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Correlation of Sunspot number with Interplanetary magnetic field, Solar wind velocityand Dst

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Abstract-Earth's magnetic field is widely affected by the various phenomenon occur on Earth's mental and core region.Very strong Earthquakes are the results of disturbance (fluctuations) in the Earth's internal region (inner Earth's crust).Volcanoes are the results of eruptions in the mantle region (temperature approximately 1000^0C-3000^0C) on the Earth.Various phenomena occur in the Sun i.e., Solar Wind Plasma (SWP)&Coronal Mass Ejections(CMEs), Solar Proton events(SPEs), Solar radio bursts(SRBs), Sunspots formation, strong Solar flare and Solar radio flux emissions also affects the Earth's magnetic field.Such phenomenon and Sun's huge magnetic fieldchange the Earth-Sun climate effectively.

Keywords- Sunspot number, Interplanetarymagnetic field, Solar wind plasma velocity, Disturbance storm time index

1.Introduction- Khan, S. A., Ahmad, N., Tiwari, C.M., Jyoti, A.K., & Gupta, M. (2021) havestudiedthe Solar cycle distribution of geomagnetic storms during solar cycle 21 to 24 [9].Belov A.V. et al. (2005) have analysedthe relation of global magnetic solar field indices and solar wind characteristics with the long–term variations of galactic cosmic rays [3]. Dubey S.C. & Mishra A.P. (2015)have studied Solaractivityand large geomagnetic disturbances [6]. Gupta Meera and their research group (2007)have examinedthe Solar activity parameters and their interrelationship: Continuous decrease inflare activityfrom solar cycles 20 to 23 [8]. Ahmad, N., Khan, S.A., Singh, G. N., Jyoti, A. K.,Tiwari, C.M.,& Gupta M. (2022) have studied the Geo-effectiveness of solar andinterplanetary featuresduring solar cycles 23 and 24 [1]. Badruddin (2002) examined theeffectiveness of various solar wind parameters in the development of geomagnetic stormsduring interplanetary events [2].Boberg, F. and his collaborates (2005) have studied andanalysed the influence of solar activity cycle on Earth'sclimate [4]. Dan, A. and their investigation group (2014) have studied the Geomagnetic parameterinfluencing geomagnetic stormsin relation to the solar-terrestrial relationship [5].Feynman,J. (1982) have studied thegeomagnetic and solar wind cycles: 1900-1975[7].It has beenobserved that Sunspot number SSNTotal (SIDC-SILSO) positively correlated withSWV, IMF duringSC 21 to SC 24. These parametersare alsopositively correlated with each other. Sunspot numberstrongly anti-correlated withDisturbance stormtime index (Dst).Cross-Correlation CC ≈ -0.39, anegative correlation of weak orlow degree, and SD≈ 5.98 has been observed between SSN and Dst index for solar cycle 24. Thecross-correlationcoefficient between SSN and Dst has been found CC ≈ - 0.73, a negative correlationof middle oraverage degree for SC 21 to SC 24 covering the period 1975to 2021. The correlationbetween IMFand SSN has been recorded as CC ≈ 0.48, 0.76, 0.76 & 0.5 during SC 21, 22, 23 & 24respectively.A positive correlation with a middle or average degree hasbeen observed during SC 21and 24 forthese parameters. A high degree of positive correlation hasbeen recorded during the solarcycles 22and 23.

2.Methods of Analysis and Data Detection Techniques-Solar parameters such as monthly means of Sunspot numbers SSN(Total)have been taken from SIDC-SILSO Belgiumfrom website https://wwwbis.sidc.be.Dst data have been taken from WDC Kyoto. Most of the data have been taken from the website of NOAA (fttp://fttp.ngdc.noaa.gov/STP/SOLAR DATA.html).A detailed correlative study has been performed between solar parameters SSN, SWV, IMF. We have calculated Correlation Coefficient between IMF-SSN, IMF-Dst, IMF-SWV, SWV-SSN, SWV-Dst and SSN-Dst. Cross and linear graph have been plotted between various combination ofIMF-SSN, IMF-Dst, IMF-SWV, SWV-SSN, SWV-Dst and SSN-Dst for SC 24 covering period 2009 to 2020. Linear curve has been plotted for various combination of SSN-SWV, SSN-IMF and SSN-Dst for the period 1975 to 2021 covering SC 21 to SC 24.

3.Results and Discussions-

3.1 Correlationbetween Interplanetary Magnetic Field IMF with SSN, Dst and Solar Wind Velocity (SWV)

3.1.1Correlation between IMFand SSN

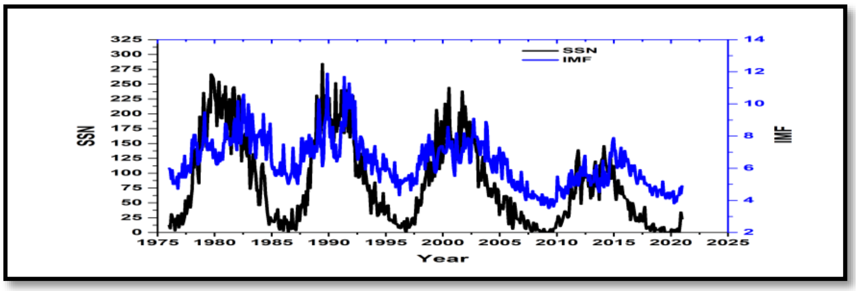

Figure-1 Linear relationship between IMF and SSN for the interval 1975 to 2021

The figure shows the comparative linear graph between yearly averaged values of IMF and SSN. The correlation between IMF and SSN has been recorded as CC ≈ 0.48, 0.76, 0.76 & 0.55 during SC 21, 22, 23 & 24 respectively. A positive correlation with a middle or average degree has been observed during SC 21 and 24 for these parameters. A high degree of positive correlation has been recorded during the solar cycles 22 and 23.This shows the comparative linear graph between yearly averaged values of SSN with IMF.As we know the sunspots are astrophysical phenomenon which is found for a long time and is important measures of SA. The changes in solar variability have being gives the 27-days and eleven-year variations. The earlier workers Ball ester (1999) and Singh et al (2018) observe the periodicity in the sunspot numbers. The magnetic position of bipolar regions remains same in each hemisphere during the 11-year solar activity cycles. These bipolar regions have opposite magnetic orientation in northern and southern hemisphere.

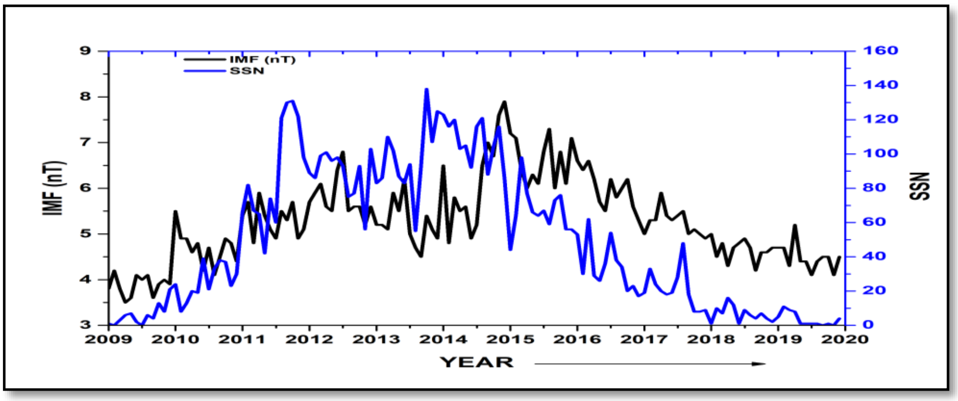

Figure-2 Linear plot between IMF and SSN during the period 2009 to 2020 (SC 24).

The less number of sunspots are observed in solar cycle 24. It is a weaker solar cycle. The figure reveals a strong positive correlation between IMF and SSN. So, in general, a similar pattern and almost linear relationship of strong strength have been observed between both the parameters.The pattern of the graph between both indicesfor solar cycle 24 shows that they are positively correlated. This figure reveals that there is a strong positive correlation between IMF (Bz) and SSN. So, in general there is a similar pattern and almost linear relationship of strong strength between both parameters. The trend line of the cross plot between SSN and IMF index in solar cycle 24 shows that SSN positively correlated with IMF index. We analyze that cross correlation in solar cycle 24 is more effective than solar cycle 23.

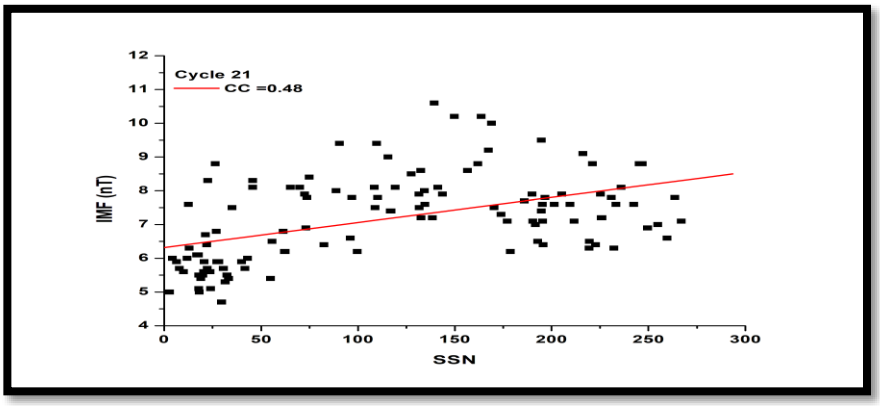

Figure-3 Cross plot between and SSN and IMF for the solar cycle 21.

Fig.3 depicts a positive correlation between SSN and IMF(nT), Correlation Coefficient CC ≈0.48, observed during solar cycle 21.

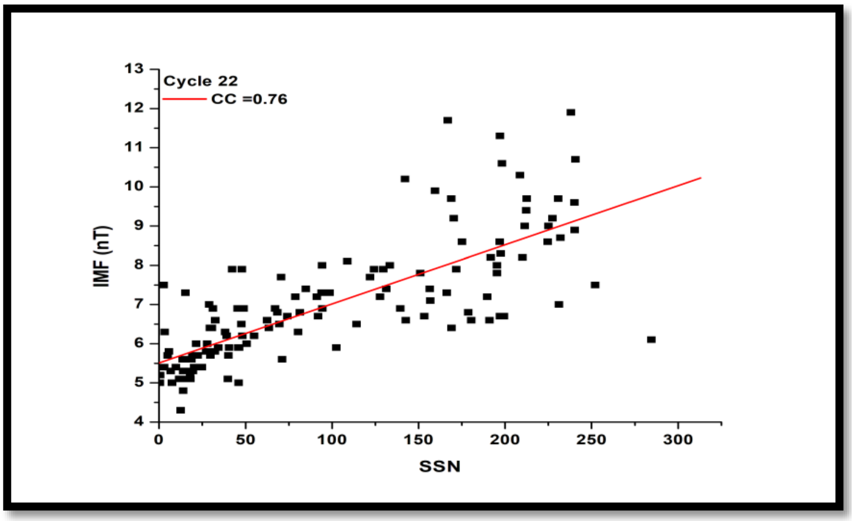

Figure-4 Cross plot between IMF (nT) and SSN for the solar cycle 22.

We have observed the positive correlation between Interplanetary Magnetic Field IMF and Sunspot Number SSN for the solar cycle 22. The correlation coefficient CC ≈ 0.76.

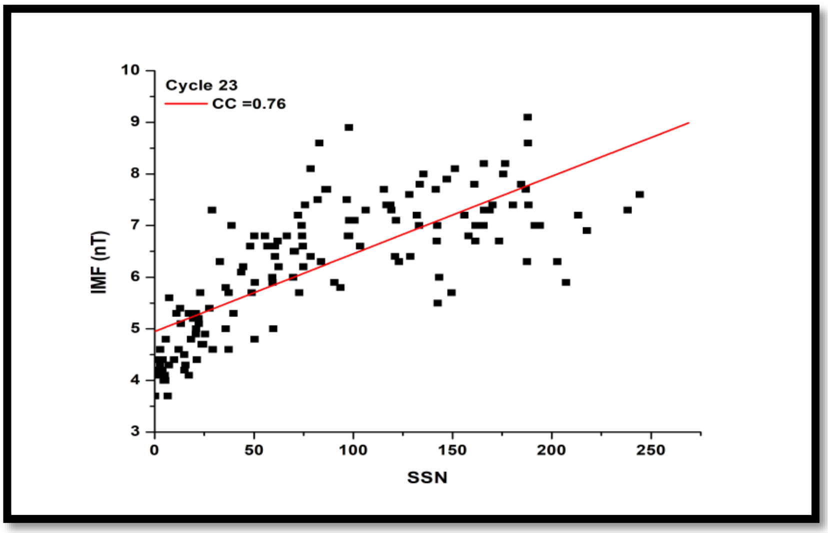

Figure-5 Cross plot between IMF (nT) and SSN for SC 23.

Strong positive correlation, CC ≈ 0.76, observed between Interplanetary Magnetic Field IMF and SSN for the solar cycle 23.

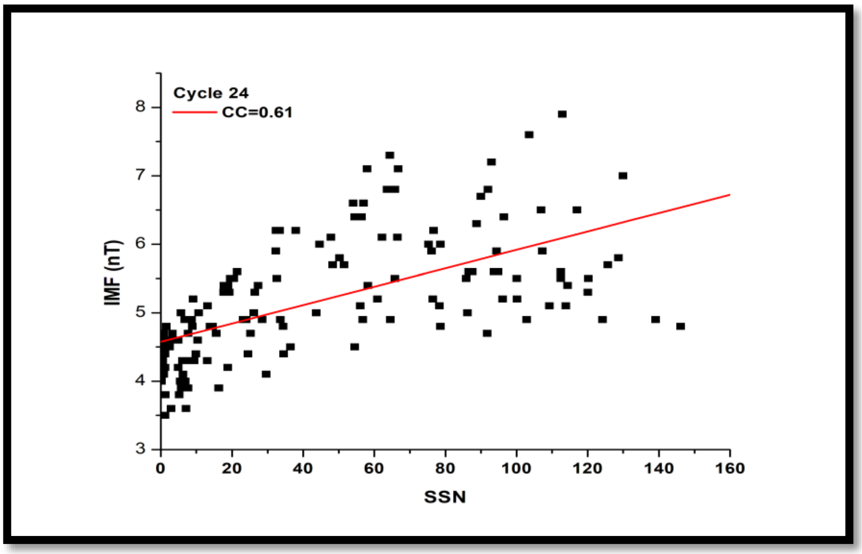

Figure-6 Cross plot between IMF (nT) and SSN for the solar cycle 24.

Peak of IMF (nT) and SSN shows the high cross-correlation during the solar cycle 24. The graph shows a cross plot between the IMF index and SSN for the solar cycle 24. The trend line shows that SSN positively correlated with the IMF index. The cross-correlation between IMF and SSN, CC ≈ 0.61 has been recordedduring the investigation period SC 24. A positive correlation with a middle or average degree and SD ≈ 34.72 has been calculated for this period.

3.1.2 Correlation between IMF and Dstindex for solar cycle 24

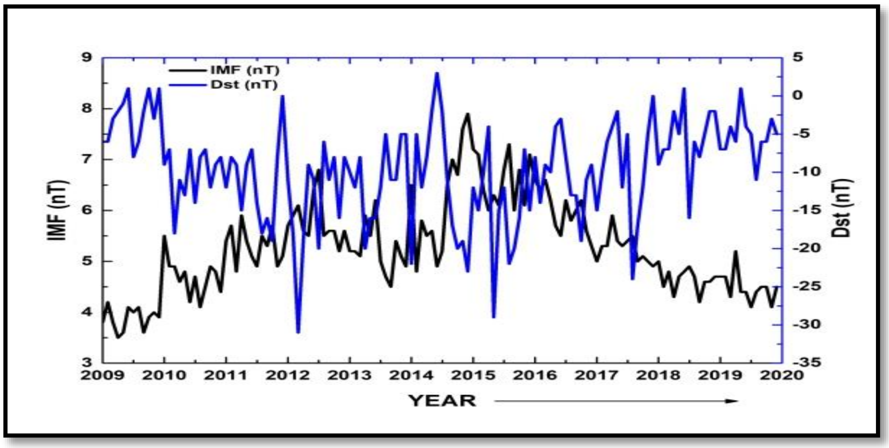

Figure-7 Linear plot between yearly averaged IMF and yearly averaged values of Dst parameter for the solar cycle 24 (January 2009 to 2020).

The graph depicts a negative pattern (anti-correlation) between IMF and Dst index, which shows an inverse relationship of moderate degree or strength between both the parameters during solar cycle 24.

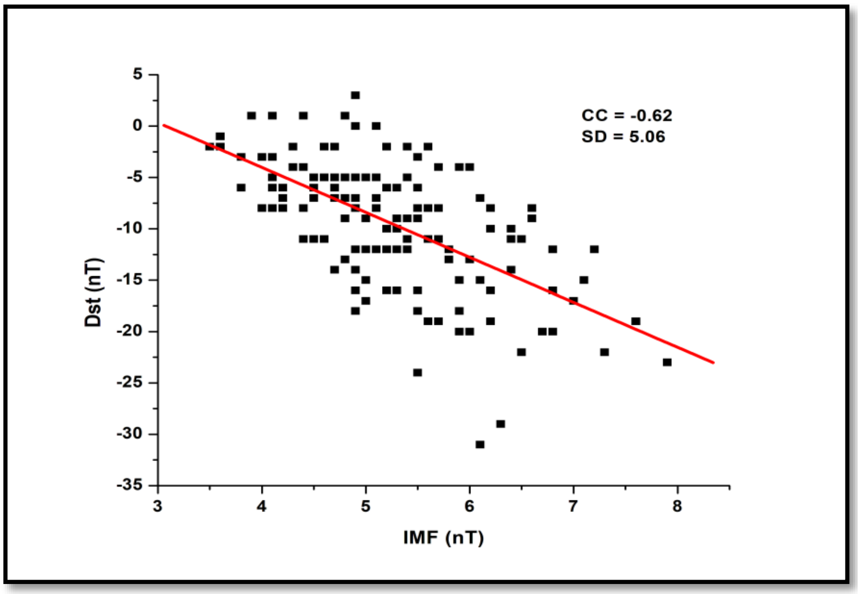

Figure-8 Cross plot between average values of IMF and Dst for the solar cycle 24.

The graph reveals that the IMF and Dst indices both are anti-correlated during solar cycle 24. CC ≈ -0.62, the negative correlation of middle or average degree, and Standard Deviation SD ≈ 5.06 have been recorded during this period.The cross-correlation between interplanetary magnetic field IMF and Dst index has been recorded as CC ≈ -0.50, -0.69, -0.61 & -0.62 during SC 21, 22, 23 & 24 respectively. A negative correlation with a middle or average degree has been recorded during the period March 1976 to December 2021, which covers SC 21 to SC 24 for these parameters.

3.1.3 Correlation between IMF and Solar Wind Plasma Velocity (SWV)

Geomagnetic disturbances are driven by the interaction of solar wind-magnetosphere couplings. Solar wind energy is injected into the magnetosphere through a field line merging the IMF and geomagnetic field. This energy injection is most efficient during southward IMF. Over long periods of strong IMFwill trigger geomagnetic storms. Usually,Bz ≥ 10nT lasting for 3 hours will always generate a geomagnetic storm.The creation of a geomagnetic storm demonstrates a strong positive correlation with the product of IMF and solar wind velocity (V), VBz. Two types of solar surface phenomena are believed to generate high VBz conditions; coronal mass ejections (CME) and coronal holes.

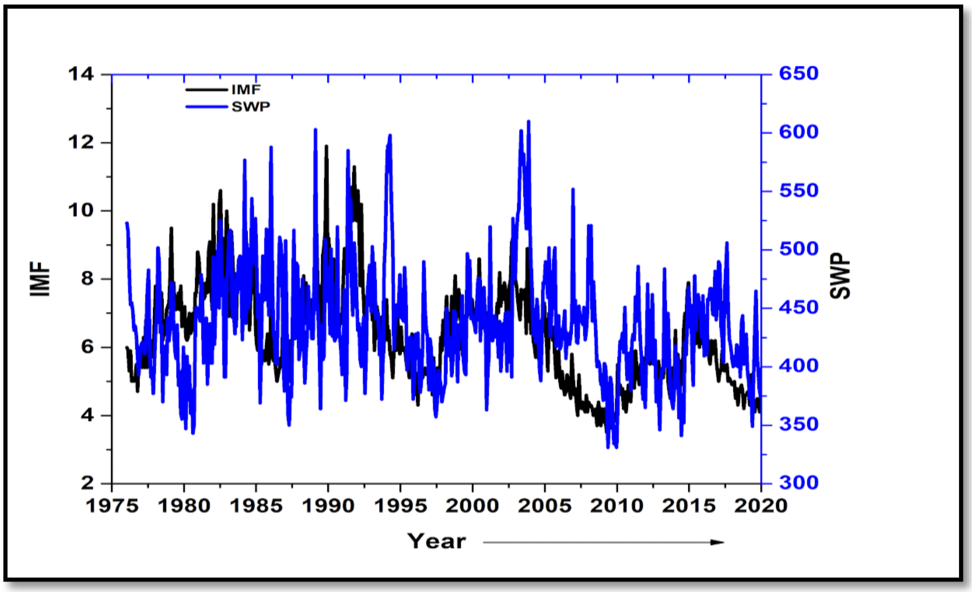

Figure-9 Linear relationship between IMF & SWP for the interval 1975 to 2021.

The correlation betweenIMF and SWPhas beencalculated during the period 1975 to 2021. The Correlation Coefficient CC ≈ 0.48, a positive correlation of weak or low degree, and a Standard Deviation SD ≈ 33.08 have been recorded during this period.

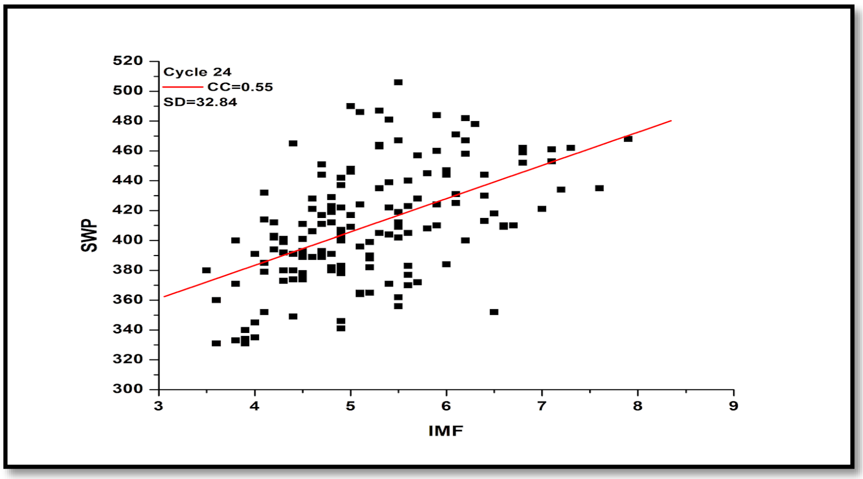

Figure-10 Cross plot between IMF & SWP during the solar cycle 24.

A positive correlation has been observed between interplanetary magnetic field IMF (nT) and Solar wind plasma speed during solar cycle 24. CC ≈ 0.55, a positive correlation of middle or average degree, and standard deviation SD ≈ 32.84 has been calculated during this period.During SC 21, 22, 23 & 24 the cross-correlation between interplanetary magnetic field IMF & Solar wind plasma speed has been recorded as approximately CC ≈ 0.30, 0.32, 0.35 & 0.55 respectively. A positive correlation with a middle or average degree has been recorded during this period for these parameters.

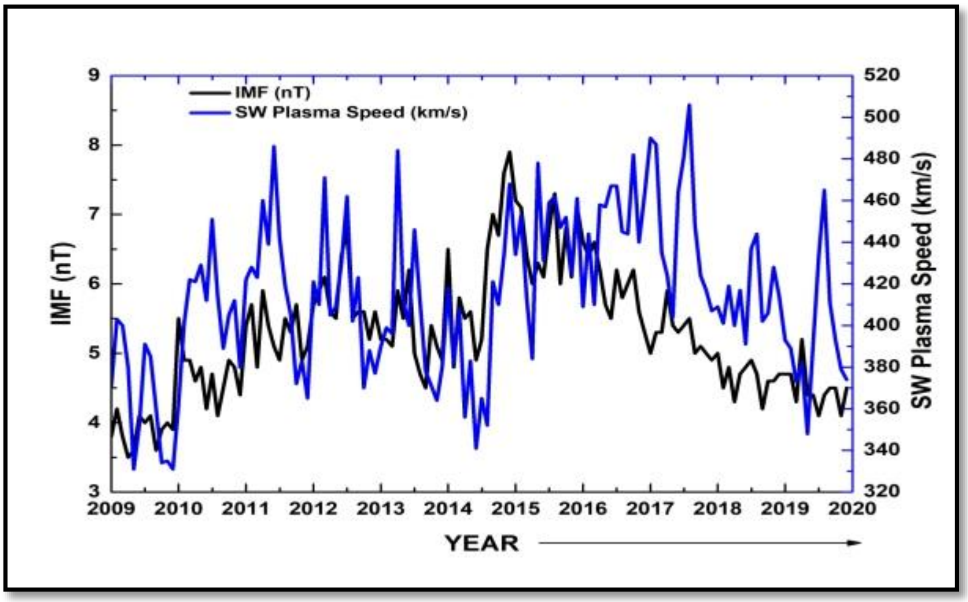

Figure-11 Linear plot between IMF and solar wind plasma speed SWV for the solar cycle 24 (January 2009 to 2020).

A positive correlation (CC ≈ 0.55)has been observed between the Interplanetary magnetic field IMF and Solar wind velocity SWVduring the period from January 2009 to 2020 (SC 24). A linear weak strength correlation has been recorded between both indices during this period. Figure reveals that during ascending period of solar cycle 24, the value of SWV decreases unevenly and almost the same patternsfollow during the descending period of solar cycle 24. SWV shows its peak value in July 2017.The figure reveals that during ascending period of solar cycle 24 the value of SWV decreases unevenly and almost same thing happen during descending period of solar cycle 24. SWV shows its peak value in year 2008 and during year 2016.

The SWV decreases in 2009, increases in 2010 and then varies almost linearly up to 2014. In the declining phase of the solar cycle, decreases continuously. The southward component of IMF (Bz) decreases in the early period of the rising stage till the year 2010 and reaches its peak value in 2011 and 2014. In the declining stage, the value starts to increase again. Thus, graph reveals that the two indices are correlated negatively. It is observed that the same situation is expected during descending stage of SC 24 same as solar cycle 17. The geomagnetic disturbances are related with solar outputs in the sun's surface and gives the energy by SWV and IMF due to the heliosphere. SWV and IMF controls the electrodynamics of the heliosphere. In this analysis we use cosmic ray intensity and different solar heliospheric and geomagnetic indices for the SCs 21 to 24.

3.2 Variation of Solar wind plasma velocity with SSN and Dst during solar cycle 24

3.2.1 Variation of Solar wind plasma velocity with SSN

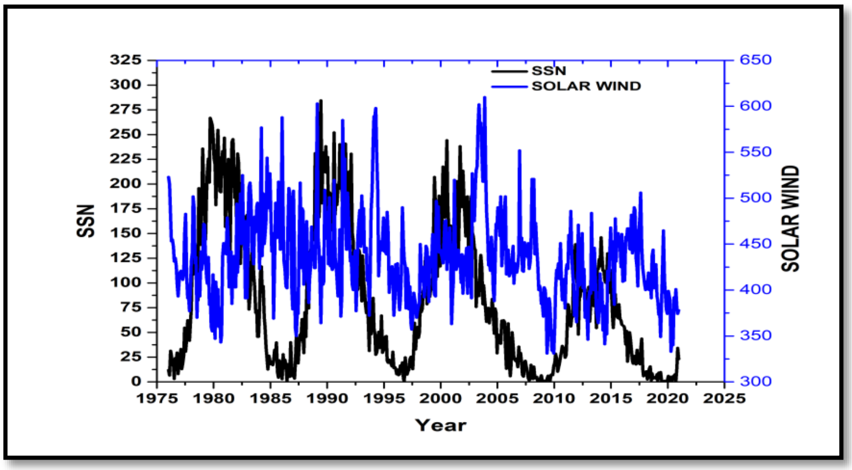

Figure-12 Linear relationship between Solar Wind Speed and SSN for the interval 1975 to 2021.

From the graph, it is clear that solar wind speed neither shows a clear phase relationship nor correlates with the sunspot numbers but shows a wide range of periodicities that could be connected to the pattern of coronal hole configuration. The characteristics of solar wind velocities reveal the solar activity and variations. The changes in activity on the surface of the sun cause variations in the solar wind output by the corona. Solar wind in the groups is modulated by solar rotation and related to solar long-life magnetic structures.

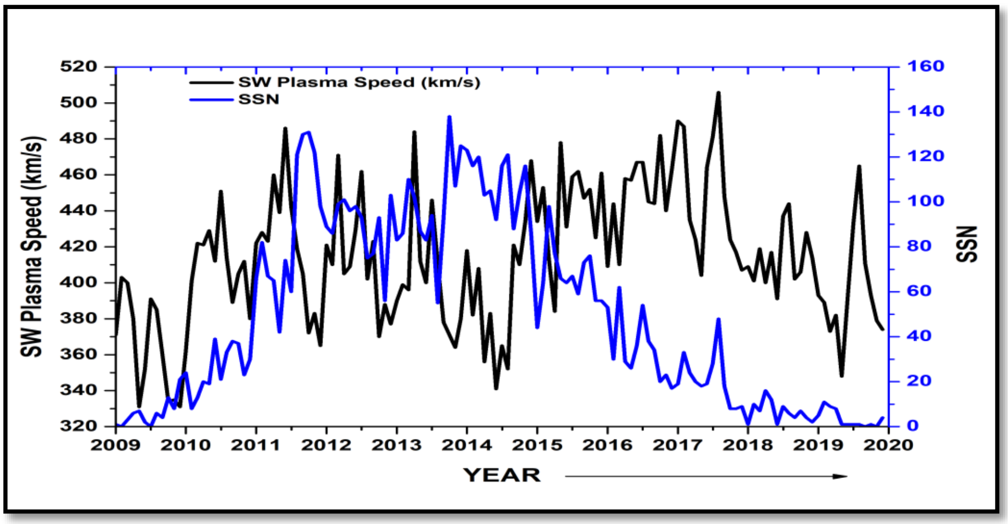

Figure-13 Linear plot between Solar Wind Plasma Speed and SSN for the solar cycle 24.

The graph shows a weak positive correlation between Solar wind plasma speed and SSN for the period 2009 to 2020. Since solar cycle 24 is weak, only fewer sunspots are found but the high intensities of solar wind speed are observed in solar cycle 24. Solar maxima follow a similar mode. The figurereveals that during ascending period of solar cycle 24, the value of SWV decreases unevenly and almost the same patterns also follow during the descending period of the same cycle.

3.2.2 Variation of Solar wind plasma velocity with Dst

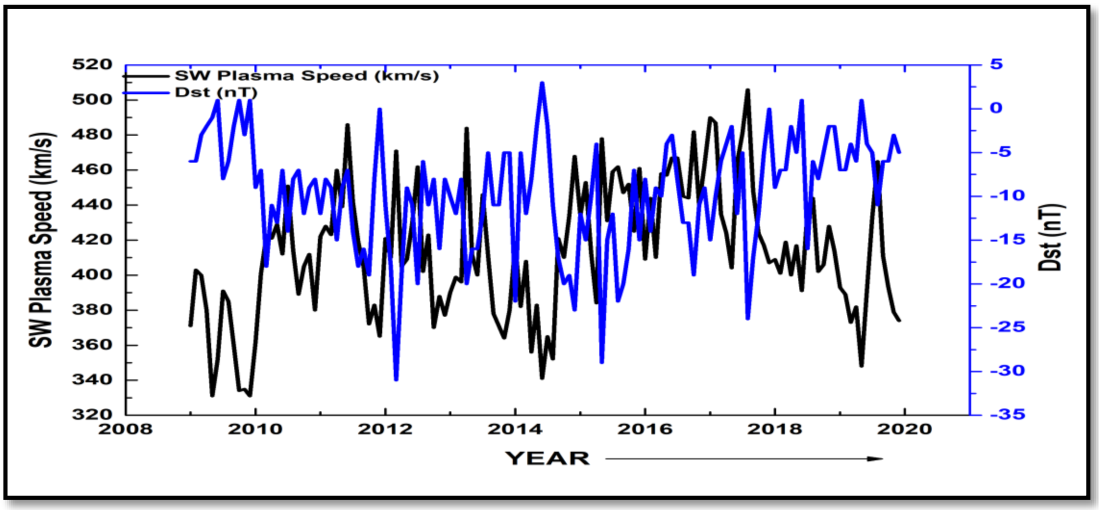

Figure-14 Linear plot between Solar Wind Plasma Speed and Dst (nT) index for the solar cycle 24.

The Dst index is an assessment of the geomagnetic movement or exertion. A negative value of Dst means, Earth's magnetic field is weakened, which is observed mainly during solar storms. There exists an inverse relation between Dst and solar wind speed, with some time lag.

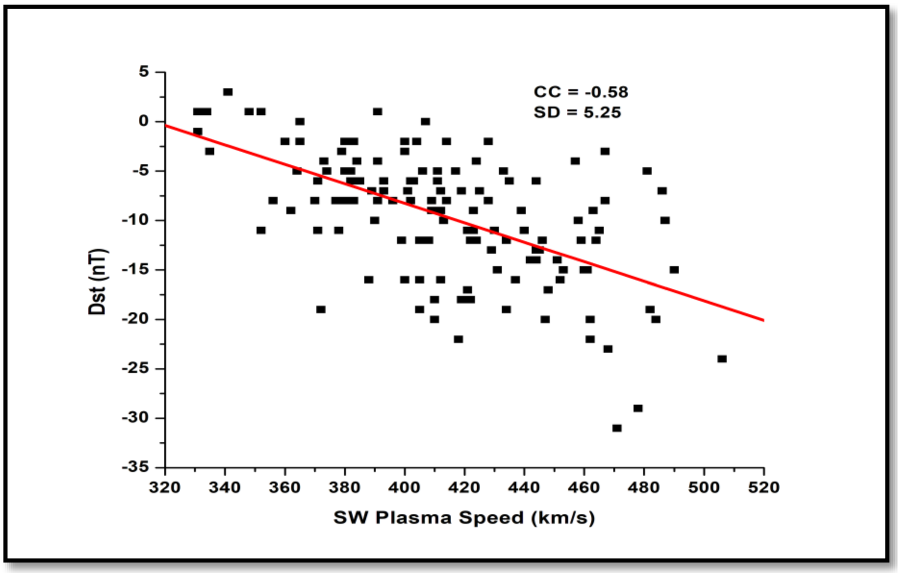

Figure-15 Cross plot between Solar Wind Plasma Speed and Dst for the solar cycle 24.

The graphshows the SW plasma variation with the annual mean variation in the Dst index during solar cycle 24 fromthe year 2008 to 2020. It has been observed that both indicesare negatively correlatedduring the period of study. The cross-correlation coefficient has been calculated as CC ≈ -0.58, and the negative correlation of middle or average degree has been calculated between these indicesand SD ≈ 5.25.

Its value starts increasing in the initial stage of ascending phase of the cycle till 2009 and then starts decreasing. It attains its smallest value in the year 2012 and again in the year 2015 its value decreases leading to a severe storm on 17th March 2015. In the decline of the cycle, the value tends to increase corresponding to low geomagnetic activity. The graph reveals that SWP increases in the ascending phase of the cycle attains its peak value in the year 2014, and starts decreasing in the decreasing phase of the cycle. The Dst index decreases in the rising phase of the cycle, reaching 42 to its minimum value in the year 2015. In the descending phase of the solar cycle the Dst index increases.

3.3Variation of Sunspot number and Dst parameter

Figure reveals that during the arising phase of the solar cycle 24, the Dst index leads towards a positive value and then it shows its negative peak in the middle of the cycle in the year 2012 and another strong negative peak (means the magnetic field of the Earth reaches minimum) observed in the year 2015. While in descending phase of the cycle, the value of Dst is almost the same as the value during the rising phase of cycle 24.

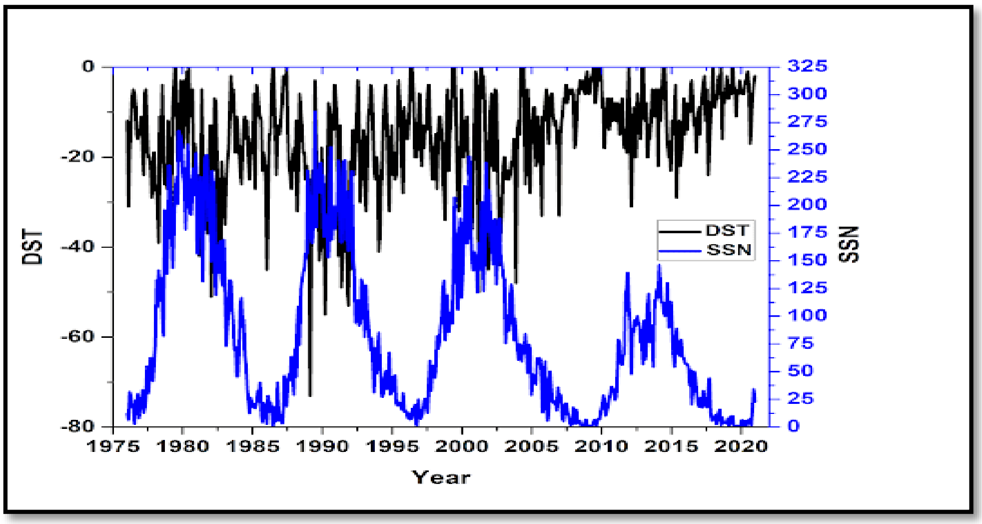

Figure-16 Linear relationship between SSN and Dst for the interval 1975 to 2021.

The Solar activity follows an eleven-year cyclic variability. The long-term variation in solar activity has a direct impact on the geomagnetic activity.The cross-correlation coefficient between SSN and Dst has been found CC ≈ - 0.73, a negative correlation of middle or average degree for SC 21 to SC 24 covering the period 1975 to 2021. The standard deviation has been reported as SD ≈ 4.43 between both indices for the same period (both the curves follow opposite phases).

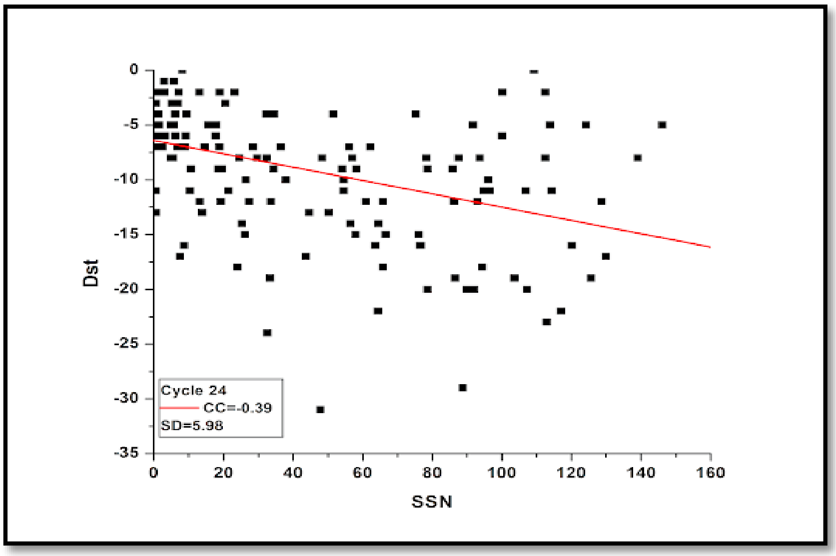

Figure-17 Cross plot between SSN & Dst during the solar cycle 24.

The correlation between SSN and Dst parameters has been calculated during solar cycle 24 (December 2008 to December 2019). In general, the Cross-Correlation CC ≈ - 0.39, a negative correlation of weak or low degree, and SD ≈ 5.98 has been observed between SSN and Dst index for this solar cycle. The SSN is found to increase with disturbance storm time Dst index for most of the period of solar cycle 24.

It is noticeable that in year 2015 the Dst minimum occurred with maximum of SSN index and both SSN approach almost towards the same value at the end of the cycle as is during inclining phase of cycle 24.

Table-1 Correlation between Interplanetary magnetic field IMF with SSN, Dst and SWV

Parameters	**Correlation Coefficient C(t)**			
	SC21	**SC22**	**SC23**	**SC24**
IMF-SSN	0.48	0.76	0.76	0.55
IMF-Dst	-0.5	-0.69	-0.61	-0.62
IMF-Solar Wind Plasma Speed	0.30	0.32	0.35	0.55

Table-2 Correlation of Dst parameter with Solar Wind Velocity and Sunspot Number (SSN) during SC 21 to SC 24.

Parameters	**Correlation Coefficient C(t)**			
	SC21	**SC22**	**SC23**	**SC24**
Dst-Solar Wind Velocity	-0.37	-0.61	-0.42	-0.61
Dst-SSN	-0.13	-0.47	-0.36	-0.39

4.Conclusions-It is clear that interplanetary magnetic field IMF positively correlated with Sunspot number and Solar wind plasma speed. The Correlation between IMF and SSN is strong for SC 22 and 23. Interplanetary magnetic field IMF, SSN and SWVnegatively correlated withDst parameter.Correlation between IMF and Dst is of average degree. SWV and SSN positively correlated with each other but correlation is weak during the period 1975 to 2021.

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