रेडियो एवं वायुमंडलीय विज्ञान

राष्ट्रीय भौतिक प्रयोगशाला का रेडियो एवं वायुमंडलीय विज्ञान प्रमाण (अराड़ाली) रेडियो विज्ञान तथा अनुप्रयोग, अंतरिक्ष मौसम और अणुप्रमाण, पृथ्वी के वायुमंडल का रसायनिक और भौतिक संगठन, वायुमंडलीय प्रसंस्करण और जलवायु परिवर्तन आदि के क्षेत्रों में राष्ट्र की वैज्ञानिक आवश्यकताओं की पूर्ति करता है। इस प्रभाव द्वारा (i) रेडियो विज्ञान, और (ii) वायुमंडलीय विज्ञान जैसे प्रमुख क्षेत्रों में अनुसंधान कार्य किए जाते हैं। वायुमंडलीय विज्ञान के अंतर्गत वायुमंडलीय रसायन विज्ञान, वायुमंडलीय विविध विवरण, वायुमंडलीय विज्ञानी के अनुकूल तथा प्रतिरूपण से संबंधित अवधारणा शामिल है।

रेडियो विज्ञान:

इस में एक अभिकृत समूह है जो रेडियो संचार, नौसमन और अन्य उपन्यास अनुप्रयोगों में सुधार लाने की दृष्टि से रेडियो संचार का प्रयोग करके आवश्यक, आवश्यक श्रृंखला के प्रयोगस्थल तथा पृथ्वी के निकट स्थित रेडियो परिणाम के अभिलक्षणों को ज्ञात करने के कार्य में सहाय है। इसमें शिरर तथा साइकोल संचार के लिए रेडियो चैनल मापन और प्रतिरूपण, विभिन्न प्रकार के तंत्रों तथा पृथ्वी और उसके अवधारणाओं के परीक्षण तथा प्रतिरूपण का विकसित करना तथा विभिन्न प्रयोजन कृतियों के साथ अनुप्रयोग संकुचन स्थापित करना अधिक है। भौतिक और तरीकों के उपर जीवन, सामाजिक रिसर्च, तिमाह, भौतिक और उसके अवधारणाओं का परीक्षण तथा प्रतिरूपण का विकसित करना तथा विभिन्न प्रयोजन कृतियों के साथ अनुप्रयोग संकुचन स्थापित करना अधिक है।

वायुमंडलीय विज्ञान:

वायुमंडलीय रसायन विज्ञान समूह विभिन्न बौद्धिक स्रोतों से ग्रीन हाउस गैसों के उत्सर्जन के संबंध में जानकारी हासिल करने, हमारे देश के ग्रीन उत्सर्जन कृतियों में प्रयोग में लाए जाने वाले कृतियों के मापन और भौतिक अवधारणाओं को ज्ञात करने के कार्य में सहाय है। इसके अतिरिक्त, वायुमंडलीय श्रृंखला के प्रचारी और भौतिक अवधारणाओं को ज्ञात करने के कार्य में जानकारी लायो है। इसमें वायुमंडलीय रसायन, वायुमंडलीय रसायनी, और अणुप्रयोगों के संबंध में व्यापक ज्ञान संग्रहीत की जाती है।

परामृष्टि, दूरदूर और इंटरनेट-आईंटरनेट वेबसाइट रेडियो संचार में वायुमंडलीय रसायनों के संबंध में जानकारी लेने के लिए व्यापक उपकरण अवधारणा शामिल है। इस प्रभाव द्वारा हाल ही में उच्च बिजनेस विवरण के लिए प्रयोग है। वायुमंडलीय रसायनी, वायुमंडलीय रसायनी, और अणुप्रयोगों के संबंध में जानकारी लेने के लिए व्यापक उपकरण अवधारणा शामिल है।
The Radio and Atmospheric Sciences Division (RASD) of NPL caters to the scientific need of the nation in the area of radio science and applications, space weather and ionosphere, chemistry and physics of the earth’s atmosphere, atmospheric pollution, climate change etc. The major research areas are: (i) Radio Science, and (ii) Atmospheric science. Atmospheric science involves study of Atmospheric chemistry, Spectroscopy of Atmosphere, simulation and modeling for atmospheric physics.

**Radio Science:**

It is a 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 modelling for fixed and mobile communications, generating new data sets in various frequency bands, testing of models and development of models over various regions of India and interaction with various user agencies. Monitoring and modelling related to ionospheric / tropospheric parameters using satellites and ground based systems including GPS, Tomographic Receivers, Ionosonde, etc., over India and polar regions is also being carried out. Ionospheric forecasting/nowcasting is being provided to users worldwide through our space weather Regional Warning center (RWC, NPL-India) and have consistently improved the International Reference Ionosphere (IRI) model through model comparisons with observed data.

**Atmospheric Sciences**

The atmospheric chemistry group is engaged in developing the Greenhouse gas (GHG) inventory from different sources, emission estimates of particulate matter (PM) and trace gases (SO\textsubscript{2}, NO and NO\textsubscript{2}) from biomass fuels consumed in rural sector of our country, emissions from land fills and wheat and rice crop fields etc.. This group also investigates 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. An ozone standard has been added in the division for traceability of measurement and other purposes. Mathematical modelling is an integral part of all the activity groups in the division.
Radio Science

Radio channel measurements and modelling for fixed and mobile communications

An experimental campaign was conducted in the urban, coastal, industrial region of Mumbai using WiMAX transmissions at 2.3 GHz, for seventeen base stations. The observed signal levels have been converted into path loss values and plotted as a function of distance. These were compared with various prediction methods like COST-231 Hata, ECC, SUI (Terrain B), ITU-R (P.1411-1) along with Least Square Regression method of measured data. A typical comparison for Hare Krishna base station is shown in figure 3.1. Path loss exponents, mean errors, standard deviations and coefficient of determination of all the methods have been deduced and compared with observed values for terrain having partly dense urban, partly light dense urban, partly open with marginal coastal zones; partly urban, partly open, partly low density vegetation environment and partly light dense urban and partly industrial zone. The cdf values of prediction errors have also been compared. The COST-231 Hata and the ECC methods give a good agreement with the measured data than the other methods. These results can be utilized to predict the signal level, path losses in these regions and can be compared to future datasets, which will be generated in this region at various frequencies. The purpose of studying theoretical models and their comparison with measured data is to find a suitable propagation model in that region so that for future network planning, that specific propagation model can be used there or in a region of similar environment. This comparison can provide inputs to radio planning tools and the model tuning capabilities. Also the measured data can be utilized for fine tuning of the default propagation model of Radio Network Planning tool in different terrains. That way service provider can utilize the tuned propagation model for coverage predictions in a similar environment, which will save time and efforts for Radio Network Planning in a region.

Fig 3.1 Comparison of observed results with those predicted from various models for Hare Krishna base station

Electromagnetic macro modelling of propagation in mobile wireless communication: Theory and experiment

The above work has been carried out in collaboration with Prof Tapan Sarkar’s group of Syracuse University. The objective of this activity to illustrate that an
electromagnetic macro modeling can properly predict the path loss exponent in a mobile cellular wireless communication. This represents the variation of the path loss with distance from the base station antenna. Specifically, it has been illustrated that the path loss exponent in a cellular wireless communication is three preceded by a slow fading region and followed by the fringe region where the path loss exponent is four. The size of these regions is dependent on the heights of the base station antennas. Theoretically this is illustrated through the analysis of radiation from a vertical electric dipole situated over a horizontal imperfect ground plane as first considered by Sommerfeld in 1909. To start with, the exact analysis of radiation from the dipole is made using the Sommerfeld formulation. The semi-infinite integrals encountered in this formulation are evaluated using a modified saddle point method for field points moderate to far distances away from the source point to predict the appropriate path loss exponents. The reflection coefficient method is also derived by applying a saddle point method to the semi-infinite integrals and it is shown not to provide the correct path loss exponent. The various approximations used to evaluate the Sommerfeld integrals are described for different regions. It is also important to note that Sommerfeld’s original 1909 paper had no error in sign. However, Sommerfeld overlooked the properties associated with the pole. Both accurate numerical analyses along with experimental data are provided to illustrate the above statements. Both Okumura’s experimental data and extensive data taken from various base stations in urban environments generated by our group at National Physical Laboratory at two different frequencies have validated the theory. Experimental data reveal that a macro modeling of the environment using an appropriate electromagnetic analysis can accurately predict the path loss exponent for the propagation of radio waves in a cellular wireless communication scenario. A typical variation of path loss exponent at 1800 MHz for Omkarnagar sec-1 base station is shown in figure 3.2.

The above work helped to achieve the following goals:

1. To illustrate that if the Hertz potential are appropriately written as originally envisaged by Sommerfeld for fields at the interface, and the various expansions using appropriate approximations are carried out in a mathematically meaningful way, it may be concluded that the path loss exponent in a cellular wireless communication system is three and in the fringe areas is four,

2. To illustrate that experimental data also demonstrate that the path loss exponent in cellular wireless communication system is three,

3. To illustrate that if one uses an accurate numerical electromagnetic code like AWAS, then it is seen that in a cellular urban environment, the path loss exponent factor is 3 and in the fringe areas it is 4, and therefore it is sufficient to carry out a macro modeling of the environment

4. To illustrate that if a modified method of steepest descent is utilized to treat a pole near the saddle point for the field near the interface, then this characteristic field can be derived when using the appropriate form of the Green’s function,

5. To illustrate that if experimental verification is carried out to measure the path loss exponent factor at 900 MHz and 1.8 GHz for various transmitters located in different urban environments, then the path loss exponent factor at moderate distances from the base station antenna settles down to a value of 3,

6. To demonstrate that there was no error in the sign in Sommerfeld’s 1909 paper; the defect was that
Sommerfeld overlooked some mathematical subtleties associated with the pole while computing his asymptotic development of the branch cut integral, to state that physics based macro modeling is sufficient to predict the propagation path loss in a cellular urban environment and a detailed micro modeling of the environment is an overkill.

Ionospheric F2 - region: Variability and sudden stratospheric warmings

The ionospheric F2 – region is known to show a large day to day and hour-to-hour variability. This variability has recently been linked to sudden stratospheric warmings (SSWs). We have investigated the extent of ionospheric changes following SSWs of years 2007, 2008 and 2009 using ionosonde data from six different stations in the Asian zone thus covering a broad latitudinal range from 8.63°N to 45.1°. We find that ionospheric F2-region shows some significant variations following stratospheric warming within a week or two from the day of the peak event. However characteristics of these variations vary from event to event and from station to station. We have also examined the data on equatorial electrojet strength (EEJ) and find there are significant changes in EEJ strength during the SSW events. A counter electrojet (CEJ) coincident with the start of warming was also observed for the event of 2008.

We then compared this SSWs linked variability observed in the normal day-to-day and hour-to-hour variability seen in the ionospheric data. It is seen that even during times when there are no SSWs and solar and magnetic indices are quite stable and close to their minimum values, the ionospheric variability is comparable and sometimes larger than the variability attributed to these warmings. Further, it seems that it is difficult to quantify with precision the changes in f0F2, as well as in the response times involved, in these events. Deviation (∆f0F2) in critical F2 layer frequency from average of pre warming period (3-12 January 2009) at different Japanese stations along with the spectral periodicity analysis are shown in Fig 3.3 and 3.4 respectively.

Daytime additional F-layer stratification over low-mid latitude station of the Indian sector under geomagnetic disturbed conditions

Observations of additional F-layer stratification are seen in a region which is situated at the outer edge of equatorial ionization anomaly (EIA) zone. The digital ionosonde data observed over Delhi (28.6° N, 77.2° E, dip 42.44° N) during March-April, 2001 has been used to carry out the present work. The observational period was geomagnetically disturbed.
and represents the high solar activity phase of 23rd solar cycle. The additional transient cusp is frequently observed in the considered months before the noon hours; however, in this study only five prominent cases are presented. From the analysis of ionograms, it is observed that the transient additional cusp is formed between the pre-existing F1 and F2 layer; hence, named as the cusp of F1.5. Study reveals that the Traveling Atmospheric Disturbances (TADs) along with the vertical expansion of F layer provides the necessary condition for the existence of this transient feature. The intensification of F1 layer along with increased altitude immediately after the disappearance of additional stratification remains one of the fascinating features of the present results. The present investigation demonstrates that the daytime F1 and F2 region over low-mid latitude station is strongly modulated by the passage of TIDs, originating at high latitudes or by atmospheric disturbances of local origin during the high solar activity period. The concurrent presence of TADs and the associated disturbance composition appears to be plausible reason behind the present observations. Sequential ionograms on March 31, 2001 showing the presence of additional cusp is shown in Figure 3.5.

Fig. 3.5 Sequential ionograms on March 31, 2001 showing the presence of additional cusp which is marked by the circle

Antarctica Activity

Radio & Atmospheric Sciences Division, CSIR-NPL participated in 31st Indian Scientific Expedition to Antarctica and successfully carried out some scientific experiments in the field of Space weather and Climate Changes. The primary objective of this activity is to study the effects of varying solar activity conditions on the southern polar region ionosphere. The study is based on the simultaneous observation of bottom side ionospheric parameters and Ionospheric Total Electron Content (ITEC) along with L-band scintillation observation by Global Ionospheric Scintillations and TEC monitoring system. The above instruments are operational at Indian Permanent Research Base “Maitri”, Antarctica (70.43°S, 11.43°E) since 2008. The investigation showed that the minor changes in space weather conditions affect the polar region ionosphere severely.

The results (Figure 3.6) reveals that the enhancement in TEC values are closely associated with an increase in particle precipitation on the polar cusp region. It is observed that the ionospheric TEC increases for a short duration as soon as proton density increases near the Earth as recorded by ACE satellite. Apart from this the result shows that the enhancement in ITEC is very much positively correlated with Z-component of

Fig.3.6 (a) Diurnal variation of Ionospheric TEC variation over Maitri, Antarctica, (b) Diurnal variation of proton density near earth space environment, (c) : Diurnal variation of Earth’s geomagnetic Z-component at southern hemisphere.
Earth’s magnetic field which is recorded at Australian Antarctic Base “Mawson” (67.60° S, 62.86° E).

**Atmospheric Chemistry**

**Assessment of Energy Generation Potentials of MSW in Delhi under Different Technological Options**

The Municipal Solid Waste (MSW) being dumped into the landfills are the important source of methane which could be harnessed as a potential energy source. This would also contribute to the climate change mitigation efforts. Delhi has three landfills namely Ghazipur (GL), Bhalswa (BL) and Okhla (OL). The methane emission potentials of these landfills have been estimated using LandGEM model. The results of the model show the potential methane emissions as 14, 12 and 8 Gg CH₄ from GL, BL and OL respectively from the dumping of segregated MSW which is the current practice. The potential methane emissions could have been 33, 27, 23 Gg CH₄ from GL, BL and OL respectively in case the waste is deposited without pre-segregation (i.e. bulk waste) in these landfills. The calorific values have been found to be 0.058-0.078 kW/kg for segregated MSW and 0.092-0.126 kW/kg for the bulk waste (MSW) being deposited in Delhi’s landfills. The MSW deposited in Delhi’s landfills have been subjected to composition analysis which revealed that its major constituent is readily decomposable material, followed by recyclable material and moderately decomposable material. It has also been found that almost 50% of the recyclables were being removed prior to the MSW reached to the landfill sites. To assess the energy generation potential from the MSW reaching to Delhi’s three landfills, two situations have been hypothesised; (i) bulk MSW waste is subjected to five available technologies namely biomethanation, incineration, gasification/pyrolysis, refused derived fuel (RDF) and plasma arc gasification and (ii) the segregated waste reaching to the landfill sites is subjected to five technologies for waste to energy generation, namely biomethanation, incineration, gasification/pyrolysis, refused derived fuel (RDF) and plasma arc gasification.

The result of this study shows that different technologies for harnessing the energy from the MSW have different potentials. It has also been found that the segregation process reduces the energy production potential by 40-60% compared to bulk MSW. The plasma arc gasification technology shows the highest potential for energy generation in the ranges of 17-35, 16-32 & 11-25 MW/day from GL, BL and OL respectively, incineration process (17-32, 16-29 & 11-25 MW/day from GL, BL and OL respectively), RDF process (9-19, 8-18 & 6-15 MW/day from GL, BL and OL respectively), biomethanation process (3-10, 3-8, 2-8 MW/day from GL, BL and OL respectively ). Thus, the plasma arc gasification seems to have highest energy generation potential but a number of other factors like installation cost, handling of by-products, environmental regulations etc. are required to be considered for identifying the most viable technology for WTE. The values derived in this study are based on theoretical ideas which provide indicative potential values that may differ from actual field measurement values due to the number of factors which influence the methane generation process.

**Urban Heat Island Study in Delhi:**

Many urban areas experience higher temperatures compared to their suburban or outlying rural surroundings due to urban heat island (UHI) effect. Urban heat islands are caused by development and changes in radiative and thermal properties of urban infrastructure. Elevated temperatures due to UHI, particularly during the summer months in India, can affect the region’s environment and quality of life. Most of the impacts of UHI are negative and include:
Increased energy consumption

Elevated emissions of air pollutants and greenhouse gases

Compromised human health and comfort

To study the causes and impacts of UHI, a study has been initiated for Delhi region under which meteorological data for the two sub-regions, namely National Physical Laboratory (NPL) region and Safdarjung region have been collected for the years of 2010 & 2011 from the NPL and IMD meteorological stations respectively. It has been found that the temperatures at Safdarjung area was higher than the NPL area during this period. The computation of Urban Heat Island Index (UHII) for these two regions is given in following figure-3.7:

The mean monthly UHII has been found to be always greater than 1°C, throughout the study period and also shows periodical fluctuations with lower values during monsoon season. An analysis of wind speed showed lower values of UHII during strong wind conditions which facilitates the dispersal of accumulated heat in the structures in the region. A detailed analysis of landuse pattern of an area of about 6.46 km² around the two stations, derived from satellite images (Table-3.1) shows that NPL area has about 61% area under vegetation and 39% area under construction compared to 18% and 82% areas under vegetation and construction respectively in Safdarjung area. This difference is responsible for observed Urban Heat Island Effect (UHII) in Safdarjung area higher compared to NPL area. Further work is in progress to analyse the impacts of UHII on local environmental parameters.

### Updating of Greenhouse Gas (GHG) emission inventories for the energy sector:

An updated inventory of greenhouse gas emissions from the energy sector in India comprising of emissions from thermal power plants, road transport, railways, aviation and marine transport has been prepared for the period of 2001-02 to 2009-10 using the guidelines provided by the Intergovernmental Panel on climate Change (IPCC). The salient observations of this updated GHG emission inventory are as follows:

- The increased number of vehicles and increased demand of electricity has increased the consumption of fossil fuels in which coal consumption shows the annual growth rate of 6.4% while diesel and gasoline shows the growth of 4.9% and 9.4% respectively.
- From energy sector CO₂ emission shows the annual growth rate of 5.5%, CH₄ 6.8% and N₂O 5.5%.
- From total CO₂ emission in energy sector 81% is from thermal power plants and 18% from transport sector while in total CH₄ 74% is from transport and 26% is

### Table 3.1: Vegetation and construction areas in NPL and Safdarjung derived from landuse map

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Station Name</th>
<th>Total Area (km²)</th>
<th>Area Under Vegetation (km²)</th>
<th>Area Under Vegetation (%)</th>
<th>Area Under Construction (km²)</th>
<th>Area Under Construction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NPL</td>
<td>6.46</td>
<td>3.92</td>
<td>60.6%</td>
<td>2.54</td>
<td>39.3%</td>
</tr>
<tr>
<td>2</td>
<td>Safdarjung</td>
<td>6.46</td>
<td>1.16</td>
<td>17.9%</td>
<td>5.30</td>
<td>82.1%</td>
</tr>
</tbody>
</table>
from electricity generation and \( \text{N}_2\text{O} \) total emission 10.5% is from transport while 89.5% is from electricity generation.

- The GHGs emissions from railway have increased at the rate of 41% \( \text{CO}_2 \), 44% \( \text{CH}_4 \) and 50% \( \text{N}_2\text{O} \) because of the increase of huge amount of diesel oil in this sector.

- Emissions of \( \text{CO}_2 \), \( \text{CH}_4 \) and \( \text{N}_2\text{O} \) in aviation sector have increased at the rate of 100%, 66%, 100% respectively.

- In marine navigation, GHGs emission have increased at the rate of 149% \( \text{CO}_2 \), 160% \( \text{CH}_4 \) and 200% \( \text{N}_2\text{O} \) because of the huge increase in the consumption of fuel oil and diesel oil in marine navigation.

**Chemical properties of PM10 over Indo Gangetic Plain (IGP) of India**

Spatial variability of organic carbon (OC), elemental carbon (EC) and water soluble inorganic ionic components (WSIC) of PM10 were studied over Chandigarh, Delhi, Varanasi and Kolkata of Indo Gangetic Plain (IGP) of India during the period of January to December 2011. The annual average of PM10 mass concentration was found to be maximum at Delhi (205.6 ± 91.3 \( \mu \text{g m}^{-3} \)) followed by Varanasi (203.5 ± 88.7 \( \mu \text{g m}^{-3} \)), Kolkata (174.3 ± 63.6 \( \mu \text{g m}^{-3} \)) and Chandigarh (149.4 ± 25.2 \( \mu \text{g m}^{-3} \)) (Fig. 3.8).

A similar pattern was also recorded in the case of OC and EC concentrations over Delhi (OC: 26.7 ± 9.2 \( \mu \text{g m}^{-3} \); EC: 9.9 ± 3.4 \( \mu \text{g m}^{-3} \)), Varanasi (OC: 17.4 ± 9.9 \( \mu \text{g m}^{-3} \); EC: 8.0 ± 6.5 \( \mu \text{g m}^{-3} \)), Kolkata (OC: 15.7 ± 8.4 \( \mu \text{g m}^{-3} \); EC: 7.7 ± 6.3 \( \mu \text{g m}^{-3} \)) and Chandigarh (OC: 13.9 ± 2.2 \( \mu \text{g m}^{-3} \); EC: 7.2 ± 2.1 \( \mu \text{g m}^{-3} \)). The maximum mean concentration OC and EC of PM10 mass were recorded as 26.7 ± 9.2 \( \mu \text{g m}^{-3} \) and 9.9 ± 3.4 \( \mu \text{g m}^{-3} \), respectively over Delhi whereas the minimum at Chandigarh (Fig. 3.9). A significant positive correlation between OC and EC over the study sites are indicative of their common sources like vehicular traffic.

Figure 3.10 shows the spatial variation of \( \text{NH}_4^+ \), \( \text{NO}_3^- \), \( \text{SO}_4^{2-} \) and WSIC-rest of PM10 mass over different locations of IGP, India. During winter, \( \text{NH}_4^+ \) positively correlated with \( \text{SO}_4^{2-} \) and \( \text{NO}_3^- \) at all the locations. Positive correlation of \( \text{SO}_4^{2-} \) and \( \text{NO}_3^- \) with \( \text{NH}_4^+ \) over IGP, India indicates the possibility of the formation of secondary aerosol \([\text{NH}_4\text{HSO}_4 \text{ and NH}_4\text{NO}_3]\) during winter. An analysis of HYPLIT seven days back-trajectories, suggested that during winter the approaching air mass at receptor sites are mainly of continental type and transported from the local (IGP), Pakistan, Afganistan and its surrounding areas. However, during monsoon season mixed type (continental and marine) air mass flow is recorded at the observational sites.

**Biological properties of aerosol over IGP of India**

Aerosol (PM\(_{10}\)) samples were collected from Delhi, Chandigarh and Kolkata of IGP using particle sampler for their biological characteristics. This study was focused on the microbial influence or its content in the formation of aerosols.
The 16S rRNA gene of the isolates was amplified by PCR using universal primers 8-27f (5’-AGAGTTTGATCCTG GCTCAG-3’) and 1492r (5’-TACGGYTACCTTGTTACGACT T-3’). The PCR product was purified using the QIAquick PCR purification kit (Qiagen, Germany). The purified amplicon was sequenced using the Big Dye Terminator cycle sequencing kit and an ABI PRISM model 310 automatic DNA sequencer (Applied Biosystems, USA). The total count of bacteria was taken as colony formation units (CFU) from different dilutions where individual colonies observed. Morphologically different colonies were purified by streaking them on fresh plates with similar medium and preserved at -70°C as 10% glycerol stocks for further study. Among the isolates few strains with differences in morphology were analyzed by 16S rRNA gene sequencing and BLAST analysis to confirm their species status (Table 3.2).

The isolates exhibiting high similarity with the species belonging to genera like Mycobacterium and Staphylococcus are to be studied in detail as many species of these genera are found to be opportunistic pathogens. However, there are few strains that exhibited low similarity at 16S rRNA gene sequence with the existing species, indicating that they could be of novel. Other strains involved in nitrogen fixation, reduction nitrate and nitrite are being studied in detail for their characterization including their role in the formation of NH₃.

Polyphasic taxonomy studies are being made to establish their taxonomic status. Studies are being made to establish the role of these microbes in the formation of aerosols in these environments. The samples obtained from Kolkata were subjected to dilution to isolate the culturable bacteria. Up to 10⁻³ dilutions were plated on different media including nutrient agar, tryptose soy agar and plate count agar to obtain the maximum microbes into culturable form. Maximum count was observed over PCA in the sample collected from air filters obtained after 30 min and 60 min. Among the isolates, most of them were found to be species of the genus Bacillus based on the morphological features. After isolation, 8 cultures have been preserved at -70°C as glycerol stocks for further studies.

Unique morphotypes were selected from the isolates and were sequenced using universal bacterial 16S rRNA gene primers. The sequence analysis revealed that the isolates obtained by anaerobic culturing technique, mostly belong to the genus Clostridium and those obtained by aerobic culturing technique mostly belong to the genera Mycobacterium, Caulobacter, Sphingopyxis. Samples obtained from Chandigarh were plated out on different media as mentioned above and the number of colonies formed on plate count agar was taken into consideration. Among the isolates 31 colonies with varying colony morphology have been preserved as -70°C glycerol stocks. Few isolates exhibiting nitrate reduction and nitrogen fixation activities are being studied.

**Abundance and sources of atmospheric carbonaceous and bioaerosols in Delhi region**

The carbonaceous aerosols which include black carbon (BC) and organic carbon (OC) are recent focus of research as important chemical pollutants which affect human health and climate. Fig. 3.11 shows the percent contribution of various chemical components of total suspended...
particulates (TSP) at Delhi. At this site, carbon accounts for maximum weight percent (~60%) followed by other elements. The presence of carbon may be as black carbon, organic carbon and carbonates. Most of the scattering and absorption of light in the atmosphere at urban sites in India may be due to carbonaceous aerosols which are contributed mainly by combustion of fossil fuel and biomass burning.

Bioaerosols may be found in the atmosphere as bacteria, fungi etc. These airborne microorganisms can be toxigenic, allergenic and infectious. The most significant sources of bioaerosols are soils, plants, vegetables, water bodies, sewage sludge, animal feeding, fermentation process, agricultural activities and human beings etc. Fig. 3.12 shows bacterial abundance in Total Suspended Particulate (TSP) during monsoon and winter seasons. The average concentrations of bacteria during monsoon and winter seasons are $2.37 \times 10^7$ and $0.57 \times 10^7$ CFU/m$^3$ respectively indicating four times higher concentrations during monsoon season than in winter season. Higher concentrations of airborne bacteria during monsoon season could be due to higher degradation of living or dead materials surrounding the buildings along with favourable meteorological conditions.

Chemical, physical and isotopic properties of aerosols over India

Detailed chemical, physical and isotopic characterization of atmospheric aerosols over India are done using different state of the art analytical facilities of NPL such as CF-IRMS, OP-FTIR, SEM-EDX and XRF. Using different air samplers of different size range of atmospheric particles, we collected atmospheric aerosols from a selected locale and do in-depth investigations using all the aforementioned analytical tools for obtaining comprehensive chemical morphological information. To inordeneto characterize mineral dust aerosols from the vicinity of Thar Desert, a field campaign was conducted in the Jaipur city, during the period of 19-25 February, 2012. To collect atmospheric PM$_2.5$ particles (and a few bulk particles; TSPs) using low volume air sampler at seven locations with varying heights from ground (~10-1000 MAGL; Fig.3.13). The selection of locations is based on the nature of aerosols of local origin characterizing background mineral dust. Aerosol particles were collected on Teflon filters (Ø37 and Ø25 mm) size for bulk chemical analyses using micro-volume air sampler (Fig. 3.13 inset) with nominal flow rate of
For individual particle morphology and elemental composition, particles were collected on pure Tin substrates (~1×1 mm²), placed on Teflon filters. Individual particles were imaged and chemical compositions were assessed using Scanning Electron Microscope equipped with Energy Dispersive X-ray (SEM-EDX) facility of NPL. Whereas, bulk chemical compositions of PM₅ particles were determined using X ray fluorescence (XRF) technique at NPL.

PM₅ mass concentrations ranged from 34.7 to 499.8 μg.m⁻³ (Figure 3.14). Crustal elements, Si, Al, Ca, Mg and Fe were found in abundance e.g. however, maximum variability was shown by Fe. Individual particle images revealed occurrence of highly non-spherical particles rich in Si, Al, Fe, Ca and Mg, supporting the dominance of mineral background dust component in ambient PM₅.

Non-crustal elements e.g. Cu, S, C, Ag and Pb were found only over main city at ground level (Birla Temple; 26.89°N, 75.82°E). PM₅ and TSP particles over Kukas hill and Kukas NH-8 highway showed highest Fe mass fractions (maximum up to ~43%). Presence of Fe rich mineral dust is of significant importance as Fe is a key element in form of hematite (Fe₂O₃) for incoming solar (visible) energy absorption. Average elemental ratios of Mg/Al, Si/Al, K/Al, Ca/Al, Mn/Al, Fe/Al were found as 0.44±0.22, 1.96±0.90, 0.65±0.22, 1.52±0.40, 0.84 and 1.54±1.67 respectively (Figure 3.14). Higher Ca/Al ratios are consistent with reported Ca rich dust over the Arabian Sea originated from the Thar Desert region. Similar elemental ratios, as found in this study, were also observed in aerosols over Bay of Bengal during late inter-monsoon season, when calcareous mineral dust originating from the Thar Desert is expected to be major contributor of crustal elements. Important to mention here, individual particle chemical compositions measured by spot-EDAX were found to be in good agreement with bulk level chemical compositions.

Morphological analyses of particles revealed predominance of “Layered” (calcite and quartz rich), “Angular” structures (quartz rich) and “Flattened” particles over all the sites (nomenclature based on NIST morphological database). The generated database is highly required for numerical estimation of regional optical/ radiative forcing by mineral dust and to use them as a tracer to identify origin of dust storms that are frequent during inter-monsoon season in northern India. More such works are required (carrying out detailed chemical composition and morphology of individual mineral dust particles), to accomplish detailed classification of dust particles from the source region.

In addition to bulk level chemical composition we also investigated individual particle shape size (morphology) and elemental composition as has been shown for just one site in Figure 3.15. It has been planned to carry out such detailed physic-chemical investigation of bulk as well
as individual particle level of aerosols over typical aerosol producing regions of India such as northwestern India (Punjab) where in pre-winter season agricultural crop residue burning is regular practice and central part of Indo-Gangetic plains such as Kanpur, Varanasi where high loading of aerosols during winter is observed.

Altitude distribution of aerosols is an important factor influencing atmospheric stability through radiative heating, modifying cloud properties, Earth's radiation budget and consequent changes in the weather and climate of the Earth-atmosphere system. Atmospheric residence time as well as long-range transport of aerosols is primarily governed by the altitude distribution. Atmospheric circulation along with the aerosol properties and altitude distribution provide a handle for inferring the source regions. Furthermore, the aerosol radiative forcing strongly depends on the altitude distribution of aerosols with respect to that of the clouds.

The EZ-Leosphere lidar has been operated during 2009-2010 which has a capability to determine the vertical profiles of aerosol extinction/backscattering, depolarization ratio and Planetary Boundary Layer (PBL) height. EZ lidar is an elastic Lidar whose light source is a tripled Neodymium-YAG laser that emits a pulse of duration of 10ns at 355nm with maximum energy of 16 mJ and repetition rate of 20Hz. The Lidar is completely eye-safe and reaches full overlap at 300m.

The variation of altitude structure of aerosols, the data corresponding to the monsoon, post-monsoon, winter and spring period from July 2009 to March 2010 were analysed. The lidar signal averaged for 30 minute is first corrected for background noise and then range normalized. Then the aerosol extinction coefficient (AEC) and particle depolarization ratio (PDR) is derived using Fernald's method. It is observed that, below 1.5 km, the AEC values are relatively high during the post-monsoon season and low during the winter season. The PDR values are high during the spring season and low during the monsoon season. The low value of PDR shows the relative abundance of spherical water droplets.

In order to understand the long range transport of aerosols, a case study has been performed. A dust layer has been observed

**Spectroscopy of Atmosphere**

**Studies on the altitude distribution of lower Tropospheric Aerosols and Clouds over New Delhi using Lidar**

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In order to understand the long range transport of aerosols, a case study has been performed. A dust layer has been observed
in the height region of 0.4 km to 1.1 km on March 12, 2010 and the layer persisted for about four days. The extinction value of the layer range from 0.46 to 0.12 km\(^{-1}\) (Figure 3.16(a)). The particle depolarization value range between 0.045 to 0.041 shows that the layer contains the dust in the lower troposphere mixed with local pollutants. The Hysplit back trajectory analysis (Figure 3.16(b)) shows that the air mass transported to the station from the arid west Asian regions.

In order to study the interaction of aerosols in the low altitude rain clouds a case study has been made using the data obtained during the monsoon season (26th August, 2009). The rain clouds appeared in the altitude range of 0.6 to 0.9 km and precipitate after 12:30hrs (IST) and the rain stops at 14:00 hrs. The low values of the particle depolarization ratio confirm the presence of water droplets in the cloud. After the rain, a cloud layer has been formed below 0.6 km with a delay of 30-40 minutes. It shows that the scavenging of the CCN and recharging of the atmosphere with fresh CCN. Further studies have been made by considering the turbulence and meteorological parameters to bring more insight to the role of aerosol on the precipitation characteristics of the rain clouds.

**Aerosol Radiative Effect at Delhi due to an unusual dust storm of March 2012:**

The aerosol direct radiative effects (DRE) in the ultraviolet, shortwave and longwave range due to an unusual dust storm during March 21, 2012 have been quantified from surface measurements of aerosol optical depth (AOD) and radiation fluxes at Delhi, a western Indo Gangetic Plain station (Figure 3.17). The intrusion of dust over Delhi caused an increase in daily average AOD at 500nm from 0.6 to 0.8 with a corresponding decrease in Angstrom Exponent from 0.4 to sub-zero value. The dust severely affected the incoming solar radiation flux in the UV, shortwave and longwave region. The DRE at surface in the UV and shortwave decreased from -4.6 to -5.9 Wm\(^{-2}\) and from -68 to -86 Wm\(^{-2}\) respectively, while the longwave DRE have increased from 27 to 45 Wm\(^{-2}\). The decrease in UV and shortwave DRE are mainly attributed to the dust storm intrusion, whereas the increase in longwave DRE also seems to be due to change in temperature and humidity (Figure 3.18).

**Planetary scale modulations in aerosol properties over Indo Gangetic Plain station Delhi**

The timeseries data during December 2001 to May 2012 is observed to be a complex function of four dominant periodicities varying from intra-seasonal to inter-annual time scales. The annual (periodicity of ~ 12 months) and semi-annual oscillations (~ 6 months) in the

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**Fig 3.17:** (a) Moderate Resolution Imaging Spectroradiometer (MODIS) dust storm across Iran, Afghanistan, and Pakistan on 19th March 2012 and (b) the image on 21st March showing the transport of dust plume across Arabian Sea to reach India.

**Fig 3.18:** Temporal variation of the surface fluxes at (a) Ultra violet (b) visible and (c) long-wave region from 19th to 23rd March 2012 at Delhi.
importance of season, QBO and ENSO in temporal variation of Aerosols Optical Depth

The observational data of Aerosol Optical Depth (AOD) at 61 AERONET stations around the globe is studied to find the relative importance of season and the atmospheric parameters QBO and ENSO in the temporal variation of AOD. A mathematical model of AOD having components of contributions from trend, 6- and 12-month periodicities caused by season and regression with QBO and ENSO is used to quantify the contributions from the considered sources. The contributions from seasonal cycles of 6- and 12-month are found to be dominating and those from regressive parameters QBO and SOI (representing ENSO) insignificant at all stations. The magnitude of importance varies with latitude and longitude. The contribution from season matches in phase and amplitude with AOD anomalies, the variation of AOD with time excluding the trend, at American and Australian stations indicating that the AOD variation is due to seasons. At most of European, African and Asian stations the amplitudes of contributions from seasons do not match exactly with the peaks of AOD anomalies and the cause of this region not falling in line with that of America and Australia may be the pollution at these stations. The contribution from 12-month cycle is significantly high for African and Asian stations as compared with the most of the American, European and Australian stations. The contribution from 6-month cycle is comparable with 12-months cycle in the region (10°–30°N, 80°-120°E) comprising India, Bangladesh, Nepal, Burma, Thailand, Myanmar and South China.

Temporal variation of methane over Indian sub-continent

Methane is the most important anthropogenic greenhouse gas (GHG) after carbon dioxide, causing both direct and an indirect radiative forcing and climate change. The anthropogenic sources include waste decomposition, paddy fields, wet lands, domestic ruminant, biomass burning etc. Because of the biodiversity and
economic conditions, the emission rates of the pollutant gases like methane are different over different regions in India. Hence it is important to find hotspots for the abundance of methane over Indian region. SCHIAMCHY (Scanning Imaging Absorption Spectrometer for Atmospheric Cartography) data (level 3) for methane for the period 2003-2009 is obtained to pinpoint hotspot for increasing methane over Indian sub-continent. The column average methane data is available at latitude, longitude mesh grid of 0.5° x 0.5°. The data is retrieved at all grid points over Indian sub-continent which includes around 2000 data files. The monthly averages of SCHIAMACHY data from 2003 to 2009 is found to be more over Indian region compared to other neighboring countries. The methane abundance is significantly high in Indo-Gangatic Plains (IGP) and some regions of Andhra Pradesh.

To find the temporal rate of change in methane abundance over India, trend is calculated using following regressive model

\[ Z(t) = \mu_0 + \omega \times t + \alpha_i \sin(2\pi \times t + \gamma_i) + \beta_i \times V_j + N_t \] (1)

where \( \mu_0 \) is a base level constant value for \( Z(t) \); \( \omega \) the slope of the trend in \( Z \) with time; \( p_i, \alpha_i, \tau_i \) and \( \eta_i \) in the model represent the coefficient of regression and value of the \( i \)th regressive variable such as QBO and N, the noise term. The unknown constants \( \mu_0, \omega, \alpha_i, \tau_i \) and \( \eta_i \) in the model are found out by the least square fit technique. The cyclic variations caused by seasonal cycles of 3, 6 and 12 months are included in the model. The variations caused by El Niño/ La Niña-Southern Oscillation (ENSO) which is a quasi-periodic climate pattern that occurs across the tropical Pacific Ocean at irregular intervals of 3–7 years with an average period-length of 5 years and lasts nine months to two years is also taken in the model. The Southern Oscillation Index (SOI) as a proxy for ENSO is used in the model. The trend in methane is found to be significantly high in western IGP.

Salient features/capabilities of the established CF-EA-IRMS are:

- Capable of measuring C, N, S, H and O isotopic analyses of particulate matter (e.g. Atmospheric dust, Soil, Sediment, biogenic products)
- Stable isotopic data of C, N, S are vital for deciphering contributing source-characterization and secondary processes involved in chemical processing of particulate matter.
- H, O isotopes of particulate matter can provide insights to degree as well as source of moisture during natural particle formation.

Establishment of new Stable isotope ratio mass spectrometer coupled with Elemental Analyzer (CF-EA-IRMS) as new R&D facility at Radio & Atmospheric Science Division

A major facility called stable isotope ratio mass-spectrometer (Isoprime 100) coupled with Elemental Analyzer (Pyro-cube) in a continuous flow mode (CF-EA-IRMS) has been procured and installed successfully for measuring concentrations as well as stable isotopes of Carbon (C), Nitrogen (N) and Sulfur (S) in a flash combustion mode and concentrations as well as stable isotopes of Hydrogen (H) and Oxygen (O) in pyrolysis mode. Figure 3.20 shows the installed instrument in Room No 108 of TEC building while accuracy and precision checks are described in Figure 3.21 & 3.22.

Major Facilities Established
Fig. 3.20: Pyro-Cube (Elemental Analyzer) coupled with Isoprime 100 Stable isotope mass-spectrometer installed in Room no. 108 of RASD.

Fig. 3.21: Accuracy of CF-EA-IRMS as determined using combination of international and national analytical isotopic standards.

Fig. 3.22: Reproducibility obtained by running nine aliquots of Sulfanilamide (a laboratory standard) is well within expected range of uncertainty known for these isotopic measurements.