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Comparison of the first long-duration IS experiment measurements over Millstone Hill and EISCAT Svalbard radar with IRI2001

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Abstract

The first long-duration incoherent scatter (IS) radar observations over Millstone Hill (42.6°N, 288.5°E) and EISCAT Svalbard radar (ESR, 78.15°N, 16.05°E) from October 4 to November 4, 2002 are compared with the newly updated version of the IRI model (IRI2001). The present study showed that: (1) For the peak parameters h_mF_2 and f_oF_2, the IRI results are in good agreement with the observations over Millstone Hill, but there are large discrepancies over ESR. For the B parameters, the table option of IRI produces closer values to the observed ones with respect to the Gulyaeva's option. (2) When the observed F_2 peak parameters are used as input of IRI, the IRI model produces the reasonably results for the bottomside profiles during daytime over Millstone Hill, while it gives a lower bottomside density during nighttime over Millstone Hill and the whole day over ESR than what is observed experimentally. Moreover, IRI tends to overestimate the topside N_e profiles at both locations. (3) The T_i profiles of IRI can generally reproduce the observed values, whereas the IRI-produced T_e profiles show large discrepancies with the observations. Overall comparative studies reveal that the agreement between the IRI predictions and experimental values is better over Millstone Hill than that over ESR.

Keywords: Ionosphere; Incoherent scatter radar; Modelling and forecasting; International reference ionosphere

1. Introduction

The International Reference Ionosphere (IRI) model is the most widely used global ionospheric model, which is recognized as the standard specification of ionospheric parameters by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). Over the past two decades, this model has undergone periodic revisions to improve its prediction capability since its first release in 1978. Recently, the most updated version of the IRI model, IRI2001 (Bilitza, 2001), which can be available on Internet, has presented a number of great changes. Further validation study of the empirical model by comparison with the incoherent scatter radar measurements is still necessary, which will open up the possibility of improving its forecast capability. The long-duration incoherent scatter radar (ISR) experiments were simultaneously carried out at Millstone Hill and EISCAT Svalbard radar (ESR) from October 4 to November 4, 2002. On the basis of

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this campaign, this paper makes a comparative study between the ISR observations at these two sites and the IRI2001 model. As ISR can probe the whole ionospheric information from bottomside to topside, rather than ground ionosondes can only see the ionosphere up to the point of highest density (the F_2 peak), the measurements are used to assess the whole electron density profiles also the plasma temperature profiles predicted by the IRI model.

2. Data set and analysis method

A long-duration incoherent scatter radar experiments were carried out at Millstone Hill and ESR from October 4 to November 4, 2002. Over Millstone Hill, these experiments included the 410 and 480 μs single-pulse (S/P) and the alternating code (A/C) measurements. In this study, the A/C data with higher height resolution ~5 km are used to deduce the peak parameters and B parameters, while the S/P data with higher upper height boundary are used to compare the IRI height profiles. Over ESR, the vertical measurements, with the variable height space from 3 to 36 km over the height range of 90–772 km, are used to analyze.

First, the peak electron density (N_mF_2) and its height (h_mF_2) are obtained with a least-squares fitting for the observed profiles from the Chapman function (Rishbeth and Garriott, 1969),

$$N_e(h) = N_mF_2 \exp[0.5(1 - z - e^{-z})],$$
$$z = (h - h_mF_2)/H(h). \tag{1}$$

Here, the scale height is taken to be $H(h) = A_1(h - h_mF_2) + H_m$ in the bottomside, and $H(h) = A_2(h - h_mF_2) + H_m$ in the topside (see Lei et al., 2004, 2005). Thus, N_mF_2, h_mF_2, H_m, A_1, and A_2 are set as adjustable variables to bring in the best match with the observed electron profiles $N_e(h)$. As for the fit analysis, the electron height profiles between 160 and 600 km are employed. We consider that the derived peak parameters N_mF_2 and h_mF_2 are reliable, given that most profiles can reach quite good agreement.

Next, the thickness parameter B0 and the shape parameter B1 are obtained by best fitting individual observational profile from the peak height h_mF_2 down to the 0.24 N_mF_2 height ($h_{0.24}$) if no F_1-layer exists or to the F_1 peak if F_1-layer occurs, using the least-squares-fitting approach, with the formula used in the IRI model,

$$N_e(h) = N_mF_2 \exp(-x^{B1})/\cosh(x),$$
$$x = (h_mF_2 - h)/B0. \tag{2}$$

We also compare the observations with those of the IRI2001 to validate the prediction capacity of the empirical model. Given that the IRI model profiles represent the monthly mean ionosphere, the monthly average representative results are obtained by using all the data in this experiment to compare with IRI results. The model values are calculated under F_{107} = 166.8 as well as with the day number 290, as representative of October 2002. Note that the observed h_mF_2, N_mF_2 are used as input parameters of IRI2001 to compute the model B parameters and density profiles $N_e(h)$. The $N_e(h)$ profiles are calculated with IRI using its standard option, but T_i, T_e profiles are calculated using the option of Truhlik et al. (2000).

3. Results

3.1. The F_2 peak parameters (h_mF_2, f_oF_2) and IRI's B parameters (B0, B1)

Fig. 1(a) and (b) show the observations (solid lines with circles) of the F_2 peak parameters (h_mF_2, f_oF_2) and the thickness and shape parameters (B0, B1) for this campaign over Millstone Hill, and ESR, respectively. The critical frequency f_oF_2 in MHz is equal to $(N_mF_2/1.24 \times 10^{10})^{1/2}$ if N_mF_2 is given in m^{-3}. To compare, the corresponding results predicted by IRI are also presented. For h_mF_2 and f_oF_2, the model results obtained from the CCIR coefficients are plotted with dashed lines. For the B parameters, the IRI model provides two options, i.e., the table option and Gulyaeva's option (Gulyaeva, 1987) and their results are plotted with solid and dotted lines, respectively.

Over Millstone Hill, h_mF_2 reaches its peak values at midnight, and then displays two daytime minima at 08 and 16 LT, creating a 'W'-like diurnal variation. The diurnal variation of f_oF_2 displays a simple pattern: higher during daytime and lower during nighttime. The IRI model reproduces the observed h_mF_2 well during daytime and underestimates its values during nighttime; while for f_oF_2, the IRI values show good agreement with the observed ones. For the parameter B0, its diurnal variation can be characterized by morning and afternoon collapse, with two peaks occurring at midday and midnight. This feature is evident over Millstone Hill in the diurnal variation of B0 for seasons other than summer as reported by Lei et al. (2004). B0-Gulyaeva value of IRI shares quite good agreement in the diurnal tendency with the observational ones, while B0-Table option generates a little closer value. In addition, the experimental B1 has a low value during daytime and a high value during nighttime. B1-Table reproduces the daytime value while overestimates the nighttime value. B1-Gulyaeva values are significantly larger during daytime than those from the measurements, given that the B1-Gulyaeva option takes the constant value of 3, and without changing with seasons and local time.

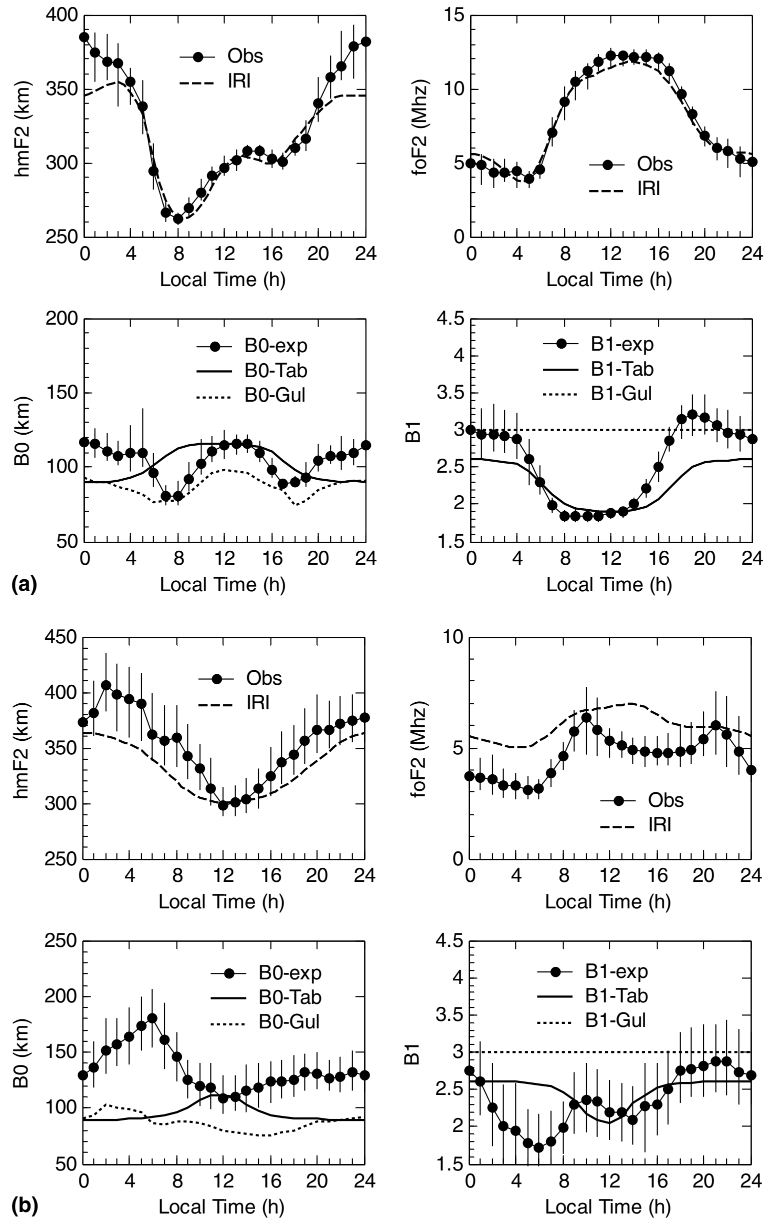

Fig. 1. (a) Comparisons of diurnal variation of the parameters h_mF_2, f_oF_2, B0 and B1 derived from the long-duration IS experiment measurements over Millstone Hill with the IRI2001 model. The vertical bars cover lower quartile (LQ) through median values to upper quartile (UQ). The detail can be seen in the text. (b) Similar to (a), but for ESR measurements.

Over ESR, the diurnal variation of h_mF_2 shows a 'V'-like shape, with a peak value at 02 LT and the minima around 12 LT; and the diurnal variation of f_oF_2 can be characterized by morning (~10 LT) and evening (~20 LT) peaks. By comparing the observations with those given by IRI, the IRI model tends to underestimate and overestimate the observed h_mF_2 and f_oF_2, respectively. Further, the local time asymmetry for the experimental B is more evident with respect with that of Millstone Hill. The table option provides a slightly better prediction for the B parameters than Gulyaeva's option does, but there are large discrepancies, especially during the nighttime.

3.2. Electron density profiles and plasma temperature profiles

Fig. 2 shows a comparison of the long-duration IS observations of N_e, T_i and T_e profiles over Millstone Hill with the IRI2001 model. The $N_e(h)$ plots, as shown in Fig. 2(a), reveal that IRI model produces reasonably good results for the bottomside profiles during daytime, while it underestimates the bottomside profiles during nighttime, and significantly overestimates the topside profiles, which was also reported by Buonsanto (1989). A multiplicative correction factor (Ne_{obs}/Ne_{IRI}) at 800 km is ~0.5 on average is applied to bring the model

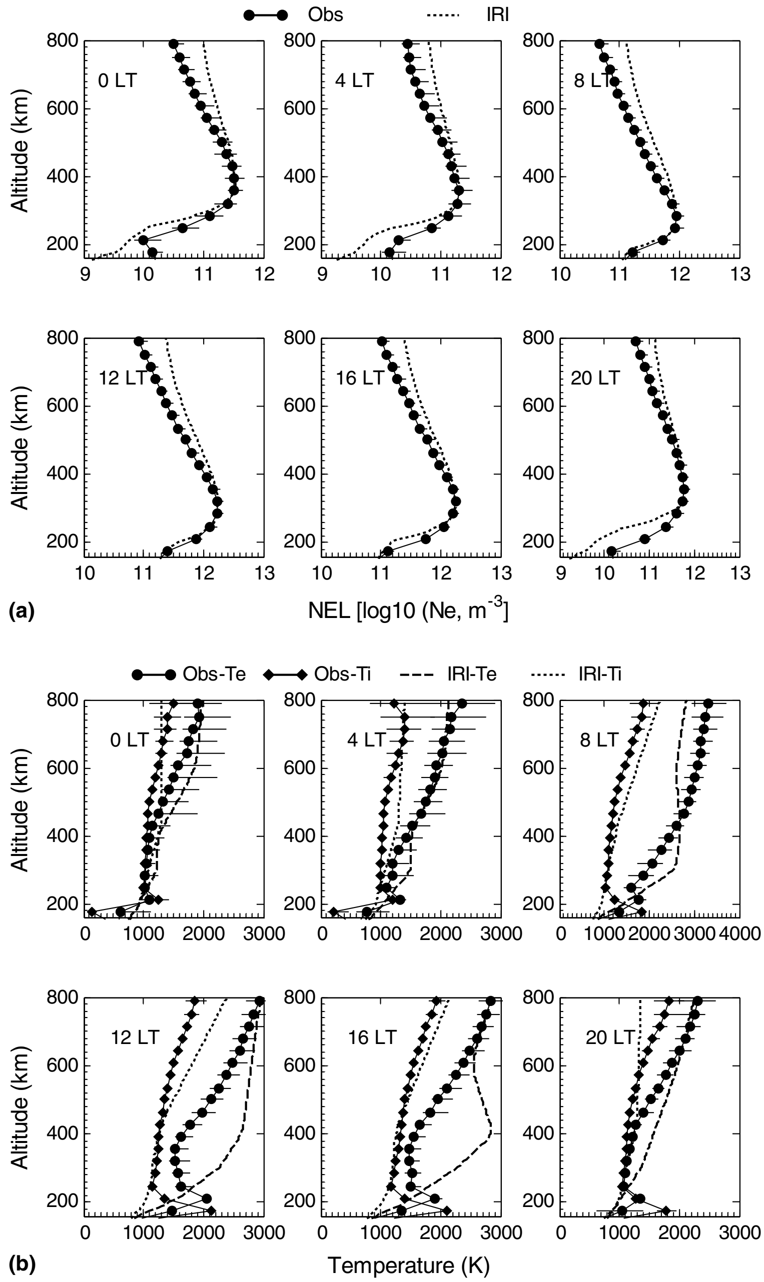

Fig. 2. Comparisons of the long-duration IS observations of electron profiles (a) and plasma temperature profiles (b) over Millstone Hill with the IRI2001 model. The horizontal bars cover LQ through median values to UQ.

in agreement with the observed topside profiles. This factor generally agrees with that of Bilitza (2004). For T_i, the main difference in magnitude occurs above 400 km, where the IRI model gives a little larger value by 100–200 K during daytimes and does not predict the height gradient of T_i during nighttime. For T_e, it can be seen that the IRI results are generally in agreement with the observations during nighttime, while overestimate the observations between 200 and 600 km during daytime. Note that the difference between two is more complex during the sunrise period.

The comparison results for the observed N_e, T_i and T_e profiles with IRI over ESR are presented in Fig. 3. It is observed that the IRI model underestimates the bottomside N_e profiles and overestimates the topside profiles at all local times. We find that the correction factor for the topside N_e over ESR is close to that over Millstone Hill. Thus, the IRI model strongly overestimates the $N_e(h)$ effective scale height at both stations. In addition, the T_i profiles of IRI can generally reproduce the magnitude rather than the height gradient, whereas the IRI-produced T_e profiles show smaller values by 200–600 K

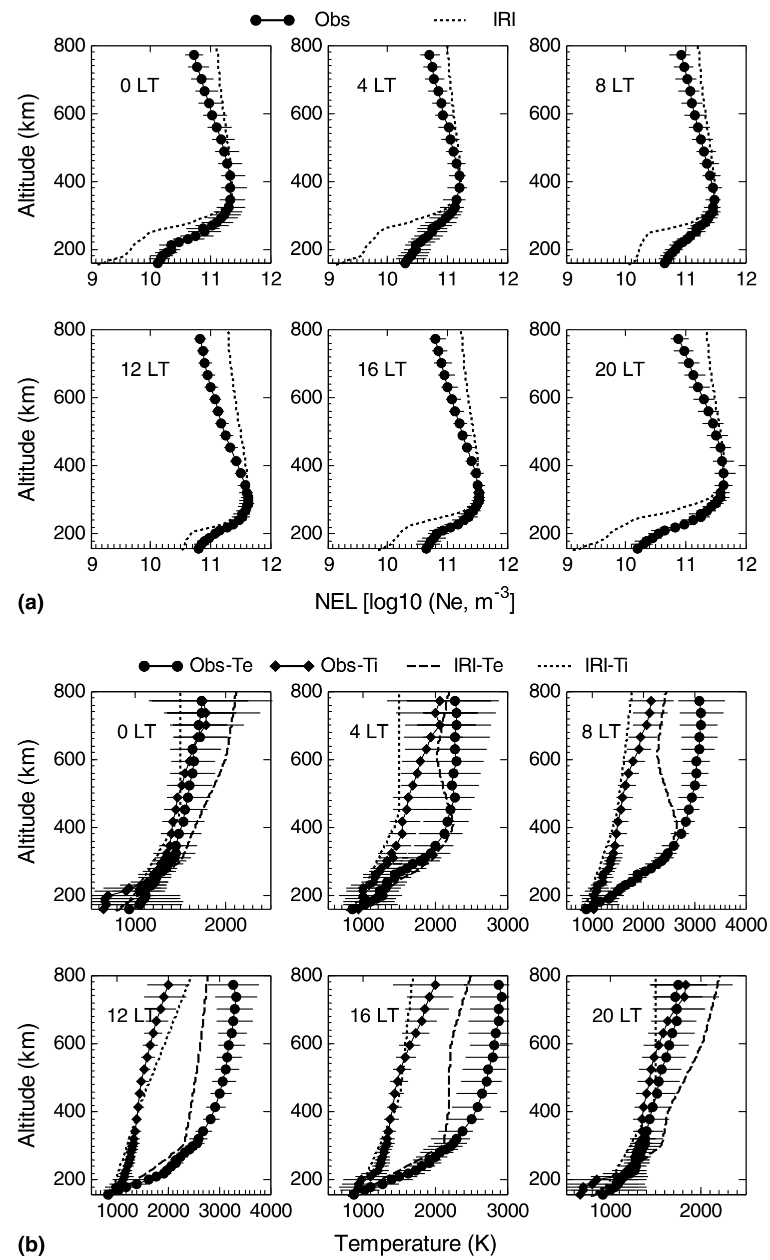

Fig. 3. Similar to Fig. 2, but for ESR measurements.

above 300 km during daytime and present large values during 20–04 LT.

4. Summary and conclusions

The first long-duration ISR observations over Millstone Hill and ESR from October 4 to November 4, 2002 are used to compare with IRI2001. Comparative studies reveal that the agreement between the IRI predictions and experimental values is better over Millstone Hill than that over ESR, which is of course expected since relatively poor data were included in the IRI at high latitudes. In the meanwhile, as seen from Figs. 1–3, the ionospheric variability is more significant over ESR than over Millstone Hill, which may be contribute to the larger effect of magnetosphere on the polar ionosphere than on the middle latitude ionosphere.

It should be mentioned that this investigation is based on the 30-day experiments and the active geomagnetic activities during this period may have significant effect on our results (Zhang, 2005). Additional studies involving a more abundant database are needed to provide more useful information for improving the forecast capability of IRI.

Acknowledgments

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