Non-orographic and orographic gravity waves above Antarctica and the Southern Ocean

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7. Summary

2 months of mesoscale simulations in parallel of the Vorcore balloon campaign

overall

**fair agreement** for mean momentum fluxes

orographic contribution ~ non-orographic contribution

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**orographic waves**

**secondary generation** important and frequent

=> long wake of inertia-gravity waves downstream of the Peninsula

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**non-orographic waves**

**moist processes** contribute to jet / front waves, even with weak updrafts

=> small-scale waves with \( k \parallel \) to wind
Outline

1. Motivation
2. Theoretical expectations
3. Observations and simulations
4. Overall
5. Orographic waves
6. Non-Orographic waves
7. Summary
1. Motivation

Need for **physical understanding** of sources of gravity waves (esp. jets / fronts)

Need for **observational constraints** on gravity waves and their sources

**Analytical studies**

**Numerical studies**
(idealized baroclinic life cycles, dipoles)

**Vorcore campaign**

27 Superpressure balloons drifting between 16 and 19 km

Simulations in parallel of VORCORE
2. Theoretical expectations

How are GWs excited by jets and fronts?
or, equivalently,
How are GWs excited by balanced motions?

**Mechanisms**:

- Lighthill radiation
  - Ford 94 a,b,c, Ford et al 02, Plougonven & Zeitlin 02, Schecter and Montgomery 06,07

- Unbalanced instabilities
  - Nakamura 88, Sakai 89, Molemaker et al 01,05, Plougonven et al 05, Vanneste & Yavneh 07, Gula et al 09a,b

- Sheared disturbances
  - Vanneste and Yavneh 04, Olafsdottir et al 08, Lott et al 10

Spatial coupling through **shear**
2. Theoretical expectations

Sheared disturbances:

In a constant, vertical shear, what motions are associated to PV anomalies of horizontal scale $L$?

$$U(z) = \sigma z$$

**ICL**: inertial critical level, where the corresponding Lagrangian timescale is the inertial period
2. Theoretical expectations

Vertical velocity (colors) associated to a PV anomaly in a vertical shear:
2. Theoretical expectations

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Vertical velocity (colors) associated to a PV anomaly in a vertical shear:

![Graph showing vertical velocity and PV anomaly in a vertical shear](image.png)
2. Theoretical expectations

Vertical velocity (colors) associated to a PV anomaly in a vertical shear:
2. Theoretical expectations

Vertical velocity (colors) associated to a PV anomaly in a vertical shear:

![Diagram](image)

- W (cm/s) and PV (0.1 PVU) at t=12hrs
2. Theoretical expectations

Vertical velocity (colors) associated to a PV anomaly in a vertical shear:
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Key rôle of **advection** in order to produce short intrinsic timescales
3. Observations ...

Momentum fluxes estimated from Vorcore balloons:

Mean fluxes of zonal momentum

Contributions from orographic regions (thin) and from non-orographic regions (dashed)

Hertzog et al. 2008
3. ... and simulations: a- strategy

- Case study of a large-amplitude mountain wave
- Preliminary simulations over a large domain
- Systematic simulations

**Done**

**Ongoing**
- WRF – Balloons comparisons
- GWs in WRF
- Further investigation of WRF: sources, propagation, impacts

4, 5, 6
3. ... and simulations:  

**b- a case study**

**Large-amplitude wave event** – October 7, 2005

Plougonven, Hertzog & Teitelbaum 2008

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**Vertical velocity (colors, -5 to 5 m/s)**

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**Table 1. Characteristics of the Waves in the Lower Stratosphere (15–20 km) at About 0600 UT on 7 October 2005**

<table>
<thead>
<tr>
<th></th>
<th>(\lambda_h) (km)</th>
<th>(\lambda_v) (km)</th>
<th>(\hat{\omega})</th>
<th>(\tilde{u}, \tilde{v}, \tilde{w}) (m s(^{-1}))</th>
<th>(\tilde{\theta}) (K)</th>
<th>(-\rho \tilde{u}' \tilde{w}') (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>80</td>
<td>8</td>
<td>18 (f)</td>
<td>(15, 12.5, 2)</td>
<td>17</td>
<td>(\geq 2)</td>
</tr>
<tr>
<td>Simulations</td>
<td>50–65</td>
<td>8–10</td>
<td>23 (f)</td>
<td>(20–25, 15–20, 3–4)</td>
<td>15–20</td>
<td>7–9</td>
</tr>
</tbody>
</table>
3. ... and simulations: preliminary runs

Please see part 5
Weather Research and Forecast Model (AR-WRF) simulations over a **large domain** (10 000 x 10 000 km²)

with **high resolution**

(dx = 20 km,
120 levels up to ~35 km)

for an **extended period** of two months: 58 days

(= 29 x (3-1) days)

+ 6 days at doubled horizontal resolution (dx = 10 km)

Balloon trajectories over simulation domain, from **21 Oct. to 18 Dec. 2005**.
4. Overall view

Mean momentum fluxes over the whole period – values between -50 and 50 mPa
4. Overall view

Mean momentum fluxes over the whole period – values between -10 and 10 mPa
Mean momentum fluxes over the whole period – values between -2 and 2 mPa
Time series of the mean zonal momentum fluxes:

(Poleward of 55°S)

1: Ant. Peninsula
2: Ant. Coast
3: Islands
4: Andes – not included here
5: Ocean
6: Drake Passage
7: Plateau
Zonal average of absolute momentum fluxes:

From Vorcore balloons (Sept 2005 - Jan 2006)
- Total
- Orographic
- Non-orographic

From WRF simulations (21st Oct. - 18th Dec.)
1: Ant. Peninsula
2: Ant. Coast
3: Islands
4: Andes – not included here
5: Ocean
6: Drake Passage
7: Plateau
5. Orographic waves

Momentum fluxes for the large-amplitude wave event of October 7, 2005:

a), b), c):
simulated fluxes averaged between $z=16$ and 19 km, and from Oct. 6, 00:00UT to Oct. 8, 18:00UT.

b):
on a coarse grid (5° lat. x 10° lon.)

c):
sampling only boxes where balloons are present

d):
fluxes estimated from the Vorcore balloons

Plougonven et al. 2010
5. Orographic waves

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Back to the 58 days of simulations:
Identifying orographic wave events in Hovmoller diagrams of zonal momentum fluxes:
5. Orographic waves

Inertia-gravity waves observed in the wake of strong orographic wave events

Balloon trajectories from Nov. 5 to 9 (period B):
5. Orographic waves

Inertia-gravity waves observed in $u$, $v$, for several days after the mountain wave event:
Significant values of momentum fluxes in the wake of the topography, far downstream

\[ p_0 <u', w'> : 5 \text{ Nov} - 9 \text{ Nov} \]
Possible mechanisms of secondary generation:
1- waves produced by the breaking process itself
2- waves resulting from the time-dependent forcing of the flow
3- waves resulting from the PV anomalies that have been generated

Scavuzzo et al 98, Vadas & Fritts 01
Martin, Lott - unpublished
6. Non-orographic waves

Looking for a clean case study of a significant wave event, clearly over the ocean (far from topographies), observed by the balloons and by satellite (HIRDLS)

* -65° < Lat. < -55°
  85° < Lon < 140°

November 15-16, 2005 (day 320)
Full Physics

Day 319, 00:00UT (Nov 15)

Pot. Temp. at 5km

$w$ at 5 km

$w$ at 20 km

Dry run

Theta and wind at 5km

$w$ and wind, day 319

$w$ and wind, day 319
**Full Physics**

Day 319, 06:00UT (Nov 15)

- **Pot. Temp. at 5km**
- **W at 5 km**
- **W at 20 km**

**Dry run**

- **Theta and wind at 5km**
- **W and wind, day 319.25**
- **W and wind, day 319.25**
Full Physics

Day 319, 12:00UT (Nov 15)

Dry run
Full Physics

Day 319, 18:00UT (Nov 15)

Dry run

**Pot. Temp. at 5km**

**$w$ at 5 km**

**$w$ at 20 km**
Dry run
Day 319, 12:00UT (Nov 15)

**Full Physics**

Vert. cross-sect. of $w$ and pot. temp.

Vert. cross-sect. of $v$ and $d_{319.5}$

**Dry run**

Vert. cross-sect. of $w$ and wind speed

Vert. cross-sect. of $v$ and $d_{319.5}$
Comparison of the absolute momentum fluxes in the runs with and without moist processes, and with Vorcore balloons:

Day 319, 12:00UT (Nov 15)
Comparison of the absolute momentum fluxes in the runs with and without moist processes, and with Vorcore balloons:

Day 320, 00:00UT (Nov 16)
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Some References:

Secondary generation:


Vorcore


Emission mechanisms


Thank you for your attention