

# Diurnal and seasonal variations of space charge, electric field and cloud condensation nuclei in the lowest layer of the atmosphere

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## ABSTRACT

Diurnal and seasonal variations of space charge, vertical electric field and cloud condensation nuclei in the lowest layers of the atmosphere during winter, pre-monsoon, monsoon and post-monsoon seasons were studied.

The curve showing the diurnal variation of space charge exhibited a double oscillation corresponding to that of the electric field during winter and pre-monsoon seasons. Similar features are absent during monsoon and post-monsoon seasons. During pre-monsoon the semi-diurnal components of space charge and electric field are in phase while in winter the semi-diurnal component of space charge occurs 1 h ahead of the electric field component.

The mean values and diurnal ranges of both space charge and electric field are high during winter/pre-monsoon and are low during monsoon/post-monsoon seasons. The diurnal range of temperature and concentration of cloud condensation nuclei are positively correlated with space charge and the electric field.

The pre-sunrise minimum in the electric field is associated with the characteristics of the F-region of the ionosphere rather than with the ground sunrise time. The variations in the F<sub>2</sub> layer critical frequency ( $f_0F_2$ ) are reflected in the diurnal and ter-diurnal components of the surface electric field. The results of the present study support the hypothesis that the increase in the electrosphere potential could be the source of the atmospheric electric sunrise effect (Muir, 1975).

## 1. Introduction

The net space charge density in the atmosphere represents the difference between the total number of positive and negative ions in a unit volume of air. Statistical studies have indicated that the average concentrations of large ions of both signs in the atmosphere under natural conditions are nearly equal and the corresponding average space charge values are expected to be low (Bricard, 1965). However, measurements of space charge have shown pronounced differences in magnitude and sign depending upon the local atmospheric pollution levels resulting from human activity (Mühleisen, 1956). Any information on the time variations of the atmospheric electric field, space charge and aerosols in the surface boundary layer

under different meteorological conditions is of significant importance for the progress of research in atmospheric electricity, cloud physics and air pollution.

The diurnal and seasonal variations in space charge, vertical electric field and cloud condensation nuclei in the lowest layers of the atmosphere at Poona (geographical co-ordinates 18°32' N, 73°51' E; geomagnetic co-ordinates 9°25' N, 144°54' E) have been investigated in the present study. The possible association between the atmospheric electric field and the F<sub>2</sub> layer critical frequency ( $f_0F_2$ ), especially during the pre- and post-sunrise periods has also been examined in order to understand whether the ionosphere could be a source of atmospheric electric sunrise effect (Muir, 1975). Harmonic and power spectral

analyses of the electric field and space charge have been performed and the phase relationships of the atmospheric electrical components are studied. The results of the study are presented below.

## 2. Location of measurements

Poona is situated on the lee side of the Western Ghats at an elevation of 559 m above M.S.L. The observational site is located in the centre of an urban area with several small industries nearby.

## 3. Meteorological conditions

A brief summary of the weather at Poona is given below:

### (i) *Pre-monsoon (March–May)*

The weather is very hot with daytime maximum temperature reaching 40°C. Surface winds are mostly gusty and cumulonimbus development takes place during afternoon/evening hours. The dust content in the atmosphere is at a maximum during this season.

### (ii) *Monsoon (June–September)*

The air flow in the lower troposphere is westerly which brings a large influx of moist air from the Arabian Sea. Under the influence of large-scale convergence due to synoptic systems the region gets light continuous/intermittent rain from cumulus- and stratocumulus-type clouds. The atmosphere is relatively free from dust during this season.

### (iii) *Post-monsoon (October–November)*

The westerly flow weakens in the lower troposphere and the easterly flow sets in accompanied by a rapid fall in the minimum temperature by the end of October.

### (iv) *Winter (November–February)*

Fair weather conditions exist with clear skies. The relative humidity is very low. Surface winds are light and least gusty. The daily surface minimum temperatures go down to 3 or 4°C. There is incursion of dry polar continental air in the wake of low-pressure systems (western disturbances) moving across the far northwestern

parts of the country. Low-level inversions are present during morning and evening hours and dust haze occurs during morning hours.

## 4. Measurements and data

### 4.1. *Space charge concentration*

The space charge concentration was obtained by the "potential gradient method" by measuring the change in the vertical electric field between two levels (Chalmers, 1967; Israël, 1973). Two identical radioactive collectors containing Polonium-210, 6 microcurie source, installed at 15 and 120 cm levels on a mast, were used for measuring the electric field. The collectors were connected to two identical electronic measuring circuits through  $10^{12}$  ohms (Victoreen, U.S.A.), 100:1 voltage dividers. The electronic circuits consisted of electrometer operational amplifiers (Analog Devices, U.S.A., Model 311 K). The field values at the two levels were simultaneously recorded on a multi-pen milliamperere strip chart recorder. The details of the instruments were reported elsewhere (Mary Selvam et al., 1977). The electric field values were corrected for ideal exposure by multiplying with a suitable reduction factor (Chalmers, 1967) determined previously. The minimum value of the electric field which the instrument can record is  $1 \text{ V m}^{-1}$  in the highest sensitivity range.

The average values of the electric field and space charge concentration were computed using the data obtained at 15-min intervals from the continuous records of the electric field at the two levels. The data collected during the period April 1973 to March 1974 were used in the study. The records obtained during thunderstorm conditions and during moderate to heavy rain conditions were not considered.

### 4.2. *Cloud condensation nuclei*

The concentration of cloud condensation nuclei (CCN) at 0.1% supersaturation was measured using a chemical diffusion chamber (Twomey, 1959). The sampling was done from the same location as that of the measurement of the electric field. These measurements were made in the afternoon hours when the convective activity was maximum. The accuracy of the measurement was estimated to be 5%.

#### 4.3. Ionospheric data

The values of the  $F_2$  layer critical frequency ( $f_0F_2$ ) published by the Research Department, All India Radio, New Delhi, for Bombay (geographical co-ordinate  $19^\circ 00' N$ ,  $72^\circ 50' E$ ; geomagnetic latitude  $10^\circ 00' N$ ) for the period April 1973 to March 1974 were considered.

#### 4.4. Meteorological data

The normal values of the surface meteorological data for Poona for the period 1931 to 1960 and the average values for the period April 1973 to March 1974 were obtained from the records maintained by the India Meteorological Department, and are given in Table 1.

The thermal stratification of the lower atmosphere during the period of other observations (April 1973–March 1974) could not be examined as no radiosonde temperature observations were made at Poona during that period. However, Shaha and Ananthkrishnan (1976) studied the thermal structure of the lowest layer (surface–40 m) of the atmosphere using continuous thermograph recordings obtained at the surface and 40 m level. These observations were made at the same location where the other observations on the electric field and CCN were made and discussed in the present paper. The study of Shaha and Ananthkrishnan (1976) was based on the data for the years 1949, 1954, 1957 and 1960 selected at random. These special observations, taken for a specific programme, were discontinued subsequently and not

available for the period April 1973 to March 1974. The average values of the temperature difference ( $\Delta T^\circ C$ ) between the surface and 40 m levels for the 4-year period taken from Shaha and Ananthkrishnan (1976) are reproduced in Fig. 2. Since the data were chosen randomly, the results may be applicable to the period of the present study.

## 5. Results and discussion

### 5.1. Diurnal variation

The diurnal variation of space charge, electric field at 120 cm and  $f_0F_2$  for the four seasons is shown in Fig. 1. The diurnal variation in the temperature difference ( $\Delta T^\circ C$ ) between the ground and 40 m level is shown in Fig. 2.

The daily mean values of space charge and electric field and the seasonal mean values of the cloud condensation nuclei along with their standard deviations for different seasons are given in Table 2. The standard deviations of space charge and electric field were also computed using the 15-min values of the electric field and space charge data shown in Fig. 1. The standard deviations of space charge and electric field during early morning hours are low and are less than 50% of the mean values. The standard deviations between 1000 and 1100 IST are maximum and are up to 200% of the mean values. Since the standard deviations around the early morning hours are low the basic con-

Table 1. Normal values of surface meteorological parameters based on 1931–69 records

Season	Temperature $^\circ C$				Highest value	Lowest value	Wind speed (kmph)	Relative humidity (%)
	Maximum	Minimum	Range	Mean				
Winter	31.1 (30.5)	13.7 (11.5)	17.4 (19.0)	22.8 (20.6)	38.9	1.7	3.3 (2.4)	51 (57)
Pre-monsoon	37.7 (37.8)	20.0 (20.6)	17.7 (17.2)	29.5 (28.9)	43.3	13.9	5.6 (7.7)	40 (41)
Monsoon	29.1 (28.5)	21.8 (22.0)	7.3 (6.5)	25.3 (24.3)	41.7	17.2	7.9 (12.5)	77 (81)
Post-monsoon	31.3 (29.9)	17.1 (15.9)	14.2 (14.0)	24.5 (22.2)	37.8	11.1	3.2 (2.9)	61 (71)

Figures in parentheses denote mean values for the period of study.

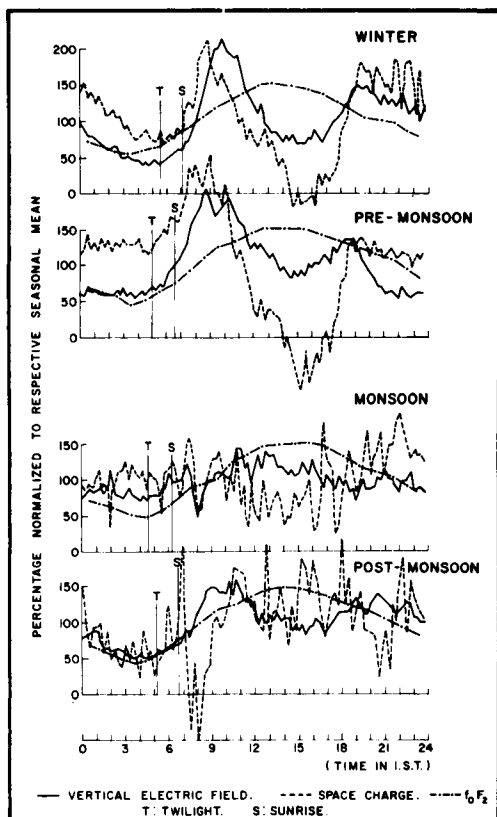


Fig. 1. Diurnal variations of electric field, space charge and  $f_0F_2$  for the four seasons. The seasonal mean values for electric field ( $V m^{-1}$ ) are: Winter (229), pre-monsoon (100), monsoon (57) and post-monsoon (150). The values for space charge ( $p Cm^{-3}$ ) are: winter (912), pre-monsoon (896), monsoon (203) and post-monsoon (211). The values for  $f_0F_2$  are: winter (7.63), pre-monsoon (7.74), monsoon (7.66) and post-monsoon (8.10).

clusions drawn from the present study are not affected.

The mean values as well as the diurnal range of variation for both space charge and electric field (Table 2) are high during winter/pre-monsoon and are low during monsoon/post-monsoon seasons. Examination of the diurnal range of variation of the surface temperature (Table 1) also shows behaviour corresponding with space charge and electric field during the four seasons.

The mean space charge is found to be positive in all the four seasons. As the measurements in the present study were made in the urban area, the positive sign noticed for space charge is consistent

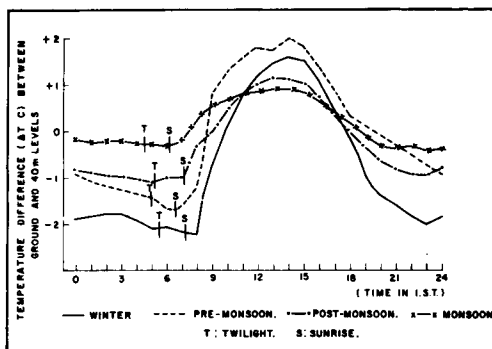


Fig. 2. Diurnal variation of temperature difference ( $\Delta T$  °C) between the surface and 40 m level (after Shaha and Ananthkrishnan, 1976).

(Mühleisen, 1956). The space charge in this case may consist of large ions produced by urban activity.

The CCN concentration is maximum during winter when the electric field is also maximum (Fig. 3). During this period the airflow in the lower troposphere is easterly which brings high concentrations of particulates of continental origin. The particulate concentration determines the conductivity and hence the absolute magnitude of the electric field. The thermal structure and its variation in the lower layers control the vertical transport of the particulates and thus influence the variations in the surface electric field.

The space charge concentration exhibited double oscillation corresponding to that of electric field during winter and pre-monsoon seasons. The rise in space charge concentration and in electric field begins in the pre-sunrise hours almost simultaneously, but the morning maximum in space charge precedes that of electric field by 30 min to 1 h. The rise in both these parameters commences again almost simultaneously in the afternoon hours. The electric field reaches its maximum earlier and starts falling more rapidly than the space charge. The differences in the time of occurrences of the maximum for space charge and electric field, both in the morning and evening hours, may be explained as follows:

The low level inversion which is strong in the morning hours starts breaking, due to ground heating, at about 0800 IST when the space charge concentration also shows a steep fall. As the day progresses, surface heating by the sun warms the air layer near the ground and erodes the inversion

Table 2. Daily mean values of (i) space charge, (ii) electric field and (iii) seasonal mean values of cloud condensation nuclei (CCN) during different seasons

Season	Space charge		Electric field		CCN cm <sup>-3</sup> (at 0.1%)	$f_0 F_2$ (Mhz)
	Mean PC m <sup>-3</sup>	Standard deviation (% of the mean)	Mean V m <sup>-1</sup>	Standard deviation (% of the mean)		
Winter	887 (119)	127	230 (119)	36	381 (78)	7.63 (79)
Pre-monsoon	917 (82)	102	105 (87)	56	311 (13)	7.74 (57)
Monsoon	229 (66)	305	65 (69)	117	210 (120)	7.66 (58)
Post-monsoon	209 (59)	341	156 (60)	59	256 (23)	8.10 (41)

Figures in parentheses denote the number of observations of which the given value is the mean.

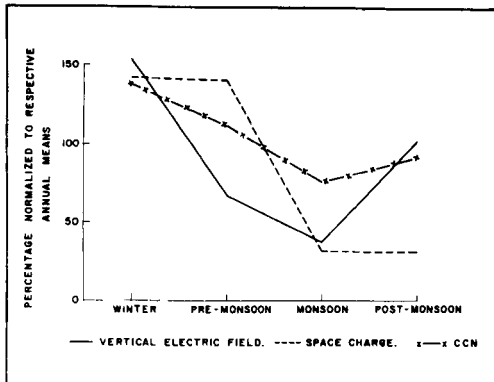


Fig. 3. Seasonal variations of electric field, space charge and cloud condensation nuclei (CCN). The annual mean values are: electric field (148 V m<sup>-1</sup>), space charge (639 pC m<sup>-3</sup>) and CCN (277 Cm<sup>-3</sup>).

from below. Thus when the inversion breaks, the concentration of particulates in the surface boundary layer starts decreasing from the lower to the higher layers as convection currents travel from lower to higher levels. This will result in the upward transport of particulates and the rate of upward transport will be dependent on the rate of break-up of the inversion. The effect on space charge is noticeable as soon as the particulate concentration decreases in the lowest layers. As the particulates move up above 120 cm charges of one sign may

have their lines of force ending on charges of opposite sign below 120 cm. Thus the electric field at 120 cm may not start decreasing till the particulate concentration above the 120 cm level decreases to an appreciable extent.

In the evening hours, when the convection currents cease at the ground surface, particulate concentration may start decreasing from the higher to the lower levels due to settling down of the particles in the gravitational field. Thus the differences in the times of occurrence of the maxima for space charge and electric field as observed in the morning and evening hours are consistent. The above observation is further corroborated by the recent measurements (Chisnall et al., 1977) made, using an instrumented aircraft, of the vertical electric field,  $E$ , and the ionic conductivity,  $\lambda$ , of the atmosphere in the vicinity of a temperature inversion. It was found—moving downwards through the inversion—that the reduction in  $\lambda$  associated with ionic immobilization upon aerosol particles occurred over an appreciably shorter vertical distance than that for the accompanying increase in  $E$ . The ionic current density was not preserved over the region of changing  $E$ . These observations suggest that the space charge created in the region of conductivity gradient was transported downwards by eddy diffusion.

During winter and pre-monsoon the space

charge and electric field showed almost a parallel variation with a double oscillation which may be due to the electrode effect (Chalmers, 1967) during inversion conditions. The space charge changes sign from positive to negative during the afternoon hours. The electric field showed a decrease during the period 2000–0500 IST in association with space charge which may be attributed to the decrease in the particulate concentration under the following meteorological conditions.

- (i) calm/very light winds and
- (ii) formation of fog and mist.

Decrease of particulates can also take place during the above period due to the subsidence of air masses leading to the settling down of large/giant-size particles. The particles of diameter  $>0.01 \mu\text{m}$  influence the space charge concentration since these particles alone can absorb and retain more than one elementary charge (Israel, 1973).

The diurnal variation of the space charge concentration does not show systematic association with the electric field during the monsoon and post-monsoon seasons. During monsoon, when the ground inversions are the weakest (Fig. 2), neither the space charge nor electric field shows double oscillation. But during the post-monsoon double oscillation is present in the electric field but not in the space charge concentration. This feature may be visualized as follows.

Israelsson (1978) observed that in stable conditions (i.e. fair weather conditions at night-time) the electric field and space charge are correlated very well and the nearest air layer determines the electric field. Under other stability conditions the correlation between electric field and space charge is smaller and the electric field seems to be influenced by a larger air layer.

During the post-monsoon low-level inversion conditions gradually set in with the reversal of the monsoon current from westerly to easterly. The reversal sets in initially in the higher levels and gradually extends to lower levels but the air layers very near the surface continue to remain homogeneous under the influence of weak maritime westerly air current (Khemani et al., 1977). With this type of stratification of the air layers, double oscillation is anticipated in the electric field but not in space charge. This observation may further be corroborated from the following simple theory.

The atmospheric electric field ( $E$ ) at the surface

may be expressed in the following form

$$E = \frac{V}{R_T} (R_C + R_A) \quad (1)$$

where

$V$  = ionospheric potential

$R_T$  = total columnar resistance

$R_C$  = resistance component of the lowermost column (120 cm in the present case) which is affected by the diurnal vertical mass transport due to convection

$R_A$  = resistance component of the lowermost column which is affected by advection of air mass or synoptic situation other than convective activity.

Differentiating eq. (1) with respect to height  $Z$ , the space charge ( $S$ ) may be written in the following form

$$S = \text{const} \left[ \frac{dR_C}{dZ} + \frac{dR_A}{dZ} \right] \quad (2)$$

The air mass regime in the region during the transition period of the post-monsoon season may be such that  $dR_C/dZ$ , which has a diurnal variation, will be small compared to  $dR_A/dZ$ . The double oscillation in space charge ( $S$ ) is not seen while the double oscillation in the electric field ( $E$ ) may be just apparent as  $R_C$  will become appreciable in comparison to  $R_A$ .

### 5.2. Influence of air mass on electric field and space charge

During winter cold waves pass through the region in the wake of western disturbances moving across north-west India. Under such meteorological conditions incursion of polar continental-type ( $P_c$ ) air masses takes place which results in a steep fall in the minimum temperature and the air mass, being of continental origin, transports high concentrations of particulates into the region. On these occasions the electric field values are found to be high and also show intense agitation. This observation is in agreement with an earlier study which showed a close association between the electric field and the characteristics of the air mass in the region (Mary Selvam et al., 1974).

The mean daily average values of electric field and space charge for days associated with cold

Table 3. Average space charge and electric field during cold wave conditions

Temperature (°C)	Percentages normalized to winter mean			
	Space charge		Electric field	
	Mean	Standard deviation	Mean	Standard deviation
8.5 (41)	135 (3082)	245	107 (3198)	85
13.0 (78)	83 (6429)	202	96 (6607)	80

Figures in parentheses denote the number of observations of which the given value is the mean.

wave conditions with minimum temperatures 5 to 10°C and with minimum temperatures greater than 10°C are given in Table 3.

On days with cold wave conditions the average values of electric field and space charge are higher by 11% and 52% respectively than the average values for other days in winter (Table 3), and are significant at 0.25 and 3.44% respectively, as estimated by the Mann-Whitney U-test (Siegel, 1956). The diurnal range of variations in space charge and electric field are also, in general, higher during the days of cold wave conditions than those during other days. The differences are not statistically significant. The difference in the values between the two categories of days is predominant during evening through morning hours when the surface inversions are present (Fig. 2).

### 5.3. Atmospheric electric sunrise effect

The variations in the electric field which are apparently linked with sunrise are generally known as the "sunrise effect". It is suggested that this effect is due to the increased ionization in the electrosphere by solar radiation (Muir, 1975). The "sunrise effect" has been examined with respect to the  $F_2$  layer critical frequency  $f_0F_2$  in the present study. The diurnal variation of  $f_0F_2$  is shown in Fig. 1. The times of onset of the astronomical twilight and ground sunrise at the station are marked in the figure by vertical lines. The following points are of interest.

The pre-sunrise minimum in the electric field in

all the four seasons occurred 1 h or more before the time of onset of the ground sunrise. The time of occurrence of the minimum coincided with the time of onset of twilight in winter and monsoon. But, it coincided with the time of occurrence of  $f_0F_2$  minimum in all the seasons except in winter.

The double oscillation in the diurnal variation of the electric field is absent during the monsoon season. This may be due to the homogeneous particulate content in the lower troposphere throughout the day due to sustained maritime air flow. Also, the particulate concentrations are expected to be low due to rain-out and wash-out effects (Khemani and Ramana Murty, 1968).

There is a high degree of correspondence between  $f_0F_2$  and the surface electric field during the monsoon season. The early morning minimum in the electric field and its subsequent rise cannot be attributed to the advection or generation of space charges in the boundary layer since the winds during the period were calm and also urban activities were absent. In addition, during the monsoon season stratiform clouds form over extended areas of the region and do not produce any significant electrical effects at the surface in the absence of rain. As mentioned earlier, the present observations do not relate to the periods of thunderstorm activity or rain. During the monsoon season the global effect in the electric field can be most easily identified since the contribution by the local affects is minimum.

From the above it may be inferred that the

diurnal variation in the surface electric field during the monsoon corresponds closely with the electro-sphere potential variations rather than the variations in the atmospheric conditions.

The above hypothesis is further corroborated from the results of the harmonic analysis of the electric field which show that the fundamental peak at about 1400 IST predominates and contributes about 60% of the total variance. Thus the time of the fundamental peak in the electric field coincides with the time of occurrence of the peak in  $f_0F_2$  (Fig. 1).

#### 5.4. *Observational evidence for the influence of ionosphere on surface electric field*

It is known that the atmospheric electric potential gradient is directly proportional to the potential of the ionosphere which depends on the ionization level. The ionization increase begins with sunrise and is maximum during mid-day. The  $f_0F_2$  variation gives the variation of the ionization level in the  $F_2$  region of the ionosphere. The following observations provide evidence that the atmospheric electric field has a maximum during mid-day when the ionospheric ionization level is a maximum.

- (i) The diurnal variation in local time for flat land stations with small pollution shows one maximum in the afternoon (Israel, 1973).
- (ii) The diurnal variation of the charge of an air column (6 km) over Leningrad, Kiev and Tashkent has a maximum between 1400–2000 true solar time (Imyanitov and Chubarina, 1967).

The above observations indicate that the times of occurrence of the minimum and maximum in the diurnal variation of the electric field correspond to those in the diurnal variation of  $f_0F_2$ .

Also, Märcz (1976), from measurements made in Hungary and Poland, observed that extremely high ionospheric night absorption can be followed by enhanced night average of the potential gradient measured at the ground. This enhancement was often found to last several days. The above study indicates that increased ionization level of the ionosphere gives rise to increase in the electric field at the surface.

Cobb (1978), from balloon measurements of the air–earth current density at the South Pole, found increases of more than 70% all the way to the

surface after a major solar flare. This study further corroborates the conclusion stated in the previous paragraph.

#### 5.5. *Mechanism of the atmospheric electric sunrise effect*

Muir (1975) suggested that an increase in the electro-sphere potential could be the source of the atmospheric electric sunrise effect. During the periods of sunrise, intense ionization takes place in the ionosphere and charge separation takes place due to the transport of charged particles by the zonal wind across the earth's magnetic field. The zonal wind in the F region over the tropics is from east to west with speeds ranging from 100 to 200 m  $s^{-1}$  (Bittencourt et al., 1976). The charge separation in the electro-sphere leads to an increase in the potential of the electro-sphere relative to the earth, which in turn would affect surface electric field. From the above it is anticipated that diurnal variation in  $f_0F_2$  would be reflected in the surface electric field. However, the order of magnitude of the charge separation produced by the above mechanism alone is smaller than that required to account for the positive ionospheric potential of  $3.6 \times 10^5$  V with respect to the earth.

After the sunrise the electron density of the  $F_2$  layer increases and reaches a peak at about 1400 IST and also the  $F_2$  layer comes down. During such conditions a corresponding variation in the surface electric field is also expected. The occurrence of the significant peak in the surface electric field at 1400 IST is in agreement with the peak in  $f_0F_2$  during monsoon and further supports the above hypothesis.

The association between  $f_0F_2$  and the surface electric field during the monsoon season is more marked compared to that in other seasons. The non-homogeneous conditions like the particulate content and the convective activity in the lower layers of the atmosphere during other seasons would mask the diurnal variations in the surface electric field caused by electro-sphere potential variations.

The  $f_0F_2$  minimum precedes the pre-sunrise minimum in the electric field by about 2 h in winter. The later occurrence of the morning minimum in winter may be explained as follows. The solar radiation during this season is less intense. But, as the sun approaches the horizon, the solar rays become less oblique and the effect of the ionosphere



on the surface electric field becomes noticeable as the lower layers are affected by solar radiation.

### 5.6. Harmonic analysis and power spectrum analysis of the diurnal variation of electric field and space charge

The phase relationship of atmospheric electric field and space charge are studied using harmonic and power spectrum analyses. The hourly average values of electric field and space charge for the 24 h were used in the analysis. The time of maxima and their contribution to the total variance of each harmonic are evaluated using the harmonic analysis method (Panofsky and Brier, 1958). The significance of the predominant harmonics are evaluated using the power spectrum analysis (W.M.O., 1966). The significance is obtained by determining the white noise level due to data scatter and the red noise level (95%) due to the persistence. A maximum lag of 12 (50% of the total length of the series) is used. The results are given in Tables 4 and 5.

5.6.1. *Electric field.* The first three harmonics together contribute up to 96% of the total variance. The first three harmonics during winter and pre-monsoon and the first two harmonics throughout the year are significant above the white noise level at 95%. The second and third harmonics during winter and pre-monsoon and second harmonic alone during post-monsoon are significant above the red noise level (95%) due to persistence. The results of the present study are in agreement with those reported by other workers (Bhartendu, 1969; Israelsson and Oluwafemi, 1975).

The association between the harmonic components of the surface electric field and the processes which may influence them have been examined. The origin of the different harmonic components of the electric field may, by and large, depend on the variations in (i) the vertical mass exchange due to convection, (ii) the ionospheric  $F_2$ -layer electron density ( $f_0F_2$ ) and (iii) global thunderstorm activity. Of these three mechanisms, the first two account for the major part of the variation of the electric field at the surface. Mechanism (i) predominates during all seasons except in the monsoon seasons. The global thunderstorm activity, which has a peak at 2400 IST (Chalmers, 1967), contributes the least to the maintenance of the electric field at the surface.

The double oscillation associated with the

vertical mass exchange due to convection predominates significantly in the semi-diurnal and ter-diurnal components. The time of maximum of this semi-diurnal oscillation occurs earlier during pre-monsoon. A similar variation in the surface electric field for land stations during summer is reported (Bhartendu, 1969). The contribution to the total variance due to semi-diurnal variation is minimum during monsoon which is due to (i) the presence of stratiform clouds over extended areas which suppress convection and (ii) the absence of surface inversions and homogeneous atmospheric conditions in the lower troposphere throughout the day due to sustained maritime flow (Section 5.3).

There is a good agreement between the variations in  $f_0F_2$  and the surface electric field. In all seasons, the early morning minimum and the afternoon peak in  $f_0F_2$  are seen reflected in the diurnal and ter-diurnal components of the electric field which are significant.

The diurnal variation of the global thunderstorm activity is seen reflected in the ter-diurnal component during all the four seasons. The ter-diurnal component is significant during winter and pre-monsoon seasons.

The double oscillation observed in the electric field can be simulated by a 12 h sine wave corresponding to the convection cycle and a 24 h sine wave corresponding to the  $f_0F_2$  variation. The convection sine wave commences at 0700 IST and has an amplitude twice that due to  $f_0F_2$  up to 1800 IST. For the remaining period the amplitudes are the same. The global thunderstorm maximum at 2400 IST has only a slight effect on the double oscillation of the field as it is also seen from the results of the harmonic analysis (Table 4).

5.6.2. *Space charge.* The harmonic analysis suggested that the first three harmonics are the major contributors (70 to 95%) to the total variance in all the seasons except during post-monsoon. During the post-monsoon the contribution by the first three harmonics to the total variance is only 40%.

The power spectral analysis suggested that only during the pre-monsoon are the semi-diurnal and ter-diurnal components significant above the red noise level (95%).

Except during winter and pre-monsoon, the various harmonics of space charge are not in phase with the corresponding harmonics of the atmospheric electric field. During pre-monsoon the

Table 4. Harmonic analysis of electric field

Possible atmospheric electric generators									
Season	Harmonic	Percentage contribution to the total variance	$f_0 F_2$ (diurnal)	Vertical mass exchange due to convection (semi-diurnal)		Global thunderstorm activity (diurnal)			
				Time (IST) of		Time (IST) of			
				Maximum	Minimum	I Maximum	I Minimum	II Maximum	II Minimum
Winter	II†	65		0905	1505	2105	0305		
	I*	15	1545 (1300-1600)						
			0345 (0300)						
Pre-monsoon	III†	13		0905	2105	1705	0505	0105	1305
	I*	55		1215				0015	
	II†	24		0700	1300	1900		0100	
Monsoon	III†	17	1515 (1300-1600)	0715	1915			2315	1115
	I*	65	1330 (1300-1600)						
			0130						
Post-monsoon	II†	13		1240	1840	0040	0640		
	I*	3		0915	2115	1715		0115	1315
			0515 (0430)						
Post-monsoon	II†	60		0900	1500	2100	0300		
	I*	33	1600 (1300-1600)						
			0400 (0330)						
Post-monsoon	III	3	1620	0820	2020			0020	1220

Figures in parentheses indicate the actual time of occurrence of maximum and minimum of  $f_0 F_2$ .

\* Significant over white noise level alone.

† Significant over both white and red noise level (95%).

Table 5. Harmonic analysis of space charge

Season	Possible atmospheric electric generators									
	Harmonic variance	Percentage contribution to the total	$f_oF_2$ (diurnal)	Vertical mass exchange due to convection (semi-diurnal)			Global thunderstorm activity (diurnal)			
				Time (IST) of Maximum	Minimum	Time (IST) of I Maximum	I Minimum	II Maximum	II Minimum	Time (IST) of Maximum
Winter	II*	65		0840	1440	2040	0240		0250	1450
	I*	22		1015	2215	1815	0615		0215	1415
	III	4								
Pre-monsoon	I*	52		0535	1735	1910	0110		0105	1305
	II†	38		0710	1310	1705	0505			
	III	4		0905	2105	1930	0130			
Monsoon	II*	37		0730	1330	2240	1040		0110	1310
	I*	27		0640	1840	0055	0655			
	III	4		1440	0240	1855	0655		2330	1130
Post-monsoon	I*	31		1255	1855	0055	0655			
	II	8		0730	1930					
	III	2		1530	0430					

Figures in parentheses indicate the actual time of occurrence of maximum and minimum of  $f_oF_2$ .  
 • Significant over white noise level alone.  
 † Significant over both white and red noise levels (95%).

semi-diurnal oscillations of the electric field and space charge are in phase while in winter the semi-diurnal component of space charge occurs 1 h ahead of the field component. The semi-diurnal components of electric and space charge are closely associated during the winter and pre-monsoon seasons since the contribution to total variance is the same for each season.

As discussed in Section 5.1., phase difference between the atmospheric electric field and space charge is controlled by meteorological conditions which change from season to season. Also, the electric field is not controlled by the space charge when the atmosphere is not stable, i.e. in the absence of inversions.

## 6. Conclusions

A study of the diurnal and seasonal variations of space charge, electric field and cloud condensation nuclei in the lowest layers of the atmosphere suggested the following :

- (i) The curve showing the variation of space charge exhibited a double oscillation corresponding to that of the electric field during winter and pre-monsoon seasons. This may be attributed to the establishment of the electrode effect during the surface temperature inversion conditions. During pre-monsoon the semi-diurnal components of space charge and electric field are in phase while in winter the

semi-diurnal component of space charge occurs 1 h ahead of the electric field component. Similar features are absent during monsoon and post-monsoon seasons. The thermal stratification *vis-a-vis* the nuclei concentration in the surface boundary layer appears to influence the space charge and the electric field under certain conditions.

- (ii) The mean values and diurnal ranges of both space charge and electric field are high during winter/pre-monsoon and are low during monsoon/post-monsoon seasons. The diurnal range of temperature and the concentration of cloud condensation nuclei are positively correlated with space charge and electric field.
- (iii) The pre-sunrise minimum in the electric field is associated with the characteristics of the F region of the ionosphere rather than with the ground sunrise time. The  $f_0F_2$  variations are reflected in the diurnal and ter-diurnal components of the electric field. The results of the present study support the hypothesis that the increase in the electrosphere potential could be the source of the atmospheric electric sunrise effect (Muir, 1975).

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#### СУТОЧНЫЕ И СЕЗОННЫЕ ВАРИАЦИИ ПРОСТРАНСТВЕННОГО ЗАРЯДА, ЭЛЕКТРИЧЕСКОГО ПОЛЯ И ОБЛАЧНЫХ ЯДЕР КОНДЕНСАЦИИ В НИЖНЕМ СЛОЕ АТМОСФЕРЫ

Для зимнего, предмуссонного, муссонного и послемуссонного сезонов изучаются суточные и сезонные вариации пространственного заряда, вертикальной компоненты электрического поля и облачных ядер конденсации. Кривая, показывающая суточный ход пространственного заряда выявляет двойную осцилляцию, соответствующую таковой для электрического поля зимой и в предмуссонный сезон. Такие особенности отсутствуют в муссонный и послемуссонный сезоны. В предмуссонный период полусуточные компоненты пространственного заряда и электрического поля находятся в фазе, в то время как зимой полусуточная компонента пространственного заряда проявляется на час раньше, чем в электрическом поле. Средние величины и интервалы суточных изменений велики зимой

и в предмуссонный период и малы в течение муссона и после него. Суточные изменения температуры и концентрации облачных ядер конденсации положительно коррелированы с пространственным зарядом и электрическим полем. Минимум в электрическом поле перед восходом солнца связан скорее с характеристиками области F ионосферы, чем со временем восхода солнца для поверхности земли. Вариации в критической частоте для слоя F<sub>2</sub> отражаются в суточной и полусуточной компонентах электрического поля у поверхности. Результаты настоящего исследования поддерживают гипотезу о том, что увеличение потенциала электросферы может быть источником влияния восхода солнца на атмосферное электричество (Мюир, 1975).