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TMTM simulations of tides: Comparison with UARS observations

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Abstract. This paper presents combined model-data interpretation of the High Resolution Doppler Imager (HRDI) and Wind Imaging Interferometer (WINDII) wind, temperature and airglow data using the tuned mechanistic tidal model (TMTM) approach, including calculation of the nighttime oxygen emission rates induced by the simulated tides. This is the first demonstration of the consistency of the tidal signatures in the HRDI/WINDII temperature, airglow and wind observations in the mesosphere and lower thermosphere (MLT). This analysis gives increased confidence in these UARS measurements and also in our TMTM methodology.

1. Introduction

The High Resolution Doppler Imager (HRDI) and Wind Imaging Interferometer (WINDII) on the Upper Atmosphere Research Satellite (UARS) have measured tidal modulation in winds, temperatures, and airglow emissions in the MLT region over the same time period [*Hays et al.*, 1994; *Ortland et al.*, 1997; *Burrage et al.*, 1994; *Shepherd et al.*, 1995; *McLandress et al.*, 1996a]. Validation efforts have been made for these measurements and some discrepancies have been noted between these UARS measurements and those from ground-based measurements, most notably between winds measured by MF radars above about 85 km and the HRDI winds [*Burrage et al.*, 1996]. Some previous works have compared these UARS measurements to model simulations [*Burrage et al.*, 1995; *Yee et al.*, 1997], but there have been no demonstration that the UARS wind, temperature, and airglow measurements are compatible with each other and accepted atmospheric physics and airglow chemistry. This paper presents the first self-consistent model-data interpretation for tides in the HRDI/WINDII wind, temperature and airglow observations using the tuned mechanistic tidal model (TMTM) approach [*Yudin et al.*, 1997], including the calculation of the nighttime $O(^1S)$ and O_2(0-0) volume emission rate (VER) variations induced by the simulated tides.

2. TMTM approach

Khattatov et al. [1997] and *Yudin et al.* [1997] have demonstrated the capability of using a combination of model results and UARS wind data to tune the dissipation in tidal models in order to reproduce observed diurnal tidal amplitudes. Their technique was based on the dominance of the diurnal tide in the UARS meridional (V) winds, and the high sensitivity of the model to the variation of dissipation in the 80-110 km region. Basically, the UARS diurnal V-wind amplitudes and modeled phases (which are close to the observed phases) have been used to predict the rest of the tidal variables and dissipation through iterative model runs that match the model results with the UARS V-wind amplitudes. The measured V wind component shows tidal signatures that are quite stable during the month so that the initial guess for the model tuning can be determined. This model-data technique was called the Tuned Mechanistic Tidal Model (TMTM). TMTM, as a tidal model, is similar in its numerical formulation to the Global Scale Wave Model of *Hagan et al.* [1995], except that UARS wind data are used to evaluate the tidal dissipation and background zonal winds, which are poorly known model parameters [*Yudin et al.*, 1997].

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To calculate the tidal oscillations of oxygen emissions we used the monthly mean zonally and local time averaged profiles of $O(^3P)$, O_2, N_2 and T from the MSISE-90 empirical model [*Hedin et al.*, 1991]. The $O(^1S)$ VERs are calculated using Barth's mechanism with the photochemical parameters employed by *Bates* [1992] and *Krasnopolsky* [1981]. For calculation of the O_2(0-0) VERs we used expression (1) from *Murtagh et al.* [1990]. Before the calculation of oxygen VERs, we compute tidal oscillations of $O(^3P)$ and O_2 using their linearised continuity equations. The similar linear estimation of wave variations in the OH emission has been described by *Gavrilov and Yudin* [1982]. A discussion of our selected results for March/April 1993 and December/January 1992-93 are presented in the next section.

3. Results and discussion

The TMTM simulations of the tidal wind amplitudes and phases are shown in Fig. 1 for March 1993 in comparison with the WINDII results between 40^oS and 40^oN [*McLandress et al.*, 1996a]. We see that the tuning of the tidal dissipation and the use of the HRDI monthly mean zonal wind in the stratosphere [*Ortland et al.*, 1996] and in the MLT region [*Burrage et al.*, 1996] allow us to closely reproduce both diurnal and semidiurnal winds. The model-data agreement is good between 40^oS and 40^oN, where tuning of the tidal dissipation has been done.

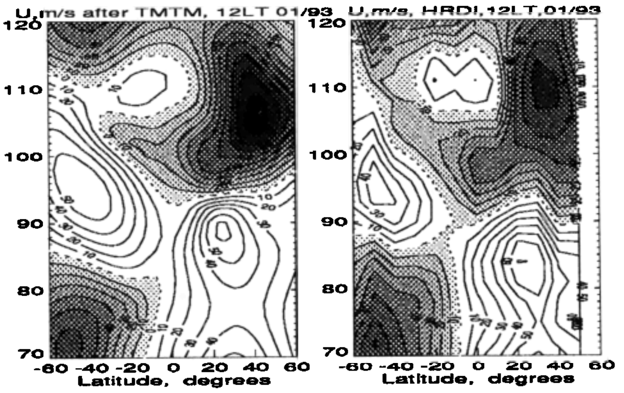

Figure 2. Zonal diurnal and semidiurnal winds simulated by the model superimposed on the refined HRDI mean zonal wind (left plot) and HRDI zonal wind observations (right plot) for Jan. 1993 at 12 LT. Westward winds are shaded. Dashed contour is the zero wind line.

A comparison between the HRDI zonal winds at 12 LT and the simulated diurnal and semidiurnal zonal (U) winds superimposed on the estimated zonal mean flow, that was calculated after removing of the diurnal tides from the daytime averages of the HRDI zonal winds, for January 1993 is shown in Fig. 2. Despite some model-data differences that can be attributed to the climatological tidal forcing and background Ts used in the model as well as the presence of planetary and gravity waves in the solstice HRDI winds, we argue that our wind simulation and decomposition of the HRDI winds into the zonal mean flow and tidal components reproduce the observed tidal signatures reasonably well.

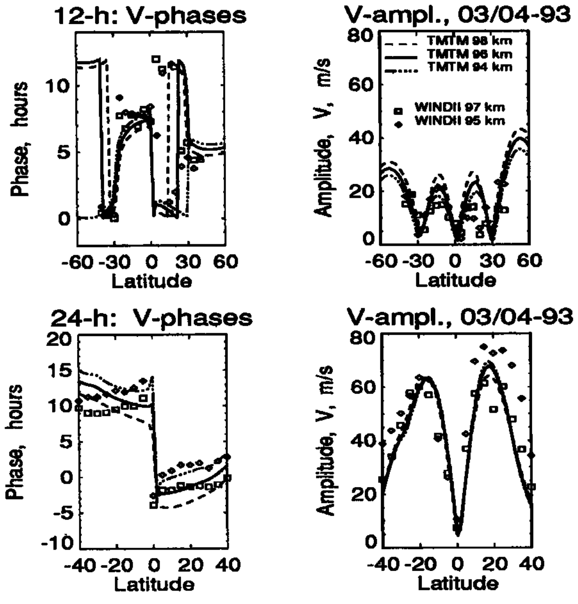

Figure 1. Semidiurnal (first row) and diurnal (second row) wind phases and amplitudes for Mar/Apr 1993, simulated by the TMTM, and obtained by a least squares fit to WINDII winds (94-98 km).The first column shows the meridional wind tidal phases as a function of latitude, the second column shows the meridional wind amplitude.

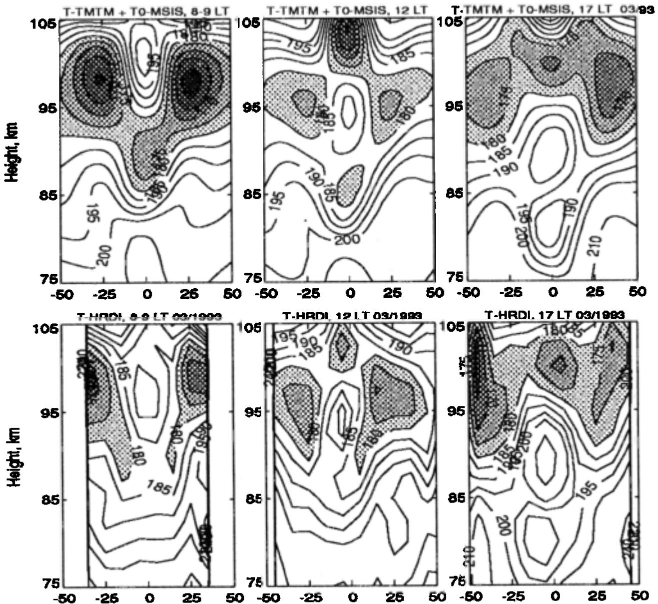

Figure 3. Temperatures (T) predicted by tidal model results superimposed on the MSISE-90 monthly averaged T (first row), and HRDI temperature retrievals (second row) for Mar 1993 at 8-9, 12, and 17 LT. Contours with T lower than $180K$ are shaded.

To show that our results simulate realistic tidal variations in T, vertical velocity W, and density ϱ, we present comparisons with the HRDI T observations [*Ortland et al.* 1997], WINDII $O(^1S)$ [*Shepherd et al.*, 1995] and HRDI O2(0-0) [*Burrage et al.*, 1994] emissions which follow from the tidal W, T, and ϱ oscillations. Figure 3 presents a comparison of the HRDI T observations with TMTM results for some selected local solar times in March 1993. It should be noted that the HRDI daytime data do not allow a straightforward separation of the monthly mean T composites into a mean component and tides due to insufficient local time coverage [*Ortland et al.* 1997]. That is why it is difficult to derive the mean HRDI T distributuion and incorporate it to the TMTM simulation, as a background T. Despite the existing differences in the mean T between the HRDI data and MSISE-90 climatology [*Ortland et al.*, 1997], the presented model-data comparisons show similar daytime patterns in T above 80 km.

The annual tidal variabilty of the UARS winds and T and its interpretation by TMTM analysis have been discussed by *Yudin et al.* [1997]. In that paper, it was shown that the seasonal variation of the dissipation is probably a key mechanism for the explanation of the equinox amplitude maxima and weakness of the solstice diurnal tidal amplitudes. In particular, these seasonal changes in tides can be also detected by the airglow observations and interpreted by our calculations.

Figure 4 compares the estimated nighttime evolution of the $O(^1S)$ VERs, using the TMTM winds, T and ϱ fluctuations, to the WINDII $O(^1S)$ observations for March/April 1993 and December/January 1992/93 in the vicinity of the equator. We see that the observations and model results show similar seasonal changes of the nighttime $O(^1S)$ emission variations: rapid and abrupt changes of the airglow intensity in March/April at midnight and relatively weak tidally driven $O(^1S)$ variations in December/January.

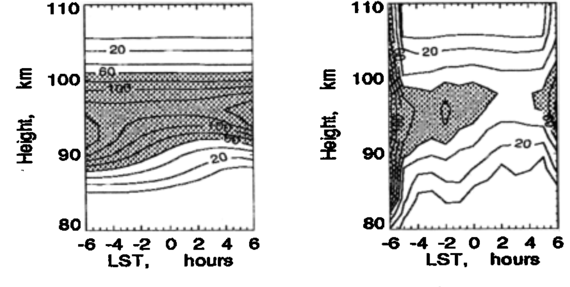

Figure 4. Nighttime evolution of $O(^1S)$ volume emission rate (VER) at the equator: left column shows the model results; right column shows the WINDII $O(^1S)$ observations. First row corresponds to Mar/Apr 1993, second row is results for Dec/Jan 1992/93. Contours with VERs higher than 60 photons $cm^{-3}s^{-1}$ are shaded

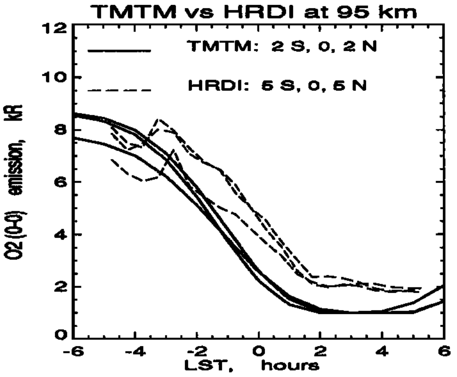

Figure 5. Comparison of the nighttime O_2(0-0) HRDI observations (thin lines) with TMTM-airglow calculations (thick lines) for March/April 1993 in the vicinity of the equator at 95 km.

Using our calculation scheme, we can define the principal physical agent of these nighttime changes in $O(^1S)$ by successively turning off the tidal oscillations in W, ϱ, T, U and V. Following this approach, we found that the W tidal variation has the largest impact on the simulated behavior of the $O(^1S)$ emission. The tidal T and ϱ variations determine the structure of the contours in Fig. 4 due to the dependence of the O_2^* production $(O + O + M \Longrightarrow O_2^* + M)$ on T and ϱ. The contributions of the U and V tidal oscillations to the calculated $O(^1S)$ VERs are relatively small.

It is interesting to compare our results with the simulations of $O(^1S)$ predicted by the NCAR TIME-GCM, *Yee et al.* [1997]. They have argued that the weak diurnal tidal forcing in the TIME-GCM (basic simulation in their paper) does not allow them to reproduce the observed strong local time variation of the $O(^1S)$ emission (Fig. 18a, in *Yee et al.*, [1997]). The 'perturbed' TIME-GCM results (with a tripled increase of tidal forcing) showed more diurnal variation in the $O(^1S)$ emission (Fig. 18b). If we compare those figures, we see that the daily averaged value of the $O(^1S)$ emission for their 'perturbed' simulation is two times smaller than that for their basic prediction and cannot reproduce the magnitudes of the WINDII $O(^1S)$ VERs [*Shepherd et al.*, 1995]. Altering the lower boundary tidal forcing in the model in order to achieve the observed amplitudes is not very well justified since other mechanisms exist in the MLT region that determine the tidal structure there. In particular, the relatively weak dissipation derived by the TMTM, gives tides, and their modulation of the $O(^1S)$ emission, comparable with observations without changing the tidal forcing. Meanwhile, if we increase the dissipation so as to match the diurnal wind amplitudes observed by the MF radar at Kauai (21°N) by *Fritts and Isler* [1994], for example, we cannot simulate the strong nighttime variation of $O(^1S)$ emission at the equator observed by WINDII in March/April 1993.

Figure 5 shows a comparison of our nighttime $O_2(0-0)$ emission calculations with the HRDI measurements for March/April 1993 in the vicinity of the equator at 95 km. Again, the agreement between the HRDI data and calculated results based on the TMTM simulations is remarkable.

4. Summary and concluding remarks

Numerical simulations of the diurnal and semidiurnal tides in the MLT region are presented using the Tuned Mechanistic Tidal Model (TMTM). Estimates of dissipation obtained using the HRDI/WINDII wind data together with the model do a good job in the determination of the tidal amplitudes and reproducing the observed tidal winds. Comparisons of the HRDI daytime temperature tidal patterns with TMTM simulations also show good agreement in the 80-105 km region. UARS MLT observations reveal a strong seasonal variation in the diurnal tide, with maxima at the equinox periods and minima at solstices. Based on the model tidal results "tuned" to the UARS wind data, our calculations of airglow tidal modulation also show strong seasonal variations in the oxygen emissions detected by HRDI and WINDII. This is the first time that independent UARS observations of the daytime temperatures, the day- and nighttime winds and the nighttime oxygen emissions are shown to be self-consistent. This analysis gives increased confidence in these independent and simultaneous space-borne measurements.

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