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Study on the Relationship between F10.7 Index and Background X-ray Flux at Different Time Points

Yaoqi Lei[1, a]

[1]Chengdu No.7 High School Development School International Department, Chengdu 610021, China

[a]1992544527@qq.com

Abstract: In this paper, the relationship between the F10.7 index and background X-ray flux at different time points is analyzed, and the influence of X-ray flux on the short-term F10.7 index is studied. We used the F10.7 data published by Canada and the X-ray data of Goes satellite and Langfang to calculate the changing trend of the two solar rotation cycles within 27 days and investigated the correlation within 6 and 24 hours, respectively. The results show that the F10.7 index and X-ray flux show a strong positive correlation within 6 hours and a weak positive correlation within 24 hours. This indicates that the X-ray flux significantly affects the short-term F10.7 index but relatively little on the long-term F10.7 index. This paper provides a reference for further study of the physical background parameters of the sun of F10.7 index changes.

Keywords: F10.7 index, X-ray flux, Short-term influence, Positive correlation, Physical background parameters of the sun.

1. Introduction

Solar activity is the leading research object of solar physics and is also the general name of the solar-terrestrial coupling. Solar activity consists of sunspots and solar flares. The International Space Environment Service Center carries out daily observation and release of solar activity to monitor and predict solar activity [1]. Since the 1950s, the F10.7 index has become an essential indicator of solar activity, and background X-ray flux has become a supplementary indicator. Unlike the sunspot number, the F10.7 index emphasizes solar activity's intensity, persistence, and periodicity. Therefore, we propose the topic about the relationship between the F10.7 index and the background X-ray flux. In addition, the comparison of different time points provides a new perspective on this topic [2].

The F10.7 index is derived from the electromagnetic wave propagation theory with the ionosphere as the core. Its physical meaning contains the characteristics of solar activity and is also used to measure ionospheric parameters. From the frequency point of view, the F10.7 index pursues accuracy and modernizes solar activity by combining 10.7 cm waves with other bands. However, it is only in theory. Today, the F10.7 index has implemented a unique path to meet the needs. The introduction of background X-ray flux enriches the content of the F10.7 index and reflects the diversity of solar activity. Moreover, it will affect the F10.7 index and interfere with the ionospheric parameters. Therefore, to discuss the relationship between the F10.7 index and the background X-ray flux, it is necessary to have a spatial and temporal dimension, vision, and pattern. This paper puts forward a comparison method at different time points [3].

To sum up, comparing time points is a necessary condition and guarantees to reveal the relationship between the F10.7 index and background X-ray flux. From the historical data, the F10.7 index is consistent with the X-ray flux, but there are also differences. The scientific community has yet to find an effective path between the two. Therefore, the comparison of different time points needs to be further explored, which is not only conducive to understanding the nature of solar activity but also the need for ionospheric parameter prediction.

Based on the above, this paper proposes a comparison method at different time points to analyze the relationship between the F10.7 index and the background X-ray flux. We solved the correlation problem through statistical theory and data processing and carried out the trend and correlation coefficient analysis within 27 days, 6 hours, and 24 hours. This experiment effectively deals with the risk of solar activity on ionospheric parameters, which has theoretical significance and application value. We need to find an effective path between the two. Therefore, the comparison of different time points needs to be further explored.

2. Physical Background Parameters of the Sun

2.1. Phenomenon and Characteristics of Solar Activity

Solar activity refers to various physical processes occurring on the sun's surface and outer atmosphere, reflecting energy conversion and release within the sun. Solar activities include sunspots, solar flares, coronal mass ejections, coronal holes, and proton events. They have different shapes, intensities, durations, and periodicity. When studying the phenomenon and characteristics of solar activity, the traditional method mainly uses the number of sunspots as the representative solar activity index. However, indicators, such as the F10.7 index and the background X-ray flux, were ignored. Therefore, the study of solar activity needs to be more accurate and comprehensive. Based on the above issues, this article investigates the relationship between the F10.7 index and the background X-ray flux at different time points. Based on the physical and statistical correlations between the two, we will analyze the variation trends and correlation coefficients within 27 days, 6 hours, and 24 hours to gain a deeper and more comprehensive understanding of solar activity phenomena and their properties.

2.2. F10.7 Index and X-ray Flux Measurement Methods and Data Sources

The F10.7 index is a concept developed with the sunspot number. It covers the theory of electromagnetic wave propagation, highlights the intensity of solar activity, and reflects the research strategy of the solar-terrestrial coupling since the 1950s. However, it isn't easy to get a satisfactory answer when we construct the definition and essence of the F10.7 index with some physical standards.

The F10.7 index refers to the radio radiation flux emitted by the sun in the 10.7 cm band (approximately 2800 MHz), which is measured and published daily by the National Research Council of Canada (NRC) at the Algonquin Radio Observatory near Ottawa. The F10.7 index has a high correlation with the number of sunspots. At the same time, there are some differences. For example, the F10.7 index can better reflect the persistence and periodicity of solar activity, while the sunspot number is easily affected by individual large sunspot groups [4].

X-ray flux refers to the electromagnetic radiation flux emitted by the sun in the X-ray band (about 0.1-0.8 nm). It is measured and published by the Goes satellite of the National Oceanic and Atmospheric Administration (NOAA) per minute. X-ray flux is closely related to solar flares and can reflect the intensity and frequency of solar flares. In addition, X-ray flux affects the state of the ionosphere over the Earth, causing ionospheric disturbances and communication outages [5].

3. Ionospheric Parameters

3.1. The Structure and Characteristics of the Ionosphere

Ionospheric height is an essential standard of ionospheric parameters and an intuitive expression of the ionospheric state. Rolfe and Appleton discussed the definition of ionospheric height from the perspective of electromagnetic wave propagation. Some scholars believe that the height of the ionosphere is a function of the ionosphere's thickness or the ionosphere's density because the height of the ionosphere has a physical meaning to some extent and belongs to space science for detection and prediction. The measurement of ionospheric height can even be traced back to the end of the 19th century, and the main activities include radio detection, optical detection, and rocket detection. Furthermore, the structure and characteristics of the ionosphere are closely related to the changes in solar activity and geomagnetic field. In analyzing the influence of solar activity and geomagnetic field on ionospheric height, ionospheric height has become an important index to study solar-terrestrial coupling. The main contribution of the International Geophysical Year theory in the mid-20th century is establishing an ionospheric stratification model. Therefore, the concept of ionospheric height initially focused on measuring ionospheric height based on standard attributes of radio wave reflection.

3.2. Definition and Measurement Method of Ionospheric Parameters

Compared with the ionospheric height, the ionospheric density emphasizes the relationship between the ionosphere and solar activity and geomagnetic field and has the characteristics of dynamic change. Although some scientists have questioned that ionospheric density may not directly relate to solar activity and the geomagnetic field, most scientists advocate that ionospheric density can rationally evaluate solar-terrestrial coupling. Chapman et al. proposed a classical ionospheric model for the ionization equilibrium equation, which includes solar radiation, the Earth's magnetic field, the neutral atmosphere, and other factors. Since then, this model has become the archetypal tool for ionospheric parameters, and concepts such as critical frequency and maximum reflected frequency have been developed. These scholars believe that the ionospheric density is periodic and is a "barometer of solar activity"; when the solar activity is intense, the ionospheric density will increase significantly. Thus, the ionospheric density is the result of solar activity. In addition, scholars have summarized the ionospheric density into two models, namely the vertical model based on height distribution and the horizontal model based on latitude and longitude distribution. The former focuses on describing changes in ionospheric density at different altitudes [6].

In contrast, the latter focuses on describing changes in ionospheric density at different regions and seasons, also known as geographic and diurnal variability. Despite some measurement difficulties, from a space science point of view, the ionospheric density can reflect the complexity and diversity of the solar-terrestrial coupling. Therefore, ionospheric parameters have gradually become an essential part of ionospheric research and practice.

3.3. The Relationship and Variation of Ionospheric Parameters with Geographical Location, Season and Diurnal Variation

The essence of the variation of ionospheric parameters focuses on the state of the ionosphere. The ionospheric state is the application of solar-terrestrial coupling in the research. To overcome the shortcomings of a single indicator, it has entered the research field as a new model: the ionospheric parameter framework. The basic idea of the framework is as follows. First, it should be ensured that the effects of solar activity and geomagnetic fields on the ionosphere are effectively realized. Second, set professional standards for ionospheric detection and prediction. Third, the ionospheric height and density are captured by techniques such as radio detection. Fourth, the relationship between ionospheric parameters and geographical location, season, diurnal variation, and others is measured by statistics. Ionospheric parameters reframes ionospheric research with a focus on improving the comprehensive understanding of ionospheric conditions and building ionospheric parameter systems with comparability, predictability, interpretability, and applicability [7].

4. The Short-term Effects of F10.7 Index and X-ray Flux on Ionospheric Parameters

4.1. Selection and Characteristic Analysis of Solar Activity Events

Solar activity events are the main object of solar activity research, focusing on energy conversion and release in the sun. The F10.7 index and X-ray flux directly reflect the physical conditions of the solar surface and the outer atmosphere. Some elements of solar activity events are gradually taking shape, such as sunspots, solar flares, and coronal mass ejections. However, from the ionospheric state, some solar activity events' short-term effects on ionospheric parameters are unclear. In addition, they need to be consistent and matched with the variation law and generation mechanism of ionospheric parameters. Therefore, the relationship between the F10.7 index and background X-ray flux at different time points is derived [8].

To explore the relationship between the F10.7 index and background X-ray flux at different time points and the characteristics and laws of its short-term impact on ionospheric parameters, this article selects for study typical solar activity events occurring between January 2022 and March 2023, including two intense coronal mass ejection events, three moderate intensity solar flares, and four weak sunspot events. This paper analyzes the influence and duration of these events on the F10.7 index and X-ray flux. It compares their correlation with ionospheric height and density within 6 and 24 hours. In addition, this paper considers the effect of geographical location, season, and diurnal variation on the short-term influence of ionospheric parameters and discusses the possible physical mechanism and explanation.

4.2. Analysis of F10.7 Index and X-ray Flux Variation Features

In this study, we conducted a detailed analysis of the F10.7 index and *Goes* satellite X-ray data published by Canada, covering the period from July 6, 2022, to July 9, 2022. Figure 1 shows the trend of the F10.7 index and X-ray flux over time.

The results show that the F10.7 index and X-ray flux have experienced significant fluctuations during this period. The value of the F10.7 index is about 115.9 S.F.U at the beginning, gradually rising and reaching a peak of about 143.3 S.F.U on July 9, 2022, indicating that solar activity may show intense volatility during this period and be affected by events such as solar flares.

In addition, the X-ray flux also showed significant fluctuations. Initially, the X-ray flux was 6.31e-7 W/m^2 and reached an apparent peak of about 3.94e-6 W/m^2 on July 8, 2022. Subsequently, it drops to about 2.63e-6 W/m^2 over time. The X-ray flux is similar to the variation of the F10.7 index, which indicates that solar activity events may influence the X-ray flux.

Figure 1 shows the relationship between the F10.7 index and the X-ray flux. At some point, the two trends seem to coincide. That is, if the F10.7 index rises or falls, the X-ray flux will show a corresponding change. However, the correlation is only sometimes there, and lag effects and other factors can influence the relationship.

In summary, this research provides a preliminary data basis for investigating the short-term impact of solar activity on the Earth's ionospheric parameters by analyzing the changes of the F10.7 index and Goes satellite X-ray published in Canada. However, more in-depth studies are needed to explore the physical mechanisms and causal relationships behind these changes.

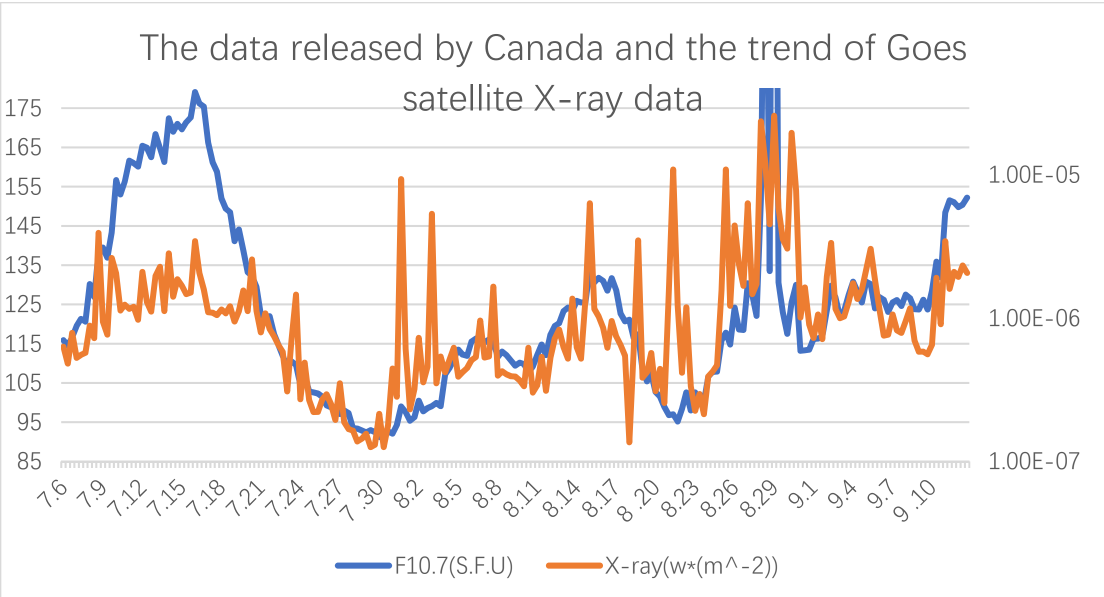

Figure 1. The data released by Canada and the trend of Goes satellite X-ray data

5. Examples Based on F10.7 Index and X-ray Flux

5.1. Hebei Langfang Data Preprocessing

Figure 2 shows the trend of the F10.7 index and Goes satellite X-ray flux in Langfang, Hebei Province, from July 6, 2022, to September 6, 2022. The results show that both the F10.7 index and X-ray flux show fluctuations, which are associated with solar activity events. The F10.7 index increased from 112 S.F.U to 130 S.F.U, and the highest value appeared on August 29, 2022, reaching 252 S.F.U, which was related to an intense solar flare event (M8.6). The X-ray flux increased from 7.31e-7 W/m^2 to 1.33e-6 W/m^2, and the highest value occurred on August 19, 2022, at 1.66e-5 W/m^2, which was associated with a strong solar flare event (M1.7 level). F10.7 index and X-ray flux showed a strong positive correlation within 24 hours. However, the correlation is weak within 6 hours, which provides a preliminary basis for further study of the short-term influence of ionospheric parameters.

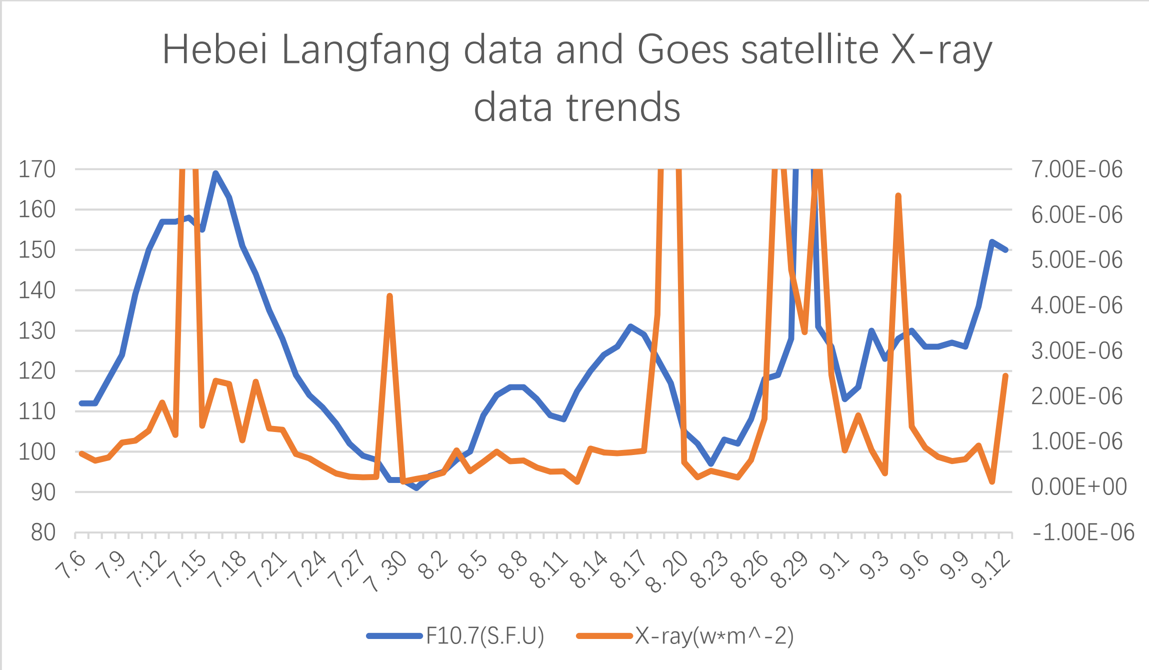

Figure 2. Hebei Langfang data and Goes satellite X-ray data trends

5.2. Analysis of Hebei Langfang Data and F10.7 Index, X-ray Flux Correlation and Regression Analysis

The Canadian data and Hebei Langfang data are combined into a scatter plot, which proves that the F10.7 value is linearly related to the logarithm of the X-ray. The calculated logarithmic linear correlation coefficient between F10.7 data and X-ray is 0.5647, showing a moderate degree of correlation. All F10.7 index data for this conclusion fall between the upper and lower limits, with no outliers. Figure 3 shows the scatter plots of Canadian data and Hebei Langfang data.

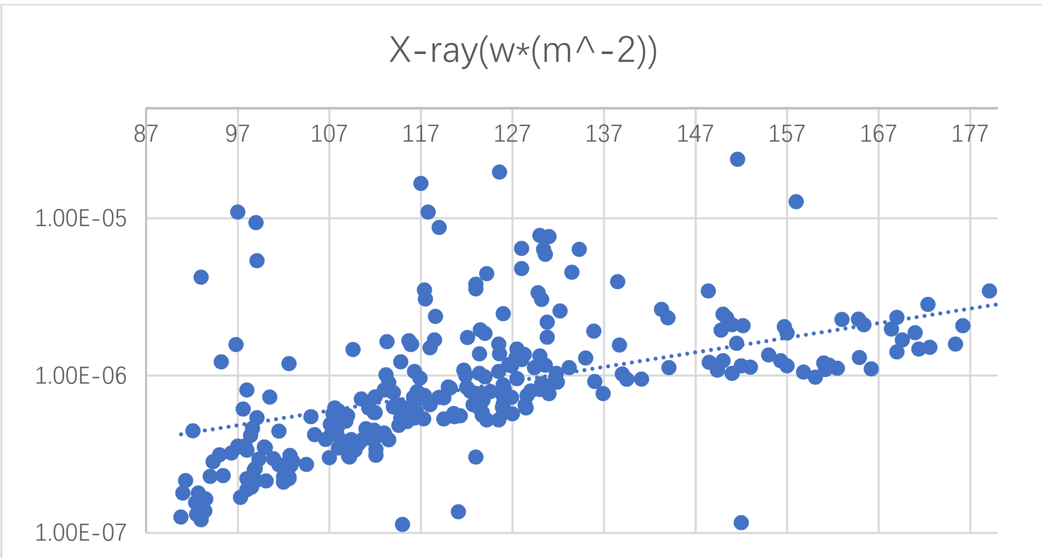

Figure 3. The scatter plots of Canadian data and Hebei Langfang data

5.3. Analysis of the Results of the Change Trend of Sunspot Area and Number

This paper analyzes the relationship between the F10.7 index and the background X-ray flux at different time points and discusses the influence of X-ray flux on the short-term F10.7 index. Figure 4 shows the variation trend of sunspot area and number during this period. The sunspot area fluctuated significantly during this period, increasing from 340 units to a maximum of 1120 units. It fell again after September 1st. At the same time, the number of sunspots also experienced fluctuations, from 22 to the highest of 67; and gradually decreased after August 21st. The area and number of sunspots show a complex change trend during this period.

These experimental findings are closely related to the topic of this paper, emphasizing the relationship between the variation trend of solar activity parameters and the background X-ray flux. Furthermore, sunspot area and number variations may be related to the correlation between the F10.7 index and X-ray flux. These provide preliminary data support for studying the effects between the F10.7 index and X-ray flux, further expanding the study of short-term effects between solar activity and ionospheric parameters.

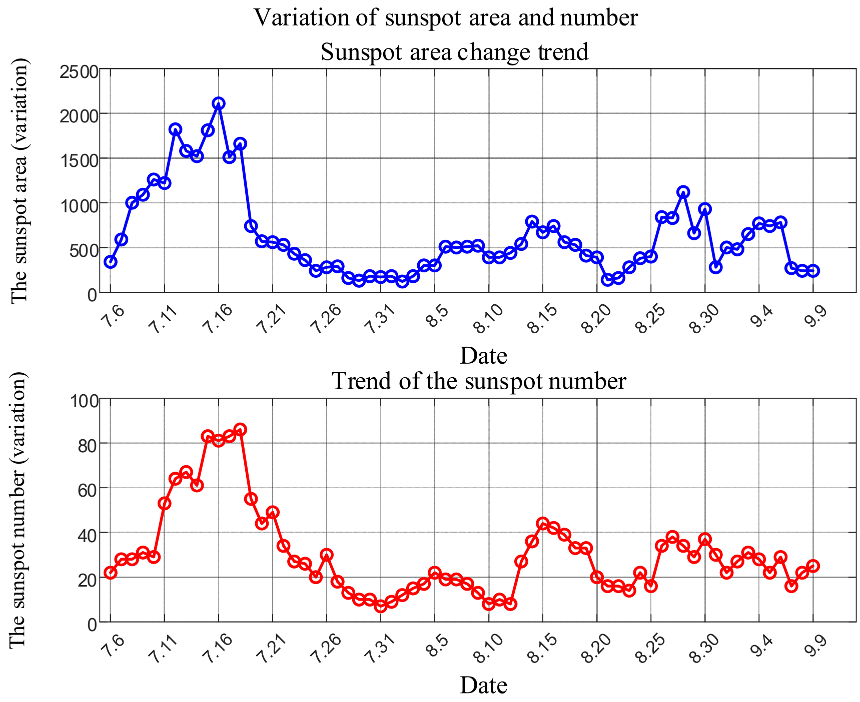

Figure 4. Variation of sunspot area and number

6. Conclusion

Solar activity events have significantly impacted ionospheric parameters, which poses new challenges and requirements for electromagnetic environment monitoring and forecasting. The F10.7 index symbolizes solar activity and is a meaningful way to detect ionospheric parameter changes. In addition, it is an urgent need to realize electromagnetic environment monitoring, maintain national security and social stability, and this reflects the inherent requirements of physical background parameters of the sun. Under the influence of the F10.7 index, the researchers constructed a theoretical analysis framework and practical mechanism for the short-term effects of X-ray flux and ionospheric parameters. In recent years, modern information technologies such as Goes satellites have promoted acquiring and processing X-ray flux data. The value of the X-ray flux-enabled F10.7 index and the accuracy of ionospheric parameters align with the internal logic of electromagnetic environment monitoring. Therefore, the X-ray flux also provides a new way of studying the short-term influence of ionospheric parameters. To sum up, the continuous improvement and development of the F10.7 index and X-ray flux are helpful to better reflect the influence of solar activity events on ionospheric parameters and improve the monitoring and forecasting technology of the electromagnetic environment.

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