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AN ALTERNATIVE APPROXIMATION FOR THE ELECTRON THERMAL CONDUCTIVITY OF F-REGION OF THE IONOSPHERIC PLASMA

ABSTRACT

In this study, an alternative approximation for the electron thermal conductivity of F-region of the ionospheric plasma is reported. The isotropic (independent of direction) electron thermal conductivity is compared with the anisotropic (dependent of direction) electron thermal conductivity. It is evaluated that while the classical thermal electron conductivity (isotropic) changes with electron temperature, the electron thermal conductivity having tensor form depends on many parameters in the ionospheric F-region such as electron temperature, electrical conductivity, collisions frequency and electron density. Moreover, the magnitude of the anisotropic thermal conductivity, in general, decreases with altitude in F-region of ionosphere for every seasonal.

Keywords: Electrical Conductivity, F-Region of Ionosphere, The Electron Thermal Conductivity.

İYONOSFERİN F-BÖLGESİNİN ELEKTRON TERMAL İLETKENLİĞİNE ALTERNATİF BİR YAKLAŞIM

ÖZET

Bu çalışmada, İyonosferin F-bölgesinin elektron termal iletkenliğine alternatif bir yaklaşım yapılmıştır. Yönden bağımsız olan elektron termal iletkenlikle, yön bağımlı olan elektron termal iletkenliği karşılaştırılmıştır. Klasik elektron termal iletkenliği (yön bağımsız) yalnız elektron sıcaklığı ile değişir. Elektron termal iletkenliği(yön bağımlı) iyonosferin F-bölgesinde birçok parametreye (elektron sıcaklığı, elektriksel iletkenlik, çarpışma frekansı ve elektron yoğunluğu) bağlıdır ve tensörel forma sahiptir. Yön bağımlı olan elektron termal iletkenliğinin büyüklüğü genel olarak iyonsoferin F-bölgesinde mevsimsel olarak yükseklikle azalmaktadır.

Anahtar Kelimeler: Elektriksel İletkenlik, İyonosferin F-Bölgesi, Elektron Termal İletkenliği

1. INTRODUCTION (GİRİŞ)

Ionosphere physics may be regarded as a branch of aeronomy, the science of upper atmosphere. Ionosphere consists of different parts with respect to electron concentration and temperature [1 and 2]. A region refers to a part of the atmosphere (such as F-region, which starts at 150 km) and a layer refers to the ionized plasma within that region (such as F1 and F2). F1 layer, which lies between 150-200 km height, is the region with the biggest ionization and F2 layer has the biggest electron density in ionosphere [1 and 3]. The F-region has been defined as the part of the ionosphere above 150 km, although in many ways a looser definition, based on physical regime, might be preferred to a strict in terms of altitude. The main property of this region consists of the free electrons. The F region has the highest electron density in ionosphere. In general, changes of F-region electron density require changes in ionizing radiation, loss mechanism and/or transport process. The present paper deals with the electron thermal conductivity (having tensor form) of ionosphere F-region, mainly which lies at 150-400 km [1, 2, 3 and 4]. Electrical conductivity is a central concept in space science [5]. It determines how driving forces, such as electric fields and thermosphere winds, couple to plasma motions and the resulting electric currents. The tensor electrical conductivity, σ, finds application in all areas of ionospheric electrodynamics and at all altitudes [1 and 4]. Naturally, expressions for σ appear in many classic textbooks. An expression for the electron thermal conductivity for a weakly ionised gas, taking into account electron-neutral collisions, was first given by Banks [6]. Banks used Chapman-Cowling mean free path theory, replacing the constant electron-neutral scattering cross section by an average momentum transfer cross section, and multiplying the results by the Spitzer-Harm factor ε=0.149, originally obtained for a fully ionosed gas, to take into account the thermoelectric effect [2, 4, 6 and 7]. The evaluation of the electron-neutral thermal conductivity, including the thermal factor ε, however, involves a knowledge of the velocity dependent collisions cross section. The different expressions obtained by Dalgarno et al.(1967), Bank, Walker and Rees (1968) for electron-neutral thermal conductivity are apparently due to the different dependence of collisions cross section on velocity they consider [7].

Unfortunately, the relationship between electrical conductivity and electron thermal conductivity hasn't been explained for ionospheric plasma up to now but there is relationship in solid state. In solid state, this relationship is explained by Wiederman-Franz law. This law is valid at high temperature especially for electron [8]. Then it may be possible to use this equation for the ionospheric F-region. Our goal in this study is to use the Wiederman-Franz law in ionospheric plasma. The results obtained have been compared to classical electron thermal conductivity results.

2. RESEARCH SIGNIFICATION (ARAŞTIRMANIN ÖNEMİ)

The present study intends to serve as a guide for researchers who make theoretical studies in ionospheric F-region. It will also constitute a background for experimental researchers.

3. THERMAL AND ELECTIRICAL CONDUCTIVITY TENSOR (TERMAL VE ELKETIRIKSEL İLETKENLİK TENSÖRÜ)

The force acting on the electron in plasma is given as follow. The effect of ions can be neglected at the high frequency approximation.

$$m_e \frac{d\mathbf{V}_e}{dt} = -e\left[\mathbf{E} + \mathbf{V}_e \times \mathbf{B}\right] - m_e \nu_e \mathbf{V}_e \qquad (1)$$

where $\nu_e = \nu_{ei} + \nu_{en}$ in which $\nu_{ei} = N_e\left[59+4.18\log\left(\frac{T_e^3}{N_e}\right)\right]x10^{-6}T_e^{3/2}$ and $\nu_{en} = 5.4x10^{-16}N_nT_e^{1/2}$ are the electron-ion and the electron-neutral collision frequencies, respectively [2 and 9]. The velocity and the fields are assumed to vary as $e^{i(\mathbf{k}\cdot\mathbf{r}-\omega t)}$. The standard notation of magnetoionic theory is used.

The electron current density $\mathbf{J}(=-eN_e\mathbf{V}_e)$ is given by,

$$\mathbf{J} = \sigma_0\mathbf{E} + \frac{e}{m_e(\nu_e - i\omega)}\mathbf{J}\times\mathbf{B} \tag{2}$$

where $\sigma_0\left(=\frac{e^2N_e}{m_e(\nu_e - i\omega)}\right)$ is the longitudinal conductivity [5]. It is assumed that the z-axis of the coordinate system with its origin located on the ground is vertical upwards. The x-axis and y-axis are geographic eastward and northward in the northern hemisphere, respectively. The geomagnetic field is assumed as.

$$\mathbf{B} = B_z\mathbf{a}_z \tag{3}$$

In a cartesian coordinates system, the solution of the eq.(2) can be written as,

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

with

$$\sigma = \begin{bmatrix} \sigma_1 & -\sigma_2 & 0 \\ \sigma_2 & \sigma_1 & 0 \\ 0 & 0 & \sigma_0 \end{bmatrix} \tag{5}$$

In here, all of the conductivities have an imaginary as well as real part. The real part is what we usually associate with conductivity. It is reciprocal of resistivity and is thus associated with energy dissipation. The imaginary part is associated with the dielectric properties of medium and is a purely alternating current parameter (inverse of reactance) [4], the conductivities can be written as follow.

$$\sigma_0 = \frac{e^2N_e}{m_e}\left[\frac{\nu_e}{\nu_e^2+\omega^2} + i\frac{\omega}{\nu_e^2+\omega^2}\right] \tag{6}$$

$$\sigma_1 = \frac{e^2N_e}{m_e}\left[\frac{\nu_e\left(\nu_e^2+\omega^2+\omega_{ce}^2\right)}{\left(\nu_e^2-\omega^2+\omega_{ce}^2\right)^2+4\,\omega^2\nu_e^2} + i\frac{\omega\left(\nu_e^2+\omega^2-\omega_{ce}^2\right)}{\left(\nu_e^2-\omega^2+\omega_{ce}^2\right)^2+4\,\omega^2\nu_e^2}\right] \tag{7}$$

$$\sigma_2 = -\frac{e^2N_e}{m_e}\left[\frac{\omega_{ce}\left(\nu_e^2-\omega^2+\omega_{ce}^2\right)}{\left(\nu_e^2-\omega^2+\omega_{ce}^2\right)^2+4\,\omega^2\nu_e^2} + i\frac{2\,\omega\omega_{ce}\nu_e}{\left(\nu_e^2-\omega^2+\omega_{ce}^2\right)^2+4\,\omega^2\nu_e^2}\right] \tag{8}$$

where $\omega_{ce}\left(=-\frac{eB}{m_e}\right)$ is electron cyclotron frequency.

As classical, electron thermal conductivity equation for ionospheric plasma is given as follow [4].

$$\kappa = 7.7x10^5T_e^{2.5}\ \text{eVcm}^{-1}\text{s}^{-1}\text{K}^{-1} \tag{9}$$

Equation 9 is one dimensional depending only on the electron temperature in the ionospheric plasma. The electrical conductivity in ionospheric plasma is a tensor, and it related to plasma parameters. The ionospheric plasma is a good conductor [4 and 5], so it is possible to use that the Wiederman-Franz law could be used for the ionospheric plasma. This law is given by,

$$\kappa = \frac{3}{2}\left(\frac{k_B}{e}\right)^2 \sigma\ T_e \qquad (10)$$

According to Equation 10, it can be said that if the electrical conductivity is a tensor, then the electron thermal conductivity must be also be a tensor in the ionospheric plasma. This shows that the electron thermal conductivity depends on direction in the ionospheric plasma [7]. The tensor form of Equation 10 can be written as follow.

$$\kappa = \begin{pmatrix} \kappa_1 & -\kappa_2 & 0 \\ \kappa_2 & \kappa_1 & 0 \\ 0 & 0 & \kappa_0 \end{pmatrix} \qquad (11)$$

Equation 11 has a the complex structure because the electrical conductivity is complex. That is, the electron thermal conductivity tensor indicates the behaviour that electron electric conductivity tensor exhibit in ionospheric plasma from a mathematical point of view.

4. NUMERICAL ANALYSIS (SAYISAL ANALİZLER)

The real parts of the electron thermal conductivity in the F-region of the ionosphere have been evaluated from the Equation 11 for geographic coordinates 39^0E, 40^0N. The used plasma parameters have been obtained by using International Reference Ionosphere (IRI) as seasonal at 12.00 LT in 1998. Besides, the wave frequency is taken equal to plasma frequency for every altitude.

5. CONCLUSIONS (SONUÇLAR)

Values of classical electron thermal conductivity calculated for one dimension that only depends on the electron temperature are compared the values of electron thermal conductivity which have tensor form depending on electrical conductivity. The calculations were done as seasonal. According to Equation 9, the classical thermal conductivity doesn't depend on any direction. It depends on the electron temperature. So, the trend of the change of the classical electron thermal conductivity with altitude is similar to the change of electron temperature for the selected months (21 March, 21 June and 21 December). But, in presence of magnetic field, the magnitude and direction of the electron thermal conductivity become different (Equation 11). Due to this, the electron thermal conductivity depends on many parameters such as electrical conductivity, magnetic field, collisions frequency and electron temperature in F-region. So, the electron thermal conductivity is less than the magnitude of the classical thermal electron conductivity (Figure 3, 4, 5). According to figures (3), (4) and (5), the change of the electron thermal conductivity with altitude (K_0, K_1, K_2) follows the change of electrical conductivity rather than electron temperature.

The real part of the electron thermal conductivity (K_1) changes non-linearly with altitude but it has different magnitudes for each season (Figure 4). The variation of the real part of electron thermal conductivity with altitude of (K_0) is shown in Figure 3. As can be seen in this figure, the real part of K_0 decreases with altitude and has a minimum value between about 150-200 km. The real part of the electron thermal conductivity (K_2) is the most interesting. While K_0 and K_1 generally decrease with altitude, K_2 indicates a different change with altitude. For example, K_2 has maximum values about 150 km and has minimum about 280 km. At this altitude for June K_2 has again a maximum value.

Consequently, it is concluded that while the classical electron conductivity changes with electron temperature, the electron thermal conductivity having tensor form depends on many parameters in the F-region such as electron temperature, electrical conductivity, collisions frequency and electron density. Furthermore, the magnitude of the electron thermal conductivity depending on direction decreases with altitude, when the classical thermal electron conductivity is compared. It is possible to say that the trend of anisotropic electron thermal conductivity is different from isotropic thermal conductivity in F-region as seasonal.

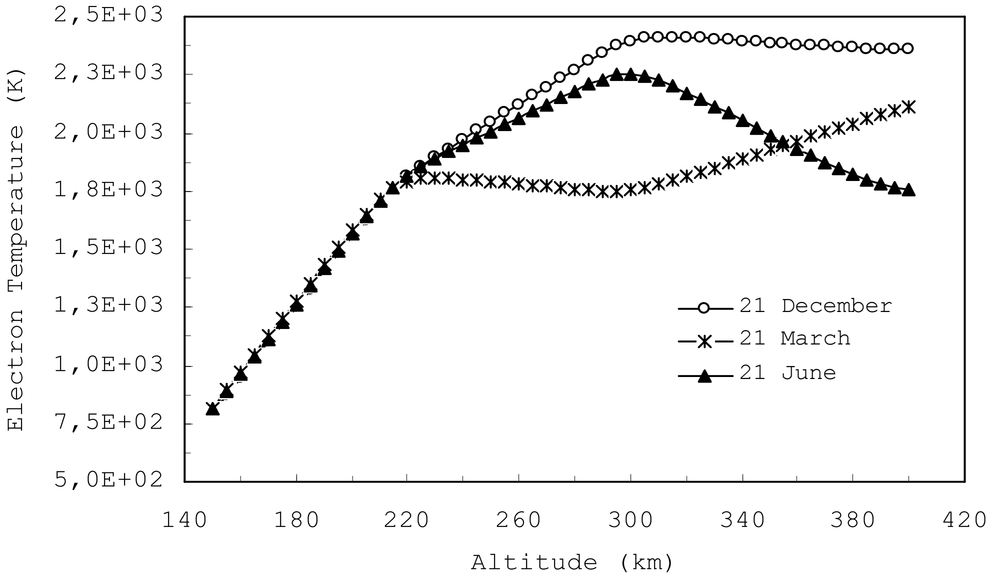

Figure 1. Electron temperature profile in the ionospheric F-region
(Şekil 1. İyonosferin F-bölgesindeki elektron sıcaklığının yükseklikle değişimi)

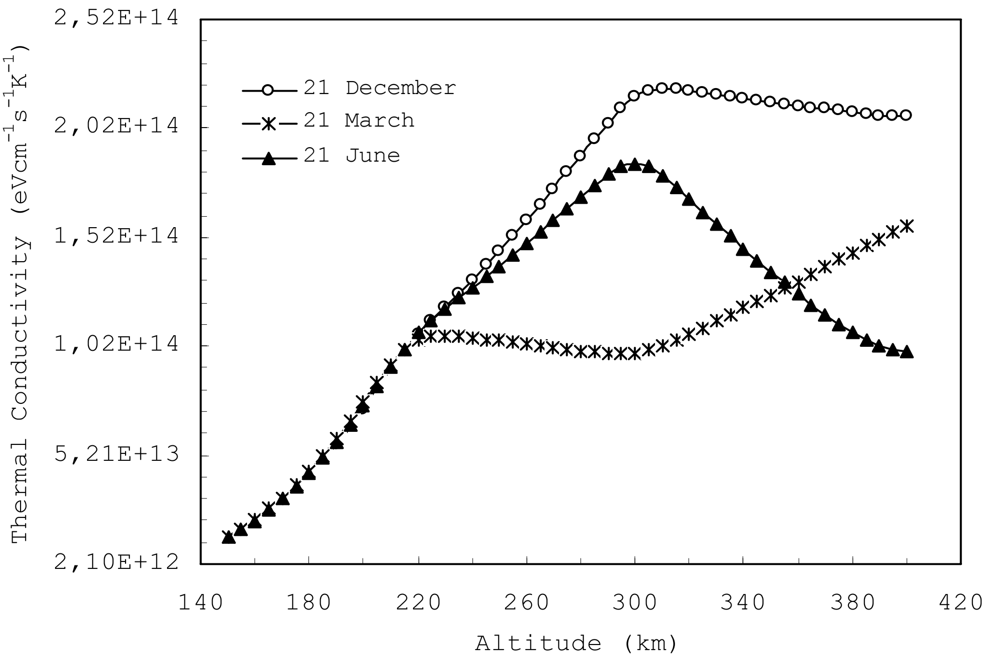

Figure 2. Profile of the classical electron thermal conductivity
(Şekil 2. Klasik elektron termal iletkenliğinin yükseklikle değişimi)

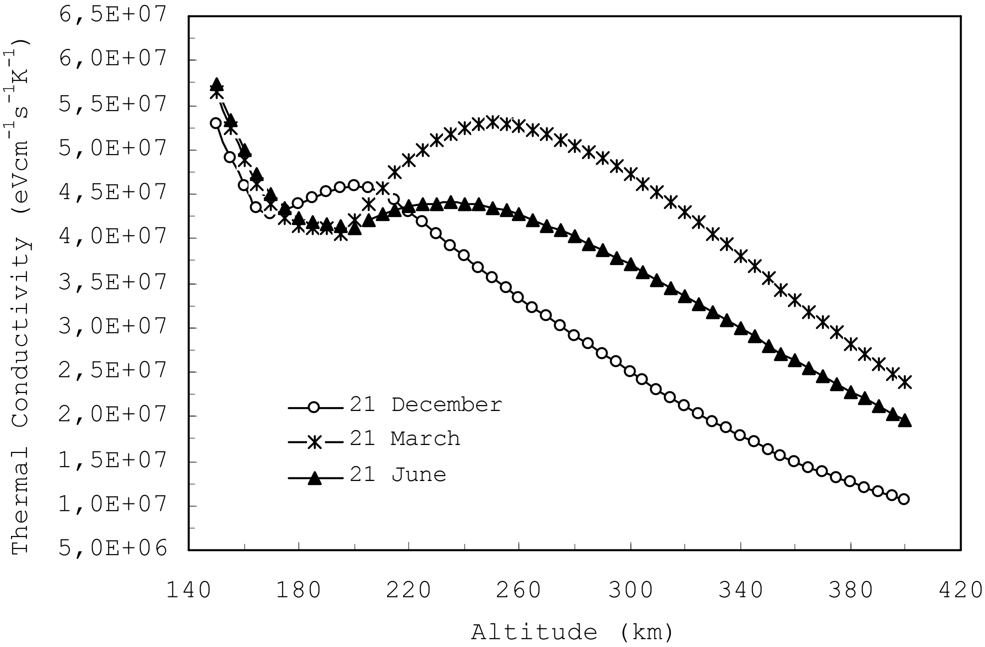

Figure 3. K_0 profile
(Şekil 3. K_0'ın yükseklikle değişimi)

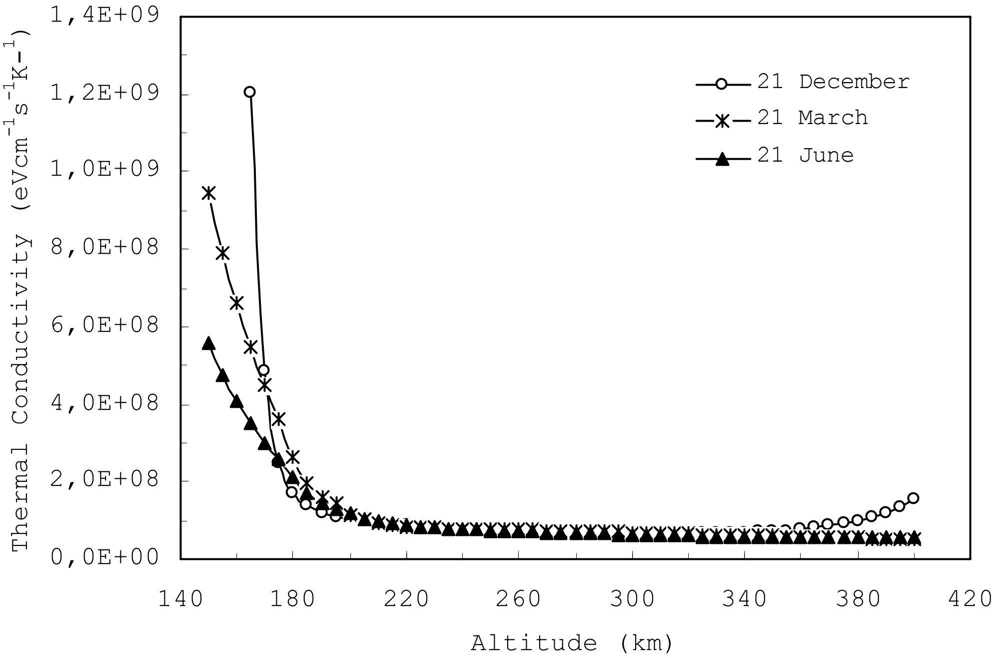

Figure 4. K_1 profile
(Şekil 4. K_1'in yükseklikle değişimi)

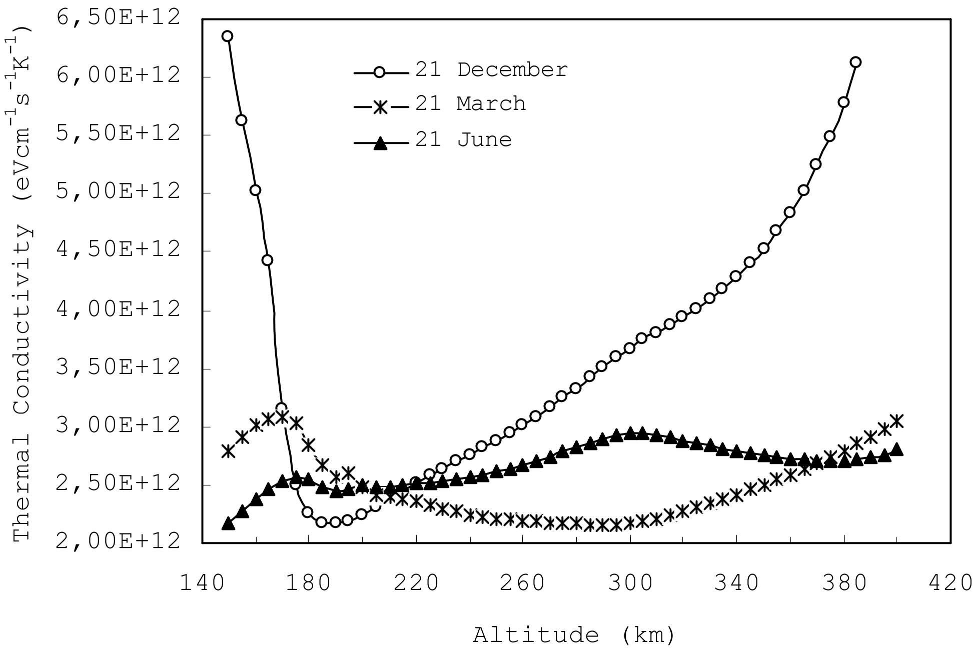

Figure 5. K_2 profile
(Şekil 5. K_2'nin yükseklikle değişimi)

List of Symbols

m_e : Electron mass
$\mathbf{J}$: The current density
K : Electron thermal conductivity
$\mathbf{V}_e$: Electron velocity
N_e : Electron density
ν_e : Electron collisions frequency
t : Time
σ : Electrical conductivity
ν_{ei} : Electron-ion collisions frequency
q_e : Electron charge
ω_{pe} : Plasma frequency
ν_{en} : Electron-ion collisions frequency
$\mathbf{E}$: Electric field
ω_{ce} : Electron cyclotron frequency
N_n : Neutral density
$\mathbf{B}_0$: Earth's magnetic field
T_e : Electron temperature
ω : Wave frequency
k_b : Boltzmann constant

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