The radar observation of vertically structured electrojet echoes and their numerical simulation

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Abstract

The São Luís (2.23° S, 44° W, dip latitude 1.3° S) radar observation of 5-meter irregularities in the electrojet region is presented. The observed irregular structures are distributed over 90-140 km altitudes and do not have any significant horizontal structures. The numerical simulation of gradient-drift instability is performed to investigate the cause of such structures.

Introduction

In this report, we present some characteristics of meter scale irregularities in the equatorial electrojet (EEJ) as observed by 30-MHz São Luís radar (de Paula and Hysell, 2003). These irregularities are extensively studied experimentally as well as theoretically since they have been first observed. The interesting aspect of EEJ echoes which has came out recently is the existence of large (~1km) waves (Kudeki et al, 1982; Swartz and Farley,1994, Patra et al, 2001). The study of large scale structures are important because they are believed to dominate the structure and dynamics of the EEJ region. They propagate horizontally and produce large scale modulations. The numerical simulations (Ronchi et al, 1991; Hu and Bhattacharjee, 1999) successfully explain the excitation of such large scales by Gradient-Drift instability (GDI). One particular feature of these studies is that such large scales have large altitude extension as large as 20-30 km which was indeed observed by the radar.

In this paper, we present an observation of EEJ region during a substorm period. The numerical simulation of GDI is performed to understand the possible cause for some of the observed characteristics.

Observation from Sáo Luís radar

In Table. 1, the radar parameters are listed. In Figure 1, we present an altitude-time distribution of signal-to-noise ratio (SNR) on a day when the substorm was present. The electrojet echoes are observed near 105 km altitude till afternoon. Unusually, they suddenly disappeared after 14:00 LT. There disappearance may be attributed to the storm effect which could possibly decelerate the electrojet. However, even during weak electrojet condition, the GDI is supposed to produce kilometer to meter scales (Ronchi et al, 1991). The absence of type-II echoes in our observation after 14:00 LT indicates that the electrojet is not only weakened by storm but it has reversed its direction. With this reversal, GDI do not find any conducive density gradient in daytime E region to grow which further explains absence of type II echoes after 14:00LT.

Table -1

IPP	2 ms
Pulse width	3.3 μs
Code length	13 bits binary code
Coherent integrations	2

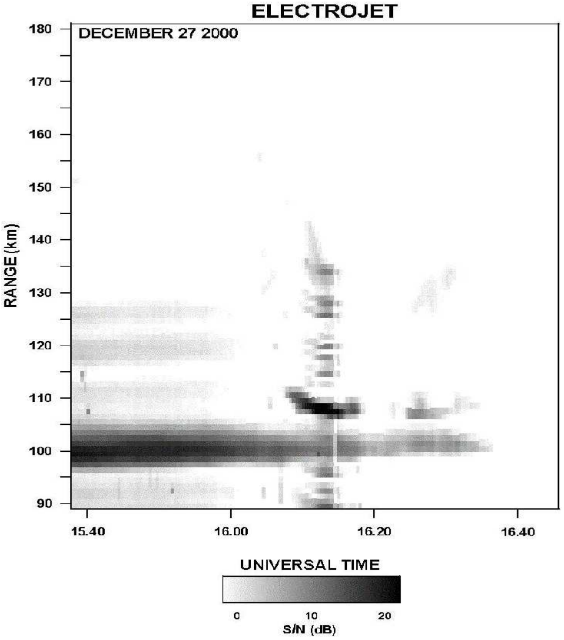

Figure - 1 The range-time-intensity (RTI) plot of EEJ echoes on 27 December 2000.

It is interesting to note the observation of altitude distribution of echoes just at the time of weakening of electrojet echoes. They are regularly distributed echoes over 90-130 km altitude region and do not have any significant horizontal structures. Though the altitude extended irregular structures are observed earlier, the horizontal structures were found to be essential and responsible for them (Ronchi et al, 1991,Swartz and Farley,1994). In this context, the present observation has some different characteristic than earlier observations. Moreover, they do not seem to be the extended structures as they are distributed in regular altitude intervals.

Numerical Simulation

In order to substantiate the existence of such structures, the numerical simulation is performed in the present investigation. Working in a plane perpendicular to the magnetic field, B**z**, we use an electrostatic, quasi-neutral, two-fluid theory of the GDI, with inertial terms neglected. The following set of equations for potential, Φ and electron number density, n, are obtained:

$$\frac{\partial^2 \phi}{\partial y^2}+\frac{\partial^2 \phi}{\partial x^2}+\frac{\partial \phi}{\partial y}\frac{\partial logn}{\partial y}+\frac{\partial \phi}{\partial x}\frac{\partial logn}{\partial x}+\mu_i \quad \frac{\partial \phi}{\partial x}\frac{\partial logn}{\partial y}$$

$$-\mu_i \quad \frac{\partial \phi}{\partial y}\frac{\partial logn}{\partial x}=-B\,\mu_i \quad \left(V_{xo}\frac{\partial logn}{\partial x}+D_i \quad \frac{\nabla^2 n}{n} \right)$$

$$\frac{\partial n}{\partial t}-\frac{1}{B}\nabla\left(n\nabla\phi\right)=-D_e\nabla^2 n$$

where x and y represent westward and upward direction respectively and

$$D_a=\frac{T}{m_a\nu_a\left(1+\kappa_a^2\right)};\ \kappa_a=\frac{\Omega_a}{\nu_a};\ \mu_a=\frac{\psi\kappa_a}{1-\psi};\ \psi=\frac{1}{\kappa_i\kappa_e}$$

$\nu_{a,}$, Ω_a are the collision and gyrofrequencies of species a while v_{xo} represents the zonal velocity.

The potential equation is solved under successive over relaxation (SOR) algorithm. The Crank-Nicholson implicit scheme+SOR is used to solve the continuity equation.
The cyclic boundary conditions for both n and Φ in the zonal direction and Neumann condition for Φ in the vertical direction are imposed. The vertical boundaries are chosen at 100 and 125 km altitudes and grid sizes Δx=50 meter and Δy=6.25 meter are chosen to resolve the tens of meter scale irregular structures.

Results

The initial density perturbation of 5% with 1 and 10 km in zonal and vertical direction are assumed. The gray-scale plot shown in fig. 2a represents the initial density perturbation over the simulation plane.The gray-scale plot shown in fig. 2b represents the density evolution at 50 seconds. The small irregular structures over regular altitude interval are evident in fig. 2b and they represent the excitation of initial density perturbation by GDI. It is interesting to note that initial density profile does not have any zero order gradient in upper E region. In spite that the GDI could excite the small initial perturbation which in non-linear stage results in small tens of meter scale irregular structures. In fact the initially given vertical perturbation acts as the first order density gradient. Since the v_{xo} is westward during daytime, the zonal perturbation of 1 km is excited by the GDI in the positive density gradients alternatively created by the vertical perturbation. Such perturbations are often observed in the ionosphere and are attributed to the gravity waves (Hines, 1974).

We would like to emphasize that the magnitude of v_{xo} is crucial for the generation of the irregularities particularly at upper E region. In our simulation, the v_{xo} is more than 100 m/s throughout the upper E region. Such values are not usual in upper E region and that may be the reason why such observations are rare. Since it is the disturbed period, the possibility of having such velocities should not be ruled out.

Conclusions

The radar observation of EEJ during substorm period is presented. The vertically structured echoes without significant horizontal structures are observed in the upper E region. The numerical simulation reveals that such structures can be generated by GDI in the upper E region itself inspit the absence of any zero order density gradient. We found that the initial perturbation which act as the first order density gradient, is responsible for the excitation of GDI. Moreover, the large zonal velocities at upper E region are found to be essential to overcome the diffusion.

Acknowledgments

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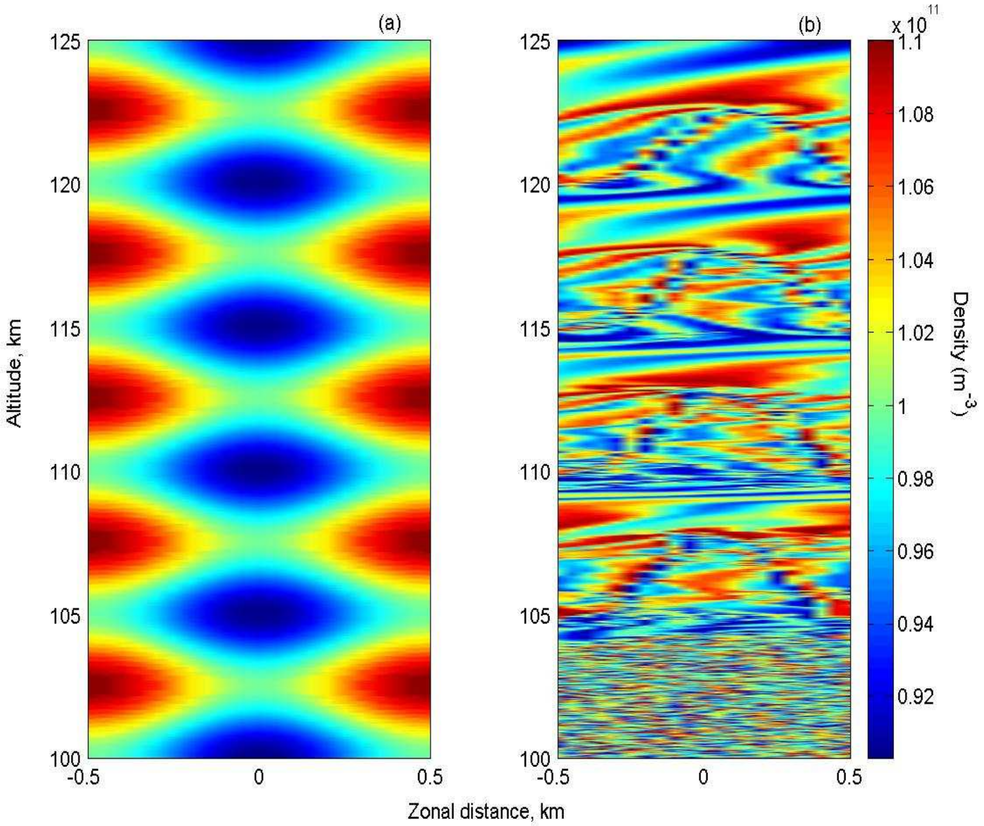

Figure 2 - The color scale density plots at (a) initial time and (b) 50 seconds.