

LOW-LATITUDE MODEL ELECTRON DENSITY PROFILES USING THE IRI AND CCIR MODELS

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Abstract. The study of low-latitude electron density profiles has been carried out on a semi-empirical basis with the International Reference Ionosphere (IRI-90) and the CCIR models. Electron density profiles are computed using the median values of ionospheric data routinely scaled from ionograms at Ibadan (7.4°N, 3.9°E) and Tsumeb (19.2°S, 17.7°E) for different scalar activities and times of the day. The results of this study revealed the possibility of using analytic semi-empirical models to produce representative electron density profiles of the equatorial and low-latitude ionospheres. The importance of incorporating results of studies on the equatorial anomaly into the IRI-90 model and further comparisons with additional sets of electron density profiles under different solar-geophysical conditions are highlighted. The need for additional ionosonde stations in the African sector in order to incorporate the results of studies on equatorial anomaly into the models is emphasized.

1. INTRODUCTION

Ionosondes are employed as probes of the E- and F- regions of the ionosphere. Unfortunately, they do not directly give the distribution of electron concentration as a function of the virtual height of reflection of the probing waves [1]. However, true height data are needed for morphological studies and for investigation of the radio propagation phenomena.

A number of procedures have been developed to convert virtual to true height profiles but they are complicated, time consuming and liable to errors [1]. It would therefore be useful if an idealized model could be developed approximating to the real ionosphere with its parameters readily determined from the internationally agreed ionospheric characteristics which are regularly measured each hour of the day at many stations throughout the world [1,2].

The availability of representative empirical model electron density profiles in the ionosphere is important in the development of practical schemes for providing reliable HF radio propagation predictions [3]. Usually, separate models are constructed for the D- region where dynamic effects are neglected and E- and F- regions where dynamics play important role.

At present, the most widely used empirical model in terms of standard ionosphere characteristics and parameters is the multi-segment model known as the International Reference Ionosphere- designated as IRI-90 in its present form [4]. IRI was established in a worldwide collaboration in the late sixties as a joint project of the International Union of Radio Science (URSI) sub-committee on Space Research (COSPAR) Study Group C.

The CCIR incorporated a complete computerized set of monthly average ionization maps into the IRI model meant to be used in all cases where there is dearth of ionosondes. For any point on the earth, the CCIR code gives as a function of hour, monthly averages of the peak

density N_mF2 and $M(3000)F2$ (an ionospheric parameter used in propagation applications).

There are three basic criteria that must be taken into account in order to ascertain the success of an ionospheric model [3]. They are: (1) how well the model matches the range of electron density profiles; (2) the ease of obtaining the external data required to specify the profiles and (3) the simplicity of the mathematical expressions used to derive the profile.

Consequently, comparison of IRI electron density profiles computed using the observed monthly median values of f_oF2 and h_mF2 with the CCIR predictions are necessary to determine the success of the model. The comparison would provide information on the correction needed to improve the CCIR predictions and electron density profile estimates through the IRI model. Hence this paper discusses these comparisons for a typical equatorial station (Ibadan) and a low-latitude station (Tsumeb) and offers some explanations for the results.

2. DATA AND ANALYSIS

The primary data used for the study were the published median values of f_oF2 and h_mF2 measured at Ibadan (7.4°N, 3.9°E) between December 1959 and March 1975 and Tsumeb (19.2°S, 17.7°E) between August 1964 and March 1973.

The smoothed monthly-observed Zurich relative sunspot number (R_{Z12}) compiled from April 1954 to December 1976 was used in the study. Since the 10.7cm solar flux ($F_{10.7}$) and sunspot number are quite correlated, $F_{10.7}$ was obtained by means of an empirical relation given by

$$COV = 63.75 + R(0.728 + 0.00089R) \quad (1)$$

where $R_{Z12} = R$ and $F_{10.7} = COV$ such that

$$R_{Z12} = 150 \text{ for } R > 150$$

$$\text{and } F_{10.7} = 193 \text{ for } COV > 193$$

RZ_{12} is the 12-months-running mean of solar sunspot number.

Typically, data recorded in the months of January or February, June and September for years with low ($F_{10.7} < 80.0$), moderate ($100.0 < F_{10.7} < 130.0$) and high ($F_{10.7} > 150.0$) solar activities were used in the analysis.

For Ibadan, consideration was given to data of the median values of parameters f_0F_2 and h_mF_2 obtained at LT: 0.00 hr (LT = Local Time) and LT: 12:00hr for the chosen months. Furthermore, due to missing ionogram data for Tsumeb, mostly during the night-time and early hours of the day, data recorded between LT: 9:00 and LT: 15:00hr were used to obtain the required electron density profiles.

The CCIR-67 predictions for f_0F_2 and $M(3000)F_2$ were also used in this study. The values of h_mF_2 are determined from $M(3000)F_2$ by means of empirical relations given below.

$$h_mF_2 = \frac{1490}{(M(3000)F_2 + \Delta M)} - 176 \quad (2)$$

with the correction factor

$$\Delta M = f_1 f_2 / f_0 F_2 / (f_0 E - f_3) + f_4 \quad (3)$$

and the solar activity functions,

$$f_1 = 0.00232RZ_{12} + 0.222$$

$$f_2 = 1 - RZ_{12} / 150 \exp(-(\Psi/40)^2) \quad (4)$$

$$f_3 = 1.2 - 0.0116 \exp(RZ_{12} / 41.84)$$

$$f_4 = 0.096(RZ_{12} - 25) / 150$$

Ψ is the magnetic dip latitude where $\tan \Psi = \frac{1}{2}(\tan \varphi)$ and φ is the magnetic inclination of the Earth's magnetic field at 300 km altitude.

3. RESULTS

Comparisons of the IRI electron density (NE/cm^3) profiles for Ibadan for the three chosen months revealed that F2-layer peak density is lowest in the month of June for the three different solar activities during night-time (Fig.1). This peculiarity is quite in agreement with observed profiles for Tsumeb at all solar activities (Fig.2) and it could therefore be inferred to be typical of low-latitude F2-layer during June solstices. The result is that the peculiarity observed is due to the seasonal variations of the ionosphere at low latitudes.

In addition, there are marked differences between the F2 peak and the E-region peak densities and their height regimes for all the three solar activities during daytime (Figs. 2 and 3). In general, the F2 peak densities are higher in magnitude and greater than those occurring in the E-region. This result confirmed the close inter-relationship between the peak heights and the peak electron densities at each of the regions or layers of the ionosphere [4,5]. Typically, the E-region is

about 20km thick while the topside is about 500km and above to the cut-off heights.

During the daytime, the F1 layer appeared in most of the profiles as small gradient discontinuities. This result is a reflection of the cusp-like trace structures of F1 layer normally observed on ionograms during daytime at low-latitudes [6]. During the night-time the F1 and E layers are observed to be absent in the electron density profiles. The absence of E and F1 layers during nighttime is a characteristic feature of the diurnal variation of low latitude ionosphere [5].

Also, the F2 peak electron densities are observed to increase consistently for all the months during low, moderate and high solar activities. This result confirms the solar activity dependence of the peak electron densities at these low latitude ionospheric stations.

The electron density profiles obtained from the IRI and CCIR models for Ibadan were compared in order to see how the two procedures differ from each other. The study covers the months of February, June and September for low, moderate and high solar activities during night-time and noon-time respectively.

The comparisons show that the best agreement between the IRI profiles and the CCIR predicted profiles was found for February 1964 (Fig.4). It is worth noting that the agreement of all comparisons for the IRI and CCIR electron density profiles during night-time and noon-time was found for the month of September.

The divergence of the profiles for the month of June was found to be too large most especially during night-time for all the three solar activities. However, the agreement for the topside profiles during nighttime and noontime respectively for the month of June 1968 was found to be good (Fig.5).

In general, both profiles represent the F2 peak region satisfactorily but show significant differences mostly at greater heights. In most cases, the CCIR profiles show too large electron densities near the F2 peak and at topside during daytime. However, better agreements were generally observed during daytime at the bottomside of the F2 layers. Also, the agreement at night-time was found to be better than at noon-time for all the solar activities.

4. DISCUSSION AND CONCLUSIONS

In this study, the electron density profiles derived from ionospheric data at Ibadan and Tsumeb with the IRI-90 model are compared with those obtained from the CCIR predictions using a data set selected in such a way that diurnal, seasonal, and solar activity conditions are adequately represented.

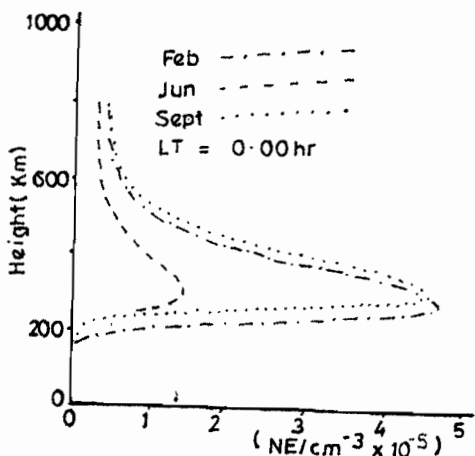


Fig.1: Electron density profiles for Ibadan (1964)

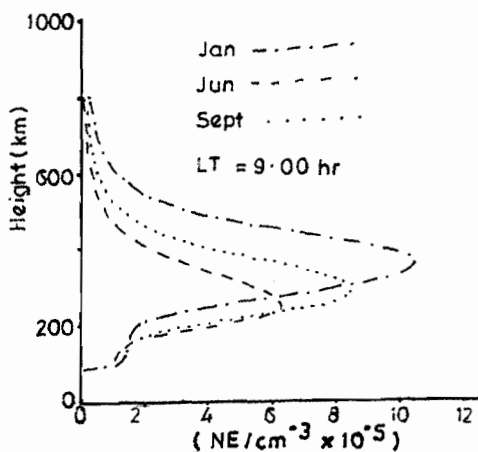


Fig.2: Electron density profiles for Tsumeb (1971)

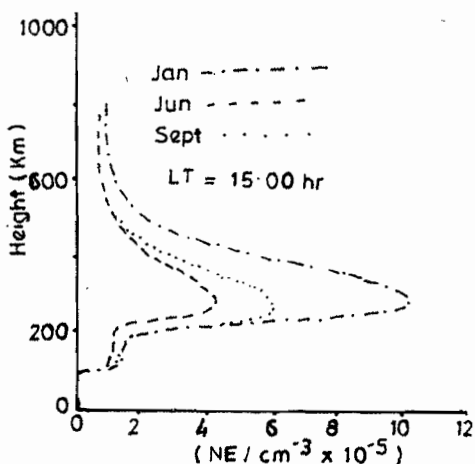


Fig.3: Electron density profiles for Tsumeb (1965)

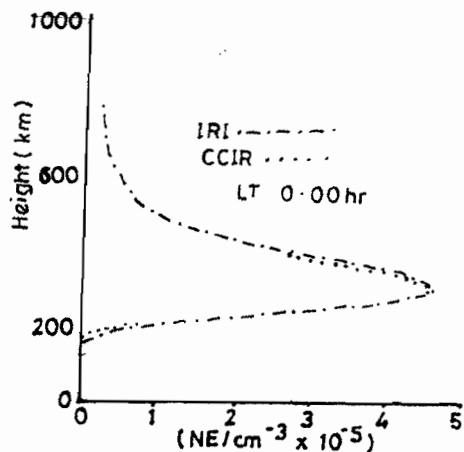


Fig.4: Comparison of IRI and CCIR electron density profiles for Ibadan (1964)

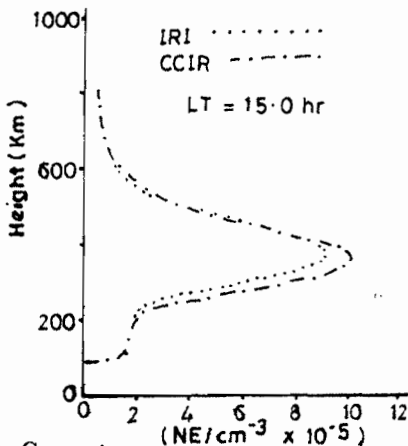


Fig.5: Comparison of IRI and CCIR electron density profiles for Ibadan (1968)

Although, the IRI-90 model was able to reproduce the features of the diurnal and seasonal variations of the electron density profiles for both data inputs, marked differences were observed in their respective representations. The reasons for these differences are indeed not far fetched. IRI-90

model in its present form excludes disturbed conditions [4].

Furthermore, IRI-90 model electron density representation make use of analytic description comprising linear parameters which could be used to satisfy certain constraints such as the E- and F- regions peak densities [7,8]. In addition, the model

comprises of some non-linear parameters, which are geometric in nature and could be interpreted as the E- and F- regions transition heights and thickness [8].

In general, many phenomena observed in the equatorial and low-latitude E- and F- regions morphology have been explained in terms of the variations in the equatorial electrojet and the $E \times B$ drifts [9,10]. Also, the month-month variation in the E peak at low latitudes has been explained in terms of the geomagnetic control of the ionospheric E- region [11]. Also, wind systems have been considered to be one of the probable factors that influence ionospheric parameters in these regions [11].

Therefore, it is important that the results of studies on equatorial anomaly be incorporated into the IRI model. For example, the 'noon bite-out' (a prenoon and postnoon peak with a minimum), during daytime and after sunset decay which is continuous at night-time has been reported as some of the general features of equatorial F2 layer peak density at Ibadan [11,10].

It is also necessary that further studies be carried out on the dependence of N_mF2 and h_mF2 on the earth's magnetic dip angle, season and solar cycle. Example of further work would be an extension of this study to cover more ionospheric stations in the African sector and derive a greater number of electron density profiles under different solar and other geophysical conditions most especially during geomagnetically quiet and disturbed conditions.

In conclusion, it is expected that, with time, the IRI topside model would be considerably improved and the results of ionospheric drifts at low latitudes for diurnal, seasonal, and solar cycle variations would be updated and incorporated into the comprehensive IRI model. Such additional information and data would enhance the prediction and planning of the operational parameters for HF circuits in regions where there are dearths of ionosonde data.

Furthermore, if the peak values of the CCIR and IRI models are updated to higher solar activity above the present IRI validity level, a more profound improvement in the profile shape close to the peak would be achieved.

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