Characteristics of gravity waves from convection using idealized model simulations

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Gravity waves from convection impact weather & climate on many scales

Simulated surface pressure perturbations from idealized model. Convectively-generated GWs interact with active convection (red).

Convectively-generated GWs in the stratosphere observed by the AIRS satellite.

Seasonal descent of the zero zonal mean wind line at 61.25 S in the MetUM. Scaife et al. (2002)
Idealized modeling approach

Full-Physics Model

Heating algorithm

Apply to observed precipitation

Run Idealized Model forced with $Q(x,y,z,t)$
Why develop an idealized model?

**Cloud-resolving model:**
- Convective cells are not in the right place at the right time
- No direct observational validation of local/instantaneous GW amplitudes possible
- These matter: turbulence, mixing, breaking levels

**Idealized model:**
- Compare to surface GW observations
- Compare to satellite GW observations
- Inform GCM GW drag parameterizations
- Disentangle complex processes
We need a full-physics model that generates realistic heating and realistic waves!

Potential problem:
Many physics schemes!
Many hydrometeor distributions!
How different will the heating distributions be?
How does this affect the waves?

<table>
<thead>
<tr>
<th>Run</th>
<th>15 km</th>
<th>3 km and 1 km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CU</td>
<td>PBL</td>
</tr>
<tr>
<td>MOR I</td>
<td>KF</td>
<td>YSU</td>
</tr>
<tr>
<td>MOR II</td>
<td>BMJ</td>
<td>MYJ</td>
</tr>
<tr>
<td>MOR III</td>
<td>G3</td>
<td>YSU</td>
</tr>
<tr>
<td>WSM6 I</td>
<td>KF</td>
<td>YSU</td>
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Full-physics model

Results from ensemble runs:
Microphysics scheme strongly affects hydrometeor distributions
But: The average heating profiles are relatively similar
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Microphysics scheme strongly affects hydrometeor distributions
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Most importantly:

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<th>Flux ( \times 10^5 \text{Pa}(m/s)^3 \text{rad}^{-1} )</th>
<th>MOR</th>
<th>WSM6</th>
<th>WDM6</th>
<th>TOM</th>
<th>MY</th>
</tr>
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<tbody>
<tr>
<td>Integrated flux ( \times 10^3 \text{Pa} )</td>
<td>13.32</td>
<td>12.42</td>
<td>14.24</td>
<td>14.45</td>
<td>16.82</td>
</tr>
</tbody>
</table>

azimuthal direction: propagation direction
radial direction: phase speed
We need a full-physics model that generates realistic heating and realistic waves!

Momentum flux spectra of GWs above simulated storms are relatively insensitive to the choice of microphysics scheme. **Time-mean, large-area average properties are robust**

But are the wave amplitudes realistic?
Heating algorithm

- Converts 4 km x 4 km 10 min precip. rates \((x,y,t)\) to vertical profile of \(Q(x,y,t,z)\)
- Derived from full-physics simulations
- Implicitly includes: advection, evaporation and ice-phase processes
Idealized model forced with NEXRAD obs.

**Idealized model snapshot**
Radar precipitation (colors) and wave vertical velocities (shades of gray)
Idealized model: Validation

Idealized model reproduces spectra of full-phys. model...
Idealized model: Validation

Idealized model reproduces spectra of full-phys. model...

...and satellite observations with correct amplitudes!
Impacts on the stratosphere

Can this model inform GWD parameterizations for GCMs?

• Key parameters: local/instantaneous amplitudes
  • Tied to strength and depth of latent heating
  • Even in most advanced parameterizations these are unresolved
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Our simulations:

June 2014: Continental US
4 km resolution; 65 km top

Based on observed precipitation

Split up into 10 domains & 24 h runs with 1d-initialization
Towards continental scale simulations

We only have *hourly* 4 km x 4 km data available (NCEP Stage IV)

\[ m = \frac{P10}{P60}, \text{ where } 0 \leq P10 \leq P60 \text{ and } 0 \leq m \leq 1 \]

\[ P(m|P60) = \frac{1}{m\sigma\sqrt{2\pi}} e^{-\frac{(\ln(m)-\mu)^2}{2\sigma^2}} \]

<table>
<thead>
<tr>
<th>category: 0 &lt; P60 &lt; 10</th>
<th>10 &lt; P60 &lt; 20</th>
<th>20 &lt; P60 &lt; 30</th>
<th>30 &lt; P60 &lt; 40</th>
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<tr>
<td>( \nu )</td>
<td>0.58</td>
<td>0.33</td>
<td>0.23</td>
</tr>
<tr>
<td>( \mu )</td>
<td>-1.29</td>
<td>-1.76</td>
<td>-1.86</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>0.97</td>
<td>0.98</td>
<td>0.96</td>
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Precipitation downscaling: Validation

- Precipitation algorithm reproduces 10 min 4 km x 4 km PDFs from hourly values.
Precipitation downscaling: Validation

- Precipitation algorithm reproduces 10 min 4 km x 4 km PDFs from hourly values

Is this good enough? Will the sub-hourly distribution change the GW spectra?

- We tested this in simulations
Lognormality

Continental simulation, USA
Lognormality

Continental simulation, USA

PreConcordiasi, Tropics
Jewtoukoff et al., 2013

Vorcore balloon & HIRDLS, 50-65°S
Hertzog et al., 2012
Self-similarity

WRF simulation, Antarctica
Hertzog et al., 2012

Stochastic parameterization
De la Camara et al., 2014

Continental simulation, USA
Beres et al., 2005 parameterization
- Tied to model convective latent heating
- Magnitude of heating is uncertain
- Assumes convective fraction of 5%
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Parameterization vs WRF

- Input to parameterization: parameters of simulated heating
- Area-mean time-average: good performance
### This table shows:

For the area covered by WRF domains:
The simulated wave drag $\times 0.16$ in units of m/s/day averaged over equally-spaced pressure levels

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<th>1 – 0.4 hPa</th>
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<td>-0.072</td>
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Things to note:
- WRF has larger forces at 100–10 hPa than MERRA and CAM
- Conv.-generated GWs can have large amplitudes → break low
- Could be improved: Use precip. downscaling instead of 5% assumption
Can we identify the sources of waves observed by the US Transportable Array?

Case study using the idealized model: Compare simulated waves in the troposphere to surface observations.
Model versus surface observations
Model versus surface observations

- Times series of model predictions and recorded data at locations of stations in the Transportable Array
- Precipitation is shown in red
- 1 deg longitude = 300 Pa
New modeling approach: Idealized WRF model forced with heating/cooling
Observationally validated with satellite and surface measurements

Momentum flux spectra are characterized by universal lognormal distributions with long tails
Neither constant- nor variable-source parameterizations include enough high-amplitude waves
Strong and highly intermittent forces at 100 hPa-60 hPa are not correctly represented in GCMs
This can be fixed: Combine Beres parameterization with a stochastic approach

This model can perform well close to the surface
More useful applications: wave-convection interactions, turbulence, ?
Precipitation downscaling: Validation

Is this good enough? Will the sub-hourly distribution change the GW spectra?

- Model based on original 10 min data
- Model based on reconstructed data
Precipitation downscaling: Validation

How about local amplitudes?