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The Atmospheric Air Ions and Air-Earth Current Density Measurements at Maitri

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ABSTRACT

Simultaneous measurements of the small, intermediate and large-positive ions and air-earth current density made at Maitri during January – February 2005 are reported. Variations in small and large positive ion concentrations were almost similar to each other. On the other hand, variations in intermediate positive ion concentrations were independent of the variations in the small/large positive ions and exhibited a diurnal variation which was similar to that in atmospheric temperature on fair weather days with a maximum during the day and minimum during the night hours. No such diurnal variation in intermediate positive ion concentration was observed on cloudy days when variations in them were also similar to those in small/large positive ion concentrations. Scavenging of ions by snowfall and trapping of α-rays from the ground radioactivity by a thin layer of snow on ground, was demonstrated from observations. Variations in intermediate positive ion concentration are explained on the basis of the formation of new particles by the photolytic nucleation process.

1. INTRODUCTION

Presence and movement of ions in the atmosphere largely determine the electrical state of the atmosphere. Ions in the lower atmosphere are generated mainly by cosmic rays and radioactivity in the ground. They can also be locally generated by a variety of other mechanisms such as the bursting of air bubbles on the air-water interface of water bodies, splashing of raindrops on the Earth’s surface, combustion activities, automobile exhausts, point discharge from the points raised above the Earth’s surface etc. Temporal and spatial variations of ions have been studied at several places [Wait and Torreson, 1934; Norinder and Siksna, 1953; Misaki, 1961; Jonassen and Wilkening, 1965; Misaki et al., 1972]. Dhanorkar and Kamra, [1991, 92, 93] have extensively studied the diurnal and seasonal variations of different categories of ions and their relative contributions to the atmospheric electric conductivity at a tropical land station, Pune.

Horrak et al. [2000, 2003] categorized the atmospheric ions in five different categories and studied their properties at a mid-latitude station, Tahkuse, Estonia.

The ions generated and introduced in the atmosphere are destroyed by several processes such as recombination of ions, attachment to aerosol particles, sedimentation and scavenging by raindrops or ice particles. However, the contribution of such individual processes to the ionic equilibrium state of the atmosphere is not easily distinguishable from each other. Measurements made over land stations are often largely disturbed by anthropogenic pollutants. The effects of individual factors are more effectively illustrated if such measurements are made at a clean place such as the open ocean, Antarctica, Arctic etc. with almost no disturbance due to anthropogenic sources. An opportunity for such a study was provided during our measurements of some atmospheric electric parameters and aerosols during the 24th Indian Scientific Expedition to Antarctica.

Antarctica provides a unique site which is practically free of anthropogenic pollution. Since more than 98% of the continent is covered by ice, the ionization produced by the ground radioactivity and its emissions which is a major source of ionization near the ground, is almost nil. However, as a result of being located near the South Magnetic Pole, the lines of force of Earth's magnetic field become perpendicular to the Earth's surface. The continent is exposed to a greater flux of high energy particles which are known to penetrate and produce more ionization in the lower atmosphere than at other sites at lower latitudes. Therefore, the sources and sinks of ions and their transport in the Antarctic environment are much different than those in the tropics and mid-latitudes. Although measurements of several atmospheric electric parameters have often been made (e.g. Kasmier, 1972; Byrne et al., 1993; Burns et al., 1995; Bering et al., 1998; Deshpande and Kamra, 2001; Virkkula et al., 2005), to the best of our knowledge, no measurements of atmospheric ions of different categories have so far been made at Antarctica. Knowledge of atmospheric ions is important not only in understanding the electrical state of the atmosphere but also in understanding the global electric circuit [Siingh et al., 2007a and references therein], nucleation and growth characteristics of aerosol particles [Tinsley and Heelis, 1993; Carslaw et al., 2002; Harrison and Carslaw, 2003; Nadykto and Yu, 2003; Hirsikko et al., 2005], monitoring of background air pollution [Cobb and Wells, 1970; Kamra and Deshpande, 1995], and solar-terrestrial relationships [Markson, 1978; Markson and Muir, 1980].

Here, we present our simultaneous measurements of the small-, intermediate-, and large- positive ions and air-earth current density made at Maitri, in January - February, 2005.

2. INSTRUMENTATION AND MEASUREMENT SITE

Positive ion concentrations were measured with an ion-counter of the type described by Dhanorkar and Kamra [1991] as shown in **Figure 1**. It consists of three coaxial Gerdiens condensers through which the air is sucked with a single fan. **Table 1** details the measurements of all the three condensers. Ranges of mobility covered by each condenser are described in **Table 2**. The detailed working principle are given in Siingh et al., (2007b).

Fig. 1 (a) : Ion counter installed at Maitri, (b) A high level team including Hon. Minister for Science and Technology Mr. Kabil Sibal, Secretary for Department of Ocean Development, Dr. Harish K Gupta and Director, NCAOR, Dr. P C Pandey who visited Indian station at Antarctica, have visited our laboratory at 'Maitri' on 3rd February 2005. IITM scientists explaning the work in front of Hon. Minister. (R-L Shri R.K. Seth, Dr P.C. Pandey, Dr. H.K. Gupta, Hon. Minister Shri Kabil Sibal, Dr. Rajesh Asthana, Mr. Sunil Sonbawane, Dr. Devendraa Siingh and Vimlesh Pant).

Air-earth current density was measured with a 1 m^2 flat-plate antenna kept flush with the ground (**Figure 2)**. The inputs from all the three

Fig. 2 : Air-earth current plate antenna installed at Maitri

Table 1—Dimensions and other parameters of three condensers of the ion-counter

Dimensions/ constants	Small-ion Condenser	Intermediate-ion Condenser	Large -ion Condenser
Length of the outer electrode (m)	0.4	0.8	1.2
Length of the inner electrode (m)	0.2	0.5	1.0
Diameter of the outer electrode (m)	0.098	0.06	0.038
Diameter of the inner electrode (m)	0.076	0.037	.022
Potential applied (V)	15	100	600
Critical mobility ($m^2 V^{-1}s^{-1}$)	0.766×10^{-4}	1.2×10^{-6}	0.97×10^{-8}
Flow rate ($l\ s^{-1}$)	8.6	1.8	0.29

Table 2—The mobility and size ranges of ions

Category	Small ions	Intermediate ions	Large Ions
Mobility range ($m^2 V^{-1} s^{-1}$)	$> 0.77 \times 10^{-4}$	$1.21 \times 10^{-6} – 0.77 \times 10^{-4}$	$0.97 \times 10^{-8} – 1.21 \times 10^{-6}$
Diameter range (nm)	< 1.45	1.45 – 12.68	12.68 – ~130

condensers of the ion counter and the air-earth current plate were amplified with separate amplifiers placed close to the sensors and then fed through coaxial cables to a data-logger placed in a nearby hut.

Measurements were made at Maitri located in the Schirmacher Oasis in the Dronning Maud Land, East Antarctica. The east trending oasis is exposed over an area of 35 km^2 with 16 km length and a maximum of 27 km width. It has a lake and then steep cliffs towards the ice-shelf and is covered by polar ice on the southern side. The area is dominantly covered by sandy and loamy sand type of soil. Measurements of Rn^{222} and small ions made at Maitri show that their atmospheric concentrations close to ground are very low and not much different from that over sea [Ramachandran and Balani, 1995].

Location of Maitri (70° 45’ 52" S, 11° 44’ 03" E, 130 m above sea level) at the Antarctic continent, and the location of instruments at the Maitri station are shown in **Figure 3**. Prevailing direction of winds was southeasterly. Ion counter was placed on the ground with the inlet of the

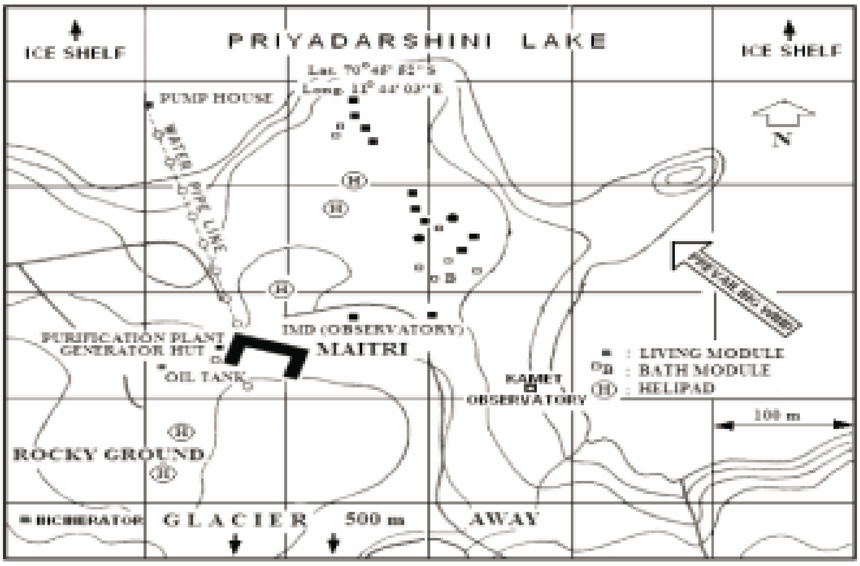

Fig. 3 : The map of Antarctica, showing the location of Maitri station. Location of instruments (Kamet observatory) at Maitri

small and intermediate positive ion condensers at 50 cm and large ion condenser at 60 cm above the ground. The air-earth current plate was placed flush with the ground. The single storeyed building of Maitri station, generators, gas plant and incinerator are about ~ 300 m away in the southwest direction from the instruments so that any pollutants released from them has no or little chance of reaching the site of measurements with the prevailing winds.

3. OBSERVATIONS

3.1. Daily average concentrations of ions

Figure 4 shows the daily average values of the small-, intermediate, and large positive ion concentrations and air-earth current density for the entire period of measurements at Maitri. Vertical bars show the standard deviations. Concentrations of small, intermediate and large positive ions varied in the ranges of 2 to 6 x 10^2 cm^{-3}, 7 x 10^2 to 3 x 10^3 cm^{-3}, and 5 x 10^3 to 1.2 x 10^4 cm^{-3}, respectively. The air-earth current density varied from 0.5 to 1.6 x 10^{-12} A m^{-2} during this period. Values of all categories of ions started increasing between the Julian day 15 to 18 and, except for a dip observed around Julian day 22, were 1.5 to 2 times larger up to the Julian day 45 as compared to the periods immediately before or after. Variations

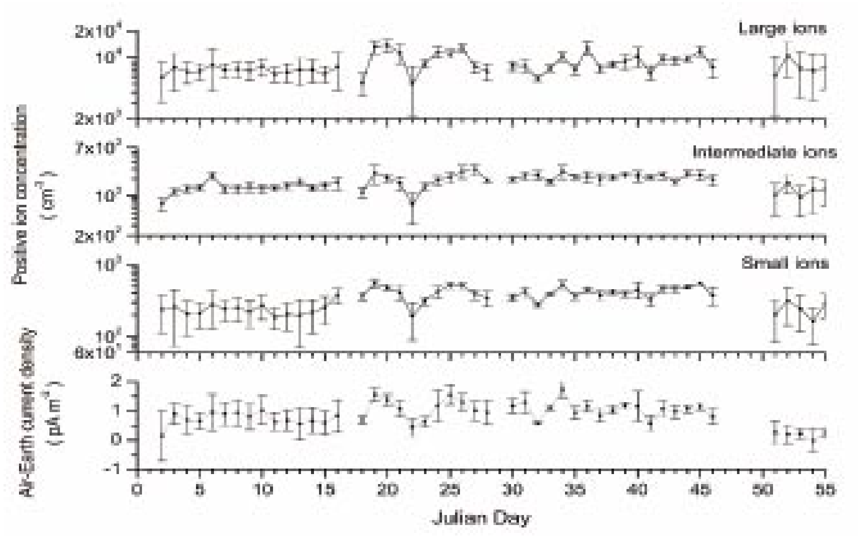

Fig. 4 : Daily average values of the small-, intermediate-, and large- positive ion concentrations and air-earth current density for Julian days in 2005. Vertical bars show the standard deviations.

in air-earth current during this period followed similar trend. In comparison to continental stations in the northern hemisphere, these values were roughly 50 – 80% lower than that at a tropical station, Pune [Dhanorkar and Kamra, 1992] and more than those at mid-latitude station at Tahkuse [Horrak et al., 2003] in the northern hemisphere. In particular, the intermediate positive ion concentration at Maitri was about an order of magnitude higher than those at Tahkuse in this season.

The variations in electrical parameters did not show much similarity with the variations in meteorological parameters at Maitri **(Figure 5)**. The

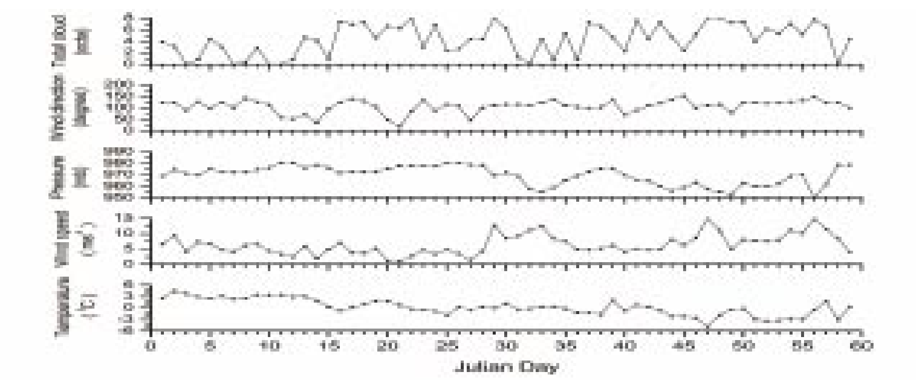

Fig. 5 : Daily average values of meteorological parameters

daily average atmospheric temperature, however, from Julian day 15 to 47 dropped by 4°C, from 2°C above freezing point to 2°C below freezing point. Very strong winds prevailed after 1800 UT and the station experienced snowfall during the night of Julian day 46.

3.2. Diurnal variations

At Maitri, concentrations of small and large positive ions did not show any systematic diurnal variations on fair weather days. However, they exhibited a very high degree of similarity in variations amongst themselves. For example, **Figure 6** shows diurnal variations of the concentrations of three categories of positive ions and the air-earth current density on a typical fair weather day, January 9, 2005. On this day, atmospheric pressure varied from 972 to 975 hPa with no trace of cloud throughout the day, except for moderately strong southeasterly winds during night and morning hours. Winds were calm or very light and temperature gradually increased from 0.1 to 6.1°C. Sunshine lasted for almost all the 24 hours of the day. Small positive ion concentrations on this day were less than 488.26 cm^{-3} and were minimum at about 1500 UT. Large positive ion concentrations, though more than an order of magnitude higher, closely followed the variations in small positive ion concentration. The intermediate positive ion concentrations

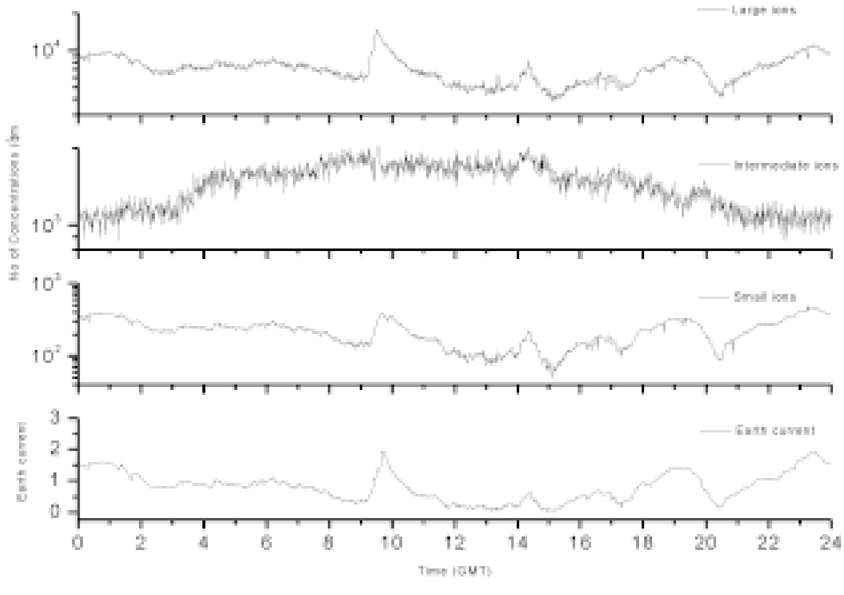

Fig. 6 : Diurnal variations of small-, intermediate- and large- positive ion concentrations and air-earth current density on a fair-weather day, January 9, 2005

changed little in the range of 875 to 2502 cm^{-3} and varied independent of variations in small/large positive ion concentrations. In contrast to the small/large positive ion concentrations, the diurnal variation in intermediate positive ion concentrations were much regular and generally followed the trend in atmospheric temperature and were comparatively higher during the day than at night hours. The air-earth current density varieed from 0.0159 to 1.9706 x 10^{-12} A m^{-2} and almost exactly followed the variations in small/large positive ion concentrations.

In sharp contrast to the diurnal variations on fair-weather days, the intermediate ion concentrations on cloudy days did not show any maximum in the afternoon hours and followed the variations in small/large positive ion concentrations **(Figure 7)**. For example, on January 14, 2005, the sky remained covered for the entire day with more than 6 octa of clouds. Southeasterly winds of $7ms^{-1}$ and temperatures from -0.2 to + 5.0 °C prevailed over the station. Concentrations of all categories of positive ions were comparatively small and showed much smaller variability during the whole day. Variations in air-earth current density on such cloudy days closely followed the variations in either category of positive ions.

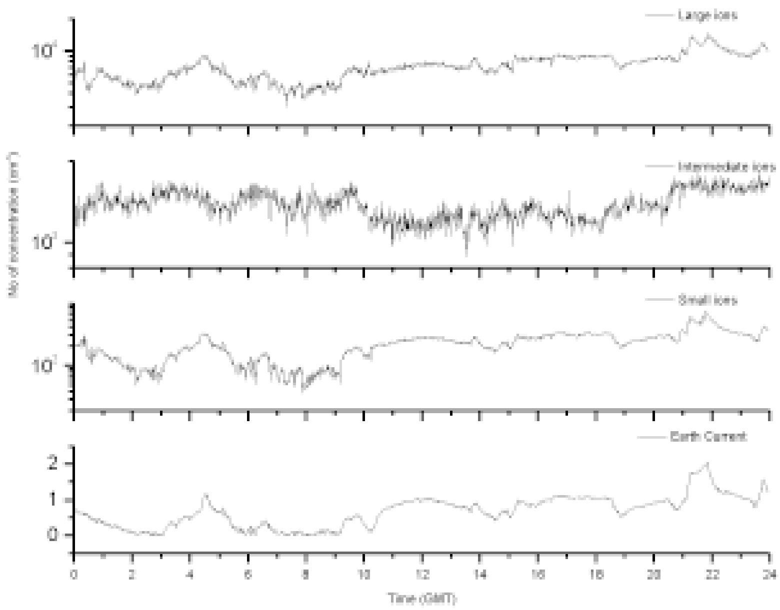

Fig. 7 : Diurnal variations of small-, intermediate and large-positive ion concentrations and air-earth current density on a cloudy day, January 14, 2005

3.3. Effect of snowfall

Snowfall, like rainfall, is considered to be an effective scavenger of atmospheric aerosols and ions. Our observations at Maitri provided several good cases of its demonstration. For example, **Figure 8** shows that with the start of snowfall at about 0400 UT on the Julian day 22, the concentrations of all categories of ions fell by about an order of magnitude and continued to be low until 0800 UT when observations had to be discontinued due to heavy snowfall. During this period, sky remained overcast with southeasterly winds remaining below 5 ms^{-1} and atmospheric temperatures in the range of 0 to – 2°C. The lowest values of the ion concentrations encountered during this period were 10 ions cm^{-3} for small positive ions, 10^2 ions cm^{-3} for intermediate positive ions and 3 x 10^2 ions cm^{-3} for large positive ions. Although ion concentrations in each category fell, time-variations in one category did not exactly follow the variations in other category. Air-earth current density also fell to very low or almost zero value during the period of snowfall.

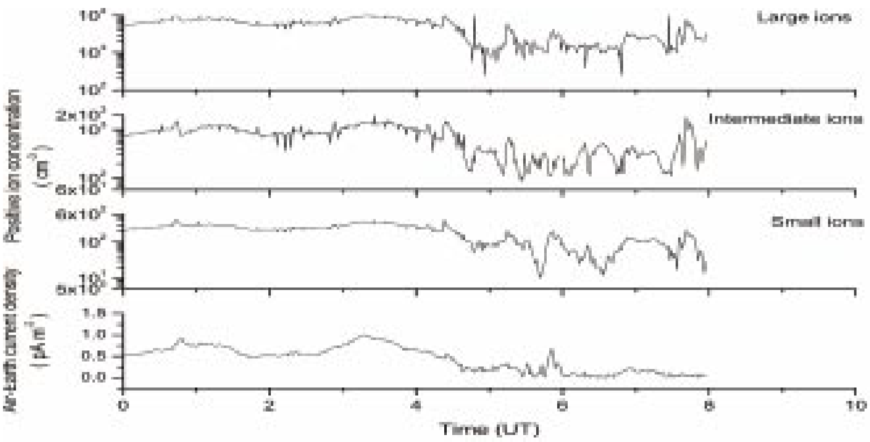

Fig. 8 : Change in concentrations of positive ions and air-earth current density due to snowfall on January 22, 2005

3.4. Effect of blizzard

Simpson [1919] observed that blizzards are intensely electrified and produce high positive potential gradients on the ground. We observed that whenever high winds were accompanied with some snowfall, i.e., atmospheric temperature were below freezing point, positive ion concentration of all the three categories decreased about 3 – 4 hours before the appearance of snow. For example, on February 15, 2005, winds began to strengthen at 1800 UT and snowfall started from 2255 UT. Concentrations of all the three ion categories began to decrease at 1830 UT and decrease by approximately 2 - 4 times by 2200 UT **(Figure 9)**. Although blizzard continued for the next two days, our observations could not be continued beyond midnight on February 15 when wind speed exceeded 30 ms^{-1}.

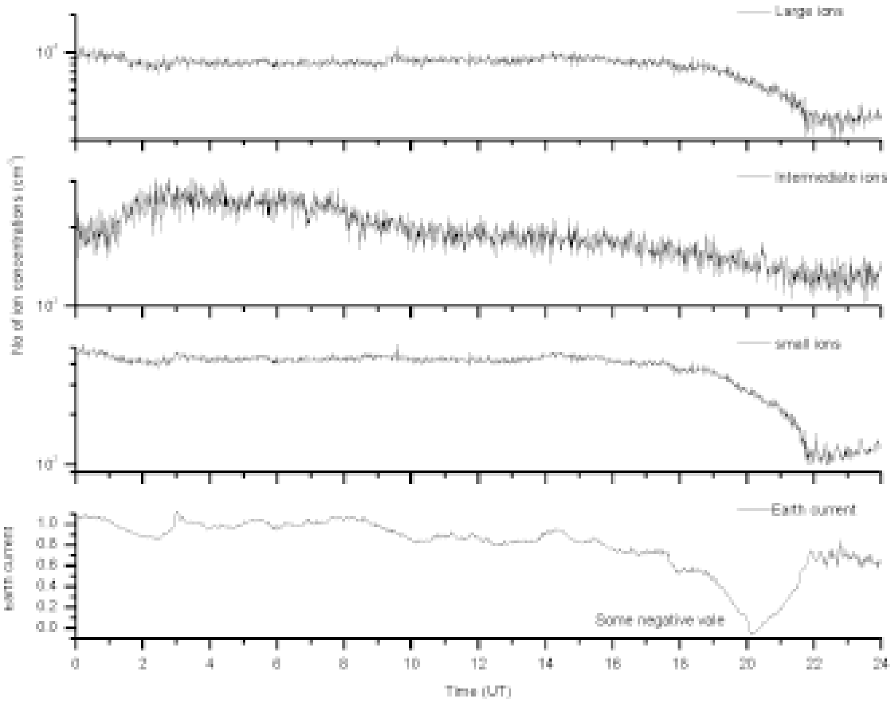

Fig. 9 : Change in concentrations of positive ions and air-earth current density during a blizzard on February 15, 2005

Ion concentrations of all the three categories started decreasing after 1700 UT and the decrease was by more than an order of magnitude in the next 1 to 3 hours as the wind speed increased from 9 to 17.5 ms^{-1}. The rate of decrease was the highest for the large ions, the lowest for small ions and in between the two for intermediate ions.

Our observations of different rates of decrease in the case of different categories of ions in **Figure 9** can be explained in terms of the scavenging of atmospheric ions and aerosols by the drifting snow particles. The small ions generated close to the ground were soon attached to the aerosol particles of different sizes. As a result of the difference in size of the blowing snow particles and atmospheric ions of different categories, snow particles and ions will develop a relative velocity. While ions of all size-categories will be carried by the air, snow particles will experience a drag force and attain somewhat lower velocities. This difference in velocities of snow particles and ions will cause the scavenging of ions by snow particles. Now, collection efficiencies of particles of the size of blowing snow are 3 – 4 orders of magnitude higher for particles of the size of large ions than for small ions (Wang et al., 1978). So the blowing snow particles will collect the large ions much more efficiently than smaller ions. In addition, large ions, because of having larger terminal velocities, will quickly settle to the ground by sedimentation. This might have caused higher rate of decrease of large ions compared to that of small ions in our observations.

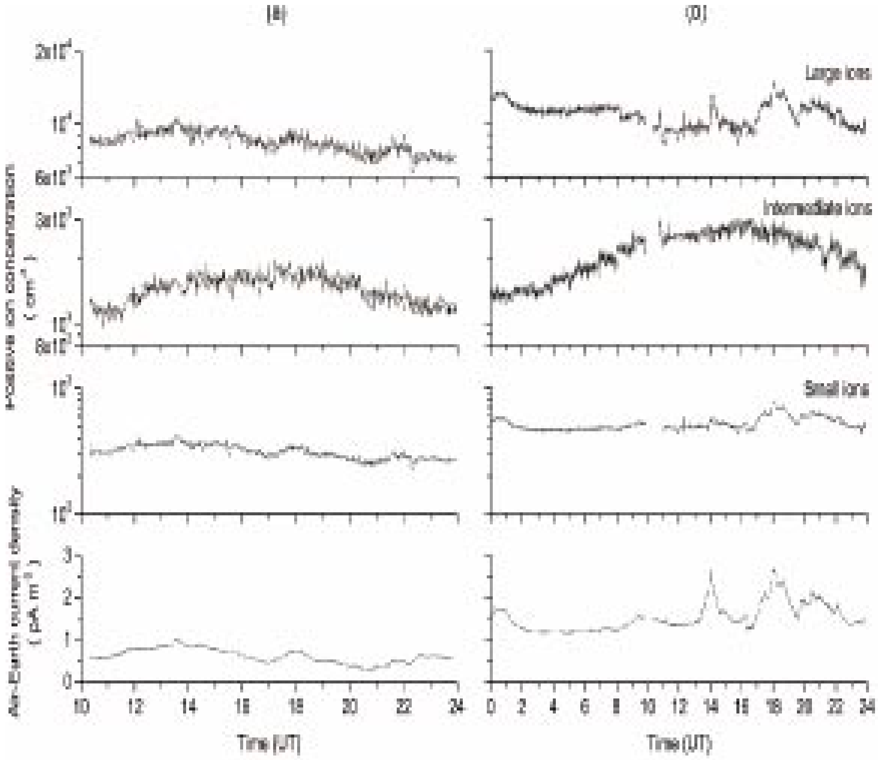

Fig. 10 : Diurnal variations of the small, intermediate and large positive ion concentrations and air-earth current density on two fair-weather days when the ground was covered with snow on January 23, 2005 (a) or was bare on January 25, 2005 (b)

3.5. Effect of snow-covered ground

α-and β-rays emitted from the ground are primary sources of ionization close to ground. α-rays are emitted by the radioactive decay of radon. The soil around Maitri is found to have an uranium (U^{238}) content varying from 0.036 to 0.364 ppm which is very small in comparison to the range of levels of 1.47 to 4.07 ppm estimated from various types of Indian soil [Ramachandran and Balani, 1995]. In the region free of human activity, such as at Maitri, presence of U^{238} in the soil is mainly attributed to geochemical processes. These emissions can be effectively trapped by a thin layer of ice over ground. During the period of our observations, ample opportunity was provided when the earth's surface at Maitri was completely bare or covered with a layer of snow. The snow that deposited on the ground during the snowfall on January 22 - 23, 2005 completely covered the ground but melted away and left the ground bare by January, 25, 2005. **Figure 10** shows the positive ion concentrations and air-earth current density on January 23 and 25, 2005 when the ground was completely covered or bare, respectively. Both days were otherwise marked with fair weather and bright sunshine. Concentrations of all categories of positive ions increased by 100 to 400% on January 25. An important feature of observations was that almost uniform concentration of about 3×10^2 ions cm^{-3} of small positive ions occurred throughout the day on January 23 when the ground was covered with snow.

4. DISCUSSION

The small ions produced in the atmosphere soon get attached to aerosol particles and form large ions. In the absence of any other mechanisms directly producing large ions, the variations in small and large ion concentrations are expected to closely follow each other. The close parallelism observed here between the small- and large- positive ion concentrations during the fair- weather periods strongly supports the fact that the ion-aerosol attachment process is the only dominant source for the production of large ions at Maitri. It also demonstrates almost total absence of any effect of ions or aerosols produced on land from anthropogenic sources on the Antarctic measurements. Further, almost parallel variations in the air-earth current density and small/large positive ion concentrations confirm the fact that the air-earth current is mainly determined by the small ions.

On the contrary, almost independent behavior of the variations of intermediate positive ion concentrations at Maitri suggests that the mechanism responsible for their production is independent of the mechanism responsible for small/large positive ion production. Moreover, the observations that the variations in intermediate positive ion concentration and atmospheric temperature were almost parallel to each other on the fair-weather days and this parallel behavior between the two parameters disappeared on cloudy days, strongly suggest that the mechanism responsible for the production of intermediate positive ions is strongly dependent on the solar radiation. Horrak et al. [1998] suggested that cluster ions can grow into intermediate size ions through ion-induced nucleation processes i.e. accumulation of environmental vapors under proper conditions.

The decrease observed in all types of positive ion concentrations and the air-earth current density during snowfall indicates that snow particles effectively scavenge the ions. The fact that the air-earth current density almost reduced to zero value indicates that scavenging of atmospheric ions was almost total at that time. The observations that the decrease in different ion categories was not always parallel to each other are likely to result from the non-uniform rate of scavenging of the ions of different sizes.

The observed decrease in all categories of positive ion concentrations when the ground was covered by a thin layer of snow shows an effective trapping of á and â rays from the ground by a thin layer of snow. Though small but rather distinct difference in small ion concentration over a snow-covered or bare ground supports the observations of Ramachandran and Balani [1995] that radioactive emissions from the rocks at Schirmacher are low and almost comparable to that of sea water. Further, almost constant concentration of small positive ions throughout the day when the ground was covered with snow indicates almost uniform production of small ions by cosmic rays and g rays in the lower atmosphere.

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