THE USE OF Ap GEOMAGNETIC INDICES FOR THE CHARACTERIZATION AND RANKING OF MAJOR GEOMAGNETIC DISTURBANCES FROM 1932 TO 2022

DINU Luminița, NICULICI Eugen Laurențiu, FILIPCIUC Constantina

Abstract. The Earth's magnetic field is a result of the interaction between the internal field, the crustal field and the external magnetic field. The rapid variations of the geomagnetic field are due to its external component, with the solar wind as its main source. Although these variations account for no more than 5% of the total field, they can cause serious problems for Earth's energy and communication infrastructures. Several calculation methods have been used to quantify these variations, resulting in various indices of magnetic activity. They are calculated either at the planetary level or for certain areas on Earth – auroral index (AE), planetary indices (Kp, Ap), equatorial index (Dst). In this paper we will compare and rank the major geomagnetic events of the last 8 solar cycles using the Ap indices. We will also establish a relation between these indices and the solar activity quantified through the number of sunspots.

Keywords: solar activity, geomagnetic storm, disturbances, geomagnetic indices.

Rezumat. Utilizarea indicilor geomagnetici Ap pentru caracterizarea și ierarhizarea perturbațiilor geomagnetice majore din perioada 1932 – 2022. Câmpul magnetic al Pământului reprezintă o rezultantă a interacțiunii dintre câmpul intern, cel crustal și câmpul magnetic extern. Variațiile rapide ale câmpului geomagnetic se datorează în principal componentei externe a acestuia, având ca sursă principală vântul solar. Deși aceste variații nu reprezintă mai mult de 5% din câmpul total, ele pot cauza probleme grave la nivelul infrastructurilor de comunicații și energetice de pe Pământ. Pentru a cuantifica aceste variații au fost utilizate mai multe metode de calcul, rezultând diverși indici de activitate magnetică. Aceștia sunt calculați fie la nivel planetar fie pentru anumite zone de pe Pământ - indice auroral (AE), indici planetari (Kp, Ap), indice ecuatorial (Dst). În această lucrare vom realiza o comparare și ierarhizare a evenimentelor geomagnetice majore din ultimele 8 cicluri solare cu ajutorul indicilor Ap. De asemenea vom stabili o relație între acești indici și activitatea solară cuantificată prin intermediul numărului de pete solare.

Cuvinte cheie: activitate solară, furtună geomagnetică, perturbații, indici geomagnetici.

INTRODUCTION

The main component of the magnetic field, about 95% of the total value, is created by processes and materials inside and on the Earth's surface. These internal and crustal components are supported by the external one, having as sources the electric currents from the ionosphere and magnetosphere and which disturb the internal geomagnetic field. If certain specific conditions are met, this system of external currents can generate significant variations of the magnetic field at the Earth's surface with important implications in the economic-financial field, air transport, global positioning, satellite missions, etc. The magnetospheric and ionospheric fields are the result of the interaction between the Sun and our planet.

The geomagnetic phenomena associated with external sources and observable on the Earth's surface are presented in table 1 (MERRILL et al., 1998).

Table 1. Geomagnetic phenomena associated with external sources and visible on the Earth's surface (MERRIL et al., 1998).

Phenomenon	Period	Amplitude (nT)
Micropulsations	1 ms – 3 min	~<1
Magnetospheric gulfs and substorms	1-2 h	~10
Calm solar diurnal variation **- middle latitudes, Sq** **- low latitudes, EEJ**	24 h	20 – 50 50 – 100
Disturbed solar diurnal variation, SD	24 h	~ 5 – 20
The monthly diurnal variation, L	25 h	~1
The variation during the storm, Dst **- the initial phase** **- the main phase** **- the recovery phase**	 ~4 h ~8 h ~60 h	 ~15 ~35 ~35
Semi-annual variation	6 months	5
Annual variation	12 months	5
The decennial variation	11 and 22 years	10 – 20

Essentially, the main cause for the production of geomagnetic storms is represented by the extreme electric fields associated with the southward oriented interplanetary magnetic fields (IMF) while the geomagnetic substorm is a violent discharge of magnetic energy accumulated in the tail of the magnetosphere. Thus, the physical processes through which the energy from the solar wind is redistributed in the magnetosphere-ionosphere system are at the origin of storm and substorm phenomena (McPHERRON, 1991; TSURUTANI et al., 2004; LAKHINA et al., 2006).

Geomagnetic storms are characterized by three phases: initial, main and return phase. Thus, in the initial phase, the storm can start gradually or go through an abrupt change and can persist for up to 16 hours. In addition to the SD component, at the time of the storm, there is also the component related to the start of the storm, called the variation during the storm, Dst. The main phase of the storm is defined when the value of Dst falls below the value that suddenly increased and ends when it reaches the minimum value.

Geomagnetic storms are usually small and do not cause damage. In the less common cases where geomagnetic storms are more intense, they can cause damage to infrastructure and people.

One of the important problems produced by magnetic storms is that satellites risk being affected by the action of energetically charged particles, which can damage their structure or affect their operation. This could affect positioning systems, navigation systems, or communications satellites, causing significant damage and financial loss to all infrastructure that relies on these systems to function.

Another important problem produced by magnetic storms is that power distribution networks and underground metal pipelines that can conduct geomagnetically induced currents (GICs) are very sensitive. This type of current can be extremely damaging to power grids, causing high-voltage transformers to overheat or even burn out, as happened during the geomagnetic storm of March 13, 1989, which famously caused a blackout in Quebec (Canada). Oil and gas pipelines are susceptible to corrosion or overheating from GIC, while signalling systems for rail traffic can be damaged, posing a risk.

DATA AND METHODS

Geomagnetic indices are used to analyse geomagnetic activity: the K/Kp index, the Ap index, the AE index and the Dst index (MAYAUD, 1980; RANGARAJAN, 1989; CAMPBELL, 2003).

Index K. Geomagnetic activity is described by discrete series of indices that characterize the local or global variation of the magnetic field, in time intervals greater than the data acquisition interval in the observatories. Thus, the effects of the sun's complicated electromagnetic and corpuscular phenomena in the magnetosphere, respectively in the variation of the geomagnetic field, are highlighted. This external component does not exceed 5% of the total field component, but has major implications in the long-term quantification of solar activity variation and space climate near Earth.

The most used index for such long-term evaluations is the K (Kennziffer) index, selected by Julius Bartels in 1938 and later recalculated from 1932. It describes, on a scale from 0 to 9, the irregular disturbances of the geomagnetic field, caused by solar corpuscular radiation, in a three-hour interval. It was first introduced at the Niemeqk Observatory, remaining to this day a local index, describing the level of disturbances in the vicinity of each observatory. And in the Surlari observatory, the K index is calculated automatically, in real time - every three hours.

The K index is evaluated by following one of the two horizontal components (geomagnetic elements X, Y or H, D), taking into account the element with the highest amplitude in the three-hour interval. The amplitude measure is given by the difference between the two extreme values of the geomagnetic element, compared to the levelled value of the curve that best represents the course of the undisturbed element. Currently, three-hour K indices are determined starting from digital geomagnetic records, through digital processes, which allows for a better estimation of the calm diurnal variation curve to which the recorded values are related for the calculation of three-hour activity indices.

The K indices, as proposed by 13 geomagnetic observatories, distributed in different areas of the globe, are used to calculate the planetary indices Kp, currently used in the study of planetary scale phenomena. The calculation of the planetary indices Kp and their linear equivalent, the Ap indices, is carried out monthly by ISGI (***. https://isgi.unistra.fr/). The Kp indices have a denser evaluation scale than the K indices and therefore intermediate values are introduced, marked with + or – (table 2) (GFZ -Potsdam, 2006).

Table 2. Evaluation scale of Kp indices (***. www.ngdc.noaa.gov).

Kp	0	0+	1-	1_0	1+	2-	2_0	2+	3-	3_0	3+	4-	4_0	4+
Ap	0	2	3	4	5	6	7	9	12	15	18	22	27	32
Kp	5-	5_0	5+	6-	6_0	6+	7-	7_0	7+	8-	8_0	8+	9-	9_0
Ap	39	48	56	67	80	94	111	132	154	179	207	236	300	400

For the calculation of other planetary geomagnetic indices, data from other observatories are used, depending on their geographical position. Figure 1 shows the observatories used for the calculation of various geomagnetic indices (AE-auroral electrojet index, Kp-planetary three-hour index, Dst-storm index describing the variation of the geomagnetic field in the equatorial ring current EE, etc.).

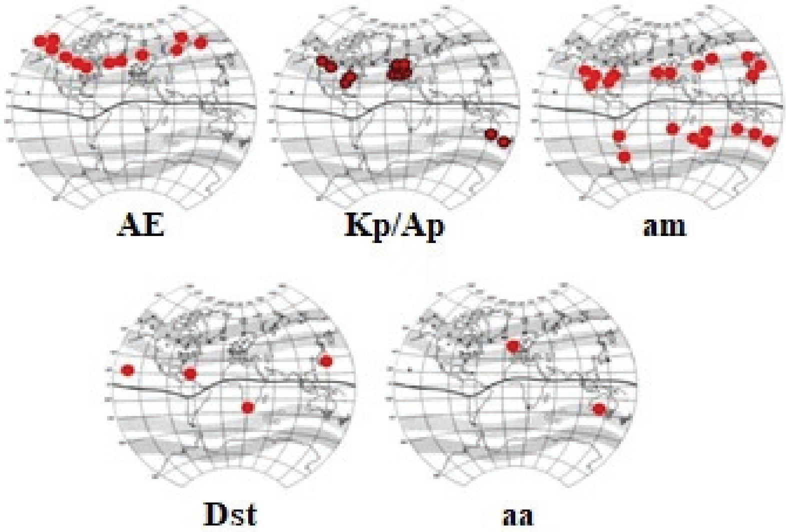

Figure 1. Representation of the stations whose data are used to calculate the indices (IANCU, 2019).

The Ap index is a daily index that is obtained by averaging the eight daily values of ap, this being an index calculated over a period of 3 hours, derived from the values of the Kp index (table 2). Compared to the scale of the Kp index which is quasi-logarithmic, the scale of ap is linear. For the calculation of the ap and Ap indices, data from 13 observatories are used, which are located at mid-latitudes. The 13 observatories are shown in figure 1.

The aa index is a planetary or global index (MAYAUD, 1972) and is derived from the K index and is defined using the variation range of the geomagnetic field, more precisely with the horizontal component at 3-hour intervals (BARTELS et al., 1939) at two approximately antipodal observatories, one in England and one in Australia (Fig. 1). The calm solar variation Sq is removed from the data. It can be used to identify intervals of calm and geomagnetic disturbance.

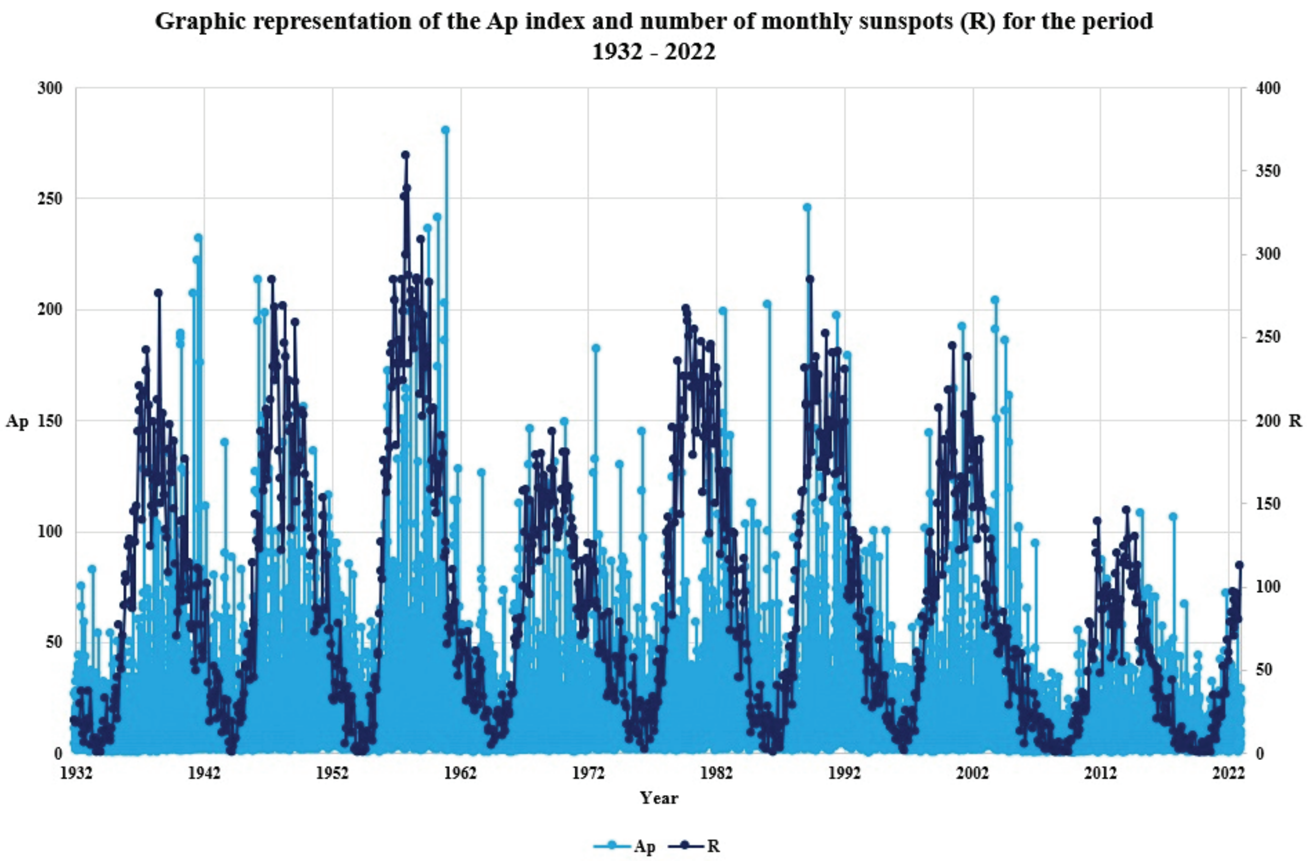

Figure 2. Graphic representation of sunspots (R) and of the Ap index for the period 1932 – 2022 (original).

The Dst index, introduced by SUGIURA in 1964, represents the axially symmetric perturbation of the magnetic field at the Earth's surface at the dipole equator. Major perturbations of the Dst index are negative, indicating decreases in the geomagnetic field. Currently, Dst is obtained from records of the horizontal component of the magnetic field from four low-latitude magnetic observatories (Figure 1). The four observatories are: Honolulu (HON), San Juan (SJG), Hermanus (HER) and Kakioka (KAK).

In the four-observatory network, the value of the Dst index is calculated as the average of the residual field for each hour of universal time. The residual field is obtained by eliminating the secular variation of the geomagnetic field and then the calm diurnal variation Sq.

In the study, in addition to the geomagnetic indices, the sunspot number (R) was also used (***. https://www.sidc.be/).

An interesting aspect of the Sun are its sunspots. Sunspots are areas where the magnetic field is about 2,500 times stronger than Earth's, far greater than anywhere else on the Sun. Because of the strong magnetic field, the magnetic pressure increases while the surrounding atmospheric pressure decreases. This, in turn, lowers the temperature relative to the surroundings, as the concentrated magnetic field inhibits the flow of new, hot gas from the Sun's interior to the surface.

Sunspots tend to appear in pairs that have magnetic fields pointing in opposite directions. A typical spot consists of a dark region called the shadow, surrounded by a lighter region known as the penumbra. Sunspots appear relatively dark because the Sun's surrounding surface (photosphere) is about 10.000 °F (about 5.537°C), while the shadow is about 6.300°F (about 3.482 °C). Sunspots are quite large, as an average size is about the same size as the Earth.

The abundance of sunspots varies over time intervals from a few hours to several years. The index called Țsunspot number” was used to quantify the abundance of sunspots. This index is still widely used, although for some purposes it has been superseded by more easily and consistently measured indices such as the 10. centimetre solar flux. The main advantage of the sunspot count is that it is the only index for which we have a long and detailed historical record.

A graphical representation of the sunspot number, R, and the geomagnetic index Ap, during the last 8 solar cycles, is given in figure 2.

RESULTS AND DISCUSSIONS

A geomagnetic storm is a major disturbance in the Earth's magnetosphere that occurs when there is a very efficient transfer of energy from the solar wind into the space environment around the Earth.

The largest storms resulting from these conditions are associated with solar coronal mass ejections (CMEs) in which about a billion tons of plasma from the sun reach near the Earth and generate an additional magnetic field. CMEs typically take several days to reach the Earth's atmosphere, but for some of the most intense storms, they have been observed to arrive in as little as 18 hours.

During storms, ionospheric currents as well as energetic particles penetrating the ionosphere add energy in the form of heat that can change the density and density distribution in the upper atmosphere, causing additional stress on low-Earth orbiting satellites. Local heating also creates strong horizontal variations in ionospheric density that can alter the path of radio signals and create errors in the positioning information provided by GPS. While storms create a beautiful aurora, they can also disrupt navigation systems such as the Global Navigation Satellite System (GNSS) and create geomagnetically induced currents (GICs) that are harmful to power grids, communications infrastructure and pipelines. The geomagnetic storms (Table 3) were classified based on the Kp index into extreme, severe, strong, moderate and minor storms.

To analyse the major geomagnetic disturbances I chose to use the Ap index and with its help I can evaluate them.

Ap indices for the period 1932 – 2022 were analysed and those with values greater than 50 were selected, which may indicate a substorm or a geomagnetic storm. 906 days are identified in which the Ap index is greater than 50 as it can be seen in figure 3 where they are represented in green, and in blue the total number of monthly sunspots are represented.

The number of sunspots best delimits a solar cycle, in this way we can see that major storms do not fall on the maximum of a solar cycle. Table 4 includes a classification according to the Ap index of the most important geomagnetic disturbances.

Large geomagnetic disturbances are fairly rare events, even near the top of the solar cycle. However, they have a number of interesting effects on global radio communications, satellite and spacecraft operations, geophysical exploration, and a multitude of technological systems. One way to compare these perturbations is to use the Ap index and rate them according to its value. This was also done in table 4, which lists the 50 most disturbed days (from 01.01.1932 – 31.12.2022).

Table 3. Classification of geomagnetic storms according to Kp (/www.swpc.noaa.gov/).

SCALE	DESCRIPTION	Kp	FREQUENCY	EFFECT
G1	Minor	Kp = 5	1700/cycle (900 days/cycle)	***Power systems****:* Weak power grid fluctuations can occur. ***Spacecraft operations****:* Minor impact on satellite operations possible. ***Other systems***: Migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).
G2	Moderate	Kp = 6	200/cycle (130 days/cycle)	***Power systems*****:** High-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. ***Spacecraft operations*****:** Corrective actions for orientation may be required by ground control; possible changes in drag affect orbit predictions. ***Other systems*****:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).
G3	Strong	Kp = 7	600/cycle (360 days/cycle)	***Power systems***: Voltage corrections may be required, false alarms triggered on some protection devices. ***Spacecraft operations***: Surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. ***Other systems***: Intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).
G4	Severe	Kp = 8, incluiding a 9-	100/cycle (60 days/cycle)	***Power systems***: Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. ***Spacecraft operations:*** May experience surface charging and tracking problems, corrections may be needed for orientation problems. ***Other systems:*** Induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).
G5	Extreme	Kp = 9	4/cycle (4 days/cycle)	***Power systems***: Widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. ***Spacecraft operations***: May experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. ***Other systems***: Pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).

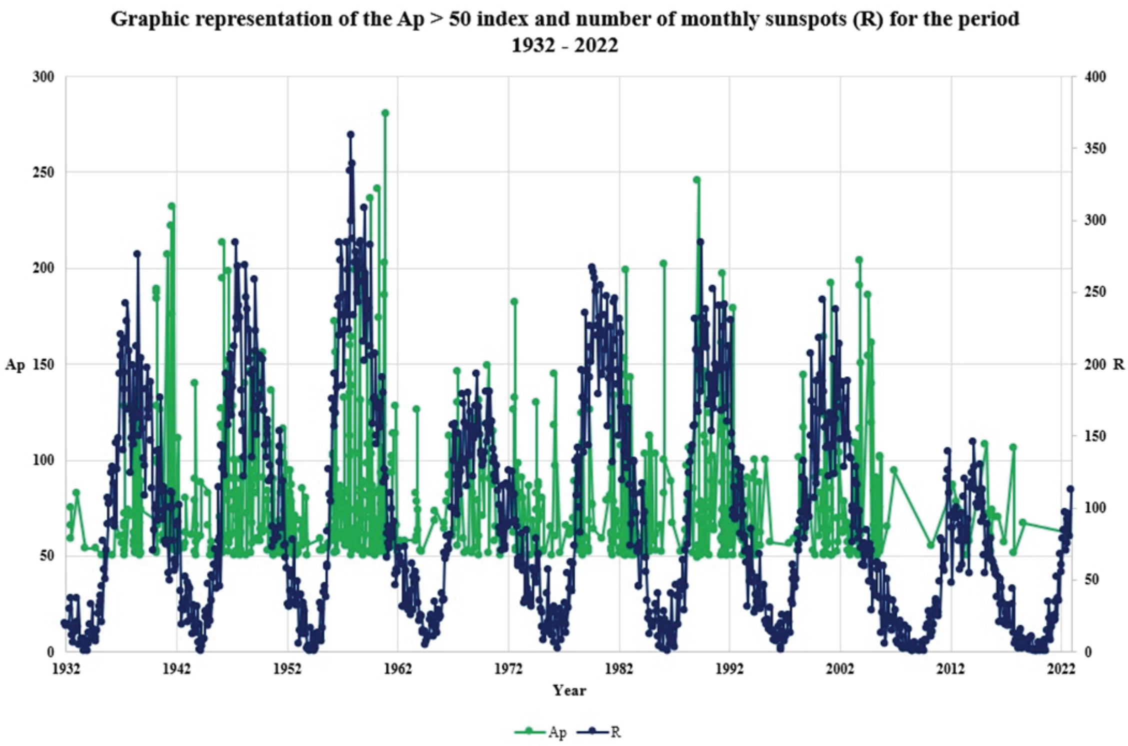

Figure 3. Graphic representation of sunspots (R) and of the Ap index (≥ 50) for the period 1932 – 2022 (original).

From the analysis of the above table and figure 3 an interesting number of features can be observed:
- the most solar events (14) were in the solar cycle 19, and the largest number of sunspots was 359.4 in October 1957, and the solar maximum was in March 1958.
- 9 events were in the solar cycle 18, having the highest number of sunspots 285 was recorded in May 1947.
- 8 events were in the solar cycle 23, having the highest number of sunspots 244.3, recorded in July 2000.
- the rest of the solar cycles had the following values: cycle 17 – contributed with 7 solar events, cycle 22 contributed with 6 solar events, and solar cycles 20 and 21 with 3 events each.

If we also take into account the classification of geomagnetic storms, see table 3, it appears that the 50 analysed storms are part of the category of severe and extreme storms.

Table 4. Classification of the most important geomagnetic disturbances according to Ap (original, using data from https://wdc.kugi.kyoto-u.ac.jp/)

Top	Data (YYYYMMDD)	Ap value	Kp index								Sum of indices Kp	Solar Cycle
			00-03 h	03-06 h	06-09 h	09-12 h	12-15 h	15-18 h	18-21 h	21-00 h		
1	19601113	280	9-	9-	9	9	9-	8+	8	6+	67-	19
2	19890313	246	6	8-	9-	8+	8+	8+	9-	9	65	22
3	19600401	241	9-	9-	7	8	8+	9-	9-	7+	65+	19
4	19590715	236	4+	5	8	9-	9-	9	9-	9-	61	19
5	19410918	232	2	7-	8+	9-	9-	9-	9-	9-	60+	17
6	19410705	222	6+	6+	9-	9-	9	9-	7-	8-	62	17
7	19460328	213	5	6	8+	9-	9-	9-	8+	8	62-	18
8	19410301	207	3	6+	8	8	9-	9	9-	7	59-	17
9	20031029	204	5-	4	9	8	8-	8-	9-	9-	58+	23
10	19601006	203	6	8	7+	8	8	8+	8+	9-	63-	19
11	19860208	202	7	7	7+	7-	8	8-	9	9-	61+	21
12	19580708	200	3	3-	7+	8-	8+	9	9-	9-	55+	19
13	19580211	199	9	8+	9-	8+	8	5+	6	6	60-	19
14	19820906	199	8	8+	8+	8+	9-	7+	7	6+	62+	21
15	19460922	198	4-	8+	8-	9-	9	8+	7	6	59-	18
16	19910605	197	7-	7+	8	8	8	9-	8	8-	62+	22
17	19460325	195	8-	7+	7+	8-	8+	9-	8-	8-	62+	18
18	20010331	192	7-	9-	9-	6+	7	8	8+	7+	61	23
19	20031030	191	9-	7+	5+	5-	5	7	9	9	56	23
20	19400330	189	9-	8+	8+	8	7+	8-	7	6-	61	17
21	19400324	187	6+	6	5	4+	8	9	9	8+	56	17
22	19601007	186	9	9-	8-	8-	7+	7	6-	6	59	19
23	20040727	186	8+	8-	7+	8	9-	8+	6+	6	61-	23
24	19400325	184	9-	8+	8+	8	7	5-	7-	8	60-	17
25	19720805	182	8+	8+	7	7+	8-	9-	7+	6-	60+	20
26	19920510	179	5+	6+	8	9-	8+	8-	8	7+	60-	22
27	19590327	178	7+	8-	8+	7-	8+	8+	8-	6+	61-	19
28	19410919	176	9-	9	9-	7+	4	5	7+	4	54	17
29	19600430	174	7-	7-	6-	6-	9-	9	8	7	57+	19
30	19560427	172	9-	9-	8-	8-	7-	7-	7	6-	59-	19
31	19570923	164	8	9-	8-	8-	8-	7-	7-	5	58	19
32	20000715	164	3	4-	5-	4+	8	9-	9	9-	50	23
33	19910324	161	3	9-	8	7+	5+	5	8	9-	54	22
34	20041110	161	8-	8+	9-	8+	7+	6+	5+	4+	56+	23
35	19570913	160	8-	8+	9-	9-	7	6	4	4	54+	19
36	19890314	158	9	8-	8-	6-	5	5+	8-	7+	55+	22
37	19490125	156	9-	8	7-	4+	5	6	8+	8+	55+	18
38	19491015	156	6	6	7+	8	7+	7+	8+	8-	58	18
39	19560516	156	5+	7+	8-	7	8+	8-	7	8-	58	19
40	20040725	154	7	7+	6+	8-	7+	8	7+	7+	58+	23
41	19490512	153	2	2	7+	7+	8+	9-	8+	7	51	18
42	19820714	153	9	8-	7-	7	6	7	7-	6	56	21
43	19460727	152	9-	9-	9	7-	5+	4-	4-	2+	48	18
44	19570630	150	3	6+	5+	8-	8	8	8	8+	55-	19
45	20031120	150	1	4-	6+	6+	8-	9-	9-	8	50+	23
46	19700308	149	4+	5	6-	5	7+	8	9	8+	53-	20
47	19460923	146	7+	8-	8	6+	7	8	6	7-	57	18
48	19480808	146	5+	7-	7+	8-	8-	7	8-	8-	57	18
49	19670526	146	9	9-	7+	7-	7-	4-	4	5-	51-	20
50	19891021	146	6+	7-	7	8+	8-	7-	8	6+	57	22

Most of the events occurred between March – April (15) and September – October (13).

In figure 3, solar cycles 17 – 24 are represented, for solar cycles 22,23 and 24 it can be seen that they register 2 solar maxima, different from the others.

CONCLUSIONS

Ap indices were used because they have a linear scale, while K pis quasi – logarithmic.

We believe that this index is a good parameter to monitor and quantify the amplitude of geomagnetic disturbances and represents a parameter that we want to use within the Surlari National Geomagnetic Observatory for a real-time monitoring of geomagnetic storms.

One of the directions of this work is represented by the more extensive exploitation of the long time series of the Ap index for a period of 91 years (1932 – 2022) (https://wdc.kugi.kyoto-u.ac.jp/). 906 values of Ap ≥ 50 from a total of approximately 33,238 days were analysed.

From the analysis of the Ap index and sunspots, we can see that there are storms that do not fall on the maximum of solar activity, as the last 3 solar cycles have two solar maximums each.

Most of the major disruptions occurred during March-April and September-October.

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REFERENCES

BARTELS J., HECK N. H., JOHNSTON H. F. 1939. *The three-hour range index measuring geomagnetic activity. Terrestrial Magnetism and Atmospheric Electricity.* American Geophysical Union. Washington, D. C. **44**(4): 411-454.

CAMPBELL W. H. 2003. *Introduction to Geomagnetic Fields*. Second Edition. Cambridge University Press. 337 pp.

IANCU L. 2019. *Studiul variației temporale a fenomenelor geomagnetice tranzitorii de perioadă scurtă din date de observator.* Teză de doctorat. Facultatea de Geologie și Geofizică. Universitatea din București. 292 pp.

LAKHINA G. S., ALEX S., MUKHERJEE S., VICHARE G. 2006. On magnetic storms and substorms. In: *ILWS WORKSHOP 2006, GOA.* 8 pp.

MAYAUD P. N. 1972. The aa indices: A 100 – year series characterizing the magnetic activity, *Journal of Geophysical Research.* American Geophysical Union. Washington, D. C. **77**(34): 6870-6874.

MAYAUD P. N. 1980. Derivation, meaning, and use of geomagnetic indices. *Geophysical Monograph Series*. American Geophysical Union. Washington, D. C. **22**. 154 pp.

MANDEA M. & PURUCKER M. 2005. Observing, Modeling, and Interpreting Magnetic Fields of the Solid Earth. *Surveys in Geophysics.* Springer. Berlin. **26**: 415-459.

MCPHERRON R. L. 1991. Physical processes producing magnetospheric substorms and magnetic storms. *Geomagnetism*. Academic Press. London. **4**: 593– 739.

MERRILL R. T., MCELHINNY M. W., MCFADDEN P. L. 1998. *The magnetic field of the Earth – Paleomagnetism, the core and the deep mantle*. Academic Press. London. 531 pp.

SUGIURA M. 1964. Hourly values of equatorial Dst for the IGY. *Annals of the International Geophysical Year.* Pergamon Press. Oxford. **35**. 9 pp.

TSURUTANI B. T., GONZALEZ W. D., GUARNIERI F., KAMIDE Y., ZHOUA X., ARBALLO J. K. 2004. Are high–intensity long-duration continuous AE activity (HILDCAA) events substorm expansion events qm. *Journal of Atmospheric and Solar-Terrestrial Physics*. Elsevier. Amsterdam. **66**: 167-176.

RANGARAJAN G. K. 1989. Indices of geomagnetic activity. *Geomagnetism*. Academic Press. London. **3**: 385-460.

***. www.ngdc.noaa.gov (Accessed: January 11, 2023).

***. www.swpc.noaa.gov (Accessed: January 11, 2023).

***. https://wdc.kugi.kyoto-u.ac.jp/ (Accessed: January 12, 2023).

***. https://www.sidc.be/ (Accessed: January 12, 2023).

Dinu Luminița, Niculici Eugen Laurentiu, Filipciuc Constantina
Geological Institute of Romania, 1st Caransebeş Street, 012271 - Bucharest, Romania.
e-mail: luminita_iancu84@yahoo.com; niculicie@yahoo.com; tatiana0906@yahoo.com

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