Stochastic parameterizations of non-orographic GW drag in LMDz GCM

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Motivation

- Stochastic **parameterizations** can help create ensemble members (GCMs) that spread wider (*Palmer et al. 2005*).

- Inherent **unpredictability of subgrid scale processes from the resolved dynamics** (*Palmer et al. 2005*).

- Observed **intermittency** of the GW field from satellites and **super-pressure balloons**. *Hertzog et al. JAS 2012; Jewtoukoff et al. JGR 2013; Plougonven et al. QJRMS 2013 Wright et al. JGR 2013*

**Intermittency**: High amplitude GWs that appear sporadically in the wave field and account for a large fraction of the total GW momentum flux.
We represent the GW momentum (EP) flux \( (F \sim \rho u'w') \) with a stochastic series:

\[
\vec{F} = \sum_{n=1}^{\infty} C_n^2 \vec{F}_n \quad \sum_{n=1}^{\infty} C_n^2 = 1
\]

\( \vec{F}_n \) monochromatic wave

\[
|\vec{F}_n|, \quad \vec{k}_n, \quad \Omega_n = \omega_n - \vec{U} \cdot \vec{k}_n \text{ chosen randomly}
\]

Vertical propagation of momentum flux:

\( M=8 \) waves are emitted each model time step \( \Delta t=30\text{min} \), but the forcing is redistributed over \( \delta t=1\text{day} \)

Lott, Guez and Maury (GRL 2012)
The stochastic scheme parameters can be tuned to produce pdfs close to those observed by Concordiasi balloons over the ocean.

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>90th perc</th>
<th>99th perc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concordiasi</td>
<td>8.1</td>
<td>15.5/35%</td>
<td>38.5/8%</td>
</tr>
<tr>
<td>BCGWD</td>
<td>5.5</td>
<td>14.3/48%</td>
<td>42.5/10%</td>
</tr>
</tbody>
</table>

Southern ocean 65S-50S

*de la Cámara, Lott and Hertzog (JGR 2014)*
Sources, like $P^2$ for convection or $\zeta^2$ for fronts have lognormal distributions
(P precipitation, $\zeta$ relative vorticity)
Lott et al (JAS 2010, 2012)

PDFs of GW sources (convection and fronts)

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de la Cámara, Lott and Hertzog (JGR 2014)
Introducing GW sources: Convection and fronts/jet imbalances

**Convection**  
*Lott and Guez (JGR 2013)*

The diabatic heating released by precipitation is redistributed over a depth $\Delta z$ *(similarly to Beres et al. JAS 2004)*

\[ \left| \hat{P}_n \right| = P_r \]

**Fronts and jet imbalances**  
*de la Cámara and Lott (GRL 2015)*

\[ \mathcal{F} = \frac{\rho_r g^2}{f \theta_r N^3 \left( \rho_r q_r \sigma_z \right)^2} \frac{e^{-\pi \frac{N}{\partial_z U}}}{4} \]

PV anomaly  
Characteristic depth of the PV anomaly

*Lott, Plougonven and Vanneste (JAS 2010, 2012)*

Subgrid scale precipitation and vorticity:  
Stochastic series of monochromatic waves  
\[ \left| \hat{q}_n \right| = q_r \]

Emitted EP flux

\[ \tilde{F}_n^{z_i} \propto \left( \frac{R L_W}{\rho_r H C_p} \right)^2 P_r^2 \]

\[ \tilde{F}_n^{z_i} \propto \int_0^{z_{\text{top}}} \xi_r^2 e^{-\pi \sqrt{Ri}} dz' \]
Introducing GW sources: Convection and fronts/jet imbalances

Convection

Precipitation Kg.s\(^{-1}\) day\(^{-1}\)

Fronts and jet imbalances

Surface Stress amplitude (mPa)

Lott and Guez (JGR 2013)

de la Cámara and Lott (GRL 2015)
Introducing GW sources: Convection and fronts/jet imbalances

Convection

Precipitation Kg.s$^{-1}$ day$^{-1}$

Surface Stress amplitude (mPa)

Fronts and jet imbalances

Launched stress (mPa)

GW param (fronts+conv) Oct 2010

Lott and Guez (JGR 2013)
de la Cámara and Lott (GRL 2015)
Introducing GW sources: Convection and fronts/jet imbalances

Benefit of having few large GWs rather than a large ensemble of small ones:

Real precip. Stress amplitude (CI=2mPa)

Uniformized precip. Stress amplitude (CI=2mPa)

Same zonal mean stress

CGWs stress

Real precip. du/dt *e(-z/2H), CI= 0.1 m/s/d

Uniformized precip. du/dt *e(-z/2H), CI= 0.1 m/s/d

More drag near and above stratopause

Slightly less drag in the QBO region

Lott, Guez and Maury (GRL 2012)
Introducing GW sources: Convection and fronts/jet imbalances

Simulated quasi biennial oscillation

LMDz with convective GWs  LMDz+CGWs

MERRA

Histogram of QBO periods

- LMDz with $G_{\mu0}=2.4$ (Cycles: 39, Mean: 26 month)
- Radiosonde (1953-2012) (Cycles: 19, Mean: 27.75 month)

Lott and Guez (JGR 2013)
Simulated equatorial planetary (Rossby-gravity) waves

Lott, Guez and Maury (GRL 2012)
Conclusions

• Using only source-related GW parameterizations (i.e. fronts, convection and orography) in the LMDz GCM suffices to reproduce a good zonal mean climatology, and a realistic QBO in the equatorial stratosphere.

• Long-duration balloon measurements are useful to help constrain GW drag parameterizations (intermittency, momentum-flux – phase speed spectrum).

• However, balloon measurements at 20 km provide mean values 4-5 times larger, and present stronger momentum flux intermittency than those simulated with the stochastic schemes.

Perspectives

• Evaluate the impacts on the variability in the middle atmosphere. QBO, SSWs, timing of SH final warmings (the cold-pole bias), …

• What is the impact of our source-related GW parameterizations in future climate conditions? (Palmeiro et al 2014)
What is the impact of the source-related GW parameterizations in future climate conditions?

4xCO2 +4K SST experiments, Quasi-Biennial Oscillation

Present Climate

Future Climate

GWs with sources

GWs without sources
Perspectives

What is the impact of the source-related GW parameterizations in future climate conditions?

4xCO2 +4K SST experiments, results for October (SH final warming)

Zonal mean zonal wind

Present Climate

Future Climate

Break-up delayed
Surface Impact

Difference future-Present without GWs sources

Difference future-present with GWs sources
Extra slide

- We represent the GW field with a stochastic series:

\[ w' = \sum_{n=1}^{\infty} C_n w'_n \]
\[ \sum_{n=1}^{\infty} C_n^2 = 1 \]

\[ w'_n = \Re \left\{ \hat{w}_n(z) e^{z/2H} e^{i(k_n x + l_n y - \omega_n t)} \right\} \]
\[ \hat{w}_n, \hat{k}_n, \hat{\omega}_n = \omega_n - \vec{U} \cdot \vec{k}_n \quad \text{chosen randomly} \]

- Vertical propagation of momentum (EP) flux (\( F \sim \rho u'w' \)):

\[ \vec{F}(z + dz) = \frac{\vec{k}}{|\vec{k}|} \text{sign}(\Omega) \left( 1 + \text{sign}(\Omega(z + \delta z) \cdot \Omega(z)) \right) \frac{1}{2} \text{Min} \left( |\vec{F}(z)| e^{-2 \frac{\nu M}{N} \delta z}, \rho_r \frac{\Omega^3}{N} e^{-(z + \delta z)/H} S_c^2 k^* \right) \]

- Critical level
- Eliassen-Palm theorem with dissipation
- Breaking (Lindzen 1981)

- GW drag:

\[ \frac{\partial \tilde{u}}{\partial t} \bigg|_{GWS} = \frac{\delta t}{M \Delta t} \sum_{n=1}^{M} \frac{1}{\rho} \frac{\partial \tilde{F}_n^z}{\partial z} + \Delta t - \delta t \left( \frac{\partial \tilde{u}}{\partial t} \right)^t \bigg|_{GWS} \]

Lott, Guez and Maury (GRL 2012)
Lunching momentum (EP) flux

Convective GW drag scheme

\[ \vec{F}_{\text{c}}^{z_i} = \rho_r \frac{\vec{k}_n}{\|\vec{k}_n\|} \frac{\|\vec{k}_n\|^2 e^{-m_n^2 \Delta z^2}}{N \Omega_n^3} G_{uw} \left( \frac{R L_W}{\rho_r H c_p} \right)^2 P_r^2 \]

Frontal GW drag scheme

\[ \vec{F}_{\text{f}}^{z_i} = G_0 \frac{\Delta z}{4 f} \frac{\vec{k}_n}{\|\vec{k}_n\|} \int_0^{z_{\text{top}}} \rho_0 N \zeta_r^2 e^{-\pi \sqrt{J}} dz' \]
The spontaneous emission theory predicts about the right amount of drag compared to a highly tuned globally spectral scheme (January, all in m/s/day)
Averaged time of the SH vortex breakdown very close to reanalysis data

de la Cámara and Lott, (GRL 2015)
Extra slide

Zonal mean GW zonal drag
(January, 5 years)

Zonal mean zonal wind
(January, 5 years)

Frontal GW drag

Convective GW drag

LMDz - FC

LMDz – HC (Lott & Guez 2013)

ERA Interim

LMDz version:
- 71 vertical levels (top at 1 Pa)
- Lon-Lat 3.75° x 1.875°

de la Cámara and Lott, (GRL 2015)