# LOCALTIME AND SEASONAL VARIATIONS OF foF2 AND foF3 IN DIFFERENT SOLAR ACTIVITY CONDITIONS

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## Abstract:

foF2 and foF3 as a function of local time (during 07:00-18:00 LT) and day of the year based on ionosonde observations. Local time variations of foF2, foF3 and the difference of foF2 and foF3, foF3-foF2 in different seasons and different solar activity conditions. Since the F3 layer is formed by plasma transport, foF3-foF2 is expected to provide some insight into the local time variations of plasma transport. For seasonal analysis, 10 February-9 May as March equinox, 10 May-9 August as summer, 10 August-9 November as September equinox, and 10 November-9 February as winter. Mean and standard deviation (SD) of FoF2, foF3 and foF3-foF2, respectively, observed in different seasons (March equinox, summer, September equinox and winter) and different solar activity conditions. To illustrate seasonal variations we show mean and SDs of foF2, foF3, and foF3-foF2, for three local times, viz., 10:00, 13:00 and 16:00 LT as a function of day number Observations made for three different stations namely Jicamaca,Kwajalein and Madimbo. Low-latitude F2 layer critical frequency (foF2) is directly related to the formation of the F3 layer, which varies remarkably with season and solar activity .

Solar activity dependence of low-latitude ionospheric foF2 has been studied based on observations made from three stations (Kodaikanal, Ahmadabad and Delhi) in the Indian sector. They also found saturation in foF2 for high values of F10:7 (> 120 sfu) similar to that shown here. They found that at the equatorial station Kodaikanal foF2 values in equinoxes are roughly equal to or slightly higher than those in winter and the winter values of foF2 are always higher than those of summer

**key words:** Inosonde, Seasonal Variations, Solar Activity, Lower deciles(LD), Upper deciles(UD), foF2(Top Plasma Recurrence), hmF2 (Crest Tallness)

## 1.Introduction:

The atmosphere surrounding the earth is neutral to some extent (due to high turbulence and mixing of gases) but becomes conducting (electrically) above 50 Km altitude due to the detachment of electrons from the neutral atom by Extreme Ultraviolet (EUV) flux radiated from sun, resulting in the existence of equal number of electrons and ions at higher altitudes. The upper part of the atmosphere above 50 KM is of great practical importance to mankind. Besides acting as a shield to various extreme ultraviolet and X-radiation of solar origin which are harmful to human life, it plays an important role in the major areas of distance communication, navigation and environmental control. The existence of a conducting layer in the earth's atmosphere is first inferred from magnetic observations by Stuart in 1882, then from very low frequency (VLF) propagation results of Heaviside in 1902 (Rawer, 1986). The very detection of an ionosphere might, however, be attributed to those radio amateurs who in 1921 realized almost lossless transatlantic communication via high frequency (HF) waves. The region of the upper atmosphere where ion kinetics play an important role is called "Ionosphere" and is characterized by its property of effecting the propagation of radio waves. Hence, radio waves are certainly the most powerful diagnostic tool for investigation of the Ionosphere. The enormous practical use of ionospheric radio propagations for communication has served to justify and subscribe its study by researchers since early days and has resulted in a considerable accumulation of knowledge, which this space is finding to be great scientific significance.

## New Global Models For The F2 Peak Parameters:

The point of highest density in the ionosphere, the F2 peak, is defined by two parameters the peak height (hmF2) and the peak plasma frequency (foF2) which is directly related to the square-root of the F2 peak density. A third parameter also of interest here is the propagation factor M(3000)F2, which can be monitored from the ground with the help of ionosondes and which is inversely related to hmF2. Currently, new neural network (NN) based global models for the F2 peak parameters (foF2 and M(3000)F2) are being developed and evaluated as a possible replacement for the CCIR (1966) and URSI (Rush et al. 1989) models presently used as IRI F2 peak parameter prediction tools. The NN is the technique, whereby a computer is trained to learn the relationship between a given set of inputs and a known output. This technique is very useful in predicting non-linear relationships, and makes use of the history of what has come before. Therefore, it is crucial to have a large database of archived data from which to develop the NN based model. The NNs used in this work make use of the feed forward back propagation algorithm and the reader is referred to Haykin (1994) for more details on the working of NNs.

## 2.Research Methodology:

Initially, a global foF2 model was developed using hourly values of foF2 from 85 global ionospheric stations, spanning the period 1995-2005 and for a few stations from 1976 to 1986. Data from various resources of the World Data Centre (WDC) archives (Space Physics Interactive Data Resource SPIDR, the Digital Ionogram Database, DIDBase, and IPS Radio and Space Services) have been used in the development of the model. To satisfy all requirements for the model, data from all latitude regions with different levels of magnetic and solar activity and season were used to test for the predictive ability of the NN model and the results were compared with the URSI and CCIR predictions of the IRI model. As shown in Oyeyemi and McKinnell (2008), a large percentage of the data used is from the northern hemisphere, while few of the data are from the southern hemisphere with not much around the equatorial region. A significant paucity of data from the polar sectors (north and south) was also found. The database consisted of a mixture of manually edited and automatically scaled data. Because it was too man-hour intensive to manually edit all of the data, a general trend analysis was performed on all of the data to ensure that there were no extreme outliers and obvious defects in the scaling. The NN technique is able to cope with minor problems in the data in that the technique aims for the best average solution, and will ignore a few serious outliers. The final NN input space for the first version of the foF2 global model consisted of day number, universal time, solar zenith angle, solar activity, magnetic activity, day-of-year, geographic latitude, magnetic inclination and declination.

The NN model for predicting the global foF2 value has been tested extensively to judge its ability to meet the requirements for the replacement of the IRI foF2 maps. Figure 1 shows the bar graphs illustrating the RMSE differences between observed foF2 values and predictions by the NN model and the IRI model (URSI and CCIR coefficients) for the foF2 hourly values for a few stations.

## 3.LOCAL TIME AND SEASONAL VARIATIONS OF foF2 AND foF3 IN DIFFERENT SOLAR ACTIVITY CONDITIONS

foF2 and foF3 as a function of local time (during 07:00-18:00 LT) and day of the year based on ionosonde observations made during 1995 (LSA), 1998 (MSA), 2002-2003 (HSA) and 2004 (MSA) (shown in the panels from top to bottom). It should be noted that for 2002-2003 observations, we have reorganized the data to plot from January to December so as to compare these results with those observed in other years.

White portions in the figures represent data gaps. Black squares in each panel represent occurrence rate of the F3 layer (in percent) in the respective year. Occurrence rate, S, has been computed based on quarter-hourly daytime observations made during a period of 10 consecutive days as S D (NF3/No/ 100, where NF3 and No represent the number of times the F3 layer was observed and the total number of observational runs in the 10-day period, respectively.

These results suggest that f oF2 and f oF3 are high in HSA, moderate in MSA and low in LSA as expected from solar flux dependence of the photoionization process. The occurrence rate of the F3 layer is found to vary from one year to another, with the occurrence rate being maximum in June-August (75-90%), minimum in October-December (10-40%) and moderate in other months (40-70%). Seasonal dependence of the F3 layer occurrence shown here is similar to those reported earlier by Pavan Chaitanya et al. (2012) based on limited observations from the same location. Notwithstanding these detailed variations observed in different years, foF2 is found to have lower values during noon hours than those in the morning and late afternoon hours. This feature, however, is less conspicuous during October-December. Note that the local time in which foF2 values are low coincides with the occurrence of the F3 layer.

Also note that this pattern is conspicuously present in all solar activity conditions. In the following, we present more details on the variations of foF2 and foF3.

## 4.LOCAL TIME VARIATIONS IN foF2 AND foF3

Local time variations of foF2, foF3 and the difference of foF3 and foF2, foF3-foF2 in different seasons and different solar activity conditions. Since the F3 layer is formed by plasma transport, foF3-foF2 is expected to provide some insight into the local time variations of plasma transport. For seasonal analysis, 10 February-9 May as March equinox, 10 May-9 August as summer, 10 August-9 November as September equinox, and 10 November-9 February as winter. Figure 2a, b and c show mean and standard deviation (SD) of FoF2, foF3 and foF3-foF2, respectively, observed in different seasons (March equinox, summer, September equinox and winter) and different solar activity conditions. Results corresponding to 2015-2016 (HSA), 2015 (MSA) and 2016 (LSA) are presented in red, blue and black, respectively. Mean values of both foF2 and foF3 show clear variations with solar activity as well as season. Mean values of foF2 are found to be in the range of 5.5-14.5 MHz in HSA, 5-14.1 MHz in MSA, and 4.3-13.4 MHz in LSA. Similarly mean values of f oF3are found to be in the range of 7.3-14.3 MHz in HSA, 6.2- 12.3 MHz in MSA, and 4.6-12.7 MHz in LSA. Variability (estimated as / μ 100 %, where represents SD and μ represents mean) in f oF2 are found to be in the range of 10-15 % and it is higher in the afternoon than forenoon in all seasons except for September equinox. Further, variations in foF2 are found to be minimum in HSA, moderate in MSA, and maximum in LSA. Variations in foF3 are found to be in the range of 5-10% and no significant seasonal and solar activity dependences have been noticed. As far as local time variations are concerned, both foF2 and foF3 show remarkable variations in almost all seasons and solar activity conditions. Notably, local time variations of foF2 show a conspicuous feature of noon bite-out in all solar activity conditions with decreasing

values of foF2 with decreasing solar activity. The observed bite-out of foF2 is pronounced in equinoxes when compared to those in summer and winter.

Notably, the noon values of foF2 are similar to those of early morning in almost all seasons and solar activity conditions. The noon bite-out can also be noted in foF3 although it is not as noticeable as in foF2 due to the absence of the F3 layer in the morning and evening. Interestingly, a signature of noon bite-out can also be noted in foF3-foF2 and in all solar activity conditions. They are found to be in the range of 0.5-3 MHz with larger values in the afternoon than in the morning.

## 5.SEASONAL VARIATIONS OF foF2 AND foF3

To illustrate seasonal variations we show mean and SDs of foF2, foF3, and foF3-foF2, for three local times, viz., 10:00, 13:00 and 16:00 LT (shown from top to bottom) as a function of day number. Observations made in 2015-2016 (HSA), 2015 (MSA), and 2016 (LSA) are shown in red, blue and black, respectively.

Large values in HSA, moderate values in MSA and small values in LSA as expected from variations in solar ionization flux. Most importantly, foF2 and foF3 are found to be minimum in summer, moderate in winter, and maximum in equinoxes and these features are apparent in all solar activity conditions. Variations in foF3-foF2 are found to be in the range of 0.5-2 MHz and these do not show any noticeable seasonal and solar activity dependent patterns except for the fact that the differences in foF3 and foF2 at 13:00 LT are somewhat higher in HSA than those in MSA/LSA. Considerable equinoxial and solstice asymmetry in foF2 and foF3, however, can be noticed, which are addressed in the following.

## 6.SOLAR ACTIVITY DEPENDENCE

Seasonal mean and SD of foF2, foF3 and foF3 - foF2, respectively, observed at 13:00 LT in different years along with solar activity. These are shown in different colors. Both foF2 and foF3 increase with solar activity. We also note that both foF2 and foF3 observed in summer are remarkably lower than those observed in other seasons. Variations in foF3-foF2, however, do not show any systematic pattern. For more clarity on the solar dependence of these parameters, we present mean and SDs of foF2, foF3 and foF3-foF2 as a function. Note that observations shown in red correspond to summer and those shown in blue correspond to other seasons (winter and equinoxes). It is very clear from these figures that both foF2 and foF3 are smaller in summer than those in other seasons and thus we have fitted summer observations separately to distinguish the summertime features from those observed in other seasons. Despite the differences in foF2 and foF3 observed in summer and in other seasons, all foF2 and foF3 are found to increase up to a value of 120 sfu and saturate afterwards. This implies that F layer critical frequencies did not increase much with solar flux.

Similar variations have been observed at other local times as well (not shown) except for the fact that foF2 is the highest at 16:00 LT, moderate at 10:00 LT and lowest at 13:00 LT at all solar activity conditions. Nearly similar features were noted in foF3 although local time variations are not as great as observed in foF2. Low values of foF2 and foF3 during 13:00 LT are consistent with those observed as noon bite-out, which is linked with vertical transport of F region plasma, presumably governed by vertical E B drift.

Given the fact that both foF2 and foF3 display noon bite out, modeling of foF2 and foF3 as a function of solar flux would require knowledge of E B drift, which varies with longitude, latitude and season.

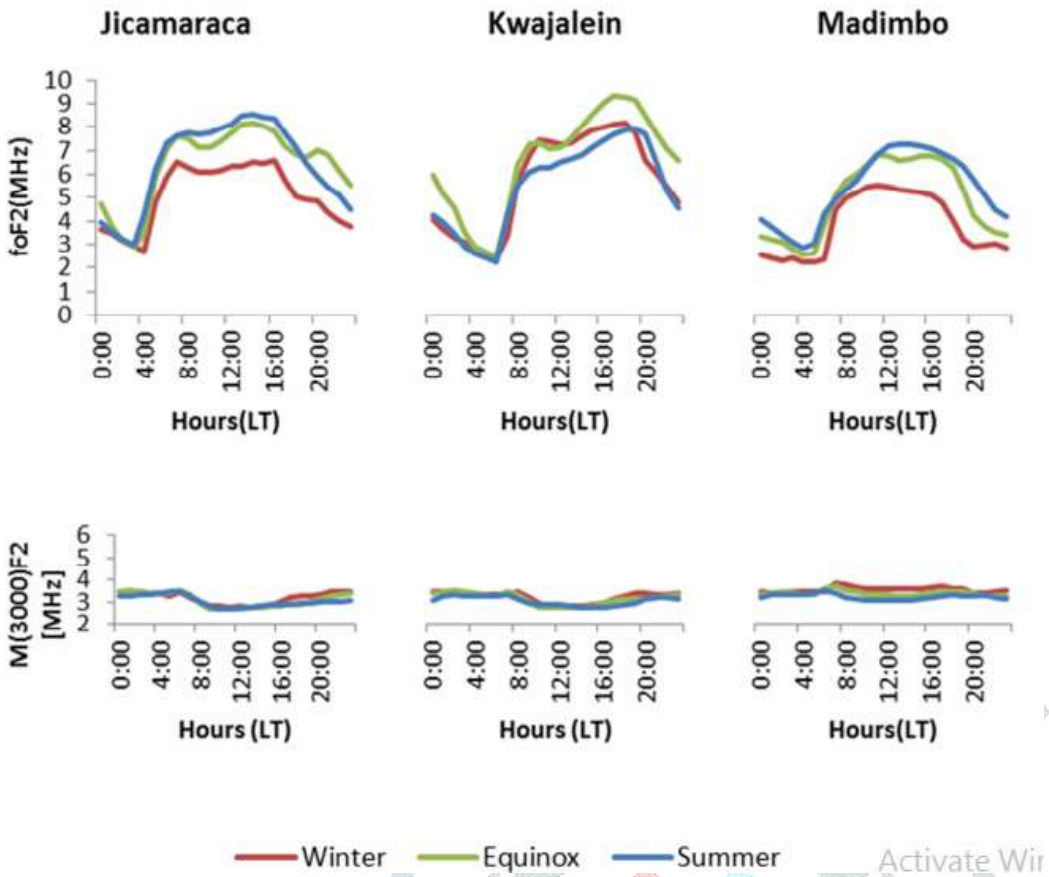
Solar activity dependence of low-latitude ionospheric foF2 has been studied earlier based on observations made from three stations (Kodaikanal, Ahmadabad and Delhi) in the Indian sector. They also found saturation in foF2 for high values of F10:7 (> 120 sfu) similar to that shown here. They found that at the equatorial station Kodaikanal foF2 values in equinoxes are roughly equal to or slightly higher than those in winter and the winter values of foF2 are always higher than those of summer. With regard to the off-equatorial observations, they found that while over Ahmadabad the foF2 values in equinoxes are roughly equal to or higher than those at the solstices, over Delhi they are higher than those of solstices. They have also found that during some period, the winter values of foF2 are higher than those of summer. We found that foF2 values in winter solstice are similar to those of equinoxes and f oF2 values in summer are always lower than those of equinoxes and winter. It should be noted that the observations used in this study were made from Sriharikota, which is located at a latitude higher than that of Kodaikanal and much lower than those of Ahmadabad and Delhi. The observed difference could be related to the dynamical and electrodynamical effects on foF2 owing to the difference in latitude. It should be noted that most of the earlier studies were based on foF2. In the present study, we show that f oF3 also shows similar saturation for F10:7 > 120 sfu. Balan et al. (1994) used ionospheric electron content (IEC) to study variation of ionospheric ionization with solar flux and found the saturation effect in IEC.

The saturation effect was very clear for F10:7 > 200 sfu and at times for F10:7 > 150 sfu. They found that this saturation is due to the nonlinear relationship between F10:7 and solar Xrays, extreme ultraviolet and Lyman- fluxes for high values of F10:7. In the present observations, however, we find the saturation effect for F10:7 > 120 sfu. It is important to mention that Balan et al. (1994) used IEC data from stations well beyond the equatorial/low-latitude region (19.6-58.6 magnetic latitude). The present and earlier observations from Indian low latitudes clearly suggest that the saturation effect in the F layer critical frequency occurs at lower values of solar flux than that in mid-latitude. It is quite likely that the saturation effect reported here for low latitudes is due to the ubiquitous presence of dynamical and electrodynamical forcing on plasma density distribution. The role of vertical transport on the noon bite-out of f oF2 and f oF3 seems to support this viewpoint although this needs to be ascertained through further study.

**Table : Variability of fof2 at Three Different Station**

| **Stations** | Month | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jicamaca | Day | | | | | | | | | | | | |
| | UD | 0.14 | 0.13 | 0.13 | 0.14 | 0.14 | 0.14 | 0.14 | 0.15 | 0.14 | 0.14 | 0.14 | 0.12 |
| | LD | -0.14 | -0.14 | -0.12 | -0.11 | -0.13 | -0.12 | -0.12 | -0.13 | -0.12 | -0.12 | -0.13 | -0.13 |
| | Night | | | | | | | | | | | | |
| | UD | 0.23 | 0.26 | 0.24 | 0.26 | 0.26 | 0.24 | 0.23 | 0.23 | 0.29 | 0.24 | 0.25 | 0.23 |
| | LD | -0.20 | -0.22 | -0.20 | -0.19 | -0.19 | -0.20 | -0.17 | -0.19 | -0.16 | -0.19 | -0.20 | -0.19 |
| Kwajalein | Day | | | | | | | | | | | | |
| | UD | 0.16 | 0.16 | 0.16 | 0.17 | 0.17 | 0.14 | 0.17 | 0.20 | 0.16 | 0.14 | 0.14 | 0.26 |
| | LD | -0.12 | -0.13 | -0.12 | -0.11 | -0.12 | -0.14 | -0.13 | -0.13 | -0.12 | -0.10 | -0.11 | -0.11 |
| | Night | | | | | | | | | | | | |
| | UD | 0.28 | 0.27 | 0.25 | 0.25 | 0.29 | 0.28 | 0.28 | 0.27 | 0.29 | 0.25 | 0.27 | 0.25 |
| | LD | -0.25 | -0.25 | -0.23 | -0.23 | -0.24 | -0.23 | -0.21 | -0.21 | -0.27 | -0.22 | -0.23 | -0.22 |
| Madimbo | Day | | | | | | | | | | | | |
| | UD | 0.15 | 0.14 | 0.11 | 0.15 | 0.15 | 0.15 | 0.13 | 0.11 | 0.13 | 0.13 | 0.15 | 0.14 |
| | LD | -0.12 | -0.10 | -0.10 | -0.09 | -0.09 | -0.09 | -0.09 | -0.08 | -0.09 | -0.10 | -0.16 | -0.12 |
| | Night | | | | | | | | | | | | |
| | UD | 0.22 | 0.22 | 0.17 | 0.20 | 0.17 | 0.19 | 0.22 | 0.17 | 0.18 | 0.18 | 0.22 | 0.18 |
| | LD | -0.14 | -0.14 | -0.12 | -0.12 | -0.12 | -0.11 | -0.11 | -0.11 | -0.12 | -0.12 | -0.14 | -0.13 |

Further on the basis of monthly median values of hourly data of both parameters mean diurnal variations have been derived for different seasons during the period 2012-2016 separately. These results are presented in the figure given below. These results are presented illustrates that the winter anomaly is slightly presented in northern hemisphere and totally absent in southern hemisphere. It is clearly indicated that the winter anomaly decays in amplitude or not present with decreasing solar activity. Furthermore, during winter and equinox months a clear frequent noon-time bite outs are observed at the station Kwajalein.




I have examined the effect of magnetic disturbances by considering five international most quiet (Q) days and disturbed (D) days during the low solar activity period (2012-2016) to investigate the effect of magnetic activity on diurnal variation of foF2 and M(3000)F2 over all three stations .We have computed the lower and upper deciles of both parameters for each five International quiet (Q) and disturbed (D) days during the period January 2012 to December 2016.The diurnal variations of foF2 during quiet and disturbed days are shown in fig. 4 as a function of local time. It is found that for quiet days the upper and lower limits of foF2 variability are .15 (in absolute value) on average over Jicamarca during the day time but they are .23 during night time whereas for disturbed days they become .17 during daytime and .25 during night. At Kwajalein the bounds of variability for quiet days are on average .16 (in absolute value) during day time but they become higher reaching an average value .28 for night time conditions while for disturbed days the bounds of variability are .18 and .31 during day time and night-time respectively. Further, in case of Madimbo the upper and lower limits of foF2 in absolute value are .14 during daytime and .16 during night time whereas for disturbed days the bounds are.16 during daytime and .19 for night-time conditions. In general, the ionospheric variability is slightly enhanced during geomagnetically active periods for foF2. In connection with propagation parameter M(3000)F2, it is found that for the stations Jicamarca and kwajale in the variability is slightly lower on disturbed days compared with quiet days during daytime. While for the station Madimbo the ionosphric variability is slightly enhanced during geomagnetically active periods.

## 7. Conclusion:

Low-latitude F2 layer critical frequency (foF2) is directly related to the formation of the F3 layer, which varies remarkably with season and solar activity. Observations show that the occurrence rate of the F3 layer is maximum in June–August, minimum in October– December and moderate in other months and these have direct influence on foF2.

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