GLOBAL GRAVITY WAVE DISTRIBUTIONS

Inferred from satellite observations and NWP models

21 Nov 2019 | Peter Preusse, Manfred Ern, Cornelia Strube | ECMWF
Gravity waves are waves visible in:
- Temperatures → Clouds
- Horizontal and vertical winds
- Density
PROPERTIES OF GWS

- Pure GWs: winds along phase lines
- Intrinsic phase velocity perpendicular to phase lines
- Intrinsic group velocity parallel to phase lines
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- Slow waves (relative to ground) are tilted versus the wind
- Vertical wavelength of a mountain wave:

\[ \lambda_z \simeq 2\pi \frac{u}{N} \quad (1) \]
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- Carry energy flux and momentum flux
- Deposit this flux when dissipating

\[ F_{px} = \bar{\rho}(1 - \frac{f^2}{\hat{\omega}^2})u'w' = \frac{1}{2}\rho \frac{k}{m} \left( \frac{g}{N} \right)^2 \left( \frac{T}{\bar{T}} \right) \] (2)

\[ \bar{X} = -\frac{1}{\rho} \frac{\partial}{\partial z} F_{px} \] (3)
Atmospheric waves convey momentum
- Depositing this momentum, they drive the residual circulation
- By downward coupling this induces synoptic temperature changes up to 2°C
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Atmospheric circulation as a source of uncertainty in climate change projections

Theodore G. Shepherd

„The most uncertain aspect of climate modelling lies in the representation of unresolved (sub-gridscale) processes such as clouds, convection, and boundary-layer and gravity-wave drag, and its sensitive interaction with large-scale dynamics.“
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Can satellite observations give guidance?

Satellite observations used to tune Non-Oro Scheme in IFS
Ern et al., ACP, 2006; Orr et al., J. Clim., 2010
SH POLAR VORTEX LASTS TOO LONG

This is a multi-model finding

And depends on GW drag

But what are these GWs and their sources?

Butchart et al., SPARC report, 2011

Polichtchouk et al., JAS, 2018
Limb Sounding: resolution limited by geometry, good vertical and moderate horizontal resolution
Only absolute values of GWMF

Nadir Sounding: resolution limited by radiative transfer, moderate vertical and good horizontal resolution
Only very long vertical wavelengths

Preusse et al, JGR, 2008
Alexander et al, QJRMS, 2010
ACTIVITIES WORLDWIDE

Review papers:
- Fritts and Alexander, RG, 2003
- Kim, Eckermann, Chun, Atmos. Ocean, 2003
- Alexander et al, QJRMS, 2010
- Geller et al., J. Clim., 2013

Groups all around the world are evaluating satellite data and global models

→ From here on, a Juelich perspective
GLOBAL DISTRIBUTION: LOWER STRATOSPHERE

Salient patterns (climat.):
- Polar vortex: mountain waves + general enhancement (sources ?)
- Subtropical convection

Ern et al., ESSD, 2018

30 km
No observational filter applied!

Calculating GW momentum flux from real(istic) data is non-trivial

Large range of different scales: **Caution!**

Satellite methods applicable; new satellites needed
Stephan et al., JGR, 2019
(MPI & FZJ, MS-GWaves)
Convective maxima
- propagate polewards
- relatively gain in strength

Polar vortex
- stronger on SH
- overlap in latitude with summer maxima

Ern et al., ESSD, 2018
Pulse-like occurrence of subtropical convective GW cause a Terrannual Variation

TAV is a higher harmonic of the annual cycle

Dan Chen et al., Annales Geophys., 2019
TAV → POLEWARD PROPAGATION

Dan Chen et al., Annales Geophys., 2019

- TAV emphasizes poleward propagation from convective centers
Momentum flux is directed opposite to background wind:
- westward in polar vortex
- eastward in subtropics
- behavior enhanced by long vertical wavelength (observational filter!)

Ern et al., GRL, 2016 and work in progress
AIRS: NET MOMENTUM FLUX (MERIDIONAL)

- Confluence at 60°S
- Nortward tendency in NH winter

Ern et al., GRL, 2016; work in progress
There is need to replace GW parametrization in the grid column

- Oblique propagation avoids critical level filtering
- Relevant for:
  - Summer mesopause
  - Stratwarmings (Ern et al., 2016)

cf. also Sato et al., 2009; Preusse et al., 2009

Vortex-GW already at 20 km ⇒ Local sources?

Kalisch et al., JGR, 2014
In 2016 the HALO aircraft was deployed from Kiruna. The flight towards Iceland on 25 January targeted a mountain wave event.
FORWARD AND BACKWARD RAY-TRACING

Krisch et al., ACP, 2017

Krisch et al. 2017
ECMWF ANALYSIS DATA ON SH
Case study for DeepWave: 01-Jul-2014

Strube et al., work in progress
OBLIQUE PROPAGATION

- gravity waves propagate up to 25° poleward
- major part from New Zealand
- additional sources: fronts, jet-exit regions
- oblique propagation in particular in the UTLS (10-15km)
GWs are important for middle atmosphere circulation
Prominent example: SH polar vortex
Satellite observations show global picture
NWP models resolve already large part of GW spectrum → Danger of double counting
Extremely-oblique propagation can redistribute drag → Not in GW parametrization

Global limb imaging needed!
Global data need to be complemented with case studies!
Campaign at world-hot-spot of GWs: Tierra del Fuego