

Full Length Research Paper

Ouagadougou station F2 layer parameters, yearly and seasonal variations during severe geomagnetic storms generated by coronal mass ejections (CMEs) and fluctuating wind streams

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Solar sources of geomagnetic activity are determined by means of (1) Mayaud aa index values from 1868 to now; (2) sudden storm commencement (SSC) dates and (3) pixel diagrams. From 1966 to 1998 that is, during 33 years severe geomagnetic storms characterised by $aa \geq 100$ nT have been identified and their solar sources determined. During these three solar cycles (cycles 20, 21 and 22) the effects of these solar disturbance events on Ouagadougou ionosphere F2 parameters (foF2 and h'F2) variations are studied. Each disturbed F2 parameters morphology variations are computed and shown and after compared to each whole F2 parameters morphology variation. The analysis of whole and disturbed F2 parameter morphologies and their variations gives the main following results: (1) Severe storms are responsible for equinoctial anomaly in foF2; (2) shock activity causes vernal equinoctial asymmetry in foF2 and autumnal equinoctial asymmetry in h'F2; (3) fluctuating wind streams produce autumnal equinoctial asymmetry in foF2 and vernal equinoctial asymmetry in h'F2; (4) Geomagnetic activities produced negative storms from 1966 to 1981 and positive storms from 1981 to 1987; (5) For the seasonal variation we have positive storms all through the year except in April where we observe negative storms.

Key words: Coronal mass ejections (CMEs), fluctuating wind streams, equinoctial anomaly, geomagnetic activity.

INTRODUCTION

It is well-known the four geomagnetic classes of activity (Legrand and Simon, 1989; Simon and Legrand, 1989; Richardson and Cane, 2000; Richardson et al., 2002). Following Legrand and Simon's Classification, we distinguish: (1) quiet days activity and disturbed days activity which is divided into three classes: (2) shock activity generated by coronal mass ejections (CMEs), (3) recurrent activity due to high wind streams coming from coronal hole and (4) Fluctuating activity caused by

fluctuating winds stream due to the fluctuation of solar heliosheet. Quiet days activity is obtained by considering daily $aa < 20$ nT and disturbed activity is determined by taking into account daily $aa \geq 20$ nT. This paper is concerns with disturbed activity characterized by daily $aa \geq 100$ nT. For this aa condition, only shock and fluctuating activities are concerned. Recurrent activity is excluded by this study for the major daily aa which contributed to this geomagnetic activity is inferior to 100 nT (Ouattara and Amory, 2009). Our goal is to study the impact of severe geomagnetic storms ($aa \geq 100$ nT) generated by CMEs and fluctuating wind streams in F2 region. Thus, we use aa pixel diagrams (for example, Figure 1: pixel diagram of year 2004) to determine each daily class of activity. In Figure 1, white and blue colours correspond to quiet day activity and the others to disturb

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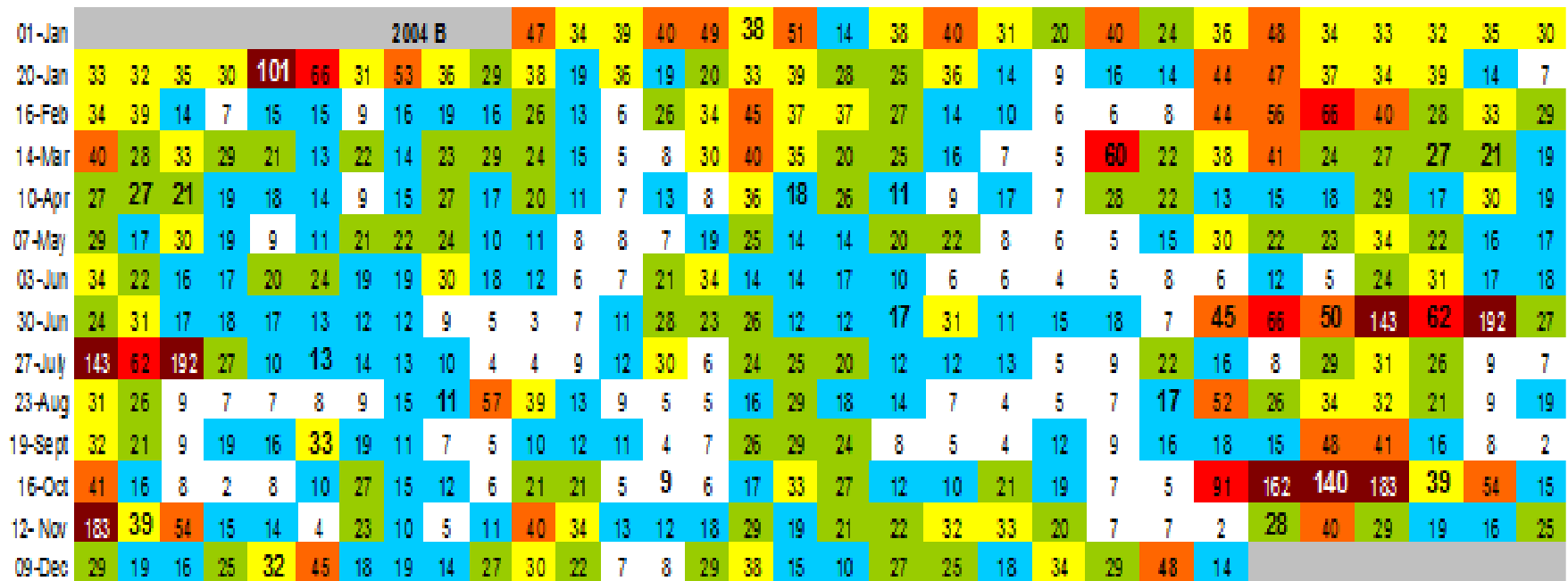


Figure 1. Different classes of geomagnetic activity during year 2004: Pixel diagram of year 2004.

one. As each line of the diagram corresponds to one Bartels rotation, several rotations with orange or red colour indicate recurrent activity. The merged disturb colours (green, yellow, orange, red and olive red) indicate the presence of fluctuating activity. Shock activity begins by sudden storm commencement (SSC) days (days with black thick aa value in Figure 1) and is identifying by one, two or three days with orange, red or olive red colour. After that, we select the corresponding days values of F2 layer parameters (foF2 and h'F2). Yearly and seasonal variation of these selected days (CMEs and fluctuating days) F2 layer parameter values are performed and compared with the whole yearly and seasonal F2 layer parameter values respectively. This study

objectives are (1) to show the effects of disturbed solar events (CMEs and fluctuating wind streams) in African equatorial F2 region parameters (foF2 and h'F2) yearly and monthly morphological variations; (2) to point out the contribution of each type of disturbance on the variability of foF2 equinoctial maxima, and (3) to exhibit ionosphere variability under each type of disturbance.

DATA SETS

Data used in this work are provided by ENST Bretagne. The data concern F2 layer parameters (foF2 and h'F2) which are obtained by using Ouagadougou ionosonde station (12.4°N, 1.5°W; dip +5.9). This station worked from June 1966 to February 1998. We also used geomagnetic activity indice (aa) computed by Mayaud (1971, 1972,

1973) and solar activity indice F10.7 obtained from National Geophysical Data Center (NGDC) data base.

METHODOLOGY

Determination of daily values of aa, foF2 and h'F2 contributing to shock activity and fluctuating activity

In this paper, we analyse the effect of severe shock and fluctuating activities ($aa > 100$ nT) in the F2 layer parameter (foF2, h'F2) behaviours. The whole values of $aa > 100$ nT from June 1966 to February 1998 (72 values) are identified in aa pixel diagrams which corresponding to 33 years (from 1966 to 1998). The method of identifying the contribution of the shock activity and the part of the fluctuating activity is: (1) we identify in given pixel diagrams severe geomagnetic activities (shock and fluctuating activities) by olive red colours corresponding to $aa > 100$

Table 1. Severe shock and fluctuating activities days and Aa values during year 2004.

Line 1			Line 8			Line 12				
	Date	Aa (nT)	Date	Aa (nT)	Date	Aa (nT)	Date	Aa (nT)	Date	Aa (nT)
Shock	22 January	101					9 November	140	10 November	183
Fluctuating			25 July	143	27 July	192	8 November	162		

nT. SSC dates help us for the determination of shock activity days. These days aa values are expressed by thick black daily values of aa in pixel diagrams. (2) Daily values contributing to shock activity are those with no recurrent SSC. This condition includes effectively the corresponding day and one or two additional days after the non recurrent SSC day. Fluctuating wind stream activity days are obtained by selecting on the one hand days with recurrent SSC and on the other hand by taking into account days with severe geomagnetic activity days without SSC. For example, Table 1 gives severe shock activity and fluctuating activity day values and aa values for the year 2004 extracted from 2004 pixel diagram. It can be seen in this table that during the year 2004, we have 3 severe shock activities and 3 severe fluctuating activities. After the determination of daily foF2 and h'F2 which contribute to severe shock and fluctuating activities by mean of pixel diagrams of years 1966 – 1998, we calculate these parameters monthly values by averaging daily values. Annual values are obtained by averaging daily values also.

Determination of “theoretical” and “anomaly” values of F2 parameters

Figure 2 shows foF2 (panel a) and h'F2 (panel b) variations as F10.7 function. In panel a of Figure 2, one can see very good correlation between the critical frequency of F2 layer and the solar activity parameter F10.7 (correlation coefficient 0.953) and good anti correlation between the latter parameter and the virtual height of F2 layer (anti correlation coefficient 0.585) in panel b. Such results show the 11-years periodicity of yearly foF2 and yearly h'F2 data. This periodicity is not consistently 11-years when the time scale is changed. In fact, according to Somoye (2009) hourly average of foF2, some hours exhibits 8-years periodicity while in some the periodicity is 14-years. The present results show that each F2 layer parameter can be expressed as a proxy of F10.7. For that, we are able to appreciate each severe disturbed storm effect by using regression analysis. For this analysis, “theoretical” value (named here Y') of each experimental F2 layer parameter values (named here Y) is defined as a function of F10.7 by reference to the linear dependence between each F2 layer parameter and F10.7 (Figure 2). This function can be expressed as: $Y' = a F10.7 + b$ with a and b as coefficients. The “anomaly” parameter (expressed here by ΔY) is obtained by subtracting theoretical values (Y') from experimental values (Y). “Anomaly” parameter is given by the following equation:

$$\Delta Y = Y - Y'.$$

It is important to note that Y' corresponds to the part of sunspot cycle that is, the part due to the toroidal component of solar magnetic field, and ΔY evaluates the part of the action of the poloidal component of solar magnetic field. Thus each parameter depends on the effect of the two components of solar magnetic.

RESULTS AND DISCUSSION

Yearly variations of “theoretical” and “anomaly” values of

F2 layer parameters (foF2 in panel a and h'F2 in panel b) are shown in Figure 3. In Figure 3, theoretical value variations are given by full curve while dotted curve expresses anomaly value variations. Figure 3 highlights the part of each solar magnetic component in foF2 and h'F2 variability during fairly 3 solar cycles. In panel a, it can be seen that maximum peaks of foF2 “anomaly” variation appear during increasing and decreasing solar phases. These observations show that out of solar maximum the annual variability of foF2 may be due to severe geomagnetic activity (fluctuating activity) provoked by the fluctuation of solar heliosheet. In fact, it is well known that shock due to CMEs is a manifestation of solar toroidal magnetic field, and fluctuating solar wind is due to solar poloidal magnetic field (Legrand and Simon, 1989; Simon and Legrand, 1989; Ouattara, 2009). Panel b shows that during solar minimum h'F2 is maximum. We can retain from Figure 3 that CMEs increase electron density at solar maximum and fluctuating solar wind increases electron density during increasing and decreasing phases. The height of F2 layer is higher at solar minimum and lower at solar maximum. Figure 4 concerns the distribution of the number of severe disturbed days throughout the year for the whole 3 solar cycles. Figure 4 shows that there are more disturbed days during equinoctial months. It can be seen equinoctial asymmetry in the evolution of severe disturbed days. Figure 5 gives monthly F2 layer parameter variations. Experimental values (which can be also called here global values: sum of “theoretical” values and “anomaly” values) variability is given by full curve. Disturbed values variability is expressed by dotted curve. Figure 5 describes the impact of disturbed geomagnetic activity in foF2 and h'F2 monthly variations. Panel a shows that, disturbed activity has no effect in foF2 profile trough. Equinoctial peaks are due to disturbed activity. In panel b it emerges that the trough of March equinox is not due to disturbed activity. Figure 6 highlights the effect of each disturbed activity (shock and fluctuating activities) on monthly F2 critical frequency. In panels a and b, full curves concern experimental and disturbed value variations respectively. Dotted curves give the variation of shock geomagnetic indice aa values. In panels c and d, full curves show experimental and disturbed values variability respectively. Dotted and dashed curves highlight fluctuating geomagnetic aa value variations. Panel a shows that, shock activity has no effect in foF2 profile trough. March equinoctial peak may be due to shock activity. Panel b confirms that March equinoctial peak is

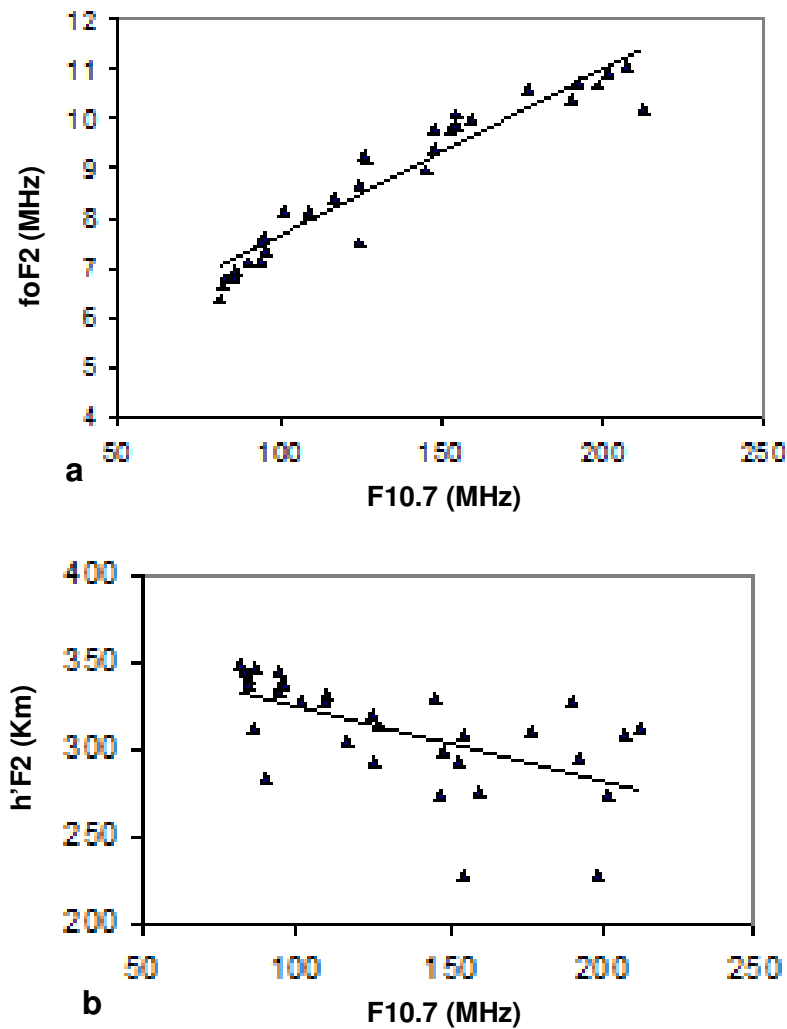


Figure 2. Correlation between F2 layer parameters and solar flux index (a) Correlation between $foF2$ and $F10.7$ (b) Correlation between $h'F2$ and $F10.7$.

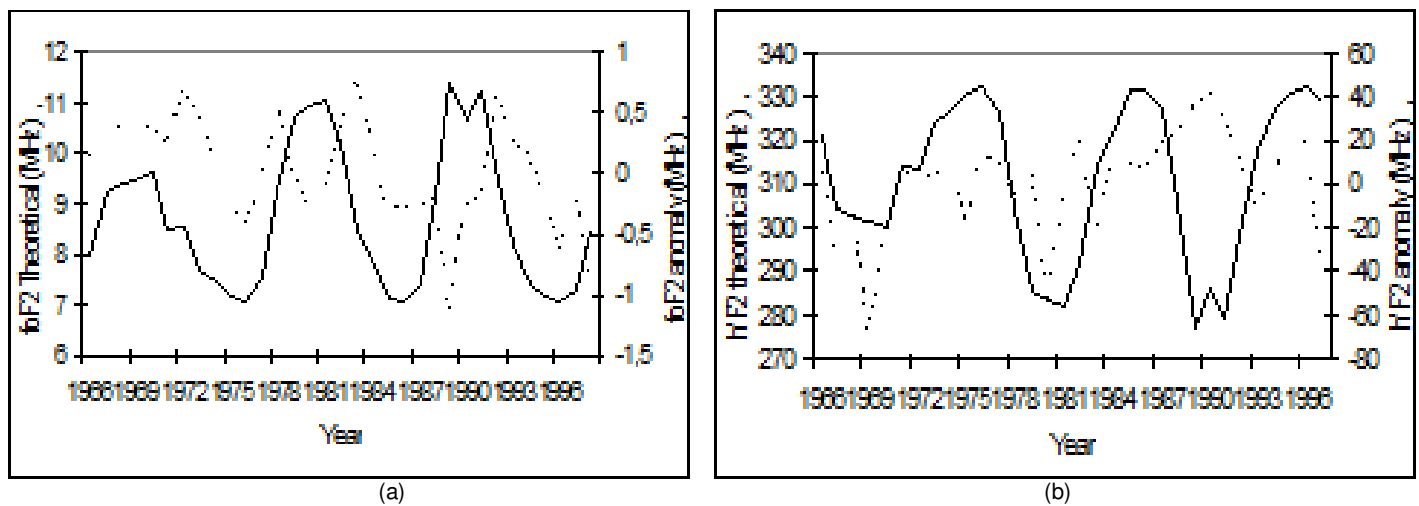


Figure 3. Yearly variation of theoretical and anomaly values of F2 layer parameters. a) Yearly variation of theoretical and anomaly values of $foF2$. b) Yearly variation of theoretical and anomaly values of $h'F2$.

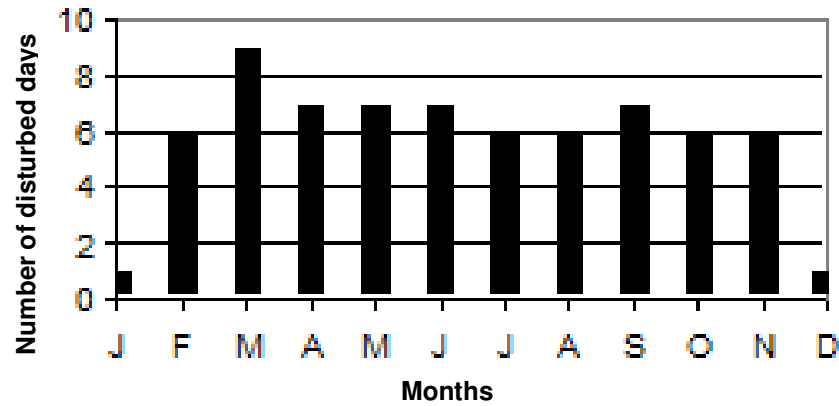


Figure 4. Monthly evolution of disturbed days number.

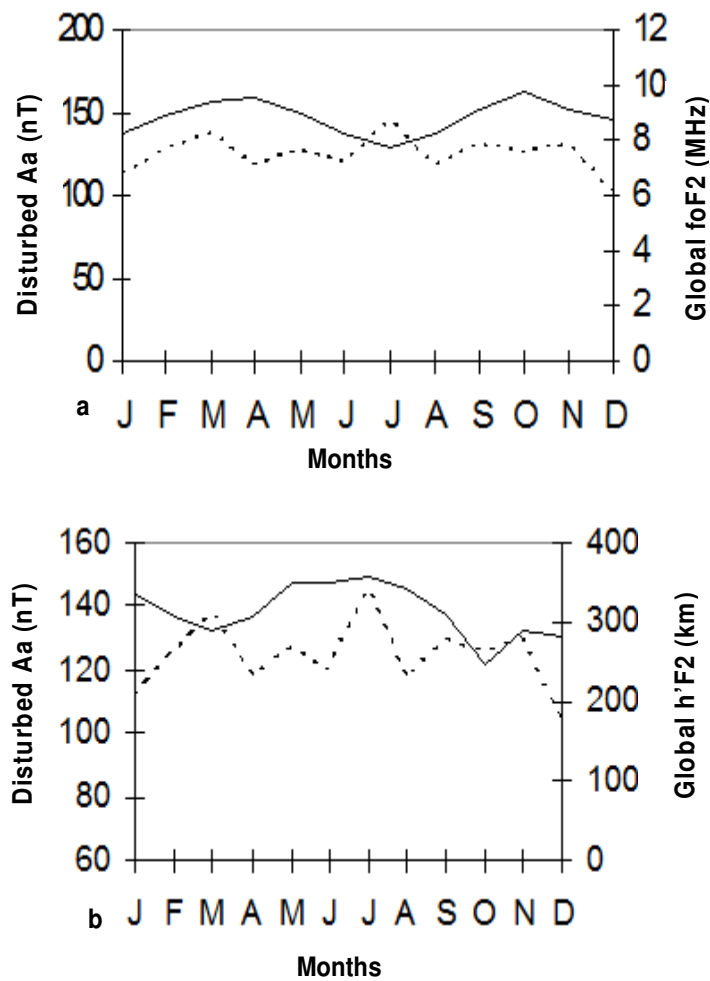


Figure 5. a, Monthly effects of disturbed Aa in whole foF2; b, Monthly effects of disturbed Aa in whole h'F2.

due to the effect of shock activity. In panel c, it can be seen that October equinoctial peak is due to fluctuating

activity. Panel d exhibits the effect of fluctuating activity in October equinoctial peak. Figure 7 describes the effect of

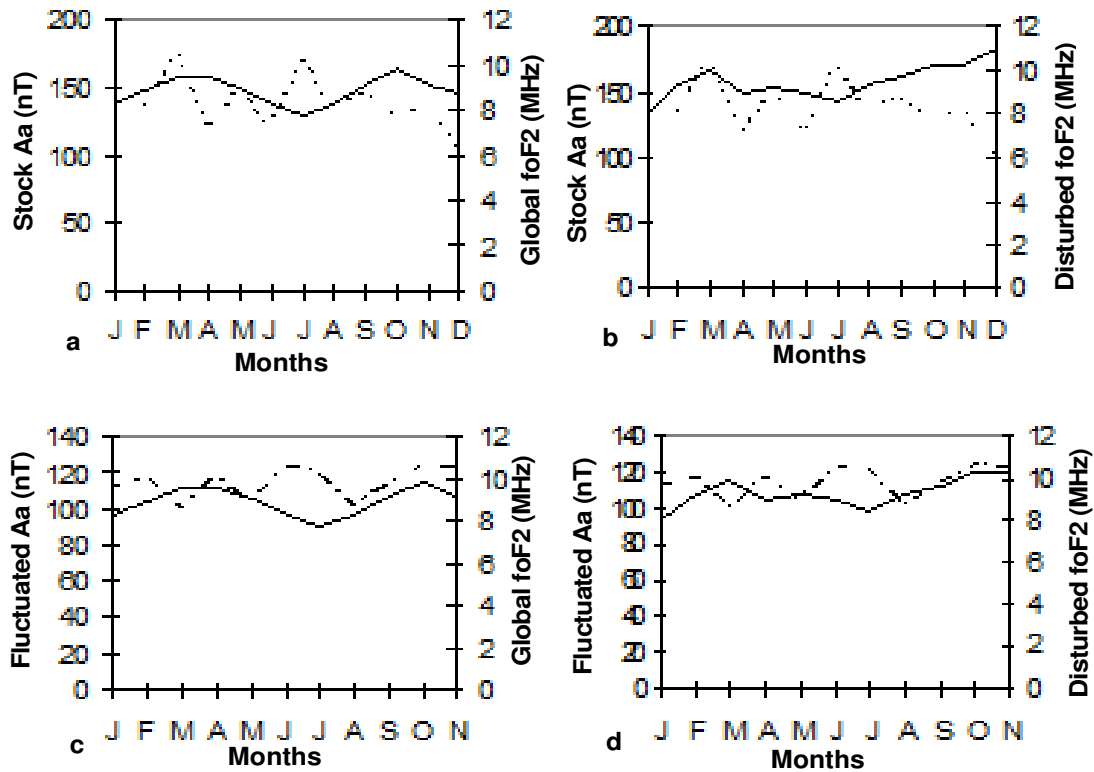


Figure 6. Monthly effects of shock and fluctuated Aa in F2 layer global critical frequency and disturbed critical frequency values (a) Monthly effects of shock Aa in whole foF2 (b) Monthly effects of shock Aa in disturbed foF2 (c) Monthly effects of fluctuated Aa in whole foF2 (d) Monthly effects of fluctuated Aa in disturbed foF2.

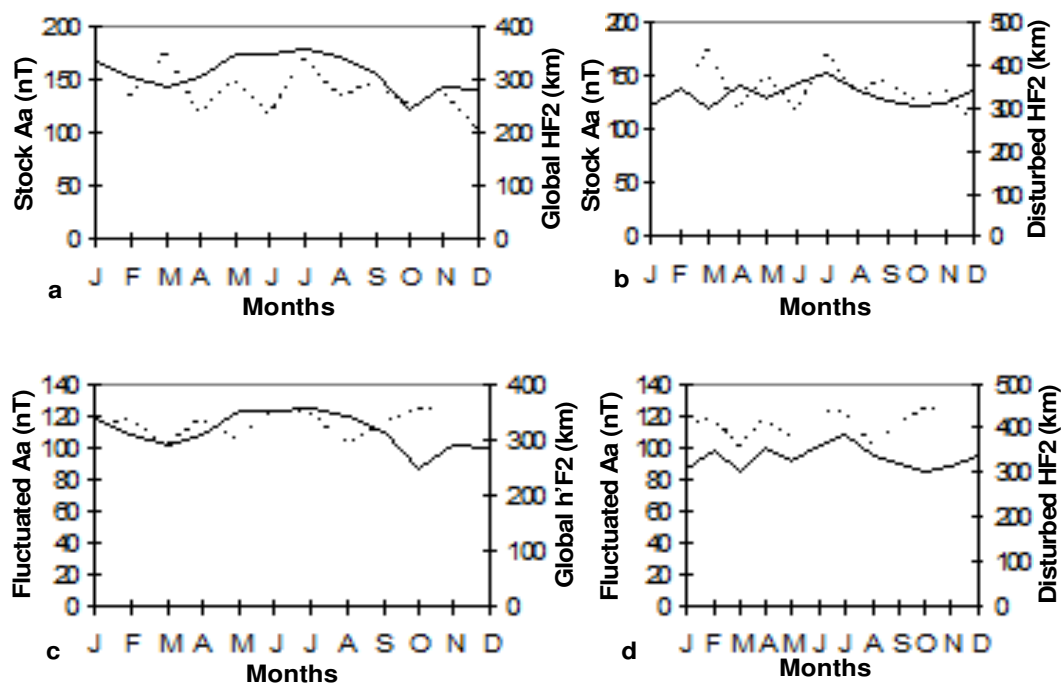


Figure 7. a, Monthly effects of shock Aa in whole h'F2; b, monthly effects of shock Aa in whole disturbed h'F2; c, monthly effects of fluctuated Aa in whole h'F2; d, monthly effects of fluctuated Aa in disturbed h'F2.

different disturbed activities (shock and fluctuating activities) in the h'F2 monthly profile. In panels a and b, full curves concern experimental and disturbed value variations respectively. Dotted curves express the variation of shock geomagnetic indice aa values. In panels c and d, full curves show experimental and disturbed value variability respectively. Dotted curves highlight fluctuating geomagnetic aa value variations. One can see that in panel a, shock activity contributes to summer maximum, and is responsible for October equinoctial trough in h'F2 profile. Panel b confirms such observation and highlights that from July to December h'F2 monthly profile is due to shock activity. In panel c fluctuating activity contributes to summer maximum and is responsible for March equinoctial trough. Panel d shows that from January to July fluctuating activity determines h'F2 monthly profile.

Conclusion

This study allows us to identify the effect of each solar magnetic field component in F2 layer parameters. Severe fluctuating activity acts during increasing and decreasing phases, and severe shock activity produces severe geomagnetic storms during solar maximum. Monthly severe disturbed days show equinoctial asymmetry. Severe geomagnetic storms occur during equinoctial months. Severe shock produces March peak and fluctuating wind provokes October peak in foF2 profile. Shock activity contributes to summer maximum and is responsible for October equinoctial trough in h'F2 profile. Fluctuating activity contributes to summer maximum and is responsible for March equinoctial trough. The present results constitute the first step toward the analysis of the impact of each class of disturb activity (shock activity, re-current activity and fluctuating activity) in foF2 asymmetry and equinoctial through in h'F2 profile.

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