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Comparative study of electron density from incoherent scatter measurements at Arecibo with the IRI-95 model during solar maximum

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Abstract. Arecibo (18.4 N, 66.7 W) incoherent scatter (IS) observations of electron density N(h) are compared with the International Reference Ionosphere (IRI-95) during midday (10–14 h), for summer, winter and equinox, at solar maximum (1981). The N(h) profiles below the F2 peak, are normalized to the peak density NmF2 of the F region and are then compared with the IRI-95 model using both the standard B0 (old option) and the Gulyaeva-B0 thickness (new option). The thickness parameter B0 is obtained from the observed electron density profiles and compared with those obtained from the IRI-95 using both the options. Our studies indicate that during summer and equinox, in general, the values of electron densities at all the heights given by the IRI model (new option), are generally larger than those obtained from IS measurements. However, during winter, the agreement between the IRI and the observed values is reasonably good in the bottom part of the F2 layer but IRI underestimates electron density at F1 layer heights. The IRI profiles obtained with the old option gives much better results than those generated with the new option. Compared to the observations, the IRI profiles are found to be much thicker using Gulyaeva-B0 option than using standard B0.

Key words: Ionosphere (modeling and forecasting)

1 Introduction

The International Reference Ionosphere (IRI) (Bilitza, 1990) is a global empirical model which specifies the monthly average of the electron density, electron temperature, ion temperature and ion composition from 80 to 1000 km. Over the years, testing and modification of IRI has continued with extensive participation by international research community and it has led to improvements through several versions (IRI-80, IRI-86, IRI-90, IRI-95). The electron density distribution in the IRI model (Bilitza, 1990) below the F2 peak is described by an analytic function parameterized in terms of a thickness parameter. (Ramakrishnan and Rawer, 1972). It is defined as

$$N(h) = NmF2 \times \exp(-x^{B1})/\cos h(x) \quad (1)$$

$$\text{with } x = (hmF2 - h)/B0 \quad (2)$$

B0 is the bottomside thickness parameter and B1 determines the profile shape. The IRI model provides two options for B0, for describing the bottomside electron density distribution below the F2 peak. The old option makes use of table of values of B0 deduced from profile inversion of ionograms from midlatitude stations (Bilitza, 1990). The new option (recommended option), which is considered the better choice especially at low latitude (Bilitza, 1990), uses Gulyaeva's (1987) model for B0 based on the half density height (h0.5), (the height below the F2 peak where the density falls off to half the peak value: N(h0.5) = 0.5 NmF2). The new B0 is given as

$$B0 = (hmF2 - h0.5)/C \quad (3)$$

where C is a function of B1.

Since the IRI assumes a constant value of 3 most of the time for B1, the parameter C correspondingly is assigned a value of 0.75556 (Bilitza, 1990). These formulations are based upon data mostly from midlatitude stations, and need to be validated against measurements at low latitudes.

In an earlier study observed N(h) profiles derived from ionograms at low latitudes, below the F2 peak, during solar minimum and maximum periods, have been compared with those produced from the IRI-90 model (de Gonzalez, 1996; Aggarwal *et al.*, 1996). Their studies have shown that the IRI model overestimates the

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bottomside thickness parameter during summer and equinox for both the solar minimum and maximum periods, while for winter, the IRI model shows a better agreement with the observations. Using IS radar measurements at Arecibo, during solar minimum period (1974–1977), similar results had been found by Pandey and Sethi (1996) using the new option of the IRI-90 model. In the present work we investigate how well the midday electron density distribution below the F2 peak, at Arecibo, for the period 1981, agrees with those generated by IRI-95 model.

2 Experimental data

The data employed in this study are the high-resolution electron density measurements taken from NCAR (National Center for Atmospheric Research), Incoherent Scatter Data Base, Boulder, Colorado. The effective height resolution is 600 m by using 4 µs pulse length. The power profile is converted into electron density profile by using simultaneously measured electron to ion temperature ratio profile. The profile is finally calibrated by reading NmF2 from an on-site ionosonde. We have employed the data for the period 1981, containing some 116 bottomside N(h) profiles below the F2 peak down to 100 km, within the period 1000 to 1400 h local time, with monthly averages of F10.7 varying between 174 and 224 flux units.

3 Analysis and results

In our analysis, we have considered the data restricted to quiet days with magnetic index A_p less than 25. We have grouped the midday N(h) profiles into three seasons: summer (35 profiles), winter (48 profiles) and equinox (33 profiles). The IRI95 midday normalized profiles are generated using both the old and new options for the bottomside thickness parameter offered in the IRI for (RZ12 = 140, Day: June 15, January 15, March 15 and LT: 12 h). Figure 1a–c shows the mass plots of N/NmF2 against (h − hmF2) for summer, winter and equinox along with the IRI normalized profiles using both the old and new options. It can be noted that for the cases during winter months, the IRI shows reasonable good agreement with the experimental data for both the options in the bottom part of the F2 layer but underestimates electron density values in the intermediate region at F1 heights. However, during summer and equinox, the IRI model profiles generated with the new option, in general overestimate electron densities at all the heights below the F2 peak. The IRI profiles obtained with the old option gives much better results than those generated with the new option.

Figure 2a–c shows the comparison of individual observed profiles for summer (May 13, 1981), winter (January 14, 1981) and equinox (April 01, 1981) with those generated by the IRI model using both the options, by inputting the experimental values of NmF2 and corresponding hmF2 into the IRI model.

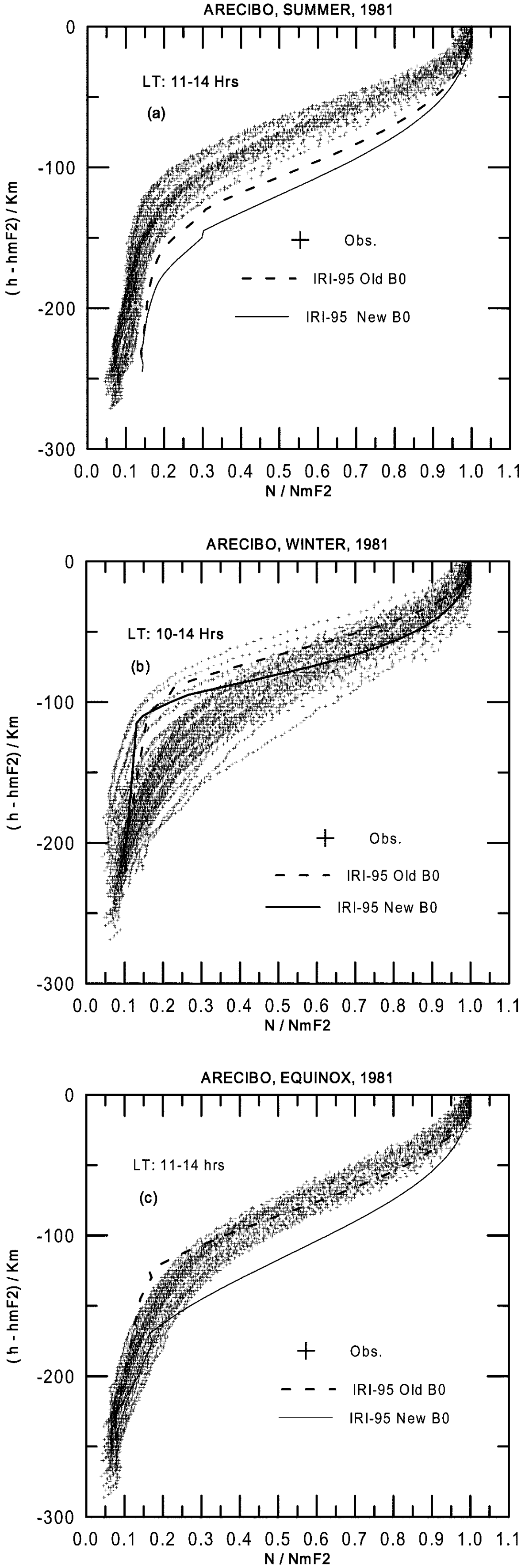

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Fig. 1a–c. This shows a mass plot of N/NmF2 observed with the IS measurements at Arecibo, against (h − hmF2) with the IRI-95 model using both the old (standard B0) and new (Gulyaeva-B0) options for **a** summer, **b** winter and **c** equinox

It can be noted in Fig. 2 that the model using old option, is close to experimental observations from the F2 peak down to a point around half density height for all the seasons. The electron density profiles produced by IRI using new option are found to be thick during summer and equinox as compared to observational results as can be seen in Fig. 2a, c. For winter, as shown in Fig. 2b, both options are closer to experimental values, but underestimate electron density at F1 heights.

As stated earlier, the recommended option in the IRI comes from Gulyaeva's (1987) model for half-density height h05. Mahajan *et al.* (1995) showed using Arecibo incoherent scatter radar data during solar minimum period (1974–1977) that IRI with recommended option produced a bottomside thickness, which was too thick by varying amounts depending on season and improvements to IRI have been suggested based on this work. In order to examine the variability of B0 around midday (10–14 h), we have deduced it from Arecibo measurements using Eq. (3). Figure 3a, b shows mass plot of

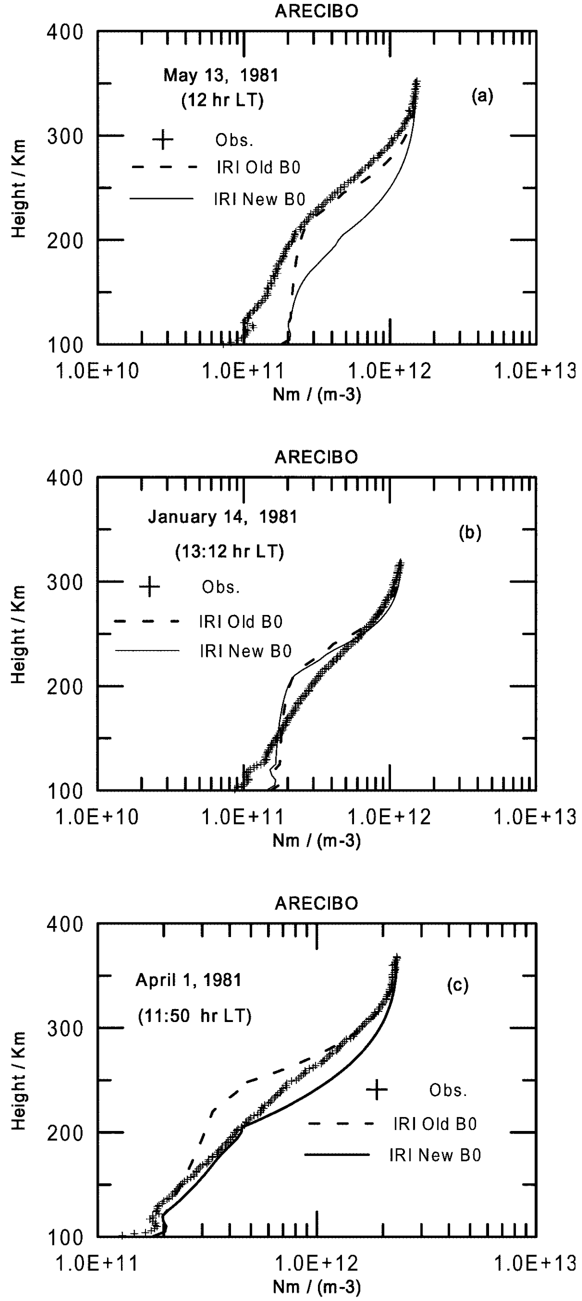

Fig. 2a–c. Comparisons of individual electron density profiles observed with the IS measurements at Arecibo, with the IRI-95 model using both the old (standard B0) and new (Gulyaeva-B0) options for **a** summer, **b** winter and **c** equinox

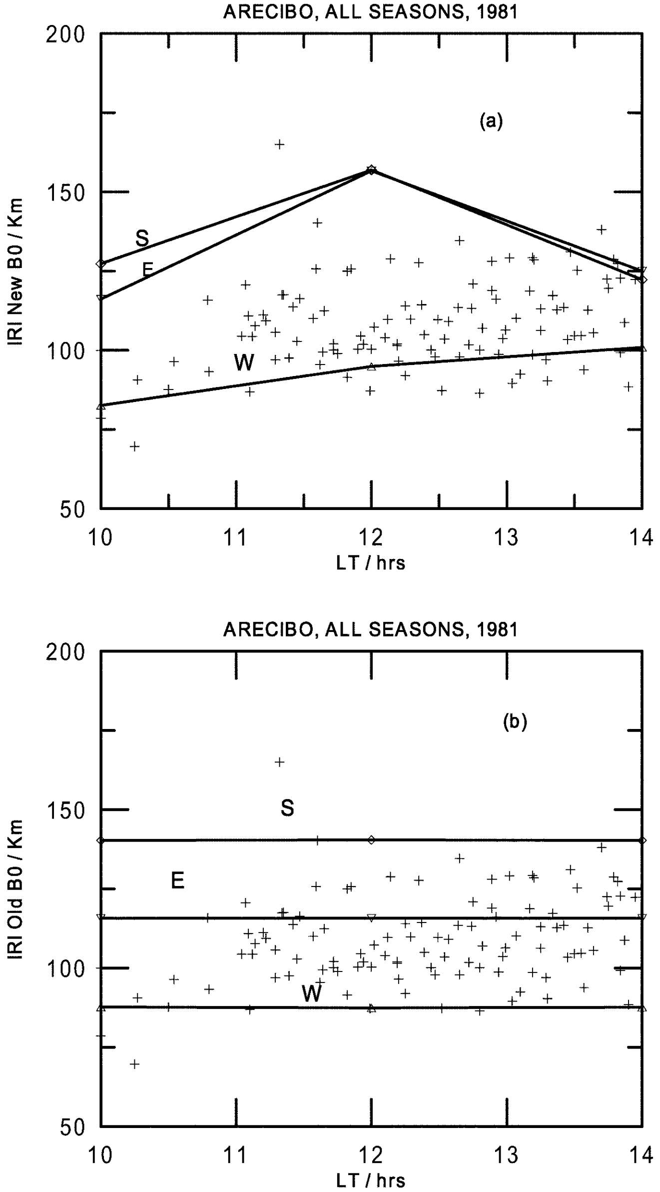

Fig. 3a, b. A mass plot showing variations of the observed B0 obtained during all the seasons against local time during midday. IRI-95 values of B0 are shown by *solid lines* for summer (*S*), winter (*W*) and equinox (*E*), **a** using Gulyaeva model and **b** standard option observed B0 against local time during all the seasons. The solid lines in the same figures show the IRI predicted values of B0 for three seasons using the new option (Fig. 3a), and old option (Fig. 3b). It can be noted from Fig. 3a that the IRI predicted values of B0 are found to be higher for summer and equinox and exhibit both seasonal and local time changes. In contrast to new option, the IRI predicted values of B0 using old option as shown in Fig. 3b, show seasonal change, but does not show local time changes. It can be noted that the discrepancies between the observed and predicted B0 using standard option are smaller than those obtained from Gulyaeva's (1987) model.

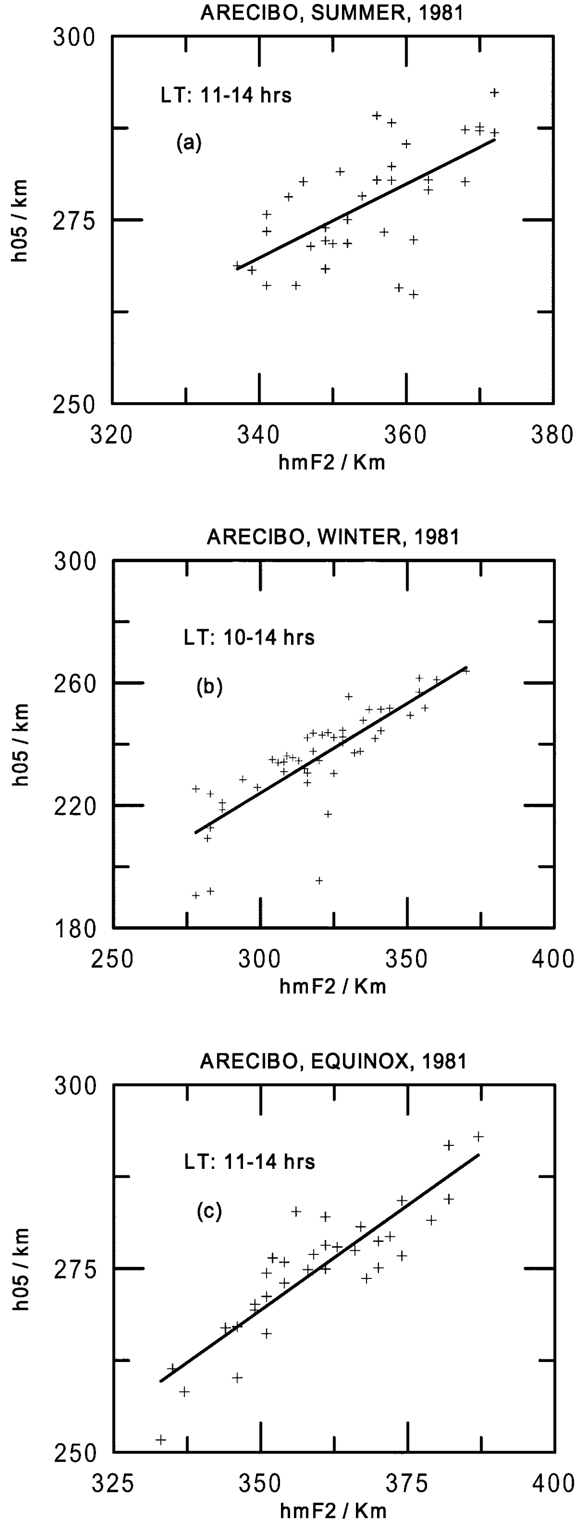

Fig. 4a–c. Mass plots of h05 against hmF2 for various seasons during midday for **a** summer, **b** winter and **c** equinox. Best fits are also given

In view of similarity between the behaviour of hmF2 and h05 as shown earlier by Mahajan *et al.* (1995) using Arecibo N(h) profiles during solar minimum period (1974–1977), we have examined the relationship between these two parameters for summer, winter and equinox. Figure 4a shows plot of h0.5 against hmF2 along with the best fits during summer, winter and equinox. A linear relationship between the two parameters can be noted during all seasons. However, during summer, as can be seen in Fig. 4a–c, the dispersion is found to be large. Mahajan *et al.* (1995) has also found that during daytime the lower values of h0.5 are often coincident, whenever there is F1 layer between h0.5 and hmF2.

4 Conclusions

The profile shape below the F2 peak, mainly depends upon B0, B1 parameters. In general, the standard B0 option in the IRI provides a better agreement with the observed profiles during midday from F2 peak down to a height around half density point, although the Gulyaeva-B0 option is the recommended choice in particular for low latitudes. This recommended option does not reproduce observed profiles well below the F2 peak especially during summer and equinox season. A more detailed study of the half density point on which the B0 parameter is based, needs to be done by analyzing more stations at low latitudes, in order to remove the discrepancies between the IRI model and observations.

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