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Low latitude vertical drifts due to intensified electric fields on the F2-region during storm conditions

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Summary. — The low latitude and longitude effects of an enhanced electric field on the daytime ionospheric F2-region are analyzed using a simple model. The calculations performed have been applied to the early stages of a geomagnetic storm, when the magnetospheric electric field is intensified. For storms with commencement near local noon it has been found that the electric field effect on the vertical drift and peak electron density of the F2 region is pronounced at equatorial latitudes, decreasing with increasing latitude, which indicates a smoothing of the equatorial anomaly shortly after the geomagnetic storm starts. The results obtained with the model are in concordance with experimental observations.

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1. – Introduction

It is well known that an east-west electric field plays an important role at the magnetic equator. It produces an upwards electrodynamics drift of ionospheric plasma in conjunction with the geomagnetic field at daytime. Ionization diffuses along the geomagnetic field lines toward higher latitudes, thus causing a depletion of electron density around the equator and two peaks (crests) on both sides of the equator. This effect is called the Appleton or equatorial anomaly.

During the initial stages of geomagnetic storms, a temporary enhancement of the eastward-directed electric field is produced. This enhancement increases the upward drift and a subsequent drainage of ionization from equatorial latitudes occurs.

Equatorward thermospheric winds developed during storm periods also play an important role in the equatorial F region. These winds oppose the poleward transport of ionization along the magnetic field lines. This prevents the formation of equatorial anomaly and generates depressed values of electron density in the anomaly crests regions and enhanced values near the equator [1]. However, this effect is expected to be seen with a delay with respect to the storm commencement since a few hours are required for the generation and propagation from high to low latitudes of these storm winds. Therefore, it is reasonable to assume that the effects at low latitudes during the initial phase of geomagnetic disturbances are mainly caused by an enhanced electric field of magnetospheric origin.

The aim of this paper is to examine the response of the daytime ionosphere at equatorial and low latitudes to an increased electric field produced during the initial phase of a geomagnetic storm, when the meridional wind effects are not yet significant. In particular, the latitudinal and longitudinal variations of the upward drift and of the peak electron density of F2 layer in the early stages of storms are shown by using a simple model based on equations already published.

2. – Theory

An eastward electric field **E** in the presence of the geomagnetic field **B** produces a vertical plasma drift given by [2]

$$v_E = (E/B)\cos I\,, \tag{1}$$

where I is the dip angle.

By assuming a dawn-dusk electric field produced in the magnetosphere and mapped into the ionosphere, it can be shown that the plasma undergoes a vertical drift given by [3, 4]

$$v_E = (-E_0/B_0)(1 + h/R_{\mathrm{E}})^3 F(\lambda)\cos(\pi t/12)\,, \tag{2}$$

where

$$F(\lambda) = \sec^2\lambda/(1 + 3\sin^2\lambda)\,, \tag{3}$$

with λ the magnetic dipole latitude, E_0 the magnetospheric dawn-dusk electric field in the equatorial plane, B_0 the magnetic flux density at the ground and at the geomagnetic equator, h the height, t the local time and R_{E} the Earth's radius. Equation (2) is valid for $h \ll R_{\mathrm{E}}$.

At any instant the F2 peak has a reduced height z_m and an "equilibrium" height z_b. In the absence of vertical drift, z_b is determined by the relation between the loss β and the rate of diffusion d (which are assumed to vary exponentially with height in the form $\beta(z) = \beta_0 e^{-Kz}$ and $d(z) = d_0 e^z$):

$$z_b = \{\ln(\beta_0/d_0) - \ln L\}/(K + 1)\,, \tag{4}$$

where $L = \beta(z_b)/d(z_b)$ and K is the mass ratio of molecular nitrogen to atomic oxygen ($K = 1.75$).

The reduced height z_m (determined by assuming a steady state, that is: $\mathrm{d}z_m/\mathrm{d}t = 0$) is displaced from its undisturbed "equilibrium" height z_b to a "perturbed" height, due to the vertical drift (2):

$$z_m = z_b + f(v_E)\,, \tag{5}$$

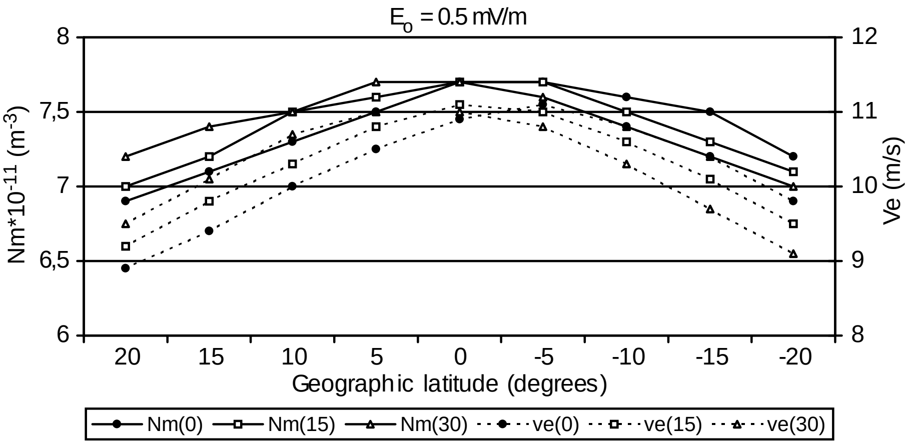

Fig. 1. – Vertical drift and peak electron density values *vs.* geographic latitude for $E_0 = 0.5$ mV/m at different longitudes (0°, 15° and 30°).

where $f(v_E)$ is related to the drift velocity by

$$f(v_E) = C_W v_E / H d(z_b)\,. \tag{6}$$

The peak electron density N_m is determined by the relation

$$N_m = q_m / C_0 \beta_m\,, \tag{7}$$

where q_m is the production rate evalued at the level of the peak and $\beta_m = \beta_0 e^{-Kzm}$. Equation (7) can be obtained from the assumption $\mathrm{d}N_m/\mathrm{d}t = 0$.

The production rate follows the Chapman law:

$$q_m = q_0 \exp\Big[1 - z_m - \sec\chi \exp[-z_m]\Big]\,, \tag{8}$$

q_0 being the production rate when the Sun is overhead and χ the solar zenith angle.

The parameters used in eqs. (6)-(8) are [5]: $q_0 = 5.3 \times 10^{-8}$ m^{-3}s^{-1}; $\beta_0 = 0.015$ s^{-1}; $d_0 = 2.5 \times 10^{-5}$ s^{-1}; $L = 0.6$; $H = 50 \times 10^3$ m; $C_0 = 1.25$; $C_W = 1.25$.

The constants L, C_0 and C_W are dimensionless and change at different periods of the day. The values considered here are valid at daytime.

3. – Results

Vertical drift and peak electron density values during quiet and perturbed conditions were computed using two values of E_0: 0.5 mV/m and 2 mV/m, respectively. The second value of E_0 was selected taking into account that under moderately disturbed conditions the magnetospheric electric field takes values of 1-2 mV/m [6]. All the calculations are carried out for equinox at 15 LT. The value utilized for B_0 was 3.2×10^{-5} T.

Figure 1 shows the equatorial and low geographic latitude upward drift (dashed lines) and peak electron density (solid lines) of the ionospheric F2 region at different geographic longitudes (0°, 15° and 30°) for $E_0 = 0.5$ mV/m. The calculated values of v_E at low

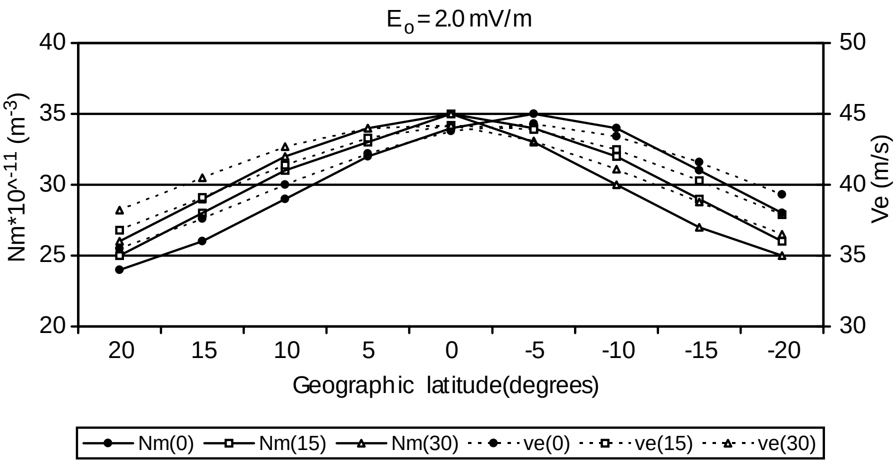

Fig. 2. – The same as fig. 1 but for $E_0 = 2.0$ mV/m.

latitudes are consistent with both measurements obtained at Jicamarca (12° S; 77° W) during quiet conditions corresponding to east-west electric fields of the order of 0.5 mV/m [7] and results derived from a recent global empirical model [8], which confirm the model predictions during quiet magnetic conditions.

The corresponding peak electron densities present the largest values at latitudes around the geographic equator at all the longitudes. At low latitudes, they decrease with increasing longitude in the south hemisphere and increase in the north hemisphere.

Figure 2 is the same as fig. 1, for $E_0 = 2.0$ mV/m. As expected, for the largest electric field greater values in drift velocities and peak electron densities are produced. The greatest values are presented between 0° and –5° geographic latitude. A slow decay is also produced when latitude increases. The longitudinal variations of both parameters are smaller than the latitudinal variations. Vertical velocities measured at Jicamarca during magnetically disturbed days [7] are of the same order of magnitude as that obtained with the model.

The results obtained for N_m are supported by observations during geomagnetic disturbances which indicate that they are more significant around the geographic equator and at low latitudes (for example, [9, 10]). The crests of the equatorial anomaly in both hemispheres are not observed. This is due to the fact that the model does not consider the "fountain effect" in which the ionospheric plasma diffuses along magnetic field lines to subtropical latitudes.

4. – Conclusions

The initial effect of an enhanced electric field at equatorial latitudes is to produce largest vertical drifts and consequently a faster uplifting of plasma. The uplifting of ionospheric layers to greater altitudes where fewer molecular constituents are present produces positive storm effects (increases of peak electron density). At low latitudes also positive storm effects are produced, but of smaller magnitude. Enhanced N_m values at low latitudes in a stormy day when the onset of the geomagnetic storms is produced around local noon have been observed [11]. Also it has been found that several hours after the storm onset the equatorial anomaly tends to disappear during magnetic storms: above the magnetic equator the electron concentration in a disturbed day is greater than that in a quiet day [12]. This effect is attributed to storm-time winds as is mentioned above.

Thus, the initial behavior of N_m indicates a smoothing of the equatorial anomaly shortly after the commencement of the geomagnetic storm when the magnetospheric electric field is enhanced.

The ionospheric behavior is highly variable during storm conditions and the assumptions used in the formulation of the model may be inaccurate in some cases not describing exactly the ionospheric parameter variations; however, from the concordance observed between experimental and computed values, it is reasonable to conclude that the model allows to obtain a good approximation of the order of magnitude of the initial upward drift and of the peak electron density of the F2 region, which may have applications to predict and describe some of the storm effects in the equatorial F2 layer.

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