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Relatório Final

Bolsista

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Título

"Estudos experimentais da Ionosfera Equatorial"

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• Aos meus pais Mario e Graça, que sempre me deram todo o apoio;

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ÍNDICE

LISTA DE FIGURAS

1- INTRODUÇÃO

O conhecimento da ionosfera é útil em diversas aplicações, tais como: sistema de comunicação via satélite, sistema de localização geográfica e sistemas de navegação terrestre, aéreo, e marítimo.

O principal objetivo deste trabalho foi o de estudar experimentalmente *a Ionosfera Equatorial*, verificando através de ionogramas vários parâmetros como tempestade magnética, bolhas de plasma, entre outras anormalidades que são capazes de alterar consideravelmente a trajetória de ondas de rádios de alta freqüência.

2- CONCEITOS BÁSICOS

2.1- A IONOSFERA TERRESTRE

A ***ionosfera*** é uma camada da atmosfera que está aproximadamente de 50 à 1.000 km acima da crosta terrestre. É uma camada condutiva, por conter íons e elétrons. É definida como sendo a região da atmosfera superior onde íons e elétrons existem em quantidades suficientes para influenciar a propagação de ondas de rádio. Ela é o resultado da interação de radiação ionizante, eletromagnética e corpuscular, com os constituintes neutros da atmosfera, formando pares elétron-íon que, finalmente, se recombinam. Ela é mantida por um balanço de produção elétron-íon, mecanismos de perda físicos e químicos, e processos de transporte.

Por ser boa condutora e refletora de ondas eletromagnéticas, a ionosfera é muito utilizada nas comunicações e telecomunicações, via sinal de rádio.

Os limites inferior não são perfeitamente definidos, porém a concentração de íons se torna muito pequena, abaixo de 70 km e acima de 1.000 km. A essa região, entre 70 e 1.000 km, dá-se o nome de "**Plasma Ionosférico**".

São nas irregularidades do plasma ionosférico que se dá o maior problema de interferência nas transmissões. As interferências existem devido às alterações ocorridas na densidade eletrônica do plasma ionosférico, ou seja, há um aumento ou diminuição da densidade eletrônica. E estas flutuações da densidade são resultados dos processos dinâmicos e eletrodinâmicos da ionosfera. As bolhas são flutuações da densidade de grande escala.

A figura 1 ilustra as camadas da atmosfera da terra normalmente definidas em função do perfil de temperatura, localizando a ionosfera.

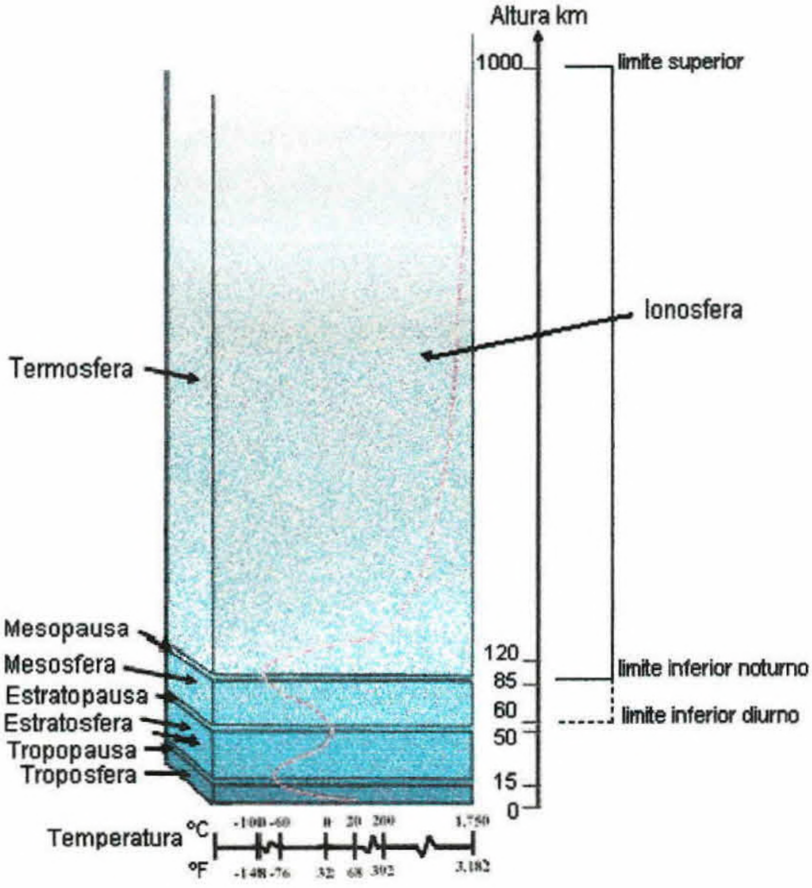

FIGURA 1 - Localização da ionosfera através da ilustração das camadas atmosféricas em relação a temperatura

2.2- REGIÕES DA IONOSFERA

A ionosfera, por conveniência de estudo, está dividida em diversas camadas e cada uma delas com suas propriedades características (vide figura).

A região D, consiste na parte inferior da ionosfera, até cerca de 80 km. Devido à densidade atmosférica ser maior nesta região do que nas outras, a importância de colisões entre íons, elétrons, e partículas neutras é considerável.

A região E fica entre a região D e F, aproximadamente entre 80 e 130 km de altura. Esta região é importante pela presença de correntes elétricas que nela fluem e sua interação com o campo magnético.

A região F engloba as regiões superiores da ionosfera, inclusive o pico de densidade em torno de 300 km, com a região F1 em torno de 200 kme a região F2 acima. A região F1 é definida pela aparição esporádica de um pequeno pico secundário na concentração eletrônica, ou de apenas uma inflexão na curva em torno de 180 km. A região F2 consiste de toda a região superior da ionosfera e é nessa região que se concentram os íons e elétrons da ionosfera.

Os estudos das regiões da ionosfera são interessantes por sustentar uma ampla área de fenômenos físicos. Muitos destes estudos tem como objetivo detectar e interpretar a variação de elétrons livres com a altura.

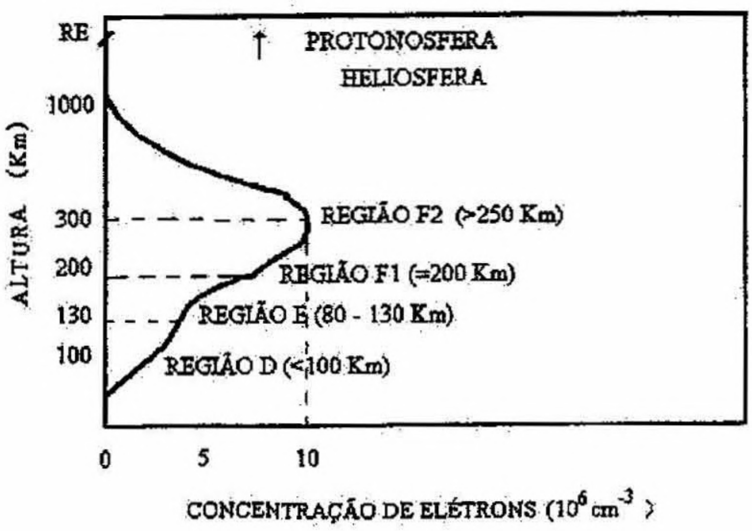

FIGURA 2 – Nomenclatura e localização das camadas ionosféricas em função da densidade eletrônica

2.3- IRREGULARIDADES DA IONOSFERA

Devido a sua complexidade e variabilidade, a ionosfera necessita ser monitorada continuamente através de intensas atividades de medidas de modo a fornecer um quadro claro da dinâmica da região.

Com o advento dos satélites artificiais norte-americanos no início dos anos 60, como meio de comunicação, a ionosfera foi "substituída" pelos satélites de comunicação, os quais funcionam de forma muito mais eficiente pois recebem, amplificam e retransmitem em direção à Terra as ondas de rádio. As comunicações via satélite passaram então a ser feitas em freqüências muito elevadas, da ordem de GHertz (10^9), em cujas freqüências, as interferências ionosféricas deveriam ser desprezíveis. Entretanto, no início dos anos 70, para a surpresa dos especialistas norte americanos, as comunicações via satélites sofreram altíssimas interferências ionosféricas na região equatorial.

Muitos pesquisadores consideram até hoje tal fenômeno como sendo a maior surpresa daquela década no campo de estudos da rádio propagação ionosférica. Inicialmente, tal interferência era inexplicável e representava um desafio para os cientistas. Descobriu-se depois, que tais interferências decorriam de fortíssimas irregularidades na distribuição de elétrons e íons no plasma ionosférico.

2.3.1- ELETROJATO EQUATORIAL

A ionosfera como já se sabe possui grandes quantidades de cargas elétricas. O eletrojato equatorial é um sistema de correntes naturais das partículas carregadas que correm durante o dia numa faixa de latitude de aproximadamente 15° em torno do equador geomagnético, numa faixa de altura de 95-120 km (região E da ionosfera equatorial, na direção leste-oeste). Na região do eletrojato, o plasma ionosférico é altamente instável e irregularidades de plasma de vários tipos são gerados nesta região. Possui dimensões de dezenas de km na direção vertical e centenas de km na direção norte-sul.

Este fenômeno ocorre quando há o surgimento de "impulsos" dado aos íons pelos Ventos Neutros (Movimento Global das Partículas não Ionizadas). Diante deste fato pode-se afirmar que o eletrojato equatorial exibe correntes elétricas.

Este fenômeno tem grande importância tanto para um entendimento da física da ionosfera, quanto para questões práticas de prospecção em **Geologia**, que utilizam o **campo magnético** como um parâmetro para estudos.

2.3.2- INSTABILIDADES DE PLASMA

O plasma ionosférico, em determinadas condições da ionosfera, torna-se instável produzindo irregularidades de plasma na escala de alguns centímetros à centenas de quilômetros. Estas irregularidades de plasma afetam os processos de comunicação pelas ondas de rádio, e poderão ser detectadas nos sinais de rádio refletidos das regiões E (70–150 km de altura) e F (150-1000 km de altura) da ionosfera. Os processos de geração, evolução e transporte destas irregularidades, apesar de ser amplamente estudados, ainda estão bem longe de ser conhecidas completamente. Bolhas de plasma, SPREAD-F, Sporadic-E, etc são manifestações destas irregularidades de plasma na ionosfera equatorial.

2.3.3- BOLHAS DE PLASMA

Bolhas de plasma são regiões de depleções alinhadas de tubos de fluxo magnético, localizadas acima do equador magnético e estendendo acima de milhares de quilômetros ao longo das linhas do campo geomagnético em ambos os hemisférios.

Desde então sua descoberta nos anos setenta por radares, satélites e foguetes o fenômeno das *bolhas de plasma ionosféricas* foi o enfoque de investigações científicas e tecnológicas através de grupos internacionais. Sua descoberta na ionosfera brasileira foi documentada através de medidas por foguetes, fotômetros, ionossondas dos territórios brasileiros. Parâmetros observados: densidade numérica de plasma, campo elétrico, temperatura cinética de plasma, distribuição espectral das irregularidades de plasma.

Hoje sabemos que as bolhas ionosféricas são formadas em baixas latitudes, mais freqüentemente no equador magnético. Elas se desenvolvem na ionosfera noturna com sua freqüência de ocorrência que depende da estação do ano e da longitude do setor equatorial.

É agora mais bem estabelecido que as bolhas são produzidas por causa de processos de instabilidade de plasma não-lineares, o mais importante entre eles é o mecanismo de Rayleigh-Taylor. Sob a ação de campos magnéticos, a ionosfera tropical, ao entardecer, é sujeita ao movimento vertical rápido. E na presença de forte gradiente da ionização, que caracteriza a parte inferior da camada F nestas horas, torna-se instável às pertubações induzidas pela atmosfera neutra. O crescimento em amplitude destas perturbações ocorre através do mecanismo Rayleigh-Taylor da instabilidade de plasma, resultando na geração de regiões de rarefações de densidade, chamadas de bolhas de plasma. Processos de cascata resultam na geração de irregularidades de plasma, associada com a bolha cuja escala espacial varia até dezenas de quilômetros. Porém aspectos diversos destes fenômeno, principalmente as condições ionosféricas ambientes e as eletrodinâmicas (que são responsáveis por sua variabilidade grande na freqüência de ocorrência como também a intensidade de ocorrência) permanece desconhecida até hoje. Por outro lado, um entendimento melhor destes aspectos é fundamental, atingindo nossos objetivos de melhorar a prognosticabilidade da ocorrência destes fenômenos. O efeito combinado destas irregularidades nos sistemas diagnósticos é conhecido como Spread-F equatorial.

Quando um sinal emitido encontra uma bolha, o mesmo penetra nela. Este não conseguirá sair, porque no interior da bolha há irregularidades de plasma. O sinal emitido sofre uma interferência no interior dela, fazendo com que o sinal não chegue ao seu destino. Diante desta situação os processos de comunicação ficam comprometidos.

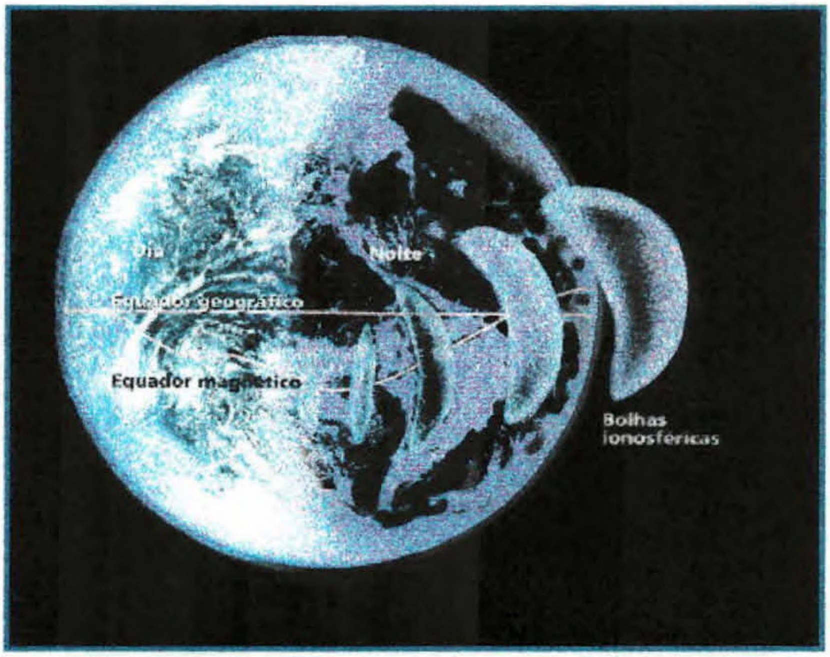

FIGURA 3 -Bolhas de Plasma Ionosféricas

2.4- EQUIPAMENTOS PARA COLETA DE DADOS

Para monitorar continuamente a ionosfera é necessário descrever alguns equipamentos disponíveis para a obtenção dos dados, como:

- **POLARÍMETRO:** O equipamento recebe um sinal polarizado linearmente que atravessa as camadas ionosféricas e é transmitido por um satélite geoestacionário. A medida da fase e o ângulo de amplitude desse sinal permite o estudo da variação integral da densidade eletrônica das camadas, bem como das perturbações (variações irregulares da densidade) que causam o espalhamento do sinal enviado pelo satélite.

- **RECEPTOR DE GPS:** sistema de navegação usado para determinar a posição e a velocidade de um objeto, fixo ou móvel;

- **CARGA ÚTIL:** São sensores devidamente projetados acoplados aos foguetes com uma trajetória preestabelecida que quando expostos no Plasma Ionosféricos medem os campos elétricos e a densidade eletrônica in loco. Mais detalhes será descritos abaixo.

- **SATÉLITE:** Através de cargas úteis a bordo de satélites é possível efetuar sondagem do topo da ionosfera, vindo assim, completar as informações das digissonda já que estas mostram o perfil até a altura do pico.

- **IONOSSONDA:** É um dos instrumentos mais representativos para a medida de parâmetros ionosféricos. Trata-se de um sistema transmissor-receptor que emite pulsos de energia eletromagnética em freqüência variável, em sequência, tipicamente de 1 a 5MHZ. O sinal emitido, normalmente na vertical, e refletido pela ionosfera e em função do tempo decorrido entre a transmissão e recepção do pulso à freqüência f, obtêm-se as chamadas curvas de h'(f) ou ionogramas.

- **DIGISSONDA:** Possui o mesmo princípio de funcionamento da ionossonda, mas é um equipamento digital mais moderno e preciso.

2.4.1- CARGA ÚTIL

Para se conceituar melhor sobre cargas úteis podemos dizer que são mecanismos (sensores) desenvolvidos para colhetarem dados específicos sobre determinadas ocorrências físicas, que tentam minimizar e melhorar os estudos da ionosfera e ainda que servem de suporte tecnológico para o desenvolvimento de satélites.

Seu funcionamento se dá com seus mecanismos acoplados aos foguetes que por sua vez possuem uma trajetória estabelecida com tempo determinado para a obtenção dos dados.

3- REDUÇÃO DE IONOGRAMAS

Dando continuidade ao trabalho anterior, foram reduzidos os dados coletados pelas estações de Porto Rico, Panamá, Talara, Chiclayo, Bogotá, Chimbote, La Paz, Tucuman e Concepcion.

Estas estações são de médias e baixas latitudes. Os ionogramas são de 1958 e 1959 (período de máxima atividade solar nos locais acima citados).

São reduzidos os seguintes parâmetros:

- h'F: altura virtual mínima do traço extraordinário em toda região F;
- f0F2: freqüência crítica da onda ordinária da camada F, a camada mais alta na região F;
- fM3000: fator de MUF para um percurso de 3000 km, usando a camada F.
- hmF2: altura real do pico a partir do fator M3000.

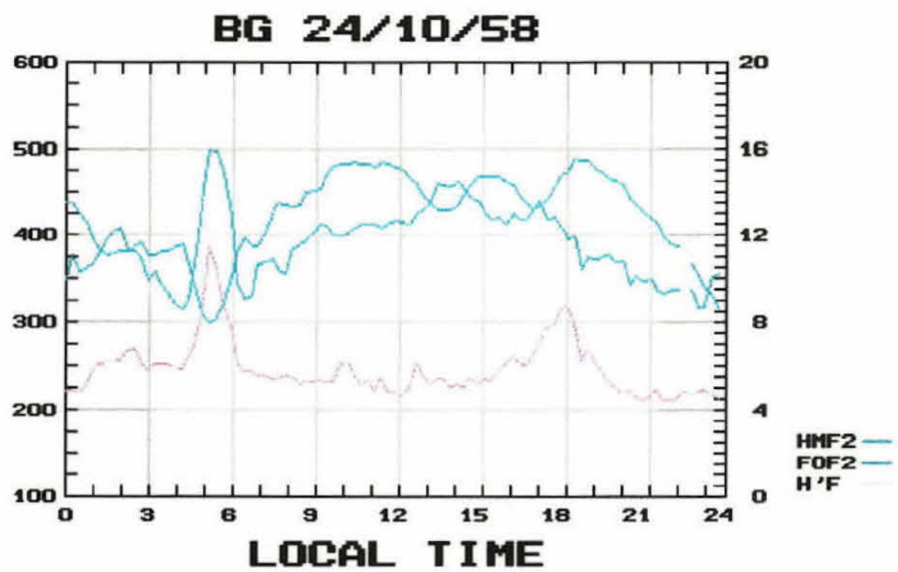

Figura 4- Gráfico dos dados obtidos através de ionograma de Bogotá (outubro de 1958)

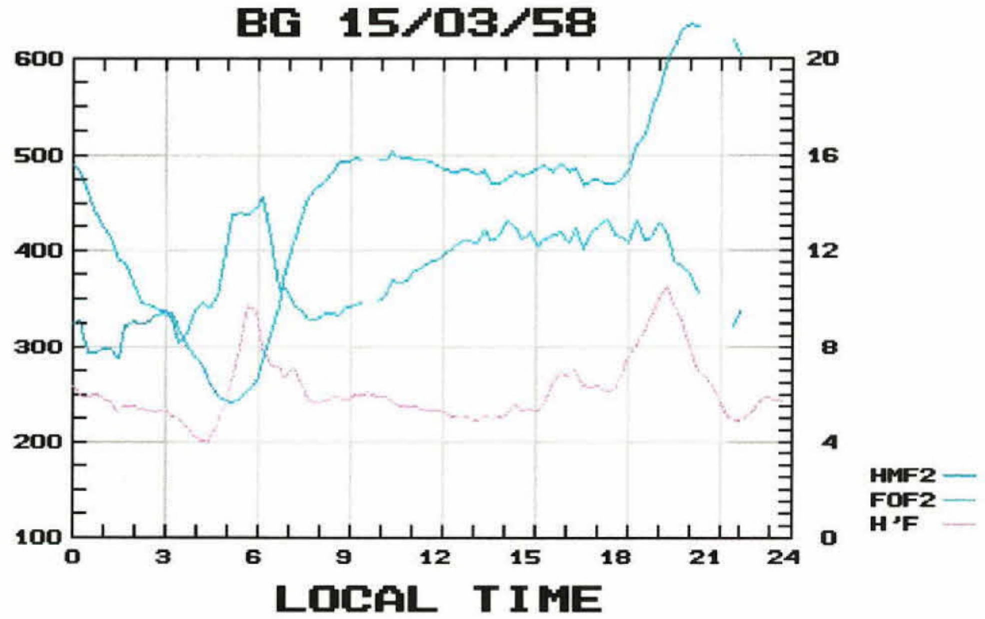

Figura 5 - Gráfico dos dados obtidos através de ionograma de Bogotá (março de 1958)

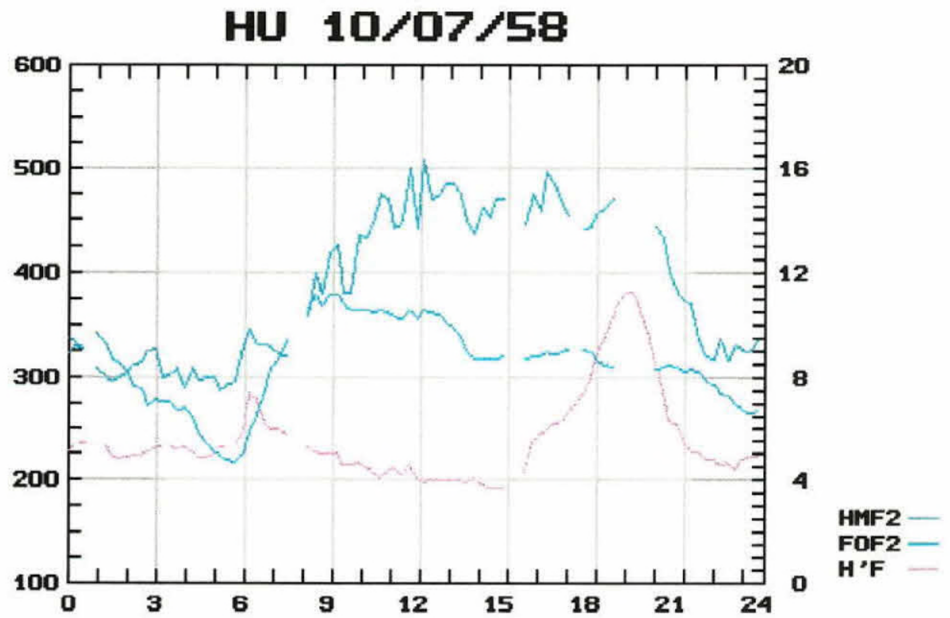

Figura 6- Gráfico dos dados obtidos através de ionograma de Huancayo (julho de 1958)

Como se pode ver este trabalho é bastante demorado e como os ionogramas são do Data Center (EUA) e tem um prazo pré-determinado para ficar no Brasil, precisamos fazer cópias dos originais, isto gerou grande trabalho, pois foi preciso tirar parte do original e mandar via malote para serem copiados em Cachoeira Paulista; e quando retornados (cópia e original), estes eram conferidos, catalogados e arquivados, aguardando para serem reduzidos.

4- COMENTÁRIOS

É bom lembrar, que pedi substituição da minha bolsa em 28/02/00, quando entreguei o relatório parcial. Assim por uma exigência do CNPq/PIBIC venho aqui entregar o relatório final e apresentá-lo no VIII Seminário de Iniciação Científica que será realizado em 03 e 04 de julho de 2000.

Seguem em anexo dois papers que foram apresentados na SBGF no Rio de Janeiro no ano passado, que levam o título de "Phase relationship between F-region electric field fluctuations – some new observations" e "Equatorial spread-F irregularities as observed by three different rocket-borne plasma density probes", dos quais participei.

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ANEXOS

PHASE RELATIONSHIP BETWEEN F-REGION ELECTRON DENSITY AND ELECTRIC FIELD FLUCTUATIONS - SOME NEW OBSERVATIONS

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Abstract

In-situ measurements of the height variation of the ionospheric electric field and electron density variations were made with a rocket-borne electric field double probe and two different types of electron density probes. A Brazilian made SONDA III rocket carrying these experiments in addition to other airglow experiments was launched on 18-th December, 1995 at 2117 hrs (LT) from the equatorial rocket launching station, Alcantara. The rocket reached an apogee altitude of 557km and covered a horizontal range of 589km. Several ground equipments were operated during the launch campaign with the specific objective of knowing the ionospheric conditions at the time of launch and thereby to launch the rocket into an F-region prone to the presence of large plasma bubbles. The rocket in fact passed through several medium scale plasma bubbles and the electric field double probe and the electron density probes detected the presence of a wide spectrum of electric field and electron density irregularities. In the base of the F-region the electric field double probe measurements clearly indicated the presence of large amplitude fluctuations, closely associated with large amplitude electron density irregularities But in the height region close to the rocket apogee though the electron density profile showed the presence of large scale spatial structures, the electric field measurements did not show fluctuations of similar amplitude. Being a nighttime launch one would expect the electron density irregularities, if generated by the well-known cross-field instability mechanism, in height regions where the electron density gradient is downward, i.e in the same direction as the ambient Hall electric field. An FFT algorithm was then used to estimate the spectral distribution of the electric field and electron density fluctuations, thus estimating the height variation of the spectral variation. Some new results on the phase relationship between the electric field and electron density fluctuations are presented here.

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 radar echoes 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 (see Bowles et al 1963 and Balsley, 1969), from their spectral characteristics as observed by the VHF radar, classified the plasma irregularities into two groups, namely Type I and Type II. While the Type I irregularities are now identified to be consistent with the two-stream instability mechanism (Farley, 1963), the Type II irregularities are known to be produced by the nonlinear cross-field instability mechanism (see Rogister and d'Angelo, 1972; Balsley and Farley, 1973). Direct observations by Prakash et al (1970) using rocket-borne Langmuir probes flown from India, confirm the existence of the Type II irregularities in the equatorial E-region. Type II irregularities are characterized by scale sizes extending from a few meters upto tens of kilometers. The short wavelength irregularities apparently seem to be generated from larger scale sizes through nonlinear coupling or cascading processes (see Rogister and d'Angelo, 1972; Sato 1973; Sudan et al 1973). Neutral turbulance also 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 the height variation of the ionospheric electric field and electron density variations were made with a rocket-borne double probe and two different types of electron density probes. A Brazilian made SONDA III rocket launched on 18-th December, 1995 at 2117 hrs (LT) from the equatorial rocket launching station, Alcantara reached an apogee altitude of 557km and covered a horizontal range of 589km. Several ground equipments were operated during the launch campaign with the specific objective of knowing the ionospheric conditions at the time of launch and thereby to launch the rocket into an F-region prone to the presence of large plasma bubbles.

EXPERIMENT AND FLIGHT DETAILS

The rocket payload designated IONEX-II had the principal objective of measuring the electric field, the electron density, the electron kinetic temperature and the spectral distribution of plasma irregularities associated with what are known as ionospheric plasma bubbles. The payload consisted of the following experiments in addition to other airglow photometers.

- •Electric Field Double Probe (EFP)
- •Langmuir Probe (LP)
- •High Frequency Capacitance probe (HFC)

Figure 1. shows the schematic of the rocket payload indicating the locations and mounting of the various experiment packages including the EFP, LP and HFC probes and the sensors of these experiments mounted on deployable booms.

The main objective of the EFP was to measure the dc electric field and the fluctuating component of it associated with the ionospheric plasma irregularities. Two spherical electric field sensors were mounted at the extremities of two booms that were deployed after the rocket nosecone was ejected at an altitude of about 65km. Though, in the fully deployed state the separation between the sensors was expected to be more than 3m, the booms did not open fully due to the unexpectedly low spin rate attained by the rocket and the separation between the sensors obtained was only about 1.3m.. This made the already difficult task of obtaining the dc component of the electric field practically impossible. However the ac component of the horizontal electric field were made in the altitude region of about 95 to 557km, the apogee altitude reached by the rocket and are being analysed.

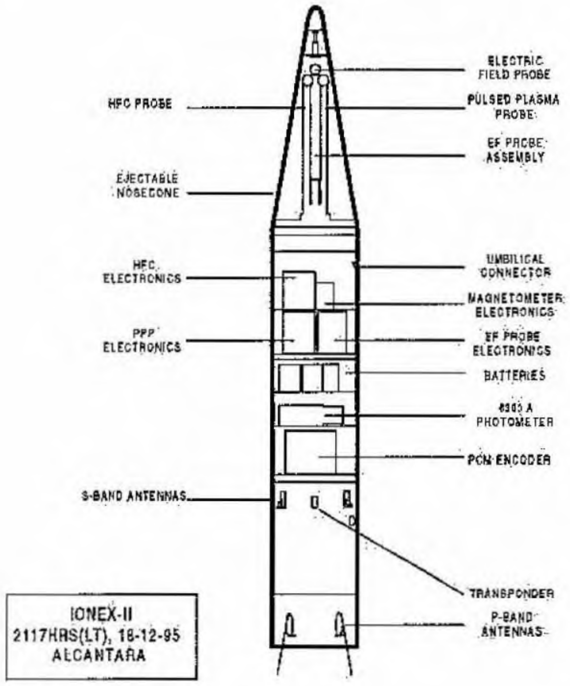

Figure 1.: Schematic of the IONEX-II rocket payload

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. A 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 sweep 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 the 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 electron density and the electric field fluctuation data have a sampling rate of 1250 per second that decided the lower limit for the measurable scale size. The maximum observable fluctuation frequency is 625Hz. This corresponds to different scale sizes at different height regions beacuse of the continuously changing rocket speed. For example in a height region where the rocket velocity is about 2km per second the LP and EFP experiments could measure the ac fluctuations of wavelength down to about 3,2m. Close to the region of apogee where the vertical component of the rocket velocity is very small the lowest vertical scale size of irregularities that can be measured with the LP and EFP goes down to practically zero. The HFC data does not permit the measurement of fast fluctuations in the electron density. Since the time duration needed to obtain one measurement with the HFC experiment is about 120ms, the distance between data points in a height region where the rocket velocity is about 2km/sec. is roughly 240m, or in other words the minimum scale size of irregularities that can be measured with HFC in this height region is about 480m. It should be noted here that the rocket was launched at a time when the network of ground experiments indicated possible development of plasma bubble events. The electron density profiles show that the rocket indeed passed through a series of plasma bubbles of varying amplitudes during the ascent and descent of the rocket. It should also be noted here that the E-Filed double probe measurements are modulated by the rocket spin and precession and there exists large base level noise in the fluctuation amplitude indicated. This base level noise can be removed by passing the E-field fluctuation data through appropriate band pass filters. However the existence of fluctuations with amplitudes higher than the base level noise can be clearly seen both in the electron density and the elctric field. Typical electron density and electric field fluctuation data observed at different times during the rocket ascent are presented in figures 2 to 5. Time after launch is indicated along the x-axis and the electron density and electric field fluctuation amplitudes on a relative scale are shown alon the y-axis. The total time duration of each block of data is about 0.8 seconds.

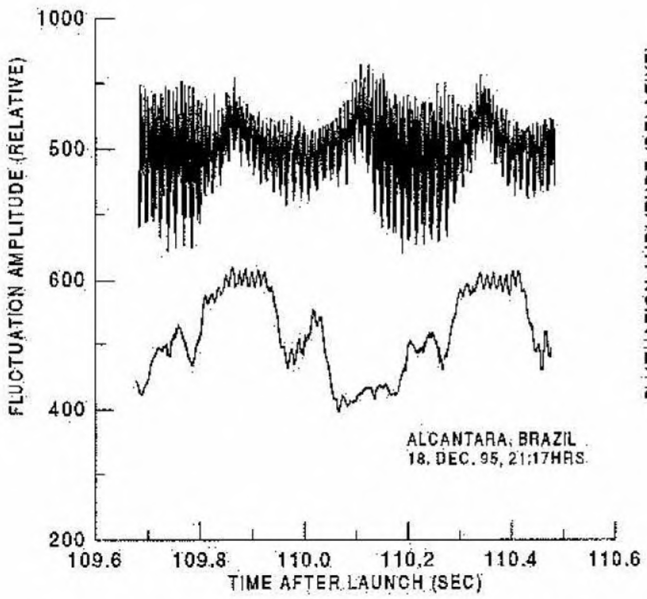

Figure 2.: Amplitude fluctuations in electron density (top) and electric field (bottom) on a relative scale as measured by the LP and EFP

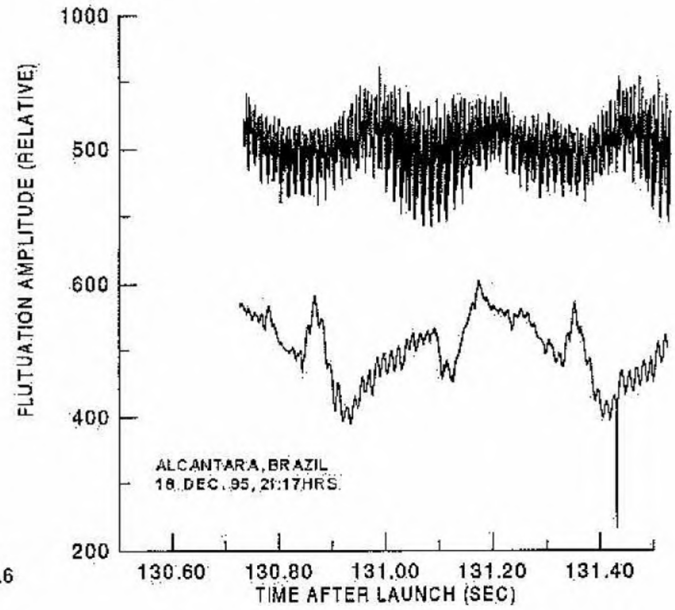

Figure 3.: Amplitude fluctuations in electron density (top) and electric field (bottom) on a relative scale as measured by the LP and EFP

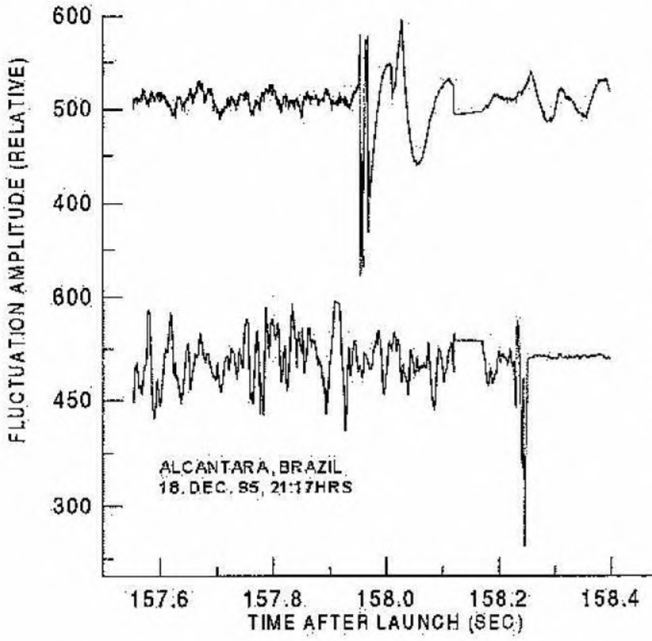

Figure 4.: Amplitude fluctuations in electron density (top) and electric field (bottom) on a relative scale as measured by the LP and EFP

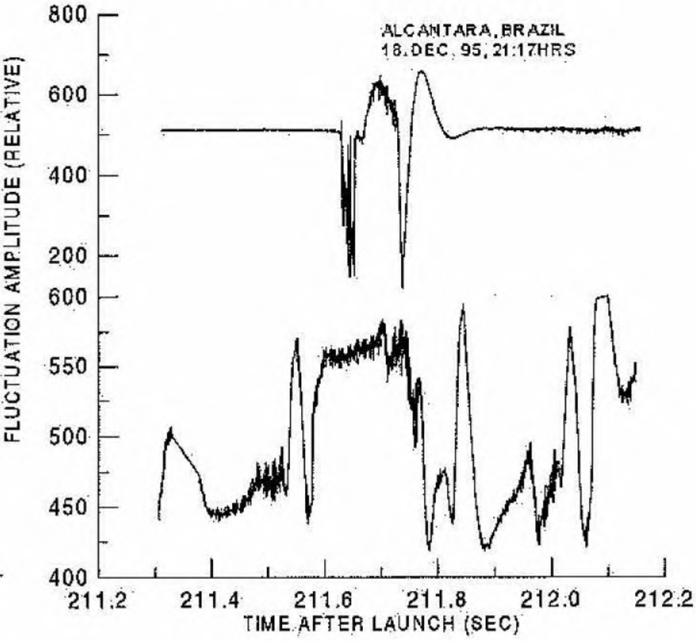

Figure 5.: Amplitude fluctuations in electron density (top) and electric field (bottom) on a relative scale as measured by the LP and EFP

The large amplitude variations seen in almost all these figures are mainly caused by the rotation and precession of the rocket. These rocket motions contribute to slow varying sinusoidal components to the signals. As one can clearly see in practcally all these figures there exist fluctuations that are not sinusoidal in nature in all these figures. A closer observation of these figures shows the following.

1. A definite phase relationship between the electric field and electron density flucutions seems to exist in all the height regions. One should note here that the EFP and the LP sensors are mounted in the same horizontal plane on board the rocket, but at right angles to each other. This will result in a fixed (varying only with the rocket spin rate) phase difference between the fluctuations.
2. The rise time for a particular structure is always more than the fall time. This is particularly evident in the electric field data. This saw tooth structure of the plasma density and electric field irregularities seems to be realted to

the generatiopn mechanism these irregularities and the nature of coupling between the large scale and small scale irregularities.

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..

CONCLUSIONS

- Bubble regions are associated with both electron density and electric field fluctuations.
- A definite phase relationship between the electric field and electron density flucutions seems to exist in all the height regions.
- The rise time for a particular structure is always more than the fall time. This is particularly evident in the electric field data

Spectral analysis of the ac data is being under taken, and is expected to give valuable information about the plasma instability mechanisms operating, among which the cross-field instability mechanism seems to be a definite one confirming the earlier observations. It should be noted here that the information that one gets from looking up at the phase relationship between fluctuating data is lost when one does the spectral analysis.

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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 Instituto 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 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.

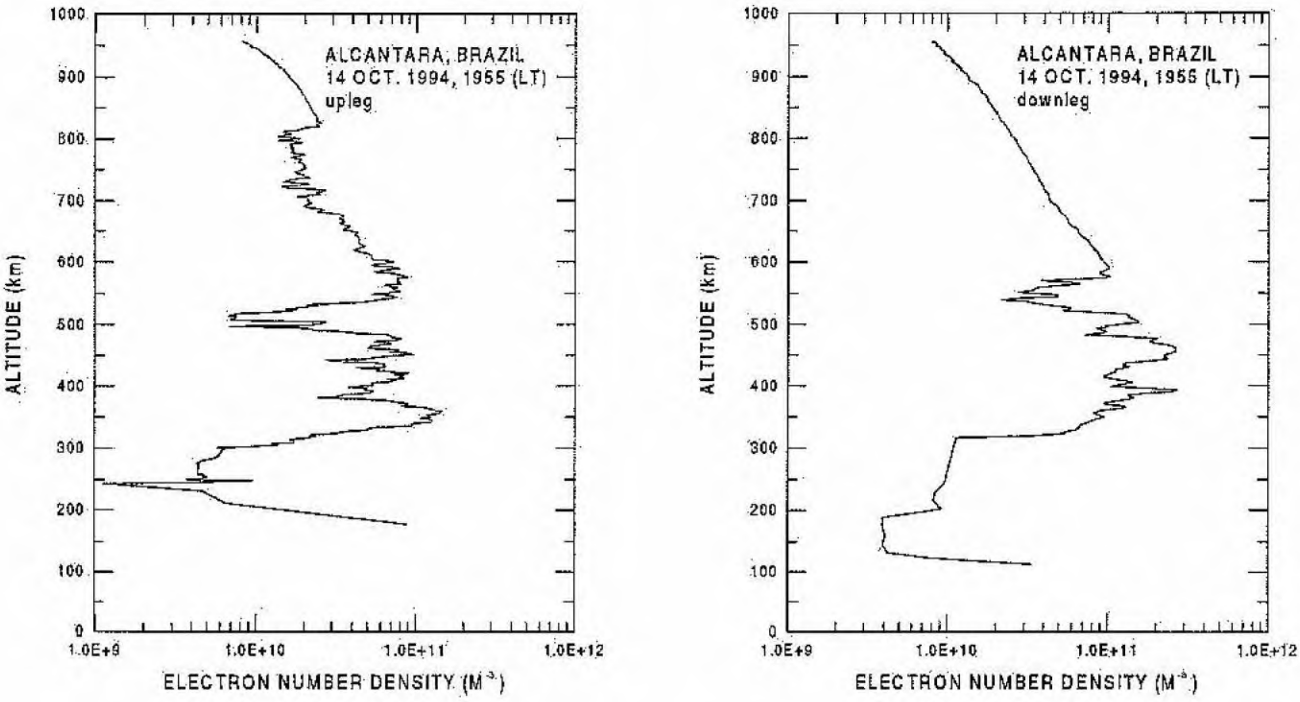

Figure 1: Electron density height profiles obtained with HFC data for rocket upleg (left) and downleg (right)

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.

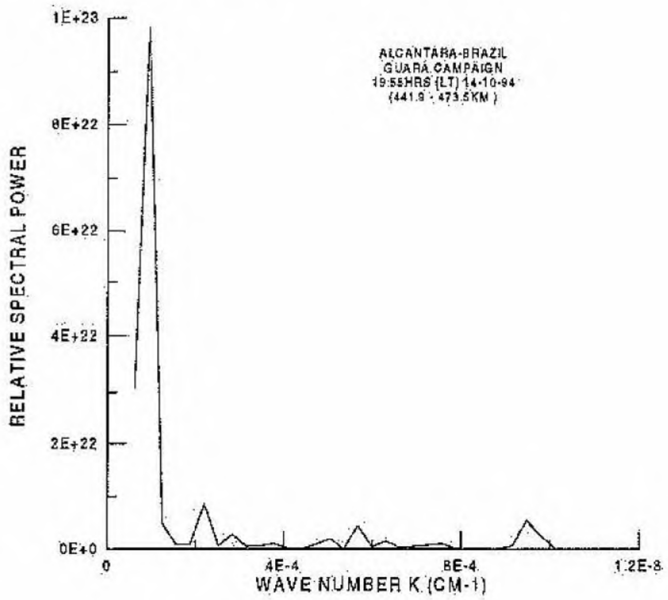

Figure 2: Typical k-spectrum of plasma irregularitie observed by the HFC experiment

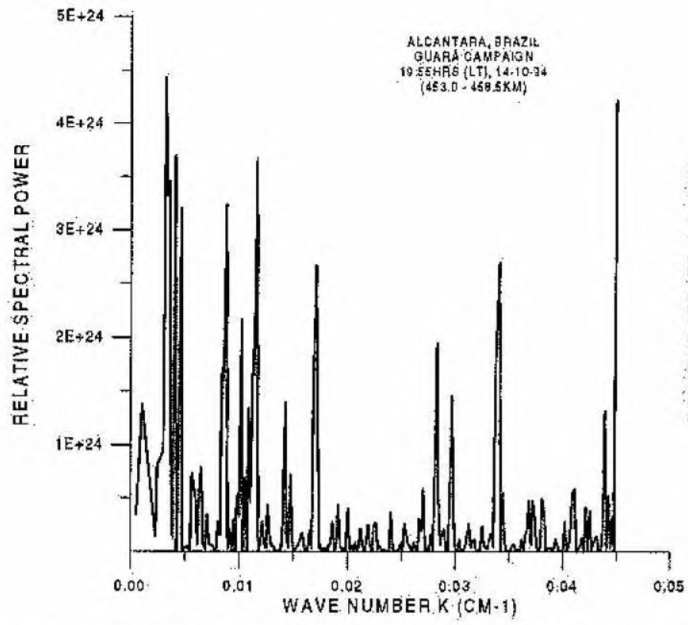

Figure 3: Typical k-spectrum of plasma irregularitie observed by the LP experiment

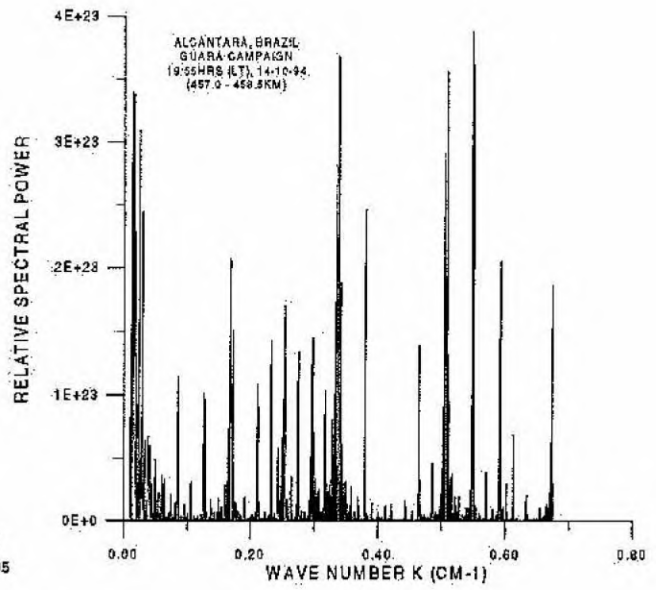

Figure 4: Typical k-spectrum of plasma irregularitie observed by the PFP experiment

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.

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