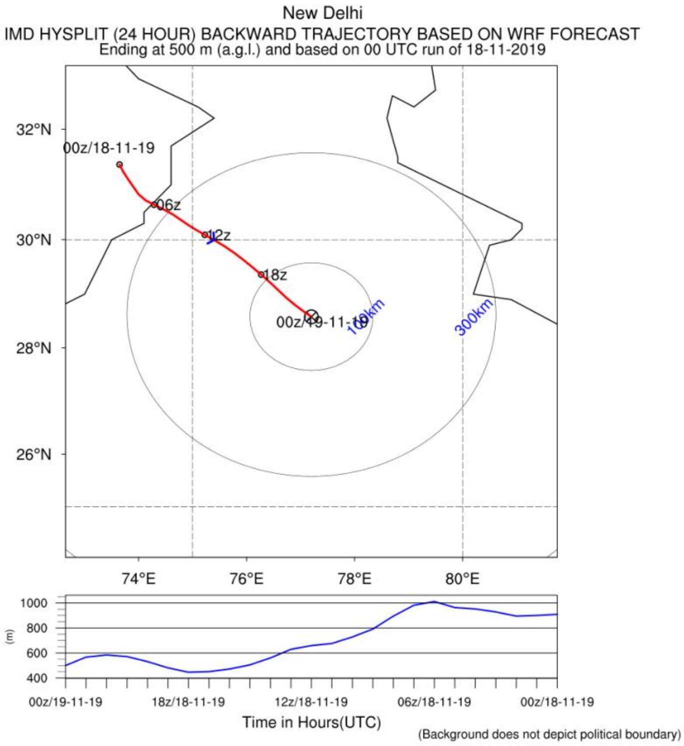


Airmass Trajectories

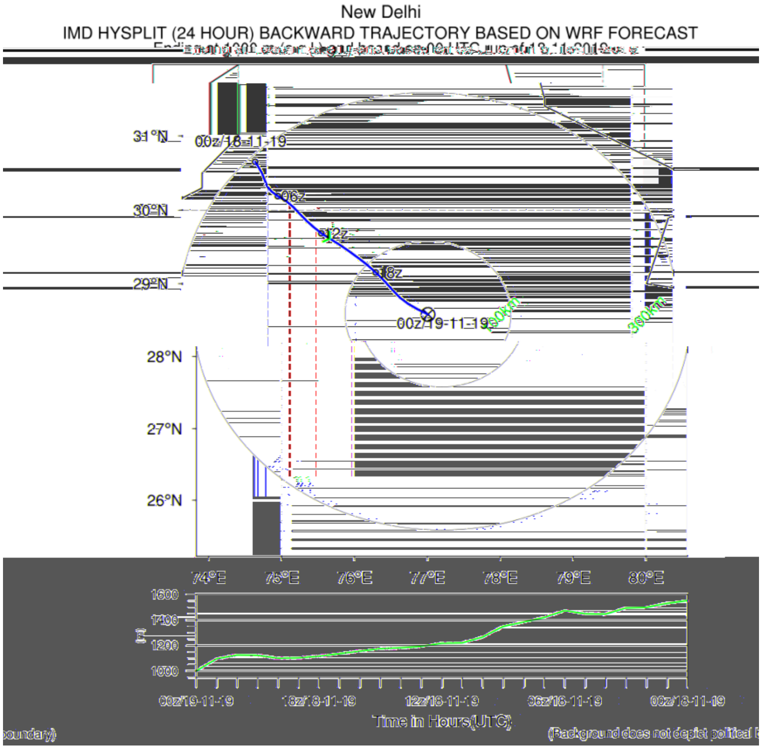
1. Backward Trajectories Ending at 100 m (above Ground Level)

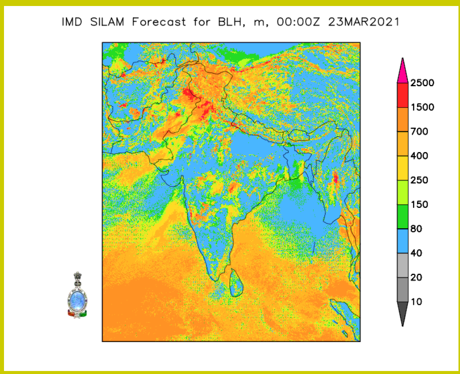


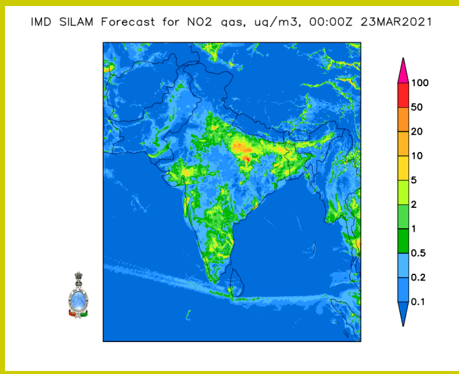
2. Backward Trajectories Ending at 500 m (above Ground Level)

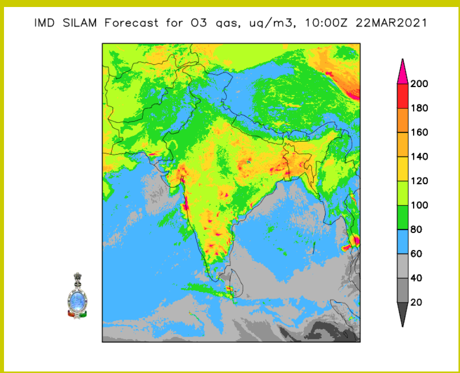


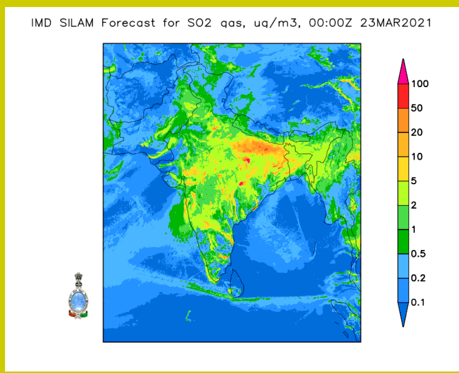
3. Backward Trajectories Ending at 1000 m (above Ground Level)











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