Variations of the Horizontal Electric Field near the Ground

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Investigations of the diurnal variations and "agitations" of the horizontal electric field, based on continuous registrations of the horizontal electric potential difference between closely spaced radioactive probes, show that the variations and "agitations" result from the advection of natural space charge over the probes. Since the horizontal field is wind-aligned and space-charge dependent, there is invariably poor correlation in the registrations of two probes lined up in the wind direction.

1. Experimental Arrangement

Using a field mill of special design, Imyanitov (1949) detected close to the ground horizontal electric fields of the same order of magnitude as the prevailing vertical potential gradient. These horizontal electric fields imply the existence in the atmosphere of significant horizontal potential differences; the variations and "agitations" of which can conveniently be investigated on a routine basis using radioactive probes.

For the investigation, three identical Ra 226 radioactive probes (height 1 m and activity 20 μCi), spaced 10 m apart in the wind and cross-wind directions (Fig. 1a) on a fairly open site, were fed into three Keithley model 301 differential amplifiers connected up as in Fig. 1b. The outputs $V_{01}$, $V_{02}$ and $V_{03}$ of the amplifiers yielded directly and simultaneously the potentials $V_A$, $V_A-V_B$ and $V_B-V_C$ respectively at the probes. These parameters, together with the windspeed measured with a sensitive Casella anemometer and the space-charge density measured with a filtration apparatus of the Bent (1964) construction, were registered on strip-chart recorders run at chart speeds of about 15 cm·hr$^{-1}$. Both the anemometer and the filtration apparatus were mounted at the same height as the probes some 30 m away from the probes to avoid possible interference from the radioactive sources.

2. Results

Measurements covering fair-weather and Harmattan conditions were made both at Ibadan (7°24'N, 3°54'E) and at Zaria (11°7'N, 7°44'E) in the north of
the country. During the Harmattan months (November to March) the weather is normally disturbed during daytime by the presence in the air of large concentrations of charged dust; the effect being more pronounced in the northern part of the country.

Figure 2 depicts the mean diurnal variations of the parameters recorded at Ibadan during some fair weather days. The horizontal electric field, $E_h$, was determined as the resultant of the field components along AB and BC; these components being reckoned positive if the potentials of probes A and C were higher than the potential of probe B. The horizontal electric field—and to some extent the vertical potential gradient—shows a dependence on windspeed. The situation on Harmattan days is similar, with the major difference however that the horizontal field invariably reverses in sign roughly in step with the vertical potential gradient during the “austausch” regime; both parameters then being
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Inversely correlated with windspeed, as shown in the mean curves of Fig. 3 for Zaria. There was almost always a poorer correlation between the potentials of probes A and B, roughly in the wind direction, than between those of probes B and C; the correlation coefficient for the former case sometimes being as low as 0.08.

Although the correlation between the horizontal electric field, \( E_H \), and the space-charge density, \( \rho \), is generally poor, there is invariably good correlation between the "agitation" amplitudes and frequencies of both parameters, as may be seen in Figs. 4 and 5 depicting fair-weather and Harmattan conditions respectively. The "agitation" parameters are here defined in accordance with Israel (1959). Like the "agitations" in the air-earth current and the vertical potential gradient, these "agitations" increase with windspeed.

3. Discussion

3.1 The horizontal electric field and its "agitations"

The establishment by wind of horizontal space-charge gradients near the
ground may be expected to lead to horizontal electric fields directed downwind or upwind according as the space-charge is positive or negative. The existence of such wind-aligned horizontal fields, of magnitude determined by the atmospheric charge content, accounts for the poor correlation observed between the potentials of two probes aligned in the wind direction.

The close correlation, revealed in Figs. 4 and 5, between the “agitation” parameters of the horizontal electric field and of the space-charge density, as well as the marked dependence of these parameters on windspeed, suggests that the “agitations” are due to the advection over the probes of space-charge inhomogeneities. The observed increase in the “agitation” amplitudes of $E_h$ and $\rho$ with windspeed points to an augmentation by wind of the space-charge density. Such augmentation, which would also explain the general increase of $E_h$ and $\rho$ with windspeed, has been suggested by Kamra (1969) to account for the single periodic variation of the vertical potential gradient “agitations” on windy days.

3.2 Effect of probe ionization

A radioactive probe constitutes an additional source of ionization in the
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atmosphere; and in the set-up used in these investigations it may be expected that the space-charge produced by the upwind probe would affect the indications of probes downwind.

Each of the Ra 226 collectors emits some $7.4 \times 10^5 \alpha$-particles per second; and with each of these producing about $1.39 \times 10^6$ ion pairs within a roughly hemispherical ionization volume of radius 3.4 cm, some $1.25 \times 10^6$ ion pairs—with a mean life-time of about 0.02 seconds—are produced per second per cm$^3$ by a probe. The life-time is considerably increased when the ions are blown into regions of low ion concentration outside the ionization volume. However, because of the low mobility of ions in air, the vertical velocity of separation for ions of opposite signs in the prevailing field (typically about 0.04 m·sec$^{-1}$ in a vertical field of 100 V·m$^{-1}$) is too low for these ions to remain separated against the natural exchange processes in the atmosphere. Ions of both signs therefore remain mixed and make no contribution to the ambient space-charge density.
within the ion plume. The net effect of a probe may thus be attributed solely to the $\alpha$-particles leaving the ionization volume. Calculations based on SUTTON'S (1953) diffusion law indicate that the maximum possible excess charge-density 10 m downwind of each probe (treated as a continuous point source of constant strength $7.4 \times 10^9 \times 3.2 \times 10^{-19} = 2.37 \times 10^{-13}$ A) ranges between $8.3 \times 10^{-15}$ cm$^{-3}$ (under conditions of large lapse rate) and $6.9 \times 10^{-13}$ cm$^{-3}$ (under conditions of large inversion) for a windspeed of 2 m·sec$^{-1}$. As the space-charge density encountered during these investigations were of the order of $10^{-11}$ cm$^{-3}$, the effect of probe ionization can be ignored. It will nevertheless be useful to repeat the investigations using passive (CROZIER, 1963) potential gradient probes.

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