Characterization of last four and half solar cycles on the basis of intense geomagnetic storms

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Abstract- In the present study, we have restricted ourselves to three categories only i.e., intense, severe and great i.e. Dst < -100nT. We have examined the characteristic properties of storms observed during the years 50 years (1964 - 2013) falling into the solar cycles 20 to 24. During the process, we analyzed 579 cases of storms observed during solar cycle 20, 924 cases in solar cycle 21, 1163 cases in solar cycle 22, 1038 cases in solar cycle 23 and only 55 cases of geomagnetic storms observed during the years 2008 – 2013 of solar cycle 24. We have also examined the variation in sunspot numbers during the same period 1964 - 2013 and have correlated their association with storms and other phenomena. The sunspot numbers (yearly mean total sunspot number) observed for solar cycle 20 were 105.8 while for cycles 21, 22 and 23 observed numbers were 155.4, 157.6 and 119.6 respectively. During the half period of solar cycle 24 (2008-2013) the yearly mean sunspot numbers were observed 64.9. Based on above facts, we found that solar cycle 22 was comparatively more active and solar cycle 24 is comparatively less active than other cycles. We have also noticed and analyzed seven cases of great storms that occurred in last fifty years.

Key words: Solar cycle; solar activity; sunspot numbers; geomagnetic storms.

1. INTRODUCTION

Space weather and its impact on technological infrastructures as well as on mankind is most talked topic of research in recent years [15, 17]. One of the most known reasons of space weather is impact of geomagnetic storms. Violent eruptions of plasma and magnetic fields from the Sun are the origin of geomagnetic storms. Geomagnetic storms create disturbances that affects the Earth`s magnetic field and can disrupt the operation of critical infrastructures relying on space-based assets including satellites' signal strength and global positioning system (GPS) as well as have terrestrial effects including electricity distribution networks and water pipelines [15]. In fact a geomagnetic storm has three phases namely an initial phase, a main phase and a recovery phase. The initial phase which is also referred as storm sudden commencement (SSC) is characterized by Dst increasing by 20 to 50 nT in few minutes. The main phase is defined by Dst decreasing to less than -50 nT. The minimum Dst value during a storm can reach as low as -500 nT while the duration may vary between 2 and 8 hours. Recovery phase is the period when Dst changes from its minimum value to its quiet time value and its period may vary from few hours to few days [5]. Storms based on minimum Dst index values can be classified into various categories such as: weak (Dst < -30 to -50 nT), moderate (Dst < -50 to -100 nT), intense (Dst < -100 to -200 nT), severe (Dst < -200 to -350 nT) and great (Dst < -350nT).

Geomagnetic storms are very much connected with the solar activities and sunspot numbers and vary with the well-known 11-year cycle [5,6,18]. Large active sunspots are responsible for severe geomagnetic storms. The intense magnetic field of sunspots leads to sudden release of magnetic energy manifested by flares and coronal mass ejections that ultimately produces geomagnetic storms [14, 18]. Sunspot number provides the most useful data for the prediction of solar cycle and geomagnetic activity [4] In recent past, solar cycle 23 and solar cycle 24 have been the subject of numerous studies that have emphasized various unusual properties [3, 1,12, 11,14, 9, 18].

In the present paper, we have examined the trend of geomagnetic storm occurrence observed during last fifty years (1964 - 2013) i.e., for solar cycle 20, solar cycle 21, solar cycle 22, solar cycle 23 and till mid of solar cycle 24. We have noticed 3,759 total cases of geomagnetic storms of intense and above (Dst < -100 to -600 nT) categories. We have also studied the variation in sunspot numbers occurred during last fifty years (1964 - 2013) and have found that sunspot numbers varied from 157.6 to 64.9 in last fifty years.

2. PHYSICAL PARAMETERS AND SELECTION CRITERIA

2.1 Solar Activity

The Sun’s magnetic field structures its atmosphere and the out layers all the way through the corona and into the solar wind. Its spatial/temporal variations lead to a host phenomenon collectively known as solar activity. Solar activities and related events have been regularly recorded since the 8th century. This activity includes the solar wind acceleration, flux emergence, light and energy particles released from the Sun such as solar flares, coronal mass ejection or solar energetic particle [13]. The coronal heating as well as sunspots are also the most commonly noticed forms of solar activity. One of the major components of space weather phenomenon is Solar wind, a stream of plasma is also responsible for aurora and storms and ultimately for space weather problems [15].

2.2 Sunspot Numbers

It is well known fact now that sunspots are cooler and darker region on the Sun`s photosphere comparing to their surrounding regions. These are the places where the Sun`s magnetic field rises vertically out of the Sun. High incidences of sunspot activity are the effects of increased disturbances in the Sun`s magnetic field. Sunspots can serve as channels for magnetically charged particles that are thrown out of the Sun`s atmosphere. These charged particles when swept up by the Earth`s magnetic field are drawn down into the atmosphere of the Earth and produce various temporary disturbances. The number of sunspots that are visible on the surface of the Sun may increase and/or decrease in a regular pattern known as solar cycle. In the present study, the data for sunspot number has been taken from solar influence data center in Belgium (http://sidc.oma.be/silso/datafiles). Fig.1 shows the variation of sunspot numbers and cycle wise variation in geomagnetic storms observed during the years 1964 to 2013. Figure itself reveals that the sun spot number (SSN) index provides a very useful indicator for the occurrence of geomagnetic storms.

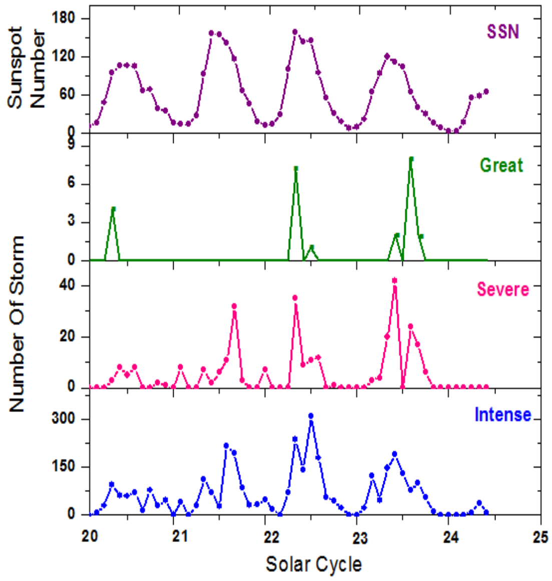

Fig.1: Variations ingeomagnetic storms of various categories (intense, severe and great)and sunspot numbers observed during solar cycle 20 - 24

2.3 Geomagnetic Storms

Geomagnetic storms are temporary and large disturbances in the terrestrial magnetosphere persisting for several hours to a few days. These are caused by disturbance originated at solar atmosphere in the form of solar flares and coronal mass ejections (CMEs), interplanetary shock interfaces associated with high speed solar wind streams [5,10 18] .Geomagnetic storm is characterized in terms of storm-time Disturbance Index (Dst index) which is estimated over the globally averaged change in the horizontal component of the Earth’s magnetic field at the magnetic equator based on measurement from a few magnetometer stations. In the present study we have considered only intense, severe and great categories of storms (Dst < -100nT). The estimated frequencies for geomagnetic storms of different magnitude observed during last 50 years are 68.7, 5.7 and 0.5 per year respectively. Fig. 1 shows the variation of occurrence numbers in geomagnetic storms of various categories (strong, severe and great) observed during the years 1964 - 2013 (last 4.5 solar cycles). From the figure, we can also examine that maximum number of geomagnetic storms (1163) are recorded during solar cycle 22 and only 22 cases of storms are recorded during solar cycle 24 (2008 - 2013) which indicates that solar cycle 22 was geomagnetically more active while solar cycle 24 is less active in last fifty years.

2.4 Solar cycles 20 – 24: some facts

Solar cycle is the periodic change in the Sun's activity and has an average duration of about 11 years. Since the year 1755 when extensive recording of sunspot activity began, the solar cycle 20 was started in October 1964 and lasted for 11 years and 7 months and was completed in May, 1976. This cycle peaked in November 1968. Yearly mean total number of sunspots observed during this cycle were 105.8 and total 579 cases of intense geomagnetic storms (Dst < - 100 nT) occurred during this period. During the analysis process of solar cycle 20, we found that there were a total of 272 days with no sunspots occurrence. This cycle was marked by a series of geomagnetic disturbances and cosmic ray variations caused by the MacMath plage region 8818 during the latter half of May 1967 [2]. Solar cycle 20 data was used to build the K-1974 solar proton fluence model used for planning space missions during solar cycle 21. Fig. 2 depicts the variation in sunspot numbers and number of geomagnetic storms of various categories observed during the solar cycle 20.

Solar cycle 21 was started in May 1976. It lasted for 10 years and 3 months and ended in August of 1986. During this cycle there were a total of 273 days with no sunspots and yearly mean total number of sunspots observed were 155.4 and the number of storms occurred were 924. December 1979 was peak period of the Cycle 21. Fig. 3 shows the variation in sunspot numbers and number of storms of various categories observed during this cycle.

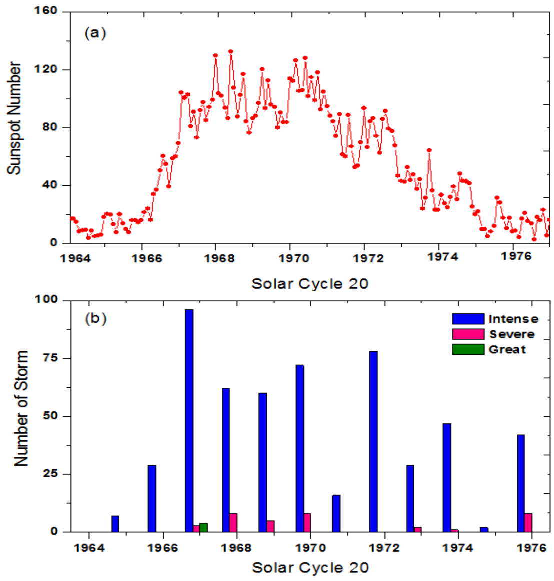

Fig. 2: Variations in (a) sunspot numbers and (b) number of storms of different categories observed during solar cycle 20

Solar cycle 22 was started in September 1986 and ended in April 1996 and lasted for 9 years and 8 months. There were a total of 309 days with no sunspots during this cycle. Yearly mean of total sunspot numbers observed during this cycle were 157.6 while the number of geomagnetic storms observed were 1163 which were maximum during last fifty years.

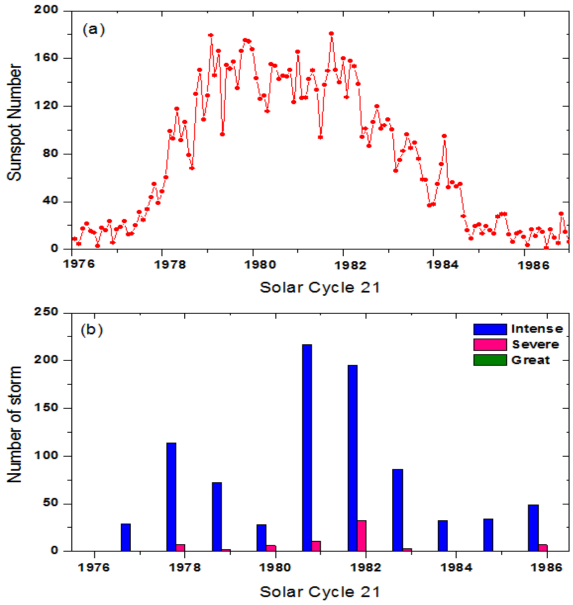

Fig. 3: Variations in (a) sunspot numbers and (b) number of storms of different categories observed during solar cycle 21

Cycle 22 is remembered for the notorious geomagnetic storm of March 1989 which caused the collapse of Hydro-Quebec`s electricity transmission system. The variation in sunspot numbers and number of storms of various categories observed during this cycle is shown in Fig. 4.

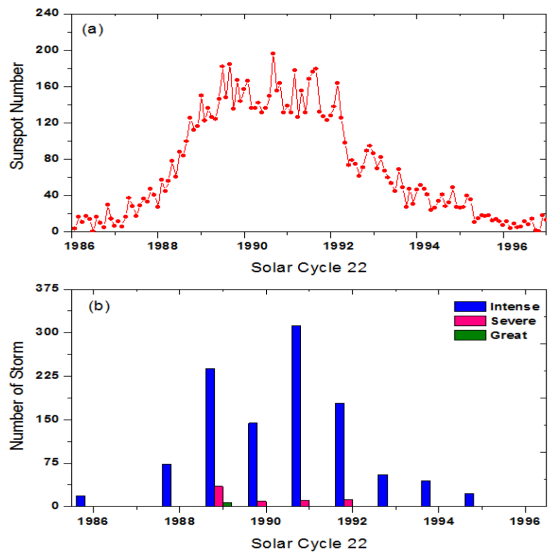

Fig. 4: Variations in (a) sunspot numbers and (b) number of storms of different categories observed during solar cycle 22

Solar cycle 23 which started in May of 1996 and ended in December 2007 lasted for 11 years and 5 months. During this period there were a total of 805 days with no sunspots while yearly mean total of 119.6 cases of sunspot numbers were observed. Number of geomagnetic storms (Dst < -100 nT) observed during this cycle were found to 1038. The infamous Halloween storms of the year 2003 marks this solar cycle. Based on sunspot number cycle 23 peaked in April 2000 but the period from October 19 to November 5, 2003 provided various unexpected results related to solar activity. Seventeen major flares erupted on the Sun between this periods including one of the most intense flare ever measured on the GOES XRS sensor – a huge X28 flare. There were also several geomagnetic storms with two of them reaching the extreme level (Dst < -422 nT). Fig. 5 shows the variation in sunspot numbers and number of storms of various categories observed during the cycle.

Solar cycle 24 started in January 2008 and is continued. The yearly mean of sunspot number for the period 2008 - 2013 were observed to 64.9 while the number of geomagnetic storms observed during the same period were 55. After many ifs and buts this solar cycle proved to be a quietest at activity level. According to one prediction, solar cycle 24 will be smallest in length (9.8 years) and nearly 23% shorter in comparison of cycle 23 [11]. Fig. 6 shows the variation in sunspot numbers and number of storms of various categories observed during this cycle. Solar cycle 24 has been a subject of various hypotheses pertaining to its potential effects on the Earth. The yearly mean variation of total sunspot number and number of geomagnetic storms of various categories for the period 1964 to 2013 is already shown in Fig. 1. We can see that solar cycle 22 is comparatively more active than other cycles, in which we have found 1183 cases of geomagnetic storms and 157.6 sunspots number (yearly mean total sunspot number) have been observed and solar cycle 24 less active than other cycles, in which we have found only 55 cases of intense storms observed during the years 2008 to 2013.

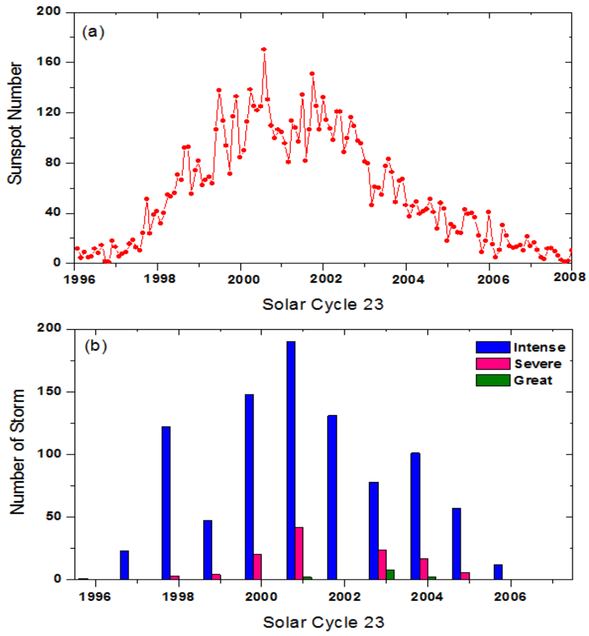

Fig. 5: Variations in (a) sunspot numbers and (b) number of storms of different categories observed during solar cycle 23

3. GREAT STORMS - A CASE STUDY

As we know that geomagnetic storm is a temporary disturbance on the Earth`s magnetosphere caused by the interaction of solar wind and cloud of magnetic field which interacts with the Earth`s magnetic field. During a geomagnetic storm (at the time of main phase) electric current in the magnetosphere creates a magnetic force which pushes out its boundary. In this section, we have selected seven cases of great storms (Dst < -350 nT) observed during the last fifty years (1964 - 2013) as a case study. Fig. 7 has depicted seven greatest storm cases observed during last fifty years.

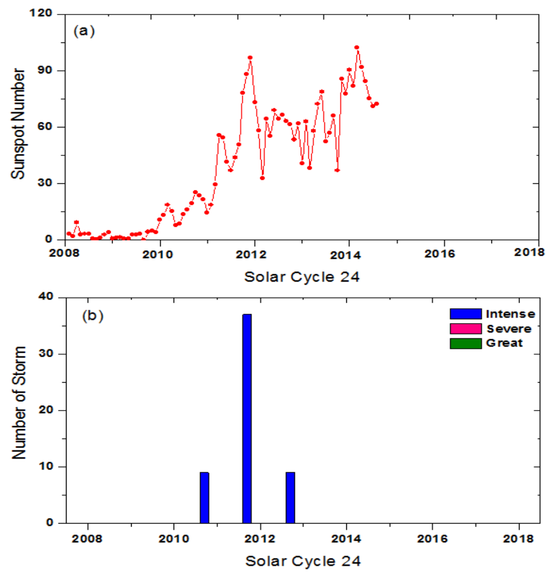

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Fig. 6: Variations in (a) sunspot numbers and (b) number of storms of different categories observed during solar cycle 24 (2008-2013)

First case of great storm under consideration was occurred on May 26, 1967 and its main phase lasted for about four hours with Dst reaching as low as -387 nT at 0500 hrs while the Dst on that day was recorded at the level of -127 nT. Three hourly (3-h) K_P index during the storm period was recorded as 9. Second case of the great storm occurred during March 13/14, 1989 (also known for the Quebec Blackout Storm) and main phase lasted for around eight hours and minimum value of Dst reaches to -589 nT at 0200 hrs on March 14 while maximum Dst value was recorded as -114 nT and the K_P index was recorded as maximum (9) during the storm period. Third case was observed on November 9, 1991 and minimum Dst reaches to -354 nT at 0200 hrs while the maximum Dst value observed on that date was -132 nT and again the 3-h K_P index was recorded its maximum (9). Another (fourth) case of great storm was recorded on March 31, 2001 and Dst reaches to -387 nT at 0900 hrs and maximum value of Dst recorded was +26 nT and the three hourly K_P index was recorded as 9. Fifth case of considered great storm was recorded during Halloween Storm period (Oct. 20, 2003). On that day Dst reaches as low as -383 nT at 2300 hrs and the maximum Dst value was recorded as -97 nT and the three hourly K_P index was observed its maximum value. Next (sixth) case was observed on November 20, 2003 and on that day Dst reaches to -422 nT at 2100 hrs and the observed K_P index were 9. The last (seventh) case of great storm series was recorded on November 8, 2004 and minimum Dst was recorded to -374 nT at 0700 hrs and maximum Dst during the day was observed as -118 nT. The 3-hourly observed value of K_P index was its maximum. The variation of Dst index and the K_P index of the most severe categories of storms are shown in Fig. 7. Interesting point in all seven great storms are the maximum values of Dst index which are even lower to intense storm cases. K_P index for all cases were recorded to its maximum that means it gives just feeling of the intensity of storm related problems.

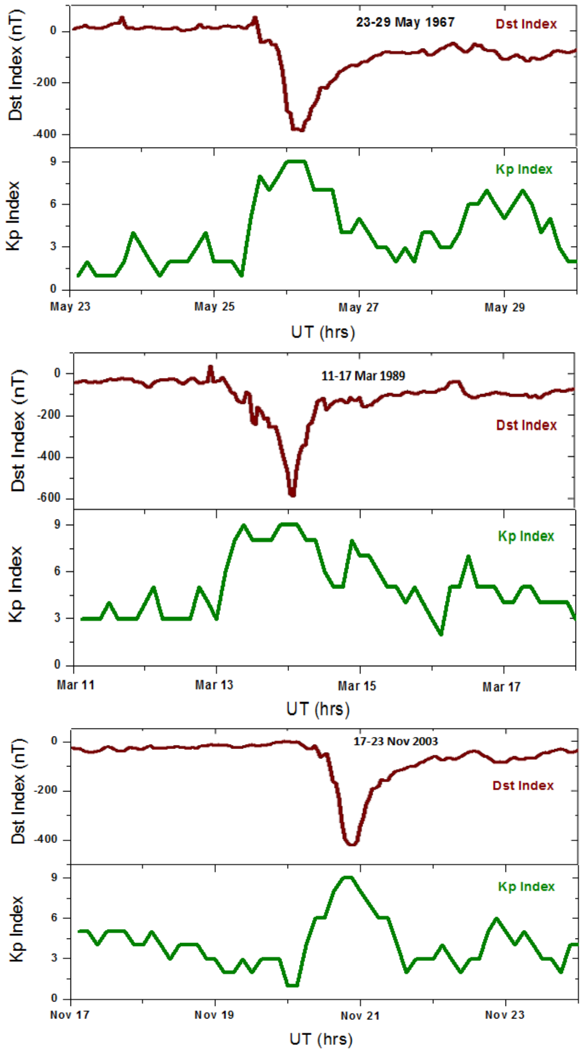

Fig. 7: Typical graphical representation of 3 super storms (based on Dst index) observed during the last 50 years .

4. RESULTS AND DISCUSSION

In the present study we have considered last four and half solar cycles as our input source. Cycle 20 lasted during the years 1964 - 1976. For solar minima to maxima, the sunspot numbers varied during this cycle from 4.4 to 132.3. Variations of monthly sunspot number and the number of geomagnetic storms of various categories observed during solar cycle 20 are shown in Fig. 2(a, b). The figure 2 (a) revealed that the maximum peak of this cycle was found in May 1968 which means 3 years and 8 months after starting the solar cycle. This cycle experienced 540 cases of intense, 35 severe and 4 cases of great storms.

The variations of sunspot numbers observed during solar cycle 21 which lasted during the years 1976-1986 are shown in Fig. 3 (a). For solar minima to maxima, the sunspot numbers varied from 0.9 to 180.7. From the figure we can see that peak of this cycle has originated in September 1981 after 5 years and 3 months after its beginning. Total 281 storm cases were recorded during the year 1981. Fig.3 (b) revealed that the number of geomagnetic storms of various categories observed during the cycle were 856 and 68 cases of intense and severe category respectively. Not a single case of great storm was observed in this cycle. Overall cycle 21 was more active in comparison of cycle 20.

The monthly variation in sunspots number and geomagnetic storms numbers observed during solar cycle 22 are shown in Fig. 4. The solar minima to maxima of the sunspot numbers in this cycle varied from 4.4 to 195.9. Fig. 4 (a) has revealed that the peak of this cycle occurred in August 1990 after four years of its start. Year 1991 of this cycle experienced the occurrence of 324 cases of storms. Very precisely 1087 cases of intense storms, 68 cases of severe storms and 8 cases of super storm cases were observed during this cycle (Fig. 4 (b)). Fig. 5 showed the variations in (a) sunspot numbers and (b) number of storms of different categories observed during solar cycle 23. Cycle 23 lasted for years 1996 - 2007. In this cycle the solar minima to maxima of the sunspot numbers varied from 0.9 to 170.1.The figure has revealed that peak of this cycle occurred in July 2000 that means 4 years and 3 months after starting the cycle. Fig. 5 (b) showed that total number of storms occurred in this cycle were found to be 1038. Out of them 910 cases of storms were of intense category, 116 cases of severe category and 12 cases of great storm categories were occurred during the cycle. This cycle was marked for Halloween space weather storms of 2003. Fig. 6 (a) showed the monthly variation of sunspot number for the period January 2008 to August 2014 of solar cycle 24. The maximum sunspots have been observed about 102.3 during this period of cycle 24. Fig. 6(b) showed the number of geomagnetic storms observed during this period. Only 55 cases of geomagnetic storms of intense category were observed during the period of years 2008 to 2013.Not a single case of storm of severe or great categories were observed in this cycle. During the last 50 years cycle 22 was more pronounced in terms of solar activity while the ongoing cycle 24 is quietest in comparison. Seven great storms were observed during last fifty years and the Quebec Blackout Storm and the Halloween Storm created history regarding their academic and social aspects.

5. CONCLUSIONS

Solar cycle contains maximum peak where sunspot number is maximum. In this paper, we have inferred that the maximum phase of a solar cycle lie between 3 to 7 year. In solar cycle 20, peak has been obtained 3 years and 8 months after the start of the cycle. In solar cycle 21, peak has been obtained 5 years and 3 months after the starting of cycle. In solar cycle 22, peak has been obtained 4 years after the starting of cycle. In solar cycle 23, peak has been obtained 3 years and 8 months after the starting of solar cycle. The maximum phase of solar cycle 24 has been observed during 2010 to 2013 i.e. the peaks of solar cycle 24 have been obtained. In solar cycle 24, there are no severe and great storms. In the rest of solar cycle 24, we did get monthly averaged sunspots more than 102.3. In the rest period of solar cycle 24, there was no possibility to get any severe and great storm. It is very strange situation observed last 50 years. It is clear from the Figs. 2, 3, 4, 5 and 6, the occurrence of geomagnetic storms are strongly correlated with solar cycles and proportional to the sunspot numbers. We also can conclude that solar cycle 22 was the most active and the solar cycle 24 is the least active cycle in last fifty years.

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