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Diurnal variation of Atmospheric Electric Potential Gradient at Colaba (Bombay) examined for the Universal Component and relationship with meteorological elements

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ABSTRACT. The atmospheric electric potential gradient (P.G.) data of Colaba (Bombay) are averaged over the period 1936 to 1955 to obtain the mean diurnal variation for the different months of the year. The diurnal variations are regular and of large amplitude only for the winter months of November to February. The diurnal variations for these months are harmonically analysed to see if the universal component of the diurnal variation found for the ocean areas as well as some land stations by Mauchly (1923), is manifested in the variations at Colaba. The phase of the 24-hour wave is found to differ from that found by Mauchly by 5 to 10 hours. It is concluded that the universal component of the diurnal variation in P.G. does not readily manifest itself at Colaba.

The relationships between diurnal variation of P.G. and those of the meteorological elements, barometric pressure, air temperature and relative humidity are next examined. The statistical correlation coefficient between P.G. and barometric pressure variations is +0·71, that between P.G. and air temperature variations —0·67 and the value between P.G. and relative humidity is +0·57.

A confirmation of the relationships is sought for in the phase relationships of the significant harmonic components of the diurnal variations of P.G. and the meteorological elements for the winter months. For the P.G. diurnal variation both the 24-hour wave and the 12-hour wave are almost equally significant. For barometric pressure it is the 12-hour component which is significant, while the 24-hour components predominate in the diurnal variations of air temperature and relative humidity. It is found that the 12-hour waves of P.G. and barometric pressure variations are very nearly in phase. The 24-hour waves of P.G. and air temperature are in antiphase while those of P.G. and relative humdity are nearly in phase.

Assuming the electrical state of the atmosphere to be in quasi-static equilibrium an attempt is made to examine possible ways by which meteorological elements can influence P.G.

1. Introduction

1·1. It is generally recognised that there are two types of diurnal variations of atmospheric electric potential gradient (P.G.), one depending on universal time and the other on local time. The universal time variation which is the characteristics of the atmosphere over the oceans, is caused by the changes in the potential of the lower ionosphere, which on account of its great conductivity is of the same potential all over the world at any instant. The local time variation, which is the characteristics of the urban atmosphere, is controlled by local factors like air pollution, turbulence and meteorological conditions. The former type of variation is essentially a single diurnal wave while the latter type is a double oscillation in the course of the day. The universal type of variation, from its cause, is expected to be present everywhere, over the oceans as well as over land. Its manifestation is however masked in varying degrees by the variation following local time.

1·2. The existence of the universal type of diurnal variation of potential gradient was first brought to light by Mauchly (1923), who analysing the potential gradient measurements of the cruises of the survey ship *Carnegie* showed that the diurnal variation over the oceans progressed according to universal time. Mauchly has also shown that the universal type of variation manifests itself in the 24-hour wave of the diurnal variation of many land stations. The dependence of the local time variation on air pollution and meteorological factors has been shown by several workers. Whipple (1929) brought out the dependence of the diurnal variation of potential gradient at Kew on the concentration of air pollution and Kwano (1957) has shown its dependence on turbulence of the lower atmosphere at Tokyo.

1·3. Varying degrees of control of potential gradient by meteorological elements have been found by different investigators. Wait (1931) attributed the secondary minimum in the variation at many land stations during the warmest time of the day to convection currents in the lower atmosphere. More direct relationship with temperature was noticed by Simpson in the measurements of atmospheric electric elements in Lapland. The fact that conductivity of the atmosphere is greater in summer than in winter at a number of places is attributed partly to a temperature effect (Gish 1951). Some measure of direct relationship between P.G. and relative humidity was shown by Wait (1927). The dependence of the mobility of ions in air on relative humidity was seen by Griffiths and Aubery (1929). Dependence of conductivity on atmospheric pressure too was noticed by Markgrof (1924).

1·4. The present investigation has been undertaken to examine for the manifestation of the universal type of variation in the diurnal variation of P.G. at Colaba and examine the relationship between variations of P.G. and the meteorological elements of barometric pressure, air temperature and relative humidity which are simultaneously recorded at Colaba. Incidentally the potential gradient data of a number of years are averaged to obtain normal values for the different months of the year. Potential gradient variations at Colaba have been examined by Mukherjee (1937) with respect to electrically quiet days. His investigation, though spread over only a short period, showed the inverse relationship between atmospheric conductivity and P.G. Seasonal characteristics of the quiet day variation have also been shown in addition to the dependence of P.G. on meteorological conditions like direction and speed of wind.

2. The recording instrument and data

2·1. The instrument used at Colaba to record P.G. is a Dolezalek quadrant electrometer in combination with a Cambridge Instrument Company's photographic recorder. The instrument is located in a room close to the sea coast. For collecting the electric potential a spiral radium collector is used. It projects out of the wall away from the sea coast through a circular hole at a height of 168 cm from the ground. The radium collector is ordinarily kept at 40 cm from the wall but during disturbed weather it is kept at 20 cm from the wall. The recorded P.G. values are reduced to standard conditions of exposure by reduction factors determined by simultaneous observations over the neighbouring sea coast by means of an ionium collector exposed under standard conditions and a Wulf's Bifilar Electrometer.

2·2. The P.G. data used for the present investigation is spread over the period 1936 to 1955, omitting the years 1944, 1945, 1946, 1950 and 1951 during which years there have been many breaks in the records. The hourly values used are the means over periods of an hour centred at the mean local half hour. The mean hourly values for each month of the year are averaged over the period of fifteen years and therefrom the mean diurnal variation computed monthwise. The P.G. data are from all days quiet as well as disturbed so that the seasonal characteristics can be brought out in its entirety.

3. Monthly mean diurnal variation

3·1. The monthly mean diurnal variations of P.G. averaged over the fifteen-year period are presented in Fig. 1. In Table 1 are given the monthly mean absolute value of P.G. and its mean diurnal range. The following characteristics may be observed from Fig. 1 and Table 1.

(*a*) The mean absolute values of P.G. are larger in the winter months of December and January, than in the summer and monsoon months. The mean values are the least in the monsoon months, June to September.

(*b*) The mean diurnal ranges of P.G. are also large in the winter months. But the maximum diurnal range occurs in March, a transition month between winter and summer.

(*c*) The character of diurnal variation (Fig. 1) is strikingly different in the different seasons. In the winter months of November to February the diurnal variation is a double oscillation with the first maximum occurring a few hours before local noon and the second maximum occurring before local midnight. The principal minimum occurs between 14 and 16 hours local time and the secondary minimum a little before sunrise. The variation curves in these months are typical of the urban atmosphere. The winter months at Bombay are the quietest with practically no meteorological disturbance except for occasional early morning mist and slight clouding. The whole winter period conforms to electrically quiet conditions. This is in fact shown by the P.G. diurnal variation curves for the season which are very regular.

(*d*) In the summer months of March to May the diurnal variation of P.G. undergoes a change. The night maximum is not developed. The prenoon maximum is very prominent in the month of March. With the progress of the season towards the monsoon season, even this maximum gets progressively flattened. The summer months especially April and May experience thundery conditions in the afternoon and night hours and the prenoon hours are generally sunny with clear skies and almost no meteorological disturbance. The mean variation curves for these months seem to indicate that during the afternoon and night hours the P.G. variations are minimum, which is far from actual conditions. The

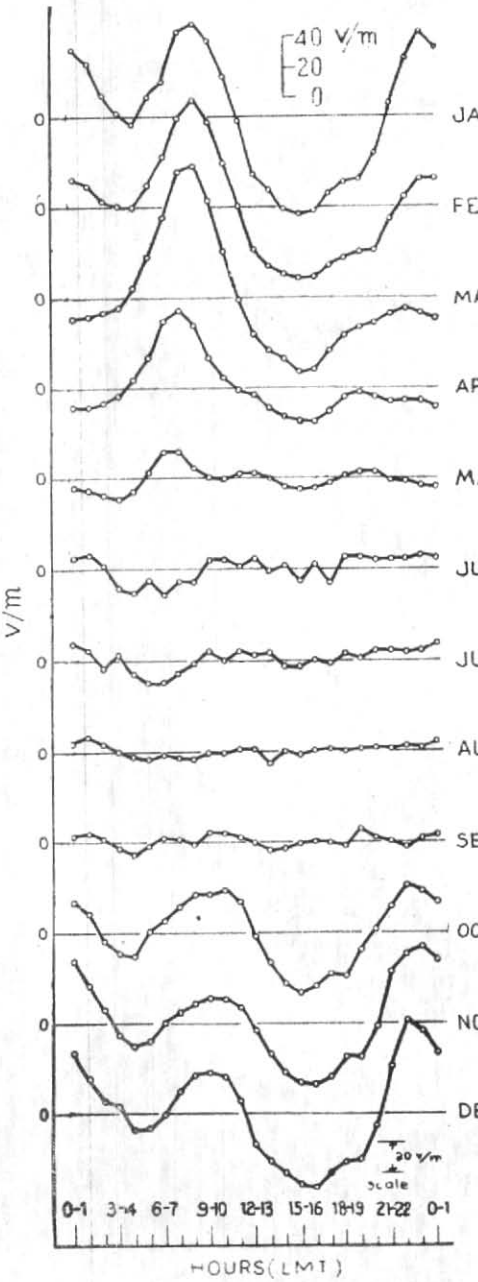

Fig. 1. Mean diurnal variation of atmospheric electric potential gradient at Colaba for each month of the year, for the period 1936–55

TABLE 1

Potential Gradient at Colaba (Bombay)—Mean absolute values and Mean diurnal ranges for the period 1936 to 1955

	Mean absolute value (V/m)	Mean diurnal range (V/m)
Jan	178	133
Feb	144	123
Mar	111	143
Apr	86	78
May	93	32
Jun	93	27
Jul	102	26
Aug	102	18
Sep	87	19
Oct	135	75
Nov	145	97
Dec	174	115

P.G. very often fluctuate very violently during the afternoon thundery conditions and the showery rain. But since these fluctuations are sometimes positive and sometimes negative and occur at random the averaged values do not show their effect.

(*e*) With the commencement of the rains in the monsoon months, the diurnal variation curve gets changed entirely. There appears to be no regularity at all in the variation. The overcast skies and the rain during the season do not permit any regularity in the variation.

(*f*) The P.G. diurnal variation shows an immediate resumption of regularity with the break in the monsoon. This may be seen in the variation curve for October. Therefrom it progresses to the winter type of variation seen earlier.

3·2. A feature that can be seen in Fig. 1 and Table 1 is that, in the month of March the diurnal range of P.G. is very large though the mean absolute value is much less than those for the winter months. The diurnal range is 143 V/m and the daily mean for the month is only 111 V/m. The month of March is the transitional month from winter to summer and is generally sunny with little meteorological disturbance. The quiet heating by the sun of the surface layers and the eventual development of turbulence and convection currents may be the cause of the large diurnal range seen for the month.

3·3. If the diurnal variation curves in Fig. 1 are examined closely one notices that the forenoon maximum occurs progressively earlier in the day, from November to May. This tendency is specially marked from January to May. This indicates some solar control of the phenomenon. The progressive earlier rising of the sun in the course of these months and the consequent hastening of turbulence effects on the lower atmosphere are the likely causes of the feature. Another feature that can be seen in the mean variation curves of Fig. 1 is the pause for about an hour in the rising trend of the curves after the afternoon minimum. This pause is seen in all the winter months November to February as well as in October. It occurs soon after sunset, except in October when it occurs a little earlier. The cause of this feature is not clear.

4. Examination for the universal component of diurnal variation

4·1. As mentioned earlier Mauchly had shown that the universal component of diurnal variation of P.G. manifested at many land stations, as well as over the ocean areas. The average phase angle (reckoned from 0^h GMT) for the 24-hour wave for land areas for the period of northern winter was 219° (maximum at $15^h{\cdot}3$ GMT). The corresponding angle for the ocean areas was 204° (maximum at $16^h{\cdot}4$).

4·2. An examination for the manifestation of the universal component of diurnal variation at Colaba is necessarily restricted to the P.G. diurnal variation in the winter months (November to February) since, as seen earlier, these constitute the quietest period of the year both meteorologically and electrically. Its presence should be manifested in the 24-hour wave of the diurnal variation of these months, if it is not entirely masked by local factors like air pollution and turbulence. The mean hourly inequalities of P.G. for these months were harmonically analysed. Since the month of March was seen to be unique, the analysis was extended to this month also. The results are given in Table 2. The phase angles are reckoned from $0^h{\cdot}5$ LMT.

4·3. It is at once seen in Table 2 that for all the five months the predominant components of diurnal variation are the 24-hour and the 12-hour waves. Their amplitudes are of comparable magnitude. The phase angle of the 24-hour waves for the different months, when reckoned according to GMT however, do not agree with the value determined by Mauchly. The phase angles of the 24-hour waves are such that the time of occurrence of the maximum of the wave progressively increase from $21^h{\cdot}6$ to $1^h{\cdot}9$ GMT from November to March. Thus the 24-hour waves lag behind those for ocean areas found by Mauchly by $5^h{\cdot}2$ to $9^h{\cdot}5$. The obvious conclusion is that local factors have such a predominant control over the diurnal variation of P.G. at Colaba (Bombay) that the universal component of the variation is masked to a great extent.

5. Relationship between P.G. variation and the variations of meteorological elements

5·1. The relationship between P.G. variation and the variations of meteorological elements, barometric pressure, air temperature and relative humidity, is examined, (1) by deriving the statistical coefficient of correlation between the variations of P.G. and each of the meteorological elements and (2) by examining for phase relationship in the different significant harmonic components of their diurnal variations. The months chosen for investigation are the winter months (November to February), since the diurnal variation of P.G. is regular only during these months. The mean hourly values of the meteorological elements for each month were averaged over the fifteen years as were done for the P.G. data. The hourly values of the meteorological elements were instantaneous values at exact hours of LMT. Since the hourly values of P.G. were centred at half hours LMT it has to be noted that in computing the coefficient of correlation the relationship obtained will be for the inequality of the meteorological element at a certain hour and the inequality of the P.G. half an hour later. The coefficient of correlation between variations of P.G. and those of the different meteorological elements for the four winter months are given in Table 3.

5·2. The relationship obtained between the hourly inequalities of P.G. and barometric pressure is very striking. The coefficient of correlation is consistent from month to month and the mean is $+0{\cdot}71$. Thus the two elements appear to have a good direct relationship. The coefficients of correlation between P.G. and air temperature vary from $-0{\cdot}54$ to $-0{\cdot}77$, the mean being $-0{\cdot}67$. Though the coefficients of correlation are not consistent from month to month they appear to be quite significant. The variations of the two elements seem to have an inverse relationship. The corresponding coefficient of correlation for P.G. and relative humidity are the least and range from $+0{\cdot}48$ to $+0{\cdot}65$ the mean for the period being $+0{\cdot}57$. Thus variations of P.G. tend to have a direct relationship with variations of relative humidity.

5·3. The statistical coefficients of correlation in Table 3 do seem to indicate an intimate relationship between the variations of P.G. and the meteorological elements, especially barometric pressure and air temperature. A confirmation of the relationship is sought for in the phase relationship of the different harmonic components of the diurnal variation of P.G. and the meteorological elements. The results are given in Table 4. The following features may be gleaned from the table.

(*a*) The 12-hour wave of the diurnal variation of barometric pressure is the most

TABLE 2

Results of harmonic analysis of the mean diurnal variation of P.G. for the months November to March, 1936-1955

Amplitude (C) and Phases (ϕ)	Nov	Dec	Jan	Feb	Mar
C_1 V/m	23	31	48	41	44
C_2 ,,	30	33	32	25	33
C_3 ,,	7	9	19	16	11
C_4 ,,	3	7	1	1	6
ϕ_1	60°35′	51°54′	32°11′	11°32′	355°43′
ϕ_2	141°35′	147°16′	163°01′	181°34′	210°40′
ϕ_3	115°26′	107°17′	95°05′	88°15′	98°57
ϕ_4	153°26′	208°25′	160°21′	340°21′	350°42′
Time of max. 24-hour wave in GMT hour	21·6	22·2	23·5	0·9	1·9

The phase angles (ϕ) are reckoned from $0^h \cdot 5$ LMT

TABLE 3

Coefficient of correlation between diurnal variations of P.G. and the meteorological elements, barometric pressure, air temperature and relative humidity for the months Nov to Feb, 1936-1955

	Coefficient of Correlation				Mean for the four months
	Nov	Dec	Jan	Feb	
Barometric pressure	+0·70	+0·74	+0·70	+0·69	+0·71
Air temperature	−0·53	−0·65	−0·78	−0·72	−0·67
Relative humidity	+0·48	+0·55	+0·65	+0·59	+0·57

TABLE 4

Results of harmonic analysis of mean diurnal variation of P.G. and the meteorological elements, barometric pressure, air temperature and relative humidity for the months of November to February, 1936-1955

Amplitude (C) and Phases (ϕ)	Pressure (mb)	Temperature (°C)	Relative humidity (%)	P.G. (V/m)	Pressure (mb)	Temperature (°C)	Relative humidity (%)	P.G. (V/m)
	NOVEMBER				DECEMBER			
C_1	0·7	2·8	10·4	23	0·7	2·9	10·3	31
C_2	1·4	0·9	4·4	30	1·4	1·1	4·8	33
C_3	0·2	0·2	1·3	7	0·2	0·3	1·7	9
C_4	0·1	0·1	0·4	3	0·1	0·1	0·3	7
ϕ_1	349°01′	228°38′	67°09′	60°35′	345°46′	225°00′	68°51′	51°54′
LMT of max. of relevant 24-hr. wave		14^h05^m	1^h31^m	2^h28^m		15^h00^m	1^h25^m	3^h02^m
ϕ_2	168°41′	56°30′	243°47′	141°35′	165°29′	49°38′	239°40′	147°16′
LMT of 1st max. of relevant 12-hr wave	9^h23^m			10^h47^m	9^h29^m			10^h36^m
ϕ_3	11°19′	280°00′	46°12′	115°26′	356°59′	245°23′	31°30′	107°17′
ϕ_4	254°03′	276°20′	341°04′	153°26′	231°21′	228°01′	25°34′	208°25′
	JANUARY				FEBRUARY			
C_1	0·7	2·7	8·5	48	0·8	2·7	9·5	41
C_2	1·4	0·9	3·8	32	1·5	0·9	3·4	25
C_3	0·2	0·2	1·1	19	0·2	0·2	1·0	16
C_4	0·1	0·1	0·5	1	0·1	0·2	0·8	1
ϕ_1	342°23′	223°49′	65°08′	32°11′	342°31′	226°04′	61°42′	11°32′
LMT of max. of relevant 24-hr wave		15^h05^m	1^h39^m	4^h21^m		14^h16^m	1^h53^m	5^h44^m
ϕ_2	160°48′	53°38′	243°10′	163°01′	155°55′	54°51′	246°51′	181°34′
LMT of 1st max. of relevant 12-hr wave	9^h38^m			10^h04^m	9^h42^m			9^h27^m
ϕ_3	2°29′	251°34′	40°56′	95°05′	356°38′	273°49′	97°48′	88°15′
ϕ_4	262°52′	222°16′	352°11′	160°21′	216°52′	213°42′	356°17′	340°21′

The phase angles for P.G. and the meteorological elements are reckoned respectively from $0^h{\cdot}5$ and $0^h{\cdot}0$ LMT predominant component, its amplitude being consistently double that of the 24-hour wave. The phase angles of both these waves show slight decrease from November to February. In the case of the P.G. variations it has already been seen that both the 24-hour and 12-hour waves are equally significant. Since, for variations of barometric pressure the 12-hour wave is the predominant component, any phase agreement in the variations of the two elements has necessarily to be looked for in the 12-hour wave of their diurnal variation. The phase agreement is fairly good, the difference being only about an hour. The 12-hour wave of P.G. lags behind that of the barometric pressure by this amount. This finding together with the earlier statistical result indicates the existence of a direct relationship between diurnal variations of P.G. and barometric pressure.

(*b*) In the case of air temperature the 24-hour wave is the most predominant component of the diurnal variation, its amplitude being three-fold the amplitude of the 12-hour wave. Its phase angle shows very little change from month to month. Relationship between variations of P.G. and air temperature has to be looked for in their 24-hour waves. An inverse relationship as seen earlier statistically, is noticeable, especially for the months of November and December. On an average the 24-hour wave of the P.G. diurnal variation lags behind that of the air temperature by about 11 hours. This certainly indicates a good inverse relationship between the two elements.

(*c*) The results for relative humidity show that the predominant component of the diurnal variation is the 24-hour wave, the amplitude of which is more than double that of the 12-hour wave. The phase angles are fairly steady from month to month. As in the case of air temperature a relationship between variations of P.G. and relative humidity has to be looked for in the 24-hour waves. A fairly good measure of phase agreement of the two waves may be seen, though the relationship is not so striking as found for the other two meteorological elements. On an average the 24-hour wave of P.G. lags behind that of the relative humidity by about 2 hours. The lag in November is only about an hour but in February it is as much as 4 hours. The statistical coefficient of correlation found for the variations of the two elements was also a little less than those found in the case of the other two meteorologial elements.

6. Discussion

6·1. The electrical state of the atmosphere is considered to be one of quasi-static equilibrium in fair weather and the potential gradient E is given by

$$E = V/R\lambda \qquad (1)$$

where V is the potential of upper conducting layer with respect to the earth's surface, R is the columnar resistance of the atmosphere and λ is the electrical conductivity in the lower atmosphere. The time variation of E may then be expressed by

$$\frac{1}{E}\frac{dE}{dt} = \frac{1}{V}\frac{dV}{dt} - \frac{1}{\lambda}\frac{d\lambda}{dt} - \frac{1}{R}\frac{dR}{dt} \qquad (2)$$

6·2. If both λ and R are supposed to be constant the time variation of E follows strictly that of V. These conditions are generally achieved over the oceans and over some land areas where both λ and R vary little compared to V. The universal type of variation of potential gradient will then manifest itself over these regions. On the other hand if either or both λ and R predominate then the time variation of E will be entirely controlled by their variation and the variation due to V will be masked to a great extent. It was seen that at Colaba the universal type of diurnal variation in E was not apparent. The variation in E is therefore, largely controlled by the changes in λ and R.

6·3. Both λ and R are influenced by local factors like air pollution and turbulence in the lower layers. λ is given by $\Sigma n_r e_r k_r$ where n, e, k are respectively the number, charge and mobility of ions, r indicating different types of ions. Air pollution results in the increase of large ions with low mobility and therefore causing a fall in conductivity. Variation in the density of the air can cause fluctuations in R.

6·4. The meteorological elements barometric pressure, air temperature and relative humidity which were seen to have intimate relationship with potential gradient, should be expected to influence its variations through λ and R. A change in the pressure of the air column will mean corresponding change in its density and therefore in the columnar resistance R. A higher density will result in the decrease in R and *vice versa*. A higher density of the air column especially in the lower atmosphere will not only decrease the mobility of ions but will also be favourable for the formation of larger ions by the attachment of small ions to larger particles. This will result in a decrease in λ. Thus ultimately higher barometric pressure tends to decrease both λ and R, thereby increasing E. A decrease of pressure will have the reverse effect. If the number and type of ions is supposed constant their mobility will increase with increase in air temperature. This will result in an increase in λ thereby causing a drop in E. A decrease of air temperature will then result in an increase in E. Humidity also may be considered to affect chiefly λ. The attachment of small ions to particles of water vapour cause a drop in mobility and therefore in λ, resulting in an increase in E. These may be the main processes by which meteorological elements influence E. The large measure of correlation met with between variations of E and those of the meteorological elements does seem to be real and not merely an accidental statistical relationship.

6·5. It is, however, not to be construed that variations of these meteorological elements are the chief causes of the variations in P.G. An examination of the magnitudes of the different variations makes this plain. The amplitude of the P.G. diurnal variation is 22 per cent of the absolute value for the 24-hour wave and about 19 per cent for the 12-hour wave. In contrast with these the amplitude of diurnal variations of barometric pressure is only a few thousandths per cent of the absolute value and the amplitudes of air temperature and relative humidity diurnal variations are only a few per cent of their respective absolute values. Major causes of the P.G. diurnal variation for a typically urban atmosphere of Bombay must necessarily be the variations in air pollution giving rise to large ions, coupled with variation in the potential of the conducting layer of the upper atmosphere.

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