ATMOSPHERIC ELECTRICITY MEASUREMENTS IN THE UPPER AIR OVER POONA

BY ANNA MANI, F.A.SC. AND B. B. HUDDAR

(*Meteorological Office, Poona*)

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ABSTRACT

Atmospheric electricity measurements made during the last decade at Poona using balloon-borne sondes are briefly reviewed. The vertical distribution of potential gradient in the free atmosphere follows theoretical values only during the monsoon months, when the air is comparatively free from dust. During the summer months, the potential gradient is constant above the exchange layer and this is associated with the presence of the deep, dense dust layer that lies over the region and extends to over 10 km. into the atmosphere. The increase with height of the potential gradient above the 10 km. level during winter is shown to be closely related to the presence of the subtropical jet stream, which presumably transports electric charges to the upper levels over Poona.

1. INTRODUCTION

ATMOSPHERIC electricity phenomena have been studied for many years at Poona and attempts made to correlate it with small and large-scale meteorological processes. The present paper briefly describes the results of these investigations, as far as fair weather electricity phenomena are concerned.

While various quantities connected with atmospheric electricity have been observed and measured at a number of stations during the last hundred years, most of the measurements made till very recently were confined to the surface of the earth or very near it. Assuming ionization at great heights to be due entirely to cosmic rays and if large ions and condensation nuclei at these levels are neglected, one can calculate the equilibrium number of small ions and therefore the electrical conductivity. From the known variation of cosmic ray intensities with height and latitude, Callahan *et al*[1] (1951) calculated conductivity at various levels and showed it to increase exponentially with height. Since the air-earth conduction current is the same at all levels, the potential gradient should decrease with height and a positive charge equal and opposite to that upon the surface of the earth should appear in the atmosphere below the point where the potential gradient is small.

This is the generally accepted theoretical picture of fine weather atmospheric electricity phenomena. The mean values of the electrical potential gradient, air-earth current and conductivity measured in the free atmosphere over Poona generally conform to this, but significant diurnal and seasonal variations are observed quite independent of local influences but correlated with meteorological factors.

2. RESULTS OF OBSERVATIONS AT POONA

The techniques of measurement of the electrical potential gradient and conductivity in the air by radiosonde used at Poona have been described in detail in earlier published papers.[2] Over a hundred potential gradient soundings and twenty-five conductivity soundings extending to 100 mb. have been made since 1953. The results are summarised in Figs. 1 and 2 where the vertical distribution of potential gradient and conductivity during different seasons at Poona and Hyderabad are shown. The mean values of potential gradient and conductivity are summarised in Tables I and II.

In Fig. 3 are plotted observed values of potential gradient F and conductivity λ, taken from simultaneous soundings on four days at Poona, with computed values of the air-earth conduction current i. The conduction current is approximately constant with height and the observed values are of the same order as those obtained in Japan by Uchikawa[3] and in the U.S.A. by Kasemir.[4] Increases in the conduction current occur, however, in the exchange layer and even above it.

The mean columnar resistance calculated from the potential gradient and conductivity measurements over Poona is about $1 \cdot 2 \times 10^{17}$ ohms/m.[2] The potential difference between the earth and the equalising layer above was computed by integrating the potential difference from the ground to a height of 70 km. using the mean monsoon values of potential gradient above the exchange layer. The "ionospheric potential" comes to about 5×10^5 volts, a value slightly higher than those obtained over Europe and the U.S.A.

2.1. *Conductivity*

The variation of conductivity with height over Poona is illustrated in Fig. 2 (*c*). The mean values of conductivity at different levels are given in Table II with similar values over Sapporo, Japan[3] and theoretical values computed by Callahan.[1] It will be seen that while there is fairly good agreement at lower levels, at the higher levels the Poona values are much lower than the computed values and those over Japan. While conductivity shows

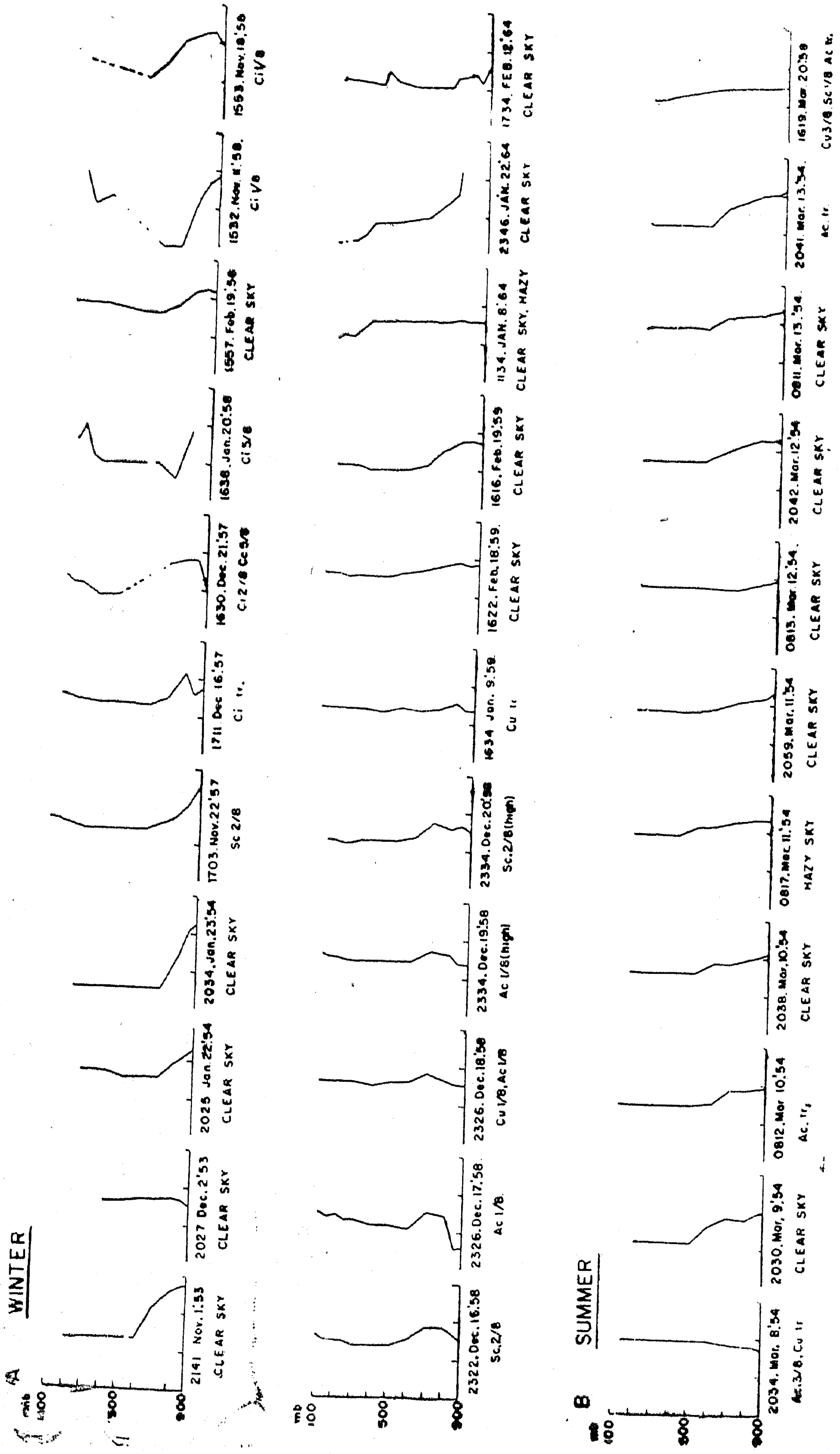

FIG. 1.

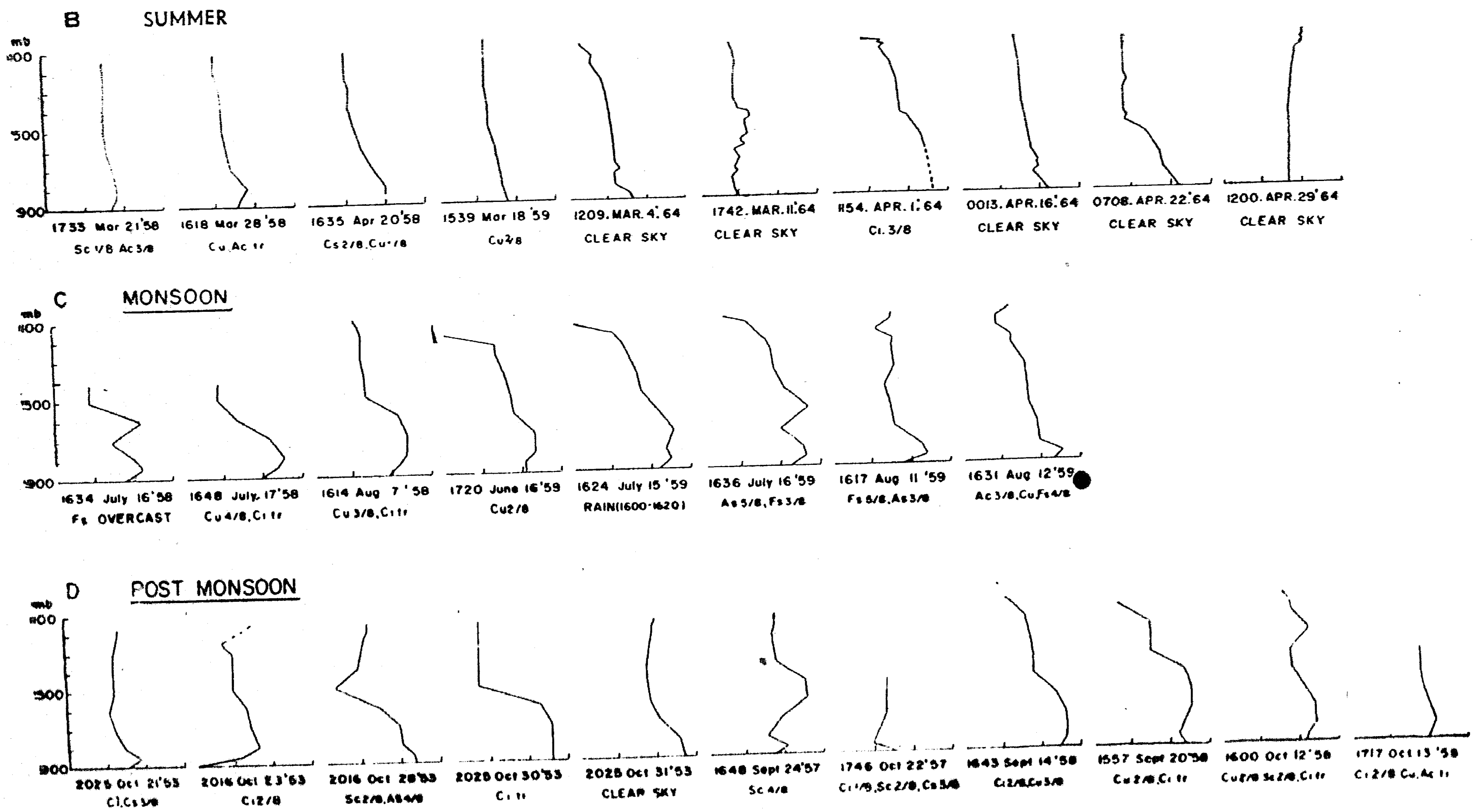

FIG. 1 (*Contd.*). Variation of potential gradient with height at Poona. The horizontal scale of each graph is logarithmic, with potential gradient by radiosonde from 1 to 1,000 $Vm.^{-1}$

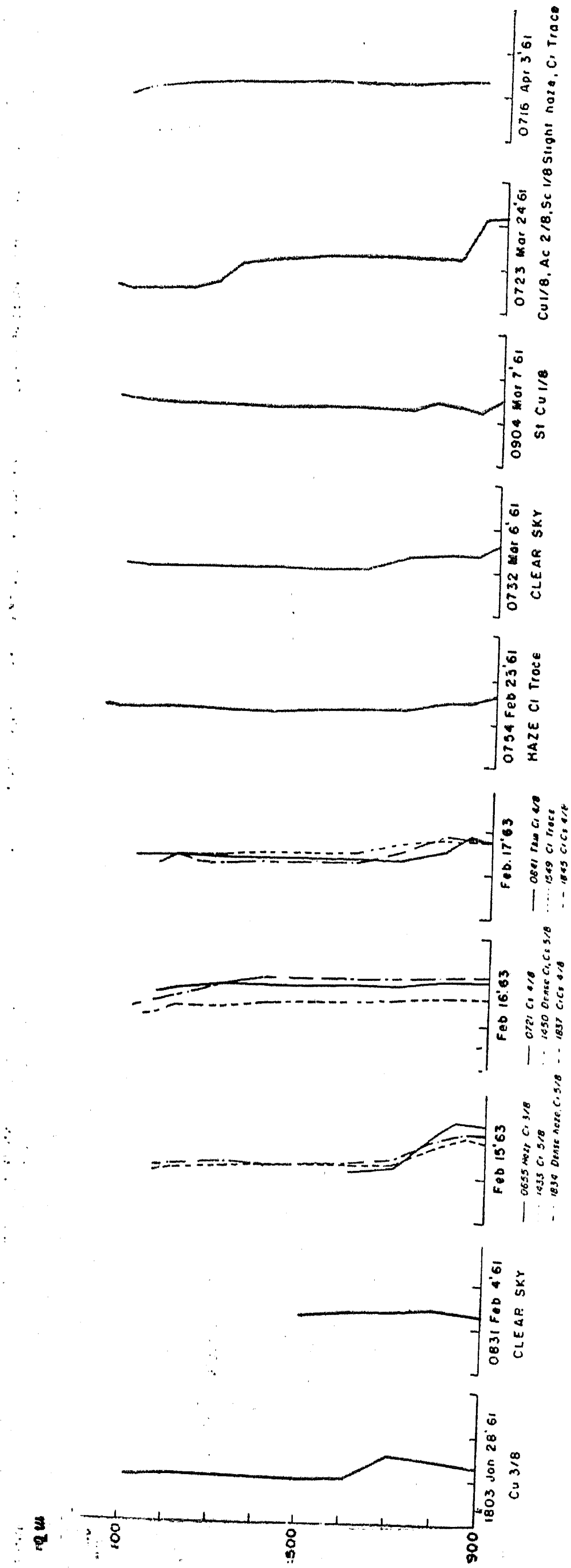

FIG. 2 (*a*) Variation of potential gradient with height at Hyderabad. The horizontal scale of each graph is logarithmic, with potential gradient by radiosonde from 1 to 1,000 $Vm.^{-2}$

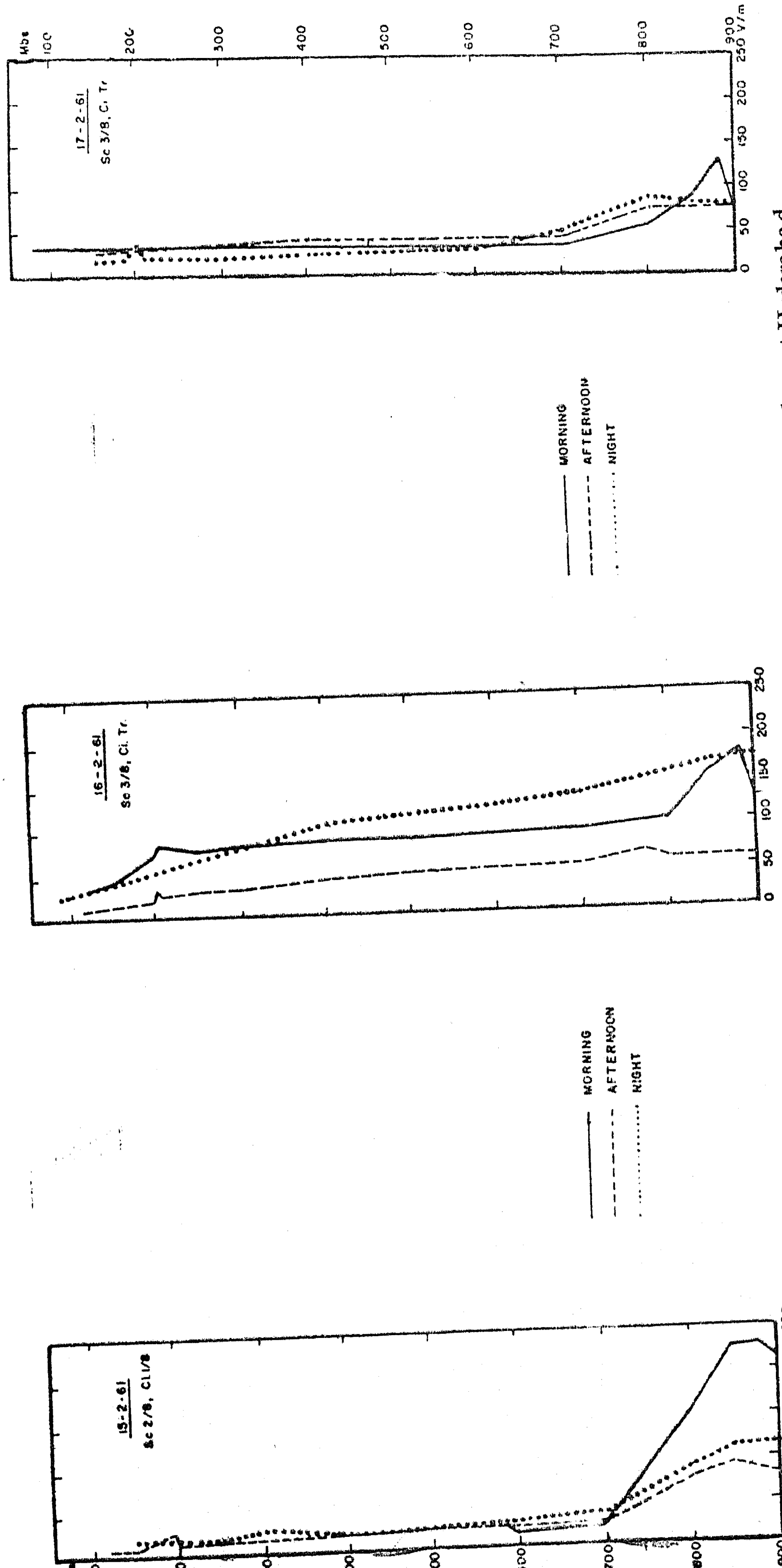

FIG. 2 (*b*) Diurnal variation in potential gradient on three consecutive winter days at Hyderabad.

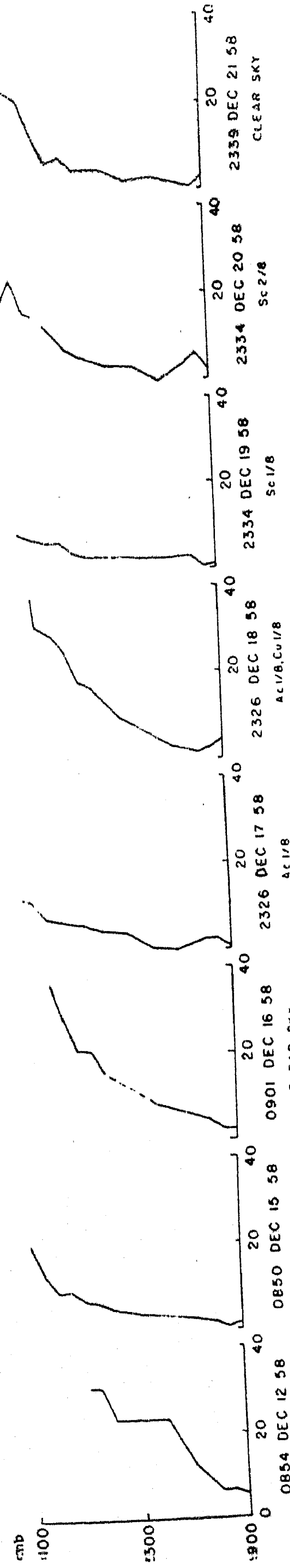

FIG. 2 (*c*) Variation of conductivity with height at Poona.

TABLE I

Mean values of potential gradient over Poona during different seasons

Pressure mb.	Winter Nov.–Feb. Vm.$^{-1}$	Summer March–May Vm.$^{-1}$	Monsoon June–Aug. Vm.$^{-1}$	Post-monsoon Sept.–Oct. Vm.$^{-1}$
900	91	125	118	163
850	84	99	263	155
800	76	92	222	146
700	44	74	146	156
600	27	63	134	116
500	27	43	41	50
400	28	37	30	29
300	28	36	26	32
250	23	36	24	30
200	24	34	15	36
150	36	33	13	31
100	34	13	12	42

a general increase with height in agreement with earlier observations, appreciable day-to-day variations are present, as in the case of potential gradient.

2.2. *The Exchange Layer*

The effect of austausch on the diurnal variation of the vertical profile of potential gradient over Hyderabad is illustrated in Fig. 2 (*b*), where the results of the soundings made at 0800, 1400 and 2000 IST on three consecutive winter days are presented. The exchange layer is the region of small-scale convection currents and turbulent mixing, characterised by large values of potential gradient. It is confined to a layer extending from the ground to about 4·5 km. in winter and to 6·0 km. in summer, over both Poona and Hyderabad. Within this layer, large diurnal variations in potential gradient are noticed, potential gradient being a minimum and almost constant with

TABLE II

Mean values of conductivity over Poona

Mean for June–October

Pressure mb.	Poona $\times 10^{-14}$ mho.	Computed $\times 10^{-14}$ mho.	Sapporo (A) $\times 10^{-14}$ mho.	Japan (B) $\times 10^{-14}$ mho.
900	2·7	2·8	1·5	1·1
850	2·7	2·8	1·5	1·1
800	2·9	3·3	..	..
700	3·7	4·4	2·9	2·5
600	5·8	6·7	..	..
500	6·8	8·9	6·0	5·2
400	9·4	16·7	8·4	8·1
300	14·4	26·6	13·7	13·1
250	15·3	35·5	..	..
200	18·9	55·5	25·1	21·1
150	19·9	65·5	32·3	29·2
100	20·4	99·9	45·2	41·6

(A) Mean value when jet stream is present.
(B) Mean value in the absence of jet stream.

height in the afternoon and showing a large increase early in the morning and at night. These are obviously caused by local changes in the number and types of condensation nuclei in the lower layers of the atmosphere.

2.3. *Potential Gradient in Cirrus Layers*

The remarkable variations in electrical potential gradient and conductivity in cirrus cloud levels over Poona have been reported by Venkiteshwaran *et al.*[5] The sharp increase and decrease in potential gradient in a relatively thin layer is clearly indicated in the soundings over Hyderabad on three consecutive days [Fig. 2 (*b*)]. There were also sudden increases noticed in the potential of the central electrode of the Gerdien condenser of the conductivity sonde and the values of positive conductivity also showed an increase after this. These variations normally occur between 300–200 mb. levels and are in contrast to observations at lower levels, where the conductivity decreases in low and medium clouds with corresponding increase in potential gradient.

2.4. *Seasonal Variation in Potential Gradient*

The significant variations in the vertical distribution of potential gradient in the upper air over Poona during the winter, summer, monsoon and post-monsoon seasons are illustrated in Fig. 1. The mean values of the potential gradient during the four seasons at Poona are given in Table I. The vertical profiles of potential gradient for Hyderabad for winter and summer of 1961 are shown in Fig. 2 (*a*). The main features of the 2 sets of curves are similar. During the monsoon months June to August, the potential gradient shows a decrease with height above the exchange layer, conforming to theory, although appreciable departures do occur from the theoretical curve. During the summer months March to May, it shows more or less constant values above the exchange layer. But the winter values show even greater disparity with theory. The potential gradient is either constant above the exchange layer or actually increases with height.

A small maximum in the field intensity at the lower level of the stratosphere was noticed by Uchikawa[3] over Japan. From a study of the 500 mb. upper air charts and the variations in the potential gradient profiles over 4 stations in Japan he showed that the electrical features north of the subtropical jet stream over Japan were different from those to the south, *i.e.*, the maximum ion density was to the south of the jet stream and therefore he concluded that the electric characteristics in the atmosphere over Japan are closely associated with the jet stream.

3. Discussion

3.1. *The "Jet Stream Effect" in Winter*

A study of the vertical time sections over Poona for the winter months of 1957, 1958, 1959 and 1964 shows that whenever the potential gradient showed an increase with height, a jet stream was present over Poona or to the north of it. This is illustrated in Fig. 3 where the wind speeds at different levels are plotted with the potential gradient profiles for 4 days at Poona. There is a marked increase in potential gradient with height on 15, 19 and 20

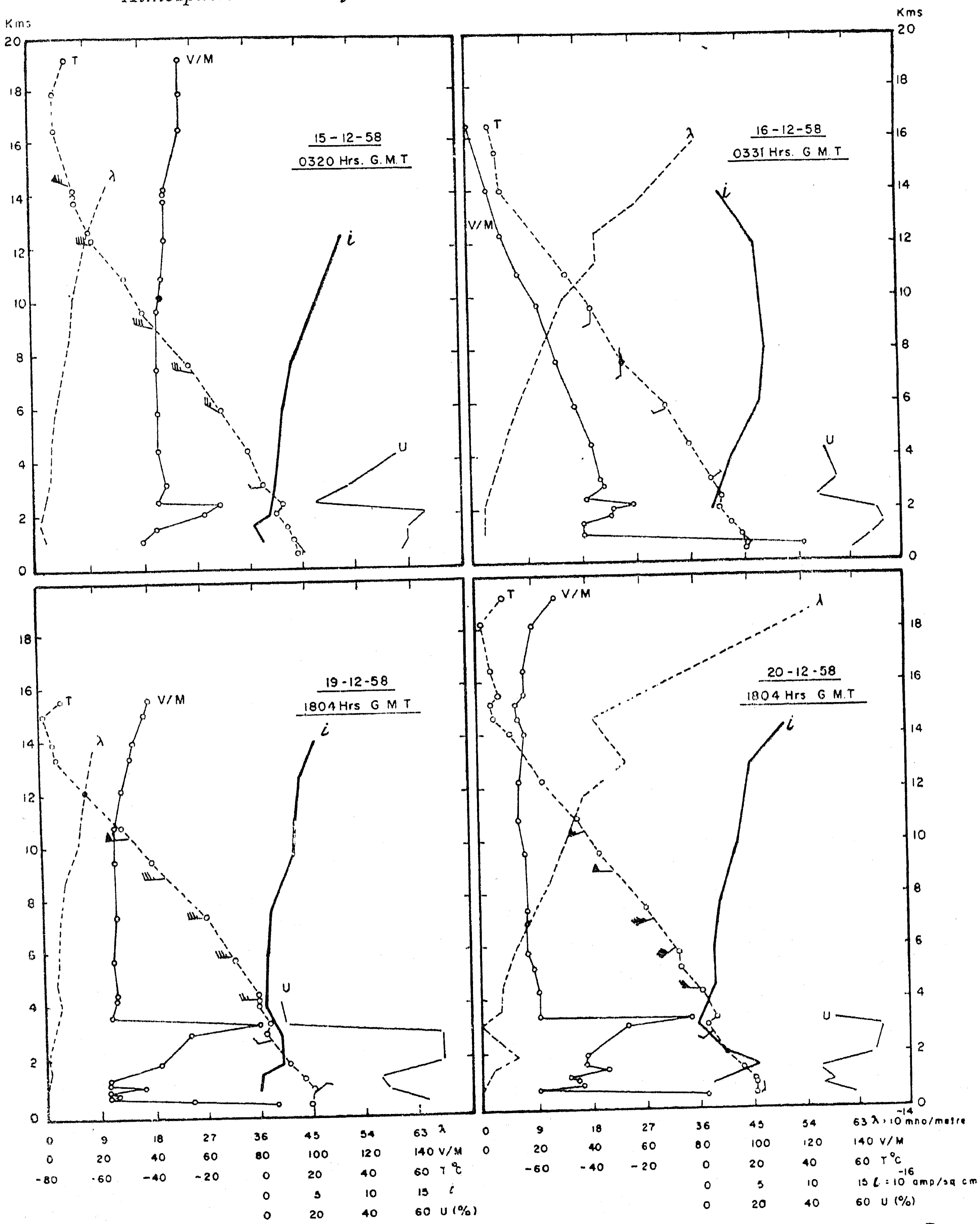

FIG. 3. Profiles of potential gradient, conductivity, air-earth current, temperature and humidity over Poona.

December and a strong jet stream associated with it. On 16 December 1958 the winds had weakened and no increase in potential was observed.

It was, however, noticed that whenever a jet stream was present, there was no corresponding increase in the potential gradient. One has therefore to assume that the jet stream is not the cause of the phenomenon but only a vehicle bringing over the station atmospheric electrical conditions that lead to an increase in the number of large ions and a corresponding increase in the positive potential gradient. The 300 mb. region nearly corresponds to the base of the stratosphere in extra-tropical latitudes; it nearly corresponds also to the altitude of the jet stream over the region north of Poona. The increase in the potential gradient above 300 mb. therefore suggests the existence of finely suspended particles presumably of extra terrestrial origin, in a large concentration just above the level where the extra-tropical stratosphere flows into the troposphere, through the region of the jet stream between the tropical and extra-tropical stratospheres. Since the jet stream moves to northern latitudes in the summer and monsoon months, this feature is not then observed in the troposphere over Poona. In October when winter conditions are being established over India, it is observed occasionally.

Falconer[6] and Schaeffer[7] were the first to report exceptionally high values of the fine-weather potential gradient when a jet stream was close to the place of observation. Koenigsfeld[8] also reported a strong potential gradient reaching to about 300 mb. after the passage of a cold front, *i.e.*, in the region of a jet stream. Bent[9] found no regular relation but did observe several occasions when there was an unusually high current with a well-developed jet stream close. Uchikawa[3] found the day-to-day variations of the electric elements in the upper troposphere to be closely related to the intensity and location of the jet stream. But the nature of the mechanism involved was left unspecified.

According to Reiter[10] convective clouds and thunderstorm activity should be expected in the jet stream region. He pointed out that following the induction theory of thunderstorm formation, which operates with an external electrical field, the processes separating electric charges should be especially active in the jet stream region.

3.2. *The Effect of Dust in Summer*

The potential gradient during the summer months is more or less constant with height above the exchange layer. The "jet stream effect" is inoperative during summer and the answer for the departure from theoretical values has to be sought elsewhere.

Turbidity measurements at Poona[11] show that the atmosphere during summer is twice as turbid as that in winter and four times that during the monsoon. The existence of the deep, dense layer of dust that lies as an unbroken layer across north and central India and extending to over 10 km. into the atmosphere during the pre-monsoon months is well known. To study the vertical structure of the dust layer and its effect on the infra-red radiation flux distribution, a series of soundings with Suomi-Kuhn radiation sondes was made in April 1963 at 4 stations in India, as a joint effort of the University of Wisconsin and the India Meteorological Department. From the observed distribution of infra-red flux, the number of dust particles per c.c. in the lower atmosphere over Poona was computed and was found to be as high as 2,200 per c.c. from surface to 700 mb. and 4,000 per c.c. in the lowest 100 mb. (Bryson *et al.*).[12]

The effect of dust on potential gradient is well known (Rudge).[13] It arises from a separation of electric charge between the large particles of dust on the one hand and either smaller particles or the air on the other. The charge produced is, however, less than that brought by the jet stream over the region.

4. Conclusion

The main results of the atmospheric electrical studies over Poona can now be summarised.

(1) The main air-earth conduction current in the free atmosphere over Poona is approximately constant at all levels, but individual values show significant variations in the austausch layer and above.

(2) The mean conductivity of air shows a steady increase with height but appreciable variations are present both in the exchange layer and above.

(3) The potential gradient shows a decrease with height in accordance with theory only during the monsoon months, when the air is washed clear of dust particles and is free from the jet stream effect. The ionospheric potential calculated on the basis of the mean monsoon values is about 5×10^5 volts and the columnar resistance $1 \cdot 2 \times 10^{17}$ ohm./sq. metre.

(4) The increase in potential gradient observed above 300 mb. during winter is associated with the presence of the sub-tropical jet stream over the region. Since no increase in potential gradient is observed on all occasions when a jet stream is present, the jet stream must be considered merely to be a vehicle that brings over the station, electric charges that cause an increase in the potential gradient.

(5) The large values of potential gradient observed during the summer are associated with the existence of the deep dense layer of dust that extends to levels over 10 km. over Central and North India.

The vertical distribution of potential gradient, conductivity and air-earth current as well as of small ion and large ion densities depends very closely on meteorological conditions and a synoptic study of these parameters should lead to a better understanding of atmospheric electrical phenomena and help in the solution of meteorological problems.

5. ACKNOWLEDGEMENT

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