In Situ Measurement of High Altitude Spread-F Characteristics by Three Different Plasma Density Probes

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During the Guara campaign, conducted from Alcantara in Brazil, a Black Brant X sounding rocket was launched on 14-th October 1994 at 1955hrs (LT) to investigate into the phenomenon of high-altitude equatorial spread-F events. The rocket, as expected passed through an active topside spread-F event, monitored simultaneously by several ground-based instruments. The electron density height profile and the amplitude of the electron density fluctuations were measured simultaneously by three different plasma density probes; a High Frequency Capacitance (HFC) probe, a conventional Langmuir Probe (LP) and a Plasma Frequency Probe (PFP). While the PFP provided the absolute electron density, the LP gave the relative variation in the electron density. The electron density profile obtained from the HFC probe measurements is practically absolute except for a plasma sheath factor. But this technique does not provide the small-scale electron density fluctuation amplitude. Thus, the three experiments provided data, which could be used not only to obtain reliable electron density data, but also could be used to arrive at some of the inherent difficulties associated with each of these techniques. For example the electron density profiles estimated from the HFC and PFP experiments are almost identical except for a small factor varying with altitude. The amplitude of large-scale fluctuations provided by the LP measurements is considerably less than that provided by HFC and PFP. Characteristic features of the high-altitude spread-F as observed by these experiments are presented here.

INTRODUCTION

Plasma bubbles, flux tubes of depleted plasma density, observed frequently in the equatorial nighttime ionosphere have been the subject of active investigation in the last couple of decades (see Abdu et al, 1991 and references therein). These bubbles are characterised by scale lengths of thousands of kilometres along the geomagnetic field lines and tens to hundreds of kilometres perpendicular to the field lines. Their generation through the Rayleigh-Taylor (R-T) gravitational instability process and subsequent cascading, by secondary processes, into a hierarchy of irregularities was suggested by Haerendal (1974).

Black Brant X rocket launched during the Guará campaign conducted from Alcantara, Brazil, had the main objective of studying the equatorial ionosphere during the presence of high altitude plasma bubbles. The electron density height profile and the amplitude of the electron density fluctuations were measured simultaneously by three plasma density probes: (1) High Frequency Capacitance (HFC) probe, (2) Langmuir Probe (LP) and (3) Plasma Frequency Probe (PFP)

While the PFP provided the absolute electron density, the LP gave the relative variation in the electron density. The electron density profile obtained from the HFC probe measurements is practically absolute except for a plasma sheath factor. But this technique does not provide the small-scale electron density fluctuation amplitude. The principal objectives of the experiments were (1) to obtain the height profile of the electron density and (2) to study the characteristic features of high altitude spread-F irregularities. On 14-th October 1994 when the rocket was launched at 1955hrs (LT) a network of ground instruments operated during the campaign clearly indicated the presence of plasma bubbles extending to altitudes over 900km. The plasma diagnostic experiments performed well throughout the flight giving useful data in the height range of about 167km upto the rocket apogee of 956.6km during the upleg and from the apogee down to the E-region altitudes during the downleg. The first results of a comparative study of the electron density measurements made with the three plasma probes in relation to some of the Spread-F characteristics are presented here.

EXPERIMENT DESCRIPTION

During the experiment reported here the HFC Probe used a spherical sensor of 52mm diameter mounted on a short boom deployed 108s after the launch of the rocket. To cover the large dynamic range of the electron density and also to study the relative behaviour of the ion sheath the HFC experiment operated in two modes alternately with frequencies of about 5MHz and 10MHz. The duration of operation in each mode was about 60ms, thus giving a data point in each mode every 120ms. When the oscillator operates at one frequency the frequency information in the other mode is transmitted. For calibration purposes (namely, for obtaining conditions approaching those of free space) a negative voltage of 100V is applied to the sensor during one out of every 32 cycles of operation. Other technical details of the HFC experiment are given below.

Oscillator Frequency
Low Freq. Mode: 5.3MHz
High Freq. Mode: 10.3MHz
Observable Electron Density Change
Low Freq. Mode: $1.28 \times 10^7/m^3$
High Freq. Mode: $2.07 \times 10^7/m^3$
Maximum Observable Electron Density
Low Freq. Mode: $3.76 \times 10^{11}/m^3$
High Freq. Mode: $1.18 \times 10^{12}/m^3$
Height Resolution (typical): 300m

A swept frequency type of Plasma Frequency Probe (PFP) and a conventional Langmuir Probe were also launched along with the HFC probe to measure the plasma density and the fluctuations in it. In the PFP at fixed short intervals of time a signal with swept frequency is transmitted using a short antenna on board the rocket and the signal that traverses through the ambient plasma and thereby gets modified by the plasma is also received using another short antenna on board. When the signal frequency becomes equal to the ambient plasma frequency the signal amplitude falls down drastically due to the resonant absorption by the ambient plasma. What is monitored in this experiment is the height variation in the plasma frequency that is decided by the ambient plasma density. In the conventional Langmuir probe the electron or ion current collected by a metallic sensor is measured as a function of the potential applied to the sensor. When the sensor operates in the saturation electron current mode the current collected is directly proportional to the ambient electron density. The High Frequency Capacitance probe was designed and developed in the laboratories of the Aeronomy Division of the Instituto Nacional de Pesquisas Espaciais-INPE/MCT, while scientists from the Department of Physics and Astronomy, Dartmouth College, USA were responsible for PFP and LP experiments.

RESULTS AND DISCUSSION

Electron density height profiles obtained from the analysis of the HFC, LP and PFP data for the upleg and downleg of the rocket are shown in Figures 1 to 6.

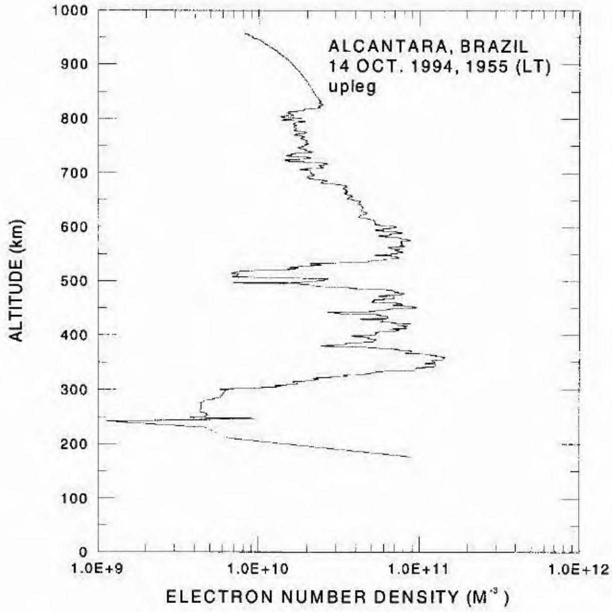

Figure 1.: Electron density height profile estimated from the HFC experiment data for the rocket upleg

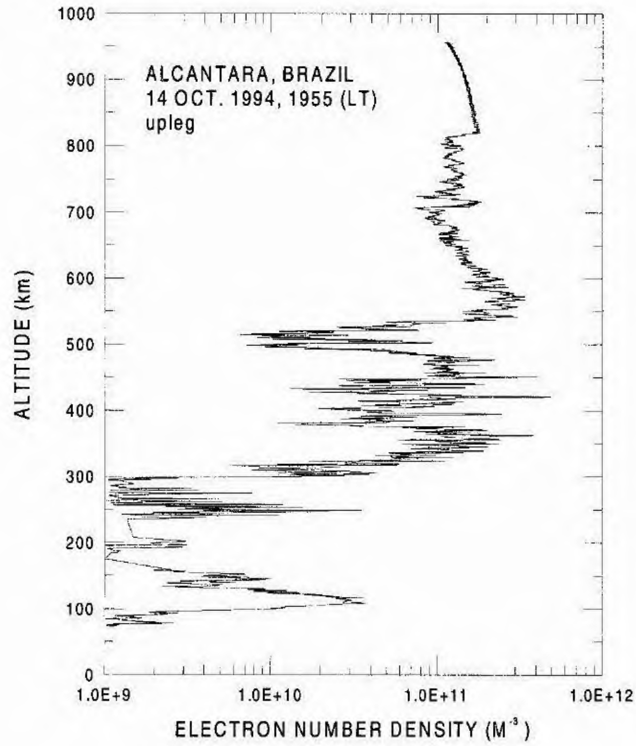

Figure 2.: Electron density height profile estimated from the LP experiment data for the rocket upleg

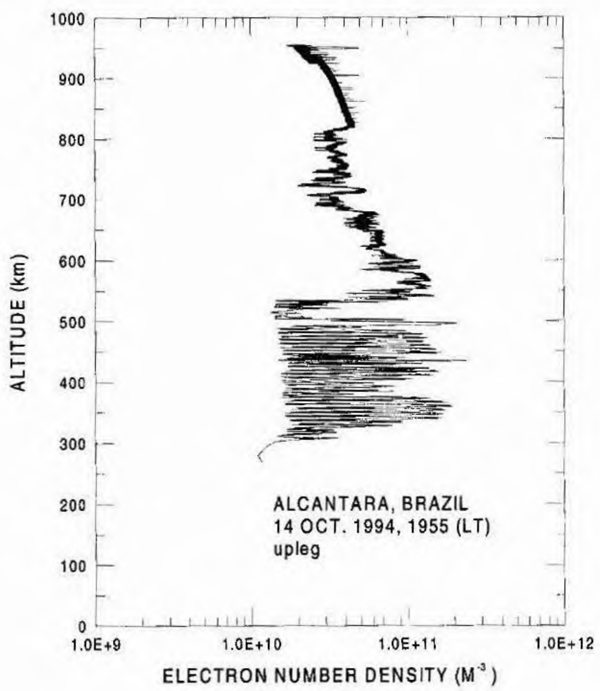

Figure 3.: Electron density height profile estimated from the PFP experiment data for the rocket upleg

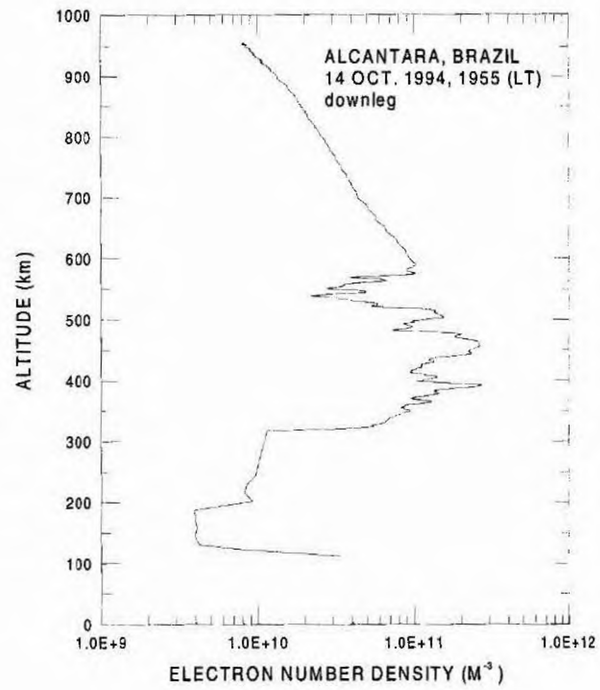

Figure 4.: Electron density height profile estimated from the HFC experiment data for the rocket downleg

The plasma density profiles estimated from the three experiments agree very well with each other It should be mentioned here that the HFC experiment gives the height profile of the electron density with a height resolution of a few hundred meters (typical value is 300m) as mentioned above Therefore it is impossible to study the height profiles of small scale electron density irregularities using this method. But the LP and PFP experiments have sufficient height resolution to study the amplitude fluctuations in the small-scale plasma irregularities. A close look at the electron density height profiles clearly show the existence of a wide spectrum of scale sizes in the plasma irregularities. All the upleg height profiles clearly show the presence of irregularities associated with what is known as the phenomenon of high altitude Spread-F. The presence of medium amplitude plasma bubbles in the high altitude region can be seen in the HFC upleg profile while the other two profiles from the LP and PFP experiments give an idea of the distribution of the small scale irregularities in this height region. These small-scale irregularities are confined mainly to the height region of 550km to 800km where the electron density gradient is predominantly downward. This observation supports the hypothesis that these irregularities are produced by the famous cross-field instability mechanism which need that the ambient electric field (normally downward in the night-time ionosphere) be in the same direction as the electron density gradient.

The rocket downleg profiles donot show the presence of neither large scale nor small-scale irregularities in this high altitude region. This probably is due to the limited horizontal extent of the high altitude Spread-F event The horizontal separation of the upleg and downleg trajectory of the rocket in this height region can vary from few tens to about 200km. This distance, therefore, roughly represents the east-west horizontal extension of the high altitude plasma bubbles or the phenomenon of high altitude Spread-F associated with these bubbles. Detailed spectral analysis of the density data at different height regions is being done to know the power spectral index of these plasma irregularities and thereby to know the plasma instability mechanisms responsible for their generation.

From Height	To Height	Amplitude of Irregularities
Rocket Ascent		
309km	506km	Large
534km	608km	Large
608km	820km	Small
Rocket Descent		
723km	576km	Small
576km	316km	Large

Table 1. Summarises the observation of the irregularities in different height regions in upleg/downleg of the rocket trajectory.

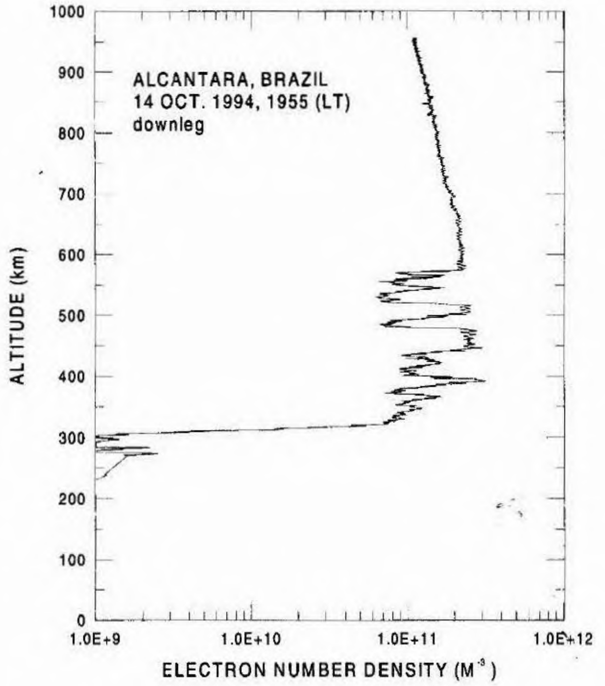

Figure 5.: Electron density height profile estimated from the LP experiment data for the rocket downleg

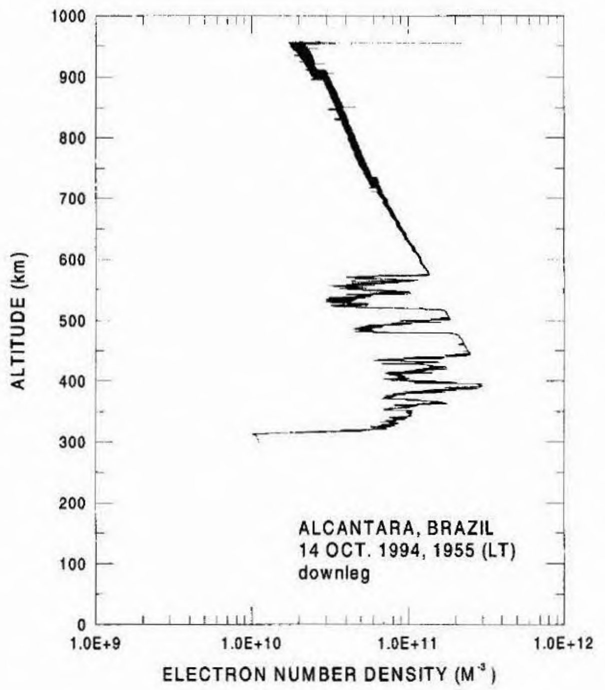

Figure 6.: Electron density height profile estimated from the PFP experiment data for the rocket downleg

CONCLUSIONS

Electron Density height profiles estimated from three different types of experiments namely a High Frequency capacitance probe, a Langmuir probe and a Plasma Frequency Probe during the occurrence of the phenomenon of High Altitude Spread-F agree well with each other. Plasma irregularities of a wide spectrum of scale sizes are dominantly seen in the height regions of downward electron density gradients, confirming their association with the well-known cross-field instability mechanism for the generation of plasma irregularities. Plasma irregularity observations made from the High Frequency Capacitance probe clearly indicate their close association with regions of depleted plasma densities or plasma bubbles as observed the Langmuir Probe and the Plasma Frequency Probe. Detailed discussions about the structure and spectral index of these plasma irregularities can be made only after further detailed analysis of the plasma density and irregularity data.

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REFERENCES

Abdu, M.A., P. Muralikrishna, I.S. Batista and J.H.A. Sobral, Rocket observation of equatorial plasma bubbles over Natal, Brazil, using a High Frequency Capacitance Probe, J. Geophys. Res., 96, 7689, 1991.

Haerendal, G, Theory of equatorial spread-F, Max Planck Institut fur Physik und Astrophysik, Garching, Germany, 1974.

Heikkila, W.J., N. Baker, J.A. Fejer, K.R. Tipple, J. Higill, D.E. Scheneible and W. Calvert, Comparison of several probe techniques for ionospheric electron concentration measurements, J. Geophys. Res., 73, 3511, 1968.

Rao, U.R., S.S. Degaonkar, M.A. Abdu, S. Bansidhar and R.M. Patel, Rocket based ionospheric measurements at Thumba with High Frequency Capacitance probe, Space Research X, 703, 1970.