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Counter-electrojet and *Esq* disappearance

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Abstract—The disappearance of *Esq* type traces from ionograms at the magnetic equator during magnetically quiet periods is related to inverted latitudinal profiles of the regular daily magnetic S_R variation (in its horizontal and vertical components). Latitude profiles obtained from a meridian chain of nine magnetometers across central Africa are compared with corresponding quarter-hourly ionogram sequences from Fort-Archambault-Sarh (Chad). Between 0900 and 1500 LT, the magnetic reversal coincides exactly with the disappearance of *Esq* traces. This evidence gives additional weight to the hypothesis of a counter-electrojet current belt, located on exactly the same latitudes as the normal electrojet and probably flowing below it at the bottom of the *E*-layer. It agrees well with present theory on type II slow turbulent modes, and confirms the $V_e \wedge B$ plasma instability mechanism as the cause of *Esq* inhomogeneities at this level.

1. Introduction

It is well established that the equatorial electrojet current results from the amplification of the regular daily S_R variations along the magnetic dip equator.

The symbol S_R (Mayaud, 1967) denotes the variation which occurs regularly every day whatever the level of magnetic activity because of the permanent existence of field sources such as ionospheric current systems. This definition of S_R differs from the more usual one of *Sq*, a statistical concept for the mean variation of the five international quiet days of a month (like *Sd* for the five international disturbed days). S_R expresses what would be the *Sq* for each day, if *Sq* were taken apart from its statistical sense.

Normal electrojet effects

The effect of the electrojet on magnetic field components has been compared to that of a belt of current of limited width, running along the magnetic dip equator from west to east: the horizontal *H* component shows a sharp maximum at the dip equator itself negative and positive peaks in *Z* appear about 300 km to the north and south of this line.

During magnetically quiet periods the electrojet effect on ionograms is a trace rather like sporadic-*E* but thicker and more diffuse, which lasts throughout the day without occulting upper ionospheric layers. Skinner and Wright (1962) described some of its statistical properties for the I.G.Y. period. Using diffraction geometry, Cohen and Bowles (1963) showed that the structure responsible must be a thin regular pattern of horizontal field-aligned inhomogeneities. Passing through this structure, incident square-pulsed sounding waves scatter and reflect at the ambient plasma frequency levels to give a multi-angular uniform spectral distribution of echoes within a wide virtual E-region range. The bottom limit of the echoes lies at the true height of the inhomogeneities in the lower E-region.

The analysis of the Jicamarca backscatter radar records revealed two types of plasma instabilities with different Doppler shifts (BALSLEY, 1969): a high-velocity *type* I, which maintains plasma wave structures through a two-stream mechanism whenever $V_e - V_i > V_{\text{acoustic}}$ (FARLEY, 1963; WALDTEUFEL, 1965; ROGISTER, 1971); and a continuous series of slower *type* II turbulent modes.

Counter-electrojet effects

At Addis Ababa in 1962, Gouin has already pointed out some negative noon-time values of the S_R variation (in relation to the night level) of the H magnetic field component, lasting up to 3 hr. He and MAYAUD (1967) found these distortions to be less frequent at noon than in the morning and evening; as they occur at the same time on several consecutive days, they cannot be due to lunar effects. Comparing their magnetograms with those from other stations, Gouin and Mayaud became convinced that these negative variations were confined to equatorial latitudes in exactly the same way as the electrojet amplification itself. As the negative variations in H were not related to any S_R variation of the declination, these authors attributed them to a belt of current flowing from east to west. They named it the counter-electrojet.

Using a meridian chain of nine magnetometers across the magnetic equator in central Africa, FAMBITAKOYE (1971) obtained latitude profiles for the S_R variation of H and Z. At times, these profiles are shaped exactly as might be expected if the belt of current which usually flows eastward has reversed completely, H showing a trough instead of a peak at the magnetic equator and Z being minimum in the south and maximum in the north.

The Gouin–Mayaud hypothesis was thus confirmed: a 'counter-electrojet' belt of current running from east to west must occasionally predominate over the normal west–east electrojet flow.

Slightly earlier, HUTTON and OYINLOYE (1970) had compared 1963 ionograms and magnetograms from Ibadan, in the electrojet zone. They found *Esq* disappearance to be related to a negative variation of the horizontal component H, as already described by BANDYOPADHAY and MONTES (1963) at Huancayo.

In 1971, Rastogi *et al.* compared simultaneous observations of the H magnetic field component with *Esq* traces and electron drift velocities at Trivandrum. During both quiet and disturbed periods, abnormally sharp falls of H relative to its night-time level are always accompanied by *Esq* trace disappearance and a reversal of the electron drift. This suggests temporary reversals of the electrojet current, due to an electrostatic field in the opposite direction to that of the normal S_R system (RASTOGI *et al.*, 1971; RASTOGI, 1972).

We here present some results which relate reversal of the S_R variation in H and Z with the disappearance of the ionospheric *Esq* traces.

The important fact emerges that during the magnetically quiet periods of the present study, the disappearance of *Esq* is linked to the reversal of the magnetic latitude profile, but does not require S_R of H to become negative.

2. Description of the Results

Six temporary magnetic stations operated in 1969 across the magnetic equator on the 17° east meridian in central Africa (Chad and Central African Republic). With the three permanent observatories in Tamanrasset, Bangui and Binza, they provided latitude profiles over a 3000-km zone. An ionosonde took quarter-hourly records at Fort-Archambault-Sarh, a station located 140 km south of the magnetic equator on the 18° east meridian.

We have selected for study four quiet days of typical *Esq* disappearance and four adjacent normal days. Figure 1 describes the phenomenon for one pair of days, while Figs. 2–5 give time curves for all four pairs of days.

On Fig. 1, S_R latitude profiles and ionograms are compared for four successive hours (1230–1530 LT) of 15 (counter-electrojet day) and 16 July (normal day). The profile is obtained by plotting for each hour the ΔH or ΔZ deviation relative to

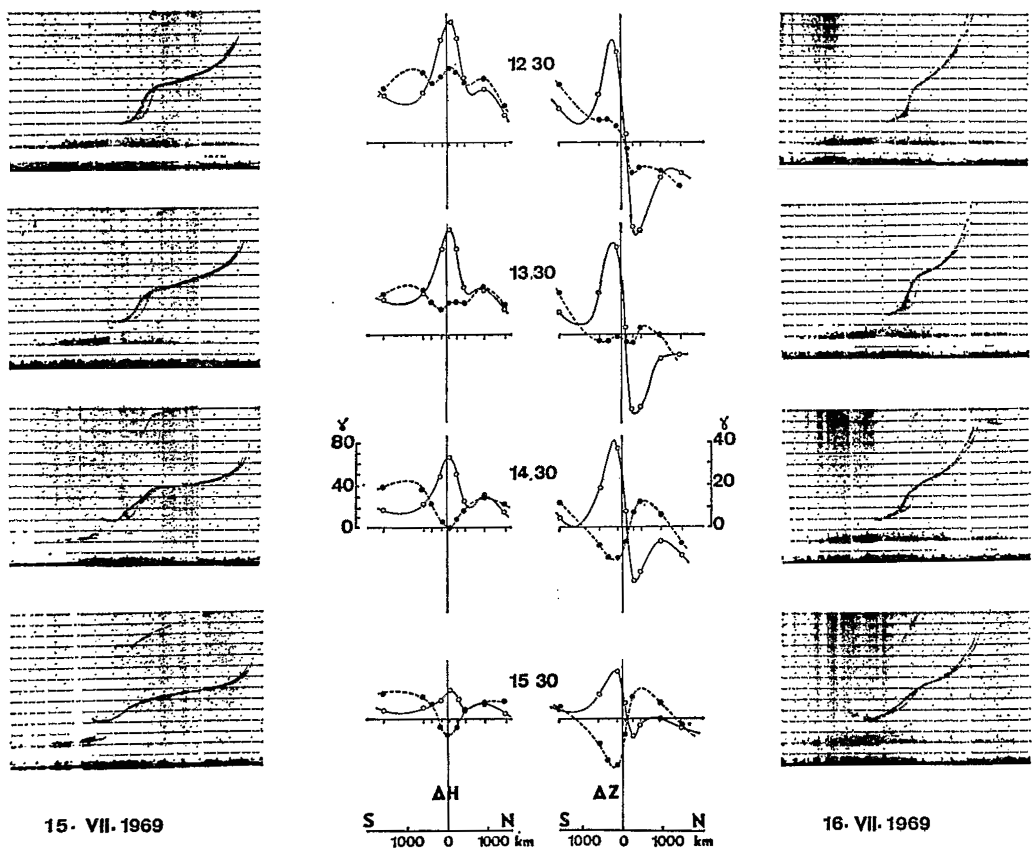

Fig. 1. Centre: latitude profiles of H and Z across the magnetic equator in central Africa. 15 July 1969, counter-electrojet day, broken line. 16 July 1969, normal day, solid line. Local time marked at the center of each horizontal row, increasing downwards. Sides: comparison with corresponding ionograms at Sarh (left) 15 July; (right) 16 July.

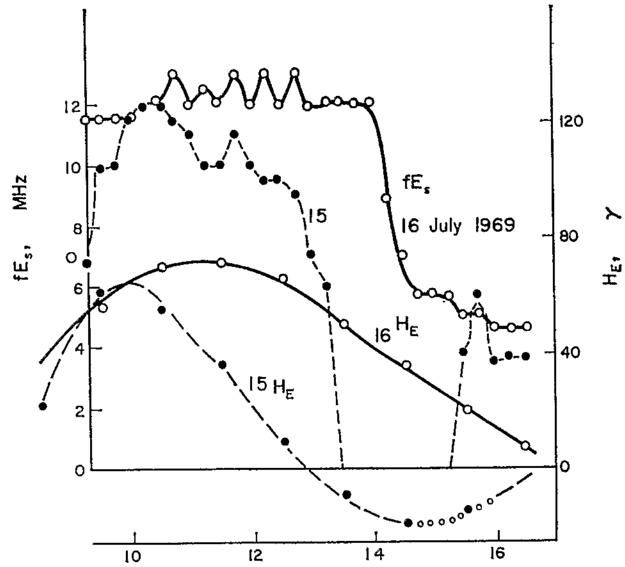

Fig. 2. LT variation of $H_E = H_{\text{equator}} - H_{\text{tropics}}$ in gamma: (right ordinate scale, thick curve) and of $fEsq$ in MHz (left ordinate scale, thin curve) for the same days and with the same code as in Fig. 1.

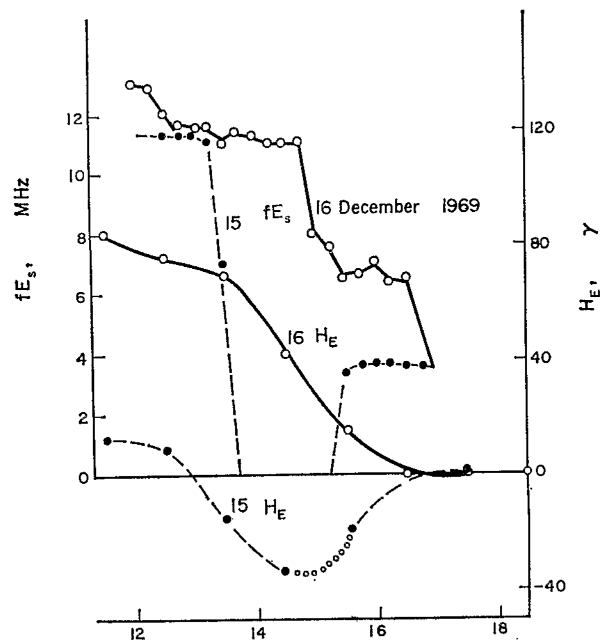

Fig. 3. Same variation and codes as in Fig. 2, for 14 and 15 December 1969.

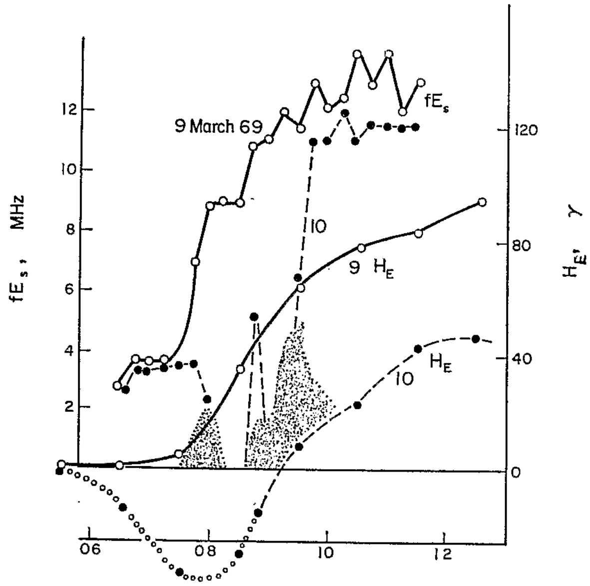

Fig. 4. Same as Fig. 2, for 9 and 10 March 1969. Shaded area: $fEsq < f_{min}$, due to D-region absorption.

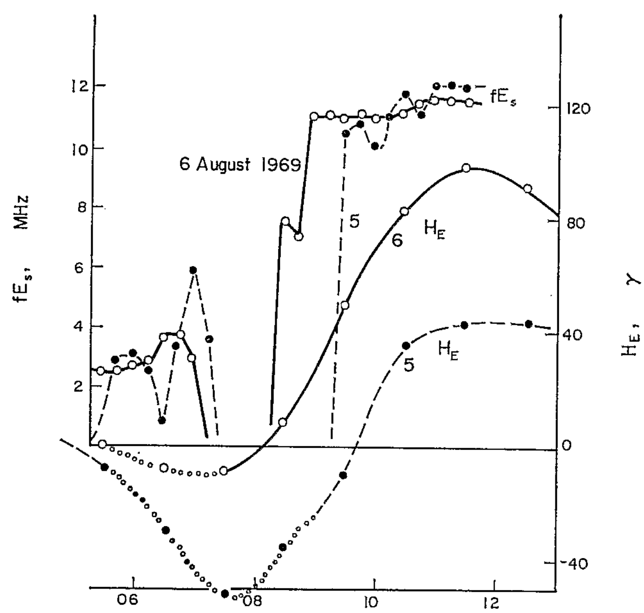

Fig. 5. Same as Fig. 2, for 5 and 6 August 1969.

the night-time level chosen in the same way for all stations. The curves for 16 July are in solid lines; those for 15 July in broken lines. On 15 July, the profile distortion, already present at 1230 and pronounced at 1330 is followed by a complete inversion of the H and Z profiles at 1430 and 1530. The ionograms for the normal day 16 July (on the right) show continuous *Esq* traces. Those for 15 July (counter-electrojet day) show *Esq* decreasing at 1330, just at the moment of magnetic reversal. Note that *Esq* has vanished by 1430, when the magnetic profiles are reversed but while ΔH is not yet negative.

Figures 2–5 illustrate the time variation of the magnetic and ionospheric phenomena for our four examples. The quarter-hourly value of *fEsq*, top frequency of the trace in MHz (left ordinate scale) is plotted in thin curves (solid line for the control day, broken line for the abnormal day). On the same diagram the value H_E in gamma (right ordinate scale, thick curve) gives an indication of electrojet intensity. This quantity is the difference between ΔH at the magnetic equator and ΔH at the two stations clear of electrojet influence, Tamanrasset and Binza. H_E is only an approximation to the magnetic effect produced at the dip equator by the electrojet current, but is useful in providing information on the ΔH profile reversal.

However in Fig. 1, Z and H profiles for 15 July are clearly reversed before ΔH reaches negatives values at the magnetic equator. In order to illustrate this difference between H_E and ΔH at the magnetic equator, the part of the H_E curve in Figs. 2–5 which correspond to negative ΔH is plotted with open circles.

The variations of the Z profiles, not given on Figs. 2–5 are in every case analogous to those of Fig. 1 in relation to the value of H_E.

Table 1 indicates the magnetic activity for our sample days: control days are underlined in the usual way and abnormal days are shown with broken underlining.

Table 1

	Figs. 1 and 2		Fig. 3		Fig. 4		Fig. 5	
Days	15/7	16/7	15/12	16/12	9/3	10/3	5/8	6/8
A_p	5	10	5	11	9	5	7	5

Conditions of magnetic calm did not obtain for all control days (especially in July and December) but all the counter-electrojet days were magnetically quiet.

Figures 2–5 suggest the following remarks:

In afternoon cases (Figs. 2 and 3), the *fEsq* fall and *Esq disappearance* occur at approximately the *beginning* of the magnetic reversal, but more than 1 hr before ΔH becomes negative (circles on the H_E curve); on the other hand, *Esq* reappears (after 1500 LT) while the magnetic profile is still reversed *and* ΔH *itself still negative.*

In morning cases (Figs. 4 and 5), events are similar except that it is the *Esq reappearance* time, which coincides well with the *end* of the magnetic reversal, while *Esq* complete disappearance occurs some time later than it would have done on a normal day. The 2 days given on Fig. 5 are more difficult to compare as *Esq* disappears and the magnetic profile reverses on both of them (although the reversal is very short on 6 August). They provide a useful example however, as they show the same time difference for the *Esq* reappearance on both days and for the return of

H_E to positive values. It must be stressed here that while *Esq* disappearance and reappearance times can be defined on our ionograms to the nearest 15 min, the reversal time of the S_R profiles (here evaluated for $H_E = 0$) is not precisely known. The magnetic profiles for ΔH and ΔZ on Fig. 1 give an idea of the difficulty of determining this time.

3. Summary of the Results

(a) The disappearance of *Esq* and the reversal of the S_R profile are (approximately) simultaneous during the hours of electrojet full development, from 0900 to 1500 or 1600 LT only.

(b) During this period, the condition for *Esq* disappearance is not ΔH becoming negative at the magnetic equator (relative to the night-time level) but H and Z profiles reversing. If the first condition (ΔH negative) is used, the reference level uncertainty in measuring ΔH makes it difficult to define whether the current is reversed. The profile reversal condition we have adopted coincides best with the *Esq* disappearance, and indicates clearly that a belt of current does flow in the reverse direction.

Conclusion

The relation between our two phenomena cannot yet be extended to all electrojet levels and to all inhomogeneity scales. However, recent work by Prakash *et al.* (1971) and by Rogister and Jamin suggests that the electrojet instability responsible for *Esq* is due to the Hall polarization field—$V_e \wedge B$ pointing in the same direction as the electron density gradient. In the presence of a downward polarization field the instability cannot be maintained and the *Esq* inhomogeneities disappear within a few seconds. As during the period of full electrojet development the inhomogeneities lie in the strong positive density gradient of the bottom of the E-layer, the disappearance of *Esq* at times of current reversal confirms the $V_e \wedge B$ instability mechanism.

We may also deduce that during its period of full development, the counter-electrojet must flow in the lower part of the E-layer.

It is hoped that simultaneous studies with spaced-aerial drift measurements and radar methods will clarify the altitude dependence and the inhomogeneity regimes of the two equatorial currents.

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