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Atmospheric electric potential gradient at Kolkata during solar eclipse of 22 July 2009

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Measurement of atmospheric electric potential gradient (PG) at Kolkata (latitude 22.56°N, longitude 88.5°E) during solar eclipse of 22 July 2009 has been carried out. The effects of solar eclipse on the potential gradient are presented in the paper, which show significant changes in the value during the eclipse period than their ambient values for the same period on other days. It shows that the PG value decreases about 38% during the eclipse period with some irregular variation during rest of the day. The results of measurements of ground level conductivity, temperature and relative humidity are also presented and discussed on the basis of change in conductivity due to eclipse, effects of global thunderstorm centers and local effects.

Keywords: Potential gradient, Atmospheric electric potential gradient, Ground level conductivity

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1 Introduction

The atmospheric electric potential gradient near the Earth's surface is governed by global thunderstorm and lightning activities[1,2]. These put the Earth-ionosphere waveguide into resonance producing various characteristic spectra[3]. This potential gradient also depends on local environmental factors. There exists a correlation between the local potential gradient and worldwide thunderstorm distribution. The disturbances in the ionosphere during solar eclipse are reported in terms of VLF amplitude of sferics, amplitude and phase changes in transmitted signals[4-6] as well as changes in the Earth's near surface vertical electric potential gradient[7,8].

The variation of air temperature, electric field, current density and conductivity over the surface of the Earth at tropical latitudes (± 25º) and temperate latitudes (± 60º) are interrelated with the solar radiations, global lightning activity and concentration of the aerosol content in the lower ionosphere[9-15]. Below 90 km altitude, the electron concentration is controlled by photo-ionization, recombination and different attachment-detachment processes leading to the formation and destruction of negative ions. The production of high potential difference between the Earth and the ionosphere due to the total number of thunderclouds acting together at any time drives the air-earth current downward from the lower region of the ionosphere to the surface of the Earth, which varies in accordance with the ionospheric potential and columnar resistance. In the polluted areas, the aerosol content enhances the columnar resistance. The vertical conduction current, electric field and its variation with altitude is changed. High concentration of pollutants decreases the conductivity of air at the lower layer. Its influence in the magnitude of potential gradient is much higher than the effect of increase of columnar resistance at that time.

Surface potential gradient also depends on change in pressure, temperature, formation of dense fog, which also governs the conductivity of the medium. Thus, the meteorological effects have some significant role for the lowering of potential gradient during eclipse[16,17].

Previous studies on the measurement of atmospheric vertical electric potential gradient, an important parameter of global electric circuit, during eclipse by various researchers at different observational sites throughout the world reveal surprising results. Some showed the increase in potential gradient, others a decrease and yet others got no noticeable signatures at all. Hence, it is almost a routine work to study the atmospheric electricity parameters during eclipse to find out the exact nature of variations and also their reasons.

In the area of atmospheric electricity, continuous records of atmospheric vertical electric potential gradient are being taken from Kolkata (latitude 22.56°N, longitude 88.5°E)[18]. The potential gradient is recorded in the form of signals. These are processed and finally viewed in a computer through data acquisition system.

In this paper, the outcome of the measurements of vertical electric potential gradient during the solar eclipse has been presented. Some marked deviations are observed in the values of vertical electric potential gradient. Also, the results of the analyses of air-Earth conductivity, temperature and relative humidity are presented, which are in support of the potential gradient variation.

2 Methodology and Instruments

The vertical electric field has been measured on a continuous basis with an ac field-mill. The alternating signal from the field-mill is amplified using a signal processor having one-second time constant. IC LF356N has been used at the input stage of the amplifier because of its high input resistance (~ 10^{12} Ω) and good signal-to-noise ratio. The sensitivity of the field-mill has been calculated to be (0.33±0.03) Vm^{-1}. The output is recorded by digital data acquisition system that uses a PCI 1050, 16 channel 12 bit DAS card (Dynalog), which has a 12 bit A/D converter, 16 digital input and 16 digital outputs. The data are recorded at a sample rate of one data per second.

Simultaneous measurements of air-Earth conduction current, conductivity of the atmosphere near ground, relative humidity and temperature were carried out continuously. Natural sources like cosmic rays, radioactive decay of radon gas in air, minerals with diameter < 1 nm, generate small ions in the atmosphere frequently. Those ions escaped by hydration and ion-cluster formation into charged clusters. These tiny air-ions last for nearly one minute. The air-ion concentration is measured through Gerdien condenser where air between the electrodes (two co-axial cylinders) is supplied by a fan. Air-ions with desired polarity and mobility are forced by electric field to supply their charge to the collecting electrode which gives the generating current $I = neQ$. Here, Q is the amount of air flow through the electrode (~0.0022–0.0026) m^3s^{-1} and e is 1.609×10^{-19} C. Current is measured by an electrometer[19]. It is represented as the concentration of air-ions cm^{-3}.

Polarizing voltage (U) and air flow determine the critical mobility μ_c of the measured ions, given by the following expression:

$$\mu_c = \frac{V_s(R_1^2 - R_2^2)\ln\dfrac{R_2}{R_1}}{2LU}$$

where, R_1, R_2, are the radii of the polarizing and collecting electrodes; L, the electrode length; and V_s, the air-flow speed.

The instrument is used under varying concentration (air conductivity) measurements and scanning of air-ions through mobility. The current is typically ~ 10^{-14} A, which is related to the change of temperature, relative humidity, wind and electromagnetic noise. Alternating ion polarities would require alternative supply of applied polarizing voltage that produces capacitive current spikes[19,20].

Kestrel® 4500 pocket Weather Tracker is useful to measure the wind direction (crosswind, headwind/tailwind), altitude, pressure trend, barometric pressure. It also measures wet bulb temperature, relative humidity (%), heat stress index, dew point, density altitude, wind chill, air, water, and snow temperature. Also, the current, average, and maximum air velocity can be measured. The temperature of the near Earth surface and the relative humidity at an interval of 15 min was measured. Well-sealed, precision thermistor is mounted externally and is thermally isolated for rapid response to measure temperature with ± 0.5 °C and 0.1 °C resolution. Operational range is -29.0 to 70.0 °C. Relative humidity is measured with ± 3.0% accuracy with high resolution. Operational range is 0 to 100%. Polymer capacitive humidity sensor is mounted in the thin-walled chamber external to the case for rapid and accurate response.

3 Observational results

The eclipse started at 05:28:48 hrs IST and continued till 07:30:54 hrs IST, which was visible (maximum about 91.1%) from Kolkata throughout the period. The local sunrise and sunset time were 05:04 and 18:21 hrs IST, respectively. The sky was clear in the beginning of the eclipse and it remained clear only for about 10 min from the start, then partly cloudy for about 40 min, then it became almost clear till the end of eclipse. There was no rainfall during eclipse period. The thundershower occurred around 09:00 hrs IST, which continued upto 10:20 hrs IST. The sun was visible after the end of eclipse till the sunset time at 18:21 hrs IST.

The path of the solar eclipse over India is depicted in Fig. 1 wherein various places of Indian subcontinent are shown from where the different phases were visible. At Kolkata, obscuration was 0.904. The minimum distance of Kolkata from the path of totality is about 300 km.

Figure 2 represents the temporal variation of vertical electric potential gradient on 22 July 2009 during the solar eclipse (continuous line) and its value averaged over other 5 days adjacent to the date of occurrence (dotted line) along with the standard deviations from the average value plotted as error bars. It is found that vertical potential gradient showed a lower value in pre-eclipse duration, i.e. between 00:00 and 04:00 hrs IST in comparison to five days average value. At the start of the solar eclipse, it started decreasing from about 05:30 hrs IST and reached minimum during the eclipse period (07:00 hrs IST). The minimum value was around 90 Vm^{-1}. The average value of the potential gradient of 5 adjacent days from the day of solar eclipse was around 145 Vm^{-1}. Again, a deviation has been noticed during post-eclipse period time 10:00 to 16:00 hrs IST with regard to the adjacent 5 day mean. It is significant that the continuous curve showed prominent variations from the average values during the period of eclipse since the variation was well beyond the standard deviation of the average trend. During the other period of the day of the eclipse, the continuous curve maintained the similar trends except some variations.

In the night time, the absence of solar radiation on the surface of the Earth occurred. Nocturnal variations of PG averaged over 90 fair weather days are available from the measurement during January 2006 - February 2009, which are depicted in Fig. 3.

During the period of the eclipse, ground level conductivity value increased and reached the maximum almost at the time of the greatest phase of the eclipse. It started changing from 2×10^{-13} $mho.m^{-1}$ in the beginning of eclipse to 3×10^{-13} $mho.m^{-1}$, at the time of greatest phase, shown by the continuous line curve (Fig. 4). Then, it started decreasing slowly and attained the average value ~ 1.75×10^{-13} $mho.m^{-1}$, shown by the dotted line curve. Error bars on the five days average curve showed the standard deviation of conductivity parameter. The variation influenced the vertical electric potential gradient values measured during the period.

Figures 5 and 6 show the variation in temperature and relative humidity on the day of eclipse during the period 02:00 and 12:00 hrs IST. The temperature was 28.4° C at the start of the eclipse which gradually reduced to 26.2° C at the greatest phase at 06:26:24 hrs IST. The relative humidity was 84.8% at

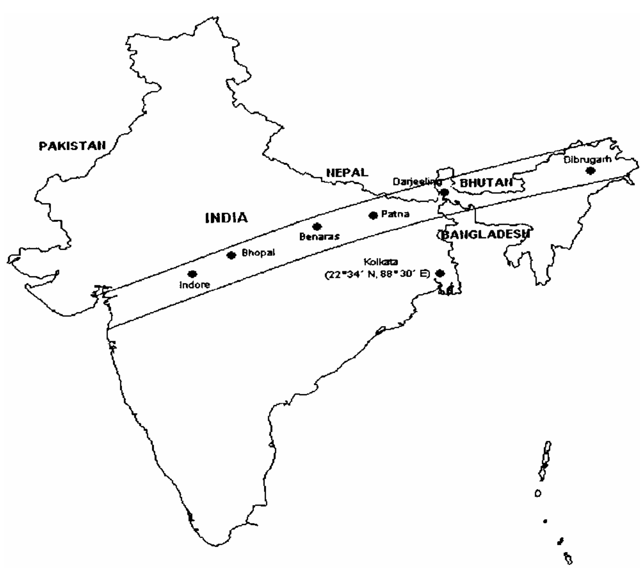

Fig. 1 — Path of solar eclipse of 22 July 2009 over Indian subcontinent

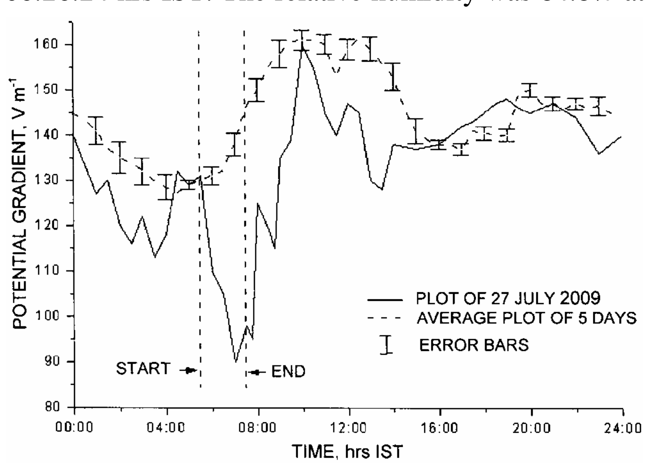

Fig. 2 — Temporal variation of atmospheric vertical electric potential gradient over Kolkata presented by the continuous line curve during solar eclipse on 22 July 2009 [dotted line indicates averaged value over adjacent five days; standard deviation from the average are shown by error bars]

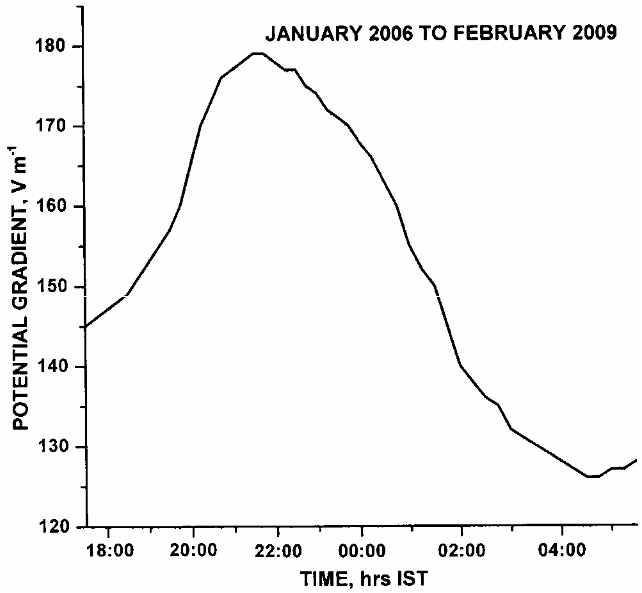

Fig. 3 — Night time variation of atmospheric vertical electric potential gradient averaged over 90 fair-weather days during January 2006 - February 2009

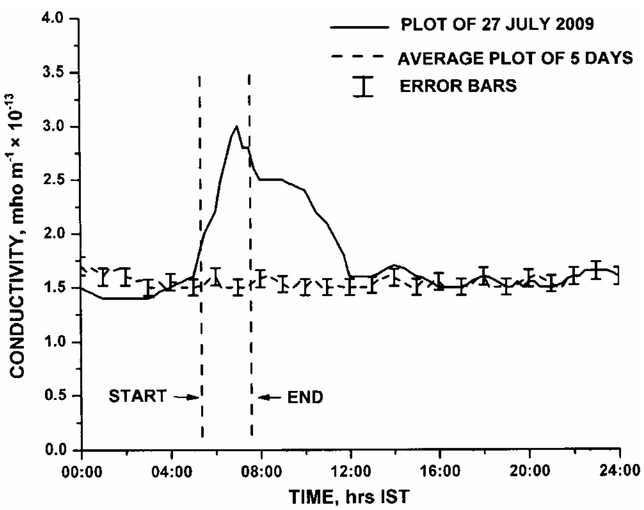

Fig. 4 — Temporal variation of ground level conductivity at Kolkata presented by the continuous line curve during solar eclipse on 22 July 2009 [dotted line curve represents averaged value over adjacent five days; standard deviation from the average are shown by error bars]

the start which increased to 87.2% at the greatest phase. The atmospheric vertical electric potential gradients as measured by other investigators during different eclipses are tabulated in Table 1.

4 Discussion

The observed variation of the electric field during the eclipse period may be interpreted in terms of separation of electric charges. Galactic cosmic rays produce electric charges in the atmosphere which get separated due to field of gravity of the Earth. Negative charges condense water vapour more rapidly than the positive ones and appear heavier than those of positive charges. During the process, relative humidity is enhanced and temperature (T) is lowered. The duration of solar eclipse is comparable with the characteristic time of the conductivity in the medium. Hence, during the discharge of the Earth-ionosphere capacitor, a displacement current $\varepsilon_0 \frac{\partial E}{\partial t}$ would appear[21]. It implies that $E \sim \sigma(j + \varepsilon_0 \frac{\partial E}{\partial t})$. In general, $E \sim \frac{1}{T}$. Thus, $E \sim (j - \frac{\varepsilon_0}{T^2}\frac{\partial T}{\partial t})$. Hence, the variation

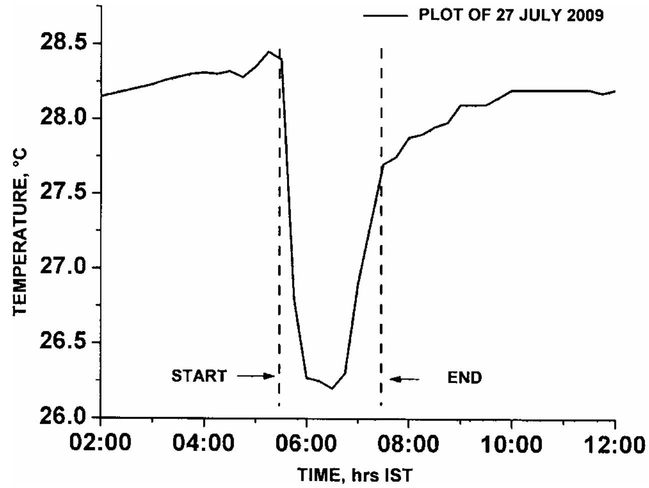

Fig. 5 — Temporal variation of temperature on the day of eclipse (22 July 2009) during 02:00 - 12:00 hrs IST

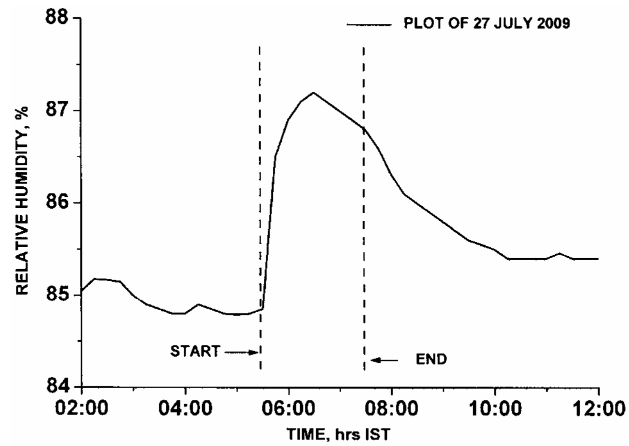

Fig. 6 — Temporal variation of relative humidity on the day of eclipse during 02:00 - 12:00 hrs IST

Table 1 — Works on potential gradient of different group

Researchers	Location of study	Eclipse date	Variation in potential gradient value during the eclipse, %	Nature of variation
Kamra & Varshneya (1967)[25]	Roorkee, India	20 May 1966	780	decrease
Retalis (1981)[26]	Santorini, Greece	29 April 1976	45	decrease
Manohar *et al.* (1995)[27]	Raichur, India	16 February 1980	60	decrease
Dhanorkar *et al.* (1989)[8]	Pune, India	18 March 1988	600	increase
De *et al.* (2010)[28]	Kolkata, India	01August 2008	78	increase
Babakhanov *et al.* (2013)[29]	Novosibirsk, Russia	01 August 2008	165	decrease
De *et al.* (Current work)	Kolkata, India	22 July 2009	38	decrease

in E is restricted to the maximum decrease in temperature. It corresponds to the phase of the total eclipse. During the start of the eclipse, the present records showed the variation of E due to displacement current $\varepsilon_0 \frac{\partial E}{\partial t}$. The distortion of the field as seen from the curve of Fig. 2 is due to the simultaneous existence of the variation of conduction and displacement currents.

The vertical electric potential gradient at the surface of the Earth starts decreasing as the eclipse begins and reaches its minimum value at its time of greatest phase. The vertical potential gradient decreases in the absence of solar radiation during eclipse because of the absence of ionization. But as soon as the eclipse seizes, solar radiations enhance the causality background quickly showing the signature of approaching the ambient value. The potential gradient reduced slightly during the next about fifteen minutes and then grows sharply to reach its ambient value at about 10:00 hrs IST. But this come back situation can not be achieved quickly. The total process is highly quasi-static, for which the relaxation time for the process takes longer value. In the absence of solar radiation during eclipse, ionization and recombination processes get perturbed near the ground and an overall instability in the space charge distribution is attained. Atmospheric temperature is dropped by 2.2ºC and relative humidity increased by 2.4% during the period. These factors grow the instability more[15]. From the time of the greatest phase, the charge distribution in the perturbed state introduces nonlinearity in the medium that enhances the random migration of ions in the process of transportation, thereby, increasing the conductivity (Fig. 4), which is responsible for the observed fall of potential gradient.

July is the most effective month of monsoon season in Kolkata. At the time of solar eclipse on 22 July 2009, the fall of potential gradient was much steeper as shown in Fig. 2. During monsoon season, the location of the Asia-Australia thunderstorm centre is nearer to Kolkata than the other thunderstorm regions. So, the influence of this centre affects more in the value of the potential gradient over Kolkata. Uneven distribution of the thunderstorm regions over the globe influences the value of potential gradient which produces bite-out zones in the curve during pre-eclipse (00:00 – 04:00 hrs IST) and post-eclipse period (10:00 – 16:00 hrs IST).

The absence of solar radiation on the Earth's surface, other than solar eclipse situation, occurs at night. Also, there are some events when the solar radiation is much reduced. This may be associated with major volcanic eruptions releasing enormous quantities of opaque ash in the atmosphere. One s uch event occurred in Iceland in the late 1700s and caused a major cold spell in North America. The variations of PG during solar eclipse and nocturnal variations of PG are completely different as seen from Fig. 3.

Eclipse observation aims at the search for the distribution of sources of ionizing radiations (UV and X-radiations) from the Sun where the ionosphere acts as the detector. Also, it supports the investigations of the production and loss processes in the ionospheric medium. During any eclipse, ionospheric transport processes initiated by the changes of electric field, temperature and the other related changes in the neutral atmosphere can be studied. There is very often enhancement of F_2 layer electron concentration in the eclipse period which initiates thermal contraction causing a downward movement of the topside ionosphere as observed through the Alouette I satellite[22].

The eclipse phenomena in the ionosphere are interpreted through the continuity equation for the electron concentration $N(h,t)$, a function of height and time. The equation may be written as:

$$\frac{\partial N(h,t)}{\partial t} = E(h,t)\,q - L(N) - \nabla\cdot(N\vec{v}) \qquad \ldots(1)$$

Here, q, is the rate of production of ionization in the absence of eclipse; and *L(N),* the rate of loss. The effect of the drift velocity of the ionization caused by diffusion, electric fields and neutral air winds is represented by $-\nabla\cdot(N\vec{v})$. The eclipse function *E(h,t)* is the non-obscured geometrical fraction of the Sun during the eclipse.

Also, Kolkata is a densely populated and polluted city. So, Kolkata falls under small-scale fair weather condition where fluctuation in electric field is perturbed by ionization and different aerosol contents which are produced locally. These are sufficient to influence the PG by way of reducing its magnitude. The situation may be studied by substituting $\frac{\partial N}{\partial t}$ from the equation of continuity[23]:

$$\frac{\partial N}{\partial t} = (\nu_i - \nu_\alpha)N - \alpha N^2 \qquad \ldots(2)$$

where, ν_i, is the ionization frequency due to electron impact on neutrals; ν_a, the electron-neutral molecule attachment frequency; and *N*, the electron number density. The ν_i may be given by:

$$\nu_i(T_e) = n\left(\frac{8kT_e}{\pi m}\right)^{1/2}\left(\pi a_0^2\right)\exp\left(-\frac{Q_i}{kT_e}\right) \qquad \ldots(3)$$

where, *n*, is the pollutant particle content; Q_i, the ionization energy of the medium; *T*e, the electron temperature; and a_0, the Bohr radius. The momentum transport equation in this context is given as:

$$\frac{\partial\vec{v}}{\partial t} + (\vec{v}.\nabla)\vec{v} = \frac{e}{m}\vec{E}(t) - \upsilon_e(T_e)\vec{v} - \frac{e}{m}(\vec{v}\times\vec{H}) - \frac{\nabla p}{m} + \frac{\eta}{m}\nabla^2\vec{v} \qquad \ldots(4)$$

The expression of $\vec{v}$ is obtained from the above equation (Eq. 4) as:

$$\vec{v} = \exp(-A)\frac{e}{m}\int_0^t \vec{E}(t')\exp\{A + \int_t^{t'} M dt''\}dt' \qquad \ldots(5)$$

where,

$$A = \int_0^t \{(\vec{v}.\nabla) + \nu_e(T_e) + \frac{\eta k^2}{m} + \frac{C}{m}\}dt' \qquad \ldots(6)$$

$$M = \begin{pmatrix} 0 & H_z & -H_y \\ -H_z & 0 & H_x \\ H_y & -H_x & 0 \end{pmatrix}$$ and C is the Reynold's number.

Substitution of Eqs (2), (3) and (5) in Eq. (1) yields:

$$\left[n\left(\frac{8kT_e}{\pi m}\right)^{1/2}\left(\pi a_0^2\right)\exp\left(-\frac{Q_i}{kT_e}\right) - \nu_\alpha\right]$$
$$N - \alpha N^2 = E(h,t)\,q - L(N) -$$
$$-\nabla\cdot\left[N\exp(-A)\frac{e}{m}\int_0^t \vec{E}(t')\exp\{A + \int_t^{t'} M dt''\}dt'\right] \qquad \ldots(7)$$

Due to the presence of large number of pollutant particles (n) in air near the surface of the Earth, the collision rate between those particles is increased producing large number of ions which are accumulated near about 2 m level above from the ground[7]. This increases the atmospheric conductivity, which may be considered to be the other possible reason for the low value of potential gradient over Kolkata during the eclipse. Thus, the impact of solar eclipse together with the number of pollutant particle-content on the reduction of PG may be attributed from Eq. (7).

The increase of ionization at the ground level may also be explained in terms of the atmosphere becoming stably stratified before and during the greatest phase of the eclipse. Radioactive emissions from the soil are, therefore, least well-mixed and enhance the ionization rate near the surface[24]. Thereby, increasing the surface conductivity and decreasing the potential gradient.

5 Conclusions

The effects of solar eclipse upon the meteorological parameters in fair weather and cloudy conditions result from the sudden change in isolation introducing cooling in the surface layers of the atmosphere. From the ground surface to upwards, there is clamminess in atmospheric turbulence. At the start of the eclipse, changes in PG were slow, immediately after it grew rapidly. About 38% decrease in PG value was obtained during the eclipse on 22 July 2009. The observed variations are due to the generation of electric charges in the near surface of the Earth. The process is connected with the temperature change, changes of wind flow and thermal flux with the decrease of solar radiation, enhancing induction of internal pressure wave, i.e. gravity waves that can propagate on the surface of the Earth. Also, the presence of large number of pollutant particles is another reason for the increase in atmospheric conductivity, reducing the PG. More investigations are required during solar eclipse to know the exact nature of variation of PG and the reasons behind it.

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References

1 Bering III E A, Few A A & Benbrook J R, The global electric circuit, *Phys Today (USA),* 51 (1998) 24.

2 Rycroft M J & Price C, The global atmospheric electric circuit, solar activity and climatic change, *J Atmos Sol-Terr Phys (UK),* 62 (2000) 1563.

3 Rycroft M J & Cho M, Modelling electric and magnetic fields due to thunderclouds and lightning from cloud top to the ionosphere, *J Atmos Sol-Terr Phys (UK),* 60 (1998) 889.

4 Pant P & Mahra H S, Effect of solar eclipses on VLF propagation, *Indian J Radio Space Phys*, 23 (1994) 399.

5 Lele P D, Jani K G & Patel A P, Field strength measurements A-3 method (Oblique incidence) at Ahmedabad during total solar eclipse in October 1995, *Kodaikanal Obs Bull (India),* 13 (1997) 213.

6 Clilverd M A, Rodger C J, Thomson N R, Lichtenberger J, Steinbach P, Carinon P & Angling M J, Total solar eclipse effect on VLF signals: Observations and modelling, *Radio Sci (USA),* 36 (2001) 773.

7 Kamra A K, Teotia J K S & Sathe A B, Measurements of electric field and vertical distribution of space charge close to the ground during the solar eclipse of February 16, 1980, *Geophys Res Lett (USA),* 87 (1982) 2057.

8 Dhanorkar S, Deshpande C G & Kamra A K, Atmospheric electricity measurements at Pune during the solar eclipse of 18th March, 1988, *J Atmos Sol-Terr Phys (UK),* 51 (1989) 1031.

9 Meyerott R E, Reagan J B & Evans J E, Tropospheric aerosol perturbations due to volcanism as measured by electrical conductivity of ocean air, *J Geophys Res (USA),* 90 (1985) 5925.

10 Morita Y & Ishikawa H, *Electrical processes in atmospheres,* Dolezalek H and Reiter R, Eds (Steinkopff, Darmstadt, West Germany), 1977, pp 126-130.

11 Hays P B & Roble R G, A quasi-static model of global atmospheric electricity, Pt 1: The lower atmosphere, *J Geophys Res (USA),* 84 (1979) 3291.

12 Tzur I & Roble R G, The interaction of a dipolar thunderstorm with its global electrical environment, *J Geophys Res (USA),* 90 (1985) 5989.

13 Meyerott R E, Reagan J B & Evans J E, *Weather and climate responses to solar variations,* McCormac B M, Ed (Colorado Associated University Press, Boulder), 1983, pp 450-460.

14 Harrison R G & Aplin K L, Mid-nineteenth century smoke concentrations near London, *Atmos Environ (UK)*, 36 (2002) 4037.

15 Harrison R G & Aplin K L, Nineteenth century Parisian smoke variations inferred from Eiffel Tower atmospheric electrical observations, *Atmos Environ (UK),* 37 (2003) 5319.

16 Anbar O M Y, *Solar eclipse effects on the air layer near the surface over Makkah region*, Department of Meterology (Environment and Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Arabia), http://www.kau.edu.sa/meteorology/files/met/229erid.pdf (2006).

17 Founda D, Melas D, Lykoudis S, Lisaridis I, Gerasopoulos E, Kouvarakis G, Petrakis M & Zerefos C, The effect of the total solar eclipse of 29 March 2006 on meteorological variables in Greece, *Atmos Chem Phys (Germany),* 7 (2007) 5543.

18 De S S, De B K, Adhikari S K, Sarkar S K, Bera R., Guha A & Mandal P K, A report on some specific features of the atmospheric electric potential gradient in Kolkata, *Indian J Phys,* 80 (2006) 167.

19 Kolarz P, Miljkovic B & Curguz Z, Air ion counter and mobility spectrometer, *Nucl Instrum Methods Phys Res B (Netherlands)*, 279 (2012) 219.

20 Vojtek T, Steinbauer M, Fiala P & Bartusek K, *Gerdien condenser measuring and numerical modeling of air ion fields*, International Conference on Applied Electronics (IEEE, New York), 2006, pp 225-228.

21 Kuznetsov V V, The atmospheric electric field during the total solar eclipse of 2008, *Dokl Earth Sci (Russia),* 435 (2010) 1471.

22 King J W, Legg A J & Reed K C, Observations of the topside ionosphere during three solar eclipses, *J Atmos Terr Phys (UK)*, 29 (1967) 1365.

23 De S S, Adhikari S K, De M, Bandyopadhyay B, Guha A, Paul S & De B K, A study on heating of the lower ionosphere during lightning, *Indian J Radio Space Phys,* 37 (2008) 109.

24 Aplin K L & Harrison R G, Meteorological effects of the eclipse of 11th August 1999 in cloudy and clear conditions, *Proc R Soc London (UK),* 459 (2003) 353.

25 Kamra A K & Varshneya N C, The effect of a solar eclipse on atmospheric potential gradients, *J Atmos Terr Phys (UK)*, 29 (1967) 327.

26 Retalis D A, Atmospheric electrical potential gradient measurements during the annular solar eclipse of 29 April 1976, *J Atmos Terr Phys (UK)*, 43 (1981) 999.

27 Manohar G K, Kandalgaonkar S S & Kulkarni M K, Impact of a total solar eclipse on surface atmospheric electricity, *J Geophys Res (USA),* 100 (1995) 20805.

28 De S S, De B K, Bandyopadhyay B, Sarkar B K, Paul S, Haldar D K, Barui S, Datta A, Paul S S & Paul N, The effects of solar eclipse of August 1, 2008 on Earth's atmospheric parameters, *Pure Appl Geophys (Switzerland)*, 167 (2010), 1273.

29 Babakhanov I Y, Belinskaya A Y, Bizin M A, Grekhov O M, Khomutov S Y, Kuznetsov V V & Pavlov A F, The geophysical disturbances during the total solar eclipse of 1 August 2008 in Novosibirsk, Russia, *J Atmos Sol-Terr Phys (UK)*, 92 (2013) 1.