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Statistical Analysis of Geomagnetic Activity and Solar Activity Features during Solar Cycle 23 & 24

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Abstract

We present a statistical analysis of the geomagnetic storm (GMSs) with the solar activity features (Sunspot number (SN), H-α flare and coronal mass ejection (CME)) during solar cycle 23 and 24. Sunspot number (SN) shows good correlation with peak values of GMSs indices (correlations coefficient R= 0.76) while CME(R=0.59) and H-α (R=0.55) show moderate correlation. So we conclude that GMSs have good correlation with solar activity features during major geomagnetic storms of solar cycle 23 and 24. These parameters may act as reliable indicators for predicting GMSs and their strength. We have also correlated peak values of various geomagnetic indices among themselves with the highest correlations between Dst-ap (R=0.80) and A.E-ap (R=0.71). We have analyzed the GMSs data during different phases of the solar cycle 23 and 24 and concluded that CMEs are more important drivers of GMSs during the maximum phase of solar cycle while CIR are more significant drivers of GMSs during the decay phase.

Keywords: *GMSs, Solar Cycle, GI indices*

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INTRODUCTION

The condition of immediate space surrounding Earth (Thermosphere, Ionosphere, Magnetosphere and the interplanetary space between Earth and Sun) is modulated by magnetic activity of the Sun. The Sun activity features such as sunspot numbers (SN), solar active prominences (SAP), solar flare (SF) and coronal mass ejection (CME) etc. are responsible for space weather events. A space weather event is typically associated with the Sun ejecting huge amount of magnetized plasma and energetic particle into space. Solar energetic particles affect the space environment in multiple ways. In the outer magnetosphere (especially, near the geostationary region), their presence is a hazard for the satellite and instrumentation [1]. If they became trapped in the inner magnetosphere dipolar field, they populate the van Allen belts, residing in the magnetosphere for extending periods [2]. Seppala et al. [3] stated that solar activity affects the long term balance of the atmospheric chemistry. Thus, solar irradiation, energetic particle fluxes from the Sun and the solar wind with its multiple structures all drive geomagnetic activity. A geomagnetic storm is a temporary disturbance of earth magneto-sphere caused by a Solar wind shock wave and clouds of magnetic field that interacts with magnetic field of Earth. The increase in solar wind pressure initially increases the compression in magneto-sphere and solar wind magnetic field interact with the earth magnetic field and transfers the energy into magneto-sphere and appears an increase in momentum of plasma which is driven by electric field inside the magnetosphere. This dynamics of geomagnetic storms (GMSs) can be explained by magnetic reconnection, which occurs between earth's magnetic field and southward components of interplanetary magnetic field (IMF). After reconnection a neutral point is formed through which charged particles enter the magnetosphere. High energy particles deflected in a circular orbit, form a ring current which causes geomagnetic reduction [4].

Geomagnetic field is an important element of solar terrestrial research. The interaction between solar wind and interplanetary magnetic field produces a disturbance in magnetosphere ionosphere current system called geomagnetic disturbance. For a short time scale of space weather the geomagnetic field can be considered constant while for long time scale when space weather climate is taken into account a change in geomagnetic field appears. Some indices are used to describe the variation in geomagnetic field called geomagnetic indices. Dst, kp, ap, A.E are most commonly used geomagnetic activity indices [5]. The Dst index estimates the globally averaged change of horizontal components of Earth magnetic field at the equator based on measurements from few magnetometer stations. Kp index measures the magnetic radiation of solar particles. Its value varies from quasi-logarithmic integers 0 to 9 for each 3 h interval of universal time day (UT). Its value is observed from 44° and 60° northern and southern geomagnetic latitudes. Kp index was first introduced by Bartels J. [6]. Quasi-logarithmic scale Kp index is converted into linear scale index called ap. An enhanced ionosphere current following below and within the auroral oval by which the magnetic activities varies in auroral zone is measured by an Auroral Electrojet (A.E) [7].

The geoeffectiveness of geomagnetic field is measured by Dst index. GMSs are classified on the bases of Dst index as Intense storms (Dst≤ -100nT), moderate storms (-100nT <Dst<-50nT) and weak storms (Dst> -50nT) [8]. If Dst index gradually increases to positive value by a sudden change called sudden commencement value, this would be the initial phase of geomagnetic storms. After sudden commencement Dst index start decreasing to a negative value and reaches its minimum. This phase is called main phase. Finally, the Dst index starts to regain pre-sudden commencement value and this phase is called recovery phase. During main phase of GMSs, magnetosphere current increases and establishes a magnetic force which creates a magnetopause boundary between solar wind and magnetosphere. The solar wind and CMEs originate from the Sun, connect to Earth's magnetosphere and give rise to several changes in interplanetary and terrestrial environment [9,10].

There have been some studies which address the solar and interplanetary sources of geomagnetic storms. One type of GMSs is associated with interplanetary (IP) coronal mass ejection (ICME). It is the counterpart of CMEs at Sun. ICMEs also called magnetic cloud (MC). The second type of GMSs is associated with a fast solar wind originating from solar coronal hole which interacts with preceding slower ambient solar wind. This particular event is associated with co-rotating interaction regions (CIRs) [11]. Echer et al. [12] focused on interplanetary conditions causing intense geomagnetic storms (Dst≤ -100nT) during solar cycle 23 (1996–2006). Zhang et al. [11] found the solar and interplanetary source of major geomagnetic storms during 1996–2005. Zhang et al. and Echer et al. [11, 12] decided the 88 major geomagnetic storms events during the period of 1996 to 2005 and explained that how to decide the solar and interplanetary sources of GMSs. On the basis of this study, Joshi et al. [13] represented a statistical study of interplanetary field parameter with intense geomagnetic storm (Dst ≤ -100 nT) during the period of 1996–2006 (cycle 23). In order to understand the connection between various solar activity features and occurrence of GMSs, we present a correlative study during intense geomagnetic indices (GI) by using a large data set of solar cycle 23 and 24(during 1996 to 2016).

DATA ANALYSIS AND STATISTICAL STUDY

In the present work we have attempted a detailed study of intense geomagnetic storms (Dst index ≤ -100nT) and analysed the dependence of intense geomagnetic storms on solar activity features (SN,H-alfa, CME) for a period 20 years during 1996 to 2016 (solar cycle 23 and 24). During this period 109 intense geomagnetic storms appeared. Out of them 92 occurred in cycle 23 and 16 occurred in cycle 24. Solar cycle 24 contains lesser number of GMSs since there is a significant drop in density, magnetic field, total pressure and Alfven wave speed in the inner Heliosphere [14]. The total numbers of events during this period were classified in two groups- 95 CME driven events and 14 CIR driven events. The data sets were obtained from following websites: Solar data is taken from: http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-indices/sunspot-numbers/

http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/h-alpha/

CME data is taken from SOHO-LASCO CME catalog

http://cdaw.gsfc.nasa.gov/CME_list/

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Geomagnetic indices (GIs) data are taken from OMNI website at http://swdc.kugi.kyoto.u.ac.jp/dstdir

We represent bar graph depicting yearly variations of various solar activity features and total intense geomagnetic storms during 1996–2016 in Figure 1. The intense geomagnetic events are studied in three phases of the solar cycles 23 and 24: Rising phase (1996–1999 for solar cycle 23 and 2008–2011 for solar cycle 24), Maximum Phase (2000–2002 for solar cycle 23 and 2012–2014 for solar cycle 24) and Decay phase (2003–2008 for solar cycle 23 and 2015–2016 for solar cycle 24). We represent pie charts of total events GMSs, CME driven GMSs and CIR driven GMSs during rising, maximum and decay phase in Figure 2.

In order to understand the connection between various solar activity features and occurrence of GMSs we present a correlative study represented by Figure 3 between various solar activities (Sunspot number (SN), H-α flare (H-alfa) and Coronal mass ejection (CME)) and total intense GMSs during 1996–2016.We have considered geomagnetic indices Kp, ap, A.E and Dst corresponding to intense geomagnetic storms of Dst index ≤ -100nT during 1996–2016 (cycle 23-24). We present a statistical study between geomagnetic indices with one another during 1996–2016 in Figure 4. For all the 109 events the peak values of Geomagnetic indices (GIs), and solar activity features are taken from different websites mentioned above and We have used a linear regression analysis

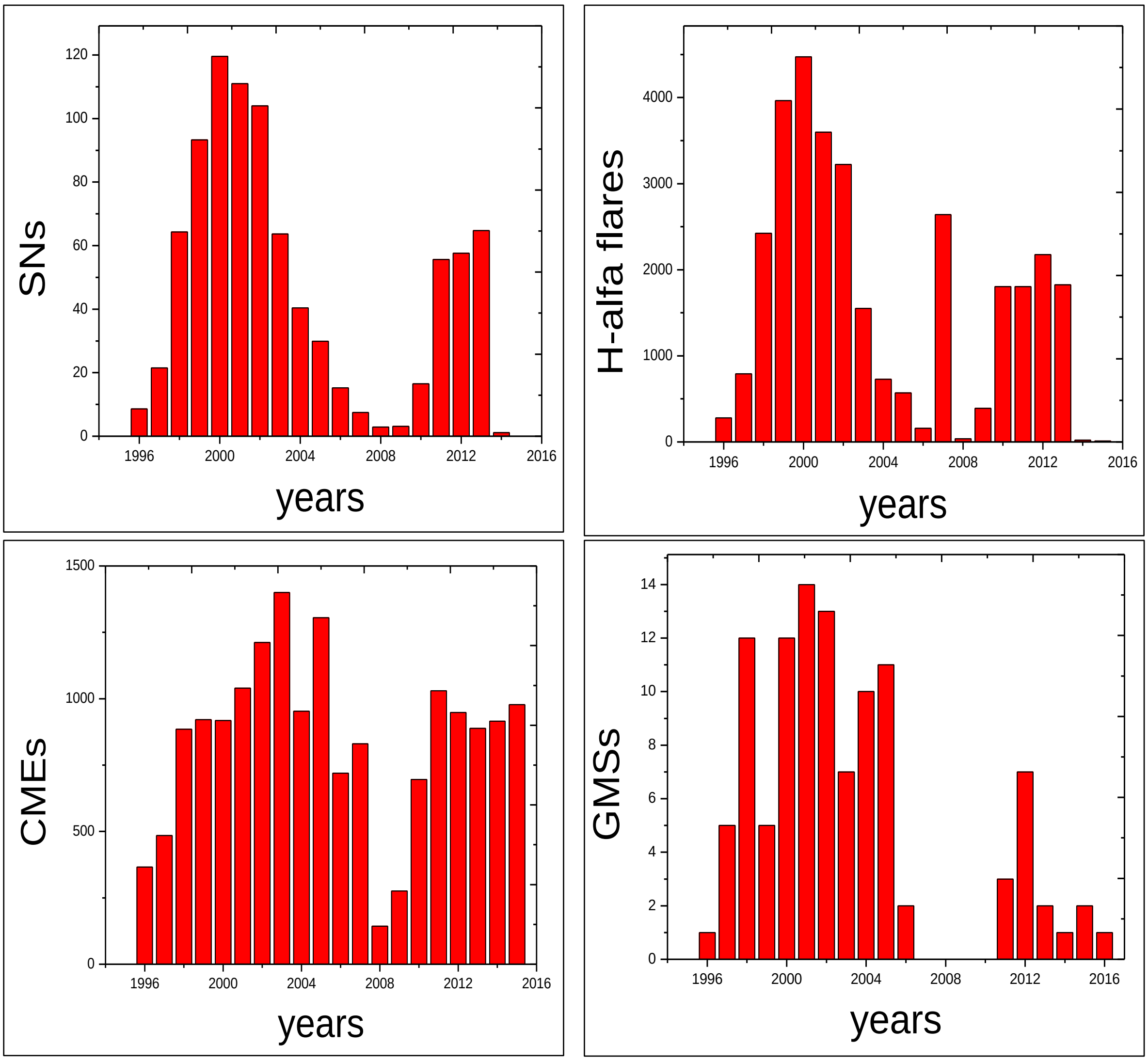

Fig. 1: *Yearly Variation of Sunspot Numbers (SNs), CMEs, H-α Flares and Total Intense GMSs during 1996–2016.*

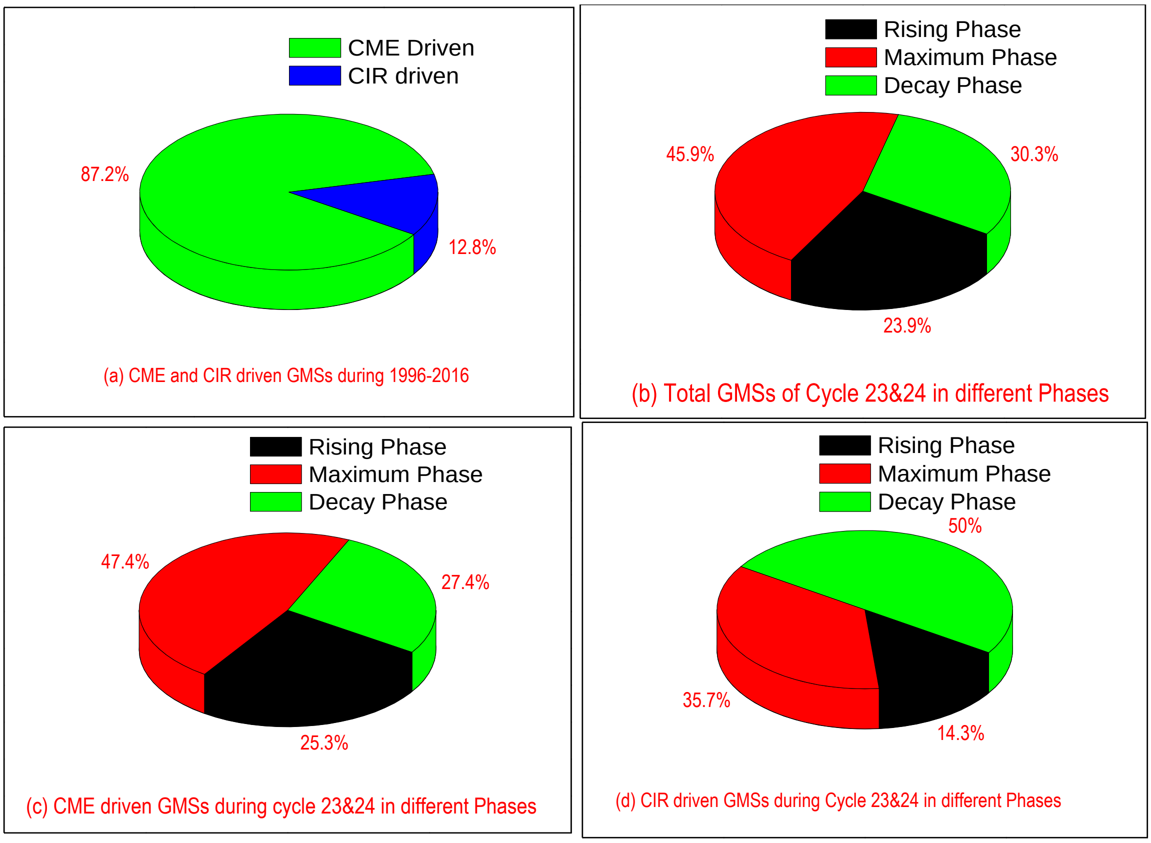

Fig. 2: *Pie Charts of GMSs Events during Solar Cycles 23 and 24 (1996–2016).*

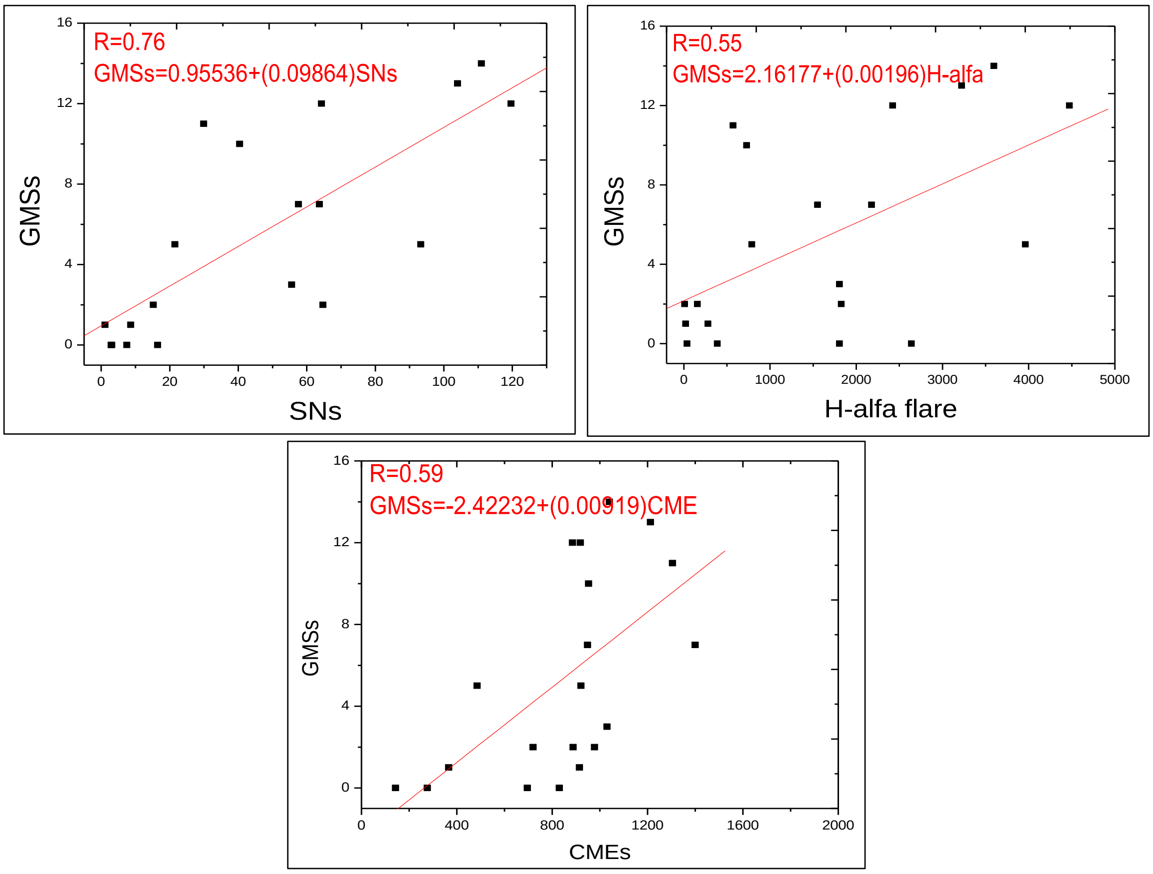

Fig. 3: *Relation between Total GMSs Events and Solar Activity (SN, H-alfa Flares and CMEs) during 1996–2016.*

$Y = A + BX$ for these parameters where Y is peak value of GIs and X is interplanetary field/plasma parameters. We have studied the relationship between these parameters in different phases of solar cycle 23 and 24 namely rising phase (1996–1996, 2008–2011) maximum phase (2000–2002, 2012–2014) and decay phase (2003–2008, 2015–2016). We have calculated average, median and standard deviation of peak values of various GIs and interplanetary/plasma field parameters in different phases of solar cycle 23 and 24 as well as for total period 1996–2016 (Table 1).

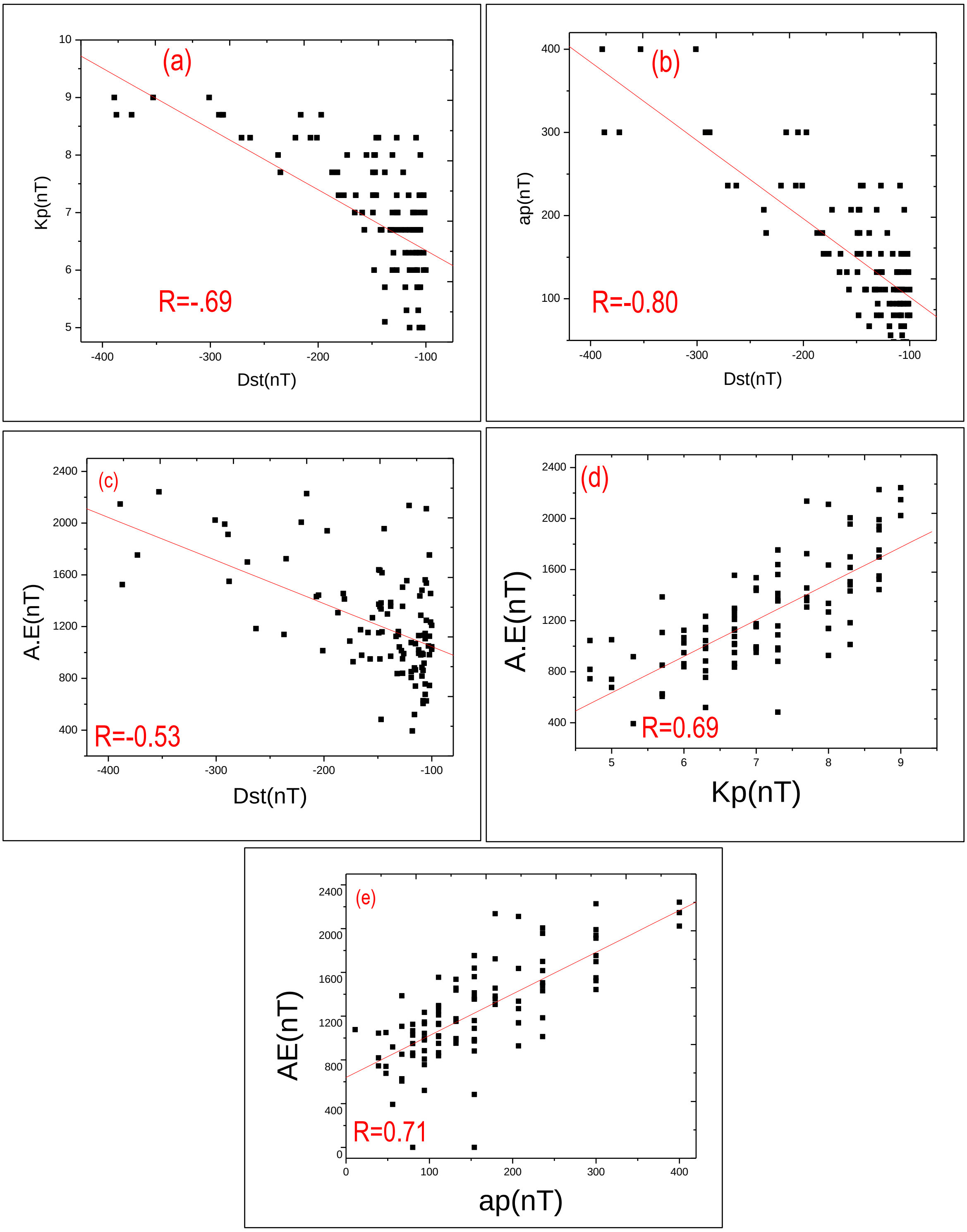

***Fig. 4:** Relation between Peak Values of GIs during 1996–2016.*

Table 1: *Average (AV), Median (Med) and Standard Deviations (SD) of Various Geomagnetic Indices (GIs), during the Rising, Maximum and Decay Phases of Cycle 23 and 24 as well as the Total Period 1996–2016.*

	Rising Phase (cycle 23 and 24)			**Maximum Phase (cycle 23 and 24)**			**Decay Phase (cycle 23 and 24)**			**Total Phase (1996–2016)**		
	AV	**Med**	**SD**	**AV**	**Med**	**SD**	**AV**	**Med**	**SD**	**AV**	**Med**	**SD**
Dst(nT)	-133.5	-117	35.98	-150.5	-127	63.43	-185.4	-146.5	97.79	-154	-128	70.29
Kp(nT)	6.89	6.85	0.94	6.90	6.85	1.05	7.49	7.7	1.17	7.06	7	1.07
ap(nT)	135.65	121.50	60.25	139.26	121.50	78.55	192.42	179	97.9	152.6	132	81.99
A.E(nT)	850	949.50	452.81	1192.8	1129	376.20	1476	1446	490.46	1228	1153	441.8

ANALYSIS AND RESULTS

Relation between Solar Activity Features and Geomagnetic Active Indices

The yearly variation of sunspot number (SNs), H-alfa flares, CMEs and total intense GMSs during 1996–2016 are represented in Figure 1 which indicates that GMSs vary in a manner similar to SNs, CMEs and H- alfa flare. There are no intense GMSs during 2007–2009 because during this period a significant drop in the density, speed, magnetic field and total pressure has taken place in Heliosphere [14]. In the present study two sources are considered namely ICME and CIR based on the studies of GMSs by Zhang et al. and Echer et al. [11,12]. We find that out of 109 events 95 events are CME driven and 14 events are CIR driven GMSs events. It can be seen from Figure 2(a) that 87.2% events are CME driven and 12.8% events are CIR driven GMSs. Figure 2(b) indicates that 45.9% GMSs events are observed in rising phase of solar cycle 23 (1996–1999) and solar cycle 24 (2008–2011), 45.9% events are observed in maximum phase of solar cycle 23 (2000–2002) and solar cycle 24 (2012–2014) and 30.3% events are observed in decay phase of solar cycle 23 (2003–2008) and solar cycle 24 (2015–2016). Therefore, maximum GMSs events are observed in maximum phase of solar cycle 23 and 24. Figure 2(c) indicates that 25.3% CME driven events are observed in rising phase, 47.4% events observed in maximum phase and 25.3% events are observed in decay phase of solar cycle 23 and 24. For CIR driven events 14.3% events are observed in rising phase, 36.7% events are observed in maximum phase and 50% events in decay phase of solar cycle 23 and 24. This study indicates CMEs are more active driver of GMSs than CIRs, however, the geoeffectiveness of CIR increases drastically in the decay phase of solar cycle 23 and 24. We have also presented a linear regression analysis using yearly values of solar activity features with peak values of GMSs indices. Figure 3 indicates that sunspot number (SN) shows good correlation with peak values of GMSs indices (correlations coefficient R= 0.76) while CME(R=0.59) and H-α (H- alfa) (R=0.55) show moderate correlation. So we conclude that GMSs have good correlation with solar activity features and indicate that they are active producers of geomagnetic activity.

Relationship amongst Peak Values of Geomagnetic Activity Indices (Dst, Kp, ap, A.E) during Intense Geomagnetic Storms

Geomagnetic indices play an important role for the study of storms. Statistical study amongst different GIs is represented in Figure 4. The correlation coefficient between Dst-Kp, Dst-ap, Dst-A.E, are -0.69, -0.80, -0.53, respectively. The Correlation coefficient between A.E-Kp and A.E-ap are 0.69, 0.71, respectively. These correlation indicate that Dst shows good correlation (-ve) with Kp and ap while it shows moderate correlation with A, E. A.E index shows good positive correlation with Kp and ap indices.

CONCLUSION

The present study intends to examine the dependence of GIs on solar activity features. We have found that GIs are in good correlation with solar activity features (SNs, H- alfa, CMEs). This indicates that solar activities are the main drivers of geomagnetic storms. These may also prove vital in making predictions about geomagnetic storms and their strength. We also conclude that CMEs are more effective drivers of GMSs than CIR. The phase analysis (rising phase, maximum phase and decay phase) for the two solar cycles 23 and 24 indicates that most of the events (45.9% of total events) occurred in maximum phase which implies that maximum phase is more geoeffective than the other phases. However, when we made the phase analysis separately, we found that maximum number of events occurred in the maximum phase (47.4%) for CME driven events while maximum number of events occurred in the decay phase (50%) for CIR driven events. This indicates that CMEs are more important drivers of GMSs during the maximum phase of solar cycle while CIR become more significant drivers of GMSs during the decay phase of solar cycle. We have presented a comparison of average and median of peak values of GIs during the rising, maximum and decay phase of solar cycles 23-24. It is clear that average of GIs, increase during the decay phase as compared to the rising and maximum phase. Though the number of events in decay phase is less (29 events) but there intensity is relatively high (Dst index reaching up to -442nT in solar cycle 23 and up to -223nT in solar cycle 24) as compared to the events of rising and maximum phase. This accounts for the higher average values in decay phase.

REFERENCES

1. Baker DN. *IEEE Trans Plasma Sci.* 2000; 28: 2007–2016 p.
2. Hudson MK, Kress BT, Mazur JE, *et al. J Atmos Terr Phys.* 2004; 66: 1389–1397p.
3. Seppala A, Verronen PT, Sofieva VF, *et al. Geophy Res Lett*. 2006; 33: 2 8.3.
4. Zhang Y, Sun W, Feng XS, *et al. J Geophy Res.* 2008; 113: A08106.
5. Rostoker G, *Rev Geophy*. 1972; 10: 935–950p.
6. Bartels J. *Geomagnetism*. Clarendon Press Oxford, 1938.
7. Davis TN, Sugiura M. *J Geophy Res*. 1966; 71: 785.
8. Gonzalez WD, Joselyn JA, Kamide Y, *et al*. *J Geophy Res*. 1994; 99: 5771–5792p.
9. Echer E, Gonzalez WD, Guarnieri FL, *et al. Adv Space Res*. 2005b; 35: 855–865p.
10. Gonzalez WD, Echer E. *Gephy Res Lett*. 2005; 32: L18103.
11. Zhang J, Richardson IG, Webb DF, *et al. J Geophy Res*. 2007; 112: A10102.
12. Echer E, Gonzalez WD, Tsurutani BT, *et al. J Geophy Res*. 2008; 113: A05221.
13. Joshi NC, Bankoti NS, Pande S, *et al. New Astron*. 2011; 16: 366–385p.
14. Gopalswamy N, Akiyama S, Yashiro S, *et al. 14th International Ionospheric Effects Symposium on Bridging the Gap between Applications and Research Involving Ionospheric and Space Weather Disciplines*, Alexandria, VA, May 12-14, 2015.

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