12-2014

Investigating Mesospheric Gravity Wave Dynamics Over McMurdo Station, Antarctica (77° S)

Jonathan Pugmire
Utah State University

Michael J. Taylor
Utah State University

Yucheng Zhao
Utah State University

Dominique Pautet
Utah State University

Investigating mesospheric gravity wave dynamics over McMurdo Station, Antarctica (77° S)

Jonathan R. Pugmire, Mike J. Taylor, Yucheng Zhao, P.-Dominique Pautet
Center for Atmospheric and Space Sciences, Utah State University

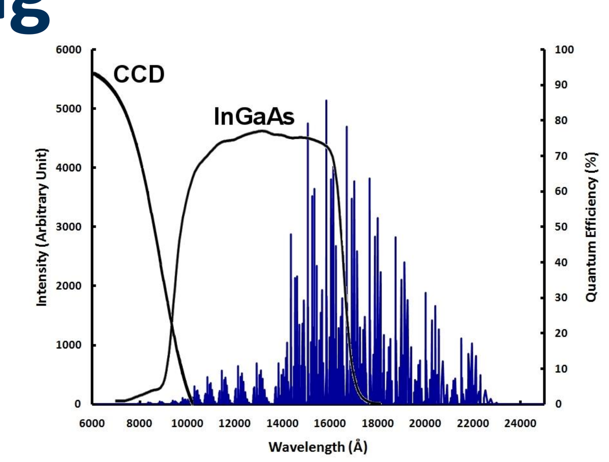
Introduction

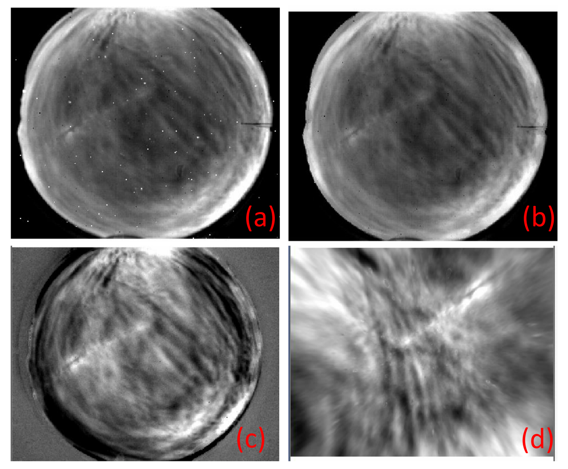
The Antarctic Gravity Wave Instrument Network (ANGWIN) is an NSF sponsored international program designed to develop and utilize a network of gravity wave observatories using existing and new instrumentation operated at several established research stations around the continent. Utah State University's Atmospheric Imaging Lab operates all-sky infrared imagers at several research stations. Here we present novel measurements of short-period and larger-scale mesospheric gravity waves imaged during 2012 from McMurdo Station (77.8°S, 166.7°E) on Ross Island. This IR camera has operated at Arrival Heights alongside the University of Colorado Fe Lidar during the past three winter seasons (March-September 2012-2014). Two initial primary goals are:

- Quantify the properties of small- and medium-scale mesospheric gravity wave climatology over this region of Antarctica.
- Combine results with similar measurements from other ANGWIN stations to investigate continental-wide gravity wave dynamics (see SA31B-4100).

IR Imaging

All-sky observations of the OH emission layer (~87 km) were made using an infrared (0.9-1.7 µm) cooled InGaAs camera. The OH airglow emissions are much stronger in the infrared region (>1 µm), as shown in blue in the figure to the right, and we use new InGaAs cameras to obtain high-quality short-exposure images of gravity waves under auroral and full moon observing conditions.





Example image processing from June 25, 2012, 09:57 UT.

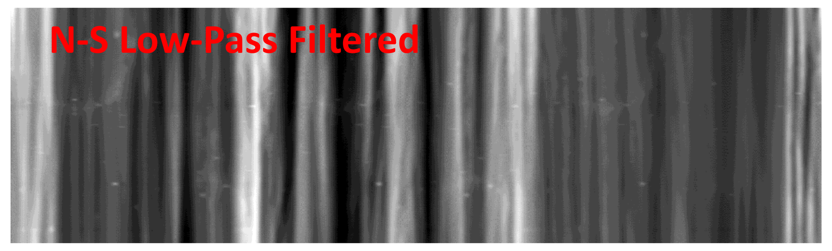
Raw all-sky (180°) OH image data were recorded every 10 s with a 3 s exposure enabling detailed measurements of individual gravity wave events.
(a) Raw image oriented using the IR star field.
(b) Stars removed
(c) Flat fielded: Average nightly image subtracted.
(d) Unwarped to 350 x 280 km geographic grid at 87 km altitude.

Gravity waves were analyzed using well-developed Fourier analysis techniques to determine direction of propagation (θ), horizontal wavelength (λ), observed horizontal phase speed (v) and wave period (T) [e.g. Taylor, et al, 1997].

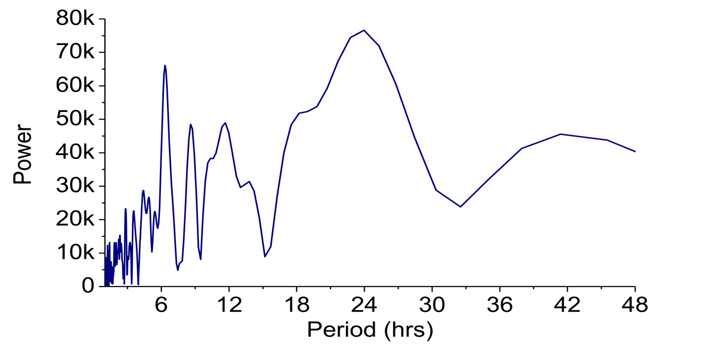
During the 2012 observing period (March-September, nighttime hours) at McMurdo over 400 short-period (<1 hr) gravity wave events were observed.

Optical site at Arrival Heights, McMurdo Station

Large-Scale Tidal Analysis

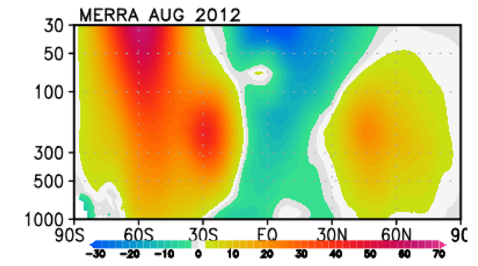


A **low-pass filter (>1 hr periods)** of the large 73 hour keogram revealing strong tidal features with characteristic periods as identified in the FFT analysis.

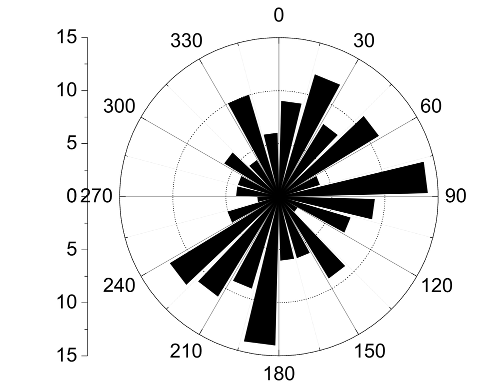


FFT power spectrum analysis identifying mesospheric tidal signatures. Note the strong diurnal tide at 24 hours and several harmonics at 6, 8, and 12 hrs.

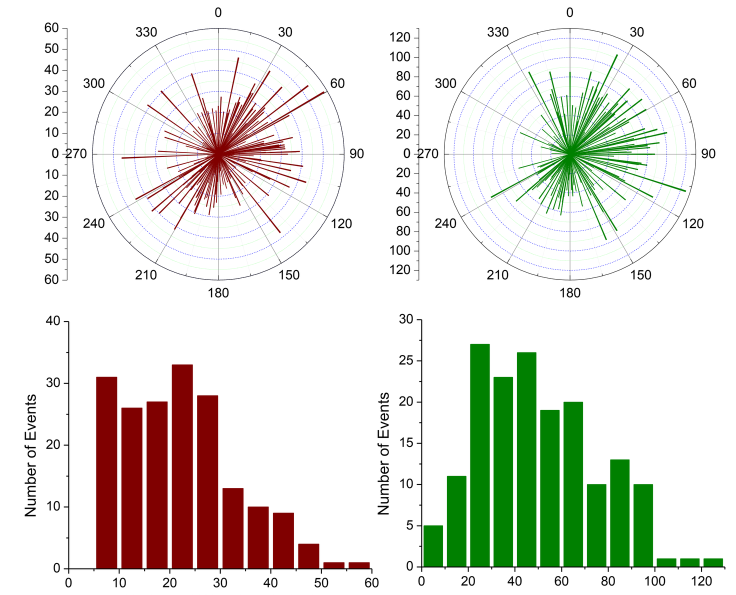
Two Awesome Weeks in August



Zonal Mean Wind: Eastward winds throughout the stratosphere (77°S) create a critical layer for eastward wave phase speeds less than ~30 m/s [MERRA].

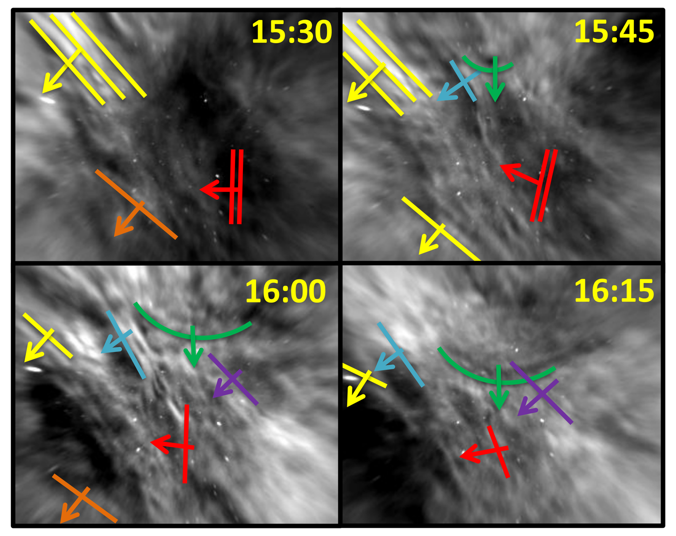


Wave headings for 180 events on UT days 214-230.



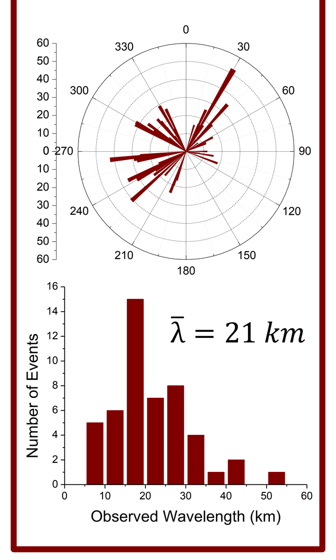
On August 2-18, 2012 (UT day 214-230) over 180 small-scale gravity wave events were observed. Their characteristics were similar to the full season results except their average phase speeds (50 m/s) were significantly higher. These wave events dominated the end of season results. The phase speed distribution is consistent with critical level wind-filtering [Nielson, et al, 2012] with much higher eastward phase speeds.

Three Continuous Days in June

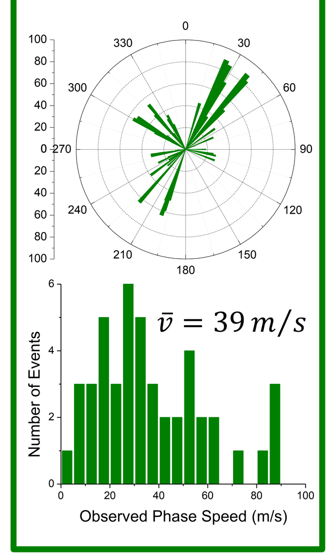


In mid-winter there is continuous darkness at McMurdo. From June 23-26, 2012 (day 175-178) over 40 small-scale gravity wave events were analyzed during 73 continuous hours of observations. Their properties are shown in the figures below.

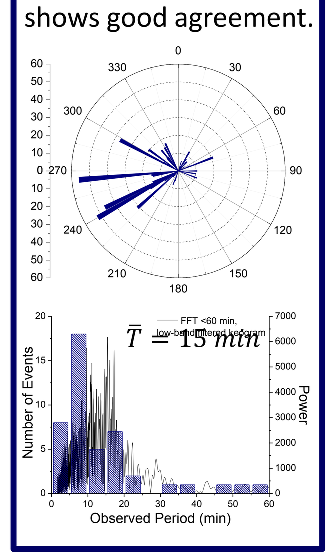
Observed Wavelength
Note the prevailing NE and SW wave motions, similar to the winter summary plot.



Observed Phase Speed
Note the large spread and preferential direction of waves with higher phase speeds.



Observed Period
The black line is a power spectrum of the keogram using a high-pass (<60 min) filter and shows good agreement.



The four unwarped images above show example 350 x 280 km airglow images taken on day 176 every 15 minutes revealing both the high level of wave activity and quality of the images. Several wave features are highlighted as they propagate through the images. The blue and green lines can also be seen in keogram data below, wave event #1.

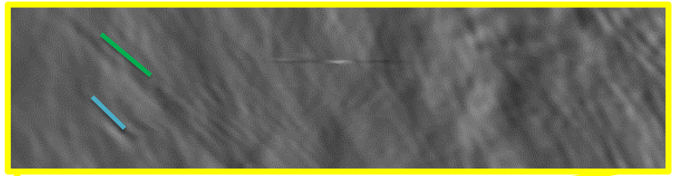
Keograms

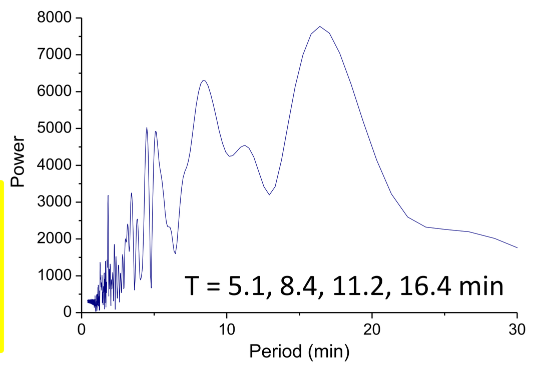
Both large- and small-scale gravity wave features can be studied by creating keograms. A keogram is made by stacking vertical (and horizontal) slices through the center of each image together to form a time series revealing wave activity as a function of time. The large keograms along the bottom of the poster shows 73 continuous hours of wave data starting (day 175, 01:33 UT to day 178, 03:09 UT). These data illustrate the high quality of our gravity wave measurements from Antarctica.

Small-Scale Gravity Waves

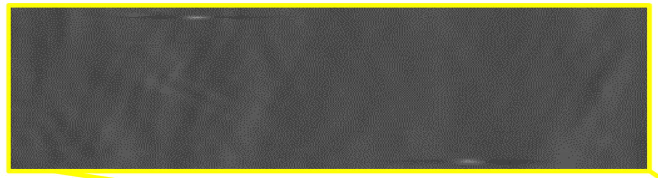
A **high-pass filter** was applied to the keogram to measure small-scale gravity waves with periods of 5-60 min (as highlighted in yellow boxes). Two selected wave events are shown together with their FFT power spectrum. These are compared with the event properties analyzed from the individual airglow images.

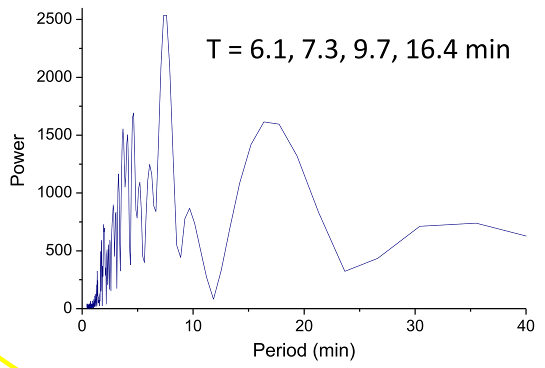
Wave Event #1: Day 176, 15:30-19:00
λ = 22 ± 3 km θ = 217° ± 5°
v = 44 ± 5 m/s T = 8 ± 3 min



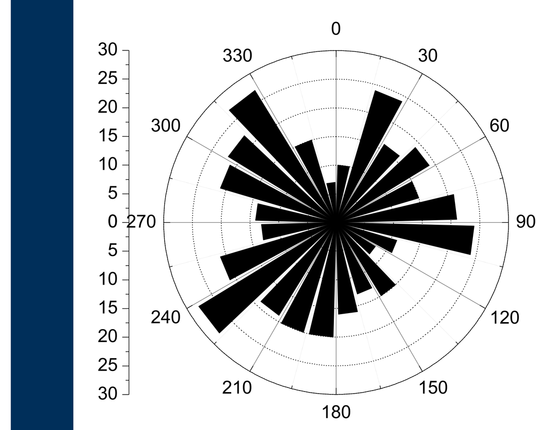


Wave Event #2: Day 177, 16:50-20:00
λ = 24 ± 3 km θ = 318° ± 5°
v = 42 ± 5 m/s T = 10 ± 3 min



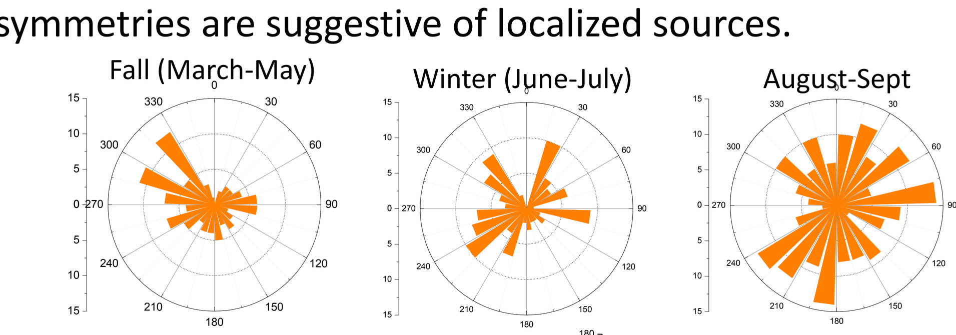


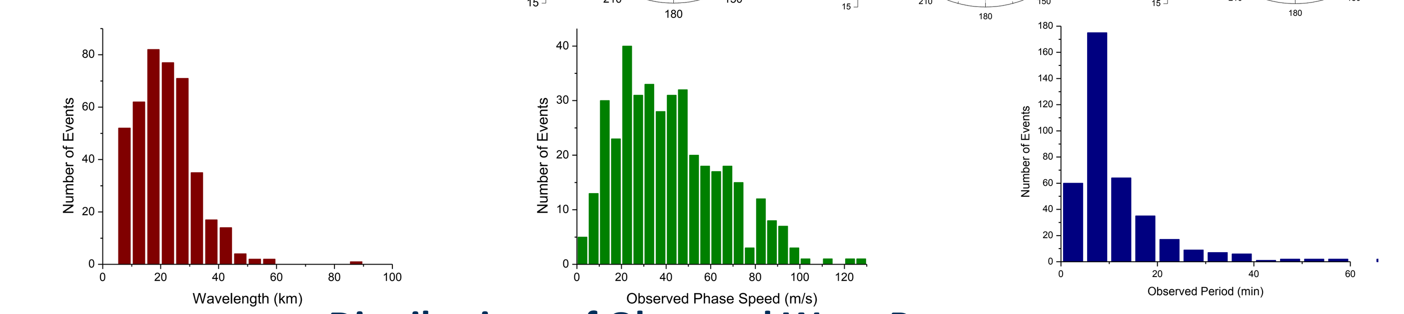
Summary: 2012 Wave Parameters



Distribution of Wave Headings: Winter season wave motions were prominent in several directions.

The data show evolution from NW propagation (107 events) in the fall which expands to NE and SW wave motions during mid-winter (110 events). The late winter was dominated by many waves (202 events) again exhibiting strong NE and SW motions but more isotropic than earlier. The strong asymmetries are suggestive of localized sources.





Distributions of Observed Wave Parameters

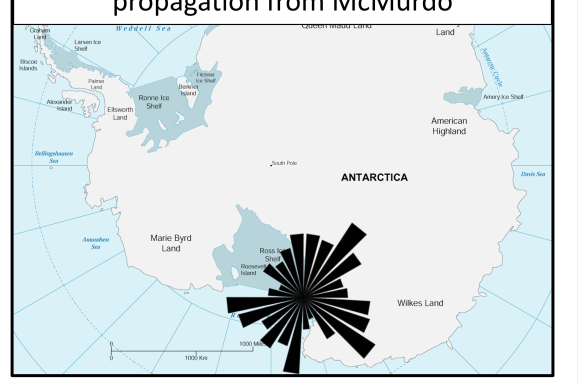
A total of 419 events were analyzed. Their average values were λ= 22 km, v = 42 m/s, T = 12 min. These mean values and their ranges are typical for short-period gravity waves observed at several sites around Antarctica as part of ANGWIN.

Summary

We have analyzed one year of data to date from McMurdo Station, Antarctica. The results are as follows:

- A large number (400+) of short-period gravity waves observed over McMurdo, Antarctica enabling the wintertime mesosphere wave climatology to be investigated for the first time.
- McMurdo waves exhibits a large spread of phase speeds with a tendency for high phase speeds up to ~120 m/s.
- New keogram analysis enables the investigation of larger period gravity waves and tidal perturbations in the mesosphere revealing 6, 8, 12, and 24 hr tides and harmonics.
- The sources of the wave events observed from McMurdo are probably associated with strong localized weather systems associated with the polar vortex.
- Small-scale wave event analysis results are comparable using FFT and keograms.

Sketch illustrating direction of propagation from McMurdo



Future Work

- Ongoing measurements from the South Pole station in combination with other ANGWIN sites will be used to investigate pan-Antarctic anisotropy and wave parameters.
- New analysis of McMurdo data from 2013 and 2014 data will further clarify the asymmetries in the wave propagation at this site for understanding the climatology of gravity waves observed at McMurdo.
- Comparison with onsite Fe Boltzmann Lidar measurements and MF radar wind measurements.

References

MERRA Atlas, GEOS-5, August 2012, NASA Goddard Space Flight Center, Retrieved December 11, 2014.

Nielsen, K., Taylor, M. J., Hibbins, R. E., Jarvis, M. J., & Russell, J. M. (2012). On the nature of short-period mesospheric gravity wave propagation over Halley, Antarctica. *Journal of Geophysical Research: Atmospheres (1984–2012)*,*117*(D5).

Taylor, M.J., W.R. Pendleton, Jr, S. Clark, H. Takahashi, D. Gobbi, and R.A. Goldberg (1997). Image measurements of short-period gravity waves at equatorial latitudes, *J. Geophys. Res.*, *102*, 26,283-26,299.

Acknowledgements This research was supported by NSF grant ANT-1045356.