GEOMAGNETIC CONSEQUENCES OF THE SOLAR FLARES DURING THE LAST HALE SOLAR CYCLE (II)

Georgeta Maris, Miruna-Daniela Popescu, Marilena Mierla

Astronomical Institute of the Romanian Academy
Str.Cutitul de Argint 5, Bucharest 28, RO-75212
gmaris@aira.astro.ro, miruna@aira.astro.ro, marilena@aira.astro.ro

ABSTRACT/RESUME

The effects of the solar energetic phenomena cover the entire terrestrial environment, from the outer atmospheric layer to the ground. The energy source of all these geomagnetic disturbances is the solar plasma that may originate from solar eruptive phenomena that take their energy from magnetic field of the Sun. This paper is part of a larger study concerning the geomagnetic effects produced by solar phenomena. We analyze the cyclic variability of solar flares (registered in H_α and X-ray) and compare it with the variations of some geomagnetic indices (*aa* index and the number of sudden storm commencements (SSCs)) for the last Hale cycle. The solar cycles 22 and 23 are different in the level of flare activity and in the slope and the duration of their ascending branch.

1. INTRODUCTION

The interpretation of solar-terrestrial connections is a major goal of solar researches as the Sun affects the Earth directly, through its radiation, and indirectly, through the induced geomagnetic variations. Solar radiation monitoring and studies of solar variability mechanisms facilitate an understanding of the sources and amplitudes of the Sun's changing radiation. The results are of a high interest not only for solar physics but also for other interdisciplinary studies, because this variation can have significant social impacts.

The effects of the solar energetic phenomena cover *all the terrestrial environment*, from the outer atmospheric layer to the ground, perturbing the satellites, telecommunication systems, ground networks, producing biological and climatic disturbances. The *source* of all these geomagnetic effects is the *solar plasma that reaches the Earth magnetosphere*; this is in the form of *high-energy solar particles* that may originate from solar flares, eruptive prominences, coronal mass ejections or coronal holes.

Therefore, *forecasting space weather is extremely important,* not only for the space missions having astronauts on board, but also for avoiding money losses due to damages that more and more spatial and terrestrial technological systems can suffer because of some space weather disturbances. For over 35 years, the forecasts are continuously improved but they are still not perfect. There are a lot of difficulties in making a complete, rapid and effective prediction.

We are performing a comparative study of the geomagnetic effects produced by solar energetic phenomena with the aim of improving the capability making a better space-weather forecasting. In this respect, we analyze the geomagnetic variations through *aa* index as well as the number of *SSC* and compare them with *the cyclic variability of flares and coronal mass ejections* for the *last Hale cycle*. In the present paper (numbered as paper II) we analyze *flare's activity and some aspects of geomagnetic variations.*

2. HALE CYCLE

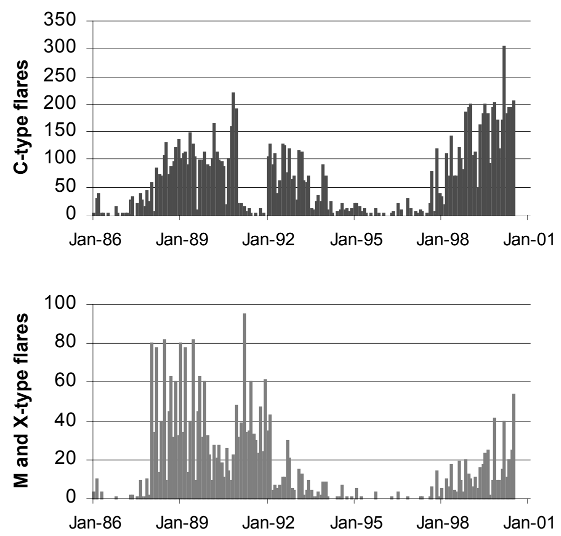
It is well known that the magnetic polarities of preceding and following sunspots in each hemisphere, as well as the polarity of the poles, reverse from one activity cycle of 11-year to the next. Thus, the magnetic activity exhibits a 22-year repeatability, known as the Hale cycle. In 1965, Vitinskii, based on previous studies of Gnevyshev and Ohl (1948) suggested that the correct choice for grouping the two 11-year cycles is "even-odd", the second being more powerful. So, the present Hale Cycle has number 12.

The 11-years solar cycle (SC) no. 23 reached the maximum smoothed number of 120.8, much lower than the predicted value (Maris et all., 2000). *Obviously, we are facing the third Hale cycle that does not obey the rule that the odd cycle should have bigger amplitude that the even one; we met this situation before at the Hale cycles nos. 3 and 5.* Solar cycle 23 is now developing his maximum phase. Into a previous paper (Maris et all., 2001a, paper I) we have tried to analyze the ascending phase of the SCs 22 and 23 using the sunspot and 10.7 cm radio flux data in order to reveal some differences in supporting or against the above-mentioned rule. We investigated spectral features in our time series data together with their time evolution using some of the tools provided by Joint Time-Frequency Analysis. We found substantial lack of correlation between the two ascending phases. Our JTF Analysis showed also different trends in time behaviour and variability content. We have limited ourselves to the ascending phases only because these periods are less influenced by the overlapping effect seen usually on the descending phase. However the analysis of the 22-years magnetic cycle has to be done over the whole 11-years components. So, the same analysis will be done on the descending phases and on the whole solar cycles 22 and 23. This step of our work is to be postponed until the end of the 23rd solar cycle!

3. FLARE AND GEOMAGNETIC DATA

We have analyzed the time distribution of X-ray flares during the ascending phase of the SC 22 and 23, by the monthly values of the events. The C class and M & X classes of X-ray flares were taken separately and, the following remarques could be made (figs. 1):

- SC 22: the X-ray flares showed a remarkable increasing activity during 1988, a high activity



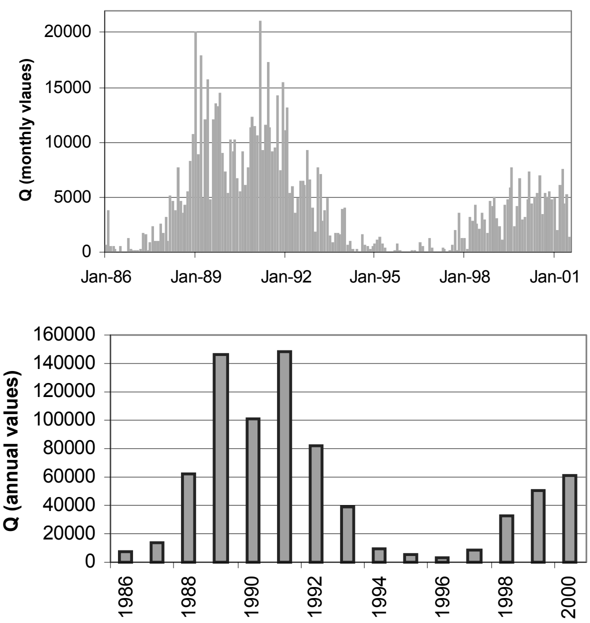
  during the 1988-1989 years and a second maximum on 1991 year. After 1992, the activity decreased and maintained so for 5 years (1993-1997). It is worth to note the period 1990-1993 that is characterized by an alternation of the activity between C-type and, M&X-type solar flares;
- SC 23: The X-ray flare's activity was continuously increasing after the end of 1997 for both considered groups of X-ray flares, C-type and M&X-type. The high flare activity after November 1999 can be remarked. The highest number of C-type X-ray flare took place in March 2000. Three maxima are revealing for the M&X-class of X-ray flares in November 1999, March and July 2000, the last one being the highest.

Similar variation was also found in the Hα flare numbers, for different classes of importance (Maris et all., 2001b).

We analyze here, the Hα flare activity using the daily flare index (Kleczeck, 1952),

$$Q = i \times t, \quad (1)$$

to quantify the daily flare activity over 24 hours per day. It is assumed that this relationship gives roughly the total energy emitted by the flares in H_α line. In this relation, *i* represent the intensity scale of importance and *t,* the duration (in minutes) of the flares. We have taken the *Q* values from NGDC On-Line Data, at: http://www.ngdc.noaa.gov. The histograms of the Q index are given in figs. 2 (upper panel – monthly values and bottom panel – annual values) during the 1986 –2000 period.



For a similar evaluation of the flare energy released in X-ray we introduced the index Q_x. We calculated it in the same manner:

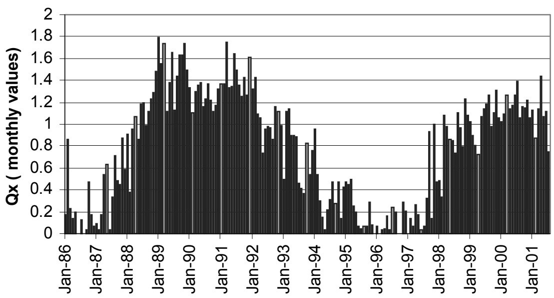
$$Q_x = i_x \times t, \qquad (3)$$

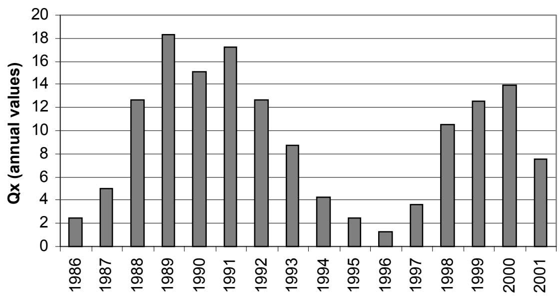
where i_x is the importance coefficient of the X-ray flare and t is the duration of the flare in minutes. There are the C, M, X classes of the solar flares in X-ray classified according to the order of magnitude of the peak burst intensity measured at the Earth by satellites in the 1-8 Å. Based on this classification we defined i_x as in Table 1.

Table 1. The i_x coefficient values for the different spectral classes of X-ray flares

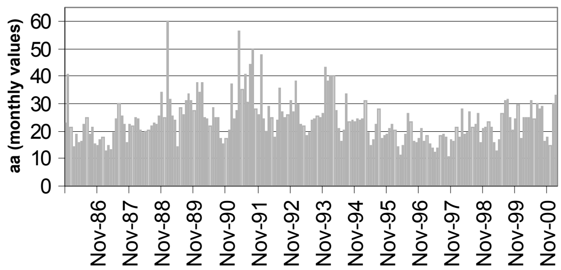
X-ray class	i_x
1.1-5.0 C	1.0
5.1-9.9 C	1.5
1.1-5.0 M	2.0
5.1-9.9 M	2.5
1.1-5.0 X	3.0
5.1-9.9 X	3.5

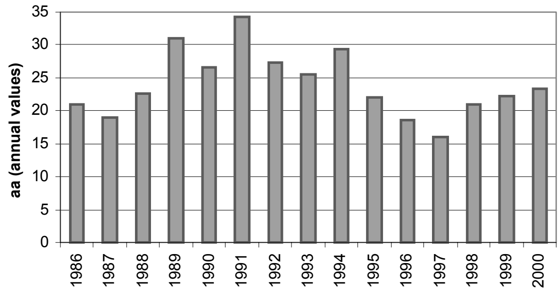
Figs. 3 present the Q_x variation during the 1986 – 2000 period by it monthly values (upper panel) and annual values (bottom panel).





For geomagnetic variations we have chosen the *aa* index (figs. 4) and the number of Sudden Storm Commencements (figs. 5), by their monthly (upper panels) and annual values (bottom panels). The aa index gives an evaluation of the geomagnetic disturbance level whereas the number of SSCs gives the number of the shock waves which arrive to and hit the magnetosphere of the Earth. Such shock waves are, as a rule, associated with the flares and coronal mass





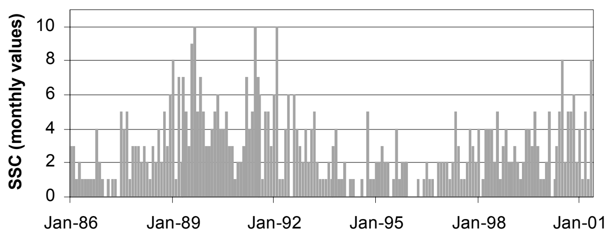
ejections.

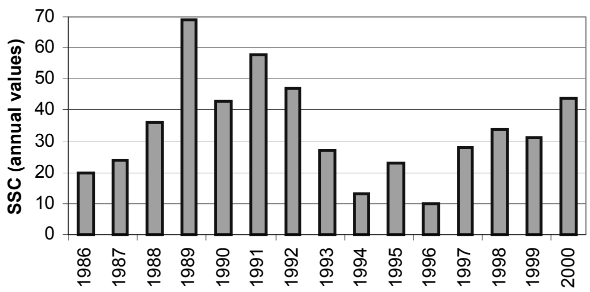
4. RESULTS AND DISCUSSIONS

The annual values of the *Q* index (fig. 2b) show a very sharp grow during the ascending branch of the SC 22 and two maxima: 1989 and 1991. These epochs are coincident with the maximum epochs for the sub-flares and the flares of ≥ 2 importance, respectively. It could be remarked the values of the two maxima: they are practically equal. This means that the *Q* index appreciates the same energy released by the flares of two importances (annual values). The SC 23 presents a very low flare activity on the ascending branch, in comparison with SC 22, and, a lower slope, too.

The values of the Q_x index reveal practically the same variations as the ones of the *Q* index. It is worth to notice the maximum of the 1989-year, higher that the second one (1991) and, a steeper slope of the ascending branch for SC 23. The figs. 3 extend the data over the first half of the 2001-year. The upper panel of the figs. 3 shows a decrease of the flare activity evaluated by the monthly values of the Q_x.

We have used the geomagnetic data of NGDC On-Line Data, at: http://www.ngdc.noaa.gov/stp/GEOMAG. The geomagnetic variations (by aa index, figs. 3) reveal three maxima for the SC 22: 1989, 1991 and 1994. The two first coincide with the maxima for flare activity, but the second one is higher. The last one is coincident with some flare-generated HSPS in solar wind (Maris & Maris, 2001). The geomagnetic activity by the SSC number shows the same two maxima (1989 and 1991) with the 1989 the highest one. The third maximum of the SC 22 is moved to 1995, the year with high activity of the HSPS generated by flares, too (Maris & Maris, 2001).





The SCs 22 and 23 are different in the level of flare activity and in the slope and the duration of their ascending branch. The SC 23 is very alike with SC 20 but they have different position into a unit of 22-year cycle.

Taking into account the physical nature of the Hale cycle (22 years) we consider that the order of their two component (11-year cycle) is not important and the level of the two components' activity is dependent of other physical factors referring to the magnetic field of the Sun

ACKNOWLEDGEMENTS

Georgeta Maris is grateful to the organizers of the Second SOLSPA Euroconference for financial support to attend the meeting. This paper was partially supported by the priority program no.3/2001of the Romanian Academy of Sciences.

REFERENCES

Gnevyshev, M.N. and Ohl, A.I.: 1948, *Astron. Zh.*, 25, 18.

Kleczek, J.: 1952, *Publ. Inst. Centr. Astron.*, No. 22, Prague.

Maris, G., Maris, O., 2001, this volume.

Maris, G., Popescu M.-D., Oncica A., Donea A.-C.: 2000, in: A. Wilson (ed.), *The Solar Cycle and Terrestrial Climate,* Proc. First Solar and Space Weather Euroconference, Santa Cruz de Tenerife, Tenerife, Spain, 25-29 Sept. 2000, ESA SP-463, 371.

Maris, G., Popescu M.-D., Oncica A.,2001a, *Rom. Astron. J.*, **11**, (in press).

Maris G., Oncica, A., Popescu, M.-D., Donea A. C., Mierla M., 2001b, in: Proc. of Regional Meeting "Solar Researches in the South-Eastern European Countries: Present and Perspectives", 24-28 April 2001, Bucharest, Romania, (Maris G., ed.), OBSERVATIONS SOLAIRES, Ed. Acad. Romane (in press).

Vitinskii, Yu. I., 1965, *NASA TT F-289*, NASA, Washington, D. C., 129.