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Effects of Sunspot Cycles on Diurnal and Seasonal Trend of foF2

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ABSTRACT

In this paper the impact of the sunspot cycle, its influence on the composition of F2 layer of ionosphere at day and night time over the mid-latitude region has been investigated for Wakkanai (45.39ºN, 141.68ºE) Japan. To carry out the study, we have considered the 21st solar cycle (1976-1986) and 23rd solar cycle (1996-2008). The trends of critical frequency (foF2) for a different local time, months and solar cycles have been analyzed which illustrated the dynamics of the F2 layer. The sunspot cycle extensively effect the foF2 for any local time and month, while the seasonal trend, showed the foF2 non-dependence on solar zenith angle in which the seasonal and semiannual anomalies were pragmatic in the months of December and March respectively. However, the tendency of diurnal foF2 is usually high in the daytime and low at night time, although the Midlatitude Summer Nighttime Anomaly (MSNA) has been experiential in the diurnal cycle of foF2 in the month of June. This communication augments the knowledge and will provide guideline to researchers working in the field of solar activity varying the dynamics of the ionosphere correlating fluctuating sunspot numbers.

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INTRODUCTION

Solar activity is one of the indication of the intensity of radiations from the Sun at the frequencies in the range of X-rays and Extreme ultraviolet (EUV). The complexity of the direct measurement of solar EUV and X-ray radiations and due to intermittently owing to their expense, researchers largely depend on solar proxies to indicate the strength of solar activity. The departures from symmetry of the solar surface are sunspots. Sunspots are the darker regions on the solar surface, consists of a dark region called umbra which is surrounded by a lighter region known as the penumbra. Sunspot numbers (SSN) have the average cycle of about 11-years in which the number of sunspots enlarge and decline. The strongest cycles are those, which are asymmetric in shapes, spots rise sharply to the maximum but slowly decline, while the weakest cycle shows opposite form (Taylor et al., 1991), (Lean et al., 2001) and (Bilitz et al., 2000). Solar indices, which are well known and frequently used include, the sunspot number, the solar radio flux at 10.7cm wavelength F10.7, He 1083, and MgII core-to-wing index. Relative sunspot number is the most appropriate parameter to measure solar

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activity and it is broadly used in the solar terrestrial relation researches. There is statistically high correlation between sunspot number, F10.7, and solar EUV (Floyd et al., 2005), (Tobiska et al., 1990), (Barth et al., 1990), (Kane et al., 2005), (Kane et al., 2003), (Chen et al., 2011) and (Richards et al., 1994).

The Earth's upper atmosphere absorbs the space radiations especially the radiations coming from the Sun, which result in heating and ionization. The region of the upper atmosphere where charges, either positive or negative are present in large sufficient amount to influence the trajectory of radio waves is called Ionosphere. The ionospheric layers are formed by EUV and X-ray radiations from the Sun. The ionosphere is divided into four layers in which F2 layer is the most important layer for radio wave propagation. These layers persist 24 hours under all solar and terrestrial conditions. The dominant charge carriers are O^+ ions with secondary H^+ and He^+ in F2 layer. The F2 layer is responsible for high-frequency long distance ionospheric communication. The EUV in the range of (5nm<λ<102.7nm) is the main source of photo-ionization process in the F2 layer (Zolesi et al., 2014).

2. METHODOLOGY

In order to analyze and elaborate the significance of variations in sunspot number and the relative impact on the critical frequency of F2 layer we have used standard statistical tools and to depict parameter trends time series analysis has been carried out (Liu et al., 2003). The data of foF2 have been used from the website "World Data Center for Ionosphere and Space Weather, Tokyo, National Institute of Information and Communications Technology". In our study ionospheric foF2 data recorded by ionosonde station located at Wakkanai in Japan has been utilized. The geographic latitude and longitude of Wakkanai station are 45.39°N and 141.68°E respectively. The data of international sunspot number are provided by the "Royal Observatory of Belgium" obtained from http://www.sidc.oma.be/. The monthly mean international sunspot number data are used for solar cycles 21 and 23 while the monthly median hourly foF2 values are used for the years of 1976-1986 and 1996-2008 for analyses. The time difference in the data of foF2 for Japanese standard time is (JST) (JST = UT+9 hours).

3. DATA ANALYSIS

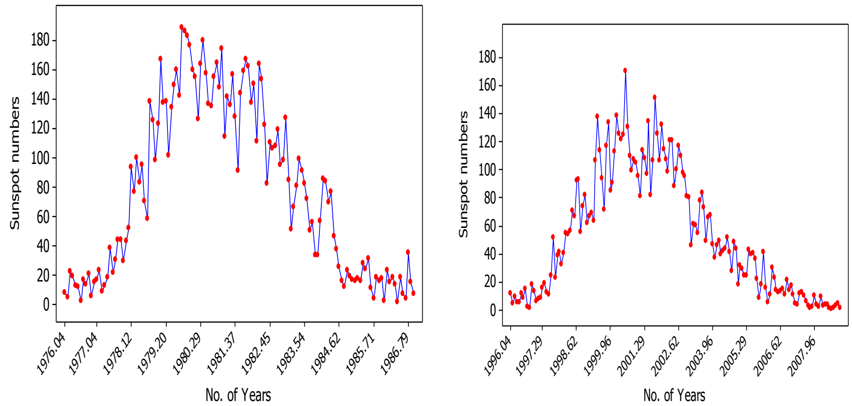
3.1 Temporal Analysis of Data

One of the definition of a time series is a successively measured an observational value that are evenly spaced in time. Time series analysis comprises methods for analyzing time series data in order to extract meaningful statistics and provide explanation regarding the physical process occurring in the ionosphere particularly in F2 layer effecting critical frequency (foF2) with reference to SSN.

3.1.1 Time Series Illustration of Sunspot

The temporal plots of the monthly mean sunspot number of solar cycles 21 and 23 are illustrated in Fig-1. These plots represent the behavior of sunspot number that changes from minimum to maximum and then from maximum to minimum. The Fig-1(a) is of 21st solar cycle from 1976 to 1986 and the Fig-1(b) is of 23rd solar cycle from 1996 to 2008. It has been witnessed that the sunspot number is greater in 21st solar cycle as compared to 23rd solar cycle. In both cycles, sunspots were rapidly increased in number while it was decreased slowly. The maximum monthly mean

International sunspot number occurred in September 1979 and July 2000 in 21st solar cycle and 23rd solar cycle respectively. In solar cycle 21, the monthly mean sunspot numbers are greater than 100 in foF2 clearly shows that the pronounced solar activity also puts impact on the foF2 during night time. The foF2 is lower down at minimum solar cycle years and it is elevated at the time of the maximum solar cycle. It is noticed that the pattern of foF2 formed at midnight in the month of June is higher as compared to others especially in December.



(a) (b)

Fig. 1: Time series plots of monthly mean sunspot number of 21st and 23rd solar cycles

Table 1. Basic statistics of monthly mean sunspot numbers for solar cycle 21 and 23.

Variable	Mean	Standard deviation	Minimum	Maximum
SSN from 1976-1986	76.65	58.3	1.1	188.4
SSN from 1996-2008	52.41	43.61	0.5	170.1

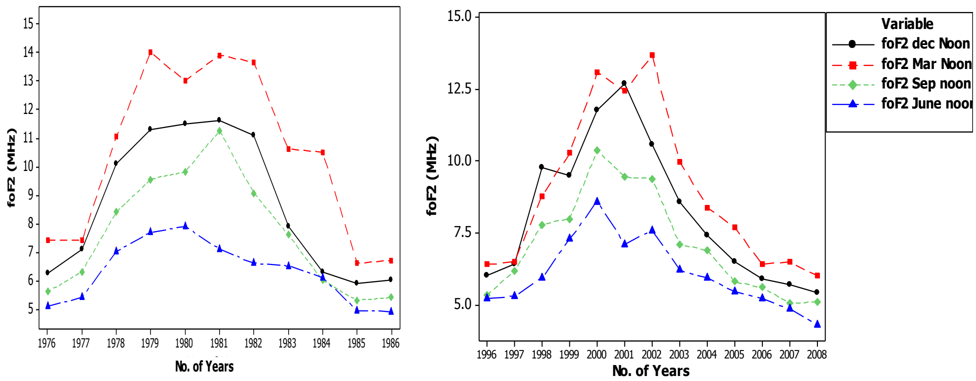


Fig. 2: Time series of noontime monthly median values of foF2 during 21st and 23rd Solar Cycles

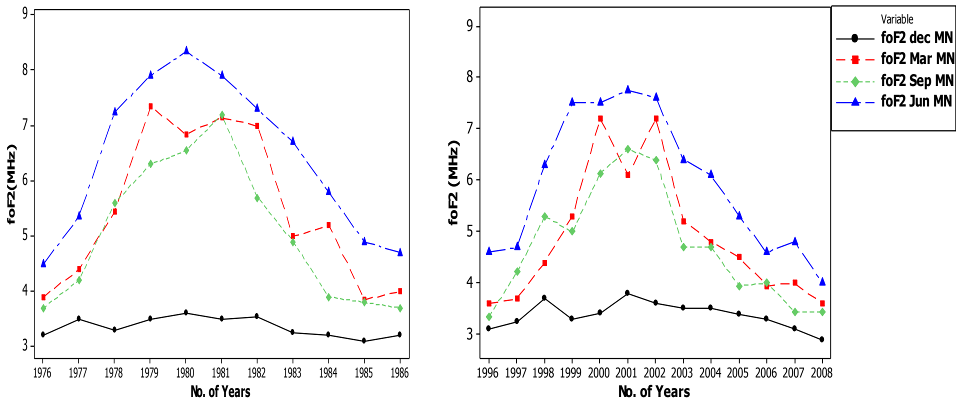
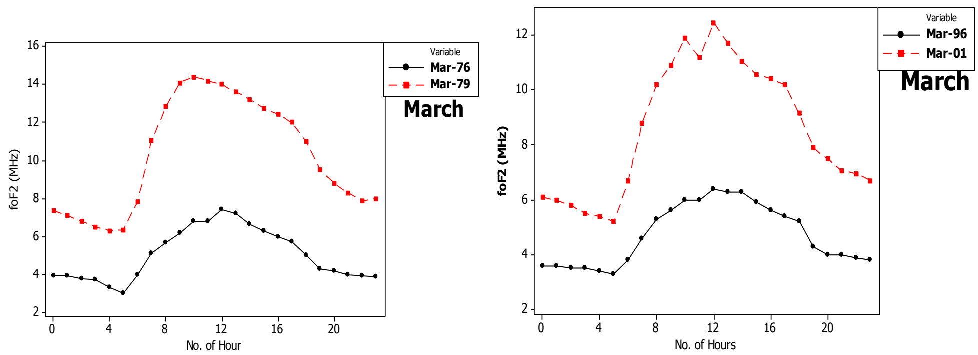


Fig. 3: Time series of midnight time monthly median values of foF2 for 21st and 23rd Solar Cycles

The seasonal or winter anomaly can be noticed, in which at noontime electron density in F2 layer becomes greater in winter (i.e., December) than in summer (i.e., June). Fig-2 shows not only winter anomaly, but also the high values at equinox, which represent the semiannual variation. The maxima of the semiannual variation occur in April and October (Rishbeth et al., 1969), which are also seen in Fig-2 in the month of March and September (which are near to April and October). The reason of the anomalies is the seasonal composition changes in the atmosphere, especially the neutral O/N_2 concentration ratio. The summer-to-winter neutral circulation results, in winter hemisphere O/N_2 ratio increases while it decreases in the summer hemisphere. The increased O and decreased N_2 densities in winter act to increase the O^+ densities, due to the relative increase in the production rate and decrease in the loss rate (Schunk et al., 2000).

3.1.3 Diurnal Analysis of foF2

A diurnal cycle is pattern that returns every 24 hours as a consequence of one complete rotation of the Earth with respect to the Sun. The diurnal cycle is one of the vital forms of climate patterns. The diurnal cycle also affects the ionosphere significantly.



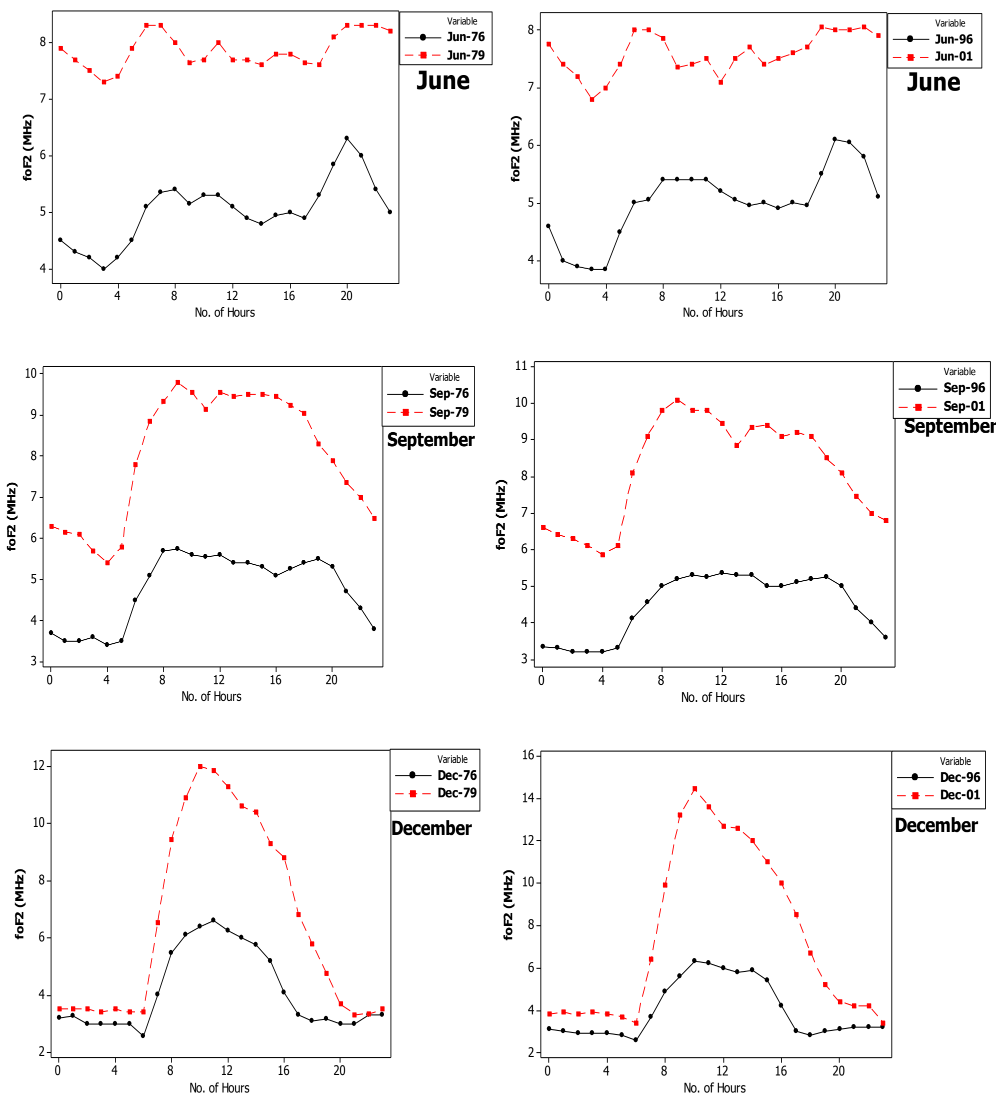


Fig. 4: Diurnal variation in foF2 of different months at solar maximum and solar minimum for 21st and 23rd Solar Cycles.

At day time, solar radiations increase the photoionization in the ionosphere which increases the critical frequency, but during night time in the absence of solar radiation the recombination process is becoming faster than ionization process (Schunk et al., 2000). The effects of diurnal cycles on foF2 for different months/seasons for solar maximum and minimum could be witnessed in Fig-4. The diurnal variation of foF2 for the months of March, June, September and December of the years when the sunspot maximum (i.e., 1979 and 2001) and sunspot minimum (i.e., 1976 and 1996) of the sunspot cycle 21st and 23rd cycle. Two most visible variations in foF2 could be seen:

i) The effect of solar maximum and solar minimum in which foF2 values are higher in solar maximum and values are much lower in solar minimum.
ii) The variation in foF2 due to day time and the night time period in which at day time foF2 is relatively higher than at nighttime. However.

However, there is an extraordinary trend occurring in the month of June for both solar maxima and minima in which foF2 fluctuates at daytime, but at night time it changes periodically. This enhancement in nighttime foF2 at mid-latitude is called MSNA, the combined effects of neutral wind and the geomagnetic configuration could be explained by both the daytime depletion and the nighttime enhancement. At the nighttime upward wind lifted the ionosphere up to regions of lower recombination rate, but during the daytime at the same location the strong downward wind pushed the ionosphere up to regions of high recombination rate. This potentially leads to electron density enhancement at night and depletion at noon (Liu et al., 2010). Table-2 explain that the mean behavior of foF2 shows the maximum and minimum values of foF2 which occurred in solar maximum years (i.e., 1979 and 2001), solar minimum years (i.e., 1976, 1996) and the corresponding time in hours. For the months of March and September the occurring time of maximum and minimum foF2 are same for solar maximum years and for solar minimum years and the slightest change in hours for maximum values occurs in the months of June and December while the timings of minimum values are remain same for solar maximum and solar minimum years.

Table 2: Maximum and minimum foF2 in diurnal variation for solar maximum and solar minimum

Months	Solar maximum				Solar minimum			
	Max values of foF2 (MHz)	**Time (hrs)**	**Min values of foF2 (MHz)**	**Time (hrs)**	**Max values of foF2 (MHz)**	**Time (hrs)**	**Min values of foF2 (MHz)**	**Time (hrs)**
March	13.22	12	5.77	05	6.90	12	3.15	05
June	8.17	22	7.05	03	6.20	20	3.92	03
September	9.95	09	5.62	04	5.47	09	3.30	04
December	13.22	10	3.40	06	6.40	11	2.57	06

4 DISCUSSIONS AND RESULT

The maximum monthly mean international sunspot number occurred in September 1979 and July 2000 in 21^{st} solar cycle and 23^{rd} solar cycle respectively. For both solar cycles, sunspot numbers raises at great rate while spot numbers reduces slowly. In solar cycle 21, the monthly mean sunspot numbers are greater than 100 from September 1978 till December 1982, in these total months are 47 in which sunspot numbers are greater while in solar cycle 23, from May 1999 till September 2002 monthly mean sunspot numbers are greater than 100, in these total months are 29 in which monthly mean sunspot numbers are greater than 100. Therefore it has indicated that the strength of solar activity was much higher in 21^{st} solar cycle as compared to 23^{rd} solar cycle. In the seasonal trends, we observed that at day time foF2 have higher values as compare to the night time, but the month of June show approximately the same range of values at night as well as at day time. The most diurnal variation occurs in December in which at night time foF2 show lowest trend than the other three months and at day time foF2 show second higher trend (i.e., higher than June and September but lower than March). While in March and September, trends of foF2 mostly same in day and night, but difference in range of data values. In a diurnal variation for both solar cycles, in the month of March, the maximum foF2 increase rate occurs at a time of 7:00 and the maximum decrease rate occurs at a time of 18:00 for solar maxima year and 17:00 for solar minima year. In the month of December at time 8:00 foF2 has greatest raise rate and foF2 has the greatest decline rate at time 17:00 for solar maximum year and 16:00 for solar minimum year. In September foF2 amplifying rate occur at time 6:00 and maximum drop off rate at time 20:00 for solar maximum year and 21:00 for solar minimum year. The basic interpretation is that foF2 is generally increased in daytime and afternoon or in the night time foF2 decreases. However, this interpretation cannot be valid for the month of June, where foF2 rise and decline periodically during night time and fluctuates in daytime. For solar minimum years in the month of June, around at 6:00 and 18:00 the rate of increasing is maximized while the decreasing rate is maximum at 23:00 and 00:00, for solar maximum year in the month of June, the highest rate of increasing and decreasing occurs at 5:00 and 1:00 respectively.

CONCLUSION

We recapitulate our conclusion that the sunspots are the most distinct features of the Sun. It is one of the solar proxies that indicate solar activity on the Sun. It has been concluded that the Sun is less active in solar cycle 23 as compared to solar cycle 21.We have analyzed the monthly mean sunspot number and monthly median hourly foF2 of yearly, seasonally & diurnal variations for solar cycles 21 and 23. In this research work we have studied the effect of the sunspot cycle on foF2 and how does it varied in the months of March, June, September and December. These months are vital when the solar zenith angle is taken into account. The solar activity greatly impacts on diurnal variations. We evaluated how much changes in foF2 occur at noon and at midnight time and what are the diurnal and seasonal variations occur in the ionospheric F2 layer at solar maximum and solar minimum years. The difference in foF2 clearly shows the non-dependency of foF2 on solar zenith angles. The trends of foF2 for any month are high in solar maximum years while trends are low in solar minimum years.

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