Solar Wind (SW) variation with Sun Spot Number (SSN) and Geomagnetic Strom (GS) For solar cycle 23 and 24

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Abstract: The intent of this paper is to study the association between solar wind speed (SW), geomagnetic storms (GS) and sunspot number (SSN) for the period 1996- 2016. We have taken interplanetary solar wind data at the instant of Dst minimum. Our study consists of geomagnetic storms weighed by disturbance storm time (Dst) < −50 nT, observed during solar cycle 23, 24. Geomagnetic disturbances are caused by enhanced solar wind magnetosphere energy coupling process. The principal cause of geomagnetic disturbance is the magnetic reconnection that establishes an electro dynamical coupling between the solar wind plasma and magnetosphere. We conducted a Chree analysis by the super epoch method for relevant study. From the study we found that SW and SSN are shows inverse relation with each other for even years while positive slop is observed for odd years with few exceptions. We have observed the pattern of SW and Dst for both the solar cycle and found that for SC-23 SW decrease for odd year except 2007 while for SC-24 SW increases for all the years except 2010. By comparing the average correlation coefficients of Dst and SSN with solar wind we found that Dst and solar wind are poor correlation with each other for both solar cycles while high correlation between SW and SSN (-0.9) is observed for solar cycle 24 as compared to SC 23 (-0.5).

Keyword: Sunspots, Geomagnetic Storms, Coronal Mass Ejections, Solar Wind.

Introduction

The idea of computing sunspot numbers was originated by Rudolf Wolf in 1848 in Zurich, Switzerland and, thus, the procedure he initiated bears his name (or place). The combination of sunspots and their grouping is used because it compensates for variations in observing small sunspots. This number has been collected and tabulated by researchers for over 150 years. They have found that sunspot activity is cyclical and reaches its maximum around every 9.5 to 11 years.This cycle was first noted by Heinrich Schwabe in 1843. Due to weather and researcher unavailability, "the" sunspot count is actually an average of observations by multiple people in multiple locations with different equipment, with a scaling factor *k* assigned to each observer to compensate for their differing ability to resolve small sunspots and their subjective division of groups of sunspots. Sunspots are storms on the sun's surface that are marked by intense magnetic activity and play host to solar flares and hot gassy ejections from the sun's corona. Scientists believe that the number of spots on the sun cycles over time, reaching a peak—the so-called Solar Maximum—every 11 years or so. Some studies indicate that sunspot activity overall has doubled in the last century. The apparent result down here on Earth is that the sun glows brighter by about 0.1 percent now than it did 100 years ago.

A geomagnetic storm is a major disturbance of Earth's magnetosphere that occurs when there is a very efficient exchange of energy from the solar wind into the space environment surrounding Earth. These storms result from variations in the solar wind that produces major changes in the currents, plasmas, and fields in Earth's magnetosphere. The solar wind conditions that are effective for creating geomagnetic storms are sustained (for several to many hours) periods of high-speed solar wind, and most importantly, a southward directed solar wind magnetic field (opposite the direction of Earth's field) at the dayside of the magnetosphere. This condition is effective for transferring energy from the solar wind into Earth's magnetosphere.

Solar wind is a stream of plasma that varies in speed and when reaches near the earth increase the level of geomagnetic activity and Sunspots. The variations in the solar wind speed are designated as one of the important parameter for the occurrence of geomagnetic storms **Kharayat, et al., 2016**. Solar wind are storms on the sun's surface that are marked by intense magnetic activity and play host to solar flares and hot gassy ejections from the sun's corona further studies shows that there are various other parameters and it also creates disturbances in the solar wind such as coronal mass ejections (CMEs), interplanetary magnetic field (IMF), solar flares, solar prominences etc.

Therefore we can't say that a single parameter is responsible for the occurrence of GS. Geomagnetic Storm has mainly three phases an initial phase, a main phase, and a recovery phase **Hafez, et al., 2011** and the strength of GS is measured by the disturbance storm-time (Dst) index **Gonzalez et al., 1994. Kaushik, S.C., et al, 2011** found that perturbations in the IMF and passage of magnetic clouds are the main reason for the occurrence of geomagnetic storms.

When the Dst index gets to extreme values, such as 400nT, due to the large intensity of the ring current and to the rarity of such Dst excursions, the storms of this type could be called extreme storms.

Tsurutani et al. 2003 reported extreme historical storms for which the Carrington storm of September 2, 1859 showed up as the most intense, whereas during the space era the most extreme recorded storm was that of March 13, 1989, with a peak Dst about 600nT.

Sabbah, et al. 2013 , Liu et al. 2014 have reported that the geo-effective events such as GS are further associated with CME's, solar flares, SEPs and also with other solar wind transients.

Richardson et al., 2001; Zhang et al., 2007; Youssef et al., 2012; Fathy et al., 2014 found that solar wind associated with coronal mass ejections (CMEs) are more stronger as compared that are associated with co rotating interaction regions (CIRs). The entire study of these storms is essential for good understanding of solar terrestrial environment.

2. Data analysis and method

A Chree analysis technique by the super epoch method(is a statistical tool used in data analysis either to detect periodicities within a time sequence or to reveal a correlation between two data sequences) has been introduced for the present study with the occurrence day of moderate geomagnetic storms (criteria -50 nT ≤ Dst< -100 nT) as zero day. The hourly mean values of the Dst index and the sunspot number (SSN) are taken from the Omni web data center (omniweb.gsfc.nasa.gov/form/dx1.html) for the period 1996-2016. We have also established the correlation coefficient between Dst and SSN for the period 1996-2016.

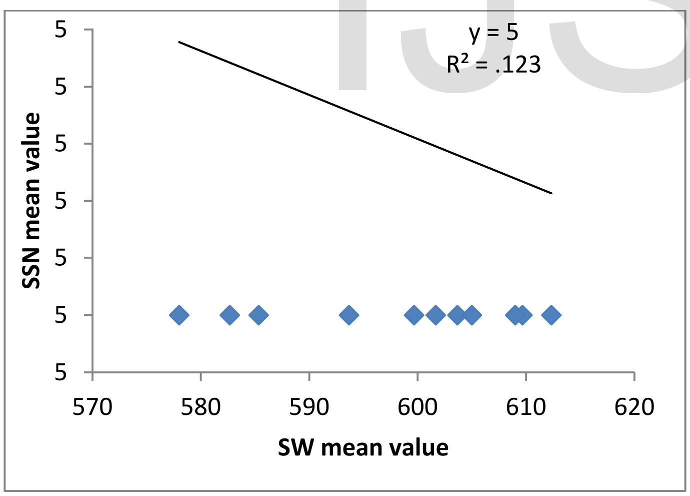
3. Results and Discussion

3.1 Solar Wind (SW) and Sun Spot Number (SSN)

Relationship between SW and SSN for solar cycle 23 as well as for solar cycle 24 with the help of scattered plot studies and we found that,

Analysis of (**Figure 1 Solar cycle 23)** shows that except for the year 1998 and 2004 all the even years shows negative slope which indicate that for even years SW and SSN are anti correlated with each other, While for the odd years except 2007 and 2009 positive slope is observed which shows direct relationship between these two parameter. With few dissonance during inclining and declining phase of solar cycle 23 (1996, 1997, 1998, 2007) almost for all the years the points are observed near the trend line and hence the value of R^2 is large indicating good correlation between SW and SSN.

SC 24 (**Figure 2)** also show similar pattern as solar cycle 23 i.e. for the even years negative slope is obtain while for odd years positive slope is noticed with few exceptions. Years (2011, 2013, and 2014) shows high correlation coefficient while for the years (2008, 2010, and 2015) the value of correlation coefficient is poor.



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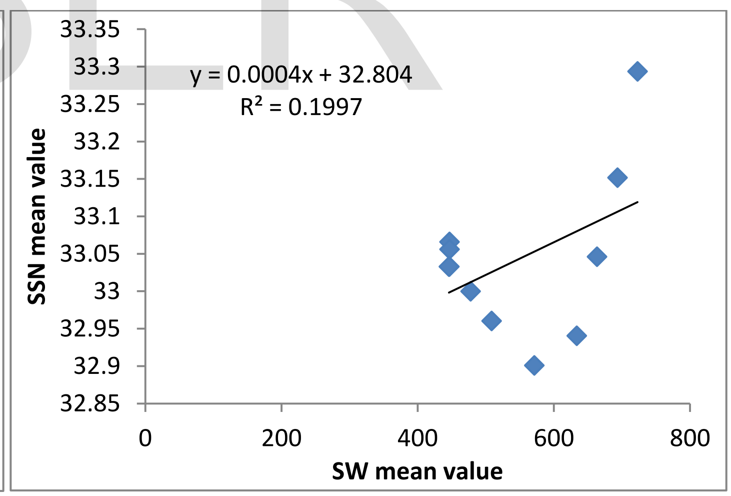

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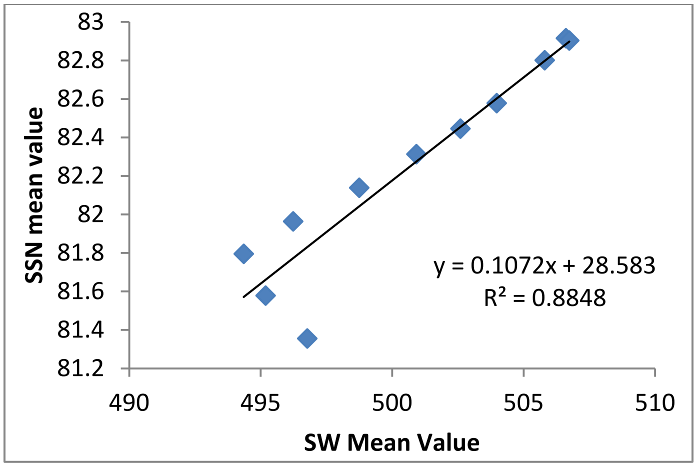

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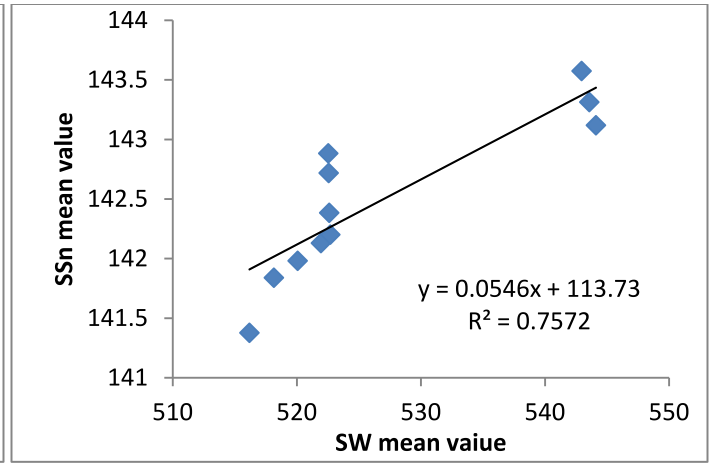

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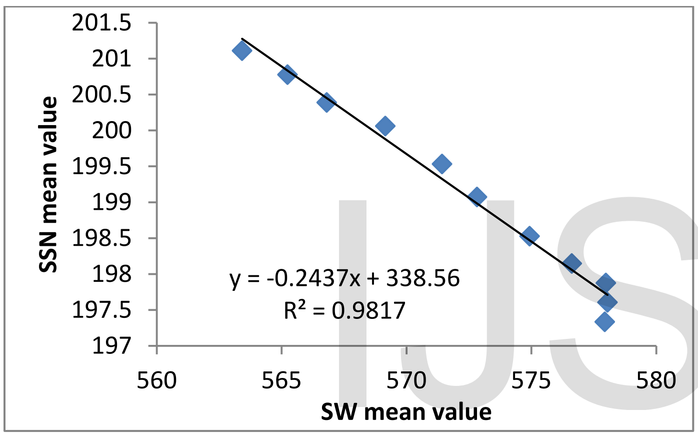

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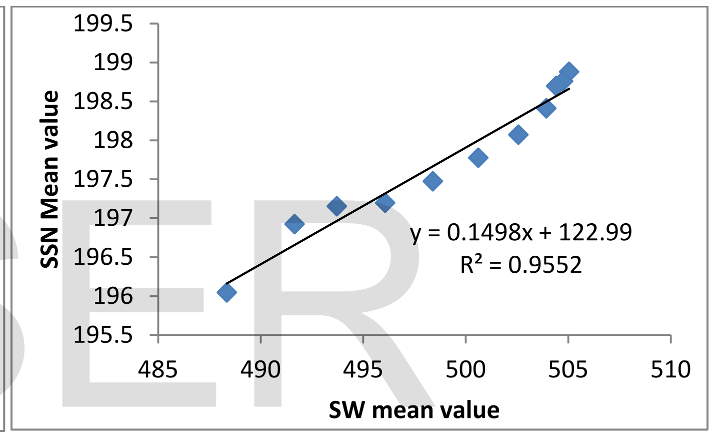

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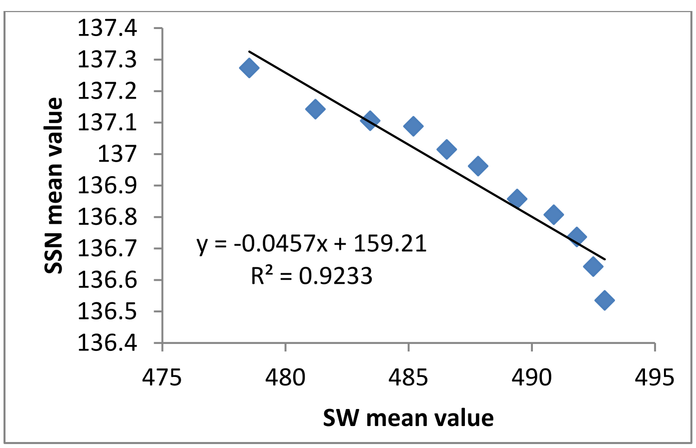

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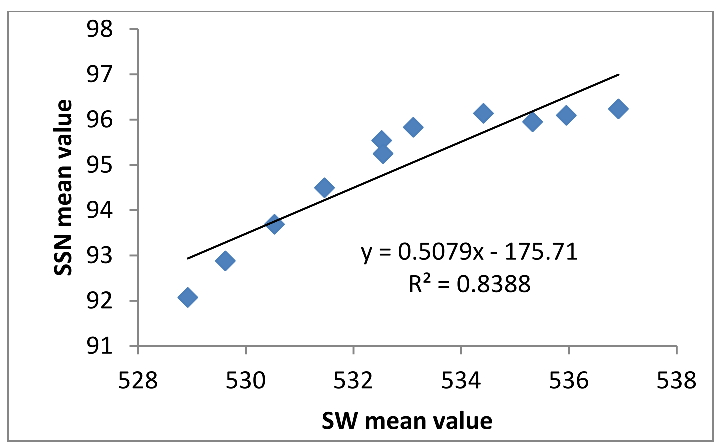

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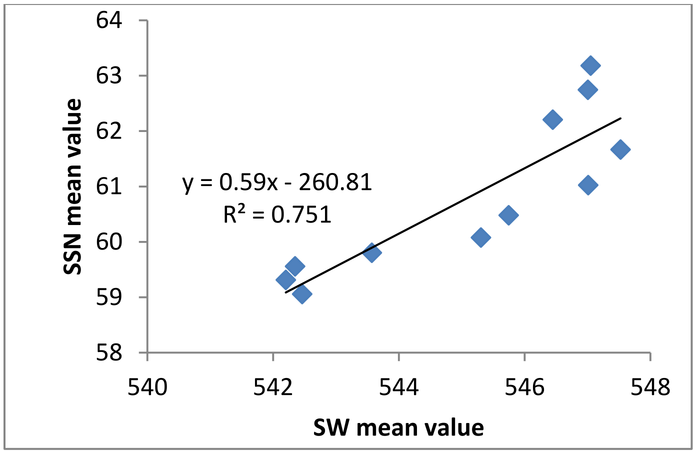

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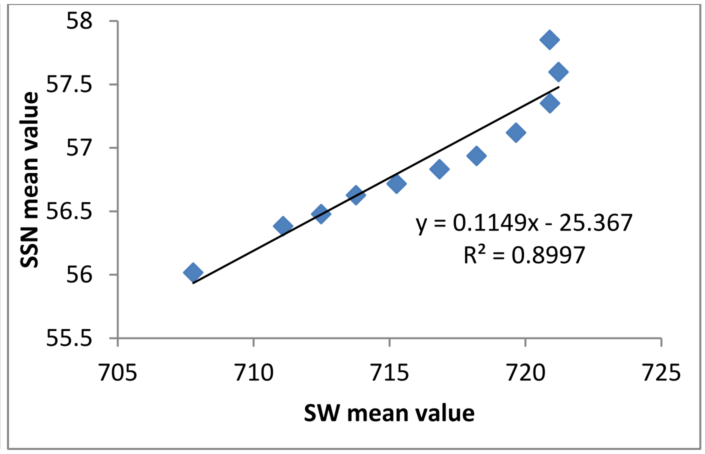

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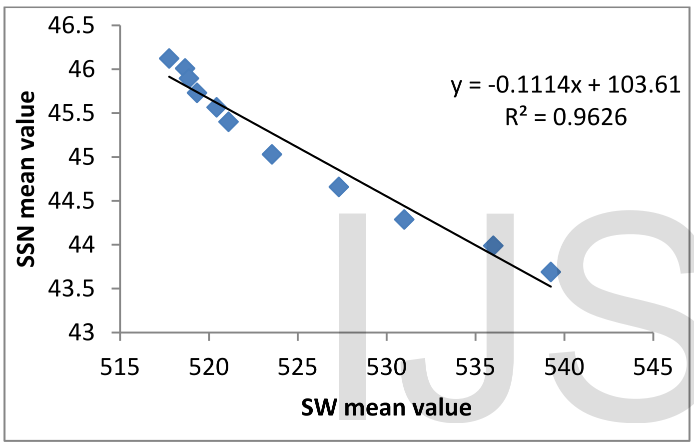

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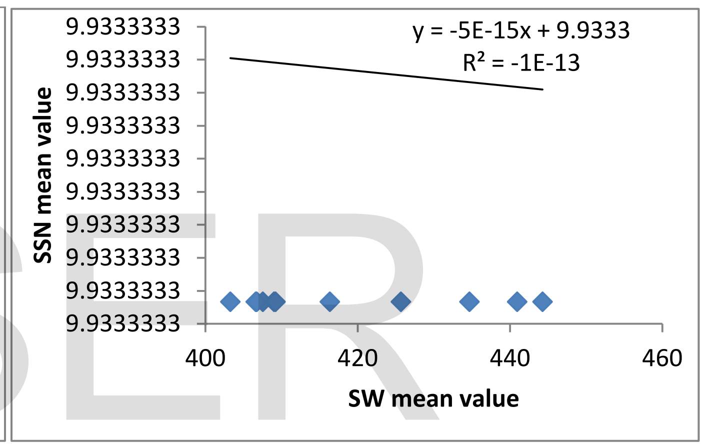

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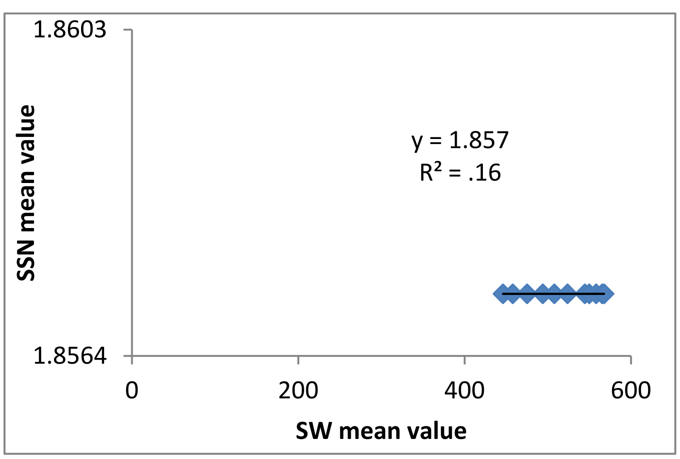
Figure1. Scattered plot between SSN mean value and SW mean value for SC-23.



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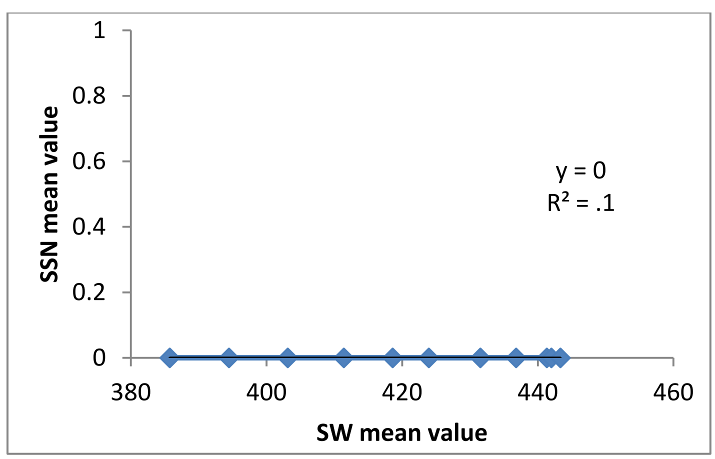

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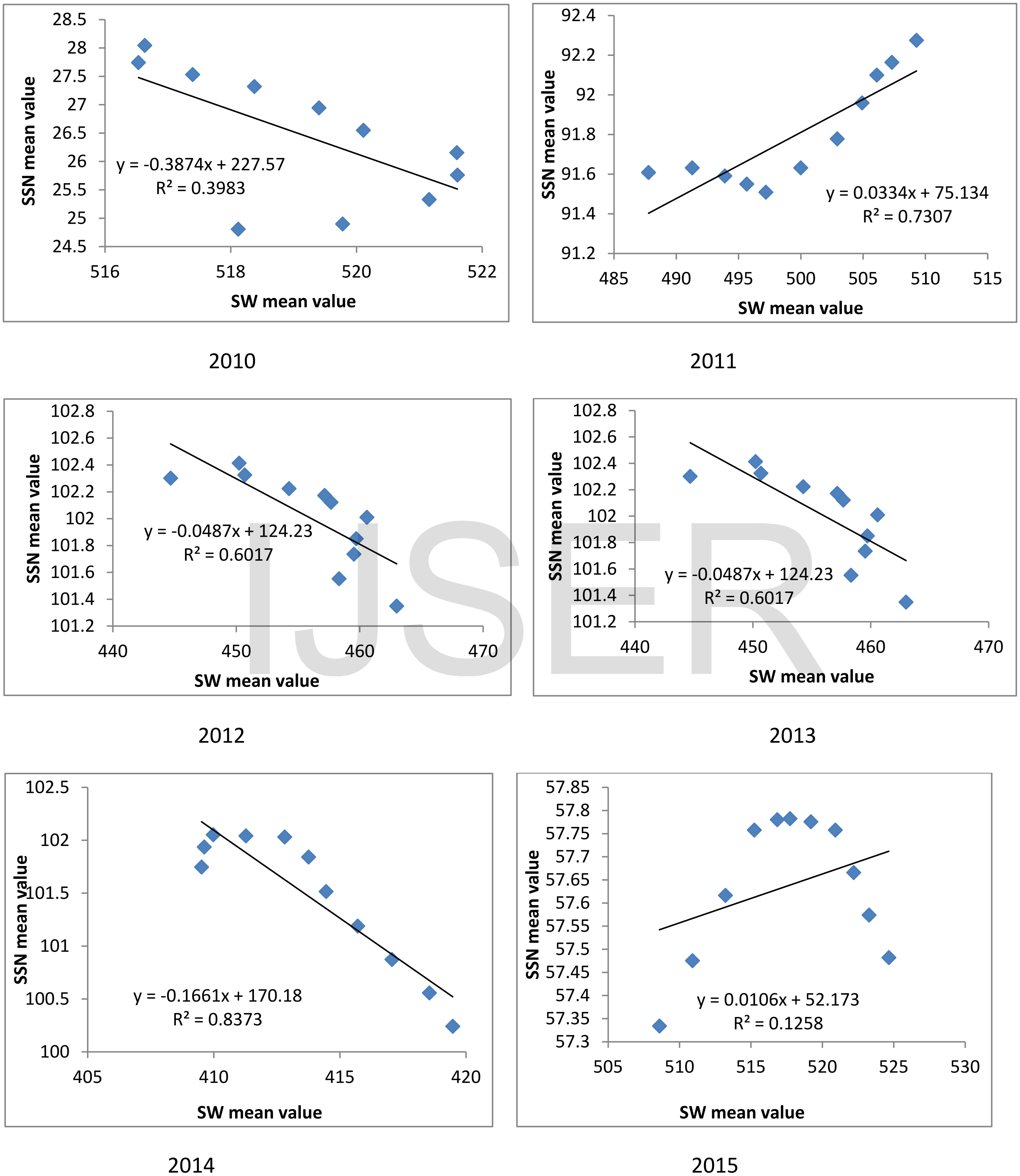
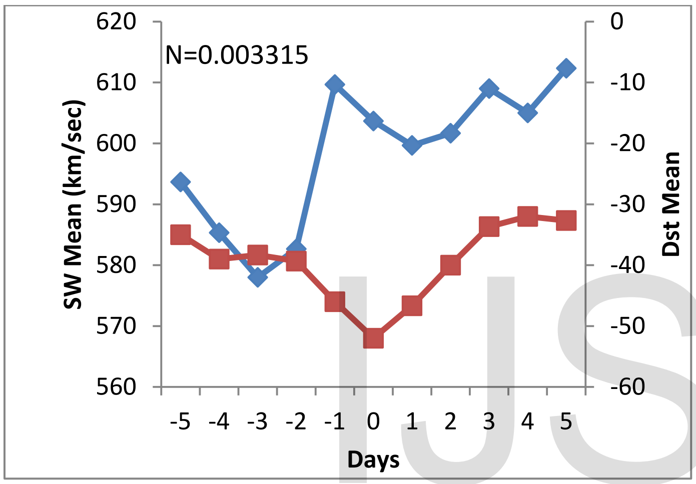


Figure 2 Scattered plots for SSN mean value and SW mean value for SC-23.

For solar cycle 23(**Figure 3**) we have observed that the solar wind is decreasing for odd years except 2007 which indicate that we are heading towards the ending phase of SC 23, while for even years solar wind is increasing with Dst except 2004.But for the years 1996 and 2000 we didn't found any regular variation between solar wind and Dst Further high correlation coefficient found for year 2007 2004 2005 between SW and Dst while the year 1996,1997,1999,2000,2002,2003 shows poor correlation coefficient.

On comparing with SC 23 we observed that in SC 24 (**Figure 4)** except 2010 in all the years SW is increasing with Dst. One fact is also noticeable here that almost in every year the SW and Dst are inversely related with each other and after zero day a direct relation between these two parameter is observed.



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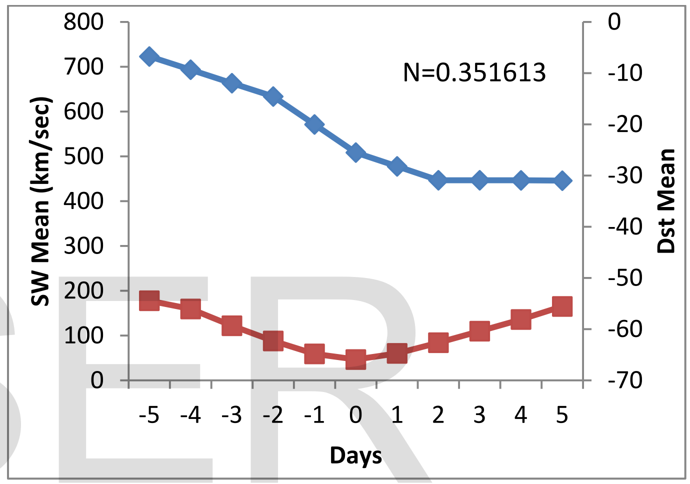

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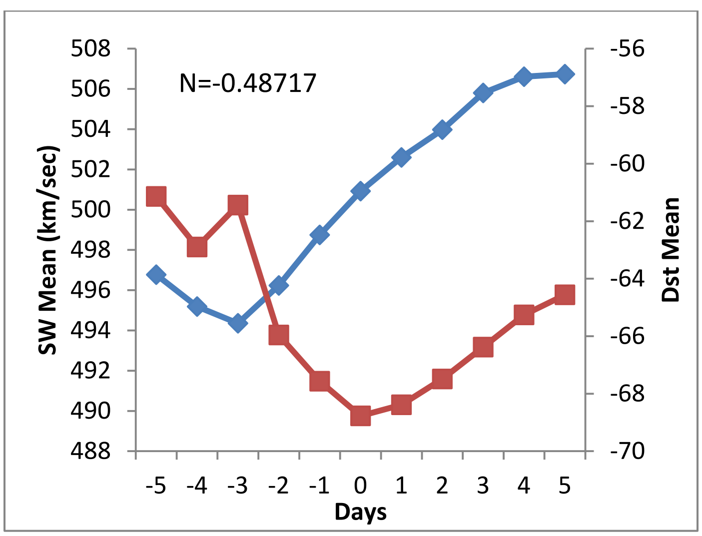

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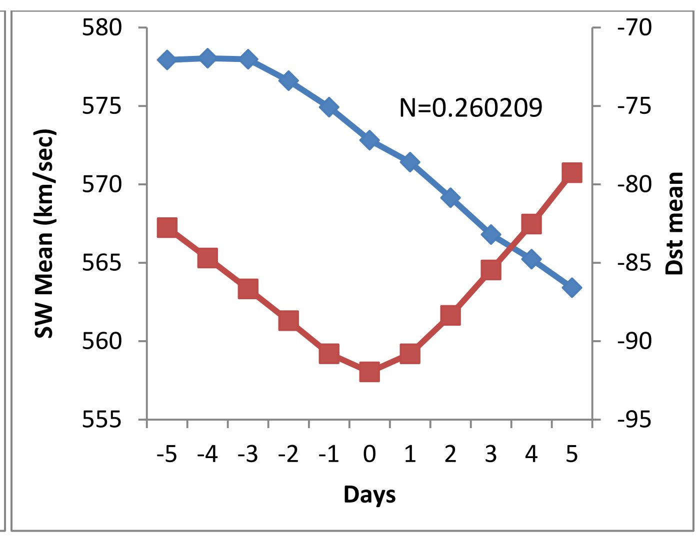

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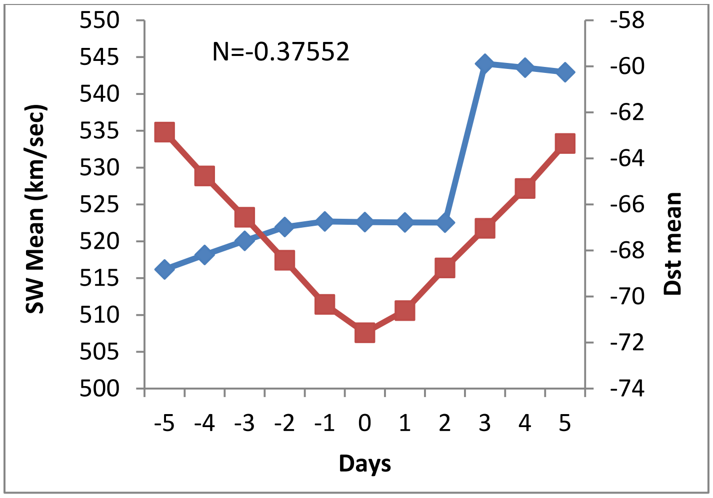

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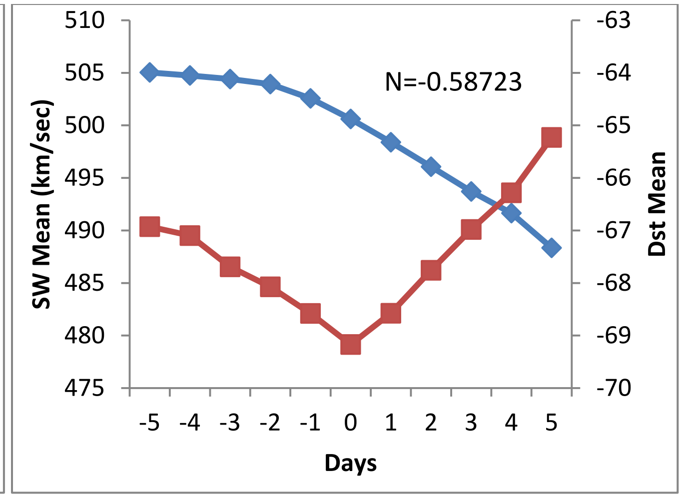

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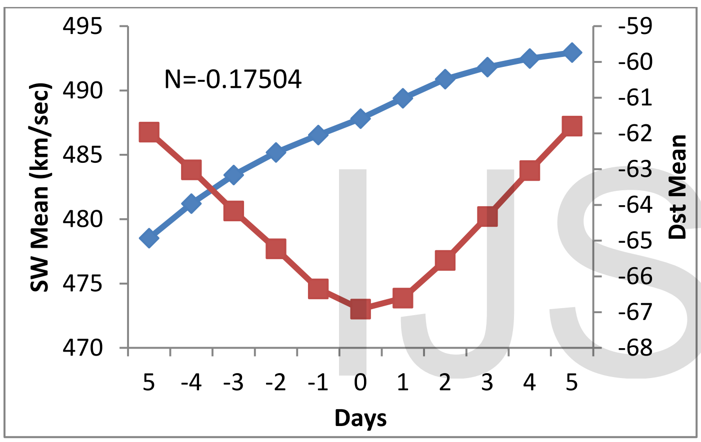

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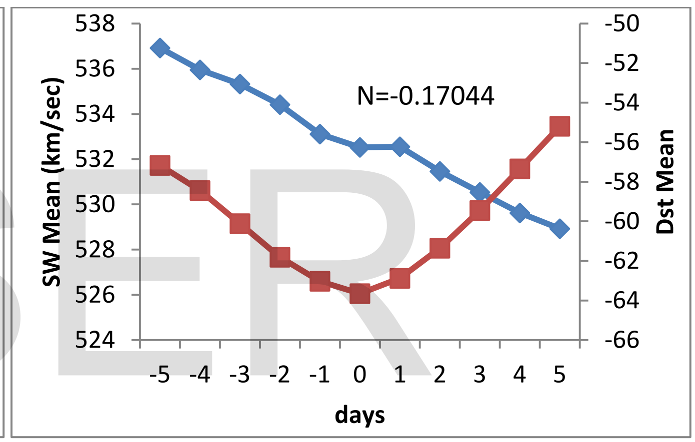

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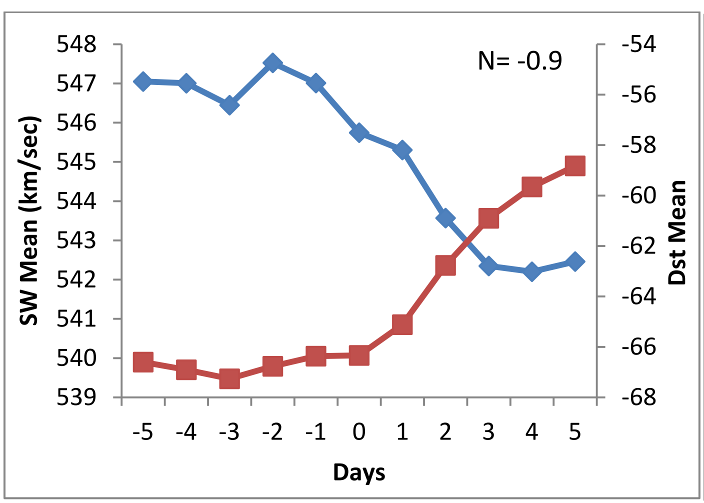

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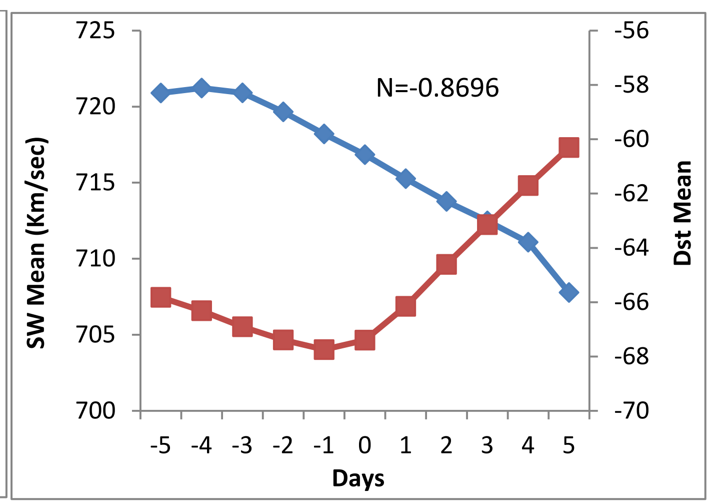

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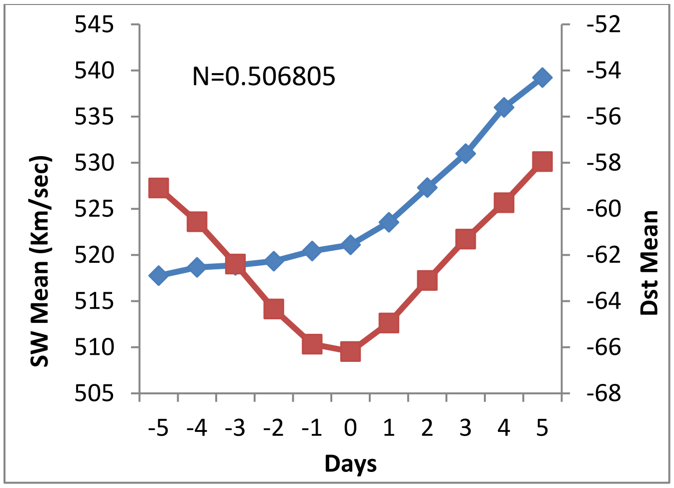

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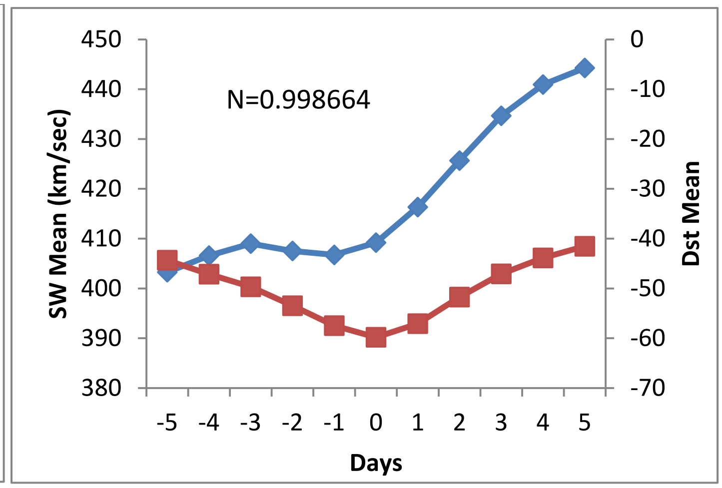

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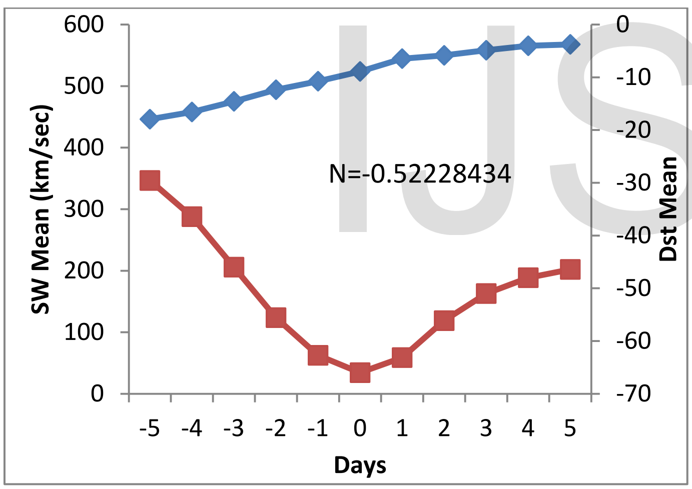
Figure 3 The result of Chree analysis from -6 day to +6 days with respect to zero epoch days.The variation of mean values of SW and Dst is plotted. Zero day corresponds to the starting dayfor the occurrence of geomagnetic storm.



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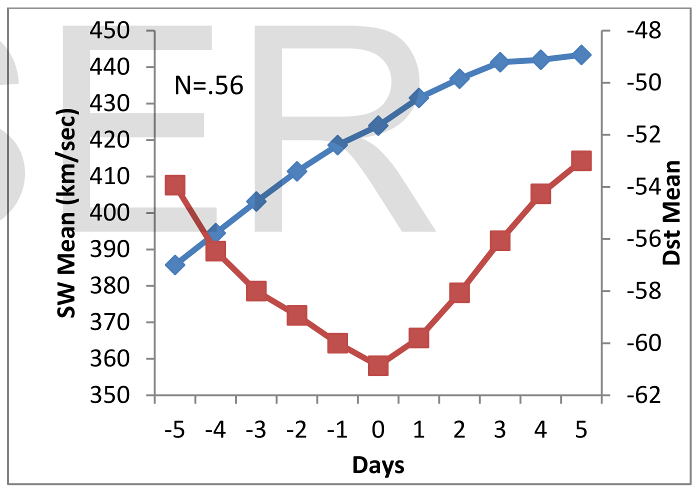

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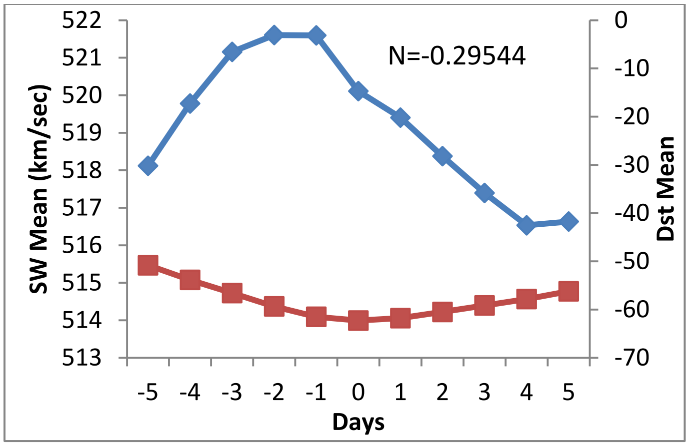

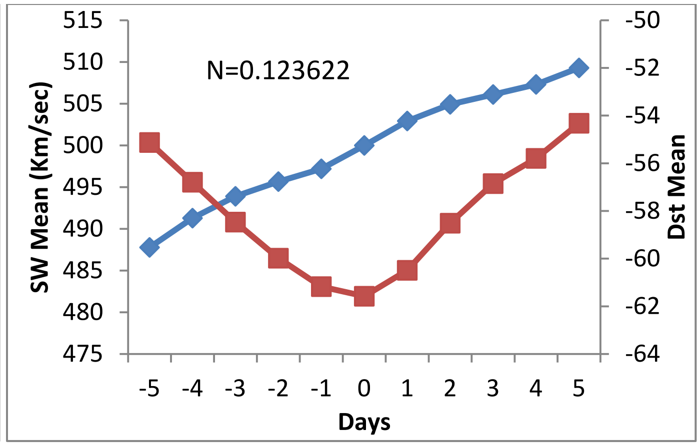

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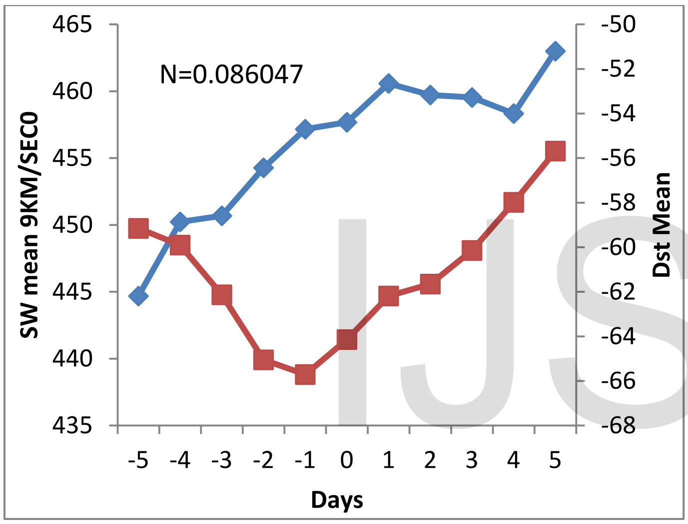

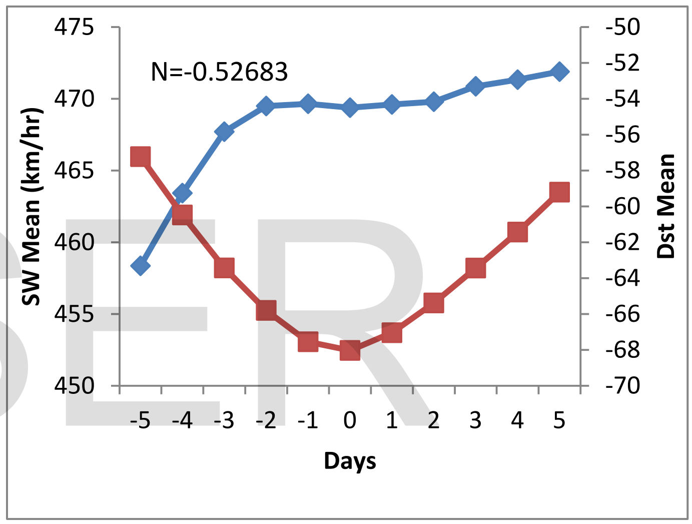

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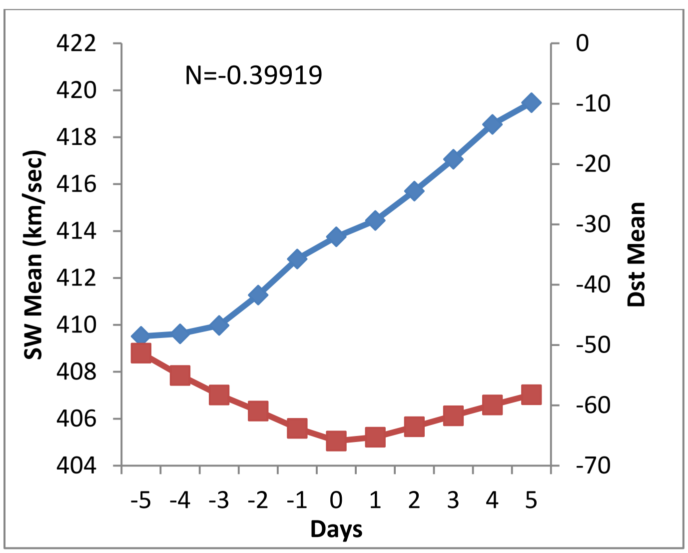

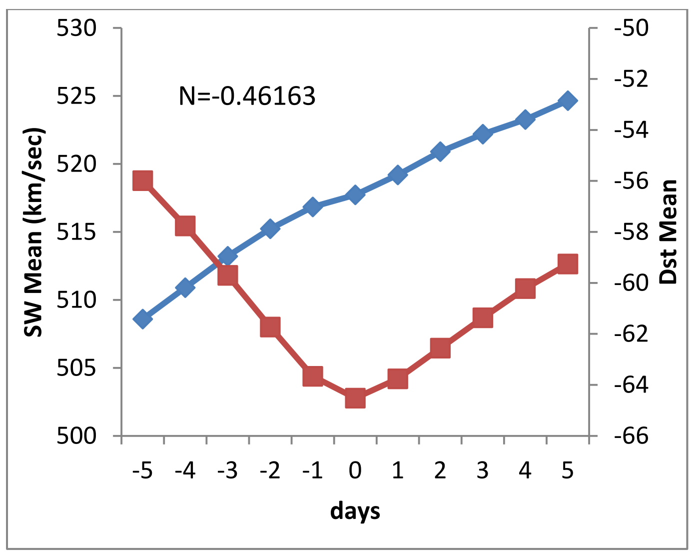

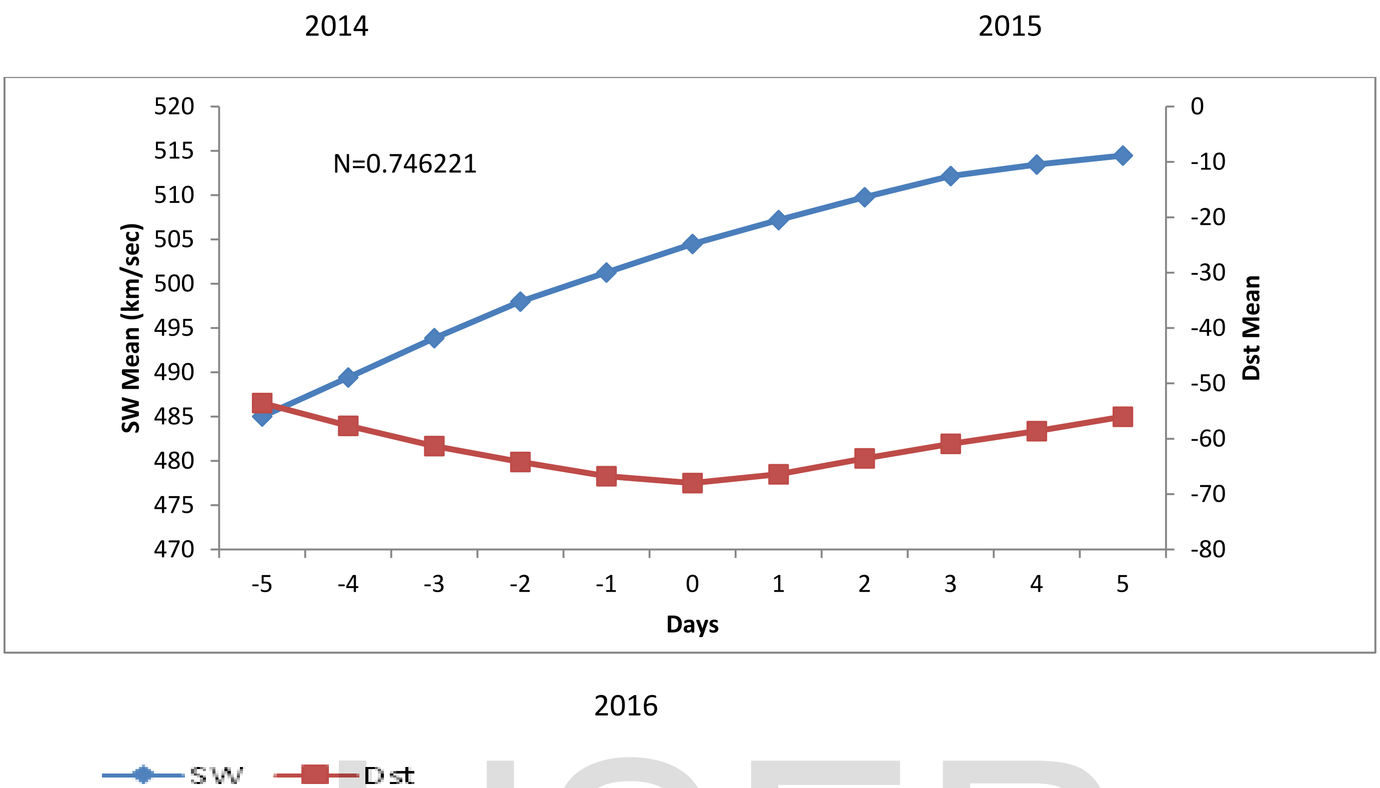

Figure 4.The result of Chree analysis from -6 to +6 days with respect to zero epoch days.The variation of mean values of SW and Dst is plotted. Zero days corresponds to the starting dayfor the occurrence of geomagnetic storm.

Conclusions

In SC 23 for odd years except 2007 positive slope is observed which shows direct relation between SW and SSN. SC 24 also show similar pattern as solar cycle 23 i.e. for the even years negative slope is observed while for odd years positive slope is noticed with few exceptions.

For solar cycle 23 we have observed that the solar wind is decreasing for odd years except 2007 while for even year solar wind is increasing with Dst except 2004.

For solar cycle 24 Years (2011, 2013, and 2014) shows high correlation coefficient while for the years (2008, 2010, and 2015) the value of correlation coefficient is poor for SW and Dst.

On comparing SC 23 with SC 24 except 2010 in all the years SW is increasing with Dst. The average correlation coefficient between SW and Dst for solar cycle 23 (-0.1) and 24 (.09) is found to be poor. The average correlation coefficient between SW and SSN is found to be good -0.9 for SC 24 as compared to SC 23 (-0.5).

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