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Effect of Geomagnetic Field Curvature on Atmospheric Current Densities and Earth's Climate

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Abstract:

Clustering of particles and cloud formation affects global climate. Many factors such as pressure, currents, charge density etc cause particle clustering. In this work, the current density in the atmosphere due to non-uniformity of the geomagnetic field caused by gravity, magnetic field curvature, and the magnetic field gradient are studied. The current density of different ions caused by drift in the curved-gradient magnetic field and gravitational force is derived and calculated. The analysis is done in the F layer of the ionosphere and the result is extended to different atmospheric layers.Particle motion in a magnetic field is governed by Lorentz force. Additional forces such as gravitational and centrifugal force experienced by particles in the ionospheric plasma will drift positive and negative charged particles in opposite direction or in the same direction with different velocities resulting in current density. In this work current density of different ionospheric constituents such as N^+, O^+ and NO^+ at 300km altitude are calculated and compared, to account for cluster formation caused by current density.

IndexTerms - Gravitational field drift, Gradient drift, Curvature drift, curved-gradient field, Larmor radius and gyration frequency

I. INTRODUCTION

Charged particles in a magnetic field experiences Lorentz force. In a non-uniform magnetic field, non-uniformity will result in additional forces over to Lorentz force. Some of these additional forces will result in drifting oppositely charged species in opposite directions or in the same direction with different velocities resulting in current density. Earth's ionosphere is a plasma of ions, electrons, and neutrals existing in a dynamic magnetic field. F layer of the ionosphere is known to have the highest density of charged particles. Ionospheric current density depends on different conductivities which in turn depends on collision frequencies of ions and electrons with the neutrals. Ionospheric particle density also changes with changes in terrestrial as well as the solar environment. Earth's magnetosphere is a vast region of the magnetic field which responds to solar, interstellar and terrestrial conditions. The magnetic field of earth exhibits changes of periods ranging from fractions of seconds to thousands of years. Thus the force experienced by the ionospheric particles due to geomagnetic field is highly non-uniform.

Abbreviations

$\mathbf{j}_{curv}$ – Current density due to the combined effect of curvature and densitygradient of earth's magnetic field

$\mathbf{j}_{grav}$ – Current density due to the gravitational force experienced by ions

II. THEORY

In a uniform magnetic field, oppositely charged particles move in the same direction in a helical trajectory defined by the equations

$$(x - x_0)^2 + (y - y_0)^2 = \boldsymbol{r_L}^2$$

and

$$z - z_0 = Ct$$

Where is the Larmor radius and **z** is the direction of the uniform magnetic field.

2.1 Gravitational field drift

In the presence of an external force such as gravity, the force equation changes to

$$m\frac{d\boldsymbol{v}}{dt} = -mg\hat{\boldsymbol{\jmath}} + q(\boldsymbol{v} \times \boldsymbol{B})$$

This additional force acting in the negative **y**-direction will result in a drift in the **x**-direction in addition to normal helical motion.

This gravitational field drift is calculated as

$$\boldsymbol{v}_g = \frac{m\boldsymbol{g} \times \boldsymbol{B}}{qB^2}$$

which is charge dependent. Thus positive and negative particles drift in opposite directions resulting in a net current density in plasma given by

$$\boldsymbol{j}_g = n(M+m)\frac{\boldsymbol{g} \times \boldsymbol{B}}{B^2} \equiv \boldsymbol{j}_{grav}$$

where, M and m are the mass of ion and its electron respectively.

2.2 Gradient drift

Geomagnetic field has a spatial gradient. The field density decreases outwards. In a gradient magnetic field with straight lines of force, Larmor radius of the particle decreases with increasing field density . In such a field, electrons and ions drift in a direction perpendicular to both **B** and , and opposite to each other. This force experienced by the particle due to field gradient in the direction of the gradient is

$$\bar{F}_\nabla = \mp \frac{1}{2} q v_\perp \nabla B$$

The grad-B drift is

$$\boldsymbol{v}_{\nabla\mathbf{B}} = \pm \frac{1}{2} r_L v_\perp \frac{\boldsymbol{B} \times \boldsymbol{\nabla B}}{B^2}$$

is in opposite direction for electrons and ions and causes a current transverse to **B**. can be calculated by analysing curl in a vacuum. has only a component where,

$$B_\theta \propto \frac{1}{r}$$

And have only an **r** component. Thus can be shown that

$$\frac{\nabla|B|}{|B|} = -\frac{\boldsymbol{R}_c}{{R_c}^2}$$

where is the radius of curvature of the geomagnetic field. On substitution, the equation for gradient drift becomes

$$\boldsymbol{v}_{\nabla B} = \frac{1}{2}\frac{m}{q} v_{\perp}{}^{2} \frac{\boldsymbol{R}_c \times \boldsymbol{B}}{R_c{}^{2} B^{2}}$$

is the drift velocity of the particle in the non-gradient field and perpendicular to .

c) Curvature drift

Earth's magnetic field is curved with a radius of curvature increasing outwards. Particle experiences a centrifugal force during their thermal motion in a curved field. This centrifugal force can be obtained as

$$\boldsymbol{F}_{cf} = m v_{\parallel}{}^{2} \frac{\boldsymbol{R}_c}{R_c{}^{2}}$$

Where denotes the average square of the component of random velocity along **B.** The curvature drift (guiding center drift due to) can be written as

$$v_R = \frac{m v_{\parallel}{}^{2}}{q B^{2}} \frac{\boldsymbol{R}_c \times \boldsymbol{B}}{R_c{}^{2}}$$

which is charge dependent and thus will be opposite for ions and electrons.

The geomagnetic field is curved as well as it has a spatial gradient. Thus both gradient drift and the curvature drift can be added to get the net drift in the curved-gradient magnetic field. On adding the drifts and substituting for velocities from Maxwell's distribution, we get

$$\bar{\boldsymbol{v}}_{\nabla B+R} = \pm \frac{v^{2}{}_{th}}{R_c \omega_c} \widehat{\boldsymbol{y}} = \frac{\bar{r}_L}{R_c} v_{th} \widehat{\boldsymbol{y}}$$

depends on the charge of the species but not directly depend on its mass. The corresponding current density can be written as

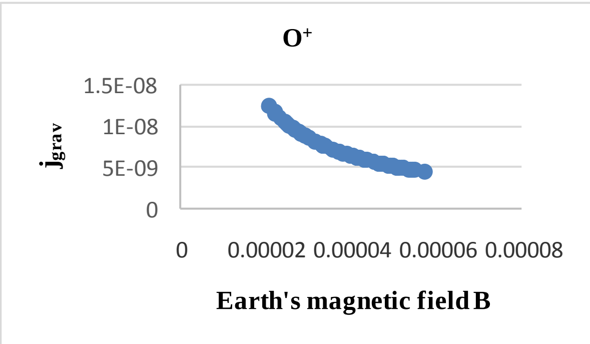
$$\boldsymbol{j}_{R+\nabla B} = n(M+m)\frac{v^{2}{}_{th}}{B R_c} \equiv \boldsymbol{j}_{curv}$$

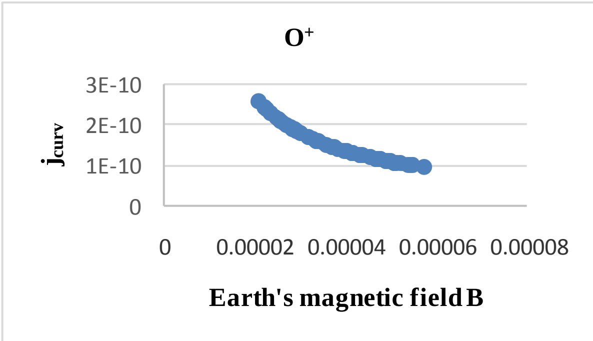
where is the thermal velocity which can be calculated as

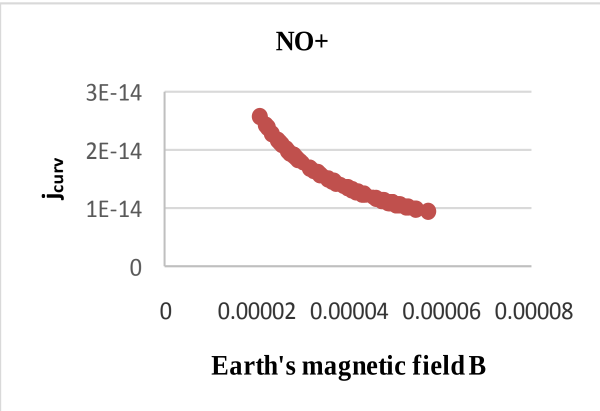
$$v_{th} = \left(\frac{2KT}{m}\right)^{1/2}$$

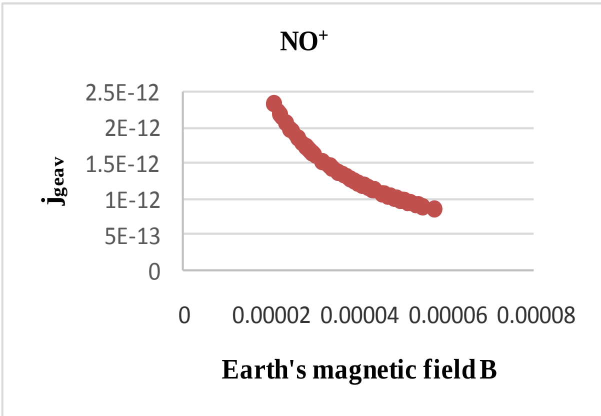
III. RESULTS AND DISCUSSION

Earth's ionosphere is divided into blocks and the current density due to gravity (**j**$_{grav}$) and curved-gradient magnetic field of the earth (**j**$_{curv}$) is calculated at different regions. Calculations are done at F layer (300 km from earth's surface) of the ionosphere. Current density (**j**) v/s magnetic field intensity (**B**) plot for different ionospheric constituents is shown below.









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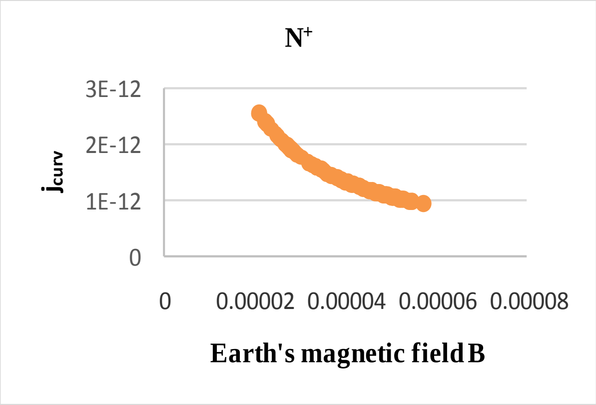

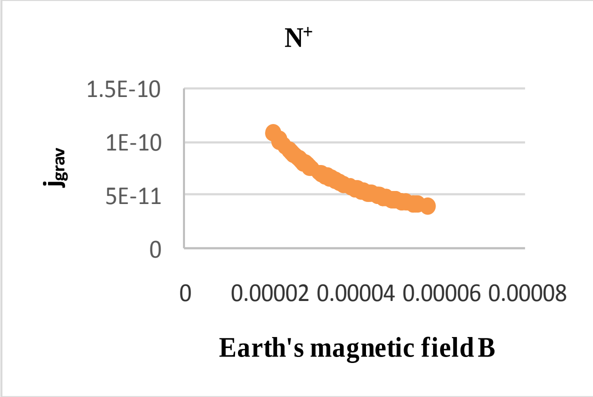

The equation of current density in the ionosphere is derived from the concept of single particle motion. Electrons and ions in a magnetic field drift in the opposite direction when acted upon by an additional force over to Lorentz force. The calculated values show that current densities decrease with an increase in strength of magnetic field **B**.

The gravity exerts a force on a particle which tends to drift ions and electrons in opposite directions, perpendicular to both **g** and **B**(i.e., along x-direction). Current density caused due to drift under gravity has values of the order 10^{-10} for N^+,$10^{-8}$for O^+ and 10^{-12} for NO^+.

The particle experiences a centrifugal force when they move through a curved-gradient magnetic field. This force tends to drift particles perpendicular to $\mathbf{R_c}$and **B**. Current density caused by curvature and gradient drift has values of the order 10^{-10} for O^+, 10^{-12} for N^+ and 10^{-14} for NO^+.

O+ ion contributes more toionospheric current density than N+ and NO+ ions. This is due to its higher concentration at F layer. Current density NO+ is much less than that of other ions. This could be due to its lower concentration as well as its higher mass which lowers its thermal drift velocity. Current density will result in clustering of molecules and cloud formation. The results could be extended to other layers also.

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