Role of Earth’s plasmasphere in coupling of upper atmosphere

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Abstract- The near-Earth space environment is a complex, ever changing system of magnetized plasmas whose behaviour has a profound impact upon our technology dependent society. The exploration of the cold, relatively dense, inner region of upper atmosphere (the plasmasphere) and its unexpectedly sharp outer boundary (the plasma pause) has proceeded through a combination of in-situ observations and ground based whistler observations. Studies have shown that plasmasphere is highly variable both spatially and temporally responding to changes in geomagnetic indices, ring current, penetration and shielding electric fields and subauroral electric fields. Consequently the plasmasphere exhibits erosion, emptying and refilling during active times. Infact, it is the electric field that plays one of the most important roles in coupling of upper atmosphere. The atmospheric dynamo is the main generator of the large-scale electric field in the upper atmosphere. It arises because of a special situation which electrons and ions move with different velocities across the magnetic field because of different collisions between electrons and neutral particles and ions with neutral particles. This process leads to charge separation and consequently to an electric field. In the present paper, storm/quiet period VLF whistler data recorded at lower latitudes/mid latitudes are analyzed and attempt has been made to look at plasmasphere response on coupling of ionosphere and magnetosphere.

Key words: Plasmasphere, Magnetosphere, Electric Field, Coupling

1. Introduction

The exact nature of the Earth’s plasmasphere, and its coupling to ionosphere and magnetosphere has long been a topic of interest. One of the primary goals has been to elucidate the physical processes that determine the quiet time structure and the dynamic variability of plasma density and temperature, as well as coupling of ionosphere-plasmasphere and plasmasphere-magnetosphere. Another goal has been to understand the physical mechanism that generates the plasmapause, and the geospace conditions under which they occur. In the present paper, influence of plasmasphere on ionospheric and magnetospheric dynamics has been discussed. Since the famous discovery of ‘knee whistlers’ by Carpenter [1], the plasmasphere and plasmapause has evolved as a bridge to understand ionospheric-magnetospheric

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dynamics. The electric fields produced in the interaction between the solar wind and the magnetosphere penetrate to geocentric distances of about 4-6 earth radii in the equatorial plane, depending on the level of magnetic activity. Within these distances low energy plasma that escapes from the ionosphere accumulates and rotates with the earth. This reason is the plasmasphere. In quiet times the plasmasphere and plasmasheet generally occupy separate regions. However, in active times the magnetospheric electric field intensity, some times impulsively, and the earthward edge of the plasmasheet is driven into the plasmasphere. During such times interaction between the cold plasma population of the plasmasphere and the hot plasma of the plasmasheet cause energy to be deposited into the upper atmosphere. During the storms a visible emission, known as the stable auroral red arc, is produced at midlatitudes on magnetic lines of force that connect.

2. Data Source and Processing

Broadband ELF/VLF radiowave data have been collected at Varanasi (geomagnetic latitude = 15º). In this paper we use data of 1991 when incoming signals in the frequency range 1.5 - 6.0 kHz were recorded on audio tape. The data were 12-bit digitized and fast Fourier transformed using the advanced VLF data analysis system (AVDAS). The resulting spectrograms were displayed on the screen and saved in digital form. For the present study the AVDAS was set to produce 0-10 kHz spectrograms with a 512 transform size. Since the famous discovery of knee whistlers and the evolution of plasmasphere and plasmapause, whistlers are produced to become more powerful diagnostic tool for probing the geospace system. The estimation of medium parameters involves various assumptions about the wave propagation and about the medium. Some of these assumptions are:

1. Whistler waves recorded on the ground propagate in a ducted mode or prolongitudinal mode along the geomagnetic field lines. Whistlers can simultaneously propagate along several ducts. For field aligned propagation of Whistler waves, the wavelength at any given wave frequency increases with the decreasing altitude (as the wave travels from the equator towards the earth surface). Due to divergent nature of geomagnetic field, the duct width decreases with decreasing altitude. The wave leaks out from the duct wherever the wavelength becomes of the same order as the duct width. As a result of the combined effect of wavelength and duct width variation, there is progressive leakage of down coming ducted waves.

2. The propagating whistler waves interact with the energetic electrons in the plasmasphere. During such an interaction, the wave amplitude may be amplified or attenuated depending upon the nature of the distribution function of the energetic electrons. It is assumed that the wave particle interaction does not influence the Whistler wave mode propagation.

3. The non-linear interaction between the electrons and the waves causes the deformation of the wave packet and hence modifies the group velocity. The effect of this deformation of the wave packet on the group velocity is neglected.

4. The plasma is considered to be cold, i.e. the effect of the thermal velocity of the electrons on the wave propagation is neglected (thermal velocity << phase velocity of the wave). Further it is assumed that \( f_{pe}^2 > f \cdot f_{He} \), where \( f_{pe}, f_{He} \) and \( f \) are the electron plasma frequency, electron gyro frequency and wave frequency respectively.

5. The geomagnetic field lines throughout the region of Whistler wave propagation are assumed to be dipolar in nature. They may be deformed during a severe magnetic storm at higher L values, but the deformation may not be appreciably changed the propagation time because the total path length is very large.
3. **Electric Fields and Plasmasphere-Magnetosphere dynamics**

The activity dependence of the plasmapause position can be estimated by equating the competing convection (cross-tail) and co-rotation electric fields. The co-rotation electric fields, pointing Earthward in the equatorial plane, is responsible for the co-rotation of the plasma inside the plasmasphere (in the EXB direction). Co-rotation field line is important in the inner magnetosphere because the large scale convection electric field can not penetrate into it. This shielding is due to zonal charge separation as the plasmasheet electrons drift downward and protons duskward around the Earth and it is related to the field aligned currents. It is not possible to shield the plasmasphere completely from the convection electric field, since these are no steady state conditions. The penetration of the convection field into the plasmasphere reduces the zonal flow in the evening sector and enhances it in the morning sector [2]. During increasing activity, stronger cross tail electric field pushes the plasmapause closer to the earth and peels off the outer layers of the old plasmasphere. Conversely, during decreasing activity plasmapause moves outward, and a slow refilling process from the day side F-region ionosphere begins. The details of this refilling are not quite understood yet, [3]. Movement and redistribution of plasma occurs both through diffusion and advection. Diffusion through the neutral atmosphere is driven by an imbalance between plasma pressure gradient and gravitational forces. Plasma advection occurs as a result of interaction and the atmospheric winds and as a result of electrodynamic drifts caused by the electric fields. Electromagnetic drifts are directed perpendicular to the magnetic field, so the geometry of the plasma advection by electric fields differs from that caused by winds. For an electric field whose strength and direction is symbolized by the vector $E$, with the magnetic field represented by the vector $B$. The mean drift velocity of both ion and electrons is perpendicular to both $E$ and $B$ and given by the vector expression $E \times B / B^2$ (neglecting the effect of collisions with neutrals). A regular pattern of plasma uplifting during the day and sinking at night occurs at the equator due to east west electric fields.

4. **Result and Discussions**

The electric field is an important parameter in the study of ionosphere-plasmasphere-magnetosphere dynamics. Out of various techniques developed to measure plasmasphere electric fields, the Whistler wave technique, based on cross L plasma drifts in the equatorial plane. The nose frequency derived from whistler spectrograms specifies the path of Whistler wave propagation in terms of L-value. Thus, measuring the nose frequency $f_n$ for successively recorded Whistlers, the variation of L with time in the equatorial plane is determined (Figure 1). Plasma drift velocity derived from Whistler data is related with the magnetospheric plasma drift caused by a large scale East-West electric field $E$. The dipolar magnetic field, $E$ is given by:

$$E = 2.07 \times 10^{-2} \frac{d}{dt} \left( f_n^{2/3} \right) \text{ Vm}^{-1}$$

Where $f_n$ is the Whistler nose frequency measured in Hz. For $df_n / dt > 0$, $E$ is directed from east to west. We have estimated the westward electric field of whistlers recorded at Varanasi in the range of 0.2-0.3 mV/m. If a large number of whistlers are analyzed then $E$ can be determined with a precision of typically 0.1 mV/m [4].
5. Conclusions

Following points emerges from the present study:
1. The electric field is an important parameter in the study of the coupling of ionosphere-plasmasphere-magnetosphere dynamics. Out of various techniques developed to measure plasmaspheric electric fields, whistler wave technique based on cross-L plasma drifts in the equatorial plane has been widely used to evaluate the east west component of electric fields.
2. Plasmasphere play the key role in the ionosphere-magnetosphere dynamics.
3. Energy from the outer regions of solar corona is now known to penetrate the boundary layers of earth’s magnetosphere in the form of kinetic drift energy of solar wind plasma. The role that electric current system plays in degrading the drift energy to heat provides an important clue in upper atmosphere dynamics.

Acknowledgements
AKS is thankful to Department of Science and Technology (DST), Government of India for providing financial support as a research project (File No. SR/SS/AS: 261/06).

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