Revista Brasileira de Geofísica; 1985, Vol. 3, 103-106

doi: 10.22564/rbgf.v3i2.1024

EFFECTS OF IONOSPHERIC BUBBLES ON F-REGION PLASMA DRIFTS AT THE EQUATOR

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A model for the ionospheric electrodynamics that takes into account the affects of both E-region and F-region dynamos has been developed in this research. The effect of ionospheric plasma bubbles (plasma depletions) on the equatorial F-region zonal plasma drifts have been estudied in this work. Some of the nightime results are: 1. The plasma drift inside the bubble lags behind that of the background plasma; 2. The presence of a bubble might affect measurements of plasma drifts based on ionospheric irregularities; 3. The field aligned currents inside a bubble are reduced in magnitude, and may even reverse direction for large plasma depletions (depletions larger than 80%).

Desenvolveu-se um modelo para a eletrodinâmica da ionosfera, que considera os efeitos da região E e da região F. Estudou-se o efeito das bolhas no plasma ionosférico (depleções no plasma) nas derivas zonais do plasma da região F equatorial. Alguns dos resultados correspondentes ao período noturno são: 1) O plasma dentro da bolha tem uma velocidade de deriva menor que a do plasma de fundo; 2) a presença da bolha pode afetar as medições de derivas de plasma que são baseadas em irregularidades ionosféricas; 3) as correntes paralelas ao campo magnético, dentro da bolha, são reduzidas em magnitude, podendo até mudar de sentido para grandes depleções no plasma (depleções maiores que 80%).

INTRODUCTION

The sun, through heating, and the moon, through gravitation, cause the earth's upper atmosphere to develop pressure gradients. These gradients, in turn, cause air motion with periods of solar and lunar days, and their harmonics. These winds are called "tidal" winds, by analogy with the ocean tides, and flow mostly horizontally at heights above 60 km.

Tidal winds blow the ionospheric ionization along and, if there is a component of motion perpendicular to the geomagnetic field, polarization electric fields may appear. This process is usually referred to as the "ionospheric dynamo" and is the basis of this work.

The conductivity in the ionosphere depends strongly on the neutral and charged particle densities and on the direction of the magnetic field. For this reason, it changes with height, latitude, and longitude. These spatial gradients are important for the dynamo theory because by preventing a uniform flow of electric currents, driven by the winds, they cause polarization electric fields to build up. These fields, in turn, cause the initial currents to change, in a self-consistent way. The current network so established causes the fluctuations of the magnetic field, as observed on the ground.

Until a decade ago (Rishbeth, 1971a, b), the dynamo process was supposed to take place only in the range from 90 to 140 km, the ionospheric E-region, where the transverse (to the magnetic field) conductivities are larger than at any other height. The electrical conductivity along the magnetic field lines, though, is always large, so that the E-region polarization electric fields are "mapped" into the F-region around 400 km. There, these fields cause the plasma to exhibt an **E X B** drift. These fields are not shorted out due to the fact that the F-region perpendicular conductivities are much smaller than the E-region ones.

From the work of Rishbeth (1971a, b), we now know that the electric fields in the F-region are not due only to the E-region dynamo: they have a contribution from the F-region dynamo, driven by thermospheric winds, also of tidal nature. During the day, the F-dynamo electric field is shorted, in the E-region, due to the high conductivity there. At night, however, the E-region conductivities are much smaller (Rishbeth & Garriott, 1969), and the F-region can generate electric fields that are larger or comparable to the ones due to the E-dynamo.

Models based on the above description of the dynamo process have been carried out with success (Heelis et al., 1974; Bonelli et al., 1984). Now we consider the effects of ionospheric bubbles on the dynamo electric fields. Ionospheric bubbles are plasma depletions (enhancements) originated due to Rayleigh-Taylor instabilities at the bottom of the F-region (around 300 km). The east-west typical dimension of a bubble is of order of hundreds of kilometers (e.g., Kelley & McClure, 1981). From the above discussion on dynamo theory, we see that extra density gradients may alter the electric fields. It is the purpose of this work to show that this effect actually occurs.

THE MODEL

The present model is a modification of the model of Hellis et al, (1974). It considers a thin (negligible width) E-region and a realistic F-region, where we take into account height profiles of the wind field, of the electron and neutrals density. The model atmosphere used is that of Jacchia (1977), while the experimental parameters are from Heelis et al. (1974).

A brief description of the model is as follows: in the F-region, thermospheric winds generate polarization electric fields, perpendicular to the geomagnetic field. Because the magnetic field lines can be considered as equipotential lines (Farley, 1960), these F-region generated electric fields can be partially shorted by the E-region below, through field-aligned currents. In the E-region, the model considers a height integrated conductivity tensor and an "effective" wind, which flows in a thin layer. In this region, an electrostatic potential, which represents the polarization electric field, is calculated taking into account the flow of current into (and out of) the upper boundary of the layer. From this potential, we calculate the E-region electric fields. These fields, in turn, map into the F-region affecting the plasma motion and consequently, changing the field-aligned currents. For this reason, the model is solved self-consistently. For details about the numerical computations, the reader is referred to the paper of Heelis et al. (1974).

Now we present a simple model for an ionospheric bubble. In the vertical direction, the bubble density is given by

$$n_B = N\{1\text{-}d\exp[-0.5\,(R-H_B)^2/Z_B{}^2]\}$$

where Z_B is a vertical characteristic size of the bubble, H_B is the height of its center, R is the height where we want to calculate the plasma density. Here d is the bubble depletion, given by $d = 1 - n_{B0}/N$, where n_{B0} is the plasma density at the center of the bubble, and N is the background plasma density. In the approximation used in this work, the motion of the bubble is not taken into account, this is because our calculation is done for a single universal time. The results for the different local times represent the point of view of observers at different longitudes.

Our finite difference solution has resolution of 10 km in altitude and of 500 km in longitude. The later is too large when we compare it to the size of a typical bubble, which is of 100 km (see, for example, Kelley & McClure, 1981). For this reason we will only consider effects on the vertical electric fields, which depend mostly on the vertical gradients in the plasma density.

RESULTS AND CONCLUSION

We calculated winds, currents and electric fields for both the no-bubble case and for the case including a bubble. In both cases the ionospheric and solar parameters were the same so that the difference between the results would be due only to the inclusion of the plasma depletions in the calculations.

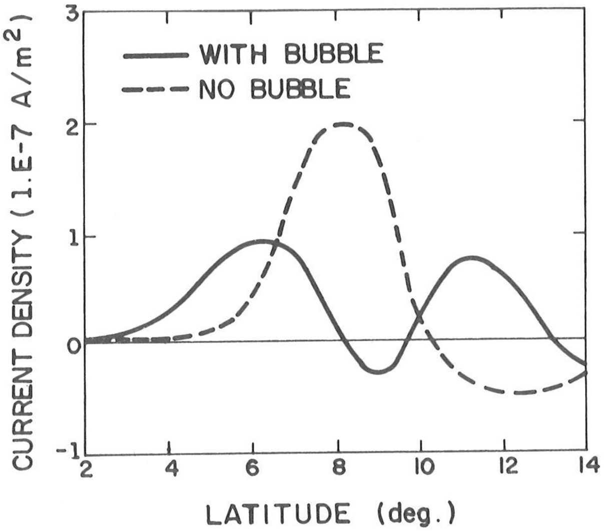

Figura 1 — Field aligned current density at the 2000 LT meridian, as a function of latitude at the top of the E-region.

In Fig. 1 we show the field aligned current density flowing out of the E-region for 2000 local time, as a function of the latitude where the field lines enter the E-region. The solid line represents results for a bubble at 350 km, with a maximun depletion of 80%. The dashed line represents currents for the nobubble case. The effect of the field aligned depletion is to reduce the field aligned current inside a given flux tube, being able to even reverse it inside the tube where the depletion is maximum (flux tube at 8° in Fig. 1).

Fig. 2 shows the eastward (west to east) plasma drifts as a function of height at 2000 local time. As for Fig. 1, the solid line corresponds to the case including a depletion, and the dashed line corresponds to the no-bubble case. Inside the bubble (around 350 km), the plasma drifts more slowly than the neighboring plasma. In the figure we see that the center of the bubble actually drifts westwards! This is not surprising, since around this local time the E-region dynamo contributes with an upward electric field. Since the F-region does not drive the bubble strongly, the E-region may dominate drifts in the case of strong plasma depletions. The reversal of the drifts at around 600 km is not related to the problem of bubbles and will be discussed elsewhere.

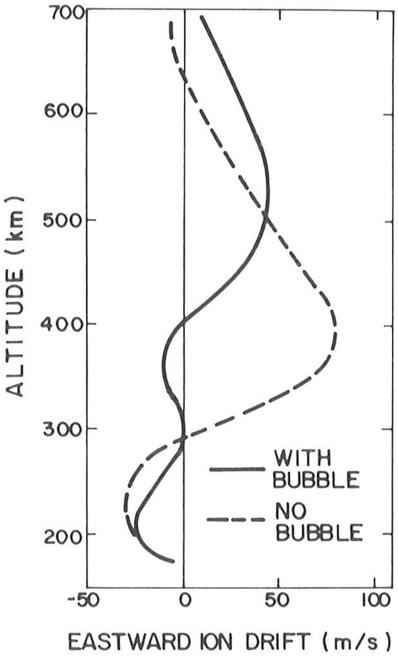

Figura 2 — Eastward ion (plasma) drift at the equator, as a function of height, at 2000 LT.

Kudeki et al. (1981) present some few drift measurements where the reversal of the zonal drift occurs at higher heights for later times, between 1900 and 2000 hours, local time. In Fig. 3 we see that the presence of a bubble could explain this result. Without the bubble, the reversal of the 1900 hours, local time, profile (light dotted line) occurs above the reversal of the 2000 LT profile (light solid curve). After the inclusion of a bubble in the calculation, however, the situation is changed, and the 2000 LT reversal (heavy solid line) occurs at a higher height than for the 1900 LT profile (heavy dotted line). This suggests that Kudeki et al. (1981) might be observing the bottomside of a very large plasma depletion.

Another interesting result is that although the drifts and currents are reduced around the bubble, they are enhanced outside it, as compared to the no-bubble results. These enhancements occur several bubble-lengths away from the bubble. This suggests that, in experiments, we should look for long range effects of plasma depletions.

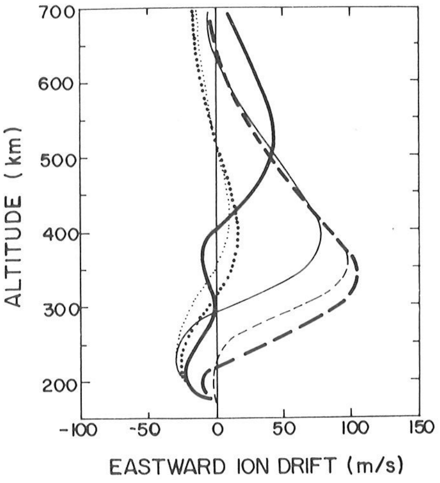

Figura 3 — Eastward ion (plasma) drift at the equator, as a function of height, for 1900 LT (dotted lines), 2000 LT (solid lines), and 2100 LT (dashed lines). For each line style, the heavier one indicates results including a bubble.

This discussion would not be complete if we did not mention the effect of plasma enhancements and of a mixture of plasma depletions and plasma enhancements, as this actually is the case in the ionosphere [e. g., Yeh et al., 1979]. A plasma enhancement would have the opposite behavior of a plasma depletion: it would drift faster than the background plasma. Furthermore, a mixture of depletions and enhancements creates a complicate pattern of vertical electric fields and consequently of eastward drifts. For this reason we should expect that drift measurements would show oscillations around a mean value, of walelengths equal to the bubbles east-west characteristic sizes.

ACKNOWLEDMENTS

I thank Cornell University Space Plasma Physics Group for letting me use their Harris H-800 computer to do the calculations of the present work. Thanks are also due to Mr. José Pereira de Lima, who made the drawings.

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Versão original recebida em Jul./85;
Versão final em Jun./86.