EQUATORIAL PLASMA BUBBLE DEVELOPMENT AND DYNAMICS, AND SPORADIC E LAYER STRUCTURING, UNDER DISTURBANCE ELECTRIC FIELDS.

M. A. Abdu[1, 2], A. M. Santos[1], J. R. Souza[1], I. S. Batista[1], J. H. A. Sobral[1]

[1] Divisão de Aeronomia, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 12227-010, São Paulo, Brazil.
[2] Instituto Tecnológico de Aeronáutica (ITA), DCTA, São Jose dos Campos, Brazil.

This paper was prepared for presentation during the 14th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 3-6, 2015.

Abstract

Disturbance electric field during space weather events can cause severe modifications in the Equatorial and low - midlatitude ionospheric plasma dynamics and related phenomenology. Penetration electric fields, of under-shielding or over-shielding types, and disturbance dynamo electric field can cause anomalous development of plasma bubbles even during their non-occurrence season, or can lead to suppression of their normal development. These effects are dependent on the local time and longitude of the observations. Large changes in the Hall and Pedersen conductivities can occur due to storm induced extra E layer ionization or modifications in F layer plasma density, as a result of which the penetration electric fields may produce, among other effects, (1) plasma bubble zonal drift velocity reversal to westward, (2) large/abnormal F layer plasma uplift, (3) sporadic E layer disruption or its formation with instabilities. Beside these effects, the equatorial ionization anomaly is known to suffer latitudinal expansion and retraction. In this paper we will discuss some outstanding response features of the low altitude ionosphere under disturbance electric field as diagnosed by Digisondes, radars and optical imagers in the South American longitude sector, a region that is strongly influenced by the South Atlantic Magnetic anomaly (SAMA). The results will be compared and discussed with satellite observations (DMSP and C/NOFS) and modeling results based on SUPIM simulation of a realistic low latitude ionosphere.

Key words: Low latitude ionosphere, Plasma bubbles, Penetration electric fields, Sporadic E layers.

Introduction

The electrodynamics of the equatorial and low latitude ionosphere over Brazil is strongly influenced by the South American (or South Atlantic) Magnetic Anomaly (SAMA). The precipitation of energetic particles in the SAMA region becomes enhanced during magnetic storm events that can cause significant enhancement and large scale spatial gradient in the E layer (especially, night time E layer) electron density and conductivity distributions. In the presence of storm time penetration electric fields, these changes, can lead to the development of anomalous sporadic E layers formed by the process of ionization convergence driven by vertical Hall electric field that is induced by the primary penetration zonal electric field. They can also cause disruption of an ongoing *Es* layer development. The prompt penetration zonal electric field can cause also large scale modification in the plasma bubble development process, while the associated vertical electric field can contribute to significant modification in the plasma bubble dynamics. The bubble zonal drift can reverse westward from its normally eastward drift. This talk will focus on the modifications in the bubble dynamics and changes in sporadic E layer structuring observed during magnetic storms, presenting also their possible explanations.

Results and discussion

Figure 1 shows the variations in interplanetary magnetic field, Bz, the auroral activity indices, AU/AL together with the F region vertical drift as measured by the Digisonde at Sao Luis, during the magnetic storm of 31 March 2001. The Bz was strongly southward (reaching 40 nT) starting at 14 UT and it decreased at a slow rate recovering to northward by 22 UT. A series of auroral substorms, indicated by episodes of AL activity intensifications may be noted during this period. Prompt penetration electric field associated with these disturbances caused large fluctuations in the vertical drift. The substorm activity showed recovery, indicated by the steady decrease in the AL activity index, starting at ~21 UT. The associated over-shielding electric field of westward polarity caused large downward plasma drift that peaked at 22 UT and -55 m/s, which occurred exactly at the same local time and with the similar magnitude as that of the quiet time prereversal vertical drift (PRE). Under quiet conditions the PRE upward drift of 55 m/s is known to be significantly higher that that is required to cause development of plasma bubble irregularities (Abdu et al., 2009). In contrast to this, on the evening of 31 March the post sunset ionosphere was stable and no spread F development occurred. Instead, strong sporadic E layer development occurred that presented anomalous characteristics in the form of range spreading echoes as shown in Figure 2. We may note that under the westward over-shielding electric field the F layer descended starting at 21:15 UT (18:15 LT), as can be noted in the ionogram, the descent continuing till at least 23:45 UT (20:45 LT). The *Es* formation continued during the same period and even beyong. Further the *Es* echoes presented range spreading, with the spread range increasing as the sounding frequency increased. A detailed discussion on the mechanism responsible for such *Es* layer developments will be presented in this paper.

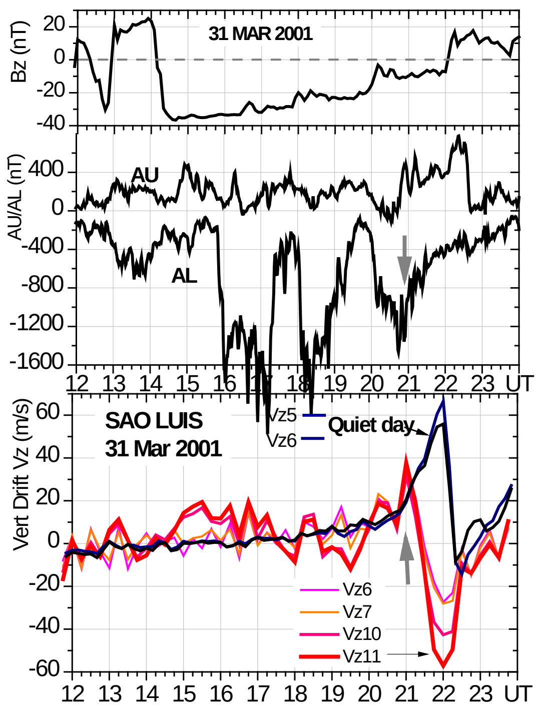

Figure 1: The interplanetary magnetic field componente Bz and the auroral activity indices AU/AL during the storm of 31 March 2001 (upper two panels). The corresponding F region vertical plasma drift as measured by a Digisonde at Sao Luis at four plasma frequencies: 6MHz, 7MHz, 10 MHz and 11MHz (red curves), and the quiet day reference curve (black curve) for comparison (bottom panel).

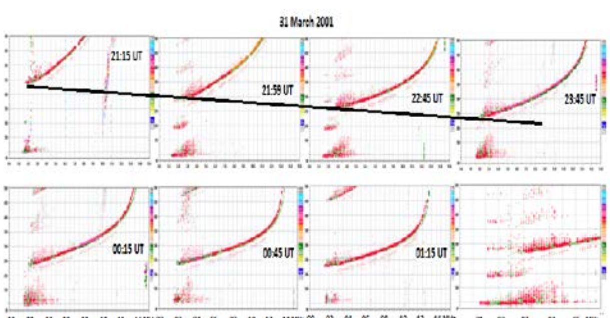

Figure 2: Ionograms from Digisonde at Sao Luis, showing the non-occurrence of spread F and the occurrence of sporadic E layer on the evening of 31

It will be shown that anomalous *Es* layers can form near 100 km due to vertical ionization convergence by vertical Hall electric field that is induced by the prompt penetration zonal electric field occurring in the presence of enhanced *E* layer conductivity. The enhancement in the *E* layer conductivity can arise from storm time energetic particle precipitation in the SAMA region. The same vertical Hall electric field can also modify the zonal drift of plasma bubble irregularities. The zonal drift of the bubbles, which is normally eastward can reduce in intensity and/or even reverse to westward as illustrated in the Figure 3. This figure shows an event of drift velocity reversal as observed by an all-sky optical imager (630 nm) at Cariri (north east of Brazil) and Digisonde at Fortaleza, on the night of 8-9 November 2004, plotted together with the simultaneous variations in the Bz and auroral electrojet (AE) activity. We note (1)- that under Bz south conditions, during the period from 2020 LT to 2315LT, the AE activity intensified suggesting the presence of prompt penetration electric field of eastward polarity, which caused the ESF irregularity downward drift to decrease and to reverse to upward at around 22 LT (panel d); (2) the zonal drift (Vy) observed by the optical imager (panel c) and by the Digisonde (panel e) that was eastward, decreased in velocity and reversed to westward at 21:45 LT which was caused in large part by a vertical Hall electric field induced by the primary zonal electric field; (3) the zonal drift velocity measured by the Digisonde is nearly the same as that observed by the optical imager; and (4) in a gross way an anti-correlation between the Vy and Vz may be noted in the Digisonde data.

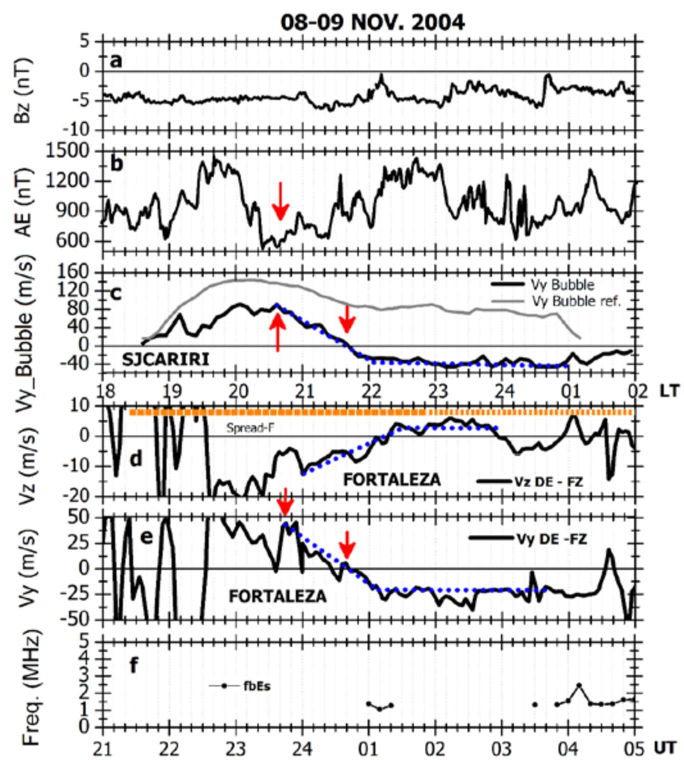

Figure 3: The IMF Bz and AE variations (panels a, b) on the night of 8-9 November 2004; Bubble zonal drift measured by optical imager at Cariri (panel c); Spread F irregularity vertical drift (panel d) and zonal drift (panel e), and sporadic E layer blanketing frequency (panel f) as measured by Digisonde at Fortaleza.

Conclusions

We modeled this zonal velocity variation using a realistic low latitude ionosphere simulated by the SUPIM (Bailey et al., 1993). The zonal drift was calculated using the zonal wind adopted from the Horizontal wind model HWM (Hedin et al., 1996) and field line integrated Hall and Pedersen conductivities and their ratio calculated using the SUPIM results on electron density distribution in the low latitude ionosphere. Calculations were performed by including an extra ionization in the E region due to energetic particle precipitation, as well as by excluding such extra ionization. It is found that the storm time disturbance zonal drift of the bubbles can be explained only on the basis of conductivity modification due to an extra ionization by energetic particle precipitation as well as by adjustment in the HWM zonal wind.

These effects are largely observed in the longitude zone of the South Atlantic/ South American Magnetic Anomaly region. But depending upon the changes in the conductivity ratio that can occur during storm they should be observable at other longitudes as well.

References

1- Abdu, M. A., I. S. Batista, B. W. Reinisch, J. R. de Souza, J. H. A. Sobral, T. R. Pedersen, A. F. Medeiros, N. J. Schuch, E. R. de Paula, and K. M. Groves (2009), Conjugate Point Equatorial Experiment (COPEX) campaign in Brazil: Electrodynamics highlights on spread F development conditions and day-to-day variability, J. Geophys. Res., 114, A04308, doi:10.1029/2008JA013749.

2- Bailey, G. J. R. Sellek, and Y. Rippeth (1993), A modeling study of the equatorial topside ionosphere, Ann. Geophys., 11(4), 263–272.

3- Hedin, A. E. et al. (1996), Empirical wind model for the upper, middle and lower atmosphere, J. Atmos. Terr. Phys., 58, 1421–1447, doi:10.1016/ 021-9169(95)00122-0.

4- Santos, A. M., M. A. Abdu, J. R. Souza, J. H. A. Sobral, I. S. Batista, and C. M. Denardini (2016), Storm time equatorial plasma bubble zonal drift reversal due to disturbance Hall electric field over the Brazilian region, J. Geophys. Res. Space Physics, 121, doi:10.1002/ 2015JA022179.