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To Study the geoeffectiveness of High Speed and Slow Speed Interplanetary Coronal mass ejection for Solar Cycle 23 and 24

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Abstract: In the present study, 126 events of ICMEs have been utilized to derive their relationship with geomagnetic activities for the study period of 1996-2018 (a period encompassing solar Cycle 23 and 24). To discover the interconnection of ICMEs speed and geomagnetic activities, we incorporate the analysis technique by superposed epoch method. The current analysis depict that high-speed ICMEs and dst index are highly anti-correlated with each other for severe geomagnetic storm with a correlation coefficient of -0.7 for solar Cycle 23 and -0.5 for solar Cycle 24 whereas moderately anti-correlated with each other for moderate and intense geomagnetic storms. Furthermore, we observed that solar wind high-speed streams (HSSs) is a geo-effective parameter while solar wind slow-speed streams (SSSs) is not a geo-effective parameter. Morever, the time delay analysis has also been performed by the method of correlation for the introduced parameters.

Keywords: Geomagnetic storms, High speed solar wind streams, Slow speed solar wind streams, Interplanetary coronal mass ejections,

1 INTRODUCTION

A major disturbance in the Earth's magnetic field usually occurring due to irregular condition of interplanetary magnetic field (IMF) and solar wind plasma discharge caused by various solar phenomena is called as geomagnetic storm **[1, 9].** Geomagnetic storms (GSs) are categorized as severe storm (Dst ≤ -200nT), intense storm (-200nT < Dst ≤ -100nT) and moderate storm (-100nT < Dst ≤ -50nT).

Solar wind speed can be classified in to its two components as solar wind high speed streams (HSSs) and solar wind slow speed streams (SSSs). HSSs is considered to be an important parameter that drives the geomagnetic storms studied by the number of authors [**2, 3, 8, 15, 16, 20].**

In the present paper, we study the geoeffectivenes of related chosen parameter such as solar wind high speed streams (HSSs) and solar wind slow speed streams (SSSs), the occurrence hour of HSSs (criteria 450 $kms^{-1} \leq Vsw < 800\ kms^{-1}$) and SSSs (criteria 300 $kms^{-1} \leq Vsw < 450\ kms^{-1}$) are taken as zero epoch. In our one of the previous published paper, we also discussed the effect of Cosmic ray intensity (CRI) in relation to the interplanetary magnetic field (IMF) and geomagnetic storms for solar cycle 24 by using the criteria Dst ≤ -50 nT **[10].**

Coronal mass ejection is a major release of plasma from the solar corona and its associated magnetic field. The Interplanetary coronal mass ejection (ICMEs) is a large-scale transient heliospheric phenomenon that originates from the sun and causes weather disturbances in the space. The ICMEs which are the main carrier of the intense south component of the interplanetary magnetic field, are thought to be the main source of the geomagnetic storms especially for the intense geomagnetic storms **[12, 18, 7, 19].**

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Similarly to study the geoeffectiveness of ICMEs, the occurrence days of GSs are used as a zero day with criteria -100nT < Dst ≤ -50nT for moderate geomagnetic storm, -200nT < Dst ≤ -100nT for intense geomagnetic storm and Dst ≤ -200nT for severe geomagnetic storm. To observe the average behavior of geomagnetic perturbations during the ICMEs period, the Chree analysis as shown in Figure 2 has been performed. A substantial increase in speed of ICME on zero day (occurrence day) is seen for almost every year starting from 1996-2018.

2.DATA ANALYSIS AND STATISTICAL

To analyse the GSs variation with solar wind high-speed streams (HSSs) and solar wind slow-speed streams (SSSs), interplanetary coronal mass ejections speed, we used a chree analysis by the superposed epoch method. In order to study the variation of HSSs and SSSs, the occurrence hour of HSSs (criteria 450 kms^{-1} ≤ Vsw < 800 kms^{-1}) and SSSs (criteria 300 kms^{-1} ≤ Vsw < 450 kms^{-1}) taken as zero epoch. The hourly mean values of HSSs, SSSs and GSs are taken from the omniweb data center (omniweb.gsfc.nasa.gov/form/dx1.html) for the studied period 2009-2018 (Solar Cycle 24). In this paper, we present a revised and updated catalog of 126 events (Table 1) of ICMEs taken for the period 1996-2018, these period encompassing solar cycle 23 and 24, where the analysis maintained by Richardson and Cane Since 1996. Furthermore, we calculated the average correlation coefficient of GSs with respect to the introduced parameters.

3 RESULTS DISCUSSION

In the present paper, we study the geoeffectiveness of ICMEs speed for the period 1996-2018 (Solar Cycle 23 and 24). Beside this, we also study the correlative importance of solar wind high-speed streams (HSSs) and solar wind slow-speed streams (SSSs) for the solar cycle 24.

3.1. Dst Index and High Speed Solar Wind Streams:

We analyzed the geoeffectiveness of 22,891 HSSs **(i.e. 450 ≤ V <800)** registered from 2009 to 2018. Maximum number of HSSs is observed in 2017 while minimum number of HSSs is observed in 2018 (Figure 3). From Figure 1, it can be clearly seen that the strongest increment in HSSs does not always occurs on the happening hour of dst i.e. a time delay of few hour found between the extreme value of HSSs and least value of dst. The average correlation coefficient which we have acquired from our study displayed here firmly recommend that HSSs has a strong impact as the cause of GSs (r = -0.8). Our outcome is in good agreement with the findings of **[17, 11, 5, 6].** Various studies have shown the geoeffectiveness of solar wind high-speed streams (HSSs) among various solar wind disturbance is determined by their speed.

3.2. Dst Index and Slow Speed Streams

The solar wind slow-speed streams have a velocity range **300 ≤ v < 450 kms^{-1}**. From Figure 3, it can be clearly shown that maximum number of SSSs is found in the year 2009 while minimum number of SSSs are found in the year 2018.

Our findings summarized in the form of figures and tables shows that HSSs are progressively able parameter to give rise to geomagnetic storms when contrasted with SSSs.

3.2. Fast Speed ICME (v ≥ 450 kms^{-1})

The geoeffectiveness of ICMEs speed is a major issue in space weather research and forecasting. The ICMEs speed is an important factor regulating the geoeffectiveness of the CME **[13].** Based on the ICME catalog, we study and compare the geoeffectiveness of ICMEs speed from 1996 to 2018. We divided the ICMEs speed in to its high and slow speed ICME to study their geoeffectiveness. When high speed and slow speed ICMEs is plotted against dst index, we observed some interesting and important results.

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From Figure 2, it is easy to perceive that the strongest increment in high speed ICME occurs on the happening day of dst index for the years 1998, 2000, 2001, 2004 and 2005. No time delay is found between the extreme value of high speed ICME and least value of dst index for these years while a time delay of one to two day is found between the extreme value of high speed ICME and least value of dst index for the years 1999, 2003 and 2005. The correlation coefficient between high speed ICME and dst index for severe geomagnetic storm is found to be -0.7 for solar cycle 23 and -0.5 for solar cycle 24, which may indicates that during the initiation process, high speed ICME acquire far higher internal energy from the source active regions that effectively overcomes the air resistance force as they pass through the interplanetary medium **[14].** In other words we can say that high speed ICME is more geoeffective in Solar cycle 23 than 24. Our outcome is in good agreement with the findings of **[5].**

Furthermore, we compared the average correlation coefficient of high speed ICMEs and dst index for moderate and intense geomagnetic storms for solar cycles 23 and 24. In our study, we observed that there always exit a time delay of few hours between the extreme value of high speed ICME and least value of dst index for every year. No regular variation is found between these two parameters for the moderate and intense geomagnetic storms while the symmetrical sharp V-shaped pattern was observed during our annual high speed ICMEs profile analysis for severe geomagnetic storms, which implies a sharp increase in high speed ICME during these years followed by a sharp decrease in dst index. An average correlation coefficient we obtained from our analysis shown here strongly recommends that high speed ICMEs has an average impact as the cause of GSs for moderate and intense geomagnetic storm (Table 2 and 3).

3.3. Slow Speed ICME (v < 450)

For the same studied period (period encompassing solar cycles 23 and 24), we found that slow speed ICMEs does not show any relationship with dst index. An average correlation coefficients between slow speed ICMEs and dst index for solar cycles 23 and 24 are found to be very poor for moderate and intense geomagnetic storms (Table 2 and 3), which indicates that slow speed ICMEs is not a geoeffective parameter.

4 CONCLUSIONS

After the detailed analysis of our study various conclusions has been observed that are discussed below-

i). Existence of time delay between the extreme value of HSSs and least value of dst index indicates that southward Bz component is also one of the parameter which can be considered as the driver of geomagnetic storms.

ii). The average correlation coefficient between HSSs and GSs (-0.8) is found to be very high, which indicates that HSSs is a driver of geomagnetic storm.

iii). The weak correlation coefficient between slow speed solar wind streams and geomagnetic storms indicates that SSSs is not a driver of geomagnetic storms.

v). For all the geomagnetic storms caused by groups of ICMEs, there are 90 moderate storms, 60 intense storms, 18 severe storms for Solar cycle 23. Thus large fraction (54%) of the geomagnetic storms caused by the ICMEs groups are moderated storms. Out of which there are 53 high speed ICMEs and 37 slow speed ICMEs for moderate storms, 37 high speed ICMEs and 23 slow speed ICMEs for intense storms and 18 severe storms for high speed ICMEs.

vi). For all the geomagnetic storms caused by groups of ICMEs, there are 54 moderate storms, 16 intense storms, 1 severe storms for Solar cycle 24. Thus large fraction (76%) of the geomagnetic storms caused by the ICMEs groups are moderated storms. Out of which there are 22 high speed ICMEs and 32 slow speed ICMEs for moderate storms, 6 high speed ICMEs and 10 slow speed ICMEs for intense storms and 1 severe storms for high speed ICMEs.

vii). We also compare the geoeffectiveness of ICMEs group in Solar Cycles 23 and 24 by calculating the average correlation coefficient between high speed ICMEs and GSs. The average correlation coefficient between high speed

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ICMEs and GSs are found to be -0.7 for Solar Cycle 23 and -0.5 for Solar Cycle 24. This indicates that high speed ICMEs is strongly tied with GSs for Solar Cycle 23 than 24.

viii). The average correlation coefficient between high speed ICMEs and GSs for Solar Cycles 23 and 24 (-0.5) are found to be same for intense geomagnetic storms.

ix) The average correlation coefficient between high speed ICMEs and GSs for Solar Cycles 23

(-0.5) and 24 (-0.4) are found to be differnt for moderate geomagnetic storms.

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Table 1. In the given table, we analyzed the geoeffectiveness of 66 high speed ICME (v ≥ 450) and 60 slow speed ICME (v < 450), the occurrence days of GSs are used as a zero epoch with criteria -100nT < Dst ≤ -50nT for moderate geomagnetic storm, -200nT < Dst ≤ -100nT for intense geomagnetic storm and Dst ≤ -200nT for severe geomagnetic storm.

Years	**High speed ICME (v≥450)**	**Slow speed ICME (v<450)**
1996	-	-
1997	2	3
1998	4	7
1999	5	2
2000	8	4
2001	7	7
2002	2	3
2003	7	1
2004	3	1
2005	9	4
2006	2	2
2007	1	-
2008	-	-
2009	-	1
2010	2	2
2011	3	3
2012	8	8
2013	6	6
2014	4	4
2015	-	-
2016	2	2
2017	-	-
2018	-	-

Table 2. The correlation coefficient of high speed and slow speed ICME for moderate, intense and severe geomagnetic storms for Solar Cycle 23 (1996-2008) is shown below-

	Moderate		**Intense**		**Severe**	
Correlation coefficient	**High speed ICME**	**Slow speed ICME**	**High speed ICME**	**Slow speed ICME**	**High speed ICME**	**Slow speed ICME**
r =	**-0.5**	**0.1**	**-0.5**	**-0.1**	**-0.7**	**-**

Table 3. The correlation coefficient of high speed and slow speed ICME for moderate, intense and severe geomagnetic storms for Solar Cycle 24 (2009-2018) is shown below-

	Moderate		**Intense**		**Severe**	
Correlation coefficient	**High speed ICME**	**Slow speed ICME**	**High speed ICME**	**Slow speed ICME**	**High speed ICME**	**Slow speed ICME**
r =	**-0.4**	**0.1**	**-0.5**	**0.03**	**-0.5**	**-**

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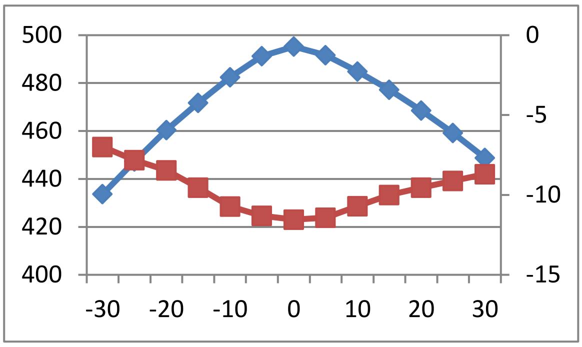
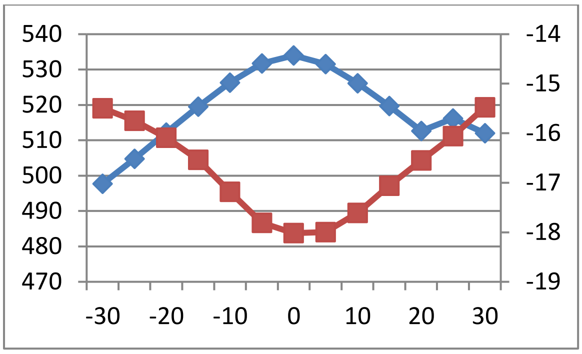
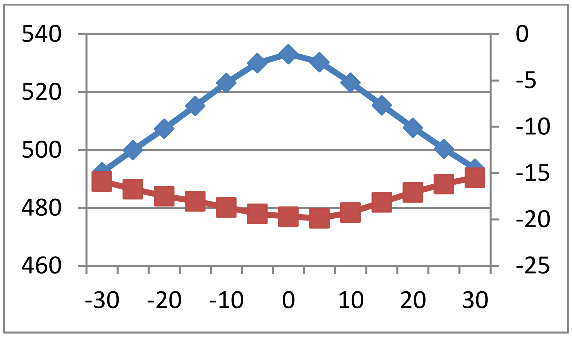
2009



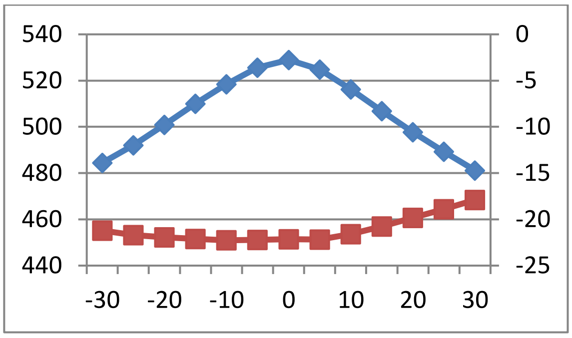
2010



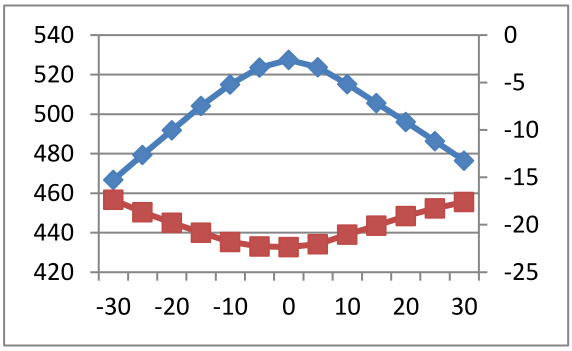
2011



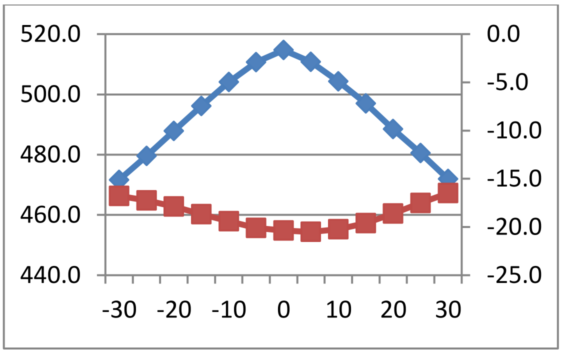
2012



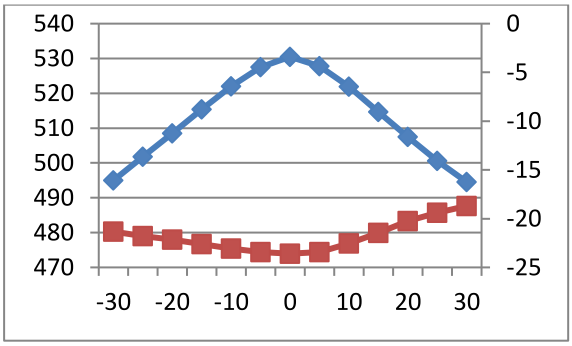
2013



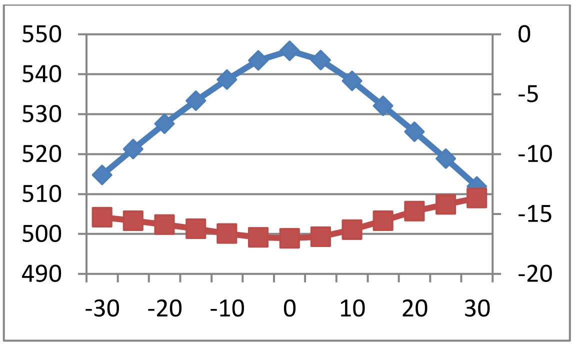
2014



2015



2016



2017

2018

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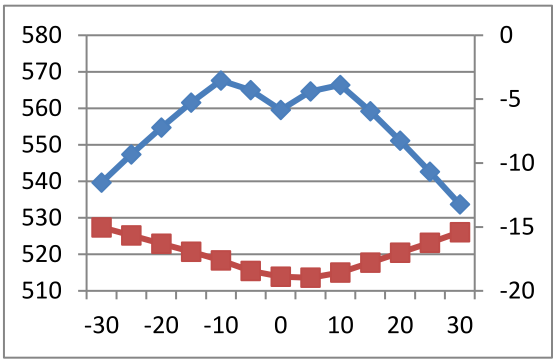
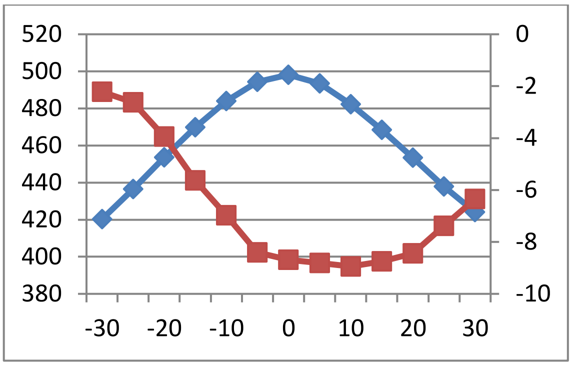




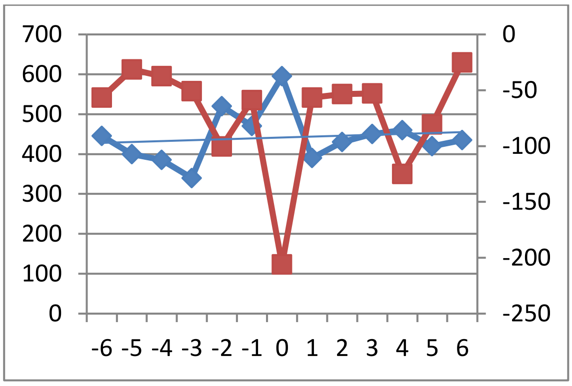
Left Y-axis Mean Value of HSSs

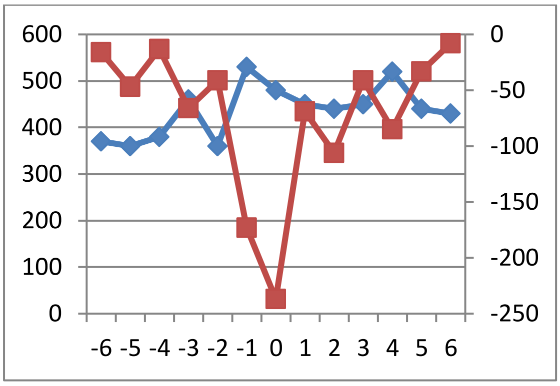
Right Y-axis Mean Value of Dst Index

X-axis Time in hour

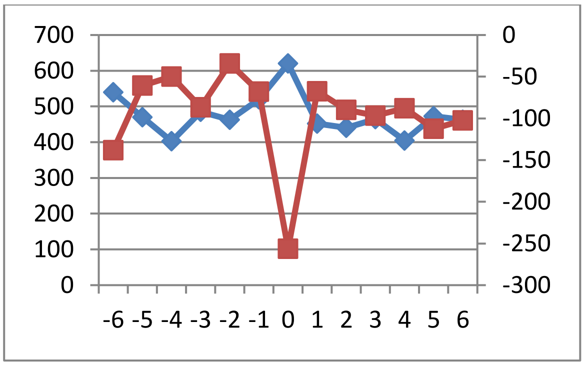
Figure 1: The conclusion of Superposed epoch analysis with respect to the happening hour of GSs (zero epoch). The discrepancy of average values of HSSs in blue and Dst index in red is demonstrated.

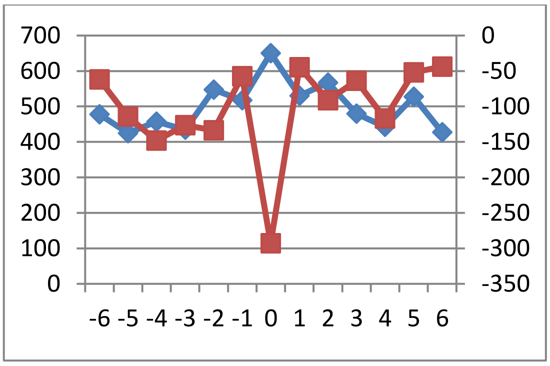
1998 **1999**





2000 **2001**





2003 **2004**

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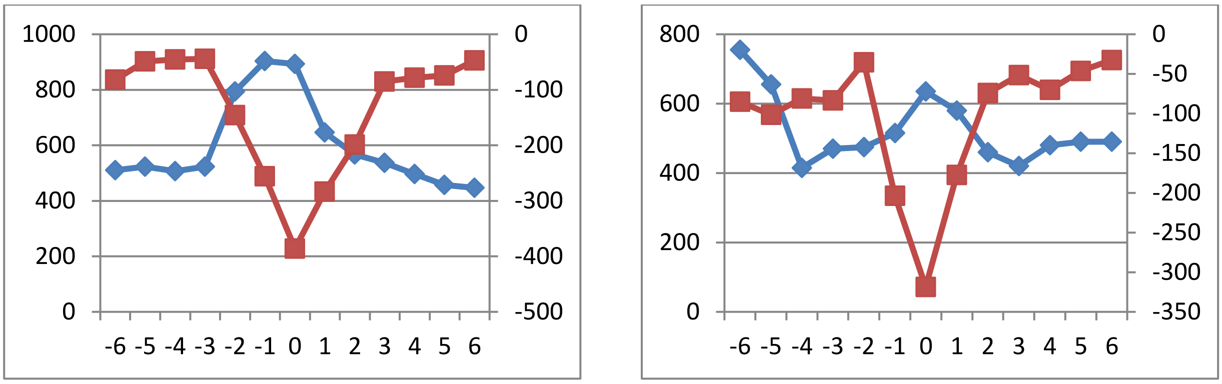
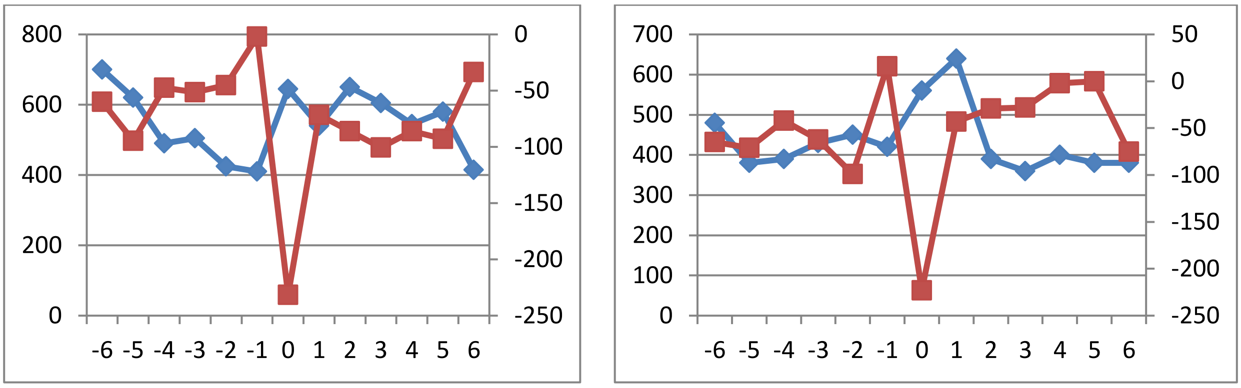


2005 **2015**



Left Y-axis: Mean Value of V-ICME

Right Y-axis: Mean Value of Dst Index

X-axis: Time in hour

Figure 2: The conclusion of Superposed epoch analysis with respect to the happening hour of GSs (zero epoch). The discrepancy of average values of high speed interplanetary coronal mass ejection (V ICME) in blue and Dst index in red is demonstrated for severe geomagnetic storm. No datas are observed in 1996, 1997, 2002, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2016, 2017 and 2018 for severe geomagnetic storms.

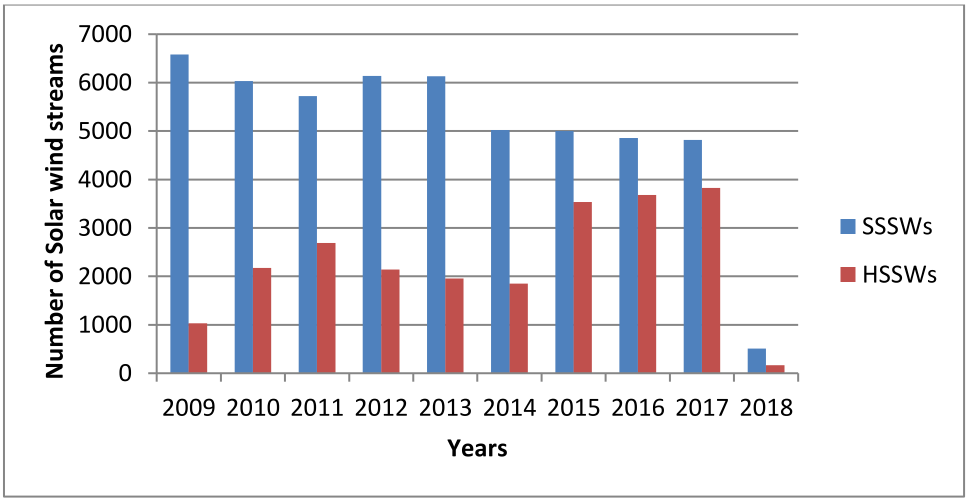


Figure 3. Annual distribution of solar wind streams for solar cycle−24.