Short-period gravity waves over a high-latitude observation site: Rothera, Antarctica

Goals

• Wave detection and climatology
• Effects of critical layer filtering
• Nature of wave propagation and wave source region/function
• Investigate orographic waves via observations and ray tracing
• Open to new and interesting science

Tools

• Airglow imaging data
• Meteor radar winds
• NOGAPS-ALPHA assimilated temperature and winds
• Ray tracing code
• SABER temperature profiles
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- Effects of critical layer filtering ✔
- Nature of wave propagation ✔ and wave source region/function
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Tools

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- NOGAPS-ALPHA assimilated temperature and derived winds
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Climatology of Short-period Gravity Waves Observed by Airglow Imagers
A Decade of Antarctic Airglow Imaging Data

- 76°S, 27°W
- Located on the vast Brunt Ice Shelf.
- Deep within the Antarctic winter polar vortex.
- In close vicinity of the auroral boundary zone.

- 68°S, 68°W
- Located on Adelaide Island on the Antarctic Peninsula.
- In close proximity to steep cliffs raising as high as 2 km.
- Near the edge of the polar vortex.
- Equatorward of auroral zone.

Data
  - OH imagery (March-Sept).
  - IDI radar wind data.
  - OH imagery (March-Oct).
  - Meteor Radar.
Observation Time: Rothera

- 6 years of observations.
- Black:
  - Total observation hours (2003 and 2008 not included).
- Dark Grey:
  - Hours of clear skies.
- Light Grey:
  - Hours with wave signatures present.
- Numbers indicate % presence of waves vs. clear skies

CEDAR Workshop, Boulder, 6/28/2013
Observed Wave Characteristics: Rothera

- A total of six years of data!
- Observed wave parameters similar to other studies.
Direction of Propagation: Rothera

- 6 years of data!
- A clear preferential propagation direction towards the west.
- The small fraction of eastward propagating waves exhibit relatively large observed phase speeds (>40 m/s).
- The majority of westward propagating waves exhibit observed phase speeds <40 m/s.
Year-to-Year Propagation Direction: Rothera
Critical Layer Filtering over Rothera

- The blocking regions are shown at 00 (black), 06 (red), 12 (blue), and 18 (grey) UT, respectively.
- The period from April – August exhibit little variation with local time.
- Significant local time variability is evident from October – March.
Critical Layer Filtering over Rothera

- Zonal wind profiles are shown at 00 (black), 06 (red), 12 (blue), and 18 (grey) UT, respectively.
- The strong Antarctic jet located near 50-km is a stable winter feature.
- During the austral summer months, the upper mesospheric winds dominate and are driven by tidal motions.
- This explains the local time dependence of blocking regions.
Propagating Halley vs. Rothera

- Distinctive wave events, with coincident wind measurements, were measured in the OH airglow emission.
- Wave events with TIMED satellite overpass within +/-6 hours of wave observations (near coincident temperature measurements).
- 13% potentially ducted wave events.
- 14% wave events exhibited damped motion (evanescence).
- The remaining 73% wave events were determined to exhibit freely propagating wave motion.

<table>
<thead>
<tr>
<th>Site</th>
<th>Free (%)</th>
<th>Ducted (%)</th>
<th>Damped (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halley</td>
<td>80</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Rothera</td>
<td>73</td>
<td>13</td>
<td>14</td>
</tr>
</tbody>
</table>

NOTE: there were no coincident temperature measurements at Halley during 2000-2001.
Role of Mesospheric Inversion Layers on Wave Propagation

SABER Profiles

Orbit 28823

Latitude

Longitude
Role of Mesospheric Inversion Layers on Wave Propagation

Orbit 28823

8°S → 34°S ~3000 km
On 11 August 2007, a potential stationary wave was observed in the airglow emissions. The wave exhibited a near-zero observed phase speed, horizontal wavelength of 29 km, and aligned phase fronts at an apparent propagation angle of $118^\circ$ (measured clockwise from north).
Fourier Ray Tracing
Conclusions

• A combined 10 years of short-period gravity wave imaging over two Antarctic stations.
• Observed wave parameters are similar to studies at other latitudes.
• Halley exhibit both seasonal and intra-seasonal variability in wave propagation directions.
• Rothera exhibit a clear westward propagation direction throughout the season and from year-to-year.
• Although wind filtering can explain some of the observed features, there are characteristics for which it cannot account for.
• The observed wave field exhibit freely propagating characteristic within the 75-95 km altitude range.
• High-latitude thermal inversion layers are not a likely source to create a thermally ducting environment.
• Relatively few stationary waves are observed and can be attributed to the weak wind field, which are likely to filter out these waves.
Extras
Local Time Variability

MAX Color scale: 10% Occurrence rate (summer months)
Effects of Critical Layer Filtering: Rothera

- Plot showing wave phase speeds of individual events versus azimuth with superposed blocking region (shaded area).
- Critical layer filtering only affects eastward propagating waves.
- The blocking region is stronger over Rothera than over Halley.
- It can account for the absence of eastward waves with low observed phase speeds over Rothera.
Gravity Wave Propagation

- Waves propagating in the atmosphere are subject to dispersion and reflection/transmission due to variations in the background temperature and wind fields.
- How the background conditions determine gravity wave propagation in the atmosphere is governed by the dispersion relation (with appropriate assumptions):

\[ m^2 = \frac{N^2}{c-u_0} + \frac{u''}{c-u_0} \frac{1}{H_s} \frac{1}{c-u_0} \frac{1}{4H_s^2} k_h^2 \]

- Freely propagating regions have \( m^2 > 0 \), while evanescent regions are characterized by \( m^2 < 0 \).
- A freely propagating region bounded by evanescent regions is a necessary condition for ducting.
Results from Rothera 2007

- A total of 122 waves with coincident wind measurements were measured with the OH airglow imager.
- 73 wave events with SABER temperature measurements within +/-6 hours of wave observations.
- 16 (~13%) potentially ducted wave events.
- 17 (~14%) events exhibited damped motion (evanescence).
- The remaining 89 (73%) wave events were determined to be freely propagating in the OH airglow layer (nominal altitude of ~87 km).

Examples of a freely propagating wave (top) and an evanescent wave (below). The observed wave parameters (horizontal wavelengths and phase speeds) are shown in the top left corners.
An example of a potentially ducted wave. The vertical wavelength squared profile (right) shows a freely propagating region bounded above and below by evanescent regions. The wind profile exhibit a small jet in the direction of wave motion, while the temperature profile shows a reversal in the temperature gradient near 85 km.
GW Parameters from Rothera (2007)

**Distribution of horizontal wavelengths over Rothera for the 2007 season.**
Median = 22 km
IQR1 = 19 km
IQR3 = 26 km

**Distribution of intrinsic phase speeds over Rothera for the 2007 season.**
Median = 43 m/s
IQR1 = 33 m/s
IQR3 = 60 m/s
Utilizing Winds From a Numerical Weather Prediction System

- Can we rely on climatological winds?
- Daily averaged wind data over Rothera, Antarctica.
- Red curve is meteor radar.
- Blue curve is NOGAPS-ALPHA.
- The cross-correlation coefficient is calculated for meteor radar vs. NOGAPS-ALPHA.
Fourier Ray Tracing

• Ray-trace in Fourier space. Synthesize ray solutions by inverse Fourier transform
• 512 by 512 grid.
• Hydrostatic.
  – Remove rays with intrinsic freq. > N(z).
• Rotation ignored.
  – Remove rays with intrinsic freq. < f at 67°S.
• Connected and detached topography.
Fourier Ray Tracing
Case 1
05312008_06UT.txt

U,V,N soundings held constant below $z = 3\text{km}$.
• Turning point (CP) and critical level (CL) histograms as percentage of total number of k,l Fourier components.
• 92% of all Fourier components filtered by TP or CL between ground and z = 93km.
Fourier Ray Tracing: Case 1
Vertical Displacement
Case 2
05312008_00UT.txt

U,V,N soundings held constant below z = 3km.
Fourier Ray Tracing: Case 2

- Turning point (CP) and critical level (CL) histograms as percentage of total number of $k,l$ Fourier components.
- 96% of all Fourier components filtered by TP or CL between ground and $z = 93$km.
Fourier Ray Tracing: Case 1
Vertical Displacement
• 154 SABER temperature profiles from 2002-2010 measured over Halley exhibited significant variability, which is not captured by climatological model.
• The figure shows the estimated vertical wavelength squared.
• Analysis showed that up to ~28% of SABER temperature profiles potentially could support thermal ducted motion over Halley (based on median observed wave parameters).
NH and SH Polar Clear Channels

Zonal

MAX: 10%

Meridional

MAX: 5%
MIL Occurrence in the Polar Regions

- Fraction of MILs (in %) as a function of longitude/latitude. The data is binned in 10° longitude and 5° latitude. There is strong evidence of higher occurrence rates away from the poles.