2012

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Short–Period Gravity Waves Over Alaska

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¹Utah State University, ²Utah Valley University, ³University of Alaska, Fairbanks
Gravity waves are essential parts of the dynamics of the atmosphere.

An important property is their ability to transport energy.

Gravity waves transport energy away from the disturbances that generate them and act to distribute this energy throughout the atmosphere.
The term gravity wave suggests that gravity is the restoring force acting on a fluid parcel which has been displaced from its equilibrium position.

However, it is the fluid buoyancy rather than gravity that is acting.
If it were possible to see gravity waves and to speed up their motions, we would see a wide variety of wave shapes moving in many directions.

Since we cannot see gravity waves, we can only study their effects on the atmosphere.
The propagation and sources of short-period (<1 h) gravity waves have been studied extensively at low and mid-latitudes, while their characteristics in the polar regions are less known.

The Mesospheric Airglow Imaging Dynamics (MAID) project was initiated in January 2011 to investigate short-period gravity wave dynamics over central Alaska.
The primary instruments used for this research are a Keo Sentry airglow imager and the NICT Rayleigh lidar both located at Poker Flat Research Range (PFRR), Alaska.
The imager is designed to remotely sense several faint airglow emissions primarily in the mesosphere lower thermosphere (MLT) region.

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<th>Mean Layer Height (km)</th>
<th>Exposure Time (sec)</th>
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<td>~250</td>
<td>120</td>
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<td>~90</td>
<td>90</td>
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<td>O₂ (0,1)</td>
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<td>~94</td>
<td>120</td>
</tr>
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</table>
Example Imager data

(a) 06:40:41 UT
(b) 06:40:57 UT
(c) 06:38:39 UT
(d) 06:36:21 UT

January 14, 2012
The Rayleigh lidar has operated at PFRR since 1997.

Raw signal profiles are acquired every 50 sec.

The data are integrated to yield 15 min. profiles for density fluctuations and 30 min. temperature profiles over the altitude range ~40–90 km.
The **all-sky imager** permits accurate measurements of the horizontal wave parameters.

The **lidar** provides essential temperature profiles.

Together, these two instruments can measure several of the key parameters needed to characterize the wave motions as well as investigate their propagation nature.

Additional **radar measurements** of the background wind field enables the true motion of the gravity wave such as its intrinsic period, phase speed, and angle of ascent/descent.
Image Data Processing

- Raw OH image
- Rotated Image
- Star Removal
- Calibrated and Unwarped
A region of interest is selected from the processed image.

Unwarped to 500 km x 500 km
Traditional spectral analysis techniques give an inherent 180° ambiguity in the derived wave-propagation.
Ambiguity can be resolved by using images obtained sequentially in time to determine the unambiguous 3–D horizontal wavenumber spectrum.

The 3–D spectrum is computed as follows:

- Calculate the \((\omega, k, l)\) spectrum from the processed images (where \(\omega\) is the temporal frequency, \(k\) is the zonal wavenumber, and \(l\) is the meridional wavenumber.
- Then integrate over the negative frequencies only.

What you obtain is a single peak in the 3–D spectrum corresponding to the horizontal wavelength and direction of propagation.

\[\lambda = 22.2 \pm 0.3 \text{ km} \quad \theta = 90.0 \pm 0.9 \, ^\circ\]

The peak in the spectrum.
### Results

<table>
<thead>
<tr>
<th>Event</th>
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<th>Duration</th>
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<th>$\theta$ (deg)</th>
<th>$C$ (m/s)</th>
<th>$T$ (min)</th>
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OH data coincident with lidar for 2011.
<table>
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<tr>
<th>Event</th>
<th>Date</th>
<th>Duration</th>
<th>$\lambda$ (km)</th>
<th>$\theta$ (deg)</th>
<th>C (m/s)</th>
<th>T (min)</th>
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</table>

OH data coincident with lidar for 2012.
2011 Velocity graphs coincident with lidar

OH

Na

O$_2$
2011/2012 Velocity graphs coincident with lidar

OH

Na

O₂
Wave Ducting

There are two kinds of wave ducting which can occur:

• **Doppler ducting** – which is created by a jet in the background wind in the direction of wave propagation.
• **Temperature duct** – which is caused by a discontinuity in the temperature lapse rate.
Night of February 7, 2011

3:52 UT to 16:21 UT
6:39 UT to 8:46 UT
OH Observed Parameters

PFRR Imager Wave Characteristics

- Wavelength (km)
- Direction (deg)
- Speed (m/s)

Time (UT hour)

PFRR Rayleigh Lidar 2\7\11

Altitude (km)

Temperature (K)
Lidar Data

PFRR Rayleigh Lidar 2\/7\/11 630 to 900 UT

Altitude (km)

Temperature (K)

PFRR Rayleigh Lidar 2\/7\/11

Altitude (km)

Temperature (K)
Check to see if the wave is ducted, we estimate the vertical wavenumber squared ($m^2$) profile.

A ducted region is characterized by a positive $m^2$ region bounded above and below by negative $m^2$ regions.

The $m^2$ profile is calculated using the following dispersion relation:

$$m^2 = \frac{N^2}{(c - u_0)^2} - k^2 - \frac{1}{4H^2}$$

where $c$ is the observed phase speed, $u_0$ is the background wind in the direction of the wave propagation, $k$ is the horizontal wavenumber, $H$ is the scale height, and $N$ is the Brunt–Vaisala frequency given by

$$N^2 = \frac{g}{T} \left( \frac{dT}{dz} + \frac{g}{c_p} \right)$$

- Background winds were obtained from the horizontal wind model 07.
Vertical Wavenumber squared

PFRR 2/7/11 630 to 900 UT

PFRR 2/7/11 Vertical Wavenumber
Gravity waves are important because they deposit energy into the atmosphere.

MAID was initiated to investigate short-period gravity wave dynamics over central Alaska.

The airglow imager, Rayleigh lidar, and MF wind radar allows us to find the true motion of gravity waves.
Future work

- Continue to utilize coordinated imager, lidar, and wind data (when available) to investigate the characteristics and propagation nature of waves in the MLT at high Arctic latitudes and compare with the existing Antarctic studies.
- Study effects of tidal and planetary motion on short-period gravity waves in the Arctic MLT region.
- Search for special wave events such as mesospheric bores, fronts, and standing waves.

3–7–11 6:33 UT