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Electron temperature enhancements in nighttime equatorial ionosphere under the occurrence of plasma bubbles

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ABSTRACT

Simultaneous in-situ measurements of electron density and temperature in the nighttime equatorial region were performed by a rocket experiment launched under solar minimum and geomagnetic quiet conditions from the station of Alcântara (2.24°S; 44.24°W), Brazil, on Dec. 18, 1995, 21:17 LT. These measurements detected during the upleg flight a large overheated area around the base of density profile. The presence of plasma bubbles was revealed during the downleg phase, as well as temperature enhancements detected preferentially at altitudes where plasma depletions are found. It was assumed that the region traversed by the rocket during the downleg was preceded before the bubble's onset by a large overheating as observed during the upleg flight. Analyzing this framework under the light of the Global Self-Consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP), as well as a 2D numerical code that simulate the growth of an instability and the evolution of thermal energy inside a bubble, we found that despite an overheated area in the F-region bottomside can disturb the electron density profile around the altitude interval where such heat is deposited, it seems not have a direct influence over parameters responsible for the bubble onset. Additionally, the phenomenon of the intra-bubble thermal enhancement could be formed due to the convection of hot-electron fluid transported from the overheated region surrounding the base of the F-region to upper altitudes by the underlying mechanism of bubble generation.

1. Introduction

One of the most fundamental physical parameters for the characterization of the topside ionospheric plasma is the electron temperature, whose measurements are of great value to advancing knowledge about the chemistry and physics of this region (Richards and Khazanov, 1997; Peverall et al., 2000; Stolle et al., 2011). The state-of-art about this parameter comes largely from observations carried out at different latitudes during the last seven decades by incoherent scatter radars, satellites and sounding rockets (Reifman and Dow, 1949; Brace et al., 1969; Hanson et al., 1969; Kantor et al., 1990; Dabas et al., 2000; Rother et al., 2010).

In this context, despite being of key importance, simultaneous vertical in-situ measurements of electron density and temperature in the nighttime equatorial upper ionosphere have been scarcely investigated in recent past by rocket-borne instruments (e.g., Muralikrishna et al., 1994, 1999; Thiemann et al., 1999; Hirt et al., 2001). Adding to this effort, vertical profiles for both parameters were obtained by IONEX-II (hereafter IONEX) and DEOS rocket experiments launched into the F-region, respectively, over Alcântara (2.24°S; 44.24°W) Brazil, on Dec. 18, 1995, 21:17 LT (Muralikrishna, 2006), and Sriharikota (13.7°N; 80.2°E), India, on April 19, 1998, 19:21 LT (Thiemann et al., 2001). Both experiments, carried out under solar minimum and geomagnetic quiet conditions (IONEX: F10.7 = 67.1, $\sum K_p = 6$ and D_{st} min = −14 nT; DEOS: F10.7 = 99.4, $\sum K_p = 8+$ and D_{st} min = −13 nT), detected an electron density profile with a well-defined base during the upleg phase. Still in this part of the flight, electron temperature bulges were observed below the density gradient region for both cases. The presence of large scale plasma depletions (plasma bubbles) was

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observed during the downleg flight, where a prominent feature for both experiments was simultaneous depletion in electron density and enhancement in electron temperature spatially located at the same altitude intervals.

From their peculiar measurements, the rocket experiments mentioned above could detect heated bubbles within the altitude range 250–540 km, whereas the occurrences of bubbles with enhanced ion and electron temperatures have been also occasionally observed by satellite measurements above 600 km of altitude (Oyama et al., 1993; Dabas et al., 2000; Su et al., 2003; Park et al., 2008). However, a possible connection between this phenomenon and the background of plasma temperature found below a satellite orbit can only be investigated by it through indirect probing, so that sounding rockets seems to be a very suitable technique to perform in-situ measurements of phenomena vertically connected.

Analyzing the oxygen ion fraction inside bubbles with enhanced temperature, Park et al. (2008) concluded that these hot bubbles are originate from the bottomside F-region as the usual plasma bubbles, i.e., bubbles without T_e enhancements. However, the nature of the intra-bubble overheating, whether caused by endo or extra-ionospheric sources, still divides opinions. Some mechanisms such as local inverse correlation between electron density and temperature; influence of geomagnetic disturbance; collisions with energetic particles from magnetic anomaly regions and energy input from photoelectrons moving along the geomagnetic lines were suggested by Oyama et al. (1988) in order to explain intra-bubble enhanced temperature measured by Hinotori satellite (h~600 km). Mainly from the standpoint of regions with preferential heating and independence on geomagnetic activity, these explanations do not seem plausibly support all heated bubble events reported by other authors (e.g., Su et al., 2003; Muralikrishna, 2006; Park et al., 2008). Furthermore, the large amount of physical processes contained therein, as several sources of heating (cooling) and energy flows, lead us to suspect that there should be a fauna of hot bubbles.

From observations of ROCSAT-1/IPEI, KOMPSAT-1/SPS and DMSP F15/SSIES satellites, Park et al. (2008) summarized occurrences of high altitude plasma bubbles with enhanced temperatures as being independent of geomagnetic activities and found preferentially around geomagnetic latitudes of 10° in the summer hemisphere. According to these authors, the intra-bubble temperature would be then enhanced by adiabatic compression associated with a fast poleward field-aligned transport of plasma along magnetic flux tubes. Such interpretation is compatible with the results of a recent and seminal simulation study about the ion and electron temperatures evolution during equatorial spread F (Huba et al., 2009). Maybe, it would be also suitable to explain the heated bubbles found during the rocket experiments listed above. However, the unavailability of simultaneous in-situ measurements of ion drift velocities for these cases does not allow us to investigate such extension.

A possible connection between ionospheric overheatings and density depletion had been previously noted by Djuth et al. (1987) and Djuth (1989) during HF experiments conducted under solar minimum conditions over Arecibo (18.34°N; 66.75°W), Puerto Rico, where the nighttime ionosphere became dynamically unstable resulting in the arising of geomagnetic field-aligned striations in response to local electron temperatures (as large as 2000 K) induced by injection of radio wave energy. These striations were characterized by both depleted electron densities and enhanced electron temperatures. Computational modeling carried out by Newman et al. (1988), seeking to better understand the ionospheric mechanisms by which a HF thermal energy input could be intensified, as well as how the ionosphere holds awhile these overheated regions, revealed that reduced electron densities regions, found for example at the F-layer valley, lead to low collisional cooling rates, thereby mostly contributing to raise the temperature locally that remains high until the heat conduction starts after a temperature gradient threshold to be reached. Unfortunately, aspects involving connections with generation of plasma irregularities were not explored in such work.

In the light of the results provided by the Global Self-Consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP) model and a 2D numerical simulation of Collisional Interchange Instability (CII), the present paper examines if a region of high electron temperature near the F-layer base could plays a role both in the generation of plasma instabilities as well as injecting energy into the bubble, thus feeding the T_e enhancements observed by rockets at low altitude bubbles.

2. Rocket-borne Langmuir probe measurements

A Brazilian sounding rocket type Sonda III carrying a payload equipped with a spherical Langmuir Probe (LP) was launched on Dec. 18, 1995 (21:17 LT) from the equatorial station Alcântara (2.24°S; 44.24°W), Brazil. The rocket's flight covered a horizontal range of about 589 km, reaching an apogee of 557 km along a parabolic trajectory (Fig. 1). A detailed discussion about the contents of the probe payload and operation of the IONEX experiment can be found in Muralikrishna et al. (2003) and Muralikrishna (2006).

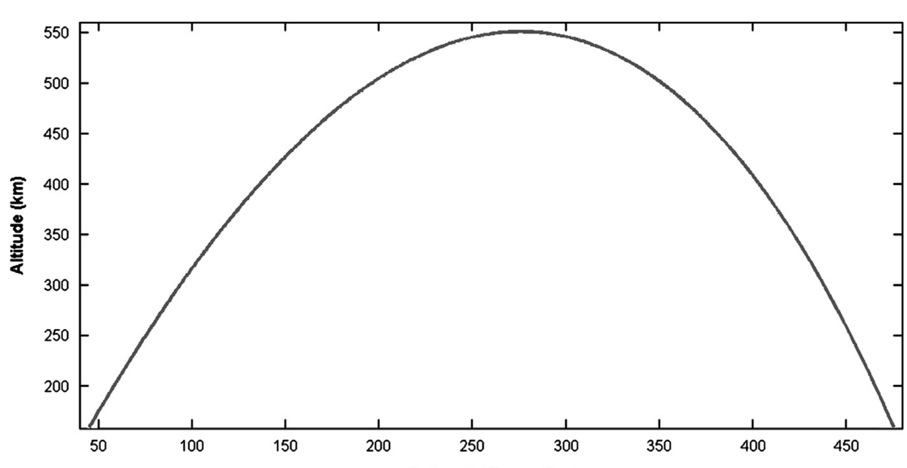

Fig. 1. Eastward flight trajectory of the IONEX experiment.