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Space disturbance effect on equatorial sporadic-E during sunrise

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The space weather event of 25 September 1998 and its effect in the E-region near magnetic equator has been studied. The geomagnetic H field variations recorded at low latitudes was normal on 24 and 26 September 1998 but there was a geomagnetic storm on 25 September with sudden commencement at 0445 hrs LT (75° EMT). There was a strong counter electrojet after sunrise associated with the magnetic storm. Solar wind speed and ion density and the interplanetary magnetic field (IMF) data show the IMF B_Z turning towards south in the morning on 25 September 1998 and solar wind velocity was 850 kms^{-1}. Quarter hourly ionograms at Thumba, located close to the dip equator were examined during morning hours on 24-26 September 1998. On 24 and 26 September 1998, E-region irregularities (E_{s-q}) were first generated about an hour after the appearance of fresh E-region ionization following sunrise and by the time ΔH at Trivandrum started increasing above the corresponding value at Alibag. On the disturbed day, 25 September 1998, E_{s-q} appeared later due to occurrence of counter electrojet after sunrise. This is caused by electric field changes associated with the magnetic storm rather than the late reversal of the electric field in the morning.

Keywords: Equatorial electrojet, Equatorial sporadic-E, Magnetic disturbance
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1 Introduction

The enhancement of solar daily range of the horizontal (H) component of geomagnetic field[1] and later of the maximum frequency reflected from the ionospheric sporadic layer E_s by Matsushita[2] over the magnetic (dip) equator opened up a new phase of equatorial aeronomy. Knecht[3] described special features of the E_s at equatorial latitudes and called it q type of E_s or E_{s-q}, viz.: (1) This layer is always transparent to radio waves, i.e. never blanks reflections from higher layers; (2) No multiple echoes are observed from this layer; and (3) A well defined lower edge between 100 and 110 km with diffuse echoes above the principal echoes.

The E_{s-q} was found to disappear suddenly at different times of the day at equatorial stations[3-5] and such an event was shown to coincide with a decrease of H field[6]. Rastogi *et al*.[7] first showed that sudden disappearance of E_{s-q} are coincident with the decrease of H below the night time base level and the reversal of E region electric field. Rastogi[8-9] identified E_{s-q} as the gradient-drift instability at the base of E region of the ionosphere. Radar measurements later showed that the irregularities associated with the gradient-drift instability disappear during counter electrojet and the current flow is reversed to westward[10-12]. In the Indian region, the occurrence of counter electrojet is mainly in the afternoon and seasonally the maximum during June-solstices[13]. Bhargava & Subrahmanayam[14] and Rastogi[15-16] described the disappearance of E_{s-q} during magnetic storms. Chandra & Rastogi[17] showed that during geomagnetic storms, there are daytime counter electrojet event with eastward electron drift and disappearance of E_{s-q} irregularities.

The association between the interplanetary magnetic field (IMF) and geomagnetic activity is well known[18-19]. Increasing southward component of IMF increases the reconnection rate at the southward side of the magnetosphere. Nishida[20] showed good correlation between the geomagnetic horizontal component at Huancayo and the B_Z component of IMF.

There have been numerous studies related to geomagnetic storm effects in the ionosphere and thermosphere[21-25]. Prompt penetration and disturbance of dynamo electric fields, though of smaller magnitude, are the important sources of low latitude ionospheric electrodynamic disturbances. Sharp electric field perturbations with time scales typically shorter than an hour are mostly due to the prompt penetration of solar wind / magnetospheric electric fields to middle, low and equatorial latitudes[22]. Quasi-period (DP2) magnetic field fluctuations with time scale of about half an hour to several hours at high latitudes and in the dayside of magnetic equator are signatures of convection electric fields controlled by IMF B_Z. Slower varying electric field disturbances with time scales of few hours to tens of hours are identified as ionospheric disturbance dynamo electric fields caused by enhanced energy deposition in to the auroral ionosphere[26]. There have been a number of case studies of major space weather events and associated response to ionosphere but largely dealing with F-region of ionosphere.

A major space weather event occurred on 25 September 1998. The sudden commencement (SC) occurred at 2345 hrs UT (0453 hrs LT) corresponding to the time of maximum dawn – dusk electric field. This paper describes the interplanetary magnetic field and solar wind parameters during the space weather event and associated effects in the E-region at Thumba (Latitude 8.5°N, Longitude 77.0°E) situated close to the magnetic equator.

2 Observations

The tracings of the H magnetograms at Trivandrum (dip equator) and Alibag (away from dip equator) during 0000-0900 hrs (75° EMT) on 24, 25 and 26 September 1998 are shown in Fig. 1. On 24 and 26 September, there were small and slow increase of H at Alibag (ABG) from 0000 to 0900 hrs LT. At Trivandrum (TRD), the magnetic H field increased slowly up to 0700 hrs LT and increased sharply after 0700 hrs LT suggesting the start of the eastward electrojet current. On 25 September, there were similar fluctuations at ABG and TRD during 0000-0400 hrs LT. A sudden commencement (SC) occurred at 0445 hrs LT in two steps and it was interesting to note that the amplitude of SC (ΔH) was stronger at ABG than at the equatorial station TRD. The value of ΔH, with reference to pre-SC value at 0400 hrs LT after the SC, were consistently smaller at TRD than at ABG all the time up to 0900 hrs LT suggesting the existence of counter electrojet (westward electric field). The occurrence of the counter-electrojet on 25 September 1998 is clearer on the plots of hourly values of the daily range of H at a chain of stations in India after subtracting Sq and Dst values as shown in Fig. 2. The counter electrojet is clearly seen at stations Trivandrum (TRD), Ettiapuram (ETT), Kodaikanal (KOD) and Pondicherry (PON) situated closer to the magnetic equator. Rapid decrease is seen following the SC and from 0700 to 0900 hrs LT, the values are 40-50 nT below night time values at TRD, 20-30 nT below night level at ETT and just below night level at KOD. Though the values at PON (or KOD) do not fall below night level but decrease is clearly seen similar to KOD, ETT and TRD. However, away from the magnetic equator at Alibag (ABG) and Ujjain (UJJ), no such decrease is seen.

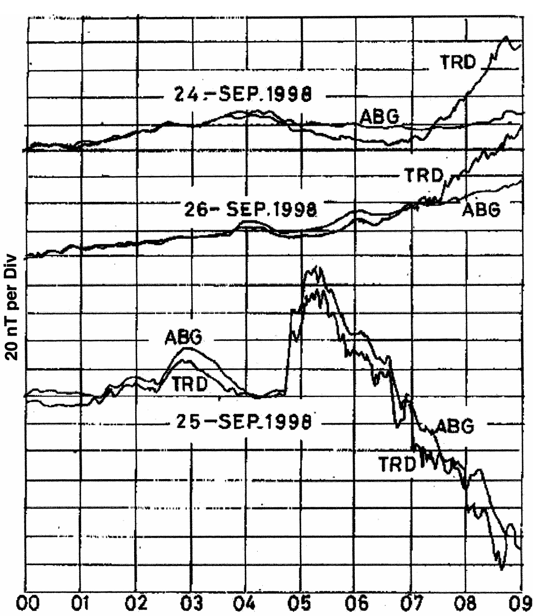

Fig. 1 — Recording of H magnetograms at Trivandrum(TRD) and Alibag (ABG) on 24-26 September 1998

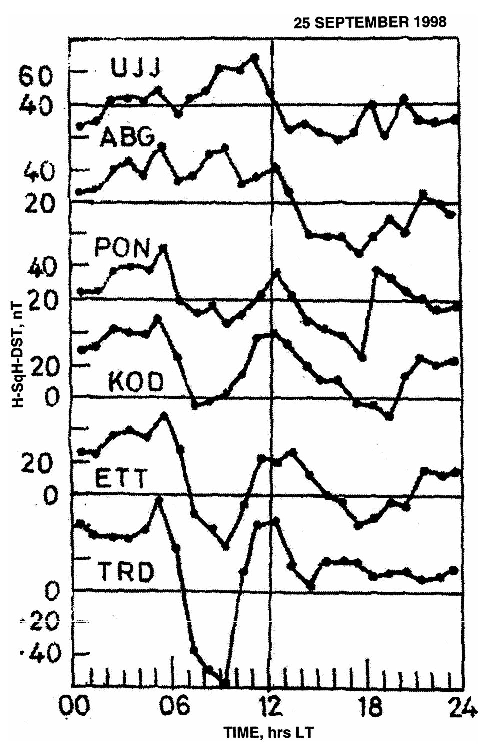

Fig. 2 — Hourly values of the range in H after subtracting Sq and Dst on 25 September 1998 at a chain of stations in India showing counter electrojet in the morning hours

The variations of the solar wind density and speed and the southward component of the interplanetary magnetic field from satellite measurements (ACE, IMP8, WIND) on 25 September 1998 are shown in Fig. 3. Also shown in the figure are Dst values, the range in H after subtracting S_q (H) for both Trivandrum and Alibag and the difference between the range at Trivandrum and Alibag (measure of electrojet strength). It is interesting to note that B_Z component of IMF remained southward right from 0500 to 2100 hrs LT on 25 September 1998. The solar wind speed was less than 500 kms^{-1} till 0500 hrs LT and then sharply increased and reached peak value of 850 kms^{-1} at 1300 hrs LT. Solar wind density also showed increases twice on this day, first from 0500 to 0700 hrs LT and then again around midday from 5 cm^{-3} to 20 cm^{-3}. Dst values reached to about –200 nT around midday. The range in H at Trivandrum after subtracting S_q (H) shows close similarity with the variation in the B_Z component of IMF. The difference in the range in H at Trivandrum and Alibag shows strong counter electrojet from 0530 to 1100 hrs LT with values of more than –100 nT. The counter electrojet around sunrise is due to the dusk-dawn electric field generated due to the action of the rapid decrease of IMF B_Z simultaneously with the rapid increase of solar wind velocity. This effect is superimposed on the effect due to decreasing Dst index caused by the development of the disturbance ring current. The dusk-dawn electric field decreased when the gradient of IMF B_Z as well as solar wind velocity became steady. The event is closely associated with the sudden turning of Bz, therefore, reversal of ionospheric current is suggested due to the magnetopause electric field (VxB) communicated through polar latitudes to the equatorial region**.** Thus, the unique case of the counter electrojet in the morning on 25 September 1998 is not the late reversal of electric field but a counter electrojet due to the space weather event. Sastri *et al.*[24] also reported a counter electrojet in the morning on 4 November 1993 with absence of q type of E_S at Thumba between 0645 to 0815 hrs LT (75 EMT) in response to the major magnetic storm on 3 November 1993. Figure 4 shows some selected

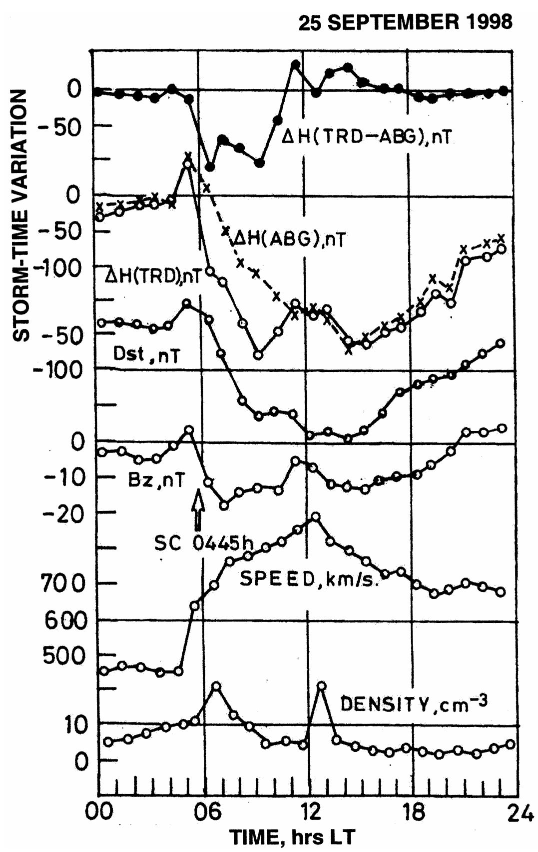

Fig. 3 — Variation of solar wind density, solar wind speed, B_Z component of IMF, equatorial Dst, range in H at both Trivandrum and Alibag after subtracting the S_q(H) and of the difference in the range in H at Trivandrum and Alibag plotted from 1800 hrs LT on 24 September 1998 to 0600 hrs LT on 26 September 1998

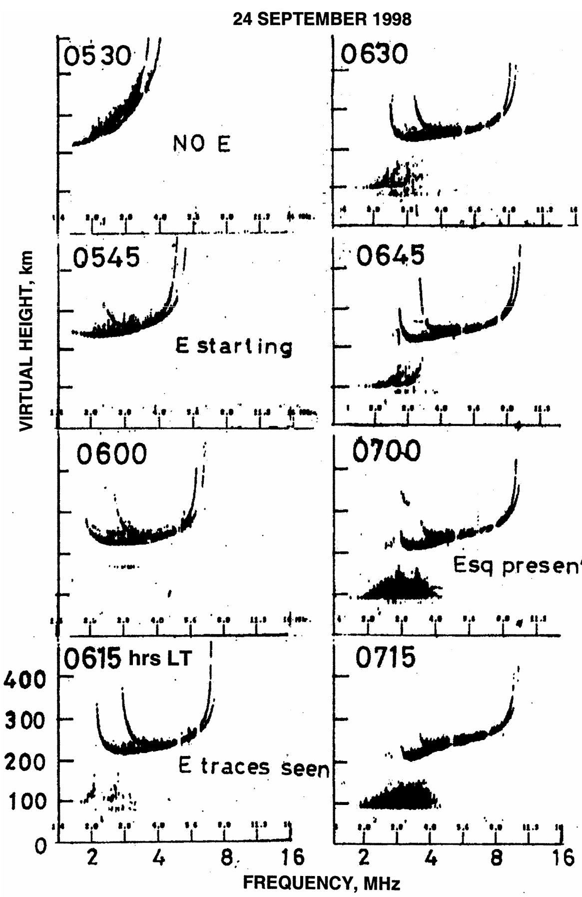

Fig. 4 — Selected ionograms at Thumba during morning hours on 24 September 1998

ionograms between 0530 and 0715 hrs LT on 24 September 1998. At 0530 hrs LT, only F layer traces were recorded and no indication of group retardation were seen at the start of the F region trace suggesting absence of E layer ionization at that time. At 0545 hrs LT, F region critical frequencies increased indicating the effect of sunrise in the ionosphere. Clear group retardation was recorded at the start of F layer traces suggesting the creation of fresh ionization in the E-region. At 0615 hrs LT, the normal E region traces were recorded. At 0630 and 0645 hrs LT, some weak scatter echoes were seen. At 0700 hrs LT, fully developed $E_{s\text{-}q}$ configuration of echoes was recorded. It is to be noted that $E_{s\text{-}q}$ was recorded more than an hour after the creation of normal E-region ionization.

Figure 5 shows some reproduced ionograms at Thumba on 26 September 1998. On this day even at 0530 hrs LT, new E-region ionization were indicated by the group retardation at the start of F region traces. At subsequent intervals, both E and F layer ionizations continued to increase and the E-region traces were first seen at 0615 hrs LT. The critical frequencies of E-layer marked for ionograms at 0530, 0545 and 0600 hrs LT are scaled from the cusp of F-layer traces at the lower frequency side due to the group retardation effect of underlying ionization. Some weak stray scatter echoes were seen in the ionograms at later times but the equatorial type $E_{s\text{-}q}$ was recorded only at 0715 hrs LT. Thus, E-region irregularities seem to have developed more than 90 min later than E-region ionization itself.

Figures 6 (a) and (b) show selected ionograms at Thumba on 25 September 1998. The ionogram traces at 0530 hrs LT indicate a rather stretched F layer due to fresh ionization starting above the remaining nighttime F layer. The fresh ionization in the E-region is also indicated. At 0615 hrs LT, the F region traces were normal and the E-region traces with weak sporadic-E echoes at 100 km were also seen. The sporadic-E layer echoes were fairly strong at 0630 hrs LT but no slant echoes were recorded to give the triangular configuration of $E_{s\text{-}q}$. Very weak $E_{s\text{-}q}$ trace is seen at 0645 and 0700 hrs LT, however, at 0715 hrs LT, scatter signals were completely absent. In subsequent ionograms, both normal E and sporadic-E traces were recorded with clear separate identifications. At 0930 hrs LT, strong equatorial sporadic-E echoes were recorded in the ionograms.

Ionograms at selected times between 0615 and 0945 hrs LT on 24-26 September 1998 are reproduced in Fig. 7. This again shows that development of

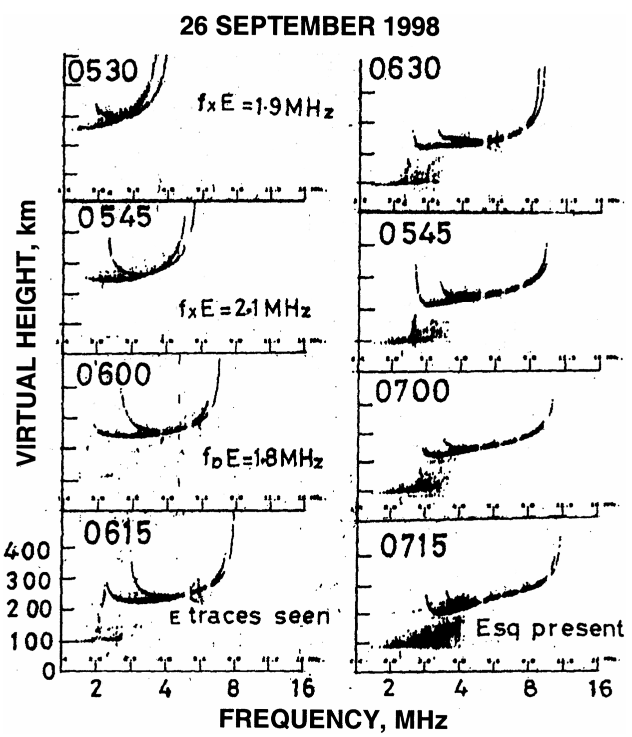

Fig. 5 — Selected ionograms at Thumba during morning hours on 26 September 1998

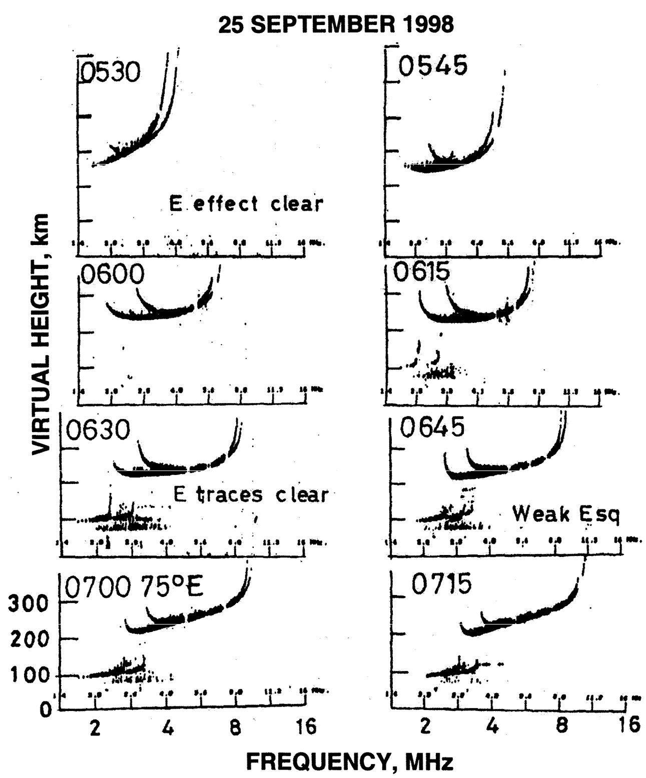

Fig. 6(a) — Selected ionograms at Thumba during morning hours on 25 September 1998

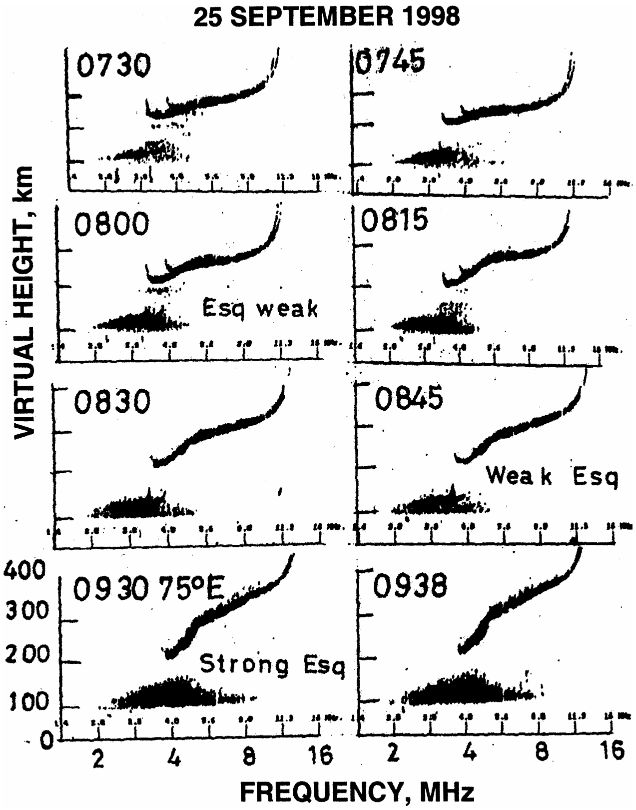

Fig. 6(b) — Selected ionograms at Thumba during morning hours on 25 September 1998

sporadic-E on 24 and 26 September is identical with clear E-region traces at 0615 and 0645 hrs LT and q type of sporadic-E developing from 0715 hrs LT. However, on 25 September, clear E-region traces are seen up to 0715 hrs LT. From 0745 hrs LT, there are q-type sporadic-E echoes but comparatively weaker than on other two days. Strong sporadic-E echoes are seen only from 0945 hrs LT. Figure 2 shows geomagnetic H variations based on hourly values at Indian stations. The tracing of geomagnetic H records at Trivandrum and Alibag during 2300-0400 hrs UT are shown for 24-25 and 25-26 September in Fig. 8. On 25-26 September, values at Trivandrum increase rapidly after 0700 hrs LT with respect to the values at Alibag indicating the normal electrojet. On 25-26 September, similar fluctuations are seen at the two locations from 0500 to 0630 hrs LT (0000 to 0130 hrs UT). Between 0630 and 0645 hrs LT (0130 and 0145 hrs UT), values at Trivandrum are lower than at Alibag. There is an increase in H at Trivandrum from 0645 to 0700 hrs LT (from 0145 to 0200 hrs UT). From 0720 to 0815 hrs LT (0220 to 0315 hrs UT), the values at Trivandrum are lower than at Alibag indicating counter electrojet. This is followed by another counter electrojet event from 0815 to 0845 hrs LT (0315 to 0345 hrs UT). Both the counter electrojet events are shown as shaded in the figure. Rapid sequence of ionograms are not available to correlate the rapid changes in the geomagnetic H variation but the quarter hourly ionograms in Figs 6 (a) and (b) show weak $E_{s\text{-}q}$ traces for some ionograms.

3 Discussion

Using ionograms taken at interval of 1 min, Rastogi *et al.*[27] showed that $E_{s\text{-}q}$ can disappear or reappear on two consecutive records spaced by 1 min interval and suggested that time of growth of $E_{s\text{-}q}$ is less than a min. Using modified Range-Time-Intensity records of VHF backscatter echoes at Jicamarca, Rastogi *et al.*[28] showed that E-region irregularities during daytime geomagnetic disturbed periods

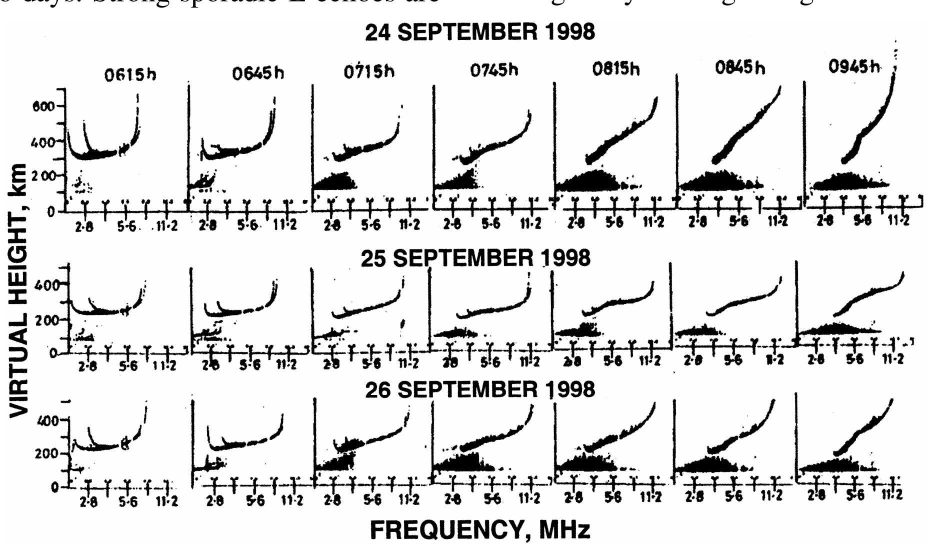

Fig. 7 — Ionograms at selected local times between 0615 and 0945 hrs LT at Thumba for each day during 24-26 September 1998

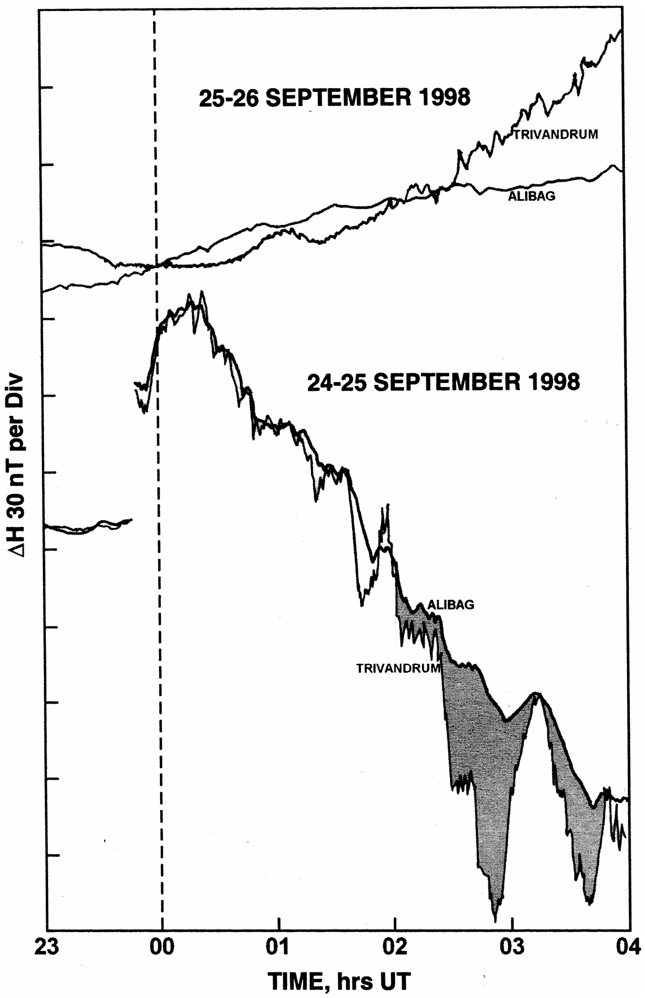

Fig. 8 — Recording of H magnetograms at Trivandrum and Alibag on 24-25 and 25-26 September 1998 during 2300-0400 hrs UT

disappeared (or reappeared) precisely when ΔH decreased below (or increased above) the night time base level, suggesting a rapid growth of irregularities.

High time-resolution VHF Doppler radar observations at Thumba have been useful in studying the growth of irregularities during sunrise. Rastogi & Patil[29] found that the radar echoes at Thumba start in the morning only after ΔH at TRD exceeds 20 nT above the night value, suggesting the requirement of a base level of E-region ionization when only the electric field can generate irregularities. The equatorial type of sporadic-E was shown to start about 10 min later than S_q current system. The results presented here also show that $E_{s\text{-}q}$ at Thumba appears on the ionograms about an hour after the initiation of E-region ionization after sunrise. Thus, there could be a minimum threshold ambient ionization required for the backscatter signal to be strong enough to be detected. Booker and Gordon[30] developed the theory of radio wave backscattering by turbulent fluctuations of the atmosphere. Coherent backscatter is dependent on relative mean square fluctuations in the radio refractive index. For the ionized medium, it depends on the relative mean square fluctuations in electron density and also to the fourth power of plasma frequency. Thus, the backscatter depends both on percentage fluctuations of irregularities with scale size corresponding to half of the probing wavelength and to ambient ionization.

The presence of the irregularities would also depend on the electric field. For the upward plasma density gradient, electric field has to be eastward. Looking at the magnetograms in Fig. 1, the difference between H at Trivandrum and Alibag, a measure of the electrojet, becomes positive only around 0700-0715 hrs LT on 24 and 26 September 1998 but after 0900 hrs LT only on 25 September 1998. Thus, the late appearance of q type of sporadic-E on 25 September 1998 is due to the counter electrojet in the morning.

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