VariabilityoffoF2 at Low Latitude during High, Moderate and Low Solar Activity

Geeta Khoobchandani[#1], S.D Mishra[*2], S.K Vijay[#3]

[#1]*Department of Physics, Sri SatyaSaiUniversity of Technology and Medical Sciences,Sehore M.P. INDIA*
[*2]*Department of Physics, AtalBihari Vajpayee Hindi Vishwavidyalaya, Bhopal.*
[#3]*Department of Physics & electronics, Institute for excellence in Higher Education, Bhopal*

Abstract—*In the present work we studied day to day variability of the F region of the ionosphere at low latitude station Darwin* (12^0S,131^0E)*of Australia during the high, moderate and low solar activity period of 23*rd *solar cycle. We have investigated diurnal, seasonal and annual variability of foF2.The relative standard deviation of hourly values for all the months for the year of High (2000), Moderate (2003) and Low (2008) solar Activity period are analysed to study the variability. To understand the seasonal variation of foF2 more clearly, we have divided the year into five seasons including winter-1 (January and February), equinox-1(March and April), summer (May, June, July and August), equinox-2(September and October) and winter-2(November and December). It has been observed that variability in foF2 is less during day time as compared to night time for moderate (2003) and low (2008) solar activity period.It has also been observed that variability in foF2 is more during pre and post sunset timeas compared to day time for moderate (2003) and low (2008) solar activity period. For high (2000) solar activity period results shows more variability during day time in comparison to night which is an abnormal behaviour.*

Keywords—*foF2, Variability, Solar Activity*

I. Introduction

The ionosphere is that layer of the Earth's atmosphere which extends from 80 to 1000Km.It affect the propagation of radio waves significantly. Ionosphere is being used by many communication systems to reflect radio signals over long distances. The ionosphere can reflect waves of frequencies below about 30 MHz, allowing (HF) radio communication to distances of many thousands of kilometres .

The critical frequency (foF2) is the limiting frequency at or below which a radio wave is reflected by ionosphere in HF radio propagation If the frequency is above this value the wave penetrates through an ionosphere F-layer. For long distance high frequency communication F2-region plays important role in the ionosphere because of its thickness and minimal attenuation for probing radio waves. Variations in the critical frequency provide hints on the happenings within the F2-layer. Observations show that after sunrise foF2 rises, reaches to its maximum value in the early afternoon, and there is a rapid fall shortly after sunset. This layer of the ionosphere is affected by several influences such as solar wind, solar ionizing radiation, neutral atmosphere, geomagnetic activity and electrodynamics effects. (Rishbeth and Mendillo, 2001) Various authors have examined ionospheric variability. Number of studies have been done for investigating the variability of the ionosphere. These studies vary in terms of selecting parameter whose variability is being examined. (e.gJayachandran et al.,1995; Forbes et al.,2000;Rishbeth and Mendillo,2001;Kouris and Fortiadis, 2002; Fortiadis et al, 2004). Adebesin et al. (2014), had investigated diurnal, seasonal annual fof2 variability and response of the F2 layer height over Jicamarca during periods of low, moderate and high solar activities. They found that the F2 layer critical frequency pre-noon peak increases by a factor of 2 more than the post noon peak as the solar activity increases i.e the ionospheric F2 layer height rises to the higher level with increasing solar activity.Adebesin (2012), had investigated the depiction of foF2 ionospheric variability during various seasons, time of the day latitudes and solar cycles. Adeniyi et al. (2007), studies on variability vary from those that analyse specific parameters on a large geographical area, to those that are limited to a few or one station.

The present study characterizes equatorial foF2 variability on hourly, diurnal, seasonal and solar cycles scales by analyzing observed foF2 data from low latitude station Darwin(131^0E,12^0S) of the Australian sector.

II. Data and Method of Analysis

The data used for this research are the foF2 hourly values from the low latitude Australian station *Darwin* (12^0S,131^0E).The data sets cover years of low, moderate and high solaractivities were obtained from the Space Physics Interactive Data Resource (SPIDR) website (http://ngdc.noaa.gov/) In the present study, twelve months running average sunspot number (Rz) has been used as an index to define the solar activity level of the years under consideration.

TABLE 1

Data years used in this study and their average sunspot number.

Year	Solar activity	Sunspot number(Rz12))
2000	High	119.6
2003	Moderate	63.7
2008	Low	2.9

TABLE 2

Seasonal effects were investigated by grouping data into five seasons.

Seasons	Months
Winter -1	January& February
Equinox-1	March& April
Summer	May, June, July& August
Equinox- 2	September& October
Winter-2	November &December

The coefficient of foF2 variability was evaluated with the help of relative standard deviation .Here it is evaluated in two phases seasonally and annually

VR (%) =$\sigma/\mu*100$ ……. (1)

Where, µ, is the mean; and σ is the standard deviation of the foF2 values.

The relative standard deviation is the statistical tool that describes the extent of deviation or spread of each point from the calculated mean for the entire data sets.

The standard deviation approach provides a good means to describe average deviation from the mean.The coefficient of variability is often expressed as a percentage. A lower percentage indicates as a lowervariability in thedataset equally, a higher percentage indicates the datasets is more varied.

III.RESULTS

The results of the coefficient of variability,i.e. relative standard deviation evaluated using Eq. (1), have been plotted against local time for low latitude station Darwin so as to observe the diurnal, seasonal and solar activity dependence of foF2 variability.

SEASONAL VARIATION OF FOF2

Figure1, Figure-2 and Figure-3 shows the diurnal plots of relative standard deviation for all the seasons during years of high (2000), moderate (2003)and low (2008) solar activities respectively. Eachplot shows the variability with local time for all five seasons.

ANNUAL VARIATION OF FOF2

Show the plotfor hourly values of variability on a yearly basis for all three levels of solar activity

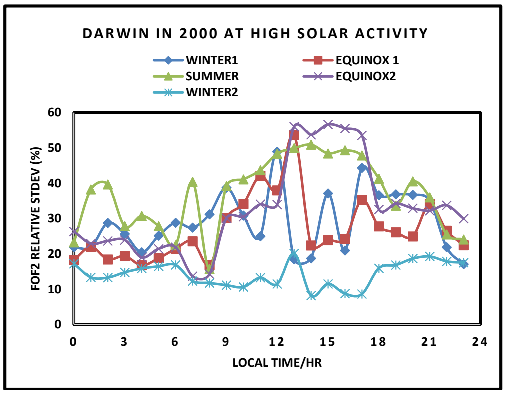

Figure 1Diurnal variation of the relative standard deviation for all five the seasons during high solar activity for Darwin.

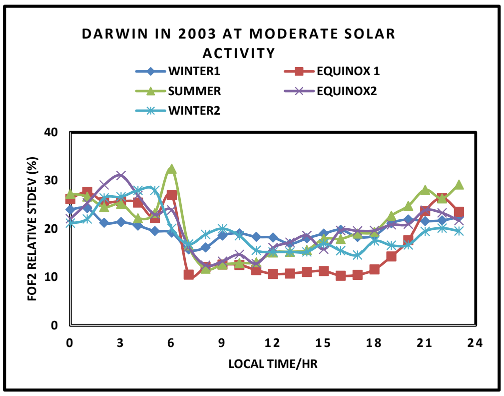

Figure 2Diurnal variation of the relative standard deviation for all five the seasons during Moderate solar activity for Darwin.

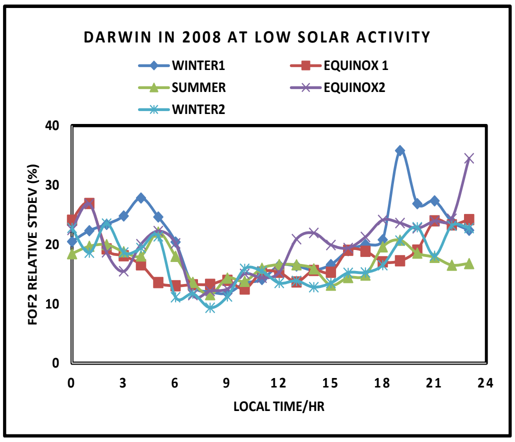

Figure 3Diurnal variation of the relative standard deviation for all the five seasons during Low solar activity for Darwin

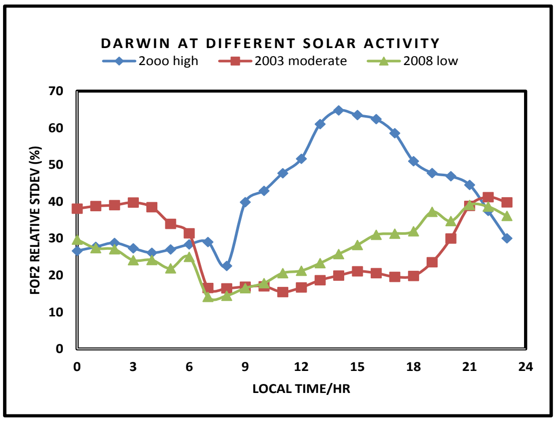

Figure-4-Diurnal variation of the relative standard deviation averaged over the whole year for low, moderate and high solar activity for Darwin.

Figure1, Figure2 and Figure 3 show diurnal plots of coefficient of variability for high moderate and low solar activities, respectively. Each plot shows the variation with local time for all five seasons. Generally, the average diurnal variation of coefficient of variability follows the same trend at moderate and low solar activity levels but variability is different at high solar activity. Variation is lowest during daytime (15–20%) and variation during nighttime is more (20–35%). The peaks at sunrise and sunset are a result of the steep density gradients that are caused by the onset and turnoff of solar ionization.

Figure 4 show the plot for hourly values of variability calculated on yearly basis for all the three levels of solar activity respectively. Here also the average diurnal variation ofcoefficient of variability follows the same trend at moderate and low solar activity levels but variability is different at high solaractivity.

Variability is low at daytime and more at night time for moderate and low solar activity. But pattern of variability is different at high solar activity. For high solar activity variability graph is not showing normal behaviour. Here variability is more at the daytime in comparison to night.

IV. DISCUSSION

Approximately same diurnal features are seen for moderate and low solar activity period. Coefficient of variability is low during theday in comparison to night. They are also characterized by two peaks: post –midnight peak and post-sunset peak. Dominant role is played by equatorial zonal electric field in shaping the development of both the day time equatorial anomaly and the night time density irregularities. During the day the direction of this field is eastward and the direction is reverse to the west after sunset. At low latitude during sunset, the pre-reversal enhancement develops at F-region heights due to enhanced eastward electric field (Woodman R F &La Hoz C, 1976). This prereversal enhancement of electric field cause a redistribution of ionization, in conjunction with am-bipolar diffusion. As a result fountain like effect is caused to both the sides of the magnetic equator at magnetic latitudes of $15^0$to form the equatorial anomaly (BalanN &Bailey G J, 1995).Two peaks of variability,post –midnight peak and post-sunset peak can be attributed to steep electron density gradients generally caused by onset and turnoff of solar ionization and superimposition of ionospheric F-region irregularities on the background of electron density (Akala et al, 2010a). Adebesin et al. (2008) had also suggested that during ionospheric disturbances there is considerable intra-hour variability of foF2. At night, the ionospheric electron density is dependent on the recombination rate, which is affected by the gas compositions (Chou and Lee 2008) and equatorial electric field (EEF).According to(Forbes 1981), EEF causes vertical E × B plasma drift enhancement to altitude above F2-peak at the equator. The EEF is caused by the tidal winds in the Eregion, which drive ionospheric currents to higher latitudes. This current theninteracts with the Earth’s magnetic field and result positive and negative changes arebuilt at the dawn and dusk terminal, respectively. It has also been suggested that gravity waves could be responsible for the nighttime ionospheric density gradient enhancement. This may be the reason for the observed higher depletion in foF2 at nighttime rather than during daytime. However, the variability increases clearly as the solar activity decreases.

The inverse relationship of increasing coefficient of variability to decreasing solar activity is not so clear between the moderate solar activity and higher solar activity periods during the daytime. It is worth mentioning that apart from the photochemistry eff ect, the downward foF2 perturbation could have been due to increase (upward or eastward electric field increase) in vertical drifts. This drift raiseionospheric plasma by beginning from the F2 region, and then drifts along the magnetic field lines apart from the geomagnetic equator. Moreover, observed changes in neutral composition at equatorial latitudes may not be sufficient to cause depletion in foF2 variations, but an increase in atomic oxygen [O] may have contribution to the enhancement in foF2 variability when E × B drifts are small. It is important to emphasize that the increase in concentration of absolute atomic oxygen provides a background foF2 increase. On the other hand, a very strong downward drift (or westward electric field) may also result in downward foF2 variability eff ect when F2 layer is pushed down to lower heights where recombination is strong (Mikhailov and Leschinskaya 1991).

As we have observed abnormal pattern of variability of foF2 parameter for high solar activity period. Many researchers have observed some or the other kind of abnormal behaviour during their research work. Like NuzhatSardar et al (2012) found that the slab thickness at low latitude location

Kwajelin (167^{0}E, 09^{0}N) and Learmonth (114^{0}E, 22^{0}S) is just opposite to that of midlatitute and high latitude locations. Which clearly indicate that nature of ionosphere at low latitude shows abnormal deviation from the mid latitude and high latitude.

V. Conclusions

We have used three (different) years' worth of data of 23rd solar activity from the ionosonde stations darwin in australia. The year chosen for high solar activity is 2000, for moderate solar activity 2003 and for low solar activity 2008.level of solar activity is based on average yearly sunspot number. It is clear from above discussed result that for moderate and low solar activity variability is low during daytime and high during night time but variability in high solar activity year follow different trend. The results for low and moderate solar activity are approximately same as the results obtained by bilitza et al.

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