Balloon-Borne Observations of Gravity-Wave Momentum Fluxes over Antarctica and Surrounding Areas

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http://www.lmd.polytechnique.fr/VORCORE/McMurdoE.htm
Motivations

• The forcing imposed by atmospheric gravity waves on the mean flow is parameterized in GCMs
• GWD parameterizations are tuned to reproduce climatological features (mesospheric jet closure, winter temperature in polar stratosphere and mesosphere)
• Parameterized GW momentum fluxes significantly vary from one scheme to the other
• Global observations of gravity-wave momentum fluxes may provide constraints on the parameterizations

… but only recently available: space-borne obs, radiosoundings, assimilation, and long-duration balloons
Superpressure balloons

- Closed balloon w/ stiff envelop, helium filled
- Constant-density (isopycnic surface)
  \[ \rho_b \frac{dw_b}{dt} = (\rho_a - \rho_b) g \]
- Adveected by the horizontal wind
  => quasi-Lagrangian
- 10 m diam. (50 hPa, 19 km), 8.5 m (70 hPa, 17.5 km) and now 12 m
- Flight duration up to 3-4 months
- Payload: 15 kg – 50 kg
Vorcore campaign
McMurdo, Antarctica, 2005
27 balloon flights
Launch: September 5 - October 28
Last obs: February 1st, 2006
Mean duration: 58.5 days
Longest flights: 109 days

Concordiasi campaign
McMurdo, Antarctica, 2010
Vorcore campaign
McMurdo, Antarctica, 2005

27 balloon flights
Launch: September 5 - October 28
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Mean duration: 58.5 days
Longest flights: 109 days
Observations

3D positions from GPS => u, v
Pressure
Temperature

Every 15 minutes
Estimation of GW momentum flux

- Wavelet decomposition of u, v, P → (time, intrinsic frequency)
- Rotation of (u, v) to get $u_\parallel$
- Pressure disturbance
  \[ p'_l = p' + \zeta'_\rho \frac{\partial p}{\partial z} \]

The Lagrangian term
- Dominates, is linked to $w'$
- is in quadrature with $p'$
  \[ u'_\parallel w' = -\frac{\hat{\omega} g}{\bar{\rho} N^2} \Im(p'_l u'_\parallel) \]

(Hertzog and Vial, 2001; Boccara et al, 2008)
Estimation of GW momentum flux

- Simulated balloon observations (w/ instrumental noise) to check GW retrievals
Estimation of GW momentum flux

- Simulated balloon observations (w/ instrumental noise) to check GW retrievals

Retrieved wave azimuth vs. Input wave azimuth

Momentum fluxes underestimated by ~ 15%

Directionnal momentum fluxes
Absolute momentum fluxes

- $\rho_0 <u'_w''>$ in $10^\circ$-$5^\circ$ longitude-latitude boxes (period $> 1h$)

Mean value $\sim 2.5$ mPa
Mean over $50$ mPa above Peninsula
Extreme events up to $\sim 1$ Pa

Hertzog et al., 2008

Gravity wave Chapman conference, Honolulu, 2011
Absolute momentum fluxes

- $\rho_0 <u'_\parallel w'>$ in 10°-5° longitude-latitude boxes (period > 1h)

Mean value ~ 2.5 mPa
Mean over 50 mPa above Peninsula
Extreme events up to ~ 1 Pa

Hertzog et al., 2008

Mean value btw 2-3 mPa over Atlantic and Idian ocean
Less than 1 mPa over Plateau

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Orographic/Non-orographic waves

- Geographical criterion (based on topography gradients) to flag boxes as mountainous or non-mountainous
- Compute zonal-mean absolute fluxes and the contribution of both types of areas

[Diagram showing geographical criterion and zonal-mean momentum flux]
Orographic/Non-orographic waves

- Geographical criterion (based on topography gradients) to flag boxes as mountainous or non-mountainous
- Compute zonal-mean absolute fluxes and the contribution of both types of areas
\( \rho_0<u'w'> \) negative almost everywhere (including Atlantic Ocean)
No net tendency on \( \rho_0<v'w'> \)
Gravity-wave intermittency

For a given time-mean momentum flux, intermittent/permanent GWs break at different levels

(Over-)simplistic Bernoulli random process: on/off phases, and when “on”, always the same flux (Buhler, 2003) →

\[ p(\text{on}) = \left(1 + \frac{\sigma^2}{\mu^2}\right)^{-1} \]

Lower \( p(\text{on}) \) (ie sporadic source) over mountains (10%) Larger \( p(\text{on}) \) above ocean (50-70%)
Gravity-wave intermittency

Observed (balloon) probability density functions (pdf)

Broader tail over mountain $\rightarrow$ larger intermittency

« Spectrum » of MF values even for waves over the oceans
Momentum fluxes: HIRDLs/balloons

Limited to 50-65S, October, and zonal momentum flux
Momentum fluxes: HIRDLS/balloons

Limited to 50-65S, October, and zonal momentum flux

Good agreement between balloons and HIRDLS but large variations of PDFs w/ time and altitude

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Momentum fluxes: WRF/balloons

November and total momentum flux

Balloons

WRF
Concordiasi

- 19 flights
- Sept. 2010- Jan. 2011
- Mean duration > 2 months

- Several improvements
  - Obs. every 30 s
    → whole range of GWs
  - Improved GPS accuracy
    → c, \( \langle p'w' \rangle \)
Concordiasi

Diagnose momentum fluxes from $f$ to $N/2$

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Summary

- Long-duration superpressure balloons are one of the techniques to diagnose GW momentum fluxes over wide geographical areas
- Vorcore results have highlighted strong orographic GW momentum fluxes, but also that zonally-averaged non-orographic wave momentum fluxes are equally important
- Evidence of consistent GW intermittency in balloons/HIRDLS/WRF datasets
- Should get improved results w/ Concordiasi campaign
- Equatorial campaign in ~ 5 years