The impact of the convective gravity wave drag on CWBGFS

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Abstract

This study investigated the impact of the gravity wave drag generated by convection systems in the 60 vertical levels of the Central Weather Bureau global forecast model (CWBGFS). The gravity wave drag parameterizations is developed by Chun and Baik (1998) and has been tested in NCAR CCM3 (Chun et. al., 2004). The magnitude of gravity wave momentum flux is depended on the thermal forcing and background wind. Momentum flux is zero below the forcing bottom, varies with height in the forcing region, and remains constant above the forcing top. Gravity wave is launched on the cloud top within the convection region. Results demonstrate that convective gravity wave drag has strong impact on the large-scale flow in midlatitude winter hemisphere and in the tropical area where deep cumulus convection persistently exists. The strength of westerly jet in the midlatitude is decreased, and the temperature in the polar area is getting warmer.

Key word: convective gravity wave drag

1. Introduction

Convection is one of the major sources for gravity wave drag generation. Numerous studies demonstrate that gravity waves play an important role in forcing the circulations of the middle and upper atmosphere (e.g., Lindzen and Holton 1968; Dunkerton 1997; Alexander and Vincent 2000), like quasi-biennial oscillation (QBO) in the lower stratosphere; and semiannual oscillations (SAO) at higher altitudes. Gravity wave breaking plays the dominant effect in the global momentum budget (Lindzen, 1981; Holton, 1982, 1983; Vincent and Reid,1983). Studies have shown that the westerly bias and the cold bias of the Northern Hemisphere winter mean flow can be reduced by including gravity wave drag parameterization in the model (Palmer et al., 1986; McFarlane 1987).

Gravity waves are not resolved in GCMs due to their small horizontal wavelengths (10–200 km) and short periods (10–100 min). The accurate parameterization of such waves has been difficult due to the incomplete understanding of gravity wave generation from convection. The spectrum of convectively generated gravity waves is currently not resolved in general circulation models and must be parameterized. Several studies have demonstrated that the spectral characteristics of convectively forced gravity waves can be deduced from the knowledge of convective heating (Lane et al. 2001; Beres et al. 2002, 2004;Song et al. 2003), both diabatic and nonlinear sources are important for wave generation by convection.

Studies have concluded that there is a strong connection between the vertical wavelength and the depth of the heating region (Alexander et al., 1995; Salby and Garcia, 1987). Convectively generated gravity waves are primarily forced by the latent heating and nonlinear advection terms within the convective region (Song et al. 2003, Lane et al. 2001). Beres et al. (2002) presented a sensitivity study of gravity wave characters to different profiles of tropospheric wind. They found that the dominant phase speed and vertical wavelength of gravity waves are primarily controlled by the tropospheric convection properties. Beres et al. (2004a, and 2004b) have developed a method of specifying the gravity wave spectrum above convection based on the latent heating properties and background winds in the convective region. Beres et al. (2005) implemented a convectively generated gravity wave spectrum into Whole Atmosphere Community Climate Model and noted an improvement of the tropical stratospheric semiannual oscillation (SSAO) and the mesospheric semiannual oscillation (MSAO). Richter et al. (2014) follow the same gravity wave parameterization to examine the role of the convective gravity wave to the various of QBO in the Community Atmosphere Model, version 5 (CAM5) and concluded that with the combination of higher vertical resolution and the proper convective gravity wave source, the QBO had a better seasonal cycle in the general circulation model (GCM).

The current settings of CWBGFS include a non-orographic gravity wave parameterization followed by Scinocca, 2003. The method of “back-reflection” is developed by Warner and McIntyre (1996). Since the latest NCEP is using Chun and Bail’s as their convective gravity wave scheme, and the convection properties have strong impact on the convective gravity wave distribution, it would be a proper way to switch the convective gravity wave scheme into Chun and Bail’s parameterization. we present a study herethe impacts of gravity wave by Chun and Baik’s scheme.

2. Model Description

The simulations carried out in our study use the Central Weather Bureau global forecast model (CWBGFS) with T511 resolution. There are 60 levels in vertical with the model top at ~ 0.65 hPa. More detail about the method of convective gravity wave parameterization implementation can be found in Chun and Baik [1998]. Convective gravity waves are launched at the top of convection wherever convection and are present globally, not only in the tropics. Both deep and shallow convection have the contribution to the gravity wave characteristics. The source spectrum and the magnitude of the convectively generated gravity wave are dependent on the heating depth, amplitude, and the mean background wind. The momentum flux is zero below the cloud bottom, varies with height in the forcing region, and remains the constant value above the forcing top. Two simulations presented in our study were carried out for five days forecast in July 2015 and January 2017. Both are conducted with the Scinocca convective gravity wave parameterization and Chun and Baik scheme separately, and are compared their difference.

3. Result

This section we describe the changes of the mean state in our simulation due to the different convective gravity wave drag parameterizations. Generally, the cold temperature bias in the polar region is the common problem in the global circulation model. The zonal mean of zonal winds and temperature are in Figure 1 (for zonal wind)and Figure 2 (for temperature). Figure 1 is the zonal wind in 2015 (left) and 2017 (right). Top panel is the original CWGBFS setting (with Scinocca's scheme), middle is the running with Chun and Baik's setting, the bottom is the difference between Chun and Scinocca (middle figure minus top). Result shows there is significant 15 m/s decreasing in westerly jet strength. The easterly wind in the tropic area at the height of 100-500 hPa decreases around 6 m/s. Simulations in July (Figure 1 left panel) and January (right panel) all present the weakening westerly jet when we replaced Chun's convective gravity wave drag in the model. The winter southern hemisphere shows the stronger respond than the winter northern hemisphere. Figure 2 is the zonal mean temperature in the same time zone setting. Figure 2 has the same figure illustration with Figure 1. The bottom panel presents the warming effect in polar region when the simulation run with Chun and Baik's parameterization. The warming effect mainly occurs in the middle troposphere to the upper troposphere. Temperature increases about 3 degrees in the winter polar region. The winter southern hemisphere has more significant warming effect than northern hemisphere.

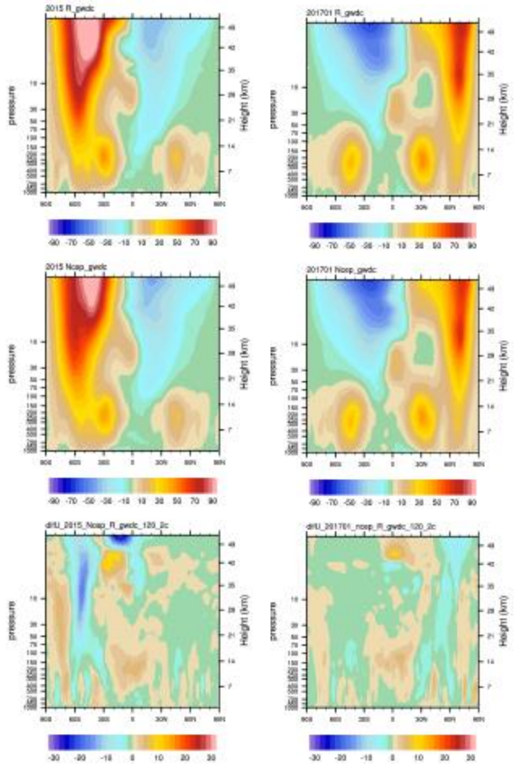

Figure 1. The zonal mean of zonal wind (m/s) in July 2015 (left) and January 2017 (right). Top panel is the original CWGBFS setting (Scinocca's scheme), middle is Chun and Baik's, the bottom is their difference between Chun and Scinocca (middle figure minus top).

4. Discussion

We have shown the effects of the added Chun and Baik's scheme in CWBGFS with 60 vertical levels and T511 resolution. Results present Chun and Bail's scheme has a significant impact on the basic fields, such as wind and temperature. The weakening westerly jet strength could be related with the westward gravity wave propagation in the upper air in the mid-latitude. The decreasing jet strength reflects the reduction of the meridional temperature gradient. The warming effect on the polar regions indicate the temperature gradient between the tropic and polar region has been decreased. Researches have concluded the connection between the residual circulation and the warming effect in the polar region (Andrews et. al., 1987; Baldwin, et. al., 1994). The downward branch of the residual circulation in the polar region induces the warming effect there. The increasing temperature in our simulation may as a result of enhancement of the residual circulation.

Our preliminary result demonstrate that the Chun and Bail's scheme can decrease common model problems of the strong westerly jet bias in the mid-troposphere, and cooling bias in the polar region. Further investigation is required to confirm the results shown here, and to understand the dominate processes which are sensitive to the parameterizations of the convective gravity wave drag.

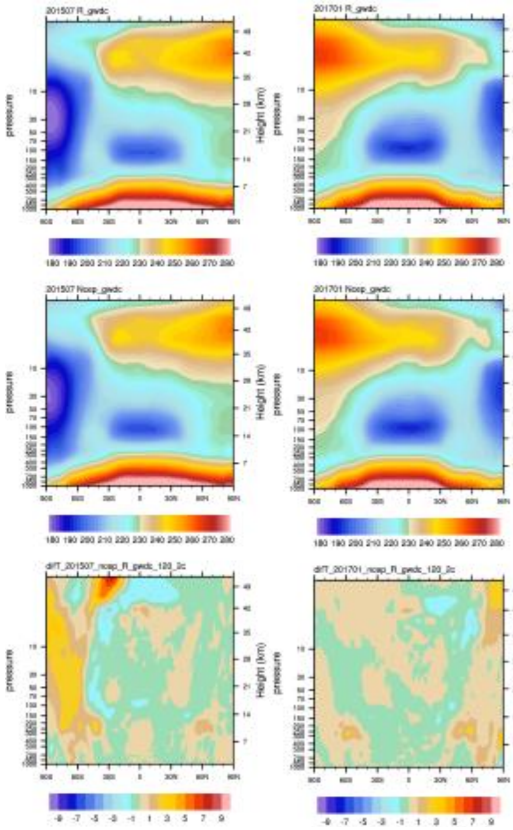

Figure 2. The zonal mean temperature (^oC). It has the same panel description with Figure 1.

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