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Energetic Dynamics of the Inner Magnetosphere in Contact with Fast Solar Wind Currents: Case of the Period 1964-2009

Inza Gnanou[1,2,3*], Aristide Marie Frédéric Gyébré[2,4], Karim Guibula[2,5], Christian Zoundi[2,4], Frédéric Ouattara[2,4]

[1]École Normale Supérieure, Koudougou, Burkina Faso
[2]Laboratoire de Recherche en Energétique et Météorologie de l'Espace (LAREME), Université Norbert ZONGO, Koudougou, Burkina Faso
[3]Laboratoire de Chimie @nalytique de Physique Spatiale et Energétique (LAC@PSE), Université Norbert ZONGO, Koudougou, Burkina Faso
[4]Université Norbert ZONGO, Koudougou, Burkina Faso
[5]Université Virtuelle du Burkina Faso, Karpala, Ouagadougou, Burkina Faso
Email: *gnanouinza@gmail.com

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Abstract

The Earth's magnetosphere is a magnetic shield that protects Earth from high-energy particles and is subject to a series of internal processes caused by jets of the solar wind (SW) that destabilize it. These disturbances affect health as well as technology and become more extreme when SW is more accelerated. Thus, to better understand the impact of high-speed solar wind (HSSW) invasion on the dynamics of the magnetospheric system, a statistical study of HSSW populations was conducted for even (20 and 22) and odd (21 and 23) solar cycles. The regression analysis using the solar-derived fields from all solar cycles, indicates three states of the inner magnetosphere: 1) the 00:00UT-15:00UT period marked by a magnetic reconnection on the day side of the Earth closest to the Sun with the interplanetary magnetic field (IMF) facing South; 2) the 15:00UT-21:00UT period where IMF changes from South to North and remains there until 21:00UT; and 3) the 21:00UT-24:00UT period where there is a reconnection on the night side with stretched field lines. Observations made at different phases of solar activity lead us to suggest that the magnetospheric electric field (E_M) and the Bz component of IMF (IMF-Bz) are strongly correlated not only at a particular time scale, but at different time scales. We believe that the daily fluctuations of the electrical and magnetic effects of magnetospheric origin currents play a very important role in the dayside magnetic reconnection rate. Moreover, examination of the cycles with different parities shows important amplitudes of the solar causes for the even cycles compared to the odd solar cycles. Therefore, even solar cycles have a strong influence on our socio-economic system compared to odd cycles.

Keywords

Magnetosphere, Magnetospheric Electric Field, Magnetic Field, Solar Wind, Solar Cycles

1. Introduction

The Sun is a magnetic body in motion among the 200 billion that our galaxy counts. It continuously emits into interplanetary space, various electromagnetic radiations (UV, X-rays, etc.) and very energetic particles (solar wind jets, interplanetary coronal material ejections ICMEs, etc.). Due to the progress of space exploration and the rapid growth of the information society, our socio-economic system supported by highly developed infrastructures such as communication systems, artificial satellites, electrical and aviation networks, may become more vulnerable to space weather variability. The electric fields induced in the ground by these variabilities can also cause damage to these infrastructures. All these solar disturbances have economic consequences whose cost can only be correctly evaluated by a precise knowledge of the climatic variability of the Earth's radiative environment, which has led to the emergence of a new science: space weather. Space weather is concerned with the solar wind (SW), a stream of energetic particles consisting mainly of protons and electrons. The most important large-scale magnetospheric events in the deficiency of societal services, are strongly influenced by high-speed solar winds [1] [2] [3] whose sources are coronal holes [4] [5] [6] [7]. Furthermore, since the publication of [8] on the formation of the Earth's magnetosphere, the nature of solar wind/magnetosphere interaction is one of the problems that have been widely discussed until today. It is nowadays proposed that interaction between solar winds and magnetosphere constitutes a dynamo, which provides electrical energy (Poynting flux) for auroras and geomagnetic storms [9] [10] [11]. Geomagnetic storms characterized by geomagnetic activity [12] [13], are caused by a magnetic disturbance field that allows a transfer of energy from the SW to the Earth's magnetosphere [14]-[26]. This transfer would require reconnection of the interplanetary magnetic field (IMF) lines, which is most effective only when the Bz component of IMF has a meridional orientation [20] [27]-[32]. If it seems that the reconnection of magnetic field lines is more active when the IMF is oriented towards the South; but the publications do not show when and how this magnetic phenomenon starts, nor to what extent this triggering is linked to HSSW. Furthermore, rapid variations in solar activity (daytime scale and below) have often been obscured under the pretext that they are embedded by the large time constants of the climate system. Although solar activity can have an impact on the Earth's environment and socio-economic systems [33], the solar-derived energy potential of the inner magnetosphere, especially for even and odd solar cycles (SC), has not yet been defined. Also, [34] claims that the solar wind magnetic field influences the cosmic rays responsible for cloud formation. However, until now, daily contribution of the IMF to the stability of Earth's magnetosphere has not been elucidated to our knowledge. This paper presents a brief analysis of the geomagnetic variability of HSSW parameters during the rising/falling phase periods of solar cycles 20 to 23. Adopting an electric current approach, the objective of this manuscript is to examine the response of the inner magnetosphere to high-speed solar wind (HSSW) fluctuations for the even (SC20 and SC22) and odd (SC21 and SC23) solar cycles of the period 1964-2009. To this end, HSSW intensity, indices and methods used are presented in Section 2. The results are discussed in Section 3 and we conclude this study with a brief conclusion.

2. Data and Methodology

The data analyzed in this paper, were retrieved from the Internet Web system via "http://omniweb.gsfc.nasa.gov/form/dx1.html", "https://cdpp-archive.cnes.fr/" and "http://isgi.unistra.fr/". These data are carefully examined to identify HSSW currents (velocities ≥ 450 km/s averaged over a day) by removing excursions due to misidentified events or interacting with ICMEs. Only the cases where the solar parameters By (y-component of the IMF), Bz (z-component of the IMF), V (HSSW velocity), E_y (frozen electric field: $E_y = -V \times B_z$) and Aa (geomagnetic indices) available simultaneously in solar magnetospheric geocentric coordinates (GSM), were considered in this study. To understand the response of the magnetospheric system to the invading solar wind particles, various statistical methods such as multiple regression, cross-correlation and visual correlation are developed. In this paper, we instead applied cross-correlation method via the Pearson coefficient (r), a more familiar method for statistical studies [35] [36]. Pearson correlation coefficient ranges from −1 to +1, where a value around zero means a poor fit and a positive or negative value represents a good linear fit. In addition to these methods, structure of E_M field [mV/m] at high latitude was determined using the linear relationship of [37] and later validated by [38]:

$$E_M = 0.13E_y + 0.09 \tag{1}$$

where E_y [mV/m] represents the electric field frozen in SW. It should be noted that E_M field results from the difference between total electric field and field related to the Earth's rotation. HSSW is generally observed at high latitudes, so the corrotational aspect would be neglected in this study.

Furthermore, to evaluate the power (amount of energy) transmitted to the Earth's magnetosphere via extreme solar outflows, with the exception of the IMF-Bz, several energy coupling functions have been established [20] [39]-[43]. However, the choice between these different functions remains a very difficult question [35]. In this manuscript, we use the coupling function established by [44], a function that can best represent the energy flux transferred to the magnetosphere via solar wind particles:

$$E_{in} = 3.78\times10^{7} n^{0.24} V^{1.47} B_T^{0.86} \left[\sin^{2.70}\left(\frac{\theta}{2}\right) + 0.25\right] \quad (2)$$

The empirical function E_{in} [W] on the left, obtained on the basis of 240 numerical tests, represents the incoming power to the Earth's magnetosphere. Variables n, V, θ, and $B_T = \sqrt{B_x^2 + B_y^2}$ (see Equation (2)) denote the SW species density in cm^{-3}, the SW velocity in km/s, the IMF polar angle in degrees, and the SW magnetic field amplitude in nT, respectively.

3. Discussion of Results

3.1. Cross Correlation between Bz Component and E_M Field

In this section, various combinations of basic HSSW parameters from the period 1964 to 2009 were examined. Since the Bz component of IMF (IMF-Bz) is created by solar flux perturbations, **Figure 1** shows its temporal variability. In **Figure 1**, the blue and red plots represent respectively the evolution of the magnetospheric electric field E_M and of the Bz component of the IMF.

From panels (a), (b), (c) and (d) of **Figure 1**, E_M and IMF-Bz fields of solar origin evolve in phase opposition with very satisfactory correlations (r) according to the solar cycles: −0.98 for SC20, SC22 and SC23, then −0.95 for SC21. These strong correlations are justified by the fact that no parameter of the SW can be dissociated from the interaction between HSSW and terrestrial magnetosphere. It is therefore obvious that HSSW cannot independently drive the ring current, nor the Bz-South, nor their velocity and even the electric field of the solar flux. This result is corroborated by the work of [45]. Thus, we believe that such a high amplitude of the correlation coefficients between E_M and IMF-Bz fields could have occurred due to the very important role played by IMF-Bz in injecting energetic HSSW particles inside the Earth's magnetosphere [15]-[22].

Furthermore, to quantitatively and qualitatively predict impending geomagnetic storms on Earth, one would have to examine the causes that are responsible for interplanetary events and their origin. Indeed, **Figure 2** presents the daily variation of E_M and IMF-Bz fields during intense geomagnetic storms of the whole solar cycles 20-23. In said **Figure 2**, the error bars represent estimates of the statistical uncertainties in these averages. For almost all HSSW currents, data set is sufficiently complete that the uncertainties in the parameters (IMF-Bz and E_M) are small.

According to **Figure 2**, E_M and IMF-Bz quantities show three trends (00:00UT-15:00UT; 15:00UT-21:00UT then 21:00UT-24:00UT) with highly significant correlations (see **Table 1**). On the one hand, according to several works [46] [47] [48], increasing and decreasing trends of the E_M field emphasize the Southern (disturbed period) and Northern (quiet period) orientation of the IMF-Bz, respectively. On the other hand, [49] revealed that the quiet period could be identified by a magnetic reconnection between the North-oriented IMF-Bz lines and those of the geomagnetic field. Analyzing the three phases in **Figure 2**,

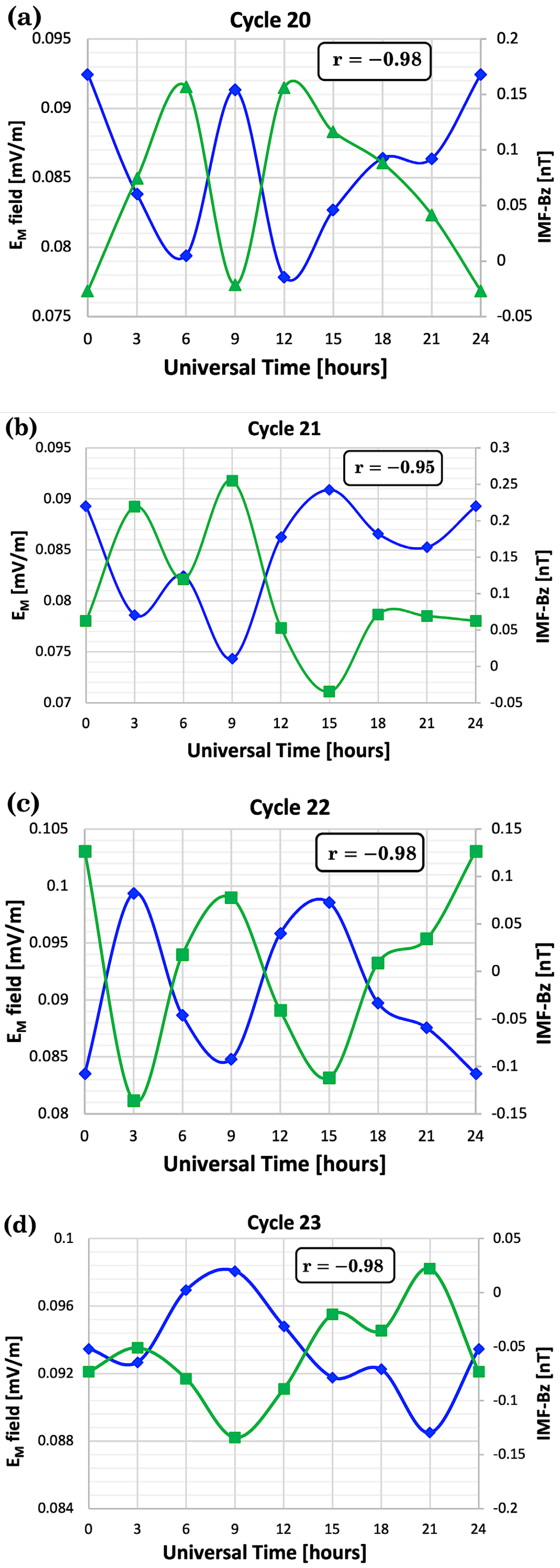


Figure 1. Evolution of E_M field and IMF-Bz as a function of Universal Time (UT).

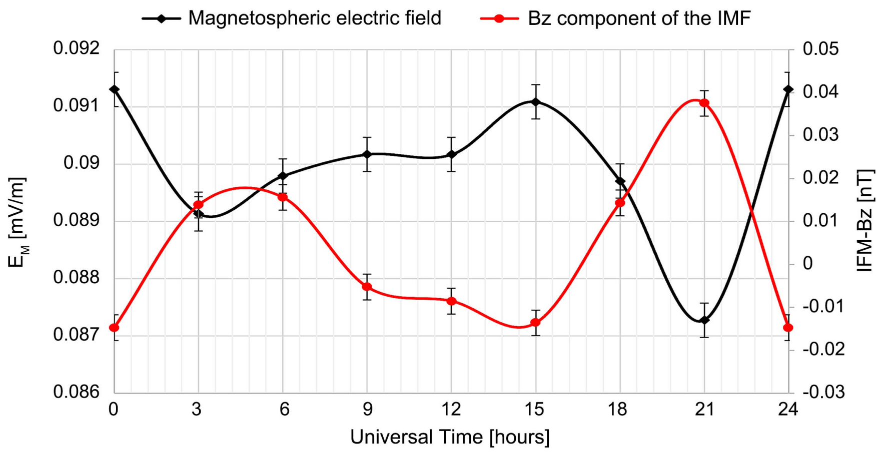


Figure 2. Temporal evolution of E_M and IMF-Bz from HSSW.

Table 1. Correlations and slopes of E_M and Bz fields for all cycles 20-23.

Universal time [hours]	Slope of E_M [mV/m.s]	Slope of IFM-Bz [nT/s]	Correlation E_M & IFM-Bz	$\left\lvert\frac{\Delta B_z}{\Delta E_M}\right\rvert$
00:00-15:00	$+2 \times 10^{-5}$	-11×10^{-4}	−0.88	55.00
15:00-21:00	-6×10^{-4}	$+85 \times 10^{-4}$	−0.98	14.17
21:00-24:00	$+13 \times 10^{-4}$	-16×10^{-3}	−1	12.31

the event starts with the invasion of a Southward directed IMF-Bz of negative intensity (−0.0021 nT) containing a population of average velocity 501.07 km/s and whose convection is controlled by an E_M field of intensity 0.09 mV/m. Then, IMF-Bz of intensity 0.013 nT is oriented towards the North and is maintained there until 21:00UT reaching a peak of 0.037 nT. Finally, from 21:00UT-24:00UT, IMF-Bz turns South again with a HSSW current of 499 km/s on average. For this Southern orientation of IMF-Bz, E_M field gradually increases from 0.087 to 0.091 mV/m. From the analysis of the three identified phases, we can confirm that, each time IMF-Bz turns Southward (00:00UT-15:00UT then 21:00UT-24:00UT), the magnetospheric activity of E_M field progressively increases. The cause is the day and night side magnetic reconnection of the South-facing IMF-Bz with the geomagnetic field lines which allows the energetic HSSW particles to induce intense geomagnetic activity: substorms. This result is corroborated by several works [16] [23] [50]-[55]. It is important to note that the day side magnetic reconnection (00:00UT-15:00UT) highlights the main phase of the magnetic storm [56]. However, daytime reconnection (15:00UT-21:00UT) begins when IMF-Bz turns Southward and characterizes the substorm growth phase. According to [57], substorms are generally accompanied by an increase in aligned currents and an abrupt release of energy to Earth's magnetosphere. In this manuscript, the decreasing phase of E_M field occurs between 15:00UT and 21:00UT. This phase expresses the change of IMF-Bz from South to North which leads to the disappearance of the injection term ($V \times \mathbf{Bz} = 0$), *i.e.*, the cessation of the development of magnetic storms. Thus, in this phase, aurora and ring currents gradually return to their original locations toward the equator while they simultaneously decrease in brightness and strength. This result emphasizes that the period 15:00UT-21:00UT presents the steady state of the inner magnetosphere during which, 15:00UT and 21:00UT characterize the moments of the state change of the Earth's magnetosphere. During this phase, we observe a weakening of the convection of HSSW particles in the Earth's magnetosphere (confirmed by the reference [58]) where E_M field drops sharply to its lowest value: 0.087 mV/m. The changes of IMF-Bz were discussed by [48] in a study of one-to-three-day ICMEs; however, a difference (03 to 06 h gap) is observed between phases with weaker correlations. To explain why our analysis has a somewhat different result, we must consider that when analyzing the four complete solar cycles (20 - 23), the contributions to the geomagnetic activity of ICMEs are included. Because different magnetospheric current systems may respond differently to the magnetic perturbations of the solar wind related to HSSW and ICMEs, the statistical results are likely to be somewhat different if HSSW-related activity is analyzed separately. **Table 1** summarizes the correlations for all solar cycles 20 - 23 from 1964-2009. In this **Table 1**, the slopes of the E_M and IMF-Bz quantities were obtained from the least squares method.

Except for quiet period of the inner magnetosphere, analysis of the last column of **Table 1** shows that the ratio of IMF-Bz and E_M fields is large (67%) on the day side and small (15%) on the night side. These observations suggest the very important contribution of magnetic and electric effects respectively in the morning and evening of the currents of magnetospheric origin. The models proposed by [59] and [60] explain these strong electric currents in the evening (towards the West). In view of these arguments, we can suggest in this study that the inner magnetosphere is more active on the day side (00:00UT-15:00UT) than on the night side (21:00UT-24:00UT). This contribution is in good agreement with the work of [61]. Moreover, for [62] and [63], the low conductivity observed in the ionosphere (and thus in the magnetosphere because closely coupled) during the night makes that the signatures of the perturbations experienced, are essentially those of the magnetopause current and the magnetospheric tail current. Our results are in agreement with these two publications.

3.2. Hourly Estimate of the Magnetospheric Disturbance

Figure 3 presents the daily evolution of the geomagnetic activity of solar cycles (SC) 20 to 23. Analysis of this Figure shows that the odd solar cycles (SC21 and SC23) remain the least magnetically disturbed of the four solar cycles since the 1964s. This observation is corroborated by the work of [64] as well as by the spot numbers (https://www.spaceweatherlive.com/en/solar-activity/solar-cycle/historical-solar-cycles). Furthermore, the interplanetary and solar causes of geomagnetic activity during SC21 and SC23 have been studied by several authors [65] [66] and minima in geomagnetic activity have been identified. This is in good agreement

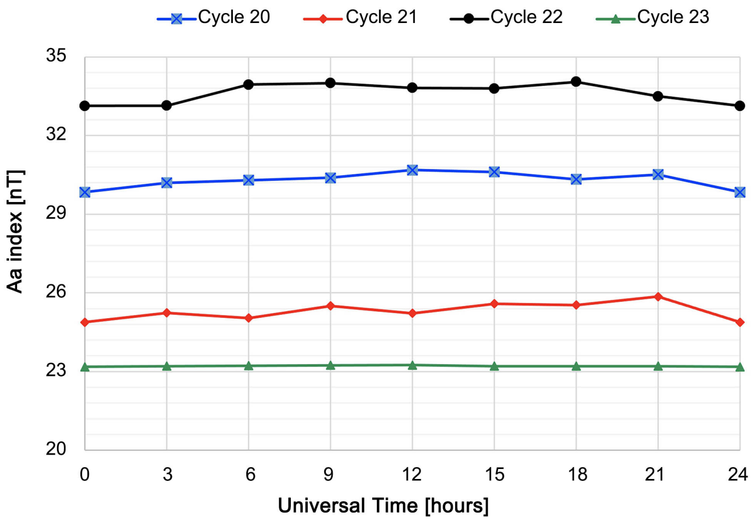


Figure 3. Cycle evolution of geomagnetic activity in solar cycles 20-23.

with our results as well as with the geomagnetic activity that occurs after the sunspot minimum, as can also be seen, e.g., through the geomagnetic index Aa in the work of [67] and [68]. In contrast, large amplitudes of geomagnetic activity for SC20 and SC22 were recorded, while SC21 and SC23 show small amplitudes. This result is corroborated by the work of [69] [70] [71]. The differences between even and odd solar cycles have in the Sun, a very random character. Indeed, according to [71] and [72], these differences are related to the amplitudes and/or Gnevyshev (GG) differences between the ascending and descending phases of solar cycles. Among the four solar cycles studied, SC23 with its almost linear characteristic in constant evolution, fluctuating with a vigor lower than 0.07 nT (see **Figure 3**), was one of the least intensive solar cycles in sunspot activity. This result is well corroborated by the work of [73] and [31]. Since the geomagnetic index Aa expresses the intensity of magnetospheric disturbances, we estimate that even cycles were more disturbed than odd cycles.

In order to better understand the daily fluctuations of the Earth's magnetic activity, we examined the average geomagnetic activity Aa for all solar cycles 20 - 23 combined (see **Figure 4**). In general, examination of **Figure 4** shows that the geomagnetic activity increases from 00:00UT-15:00UT, decreases slightly from 15:00UT-21:00UT, and then drops rapidly from 21:00UT-24:00UT. While E_M field is pointed South from 21:00UT-24:00UT according to **Figure 2**, the trend of geomagnetic activity was expected to be increasing in **Figure 4**. However, geomagnetic index Aa decreases rapidly from 21:00UT-24:00UT. This anomaly may be due to the effect of magnetic reconnection on the night-side. Indeed, as the magnetospheric plasma dynamics are affected by the night-side magnetic reconnection and which leads to the activity of geomagnetic storms and substorms [74], this reconnection favors the massive entry of charged particles into inner magnetosphere. Facing the Sun, direct particle entries are possible depending on the magnetic state of the Sun and the HSSW. Particles that find themselves in the Earth's magnetospheric cavity, undergo a strong acceleration towards the Earth under the combined effect of the electric field and the variations of the IMF.

3.3. Energy Contribution of HSSW to the Inner Magnetosphere

In this section, in addition to the semi-empirical E_{in} [en W] function established by [44], understanding the influence of HSSW invasion on the dynamics of the magnetospheric system is highlighted by examining the SW parameters. E_{in} function giving the maximum energy transferred via the solar flux, largely induces the internal magnetospheric dynamics. Focusing on the three states of the inner magnetosphere (see **Figure 2**), we have drawn up **Table 2**. Although not a surprising inference, **Table 2** quantitatively gives how various aspects of magnetospheric behavior are directly influenced.

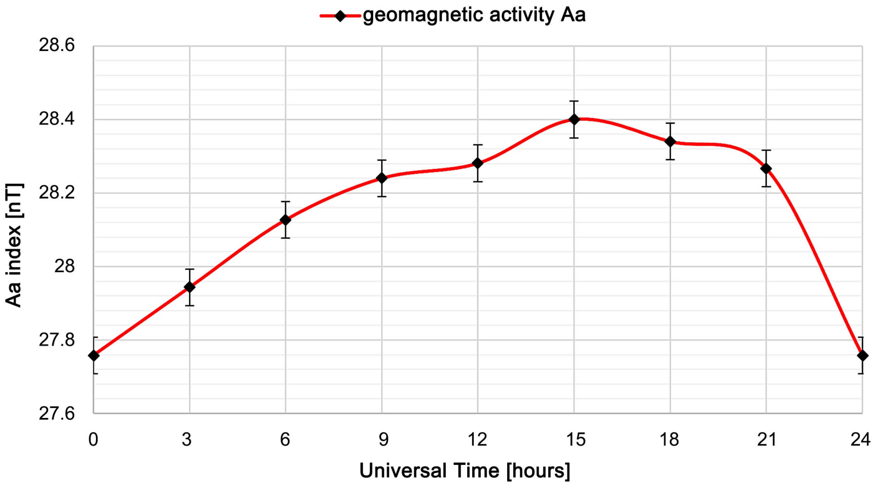


Figure 4. Daily evolution of geomagnetic activity Aa from 1964-2009.

Table 2. Average HSSW parameters for solar cycles 20-23.

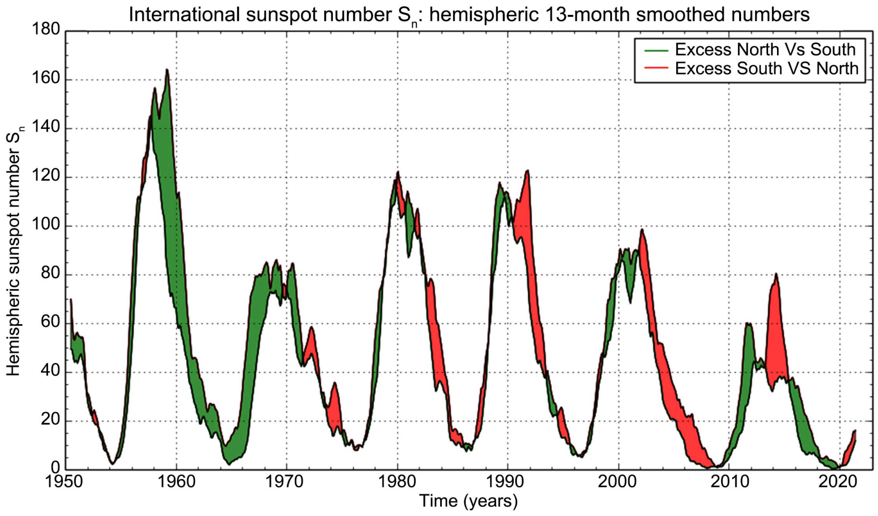
Cycles	Universal time UT [h]	Bz [nT]	B_T [nT]	V_{moy} [km/s]	E_{in} [10^{11} W]
Cycle 20	00:00-15:00	Nord	6.59	550.86	9.12
	15:00-21:00	Nord	6.16	549.79	9.16
	21:00-24:00	Nord	6.37	548.46	10.51
Cycle 21	00:00-15:00	Nord	7.62	485.49	8.62
	15:00-21:00	Nord	7.33	484.80	9.00
	21:00-24:00	Nord	7.50	482.91	9.23
Cycle 22	00:00-15:00	Sud	7.36	551.77	10.84
	15:00-21:00	Sud	6.91	550.32	11.17
	21:00-24:00	Nord	7.27	547.88	11.24
Cycle 23	00:00-15:00	Sud	4.35	473.99	5.91
	15:00-21:00	Sud	4.20	472.98	6.29
	21:00-24:00	Sud	4.30	472.46	7.70

The analysis of **Table 2** shows that all the first two solar cycles (SC20 and SC21) were stable (Bz pointing North) compared to the last two (SC22 and SC23). Note the southward orientation of the IMF-Bz for the entire period 1996-2009 (SC23) during which, no HSSW stream with a maximum velocity greater than 500 km/s, was observed on the Earth orbit. The empirical models [75] [76] give southward velocities of very low amplitudes for a southern orientation of the IMF (Bz < 0). Our processing of radar data obtained from OMNIWeb and CDPP are partly in good agreement with these models insofar as the amplitude of the observed velocities is very low in SC23. Moreover, according to [77], a strictly South IMF for B_T (0, 0, −Bz) is quite rare in practice, therefore, SC22 and SC23 deserve very special attention.

Indeed, the last solar cycle (SC23) of our study, was extreme in several respects during which, many severe and strong effects were observed in the environment of the Earth and other planets. Our results are corroborated by the publications of [78] and [79]. Solar magnetic field geometry of SC23 was more complicated, which is reflected in the solar flux velocity distribution (e.g. [80]). In addition to the low average velocity observed in SC23, B_T magnitude of the IMF was the lowest in recent history. Associated with this feature, duration of SC23 was extended compared to SC20-SC22 (see [81]). The minimum solar wind speed was 472.30 km/s (with an average of 473.52 km/s) and the integrated B_T IMF was exceptionally low (about 4.31 nT). These low values of B_T magnitude and mean velocity, all observed around 21:00UT, caused an about 68% drop in the energy averages of SC20-SC22, energy transfer from HSSW to the inner magnetosphere. This decrease in energy transfer to the Earth's magnetosphere for SC23, caused the lowest value of geomagnetic activity, quantified by the Aa index and shown in **Figure 3**.

On the other hand, from the South orientation observed throughout SC23, IMF-Bz may not turn immediately North. It may fluctuate between South and North as shown in SC22 (see column 3 of **Table 2**). In such cases, auroral and magnetic disturbances become much more complex and therefore, are not easy to characterize. Situations of this type of event usually persist for a sufficiently long time, so that many particles in the solar flux are energized and trapped to produce a magnetic storm. As we can see, SC22 having revealed large amplitudes and abrupt variations of HSSW and E_M field (see [3]), recorded a fluctuating IMF-Bz between South and North and a rather large energy compared to the other studied solar cycles: $E_{in} = 1.12 \times 10^{12}$ W. However, this energy is still small compared to the charging threshold for magnetic storms: 1 TW (see [56] [82] [83] [84]). The energy generated by the solar wind/magnetosphere dynamo flows in the direction of the Poynting ($\boldsymbol{E} \times \boldsymbol{B}$) flux. The SC22 IMF-Bz resembles an aligned dipole and the SW exhibits a bimodal velocity distribution, with faster currents emerging from coronal holes at high latitude. Because of this dipole configuration, SC22 recorded a large fraction (32% of the energy averages from **Table 2**) of the total power generated by this dynamo. Therefore, magnetospheric cavity becomes very "swollen" due to the accumulated energy that was manifested by the resulting changes in the IMF-Bz configuration. In addition to the variability of the IMF activity is influenced by the sunspot number [85], records from the WDC-SILSO observatory (https://wwwbis.sidc.be/silso/datafiles) confirm the North-South fluctuations of the IMF-Bz for SC22 and SC23 studied in this paper. Indeed, from **Figure 5**, the North and South components of the monthly smoothed sunspot number for the last five solar cycles (SC20-SC24), indicate a green filling when the North number is greater than the South number, and a red filling when the South is greater than the North. While it appears that the red filling is present for every year of the period 1950-2020 according to **Figure 5**, however, it is more persistent beyond the year 1982. Our results are therefore in very good agreement with these WDC-SILSO observations.

In general, for all SC20-SC23 studied, the influence of the HSSW invasion on the energy dynamics of magnetospheric system was the weakest in the space age. Probably, the cause is the combination of low intensity of the solar wind parameters (V, B_T, Bz). Low B_T magnitude values are a consequence of weak solar fields. In addition, average values of speed and energy were lower for odd solar cycles due to the location of coronal holes (CHs). It is well known that high-speed solar wind currents emanate from higher latitude solar CHs [86] [87] [88] [89]. For all solar cycles studied, on the night side (21:00UT to 24:00UT), energy transfer to the Earth's magnetosphere was greater (more "inflated" magnetosphere) for even-numbered solar cycles than for odd-numbered cycles. The behavior of the energy injected into the upper atmosphere during HSSW impact for SC20 and SC22, have consequences on the chemistry of the atmosphere according to several authors [90] [91] [92]. Such consequences suggest that the Earth's environment, and perhaps even the Sun, are sources of disruptions and failures in new technologies such as wireless communications and power systems at local and geographical scales.



SILSO graphics (http://sidc.be/ilso) Royal Observatory of Belgium 2022 January 3

Figure 5. North-South fluctuations in sunspot numbers from 1950-2020; Source: https://wwwbis.sidc.be/silso/datafiles.

Once it was realized that IMF is continuous and varies continuously, the importance of IMF-Bz and fusion was considered. Indeed, according to [14], IMF-Bz predicts the behavior of the inner magnetosphere better than speed or pressure of solar winds. However, in most published studies (such as, e.g. [20] [43] [77]), quantifying it on a general basis, IMF-Bz predicts only slightly better than a quarter of the variance of the magnetosphere state variables. In this study, for an IMF-Bz South, the energy transfer was not as efficient as one would think for SC23. Therefore, we believe that a South-facing IMF-Bz as the main driver of the geomagnetic activity, would not be the only crucial parameter. This hypothesis is corroborated by the work of [93] [94] [95]. Indeed, an important role is also played by energy transported by the fluctuation of solar winds located at high latitudes. First, according to [96] [97], HSSW currents and southern IMF-Bz lead to the production of high energy electrons. Precipitation of the produced electrons, is closely associated with the pressure, and thus the velocities of the plasma HSSW in the magnetosphere according to [98]. Second, a superimposed epoch analysis showed that the solar wind speed, in combination with the southern IMF-Bz, largely governs the magnetospheric response to HSSW [99]. Finally, [100] investigated the correlation between total energy and Disturbed storm time index (Dst). They found that plasma of high-energy solar winds can severely disturb the near-Earth space environment even without reconnecting with the day-side geomagnetic field. Our results are in good agreement with this work when the periods are compared. Undoubtedly, these disturbances can impact airplanes, rockets or space shuttles during their journey.

Moreover, we find that over the whole solar cycles, B_T magnitude of IMF is higher in the mornings than in the evenings UT. This may be due to the compression of the daytime geomagnetic field lines by those of the solar wind. This argument is in good agreement with the work of [101] and confirmed by the Explorer 12 spacecraft records [21]. While it appears that B_T magnitude is large in the mornings, the finding is quite the opposite for the power generated by the solar wind/magnetosphere dynamo in this study. Indeed, examination of the last column of **Table 2** highlights that the inner magnetosphere accumulates less "deflated" energy in the mornings than in the evenings UT. This may be due to the fact that the total electrical energy (too small in intensity) of the Van Allen radiation belts, cannot contribute much to the main phase of magnetospheric substorms. This argument is supported by the work of [22].

4. Conclusion

Scale-invariant dynamics of HSSW at three-hourly rates and of the inner magnetosphere discussed under various parameters of solar origins in this manuscript, allowed us to conclude important information. A total of 5053 days from 1964-2009 covering even (20 and 22) and odd (21 and 23) solar cycles are involved in this study. While it appears that the solar causes were weak for all the solar cycles studied, however, the high-latitude solar flux energy particle statistics reveal that the even cycles were more disturbed than the odd cycles. Among the even cycles, SC22 was the most active and characterized by a dipolar magnetic field. Moreover, the strong amplitudes of the correlations between the solar fields clearly support that IMF-Bz and E_M play a major role in the magnetic reconnection, respectively on mornings and evenings. Therefore, magnetospheric cavity is more active on the day side than on the night side. From the analysis of the fields of solar origin, the results we have reached, reveal that the inner magnetosphere is characterized by three states: 1) from 00:00UT-15:00UT which highlights the main phase of the magnetic storm or the magnetic reconnection on the day side; 2) from 15:00UT-21:00UT indicating the recovery phase of the magnetic storm during which, the IMF changes orientation; and 3) from 21:00UT-24:00UT which manifests itself as the magnetic reconnection on the night side. During this daytime reconnection, we found that Earth's magnetosphere has accumulated a significant amount of power generated by the solar wind/ magnetosphere dynamo. While several literatures emphasize the southern orientation of the IMF as the main driver of geomagnetic activity, our study reveals that an important role is also played by the energy carried by the HSSW fluctuation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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