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# The Effects of Solar Eclipse of August 1, 2008 on Earth's Atmospheric Parameters

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*Abstract*—Several experiments were undertaken at Kolkata (latitude: 22°34′N, longitude: 88°30′E) on the solar eclipse day of August 1, 2008 to observe the effects of the solar eclipse on Fair Weather Field (FWF) and VLF amplitude and phase. The experimental results presented here show significant deviations of the observed parameters from their normal values, as they are determined by the average of the records obtained on 5 days adjacent to the day of the solar eclipse.

**Key words:** Solar eclipse, lower ionospheric modification, atmospheric electricity parameters, non-linear interaction.

## 1. *Introduction*

The quasi-static electric fields near the Earth's surface, i.e., Fair Weather Field (FWF), are governed by global thunderstorm and lightning activities (Bering *et al.*, 1998; Rycroft and Price, 2000). This put the Earth-ionosphere waveguide into resonance producing characteristic spectra in ELF and VLF ranges (Nickolaenko, 1997; Rycroft and Cho, 1998). The atmospheric electricity parameters are directly related to the global thunderstorm activities and the solar radiation. There are several papers that report changes in the Earth's near-surface vertical electric potential gradient during solar eclipses (Kamra and Varshneya, 1967; Dolezalek, 1972; Kamra *et al.*, 1982; Dhanorkar *et al.*, 1989), while others report the disturbances in the ionosphere during solar eclipses in terms of changes in the phase of VLF transmissions (Kaufmann and Schaal, 1968; Hoy, 1969; Ricardo *et al.*, 1970; Pant and Mahra, 1980; Pant and Mahra, 1994; Lele *et al.*, 1997; Clilverd *et al.*, 2001). These changes are considered to be path- and frequency-dependent (Crary and Schneible, 1965; Kaufmann and Schaal, 1968; Reeve and Rycroft, 1972; Mahra, 1976; Pant and Mahra, 1980; Sengupta *et al.*, 1980; Lynn, 1981; Mendes da Costa *et al.*, 1995). The spectral behaviour of the effects for constant path has yet to be explored. For this purpose, one may take advantage of sferics over a common path. Sferics are electromagnetic pulses generated by lightning strokes, which propagate in the atmospheric waveguide between the Earth's surface and the lower ionosphere. It can reach several thousand kilometers from its source (Williams and Heckman, 1993), therefore thunderstorm activities at long distances can be monitored by studying the intensity of the sferics.

The simultaneous effects of the solar eclipse on the vertical potential gradient, the amplitude of VLF sferics and the amplitude and the phase of VLF sub-ionospheric transmissions, monitored from one single station, are reported in this paper and this is attempted, to the extent we know, for the first time. Change in ionospheric heights and ionization jointly affect the amplitude of sferics, as well as the amplitude and the phase of the transmitted signal. The question raised is whether or not these changes are coupled with the near-surface potential gradient during solar eclipses. The answer was sought out here by analyzing simultaneous observations from different experiments carried out over Kolkata (latitude: 22°34′N, longitude: 88°30′E) during the solar eclipse which occurred on August 1, 2008.

The eclipse was partially visible over Kolkata (maximum obscuration about 55%) from 16:18 to

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18:05 local time, while local sunrise and sunset are determined at 05:10 and 18:16, respectively. The temperature dropped gradually from 32.8°C at the beginning to 29°C at the end of the eclipse. The relative humidity increased from 89 to 95.5%. The sky remained clear for the first 70 min but became cloudy thereafter, accompanied by weak rainfall toward the end of the eclipse. The sun was visible after the solar eclipse occurrence until sunset at 18:16.

## 2. Experimental Arrangement

The vertical electric field is measured with an ac field-mill. The output is recorded by a 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 output. The data are recorded at a sample rate of one record per second.

Regular records of sferics (<30 kHz) at frequencies 1, 3, 5, 7, 9, and 12 kHz are available for the purposes of the current paper. Continuous recording of a subionospheric VLF signal of 25 kHz frequency transmitted from the Russian Navy's communication centre at Arkhangelsk (latitude: 64°22′N; longitude: 41°35′E) are also being carried out from Kolkata. The great circle distance of this center is about 5761 km from Kolkata.

The experimental set-up for VLF recording consists of an inverted L-type antenna made from 8 SWG copper wire of 120 m in length to receive vertically polarized atmospherics in the VLF bands from near and far sources. It is installed horizontally at a height of about 30 m above the ground. The signal processor is tuned to the desired frequencies. The overall Q-factor of the tuning circuit is around 300. The signals from the tuning stage are fed to a log amplifier. The data are recorded by digital data acquisition system card.

## 3. Data Analysis

In Fig. 1, the geometry of the propagation path of the 25 kHz signal from Russia to Kolkata is shown by the curve AB. The eclipse was partial covering 95% at the Russian transmitting station to 55% at the Kolkata receiving station. The path of totality of eclipse is shown by the curve path CD. The eclipse covering 60% obscuration is located within EF.

Figure 2 depicts the temporal variation of the vertical potential gradient recorded on August 1, 2008 (continuous line) together with its normal trend obtained from the average of five days adjacent to the solar eclipse day (dotted line). Error bars denote standard deviations. It is found that the vertical potential gradient starts to increase from about 13:00 LT (prior to the occurrence of the solar eclipse over Kolkata) and reaches maximum during the eclipse at 17:15 LT. The peak value is around 490 $Vm^{-1}$. Then it progressively decreases until local midnight registering values below the normal ones. The corresponding maximum value of the normal variation is around 275 $Vm^{-1}$. It is important to say that the observed increase is well beyond the standard deviation. During the balance of the eclipse day, the observed variation lies within the standard deviation range and reflects similar than normal trends.


Figure 1
The propagation path of 25 kHz VLF sub-ionospheric signal from Russia to Kolkata has been marked by the line AB. CD is the path of totality. The line AB lies within the partial eclipse zone, i.e., 95% at Russia and 55% at Kolkata. The line EF illustrates the boundary for 60% occurrence

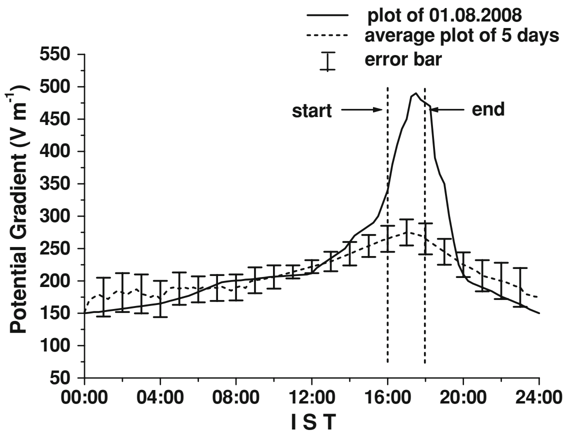


Figure 2
Temporal variations of atmospheric potential gradient are presented by the continuous line curve during solar eclipse on August 1, 2008. The dotted line indicates the averaged value over the adjacent 5 days. The standard deviations from the average are shown by *error bars*

Figure 3 presents the variation of the normalized amplitudes of sferics at 5 different frequencies (1, 3, 5, 9, 12 kHz) during the solar eclipse day. The amplitudes are significantly higher than their normal values during the solar eclipse.

In spite of the occurrence of the partial eclipse on August 1, 2008, significant deviation in the amplitude of the 25 kHz signal is also observed (Fig. 4). It has been enhanced by about 9.3 dB compared to the average of the five adjacent days. The enhancement is considerably greater than the standard deviation. The observations also generate evidence of noticeable phase retardation as is shown in Fig. 5 that exceeds 8 µs.

Table 1 further describes the enhancements in the observed parameters. Concerning the sferics, the maximum enhancement occurred at 3 kHz and the minimum, which is very low (only 1.01 dB) at 12 kHz. The frequency dependence of the sferics amplitude enhancement is depicted in Fig. 6.

## 4. Discussion

Observations of atmospheric vertical electric potential gradient, VLF sferics and subionospheric propagation during the solar eclipse on August 1, 2008 are presented here. Although the propagation path was away from the eclipse totality, the effects were highly remarkable. The trends of the observed effects somewhat resemble the results of earlier works regarding the vertical potential gradient and VLF transmissions (Dhanorkar *et al.*, 1989; Kaufman and Schaal, 1968; Pant and Mahra, 1994).

The amplitude of the sferics at the observed frequencies is also increased, while the maximum normalized amplitude decreases for higher frequencies. Reduction of the ionization and the conductivity of medium during the eclipse is probably responsible for such enhancements.

The D-layer of the ionosphere is mostly responsible for signal absorption. It is also most sensitive to the loss of sunlight during solar eclipse. This is because it is the lowermost of the layers and is quickly overwhelmed by the neutral air around it once the active ionizing source of radiation is removed. However, E-layer above the D-layer is more resilient to the loss of radiation and persists much longer, even for a while after the solar eclipse. Thus an eclipse hole is formed in D-layer.

The enhancement in radio field strength of Fig. 6 may be the consequences of several processes that take place during the solar eclipse: (i) The change in phase of 25 kHz signal ascertains that the reflection height increases due to the ionization reduction at the D-layer. At the new altitude, the reflection coefficient relatively increases. (ii) The absorption of radio waves in the region below the reflection zone decreases. (iii) The formation of shadow in the ionospheric D-region gives rise to a transfer of energy from first mode to the second mode. This is due to discontinuities raised around the shadow region. In this case, interference of first and second modes can amplify the amplitude of the resultant wave (Lynn, 1973). These points are further discussed below.

The waveguide formed between the lower ionosphere and Earth's surface is good for extremely low frequency (ELF) and very low frequency (VLF) propagation around the Earth. The conductivity parameter that determines the status of the ionospheric radio propagation is controlled by the solar conditions.

The attenuation factor ($\alpha_M$) is given by:

$$\alpha_M = -8.68\,(2\pi/\lambda)\,\mathrm{Im}\,(S_M)\ \mathrm{dB\ km^{-1}}, \qquad (1)$$

where $S_M = (1 - C_M^2)^{1/2}$, $C_M$ being the root of modal equation given by

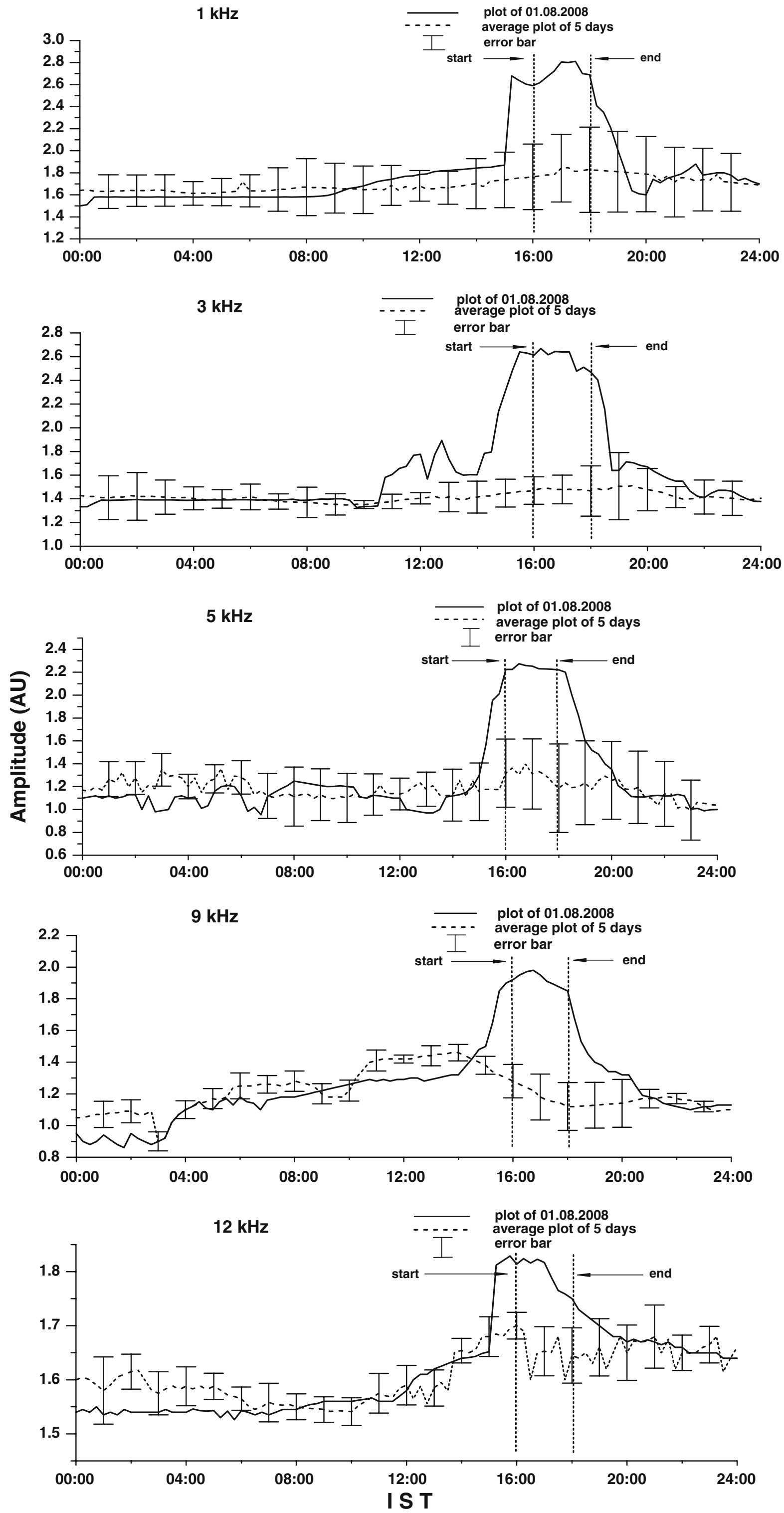


Figure 3
The graphs depict the changes of amplitude of sferics for five different frequencies during the eclipse period. The averaged values for the adjacent 5 days, along with their standard deviations from the average, are shown by *error bars*

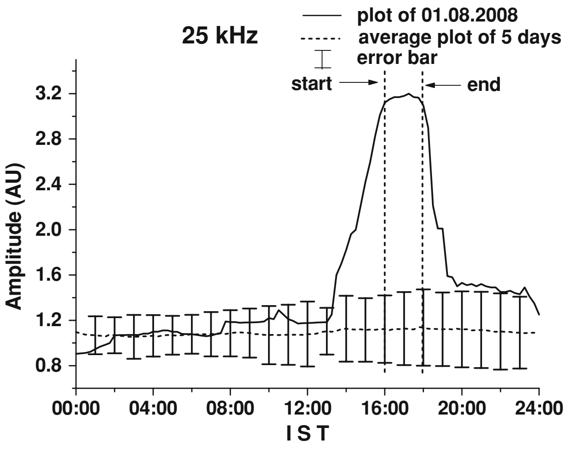


Figure 4
It represents the amplitude of 25 kHz signal during solar eclipse along with its averaged value for the adjacent five days. The standard deviations from the average value are given by *error bars*

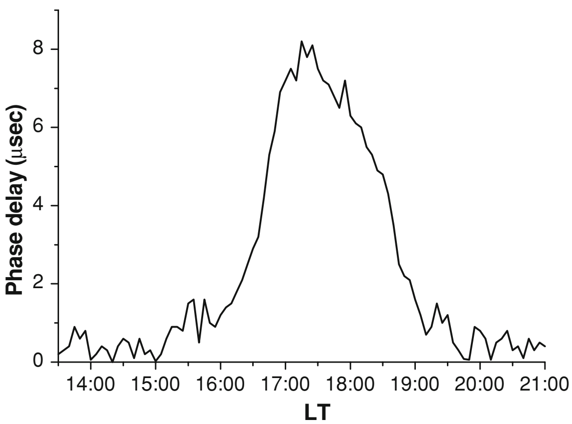


Figure 5
Phase retardation of 25 kHz signal in the propagation path as measured from Kolkata. It is found to be 8 μs

$$R_i \exp(i\,k_o h\,C_M) = \exp(-i2\pi M), \tag{2}$$

where $h$ = height of the boundary of the ionosphere.

The Fresnel's reflection coefficient $R_i$ of the lower boundary of the ionosphere is given by

$$R_i = \frac{\left(1-\frac{\omega_r}{\omega}\right)^2 C_M - \left\{\sqrt{\left(1-i\frac{\omega_r}{\omega}\right)^2 - S_M^2}\right\}^{\frac{1}{2}}}{\left(1-i\frac{\omega_r}{\omega}\right)^2 C_M + \left\{\sqrt{\left(1-i\frac{\omega_r}{\omega}\right)^2 - S_M^2}\right\}^{\frac{1}{2}}}, \tag{3}$$

where, $\omega_r = \frac{\omega_0^2}{v}$, $\omega_0$ is the angular plasma frequency and $v$ is the collision frequency.

The phase delay due to an increase in reflection height can be written as (Pant and Mahra, 1994):

$$\Delta\phi = 2\pi\left(\frac{d}{\lambda}\right)\left(\frac{1}{2a} + \frac{\lambda^2}{16h^3}\right)\Delta h, \tag{4}$$

where $d$ = distance between transmitter and receiver in km, $\lambda$ = wavelength in km, $a$ = radius of the earth, and $\Delta h$ = increase in reflection height.

If $\Delta t$ = time delay, then

$$\Delta\phi = 2\pi\left(\frac{\Delta t}{T}\right) \tag{5}$$

$$\therefore \frac{\Delta t}{T} = \left(\frac{d}{\lambda}\right)\left(\frac{1}{2a} + \frac{\lambda^2}{16h^3}\right)\Delta h. \tag{6}$$

Using the experimental value of $\Delta t$ as observed in the case of 25 kHz transmitted signal and taking $h = 72$ km, it is found that $\Delta h \cong 3.75$ km.

$\omega_r$ can be expressed as

$$\omega_r = 2.5 \times 10^5 \exp\left\{\beta\left(h - H'\right)\right\}, \tag{7}$$

(Wait and Spice, 1964; Thomson, 1993; Clilverd *et al.*, 2001).

In exponentially stratified ionospheric model, $H'$ is called the effective height of the lower ionosphere and this is the height at which the conductivity parameter $\omega_r$ becomes $2.5 \times 10^5$ rad sec$^{-1}$ and is

Table 1

*Enhancement Spectrum of ELF-VLF sferics and potential gradient*

| | Sferics Frequency (kHz) | | | | | Signal Frequency | Potential gradient |
|---|---|---|---|---|---|---|---|
| | 1 | 3 | 5 | 9 | 12 | 25 | |
| Amplitude peak value (arbitrary unit) | 2.8 | 2.65 | 2.3 | 1.95 | 1.83 | 3.2 | 490 Vm$^{-1}$ |
| Average value | 1.85 | 1.5 | 1.4 | 1.25 | 1.7 | 1.1 | 275 Vm$^{-1}$ |
| % Enhancement | 51.35 | 76.67 | 64.29 | 56 | 7.65 | 190.9 | 78.18 |
| Enhancement in dB | 3.58 | 4.96 | 4.30 | 3.86 | 1.01 | 9.27 | 5.01 |

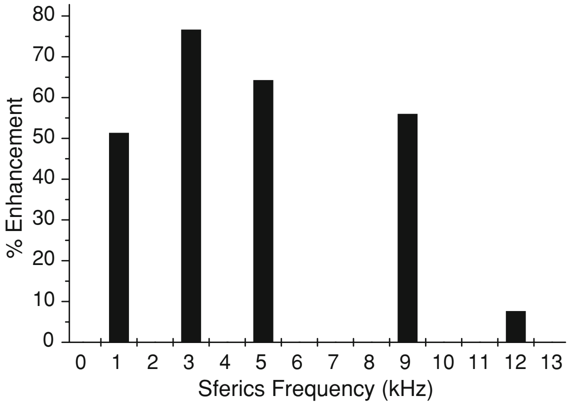


Figure 6
It shows the variation of enhancement in sferics amplitude with frequency

usually taken as the standard value for VLF propagation. $\beta$ is called the sharpness parameter governing the rate of variation of the conductivity parameter in the lower ionosphere (Wait and Spice, 1964).

For normal ionosphere, $\beta = 0.43\ \mathrm{km}^{-1}$ and $H' = 72$ km, since these are appropriate (Thomson, 1993). During solar eclipse, $\beta$ may be increased to $0.5\ \mathrm{km}^{-1}$ (Clilverd *et al.*, 2001) whereas $H'$ is increased to $72 + 3.75 = 75.75$ km. The purposes of different equations are stated in the text.

The parameters $\beta$ and $H'$ jointly affect the attenuation factor which is decreased during solar eclipse. In the shadow region, variation in electron density above 80 km is negligible (Verronen *et al.*, 2006). On the other hand, below 72 km, the decrease in electron density during eclipse is high. Consequently, the absorption of ELF and VLF radio waves decreases during eclipse showing enhancement in amplitude. Various combinations of $\beta$ and $H'$ reveal that the maximum enhancement that can occur is about 4 dB if the first mode is considered only (Clilverd *et al.*, 2001). The results for frequencies 1–9 kHz are in good agreement with the theoretical values, however, the comparatively low enhancement at 12 kHz sferics and very high enhancement at 25 kHz require the second mode into consideration. One has to look for the effect of modal conversion. On both sides of the eclipse track daylight is present. Due to discontinuity at the boundary of the eclipse track, modal conversion (Lynn, 1973) can occur at VLF. Sufficient energy may be transferred from the first mode to the second mode, making the two modes comparable in their amplitudes. The interference of two modes can result in an effect greater than 4 dB, as well as smaller than 4 dB depending upon the phase difference between the first and the second modes. This is the reason for frequency dependence enhancement in amplitude during solar eclipse. The lowest enhancement at 12 kHz is due to the fact that the phase difference between the first and the second modes is around $\pi$ radian. The two modes in the case of 25 kHz signal on arrival at the receiver are in the same phase to reinforce with each other.

The increase in vertical potential gradient suggests a decrease in ionization during the period of solar eclipse, which is in agreement with the result of an earlier work (Dhanorkar *et al.*, 1989). The enhancement in potential gradient during eclipse is significant as regards the fact that it provides a good coupling between the Earth's near-surface atmosphere and the lower ionosphere. The removal of electrons from the lower part of the ionosphere due to recombination mechanism during the solar eclipse may give rise to an increase in vertical potential gradient. Moreover, during the eclipse period, ions from the lower regions are carried out somewhat due to convection current and become neutralized to some extent by the recombination process, thereby reducing the conductivity of the medium. For this reason, potential gradient may be increased. Also during the period of this eclipse temperature dropped by nearly 4°C, as a result, there was sufficient wind which changed the distribution of charged particles in the air to some extent, which may be another contributory reason for the conductivity decrease. Thus, whether the increase of vertical electric potential gradient during the eclipse would be attributed to any of the above reasons or others—that is to be explored.

Based on the different observations during solar eclipse, the following conclusions can be made:

1. The enhancement in amplitude of sferics is frequency dependent, source distance remaining constant.
2. The enhancement in signal is higher than that in sferics.

3. There occur simultaneous increases in amplitude in sferics, signal amplitude and vertical electric potential gradient at the surface of the Earth.


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