Effect of Seasonal Anomaly or Winter on The Refractive Index of in Height of The Ionospheric F2-Peak

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Abstract-- **In this paper, we deal with the effect on the refractive index of seasonal anomaly in height of the ionospheric F2 peak for both, collisional and collisionless cases in the by using the real geometry of Earth's magnetic field for north hemisphere. It is possible to say that there is an anti-symmetric harmony between the electron density and the all waves (for collisional and collisionless cases) at in hour when the seasonal anomaly occurs while there is an exact harmony in the real part of extra-ordinary wave (Z≠0).**

Index Term-- **Ionosphere, Refractive Index, Seasonal Anomaly, F2-peak**

I. INTRODUCTION

The ionosphere, the layer of the Earth's atmosphere that extends from 50 to 1000 km, can significantly affect the propagation of radio waves. Many communication systems utilize the ionosphere to reflect radio signals over long distance [4,10,13]. Usually, the ionosphere with respect to the electron density is separated into five independent regions, sometimes called layers. The bottom one, from 50 to 80 km, is called D layer, from 80 to 130 km is the E layer, and above 150 km is F layer. The F region is usually separated at the F1 layer, from 130 to 200-250 km, and the F2 layer is above 250 km [4, 10]. Especially, it shows different behavior according to seasonal, latitude, daily. These behaviors are called the anomalies in F2 region The F2 layer anomalies generally departure from simple solar-controlled behavior. The principal anomalies observed at mid-latitudes may be characterized .Firstly, 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. The second, semiannual anomaly: NmF2 is greater at equinox than at solstice. Third, annual or non-seasonal anomaly; in the world as whole December NmF2 is on average greater than June NmF2, both by day and by night. The seasonal anomaly is greater in Northern than the Southern Hemisphere [12-15]. In addition to all these, the ionosphere may act as an efficient reflector with frequencies below 30 MHz, allowing high frequency (HF) radio communication to distances of many thousands of kilometers [1-9]. The radio waves show different behaviors depended on their frequencies, oscillation frequency of the electron and the refractive index of the ionospheric plasma [5-11]. Due to these behaviors the wave reflects, refracts or absorbs from the ionosphere. Radio waves in the ionosphere are subject to some attenuation because the motions of the electrons and ions are damped through the collisions with other particles. In recent years the information about the state of the Earth's ionosphere has been improved [6, 8, 9]. Hence, most of the used approximations for ionospheric calculations are unrealistic. To see the effects of the ionosphere on the wave propagation, more detailed theoretical investigation of the refractive index of ionosphere are needed [11]. The authors made some certain assumptions that the ambient magnetic field is unrealistic in the ionosphere. However, as in the vertical and oblique sounding of the ionosphere by radio pulses, small differences can be important or sometimes necessary when high accuracy is required allow for the refractive index or wave vector[9,11] The most dramatic features of the solution are resonances and cut-offs. Resonances are characterized by a phase velocity going to zero ($v_p=\omega/k\rightarrow 0$) which is equivalent to the index refraction $n=kc/\omega$ going to infinity ($k\rightarrow\infty$). The wave energy is absorbed by ionospheric plasma at resonance points. Cut-offs are defined by index of refraction going to zero ($k\rightarrow 0$). At these cut-offs points, the wavelength goes to infinity and the waves are reflected. Cut-off points can be used for plasma density measurements [3, 5, 7, 8].

In this paper, the effects of the winter or seasonal anomaly in height of the ionospheric F2 –peak on the refractive indexes of HF waves traveling vertical into the ionosphere have been studied as depending on various parameters in the ionosphere.

II. 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 written as:

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

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. Equation (1) is the basic dispersion relation from where **n** can be obtained in terms of plasma parameters. At high frequencies, the ratio between the electron collision frequency (ν) and the wave frequency (ω), that is Z (=ν/ω), is small and can often be neglected. However, small differences become relevant when higher accuracy is needed. In the present work, a first 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-axis are geographic eastward and northward respectively, in the northern hemisphere. 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 we have the ordinary (O) and extraordinary (X) waves with a refractive index (n_O and n_X) given by equations (2) and (3) respectively [9, 11]:

$$n_O^2 = 1 - \frac{X}{1+Z^2} + iZ\frac{X}{1+Z^2} \quad (2)$$

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

In the case along the magnetic field, we have the circularly polarized waves with a refractive index (n_p) given by equation (4) [3-4]:

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

Where the signs (-) and (+) correspond to right and left hand polarization respectively.
Equations (2), (3) and (4) are written 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, it is possible to write the refractive index as $n^2 = (\mu + i\chi)^2$ = M + iN. The real part of n (μ) becomes then:

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

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, as follows [9].

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

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

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

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 $\nu_{ei} + \nu_{en}$, where ν_{ei} and ν_{en} are the electron-ion and the electron-neutral collision frequencies respectively. According to Rishbeth and Garriott [5] these frequencies are given by:

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

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

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

III. Numerical Analysis and Results

In this study, the effects of the winter or seasonal anomaly in height of the ionospheric F2 –peak on the refractive indexes (for both collisional and collisionless cases) of HF waves traveling vertical into the ionosphere were seasonally studied. The calculations were done at geographic coordinates of (38.7^o N, 39.2^o E, I=55.6^o, d=3°, R=10, ω=30.7 E+6(rad/sn)) by using Eq. (2-8) for year 1996. The ionospheric parameters used for calculation were obtained by using IRI model. "For given location, time and date, IRI describes the electron density, electron temperature, ion temperature, and ion composition in the altitude range from about 50 km to about 2000 km; and also the electron content. It provides monthly averages in the non-auroral ionosphere for magnetically quiet conditions".

Fig. 1. seasonally indicates the electron densities in F2-peak and hmF2 heights with local time at the mid- latitude coordinate. The electron density and hmF2 heights are greater

in 21 March than from other seasons approximately around 12 o'clock the ionospheric plasma. Fig.2. (March 21-June 21) and 3. (Sempt.23-Decem.21) show the refractive index at the hmF2 peaks for both collisional (μ^2 for ($Z\neq0$) and collisionless (n^2 for ($Z=0$)) in the ionospheric plasma. According to these Fig, at the time (around 12 o'clock by day) when the winter anomaly occurs , all the refractive index values in both collisional and collisionless cases have been taking the minimum values for every season except the x-wave(Eq.(7)) in the ionospheric plasma. The x- wave in collisional case with respect to other waves displays a reverse behavior to the winter anomaly in the ionosphere plasma. There is a harmony between the electron density and the real part of refractive index of the x- wave in collisional case in the height of the ionospheric F2-peak; but there is dissonance between the other waves and both the electron density, hmF2 and the refractive indexes at the time (around 12 o'clock by day) when the winter anomaly take places. This could be interpreted that the denominator of the collision term in Eq.(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

Finally, there is dissonance between the electron density in height of the ionospheric F2-peak and the refractive indexes of the ordinary, the polarized and the extra-ordinary waves for both collisional and collisionless cases except the real part(μ_x) of the refractive index of the x-wave at mid-latitudes in the ionospheric plasma. It possible that this dissonance can result from the collision term in Eq.(2,4).

IV. CONCLUSIONS

The effects of the winter or seasonal anomaly in height of the ionospheric F2 –peak on the refractive indexes (for both collisional and collisionless cases) of HF waves traveling vertical into the ionosphere were seasonally studied in mid-latitude. The figures show that the winter or season anomaly only affects the real part(μ_x) of the refractive index of the extra-ordinary for collisional case in height of the ionospheric F2 –peak. There are dissonance between the electron density and the real part(μ_x) of the refractive index of the extra-ordinary 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 our results, it is understood 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 ($Z\neq0$) increase at the time when the winter anomaly occurs. Due to this, the reflection heights of the all the waves except the real part of the extra-ordinary ($Z\neq0$) in the winter anomaly increases. The procedure may be useful in the assessments of the ionosphere variables such as conductivity and it could be used for ionospheric plasma density measurements. This study could become important in mid-latitude stations for ionosonde measurements because the refractive index of the medium determines the medium of behavior against any external influence.

REFERENCES

[1] Zhang, D.Y., 1991. New method of calculating the transmission and reflection coefficients and fields in a magnetized plasma layer. *Radio Science*, Vol. 26, pp. 1415-1418.

[2] Lundborg , B., Thide, B., 1986. Standing wave pattern of HF radio waves in the ionospheric reflection regions 2. Applications. *Radio Science*, Vol. 21, pp. 486-500.

[3] Ratcliffe, J.A., 1959. The Magneto-Ionic Theory and its Applications to the Ionosphere. *Cambridge University Press*, pp. 81,103.

[4] Rishbeth, H., O. K. Garriott, 1969, Introduction to Ionospheric Physics, Academic Press, New York and London, pp.130-136.

[5] Budden, K.G., 1988, The propagation of Radio Waves, *Cambridge University Press*, pp.137-139.

[6] Aydoğdu, M., Özcan, O., 1996, Effects of magnetic declination on refractive index and wave polarization coefficients of electromagnetic waves in mid-latitude ionosphere, *Indian Journal of Radio and Space Physics*, Vol. 25, pp. 263-270.

[7] Hagfors, T., 1984, Electromagnetic wave propagation in a field-aligned-striated cold magnetoplasma with application to the ionosphere. *J. Atmos. and Solar Terr. Phys.* Vol. 46, pp. 211-216.

[8] Al'pert, Ya. L., 1980, The direction of the group velocity of electromagnetic waves in a multicomponent magneto-active plasma in the frequency range $0 < \omega < \infty$ *J. Atmos. and Solar Terr. Phys.* Vol. 42, pp. 205-216.

[9] Aydoğdu, M., Yeşil, A. and Güzel, E., 2003, The group refractive indices of HF waves in the ionosphere and departure from the magnitude without collisions *J. Atmos. and Solar Terr. Phys.* Vol. 66, pp. 343-348.

[10] Ataç, T., Özgüç, A., Pektaş, R., 2009, The Variability of f0F2 in Different Phases of Solar Cycle 23., *Journal of Atmospheric And Solar-Terrestrial Physics*, 71 (2009) pp 583-588.

[11] Aydoğdu, M., Güzel, E., Yeşil, A., Özcan, O. and Canyılmaz, M., 2007, Comparsion ot the calculated absorption and the measured field strength HF waves reflected from the ionosphere. *Nouovo Cimento c*, pp.243-253.

[12] Zou, L., Rishbeth, H., Müller-Wodarg, I.C.F., Aylward, A.D., Millward, G. H., Fuller-Rowell, T.J., Idenden, D.W., Moffett., 2000, Annual and Semiannual variations in the ionospheric F2-layer. I. Modelling. *Annales Geophysicae*, 18, pp 927-944.

[13] Rishbeth, H., 2006, F-region links with the lower atmosphere?, *Journal of Atmospheric and Solar-Terrestrial Physics*, 71 , pp 469-478.

[14] Rishbeth, H., Müller-Wodarg, I.C.F., Zou, L., Fuller-Rowell, T.J., Millward, G. H., , Moffett, R.J., Idenden, D.W., Aylward, A.D.,., 2000, Annual and Semiannual variations in the ionospheric F2-layer. II. Physical dissussion., *Annales Geophysicae*, 18, pp 945-956.

[15] Rishbeth, H., 2000, Semiannual and annual variations in the height of the ionospheric F2-peak., *Annales Geophysicae*, 18, pp 285-299.

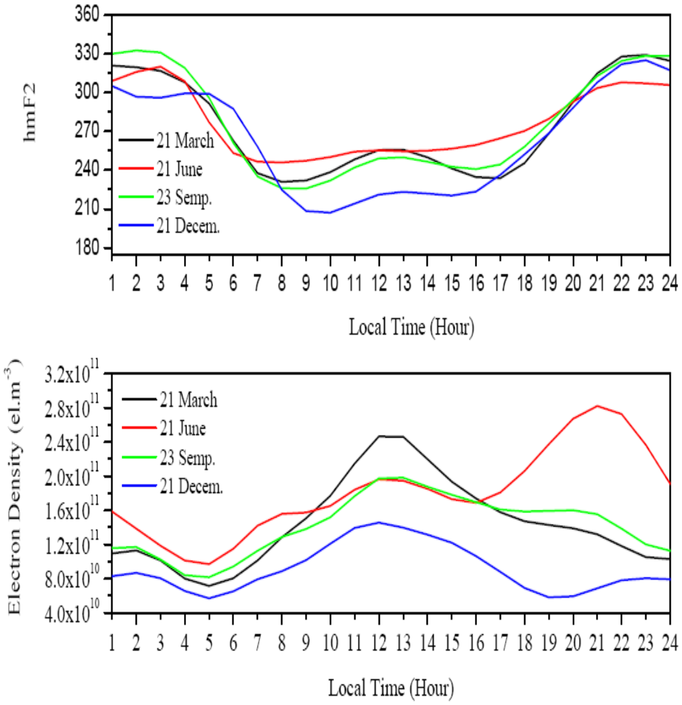

Fig. 1. Diagram of electron density and hmF2 peaks in ionospheric plasma

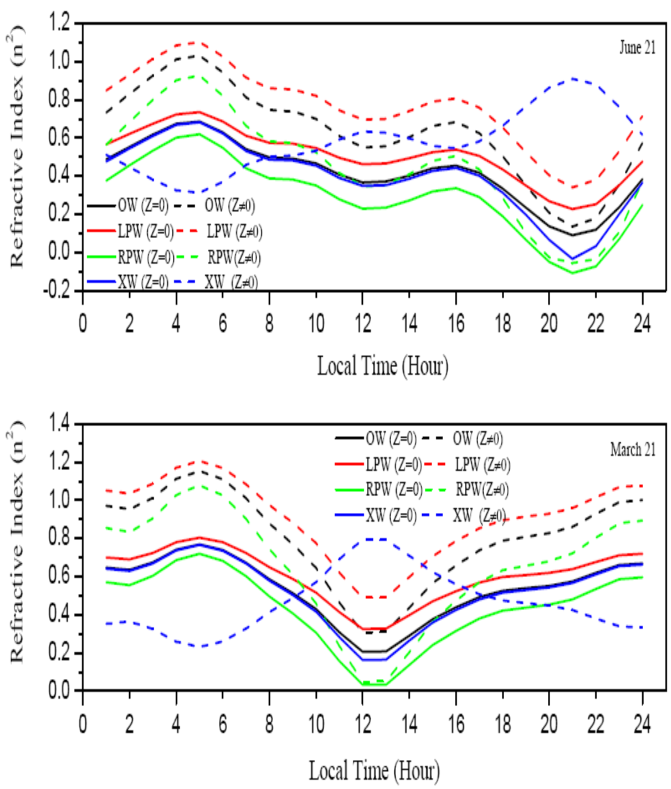

Fig. 2. Diagram of refractive indexes at the hmF2 peaks in the ionospheric plasma

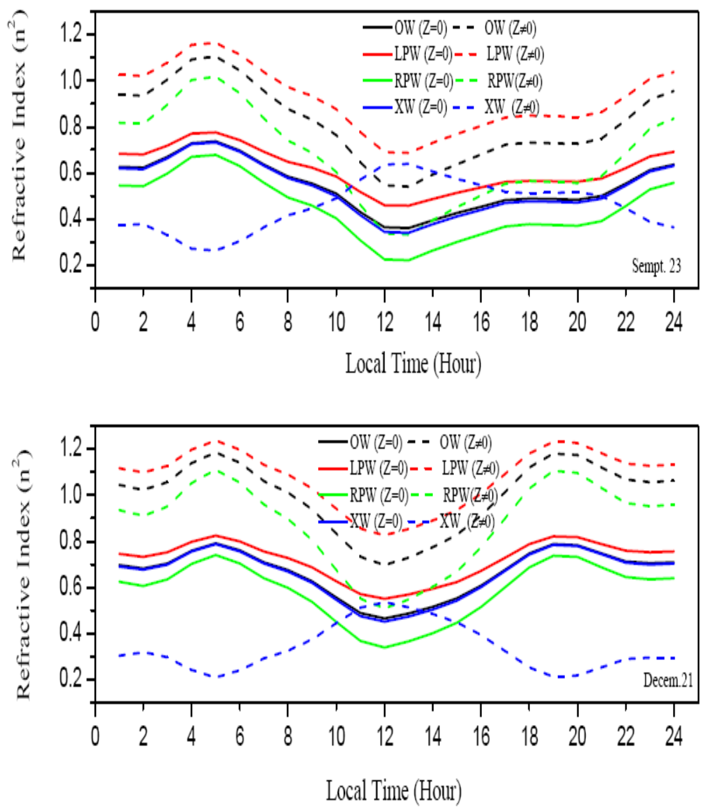

Fig. 3. Diagram of refractive index at the hmF2 peaks in the ionospheric plasma (923-1221)