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RESEARCH ARTICLE

DENSITY MHD SIMULATION IN THE BOTTOM SIDE OF IONOSPHERE PLASMA (90-200KM HEIGHT ABOVE EARTH SURFACE) BY VLASOVE EQUILIBRIUM EQUATION

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ABSTRACT

Ionosphere is a part of atmosphere that caused by the solar UV radiation, in turn produced different layers including D, E, etc. Then the matters ionized into electrons and ions etc…Ionosphere affects severely to propagation of radio wave between the points on the earth. By means of ion sounds one could considered the ionosphere layers, their opacity and clearance on the radio waves propagation. These are possible by studies the critical frequency of the layer or the blanketing frequency of it. In our research we used the data obtained from one of the top side sounder station, then by using MHD equilibrium VLASOVE equation we obtained the E layer plasma electron density.

INTRODUCTION

As usual plasma is a neutral gas with collective behavior (**Francis F. Chen, 1994**). Plasma media behave sometimes in the particle like forms and sometimes liquid forms depending upon the plasma density and mean free path of the particles.

In the liquid form the MHD formalism (Magneto Hydro, Dynamic) governing to the plasma. If we neglect the reconnecting phenomenon in the plasma we would have the following for the electron density:

$$n_e = \left(\frac{q_{ke}}{\beta_r}\right)$$

In most cases the electron density in the E layer would be in the order of $n_{max}=10^{12}cm^{-3}$

In this state the radio wave critical frequency of the plasma layer would be about 10MHz (**Budden, 1985**)

Simulation of E layer plasma through MHD system

In the bottom side of the ionosphere plasma that is in the E layer refer to the earth magnetic field we have:

$$\left(\vec{E} + \vec{v_e} \times \vec{B}\right) = -\frac{m_e v_c}{e}\vec{v_e}‘\vec{J} = \sigma_0 \vec{E} - \frac{\sigma_0 \vec{J}}{n_e e} \times \vec{B} \qquad (1)$$

We assumed that

$\left(\vec{B} = B_e \hat{z}\right)$soastheplasmaresistiritywouldbe:

$$\vec{J}_x = \sigma_0 \vec{E}_x + \frac{\omega_{ge}}{v_c}\vec{J}_y \qquad (2)$$

$$\vec{J}_y = \sigma_0 \vec{E}_y + \frac{\omega_{ge}}{v_c}\vec{J}_x \qquad (3)$$

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$$\vec{J}_z = \sigma_0\vec{E}_z \quad (4)$$

We combine two first equations and dismissed J_y:

Then:

$$\vec{J}x = \frac{v_c^2}{v_c^2+\omega_{ge}^2}\sigma_0\vec{E}_x + \frac{\omega_{ge}v_c}{v_c^2+\omega_{ge}^2}\sigma_0\vec{E}_y \quad (5)$$

$$\vec{J}_y = \frac{v_c^2}{v_c^2+\omega_{ge}^2}\sigma_0\vec{E}_x + \frac{\omega_{ge}v_c}{v_c^2+\omega_{ge}^2}\sigma_0\vec{E}_x \quad (6)$$

$$\vec{J}_z = \sigma_0\vec{E}_z \quad (7)$$

In these equations we used$\vec{J} = \sigma\vec{E}$.

Or:

$$\sigma = \begin{bmatrix} \sigma_P & -\sigma_H & 0 \\ \sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_\parallel \end{bmatrix}$$

For conductivity tensors.

As here$\sigma_P = \frac{v_c^2}{v_c^2+\omega_{ge}^2}\sigma_0$ is the Pederson conductivity and $\sigma_H = \frac{\omega_{ge}v_c^2}{v_c^2+\omega_{ge}^2}\sigma_0$ is the hale conductivity, and$\sigma_\parallel = \sigma_0 = \frac{n_e e^2}{m_e v_c}$ is the conductivity for a part of$E_\perp$ that is perpendicular to B (**Krall and Trievelpiece, 1973**).

For B in general:

$$\vec{J} = \sigma_\parallel\vec{E}_\parallel + \sigma_P\overrightarrow{E_\perp} - \sigma_H\left(\overrightarrow{E_\perp}\times\vec{B}\right)/B \quad (8)$$

In ionospheres because of the electrons and neutral particles we have:

$$\vec{J} = \sigma_\parallel\vec{E}_\parallel + \sigma_P\overrightarrow{E_\perp} - \sigma_H\left(\frac{\vec{E}\times\vec{B}}{B}\right) \quad (9)$$

Now if we replace ω_{ge},v_{en} with ω_{gi},v_{in}

Then we reach to the following:

$$\sigma_P = \left(\frac{v_{en}}{v_{en}^2+\omega_{ge}^2} + \frac{m_e}{m_i}.\frac{v_{in}}{v_{in}^2+\omega_{gi}^2}\right).\frac{n_e e^2}{m_e} \quad (10)$$

$$\sigma_H = \left(\frac{\omega_{en}}{v_{en}^2+\omega_{ge}^2} + \frac{m_e}{m_i}.\frac{\omega_{in}}{v_{in}^2+\omega_{gi}^2}\right).\frac{n_e e^2}{m_e} \quad (11)$$

$$\sigma_\parallel = \left(\frac{1}{v_{en}} + \frac{m_e}{m_i}.\frac{1}{v_{in}}\right).\frac{n_e e^2}{m_e} \quad (12)$$

Here it assumed that in every ion sphere in E layer shape only one type of ion exists. The impacting of electromagnetic waves to the plasma medium based upon calculation would have absorption coefficient and dielectric constant, attenuation and reflection coefficients respectively. For simulation we assumed that if an electromagnetic wave toward ionosphere from the earth as below:

$$\vec{E} = \vec{E}_0 e^{i(\mp\vec{k}.\vec{r}-\omega t)} \quad (13)$$

So as:

$$\vec{k} = \frac{\omega}{c}\vec{n}‹\vec{n} = \mu + \hat{\imath}\chi \quad (14)$$

That n is the reflection coefficient of the medium and χ isits absorption coefficient, then we would have:

$$\vec{E} = \vec{E}_0 e^{i\left(\mp\frac{\omega}{c}\mu r-\omega t\right)} e^{\frac{\omega}{c}\chi} \qquad (15)$$

Here χ is the absorption coefficient of above function (4).In the atmosphere we have the following Tensor:

$$\sigma = \begin{bmatrix} \sigma_P & -\sigma_H & 0 \\ \sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_\parallel \end{bmatrix} \qquad (16)$$

There we have the Pederson conductivity as$\sigma_P = \frac{v_c^2}{v_c^2+\omega_{ge}^2}\sigma_0$

And Hal conductivity $\sigma_H = \frac{\omega_{ge}v_c^2}{v_c^2+\omega_{ge}^2}\sigma_0, \sigma_\parallel = \sigma_0 = \frac{n_e e^2}{m_e v_c}$

That$\sigma_\parallel$ is depended to a part of electric field perpendicular to B.

Here ω_{ge} is negative and$\sigma_\parallel$ is conductivity depending to$B_\parallel$ and$E_\parallel$ in plasma media we would have:

$$\sigma = \begin{bmatrix} \sigma_1 & -\sigma_2 & 0 \\ \sigma_2 & \sigma_1 & 0 \\ 0 & 0 & \sigma_\parallel \end{bmatrix} \qquad (17)$$

And

$$\sigma_0 = \frac{\varepsilon_0\omega_{pe}^2}{(\upsilon_e - i\omega)^2} ‘\sigma_1 = \frac{\varepsilon_0\omega_{pe}^2(\upsilon_e - i\omega)}{[\omega_{ce}^2 + (\upsilon_e - i\omega)^2]} ‘\sigma_2 = \frac{\varepsilon_0\omega_{pe}^2\omega_{ce}^2}{[\omega_{ce}^2 + (\upsilon_e - i\omega)^2]}$$

Thatσ_2 showing Hall effectsσ_1 also shows the Pederson effect.

$$\omega_{pe}^2 = \left(\frac{e^2 N_e}{m_e \varepsilon_0}\right)$$

Is the electron plasma frequency and $\omega_{ce} = \left(-\frac{eB_0}{m_e}\right)$is the electron cyclotron frequency.
For electron frequencies we have:

$$\nu_e = \nu_{ei} + \nu_{en} \qquad (18)$$

$$\nu_{ei} = N_e\left[59 + 4.181\log\left(\frac{T_e^3}{N_e}\right)\right] x10^{-6} T_e^{-\frac{3}{2}} \qquad (19)$$

$$\nu_{en} = 5.4 \times 10^{-16} N_n T_e^{\frac{1}{2}} \qquad (20)$$

After solution of Maxwell equations around the IONO sound we reach to the following:

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad (21)$$

$$\vec{\nabla} \times \vec{B} = \mu_0\vec{J} + \mu_0\varepsilon_0\frac{\partial \vec{E}}{\partial t} \qquad (22)$$

$$[\vec{J}] = [\sigma].[\vec{E}] \qquad (23)$$

$$n^2\vec{E} - \vec{n}(\vec{n}.\vec{E}) = \left[I + \frac{i\sigma}{\varepsilon_0\omega}\right].\vec{E} \qquad (24)$$

$$\begin{bmatrix} M_{xx} & M_{xy} & M_{xz} \\ M_{yx} & M_{yy} & M_{yz} \\ M_{zx} & M_{zy} & M_{zz} \end{bmatrix} . \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} = 0 \qquad (25)$$

$Det(M) = 0$:

$$M_{xx} = M_{yy} = n^2 - 1 - \frac{i\sigma_1}{\varepsilon_0\omega} \qquad (26)$$

$$M_{xz} = M_{yz} = M_{zx} = M_{zy} = 0 \quad (27)$$
$$M_{xy} = -M_{yx} = \frac{\sigma_2}{\varepsilon_0 \omega} \quad (28)$$
$$M_{zz} = -1 - \frac{i\sigma_0}{\varepsilon_0 \omega} \quad (29)$$

Then:

$$\left(-1 - \frac{i\sigma_0}{\varepsilon_0 \omega}\right)\left(n^2 - 1 - \frac{i\sigma_1}{\varepsilon_0 \omega} - \frac{\sigma_2}{\varepsilon_0 \omega}\right)\left(n^2 - 1 - \frac{i\sigma_1}{\varepsilon_0 \omega} + \frac{\sigma_2}{\varepsilon_0 \omega}\right) = 0 \quad (30)$$
$$n_1^2 = \mathrm{A} + \mathrm{iB} \;،\; n_2^2 = \mathrm{C} + \mathrm{iD} \quad (31)$$
$$A = 1 + \frac{\omega_{pe}^2}{\omega}\left[\frac{(\omega-\omega_{ce})(\omega_{ce}^2+\nu_e^2-\omega^2)-2\omega\nu_e^2}{(\omega_{ce}^2+\nu_e^2-\omega^2)^2+4\omega^2\nu_e^2}\right] \quad (32)$$
$$B = \frac{\omega_{pe}^2}{\omega}\left[\frac{2\omega\nu_e(\omega-\omega_{ce})+\nu_e(\omega_{ce}^2+\nu_e^2-\omega^2)}{(\omega_{ce}^2+\nu_e^2-\omega^2)^2+4\omega^2\nu_e^2}\right] \quad (33)$$
$$C = 1 + \frac{\omega_{pe}^2}{\omega}\left[\frac{(\omega+\omega_{ce})(\omega_{ce}^2+\nu_e^2-\omega^2)-2\omega\nu_e^2}{(\omega_{ce}^2+\nu_e^2-\omega^2)^2+4\omega^2\nu_e^2}\right] \quad (34)$$
$$D = \frac{\omega_{pe}^2}{\omega}\left[\frac{2\omega\nu_e(\omega+\omega_{ce})+\nu_e(\omega_{ce}^2+\nu_e^2-\omega^2)}{(\omega_{ce}^2+\nu_e^2-\omega^2)^2+4\omega^2\nu_e^2}\right] \quad (35)$$

In about relationship:

$$n^2 = (\mu + i\chi)^2 = A + iB$$

That imaginary part depended to the absorption and real part dedicated to impacts (**Stocker *et al.*, 1997**).

Then:

$$\chi_{1،2} = \left[\frac{\pm(A^2+B^2)^{1/2} - A}{2}\right]^{1/2} \quad (36)$$

$$\vec{E} = \vec{E}_0 e^{i\left(\mp\frac{\omega}{c}\mu z - \omega t\right)} e^{-\frac{\omega}{c}\left[\frac{\pm(A^2+B^2)^{1/2} - A}{2}\right]^{1/2} z} \quad (37)$$

And the total absorption would be obtained in the following form:

$$\text{Total absorption} = \int_{z_0}^{z_{rofl}} e^{-\frac{\omega}{c}\left[\frac{\pm(A^2+B^2)^{1/2} - A}{2}\right]^{1/2} z} dz + \int_{z_{rofl}}^{z_0} e^{-\frac{\omega}{c}\left[\frac{\pm(A^2+B^2)^{1/2} - A}{2}\right]^{1/2} z} dz \quad (38)$$

And the particle density in the following form obtained

$$n_n m_n g = \frac{dp}{dh} = -\frac{d}{dh}(n_n K T_n) \quad (39)$$
$$n_n = n_0 exp\left(\frac{-(n-n_0)}{H}\right) \quad (40)$$

And from Chapman equations:

$$\mathrm{q_m = \sigma n_m I_m \Longrightarrow q_m = \sigma H_n n_0 exp\left(\frac{-(n-n_0)}{H}\right). \cos\alpha \text{،} H_n = \frac{KT}{mg}} \quad (41)$$

$$\mathrm{I(h) = I(\infty)exp(-\sigma n_n H_n \sec\alpha). exp\left(\frac{-(n-n_0)}{H}\right)} \quad (42)$$

Numerically obtained values confirmed completely the simulated values in the particle shape of the plasma.

For plasma fluidity form we should solved the NAVIER-Stocks formalism. For this we reached to the MHD of ionosphere plasma or:

$$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \text{،} \vec{E} \approx \vec{\nabla} \times \vec{B} \quad (43)$$

$$\Rightarrow \frac{\mu_0\varepsilon_0}{\vec{\nabla}\times\vec{B}}\cdot\left(\frac{\partial\vec{E}}{\partial t}\right) \approx \frac{vB/_{\tau c^2}}{B/_L} \approx \left(\frac{v}{c}\right)^2 \quad (44)$$

And with B at hand we could calculate plasma current refer to the height above earth surface:

$$\Sigma_p = \int \sigma_p dz \text{ و} \Sigma_H = \int \sigma_H dz \quad (45)$$

$$j_\perp = \int j_\perp dz \quad \text{و} j_\perp = \Sigma_p E_\perp - \frac{\Sigma_H}{B}$$

$$j_\perp = \sigma_p E_{\parallel} - \frac{\sigma_H(E_\perp \times B)}{B} + \sigma_H E_{\parallel} \quad (46)$$

But we knew:

$$\rho = ne\text{،}\vec{i} = \vec{j}A \quad (47)$$

And:

$$\vec{\nabla}.\vec{j} + \frac{\partial\rho}{\partial t} = 0 \quad (48)$$

$$\Rightarrow \frac{\partial\rho}{\partial t} = -\vec{\nabla}.\vec{j} \Rightarrow \frac{\partial\rho}{\partial t} = \vec{\nabla}.\left(\sigma_p\vec{E}_{\parallel} - \frac{\sigma_H(\vec{E}_\perp\times\vec{B})}{B} + \sigma_H\vec{E}_{\parallel}\right) \quad (49)$$

For equilibrium situation we have $\frac{\partial\rho}{\partial t} = 0$

Then $\vec{\nabla}.\vec{j} = 0$

J=const.

For ionized plasma we have

$$\vec{j} = n_e e\vec{v}_e$$

$$n_e = \frac{\vec{j}}{e\vec{v}_e}$$

In below we put our calculation with tabulated data obtained from IONO sound in June, 2007 (The data obtained from Rom iono sound station).

Conclusion remarks

1- As seen from the Figs 1- and 2 the density picks that obtained from IONO sound data and the simulation are the same in the equal altitudes.
2- There are differences for electron density from obtained of IONO sound data and the values obtained from calculation. These may be because of some approximation in the calculations (eg. sometimes diagrams we used $f_o \approx 9\sqrt{n}$)
3- As we see for ionosphere E layer plasma we obtained very exactly values by means of VLASOVE equilibrium equation similar to its MHD values.

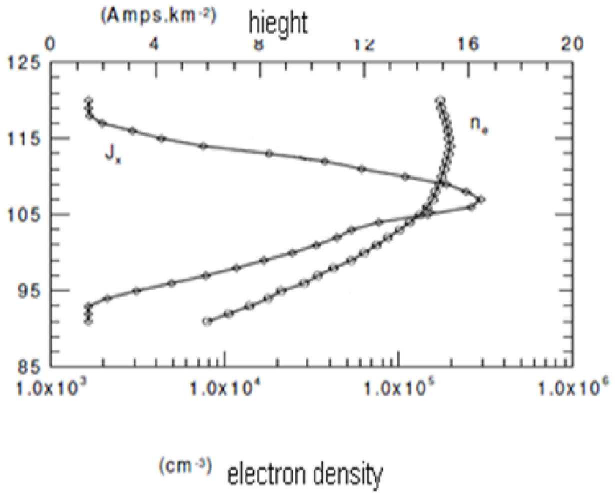

Fig. 1. Electron density in JUNE

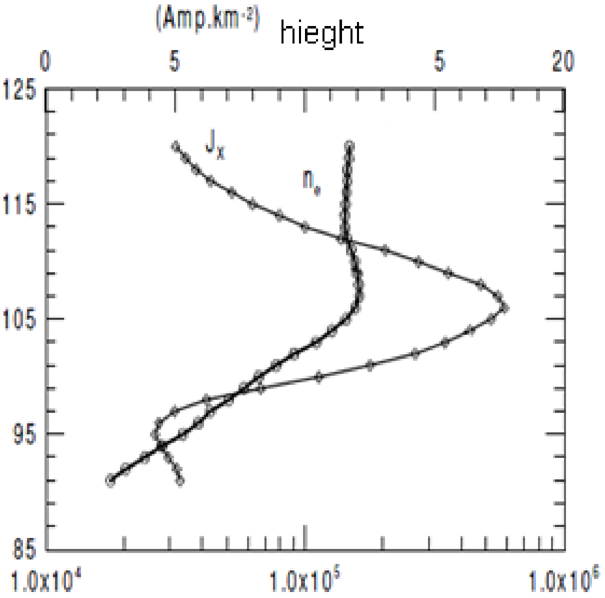

Fig. 2. Electron density in SEPTEMBER

Then refer to the conductivity tensor we reached to the following:

$$\begin{bmatrix} M_{xx} & M_{xy} & M_{xz} \\ M_{yx} & M_{yy} & M_{yz} \\ M_{zx} & M_{zy} & M_{zz} \end{bmatrix} . \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} = 0 \qquad (50)$$

$$n^2 = (\mu + i\chi)^2$$

Scattering of the waves in the ionosphere plasma would necessitate that:

$$\text{Det(M)} = 0$$

From which:

$$M_{xx} = M_{yy} = n^2 - 1 - \frac{i\sigma_1}{\varepsilon_0 \omega} \qquad (51)$$

$$M_{xz} = M_{yz} = M_{zx} = M_{zy} = 0 \qquad (52)$$

$$M_{xy} = -M_{yx} = \frac{\sigma_2}{\varepsilon_0 \omega} \qquad (53)$$

$$M_{zz} = -1 - \frac{i\sigma_0}{\varepsilon_0 \omega} \qquad (54)$$

$$\left(-1 - \frac{i\sigma_0}{\varepsilon_0 \omega}\right)\left(n^2 - 1 - \frac{i\sigma_1}{\varepsilon_0 \omega} - \frac{\sigma_2}{\varepsilon_0 \omega}\right)\left(n^2 - 1 - \frac{i\sigma_1}{\varepsilon_0 \omega} + \frac{\sigma_2}{\varepsilon_0 \omega}\right) = 0 \qquad (55)$$

$$n_1^2 = \text{A} + \text{iB} \quad ‹ n_2^2 = \text{C} + \text{iD} \qquad (56)$$

$$A = 1 + \frac{\omega_{pe}^2}{\omega}\left[\frac{(\omega - \omega_{ce})(\omega_{ce}^2 + \nu_e^2 - \omega^2) - 2\omega\nu_e^2}{(\omega_{ce}^2 + \nu_e^2 - \omega^2)^2 + 4\omega^2\nu_e^2}\right] \qquad (57)$$

$$B = \frac{\omega_{pe}^2}{\omega}\left[\frac{2\omega\nu_e(\omega - \omega_{ce}) + \nu_e(\omega_{ce}^2 + \nu_e^2 - \omega^2)}{(\omega_{ce}^2 + \nu_e^2 - \omega^2)^2 + 4\omega^2\nu_e^2}\right] \qquad (58)$$

$$C = 1 + \frac{\omega_{pe}^2}{\omega}\left[\frac{(\omega + \omega_{ce})(\omega_{ce}^2 + \nu_e^2 - \omega^2) - 2\omega\nu_e^2}{(\omega_{ce}^2 + \nu_e^2 - \omega^2)^2 + 4\omega^2\nu_e^2}\right] \qquad (59)$$

$$D = \frac{\omega_{pe}^2}{\omega}\left[\frac{2\omega\nu_e(\omega + \omega_{ce}) + \nu_e(\omega_{ce}^2 + \nu_e^2 - \omega^2)}{(\omega_{ce}^2 + \nu_e^2 - \omega^2)^2 + 4\omega^2\nu_e^2}\right] \qquad (60)$$

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