Response of the equatorial ionosphere to solar magnetic sector crossing

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A superposed epoch analysis has been carried out of $h'F$ values at Kodaikanal (10°14′N, 77°28′E, dip 3.0°N) pertaining to years of high sunspot activity using solar wind sector boundary passages past the earth as key days. It is found that there is a reduction in $h'F$ values at 2000 LT 1 or 2 days after the sector boundary crossing. The amplitude of this effect which is noticed with both (+, −) and (−, +) sector boundary crossings is higher in equinoxes than in solstices. The response of the equatorial F region to sector boundary crossing seems to originate from perturbations of the equatorial east–west electric field in the post-sunset period associated with the enhancement in geomagnetic activity in the wake of sector boundary crossing.

On a effectué une analyse par superposition d'époques des valeurs de $h'F$ à Kodaikanal (10°14′N, 77°28′E, inclinaison 3.0°N) pour les années de haute activité solaire, en utilisant comme jours clés les passages de la terre à travers les frontières sectiorielles du vent solaire. On trouve qu'il y a une réduction dans les valeurs de $h'F$ à 2000 LT 1 ou 2 jours après un passage. L'amplitude de cet effet, qui est observé pour les deux sens de passage à travers les frontières sectorielles (+, −) et (−, +) est plus grande aux équinoxes qu'aux solstices. La réponse de la région F équatoriale à la traversée de la frontière sectorielle semble due a des perturbations du champ électrique équatorial est–ouest dans la période post-crépusculaire associées avec l'augmentation de l'activité géomagnétique consécutive à la traversée de la frontière de secteur.

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1. Introduction

Abundant evidence is available to show that the characteristics of the ionospheric and magnetospheric environment of Earth are influenced by the solar magnetic sector structure (e.g., refs. 1–11). Of particular relevance to the theme of this paper are the studies (8–10) which show that at nonequatorial latitudes parameters such as F-region peak electron density and total electron content of the ionosphere undergo characteristic changes, depending on local time and season, in the vicinity of solar magnetic sector boundaries. These variations are interpreted in terms of perturbations in the electric field – atmospheric neutral composition associated with the widely documented (e.g., ref. 4) enhancement of geomagnetic activity at and after sector boundary crossings (9, 10). In contrast, the response of the equatorial ionosphere to sector boundary passage has not been explored hitherto.

The zonal electric field (E) of dynamo origin is well understood to influence the F region near the dip equator through its interaction with the horizontal (north–south) magnetic field (B) there, resulting in an $E \times B$ vertical drift of F-region plasma (12). The vertical drift is upward (downward) during daytime (nighttime) with reversal around sunset (sunrise) (13). During years of high sunspot activity the F-region upward vertical drift undergoes a conspicious short-lived enhancement after sunset (14) because of an increase in the eastward electric field (15). This characteristic feature is mirrored in the ground based ionosonde data as an abnormal increase of $h'F$ (minimum virtual height of F-region reflection that is widely taken to represent the height of bottom-side F region during nighttime) in a narrow latitudinal region around the dip equator (16). The evening rise of $h'F$ which maximizes around 2000 LT is dependent on geomagnetic activity (17). It is becoming increasingly evident from recent studies that during disturbed geomagnetic conditions a close global-scale electrodynamic coupling exists between the dynamo regions at high latitudes and elsewhere, i.e., low and equatorial latitudes (e.g., refs. 18–20). Further, the zonal equatorial electric field and associated E- and F-region effects–phenomena are found to respond (though not on a one-to-one basis) to fast temporal variations in the B_z component of the interplanetary magnetic field (IMF) (e.g., refs. 21, 22). In view of these considerations it is felt worthwhile and necessary to ascertain the response to sector boundary passage of the characteristics of the equatorial F region that are primarily associated with the zonal electric field. In this paper we present the positive evidence obtained in a preliminary study concerning the nocturnal behaviour of $h'F$ at Kodaikanal (10°14′N, 77°28′E, dip 3.0°N) in relation to sector boundary crossings.

Results

Kodaikanal ionograms pertaining to 6 years of high sunspot activity (1957–1959 and 1968–1970) are scaled for $h'F$ and the reduced data are studied with reference to sector boundaries over the periods taken from the listing of Svalgaard (23). Only sector boundaries for which the sector polarity was the same for 4–5 days on either side of the boundary are considered. A total of 73 sector boundaries with corresponding $h'F$ data became available. The data are subjected to conventional superposed epoch analysis with the difference that instead of absolute values of $h'F$, the deviations of the same from the mean over a 11-day period centred on the key day are used. This is felt desirable because the nocturnal variation of $h'F$ at Kodaikanal depends on season and level of sunspot activity (17, 24).

Figures 1a and 1b depict the results corresponding to different local times separately for (+, −) and (−, +) sector boundaries and for all boundaries together. The standard errors in the data are also shown in the figures. As per convention, the plus sign stands for solar wind magnetic fields away from the sun and the minus sign for those towards it. The prominent feature in the results is the reduction in $h'F$ values in the post-sunset hours especially at 2000 LT, 1 or 2 days after the sector boundary passage, as may be seen from Fig. 1a. This behaviour is apparent with both (+, −) and (−, +) boundaries. The decrease in $h'F$ at 2000 LT from the 11-day mean is 22 km for the (+, −) boundary and 19 km for the (−, +) boundary. The reductions in $h'F$ are 1.5 and 1.1 times the standard error of the 11-day means for the (+, −) and (−, +) boundaries respectively. To infer the seasonal pattern in the sector

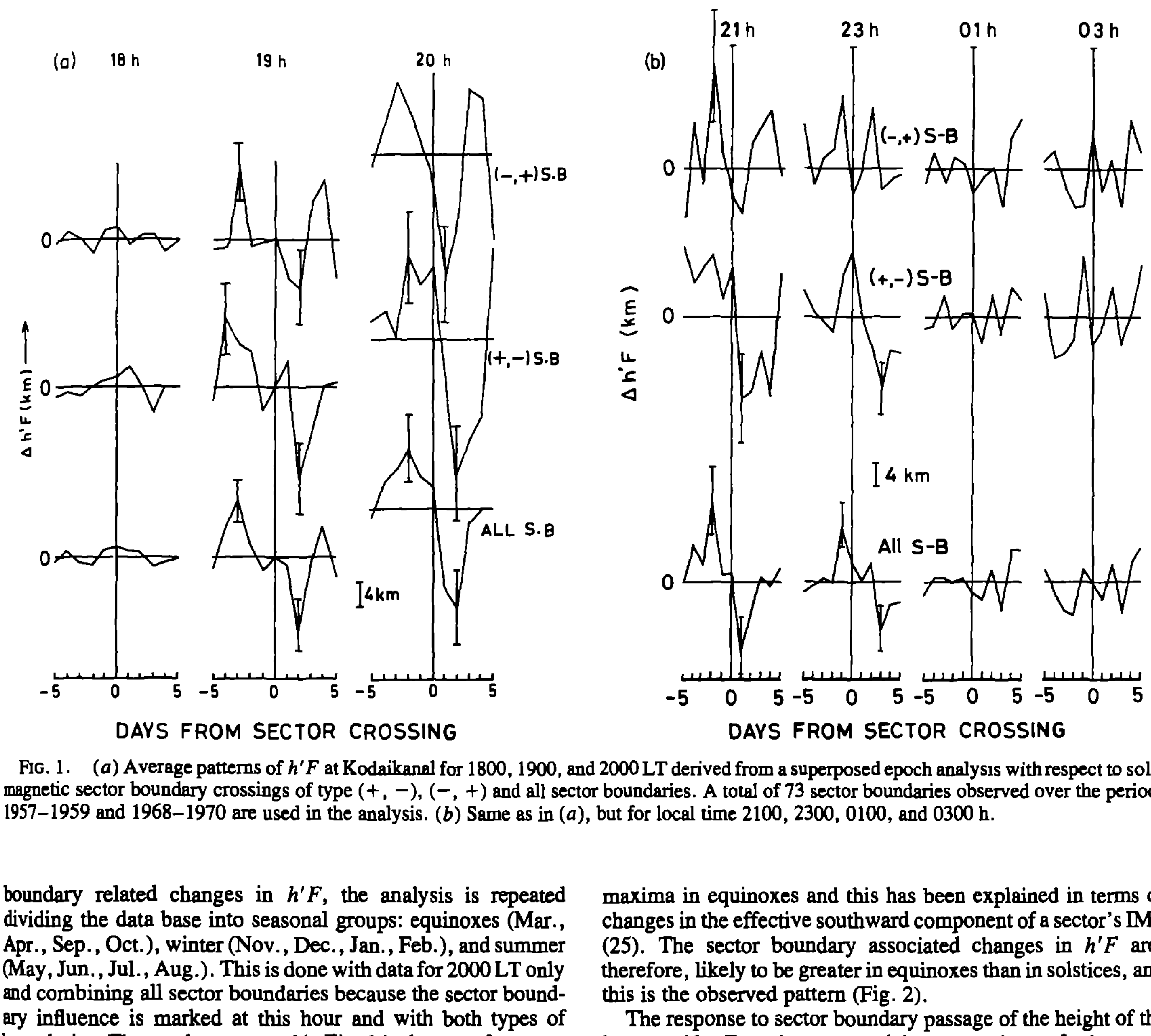

FIG. 1. (*a*) Average patterns of $h'F$ at Kodaikanal for 1800, 1900, and 2000 LT derived from a superposed epoch analysis with respect to solar magnetic sector boundary crossings of type (+, −), (−, +) and all sector boundaries. A total of 73 sector boundaries observed over the periods 1957–1959 and 1968–1970 are used in the analysis. (*b*) Same as in (*a*), but for local time 2100, 2300, 0100, and 0300 h.

boundary related changes in $h'F$, the analysis is repeated dividing the data base into seasonal groups: equinoxes (Mar., Apr., Sep., Oct.), winter (Nov., Dec., Jan., Feb.), and summer (May, Jun., Jul., Aug.). This is done with data for 2000 LT only and combining all sector boundaries because the sector boundary influence is marked at this hour and with both types of boundaries. The results presented in Fig. 2 in the same format as Fig. 1 clearly show that the reduction in $h'F$ after the sector boundary passage is higher in equinoxes than in solstices.

Discussion

The present study demonstrates the response of the equatorial F region to solar magnetic sector structure during epochs of high sunspot activity. The response is manifested as a decrease in $h'F$ values in the post-sunset hours (prominent at 2000 LT) 1 or 2 days after the passage of either type of sector boundary and is greater in equinoxes than in solstices. Viewed in the light of established facts that (a) geomagnetic activity increases at and after (1–2 days) the crossing of sector boundaries (4) and (b) during periods of high sunspot activity the post-sunset $h'F$ values in the vicinity of dip equator are reduced with increase of geomagnetic activity (17), the evidenced response is in conformity with the prevailing opinion (10) that sector boundary influence on the F region is a second-order effect brought about by changes in geomagnetic activity. The seasonal variation of the response is also consistent with this view. Geomagnetic activity is widely known to exhibit a semi-annual variation with maxima in equinoxes and this has been explained in terms of changes in the effective southward component of a sector's IMF (25). The sector boundary associated changes in $h'F$ are, therefore, likely to be greater in equinoxes than in solstices, and this is the observed pattern (Fig. 2).

The response to sector boundary passage of the height of the bottom-side F region reported here constitutes further supportive circumstantial evidence for the electrodynamic coupling of equatorial and high latitude dynamo regions during disturbed geomagnetic conditions (19, 20). This is because, as already mentioned, the post-sunset behaviour of $h'F$ near the dip equator reflects that of the pre-reversal enhancement in the F-region vertical drift and hence in the eastward electric field. Recent theoretical studies have shown that perturbations in the zonal equatorial electric field may be caused during conditions of enhanced geomagnetic activity by (a) direct penetration of high latitude electric fields associated with changes in magnetospheric convection or changes in auroral or ring current systems (e.g., refs. 26–28) and (b) delayed changes in the atmospheric dynamo associated with large-scale perturbations in thermospheric circulation owing to energy input to the high latitude thermosphere (29, 30). The magnitude and direction of the perturbation electric field depend on a variety of conditions and they can enhance, oppose, or even reverse the normal equatorial electric field. A detailed comparison of the results with those of model calculations is not done, as the statistical analysis attempted here cannot discern among the various coupling

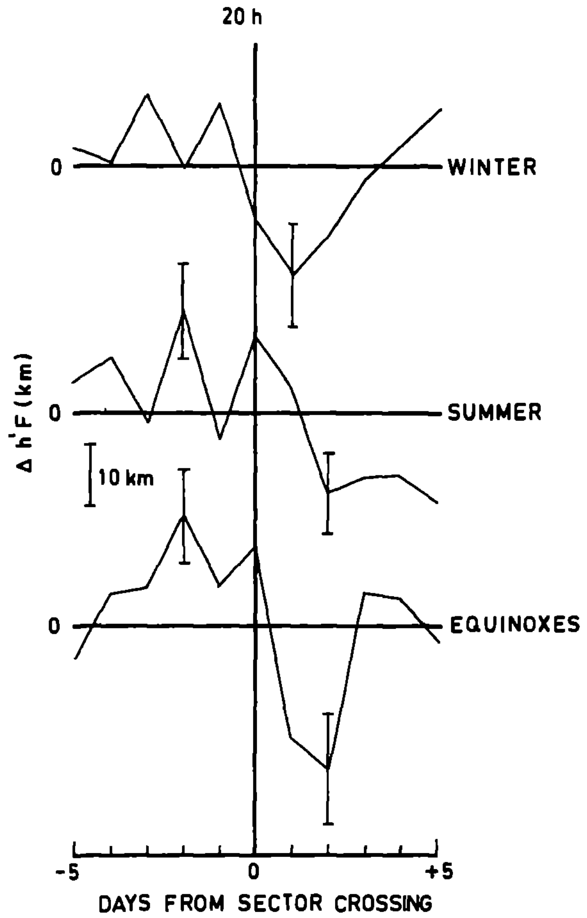

FIG. 2. Same as in Fig. 1, but showing the seasonal pattern at 2000 LT which is derived taking all sector boundaries.

mechanisms. All that can be inferred is that, on the average, westward (negative) perturbation electric fields prevail in the equatorial regions during the post-sunset period in the wake of sector boundary passage owing to enhanced geomagnetic activity.

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