Aerosol and Air Quality Research, 10: 154–166, 2010

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2009.10.0066

Diurnal and Seasonal Air Ion Variability at Rural Station Ramanandnagar (17°2′N, 74°E), India

S.D. Pawar[1*], G.S. Meena[2], D.B. Jadhav[2]

[1] *Department of Physics A.C.S. College Palus, Dist Sangli Maharashtra Pin: 416310, India*
[2] *Indian Institute of Tropical Meteorology, Pashan, Pune - 411 008, India*

ABSTRACT

High-energy radiations, such as alpha and beta particles or gamma radiation, ionize air molecules into pairs of positive ions and free electrons. The diurnal and seasonal variations of these air ions were measured for the first time at a rural monitoring station in Ramanandnagar (17°2'N, 74°E), India, and the urban tropical station in Pune (18°31'N, 73°55'E) from June 2007 to May 2008. Air ion concentrations, measured using a Gerdien condenser at Pune station, increased from nighttime and reached maximum in the early morning. Compared to Pune, air ion concentration and positive-to-negative air ion ratios at Ramanandnagar increased from morning and reach maximum in the afternoon (12:00–14:00). Plant transpiration and waves in the flooded Krishna River during July–September 2007 were determined as additional sources of atmospheric ion production at Ramanandnagar. Intensive temperature inversion during winter lead to the accumulation of radon and radioactive aerosols near the Earth’s surface, and hence increased the rate of ionization. Annual peaks of positive/negative ion maxima and positive-to-negative small ion ratios were observed in January 2008. It was also observed that as human activities increased, more aerosol particles were introduced into the atmosphere between 12:00–14:00 hours, during which time the average positive-to-negative air ion ratio reached peak values. During summer, radioactive gases moved upward, carrying radon and radioactive aerosols, and thereby reducing ionization. Results show a decrease in average positive and negative small ion maxima from February 2008 to May 2008.

Keywords: Gerdien condenser; Transpiration; Vegetation; Temperature inversion; Radio-active aerosol.

INTRODUCTION

The production of atmospheric ions from ionization up to their final stable form falls into three phases: ionization, attachment and clustering. Ionization is a process in which electrons are released from the outer electron shell of a gas molecule or atom. An electron detached from a molecule or atomic bond cannot exist freely in air at normal temperature and pressure, but readily attaches itself to a neutral atom or molecule. These ions cannot remain stable in the atmosphere under normal conditions, and consequently surround themselves with a number of neutral molecules and from clusters of approximately 10–30 molecules. Only then do they reach certain stability in the form of so called “small ions” (cluster ions).

Previous studies have measured air ion concentrations at an urban site in Helsinki (60°10'N, 24°57'E) (Hirsikko *et al*., 2005), along a roadside at Kuopio (62°53'N, 27°38'E), Finland (Titta *et al*., 2007), along the Trans-Siberian railroad (Vartiainen *et al*., 2007), and in an earlier study from 2001 (Aplin and Harrison, 2001). Tammet (2006) demonstrated secondary charged aerosol particles in the urban atmosphere of Tartu (58°21'N, 26°44'E), Estonia. Arabian Sea nighttime small-ion concentrations (during 18:00–20:00 and 06:00–09:00 hours) are on about an order of magnitude higher than their daytime values (Siingh *et al*., 2005). Kolarž and Filipović (2008) have made diurnal atmospheric air-ion concentrations, synchronous aerosol, ozone, temperature and relative humidity measurements at a site in Belgrade (44°50'N, 20°37'E). Daily variations of the measured parameters were analyzed and showed that air ions of both signs and ozone are positively correlated, while aerosols show strong inverse correlation with air ions. Also, concentrations of air ions and ozone decrease with temperature, while aerosol concentration and humidity are increasing. Meena and Jadhav (2007), making daily maximum/minimum temperature and ozone observations at tropical station Pune (18°31'N, 73°55'E), have noticed that minimum temperature and ozone are in correlation, while maximum temperature and ozone are in inverse correlation. These processes could be explained concerning properties of the specified parameters,

* Corresponding author. Tel.: +91-2346-222888;
Fax: +91-2346-222888
E-mail address: sdpawar_ath345@yahoo.com

measuring place properties and weather conditions. Long-term data sets on small ions have been lacking from both rural and urban atmosphere. In this paper we present, for the first time, annual variation of cluster air ions in the rural background atmosphere at Ramanandnagar (17°2'N, 74°E), India. This station lies in the agricultural Sangli (16°52'N, 74°36'E) district of Maharashtra state, through which the river Krishna flows, characterized by a moderate to high rain fall during the Indian monsoon season.

In addition to ionizing radiation, several other sources produce charge carriers of very different sizes and nature on a local scale; for example, dust storms known to be intensely electrified. Charge produced in these storms can be transported up to several kilometers in altitude and over many square kilometers of the earth's surface. Electrical discharges can cause the formation of ions in the atmosphere. This requires a high electric field that generally occurs in the disturbed weather inside or in the vicinity of thunderstorms. In such conditions, field intensity is enhanced around grounded elevated objects and when it increases to breakdown value or above, a large number of uni-polar ions are injected into the atmosphere. This phenomenon of point discharge can occur at tall trees or buildings below thunderstorms. Lightning flashes from thunderclouds also produce local, but intense, ionization in the atmosphere.

Combustion of various materials in volcanoes and the volcanic clouds that are formed when molten lava comes in contact with water produce charged clouds, which produce lightning flashes. There are several manmade sources of ionization, such as the exhaust from automobiles or aircrafts, industrial processes, etc.; some of which are discussed by Kamra (1991). Contributions of such local sources to the ion concentration in the atmosphere may be dominant in the neighborhood of such activities. The production of ions by ionizing radiation in air is discussed by Jesse (1968). He reports values of W, the average energy required to produce an ion pair in air, of W, the average energy required to produce an ion pair in air, of 35 eV for alpha particles and 33.8 eV for β rays, X rays and gamma rays. On this basis, ion production by ^{222}Rn plus equilibrium of its decay products is nearly 6.4×10^5 ions per ^{222}Rn disintegration. Ion pair production by radioisotopes is usually confined to the lower several meters above soils and under the vegetation canopy.

The open question that we try to answer in this paper is: How does plant transpiration of radon and thoron produce a high magnitude of air ions in rural areas in India as compared to urban? We measured the concentration of small ions during June 2007 to May 2008, comparing ion measurements at rural station Ramanandnagar (17°2'N, 74°E) with tropical urban station Pune (18°31'N, 73°55'E), India. We also highlight the need to carry out observations over other rural areas in India.

MEASUREMENTS AND METHODS

The Ramanandnagar air quality monitoring station is located in a rural area 210 km southeast of Pune and 370 km southeast of Mumbai (18°55'N, 72°50'E), capital of Maharashtra, India. The surrounding terrain is characterized by groups of trees (about 80–90 trees in a 120 m radius), small forests, grassland, and agricultural land. Behind is open agricultural land with sugarcane, wheat, corn fields as shown in Fig. 1. The river Krishna flows 4 km to the west. In front of the monitoring station, at a distance of 50 feet, is a road 20-feet wide with an average traffic frequency of about 1–2 motor vehicles per minute. The monitoring station was located on the ground floor and was used for measuring air ion concentrations. The floor area and volume of laboratory were 10 m^2 and 42 m^3 respectively. The overall surface area (floor, walls, ceiling and the surface of tables and cabinets) of the laboratory was approximately 63 m^2.

The area was farmed for sugarcane and corn crops from July to September 2007; some crops, except sugarcane, were cut and harvested in October 2007. Then wheat and channa were grown between November and February. All these crops, including sugarcane, were harvested in the following March and April 2008. In May, crops were grown in one or two places, but the major part of the land was empty. Data were collected during the period June 1, 2007 to May 31, 2008, with a total analysis period of 8,040 hours. Owing to

Fig. 1. Air quality monitoring station at rural site Ramanandnagar (17°2'N, 74°E), India.

instrument pauses in the measurements, and instrumentation and power failure, about 16% of observations were not possible for measurement. About 6,754 hourly concentrations of both signs were available for statistical analysis.

A small air-ion counter indigenously designed and developed at the Indian Institute of Tropical Meteorology, Pune, was operated at rural station Ramanandnagar. The instrument which is shown in Fig. 2 consists of a Gerdien condenser, which is shielded from external fields by a co-axial cylinder fitted around the outer electrodes with Bakelite spacers in between (Gerdien, 1905). The Gerdien condenser dimensions are given in Table 1. The inner electrode is co-axially supported inside and outer the electrode is supported with the help of Teflon legs. The condenser is made from brass sheet and chrome plate. The air is sucked through the condenser with a suction pump fitted at the end of a conical structure. Air flow rates in the condenser can be varied by adjusting the voltage of the suction pump. The air velocity in the condenser is measured with an air meter having an accuracy of 0.005 m/s. The mean value of air velocity, V, was measured using an ANEMOMETER (velocity meter, model AM-4201). The air velocity sensor structure in this model is conventional with twisted vane arms and low frication ball-bearing design. The flow rate is $Q = V\pi(ro^2 - ri^2)$. The central electrode is electro-statically separated from the fan by a non-magnetic stainless-steel grid. The collecting electrode is at virtual ground potential because of very high input resistance of the femtoamperometer. An operational amplifier (AD549LH) was utilized for the conversion of the initial current to the potential signal, which is stored in computer memory. For fixed bias voltage, the ion current flowing through the inner electrode is proportional to the ion concentration. After each bias voltage is switched on, settling time is allowed before sampling of ion current is begun. Noise may be defined in an electrical sense; many disturbances of an electrical nature produce noise in receivers. Sometimes, noise even forces a reduction in the system's bandwidth. To avoid this noise effect, the amplifier is kept inside an aluminum box. For convenience, average air ions, which are plotted in a Y-axis are taken as 3.1×10^7 ions per cm^3 and summarized in bar diagrams and deprecated under each figure for brevity.

RESULTS AND DISCUSSION

There exists a conspicuous change from June 2007 to May 2008. The positive air ion count dropped from 9 units in June 2007 to about 1.0 in May 2008. There were fluctuations in daytime measurements, as Fig. 3(a) shows. The fluctuations corresponding to twilight hours are slightly higher by 10 units. A positive ion count of 9 units is observed in June 2007 (Fig. 3(a)), whereas it is reduced by 2 units in July 2007 (Fig. 3(b)). The daytime fluctuations are seen over time and these variations may be due to weather conditions, such as rainfall, wind speed, temperature and humidity. Large fluctuations in the positive ion count, varying between 0 and 14 units, are observed in August 2007, as shown in Fig. 3(c). It is very difficult to identify any phenomenon to explain this. In the September 2007, the variations of positive ion count are more or less similar to July, except for during twilight. The values vary between 1 and 4 units. The value 1 is a flat value throughout the day and the value 4 is confined to 10:00–11:00 hours. Fig. 3(e) shows fluctuations with low values at night and high values during daytime hours. During daylight hours, additional positive ions are produced due to plant transpiration of radon and thoron. In October 2007, positive ion counts varied between 2 and 5 units. The positive ion count in December 2007 varied between 6 and 8 units. The variations are almost uniform up to 7:00 hours; thereafter, the variations decreased up to 11:00 o'clock by 5 units, then increased by 7 units around 19:00. In January 2008, positive ion count varied between 7 and 12 units with a dip of 6.5 units around 06:00 hours and maximum was observed at 10:00. Fig. 3(h) shows almost stable values throughout the day with few fluctuations. In February 2008, the positive ion count was 5 units. Fig. 3(i) conspicuously shows a curve in March 2008 with low values varying from 1 to 1.75 units between 04:00 and 07:00 hours in the early morning. The curve is flat 10:00–20:00 hours with a value around 2 units. Fig. 3(j) shows a maximum by 1.8 units during the night and

Fig. 2. Cluster air ion counter: with power supply, fan, electrostatic shield, digital voltmeter, data logger, and personal computer.

Table 1. Dimensions of Gerdien condenser.

Diameter of outer electrode, (m)	0.035
Diameter of inner electrode, (m)	0.008
Length of outer electrode, (m)	0.25
Length of inner electrode, (m)	0.22

a minimum by 0.5 units during the day at 11:00 in April 2008. There is similarity in the positive ion concentration between April and May 2008.

In case of negative ions, high values are observed on the order of 10 units during twilight (around 17:00–19:00 hours) and 9 units throughout the day (Fig. 4(a)). Fig. 4(b) shows high fluctuations in the negative ion count, which varied between 0.5 and 4 units during 07:00–22:00 hours. These fluctuations may be due to fluctuations in wind speed, rainfall and humidity during the monsoon season (July). In the August 2007, high negative ions fluctuate from 0.5 to 14 units, as shown in Fig. 4(c). This is may be due to a drizzle-type rain, which was going on continuously. Whenever water is collected on the ground, emanations of radon and thoron stop and production of air ions decreases. In September 2007, the fluctuations were similar to August, but the curve is smooth to some extent (Fig. 4(d)). The negative ion count varied between 5 and 11 units for the specific day and night. In October 2007 (Fig. 4(e)), nighttime fluctuations were low and daytime fluctuations were also low, with 5 unit values from 12:00–14:00 hours while during twilight (16:00–19:00 hours) the fluctuations observed were high at 12 units. In Fig. 4(f), the negative ion count varied between 6 and 12 units. These fluctuations may be due to variations in the meteorological parameters. Negative ion fluctuation was negligible in January 2008 (Fig. 4(g)). It varies up to 8 units with a dip of 5.8 units around 11:00, with a maximum observed at 18:00. Fig. 4(h) shows negligible fluctuations throughout the day, with negative ions observed at around 6 units. In March 2008, conspicuously high values of negative ion counts of 4–4.6 units were observed in the early morning (4:00–7:00 hours). The curve is flat between 10:00–24:00 hours with a negative ion count around 3 units. Fig. 4(j) shows a maximum of 2 units during the night, and a minimum of 0.5 units during the day at 11:00. There is a similarity in the negative ion concentration between April and May 2008.

During July to December 2007 and in March 2008, positive ion count began to increase from early morning at 07:00 hours and reached a maximum around 12:00–14:00 hours. Ion counts fluctuated the most in August 2007 and steadiest positive ion counts were observed in February 2008. The 24-hour low positive ion count was observed in April 2008. In May 2008, a minimum positive ion count was measured at 10:00 hours, increasing from 10:10 and reaching

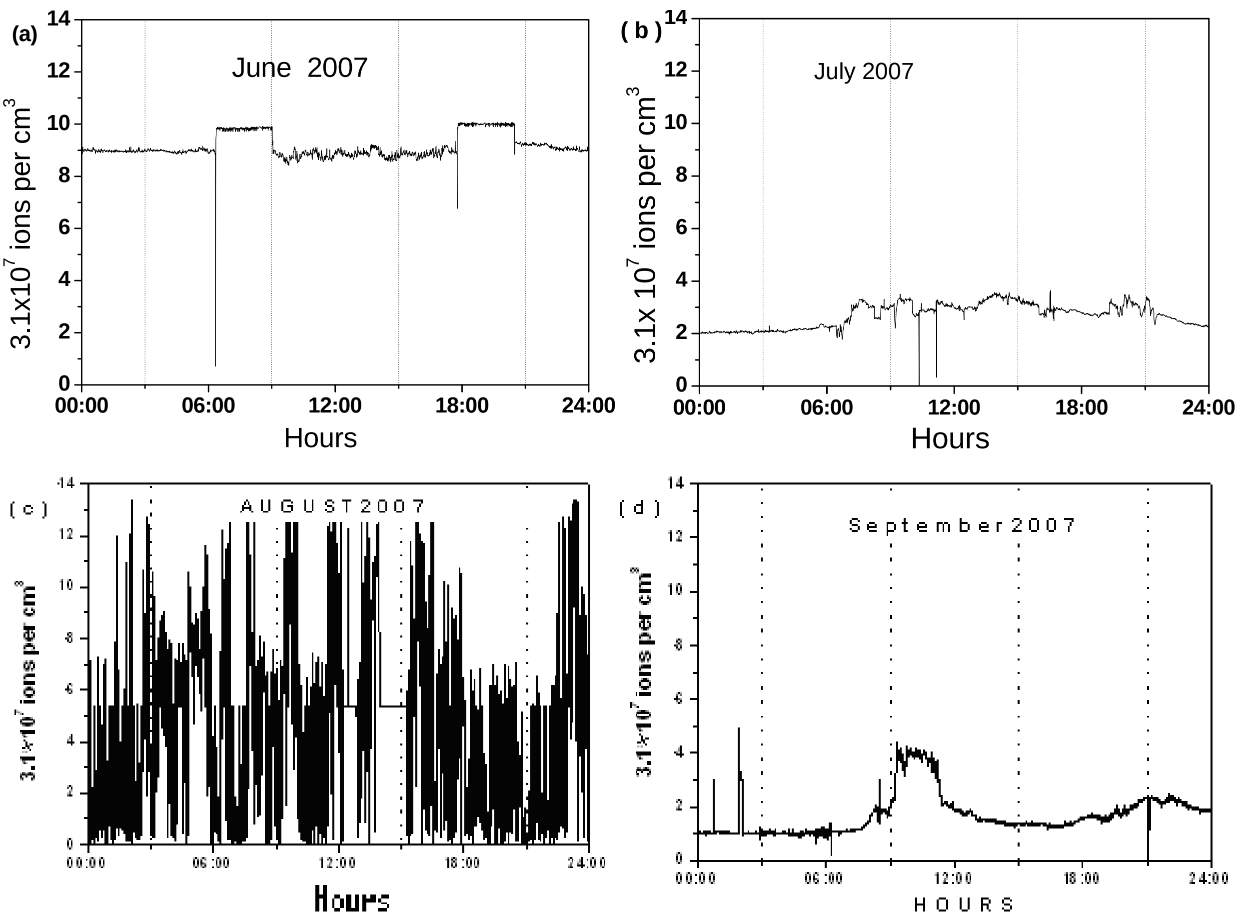

Fig. 3. Diurnal variation of positive air ions.

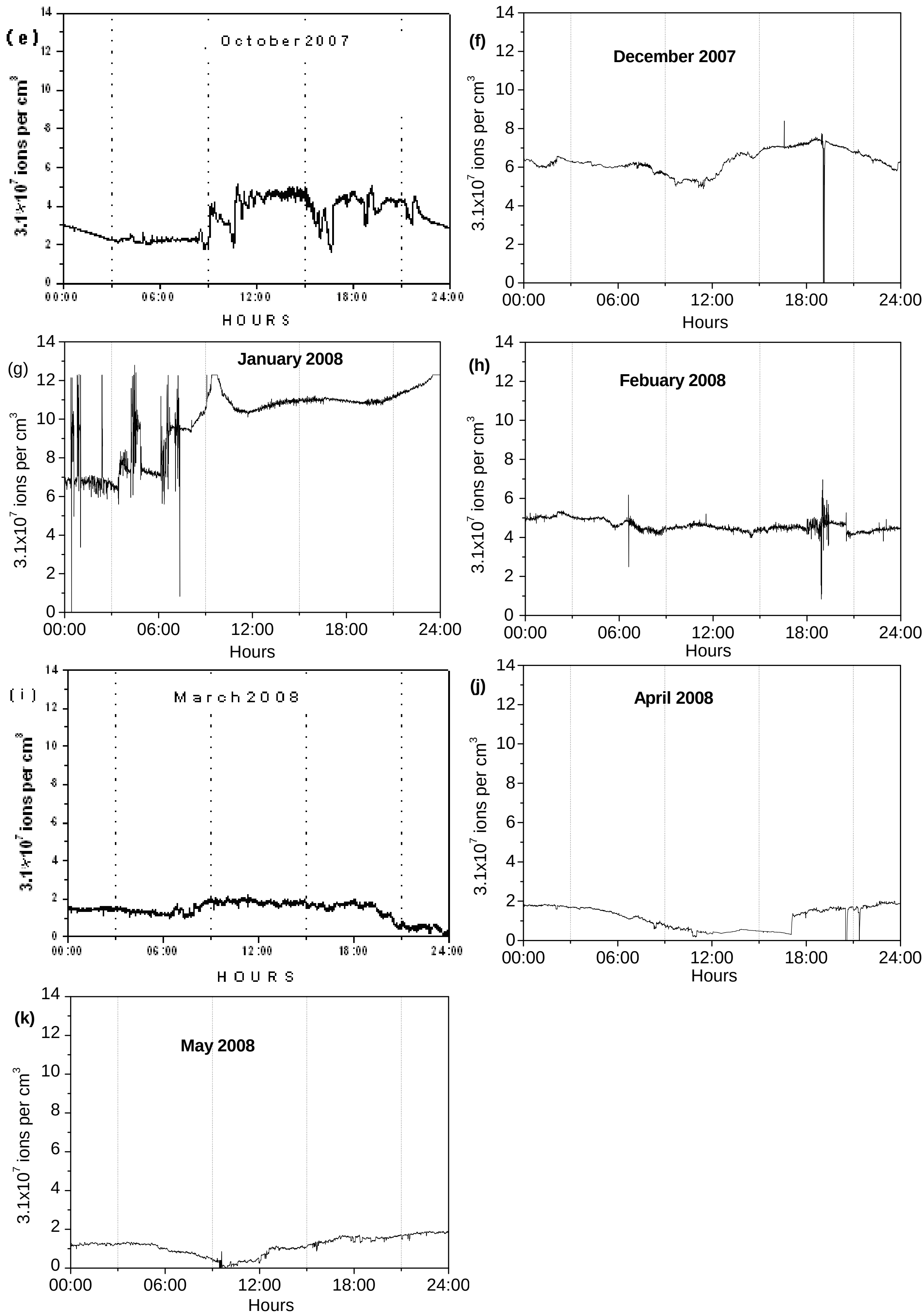

Fig. 3. *(continued).*

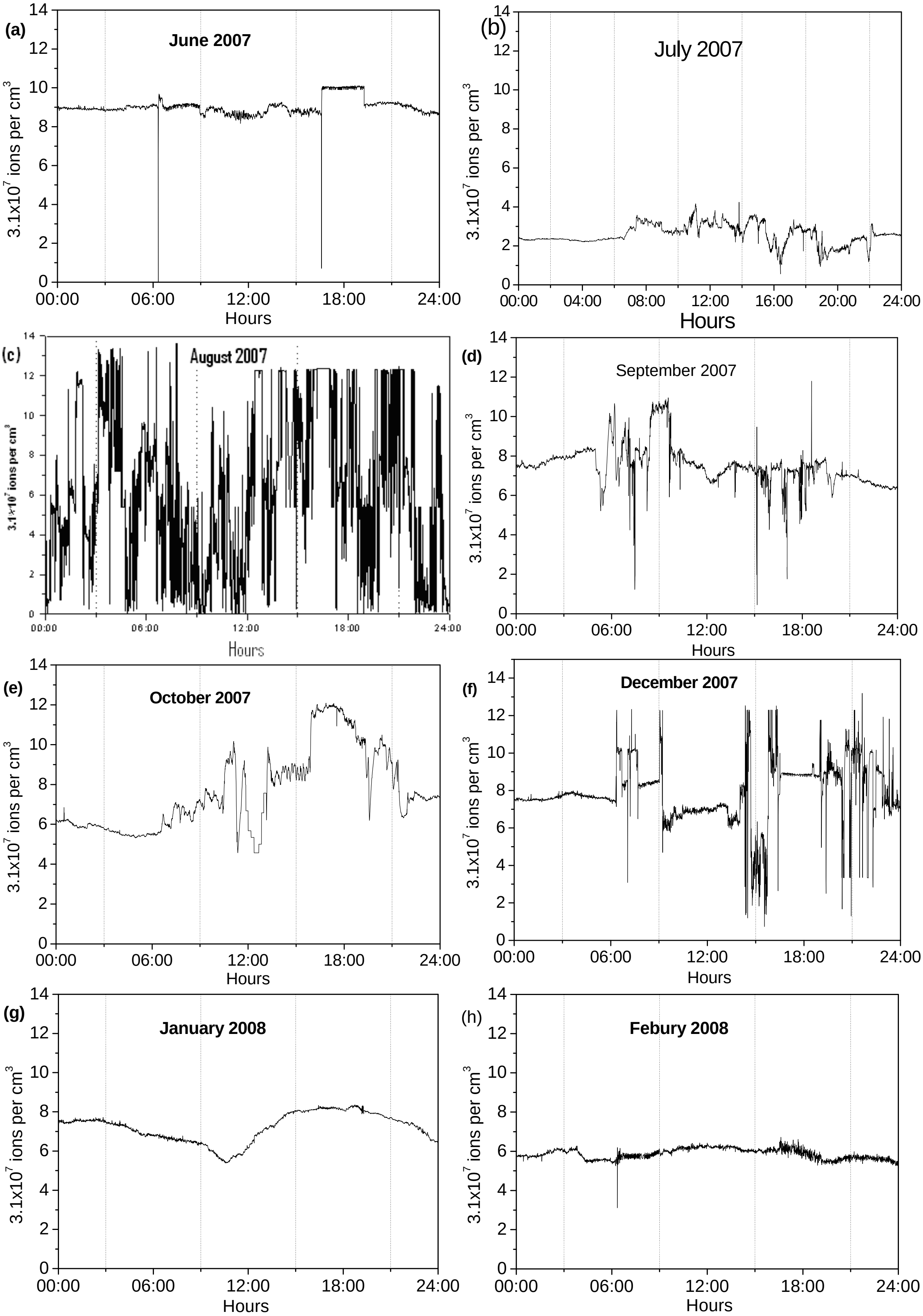

Fig. 4. Diurnal variation of negative small ion.

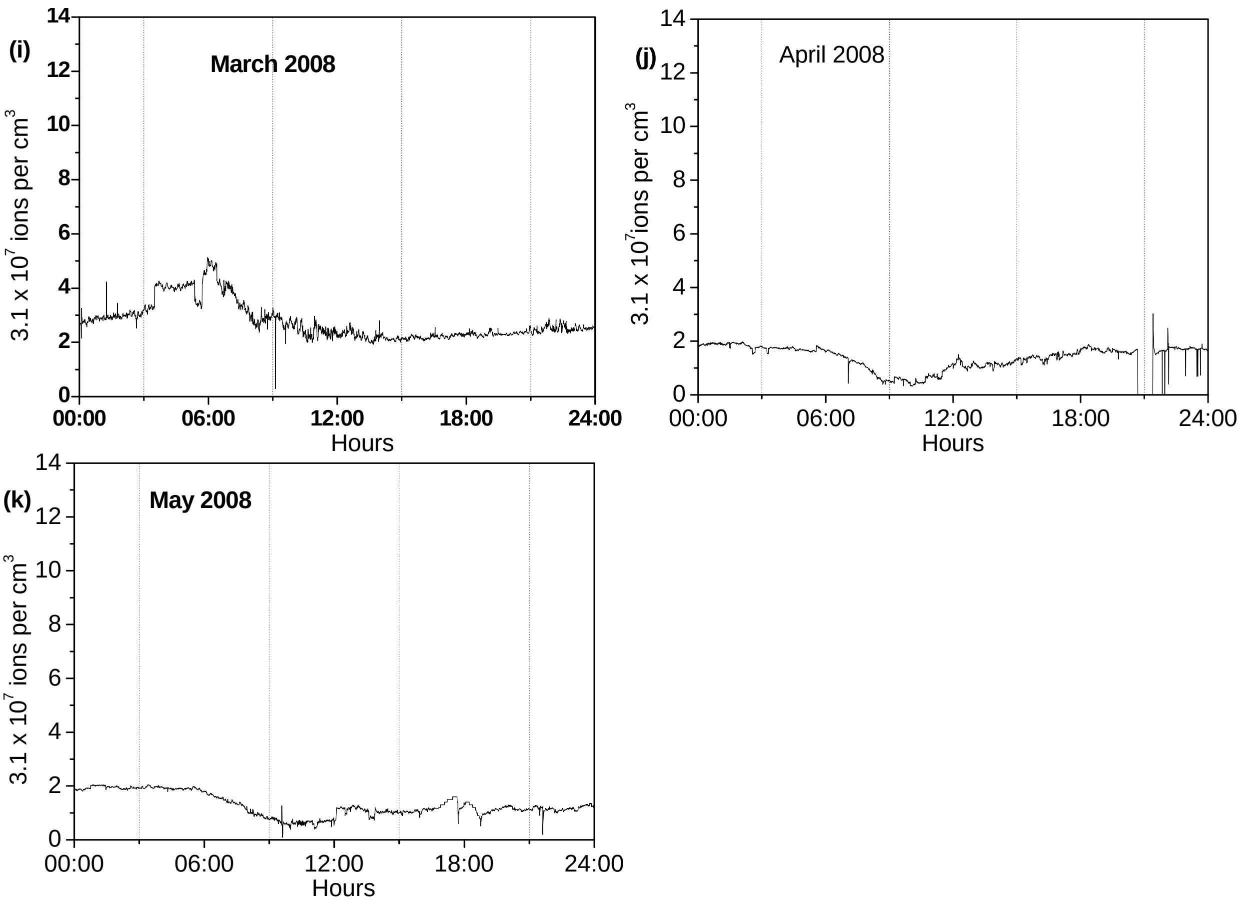

Fig. 4. *(continued).*

maximum concentration at 24:00. In January, April and May 2008 the positive ion count curve showed very high values during nighttime as compared to daytime. In contrast, the daytime positive ion count curve shows high values in the July, September, October and December 2007 as compared to nighttime.

Maximum positive daytime ion counts were observed for June, July, September, October 2007 and January, March 2008. Maximum nighttime positive ion counts were observed August and December 2007, and February, April, and May 2008. Minimum daytime positive ion counts occurred in June, July, October, and December 2007 and April and May 2008. Minimum positive nighttime ion counts were recorded in August and September 2007 and January, February, and March 2008.

The maxima of negative ion counts were observed at midnight (00:00 hours) in February, April and May 2008. Early morning maxima of negative ion counts were observed in August and December 2007, and in March 2008. Afternoon maxima of negative ion counts were observed in June, July, September and October 2007, and January 2008. Minimum daytime negative ion counts were observed in June, July, September, October, and December 2007, and February, March, April, and May 2008. Minimum nighttime negative ion counts were observed in August 2007 and January 2008. At 00:00 hours, a maximum negative ion count of 7.5 units was observed in Jan. 2008, and 8.85 units in June 2007. A minimum negative ion count of 1.75 units was observed in May 2007 and 1 unit in August 2007 at 00:00 hours. The most-fluctuating negative ion count occurred in August 2007; while the most stable negative ion count was recorded in February 2008. In the months of July, September, October and December 2007, negative ion count was lower during nighttime, increasing at 07:00 hours and reaching maximum value within half an hour.

The average positive ion maxima, as shown in Fig. (5a–c), was observed in June 2007, which decreased in July 2007 and again increased from July to September 2007. Positive ion count minima observed in October 2007 increased in December 2007 and January 2008. The average positive ion count (Fig. (5a–c)) remained steady for 00:00–02:00, 06:00–08:00 and 12:00–14:00 hours in June 2007; while the observed maxima of positive ion count was 12:00–14:00 hours from July 2007 to January 2008. The average minimum positive ion count was observed from 12:00–14:00 hours from February to May 2008.

Average negative ions as shown in Fig. (6a–c) decreased from January to May 2008, while increasing from July to October 2007. Also, from July to October 2007, average negative ion maxima from 12:00–14:00 were measured in larger concentration in comparison to 00:00–02:00 and 06:00–08:00 hours. An average negative ion maximum was observed in June 2007 and the average negative ion

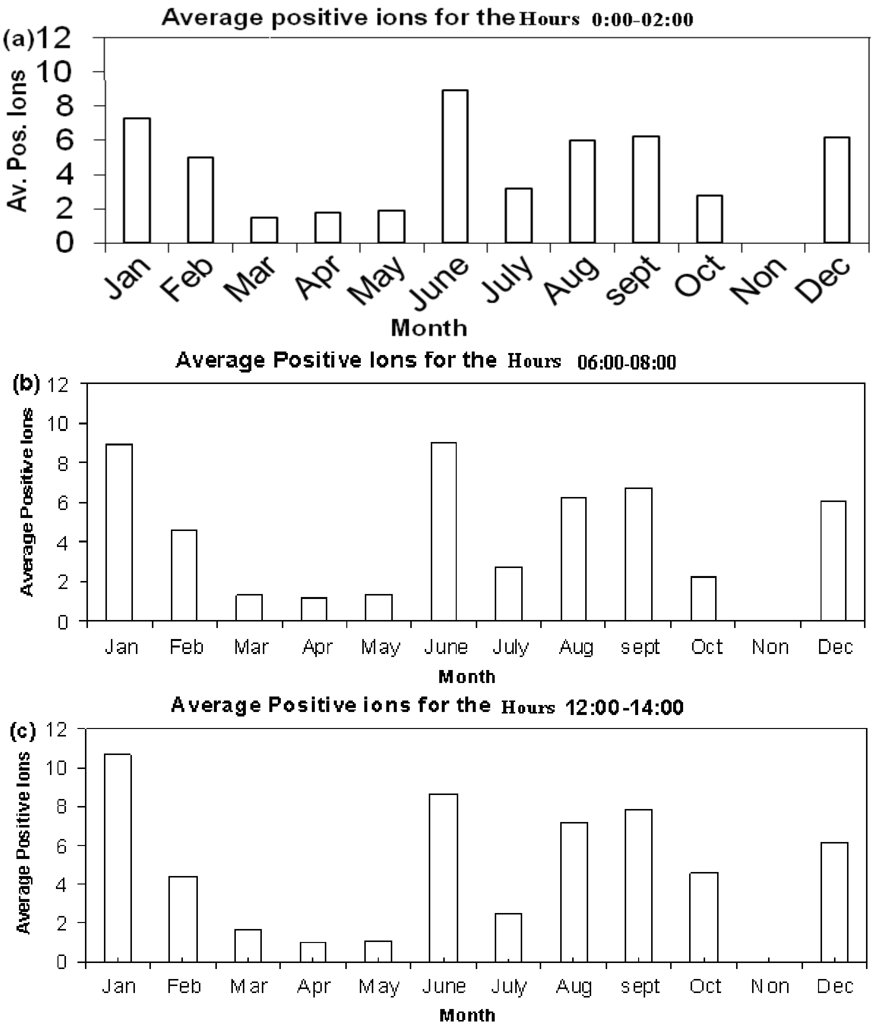

Fig. 5. Annual variation of average positive ions during 00:00–02:00, 06:00–08:00 and 12:00–14:00 hours for 2007 and 2008.

minimum was observed in May 2008.

Emanation of radioactive gases from the ground varies with soil porosity (Pearson and Jones, 1966), soil humidity, soil temperature, ground coverage, air pressure, solar radiation and plant transpiration. At Ramanandnagar, several days during the months of July, August, September and October, the ground is covered with water due to heavy rain. During the remaining months, the ground is more susceptible to radioactive emanation (Damon and Kuroda, 1954). Therefore, during these months both positive and negative ion curves show lower concentration (Moses *et al.*, 1963; Mattsson, 1970) and fluctuating as compared to non-flooded months. The area around the station is planted with sugarcane, corn, and other crops as noted, therefore plant transpiration enters the picture during these months (Guedalia *et al.*, 1970). Plant transpiration produces radon and thoron gases (Allen *et al.*, 1964), which in turn produce ion pair production. Therefore, the air ion curve of both the polarities increases from early morning and reaches maximum at noon rather than night (Israel, 1965; Israel *et al.*, 1969). Positive ions can be produced by various kinds of friction: between air masses, between air and sand or dirt particles swept up by the wind, and between weather fronts that march endlessly across the globe. Friction tends to knock off the negative electrons and produce an overdose of positive ions. On a dusty or humid day this overdose may be massive because the negative ions (Gabbay, 1990) promptly attach themselves to particles of dust, pollution or moisture and lose their charge. Therefore, as shown in Fig. 6, in the pre-monsoon season (March–May 2008) average negative ions decrease and a minimum is observed in May 2008. The energy in moving water also generates a lot of negative ions. As flood water breaks up, the positive charge remains with the larger drop and the negative charge flies free with the fine spray, forming negative ions. As the Krishna river, four km west of the monitoring station is flooded during monsoon, the waves and water droplets produce air ions of both polarities. Wind blowing in a west-east direction at very high velocity also brings air ions with it (Blanchard, 1963, 1966; Gathman and Hoppel, 1970; Gathman and Trent, 1968), suggesting that air ions increase and decrease with wind speed. Due to these reasons, air ion concentrations of both polarities will fluctuate during the monsoon period.

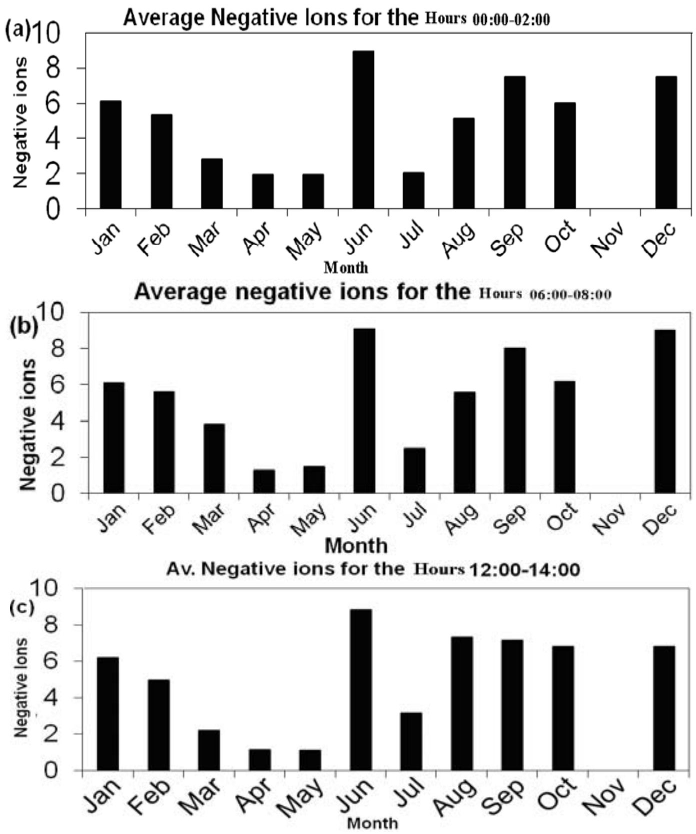

Fig. 6. Annual variation of average negative ions during 00:00–02:00, 06:00–08:00 and 12:00–14:00 hours for 2007 and 2008.

Great variations with time and place are noticed in the concentration of small cluster ions. The lower atmosphere varies markedly in its content of gas and suspends impurities from place to place. It is cleanest over the ocean. If this standard is taken as a unity, then the average pollution in rural air would be 10 times greater, pollution over small towns would be about 35 times as much, and over cities, pollution would be 150 times greater than that of ocean. Pollution, for instance, is not seasonal. Humans build cities and cover the land with asphalt and concrete, which prevents the normal generation of ions; so there would be fewer ions in urban areas. In a rural area like Ramanandnagar, the magnitude of air ions is very large compared to an urban area like Pune (Dhanorkar and Kamra, 1992), some 210 km northwest of Ramanandnagar. The measurement site at Pune, which is surrounded by very high buildings, show much less radioactive emanation from the ground. There are no sugarcane or corn crops around the site and wind speed is low; therefore plant transpiration of radon or thoron gas cannot take place, hence no additional air ions pairs are produced. At Pune during the early morning, wind flows from the hills to city, therefore early morning maxima of air ions are observed. Decreased wind speed and solar radiation intensity during the night reduce vertical atmospheric mixing, and as a result the contribution of local ion sources (radon and gamma radiation) will increase during nighttime and the concentration cluster of ions will increase (Dhanorkar and Kamra, 1991).

Each January, radon concentrations peak (Debaje *et al.*, 1996) in which large cluster-ion pairs are produced. This may be due to intense temperature inversions during the colder period (January), leading to the accumulation of more radon near the Earth's surface and increasing the ionization rate (Parsad *et al.*, 2005). Therefore, as compared to all other months we observed a greater number of positive and negative cluster ions in January 2008. The radioactive aerosol produced in the presence of radon gas (^{222}Rn), which consists of the radon daughter nuclide ^{218}Po attached to a pre-existing aerosol (Black, 1990). Radioactive aerosols acquire a charge, in general, more readily than a comparable non-radioactive aerosol. Radioactive aerosols are charged by the usual mechanism of external ion attachment, but additional external ions are created by radioactive decay particles. A further form of electrification for radioactive aerosols is self-charging. This occurs when a radioactive source is actually within the aerosol particle. The self-charging of a beta-active aerosol radioactive decay causes electrons to be emitted from the particle's surface and ions for both signs are produced. Positive ions are nothing but these radioactive aerosols (Dua *et al.*, 1978), which are accumulated near the ground surface in cold temperatures (January). Therefore, in January 2008 as shown in Fig. 5, the average positive ion count is very large on the order of 8 to 10 during all the time periods, and as compared to average negative ion count. This may also be observed when a radioactive nuclide decays and electrons are stripped from the parent atom by its recoil and decay products are formed as positive ions. Radioactivity, however, has been shown to have a large effect on aerosol charging, since it is accompanied by the emission of charge and the production of large quantities of ions (Harrison, 1992). Therefore, the average positive-to-negative ion ratio is equal to one or smaller than one in all months except January 2008. Average positive-to-negative ion ratio was 1.1 for 00:00–02:00 hours, 1.4 for 06:00–08:00 hours and 1.75 for 12:00–14:00 hours in January 2008, as shown in the Fig. (7a–c). Average positive-to-negative ion ratio minima were observed in July and October 2007, and March 2008. This high magnitude of positive ions observed in January is dangerous to human beings (Krueger and Reed, 1976).

The Ramanandnagar station is a rural site, in which small ion concentrations are affected more by the sink due to pre-existing aerosol particles than by ion production due to ionization (Hirsikko *et al*., 2007). In addition to the aerosol sink and ion production, the composition of aerosol particles and gaseous compounds differ significantly between the two sites; the Pune area is dominated by anthropogenic sources, especially traffic exhaust, whereas Ramanandnagar is a rural site where plant transpiration of radon and thoron takes place. As January is a dry month with no rainfall activity, negative ions that are produced immediately attach to aerosol particles. Therefore, the average positive-to-negative ion ratio curve shows a large magnitude in January as compared to all other months. As human activities start from early morning and reach maximum around noon and afternoon more aerosols are introduced in the atmosphere in the afternoon (Cobb and Wells, 1970).

This results in decreased negative ion concentration, and hence and increase in positive-to-negative ion concentrations during 12:00–14:00 hours as compared to 00:00–02:00 and 06:00–08:00. During the monsoon, rain clears the pollutants and aerosols, while splashing rain drops, plant transpiration and waves of the Krishna River introduce to the atmosphere a greater number of negative ions compared to positive ions. Due to these reasons there is balance between positive and negative cluster ions and hence positive-to-negative ion ratio is one or close to one from July to September 2007. As the monsoon progresses from July to September, the height of the crops around monitoring site increases and pollution decreases (Flanagan, 1966). Therefore, plant transpiration of radon and thoron introduces into the atmosphere more negative ions than positive (Slatyer, 1967; Tanner, 1960). Due to these reasons, the average negative ion graph increases from July to September 2007. The pre-monsoon period is a much-polluted and dusty period, which results in more negative ions attached to aerosol particles (Flanagan, 1966). Therefore, as shown in Fig. 6, the average of negative ions decreases from March to May 2008. In the month of June, few thunderstorms were observed, which generated a corona discharge of negative air ions from trees (Harrison, 1992). This additional source of negative ions results greatly

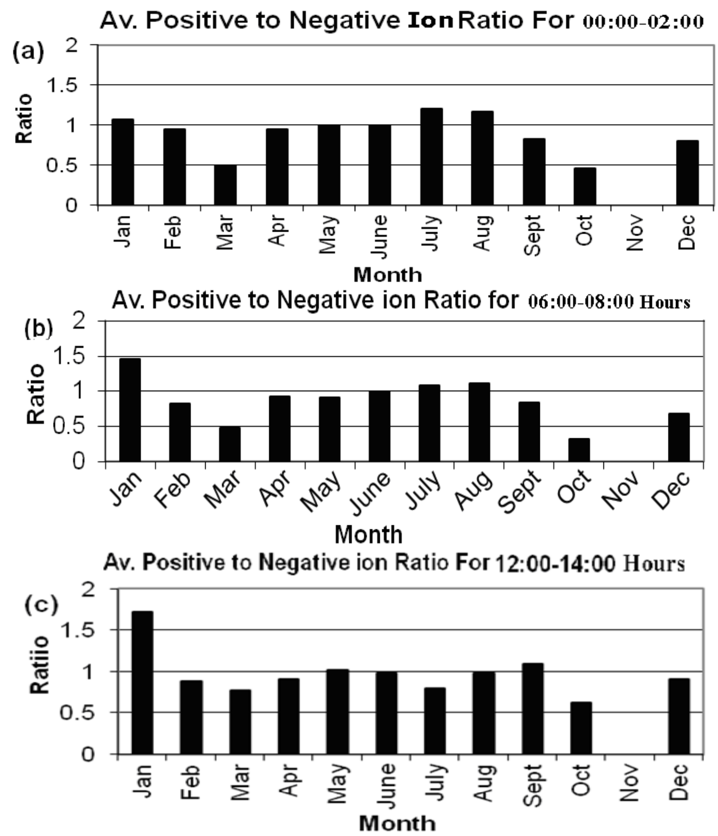

Fig. 7. Annual variations of positive-to-negative small ion ratio during 00:00–02:00, 06:00–08:00 and 12:00–14:00 hours for 2007 and 2008.

increased the concentration of negative ions (Orville and Spencer, 1979; Turman and Edgar, 1982). Therefore, in June the average negative ion count (Fig. 6) shows sharp increases (Gunn, 1956) as compared to May. As crop cultivation decreases from February to April 2008, plant transpiration of radon and thoron (Martell and Poet, 1982), so does ion pair production decrease. During summer, the gases move upward carrying radon with it, thereby reducing ionization (Parsad *et al.*, 2005) near the earth's surface. Therefore, both average (Figs. 5 and 6) and maxima (Figs. 8(a) and 9(a)) of positive and negative ions decrease from February 2008 to April 2008. May 2008 is a very hot month of the year, so agricultural crops are few, hence plant transpiration (Bondietti *et al.*, 1984) of radon and thoron is lowest. Therefore, both average (Figs. 5 and 6), as well as maxima (Figs. 8(a) and 9(a)), of positive and negative ions show the lowest values in May 2008.

The main cause of reduction of the ion concentration is increasing aerosol, which removes ions, due to the aerosol acquiring charge (Harrison, 1992). From this, it can be seen that increasing the aerosol concentration reduces small ion concentration. Many observations have been carried out in atmospheric air research since polluted- or fog-laden air is known to have a lower small ion concentration than clean mountain air (Reiter, 1986). Therefore, as shown in the Figs. 5 and 6, the average ion concentrations are decreasing from January 2008 to May 2008. Due to high temperatures, radon escapes to higher altitudes (Debaje *et al.*, 1996, Parsad *et al.*, 2005), therefore in May 2008 the minimum average for air ions was observed for all time periods.

CONCLUSIONS

Annual variations of small positive and negative ions at urban tropical places like Pune, India and mid-latitude locations such as Finland have been observed; but observation of the variations of small ions at rural

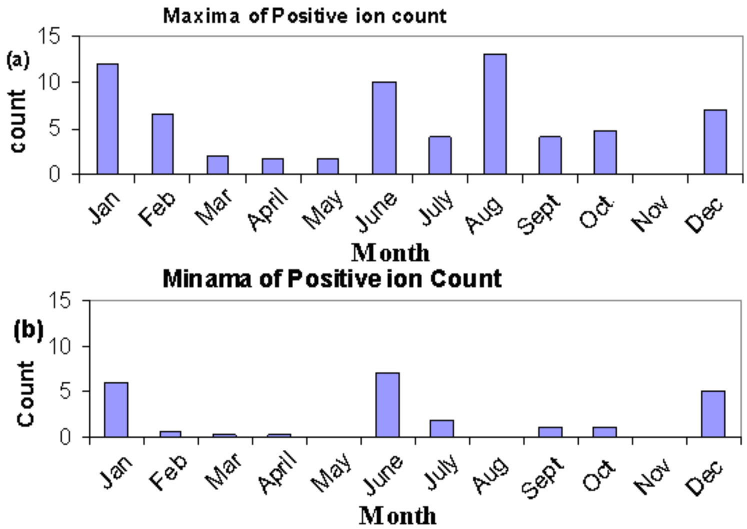

Fig. 8. Annual variation of maxima and minima of positive small ions for 2007 and 2008.

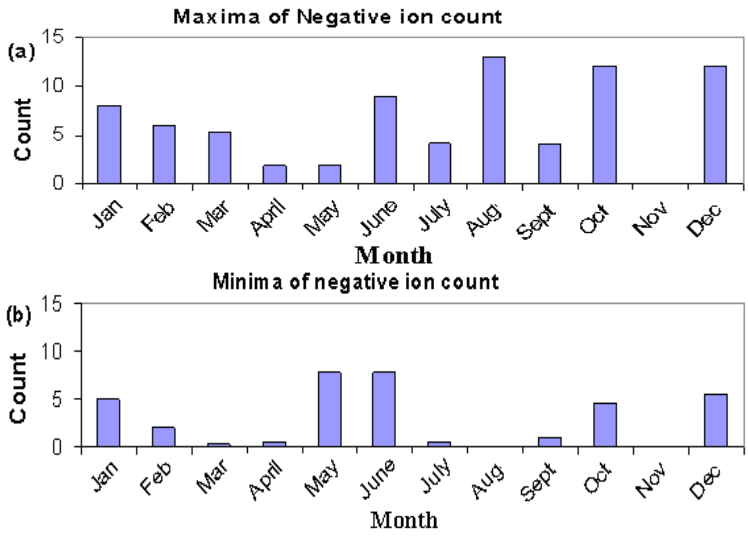

Fig. 9. Annual variation of maxima and minima of negative air ions for 2007 and 2008.

environments is lacking throughout the world. In this study plant transpiration of radon and thoron were examined as additional sources of ion production at a rural monitoring station in Ramanandnagar, India. Results show that atmospheric ion variations in Ramanandnagar differ from those in the urban environment of Pune. Annual variations of positive and negative small ions were measured June 2007 to May 2008. Due to clean air and plant transpiration of radon and thoron at rural station Ramanandnagar, the peak of small ion concentration was observed at noon hours rather than night from June to October 2007. Since tropical urban Pune is more polluted, small ion decreases from morning to noon hours were observed, but increases from night to morning, peaking during morning hours, was observed. The presence of crops at Ramanandnagar decreases annually from February to May 2008, hence plant transpiration of radon and thoron decreases. At the same time, aerosol particles increase, which in turn has shown a decrease in positive and negative small ion maxima from February to May 2008. Average positive-to-negative small ion ratio is found to be an indicator of increased pollution during 12:00–14:00 hours from July to October 2007. In keeping with January as the month of maximum radon concentrations throughout the world, the annual maxima of positive and negative small ions was observed in January 2008. As there is no rainfall and due to temperature inversions, radioactive aerosols accumulated close to the ground surface. At the same time, crop cultivation introduced more aerosol particles into the atmosphere, which resulted in an annual peak of average positive-to-negative ion ratios in January 2008. Also, the positive-to-negative small ion ratio increases from night hours (00:00–02:00) and peaked at noon (12:00–14:00 hours).

ACKNOWLEDGMENTS

The authors are grateful to Prof. B. N. Goswami, Director, Indian Institute of Tropical Meteorology (IITM) Pune, and Dr. P.C.S. Devara, Head of PM&A division for providing the observational facilities in IITM and Principal, A.C.S. College, Palus during the course of the study.

REFERENCES

Allen, L.H., Youcum, C.S. and Lemon, E.R. (1964). Photosynthesis under Field Conditions. VII. Radiant Energy Exchanges within a Corn Crop Canopy and Implications in Water Use Efficiency. *Argron. J.* 56: 253–359.

Aplin, K.I. and Harrison, R.G. (2001). A Self-Calibrating Programmable Mobility Spectrometer for Atmospheric Ion Measurements. *Rev. Sci. Instrum.* 72: 3467–3469.

Black, A. (Ed.) The Hazards of Radon, Proceeding IV Annual Conference. Guildford. 1990, The Aerosol Society, p. 101–116.

Blanchard, D.C. (1963). Electrification of the Atmosphere by Particles from Bubbles in the Sea. *Prog. Oceanogr.* 1: 171–202.

Blanchard, D.C. (1966). Positive Space Charge from the Sea. *J. Atmos. Sci.* 23: 507–515.

Bondietti, E.A., Hoffman, F.O. and Larsen, I.L. (1984). Air-to-Vegetation Transfer Rates of Natural Submicron Aerosols. *J. Environ. Radioact.* 1: 5–27.

Cobb, W.E. and Wells, H.J. (1970). The Electrical Conductivity of Ocean Air and Its Correlation to Global Atmospheric Pollution. *J. Phys. D: Appl. Phys.* 11: 125–136.

Damon, P.E. and Kuroda, P.K. (1954). On the Natural Radioactivity of Rainfall. *Eos. Trans. AGU.* 35: 208–216.

Dhanorkar, S. and Kamra, A.K. (1991). Measurement of Mobility Spectrum and Concentration of All Atmospheric Ions with a Single Apparatus. *J. Geophys. Res.* 96: 18671–18678.

Debaje, S.B., Ramachandran, T.V. and Vernerkar, K.G. (1996), Study of Atmospheric Radon Concentrations at Pune. *Indian J. Environ. Prot.* 16: 755–760.

Dhanorkar, S. and Kamra, A.K. (1992). Relation between Electrical Conductivity and Small Ions in the Presence of Intermediate and Large Ions in the Lower Atmosphere. *J. Geophys. Res.* 97: 20345–20360.

Dua, S.K., Kotrappa, P. and Bhanti, D.P. (1978). Electrostatic Charge on Decay Products of Thoron. *Am. Ind. Hyg. Assoc. J.* 39: 339–345.

Flanagan, V.P.V. (1966). Measurement of the Coefficient of Combination of Small Ions, with Aerosol Particles. *Pure Appl. Geophys.* 64: 197–203.

Gabbay, J. (1990). Effect of Ionization on the Microbial APr Pollution in the Dental Clinic. *Environ. Res.* 52: 99–106.

Gathman, S.G. and Trent, E.M. (1968). Space Charge over the Open Ocean. *J. Atmos. Sci.* 25: 1075–1079.

Gathman, S.G. and Hoppel, W.A. (1970). Electrification Process over Lake Superior. *J. Geophys. Res.* 75: 1041–1048.

Gerdien, H. (1905). Ein Neuer Apparat Zur Messing Der Elektrischen Leitfahigkeit Der Luft. *Nachr Ges. Wiss. Gott. Math. Phys. Ki.* 240–251.

Guedalia, D., Laurent, J., Frontan, J., Balnc, D. and Druilhet, A. (1970). A Study of Radon- 220 Emanation from Soil. *J. Geophys. Res.* 75: 357–369.

Gunn, R. (1956). Initial Electrification Processes in Thunderstorms. *J. Meteor.* 13: 21–29.

Harrison, R.G. (1992). Aerosol Charging and Radioactivity, Ph.D. Thesis. University of London.

Hirsikko, A., Laakso, L., Horrak, U., Aalto, P.P., Kerminen, V.M. and Kulmala, M. (2005). Annual and Size Dependent Variation of Growth Rates and Ion Concentrations in Boreal Forest. *Boreal Environ. Res.* 10: 357–369.

Hirsikko, A., Yli-juuti, T., Nieminen, T., Vartiainen, E., Laakso, L., Hussen, T. and Kulmala, M. (2007). Indoor and Outdoor Air Ions and Aerosol Particles in the Urban Atmosphere of Helsinki: Characteristics, Sources and Formation. *Boreal Environ. Res.* 12: 295–310.

Israel, G.W. (1965). Thoron (Rn-220) Measurements in the Atmosphere and Their Application to the Atmosphere. *Tellus*. XVII: 383–388.

Israel, H., Hobert, M. and De La Riva, C. (1969). Measurements of the Thoron Concentration of the Lower Atmosphere in Relation to the Exchange in This Region. *Technical Report, U. S. Army Contract DAJA.* 37-68-C-0967.

Jesse, W.P. (1968). Precision Measurements of W for Polonium Alpha Particles in Various Gases. *Radiat. Res.* 33: 229–237.

Kamra, A.K. (1991). Inadvertent Modification of Atmospheric Electricity, Current Science. *Science* 60: 639–646.

Kolarž, P. and Filipović, D. (2008). Measurements and Correlations Between Several Atmospheric Parameters. *Phys, Chem. Technol.* 6: 99–104.

Krueger, A.P. and Reed, E.J. (1976). Biological Impact of Small Ions. *Science* 193: 1209–1213.

Mattsson, R. (1970). Seasonal Variation of Short-Lived Radon Progeny ^{210}Pb and ^{210}Po in Ground Level Air in Finland. *J. Geophys. Res.* 75: 1741–1744.

Martell, E.A. and Poet, S.E. (1982). In *Natural Radiation Environment—Radon Progeny on Biological Surfaces and Their Effects,* Vohra, K.G., Mishara, U.C., Pillai, K.C. and Sadasivian, S. Wiley Eastern, New Delhi. p 283–289.

Meena, G.S. and Jadhav, D.B. (2007). Study of Diurnal and Seasonal Variation of Atmospheric NO_2, O_3, H_2O and O_4 at Pune, India. *Atmósfera* 20: 271–287.

Moses, H., Lucas, H.F. and Zerbe, G.A. (1963). The Effect of Meteorological Variables upon Radon Concentration Three Feet above the Ground. *J. Air Pollut. Contr. Assoc.* 13: 12–19.

Orville, R.E. and Spencer, D.W. (1979). Global Lightning Flash Frequency. *Mon. Weather Rev.* 107: 934–943.

Parsad, B.S.N., Nagaraja, K., Chandrashekara, M.S., Paaramesh, L. and Madhava, M.S. (2005). Diurnal and Seasonal Variations of Radioactivity and Electric Conductivity near the Surface for a Continental Location Mysure in India. *Atmos. Res.* 76: 65–77.

Pearson, J. E. and Jones, G.E. (1966). Soil Concentration of Emanating Radium-226 and Emanation of Radon-222 from Soils and Plants. *Tellus*. 18: 655–661.

Reiter, R. (1986). *Fields, Currents and Aerosols in the Lower Troposphere*, Balkema, Rotterdam.

Siingh, D., Pawar, S.D., Gopalakrishnan, V. and Kamra, A.K. (2005). Measurements of the Ion Concentrations and Conductivity over the Arabian Sea during the ARMEX. *J. Geophys. Res.* 110: D18207.

Slatyer, R.O. (1967). *Plant-Water Relationship*. Academic, New York.

Tammet, H. (2006). Continuous Scanning of the Mobility and Size Distribution of Charged Clusters and Nanometer Particles in Atmospheric Air and Balanced Scanning Mobility Analyzer BSMA. *Atmos. Res.* 82: 523–535.

Tanner, C.B. (1960). Energy Balance Approach to Evaportranspiration from Crops. *Soil Sci. Soc. Am. J.* 24: 1–9.

Titta, P., Miettinen, P., Laaksonen, A., Joutsensaari, J., Hirsikko, A., Aalto, P. and Kulmala, M. (2007). Road-Side Measurement of Aerosol and Ion Number Size Distributions: A Comparison with Remote Site Measurements. *Boreal Environ. Res.* 12: 311–321.

Turman, B.N. and Edgar, B.C. (1982). Global Lightning Distribution at Dawn and Dusk. *J. Geophys. Res.* 87: 1191–1206.

Vartiainen, E., Kulmala, M., Ehn, M., Hirsikko, A., Junninen, H., Petaja, T., Sogacheva, L., Kuokka, S., Hillamo, R., Skorokhod, A., Belikov, I. Elansky, N. and Kerminen, V.M. (2007). Ion and Particle Number Concentrations and Size Distributions along the Trans-Siberian Railroad. *Boreal Environ. Res.* 12: 375–396.

Received for review, October 17, 2009
Accepted, December 11, 2009