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Structure of the migrating diurnal tide in the Whole Atmosphere Community Climate Model (WACCM) ☆

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Abstract

As part of an ongoing effort to understand the migrating diurnal tide generated by the NCAR Whole Atmosphere Community Climate Model, version 3 (WACCM3), we compare the WACCM3 migrating diurnal tide in the horizontal wind and temperature fields to similar results from the Global Scale Wave Model (GSWM). The WACCM3 diurnal tidal wind fields are also compared to tropical radar measurements at Kauai (22°N, 200.2°E) and Rarotonga (21.3°S, 199.7°E). The large-scale features of the WACCM3 results, such as the global spatial structure and the semiannual amplitude variation are in general agreement with past tidal studies; however, several differences do exist. WACCM3 exhibits a much higher degree of hemispheric asymmetry, lower overall amplitudes around the equinoxes, and peaks which are more confined in latitude when compared with the GSWM. Factors which may contribute to such differences between WACCM3 and GSWM are the solar heating profiles from ozone and water vapor, dissipation, and the zonal mean zonal winds. We find that the internally generated heating in WACCM3 and eddy dissipation values are both smaller than the values specified in the GSWM; the eddy dissipation fields and zonal mean zonal winds of the two models also display measurable differences in spatial structure. Comparisons with radar data show several differences in spatial and seasonal structure. In particular, the diurnal tide zonal winds in WACCM3 above Kauai are considerably larger in amplitude than those observed in the radar data, due to contributions from nonmigrating tidal components including wave numbers eastward 1 through 3, westward 2, and stationary components, which interfere constructively with the migrating component around equinox in WACCM3.

Keywords: Atmospheric tides; Mesosphere and lower thermosphere; WACCM

1. Introduction

1.1. The migrating diurnal tide

The dominant dynamical feature in the mesosphere and lower thermosphere is the migrating diurnal tide, which is a westward propagating global scale oscillation present in all dynamical fields with a period of 24 h and a zonal wave number of 1. This tidal component is driven primarily through the absorption of solar radiation in the stratosphere and troposphere, as well as the release of latent heat in the troposphere. This tidal perturbation in the lower atmosphere propagates upwards, increasing in amplitude with the decreasing atmospheric density, before depositing momentum in the mesosphere and lower thermosphere (MLT) as it dissipates. Past observations and modeling efforts have shown that this lower atmosphere forcing can drive tidal wind fields in the excess of 40–80 m/s in the lower thermosphere.

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A strong semiannual variation in the amplitude of the migrating diurnal tide exists, maximizing around equinox (March/September) and minimizing around solstice (June/December). Space based observations such as those by the High Resolution Doppler Imager (HRDI) and the Wind Imaging Interferometer (WINDII) onboard the UARS satellite have shown that the low and mid latitudinal structure of the migrating diurnal tide can be largely represented by the hemispherically symmetric (1, 1) Hough mode around equinox, but becomes asymmetric towards solstice as contributions from higher order modes become increasingly important (Hays and Wu, 1994).

1.2. WACCM3 and GSWM

The Whole Atmosphere Community Climate Model (WACCM3) is the next generation general circulation model currently being developed at the National Center for Atmospheric Research (NCAR). WACCM3 utilizes the finite volume dynamical core from the Community Atmosphere Model (CAM), which solves the flux form semi-Lagrangian equations derived by (Lin and Rood, 1996, 1997). Chemistry and tracers are calculated using the Model for Ozone and Related Tracers (MOZART), while mesospheric and thermospheric physics are implemented from the Thermosphere Ionosphere Mesosphere Electrodynamics General Circulation Model (TIME-GCM). The model spans the range of altitude from the surface to 140 km. Important mesospheric and lower thermospheric dynamical features such as the atmospheric tides and global scale planetary waves are excited self-consistently in the model and are free to interact.

The Global Scale Wave Model (GSWM) developed by Hagan et al. (1995), solves the two-dimensional linearized perturbation equations based upon classical tidal theory as laid out by Chapman and Lindzen (1970). The model also includes nonclassical effects due to molecular and eddy diffusion, differential cooling, ion drag, and background wind and temperature gradients. Solar heating rates for ozone and water vapor, as well as latent heating in the GSWM are specified as described in Hagan (1996). Through extensive comparisons with ground based observations in the MLT, the GSWM has been found to correctly generate many of the large-scale features of the migrating diurnal tide, such as the semiannual variation in amplitude, as well as the spatial structure (Burrage et al., 1995; Hagan et al., 1999).

As WACCM3 is significantly more complex than the GSWM, it is expected that WACCM3 will exhibit a higher degree of variability than the GSWM, particularly due to nonlinear wave–wave interactions. As the GSWM has undergone many comparisons with observations of the MLT region, it is a logical starting point for comparisons with WACCM3. Additionally, important fields in linear tidal modeling such as lower atmospheric heating and MLT dissipation can be extracted from WACCM3 and compared with the GSWM fields to gain insight into any observed tidal differences in the MLT.

1.3. Radar observations

Also presented in this study are MF radar measurements of zonal and meridional wind fields from 2002 and 2003 above Kauai (22°N, 200.2°E) and Rarotonga (21.3°S, 199.7°E), which are situated near the theoretical latitudinal maxima of the diurnal tidal horizontal wind fields. Ground-based radar measurements provide excellent temporal coverage of the diurnal tide in the MLT between 80 and 100 km height. However, due to their lack of spatial coverage, the radars cannot resolve the individual components of the migrating and nonmigrating diurnal tide. While the migrating component is usually dominant, increased contributions from various nonmigrating components can significantly alter the observed diurnal tidal amplitudes and phases, complicating the interpretation of observations.

2. Model output and analysis

WACCM3 was run for a two-year period using a horizontal grid spacing of $1.9° \times 2.5°$, a vertical grid spacing of roughly two points per scale height, with 3 hourly output of wind, temperature, solar heating, and eddy diffusion fields as functions of latitude, longitude, and height. The migrating diurnal tide was then extracted from the 3 hourly output data using a least squares fitting algorithm as a function of latitude and altitude. The WACCM3 output height levels were given in terms of pressure coordinates, which were converted to geometric height for comparison with the GSWM results and radar observations.

For comparison with radar data, wind fields from the model and radar measurements were used to create composite days representative of each month. The data from the composite days were then fit to a periodic function with a period of 24 h, thus providing a monthly average amplitude and phase for the diurnal tide over the radar sites.

3. WACCM3 migrating diurnal tide

Fig. 1 shows WACCM3 and GSWM results for the migrating diurnal tidal amplitude fields during January (representative of solstice). Both models generate the expected bimodal structure in the wind fields, with maxima occurring in the tropical lower thermosphere, and temperature maxima occurring at the equator. The amplitudes are of similar magnitude, though the WACCM3 peak amplitudes are slightly stronger by roughly 5 m/s in the wind fields, and 5 K in the temperature fields.

The WACCM3 fields exhibit significantly more asymmetry, with the summer hemisphere peaks roughly 10 km higher, and the tidal structure shifted towards the summer hemisphere. These distortions in horizontal structure may be attributed to zonal mean zonal wind effects (McLandress et al., 1996; Ortland, 2005), which are known to perturb the latitudinal structure of the tide.