Diurnal and seasonal variations of hmF2 deduced from digitalionosonde over New Delhi and its comparison with IRI 2001

N. K. Sethi, R. S. Dabas, V. K. Vohra

Annales Geophysicae (2004) 22: 453–458 © European Geosciences Union 2004

Annales Geophysicae

Diurnal and seasonal variations of *hm*F2 deduced from digital ionosonde over New Delhi and its comparison with IRI 2001

N. K. Sethi, R. S. Dabas, and V. K. Vohra

Radio and Atmospheric Sciences Division, National Physical Laboratory, Dr. K. S. Krishnan Road, New Delhi, 110 012, India

Received: 21 August 2002 – Revised: 12 May 2003 – Accepted: 4 July 2003 – Published: 1 January 2004

Abstract. Using digital ionosonde observations at a low mid-latitude station, New Delhi (28.6° N, 77.2° E, dip 42.4° N), we have derived hourly monthly values of *hm*F2 (the real height corresponding to the peak electron density in the F2-region), employing both the Dudeney (1983) and Bilitza (1990) empirical formulations for the period from January 2001 to August 2002. The diurnal and seasonal variations of *hm*F2 are analyzed. Further, to assess the predictability of the latest available model, International Reference Ionosphere, (IRI-2001), we have obtained the median values of *hm*F2 derived from M(3000)F2 for each hour during different seasons and compare these with the model. Our results show that both the Dudeney (1983) and Bilitza (1990) formulations reveal more or less a similar diurnal trend of *hm*F2, with higher values around midnight and lower during sunrise, in all the seasons. It is also noted that the *hm*F2 shows a larger variability around midnight than by daytime, in all the seasons. Further, the study shows that median values of observed *hm*F2, using both formulations, are somewhat larger than those predicted by the IRI, in all seasons and at all local times. During summer, the IRI values agree comparatively well with the observations, especially during daytime. Major discrepancies occur when the IRI underestimates observed *hm*F2 for local times from about 14:00 LT to 18:00 LT and 04:00 LT to 05:00 LT during winter and equinox, where the percentage deviation of the observed *hm*F2 values with respect to the IRI model varies from 15 to 25%. The difference between the model and observations, outside this time period, remains less than 20% during all the seasons.

Key words. Ionosphere (modelling and forecasting; equatorial ionosphere)

1 Introduction

Information about the height of the peak density of F2-layer (*hm*F2) is of great importance for ionospheric radio-wave propagation studies, as well as for understanding the physics of the F2 region. The *hm*F2 values also provide useful information from which the meridional winds may be deduced for understanding ionospheric behavior and also for validating thermospheric general circulation models (e.g. Miller et al., 1986, 1997). As the real heights are difficult to obtain from ionograms, a propagation factor M(3000)F2, defined as MUF/*fo*F2 (where MUF is the maximum usable frequency refracted from the F2-layer of the ionosphere, could be received at a distance of 3000 km and *fo*F2 is the critical frequency of the F2-layer), was therefore devised that could be derived graphically, directly from ionograms, and its numerical maps CCIR (1967) had been established. The description of *hm*F2 had been reported earlier by Shimazaki (1955), who was first to describe the strong anticorrelation between *hm*F2 and M(3000)F2 and his empirical formula for *hm*F2, based on simplified assumptions, overestimated the peak heights, as it did not take into account the amount of group retardation suffered by radio waves going through the underlying ionospheric regions. Shimazaki's formula was modified by subsequent workers, e.g. Bradley and Dudeney (1973), Dudeney (1983), Bilitza et al. (1979) and Bilitza (1990), who added the correction for retardation by all underlying layers. Dudeney (1983) considerably improved the *hm*F2-M(3000)F2 formula based on more detailed considerations of density profiles deduced from ionograms at Argentine Islands (65° S, 64° W). Using more reliable measurements from incoherent scatter measurements, at Millstone Hill, Arecibo and Jicamarca, *hm*F2-M(3000)F2 relationship was modified by introducing an additional dependence on solar activity and magnetic dip angle (Bilitza et al., 1979; Bilitza, 1990).

At present, one of the most widely used empirical models is the international Reference Ionosphere (IRI). It is an empirical standard model of the ionosphere updated periodically. Over the years, testing and modification of the IRI has continued with extensive participation by the International research community and it has led to improvements through several versions (IRI-80, IRI-86, IRI-90, IRI-95, IRI-2000, IRI-2001). For a given location, local time and sunspot num-

Correspondence to: N. K. Sethi
(nksethi@mail.nplindia.ernet.in)

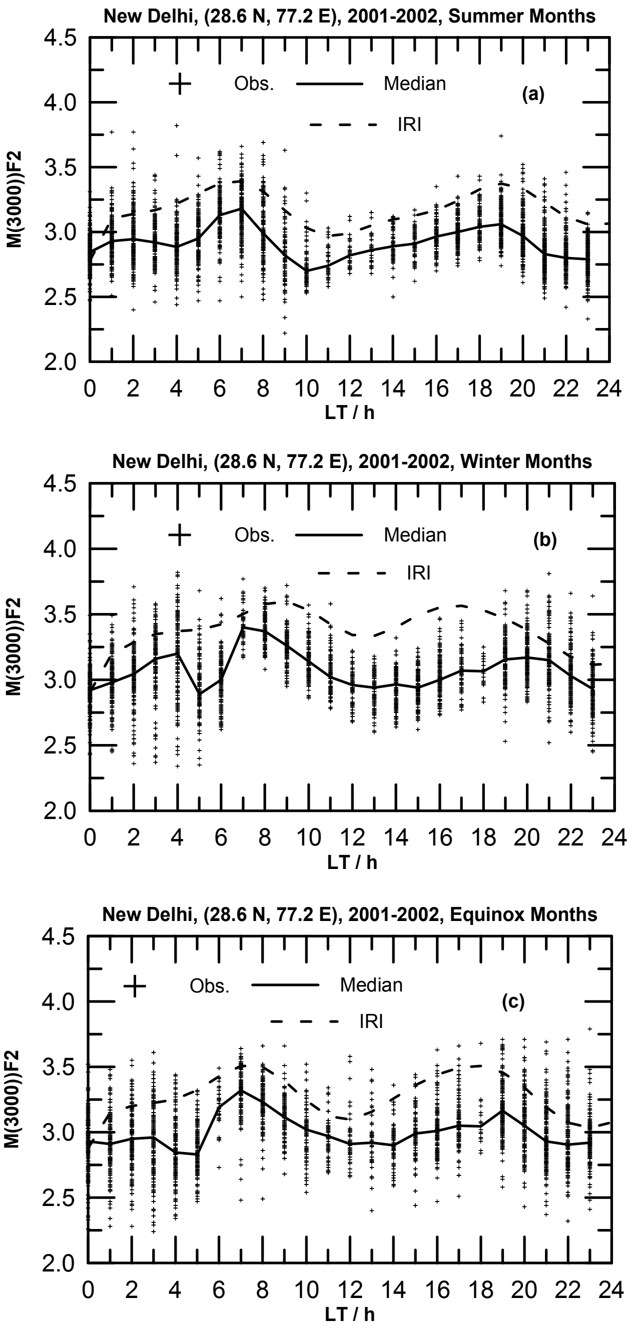

Fig. 1. A mass plot showing diurnal variation of transmission parameter M(3000)F2, obtained from manual scaling of data using digital ionosonde, over New Delhi, (28.6° N, 77.2° E), for **(a)** summer, **(b)** winter and **(c)** equinox. The median values are shown as a solid line. The IRI predicted values are shown as a dashed line.

ber, the IRI describes the median value of peak altitudes and densities of F2-, F1- and E-regions of the ionosphere (*hm*F2, *Nm*F2, *hm*F1, *Nm*F1, and *hm*E, *Nm*E), respectively, including electron density, electron temperature, ion temperature, ion composition and total electron content as a function of height. The latest available model at present is IRI-2001, which is a modified version of IRI-2000, Bilitza (2001). It has additional features providing the information on equator vertical ion drifts, F1 occurrence probability and storm time behavior of ionospheric peak parameters.

A few of the workers, e.g. Bittencourt and Chryssafidis (1994), Pandey and Sethi (1996) and Batista et al. (1996), have compared observed *hm*F2 with the IRI-90 (Bilitza, 1990), during low and high solar activity periods at low latitude stations. They have shown that in general, the IRI model predictions are quite reasonable for both levels of solar activity, except for post-sunset conditions during high solar activity, when the IRI highly underestimates the observed *hm*F2. Bittencourt and Chryssafidis (1994) have attributed these discrepancies to be mainly due to pre-reversal enhancement in the $\boldsymbol{E} \times \boldsymbol{B}$ vertical plasma drifts, which occur round sunset hours (Woodman, 1970; Fejer et al., 1991), and is responsible for the dynamical behavior of the ionospheric plasma at low latitude. In view of the discrepancies mentioned above and also, since the *hm*F2-M(3000)F2 formulation is based upon propagation factor M(3000)F2, mostly from mid-latitude stations in the IRI model, these measurements should be validated against the IRI model at low latitude. Therefore, in the present task, modern digital ionosonde measurements at a low mid-latitude station, New Delhi (28.6° N, 77.2° E, dip 42.4° N), in the Indian region, have been used to check the validity of latest model IRI-2001 available on Internet.

2 Data base

Modern digital ionosonde system IPS71 of KEL Aerospace LTd., Australia, was installed during July 2000 at National Physical Laboratory, New Delhi (28.6° N, 77.2° E, dip 42.4° N), India. The system is fully computer controlled, operates in the vertical incidence mode, and has additional features like HF spectrum, Phase and Doppler ionograms, in addition to the usual amplitude ionograms. At present, the regular vertical sounding is carried out systematically every 15 min, round the clock, and the scaling of ionospheric parameters is done manually on a regular basis. In the present studies, we have obtained the hourly monthly values of *fo*E, *fo*F2 and M(3000)F2 scaled at an accuracy of 0.1 MHz from the ionograms, for the period from January 2001 to August 2002, pertaining to the declining phase of solar cycle 23, during which the R12 (12-month running average sunspot number) varies between 100 and 108. These scaled values have been utilized to derive the *hm*F2 parameter using both the Dudeney (1983) and Bilitza (1990) empirical formulations and also comparisons are made with those obtained from the IRI-2001 model.

3 Analysis and results

To examine the seasonal variations, the data has been grouped into three seasons, i.e. summer (May, June, July and August of 2001 and 2002), winter (January, February, November and December of 2001, January and February of

2002) and equinox (March, April, September and October of 2001, March and April of 2002) containing 3125, 2747 and 2596 observations, respectively. Since M(3000)F2 is the basic parameter, from which *hm*F2 is derived, so we have compared its diurnal and seasonal variation with those obtained from the IRI predicted model. Figures 1a–c shows the mass plot of observed M(3000)F2 against local time along with the median values (solid line) and the IRI predicted values (dash line), for summer, winter and equinox, respectively. The median values of observed M(3000)F2 are calculated for one-hour bins of local time while the IRI predicted value of M(3000)F2 is obtained for the given local time and month relating to the three seasons, as mentioned above, and R12 corresponding to a given month. The M(3000)F2 values thus obtained are averaged over the respective months to represent the seasonal predicted value. It can be noted from Figs. 1a–c, that observed M(3000)F2 shows a large diurnal and day-to-day variations, with values varying from about 2 to 3.75 during all the seasons, while the median values of M(3000)F2 vary from between about 2.75 and 3.25 in all the seasons. As can be noted from the figure, both the median and the IRI predicted values of M(3000)F2 show, in general, a similar diurnal trend during all the seasons. The IRI predicted values, at all local times, are, however, somewhat higher than the observed median values. The IRI predicted values of M(3000)F2, in general, varies from about 2.8 to 3.5 in all the seasons. Figures 2a–c demonstrates the mass diurnal plots of *hm*F2 derived from M(3000)F2 using Dudeney (1983) empirical formulation, respectively, for summer, winter and equinox seasons. Here also the median values of *hm*F2 are shown as a solid line, while the IRI predicted values (obtained in a similar manner as that for M(3000)F2) are shown as dashed lines. It can be seen from the figure that *hm*F2 shows a large diurnal and day-to-day variability during all the seasons, with higher values around midnight than by day. At any fixed local time, large dispersion is seen during the nighttime, with values of *hm*F2 varying from around 225 to about 475 km. As can be noted from Figs. 2a–c, the median values of *hm*F2 increase gradually from around 07:00 LT onwards during all the seasons, and a diurnal peak is found to occur around 14:00 LT during winter and equinox months; however, during summer, the diurnal peak remains at around 10:00 LT. Thereafter, the median values of *hm*F2 show a gradual fall, reaching a minimum value around 19:00 LT. Similar to Figs. 2a–c, the mass diurnal plots of *hm*F2 (figure not shown) are also derived from M(3000)F2 using Bilitza (1990) empirical formulation and it is noted that both the formulations exhibit more or less similar results. Both the formulations exhibit a morning peak of *hm*F2 around 05:00 LT, which is more evident during winter and equinox months. A similar rise of the F2-layer at low latitude, before sunrise, was also reported by Batista et al. 1996; Pandey et al. (2003) using data for a solar maximum period.

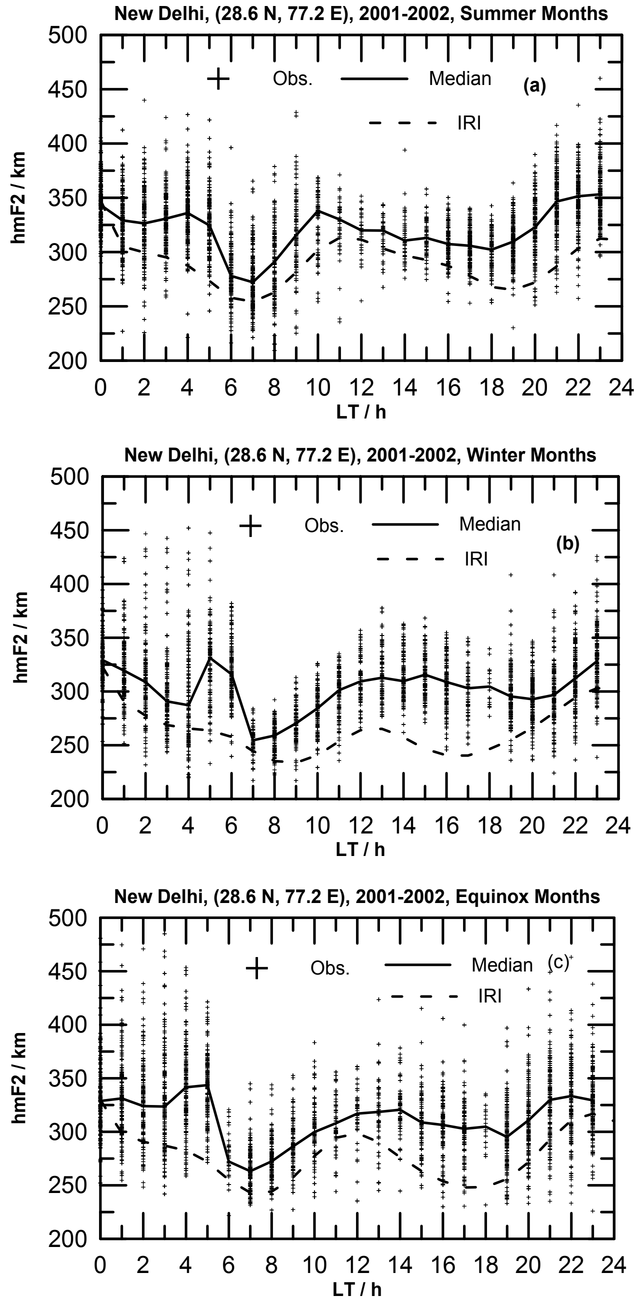

Fig. 2. A scatter plot showing diurnal variation of the parameter *hm*F2 derived from scaled ionospheric parameters using digital ionosonde over New Delhi, (28.6° N, 77.2° E), employing Dudeney (1983) empirical formulation, for **(a)** summer, **(b)** winter and **(c)** equinox. The median values are shown as a solid line. The IRI predicted values are shown as dashed lines.

Comparing median values of the *hm*F2 with those predicted by IRI, it can be observed in Figs. 2a–c, that IRI predicted values of *hm*F2 show, in general, more or less a similar diurnal trend with smooth variation during all the seasons. The plot between median and IRI predicted *hm*F2, as shown in Figs. 2a–c, further illustrates the fact that the IRI tends to underestimate the median *hm*F2 at all local times during different seasons. It can be noted in Fig. 2a that during summer, the percentage deviation of the median values with respect to the IRI model, remains less than 10% in the time period

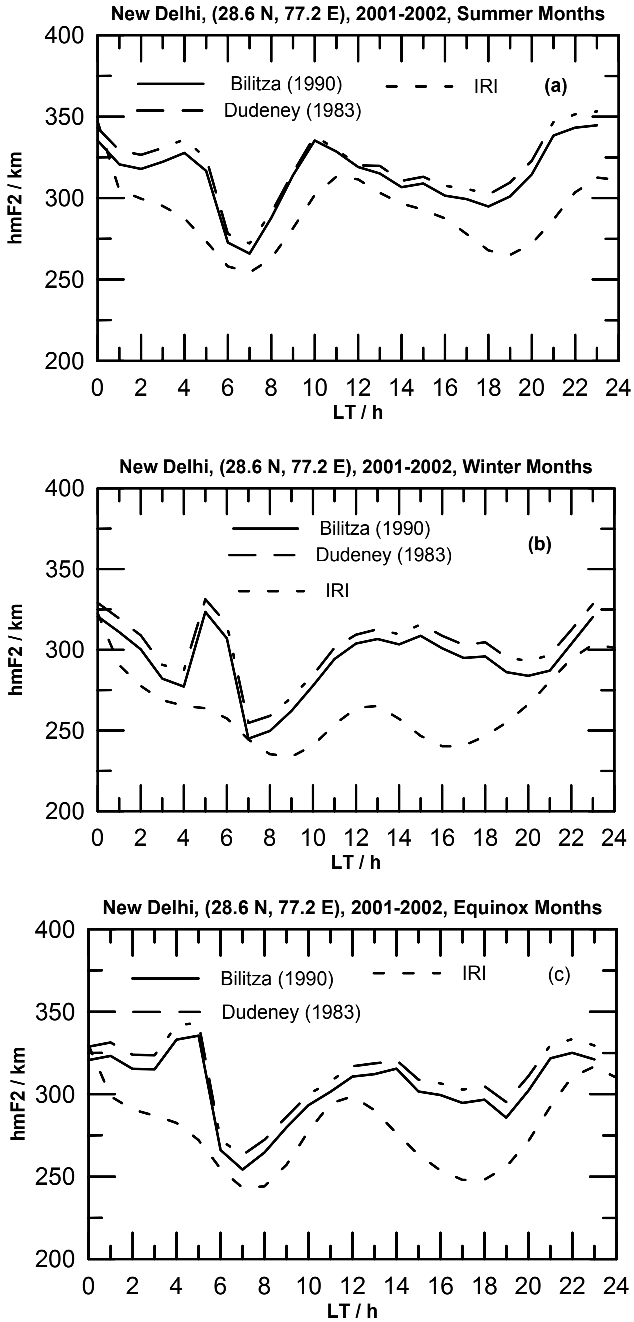

Fig. 3. Shows a comparison of observed median values of *hm*F2 using Dudeney (1983) (shown as a double dashed line) and Bilitza (1990) (shown as solid line) schemes, with those obtained from the IRI predicted (shown as dash line) model over New Delhi, 28.6° N, 77.2° E) for **(a)** summer, **(b)** winter and **(c)** equinox.

from 06:00 to 18:00 LT, while outside this time period, the percentage deviation between the observed median and IRI varies from about 10 to 15%. During winter and equinox, as can be noted in the Figs. 2b–c, the discrepancies between the IRI predictions and the median values are more pronounced around pre-sunrise hours, around 05:00 LT and in the afternoon, from 14:00 to 18:00 LT hours, and during these time periods the percentage difference between the model and observations varies from about 15 to 25%. Nighttime *hm*F2 values predicted by the IRI match well with median values during winter and equinox, with the deviation between the two being less than 10%.

To see clearly between the two formulations, i.e. Dudeney (1983) and Bilitza (1990), which one is closer to the IRI prediction, the comparisons of median values of *hm*F2, using both the formulations along with the IRI predicted values, have been shown in Figs. 3a–c for summer, winter and equinox, respectively. It can be noted from the figures that both the formulations provide almost a similar diurnal trend during all the seasons, with somewhat higher values in the case of the Dudeney (1983) scheme. The percentage difference between the *hm*F2 values derived from both the formulations during all the seasons and at all local times is less than 4%. This might be due to the fact that the *hm*F2 derived from both the formulations use the same set of parameters of M(3000)F2, *fo*F2 and *fo*E. Between the two formulations, the Bilitza (1990) scheme appears to be relatively closer to the IRI predictions. Also, as can be seen clearly in Figs. 3a–c, the IRI prediction exhibits two minima, one between 07:00 and 08:00 LT and the other one between 16:00 and 19:00 LT. The forenoon IRI minima of *hm*F2, in general, matches well with observations during all the seasons, while afternoon observed minima of *hm*F2 are not that well represented by the IRI. As stated earlier, the median values of *hm*F2 show distinct peak values between 04:00 and 06:00 LT, during all the seasons, while the IRI in this time period, shows the decreasing trend, and the percentage deviation of the median values with respect to the model, in this time period, is around 25%.

4 Discussion

The present study describes the variation of *hm*F2 at New Delhi, which lies on the verges of low and mid-latitude and hence, will be effected by equatorial $\boldsymbol{E} \times \boldsymbol{B}$ drift, as well as by thermospheric neutral winds. Therefore, the results described above are explained both in terms of $\boldsymbol{E} \times \boldsymbol{B}$ drifts and thermospheric winds. The maximum values of *hm*F2 around midnight are caused by an increase of upward drifts produced by meridional winds in the neutral air (Hanson and Patterson, 1964; Kohl and King, 1967), while around sunrise hours, with the beginning of intensive ionization, the electron concentration near the F2-peak increases at a rate which depends primarily upon the production rate, and thus, the layer maximum shifts downwards due to rapid production of ionization in the lower F-region (see, e.g. Rishbeth and Garriot, 1969). In the daytime, as the temperature increases, the concentration of atomic oxygen and loss coefficient, which is proportional to the molecular components, both increase, resulting in higher altitudes of layer maximum; accordingly, the increase of *hm*F2 from morning to afternoon is due to an increase in the temperature. In the evening as the rate of ion formation decreases, a transitional period follows during which the height of layer maximum increases to its nighttime value, and this process is enhanced by a change in the direction of the thermospheric winds, since an upward drift causes an additional uplift of the layer. The drift rate increases towards midnight, resulting in a rise in the F2-layer around midnight. Thus, thermospheric winds play a significant role in the diurnal variation of *hm*F2. The main discrepancies between the observations and the model occur during the pre-sunrise hour around 05:00 LT and post-noon hours from 16:00 to 20:00 LT, especially during winter and equinox months. During the morning hour at 05:00 LT, the observations show a sharp peak of *hm*F2, while the IRI model shows a decreasing trend during this time, as can be seen in Figs. 3b–c. These sharp peaks of *hm*F2 are due to a dip in observed M(3000)F2, which is not evident in the IRI model, as shown in Figs. 1b–c. Also, the disagreement between the IRI and observations exists from 16:00 to 20:00 LT. During this time period, the IRI predicts a dip in *hm*F2 between 16:00 and 20:00 LT, while the observations reveal a gradual fall. However, in both discrepancies, the IRI model underestimates the observations by about 25%. The discrepancies between the IRI model and observations were reported earlier by several workers, (Bittencourt and Chryssafids, 1994; Batista et al., 1996; and Pandey et al., 2003). Bittencourt and Chryssafids (1994) made comparative studies of the IRI-90 (Bilitza, 1990) model with ionospheric measurements, obtained from ionosonde, at a magnetic equatorial station, Fortaleza (4° S, 38° W, dip 2° S) during low and high solar activity periods. Their studies had shown, that in general, the model predictions were quite reasonable for both levels of solar activity, except during high solar activity, when the IRI model highly underestimated the *hm*F2 after sunset hours. They attributed these discrepancies to ionospheric F-region vertical plasma drifts over the magnetic equator, depending on the intensity of the eastward electric field and on the meridional winds, which are not satisfactorily reproduced in the IRI model. Using digisonde measurements at a low-latitude station, Cachoeira Paulista (22° S, 45° W), Batista et al. (1996) compared the observations during a high solar activity period, with the IRI-90 model (Bilitza, 1990). They also found a sharp rise of F-layer after sunset (18:00 LT) and also a rise in the layer before sunrise (0600 LT). Recently, Pandey et al. (2003) used the *hm*F2 values obtained from incoherent scatter radar measurements at Arecibo, (18° N, 67° W, dip 50) during a high solar activity period and compared these with the IRI-95 model. They, too, reported peaks of *hm*F2 around 05:00 LT during winter and equinox months, and other peaks at around 20:00 LT. The IRI, however, underestimated the observations during evening and night hours, while during pre-noon hours, the IRI was closer to observations. To summarize, we mention that, except for the magnetic equatorial station, the variation of *hm*F2 at New Delhi is found to be similar to those observed at two low-latitude stations, shown by Batista et al. (1996) and Pandey et al. (2003). The only departures are during post-sunset hours, with the sudden rise in *hm*F2, which is not well pronounced in our results. In fact, our results are more consistent with those obtained by Pandey et al. (2003), which may be due to the fact that both Arecibo and New Delhi are located at similar magnetic latitudes.

5 Conclusion

The modern digital ionosonde observations at a low-latitude station, New Delhi, in the Indian sector, have been used to derive the *hm*F2, using both the Dudeney (1983) and Bilitza (1990) empirical formulation. Both formulations exhibit almost a similar diurnal variation of *hm*F2, during different seasons. The comparison between the median *hm*F2 values, obtained using both formulations, with the IRI model, shows that the IRI underestimates the observed *hm*F2 values during all the seasons and at all local times. Overall, the agreement between the IRI model and measurements is good during daytime, especially around the noon hours in summer and equinox, and during the nighttime hours for winter and equinox. The discrepancies between the model and observations are evident during pre-sunrise and post-noon hours during all the seasons, while the post- noon discrepancies are more intense during winter and equinox months. To conclude, the IRI-2001 version seems to reproduce the average behaviour of low-middle latitude ionosphere, though some discrepancies between the model and observations do exist. It is suggested to carry out broad comparative studies employing more ionosonde data, especially of M(3000)F2, from other low mid-latitude stations, to improve the IRI model and to aim at a better representation of low-middle latitude ionosphere.

Acknowledgements. Topical Editor M. Lester thanks P. Wilkinson and another referee for their help in evaluating this paper.

References

Batista, I. S., Abdu, M. A., de Medeiros, R. T., and de Paula, E. R.: Comparison between IRI predictions and digisonde measurements at low latitude station, Adv. Space Res., 18, 49–52, 1996.

Bilitza, D., Sheikh, N. M., and Eyfrig, R.: A global model for the height of the F2-peak using M3000 values from the CCIR, Telecomm. J, 46, 549–553, 1979.

Bilitza, D. (Ed.): NSSDC 90-22, World Data Center A, Rockets and Satellites Greenbelt, Md, USA, (November) 1990.

Bilitza, D.: International Reference Ionosphere 2000, Radio Science, 36, 2, 261–275, 2001.

Bittencourt, J. A. and Chryssafidis, M.: On the IRI model predictions for the low-latitude ionosphere, J. Atmos. Terr. Phys., 56, 995–1009, 1994.

Bradley, P. A. and Dudeney, J. R.: A simple model of the vertical distribution of electron concentration in the ionosphere, J. Atmos. Terr. Phys., 35, 2131–2146, 1973.

CCIR: Comite Consultatif International des Radio communications, Reports, 340, 340-2 and later supplements, Geneva, 1967.

Dudeney, J. R.: The accuracy of simple methods for determining the height of the maximum electron concentration of the F2-layer from scaled ionospheric characteristics, J. Atmos. Terr. Phys., 45, 629–640, 1983.

Fejer, B. G., de Paula, E. R., Gonzalez, S. A., and Woodman, R. F.: Average vertical and zonal F-region plasma drifts over Jicamarca, J. Geophys. Res., 96, 13 901–13 906, 1991.

Hanson, W. B. and Patterson, T. N. L.: The maintenance of night-time F-layer, Planetary Space Sci., 12, 979–997, 1964.

Kohl, H. and King J. W.: Atmospheric winds between 100 and 700 km and their effects on the ionosphere, J. Atmos. Terr. Phys., 29, 1045–1062, 1967.

Miller, K. L., Torr, D. G., and Richards, P. G.: Meridional winds in the thermosphere derived from measurement of F2 layer height, J. Geophys. Res., 91, 4531–4535, 1986.

Miller, K. L, Lemon, M., and Richards, P. G.: A meridional wind climatology from a fast model for the derivation of meridional winds from the height of the ionospheric F2-region, J. Atmos. & Solar Terr. Phys., 59, 1805–1822, 1997.

Pandey, V. K. and Sethi, N. K.: Comparison of *hm*F2 and midday bottomside electron density profile obtained from IRI and incoherent scatter measurements, Adv. Space Res., 18, 33–37, 1996.

Pandey, V. K., Sethi, N. K., and Mahajan, K. K.: Dependence of F2-peak height on solar activity: A study with incoherent scatter measurements, Adv. Space Res., 31, 3, 543–548, 2003.

Rishbeth, H. and Garriot, O. K.: Introduction to Ionospheric Physics, Academic Press, New York., 1969.

Shimazaki, T.: World daily variability in the height of the maximum electron density of the ionospheric F2-layer, J. Radio Res. Labs., (Japan) 2, 85–97, 1955.

Woodman, R. F.: Vertical drift velocities and east-west electric fields at the magnetic equator, J. Geophys. Res., 75, 6249–6259, 1970.