

Research Article

The Comparison of the Group and Phase Velocity of the Polarized Wave and the Equatorial Anomaly of the Ionosphere

Kadri KURT¹, M. Buğra YEŞİL²

¹Batman University, Beşiri OSB Vocational School, Batman, 72000
(email: kadrikurt@hotmail.com, ORCID: 0000-0002-6507-8234)

²Osmaniye Korkut Ata University, Düziçi Vocational School, Motor vehicles and transportation technology department, rail systems machine technology program, Osmaniye, 80100. (email: melikbugray@gmail.com, ORCID: 0000-0002-4668-6787)

(First received January 05, 2022 and in final form June 06, 2022)

Reference: Kurt, K., & Yeşil, M. B. The Comparison of the Group and Phase Velocity of the Polarized Wave and the Equatorial Anomaly of the Ionosphere. *The European Journal of Research and Development*, 2(2), 466–474.

Abstract

The behavior of phase and group velocities of a left-polarized wave in the F-region of the ionosphere is studied in this paper. Despite the fact that the magnitudes of a left polarized wave's phase and group velocities in the F-region of the ionosphere are almost identical at low latitudes, they are schematically asymmetric under acceptable conditions. Under the same conditions, the group velocity changes in the same way as the electron density in this region; however, the phase velocity changes in the opposite direction. According to the findings, the left-polarized wave's group velocity and electron density have a linear connection. The phase velocity, on the other hand, cannot be said to be the same.

Keywords: Ionosphere, The polarized wave, Group-phase velocity, Equatorial anomaly

1. Introduction

Many scientists have done very valuable studies about many properties, physical structure, and chemical structure of the Earth's ionosphere so far [1-8;11-13; 25]. Since the ionosphere has a conductive structure, the behavior of the electromagnetic wave in this environment under various conditions and its response to the wave for high-frequency waves have been studied and continue [14-24]. To measure the parameters of the

ionosphere, especially the electron density, the remote sensing method the ionosphere is widely used [10- 21]. In this method, the electromagnetic wave is sent to the ionosphere by a transmitter and received by a receiver [14-19]. By comparing the characteristics of the incoming and sent wave, information about the ionosphere is obtained [21-24]. Vertical and horizontal ionosondes used in the world are used for this. The wave sent for the vertical ionosonde is the ordinary wave and the medium is considered collision-free. Group velocity is often thought of as the rate at which energy or information is carried along with a wave [1-8]. In many cases this is true and the group velocity can also qualify as a waveform signal. However, this information is not always correct if the wave is traveling in an absorbing medium. Many studies and experiments since the 1980s have shown that the group speed of laser light sent with specially prepared materials can exceed the speed of light in an air gap. However, in this case, faster-than-light communication is not possible because the signal speed remains slower than the speed of light in every way. It is also possible to reduce the group velocity to zero by stopping the current or creating a negative group velocity. In all cases, however, photons continue to propagate in the medium at the expected speed of light [1-3,24]

The behavior of the F2 region is different at low latitudes. In some timeframes, midnight is greater than noon. The vertical diffusion is neglected. Ionization is not distributed across the earth's magnetic field lines but along the field lines. This distribution can affect the latitude distribution of ionization. Meanwhile, electromagnetic drift greatly influences the diurnal variation of electron density [1-3;8;13]. Depending on the latitude, the maximum electron density (NmF2) of the F2 peak at night time, peaks at latitudes (150-200) in the northern and southern hemispheres, forming a focused trough on the magnetic dip equator. There are two main theories in the literature on this sink. First, it has to do with diffusion under gravity in pit formation, below the earth's magnetic field lines. this affects the discharge of the plasma and the electron density in the north and south. The idea was put forward that the anomaly was caused by the dispersion of the condensation in the equatorial region, causing the condensation of electrons in the northern and southern hemispheres. In the second, drifts have been used that move the plasma upwards during the day through the magnetic field. This view is obtained by solving the diffusion equation, taking into account the geometry of the magnetic field. When electromagnetic drift is taken into account, eastward electric fields produce upward plasma drift throughout the day. The plasma is lifted in this way, moving away from the equator and

dispersing below the magnetic field lines. Electromagnetic drift and diffusion combine to cause an upward increase of electrons like a "sprinkler" in plasma motion[1-8; 11;13] Generally, the accepted mathematical inferences are based on this basis. Although this is an acceptable approach in some cases, it is not a realistic approach. It is necessary to know all the features of the ordinary wave, which is the basis of the working principle of the vertical ionosonde. In this study, we studied the phase and group velocities of the ordinary wave in the collisional ionosphere, which is an indicator of propagation and energy transport environment[9-19].

How do the phase and group velocities of the polarized wave, which is connected to the magnetic field, behave in the equatorial anomaly region? For this, we analyzed the complex phase and group velocity of this wave analytically by taking the collisions into account, then we calculated the magnitudes of the real and imaginary parts of these velocities numerically according to the accepted conditions.

2. The Numerical Analysis Of The Group And Phase Velocity Of The Left Polarized Wave In The Equatorial Anomaly Of The Ionosphere

if the collisions are taken into account, the ordinary wave from well-known equations is as follows[25].

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

In which, the plasma parameters;

$$X = \frac{\omega_p^2}{\omega^2}, \quad Z = \frac{\nu}{\omega} \quad \text{and} \quad Y_z = \frac{\omega_{cz}}{\omega}$$

ω_p : (electron plasma frequency), $\nu = (\nu_{ei} + \nu_{en})$ electron collision frequency ω : wave frequency. The group velocity of any wave[1-20].

$$V_g = \frac{c}{n_p + \omega \frac{\partial n_p}{\partial \omega}} \quad (2)$$

After some mathematical manipulations to get the group velocity of the ordinary wave

$$V_{gp} = \frac{c}{n_p + \omega \frac{\partial n_p}{\partial \omega}} = \frac{cV_{gR}}{(V_{gR}^2 + V_{gI}^2)} - i \frac{cV_{gI}}{(V_{gR}^2 + V_{gI}^2)}$$

(3)

The phase velocity of the polarized wave for the accepted conditions is obtained by

$$V_{pp} = \frac{c}{n_p} = \frac{c\mu_R}{(\mu_{pR}^2 + \mu_{pI}^2)} - i \frac{c\mu_I}{(\mu_{pR}^2 + \mu_{pI}^2)}$$

(4)

In which;

$$\mu_R = \sqrt{r} \cos\left(\frac{\theta}{2}\right), \mu_I = \sqrt{r} \sin\left(\frac{\theta}{2}\right) \text{ and } r = (A^2 + B^2)^{1/2}, \theta = \text{Arctan}\left(\frac{B}{A}\right)$$

$$A = 1 - \frac{X(1 \mp Y_z)}{(1 \mp Y_z)^2 + Z^2} \text{ and } B = Z \frac{X}{(1 \mp Y_z)^2 + Z^2}$$

$$\sigma_R = \frac{dA}{d\omega} \text{ and } \sigma_I = \frac{dB}{d\omega}$$

$$V_{gR} = \mu_R + \omega(\sigma_R \mu_R + \sigma_I \mu_I)$$

$$V_{gI} = \mu_I + \omega(\sigma_I \mu_R - \sigma_R \mu_I)$$

(5)

3. Numerical analysis and Results

We used the results of previous research by Aydodu. et al. (2002) to investigate the magnitudes of the phase and group velocity of the left polarized wave utilizing the data of previous studies by Aydodu. et al. (2002) in 1990 "sunspot is maximal," on the equinox days. On equinox days, the sun's rays are perpendicular to the equator at midday, resulting in equal day and night. The longest day occurs on June 21 in the northern

hemisphere, and the days begin to shorten, while the shortest day occurs on June 21 in the southern hemisphere, and the days begin to lengthen.. This day is regarded the start of summer in the northern hemisphere and the start of winter in the southern hemisphere in some countries. In certain nations, however, it is considered as noon in the equatorial anomaly zone of the ionosphere (F-region 390,410,450,500,550, and 600 Km) in the middle of summer or winter.

Figure 1 shows the change in electron density for some heights of the F-region at low latitudes, which was previously discovered by scientists. Our primary goal is to determine how the phase and group velocity of the left polarized wave will behave at different heights. To answer this topic, we first calculated the magnitudes of the phase and group velocities analytically. When collisions are taken into account, the phase and group velocities get complicated, as seen in the equations. Figures 2 and 3 show the results of the numerical calculations.

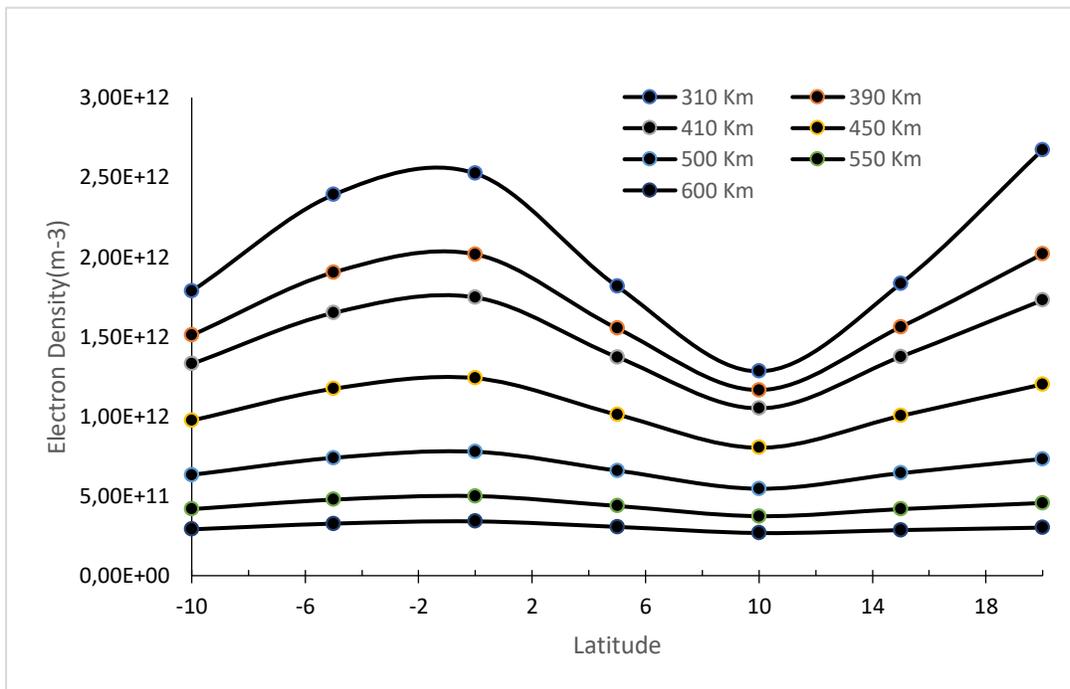


Fig.1 Diagram of electron density with Geographic Latitude for some altitudes of F-region in the ionosphere

In general, the change in polarized wave group velocity at low latitudes corresponds to the change in electron density in the equatorial region with latitude for both March 21 and June 21 (see Figures 2-3). However, when examining the same figures, the change in amplitude of the left-polarized wave's phase velocity at low latitudes in the

equatorial zone demonstrates a nearly symmetrical relationship with the group velocity. However, when examining the same figures, the change in amplitude of the left-polarized wave's phase velocity at low latitudes in the equatorial zone demonstrates a nearly symmetrical relationship with the group velocity.

On June 21, the group and phase velocity readings are higher than they were on March 21. In both seasons, group speed is at a minimum of 100 in the northern hemisphere and a maximum of 5 -150 in the southern hemisphere. The asymmetrical nature of this change is the condition in phase velocity.

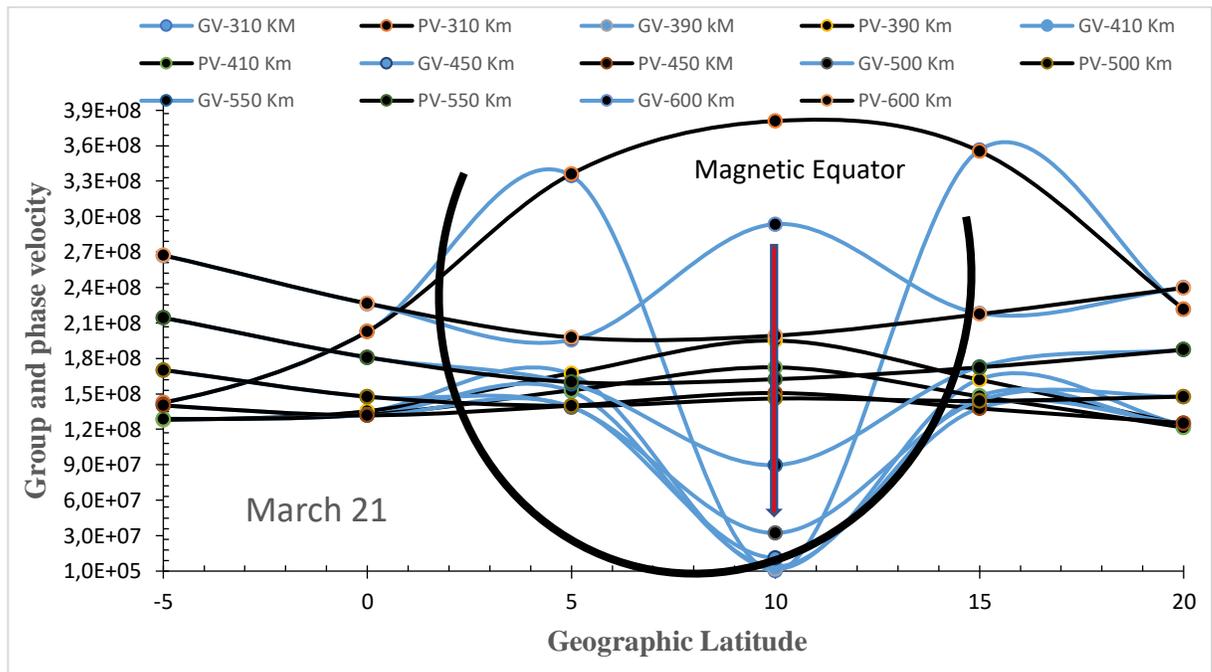


Fig.2 Change of the group and phase velocity of the left polarized with Geographic Latitude for some altitudes of F-region in the ionosphere (March 21, Hour 12.00 LT,1990 Year)

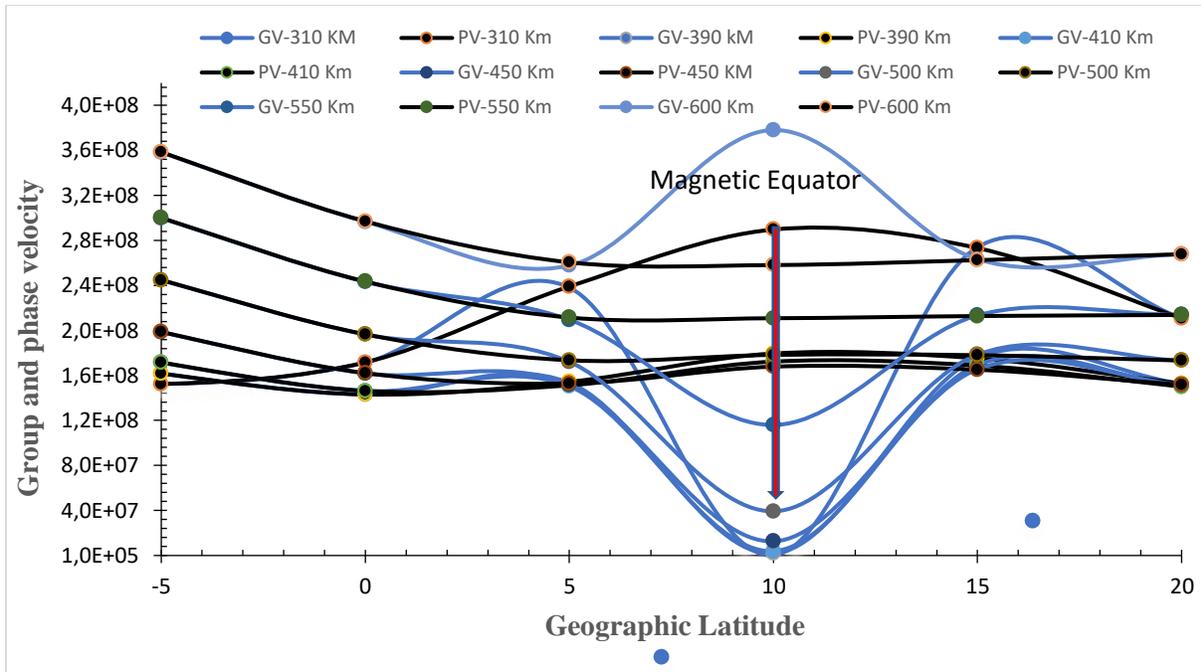


Fig.3 Change of the group and phase velocity of the left polarized with Geographic Latitude for some altitudes of F-region in the ionosphere(June 21, Hour 12.00 LT,1990 Year)

4. Conclusion

We evaluated the magnitudes of phase and group velocity for the left polarized wave (F-region 390,410,450,500,550, and 600 Km at midday), which is dependent on the magnetic field and occurs in the ionosphere in the case of medium collisions under acceptable conditions. The magnitudes of the group and phase velocities are nearly similar when the findings are evaluated in general, according to the regarded and approved criteria. The group velocity is slightly higher than the phase velocity. In the equatorial zone, the change in group velocity with latitude corresponds to the change in electron density, but the change in phase velocity is asymmetrical in trend to the group velocity. At 10 degrees north, the group velocity is at a minimum for each elevation.. Each elevation has a minimum group velocity of 10 degrees north, a maximum of 15 degrees north, and a minimum of 5 degrees north. In comparison to the group velocity, the phase velocity of this wave exhibits the opposite behavior at these latitudes.

References

- [1] Rishbeth, H.(1973). Physics and chemistry of the ionosphere *Contemp, Phys*, 14(3), 229-240
- [2] Rishbeth, H. and Garriot, O.K. (1969). Introduction to Ionospheric Physics, *Academic Press*, Pages iii-vii, 1-331 (1969)
- [3] Rishbeth, H. (1967). A Review of Ionospheric F Region Theory, *Proceedings of The IEE*. 55: 16-35.
- [4] Swanson, D.G. (1989). Plasma waves, *Academic Press*, New York.
- [5] Budden, K.G.(1988). The Propagation of Radio Waves, *Cambridge University Press*, Cambridge,
- [6] Budden, K.G. Stott, G.F.(1980). Rays in magneto-ionic theory-II, *J Atmos Sol Terr Phys*, 42,791–800.
- [7] Richard, F. (2014). The physics of Plasma, *CRC Press*, New York 50–140.
- [8] Rawer, K. (1993).Wave Propagation in the Ionosphere, *Kluwer Academic Publishers*, London
- [9] Yesil, A. (2006).The Effect of the Electron Temperature on the Electric Polarization Coefficient of Ionospheric Plasma, *International Journal of Science & Technology*; 1 (2),125-130.
- [10] Yesil, A., Unal, I.(2011). Electromagnetic Wave Propagation in Ionospheric Plasma, *Behaviour of Electromagnetic Waves in Different Media and Structures*, 189.
- [11] Hunsucker, R.D. (2003). and Hargreaves, J., K., The High-Latitude Ionosphere and its Effects on Radio Propagation, *Cambridge University Press*, 1-50.
- [12] Budden K G. (1985). The Propagation of Radio Waves, *Cambridge University Press*, Melbourne Sydney.
- [13] Whitten, R.C. Poppoff, I.G. (1971). Fundamentals of Aeonomy, *John Willey and Sons*, New York.
- [14] Timocin, E. Yesil, A. Unal, I. (2014) The Effect of the Geomagnetic Activity to The Hourly Variations of Ionospheric foF2 Values at Low Latitudes, *Arab. J. Geosci*, 7 (10), 4437 – 4442.

- [15] Timocin, E. Yesil, A. Unal, I. (2020). The Responses of Ionospheric Conductivities on the Mid-Latitudes to Changes in the Bz Component of Interplanetary Magnetic Field, *Wireless Personal Communications*, 114 (4), 2923-2932.
- [16] Timocin, E. Unal, I. Yesil, A.(2019). The Effect of the Mid-latitude Electron Density Trough on the Ionospheric Conductivities, *Iran. J. Sci. Technol. Trans. A: Sci*, 43 (1), 297–307.
- [17] Yesil, A. Sagir, S. (2019). Updating Conductivity Tensor of Cold and Warm Plasma for Equatorial Ionosphere F2-Region in The Northern Hemisphere, *Iran. J. Sci. Technol. Trans. A: Sci*, 43 (1), 315–320.
- [18] Sagir, S. Yesil, A. (2018). The Relation Between the Refractive Index of the Equatorial Ionospheric F2 Region and Long-Term Solar Indices, *Wireless Personal Communications*, 102 (1),31–40.
- [19] Yesil, A. Kurt, K. (2018). Calculation of Electric Field Strength in The Ionospheric F-region, *Thermal Science*, 22, 159–164.
- [20] Sagir, S. Yesil, A. Sanac, G. Unal, I. (2014). The Characterization of Diffusion Tensor for Mid-Latitude Ionospheric Plasma, *Ann. Geophys*, 57 (2), A0216.
- [21] Senalp, E.T. Unal, I. Yesil, A. Tulunay, Y. Tulunay, E. (2011). Two Possible Approaches for Ionospheric Forecasting to be Employed along with the IRI Model, 2011 30th URSI General Assembly and Scientific Symposium, URSI GASS, 6050921.
- [22] Unal, I. Senalp, E.T. Yesil, A. Tulunay, E. Tulunay, Y. (2011). Performance of IRI-Based Ionospheric Critical Frequency Calculations concerning Forecasting, *Radio Science*, 46 (1): RS1004.
- [23] Sağır, S. Yaşar, M. Atici, R. (2019). The Relationship between Dst, IMF-Bz and Collision Parameters for $O^+ + N_2 \rightarrow NO^+ + N$ Reactive Scattering in the Ionosphere, *Geomagnetism and Aeronomy*, 59, 1003–1008.
- [24] Yasar, M. (2021). The Solar Eclipse Effect On Diffusion Processes Of $O^+ + O_2 \rightarrow O_2^+ + O$ Reaction For The Upper Ionosphere Over Kharkiv. *Thermal Science*, 25, Special Issue, S57-S63.
- [25] Aydoğdu, M., Güzel, E. and Yeşil, A. (2002). Effects of the collisions on the phase and group velocities of HF waves propagating in the ionosphere around reflections points, *Turkish Journal of Telecommunications* Vol:1, pp-79-89.