# Correlative Study of Sunspot Number with Interplanetary Magnetic Field During Solar Cycle 24

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**Abstract**: The structure and dynamics of the heliosphere are determined by the solar magnetic activity that has a powerful impact on the near space conditions around the Earth. The sunspots number is a commonly used measure of the magnetic activity of the solar surface and the interplanetary magnetic field is the measure of the extension of this activity into space in the form of the solar wind.In this paper, a correlative study of sunspots numbers (SSN) and the magnitude of the interplanetary magnetic field (IMF) is provided, with regard to the Solar cycle 24 (2008-2019), which has been marked by exceptionally low magnetic activity. The correlation between the solar surface magnetic activity and the heliospheric magnetic conditions around the earth was studied by comparing monthly mean sunspot numbers of SILSO database and interplanetary magnetic field data of OMNI database. Time-analysis comparison of SSN and IMF reveals that both are affected by solar cycle variations, with an even stronger IMF strength usually being observed when the sunspots are active. The variability of IMF has however very large short-term oscillations at the solar maximum, and declining phases, which suggests the effects of transient and recurring solar wind structures. The statistical analysis done on the basis of Pearson correlation coefficient shows a moderate positive correlation between SSN and IMF magnitude during the whole cycle. Phase-wise analysis indicates a higher correlation in rising phase and lower correspondence in the maximum and declining phases owing to growth in the contribution of coronal mass ejections and high-speed streams of the solar wind. Such findings imply that although the sunspots numbers continue to be one of the most important indicators of the solar magnetic activity, the behavior of interplanetary magnetic fields is also dictated by the large-scale processes taking place in the heliosphere particularly during the weak cycles. The results also help in understanding solar-interplanetary coupling better, and have significant implications on the modeling of the heliosphere as well as space weather prediction.

**Keywords**: Sunspot number, Interplanetary magnetic field, Solar cycle 24, Solar activity,Heliospheric magnetic field, Solar wind, Space weather.

## INTRODUCTION

Hydroelectric activity of the Sun is caused by the complicated and changing magnetic field, which constantly evolves on various temporal and spatial levels (Lockwood, 2013)[1]. Among the most apparent results of this magnetic activity, the sunspots on the solar surface should be mentioned. Sunspot number (SSN) is one of the most widely used indicators of measuring solar activity as it is used to measure the intensity and structure of the solar magnetic fields at the photosphere. Solar long-term variability and impacts on the heliosphere since the time systematic observations were first made have greatly depended on sunspot number. There is a temporal change in the sun spot number with an approximate cycle of 11 years with variations between the solar minimum and solar maximum. When the Sun has a high number of sunspots, the Sun becomes more complex in terms of magnetism, experiences more solar wind events, and eruptive events on the Sun, including solar flares and eruptions known as coronal mass emissions (CMEs)(Zhang et al., 2021)[2]. These processes play a large role in affecting the interplanetary environment and also cause fluctuations of the interplanetary magnetic field.

The Interplanetary Magnetic Field (IMF) is formed by the solar magnetic field, but it is expelled by the solar wind into the space between planets. An overall interaction of solar rotation and plasma flow causes the IMF to take a helical shape in the form of a Parker spiral as the solar wind flows out radially away from the Sun(Clette& Lefèvre, 2016)[3]. The scale and direction of IMF are thus highly reliant on the large scale solar magnetic field arrangement and the solar wind. Fluctuations in IMF parameters are of importance in regulating the interaction of the solar wind and the magnetospheres of the planets, especially that of Earth. Learning the correlation between the number of the sunspots and the interplanetary magnetic field is critical in explaining the mechanisms that convey solar magnetic activity to the heliosphere. Although the sun spot number measures the activity of the magnetism at the surface of the sun, IMF measures the spread of the magnetic activity of the sun into space between earth and the sun. Correlational study of these two parameters assists in closing the gap existing between phenomena on the surface of the Sun and the dynamics of the heliosphere. Ashutosh Kumar Tiwari et al. (2025) observed the correlation between cosmic ray intensity CRI and a number of solar wind (SW) indicators, GSs, IMF-B, Ap index, and SSN [4]. Kumar, Ashok et al, (2024) found that the magnetic field in the Earth is generally influenced by the numerous phenomenons that take place in the mental and core part of the earth [5]. Goyal, Sanjay et al (2023) studied the correlation between sunspots numbers (Rz), IMF and geomagnetic indices was positive. IMF, sun spot number and indices are most variable between the onsets of cycle till the cycle conclusion [6].Abha Singh et al. (2021) studied that the solar magnetic field causes all the solar activities [7]. Jothe, M.et al. (2015) observed the CRI and SSN have high and negative correlation coefficients (r= -0.78) that change randomly each year Equally important, X-rays and UV radiations released by solar flares [8].

Other previous studies have indicated that there are some inconsistencies of coefficient of correlation among sunspot number and IMF strength, solar wind speed, and geomagnetic indices. These relationships are however not necessarily linear and can vary with each solar cycle. The observed correlations can be affected by changes in the heliospheric structure, transient solar events, and reversal of the polarity of the magnetic field of the sun (Gonzalez &Tsurutani, 1987)[9]. Thus, a closer look at solar cycle by cycle is significant in order to receive cycle-specific information. Solar cycle 24 that lasted between around 2008 and 2019 was significantly less active than previous solar cycles in sunspots and the general level of solar magnetic activity. This abnormally low activity level gives a special background to its study of solar-interplanetary interaction in a weak solar cycle. Analysis of the relationship between the number of sunspots and the IMF parameters in this period can be used to determine whether the decrease in solar activity results in similar decreases or different behaviour of the interplanetary magnetic field properties.

The main aim of our work is to carry out the statistical correlation analysis of the parameters of the interplanetary magnetic field and sunspots number during the Solar Cycle 24. This work will measure the strength of association between these variables using long-term observational data, which would study the temporal changes of these variables during the cycle. It is hoped that the findings of this work will improve the knowledge of the magnetic field propagation in the solar and can be used to come up with better models of heliospheric variability and space weather forecasting.

## METHODS AND TECHNIQUES

### Data Sources

The current research adopted long-term observational records of sunspots number and interplanetary magnetic field (IMF) parameters in Solar Cycle 24 to determine the correlation between these two parameters. Solar Cycle 24 is typically deemed to stretch between January 2008 through December 2019 through the rising phase, the solar maximum, and the cycle decline stage (Hathaway, 2015)[10].The World Data Centre of the Sunspot Index and Long-term Solar Observations (SILSO), Royal Observatory of Belgium was used to acquire the sunspot number (SSN) data. The SILSO dataset is a source of internationally standardized continuously updated sunspots numbers, thus it is among the most reliable sources of solar activity. In this study, the monthly mean sunspots numbers were employed so as to minimize the short-term variations and focus on the long-term variations in the solar cycles.The OMNI has NASA Space Physics Data Facility as its keeper and provides the interplanetary magnetic field (IMF) data. The OMNI database puts together near-Earth solar wind and IMF measurements of various spacecrafts and time-shifts them to the bow shock of the Earth to give a consistent and continuous data.(King &Papitashvili, 2005)[11]. The magnitude of the IMF total (IMF) was chosen as the main IMF parameter to be used in this study because it is the overall strength of the interplanetary magnetic field, and has been extensively deployed in heliospheric studies.

**Data Processing**

Both IMF data and sunspot number have been collected on similar time span to achieve similarity in the data sets. Means of IMF were calculated every day and then averaged to get monthly averages which corresponded with the time resolution of the sun spot number data. This method can reduce the effect of the short-term fluctuation of the transient solar wind and temporary variations that happen due to the individual occurrences like coronal mass ejections.(Emery & Thomson, 2001)[12].The IMF data had gaps and missing values and these were scrutinized. Months that had low data coverage were not included in the analysis in order to prevent the introduction of bias in the correlation results. The resultant time series was a continuous monthly values series that covered the Solar Cycle 24 in its entirety.

**Statistical Methods**

The correlation analysis was used to determine the relationship between the sunspot number and the interplanetary magnetic field. To measure the level of linear relationship, Pearson correlation coefficient (r) was used to determine the extent level of linear relationship between the two variables. The Pearson technique is appropriate when the researcher is seeking the strength and direction of the correlation between continuous datasets and has mostly been applied in solar-terrestrial studies.(Bendat& Piersol, 2010)[13].

The correlation coefficient has been calculated by using the standard formula:

$$r = \frac{\sum(SSN_i - S\bar{S}N)(IMF_i - I\bar{M}F)}{\sqrt{\sum(SSN_i - S\bar{S}N)^2 \sum(IMF_i - I\bar{M}F)^2}}$$

where $SSN_i$ and $IMF_i$ represent monthly values of the sunspot number and IMF magnitude respectively, and the overbars represent the mean values.The time-series analysis of the temporal behaviour of the two parameters was also performed in addition to the overall correlation of the entire solar cycle. This enables one to identify similarities and differences in their development at various stages of the solar cycle such as the rising stage, solar maximum stage and declining stage. (Chatfield, 2004)[14].

### Graphical Representation

The relationship between IMF parameters and sunspots number was studied visually by the help of graphical methods. Time-series plots were created in order to compare the change in monthly mean sunspots number with the IMF magnitude during Solar Cycle 24. Scatter plots were also made to demonstrate the correlation between the two variables as well as evaluate the nature of their relationship. The graphical representations are an add-on to the statistical analysis, and they give an intuitive understanding of the relationship between the interplanetary magnetic field behaviour and solar surface activity. (Wilks,2011)[15].

### Software Tools

All data calculation, statistics, and graphical representation were done with conventional data analysis programs like Python/MATLAB. These were used in averaging data, computing correlation and creating publication quality figures.

## RESULTS AND ANALYSIS

### Temporal Evolution of Sunspot Number in Solar Cycle 24.

Figure 1 gives the temporal variation of the monthly average sunspot number (SSN) of Solar Cycle 24. It starts with a long and unusually deep sun minimum in 2008-2009 with very low levels of sunspots. This long minimum is characteristic of the Solar Cycle 24 and it shows the poor state of the magnetic field that the cycle started with (Pesnell, 2016)[16].

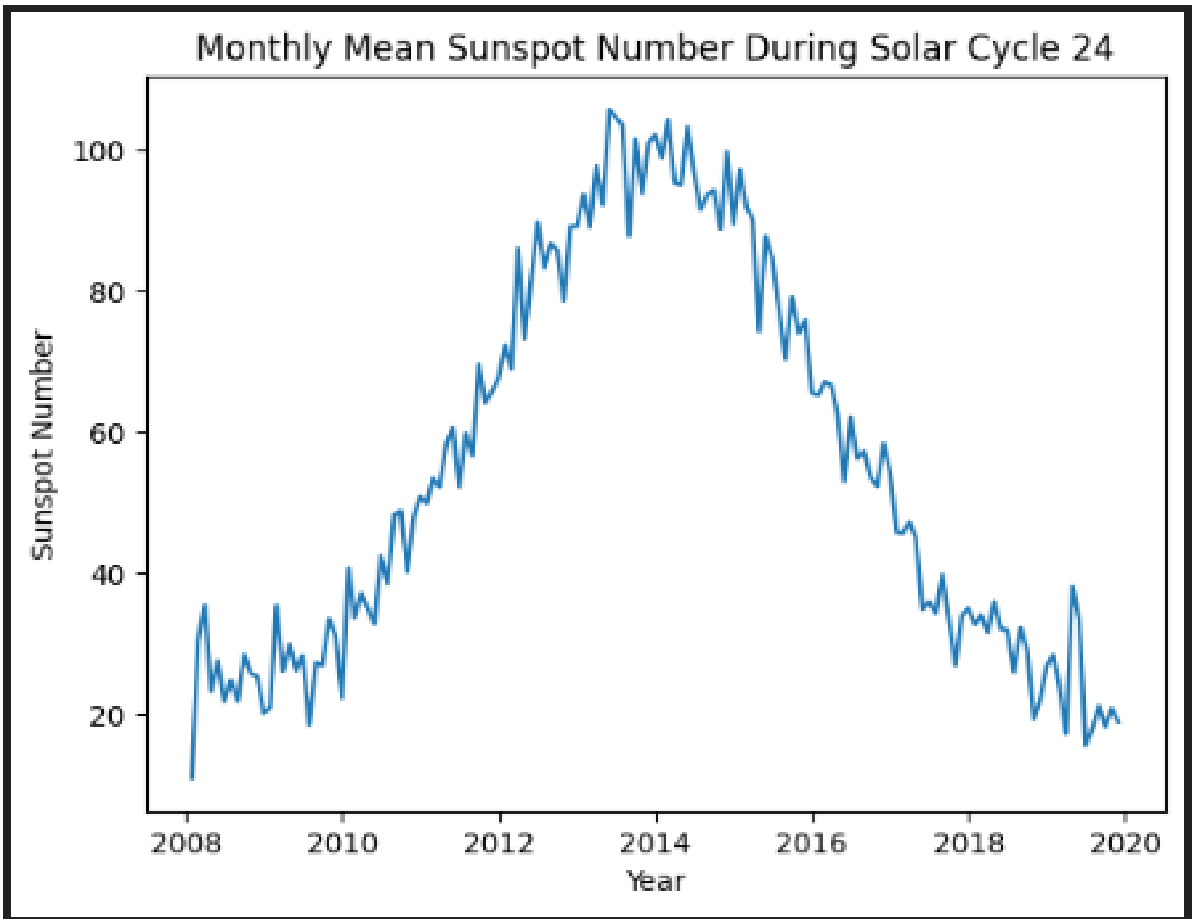


**Figure 1: Monthly average sunspots number During Solar Cycle 24**

The sun spot number, after this minimum, shows a slow rise in the rising phase where a broad and asymmetric peak can be observed in the period between 2013 and 2014. The Solar Cycle 24 unlike the earlier periods exhibits a relatively smaller sunspot number which attests to it being a weak solar cycle (Petrovay, 2020)[17]. The maximum phase is followed by the declining phase during which the activity of the sun spots is steadily reduced until the cycle is nearing the next minimum year around 2019. The measured change in the number of sunspots gives the basic leading design of studying the matched reaction of the interplanetary magnetic field because the sunspots are direct evidence of the emergence of the magnetic flux of the sun.

**Fluctuation of Interplanetary Magnetic Field Magnitude**

Figure 2 illustrates the temporal behaviour of the monthly mean interplanetary magnetic field magnitude (|B|) over the same period. There is noticeable variability in the IMF magnitude across the Solar Cycle 24, and both the long-term trends and short-term changes are overlaid on the other (Smith & Balogh, 2008)[18].

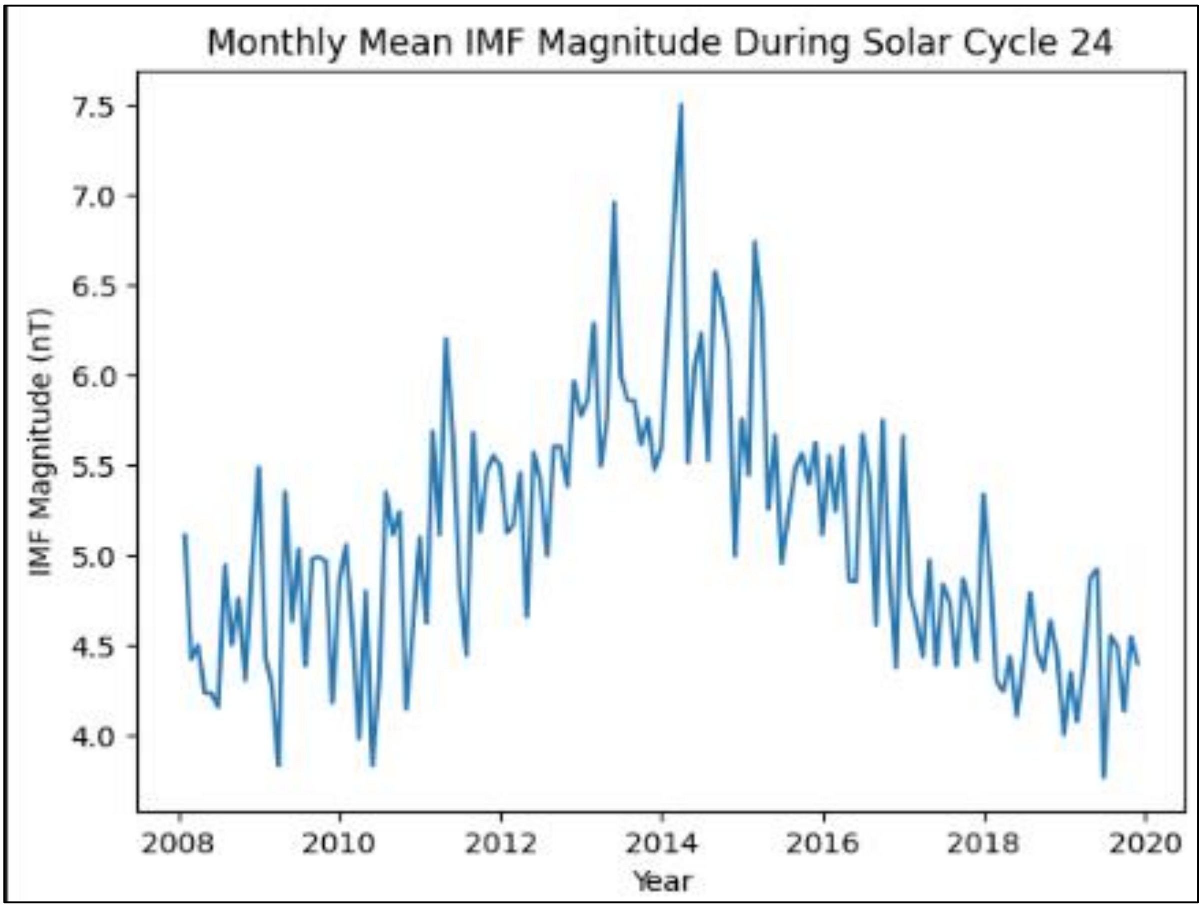


**Figure 2: Monthly average IMF Magnitude During Solar Cycle 24**

At this stage of the solar minimum (2008-2009) the IMF magnitude is relatively small, which marks the lack of solar magnetic flux and the weakening of the disturbances of solar wind. With the cycle moving into the rising stage, there is gradual strengthening of the IMF which is widely accompanied by the rising sunspots activity. Higher average values of the IMF are achieved when the solar maximum period is observed, showing that the solar magnetic effect is stronger than normal in the interplanetary space. But, in contrast to the smoother variant of the sunspots number, the IMF magnitude has strong oscillations, particularly when the maximum and falling periods occur. Such variations may be explained by the temporary interplanetary structures like coronal mass ejections, interaction regions, and high-speed stream of solar winds(Borovsky & Denton, 2006)[19]. This emphasizes the fact that the behaviour of IMF is governed by solar activity in addition to being perturbed by dynamic processes in the heliosphere.

**Comparative Time-Series Analysis of SSN and IMF**

The direct comparison of the profiles of SSN and IMF magnitude time-series (Figure 3) shows that there are similarities and differences in the development of them. On a larger time scale, it can be seen that times of elevated sunspot activity are associated with large magnitudes of the IMF indicating that there is a relationship between the magnetic activity on the surface of the sun and the magnetic environment of the heliosphere (Cliver & Ling, 2011)[20].

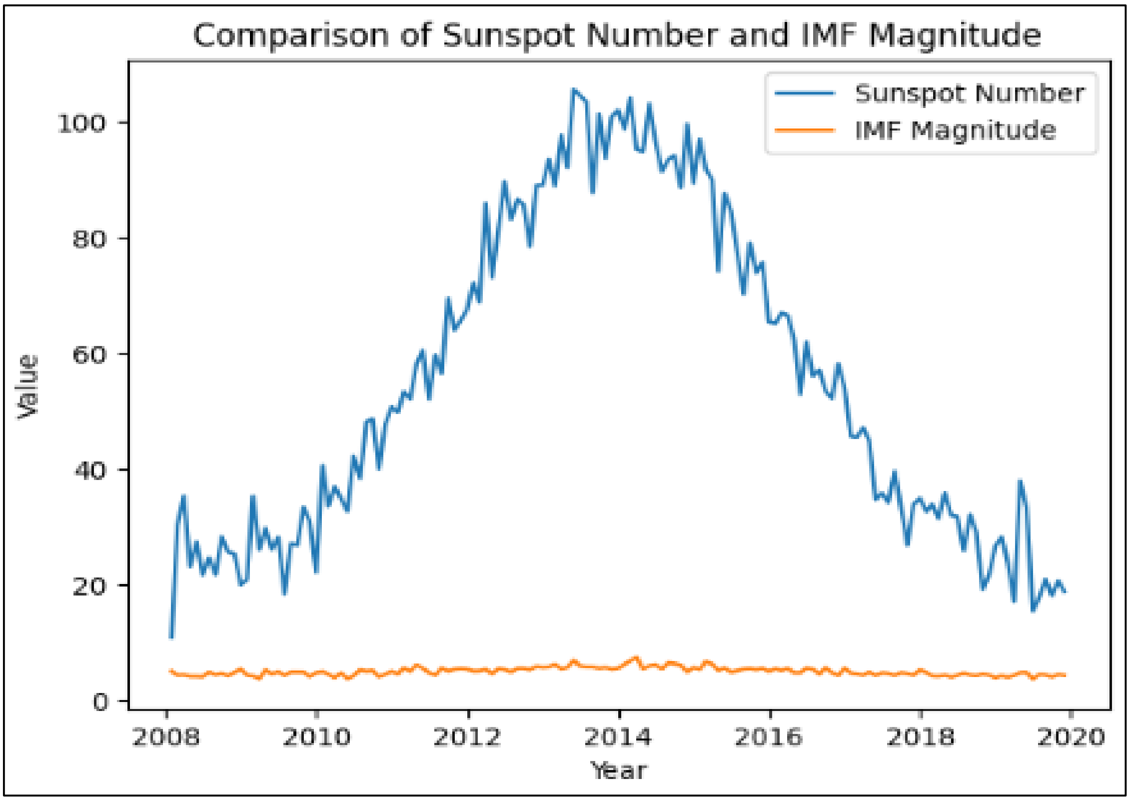


**Figure 3: Comparison of time-series plot of monthly mean sunspot number and IMF magnitude in Solar Cycle 24.**

However, inconsistencies are also present. The IMF magnitude is high in some periods especially at the falling phase when sunspots number is low. This tendency is the sign of the impact of the large-scale structures of solar wind like the coronal holes that become even more prominent during the declining phase and contribute to the increased IMF strength regardless of the sunspots (Grandin et al., 2019)[21].This comparative study has shown that sunspot number records the world solar magnetic activity whereas IMF magnitude records the world and local heliospheric events.

**Correlation Analysis Between Sunspot Number and IMF**

In order to obtain a quantitative estimate of the dependence between the sun spot number and the magnitude of the interplanetary magnetic field, a scatter plot of mean SSN per month and IMF magnitude is presented in Figure 4. The trend in the distribution of data points has a positive trend in general, with greater values of sunspots corresponding to the greater values of IMF.

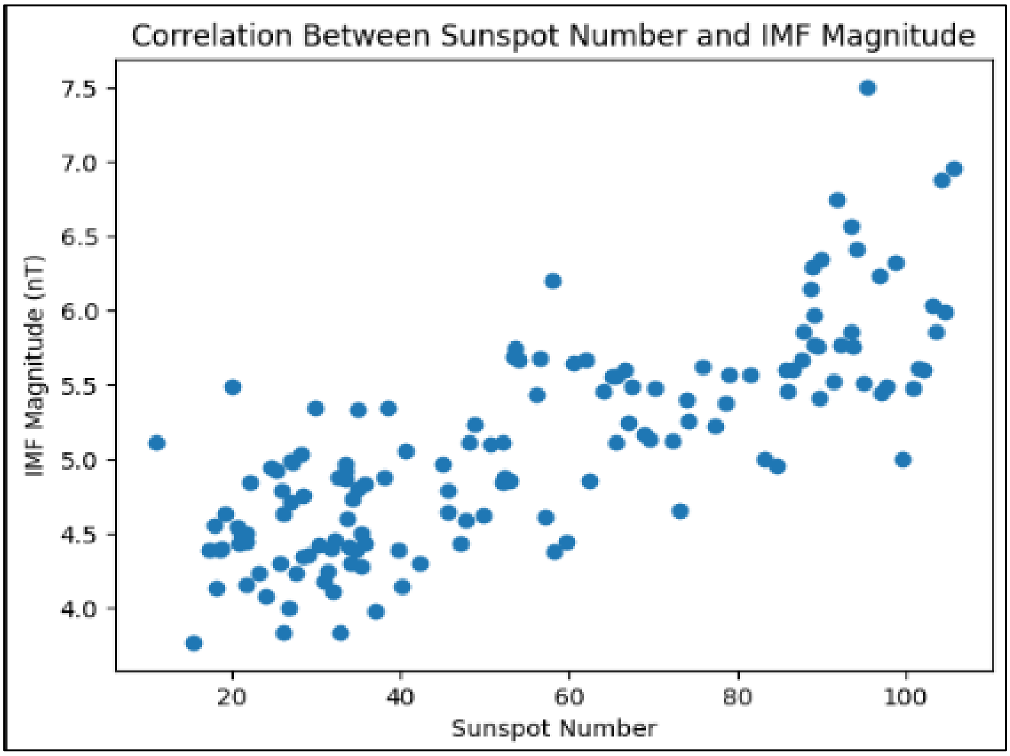


**Figure 4: Scatter plot of the relationship between the interplanetary magnetic field magnitude and the monthly mean sunspot number.**

The obtained **Pearson correlation coefficient** shows that there was a moderate positive correlation between SSN and IMF magnitude at Solar Cycle 24. This has been confirmed that the changes in solar magnetic activity in the surface are transferred to the interplanetary magnetic field around Earth (Chifu et al., 2022)[22]. However, the data points that are distributed around the regression line indicate that they are not directly linear in nature. Outliers especially at the moderate sunspots and the relatively high IMF values point to the contribution of the transient solar and interplanetary processes that increase the strength of IMF without depending on sunspots.

**Phase-wise Correlation Behaviour**

To have a greater understanding, the solar cycle was further divided into three stages, which included rising stage, solar maximum, and declining stage. At the rising stage, the SSN and IMF magnitude grow in a coherent and gradual manner, which causes the relatively stronger association. This is the period of the systematic accumulation of solar magnetic flux. The correlation slightly weakens at the solar maximum phase because the scattering is greater. This is credited to the common nature of coronal mass ejections and complicated magnetic structures, which bring about high variability of IMF magnitude in short periods (Owens et al., 2017) [23]. During the declining phase, the number of sunspots in the solar system steadily gets lower, and the IMF magnitude tends to be high as a result of frequent high-speed streams of solar wind caused by long-lasting coronal holes. This means that the correlation in this phase is weaker than in the rising phase due to the increasing contribution by non-sunspots-related drivers of solar wind.

**Weak-Cycle Characteristics Interpretation.**

The middle-level correlation seen in Solar Cycle 24 should be seen within the framework of its low activity in terms of the magnetism. The decrease in the number of sunspots suggests that the overall emergence of magnetic flux decreases, but not in roughly the same proportion as the number of sunspots. This implies that dynamics in large scales of open magnetic flux and heliospheric current sheets are significant in maintaining the strength of IMFs even in feeble solar cycles.

These results point to the fact that Solar Cycle 24 is characterized by specific solar-interplanetary coupling properties in comparison with more stronger cycles and it stresses the necessity to make cycle-specific analyses during the development of heliospheric and space weather models(Schrijver & Siscoe, 2010)[24]. The current paper is an investigation of the correlation between sunspots number and the magnitude of the interplanetary magnetic field in Solar Cycle 24 that can shed light on the solar-interplanetary coupling in the weak solar activity conditions. These findings indicate that despite the fact that Solar Cycle 24 is characterized by much lower sunspot activity than the last several cycles, the interplanetary magnetic field still possessed a noticeable response to the changes in the magnetic activity of the solar surface(Hapgood, 2017)[25].

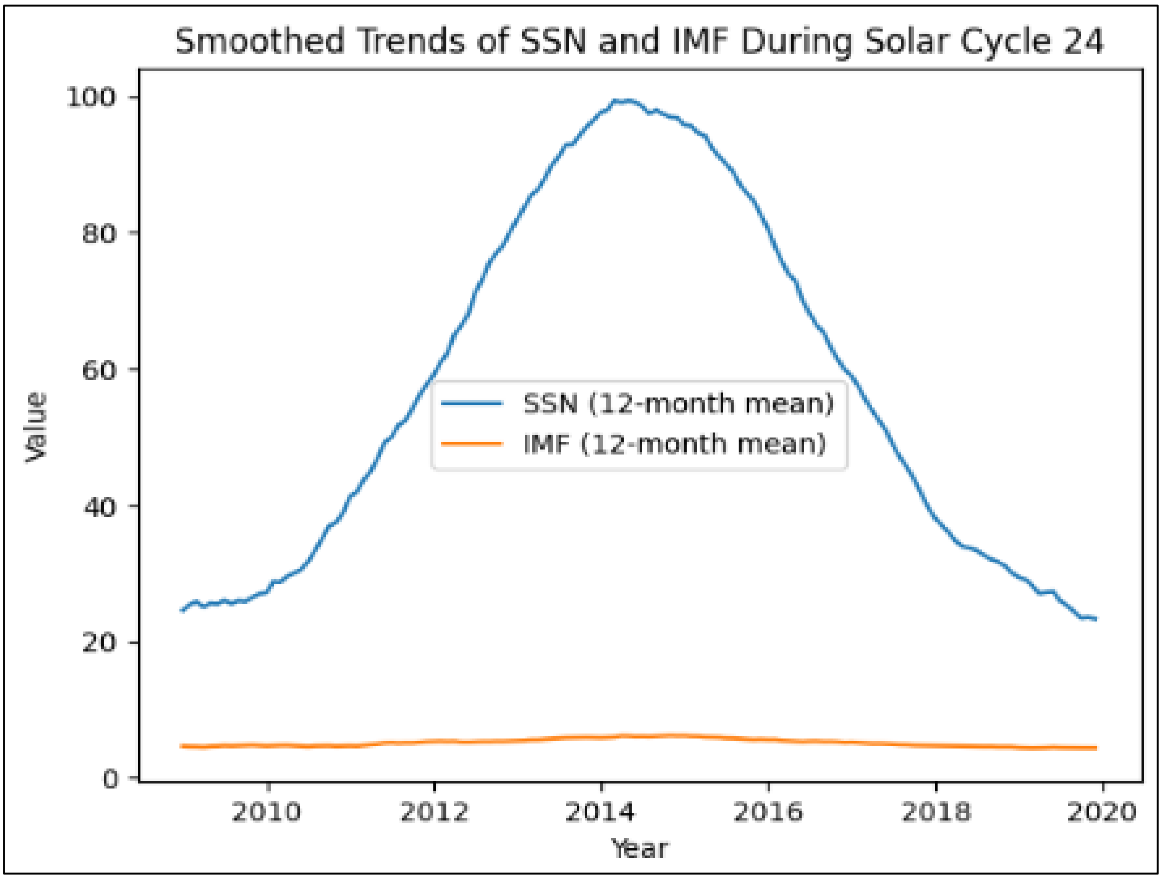


**Figure 5.Smoothing of solar cycle 24 sunspots number and IMF magnitude with 12 months running mean.**

The time plot reveals that the IMF magnitude generally obeys the long-term curve of the sun spot number, with lesser values during the prolonged solar minimum of 2008-2009 and greater values during the solar maximum of the years 2013-2014. This action confirms the opinion that the sunspot number as a proxy of solar magnetic flux emerging is significant in the formation of the heliospheric magnetic field. The IMF however show a lot of variation in the short run compared to the sun spot number, especially at the peak and the falling stages of the cycle. This means that the action of the IMF is not only subject to world solar activities but it depends on the temporary and repeated interplanetary actions. The positive linear relationship that was found to be moderate between SSN and IMF magnitude is mirrored by previous studies that solar magnetic activity is an enhancement factor to the interplanetary magnetic field. However, the scatter of the correlation plots shows the non-linear and multi-scale character of the solar-heliospheric interactions. Cases in which IMF magnitude is still high when the sunspots wells have decreased indicate the prevalence of high-speed solar wind streams of the long-lived coronal holes, which are more common in the fading step of the solar cycle. These constructions are used to augment the open magnetic flux and give relatively high IMF conditions regardless of the presence of sunspots.

These differences are further stressed out by phase-wise analysis. The systematic accumulation of solar magnetic flux causes weaker correlation during the rising phase in the coherent increase of both SSN and IMF magnitude. On the contrary, during the solar maximum period, the scatter is greater because of the high rate of coronal mass ejections and complicated magnetic fields that present some sudden increase in the strength of IMF. The least strong correlation is experienced in the declining phase which is characterized by the prevalence of recurrent structures of solar winds in the heliospheric conditions. These results have a valuable context that is the weak nature of Solar Cycle 24. The interplanetary magnetic field is maintained despite the decline in sunspots activity due to the continuing moderate level of IMF strength, which indicates that the large-scale solar magnetic structure and heliospheric current sheet processes are important in maintaining the interplanetary magnetic field. This discovery has major consequences concerning the research of the space weather since it demonstrates that weak sunspot cycles do not likely imply equally weak conditions in the heliospheric magnetism. It can be concluded that the discussion shows the weakness of using sunspot number to explain interplanetary magnetic variability only. Multiple solar and heliospheric parameters have to be taken into account to have a full picture of solar-terrestrial interactions. The findings of the present research support the significance of an analysis by cycle and add to the meaningful knowledge regarding the dynamics of the heliosphere during weak solar cycles.

## CONCLUSION

This paper is a correlative investigation of the sunspots number (SSN) and interplanetary magnetic field (IMF) strength across the Solar Cycle 24, which is a solar cycle with an abnormally weak magnetic flux. Using long term observational data on a monthly scale, the connection between solar surface magnetic activity and heliospheric magnetic conditions in the vicinity of the earth has been studied in a systematic manner. The time series analysis shows that sun spot number has the typical pattern of solar cycle, where it has a long and mild minimum period, a weak solar maximum, and a slow decaying period. The magnitude of the interplanetary magnetic field follows a long-term variation that is seen to be generally similar, with increased values tending to be at times when sunspots tend to increase in activity. IMF variability is however characterized by high short-term fluctuations and this is a result of the impact of the temporary and recurrent structures of solar winds.

The correlation analysis shows that during Solar Cycle 24, sun spot number and IMF magnitude are positively correlated, though moderately. This observation proves the fact that solar surface magnetic activity is significant in the control of the strength of the interplanetary magnetic field. Meanwhile, the non-linearity of the relationship and the scatter in the correlation plots show that the IMF behavior is not the one that can be attributed to sunspot number only. The solar cycle is analyzed phase-by-phase and significant variations in solar-interplanetary coupling can be seen. The highest alignment between SSN and IMF magnitude takes place during the rising period whereas the low level is observed during the solar maximum and falling period as a result of the growing impact of coronal mass ejections and fast high-speed streams of solar wind generated by coronal holes. These findings highlight the multi-scale and complicated aspects of modulation of the heliospheric magnetic fields. The results of this paper indicate that in weak solar cycles, like Solar Cycle 24 the Sun can still can support a considerable strength in interplanetary magnetic fields through the intense dynamics of large-scale open magnetic flux and heliospheric current sheaths. Such implications are significant to the space weather research, since it highlights the significance of incorporating various solar and heliospheric parameters in the evaluation of near-Earth space conditions.

Future studies can also build upon this study by considering other IMF components (such as $B_z$), solar wind velocity and geomagnetic indices in order to better elucidate the processes of solar-terrestrial coupling. Inter-comparative analysis of the various solar cycles would also assist in finding out whether the observed correlations are particular to Solar Cycle 24 or they are a common characteristic of weak solar cycles.

## References

1. Lockwood, M. (2013). *Reconstruction and prediction of variations in the open solar magnetic flux*. Living Reviews in Solar Physics, 10(4). https://doi.org/10.12942/lrsp-2013-4
2. Zhang, J., Temmer, M., Gopalswamy, N., Veronig, A. M., Shen, F., Wang, Y., & Chi, Y. (2021). *Earth-affecting solar transients*. Progress in Earth and Planetary Science, 8(33). https://doi.org/10.1186/s40645-021-00426-7

3. Clette, F., & Lefèvre, L. (2016). *The new sunspot number: Assembling all corrections*. Solar Physics, 291(9–10), 2629–2651. https://doi.org/10.1007/s11207-016-0980-2
4. Ashutosh Kumar Tiwari, Devendra Gautam, C.M. Tiwari, Sri Krishna Singh, Vidya Sagar Chaudhary (2025) "Study of Cosmic Ray Intensity in relation with Interplanetary Magnetic Field and Dst for Solar Cycle 23 & 24". JETIR.. PP 90-06.
5. Kumar, Ashok & Gupta, Meera. (2024). International Journal of Engineering Research & Management Technology Correlation of Sunspot number with Interplanetary magnetic field, Solar wind velocityandDst.
6. Goyal, Sanjay & Chaurasiya, Deepak & Shrivastava, P. (2023). Study of solar parameter and interplanetary medium with geomagnetic parameter on the solar cycle 24 Citation. 10.26671/IJIRG.2023.4.12.102.
7. Abha Singh and Kalpana Patel (2021) "Statistical Study of Solar Activity Parameters of Solar Cycle 24" Journal of Scientific Research, Volume 65, Issue 1. pp-197-200
8. Jothe, M. (2015). Correlative Study of Cosmic Ray Intensity and Sunspot Number for the Period of Solar Cycles 23 and Ascending Phase of 24. International Journal of Science and Research (IJSR). https://doi.org/10.21275/V4I12.NOV152547.
9. Gonzalez, W. D., &Tsurutani, B. T. (1987). *Criteria of interplanetary parameters causing intense magnetic storms*. Planetary and Space Science, 35(9), 1101–1109. https://doi.org/10.1016/0032-0633(87)90015-8
10. Hathaway, D. H. (2015). *The solar cycle*. Living Reviews in Solar Physics, 12(4). https://doi.org/10.1007/lrsp-2015-4
11. King, J. H., &Papitashvili, N. E. (2005). *Solar wind spatial scales in and comparisons of hourly Wind and ACE plasma and magnetic field data*. Journal of Geophysical Research: Space Physics, 110(A2). https://doi.org/10.1029/2004JA010649
12. Emery, W. J., & Thomson, R. E. (2001). *Data analysis methods in physical oceanography*. Elsevier.
13. Bendat, J. S., & Piersol, A. G. (2010). *Random data: Analysis and measurement procedures* (4th ed.). Wiley.
14. Chatfield, C. (2004). *The analysis of time series: An introduction* (6th ed.). Chapman & Hall/CRC
15. Wilks, D. S. (2011). *Statistical methods in the atmospheric sciences* (3rd ed.). Academic Press.
16. Pesnell, W. D. (2016). *Solar cycle predictions (invited review)*. Solar Physics, 291, 1353–1364. https://doi.org/10.1007/s11207-016-0897-9

17. Petrovay, K. (2020). *Solar cycle prediction*. Living Reviews in Solar Physics, **17**(2). https://doi.org/10.1007/s41116-020-0022-z.
18. Smith, E. J., & Balogh, A. (2008). *Decrease in heliospheric magnetic flux in this solar minimum: Recent Ulysses magnetic field observations*. Geophysical Research Letters, 35, L22103. https://doi.org/10.1029/2008GL035345
19. Borovsky, J. E., & Denton, M. H. (2006). *Differences between CME-driven storms and CIR-driven storms*. Journal of Geophysical Research: Space Physics, 111, A07S08. https://doi.org/10.1029/2005JA011447
20. Cliver, E. W., & Ling, A. G. (2011). *The floor in the solar wind magnetic field revisited*. Solar Physics, 274, 285–301. https://doi.org/10.1007/s11207-010-9657-6
21. Grandin, M., Kalliokoski, M., &Kilpua, E. K. J. (2019). *Properties and geoeffectiveness of solar wind high-speed streams*. Journal of Geophysical Research: Space Physics, 124, 1–18. https://doi.org/10.1029/2018JA026396
22. Chifu, I., Mackay, D. H., & Petrie, G. J. D. (2022). *Coronal magnetic field evolution over solar cycle 24*. Astronomy & Astrophysics, 657, A62. https://doi.org/10.1051/0004-6361/202141804
23. Owens, M. J., Crooker, N. U., & Lockwood, M. (2017). *How is open solar magnetic flux lost over the solar cycle?*Journal of Geophysical Research: Space Physics, 122, 6–19.
24. Schrijver, C. J., & Siscoe, G. L. (2010). *Heliophysics: Space storms and radiation*. Cambridge University Press.
25. Hapgood, M. (2017). *Space weather: Its impact on Earth and implications for business*. Living Reviews in Solar Physics, 14(1). https://doi.org/10.1007/s41116-017-0008-7