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On the Generation of Ionospheric E Region Irregularities during Equatorial Counter Electrojet

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ABSTRACT

Comparing the geomagnetic horizontal field H at the equatorial station Trivandrum and non electrojet station Alibag with the vertical incidence ionograms at Thumba (near Trivandrum) it has been shown that equatorial sporadic Esq layer disappears during the period of counter electrojet. On certain occasions the absence of Esq may be followed by reappearance of Esq type of echoes or the blanketing (Esb) layer or by multiple scattering layers. The sporadic layers are observed during the counter electrojet period only when either cusp type sporadic Esc or E2 layer is present before the start of the counter electrojet. The plasma instability associated with these Esq type of echoes during CEJ are suggested to be the cross field instability generated at the upper part of the intermediate (E2 or Esc) layers where the plasma gradient and Hall polarization field are both upward in direction.

INTRODUCTION

The solar daily (Sq) variations in the geomagnetic field was suggested by Stewart (1882) to be the result of the movement of conducting upper atmosphere across the vertical component of the geomagnetic field caused by the thermal winds. The discovery of ionosphere in 1925-26 and the studies of Chapman (1929) of tidal wind placed the dynamo theory on a firm footing. The disparity of the ratio of gyro frequency (ω) to the collision frequency (ν) for the ions and electrons causes them to move differently under the influence of applied electric field or a neutral wind. Considering the altitude variation of ω/ν for ions and electrons and the electron density, the current layer in the ionosphere was suggested to be between 100 and 125 km, the E region of the ionosphere. The abnormal enhancement of the solar daily variation of the horizontal geomagnetic field (H) within ± 3° from the dip equator discovered by Egedal (1947) was suggested by Chapman (1951) as due to eastward flowing band of current in ionospheric E region over the dip equator named by him as "Equatorial Electrojet Current" (EEJ). The horizontal electric and magnetic field in the equatorial ionospheric E region are eastward and northward respectively during the daytime hours causing vertical Hall polarisation electric field which in turn increases the electric conductivity in the EEJ region (Chapman 1956).

Soon after the discovery of EEJ, Matsushita (1951) showed that the top frequency reflected from the ionospheric sporadic E layer (fEs) shows similar enhancement over the equator as the solar daily range of H field, suggesting close relation between Es and EEJ. Rangarajan (1954) showed that the sporadic E at the equatorial station Kodaikanal is broadly of two types. The first consists of diffuse scatter due to now known equatorial type of sporadic E layer (Esq). These scatter echoes at the constant minimum height of 100 km do not blanket any reflection of radio waves from uniform layers in the upper E, F1 or F2 layers and extend upto frequency range greater than the critical frequency of the F2 layer. In case of good ionospheric sounder and sensitive antenna system, a triangular area between 100 km and normal E region critical frequency is full of scatter echoes, due to which normal E trace may not be clearly identified. The second main type of sporadic E consists of blanketing type of echoes called Esb, which partially or completely blankets reflections from upper E, F1 and F2 layers. Esb on occasions may show multiple reflections. Daily, seasonal and solar cycle variations of these two type of sporadic E layers at Kodaikanal have been described by Chandra & Rastogi (1974).

Gouin & Mayaud (1967) showed that the geomagnetic H field at Addis-Ababa on some occasions during the daytime hours decreased below the nighttime base level. They suggested the event as suggestive of a westward narrow ribbon of current and called it as Counter Electrojet (CEJ). The detailed morphology of the phenomenon as observed at different equatorial stations has been described by Rastogi (1974, 1989), Mayaud (1977) and Marriott, Richmond & Venkateswaran (1979).

Hutton & Oyinloye (1970) described the disappearance of Esq during CEJ events at Ibadan and Zaria. Rastogi, Chandra & Chakravarty (1971) showed that the sudden disappearance of Esq, CEJ and reversal of equatorial electric field are concurrent phenomena. Fambitakoye et al. (1973) showed that the Esq disappears not necessarily when the deviations of H field from its nighttime level (Δ H) becomes negative at the magnetic equator but rather when the latitudinal profiles of ΔH and ΔZ are reversed. For Indian sector Esq disappears when ΔH at Trivandrum minus H at Alibag [ΔH (TRD-ABG)] becomes less than zero i.e. becomes negative (Rastogi 1975a).

Events when ΔH (TRD) is positive but ΔH (TRD-ABG) is negative is named as partial CEJ. Chandra & Rastogi (1975) found that on certain CEJ events the disappearance of Esq is followed by Esb. During these events of Esb a significant southward movement of irregularities were noticed at Ahmedabad.

Comparing simultaneous observations of vertical incidence ionospheric drift, vertical incidence ionosonde and geomagnetic field data during CEJ events, Rastogi (1975b) suggested the existence of a westward current at 100 km simultaneously with the eastward normal Sq associated current at 106 km over the equator during CEJ. Carter, Balsley & Ecklund (1976) observed experimentally the simultaneous oppositely flowing current over the magnetic equator during CEJ events, the lower one flowing westward. Comparing the simultaneous rocket observations of electron density and ionospheric current profiles over the equatorial region, Rastogi (1972) showed that both the upward Hall polarisation field and the upward gradient of electron density are maximum at 100 km, the seat of Esq irregularities. Thus Esq was suggested to be due to cross-field instability mechanism.

The Doppler shift power spectra derived from the VHF forward and back scatter Doppler radar have enabled the verification of the direction of ionospheric electric field and the characteristics of plasma irregularities in the equatorial ionosphere. Bowles, Balsely & Cohen (1963) observed at Jicamarca VHF irregularities associated with a two stream instability when the electron velocity was larger than the ion acoustic velocity now called Type 1 irregularities. Later another type of Doppler spectrum called Type 2 was identified by Cohen & Bowles (1967) and was associated with the cross-field instability. Further Type 1 irregularities were associated with peak E region drifts around 108 km while Type 2 was associated with Esq at 100 km (Fejer et al. 1975).

During the counter electrojet both type 1 and 2 echoes were shown to disappear [(Rastogi 1973; Fejer et al. 1976; Carter, Balsley & Ecklund (1976)]. Crochet, Hanuise & Broche (1979) reported the reappearance of the two-stream, type 1 instabilities when the amplitude of the decrease of H field was large. Reddy, Somayajulu, & Viswanathan (1980) reported a reverse flow of the electrojet over Thumba during a strong CEJ. Somayajulu & Viswanathan (1987) reported the occurrence of blanketing Es layers during CEJ. Somayajulu et al., (1994) for the first time reported the occurrence of type 2 echoes by VHF backscatter radar at Thumba during a strong CEJ on 30 June 1987.

Thus there seems to exist some contradictory observations of ionospheric irregularities during counter electrojet period. Since the installation of Australian KEL IPS-42 ionosonde at Thumba in April 1986 and a reasonable antenna system, good ionograms are now available. It was felt useful to study these ionograms during some moderately strong counter electrojet days. The present paper describes the result of inter- comparison of the ionograms with simultaneous geomagnetic data at Trivandrum and Alibag.

OBSERVATIONS

The counter electrojet on 27 February 1996

Fig.1 shows the daily variations of the geomagnetic H field at Alibag (ABG), Trivandrum (TRD) and ΔH at Trivandrum minus ΔH at Alibag [ΔH (TRD-ABG)]. The figure also shows few ionograms at Thumba.

The daily variation of ΔH (TRD) showed a clear CEJ beginning shortly after 1130 LT and ending around 1500 LT. The ΔH(TRD-ABG) showed a deeper depression from 1100 to 1530 LT. The ionograms showed the clear signatures of Esq at 07 LT which continued till 1030 LT. The ionogram at 1130 LT showed complete absence of any sporadic E signals and this No - Es condition continued until Esq reflections were again recorded at 1600 LT. This is a very clear and normal case of the disappearance of Esq during CEJ period at an equatorial station. It is to be noted that throughout the day complete F1 traces were recorded without any blanketing of the F1 trace. The group retardation at the very beginning of F1 trace confirms the absence of any ionisation layer between E and F1 layers.

The partial counter electrojet on 26 February 1996

Fig.2 shows the daily variation of H field at TRD, ABG and TRD-ABG, together with the reproduction of few ionograms at Thumba. The H field at TRD showed a depression during midday hours but the minimum value of ΔH (TRD) was clearly positive. The value of ΔH (TRD-ABG) was negative from 1000 to 1430 LT. The ionograms showed a well developed Esq at 0800 LT to 0930 LT. At 1000 LT the Esq had disappeared and normal E region traces with minimum virtual height at 100 km were clearly recorded with both ordinary and extraordinary frequencies. The F1 traces did not begin at the end of E region critical frequencies but an intermediate layer between E and F1 layers was very clearly recorded. This is classified as cusp type of Es layer (Esc). It is noted that both ordinary (O) and extraordinary (X) critical frequencies of the intermediate layer had a separation similar to that between two critical frequencies of normal E layer.

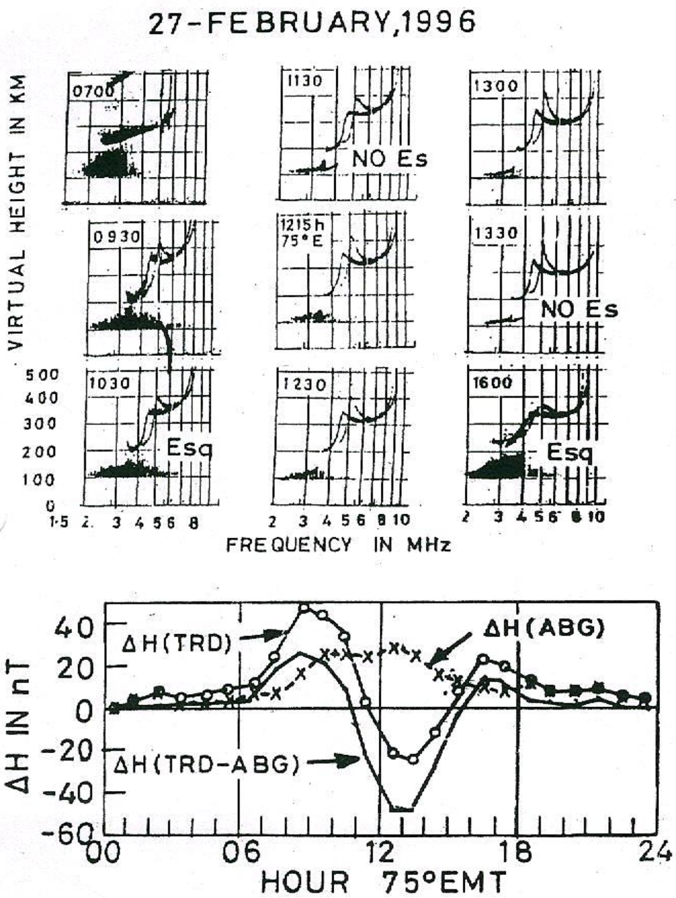

Figure 1. The daily variations of the geomagnetic H field at Trivandrum (TRD), at Alibag (ABG) and ΔH (TRD-ABG) on 27 February 1996. Some of the ionograms at Thumba are also reproduced showing the disappearance of Es during counter electrojet period.

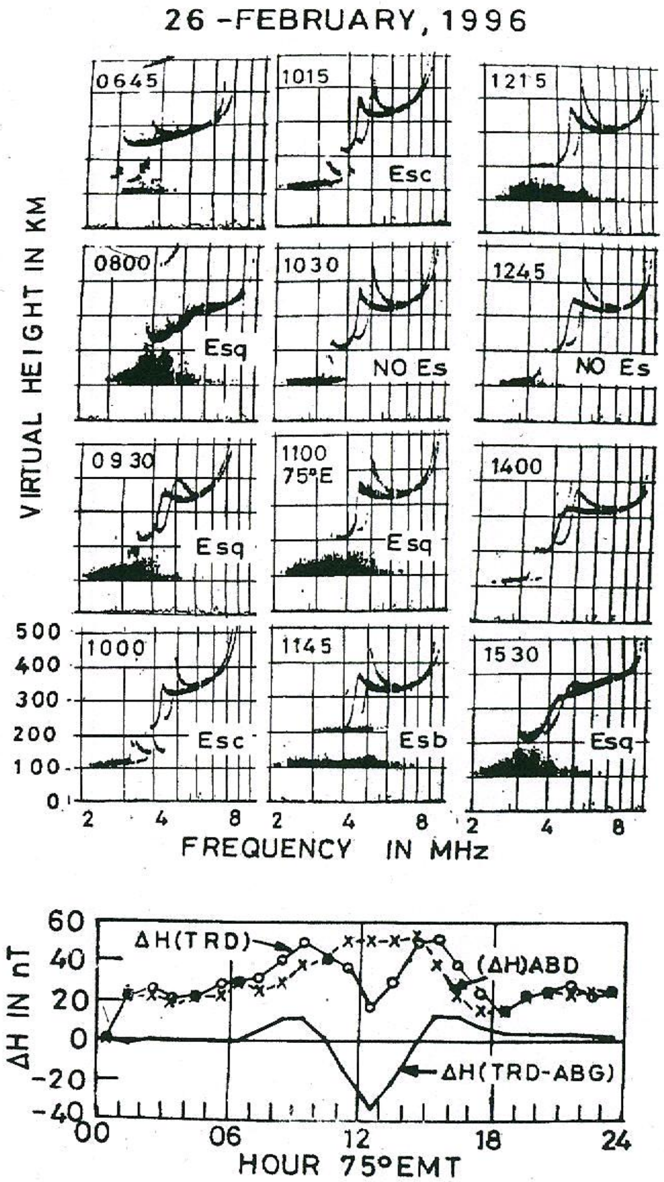

Figure 2. The variations of ΔH at Trivandrum, Alibag and Trivandrum - Alibag as well as some of the ionograms at Thumba showing disappearance of Esq, reappearance of Esq and Esb during the partial CEJ on 26 February 1996.

Thus Esc should be considered as a thin layer of ionisation and not a thin layer of plasma irregularity as Esq. At 1015 and 1030 LT the ΔH(TRD-ABG) was negative and the Esc seems to descent due to downward Hall polarisation field existing in the E region. At 1100 LT diffuse scatter echoes, similar to Esq were recorded. This transformed into Esb characteristic at 1145 LT and at 1245 LT all the Es reflections disappeared. The normal Esq layers were again clear at 1530 LT when CEJ had ended.

This example shows that when Esc is present at the start of CEJ the sequence of events are the disappearance of Esq, appearance of Esq type sometimes afterwards followed by Esb and disappearance again of all sporadic E echoes till the end of CEJ when normal Esq is again restored.

Observations during full day CEJ on 31 January 1996

The third example relates to the CEJ event of 31 January 1996. The magnetograms and some related ionograms are shown in Fig. 3. ΔH(TRD) showed negative values between 1200 and 1500 LT but ΔH(TRD-ABG) showed negative values indicating CEJ almost for the whole daytime hours. The ionogram for 0715 LT showed well developed Esq layer. At 0745 LT the Esq had disappeared but some additional echoes on both the ordinary and extraordinary traces were noticed intermediate between E and F1 layers. The beginning of F1 traces showed prominent group retardation suggesting that the underlying layer had a uniform ionisation structure. At 0800 LT very clearly the normal E and intermediate E2 layers were recorded on the ionogram with no Es layer seen. This feature continued in later records and the minimum virtual height of E2 layer decreased suggesting the slow descent of the ionisation ledge due to the downward Hall polarization field. At 1045 LT multiple mixture of Esq and Esb scatter echoes were recorded between 100-150 km altitude. At 1100 LT very clear normal E layer traces at 100 km and Esc traces at 115 km were recorded. At 1115 LT all scatter echoes again disappeared and only clean E and E2 traces reappeared. At 1315 LT E2 layer also disappeared and clean normal E traces were observed until the end of CEJ period after which strong Esq reappeared.

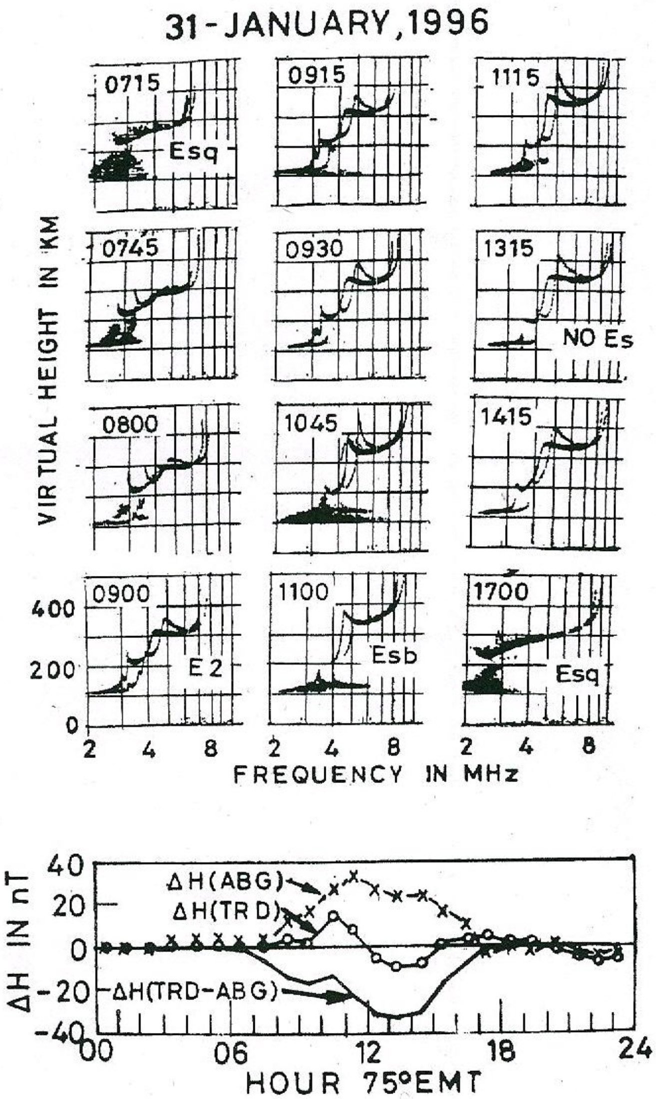

Figure 3. The variation of ΔH(TRD), ΔH(ABG) and ΔH(TRD-ABG) and the ionograms at Thumba showing the disappearance of Esq and appearance of Esb during the CEJ period on 31 January 1996 .

DISCUSSION & CONCLUSIONS

Rastogi (1972) had shown that the equatorial sporadic E layer (Esq) occurs at an altitude of 100 km at any of the equatorial electrojet station around the world. The vertical plasma density gradient and the Hall polarization field are also maximum at 100 km and both are directed upward during normal eastward flowing electrojet current periods. Thus the electric field interacts with plasma density gradient generating the cross field plasma instability at 100 km altitude which are detected as Esq layer by HF ionosondes and as type 2 irregularities by HF and VHF Doppler radar. During periods of complete or partial CEJ, the horizontal electric field at 100 km is reversed to westward direction with the result that Hall polarization field too gets reversed to downward direction. Insitu measurements of electron density by rocket borne equipment have shown that the electron density profile in the E region during counter electrojet periods is not changed with comparison to that during normal electrojet (Prakash et al. 1979).

Thus, the vertically downward directed Hall polarization field and upward directed plasma density gradient makes the E region irregularities to disappear. The growth rate or the decay rate of these Esq type of irregularities are less than 1 minute (Rastogi, Deshpande & Sen 1975).

On certain occasions intermediate layer (E2) or ledge of ionisation (Esc) are observed before the start or during CEJ. Such ionisation layers have been observed directly by rocket borne experiments at Thumba, India (Prakash et al. 1979). The reversed electric field causes this ledge to descend and when it reaches region of now reversed Hall polarization field, cross field instabilities are generated in the topside of the intermediate E layer or Esc where the plasma density gradient is also downward. With continued descend the intermediate layer may become sharper and blanketing type of Es layer, Esb may develop. With time the ionisation in the intermediate layer may decay and No- Es condition may be again restored till the end of the CEJ period. The equatorward movement of Esb (Chandra & Rastogi 1975) may be the cause of triggering of ionisation ledge above the normal E layer.

Further studies of simultaneous ionograms, VHF Doppler radar data at Thumba with high resolution geomagnetic data at Trivandrun and Alibag are recommended.

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