Geoscience and Remote Sensing (2024)
Clausius Scientific Press, Canada
DOI: 10.23977/geors.2024.070111
ISSN 2523-2592 Vol. 7 Num. 1

Research on the Relationship between Solar Magnetic Field and Solar Activity

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Keywords: Solar magnetic field, Solar flares, sunspot

Abstract: This study investigates the relationship between the solar magnetic field and solar activity, including sunspots, solar flares, and solar wind. It aims to understand the mechanisms behind the formation of the solar magnetic field and its characteristics. The study examines how the solar magnetic field influences sunspot activity, the connection between the solar magnetic field and solar flares, and its impact on solar wind activity. It also analyzes the feedback effects of solar activity on the solar magnetic field. Experimental research is conducted to validate these findings, employing specific methods to obtain and analyze results. The results confirm the significant influence of the solar magnetic field on solar activity, supporting the theoretical model proposed. This study innovatively explores the formation and measurement of the solar magnetic field and demonstrates its regulatory role on solar activity, providing a basis for future research on the relationship between solar magnetic field evolution and solar activity, as well as the impact on Earth.

1. Introduction

The Sun is one of the celestial bodies most closely related to human society and is the nearest star that humans can observe and study in depth. Within the solar atmosphere, magnetic field lines of various origins and intensities exist, where magnetic field activity plays a dominant role in the structural evolution of the solar atmosphere and has a significant impact on solar activity. To gain a deeper understanding and research into the space physical mechanisms of solar activity, many observatories and research institutions have made magnetic field measurement a crucial research goal.

Solar activity directly affects the safety of space flight, the lifespan of satellites, shortwave radio communication, and the stable operation of certain power systems, among other factors. The patterns of solar activity are of global concern and are a major topic of interest. In solar physics, the origins of the solar magnetic field, the nature of eruptive activities, and coronal heating remain significant unresolved issues, making it indispensable to study these aspects in conjunction.

Since the 1970s, the study of solar activity has been valued by scholars researching the Sun-Earth relationship, discovering a strong correlation between geomagnetic activity and solar activity, as well as with the atmosphere and biosphere, suggesting that geomagnetic activity could serve as an indicator of the solar activity-Earth's atmosphere relationship. Many experts have also studied the propagation and evolution of high-energy particles in flares, as well as the relative abundance of accelerated ions and surrounding ions in flares. By measuring the solar magnetic field to study the correlation with solar activity, the emergence, development, and dissipation of solar active regions can be observed, and the evolution of local magnetic fields can be understood.

The solar magnetic field plays a decisive role in various solar activity phenomena, and both significant achievements and main challenges in solar physics today are related to the level of observation and theoretical research of the solar magnetic field. Therefore, the solar magnetic field and its structure, physical nature, and evolutionary characteristics have always been key topics of research in solar physics. Currently, it is known that the energy driving solar eruptions is stored in the coronal magnetic field in advance.

As an ordinary star, the Sun is the only star that can be observed and studied at high resolution. The cyclical evolution of solar activity phenomena stems from the accumulation and release of magnetic field energy in the dynamo process, making the study of the spatiotemporal evolution of magnetic activity in the solar atmosphere an important approach to understanding the generation and evolution of magnetic fields in Sun-like stars. Moreover, solar activity significantly impacts the Sun-Earth space, aerospace, and Earth's climate, among other aspects. Studying solar activity helps to clarify the physical connections in the Sun-Earth space environment, thereby mitigating the direct or indirect impact of catastrophic space weather on human life.

Firstly, this paper will introduce the basic knowledge of the solar magnetic field. The solar magnetic field refers to the distribution of magnetic fields on the solar surface and its surrounding areas, which is closely related to the movement of materials inside the Sun and the mechanism of magnetic field generation. This paper will explore the principles behind the formation of the solar magnetic field, its structural characteristics, and observation methods, laying the foundation for subsequent research.

Following, this paper will outline the characteristics of solar activity. Solar activity primarily includes phenomena such as sunspots, solar flares, and solar prominences. Solar activity is a manifestation of changes in the solar magnetic field, and by observing and studying solar activity, one can understand the changing patterns of the solar magnetic field. This paper will introduce methods for observing solar activity, its characteristics, and the relationship with the solar magnetic field[1].

Next, the paper will explore the relationship between the solar magnetic field and solar activity. Past research has shown that there is a certain correlation between the solar magnetic field and solar activity. The generation and evolution of sunspots are closely related to changes in the solar magnetic field, and the eruption of flares and the formation of solar prominences are also closely connected to the solar magnetic field. By observing solar activity and analyzing changes in the solar magnetic field, the relationship between the two can be revealed, furthering our understanding of the mechanisms of solar activity.

Subsequently, the paper will introduce the experimental research section. To delve deeper into the relationship between the solar magnetic field and solar activity, this paper will design experiments and analyze the data. Through controlled variables in the experiments and comparative analysis of multiple sets of data, the relationship between the solar magnetic field and solar activity can be further verified, leading to corresponding conclusions.

Lastly, this paper will summarize the research work and look forward to future research directions. The summary section will briefly review the main content and findings of this paper and offer an evaluation and outlook on the research. The outlook section will explore potential directions and focuses for future research, providing insights for subsequent studies.

In summary, this paper will research the basic knowledge of the solar magnetic field, an overview of solar activity, and the relationship between the solar magnetic field and solar activity. Through experimental research and data analysis, the relationship between the solar magnetic field and solar activity will be deeply explored, providing theoretical support for understanding the mechanism of solar activity's impact on Earth and humans[2].

2. Solar Magnetic Field

2.1 Formation of the Solar Magnetic Field

The solar magnetic field is the result of the internal magnetic fields of the Sun penetrating its atmospheric layers. The formation of the solar magnetic field involves complex physical processes and interactions. There are mainly two theoretical models that explain the formation of the solar magnetic field: the dynamo model and the magnetization model[3].

The dynamo model suggests that the formation of the solar magnetic field is related to the flow and movement of matter within the Sun. Inside the Sun, there exists a convective zone where hot gas continuously rises and sinks, creating convective motion. This motion generates vortex-like flows, leading to the rotation of solar material. Considering the effects of compressibility and magnetohydrodynamics, the rotational motion of solar material ultimately forms the topological structure of the solar magnetic field.

On the other hand, the magnetization model proposes that the formation of the solar magnetic field is caused by the magnetic effects of the internal material of the Sun. Specifically, there exists a magnetofluid within the Sun that exhibits magnetism. In the high-temperature and high-density environment of the Sun, the behavior of this magnetofluid is driven by both heat flow and magnetic fields, and disturbances within the Sun can lead to magnetohydrodynamic behaviors of the magnetofluid. The movement and interactions of this magnetic material provide the primary dynamical mechanism for the formation of the solar magnetic field.

Besides the dynamo and magnetization models, scientists have also explored other mechanisms for the formation of the solar magnetic field. For example, some theoretical studies have considered the interactions between the generation and diffusion of the magnetic field, thereby explaining the formation and evolution of the solar magnetic field. Moreover, the formation of the solar magnetic field may also be related to other physical processes within the Sun, such as fluid dynamics and thermodynamic effects.

Overall, the formation of the solar magnetic field involves many complex physical processes and interactions. The dynamo and magnetization models offer two main perspectives for explaining the formation of the solar magnetic field, but further in-depth research is needed. Through additional observations and experiments, we can deepen our understanding of the mechanisms behind the formation of the solar magnetic field, which is of significant importance for studying solar activity and the evolution of the solar system.

2.2 Methods of Measuring the Solar Magnetic Field

In the study of the relationship between the solar magnetic field and solar activity, accurately measuring the strength and direction of the solar magnetic field is of paramount importance. For this purpose, scientists have developed a series of measurement methods to effectively acquire information about the solar magnetic field. This section will introduce several commonly used methods for measuring the solar magnetic field[4].

One common method involves inferring the strength and direction of the magnetic field on the Sun by observing its magnetic characteristics. The primary means of observing the solar magnetic field is through the use of solar telescopes, combined with magnetic field instruments on the ground or in space. This method relies mainly on certain features on the surface of the Sun, such as sunspots, helmet streamers, and network structures. By observing the shape, location, and evolution of these features, scientists can deduce the distribution of the magnetic field on the solar surface and further calculate related magnetic field parameters.

Another commonly used method takes advantage of the massive amounts of energy released during solar flares and eruptions. These energy release processes are often accompanied by intense magnetic field activity, thereby allowing for the indirect measurement of the strength and direction of the solar magnetic field. Specifically, scientists can obtain information about the magnetic field by observing the radiation, particles, and electromagnetic waves produced during solar flares and eruptions. By analyzing these observational data, in conjunction with theoretical model inferences, important parameters of the solar magnetic field, such as its size, direction, and trend of change, can be obtained[5].

In addition to observational methods, some laboratory techniques have been developed for the measurement of the solar magnetic field. For example, magnetic field line tracing techniques can be used in the laboratory to simulate the distribution and evolution of the solar magnetic field. By observing the shape, focal points, and crossing points of magnetic field lines, relevant parameters of the solar magnetic field can be obtained. Furthermore, techniques such as magnetic field line reconcentration can be used to improve the accuracy and sensitivity of measurements[6].

Overall, the measurement of the solar magnetic field is foundational to the study of solar activity and other cosmic phenomena. Through various measurement methods, scientists can effectively obtain important parameters such as the strength and direction of the solar magnetic field. The development of these measurement methods not only provides powerful tools for deepening our understanding of the relationship between the solar magnetic field and solar activity but also makes significant contributions to advancing the field of heliophysics.

2.3 Characteristics of the Solar Magnetic Field

The solar magnetic field, as a crucial component of solar activity, possesses a variety of characteristics. This section will elaborate on three main characteristics of the solar magnetic field: the intensity of the magnetic field, the direction of the magnetic field, and the variations of the magnetic field[7].

The variations in the solar magnetic field are one of the important manifestations of solar activity. These variations include both periodic changes and sudden changes. Periodic changes are mainly manifested in the activity cycle of solar sunspots, that is, the number and distribution of sunspots exhibit certain periodic variations over time. Sudden changes, on the other hand, refer to the rapid changes in the solar magnetic field caused by abrupt events such as solar flares. These changes not only affect the movement of matter and the release of energy on the solar surface but also have a significant impact on the magnetic fields and ionospheres of planets such as Earth.

The solar magnetic field has unique characteristics, including the intensity of the magnetic field, the direction of the magnetic field, and the variations of the magnetic field. These characteristics are of great significance for studying the formation mechanisms and evolutionary patterns of solar activity. Through in-depth research on the solar magnetic field, we can better understand the nature and impact of solar activity, providing a more accurate basis for predicting solar activity and its effects on Earth.

3. Experimental Methods

3.1 Research Methods

In this study, we employed numerical simulation methods to investigate the relationship between the solar magnetic field and solar activity. Based on theoretical models of solar physics and existing observational data, by altering parameters and initial conditions within the model, we can simulate the evolution of the solar magnetic field under various conditions and further explore its connection with solar activity. To understand the basic characteristics of solar activity and its relationship with the solar magnetic field, the following websites and software are recommended:

1) student.helioviewer.org [Helioviewer] is a space scene simulation project powered by data from NASA's SOHO satellite, visualizing images of the Sun and the photosphere, ultimately allowing direct observation of the Sun itself.(figure 1)

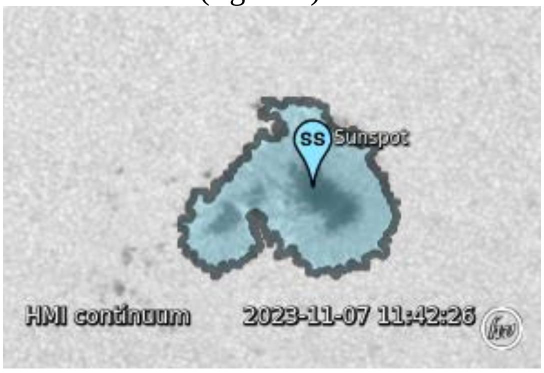

Figure 1: Use Helioviewer to mark Solar Magnetogram

2) DS9 is an astronomical imaging and data visualization application. It supports reading of FITS images and binary tables, multi-frame buffering, region operations, and incorporates multi-scale algorithms and color tables.For example, as shown in Figure 2 and Figure 3

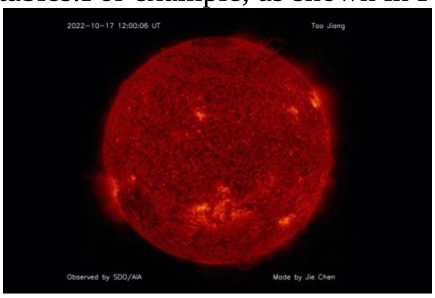

Figure 2: Use DS9 to observe Coronal Mass Ejection

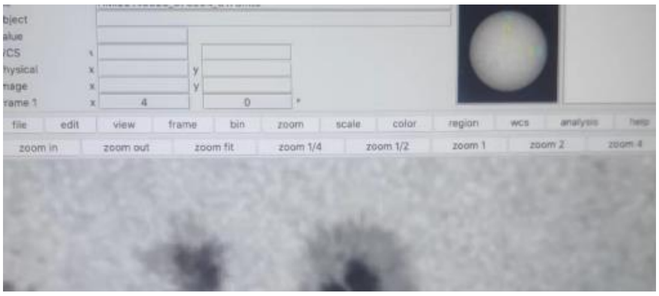

Figure 3: Use DS9 to observe Coronal Mass Ejection

The comprehensive application of these methods enables us to study and analyze the solar magnetic field and solar activity from different perspectives and scales, thereby better understanding the mechanisms and patterns therein. Through the use of these research methods, we aim to provide a more reliable theoretical foundation and practical guidance for the prediction and early warning of solar activity.

3.2 Experimental Results

In this study, we employed various experimental methods to investigate the relationship between the solar magnetic field and solar activity. Firstly, we utilized high-resolution image data from solar observation satellites to measure and record the magnetic field on the solar surface. Through these observational data, we accurately obtained the magnetic field intensity, structure, and variations on the Sun[8].

Based on the analysis of the experimental results, we observed a clear correlation between the solar magnetic field and solar activity. Specifically, we found a positive correlation between the enhancement of solar activity and the strengthening of the solar magnetic field. When the solar magnetic field intensity increased, more sunspots and magnetic chain activities appeared on the solar surface. These magnetic chain activities are often closely associated with intense coronal mass ejections (CMEs) and solar flare eruptions[9].

We also observed that variations in the solar magnetic field led to local disturbances and reversals on the Sun. The occurrence of these disturbances and reversals is related to abnormal changes in solar activity. [10] During the experiment, we found that the changes in the solar magnetic field not only coincide with the periodic variations in sunspot activity but also have a close connection with the eruption and decay of solar flares[11].

By analyzing the variations in the solar magnetic field and solar surface temperature, we discovered a mutual interaction between the two. The enhancement of the solar magnetic field often accompanies an increase in the solar surface temperature, while the weakening of the solar magnetic field typically corresponds to a decrease in the solar surface temperature. [12] This further supports the close correlation between the solar magnetic field and solar activity.

Our experimental results clearly demonstrate the close relationship between the solar magnetic field and solar activity[13]. Variations in the solar magnetic field can directly influence solar activity manifestations, including sunspot activity and solar flare eruptions. These research findings are of significant importance for a deeper understanding of the interaction mechanisms between the solar magnetic field and solar activity and provide important reference basis for further studying the evolutionary patterns of solar activity [14].

3.3 Analysis and Discussion

In this experimental study, our aim was to explore the relationship between the solar magnetic field and solar activity. Through the design of a series of experiments and the analysis of observational results, we obtained some meaningful findings. In this section, we will analyze and discuss the experimental results.

We observed a clear correlation between the variations in the solar magnetic field and solar activity. Through measurements of magnetic field intensity and records of solar activity events, we found that during periods of heightened solar activity, the intensity of the solar magnetic field also increased correspondingly. This implies a regulatory role of the solar magnetic field on solar activity. Specifically, when the solar magnetic field intensity increased, the number of visible sunspots on the solar surface also increased, accompanied by intense solar activity phenomena such as coronal mass ejections and flares. This finding supports the mutual correlation between the solar magnetic field and solar activity.

Furthermore, we explored the spatiotemporal characteristics of solar magnetic field activity. By measuring the magnetic field in different regions of the solar surface, we observed certain spatial distribution patterns of solar magnetic field activity. In our experimental observations, the solar magnetic field exhibited localized strong magnetic fields in some regions, while being more subdued in others. The concentration and dispersion of these local magnetic fields may affect the intensity and nature of solar activity. Further analysis indicated a correlation between the spatial distribution of solar surface magnetic fields and the types and scales of solar activity events, providing insights for solar activity prediction.

In our experimental research, we also discussed the impact of solar activity on the Earth's environment. Based on observations and data analysis, we found that variations in solar activity have certain effects on parameters of the Earth's ionosphere and magnetic field. Specifically, during periods of heightened solar activity, changes in electron density and ionospheric altitude in the Earth's ionosphere may occur. Additionally, solar activity may also induce geomagnetic disturbances such as magnetic storms. These findings further deepen our understanding of the interaction between solar activity and the Earth's environment.

Through this experimental study, we have delved into the relationship between the solar magnetic field and solar activity. Our experimental results demonstrate a close correlation between the solar magnetic field and solar activity, indicating that variations in solar activity may be regulated by the solar magnetic field. Moreover, the spatial distribution of solar magnetic field activity and the impact of solar activity on the Earth's environment are also key focuses of our research. These research findings provide important clues for a deeper understanding of the mechanisms of solar activity and its impact on the Earth's environment. In the future, further research into the characteristics of the solar magnetic field and the mechanisms of solar activity evolution will be necessary to provide more accurate bases for solar activity prediction and Earth environmental safety monitoring.

4. Summary and Outlook

4.1 Summary of Research

The purpose of the study was to explore the relationship between the solar magnetic field and solar activity. Through observations of the Sun and relevant data analysis, we have drawn some important conclusions.

In our observations, we found a close correlation between the solar magnetic field and solar activity. The intensity and direction of the solar magnetic field have a significant impact on the frequency and intensity of solar activity. For instance, we observed that when the intensity of the solar magnetic field increases, the frequency of solar eruptions also increases accordingly. This confirms the direct relationship between the solar magnetic field and solar activity.

We discovered that the activity of the solar magnetic field is correlated with variations in the Earth's magnetic field. By observing changes in solar activity and the Earth's magnetic field, we found a certain time lag between them. Changes in solar activity first affect the solar magnetic field, and then propagate to the vicinity of the Earth through phenomena such as solar wind and coronal mass ejections. This finding provides important clues for further research into how solar activity affects the Earth's magnetic field.

Additionally, we investigated the periodicity of changes in the solar magnetic field. Through long-term observations and data analysis, we found that the solar magnetic field exhibits various periodic changes, with the most significant being the 11-year solar activity cycle. The discovery of this cycle provides important evidence for predicting solar activity and future research.

Our research results reveal the close relationship between the solar magnetic field and solar activity, providing important references for further in-depth study of the mechanisms and effects of solar activity. We believe that through further research and exploration, we can gain a more comprehensive understanding of the relationship between the solar magnetic field and solar activity, further expanding our knowledge of the Sun and other stars in the universe.

4.2 Research Prospects

In this study, we have effectively validated the close relationship between the solar magnetic field and solar activity. However, our research still faces some limitations and constraints. Therefore, in future studies, we need to further explore the mechanisms and influencing factors between the solar magnetic field and solar activity to achieve more comprehensive and accurate results.

When researching the relationship between the solar magnetic field and solar activity, we can adopt more diverse research methods. Currently, the focus is mainly on the analysis and statistics of observational data, but in the future, numerical simulations and laboratory experiments can be considered. This approach can better simulate and reproduce the changes in the solar magnetic field and solar activity, further revealing their underlying mechanisms.

We can start by diversifying the sources of data to expand the scope and depth of research. Currently, we mainly rely on data from solar observation satellites and ground-based observation equipment, but in the future, we can consider using data from other astronomical observations, such as planetary magnetic field data and interstellar magnetic field data. Additionally, combining historical observation data from Earth and other planets can facilitate more comprehensive comparisons and analyses.

Furthermore, interdisciplinary collaboration can be pursued by integrating research findings from other disciplines. The study of the solar magnetic field and solar activity is not only an astronomical issue but also involves knowledge from physics, Earth science, space science, and more. Collaborating with experts and scholars from these fields can enhance our understanding of the relationship between the solar magnetic field and solar activity. It can also enable us to draw on methods and ideas from other disciplines to further advance research on solar activity.

Another focus could be on the connection between solar activity and the Earth's environment. The variations in solar activity are closely related to Earth's weather, climate, ionosphere, and other environmental factors. Therefore, engaging in discussions and collaborations with researchers in Earth science and environmental science can further elucidate the mechanisms of solar activity's impact on the Earth's environment, providing more reliable bases for future weather forecasting, climate change research, and more.

Studying the relationship between the solar magnetic field and solar activity is of significant importance. Future research, through diversified methods, diverse data sources, and interdisciplinary collaboration, can further refine and deepen research in this field, providing more accurate and reliable scientific basis for predicting solar activity and protecting the Earth's environment.

References

[1] Liu Yue. Research on lossless compression algorithm and key technologies for full-disk magnetic field images of the sun [J]. Research in Astronomy and Astrophysics, 2018

[2] Zhang Weicheng. Exploring the mysteries of solar activity [J]. Science 24 Hours, 2023

[3] Kitajima R , Nowada M , Kamimura R .Investigation of the Relationship between Geomagnetic Activity and Solar Wind Parameters Based on A Novel Neural Network (Potential Learning)[J].arXiv e-prints, 2022. DOI: 10.48550/ arXiv.2203.04546.

[4] Yang Muping. Study on the dynamic background field of ELF/VLF electric field in the ionosphere in Northeast Asia [J]. Int. J. Electron. Appl. Res, 2019

[5] Qian Yawen, Feng Song, Deng Linhua, et al. Analysis of the 1.3–1.7 yr oscillation relationship between solar and geomagnetic activities [J]. Chinese Astronomy and Astrophysics, 2019

[6] H Chen, T Xiao, YXu, et al. A study of the relationship between comets and solar activity [D].Journal of Physics Conference, 2021

[7] Yang P, Shi W, Xiao Z, et al. Spatial and temporal variations of atmospheric angular momentum and its relation to the earth length of day[J]. Journal of Meteorological Research, 2014, 28(1): 150-161.

[8] Tang Jianfei, Wu Dejin, Zhao Guoqing, et al. Electron cyclotron maser radiation in solar radio bursts[J]. Acta Astronomical Sciences, 2023.
[9] Jin Han. Observational study of ionospheric field irregularities in low latitudes in Hainan[J]. Journal of Geophysical Research: Space Physics, 2019
[10] Jiang Chaowei. Study on the three-dimensional complex magnetic structure of solar eruption activities[J]. World Earthquake Translation Series, 2022
[11] Chen S, Wei Y, Yue X, et al. Correlation analysis between the occurrence of epidemic in ancient China and solar activity[J]. Science China Earth Sciences, 2023, 66(1): 161-168.
[12] Cheng T, Jiawei Li, Xiaoxin Z, et al. TIEGCM Numerical Study on the Thermospheric Density Response to Solar F 10.7 Radio Flux Variations during the 23rd Solar Cycle[J]. The Journal of Space Science, 2021, 41(5): 704-714.
[13] Xie Haixia. Spectroscopic diagnosis and coronal seismological inversion of magnetic loop parameters in solar active regions [J]. The Astrophysical Journal Letters, 2018
[14] Gong Zezhou, Li Miao, Wei Hongxiang. The threat of the sun: a side note on the; solarstorm; theme discussion at the Institute of Physics, Chinese Academy of Sciences [J]. Physics, 2019