Wave structures observed in the Equatorial F-region plasma density and temperature during the sunset period

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Abstract

Electron density and temperature measurements were made recently with rocket-borne Langmuir probes on 2-nd December 2011 using a Brazilian VS-30 single stage rocket and on 8-th December 2012 using a two stage VS-30/Orion rocket. The first launch was made from the equatorial rocket launching station CLBI in Natal, Brazil and the second one from the CLA in Alcântara-MA. Both the launches were made soon after the local sunset. The ground equipments operated during the rocket launches clearly showed the rapid rise of the F-region base indicating probably the pre reversal enhancement of the F-region vertical plasma drift. At the time of launch the bubble activity was also at its peak as indicated by the presence of strong spread-F traces in the ionograms. The electron density and temperature height profiles could be estimated from the LP data up to the rocket apogee altitudes of 139km during the first launch and 428m km during the second launch. During the first launch the F-region valley region showed the presence electron temperatures as high as 2000 ºK while the temperatures expected from the existing models are around 500 ºK. During the second launch also ground equipments operated at equatorial stations showed rapid rise in the base of the F-layer creating ionospheric conditions favorable for the generation of plasma bubbles. During this launch also electron temperatures as high as 3500ºK were observed in the valley region both during the rocket upleg and downleg. These profiles are compared with model electron density and temperature profiles as well as with electron density and temperature profiles observed under conditions of no plasma bubbles. The electron density and temperatures profiles observed during both the launches showed the presence of significantly large amplitude waves indicating intense wave activity in the valley region close to sunset period. These wave activities are probably related to the electrodynamic processes that exist in this region during the sunset period.

Introduction

E- and F -region plasma exhibit special properties and features close to the morning and evening electric field reversal times associated with sunrise and sunset. Two of these features are:

1. Pre reversal enhancement in the vertical plasma drift,

2. Post sunset upward lift in the base of the F-layer.

Sunrise and sunset periods are also associated with change in the direction of flow of the electrojet currents. This results in an F-region plasma highly dynamic close to the sunrise and sunset times. To study these effects rocket measurements were made of electron density and electron temperature from Brazil using rocket-borne swept-bias Langmuir Probes on 2 occasions and the preliminary results are presented and discussed here.

Method

On both the occasions almost identical swept bias Langmuir probes were used to measure the electron number density and the electron temperature. The probe bias was continuously swept between -1,0V and +2,5V in about 2,5 seconds, the bias being increased from -1,0V to 2,5V linearly in 1,5s and then maintained at 2.5V for 1,0s. While the probe current collected during the swept potential part is used to estimate the electron temperature Te the probe current collected during the fixed potential part is used to estimate the electron number density. Figure 1 shows the conical metallic Langmuir probe sensor being tested and calibrated in the laboratory.

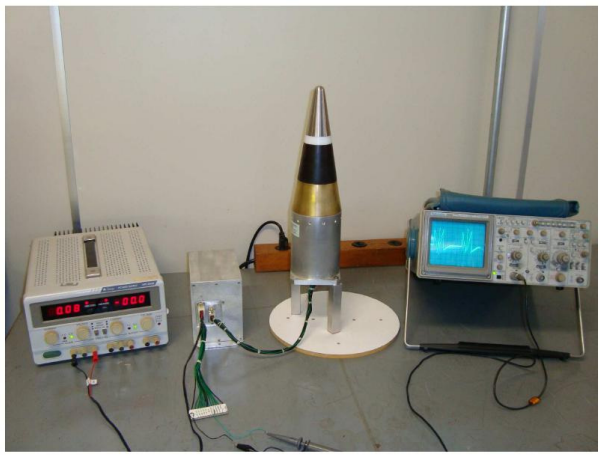

Figure 1: Langmuir probe used during the launches being tested and calibrated in the laboratory.

While LP (Langmuir Probe) the sensor current at fixed positive potential is proportional to the ambient plasma number density the sensor current-voltage curve obtained during the swept potential part can be used to estimate the electron temperature. Each sweep with duration of about 2,5 seconds can give just 1 value of the electron temperature and more than a thousand measurements of the electron density depending on the sampling rate of the current signal and the frequency response of the electronic system used.

Results

The first rocket, a VS-30 rocket of Brazil was launched at 19:00 hrs local time on the 2-nd of December, 2011 from the Centro de Lançamento de Barreira de Inferno (CLBI) in Natal-RN, close to the geomagnetic equator. Figure 2. shows the trajectory of the rocket.

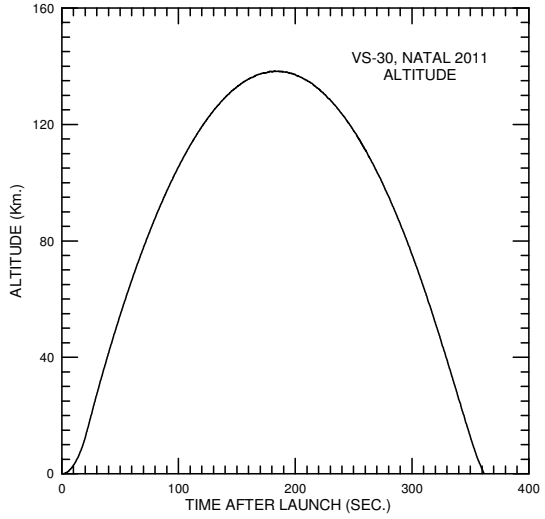

Figure 2: The trajectory of VS-30 rocket

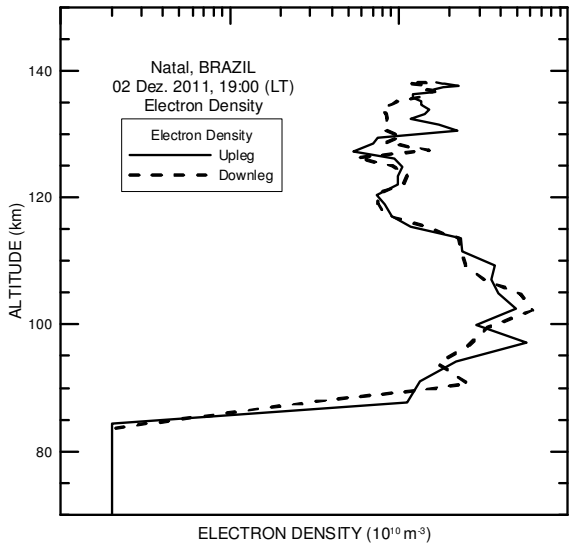

Figure3: Electron density profile obtained during the rocket upleg and downleg

With the main objective of launching the rocket into an ionosphere favorable for the generation of plasma bubbles the ionospheric plasma was monitored at selected locations in Brazil using a digissonde network. The rocket was launched soon after sunset under spread-F conditions and the rocket reached an apogee altitude of 140km and horizontal range of 130km. During both upleg and downleg of the rocket the electron density profiles (Figure 3) showed large amplitude fluctuations in the valley region below the F-layer. Electron temperature profiles estimated from the LP data (Figure 4) also showed large amplitude fluctuations mostly anti correlated with the electron density fluctuations.

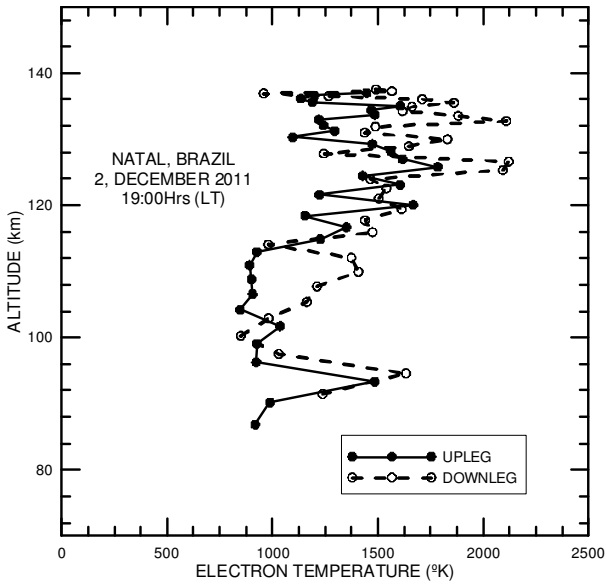

Figure 4: Electron temperature height profiles estimated for the rocket upleg and downleg.

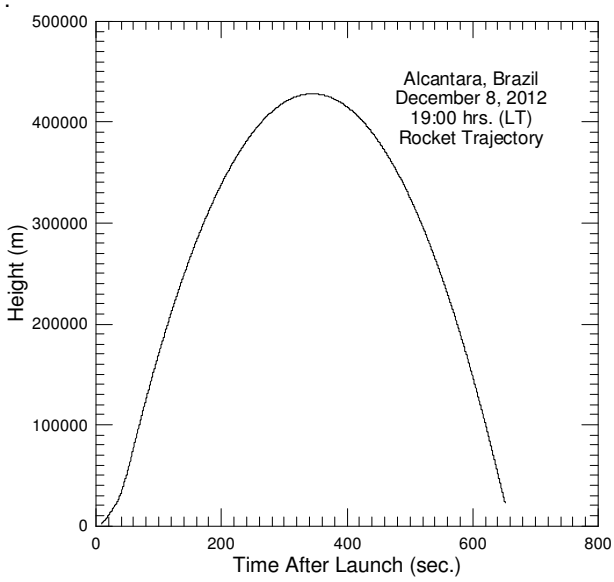

Figure 5: Trajectory of VS-30/Orion rocket launched from Alcântara on 8-th December, 2012

The second rocket, a two stage one with the Brazilian VS-30 as the first stage and an American Orion as the second stage. This launch was also made soon after sunset under strong spread-F conditions and the rocket reached an apogee altitude of 428km and horizontal range of 383kmas shown in figure 5.

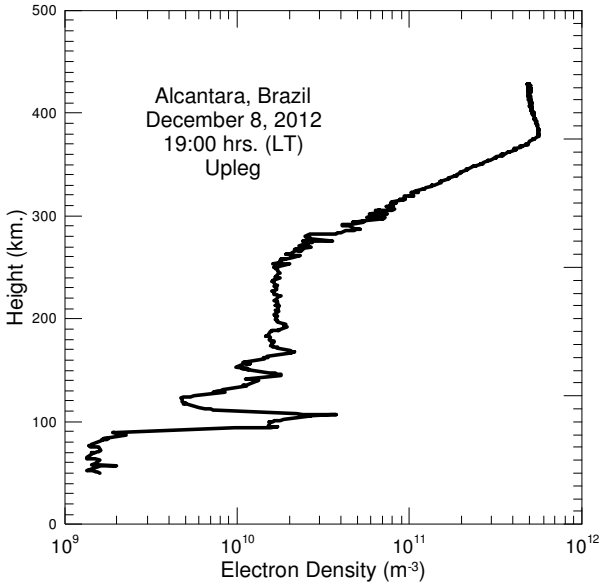

Figure 6: Upleg electron density profile observed during the VS-30/Orion launch

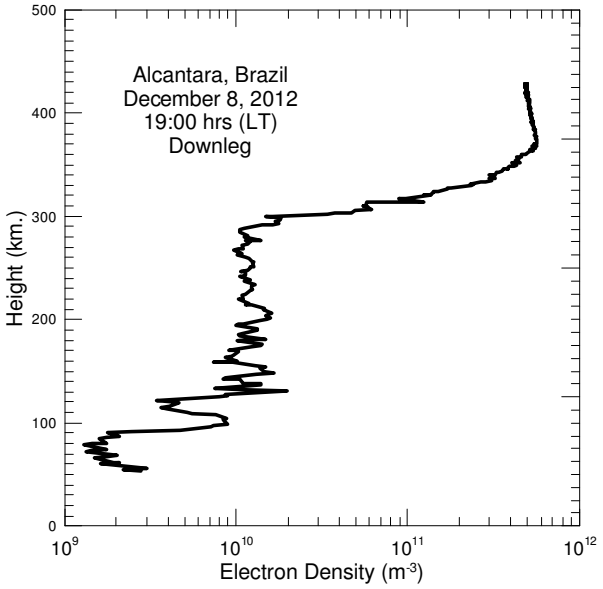

Figure 7: Downleg electron density profile observed during the VS-30/Orion launch

During both upleg and downleg the electron density profiles (Figures 6 and 7) showed large amplitude fluctuations in the valley region below the F-layer. Electron temperature profiles estimated from the LP data (Figures 8 and 9) showed abnormally high Te values (> 3500 ºK) during both upleg and downleg in the valley region, with large amplitude fluctuations.

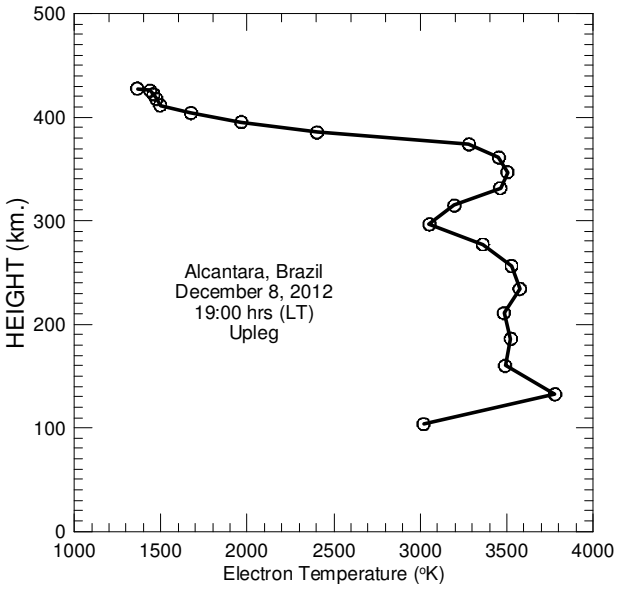

Figure 8: Upleg electron temperature profile observed during the VS-30/Orion launch

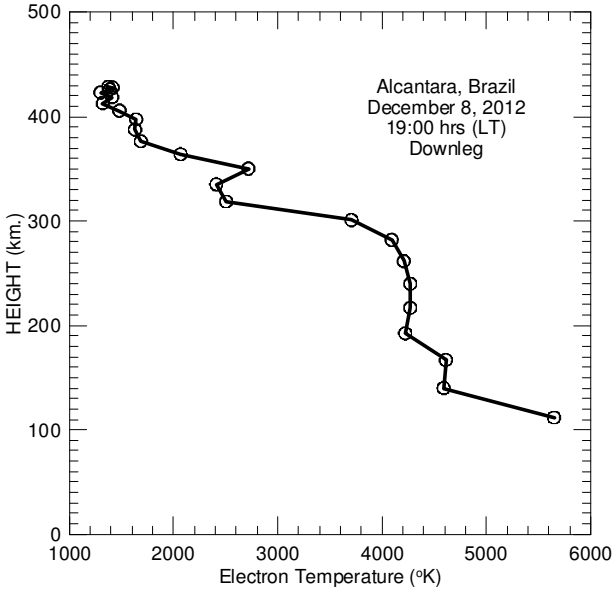

Figure 9: Downleg electron temperature profile observed during the VS-30/Orion launch

Discussion

It is now well known that in the low latitude region the vertical plasma drift exhibits a pre-reversal enhancement (PRE) in the evening hours. The PRE also exhibits a seasonal variation. PRE in the vertical plasma drift is mainly attributed to the increase in the driving electric

fields associated with sunsets in the E-region altitudes conjugate to the F-region altitudes considered. Present observations indicate that the valley region is extremely active during the sunset period with the presence of large Te values and also the presence of large amplitude waves.

The PRE in the plasma drift is also normally associated with vertical drift in the F-layer base as observed by Ionossondes e Digissondes. One must take care not to interpret the height increase in the F-layer as PRE in the plasma drift. The height of the F-layer can increase due to the rapid rise of the solar terminator close to sunset hours that will almost immediately affect the electron number density in the region where the solar radiation is cut off, below the base of the F-region. For the tropical latitudes the height of solar terminator after sunset and the vertical velocity of the terminator are given by:

$$h = R_0\left[\sec\frac{2\pi\ t}{T} - 1\right]$$

$$\frac{dh}{dt} = \frac{2R_0\pi}{T}\sec\left(\frac{2\pi\ t}{T}\right).\tan\left(\frac{2\pi\ t}{T}\right)$$

where, t - is the time after ground sunset,
h - is the solar terminator height,
T - is 24x60 minutes.

Table showing the variation of h with t and the terminator upward velocity

t(min)	h(km)	dh/dt (m/s)
40	98,3	83
50	154,7	105
60	224,7	128
70	309,1	153
80	408,8	179

It should be noted here that in the month of December, sunsets at magnetically conjugate latitudes of the launch stations occur practically simultaneously.

Shown in Figure 10 is the sequence of ionograms observed at Fortaleza, (close to the launch station Natal), during the launch of the first rocket. The ionograms indicate fast upward movement of the F-layer prior to the sunset. The virtual height of the F-layer as a function of the local time is shown in Figure 11 for the stations Fortaleza and São Luís. The upward movement of the F-layer started around 16:00 hrs local time at both the locations and continued till the launch time of 19:00hrs. At the time of launch strong spread-F traces were seen at both the stations.

An interesting and important observation to be made here is the fact that the upward movement of the F-layer that started before sunset continued throughout the sunset period and ended only with the appearance of spread-F. If one considers the pre reversal enhancement in the vertical plasma drift one would expect a reversal in the drift at the time of electric field reversal. It is impossible to notice this point in the upward drift of the F-layer. This is yet another reason why one must not compare the uplift of the F-layer with the pre reversal enhancement. An apparent upward lift of the F-layer can also be caused by the vertical movement of the solar terminator (see table). The terminator upward speed is very much comparable to that of the pre reversal enhancement in the vertical plasma drift.

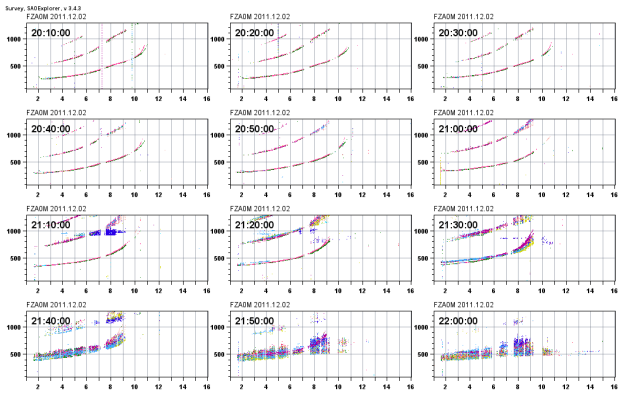

Figure 10: Sequence of ionograms from Fortaleza showing the upward (downward) movement of the F-layer during the launch period

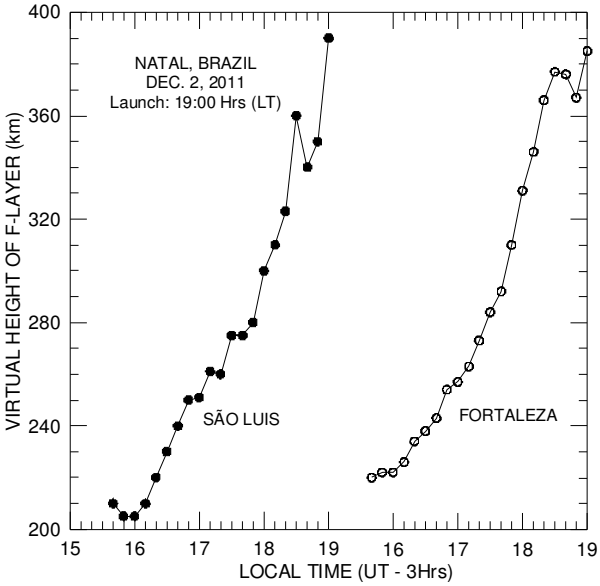

Figure 11: Upward movement of the F-layer observed at São Luís and Fortaleza during the launch of the rocket on 2-nd December, 2011.

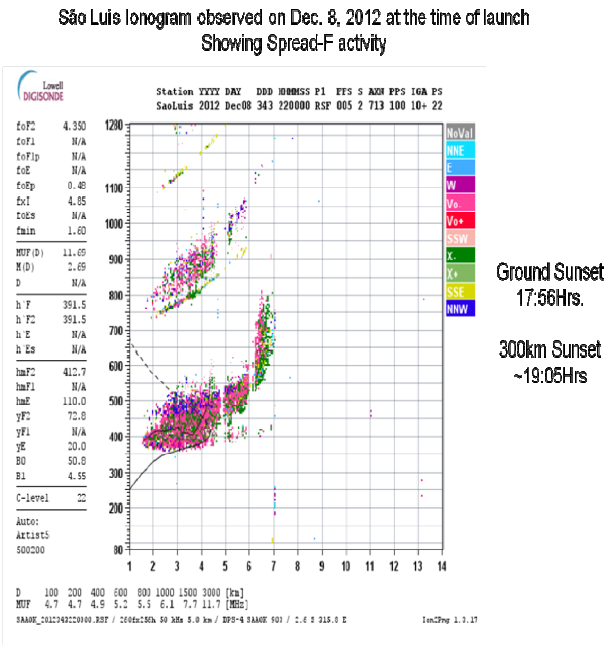

Figure 12: São Luís Ionogram observed on 8-th December, 2012 at rocket launch showing spread-F activity

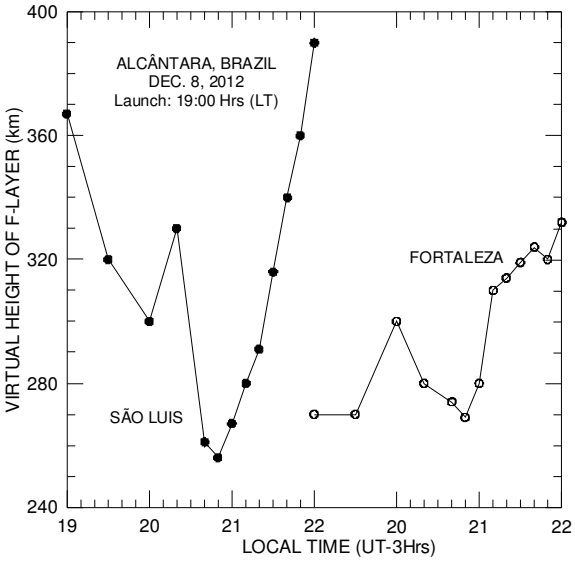

Figure 13: Upward movement of the F-layer observed at São Luís and Fortaleza during the launch of the rocket on 2-nd December, 2011.

Conclusions

- Wave structures in ne and Te were observed in the second and third launches made at 19:00 hours. This probably is related to the fast uplift of the F-layer at the time of launch as well as with the PRE activity still at its peak.
- In both the cases presented the valley region showed abnormally large Te values. This high temperature observed during upleg reduced to practically normal values during downleg when the plasma bubbles were observed.
- The absence of high electron temperatures in the downleg profile is probably due to the fact that the PRE activity in the region of downleg had stopped at the time of rocket descent and also the plasma bubbles had developed in that region.
- In both the cases strong spread-F traces were present in the ionograms at the time of launch.
- Probably the high electron temperatures observed in the valley region are due to the intense wave activity and upward movement of plasma (PRE) close to sunset and the Te values become normal once the plasma bubbles develop.

Acknowledgments

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- Alcântara Launch Center – CLA/MAER, Alcântara

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