Short Period Gravity Waves in the Arctic Atmosphere Over Alaska

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Introduction

Momentum deposition by short-period (<1 h) gravity waves is known to play a major role in the global circulation in the mesosphere and lower thermosphere (MLT) region (~60-100 km) (e.g., Frith and Alexander, 2003). The propagation velocity and sources of these waves have been studied extensively at low and mid-latitudes, while their characteristics in the polar regions are less known. Observations from Antarctica have revealed a significant presence of short- and medium-period waves and unexpected dynamical behavior (Nielsen et al., 2009, 2012). In contrast, observations over the Arctic region are few (Suzuki et al., 2009), and the dynamical behavior is unknown.

The Mesospheric Airglow Imaging and Dynamics (MAID) project was initiated in January 2011 to investigate medium and short-period gravity waves over central Alaska. MAID is a collaborative project between Computational Physics Inc. (CPI), the University of Alaska, Fairbanks (UAF), the National Institute of Information and Communications Technology (NICT) in Japan, and the University of Alaska, Fairbanks (UAF).

The main goals of this program are to:

- Establish a long-term climatology of short-period gravity waves observed in the Arctic MLT region.
- Determine dominant source regions and potentially wave sources of the observed waves.
- Investigate the impact of large-scale waves (tidal and planetary wave motions) on the short-period wave field.
- Perform quantitative comparison between Arctic and Antarctic winter-time dynamic processes.

Instruments

The primary instruments used for this research are a Keck Aessory airglow imager on the NICT Rayleigh lidar and both located at PFRR, Alaska (65° N, 147° W). The imager has operated at PFRR since January 2011. It is a state of the art system designed to remotely sense atmospheric gravity waves primarily in the MLT region. A suite of narrow band filters (2 nm FWHM) is used to isolate several emissions (as listed in Table 1). The imager uses 3-inch telecentric all-sky plates and a 70.95 imaging onto a Princeton Instruments Acton Pixis CCD. The observation sequence is OH-Na-OH-ClO-OH-O_2, yielding a fast OH cadence 2 min and a ~6 min cadence for the other emissions.

Table 1

<table>
<thead>
<tr>
<th>Filter</th>
<th>Wavelength (nm)</th>
<th>Beam Size (mm)</th>
<th>Exposure Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClO</td>
<td>630.0</td>
<td>~250</td>
<td>~120</td>
</tr>
<tr>
<td>Na</td>
<td>589.2</td>
<td>~90</td>
<td>~120</td>
</tr>
<tr>
<td>OI</td>
<td>130.5</td>
<td>~67</td>
<td>~15</td>
</tr>
<tr>
<td>ClO</td>
<td>130.5</td>
<td>~85.5</td>
<td>~94</td>
</tr>
</tbody>
</table>

The NICT Rayleigh lidar (Figure B), located at PFRR since 1997, is a lidar that is a zenith pointing system consisting of a N2 YAG laser. It has a 300 m diameter field of view for the observation of mesospheric density measurements, while the outer circle shows the FOV at 250 km for the OH measurements. The observation sequence is OI-Nh-OH-ClO-O_2 yielding a fast OH cadence 2 min and a ~6 min cadence for the other emissions. Figure (a) shows the location of the PFRR. The inner circle is the field of view (FOV) of the imager at ~60 km altitude, the white cross shows the FOVs for different wave measurements, while the outer circle shows the FOV at 250 km for the OI measurements.

Imager Observations:

- Images of different airglow emissions allow for observations of gravity waves at different altitudes (as illustrated in Figure 1). A sequence of images observed on 14 January 2012 exhibiting an extensive wave field is shown in Figure 2. The wave signature was strongest in the OH (a) and Na (b) emissions, while little evidence of it in the O_2 emission. As expected, the thermospheric OI emission shows no signature of the wave field (d).

Lidar Observations:

- Figure 3 shows the average temperature profile measured by the lidar for this night of 14 January 2012. While 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 are observed by the lidar: the signature of the gravity wave such as its intrinsic period, phase speed, and angle of ascension/descent through the atmosphere to be determined (Taylor et al., 1995).

Observations

Using traditional spectral analysis techniques there is an inherent 180° ambiguity in the derived wave propagation. This can be resolved, by using images obtained sequentially in time to determine the unambiguous 3-dimensional horizontal wave number spectrum (Coble, 1998). This 3-D spectrum is computed as follows (Gardner et al., 1998):

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

Figure 5 illustrates the methodology of the unambiguous 3-dimensional spectrum showing an isolated peak corresponding to the observed wave event.

Table 2: example results for 2012

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
<th>Duration (min)</th>
<th>Range (km)</th>
<th>T (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11/12</td>
<td>04:30–15:22</td>
<td>37.6 ± 1.3</td>
<td>8.6 ± 0.2</td>
</tr>
<tr>
<td>2</td>
<td>11/12</td>
<td>15:18–16:57</td>
<td>23.2 ± 1.0</td>
<td>6.7 ± 0.2</td>
</tr>
<tr>
<td>3</td>
<td>11/12</td>
<td>16:09–17:04</td>
<td>8.7 ± 0.3</td>
<td>3.8 ± 0.1</td>
</tr>
<tr>
<td>4</td>
<td>11/12</td>
<td>16:20–17:04</td>
<td>17.3 ± 0.4</td>
<td>5.9 ± 0.1</td>
</tr>
<tr>
<td>5</td>
<td>11/12</td>
<td>03:14–04:59</td>
<td>32.7 ± 1.1</td>
<td>13.2 ± 0.2</td>
</tr>
<tr>
<td>6</td>
<td>12/01</td>
<td>08:15–09:46</td>
<td>28.6 ± 1.1</td>
<td>7.9 ± 0.2</td>
</tr>
</tbody>
</table>

Several observed factors suggest that this was an extensive ducted wave event:

- Long-lasting and spatial extensive.
- Several signatures in the OH and Na emission, while the higher altitude O2 emission shows a very weak signature.
- The nightly averaged temperature profile exhibits a significant mesospheric inversion layer (MLI) near the altitude of the OH layer, which may favor a thermally ducted environment.

Results

Figure 7 illustrates the lidar temperature profiles and their integration over the night time, which is shown in Figure 6.

References


Acknowledgments

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