



A COMPARISON OF THE LOWER TRANSITION HEIGHT OBTAINED WITH A THEORETICAL MODEL AND WITH IRI

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ABSTRACT

The ionospheric low transition height obtained from a theoretical model is compared to the IRI model using the standard ion composition option and the Danilov and Yaichnikov model option, and to Oliver's model. It is found that 1) the three models agree rather well by day except in summer for low solar activity, while large differences exist by night; 2) the day-night difference of the transition height by the IRI standard option is much smaller in summer and in winter, but is larger in equinox seasons in low solar activity, while the Danilov and Yaichnikov model always yields a rather small difference; 3) increasing solar activity leads to higher theoretical levels particularly by night, while IRI shows an opposite trend. 4) due to transport by wind the simulation gives a transition height depending on local time, while both IRI options take the solar zenith angle for variable. As for the ion composition above 150 km, the distributions of the relative percentage of O^+ as well as NO^+ at noon in summer and winter under low solar activity predicted by the theoretical model are approximately consistent with those of the Danilov and Yaichnikov model.

INTRODUCTION -- LOWER TRANSITION HEIGHT

The region where oxygen ions are the dominant species in the ionospheric F region is characterized by two limits. The upper one is defined as the transition from prevailing O^+ ions to hydrogen ions ($O^+ - H^+$ transition), the low limit, however, from prevailing molecular to atomic ions ($M^+ - O^+$ transition). Precisely, the lower transition height (LTH) is defined as the altitude where the density of atomic oxygen ions equals the sum of molecular ions. Figures 1(a) and (b) show the height profiles of electrons, O^+ and molecular ion species for midday and midnight in December 1982 over Wakkanai (45.6°N, 141.7°E), as calculated from the theoretical model described below. By day, this height is around 180 km, and by night 250 km. In order to demonstrate the performance of the theory up to the F_2 -layer typical diurnal variations of a few characteristic heights obtained from the theoretical simulation are given in Figure 2 together with hmF_2 deduced from observed $M(3000)F_2$ data by the well-known relation. Theoretically obtained parameters are the height of the peak, the height where $\partial N/\partial h$ is maximum (the so-called base-point), and the height of half maximum electron density, $h_{0.5}$. The later two parameters are discussed in [1]. A very close relation between the transition height, hmF_2 , and $h_{0.5}$ can be found in this Figure.

The LTH is an important parameter. Above it, O^+ can be regarded as the dominant specie, and the loss rate of electrons can then be described by a linear recombination coefficient, so that the corresponding height is very important for aeronomical studies of electron density distribution. The LTH lies in a region where either dynamical or photo-chemical processes are almost equally important. It has been shown that, the behaviour of the electron, oxygen ion and molecular ion species at this level and in the

surrounding height range are decisive in the formation and evolution of the F₁-ledge and the F₁-F₂ valley /2, 3/, see Figure 1(a).

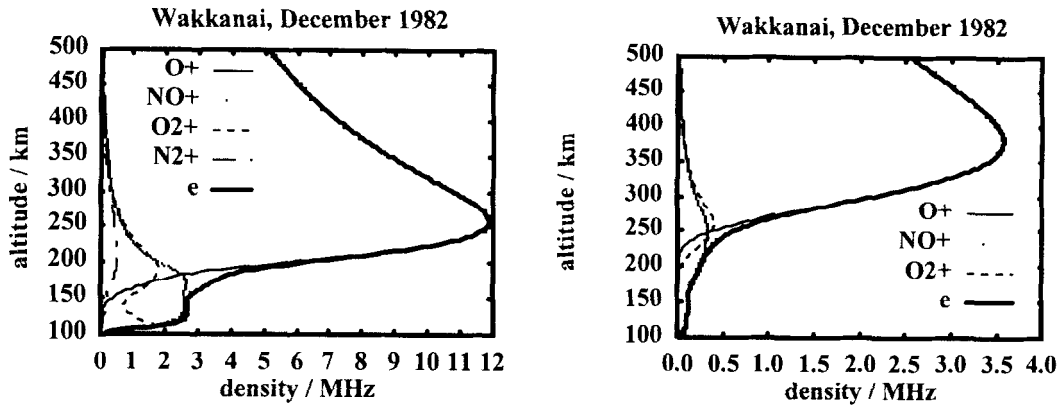


Fig. 1 Theoretical profiles of each ion species at noon of December 1982, Wakkanai. (a) 12 LT (left panel) (b) 00 LT (right panel)

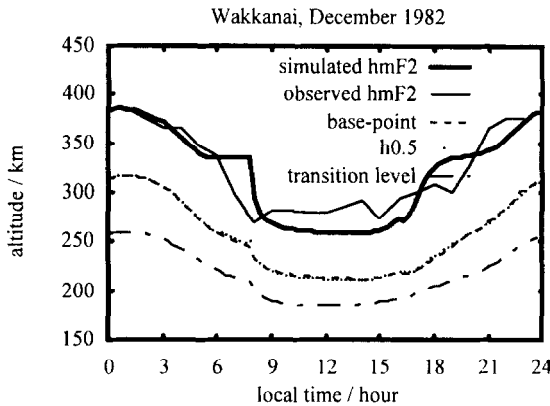


Fig. 2 Diurnal variation of the transition height and other F₂ height parameters: base-point, half maximum density height h_{0.5} (see text) and hmF₂ for December 1982, Wakkanai. All values are obtained with the theoretical model described in the text except the “observed hmF₂” derived from M3000 F₂ data.

On the other hand, in connection with the empirical modeling, the LTH can be used to specify the ion species distribution /4, 5, 6/, and it is clear that a good understanding of this characteristic height will be very helpful in order to simplify the IRI ion composition representation. Oliver /4/ investigated the ion composition in the F₁-layer with rockets and satellites data, and proposed a formula for the O⁺-M⁺ transition height h_t , which was fitted to the experimental database. It reads /5/,

$$h_t / km = h_s / km + 203.7 + 24.7 \tanh[-(88.4^\circ - \chi) / 19.7]$$

$$h_s / km = -16.8 \cos[(d + 22) \frac{2\pi}{365}] - 9.4 \sin[(2d + 10.5) \frac{2\pi}{365}]$$

where χ is solar zenith angle (in degree) and d the day number. The Oliver model involves zenith angle, seasonal, annual and semi-annual variations though, distinct from Danilov and Yaichinikov /7/, no solar activity dependence. Seen over all, not too much work has been published on the morphology of the LTH. In the present, it seems that theoretical calculations may be used to fill holes where empirical input is missing.

In the following we discuss the LTH and ion composition obtained with a theoretical model for mid-latitudes, comparing these to the IRI standard option, Danilov and Yaichinikov model for the ion composition, as well as the Oliver empirical model. We first give a brief description for the theoretical model used for this study.

THEORETICAL MODEL

A numerical model of the mid-latitude ionosphere was constructed using the theoretical consideration of equations governing the production, loss and movement of ion species of atomic ion O^+ , and molecular ions NO^+ , O_2^+ and N_2^+ . For O^+ , a diffusion equation is obtained by combining the continuity and the momentum equations taking ambi-polar diffusion and neutral wind induced drifts into account. Transport of molecular ions is ignored in the present study since it is felt to have small effects in the height range where these are prevailing. The set of equations and coefficients can be found in /8/. In the photo-chemical scheme of the model, three branches for the photoionization of neutral oxygen to the $O^+(^4S, ^2D, ^2P)$ are considered, so 13 reactions for meta-stable ions as well as 8 for the stable oxygen ion are included. We take special attention to the meta-stable ions, because they are very important at the heights considered here /3, 9/. Oversimplification is not indicated in this respect. The reaction equations, the rates, references and other details were shown in /3/. Since a share of H^+ has been excluded, the topside boundary is at 500 km; while the lower boundary is at 100 km where photo-chemical equilibrium is assumed. Numerical procedure for this system is the same as /8/.

The theoretical model depends on five external models which are used to specify the environment parameters: the neutral atmospheric densities for O, N_2 and O and the temperature are from MSIS86 /10/ (the NO density is based on the Mitra model /11/), the neutral thermospheric wind from HWM90 /12/; the radiation model EUV91 /13/ is used to generate the solar extreme ultraviolet flux, and IRI90 is adopted to yield the topside O^+ density, and electron and ion temperatures where when necessary.

In summary, the present one-dimensional and time-dependent theoretical model of the ionospheric structure integrates the principal dynamical and photo-chemical processes within the middle ionosphere over mid-latitudes. The inputs for the model are the geographic latitude, longitude, day number, A_p index, daily and 81-day-mean 10.7 cm fluxes. Outputs are the variations of electron and ion species as a function of altitude and local time. With a time interval of 15 min and a height interval of 2 km, the result will be available in 3 to 5 minutes on a 486 PC of 33 MHz frequency.

COMPARISONS OF LOW TRANSITION HEIGHTS

Calculations were carried out for the location of Wuchang (30.5°N, 114.4°E) for 4 seasons in years of high solar activity (1982) and low solar activity (1986). Theoretical electron and ion composition profiles are obtained first, and the corresponding peak density and height are used as inputs for the IRI specification. IRI90 offers two options for the ion composition profile, namely standard option /14/ and that of Danilov and Yaichinikov (D&Y) option. We shall first focus on the lower transition height (LTH), see Figures 3 and 4. In the standard option the LTH is just switched between one day and one night value, both depending on the season. A substantial day-night change is only appearing at the equinoxes.

(i) Low Solar Activity (Figure 3)

Equinoxes: By day there are only insignificant LTH differences (< 20 km) between all models. By night, however, the standard IRI generates the largest values and the D&Y model the smallest ones, and the simulation and the Oliver model are in between. From 00 to 17 LT, the theoretical results are closest to the Oliver model, from 07 to 20 LT to D&Y. In summer, the transition heights of the Oliver model and the simulation lie between the IRI options which yield very small day-night differences. Daytime values as high as 250 km (in the standard option) are felt to be unrealistic. During day and evening, from 06 to 21 LT, the theoretical altitude approaches the D&Y model. In winter, the IRI options also give smaller day-night differences, particularly the D&Y model. By day the standard IRI is almost identical with the Oliver model, and from 00 to 07 LT theoretical heights are near to the Oliver model. As regards the day-night LTH difference at low solar activity we obtain the general conclusion that the D&Y model gives the smallest values while in the standard IRI it is small in summer and winter but largest in the equinox months. A recent work by Danilov and Smirnova /15/ may have improved the current IRI ion composition model.

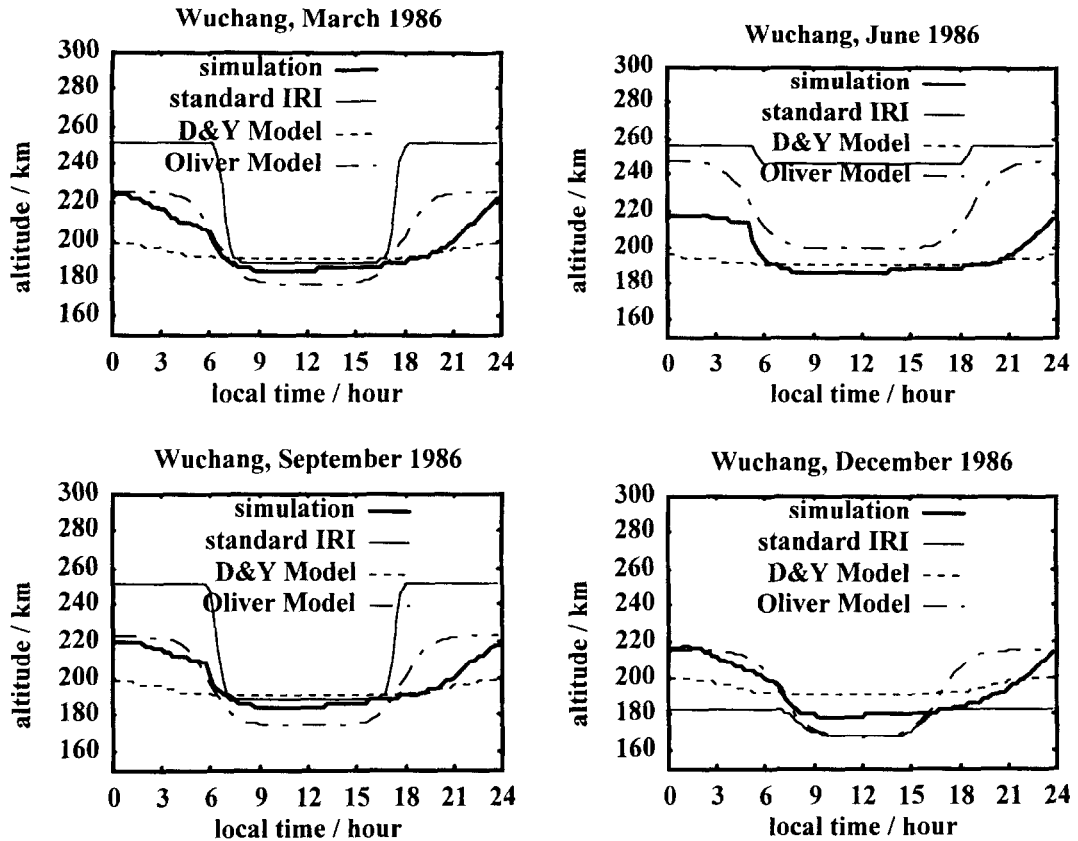


Fig. 3 Diurnal variations of the LTH obtained with the theoretical model, the IRI standard option, Danilov and Yaichinikov (D&Y) option and the Oliver model, over Wuchang for 4 seasons of 1986 (low solar activity).

(ii) High Solar Activity (Figure 4)

The D&Y model also gives very small day-night difference as in low solar activity. Equinoxes: By day the Oliver LTH is between the standard option and the simulation which is always higher particularly by night. The three models agree better by day. In summer, the D&Y model and the standard IRI predict small day-night differences (there is almost no difference for the D&Y model); while day values of all models are near together and the D&Y model prediction gives the lowest LTH by night. The diurnal variation of the simulated LTH resembles that of the Oliver model which gives an enhanced LTH for this season. In winter the standard IRI shows a still smaller day-night. The D&Y and the Oliver LTH's vary between those of the simulation and the standard IRI. Quite generally the agreement is quite good by day while by night the models differ by up to 70 km when the simulation specifies highest, D&Y option (in winter the standard option) lowest LTH values.

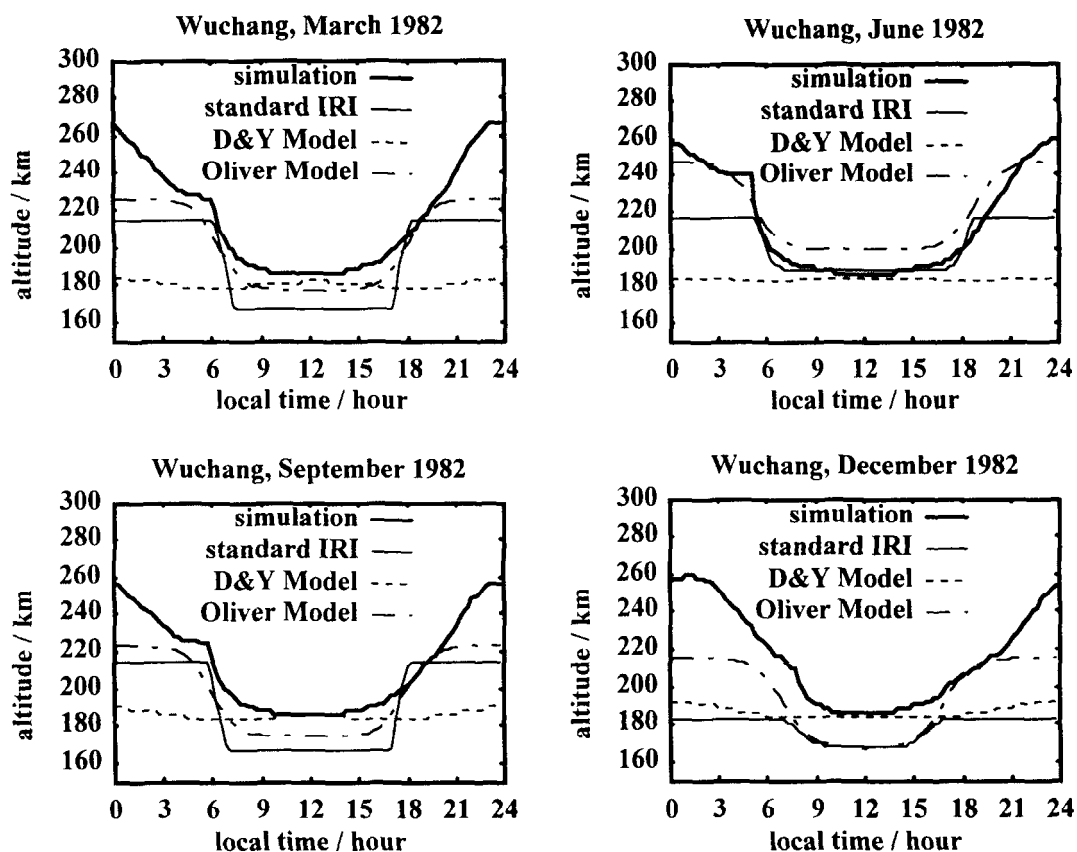


Fig. 4 Diurnal variations of the LTH obtained with the theoretical model, the IRI standard option and Danilov and Yaichnikov (D&Y) model option, and the Oliver model, over Wuchang for 4 seasons of 1982 (high solar activity).

We note two features appearing in the simulation but not in the empirical models. With increasing solar activity the simulated LTH becomes greater. This is particularly evident by night. The IRI options show an opposite trend (in winter the height does not change in the standard option) as is illustrated in Figures 3 and 4. In all three empirical models the diurnal variation of the ion composition goes with the solar zenith angle. The simulation, however, uses local time (LT) so that diurnal curves are not symmetric to local noon. LTH values are lower in the afternoon. We found the heights at sunset to be much lower than those at sunrise, as shown below.

We now discuss influences that may be responsible for the transition height behaviour. Atmospheric composition as a function of altitude, time, season and solar activity is the essential factor as can be expected. When the atomic oxygen density increases, the transition height will descend slightly by day and ascend by night, and when the molecular nitrogen density increases, the height moves up throughout the day (see Figure 5). Changes resulting from modifying the molecular oxygen density are quite similar to those due to molecular nitrogen. This implies that the time-dependent response of the LTH to the atom/molecule ratio is quite complicated.

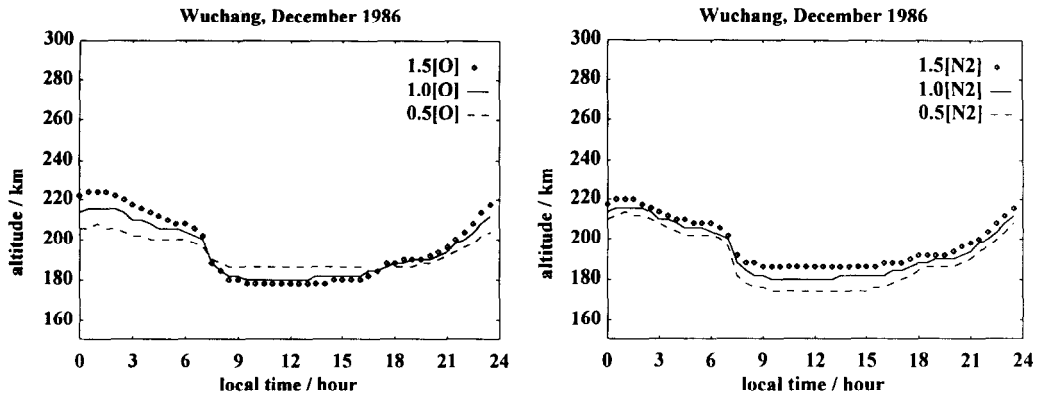


Fig. 5 Effects of neutral atmospheric composition on the LTH according to theoretical calculations. The share of atomic oxygen (left panel) or molecular nitrogen (right panel) was enhanced or deduced by 50% relative to the corresponding MSIS86 model values, while other parameters remained unchanged. For example, the symbol "1.5[O]" means a 50% increase of the oxygen density for all the height and time.

Theoretical calculation also shows that, with using different electron and ion temperature model, the height is not much affected (see case 1 and 2 in Figure 6). This result justifies our simplification of equal neutral and plasma temperatures near the LTH we made in the theoretical model. If, however, the neutral wind is not considered, the night-time LTH will be dramatically decreased, that at sunset increased, while the daytime values do not change. Thus, without neutral winds the day-night difference of the LTH is reduced leading to a result similar to the D&Y. In this condition, the variation of this height becomes symmetric to local noon, and shows the solar zenith angle control as in empirical models. If the diurnal variation of the neutral wind pattern is asymmetric as found in /12/ (Figure 7), an asymmetry in the LTH can be understood. If O^+ moves up or down in the vertical direction driven by south- or northward wind (case 2 in Figure 6), or not (case 3 in Figure 6) the changes with or without HWM90 may become understandable.

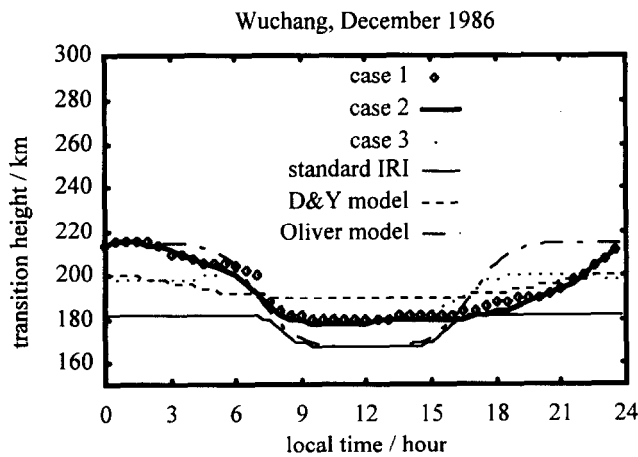


Fig. 6 Responses of the LTH to different temperature and neutral wind conditions (see Table below). The theoretical model was applied in the calculations.

Cases	Te and Ti Model	Neutral wind
1	IRI90	HWM90
2	Te=Ti=Tn (MSIS86)	HWM90
3	Te=Ti=Tn (MSIS86)	without wind

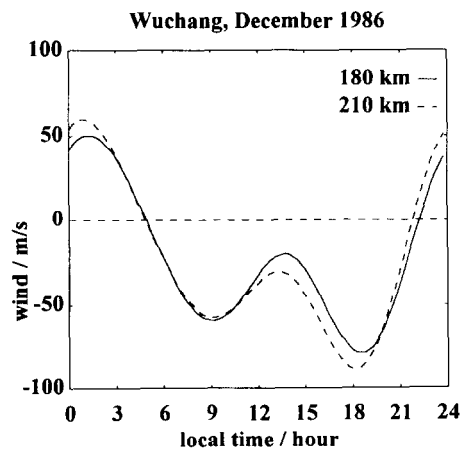


Fig. 7 Diurnal variations of the N-S. neutral winds at 180 km and 210 km for Wuchang, December 1986, obtained with HWM90 /12/. [southward positive]

ION COMPOSITION

We describe briefly results of the ion composition comparison since it is directly relevant to the transition height specification. The relative dependences of O^+ , NO^+ and O_2^+ were calculated with the theoretical model and with both IRI options at noon for June and December, 1986 (a low solar activity year).

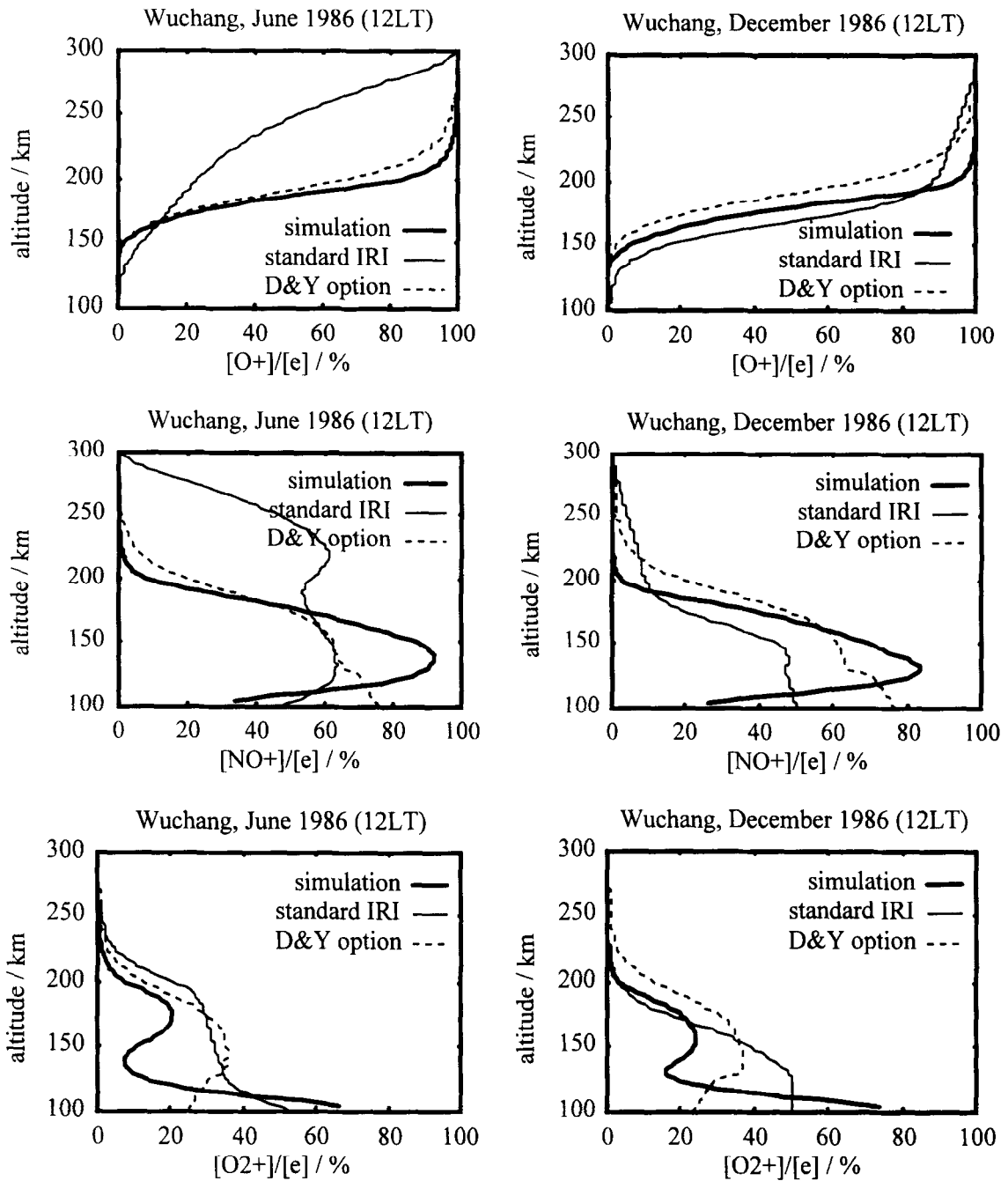


Fig. 8 Profiles of relative ion composition obtained with the theoretical model and IRI models for noon of June and December 1986. The upper panel in the plots is for O^+ , the middle panel for NO^+ and low one for O_2^+ .

It has been found (Figure 8) that, for O^+ in summer, the simulated distribution is similar to the D&Y model, while the IRI standard option yields a different profile. This corresponds to the occurrence of a

large difference of the LTH between the standard option and all other models. The differences are not pronounced in winter for the three models. For NO^+ , above about 150 km there is a very good agreement between the D&Y model and the theoretical model. The IRI standard option differs from the other two. In winter, these three profiles are essentially consistent above 150 km. For O_2^+ the IRI options which give generally a similar distribution above 150 km differ not so evidently from the simulation above 175 km. We should note that, IRI positive ions models do not involve the contribution of N_2^+ , but in the present theoretical model, N_2^+ is considered although it has a very small share.

CONCLUSIONS

The present paper discusses the ionospheric low transition height (LTH) and the ion composition with the help of a theoretical model, two IRI options and the Oliver model therewith. Comparative investigations of the height and ion composition distributions as well as the properties of the transition height are carried out. The results thereinbefore lead to the following conclusions:

- 1) For all models, agreement exists between the LTH's by day, except in summer for low solar activity, and by night when there exist larger departures.
- 2) The day-night difference of the height obtained with the IRI standard option, comparing with those from simulations as well as the Oliver model, is much smaller in summer and in winter, but is higher in equinox seasons for low solar activity. The Danilov and Yaichnikov model always yields a quite small day-night difference.
- 3) The simulation gives higher transition levels particularly by night with increasing solar activity, while IRI has an opposite trend.
- 4) The theoretical model shows the local time dependence of the transition height (asymmetric to noon) instead of the zenith angle used in the empirical models. The asymmetry is due to the atmospheric wind induced transport.
- 5) The simulated distributions of the relative percentage of O^+ as well as NO^+ (at heights above 150 km) at midday in summer and winter for low solar activity are consistent with those predicted by the Danilov and Yaichnikov model.

ACKNOWLEDGEMENTS

The authors are grateful to the NSSDCA, GSFC for providing us with the MSIS86, HWM90, EUV91 and IRI90 models. (S.-R.Z.) would like to thank Professor Abdus Salam, the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste. The work by S.-R. Z. and X.-Y. H. was partly supported by the Natural Science Funds of China.

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