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Short Communication

On the altitude of initiation of the gradient drift waves at different longitude sectors in the vicinity of the dip equator

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ABSTRACT

In order to understand the variation in the altitudes of initiation (h_{aoi}) of E region gradient drift (GD) waves at different longitude sectors in the vicinity of the dip equator, the linear growth rate expression was examined. This revealed that the growth rate of the primary GD waves in an altitude region of 85–93 km depends on the square of the geomagnetic field strength (B). This is shown to explain the lower h_{aoi} of GD waves over Indian longitude vis-a-vis American longitudes. The available observations on the GD waves from different longitude sectors reveal that the h_{aoi} is inversely proportional to B^2.

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1. Introduction

It is well known that E-region of ionosphere over equatorial regions supports the generation of plasma waves. The streaming plasma waves and the gradient drift waves have been measured over several years using radar (Fejer et al., 1975; Krishna Murthy et al., 1998; Tiwari et al., 2003) and *in situ* probes (Prakash et al., 1969; Klaus and Smith, 1978; Pfaff et al., 1985). The streaming plasma waves are generated in closest vicinity of the dip equator (Sekar et al., 2013), while the gradient drift waves are observed at low latitude region as well. The characteristics of these waves and the generation mechanisms are well documented (Kelley, 2009). Linear and nonlinear theories were developed to understand the measured characteristics of these waves using radar and *in situ* probes. The present investigation deals with the gradient drift waves in the lower altitude region where collisions play an important role.

The *in situ* measurements of electron densities and their fluctuations using rocket flight from Thumba, India, revealed the presence of electron density fluctuations from 87 km onwards (Prakash et al., 1969). The results from the same flight also revealed the co-existence of large (30–300 m) and small (3 m) size irregularities at 87 km altitude. The amplitude of the former is ~10–20% (Prakash et al., 1971) and the latter is 1–2%. Subsequently, the presence of electron density fluctuations at 87 km altitudes in the positive electron density gradient region during normal electrojet condition (eastward electric field) and the absence of them during counter-electrojet (westward electric field) condition (Prakash et al., 1979) suggest that the plasma instability process governs their generation. The spectral analysis based on several rocket flights conducted from Thumba revealed (Prakash et al., 1980) that the spectral indices of fluctuations above 87 km lie between -3.5 ± 1.5 indicating the plasma turbulence. On the other hand, the spectral indices of the fluctuations below 80 km lie between -1.6 ± 0.7 indicating that causative mechanism is due to neutral turbulence. Thus, the presence of these irregularities observed around 87 km is due to the gradient drift waves. These waves at lower altitude could not be damped by enhanced neutral collisions and/or by increased recombination effect in the presence of sunlit condition. In contrast to these observations over Indian sector, large and small scale size irregularities were observed only above 93 km during afternoon hours over the American sector (Klaus and Smith, 1978). The VHF radar observation from Jicamarca consisting of the temporal sequence of backscatter power of small scale size irregularities (Fejer et al., 1975) supports the above findings. The linear growth rates were evaluated based on the measurements from three different rocket flights and radar observations (Pfaff et al., 1985). Their work indicated that the growth of the irregularities by gradient drift mechanism is possible only above 93 km altitude in the American zone.

It is to be noted here that the present investigation is restricted to the vicinity of the dip equator as the vertical polarization electric field that drives the gradient drift waves is substantially reduced at the off-equatorial region. Further, it is assumed following Sudan et al. (1973) that the small-scale irregularities (a few meters) are generated as a consequence of primary gradient drift

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waves with sufficient amplitudes. In addition, as the present investigation pertains to 85–93 km altitude region where collisions dominate, isothermal condition is assumed. Based on these assumptions, the linear growth rate expression of the primary gradient drift waves is examined to address the differences in the h_{aoi} of the generation of gradient drift waves over Indian and American sectors. In this short note, the possible explanation for this difference is provided.

2. Examination of growth rate expression

The growth rate (γ_k) of the primary waves of equatorial electrojet irregularities (Sudan et al., 1973; Rogister and D'Angelo, 1970) is as follows:

$$\gamma_k = \frac{\Psi}{1+\Psi}\left[\frac{\Omega_e}{\nu_e}.\frac{\omega_k}{kL} + \left(\omega_k^2 - k^2C_s^2\right)\frac{1}{\nu_i}\right] \quad (1)$$

where

$$\omega_k = \frac{kv_d}{1+\Psi} \quad (2)$$

$$\Psi = \frac{\nu_i\nu_e}{\Omega_i\Omega_e} \quad (3)$$

and plasma scale length (L) in the vertical direction (Z) is given by

$$L = \left(\frac{1}{N}\frac{dN}{dZ}\right)^{-1} \quad (4)$$

The symbols N, ν, and Ω represent plasma density, collision frequency and gyro frequency respectively. The subscripts i and e correspond to the species ions and electrons, respectively. The symbols k, v_d and C_s denote wave number, electron drift in the zonal direction and ion acoustic speed, respectively. The primary waves in the zonal direction grow in the region whenever the growth rate γ_k is larger than the recombination rate ($2\alpha N$, where α is the recombination coefficient). The first term in Eq. (1) represents the growth of gradient drift waves while the second term corresponds to the growth of two stream waves. In the lower altitude (85–95 km) region, for the generation of gradient drift the first term is important.

The altitude variation of Ψ is large due to the exponential variation of collision frequencies. In earlier studies on equatorial electrojet, the value of Ψ is taken to be 1 around 100 km altitude (Rogister and D'Angelo, 1970) and 0.22 at 105 km (Kelley, 2009). However, the value of Ψ is much higher in the altitude range of 85–93 km, the region where the initiation of the gradient drift waves occur at different longitude sectors (to be discussed later). The present investigation aims to understand this longitudinal variation. Therefore, the values of Ψ fall in the range of a few hundred at 85 km to ~10 at 93 km. Thus, in this altitude range, the value of $1+\Psi$ can be assumed to be equal to Ψ.

Thus

$$\gamma = \frac{v_d\Omega_e}{\Psi\nu_e L} \quad (5)$$

in other words

$$\gamma = \frac{\left(\frac{E_z}{B}\right)\Omega_e}{\Psi\nu_e L} \quad (6)$$

or

$$\gamma = \frac{E_z}{BL}\frac{\Omega_i\Omega_e^2}{\nu_i\nu_e^2} \quad (7)$$

Here E_z and B are the vertical polarization field and strength of geomagnetic field respectively. Since the gyro frequencies (Ω_i, Ω_e) of ions and electrons are proportional to B, the growth rate (γ) at lower altitude is proportional to B^2.

Simultaneous measurements of electric field, electron density profiles and neutral densities from Indian and American sectors are not available to evaluate the growth rate over American (γ_A) and Indian (γ_I) sectors. Therefore, the growth rate at 93 km altitude over American zone (γ_{93A}) is taken as a reference growth rate where the systematic measurements using Jicamarca radar reveal the initiation of Type-II echoes. The other growth rates are normalized to these values.

Examining Eq. (7), it is found that the variation of collision frequencies with altitude is dominant and hence this variation is only considered for further analysis. ν_i and ν_e are proportional to neutral densities which increase exponentially as the altitude decreases with respect to the reference altitude of 93 km. Thus, the altitude variation of the growth rate can be expressed as

$$\gamma_{hA}^h = \left(\frac{E_z}{BL}\right)_A \times \frac{\Omega_i\Omega_e^2}{(\nu_{i93})(\nu_{e93})^2 e^{(3(93-h))/H}} \quad (8)$$

where 'h' is the altitude lower than the reference altitude 93 (i.e. $93 \geq h > 85$) and H is the neutral density scale height.

Therefore,

$$\frac{\gamma_{hA}}{\gamma_{93A}} = \frac{1}{e^{(3(93-h))/H}} \quad (9)$$

Assuming the similar neutral atmospheric parameters over the Indian sector, the corresponding variation of growth rate can be written as

$$\frac{\gamma_{hI}}{\gamma_{93I}} = \frac{1}{e^{(3(93-h))/H}} \quad (10)$$

3. Results and discussion

It is clear from Eq. (7) that the growth rate of primary GD waves is proportional to the square of the strength of the geomagnetic field. As the growth rate increases with geomagnetic field strength, the h_{aoi} can be expected to be less. In order to verify the possible relation between the square of the geomagnetic field strength and h_{aoi}, observations where either radar or rocket data is available in the literature containing the h_{aoi} over certain dip equatorial stations are compiled and provided in Table 1 along with the strengths of the magnetic field based on the International Geomagnetic Reference Field (IGRF) model. Fig. 1 depicts the

Table 1
Location, geographic latitude and longitude, magnetic field strength (Gauss) obtained from the IGRF model, h_{aoi} of gradient drift waves obtained from either radar or in situ measurements and the relevant references are given.

Location	Geog. lat./ long. (deg)	B (Gauss)	h_{aoi} (km)	References
Thumba	8.5N/77E	0.40	87.0	Prakash et al. (1969) and Tiwari et al., 2003
Pohnpei	6.95N/158.2E	0.33	88.7	St. Maurice et al. (2003)
Alcantara	2.33S/44.4W	0.31	91.0	Lehmacher et al. (1997)
Jicamarca	12.5S/76.8W	0.26	93.0	Fejer et al. (1975) and Klaus and Smith (1978)

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