Electrical Conductivity Tensor for Low and Mid-latitude Ionospheric Plasma

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EIGHTH WORKSHOP

Solar Influences on The Megnetosphere, Ionosphere and Atmosphere
Sunny Beach, Bulgaria, June 1, 2016

What is ionosphere?

Earth's atmosphere is divided into various regions according to:

1. Temperature
2. Physical Processes
3. Chemical Components

Figure 1 shows the regions of the earth’s atmosphere

up to 200 km.

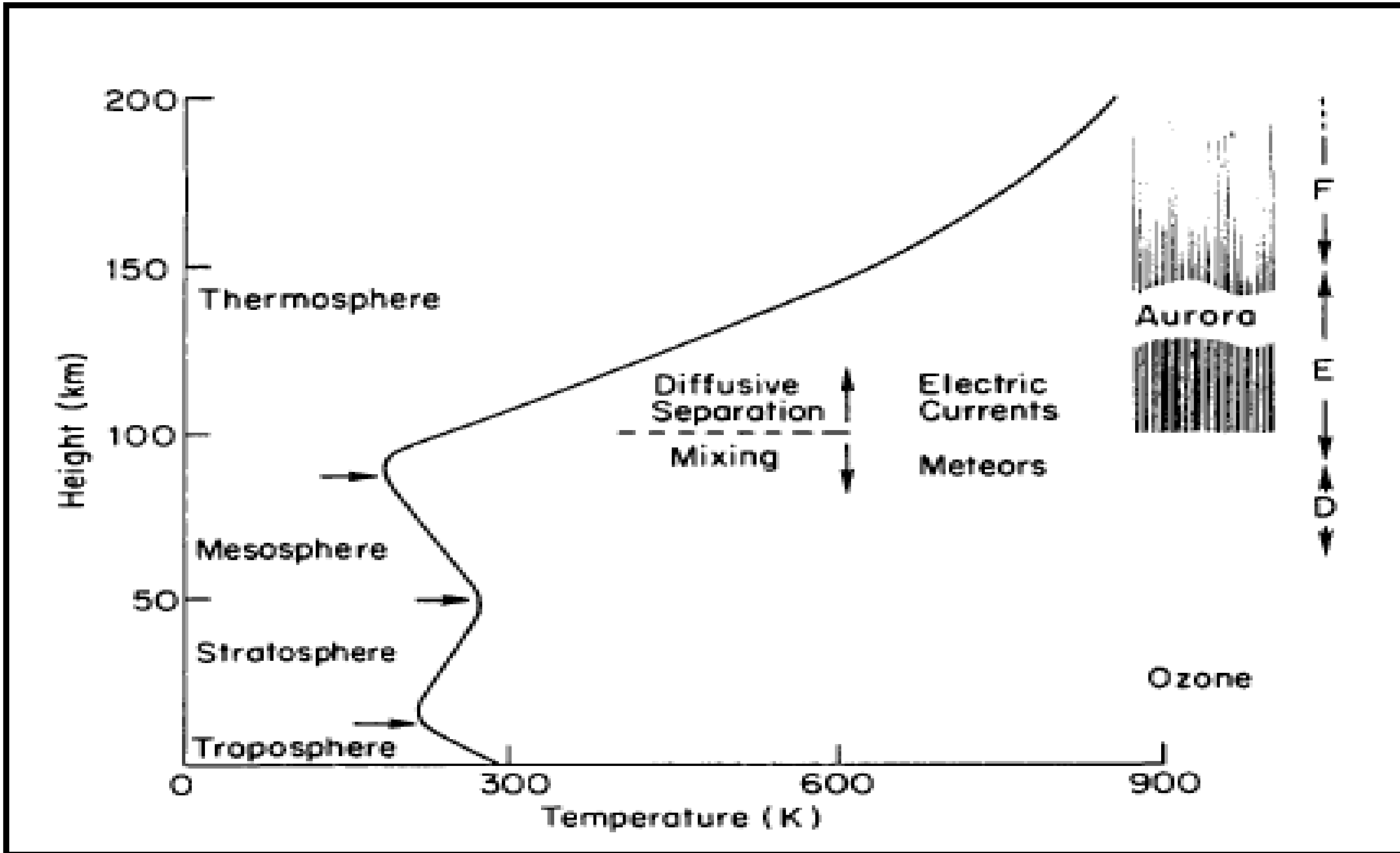


Figure 1. The regions of the earth’s atmosphere up to 200 km.

The ionosphere is defined as the part of the upper atmosphere in which free electrons are sufficient to influence the propagation of radio wave. For practical purposes it may be taken to extend in height from about 60 to 600 km, but these are not well-defined boundary. Upper boundary is accepted height where the hydrogen ion concentration being more then oxygen ion.

Historically, the ionosphere was discovered by Marconi when he sent radio signals across the Atlantic in 1901. In 1924 with Appleton and Barnett, Breit, and Tuve whose experiments measured the height of the conducting layer and revealed its stratified nature.

The most important ionospheric parameter—from the point of view of radio propagation and also of the physics—is the electron concentration. Typical height profiles electron concentration for mid-latitudes are shown in Figure 2.

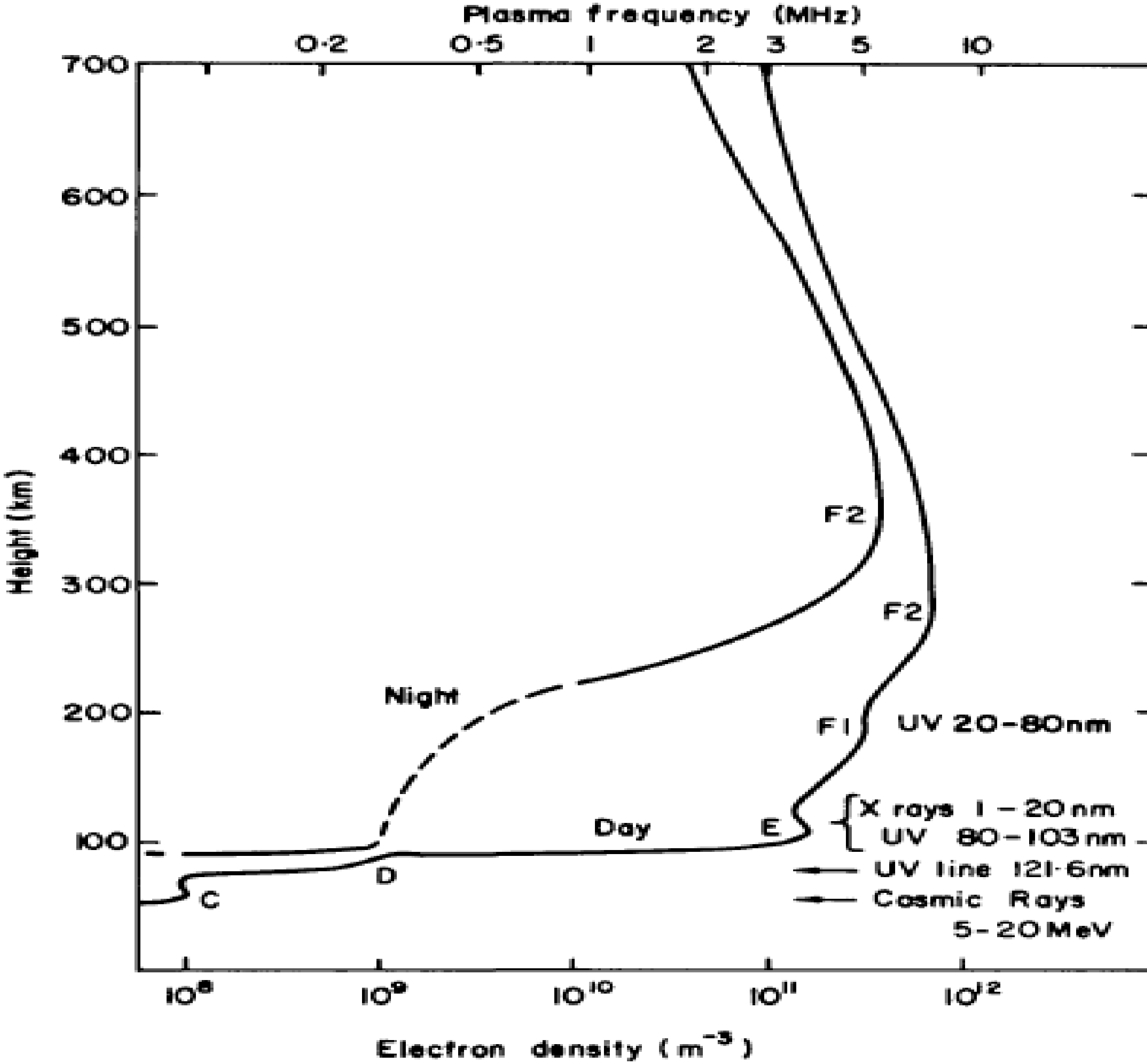


Figure 2. Typical mid-latitude electron concentration profiles for moderate solar activity.

Ionospheric paramettérs can be measured by ionosonde, satellite or purely descriptive empirical models, in which mathematical formula are constructed to match the observed variations of *parameter.* *(International Reference Ionosphere-IRI).*

The ionosphere acts not only as the reflection or absorption layer of the radio wave, but also as an electric current layer. The ionospheric currents cause the geomagnetic field variation.

Conductivity Tensor

Langevin equations for charged particles in the plasma medium can be written as;

$$m\frac{du}{dt} = q(E + u \times B) - m\nu u \qquad \textbf{(1)}$$

where **m**, **q**, ν, **E** and **B** are respectively mass, charge, collision frequency, electric and magnetic field. İf we consider the steady-state (or dc), Eq.(1) becomes as

$$0 = \frac{q}{m}(E + u \times B) - \nu u \qquad (2)$$

The eq. (2) in their present form are not yet quite simple because of the nonlinear term **uxB** (involving the product of two variables) This difficuly can generally be eliminated by the following thecnique. First, **B** is divide into two parts.

$$\mathbf{B}(r,t) = B_o + \mathbf{b}(r,t)$$

with B_o constant independent of space and time. With this assumption we can write

$$\mathbf{E} + \mathbf{U} \times \mathbf{B} = \mathbf{E} + \mathbf{U} \times \mathbf{B}_0 + \mathbf{U} \times \frac{\mathbf{k} \times \mathbf{E}}{\omega}$$

Where the last term on the right is the nonlinear one. The magnitude of this nonlinear term is always less then $|ukE/\omega|$, the first term on the right has magnitude $|E|$. Hence the nonlinear term can be neglected, $|uk/\omega|$ is much less than unity or

$$|u| << |\omega/k|$$

In general, ω/k the complex velocity, is of the order of c, whereas u the average electron velocity, is general much smaller.

Multiplying the equation (2) by ne/ν, we obtain

$$\frac{ne^2}{m\nu}(E + u \times B_0) - qnu = 0 \qquad (3)$$

where **n** are electron and ion concentration. As you know, qnu = j current density. Assuming that J current density generated by electrons and ions. According to this assumption, we can write Eq. (3) as follow;

$$J = ne^2\left(\frac{1}{m_e\nu_e} + \frac{1}{m_i\nu_i}\right)[E + u \times B_0] \qquad (4)$$

If we taka $\sigma_o = ne^2\left(\frac{1}{m_e\nu_e} + \frac{1}{m_i\nu_i}\right)$, Eq (4) becomes;

$$J = \sigma_o\,[E + u \times B_0] \qquad (5)$$

This is often referred to as a generalized Ohm's law. Where σ_o is (dc) conductivity of ionospheric plasma.

The generalized Ohm's law (Eq. 5) is not yet in a form where we can easily calculate J for given electric field **E**. Therefore, we choose our coordinates so that, magnetic field $\mathbf{B}_0$ lies in the **z** direction. If we replace **u** by –J/en, then Eq. (5) can be written as;

$$J = \sigma_o E + \frac{\omega}{\nu} J \times \hat{x}, \qquad \omega = \pm\frac{eB_0}{m} \qquad (6)$$

If we write each component of this equation more explicitly, we have

$$J_x \pm \frac{\omega}{\nu} J_y = \sigma_o E_x \tag{7}$$

$$\mp \frac{\omega}{\nu} J_x + J_y = \sigma_o E_y \tag{8}$$

$$J_z = \sigma_o E_z \tag{9}$$

From equations (7)-(8) we find

$$J_x = \sigma_\perp E_x + \sigma_H E_y \tag{10}$$

$$J_y = -\sigma_H E_x + \sigma_\perp E_y \tag{11}$$

Where

$$\sigma_{\perp} = \sigma_0 \left(\frac{\nu_e^{\,2}}{\omega_e^{\,2} + \nu_e^{\,2}} + \frac{\nu_i^{\,2}}{\omega_i^{\,2} + \nu_i} \right),$$

$$\sigma_H = \sigma_0 \left(\frac{\omega_e \nu_e}{\omega_e^{\,2} + \nu_e^{\,2}} + \frac{\omega_i \nu_i}{\omega_i^{\,2} + \nu_i} \right), \qquad \omega_{e,\mathrm{i}} = \mp \frac{eB_0}{m_{e\,i}}$$

We find that the current produced by a stationary electric field in the presence of a magnetic field in the z-direction is given by Eq.(9)-Eq.(11). Hence, these equations can be written as,

$$J = \sigma \cdot E \qquad (12)$$

where σ is the dc conductivity tensor for ionospheric plasma.

$$\sigma = \begin{bmatrix} \sigma_\perp & \sigma_H & 0 \\ -\sigma_H & \sigma_\perp & 0 \\ 0 & 0 & \sigma_0 \end{bmatrix}$$

$$= \begin{bmatrix} \sigma_0 \left(\frac{\nu_e^{\,2}}{\omega_e^{\,2}+\nu_e^{\,2}} + \frac{\nu_i^{\,2}}{\omega_i^{\,2}+\nu^2_{\,i}} \right) & \sigma_0 \left(\frac{\omega_e \nu_e}{\omega_e^{\,2}+\nu_e^{\,2}} + \frac{\omega_i \nu_i}{\omega_i^{\,2}+\nu^2_{\,i}} \right) & 0 \\ -\sigma_0 \left(\frac{\omega_e \nu_e}{\omega_e^{\,2}+\nu_e^{\,2}} + \frac{\omega_i \nu_i}{\omega_i^{\,2}+\nu^2_{\,i}} \right) & \sigma_0 \left(\frac{\nu_e^{\,2}}{\omega_e^{\,2}+\nu_e^{\,2}} + \frac{\nu_i^{\,2}}{\omega_i^{\,2}+\nu^2_{\,i}} \right) & 0 \\ 0 & 0 & \sigma_0 \end{bmatrix}$$

$$\omega_{e,i} = \mp \frac{eB_0}{m}$$

The currents flow according to the Ohm's law, but the electric conductivity is anisotropic because of the geomagnetic field effect, and three conductivities are defined as parallel, Pedersen(perpendicular) and Hall.

σ_0 " **Parallel conductivity** ".

Parallel conductivity governs the flow of electric current in the magnetic field direction.

$\sigma_\perp$ or σ_1 " **Pedersen conductivity** "

Pedersen conductivity is for the direction vertical to the magnetic field and parallel to the electric field.

σ_H or σ_2 " **Hall conductivity** "

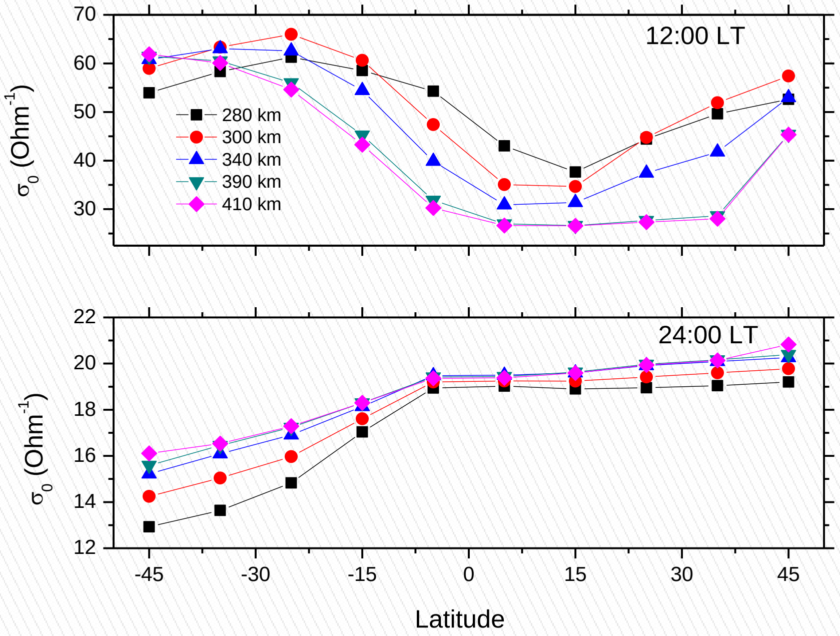
Hall conductivity is for the direction vertical to both the magnetic and electric fields. In the ionosphere this conductivity is due to the drift motion of the electron (ExB drift) and maximum in the E region where only electron practically drifts to the direction of ExB.

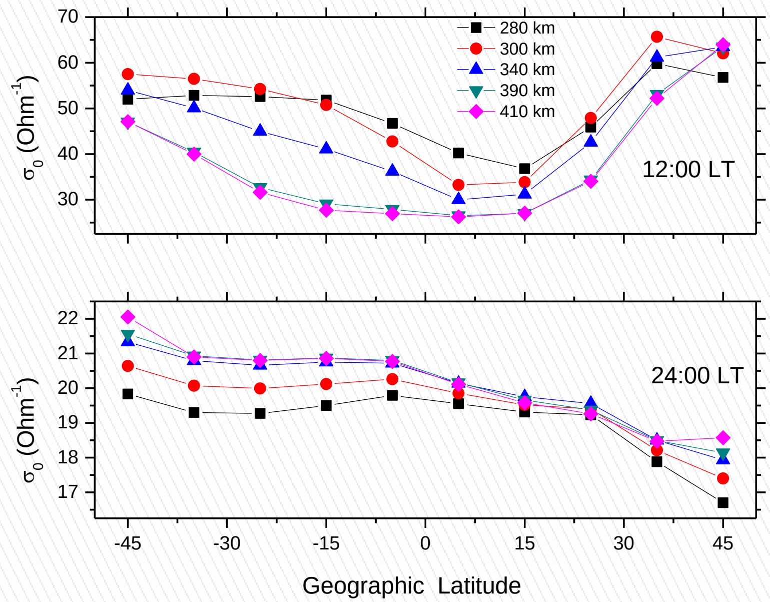
Parallel, Pedersen and Hall conductivity are equal when there is no magnetic field.

Calculation and Results

We have calculated the numerical values of σ_o, $\sigma_\perp$ and σ_H conductivities using the above equations. The necessary parameter for calculation (electron and ions concentration, electron, ion and notr temperature and magnetic field) have been obtained by using **International Reference Ionosphere-IRI model.** Calculations have been made for 21 June and 21 December solstice. Solar activity is maximum in the days when computing is done.

Paralel Conductiviy (σ_0)

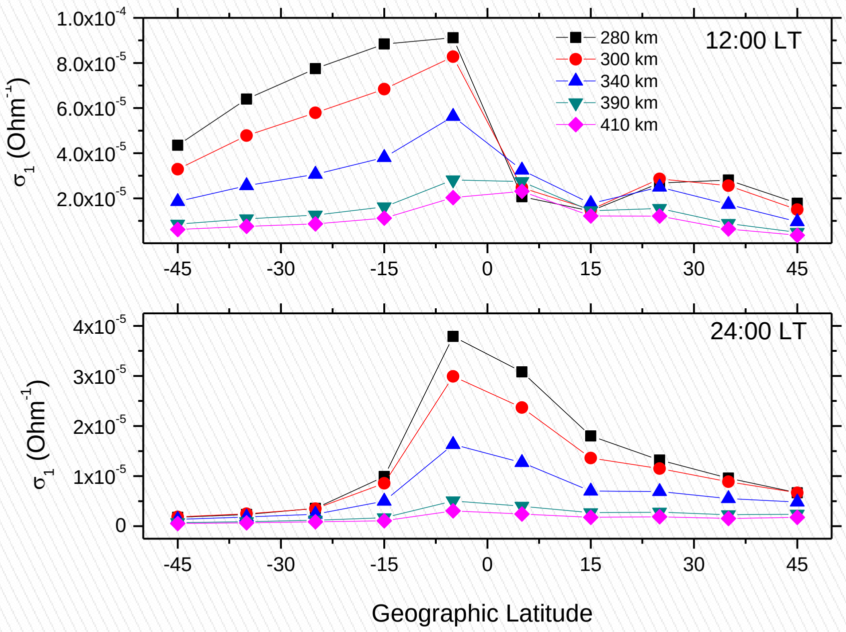


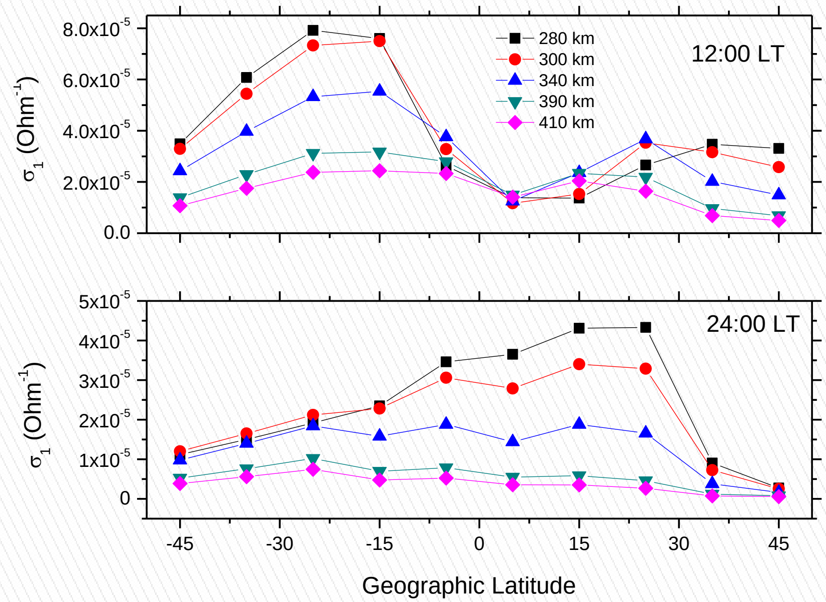


For June solstice, latitudinal and altitudinal variations

For December solstice, latitudinal and altitudinal variations

Pedersen Conductivity (σ_1)

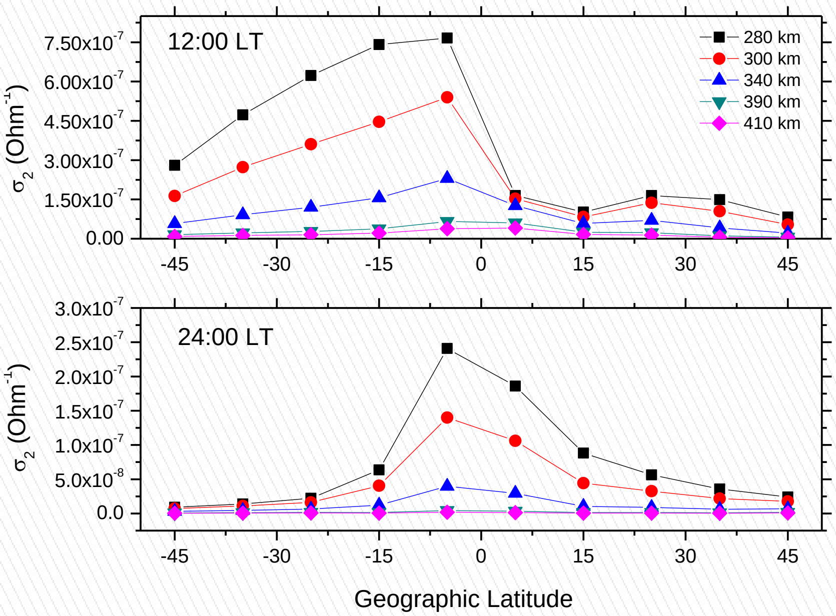


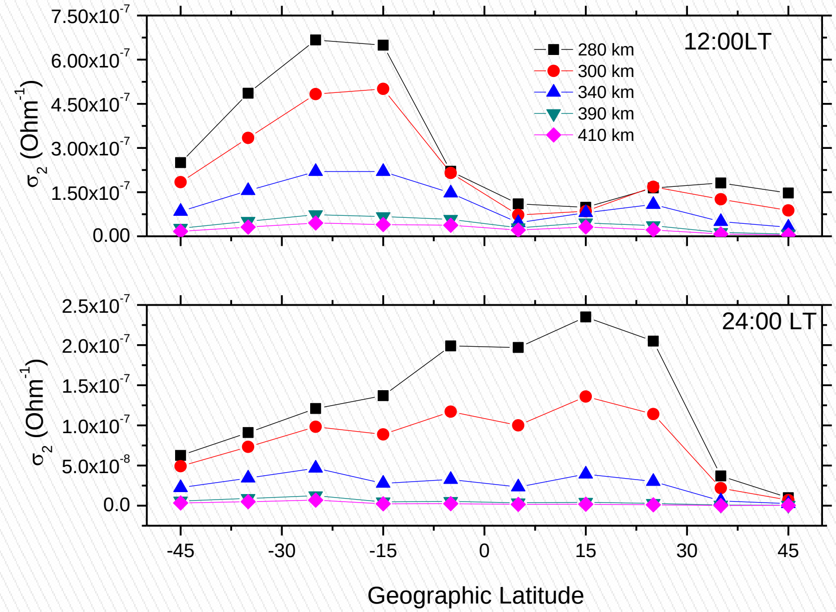


For June solstice, latitudinal and altitudinal variations

For December solstice, latitudinal and altitudinal variations

Hall Conductivity (σ_2)





For June solstice, latitudinal and altitudinal variations

For December solstice, latitudinal and altitudinal variations

Thank you so much for listening me