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Research Article

Optical particle sensor based measurement and analysis of atmospheric aerosol number concentration of various sizes over a tropical region of Northern India.

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Abstract

The measurement of atmospheric aerosol number concentration has been carried out at a remotely polluted site (Roorkee, 29º 52' N, 77º 53' E, 275 m above mean sea level) in northern India during pre monsoon period of 2009 at a height of 9 m above ground level. The aerosol number concentration having different sizes (0.3-0.5, 0.5-1.0, 1.0-2.0 and 2.0-5.0 μm) in pre monsoon summer season 0f 2009 has been analyzed, and the daily variation of aerosol number concentration has been related to selected meteorological parameters like as relative humidity, temperature, rainfall and wind speed. The measurements were made with an optical partical counter. The aerosol number concentration for upper size ranges (1.0-2.0 and 2.0-5.0 μm) is maximum in June and minimum in July. The aerosol number concentration in small size ranges (0.3-0.5 and 0.5-1.0 μm) decreases monotonically till the end of July.

Keywords: Aerosols, Optical Particle counter, Temperature, Relative humidity, Rain fall

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1. INTRODUCTION

Atmospheric aerosols control the atmospheric radiation budget and hence are important in the variation of weather and climate[1,2]. Atmospheric aerosols either independently or in combination with atmospheric ions act as cloud condensation nuclei or affect precipitation[3,4]. Devara and Raj[5] measured the aerosols during two successive monsoon seasons. Saxena *et al.*[6] measured the concentration of aerosols during monsoon period and found that the concentration decreases with increasing precipitation. This phenomenon has been attributed to the scavenging of large aerosol particles due to rain[7].

The study on aerosol distribution can be done by using various techniques available[8-24] such as Cascade impactor[12], Lidar[17], Low-pressure impactor[19,25], Laser scatterometer[13] and Optical counter[3,26] etc. In the present study, we have measured the aerosol number concentration with an optical counter. The summer variation of atmospheric aerosol number concentration in different size bins for morning, noon and evening periods and their behavior with some selected meteorological parameters such as relative humidity, temperature, rainfall and wind speed have been studied.

2. METHODOLOGY

For the present study, the optical counter model KC-01 A (Rion Co Ltd, Tokyo, Japan) has been used, which is based on the principle of Mie scattering of light. The instrument has been well calibrated and has a provision for inbuilt calibration. A light beam intersects a flow of ambient air containing aerosols. The light incident on aerosol particles is scattered and received by a photo-multiplier tube at an angle of 90º. Output of the photo-multiplier tube is amplified and then fed to a pulse height analyzer, which divides the aerosol response into different size ranges. The pulse height is directly proportional to the particle size. The instrument sucks the ambient air at the rate of 1litre for 2min. The sucked air is monitored for 2 min only and the number concentration of particles is measured in the unit of particles/l. The whole equipment is microprocessor based and gives direct printout of aerosol particle number concentration for different size ranges of 0.3-0.5, 0.5-1.0, 1.0-2.0 and 2.0-5.0 μm. Detailed description of the instrument can be found elsewhere[27]. The observations were made at a height of 9 m above the ground surface on second floor of the Physics department building of the institute at Roorkee (29º 52’ N, 77º 53’ E, 275 m above mean sea level). The surrounding is free from industries. Therefore the man made aerosols are chiefly due to automobile and day to day domestic activities.

The time period of observations for the present study was chosen from April to July, 2009 and data were recorded continuously from 9:00 AM to 6:00 PM. The number concentration of aerosols in the above size ranges was recorded at every half an hour interval and the data of meteorological parameters were recorded simultaneously.

3. RESULTS AND DISCUSSION

Observation period from April to July has been chosen for the present study because in this period both the premonsoon and monsoon activities occur. The aerosol number concentration has a diurnal variation[13]. Aerosols data have been recorded for four size ranges (0.3-0.5, 0.5-1.0, 1.0-2.0 and 2.0-5.0 μm).

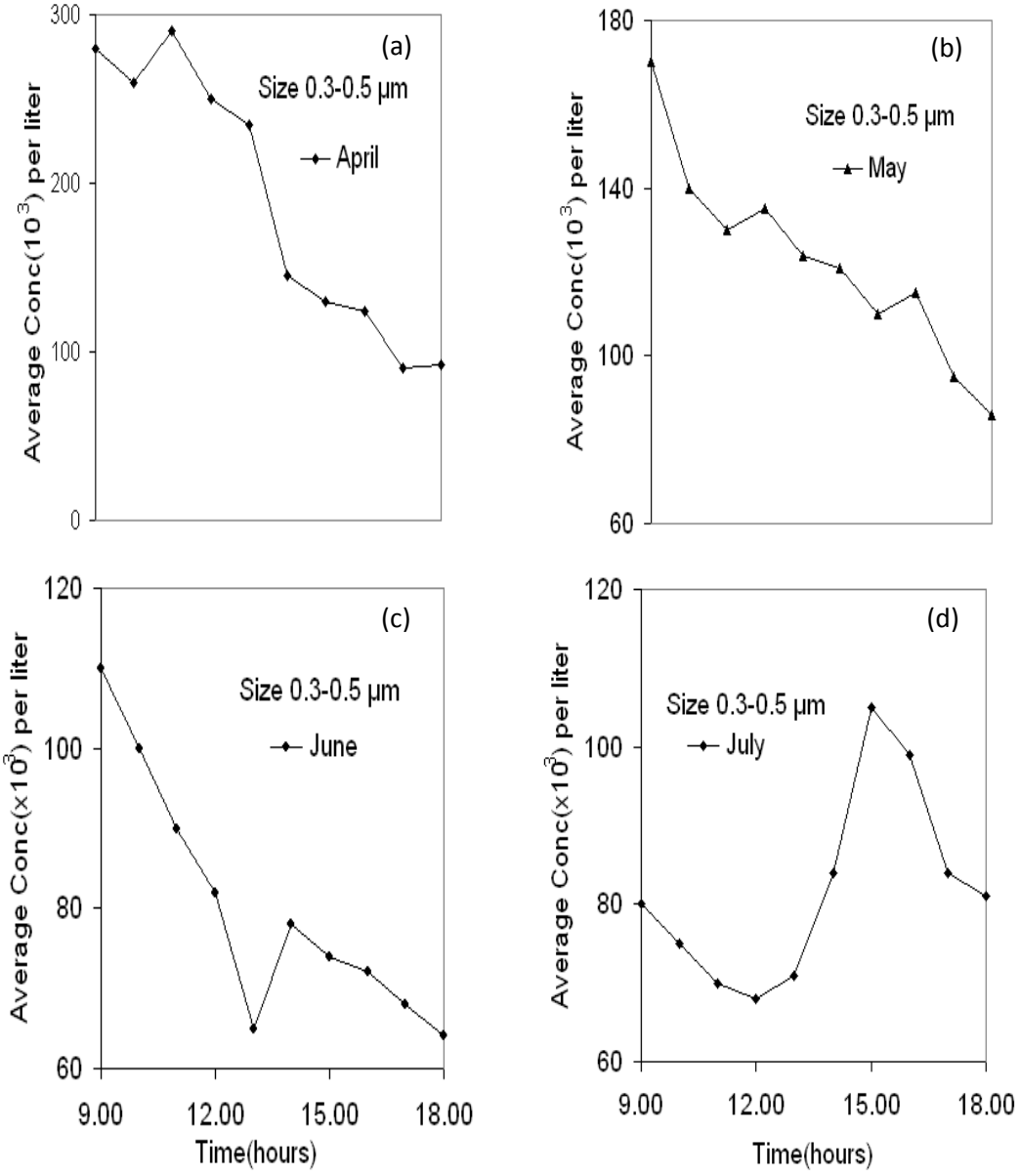

Figure 1: Time variation (IST) of average number concentration of aerosols in season (April-July, 2009) for lower size range.

The time variation of average number concentration of aerosols for the smaller size range (0.3-0.5 μm) is shown in Figure 1. In the lower size range 0.3-0.5 μm, the average aerosol concentration varies from about $3x10^5$ to $1x10^5$ particles/l in the month of April [Figure 1(a)]. The aerosol concentration decreases from morning to evening (9:00 to 18:00

hrs) in this month of April, 2009. The similar trend continues in the month of May 2009 [Figure 1(b)].

However in the month of June [Figure 1(c)], the concentration of these particles was decreased in noon period (12:00 to 15:00 hrs). Most of the particles remain in the range $1.1x10^5$ to $7x10^4$ particles/l. The sudden drop in particle concentration might be due to the local effects of instrumental conditions at experimental site. In the month of July, the concentration was first increased from morning to noon and then decreased from noon to evening [Figure 1(d)]. Most of the particles fall in the range $8x10^4$ to $1.2x10^5$ particles/l.

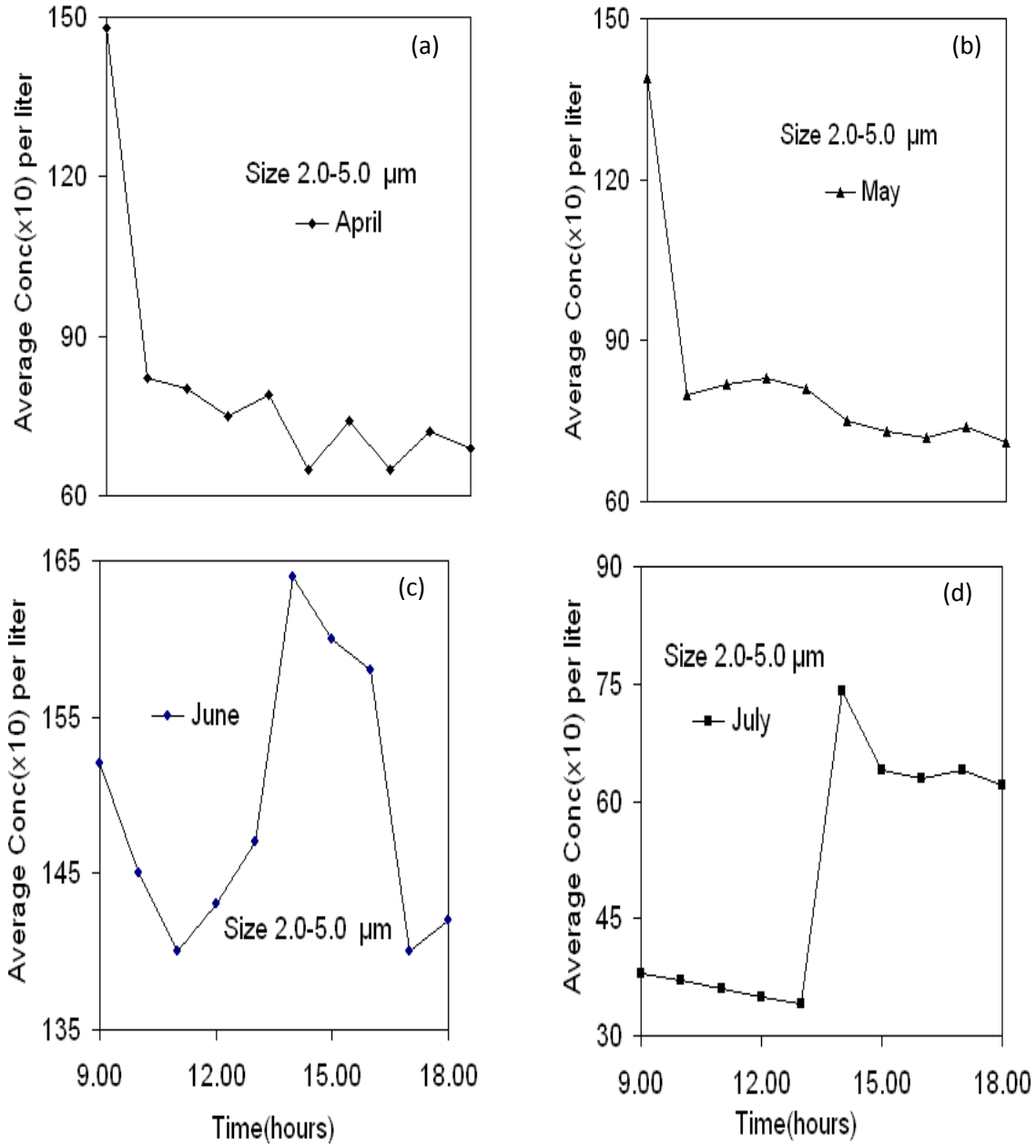

Figure 2: Time variation (IST) of average number concentration of aerosols in season (April-July, 2009) for upper size range.

Figure 2 shows the time variation of average number concentration of aerosols for the larger size range (2.0-5.0 μm) from morning to evening. In the bigger size range 2.0-5.0 μm, the average aerosol concentration varies from about $1.482x10^3$ to $7.1x10^2$ particles/l in the month of April [Figure 2(a)]. The aerosol concentration decreases from morning to evening (9:00 to 18:00 hrs) in this month of April, 2009. The similar trend continues in the month of May 2009 [Figure 2(b)].

However in the month of June [Figure 2(c)], the concentration of these particles was first decreased up to 11:00 AM, then increased in noon period (12:00 to 15:00 hrs) and finally decreased in the evening. In the month of July, the concentration was first increased from morning to noon and then slightly decreased from noon to evening [Figure 2(d)]. Most of the particles in the bigger size range (2.0-5.0 μm) fall in the range 350 to 750 particles/l.

The time variation of aerosols in three size ranges shows that for 0.3-0.5, 0.5-1.0, 1.0-2.0 μm the morning concentrations are larger than the evening concentration and shows a steady decrease from 09:00 to 14:00 h and then became steady. The reasoning of high values of aerosols in the morning hours may be attributed to boundary layer variation height rather than condensation. Further, the increase in aerosol concentration during day time was also due to local emission by vehicular traffic etc[28-30]. With the rise of sun, the temperature increases and droplets get evaporated. However, the large size range of 2.0-5.0 μm dominates. With the rise of temperature and occurrence of high velocity winds, the aerosol number concentration increases. The atmospheric temperature becomes high around 14:00 h and after that both the temperature and wind speed decreases. This causes a maximum around 14:00 h in large size range in the aerosol concentration. This trend is clearly visible in the months of April and July. In July, the concentration is lowest in all size ranges due to scavenging. But the high wind speed around 14:00 h might have caused a peak at that time in the size range 2.0-5.0 μm in the months of May and June. After about 10:00 h the concentration (2.0-5.0 μm size) becomes almost constant till evening.

Devara and Raj[5] studied the columnar content of aerosol over Pune using lidar. Their results revealed contrasting nature of variation in the years 1987 and 1988. In 1987, the concentration was minimum in the month of May while in 1988 it was maximum in this month, however the experiments were performed at a height range 50-1100 and 50-200 m from the ground surface in both the years respectively. Their results showed that the aerosol concentration was minimum during rainy season. This is in good agreement with our observations that the aerosol number concentration had gone minimum in the month of July when the monsoon was in full swing[30-32].

Pahwa *et al.*[18] studied the aerosols of different composition and the total suspended particulates at Delhi. Their study revealed that during May 1986, the total suspended particulates concentration was 543 $\mu g/m^3$. It had increased to 777.17 $\mu g/m^3$ in the month of June. In July and August, the concentration had gone to 231.88 and 173.36 $\mu g/m^3$, respectively. As the onset of monsoon was nearly at the same time, their results can be compared with our observations that in July the aerosol number concentration in all size

ranges is decreased drastically. In their studies, the minimum concentration was in August. Maximum rain occurred in August, which decreased the aerosol number concentration due to scavenging.

In Figures 3 and 4, day-to-day variation of aerosol number concentration is depicted. It is seen that the variation of average concentration of aerosols for different size ranges differs. For large size particles (2.0-5.0 μm), the concentration is lowest and the concentration is maximum for small size particles (0.3-0.5 μm) during the whole period of observation.

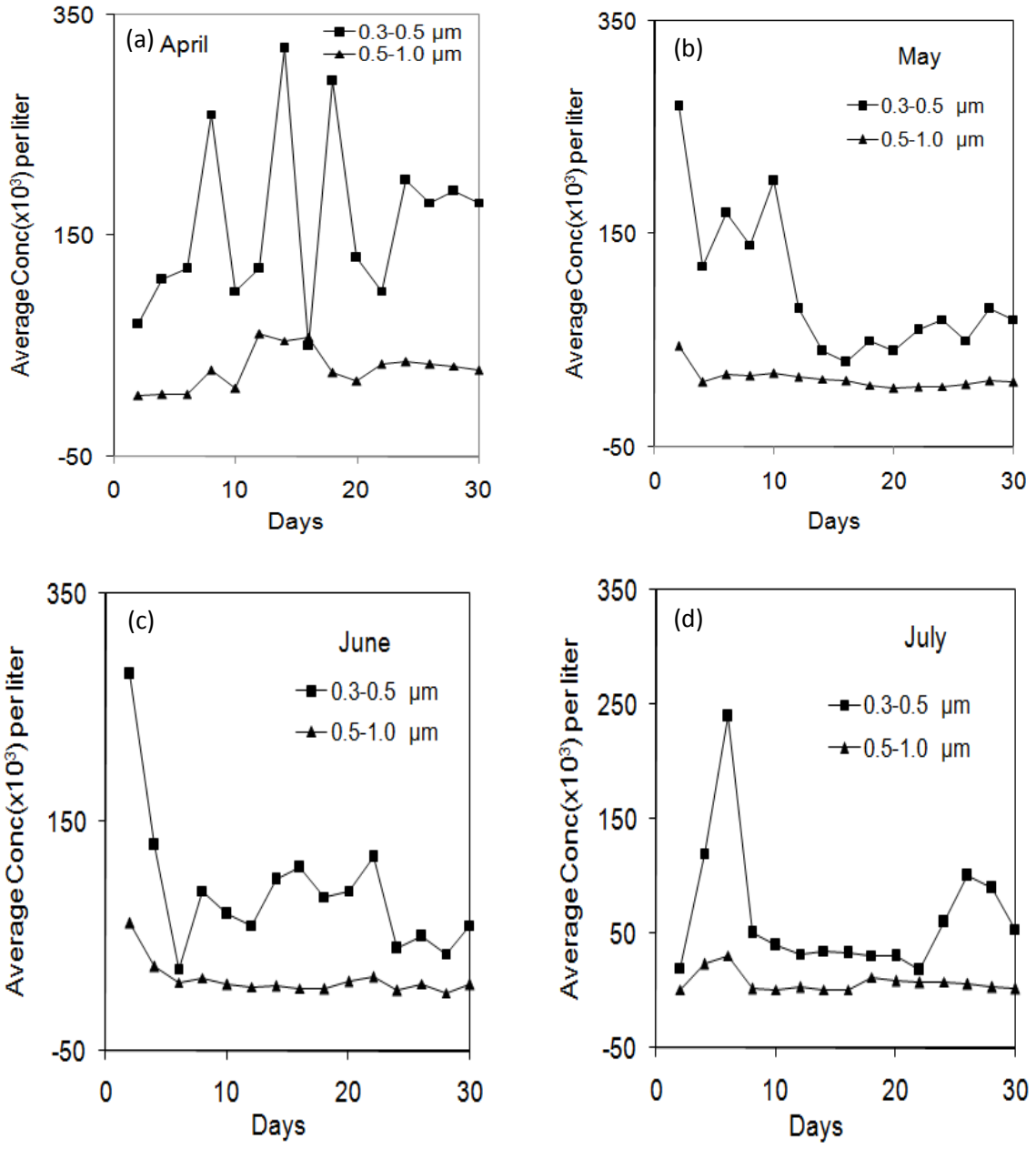

Figure 3: Daily variation of average number concentration of aerosols in season (April-July, 2009) for smaller size ranges ((0.3-0.5 & 0.5-1.0 μm).

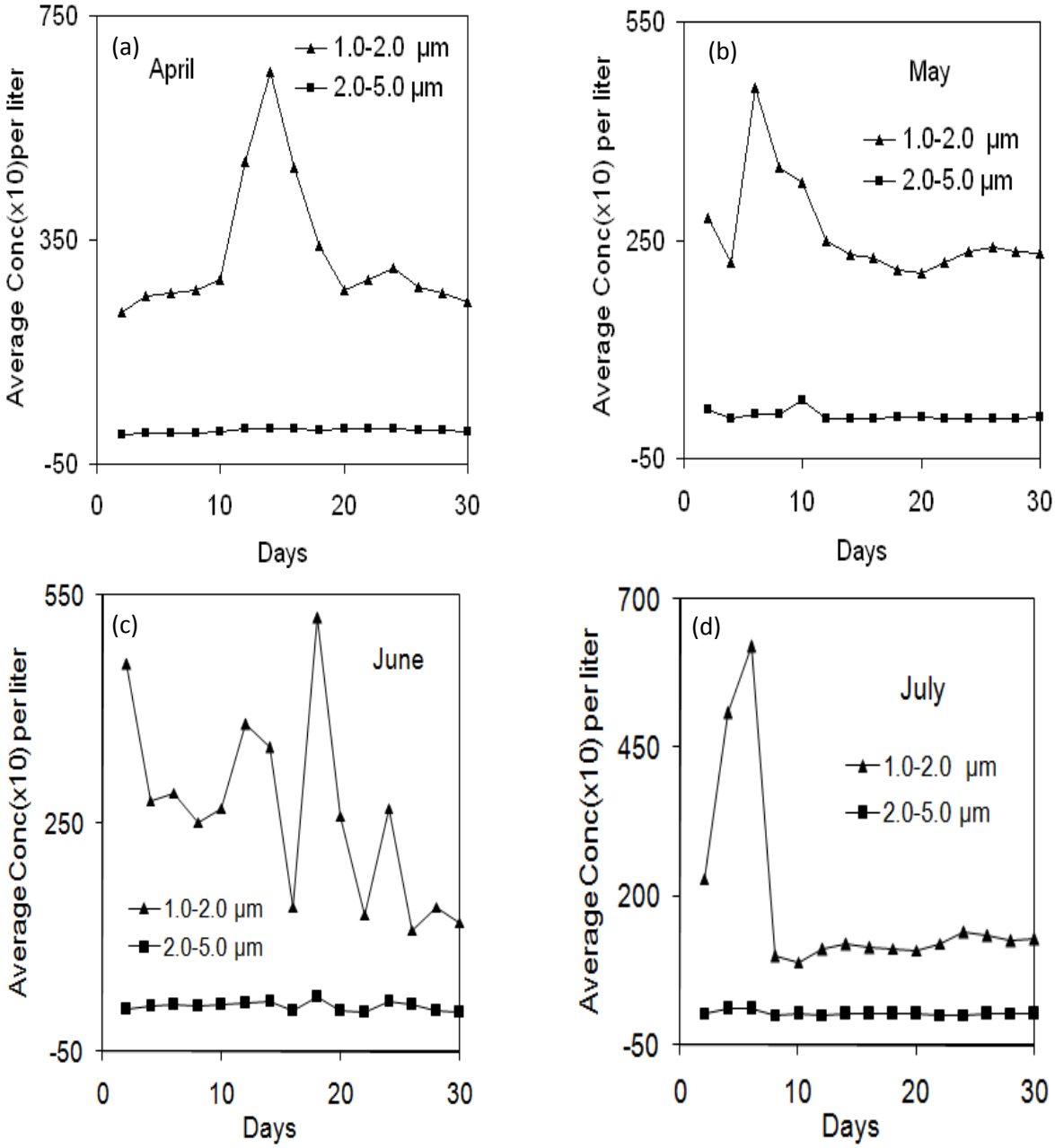

Figure 4: Daily variation of average number concentration of aerosols in season (April-July, 2009) for bigger size ranges (1.0-2.0 & 2.0-5.0 µm).

The small size 0.3-0.5 µm, aerosol number concentration is about $3x10^5$ particles/l in the month of April. Most of the particles remain in the upper range of 10^5 particles/l [Figure 3(a)]. The concentration of particles is nearly the same in the month of May but is less in comparison to the month of April. In the month of June, the concentration of aerosol decreases and most of the particles remain in the concentration range $2.3x10^5$-$9x10^4$ particles/l. A further decrease in concentration is observed in the month of July [Figure 3(d)].This trend continues in the size range 0.5-1.0 µm. Most of the particles remain in the range $7x10^4$-$8x10^3$ particles/l in the months of April and May [Figure 3(a,b)]. The

concentration in this range decreases in the month of June and July [Figure 3(c,d)]. However, the lowest concentration goes to 10^3 particles/l.

In the size range 1.0-2.0 μm [Figure 4], the concentration is lower than that in the previous range. In the month of April the concentration ranges from $2.5x10^2$ -$6.4x10^3$ particles/l. It is nearly the same in the month of May and is lower in June than in July [Figure 4(b,c,d)]. In the month of July, the aerosol number concentration varies from $6.4x10^3$-$1x10^2$ particles/l. A similar situation prevails in the size range 2.0-5.0 μm. During the months of April and May [Figure 4(a,b)], the concentration of aerosol was nearly the same (50-100 particles /l), while in June [Figure 4(c)], the concentration increases, ranging from 50-200 particles/l. There is a significant decrease in the concentration in July [Figure 4(d)] and most of the particles lie in the concentration range 15-50 particles/l.

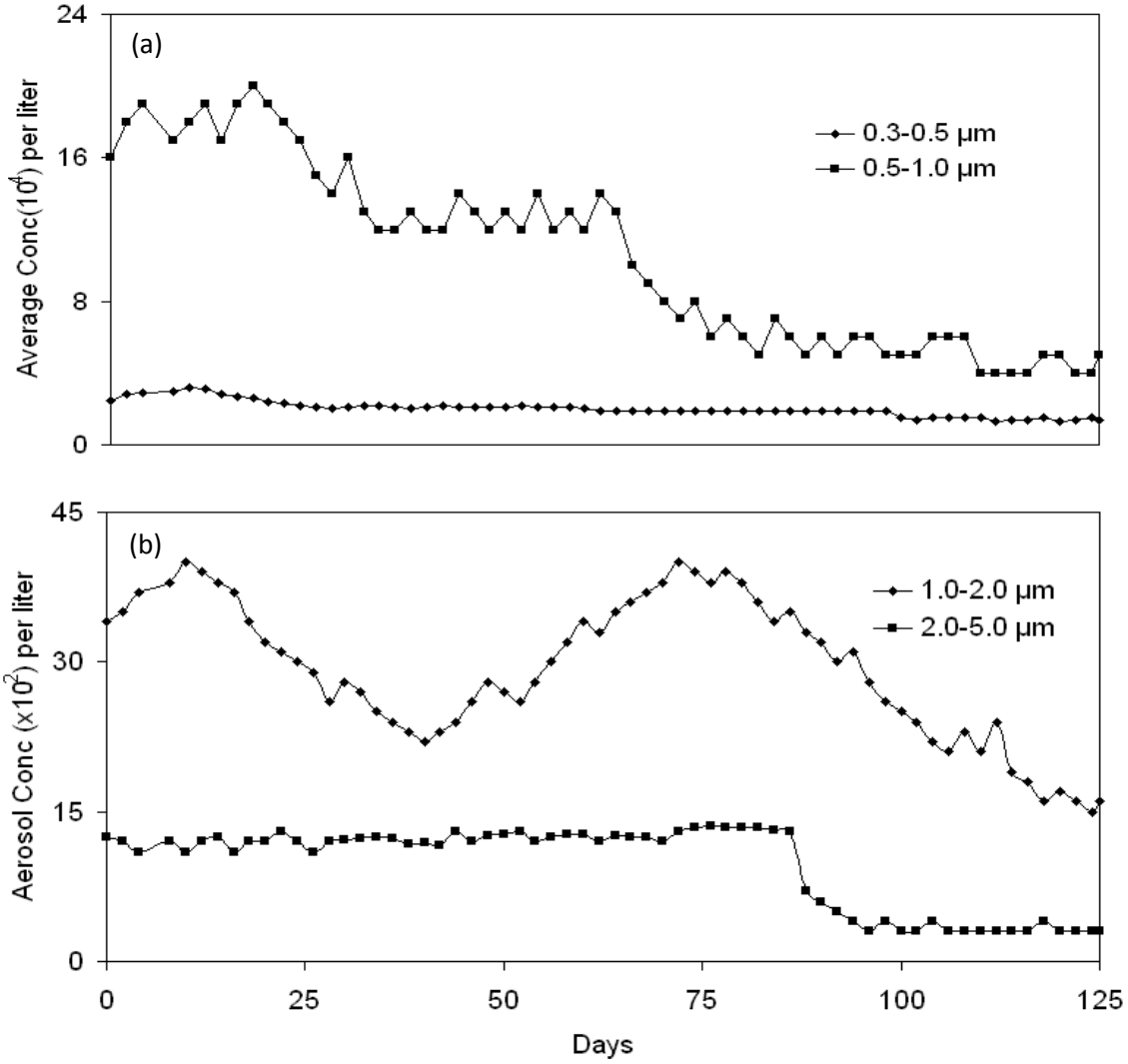

Figure 5: The daily mean average number concentration of aerosols in summer season (April –July, 2009).

Figure 5 shows the daily mean average number concentration of aerosols of different sizes for the whole season (April –July, 2009). In the small size ranges (0.3-0.5 and 0.5-1.0 μm) average particle concentration is maximum in the month of April and May and decreases continuously in June and July [Figure 5(a)]. In the large size ranges (1.0-2.0 and 2.0-5.0 μm), the average particle concentration increases, reaches maximum in the middle of June, after which it starts decreasing [Figure 5(b)]. However, It was found [Figures 5(a,b)] that the average number concentration of aerosols having bigger sizes (2.0-5.0 μm) has been found to be lower as compared to the smaller size ranges(0.3-0.5 μm).

The fluctuation of aerosol number concentration depends upon meteorological parameters[33]. The maximum temperature was slightly lower in July than the month of April and has been found maximum in first few days of May and also decreases slowly in the month of July [Figure 6(a)]. The minimum temperature was higher in July and nearly the same in June and is lower in the month of April and increases slightly in May [Figure 6(a)]. The relative humidity (RH) was minimum in the month of April and increases in May and became maximum in July [Figure 6(b)]. In the month of June, RH was less than the month of July. The present study reveals that the aerosol number concentration was more affected by RH during South-East (SE) premonsoon season. Parameswarn and Vijaykumar[19] found that the RH significantly affects the aerosol concentration and size distribution above about 90%. Here in the months of June and July 2005, average RH was almost close to this limit. Devara and Raj[5] observed a higher humidity and lower temperature during South-West premonsoon in the year 1988 at Pune. Aher and Agase[11] found that higher rainfall at Pune, India was due to the growth of cloud droplets under the effect of premonsoon. The same physical process appears to have taken place presently at Roorkee during SE premonsoon. The wind speed is nearly the same in the months of April and May and is higher in June and again decreases in the month of July [Figure 6(c)]. The rain plays an important role to modulate the aerosol size since larger particles take part in the scavenging process[17,31] .In the month of April and May, the rainfall is nearly zero [Figure 6(d)] so there is no significant effect on aerosol number concentration. The SE monsoon is effective after mid-June, therefore the concentration of aerosol decreases and it is in phase with the increasing monsoon activity. This is attributed to the rainfall, which is a powerful factor to lower the aerosol number concentration involving rainout process.

The aerosol number concentration is expected to be dependent on meteorological parameters[34]. Therefore, we have made comparisons of aerosol number concentration of various sizes with meteorological parameters (temperature, relative humidity, wind speed and rain fall). These have been shown in Figures 7-11 along with the best fit linear regression curves.

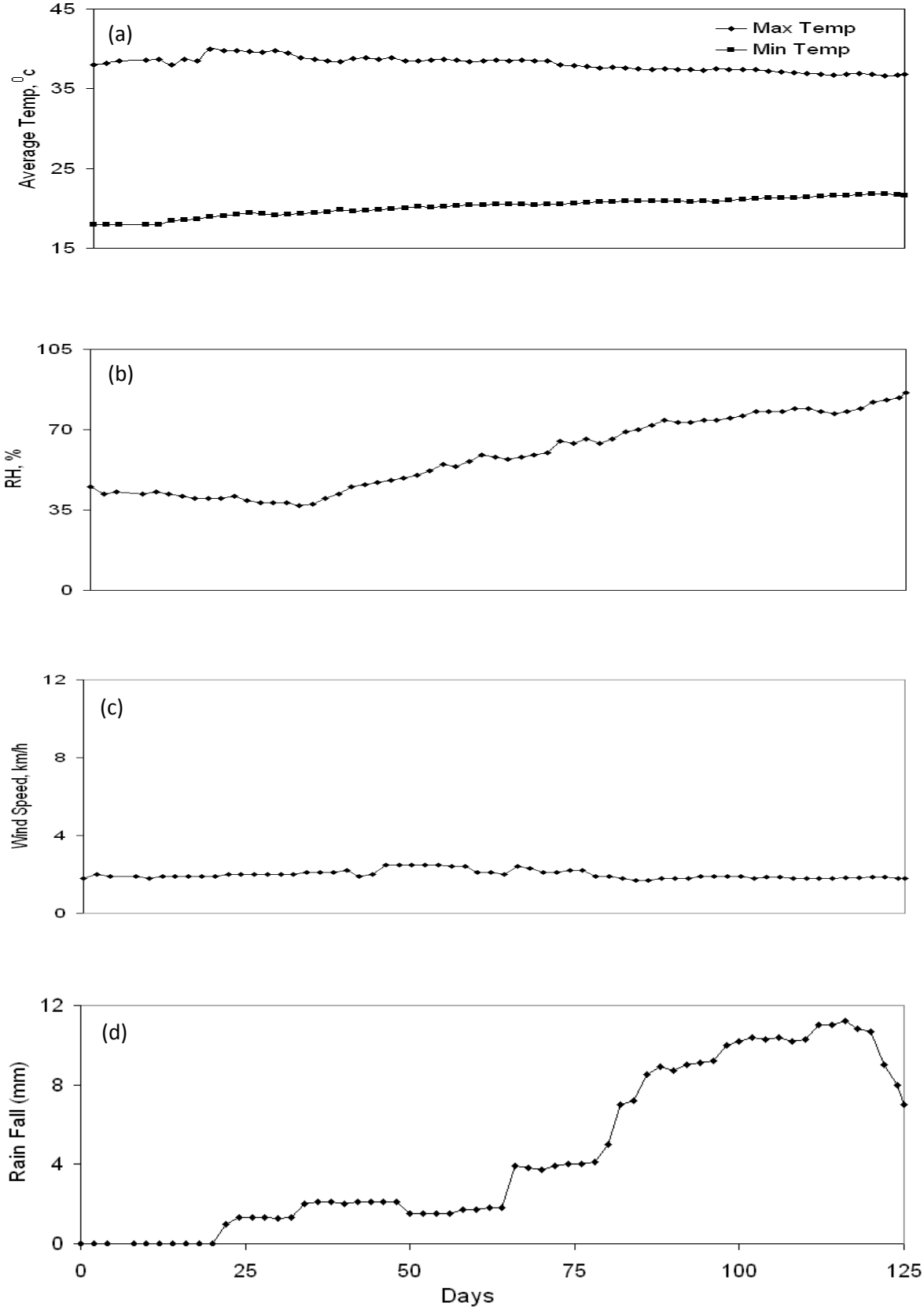

Figure 6: The daily mean average of meteorological parameters (temperature, RH, wind speed and rain fall) in summer season (April-July, 2009).

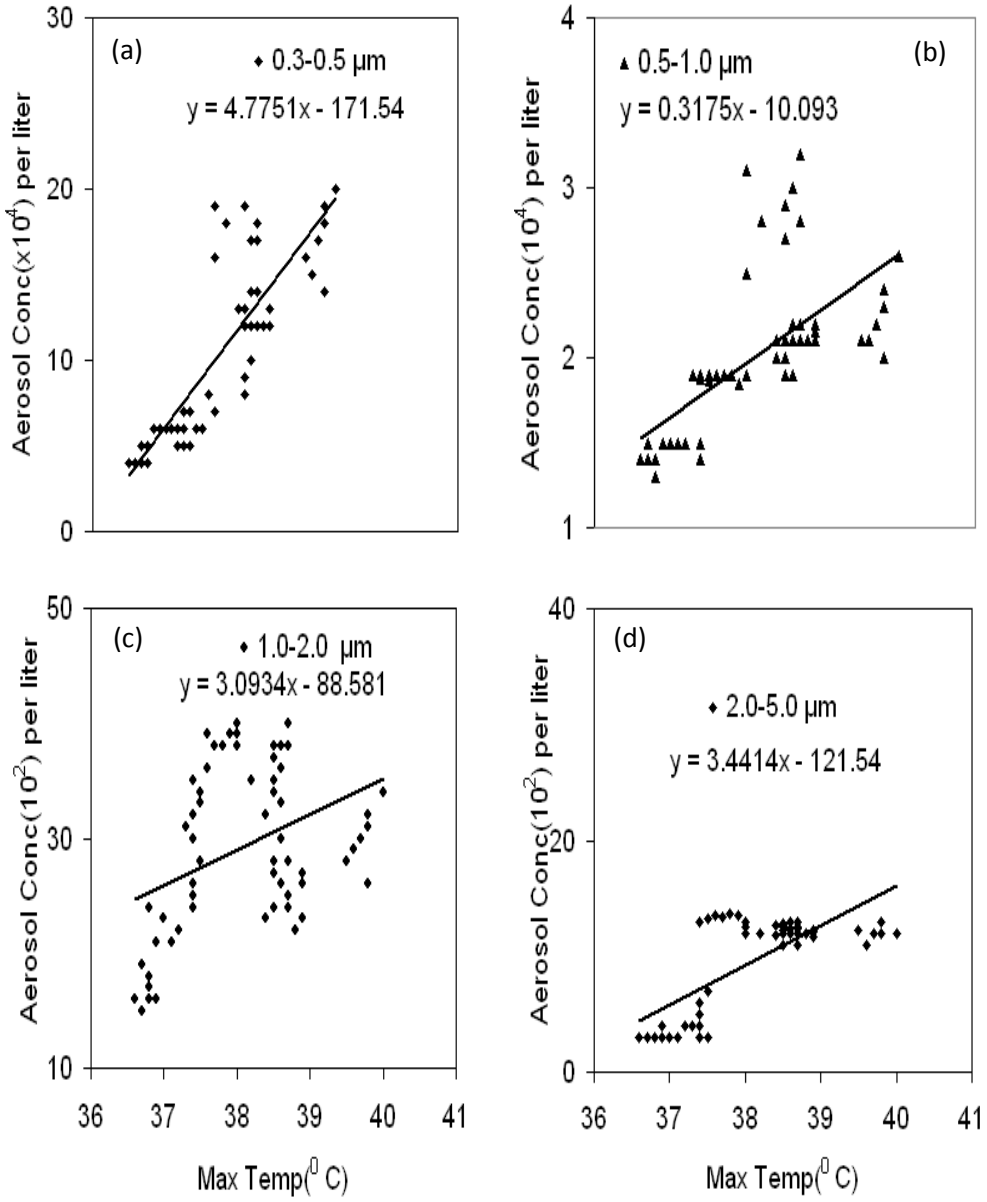

Figure 7: Plots of average aerosol concentration versus maximum temperature during April-July, 2009 for different size ranges.

Figure 7 shows the variation of the average concentration with maximum temperature. The average aerosol concentration slightly increases with increasing maximum temperature. This is due to the fact that with the rise of maximum temperature, more and more drops are vaporized leaving behind the aerosols. On the other hand, Figure 8 shows the variation of aerosol number concentration with minimum temperature. The concentration decreases slightly with increases minimum temperature. This has further been attributed to the process of condensation at small size particles. The increasing minimum temperature

decreases the condensation and hence a negative trend in the regression line of fit has been obtained.

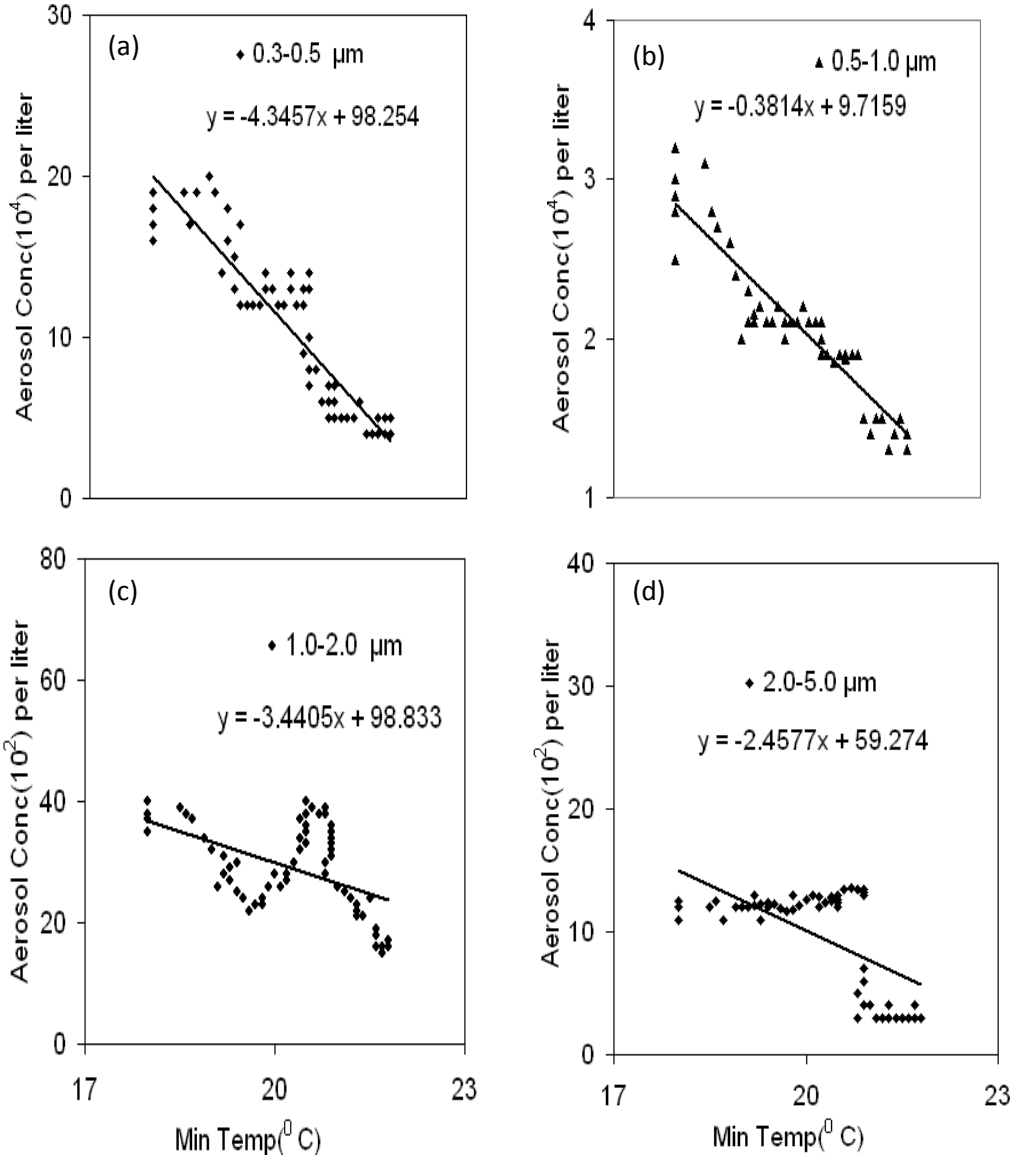

Figure 8: Plots of average aerosol concentration versus minimum temperature during April-July, 2009 for different size ranges.

Figure 9 shows the plot of average aerosol number concentration to the relative humidity. The number concentration in all size ranges decreases with humidity. The increasing humidity removes the aerosol particles in all size ranges due to condensation on aerosol particles and subsequent falling down of the drops to the ground. Pranesha and Kamra[20] in their laboratory studies have found that the particles are actually removed from the air due to condensation. The correlation coefficient is large for the smaller size particles (0.3-0.5 and 0.5-1.0 µm) and small for upper size particles (1.0-2.0 and 2.0-5.0 µm). This

shows that smaller particles act as condensation nuclei and the contribution of larger particles to this process is very small.

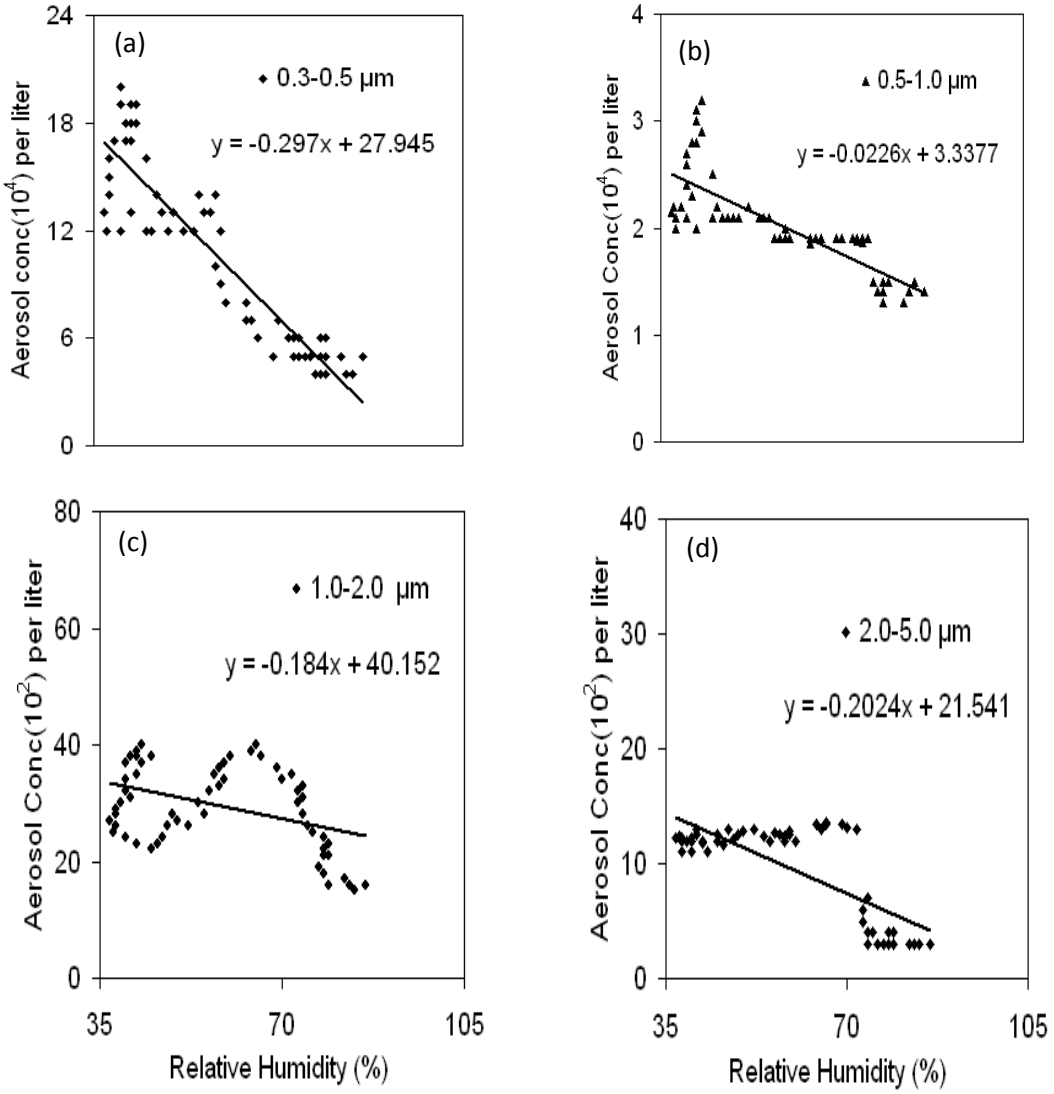

Figure 9: Plots of average aerosol concentration versus relative humidity during April-July, 2009 for different size ranges.

In Figure 10, there is a slight increase in aerosol concentration with increasing wind speed. This can be attributed to the dust particles from the soils which become air borne due to wind and therefore an increase in the aerosol number concentration is expected. The correlation coefficient in all the size ranges was found to be very small. It is clear from Figure 11, that the aerosol number concentration decreases with rain fall which is attributed to the scavenging of aerosol particles[5, 21].

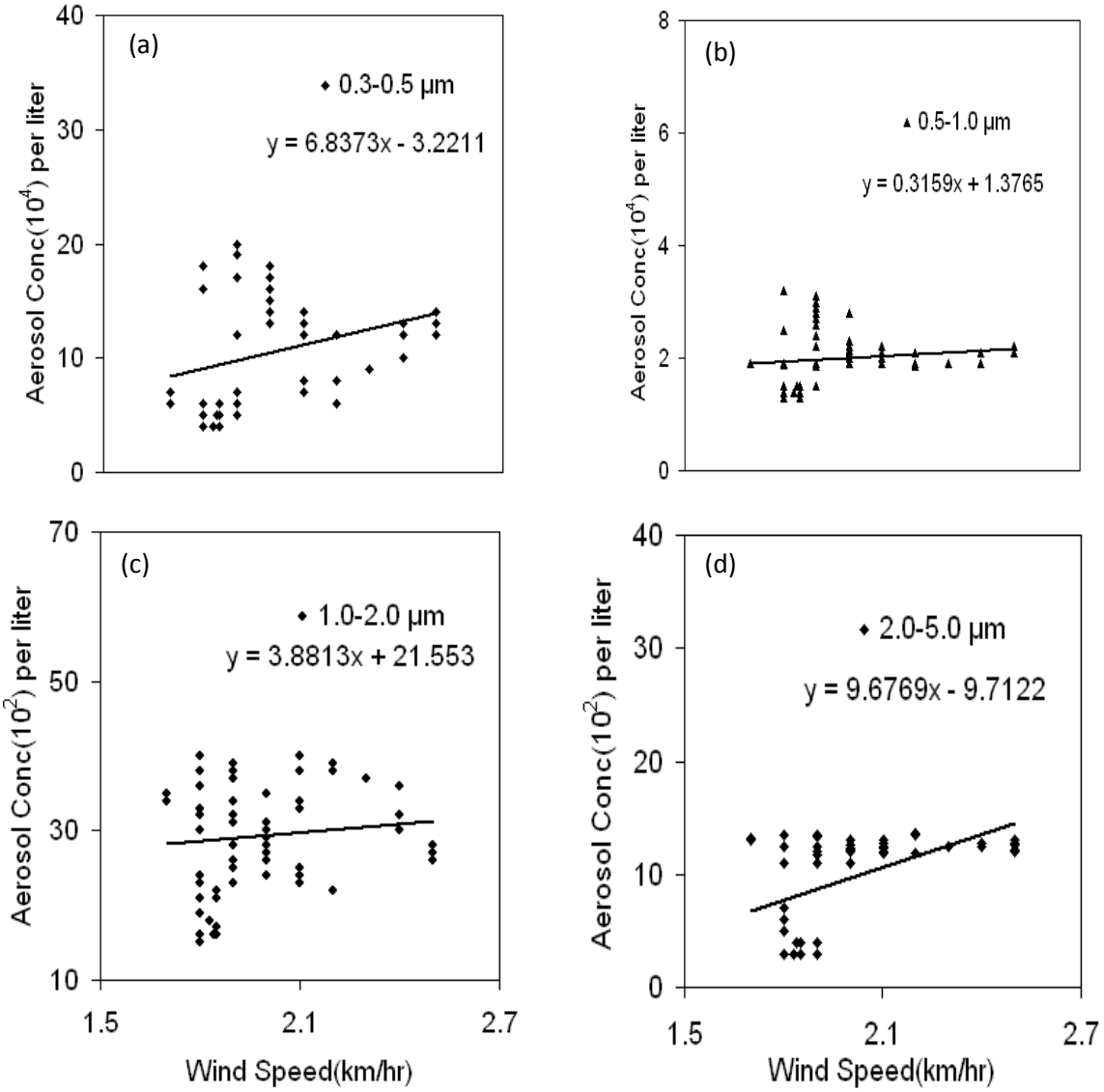

Figure 10: Plots of average aerosol concentration versus wind speed during April-July, 2009 for different size ranges.

Singh *et al.*[29] found that the particle size decreases with decrease in RH. Parameswarn and Vijaykumar[19] determined the aerosol size distribution with a low pressure impactor and concluded that the aerosol size decreases with decreasing RH. Vakeva *et al.*[32] also studied the effect of wind on aerosol concentration. They found that during medium wind the sub-micron size particles increase in concentration in the urban environment. In our studies, we have found that the aerosol number concentration increases with increasing wind speed. Shaw[28] has found that the aerosol concentration in the size range 0.36-0.40 µm increases with increasing temperature. From his studies, it was found that during summer months there was a four-fold aerosol concentration than the winter months. Further the sun increased the aerosol concentration in the above size range.

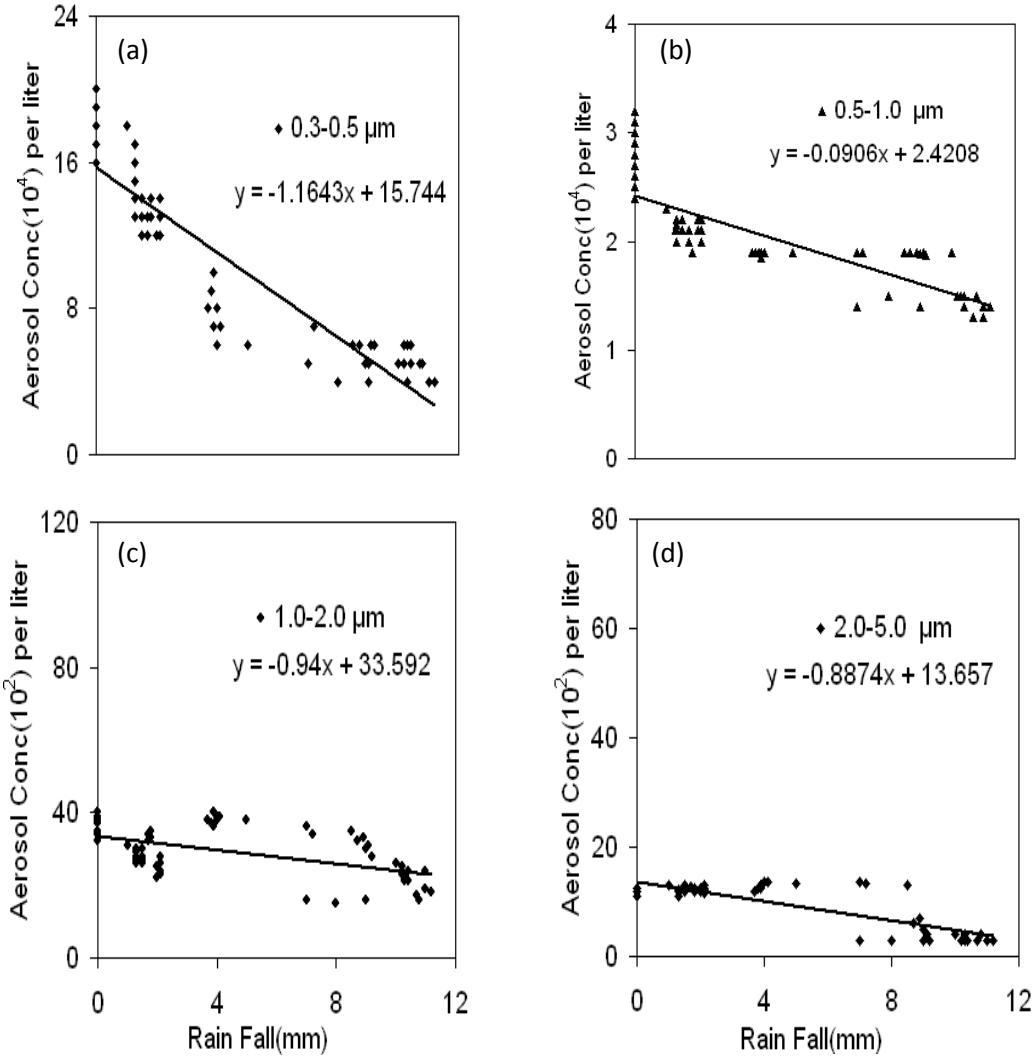

Figure 11: Plots of average aerosol concentration versus rain fall during April-July, 2009 for different size ranges.

The aerosol concentration dependence on both maximum and minimum temperatures are shown in Figures 7 and 8. In all size ranges, the aerosol number concentration decreases with increasing the minimum temperature. However, the variation with maximum temperature has been found to be opposite. In all size ranges, aerosol concentration increases with increasing maximum temperature. In all the above discussions, the data points between aerosol particle concentration and meteorological parameters are not scattered. This is because of the fact that the aerosol particles depend upon many parameters including man-made and natural sources and almost all the meteorological conditions should act at the same time. Therefore the paper draws important highlights on air quality over regional basis. The aerosols concentrations due to different pollution sources like vehicular traffic, industrial emissions, dust particles etc. are more & more predominant during day hours as compared

to night since during night time, the atmospheric conditions on an average are calm. Therefore, considering the effects of various air pollution sources, only day time 9 AM to 6 PM observations are presented in this paper in order to understand the real picture of aerosol distribution due to air pollution.

4. CONCLUSIONS

In the present study, the behavior of aerosol number concentration for different size ranges has been investigated in the season of April-July, 2009. Aerosol number concentration for small size ranges (0.3-0.5 and 0.5-1.0 μm) was higher than that of large size ranges (1.0-2.0 and 2.0-5.0 μm). The time variation of aerosols was found to be highly dependent on size. The investigations reveal the fact that the aerosol size and number concentration are highly influenced by the meteorological parameters. The meteorological parameters such as relative humidity, temperature, rainfall and wind speed play important roles to investigate the aerosol behavior but large amount of precipitation can change the number density and size distribution of aerosols more efficiently than RH and wind speed.

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REFERENCES

1. M. K. Bansal and T. S. Verma, *Aerosol measurements at Roorkee relating to the total solar eclipse of 24 October 1995*, Ind. J. Rad. Spa. Phys. 27, (1998) 260-265.

2. A. Kumar, *Variation of atmospheric electrical conductivity during monsoon period at a semi-urban tropical station of Northern India*, Ind. J. Phys. 87, (2013) 411-418. http://dx.doi.org/10.1007/s12648-013-0250-3

3. J. Burkart, G. Steiner, H. Reischl, M Moshammer, M Neuberger and R Hitzenberger, Characterizing the performance of two optical particle counters (Grimm OPC1.108 and OPC1.109) under urban aerosol conditions, J. Aeros. Sc. 41(10), (2010) 953-968. http://dx.doi.org/10.1016/j.jaerosci.2010.07.007

4. M. A. Byrne and S. G. Jennings, *Scavenging of sub-micrometer aerosol particles by water drops*, Atmos. Env. 27, (1993) 2099-2105. http://dx.doi.org/10.1016/0960-1686(93)90039-2

5. P. C. S. Devara and P. E. Raj, *A lidar study of atmospheric aerosols during two contrasting monsoon season*, Atmosf. 11, (1998) 199-204.

6. D. Saxena, R. Yadav, A. Kumar and J. Rai, *Measurement of atmospheric aerosols during monsoon and winter seasons at Roorkee, India*, Ind. J. Rad. Sp. Phys. 39, (2010) 208-217.

7. A. Kumar**,** *Long term (2003-2012) spatio-temporal MODIS (Terra/Aqua level 3) derived climatic variations of aerosol optical depth and cloud properties over a semi arid urban tropical region of Northern India*, Atmos. Env. 83, (2014) 291-300. http://dx.doi.org/10.1016/j.atmosenv.2013.10.030

8. A. Kumar, *A comparative study on orographic and latitudinal features of global atmospheric electrical parameters over different places at three Asian countries*, Ind. J. Phys. 88(3), (2014) 225-235. http://dx.doi.org/10.1007/s12648-013-0405-2

9. A. Kumar, *Variations in atmospheric aerosol concentration of various sizes during the total solar eclipse of 22 July 2009 over a semi urban tropical site of Northern India*, Ind. J. Phys. 88(5) (2014) 449-453. http://dx.doi.org/10.1007/s12648-013-0434-x

10. A. Kumar, *Variations of aerosol optical depth and cloud parameters over North Eastern regions of India retrieved from MODIS satellite data*, J. Atmos. Solar Terres. Phys. 100-101, (2013) 34-49. http://dx.doi.org/10.1016/j.jastp.2013.03.025

11. G. R. Aher and V. V. Agashe, *Effect of premonsoon scenario on aerosols at Pune*, Proc. Nat. Conf. TROPMET, Bangalore, India (1997) 31-32.

12. A. Kumar, *Mountainous Features of Global Atmospheric Electrical Parameters Over Various Tropospheric Regions of China*, Canad. J.Bas. App. Sc. 1, (2013) 10-18, 2013.

13. A. Kumar and H. P. Singh, *Impact of High Energy Cosmic Rays on Global Atmospheric Electrical Parameters over Different Orographically Important Places of India*, ISRN H. Ener. Phys. (2013) 1-7.

14. A. Kumar, *A critical review of earth's electrical atmosphere,* J. Sp. Exp. 2(1), (2013) 39-48.

15. A. Kumar, D Saxena and R. Yadav, *Measurement of atmospheric aerosols during monsoon period at Roorkee*, Atmos. Sc. Lett., 12(4), (2011) 345-350. http://dx.doi.org/10.1002/asl.347

16. A. Kumar, M. J. Nigam, A. K. Singh, S. Niwas and J Rai, *Effect of orographic features on atmospheric electrical parameters over different cities of India*, Ind. J. Rad. Sp. Phys. 27, (1998) 215-223.

17. X. Lu, Y. Jiang, X. Zhang, X. Wang and N. Spinelli, *Two-wavelength lidar inversion algorithm for determination of aerosol extinction-to-backscatter ratio and its application to CALIPSO lidar measurements*, J. Quan. Spect. Rad. Trans. 112 (2), (2011) 320-328. http://dx.doi.org/10.1016/j.jqsrt.2010.07.013

18. D. R. Pahwa, S. P. Singhal and L. T. Khemani, *Study of aerosols at Delhi*, Mausam, 45(1), (1994) 49-56.

19. K. Parameswarn and G. Vijaykumar, *Effect of atmospheric relative humidity on aerosol size distribution,* Ind. J. Rad. Sp. Phys., 23, (1994) 175-188.

20. T. S. Pranesha and A. K. Kamra, *Scavenging of aerosol particles by large water drops, 1-Natural case*, J. Geophys. Res. 101, (1996) 23373-23381. http://dx.doi.org/10.1029/96JD0131

21. C. Qi, C. Da-Ren and P. Greenberg, *Performance study of a unipolar aerosol mini-charger for a personal nanoparticle sizer*, J. Aeros. Sc. 39 (5) (2008) 450-459. http://dx.doi.org/10.1016/j.jaerosci.2008.01.003

22. J. Qiu, Z. Xuemei and Z. Xiaoye, *A study of the scaling height of the tropospheric aerosol and its extinction coefficient profile*, J. Aeros. Sc. 36 (3), (2005) 361-371. http://dx.doi.org/10.1016/j.jaerosci.2004.10.00

23. D. Saxena, R. Yadav and A. Kumar, *Orographic features of global atmospheric electrical parameters over different places of Sri Lanka*, Sri Lankan Journal of Physics 13(1), (2012) 09-16. http://dx.doi.org/10.4038/sljp.v13i1.2104

24. X. Zhang, R. Arimoto, J. J. Cao, S. A. Zhi and D. Wang, *Atmospheric dust aerosol over Tibetan Plateau*, J. Geophys. Res. 106, (2001) 18471-18476. http://dx.doi.org/10.1029/2000JD900672

25. D. Saxena, R. Yadav and A. Kumar, *Measurements of atmospheric electrical conductivities during the total solar eclipse of 22 July 2009*, Ind. J. Phys. 84(7), (2010) 783-788. http://dx.doi.org/10.1007/s12648-010-0051-x

26. D. Saxena, R Yadav and A Kumar, *Effect of orographic features on global atmospheric electrical parameters over 160 different places of US*, Ind. J. Phys. 84 (4), (2010) 383-389.

27. D. K. Sharma, J. Rai, M. Israil and P Singh, *Summer variations of the atmospheric aerosol number concentration over Roorkee, India*, J. Atmos. Sol. Terres. Phys. 65, (2003) 1007-1019. http://dx.doi.org/10.1016/S1364-6826(03)00146-9

28. G. E. Shaw, *Aerosol-size temperature relationship*, Geophys. Res. Lett. 15, (1988) 133-135. http://dx.doi.org/10.1029/GL015i002p00133

29. A. K. Singh, S. Niwas, A. Kumar, J. Rai and M.J. Nigam, *Variation of atmospheric aerosols and electrical conductivity at Roorkee during the total solar eclipse of October 1995*, Ind. J. Rad. Spa. Phys. 28, (1999) 1-10.

30. N. Singh, *Role of atmospheric ions on condensation and cloud formation processes*, Ph. D. thesis, University of Roorkee, India, 1985.

31. H. Sparmacher, K. Fullberg and H. Bonko, *Scavenging of aerosol particles: particle-bound radionuclides-experimental*, Atmos. Env. 27, (1993) 605-618. http://dx.doi.org/10.1016/0960-1686(93)90218-N

32. M. Vakeva, K. Hameri, T. Puhakka, E. D. Nilsson, H. Hohti and J. M. Makela, *Effect of meteorological process on aerosol particle size distribution in an urban background area*, J. Geophys. Res. 105, (2000) 9807-9821. http://dx.doi.org/10.1029/1999JD901143

33. S. Vinchurkar, P. W. Longest, and J. Peart, *CFD simulations of the Andersen acscade impactor: Model development and effects of aerosol charge*, J. Aeros. Sc. 40 (9), (2009), 807-822. http://dx.doi.org/10.1016/j.jaerosci.2009.05.005

34. J. Geel, J. Magill and H. E. Schmidt, *A survey of aerosol research in European community programmes*, J. Aeros. Sc. 23 (1), (1992) 9-13. http://dx.doi.org/10.1016/0021-8502(92)90336-T