doi: 10.22564/rbgf.v11i3.1150

IONOSPHERIC E- AND F-REGION DYNAMOS AND THEIR EFFECTS ON THE EQUATORIAL ELECTROJET

E. Bonelli and M.A.G. Carvalho

Universidade Federal do Rio Grande do Norte
Departamento de Física, Centro de Ciências Exatas
59000-000, Natal, RN, Brasil

A dynamo model, where the E- and the F-region dynamos interact through the flow of currents along the geomagnetic field lines, is used to generate the seed electric field for the equatorial electrojet. The model calculations show that the seed zonal electric field is well-correlated with the F-region vertical plasma drifts at all local times. Effects of both the E- and F-region dynamos are present in the seeding field, showing that the electrojet can be thought of as a consequence of a large scale process, although it is localized in a narrow belt along the magnetic equator.

DÍNAMOS IONOSFÉRICOS DAS REGIÕES E e F E SEUS EFEITOS NO ELETROJATO EQUATORIAL *Usa-se um modelo de dínamo ionosférico onde as parcelas das regiões E e F interagem através do fluxo de correntes elétricas ao longo do campo geomagnético para gerar o campo elétrico básico do Eletrojato Equatorial. Os resultados do modelo mostram que o campo elétrico zonal está bem correlacionado com as velocidades de deriva verticais do plasma da região F, em qualquer horário. Os efeitos do dínamo das regiões E e F estão presentes no campo elétrico básico, o que mostra que o Eletrojato pode ser considerado como uma conseqüência de um processo de larga escala, embora esteja limitado a uma faixa estreita ao longo do equador magnético.*

THE E- AND F-DYNAMOS

We use a numerical model for the E- and F-region dynamos, which enables us to compute the polarization electric fields in the E and F regions. In the E-region, the (1,-2) tide drives the positive ions perpendicularly to the geomagnetic field, causing a polarization electric field to build up. In the F-region, zonal wind causes a similar effect. During the day, however, this dynamo is less efficient due to the increase in E-region electron density and consequent increase in the conductivity. In this case, currents flowing along the geomagnetic field lines into and out of the E-region short out the circuit, not allowing polarization fields due to the F-dynamo to build up. The two dynamos are interconnected, since the E-region electric field maps into the F-region and causes the plasma to undergo $\mathbf{E} \times \mathbf{B}$ drift. This drift changes the dynamo effects of the zonal wind and the wind itself, because it changes the relative velocities between neutrals and ions (both considered to be atomic oxygen). There is a feedback into the E-region, where the currents flowing between the E- and F-regions affect the calculation of the electrostatic potential (Farley et al., 1986).

The geomagnetic field is assumed to be dipolar with the dipole's axis coincident with the earth's axis of rotation. Furthermore, symmetry between the two hemispheres is assumed, so that no current flows across the equatorial plane. The consequence of these two assumptions in the calculation results is that the electrostatic equipotential lines are perpendicular to the equatorial plane for latitudes up to 15 degrees.

This is an extension of the model by Heelis et al., (1974). We moved further toward self-consistency by solving the continuity equation for the F-region electron density simultaneously with both the F-region zonal wind and plasma drifts (Bonelli and Farley, 1990). To attain this self-consistency, we solve the equation for the zonal thermospheric wind (equation 1 of Heelis et al.) in an explicit form, where the solution is updated for all heights at each point in the latitude-longitude mesh, using a method given by Potter (1980). For each of these points in the horizontal mesh, the continuity equation for the electron number density is also explicitly updated for all heights, with the new electron number density entering immediately in the wind equation as the ion number density (since the plasma is assumed to be neutral). The continuity equation is given by

$$\frac{\partial N}{\partial t} = q - l(N) - div(N\mathbf{V_i}), \qquad (1)$$

where N is the electron number density, q is the production rate and $l(N)$ is the loss term, given by

$$l(N) = \alpha N^2 + \beta N, \qquad (2)$$

with q, α, and β chosen from a table in Rishbeth and Garriot (1969), for solar maximum conditions at 300 km and calculated for other heights using adequate scale heights. For q we use a Chapman production function modulated by a $cos(\chi)$ factor to give the daily variation, where χ is the solar zenith angle. The last term in the equation is the divergence of the flux of electrons, where $\mathbf{V_i}$ is the plasma drift velocity.

The solution of the continuity equation with different boundary conditions and loss coefficients is important for the pattern of the drifts and currents. It is important to notice, however, that this self-consistency is not necessary for the connection between the low latitude dynamo and the equatorial electroject. It will only make the drift results more realistic. The connection between the equatorial electrojet and the low latitude dynamo is already present in the model of Heelis et al. (1974), but it was not dealt with by those authors.

THE SEED ELECTRIC FIELD AND THE ELECTROJET

A minor result from the whole dynamo calculation is the equatorial zonal electric field in the E-region, $\mathbf{E_0}$. Due to the small thickness of the E-layer, as compared to its horizontal dimensions, the Hall currents due to $\mathbf{E_0}$ cause a vertical electric field to build up. In the equilibrium situation, this field has magnitude $(\sigma_H/\sigma_P)E_0$, where σ_H and σ_P are the Hall and Pedersen conductivities (e.g., Kelley, 1989). This vertical electric field causes the electrons to drift with velocity $-(\sigma_H/\sigma_P)\mathbf{E_0}/B$, where B is the intensity of the geomagnetic field. Since the motion of the ions is collision-dominated in the E-region, the electron drift corresponds to an electric current, which is the equatorial electrojet.

COMPARISON BETWEEN CALCULATED ELECTROJET AND VERTICAL F-REGION PLASMA DRIFTS

As discussed for the E- and F-dynamos, the elec-

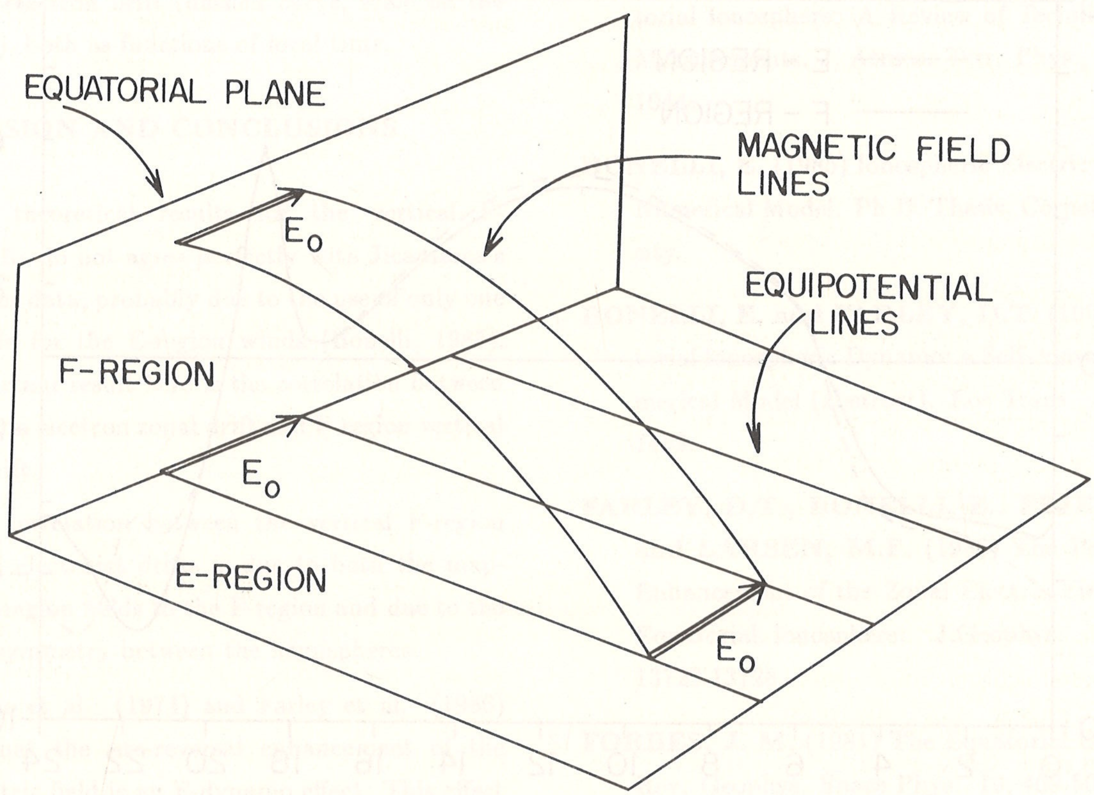

Figure 1. A sketch of the mapping of the E-region electrostatic field into the F-region equatorial plane, exemplifying the correlation between the zonal field in the two regions.

Um esboço do mapeamento do campo eletrostático da região E no plano equatorial da região F, exemplificando a correlação dos campos zonais nas duas regiões.

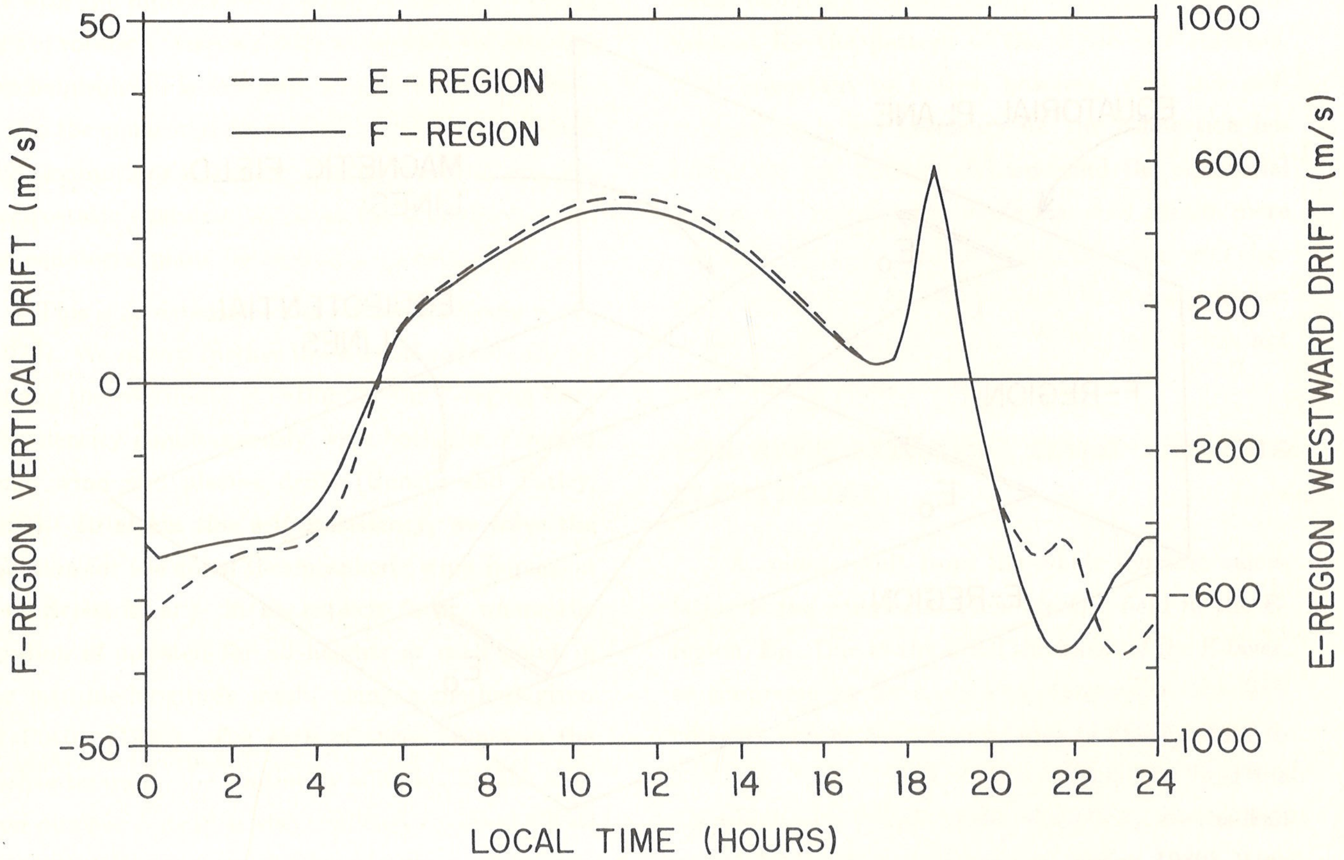

Figure 2. Vertical F-region plasma drift (solid line, scale on the left side axis) and E-region westward electron drift (dashed line, scale on the right side axis).

Deriva vertical do plasma na região F (linha cheia, escala do eixo esquerdo) e deriva dos eletrons da região E equatorial para Oeste (linha tracejada, escala do eixo direito).

trostatic equipotential lines are perpendicular to the geomagnetic equator. For this reason, there is a correlation between the zonal electric field in the F-region, which maps from the E-region, along the lines of geomagnetic field, and the zonal equatorial electric field, which is the seed field for the electrojet (Fig.1). This correlation is exemplified in Fig. 2, where we show the vertical F-region plasma drift at 500 km of altitude (solid line, scale on the left axis) and E-region westward electron drift (dashed curve, scale on the right axis), both as functions of local time.

DISCUSSION AND CONCLUSIONS

The theoretical results for the vertical F-region drifts do not agree perfectly with Jicamarca's backscatter data, probably due to the use of only one tidal mode for the E-region winds (Bonelli, 1985). The important result here is the correlation between the E-region electron zonal drift and F-region vertical plasma drift.

The correlation between the vertical F-region drifts and electrojet drifts is due to both the mapping of E-region fields to the F-region and due to the assumed symmetry between the hemispheres.

Heelis et al. (1974) and Farley et al. (1986) showed that the pre-reversal enhancement of the zonal electric field is an F-dynamo effect. This effect gets reflected in the electrojet drifts, as can be seen in Fig. 1, around 19 hours. This correlation is also extremely high in experiments, as shown by Balsley (1973) for Jicamarca data.

The idea that the electrojet is due mostly to non-local global dynamo has already been discussed by other authors with respect to the E-region dynamo (e.g., Forbes, 1981).

The local effects of electrojet plasma turbulence on the E- and F-region drifts correlation remain to be investigated since during turbulence the concept of an equilibrium vertical electric field in the E-region, as discussed previously would be meaningless.

REFERENCES

BALSLEY, B.B. (1973) Electric Fields in the Equatorial Ionosphere: A Review of Techniques and Measurements. J. Atmos. Terr. Phys., 35, 1035-1044.

BONELLI, E. (1985) Ionospheric Electric Fields: a Numerical Model. Ph.D. Thesis, Cornell University.

BONELLI, E. and FARLEY, D.T. (1990) Equatorial Ionospheric Dynamo: a Self-consistent Numerical Model (abstract). Eos Trans. AGU, 71, 1489.

FARLEY, D.T., BONELLI, E., FEJER, B.G. and LARSEN, M.F. (1986) The Prereversal Enhancement of the Zonal Electric Field in the Equatorial Ionosphere. J.Geophys. Res., 91, 13723-13728.

FORBES, J. M. (1981) The Equatorial Electrojet. Rev. Geophys. Space Phys., 19, 469-504.

HEELIS, R.A., KENDAL, P.C., MOFFETT, R.J., WINDLE, D.W. and RISHBETH, H. (1974) Electric Coupling of the E and F-regions and its Effect on F-region Drifts and Winds. Planet. Space Sci., 22, 743.

KELLEY, M.C. (1989) The Earth's Ionosphere: Plasma Physics and Electrodynamic. Academic Press, San Diego, 487 pp.

POTTER, D. (1980) Computational Physics. John Wiley and Sons, New York, 304 pp.

RISHBETH, H., and GARRIOTT, O. K. (1969) Introduction to Ionospheric Physics. Academic Press, New York.

Submetido em 05.03.93
Revisado em 17.07.93
Aceito em 29.07.93
Editor responsável V.W.J.H. Kirchhoff

Palavras chave	Key words
Ionosfera	Ionosphere
Dínamo	Dynamo
Eletrojato	Electrojet