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AN OVERVIEW ON THE STUDY OF THE EQUATORIAL ELECTROJET

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ABSTRACT

In this work, a balance on the present status of the study of the equatorial electrojet is presented. Particular attention is paid to a better understanding of what one can expect from the worldwide cooperation for the International Equatorial Electrojet Year, (IEEY) regarding the theoretical and experimental aspects. It will be seen that our limited knowledge of this phenomenon is due to the impossibility of the existing observatories to provide data with satisfactory time and height resolutions for all parameters required to test the theoretical models. We also investigate the possibility that equatorial phenomena related with the electrojet may contribute to evaluate some of these parameters.

1. INTRODUCTION

The interaction between the neutral and ionized parts of the upper atmosphere, at equatorial latitudes, is responsible for the generation of a wide range of phenomena: sporadic E layers, equatorial electrojet, spread F, plasma instabilities, etc. (see review by Rishbeth, 1979). Sporadic E layers result from a vertical tidal wind which under special conditions can confine ionization in a narrow layer located somewhere in the height range 90-115km (see Zamlutti, 1983). The equatorial electrojet is attributed to the action of tidal winds, which moving the ionosphere across the magnetic field, provoke the appearance of a current flowing along it (see review by Forbes, 1981). This occurs mainly in the height range 100-160 km. Plasma microinstabilities are produced by perturbations, on the electrostatic field responsible for the electrojet current (see Farley, 1963). Fluid type instabilities are due probably to two stream or to gradient drift amplifications processes also present at the same altitude range, namely 90-115 km (Fejer and Kelley, 1980). Equatorial spread-F is due to a collisional Rayleigh-Taylor type instability driven by an electrostatic field in the range 250-450 km (see Ossakow, 1991) which amplifies the gravity waves oscillations transferred to the ions and electrons by the neutrals. Interrelations among all these local phenomena are still not completely established in spite of the considerable efforts made so far (see Richmond, 1992 for references). The reason is that the local phenomena are sometimes strongly related to the global dynamics of both the ionosphere and thermosphere (see for example Takeda and Maeda, 1980; Fejer, 1986). A complete study of the coupling processes was presented by Schunk (1988) considering the global dynamics of the regions contained within the plasmaphere limits.

The equatorial electrojet, as part of the global upper atmosphere dynamics, can be properly studied if its theoretical model includes both the hydrodynamic and electrodynamic aspects of the problem in a self-consistent manner. This was done by Zamlutti et al (1989) and is now being implemented in numerical models (see Richmond et al 1992). The first results (Richmond et al 1992) reveal the ability of the model to study the neutral and plasma dynamics and electrodynamics in the vicinity of the magnetic equator. The past history of electrojet models can be found in Forbes (1981). Other potential models to study the global dynamics are those of Namgaladze et al (1990) and Roble et al (1988).

The new trend of trying to predict electrojet characteristics using global models can change the importance of the local measurements of electrojet behavior. Since these measurements are now used to improve the specifications of the inputs of the global models, it will be imperative to rely on high quality data rather than to worry about good space time coverage with poor resolution.

In this paper we overview the major theoretical and experimental aspects of the study of the equatorial electrojet, with emphasis on the new trends of this study. As for the theoretical aspects we compare the grounds of the new with the old theories to establish the expected differences. Regarding the experimental aspects we comment on the importance of the data collected by different techniques to complement our study.

2. THEORETICAL ASPECTS

The basic equations which describe the global self-consistent equatorial electrojet structure were presented by Zamlutti et al (1989) as:

$$\partial \underline{h}/\partial t = \delta \underline{h} - \nabla . \underline{\underline{\phi}} + \underline{f}(\underline{a}) \tag{1}$$

$$\frac{\partial}{\partial t}\begin{pmatrix} \varepsilon_0 \underline{E} \\ -\underline{B} \end{pmatrix} = \nabla x \begin{pmatrix} \mu_0^{-1} \underline{B} \\ -\underline{E} \end{pmatrix} - \begin{pmatrix} j \\ \underline{O} \end{pmatrix} \tag{2}$$

where $\underline{h}$ represents a 5-dimensional vector whose components are the density, the three space components of the momentum and the energy. The symbol δ stands for the local rate of change of the parameter which follows it. The matrix ϕ is the matrix of the fluxes of the respective parameters. The hydrodynamic parameters, h_j, are affected by the action of electric, $\underline{E}$, and magnetic, $\underline{B}$, fields. The interrelationship of these fields is described by Maxwell equations, Eqs. 2, where ε_0 and μ_0 represent respectively the permitivity and permeability of the vacuum and j denotes the local macroscopic current. Their effect on the hydrodynamic equations was specified here by the vector function of the acceleration, $f(\underline{a})$.

To completely specify the above system of equations we must characterize the various parameters involved. We start with the acceleration which is given by:

$$\underline{a}_i = \underline{g} + (e/m_i)(\underline{E} + \underline{v}_i \mathrm{~x~} \underline{B}) \tag{3}$$

where $\underline{g}$ is the acceleration of gravity, e is the electron charge, m_i is the mass of the considered particle species and $\underline{v}_i$ its flow velocity. The first components of the vectors are:

$$h_{1i} = \rho_i = n_i m_i \ , \quad \delta h_{1i} = q_i - l_i , \quad f_{1i}(\underline{a}_i) = 0$$

where ρ_i is the density of mass, n_i its number density, q_i its production rate and l_i its loss rate. The next three vector components can be comprised into vectors as:

$$\begin{pmatrix} h_{2i} \\ h_{3i} \\ h_{4i} \end{pmatrix} = \rho_i \underline{v}_i , \quad \begin{pmatrix} \delta h_{2i} \\ \delta h_{3i} \\ \delta h_{4i} \end{pmatrix} = \sum_j \rho_i \nu_{ij} \left(\underline{v}_i - \underline{v}_j \right), \quad \begin{pmatrix} f_{2i}(\underline{a}_i) \\ f_{3i}(\underline{a}_i) \\ f_{4i}(\underline{a}_i) \end{pmatrix} = \rho_i \underline{a}_i \ ,$$

where ν_{ij} is the collision frequency of particle species i with particle species j. The last components of the vectors are:

$$h_{5i} = n_i k T_i , \quad \delta h_{5i} = Q_i - L_i , \quad f_{5i}(\underline{a}_i) = \rho_i \underline{a}_i . \underline{v}_i ,$$

where k is the Boltzmann constant, T_i the particle temperature, Q_i and L_i the rates of production and loss of energy respectively. The matrix of the fluxes is such that one may separate them for the three hydrodynamic equations. One then gets:

$$\left(\nabla . \underline{\underline{\phi}} \right)_{1i} = \nabla . \left(\rho_i \underline{v}_i \right)$$

$$\begin{pmatrix} \left(\nabla . \underline{\underline{\phi}} \right)_{2i} \\ \left(\nabla . \underline{\underline{\phi}} \right)_{3i} \\ \left(\nabla . \underline{\underline{\phi}} \right)_{4i} \end{pmatrix} = \nabla . \left[\rho_i \underline{v}_i \underline{v}_i + \left(n_i k T_i \underline{\underline{I}} + \underline{\underline{\tau}}_i \right) \right]$$

$$\left(\nabla . \underline{\underline{\phi}} \right)_{5i} = \nabla . \left[1.5 \left(n_i k T_i \right) \underline{v}_i + \underline{q}_i + \underline{\underline{\tau}}_i . \underline{v}_i \right]$$

where $\underline{\underline{\tau}}_i$ is the stress tensor and $\underline{q}_i$ is the heat flow vector. There $\underline{\underline{I}}$ stands for the identity matrix. The stress tensor and heat flow vector are given by:

$$\underline{\underline{\tau}}_i = -\eta_i\left[\nabla \underline{v}_i + \left(\nabla \underline{v}_i\right)^t - (2/3)\left(\nabla . \underline{v}_i\right)\underline{\underline{I}}\right]$$

$$\underline{q}_i = -\lambda_i \nabla T_i$$

where η_i is the coefficient of viscosity, λ_i is the thermal conductivity and superscript t denotes transposed. The last parameter to be identified is the current $\underline{j}$ which is given by:

$$\underline{j} = \left(\sum_{ions} n_i \, \underline{v}_i\right) - n_e \, \underline{v}_e$$

where subscript e represents electrons.

The system of Eqs. (1) and (2) constitutes the mathematical description of the new trend to study the equatorial electrojet, which is called thermosphere-ionosphere-electrodynamic general circulation model in Richmond et al (1992). The reader may easily verify that the behavior of neutrals, ions and electrons, in the range 90-600km of altitudes, can be described by fluid dynamic equations of the form of Eqs. (1) (Schunk, 1977).

To retrieve the traditional formalism to study the equatorial electrojet we must simply consider the steady state for Eqs. (2) as well as for the momentum components of the ionized particles in Eqs. (1). When this is done we are excluding the possibility of studying simultaneously the existence of associated plasma instabilities.

The study of plasma microinstabilities can be done independently of the fluid type formulation of Eqs. (1). In fact these instabilities are studied splitting the particles' distribution function, $f\left(\underline{r}, \underline{v}, t\right)$, into two parts:

$$f = f_0 + f_1 \qquad (4)$$

(see Farley, 1963) where f_0 is the basic distribution function which governs the derivation of the fluid equations and f_1 is a perturbation which produces the plasma microinstabilities.

Perturbation f_1 depends partially on the perturbations of the electric field, $\underline{E}$, and partially on the basic distribution function, f_0 , (see Gary, 1984). At the equatorial electrojet altitudes, where collision frequencies are large, the dependence of f_0 cannot be negleted (see Gary, 1984). It is, therefore, understandable that most of the equatorial phenomena be interconnected. However, one may assume that the small perturbations due to microinstabilities do not disturb the basic electrojet flow. In this case, the hydrodynamics and electrodynamics equations constitute a self-consistent set of equations to determine the dynamics and electrodynamic characteristics of the upper atmosphere.

The solution of the system of Equations (1) and (2) in a global scale with improved resolution at equatorial latitudes seems, to date, the best form to theoretically study the equatorial electrojet. Numerical computations of this system have already started (see Richmond et al., 1992) but are still using the steady state approach for Eqs. 2 (see Richmond and Roble 1987). The success of this method depends on the accuracy to determine the driving mechanisms of Eqs. (1), namely, the chemical $\left(q_i\right)$ and thermal $\left(Q_i\right)$ local action of solar radiation on the upper atmosphere.

The theoretical predictions of the equatorial electrojet are limited by:

a) The numerical accuracy to solve the system of Eqs. (1) and (2).

b) The fitting of the inputs q_i and Q_i to existing conditions.

c) The approach or the time scale considered to account for the system memory (the dependence of the actual parameters on what happened in the past).

d) The simplifications used by the considered method to approach the system of Eqs. (1) and (2).

The advances in numerical modeling of the upper atmosphere behavior at equatorial latitudes (Richmond et al., 1992) are encouraging and expectations exist that a signficant progress can be achieved during the IEEY.

3. EXPERIMENTAL ASPECTS

If on the one hand the theory has evolved considerably in the past 10 years, on the other hand experimental techniques have had only moderate improvement. Reasons are manifold but the critical one is the high cost of equipments to provide high resolution data. We will now start our comments with ground-based techniques.

3.1 - GROUND-BASED TECHNIQUES

There are essentially two equipments which provide useful data to study the equatorial electrojet: magnetometer and radar.

a) Magnetometers

Magnetometers are probably the oldest type of equipment to study the equatorial electrojet. They are even related to the history of this phenomenon (see Forbes, 1981). The triaxial fluxgate magnetometers presentely used are essentially composed of a primary coil which, under the influence of the earth's magnetic field, transfer to a secondary coil its induction that is transformed into an electric signal. The system operates with saturated nucleus and provides information about the variations of the earth's magnetic field, necessary to compute the current flowing in the electrojet region. Unfortunately the current derived from these measurements is a height integrated value and besides contains a component from the current flowing within the earth's. The height integrated value includes not only the electrojet current but also another component due to currents flowing in the magnetosphere (see Kamide et al. 1981). At equatorial latitudes this last component may be neglected and the separation of the space and ground components can be made using a meridional chain of magnetometers (see Forbes, 1981). However, as commented on by Rastogi (1992) the space and the ground components of the current may be due to magnetospheric currents. This increases considerably the complexity of the interpretation of magnetometer data.

Among the advantages of this equipment we mention its low cost and widespread use. The disadvantage is that it provides only height integrated values of the current of difficult interpretation. One can expect magnetometers to contribute only with complementary data to be used in combination with other equipment measurements, during the IEEY besides providing a continuous monitoring of the electrojet phenomenon. It is expected that the electrojet current can be utilized effectively to study the Earth's conductivity using magnetometer data (Reddy, 1992).

b) Radars

Radar now constitutes a very important ground equipment to be used in the study of upper atmosphere phenomena. It operates in the HF, VHF or UHF ranges and the prices, quality and complexity are intimately connected. These characteristics are basically determined by two factors:

a) The required altitude resolution.

b) The nature of the target particle response.

As far as altitude resolution is concerned, one wishes an altitude resolution better than 5km which is about half the thickness of the electrojet width. Regarding the nature of the target particle response radars may observe coherent or incoherent scatter echoes. Echoes from the equatorial electrojet region are essentially coherent (see Fejer and Kelley, 1980) and are stronger when compared to incoherent scatter echoes (about 0^7 times).

Coherent scatter transmitters and receivers are much less expensive than those used in incoherent scatter since their operational system is similar to those of the usual reflection type radars. They are designed to operate in CW mode for bistatic measurements or else in pulsed mode for monostatic measurements. The description of these techniques is found in Evans (1969). The bistatic radars have the transmitter and receiving antennas at different sites and so the scattering volume is determined by the intersection of the two antenna beams. The monostatic radar use the same antenna for transmission and reception having its scattering volume controlled by the pulse width. Satisfactory antenna beams for electrojet measurements cannot be wider than 1° (pencil beams) and pulse widths no larger than 15 μsec.

Radars provide measurements of the Doppler shift, Δf, between the transmitted and received frequencies, produced by the target motion. The line-of-sight phase velocity is expressed by:

$$V_r = C\Delta f / 2f \tag{5}$$

where C is the velocity of light (in vacuo) and f is the transmitted frequency (Balsley, 1969). When this velocity is computed for the electrojet it refers to the electron velocity and may be used to derive the electric field (Viswanathan, 1990). However, since the electrojet is dominated by irregularities one observes a frequency spectrum instead of a single frequency shift (see Fejer and Kelley 1980). This spectrum gives information on the two-stream instability and the gradient drift instability, from which it is possible to determine the electrojet drift velocity (Balsley, 1969, 1973). A recent review on radar studies of the equatorial electrojet was publiched by Viswanathan (1990).

In spite of the fact that the radar constraints for good quality data collection are well known, they have not been obtained in most of the radar equipments (see Fejer and Kelley, 1980). The reason is the high cost required to get good altitude resolution together with reasonable signal strength. Therefore, it is necessary to understand what is actually measured when poor altitude resolution is employed. We give next a guide rule for these cases:

a) For beamwidth larger than 5^0 it is the geometrical and physical characteristics of the experiment which determine the altitude resolution as in Ierkic et al. (1980). The resulting data is height integrated over the entire electrojet altitude range.

b) For beamwidths around 3^0 the altitude resolution is determined by the antenna characteristics and it is possible to separate the upper and lower portions of the electrojet in the analysis of the data as in Fejer et al. (1980).

c) For beamwidths about 1^0 the altitude resolution is determined by the antenna apperture and it is possible to determine the height structure of the electrojet as in Balsley and Farley (1973) or in Fejer et al. (1975).

The poor quality radar data of item a can be used only to identify the ionosphere component of the currents measured by the magnetometers. One can use the measured height integrated values of the phase velocity or compute height averages. The radar results of item b can be employed to separate the lower collision affected part of the electrojet from the upper instabilities dominated portion of this phenomenon (see Fejer and Kelley, 1980). The radar data of item c provide information about the height structure of the electrojet and constitute the most complete ground-based result which can be collected about it.

The disadvantage of high quality radars is their high cost for both installation and operation. The advantage is that it provides a good space-time coverage for the behavior of the equatorial electrojet besides providing a satisfatory amount of information which includes: phase velocities, electric fields, frequency spectra, height structure and type of instabilities. A significant contribution is expected from these radars to elucidate mainly the following problems:

a) Dependence of phase velocity of Type I waves on the electron velocity and elevation angle
b) Interrelationship of Type I and Type II waves.
c) Effects of winds on the equatorial electrojet.
d) Disturbance-time electric fields.
according to Reddy (1992).

3.2 - IN-SITU TECHNIQUES

In situ probes carried on space vehicles can provide significant scientific data which would otherwise not be known. At the equatorial electrojet altitudes these data are obtained from instruments carried on rockets.

In principle the same instruments used in ground type observations can be carried on rockets. Thus magnetometers and radar receivers can be used, with proper case to reduce their weight and to adapt them to quick measurements required because of rocket motion.

Besides, more appropriate devices and instruments have been designed for spacecraft measurements of:
a) Electron particle characteristics;
b) Ion particle characteristics;
c) Neutral particle characteristics;
d) Electrical characteristics.

These equipments use electrical, magnetic and sometimes chemical properties of the plasma in order to evaluate their characteristics. Next we will comment on them.

a) Electron probes

These probes are designed to measure electron density and temperature. The usual Langmuir type probes use the DC characteristic which is established between the polarization voltage applied to a metal electrode immersed in a plasma and the resulting electron current (Sayers, 1970). Sweeping the applied voltage from negative to positive values it is possible to evaluate the electron temperature (retarding potentials) and the plasma electron density (accelerating potentials). The accuracy of this type of data is quite satisfactory for density evaluations (Schlegel, 1992) and even for temperature derivations (Sayers, 1970).

Other types of probes are sometimes employed as for example the RF impedance or capacitance probes, which behave, like antennas. The simple measurement of the RF impedance as a function of the frequency allows the determination of the plasma resonances, from which the electron density can be determined. High accuracy can be obtained in this way (Sayers, 1970). Capacitance type probes use metallic sensors as the frequency determining element of a stable RF oscillator in which the frequency variation is used to determine the electron density (Heikkila et al. 1968). The accuracy of this type of probes is equivalent to that of the Langmuir probes (Muralikrishna and Abdu, 1991).

High accuracy rocket measurements are required as far as electron characteristics are concerned (Pfaff, 1991). One can expect these requirements to be fulfilled for electron density data with RF impedance type probes. For temperature measurements of the low temperature plasma of the E region they will be obtained with difficulty (Schlegel, 1992).

b) Ion probes

Ion density and temperature measurements can be performed with Langmuir probes operating with negative bias. However, more effective devices were developed as the retarding potential analyser which is essentially a negatively biased grid surrouding a probe positive with respect to the ionosphere (Sayers, 1970) and is recommended for temperature measurements with 10% accuracy. More reliable data on ion density is obtained with mass spectrometers mainly those of the quadrupole type (Steinweg et al. 1992). The quadrupole consists of four circular rods, spaced in a parallel array, where RF and DC voltages are applied such that the ions injected along the axis of the rod structure are selected by their mass to charge ratio. A mass spectrum is obtained sweeping the rod voltages. The ion density is determined by the ion current collected at the end of the rod axis trajectory. The obtained accuracy is of the order 20% (Sayers, 1970).

The accuracy in determining the ion characteristics at present is satisfatory to meet the requirements for the equatorial electrojet (Pfaff, 1991). One can thus expect reliable data about the ions from rocket measurements.

c) Neutral particle characteristics.

Neutral densities are determined by impact ionization of these particles by means of an electron stream with high energy (16-18eV). Since the ion production rate is proportional to the gas density it is possible to determine this density collecting the produced ions in a retarding potential analyzer or mass spectrometer (see Arnold et al. 1977). The accuracy of these measurements can be about 40% (Friker and Lubken, 1992). The neutral temperature relates to the density by means of the differential equation:

$$d(nT)/dz = -nmg/k \tag{6}$$

(Hedin, 1965), which, integrated, yields the desired temperature. In practice an iterative procedure is necessary between the computation of densities and temperatures (see Friker and Lubken, 1992). The accuracy of temperature derivations is the same as that for densities, namely, 40%.

The requirements of accurate measurements for determination of neutral number densities to study the equatorial electrojet (Pfaff, 1991) are not expected to be met during the IEEY.

d) Electrical characteristics.

The DC electric field and currents in the lower ionosphere can be measured using an electric field double probe and a magnetometer. The DC electric field probe consists of two spaced electrodes which, when immersed in a plasma, present a voltage difference proportional to the plasma electric field. Only the component of the electric field along the axis of the two electrodes can be determined. The measurements are strongly affected by many sources of voltage differences unrelated to the desired electric field (Fejer and Kelley, 1980). Nevertheless these measurements contain essential information being thus extremelly valuable (Pfaff, 1991). The AC electric fields can now be determined by an spherical metallized plastic probe divided into six spherical segments which are connected at the center to constitute three electric dipoles perpendicular to each other (Rose, 1992). The AC electric fields are essentially the wavelike perturbations which drive the instability processes and are therefore important data for the understanding of the electrojet phenomena (Pfaff, 1991). There is no mention for the actual accuracy of the electric field data, however, a noise level of 0.5 mV/m seems always to be present.

The DC current density is measured using a triaxial fluxgate magnetometer (see Lükr, 1992). This equipment monitors the changes in the field magnitude when traversing the current sheet. The data processing involves a length procedure in order to determine the current density from the measurement (see Lükr, 1992). The results seem rather convincing to expect this type of data to be collected during the IEEY.

As could be observed, in situ data taking involves an electronic apparatus which faces many problems that range from the short period available to collected data to the highly complex structure of the observed medium. As for the data processing many drastic assumptions are made in order to derive the desired parameter from the obtained data. Nevertheless good expectations that rocket data may help to solve some outstanding problems in electrojet physics were expressed by Pfaff (1991). Most of these expectations are based on the possibility of in situ measurements of electric fields and density perturbations with satisfactory accuracy. They may be categorized as:

a) Observations of the basic electrojet structure, which include the determination of the vertical and horizontal DC electric fields, for the purpose of solving the problem of the nature and relations of the vertical electric field.

b) Observations of the unstable microscopic behavior of the electrojet, which include the determination o the AC electric fields and density perturbations, for the purpose of examining the spectral characteristics of primary and secondary wavelike phenomena and possible relations among them.

4. DISCUSSION

Our present knowledge about the equatorial electrojet phenomenon is limited both theoretically and experimentally. On the theoretical side we are constrained by the present capability of the computer programs, for modeling the upper atmosphere dynamics, to handle the large amount of complex interactions at the same time with the necessary space resolution. On the experimental side the parameters are computed grounded on the simplified expressions derived from the steady state model besides being measured most of the time with unsatisfactory space resolution. Nevertheless we have now a fair idea about the diving local mechanism for the phenomenon, a reasonable steady state model providing a macroscopic view of it and perturbation type derivations to explain the microscopic behavior of the electrojet (e.g. Forbes, 1981; Fejer and Kelley, 1980).

Based on this bounded knowledge balances about the actual unsolved problems and expectations for the IEEY were made by Rastogi (1992), Reddy (1992) and Pfaff (1991). We will consider now these evalutations grounded on what was presented in Sections 2 and 3.

The equatorial electrojet is classically attributed to the appearance of an electric field in the E layer dynamo region, where the ions are constrained to move with the neutral air wind because of the strong ion-neutral interaction $\left(\nu_i \rangle \Omega_i\right)$ whereas the electrons are free to move by the action of electromagnetic forces $\left(\nu_e \langle \Omega_e\right)$. Undergoing different forces electrons and ions move with different velocities and this produces a current flowing with magnitude:

$$-\underline{j} = n_e \underline{v}_e - \sum_i n_i \underline{v}_i . \qquad (7)$$

It is then quite desirable to measure the actual electron and ion densities as well as their respective tridimensional velocities. The simultaneous measurement of the current density is very useful to test the theory and also the equipment accuracy. The importance of measuring simultaneously all these parameters was stressed by Pfaff (1991) although not being so rigorous as to require the measurement of all ionized particle velocities. Ground measurement expectations are more modest with ionized particle densities derived from ionogram records and an integrated current density obtained using magnetometers (Rastogi, 1992).

Electric currents and fields are related by Ohm's law which in the present case is written as:

$$\underline{j} = \underline{\underline{\sigma}} . \left(\underline{E} + \underline{u} \ x \ \underline{B} \right), \tag{8}$$

valid within the equatorial electrojet range. Here $\underline{\underline{\sigma}}$ is the conductivity tensor. Therefore, to test the consistency of this simple steady state model the vector measurements of both the wind velocity and the electric field are required. This was pointed out by Pfaff (1991) for in situ observations of the electrojet phenomenon. Ground type observations just evaluate the electric field from radar measurements and use the wind velocities computed from model approximations for the thermosphere (Rastogi, 1992; Reddy, 1992). The conductivities are also evaluated from model calculations of ionized neutral interactions.

The expectations concerning the steady state model for the IEEY expressed by Pfaff (1991), Reddy (1992) and Rastogi (1992) are just that more accurate measurements of the mentioned parameters can be made to improve our limited knowledge about the phenomenon under consideration. Critical problems appear when the geophysical conditions are not favorable to employ steady state models, mainly during sunrise and sunset periods.

The equatorial electrojet irregularities are explained in terms of two-stream and gradient drift instability processes. Both of these processes are developed in terms of a linear fluid perturbation theory (see Fejer and Kelley, 1980; Farley, 1985) the relevant aspects of this theory are:

a) A wavelike perturbation, proportional to $exp\,[i\,(\underline{k}_i \cdot \underline{r} - \omega\, t)]$, is imposed on the electric field which drives similar wavelike perturbations in densities and velocities of the ionized particles.

b) The plasma oscillations may grow, becoming an instability. A dispersion relation is established which links ω to $\underline{k}_1$ and determines the conditions under which instabilities occur (Fejer et al., 1984). It is expressed by:

$$\omega_r = \underline{k}_1 . \underline{v}_d (1+\psi)^{-1} \tag{9}$$

for the oscillation frequency and

$$\gamma = (1+\psi)^{-1} \left[\nu_i^{-1} \psi \left(\omega_r^2 - k_1^2 C_s^2 \right) + \omega_r \nu_i \left(k_1 L \Omega_i \right)^{-1} \right] - 2\alpha\, n_e \tag{10}$$

for the growth rate. Here:

$$\underline{v}_d = \underline{v}_e - \underline{v}_i, \quad \psi = \nu_e \nu_i \left(\Omega_e \Omega_i\right)^{-1}, \quad C_s^2 = k\left(T_e + T_i\right)/m_i, \quad L = n_e\left(\partial n_e/\partial z\right)^{-1}$$

with Ω = gyro-frequency, α = recombination coefficient.

These aspects show that the important parameters to be determined in the study of irregularities are:

1) The amplitude of density perturbations
2) The amplitude of the electric field perturbation
3) The power spectrum of the irregularities
4) The electron density profile
5) The electric field profile

A combined experiment involving in situ and ground type measurements can give important information on these parameters. There are other parameters like electron and ion temperatures and collision frequencies which are of interest but of difficult evaluation with the presently available facilities. The above requirements were expressed by Farley (1985), who stressed the importance of other theories, besides the linear one mentioned above, to explain mainly two aspects of the observation, namely:

a) The appearance of vertically propagating waves.
b) The existence of saturation in the amplitude of instabilities.

Many questions concerning the behavior of irregularities were raised and may be found in Farley (1985). Pfaff (1991) summarized them and four aspects need to be emphasized:

i) There are somobserved spectral features which need further examination and concern to the linear theory of types 1 and 2 irregularities.

ii) The occurrence of vertically propagating waves in the equatorial electrojet require additional observations and a responsible mechanism to explain them.

iii) Much understanding is necessary about the nature of broad-band turbulence during night-time.

iv) The possibility of a plasma heating by instabilities.

The expectations concerning the study of the irregularities of the equatorial electrojet, expressed mainly by Pfaff (1991) are that the combined theoretical and experiment efforts during the IEEY be successful, to explain the above-mentioned aspects. This is a hard task regarding ground type observations since the required measurements are close to equipment sensibility. In situ measurements face a similar problem with the small currents available to evaluate the ionospheric parameters. As for the theory, the low plasma density $(\approx 10^3 cm^{-3})$ brings it to the uncomfortable position where fluid type models do not allow satisfatory modeling

From what has been seen throughout this work, one can infer that:

a) The equatorial electrojet is a localized phenomenon undergoing influences from the global dynamics.

b) It can be described as a macroscopic current flow with irregular microscopic structure dominated by instabilities.

c) Fluid type models and perturbations on them yield satisfactory results to describe their daytime macroscopic and microscopic behavior.

d) The kinetic approach should be preferred for the studies of the equatorial electrojet irregularities during night-time.

5. CONCLUSIONS

An overview on the theoretical and experimental aspects of the equatorial electrojet was presented with a final balance on the present knowledge about the phenomenon and the prospective forms of studying it. Concerning the theory, the bulk flow behavior can be described using fluid type global models and the daytime microscopic behavior derived from perturbations imposed on the parameters by a driving electric field disturbance. Night-time irregularities are better described using the kinetic approach. As far as experimental observations are concerned the present accuracy of the measurements do not allow a complete consistent set of data to be obtained, so that a test of all the features of the phenomenon be possible between theory and experimental results.

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