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October 31, 2018

To,
Prof. A. K. Chhangani (Project Investigator)
Department of Environmental Sciences
Maharaja Ganga Singh University
NH-15, Jaisalmer Road
Bikaner-334004, Rajasthan

Subject: MOU for air quality monitoring at Maharaja Ganga Singh University under National Carbonaceous Aerosol Program-CarbOnaceous AerosoL Emissions, Source apportionment & Climate Effects (NCAP-COALESCE).

Respected Prof. Chhangani,

As per our discussion and meeting with honorable vice chancellor, registrar and finance officer on 29/10/2013 at Maharaja Ganga Singh University, Bikaner, the air pollution monitoring activity at your institute under NCAP-COALESCE project funded by Ministry of Environment and Forest-Climate Change will start soon. This activity at MGSU under academic collaboration with IIT Delhi will benefit your institute in following aspects.

1. Training of man power for measurement of emissions from various sources including biomass fuel in cooking stoves, open biomass burning after harvest, brick kiln and vehicles using a custom build source sampling train developed by IIT Delhi and IIT Bombay.
2. Training of man power for Super SASS 8-channel aerosol collection sampler with denuder.
3. Participation of students in survey related to residential sector, agricultural sector, brick kiln and vehicles using digital application provided by IIT Bombay.
4. Enabling Msc/MTech theses of students of MGSU (co-guided by Prof. A. K. Chhangani & Prof. Gazala Habib), exploiting the field survey and sampling data, along with additional analysis using meteorology/ trajectory/ source apportionment/ other models.
5. TA/DA of one student visiting any collaborative institutes for training will be paid from 'Travel head' of the NCAP-COALESCE project at IIT Delhi.
6. TA/DA of PI (Prof. A. K. Chhangani) for attending review meetings will be paid from 'Travel head' of the NCAP-COALESCE project at IIT Delhi.
7. The infrastructure and consumable for conducting the measurement at MGSU will be supported by IIT Delhi.
8. The authorship on publication/publications will be decided as per NCAP policy document approved to MOEF-CC.

A technical staff appointed by IIT Delhi will be responsible for operation and maintenance of instruments. The accommodation of technical staff in guesthouse/hostel will be provided by MGSU. The electricity for running the instrument will be provided by MGSU. The instruments including SASS sampler, aethalometer, nephelometer etc. will be loaned to MGSU and will remain the property of IIT Delhi.

Looking forward to your support,

Thanking you,

Yours Sincerely,

Prof. Gazala Habib
(PI: IIT Delhi)

Prof. A. K. Chhangani
(PI: MGSU) BIKANER

Professor & Head
Department of Environmental Science
Maharaja Ganga Singh University
Bikaner

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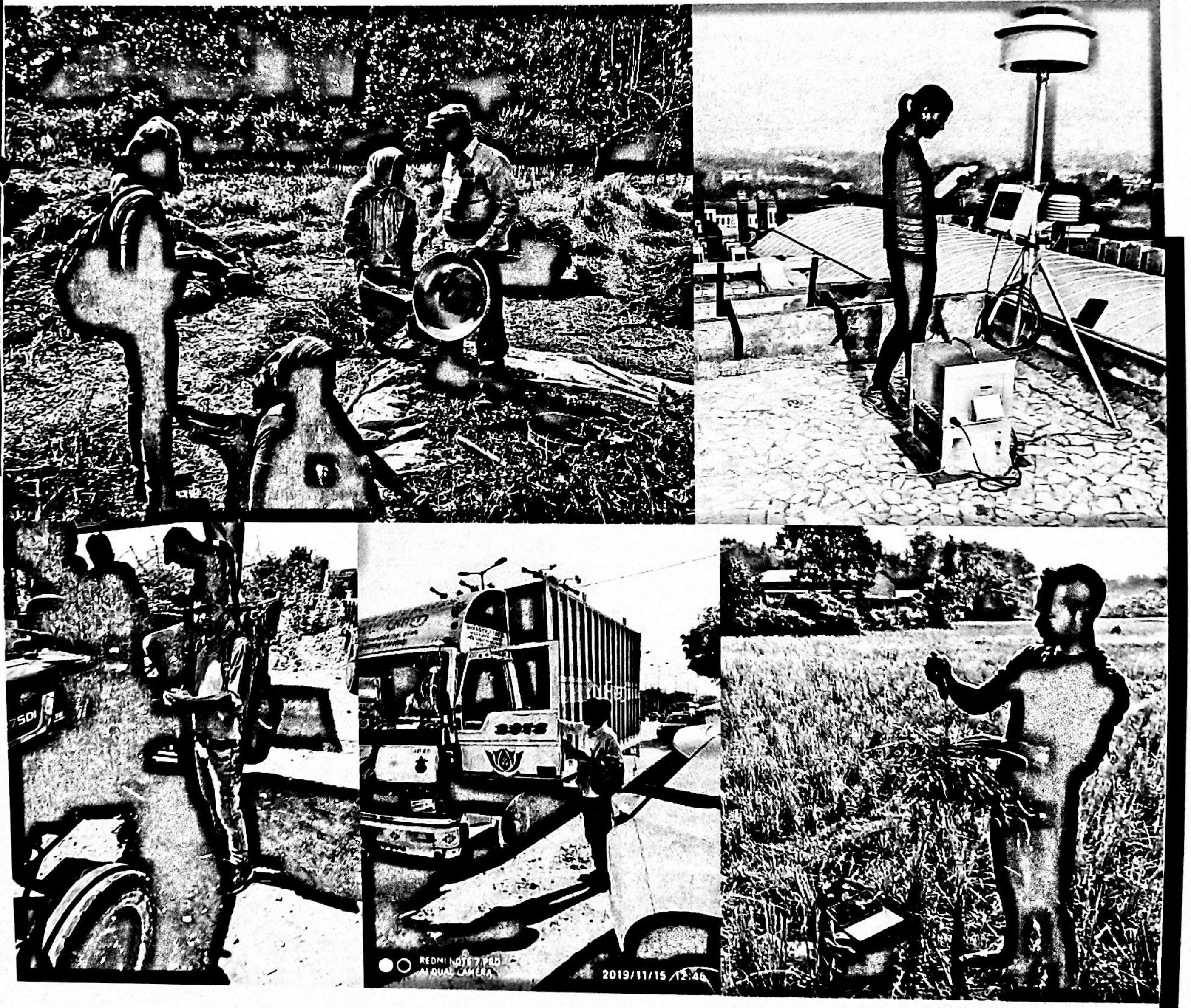
National Carbonaceous Aerosols Programme

COALESCE

Understanding scientific complexities related to carbonaceous aerosols, focussing on issues underlying their origin and fate, and their role as drivers of regional climate change over India

CarbOnaceous AerosoL Emissions, Source apportionment & ClimatE impacts



ANNUAL PROGRESS REPORT

(APRIL 2020—MARCH 2021)

Sanction No.:14/10/2014-CC (Vol. II)
Total cost of the project: 67.16 Cr
Duration: 7 Years
Start date of the project: 01.04.2016
Closing date of the project: 31.03.2023

Key objectives and specific scientific problems of NCAP-COALESCE:

The NCAP-COALESCE is a multi-institutional project envisaged to **understanding scientific complexities related to carbonaceous aerosols, focussing on issues underlying their origin and fate, and their role as drivers of regional climate change over India**

Key objectives	**Specific scientific problems**
1.Reduce current uncertainty in the magnitude and sectoral distribution of carbonaceous aerosols (and co-pollutant) emissions over India.	a) Measurement of field emission factors of carbonaceous aerosol fractions (BC, OC and BrC), speciated $PM_{2.5}$ and selected co-emitted gases from major sources of regional importance (i.e., residential cooking, space heating, water heating and lighting, brick kilns, on-road diesel transport, and agricultural residue burning).
	b) Understanding the influence of technology, operating practice and fuel properties on microphysical, chemical and optical properties of aerosol emissions under field conditions.
	c) Identification of sources which emit the darkest (net warming) particles, through measurement of spectral mass absorption and scattering cross-section and microphysical properties.
	d) Estimation of activity rates in the use of different fuels, technologies, and practices in key carbonaceous aerosol emitting sectors over India.
	e) Development of a gridded carbonaceous aerosol emission inventory for India, with improved sectoral methodologies from ground-truthing and validation with field survey data.
2.Identify and quantify sources influencing abundance and properties (chemical and optical) of anthropogenic aerosols and carbonaceous constituents over India.	a) Seasonal and spatial variation in aerosol chemical composition and optical properties at eleven regionally representative sites across India.
	b) Quantitative source apportionment of $PM_{2.5}$ and carbonaceous aerosols and identification of sources and geographical regions influencing high pollution episodes.
	c) Distinguishing similar sources of carbonaceous aerosol emissions using chemical fingerprinting (organic markers, thermally resolved carbon fractions and C-isotopes).
	d) Source apportionment of aerosol optical properties and resolution of primary versus secondary sources of aerosols using multi-linear extended models.
	e) To quantify source-sector influence on $PM_{2.5}$ and carbonaceous aerosol abundance, through quantitative comparison of RCM predictions with PMF receptor modelling by season and region.
3.Estimate the impact of aerosols (anthropogenic and carbonaceous) on regional climate variables, along with climate feedback on air-quality.	a) Multi-model ensemble simulations, with RCMs and GCMs, for evaluation of model diversity in annual and seasonal anthropogenic aerosol variables and aerosol processes, including mass and species concentrations, sulphate formation (SO_2/SO_4 ratios), dry and wet deposition, total and species AOD, SSA, asymmetry parameter and radiative forcing.
	b) Estimating aerosol radiative forcing over India and the contribution of carbonaceous aerosols, resolved by source, season and region.
	c) Estimating the response of South Asian monsoon precipitation response to radiative forcing of aerosol direct, indirect and total effects.
	d) Special hypotheses including: - Sensitivity of radiative forcing to changes in emissions, mixing state and aerosol optical properties (mass absorption cross-section); - Carbonaceous aerosol influence on temperature response and frequency of high temperature extremes; - Influence of anthropogenic aerosols on circulation patterns and cloud microphysics; - Trends in aerosol deposition and radiative forcing, temperature and snow cover in the Himalaya.
4. Evaluating secondary aerosol formation, improving organic aerosol source resolution (impacts on air quality) and estimating brown carbon absorption (impacts on climate).	a) Evaluation of secondary inorganic and organic aerosol (SIA and SOA) formation.
	b) Identification of Organic Aerosol (OA) and Brown Carbon (BrC) tracers for input to PMF modelling organic aerosol sources.

FISCAL STATUS

Grants received from MoEFCC under both General and Capital heads alongwith the expenditure and interest returned by Consortium partners, as of February 2021 is shown in Figure 1.1 The project has incurred INR 23.37 Cr. capital expenditure on instrumental infrastructure for 205 instrument items. An amount of INR 78 Lakhs interest earned from the grant was returned to MoEFCC by the consortium partners till F.Y. 2020-21

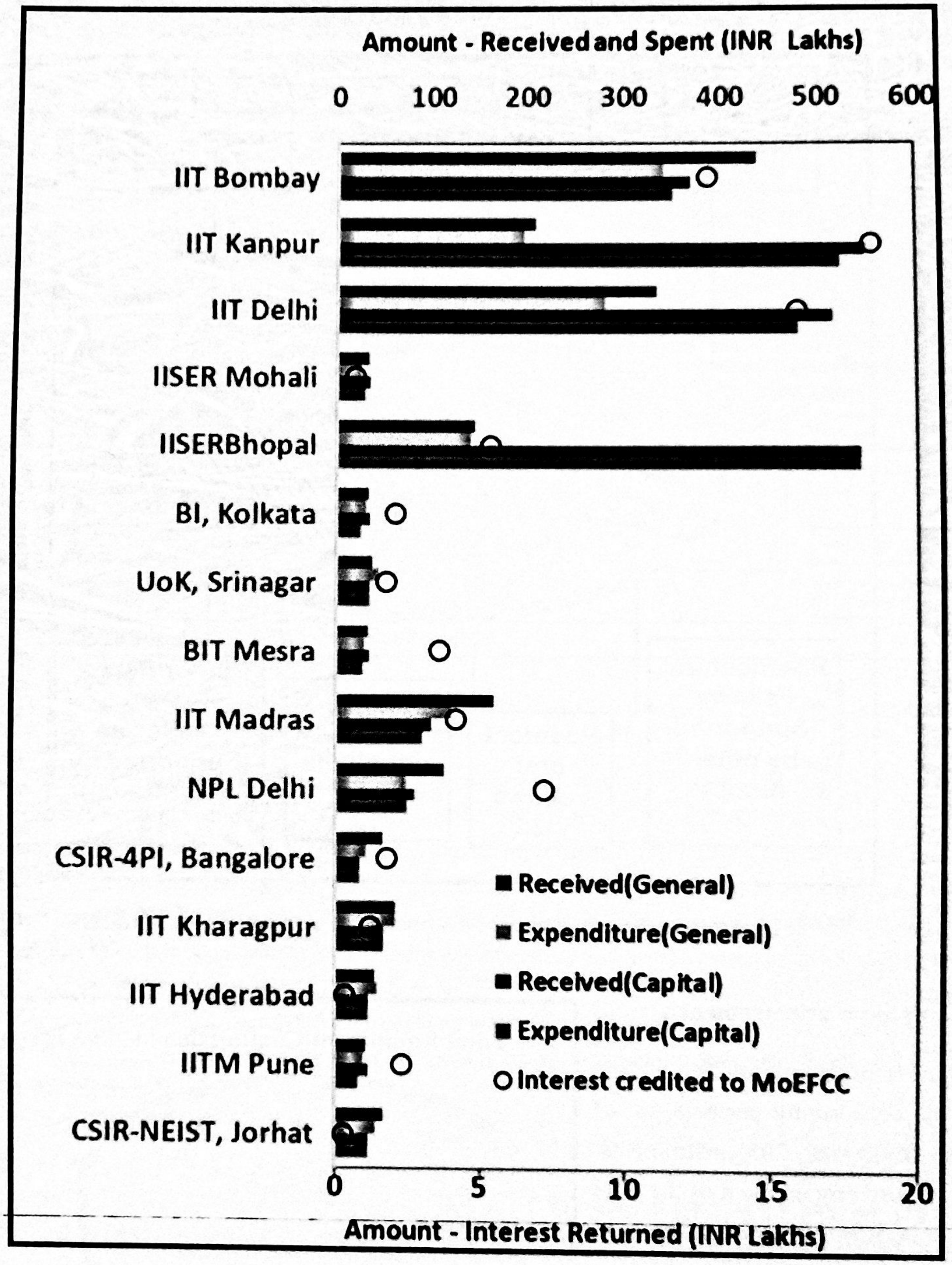


Figure 1.1: Funds received, expenditure and interest deposited as on February 2021 institute-wise

2 MANPOWER AND INFRASTRUCTURE

2.1 Manpower Deployed

Manpower deployed by consortium partners during April 2020—March 2021 for the project is shown in Figure 2.1.

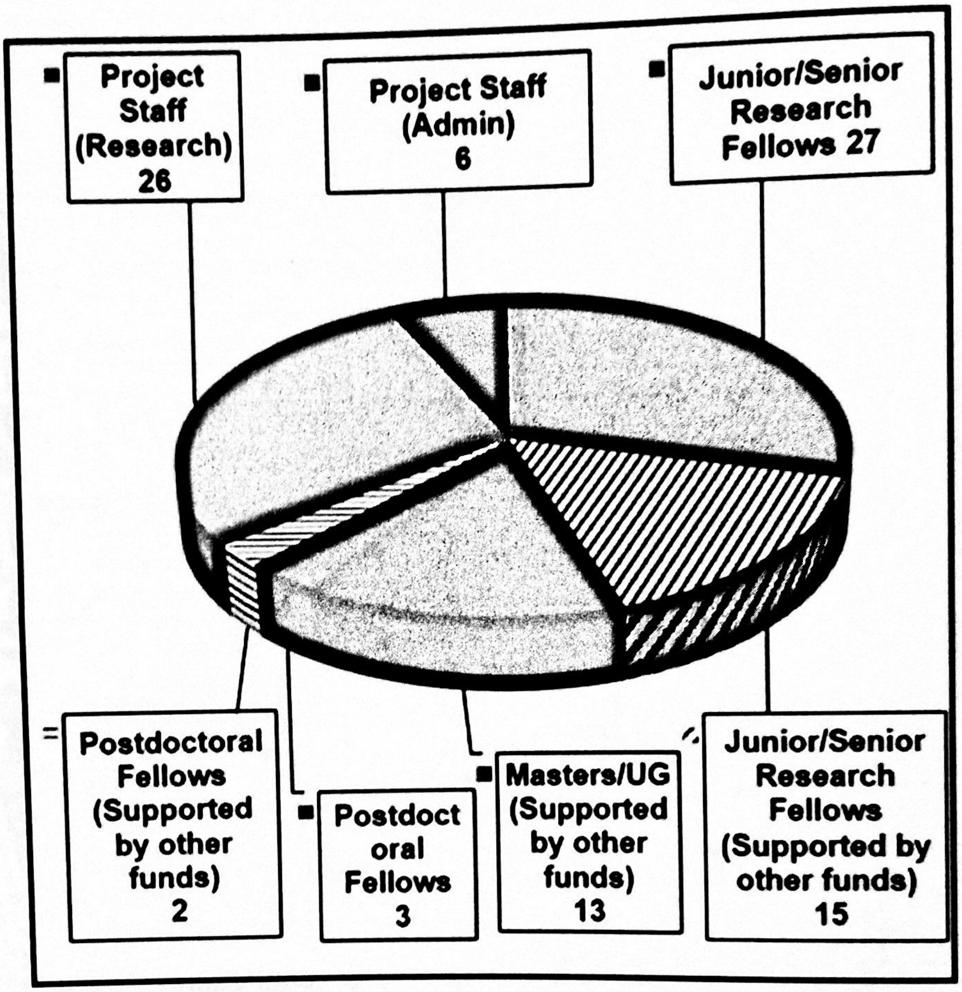


Figure 2.1: Designation-wise distribution of manpower in the project

2.2 Equipment procurement

Total equipment commissioned in the project by consortium partners as of February 2021 was 205 instruments. The sector-wise procurement of the total equipment is shown in Figure 2.2.

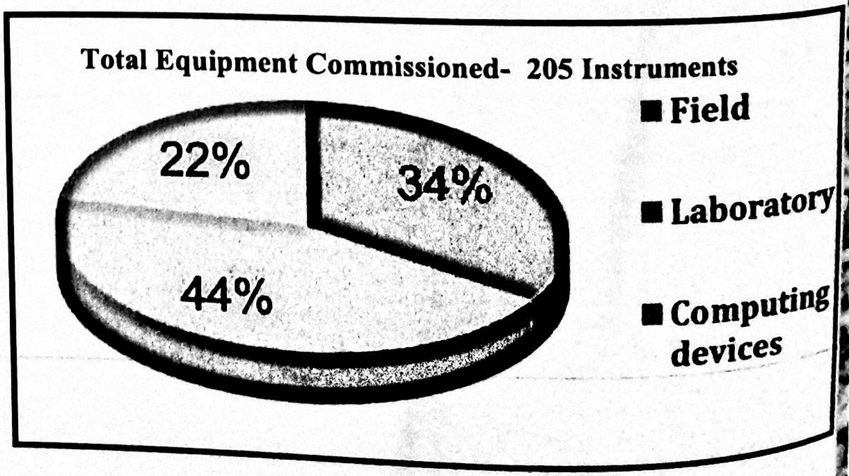


Figure 2.2: Sector-wise percentage allocation of total equipment

SCIENTIFIC PROGRESS: WP-1
SOURCE CHARACTERIZATION & EMISSIONS

3

3.1 SMoG-India-COALESCE National Emission Inventory

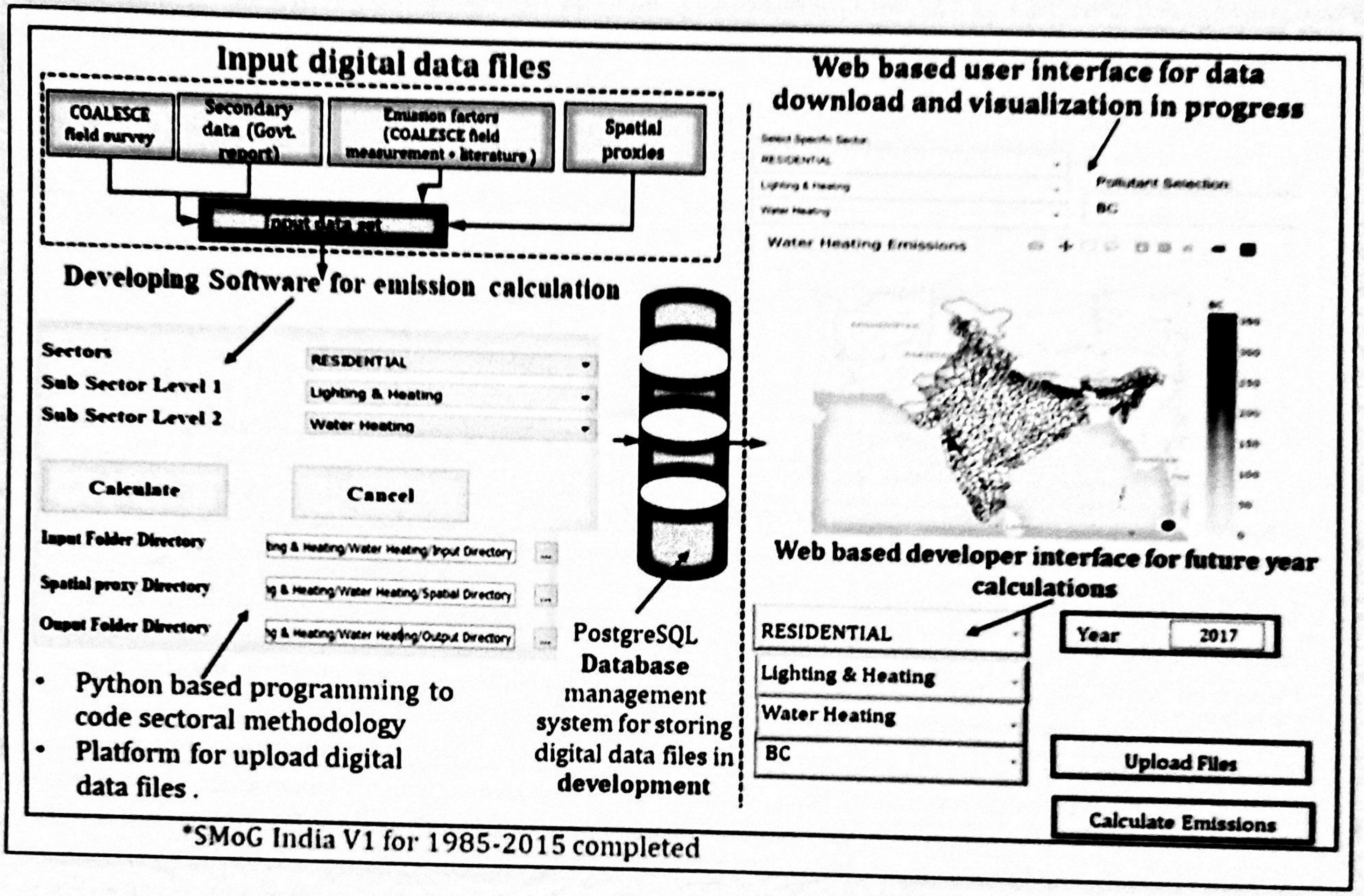


Figure 3.1: SMoG-India-COALESCE: National emission inventory management system (Speciated Multi-pOllutant Generator)

SMoG-India- COALESCE: National emission inventory management system (illustrated in Figure 3.1) is an integrated platform for estimating, storing, handling and visualizing the SMoG-India-COALESCE: National emission inventory. Flow of this management system starts from preparing digital input data from various sources which are fed into the software for emission calculation. The input as well as the generated output are stored in PostgreSQL database. Finally, a web based user interface fetches data from the database based on user specified queries for download and visualization. The system is designed to enable regular update of present day inventory and also to generate future scenarios.

Emission inventory and analysis based on NCAP survey data was conducted by the four associate institutes in agriculture, brick, residential and vehicular sectors spread over a period of approximately one year. Sector-wise coverage and achievements are described in the following sections.

3.1.1 Residential (Cooking)

The Census 2011 report revealed that over two-thirds of households in rural India relied on firewood and dung cake for their primary cooking fuel needs. The NCAP survey conducted in 42 districts of rural India showed the shift from solid fuel use to LPG over the years (see Figure 3.2). Survey results showed that despite having an active LPG connection, households stack LPG with biomass for cooking. Among biomass fuel combustion technology, traditional stove dominates followed by small fraction of improved stove. The dependent variables (e.g., fuel use) from NCAP survey and the independent variables (e.g., number of members, banking, literacy) given by Census India have been used to develop the multi-variate regression model and establish the equation to estimate the fuel use for the non surveyed districts. Similarly multi-variate regression model were developed to estimate the stove user in 640 districts of India.

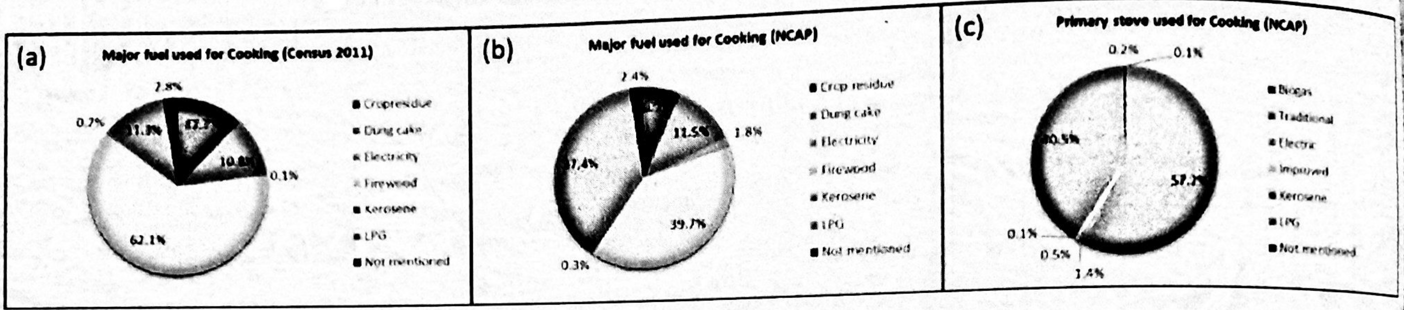


Figure 3.2: Percentage of households using (a) Major fuel for cooking reported in Census 2011 (b) Major fuel use for cooking from NCAP 2019 survey (c) Major stove use for cooking in rural India

3.1.2 Residential (Non-Cooking)

The total number of survey responses (~5100) is used to prepare input variables for the non-cooking residential sector. These input variables such as time of water heating, type of fuel, and devices are available at the district level where NCAP survey has been completed. These districts can be classified based on demographic and housing information (e.g., Literacy, workers, household size) given by the Census India. The quantitative information from supporting data (such as Census) over the surveyed district can be used to find an association with the input variable. Further, the established relationship will be used over the non-surveyed district to estimate input variables (Figure 3.3) for this sector.

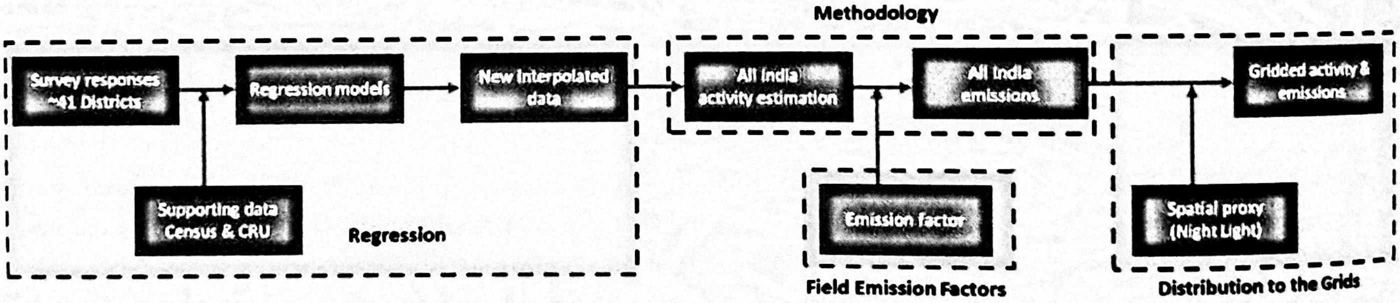


Figure 3.3: Flowchart for non-cooking residential gridded inventory

An extrapolated input variables combined as per the methodology (Lam et al., 2012; Sadavarte et al., 2019) to derive month-device-district specific fuel consumption for each non-cooking residential activity. The field campaign will be conducted to obtain realistic emission factors for these activities, which have been overlooked in the earlier studies. The total emissions for greenhouse gases (GHGs) and co-emitted aerosols will be converted to gridded emission using spatial proxy provided by the night-time light radiance (Ravishankara et al., 2020).

3.1.3 On-road Transport Sector

Emission estimates for on-road transport sector can be made after assessing the on-road vehicle population for all cities of each state. On-road vehicle population for each city has been estimated using survival fractions calculated from log-logistic model. Spot vehicular survey has been performed by 13 institutes in 14 states covering 42 cities across India. A total of 16382 number of vehicles has been surveyed. The survey data has been analyzed for each tier city and for each vehicle category for estimating survival function parameters (shape factor α and retirement life L50) and mileage of ~~vehicle. The~~ ~~survey data has~~ also been analyzed for ~~average annual~~ distance travel for ~~each vehicle~~ category and ~~was~~ found more than reported in literature. The average annual distance travel was used from previous study done by (Sadavarte and Venkataraman, 2014).

The fuel consumption for each vehicle category has been estimated by using on-road vehicle population, average annual distance travel, mileage and fuel density. Simultaneously, spot surveys are also being conducted to figure out the super emitter fraction in different cities, this would help in improving the calculated emissions for super-emitter and non-super-emitter vehicles. For estimating emissions for each pollutant from each vehicle category, fuel consumption for the particular vehicle category will be multiplied by respective emission factors. Measurement will be performed for each vehicle category in each tier of city to determine the emission factor for different pollutants.

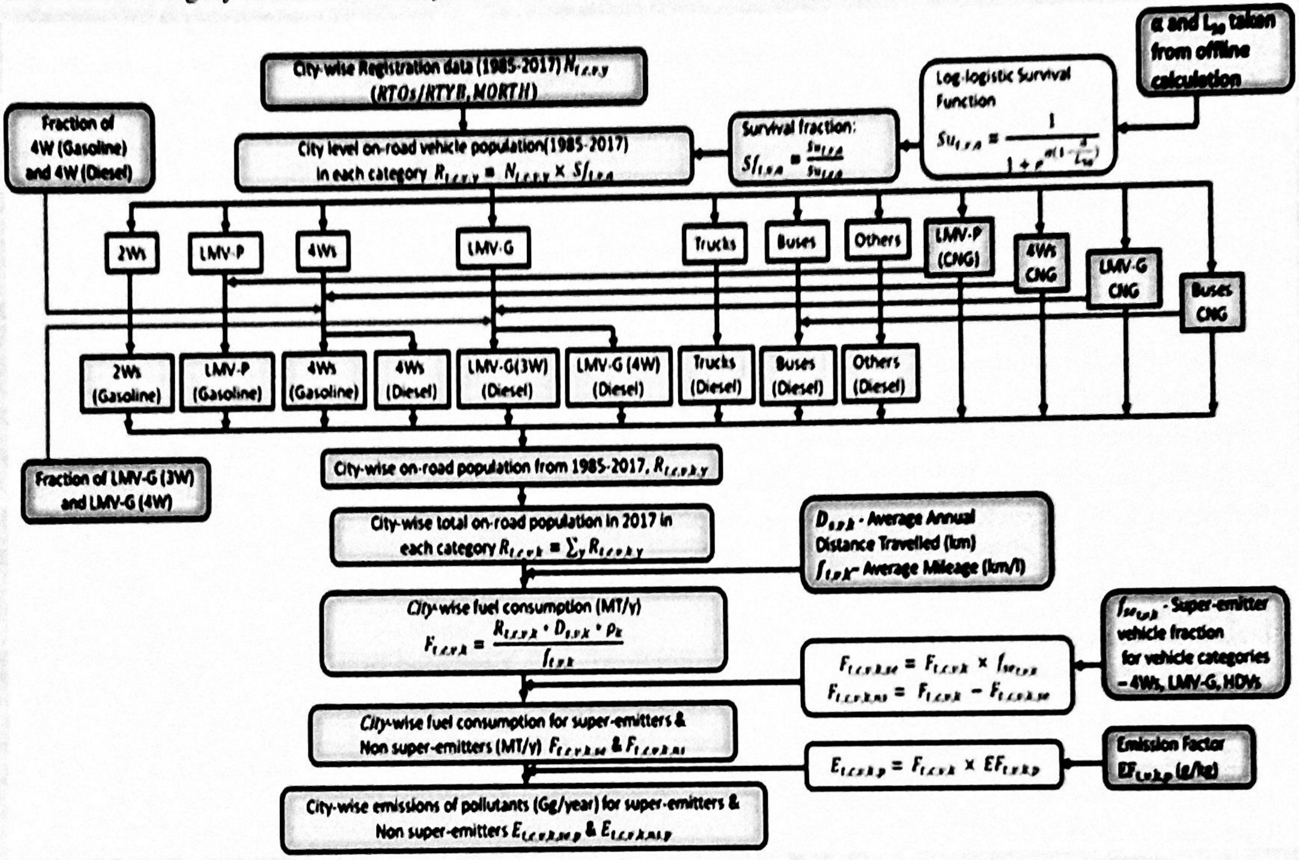


Fig 3.4: Methodology to estimate on-road vehicle population, fuel consumption and total emissions

3.1.4 Agricultural crop residue burning

To prepare an emission inventory using the bottom-up inventory approach for the crop residue burning sector, information is gathered from governmental resources (crop production), existing literature (burn efficiency, emission factors, dry matter fraction) and field surveys (residue to crop ratio and dry matter fraction). Field surveys gather information on the fraction of the generated crop burning that is subjected to on-field burning, which is the most uncertain parameter when preparing an emission inventory. While our surveys span the whole country, the information gathered is only available for a subset of the total number of districts. Hence, to extrapolate it to the remaining districts, multivariate regression modeling approach is employed. The multivariate linear regression models take into account the following at district level: kind of crop residue, livestock numbers, socioeconomic condition and the crop production. The model yields an acceptable agreement (adj-R2 = 0.47) with the surveyed crop-district specific fraction burned parameter and used to estimate the parameter for the non-surveyed districts across the country. The residuals of the developed model are not normally distributed indicating the need for additional improvement in the model. Further possibilities of using categorical location variables and preparation of crop specific models are being explored. This information can be further used to prepare a district-wise emission inventory for the country. Further, these district-wise emissions will be converted into gridded emissions, especially to enable usage by climate models, by using the land cover type dataset available from the MODIS sensor aboard the NASA Aqua/Terra satellites.

3.1.5 Brick sector

Field surveys of brick kilns had to be stopped after February, 2020 owing to the nation-wide lockdown to contain the COVID pandemic. Field visits resumed starting January 2021 as most of the activities across the nation resumed to a certain level of normalcy. The recent visits added another 130 kilns across 5 districts – Krishna (Andhra Pradesh), Rajgir (Bihar), Sriganganagar (Rajasthan), Hanumangarh (Rajasthan) and Alwar (Rajasthan). As of March 2021, the total number of kilns surveyed is around 480, spread across 20 districts in 9 states. The survey data forms the primary source of information for the operational characteristics of the brick kilns across the nation. The information on mean production capacity, months of operation, fuel mix used and energy consumption for different kiln technologies is fed as input to a framework to obtain sub-national emissions from manufacturing of fired-clay bricks. Besides the survey data, an effort is made to utilize satellite images to manually scan the area and locate brick kilns (geo-tagging) and the technology types. The aim is to enumerate the district-wise number of different types of kilns across the country. Since, it is a humungous task to manually scan the whole country and locate every kiln, the number of kilns obtained for selected districts will be combined with Census brick-walled houses trend in a regression model to extrapolate the information for the non-geo-tagged districts. This will form a key step in the emissions estimation methodology, enabling us to estimate the total brick production more accurately. Moreover, field campaigns are being planned to measure emission factors for a variety of fuel mix and kiln technology combination prevalent in the country.

3.1.5.1 Geo-mapping of Brick Kilns

Fired-clay brick kilns is one of the unorganized sectors with likely high emissions and very little information on the number of operational kilns and technology types across India. The COVID-19 pandemic constraints allowed us to work around this sector by exploring satellite imagery data for enumeration of brick kilns and technology types. To estimate the number of kilns and technology distribution of different brick kiln types, brick geo-mapping exercise was carried out, where total area of each of the selected districts was scanned grid by grid, and the kilns were geo-tagged/marked manually. The districts were selected from different regions of the country based on the surveys and other available information from published research articles/reports resulting in mapping of a total of 79 districts (see Figure 3.5).

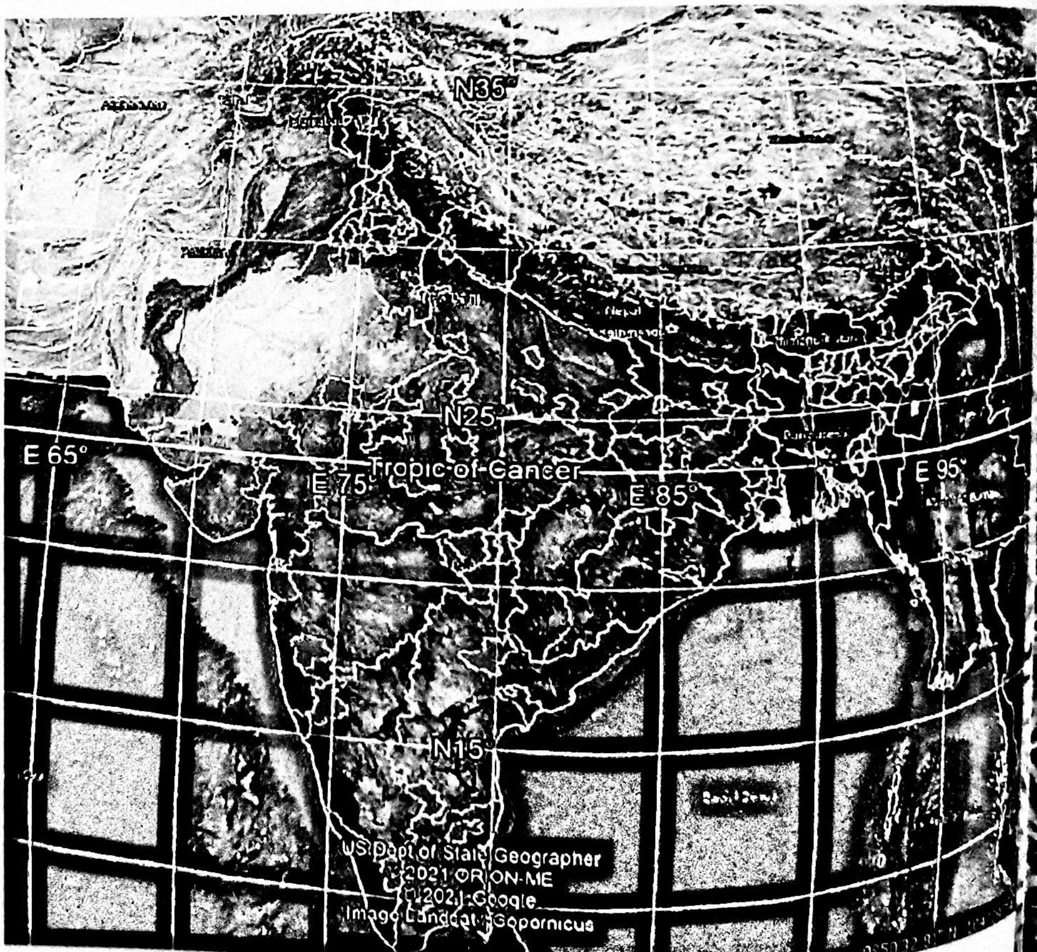


Figure 3.5: Geo-mapped districts

The geo-mapping exercise revealed that the Indo Gangetic Plains, North and Eastern region of India are dominated by bulls trench kilns (BTK) followed by zig-zag kilns whereas the Western region is dominated by clamp types (90-100%). In Southern region a mix of clamps, Hoffman kiln and Down Draft Kiln (DDK) are observed. Combining the NCAP-COALESCE survey data on average brick production with the number of brick kilns and technology types, identifies the West Bengal and Uttar Pradesh dominating the country's annual average brick production per district with ~2000 and 1800 million bricks per year per district, respectively.

3.2 Spatial Distribution

Emission data from the national inventories are often used as input to model air quality, to make a more suitable input for air quality models, emissions must be given on a more disaggregated level than the national level. The emissions from area (Agriculture, Residential), line (Transport), and point (Large Industry) sources are calculated as district totals and are distributed 5 km x 5 km resolution grid maps. Regarding point sources, in most cases, the emissions are distributed in the grid cells where they are located using the coordinates of each facility. Figure 3.6 shows annual firewood consumption for water heating activity only at Giga-grams per pixel is unit, and each pixel is at 5km resolution. It depends on a combination of many parameters such as members per household, fraction of firewood users, population, and time required for water heating.

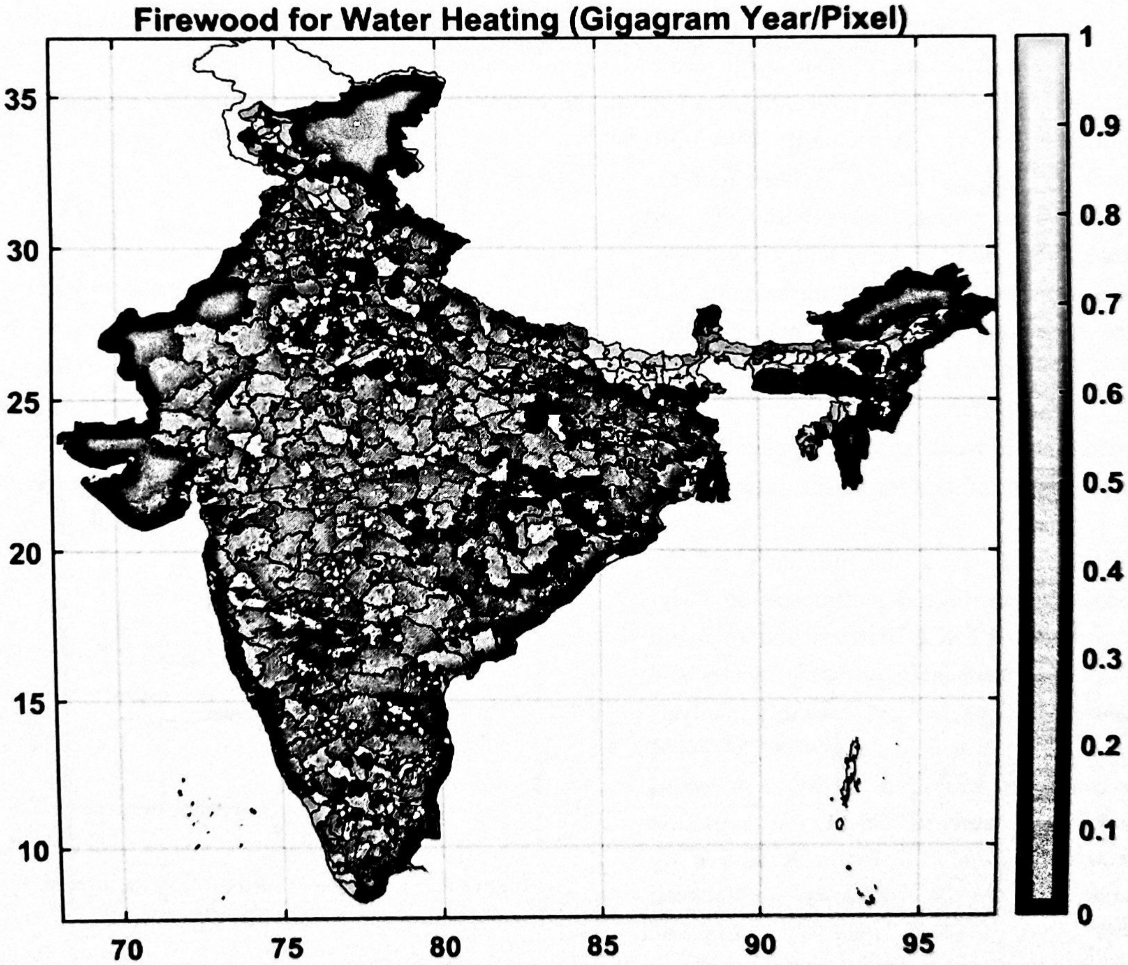


Figure 3.6: Annual firewood consumption for water heating

4 SCIENTIFIC PROGRESS: WP-2, SOURCE APPORTIONMENT & ATMOSPHERIC TRANSFORMATION

4.1 Summary of $PM_{2.5}$ concentrations and its chemical constituents

Sampling for fine PM and its chemical constituents, although interrupted due to COVID-19 during 2020 was performed to varying extents at all 11 sampling sites. Chemical analyses of 2019 samples were also performed. In the following sections, a summary of findings focusing on samples collected during 2019, including fine PM mass, meteorology and chemical species behaviour across the COALESCE network will be discussed.

4.1.1. $PM_{2.5}$ mass concentrations and associations with meteorology

The annual (2019) average $PM_{2.5}$ concentrations across the COALESCE network are shown in Figure 4.1. Rohtak (126.89 µg m^{-3}), Shyamnagar (81.61 µg m^{-3}) and Mohali (74.26 µg m^{-3}) had the highest while Mysuru (30.4 µg m^{-3}) and Mahabaleshwar (33.01 µg m^{-3}) had the lowest $PM_{2.5}$ concentrations during 2019.

Annual mean of daily $PM_{2.5}$ concentrations over all the stations except for Mysuru and Mahabaleshwar were higher than the National Ambient Air Quality (NAAQS) standard for $PM_{2.5}$. Further, Rohtak had the most number of polluted days with 79% and Mahabaleshwar had the least with only 4% of samples collected during 2019 above daily 24 h average standard (60 µg m^{-3}) as prescribed by NAAQS. Day of the week analysis suggested that the difference between mean concentrations of weekdays and weekends were statistically insignificant for all the eleven sites.

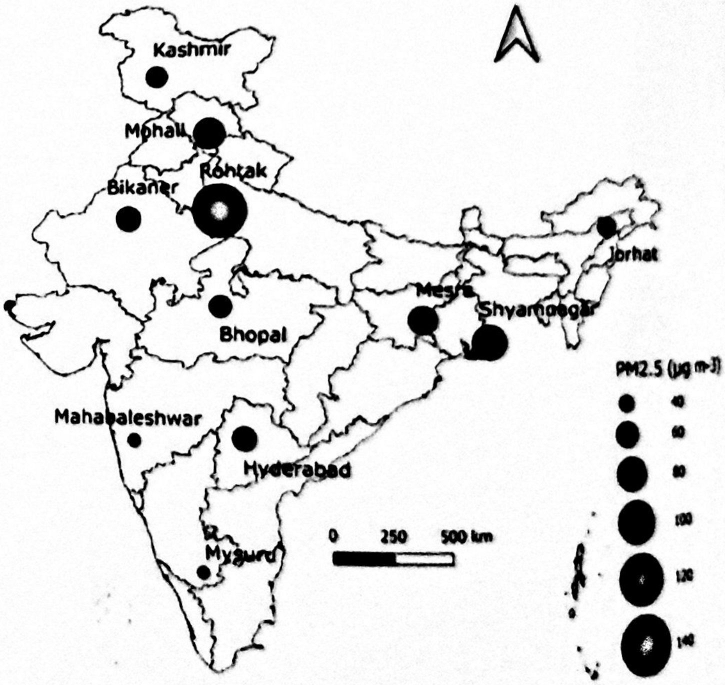


Figure 4.1: Influence of meteorology on 2019 $PM_{2.5}$ across the COALESCE network

Further to understand the influence of the individual meteorological parameters on $PM_{2.5}$ mass over COALESCE stations and to avoid the influences from other probable factors and mirage correlations, robust causality analysis approach; the Convergent Cross Mapping (CCM) analysis was used. CCM, is a robust methodological test to detect the causation between two given time series X and Y by examining the similarity between corresponding shadow manifolds Mx and My, constructed using the lagged coordinates of time series values of X and Y, respectively. The influence of meteorological parameters on $PM_{2.5}$ for all the stations, as assessed by CCM maps are shown in Figure 4.1. A line that becomes th shows causal relationship between a given meteorological parameter and $PM_{2.5}$ mass. The CCM maps in Figure 4.2 also provide a comparison of the magnitude of influence of different meteorological parameters on $PM_{2.5}$ concentrations. Our results show that not all meteorological parameters have a causal effect on the $PM_{2.5}$ mass concentrations over NCAP stations for 2019.

Temperature and relative humidity had strong influence on $PM_{2.5}$ mass concentrations over sites located in the Indo Gangetic Plain (IGP) and a weak influence over Bhopal with rho (ρ) values (Temperature, RH) over Jorhat (0.82, 0.88), Shyamnagar (0.77, 0.82), Rohtak (0.67, 0.76), Mesra (0.51, -), Mohali (-, 0.50) and Bhopal (0.43, 0.20). While the height of the planetary boundary layer has influence only over Mesra (0.44) and Mysuru (0.41). To further investigate the potential source locations affecting $PM_{2.5}$ concentrations over these sites ensemble air parcel trajectory models were utilized in conjunction with the $PM_{2.5}$ mass. The source location probability fields of these maps were compared with $PM_{2.5}$ from SMoG 2015 emissions inventory to yield likely sectoral shares of various primary sources to $PM_{2.5}$ across the network sampling locations, the details of which are presented in the COALESCE 2020-21 technical report.

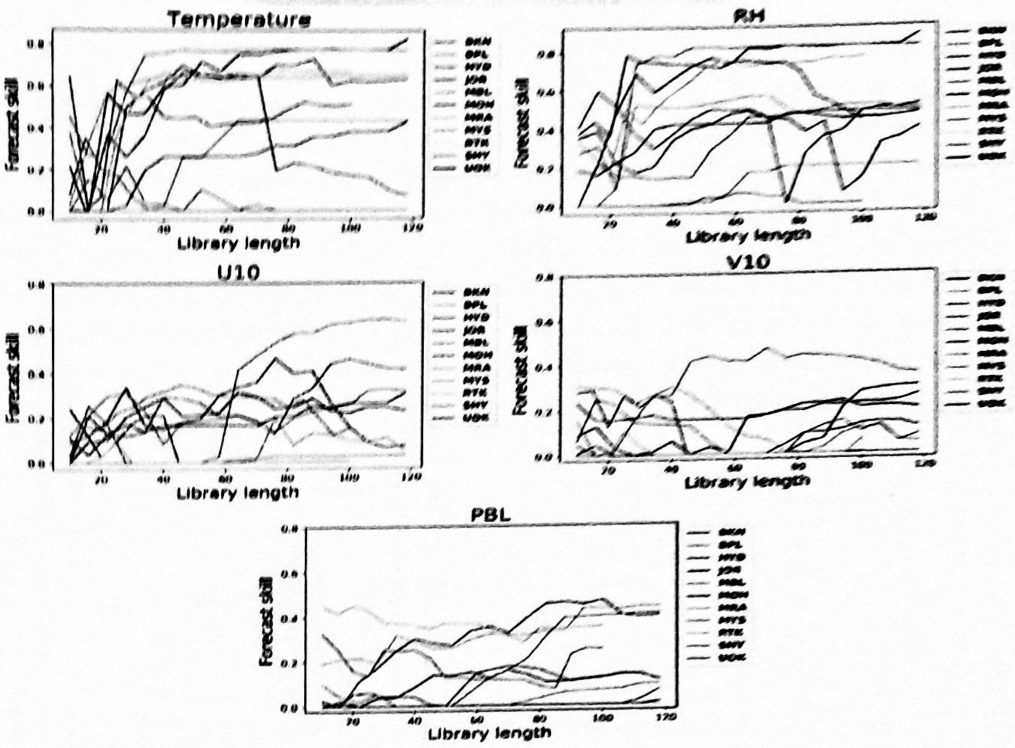


Figure 4.2.: Influence of meteorology on 2019 PM2.5 across the COALESCE network

4.1.2 Stable carbon isotope ($\delta^{13}C$) values

The $\delta^{13}C$ of aerosols in all sites varies in the range: -28.84‰ (in Kashmir) to -16.04‰ (in Bikaner), with an overall variability of 12.8% (Figure 4.3). This suggests emission from a mixture of sources from C_3 plant dominated or fossil fuel sources (average $\delta^{13}C$: -27‰) to C_4 plant source (average $\delta^{13}C$: -13‰).

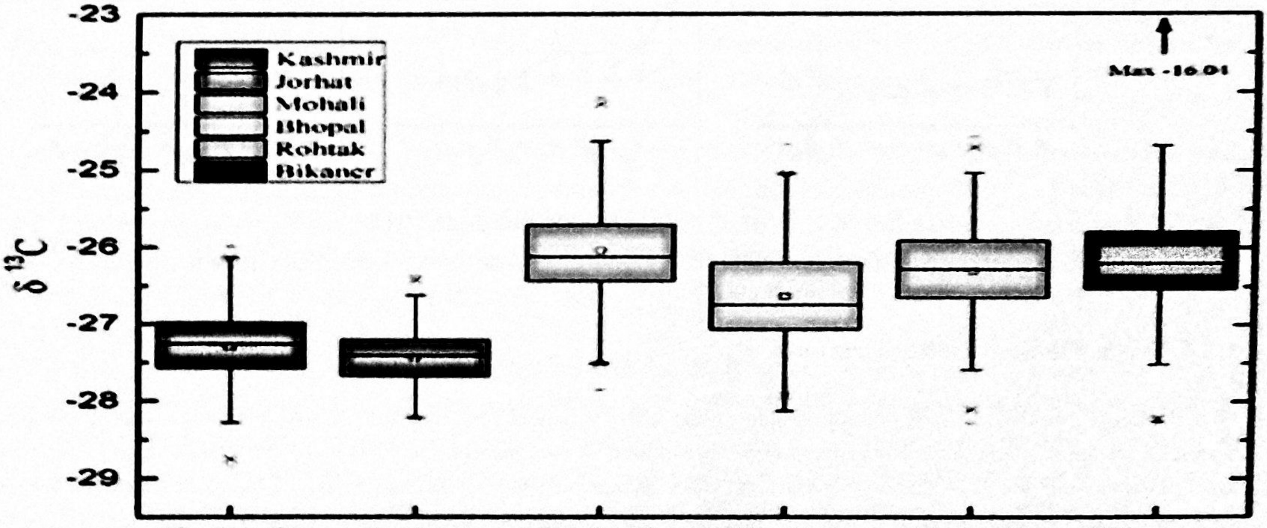


Figure 4.3: Box plot showing range of $\delta^{13}C$ (‰) values in fine PM across six COALESCE network locations.

4.1.3 Thermally fractionated carbonaceous aerosol concentrations

Organic Carbon (OC) and Elemental Carbon (EC) monthly average concentrations between January and October, 2019 across the network are shown in Figure 4.4. Amongst all the study sites, the highest concentration of OC and EC was observed at Shyamnagar followed by Mesra, whereas the lowest concentration of OC and EC was observed at the high-altitude site Mahabaleshwar followed by Mysuru. At all the sites highest concentration of OC and EC was observed during January except for Hyderabad, which has the highest concentration during March. These temporal variations of carbonaceous aerosols mass concentration could be mainly due to the influence of temporal source activities and local meteorological conditions.

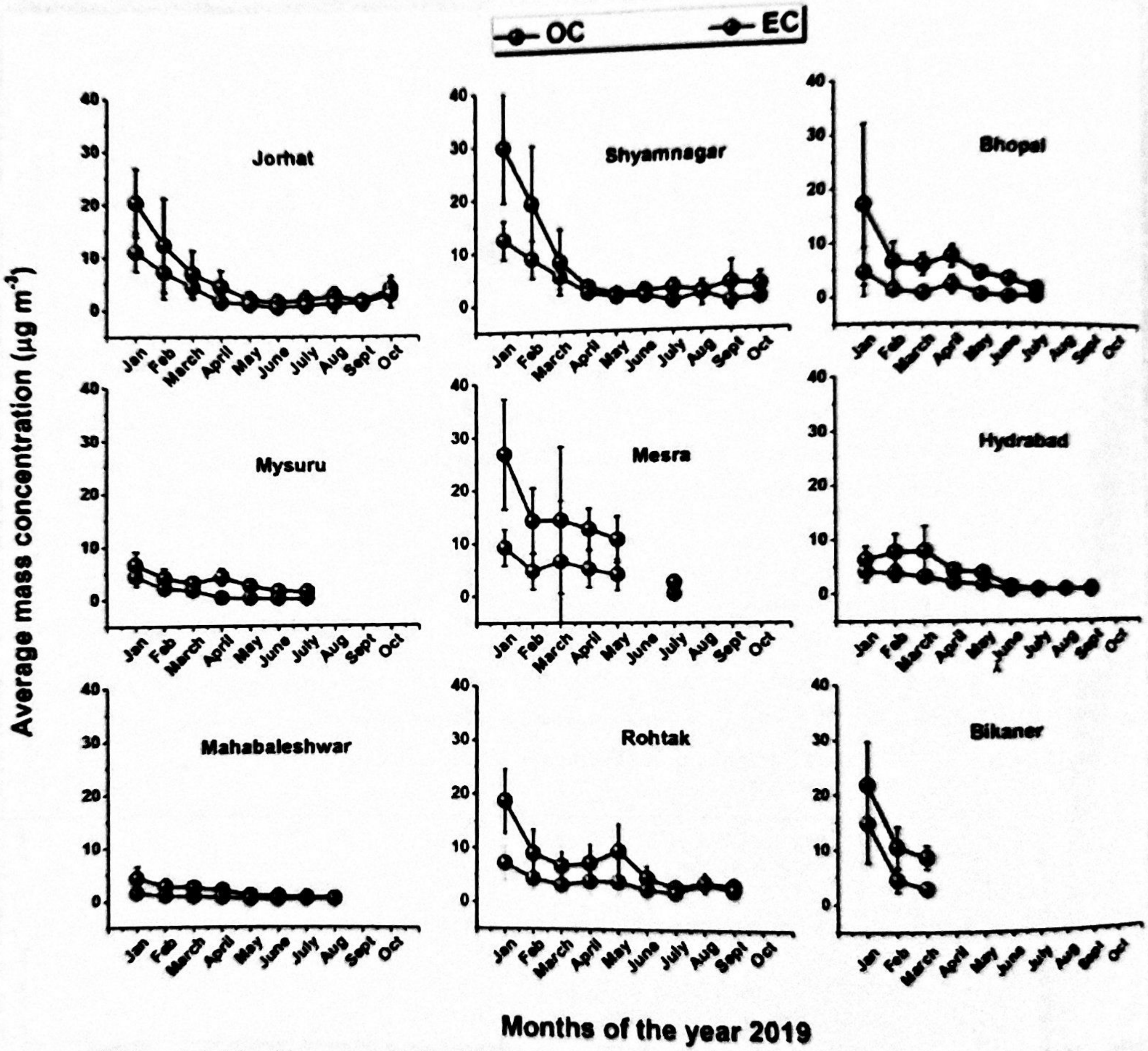


Figure 4.4: Monthly average OC and EC concentrations across the COALESCE network

4.1.4 Trace Element Concentrations

Elemental concentrations of $PM_{2.5}$ collected onto Teflon filters (Channel 1) during 2019, across 8 locations were determined on an Epsilon 4 Energy Dispersive X-Ray Fluorescence are reported. A summary of annual average concentrations of reconstructed soil and key elements S, K and elements of interest and NAAQS regulated species Ni and Pb for all 8 locations are shown in Figure 4.4. Reconstructed soil (Malm et al., 1994) mass annual average contribution ranged between 6% and 20% to the $PM_{2.5}$ mass across sites. Further, soil concentration was comparable across all sites (~5.5 µg m-^{3}), except at Rohtak (7.5µg m-^{3}) and Shyamnagar (8.5 µg m-^{3}) (Figure 4.5). A similar trend was observed for potassium. High soil and potassium is not unusual at these locations given their geographical setting favoring high re-suspension of dust and the prominence of crop residue burning, respectively.

On the other hand, average sulphur concentrations were similar at all sites (~3 µg m^{-3}) except Rohtak and Mesra with annual means of 4.5 µg m^{-3} and 4.0 µg m^{-3}, respectively. The location of Rohtak and Mesra in the outflow of emissions from thermal power plants is a possible explanation for this observation. Pb and Ni are included in India NAAQS as criteria pollutants. Annual average concentration of both these species varied substantially (order of magnitude) between locations (Figure 4.5). Pb was below the daily average NAAQS (1 µg m^{-3}) at all locations while Ni concentrations exceeded the NAAQS standard (0.02 µg m^{-3}) at all locations, except Shyamnagar and Jorhat. Ni NAAQS exceedances merit further investigation.

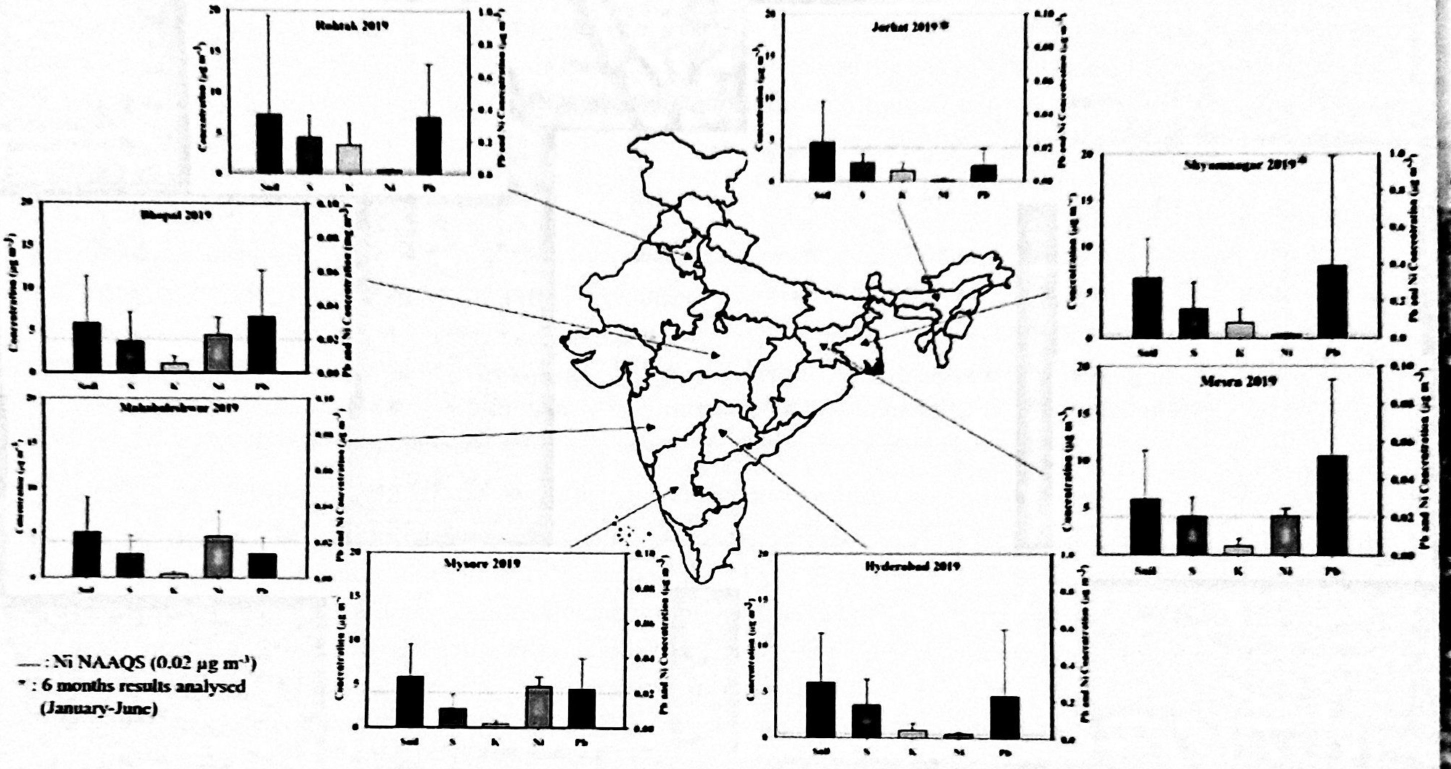


Figure 4.5: Annual average concentrations of soil and key elements across the COALESCE network

4.1.5 Water soluble inorganic ion concentrations

The 2019 annual average concentrations of nine major water-soluble inorganic components - anions (F^-, Cl^-, NO_3^-, SO_4^{-2}) and cations (Na^+, NH_4^+, Mg^{+2}, K^+, Ca^{+2}) across the network is summarized in Figure 4.6. Out of the nine water-soluble ions, NO_3^-, SO_4^{-2} and NH_4^+ were found to be the major contributors to ionic species mass.

The annual mean concentration results for 8 locations of the 11 NCAP network sites (Mahabaleshwar, Hyderabad, Mysore, Mesra, Bhopal, Bikaner, Shyamnagar, and Jorhat) for the period from January 2019 to December 2019 are reported. Only 6 months (Jan-June19) of samples were analyzed for Jorhat and Shyamnagar, followed by Bikaner for 3 months (Jan-Mar19) and Rohtak for 2 months (Jan-Feb 19), due to instrument breakdown and COVID 19 lockdown at all the associate institutes (IIT-K, IIT-D, IISERB and IITB).

However, now all the systems are in working condition and the analyses are under progress. A summary of annual average concentrations of Ions for all 8 locations shown in Figure 4.6 which represents a similar seasonal trend throughout the sites, high concentrations were observed during Winter (Jan to Feb) and post-monsoon (Oct, Nov, Dec) and low concentrations during Pre-monsoon (March to May) and Monsoon (June to September). At all the locations, the majority of anionic species (Cl-, NO_3^-, SO_4^{-2}) contributed followed by cationic species (NH_4^+ and K^+) in the atmospheric activities.

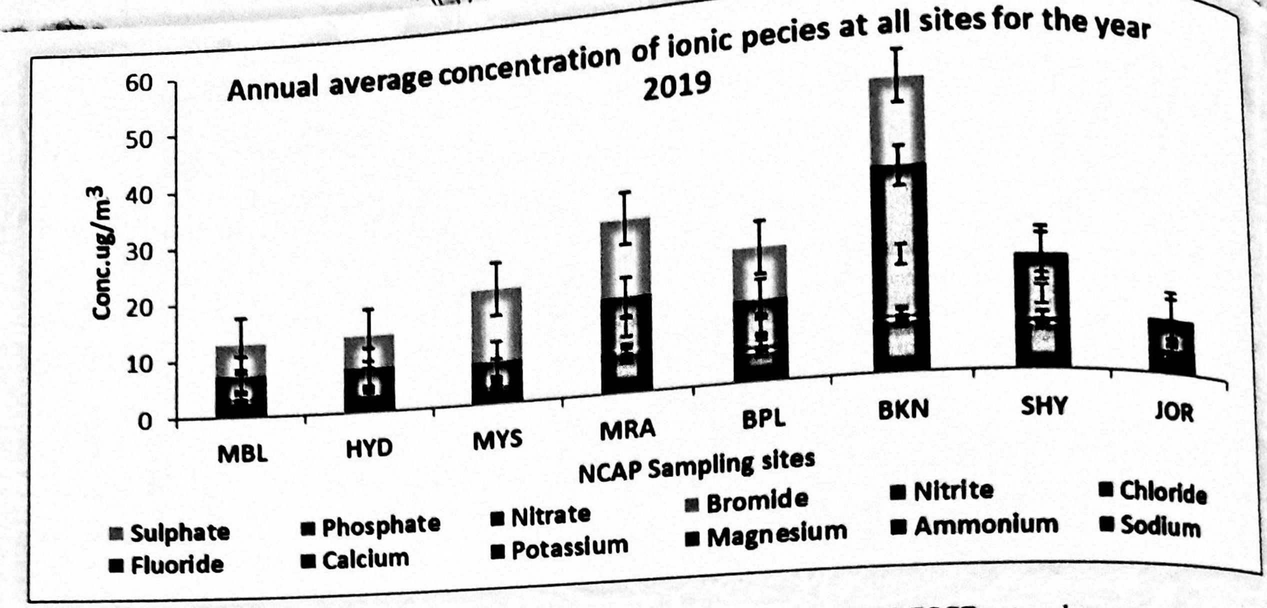


Figure 4.6: Annual average concentration of ions across the COALESCE network

The NCAP-COALESCE sampling sites are distributed across India such as western India (Mahabaleshwar and Bikaner) where major ions found were SO_4^{-2}> NH_4^+>Cl^-> NO^{-3}, whereas in central India (Bhopal) it was observed that it is significantly similar to the western sites. However, Eastern India consists of Shyamnagar, Jorhat, Mesra where the major abundant ionic species found were NH_4^+> Cl^-> SO_4^{-2}> K^+, and southern India with Hyderabad and Mysore showed similar trend with NH_4^+> Cl^-> SO_4^{-2}>NO^{-3}. A similar trend was observed for ionic potassium (K^+) with its annual average concentration being a maximum at Jorhat (0.8 µg m^{-3}), followed by Mesra (0.µg m^{-3}) and Shyamnagar (0.6µg m^{-3}) which may be an indicator of biomass/crop burning.

4.2 $PM_{2.5}$ Mass Concentrations (2020)

The multichannel MetOne Speciation Air Sampling System (SASS) was continued to be used to collect ambient fin particulate matter ($PM_{2.5}$) samples on different filter substrates for the second consecutive year (2020). Mas measurements were done on Teflon® filters from channel 1. Across the COALESCE network, a total of 2299 sample (209 samples*11 sites) including field blanks were targeted during 2020. Sampling was on a hiatus in the middle of 202 (between March to September) at most of the sites due to COVID-19 surge and nation-wide lockdown. At the end 2020, network wide sample collection was 1450 samples (63%) ranging from 208 (100%) samples in Bhopal and (26%) in Mesra and Shyamnagar (Table 4.1).

Table 4.1: Sample collection summary for the year 2020 across COALESCE network sites.

Site	Sampling days(n=209)	Percentage collection (%)	Site	Sampling days (n=209)	Percentage collection (%)
BPL	208	99.5	KMR	194	92.8
MYS	168	80.4	RTK	102	48.8
MRA	54	25.8	MBL	177	84.7
JOR	79	37.8	HYD	112	53.6
SHY	54	25.8	MOH	206	98.6
BKN	96	45.9	Total	1450/2299*	63.1

SCIENTIFIC PROGRESS: WP-3
CLIMATE & AIR QUALITY IMPACTS

5

5.1 Special Hypotheses Simulations (RCM)

5.1.1 Dynamic ageing scheme and region-specific emission inventory in RegCM4

The RegCM is customized to address the two key factors contributing to uncertainty in aerosol radiative forcing - (1) region-specific emission inventory and (2) improved representation of aerosol processes. A dynamic ageing scheme for carbonaceous aerosols is implemented and then implemented an India-specific emission inventory.

The dynamic ageing parameterisation scheme allows conversion from hydrophobic to hydrophilic tracer depending on the aerosol cocnentration, rather than a fixed timeline of 27.5 hrs. A much faster conversion in the polluted regions than in the relatively clean regions. Evaluation of simulated meteorology and aerosol properties with observations suggest the importance of considering a more representative emission inventory. The sensitivity of carbonaceous aerosol distribution to various parameterisation schemes in the model has been explored. In the second step, an India specific emission inventory, for the year 2010, prepared by IIT Bombay at 0.25° ' 0.25° resolution has been incorporated in RegCM4. While the model performance improved by either incorporating the regional inventory or the dynamic ageing scheme, the combination provides the best model-to-observation comparison. The anthropogenic AOD shows an increase of ~40% due to new ageing scheme coupled with region specific emission inventory compared to the default configuration (Figure 5.1). Customization of the model also resulted in an increased burden and surface concentration of carbonaceous aerosols and thus lowered the model-to-reanalysis ratio. This improved model is now being used to study the climate feedback of carbonaceous aerosols over this region.

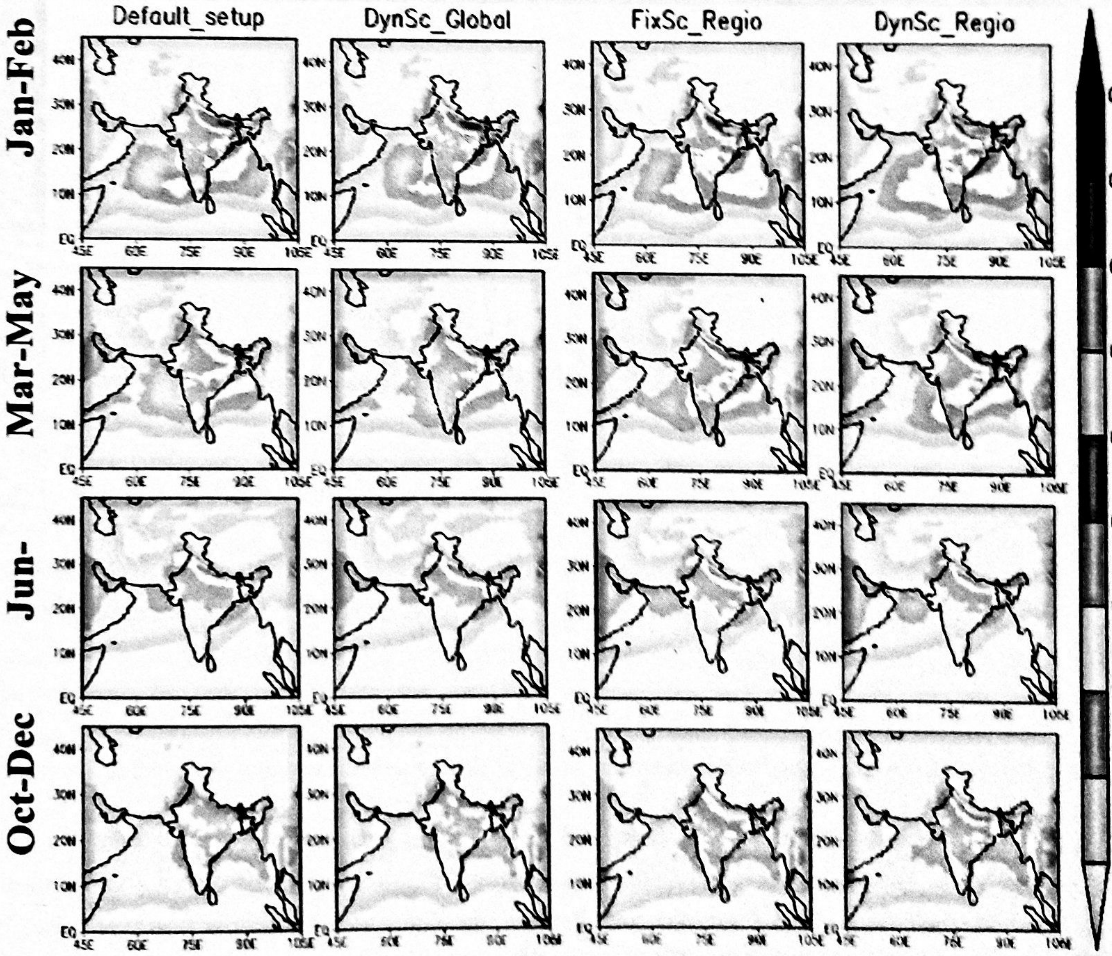


Figure 5.1: Seasonal variation of anthropogenic AOD for the year 2010 for the (1st left) default configuration, (2nd left) dynamic ageing and global emission, (2nd right)fixed ageing and regional emission, (right) dynamic ageing and regional emission inventory

5.1.2 Aerosol radiative feedback on meteorology and pollutant fields: WRF-Chem RADM2

Fully coupled WRF-Chem simulations running in "feedback" and "no radiative feedback" configurations were compared against each other and observations as part of the COALESCE project. In the "no radiative feedback" interactions between the meteorology and chemistry through the aerosol direct effects (absorption and scattering of sunlight) were disabled, with the model reverting to de-facto no-aerosol simulation. Winter months are analysed from the 2015 annual simulations for estimating differences related to feedback effects. The feedback effects cause a decrease in $PM_{2.5}$ which has a larger spatial extent spanning the entire Gangetic plains. The increases in primary aerosol concentrations like black carbon shows increases in NoARI simulation compared with BASELINE simulation. These results are consistent with other studies; however, we need to find out the underestimation of total $PM_{2.5}$ surface concentrations by the inclusion of only aerosol direct forcing. The planetary boundary layer height and surface air temperature shows increases in NoARI compared to the BASELINE simulations. The increases in these meteorological variables causes increases in aerosol concentrations in NoARI run.

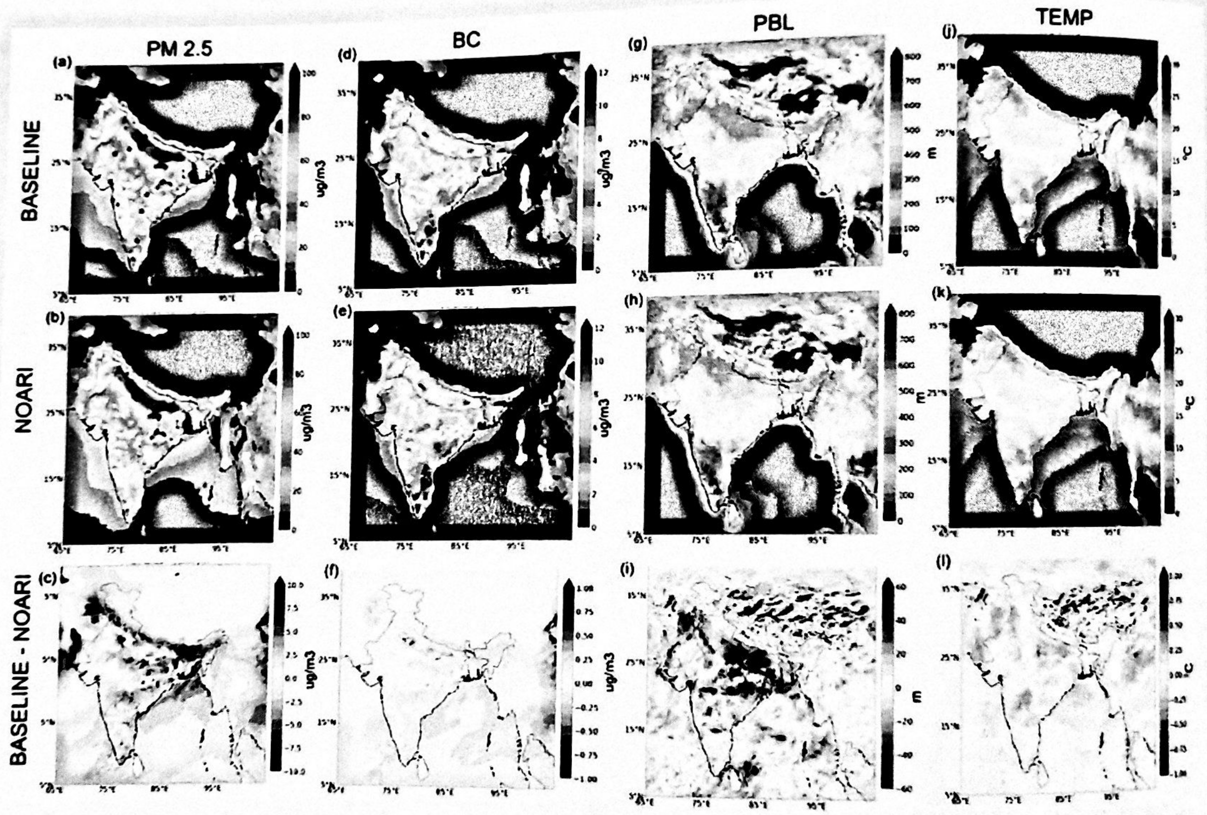


Figure 5.2: Spatial distribution of January average for the south Asian monsoon region is shown for (a, b, c) $PM_{2.5}$; (d, e, f) black carbon; (g, h, i) planetary boundary layer height and (j, k ,l) surface air temperature. The first row shows the mean of BASELINE simulation, the second row shows the mean of NoARI run and the third row shows the difference between BASELINE and NoARI.

5.1.3 WRF-Chem RADM2 and CBMZ chemical mechanisms intercomparison

One year of baseline simulation utilizing Weather Research and Forecasting model coupled with Chemistry with Carbon Bond Mechanism version-Z (Zaveri and Peters, 1999) gas phase chemistry scheme and Model for Simulating Aerosol Interaction and Chemistry (Zaveri et al., 2008) has been completed. The model was run at a high-performance petaflop computing facility available at National Atmospheric Research Laboratory Gadanki, on remote access from IISER Bhopal, with the set-up reported in the previous report. To evaluate simulated results with the observation, CPCB $PM_{2.5}$ data for 22 sites across India have been collected. Also collected are various in-situ measurements for particulate matter ($PM_{2.5}$ and PM_{10}) and PM species e.g., black carbon (BC), organic mass (OC), sulphate (SO_4^{2-}), nitrate (NO_3^-), ammonia (NH_4^+) sodium (Na), chloride (Cl) are requested from different groups (Jain et al., 2018, Kumar and Sunder Raman, 2016) and reported in the literature.

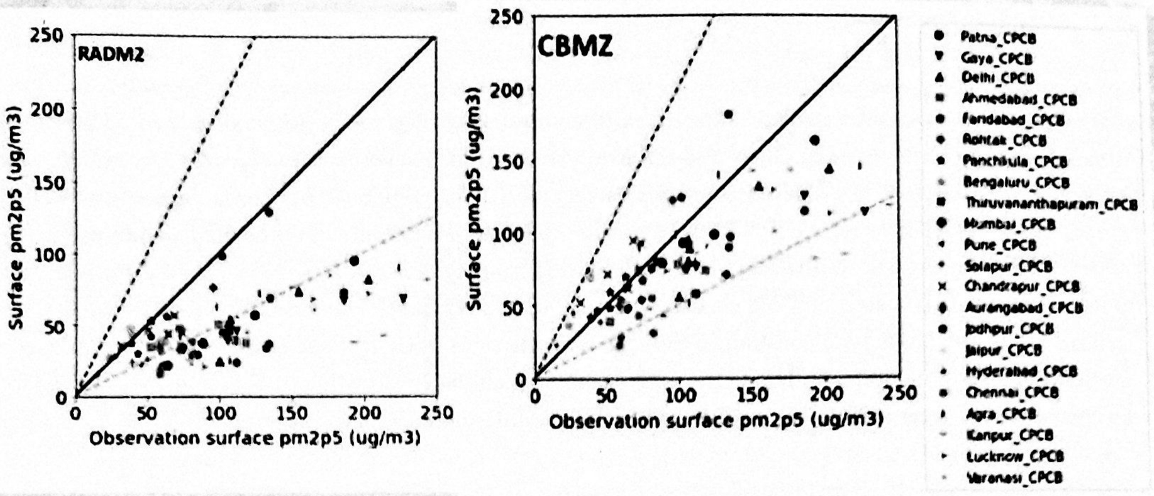


Figure 5.3: Scatter plots showing comparison of modelled dry $PM_{2.5}$ concentration with CPCB in-situ observations (solid black line: 1:1, red dotted line: 2:1, yellow dotted line 1:2)

As a part of model intercomparison study, WRF-Chem (with RADM2 and CBMZ chemical mechanisms) generated dry $PM_{2.5}$ variables were compared with monthly mean CPCB $PM_{2.5}$ data. It was found that both mechanisms compare satisfactorily with CPCB $PM_{2.5}$ data as most of the sites lie between 2:1 to 1:2 slope lines (Figure 5.3).

These baseline simulations will be used for the multimodel intercomparison studies utilizing results from different models participating in WP-3. Multi-model aerosol and gaseous fields are currently being analyzed with the available model results.

5.1.4. WRF-Chimere Radiative Forcing

In the present study we aim to evaluate the efficacy to simulate the aerosol burden (surface concen and aerosol optical depth), modelleed with new emission inventories (constrained and bottom-up) in a chemical transport model, CHIMERE with high performance computing system, and finally to estimate the direct radiative effect (DRE) of aerosols over India. The observationally-constrained emissions or so-called constrained emissions were estimated using integrated forward and receptor modelling approaches. The constrained BC emissions were obtained, modifying the initial or base-line bottom-up BC emissions of the GCM corresponding to the emission source fields of BC, constraining the simulated BC concentration in the GCM with the observed BC. BC transport simulation was carried out in CHIMERE, over Indo-Gangetic Plain (IGP) for the winter month of December, 2015, with a horizontal resolution of 0.1° × 0.1°, implementing constrained black carbon (BC), organic carbon (OC), sulphur-dioxide (SO_2) and PPMr (the remaining part of primary emissions). Simulation experiments were also carried out with recent bottom-up emissions (India-based: Smog-India, and global: Coupled Model Intercomparison Project phase 6 (CMIP6), Emission Database for Global Atmospheric Research-V4 (EDGAR-V4) and Peking University BC Inventory (PKU) extracted over India). A low estimated value of the normalised mean bias (NMB) from constrained estimated BC concentration (NMB: <17%) and aerosol optical depth due to BC (BC-AOD) (NMB: 11%) indicated that simulation with constrained BC emissions could simulate the distribution of BC pollution over the IGP more efficiently than with the bottom-up. The large BC pollution covering the IGP region comprised of wintertime all-day (daytime) mean BC concentration and BC-AOD, respectively, in the range 14–25 (6–8) $\mu g\ m^{-3}$ and 0.04–0.08 from the simulation with constrained emissions. Finally, DRE due to BC at top and bottom of the atmosphere and at atmosphere was estimated over IGP during winter, with the simulated BC distribution with constrained emissions.

DRE due to BC aerosols was also estimated with constrained emissions, at top and bottom of the atmosphere and at atmosphere over India (6° N to 38° N and 68° E to 99.25° E) for twelve months (January-December), with a horizontal resolution of 0.25° × 0.25°. The observed seasonality in the magnitude of BC concentration was well reproduced by model as seen by comparing the simulated daytime (1000-1600 LT) mean with measured counterparts at sixteen stations allover India showing low normalised mean error (NME), ranging between 11%-22%. A low estimated value of the NME from Constrained estimated sulphate concentration (NME= 15%) and OC concentration (NME= 17%) during December, indicated that simulation with constrained SO_2 and OC emissions in CHIMERE could simulate the distribution of aerosol chemical species pollution over India efficiently. Similarly, an underestimation of 63% and 76% (NME) for sulphate and OC respectively, was observed during December using SMoG-India-COALESCE emissions.

The aerosol optical properties (aerosol optical depth (AOD) and single scattering albedo (SSA)), simulated during winter and pre-monsoon period were also evaluated with respect to observed data available from MODIS and AERONET, over India. India based bottom up emission: SMoG-India and constrained emission were used in a high resolution (0.25° × 0.25°) chemical transport model- CHIMERE for simulating AOD and SSA ultimately. A comparatively low estimated value of the normalised mean bias (NMB<15%) and root mean square error (RMSE<0.24) from constrained indicated that CHIMERE could simulate the AOD over India more efficiently with constrained emission than with SMoG emission during winter. Simulated monthly mean modeled SSA at 500 nm is compared relatively well(bias<20%) with AERONET SSA thus indicating that relative distribution of scattering to absorbing aerosols are reasonably consistent in the model.

5.2 Multimodel GCM Intercomparison: Standard Simulations–I

The standard simulations were made with three models ECHAM6.3-HAM2.3, CAM5.3, NICAM-SPRINTARS and analyzed for various aerosol processes as shown in Figure 5.4 below for the 10-year period from 2005 to 2014 with model meteorology nudged towards the ERA-Interim reanalysis data and using SMoG-India-v1 aerosol emission inventory data for India merged with global emission inventory developed for the IPCC-CMIP6 simulations

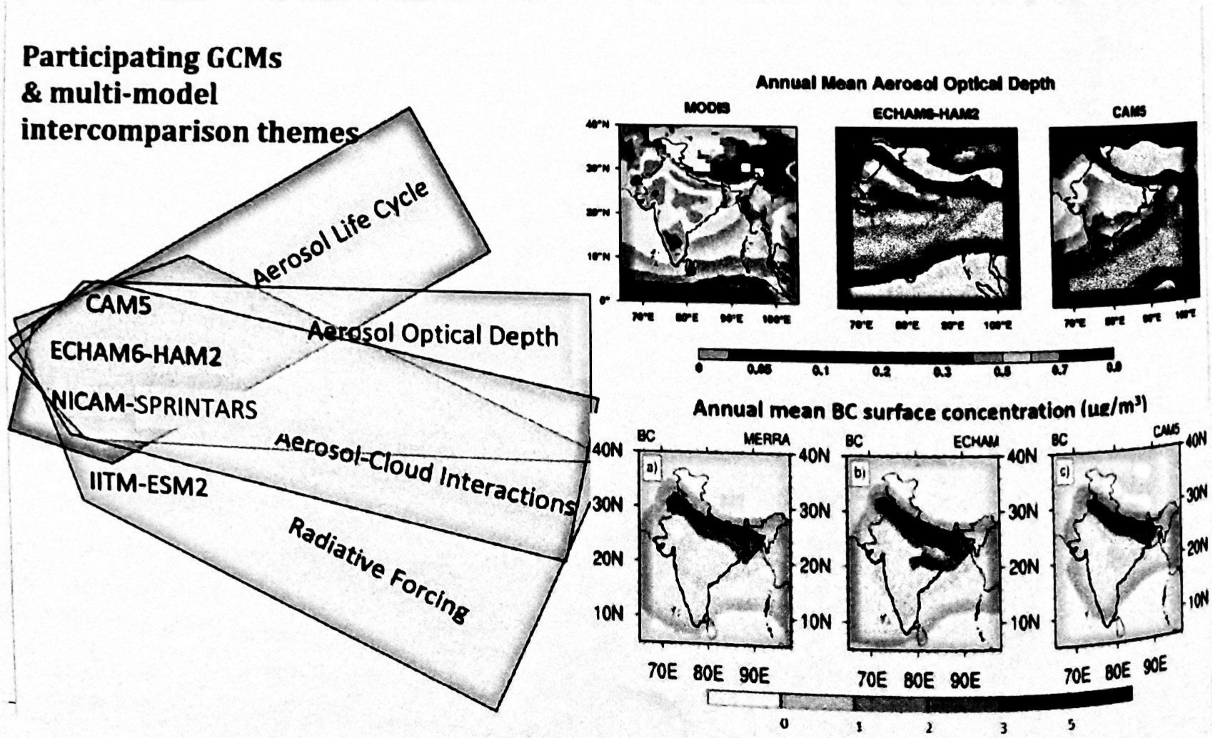


Figure 5.4: Participating GCM models and multi-model intercomparison themes

5.2.1. Model Intercomparison and Simulation of Aerosol Surface Concentrations

Figure 5.5 shows a comparison among aerial means of surface concentrations of different species estimated by MERRA-2, and simulated by ECHAM-HAM, CAM5 and NICAM-SPRINTARS during four seasons over Indian landmass. In this figure every three months is considered a season and consequently December-January-February as winter, March-April-May as spring, June-July-August as summer and September-October-November as autumn are considered to generate four subfigures. In those subfigures (for each season) areal average of 10 years (2005-2014) data of different species are plotted with different symbols. The year-to-year standard deviations of each species for each dataset are shown by small black vertical lines in Figure 5.5. The standard deviations are very low compared to their corresponding mean values. It implies that no significant inter-annual variations exist in surface concentration data. Most of the models underestimate aerosol surface concentrations (Solazzo et al., 2012). However, carbonaceous aerosols are overestimated by ECHAM-HAM (BC and OA) and NICAM-SPRINTARS (only BC). ECHAM-HAM has very low biases for OA (2%). For BC, NICAM-SPRINTARS gets the lowest bias (21%) among the models.

The high values of BC and OA (ug/m^3) is a signature of agricultural waste burning during autumn to spring (Figure 5.5) because of widespread burning associated with decreasing PBLH during this season. For BC predictions, minimum deviations are shown by NICAM-SPRINTARS during all the seasons except JJA. The deviations are 5% and 15% during autumn and winter respectively. Natural aerosols are emitted from desert surfaces (dust), and oceans (sea-salt). Dust emission flux increases with wind fields above a threshold. No dust is produced when wind speed is below the threshold value, which is regionally varying with soil property. Dust concentrations as well as dust lifecycle are highly dependent on water cycle and atmospheric circulations which is controlled by the surface warming (Tegen and Schepanski, 2018). Thus dust concentrations show a highest seasonal variability with higher values during spring and summer (Figure 5.5).

All the models underestimate SS concentrations compared to MERRA-2 (Figure 5.5). Lower sea-salt emission in ECHAM-HAM, and NICAM-SPRINTARS than that in CAM5 results in lower sea-salt concentrations in ECHAM-HAM, NICAM-SPRINTARS as compared to CAM5.

It is difficult to diagnose secondary aerosol formations by the models (Glib et al., 2021). For sulfate (SO_4) concentrations, which is mainly produced by oxidation of SO2, is underestimated by 1-7% (surface concentrations) during MAM, JJA, and SON compared to MERRA data in ECHAM-HAM (Figure 5.5).

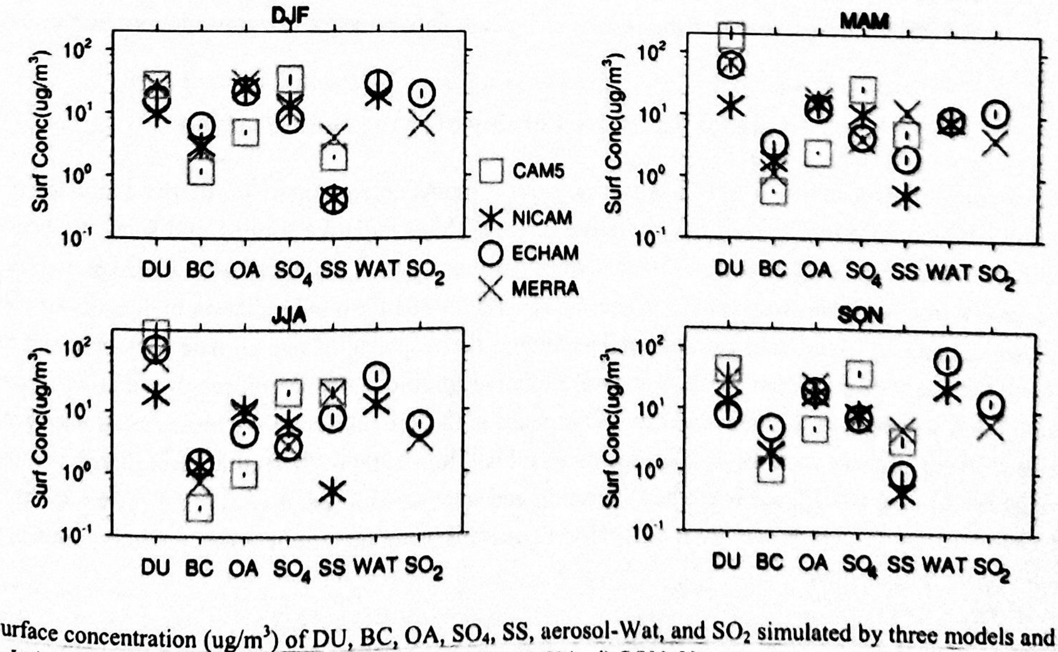


Figure 5.5: Surface concentration (ug/m^3) of DU, BC, OA, SO_4, SS, aerosol-Wat, and SO_2 simulated by three models and MERRA-2 data over Indian Landmass at four seasons (a) DJF, b) MAM, c) JJA, d) SON. Year-to-year standard deviations of individual species simulated by each model are shown by the black lines.

5.2.2. An Analysis of Variation of Aerosol life Cycles among three GCMs over the Indian Region

In this study, mean aerosol life-cycle, columnar and surface mass concentration, vertical dispersions of different aerosol species over India are calculated and discussed from simulations of three GCMs, i.e., ECHAM6.3-HAM2.3, CAM5.3, NICAM-SPRINTARS, during 2005-2015. The models are able to capture the observed columnar loading with acceptable deviations over Indian region. The main reason behind these deviations for anthropogenic aerosols are underpredictions of organic aerosols (OA) by ECHAM and CAM5, and overprediction of sulfate by CAM5 and NICAM-SPRINTARS. Higher removal rate in CAM5 results in a lower life span and lower burden of carbonaceous aerosols. An implementation of observation based OA to organic carbon (OC) ratio over India improved the total aerosol optical depth over India. It suggests an implementation of spatially varying OA/OC ratio in the GCMs. The corrections in parameterization of dust emissions in ECHAM-HAM improved dust concentrations and aerosol optical depth over India. A lower removal rate increased lifespan of natural aerosols in NICAM-SPRINTARS. It is related to the aerosol size distribution in this model and could be improved. Comparison with the in situ measurement suggests that model performance in estimating particulate matter is better in south, east and west India compared to that in north India. Vertical dispersions are higher near sources. Seasalt shows a horizontal dispersion from the western boundary of India. Both natural aerosols show west to east decreasing trends, whereas anthropogenic aerosols show opposite trends..

5.2.3. Comparison of Aerosol Optical Depth among three GCMs over the Indian region

Various optical properties such as aerosol optical depth (AOD), single scattering albedo (SSA) and angstrom exponent (AE) determine how aerosols interact with incoming and outgoing longwave and shortwave radiation. Detailed investigation of these aerosol optical properties, including their spatial and temporal distributions, would be very useful to better quantify the aerosol–radiation interactions. Three GCMs participating in the WP3 exercise simulated these properties for the period 2005-2014. All models show prominent pattern in IGP region; NICAM-SPRINTARS shows high AOD value over south India. It is important to carry out comparison exercise between various models and observation and further interpretation of the results using calculation methodologies adopted by these GCMs. The work is in progress.

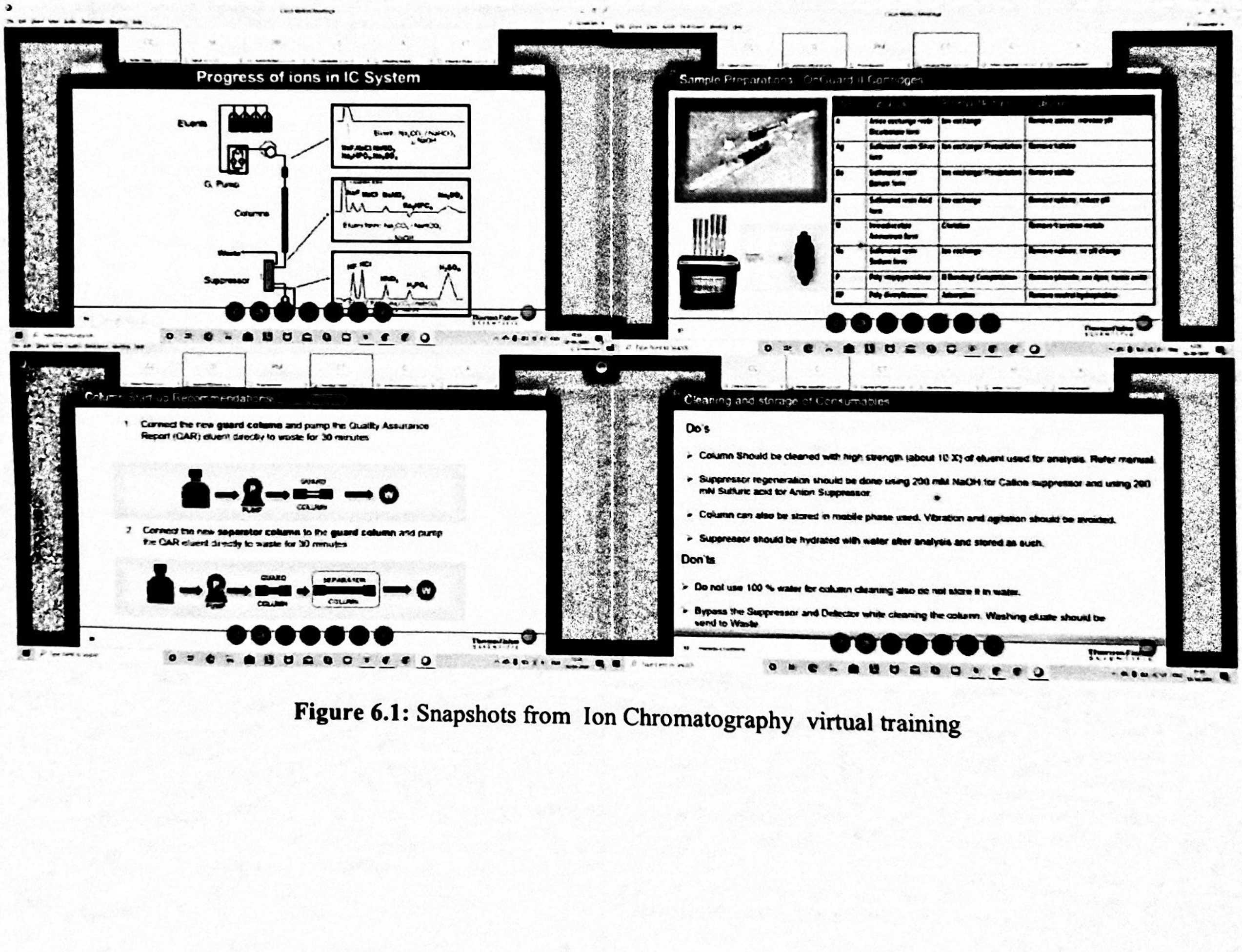
5.2.4. Comparison of Aerosol Radiative Forcing over the Indian region

One of the research objectives of WP-3 is to carry out a model intercomparison of the estimates of aerosol radiative forcing and its decomposition in to direct radiative forcing, cloud radiative forcing and surface albedo radiative forcing over the south Asian region. The purpose of this work is to understand the effect of the change emission of aerosols and their precursors from pre-industrial (1850) to present day (2005-2014) on the radiation budget of our planet, referred to as radiative forcing, as an initial step towards understanding the response of our climate system at the regional (eg. south Asian monsoon) as well as global scale to aerosol radiative forcing. The differences in radiative forcing estimates from different models will help us to understand the differences in the complexity of the representation of aerosols, clouds, and chemistry schemes in these models. The annual mean climatology (2005-2014) of aerosol direct radiative forcing (DRF), cloud radiative forcing (CRF), surface albedo forcing, and total aerosol radiative forcing (TRF) at top of the atmosphere (TOA) estimated by CAM5.3 and ECHAM6-HAM2 models over the south Asian region. More results with greater details are being investigated.

TRAINING AND OUTREACH 6

6.1. Workshop on Ion Chromatography

Virtual Ion Chromatography training over WebEx was organised on June 2, 2020 under Work Package - 2 for 16 participants. The training was conducted by Thermofisher Scientific India Pvt. Ltd. covering instrument overview, chemical analysis procedure, Do's & Don'ts, instrument maintenance & troubleshooting. Snapshots from the training are shown in Figure 6.1.



1 Connect the new guard column and pump the Quality Assurance Report (QAR) eluent directly to waste for 30 minutes

2 Connect the new separator column to the guard column and pump the QAR eluent directly to waste for 30 minutes

Do's

- Column Should be cleaned with high strength (about 10 X) of eluent used for analysis. Refer manual.
- Suppressor regeneration should be done using 200 mM NaOH for Cation suppressor and using 200 mN Sulfuric acid for Anion Suppressor
- Column can also be stored in mobile phase used. Vibration and agitation should be avoided.
- Suppressor should be hydrated with water after analysis and stored as such.

Don'ts

- Do not use 100 % water for column cleaning also do not store it in water.
- Bypass the Suppressor and Detector while cleaning the column. Washing eluate should be send to Waste

Figure 6.1: Snapshots from Ion Chromatography virtual training

7 DEVELOPMENTS UNDER DELVE

7.1 Data Portal (DELVE)

The Data Exploration analysis Visualization and Extraction (DELVE) system was launched in November 2018. The URL of the website is https://ncapcoalesce.iitb.ac.in. The latest advancements to the portal include an updated Graphic User Interface (GUI) for data sharing, analysis and visualisation features implemented for sector-wise WP-1 Survey data (Figure 7.1) and data upload and download feature for Network observational data (Figure 7.2). Analysis and visualisation features are currently being implemented for WP-2 instrument data.

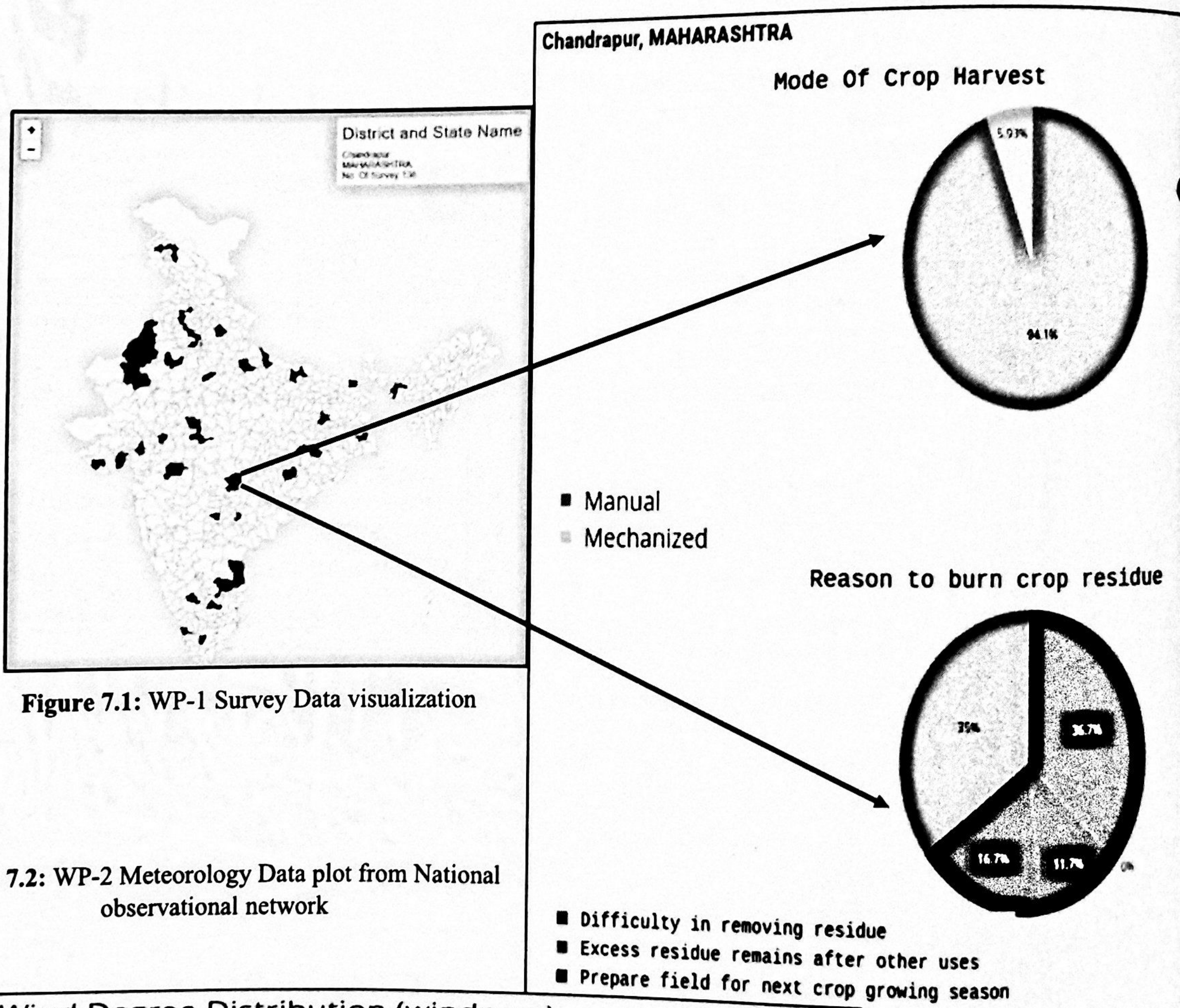


Figure 7.1: WP-1 Survey Data visualization

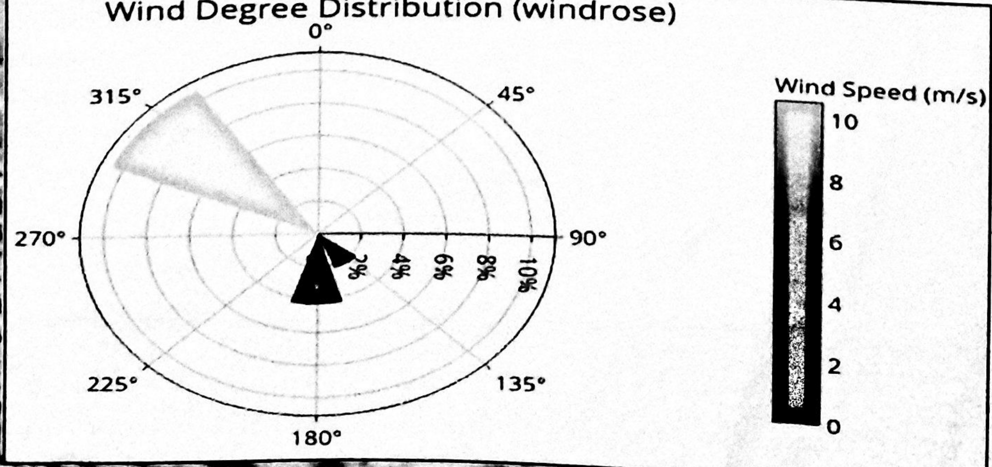
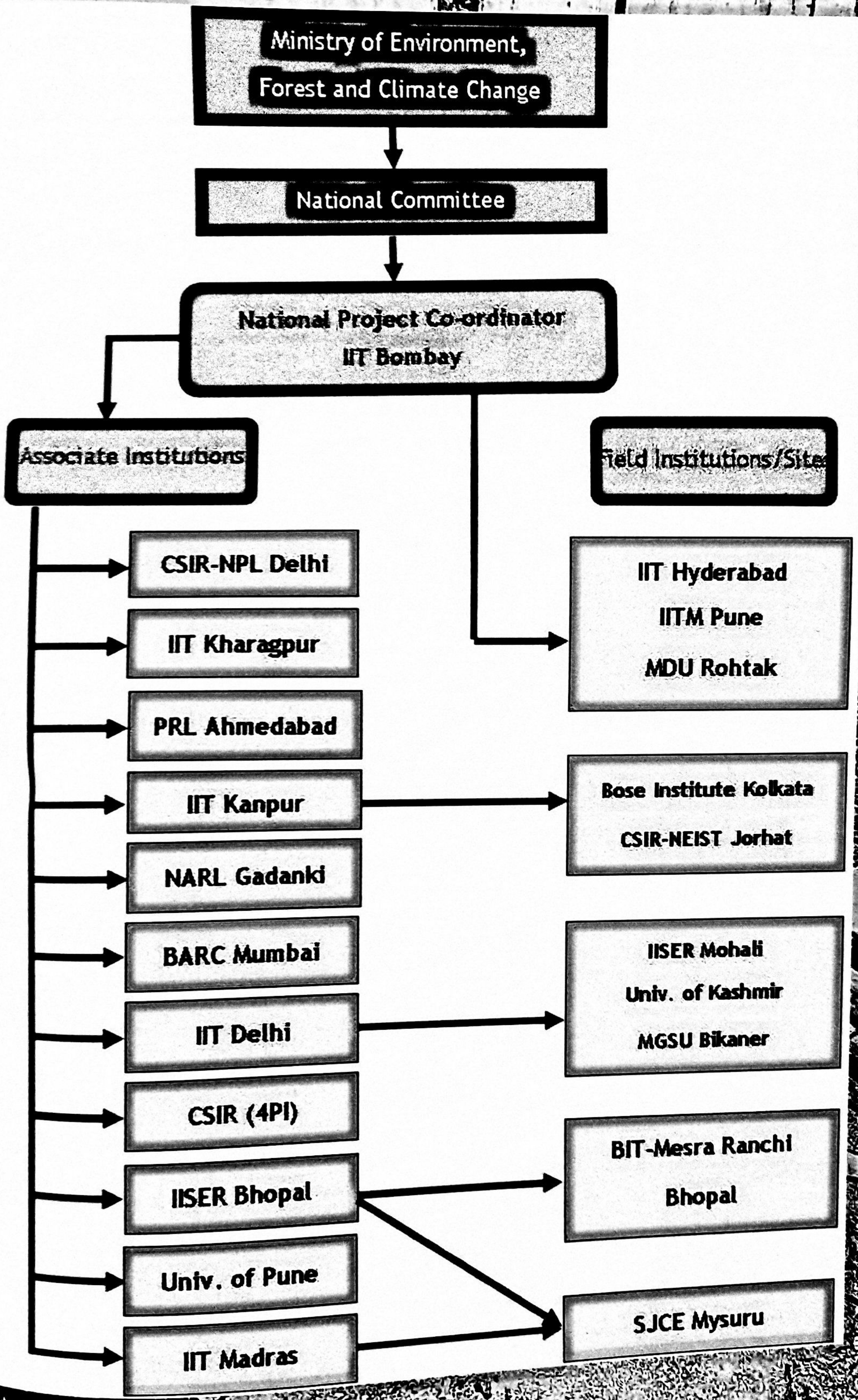


Figure 7.2: WP-2 Meteorology Data plot from National observational network



Ministry of Environment, Forest and Climate Change

National Committee

National Project Co-ordinator
IIT Bombay

Associate Institutions

Field Institutions/Site

CSIR-NPL Delhi

IIT Kharagpur

PRL Ahmedabad

IIT Kanpur

NARL Gadanki

BARC Mumbai

IIT Delhi

CSIR (4PI)

IISER Bhopal

Univ. of Pune

IIT Madras

IIT Hyderabad
IITM Pune
MDU Rohtak

Bose Institute Kolkata
CSIR-NEIST Jorhat

IISER Mohali
Univ. of Kashmir
MGSU Bikaner

BIT-Mesra Ranchi
Bhopal

SJCE Mysuru

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MEMORANDUM OF UNDERSTANDING

The Memorandum of Understandings (herein referred to as MOU) is made between

Mohanlal Sukhadia University, a UGC recognized, Autonomous State University of Government of Rajasthan established by an Act in 1962, having its headquarters at Udaipur, represented through Registrar which expression shall repugnant to the context of meaning thereof includes its successors and permitted assignees of the FIRST PARTY

AND

Maharaj Ganga Singh University, a UGC recognized, Autonomous State University of Government of Rajasthan established by an Act in 2003, having its headquarters at Bikaner, represented through Registrar which expression shall repugnant to the context of meaning thereof includes its successors and permitted assignees of the SECOND PARTY.

The First and the Second Party, Collectively also referred to as the `Parties`

WHEREAS, The Mohan Lal Sukhadia University was established by Government of Rajasthan by an Act in 1962, to cater the needs of people of South Rajasthan. It has 13 departments under four constituent colleges of which the Department of Geology under the College of Science is one.

AND WHEREAS. the Mohanlal Sukhadia University was established to provide knowledge and quality education to all sections of the society. Its prime goal is intellectual and academic development of society and students.

WHEREAS, The Department of Geology under the College of Science is having a Research Project sponsored by the Seismology Division of the Ministry of Earth Science, New Delhi for establishment of Permanent Global Positioning Receiver Stations at four sites in Rajasthan as a part of the National Network of GPS Receivers and Bikaner is one of the selected locations.

WHEREAS, The Maharaj Ganga Singh University was established by Government of Rajasthan by an Act in 2003, to cater the needs of people of North Rajasthan. It has 5 departments of which the Department of Environmental Sciences is one.

AND WHEREAS the Maharaj Ganga Singh University was established to provide knowledge and quality education to all sections of the society. Its prime goal is intellectual and academic development of society and students.

WHEREAS both the parties and their respective departments viz. the Department of Geology at Mohanlal Sukhadia University and Department of Environmental Sciences at Maharaja Ganga Singh University at Bikaner have recognized the potential of being the part of the National Network of Global Positioning Receivers.

Now this Deed of MoU witnessed is as follows:

Objectives:

To collaborate in establishing a Permanent Global Positioning Station in the campus of Maharaja Ganga Singh University, Bikaner, this will be a part of National Network of GPS receivers.

Scope:

1. The Global Positioning System collects data from the satellites which can be used for the study of crustal movements, atmospheric behaviour, weather forecasting etc.

Modalities of working:

1. The Principal Investigator and the Co Principal Investigator of the sponsored project at Mohan Lal Sukhadia University, Udaipur will coordinate with a nominated Coordinator from Maharaja Ganga Singh University, Bikaner for the identification of GPS Receiver site as per the norms, its construction as per the design and the existing BSR Rates and its maintenance and safety during the duration of the project.

Funding:

1. The funding for the construction and contingencies for the Receiver site will be provided by the Mohan Lal Sukhadia through the funds received by them by the Seismology Division of the Ministry of Earth Science, New Delhi.
2. A sum of Rs 3000.00 per month will be sent to the Coordinator at Maharaja Ganga Singh University, for the Ward and Watch of the GPS Receiver site at their campus.
3. All stations establishing under National GPS program are permanent. Therefore, the operation and maintenance of the station will be in continuous mode for long run.

Data Sharing:

1. Regarding data sharing policies, the data may be shared among Indian Scientists but it should not be shared with any private/ foreign agency without prior approval of the Ministry

Applicabe Law:

The MoU shall may be governed, construed and enforce in accordance with the laws of India.

Witnesses:

In witness whereon the Parties hereto have signed and executed this Meomrandum of Understanding at ________ on the 31 Day of May, 2012, in the presence of each other and in presence of attending witnesses.

For on behalf of ML Sukhadia University
University

(Mr L.N. Mantri)

Registrar

Registrar
MOHANLAL SUKHADIA UNIVERSITY
UDAIPUR

ML Sukhadia University

For on behalf of Maharaja Ganga Singh

7/5/2012

(Mr ARVIND SINGH)

Registrar

Registrar
M.G.S. University,
Bikaner (Raj.)

Maharaja Ganga Singh University

Witnesses:

1.____________________________ 2.____________________________

3.____________________________ 4.____________________________