In situ observation of electron temperature enhancement inside equatorial plasma bubbles

P. Muralikrishna, Instituto Nacional de Pesquisas Espaciais – INPE, C.P. 515, 12 201-970, São José dos Campos-SP, BRAZIL

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Abstract

In-situ measurements of the height variation of the ionospheric electron density and electron temperature were made on 18-th December, 1995 at 2117 hrs (LT) from the equatorial station Alcantara (2,31°S;44,4°W) in Brazil, with a rocket-borne Langmuir probe. The main objective of the experiment was to study the characteristic features of plasma bubbles. The rocket reached an apogee altitude of 557km covering a horizontal range of 589km, and passed through several medium scale plasma bubbles mainly during the downleg. The upleg electron density profile showed the presence of a clearly defined base for the F-region around 300km, while the downleg profile showed the presence of a large number of plasma bubbles in this height region as well as in the upper F-region. Electron temperature was estimated by applying a sweep potential varying from –1.5V to +2.5V in about 2.5 seconds, to the Langmuir probe During the rocket upleg the valley between the E-region and the base of the F-region showed abnormally large electron temperatures reaching more than 3000 deg K just below the base of the F-region at 300km. The maximum electron temperature observed above the F-peak was only about 700 deg K close to the rocket apogee. During the downleg of the rocket, the electron temperature exhibited a completely different variation pattern. Relatively larger temperatures were observed inside the plasma bubbles, especially at the topside of the bubbles. Bottomsides of the bubbles were associated with relatively lower electron temperatures. The valley between the E- and F-regions also showed much lower electron temperatures during the rocket downleg compared to the upleg. The region below the base of the F-region seems to be associated with very large electron temperatures just before the development of plasma bubbles as in the present case of the rocket upleg. Once the bubbles develop and start rising up the electron temperature falls down except inside the plasma bubbles as in present case of the rocket downleg. Rising bubbles seem to have larger electron temperatures inside especially on their top sides. Theoretical implications of these observations in the dynamics of plasma bubbles and in the generation of plasma irregularities inside the bubbles are presented and discussed in this paper.

Introduction

With the objective of in situ measurements of the height variation of the ionospheric electron density, electron temperature and the ambient electric a rocket-borne electric field double probe and two different types of electron density probes were launched on board a Brazilian SONDA III sounding rocket. The rocket was launched on 18-th December, 1995 at 2117 hrs (LT) from the equatorial rocket launching station, Alcantara (2,31°S;44,4°W) in Brazil. The principal objective of the plasma experiments was to measure the electric field, the electron density, the electron kinetic temperature and the spectral distribution of plasma irregularities associated with plasma bubbles. The payload consisted of the following experiments.

1. *Electric Field Double Probe (EFP):*
2. *Langmuir Probe (LP)*
3. *High Frequency Capacitance probe (HFC)*

The rocket was launched at an azimuth angle of about 70 deg. that ensured a trajectory plane almost perpendicular to the geomagnetic field lines. The elevation angle at launch was about 72.4 deg. The rocket reached an apogee altitude of 557km and covered a horizontal range of 589km. The mean azimuth angle of the plane of the trajectory was about 61.2 deg. The rocket in fact passed through several medium scale plasma bubbles mainly during the downleg. The upleg electron density profile showed the presence of a very clearly defined base for the F-region around 300km, while the downleg profile showed the presence of a wide spectrum of electric field and electron density irregularities in this height region as well as in the upper F-region.

Experiment details

The Langmuir Probe [Figures 1(a) and 1(b)] was used to measure the electron density and the electron kinetic temperature. The spherical LP sensor of diameter 60mm was mounted at the extremity of a short boom of about 50cm in length that was part of the boom assembly .mounted inside the 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 was applied to the LP sensor in order to measure both the electron density and the electron kinetic temperature. During each experiment cycle the sensor potential varied from –1V to +2.5V linearly in about 1.5 sec. and then remained at +2.5V for about 1 sec. The probe current collected during the sweep part of the sensor potential was used to determine the electron temperature, while that collected during the period of 1 sec corresponding to the fixed sensor potential (+2,5V) was used to estimate the electron density and its fluctuations. The slow varying part of the probe current separated using a low pass filter with 3db cut-off frequency at about 50Hz was sampled at 44.64/sec to estimate the electron density profile. The fluctuating part of the current separated using a high pass filter with 3db cut-off frequency at about 10Hz was sampled at 1250/sec. to study the spectral characteristics of the electron density irregularities. The data collected by the LP in the swept voltage mode, used for estimating the electron temperature are not presented here. The basic principle of operation and the details of the electronic subsystem of the LP experiment are given in Muralikrishna and Abdu (1991).

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 plasma bubbles. Ionograms were obtained at São Luis, a station close to the launch site and at Cachoeira Pasulista, a station outside the low latitude belt, but more or less at the same geomagnetic longitude as São Luis. Appearance of spread-F traces in the ionograms recorded at São Luis and the consequent appearnce of Spread-F traces at Cachoeira Paulista was considered to be a strong indication for the presence of plasma bubbles in the ionosphere over that launch station. The rocket was launched under ionospheric conditions favourable for the presence of bubbles.

In the case of LP data the variations observed in the probe current collected can be directly related with the ambient plasma density variation. As in the case of the E-filed measurements, the effect of the rocket spin may appear as a modulation in the current measured, but is definitely less pronounced than in the case of the electric field. In this case also, the scale sizes of the electron density fluctuations obtained by using the height of the rocket as the independent variable will represent closely the real scale sizes of the irregularities if they are horizontally stratified. The sampling rate of 1250/sec used for the **E** and n_e fluctuation data 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 because of the continuously changing rocket speed. The LP data corresponding to the time intervals when the LP sensor is in the sweep potential mode (-1V to +2.5V bias) only are chosen for estimating the electron temperature reported here.

Results and discussion

The electron density profiles estimated from the LP current for the rocket upleg and downleg are shown in Figure 2. Though the general features of the electron density profiles measured by the HFC experiment are similar to those measured by the LP, the absolute values of the electron densities at different height regions showed some differences. Muralikrishna and Abdu (1991), tried to explain similar differences observed in one of their earlier in situ measurement as due to certain inherent problem associated with the two techniques of measurement. However what is more important in the present studies is the relative variation of the electron density with altitude. As can be seen from Figure 2 the upleg profile shows the presence of a rather steep F-region base, free of any large scale electron density depletions or bubbles, while the downleg profile shows the presence of a large number of plasma bubbles. The downleg profile does not show a sharp F-region base.

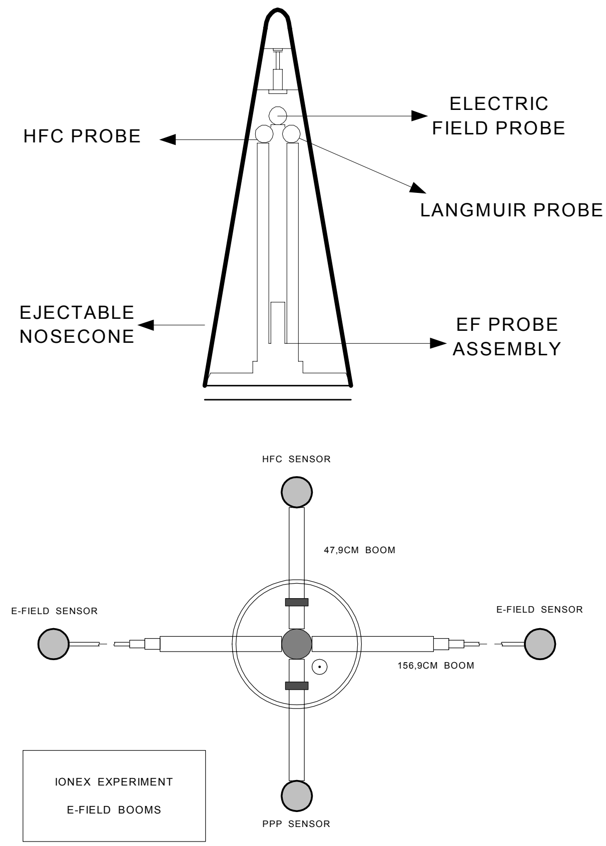

Figure 1(a) (Top): Rocket nosecone showing the folded booms of Electric Field double probe, the Langmuir Probe, and the High Frequency Capacitance Probe.1(b) (Bottom): The booms in the unfolded position.

Electron temperature was estimated from the slope of the current voltage characteristics of the Langmuir Probe. In estimating Te from the slope of the I-V characteristic curve one generally assumes that the positive ion current is much less than the electron current (consequences of such an assumption will be discussed later). The exact shape of the current – voltage characteristic of a Langmuir probe is decided by the plasma temperature and the shape and size of the plasma sheath that forms surrounding the sensor surface. By solving Poisson equation for the distribution of potential in a plasma sheath, one can obtain the following approximate relation for the current of particles moving in a retarding field as,

$$I_p = \frac{env}{4} a.\exp\left(-\frac{eV}{kT_e}\right)$$

where a is the surface area of the probe. This relation is valid regardless of the shape of the probe and consequently ln I_p has a linear dependence on the potential V applied to the probe (in a given potential range). From this linear relation one can get the electron temperature as,

$$T_e = \frac{-5040}{d(\ln . I_p)/dV}$$

Thus measuring the probe current collected at two different probe potentials one can, in principle, estimate both the plasma number density and the temperature using the above relations. Table 1 below shows the electron temperature values estimated for different height ranges. The mean height corresponding to each estimate is given in the first column, The estimated electron temperature is shown in the second column. In the third column the observational remark is given. Comparison of the mean height in the first column with the electron density profiles given in figure 2, will indicate whether the mean height of the temperature estimate corresponds to a region of plasma bubble, or to a region outside the plasma bubble.

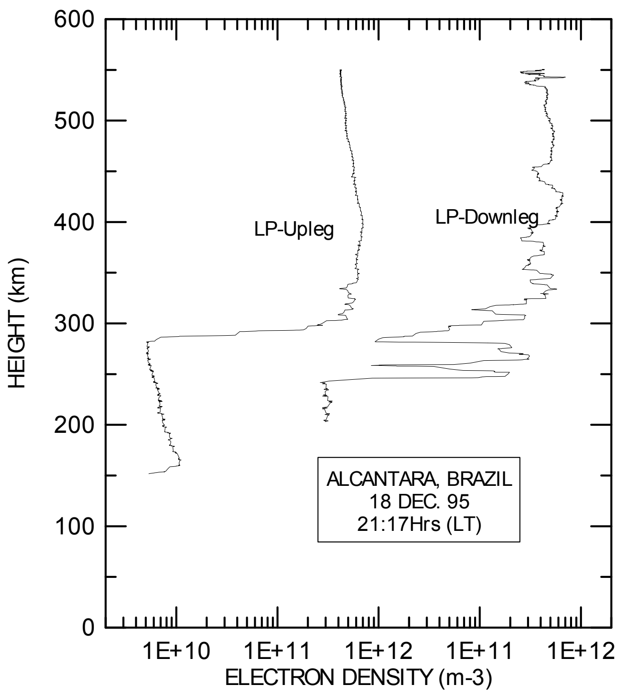

Figure 2: Upleg and downleg electron density profiles estimated from the Langmuir Probe (LP) data. Note that the x-axis for the downleg profile is shifted by two orders to the right.

The upleg electron density profile (Figure 2.) shows the presence of a clearly defined base for the F-region around 300km, while the downleg profile showed the presence of a large number of plasma bubbles in this height region as well as in the upper F-region. The maximum electron temperature observed above the F-peak was only about 700 deg K close to the rocket apogee. During the downleg of the rocket, the electron temperature exhibited a completely different variation pattern. Relatively larger temperatures were observed inside the plasma bubbles, especially at the topside of the bubbles. Bottomsides of the bubbles were associated with relatively lower electron temperatures. The valley between the E- and F-regions also showed much lower electron temperatures during the rocket downleg compared to the upleg. The region below the base of the F-region seems to be associated with very large electron temperatures just before the development of plasma bubbles as in the present case of the rocket upleg. Once the bubbles develop and start rising up the electron temperature falls down except inside the plasma bubbles as in present case of the rocket downleg. Rising bubbles seem to have larger electron temperatures inside especially on their top sides.

A possible reason for the increase in the plasma temperature inside a plasma bubble is the operation of different plasma instability mechanisms inside the plasma bubbles and the dissipation and transference of energy to the individual electrons. This hypothesis supports the observation of higher electron temperatures on the upper slopes of plasma bubbles, where the physical conditions are favorable for the generation of plasma irregularities.

Table 1: Electron Temperature Estimated from the LP Current-Voltage Characteristic for both the Rocket Upleg and Downleg

Height (km)	Electron Temperature (Deg. K)	Remark
157.5	1337	Valley Region
209.3	2180	Valley Region
263.2	3123	Valley Region
280.1	3050	Bottom F-Region
337.8	475	F-Max
366.4	258	Above F-Max
401.2	502	Above F-Max
453.4	329	Above F-Max
501.8	703	Above F-Max
541.9	447	Above F-Max
544.2	734	Bubble Region
513.8	453	No Bubble
490.5	501	No Bubble
455.0	635	Bubble-Upper Slope
419.2	254	No Bubble
386.3	267	Bubble-Lower Slope
354.6	298	Bubble-Lower Slope
309.7	399	Bubble
288.3	269	Bubble-Lower Slope
265.9	222	No Bubble

Conclusions

- Bubble regions are associated with relatively larger electron temperatures in comparison with the regions out side the bubbles.

- In side a plasma bubble the electron temperature clearly shows a tendency to be more on the upper slope of the bubble than the lower slope.
- A possible reason for the higher electron temperature observed in side a plasma bubble is the operation of various plasma instability mechanisms and the transference of kinetic energy to the individual electrons.

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