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Short Period Gravity Waves in the Arctic Atmosphere Over Alaska

Michael Negale
Utah State University

Kim Nielsen
Utah Valley University

Michael J. Taylor
Utah State University

Britta Irving
University of Alaska, Fairbanks

Richard Collins
University of Alaska, Fairbanks

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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 ~80-100 km (e.g., Frith and Alexander, 2003). The propagation directions 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-period gravity waves associated with downstream dynamics and unexpected dynamical behavior (Nielsen et al., 2009, 2012). In contrast, observations over the Arctic region are few (Szudy et al., 2009), and the dynamical behavior is unknown.

The Mesospheric Airglow Imaging and Dynamics (MAID) project was initiated in January 2011 to investigate short-period gravity waves in the lower and middle Arctic MLT. MAID is a collaborative project between Computational Physics Inc. and the University of Alaska, Fairbanks (UAF). The project combines a multi-wavelength airglow imager with a colocated Rayleigh lidar at Poker Flat Air Research Range (PFARR), with additional campaign data from the Polar Flat Incoherent Scatter Radar (PFISR) and the National Inst. of Information and Communications Technology (NICT) MF radar.

The main goals of this program are:

- Establish a long-term climatology of short-period gravity waves observed in the Arctic MLT region.
- Determine source regions and potential gravity 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 dynamics.

Instruments

The primary instruments used for this research are a Kec Sentry airglow imager at the NICT Rayleigh lidar and both located at PFARR, Alaska (65° N, 151° W), and a Nd:YAG laser receiver. The airglow imager, which has operated at PFARR since January 2011, is a state of the art system designed to remotely sense gravity waves in both polar regions. The Nd:YAG laser system has been used to isolate several emissions (as narrow band filters (2 nm FWHM) is used to isolate several faint airglow emissions since January 2011. It is a state of the art system designed to remotely sense gravity waves in both polar regions.

Figure 1: Attitude profiles of the MLT airglow emissions.

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Figure 2: Average airglow temperature profile.

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 exhibited an extensive wave field is shown in Figure 2. The wave signature was strongest in the OH (a) and Na (b) emissions while there was little evidence of it in the O2 emission (c). 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 behavior. Additional radar measurements of the background wind field are observed in the gravity wave such as its intrinsic period, phase speed, and angle of ascent/descent through the atmosphere to be determined (Taylor et al., 1995).

Data Analysis

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 3D horizontal wavenumber spectrum (Cobble et al., 1998). This 3-D spectrum is computed as follows (Gardner et al., 1998):

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

Figure 5 illustrates the methodology of the unambiguous 3D horizontal wavenumber spectrum showing the isolated peak corresponding to the observed wave event.

Results

Table 2: example wave results for four coordinated observation nights. Figure 6 focuses on event #1 (as shown in Figure 2) with detailed plots of the observed wave parameters as a function of time for this extensive wave event. The resulting data points from 08:30 to 10:50 UT are due to data contamination by auroral activity. It is evident that observed wave parameters varied significantly throughout the night, as much as 20-50%.

Wave Ducting in the MLT region:

- There are two kinds of wave ducting which can occur. Dropper ducting which is created by a jet in the background wind in the direction of wave propagation, and the existence of a temperature duct, which is caused by a discontinuity in the temperature lapse rate (Nappo, 2002). At the time of the wave event #1, no wind observations were available, however, a variable temperature duct is present in the vicinity of the OH layer.

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

- Long-lasting and spatial extensive.
- Strong 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.

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.

Acknowledgments

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