Turkish Journal of Science & Technology
16(1), 31-38, 2021

The Change of The Magnitude of The Electric Field Vector (E_y/E_0) in The Ionosphere in The Magnetic Equator Through

A.Yeşil[1],O. Özcan[1], M. Inc[1], S. Sağir[2], K. Kurt[1],L.V. Tsamalashvili[3], T.D. Kaladze[3,] and D.T. Kaladze[4]
[1] Firat University, Science Faculty, Elaziğ, Turkey
[2]Department of Physics, Faculty of Arts and Science, Mus Alparslan University, Mus, Turkey
[3]I. Vekua Institute of Applied Mathematics, I. Javakhishvili Tbilisi State University, 2 University Str., 0186 Tbilisi, Georgia
[4]E. Andronikashvili Institute of Physics, I. Javakhishvili Tbilisi State University, Tbilisi 0128, Georgia
[*1] ayesil@firat.edu.tr, [1] osmanozcan@firat.edu.tr, [1] minc@firat.edu.tr, [2] s.sagir@alparslan.edu.tr, [1]kadrikurtt@hotmail.com, [3] luba_tsamal@yaho.com, [3] tamaz_kaladze@yahoo.com, [4] tamaz_kaladze@yahoo.com

(Geliş/Received: 22/08/2020; Kabul/Accepted: 17/09/2020)

Abstract: The seasonal changes of (E_y/E_0), which was obtained from the WKB (Wentzel, Kramers, Brillouin) solution, for (-30^{0}N; 30^{0}S geographic latitudes and (390, 410, 450, 500, 550 and 600 Km) altitudes in the equatorial anomaly region were investigated. (E_y/E_0) ratio takes minimum value in latitudes, where the electron density is at maximum levels and takes maximum value in places where the electron density is at minimum levels, respectively. It is possible to say that in places where the electron density is at maximum, the wave transfers energy to the medium, otherwise it receives energy from the medium.

Key words: Ionosphere, WKB, Refractive index, Equatorial Anomaly.

Manyetik Ekvator Bölgesinde İyonosferde Elektrik Alan Vektörünün (E_y/E_0) Büyüklüğünün Değişimi

Öz: Ekvatoral anomali bölgesinde (390, 410, 450, 500, 550 and 600 Km) yüksekliklerinde (30^{0}N; 30^{0}S) coğrafik enlemler için WKB (Wentzel, Kramers, Brillouin) çözümünden elde edilen (E_y/E_0) mevsimsel değişimi araştırıldı. (E_y/E_0) değişimi elektron yoğunluğunun maksimum olduğu yüksekliklerde minimum, maksimum olduğu yerlerde minimum değer almaktadır. Elektron yoğunluğunun maksimum olduğu yerlerde dalgaya ortamdan enerji aktarılmakta, minimum olduğu durumlarda dalgadan enerji ortama aktarılmaktadır.

Anahtar kelimeler: İyonküre, WKB, Kırılma İndisi, Ekvatoral Anormallik.

1. Introduction

Electron density, which is the main backbone that characterizes the ionosphere, depends on parameters inside and outside the ionosphere such as solar activity, geomagnetic activity, geographic latitudes, local time and seasons [1-13; 31-36].The electron density strongly affects the behavior of the electromagnetic wave in the ionosphere. The reflection of the waves from the ionosphere depends on the refractive index of the medium, the frequency of the wave and the vibration frequencies of the charged particles in the ionosphere. The highest wave frequency reflected from the ionosphere is called the critical frequency. The ionosphere acts like a very lossy medium during the day and a little lossy medium at night. This causes the waves to attenuation by creating differences in medium and long wave propagation [13-36]

F layer, which is the richest region in terms of electron density of ionosphere, exhibits different behaviors as anomalies, seasonal anomaly and semester-year changes, night F2-peak, equatorial anomaly under different time and geographical latitudes. Many anomalies of seasonal change at the value of NmF2 (maximum electron density in the F2 region) were recorded at noon. As a result of the observations, NmF2's winter values were found to be much larger than the summer values at noon. This is in contrast to the expectation that ion and electron production will be very small in winter. This situation is generally called either "seasonal anomaly" or "winter anomaly". Considering the annual change of NmF2 in the ionosphere, the electron density was measured to be 20% higher in December than in June. The Sun is the largest in January due to the change of distance between the Sun and Earth. This is called "annual anomaly" [19-22]. The behavior of the F2 region is quietly different at low latitudes. At some times, the electron density is greater at midnight compared to noon. There is not the vertical diffusion. Because ionization is not distributed from one side of the magnetic field lines of the earth to the other side, it is

* Corresponding author: ayesil@firat.edu.tr. ORCID: [*1] 0000-0003-5997-897X , [1] 0000-0003-3219-146, [1] 0000-0003-4996-8373, [2] 0000-0002-5698-0154, [1] 0000-0002-6507-8234, [3] 0000-0002-4151-8792

distributed along the field lines. Actually, this distribution affects the latitude distribution of ionization. Besides, it affects the daily change of electron density in electromagnetic drift [1-11, 19-36].

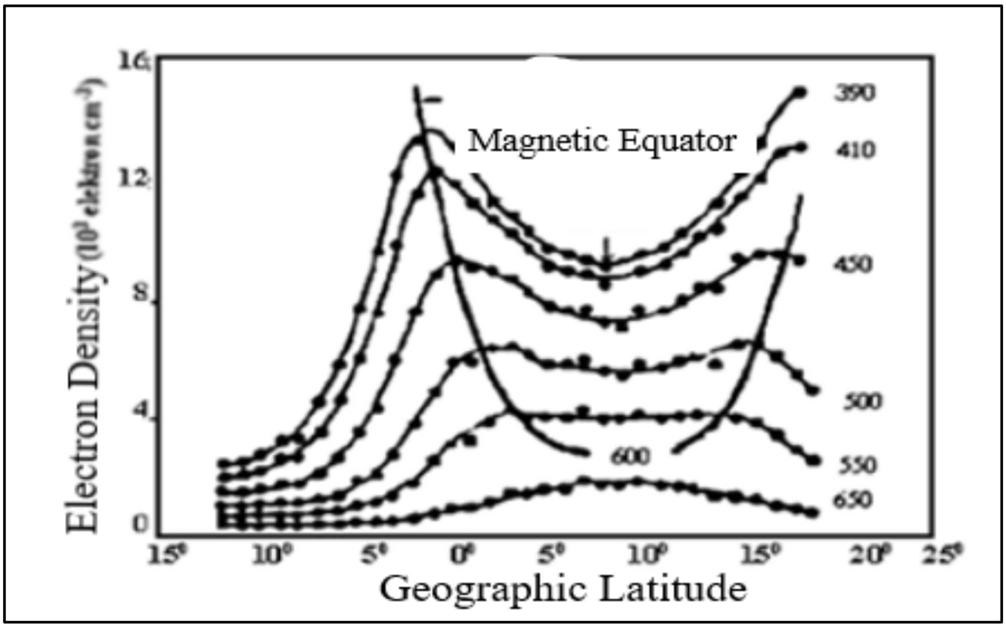

Figure 1. Equatorial peaks and cavities in the northern and southern hemispheres [19, 22].

According to figure 1, the values of NmF2 during the night as a function of the latitude exhibit a condition so-called "cavity" focused on the lowest magnetic point of Equator with "peaks" in 15^0-20^0 latitudes in the northern and southern hemispheres. Electromagnetic drift ($\perp$**B**) and diffusion (// **B**) combine and cause an upward increase in plasma motion like a "fountain". In this way, anomaly peaks are fed from the high regions on the Equator by diffusion. The production rate is very low here. However, plasma is drawn from lower levels around F2-peak, where the production rate is greater [7-11].

By this time, many researchers have conducted theoretical and experimental studies about the reciprocal interaction between electromagnetic wave and ionospheric plasma [3-13]. In this work, the variation of wave amplitude at the equatorial trough for some heights of the F2 region of an electromagnetic wave traveling in the z direction polarized in the y direction "in geographic latitudes where magnetic equatorial trough occurs" was investigated. We used the ordinary wave obtained before for the refractive index (n) of the medium, which is one of the most powerful parameters that characterizes the medium. Because this wave is independent of the magnetic field of the earth and forms the theoretical infrastructure of the working principles of the ionosonde.

2. Wave Equations and Refractive Index of The Plasma

According to Newton law, the force acting on an electron with mass m and velocity **V** is described eqn. (1) as follow.

$$m\frac{d\mathbf{V}}{dt} = -e[\mathbf{E} + \mathbf{V}\times\mathbf{B}] - m\nu\,\mathbf{V} \tag{1}$$

In which, **V**; the velocity of the charged particle, **E** and **B** are electric and magnetic field, m; mass of particle ν: the collision frequency of electron-other particles, the velocity and fields change in accordance with $e^{i(\mathbf{k}.\mathbf{r}-\omega t)}$. The wave in the northern hemisphere travels in the z direction. The magnetic field of the earth for this condition,

$$\mathbf{B} = B_x\mathbf{a}_x + B_y\mathbf{a}_y + B_z\mathbf{a}_z \tag{2}$$

where $B_x = BCosISind$, B_y=BCosICosd and $B_z = -BSinI$. I is the lowest magnetic point and D is the magnetic declination angle. If the equation 2 is written within the equation 1, the current density is obtained as

$$\mathbf{J} = \sigma_0 \mathbf{E} - \frac{e}{m(\nu - i\omega)} \mathbf{J} \times \mathbf{B} \tag{3}$$

where $\sigma_0 = \dfrac{Ne^2}{m(\nu - i\omega)}$ is the parallel conductivity. According to this equation, if current is used as

$$\mathbf{J} = \sigma \mathbf{E} \tag{4}$$

conductivity tensor σ is obtained.

If Maxwell's equations are used to obtain the refractive index of the medium,

$$\nabla \times \mathbf{E} = i\omega \mathbf{B} \tag{5}$$

$$\nabla \times \mathbf{B} = \mu_0 \sigma \mathbf{E} - i\omega\mu_0 \mathbf{E} \tag{6}$$

and from here,

$$n^2 \mathbf{E} - n(n.\mathbf{E}) = \left[I + \frac{i}{\varepsilon_0 \omega} \sigma \right] \mathbf{E} \tag{7}$$

If solved by adding collisions and magnetic field to equation (7) , the known waves as depending on magnetic field geometry and collisions are obtained for the plasma of the ionosphere.

As in vertical ion-probes, the wave propagates in the z direction (**k** // **B**). Therefore, the vertical component of Earth's magnetic field affects the propagation of the wave. When the wave moves parallel to the magnetic field, the wave creates two waves perpendicular to each other due to the double refraction structure of the ionosphere.

$$\text{a) } n_0^2 = 1 - \frac{X}{1+Z^2} + iZ\frac{X}{1+Z^2} \tag{8}$$

is an ordinary wave and it does not related to Earth's magnetic field. The other is an extraordinary wave,

$$\text{b) } n_{ex}^2 = 1 - \frac{aX(1-X) + Z^2X(2-X)}{a^2+b^2} + iZ\frac{X(1-X)(2-X) - aX}{a^2+b^2} \tag{9}$$

Where $a = 1 - x - Yy^2 - Z^2$ve $b = z(2-x)$. The wave given by formula (9) is also seen in the x direction. Only the ones in a and b will be Y_y, Y_x. The first of these waves is known as the ordinary, which is independent of the magnetic field, and the second is called the extra-ordinary wave.

Consider an electromagnetic wave polarized in the y direction propagating in the z direction in the ionosphere. The propagating wave depends on the refractive index n of the medium [2]. If the wave normal (**k**) is assumed to be constant and the polarization direction of the wave does not change, the linear polarized wave in the y direction is identified as [23],

$$E_y(z,t) \equiv E_y(z)\exp(-i\omega t) \tag{10}$$

and

$$B_x(z,t) \equiv B_x(z)\exp(-i\omega t) \quad (11)$$

When Maxwell's equations are resolved for these wave fields, For E_y (z) and B_x (z), the following equations are obtained:

$$\frac{d^2E_y}{dz^2} + k_0^2 n^2 E_y = 0 \quad (12)$$

and

$$\frac{dcB_x}{dz} = -ik_0^2 n^2 E_y \quad (13)$$

Where, $k_0=\omega/c$ is the number of waves in space. The real number of waves is obtained as **k**=k_0 **n.** from WKB approaches, the values of E_y and magnetic field depending on the refractive index are founded as follows:

$$E_y \cong E_0 n^{1/2} \exp\left(\pm ik_0 \int^z n dz\right) \quad (14)$$

$$cB_x \cong E_0 n^{-1/2} \exp(\pm ik_0 \int^z n dz) \quad (15)$$

Solutions for non-uniform wave equations are usually related to WKB solutions. When a progressive wave normal reaches an interface, refractive index changes abruptly at this interface, where most of the wave is reflected.

WKB solutions, according to (14) - (15) equations, when the refractive index of the medium changes very slowly in the direction of the wave travel, the wave does not reflect in any way when it comes to the medium normally.

This refractive index is linear in the direction of wave propagation, even if it changes excessively. WKB solutions show that when the wave travels through the medium, its wavelength changes slowly. In fact, the wavelength at position z is approximately $\lambda(z)=2\pi/k_0$. Solutions of the equations (14)-(15) shows that the amplitude of the wave gradually changes as the wave travels. In fact, the amplitude of the electric field component is inversely proportional to $n^{1/2}$, whereas the amplitude of the magnetic field component is directly proportional to $n^{1/2}$. However, $-(E_yB_x^*+E_y^*B_x) / (4\mu_0)$ given by the Poynting vector, the energy flux in the z direction remains constant (n is generally real)[30-36].

In fact, when the refractive index is a slowly changing function of the position, a wave entering the medium is subjected to a small amount of reflection. However, the ratio of reflected amplitude to incoming amplitude is at the level of (dn/dz) / (k_0n^2). The reflected wave is negligibly small as long as the radiation changes on a much longer scale than wavelength. Therefore, we expect a strong reflection of the wave that has reached such a point. Furthermore, WKB solutions disturb at a point where $n^2 \to \infty$, the B_x amplitude becomes infinite.

The equation (10) is a wave independent of the constant magnetic field, dependent only on the collisions of the particles and the plasma frequency. When the refractive index of this wave is used in the equation (16), it can be written as follows:

$$E_y \cong A\sqrt{n_o} \exp\left(\pm ik_0 \int^z n_o dz\right) = A\sqrt{n_o} e^{\left(\pm ik_0 \int^z n_o dz\right)} \quad (16)$$

3. Numerical Analysis and Discussion

In this study, we researched the electric field component of an electromagnetic wave with a linear polarization in the y direction and moving in the z direction, known as the WKB solution, in an medium with a slow change in the refractive index of the ordinary wave in the non-collision medium , which is given by equation (9) and generally constitutes the theoretical background of the ionosondes, in the equatorial anomaly region of the F2 region, at some altitudes (390, 410, 450, 500, 550 and 600 km), at 12.00 LT and for 21 March-December months.

In Figure 2, the change of electron density with latitude is given for the conditions accepted above. Electron density is the basic parameter for ionospheric plasma. In other words, the fundamental change either from outside (applying electric or magnetic field; neutral winds etc.) or within the ionosphere plasma (internal dynamics) in this medium occurs in the electron density and all ionosphere parameters (conductivity, refractive index, etc.) change accordingly. We have examined the electron density change for the conditions considered for electron peaks and cavities, where this interesting feature occurs. According to Figure 2, the change of electron density is consistent with the figure given in (Rishbeth, H.,1967).

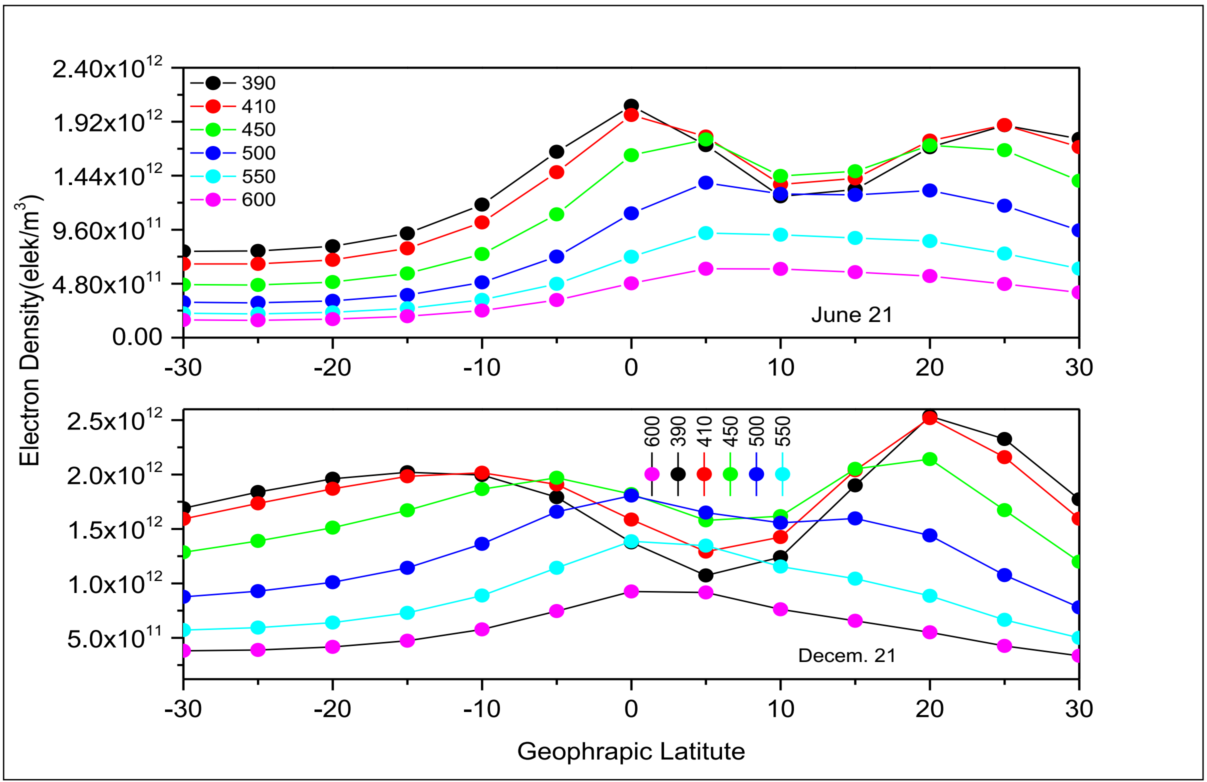

Figure 2. Change of electron density with low latitude in some F2 region altitudes (June 21st-December 2nd, Time: 12.00 LT)

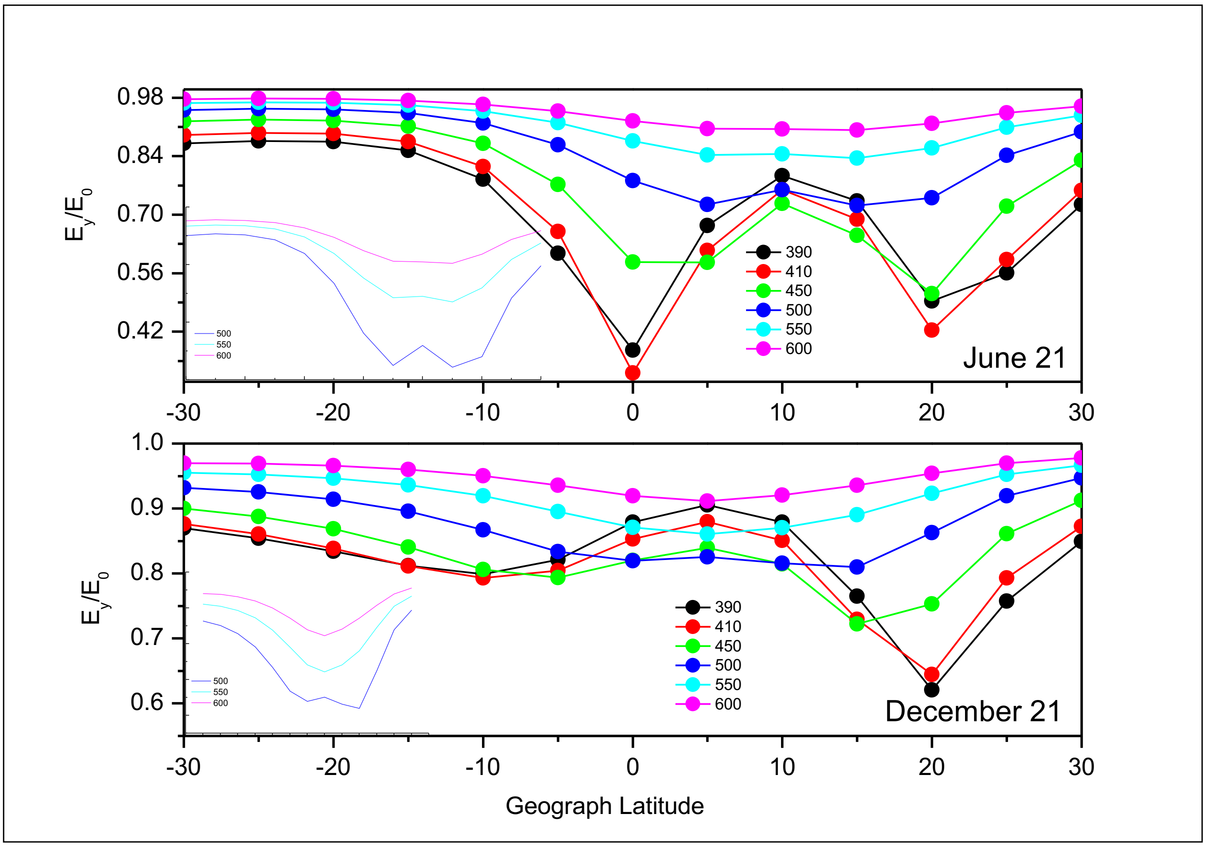

Figure 3. Change of (E_y/E_0) for some altitudes at low latitudes (Time: 12.00 LT)

In Figure3, the cosine component of the equation is given in the cold plasma medium without collision with the expansion of the equation (11-16) for some conditions considered. Accordingly, the ratio of (E_y/E_0) exhibits an opposite behaviour with the change of electron density in both seasons in 0-150 geographical latitudes, where the equatorial anomaly occurs. Even though the electron density forms peaks at 0-150 latitudes, sharp decreases are observed at the same latitudes, especially at altitudes (390, 410, 450 km), for (E_y/E_0). This is also observed at other altitudes, but these decreases are not sharp. There is an increase in the ratio of (E_y/E_0) in both seasons between these latitudes. Considering the change of electron density given in Figure 2, it can be said that there is an opposite behaviour. This is same for both seasons for the altitudes considered. However, in Figure 2, electron density is higher in summer season (June 21st) than in winter (December 21st). In reality, this is not an expected result. Because electron production in summer is higher and losses are less depending on the Sun. In winter, this is vice versa. This is called winter anomaly. In Figure 3, the ratio of (E_y/E_0) is higher in winter (December 21st) than in summer (June 21st). The magnitude of (E_y/E_0) is parallel to the behaviour of electron density in both seasons. However, it is in contrast with the change of electron density as a trend.

4. Results

In this study, which is conducted in accordance with the conditions accepted, the magnitude of (E_y/E_0) at lower altitudes is higher in winter (December 21st) than in summer (June 21st). This conclusion is in line with the literature. Because the change of electron density with latitude is higher in December than in June. However, (E_y/E_0) takes the lowest values in the peaks and the highest values around the magnetic equator for all altitudes in the latitudes with anomaly. In this regard, the ratio of (E_y/E_0) gets the minimum values at points, where the electron density is at the maximum level and vice versa. When this electron density increases, (E_y / E_0) the values decrease or otherwise. as the density increases, the wave transfers more energy to the medium and the kinetic energy of electrons increases. The increase of (Ey/E_0) magnitude can be interpreted as taking the energy of the wave from the medium.

Acknowledgements. The carried out investigation is supported through the grant No. 04/01 of 2017 Joint Call of Shota Rustaveli National Science Foundation of Georgia and the Scientific and Technological Research Council of Turkey (TUBITAK).

References

[1] Kurt, K., Yeşil, A., Sagir, S., Atici, R. The relationship of stratospheric QBO with the difference of measured and calculated NmF2, Acta Geophysica 2016; 64 (6): 2781-2793.
[2] Unal, I., Senalp, E.T., Yeşil, A., Tulunay, Y., Tulunay, E. Performance of IRI-based ionospheric critical frequency calculations with reference to forecasting, Radio Science 2011; 46 (01): 1-10.
[3] Yesil, A., Sagir S., Kurt, K., The Behaviour of the Classical Diffusion Tensor for Equatorial Ionospheric Plasma, Journal of Science 2016; 13:123-127.
[4] Yesil, A., Unal, I., Electromagnetic Wave Propagation in Ionospheric Plasma, Behaviour of Electromagnetic Waves in Different Media and Structures 2011; 189.
[5] Yesil, A., Sagir, S., Updating Conductivity Tensor of Cold and Warm Plasma for Equatorial Ionosphere F2-Region in The Northern Hemisphere, Iranian Journal of Science and Technology, Transactions A: Science 2019; 43 (1): 315-320.
[6] Sagir, S., Yesil. A., The Relation Between the Refractive Index of the Equatorial Ionospheric F2 Region and Long-Term Solar Indices, Wireless Personal Communications 2018; 102 (1): 31-40.
[7] Yesil, A., Sagir, S., Kurt, K., The Behavior of the Classical Diffusion Tensor for Mid-Latitude Ionospheric Plasma, Bitlis Eren Üniversitesi Fen Bilimleri Dergisi 2016; 5 (2).
[8] Sagir, S., Karatay, S., Atici, R., Yesil A., Ozcan, O., The relationship between the Quasi Biennial Oscillation and Sunspot Number, Advances in Space Research 2015; 55(1): 106-112.
[9] Yesil, A., The Effect of the cold plasma on the propagation of the electromagnetic waves, Firat University, Elazig, 1995
[10] Yesil, A.and Unal,İ The Electromagnetic waves in the fully ionozed plasma, Firat University, Elazig, 2002.
[11] Yesil, A., The Effect of the Electron Temperature on the Electric Polarization Coefficient of Ionospheric Plasma, International Journal of Science & Technology 2006; 1 (2):125-130.
[12] Kaladze, T., Tsamalashvili, L., Kaladze, D., Ozcan, O., Yesil, A., Inc, M., Modified KdV equation for magnetized Rossby waves in a zonal flow of the ionospheric E-layer, Physics Letters A 2019; 383 (32): 125888.
[13] Sagir, S., Atici, R., Akalin, Y., Yesil, A., The assessment in terms of QBO of NeQuick 2 model, The Egyptian Journal of Remote Sensing and Space Science 2019; 22 (1): 67-72.
[14] Timucin, E., Unal, I., Yesil, A., The Effect of the Midlatitude Electron Density Trough on the Ionospheric Conductivities, Iranian Journal of Science and Technology, Transactions A: Science 2019; 43 (1): 297-307.
[15] Yesil, A., Kurt, K., Calculation of electric field strength in the ionospheric F-region, Thermal Science 2019; 22 (Suppl. 1): 159-164.
[16] Timocin, E., Yesil, A., Unal, I., The effect of the geomagnetic activity to the hourly variations of ionospheric foF2 values at low latitudes, Arabian Journal of Geosciences 2014; 7 (10): 4437-4442.
[17] Sağir, S., Yaşar, M., Atici, R. The Relationship between Dst, IMF-Bz and Collision Parameters for O+ +N2 NO+ + N Reactive Scattering in the Ionosphere, Geomagnetism and Aeronomy 2019; **59:** 1003–1008.
[18] Swanson, D.G., Plasma waves, Academic Press, New York, 1989.
[19] Whitten, R.C., Poppoff, I.G., Fundamentals of Aeoronmy, John Willey and Sons, New York, 1971.
[20] Budden, K.G., The Propagation of Radio Waves, Cambridge University Press, Cambridge, 1988.
[21] Budden, K.G., Stott, G.F., Rays in magneto-ionic theory-II, Journal of Atmospheric and Solar Terrestrial Physics, 1980; 42: 791–800.
[22] Richard, F. The physics of Plasma, CRC press, New York 2014; 50–140.
[23] Hunsucker, R.D. and Hargreaves, J., K., The High-Latitude Ionosphere and its Effects on Radio Propagation, Cambridge University Press, 2003; 1-50.
[24] Aydoğdu M,Yeşil A,Güzel E, The Group Refractive Indices of HF Waves in the Ionosphere and Departure From the Magnitude Without Collisions, Elazığ, 2003.
[25] Özcan, O., Aydoğdu, M., Yeşil, A., Güzel, E., The Damping of Radio Waves in the Ionospheric Plasma over Elazığ, F. Ü. Fen ve Müh. Bilimleri Dergisi 1996; 113–123.
[26] Rishbeth, Henry, Physics and Chemistry of the Ionospheric Contemp, Phys 1973; 14: 229-240
[27] Rishbeth, H. ve Garriot, O.K., Introduction to Ionospheric Physics, Academic Pres, New York 1969.
[28] Bailey, G. J., Su, Y. Z. and Oyama, K.-I., Yearly Variations In The Low-Latitude Topside Ionosphere, Ann. Geophysicae 2000; 18: 789-798.
[29] Rishbeth, H., A Review of Ionospheric F Region Theory, Proceedings of The Iee 1967; 55: 16-35.
[30] Zhang, S. R., Oliver, W. L., Fukao, S. and Otsuka, Y., A Study of The Forenoon Ionospheric F2-Layer Behavior Over The Middle And Upper Atmospheric Radar, Journal of Geophysical Research 2000; 15: 823-833.
[31] Millward, G. H., Rishbeth, H., Fuller-Rowell, T. J., Aylward, A. D., Quegan, S. and Moffett, R. J., Ionospheric F2-Layer Seasonal And Semiannual Variations, Journal of Geophysical Research 1996; 101: 5149-5156.
[32] Rapoport, Z. Ts. and Sinel′nikov, V. M., Experimental Electron Concentration Profiles Of The Midlatitude Lower Ionosphere And The Winter Anomaly, International Journal of Geomagnetism and Aeronomy 1998; 1: 2-7.
[33] Chien-Chih Lee, Bodo W. Reinisch, Quiet-Condition hmF2, NmF2, and BO variations at Jicamarca and comparison with

IRI-2001 during solar maximum, Journal of Atmospheric and Solar-Terrestial Physics 2006; 68(18): 2138-2146.
[34] Rawer, K, Wave Propagation in the Ionosphere , Kluwer Academic Publishers, London 1993.
[35] Budden K G, The Propagation of Radio Waves, Cambridge Unıversıty Pres, Melbourne Sydney 1985.
[36] Fitzpatrick R, The Physics of Plasmas, The Univ