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Study of amplitude spectrum of VLF sferics and vertical electric field at Kolkata

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From the measurements of atmospheric electric field and VLF sferics at Kolkata (22°34´ N, 88°30´ E), some correlation studies have been made. It is observed that the diurnal variation of vertical electric field averaged for 20 fair weather days maintains good connectivity with diurnal variation of VLF sferics activity. The variations are in contrast with the accepted unitary diurnal changes of vertical electric field and thunderstorm occurrence frequency curve with a maximum around 1900 hrs UT and a minimum around 0400 hrs UT. Some results in this context are presented in this paper.

Keywords: Vertical electric field, VLF sferics, Thunderstorm activities, Global electric circuit

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1 Introduction

The relationship between atmospheric electric field and global thunderstorm activity has been studied by many workers. In many observations[1-3], the diurnal variation of electric field matches closely with the Carnegie curve, which is the generally accepted global unitary variation of electric field on earth with a maximum around 1900 hrs UT and a minimum around 0400 hrs UT. Most of these observations were made at high latitude stations at open oceans or at Polar Regions to avoid the effects of local generators, which may significantly alter the variation of the observed parameter. But some recent studies[4] in tropical region (± 5°) show large changes in the diurnal pattern of the electric field, in which the 40-day average field curve shows a maximum at 1000 hrs UT and a minimum at 0000 hrs UT with a small secondary peak at 1900 hrs UT.

The results of some more recent observations[5] at the Indian Station Maitri, in Antarctica (70°45´52´´ S, 11°44´3´´ E) are also in contrast to the generally observed unitary diurnal variation, where 20 fair-weather-day field curve shows a maximum at 1300 hrs UT, a secondary maximum at 1900 hrs UT and a minimum at 0100 hrs UT. Since Antarctica is a region free of man-made pollution, the measurements at Maitri are quite significant in understanding the relationship between global thunderstorm activity and atmospheric electricity parameters.

Our measurements at Kolkata also indicate a departure from the general picture. We are regularly measuring the atmospheric vertical electric field and VLF sferics (< 30 kHz) at frequencies 1, 3, 5, 7, 9, and 12 kHz. 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 away from its source[6]. So thunderstorm activities at large distances can be monitored by studying the intensity of power of the sferics. In this paper, we have compared the diurnal variation of vertical electric field with the diurnal variation of amplitude spectrum of intensity of the sferics. The possible reasons of deviation of these results from the general one are also discussed briefly.

2 Experimental set-up

Observations were taken from the roof top at a height of 26 m from the ground. The vertical electric field is measured with an ac field-mill, which has an aluminium rotor plate 12 cm in diameter. The output from the amplifier is recorded through computer sound card at a sample rate of 44,100 per second. The rms value of the recorded signal is used to find the required electric field from the calibration chart. The field-mill has been calibrated in a vertical field set-up between two large aluminium cover plates, electrically isolated at a given potential, through a fixed distance between them. The outer shield of the field-mill is grounded properly to ensure protection from possible field distortions. The sensitivity of the field-mill is (0.33 ± 0.03) Vm^{-1}.

For the observation of power spectrum of VLF sferics at 1, 3, 5, 7, 9, and 12 kHz, an 8 SWG straight copper wire of 120 m in horizontal length is used as the antenna. The antenna, which is installed 30 m above the ground, is sensitive to the vertical electric field component of the electromagnetic noise. The signal processors are tuned to the desired frequencies. The overall Q-factor of the tuning circuit is around 300. The signal from the tuning stage is rectified and fed to a log amplifier. The time constant of the output from the signal processor is 10 s. The data are recorded simultaneously at six channels using a 12-bit ADC at a sample rate of 5 per second.

For a period of previous eight months (January 2004 to August 2004), the outputs from these two instruments have been found to be steady and consistent.

3 Observational results

We have analyzed the vertical electric field data statistically following Deshpande and Kamra[5] and Williams and Heckman[6]. For the analysis, we have taken data of 20 fair weather days. We define a fair weather day when there is no precipitation at the site, high clouds are less than 3 octas throughout the day and wind speed is less than 10 ms^{-1}. Quarter hour interval values from records of vertical electric field for 20 fair weather days have been used to obtain a histogram (Fig. 1). Histogram of frequency distribution of daily mean values (Fig. 2) and that of daily amplitude ratio (maximum–minimum/mean) (Fig. 3) have also been plotted. Our results also show considerable deviations from those of the Carnegie curve. The two primary maxima at our results are at 0500 and 0745 hrs UT, with a secondary maximum at 1415 hrs UT and a minimum at 0000 hrs UT (Fig. 1), respectively, instead of a single maximum at 1800-1900 hrs UT and a minimum at 0300-0400 hrs UT of Carnegie curve. The mean value in our results (Fig. 1) is 179.3 Vm^{-1} compared to 132 Vm^{-1} in the Carnegie result. The mean amplitude ratio in our result (Fig. 3) is 0.89 with some values as large as 2.06, whereas the mean amplitude ratio in the Carnegie results is 0.47, with the observed value not exceeding beyond 1.0.

In Fig. 4, we compared the amplitude spectrum of VLF sferics from lightning activities at six different frequencies. Five minute averaging has been used to nullify any transient effects. The diurnal variation at all frequencies is almost the same, which is in phase

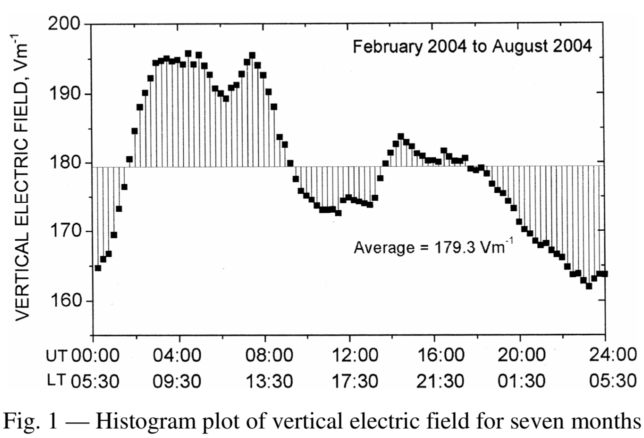

Fig. 1 — Histogram plot of vertical electric field for seven months

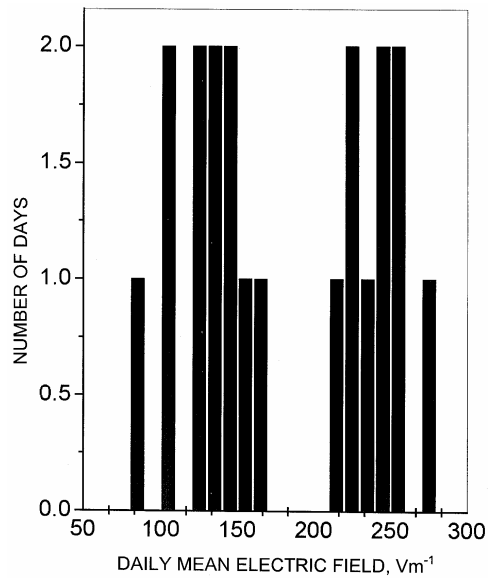

Fig. 2 — Frequency distribution of mean value versus number of days plot for the vertical electric field

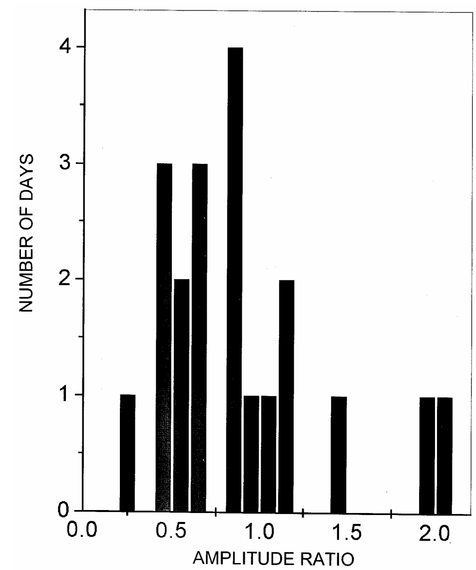

Fig. 3 — Histogram of daily amplitude ratio versus number of days plot for the vertical electric field

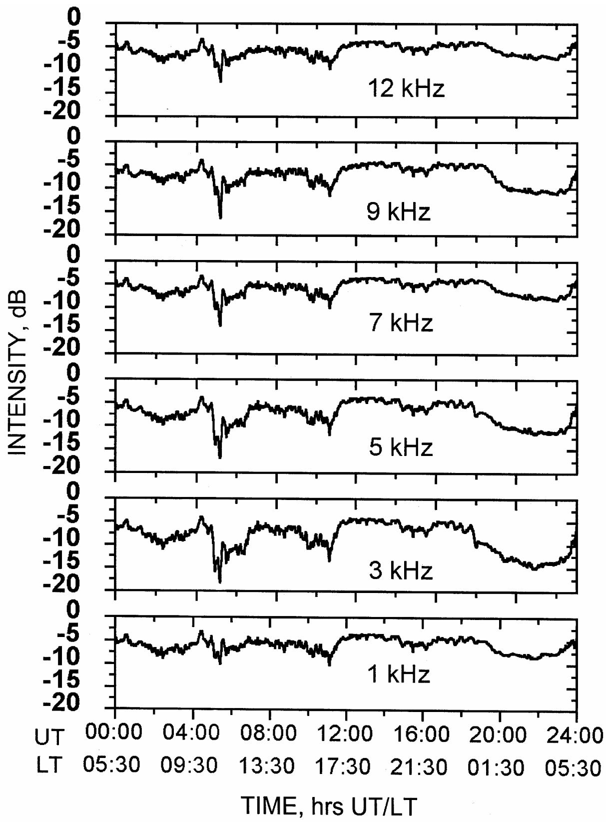

Fig. 4 — Diurnal variation of VLF sferics intensity at different frequencies observed at Kolkata

with the well-known sunrise effect that begins to start just before 0000 hrs UT (0530 hrs LT). At sunrise, D-region of the ionosphere starts to form. Before the complete formation, this layer behaves as an absorbing layer and absorption goes on increasing as electron density increases. After the D-region is completed, the VLF electromagnetic waves cannot enter the D-region, but is reflected. As a result, the level starts to increase. It can be seen from Fig. 4 that the signal level starts to decrease from 0000 hrs UT (0530 hrs LT) and it continues up to 0200 hrs UT (0730 hrs LT). After 0200 hrs UT (0730 hrs LT), the signal level again increases as all the VLF electromagnetic waves are reflected from the completed D-region. During sunset, the sequence of events is just the opposite. The decomposition of D-region begins due to gradual decrease in solar radiation. As a result, VLF signals reflected from the E-regions of the ionosphere can reach the receiving site, increasing the signal level. It can be observed from Fig. 4 that at all frequencies, the signal level begins to increase from 1100 hrs UT (1630 hrs LT), which is known as sunset effect.

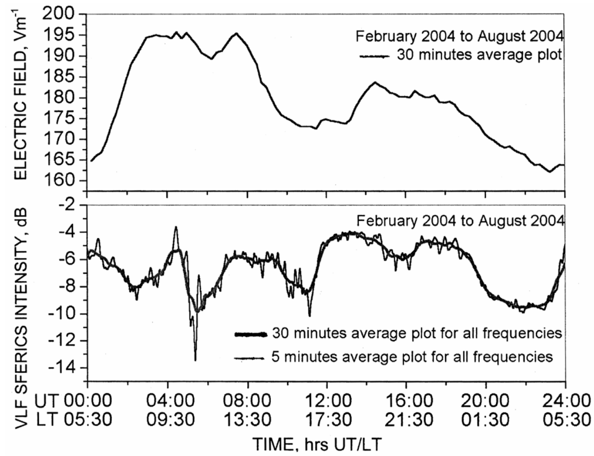

Fig. 5 — Comparison of diurnal variation of the vertical electric field with that of the average sferics intensity for all frequencies

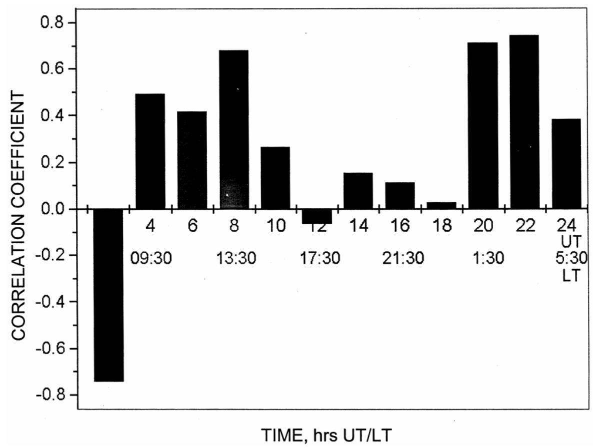

Fig. 6 — Correlation study of VLF sferics and vertical electric field

It is seen that nighttime fall of amplitude at 3 kHz is much larger compared to other frequencies. Also the sudden rise and fall in amplitude at all frequencies between 0400 and 0500 hrs UT respectively, indicate an increase and decrease in lightning activity at this period. Interestingly, this enhancement is also the largest at 3 kHz.

Figure 5 is shown for comparison of diurnal variation of vertical electric field and average VLF sferics intensity at Kolkata. The diurnal variation of sferics intensity averaged for 30 min at all frequencies matches closely with the diurnal variation of electric field averaged for 30 min except around the local sunrise time 0000 hrs UT (0530 hrs LT).

The result of correlation study of our data is depicted in Fig. 6. The data of two hours have been taken to find out each correlation coefficient *r*. From Fig. 6, it is clear that the values of *r* remain positive most of the time, except from 0530 to 0730 hrs LT and 1630 to 1830 hrs LT, which coincide with the sunrise and sunset periods respectively, at Kolkata.

4 Interpretations of the observed results

Since we are taking measurements from a ground station in tropical region (± 25°), the local pollution due to man-made activities is expected to influence the diurnal variation of vertical potential gradient due to global and regional thunderstorm activities. First of all, we took our measurements on such fair-weather periods when visibility was good, wind speed below 3 knots; nil precipitation on the site and high clouds less than 3 octa throughout the periods. Secondly, we made the average of 7-8 fair weather diurnal variations to get the standard variation. For averaging, we took the principle of quasistatic state. The electric processes, such as changes in the potential gradient are related with the relaxation time of the air, as $\tau = \varepsilon/\lambda$, where ε is the permittivity of air and λ its conductivity. Relaxation time is the average lifetime of a single ion-pair in the atmosphere. So, as far as treating variations with rather larger periods than the relaxation time, the atmosphere can be considered to be in a state of quasistatic equilibrium and the principle of quasistatic state is adopted.

Since actual values of the atmospheric relaxation time are from 5 to 40 min at Earth's surface, it is possible to apply the quasistatic principle to variations with periods of over an hour. Following this principle, Ogawa[7] eliminated the short period fluctuations due to local pollutants and aerosols in his measurements. First of all, he took overlapping mean values of 30 min, which covered the maximum relaxation time during the concerned period. Next, he continued taking overlapping means until the short-time fluctuations vanished. In his analysis, when 4 or 5 h was taken as the period, it was found that fluctuations were almost eliminated and the diurnal courses of elements were characterized. In the same manner, we eliminated the short period fluctuations on each diurnal variation, taking an overlapping averaging period of one hour, which is almost double the atmospheric relaxation time in fair weather. After obtaining each diurnal variation, we further averaged our data to get the seasonal and statistical results.

We obtained the average value of the vertical electric field at Kolkata to be 179.3 Vm^{-1}, which is higher than the values measured by others[1-3]. This is due to the reduction in the value of conductivity of the air over Kolkata, because of high concentration of airborne particles and aitken nuclei. Average concentration of airborne particles is given in Table 1, where SPM and RPM concentrations are higher than the normal values (based on the available data of three months during 2004 from West Bengal Pollution Control Board, India).

In our analysis, we averaged our data for 20 fair weather days, which greatly nullified the effects of local fluctuations due to man-made pollution. The distinguished sunrise effect observed in VLF sferics, which does not fit with electric field variation, clearly suggests that we are observing the effects of distant thunderstorm activities. If the increase of sferics intensity were due to increase of locally generated thunderstorms, it should have a clear signature on the vertical electric field variation, which is not present in the present case. The earlier works on power spectrum analysis of sferics from lightning[8] show that the diurnal variation of sferics rate observed at Roorkee (29°31´ N, 77°35´ E) and Pretoria (25°26´ S, 28°7´ E) exhibits similarity with the diurnal variation of vertical electric field at Kew and Potsdam[9]. This establishes the fact that by observing sferics intensity, the relationship between vertical electric field and thunderstorm activities can be rigorously studied.

The main feature in our observation is the marked variation from Carnegie's oceanic field curve, which is a statistical average of about 130 days spread over several years. Similar deviations have been reported by Kamra *et al.*[4], Deshpande and Kamra[5] and Anderson.[10] As pointed out by Takagi[11], columnar resistance, electrical conductivity, seasonal variation of ionospheric horizontal electric field and distance from active thunderstorm areas may also influence the universal vertical electric field on a regional scale. It must be remembered that the generally accepted thunderstorm occurrence frequency curve of Whipple

Table 1 — Distribution of some air borne particles available for three months of 2004 over Kolkata, India

Month	Air borne particle, $\mu g/m^3$			
	SPM	RPM	SO_2	NO_x
February 2004	366.5	191.5	17	89.88
March 2004	294.33	166	12.33	59
April 2004	236.25	98.5	6.75	49.5
Kolkata average for three months	299.02	152	12.02	66.12
Normal value	200	100	80	80

and Scarce[12] with a maximum around 1900 hrs UT and minimum around 0400 hrs UT is the average of three major continental thunderstorm activity centers, namely, Asia and Australia, Africa and Europe, and America (Orville and Henderson[13]). Moreover, each continental average is over 81 years.[4]

Recent satellite observations[6] show that there exists a great variability in the longitudinal distribution of thunderstorm activity centre. Observations also show seasonal variations. Figure 7 shows the global lightning distribution from January 1998 to February 2005 taken from LIS satellite (http://thunder.nsstc.nasa.gov). It confirms the prediction of Williams and Heckman.[6] One interesting feature of the LIS lightning distribution shows that the thunderstorm activity in the Himalayan region is more prominent than Asia-Australia region. The Asia-Australia has long been thought of as one of the largest thunderstorm producing regions, but recent record confirms that the thunderstorm from Himalayan regions is also strong enough to be one of the distinguished lightning centres all over the world.

We feel that short-time seasonal analysis extending not beyond a few months can reveal a lot about the relationship between the thunderstorm activity and atmospheric vertical electric field at a regional scale. The results of many short-term analyses can then be integrated to discuss the validity of Wilson's hypothesis for the classical picture of a global electric circuit and to study the dependence of vertical electric field on global thunderstorm activities.

5 Discussion

In order to find out the degree of correlation between VLF sferics intensity and vertical electric field, we have statistically analysed our data to find out the correlation coefficient between these two parameters. Positive and negative values of

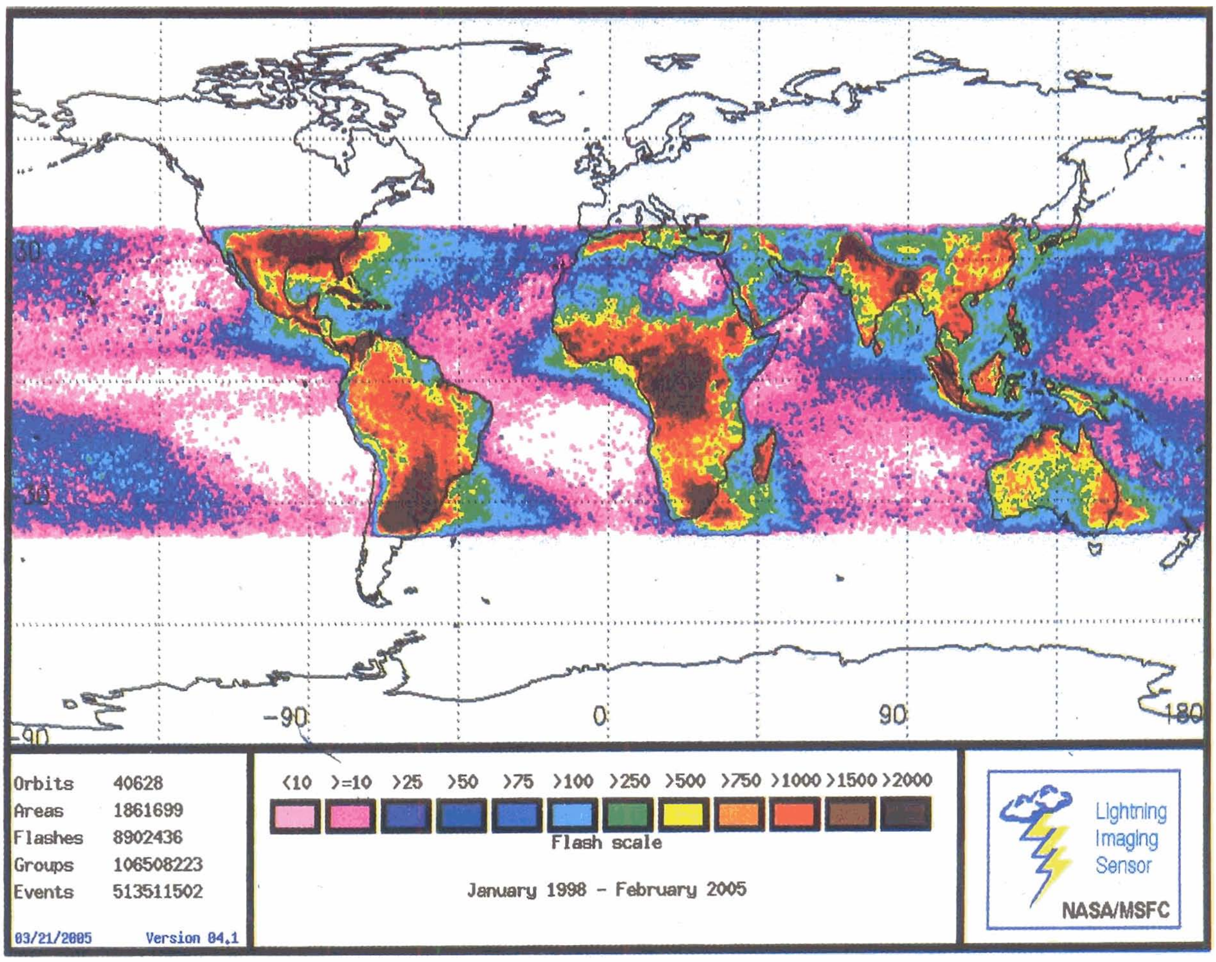

Fig. 7 — Global lightning distribution from January 1998 to February 2005 (LIS satellite data)

correlation coefficient signify positive and negative correlation between the two. The average correlation coefficient for the 24 hrs period is 0.264, which indicates a positive correlation between diurnal variation of sferics intensity and vertical electric field. It must be noted that this correlation value includes a negative value of correlation coefficient during sunrise and sunset. The statistical significance of correlation coefficients plotted in Fig. 6 is that the diurnal variation of vertical potential gradient is mostly in phase for most of the time with the diurnal variation of VLF sferics. A correlation coefficient value of '1' means 100% matching between two variations. But in our results, it never became '1'. The significance is that the thunderstorm activity, which also generates the VLF sferics apart from charging the lower level of the ionosphere, is not the only source contributing to the ionospheric potential. There may be other sources modulating the Global Electric Circuit, which we have discussed in detail earlier.

To explore regional thunderstorm activities and their effects on global electric circuit, the data of atmospheric conductivity, Maxwell current and Schumann resonance phenomenon would be helpful along with vertical electric field and VLF sferics. Simultaneous measurements of the above mentioned parameters at different latitudes would definitely help us to understand global as well as regional thunderstorm activities. It will also allow us to critically re-examine certain parameters of atmospheric electricity, which have long served as de facto standards of global electric circuit[14].

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