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Research Article

The Group and Phase Velocity of the Ordinary Wawe in the Ionosphere; A Complete Solution and Numerical Analysis

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Abstract: The ionosphere is a conductive and natural plasma layer of the atmosphere that starts from 50 km above the ground and continues up to approximately 1000 km. To neglect the magnetic field effect on the ionosphere, both vertical and horizontal ionosondes are used to detect the electron density of the ionosphere in many parts of the Earth. In this study, in ionosphere plasma; Without any approximation, the phase and group velocities of the ordinari wave, which is independent of the magnetic field in the collisional ionosphere plasma (electron-ion; electron-neutral), were obtained analytically and its seasonal behavior was calculated numerically. According to the results obtained; There is a strong similarity between the change trends in the phase and group velocities of the ordinari wave at local times of 05:00 in the morning and 20:00 in the evening. It can be said that in these time intervals in the E and F regions of the ionosphere, the wave energy is constant and the directions of the phase and group velocities are in the same direction but in opposite directions.
Keywords: Ionosphere; ordinary wave; group-phase velocity

İyonküredeki Ordinari Dalganın Grup ve Faz Hızı; Tam Çözüm ve Sayısal Analizler

Özet: İyonosfer yerden 50 km den başlayıp yaklaşık olarak 1000 km ye kadar devam eden atmosferin iletken ve doğal bir plazma tabakasıdır. İyonkürede manyetik alan etkisini ihmal etmek için hem dikey hem de yatay iyonosondalar, Dünya'nın birçok yerinde iyonosferin elektron yoğunluğunu tespit etmek için kullanılmaktadır. Bu çalışmada iyonküre plazmasında; hiçbir yaklaşım yap-madan, çarpışmalı iyonküre plazmasında(elektron-iyon; elektron-nötr) manyetik alandan bağımsız olan ordinari dalganın faz ve grup hızları analitik olarak elde edilerek, mevsimsel dav-ranışı nümerik olarak hesaplanmıştır. Elde edilen sonuçlara göre; ordinari dalganın faz ve grup hızları sabah saat 05.00 ve akşam saat 20.00 yerel zamanlarında değişim trendleri arasında kuvvetli bir benzerlik görülmektedir. İyonosferin E ve F bölgelerinde bu zaman aralıklarında dalga enerjisinin sabit, faz ve grup hızlarının yönlerinin aynı doğrultuda fakat zıt yönde olduğu söylenebilir.

Anahtar Kelimeler: İyonküre; ordinari dalga; grup- faz hızı

1. Introduction

The chemical composition, physical make-up, and characteristics of Earth's ionosphere have been the subject of substantial scientific investigation [1-3]. The conductive nature of the ionosphere has prompted much study into the electromagnetic waves' (EMWs') behavior in this medium under different conditions and their response to waves with a high frequency [4-9]. To measure ionosphere parameters, especially electron density, ionosphere remote sensing is a commonly used technique. One device, called a transmitter, sends an electromagnetic wave into space, where another, called a receiver, picks it up [10-14]. Through comparing the characteristics of emitted and received waves, one can learn about the ionosphere [15, 16]. To achieve this, ionosondes, both vertical and horizontal, are used, and they come from all around Earth. There is a constant wave acting on the vertical ionosonde. The standard wave is sent towards the vertical ionosonde while the medium is thought to be collisionless. The "group velocity" of a wave is the speed at which its components move through the medium, be it energy or information [4-9]. Impossibility of achieving faster-than-light communication arises from the fact it is always the case that the speed of the signal is slower than the speed of light. You can either produce a negative group velocity or cut off the flow of electric current to get the group velocity close to zero. Similar to how photons act in the ionosphere [1-3, 17, 18], photons keep on propagating through the medium at the constant, predictable speed of light irrespective of the circumstances. Based on the data that is currently available, it appears that the ionosphere is theoretically collision-free [1-3, 19]. This is the main premise upon which most widely accepted mathematical judgments are based. You can make an argument for this approach in some contexts, but it won't work in others [5, 6, 11, 13, 20]. A thorough familiarity with all the features connected with the regular wave is required to guarantee the correct operation of the vertical ionosonde. Examining the ordinary the phase and group velocities of a wave in the collisional ionosphere was the main goal of this study. There is a widespread belief that these speeds significantly indicate wave propagation and energy transmission. The normal wave's group and phase velocity in the ionosphere's E and F regions, as found via ionospheric layer numerical evaluation. The ordinary wave can be calculated using well-established formulate by taking collisions into account.

2.The phase and group velocity for ordinary wave

In all studies conducted so far on the waves' interaction with the ionosphere plasma, the refractive index of the ordinary wave is given as follows, depending on the ionosphere parameters [1-13]

$$n_o^2 = 1 - \frac{\omega_p^2}{\omega^2 + \nu^2} + i\frac{\nu\ \omega_p^2}{\omega^2 + \nu^2} \tag{2.1}$$

ω_p: (plasma frequency of electrons), $\nu=(\nu_{ei}+\nu_{en})$ frequency of electron collisions ω: wave frequency. At any given wave, the group velocity [1-9].

$$V_g = \frac{c}{n + \omega\ \dfrac{\partial n}{\partial \omega}} \tag{2.2}$$

Once the group velocity of an ordinary wave has been determined using mathematical manipulations

$$V_{go} = \frac{c}{n_o + \omega\ \dfrac{\partial n_o}{\partial \omega}} = \frac{c\sigma_R}{\left(\sigma_R^2 + \sigma_I^2\right)} - i\frac{c\sigma_I}{\left(\sigma_R^2 + \sigma_I^2\right)} \tag{2.3}$$

$$\left.\begin{aligned}
\sigma_I &= \sqrt{b_{1,2}} + \omega\gamma_I \\
\sigma_R &= \sqrt{a_{1,2}} + \omega\gamma_R \\
\gamma_R &= \frac{\alpha\sqrt{a_{1,2}} + \beta\sqrt{b_{1,2}}}{2} \\
\gamma_I &= \frac{\alpha\sqrt{b_{1,2}} - \beta\sqrt{a_{1,2}}}{2} \\
a_{1,2}^2 &= \frac{M \pm \sqrt{M^2 + N^2}}{2} \\
b_{1,2}^2 &= \frac{-M \pm \sqrt{M^2 + N^2}}{2}
\end{aligned}\right\} \tag{2.4}$$

The coefficients that are dependent on plasma parameters are as follows.

$$\left.\begin{aligned}
&\alpha = \frac{2\ \omega\ \omega_p^2}{\left(\omega^2 + \nu^2\right)^2} \text{ and } \beta = \frac{\left(3\omega^2 + \nu^2\right)\nu\ \omega_p^2}{\omega^2\left(\omega^2 + \nu^2\right)^2} \\
&M = 1 - \frac{\omega_p^2}{\omega^2 + \nu^2}\ \ and\ \ N = \frac{\nu\ \omega_p^2}{\omega\left(\omega^2 + \nu^2\right)}
\end{aligned}\right\} \tag{2.5}$$

On the other hand, the phase velocity of the ordinary wave (from eq. 1) is obtained by

$$V_{pho} = \frac{c}{n_o} = \frac{c\ \mathrm{a}_{1,2}}{\left(\mathrm{a}_{1,2} + b_{1,2}\right)} - i\frac{c\ \mathrm{b}_{1,2}}{\left(\mathrm{a}_{1,2} + b_{1,2}\right)} \tag{2.6}$$

3. Numerical Analysis and Results

At the E layer (140 km) and F layer (240 km) ionosphere plasma region in Elazig Geographic coordinates, these computations were carried out using Equations (3 and 6). For the “Sunspot number is maximum” in 1990, the figures were computed using IRI (International Reference Ionosphere) data.

Analytical examination of the equations reveals that in collision cases induced by medium collisions, both the phase velocity and the group velocity exhibit a complicated structure. Both the group velocity and the phase velocity show signs of speed attenuation in their imaginary components. Variations in the total magnitude of the phase velocity with respect to local time are shown in Figure 1. Thus, the phase velocity is at its lowest before sunrise (about 5:00 a.m. LT) and rapidly increases between 5:00 a.m. and 18.00 p.m. LT, while keeping its amplitude constant all the way through. There is a precipitous decline in temperature after 18 p.m., and by 20 p.m. LT, all seasons have dropped to their lowest point.

The symmetry between Figure 2 and Figure 1 pertains to the change in group velocity. But it's not that high when put next to the phase velocity. As can be observed in the other figures, figures 3 -4 are similar to the trend of phase velocity change in figure 1 and the behavior of group velocity in figure 4. Though they are conceptually equivalent, the E-region's higher phase and group velocities set it apart from the F-region.

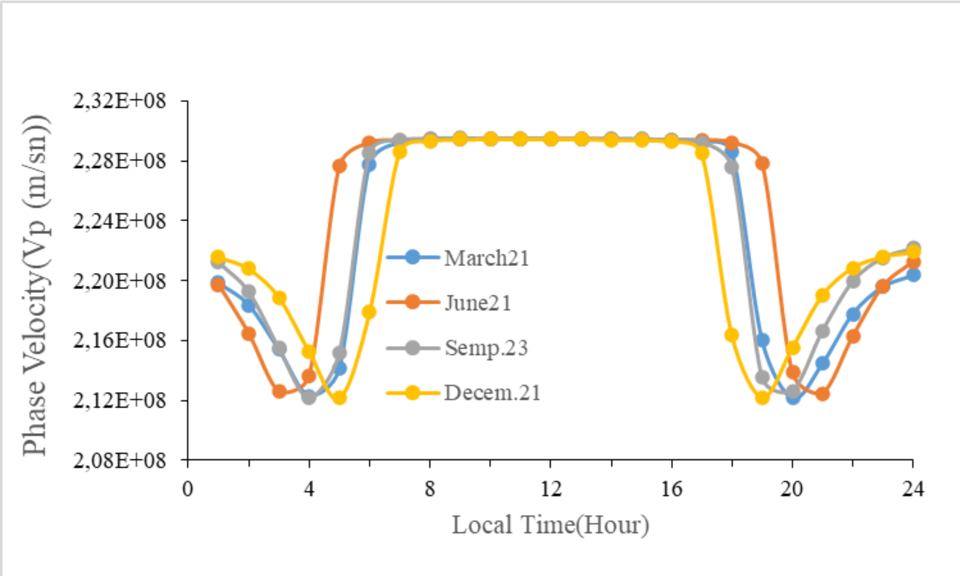

Figure 1. Seasonal diagram of the phase velocity of the ordinary wave in the E-region

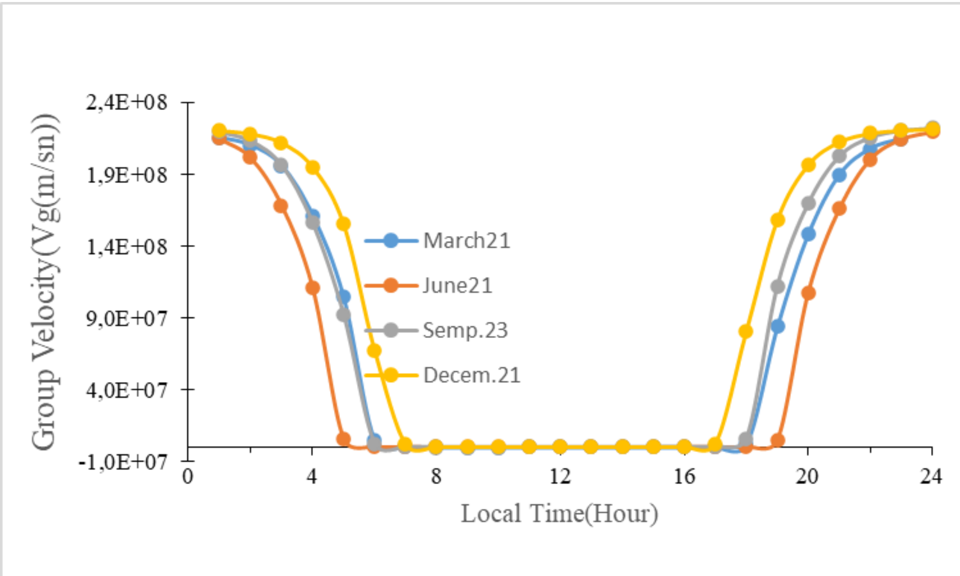

Figure 2. Seasonal diagram of the group velocity of the ordinary wave in E-region

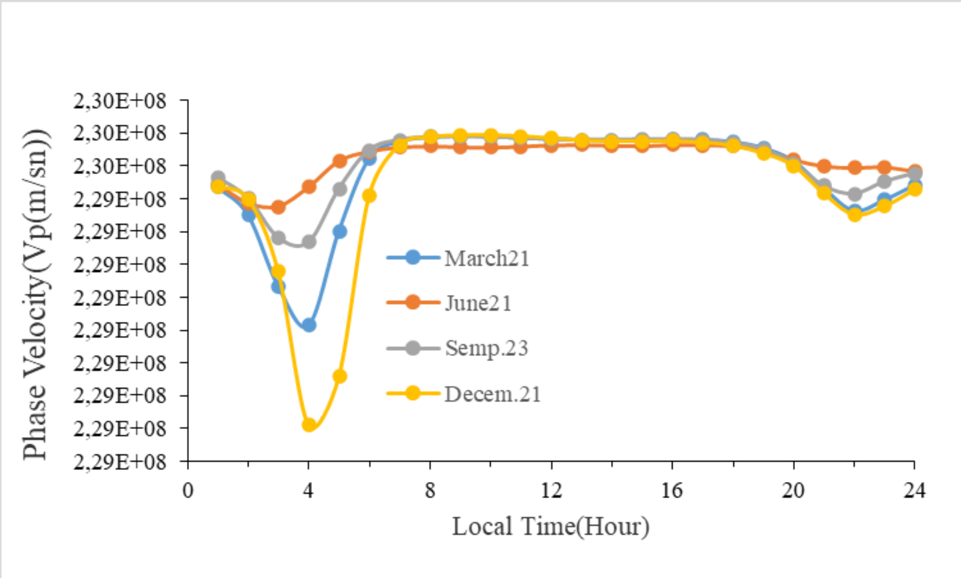

Figure 3. Seasonal diagram of the phase velocity of the ordinary wave in the F-region

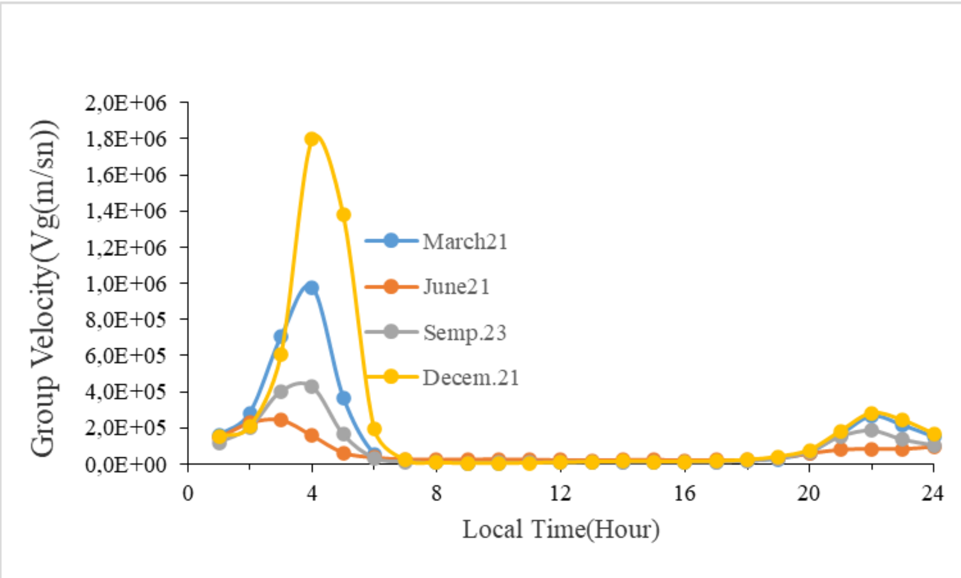

Figure 4. Seasonal diagram of the group velocity of the ordinary wave in the F-region

4. Conclusion

A key component of the ionosphere's operation and the transmission of high-frequency signals is the ordinary wave, which controls electron density. In order to lay the framework for future studies and experiments in this area, it is crucial to understand how a typical wave behaves in the ionosphere. Investigating the magnitudes of the group velocity and phase in the E and F layers of the ordinary wave was the aim of this research. Under the right conditions, these areas can be seen in the iono-sphere during medium collisions, and they are unaffected by Earth's magnetic field. While the wave's phase and group velocities are symmetrical in both the E and F sections, the E region shows higher velocities and phases than the F region. The computed group velocities of the ordinary wave are assumed to be always smaller than the speed of light throughout the year. One thing to keep in mind is that the phase velocity is getting closer to the speed of light. It follows that, under normal conditions, the energy of the ordinary wave is distributed to the particles when they enter the medium.

The Statement of Conflict of Interest

Article authors claim no conflicts of interest between them

Contribution Rate Statement Summary of Researchers

The authors affirm that they have made equal contributions to the article.

Research and Publication Ethics Statement

The authors affirms that this study adheres to the principles of research and publication ethics.

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