

# Magnetospheric Convective Electric Field (MCEF): Comparative Diurnal Statistical Variability of Different Types of Shock and Magnetic Cloud Activity Days

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## Abstract

In this paper we make a comparative investigation of the signatures of shock activities caused by geoeffective interplanetary coronal mass ejections (ICMEs) and magnetic clouds on the day/night variability of the magnetospheric convective electric field (MCEF) during solar cycles 23 - 24. The investigation is carried out with reference to reconnection phenomena between interplanetary magnetic field lines (IMF) and geomagnetic field lines, taking into account the duration of geomagnetic effects. During days of shock or magnetic cloud activity whose effects last one (1) day, the MCEF begin and end the day in a decreasing phase. During two-day activities, MCEF begin and end the day in an increasing phase. During three-day activities, MCEFs start the day in a decreasing phase and end the day in an increasing phase. The daily mean values of the MCEF during shock periods caused by geoeffective ICMEs are 0.1260966 mV/m, 0.14829124 mV/m and 0.21189352 mV/m respectively for shock activities lasting one (1) day, two (2) days and three (3) days. On the other hand, the average daily intensities of the MCEF on days of disturbance caused by magnetic clouds are 0.0932402 mV/m, 0.08539255 mV/m and 0.0820986 mV/m respectively for magnetic clouds whose effects last one (1) day, two (2) days and three (3) days. The activity of magnetic clouds on magnetospheric convection appears to be correlated with both shock activity and sunspot activity. The geoeffective ICMEs responsible for the shock activity are

more geoefficient than the magnetic clouds, which suggests that the Bz component of the orientation IMF is more durable in a southerly orientation and stronger in intensity on days of shock activity than on days of geomagnetic disturbance caused by magnetic clouds.

## Keywords

Magnetosphere Convection Electric Field, Interplanetary Magnetic Field, ICMEs, Shock Activity, Magnetic Cloud Activities, Duration of Geomagnetic Activity

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## 1. Introduction

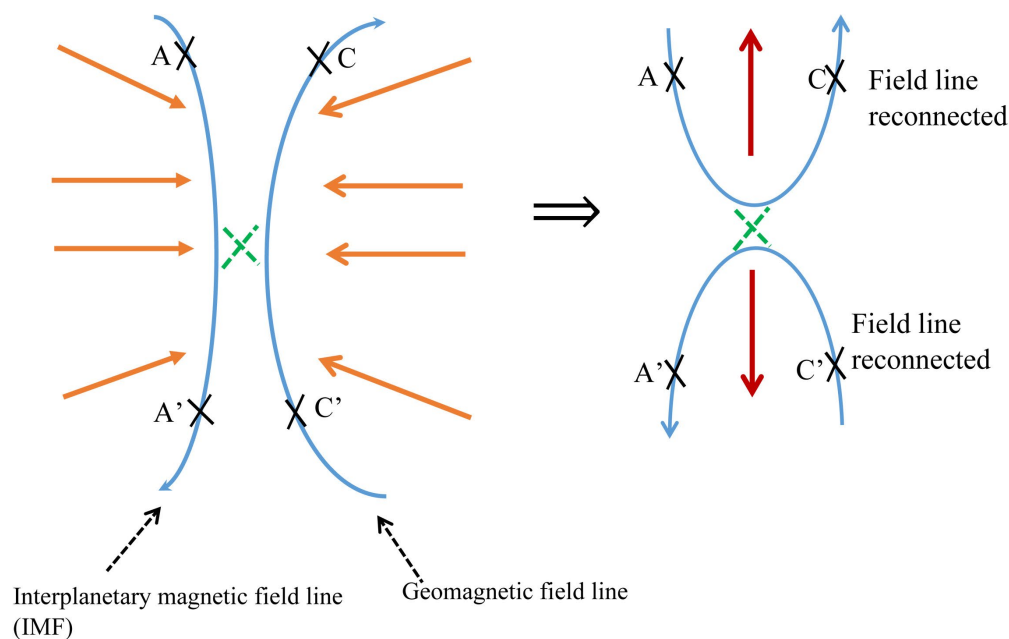
The Sun continuously emits a stream of charged particles in the form of the solar wind, in which a tiny part of the solar magnetic field is frozen. In the interplanetary medium, this magnetic field is known as the interplanetary magnetic field (IMF). The IMF lines in the context of the Sun-Earth relationship are open magnetic field lines. When the solar wind is emitted in the direction of the Earth, it interacts with the geomagnetic field lines—closed magnetic field lines—and compresses them in a cavity in the solar wind that [1] called the magnetosphere or, more precisely, the terrestrial magnetosphere. Due to the pressure of the solar wind, the magnetosphere is compressed on the day side and extends between six and ten Earth radii RT, whereas on the night side it is stretched and extends up to two hundred (200) times the Earth radius (1 RT  $\approx$  6370 km). The dynamics of the magnetosphere and these limits are highly dependent on solar activity.

Above the photospheric disc rise the prominences, which are pockets of hot plasma suspended in the solar corona against gravity and thanks to magnetic forces. When the magnetic forces outweigh the gravitational ones, the balance is upset and large quantities of matter are ejected. When directed towards Earth, these coronal mass ejections (CMEs) can cause damage to the solar panels of satellites, loss of control of satellites, disruption of communications and the appearance at low latitudes of the aurora borealis usually observed in high latitude regions (60° to 75° latitude).

Interplanetary magnetic field lines (IMF) in the context of Sun-Earth relations are open magnetic field lines, whereas geomagnetic magnetic field lines are closed lines. The most plausible and advanced physical theory to explain the solar wind magnetosphere interaction is the reconnection between interplanetary magnetic field lines (IMF). In simplified terms, magnetic reconnection occurs when magnetic field lines “intersect” and connect in different ways. A simplified diagram of the principle of magnetic reconnection is shown in **Figure 1**.

*Antiparallel magnetic field lines (in blue) approach a magnetic neutral point labelled X (dotted line in the figure), pushed by plasmas whose velocities are directed along the orange arrows.*

*If reconnection occurs at point X, point A, initially magnetically connected to*



**Figure 1.** Schematic diagram of the magnetic reconnection between interplanetary magnetic field lines and geomagnetic field lines.

*point A' (left), may suddenly find itself connected to point C (right), and point A', initially magnetically connected to point A (left), may suddenly find itself connected to point C (right). Once the reconnection is made: (a) an interplanetary magnetic field line (solar magnetic field line initially frozen in the solar wind) may suddenly find itself connected to a geomagnetic field line and (b) the magnetic plasma and the connected magnetic field lines undergo convection and are strongly accelerated (red arrows) by the tension force of the field lines (Inspired by [2]).*

Such a magnetic reconnection can link the inside and outside of the magnetopause, the boundary between the magnetosphere and interplanetary space. In addition, this reconnection, which causes geomagnetic field lines to open up, leads to the penetration of solar particles into the magnetosphere. According to [2], all magnetospheric phenomena are more or less direct consequences of magnetic reconnection phenomena. Importantly, the aim of this paper is to contribute to a better understanding of the behaviour of the Earth's magnetosphere during periods of shock and magnetic cloud activity. In this paper, we make a comparative analysis of the variability of the electric field of the magnetospheric convection during days of shock activity caused by geoeffective interplanetary coronal mass ejections (ICMEs) that are accompanied by fast solar winds, and during days of magnetic cloud activity, which include shock events generated by areas of intense magnetic fields with rotational motion ([3] [4]). This analysis is carried out using magnetic reconnection phenomena. In the remainder of this article, we first present the data and methods used, then the results and discussions, followed by the conclusion, and finally we conclude with the limits and prospects for further research.

## 2. Data and Methods

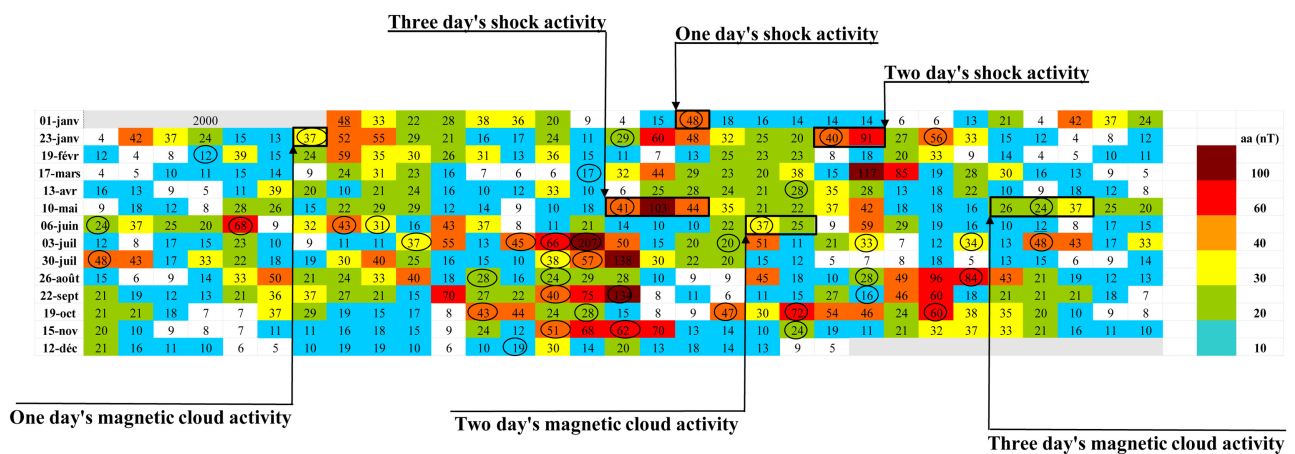
### 2.1. Determining the Different Types of Magnetic Clouds and Shock Activity

Pixel diagrams were used to determine the days of magnetic cloud activity and the days of shock activity. These diagrams are constructed from the daily mean values of the Aa index and the SSC dates. We also followed the criteria defined by [5]. Aa index data and SSC dates were collected from the website via the link: [https://isgi.unistra.fr/data\\_download.php](https://isgi.unistra.fr/data_download.php).

The different types of magnetic clouds and shocks are identified from twenty-four (24) pixel diagrams, representing those from 1996 to 2018. **Figure 2** is an example of a pixel diagram, also known as a Bartels diagram, showing the different types of shock activity and magnetic clouds.

The three types of magnetic cloud activity were identified according to the duration of their action: (a) magnetic cloud activity lasting one (1) day; this corresponds to the only day on which the sudden storm commencement (SSC) occurs: Aa is such that  $20 \text{ nT} < Aa < 40 \text{ nT}$  on a single day (day corresponding to the sudden storm commencement); (b) magnetic cloud activity lasting two (2) days; the activity lasting two days is identified by the day on which the SSC appears and the following day. Aa remains between 20 nT and 40 nT over two days; (c) activity lasting three days is identified by the day of appearance of the SSC and the following two days. Aa remains between 20 nT and 40 nT over three days ([6] [7]). Examples of these days are shown in **Figure 2**.

The three types of shock day activities were identified according to the duration of their action: (a) shock lasting one (1) day; this corresponds to the only day on which the Sudden Storm Commencement (SSC) occurs:  $Aa > 40$  on a single day (day corresponding to the Sudden Storm Commencement); (b) shock lasting two (2) days; The shock lasting two days is identified by the SSC and the following day. The aa index remains above 40 nT over two days; (c) shock lasting three days is identified by the day the SSC appears and the following two days. Aa remains above 40 nT over three days ([8] [9]).



**Figure 2.** Pixel diagram for the year 2000, showing the different days of magnetic clouds and shock activity.

This figure shows selections of days of magnetic cloud activity lasting one (1) day (activity on 27 January 2000); two (2) days (activity on 23 - 24 June 2000); three (3) days (activity on 4 - 6 June 2000) and selections of days of shock activity lasting one (1) day (11 January 2000); two (2) days (11 - 12 February 2000) and three (3) days (23 - 25 May 2000).

## 2.2. Determining the Magnetospheric Convection Electric Field Intensity

The hourly intensity of the magnetospheric field ( $E_M$ ) will be calculated using the linear correlation between the hourly data for the frozen electric field in the solar wind ( $E_y$ ) and those for the electron density established by [10]) and validated by [11] and given by the equation  $E_M = 0.13 E_y + 0.09$ , an equation whose correlation coefficient is 0.97. The hourly values of the intensity of the  $E_y$  component [mV/m] of the electric field frozen in the solar wind for solar cycles 23 - 24 are obtained from the OMNIWEB site <http://omniweb.gsfc.nasa.gov/form/dx1.html> and those for the MCEF are calculated using the above equation for the period (1996-2018) corresponding to the two solar cycles concerned in the study. It is important to note that each hourly  $E_M$  value is calculated using the hourly arithmetic mean values of  $E_y$  during the days of magnetic activity concerned for the duration of the activity concerned.

## 3. Results and Discussion

### 3.1. Comparative Diurnal Variability of the MCEF in Shock Activities and Magnetic Clouds Lasting One (1) Day

Figure 3 illustrates the diurnal variability of the MCEF during days of shock activity (red curve) and days of magnetic cloud activity (green curve) whose effects last one day.

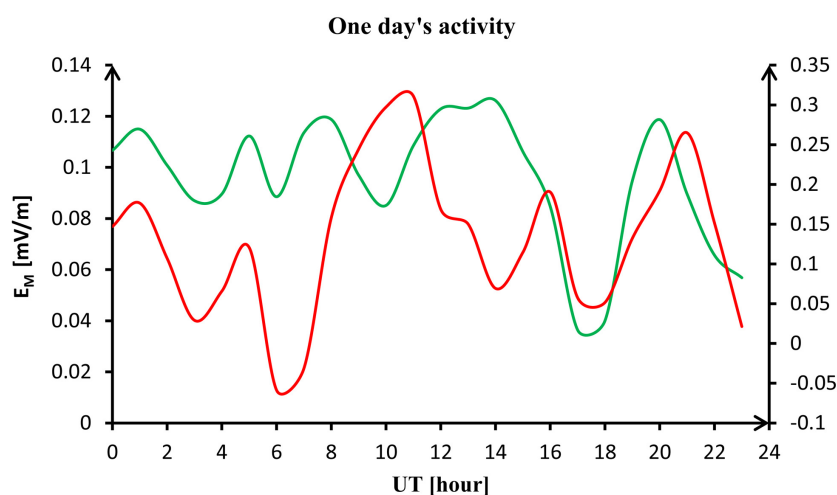


Figure 3. Diurnal variability of the magnetospheric convection electric field during shock (red curve) and magnetic cloud (green curve) activities, the geomagnetic effects of which last one day.

We note that during the hourly intervals 0000 UT - 0100 UT; 0300 UT - 0500 UT and 0600 UT - 0800 UT the two MCEF variability curves are increasing. These increases observed on the morning side can be interpreted as the consequence of a reconnection on the front side of the Earth's magnetosphere (the region between the Sun and the Earth) between the lines of the IMF oriented south and those of the Earth's magnetic field naturally oriented north. Reconnection with a south-facing IMF creates new open magnetic field lines through which the charged particles of the solar wind penetrate, resulting in an increase in EM. This interpretation is in line with that of [12], for whom the increasing phase corresponds to the main magnetic phase. The start of this phase corresponds to the start of the change in orientation of the IMF from north to south. Since such a change in orientation implies an intensification of the ring current ([13] [14]) and the geomagnetic storm is identified by the intensification of the ring current ([15]), we can conclude that the increasing phase of the MCEF expresses the phase of increasing geomagnetic activity. Furthermore, according to [16] the consequence of a reconnection with a South-facing IMF is the massive entry of implosions, charged particles and energy into the magnetosphere. [17] specifies that this type of reconnection is the consequence of the electromagnetic coupling between the solar wind and the Earth's magnetosphere, which results from the process of magnetic connection between magnetic lines occurring on the front of the magnetopause.

The MCEF also increases: (a) from 1000 UT to 1400 UT on days of magnetic cloud activity lasting one (1) day, and (b) from 1400 UT to 1600 UT on days of shock activity generated by geoeffective ICMEs. Such growths can be interpreted as the consequence of magnetic reconnections at the level of the magnetosphere lobes between the initially northerly oriented IMF lines and the Earth's magnetic field lines. According to [16], when the IMF is oriented 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 varying directions on its surface. At certain points in the lobes of the magnetosphere, the two types of field line may be antiparallel. Then, at these magnetic neutral points, the two field lines can reconnect. This interpretation is also in line with those of [18] and [19], for whom, when the MFI is directed purely northwards, the reconnection between the field lines occurs behind the polar cones in the regions of the magnetospheric lobes. However, it is important to point out that such a reconnection: (a) stirs up the magnetospheric plasma and transfers the impulse from the solar wind to the magnetosphere, (b) does not ensure a strong coupling between the magnetosphere and the solar wind ([16] [20]).

The two MCEF continue to increase: (a) from 1800 UT to 2000 UT on days of magnetic cloud activity lasting one (1) day, and (b) from 1800 UT to 2100 UT on days of shock activity generated by geoeffective ICMEs. Such growths observed in the night sector can be interpreted as the consequence of a reconnection in the night sector. It is important to point out that reconnection in the night sector or night reconnection is consistent with the transport principle of interconnected

magnetic lines open towards the night side (from the front to the back of the magnetosphere). Such magnetic field lines open following reconnection on the front side of the magnetosphere reconnect and close at magnetic neutral points in the night sector. It is important to point out that during such a reconnection: (a) a much stronger coupling occurs between the magnetosphere and the solar wind. The consequence of such a reconnection is a much stronger entry of mass, momentum and energy into the magnetosphere than when the IMF is oriented northwards [16], (b) a reconstitution of terrestrial and interplanetary magnetic field lines, and (c) the formation of new closed terrestrial magnetic field lines.

During the following time periods: 0100 UT to 0300 UT; 0500 UT to 0600; 1000 UT to 1400 UT; from 1600 UT to 1800 UT and from 2000 UT to 2400 UT the MCEF on a day of shock activity is decreasing. On a day of magnetic cloud activity, this decrease is observed from 0100 UT to 0300 UT; 0500 UT to 0600; 0700 UT-1000 UT; 1400 UT to 1700 UT; and from 2000 UT to 2300 UT. These decreases in the diurnal variability of the MCEF can be interpreted in two ways. Firstly, they can be interpreted as an absence of interaction between magnetic flux tubes ([21]). Secondly, they may also reflect a lack of magnetic reconnection between the interplanetary magnetic field lines and the geomagnetic field lines, the causes of which may include the non-thawing of the IMF or a IMF that remains in a northerly orientation. Indeed, according to [22] and [23] MCEF values decrease after the IMF tilts from south to north. In the end, each of the MCEF growth and decay phases can therefore be interpreted as being the consequence of magnetic reconnection with a south-facing IMF or the absence of reconnection.

From 0000 UT to 0800 UT and then from 1600 UT to 2400 UT and during the same time intervals, we note a similar signature in the dynamics of the magnetosphere for days of shock activity and days of magnetic cloud activity. The graphs in **Figure 3** show that during this period there are reconnections on the day side at 0300 UT and 0600 UT, and a reconnection at the magnetospheric flanks at 1700 UT.

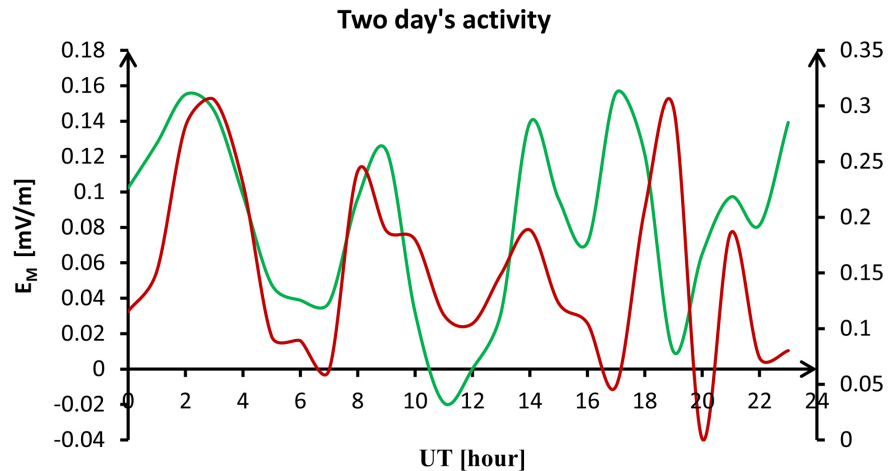
In contrast, from 0800 UT to 1600 UT, we note that during the two (2) hour to four (4) hour time slots (from 0800 UT - 1000 UT; from 1000 UT - 1400 UT and from 1400 UT - 1600 UT) there is an inverse variability in the MCEF, thus illustrating two different signatures in the orientation of the IMF for the said time slots.

From 0000 UT to 0400 UT and from 2100 UT to 2400 UT the two MCEFs are decreasing: during days of magnetic shock or magnetic cloud activity whose geoeffectivities last one day, the MCEF begin and end the day without any reconnection between the geomagnetic and interplanetary field lines.

### **3.2. Comparative Diurnal Variability of the MCEF in Shock Activity and Magnetic Clouds of Two (2) Days Duration**

**Figure 4** shows the diurnal variability of the MCEF during days of shock activity (red curve) and days of magnetic cloud activity (green curve), when the geomag-

netic effects last for two days.



**Figure 4.** Diurnal variability of the magnetospheric convection electric field during shock activity (red curve) and magnetic cloud activity (green curve), the geomagnetic effects of which last two days.

We note that over the hourly intervals from 1 h to 5 h: 0000 UT - 0500 UT; 0700 UT - 0800 UT and 1200 UT - 1400 UT; 1700 UT - 1900 UT, 2000 UT - 2100 UT; 2200 UT - 2400 UT the MCEF variability curve on days of shock activity caused by geoeffective ICMEs is increasing. On days of disturbance caused by magnetic clouds, the MCEF growth phases are generally observed at 0000 UT - 0200 UT from 0700 UT - 0900 UT and 1100 UT - 1400 UT; 1600 UT - 1700 UT, 1900 UT - 2400 UT. The growth observed at the beginning of the day (0000 UT - 0500 UT) and at the end of the day (2200 UT - 2400 UT) means that whether it is a day of geomagnetic activity caused by geoeffective coronal ejections or a day of geomagnetic activity caused by magnetic clouds, the effects of which last for two days, the MCEF begins and ends the day with a south-facing IMF.

A detailed analysis of the different phases of growth observed shows that on a day of shock activity, reconnections: 1) on the front side of the magnetosphere are observed at 0000 UT and 0700 UT; 2) on the flanks (lobes) of the magnetosphere at 1200 UT and 1700 UT and 3) at night at 2000 UT and 2200 UT. During disturbances caused by magnetic cloud ejections whose geomagnetic effects last two days, reconnections on the front side of the magnetosphere are observed at 0000 UT and 0700 UT. Similarly, on a day of disturbances caused by magnetic clouds, reconnections: a) on the flanks of the magnetosphere are respectively observed one hour before, that's to say at 1100 UT and 1600 UT; b) and night-time reconnections at 1900 UT and 2200 UT.

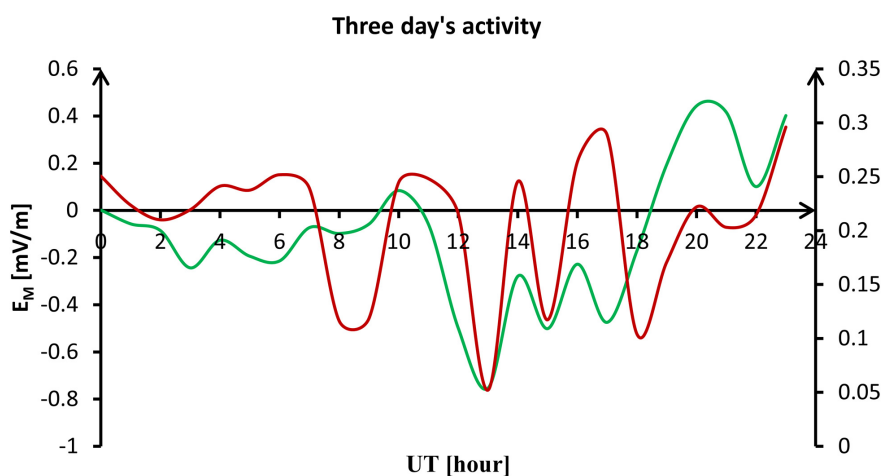
On days caused by shock activity of two days duration, MCEF decays, indicating an absence of reconnection, are observed during the following time slots: 0500 UT to 0700 UT; 0800 UT to 1200 UT; 1400 UT to 1700 UT; from 1900 UT to 2000 UT and from 2100 UT to 2200 UT the MCEF. On days when magnetic clouds are active, there is no magnetic reconnection of the MCEF from 0200 UT to 0700 UT;

0900 UT to 1100 UT; 1400 UT - 1600 UT; 1700 UT to 1900 UT.

With the exception of 17h00 - 20h00, when the two MCEFs seem to vary in opposite directions, the two MCEFs have identical variability signatures throughout the day. For both types of geomagnetic activity, one hour universal Time (0100 UT), 0700 UT, 1100 UT, 1700 UT and 1900 UT are the times when the magnetic field lines begin to reconnect magnetically.

### 3.3. Comparative Diurnal Variability of the MCEF in Shock and Magnetic Cloud Activities of Three (3) Days Duration

**Figure 5** illustrates the diurnal variability of the MCEF during days of shock activity (red curve) and days of magnetic cloud activity (green curve) whose geomagnetic effects last three days. Comparative Diurnal Variability of the MCEF in Shock and Magnetic Cloud Activities of Duration Three (3) Days **Figure 5** illustrates the diurnal variability of the MCEF during days of shock activity (red curve) and days of magnetic cloud activity (green curve) whose geomagnetic effects last three days.



**Figure 5.** Diurnal variability of the magnetospheric convection electric field during shock activity (red curve) and magnetic cloud activity (green curve), the geomagnetic effects of which last three days.

During periods of MCEF disturbances caused by magnetic cloud ejections whose effects last three days, global growth phases are observed between 0200 UT - 1000 UT; 1300 UT - 2000 UT; and 2200 UT - 2400 UT. During periods of magnetospheric disturbances caused by shock activity from geoeffective ICMEs, these growth phases are observed during the time intervals 0200 UT - 0600 UT; 0900 UT - 1100 UT and 1300 UT - 1400 UT, 1500 UT - 1700 UT from 1800 UT - 2300 UT. From these MCEF variabilities, we can see that during periods of magnetic cloud ejections there is a reconnection: 1) on the front side of the magnetosphere at 0200 UT; 2) on the flanks of the magnetosphere at 1300 UT and 3) a reconnection on the night side at 2200 UT. This last reconnection could be interpreted as the consequence of the closure of the open magnetic field lines formed during the

magnetic reconnection with the south-facing IMF observed earlier at 0200 UT. However, in days of shock activity caused by geoeffective ICMEs, we have reconnection (s): a) on the front side of the magnetosphere at 0200 UT and 0900 UT; b) on the flanks of the magnetosphere at 1300 UT and 1500 UT; c) on the night side at 1800 UT.

During the following time periods: 0000 UT to 0200 UT; 0600 UT to 0900 UT; 1000 UT to 1300 UT; from 1400 UT to 1500 UT and from 1700 UT to 1800 UT; 2000 UT - 2200 UT the MCEF on a day of shock activity is decreasing. On days of magnetic cloud activity, these decreases are observed from 0000 UT to 0300 UT; 1000 UT to 1300 UT and from 2000 UT to 2200 UT. According to [23] and [15], the start of each of these time periods corresponds to the times when the geomagnetic and IMF field lines begin to reconnect magnetically.

From 0000 UT to 0300 UT the two MCEFs are decreasing and from 2200 UT to 2400 UT the two MCEFs are increasing. From this we can deduce that during days of magnetic shock or magnetic cloud activity whose geoeffectivities last three days, the MCEFs begin the day without magnetic reconnection and end it with a magnetic reconnection between the geomagnetic and interplanetary field lines with a southern IMF.

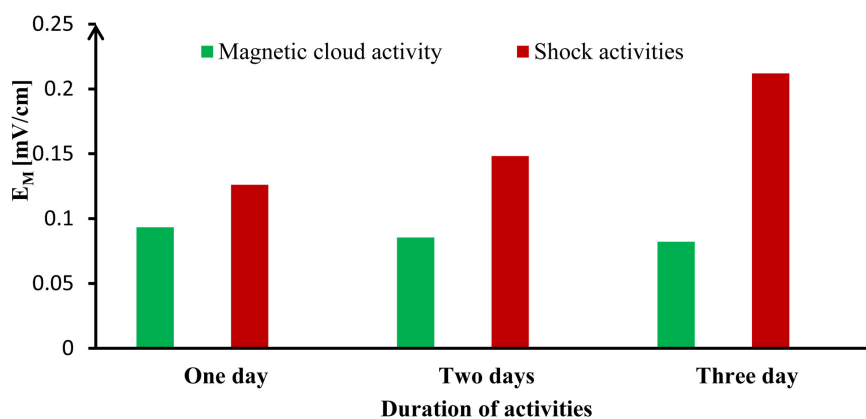
As in periods of shock activity due to geoeffective coronal mass ejections or magnetic clouds lasting two days, we note that for almost every hour of the day the two MCEFs have similar signatures (vary almost in phase). This result shows that the activity of magnetic clouds in the Earth's magnetosphere is correlated with that of the geoeffective CMEs responsible for shock activity. And as the activity of CMEs is correlated with that of sunspots ([24]), it appears that the activity of magnetic clouds is correlated with both that of the geoeffective CMEs responsible for shock activity and that of sunspots. Since shock activity is caused by geoeffective ICMEs from coronal holes, we can conclude that magnetic clouds come from the same solar source. Comparative analysis of the variability of the MCEF during days of shock and magnetic clouds whose effects last one (1) day, two (2) days or three (3) days shows that the MCEF varies according to the duration of the geomagnetic disturbance, whether on days disturbed by shock activity or by magnetic clouds. These results show that the intensity of magnetic storms varies with the duration of the disturbance. These results validate the need to take into account the duration of the action for any fine modelling of magnetospheric dynamics.

### 3.4. Daily Mean Values of the MCEF during the Various Days of Shock and Magnetic Cloud Activity

**Figure 6** shows the daily mean values of the MCEF during days of magnetic cloud activity and days of shock activity as a function of the duration of the disturbance in geomagnetic activity.

The average daily MCEF values for shock periods caused by geoeffective ICMEs are 0.1260966 mV/m, 0.14829124 mV/m and 0.21189352 mV/m respectively for

shock activities lasting one (1) day, two (2) days and three (3) days. On the other hand, the daily mean intensities of the MCEF on days of disturbance caused by magnetic clouds were 0.0932402 mV/m, 0.08539255 mV/m and 0.0820986 mV/m respectively for magnetic clouds whose effects lasted one (1) day, two (2) days and three (3) days. These results show that the daily mean value of the MCEF increases with the duration of geomagnetic effects on days of shock activity and decreases on days of magnetic cloud activity.



**Figure 6.** Daily mean values of the MCEF as a function of the different types of shock and magnetic cloud activity.

For the same duration of the effects of the disturbance, we note that the daily mean value of the MCEF in days of shock activity caused by geoeffective ICMEs is higher than that caused by magnetic clouds. Better still, the relative difference between the daily mean intensities of the MCEF during days of shock activity and those of magnetic clouds, expressed as a percentage, is 26% for disturbances lasting 1 day, 42% for disturbances lasting 2 days and 61% for disturbances lasting 3 days. On days of magnetospheric disturbance due to the ejection of magnetic clouds, the Sun emits fewer charged particles and the magnetospheric electric field is therefore less disturbed and therefore less dynamic. These results corroborate those of [25] and [7] for whom compared to shock activities, magnetic clouds cause a moderate disturbance of geomagnetic activity [25] and [26] also agree that the occurrence and intensity of magnetospheric storms vary according to geomagnetic activity and the duration of the geoeffectivity of the disturbance. These disturbances are more frequent during periods of geomagnetic activity lasting three days, and less pronounced during periods of magnetic cloud activity lasting three days.

Finally, the high intensities of the MCEF observed on shock days compared with magnetic cloud days show that: 1) the geoeffective ICMEs responsible for the shock activity are more geoefficient than the magnetic clouds and 2) the  $B_z$  component of the south-facing IMF—an orientation favourable to magnetic reconnections—is longer-lasting and stronger in intensity in the ICMEs than in the magnetic clouds.

## 4. Conclusions

This article shows that the variability of the electric field of the magnetospheric convection depends on the duration of the geomagnetic activity, whether on days of shock activity or on days of magnetic cloud activity. Whatever the duration of the geomagnetic activity, magnetospheric convection is more disturbed on shock days than on magnetic cloud days. However, both types of geomagnetic activity appear to be generated by the same solar source, coronal holes.

The daily mean value of the MCEF increases with the duration of the action on days of geomagnetic shock activity caused by geoeffective ICMEs. On the other hand, it decreases with the duration of the action on days of magnetic cloud ejections. The relative difference between the daily mean intensities of the MCEF during days of shock activity and those of magnetic clouds, expressed as a percentage, is 26% for disturbances lasting 1 day, 42% for disturbances lasting 2 days and 61% for disturbances lasting 3 days.

During days of magnetic shock or magnetic cloud activity whose geoeffectivities last one (1) day, the MCEF begin and end the day without any reconnection between the geomagnetic and interplanetary field lines.

However, for shock or cloud activities lasting two days, the MCEF begin and end the day with a magnetic reconnection of the south-facing IMF.

During geomagnetic activities (shock or magnetic cloud activities) lasting three days, the MCEF begin the day with a weakening of the convection phenomenon and end the day with a magnetic reconnection. We note that regardless of the geomagnetic activity (shock or magnetic cloud activity) and its duration, nighttime reconnections always occur. However, whatever the geomagnetic activity, the magnetic reconnection phenomena that can occur during the solar wind magnetosphere interaction are unpredictable and irregular in time.

The activity of magnetic clouds on the Earth's magnetosphere seems to correlate not only with that of the fast solar winds that accompany the ejection of the geoeffective CMEs responsible for shock activity, but also with sunspot activity. The geoeffective CMEs responsible for shock activity impact magnetospheric convection more effectively than magnetic clouds, which would show that the Bz component of the IMF is not only longer-lasting in a southerly orientation but is also stronger during days of shock activity than during days of geomagnetic activity caused by magnetic clouds.

## 5. Limits and Perspectives

The main limitations of this work lie not only in the fact that the statistical investigations were carried out only on the last two complete solar cycles (cycle 23 - 24), but also in the fact that the analyses and interpretations of the results obtained were mainly made with reference to the orientation of the MFI and to magnetic reconnection phenomena. A long-term statistical study covering a longer period than 1964-2018, *i.e.* the 20 - 24 solar cycle (1964 being the year of the first measurements on the solar wind and 2018 being the date of the end of the last complete

solar cycle), would lead to results whose generalisation would be more unambiguously accepted. Better still, an investigation integrating other underlying physical mechanisms that can influence the variability of the MCEF, such as solar wind pressure, pre-existing magnetospheric conditions (before the solar wind-Earth magnetosphere interaction), etc., would shed additional light on the physical mechanisms behind the differences in the intensities of the various MCEFs observed.

In our forthcoming research on the Earth's magnetosphere, we will use in situ data from satellites dedicated to observing the Earth's magnetosphere to assess the microphysical mechanisms that govern magnetic reconnection phenomena and their impact on the heating and acceleration of magnetospheric plasma.

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### Conflicts of Interest

The authors have not declared any conflict of interests.

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