Quasi-Biennial Oscillation in WACCM: Parameterization and Evaluation

Han-Li Liu\textsuperscript{1}, Xianghui Xue\textsuperscript{2}, Rolando Garcia\textsuperscript{3}, Mike Mills\textsuperscript{3}

1. High Altitude Observatory, National Center for Atmospheric Research
2. University of Science and Technology of China
3. Atmospheric Chemistry Division, National Center for Atmospheric Research
Overview

• Absence of QBO in WACCM and possible causes.
• Development of an inertio-gravity wave (IGW) parameterization scheme.
• Evaluation of WACCM simulations with the IGW.
  – Zonal mean wind, temperature, ozone at the equator.
  – Extratropical effects.
  – Surface signature.
Possible Driving Forces of QBO

- $F(GW/IGW)$ likely much larger than $F(PW)$
- PW (Kelvin waves, Rossby-gravity waves) resolved by WACCM (albeit weak).
- Mesoscale GW parameterized, breaking mainly in mesosphere.
- IGW poorly resolved, and not parameterized.

Baldwin et al, 2001
Requirement for QBO Forcing

• QBO Acceleration rate:
  - 50 m/s/14 months ~ 10^{-6} m/s^2
  - \( Q \frac{\partial u}{\partial t} = -\frac{1}{\rho} \frac{\partial \tau}{\partial z} \approx -\frac{1}{\rho} \frac{\Delta \tau}{\Delta z} \)
    \( \Delta \tau \sim 10^{-3} \text{ Pa} \) (\( \rho_{\text{strat}} \sim 0.1 \text{kg/m}^3 \), \( \Delta z \sim 10 \text{km} \))

• For GW with such momentum flux to break in the stratosphere, the horizontal wavelength is ~1000 km according to linear saturation theory.

• Also possible: intermittent mesoscale GW with large momentum flux (e.g. \( t \sim 10^{-2} \text{ Pa} \), occurring 10% of the time). Not considered in this study.
Parameterizing Inertia-GW

- Similar to Lindzen (1981), though considering Coriolis effect (Xue et al., 2011).

\[
\frac{\partial u}{\partial t} = - \frac{1}{\rho_0} \frac{\partial \tau^*}{\partial z} = \frac{k[(c-u)^2-f^2/k^2]^{1/2}(c-u)^2}{2NH}
\]

- A discrete spectrum of IGWs is launched at each grid point from tropopause between 30S-30N. Uniform longitudinal distribution.

Zonal Wind Spectrum: Equator

U spectral amplitude (m/s) at the Equator

Wavelet power: zonal mean U, equator 10 hPa

Wavelet power: zonal mean U, equator 10 hPa
Composite Zonal Mean U: Equator

- 10 hPa: Westerly phase 18 mon. in WACCM, compared with 10 mon. in reanalysis.
- Westerly phase becomes shorter at lower altitude, opposite to the reanalysis.
- Westerly phase stops at 40 hPa.
Temperature Spectrum: Equator

Wavelet power: zonal mean T, equator 10 hPa

Wavelet power: total O3, equator
DJF Composite Diffs: W-E

Holton and Tan, 1980
Planetary waves (1-2): W-E

Holton and Tan, 1980
DJF Composite T Diff: W-E
Correlation Between $Z/Z_1$ with $U(43\text{hPa})$
Surface Pressure: W-E

Holton and Tan, 1980
Summary

• The new IGW parameterization scheme produce QBO-like oscillations in CESM/WACCM4 simulation (1850-2004).
• Stratosphere zonal mean zonal wind around equator oscillates with a mean period of 28 months. Wavelet analysis shows that the period and strength of the oscillation vary with time.
• Lengths of QBO W/E phase differ from observations.
• Mesosphere QBO weak compared with observations.
• Holton-Tan relation reproduced: W phase -> lower geopotential/temperature, stronger jet at high latitudes of winter hemisphere.
• Surface pressure change consistent with reanalysis. W phase -> low pressure anomaly over winter pole and high pressure anomaly over northern Pacific (50N) and Atlantic (40N) oceans.