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Journal of Atmospheric and Solar-Terrestrial Physics 67 (2005) 1533–1543

Journal of ATMOSPHERIC AND SOLAR-TERRESTRIAL PHYSICS

www.elsevier.com/locate/jastp

A space-based climatology of diurnal MLT tidal winds, temperatures and densities from UARS wind measurements

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Received 13 November 2004; received in revised form 30 July 2005; accepted 1 August 2005

Abstract

A self-consistent global tidal climatology, useful for comparing and interpreting radar observations from different locations around the globe, is created from space-based Upper Atmosphere Research Satellite (UARS) horizontal wind measurements. The climatology created includes tidal structures for horizontal winds, temperature and relative density, and is constructed by fitting local (in latitude and height) UARS wind data at 95 km to a set of basis functions called Hough mode extensions (HMEs). These basis functions are numerically computed modifications to Hough modes and are globally self-consistent in wind, temperature, and density. We first demonstrate this self-consistency with a proxy data set from the Kyushu University General Circulation Model, and then use a linear weighted superposition of the HMEs obtained from monthly fits to the UARS data to extrapolate the global, multi-variable tidal structure. A brief explanation of the HMEs' origin is provided as well as information about a public website that has been set up to make the full extrapolated data sets available.

Keywords: Hough mode extensions; Mesosphere–lower-thermosphere; Diurnal; Tides; Wind; Temperature; Density

1. Introduction

Horizontal winds as measured by the HRDI and WINDII instruments on the Upper Atmosphere Research Satellite (UARS) show a great deal of longitudinal variation between $\pm 40^{\circ}$ due to combination of the most prominent diurnal components of zonal wave numbers $s = -3$ (eastward, DE3), $s = 1$ (westward, DW1), $s = 2$ (westward, DW2), and $s = 0$ (standing, D_0) (Forbes et al., 2003). Significant density and temperature tidal variations accompany these wind perturbations. Because tidal variations represent repeatable fluctuations in atmospheric density, these variations should be able to be reasonably modeled. However, density measurements with adequate local time, longitude and latitude distributions do not exist, especially in the lower thermosphere. Therefore, existing density models do not adequately model migrating tides, and do not include nonmigrating tides at all. Herein, we demonstrate how a set of basis functions called Hough mode extensions (HMEs) can be used to estimate densities, vertical winds, and temperatures from tidal variations in horizontal winds.

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1364-6826/$ - see front matter
doi:10.1016/j.jastp.2005.08.018

HMEs are numerically computed global modifications of Hough modes and velocity expansion functions that account for dissipative effects in the atmosphere (Forbes and Hagan, 1982). The dissipation results in modified vertical and latitudinal structures, therefore leading to a more realistic representation of tidal structures. In addition, the HMEs maintain global self-consistency in amplitude and phase between zonal and meridional winds, vertical wind, temperature and density. This feature is paramount as it is what allows us to use the HMEs to create a complete global picture from the limited amount of horizontal wind data we get from UARS.

In this paper, we elucidate this process beginning with an overview of the Kyushu general circulation model and the global-scale wave model (GSWM) followed by a brief discussion of the origin and calculation of the HMEs. We then demonstrate the accuracy of the fitting technique by treating the Kyushu general circulation model output as a proxy data set, and with it, simulate the work done with the actual UARS data. Finally, we concentrate on the primary purpose of this effort; we produce a global monthly climatology of diurnal tidal winds, temperatures, and density resulting from fitting the HMEs to UARS tidal wind determinations (Forbes et al., 2003). The resulting HME-reconstructed tidal fields can be used, for instance, as data-driven lower boundary conditions for general circulation models in the 80–100 km height regime, or to generate vertical amplitude and phase profiles of diurnal tides at any place on the globe, for comparison with and interpretation of local radar and lidar tidal measurements. These vertical profiles have been produced and are available on the web as will be explained in Section 5. We expect in the future to extend this technique to winds and temperatures measured from the TIMED satellite, and to the semidiurnal and terdiurnal tides as well.

2. Models employed

Two models are employed in this study: The Kyushu University general circulation model (KGCM) to generate a mock data set for testing of the methodology wherein the correct answer is known, and the GSWM for generation of the HMEs. The GSWM (Forbes and Hagan, 1982; Hagan et al., 1995, 1999; Hagan, 1996) is a numerical steady-state solution to the linearized equations for oscillations in a spherical atmosphere, in the presence of prescribed zonal mean wind, temperature, and dissipation distributions. Given the forcing for an atmospheric oscillation with a particular zonal wave number and period, the GSWM computes the height vs. latitude distribution of the amplitude and phase of the response. The KGCM (Miyahara et al., 1993, 1999; Miyahara and Miyoshi, 1997) is a general circulation model extending up to about 140 km with complete tropospheric physics and diurnal cycle throughout the model domain. Migrating tides are primarily excited by H2O and O3 insolation absorption in the troposphere and stratosphere, respectively, and UV/EUV absorption in the lower thermosphere. Non-migrating tides are primarily excited by tropospheric latent heating and planetary wave modulation of migrating diurnal tides.

3. HMEs

Hough modes represent the solutions to Laplace's tidal equation for a periodic oscillation with zonal wave number s and frequency σ in an isothermal atmosphere without mean winds and dissipation. For a given s and σ, there is a series of solutions that are alternating symmetric and antisymmetric about the equator; the lowest-order solutions represent the largest vertical scales, are characterized by the most smoothly varying latitudinal shapes, and hence usually contain most of the energy. In a realistic atmosphere, the latitudinal and vertical shapes of the response to some forcing are distorted due to the effects of mean winds and dissipation; in fact, the horizontal structure changes shape with height, or equivalently, the vertical structure varies with latitude, due to the mathematical inseparability of the system for a realistic atmosphere. The concept of HMEs was developed by Lindzen et al. (1977) and Forbes and Hagan (1982) in order to deal with the changes in shape of Hough modes as they encountered dissipation in an atmospheric regime above that of wave forcing. A HME represents the solution to the linearized dynamical equations of the atmosphere taking into account dissipative effects above the forcing region. For a given s and σ, an HME can be thought of as a latitude vs. height table of amplitudes and phases for the velocity, temperature and density perturbation fields (u, w, v, T, ρ) of the oscillation. The u, w, v, T, ρ perturbation fields maintain internally self-consistent relative amplitude and phase relationships for any given HME. So, if the amplitude and phase of the perturbation wind field is