Observed and Resolved Mountain Waves from the Surface to the Mesosphere Near the Drake Passage

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Objective 1:
To provide estimates of middle-atmosphere momentum flux and drag anchored to reality

Objective 2:
Use these estimates to improve/constrain MW drag parameterizations

Approach:
Use primarily satellite observations and multiple validated MW-resolving models to quantify MW MF and drag
Model Validation, Comparison

This Talk/Paper
Participating Models, Configurations

• Four MW-resolving models participating (soon five):
  • Limited Area - *WRF (dx=3km), Met Office UM (dx=3km)
  • Global – ECMWF IFS (dx~9km), German ICON (dx~13km)
  • All forced/initialized with 2010 operational IFS analyses

• $2^\circ$ WACCM nudged to MERRA-2 with two OGWD params
  • Old param: isotropic, McFarlane type OGWD parameterization
  • New param: anisotropic, better SGS ridge heights
  • Strong nudging: 6 hour nudging time scale

• Performed deep ($z = 0 – 80 \text{ km}$) hind-casts of 8-19 Oct 2010 over the Drake Passage
  • Allows AIRS kernels to be contained within domains => model/AIRS comparison possible
  • Deep, realistic simulation a new capability of WRF
AIRS/Model Comparison

- Synthetic AIRS “data” generated from 4-D model fields (done by Lars Hoffmann)
  - Quite involved! Take into account:
    - Obs time
    - Viewing geometry
    - Radiative transfer of individual relevant channels to estimate radiation to sensor
AIRS/Model Brightness $T'$ Comparison

Fig. 4. A good comparison, by eye.
FIG. 5. An ok comparison, by eye. Clear difference in waves as a function of resolution.
AIRS Swaths Used in Model Validation

• Observed $T_b$’ Contoured

• Areas contoured contained within all model domains

• 24 Overpasses used in MIP validation
Observed, Simulated Brightness T' Spectra

- Averaged over all overpasses (prev. slide)
- All models under-represent observed T_b'

Modeled, Overpass-Avg T_b’ spectra have same shapes as observed, except for observed scales influenced by noise

Amplitude error metrics averaged over all overpasses.

\[
\frac{\Delta T_b'}{\sigma_{T_b'}} = \text{spatial standard deviation of } T_b'
\]

\[
\Delta T_b' = T_{b', model} - T_{b', obs}
\]

<table>
<thead>
<tr>
<th>Waveband</th>
<th>WRF</th>
<th>UM</th>
<th>IFS</th>
<th>ICON</th>
</tr>
</thead>
<tbody>
<tr>
<td>15\mu m High</td>
<td>( \frac{\Delta T_b'}{\sigma_{T_b'}} ) (%)</td>
<td>-18.63</td>
<td>-30.41</td>
<td>-32.30</td>
</tr>
<tr>
<td>15\mu m Low</td>
<td>( \frac{\Delta T_b'}{\sigma_{T_b'}} ) (%)</td>
<td>-8.30</td>
<td>-23.06</td>
<td>-21.34</td>
</tr>
<tr>
<td>4.3\mu m</td>
<td>( \frac{\Delta T_b'}{\sigma_{T_b'}} ) (%)</td>
<td>-3.94</td>
<td>-18.54</td>
<td>-39.13</td>
</tr>
<tr>
<td>4.3\mu m</td>
<td>( \frac{</td>
<td>\Delta T_b'</td>
<td>}{\sigma_{T_b'}} ) (%)</td>
<td>16.52</td>
</tr>
</tbody>
</table>
U, MF\(_x\), and MWD\(_x\) Intercomparison
• Global models (IFS, ICON) under-represent middle-atmosphere MFs and GWDs

• Even with parameterized drags in IFS
Mini-MIP, Parameterization Comparison

- Previous and new MWD parameterizations evaluated in $2^0$ WACCM strongly nudged to MERRA-2

- Previous param:
  - Mountain height from sub-grid-scale (SGS) variance
  - SGS terrain assumed isotropic

- New Param (Bacmeister et al., in prep):
  - Dominant ridges in SGS determine mountain heights
  - Ridge orientation accounted for
  - In latest version of CESM/CAM
High-Res Model, Parameterization x-Comparison

- WRF, UM dx ~ 3 km U, MF_x, and MWD_x over the Southern Andes

- Previous, New parameterized MW MF_x and drag
High-Res Model, Parameterization y-Comparison

- WRF, UM dx ~ 3 km, MF$_y$, and MWD$_y$ over NW/SE-oriented South Georgia

- Previous, New parameterized MW MF$_y$ and drag
CAM OGWD Param. Summary

- New anisotropic, SGS-ridge-based OGWD parameterization significant improvement over previous parameterization
- Still lots of room for improvement; too much drag at too low an altitude

Hypotheses:
- Source MW amplitudes too large?
  - True for Antarctic Peninsula, South Georgia
- Lateral MW propagation, spreading?
  - Eckermann et al. 2015, 2016
- Vertical/Temporal spreading?
  - Kruse and Smith 2018
Lateral Spreading Strongly Influences MW Breaking Levels

Normalized Max MW Amplitude

Param: $z_{\text{break}} \sim 40\text{km}$

Linear theory for isotropic mountain: $z_{\text{break}} \sim 80\text{km}$!
Summary

• State-of-the-Science models can reproduce observed middle-atmosphere mountain waves surprisingly well

• Mountain wave parameterization still needed in current O(10km) resolution NWP models
  • Resolved drags in dx~9km IFS, dx~13km ICON significantly lower than dx=3km WRF, UM
  • Significant MF, GWD contributions from 10-60 km scales that are poorly resolved/unresolved by O(10km) resolution models (last extra slide)

• New anisotropic, SGS-ridge-based mountain wave drag parameterization in latest version of CESM/CAM a significant improvement over previous isotropic, SGS-variance-based parameterization
  • Still, lots of room for improvement; incorporate lateral spreading to raise drag levels upward?
Thanks!

• Apologies for way too many slides

• Any comments/feedback appreciated! ckruse@ucar.edu
Orog Spectra MIP

(a) Southern Andes

(b) Southern Andes Slope PDF

(c) Antarctic Peninsula

(d) Antarctic Peninsula Slope PDF

(e) South Georgia

(f) South Georgia Slope PDF
10-m Wind MIP by Sub-Domain
Overview by Sub-Domain
MF_x, GWD_x
Cospectra MIP