The Behavior of the Refractive Index of the Equator Region of the Ionosphere

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ABSTRACT: *In this study, the seasonal behavior of the refractive index over the dip equator is investigated both for collisional and collisionless cases in the by using the real geometry of Earth's magnetic field for north hemisphere with respect to latitudes. It is observed that there is a harmony between the behavior of the electron density distribution and ordinary and extra-ordinary waves both for collisional and collisionless cases at hmF2 peak in the ionosphere.*

1. INTRODUCTION

The ionosphere significantly affects the propagation of radio waves so the variabilty of the ionosphere is important for the ionospheric phsics and radio comunications. The ionosphere can be characterized with its electron density distribution which is a complex function of spatial and temporal variations, geomagnetic and solar activity. Usually, the ionosphere with respect to its electron density distribution is separated into five independent regions, sometimes called layers: D layer, E layer and F layer. [1]. The temporal and the spatial behaviors of the the ionosphre depend on earht's diurnal and annual rotation and the distribution of the magnetic field lines of the magnetic dipole. Some of the studies in the literature [1-5] investigate the annual and the semiannual variations of the electron density profiles suggest that these ionospheric behaviors can cause deviations in the electron density distributions which are called as anomalies. The ionospheric anomalies generally departure from simple solar-controlled behaviors. The principal anomalies observed at mid-latitudes may be characterized .One of these is winter or seasonal anomaly: NmF2 is greater in winter than in summer by day, but the anomaly disappears at night, NmF2 being greater in summer than in winter. [2-7].

In this study, seasonal anomaly effects on electron density distribution in the F2–layer and the refractive indeces of HF waves traveling vertical into the ionosphere are investigated as depending on various parameters in the ionosphere. The results are obtained for 38.7^o N, 39.2^o E geographical coordinates and for year 1996. The ionospheric parameters used in the study are obtained from IRI model. The method used in the study and the results are presented in Section 2 and 3, respectively.

2. DISPERSION RELATIONS

Assuming a plane wave solution, where the velocity and the fields vary as exp[i(**k.r**-ωt)], a general wave equation for electromagnetic waves can be defined as:

$$n^2\,\mathbf{E}-\mathbf{n}\left(\mathbf{n}\cdot\mathbf{E}\right)-\left[I+\frac{i}{\varepsilon_0\omega}\sigma\right]\mathbf{E}=0 \tag{1}$$

where **n** (=**k**c/ω) is the refractive index, **k** the wave vector, **E** the electric field, I the unit matrix, σ the conductivity tensor and ε_0 the free space electric permittivity coefficient. In this study, a approximation is made to include collisions in the calculation of **n**. A vertical electromagnetic wave is considered, which travels in the z direction in the ionosphere. The z-axis is vertical with its origin located on the ground. The x and y-axes indicate the geographic eastward and the northward in the northern hemisphere, respectively. Being I and d the magnetic dip and declination angles, respectively, the geomagnetic field in terms of its components is $\mathbf{B} = B_x\,\mathbf{a_x} + B_y\,\mathbf{a_y} + B_z\,\mathbf{a_z}$, where B_x=Bcos(I)sin(d), B_y=Bcos(I)cos(d), B_z=-Bsin(I). The travelling electromagnetic wave presents a component propagating in a direction perpendicular to the magnetic field and other along the magnetic field. In the first case, the ordinary (O) and extraordinary (X) waves with a refractive index (n_O and n_X) are defined by Equation (2) and Equation (3), respectively [8-10]:

$$n_0^2 = 1 - \frac{X}{1+Z^2} + iZ\frac{X}{1+Z^2} \tag{2}$$

$$n_X^2 = 1 - \frac{X\left[(1-X)\left(1-X-Y^2\cos^2 I\cos^2 d\right)+Z^2\right]}{\left[1-X-Z^2-Y^2\cos^2 I\cos^2 d\right]^2+Z^2\left[2-X\right]^2} + iZ\frac{X\left[(1-X)^2+Z^2+Y^2\cos^2 I\cos^2 d\right]}{\left[1-X-Z^2-Y^2\cos^2 I\cos^2 d\right]^2+Z^2\left[2-X\right]^2} \tag{3}$$

In the case along the magnetic field, the circularly polarized waves with a refractive index (n_p) can be given as [10,12]:

$$n_p^2 = 1 - \frac{X\left[1\mp Y\sin I\right]}{\left[1\mp Y\sin I\right]^2+Z^2} + iZ\frac{X}{\left[1\mp Y\sin I\right]^2+Z^2} \tag{4}$$

Where the signs (-) and (+) correspond to right and left hand polarization, respectively. Equation (2), Equation (3) and Equation (4) are defined in terms of the magneto-ionic parameters X ($=\omega_P^2/\omega^2$), Y ($=\omega_C/\omega$) and Z($=\nu/\omega$), where ω_P and ω_C are the plasma frequency and the electron gyrofrequency, respectively. From these equations' from, the refractive index can be defined as $n^2 = (\mu + i\chi)^2 = M + iN$. The real part of n ($\mu$) becomes then:

$$\mu^2 = \frac{1}{2}\left[\left(M^2 + N^2\right)^{1/2} + M\right] \tag{5}$$

For HF waves ($Z^2<<1$), so the expression $(1+Z^2)^{-1}$ in the refractive indices can be approximated by $(1-Z^2)$, using binomial expansion and neglecting terms of order higher than Z^2. By using these approximations, μ results for the ordinary, extraordinary and cicularly polarized waves can be defined as follows [15]:

$$\mu_o^2 \approx (1-X) + Z^2\frac{X(4-3X)}{4(1-X)} \tag{6}$$

$$\mu_x^2 \approx \frac{(1-X)^2 - Y^2\cos^2 I\cos^2 d}{1-X-Y^2\cos^2 I\cos^2 d} + Z^2\frac{X^2\left[(1-X)^2+Y^2\cos^2 I\cos^2 d\right]^2}{4\left[1-X-Y^2\cos^2 I\cos^2 d\right]^3\left[(1-X)^2-Y^2\cos^2 I\cos^2 d\right]} \tag{7}$$

$$\mu_p^2 \approx (1-X') + Z'^2\frac{X'(4-3X')}{4(1-X')} \tag{8}$$

with X'=X/[1-Y sin (I)] and Z'=Z/(1-Y sin I). These equations hold for X<1 and X'<1. The collision frequency ν is the sum of ν_{ei} and ν_{en}, where ν_{ei} and ν_{en} are the electron-ion and the electron-neutral collision frequencies, respectively. These frequencies are defined as [8]:

$$\nu_{ei} = N\left[59 + 4.18\log\left(\frac{T_e^3}{N}\right)\right]x10^{-6}T_e^{-3/2}\ \ [\text{m.k.s.}] \tag{9}$$

$$\nu_{en} = 5.4x10^{-16}N_n T_e^{1/2}\ \ [\text{m.k.s.}] \tag{10}$$

where N is the electron density, N_n is the neutral particle density, and T_e is the electron temperature.

3. NUMERICAL ANALYSIS AND RESULTS

In this study, the results are obtained for geographic coordinates of 38.7° N, 39.2° E, I=55.6°, d=3°, R=10, ω=38.7 E+6(rad/sn) and for year 1996 by using Equations (2)-(8). The ionospheric parameters used for calculations are obtained by using IRI model. It is observed that the maximum electron density is observed in equinoxes at midnight. In the solstices, maximum electron density is observed at noon. At midnight times, it is observed that electron densiy in December and March are greater than in June and September. It is also observed that refractive indices have similar values for the collisional and collisionless cases. When the electron density profiles and the refractive indices profiles are compared with each other's, it is observed that there is a harmony between the electron density and the the real part of the refractive index of the x- wave in the height of the ionospheric F2-peak. But there is a dissonance between the other waves and both the electron density, hmF2 and the refractive index at the time (around 12 o'clock by day) when the winter anomaly take places.When the winter anomaly occurs (in December and March), all the refractive indices values of the extra ordinary wave (n_x) obtained from Equation (3) both for collisional and collisionless cases have the minimum values in the ionospheric plasma. This result can be interpreted that the denominator of the collision term in Equation (7) decreases. Due to this; the real part (μ_x) of the refractive index of the x-wave seasonally increases at the height of the ionospheric F2-peak for winter anomaly case in the ionospheric plasma. Figure 1-4 represents the refractive index values of the extra ordinary wave at the hmF2 peaks in the ionospheric plasma for the collisional case at the heights from 250 km to 650 km. It is observed from Figure 3b, Figure 4a, Figure 5b and Figure 6a, around 12 o'clock, when the winter anomaly occurs, refractive index values in both collisional and collisionless cases have been taking the minimum values both for collisional and collisionless cases. This result is depend on the behavior of the extra ordinary wave in collisional case with respect to other waves that displays a reverse behavior to the winter anomaly in the ionospheric plasma.

4. CONCLUSIONS

In this study, the effects of the winter or seasonal anomaly in height of the ionospheric F2–peak on the refractive index both for collisional and collisionless cases of HF waves traveling in a direction vertical to the ionosphere are investigated for mid-latitudes and midnight and noon hours in the equinoxes and solstices. It is observed that the winter anomaly can only affects the real part (μx) of the refractive index of the extra ordinary wave for collisional and collisionalless cases in height of the ionospheric F2–peak. There are dissonance between the electron density and the refractive index of the extra ordinary wave in height of the ionospheric F2-peak. But, there is seasonally an exact harmony between the electron density and the real part of the refractive index of the x-wave, except the other waves (ordinary and polarized waves). From this results, it is observed that in the case of high frequency waves traveling vertically into ionosphere, the phase velocity of all of the waves except the real part of the extra ordinary ($Z \neq 0$) increases at the time when the winter anomaly occurs. Due to this fact, the reflection heights of the all waves, except the real part of the extra ordinary ($Z \neq 0$), increases depending on the winter anomaly. The proposed procedure can be used in the assessments of the ionosphere variables, such as conductivity and it can be also used for ionospheric plasma density measurements. This study can become important in midlatitude stations for ionosonde measurements because the refractive index of the medium determines the medium of behavior against any external influence.

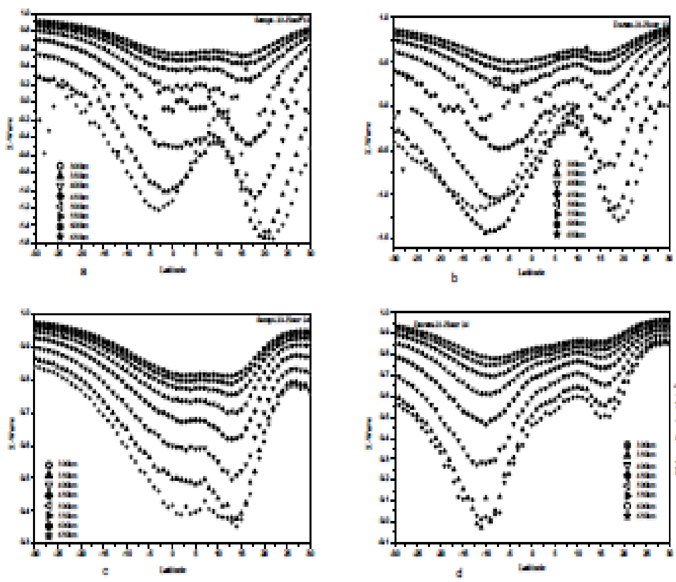

Figure 1. Electron density distributions at the heights from 300 km to 650 km for: a) September 23, 12 o'clock; b) December 21, 12 o'clock; c) September 23, 24 o'clock; d) December 21, 24 o'clock.

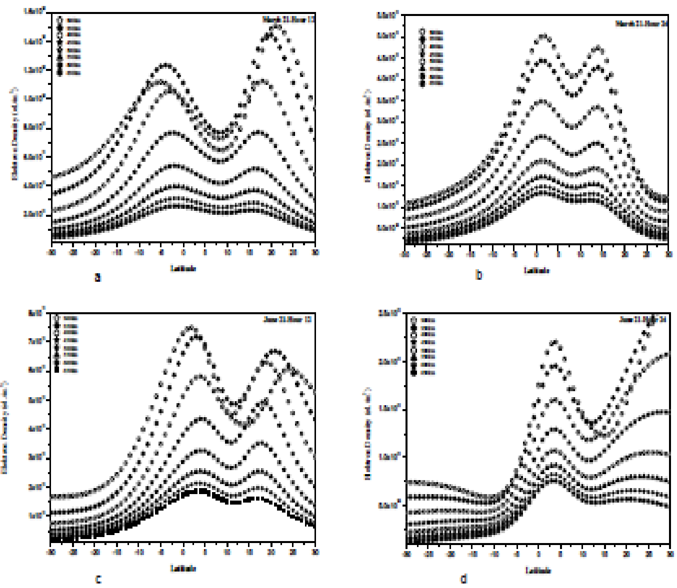

Figure 2. Electron density distributions at the heights from 300 km to 650 km for: a) March 21, 12 o'clock; b) March 21, 24 o'clock; c) June 21, 12 o'clock; d) June 21, 24 o'clock.

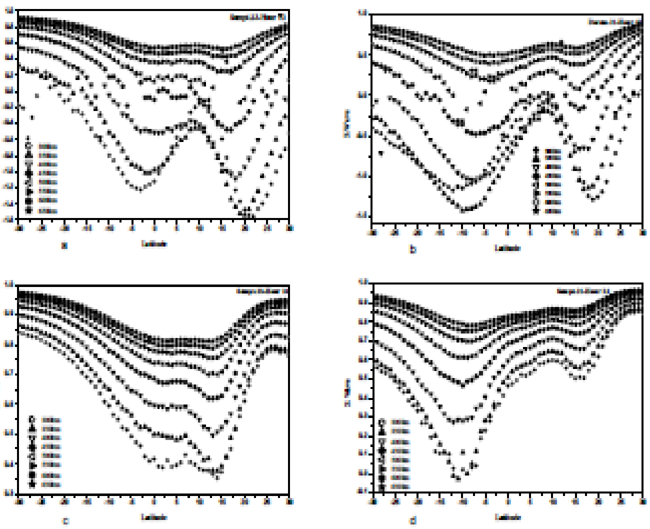

Figure 3. The refractive index values of the extra ordinary wave at the hmF2 peaks in the ionospheric plasma for the collisional case at the heights from 250 km to 650 km for: a) September 23, 12 o'clock; b) December 21, 12

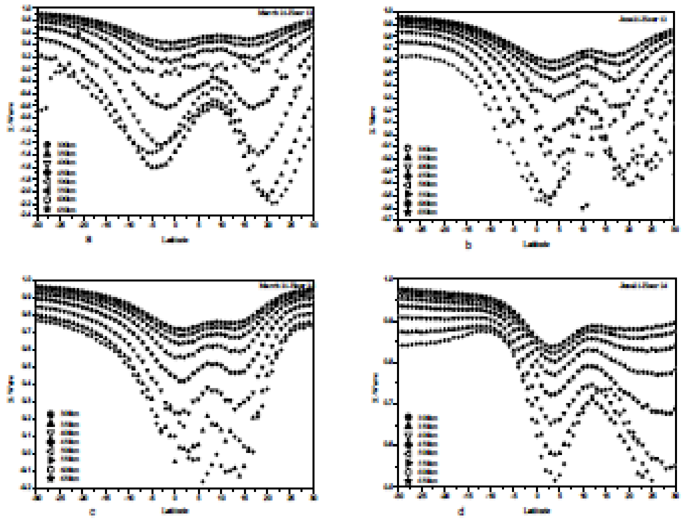

Figure 4. The refractive index values of the extra ordinary wave at the hmF2 peaks in the ionospheric plasma for
the collisional case at the heights from 250 km to 650 km for: a) March 21, 12 o'clock; b) March 21, 24

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