रेडियो एवं वायुमण्डलीय विज्ञान

रेडियो एवं वायुमण्डलीय विज्ञान प्रभाग की गतिविधियों में दो प्रमुख परियोजनाएं हैं। पहली परियोजना रेडियो भौतिकी और उसकी अनुप्रयोग पर। इसमें आयनमण्डलीय एवं ट्रोपोस्फीरिक संग्रहण के लिए रेडियो पर्यावरण और उससे सम्बन्धित दूसरे अनुप्रयोग हैं। आयनमण्डलीय संग्रहण के लिए, विशेष तौर पर अंतरिक्ष भौतिकी, उच्च आवृति संग्रहण, नेवीगेशन अनुप्रयोग शामिल हैं जबकि ट्रोपोस्फीरिक संग्रहण में रेडियो आवृत्तियों का स्थानीय एवं पृथ्वी के स्पेश पर फैलाव का अध्ययन किया जाता है। यह बहुत उच्च आवृति से लेकर कई गीगा आवृत्ति तक है। अंतरिक्ष भौतिकी के अंतर्गत अलग–अलग वायुमण्डलीय पैरा मीटर का मापन, आव्युषों दे जीपीएस और CRABEX रिसोवर के द्वारा विभिन्न मार्गों एवं एंटार्क्टिका पर किया जाता है। इससे प्राप्त परिणामों का विश्लेषण करके आयनमण्डलीय चलाव मानक एवं आयनमण्डलीय माइक्स का प्रतिस्थापन किया जाता है। इसमें आने वाली सोलर चक्र 24, टोटल इलेक्ट्रोन संदर्भ की भविष्यवाणी संबंधित आंकड़े प्रस्तुत किए गए हैं। भारतीय एंटार्क्टिका स्टेशन पर एल बैच एक्स्प्रेस (सिन्दितेन्शन) का आयन, सूर्य ग्रहण का आयनमण्डलीय घटकों पर प्रभाव, भारतीय भूमीय परिसरों से निम्न अंतर विभिन्न पर इसकें प्रभाव का अध्ययन किया जाता है। सूर विस्तार (सोलर फ्लेशर) का मंगल के आयन मण्डल पर प्रभाव एवं फिक्सिट म उभयक्षेत्र के माइक्स का अध्ययन भी किया जाता है। अन्य परियोजना जैसे ग्रीन हाउस गैसों का प्रभाव एवं उसका गुणात्मक अध्ययन, ग्रीनहाउस जैसे व्यापार जल ज्वाला एवं पानी की मात्रा का अध्ययन भी किया जाता है।

दूसरी परियोजना प्रबल मण्डलीय पर्यावरण और जलवायु परिवर्तन से यथायोग्य विषय पर है। इसमें प्रमुख है बंगाल की खाड़ी के ऊपर मैरीन वातावरण की तपाय से अभिनव बाजारियों में एरोसोल और इसकी प्रारंभिक गैसों का वितरण में, सूर्य ग्रहण का स्थानीय आंकड़े, नाइट्रोजन आक्साइड, नाइट्रिक आक्साइड, अमोनिया, कार्बनमोनो आक्साइड और उनका वितरण अनुपात और सल्फोड आक्साइड का दिल्ली पर बदलाव आदि। ट्रांसपोर्ट स्ट्रोपीलरिक आंकड़े का लेबल अंतराल में बदलाव, अलग–अलग प्रकार के एरोसोल जैसे PM10 वायुमण्डलीय ऐसोसोल की रसायन शास्त्र इत्यादि। एरोसोल की आटिकल गुणों का अध्ययन तितिया पर मापन करके किया जाता है। सूर्य ग्रहण के समय ऑजॉन काल्पनिक (Column) की मात्रा में बदलाव, ओजोन डिपलीशन जैसे घटनाओं का मार्गों आधारित विक्रियाओं में मापन जो रीढ़ 2010 की बसंत ऋतु में किया गया। ग्रीष्म वर्ष मौसम के अलिए कम कोल्ड पॉइंट ट्रोपोस्फीरिक अध्ययन वायुमण्डलीय प्रदूषण पूर्वगामी (Precursor) विधि का अध्ययन मार्गों माहनगरों पर इसके माइक्स और होट स्ट्रीट का मानवीय स्वास्थ्य पर इसके प्रभाव का अध्ययन किया गया है। इन सबसे मानवीय स्वास्थ्य पर किस प्रकार की अनुकूल नीति अपनाई जाए एतक की भी विस्तृत विवरण किया गया है।
The activities of the Radio and Atmospheric Sciences Division comprise with two major projects of the laboratory. The first project is related to “Radio Physics and Applications”. It deals with the characterization of radio environment for ionospheric and tropospheric communication and other applications related work. For ionospheric communication, the contributions are mainly on space physics, HF communication and navigational application while for tropospheric communication, it includes all aspects of radio wave propagation over both terrestrial and earth space paths covering the frequency range from VHF up to many giga hertz. Under the area of space physics, different ionospheric parameters are measured from Ionosondes, GPS and CRABEX receivers over different Indian locations and Antarctica to deduce results on ionospheric dynamics as well as to develop and validate the ionospheric models. A detailed investigation has been presented regarding the prediction of forthcoming Solar Cycle 24, GPS derived total electron content variations, occurrence of L-band scintillation over Indian Antarctica station, solar eclipse effects on ionospheric parameters over the Indian equatorial and low-latitude region as well as solar flare effects in the ionosphere of Mars. Radio channel measurements and modeling for fixed and mobile communications, development of a software for Phased Array Acoustic Wind Profiler and quantitative estimation of the greenhouse effects due to water vapour and liquid water in radiation fog also have been reported.

The second project is entitled “Atmospheric Environment and Global Change”. The main achievements in this project are the distribution of aerosol and its precursor gases in the marine boundary layer over Bay of Bengal, effects of the solar eclipse on the surface O$_3$, NO, NO$_2$, NH$_3$, CO mixing ratio, ambient ammonia distribution and variation of ambient SO$_2$ over Delhi. Long term variation in tropical stratospheric ozone and its temporal variations, studies on various aspects of aerosols such as chemistry of PM$_{10}$, atmospheric aerosols and Lidar measurements of optical properties of aerosol as well as fluctuation in ozone column during the solar eclipse, ozone depletion events observed at Indian Arctic station Himadri, during spring of 2010, occurrence of extremely low cold point tropopause temperature during summer monsoon season, atmospheric pollution precursor process modeling over mega cities and assessment of impacts of heat stress on human health and adaptation strategies have been presented in detail.
Radio Physics and Applications

Prediction of Solar Cycle 24 Using Geomagnetic Precursors: Validation and Update

Solar activity forecasting is an important topic for various scientific and technological areas, like space activities related to operations of low-Earth orbiting satellites, electric power transmission lines, high frequency radio communications and geophysical applications. The particles and electromagnetic radiations flowing from solar activity outbursts are also important for long term climate variations and thus it is very important to know in advance the phase and amplitude of the next solar and geomagnetic cycles. Solar cycle 24 has already commenced in December 2008. The maximum amplitude of solar cycle 24 might occur in mid-to-late 2012 as shown in Fig.6.1. Since, the current solar cycle 24 has already started and the observed monthly sunspots are available therefore in Fig. 6.1 the predicted along with the previous solar cycle 23 and the observed monthly sun spot numbers of sunspot cycle 24 are also shown for comparison.

GPS derived Total Electron Content (TEC) variations and the occurrence of L-band scintillation over Indian Antarctica station, Maitri

The ionospheric scintillation and TEC monitor receivers (GISTM) collect the TEC and scintillation data at every minute from the Indian Antarctic stations. Each GISTM can track up to 11 GPS signals at 1.575 GHz and 1.2 GHz and from which the slant TEC (STEC) for each of the satellites is derived and converted into vertical TEC (VTEC). The VTEC data thus obtained is processed for each of the satellite passes with an elevation mask angle greater than 30° in order to avoid the effects of low elevation angles, such as tropospheric, water vapour scattering and multi path effects. Figure 6.2 illustrates the latitudinal coverage area of GPS satellites over Maitri with an elevation mask angle of 30°. Therefore the TEC observations are restricted to a latitude grid of ±3° and longitude grid of ±3° from the observing sites.

Fig. 6.1: For comparison, the predicted cycle 24 along with the previous solar cycle 23 and the observed monthly sun spot numbers of sunspot cycles 23 and 24 are shown.

Fig. 6.2: The first panel shows the sub-ionospheric coverage of GPS over Maitri with an elevation mask angle of 30°. The second panel shows the diurnal variation of VTEC data at Maitri for December 6-7, 2009.

A total of one year of GPS-TEC data have been processed for Indian permanent station Maitri, Antarctica measured during the year of 2008.
During the month of January TEC fluctuated between the ranges of 10 to 22 TECU. This type of behaviour of TEC in polar region depends on solar zenith angles. Figure 6.3 shows 12 month TEC behaviour in all months.

The L-band scintillations and the associated irregularities, about one year observations are carried our over Indian Antarctica Station by using dual frequency GPS receiver. Season wise (as noted from Figure 6.4), their maximum percentage occurrence is observed in winter season i.e. polar night periods from May to August 2008 as compared to summer and equinox seasons.

**F-region parameters (foF2 and h’F) using Ionosonde measurements over Indian Antarctica station, Maitri**

The interaction of solar-wind and sun blown high energetic particle with polar ionosphere is higher because of the almost vertical geomagnetic field lines. By using the Ionosonde system we monitor the bottom side ionospheric parameters in real time basis.

Figure 6.5 shows the diurnal pattern of foF2 and h’F variation during the month of November, July and September 2009 representing Summer, winter and Equinox. Fig.6.5 shows the mass plot of observed foF2 and h’F observations during these months along with the median values. It is seen that the maximum number of observation are available during the solar summer time, which is due to the fact that the source of ionization i.e. sun is available through out 24 hours. While, minimum number of observation are seen during polar winter month i.e. on the month of July, when the sun is not visible through out 24 hours. The results indicate that during polar winter Ionospheric F-layer nearly collapsed. Since the observations are during the low solar activity period i.e. for the year 2010, therefore the observed values of foF2 are few. The observations reveal that the maximum foF2 was observed between 4 – 7 MHz, 3 - 4 MHz and 4 - 5 MHz during November (Summer), July (Winter) and September (Equinox) respectively.

Figure 6.6 shows the preliminary results of polar region ionospheric responses during the space weather event occurred on 10th March.2009. The results reveal that even a
minor change in space-weather affects the polar region ionosphere. This is due to the fact that the earth’s magnetic field lines are almost open at this region and allow the soft high energetic particles to penetrate and precipitate into polar region ionosphere.

Ionospheric responses to the solar eclipse of July 22, 2009 and January 15, 2010 over the equatorial and low-latitude region of the Indian zone

Two solar eclipse events, July 22, 2009 and January 15, 2010 occurred with their paths of obscuration passing over northern and southern part of the Indian region. These two events are unique as the eclipse of July 22, 2009 was the total solar eclipse (TSE) and January 15, 2010 governed the longest annular solar eclipse (ASE) of the millennium. The maximum obscuration of TSE occurs during the dawn hours over the equatorial ionization anomaly (EIA) crest region while that of ASE occurs during the noon time hours over the equatorial region.

Ionospheric responses to the TSE of July 22, 2009:

Results show that in response to the total solar eclipse of July, 22 2009 over the EIA crest region, the TEC data does not show any variation. However, significant solar eclipse induced effect has been observed at the bottom side ionosphere during the dawn hours as shown is shown in Figs. 6.7 and 6.8. The notation B, E and T stands for the beginning, end and totality period of the solar eclipse respectively. The increase in the base height of the ionosphere (h’F) is seen just after the maximum occultation period. The depletion of foF2 appears jointly with increasing h’F during occultation and opposite is true as the de-occultation begins. Considerable decrease (of about 26 %) is seen in the critical frequency of the F2 region (foF2) during the maximum occultation period in comparison to reference day values.

The temporal variation of the bottom side electron density shows the dominant changes in the peak electron density during the solar eclipse.
Thus, the electron density and foF2 follows the variations of local solar radiation flux and the maximum decrease in both the parameters is observed around the maximum solar occultation period. Thus, results suggest that during the dawn period photochemical process plays a significant role in the F2 region. The appearance of elevated and widespread sporadic-E layer was also one of the interesting features of the total solar eclipse event. The appearance of intense sporadic-E could be ascribed to the wind shearing introduced by the solar eclipse induced gravity wave.

Ionospheric response to the Annual Solar Eclipse of 15 January, 2010

The event of January 15, 2010 provided an opportunity to study the response of equatorial ionospheric to the longest annular solar eclipse. The Indian equatorial station, Trivandrum was also in the path solar eclipse. At Trivandrum the first contact (beginning) occurred at 11:04 LT and the last contact (end) occurred at 15:05 LT with a maximum obscuration between 13:10 to 13:17 LT. The study of solar eclipse induced effect over Trivandrum is performed by using the GPS derived total electron content (TEC) measurements. Study reveals the existence of trough like depression in the diurnal variability of TEC (Fig.6.9). The effect of the eclipse was detected more distinctly in the variations of TEC along individual satellite passes (Fig.6.10). The maximum depression of about 6 TECU is observed after the time of maximum occultation and the decreased values of TEC are seen up to the twilight hours i.e. after the 3 hours of the last contact of eclipse. It can also be inferred from the present results that the eclipse induced effect appears evidently during the noontime ionosphere in comparison to the daytime ionosphere.
Total Electron Content (TEC) is the most important parameter, since it provides overall description of the ionosphere and also is the key parameter for earth space telecommunications, satellite navigation systems etc. At present, one of the widely used models for the ionospheric predictions is the International Reference Ionosphere (IRI-2007). TEC observations over Indian obtained using ATS-6 geostationary satellite for sector covering stations from magnetic equator to beyond northern crest of the equatorial anomaly during low solar activity, are used to assess the IRI-2007 model as compared to IRI-2001. As an example Figure 6.11 given below illustrates the comparison of IRI 2007 and IRI 2001 estimated latitudinal variation of TEC as a function of local time for the months of January 1976 with the observed one using ATS-6 Geostationary Satellite.

**Planetary Studies**

Some aeronomically important solar flare effects in the ionosphere of Mars have been studied from the analysis of electron density profiles recorded aboard Mars Global Surveyor (MGS) (Figure 6.12). All flares result in the formation of a well defined E layer peak, not always seen on other days. Further, while majority of flares result in elevated electron densities in the E region alone, some flares affect both the E and F1 layers. These altitude related effects can provide vital information on the relative enhancement of photon fluxes in the various wavelength bands during solar flares.

By studying the dayside electron density profile, the magnetised ionospheres of Venus, the “top” moves down to altitudes near 200 km and the ionopause layers with steep altitude gradients as compared to those generated by IRI-2001 one. The IRI-2001 highly overestimates the observed TEC at all local times for all the stations. The results are same in the cases of other months as well.
Figure 6.12: Electron density profiles observed by the MGS on each of the three flare days (left panel). Elevated electron densities through out the Martian ionosphere can be noted for all the three flare-time profiles. (right) Flare-time profile is also compared with the average of non-flare profiles for the respective day (along with one standard deviation). Well formed E peaks can be noted in all the flare-time profiles. These peaks are not always seen in the non-flare profiles.

in Ne (Electron density) and Te (Electron temperature) start above this altitude (Figure 6.13).

Radio channel measurements and modeling for fixed and mobile communications

The design of future generation mobile communication systems depend critically on the suitability of path loss prediction methods and their suitability to various regions. Development of new models helps to design new mobile communication systems, evaluate the performance of existing systems and to minimize the interference potential of other systems. To investigate the radio channel behaviour as an aid to design future generation mobile communication systems in the urban and suburban regions of India, experimental measurements in 1.8GHz band have been conducted with the help of user agencies and cellular operators. This is part of our continuing endeavour to generate new data base sets in order to compare the existing models and to generate new models over these regions. The base stations used in the present study are 1. Inner circle 2. Arunachal building 3. Indra prastha extension 4. Onkar nagar sector-1 5. Onkar nagar sector-26. Trinagar. The transmitting powers of all the station are +43 dBm. All the six paths are situated in dense urban environment. The six GSM base station data collected in the dense urban region of New Delhi have been analyzed. Path loss exponents and break point distances have been deduced and observed losses have been compared with various prediction
methods. Measured regression line exhibited lowest standard deviation followed by roof top propagation method compared with COST 231 Hata and COST 231 Walfisch-Ikegami methods. Variation of observed results have been explained in terms of vertical and horizontal propagation mechanisms which is the novelty of this study. A typical figure of the above exponent variation for Inner circle base station is shown in Fig.6.14 In general at distances close to the transmitter exponents of the order of 7 are observed and then they fall steeply up to a value of 4 around 400 m and remains steady for the remaining distances. Another typical Fig.6.15 showing the comparison of observed path losses with those of predicted from COST 231WI (Walfisch-Ikegami) method for street widths of 20, 30 and 40 m and building heights of 15 and 18 m and COST231 Hata method is also presented. In this case close to transmitter, high path losses of 150 to 170 dB have been observed. The estimated measurement r.m.s. error is around 1.5 dB. Walfisch-Ikegami method with heights of 18 m passes through majority of dense cluster of observed points at all distances. The same method with heights of 15 m shows the predicted loss less than that of 18 m and passes through some of the points. As the street width increases path loss decreases for a given building height. COST 231 Hata method under estimates the values by 10 to 20 dB. The variation in path loss for a given street width of 30m when building height changes from 15 to 18 m is 5.5 dB. This figure also has regression line plotted with its coefficients. Similarly for all the remaining five base stations the deduction of path loss exponents as a function of distance and comparison of observed values with predicted values has been carried out. The break point also has been deduced as the distance at which the slope of the curve (the path loss exponent vs distance) changes. In Fig.6.14 it changes at 200 m.. In the case of other base stations same approach has been followed and the values are shown in Table 6.1.

### Table 6.1. Break point distances observed from data.

<table>
<thead>
<tr>
<th>Base station</th>
<th>Height of ant(m)</th>
<th>Observed break point(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Inner circle</td>
<td>22</td>
<td>200</td>
</tr>
<tr>
<td>2 Arunachal</td>
<td>32</td>
<td>400</td>
</tr>
<tr>
<td>3 IP extension</td>
<td>27</td>
<td>-</td>
</tr>
<tr>
<td>4 Onkarnagar sec-1</td>
<td>24</td>
<td>200</td>
</tr>
<tr>
<td>5 Onkarnagar sec-1</td>
<td>24</td>
<td>400</td>
</tr>
<tr>
<td>6 Trinagar</td>
<td>24</td>
<td>300</td>
</tr>
</tbody>
</table>

Fig 6.14 Variation of observed path loss exponent with distance for Inner circle base station

Fig 6.15 Comparison of observed path losses with COST 231 Walfish-Ikegami and COST 231 Hata
Development of Software for Phased Array Acoustic Wind Profiler in LabVIEW

A Phased Array Acoustic Wind Profiler is in operation for continuous wind measurements up to an altitude of 500 m. The profiler operates with sound waves at 2150 Hz. The antenna transmits the sound waves sequentially in three vertical directions, viz., one beam pointing towards zenith and two other beams, both tilted by 19° each towards north and west respectively, from the zenith. The beam tilting is done electronically by a phase steering mechanism. The antenna is an array of 104 piezoelectric elements. The software for control and signal processing was initially developed in C-language. Now a new software has been developed in LabVIEW for control and signal processing. This software has got more improved features than the C-based one.

Green house effects in radiation fog

Quantitative estimation of the greenhouse effects due to water vapour and liquid water in radiation fog have been made from the measurements of temperature, relative humidity, wind speed, long-wave net radiation flux (all at 2 m height) and soil temperature (5 cm below ground) by using the NPL (National Physical Laboratory) Meteorological Tower. On a dense fog night, an enhancement of ~5 W m² in the net radiation flux has been observed before the onset of fog, due to the greenhouse effect of near saturated water vapour. Once fog forms abruptly in a period about an hour to two hours, the long-wave net radiation energy fluxes are observed to enhance from the pre-to post-fog formation hours, due to the trapping of the latent heat of condensation of the excessive water vapour into liquid water in fog. The energy flux due to the release of the latent heat of condensation varies from ~30 W m² to over 60 W m² under the light to dense fog conditions. Corresponding liquid water path in the fog column is estimated to vary between 0.06 kg m⁻² and 0.17 kg m⁻². These liquid water paths would correspond to liquid water contents of 0.6 g m⁻³ to 1.7 g m⁻³, for a fog layer thickness of 100 m. Sodar data have been used to obtain the fog layer thicknesses in actual cases. Thus it is possible to estimate the fog liquid water content through the use of ‘real-time’ routine ground-based measurements, when the fog is in the process of being formed or has just set in. Liquid water content is an essential parameter for forecast models to forecast the local time of clearance of fog by solar radiation.

Atmospheric Environment and Global Change

Effects of the solar eclipse on the surface O₃, NO, NO₂, NH₃, CO mixing ratio and the meteorological parameters on 15 January 2010 at Thiruvanathapuram, India

During the annular solar eclipse on 15 January 2010, the measurement of surface O₃, NO, NO₂, NH₃, CO mixing ratio and meteorological parameters (temperature, relative humidity, wind speed and solar radiation) have been performed at the National Institute of Interdisciplinary Science and Technology (NIIST), Thiruvanathapuram to explore the effect of solar eclipse. The experimental data has demonstrated that the solar eclipse phenomenon has affected the mixing ratio of surface ozone, nitric oxide, nitrogen dioxide, ammonia as well as temperature, relative humidity, wind speed and solar radiation near the ground. The decrease in mixing ratio of surface O₃ (Fig. 6.16) and NO₂ is observed after the beginning of the solar eclipse events and lasted for four hours, probably due to
decreased efficiency of the photochemical ozone formation, whereas, the increase in mixing ratio of NO and NH₃ might have followed the night time chemistry. As expected, the ambient temperature has decreased, relative humidity has increased and the wind speed has decreased. After the end of the solar eclipse period, all the above mentioned parameters exhibited a tendency to re-gain their earlier pattern on the same day.

Ambient ammonia distribution over National Capital Region of Delhi

Ammonia (NH₃) is an important atmospheric pollutant that plays an important role in several air pollution problems and affects the soil, water system as well as climate change. It is a highly reactive gas that has important effects on atmospheric chemistry and sensitive terrestrial or aquatic ecosystems arises from both natural and anthropogenic sources. Mixing ratios of atmospheric ammonia (NH₃ and NH₄⁺) were estimated during February to April 2010 at various locations of National Capital Region (NCR) of Delhi to study the distribution and day-to-day variation of atmospheric NH₃ and its role of formation of secondary aerosol. NH₃ mixing ratio was measured using NH₃-Analyzer operating based on chemiluminescence’s method whereas water soluble ionic species of PM10 were estimated using chromatography techniques.

The average mixing ratio of atmospheric NH₃ was recorded as 32.5 ± 2.1, 33.8 ± 3.0, 29.7 ± 0.7, 24.2 ± 1.4, 22.9 ± 1.3, 16.4 ± 3.2 and 15.6 ± 0.7 ppb at Indian Agricultural Research Institute, Research Farm; Naraina Industrial Area, Naraina; Central Road Research Institute (CRRI), Mathura road; National Physical Laboratory, New Delhi; Indra Prastha University, Delhi; Delhi University, Delhi and NCMRWF, Noida, UP respectively. The minimum average mixing ratio 9.4 ± 1.2 ppb was recorded at HRDC Ghaziabad, UP which is a rural area. The average mixing ratio of ambient NH₃ over NCR was estimated as 23.06 ± 1.7 ppb. Figure 6.17 shows the diurnal variation of NH₃ over CRRI, Mathura road and Naraina Industrial Area of NCR of Delhi.

Variation of ambient SO₂ over Delhi, India

The spatiotemporal variation of ambient SO₂ and the chemical composition of particulate matter (PM10 and PM2.5) at National Physical Laboratory (NPL), Delhi and other sites of Delhi were studied during 2008 (Fig.6.18). Ambient
SO₂ is significantly high (2.55 to 17.43 ppb) at air quality monitoring sites of Delhi particularly over industrial areas (15.00 to 17.43 ppb) during winter. There is no significant difference in SO₂ mixing ratio during monsoon; however, it was recorded significantly high over industrial sites during summer. The study establishes that transport sector may not be the major source of the SO₂ in the ambient atmosphere of Delhi, as there is no significant difference of ambient SO₂ mixing ratio recorded among residential and commercial sites. SO₂/SO₄²⁻ (PM_{2.5}) ratio suggests during winter the SO₄²⁻ over Delhi might be transported from long distance sources; whereas, during summer it might be from local sources. Wind pattern at NPL site suggests that during winter the wind blows from west and northwest directions. Coal used in thermal power plants at Panipat and Faridabad (about 200 km in the northwestern side of NPL) may be contributing to the higher SO₄²⁻ during winter. However, other thermal power plants situated at Pragati (Rajghat), Indraprastha and Badarpur (southeastern part of Delhi) may contribute during summer as a local source. SO₂ measured over Bay of Bengal during 28 December, 2008 to 25 January, 2009 to study their distribution and role in formation of inorganic aerosols under Integrated Campaign on Aerosols and Radiation (ICARB). NH₃ was monitored precisely and continuously over Bay of Bengal based on chemiluminescence method. Average ambient concentration of NH₃, NO, NO₂, SO₂ and NH₄⁺, SO₄²⁻, NO₃⁻, Cl⁻ were recorded as 4.78 ± 1.68, 1.89 ± 1.26, 0.31 ± 0.14, 0.80 ± 0.30 µg/m³ (Table 6.2) and 1.96 ± 1.66, 8.68 ± 3.75, 1.92 ± 1.75, 2.48 ± 0.78 µg/m³ respectively. Higher SO₄²⁻/(SO₂ + SO₄²⁻) equivalent molar ratio during the campaign indicates gas-to-particle conversion with great efficiency over the study region. A good correlation of SO₄²⁻ and NO₃⁻ with NH₄⁺ (NH₄⁺ vs. SO₄²⁻, r² = 0.408; NH₄⁺ vs. NO₃⁻, r² = 0.867) and NH₃ (NH₃ vs. SO₄²⁻, r² = 0.353; NH₃ vs. NO₃⁻, r² =0.537) indicates the aerosol formation.

Table 6.2: Average concentration of NH₃, NO, NO₂ and SO₂ (µg/m³) over Bay of Bengal.

<table>
<thead>
<tr>
<th></th>
<th>Concentration</th>
<th>Average</th>
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<th>Night</th>
<th>D/N</th>
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<tr>
<td>NH₃</td>
<td>4.78 ± 1.68</td>
<td>4.85 ± 1.91</td>
<td>4.70 ± 1.44</td>
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<td>NO</td>
<td>1.89 ± 1.26</td>
<td>1.87 ± 1.24</td>
<td>1.90 ± 1.27</td>
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<tr>
<td>NO₂</td>
<td>0.31 ± 0.14</td>
<td>0.27 ± 0.12</td>
<td>0.34 ± 0.16</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>0.80 ± 0.30</td>
<td>0.86 ± 0.33</td>
<td>0.75 ± 0.27</td>
<td>1.15</td>
<td></td>
</tr>
</tbody>
</table>

± standard deviation

Long term variation in tropical stratospheric ozone

The Stratospheric ozone which is about 90% of total ozone column protects the Earth’s biota from potentially damaging short wavelength UV radiation. It also controls the temperature in the stratosphere. The studies of temporal and spatial variations in ozone help in the exploration of the processes governing ozone concentration and the interaction between
ozone and climate. Zonal monthly average SBUV data in 10° latitude bands over 20° S to 20° N for the period Nov. 1978 to Dec. 2008 has been analyzed to find latitude-range and height-layer wise trend in ozone in the stratosphere. The data are integrated from Umkehr layers 2 to 4 (20-30 km) as representative for lower stratospheric ozone layer (LSOC) and from layers 5 to 13 (above 30 km) as upper stratospheric ozone layer (USOC) and from 20 km to top of stratosphere as total stratospheric column ozone (TSOC). The observed ozone as shown in Fig. 6.19 indicates the existence of Turning Points (TPs) in linear trend for low latitudes.

It is found that the values of piecewise trend during the periods 1994-99 and 1999-2003 are quite significant and have significant height-wise variations. If height-wise trend is considered, the directions of trend (downward/upward) are opposite to each other in upper (> 30 km) and lower (20 km–30km) stratosphere over tropics and more specifically in 1999, the trend in lower stratosphere is decreasing in contrast to increasing in upper stratosphere (Figure 6.19).

**Temporal variations of stratospheric ozone and water vapour over Pune**

The temporal variations of stratospheric ozone and water vapour over Pune (18N, 73E) are studied by analyzing ozone data from satellite based SBUV as well as ground based Umkehr and water vapour data from HALOE. The analysis of SBUV data for the period 1978-03 gives indications to the existence of three turning points (TPs) namely June 91, January 94 and January 99 at which the slope of the trend line changes. The data for two years following the volcanic eruptions at El-Chichon and Pinatubo are excluded from the analysis. The seasonal and annual trends in ozone from SBUV data have significant negative values during 1993-99 and positive values during the period 1999-03 at Umkehr layers 6-8. However, Umkehr data being sparse and having large deviations do not give definite indications of the TPs but do not contradict the existence of TPs. Because of the TPs where the slope of trend lines changes, analysis is done for the periods 1978-91 and 1994-99 separately. The annual trends in ozone from Umkehr data have significant negative values at layer 6 and 7 during 1994-99. Because of the change in ozone trend line at the TP of January 1999, a TP of January 1999 is also assumed in the analysis of water vapour data from HALOE for the period 1994-03. An increase in water vapour from 1994-99 and decrease from 1999-03 at pressure level 3-10 hPa corresponding to layers 6 and 7 is seen suggesting an anti-correlation between water vapour and ozone. This decrease in water vapour from 1999 found over tropical station Pune is about 3 years earlier in contrast to the year 2001 found over mid-latitudes. The 3 years lag at mid-latitudes may be because of the time taken in the transportation of air from tropics to mid-latitudes.
Effect of Equivalent Effective Stratospheric Chlorine (EESC) on ozone over tropical stratosphere

Zonal monthly average SBUV data in 10° latitude bands over 20° S to 20° N for the period Nov. 1978 to Dec. 2008 is considered to find the existence of the cause–effect relationship, if any, between ozone and Equivalent Effective Stratospheric Chlorine (EESC). The representative ozone column values for lower stratosphere from 20 to 30 km, upper stratosphere above 30 km and total stratosphere are obtained by integrating ozone values from layers 2 to 4, 5 to 13 and 2 to 13 respectively. The contributions from season, known natural explanatory variables QBO (quasi biennial oscillation), solar activity and other unknown factors in ozone are obtained by fitting a regressive model to observations. The sum of contributions from other unknown factors and random error is called residual. Anthropogenic condition caused by EESC may be one of the unknown factors. It is found that the variation of residual with time does not follow variation of EESC over tropics though it follows EESC to some extent over mid-latitudes. If the residual part in the model is replaced by a regressive term with EESC as a regressive variable plus error, it is found that the contribution from EESC as compared to contributions from other regressive variables is insignificant over tropics though having some significance over mid-latitudes. Thus EESC has insignificant effect on ozone over tropics.

Studies on aerosols

The monthly average Single Scattering Albedo (SSA) over Delhi has been estimated using Optical Properties of Aerosol and Cloud (OPAC) model along with the measured Aerosol Optical Depth (AOD) and Black Carbon (BC) concentration. It is in the range 0.70 to 0.89 which is largely affected by the BC concentration that lies in the range 4 – 15 μg/m³ (as monthly average during daytime). When the dust concentration was highest (May-June) the SSA increased with wavelength however when dust concentration was low the SSA decreased with the wavelength (Fig.6.20).

Figure 6.21 shows the monthly averaged clear-sky Direct Aerosol Radiative Forcing (DARF) at the surface that varied in the range –45 W/m² to –110 W/m² throughout the year. The value of monthly DARF at (TOA) top-of-atmosphere (TOA) was found to be in the range -1 to 21 W/m² and in the atmosphere it was in the range 46 W/m² to 115 W/m² throughout the year.

The impact of long range transported dust aerosols, originating from the Thar Desert region, to a high-altitude station in the central Himalayas

![Fig. 6.20 Variation of Single Scattering Albedo (SSA) with wavelength during different months of the season](image-url)

![Fig. 6.21: Monthly average aerosol radiation forcing over Delhi](image-url)
was studied with the help of micro-pulse lidar observations at Manora Peak, Nainital. The aerosol radiative forcing was also estimated using the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) model in conjunction with Optical Properties of Aerosol and Cloud (OPAC) model. It showed a value of about -30, -45, and +15 W/m², respectively at top-of-atmosphere (TOA), surface and in the atmosphere on dust day. The positive atmosphere forcing caused an estimated heating of the lower atmosphere by ~0.4 K day⁻¹.

The chemical characterization of aerosols over Delhi for water soluble ionic components revealed that the PM$_{2.5}$ are mainly made up of secondary inorganic aerosols (26.15 μgm⁻³, 27.1%), salt aerosols (22.48 μgm⁻³, 23.3%) and mineral matter (8.41 μgm⁻³, 8.7%) with undetermined fractions (39.46 μgm⁻³, 40.9%) as shown in Fig. 6.22. The contribution of the ionic species in coarse fractions (PM$_{10-2.5}$) was obtained as the difference between analyzed fractions in PM$_{10}$ and those in PM$_{2.5}$. The analyzed coarse fractions (PM$_{10-2.5}$) mainly composed of secondary inorganic aerosols species (16.0 μgm⁻³, 13.07%), mineral matter (12.32 μgm⁻³, 10.06%) and salt particles (4.92 μgm⁻³, 4.02%). The relatively high percentage of nitrate and sulfate in PM$_{10-2.5}$ indicates their association with other coarse components.

### Chemistry of PM$_{10}$ atmospheric aerosols

A total of five heavy metals were analyzed in PM$_{10}$ (particulate matter of size ten micron and below) aerosol samples which were collected at the site of National Physical Laboratory during the year 2009. The concentration order of these metals has been found to be Zn>Fe>Cu>Mn>Cd (Fig.6.23). These metals are contributed by different anthropogenic sources into the atmosphere.

![Fig. 6.23 Concentration (ng/m³) of metal aerosols at NPL, New Delhi](image)

The sources of Cd are of anthropogenic in nature. Cd is mainly used in making alloys, stabilizers in polyvinyl plastics, Ni-Cd batteries, electroplating industries. Cd exposure may result in many respiratory and heart related diseases. Iron comes from natural as well as anthropogenic sources. The natural source of iron is of crustal origin while anthropogenic sources include iron and steel manufacturing units, weathering of iron in contact with moisture and air. Lethal exposure to iron may affect the enzymatic activities in human beings. Cu is emitted by copper alloy industries in Delhi. There are several units installed in and around Delhi. The main sources of Zn are casting of different metals, rubber and chemical industries. The vehicles running on roads also contribute zinc metal. Mn is also used as an additive in unleaded gasoline.

![Fig. 6.22 Percentage contribution of water-soluble ionic species in PM$_{2.5}$ and PM$_{10}$ sample over Delhi](image)
Morphological study of PM$_{10}$ Aerosols

Figure 6.24 shows the SEM (scanning electron microscope) analysis of a blank Quartz microfiber filter. The scan micrograph clearly shows that there is no deposition on filter before taking the sample. The fibrous structures are of micro fibers of quartz filter.

![Fig. 6.24. SEM micrograph of blank quartz microfiber filter](image)

In Figure 6.26, the scan micrograph shows spherical shapes which may possibly be carbon soot particles.

![Fig. 6.26 SEM micrograph of aerosol sample collected on quartz microfiber filter](image)

Figure 6.25 shows the scan micrograph of aerosol sample collected on the quartz microfiber filter. After collecting the sample on the filter, the heavy loading of aerosols on the filter can be seen clearly.

![Fig. 6.25. SEM micrograph of aerosol sample collected on quartz microfiber filter](image)

Figure 6.27 shows the mixture of different shapes which may belong to different compounds. The smaller irregular shaped particles may belong to crustal components.

![Fig. 6.27. SEM micrograph of aerosol sample collected on quartz microfiber filter](image)

It was further confirmed by Energy Dispersive X-ray (EDX) analysis in more details that the smaller irregular particles may be soil dust particles as these had more percentage of Ca and other crustal components. The spherical shaped particles contained more percentage of carbon suggesting that these may be carbonaceous aerosols.
Lidar Measurements of Optical Properties of Aerosol:

Lidar measurements of optical properties of aerosols is being measured by EZ Aerosol Lidar over New Delhi. The laser transmits a wavelength of 355 nm short duration light pulses of 10 ns pulse width into the receiver field of view. The height dependence of the Lidar ratio indicates layers of different aerosol types. Average profile of backscatter, extinction coefficient and Lidar ratio measured on 10th August, 2009 and 15th September, 2009 are given in the Figs. 6.28 and 6.29. The lidar ratio was found to be a useful quantity to track back different pollution sources and identify light absorbing particles. Lidar ratio > 60-70 sr indicates light absorbing particles. Lidar ratio 30 sr to 60 sr are typically found for anthropogenic non-absorbing ammonium sulphate like particle. Large lidar ratio implies the presence of absorbing soot like particle in pollution plume. Figure 6.29 shows the mean lidar role at 355 nm for Aug 10, 09 and 15 Sept., 09. The lidar ratio was found about 70 sr above 400m to 1.2 km, height on 10 August, 09 and more than 75 sr around 400 m height indicating the presence of light absorbing soot particles. The mean lidar ratio profile on 15th Sept. shows presence of several types of aerosol layers. Below 1000 km the lidar ratio varies between 45sr to 55sr and above 1 km to 1.3 km the lidar ratio increased to 56 sr indicating another aerosol layer. The extinction values measured were high ranging from 0.25 km\(^{-1}\) to 0.3 Km\(^{-1}\) up to the height of 1.2 km. as compared to 15th September, 09 values.

Fluctuation in Ozone column during the solar eclipse

The Solar eclipse occurred over Thiruvanthapuram on 15 January 2010 started
at 11.15 (IST), the maximum obscuration of the sun was 91.9% which occurred at 13.20 (IST) and the eclipse ended at 15.30 (IST). It was the longest annular solar eclipse of millennium with maximum length of 10 minutes 4 seconds. The column abundance of ozone during this event using hand held sun photometer (Microtop) with filters centered at 300, 305, 312, 940 and 1020 nm was measured. The first three UV wavelengths are used for total ozone measurements and 940 nm and 1020 nm are used for total water vapour measurements. For the period between 10.00 (IST) to 16.00, the total ozone column was changed on the day before the eclipse from 278 DU to 260 DU and on the day of eclipse it was varying from 285 DU to 262 DU (Fig. 6.30).

During the course of the eclipse a gradual decrease in the total ozone was observed before the maximum obscuration of the sun and followed by increase just after maximum obscuration. Visual inspection of observations shows a possible fluctuation in ozone column before the maximum obscuration occur. To determine the possible oscillations the data from 10:00 hrs to 14:00 hrs were subjected to Spectral Fourier Analysis (Fig. 6.31). The power spectrum of total ozone reveals significant oscillations. The principle fluctuation with a period of 15 to 20 minutes followed by a number of fluctuations of different periods of reduced amplitude were seen.

**Ozone Depletion Events observed at Indian Arctic Station Himadri, during spring of 2010**

Episodes of very low ozone concentrations are a common features at Arctic
During spring. The low ozone episodes were observed from late March to the beginning of June. The events have been attributed to the dominant role of reactive halogen species chemistry in tropospheric ozone depletion. The time series measurements of surface ozone and carbon-monoxide taken during second phase of winter expedition from 28th, March to 14th, April is depicted in the Fig. 6.32. The ozone depletion event occurred on 30-03-2010 at 03:00 hrs and lasted up to 40 hours and ozone was depleted from (45 – 54 ppb) to 24 ppb is just one day. In another event on 12-04-2010 the ozone depletion was also observed and ozone depleted from 54 ppb to 32 ppb and this event lasted for 2 days, till 14-04-2010. Trajectory analysis shows that the observed low ozone events were closely linked to the transport direction. The episodes occurred when the air mass were transported from N or NE directions indicating the region of ice covered Arctic Ocean. The depletion could be explained by the advection of previously ozone depleted air mass from oceanic region the lower graph shows the depletion event at Zeppelin Mountain station which is about 2 km away from Indian station and is at the top of hill, 474 m.a.s.l. The carbon monoxide varied from 200 ppb to 250 ppb during observation periods.

Occurrence of extremely low cold point tropopause temperature during summer monsoon season: ARMEX campaign and CHAMP / COSMIC satellite observations

Extreme low cold point tropopause (CPT) temperatures (T ≤ 191 K) are often observed during the monsoon season over the Bay of Bengal (BOB) and adjoining areas. Frequent occurrences of extreme low CPT temperature over Arabian Sea (AS) and adjoining areas using radiosonde observations during the Arabian Sea Monsoon Experiment (ARMEX) from 24 June to 15 August 2002. Day-to-day variations in temperature at and CPT and at 100 hPa level observed during ARMEX campaign show modulation by the wave activity with a period of ~15 days and it is observed to be closely associated with Tropical Easterly Jet (TEJ). Spatial and temporal distribution of low CPT temperature over a wide scale is examined using CHAMP and COSMIC satellite temperature data. These observations show occurrences of low CPT temperatures during the early period of the monsoon season over BOB, AS, and adjoining areas which often extends to the Africa’s Horn region. An enhanced low CPT temperature occurrence during the early part of the monsoon season appears to be due to the modulation of outgoing long wave radiation (OLR), CPT temperature and height by intraseasonal oscillation. Modulation of CPT by intraseasonal oscillation suggests that this oscillation could contribute to dehydration of upper troposphere and lower stratosphere (UTLS). In addition a close association is noted between the seasonal variations of the latitude of low CPT temperature and low OLR. This is similar to the anticipated seasonal movement of Inter tropical convergence zone (ITCZ).
Fig. 6.33 Plots of time series of C P T Temperature measurements on board ORV Sagar Kanya. Data gap points are joined by dashed lines. The smoothed points of time series, after 5 day running mean, are joined by thin solid line.

### Mega-city atmospheric pollution precursor process modelling

The air quality in urban areas has become an important issue having direct bearings on the human health and climate change. The increased anthropogenic activities associated with the urbanization are responsible for the deteriorating air quality. It is therefore important to quantify the urban emissions and investigate their impacts on ambient air quality through modelling which could be verified through ambient air quality measurement. During the 2009-10, emission inventory for the pollutants’ emissions of CO₂, CH₄, N₂O, CO, NOₓ and NMVOC (Non methane volatile organic carbon) from transport sector in Delhi for the period 2000 to 2007 have been generated and shown in Figs.6.34 (a to f).

These mega-city level emission inventory is being converted to grid-based inventory for incorporation of atmospheric models like WRF-CHEM to develop air-quality forecast at city level.
Assessment of impacts of heat stress on human health and adaptation strategies

Climate change currently contributes to the global burden of disease and premature deaths. Globally, the hot days, hot nights and heat-waves have become more frequent which are associated with marked short-term increases in mortality. Heat waves are normally associated with the high average temperature and the number of consecutive hot days. Heat stress-related mortality has been reported and evaluated mostly for mid-latitude countries and cities, but also in the hot subtropical and cold high-latitude environments. In India, eighteen heat-waves have been reported during the period between 1980 and 1998, with a heat-wave in 1988 affecting ten states and causing 1,300 deaths. Efforts are being made to assess the impacts of future climate change on heat stress in India. The future climate scenarios for India generated by Indian Institute of Tropical Meteorology (IITM), Pune by PRECIS climate change model for A2 & B2 Scenarios have been used to assess the likelihood of heat-wave conditions in different districts of seven most vulnerable states namely Andhra Pradesh, Gujarat, Orissa, Uttar Pradesh, Rajasthan, Bihar and West Bengal. Using the model outputs, the events of consequent three days of high temperature events in the months of April through June have been assessed. The results show the vulnerability of these regions for heat stress condition in future climate regimes. eg. in Andhra Pradesh, more than half of its districts show high temperatures in the range of 450 to 500°C for more than 15 days even in the month of April of 2071, 2080, 2090 & 2100 (Figure 6.35). The darker colours show the increasing number of high temperature events in different districts of Andhra Pradesh.

<table>
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<tr>
<th>Scenario</th>
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<th>April 2090</th>
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<td><img src="imageB2.png" alt="Image" /></td>
<td><img src="imageB2.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Fig. 6.35 Heat Stress Vulnerability of Andhra Pradesh due to continuous high temperatures ranging between 45⁰-50⁰C in the month of April of 2071, 2080, 2090 & 2100