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ROCKET BORNE MEASUREMENTS OF EQUATORIAL IONOSPHERIC ELECTRON DENSITIES AND THEIR COMPARISON WITH IRI-10 PREDICTIONS

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RESUMO-NOTAS/ABSTRACT-NOTES

Electron density height profiles of the equatorial ionosphere measured by rocket borne probes are compared with their predictions from IRI-10. Three experiments were conducted using High Frequency Capacitance probes carried on board SONDA III rockets that were launched off the coast of Natal (36°W, 12°S), Brazil. Results from two of the experiments one daytime, and one nighttime, represented quiet ionospheric conditions whereas the third experiment was launched into a nighttime ionosphere that was disturbed by a developing plasma bubble event. Degrees of agreement between the experimental results and the IRI predictions for the quiet day and night densities varied with height. These comparative studies are complemented by including the electron densities obtained from the semi-empirical Low Latitude Ionospheric Model (SLIM) as appropriate for the rocket flight

OBSERVAÇÕES/REMARKS

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ROCKET BORNE MEASUREMENTS OF EQUATORIAL IONOSPHERIC ELECTRON DENSITIES AND THEIR COMPARISON WITH IRI-10 PREDICTIONS

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ABSTRACT

Electron density height profiles of the equatorial ionosphere measured by rocket borne probes are compared with their predicitons from IRI-10. Three experiments were conducted using High Frequency Capacitance probes carried on board SONDA III rockets that were launched off the coast of Natal (36°W, 12°S), Brazil. Results from two of the experiments, one daytime, and one nighttime, represented quiet ionospheric conditions whereas the third experiment was launched into a nighttime ionosphere that was disturbed by a developing plasma bubble event. Degrees of agreement between the experimental results and the IRI predictions for the quiet day and night densities varied with height. These comparative studies are complemented by including the electron densities obtained from the semi-empirical Low Latitude Ionospheric Model (SLIM) as appropriate for the rocket flight conditions. A detailed discussion is carried out of the results of these comparative studies.

INTRODUCTION

The International Reference Ionosphere (IRI) has been developed to provide a representation, as functions of height, geographic location, local time and sunspot number, of the quiet time ionospheric behaviour, and is based largely on the observed statistical behaviour of the ionosphere on a global basis. Since its first publication in 1978 by Rawer et al (1978, see also Lincoln and Conkright, 1981) the IRI has undergone periodic modifications in attempts to improve its reliability as a global model for equatorial-low and mid-latitude ionospheres. These modifications have been mainly concerned with the topside electron density distributions over the equatorial-low latitude region within the equatorial ionization anomaly(see Bilitza, 1986, McNamara, 1984). The IRI prediction of the average behaviour of the F layer peak densities (NmF_2), that are based on the CCIR coefficients, are found to be more reliable as compared to that of their heights (h_mF_2). Concerning the reliability of the model for different geographic zones there seems to be reason to believe that it could be less realistic for regions in the southern hemisphere especially where the magnetic field delcination has large values (Abdu et al., 1981) and in the regions of the South Atlantic Magnetic Anomaly, due to the sparsity of observational data in these regions. Therefore there is need for testing the validity of the IRI model predictions against the observational data available from these regions.

Preliminary comparative studies have been carried out of the IRI predictions with the experimental data as obtained from ground based ionosonde which showed that the F-layer peak density (f_oF_2) is better predictable by the model than is the peak height (hmF_2) as deduced from ionogram true hight analysis (Abdu et al., 1988b). An earlier study by Paula et al. (1981) involving CCIR predictions of f_oF_2 for different seasons of high solar activity period also pointed to a similar conclusion. On the other hand the TEC values calculated using the IRI model would depend strongly on the representation in the model of the bottomside and topside electron density distribution scale heights. This point emphasizes the fundamental importance, and the need for, testing the IRI model with the in situ measurement of the topside and bottomside electron density distributions.

On three occasions electron density measurements were carried out using high frequency capacitance probes mounted on the Brazilian SONDA III rockets launched off the coast of Natal (6^oS, 36^oW). These experiments were carried out as part of a cooperative project between INPE and the Instituto de Atividades Espaciais (IAE/CTA), São José dos Campos. The first experiment was conducted with the launching of a SONDA III rocket into a daytime ionosphere at 15:05 LST on July 26, 1984. The second was a nighttime flight, the launch taking place at 2030 LST on December 11, 1985, into an ionosphere disturbed by a plasma bubble irregularity event. However, magnetically quiet conditions prevailed during the flight and the preceding day. The third experiment was launched, at 2259 LST on the night of October 31, 1986, into an ionosphere under quiet conditions. The apogee during these flights varied between 560 km and 444 km. In this paper we compare the electron density profiles during the upleg of the rocket flight with the IRI predictions. Further comparative study is done using the SLIM electron density profile representative of the conditions of these flights as obtained by interpolation from the tabulations for the different latitude-local time grids for solar minimum conditions as presented by Anderson et al. (1985).

ELECTRON DENSITIES FROM HIGH FREQUENCY CAPACITANCE PROBE

The technique of electron density measurements by the High Frequency Capacitance (HFC) probe has been discussed by Heikkila et al., 1968, Rao et al., 1970 and more recently by Abdu et al., 1988a. Briefly, thee HFC probe utilized in the three experiments consisted of the nose tip of the rocket used as a capacitance element that determined the frequency of a stable oscillator whose operation in a double-frequency mode (~10 MHz and ~6 MHz) was achieved by switching at a convenient rate between two suitably selected inductors (Abdu et al., 1988a). Changes in the capacitance of the nose tip produced by the ionosphere modify the oscillator frequency f, by Δf, which is related to the ambient electron density by the relation: $N = (2f^2/f_o)\Delta f/81SK$; where f_o is the free space frequency, S is a factor used to correct the ion sheath effect (approximately 0.5 at E and F region heights), and $K=C_o/(C_o+C_s)$ is a sensitivity factor, C_o being the free space capacitance of the sensor and C_s the stray capacitance of the oscillator assembly. In the derivation of the above expression the electron-neutral collision frequency and electron gyrofrequency have been neglected. In the two-frequency mode, when the oscillator operates at one frequency, the frequency information in the other mode is transmitted, and vice versa, for equal durations of ~100 ms each, thus forming an operation cycle of ~200 ms. For callibration purpose, (namely, for obtaining conditions approaching those of free space), a negative bias of -100V is apllied to the sensor during one out of every four cycles of operation (n the third flight the bias was applied only one ouyt of every 32 cycles). The height resolution of the measurements, thus, varied from about 600 m in the E region to about 100 m in the F region and near the apogee. We will present here only the results from the uplegs of the rocket flights since the downleg measurements have been influenced , to varying degress during the three flights, by the electron density sensors being located in the rocket wake region.

RESULTS OF COMPARISON WITH THE IRI-10

Electron densities were calculated during the Δf measure in the 10 MHz mode and using an S factor of 0.5 for all the cases. The results from the July 1984 daytime flight is present in Figure 1 (solid line). The E-layer peak density (f_oF_2) as obtained from the ionogram at Fortaleza (~400 km westward of the rocket launch site) is also shown. The good agreement between this value and the electron density calculated from Δf justifies the validity of the S factor used. The absence of data between 260 km and 460 km is due to the oscillator not functioning when the frequency, ~10MHz, became comparable to and exceeded the ambient plasma frequencies at these heights. There is, in general good agreement between the IRI, (shown by dashed line) and the rocket results, specially between 110 km and 260 km and again between 480 km and 560 km (the apogee). Thus the IRI seems to be a good representation of the equatorial daytime ionosphere for a wide height range (from ~ 100 to ~ 500 km) for the low sunspot and magnetically quiet condition (Σ Kp = 10^+) that characterized this first measurement. (A tendency for a deviation of the two results in the height range from 240 to 460 km could be produced by the S factor variations in this height region. This possibility should, however, be investigated further). For comparison we have shown also the electron densities obtained form the semi emprícial Low Latitude Ionospheric Model, SLIM, (Ander on et al., 1985) as interpolated, from published table, to represent the conditions of the flight. SLIM represents consistently lower densities at all the heights as compared to the IRI as well the measured values.

The results from the second measurement, namely, that of 11 December 1987, presented in Figure 2, was obtained during a plasma bubble event. The rocket apogee for this flight reached ~510 km. The low value of $\Sigma K_p(=19^-)$ represented an otherwise overall quiet ionospheric condition. The depletions in the electron densities seen on this profile will be discussed elsewhere. The ambient profile for this case shows, as expected, important departure from the IRI in the subpeak densities. This could be produced by the large equatorial electric field in the evening hours that is responsible for the layer uplift which is a precursor to the bubble generation. This profile also represents a departure from the mean nighttime behaviour (especially at subpeak altitudes) and therefore it is not suprising that the IRI yields different results at these heights. The F-layer peak density shows, however, good agreement with the IRI prediction. It is important to note that the topside electron density distribution scale height according to the IRI is somewhat higher than is suggested in the measurement. The SLIM prediction for this case also represents a certain underestimation of the peak and topside densities.

The rocket apogee for the third experiment reached 444 km and the corresponding electron density profile is shown as solid line in Figure 3 ($\Sigma K_p=13^+$ for this experiment). The agreement with the IRI is good for subpeak densities, namely, below 250 km down to ~160 km. The IRI prediction of the layer peak densities is somewhat less than the rocket measurement for this night, but this difference is within the expected day-to-day variabilities of the quiet time f_oF_2 values (see for example, Paula et al., 1981). A notable feature of these results is that the topside electron density scale height predicted by the IRI is significantly higher than that measured by the rocket probe (as was observed also for the second height discussed above). This difference is significant and real although the topside profile was apparently disturbed possibly by a "fossil bubble" structure which seems to have drifted into the rocket trajectory. The ground based diagnostics from the ionosonde at Fortaleza and scintillation receiver at Natal had confirmed the absence of any spread F events immediatley before the launch. Also the low F-layer height at this time was not conducive to irregularity generation in the region of the rocket experiment. Even with the presence of this irregularity structure the topside scale height is reasonably well defined and is smaller than that predicted by the IRI. The densities predicted by the SLIM for the ionospheric condition typical for the night of the rocket measurement is appreciably smaller than the rocket measurements and IRI prediciton for heights downward of approximately 300 km.

DISCUSSION AND CONCLUSIONS

The high frequency capacitance probe utilized in the measurements reported here has proved to be a reliable technique for electron densities within certain limits. Its sensitivity has been found to be unsatisfactory for density less than $\sim 5\times10^{3}cm^{-3}$ as also for higher densities corresponding to the plasma frequency approaching the oscillator frequency. The daytime E-layer and nighttime F-layer (for low solar activity period) fall well inside these limits. The S factor used in the calculation of the densities has been found to be reasonably precise near 100 km. Its possible departure near the F-layer peak has not been determined. However it is expected to have only small inlfuence on the main conclusions on the electron density comparison discussed in this paper since identical profiles resulted (though not shown here) at both the oscillator frequencies for the height regions where the S factor did not appear to differ for the two frequencies.

The main conclusions from the present comparative study are the following. There is in general, good agreement between the IRI prediction and the rocket measurement of the electron densities for a quiet equatorial ionosphere (especially for daytime) under low sunspot epoch. Clearly, the agreement of IRI with the measurement is expected to improve if we consider average experimental profile for several such quiet days (or nights) since the IRI is based on statistical mean behaviour of the ionospheric parameters. Even under quiet conditions the bottomside ambient density profile on nights of plasma bubble event could depart significantly from the IRI predictions, as expected, due to the specific dynamic state of the ionosphere on such occasions. An important point that has come out of the present study is the appreciable difference in the topside density scale height for the nighttime between the model prediction and measurement, the measurement suggesting significantly smaller values than preedicted by the IRI. It appears that the recent modification to improve the topside density distribution in the IRI (Bilitza, 1985, 1986) amounts to an overestimation of the topside scale height, in the case of quiettime low latitude ionosphere. It will be interesting to test the effect of this overestimated nighttime topside scale height of the IRI on the total electron content calculated by this model in comparison with the TEC measurement by polarimeters over low latitude. It may be noted that the IRI in its premodification version presented severely underestimated electron content (McNamara, 1984). We plan to undertake in the near future a comparative study of the TEC prediction from the new IRI version with observational data on TEC obtained from polarimeters during a major part of a solar cycle over the low latitude locations in Brazil.

ACKNOWLEDGEMENTS

The experiment using Brazilain SONDA III rockets would not have been possible without the collaboration by the Instituto de Atividades Espaciais IAE/CTA, São José dos Campos, through a cooperation project between that institute and INPE. The authors would like to express their thanks to the Director of INPE, Dr. Marco Antonio Raupp for his encouragement. The dedication by Sinval Domingos in the construction and testing of the payloads is greatfully acknowledged. This work was partially supported by the "FNDCT" under contract FINEP 537/CT.

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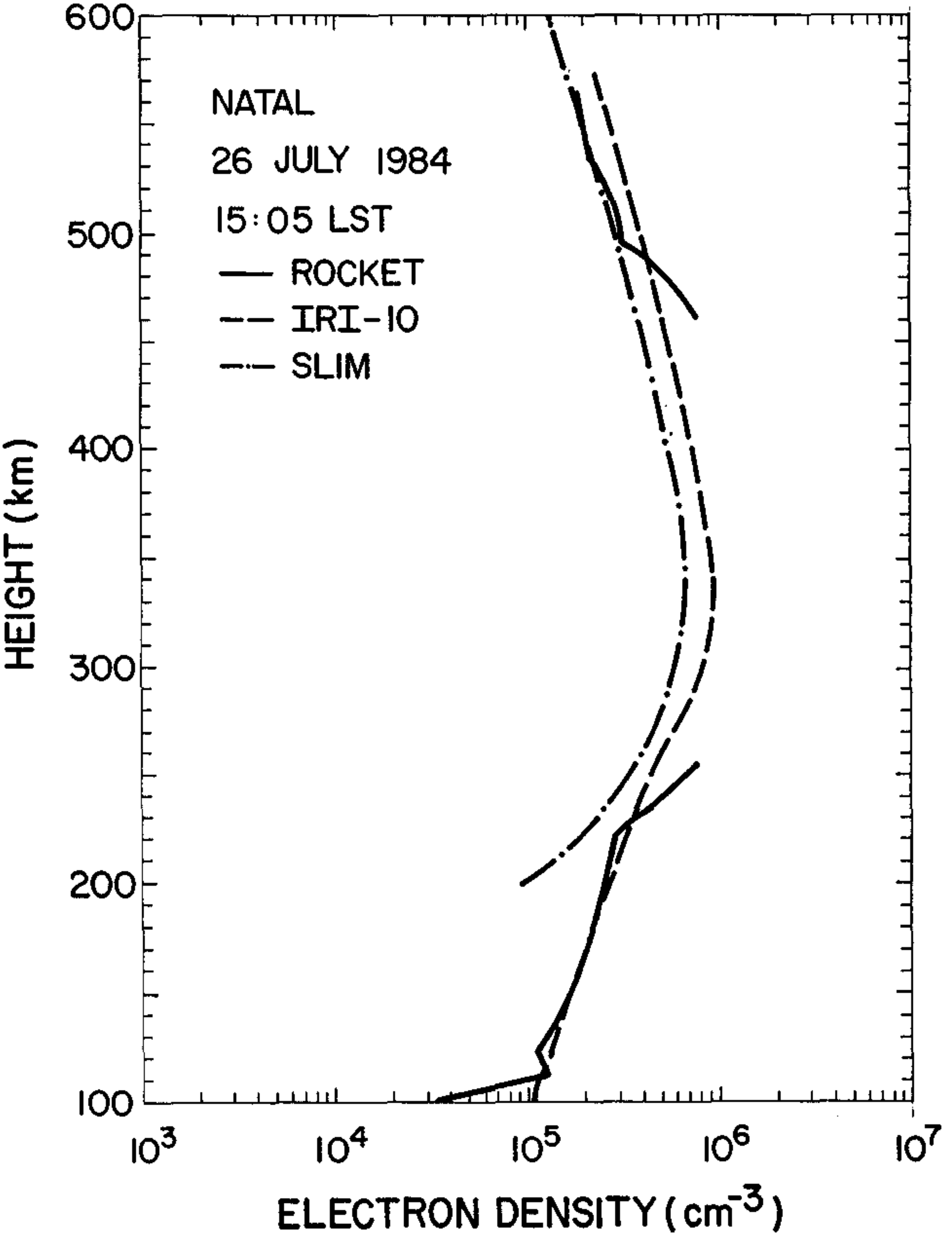
FIGURES CAPTIONS

Figure 1 - The electron density profile from upleg of the SONDA III flight at 15:05 LST (Natal) on 26 July 1984 from ~100 km to 500 km (solid line); the IRI-10 electron density profile (dashed line); and the SLIM profile (dash-dotted line) as interpolated from the tables published by Anderson et al. (1986).

Figure 2 - Similar representations of the electron density profiles, as in the Figure 1, for the nighttime SONDA III flight at 20:30 LST on 11 December 1985.

Figure 3 - Results similar to those in the Figures 1 and 2 for the SONDA III flight at 22:50 LST on 31 October 1986.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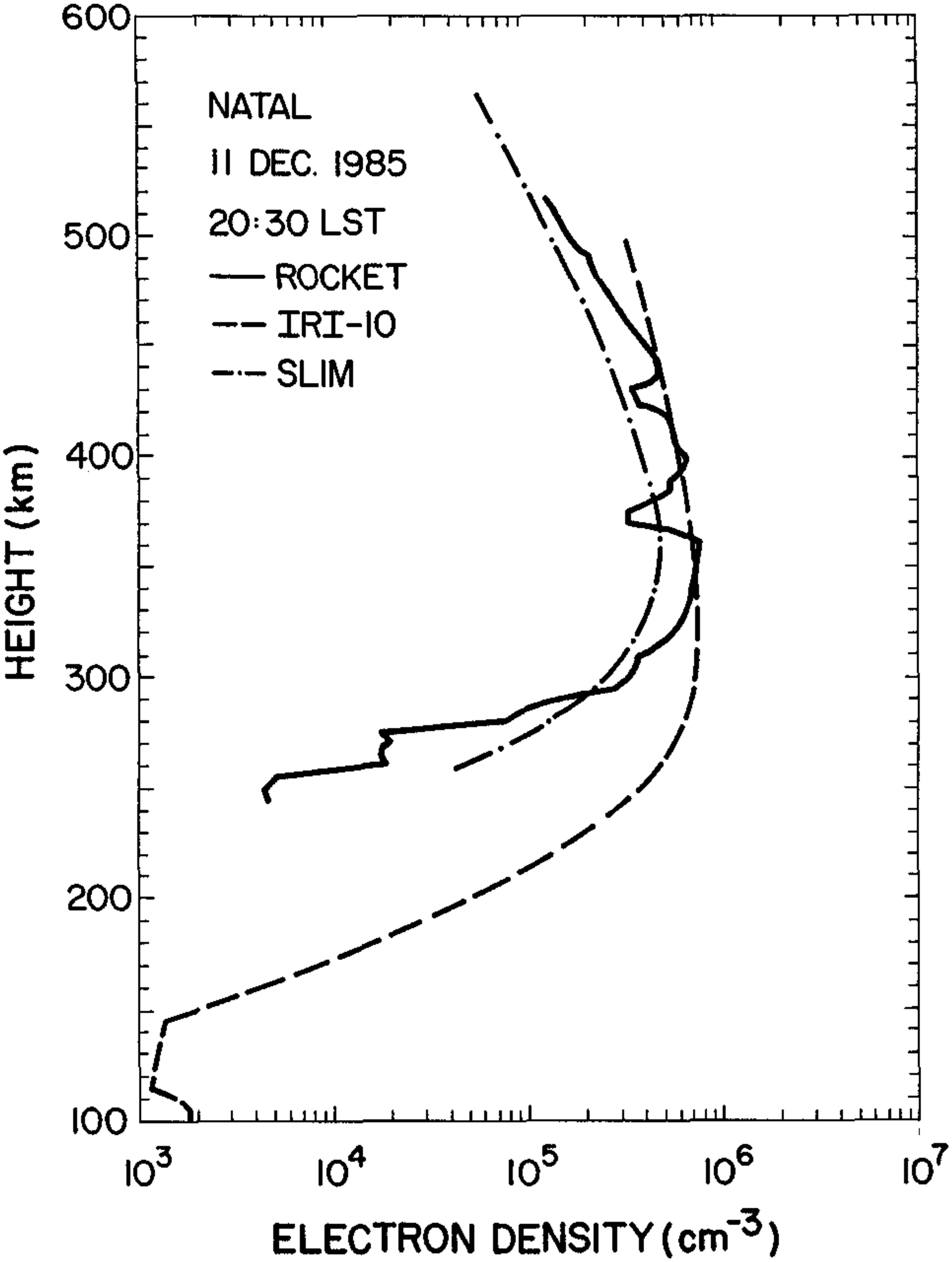
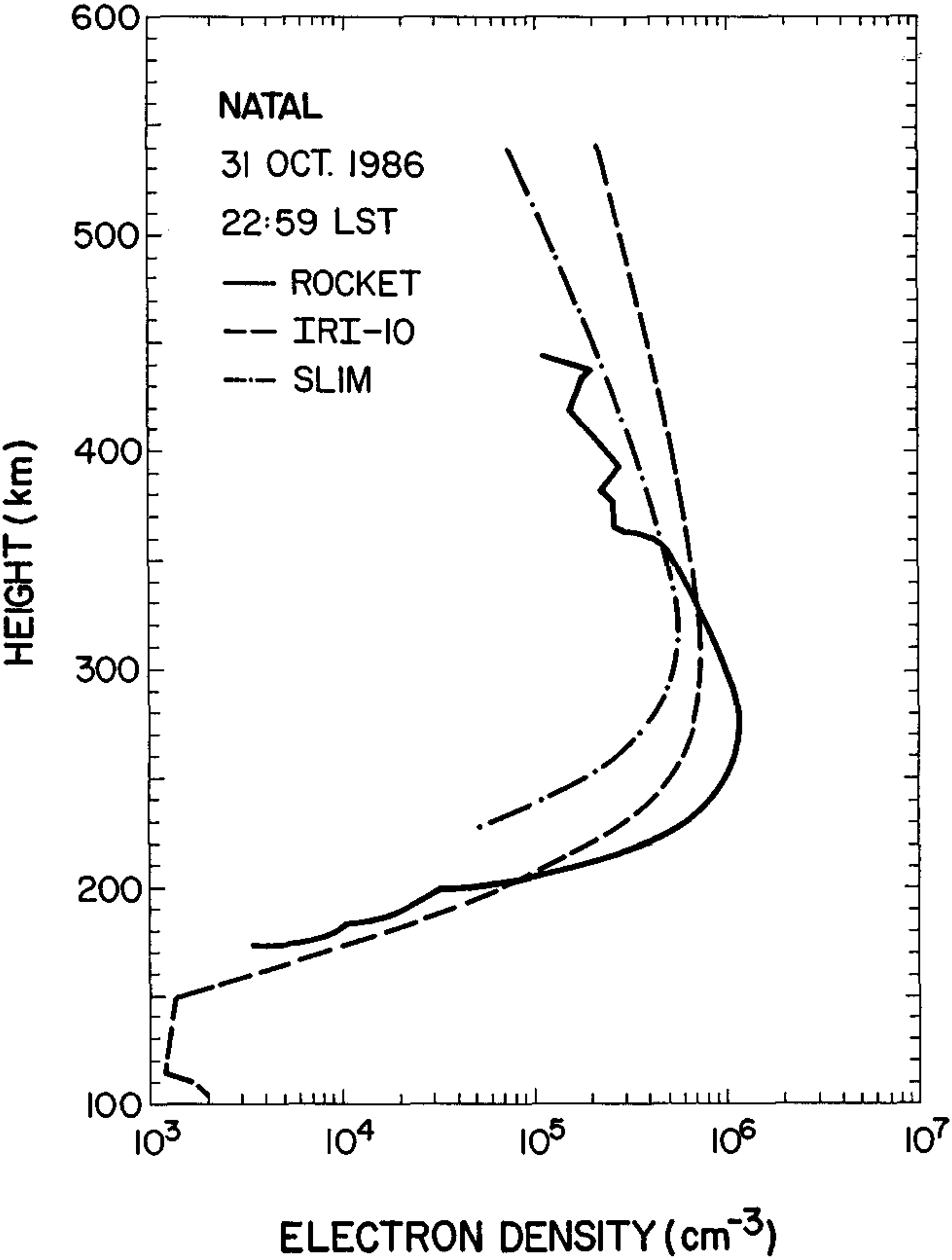
26 JULY 1984
15:05 LST
ROCKET
IRI-10
SLIM
HEIGHT (km)
600
500
400
300
200
100
10^3
10^4
10^5
10^6
10^7
ELECTRON DENSITY (cm^-3)

Fig. 1



NATAL
11 DEC. 1985
20:30 LST
ROCKET
IRI-10
SLIM
HEIGHT (km)
600
500
400
300
200
100
10^3
10^4
10^5
10^6
10^7
ELECTRON DENSITY (cm^{-3})

Fig. 2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31 OCT. 1986
22:59 LST
ROCKET
IRI-10
SLIM
HEIGHT (km)
600
500
400
300
200
100
10^3
10^4
10^5
10^6
10^7
ELECTRON DENSITY (cm^{-3})

Fig. 3

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"ROCKET BORNE MEASUREMENTS OF EQUATORIAL IONOSPHERIC ELECTRON DENSITIES AND THEIR COMPARISON WITH IRI-10 PREDICTIONS"

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M.A. Abdu
p. Muralikrishna
E.R. de Paula
I.J. Kantor

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JOSÉ MARQUES DA COSTA
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87 BOLHAS DE PLASMA
87 IONOSFERA EQUATORIAL
87 SONDA
88 ELECTRON DENSITY PROFILES
88 INTERNACIONAL REFERENCE IONOSPHERE
88 IRI
88 SLIM
88 EQUATORIAL ATMOSPHERIC
88 ROCKETS
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ABSTRACT

Three experiments were conducted using high frequency capacitance probes carried on board SONDA III rockets launched off the coast of Natal (6° S, 36°W), Brasil. Electron-density height profiles from two of the experiments, one daytime, and one nighttime, are representative of quiet equatorial ionospheric conditions whereas for the third experiment the rocket was launched into a nighttime ionosphere that was disturbed by a developing plasma bubble event. Agreement between experimental results and the IRI predictions for the quiet day and night densities varies with height. Comparisons are also made with electron densities obtained from the semi-empirical Low Latitude Ionospheric Model (SLIM).

INTRODUCTION

The International Reference Ionosphere (IRI) has been developed to provide a representation, as functions of height, geographic location, local time and sunspot number, of the quiet ionosphere, and is based largely on observed global statistical variations. Since first publication in 1978 by Rawer et al /1/ - see also Lincoln and Conkright /2/ - the IRI has undergone periodic modifications in attempts to improve its accuracy. These modifications have been concerned mainly with the topside electron-density distributions within the equatorial ionization anomaly region /3, 4/. There seems to be some evidence that the model is less accurate for certain areas in the southern hemisphere, especially those where the magnetic-field declination has large values /5/ and in the region of the South Atlantic Magnetic Anomaly, due to the sparsity of observational data. Therefore there is need for further testing the validity of the IRI model predictions against such new data as become available from these regions.

Preliminary comparative studies with experimental ground-based ionosonde data have shown that the F-layer peak density (f_oF2) is better predicted by the model than its peak height (hmF2) /6/. An earlier study /7/ for different seasons at high solar activity led to a similar conclusion. However, since total electron content (TEC) values calculated using the IRI model depend strongly on the representation of the bottom-side and topside electron-density distribution scale heights, these also need testing.

On three occasions electron-density measurements were carried out using high-frequency capacitance probes mounted on the Brasilian SONDA III rockets launched off the coast of Natal (6°S, 36°W). The first launching was into a daytime ionosphere at 1505 LST on 26 July 1984. The second was a nighttime flight, the launch taking place at 2030 LST on 11 December 1985, into an ionosphere disturbed by a plasma-bubble irregularity event. However, magnetically quiet conditions prevailed both during the flight and the preceding day. The third experiment rocket was launched, at 2259 LST on the night of 31 October 1986, into an ionosphere under quiet conditions. The apogee during these flights varied between 560 km and 444 km. In this paper we compare the electron-density profiles with the IRI predictions. Further comparisons are also made using the SLIM electron-density profile representative of the conditions of these flights as obtained by interpolation from the tabulations for the different latitude-local time grids for solar minimum conditions presented by Anderson et al. /8/.

ELECTRON DENSITIES FROM HIGH FREQUENCY CAPACITANCE PROBE

The technique of electron-density measurement by high frequency capacitance probe has been discussed in Heikkila et al. /9/, Rao et al. /10/ and more recently in Abdu et al. /11/. Briefly, the nose tip of a rocket acts as a capacitive element to determine the precise frequency of a stable oscillator. In our experiment, as a check, it is operated in a double-frequency mode (10 MHz and 6 MHz) by switching at a convenient rate between two suitably selected inductors /11/. Changes in the capacitance of the nose tip produced by condition ($\Sigma Kp = 10^+$) that characterized this first measurement. By comparison SLIM gives consistently lower densities at all the heights than the IRI as well as than the measured values.

Corresponding results from the second measurement, the night-time plasma-bubble event of 11 December 1985, are presented in Figure 2. The rocket apogee for this flight was 510 km. The low value of ($\Sigma Kp = 19^-$) represented an otherwise overall quiet ionospheric condition. The depletions in the electron densities seen on this profile will be discussed elsewhere. The ambient profile for this case shows, as expected, important departures from the IRI in the subpeak densities. These could be produced by the large equatorial electric field in the evening hours that is responsible for the layer uplift and which is a precursor to the bubble generation. This profile also represents a departure from the mean nighttime behaviour (especially at subpeak altitudes) and therefore it is not surprising that the IRI yields different results at these heights. The F-layer peak density shows, however, good agreement with the IRI prediction. It is important to note that the topside electron-density distribution scale height according to the IRI is somewhat higher than is suggested in the measurements. The SLIM prediction for this case also represents a certain underestimation of the peak and topside densities.

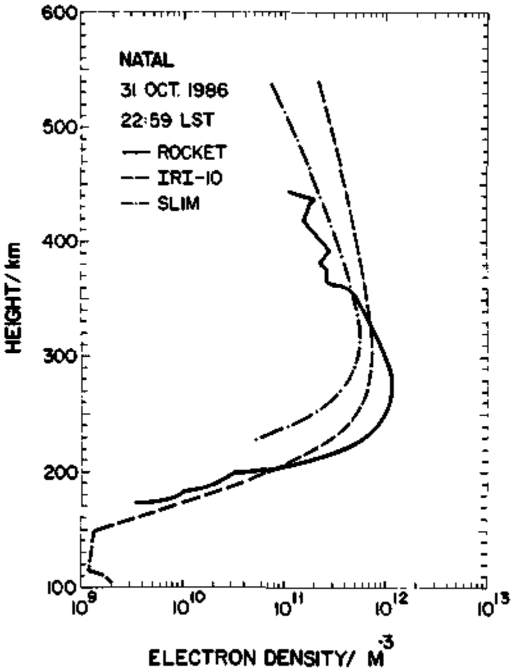

Fig. 3. Similar representations to Figure 1 for the night flight at 2259 LST on 31 October 1986.

The rocket apogee for the third experiment reached 444 km and the corresponding electron-density profile is shown in Figure 3 ($\Sigma K = 13^+$ for this experiment). The agreement with the IRI is good for subpeak densities, namely, below 250 km down to 160 km. The IRI prediction of the layer peak densities is somewhat less than the rocket measurement for this night, but this difference is within the expected day-to-day variabilities of the quiet time foF2 values (see for example /7/). A notable feature of these results is that the topside electron-density scale height predicted by the IRI is significantly higher than that measured by the rocket probe (as was observed also for the second flight discussed above). This difference is significant and real although the topside profile was apparently disturbed possibly by a "fossil bubble" structure which seems to have drifted into the rocket trajectory. The ground-based diagnostics from the ionosonde at Fortaleza and a scintillation receiver at Natal had confirmed the absence of any spread-F events immediately before the launch. Also the low F-layer height at this time was not conducive to irregularity generation in the region of the rocket experiment. Even with the presence of this irregularity structure the topside scale height is reasonably well defined and is smaller than that predicted by the IRI. The densities given by the SLIM for that night are appreciably smaller than from the rocket measurements and the IRI predictions for heights below about 300km.

DISCUSSION AND CONCLUSIONS

The high frequency capacitance probe utilized in the measurements reported here has proved to be a reliable technique for electron density determination within certain limits. However, its sensitivity is unsatisfactory for densities less than $5\times10^9 m^{-3}$ and also for higher densities ($\sim10^{12} m^{-3}$) where the plasma frequency approaches the oscillator frequency. The daytime E-layer and nighttime F-layer (for low solar activity period) fall well inside these limits. The S factor used in the calculation of the densities is reasonably precise near 100 km. Its possible departure near the F-layer peak has not been determined. However this is expected to have only a small influence on the main conclusions concerning electron density comparisons discussed in this paper, since identical profiles were generated (though not shown here) for both oscillator frequencies over those height regions where the S factor did not appear to differ for the two frequencies.