THE EFFECT OF POLAR MAGNETIC SUB-STORMS ON THE EQUATORIAL SPORADIC E

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Abstract

It is known that equatorial sporadic E disappears at night when dynamo field is east to west. During some DP_2 type magnetic sub-storms, which cause a depression of the geomagnetic horizontal field at the equator, the *q* type of sporadic E is found to disappear at the equatorial stations Huancayo and Kodaikanal. This suggests that one of the mechanisms causing the temporary disappearance of E_s—q during daytime in equatorial ionograms is the replacement of the east to west dynamo electric field by a west to east electric field due to the imposition of an electric field opposing the normal daytime S_q field.

Equatoial Sporadic E and Equatorial Electrojet

McNish in 1937, pointed out that the amplitude of solar daily variation of the horizontal component of the earth's magnetic field H at the equatorial station—Huancayo was abnormally large. He attributed it to an intense eastward electric current flowing in the ionosphere over the equator. Egedal (1947, 1948) showed that the daily range of H at equatorial stations has a sharp peak symmetrical about the dip equator and suggested that the intense current flow existed over a narrow zone of about 300 km width on either side of the dip equator. This current was named "equatorial electrojet" by Chapman (1951). The existence of these currents over the magnetic equator in different longitude zones have been shown by rocket-borne magnetometer studies (Singer *et al.*, 1951; Cahill, 1959; Maynard *et al.*, 1965; Davis *et al.*, 1967; Sastry, 1968).

The records of virtual height *versus* frequency of radio reflections from the ionosphere generally show clearly the critical frequencies of the regular

E, F_1 and F_2 layers. In addition, at equatorial stations, scattered reflections from the E-region are also regularly observed during daytime. They indicate a semitransparent layer which is called sporadic E layer. As a characteristic of the E_S layer, the maximum frequency reflected from the layer is recorded as fE_S.

Matsushita (1951) demonstrated a parallelism between the latitudinal variations of H and daytime fE_S near the magnetic equator and showed that the equatorial E_S is associated with the electrojet. The characteristics of an equatorial ionogram are shown in Fig. 1. Besides the traces corresponding to the ordinary and extraordinary components of F_1 and F_2 layers, one sees diffused reflections from a constant virtual height of 100 km from the frequency range of about 2·7 to 7 MHz. This layer is called equatorial E_S layer or E_S—*q* layer. One also sees diffuse reflections whose height increases with frequency between 3 MHz and 5 MHz and is called slant E_S (E_S—*s*). Although generally the normal E layer at the equator cannot be easily distinguished from E_S—*q* one can identify traces of h' E and the E layer critical frequencies on the ionograms. It is to be noted that h' E_S—*q* is lower than h' E. Knecht and McDuffie (1962) showed that the E_S—*q* occurs over a width of about 700 km around the dip equator which agrees well with the width of the equatorial electrojet as deduced from geomagnetic field observations.

The effect of magnetic storms on the equatorial E_S have been studied by many workers. Skinner and Wright (1957) found that fE_S at Ibadan during the daytime hours was lower on geomagnetically disturbed days than on quiet days; abnormally low values of fE_S were seen simultaneously with the decrease of H. Bhargava and Subrahmanyan (1961) observed that E_S at Kodaikanal disappeared for several hours during the main phase of magnetic storms.

Rastogi *et al.* (1971) have shown that at stations close to the dip equator large decrease of H during the daytime is accompanied by the disappearance of E_S and a reversal of the direction of electron drifts from westward to eastward. They suggested that the temporary disappearance of the equatorial E_S during daylight hours could be due to a reversal of the electrojet current caused by the imposition of an additional electrostatic field opposite in direction to the normal S_q field.

In this paper we give examples of the effects of polar sub-storms (DP_2) on equatorial E_S based on ionograms collected at the equatorial stations Huancayo (dip 2° N) and Kodaikanal (dip 3·4° N).

EQUIVALENT CURRENT SYSTEMS OR GEOMAGNETIC FIELD VARIATIONS OBSERVED AT GROUND

The geomagnetic field variations observed at ground stations on magnetically quiet days (S_q) are explained as being due to electric currents flowing in the upper atmosphere at E-region heights. The electrostatic field driving these currents is produced by the tidal movements of the electrically conducting upper air across the lines of force of the geomagnetic field. The equivalent overhead current system can be calculated by spherical harmonic analysis of the geomagnetic field variations observed at a number of places distributed on the surface of earth (Chapman and Bartels, 1940; Matsushita and Maeda, 1965). These current systems afford a simple way of representing the geomagnetic field variations although this cannot be taken to mean that the currents flow parallel to the earth at any single level in the atmosphere. The enhancement of solar daily variations of H at an equatorial station is explained as being due to increased conductivity of the ionosphere over the magnetic equator and the consequent intensification of the band of currents flowing eastward over equatorial latitudes.

The S_q current system for the northern hemisphere, as given by Obayashi and Jacobs (1957) is reproduced in Fig. 2 (*a*). It consists of three main vortices, a strong one situated over the sunlit hemisphere (between 07 and 15 hr local time) and two other weaker vortices in the night hours centred around 18 hr and 04 hr. The daytime loop corresponds to eastward current at low latitudes causing an enhancement of the magnetic field near the magnetic equator during the midday hours. The other two loops correspond to westward currents which cause a depression of geomagnetie H field around dawn and dusk periods. There are also two other weaker polar vortices within 20° of the pole with a cross-polar flow from forenoon to late evening side. Nagata and Kokibin (1962) showed that the polar quiet-day current vortices (S_q^p) which are roughly symmetrical inside the polar cap, are more pronounced in the northern hemisphere during June solstice. They suggested that the polar S_q field (S_q^p) is injected by the quiet solar plasma wind along the lines of geomagnetic force into the earth's polar ionopshere from the outer part of the magnetosphere.

Besides the world-wide effects of the geomagnetic storms with their intense disturbance in the auroral region, there is another type of weaker disturbance which is pronounced more at the poles and at the equator than at other latitudes (Nishida *et al.*, 1966). These fluctuations called DP_2 disturbances by Obayashi (1967) are found on a world-wide scale. The

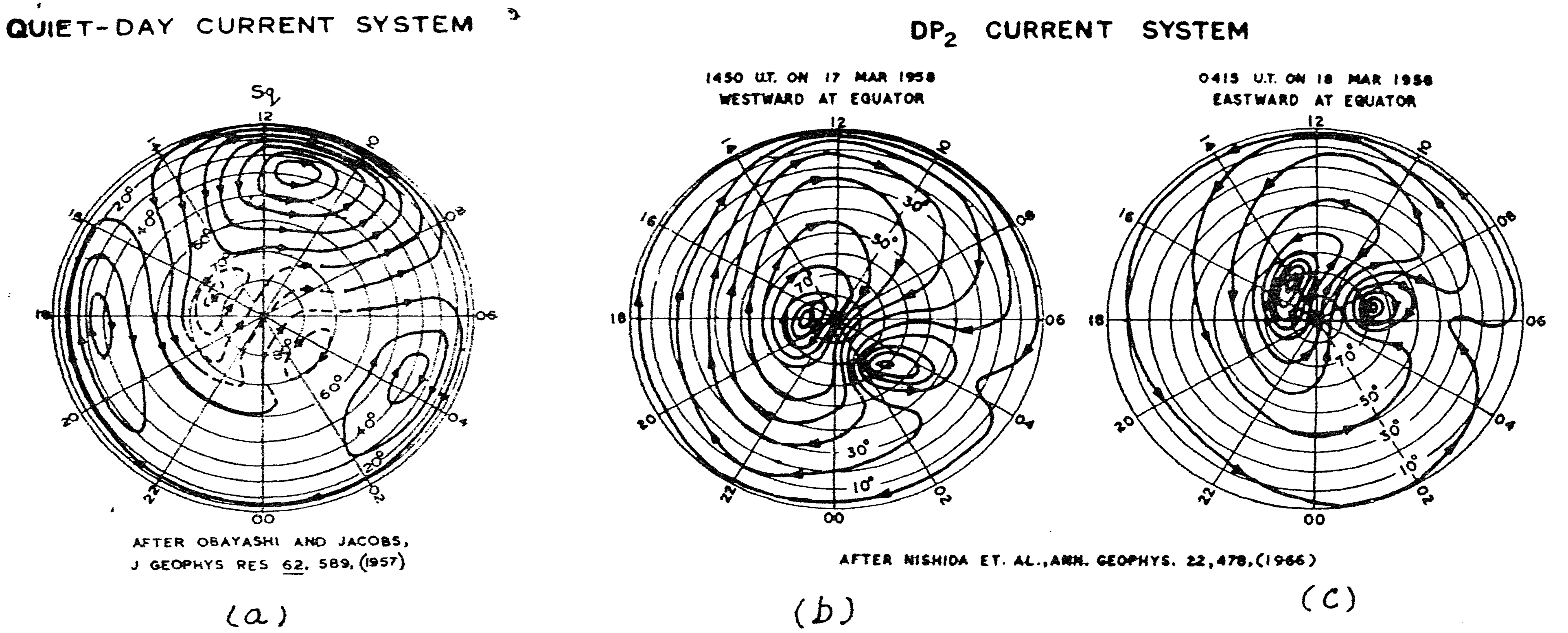

FIG. 2. Observed quiet day current system (S_q) for northern hemisphere (Fig. 2 *a*). Over the equator a strong eastward current during the midday hours and weaker westward current during dusk and dawn periods are seen. The DP_2 current systems showing the current over the magnetic equator to be westward (Fig. 2 *b*) and eastward (Fig. 2 *c*).

magnitude of DP_2 fluctuations are enhanced near the equator and show a marked diurnal variation (Nishida, 1968 *a*). Two examples of DP_2 current system for the northern hemisphere are shown in Figs. 2 (*b*) and 2 (*c*). The currents at low latitudes are westward in the afternoon in Fig. 2 (*b*) and are eastward in the early morning hours in Fig. 2 (*c*). These deviations in H can last for a period of about half an hour to several hours and their magnitude occasionally becomes comparable to that of the S_q field. The DP_2 disturbance appears coherently all over the earth and is correlated with the changes in the north-south component of the interplanetary magnetic field (Nishida, 1968 *b*). Although the DP_2 field is strong at the poles, there is no strong intensification along the auroral belt, but the field is enhanced considerably at the magnetic equator. Comparing the current system in Figs. 2 (*b*) and 2 (*c*) with that in Fig. 2 (*a*) the DP_2 currents may be considered as a temporary intensification of the $S_q{}^p$ currents.

EQUATORIAL E LAYER DURING NEGATIVE DP_2 SUBSTORMS

In Fig. 3 are shown the simultaneous magnetograms at the equatoria station Huancayo and polar station Thule; the quiet-day mean daily variation of H at Huancayo for the same month, is also shown for comparison The S_q (H) variation at Huancayo usually shows a strong peak shortly before noon, but on 18th March 1956 there was a very significant decrease of H between 1030 and 1230 hr. The fluctuations at Huancayo are coherent with those at Thule suggesting that these are typical DP_2 fluctuations. Considering now the ionograms at Huancayo for 1115 hr, one can clearly see strong E_s reflections upto about 8 MHz. At 1130 hr when the value of H was very much lower than on a normal day, the E_s reflections were very feeble and became completely absent at 1145 and 1200 hrs. At 1230 hr when the value of H had reached the normal day value, E_s layer reappeared with fE_s greater than 9 MHz. This indicates that, at the time of maximum negative phase of DP_2 storms the E_s-q disappears at the equatorial station.

Another similar example of DP_2 storm is on 3 September 1958 and the corresponding ionograms are shown in Fig. 4. The fiuctuations in the Huancayo H field and Thule D field are seen to be coherent with each other. At Huancayo the main decrease started at about 09 hr, reached the minimum value around 1000 hr and returned to normal value at about 1100 hr. The ionogram at 0915 hr clearly shows strong E_s with fE_s about 2 MHz; a 0930 hr fE_s decreased to about 5 MHz and at 0945 hr the E_s reflections were totally absent. The E_s was not seen at 1000 and 1015 hrs while it reappeared at 1030 hr. This again shows the disappearance of equatorial E_s during DP_2 sub-storms.

Figure 5 shows the magnetogram and the ionograms at another equatorial station, Kodaikanal, on 9 May 1957. A large depression in H is seen around 1200 hr. The ionograms show clearly the E_s reflections at 1130 hr extending beyond 10 MHz. At 1145 hr the E_s reflections had suddenly disappeared and remained so upto 1215 hr. At 1230 hr the E_s had again appeared. The disappearance of E_s corresponds very precisely in time with the minimum of the H field. It is thus seen that at Kodaikanal too, large depressions in H are associated with the disappearance off E_s—*q*.

Figure 6 shows another example of E_s at Kodaikanal during geomagnetic disturbance on 13 January, 1963. The full line curve shows the magnetic field H on 13 January, 1963 while the dashed curve is the mean variation of H on five quiet days of January, 1963. A magnetic storm of moderate activity started at 2215 hr U.T. on 12 January, 1963. Large periodic fluctuations in H field were recorded on the following day, major depressions of the field occurring around 0900 hr, 1015 hr and 1100 hr 75° E.M.T. The D_{st} (H) values around this period were very low suggesting that these fluctuations were mainly due to ionospheric and not to magnetospheric currents.

An examination of the ionograms shows strong E_s both of *q* and *s* type at 0845 hr. At 0900 hr around the time of a depression in H, the diffused reflections had disappeared, leaving the normal E layer reflections and a thin and weak E_s layer. At 0915 hr E_s had again appeared and continued upto 0945 hr. The E reflections disappeared from 1000 to 1030 hr and both O and X components of the normal E_s layer were clearly seen. These disappearances of E_s again coincide with depressions in the H field. The E_s was again seen at 1045 hr when the H field had a minor peak, but when H field again decreased, no E_s was seen at 1115 hr and 1130 hr. Afterwards the E_s was quite strong even showing the slant type of E_s reflections.

Discussion

The equatorial E_s has been found to be closely correlated with the equatorial electrojet currents both in temporal as well as spatial distributions. Cohen and Bowles (1963) showed that the irregularities responsible for the scattering of VHF waves from the equatorial ionosphere occur at height and latitude region in which the electrojet flows. Bowles *et al.* (1963) showed the frequency spectrum of the echoes received obliqually consists of a sharp peak with a discrete Doppler shift, the magnitude of which is roughly independent of the angle between the beam and the currents. Farley (1963) suggested that the scattering is due to electron density fluctuations resulting from the two stream instability that occurs when there is sufficient relative drift of electrons through the ions. Following this, the equatorial E_s has been generally attributed to two stream instabilities in the F-region. Cohen and Bowles (1967) have later found the existence of non-two stream irregularities in the equatorial electrojet also. Knox (1964) first demonstrated the effect of gradient of ionisation in the generation of irregularities within the equatorial electrojet region. Further theoretical investigations on the generation of the cross-field irregularities in the E-region over the magnetic equator has been carried out by Rogister and D'Angelo (1970) and by Whitehead (1971).

Rastogi (1972 *a*) has shown that the E_s—*q* suddenly disappears during the daytime hours when the drift of electrons in the E-region is towards eastward. It was suggested that the E_s—*q* is caused by the plasma gradient (or cross-field) instability in the E-region. The northward magnetic field coupled with the vertically upward Hall polarisation field over the magnetic equator causes irregularities in the E-region where the plasma density gradient is also upward. The normal duration of E_s—*q* was shown to be comparable to the duration of the electrojet and thus of the eastward electrostatic field causing the upward Hall polarisation field (Rastogi, 1972 *b*). The E_s—*q* was also shown to occur at the height where both the plasma density gradient and the Hall polarisation field are maximum (Rastogi, 1972 *c*). Krishna Murthy and Sen Gupta (1972) have shown that whenever the E_s –q disappears simultaneously at Trivandrum and Kodaikanal, there is a depression in H field range. They suggested that E_s occurred when the estimated electron velocities were less than the ion thermal velocities.

Nishida (1971) has interpreted the DP_2 over the equator as due to the ionospheric Hall current; the corresponding magnetospheric electric field would be directed almost uniformly from the morning to the evening side in the magnetosphere.

Thus the present article suggests one of the mechanisms through which such an electrostatic field opposing the normal S_q field may be imposed on the equatorial ionosphere which sometimes could cause a reversal of the net field towards westward during the day causing the disappearance of the E_s—*q* layer.

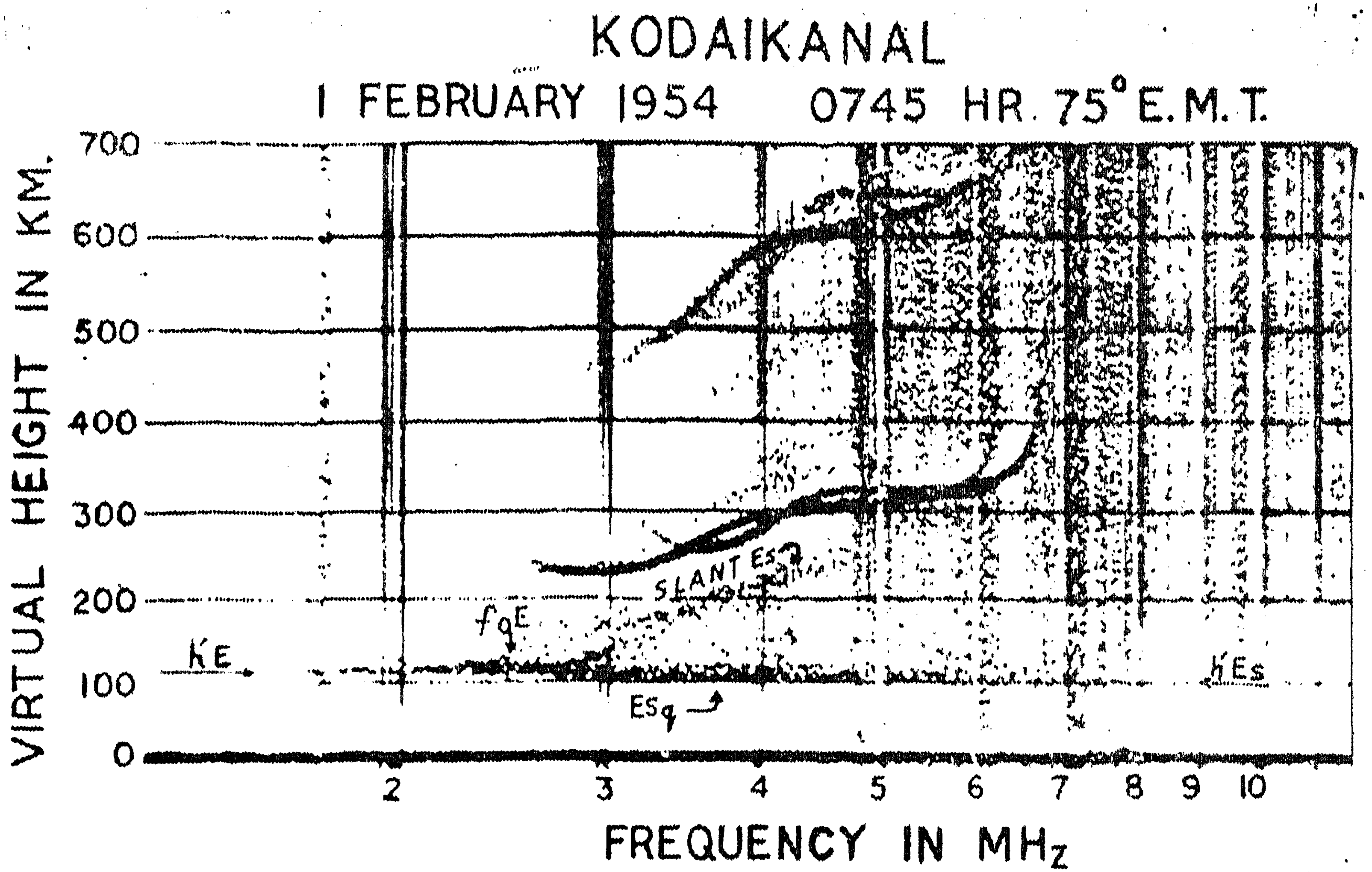

FIG. 1. An ionogram taken at Kodaikanal showing the *q* and *s* (slant) types of sporadic E, f_0 E h' E and h' E_s.

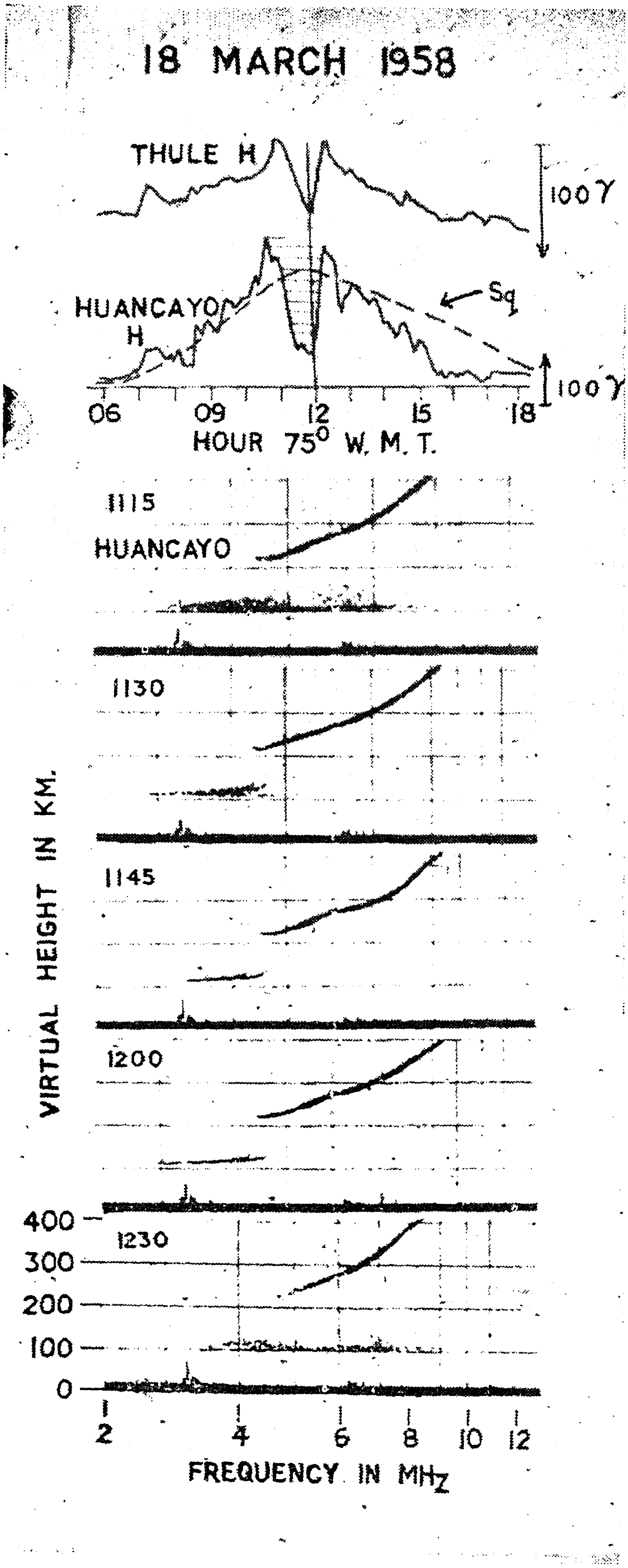

FIG. 3. Magnetograms at Huancayo during a DP_2 type polar sub-storm on 18 March 1958. Note the disappearance of E_s between 1130–1200 hrs during the depression in H at Huancayo.

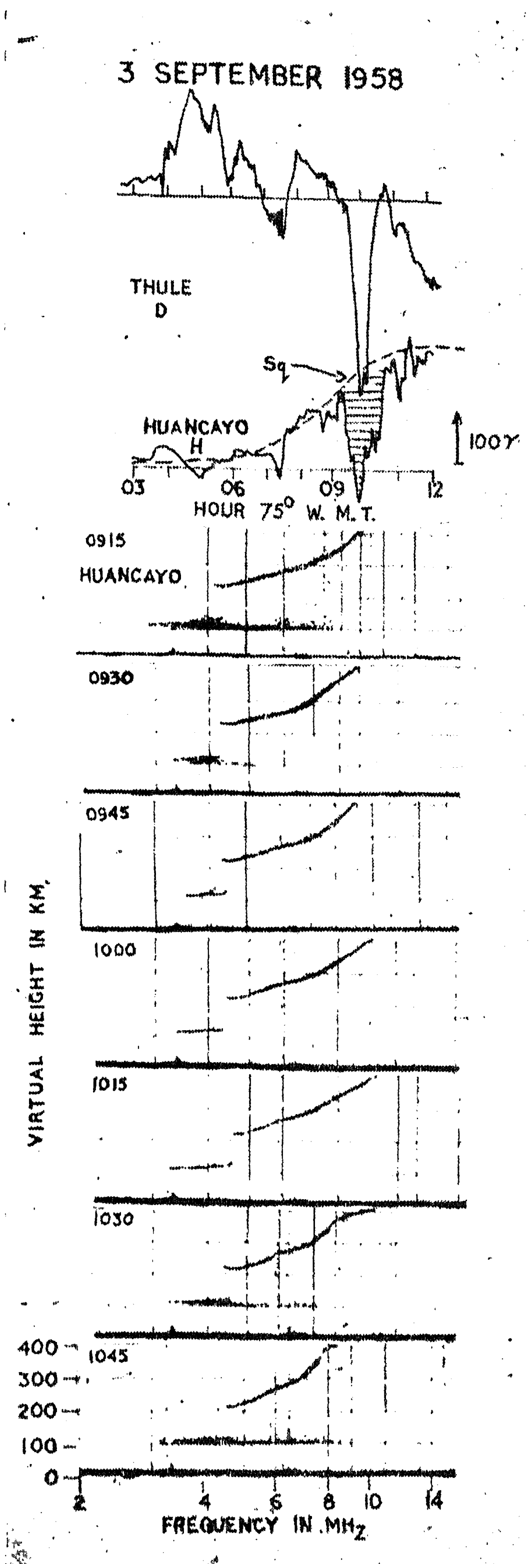

FIG. 4. Ionograms at Huancayo during the DP_2 sub-storms on 3 September 1958 inhibiting the occurrence of E_s at 0945 to 1015 hr.

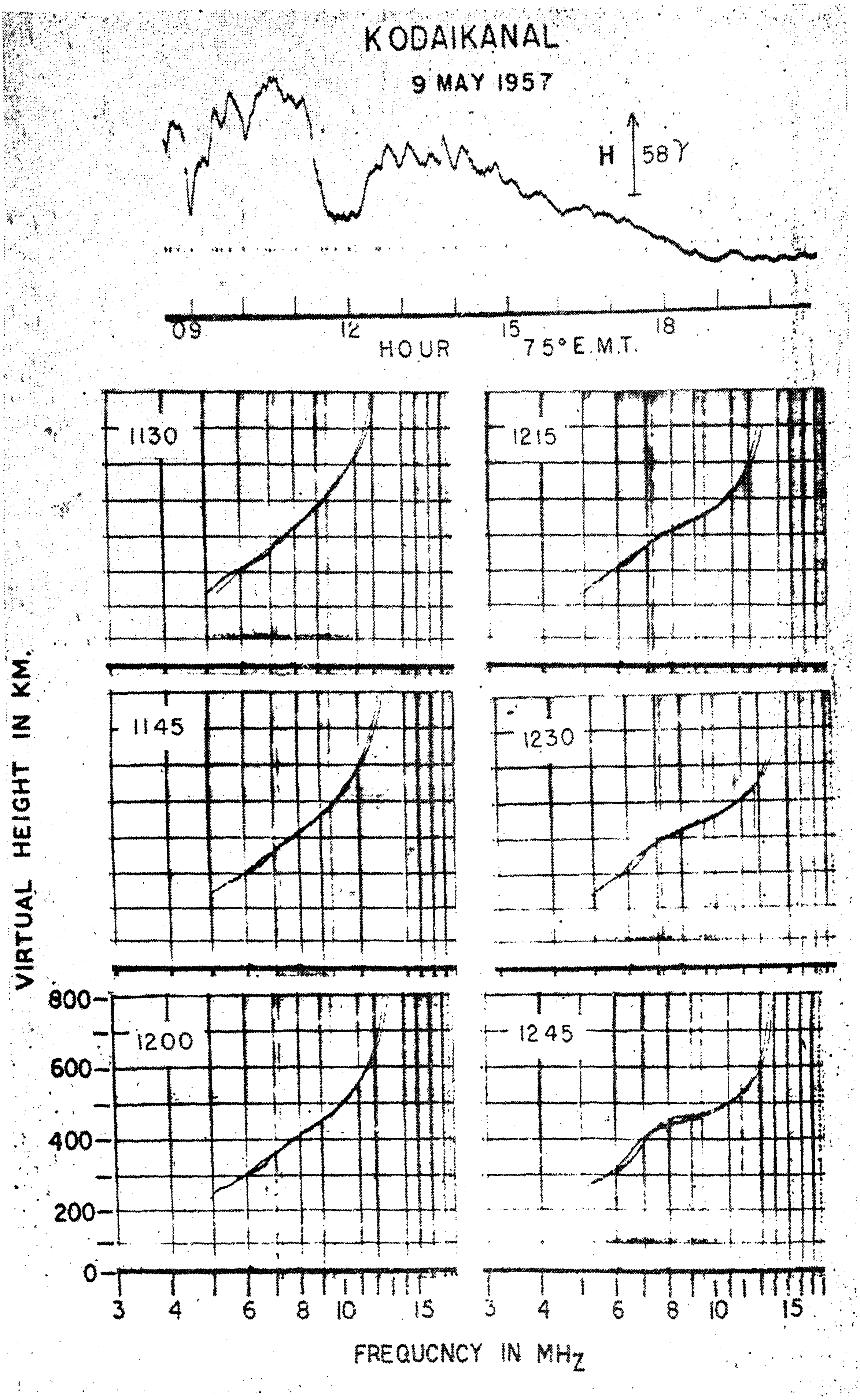

FIG. 5. Ionograms at Kodaikanal during the large depression of magnetic field on 9 March 1957 causing the disappearance of E_s—*q* reflections.

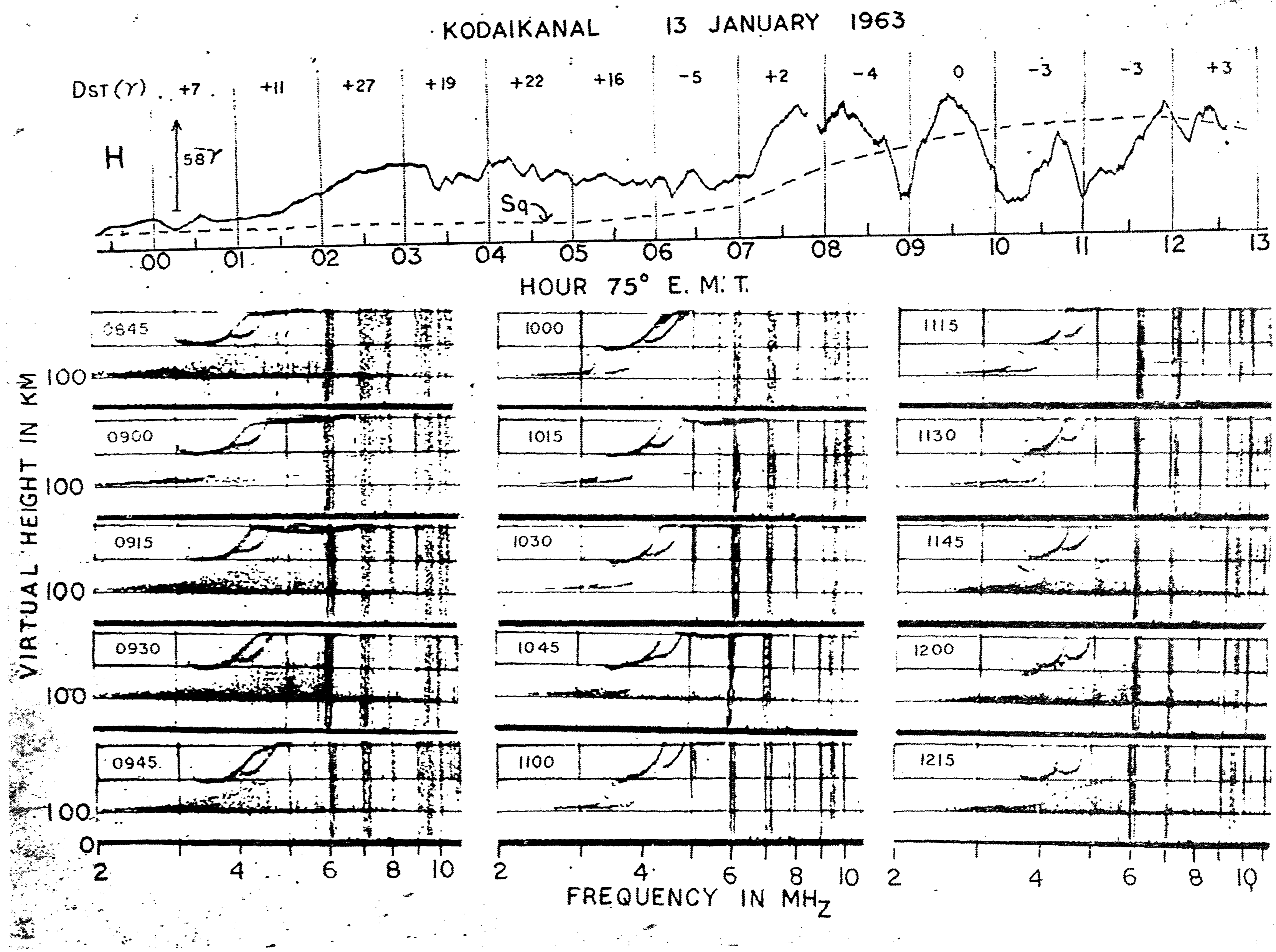

FIG. 6. Ionograms at Kodaikanal during a GC type of geomagnetic storm on 13 January 1963. Note the disappearance of E_s around 0900 hr, 1030 hr and 1100 hr corresponding to times of the minimum value of H field.

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