Radio and Atmospheric Sciences
Dr M.V.S.N. Prasad
Chief Scientist, Email: myprasad@nplindia.org

D 03.01 Radio Science
Dr M V S N Prasad
Dr Arun Kumar Upadhyaya
Dr Rupesh M Das
Ms Beena Gupta
Sh Man Mohan Gupta
Ms Susriti Tiwari Singh

D 03.02 Atmospheric Science
Dr Bhuwan Chandra Arya
Dr Meena Jain
Dr Chhamendra Sharma
Dr Tuhin Kumar Mandal
Dr Sachchidanand Singh
Dr (Ms) Monika Jain Kulshreshta
Sh Ashish Ranjan
Dr. Sunil Kumar Mishra
Dr Sudhir Kumar Sharma
Dr Rajesh Agnihotri
Dr. Radhakrishnan S.R
Sh Arun Kumar Ghoghar
Sh. Shambhu Nath
Ms Shiva Kumari Bhatia
Sh Vinod Kumar Sharma
Sh Alok Mukherjee
Radio and Atmospheric Sciences

The Radio and Atmospheric Sciences Division (RASD) of NPL caters to the scientific needs of the nation in the areas of radio science and applications, space weather and ionosphere, chemistry and physics of the earth atmosphere, atmospheric pollution and climate change etc. The major research areas are: (i) Radio Science, and (ii) Atmospheric sciences. Atmospheric science involves study of Atmospheric chemistry, Spectroscopy of Atmosphere, simulation and modeling for atmospheric physics.

Radio Science

RASD has unique group in India which is involved in the characterization of the ionized, non ionized tropospheric media and the near earth radio environment using radio wave propagation for the purpose of betterment of radio communications, navigation and other advanced applications. This consists of radio channel measurements and modeling for fixed and mobile communications, generating new data sets in VHF and UHF frequency bands, development of models over various regions of India and interaction with various user agencies. Monitoring and modeling related to ionospheric / tropospheric parameters using satellites and ground based systems including GPS, Tomographic Receivers, Ionosonde, etc., are also being carried out. Division also provides ionospheric forecasting/nowcasting to users worldwide through space weather Regional Warning Center (RWC, NPL-India) and have consistently improved the International Reference Ionosphere (IRI) model through model comparisons with observed data. Ground based techniques like ionosonde, GPS receivers are being utilized to study polar ionosphere through Antarctic scientific expeditions.

Atmospheric Sciences

The atmospheric science group of RASD is engaged in developing the Greenhouse gas (GHG) inventory from different sources, emission estimates of particulate matter (PM) and trace gases (SO₂, NO and NOₓ) from biomass fuels consumed in rural sector of our country, emissions from land fills and wheat and rice crop fields etc. At the same time group also carry out chemical characterization using state-of-the-art techniques and source apportionment of particulate matter (PM) and precursors for different regions in the country, including the surrounding oceans, Himalayas and poles. This group also studies the atmospheric ozone, its chemistry and dynamics using various models and observations.

A wide range of information about the atmospheric aerosols, trace gases, solar radiation and their interactions is generated by conducting spectroscopic measurements of the atmosphere in the UV, Visible and NIR-IR spectral range. It enables the optical and physical characterization of the atmospheric aerosols and help in identifying the trace chemical constituents in the gas samples or in the atmospheric column. The high resolution Open-Path FTIR, micro-pulse LIDAR are the recent modern equipments that supplement the study of aerosol optical depth, vertical profile of aerosols, aerosol size distribution, scattering and absorption coefficients of aerosols, single scattering albedo (SSA), effect of aerosol shape and size on optical properties, chemical characterization, etc. A ozone standard has been added in the division for traceability of measurement and other purposes. Mathematical modeling is an integral part of all the activity groups in the division, and the objective of this is to assimilate the various data sets generated in the division and elsewhere to simulate and model the atmospheric processes.
3.1 Radio Science

3.1.1 New data set generation for verification of electromagnetic macro model for path loss prediction in cellular communication systems

Cellular operators providing services in GSM bands of 900 & 1800 MHz extensively use radio planning tools for the design of cellular systems. The reason that the 0.8 to 2.1 GHz cellular band was chosen for mobile broadband is that the reflection from buildings is negligible, and yet the signals can penetrate buildings and terrain and do not significantly bounce inside the rooms. In order to investigate the variation of path loss exponent/path loss in the near and far field regions of GSM base stations extensive experimental investigations utilizing 36 base stations have been conducted in the Maharashtra and Goa regions of Western India. In Goa region experiments were conducted in Panjim city (5 base stations) and in the Maharashtra region measurements were conducted in the cities of Aurangabad (5 base stations), Pune (15 base stations), Nagpur (6 base stations), Kolhapur (5 base stations). Out of the total 36 base stations used in the study 10 stations operated on 1872 MHz and the remaining 26 operated on 900 MHz.

The transmitting power of all base station is 40dBm and transmitting gain is 8dBi for all base stations. The gain of the receiving antenna is 0 dB and the height is 1.5m. Near field distance increases with frequency and with base station antenna height. The receiver is standard Nokia equipment used in drive in tools for field trials. The position of the mobile is determined from the GPS receiver and this information with the co-ordinates of the base station was utilized to deduce the distance traveled by the mobile from the base station. The signal strength information recorded in dBm was converted into path loss values utilizing the gains of the antenna.

The observed path loss values were utilized to deduce path loss exponents for each base station as a function of distance. The variation of path loss exponent has been studied in the near and far fields of base station. The general trend observed in the case of base stations with large values of $h_s$ ranging from 35-60m is the fall of exponent from high values of 8 at distances close to transmitter to values slightly below 3, fluctuates and settles to a value of 3 and increases to a value of 4 after some intermediate distances. In the case of base stations with low $h_s$ values more or similar trend is observed, but the difference comes in the slightly higher value of settled exponent. In all the cases exponent falls to a value of 3 at distances of 200-250m. A typical variation of path loss exponent in the case of Panjim city is shown in fig 3.1 which follows the above description. The increase in path loss exponent values is observed after some intermediate distances of 1500-2500 m. It is advisable to go for smaller base station antenna heights to reduce the near field zones.

In this study, it is shown that a physics based electromagnetic macro model can provide accurate data for the path loss exponent in a cellular network using electromagnetic simulation tools that depend only on some physical parameters of the macro model. The deployment of electromagnetic macro model has been carried out in collaboration with Syracuse University, USA. In a macro model, one needs to include only the electrical parameters of the environment without including the clutter effect factors such as buildings, trees and so on. Figure

Fig. 3.1: Variation of path loss exponent as a function of distance for Panjim base station
3.2 plots the field strength as a function of the radial distance for different height of the antenna above the ground. In this figure, it is seen that near the transmitting antenna there is an interference between the direct space wave and the field from the image produced by the imperfect ground, providing variation of the total field strength. This is often labeled as fading. There is a height gain in the far field of the antenna but in the near field which is of importance in cellular communication there is actually a height loss. Hence, it is proposed that a better solution will then be to deploy the transmitting antenna closer to the ground. In that case the region of the variation in the field strength would be quite small and the field strength will decay monotonically inside the remainder of the cell minimizing fading.

3.1.2. Ionspheric Studies

3.1.2.1 A statistical analysis of occurrence characteristics of Spread-F irregularities over Indian region

We have investigated the regularities of a change in spread F probability during day-to-day, under varying solar variability, latitudinal behavior and their response to geomagnetic storm in equatorial and low-mid latitude stations. The occurrence characteristics of Spread-F irregularities, is obtained from daily hourly ionosonde data from a low-mid latitude station, Delhi (28.6°N, 77.2°E), for more than half a solar cycle (2001 to 2007). The latitudinal behavior of Spread-F is studied using ionosonde data from anomaly crest station, Ahmedabad (23.01°N, 72.36°E) and equatorial station, Kodaikanal (10.2°N, 77.5°E) for low, moderate and high solar activity periods. The maximum percentage occurrences of Spread-F were observed during the low solar activity year 2007, we believe, the low plasma and neutral density during 23/24 solar cycle minimum could be an important factor leading to the generation and propagation of TIDs and gravity waves. Figure 3.3 shows the local time behavior of percentage occurrence of spread-F during different seasons at Delhi station.
3.1.2.2 Ionospheric F2-region: Variability and sudden stratospheric warmings

The possibility of links between the meteorological phenomena and the upper atmosphere have been discussed very profoundly during the last two decades. We therefore investigate the extent of ionospheric changes following SSWs of 2007, 2008 and 2009 using ionosonde data from six different stations in the Asian zone thus covering a broad latitudinal range from 23.2°N to 45.1°N. We find that ionospheric F2-region shows some significant perturbations soon after the start of the warming. However characteristics of these perturbations vary from event to event and from station to station. We also examine the data on equatorial electrojet strength (EEJ) during these warmings and find there are significant changes in the EEJ strength during the SSW events. The following conclusions are drawn from the analysis.

1. There are perceptible ionospheric perturbations which can be linked to warmings.
2. These perturbations are in the form of enhancements and depressions in foF2 resulting in peak electron density variations which could be larger than 200% when compared with the normal magnetically quiet time ionosphere.

3. The low latitude station Okinawa (26.6°N, 121.8°E) showed semidiurnal ionospheric perturbations during the SSW event of 2009, a feature previously reported from the total electron content measurements. This feature was not found during the SSW event of 2008. On the other hand, the “EIA Crest” station Bhopal (23.29°N, 77.46°E), showed some evidence of 6-hour periodicity in ionospheric changes during the SSW event of 2007.

3.1.2.3 Systematic study of latitudinal ionospheric response to the geomagnetic storm occurred during 7th and 9th March 2012.

Global ionospheric responses to the geomagnetic storms are not homogeneous. The present work is an attempt to explore the spatial and temporal behaviour of earth’s ionized media over the southern hemispheric region during the geomagnetic storm events observed on 7th and 9th March 2012. The Ionospheric Total Electron Content (ITEC) observed with the help of South American GPS network has been utilized. The
geophysical conditions reveals that the first storm commenced on 7th March 2012 at around 0100 UT having which was lower in magnitude with respect to the second storm observed on 9th March 2012 at 1200 UT. The recorded maximum negative excursion in Dst-index is -74nT and -131nT respectively for 7th March and on 9th March 2012. However, enhanced AuroralElectrojet (AE) confirms the electro-dynamic disturbances at auroral zone during the above said period.

The analysed TEC results shown in Fig 3.4 confirm that the expansion of Equatorial ionospheric anomaly(EIA) along with state of ion density over mid latitude region was not only affected by equatorial electrojet (EEJ) strength but also by the direction of neutral wind. On the basis of different combinations of equatorial and high latitude dynamics, the results are classified and explained in two different parts.

The first part covers the process involved on 7th March 2012, when the EEJ strength is slightly lesser than that of the normal day and the AE-index is at moderate level. The combined effect of weaker EEJ and moderate AE-index leads to become favourable for equator-ward transportation of plasma which limits latitudinal expansion of EIA as compare to normal day. The consequences are clearly observed in analysed ITEC parameter over equatorial to high latitude region. The spatial and temporal behaviour of ITEC shows positive effect at equatorial and near equatorial region with simultaneous depletion at low-mid latitudes. On the other hand, elevated AE is responsible for day time equator-ward neutral wind and drives the transport of plasma from higher latitude to low latitude region along with the slope of geomagnetic field lines. Furthermore, the slope of mid-latitude geomagnetic field lines uplifts the plasma at higher altitudes.

*Fig. 3.4: Storm days along with control day Ionospheric total electron content variation over different geographic locations*
where the recombination rate is very low and cause to enhance the ITEC value over mid latitude region. The observed enhanced ITEC at high latitudes followed by depletion supports the above explanation.

The second part shows the modified ionospheric spatial and temporal variation under storm modified equatorial and high latitude electrical conditions. Reversal of EJ or occurrence of Counter electrojet (CEJ) over equatorial region along with significantly higher AE-index has been registered on 9th March 2012. This combination provided a unique opportunity to study the latitudinal behaviour of earth’s ionosphere when an unusual negative force is acting over the equator. Presence of CEJ prevented the formation EIA and shows enhanced ITEC value at equatorial region coincides with time of ion diplication over low and low mid-latitude region. Finally, the work confirms that the geomagnetic storms are responsible to perturb equatorial and high latitude dynamics in various ways and modifies the normal spatial and temporal behaviour of Ionosphere.

3.1.3 Research Activities at Antarctica:

CSIR-National Physical Laboratory has been participating regularly in the Indian Antarctic Expedition to conduct scientific research in the area of Upper and Lower atmosphere. During the year 2013-14, two Research Proposals were accepted from the CSIR-NPL, to participate in the 33rd Indian Scientific Expedition to Antarctica (33-ISEA). The titles of the proposals are: (1) Impact on Space-weather events on Polar Region Ionosphere, and (2) To study the Aerosol radiation forcing over the Antarctic region by measuring Aerosol properties and Radiation. The main aim of the proposed study are: (1) morphological study of Polar region Ionosphere i.e. day to day behavior of different ionospheric parameters like bottom side ionospheric plasma density, variation of critical frequency and height of different ionospheric layers, (2) investigation of solar wind – thermospheric - magnetospheric-ionospheric coupling over polar region during high solar activity period with special emphasis on adverse space weather conditions, (3) collection data for Aerosol Optical Depth, radiation flux in the UV and broad band and absorbing aerosol (BC) and (4) to obtain Aerosol Radiative properties including radiative forcing at Antarctica.

3.2 Atmospheric Sciences

3.2.1 CSIR Network Project “Probing the Changing Atmosphere and its Impacts in Indo-Gangetic Plains (IGP) and Himalayan Regions [AIM – IGPHim]”

The CSIR Network Project “AIM_IGPHim” (PSC-0112) is being pursued by the network partner laboratories namely CSIR (CMMACS, CRRI, IHBT, IMMT, NBRI, NEERI & NEIST) with CSIR-NPL is functioning as the nodal laboratory. This project has been initiated by the network partner laboratories to understand the causes of atmospheric changes and the impacts of changing atmosphere on agriculture, human health and bio-diversity in the Indo-Gangetic Plains (IGP) and Himalayan regions which have significant socio-economic bearings for country as a whole. In particular, the project envisages addressing following questions:

- How the atmosphere in IGP and Himalayan regions is changing and what are the major reasons for that?
- What is the magnitude and mechanism of impact of carbonaceous aerosols and dust in modifying atmospheric processes over this region?
- How will the atmospheric processes respond to future anthropogenic perturbations in the region?
- What is the impact of changing atmosphere on crops, flora and human health in IGP and Himalayan regions?

During the year 2013-14, the project activities have started picking up steam to meet the envisaged outcomes of the project. In this direction, a number of activities have been undertaken by the network partners, some of which are listed below:
Radio and Atmospheric Sciences

- NPL teams has visited a number of sites for assessing the feasibility of establishing background monitoring station in Western Himalayan region and has short-listed ‘Purara’ (N 29054.511°, E 79037.549°, height 3856 feet) in ‘Bageshwar’ District of Uttarakhand and Palampur (H.P.) as the potential sites. A final decision has been taken to establish the station at IHBT campus, Palampur (H.P.).
- Patterns of long-distance transport of pollutants have been investigated through back trajectory and forward trajectory analyses for potential background monitoring sites as well Delhi and Bhubaneswar using models like HYSPLIT and TRAJSAT (Fig 3.5)
- Continuous Ambient Air Monitoring System (CAAMS) and Lidar equipment for background atmospheric monitoring have been ordered for installation at proposed background monitoring site.
- Campaign based atmospheric measurements have been carried out in Himachal Pradesh and Thar desert areas along with regular measurements at Delhi.
- Greenhouse gas (GHG) emission inventories have been created for IGP states for transport, energy and waste sectors.
- Weather Monitoring Systems have been installed at Itanagar & Imphal besides sampling of gases and aerosols from coke oven plant site in North-East India have been started.
- T63 atmospheric transport model, MOZART has been setup for modeling of carbon fluxes

Fig. 3.5: Backward trajectory Analysis for pollutants’ transport patterns of Bhubaneswar during different seasons
which would be validated using the measured CO$_2$ values.

- Initial results of the Free-Carbon dioxide Enrichment Experiment (FACE) suggest that wheat crop will perform better under future climate change scenario with respect to elevated CO$_2$.
- Phyto-sociological sampling have been performed to record tree density and basal area in trans-Himalayan region (3658 m amsl) in the District of Lahaul&Spiti (H.P.) for assessment of impact of changing atmosphere on bio-diversity.

### 3.2.2 Estimation of emissions of Carbon dioxide and other Air Pollutants from Diesel Consumption in Cellular Base Stations in India

At present, India is the second largest global telecom market after China. The telecom industry has attracted 8% of the cumulative foreign direct investment over the last two years in India. Indian telecom companies are now starting to make a major impression globally. Indian mobile telecom industry had 584.3 million subscribers in 2010-2011 with an annual growth rate of 49%. However, this growth has bearing on climate due to the CO$_2$ and other air pollutants’ emissions associated with the diesel fuel used in this sector to provide power which is also a dominant cost component for telecom companies. Climate change and air quality are serious concerns caused due to the increasing emissions of Greenhouse gases (GHGs) and other air pollutants. Mobile communication network in India is becoming a significant source of emission in India. This sector had 400,000 Base Transceiver Stations (BTS) during 2010-2011 whose 40% power requirements was met by grid electricity while remaining 60% was met by diesel generators which consumed 4.9% of the total diesel sold in India and emit GHGs. Using the IPCC 2006 and USEPA AP-42 methodology emissions from diesel consumption in this sector have been computed. The results showed that this sector contribute 10308 Gg of CO$_2$, 1.4 Gg of CH$_4$ and 0.08 Gg of N$_2$O in 2010-11. Another estimate showed that only 1.93% of total diesel sold in India was consumed in this sector which has been estimated to emit 4010 Gg of CO$_2$, 0.54 Gg of CH$_4$ and 0.03 Gg of N$_2$O. This leads to a sectoral carbon foot print range of 1.101-2.831 million ton carbons. Estimations from BTS revealed that diesel consumption is also responsible for 22-56 Gg CO, 102-264 Gg NO$_x$, 6.7-17 Gg SO$_x$, and 7-18.5 Gg PM$_{10}$. District wise mobile tower data for the 24 states of India have also been collected which have been used to generate district-wise emission inventory of CO$_2$ for these states of India shown in following figure 3.6. However, as district-wise tower data for remaining eight Indian states could not be obtained by authors, the district wise emission inventory for these states could not be prepared, although the emissions from diesel fuel consumed in BTS in these eight states are also included in the total CO$_2$ emission inventory.

![Fig. 3.6: District wise CO$_2$ Emission from mobile towers in India (Inset figure shows CO$_2$ emissions from mobile towers in different districts of Delhi)](image)

### 3.2.3 Consultancy project on Preparation of the Third National Communication and other new information to the UNFCCC:

The Ministry of Environment, Forests Climate change (MoEF&CC) has undertaken the "Preparation of the Third National Communication
(TNC) and other new information to the United Nations Framework Convention (UNFCCC) on climate change as part of fulfillment of India’s obligation to UNFCCC. In this context, the MoEF has initiated the process of preparation of “Biennial Update report (BUR) and awarded the above consultancy project to NPL for estimation of N₂O, and integrate the measured emission factors to estimate CH₄ emission from solid waste dumping in managed landfills and open dumping sites at national scale for the period 2008 to 2010.

3.2.4 Characteristics of ambient ammonia over Delhi

Characteristics of ambient ammonia were evaluated along with other trace gases (NH₃, NO, NO₂, SO₂ and CO) and particulates (PM₃₅ and PM₁₅) over Delhi during December 2011 to June 2012. The average mixing ratios of ambient NH₃, NO, NO₂, SO₂ and CO were recorded as 21.2 ± 5.4 ppb, 19.5 ± 4.9 ppb, 17.4 ± 1.4 ppb, 1.7 ± 0.5 ppb and 1.6 ± 0.7 ppm respectively during winter, whereas the average mixing ratios of ambient NH₃, NO, NO₂, SO₂ and CO were recorded as 20.8 ± 4.7 ppb, 21.7 ± 6.3 ppb, 16.8 ± 3.1 ppb, 2.2 ± 0.8 ppb and 1.8 ± 0.9 ppm respectively during summer. The average monthly NH₃/NO₃ ratios varied from 0.28 to 2.56 with an average value of 1.46 in winter. The higher NH₃/NO₃ ratio (3.5) was observed in summer indicates the abundance of NH₃ in the atmosphere during summer. The higher fraction of particulate NH₄⁺ observed in winter than summer attributes to conversion of gaseous NH₃ into NH₄⁺. The results emphasized that the traffic could be one of the significant sources of ambient NH₃ at the urban site of Delhi as illustrated by positive correlations of NH₃ with traffic related pollutants (NOx and CO) (Fig 3.7). Surface wind analysis and wind directions also support the road side traffic and agricultural activities at the nearby areas indicating possible major sources of ambient NH₃ at the study site.

3.2.5 Source apportionment of PM₁₀ and PM₂.₅ over Delhi using receptor model

Positive Matrix Factorization (PMF, a receptor model) was used to quantify the contribution of different types of sources of PM₁₀ and PM₂.₅ over Delhi during January to December 2013. Concentrations of PM₁₀ (188.9 ± 51.9 µg m⁻³) & PM₂.₅ (153.8 ± 38.2 µg m⁻³) and its chemical compositions i.e., organic carbon (OC: 26.5 µg m⁻³ of PM₁₀ & 27.7 µg m⁻³ of PM₂.₅), elemental carbon (EC: 10.7 µg m⁻³ of PM₁₀ & 10.7 µg m⁻³ of PM₂.₅), water soluble inorganic ionic components (WSIC) and major & trace elements of were used for source apportionment. The application of PMF analysis helped to identify the emission sources for 80% of the total PM₁₀ mass and 87% of total PM₂.₅ mass at the observational site of Delhi.

3.2.6 Study on trace gases and particulate matter (PM₂.₅) over the northwestern Himalayan region of India

Ambient trace gases (NH₃, NO, NO₂ and SO₂) and black carbon (BC) were measured along with
particulate matter (PM$_{2.5}$) over the northwestern Himalayan region (Palampur, Kullu, Shimla, Solan and Nahan) of Himachal Pradesh (HP), India in a campaign mode during 12-22 March 2013 to evaluate the ambient air quality of the region. The average mixing ratio of ambient NH$_3$, NO, NO$_2$ and SO$_2$ were recorded as 7.1±2.6, 3.1±1.3, 3.9±1.4 and 1.7 ± 0.7 ppb respectively over the northwestern Himalayan region. The average concentration of BC was estimated as 2.2 ± 0.5 µg m$^{-3}$ over the region whereas average concentrations of PM$_{2.5}$ mass was estimated as 41.8 ± 7.9 µg m$^{-3}$. The spatial variation of ambient trace gases (NH$_3$, NO, NO$_2$ and SO$_2$), BC and particulate matter (PM$_{2.5}$) over the northwestern Himalayan region, India reveals that the region is mainly influenced by local activities i.e., tourism activities, agricultural activities, biomass burning and vehicular emissions (Fig 3.8). A significant positive linear correlation of NH$_3$ and NH$_4^+$ with SO$_4^{2-}$, NO$_2^-$ and Cl$^-$ (NH$_4^+$ vs. SO$_4^{2-}$, $r^2$ = 0.652; NH$_4^+$ vs. NO$_2^-$, $r^2$ = 0.701; and NH$_4^+$ vs. Cl$^-$, $r^2$ = 0.627) of the particulate (PM$_{2.5}$) indicating the possible formation of (NH$_4$)$_2$SO$_4$, NH$_4$NO$_3$ and NH$_4$Cl aerosols over the region.

### 3.2.7 Role of convection in hydration of tropical UTLS: Implication of AURA MLS long-term observations

Water vapor distribution at different levels of tropical region namely Asian monsoon region, African Monsoon region and American monsoon region has been studied. Figure 3.9 presents temporal variation of water vapor mixing ratio (WVMR) over the Asian monsoon region from 3 years of observations by AURA-MLS. An examination of WVMR at various pressure levels indicate that water vapor transport is rather fast up to a level of 147-121 hPa whereas it is relatively slow above this level. Seasonal variation in water vapor is observed and noted to be closely associated with seasonal northward movement of ITCZ.

![Fig. 3.8: Percentage distribution of OC, EC, WSIC, major and minor elements and UM (unidentified mass) of PM$_{2.5}$ mass at different locations of northwestern Himalayan region of India](image1)

Fig. 3.8: Percentage distribution of OC, EC, WSIC, major and minor elements and UM (unidentified mass) of PM$_{2.5}$ mass at different locations of northwestern Himalayan region of India

![Fig. 3.9: Time series of WVMR at 261, 215, 147, 100 and 68 hPa level along with the time series of daily mean OLR for the period of 1 January 2007–31 March 2010 over Bay of Bengal region. Arrows indicate that minimum in OLR is almost simultaneous to maximum in WVMR261 to WVMR147. Filled arrows show correspondence between occurrence of low OLR and WVMR100](image2)

Fig. 3.9: Time series of WVMR at 261, 215, 147, 100 and 68 hPa level along with the time series of daily mean OLR for the period of 1 January 2007–31 March 2010 over Bay of Bengal region. Arrows indicate that minimum in OLR is almost simultaneous to maximum in WVMR261 to WVMR147. Filled arrows show correspondence between occurrence of low OLR and WVMR100

### 3.2.8 Abundance of Atmospheric Organic Aerosols in PM$_{2.5}$ in Delhi region

Polycyclic Aromatic Hydrocarbons (PAHs) are generally contributed by the incomplete combustion of biomass, coal, oil and petroleum etc. Most of PAHs are considered as carcinogenic in nature.
Long term exposure to PAHs can lead to serious health effects such as mutation, cancers of lung and respiratory tract etc. A total of 11 PAHs i.e., Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, benzo(a)pyrene have been identified and quantified in the ambient air at Nurpur (rural site) and NPL (urban site) in Delhi region. Abundance of almost all the PAHs has been noticed higher at urban site than at rural site. PAHs such as Acy, Flu, Acen and Pyr have been noticed as dominating species at urban site while at rural site, Flu, Flan and Anths species dominated. These findings indicated that fossil fuel combustion is the major source of PAHs at urban site while biomass burning is the major contributor of PAHs at rural site. The percent contribution of individual PAH to the total PAHs at both the sites has been shown in Fig. 3.10.

n-Alkanes are stable non-polar as well as reasonably refractive, aliphatic hydrocarbons originated from biogenic sources and motor vehicle exhaust etc. Fifteen individual species of n-Alkanes (C21-C35) have been identified and quantified in the ambient air at both rural and urban sites. The percent contribution of n-Alkanes at both the sites has been shown in Fig. 3.11.
The percent contribution of n-Alkanes has shown a significant difference in their atmospheric abundance at urban and rural sites. This is probably due to the difference in source types. At urban site, the petrogenic n-Alkanes dominated over biogenic species whereas biogenic n-Alkanes dominated over petrogenic species at rural.

3.2.9 Experimental setup and standardization of a continuous flow stable isotope mass spectrometer for measuring stable isotopes of Carbon, Nitrogen and Sulfur in Environmental samples

Standardization of a newly acquired stable isotope ratio mass-spectrometer (Isoprime 100, Isoprime® UK) coupled with elemental analyzer (Pyrocube, Elementar®-Germany) in a continuous flow mode (CF-IRMS) was carried out for making accurate and precise measurements of C, N and S isotopes in a variety of natural as well as synthetic organics and sulfur containing solid samples. Instrument was calibrated using a suite of certified international standards supplied by International Atomic Energy Agency Vienna and cross-checked against several in-house laboratory standards used by other institutions of international repute. A synthetic organic compound Sulfanilamide was continuously used along with international standards to develop an in-house internal laboratory standard for the accurate and precise isotopic measurements. Overall estimated uncertainties of C, N and S isotopic measurements are better than 0.2, 0.2 and 0.3 %, respectively; which are well within the recommended limits of aforementioned isotopic data. After successful installation and setting up standardized protocols chemical and C, N, S isotopic analyses of atmospheric aerosols collected from differing environments of India and surface soil samples are currently underway.

3.2.10 High Ozone observed during summer and autumn months of the years 2012 and 2013

Surface ozone is a harmful pollutant that can negatively impact the human health. The World Health Organization (WHO), based on the epidemiological time-series studies and field studies have set a new air quality standard of ozone concentration of 50 ppb (daily maximum 8 hourly mean) in 2006. The ambient air quality and cleaner air for Europe (CAFE) have set eight hourly mean not to be exceeded 60ppb for the protection of human health. High concentrations of surface ozone have harmful effects on vegetation and crops. The severity of ozone on crops, vegetation and forest depends on the concentration and duration of exposure.

Ozone forms in the atmosphere from the chemical reaction of volatile organic compound (VOCs) and nitrogen oxides (NOx) in the presence of sun light. Its concentration is dependent on temperature and amount of sunshine. The main source of VOCs is motor vehicles, industrial processes, petroleum industries, pesticides application, fuel combustion and bio-mass burning. NOx are mostly from motor vehicle and fuel combustion from electric utilities and other industrial processes.

The 8 hourly mean of day time ozone (10 A.M to 5 P.M) in the summer month of April, May, June and Autumn months of September, October and November for year 2013 is shown in figure 3.12. The ozone concentration during the observation period exceeds WHO standard of 50ppb. Most of the summer and autumn days, it is observed to be in the range of 60 ppb to 130 ppb.

Fig. 3.12: Eight hourly mean (10:00 A.M to 05:00 P.M) value of ozone concentration during April-May-June (summer) and September-October-November (Autumn) months of the year 2013.
Radio and Atmospheric Sciences

In the month of October and November, most of the days the 8 hourly average exceed even the value observed during summer days. It may be due to excessive bio-mass burning in this season.

3.2.11 High NOx observed in foggy days

High concentrations of NOx were observed during foggy conditions as compared to clear days over the observational site at NPL, New Delhi. One of the typical diurnal variation of NOx on foggy (17th and 18th of December 2013) and clear day (19th December 2013) is shown in Figure 3.13. It has been observed that in foggy days nearly four-fold of NOx concentration were observed as compared to clear day. Fog contains small water droplets and aqueous phase chemistry became active as a result of scavenging of HOx radical by fog droplets which suppress the usual gas phase reaction \( \text{HO}_2 + \text{NO} \rightarrow \text{OH} + \text{NO}_2 \) present in the clear day. In foggy condition the sink for NO reduces and also the consumption of Ozone took place by the reaction \( \text{O}_3 + \text{HO}_2 \rightarrow \text{O}_2 + \text{HO}_2 + \text{O}_3 \). It implied that in urban areas more gaseous pollutants may present in the atmosphere.

3.2.12 Role of cloud condensation nuclei and turbulence on the precipitation characteristic of clouds

Cloud turbulence and aerosols (act as cloud condensation nuclei, CCN) play an important role in the formation, maintenance and precipitation characteristics of the clouds. In order to understand the role of turbulence and aerosol particle below the cloud on cloud precipitation the data obtained from the UV LIDAR (Light Detection And Ranging) system installed at NPL, New Delhi is used. A rain cloud appeared on a particular day of the monsoon season in 2009 (from 10:00 to 10:22 hrs, IST) is selected for the study. To study the importance of the region below the cloud (sub-cloud region) on the growth (thickness) of cloud, the quantity called cloud-to-sub cloud ratio (CSR) is calculated and is shown in figure 3.14.

Fig. 3.13: NOx concentrations during foggy days in December 2013 in Delhi

Fig. 3.14: Cloud to sub-cloud (CSR) versus cloud thickness obtained on a particular day of the monsoon season in 2009 (from 10:00 to 12:22 hrs, IST)
3.2.13 Variability in radiative properties of major aerosol types over Delhi:

Aerosol measurements over an urban site at Delhi in the western Ganga basin, northern India, were carried out during 2009 using a ground-based automatic sun/sky radiometer to identify their different types and to understand their possible radiative implications. Differentiation of aerosol types over the station was made using the appropriate thresholds for size-distribution of aerosols (i.e. fine-mode fraction, FMF at 500 nm) and radiation absorptivity (i.e. single scattering albedo, SSA at 440 nm). Four different aerosol types were identified (Figure 3.15), viz., polluted dust (PD), polluted continent (PC), mostly black carbon (MBC) and mostly organic carbon (MOC), which contributed ~48%, 32%, 11% and 9%, respectively to the total aerosols. Interestingly, the optical properties for these aerosol types differed considerably, which were further used, for the first time, to quantify their radiative implications over this station. The highest atmospheric forcing was observed for PC aerosol type (about +40 W m⁻², along with the corresponding atmospheric heating rate of 1.10 K day⁻¹); whereas the lowest was for MBC aerosol type (about +25 W m⁻², along with the corresponding atmospheric heating rate of 0.69 K day⁻¹).

![Fig 3.15: Density plot of sun/sky radiometer derived SSA (at 440 nm) versus FMF (at 500 nm) for different aerosol types over Delhi during 2009](image)

3.2.14 Radiative Impact of Fireworks at Varanasi: A Case Study

Weeklong intensive observational campaign for aerosol study was carried out at a representative urban location in the eastern Indo-Gangetic Plain (IGP), Varanasi during the Diwali festival (October 29 to November 04, 2005, Diwali on November 01, 2005), to investigate changes in aerosol properties and radiative forcing between firework affected and non-affected periods. Results show a substantial increase (~27%) in aerosol optical depth, aerosol absorption coefficients, and aerosol scattering coefficients during affected period as compared to non-affected periods. Magnitudes of radiative forcing at top of atmosphere during affected and non-affected periods are found to be 10 ± 1 and 12 ±1 Wm⁻², respectively, which are “31 ± 7” and “17 ±5 Wm⁻²”, respectively, at surface. It suggests an additional cooling of ~20% at top of atmosphere, ~45% cooling at surface, and additional atmospheric heating of 0.23 K day⁻¹ during fireworks affected period, which is 30% higher than the normal.

3.2.15 Morphological, mineralogical characterization of mineral dust over the Indian Desert and nearby: Implications to Dust Optics

The aerosols are known to play an important role in the terrestrial climate system through their direct and indirect influences on the radiation budget while the magnitude and sign of both effects remain highly uncertain. Amongst various aerosol species, mineral aerosols are radiatively most important aerosol types in the atmosphere due to their widespread distribution. Mineral dust scatters and absorbs not only solar radiation but also absorbs and emits outgoing long wave radiation. The magnitude and even the sign of the direct radiative forcing by mineral dust is highly uncertain. In common modeling practice, radiative transfer simulations and remote sensing implementations, shape of dust particles is assumed to be homogenous sphere so that the classical Lorenz-Mie theory can be used. However, based on the
measurement and modeling studies, the optical properties of real dust particles have been found to be quite different compared to that of volume-equivalent spheres. This emphasized the need of regional database on particle morphology, mineralogy and mixing states.

To generate the database on dust morphology originated from the Thar Desert and nearby regions, a series of field campaign have been organized over the Thar Desert and nearby semi-arid zones (local source of mineral dust) under CSIR XII Five Year Plan Network Project. The field observation conducted in a semi-arid region (in vicinity of the Thar Desert, Jaipur, Rajasthan) during late winter, 2012 revealed the predominance of “Layered”, “Angular” and “Flattened” particles in the background atmosphere. The morphological parameters, aspect ratio (AR) and circularity parameter (CIR) which give information on extent of particle nonsphericity, were reported to be 1.4 and 0.8, respectively based on frequency distribution of total 235 dust particles collected from the study site. The sensitivity study depicted in Figure 3.16 at 550 nm wavelength reveals that the equivalent sphere model may underestimate Single Scattering Albedo (SSA) for the dust with low hematite content while both underestimation/overestimation are probable in case of dust with high hematite content. The effect of AR on the dust scattering is significant in case of dust with high hematite content compared to that of low hematite. Therefore, a statistical representative database of regional dust morphology is imperative especially for the dust particles rich in hematite.

The optical/radiative simulation of pure mineral dust becomes further more complicated when the long range transported mineral dust form a heterogeneous mixture with the carbonaceous species. Keeping this in mind, a field campaign has also been organized at IIT, Kanpur in collaboration with Dept. of Civil Eng., IITK. The analysis reveals the predominance of complex agglomerates of dust and carbonaceous species.

3.2.16 Morphological and mixing state characterization of atmospheric particles within Atmospheric Boundary Layer over New Delhi:

To study the morphology and mixing state of atmospheric particles (within Atmospheric Boundary Layer) together with vertical profiles of meteor parameters (temperature, pressure and humidity), a tethered balloon observation has been conducted from 21-28 Feb, 2014 (7 PM-3.30 AM) at NPL in collaboration with TIFR Balloon facility under CSIR XII Five Year Plan Network Project. The morphological analysis reveals the predominance of carbon onion structures agglomerated with complex carbon nano structures at 700 m altitude while sub and super-micron size carbon fractals were observed at the surface level. The detailed analysis of particles collected at different altitude is underway.