Variations in atmospheric aerosols and electrical conductivity at Roorkee during the total solar eclipse of October 1995

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Continuous measurements of some meteorological and electrical parameters in conjunction with the total solar eclipse of 24 Oct. 1995 were made from 22 to 27 Oct. 1995 at Roorkee (29°52' N, 77°53'52" E, 275 m above sea level). Roorkee observed 90-92% maximum obscurity of eclipse, as it was close to the path of totality. The event lasted from 7.10 a.m. to 9.30 a.m. (IST; 0140-0400 hrs GMT). Considerable increase of aerosols and positive and negative conductivities were recorded during the eclipse with respect to those made on any other day. Increase in relative humidity and decrease in temperature were also observed during the eclipse.

1 Introduction

An eclipse constitutes a rapid, profound and widespread perturbation of the solar radiation received by the earth’s surface and its atmosphere. The effect of the eclipse on atmospheric parameters provides a tool to investigate the dependence of these parameters on solar radiation. Many reports1-6 of atmospheric parameters like potential gradient, electric field, air-earth current, space charge, conductivity, temperature, relative humidity and atmospheric aerosols during different solar eclipses occurring over different parts of the world are available in literature. The measurements of these parameters show interesting results.

With an objective of determining the local atmospheric response to a sudden removal of solar radiation, the continuous observations of some electrical and meteorological parameters were made during the near-total solar eclipse of 24 Oct. 1995 at Roorkee. The positive and negative conductivities of the atmosphere and aerosols of different sizes along with the meteorological parameters like temperature and relative humidity were recorded continuously from 22 to 27 Oct. 1995. Only the observations made one day before and after the eclipse along with the eclipse day were analysed and compared. An attempt has been made to give a theoretical explanation of the experimental findings.

2 Experimental site and set-up

Instruments were installed on the top of the Physics Department building of the University of Roorkee, at a height of about 12 m from the ground, far from any type of interference. In Physics Department, the measurements on electrical conductivity and aerosols were made, while other measurements on meteorological parameters like temperature, humidity and wind speed were made at National Institute of Hydrology (NIH). The NIH is situated within the university campus and it is close to the site of observation. Roorkee (29°52' N, 77°53'52" E) lies at a height of 275 m from sea level. The measurement techniques are given in the following sections.

3 Measurement of electrical conductivity

The technique for the measurement of atmospheric conductivities makes the use of the Gerdien condenser7. This instrument (Fig. 1) has been used widely for the measurement of electrical conductivity,
ion mobility and density. It has been used for balloon-borne and ground-based measurements.

The instrument comprises two parts — the sensor and the associated electronics. The sensor is basically a cylindrical capacitor and consists of two co-axial cylinders between which air is allowed to flow. Air intake was aided by an air blower with a capacity of 1500 litres per minute. When the air is drawn in, the ions of opposite polarity are attracted by the electrodes. The electrical conductivity of the air can be determined from current-voltage characteristics of the condenser.

A positive potential at the outer electrode makes electrons and negative ions move to the central electrode, thereby constituting a current. This gives the negative conductivity. The negative potential on the outer electrode similarly provides us the positive conductivity. The total conductivity $\sigma$, in terms of positive ($\sigma_p$) and negative ($\sigma_n$) conductivities, is given by

$$\sigma = \sigma_p + \sigma_n \quad \ldots (1)$$

From the measurement of output current of EMA (Fig. 1), the positive and negative conductivities can be obtained from

$$i = M \eta \frac{\omega_p}{\omega_c} = \frac{M \sigma_p}{\omega_c} \quad \ldots (2)$$

where,$$
\omega_p = \text{Mobility of positive ions} \\
\omega_c = \text{Critical mobility of ions}$$

$$M = \text{Aspiration rate} \\
e = \text{Electronic charge} \\
n_p = \text{Number of positive ions} \\
\sigma_p = \text{Conductivity of positive ions}$$

also,

$$\omega_c = \frac{M \ln (R_o / R_i)}{2\pi LV} \quad \ldots (3)$$

where,$$
R_o = \text{Radius of outer electrode} \\
R_i = \text{Radius of inner electrode} \\
V = \text{Voltage applied across the electrodes of the capacitor} \\
L = \text{Length of the cylinder}$$

Similarly, one may write

$$i = M \eta \frac{n_p \omega_p + n_e \omega_e}{\omega_c} = \frac{M \sigma_n}{\omega_c} \quad \ldots (4)$$

where, $i$ is the current due to negative ions and electrons, $n_p$ the number of negative ions and $n_e$ that of electrons, $\omega_p$ and $\omega_n$ are, respectively, the mobility of negative ions and electrons.

In the present case, since the applied voltage was the same in each case (±30V), the critical mobility is given by

$$\omega_c = 2.6624 \times 10^4 \text{ m}^2 \text{V}^{-1} \text{s}^{-1} \quad \ldots (5)$$

4 Measurement of atmospheric aerosols

The measurement of aerosols concentration and size distribution were carried out using the laser beam scatterometer. This instrument measures the intensity of the scattered laser beam by aerosols at angles of 45° and 135°. By using the intensities of the scattered laser beams the concentration of aerosols and size distribution were computed. A simplified diagram of the laser beam scatterometer is shown in Fig. 2.

When the particles are illuminated by a beam of laser light (6328 Å), the intensity of scattered light varies with size, shape, refractive index and concentration of the particles. The particle size distribution and their concentration can be calculated by the application of the Mie theory of scattering.

Assuming normal Gaussian distribution of scatterers, the number of particles $n(x)dx$ per unit
Fig. 2—Experimental set-up for aerosol measurements
The atmospheric particles. For natural aerosols, some of the workers have used normal Gaussian distribution for their measurements on atmospheric condensed droplets. Therefore, for the present study we have used the normal Gaussian distribution.

Intensity distribution functions \( I_1 \) and \( I_2 \) have been computed by other workers for different refractive indices and size parameters. For the present calculation we have taken the values of \( I_1 \) and \( I_2 \) in the modal size parameter range 0.1-30 for the refractive indices 1.30 and 1.33. Gumprecht and Sliepevich have taken the refractive indices from 1.2 to 1.6 in their studies. Holl has taken a refractive index of 1.33 for the size parameter ranging from 4.8 to 8.0. Pendorf has also taken the refractive indices ranging from 1.33 to 1.5 for the size parameter range of 0.1-30. The same value of 1.33 was considered by Houghton and Chalker for the size parameter ranging from 7 to 24. In the present case, due to sudden decrease of temperature, the condensation has already started and, therefore, we have taken representative refractive indices of 1.30 and 1.33.

The ratio of scattered intensities (theoretical values) in the direction \( \theta \) is,

\[
\frac{l(\theta)}{l(\theta)} = \frac{I_1(\theta, \lambda, m, r)}{I_0} \frac{\lambda^2}{4\pi^2} \left[ \frac{\rho_1 + \rho_2}{2} \right]
\]

where,

\[
l_0 = \text{Irradiance of incident radiation, and}
\]

\[
\rho_1 = \int I_1(\theta, \lambda, m, r) n(r) \, dr \quad \text{(8)}
\]

\[
\rho_2 = \int I_2(\theta, \lambda, m, r) n(r) \, dr \quad \text{(9)}
\]

where, \( I_1(\theta, \lambda, m, r) \) and \( I_2(\theta, \lambda, m, r) \) are the intensity distribution functions for a single particle at a scattering angle \( \theta \), wavelength \( \lambda \), the refractive index \( m \), and \( r \) the radius of the particle; \( n(r) \) is the number of particles in the radius range \( r \) and \( r + dr \), and thus \( n(r) \, dr \) represents the size distribution function.

Equation (6) is the normal distribution function for the atmospheric particles. For natural aerosols, some of the workers have taken log-normal distribution, while others have used normal Gaussian distribution for their measurements on atmospheric particles which may consist of condensed particles and particulates along with the natural aerosols. The aerosol particles at the experimental site are compared with natural aerosols, particulates and condensed droplets. Therefore, for the present study we have used the normal Gaussian distribution.

The results and discussion

The observations of temperature, relative humidity and wind speed on the day of solar eclipse (24 Oct 1995) are shown in Fig. 3. The temperature decreases with the onset of the eclipse and reaches a minimum at the time of maximum obscurity. The relative humidity increases due to the decrease of temperature. However, there is a difference of about 40 min between the times of minimum temperature and maximum humidity. This difference can be attributed to the atmospheric relaxation time which falls in the range 30 min to 1 h. The wind speed remained relatively constant and was lower than that.
on 23 or 25 Oct. 1995. The wind on the day of eclipse was about one third of that of the previous day. On the day after the eclipse, the wind doubled.

The aerosol concentration on 24 Oct. 1995 was more than twice that of the 23 October. The concentration on 25 October was the same as that for 23 October. Khemani et al.\textsuperscript{2} has reported that hygroscopic atmospheric particles, in the size range 0.1-1\,\mu m, increased by 43\% during total solar eclipse of 16 Feb. 1980 at Pune. This enhancement was attributed to the increased condensation and high relative humidity during the eclipse. In the present case, the measured total aerosol concentration in the size range of 0.05-3 \,\mu m was increased by about two times as compared to a non-eclipse day (Fig. 4). The maximum increase was observed in the 0.5-3.0 \,\mu m size range (Fig. 5). The behaviour of the variation of humidity was the same as for the aerosol concentration. This trend shows that the increase in aerosol concentration was influenced by the increase in humidity. However, Parameswaran and Vijayakumar\textsuperscript{11} found that the humidity did not affect aerosol number density appreciably up to a relative humidity of 94\%. Further, Parameswaran et al.\textsuperscript{22} has shown that the increase of wind speed increases the aerosol number density, because more surface particles become air-borne. The wind speed in the present observation decreased on the day of eclipse (Fig. 3) and, therefore, the increase in aerosol concentration cannot be attributed to the wind speed. The increase in aerosol concentration in this study is attributed to the formation of aerosols due to
Fig. 5—Time variation of aerosol concentration in different size ranges (0.05-3 μm) [(a) for 0.05 - 0.1 μm, (b) for 0.1 - 0.3 μm, (c) for 0.3 - 0.5 μm, (d) for 0.5 - 1 μm and (e) for 1.0 - 3.0 μm)]
increased condensation by atmospheric ions as discussed later in this section.

For the present calculations, the shape of the size distribution has been assumed to be Gaussian in all size ranges. Therefore, one may question the calculation of size distribution in different size bins. However, it is important to know the size range in which the maximum increase has taken place during the solar eclipse. This has been shown in Fig. 5 which reveals that on the eclipse day, the maximum increase above the average values of 23 and 25 Oct. 1995 in the aerosol concentration took place in the size ranges 0.5-1.0 μm and 1.0-3.0 μm. The minimum increase in concentration was in the size range 0.05-0.1 μm. McCartne\textsuperscript{10} has mentioned that the cloud condensation nuclei lie in the size range 0.1-1.0 μm (large) and > 1 μm (giant). Patel\textsuperscript{13} studied the effect of ions on concentration using a diffusion chamber and found that the droplet size ranged from 0.75 μm to 1.01 μm. McCartne\textsuperscript{10} citing different references has shown that the concentration of the cloud particles in the lower atmosphere peaked around 2.5 μm. Thus, the maximum increase of aerosol concentration in the present study, during the solar eclipse, lies in the range of the droplets. The decreased temperature, increased humidity and enhanced concentration of atmospheric ions\textsuperscript{25} during the solar eclipse make the concentration of aerosols to increase to a maximum in the size range 0.5-3.0 μm due to the condensation process. Wark and Warner\textsuperscript{12} describe that the particles below 0.1 μm (known as Aitken particles) behave in a way similar to the molecules undergoing random motion and collision. Any condensed particle in this range is likely to be evaporated soon.

One may also examine the variation of mode radius of aerosol particles during the total solar eclipse. The mode radius in the size range of the present observation, i.e. 0.05-3.0 μm for 23, 24 and 25 Oct. 1995, has been shown in Fig. 6. It can be seen from Fig. 6 that the mode radius ranges from 0.5 μm to above 2 μm. The slope of best fit regression line for 24 Oct. 1995 increases with time, while on other days, it decreases slowly. This can be attributed to the fall of temperature on eclipse day, while on other days, the temperature monotonically rises with time. The mode radius decreases with the rise in temperature on all the days. Similarly, the mode radius increases with relative humidity, increase being faster on the eclipse day.

The observed variation in electrical conductivity of the atmosphere is shown in Fig. 7. At the time of eclipse, the variation in negative conductivity is found to be larger than for positive conductivity. The duration of peak negative conductivity is larger than for positive conductivity. Table 1 shows the measurements of atmospheric conductivities by other workers during various solar eclipses. The observed variations in positive and negative conductivity are in good agreement with the present results. A comparison of Figs 5 and 7 shows that during the solar eclipse both aerosol concentration and electrical conductivity increase. This is contrary to normal atmospheric conditions in which the increase of aerosol concentration normally occurs with the decrease in atmospheric electrical conductivity.

The foregoing discussion on the variation of different parameters shows that the causes are not local, otherwise contrary results would have never been obtained.

Herman and Goldberg\textsuperscript{26} have concluded that the atmospheric electricity is changed by Forbush decrease effects. Agrawal\textsuperscript{25} has shown that the decrease of solar wind flux increases the galactic cosmic rays at low latitudes thereby causing the increased ionization. This is mainly because at low latitudes the main source of ionization is the cosmic rays of galactic origin, while at high latitudes the solar cosmic rays are responsible for ionization. If we assume that the solar wind particles are obstructed by moon during a solar eclipse, the flux of galactic cosmic rays coming from different directions would naturally decrease. The earth-moon distance is 3.84 \times 10^8 m and the result of stoppage of particles by moon will be exhibited by a time ranging from about 12.8 to 16 min (assuming that the solar particles travel with a speed of 400 to 500 km/s). In the present records such a trend has actually been obtained. The positive conductivity started increasing from its average value (of 23 and 25 October) after about 20 min of the onset of eclipse. However, the negative conductivity attained above the average value only a few minutes after the onset. The effect is more pronounced in aerosol concentration which started increasing about 15 min after the eclipse had started.

The increased ionization during the solar eclipse is responsible for the increase of both positive and negative conductivities. Singh et al\textsuperscript{23} have shown that the atmospheric ions increase the cloud condensation nuclei (CCN) formation. Singh\textsuperscript{24} has shown that the...
Fig. 6—Variation of mode radius w.r.t. time, temperature and relative humidity

Fig. 7—Time variation of atmospheric conductivity [(a) for positive conductivity, and (b) for negative conductivity]
Table I—A summary of measurements of electrical conductivity by various investigators

<table>
<thead>
<tr>
<th>Investigator(s)</th>
<th>Solar eclipse period</th>
<th>Place</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anderson and Dolezalek¹ (1972)</td>
<td>7 Mar. 1970</td>
<td>Waldorf Annex of the Naval Research Laboratory, Washington D.C. (USA)</td>
<td>Clear decrease in negative conductivity</td>
</tr>
<tr>
<td>Lane-Smith and Markson³ (1977)</td>
<td>10 July 1972</td>
<td>Malignant Cove, Nova Scotia (USA)</td>
<td>The negative conductivity began to rise up to high values about 5 min after the totality.</td>
</tr>
<tr>
<td>Nizamuddin et al.⁵ (1982)</td>
<td>16 Feb. 1980</td>
<td>Nagarampalam, Visakhapatnam (India)</td>
<td>Both types of polar conductivities increase, but increase in positive conductivity is more pronounced than negative conductivity.</td>
</tr>
<tr>
<td>Dhanorkar, Deshpande and Kamra³ (1989)</td>
<td>18 Mar. 1988</td>
<td>Pune (India)</td>
<td>Remarkable changes in atmospheric conductivity during the period of eclipse</td>
</tr>
<tr>
<td>Present work</td>
<td>24 Oct. 1995</td>
<td>Roorkee (India)</td>
<td>Increase in both positive and negative conductivity</td>
</tr>
</tbody>
</table>

Atmospheric ionization plays an important role in aerosol formation. The increased ionization would increase the concentration of aerosols. Thus, the atmospheric conductivity and aerosol both have been found to be increased during the total solar eclipse because of the excess atmospheric ions created by galactic cosmic rays enhanced by the obstruction of solar wind particles by the moon.

6 Conclusions

The present study reveals that during the total solar eclipse the humidity increases due to the decrease of temperature, and the aerosol particles increase with the increase of atmospheric electrical conductivity. These have been attributed to the stoppage of solar wind particles by the moon which, in turn, increases the galactic cosmic rays due to Forbush decrease. The galactic cosmic rays are the main source of ionization at low latitudes. The enhanced ionization due to increased cosmic rays increases the aerosol concentration by the process of condensation and also increases the atmospheric electrical conductivity.

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18 Holl H, Optik (Germany), 4 (1948) 173.