On thermospheric movement and heating by auroral electric field

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Abstract

Spatial velocity distribution of the upper thermosphere in the auroral region has been investigated in a rigorous way in this presentation through magnetohydrodynamic formalism. The effect of ponderomotive force on the movement of medium particles, density fluctuation and temperature fluctuation are taken into account in the analysis. The expressions of Joule and viscous heating have been deduced under certain specified situations. The variations of auroral plasma parameters are studied. The outcome of numerical analyses have been presented graphically.

1. Introduction

The auroral E-region of the ionosphere is characterized by different non-linear phenomena due to variation of the velocity distribution of the thermosphere, medium temperature, ionizing frequency, effective collision frequency and recombination co-efficient of electrons and ions [1-3].

Electron density of auroral E-layer is dependent on the rate of energy deposition by auroral precipitation [4]. The penetration, diffusion and precipitation of auroral electrons into the atmosphere introduce heating [5, 6] which is further enhanced by the level of geomagnetic activities, multiple scattering and Coulomb interactions with atomic nucleus and orbital electrons of atmospheric constituents. Energy distribution also depends on the variation of the atmospheric density with altitude. Precipitation patterns, latitudinal distribution of energy and dynamics of the incoming particles are important in auroral phenomenon. Analyses and interpretations of these physical phenomena have been modeled in terms of instantaneous spatial distribution of particle precipitation and resultant ionization in auroral region [7, 8].

Auroral electric currents and charged particle precipitation produce Joule heating, gravity waves and travelling ionospheric disturbances which initiate temperature enhancements and temperature fluctuations [9-11]. The presence of fluctuating electric field initiates Joule heating along with viscous heating [12-13]. Magnetosphere-Ionosphere coupling mechanism also provides informations about Joule heating rate along with various other electrodynamic parameters [14]. Joule and particle heating make the largest contribution to the total energy budget in the medium [15]. Both Joule heating and Lorentz force would give rise to detectable pressure fields beyond the boundaries at which the auroral currents remain confined [16]. Moreover, interaction between high frequency oscillating electric field and orthogonal geomagnetic field develops the ponderomotive force in a subtle way.

In this presentation, an explicit expression for the velocity of upper thermospheric auroral region has been deduced through magnetohydrodynamic formalism. The contribution of ponderomotive force has been included in the analysis. The spatial distribution of velocity of the thermosphere and its altitude dependence within the auroral region are explored. The expressions of Joule heating and viscous heating have been obtained. Numerical analyses are carried out to estimate their magnitudes as well as the rate of their variations with time. The results have been presented graphically.

2. Mathematical Formulation

In the formulation of the problem, it has been assumed that the plasma is considered to be bounded within the auroral region where the momentum of the electrons may be transferred to the surrounding region through the action of various forces.

The magnetohydrodynamic formulation will be adopted along with the effect of ponderomotive force. The appropriate form of momentum transport equation has been taken as

$$mN\frac{D\mathbf{v}}{Dt}+N\mathbf{F}+mN\upsilon_e\mathbf{v}-mN\mathbf{g}=-\nabla p-\sigma\left(\mathbf{E}+\mathbf{v}\times\mathbf{B}\right)\times\mathbf{B}+\mu\nabla^2\mathbf{v}+\frac{1}{3}\mu\nabla\left(\nabla\cdot\mathbf{v}\right) \tag{1}$$

where, N, particle number density; $\mathbf{F}$, ponderomotive force; $\mathbf{E}$, horizontal electric field vector; $\mathbf{B}$, geomagnetic field vector; υ_e, effective electron collision frequency; μ, co-efficient of viscosity of the medium and the other symbols have their usual meaning.

Fluctuations in the particle number density and temperature are taken as

$$N=N_0\left(1+\eta\right)$$

$$T=T_0\left(1+\theta\right)$$

where, η is the particle density fluctuation and θ is the temperature fluctuation.

In presence of perturbation, the equation (1) with these transformations can be expressed as

$$\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial z^2}-a\frac{\partial v}{\partial t}-bv=c \tag{2}$$

where,

$$a=\frac{2mN_0\left(1+\eta\right)}{\mu}$$

$$b=\frac{m\upsilon_e N_0\left(1+\eta\right)+\sigma B^2}{\mu}$$

$$c=\frac{k_B N_0 T_0}{\mu}\frac{\partial\theta}{\partial x}+\frac{\sigma EB}{\mu}-\frac{mN_0\left(1+\eta\right)}{\mu}g$$

Using the method of Fourier transform, the solution of equation (2) yields the expression of velocity in the following integral form:

$$v\left(x,z,t\right)=\frac{ac}{2}e^{-\frac{b}{a}t}\int_0^t\frac{e^{\frac{b}{a}t_1}}{t-t_1}dt_1\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\exp\left[\frac{-\left(x-\xi\right)^2-\left(z-\zeta\right)^2}{\frac{4}{a}\left(t-t_1\right)}\right]d\xi d\zeta \tag{3}$$

This has been made useful to study the rate of variations of the Joule heating and viscous heating within the medium. Moreover, the variations of velocity with altitude (*z*) and dimensionless time $\left(\tau=\frac{\sigma B^2}{\rho}t\right)$ are explored through numerical analyses. The magnitudes of Joule heating $\left(Q_J\right)$ and viscous heating $\left(Q_V\right)$ rates are determined from the following expressions:

$$Q_J=\sigma\left(E+vB\right)^2 \tag{4}$$

$$Q_V=\mu v\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial z^2}\right) \tag{5}$$

3. Results and Discussion

The distribution of velocity of the upper thermosphere has been numerically analyzed for the heights 180 km and 220 km against dimensionless time. It is found that the velocity approaches steady value after the elapse of some finite time (Figure 1). Graphs of Figure 2 depict the variation of average velocity of the thermosphere with height for different characteristic times: τ = 0.3333, 0.6667 and 1.3333.

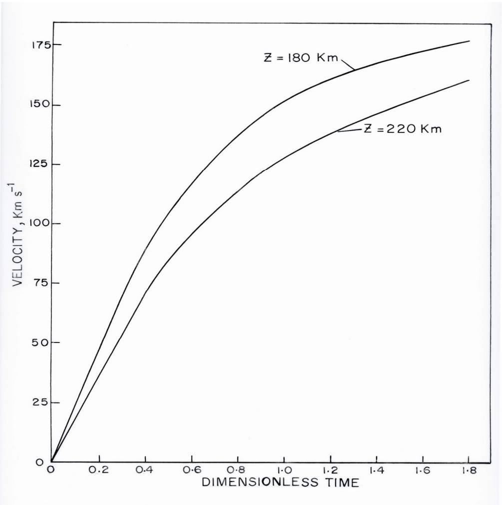

Figure 1. Velocity vs Dimensionless Time at Different altitudes

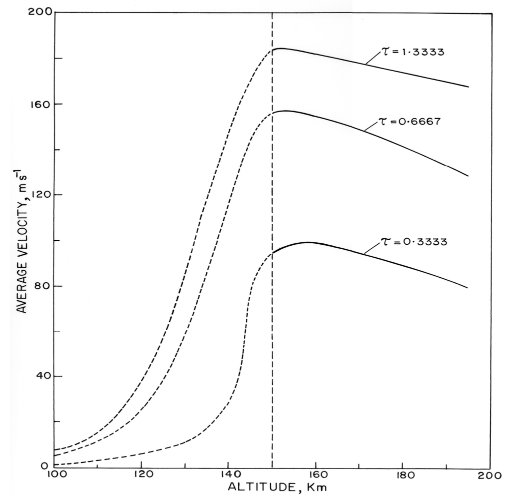

Figure 2. Average Velocity vs Altitude at different Characteristic Times

In Figure 3, the heating rate has been plotted against the characteristic time. The average values of Joule heating and viscous heating in the disturbed volume are presented separately. Joule heating is effective in the initial stage which decreases as the volume increases with time. When the motion is set-up due to dominating electric field, then only viscous heating results. This is increased due to movement of the medium and eventually it reaches a steady value.

4. Conclusion

Coupling of the magnetosphere with the ionosphere is much felt through the presence of large-scale DC electric fields and the injection of energetic particles that produce large amount of local ionization. Joule dissipation of these currents is a major ionospheric energy source at auroral latitudes. It is several times greater than directly associated with particle precipitation.

The present work may be useful to study thermospheric movement and heating enhanced by auroral electric field.

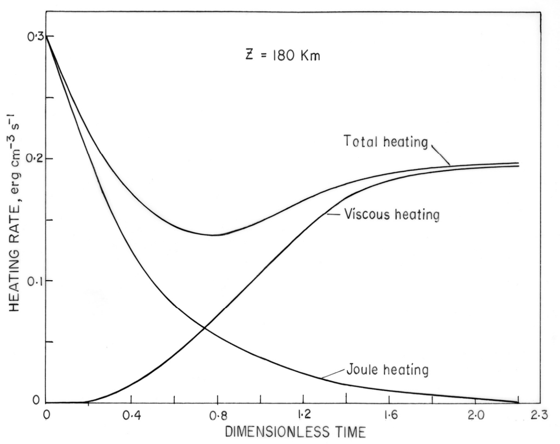

Figure 3. Heating Rate vs Dimensionless Time

at z = 180 km

5. References

1. G. W. Prölss, “Subauroral electron temperature enhancement in the nighttime ionosphere,” *Ann. Geophys.,* **24,** 2006, pp.1871-1885.

2. K. Schlegel, “Reduced effective recombination coefficient in the disturbed polar *E*-region,” *Journal of Atmospheric and Terrestrial Physics,* **44**, 1982, pp.183-185.

3. T. Yamamoto, “On the formation of Electrostatic Shock Waves associated with auroral electron precipitation,” *Planet. Space Sci.,* **24,** 1976, pp.1073-1080.

4. Howard F. Bates, and Robert D. Hunsucker, “Quiet and disturbed electron density profiles in the auroral zone ionosphere,” *Radio Science*, **9**, 1974, pp.455-467.

5. Martin J. Berger, and Stephen M. Seltzer, “Energy deposition by auroral electrons in the atmosphere,” *Journal of Atmospheric and Terrestrial Physics,* **32,** 1970, pp.1015-1045.

6. J. D. Williams, E. MacDonald, M. McCarthy, L. Peticolas, and G. K. Parks, “Parallel electric fields inferred during a pulsating aurora,” *Ann. Geophys.,* **24,** 2006, pp.1829-1837.

7. G. J. Romick, “Review of auroral morphology, auroral dynamics and modern observational techniques,” *Radio Science,* **9,** 1974, pp.323-334.

8. K. L. Miller, and R. R. Vondrak, “A high-latitude phenomenological model of auroral precipitation and ionospheric effects,” *Radio Science,* **20,** 1985, pp.431-438.

9. P. R. Fagundes, Y. Sahai, H. Takahashi, D. Gobbi, and J. A. Bittencourt, “Thermospheric and mesospheric temperatures during geomagnetic storms at 23^0S,” *Journal of Atmospheric and Terrestrial Physics,* **58,** 1996, pp.1963-1972.

10. V. V. Belikovich, E. A. Benediktov, N. P. Goncharov, and A. V. Tolmacheva, “Diagnostics of the ionosphere and neutral atmosphere at E-region heights using artificial periodic inhomogeneities,” *Journal of Atmospheric and Terrestrial Physics,* **59,** 1997, pp.2447-2460.

11. Ya. N. Istomin, and T. B. Leyser, “Small-scale magnetic field-aligned density irregularities excited by a powerful electromagnetic wave,” *Phys. Plasmas,* **4,** 1997, pp.817-828.

12. A. Brekke, and Y. Kamide, “On the relationship between Joule and frictional heating in the polar ionosphere,” *Journal of Atmospheric and Terrestrial Physics,* **58,** 1996, pp.139-143.

13. S. T. Wu, and K. D. Cole, “Transient thermospheric heating and movement caused by an auroral electric field,” *Planet. Space Sci.,***24,** 1976, pp.727-730.

14. L. Zhu, J. J. Sojka, and R. W. Schunk, “Active ionospheric role in small-scale aurora structuring,” *Journal of Atmospheric and Solar-Terrestrial Physics,* **67,** 2005, pp.687-700.

15. W. Baumjohann, G. Gustafsson, E. Nielsen, H. Ratna, and D. S. Evans, “Latitude-integrated Joule and particle heating rates during the Energy Budget Campaign,” *Journal of Atmospheric and Terrestrial Physics,***47,** 1985, pp.27-39.

16. G. Chimonas, “The equatorial electrojet as a source of long period Travelling Ionospheric Disturbances,” *Planet. Space Sci.,* **18,** 1970, pp.583-589.