Representing the missing gravity wave forcing in the SH winter stratosphere

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motivation: implementation of new heterogeneous chemistry module in WACCM

Updated het chemistry changes partitioning of condensed-phase HNO$_3$ between Nitric Acid Tri-hydrate (NAT) and Supercooled Ternary Solution (STS) [see Wegner et al., JGR, 2013.]

- Updated het chemistry decreases the amount of irreversible denitrification by decreasing NAT and increasing STS
- Less denitrification allows reformation of ClONO$_2$ in Spring ⇒ continued heterogeneous halogen activation
- Heterogeneous rate for halogen activation on STS is very T-dependent (the colder, the faster)
- Both these factors require a more accurate representation of model winter/spring LS polar temperatures
which leads to a problem...

Observed and Calculated Ozone at Haley Bay

- model with **old chemistry** (blue) was reasonably consistent with observations
- model with **new chemistry and specified dynamics** (purple) gives good results
- model with **new chemistry and free running dynamics** (green) produces unrealistically low ozone column because new heterogeneous chemistry module is very sensitive to cold temperatures
the ultimate cause of the problem

SH polar cap T climatology: 1980-2010

WACCM4

- standard version of WACCM4 has a "cold pole" bias in the SH (70°-90°S)

MERRA

- T in ozone hole region/season is as much as 5-10 K colder than observed
components of a possible solution

- polar temperatures are sensitive to wave-induced downwelling; this suggests that wave forcing is too weak in the SH

- *resolved wave* amplitudes and dissipation are not easily adjustable

- *parameterized gravity wave* forcing is adjustable, but “tuning” the existing parameterization to make GW break in the stratosphere degrades the simulation in the mesosphere

- parameterized non-orographic GW in WACCM4 are “mesoscale” (typical $L_x = 100$ km); however, any physically confined source actually excites a (“red”) spectrum in wavenumber

- add a second spectrum of waves, with $L_x \sim 300$ km (typical of the inertia-gravity range, IGW) to represent the effects of longer waves

- the longer IGW should have larger source amplitudes so that they can break in the stratosphere for reasonable values of the source stress

- orographic gw sources are fixed but it the momentum forcing can be tweaked by adjusting the “efficiency” (an intermittency factor, currently set at 0.125)
observational support for gw momentum forcing in the SH winter stratosphere

scintillation from stellar occultation
-> a measure of turbulence
-> signal not well correlated with topography

momentum forcing derived from radiosondes at 55°S

Zink and Vincent, JGR, 2001

Gurvich et al, GRL, 2007
Limits to propagation for inertia-gravity waves

The cutoff is applied to the wave after it is launched. Note that the limit is not applied to mesoscale or orographic GW.

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

This means that waves must satisfy the following in order to propagate \((m^2 > 0)\)

\[
(u - c) < -\frac{f}{k}
\]

\[
(u - c) > \frac{f}{k}
\]
1st complication: four GW parameterizations

- **convective** - assumed to have no role in polar forcing
- **spectral frontal** – drive mesosphere summer to winter circulation
- **orographic** – momentum forcing in winter stratosphere
- **new inertia gravity waves** – goal is to have momentum forcing in winter SH stratosphere that does not have much impact on the NH winter, the summer of either hemisphere, or the mesosphere

Each parameterization interacts with the background winds and therefore they affect one another and also the momentum forcing by resolved waves.

SOLUTION: much tuning
2nd complication: upward wave flux at source

observations from lower stratosphere over Antarctica
(de la Cámara et al., JGR, 2014)

We want parameterization to be compatible with obs but waves with these values of momentum flux break high (middle mesosphere)

SOLUTION: use a low efficiency but fairly high momentum flux for spectral waves
3rd complication: orographic vs non-orographic

These obs show that wave fluxes are higher over mountainous terrain than over smooth.

However, other obs suggest momentum flux and/or forcing is tied to stratospheric jet.

SOLUTION: use both, with increased efficiency for orographic GW

Herzog et al., JAS, 2012
4th complication: winter & summer forcing

Some waves in the spectrum warm the winter lower stratosphere while others reduce the wind shear in the summer mesosphere and therefore warm the summer mesopause.

SOLUTION:
• high momentum flux to concentrate wave forcing in the stratosphere
• orographic waves affect winter but have little impact in summer
monthly column ozone: WACCM vs Halley Bay

annual cycle 1995-2004
black: obs
red: WACCM
monthly T: WACCM vs SABER

January

Jan T 053 (10 yrs)
Jan T SABER (2002–2013)

July

Jul T 053 (10 yrs)
Jul T SABER (2002–2013)
seasonal evolution with new settings

OLD (30 years)

NEW (10 years)

- much improvement of temperature bias in winter, early spring
- late circulation reversal improved but still persists
impact on NH

WACCM

MERRA

difference

climatology still looks good
new settings? – currently being evaluated

<table>
<thead>
<tr>
<th>component</th>
<th>change</th>
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<tbody>
<tr>
<td>orographic</td>
<td>increased efficiency (x 2)</td>
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<tr>
<td>convective</td>
<td>no change</td>
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<tr>
<td>mesoscale</td>
<td>reduced upward flux</td>
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<td></td>
<td>changed threshold for frontal trigger</td>
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<td>inertial</td>
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<td></td>
<td>Lx=300 km</td>
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<td>wave speed spectrum as in mesoscale gw</td>
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