Geomagnetic activity for the last solar cycle recorded in PAG observatory

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The present paper provides information about the observed trends of the geomagnetic field variations, calculated local geomagnetic indices and tendencies of the secular variations of the field according to data time series of PAG observatory for the present solar cycle - 24.

Solar Terrestrial Interactions

The ***solar cycle*** (or solar magnetic activity cycle) is the periodic change in the sun's activity and appearance with average duration of 11 years. Cycles as short as 9 years and as long as 14 years have been observed, and in the double cycle of 1784-1799 one of the two component cycles had to be less than 8 years in length. Significant variations in amplitude also occur. Solar maximum and solar minimum refer respectively to epochs of maximum and minimum sunspot counts. Individual sunspot cycles are partitioned from one minimum to the next. Solar Cycle 24 is the 24th solar cycle since 1755, when recording of solar sunspot activity began. It is the current solar cycle, and began on January 4, 2008, and there was minimal activity until early 2010. Solar Cycle 24 has been the subject of various hypotheses and commentary pertaining to its potential effects on Earth. 2012 was surprisingly calm in solar activity, seeming to contradict the widely predicted late 2012-early 2013 peak in solar flares, sunspots and other activity. Since early 2014 there is rise in sunspot number. Currently (March 2015) we are in the second solar cycle maximum which is higher than the first one. Solar cycle 24 is one of the weakest since the start of solar cycle observations.

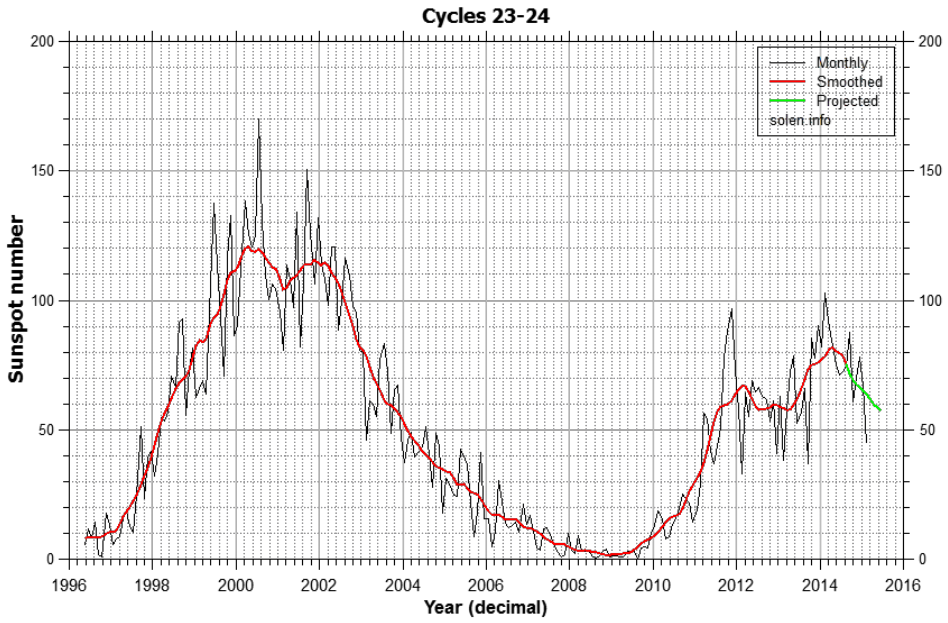

Fig.1. Solar cycle 23 and 24 sunspot number graphics. (source: solen.info)

A ***geomagnetic storm*** is a temporal disturbance of the Earth's magnetic field which is a signature of the response of the Earth magnetosphere and ionosphere to solar forcing. The increase in the solar wind pressure initially compresses the magnetosphere and the solar wind's magnetic field interacts with the Earth's magnetic field and transfers an increased energy into the magnetosphere. Both interactions cause an increase in movement of plasma through the magnetosphere (driven by increased electric fields inside

the magnetosphere) and an increase in electric current in the magnetosphere and ionosphere. The disturbance in the interplanetary medium which drives the geomagnetic storm may be due to a solar coronal mass ejection (CME) or a high speed stream of the solar wind originating from a region of weak magnetic field on the Sun's surface. The frequency of geomagnetic storms increases and decreases with the sunspot cycle. CME driven storms are more common during the maximum of the solar cycle and CIR driven storms are more common during the minimum of the solar cycle.

Geomagnetic Indices

Geomagnetic indices are a measure of geomagnetic activity, which is a signature of the response of the Earth magnetosphere and ionosphere to solar forcing.

The ***K Index*** quantifies disturbances in the horizontal component of earth's magnetic field with an integer in the range 0-9 with 1 being calm and 5 or more indicating a geomagnetic storm. It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during a three-hour interval. The planetary three-hour-range **Kp index** is introduced by J. Bartels in 1949 and is derived from the standardized K index (Ks) of 13 magnetic observatories. It is designed to measure solar particle radiation by its magnetic effects.

The ***A-index*** was invented because there was a need to derive some kind of daily average level for geomagnetic activity. Because of the non-linear relationship of the K-scale to magnetometer fluctuations, it is not meaningful to take averages of a set of K indices. What is done instead is to convert each K back into a linear scale called the "equivalent three hourly range" ***a-index*** (note the lower case). The daily ***A index*** is merely the average of eight "**a**" indices

The ***Dst*** is a geomagnetic index which monitors the world wide magnetic storm level. It is constructed by averaging the horizontal component of the geomagnetic field from mid-latitude and equatorial magnetograms from all over the world. Negative Dst values indicate a magnetic storm is in progress, the more negative Dst is the more intense the magnetic storm. The negative deflections in the Dst index are caused by the storm time ring current which flows around the Earth from east to west in the equatorial plane.

AE index is an auroral electrojet index obtained from a number (usually greater than 10) of stations distributed in local time in the latitude region that is typical of the northern hemisphere auroral zone (Davis and Sugiura, 1966). For each of the stations the north-south magnetic perturbation H is recorded as a function of universal time. A superposition of these data from all the stations enables a lower bound or maximum negative excursion of the H component to be determined; this is called the AL index. Similarly, an upper bound or maximum positive excursion in H is determined; this is called the AU index. The difference between these two indices, AU-AL, is called the AE index. Notice that negative H perturbations occur when stations are under a westward-flowing current. AE provides a measure of the overall horizontal current strenth. Excursions in the AE index from a nominal daily baseline are called magnetospheric substorms and may have durations of tens of minutes to several hours.

The Geomagnetic observatory in Panagyurishte (PAG) is established in 1937 – first on the Balkan Peninsula and unique in Bulgaria and during more than 75 years performs the absolute measurements of the geomagnetic field elements and continuous registration of their variations. From 2008 PAG observatory was equipped with digital systems for the recording of geomagnetic field element's variations. Thus, the observatory implement the technical requirements and was joined to the INTERMAGNET (International Real-time Magnetic Observatory Network), which establishes a global network of cooperating digital magnetic observatories, and facilitate data exchanges and geomagnetic products in close to real time. Preliminary recorded time series and local geomagnetic k-indices are published on the NIGGG web page (http://data.geophys.bas.bg/magn_data1/dailymag_bg.php) and automatically reported to INTERMAGNET.

Recent activity

Regardless of the fact that solar cycle 24 is amongst the weakest recorded cycles a number of high magnitude events have been observed. In 2009, which is within the solar minimum area, there are no local K-index values exceeding 5. Days with the highest K- indices for the solar cycle 24 up until March 2015 and the respective Kp values are presented in Table 1. K- index of **5** is considered minor geomagnetic storm and K- index of **6** is a moderate geomagnetic storm.

Day	Local K-index	ΣK	Kp - index	ΣKp
29 Feb 2008	5 2 3 3 3 **6** 5 5	32	4 3 4 4 3 5 4 5	33
11 Oct 2008	2 1 4 3 5 **6** 5 3	29	1 2 4 3 5 **6** 5 3	30
05 Apr 2010	3 3 4 **7** **6** 5 4 4	36	3 3 5 **8** **6** 5 4 4	38
04 Aug 2010	5 4 3 **6** 4 3 5 5	35	**6** 4 3 5 5 4 **6** 5	38
04 Feb 2011	2 3 2 2 2 3 **6** **6**	26	2 3 2 2 2 2 5 **6**	24
14 Feb 2011	0 1 1 1 1 3 4 **6**	17	0 0 0 0 1 3 4 5	14
01 Mar 2011	3 3 3 3 4 **6** 5 4	31	3 2 3 4 4 5 5 4	30
29 Apr 2011	1 1 2 2 1 3 4 **6**	20	1 2 1 1 1 2 3 5	16
05 Aug 2011	4 3 1 2 2 4 **7** **6**	29	3 2 0 0 0 3 **7** **8**	23
09 Sept 2011	1 1 2 2 5 **6** **6** 5	28	0 1 1 1 5 **6** 5 **6**	24
17 Sept 2011	1 3 4 4 **6** 5 5 3	31	1 3 4 5 5 5 4 3	31
26 Sept 2011	2 1 1 1 4 **6** **6** 4	25	1 1 1 1 5 **6** **6** 5	27
24 Oct 2011	2 1 2 1 1 1 5 **6**	19	2 0 2 1 0 1 5 **7**	18
25 Oct 2011	**7** 5 3 3 3 2 2 1	26	**7** **6** 5 3 3 2 1 1	28
27 Feb 2012	3 2 1 3 4 5 **6** 2	26	4 2 1 2 3 4 5 2	24
09 Mar 2012	4 5 **6** 5 5 5 3 3	36	5 **6** **8** **7** **7** **6** 3 2	44
15 Mar 2012	3 2 1 2 5 **6** 5 4	28	4 3 2 2 5 **6** 5 5	32
16 Jun 2012	2 2 1 3 3 3 4 **6**	24	0 1 0 2 3 3 4 **6**	19
15 Jul 2012	4 5 5 5 3 5 **6** 5	38	4 5 **7** **6** 5 **6** **7** **6**	47
13 Oct 2012	3 4 4 4 4 **6** 4 4	33	3 5 **6** 5 **6** **6** 4 4	39
17 Mar 2013	2 2 5 5 4 5 **6** **6**	35	2 2 **7** **6** **6** **6** **7** **6**	42
12 Sep 2014	5 3 2 2 2 4 5 **6**	29	5 4 2 3 2 5 5 **6**	32
29 Dec 2014	1 2 2 3 4 **6** 4 5	27	2 3 2 3 4 5 3 5	27
07 Jan 2015	2 3 **6** 5 3 2 2 4	27	2 2 **6** **6** 4 2 2 3	28
17 Mar 2015	2 5 5 **6** **7** **7** 5 **7**	44		
18 Mar 2015	5 4 3 4 **6** 5 5 4	36		

Table 1. Days with highest K-index values for solar cycle 24 and the respective Kp-index values for the same days (Kp indexes are provided by WDC for Geomagnetism KYOTO).

Looking at the daily mean values plots of the geomagnetic field horizontal component H[nT] and declination D[min], there are two major types of fluctuations occurring in both H and D graphics. The first type, marked with red star, represent daily mean values of days with local K-index ≥ 6. For example on Fig.2. there are two events of this type corresponding to 29.02 and 11.10.2008 shown in Table 1. The second type, marked with blue diamond, represent daily mean values of days with high overall local K-index values but without having a single 3-hour interval exceeding the "storm" threshold.

Figures from 2 to 9 show plots of daily mean values of the horizontal component of the geomagnetic field H[nT] and the declination D[min] for the years of Solar cycle 24 from 2008 to 2014 and part of 2015.

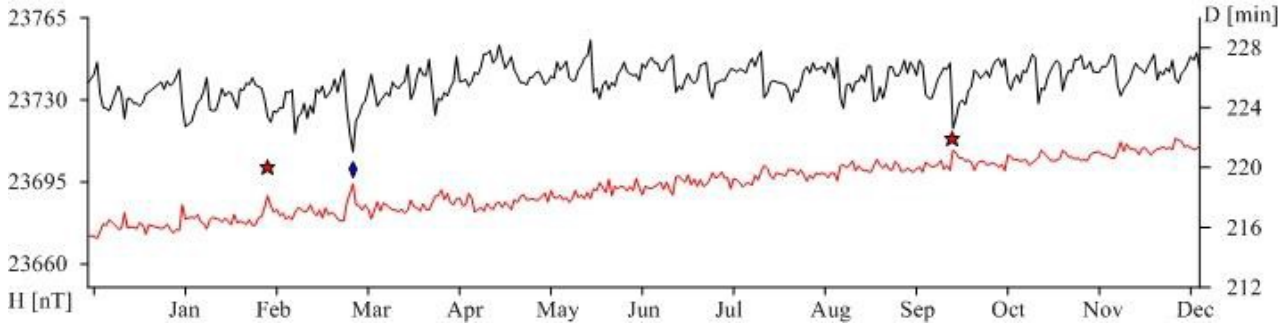

Fig.2. Daily means values of H and D for 2008.

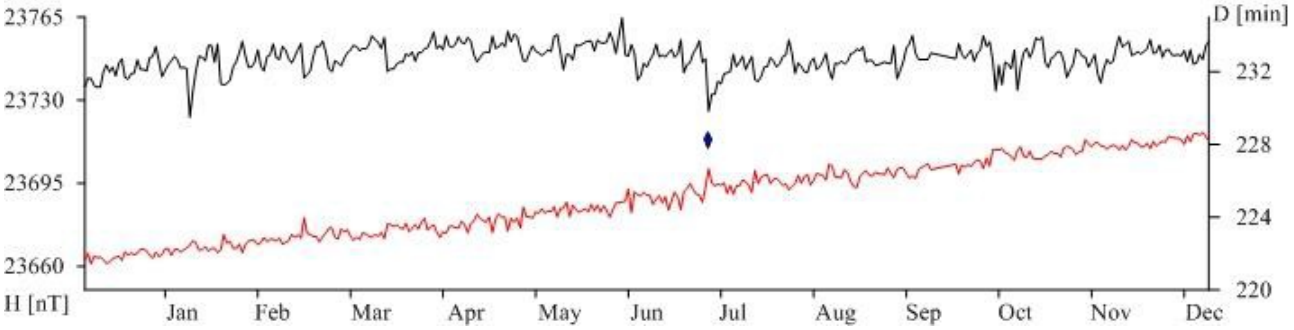

Fig.3. Daily means values of H and D for 2009.

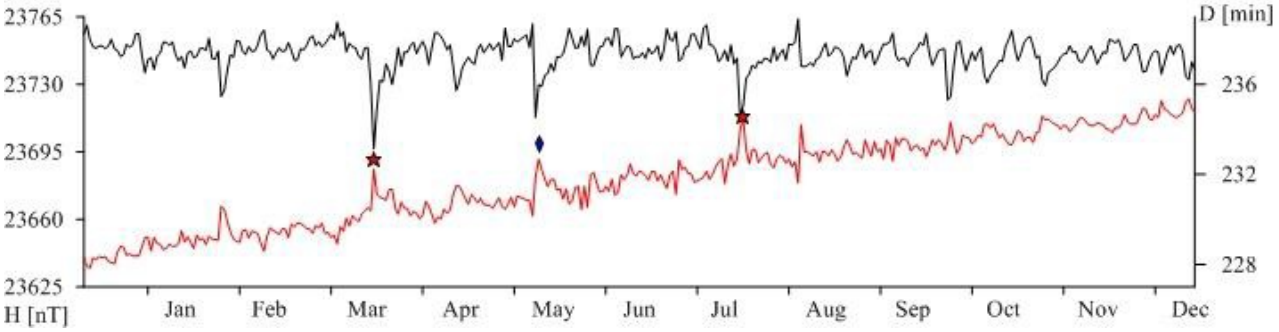

Fig.4. Daily means values of H and D for 2010.

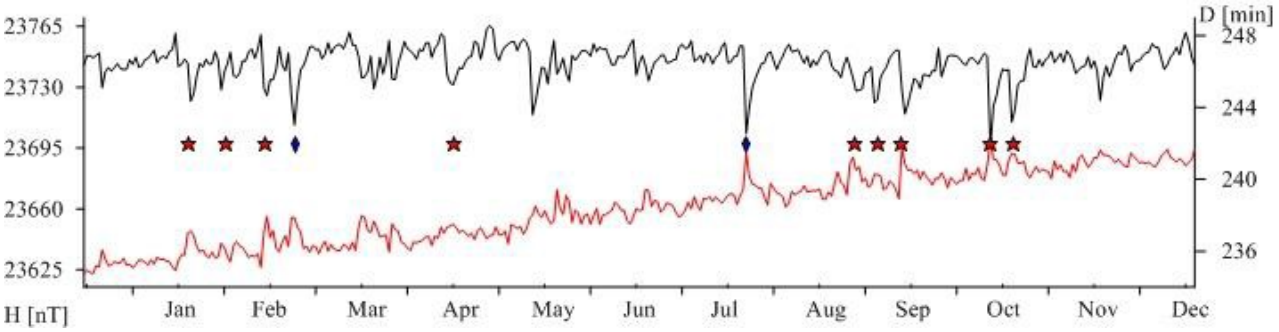

Fig.5. Daily means values of H and D for 2011.

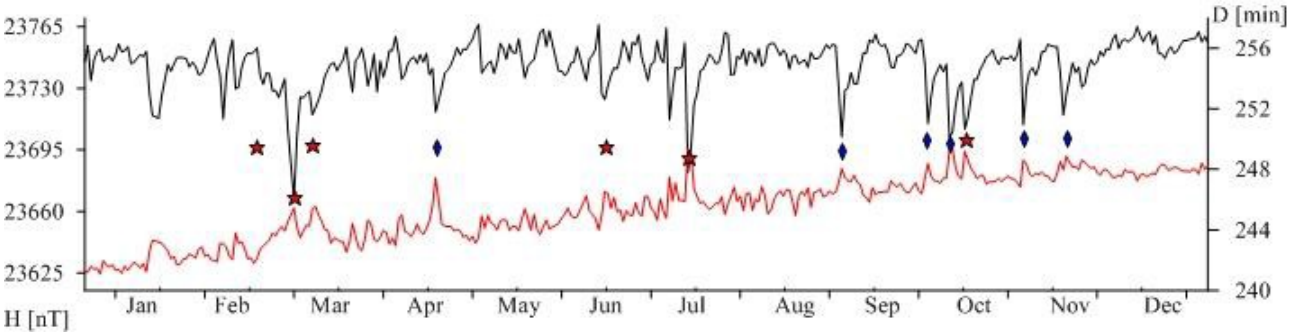

Fig.6. Daily means values of H and D for 2012.

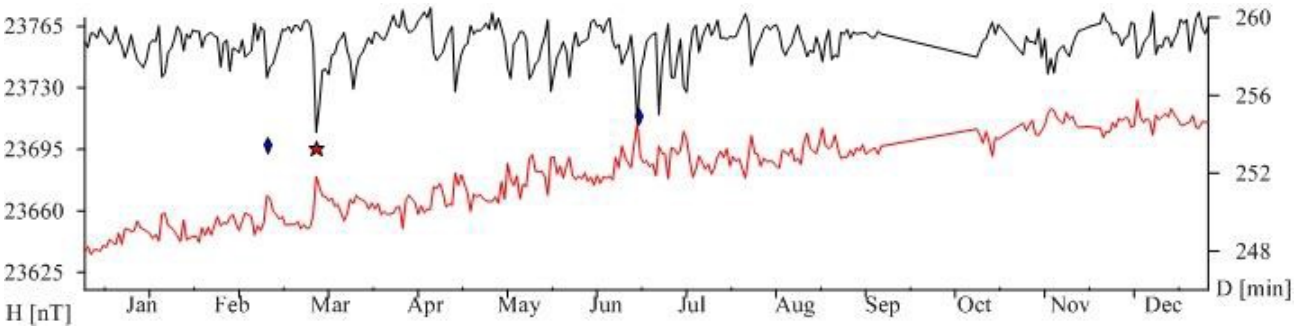

Fig.7. Daily means values of H and D for 2013.

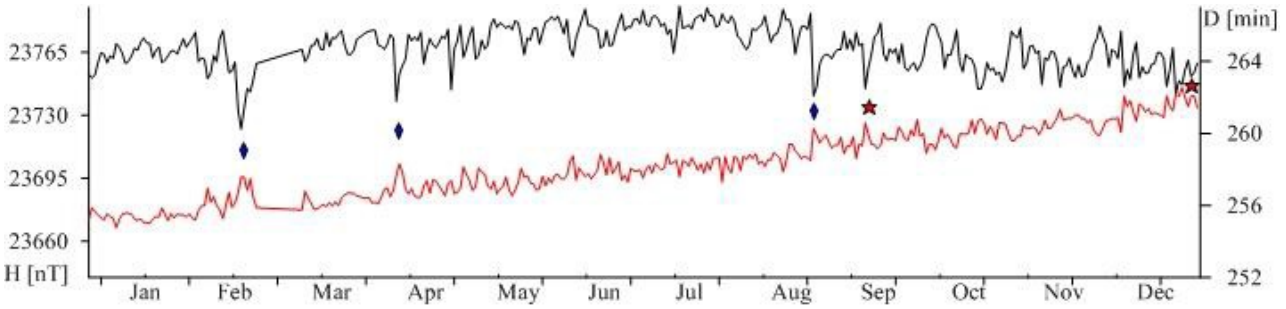

Fig.8. Daily means values of H and D for 2014.

The most severe event for solar cycle 24 so far occurred on 17th and 18th of March 2015. This magnetic storm was triggered by the combined effect of several CMEs from 15th of March.

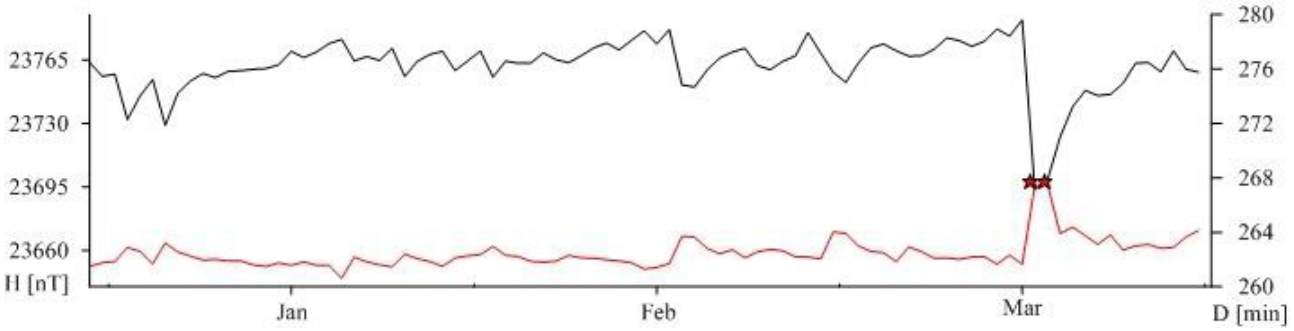

Fig.9. Daily means values of H and D for 2015 (until 30th of March)

Conclusion

From the beginning of Solar cycle 24 (4 Jan 2008) there are more than 25 days with K-indices reaching or exceeding 6. Regardless of the fact that the current Solar cycle have low sunspot numbers there have been several days with local K-index of 7 and planetary index Kp with magnitude 8. Geomagnetic storms of such magnitude could affect high-latitude power systems which may experience voltage alarms, long-duration storms may cause transformer damage. In the field of spacecraft operations corrective actions to orientation may be required by ground control as well as there might be changes in drag affect orbit predictions. Also HF radio propagation can fade at higher latitudes. (NOAA Space Weather Center)

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Настоящата публикация дава информация относно наблюдаваните тенденции във вариациите на елементите на геомагнитното поле , изчислените локални геомагнитни индекси по данни от геомагнитна обсерватория

„Панагюрище“ за настоящия Слънчев цикъл – 24. Слънчевият цикъл представлява периодична промяна в активността на слънцето и има средна продължителност от 11 години. Слънчев цикъл 24 започва на 4ти Март 2008г. като слънчевата активност към момента е значително по-малка от тази на предходните цикли. Въпреки това от 2008г. насам има реализирани над 25 магнитни бури с локален К-индекс достигащ 6 или 7, а планетарния Кр индекс нееднократно достига магнитуд 8. Магнитни бури с подобен характер могат да имат негативен ефект върху електро-преносната мрежа, управлението на спътниците и др.