MFN= 007104
01 SID/SCD
02 5692
03 INPE-5692-PRE/1852
04 CEA
05 S
06 as
10 Abdu, Mangalathayil Ali
10 Muralikrishna, Polinaya
10 Batista, Ines Staciarini
10 Sobral, Jose Humberto Andrade
12 Rocket observation of equatorial plasma bubbles over Natal, Brazil, using a high-frequency capacitance probe
14 7689-7695
30 Journal of Geophysical Research
31 96
32 A5
40 En
41 En
42 <E>
58 DAE
61 <PI>
64 May <1991>
68 PRE
76 AERONOMIA
82 <NATAL (RN)>
83 In situ measurement of electron density height profile of the equatorial nightime ionosphere, under a developing spread F event, was carried out using a dual mode high frequency capacitance (HFC) probe that was flown on board a SONDA-III rocket launched from Natal on December, 11, 1985. This represents the first measurement of plasma bubble characteristics using an HFC probe. A series of plasma bubbles in varying degrees of their growth phase was detected mostly during the upleg of the flight. A somewhat detailed discussion, and comparative studies, of the measurements at the two probe frequencies (6.17 MHz and 11.75 MHz) are presented in this paper. Among the important findings from the present study is an evidence of electron temperature enhancement in the plasma bubble possibly caused by electron heating from energetic particle precipitation in the South Atlantic magnetic anomaly.
87 SONDA-III
88 EQUATORIAL IONOSPHERE
88 IONOSPHERIC IRREGULARITIES
88 PLASMA TEMPERATURE
88 PLASMA DENSITY
90 b
91 FDB-19960311
92 FDB-MLR

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. A10, PAGE 17,911, OCTOBER 1, 1991

Correction to "Rocket Observation of Equatorial Plasma Bubbles Over Natal, Brazil, Using a High-Frequency Capacitance Probe" by M. A. Abdu et al.

In the paper "Rocket Observation of Equatorial Plasma Bubbles Over Natal, Brazil, Using a High-Frequency Capacitance Probe" by M. A. Abdu, P. Muralikrishna, I. S. Batista, and J. H. A. Sobral (*Journal of Geophysical Research*, *96*(A5), 7689–7695, 1991), Figure 3 was omitted, and Figure 2 was repeated in its place. The correct Figure 3 appears below.

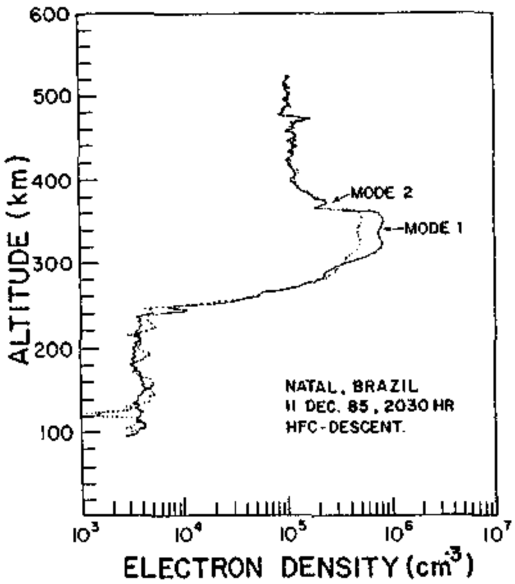

Fig. 3. Results similar to those of Figure 2 for the downleg trajectory.

(Received July 29, 1991.)

Paper number 91JA02141.
0148-0227/91/91JA-02141$02.00

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. A5, PAGES 7689–7695, MAY 1, 1991

ROCKET OBSERVATION OF EQUATORIAL PLASMA BUBBLES OVER NATAL, BRAZIL, USING A HIGH-FREQUENCY CAPACITANCE PROBE

M. A. Abdu, P. Muralikrishna, I. S. Batista, and J. H. A. Sobral

Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil

In situ measurement of electron density height profile of the equatorial nighttime ionosphere, under a developing spread F event, was carried out using a dual mode high frequency capacitance (HFC) probe that was flown on board a SONDA-III rocket launched from Natal on December 11, 1985. This represents the first measurement of plasma bubble characteristics using an HFC probe. A series of plasma bubbles in varying degrees of their growth phase was detected mostly during the upleg of the flight. A somewhat detailed discussion, and comparative studies, of the measurements at the two probe frequencies (6.17 MHz and 11.75 MHz) are presented in this paper. Among the important findings from the present study is an evidence of electron temperature enhancement in the plasma bubble possibly caused by electron heating from energetic particle precipitation in the South Atlantic magnetic anomaly.

INTRODUCTION

Plasma depleted flux tubes, namely, plasma bubbles, that mark the unstable equatorial nighttime ionosphere have been the subject of active investigation since their first identification from radar, rocket and satellite measurements [Hanson and Sanatani., 1973; Woodman and La Hoz, 1976; McClure et al., 1977] and subsequent studies using rocketborne, radio and optical measurements (see, for example, Baker et al. [1985], Kelley et al. [1976], Szuszczewicz et al. [1980, 1981], Klobuchar and Aarons [1980], Abdu et al. [1983], Sobral et al. [1980], and Weber et al. [1978]). Having field line perpendicular scale lengths of tens to hundreds of kilometers, the bubbles, themselves, represent the lower wave number limit of a spectral distribution that could, in a fully developed event, more often known as spread F event, extend to meter or even to centimeter size irregularities. 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 Haerendel [1974]. Important physical processes of the ambient ionospheric condition conducive to their generation, including the nature of the initial perturbation sources, as also of the different instability mechanisms operating in the different scale size domains need to be further clarified. In this context, in situ measurements of the bubble vertical structure and related characteristics by sounding rockets could indeed provide valuable information.

A SONDA-III rocket carrying plasma and optical diagnostic payloads was launched into a nighttime equatorial ionosphere over Natal that was marked by a developing plasma bubble event. The rocket took off at 2030 LT on December 11, 1985, from the launch base at Barreira do Inferno. A high-frequency capacitance (HFC) probe measured the electron density distribution on the upleg and downleg of the trajectory that reached an apogee of 530 km. A series of developing plasma depletions were detected mainly during the upleg of the flight. The results of these measurements are presented and discussed in this paper.

EXPERIMENT DESCRIPTION

The nose tip of the rocket, a section of 9-cm length isolated from the rest of the body of the rocket, was used as the capacitance element that determined the frequency of a stable oscillator whose operation in a dual frequency mode, at 6.17 MHz and 11.75 MHz, was achieved by switching at a convenient rate between two suitably selected inductors [see Abdu et al., 1988; Heikkila et al., 1968]. From the Appleton-Hartree formula for the plasma dielectric constant, simplified by neglecting collision and magnetic field effects, the change in capacitance C of a sensor, with respect to its free space value, C_o, (assuming a factor S for the ion sheath around the sensor) is given, in terms of the plasma frequency f_p, and the oscillator frequency, f, as

$$\Delta C/C_o = -Sf_p^2/f^2 \quad (1)$$

The corresponding change in the oscillator frequency (Δf) is given by the relation

$$f^2 = (f_o + \Delta f)^2 = f_o^2 + Sf_p^2/(1 + C_s/C_o) \quad (2)$$

$$\Delta f = Sf_p^2/[2f_o\ (1 + C_s/C_o)] \quad (2')$$

where C_s is the stray capacitance in the mounting of the oscillator elements, which should be reduced to a minimum to obtain maximum sensitivity for Δf. The frequency was measured on board the rocket and telemetered to ground through the on board pulse code modulation (PCM) telemetry transmitter. The electron density is given by

$$N = (2f^2/f_o)\ \Delta f/(81SK), \quad (3)$$

Paper number 90JA02384.
0148-0227/91/90JA-02384$05.00

where $K = C_o/(C_s + C_o)$, f is in hertz and N in electrons m^{-3}. (The C_s was determined in a prelaunch calibration procedure that involved measurement of the oscillator frequencies for three spheres of 3-, 6- and 9-cm diameter that substituted the sensor nose tip as the element determining the oscillator frequency).

At lower heights in the ionosphere, namely, at low Δf values, the electron density is nearly linearly proportional to Δf, S remaining constant. However, with f_p increasing with height toward the oscillator frequency, the change in C tends to become a significant fraction of its free space value, S approaching 1, resulting in rapid rise of Δf. As a result the oscillator functioning (determined by tuned elements) could break down at the MODE-1 frequency. Under this condition the MODE-2 operation at a higher frequency permits uninterrupted measurement of Δf and hence 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 duration of 58 ms each, thus forming an operation cycle of 116 ms. For calibration purposes, during one out of every four cycles of operation a negative bias of 100 V is applied to the sensor. The height resolution of the measurements thus varied from about 400 m in the E region to about 50 m in the F region near the apogee. The rocket was launched at an azimuth of 74° which closely corresponds to the magnetic east-west direction.

Since the experiment had the objective of studying a developing spread F bubble event, the rocket launch criteria had to be established to guarantee the success of this objective. This task was further complicated by the fact that no radar diagnostics were available to monitor the onset of a bubble event in the vicinity, especially westward of the rocket trajectory. The ionosonde at Fortaleza, situated some 300 km westward of Natal, and amplitude scintillation measurement on 255 MHz MARISAT beacon were relied upon to monitor the occurrence of irregularities westward of the rocket trajectory. These measurements do not necessarily detect plasma bubble events since the irregularities detected by them could be produced also by spread F events confined to the bottomside, namely, subpeak altitudes. Therefore a third criterion was used, namely, the detection of spread F by an ionosonde at Cachoeira Paulista situated at -28° dip and also displaced by some 9° westward in longitude with respect to the rocket launch site. Implicit in this criterion is the contention that the spread F over this low-latitude station is produced by flux tube aligned transequatorial depletions that rise up above the equator, extending their extremities to low latitudes (see, for example, Abdu et al., [1983]; Tsunoda [1980]; Weber et al. [1978]). The detection of spread F over Cachoeira Paulista therefore could suggest equatorial bubble growth in the same longitude sector. The validity of these criteria seems to be born out by the fact that the SONDA-III launched immediately after the appearance of spread F over Cachoeira Paulista and scintillation onset over Natal (Enivaldo Bonelli, Universidade Federal do Rio Grande do Norte-UFRN, private communication, 1985), when the spread F over Fortaleza had already set in, did encounter several developing bubbles in the ionosphere eastward of Natal.

RESULTS

The electron density height distribution obtained from the upleg and downleg of the flight INPE 002 are presented in Figure 1. These densities were calculated from MODE-2 data at f = 11.75 MHz and using an ion sheath effect factor S = 0.5 as was found adequate from our previous daytime experiment [Abdu et al., 1988] in which

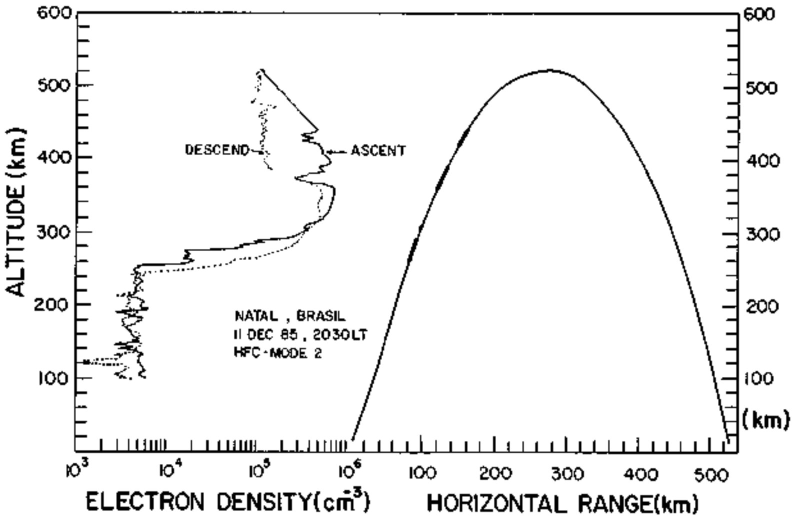

Fig. 1. Electron density profiles (left-hand side) calculated from Δf measurements in MODE-2 operation of the oscillator at 11.75 MHz. A series of depletions are seen in the upleg profile, the most pronounced being the one at 370 km in the topside. The right-hand side of the figure is the rocket trajectory on which the patched height intervals correspond to the occurrence of the depletions on the profile.

this factor was determined using ionosonde f_oE value for Fortaleza (~300 km westward of Natal). The variation of S with height is expected to be negligible, since the MODE-2 oscillator frequency was always much higher than the plasma frequencies in the F layer, the value of f_p at the F layer peak being 7.2 MHz. Significant increase of S, its value approaching 1, at the MODE-1 frequency of 6.17 MHz has been observed near the F layer peak. The considerations on this aspect to be discussed soon will point to a nearly height independent factor for the MODE-2 frequency. Any small changes in this S near the F layer peak could have been determined using simultaneous f_oF_2 measurement by ionosonde. However, we did not operate one at Natal for this flight. The right-hand part of the figure shows the rocket trajectory that was extrapolated after 391.4 km where, at 191.5 s after the launch, the radar range tracking had failed. The sensitivity of the measurements is not good below 240 km due to the low electron densities (~$5 \times 10^5 el/cm^3$) coupled with the somewhat larger stray capacitance (C_s = 12 pF as compared to C_o = 3.7 pF) that was present in this experiment.

The HFC probe has detected a series of developing depletions although there is no way for us to judge whether or not the rocket trajectory intercepted those depletions at their maximum values (namely, at the density minima). However, the two topside bubbles centered at 370 km and 430 km are clearly more developed than the ones below the F peak. This point seems to be a good demonstration of the fact that the bubble growth is associated with vertical rise under a polarization electric field. The ambient ionosphere height variation was monitored by an ionosonde operated at Fortaleza. However, the determination of the height or vertical velocity of the layer immediately preceding the launch was made impossible due to the range spread F that set in at 1945 LT. The data for the previous day and next day (December 10 and 12) of the experiment suggested either stationary or descending F layer conditions for the local time of this experiment, a phase of h'F variation that follows the prereversal evening rise of the layer (under F region dynamo development) that is a necessary precursor for the bubble associated spread F development (see, for example, Abdu et al. [1981]). A comparison of the ascent and descent part of the bottomside gradient region, namely, the base of the layer in Figure 1 would suggest a descent velocity for the layer of the order of 30 ms^{-1} or less. The gravitational R-T instability growth rate factor (see, for example, Ossakow and Chaturvedi [1978], Zalesak et al. [1982], Abdu et al. [1982]) was calculated for the ascent and descent bottomside gradient regions. The expression used was

$$\gamma = (\underline{E} \times \underline{B}/B^2 - U_n - g/\nu_{in})\nabla n/n - \nu_r$$

which is a simplified version of that given by Zalesak et al. [1982]. Here ν_{in} is the ion-neutral collision frequency, $n/\nabla n = n/(dn/dh)$ is the vertical gradient scale length of the electron density, $\underline{E}$ and $\underline{B}$ are the electric and magnetic fields, $U_{\bar{n}}$ is the zonal neutral wind taken positive westward and ν_r is the recombination rate. The calculation of the growth rate was carried out neglecting the effect of the neutral wind, assuming a vertical drift of 30 ms^{-1} downward which is an upper limit as mentioned above and using the gradient scale lengths for steepest regions (near 280 km) for the upleg and (near 260 km) for the downleg profiles and the MSIS model atmosphere. The values of γ obtained were 1.38×10^{-3} $s^{-1}$and -1.27×10^{-3} s^{-1} for the upleg and downleg, respectively. It should be noted that these values are approximate due to the limitations on the precise information for the vertical drift and zonal wind. Nevertheless, it seems to show the possibility that vertical distribution of the series of depletions encountered on the ascent profile could be produced by the onset of the instabilities at the bottomside positive gradient region of the F layer and their growth into well-developed topside depletions as predicted by the theory of R-T instability mechanism.

In the most intense of the bubbles the amplitude of the depletion reaches around 60% of the ambient density, not a particularly severe depletion compared to the amplitudes that have been observed from satellites [McClure et al., 1977]. This amplitude lies between that observed during the CONDOR campaign over Peru by Baker et al. [1985] that was 50%, and that measured in the PLUMEX 1 experiment over Kwajalein Atoll by Szuszczewicz et al. [1980] that was 85%. However, it may be of interest to note that in all these observations (over Peru, Kwajalein and Natal) the vertical extent of the bubbles varied from 20 to 30 km only. Further, it may be noted, especially in the case of the depletions observed by us (for the bubble at 370 km) that the upper part of the bubble, namely, the positive density gradient region, has more structures in the density distribution than the negative gradient region, a result that was observed also in the rocket profiles of Baker et al. [1985] and Szuszczewicz et al. [1980]. This might suggest that cascading process [Haerendel, 1974] producing smaller scale structures are perhaps more likely to occur, under the conditions that prevailed for these experiments, at the positive density gradient region (i.e, the upper wall) of the bubble. However, a statistical study involving also appropriate satellite data should be carried out to confirm such a trend. Further studies on this aspect of the irregularity generation are being pursued.

The downleg profile presents clearly different features from those of the upleg profile. Basically, the densities in the topside are significantly smaller than those in the upleg part. It is conceivable that this difference could be produced by the rocket trajectory, in its downward leg from the apogee, traversing the "neck" region of a westward tilted depletion structure, located eastward of those encountered on the upleg, and having field line perpendicular cross section similar to those proposed by Tsunoda et al. [1982]. We feel that it could also be produced due to the downward movement of the layer perhaps modulated by a horizontal density gradient. This possibility seems to be a little more favored due to the fact that the bottomside F region is displaced downward by 20-30 km in the descent profile as compared to the ascent profile. Further, the densities calculated at the two modes are nearly the same in this height region in contrast to the significant differences in their values observed inside clearly defined bubble structures (as will be discussed below).

For comparison, the profiles in MODE-2 and MODE-1 for the upleg and downleg are presented in Figures 2, 3, respectively. The densities in both the modes were calculated using the same S factor (namely, S = 0.5). Although all the density features of the MODE-2 profile are faithfully observed in the MODE-1 as well, there are some striking differences in their amplitudes. Two aspects of these differences are the following: (1) The density values calculated near the F peak are significantly higher in MODE-1 than in MODE-2, during both the upleg and downleg parts, and (2) on the other hand, inside the depletions the densities are significantly underestimated in MODE-1 compared to those in MODE-2. Regarding aspect 1 the difference (the MODE-1 values being higher than that of MODE-2) can be shown to be due to a decrease in the sheath thickness when the oscillator frequency gets close to the local plasma frequency. Thus from equation (3), denoting with subscripts m1 and m2 the frequencies and electron densities in the MODE-1 and MODE-2, respectively, we can write

$$\frac{N_{m1}}{N_{m2}} \cong \frac{(f.\ \Delta f)_{m1}}{(f.\ \Delta f)_{m2}} \cdot \frac{S_{m2}}{S_{m1}} \qquad (4)$$

Obviously, the value of this ratio should always be equal to 1. However, the ratio obtained from the calculations, based on the observed Δf, and assuming a constant value of 0.5 for S_{m1} and S_{m2}, is $\cong$ 2.0 near the F peak. This increase in the observed ratio can only be due to the sheath reducing in thickness at MODE-1 (the sensor capacitance decreasing significantly) tending to the point of vanishing so that the S factor aproaches the value of 1 instead of the 0.5 that was assumed.

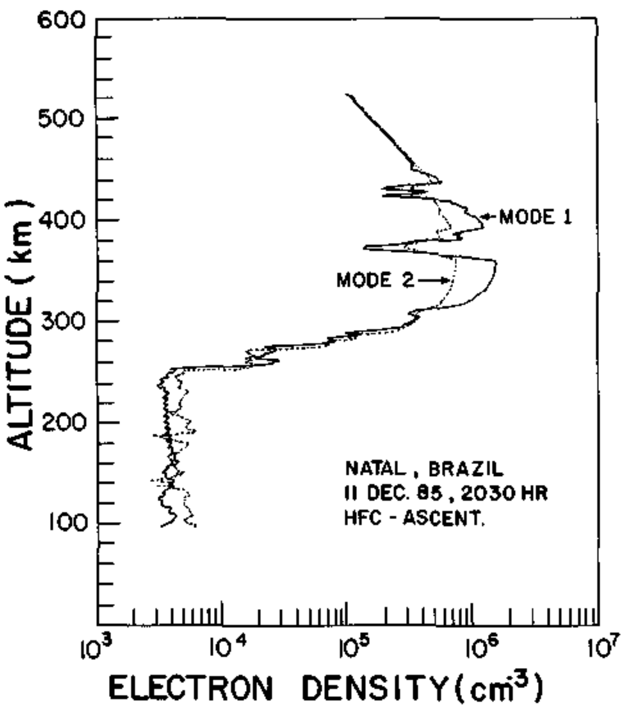

Fig. 2. Comparison of the electron densities calculated using the same S factor (0.5) for MODE-1 (dashed curve) and MODE-2 (solid curve) for the upleg of the rocket trajectory.

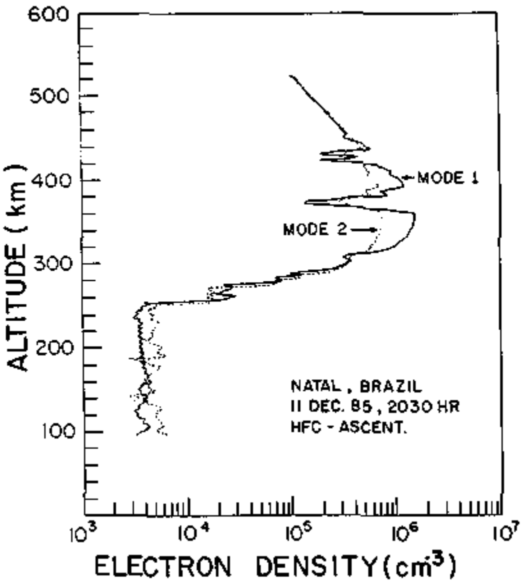

Fig. 3. Results similar to those of Figure 2 for the downleg trajectory.

The second aspect, namely, the MODE-1 values being significantly less than the MODE-2 values inside the plasma depletion seems to be more complicated to explain. Here the calculated ratio as per equation (4) assuming $S_{m1} = S_{m2} = 0.5$ is 0.464. Thus the S factor has decreased to 0.23 from the value of 0.5 that is normally assumed. This shows that the sheath has increased in thickness. This is true also for the smaller bubble centered around 430 km in the upleg. The sheath thickness is in fact dependent on the potential of the probe with respect to the plasma as also on the probe geometry and to some extent on the rocket velocity and can be expressed as a multiple of the Debye length, $\lambda_d = (kT_e/Ne^2)^{1/2}$. Thus a decrease in density and/or an increase in electron temperature T_e inside the bubble could cause increase in the sheath thickness. However, the effect being observed only at MODE-1 frequency and not at the higher frequency of MODE-2 needs to be explained. We examine below the possibility of this effect being produced by the nearness of the lower frequency of MODE-1 to the resonance rectification frequency for the sensor. Crawford and Happer [1965, and references therein] have investigated the behavior of sensors of different geometrical shapes, immersed in plasma, relating the resonance rectification effect, namely, the occurrence of a maximum rectified dc current for an ac field, applied to the sensor, at a resonant frequency ω_r lying between the electron gyrofrequency (ω_g) and the upper hybrid frequency as follows:

$$\omega_r/\omega_p = [1/(1+R/\lambda_d K) + \omega_g^2/\omega_p^2]^{1/2} \qquad (5)$$

where R is the radius of the sensor (in our case of a conical-shaped sensor with an equivalent radius of 3.3 cm); K is an empirical constant for the rf sheath thickness expressed in Debye lengths which Crawford and Harper [1965] have determined to be equal to 5.

We carried out calculations of the ratio ω_r/ω_p and the ratio of the resonance frequency to the oscillator frequency namely, ω_r/ω_{osc}, for MODE-1, for regions immediately outside the depletion and for the maximum depletion for the case of the bubble centered at 370 km. The calculations were performed for two values of electron temperature, T_e = 1000 K and 1500 K. The results are shown in Table 1. From a study of these numbers it is seen that no resonance occurs at the oscillator frequency either inside or outside the depletion since the values of ω_r/ω_{osc} are far from unity for all the cases shown here. However, it is interesting to note that the value of ω_r/ω_{osc} at the depletion maximum for T_e = 1500 K comes out to be very close to 0.5, which might signify that resonance rectification effect must have occurred at the subharmonics of the MODE-1 frequency. The conductance maximum of the sensor that occurs at ω_r could increase the sheath thickness [see Heikkila et al., 1968; Crawford and Harper, 1965]. For lower temperature the ω_r/ω_{osc} value decreases and is out of the resonance condition, as the result for T_e = 1000 K inside the bubble indicates (see Table 1). During the downleg the electron density from apogee down to 380 km is comparable to or less than that encountered in the depletion during the upleg. Nevertheless, both the MODE-1 and MODE-2 present almost equal values of electron densities (obtained using S = 0.5) in this region; in other words the sheath was identical at both frequencies. However, further down the trajectory the sensor enters a small depletion at 365 km and again the effect of increased sheath thickness at MODE-1 frequency is clearly evident. Thus for identical electron densities inside and outside a depletion the sheath enhancement (at resonance rectification) occurs only when a higher temperature is assumed inside the depletion. This result would suggest the existence of an electron temperature enhancement inside the bubble as compared to its outside value. In this connection it is interesting to note that Oyama and Schlegel [1988] have found from measurement by the satellite "Hinotori" that electron temperature in plasma bubbles around the 600-km altitude could be higher, lower, or unchanged with respect to the electron temperature outside. More interestingly, they found that in the case of bubbles occurring in the low-latitude region over the South Atlantic magnetic anomaly (and during sunlit hours in the morning or evening), the electron temperature inside bubbles was significantly higher than outside. This was suggested to be due to the electron heating by charged particle precipitation in the South Atlantic anomaly (or by solar heating in the case of the sunlit bubbles). Our measurements were conducted in a geographic region where the flux tubes are coupled to the central region of the South Atlantic anomaly. Thus the results indicating higher electron temperature inside bubbles is in good agreement with the satellite observations of Oyama and Schlegel [1988].

TABLE 1. The Ratio of the Resonant Rectification Frequency ω_r for the HFC Sensor to the Local Plasma Frequency ω_p and That of ω_r to the Oscillatory Frequency ω_{osc} Calculated for T_e = 1000 K and 1500 K

	Electron Density, cm^{-3}	ω_r/ω_p (ω_r/ω_{osc}) T_e = 1000 K	ω_r/ω_p (ω_r/ω_{osc}) T_e = 1500 K
At lower edge of the bubble	7.62×10^5	0.533 (0.568)	0.571 (0.608)
At maximum depletion	2.8×10^5	0.629 (0.466)	0.667 (0.494)
At upper edge of the bubble	6.8×10^5	0.538 (0.561)	0.572 (0.602)

Parentheses are the ratios of ω_r to the oscillator frequency (ω_{osc}). The results of calculation for the lower and upper edges of the bubble as well as for maximum depletion are presented.

DISCUSSION AND CONCLUSIONS

The results presented here represent the first attempt to measure an electron density profile through equatorial plasma bubbles using a high-frequency capacitance probe. These results, as also those reported earlier on the use of an HFC probe for daytime equatorial F region measurement [Abdu et al., 1988] show that if the frequency of the oscillator is well above the local plasma frequency, the electron densities obtained (using a sheath effect factor of 0.5) are very reliable indeed. This condition is adequately met in the cases of the MODE-2 frequency of 11.75 MHz used in the present measurements. Thus the electron density measurements outside and inside plasma bubbles should be within 10-20% of their real values (based on a calibration using the ionogram f_oE over Fortaleza carried out earlier by Abdu et al. [1988, 1990]). The lower frequency, 6.17 MHz, on the other hand, clearly demonstrates significant ion sheath contraction (namely, reduction in the sensor negative potential) as this frequency gets closer to the F peak plasma frequency. Under this condition the determination of the electron density is not reliable since the S factor is unknown.

Fortuitously, however, this frequency has provided valuable information of the sheath enhancement inside the plasma depletions. Such enhancements occur due to the oscillator frequency, namely, the rf applied to the sensor, getting sufficiently close to the resonance rectification frequency of the sensor. In the present case it looks as though the subharmonic of the MODE-1 frequency might have produced the rectification effect, namely, enhancement in the ion sheath effect. The evaluation of this effect shows that for the electron density that was present in these depletions the resonance rectification effect could be produced only if we assume an electron temperature inside the bubble that is higher than that outside. Therefore the present results provide some important evidence of electron temperature enhancement inside the bubble observed in the region of the South Atlantic anomaly. Electron heating by energetic particle precipitation in the bubble flux tube (similar to the heating by photoelectrons, [Hanson and Johnson, 1961]) could be responsible for this enhanced temperature. Detailed evaluation of the magnitude of the expected T_e enhancement, from considerations of the ion sheath processes as well as on the energy deposition from particles, needs to be carried out.

Another important result from the present analysis is the verification that the gravitational R-T instability mechanism is capable of explaining the growth of the instabilities at the positive gradient region of the bottomside F region, into vertically rising bubbles seen in the topside ionosphere. The success that we had on the launch criteria, based on the ionosonde and amplitude scintillation data (in the absence of a radar), support the view that the range type spread F, observed in the ionogram over a low latitude, are indeed produced by the flux tube aligned depletion that develop upward over the equator under the gravitational R-T instability mechanism.

Acknowledgments. The present experiment using the SONDA-III rocket was made possible through a collaboration project between the Instituto de Atividades Espaciais IAE/CTA and INPE. The authors would like to express their thanks to Sinval Domingos for his dedication in construction and testing of the payloads. Thanks are given to Enivaldo Bonelli and his group at the University of Rio Grande do Norte for operating the scintillation receiver at Natal and to the technical staff at Cachoeira Paulista and Fortaleza for special scheduling of ionosonde operation at the two sites. This work was partially supported by the "FNDCT" under contract FINEP 537/CT and by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

The Editor thanks K. B. Baker and W. B. Hanson for their assistance in evaluating this paper.

References

Abdu, M. A., I. S. Batista, and J. A. Bittencourt, Some characteristics of spread F at the magnetic equatorial station Fortaleza, J. Geophys. Res., 86, 6836, 1981.

Abdu, M. A., R. T. de Medeiros, and J. H. A. Sobral, Equatorial spread F instability conditions as determined from ionograms, Geophys. Res. Lett., 9, 692, 1982.

Abdu, M. A., R. T. de Medeiros, J. H. A. Sobral, and J. A. Bittencourt, Spread F plasma bubble vertical rise velocities determined from spaced ionosonde observations, J. Geophys. Res., 88, 9197, 1983.

Abdu, M. A., P. Muralikrishna, I. S. Batista, and A. H. P. Chaves, On the rocket-induced wave disturbances in the daytime equatorial ionosphere, J. Geophys. Res., 93, 2758, 1988.

Abdu, M. A., P. Muralikrishna, E. R. de Paula, and I. J. Kantor, Rocket measurement of equatorial ionosphere electron densities and their comparison with IRI-10 predictions, Adv. Space Res., 10, 8(41), 1990.

Baker, K. D., J. La Belle, R. F. Pfaff, L. C. Howett, N. B. Rao, J. C. Ulwick, and M. C. Kelley, Absolute electron density measurements in the equatorial ionosphere, J. Atmos. Terr. Phys., 8, 781, 1985.

Crawford, F. W., and R. S. Harper, The resonance Probe-A tool for ionospheric and space research, J. Geophys. Res., 70, 587, 1965.

Haerendel, G. Theory of equatorial spread F, report, Max-Planck-Institut Phys. Astrophys., Garching, Germany F.R.G., 1974.

Hanson, W. B., and F. S. Johnson, Electron temperatures in the ionosphere, in Les Spectres des Astres dans l'Ultraviolet Lointain, vol. 20, p. 8, Mémoires Société Royale Scientifique Liege Collect, Liege, Belgium, 4, 390, 1961.

Hanson, W. B., and S. Sanatani, Large Ni gradients below the equatorial F peak, J. Geophys. Res., 78, 1167, 1973.

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

Kelley, M. C., G. Harendel, H. Kappler, A. Valenzuela, B. B. Balsley, D. A. Carter, W. L. Ecklund, C. W. Carson, B. Hansler, and R. Torbert, Evidence for a Rayleigh-Taylor type instability and upwelling of depleted density regions during equatorial spread F , Geophys. Res. Lett., 3, 448, 1976.

Klobuchar, J. A. and J. Aarons, "Studies of equatorial irregularity patches using SIRIO VHF transmissions, Alta Freq., 49, 345, 1980.

McClure, J. P., W. B. Hanson, and J. H. Hoffman, Plasma bubbles and irregularities in the equatorial ionosphere, J. Geophys. Res., 82, 2650, 1977.

Ossakow, S. L., and P. K. Chaturvedi, Morphological studies of rising equatorial spread F bubbles, J. Geophys. Res., 83, 2085, 1978.

Oyama, K. I., and K. Schlegel, Temperature structure of plasma bubbles in the low latitude ionosphere around 600 km altitude, Planet. Space Sci., 36, 553, 1988.

Sobral, J. H. A., M. A. Abdu, and I. S. Batista, Airglow studies on the ionosphere dynamics over low latitude in Brazil, Ann. Geophys., 36 (2), 199, 1980.

Szuszczewicz, E. P., R. T. Tsunoda, R. Narcisi, and J. C. Holmes, Coincident radar and rocket observations of equatorial spread F, Geophys. Res. Lett., 7, 537, 1980.

Szuszczewicz, E. P., R. T. Tsunoda, R. Narcisi, and J. C. Holmes, Plumex II: A second set of coincident radar and rocket observation of equatorial spread-F, Geophys. Res. Lett., 8, 803, 1981.

Tsunoda, R. T., Magnetic field-aligned characteristics of plasma bubble in the nighttime equatorial ionosphere, J. Atmos. Terr. Phys., 42, 743, 1980.

Tsunoda, R. T., R. C. Livingstone, J. P. McClure, and W. B. Hanson, Equatorial plasma bubble: Vertically elongated wedges from the bottomside layer, J. Geophys. Res., 87, 9171, 1982.

Weber, E. J., J. Buchau, R. H. Eather, and S. B. Mende, North-south aligned equatorial airglow depletions, J. Geophys. Res., 83, 712, 1978.
Woodman, R. F., and C. LaHoz, Radar observation of F region equatorial irregularities, J. Geophys. Res., 81, 5447, 1976.
Zalesak, S. T., S. L. Ossakow, and P. K. Chaturvedi, Nonlinear equatorial spread F: The effect of neutral winds and background Pedersen conductivity, J. Geophys. Res., 87, 151, 1982.

M.A. Abdu, I.S. Batista, P. Muralikrishna, and J.H.A. Sobral, Instituto Nacional de Pesquisas Espaciais, Av. dos Astronautas, 1758, Caixa Postal 515, 12201, São José dos Campos, São Paulo, Brazil.

(Received December 15, 1989;
revised October 25, 1990;
accepted October 25, 1990.)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 96, NO. A10, PAGE 17,911, OCTOBER 1, 1991

Correction to "Rocket Observation of Equatorial Plasma Bubbles Over Natal, Brazil, Using a High-Frequency Capacitance Probe" by M. A. Abdu et al.

In the paper "Rocket Observation of Equatorial Plasma Bubbles Over Natal, Brazil, Using a High-Frequency Capacitance Probe" by M. A. Abdu, P. Muralikrishna, I. S. Batista, and J. H. A. Sobral (*Journal of Geophysical Research*, *96*(A5), 7689–7695, 1991), Figure 3 was omitted, and Figure 2 was repeated in its place. The correct Figure 3 appears below.

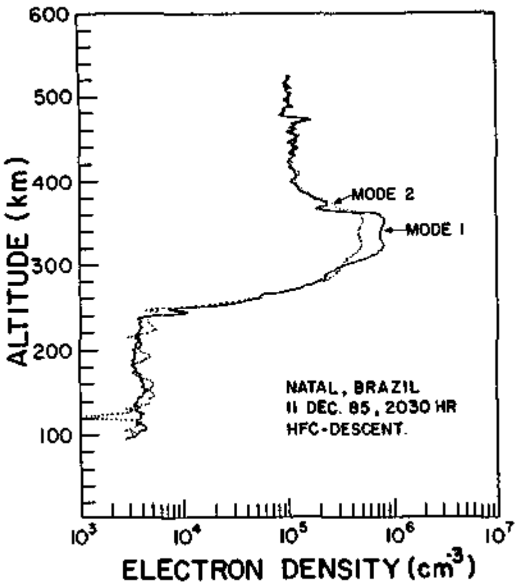

Fig. 3. Results similar to those of Figure 2 for the downleg trajectory.

(Received July 29, 1991.)

Paper number 91JA02141.
0148-0227/91/91JA-02141$02.00