Indian Journal of Radio & Space Physics
Vol 47, March-June 2018, pp 20-29

Solar cycle variation and its impact on critical frequency of F layer

Roshni Atulkar[a*], Azad A Mansoori[b], Parviaz A Khan[c] & P K Purohit[a]

[a]National Institute of Technical Teachers' Training and Research, Bhopal 462 002, India
[b]Department of Electronics, Barkatullah University, Bhopal 462 026, India
[c]Department of Physics, Islamic University of Science and Technology, Pulwama 192 301, India

Received 4 April 2017

The ionosphere exhibits the variability over different time scales. In the present paper we present the long term solar activity variations of mid latitude ionosphere. To accomplish this study we have considered a famous Australian station namely Hobart (42.88°S , 147.32°E), which falls in the mid latitudinal region. The variability has been examined over the previous three solar cycles i.e, 21, 22 and 23 solar cycles. To characterize the long term variability of the solar activity we have used four indices namely sunspot number (Rz), solar radio flux (F 10.7cm), Mg II core to wing ratio and solar flare index. Similarly, for ionospheric variability we have the critical frequency of F2 layer (foF2). From our study, we found that the long term changes in the solar activity indices which are closely and synchronously reflected in the ionospheric foF2. To quantify the magnitude of association between the long term solar activity variations and the ionsopehric variations we have performed the single regression analysis and computed the correlation coefficients between the two types of indicies, and found that there exists an extremely strong correlation between the two types of indices for all the three solar cycles. Hence, it has been concluded that the ionospheric foF2 is strongly influenced by solar activity with an 11-year variability.

Keywords: Solar cycle, foF2, Geomagnetic indices, Correlation coefficient

1 Introduction

Ionospheric variability changes from hour to hour, day to day, month to month, year to year as well as from one cycle (11 years) to other[1-3]. Each type of the ionospheric variability has its own sources and own characteristic features. Although, short time variations are caused by the transient changes like solar flares and coronal mass ejections the long term variation are thought to be caused by the long term cyclic variability of the solar activity. The short term variations are sudden and intense and last only for shorter period of time while the long term variations are smooth and follow a particular trend. The solar cycle variations of the ionosphere have been studied since past, which are thought to be caused by the cycle variation of solar irradiance - a primary source of ionization in the ionosphere[4-6]. The studies devoted to study the long term or solar activity variations of the ionosphere have been realized by using various ionospheric parameters like critical frequency and peak electron density of F2 layer, Total Electron Content (TEC) etc[6-14] and various indices like smoothed sunspot number (Rz), solar radio flux (F10.7cm), solar EUV and UV flux etc for representing the solar activity. Moreover, different studies have used the values of ionospheric parameters; while some have used daily median values[15], some have noon time values[16,17] while some others have used monthly median values[11,18] to investigate how the ionospheric variability changes with long term variations in the solar activity.

It has been found association that of long term variability of ionosphere with solar activity is very complex. In some earlier studies, before the EUV observations were made available, people used sunspot number and solar radio flux as solar indices to investigate the long term behavior of ionosphere using foF2 or NmF2[4,8,19]. However, it was found that monthly values of foF2 or TEC exhibits a linear relationship with sunspot number particularly for lower values of sunspot number, but saturates for higher values of sunspot number. This feature was known as saturation effect. Several explanations were proposed for the cause of the saturation effect[8,20] which was resolved by agreeing that neither sunspot number nor radio flux are appropriate proxies for investigating the solar activity variations of ionospheric foF2 or NmF2 and it was suggested that solar extreme ultraviolet (EUV) flux can serve as an apt and good proxy for studies concerning long term solar activity variations of ionosphere since these

*Corresponding author (E-mail: roshniatulkar@gmail.com)

radiations follow the definitive solar cycle variations and major contributors of ionospheric ionization. However, later[20] observed the saturation effect of foF2 with the EUV as well and suggested the dynamics of ionosphere among its major causes. Later another interesting feature, known as hysteresis, that for the same level of solar activity the values of the foF2 are not the same, was discovered[7,21,22]. It was found that this hysteresis effect degrades the correlation between the sunspot number and monthly median values of ionospheric parameter. The nature and association of monthly median values of ionospheric parameters with EUV have been studied thoroughly, however, only limited studies have utilized the daily values of the ionospheric parameters. The reason for this is that daily changes in the ionosphere are not necessarily due to solar variability, and in case when they are not due to solar variability they are expected to degrade the correlation[15,16,23]. Hence, it needs to be clearly examined how much the daily values depend on the solar activity.

Some studies conducted recently have also used the X-ray flux to investigate the solar cycle variations of ionospehric parameters[14,24,25]. However solar XUV observations are generally conducted over short[19,26] hence, direct measurements of the solar XUV spectrum and its unpredictability are not available for most times.

The present paper also describes the long term variability of ionospehric foF2 at mid latitudes by using several solar parameters and the monthly median values of the foF2.

2 Data Sets and Analysis

The critical frequency of F2 (foF2) layer is one of the most important and most widely used ionospheric parameters in studies concerning the solar activity variations of ionosphere. For this study, we have considered the Australian mid latitude ionosonde station, Hobart (42.88°S, 147.32°E). The National Geophysical Data Center (NGDC) maintains a huge data base of about 256 ionosonde station spread over the entire globe. The free access to the data is provided at http://spidr.ngdc.noaa.gov/spidr/. For our study we have downloaded the data from the website for the last three solar cycles (1976-2008). The data sets for solar activity indices sunspot number (Rz) and solar radio flux (F10.7 cm) were obtained from the Space Physics Data Facility, OMNI (http://omniweb.gsfc.nasa.gov/).

The solar flare index (FI) is one of the most interesting index constructed to quantify the daily flare activity and was first introduced by Kleczek[27]. It is usually denoted by Q and is defined as:

$$Q = i \times t \quad \text{... (1)}$$

Where ‘i’ represents intensity class of flare and ‘t’ the duration in minutes of the flare. The daily flare index for the three solar cycles viz 21, 22 and 23 were obtained by using the final grouped solar flares which are compiled by the NGDC. The Mg II 280 nm is also another important solar activity indicator. The Mg II index is derived from daily solar observations of the core-to-wing ratio of the Mg II doublet at 279.9 nm. It provides a good measure of the solar UV variability and can be used as a reliable proxy to model Extreme Ultra Violet (EUV) variability during the solar cycle. The data collected for the index from satellite observations are provided by the National Oceanic and Atmospheric Agency (NOAA) accessed at http://www.ngdc.noaa.gov/stp/GOES/.

The raw data obtained from different sources were processed and final data sheets were prepared which were then converted into graphical representation which is discussed in the next section (Results).

3 Results

We have first examined the variability of foF2 with the four solar activity indices individually during the each solar cycle. The variability of the two types of parameters have been compared during the different months of the each year of the solar cycle. Then the magnitude of association has been shown by performing the single regression analysis and computing the correlation coefficients which have been inserted in each panel for a particular pair of parameters.

3.1 Solar cycle 21

The monthly averaged values of foF2 and the monthly averaged values of sunspot number, flare index, Mg II and F10.7 are plotted against the months of the cycle in the four panels of Fig. 1. From the Fig. 1 we notice that there is a synchronous variation between foF2 and all the solar activity indices. As the solar activity starts increasing from 1976, the values of foF2 also start increasing and achieve the peak during 1979-1981 which is also the maximum phase of solar cycle 21 and after that solar indices starts decreasing hence the foF2 also starts decreasing.

Similarly, the yearly averaged values of foF2 and solar activity indices are plotted in Fig. 2. The similar features are also noticed in the Fig. 2. We can easily see that the two curves representing yearly pattern of foF2 and solar activity indices almost overlap, depicting very good association between the two types of variabilities.

Figure 3 shows the variations of monthly averaged values of sunspot number (Rz), flare index, solar radio flux (F10.7 cm) and Mg II core to wing ratio and ionospheric foF2 for the different years of solar cycle 21. From the figure we find that all the solar indices show a monotonic increase from the beginning of the solar cycle to their maxima. The

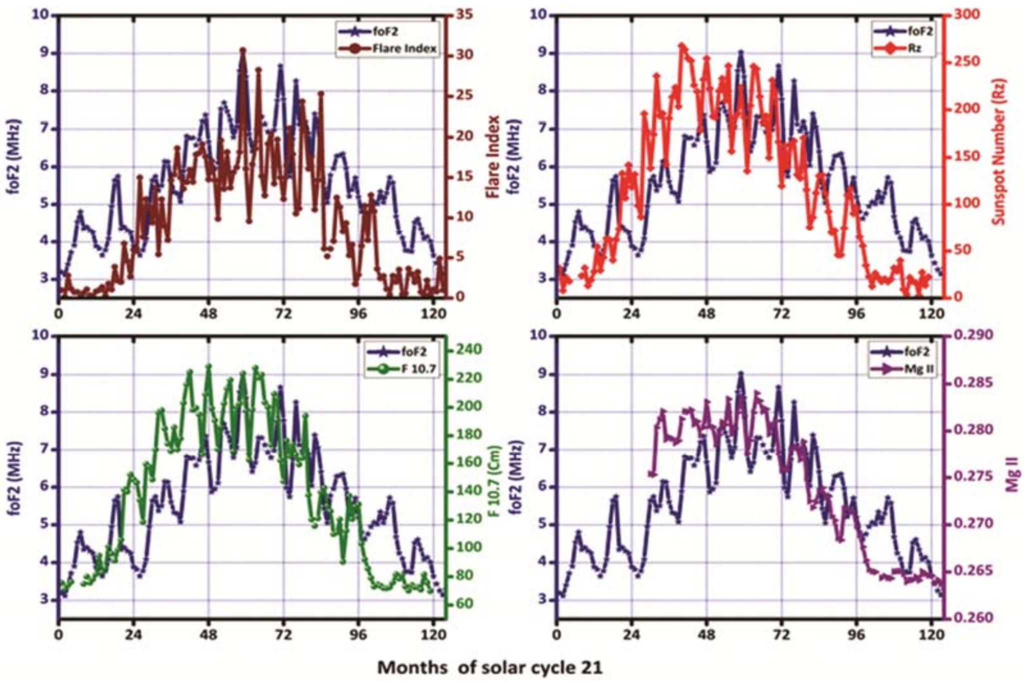

Fig. 1 — Monthly variation of foF2 with solar indices during the solar cycle 21.

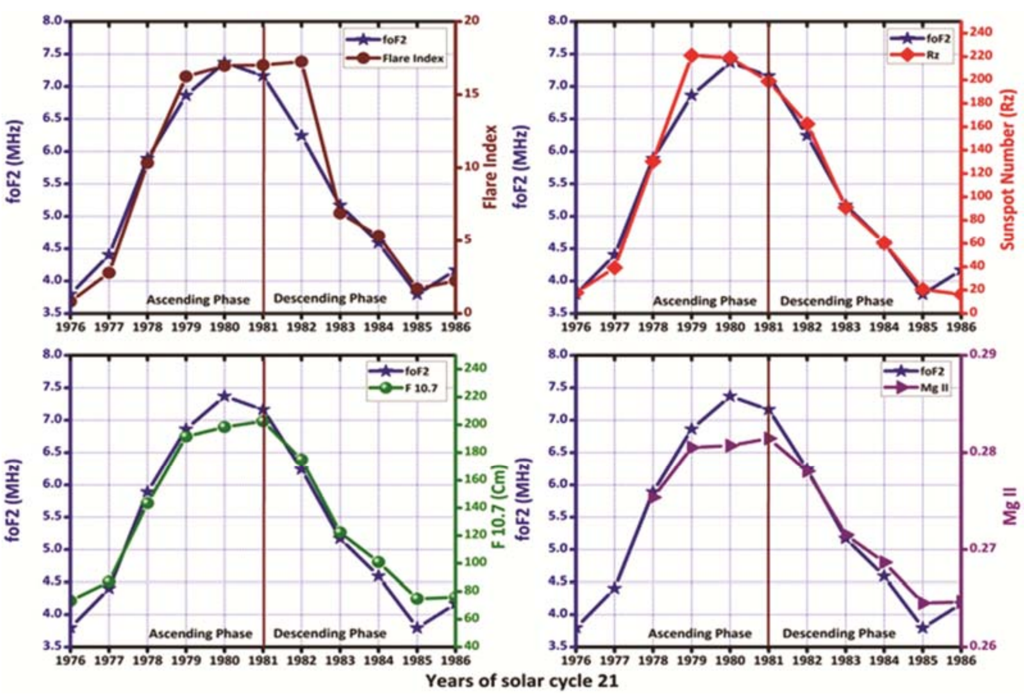

Fig. 2 — Annual variation of foF2 with solar indices during the solar cycle 21.

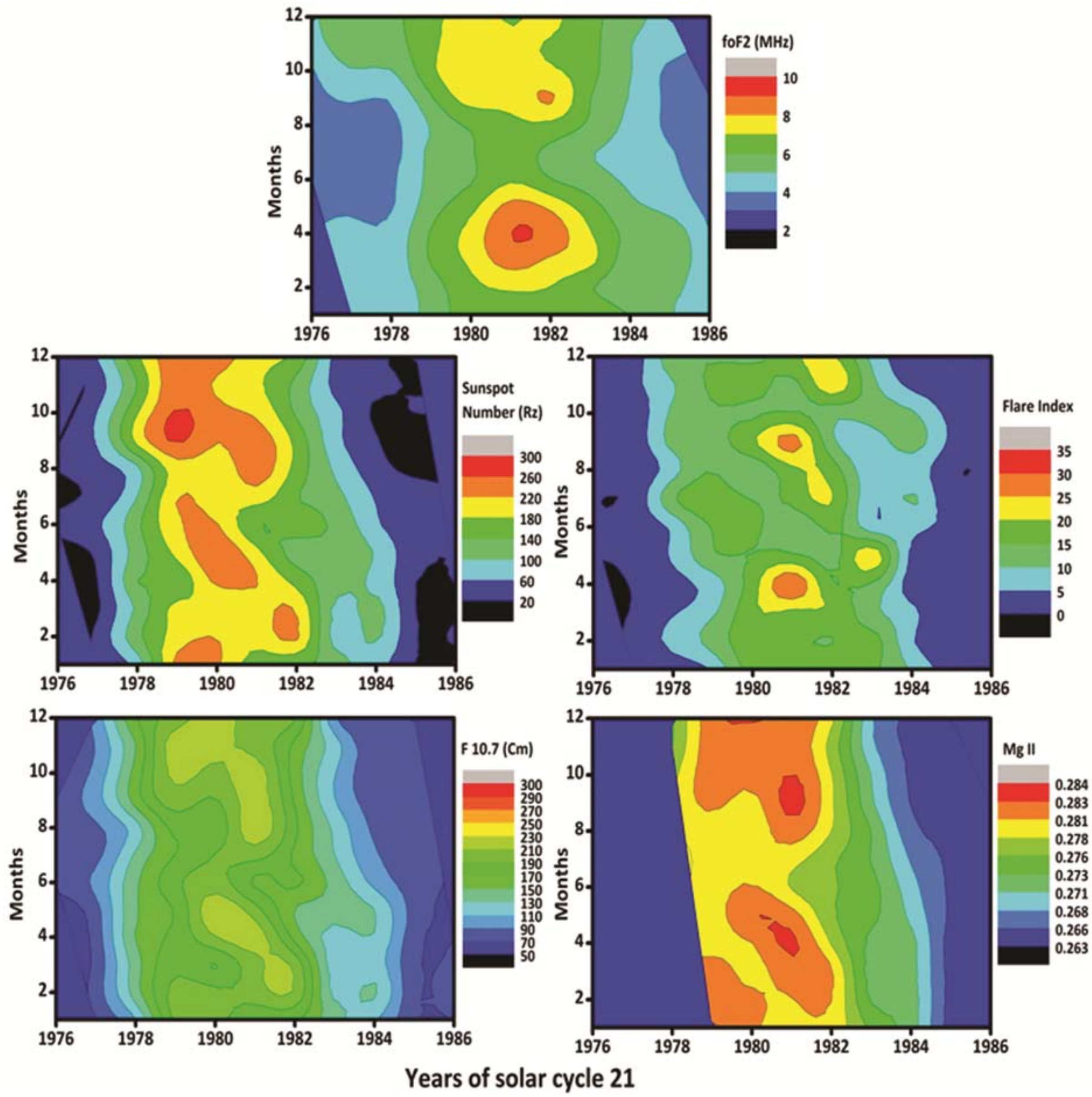

Fig. 3 — Behavior of critical frequency foF2 and solar indices during the solar cycle 21.

different solar activity indices starts increasing from year 1977 and achieve their peak during 1980 and 1981 after that all the solar indices starts decreasing describing the cyclic variation of solar activity, the similar behavior is reflected in foF2 variability.

Figure 4 depicts the single regression analysis performed to access the magnitude of correlation between foF2 and solar activity indices. To construct the scatter plot we have used the yearly averaged values of foF2 and solar indices. It can easily seen that a straight line fits very well on the data points, hence showing a linear variation between the two. All the points either lie on the straight line or lie very close to it. The correlation coefficients of foF2 with flare index, sunspot number, F10.7 cm and Mg II core to wing ratio are 0.94, 0.97, 0.98, and 0.97, respectively, during the solar cycle 21. The values of correlation coefficients clearly indicate that foF2 variability is strongly correlated with the long term variability of the solar activity.

3.2 Solar cycle 22

The monthly averaged values and the yearly averaged values of foF2 are plotted, together with monthly averaged and yearly averaged values of solar activity indices in Fig. 5 and Fig. 6, respectively, during the solar cycle 22. From both these figures, we can

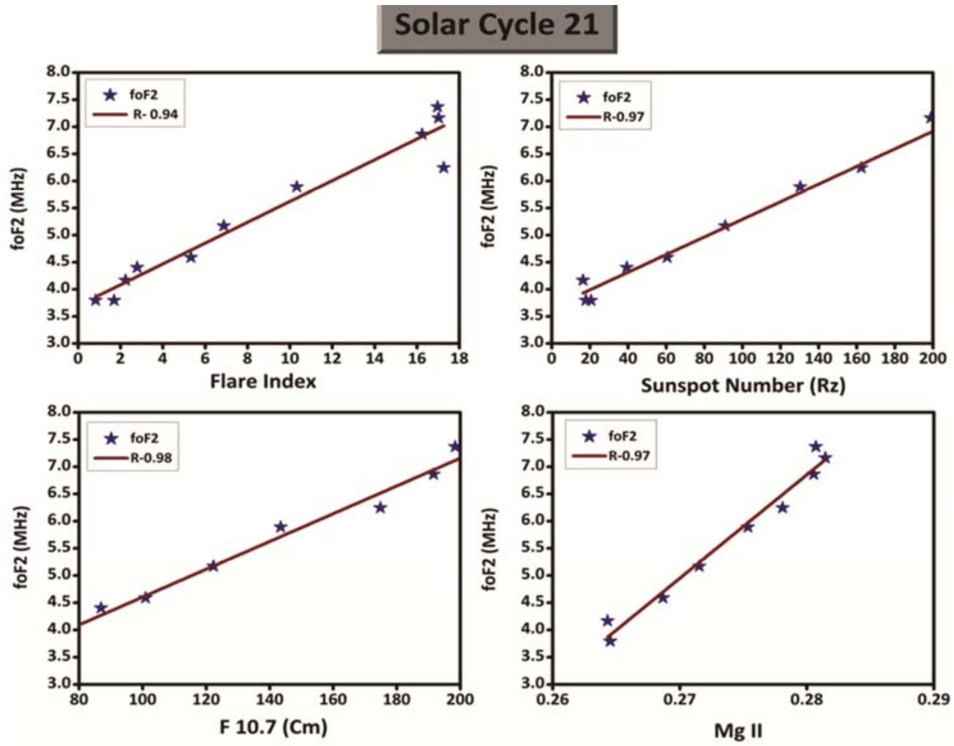

Fig. 4 — Scatter and correlation of foF2 with flare index, sunspot number, F10.7 Cm and Mg II core to wing ratio during the solar cycle 21.

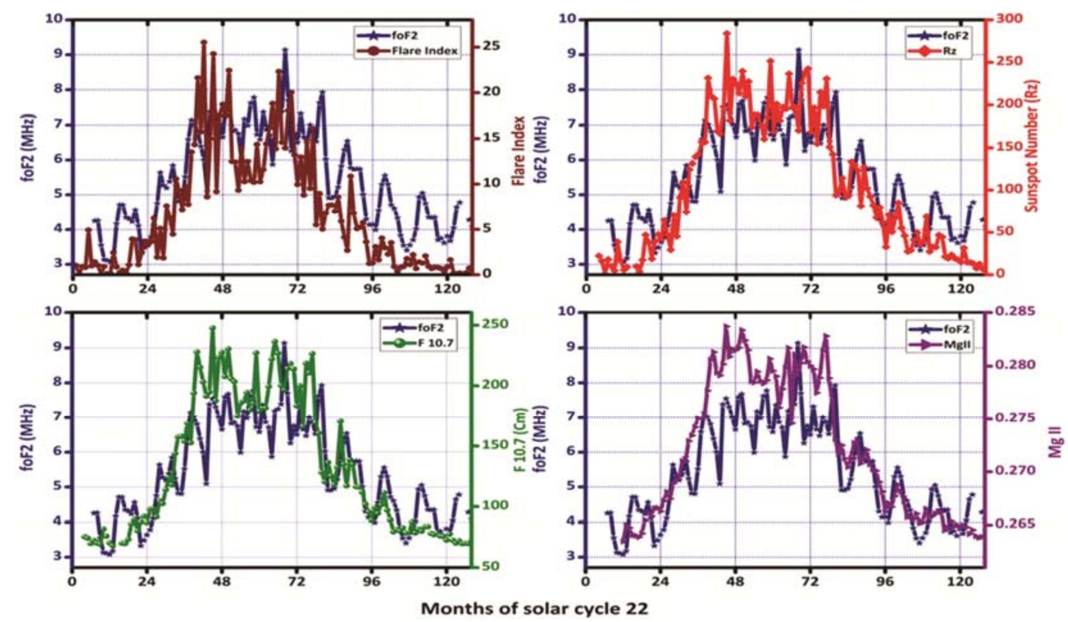

Fig. 5 — Monthly variation of foF2 with solar indices during the solar cycle 22.

clearly observe the two curves, representing variability of foF2 and solar indices, almost overlap. This is the similar feature observed for the solar cycle 21. The two curves achieve the minimum and maximum values in the same month or year. Any change in the solar activity curves is synchronously reflected in the foF2 curve.

Figure 7 depicts the variations of monthly averaged values of sunspot number (Rz), flare index, solar radio flux (F10.7 cm) and Mg II core to wing ratio and ionospheric foF2 for the different years of solar cycle 22. All the solar indices show a monotonic increase from the beginning of the solar cycle to their maxima. The different solar activity indices starts increasing

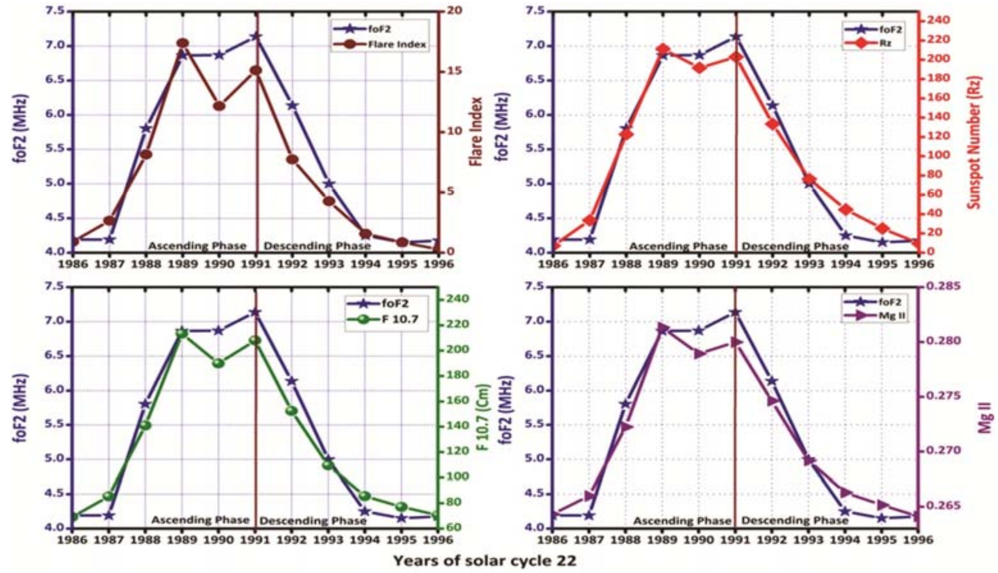

Fig. 6 — Annual variation of foF2 with solar indices during the solar cycle 22.

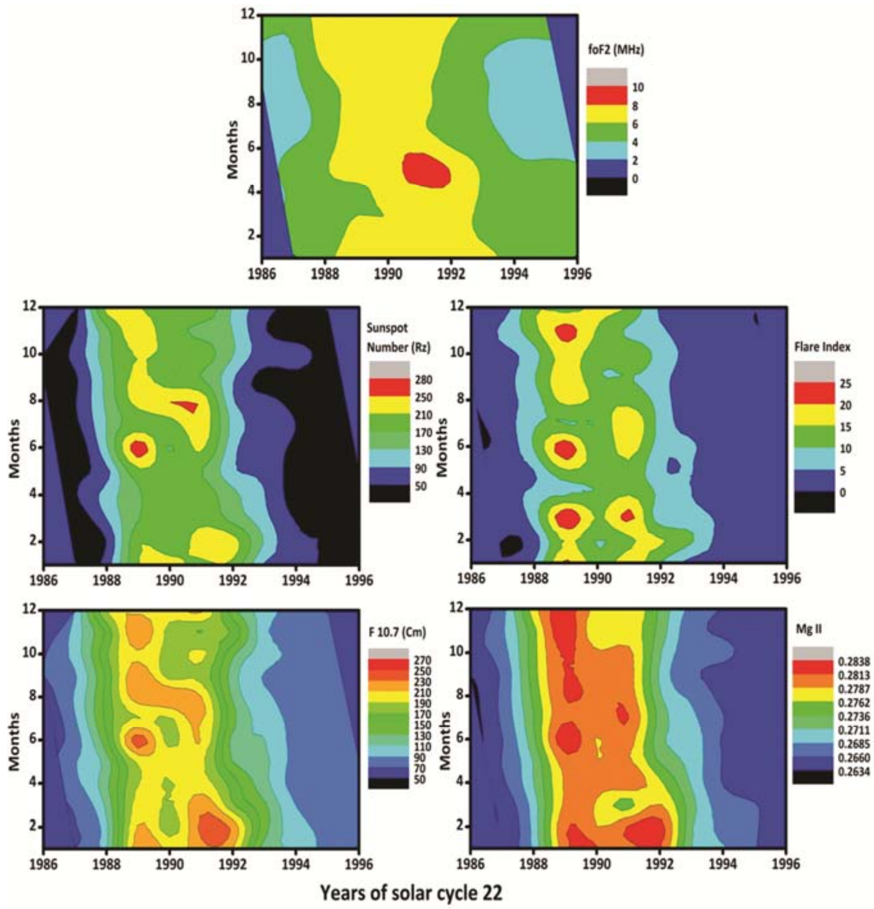

Fig. 7 — Behavior of critical frequency foF2 and solar indices during the solar cycle 22.

from year 1987 and achieve two peak during 1989 and 1992 and after 1992 the indices starts decreasing describing the cyclic variation of solar activity, the similar behavior is reflected by foF2.

Figure 8 shows the magnitude of correlation of foF2 with flare index, sunspot number (Rz), F10.7 cm and Mg II core to wing ratio during the solar cycle 22. From the figure we find that foF2 exhibits a linear relationship with all the four solar activity indices. The correlation coefficients of foF2 with flare index, sunspot number, F10.7 cm and Mg II core to wing ratio are 0.92, 0.97, 0.97 and 0.97 respectively.

3.3 Solar cycle 23

The monthly and yearly averaged values of foF2 and solar activity indices during the solar cycle 23 are plotted in Fig. 9 and Fig. 10 respectively. Again we notice that, the long term variability of two types of activities go hand in hand. Any small changes in the solar activity are clearly reflected in the ionospheric variability, indicating a strong control of long term variability of solar activity on the long term variability of ionosphere.

Figure 11 shows the variations of monthly averaged values of sunspot number (Rz), flare index, solar radio flux (F10.7 cm) and Mg II core to wing ratio and ionospheric foF2 for the different years of solar

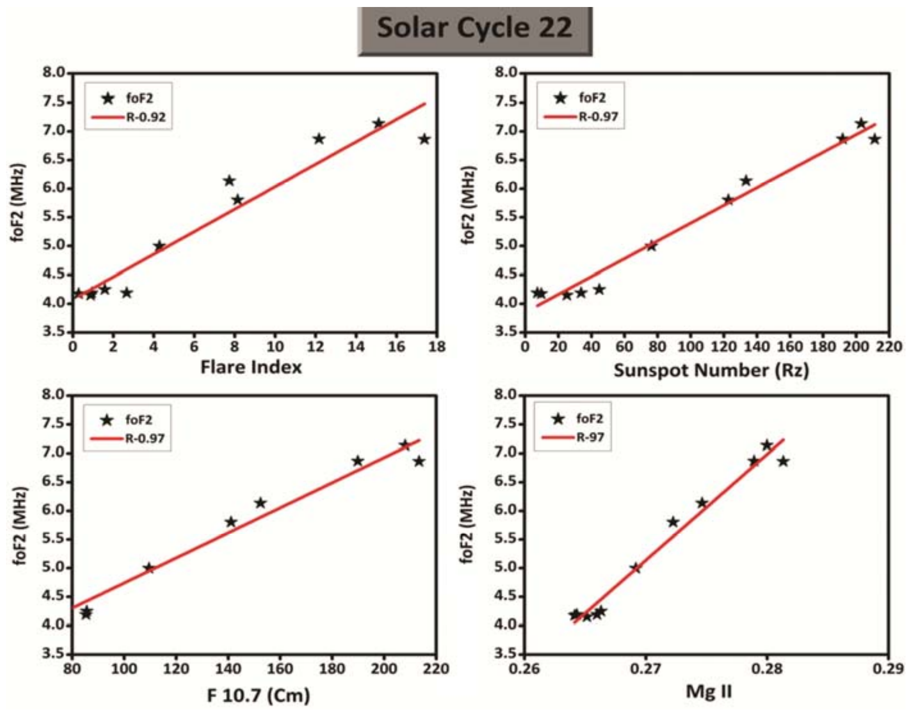

Fig. 8 — Scatter and correlation of foF2 with flare index, sunspot number, F10.7 Cm and Mg II core to wing ratio during the solar cycle 22.

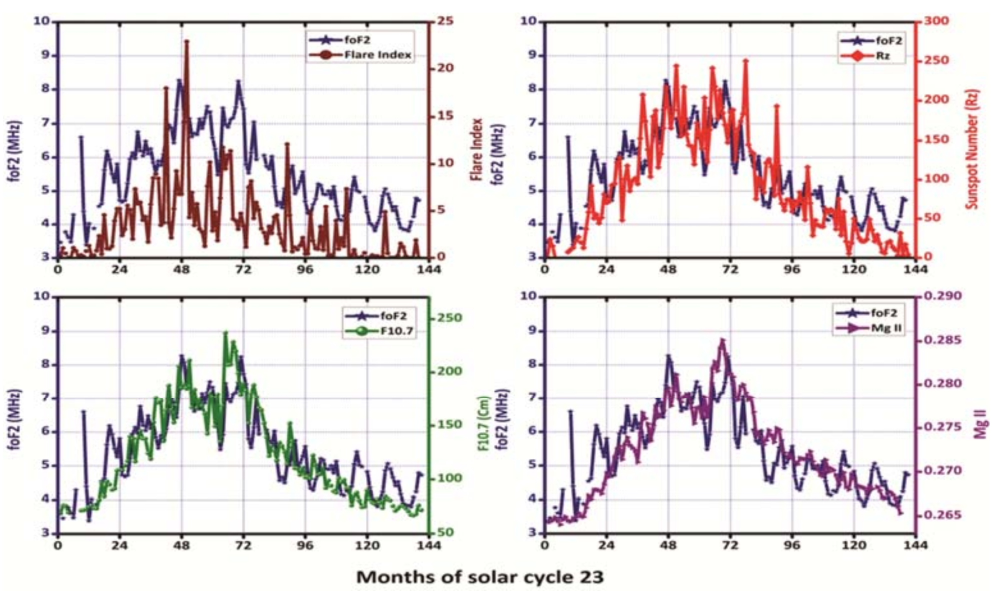

Fig. 9 — Monthly variation of foF2 with solar indices during the solar cycle 23.

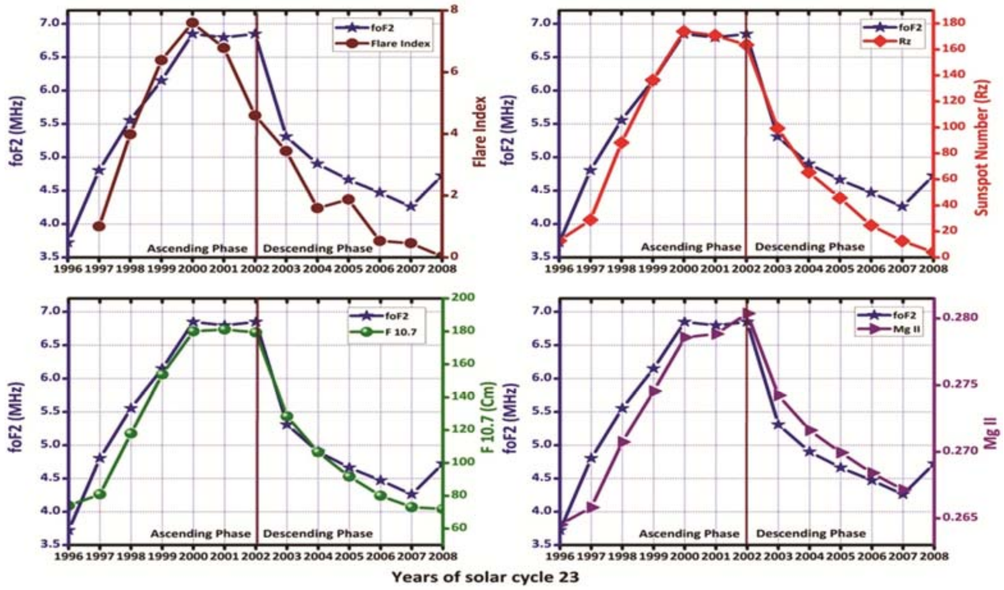

Fig. 10 — Annual variation of foF2 with solar indices during the solar cycle 23.

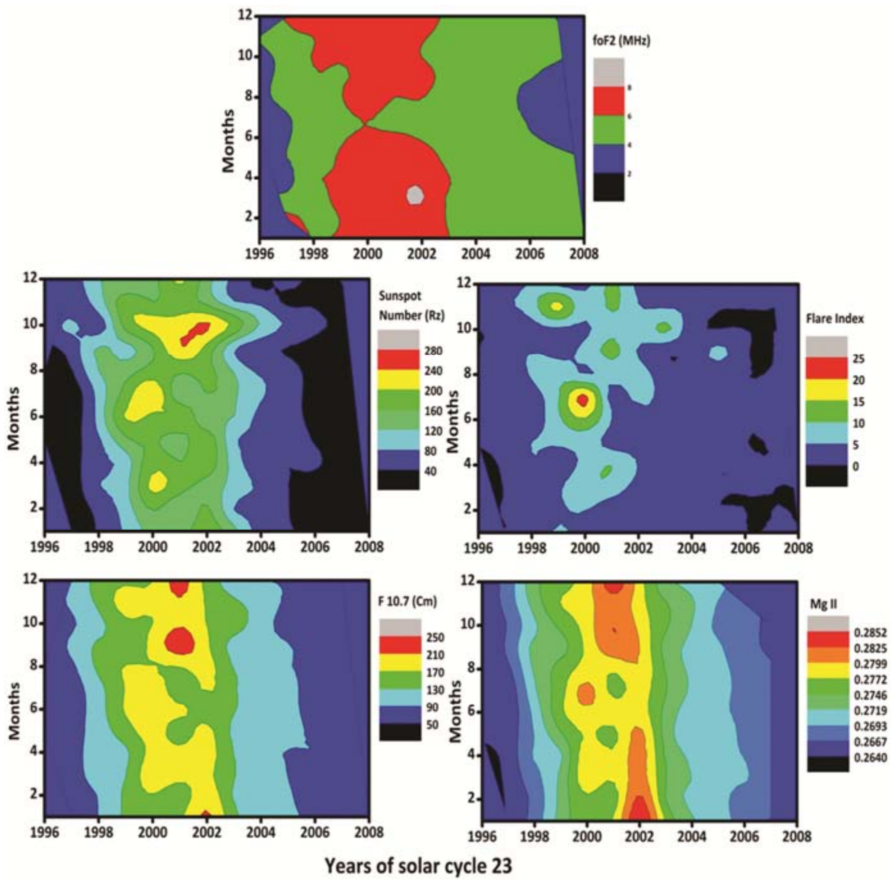

Fig. 11 — Behavior of critical frequency foF2 and solar indices during the solar cycle 23.

cycle 23. From the figure we find that all the solar indices show a monotonic increase from the beginning of the solar cycle to their maxima. The different solar activity indices starts increasing from year 1996 and achieve the peak between 2001 and 2002 and then start decreasing to the minimum in 2007, describing the cyclic variation of solar activity, the similar behavior is reflected in foF2.

Figure 12 shows the nature and magnitude of correlation of foF2 with flare index, sunspot number, F10.7 cm and Mg II core to wing ratio during the solar cycle 23. From the figure we find that foF2 exhibits a linear relationship with all the solar activity indices. The correlation coefficients of foF2 with flare index, sunspot number, F10.7 cm and Mg II core to wing ratio are 0.85, 0.92, 0.93 and 0.88 respectively. Correlation coefficient of foF2 with solar indices during solar cycle 21, 22 and 23 are given in Table 1.

The monthly averaged values of solar activity indices and foF2 during all the three solar cycles are plotted together in Fig. 13, to know how the two types of activity vary from cycle. From the figure we find that both solar activity indices and the foF2 follow similar variability during all the three cycles. However, the peak and minimum values are slightly different during the three cycles. This clearly shows that the ionospheric foF2 exhibits an eleven year variability like the solar activity.

Table1 — Correlation of foF2 with solar indices during solar cycle 21, 22 and 23.

Parameters	Correlation Coefficient		
	During Solar Cycle 21	During Solar Cycle 22	During Solar Cycle 23
Flare Index - foF2	0.94	0.92	0.85
Rz – foF2	0.97	0.97	0.92
F10.7 cm - foF2	0.98	0.97	0.93
Mg II c/w - foF2	0.97	0.97	0.88

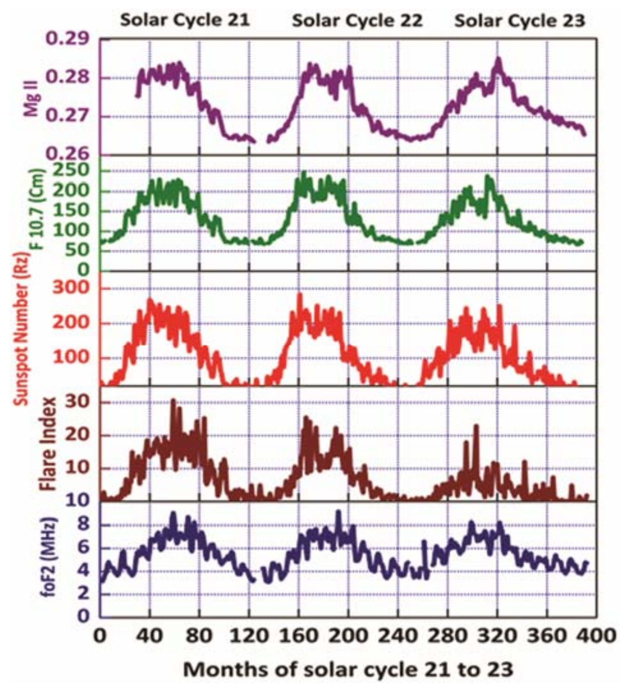

Fig. 13 — Cycle to cycle variation of foF2 with solar indices during solar cycle 21, 23 and 23.

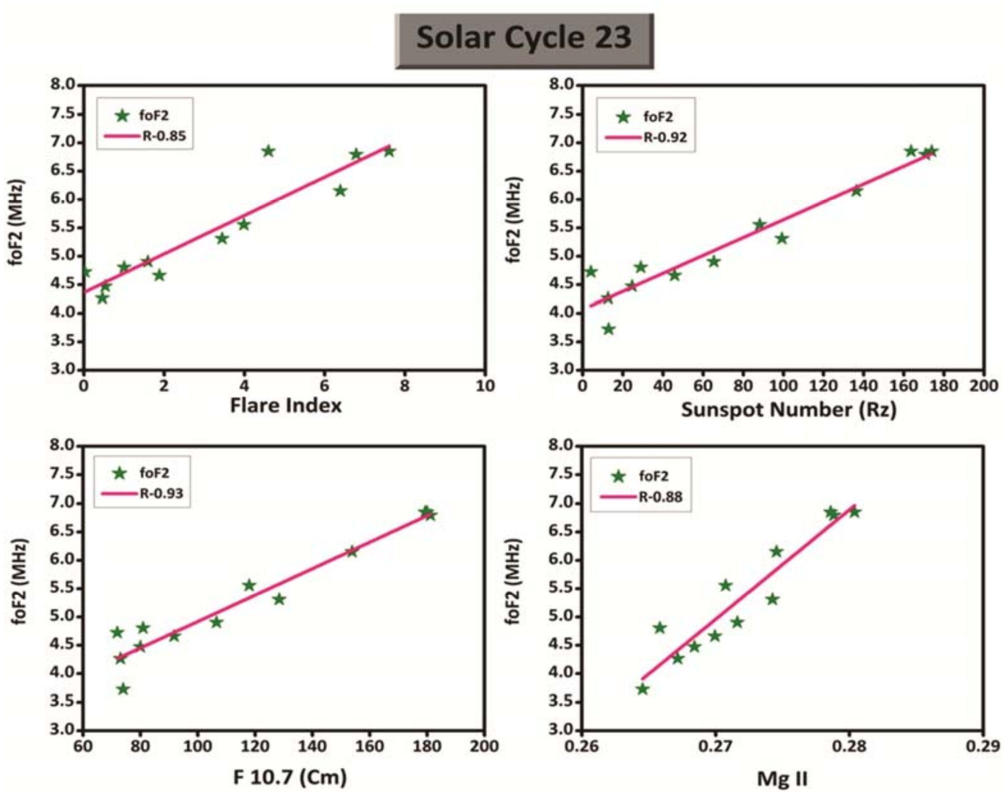

Fig. 12 — Scatter and Correlation of foF2 with flare index, sunspot number, F10.7 Cm and Mg II core to wing ratio during the solar cycle 23.

4 Discussion

It is well known that the solar irradiance which is the primary source of ionization for ionosphere follows an eleven year periodicity. Consequently, the ionosphere is also expected to reflect or follow the similar variability with the solar activity. However, the main task is to find the accurate or exact proxies for representing periodic variability of the solar activity which best suited for long term variability of the ionosphere. Although, some proxies like sunspot number and solar radio flux have been used in earlier studies, but later it was found that these are not the best proxies for studying the solar activity variability of the ionosphere. More recently, some other proxies like solar ultra violet, extreme ultraviolet and x-ray fluxes have also been identified. In our study we have attempted to explore some more parameters, which have potential to be used as proxies but it need more detailed and comprehensive study. In addition to the solar proxies, the average values of ionospheric parameters are equally important. It is to be explored whether monthly values, daily values, noontime values, day or night values are to be used concerning the long term solar activity influences of the ionosphere. Since majority of the studies favour the use of monthly median values, so we have also used the monthly values of the ionospheric parameters. However, to get make conclusive and decisive statements, more comprehensive and deep investigations are needed.

5 Conclusions

We have investigated the long term solar activity variability of the ionospheric foF2 during the last three solar cycle. From the study we found that foF2 follows the long term eleven year variability with the corresponding variability of the solar activity. The convincing evidences of this variability are reflected both in the monthly averaged as well as in yearly averaged values. The relative peak values of foF2 in various solar cycles was found to depend on the strength of the solar activity. The highest peak values of foF2 were recorded in the stronger solar cycles (21 and 22). The correlation coefficients of foF2 with different solar activity indicies during three cycles were found to exist between 0.85 to 0.98 (1 representing the perfect correlation) clearly quantifying a strong association of solar activity variations with the foF2 changes.

Acknowledgement

The author (Roshni Atulkar) would like to thank National Institute of Technical Teachers' Training and Research, Bhopal for MHRD fellowship. The authors are greatful to the National Geophysical Data Server (NGDC) and Space Physics Data Facility, OMNI Web for providing various data sets required for this work.

References

1 Rishbeth H & Garriott O K, *Introduction to ionospheric physics* (Academic Press: New York), 47 (1969), 234.
2 Kawamura S, Balan N, Otsuka Y & Fukao S, *J Geophys Res*, 107 (2002), 1166.
3 Yu T, Wan W, Liu L & Zhao B, *J Atmos Terr Phys*, 66 (2004) 1691.
4 Kane R P, *J Atmos Terr Phys*, 54 (1992) 463.
5 Tobiska W K, Woods T, Eparvier F, Viereck R, Floyd L, Bouwer D, Rottman G & White O R, *J Atmos Sol-Terr Phys*, 62 (2000) 1233.
6 Sethi N K, Goel M K & Mahajan K K, *Ann Geophys*, 20 (2002) 1677.
7 Rao, M S J G & Rao R S, *J Atmos Terr Phys*, 31 (1969) 1119.
8 Balan N, Bailey G J, Jenkins B, Rao P B & Moffett R J, *J Geophys Res*, 99 (1994) 2243.
9 Kane R P, *J Atmos Sol-Terr Phys*, 65 (2003) 1169.
10 Kane R P , *Indian J Radio Space Phys*, 34 (2005) 161.
11 Liu L, Wan W & Ning B, *Radio Sci*, 39 (2004) RS2013.
12 Ozguc A, Atac T & Pektas R, *J Atmos Sol-Terr Phys*, 70 (2008) 268.
13 Mansoori A A, Khan P A, Ahmad R, Atulkar R, Aslam A M, Purohit P K & Gwal A K, *J Phys Conf Ser*, 759 (2016) 012069.
14 Mansoori A A, Khan P A, Bhawre P, Gwal A K & Purohit P K, *Proceeding of the 2013 IEEE International Conference on Space Science and Communication*, (Melaka, *Malaysia*), 2013, 83.
15 Kouris S S, Bradley P A & Dominici P, *Ann Geophys*, 16 (1998) 1039.
16 Rishbeth H, *J Atmos Terr Phys*, 55 (1993) 165.
17 Richards P G, *J Geophys Res*, 106 (2001) 12, 803.
18 Liu J Y, Chen Y I & Lin J S, *J Geophys Res*, 108 (2003) 1067.
19 Bilitza D, *Phys Chem Earth, Part C*, 25 (2000) 515.
20 Liu L, Wan W & Ning B, *Ann Geophys*, 24 (2006) 851.
21 Naismith R & Smith P A, *J Atmos Terr Phys*, 22 (1961) 270.
22 Huang Y N, *J Atmos Terr Phys*, 25 (1963) 647.
23 Forbes J M, Palo S E & Zhang X, *J Atmos Sol-Terr Phys*, 62 (2000) 685.
24 Luhr H, & Xiong C, *Geophys Res Lett*, 37 (2010) L23101.
25 Chakrabarty D, Bagiya M S, Thampi S V & Iyer K N, *Indian J Radio Space Phys*, 41 (2012) 110.
26 Lean J L, White O R, Livingston W C & Picone J M, *J Geophys Res*, 106 (2001) 10,645.
27 Kleczek J, *Publ Inst Centr Astron*, 22 (1952) 74.