GENERATING QBO IN WACCM USING PARAMETERIZED INERTIAL GRAVITY WAVES

Xianghui Xue & Hanli Liu
NCAR/HAO
2010-02-22
OUTLINE

- Motivation
- Numerical Tests Group 1 (3 cases):
  - symmetric GW spectrum
  - Without consideration of Coriolis Force
- Numerical Tests Group 2 (1 case):
  - asymmetric GW spectrum
  - With consideration of Coriolis Force
- Conclusion
**MOTIVATION: IGW PARAMETERIZATION**

- Typical observed GW momentum flux is \( \sim 10^{-3} \) Pa.
  - \( a=86 \text{ m/s/d (70km), 11 hours for 40m/s change: parameterized in WACCM/WACCM-X by mesoscale gravity wave.} \)
  - \( a=8.6 \times 10^{-2} \text{ m/s/d (20km), 465 days for 40m/s change: QBO scale, but not resolved or parameterized in WACCM/WACCM-X.} \)

- Wanted: GWs with similar momentum flux break both in the stratosphere and in the mesosphere.

- According to Holton (1982), \( z_b \propto 2H \ln(2\pi / \lambda_h A) \), horizontal wavelength and wave amplitude are equivalent in determining wave breaking altitude. An order of magnitude increase in horizontal wavelength/wave amplitude will lead to decrease of breaking level by \( 4.6H \sim 32 \text{km} \).

- Therefore, to account for stratospheric forcing while keeping the mesospheric forcing, a spectrum of inertial GWs with the same momentum flux should be added to the parameterization.
NUMERICAL TESTS G1:
WITH SYMMETRIC GW SPECTRUM AND WITHOUT CORIOLIS FORCE

inertial GWs wavelength
\[ \lambda_h = 1000 \text{km} \]

inertial GWs spectral
\[ c = [-c_0, -c_0 + 1 \text{m/s}, \ldots, 0, \ldots, c_0 - 1 \text{m/s}, c_0] \]

inertial GWs forcing regions
latitude: \(-30^\circ, 30^\circ\)
launch altitude: 200 mb

inertial GWs tau at launch altitude
\[ \tau = 0.001 \text{Pa} \]

efficiency: \( \text{eff}_\text{QBO} \)
NUMERICAL TEST G1:

Case 1: $c_0 = 30 \text{m/s}$, $\text{eff}_QBO = 1.0$

Equatorial zonal mean zonal wind at 10 mb and its FFT spectrum.
NUMERICAL TEST G1:
Case 2: \( c_0 = 20 \text{m/s}, \text{eff}_{-QBO} = 1.0 \)

Equatorial zonal mean zonal wind at 10 mb and its FFT spectrum
NUMERICAL TEST G1:
Case 3: $c_0 = 20 \text{m/s}$, eff\_QBO $= 0.1$

Equatorial zonal mean zonal wind at 30 mb and its FFT spectrum
Case 3: $c_0 = 20\, \text{m/s}$, $\text{eff}_\text{QBO} = 0.1$

The Fourier harmonic axis indicates the number of cycles that a given periodic mode experienced during the 44 years of the ERA-40 data set. From Pascoe 2005.
GW spectral width affects the amplitudes of the oscillation of equatorial zonal wind and also have an small effect on the period of the oscillation.

Symmetric GW spectrum causes the symmetric oscillation of equatorial zonal mean wind.

The efficiency/intermittency of IGW has an evident effect on the period of the oscillation of equatorial zonal wind. The proper choice of the efficiency can produce the QBO-like oscillation in stratosphere and mesosphere.

The asymmetric GW spectrum (westward shift) will be considered
NUMERICAL TEST G2:
ASYMMETRIC GW SPECTRUM AND WITH CORIOLIS FORCE

inertial GWs wavelength
\[ \lambda_h = 1000 \text{km} \]
inertial GWs spectral
symmetric GW spectrum \( c \) + westward shift
inertial GWs forcing regions
latitude: \(-30^\circ, 30^\circ\)
launch altitude: \(200 mb\)
inertial GWs tau at launch altitude
\( \tau = 0.001 Pa \)

effeciency: \text{eff } QBO
NUMERICAL TEST G2: CORIOLIS FORCE EFFECTS

- Dispersion Relation: 
  \[ m^2 = \frac{N^2}{(c-u)^2-f^2/k^2} \]

- Critical level: 
  \[ u - |f|/k \leq c \leq u + |f|/k \]

- Saturation Stress: 
  \[ \tau^* = \frac{k\rho_0}{2N} [(c-u)^2 - f^2/k^2]^{1/2} (c-u)^2 \]

- Acceleration of zonal wind: 
  \[ \frac{\partial u}{\partial t} = -\frac{1}{\rho_0} \frac{\partial \tau^*}{\partial z} = \frac{k[(c-u)^2-f^2/k^2]^{1/2}(c-u)^2}{2NH} \]
NUMERICAL TEST G2:

Case 1: \( c_0 = 20 \text{m/s}, \Delta c = 5 \text{m/s} \) (westward shift), \( \text{eff}_\text{QBO} = 1.0 \)

Equatorial zonal mean zonal wind at 10 mb and its FFT spectrum
CONCLUSION -2

- Asymmetric GW spectrum (westward shift) causes the westward shift of the equatorial zonal mean zonal wind.

- The Coriolis effect ($f/k$) causes the critical level lower than that without the effect of $f/k$, and the higher atmospheric density in lower critical layer region reduces the acceleration of zonal mean wind and causes the oscillation with a longer period.
NEXT WORK:

- Generate QBO-like oscillation with Coriolis effect and asymmetric GW spectrum

- Combine the parameterization of IGW with the parameterization of the convective system, and try to obtain a near realistic scenario.
Thank you for your attention!