Air ion and pollution index variation for indoor and outdoor atmosphere at rural station Ramanandnagar ($17^{\circ}4'N$, $74^{\circ}25'E$) India

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In the present study, the observation of indoor air ion concentration at a rural site has been carried out for the first time. These indoor observations are compared with outdoor air ion concentration. Net charge can be introduced into the atmosphere by processes such as combustion, rainfall and ultraviolet radiation. As compared to indoors, average air ions of both the polarities at outdoors are higher. Moreover, the air ion concentrations, experience large fluctuations during daytime, as compared to nighttime values. Positive and negative air ion concentrations are lower and uniform throughout the night both for indoor and outdoor conditions. Pollution index is more or less unity for outdoors in all-the-time period, which is good for human health. Due to limited sources of air ions indoors, it is observed that pollution index decreases from 00:00–02:00 hours and minimum is reached during 12:00–14:00 hours for indoors. During 00:00–02:00 hours, the indoor pollution index is 1.55, which is very harmful to human health.

1. Introduction

Air ions are produced by different sources in the atmosphere. Exhaled radon from ground surface, cosmic ray, breaking of rain drops, waterfall and plant transpiration are sources of air ions. These air ions are produced when high-energy particles knock out electrons from neutral molecules. Therefore, rate of air ion production depends on the site where we measure air ions. Air ions produced in the atmosphere are consumed by aerosols, odours and ions of opposite polarities, present in the atmosphere. Typically, air ion measurements reveal concentration of air ions at an urban site in Helsinki (Airsick *et al.* 2007), along a roadside (Titta *et al.* 2007), along the Trans-Siberian rail road (Vartiainen *et al.* 2007), and also in an earlier study at a tropical station, Pune, India (Dhanorkar and Kamra 1991) and at University of Reading, United

Kingdom (Aplin and Harrison 2001). Tammet (2006) demonstrated that secondary charged aerosol particles in the urban atmosphere of Tartu ($58^{\circ}21'N$, $26^{\circ}44'E$), Estonia. These measurements are based on a new air ion spectrometer called balanced scanning mobility analyser. However, long-term data on the air ions have been lacking from rural atmosphere (Arnold *et al.* 1977) as well as indoor air so far. During their lifetime in indoor air, air ions act as aerosol remover (Grinshpun *et al.* 2005) and also they have an important biological influence on various micro-organisms (Shargawi *et al.* 1999) and positive effect on human beings (Krueger and Reed 1976; Takahashi 2008). Measurement of air ion concentration in this work is performed by using their electrical properties in a Gerdien-aspirated condenser (Pawar *et al.* 2010).

In the present study, observations of indoor air ion concentration at a rural site have been carried

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out for the first time. Observations are recorded when all doors and windows of the observatory are open and closed. These indoor observations are compared with outdoor air ion concentration. Ratio of positive to negative air ions is referred to as pollution index. Generally, such measurements are meagre over a rural station and this will envisage us to understand the distribution of air ions in air and their effect on rural weather and relevant atmospheric processes.

2. Methodology

The air ion counter, which is indigenously designed and developed at the Indian Institute of Tropical Meteorology (Pawar *et al.* 2010), Pune, is operated at rural station Ramanandnagar (Pawar *et al.* 2011). Calibration of the amplifier is done in the

laboratory using a resistive method of generating small currents with a milli-volt calibrator and a resistor. To minimize the error due to turbulence, the ends of the inner electrode that face the air stream are curved smoothly (Pawar *et al.* 2012).

Indoor and outdoor air ion concentrations are recorded in the monsoon period. The highest rainfall in 25 years was recorded on July 2007. The drizzle type rain with high wind speed was observed (except for two to three days) from 5 July to 26 July 2007. Therefore, most of the time, the ground was covered with water and frequency of vehicles on the road was very low. Then, all the human activities on the agricultural land also stopped. Due to heavy rainfall and high wind speed, waves were produced on the highly flooded river Krishna. Atmosphere was cloudy most of the time with two to three rain showers from 10 August to 15 September 2007. Fair weather was observed

Figure 1. Time series of the indoor air ion concentration.

from 25 September 2007 onwards. In the month of October 2007, the sky was clear, but on few occasions thunderstorm, lightning and heavy rain for one to two hours was observed. Ground was not covered with water (except for one to two hours) during October 2007.

We also measured air ion concentration outside the backyard of the observatory. The data have been collected from 1 July to 30 October 2007. The period under analysis involves 2880 hours. Owing to instrument pauses in measurements, instrumentation failure and power failure; about 14% of observations were measured and about 2470 hourly concentration of ions (both signs) was available for statistical analysis and study. Note that it is not possible to measure positive and negative ion concentrations simultaneously. Therefore, we have measured air ions of a particular kind that is positive or negative on alternate days or epochs according to our convenience. These measurements are shown in figures 1 and 2. To our convenience, for

average air ions, Y axis is taken as 10^2 ions per cm^3 and the results are summarized in bar diagrams and deprecated under each figure for brevity.

3. Observations

3.1 Diurnal variations

In the case of positive ions, count is 2.4 at 01:00 hours with slight variation; but this value was maintained up to 19:00 hours on the night of 14 July (figure 1a), while on the next night (15 July 2007), positive ion count reduced to 1.4. This decrease in positive ion concentration may be due to heavy rain when the ground was fully covered with water throughout the night (Siingh *et al.* 2007; Kolarz and Filipovic 2008). Frequency distribution of indoor positive air ion concentrations for 14 July 2007 is shown in figure 3(a); and is evident from the figure that 35% data in the interval 20–30,

Figure 2. Time series of the outdoor air ion concentration.

Figure 3. Data points for the indoor air ions.

10% data in the interval 30–40 and 5% data in the interval 40–50. For 15 July, 70% data points were obtained in the interval 10–20 and 20% data points in the interval 20–30. Maxima of average positive cluster ions are of order 2.5 for 12:00–14:00 hours (figure 5a).

Air ions were recorded continuously for 24 hours, representing a day and night. The curves shown in figure 1(c, d) (19 and 20 July 2007 ions) are negative ion concentration curves. One can easily notice from the curves that negative ion concentration count is low and smooth during nighttime when the doors and windows of the observatory were closed; whereas the count of ions are seen to be higher during day than night. At the beginning of 19 July, that is at 00:00 hours, the ion count is 2 and the same count is maintained up to about 07:20 hours. Thereafter, a sharp rise in count is seen and when the doors are opened, high value of 3.25 negative ions is attained within half an hour. On 20 July 2007, the negative ion count shows peak value of the order of 5, this is higher than 3.5 of the previous day (i.e., 19 July 2007). The frequency distribution curve (figure 3c) shows that 75% of the negative ions lie in the range of 20–30 and 25% lie in the range of 30–40. Minima of the average negative air ions (figure 5c, d) are observed for 00:00–02:00 hours and maxima are observed during 12:00–14:00 hours. In case of positive ions,

outside the observatory as shown in figure 2(a), large fluctuations are observed for 30 September 2007, while such large fluctuations are not observed for 1 October 2007 (figure 2b). The maxima of positive count are observed to be of the order of 12 for 30 September, while for 1 October 2007, it is of the order of 4.8. Similarly, minima of the order of 4.2 are observed for 30 September; while for 1 October 2007, minima is low and of the order of 1.4. In the case of positive small ions, outside the observatory, large variety of ranges of data points (figure 4a, b) are observed as compared to indoors. Also average positive small ions are higher in the outdoors as compared to those of indoors (figure 6a, b).

The negative ion concentration outside the observatory is very high during day and night as compared to indoor air ion concentration (figure 2c). For 7 October 2007, negative ion count reaches a maximum of the order of 12, at 17:30 hours; while for 8 October 2007, negative ion count reaches maximum of the order of 10.5 at 17:00 hours. This may be because 7 October was a very sunny day; while 8 October, slight cloud cover was present in the sky. The minima of negative ion count during 7 October is observed to be of the order of 4.5 in the time interval 11:00–13:00 hours; maxima of the order of 12 is observed during 16:00–18:00 hours. Nighttime negative ion count is smooth and minima are observed to be of the

Figure 4. Data points for outdoor air ions.

Figure 5. Indoor average air ions for 00:00–02:00, 06:00–08:00 and 12:00–14:00 hours.

order of 5.5 from 00:00–07:00 hours for 7 October 2007 (figure 2c). On 7 October 2007, very large fluctuations of negative ion concentrations are observed for the time interval of 12:00–16:00

hours in day time. In the frequency distribution curve of negative ion as compared to indoors (two), six different ranges of data points are observed for outdoors (figure 4c, d). Inside the observatory,

Figure 6. Outdoor average air ions for 00:00–02:00, 06:00–08:00 and 12:00–14:00 hours.

average negative ion count for 12:00–14:00 hours LT is 3 (figure 5c, d), while for the same time period outside the observatory, as shown in figure 6(c, d) average negative ion count is 7. Negative ion or positive small air ion concentration outside the observatory during the experimental days shows steady increase and the peak value thereafter declines steadily (see figure 2), whereas this does not happen in the (indoors) interior of the observatory. Instead, when observatory doors and windows are open during 00:00–01:00, 07:00–09:00, 15:00–17:00, 19:00–20:00 hours on 14 July 2007 and 06:45–07:00, 10:00–10:10, 13:00–14:30 hours on 15 July 2007, large peaks are observed.

Moreover, air ion concentrations, which experience large fluctuations during daytime, are compared to nighttime, values. When we close all the doors and windows of the observatory during nighttime, there is a decrease in the small air ion concentration of both the polarities as shown in figure 1. This may be because ionization rates and ionic loss rates are relatively constant over the time-scale of the average ionic lifetime (Misaki *et al.* 1972). The reactions may be assumed to be in a steady state condition. After their production, the ions drift, diffuse and undergo chemical reactions, and under conditions of ionic equilibrium, the rate of formation of ions is equal to the rate of destruction (Mark 1984). In some cases, such as clustering of ions by water, equilibrium can

be established. But when all the doors and windows are opened for (between 06:00 and 19:00 hours) a short interval of time, the concentration of both the polarities of air ions increases sharply. The air ion concentration reaches a typical state when all doors and windows are closed. Observations were carried out in the monsoon season when river Krishna flowing 4 km away from the observatory, was highly flooded. Then, these changes may be attributed to the large space charge densities observed to originate in the surf zones and move along with wind (Chapman 1938; Blanchard 1963a, 1963b; Gathman and Trent 1968; Gathman and Hoppel 1970a, 1970b; Woolf *et al.* 1987). When we open all the doors and windows of the room for a short interval of time, wind brings in air ions of both polarities with it. When we close all the doors and windows, then wind flow stops and hence ion concentrations are reduced. Therefore, air ion concentration reaches typical (normal) state. Such variations of large peaks of air ion concentration of both polarities are not observed in outdoors experiments. At the outdoors, wind flows continuously, therefore air ion concentration increases and decreases steadily as shown in figure 2.

The tropical station at Pune is surrounded by hills and high buildings. There is no agricultural land growing wheat, sugarcane or corn, but it is surrounded by number of buildings and always

polluted due to vehicular activities. Therefore, air ion concentration increases from night onwards and reaches a peak value at early morning (Dhanorkar and Kamra 1991, 1992). In contrast, at Ramanandnagar site, which is a rural area and surrounded by agricultural land; the flux of ^{220}Rn over the agricultural land increases with wind speed (Israel *et al.* 1969), and the diurnal maximum in ^{220}Rn concentration occurs at noon rather than at night (Israel 1965). Thus, observations over agricultural land reflect the influence of evapotranspiration. Therefore, air ions maxima is observed at noon in the rural station at Ramanandnagar.

Most experimental measurements of the ^{222}Rn and ^{220}Rn fluxes were carried out on bare soils (Crozier 1969), thus avoiding the complicating influence of vegetation, as observed at tropical station in Pune (Dhanorkar and Kamra 1991). However, in the case of Ramanandnagar, observed air ion concentration of both polarities decreases during night and starts increasing from morning as the sun rises. The highest fluxes of ^{222}Rn due to evapotranspiration (Allen *et al.* 1964) which peak at midday are masked by concurrent strong vertical eddy mixing induced by strong solar heating. Strong wind and reduced pressures in source regions enhance the rates of transpiration of soil exhalation of ^{220}Rn . During high rates of plant transpiration, average flux of bare soils and ion pair production by ^{222}Rn is some 5–10 times high and its decay products are correspondingly higher (Pearson and Jones 1966). Due to this additional source for the production of air ions outside the observatory, average air ion count is observed between 3×10^2 and 12×10^2 ions per cm^3 as shown in figure 6.

4. Discussion

Uranium naturally breaks down through radioactive decay to form radium that in turn decays to radon, which is gas. Radon then enters concrete walls, floors, floor drains and dumps. Inside any home, hotel or office, ionization sources are limited. Therefore, indoor counts of both negative and positive air ions are lower than outdoor counts. Elevated negative air ion levels are widely reported to have beneficial effects on humans including enhanced feeling of relaxation, and reduced tiredness, stress levels, irritability, depression and tension. Depleted ion levels and enhanced positive ion levels are reported to have no effect or deleterious effects. Therefore, outdoor air ion concentration is much higher than indoors, which is very healthy for human beings (Buckalew and Rizzuto 1984). The vertical distribution of ionization is

determined by the relative contribution of cosmic ray ionization and radioactive gases transported from the continental surface, such as radon. Immediately adjacent to the land surface, gamma radiation also contributes. The rate of ionization by atmospheric radioactivity is determined by vertical eddy transport of the gases away from the surface. We assumed that the radon released from the walls which contain some soil material, affected the indoor ionization rate in conditions of this study. Due to limited sources for air ion production inside the observatory, average air ions are below 3 (figure 5), which is very low as compared to 3–12 observed in the outdoor condition (figure 6).

During night hours, both the polarities of air ion concentrations decrease in both indoor and outdoor observations. It is also observed that the magnitude of outdoor air ion concentration is higher than magnitude of indoor air ion concentration. As a matter of fact, outdoor air ion concentration steadily increases and peaks at 18:00 hours. In the outdoor conditions, the plant transpirations of radon and thoron are an additional source of ion production; also waves from the river Krishna and rain drop splashing during (Chate and Kamra 1993) the monsoons introduce more air ions (Lenggoro *et al.* 2003) into the atmosphere (Andronache *et al.* 2006). Thus, magnitude of outdoor air ions is much higher than that of indoors. Net charge can be introduced into the atmosphere by processes such as combustion, rainfall and ultraviolet radiation (Harrison and Carslaw 2003). Ions are also produced by corona discharge from points or branches of trees having high potential difference with surroundings. The amount of atmospheric point discharge is a sensitive function of wind speed and electric field (Whipple and Scrase 1936). A classical experiment (Scholand 1953) measured point discharge current of the order of microamperes from an uprooted electrically isolated tree. During day time, processes such as combustion, high rates of plant transpiration of ^{222}Rn and ^{220}Rn and photodissociation of cluster ions into lighter ions by continuous ultraviolet radiation occur (Keith *et al.* 2003; Kolarz and Filipovic 2008). Observatory at the rural site is surrounded by agricultural land in the radius of 20 km. Therefore, both positive and negative outdoor air ion concentrations during day time are very high.

Although ions are continuously being formed, they are also neutralized (Kulmala *et al.* 2005) on combination with ions of opposite polarity (Lee *et al.* 2003). Therefore, their concentration in the atmosphere is fairly constant. Ionization due to cosmic rays and radioactive matter in soil is approximately constant with time at a particular location. Radioactive material in the air varies because of air turbulence and the rate of

exhalations of radioactive gases from the soil is affected by factors such as temperature, wind and ground covering (Titta *et al.* 2007). This means that sources for air ion production during night are very few. Hence, air ion concentrations (Viitanen *et al.* 2008) of both polarities are observed to be lower and steady during night and a maximum is observed in the evening.

4.1 Measurement of pollution index for indoor and outdoor atmosphere

Positive air ions are nothing but aerosols present in the atmosphere and negative air ions are consumed by these aerosols. Therefore, pollution index (which is the ratio of positive to negative air ion) above 1 means more polluted atmosphere and below 1 means less polluted atmosphere (Kolarz *et al.* 2009). Indoor pollution index is 1.55 and for outdoors it is 1.1 (figure 7) during 00:00–02:00 hours. Therefore, indoor atmosphere is more harmful to human health than outdoors during 00:00–02:00 hours. Pollution index at indoors is 1.05 and at outdoors is 1.1 during 06:00–08:00 hours. Indoor and outdoor atmosphere is healthy during 06:00–08:00 hours. Pollution index at indoors is 0.79 and at outdoors is 1.13 during 12:00–14:00 hours LT. This means negative air ions are more and positive air ions are less indoors, while positive air ions are more and negative air ions less outdoors during 12:00–14:00 hours. The wind is not moving with high speed indoors, while wind is moving with high speed outdoors. Due to friction between two air levels, more positive air ions are produced. As compared to indoors, more aerosols are present outdoors. Therefore pollution index is more at outdoors as compared to indoors during 12:00–14:00 hours. Due to limited sources of indoor air ions, it is observed that pollution index decreases from

00:00–02:00 hours and minimum is reached during 12:00–14:00 hours. There are number of sources and sinks of air ions for outdoors, therefore pollution index is more or less same for all-the-time period.

5. Conclusions

As compared to indoors, average air ions of both the polarities are higher for outdoors. Moreover, the air ion concentrations, experience large fluctuations during daytime, as compared to nighttime, values. When we close all the doors and windows of the observatory during nighttime, there is a decrease in the air ion concentration of both the polarities. As compared to indoors, sources for the outdoor production of air ions are more, therefore class of frequency distribution is more for outdoors. In a steady condition, the total number of ions in any volume of air remains constant. Therefore, both positive and negative air ion concentrations are lower and uniform throughout the night both for indoor and outdoor conditions.

Observatory at Ramanandnagar is in a totally rural area and surrounded by agricultural land. Plant transpirations of radon and thoron is an additional source for production of air ions. Magnitude of aerosol particles produced by different sources is low at rural station Ramanandnagar. Very small magnitudes of air ions are combined with these aerosols. Therefore, pollution index more or less is unity for outdoors in the all-the-time period, which is good for human health. Due to limited sources of air ions for indoors, it is observed that pollution index decreases from 00:00–02:00 hours and minimum is reached during 12:00–14:00 hours for indoors. During 00:00–02:00 hours, pollution index for indoors is 1.55, which is harmful to human health.

Figure 7. Average positive to negative air ions ratio for 00:00–02:00, 06:00–08:00 and 12:00–14:00 hours.

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