Influence of IMF $B_z$ on the variability of the minimum value of $f_o$-F2

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The critical frequency of the ionosphere, apart from the diurnal and annual variations exhibit day-to-day variations. The minimum value of $f_o$-F2 around the pre-sunrise period also has a day-to-day change. In this work, the relation between the magnitude of $f_o$-F2 minimum and $h'F2$ values around the pre-sunrise period and their relation with the sign of the north-south component of the interplanetary magnetic field (IMF) is investigated. The minimum value of $f_o$-F2 for each day is found to be related to the IMF north-south component, with the $f_o$-F2 value tending to be larger when the IMF is northward and smaller when the IMF is southward. The northward IMF $B_z$ is seen to produce an eastward electric field at the ionosphere and move the ionospheric plasma to higher altitudes resulting in higher critical frequencies. Whereas a southward IMF $B_z$ produce a westward electric field and move the ionospheric plasma to lower altitudes resulting in lower critical frequencies.

Keywords: Interplanetary magnetic field (IMF), IMF Polarity, Critical frequency, Ionospheric critical frequency

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1 Introduction

The electron density of the ionosphere changes dramatically with time of day, season and variations in solar activity. The variation of the F-region electron density distribution greatly affects the propagation of radio waves through the ionosphere. The electron density of the F2-region of the ionosphere is reflected in the values of the critical frequency, $f_o$-F2 since the critical frequency $f$ and the electron density $n$ are related as $f = 9 \sqrt{n}$, where $f$ is the critical frequency and $n$ the electron density. The ionospheric parameters, in general, exhibit diurnal, day-to-day, annual and solar activity cycle variations. Since the ionosphere responds to solar EUV radiation, it varies over the 24-h period between daytime and nighttime, over the season due to the variation in the solar zenith angle and over the 11-year cycle of solar activity due to the variation in the incoming solar flux. In the F2-layer, just before dawn, the recombination process reduces the electron density and the critical frequency $f_o$-F2 reaches the lowest level about 2-4 MHz. At the equatorial F-region, after sunrise, due to the photo-ionization, the $f_o$-F2 rises rapidly and during the day it reaches about 15 MHz and then start decreasing at sunset. Greater the solar flux, greater will be the photo-ionization in the ionosphere and hence greater will be the electron density and the critical frequency.

Variations in the solar wind pressure and interplanetary magnetic field (IMF) can cause significant disturbances in the middle- and low-latitude ionosphere. The interplanetary dawn-dusk electric field ($E = -V_{sw} B_z$) is also found to influence the ionosphere electron density distribution and the dynamics of ionosphere, causing drifts and changes in ionospheric parameters like ionospheric plasma velocity, $f_o$-F2 and $h'F2$. The interplanetary electric field that drives the magnetosphere-ionosphere convection is dependent on the IMF polarity, solar wind velocity and density. The magnetic reconnection at the magnetopause, when IMF turns southward, is the most efficient mechanism of solar wind energy transfer to the magnetosphere. The field aligned currents transfer the electric field and momentum of the magnetosphere to the ionosphere. The effect is the result of direct penetration of electric field from the field-aligned currents, which is connected with DP systems, to equatorial ionosphere. This additional electric field of the FAC (Field Aligned Currents) carries ions away from the equatorial F2 layer and consequently maximum F2 layer is observed at great heights. The energy transport between the polar and equatorial region is simultaneous. In this work, an investigation is made on the effect of the interplanetary magnetic field north-south component.
on the variation of the \( h'F2 \) and \( f_o-F2 \) minimum around the pre-sunrise period.

2 Data and method

The interplanetary magnetic field north-south component \( B_z \) data are taken from the IMP-8 satellite data available at the CDA Web facility of the SPDF (Space Physics Data Facility) of NASA (http://spdf.gsfc.nasa.gov). For the present analysis the IMF data are then analyzed and the plots of IMF \( B_z \) are observed to find the days for which IMF \( B_z \) are consistently northward or southward around the pre-sunrise period. The fact is ascertained using the Locator Graphics facility of SSC web (Satellite Situation Centre). The IMF data are selected for those days for which the position of the satellite is along the Sun-Earth line.

3 Diurnal and annual variations in \( f_o-F2 \)

A typical graph of the diurnal variation of critical frequency \( f_o-F2 \) is shown in Fig. 1. The critical frequency, in general, decreases during early morning hours and reaches a minimum just before the sunrise. Around 0500 hrs LT, then, \( f_o-F2 \) values rise sharply as the increased incident solar photon flux at sunrise causes an increase in photo-ionization at the ionosphere, thereby increasing the electron density. Thereafter, \( f_o-F2 \) reaches a peak at about 1000 hr LT and then decreases. There is another peak at around the evening and thereafter the electron density decreases during the night. The decrease in electron density in the early morning hours may be due to the recombinaton of ions and electrons. Other reasons for the decrease in \( f_o-F2 \) may be due to the diffusion of ions away from the equator forming the equatorial anomaly. This diffusion away from the equator balances the rate of production of electrons and the result is a daytime plateau. In the evening period, there is a pre-reversal \( E \times B \) drift upwards and this may cause the evening enhancement. After sunset, the rate of photo-ionization decreases and the electron density starts decreasing.

The minimum value of \( f_o-F2 \) occurs just before sunrise. The minimum value of \( f_o-F2 \) exhibits a day-to-day variation. Several factors influence the daily variability of minimum of \( f_o-F2 \). Factors influencing the recombination rate of the ions in the ionosphere may also affect the minimum value of \( f_o-F2 \). The presence of electric fields may cause an \( E \times B \) drift of the electrons and ions causing them to move upwards, where the recombination rate is low or causing them to move downwards, where the recombination rate is high. This may cause corresponding variations in the minimum value of \( f_o-F2 \). In addition to the diurnal variation, the minimum of \( f_o-F2 \) has a seasonal dependence. The ionosphere exhibits strong seasonal variations due to the changes in the source of ionization associated with the changes in solar zenith angle. These variations are reflected in the values of \( f_o-F2 \) also. The variations of the monthly mean of the pre-sunrise minimum of \( f_o-F2 \) for the years 1998, 1999 and 2001-5 are depicted in Fig. 2.

It is seen that the variations are almost identical for the years 1998 and 1999, while there is an increase in values of January and April for the year 2002. The pre-sunrise values of \( f_o-F2 \) show a minimum around local winter (May, June, July, August) and a maximum around local summer (November, December, January, February).

4 Influence of IMF on \( f_o-F2 \)

In the present study, the variation of \( f_o-F2 \) and \( h'F2 \) values at Jicamarca observatory during post-midnight period has been used to investigate under different
conditions of IMF $B_z$ polarity. The daily $f_o$-F2 values prior to sunrise and the IMF $B_z$ values for the same interval are considered for the present study. It is noticed that the minimum value of $f_o$-F2 is influenced by the polarity of IMF $B_z$. On days in which the IMF $B_z$ has variations, the $f_o$-F2 variation is distorted from the diurnal pattern. Figure 3 depicts a typical day when the IMF $B_z$ fluctuates between southward and northward. The line with circles, depict the variation of $f_o$-F2 and the dotted line depict the variation of the IMF $B_z$. The other line gives the mean $f_o$-F2 variation for the month of November 1999. The IMF $B_z$ component fluctuates between southward and northward direction within the period of observation. On 4 Nov. 1999, the IMF $B_z$ component though showed oscillations, remained northward from about 0500 hrs UT (2400 hrs LT) onwards reaching a maximum of about 10 nT around 0800 hrs UT (0300 hrs LT). The critical frequency $f_o$-F2 around the local morning hour enhanced to 7.2 MHz on 4 Nov. 1999 compared to 2.8 MHz on 3 November and 4 MHz on 5 November.

The presence of a sharp fall in IMF southward component during the pre-midnight hours causes a similar fall in $f_o$-F2 values and causes deviation from the diurnal pattern. During the post midnight period, the IMF $B_z$ turns northward and remains in that direction for a few hours. Corresponding to this change, the $f_o$-F2 values get enhanced and do not exhibit the minimum during the pre-sunrise hours. This behaviour of the low-latitude ionosphere can provide evidence of the penetration of the convection electric field associated with the interplanetary dawn-dusk electric field. In order to study the dynamic behaviour of the equatorial ionosphere associated with the IMF variations, the variation of the $h^\prime$F2 during the same period is also investigated as shown in Fig. 4. The $h^\prime$F2 depicts an inverse relation with $f_o$-F2 during the period of penetration of the interplanetary electric field to equatorial region. When the $f_o$-F2 exhibits a fall in magnitude during the pre-midnight period, $h^\prime$F2 exhibit an enhancement. Similarly, during the post midnight period, the $h^\prime$F2 exhibit a fall associated with a rise in $f_o$-F2 values.

Bettencourt and Abdu (1981) have shown that for equatorial stations, the rate of change of the $h^\prime$F2 is indicative of the variations of F-region vertical plasma drift and thus of the zonal electric field. Noticeable change of $h^\prime$F2 during the pre-sunrise hours consisting in a sudden increase or a rapid decrease generally
indicates electric field perturbation. Subsequent to the decrease observed in $h'$F2 variations at the equator noticeable from Fig. 4, the corresponding $f_o$-F2 underwent an increase that exceeded the reference quiet-time level. During the pre-midnight hours associated with the increase in $h'$F2, the $f_o$-F2 values decreased below the monthly average level. These uplifts in $h'$F2 are concurrent with the decrease in the $f_o$-F2, which means a drop in electron density simultaneously with an increase in the eastward component of the electric field; that is, an upward motion of the plasma near the magnetic equator due to the sudden increase in the eastward electric field, in agreement with Raghavarao and Sivaraman. When the IMF $B_z$ is northward for a prolonged period, the minimum value of $f_o$-F2 is enhanced whereas when the IMF $B_z$ is southward for a prolonged period, the values of $f_o$-F2 are more depressed.

Figure 5 depicts the variation of $f_o$-F2 corresponding to a period when the IMF $B_z$ was consistently southward. During this day, the $f_o$-F2 minimum value fell below 2 MHz during the pre-sunrise period. Figure 5 shows the variation in $f_o$-F2 and IMF $B_z$ component for a day for which the IMF component was consistently southward, alongwith the mean $f_o$-F2 variation for the month of April 1998. On 1 Apr. 1998, the IMF $B_z$ component was on an average southward, reaching a minimum value of about - 4 nT at 2200 hr UT. On the same day, the F2 layer critical frequency reached a minimum value of 1.8 MHz. This value is lower compared to those on other nearby days, which are 3.7 MHz on 5 Apr. 1998 and 4.4 MHz on 10 Apr. 1998. The relation between $f_o$-F2 and $h'$F2 during 1 Apr. 1998 is depicted in Fig. 6. Similar to Fig. 4 the variation in $h'$F2 is inverse of that of $f_o$-F2. During the post-midnight period, when the $f_o$-F2 values show a gradual fall in magnitude, $h'$F2 values exhibit a gradual enhancement.

5 Discussion

The critical frequency of the equatorial F-region exhibits a typical diurnal variation with a minimum around the pre-sunrise period. The diurnal pattern of the critical frequency can be explained in terms of the production of electrons by photo-ionisation, the recombination process and the zonal electric field in the region. The knowledge of the variations in the critical frequency and minimum value of critical frequency of the F2-region is very important in radio communication. In addition to the diurnal variation, the critical frequency exhibits a prominent annual variation also, with a peak around the winter solstice and a valley around the summer solstice. The connection between IMF $B_z$ and the critical frequency of the ionosphere can be explained by the penetration of interplanetary electric field into the ionosphere through solar wind-magnetosphere-ionosphere coupling by the electric field of field aligned currents.

The interplanetary electric field makes its way into the Earth’s atmosphere through the reconnection process. Reconnection takes place for both southward and northward IMF. For the southward IMF, reconnection takes place on the night side of the cusps. During the reconnection process, the interplanetary magnetic field lines connect with the terrestrial magnetic field lines. The interplanetary magnetic field's southward component ($B_z$) introduce
a dawn-to-dusk interplanetary electric field (IEF) at the magnetopause given by $E_{yy} = -V_{sw} \times B_z$. In the time interval between connection and reconnection, geomagnetic field lines are open and interplanetary electric field can penetrate to the polar ionosphere causing sudden changes in cross-polar cap potential. This electric field can be instantaneously mapped to low latitudes, adopting a transverse magnetic (TM) mode of propagation through the Earth-Ionosphere waveguide. When the IMF changes between southward and northward, the interplanetary electric field varies in the dawn-dusk direction, and the penetration electric field in the ionosphere is in the east-west direction. An eastward electric field will move the ionospheric plasma to higher altitudes, and a westward electric field will move the plasma to lower altitudes. The recombination of the ionospheric electrons is strongly dependent on the background neutral atmosphere, so the electron density will be significantly changed by the up and down motion of the F-layer. In general, it is expected that the plasma density will become higher as the plasma moves up, because of the lower recombination rate at higher altitudes and vice versa. During 4 Nov. 1999 the IMF $B_z$ remained northward in the post-midnight period, generating an enhancement in the eastward electric field in the equatorial ionosphere. Associated with the electric field, the ionospheric plasma is lifted to higher altitudes, inhibiting the recombination and associated with this the $f_o$-F2 did not exhibit the morning minimum. Whereas during 1 Apr. 1998, the IMF $B_z$ remained southward during the night, resulting in lower altitude of $h\prime F2$. Since the $h\prime F2$ altitude was lower, the recombination rate was higher and the critical frequency fell to levels below 2 MHz. So the northward IMF $B_z$ is seen to produce an eastward electric field, resulting in greater plasma density and higher critical frequencies, whereas a southward IMF $B_z$ is seen to produce a westward electric field, resulting in lower plasma density and hence lower critical frequencies.

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References