Geofísica Internacional (1992) Vol. 31, Num. 1, pp. 59-63

Nighttime F-region plasma structures observed by rocket-borne Langmuir and high frequency capacitance probes from Natal, Brazil

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RESUMEN

Se efectuaron medidas simultáneas de densidad de electrones mediante sondas de Langmuir (LP) y Capacitancia de Alta Frecuencia (HFC) a bordo de dos cohetes brasileños SONDA III lanzados desde la base ecuatorial Natal, Brasil. En ambas ocasiones, los cohetes, que llevaban una sonda LP con barredura de voltaje y una HFC de dos frecuencias, fueron lanzados en la parte nocturna de la ionosfera. En el primer lanzamiento, el cohete pasó por la región F a través de burbujas de plasma en desarrollo, mientras que en el segundo lanzamiento el cohete pasó por la misma región pero casi sin encontrar ninguna burbuja. Ambas sondas observaron irregularidades en la densidad electrónica de tamaños verticales que van de unos pocos kilómetros hasta tamaños entre 40 y 50 kilómetros. Aunque las estructuras de grande escala, según las observaciones de ambas sondas, presentaron características semejantes, también existieron diferencias substanciales. Por ejemplo, las amplitudes de las estructuras de pequeña escala de la región F, según lo observado por una de las frecuencias HFC, en general fueron más grandes que las medidas por la sonda LP. En este trabajo se discuten tanto los factores experimentales como los procesos físicos responsables de estas diferencias.

PALABRAS CLAVE: Sondas de Langmuir, sondas de capacitancia de alta frecuencia, ionosfera, burbuja de plasma, irregularidades en la densidad electrónica, región F.

ABSTRACT

Simultaneous *in-situ* measurements of electron densities were made by rocket-borne Langmuir and High Frequency Capacitance probes from the equatorial station Natal in Brazil, using Brazilian SONDA III rockets. On both occasions, the rockets, carrying a swept voltage Langmuir probe and a dual frequency High Frequency Capacitance probe, in addition to other experiments, were launched into the nighttime ionosphere. During the first launch the rocket passed through developing plasma bubbles and during the second launch it passed through a practically bubbleless F-region. Electron density irregularities of vertical scale sizes ranging from a few kilometers to as large as 40 to 50 kilometers were observed by both probes. The general features of the large scale structures as observed by the two probes were similar, but there existed also considerable differences. For instance, the amplitudes of small scale structures in the F-region as observed at one of the HFC frequencies were generally larger than those measured by the LP. Experimental factors as well as physical processes responsible for these differences are discussed.

KEY WORDS: Langmuir probe, high frequency capacitance probe, ionosphere, plasma bubble, electron density irregularities, F-region.

INTRODUCTION

Electron density irregularities present in the ionosphere manifest themselves in different forms at different heights and times. Sporadic-E, spread-F, radio star scintillations and VHF scatter are a few of such phenomena familiar to ionospheric physicists. Basic knowledge of the plasma irregularities, responsible for these phenomena, has progressed considerably, both in theory and observations, since the discovery of the strong VHF radar echoes from the equatorial ionosphere (Bowles *et al.*, 1960, 1963). Balsley (1969), from the spectral characteristics as observed by VHF radar, classified the plasma irregularities into two groups, namely Type I and Type II. While Type I irregularities are now identified to be consistent with the two-stream instability mechanism (Farley, 1963; Sato, 1972), Type II irregularities are known to be produced by the nonlinear cross-field instability mechanism (Rogister and d'Angelo, 1970, 1972; Balsley and Farley, 1973). Direct observations by Prakash *et al.* (1970, 1971a, b) using rocket-borne Langmuir probes flown from India, confirm the existence of Type II irregularities in the equatorial E-region. Type II irregularities are characterized by scale sizes extending from a few meters up to tens of kilometers. The short wavelength irregularities apparently seem to be generated from larger scale sizes nonlinear coupling or cascading processes (Rogister, 1972; Rogister and d'Angelo, 1970, 1972; Sato, 1971, 1973; Sudan *et al.*, 1973). Neutral turbulence seems to be another probable mechanism responsible for the generation of plasma irregularities (Prakash *et al.*, 1970). The spectral characteristics of the different types of irregularities have been studied in detail (Prakash *et al.*, 1970; Ott and Farley, 1974).

In-situ measurements of electron density were made from the equatorial station Natal, Brazil, using rocket-borne Langmuir and High Frequency Capacitance probes on two occasions. On both occasions Brazilian made SONDA III rockets were launched into the nighttime ionosphere, one during the developing phase of F-region plasma bubbles and the other during the absence of plasma bubbles as revealed by a network of supporting ground experiments. Characteristic features of the F-region plasma structures as observed by the two basically different techniques are presented and discussed here.

EXPERIMENT AND FLIGHT DETAILS

On both occasions, a metallic segment of 9 cm length located at the nose tip of the rocket, insulated electrically from the rest of the rocket body, was used as the sensor that determined the frequency of the oscillator in the HFC experiment. The oscillator was operated in a double frequency mode at frequencies of about 6MHz and 12MHz achieved by switching between two suitably selected inductors (Abdu *et al.*, 1988). At lower heights in the ionosphere, where the plasma frequency is rather low, the lower frequency mode (Mode 1) gives better frequency and electron density resolution. At higher altitudes the higher frequency mode (Mode 2) is used to estimate the electron density. In the dual frequency mode, when the oscillator operates at one frequency the frequency information in the other mode is transmitted and vice versa, for equal durations of about 60 ms each, thus forming an operation cycle of 120 ms. For calibration purposes, during one of a predetermined number of cycles of operation a negative bias of 100 V is applied to the sensor. Further details on the basic principle of operation of the experiment as well as on the reduction of data are given in Abdu *et al.* (1988). Typical height resolution of the HFC measurements is about 400 m in the E-region and about 50 m in the F-region near the apogee of the rocket.

A metallic conical segment of about 4cm length, mounted below the HFC sensor, also electrically insulated from the rocket body, was used as the Langmuir sensor. Two metallic guard rings insulated from the rocket body were mounted, one above the LP sensor (between the HFC and LP sensors) and the other below the LP sensor. A potential swept between -1V and +4V in about 2.6 seconds was applied to the LP sensor. The same potential was also applied to the guard rings, so as to generate a uniform electric field perpendicular to the LP sensor surface. The current collected by the sensor is converted into a voltage using a high input impedance amplifier and then separated into slowly varying DC and AC components and further amplified to reach a desired output level. Details of the data reduction are given in Muralikrishna and Abdu (1991). This information along with the Δf values from the HFC probe were then transmitted to the ground station through the onboard PCM telemetry system.

The two rockets carrying the plasma and other optical diagnostic payloads were launched from the equatorial rocket launching station in Natal, Brazil. The flight information is summarized in Table 1.

The first launch designated INPE-02, had the principal objective of studying the characteristic features of large scale electron density depletions, known as plasma bubbles, associated with equatorial spread-F events. The principal objective of the second launch, designated INPE-03, was to study the equatorial ionosphere during a period of maximum airglow emission, which generally occurs in the absence of plasma bubbles.

Table 1

Flight	Date and time of launching	Rocket apogee	Experiments on board
INPE-02	11 Dec. 1985 20:30 hrs.	530 km	HFC, LP and Photometers
INPE-03	31 Oct. 1986 22:59 hrs.	445 km	HFC, LP and Photometers

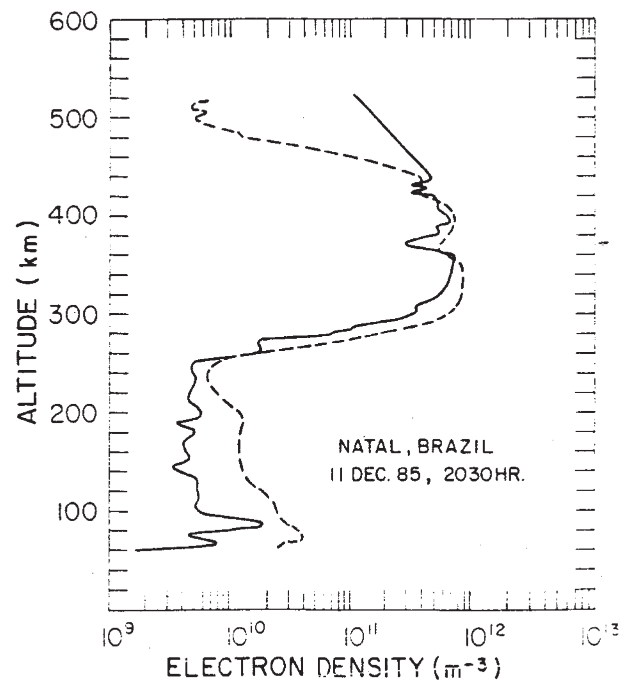

Fig. 1. Electron density height profiles estimated from the LP and HFC experiment data for flight INPE-02.

RESULTS AND DISCUSSION

Flight INPE-02

Electron density profiles estimated from the LP and HFC data, during the ascent of the rocket are shown in Figure 1. The rocket was launched at a time when the network of ground experiments indicated possible development of a plasma bubble event; as can be seen from this figure, the rocket clearly passed through a series of plasma bubbles of varying amplitudes during the ascent of the rocket. These large bubble structures were not observed during the rocket descent, probably because of the rocket descending through the neck region of a plasma bubble that is characterized by plasma density depletion (Abdu *et al.*, 1991). Though the general features of the density profiles estimated from the LP and HFC experiments are the same, there exist several differences between them which are discussed in detail by Muralikrishna and Abdu (1991). The following structural features can be clearly seen in both profiles:

1) There exists a sharp E layer peak around the altitude region of 100 km which, with much reduced amplitude, is seen in the altitude region of 90 km during rocket descent.

2) A large electron density valley is seen extending from about 140 km up to about 260 km.

3) Two large plasma bubbles are observed in the F-region around 370 km and 420 km altitude. The bubbles are dominantly seen only in the upleg profiles.

4) Large scale plasma irregularities are observed in the valley between the E- and F-regions in both the upleg and downleg profiles, while in the topside F-region large scale irregularities are observed only in the downleg profile.

Observations (1) and (2), namely the presence of a sharp E-layer and a valley above about 120 km, have been observed earlier from both rocket-borne and ground based experiments (see Prakash *et al.*, 1970). They are considered to be characteristic features of the nighttime lower ionosphere. However, they are neither completely understood on a theoretical basis, nor do the existing models explain their presence. Prakash *et al.* (1970) discuss the possibility of windshear mechanism to be responsible for the generation of some of the large scale structures observed in the E-region.

Observation (3) of bubble structures in the nighttime ionosphere is a familiar feature.

The generation of large scale plasma irregularities by the mechanism of cross-field instability is now reasonably well understood (Reid, 1968; Tsuda *et al.*, 1969). A necessary condition for the mechanism to operate is that there should exist an electron density gradient in the direction of the ambient electric field. In the nighttime ionosphere the Hall polarization electric field is generally downwards and so the height regions favorable for the operation of the C-F instability mechanism are those where the ambient electron density gradients are downwards. Present observation of large scale irregularities in the valley between the E- and F-regions, and in the topside F-region, where the electron density gradients are downwards, can then be attributed to the operation of C-F instability mechanism. However, though steep downward gradients existed in the topside electron density, large scale irregularities were dominantly seen in this region only during the rocket descent (see Figure 2). One should remember that, in the height region concerned, the upleg and downleg of the rocket are separated by a distance of about 150-200 km. The large scale irregularities are seen in the topside downleg profile range in scale sizes from a few kilometers up to about 50 kilometers. Several of these structures have amplitudes greater than 50% and hence it is difficult to attribute them to the rocket wake. They seem to be produced by the C-F instability mechanism itself.

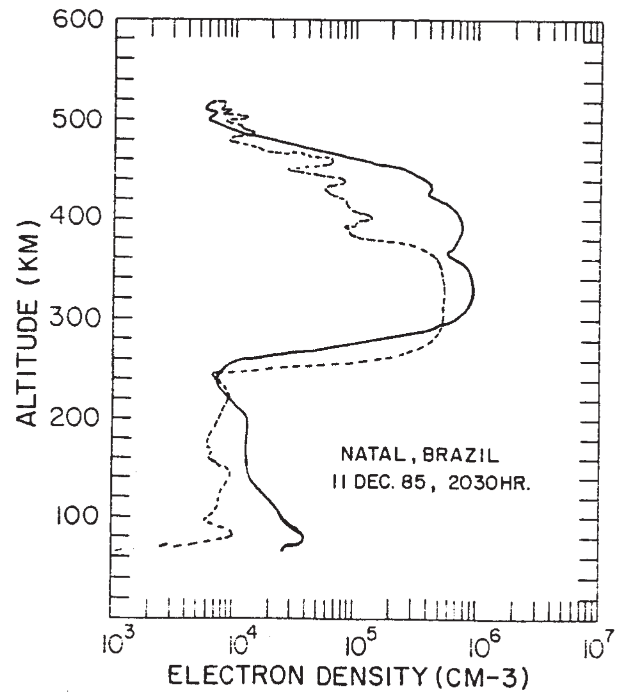

Fig. 2. Comparison between the upleg and downleg electron density profiles obtained from the LP experiment data for the flight INPE-02.

Another important observation is the horizontal scale sizes of the large scale irregularities observed in the valley between the E and F-regions. Some of the large scale electron density structures observed in the upleg profile, as shown in Figure 2, are also observed in the downleg profile. This indicates the large horizontal extension of these plasma irregularities with dimensions of a few hundred kilometers even in the east-west direction.

Flight INPE-03

The electron density profiles estimated from the LP and HFC data of flight INPE-03 are shown in Figure 3. The rocket was launched into a ionosphere marked by relatively intense airglow emissions and thus into a practically bubbleless ionosphere. This explains the rather smooth electron density profile observed during this flight. However, the following structural details can be observed from Figure 3, some of them being comparable with those observed during flight INPE-02:

1) Contrary to flight INPE-02, this flight observed no dominant electron density layer in the E-region.

2) The F-layer peak, which was at about 340 km in the case of flight INPE-02 was now at about 240 km, or about 100 km lower.

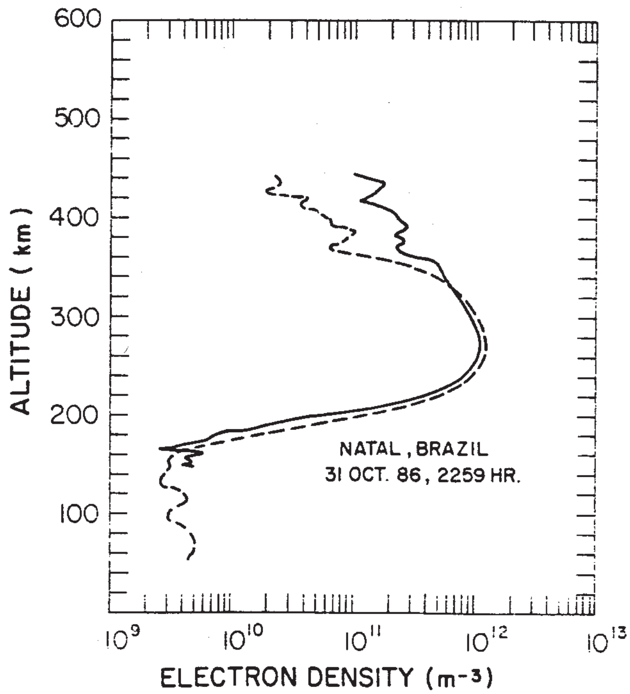

Fig. 3. Electron density height profiles estimated from the LP and HFC experiment data for flight INPE-03.

3) Practically no valley region existed between the E- and F- regions.

4) As in the case of INPE-02, large scale irregularities were observed in the topside F-region.

Observation (2) of a much lower F-region peak is perfectly in agreement with the hypothesis that the formation of plasma bubbles generally occurs associated with an upward lift in the F-region. Flight INPE-03 was launched into a practically bubbleless ionosphere and should therefore observe a lower F-peak. Other observations are common to both flights and hence can be interpreted the same way as in the case of the observations made during flight INPE-02.

CONCLUSIONS

1) Large scale irregularities, apparently generated by the crossfield instability mechanism, are observed in the topside F-region, as also in the valley between the E- and F-regions, where it exists.

2) Observation of large amplitude plasma bubbles is associated with a high F-peak.

3) Some of the large scale electron density irregularities observed in the valley between the E- and F-regions have dimensions of a few hundred kilometers even in the east-west direction.

ACKNOWLEDGEMENTS

The authors are grateful to the Director of IAE/CTA for providing the rockets and the launch facilities at CLBI, Natal, and to the staff of IAE and CLBI for their help during the pre-launch tests of the experiments and during the launching of the rockets. Sincere thanks are due to Sinval Domingos, Agnaldo Eras and Narli Baesso Lisboa for their technical help in the development, testing and integration of the experiments. This work was partially supported by FINEP under contract FINEP-537/CT, and by CNPq under process 300253/89-3/GM/FV.

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