SBGf04299

EQUATORIAL SPREAD-F IRREGULARITIES AS OBSERVED BY THREE DIFFERENT ROCKET-BORNE PLASMA DENSITY PROBES

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ABSTRACT

Some new results obtained from in-situ measurements of the height variation of the ionospheric electron density made with rocket-borne electron density probes during a campaign conducted from Alcantara (2.31°S; 35.2°W) in Brazil are presented here. The campaign designated Guará was conducted in collaboration with NASA. In addition to several plasma diagnostic instruments provided by other participating institutes the Aeronomy Division in the Instiuto Nacional de Pesquisas Espaciais in Brazil provided a High Frequency Capacitance probe that measured the height profile of the electron density. During the Guara campaign, 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. The three experiments provided data, which could be used not only to obtain reliable electron density data, but also to arrive at some of the inherent difficulties associated with each of these techniques. For example the elctron 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. The k-spectra of the plasma irregularities were obtained by the spectral analysis of the electron density fluctuation data. The electron density irregularites associated with the plasma bubbles were seen to have rather sharp lines in their k-spectra extending over a wide range of altitude. What one would expect from the existing theories on the generation of small scale irregularities by the cascading process is a flat k-spectrum. Present results may be indicative of the presence of preferred wave modes in developing plasma bubbles .

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 kilometers along the geomagnetic field lines and tens to hundreds of kilometers perpendicular to the field lines. Their generation through the Rayleigh-Taylor (R-T) gravitational instability process and subsequent cascading, by secondary processes, into a heirarchy of irregularities was suggested by Haerendal (1974). The short wavelength irregularities apparently seem to be generated from larger scale sizes nonlinear coupling or cascading processes. Neutral turbulance also seems to be another probable mechanism responsible for the generation of plasma irregularities. The spectral characteristics of the different types of irregularities have been studied in detail (Prakash et al, 1970; Ott and Farley, 1974). Some new results obtained from in-situ measurements of the height variation of the ionospheric electron density made with three different rocket-borne electron density probes from Alcantara (2.31°S; 35.2°W) in Brazil are presented here.

EXPERIMENT AND FLIGHT DETAILS

During the Guará campaign conducted from Alcantara, Brazil, a Black Brant X rocket was launched on 14-th October, 1994 at 1955hrs (LT) with 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 the following three plasma density probes:

A High Frequency Capacitance (HFC) probe
A conventional Langmuir Probe (LP)
A Plasma Frequency Probe (PFP)

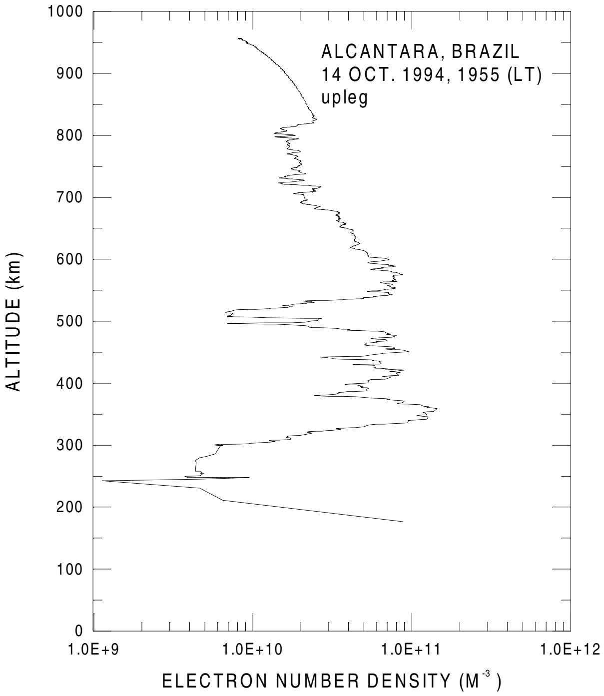
The HFC Probe used a spherical sensor of 52mm diameter mounted on a short boom deployed 108s after the launch of the rocket. To cover the large dynamic range of the electron density and also to study the relative behaviour of the ion sheath the HFC experiment operated in two modes alternately with frequencies 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. A swept frequency type of Plasma Frequency Probe (PFP) and a conventional Langmuir Probe were also launched along with the HFC probe to

Sixth International Congress of the Brazilian Geophysical Society

measure the plasma density and the fluctuations in it. 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.
The basic principle of operation, and the details of the electronic subsystem of the LP and HFC experiments are given in Muralikrishna and Abdu (1991). The Langmuir Probe was used to measure the electron density and the electron kinetic temperature. The spherical LP sensor of diameter about 60mm was mounted at the extremity of a short boom of about 50cm in length that remained inside the rocket nosecone. This boom was deployed along with the EFP booms soon after the ejection of the rocket nosecone.. A swept voltage varying from -1V to +2.5V in about 2.5sec. was applied to the LP sensor in order to measure both the electron density and the electron kinetic temperature. The main objective of the HFC probe was to measure the electron density height profile. The HFC sensor was identical to the LP sensor and was mounted also at extremity of a short 50cm boom kept folded inside the rocket nosecone till the ejection of the nosecone like the LP sensor boom. The sensor formed part of the tank circuit of an electronic oscillator and any change in the sensor capacitance caused by changes in the ambient electron density, is measured through a counting circuit and this information is telemetered to the ground.

RESULTS AND DISCUSSION

The rocket upleg and downleg electron density height profiles obtained during the Guará campaign from the analysis of the HFC data are shown in Figure 1. It should be noted here that the plasma density profiles estimated from the three experiments agree well with each other and that the LP and PFP experiments have sufficient height resolution to study the amplitude fluctuations in the small scale plasma irregularities.



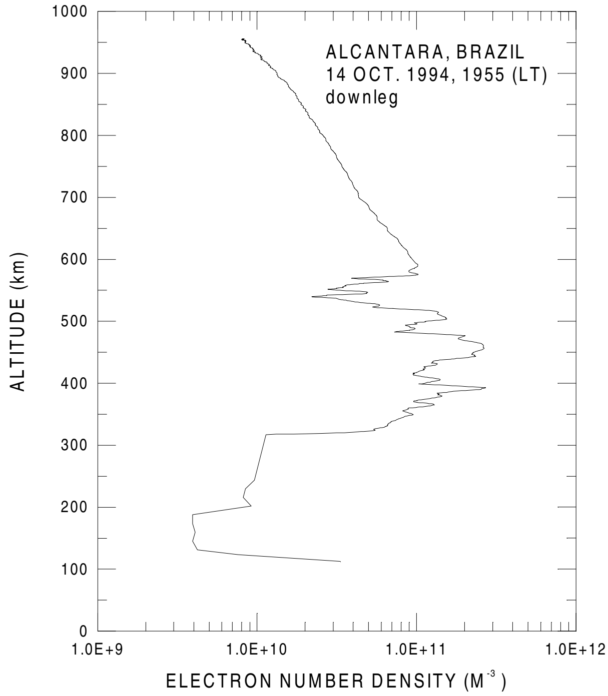


Figure 1: Electron density height profiles obtained with HFC data for rocket upleg (left) and downleg (right)

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. The rocket downleg profile shows the presence of a wide spectrum of irregularities in the height region of 300-600km, but not in the high altitude region. This probably is due to the limited horizontal extent of the high altitude Spread-F event responsible for the generation of plasma irregularities. 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 region was done to know the spectral distribution of these plasma irregularities and thereby to know the plasma instability mechanisms responsible for their generation.

Typical k-spectra obtained from the spectral analysis of the electron density fluctuation data of the HFC, LP and PFP experiments are shown in figures 2, 3 and 4 respectively. The striking feature of the spectra is the presence of spectral peaks of large amplitudes in practically all the k-spectra, a hitherto unobserved feature.

Observation of bubble structures in the nighttime ionosphere is rather 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 polarisation 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. Presence of large bubble structures in the bottom side F-region where the E-field is supposed to be downwards and the electron density gradient is upwards cannot be attributed to the operation of the cross-field instability mechanism. However, small scale plasma irregularities can be generated in the region of downward electron density gradients associated with the large scale bubbles.

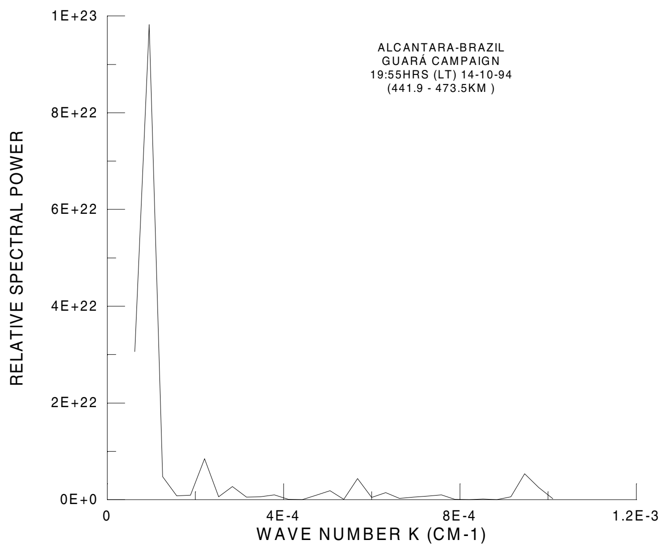


Figure 2: Typical k-spectrum of plasma irregularitie observed by the HFC experiment

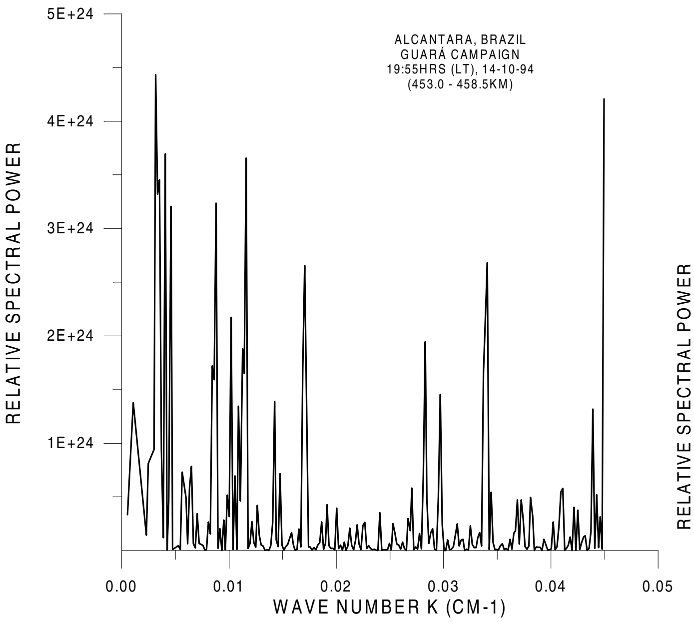


Figure 3: Typical k-spectrum of plasma irregularitie observed by the LP experiment

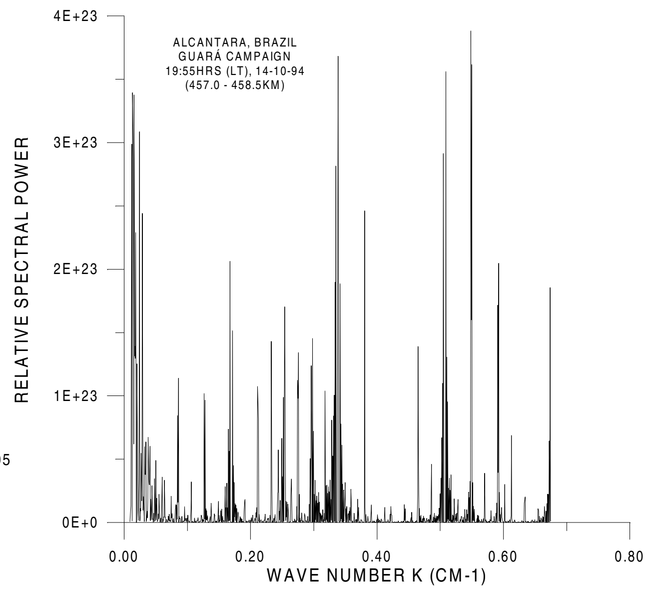


Figure 4: Typical k-spectrum of plasma irregularitie observed by the PFP experiment

It is now rather well established that the plasma bubbles are characterised by scale lengths of thousands of kilometers along the geomagnetic field lines and tens to hundreds of kilometers perpendicular to the field lines. Their generation through the Rayleigh-Taylor (R-T) gravitational instability process and subsequent cascading, by secondary processes, into a heirarchy of irregularities was suggested by Haerendal (1974). The spectral characteristics of the different types of irregularities associated with the phenomenon of spread-F have been studied in detail (Prakash et al, 1970; Ott and Farley, 1974). These small scale irregularities are expected to have a rather flat k-spectrum as the earlier observations showed and as predicted by the existing theories on the generation of plasma irregularities. A striking new feature observed during the experiments reported here is the presence of large spectral peaks in the k-spectra of the plasma irregularities. One should note here that both the rocket flights reported here were conducted during the onset period of the ionospheric plasma bubbles and there fore represent the characteristic features of plasma irregularities associated with new or developing plasma bubbles. It is possible that as time progresses the plasma irregularities responsible for these spectral peaks, transfer their energy to lower and lower scale size irregularities and thus eventually leading to a flat k-spectrum when the process attains a stable state. But a theory that can explain these spectral peaks even during the development phase of the plasma bubbles is not known yet.

CONCLUSIONS

- Electron Density height profiles estimated from 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.
- The generation of large scale plasma structures in the bottom side of the F-region cannot be explained by the cross-field instability mechanism that needs the vertical electric field and the electron density gradient to be in the same direction
- Bubble regions are associated with a wide spectrum of plasma irregularities or electron density fluctuations. Spectral analysis of the ac data clearly show the presence of large peaks in the k-spectra of the plasma irregularities
- The existing theories for the generation of plasma irregularities cannot explain the sharp spectral peaks observed in the k-spectra.
- One possible explanation for the presence of large peaks in the k-spectrum of irregularities is that they may be associated only with developing plasma bubbles and may dissipate their energy with time thus leading to a flat k-spectrum as the steady state is reached.

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**, 7689-7695, 1991.*

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

*MURALIKRISHNA, P. and M. A. ABDU, In-situ measurement of ionospheric electron density by two different techniques - a comparison, J. Atmos. Terr. Phys., **53**, 787-793, 1991.*

*OTT, E. and D. T. FARLEY, The k spectrum of ionospheric irregularities, J. Geophys. Res., **79**, 2469-2472, 1974.*

*PRAKASH, S.; S. P. GUPTA and B. H. SUBBARAYA, A study of irregularities in the nighttime equatorial E-region using a Langmuir probe and a plasma noise probe, Planet. Space Sci., **18**, 1307-1318, 1970.*

*PRAKASH, S.; S. P. GUPTA and B. H. SUBBARAYA, Cross-field instability and ionization irregularities in equatorial E-region, Nature Phys. Sci., **230**, 170, 1971a.*

*PRAKASH, S.; S. P. GUPTA; B. H. SUBBARAYA and C. L. JAIN, Electrostatic plasma instabilities in the equatorial electrojet, Nature Phys. Sci., **233**, 56, 1971b.*

*REID, G. C., Small scale irregularities in the ionosphere, J. Geophys. Res., **73**, 1627-1640, 1968.*

*ROGISTER, A., Nonlinear theory of cross-field instability with application to the equatorial electrojet, J. Geophys. Res., **77**, 2975-2981, 1972.*

*ROGISTER, A. and N. D'ANGELO, On the origin of small scale Type II irregularities in the equatorial electrojet, J. Geophys. Res., **77**, 6298-6299, 1972.*

*SATO, T., Nonlinear theory of the cross-field instability - explosive mode coupling, Phys. Fluids, **14**, 2426-2435, 1971.*

*SATO, T., Stabilization of the two stream instability in the equatorial electrojet, Phys. Rev. Lett., **28**, 732-734, 1972.*

*SATO, T., A unified theory of Type I and II irregularities in the equatorial electrojet, J. Geophys. Res., **78**,2232-2243, 1973.*

*SUDAN, R. N.; J. AKINRIMISI and D. T. FARLEY, Generation of small scale irregularities in the equatorial electrojet, J. Geophys. Res., **78**, 240-248, 1973.*

*TSUDA, T.; T. SATO and S. MATSUSHITA, Ionospheric irregularities and cross-field plasma instability, J. Geophys. Res., **74**, 2923-2932, 1969.*

ACKNOWLEDGMENTS

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