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Characteristic of Ionospheric foF2 and Solar Indices during the 23rd Solar Cycle over High Latitude Station, Syowa, Antarctica

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Abstract

The behavior and dynamics of ionosphere are completely dependent on the solar activity. We have investigated the long term variability of ionospheric parameter foF2 with corresponding changes in the solar activity during the 23rd solar cycle. The variation of the critical frequency of ionospheric foF2 at Syowa Station Antarctica, (69˚S, 39˚E) is examined with four different solar activity indices characterizing the long term variability of solar activity wise Flare Index, relative sunspot number (Rz), solar flux F10.7 cm and CME occurrence index. We compared the dependency of foF2 and other solar activity indices on each other by using linear correlation investigation, and showed the qualitative similarity of the ionospheric foF2 with the solar indices. We notice that hysteresis of foF2 is lower for the growing branches of the solar cycle. The individual dissimilarity of critical frequency foF2 demonstrated the dependency on the solar cycle but this variation was different during the months, which depended on solar activity and polar ionospheric behavior. The peak to peak variation between monthly average of critical frequency foF2 and solar indices parameter is evidence for the absolute dependency for each other. The linear correlation between the solar indices and foF2 is very strong during the climbing and downward branches of the solar cycle. However the incline of their linear fits shows variations from index to index.

Keywords

High Latitude, foF2, Solar Cycle, Solar Indices

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1. Introduction

The sun follows a periodic cycle of activity, called solar cycle. The solar cycle is the periodic recurrence of sunspot or darker relatively cool regions at the sun's surface. During the solar cycle, the sun emits a wide variety of solar radiation originating in different parts of the solar atmosphere. Solar Ultraviolet (UV) irradiance (115 - 420 nm) plays a dominant role in the temperature distribution, photo chemistry, and overall momentum balance in the stratosphere, mesosphere and lower thermosphere [1]. However, electron concentration in the F2-region of the ionosphere is primarily due to ionization of the neutral atmosphere by the solar UV radiations. These radiations are now known to show very definitive solar cycle variations. Consequently, electron concentrations and thus, the critical frequency of the F2-region (foF2) are also expected to reflect these variations. Although there were no solar UV measurements during the early years of ionospheric research, traditionally, the smoothed monthly mean sunspot number Rz (Zurich Sunspot Number) was considered a primary index of solar activity for the prediction of ionospheric parameters. The dependence of foF2 on Rz has been defined by various authors since a long time ago [2]-[6]. However, several efforts have been made to establish a new solar activity index; for this prediction [7] proposed to use extreme ultraviolet EUV data. For the long-term predictions of the monthly median ionospheric parameters [8] reported that in the absence of solar EUV data, solar radio flux (10.7 cm) may be better than sunspot numbers while making ionospheric predictions. Flare index (FI) was introduced by Kleczek in 1952. The relationship "FI = IT" quantifies the daily flare activity over 24 hours period. In this relationship, "I" represents the intensity scale of importance of a flare in H*α* and T is the duration of the flare in minutes [9]. The flare index is a parameter and is an important measure of the short-lived activity on the Sun [3] [10]. Some powerful and explosive events on the sun, such as Coronal Mass Ejections (CMEs) can lead to worldwide disturbances of ionospheric and gamogenetic conditions. These events can, and do, have an impact on the performance and reliability of space and ground based operational system [3].

Solar activity variations are manifesting themselves not only in electromagnetic radiation from radio frequencies to powerful gamma rays but also in particle flux. In broad physical terms, solar activity may be understood in terms of the properties and the behavior of the magnetized solar plasma. Solar structures and phenomena all arise from magnetic fields embedded in dynamic plasma. Some of these structures are remarkably long-lived, and a variety of structures are observed over the entire electromagnetic spectrum from radio through visible to X-rays and gamma rays. Continuous observations are required to catch short-lived and infrequent phenomena. One important example is solar flares. Images of the Sun show that solar flares are one of the most powerful and explosive of all forms of solar activity. Many studies conducted in the past have solar flares as one of the most important solar events affecting the Earth [11].

Antarctica provides important opportunities for testing critical hypotheses relating observations to current theories, both because of its advantageously unique geophysical attributes and because of its remote location with respect to localized anthropogenic sources. One of the goals of this study was to demonstrate, which solar activity is more convenient for ionospheric predictions.

Ionospheric variations can be considered in different time scales viz day to day variability, semiannual, annual, and solar cycle. In this present study, examination is made only on the long-term basis (Solar-Cycle). We investigate the response of the ionosphere to the solar activity by using the flare index, the sunspot number (Rz), the solar radio flux at 10.7 cm and Coronal Mass Ejections (CMEs) occurrence during the 23rd solar cycle over the Japanese Antarctic Station Syowa (Geographic Lat. 69˚S and Long. 14.79˚E, Geomagnetic Lat. 39.34˚S and Long. 55.90˚E).

2. Data and Methods

Present paper is describing about the high latitude ionospheric variation with different solar indices like Coronal Mass Ejection (CME), Sunspot Number (Rz), and Flare Index (FI) and Radio Flux (F10.7). These all parameters depends on short and long term solar activities and they are shows the correlations with each other. For the study we chooses the data from Japanese scientific research station Syowa, Antarctica showing in **Figure 1**. The critical frequency of ionospheric F2 layer (foF2) is one of the most important parameters in the ionospheric research which is observed regularly by several observatories. In our study we have used the hourly averaged value of foF2 which is taken from Syowa station, Antarctica, provided by National Institute of Information and Communications Technology (NICT), Japan (http://wdc.nict.go.jp/IONO/HP2009/ISDJ/index-E.html).

The daily data of sunspot number (Rz) provided by Center of Royal Observatory of Belgium were used for

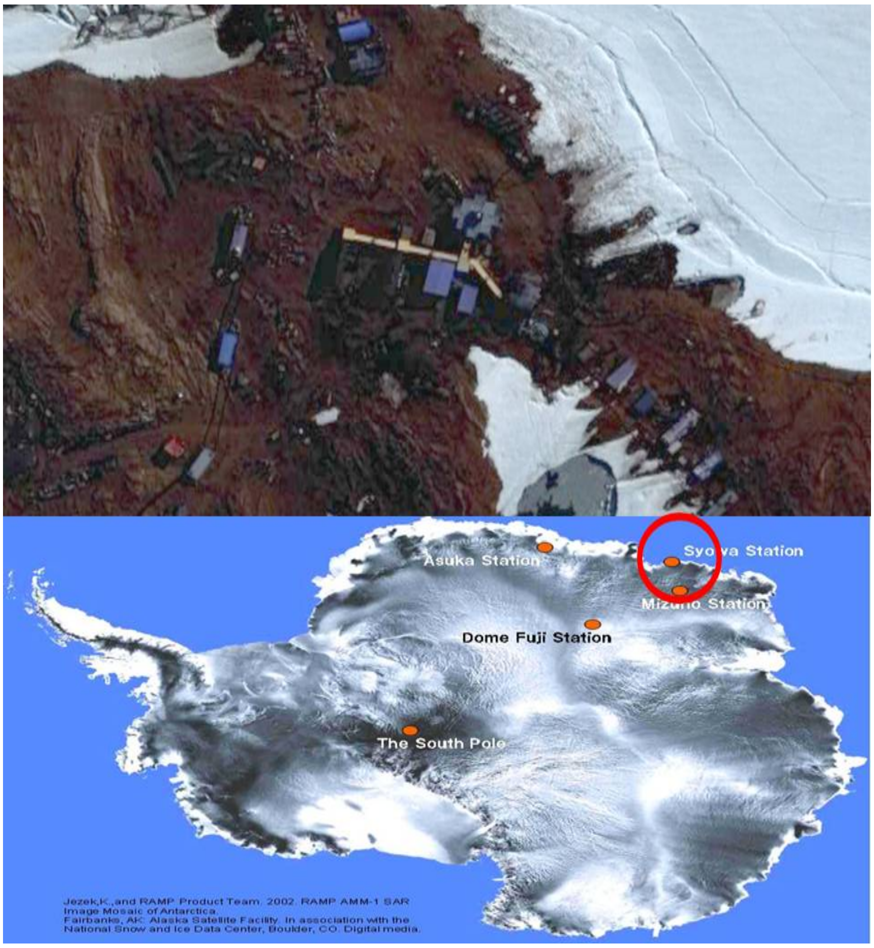

Figure 1. Map of Syowa Station, Antarctica. (http://www.intechopen.com/source/html/16894/media/image4.jpeg).

our analysis. This data represents the definitive relative number of the sunspots calculated on the basis of all observations available from different observatories.

The Solar flare index (FI) is an interesting parameter for the study of activity variations in the chromospheres. It is provide a short-term activities (minutes to hours) on the sun. Catalogs of flare activity using Kleczek's method are given for each day from 1936 to 1986 [12]-[14] and for 1986-1995 [2]. This data of flare index is collected from National Geophysical Data center (NGDC) (http://www.ngdc.noaa.gov/stp/solar/solardataservices.html).

Coronal Mass Ejections (CME) occurrence is also an important powerful parameter that represents the changes in this solar activity.

In this study we are presenting individual behavior of monthly average value of critical frequency foF2, flare index, CME occurrence, sunspot number and radio flux during the whole solar cycle 23rd. Second method are using for cyclic variation of foF2 with other indices. Third method is showing peak to peak variation of foF2 with other indices and last method of data analysis is showing the linear correlation with foF2 and other indices during ascending and descending branch of solar cycle.

As we know the Antarctica is very important for the upper atmospheric study because magnetic field lines play very important role for change the upper atmospheric conditions. The main glimpse of our study is solar cycle variation of ionospheric critical frequency foF2 and its correlation with other solar parameters over high latitude. This study is very useful for those who are working in upper atmosphere and as well as solar terrestrial physics and its show upper atmospheric environmental condition during space weather.

3. Results

Figure 2 represents the correspondence between solar activity indices and foF2. The variations of monthly

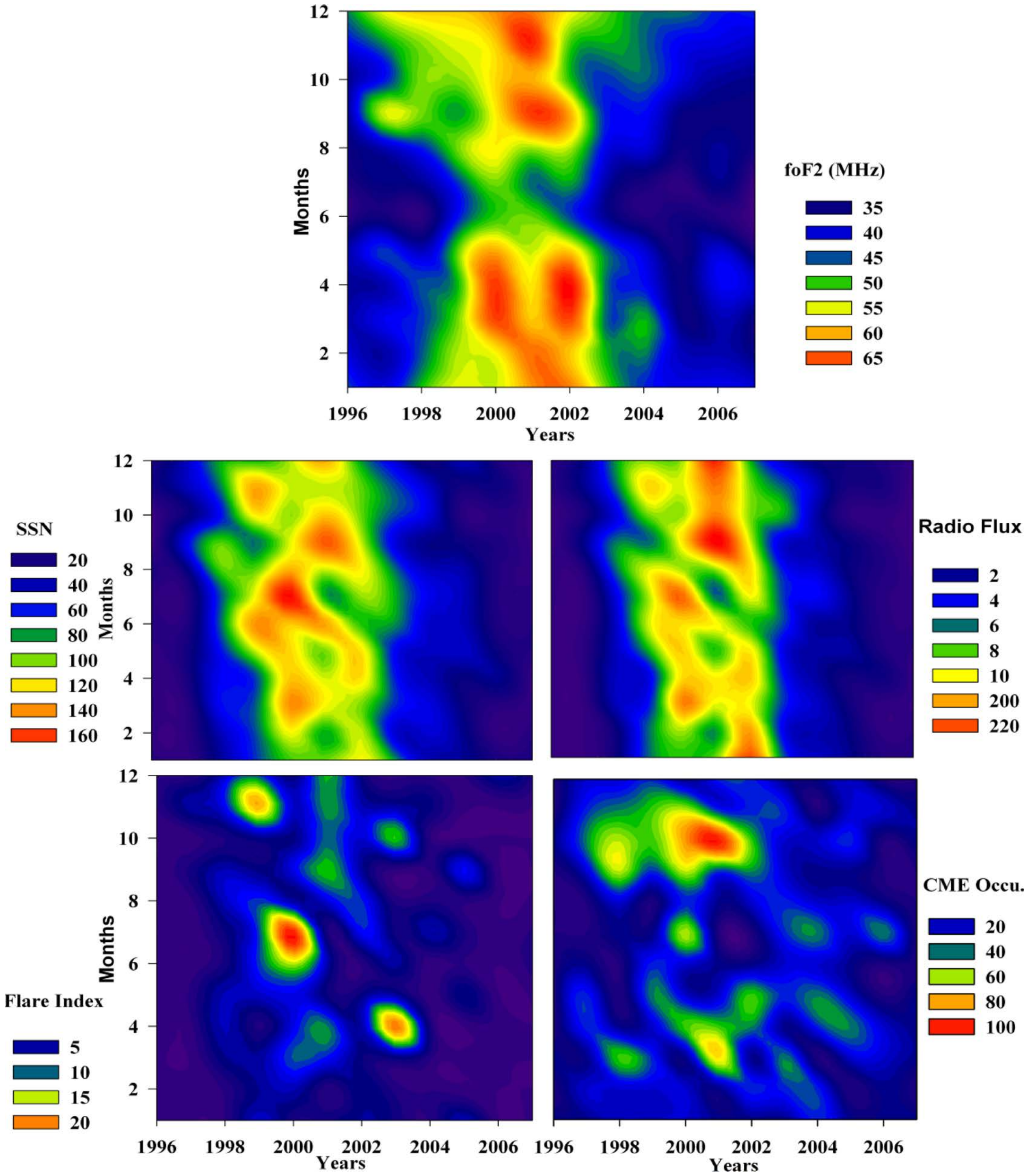

Figure 2. Behavior of critical frequency foF2 and solar indices during the solar cycle 23 over Syowa, Antarctica.

averaged values of various solar indices and monthly averaged values of foF2 for the different years of solar cycle 23 from the figure we find that all these indices show a monotonic increase from the beginning of the solar cycle to their maxima. The different solar activity indices start increasing from year 1998 and achieve their peak during 2001 and remain so far 2002 after which these start decreasing describing the cyclic variation of solar activity, the similar behavior is reflected by foF2. It also remains at its peak during 2001-2003. However during the months of May, June, July and August of every year, the values of foF2 represent a decrease this is quietest natural since there months correspond to Antarctic weather. These from the **Figure 2**, we find that solar activity indices representing cyclic variation of solar activity vary monotonically with foF2.

Figure 3 represents the variation of monthly mean foF2 with each of the solar activity indices, during all the months of solar cycle 23. From the **Figure 3** we find that there is a synchronously variation between foF2 and the solar activity indices. As the solar activity starts increasing from 1998 the values of foF2 also start increasing and achieve the peak during 2001-2002 which is also the peak of solar cycle 23.

Figure 4 shows the yearly variation of foF2 with solar cycle through different indices which characterize the cyclic variation of solar cycle. Here again we find the monotonic increases of both solar activity indices and foF2. We can notice the dual peak of both foF2 and solar activity indices, the first peak correspondence to sunspot, CMEs activity and second peak in through to be first solar wind streams which increase during the delay these of solar cycle.

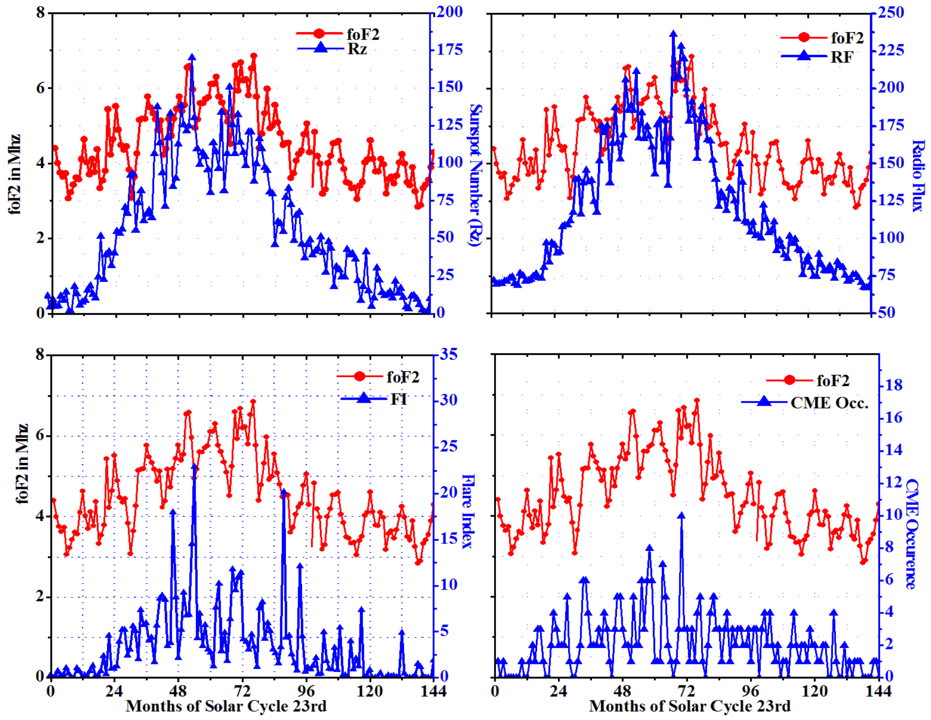

Figure 3. Variation of solar indices with critical frequency foF2.

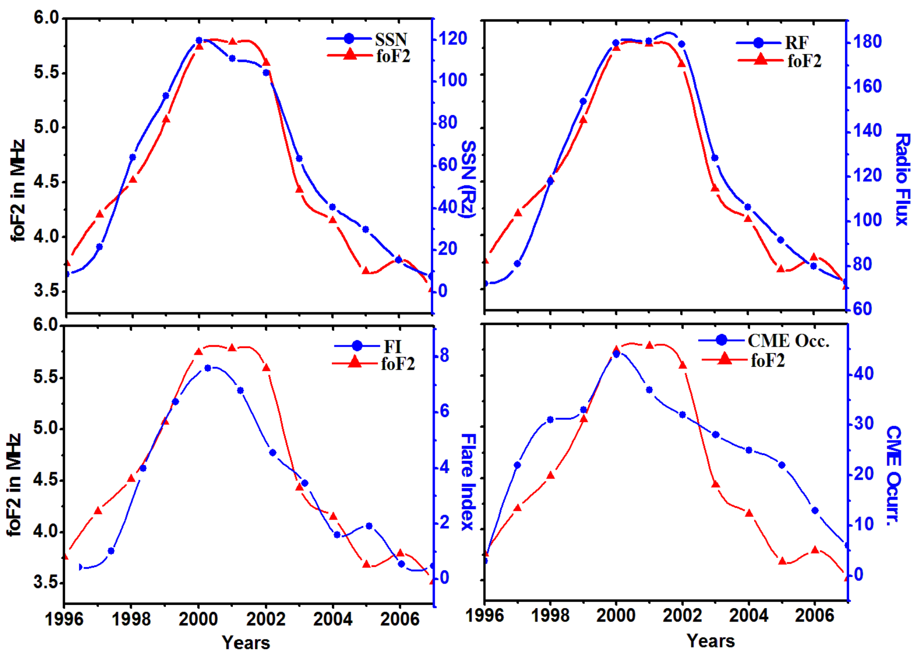

Figure 4. Peak to peak variation between solar indices and critical frequency foF2 during the solar cycle 23, Syowa Station, Antarctica.

In order to determine the relationship between foF2 and the solar activity indices, a liner correlation is carried out. The result of the analysis is as shown in **Figure 5**. If illustrates the relationship during the ascending and descending branch of solar cycle 23. a linear fit exist between the foF2 and all solar indices, however the slop of curve varies from index to index as well as for ascending and descending branch of solar cycle. A strong correlation exist (0.84 - 0.99) between solar indices and for during ascending as well as descending branch of the solar cycle.

In order to determine the relationship between foF2 and the solar activity indices a liner correlation analysis was carried out, results are shown in **Figure 5**. **Figure 5** demonstrates the variations of foF2 with the solar parameters for ascending and descending branches of solar cycle 23. An almost liner relationship between foF2 and solar activity indices can be clearly shown in Figure. We may note that the sunspot and foF2 hysteresis exist generally for lower foF2 value for rising branch as compared with falling branches of solar cycle.

4. Discussion

Being able to express aspects of solar activity by many indices, such as the sunspot number, radio flux, flare

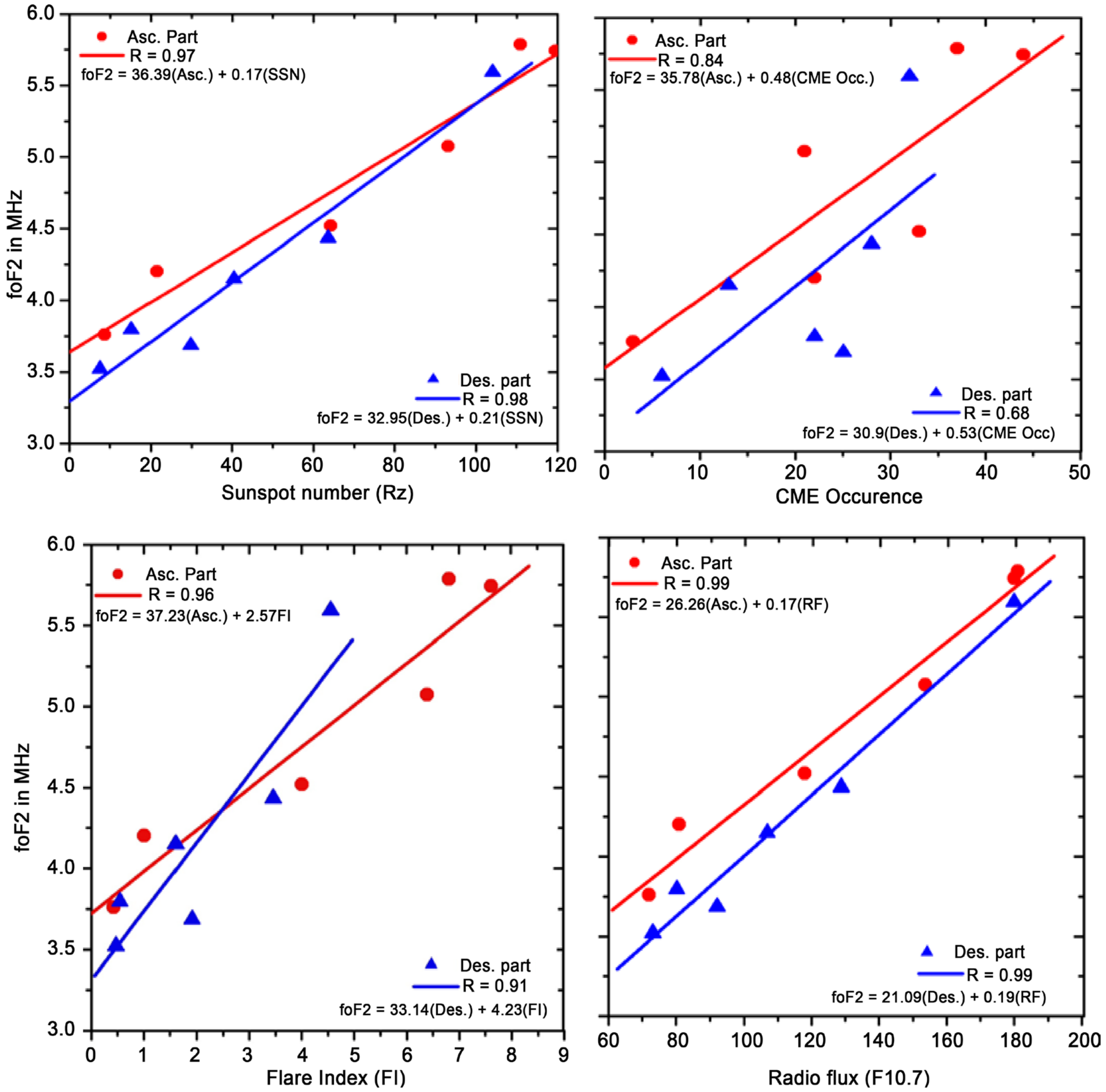

Figure 5. Twelve months moving average of foF2 over Syowa Station, Antarctica, versus solar indices. Full dots refer to the ascending phase (1996-2000) of solar cycle 23 and triangles the descending phase (2001-2008). The single regression fits are shown as solid lines for the both the phases of solar cycle 23.

index and CMEs occurrence, they are, useful for studying the Sun's long-term behavior and its interaction with our near Earth space environment. Long-term predictions of the critical frequency have traditionally been based on the relationship between the predicted ionospheric parameters and 12-month running mean of the sunspot number (Rz). For a given station and a constant value of the solar activity indices, foF2 differs for the ascending and the descending parts of the 11-year solar cycle [15]-[18]. In this connection, we investigated the solar cycle variation of foF2 by using the solar flare index and the CMEs occurrence, relative sunspot number, and radio flux. The examination of the liner correlation between the monthly average values of foF2 and several indices of solar activity showed that independently from the kind of index and location, significant hysteresis is present during cycles 23 [7]. The explanation for the lag is in the dual peak structure of indices. The first peak is related to sunspots' CME activity and the second peak is thought to be caused by fast solar wind streams, which increase during the declining phase of the solar cycle, as more and more mid-latitude coronal holes appear on the solar surface [19] [20]. Indeed, according to Abramenko [21], the declining phase of the 23rd solar cycle displayed an excess of low-latitude coronal holes.

The linear correlation between the solar activity indices and foF2 is very strong during the ascending and descending branches of the cycle (**Figure 4**). The slope of their linear fits shows variations from index to index. The hysteresis effect in ionospheric parameters, such as foF2, may be compatible with a geomagnetic control for each solar cycle. Geomagnetic disturbances are accompanied by large changes in the ionospheric F2 layer. Although the ionospheric response to geomagnetic activity is highly complex due to the many physical processes involved, there are underlying trends that are useful in characterizing the ionosphere response to storms [1] [4] [6] [22]. Taking into account that geomagnetic activity is higher on average during the descending phase of the solar cycle than during the ascending phase, a clockwise or counter-clockwise hysteresis should be expected at a location depending on its prevalent negative or positive ionospheric storms. This implies negative or positive hysteresis magnitude, respectively [23]. A linear relationship between two parameters is used in forecasting and in long term trend estimations [24]. According to our findings the hysteresis of foF2, varies non-systematically with the solar cycles, so the conclusion of the hysteresis into the long-term ionospheric predictions seems not suitable.

In a study [25] [26] showed that most of the solar parameters as well as the (foF2) show two maxima, with the second maximum higher than the first maximum. The magnitudes of the second maxima relative to the first one were different for different solar indices. We found the same result with our parameters.

Ionospheric foF2 changes differ from location to location, indicating that direct linear relationship of foF2 with solar intensities is not maintained, and complex effects of other parameters are involved. Many previous researches, which were completed with the ascending branch data, have resulted in an extensive range of the solar periodicities. This is not easy to explain and indicates that the problem of solar periodicities is still awaiting more systematic efforts. Hence over an 11-year solar cycle the amplification sometimes regenerates more polar field and sometimes less. This is reported strong observational evidence that the speed of deep meridional flow toward the equator is driving the sunspot cycle [27] [28]. Obviously, other mechanisms, such as fluctuations in the meridional flow [29] [30], believed to be a product of turbulent convection and variations in the gradient of the rotation rate, and also contribute to the cycle amplitude variations. The differences in the speed of the meridional circulation during cycles with different amplitude and all the mechanisms mentioned above can act as an intrinsic dynamics which would explain the midrange solar activity periodicities.

5. Conclusions

This paper investigated the dependence of foF2 on the solar activity. Four solar activity indices namely flare index, relative sunspot number, solar flux at 10.7 cm, and CMEs occurrence indexes were correlated with foF2 data of Syowa, Antarctica. These indices provide a good opportunity to study the solar activity variability in the ionosphere. The conclusions can be drawn as follows:

The individual variation of critical frequency foF2 and solar indices demonstrated the dependency of foF2 on the solar cycle variability but this variation was different during the months, which depended on the solar activity and polar ionospheric behavior.

The solar indices and critical frequency foF2 vary synchronously with each other during the rising and falling phases of solar cycle.

The peak to peak variation between monthly average of critical frequency foF2 and solar indices is evidence for the absolute dependency of foF2 on solar indices representing solar activity.

The linear correlation between the solar activity indices and foF2 is very strong during the ascending and descending branches of the cycle. The slope of their linear fits shows variations from index to index. The hysteresis of foF2, varies non-systematically with the solar cycle, so the inclusion of the hysteresis predictions of ionosphere seems not suitable for long-term.

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