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Estimates of mesospheric gravity wave activity over convection from a global model

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Abstract

A new convective gravity wave source spectrum parameterization has been implemented in the Whole Atmosphere Community Climate Model version 2 (WACCM2). This parameterization specifies the momentum flux phase speed spectrum of gravity waves in the Tropics based on the properties of underlying convection; Hence, this parameterization provides realistic global estimates of gravity wave activity. In this paper, we show the estimated gravity wave phase speed spectra in the Tropics from a WACCM2 simulation, at the source level and at 85 km. Spatial distribution of gravity wave activity at 85 km is also presented. Subsequently, we discuss the factors that are primarily responsible for the estimated differences in gravity wave distribution across phase speeds with latitude and asymmetries in direction of gravity wave propagation in the mesosphere. We also examine which of the model assumptions can lead to uncertainties in our estimates of mesospheric gravity wave activity and we discuss how these assumptions provide challenges for comparison with observations of gravity waves in the mesosphere.

Keywords: Gravity waves; Mesosphere; Global model; Convection

1. Introduction

Mesoscale gravity waves in middle atmospheric Global Circulation Models (GCMs) are typically parameterized by assuming that gravity waves are uniformly distributed in space and time. Hence, in GCMs it is only the wind and temperature differences with height that determine variations in upper atmospheric forcing due to gravity waves. Such representations of gravity waves do not account for spatial variations in gravity wave sources, nor do they account for changes in gravity wave properties, such as vertical wavelength and phase speed, as a result of differences in their tropospheric forcing region. In this paper, we present results from a Whole Atmosphere Community Model version 2 (WACCM2) simulation with a convective source spectrum parameterization of Beres et al. (2004b). This parameterization launches gravity waves only when convection is present, and links the characteristics of those waves to the properties of the underlying convection. Therefore, the properties of the parameterized waves in the presented simulation, just above the tropopause and in the mesosphere, reflect both: filtering of waves by the mean wind in the stratosphere and mesosphere, and variation in gravity wave sources. We present here the estimated momentum flux phase speed spectra of parameterized waves in the Tropics in WACCM2 at 100 hPa and at 85 km, during four different seasons, as well as latitudinal and longitudinal distribution of gravity wave activity at 85 km.

As many assumptions and simplifications go into gravity wave parameterization in global models, it is important to understand how they influence the global gravity wave estimates presented here. Hence, we discuss how the assumptions about gravity waves in the

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WACCM2 simulation cause uncertainties in our estimates as well as how they pose challenges for comparison with the observations of mesospheric gravity waves.

2. Model and gravity wave parameterization

WACCM2 is a GCM based on the NCAR Community Atmosphere Model (CAM3) (see http://www.ccsm.ucar.edu/models/atm-cam/index.html). It extends to 140 km in the vertical and in addition to CAM's parameterizations, WACCM2 includes the parameterizations of radiative heating, molecular diffusion, and ion drag as described in Sassi et al. (2002). There are 66 vertical levels inWACCM2 with variable vertical resolution ranging from $\Delta z \sim 1.1$ km in the troposphere to $\Delta z \sim 3.5$ km above about 65 km. The horizontal resolution is $2 \times 2.5°$. WACCM2 includes the deep convection parameterization of Zhang and McFarlane (1995) and the shallow/middle tropospheric convective parameterization of Hack (1994).

In the configuration of WACCM2 presented here, Beres et al. (2004b) convective source spectrum parameterization is active primarily in the tropics, between 30S and 30N. In the extratropics the standard, uniform, WACCM2 gravity wave source is used as convection cannot be regarded as the dominant gravity wave source outside of the tropics. WACCM2 uses the Lindzen (1981) parameterization for the upward propagation of gravity waves and calculation of their forcing.

The implementation of the Beres et al. (2004b) parameterization in WACCM2 is described in detail in Beres et al. (2005), however, here we provide a summary of it: this parameterization accounts for the short period (10–120 min) and short horizontal wavelength (10–200 km) gravity waves generated by vigorous convection. At each time step of the model, the vertical profile of the latent heating is used to determine the tropospheric heating depth. The heating depth is crucial to determining the vertical wavelength of gravity waves (Beres, 2004a,b). Deeper heating excites gravity waves with longer vertical wavelengths. The vertical wavelength of gravity waves is almost directly proportional to the wave horizontal phase speed. Combining of the dispersion relation for gravity waves (for waves with frequency much larger than the Coriolis parameter and assuming incompressibility (Fritts and Alexander, 2003)) with the equation for wave phase speed, $c = \frac{v}{k}$, where v is the wave frequency, and k is the horizontal wavenumber, yields the following relation:

$$c = \frac{N}{(m^2 + k^2)^{\frac{1}{2}}}, \tag{1}$$

where m is the wave vertical wavenumber, and N is the buoyancy frequency. The above relation shows that the wave vertical wavenumber is inversely proportional to the horizontal phase speed of the wave, and hence wave vertical wavelength is proportional to wave phase speed. Hence, deeper heating excites gravity waves with larger horizontal phase speeds and long vertical wavelengths.

The Beres et al. (2004b) parameterization also uses the tropospheric wind profile to determine the phase speed spectrum of gravity waves as this can cause large asymmetries between the waves propagating with and opposite to the tropospheric wind.

The current setup in WACCM2 allows only for launching of gravity waves in two directions. In the current simulation, waves are launched in the direction of 700 hPa wind, as this level predominantly determines the motion of convective disturbances (Alexander et al., 1995). Hence, gravity waves are launched in the direction of and opposite to the 700 hPa, and hence carry eastward/westward and northward/southward momentum flux.

The WACCM2 simulation with the Beres et al. (2004b) parameterization implemented in the Tropics (hereafter the B04 simulation) was carried out for 5 years. All the figures in this paper present monthly averages which are composites from the 5 years of simulation.

3. Gravity wave spectra in WACCM2

In order to show the effects of the forcing region properties on the gravity wave spectrum we first show the gravity wave momentum flux phase speed spectra at 100 hPa in the B04 simulation during January, April, July, and October. These are shown for the East–West direction in Fig. 1 and for the North–South direction in Fig. 2.

Fig. 1 shows that over the regions of most vigourous, deep, convection (south of the equator in January, north of the equator in July, and between 10S and 10N in spring and autumn), the gravity wave phase speed spectra in the East–West direction are very broad, with the dominant phase speeds of ~ 20 m s^{-1} in the eastward, and of ~ 30 m s^{-1} in the westward direction. In these regions, the momentum flux carried by eastward propagating waves is a little stronger than the momentum flux carried by westward propagating waves. Such a distribution of momentum flux is due to large heating depths, exceeding 10 km, and weak westward tropospheric winds. Away from the regions of deepest and most intense convection (north of 15N in January, and south of 15S in July), the gravity wave characteristics are very different: convectively generated gravity waves have very low phase speeds (less than 20 m s^{-1}) due to shallower tropospheric heating, and westward propagating waves dominate due to eastward shear in the troposphere.

Fig. 2 shows that gravity wave phase speed spectra in the North–South direction are much narrower than in the East–West direction. This is primarily due to our assumption that gravity waves are launched in the direction of the 700 hPa wind vector. Meridional winds are