Observations of gravity-wave momentum fluxes and intermittency over Antarctica from long-duration balloon flights in the stratosphere

A. Hertzog (Laboratoire de Météorologie Dynamique)  
R. Plougonven (LMD)  
V. Jewtoukoff (LMD)  
R. A. Vincent (U. Adelaide)

albert.hertzog@lmd.polytechnique.fr
Motivations

- In the atmosphere, gravity waves transport energy and momentum from their source regions (mainly the troposphere) to the middle atmosphere.
- Wave breaking in the stratosphere and mesosphere contribute to the driving of the global-scale Brewer-Dobson circulation.
- GW scales (10 – 1,000 km in the horizontal, 100 m – 10 km in the vertical) are such that they are only marginally resolved in AGCMs that are used to study climate change.
- Their global effects are parameterized in AGCMs, but these parameterizations are based on simplifying assumptions, especially the “non-orographic” one (e.g., homogeneous source).
Long-duration stratospheric balloons
Fly on constant-density surfaces
For 2-3 months
Advected by the wind → ˆω
Long-duration stratospheric balloons
Fly on constant-density surfaces
For 2-3 months
Advected by the wind → \( \hat{w} \)

Concordiasi campaign
19 balloons, 60 hPa
In-situ measurements of \( u, v, P \)
\( \rho u'w' \) and \( \rho v'w' \) from wavelet analysis

2,600,000 obs
Gravity-wave momentum flux

Recent improvements:

- higher time resolution (30 s) along the balloon trajectories → whole gravity-wave spectrum

- higher precision of GPS altitude and pressure measurements → Eulerian P disturbance

\[ P_e' = P_l' - \zeta' \frac{\partial \bar{P}}{\partial z} \]

and wave parameters: \( \hat{c}, c, m \) ...
Map of absolute momentum flux
(Sep.-Jan. average)

Enhanced activity over Peninsula, Drake passage and Transantarctic mountains, as well as along the continental coast
Higher activity above Austral Ocean than above the Plateau

2.5° x 2.5° boxes
Mean = 9.0 mPa

CEDAR meeting, Boulder, 2013
Map of absolute momentum flux  
(Sep.-Jan. average)

Enhanced activity over Peninsula, Drake passage and Transantarctic mountains, as well as along the continental coast.
Higher activity above Austral Ocean than above the Plateau.

2.5° x 2.5° boxes
Mean = 9.0 mPa
160 mPa
0.6 mPa
GW momentum fluxes maximize between 55S and 75S.

Fluxes are segregated according to the underlying topography (flat/sloppy terrain). Zonally averaged non-orographic gravity-wave activity above the Austral ocean is as important as orographic activity above the continents.
Zonal and meridional momentum fluxes

Zonal momentum fluxes are almost everywhere negative (mountains & ocean), whereas both positive and negatives meridional fluxes are found. The campaign-averaged net fluxes are significantly smaller than the absolute fluxes:

\[ \rho \bar{u}' \bar{w}' = -1.4 \text{ mPa} \quad \rho \bar{v}' \bar{w}' = 0.2 \text{ mPa} \]
Phase speed distribution of zonal momentum fluxes

Most of the westward flux is found between 0-40 m/s, while eastward fluxes are in 0-20 m/s. A secondary maximum in the intrinsic phase speed distribution is found between 20-30 m/s, and corresponds to mountain waves. It is shifted toward ground-based $c < 10$ m/s.

The ground-based phase speed distribution exhibits “intro waves”, i.e. waves with $c_h < u \cos \theta$.
Momentum fluxes and kinetic energy maximize for vertical wavelengths between 2-30 km. Yet, the momentum flux distribution is broader than the kinetic energy one: in particular higher frequency waves contribute more significantly to the flux than to the energy. Mountain waves induce the enhancement observed between 2-5 km, and 2-4 hr.
(k_h, m) distributions of momentum fluxes and kinetic energy

Momentum fluxes are mainly associated with waves with horizontal wavelengths shorter than 500 km, unlike kinetic energy.
Momentum-flux pdfs

<table>
<thead>
<tr>
<th>Location</th>
<th>90th percentile</th>
<th>F(f &gt; f_{90})/F_{tot}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concordia</td>
<td>15 mPa</td>
<td>50 %</td>
</tr>
<tr>
<td>Peninsula</td>
<td>50 mPa</td>
<td>65 %</td>
</tr>
<tr>
<td>Ocean</td>
<td>15 mPa</td>
<td>35 %</td>
</tr>
</tbody>
</table>

CECARE meeting, Boulder, 2013
Conclusions

- Long-duration balloon flights can provide a full characterization of GWs in the lower stratosphere (MF, phase speeds, wavelengths, etc.)
- The Antarctic Peninsula is the major GW hotspot in the SH high latitudes...
- ... yet, non-orographic gravity waves are as important when zonal means are considered
- Momentum fluxes are predominantly associated with high-frequency, short horizontal wavelength waves (unlike KE)
- Observations show that GW activity is very intermittent