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Solar activities and geomagnetism: Long-term statistical study of magnetics clouds activity day's occurrence as a function of the phases of solar cycles 11 to 24

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This article examines magnetics clouds activity day's occurrence as a function of the different phases of the solar cycle and the duration of their geoeffectiveness. The study period extends from cycle 11 to cycle 24. Magnetic clouds activity day's occurrence were identified using pixel diagram from the years 1867 to 2019, that is to say, fourteen (14) solar cycles. The results show that in the study period: (1) there were 802 days of magnetic cloud activity with an effect lasting 1 day, 284 with an effect lasting 2 days and 141 having an effect three days; (2) the largest proportions of magnetic cloud activity days are recorded at maximum phase of the solar cycle, regardless of the type of magnetic cloud activity. These results also reveal that on average, there are 13 magnetic cloud activity days per year at the solar phase maximum.

Key words: Occurrences, pixel diagram, magnetic clouds, geoeffectivity.

INTRODUCTION

The Sun has a magnetic field which results from the differential rotational speeds of its radiative zone and its convective zone. Solar activity is known as the manifestations of the solar magnetic field (Ouattara 2009). This phenomenon occurs according to a fairly regular cycle of around eleven (11) years (Ouattara et al.,

2015). In the vicinity of the Earth, certain solar events disturb the terrestrial environment (magnetosphere and ionosphere). These disturbances can give rise to short-term variation in Earth's magnetic field called, geomagnetic activity. The geoeffectiveness of a solar event is known as its ability to generate disturbances on
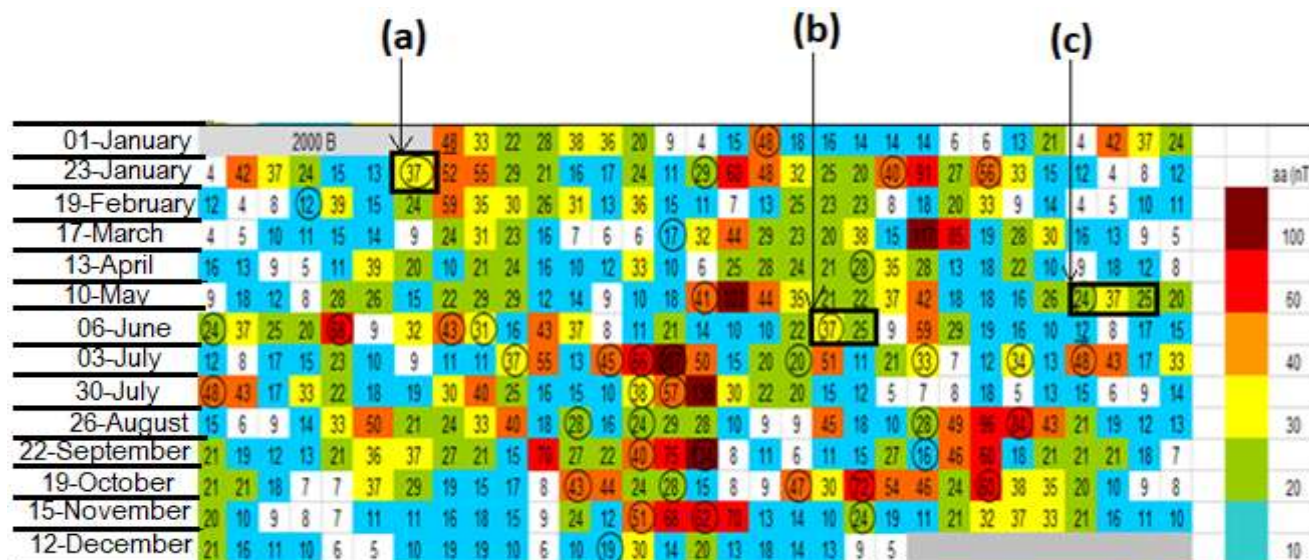

Figure 1. Pixel diagram of the year 2000. (a) Magnetic cloud activity of one (1) day duration; (b) Magnetic cloud activity of (2) days duration; and (c) Cloud activity of (3) days duration.

the Earth's magnetosphere and within this structure. In order to identify the solar sources responsible for the various geomagnetic disturbances observed in the vicinity of the Earth, Legrand and Simon (1989) and Simon and Legrand (1989) proposed to divide geomagnetic activity into four classes. Thus, we note (1) quiet activity due to slow solar wind coming from solar heliosheet, (2) recurrent activity due to solar high wind stream coming from coronal holes, (3) shock activity due to Coronal Mass Ejections (CMEs) and (4) fluctuating activity, consequences of fluctuating solar heliosheet. Zerbo et al. (2012) extends the previous study by breaking down the fluctuating activity class. In this study, we are interested in magnetic clouds activities. Indeed, previous studies have shown that around 80% of magnetic clouds are geoeffective (Zhang et al., 2004; Echer et al., 2005).

As a result, most of them are responsible for the most intense geomagnetic storms (Echer et al., 2008a, b). Magnetic clouds are a specialized subset of interplanetary coronal mass ejections (ICME) comprising between one-third (Gosling, 1990) and one-half (Cane et al., 1997) of all ICME events. In terms of composition, these clouds are regions formed by a high magnetic field, low temperature of protons, low amounts of protons and a slowly rotating magnetic field (Burlaga et al., 1981). Geomagnetic storms caused by magnetic clouds are referred to as magnetic cloud activity. Magnetic cloud activity days correspond to the days when magnetic clouds disturb the geomagnetic field and thus cause geomagnetic activity.

The aim of this article is to make a statistical study of magnetic clouds activity days occurrence taking into account the duration of their effects and the phases of

solar cycles 11 to 24. These days are identified using the pixel diagram (Ouattara and Mazaudier, 2009). It is important to note that the pixel diagram represents geomagnetic data as a function of solar activity for each Bartels rotation (27 days). They report on the geoeffectiveness of solar events in general and the activities of magnetic clouds in particular.

DATA AND METHODOLOGY

Determination of magnetic cloud activity days

For this study, we used the values of the index aa and the dates of the SSCs to construct the pixel diagram plots of the year corresponding to this study. This diagram was used to select magnetic cloud activity days. The values of the aa index and the data of the SSCs are available on the ISGI website[1]. The values of the solar index Rz were used to determine the solar phases. They are available on the OMNIWEB website[2]. The different types of magnetic clouds activity are identified from 152-pixel diagrams (representing pixel diagrams from 1868 to 2019). Figure 1 is an example of a pixel diagram (pixel diagram of the year 2000).

Magnetic cloud activity days correspond to SSC days for which Aa indices are between 20 and 40 nT over one, two or three days (Zerbo et al., 2012). Figure 1 show examples of days of magnetic cloud activity of 1 day duration (January 27 activity); 2 days duration (activity from June 23-24) and 3 days duration (activity from May 1-3).

Determination of the different phases of the solar cycle

To determine the solar phases, we used the values of the solar index Rz and adopt the method used by Ouattara (2009), Nanéma

Table 1. Different phases of a solar cycle as a function of Rz number.

Rz number	Solar cycle phases
Rz < 20	Solar minimum
20 ≤ Rz ≤ 100	Ascending phase
100 ≥ Rz ≥ 20	Descending phase
Rz> 100	Maximum solar

Table 2. List of cycles and their different phases from cycle 11 to cycle 24.

Cycle	Extension period	Average duration (years)	Minimum phase	Ascending phase	Maximum phase	Descending phase
11	1867-1878	12	1875-1878	1868-1869	1870-1872	1873-1874
12	1878-1890	11	1878-1879 and 1888-1890	1880	1881-1885	1886-1887
13	1890-1902	12	1890 and 1899-1902	1891 and 1898	1892-1894	1895-1897
14	1902-1913	12	1902 and 1911-1913	1903-1904	1905-1907	1908-1910
15	1913-1923	10	1913-1914 and 1922-1923	1915-1916	1917	1918-1921
16	1923-1933	10	1923-1924 and 1932-1933	1925	1926-1929	1930-1931
17	1933-1944	10	1933-1934 and 1943-1944	1935-1936	1937-1938	1939-1942
18	1944-1954	10	1944 and 1953-1954	1945-1946	1947-1949	1950-1952
19	1954-1964	11	1954 and 1964	1955	1956-1960	1961-1963
20	1964-1976	12	1964-1965 and 1975-1976	1966-1968	1969-1970	1971-1974
21	1976-1986	10	1976 and 1986	1977-1978	1979-1982	1983-1985
22	1986-1996	10	1986 and 1996	1987	1988-1991	1992-1995
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

Source: Adapted from Zerbo et al. (2011)

and Ouattara (2013), Guibula et al. (2017), and Sandwidi et al. (2020). According to this method, the different phases of solar cycle are defined in Table 1.

For small solar cycles, that is, those whose maximum number of spots is less than 100 (case of solar cycles 12, 13, 14 and 16), the phase maximum is obtained for number of spots greater than 0.8 times the maximum spot number (Rz > 0.8 × Rz max).

RESULTS AND DISCUSSION

Referring to Table 2, between 1868 and 2019 there are 37 years belonging to the phase minimum, 28 years belonging to the descending phase, 43 years belonging to the phase maximum and 43 years belonging to the descending phase. During the same period, we recorded: 1227 magnetic cloud activities, an average of 8 magnetic cloud activities per year.

This result is in agreement Wu et al. (2003) who finds approximately nine (9) magnetic clouds per year. Figure 2 shows total number of any type of magnetic clouds recorded per solar phase. We note 450 and 134 magnetic cloud activities respectively at the solar maximum and at the solar minimum. This observation is in agreement with Wu et al. (2006) for whom, at the solar

minimum, very few magnetic clouds are detected; on the other hand, they are much more numerous around the solar maximum. Indeed, according to Turc (2014), magnetic clouds are transient phenomena and at the solar minimum, many of them do not reach the vicinity of the Earth. This could explain their low number at the solar minimum.

Furthermore, Figure 2 shows that magnetic cloud activity days occurrence during solar phases ascending and descending is not the same (233 and 284 respectively in the ascending and descending solar phases). This observation shows that magnetic clouds activity does not follow the sunspot cycle. This result is in agreement with Wu et al. (2003) who find that the frequency of magnetic clouds occurrence does not follow the sunspot cycle or the frequency of CMEs occurrence.

Figure 3 shows the level of activity of magnetic clouds as a function of solar cycles. According to this figure, we note at solar maximum 122 and 51 magnetic cloud activities during cycles 20 and 14 respectively. This makes cycle 20 the cycle in which magnetic cloud activity was most active and cycle 14 the least active in terms of magnetic cloud activity. Analysis of the same figure (Figure 3) shows that the last eight solar cycles alone
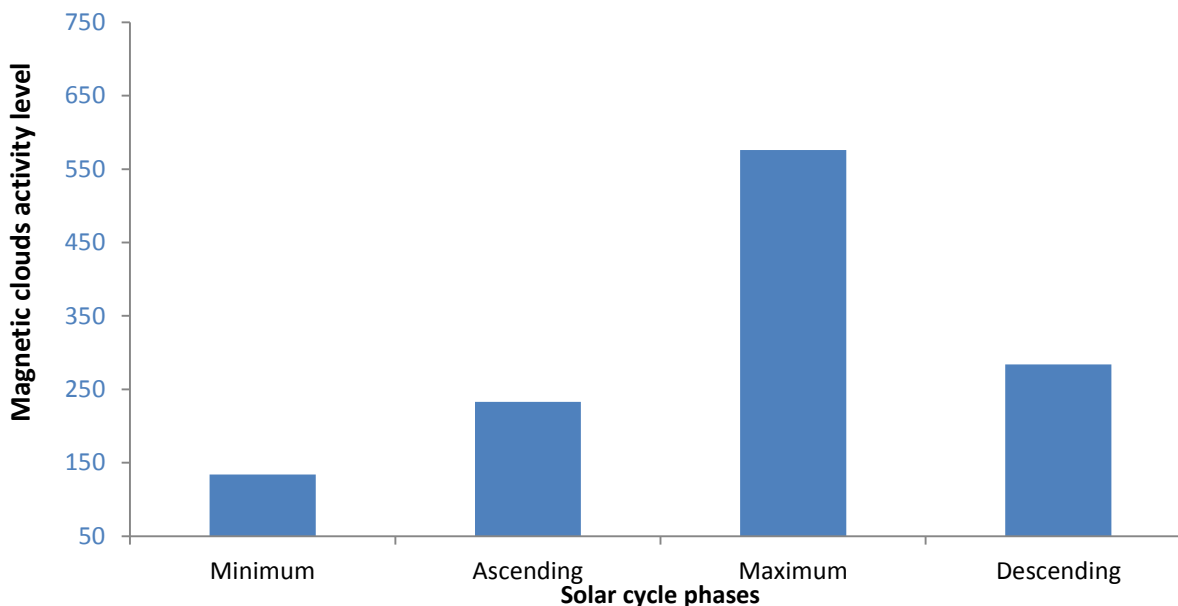
Figure 2. Occurrences of magnetic cloud activities as a function of solar cycle phases.
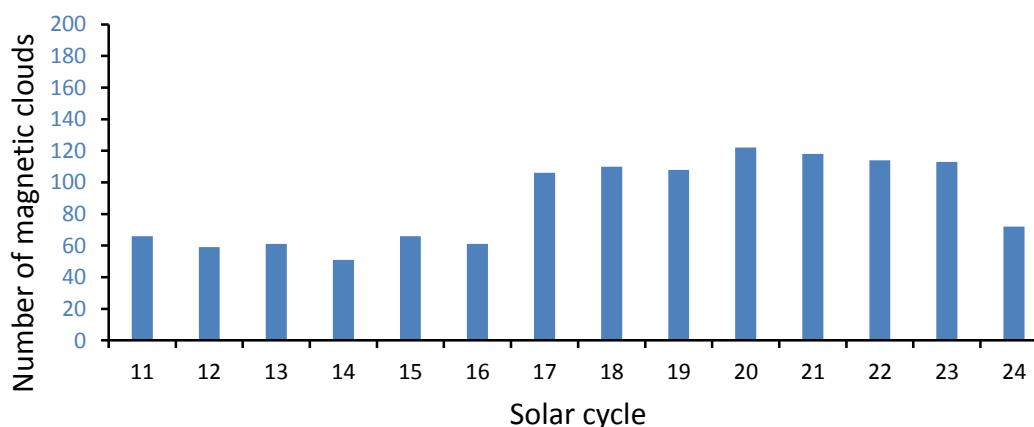

Figure 3. Occurrence of magnetic cloud activities.

record 70.33% of the total magnetic clouds recorded since solar cycle 11. However, there is a continuous decrease in the level of magnetic cloud activity for the last five solar cycles (solar cycle 20 to cycle 24).

This result indicates that solar activity decreases during the last five (5) solar cycles. Indeed, according to Wu et al. (2003), geomagnetic activity intensity linked to magnetic clouds is well correlated with solar activity.

Figure 4 shows the percentage of occurrence of different types of magnetic cloud activity. This graph shows that the proportions of magnetic cloud activities whose effect lasts 1, 2 and 3 days are respectively 66, 23 and 11%. This result is explained by the fact that during our study period, the most intense magnetic clouds in terms of geoeffectivity are less dominant compared to those which are less intense.

Figures 5 to 7 represent the occurrences of the activities of the different types of magnetic clouds of 1, 2 and 3 days respectively. For each figure, the panels (a), (b), (c) and (d) corresponds to the occurrences of the types of magnetic cloud activity, respectively, solar minimum, ascending phase, solar maximum and descending phase. In Figure 5 we observe that solar cycle 23 is the cycle which recorded the greatest number of magnetic cloud ejections at solar minimum and during the ascending phase. During maximum phase, solar cycles 19 and 22 are the cycles that recorded the greatest number of magnetic cloud ejections. During descending phases, solar cycles 17 and 20 recorded the greatest number of magnetic cloud ejections. Whatever
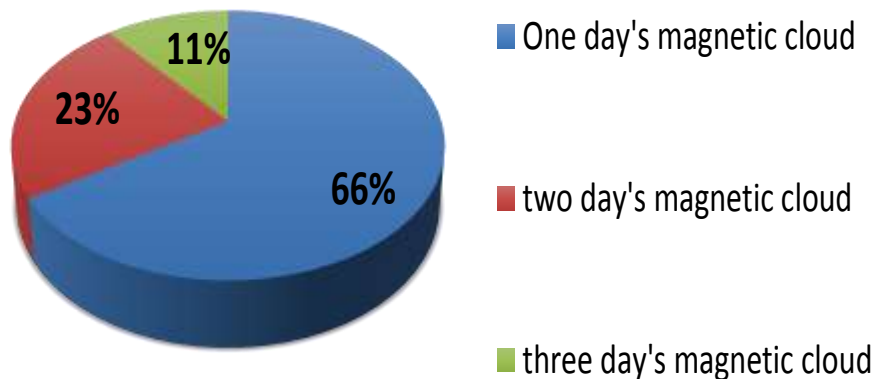
Figure 4. Percentages of magnetic clouds activity days' occurrence during the last fourteen solar cycles
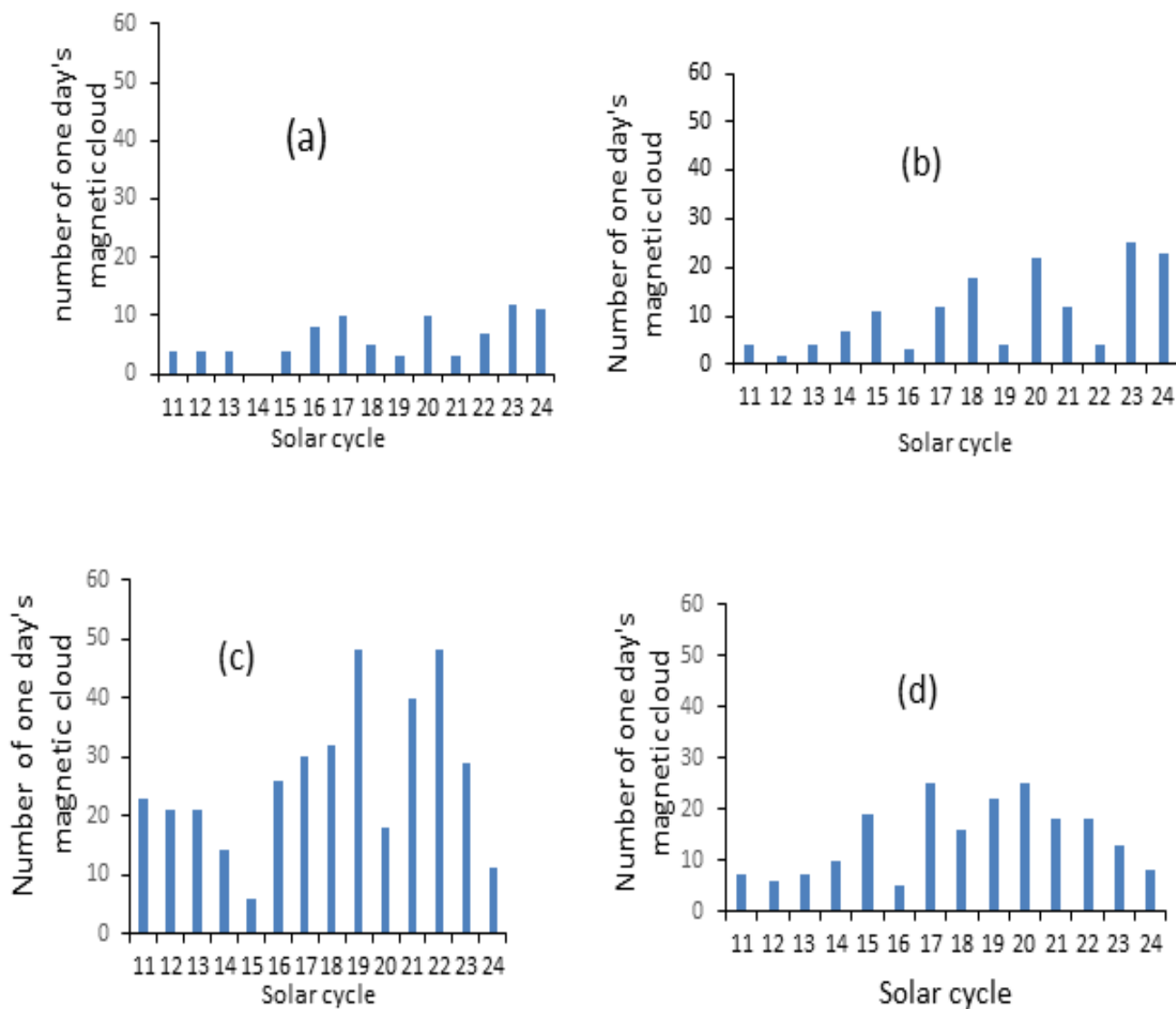

Figure 5. Occurrences of magnetic clouds whose effect lasts 1 day: (a) the upper left panel concerns the phase minimum, (b) the upper right panel the ascending phase, (c) the lower left panel the maximum phase and (d) the lower right panel the descending phase.

Figure 6. Occurrences of magnetic clouds whose effect lasts 2 days: (a) the upper left panel concerns the phase minimum, (b) the upper right panel the ascending phase, (c) the lower left panel the maximum phase and (d) the lower right panel the descending phase.
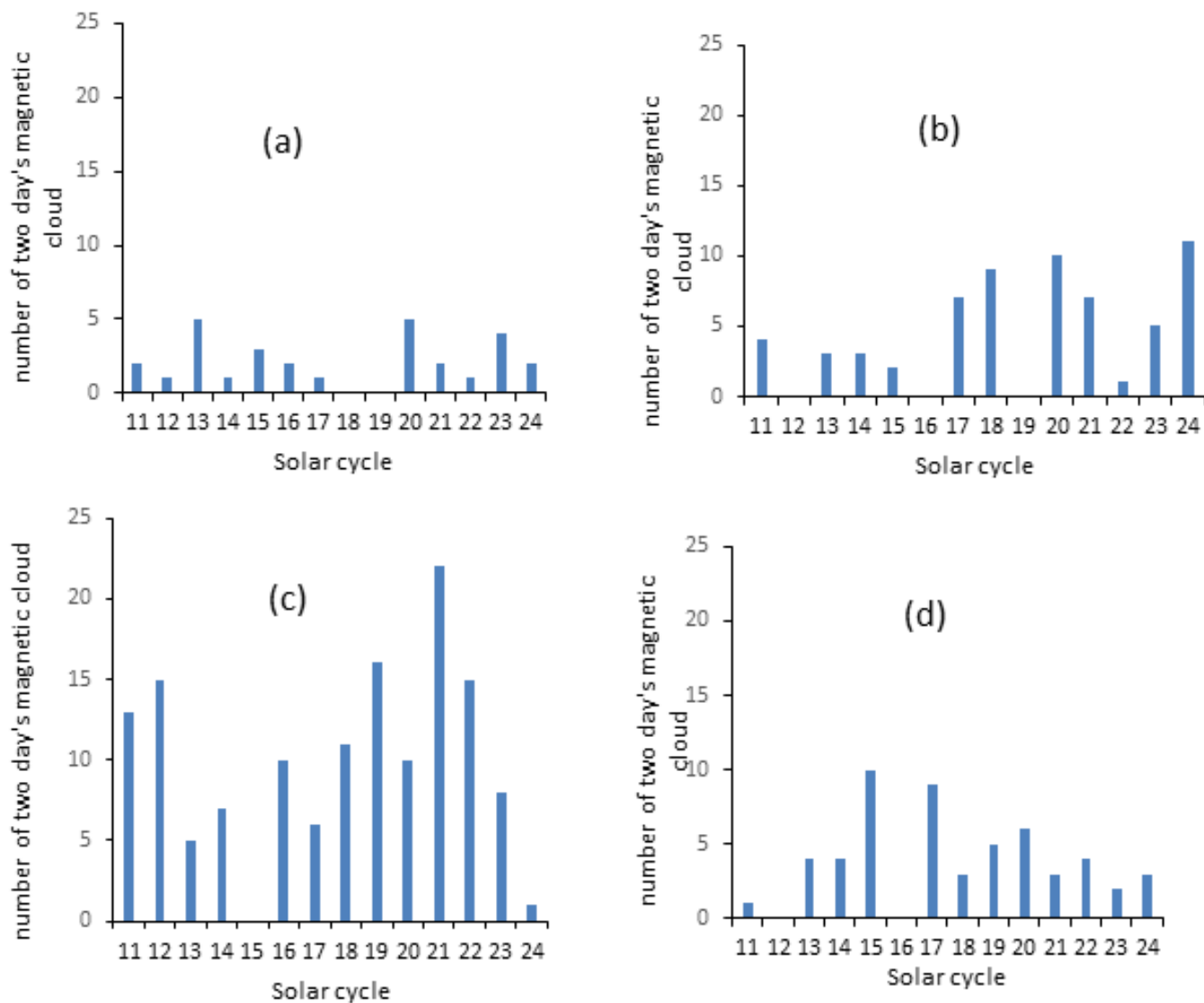
the phase of the solar cycle, there is a decrease in the number of magnetic cloud ejections for the last two solar cycles. We observe that at the minimum phase of solar cycle 14, no magnetic cloud whose effect lasts 1 day has been ejected. With 31 magnetic clouds ejected, this same cycle is the one during which less ejections of magnetic clouds with an effect lasting 1 day were recorded. On the contrary, solar cycle 23 is the cycle during which the greatest number of magnetic clouds of the same type has been recorded.

Figure 6 shows that from the phase minimum to the descending phase, the maximum number of magnetic clouds of duration 2 days ejected is respectively 5, 11, 22 and 10. During minimum solar phase, no magnetic cloud was ejected for cycles 18 and 19. The same observation

is made: (a) for cycles 12, 16 and 19 during the ascending phase, (b) for cycle 15 during the phase maximum and (c) for cycles 12 and 16 during the descending phase. For any phase combined, cycle 21, with 34 magnetic clouds ejected, is the cycle during which the greatest number of magnetic clouds have been ejected. On the other hand, cycle 16 with 12 ejected magnetic clouds is the least prolific cycle in ejection of magnetic clouds, the effect of which lasts 2 days. From cycle 21 to cycle 24 we observe a continuous decrease in the ejections of magnetic clouds.

Figure 7 shows that the phase maximum is the only phase during which the number of magnetic clouds ejected is not zero and that is regardless of the solar cycle. Solar cycles 11 and 24 are cycles during which the
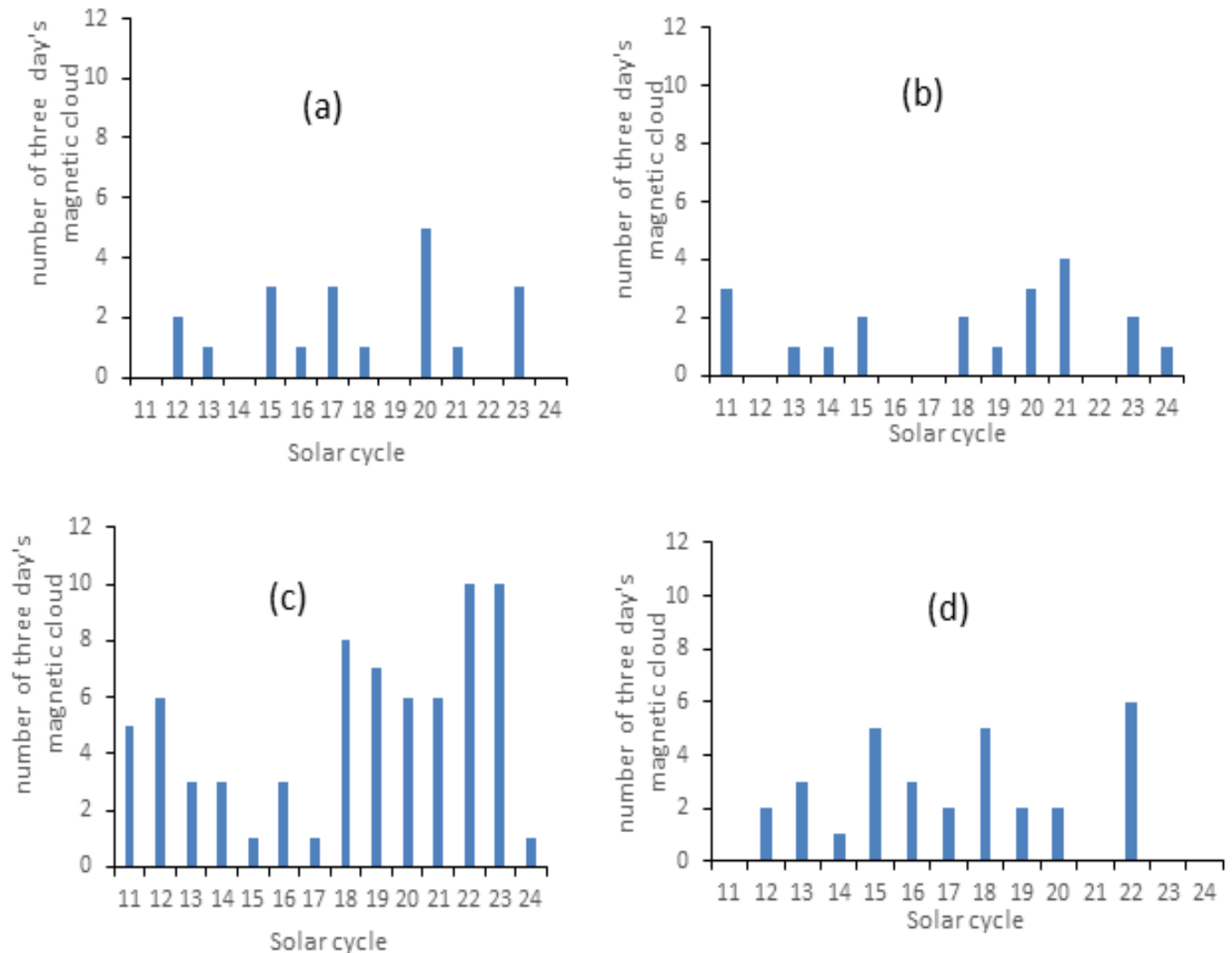
Figure 7. Occurrences of magnetic clouds whose effect lasts 3 days: (a) the upper left panel concerns the phase minimum, (b) the upper right panel the ascending phase, (c) the lower left panel the maximum phase and (d) the lower right panel the descending phase.

number of magnetic clouds recorded at the minimum phase and at the descending phase are zero. During solar cycle 22, no magnetic cloud was ejected at minimum and ascending phases. No magnetic cloud with an effect lasting 3 days was ejected during: (a) cycles 11, 14, 19, 22 and 24 at minimum phase; (b) cycles 12, 16, 17 and 22 during the increasing phases; and (c) cycles 11, 21, 23 and 24 during the decreasing phases.

From solar cycle 11 to solar cycle 24, solar cycles 18, 20, 22 each with 16 ejected magnetic clouds are the cycles from which the greatest number of magnetic clouds has been ejected; while solar cycle 24 with 2 ejected magnetic clouds is the solar cycle which recorded the small number of ejected magnetic clouds. These two magnetic clouds were ejected during the ascending phase and during the phase maximum. For the other two phases, no magnetic cloud whose effect lasts three days

was ejected.

Conclusion

We make a statistical study of magnetic clouds activity days' occurrence taking into account the duration of their effects and the phases of solar cycles 11 to 24. This study statistical study is a contribution in the understanding of Sun-Earth relations. The results show that: (1) the frequency of magnetic cloud ejections depends on the type of magnetic clouds and the solar cycle phase. Different types of magnetic clouds do not have the same occurrences.

However, regardless of the type of magnetic clouds, the phase maximum is the phase of the solar cycle during which the most magnetic cloud ejections are recorded.

(2) Whatever the solar cycle, the number of magnetic clouds whose effect lasts 1 day is greater than that whose effect lasts 2 days, which in turn is greater than that whose effect lasts 3 days. (3) For all types of magnetic clouds, cycles 20, 21, 22 and 23 were the four most active cycles in magnetic cloud ejections. Thus, Cycles 14, 12, 13 and 16 are the least active cycles in magnetic cloud ejections for the last fourteen solar cycles studied.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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