Studying ‘cold pole’ problem in WACCM and comparisons to lidar temperature morphology

Bo Tan¹, Han-Li Liu², Xinzhao Chu¹,³
1. Aerospace Engineering, University of Colorado
2. HAO/NCAR
3. CIRES, University of Colorado
Outline

• **What is Cold Pole Bias in Models**
  – Cold bias of southern winter stratosphere temperature in the polar region.
  – Winter polar vortex is too strong and breaks down too late.
  – Ozone recovery is too late.
  – Identified as an important model bias to be addressed in last WAWG meeting.

• **Possible causes of Cold Pole bias**
  – Lack of westward wave forcing in southern stratosphere (e.g. Austin et al., 2003).

• **Method to correct Cold Pole bias**
  – Add gravity waves in WACCM which will break in the stratosphere to compensate the missing forcing.

• **Simulation Results of WACCM**
  – Comparison with original gravity scheme using specified chemistry
  – Comparison with Lidar Observation
  – Comparison with ERA-40
  – Simulation results with interactive chemistry
Comparison of WACCM and Lidar temperature climatology at Rothera and South Pole

Figure: Temperature climatology at Rothera (67.5 S, 68 W) and South Pole from WACCM outputs and lidar observations. Stratopause are marked as solid black lines in each figure.
Figure: The upper two figures are temperature difference between lidar and WACCM at Rothera (upper left) and South Pole (upper right). The bottom two figures are temperature difference between South Pole and Rothera from lidar (bottom left) and WACCM (bottom right).
New gravity wave scheme

\[ z_b \propto 2H \ln \left( \frac{2\pi}{\lambda_h A} \right) \]

Gravity wave breaking level, Holton et al [1982]

- Original Scheme: Mesoscale waves, horizontal wavelength 100 km, break in the mesosphere and lower-thermosphere (MLT)
- New Scheme: Horizontal wavelength 1000 km, break in the upper stratosphere or lower mesosphere
  - case 1: Add the inertia gravity waves at Southern Hemisphere between 30 S and 90 S
  - case 2: Add the inertia gravity waves at Southern Hemisphere between 30 S and 90 S and Northern Hemisphere between 30 N and 90 N.
- This scheme has been used by Xianghui Xue and Hanli Liu to solve the QBO problems in WACCM [Xue et al., in press]
August. Zonal wind comparison of simulated results and observation

**Original GW scheme**

**HRDI on UARS**

Swinbank and Ortland 2003

**Add inertial GW at SH**

**Add inertial GW globally**

**ERA-40**
September. Zonal wind comparison of simulated results and observation

Original GW scheme

Add inertial GW at SH

Add inertial GW globally

ERA-40

Swinbank and Ortland 2003

HRDI on UARS
October. Zonal wind comparison of simulated results and observation

Original GW scheme

Add inertial GW at SH

Add inertial GW globally

HRDI on UARS

Swinbank and Ortland 2003

ERA-40
November. Zonal wind comparison of simulated results and observation

Original GW scheme

Add inertial GW at SH

Add inertial GW globally

ERA-40

Swinbank and Ortland 2003
December. Zonal wind comparison of simulated results and observation

Original GW scheme

Add inertial GW globally ERA-40

Add inertial GW at SH

Swinbank and Ortland 2003
Temperature comparison of with lidar data using new GW scheme

(a) Rothera, WACCM Data - Lidar data

(b) South Pole, WACCM Data - Lidar data

Temperature difference with lidar data using new GW scheme.
Zonal wind, specified chemistry and interactive chemistry

July

August

September

Specified Chemistry

Interactive Chemistry

WACCM U, month: 7

WACCM U, month: 8

WACCM U, month: 9
Zonal wind, specified chemistry and interactive chemistry

October

November

December

Specified Chemistry

Interactive Chemistry
Conclusions

Using new gravity wave scheme:

• Zonal mean wind speed:
  Winter: Reduced zonal mean speed.
  Summer: Tropopause wind reversal altitude is decreased, closer to ERA-40.

• Comparing with ERA-40, the zonal wind difference between WACCM simulation and ERA-40 is reduced

• Winter temperatures in the stratosphere are warmer and in the lower mesosphere are colder in new scheme, so the cold & warm biases are reduced, closer to lidar observations.

• Spring time polar vortex recovery happens earlier (now in October, rather than November)

• This study demonstrate that the inertial gravity wave breaking plays an important role in the stratosphere and mesosphere dynamics.
Thanks
Background of Cold Pole

Temperature biases at 80 N and 80 S for the winter and spring seasons, as a function of pressure. To determine the bias, a climatology determined from 10 years of UKMO data assimilation temperatures was subtracted from the model.

Eyring et al., 2006

Austin et al., 2003
Possible mechanisms of Cold Pole

**Atmosphere circulation and adiabatic heating/cooling**

- Zonal mean wind
- Brewer Dobson circulation (BD)
- Upwelling from BD
- Downwelling from BD
- Adiabatic cooling BD
- Adiabatic heating BD
- Eastward GW filtering
- Pole-to-pole circulation
- Downwelling of Pole-to-Pole circulation
- Adiabatic heating, Pole-to-pole

**Difference of circulation and adiabatic heating/cooling between model and observation**

- Larger
- Smaller
- Smaller
- Smaller
- Smaller
- Larger
- Larger
- Larger
- Larger
- Larger