PROCEEDINGS
OF THE IRI TASK FORCE ACTIVITY 1996

Edited by Sandro M. Radicella
United Nations Educational Scientific and Cultural Organization
and
International Atomic Energy Agency
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

PROCEEDINGS
OF THE IRI TASK FORCE ACTIVITY 1996

Sandro M. Radicella
Editor

MIRAMARE – TRIESTE
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This ICTP Internal Report contains the programme, summary and the write up of a number of presentations delivered during the International Reference Ionosphere (IRI) Task Force Activity 96 that have taken place at the ICTP during August 1996 and particularly centred in the week from August 19 to 23. The 1996 Task Force Activity is the third successful encounter of specialists organized by the URSI-COSPAR IRI Working Group and the Aeronomy and Radiopropagation Laboratory of the International Centre for Theoretical Physics of Trieste, Italy.

Prof. Sandro M. Radicella
Head
ICTP Aeronomy and Radiopropagation Laboratory
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INTRODUCTION

This project continues the IRI Task Force Activities at the International Centre for Theoretical Physics (ICTP) in Trieste, Italy. This year's task force has focus on the model descriptions for the bottomside F-region including the F1 layer and started the consideration of the topside ionosphere.

The main discussions and presentations have taken place in the week from August 19 to 23. The format has been similar to last year's activity with presentations and round-table discussions in the morning and follow-on work in small subgroups in front of computer terminals in the afternoon.
1996 IRI TASK FORCE ACTIVITY

Shape of the Bottomside and Topside electron Density Profile

DAILY PROGRAMME

Monday 19 August:

09.00 - 12.00
"Electron density and height at the F1 region minimum gradient at low solar activity for an equatorial station". J.O. Adeniyi and S.M. Radicella
"Global variation of N170 and N180". D. Bilitza
"F1 occurrence including L condition in Tucuman and Buenos Aires". M. Mosert de Gonzalez, R. Ezquer and R. del V. Oviedo
"Behaviour of the intermediate region of the ionosphere at F1 heights". S.M. Radicella, M. Mosert de Gonzalez, C. Scotto, B. Zolesi, C.A. Jadur and J.O. Adeniyi

12.00 - 14.30 Lunch Break

14.30 - 17.00 Laboratory work

Tuesday 20 August:

09.00 - 12.00
"Diurnal behaviour of B0 and B1 at equatorial stations". J.O. Adeniyi
"Seasonal behaviour of B0 and B1". M. Mosert de Gonzalez and S.M. Radicella
"Latitudinal behaviour of B0 and B1". M. Mosert de Gonzalez, J.O. Adeniyi and S.M. Radicella
"Some comments on the class A and B profiles over Tucuman". M. Mosert de Gonzalez
"Fitting the IRI profile function to measured profiles: determine optimum B0 and B1". B. Reimsch and X. Huang
"B0 observed with the Arecibo IS Radar Measurements". K.K. Mahajan

12.00 - 14.30 Lunch Break

14.30 - 17.00 Laboratory work

Wednesday 21 August:

09.00 - 12.00
"Topside electron density profiles during high solar activity (review of results obtained with the help of Intercosmos-19 Satellite)". N.P. Benkova, N.A. Kochenova, M.D. Fligel and S.A. Pulinets
"Topside and bottomside electron density profiles: comparison with IRI model for San Juan region". S.A. Pulinets, V.Kh. Depuev, M. Mosert de Gonzalez.
S.M. Radicella and S.R. Zhang

"Comparison of topside N(h) profiles observed using the Arecibo IS Radar with the IRI model". K.K. Mahajan

"Study of the Variation of the ionosphere in high latitude using the EISCAT data". M.L. Zhang, S.M. Radicella and T. Gulyaeva

12.00 - 14.30 Lunch Break

14.30 - 17.00 Laboratory work

**Thursday 22 August:**

09.00 - 12.00

"Theoretical topside profiles and corresponding physical conditions". S.R. Zhang and S.M. Radicella

"ISIS Topside sounder data available from NSSDC". D. Bilitza

"A computer program to calculate TEC, time delay and range error between two points in space". C.A. Jadur, S.M. Radicella and R. Ezquer

"Comparison between TEC obtained by GPS and NNSS". L. Ciraolo and P. Spalla

"TOPEX-TEC data and comparison with IRI". D. Bilitza

12.00 - 14.00 Lunch Break

14.00 - 15.00 Laboratory work

15.00 - 17.00 Discussion session

**Friday 23 August:**

09.00 - 12.00

"E-F parameters observed with the Arecibo IS Radar Measurements". K.K. Mahajan

"Meridional structure of the upper ionosphere over Southern America during early morning hours (possible coastal or Andes effect?)". S.A. Pulinets, V.Kh. Depuev and S.M. Radicella

"General Summary". D. Bilitza and S.M. Radicella

12.00 End of the activity
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THE TOPICS OF THE 1996 IRI TASK FORCE ACTIVITY AT ICTP WERE:

1. Improvement of Fl parameters (foFl, fL70, fL80) in IRI,
2. Improvement of bottomside parameters (B0, B1) in IRI,
3. Shortcomings of the current IRI topside profile shape (4)
4. IRI-computed Total Electron Content (TEC) and problem areas,
5. Results from theoretical models and applications.

Data presented included ionosonde data from many stations worldwide, incoherent scatter rader data from Arecibo, Puerto Rico and satellite data from IK 19 (Russia), TOPEX (US/France), AE-C,D,E (USA), GPS and NNSS.

**FL REGION PARAMETERS**

The most important result was the new probability model for the occurrence of an Fl (including L condition) by Radicella and the ICTP group:

\[ P = (0.5 + 0.5 \times \cos X)^2 X \]

\( X \) is solar zenith angle. Inclusion of cases with L condition simplified the modelling since differences due to solar activity and latitude disappear.

For the fL70 and fL80 point satellite data show only a small latitudinal variation but a large variability (two orders of magnitude) at nighttime. A first attempt was made to represent fL70 in terms of M300 and foF2.

**RECOMMENDATION FOR IRI:** Inclusion of the new probability function to provide users with an estimate of how likely she/he would encounter an Fl feature. The foF1 Ducharme et al. formula should now be used with the new occurrence criteria of \( P = 0.5 \).

**FUTURe TASK:** Establish an fL70 model in terms of solar zenith angle, latitude, solar sunspot number and season [Task team: Radicella and his ICTP team; Bilitza will provide his satellite data compilation]; during nighttime satellite data should be compared with incoherent scatter data to establish a better representation of the upper nighttime valley region [Mahajan, Bilitza].

**BOTTOMSIDE PARAMETERS**

Comparisons of B0 and B1 parameters obtained with the UML Artiste program, the POLAN program and from a theoretical model showed good agreement. Combining these data new B0 parameters were established for daytime winter and summer for high and low solar activity. The high solar activity case still requires data near the magnetic equator.
RECOMMENDATION FOR IRI: New B0 parameters can be included for the B0 table option for daytime summer and winter conditions; a special option for the inclusion of variable B1 based on the Jicamarca digisonde data [Bilitza].

FUTURE TASK: Establish global plots of B0 parameters for nighttime and for B1 for daytime and nighttime [Radicella and Mosert]. Analytical formulas to describe the diurnal variation of B0 and B1.

IRI PROFILE BELOW THE F PEAK

Inclusion of the new F1 and bottomside parameters in an IRI profile representation were discussed and the necessary constraints were established: (1) the point where the bottomside profile becomes independent of B1 if this point is below foF1 a higher point has to be chosen; (2) the derivative at that point; (3) a minimum in the gradient at foF1; (3) the f170 point; (4) the valley-top; (5) the gradient at the valley-top; the last two constraints could be satisfied by a separate (parabolic) merging function.

FUTURE TASK: Find a functional representation for the intermediate and F1 region that will be able to fulfil the various constraints [Reinisch and his UML team].

TOPSIDE PROFILE SHAPE
The major shortcomings of the current representation of the topside profile shape in IRI are the following:

(1) At high latitudes and high solar activity the topside gradient becomes close to 0 and can even become positive.

(2) Comparisons with incoherent scatter data and topside sounder data during this meeting showed that IRI consistently overestimates the mid-latitude measurements, especially during nighttime.

(3) Close to the magnetic equator comparisons have shown that IRI underestimates considerably the topside densities during high solar activity.

FUTURE TASK: Ways of improving the current IRI topside profile parameters have to be investigated [Bilitza]; new modelling approaches should be continued specifically in terms of a better coordinate system and a reduced number of topside parameters [Leitinger, Titheridge]. The global and altitudinal variation of the topside scale-height should be established from topside sounder data [Pulinets].
GLOBAL VARIATION OF N170 AND N180

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Abstract: We have used data from the Atmosphere Explorer C, D, and E CD-ROM to investigate the global variation of the electron density at 170 km (N170) and 180 km altitude (N180). We find large variability at nighttime and only small latitudinal differences during daytime. Comparisons with the IRI predictions for N170 and N180 indicate the need for improvement of the IRI model in the F1 region.

1. Introduction

Comparisons of the IRI electron density model with measurements in the F1 region have clearly shown the need for improvement of the model in this region (e.g. Radicella, 1996). In IRI, currently, the absolute values of electron density in the region between the E and F2 peaks are determined by the F2 peak density (NmF2) at the upper end and by the E peak density (NmE) at the lower end. The density at the F1 ledge (NmF1) is obtained with the Ducharme et al. (1971,1973) model and the F1 height (hmF1) is then determined as the height where the bottomside profile (defined by the bottomside thickness parameter B0 and the shape parameter B1) reaches the value NmF1. Below hmF1 a simple parabolic F1 layer is assumed which is then merged with the profile-function for the E-valley region coming from below.

To obtain a better representation of the intermediate region (between valley top and F1 ledge) it was recommended to introduce one or two ‘anchor’ points in this region. A natural choice would be the F1 point itself, but unfortunately it is found that the F1 height (hmF1) is highly variable (McNamara and Reinisch, 1995). This is probably due to the fact that the F1 feature marks the boundary between the solar controlled region below and the F2 region above controlled more by dynamic processes and also the transition from molecular ions below to atomic ions above. The IRI team decided to look at the densities at a constant height as potential ‘anchor’ points for the IRI profile in the intermediate region. Using digisonde data from mid and low latitude stations Reinisch and Huang (1996) showed that the density at 170 km altitude (N170) would be a good candidate for anchoring the IRI profile in the F1 region.

2. Data used in this study

The data used in this study were taken from NSSDC’s AE-C,D,E CD-ROM. This CD-ROM contains the data acquired by the Atmosphere Explorer (AE) C, D, and E satellites. The data are provided at 15-second time resolution and cover the years 1973 to 1981. The primary data source for our study is the AE-C mission (Dec. 73 - Dec. 78) with additional data from the short-lived AE-D mission (Oct. 75 - Jan. 76). AE-E was a low-inclination (19.7°) satellite and thus did not provide global observations.
Electron densities were measured on all three satellites with a number of instruments including the Cylindrical Electrostatic Probe (CEP), the Bennett Ion Mass Spectrometer (BIMS) and the Retarding Potential Analyzer (RPA). Intercomparisons between the different measurements have revealed some discrepancies, e.g. González et al. (1992) suggested that the AE-E BIMS data need to be increased by a factor of 2.15 to agree with the RPA measurements. Comparing the mass spectrometer data versus the probe data, Köhlein (1989) finds best agreement for AE-C data and discrepancies for AE-D and AE-E. We have used probe data (CEP and RPA) in this study. In comparing CEP and RPA data we found good agreement. We also found that the CEP data provided a wider diurnal coverage than the RPA data (see Figure 1) which may be due to instrument thresholds.

The AE-C satellite orbited in an elliptical orbit during the first 15 months of the mission and was then put into circular orbits first at about 300 km and then at about 400 km. The altitudes range of 165 to 185 that is of interest to this study was only reached during the elliptical orbit phase and then again during the final decay. Data shown here are therefore primarily from the solar minimum year 1975.

3. Diurnal variation of N170 and N180

In Figure 2 we have plotted the variation of N170 and N180 versus solar zenith angle. The data are for the latitude range 30 to 60 degrees and -20 to +20 degrees. We find large variability at night and an almost constant value during daytime. This behavior is even more distinct at low latitudes. As expected the plots for N170 and N180 show almost identical variation patterns.

In Figure 3 the values of N170 and N180 are plotted versus local time for the two latitude zones (N70 for 30-60 deg. and N180 for -20 to 20 deg.). Interestingly the highest variability is found in the post-midnight sector for mid-latitudes and in the pre-midnight sector for low latitudes. Again we find almost constant values from 9 to 16 LT.

4. Latitudinal variation of N170 and N180

We have studied the latitudinal variations of N170/N180 for two solar zenith ranges. Values for solar zenith angles below 70 degrees provide a good representation of the daytime behavior; as we saw in Figure 2 N170 and N180 are almost constant for these solar zenith angles. We have also studied the latitudinal variation at nighttime using all data obtained for solar zenith angles greater than 100 degrees.

In Figure 4 the daytime results are presented. Latitudinal variations for N170 are from about \(10^5\) cm\(^{-3}\) to \(2 \times 10^5\) cm\(^{-3}\) and for N180 from about \(1.2 \times 10^5\) cm\(^{-3}\) to \(2.2 \times 10^5\) cm\(^{-3}\). The characteristic inverted V features in this figure are most likely a result of the AE-C orbit and related changes in altitude and hour. These features and the detailed latitudinal variation will be investigated in a follow-on study.

The nighttime data in Figure 5 show the large variability (three orders of magnitude) encountered at night. As expected the largest variability is seen at high latitudes where auroral electron precipitation and magnetospherically induced electric fields affect the electron distribution.
5. Comparisons with IRI

In Figures 6, 7, 8, and 9, we compare the diurnal and latitudinal AE-C data plots with the corresponding plots generated with IRI; the IRI density was calculated for each data point using the orbit latitude, longitude and altitude and the date and time. The variation with solar zenith angle in Figure 6 shows artificially high IRI densities (factor of 3 compared to the AE-C data) for solar zenith angles from 50 to 75 degrees. It is interesting to note that IRI shows a similar nighttime variability as the AE-C data.

The local time plot in Figure 7 shows that the IRI misinterpretation of the data is mostly centered around noontime. During nighttime the data show highest variability in the post-midnight sector whereas the IRI predictions are highly spread in the pre-midnight sector.

The most obvious differences between the current IRI model and the AE-C N170 data are seen in the daytime latitudinal plots in Figure 8. The largest discrepancies are seen between 40 and 50 degree latitude and between -40 and 0 degree latitude. The errors are due to a combination of shortcomings of the current IRI F1 region model: (i) the height of the F1 layer, hmF1 depends strongly on the bottomside thickness parameter B0, which is most reliable at northern mid-latitudes but has shortcomings in the equatorial and southern hemisphere; (ii) the density at 170/180 km altitude depends strongly on the existence or non-existence of an F1-layer; comparisons with ionosonde data have shown that the months and hours for which IRI predicts an F1-layer do not always agree with the months and hours for which the measurements show an F1-layer (Radicella, 1996).

The nighttime latitudinal plots in Figure 9 show again that IRI overestimates the N170 in the southern hemisphere. The data show the auroral belts at high latitudes that are currently not represented in IRI.

6. References


Reinisch, B.W., and X. Huang, The F1 Region at 170 km, Adv. Space Res. 18, #6, 153-156, 1996.
Fig. 1 N170 versus solar zenith angle in the latitude range 30-60 degrees as observed by the AE-C CEP (left) and by the AE-C RPA (right) instruments.
Fig. 2 Solar zenith angle plots of N170 in the latitude range 30-60 degrees (bottom), and of N180 in the latitude range 30-60 (top, left) and -20 to 20 degrees (top, right) obtained with data from the AE-C CEP.
Fig. 3 Diurnal variation of N170 in the latitude range 30-60 degrees (left) and of N180 in the latitude range -20 to 20 degrees.
Fig. 4 Latitudinal variation of N170 (left) and N180 (right) during daytime as seen by the AE-C CEP.
Fig. 5 Latitudinal variation of N170 (left) and N180 (right) during nighttime as seen by the AE-C CEP.
Fig.6 Comparison of the solar zenith angle variations of N170 as observed by the AE-C CEP instrument (left) and as predicted by the IRI model (right).
Fig. 7 Comparison of the diurnal of N170 as observed by the AE-C CEP instrument (left) and as predicted by the IRI model (right).
Fig. 8 Comparison of the daytime latitudinal variations of N170 as observed by the AE-C CEP instrument (left) and as predicted by the IRI model (right).
Fig. 9 Comparison of the nighttime latitudinal variations of N170 as observed by the AE-C CEP instrument (left) and as predicted by the IRI model (right).
Abstract: An analysis of the occurrence of the F1 layer including the L condition has been done, using data from two Argentine stations: TUCUMAN and BUENOS AIRES, at different seasons and solar activity conditions. The comparisons between observations and the F1 occurrence predicted by the IRI-90 model show the need of reviewing the use of the DuCharme et al. (1973) formula adopted by the model to predict the occurrence of the intermediate F1 layer including the L condition.

Introduction

A typical bottomside ionogram for daytime hours shows generally the signatures of reflections from ionospheric regions E and F. Sometimes the F layer can be seen stratified in F1 and F2. When the F1 layer is very well developed a clear cusp is identified on the ionogram and the critical frequency of the layer, foF1, can be scaled. When it is not fully formed only a change of curvature is observed near the expected value of foF1. This condition is usually known as the “L condition” and it is scaled only with the descriptive letter L.

As it is known the International Reference Ionosphere 1990, IRI-90, (Bilitza, 1990) predicts the time of occurrence of the layer and the foF1 values using DuCharme et al. (1973) formula that also provides a critical solar zenith angle for the occurrence probability of the F1 layer. IRI-90 omits this layer at night and in winter.

Some authors (Ezquer et al., 1996; Mosert de Gonzalez et al., 1996; Zolesi and Mosert de Gonzalez, 1996; Mosert de Gonzalez, 1996) have shown that while the IRI-90 model predicts reasonably good the foF1 values, discrepancies in the time of occurrence of this layer occur. The objective of the present work is to analyze the occurrence of the F1 layer including the L condition, with data from two Argentine stations: TUCUMAN (26.9S; 294.6E) and BUENOS AIRES (31.5S; 301.5E).

Hourly values of ND (number of days in the month) in which F1 layer is observed have been compared with the ND predicted by the IRI-90 model using data recorded at both stations at different seasons and for the three levels of solar activity: high (HSA), moderate (MSA) and low (LSA).

Results

Tables 1 and 2 show for three typical daytime hours (LT:10.00, 12.00 and 14.00), for both stations, the four seasons (winter: July; fall: March; spring: September and summer: December) and for years of LSA (1976), MSA (1972, 1983) and HSA (1968,1979), the comparison
between Nexp (number of days in the month with F1 cusp) and NIRI (number of cases of F1 occurrence predicted by the IRI-90 model). The cases of F1 occurrence with L condition has not been taken into account in these tables.

It can be seen that during winter F1 predictions are absent, however experimental values are observed in both stations during MSA and LSA. On the contrary, during March the model predicts the F1 layer while the observations are practically absent. More frequent is the presence of foF1 values during the equinoctial month of September. The best agreement between observed and predicted F1 occurrence is found during summer (December).

Figures 1 to 6 illustrate the results of the comparison between the number of cases predicted by the IRI model (called IRI in Figures 1 to 6) and number of observed F1 occurrence including also the cases with L condition (called EXP + L in Figures 1 to 6), for BUENOS AIRES (Figures 1 to 3) and TUCUMAN (Figures 4 to 6) at different seasons and for years of HSA (1968, 1982), MSA (1972, 1983) and LSA (1976, 1977).

From the analysis of the figures can be seen:

(i) During the equinoctial months the occurrence of the F1 layer when the L condition is taken into account is closer to that predicted by the IRI-90 model during the hours in which the model predicts the F1 occurrence. Note that during March the occurrence is generally null if this condition is not considered (see Tables I and II). During both equinoctial months the model underestimates the time window of occurrence of the layer. The F1 layer is not predicted by the model for hours of large solar zenith angles.

(ii) During winter the F1 layer often occur if the L condition is taken into account, for the three levels of solar activity. Note that in winter during HSA (see Tables I and II) the occurrence of the F1 layer is null, if the cases with L condition are not considered.

(iii) During summer the agreement between observed and predicted F1 occurrence is also better during the hours in which the IRI model predicts the layer if the L condition is considered. Once more during this season the time range of the observed occurrence is larger than that given by IRI predictions.

Conclusions

The results of the present study indicate the need of reviewing the use of the DuCharme et al. (1973) formula adopted by IRI-90 to predict the F1 occurrence, in order to improve the current performance of the bottomside IRI model.

Acknowledgements: The authors undertook this work with the support of the International Centre for Theoretical Physics and the National Programme of Radiopropagation (PRONARP), CONICET, Argentina.
References


### Table I

<table>
<thead>
<tr>
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<th>JULY</th>
<th>MARCH</th>
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Nexp: Days of month for which foF1 has been observed
NIRI: Days of month for which IRI gives foF1 predictions

### Table II

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<th>JULY</th>
<th>MARCH</th>
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Nexp: Days of month for which foF1 has been observed
NIRI: Days of month for which IRI gives foF1 predictions
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Abstract: The characteristics and occurrence of the F1 ledge in the electron density profile are reviewed and discussed in terms of its relevance for the empirical modelling of the ionosphere. An updated and selected data base is used to confirm the validity the DuCharme et al. formula taking into account alternative solutions for the particular occurrence restrictions imposed by that formula and the IRI-90. The information considered includes also L conditions that indicates the presence of a less defined F1 cusp in the ionogram. A probability of occurrence of the F1 layer is introduced making use of the hourly ionogram scaling information given in monthly bulletins of ionospheric data. The possible prediction of the electron density at fixed heights in the F1 region is discussed and a formulation for such prediction is proposed as a preliminary step.

The electron density profile at F1 heights and the IRI-90 model

During daytime a ledge is often found in the electron density profile between 150 and 200km identified by the presence of a cusp in the ionogram echo that is scaled as foF1. This critical frequency corresponds most of the time to an inflection point in the electron density profile and very seldom to a real maximum of ionization. The F1 cusp in many occasions is not well defined and its presence in the ionogram is not scaled with a numerical value but only with the descriptive letter L. In these cases the electron density profile shows also the presence of a replenishment of ionization at F1 heights that is not quantified by the ionogram scaling procedures. The same replenishment is often observed for high solar activity conditions also in cases when no indication of F1 cusp is seen in the ionogram.

DuCharme et al. (1973) used a large experimental data base from 39 stations around the world for the period 1954-1966 to obtain an empirical formulation to predict the values of foF1 and the time of occurrence as a function of solar zenith angle, geomagnetic latitude and solar activity measured by R12. This formulation is not able to predict values where the L condition is found in the ionograms. Gonzalez and Radicella (1987) found that the critical frequency of the F1 ledge corresponds to the height hmF1 where the electron density vertical gradient reaches a minimum in the region and that this height could be predicted empirically from characteristics scaled in the ionograms. Finally Radicella and Gonzalez (1991) have introduced an empirical formula to predict hmF1 in terms of foF1 and geomagnetic dip angle.
Gonzalez and Radicella (1995). Radicella et al. (1994) and Zhang and Radicella (1996) have found that the electron density in the F1 height interval between 150-190 km shows a minimum in the relative variability as a function of height. This result indicates that the electron density in that height interval could be predicted with less uncertainties than at other heights even when no indication of the F1 ledge is seen in the ionograms.

The International Reference Ionosphere, the most used empirical model of the ionosphere, (Bilitza, 1990) has adopted DuCharme et al. (1973) basic formulation to calculate $f_0F1$ and its occurrence in order to model the electron density in the F1 region. The model gives $h_mF1$ as the height where the modelled F2 bottomside profile reaches the value of $NmF1$ derived from $f_0F1$. In the IRI this height is strongly controlled by the F2 region thickness parameter $B0$.

IRI introduces an additional strong limitation on the occurrence of $f_0F1$ by assuming that it is never present in winter and before sunrise and after sunset. It must be noted that there are indications that these limits imposed to the occurrence of $f_0F1$ appear to be unrealistic in several cases like winter low solar activity conditions at almost all latitudes (Adeniyi, 1996; Gonzalez et al., 1996 and Gonzalez and Zolesi, 1996).

An example is shown in Figure 1 where a local noon profile that corresponds to an ionogram with a well defined F1 cusp for Roma (41.9°N, 12.5°) during winter and low solar activity is compared with the corresponding IRI 90 profile. Figures 2 and 3 show other examples with similar comparisons for Tucuman (26.9°S, 294.6°E) when the presence of an L condition in the ionogram is seen (LT 10.00) and when a well defined F1 cusp is observed (LT 13.00). In these cases the limits imposed by the IRI on the occurrence of $f_0F1$ introduce large departures between the model and the profile obtained from ionogram inversion. It must be noted also that during high solar activity even when no indication of a F1 cusp appears in the ionogram the replenishment of ionization in the F1 height region can be important but the IRI model will ignore it. This case is shown in Figure 4 where ionogram inversion and IRI noon profiles are compared for Roma in winter and high solar activity.

Validation of the DuCharme et al. (1973) formulation

Monthly median values of $f_0F1$ from 104 ionospheric stations available on the Ionospheric Digital Database of the Boulder NGDC in the time interval from 1969 and 1990 were used to validate the DuCharme et al. (1973) formulation. Table 1 gives the average differences in MHz between calculated and measured values of $f_0F1$ when IRI assumes the occurrence of $f_0F1$ for different latitude intervals and solar activity (R12) ranges. Table 2 shows the same differences but including all the cases when experimental median values of $f_0F1$ are taken into account and DuCharme et al. (1973) formula is used without any restriction in terms of occurrence. The results confirm the validity of the $f_0F1$ prediction by DuCharme et al. (1973) even under conditions outside the limits of the original formulation and the IRI model.

Taking into account these results an empirical probability function of occurrence of $f_0F1$ has been derived from the described large data base assuming a dependence on solar zenith angle, geomagnetic latitude and solar activity. The function obtained is:

$$P(\chi, \lambda, R_{12}) = [0.5 + 0.5 \cos(\chi)]^7$$

When the limits adopted by DuCharme et al. (1973) and the IRI model for the occurrence
of foF1 are considered, the exponent $\gamma$ is given by:

$$\gamma = a + b \lambda + c \lambda^2$$

and:

$$a = 2.9798 + 0.0853993 R_{12}$$
$$b = 0.01069 - 0.0021967 R_{12}$$
$$c = -0.000256409 + 0.000146678 R_{12}$$

If the cases when the descriptive letter L is observed in the median monthly tabulation of foF1 are also taken into account the value of the exponent $\gamma$ is found to be almost independent of $\lambda$ and $R_{12}$:

$$\gamma = 2.36 \quad (2)$$

Figure 5 shows the variation of the probability $P$ as a function of the solar zenith angle when $\gamma$ is given by equation 2.

These results indicate that the limits imposed by DuCharme et al. (1973) and the IRI model for the occurrence of foF1 could be replaced by assuming the DuCharme formula without occurrence restrictions but taking into account the probability function defined by equations 1 and 2.

**Prediction of the electron density at fixed heights in the F1 region**

The small relative variability of the electron density at fixed heights found between 150 and 190 km make it possible to search for possible empirical expressions to predict values of the electron density at fixed heights independently from the presence of foF1 or even L condition in the ionogram.

About 1000 profiles from individual ionograms obtained at four different locations in Argentina at geographic latitudes from -27° to -55° for different daytime hours, seasons and solar activity were used to search for a prediction formula. Of the total set of profiles 181 have been chosen for validation and the remaining profiles were used in order to obtain multiple regression expressions. The search indicates that the electron density at fixed heights in the F1 region is not a linear function of the variables investigated and that the most statistically significant expressions are found for 170 km.

After a lengthy investigation a preliminary empirical expression that shows a dependence of $N_{170}$ on solar zenith angle, foF2, the module of the dip latitude and M(3000)F2 has been found:

$$N_{170} = A_0/\cos^{1.5}\chi + A_1 M(3000)F2 + A_2 M(3000)F2/foF2] + A_3 \cos^{(n-1.5)}\chi - A_4 |y| + A_5 |1/(foF2)^2|$$

where:

$$A_0 = -8.75, A_1 = 112.97, A_2 = -1518.20,$$
$$A_3 = 194.67, A_4 = -199.94, A_5 = 12063.52 \text{ and } n = 0.15 \text{ foF2}$$

By using the 181 profiles not included in the derivation of equation 3 the differences between the experimental values of $N_{170}$ and the predicted values obtained with the equation were
calculated. The percentage error was estimated and the corresponding histogram is shown in Figure 6. For 88.4% of the cases the percentage difference was less than 20 indicating that the formula is a reasonable first step in the search for the empirical prediction of the electron density at fixed height in the F1 region. However the formula given should be further investigated with a larger data base of electron density profiles.

The formula appears to be able to predict also the diurnal behaviour of $N_{170}$ as it can be seen in Figure 7 where experimental values for a daytime hourly sequence are compared with the IRI 90 model values and those calculated with the equation 3. These last values appear to be a better prediction of $N_{170}$.

Conclusions

The results of the analysis done in this paper show that:

1.- Empirical models like IRI-90 need alternative solutions for the representation of the electron density profile in the F1 region.

2.- A possible solution is to adopt the DuCharme et al. (1973) formula, that has been confirmed as a good prediction for foF1, without any occurrence restriction but including a probability function like the indicated above.

3.- An alternative solution, particularly valid when no F1 cusp is expected, can be to predict the electron density at a fixed height like 170 km in terms of solar position, geomagnetic location and F2 layer characteristics.

4.- The prediction formula for the electron density at 170 km indicated above should be further investigated with a larger data base of electron density profiles.

References


**TABLE 1**

Average difference (MHz) between calculated values with imposed limits (DuCharme et al. (1973)) and experimental median values of foF1

<table>
<thead>
<tr>
<th>Geomagnetic Latitudes</th>
<th>R12&lt;50</th>
<th>50&lt;R12&lt;100</th>
<th>R12&gt;100</th>
<th>All R12</th>
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<td>0.174</td>
<td>0.234</td>
<td>0.194</td>
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**TABLE 2**

Average difference (MHz) between calculated values without imposed limits (DuCharme et al. (1973)) and experimental median values of foF1

<table>
<thead>
<tr>
<th>Geomagnetic Latitudes</th>
<th>R12&lt;50</th>
<th>50&lt;R12&lt;100</th>
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<tr>
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<td>0.183</td>
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Local noon profile that corresponds to an ionogram with a well defined F1 cusp for Roma (41.9° N, 12.5° E) during winter and low solar activity (IRI does not predict foF1)

![Graph showing ionogram data for Roma on 15/01/86 with LT 12:00.](image)
Local time 10.00 profile for Tucuman (26.9° S, 294.6° E) when a well defined F1 cusp is observed in the ionogram (IRI does not predict foF1)
Local time 13.00 profile for Tucuman (26.9° S, 294.6° E) when a well defined F1 cusp is observed in the ionogram (IRI does not predict foF1)
Local noon profile for Roma in winter and high solar activity when no cusp is observed in the ionogram (IRI does not predict foF1)

Figure 4
Figure 5
Difference between measured and calculated value of N170 percentage error as a function of cases and % of cases

Figure 6
Comparison of measured, IRI - 90 model (new Bo) and calculated values of N170 for a day time sequence

Figure 7
Abstract: The data used for this study are those from Ouagadougou (Lat. 12.4° N, Dip 5.9° N) and Ibadan (Lat. 7.4° N, Dip 6.3° S). Analysis were done for only daytime period. The results indicate that BO exhibit a solar zenith angle dependent diurnal variation and some seasonal effect is present during certain hours of the day. B1 does not show pronounced seasonal effects or solar zenith angle dependence. Daytime average value of BO varied from 70 to 180 while B1 varied from 1.5 to 3.1. The average magnitudes of BO at 1000, 1200 and 1400 at Ibadan are greater than those of Ouagadougou during the winter season and the corresponding values of B1 are also greater in Ibadan during summer and winter seasons. In summer, average IRI B0 at 1200 hour for Ibadan is about the same as the experimental value but during winter, the IRI average is less than the experimental one.

Introduction

Equatorial ionospheric profiles have been compared with those obtained by the International Reference Ionosphere (IRI) model. It was observed that some differences exist between the two around the F1 region and below the F2 peak ionisation density. It was noted that the IRI model underestimates the bottomside thickness of the ionisation density (Adeniyi, 1995). One of the ways pointed out for improving the IRI model was to improve the B0 and B1 parameters. The B0 parameter determines the thickness of the bottomside of the F2 layer while B1 determines the shape of the profile below the F2 peak. There are two options for the calculation of B0 in the IRI-90. The first is based on a table of values of B0 obtained from ionograms recorded from three mid latitude stations. The second which is the newer one is based on the Gulyaevas model (Gulyaeva, 1987) which gives a relationship between the F2 peak and the half density height; h0.5 (Bilitza, 1990). The half density height is the height below the F2 peak where ionisation density is equal to half of that of the F2 peak density. The Gulyaeva model has been found to give a better result than the first option for an equatorial station (Adeniyi, 1995). The aim in this paper is to investigate the variation of B0 and B1 in order to get appropriate values of these parameters for the equatorial region.

Method of analysis

The ionograms from Ouagadougou (Lat. 12.4° N, Long. 1.5° W, Dip 5.9° N), used in this study are the records for 1994, a year of low solar activity, with an average sunspot number of 30. The NEW POLAN programme (Titheridge, 1995) is used for the ionogram inversion. This programme is essentially the same as POLAN (Titheridge, 1985) with the addition that it calculates B0 and B1 along with each profile generated. Day time ionograms (0600-1800 hours),
from this station were used for this study. The months of January, April, July and October are used to represent winter, March equinox, summer and September equinox respectively. Data for four days in each of these months were used for the analysis. These four days are scattered through the months used, but magnetic storm days are excluded. Some ionograms from Ibadan (Lat. 7.4° N, Long. 3.9° E, Dip 6.3° S) for 1964 another year of low solar activity with an average sunspot number of 10 were also used in this study. The data from this station, that was analysed were those for 1000, 1200 and 1400 hours in the month of January and July.

Results

The hourly averages of $B_0$ and $B_1$ for the days used in each of the months were calculated. The differences in the values of $B_0$ from one season to the other are more pronounced between 1000 and 1500 hours than for other hours of the day. The variation for all the seasons indicates a solar zenith angle ($\chi$) dependence. The results for $B_1$ for the same station do not show clear-cut diurnal or seasonal effect. The range of variation at the early and later part of the day is however slightly greater than those of the middle part of the day. Table 1 shows the hourly average of $B_0$ and $B_1$ for all the days of all the months used for Ouagadougou. $B_0$ varied from 70 to 185 while $B_1$ varied from 1.5 to 3.1.

The results for $B_0$ and $B_1$ for Ibadan are shown in tables 2 and 3 respectively. The average values of $B_0$ and $B_1$ are shown with the number of days in the month used. The winter values of $B_0$ are higher than those of summer for the three hours considered. Table 4 shows the comparison of the parameters between the two stations for 1000, 1200 and 1400 hours for the summer and winter seasons. The $B_0$ values for Ibadan are lower than those of Ouagadougou in winter. The trend in summer is not consistent. $B_1$ values for Ibadan are lower than those of the second station during both seasons considered. Average IRI $B_0$ for Ibadan at 1200 hour of all the days used for this station in January and July were obtained with the Gulyaevas $B_0$ options for the purpose of comparison. Table 5 shows the result. In winter, experimental value of $B_0$ is greater than the IRI one while in summer, there is no significant difference between both.

Discussion and conclusion

The results obtained in this study indicate that there is an obvious diurnal variation and some seasonal effects on $B_0$ during certain time of the day but such variations are not apparent on $B_1$. The differences observed in $B_0$ and $B_1$ between the two stations considered indicate that there might be latitudinal effects on these parameters. More wide spread stations and a larger coverage of time is needed to confirm this. A more detailed comparison of IRI $B_0$ and $B_1$ with experimental data is also necessary in order to know how these parameters should be modelled to improve the IRI model.

Acknowledgements: The author would like to thank R. Hanbaba, Centre National d'Etudes Des Telecommunications, Lannion France, who supplied most of the ionograms for this work. He would like to thank the International Centre for Theoretical Physics (ICTP), Trieste, Italy, for hospitality, where this work was done. He would like to thank the Swedish Agency for Research Co-operation with Developing Countries; SAREC for financial support during his visit at ICTP under the associateship scheme. The author would also want to thank the

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Titheridge, J. E., Ionogram analysis with the generalised program NEW POLAN, Private communication 1995

Table 1
Daytime hourly average of B0 and B1 for Ougadougou

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Table 2
Average B0 for Ibadan

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Table 3
Average Bl for Ibadan

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Table 4
Comparison of B0, B1 at Ouagadougou with those of Ibadan

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<td>July Ibadan</td>
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<td>Ouagadougou</td>
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<td>189</td>
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Table 5
Comparison of IRI B0 with experimental values for Ibadan at 1200 hour

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<td>July</td>
<td>161</td>
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Abstract: A preliminary analysis of the thickness parameter B0 and the shape parameter B1 is presented. Noon electron density profiles recorded at five ionospheric stations during different seasonal and solar activity conditions are used in the study. The results show that both parameters present a seasonal trend with minimum value for B0 during the local winter and maximum during the local summer. This behaviour is inverted for B1. Discrepancies with IRI-90 model are found.

Introduction

As it is known IRI-90 model (Bilitza, 1990) provides two options to derive the thickness parameter B0 (old and new) and assumes for B1, in most cases, a value equal to 3 (Ramakrishnan and Rawer, 1972; Gulyaeva, 1987).

Recent papers (Adeniyi, 1996; Reinisch and Huang, 1996; Zhang et al, 1996; Mosert de Gonzalez, 1996; Mosert de Gonzalez and Zolesi, 1996) have shown that the IRI-90 model does not reproduce well the thickness and shape of the bottomside electron density profile.

Taking into account the recommendation of the IRI TASK FORCE ACTIVITY that have taken place at ICTP during November 1995, a preliminary analysis of the two parameters: B0 and B1 has been done in order to determine their seasonal variation. A comparison with the corresponding IRI-90 values has been also done.

Data used

Noon electron density profiles recorded at 5 stations (See Table 1) for some days of representative months of winter, summer, fall and spring during years of different solar activity are used in the study. (Tucuman:1976, R=13; 1969, R=106; San Juan: 1971, R=70; 1981, R=141; Buenos Aires: 1970, R=100; 1975, R=17; Roma: 1986, R=14; 1990, R=146; Ushuaia: 1965, R=16; 1991, R=144).

The values of the parameters B0 and B1 have been obtained using the POLRUNT computer code (Titheridge, 1995).

Taking into account that the database is not large enough, mean values of both parameters have been obtained for each season using data at different solar activity conditions. The experimental monthly mean values of B0 have been compared with the corresponding old and new IRI model values, for the same conditions, normalising IRI-90 model with the experimental values of foF2 and hmF2. (See Table 2 where n is the number of data used in the study).
Analysis of the results

Parameter Bo
(Figures 1 and 2)

1) For the 5 stations analyzed, a clear seasonal trend is observed in the experimental values of this parameter, with minimum in the local winter and maximum in the local summer. Only one exception is found: Ushuaia presents its minimum in April. In general, the spring values are greater than the fall values.

2) The old and new IRI Bo values also present this seasonal behaviour.

3) The comparison between observed and IRI-90 values show:

   (a) For Tucuman, San Juan and Buenos Aires (Figure 1) the best agreement with the model is observed during winter (July), where both IRI options provide similar values. The greater departures between observations and the new IRI Bo are found in summer, (January) being the old option the best for this season. For the equinoctial months April and October) generally the experimental values are not well reproduced by either of the two options. Only a good agreement with the old option is found in Buenos Aires during October.

   (b) For the two middle latitude stations, Rome and Ushuaia (Figure 2), the situation is different. In Rome, the new option reproduces better the experimental values in almost all the seasons. In Ushuaia this option is the best during fall (April) and winter (July).

Parameter Bl
(Figures 3 and 4)

For the experimental shape parameter Bl, also a seasonal trend is found. In this case the minimum is observed during the local summer and the maximum during the local winter. Some exceptions are found: in Ushuaia the maximum is present during April and in Tucuman during October.

The experimental monthly mean Bl values range between 1.35 and 2.62, always lower than 3, the usual value assumed by the IRI-90 model.

Conclusions

The results of this preliminary study indicate that:

1) The parameters Bo and Bl show a seasonal variation. In general, for Bo the minimum is observed during the local winter and the maximum during the local summer. For Bl the behaviour is inverted: the minimum is found in the local summer and the maximum in the local winter.

2) Discrepancies with the IRI-90 model are found for both parameters.
(3) Taking into account that the database used in this test study has not been large enough, an extension of this analysis to more stations and local times is needed in order to confirm these results and to propose better values of $B_0$ and $B_1$ to improve the performance of the bottomside IRI-90 model.

Acknowledgements: The authors undertook this work with the support of the ICTP. They thank to Prof. Titheridge for providing the POLRUNT computer code.

References


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<th>GEOG. LAT</th>
<th>GEOG.LONG.(E)</th>
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<td>July</td>
<td>75</td>
<td>2.47</td>
<td>74</td>
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<td>October</td>
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<td>April</td>
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<td>July</td>
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<td>61</td>
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<tr>
<td>October</td>
<td>81</td>
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<td>92</td>
</tr>
</tbody>
</table>
FIGURE 3
FIGURE 4
LATITUDINAL BEHAVIOUR OF THE THICKNESS PARAMETER B0

M. Mosert de Gonzalez¹, J.O. Adeniyi² and S.M. Radicella³
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2 Physics Department University Ilorin, P.M.B. 1515, Ilorin, Nigeria
3 International Centre of Theoretical Physics, Trieste, Italy

Abstract: This paper presents a preliminary analysis of the thickness parameter B0 in order to determine its latitudinal behaviour. Noon electron density profiles of stations located in a wide modip range, recorded under different seasonal and solar activity conditions are used. The results show the latitudinal dependence of B0 and the need of an extension of this study to a larger database and others hours of the day.

Introduction

During the Second IRI Task Force Activity that have taken place at the ICTP during November 1995, some specific problems were pointed out in the performance of the IRI-90 model (Bilitza, 1990).

In order to solve them, the objectives of the next meeting were proposed. In particular, the topic 2 indicated: “To discuss the temporal and spatial range of variability of the B parameters adopted by IRI-90 model to describe the shape of the bottomside profile” (Radicella, 1996).

Taking into account this recommendation, the objective of the present study is to analyze the latitudinal behaviour of the shape parameter B0 using data recorded at 10 stations located between -49 and +49 of modified dip (MODIP).

Data used

Table 1 shows the list of the stations used in this study with its corresponding geographic coordinates and modip.

Noon ionograms recorded during some days of representative months of winter and summer and for high and low solar activity have been used to derive the thickness parameter B0 with the POLRUNT computer code (Titheridge, 1995).

Table 2 indicates for each station the mean values of B0 for summer (S) and winter (W) and for low solar activity (LSA) and high solar activity (HSA).

Analysis of the results

The results indicate:

(1) A latitudinal trend is present in both seasons, with larger values of B0 for small MODIP values. This behaviour is observed in both hemispheres.

(2) Although some values of B0 are missing, in general, the values of B0 during HSA are greater than those observed during LSA (see Table 2).
Conclusions

From the present preliminary analysis the following conclusions can be obtained:

(1) A latitudinal variation is observed in the mean values of the thickness parameter B₀ for midday, with maximum values for small MODIP. This behaviour is observed in both hemispheres, both seasons and both solar activity conditions.

(2) A solar activity dependence is also found: B₀ values are generally greater during HSA than during LSA.

(3) It is necessary to extend this test study to a larger data base during daytime hours and to analyze the behaviour of the thickness parameter during nighttime hours.

Acknowledgements: The authors undertook the present work with the support of the ICTP. They want to thank to Prof. Titheridge for providing the POLRUNT computer code and to Prof. Reinisch for providing the data of Jicamarca, Ramey and P. Madryn.

References


### TABLE 1. Station List

<table>
<thead>
<tr>
<th>STATION</th>
<th>GEOG. LAT.</th>
<th>GEOG. LONG.(E)</th>
<th>MODIP</th>
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### TABLE 2. Mean B0 values for Winter (W) and Summer (S) during low solar activity (LSA) and high solar activity (HSA)

<table>
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<th>B0 W HSA</th>
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<td>-</td>
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<td>-</td>
<td>-</td>
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<td>Ibadan</td>
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<tr>
<td></td>
<td>65</td>
<td>-</td>
<td>102</td>
<td>146</td>
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</tbody>
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SOME COMMENTS ON CLASS A AND B PROFILES
OVER TUCUMAN AND BUENOS AIRES

M. Mosert de Gonzalez¹, R. Ezquer²,³,⁴ and R. del V. Oviedo²
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² LIIF, UNT, Tucuman, Argentina
³ CONICET, Argentina
⁴ Fac. Reg. Tucuman, UTN, Argentina

The International Reference Ionosphere 1990, IRI-90, (Bilitza, 1990) includes a new option for calculating the bottomside profile shape (Gulyaeva, 1987). This option (called Gulyaeva option or new option) has been checked by several authors (Reinisch et al., 1994; Mahajan et al., 1995; Danilov and Smirnova, 1995; Mosert de Gonzalez, 1996). The studies have shown that the said option provides satisfactory profiles at mid latitudes but it needs to be improved at low and high latitudes.

Mahajan et al. (1995) proposed two classes of electron density profiles: Class A (when 0.5NmF2 is greater than NmFl) and Class B (when 0.5NmF2 is less than NmF1).

Gulyaeva et al. (1996) showed that at low latitudes Class B occurs during the first part of the day and at mid-latitudes during most of the daytime. In such cases the IRI-90 model overestimates the thickness parameter B0 and the profile shape is distorted.

From our analysis (Figures 1 to 6), done with monthly hourly medians from two Argentine stations: TUCUMAN (26.9S; 294.6E) and BUENOS AIRES (34.6S; 301.7E) recorded during different seasonal and solar activity conditions (1968, R=107; 1976, R=13; 1982, R=114 and 1983, R=75), can be seen that:

(i) Class B cases have not been observed at TUCUMAN for all levels of solar activity. However in summer (December) during high solar activity, HSA, (1982) the values foF1 and 0.7foF2 are very closed.

(ii) Class B cases have been observed at BUENOS AIRES only in winter (July) during low solar activity, LSA, (1976). Although Gulyaeva et al. (1996), based on results for Arecibo, have introduced a modification in the latitudinal variation of the new IRI option, recent studies carried out by the IRI task group (see these proceedings) indicate that the parameters B: B0 and B1 (thickness and shape parameter) behaved diurnal, seasonal and latitudinal variation. Additional analysis using a larger database are needed in order to review the IRI formulation for both parameters and to improve the bottomside shape profile predicted by the IRI-90 model.

References


Fig. 1
Fig. 2
Fig. 4
Fig. 6
FITTING THE IRI F2-PROFILE FUNCTION TO MEASURED PROFILES

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University of Massachusetts, Center for Atmospheric Research,
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E-mail: reinisch@cae.uml.edu

1. Introduction

The IRI profile for the bottomside of the F2 layer is described by an analytic function [Bilitza, 1990]

\[ \frac{N(h)}{NmF2} = \exp(-Xm)/\cosh(X) \]  

with \[ X = \frac{hmF2 - h}{B0} \]  

The entire profile is specified by only two parameters, B0 and B1, an ingenious approach as long as equation 1 is accurately representing the vertical electron density distribution in the F2 region. The performance of the IRI profile function is discussed in Section 2 by comparing measured profiles from low latitude stations with the IRI function. The currently used parameters B0 and B1 have been described in the literature [Bilitza, 1990; Ramakrishnan and Rawer, 1972; Gulyaeva, 1987; Gulyaeva et al., 1996]. Section 3 shows how the “best” B0 and B1 parameters for a given profile can be calculated in a least-squares-fitting approach. The procedure of calculating the parameters is discussed in a companion paper [Huang and Reinisch, 1997].

2. IRI F2-profile assessment

For performance evaluation the IRI profile is best compared with monthly representative profiles (MARP), as discussed in the companion paper, rather than with individual profiles. We have made such comparisons for three Digisonde sites: Ramey (Puerto Rico), Jicamarca (Peru), and Puerto Madryn (Argentina) for summer and winter seasons [Reinisch and Huang, 1996]. The results are summarized in Table 1, where the measured F2 peak values were used for the IRI profiles. The worst deviations occur at Jicamarca. To find the causes for these deviations, the best B0 and B1 parameters were calculated from the MARP data for different seasons. Figure 1 shows the diurnal variations of the best B0 and B1 values for summer (December) and winter (August) at Jicamarca. The dashed line gives the IRI values. IRI-B0 shows very good agreement for the daytime (local noon is at 17 UT) in summer but is way off in winter. A strong diurnal variation is observed for B1 in winter, not only for Jicamarca but also for Ramey (Figure 2), and to somewhat lesser degree for Puerto Madryn in summer (Figure 3).
Table 1. IRI F2 Profile Assessment

<table>
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<th>Station</th>
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<th>Daytime</th>
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<td>Too thick</td>
<td>Too thick</td>
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<tr>
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<td>(R_{12} = 39)</td>
<td>(-15, -18)</td>
<td>(-10, -15)</td>
</tr>
<tr>
<td></td>
<td>August 1993</td>
<td>Too thin</td>
<td>Slightly thin</td>
</tr>
<tr>
<td></td>
<td>(R_{12} = 52)</td>
<td>(+15, +40)</td>
<td>(+7, +10)</td>
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<tr>
<td>Ramey, Puerto Rico</td>
<td>December 1992</td>
<td>Good</td>
<td>Slightly thin</td>
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<tr>
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<td>(R_{12} = 73)</td>
<td>(+4, +8)</td>
<td>(+9, +8)</td>
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<tr>
<td></td>
<td>June 1993</td>
<td>Too thick</td>
<td>Good</td>
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<tr>
<td></td>
<td>(R_{12} = 67)</td>
<td>(-18, -20)</td>
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<tr>
<td>Puerto Madryn, Argentina</td>
<td>December 1993</td>
<td>Too thick</td>
<td>Too thick</td>
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<td>(R_{12} = 39)</td>
<td>(-20, -25)</td>
<td>(-10, -8)</td>
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<tr>
<td></td>
<td>March 1993</td>
<td>Good</td>
<td>Slightly thick</td>
</tr>
<tr>
<td></td>
<td>(R_{12} = 67)</td>
<td></td>
<td>(-10, -10)</td>
</tr>
</tbody>
</table>

3. Fitting the IRI Function to a Measured Profile

If the electron density profile between the bottom (frequency \(f_s\)) and the peak (frequency \(f_m\)) of the F layer is given in terms of Chebyshev polynomials [Huang and Reinsch, 1996]

\[ h = h_m F^2 + \sqrt{g} \sum A_i T_i^*(g) \]  

(3)

it is advantageous to also express the IRI function in this form. Replacing (1) by

\[ \frac{f^2}{f_m^2} = \frac{2 \exp(-X B_1)}{e^X + e^{-X}} \]  

(4)

or

\[ 2 \ln \frac{f}{f_m} = \ln 2 - X B_1 - \ln (e^X + e^{-X}) \]  

(5)

and setting

\[ g = \frac{\ln (f/f_m)}{\ln (f_s/f_m)} \]  

(6)

one obtains

\[ 2g \ln \frac{f_s}{f_m} = \ln 2 - X B_1 - \ln (e^X + e^{-X}) \]  

(7)

The starting frequency \(f_s\) is either the starting frequency of the F2 trace or 0.4883\(f_m\), whichever is larger. Equation (7) shows that the function \(X\) in (2) depends on the variable \(g\) and the parameter \(B_1\) as illustrated in Figure 4. As expected, \(X\) is independent of \(B_1\) at the peak were \(X=0\), and at the point \(X=1\). The electron density for \(X=1\) is given by (1) as \(N = 0.2384 N_m\), or \(f=0.4883f_m\). Since the function \(X\) for any value of \(B_1\) is given, it can be approximated by a sum of Chebyshev polynomials with coefficients \(C_i^*\):

\[ X'(B_1) = \sqrt{g} \sum C_i(B_1) T_i^*(g) \]  

(8)
Solving (2) for \( h \) and substituting (8) yields:

\[
h_{mR} = h_m F_2 + \sqrt{g} \sum B_0 C_i (B_1 T_i^*(g))
\]

\[
= h_m F_2 + \sqrt{g} \sum D_i (B_0; B_1) T_i(g)
\]

The unknown coefficients \( D_i \) are determined by minimizing the least-squares-error:

\[
ed^2 = \int_0^1 [h - h_{mR}]^2 dg
\]

B1 is incremented from 1.0 to 5.0 in steps of 0.1 and the B1 value producing the smallest error in (10) is selected. Once B1 is known, the coefficients \( C_i \) in Equation (8) can be calculated by a least-squares fit:

\[
ed^2 = \int_0^1 [X - X]^2 dg
\]

Once \( C_i \) and \( D_i \) are determined, \( B_0 \) is obtained from \( B_0 = D_i / C_i \), or

\[
B_0 = \frac{\sum A_i S_{ij} C_j}{\sum C_i S_{ij} C_j}
\]

where

\[
S_{ij} = \int_0^1 g T_i^*(g) T_j^*(g) dg
\]

Figure 5 illustrates the improvement that can be obtained when the best \( B_0 \) and \( B_1 \) parameters are used in the IRI F2 profile function. The figure shows the ARP profile at 20 UT for August 1993 calculated from the 30 individual profiles at Jicamarca, together with the adjusted IRI 90 profile and the best IRI profile using best \( B_0 \) and \( B_1 \).

4. Conclusion

Comparison with profile data from ionosondes shows that the IRI bottomside F2-profiles can be improved by using better \( B_0 \) and \( B_1 \) parameters. The best (in a least-squares sense) parameters can be easily calculated in a numerical procedure from measured profiles presented as a sum of Chebyshev polynomials. Although the procedure is applicable to individual as well as monthly average representative profiles, it is recommended to use the latter when calculating the best \( B_0, B_1 \).

Acknowledgement: This work was in part supported US Air Force contract F19628-90-K-0029.

References


Huang, X. and B. W. Reinisch. Calculating the best parameters B0 and B1 for the IRI profile from ionograms, this issue, 1997.


Reinisch, B. W., and X. Huang, Low latitude Digisonde measurements and comparison with IRI, Adv. Space Res., Vol. 18, 6, 5-12, 1996.
Figure 1. Jicamarca. IRI (dashed) and best B0 and B1 parameters for August and December 1993.
Figure 2. Ramey. IRI (dashed) and best B0 and B1 parameters for December 1992 and June 1993.
Figure 3. Puerto Madryn. IRI (dashed) and best $B_0$ and $B_1$ parameters for March and December 1993.
Figure 4. IRI function $X$ for different parameter values $B_1$. 

\[
\frac{N_e}{N_m} = \frac{\exp(-x^{**}B_1)}{\cosh(x)} \\
x = \frac{(h_m - h)}{B_0}
\]
Figure 5. The standard and the "best" IRI profile are compared with the August 1993 ARP profile at Jicamarca for 20 UT (15 LT).
CALCULATING THE BEST PARAMETERS B0 AND B1 FOR THE IRI PROFILE FROM IONOGRAMS

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University of Massachusetts, Center for Atmospheric Research, 600 Suffolk Street, Lowell, MA 01854, USA
E-mail: reinisch@cae.uml.edu

1. Introduction

The IRI profile for the bottomside of the F2 layer is described by an analytic function [Bilitza, 1990]

\[ \frac{N(h)}{N_{mF2}} = \exp(-X^{B1})/\cosh(X) \] (1)

with

\[ X = \frac{(h_{mF2} - h)}{B0} \] (2)

where B0 is the thickness parameter that specifies the height difference between \( h_{mF2} \) and the height where \( X = 1 \), i.e., \( N/N_{mF2} = 0.2384 \) (or \( fN/f_{oF2} = 0.4883 \)), and B1 is the shape parameter determining the curvature at the peak. In the current IRI profile B1 is set equal to 3 in almost all cases. The parameter B0 is a function of solar zenith angle, season, modified dip-latitude, and sunspot number. Two slightly differing B0 values can be selected [Ramakrishnan and Rawer, 1972; Gulyaeva, 1987, Gulyaeva et al., 1996].

The B parameters were derived from ionogram data at mid latitude and are not always suitable to describe the low latitude and equatorial ionosphere. In most cases IRI underestimates the bottomside thickness [Reinisch and Huang, 1996]. We have compared the Digisonde profile data from Ramey (December 1992 and June 1993), Jicamarca (August and December 1993) and Puerto Madryn (March and December 1993) with the IRI model and found substantial differences in the bottomside thickness, even when the measured values for \( h_{mF2} \) and \( f_{oF2} \) were used for the IRI profiles. Figure 1 compares IRI profiles for Jicamarca in August 1993 with profiles derived from the Jicamarca Digisonde observations. During the nighttime (top) the IRI F2 is too thin by about 10 km, and during daytime (bottom) the IRI F2 is much too thin.

Reinisch and Huang had shown at the International Reference Ionosphere (IRI) Task Force Activity meeting at the ICTP in Trieste, November 1995, how to derive B0 and B1 from measured Digisonde profiles. The technique is described in a companion paper by Reinisch and Huang [1997] in this issue. The URSI Working Group G4 on Ionospheric Informatics has agreed to coordinate an effort to determine better B0 and B1 parameters for the IRI bottomside profiles as function of time, season and solar activity. Such effort requires participation of the ionospheric community. This technical note describes the software tools developed at the University of Massachusetts Lowell for the calculation of the “best” B0 and B1 for the IRI function (1) to represent the F2 profile. A step-by-step procedure is given starting with ionograms from Digisondes or any other ionosonde. All programs can be obtained from the
authors. All programs and data files mentioned in this technical note can be downloaded from UMLCAR's server (Table 1). For access to the server please contact the authors.

Table 1. List of files in the PUBLIC directory of FTP site ulcar.uml.edu (in alphabetical order):

<table>
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<th>Program Name</th>
<th>Description</th>
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<tbody>
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<td>BESTB0Bl</td>
<td>Calculates the IRI F2-profile parameters B0 and B1 that best represent observed electron density profiles</td>
<td>BESTB0Bl.ZIP</td>
</tr>
<tr>
<td>CALENDAR</td>
<td>Converts day-of-year to month and day-of-month (and visa versa)</td>
<td>CALENDAR.ZIP</td>
</tr>
<tr>
<td>CARP</td>
<td>Calculation of Average Representative Profiles for all data in the input file. Reads SAO 3.0 formatted data</td>
<td>CARP.ZIP</td>
</tr>
<tr>
<td>CHARS</td>
<td>Monthly characteristics reports</td>
<td>CHARS93.ZIP</td>
</tr>
<tr>
<td>F_HPDATA</td>
<td>Writes user's trace data into a standard SAO 3.0 formatted file</td>
<td>F_HPDATA.ZIP</td>
</tr>
<tr>
<td>NHPC</td>
<td>True height inversion routine. Reads an SAO 3.0 file with trace data</td>
<td>NHPC.ZIP</td>
</tr>
<tr>
<td>PREDICTF</td>
<td>URSI predictions of foE, foF1, and foF2</td>
<td>PREDICTF.ZIP</td>
</tr>
<tr>
<td>SMCR</td>
<td>Station Monthly Characteristics Reports</td>
<td>SMCR.ZIP</td>
</tr>
<tr>
<td>STCONST</td>
<td>Given geographic coordinates, calculates common constants (gyrofrequency, dip angle, etc.)</td>
<td>STCONST.ZIP</td>
</tr>
<tr>
<td>TESTDATA</td>
<td>Example data from Millstone Hill, MA</td>
<td>TESTDATA.ZIP</td>
</tr>
<tr>
<td>THTABLE</td>
<td>True height data presentation utility. Reads an SAO 3.0 file Tabulates and outputs electron density vs. Height</td>
<td>THTABLE.ZIP</td>
</tr>
</tbody>
</table>

2. Profile data

In this technical note, the profile data are assumed to be derived from ionograms recorded with a digital or analog ionosonde. The use of incoherent scatter radar (ISR) profiles is not described here, although this can easily be done. Since IRI specifies the average monthly profile we recommend that the Monthly Average Representative Profiles, MARP (see Section 3) are determined for each hour of the day for each station-month. B0 and B1 are calculated by fitting the IRI profile to the MARP profile [Reinisch and Huang, 1997].

For Digisonde stations with updated ARTIST software, the real time electron density profiles can be used directly to calculate MARP, and then B0 and B1 can be calculated with program BESTB0Bl as described in Section 4. The MARP-process automatically eliminates any wrong profiles from badly scaled ionograms. If the IRI profile is fitted to an individual ionogram profile it is advisable to check/correct the results of the ARTIST scaling with ADEP to ensure that correct \( h'(f) \) traces are used for the N(h) calculation in program NHPC [Huang and Reinisch, 1996]. Input profile data for BESTB0Bl must be provided in the SAO format [Standard ADEP Output, Camache et al., 1994]. This means that all Digisonde ARTIST data must be processed in ADEP to generate the SAO files, independent of whether the data are edited or not. The program for the Calculation of the Average Representative Profile (CARP) also requires SAO.
files for the input profile data. The true height program NHPC operating in the Digisonde’s ARTIST or in ADEP must be version 3.02 or higher. The current version 3.04 allows to select the sunspot number (SSN) when running NHPC in ADEP. Past experience has shown that the SSN is not always set correctly on all Digisonde sites. Digisonde data that used older ARTIST/NHPC versions should be run through an ADEP with NHPC version 3.04 and all profiles recalculated. Alternatively, since NHPC can operate as a stand-alone program, old SAO files can be used as input to NHPC 3.04 to calculate good profiles.

For ionograms from other ionosondes, the \( h'(f) \) data of the O-traces must be arranged in an SAO file. To facilitate this we have developed program F_HPDATA. There are two options in this program, OPTION 0 is used to enter new \( h'(f) \) data and create a simple trace data file. When running OPTION 1 the data are rearranged as a SAO file. It is convenient to put each month of data from a given station into one file.

If \( h'(f) \) data files are already existing, the user must write a small program that transforms the files to the trace data file format used in F_HPDATA. Looking into the data file created by F_HPDATA OPTION 0 gives the required data format. Then F_HPDATA OPTION 1 generates the SAO file that can be read by CARP and BESTB0B1. The output of CARP is also an ASO file that can be read by BESTB0B1.

The SAO file contains electron density profile information in terms of Chebyshev coefficients and ionospheric characteristics [Huang and Reinisch, 1996]. The program THTABLE, using SAO files as input, tabulates the altitude (in km) versus plasma frequency (in MHz) and density (in electrons/cm\(^3\)).

3. **Average representative profile**

The IRI model describes the average status of the ionosphere at any location for any time and solar activity level. Meaningful comparison of IRI predictions with measured profiles is best done with the MARP profile, as mentioned above, derived from the measured set of individual profiles for a given month and hour. Reinisch and Huang [1996] have described the program CARP that calculates MARP.

When opening CARP the user can specify two program parameters. One selects the time window (in minutes) around the specified MARP time. For example, if the MARP time is 0900 UT and the time window is selected as 7 (minutes), all ionograms that started between 0853 UT and 0907 UT will be included in the calculation of MARP. A second parameter specifies which percentage of the individual profiles is to be excluded from the ensemble average. Typically the user should select 25, which means that the 25% of the individual profiles that deviate most from the average are excluded from the calculation of MARP.

The coefficients and characteristics of the individual and the MARP profiles are recorded in an output file, which should have the name extension .ARP. The MARP profile is identified by a month number above 1000. For example, the MARP for 09 UT in December 1988 is identified by 88101209 SAO.

4. **Calculation of the best B0 and B1**

The F2 layer MARP is given in the form

\[
h_{ARP} = hmF2 + \sqrt{g} \sum A_{ARP} T_1'(g)
\]  

(3)
and the IRI profile function (1) can also be expanded in terms of the shifted Chebyshev polynomials [Reinisch and Huang, 1997]

\[ h_{IRI} = h_{mF2} + B_0 \sqrt{g} \sum A_{IRI}(B1) T_i^*(g) \]  \hspace{1cm} (4)

where

\[ g = \ln\left(\frac{f}{f_{oF2}}\right) / \ln\left(\frac{f_s}{f_{oF2}}\right) \] \hspace{1cm} (5)

and

\[ f_s = \left\{ \begin{array}{ll} 0.4883 \times f_{mF2} \\ f_{sF2} \end{array} \right\} \hspace{1cm} \text{whichever is larger; } f_{sF2} \text{ is the starting frequency of the } F2 \text{ trace.} \]

For the expansion (4) the coefficients \( A_{IRI}(B1) \) have been tabulated for \( B1 = 1.0, 1.1, 1.2, \ldots, 5.0 \). The "best" \( B0 \) and \( B1 \) are found by minimizing the integral

\[ \varepsilon^2 = \int_0^1 (h_{IRI} - h_{ARP})^2 dg \] \hspace{1cm} (7)

This calculation is done with the program BESTB0B1. When the ARP files for all hours of the day for a month are used as input, the best fitted \( B0 \) and \( B1 \) parameters are tabulated as output.

5. Examples

Along with the available programs, some test data and the data files created by these programs are also available on the UMLCAR server. It is suggested to carry out some trial runs with the test data supplied before new data are processed.

(1) Exercise with F\_HPDATA.

The scaled data for two ionograms from Millstone Hill for 1 December 1988, 0059UT and 1259UT, are listed in a text file SCALED.TXT. Use the information in it and use OPTION 0 in F\_HPDATA to create a data file SCALED.DAT; then use OPTION 1 to transform SCALED.DAT into an SAO file SCALED.SAO. Inspection of the structure of the data file SCALED.DAT provides the information required to write programs for the transformation of available trace data files to the SCALED.DAT format.

(2) Exercise with NHPC 3.04.

Invoke NHPC using SCALED.SAO as input, and name the output file SCALED.NEW. Update the sunspot number to \( R12 = 138 \) and execute. Check if the file you obtained is the same as SCALED.NEW provided.

(3) Exercise with THTABLE.

Using SCALED.NEW as input and selecting 1 as the application option, 50 as the frequency step option and 2 as the format option, THTABLE will create a file which should be the same as SCALED.TAB in the provided package. With this profile tabulation the two profiles can
easily be plotted as shown in Figure 2.

(4) Exercise with CARP.

The SAO file MH8812.SAO is provided for testing the program CARP. This data file contains the trace data and the profile parameters of all the ionograms from Millstone Hill for 1988 December for 09 UT and 21 UT. Use CARP to create the ARP files MH881209.ARP and MH881221.ARP with the selection: HALF WINDOW SIZE = 3 min. and EXCLUSION PERCENTAGE = 25%. The individual profiles and the MARP are shown in Figure 3.

(5) Exercise with BESTB0B1.

With ARP files MH881209.ARP and MH881221.ARP as input, use the program BESTB0B1 to calculate the best B0 and B1, and store them in file MH8812BB.DAT. Figure 4 compares the shape of the IRI F2 profile, using the best B0 and B1, with the respective MARPs. For these two examples fs=0.4883foF2 (see equation 6). Notice that the valley shape used in NHPC version 3.04 [Huang and Reinisch, 1996] is based on Mahajan’s et al. [1995] analysis of Arecibo ISR profiles.

References


Reinisch, B.W., and X. Huang, Low latitude Digisonde measurements and comparison with IRI, Adv. Space Res., Vol. 18. 6. 5-12, 1996.

Reinisch, B.W., and X. Huang, Fitting the IRI F-2 profile function to measured profiles, this issue, 1997.
Figure 1. Differences between the IRI monthly median profile and the measured profiles for August 1993 at Jicamarca, nighttime (top) and daytime (bottom). The Digisonde hourly MARP profiles are used for this plot.
Figure 2. Typical output of program THTABLE which calculates plasma frequency as function of height from Chebyshev polynomial coefficients. This example gives the MARP profiles for December 1988 at Millstone Hill for 0059 UT and 1259 UT, i.e. 1959 and 0759 LT.
Figure 3 Typical output of program CARP. The heavy dots represent the MARP profile, the light dots the hourly measured profiles. Millstone Hill profiles at nighttime (top) and daytime (bottom).
Figure 4  The IRI F2-profiles with the best B0, B1 (dashed line) are compared with the corresponding MARP profiles (solid line).
THEORETICAL ELECTRON DENSITY PROFILES
AND CORRESPONDING PHYSICAL CONDITIONS:
FITTED B0 AND B1, TOPSIDE STRUCTURE

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Abstract: Using a theoretical model for mid-latitude ionospheric structure, this paper gives
the case study results of the fitted B0 and B1 parameters by using IRI bottomside profile
functions, and then presents model results for the topside behaviour of electron density profile
as well as that of upper base-point. Physical conditions in connection with variations of the
upper and lower base points are discussed briefly.

1. Some features of the theoretical model

A one-dimensional and time-dependent theoretical ionospheric model is used in this study.
The basic scheme of the model was present in the paper of Zhang et al. (1993). Further
improvements were made afterwards and the detailed description of the model can be found
(Zhang and Huang, 1995).

It must be noted that, two options for the top boundary determination are provided in
numerical solving the control equations in the model: using IRI model values at 500 km bound-
dary; using boundary values that can result in good agreement of the maximum electron density
between the simulation and the observation. One should be aware of the fact that the discrep-
ancy between the observational behaviour and the modelled one could be originated from a few
physical reasons, such as the background atmospheric composition, temperature and winds, the
photochemical quantities and so on, and of course from the topside treatment of the model.

2. Results and discussions about the fitted B0 and B1: A case study

The B0 and B1 parameters are used in the IRI (Bilitza, 1990) to represent the bottomside
electron density profile, given by

\[ N(h) = \frac{N_m F_2 \exp(-x B_1)}{\cosh(x)} \]

and

\[ x = \frac{(h_m F_2 - h)}{B_0} \]

Following the suggested procedure in 1995 IRI Task Force Activity (Conclusions and Action
Items. 1996), the B0 and B1 can be obtained by fitting the electron density profiles (observed
or simulated) using the above formulas.

We have chosen the case of PT Madryn (42.7°S, 294.7°E) in 1993 for this study, because the
experimental data (in March and December) were readily available for comparison (Reinisch
and Huang, 1997). The topside boundary values are taken from the IRI predictions in this
study.
The modelling results for BO and Bl are shown in Figures 1 and 2. There are larger day-night variation of BO in December than in March, and these variations are very similar to the experimental ones both in the order of magnitude and in the variation trend, implying that theoretical profiles for the cases studied here may have good agreement with the observations. The Bl values are found to be almost constant during the night, while they are smaller in December than in March, in agreement with the observational trend of variation.

3. Topside structure and related physical conditions

In order to compare the simulated topside profile with the IRI ones, we use the topside boundary values that can reproduce the observed maximum electron density. Calculations are carried out for Millstone Hill (42.6°N, 288.5°E) in January and July 1982.

Figure 3(a, b) shows the comparison of the profiles obtained with the model and with IRI for different hours of the day. The IRI profiles have been adjusted to the F2-peak given by the theoretical model. It is found that the IRI at topside overestimates generally the electron density. The relative discrepancy seems larger for the nighttime than for the daytime.

The height gradient of the electron density is shown in Figure 4. As it happens at the bottomside ionosphere, the gradient peak occurs at topside also. This gradient peak corresponds to the upper base point. As demonstrated in Figure 5 for diurnal variations of hmF2, lower and upper base points, the two base point heights are almost symmetric to the height of the F2-peak hmF2, differing from hmF2 by about 65 km almost constantly, slightly larger by night.

Looking at the photochemical status of O+ represented by the term of q (production) \(-B(O+ \text{ loss rate}) \Sigma N(O+ \text{ density})\) as shown in Figure 6, one can find that the largest departure from the photochemical equilibrium appears near the base points at both bottomside and topside ionosphere. Thus the dynamic transport has an important consequence for the electron density behaviour at the two heights. An increasing variability of the O+ transport velocity can be seen in Figure 7. Variations of O+ drifts induced by diffusion, in addition to winds, could have a significant contribution to the increasing variability.

Acknowledgements: We are using Prof. J. Titheridge’s FORTRAN subroutine to fit our theoretical model profiles to the IRI profile functions in order to obtain BO and Bl values.

References


Reinisch B. W. and X. Huang (1997), this proceeding


PT Madryn (42.7°S, 294.7°E), obtained from Theoretical Model

December 1993
March 1993

Fig. 1 Diurnal variations of the fitted $B_0$ for PT Madryn (42.7°S, 294.7°E) in March and December 1993.
Fig.2 Diurnal variations of the fitted $B_1$ for PT Madryn ($42.7^\circ S, 294.7^\circ E$) in March and December 1993.
Millstone Hill (42.6N, 288.5E), January 1982

Fig. 3a
Fig. 3b

Fig. 3 Comparisons of the electron density profiles obtained with the model and with IRI for Millstone Hill (42.5°N, 288.5°E) in (a) January and (b) July 1982.
Fig. 4 The height gradients of the electron density derived from the model for Millstone Hill in January 1982.
Fig. 5 Diurnal variations of the height of the F2-peak hmF2, the lower and the upper base points for Millstone Hill (42.6°N, 288.5°E) in January 1982.
Fig. 6 The photochemical status of O+ represented by the height profile of the term of $q$ (production) - $B$ (O+ loss rate) $\Sigma N$ (O+ density) for Millstone Hill ($42.6^\circ N, 288.5^\circ E$) in January 1982.
Fig. 7 Height profiles of the O+ transport velocity induced by the diffusion and the winds for Millstone Hill (42.6°N, 288.5°E) in January 1982.
STUDY OF THE VARIATION OF THE IONOSPHERE IN HIGH LATITUDE USING EISCAT DATA

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Abstract: The EISCAT radar data recorded in Troms, Norway for geomagnetic quiet days are used to study the variability of electron density at fixed heights starting from the bottomside to the topside ionosphere. The results obtained show that under quiet conditions: (1) In the ionosphere there exists the so-called hysteresis phenomenon for the upper ionosphere \( h > 200\text{km} \), while this phenomenon doesn’t exist in the lower ionosphere; (2) The larger absolute time variability of the electron density is mainly localized in a region between 200km to 450-500km; (3) The electron density at fixed heights seems more variable in the postnoon than in the forenoon time.

Introduction

The interaction of the earth’s magnetic field, the geomagnetic field, and the solar wind, a high speed magnetic plasma, results in the formation of the magnetosphere. In the magnetosphere many complex phenomena and processes such as magnetostorms and substorms occur. Due to the strong coupling between the magnetosphere and the ionosphere, the high latitude earth’s ionosphere is dramatically different from the ionosphere in the low and middle latitudes. The observations from the incoherent scatter radar at high latitudes provide a good way to study the high-latitude ionosphere. In this paper, the EISCAT electron density height profile data is used to study the variability of the electron density at fixed heights from bottomside and topside for the high latitude ionosphere. EISCAT is an acronym of European Incoherent Scatterer. It is an international facility supported by the Federal Republic of Germany, Finland, France, Japan, Norway, Sweden and the United Kingdom.

Data used

The data used for the present study is the electron density height profile from the EISCAT radar established in Tromsø (69.67°N, 18.95°E), Norway. This location is under the area of the auroral belt from early evening until early the next morning. The data chosen for the present study is from the 3 days of 17-19 March 1988, which are quite quiet according to the Ap indices \( \text{Ap}=9, 7, 4 \) respectively.

Results

Figures 1(a)-1(c) are samples of the plots of the electron density at fixed heights versus the solar zenith angle starting from the bottomside to the topside ionosphere for the three days of 17-19 March, 1988. It is found that for the heights greater than about 190km, which
more or less corresponds to the F1 layer height, the lower part of the curve is corresponding to the forenoon time and the upper part the postnoon time. In other words, the curve shows a clockwise circle with increasing local time. This is the so called hysteresis phenomenon (Lerner and Gesrge, 1993), i.e., the electron density at fixed heights in the afternoon is delayed relative to that in the forenoon time. The same hysteresis phenomenon is also seen in the figures 2(a)-2(c) which are the plots of the F2-peak electron density versus the solar zenith angle, while this phenomenon does not exist for the heights below 190km.

Figure 1(a). Ne(h) versus Solar Zenith Angle (17/03/1988)
From Figures 1(a)-1(c) and Figures 2(a)-2(c), it can be seen that the absolute variability of the electron density is small for the low \((h < 200\text{km})\) and high \((> 450 - 500\text{km})\) altitudes. This means that the large variations of the ionosphere are localized in a quite limited height region, which implies that the changes in TEC should be mainly due to the changes of the electron density between the heights of about 200km and 500km.

The results also show that in the F2 region, the ionosphere is more dynamic in the afternoon time than in the forenoon time. That is, the time variation of the electron density at fixed heights is much larger in the afternoon than in the forenoon time when the time change of the electron density at fixed heights is relatively smooth. This can be seen more clearly in the figure 3, where the plots of electron density at fixed heights, after filtering with a 2-hour moving average, are shown versus the universal time.
Analysis

Hysteresis phenomenon:
The results obtained above show that the so-called hysteresis phenomenon is observed in the high altitude ionosphere (h > 200 km). That is, the electron density at fixed heights and the
Figure 3. Residual of Ne(h) after filtering a 2-hour moving average (19/03/1988)
maximum electron density at F2-Peak height in the afternoon is delayed relative to that in the
forenoon time. According to Rishbeth and Garriott (1969), the ionosphere tends to show a
"sluggishness" in the postnoon time. The time delay is given by
\[ \Delta t = \frac{1}{\beta} \]
for the region near F2-peak, where \( \beta \) is the loss coefficient and
\[ \beta = k_1 [O_2] + k_2 [N_2], \]
where \( k_1 \) and \( k_2 \) are the chemical reaction coefficients, \([O_2]\) and \([N_2]\) the density of \( O_2 \) and \( N_2 \).

We take the values of \( k_1 \) and \( k_2 \) from (St. Maurice and Torr, 1978) and use the values
of \([O_2]\) and \([N_2]\) from the MSIS90 model (Hedin, 1987; Hedin et al., 1991) to estimate \( \Delta t \).

The results are shown in Figure 4. It can be seen that near 300km, the time delay is about
2.5 hours. This should explain part of the hysteresis phenomena shown in the results. Of
course the dynamical process (e.g., the transportation by wind, electric field, and the auroral
precipitation etc.) in the upper ionosphere is important in determining the behavior of the
ionosphere, especially when the high latitude regions are concerned.

Waves:
FFT analysis is made on the residual electron density at fixed heights after filtering a 2-hour
moving average. Some samples of the results are shown in figure 5. It can be clearly seen from
the figure that in the low and high altitudes, the wave spectrum do not show any real activity.
whereas at heights near F2 peak the harmonic which corresponds to a
FFT of \[ N(h) - 2Hr_{smoothed} \] (19/03/1988 69.67N, 18.97E)

146.5km (First 144 points)
Last 144 points

190.5km (First 144 points)
Last 144 points

234.5km (First 144 points)
Last 144 points

278.5km (First 144 points)
Last 144 points

322.6km (First 144 points)
Last 144 points

366.6km (First 144 points)
Last 144 points

Harmonic Number \( n \) (\( T=144/n \times 5 \text{ min} \))
Figure 5. FFT results of the residual of Ne(h) after filtering a 2-hour moving average.
A period of 72 minutes is seen clearly during all day. For the postnoon data (the "last 144 points" result in the plots), another well defined harmonic with a period of 3 hour is seen. The results also show the presence of other harmonics with smaller amplitudes and periods between 72 minutes and 20 minutes particularly in the afternoon, showing the ionosphere is more dynamic in the afternoon than in the forenoon time. These results indicate the presence of a height region where gravity waves are evidenced.

Conclusion

The present study of the variation of the ionosphere in high latitude under quiet condition shows that:

1. Due to the "sluggishness" of the ionosphere, the electron density at fixed heights in the afternoon is delayed by some time relative to that in the forenoon time for the heights above ~ 200km, whereas this phenomenon does not exist for the lower ionosphere.

2. A large absolute variability of the electron density is mainly localized in a region between 200km and 450-500km heights, implying that under quiet condition the change of TEC should be mainly due to the change of the electron density in that region.

3. The electron density at fixed heights is more variable in the afternoon than in the forenoon time when the electron density at fixed heights changes relatively smoothly with time.

4. The presence of waves with periods of 20-180 minutes are observed mainly in the region close to the F2 region peak indicating a preferred height region for the evidence of gravity wave activity.

References


A COMPUTER PROGRAM TO CALCULATE TEC, TIME DELAY AND RANGE ERROR BETWEEN TWO POINTS IN SPACE

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Given the geodetic coordinates of two points in space - two satellites or a point on the earth surface and a satellite -, the frequency of the radio wave and the IRI-90 model (ir1l1.exe) the program is able to calculate: distance between the two points, the Total Electron Content between the two points, the time delay and the range error.

The geoid model used is the Revolution Ellipsoid Krasowsky model. The distance between the two points is divided in n (variable) equally spaced intervals that define n+1 points with known geodesic coordinates. These coordinates are converted into geographic coordinates to be used as input parameter for the ir1l1.exe program together with the altitude of the point into consideration.

Tables 1 and 2 give the results obtained for different geographical positions of the pair of points and a radio wave frequency of 1616 Mhz. The columns in the tables indicate: geographical latitude, geographical longitude, altitude, date (month and day), solar activity, universal time, distance, calculated total electron content between the two points in space, calculated time delay and calculated range error. The distance steps in the slant direction is assumed as 20 km in the calculations of the table. For all the cases high solar activity is assumed.

Table 2 (Lat: -10 and -35, Lon: 285 and 300, Alt: 700) shows clearly the effect of the crest of ionization of the southern part of the equatorial anomaly in the F region of the ionosphere in April, a month of high development of the anomaly. For these conditions total electron content can reach values above 400 TEC units and range errors above 60 m. The program can be easily adapted to other electron density profile models.
TEC, Time Delay and Range Error with IRI-90 (f = 1616 MHz, Δs = 20 Km).

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<th>MD</th>
<th>Rz</th>
<th>TU</th>
<th>Dis (Km)</th>
<th>TECSS (U.Tec)</th>
<th>TD 10^-9 (sec)</th>
<th>RE (m)</th>
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Table 1
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