Balloon Measurement of Atmospheric Electric Potential Gradient

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Abstract

On September 20, 1966 the potential gradient was measured in the altitude range of 5 km to 25 km over the Pacific Ocean from the coast to about 100 km ESE of Honshu Island, giving the values of 9 V/m to 0.7 V/m. The electric field sonde consists of a pair of field antenna suspended 55 m below a plastic balloon of 1000 m³. The field antenna consists of a steel wire 5 m in length, hanging a hollow copper sphere 30 cm in diameter. The potential difference between the two antennas was measured. The result was compared with the vertical profile deduced from the conductivity-altitude profile with a constant vertical current density, both experimental and theoretical. The present measured profile is in good agreement with Gish's profile in the altitude range of 10 km to 22 km. Comparing the measured profiles of both Gish's and ours with the theoretical one, the decreasing rate of the former with altitude was found to be smaller than the latter, even considering the effects of the geomagnetic latitude concerned, and UT variation. Small scale changes of the measured potential gradient were compared with those of atmospheric temperature which were measured on the same electric field sonde. There were good correlations between both the changes. Near the temperature inversions the potential gradient showed very clear inverse phase changes suggesting strong concentrations of dust particles.

1. Introduction

The atmosphere up to about 60 km from ground surface is ionized mainly by cosmic rays, and in addition, especially near ground surface, radioactive gases in the air and radioactive radiation from underground effect the ionization. The atmosphere thus has electric conductivity which increases exponentially with height. On the other hand, the atmosphere has a positive electric potential with respect to the earth except in areas of disturbed weather. It has been estimated that the atmosphere has a potential of about 300 KV which varies diurnally and seasonally about 20% from the mean value. The electric current thus flows down at a density of about 2×10^{-12} Amp/m². Accordingly, the atmosphere has different potential-drops at different heights, i.e., it has a vertical potential gradient distribution. Under steady-state conditions the quasistatic principle can be applied, and constant current density with different height levels can reasonably be assumed, thus the potential gradient decreases exponentially with height contrary to the conductivity distribution. Stergis et al. (1955, 1957) measured the conductivity and the potential gradient using balloons up to about 30 km, and concluded that the quasistatic principle holds. Before and after the measurements of Stergis et al., the potential gradient was measured; notably in Belgium (Koenigsfeld,

1953), Japan (Hatakeyama et al., 1958), Germany (Mühleisen and Fischer, 1960), and India (Venkiteshwaran and Mani, 1962). These measurements were mainly limited to the troposphere, and the lowest limit of the measuring value was ± 5 V/m (Uchikawa, 1961). In Australia, Paltridge (1964) measured the electric field of 4 V/m to 0.5 V/m in the altitude range of 10 km to 25 km. In the present paper we will investigate the experimental vertical profile of the potential gradient, since there has been no such discussion hitherto made in the papers referred to.

2. Measuring principle and apparatus

Paltridge (1964) used two circular metal disks, 47 cm in diameter, as a field antenna, separated vertically by 20 m. The present antenna is based on essentially the same principle, but is expressed in a slightly different way. Putting two perfect conductors in the atmosphere of a constant electric field separated by h m in the direction of electric field, and connecting both conductors by a parallel RC measuring circuit, a potential difference appears between both ends of the RC circuit. After a sudden change (an increase ΔE) of the potential gradient from a constant value to a new constant value E , the potential difference V developed at R is given by

$$V = \frac{R}{r+R} E \cdot h + \left\{ \left(\frac{C_o}{C_o+C} - \frac{R}{r+R} \right) \Delta E \cdot h \right\} \exp \left\{ -\frac{t}{rR(C_o+C)/(r+R)} \right\} \quad (1)$$

where r is the inner resistance of the atmospheric generator and is given by $r \equiv \epsilon_o / C_o \lambda$, in which ϵ_o is the permittivity of free space, λ is conductivity, and C_o is the antenna capacitance including lead wire exposed in the field. The first term of the equation (1) gives sensitivity of the field antenna, and the second term gives transient effect. The denominator of the exponential term is the time constant of this antenna. Each term depends on the value of λ . From a calculation of values of the coefficients of the first and second terms by using the measured vertical conductivity profile given in the Handbook of Geophysics (1960) and the values of R , C_o , and C as will be given below, it can be shown that the calculated value of V differs from the value of $E \cdot h$ by an amount of 13% at the 6 km level, 3% at the 15 km level, and 1% at the 24 km level, respectively. The transient term gives only 6% of the field change value.

The electric field antenna consists of a steel wire of 2 mm in diameter and 5 m in length, hanging a hollow copper sphere 30 cm in diameter. A pair of field antenna was suspended 55 m below the balloon in order to keep it clear of any effect of electric charge on the balloon. The potential difference between the two antennas was measured. The electrometer is mounted in the upper sphere. It has an electrometer tube 5886, whose plate terminal is connected to the lower sphere and is kept at the same potential as the latter. The cathode terminal is connected to the upper sphere. Thus the variations of inner resistance between the grid and the cathode are transformed to frequency variations by the blocking oscillator of the transmitter. Heater voltage and bias voltage of the tube are stabilized by using zenar diodes (constant current diodes) RD6A (NEC). The electrometer circuit including power supply, is temperature-insulated by foam rubber 3 cm thick pasted

Fig. 1. Schematic diagram of the electric field sonde and inside view of the upper sphere.

Fig. 2. Circuit diagram of the electrometer and telemeter.

inside the upper sphere. The input resistance of the tube varied depending on the plate voltages and gave an average value of 1×10^{13} ohms in the range of plate voltage used. The input capacitance C is estimated at 2 pF, and antenna capacitance C_o is estimated at 24.7 pF. A schematic view of the electric field sonde and the inside view of the upper sphere are given in Fig. 1. The circuit diagram of the radiosonde is given in Fig. 2. Air temperature

Fig. 3. Balloon cruise.

Fig. 4. Sample of original record.

Fig. 5. Altitude distribution of potential gradient and temperature data.

both in and out of the sphere was measured, and for calibration of the radiosonde three resistors: 1 M Ω , 470 K Ω , and 100 K Ω were inserted.

3. Measurements

At 18 h 32 m JST on September 20, 1966, the balloon was released from Taiyo-mura, Kashima-gun, Ibaragi Prefecture. The balloon flew over the Pacific Ocean to a distance about 100 km ESE from Honshu Island and a height of 19.3 km. The balloon turned at that point and reached a height of 24.5 km where it began level flight, but telemeter signals stopped at about 21 h 51 m. The balloon cruise is given in Fig. 3, and a sample of the original record is given in Fig. 4.

The potential gradient was measured from a height of about 5 km. The measured values of the potential gradient and temperature, up to 24.4 km, are given in Fig. 5, after correction using equation (1). Though the weather was fine, in order to check the atmospheric electric condition on that day, the surface potential gradient at the Kakioka Geomagnetic Observatory (Kondo, 1966, private communication), about 40 km north west of Taiyo-mura was examined; this showed that the potential gradient variation was normal and calm, having a value of 170 V/m to 150 V/m during the balloon cruise.

4. Vertical profile

The vertical distribution of the potential gradient is given in semilogarithmic form in Fig. 6. Schweidler (1929) made an empirical expression of the vertical profile in the troposphere from the data in Europe. Gish and Sherman (1936) measured the conductivity in the stratosphere using the balloon "Explorer II". Gish (1944) used both results to get the vertical profile of the potential gradient assuming a vertical current density of 2.78×10^{-12} Amp/m²,

Fig. 6. Vertical profile of potential gradient.

and gave the vertical profile as $E = 81.8 \exp(-4.52z) + 38.6 \exp(-0.375z) + 10.27 \exp(-0.121z)$, where E represents the potential gradient in V/m and z the altitude in km. The profile is graphically given in Fig. 6. The present observed data are in good agreement with Gish's profile for the altitude range of 10 km to 22 km. In the troposphere from 5 km to 10 km the observed values are smaller than Gish's profile. This fact may be attributed to the condition of the measured places. The present result was obtained over the ocean from the coast line to about 40 km far from the coast, while Schweidler's result was obtained in the central area of the European Continent, where the air would be more polluted than over the ocean. The departure of observed values from Gish's profile in the height range over 22 km

draws attention to the notable decrease of conductivity with altitudes greater than 18 or 19 km as found by the measurements of Explorer II, but no evidence for the particular existence of stratospheric dust particles was obtained in the present case.

Fig. 6 also shows Uchikawa's (1961) data obtained by using a rotating collector which was carried aloft at Tatenos about 40 km inland, west of Taiyō-mura. The present observed values are about 1/3 to 1/5 of Uchikawa's result.

The potential of the atmosphere can be derived by integrating the vertical profile of the potential gradient. The potential is supposed to be maintained by the upward current from thunderstorms over the world. Uchikawa (1965) derived the atmospheric potential by using world data during the IGY. He pointed out that the potential derived from the Japanese measurements is twice to three times larger than those derived for European stations. Such a tendency is not seen in the present measurement and no remarkable difference is expected between the present result and European data.

The potential gradient, as a function of altitude computed from cosmic ray intensity data at geomagnetic latitude 38°N and for standard atmosphere as given in Handbook of Geophysics (1960), is reproduced in Fig. 6. It is of little interest to compare the absolute values of theoretical and experimental curves, but it is of interest to compare the decreasing rate of the curves. The decreasing rate of the experimental profile is less than the decreasing rate of the theoretical profile even considering the geomagnetic latitude effect concerned and the UT-variation of the potential gradient during the measurement. This fact may be

explained by that ionizing agency, other than cosmic rays, originating at ground surface, namely the radioactive substances, which rise to considerable heights, the tropopause.

5. Small scale variations

It can be seen in Fig. 5 that small scale variations of the potential gradient were associated with temperature inversions. An example of such an association at the height of 10–12 km is given in Fig. 7.

Another remarkable example was observed when the balloon flew through the level of 1.5–3.0 km that would be the top of the exchange layer. The data are shown in Fig. 8 in which a very clear inversion relation between the potential gradient and temperature is seen.

A similar tendency was also seen in the stratospheric flight. Paltridge (1964) noticed the same effect in his stratospheric measurements and pointed out that, “it is tempting to assign these electric field increases to the presence of higher than normal dust concentrations, but it is possible that at least part of the variation is due to a change of the ionic recombination with change of temperature”. The variations of potential gradient in the present measurements seem much larger than the predicted value by the Thomson theory, for the latter case, in Paltridge’s statement. It will be most interesting to investigate what kinds of dust particles exist, where they originated, and how they were transported there.

The present measurement was carried out as a part of the program of the measurement of atmospheric electric field for altitudes between 0 and 60 km. The measurement will be repeated and further discussions will be made, based on more experimental data.

Fig. 7. Inverse relation between small scale changes of potential gradient and temperature ; at an altitude range of 10 to 12 km.

Fig. 8. Inverse relation between small scale changes of potential gradient and temperature through the top of the exchange layer.

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