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Diurnal variability of the magnetospheric convective electric field (MCEF) from 1996 to 2019: Comparative investigation into the signatures of the geoeffectiveness of coronal mass ejections and magnetic clouds

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This paper compared the signatures of shock activity and magnetic clouds (caused by geoeffective interplanetary coronal mass ejections (ICMEs)) on the diurnal variability of the magnetospheric convective electric field (MCEF) from 1996 to 2019. The investigation is done as a function of the orientation of the interplanetary magnetic field (IMF). The temporal variabilities of the MCEF of the two geomagnetic activities are different but both show a dependence on the phase of the solar cycle. For a given phase, the daily mean value of the MCEF on shock days is higher than on magnetic cloud days. Similarly, at all times, at phase minimum and at the falling phase, the hourly MCEF values during shock days are higher than those during days of magnetic cloud activity. The same result is observed in all phase periods (regardless of the phase). At phase minimum, there is a night reconnection during shock days, whereas during magnetic cloud activity days the MCEF ends the day with a northward oriented IMF. At phase maximum, there is magnetic reconnection at the lobes of the Earth's magnetosphere for both types of activity. During the downward phase there is (1) reconnection at the magnetospheric lobes in days of shock activity (2) the IMF maintaining a southerly direction from 1000 UT to 2400 UT.

Key words: Magnetosphere convection electric field, interplanetary magnetic field, interplanetary coronal mass ejections, shock activity, magnetic cloud activities.

INTRODUCTION

The Earth's magnetosphere is that cavity in the solar wind that arises from the interaction between the solar wind and the Earth's magnetic field lines (Chapman and Ferraro, 1931). The magnetosphere is a very sensitive and dynamic entity (Russel, 1979) whose state depends on the properties of the solar wind plasma and the orientation of the solar magnetic field frozen in the solar wind (McPherron et al., 2007). In interplanetary space the solar magnetic field lines are known as the interplanetary magnetic field (IMF). According to McPherron et al.

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(2007), there are three possible magnetic topologies in the interaction between the solar wind and the Earth's magnetosphere: (1) the topology where a line of the IMF frozen in the solar wind may not intersect Earth's magnetic field lines, (2) that where a line of the IMF may intersect geomagnetic field lines with the IMF facing south; and (3) that where a line of the IMF may intersect geomagnetic field lines with the IMF facing north (Russel, 2007).

In the topology where there is an interaction between the solar wind and the Earth's magnetosphere, two mechanisms are commonly invoked to explain this interaction. The first mechanism is the viscous interaction where closed magnetic flux tubes from the solar wind are transported from the day side of the magnetosphere to the night side (Axford and Hines, 1961; Axford, 1969). The second mechanism put forward to explain the interaction between the solar wind and the magnetosphere is magnetic reconnection (Dungey, 1961). In this case, Russell (1979) notes that when the IMF is oriented south, it is antiparallel to the geomagnetic field and there can be reconnection between the two fields on the morning side of the magnetosphere. These reconnected field lines undergo convection in the antisolar direction.

When the IMF is south-north, the terrestrial and interplanetary magnetic field lines are said to be parallel. The interplanetary magnetic field lines drape the magnetosphere, which is formed by field lines of various directions on its surface. In some places in the magnetosphere lobes the two types of field lines can be antiparallel, and the field lines can reconnect. Note that when the IMF is oriented northwards, reconnection cannot take place at the nose of the magnetosphere, but rather at the lobes where the two fields can be antiparallel (Kaboré and Ouattara, 2018). One consequence of magnetic reconnection is the production of geomagnetic storms defined as global magnetic disturbances that result from the interaction between magnetised plasma propagating from the Sun and the magnetic fields of the near-Earth space environment (Tommaso et al., 2016).

Legrand and Simon (1989), as well as Ouattara and Mazaudier (2009), have demonstrated that these geomagnetic storms can be attributed to three main factors:

(a) Recurrent activity, which arises from fast solar winds originating from coronal holes and exhibiting continuous evolution over one or more Barthel rotations. (b) Shock activity caused by interplanetary coronal mass ejections (ICMEs) detected at Earth's level. Geoeffectivity is defined as the capability of a solar wind event to disrupt the Earth's magnetosphere by inducing a magnetic storm (Benacquista et al., 2017). (c) Fluctuating activity generated by variable winds (moderate and fast) whose geoeffectivity is a consequence of the Sun's neutral plate fluctuation.

Zerbo et al. (2011) validated the classification of geomagnetic activity made by Legrand and Simon (1989) and extracted from the class of fluctuating activity three new classes of activity defined as (1) co-rotational activity caused by the manifestation of solar winds, stable in co-rotation and having moderate magnetic effects in the vicinity of the Earth's environment; (2) magnetic cloud activity which groups shock events generated by areas of intense magnetic fields with rotational motion (Burlaga et al., 1981; Wu et al., 2006); and (3) unclear activity which groups the class of transient and fluctuating events that are not taken into account in the two classes previously extracted.

Magnetic clouds (or flux string) are special cases of ICMEs, characterized by a well defined magnetic structure. They are generally considered a subcategory of interplanetary coronal mass ejections (ICMEs), in which the magnetic field is structured around a central axis (Turc, 2014). In the Earth's environment, it is estimated that about one third of observed interplanetary coronal mass ejections are magnetic clouds (Richardson and Cane, 2010).

For this comparative investigation of the effect of the two types of magnetic activity on the dynamics of the magnetosphere, we consider all shock activity caused by geoeffective ICMEs and magnetic cloud activity for the period 1996-2019. We also take into account the phases of the solar cycle. However, the different types of shocks: one-day shocks, two-day shocks or three-day shocks (Ouattara, 2015; Gyébré et al., 2015) and the other types of magnetic clouds (magnetic cloud activity whose effect lasts one day, two days or three days (Kaboré et al., 2021) are not taken into account in this work. The comparative study between the effects of these activities taking into account the duration of their action will be done later.

It is important to point out that the Earth's magnetosphere forms a shield, a bulwark against the energetic charged particles carried by the solar wind which, if they were not slowed down by a shock wave upstream of the magnetosphere and deflected by the geomagnetic field, would diffuse freely towards the Earth. The aim of this manuscript is to contribute to a better understanding of the dynamics and structure of the Earth's magnetosphere in the face of shock activities caused by ICMEs and those caused by the magnetic clouds of solar cycles 23 to 24. The long-term challenge is to predict and compare the geoeffectiveness of solar events that are the source of geomagnetic activity on the dynamics of the Earth's magnetosphere.

The dynamics of the Earth's magnetosphere depends on magnetic reconnection phenomena during solar wind-Earth magnetosphere or ICME-Earth magnetosphere interactions (Mc Pherron et al., 2007). The present comparative investigation is carried out under the topology where an interplanetary magnetic field line

Table 1. List of cycles and their different phases from cycle 23 and 24.

Cycle	Extension period	Average duration (years)	Minimum phase	Ascending Phase	Maximum phase	Descending phase
23	1996-2009	13	1996 and 2006-2009	1997-1999	2000-2002	2003-2005
24	2009-2019	10	2009 and 2018-2019	2010-2013	2014	2015-2017

intersects a geomagnetic field line with a north or south oriented IMF.

For this comparative study of MCEF variability, we first present the data and methods used, then the results and discussion, and finally the conclusion.

DATA AND METHODS

Methods for determining the different phases of the solar cycle

To determine the solar phases, the authors used the values of the solar index Rz and adopted the method used by Ouattara (2015), Guibula et al. (2019), Kaboré et al. (2021) and Gyébré et al. (2022). According to this method the different phases of the solar cycle are defined as follows: (1) phase minimum: sunspot number Rz less than 20 ($Rz < 20$); (2) ascending phase: sunspot number between 20 and 100 ($20 \leq Rz \leq 100$); (3) phase maximum: sunspot number greater than 100 ($Rz > 100$) and (4) descending or decreasing phase: sunspot number between 100 and 20 ($100 \geq Rz \geq 20$). The values of the solar index Rz used to determine the solar phases are freely accessible via the Omniweb site whose URL is given: http://omniweb.gsfc.nasa.gov/. By applying this method, the different phases of the solar cycles 23 and 24 are identified as shown in Table 1.

Methods for determining days of magnetic cloud activity and ICMEs shock activity

To determine the days of magnetic cloud activity and the days of shock activity due to interplanetary coronal mass ejections (ICMEs) detected in the Earth's environment, we used the pixel diagrams that we constructed from the aa index values (Ouattara and Mazaudier, 2009) and the dates of the sudden storm commencement (SSC).

The Aa index values and SSC data are available on the ISGI website. The different types of magnetic cloud activity and shocks due to ICMEs (geoeffective interplanetary CMEs) are identified from 24 pixel diagrams (representing pixel diagrams from 1996 to 2019).

The days of magnetic cloud activity correspond to the dates of the SSC for which Aa indices are between 20 and 40 nT on one, two or three days (Zerbo et al., 2011; Kaboré et al., 2021).

Shock activity days correspond to the dates of non-recurrent (non-repeating) SSC for which the Aa indices remain above 40 nT over one, two or three days (Ouattara et al., 2015; Gyébré et al., 2015). Figure 1 shows an example of a day of magnetic cloud activity (October 26 2003) and shock activity (March 20, 2003).

Method for determining the magnetospheric convection electric field strength

The hourly magnetospheric field strength (EM) will be calculated using the linear correlation between the hourly solar wind frozen electric field (Ey) and MCEF data established by Wu et al. (1981) and validated by Revah and Bauer (1982) and given by the equation $EM = 0.13\ Ey + 0.09$, an equation with a correlation coefficient of 0.97. The hourly values of the intensity of the Ey (mV/m) component of the frozen electric field in the solar wind for solar cycles 23-24 are obtained from OMNIWEB *http://omniweb.gsfc.nasa.gov/form/dx1.html* and those for the MCEF are calculated using the above equation and for the period (1996-2019) corresponding to the two solar cycles concerned in the study. It is important to note that each hourly EM value is calculated using the hourly arithmetic mean values of Ey during the relevant events for the relevant period.

RESULTS AND DISCUSSION

This part of the study begins by presenting the results on the diurnal variability of the magnetospheric convection electric field (MCEF) during days of shock activity (solid curves) and magnetic cloud activity (dotted curves).The data used are those indicated in the previous section. In a first step, the authors compared the diurnal variability of the MCEF during days of magnetic cloud ejections and coronal mass ejections without phase distinction. In a second step, they will analyse the variability in detail, taking into account of the solar phase cycle. From the results obtained we will establish linear regression equations as a function of time. These equations will allow us to identify the phases of growth and decay of the MCEF during the day for each type of activity. This part of the study ends with the presentation of the results on the daily average values of the MCEF during the days of shock and magnetic cloud activity.

Diurnal variability of the MCEF in days of shock and magnetic cloud activity

Figure 2 illustrates the MCEF diurnal variability without distinction of phase during days of shock activity (solid curve) and days of magnetic cloud ejections (dashed curve).

It is noted that the average MCEF intensity during shock activity is at all times higher than the MCEF during magnetic cloud activity. The difference between the MCEF varies between 0.01571854 mV/m and 0.20308496 mV/m. This difference is minimal at 1800 UT and maximal at 1100 UT. Between 0900 UT and 1200 UT the MCEF during days of shock activity shows a slight dip at 1000 UT. Between 0100 UT and 1000 UT the MCEF during magnetic cloud days shows a plateau-like morphology. From 1800 UT to 2300 UT the MCEF intensities evolve almost in phase opposition.

From the same graph, it is evident that within the time frame of 0000 UT to 2400 UT, each of the MCEF

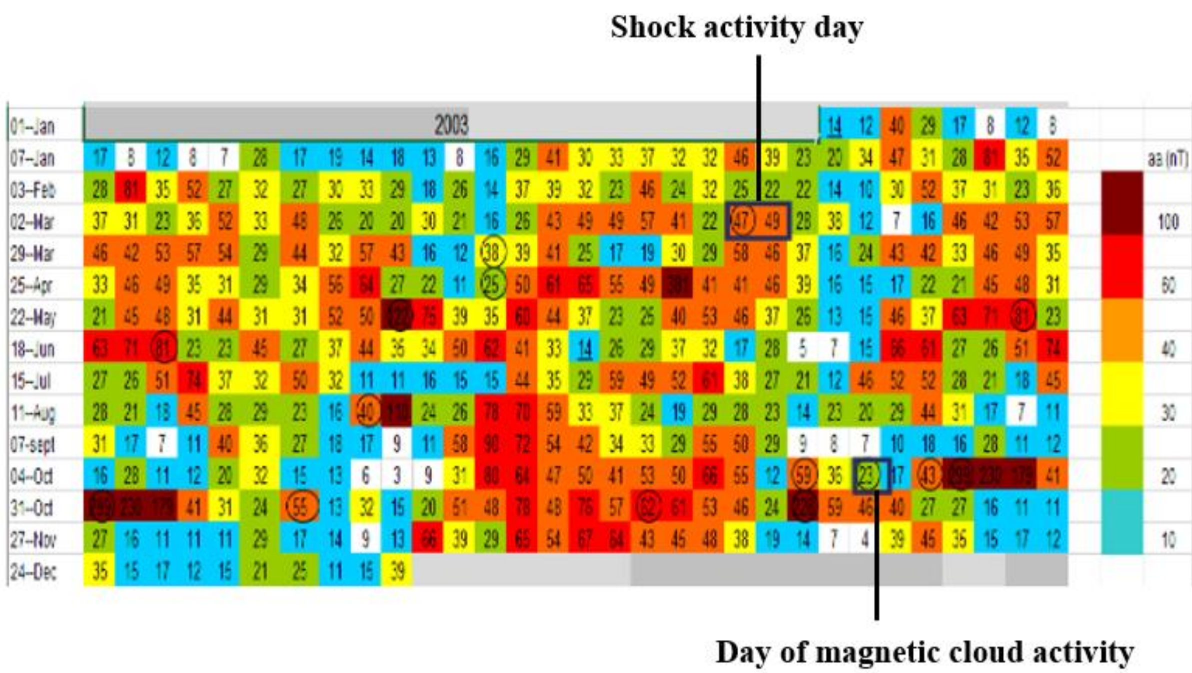

Figure 1. Pixel diagram of the year 2003 showing the days of magnetic cloud and shock activity.

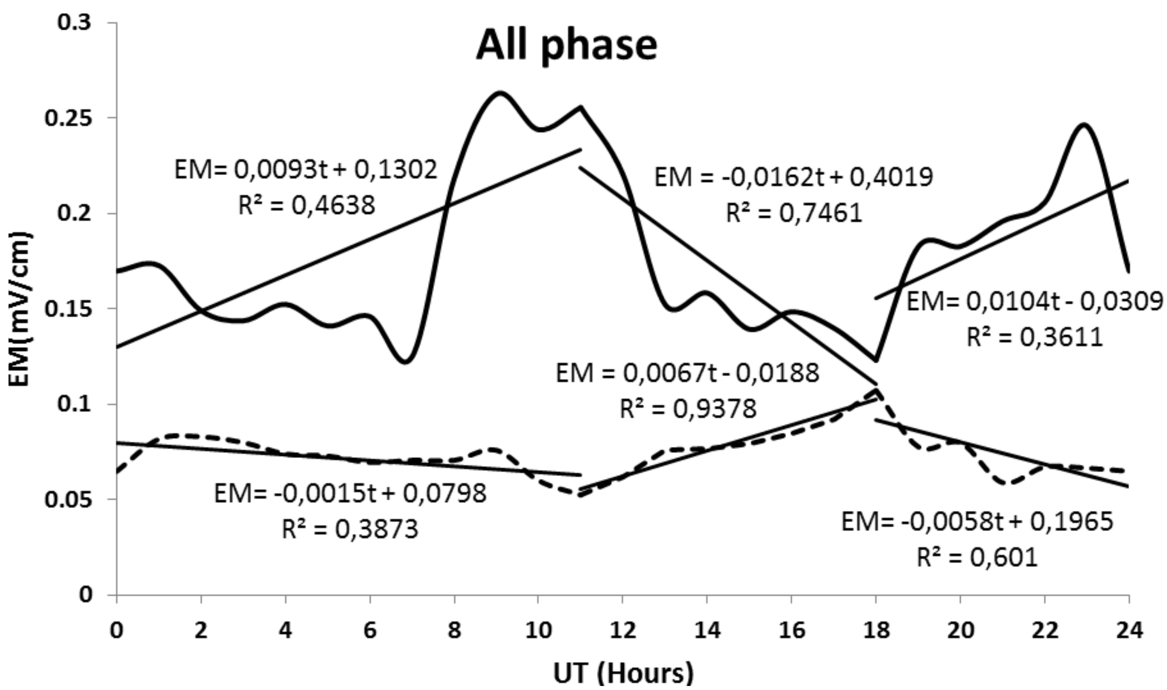

Figure 2. Variation of the magnetospheric convection electric field during magnetic shock activity days (graph line curve) and magnetic cloud activity days (dotted curve).

variability curves exhibits three distinct trends. During days of shock activity the trend is: (1) increasing from 0000 UT to 1100 UT with a slope of -1.5 10^{-3} mV/m and a correlation coefficient equal to 0.68, (2) decreasing from 1100 UT to 1800 UT with a slope of -1.62 10^{-2} mV/m and a correlation coefficient equal to 0.86, (3) increasing from 1800 UT to 2400 UT with a slope of 1.04 10^{-2} mV/cm and a correlation coefficient equal to 0.60.

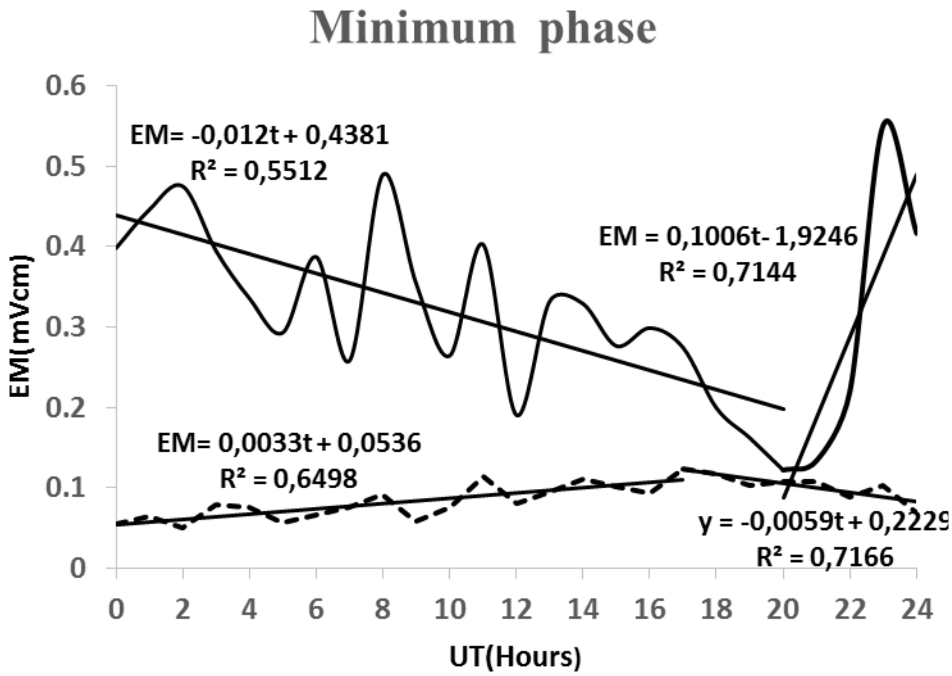

Figure 3. Variation of the magnetospheric convection electric field during minimum phase in days of shock (graph line curve) and magnetic cloud activity (dotted curve).

During days of magnetic cloud activity these trends are reversed: (a) decreasing from 0000 UT to 1100 UT with a slope of -1.5 10^{-3} mV/m and correlation coefficient equal to 0.62, (b) increasing from 1100 UT to 1800 UT with a slope of 6.7 10^{-3} mV/m and correlation coefficient equal to 0.97, (3) decreasing from 1800 UT to 2400 UT with a slope of - 5.8 10^{-3} mV/m and correlation coefficient equal to 0.78.

The high values of the hourly MCEF intensities found at all times of the day during shock activity periods compared to magnetic cloud activity days can be interpreted by the fact that the Ey intensity of the electric field frozen in the solar wind, hence the MCEF increases with the geomagnetic index. This interpretation is supported by the results of the work of Kaboré and Ouattara (2018) who note that at any time of the day the hourly intensities of the MCEF during calm days were lower than those during disturbed days. These results are also supported by Zerbo et al. (2012) for whom, relative to days of shock activity; magnetic cloud activity generates a moderate change in the level of geomagnetic activity.

Each of the growth and decay phases of the MCEF can be interpreted as the consequence of two different orientations of the IMF, hence two different states of geomagnetic activity. Indeed, Nishimura et al. (2009), Poudel et al. (2019) and Gnanou et al. (2022) have noted that the MCEF responds to the change in orientation of the IMF. Kelly et al. (1979) and Siqueira et al. (2011) point out that MCEF values decrease after the IMF switches from south to north. As magnetic shock and cloud activities cause 90% magnetic storms (Wu et al., 2006) and as the onset of the magnetic storm is identified by an intensification of the ring current, it can be concluded that the increasing phase of the MCEF expresses the phase when geomagnetic activity increases and the decreasing phase when the MCEF decreases (Kaboré et al., 2019).

Figure 3 illustrates the diurnal variability of the MCEF at phase minimum during days of shock activity (solid curve) and during days of magnetic cloud ejections (dashed curve). It can be noted that from 0000 UT to 2400 UT during shock activity days the MECF shows two trends: a decreasing trend from 0000 UT to 2000 UT and an increasing trend from 2000 UT to 2400 UT with correlation coefficients of about 0.74 and 0.64 respectively. During the same period from 0000 UT to 2400 UT, on days of magnetic cloud activity, the MECF also shows two remarkable trends: an increasing trend from 0000 UT to 1700 UT with a slope of 3.33 10^{-3} mV/(m.s), correlation coefficient about 0.81, and a decreasing trend from 1700 UT to 2400 UT with a slope of -5,9 10^{-3} mV/(m.s),, correlation coefficient about 0.84.

Furthermore, it is noted that during the phase minimum of the solar cycle, on days of magnetic cloud activity the hourly MCEF values vary between 5.08 10^{-2} mV/m and 12.41 10^{-2} mV/m with an average value of 8. 56 10^{-2} mV/m while on days of shock activity the minimum, maximum and average values of the MCEF are two to four times higher and have values of 12.95 10^{-2} mV/m;

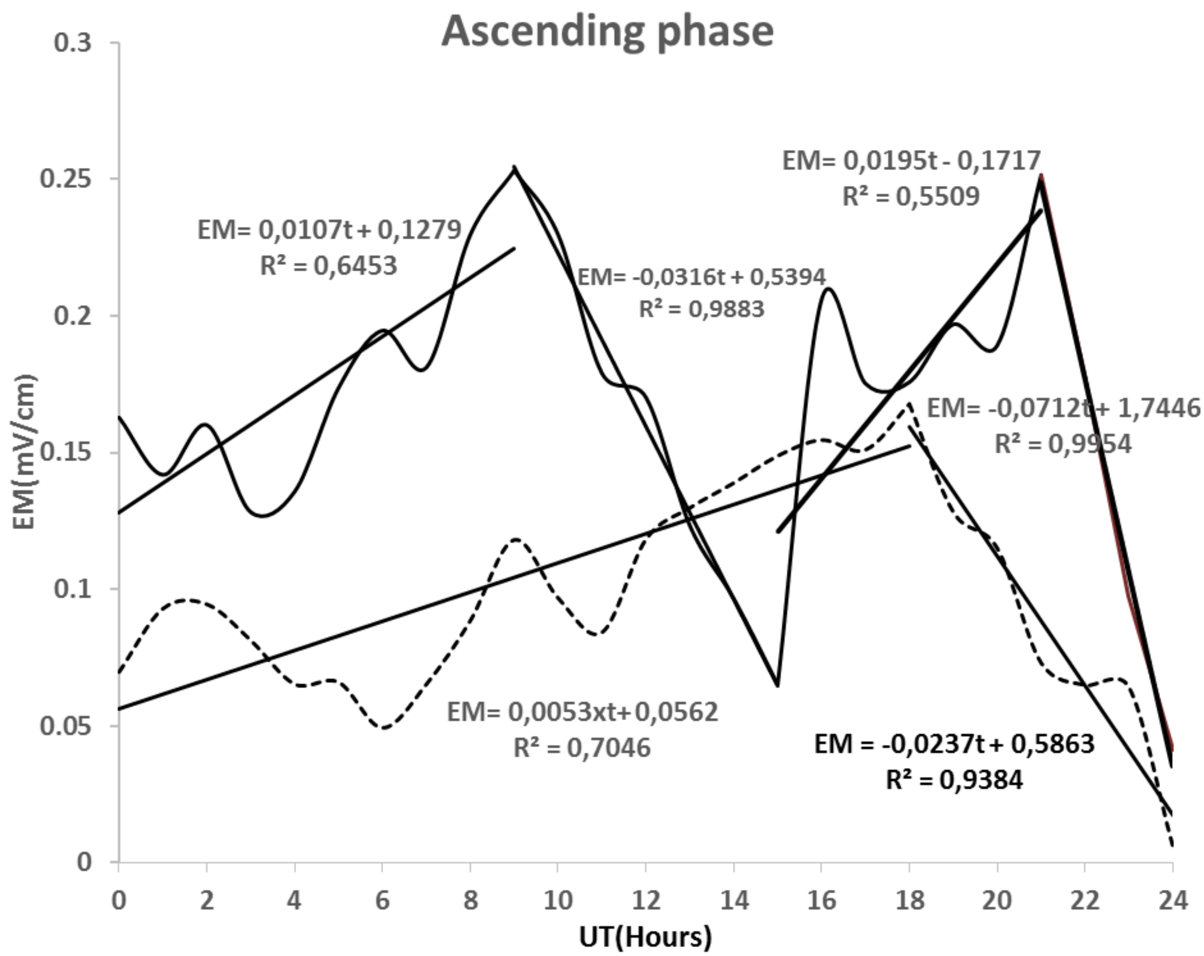

Figure 4. The same as figure 3 but ascending phase.

55 10^{-2} mV/m and 31.23 10^{-2} mV/m respectively.

It is noted that for all hours of the day, except 2000 UT, the MCEF on shock days is much higher than on magnetic cloud days, with a gap varying between 25 10^{-3} mV/cm and 448 10^{-3} mV/m. These minimum and maximum gap values are observed at 2100 UT and 2300 UT respectively. At 2000 UT the MCEF intensity on shock days is very slightly higher than on magnetic cloud days with a gap of 2.02 10^{-3} mV/m.

According to Kaboré and Ouattara (2018) and Gnanou et al. (2022) the continuous decay of the MCEF from 0000 UT to 2000 UT during days of shock activity and from 1700 UT to 2400 UT during days of magnetic cloud activity can be interpreted as the consequence of south-to-north orientation switches of the Bz component of the interplanetary magnetic field (IMF), which occur at 00:00 UT during shock activity and at 1700 UT during magnetic cloud activity. The good correlation coefficients suggest that the MFI is maintained in the south-north direction during the MCEF decay intervals.

In contrast, the MCEF growth phases observed between 2000 UT and 2400 UT during shock activity days and between 0000 UT and 1700 UT during magnetic cloud days can be interpreted as a sign of maintenance of the IMF in the North-South direction (Kaboré et al., 2019). The consequence of maintaining the IMF in this direction is a significant transfer of mass, momentum, and energy into the magnetosphere (Russel, 2007). The MCEF growth phase from 2000 UT to 2400 UT during the shock period can also be interpreted as being due to a night-side reconnection between the IMF and geomagnetic field lines.

Figure 4 shows the diurnal variability of the MCEF during days of shock activity (solid line curve) and during days of magnetic cloud ejections (dashed line curve) during the ascending phase of the solar cycle.

It was noted that between 1300 UT and 1500 UT the MCEF during shock activity is lower than the MCEF during magnetic cloud activity. The difference between the MCEFs for these times varies between 0.00654849 mV/m and 0.08367095 mV/cm. However, it is important to note that this difference is larger for the other hours of the day and the MCEF varies between 0.00802532 mV/m and 0.17849308 mV/cm. This difference is minimal

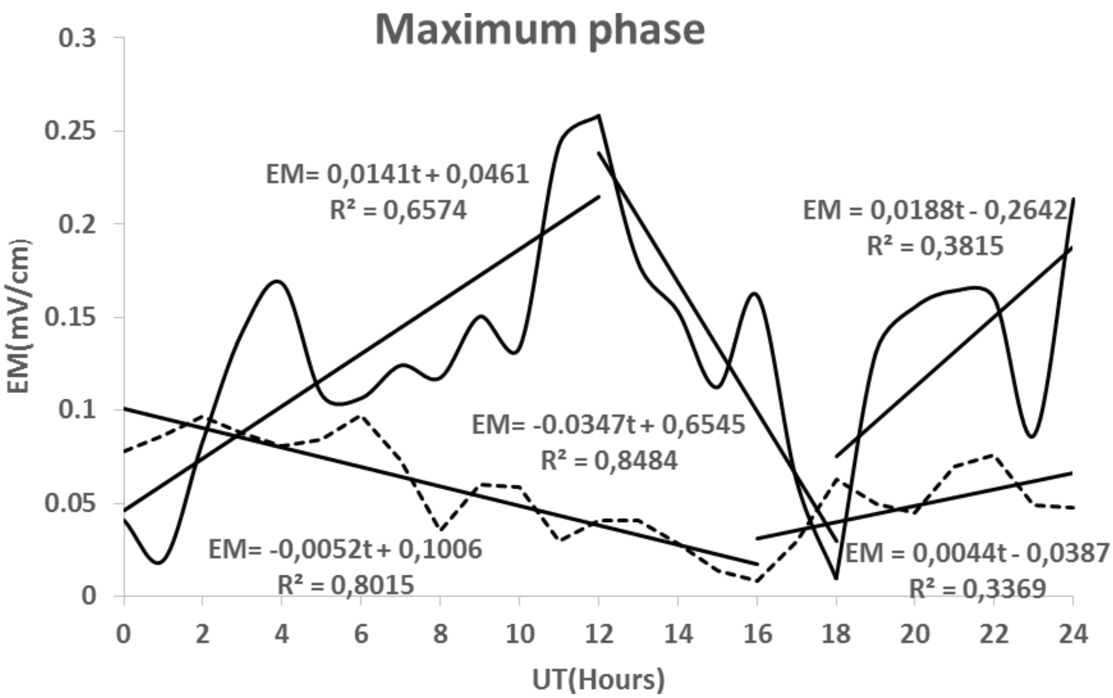

Figure 5. The same as figure 3 but maximum phase.

at 1800 UT and maximal at 2100 UT.

It was noted on the same graph that from 0000 UT to 2400 UT the MCEF variability during shock activity days shows four trends, two increasing and two decreasing, whereas during days of magnetic cloud activity the variability of the MCEF shows two trends. Thus, during days of shock activity caused by geoeffective CMEs, the MCEF is: (1) increasing from 0000 UT to 0900 UT with a slope of 1.07 10^{-2} mV/m and a correlation coefficient of 0.80, (2) decreasing from 0900 UT to 1500 UT with a slope of -3.16 10^{-2} mV/m and a correlation coefficient equal to 0.99, (3) increasing from 1500 UT to 2100 UT with a slope of 1.95 10^{-2} mV/cm and a correlation coefficient equal to 0.74 and (4) decreasing from 2100 UT to 2400 UT with a slope of -7.12 10^{-2} mV/m and a correlation coefficient equal to 0.99. During days of magnetic cloud activity the diurnal variability of the MCEF is: (1) increasing from 0000 UT to 1800 UT with a slope of 5.3 10^{-3} mV/m and a correlation coefficient equal to 0.84, (2) decreasing from 1800 UT to 2400 UT with a slope of -2.37 10^{-2} mV/m and a correlation coefficient equal to 0.97. The decay phases of the MCEF observed in the night sector suggest the non-existence of a magnetic reconnection on the night side on both shock and magnetic cloud activity days.

However, it is important to note that for both magnetic activities, all magnetospheric convections start the day with a southward oriented IMF.

Figure 5 shows the diurnal temporal variations of the MCEF on days of shock activity (solid curve) and on days of magnetic cloud ejections (dashed curve) during the phase maximum. The MCEF variations show three trends during shock days and two trends during magnetic cloud action days.

During shock activity days, first from 0000 UT to 1200 UT the MCEF shows an increasing phase with a slope of 1.41 10^{-2} mV/(m.s) and a correlation coefficient of 0.81. Then, we observe a decreasing phase from 1200 UT to 1800 UT. The slope of this phase is -3.47 10^{-2} mV/(m.s) with a correlation coefficient of 0.92. Finally, from 1800 UT to 2400 UT the MCEF presents an increasing phase with a slope value of 1.88 10^{-2} mV/(m.s) and a correlation coefficient equal to 0.62.

During magnetic cloud activity days, the MCEF is decreasing from 0000 UT to 1600 UT. The slope of this phase is -5.2.10^{-3} mV/(m.s) with a correlation coefficient of 0.90. After this phase we observe an increasing phase from 1600 UT to 2400 UT characterised by a slope of value 4.4 10^{-3} mV/(cm.s) and a correlation coefficient value of 0.58. The phases of increase of the MCEF observed in the afternoon sector, from 16000 UT- 2400 UT for the magnetic clouds and from 1800 UT-2400 UT for the shock activities correspond to periods of magnetic reconnection at the level of the tail lobes with the lines of the IMF initially oriented towards the north. These reconnections observed in the lobes of the magnetosphere are consistent with the reconnection model proposed in the open magnetosphere concept (Dungey, 1961) which illustrates the principle of field line and plasma transport (Lilensten and Blelly, 2000).

During shock activity days, the MCEF varies between a

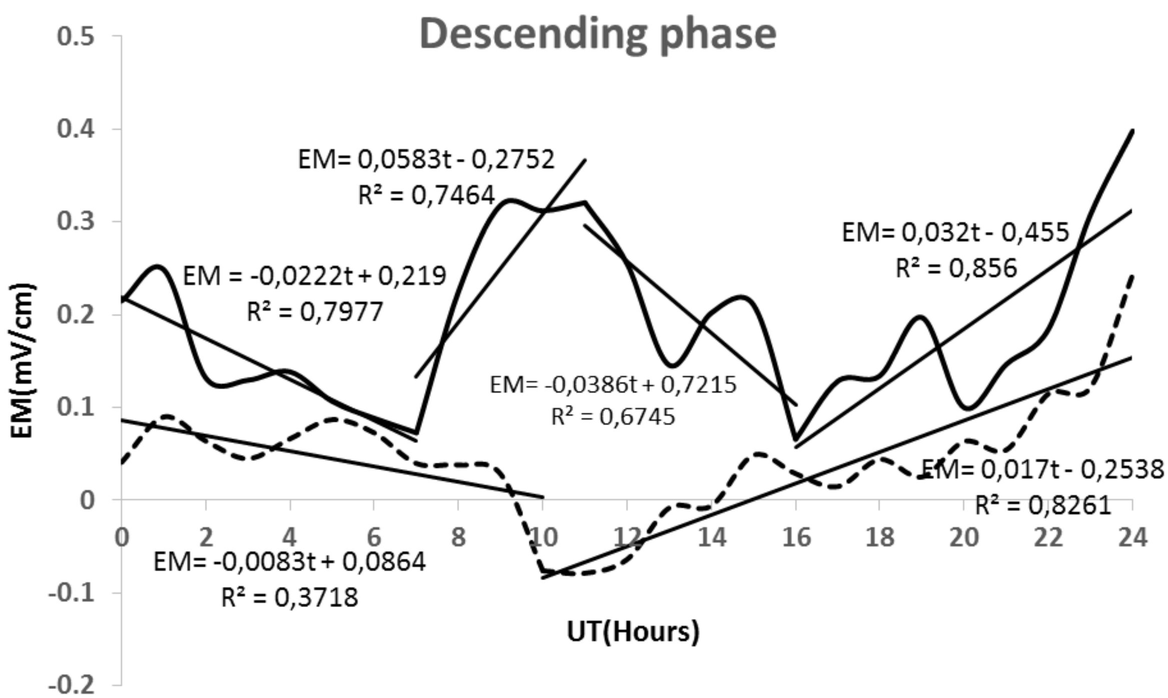

Figure 6. The same as figure 3 but descending phase.

minimum value of 0.00964762 mV/cm and a maximum value of 0.25831905 mV/cm while during magnetic cloud days these minimum and maximum MCEF values are 0.00801034 mV/cm and 0.09748621 mV/m respectively. Except for the hourly interval [0000 UT; 0200 UT] and 1800 UT where the MCEF values on magnetic cloud days are higher than those on shock days, for the other hours of the day the MCEF values on shock days are higher than those on magnetic cloud days with differences varying between 0.00898046 mV/m and 0.21758456 mV/m.

Figure 6 shows the diurnal temporal variations of the MCEF on days of shock activity (solid curve) and on days of magnetic cloud ejections (dashed curve) during the downward phase of the solar cycle. The MCEF variations show four trends during shock days and two trends during magnetic cloud activity days.

During the days of shock activity, the MCEF shows: (1) from 0000 UT to 0700 UT a decreasing phase with a slope of -2.22 10^{-2} mV/(m.s) and a correlation coefficient of 0.89; (2) an increasing phase from 0700 UT to 1100 UT with a slope of 5.83 10^{-2} mV/(m.s) and a correlation coefficient of 0. 86; (3) from 1100 UT to 1600 UT a decreasing phase with a slope value of 3.86 10^{-2} mV/(m.s) and a correlation coefficient equal to 0.82 and (4) from 1600 UT to 2400 UT an increasing phase with a slope value of 2.9 10^{-2} mV/(m.s) and a correlation coefficient equal to 0.80.

During days of magnetic cloud activity, the MCEF is decreasing from 0000 UT to 1000 UT. The slope of this phase is -8.3 10^{-2} mV/(m.s) with a correlation coefficient of 0.61. After this phase follows an increasing phase from 1000 UT to 2400 UT characterised by a slope value of 1.98 10^{-2} mV/(m.s) and a correlation coefficient value of 0.90.

During shock activity days the MCEF varies between a minimum value of 6.56 10^{-2} mV/m and a maximum value of 39.8 10^{-2} mV/cm, whereas on days of cloud activity these minimum and maximum values of the MCEF are respectively -7.87.10^{-2} mV/m and 25.13$10^{-2}$ mV/m.

At the phase minimum, in the downward phase and for all phases combined (Figure 2), the MCEF values during days of shock activity are higher than those of days of magnetic clouds with differences varying between 1.57.10^{-2} mV/m and 39.95 10^{-2} mV/m.

As at phase maximum, we note an increase of the MCEF in the afternoon sector (16000 UT- 2400 UT) for the shock activity, materializing the signature of a magnetic reconnection at the level of the lobes of the magnetosphere. However, during the days of magnetic cloud activity we cannot conclude whether or not there is a magnetic reconnection in the afternoon sector.

It is also important to note that from the phase minimum to the descending phase the MCEF variability curves on days of shock activity show respectively 2; 4; 3 and 4 trends while on days of magnetic cloud activity they show two trends and this whatever the phase of the solar cycle. This relative stability of the MCEF direction in magnetic cloud activity days compared to shock activity days could be explained by the slow rotation over a long

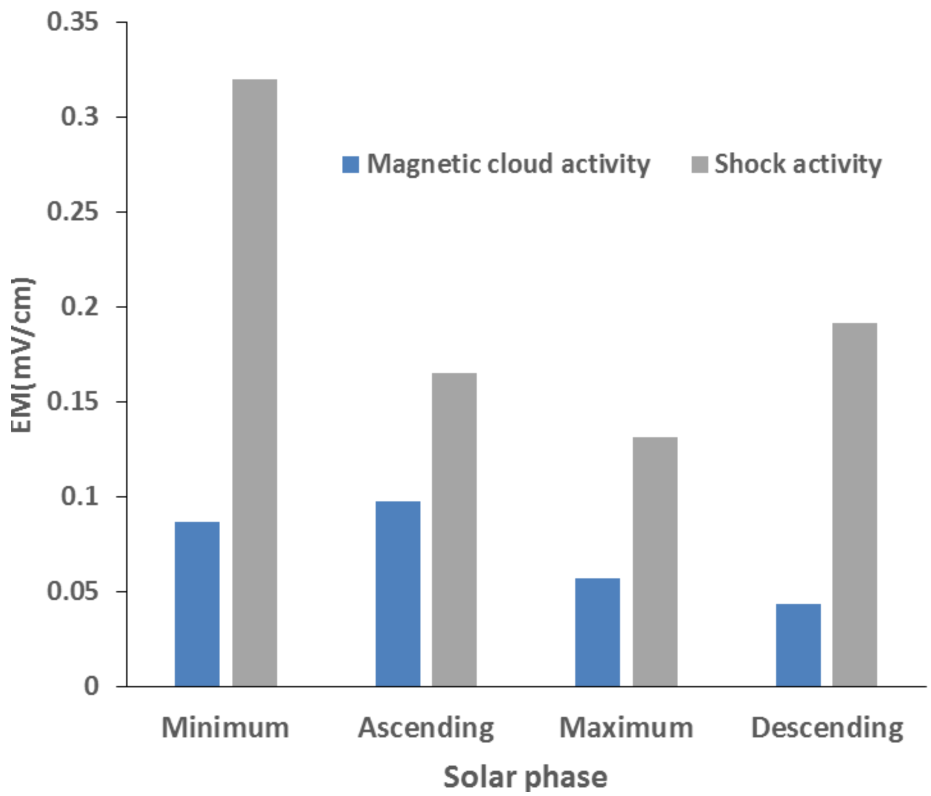

Figure 7. Daily average values of the MCEF according to the different phases of the solar cycle.

period of time that characterises the direction of the interplanetary magnetic field frozen in magnetic clouds (Turc, 2014).

Daily mean values of the MCEF during shock and magnetic cloud days

In Figure 7, the daily mean values of the MCEF during periods of magnetic cloud activity and shock activity are presented as a function of the different phases of the solar cycle.

We note that whatever the phase of the solar cycle, the mean value of the MCEF during shock activity days is higher than that during magnetic cloud days. The value of the aa index during magnetic cloud days being lower than that during shock days, this result suggests the existence of a correlation between the value of the MCEF and that of the geomagnetic aa index, thus a correlation between the MCEF and geomagnetic activity. The existence of such a correlation is supported by the results of Kaboré et al. (2019) for which the MCEF intensities in calm periods were at all times lower than those in disturbed periods (irrespective of the type of disturbance). MCEF intensities in disturbed periods were also lower than those in shock periods.

During days of shock activity caused by ICMEs the largest average MCEF value is recorded during the phase minimum and the smallest value during the maximum. During the days of magnetic cloud ejections, the maximum MCEF value is recorded during the ascending phase and the minimum value during the descending phase. These results prove that the daily mean MCEF value does not vary in phase with sunspot activity.

During days of magnetic cloud activity and shock activity, the value of the MCEF during the ascending phase differs from that during the descending phase, which proves that magnetospheric convection does not vary symmetrically with sunspot activity. We note that just as during days of shock activity (Kaboré et al., 2019), during days of magnetic clouds the MCEF varies with the phase of the solar cycle. These results corroborate those of Vijaya et al. (2011) for whom the intensity of magnetic storms varies with the phases of the solar cycle.

Conclusion

On days of minimum phase, descending phase and all phase periods, the hourly mean value of the MCEF on days of shock activity is higher than that of the MCEF on days of magnetic clouds, with a range between 0.01571854 mV/m and 0.20308496 mV/m. From the phase minimum of the solar cycle to the descending phase during days of shock activity, the MCEF have respectively for daily average values 0.2452 mV/m; 0.2210 mV/m; 0.1768 mV/m and 0.1584 mV/m. In contrast, during periods of magnetic cloud activity from the phase minimum to the descending phase of the solar cycle, the MCEF values are respectively 0.0821 mV/m; 0.1014 mV/m; 0.0533 mV/cm and 0.0461 mV/m. The study shows that for a complete solar cycle (solar cycle of 22 years duration): (1) the daily mean MCEF value depends on geomagnetic activity and is better correlated with the geomagnetic index aa, (2) magnetic cloud activity generates a moderate disturbance of the Earth's magnetosphere compared to shock activity, (3) the MCEF mean value varies with sunspot activity but is not correlated with it, and (4) magnetospheric convection is not symmetrical with respect to sunspot activity.

The MCEF variability curve during periods of shock activity, irrespective of the phase, shows three trends starting and ending with a south-facing interplanetary magnetic field (IMF). That in periods of cloud activity also shows three trends but starting and ending with a northward oriented IMF. The study shows that on both shock and magnetic cloud days: (1) during the phase maximum and the descending phase the MCEF ends the day with a south oriented IMF, (2) during the ascending phases the MCEF starts the day with a south oriented IMF which is maintained up to 1300 UT in shock period and up to 1600 UT in magnetic cloud days. For all types of phase (regardless of the phase), the MFI ends the day with a southward orientation on days of shock activity and a northward orientation on days of magnetic cloud activity.

At phase minimum during shock activity caused by geoeffective interplanetary coronal mass ejections (ICMEs) there is a night reconnection. At phase maximum there is magnetic reconnection at the lobes of the Earth's magnetosphere for both types of activity. However, in the descending phase, during the days of magnetic cloud ejections, we cannot affirm the existence or not of a magnetic reconnection at the level of the lobes of the magnetosphere.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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