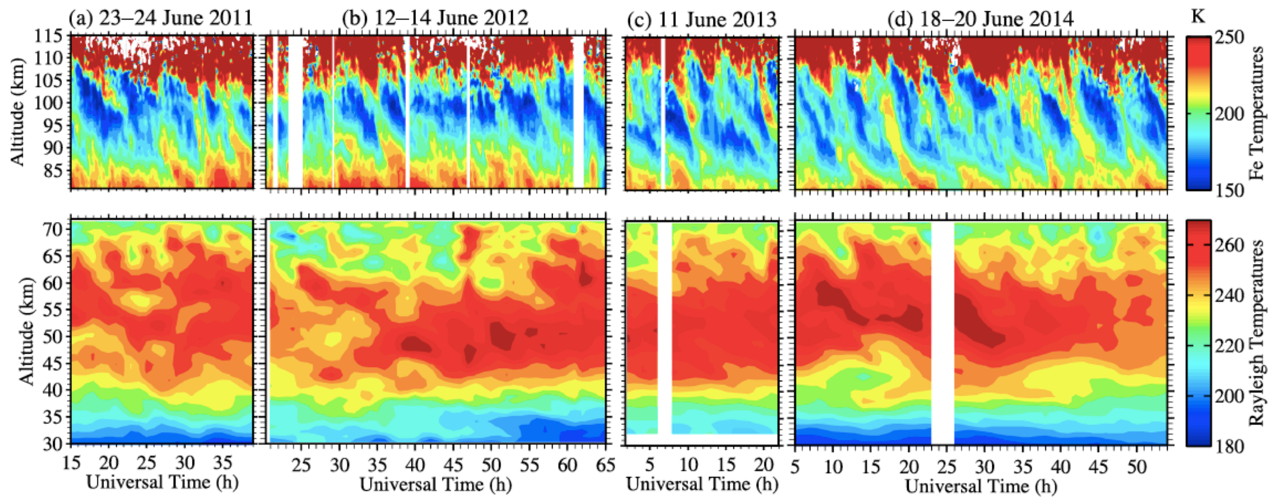
A Statistical Baseline of Gravity Wave Properties in the Mesosphere and Lower Thermosphere at McMurdo, Antarctica Derived from 10 Years of Lidar Observations

Ian Geraghty and Xinzhao Chu, University of Colorado Boulder

Introduction

Gravity waves (GWs) are important drivers of variability and coupling in the global atmosphere and consequently the performance of general circulation models is reliant on how accurately GWs are represented in these models. There is a critical need for comprehensive observational studies of GW properties and processes in order to inform the GW parameterization schemes used in models, as well as provide truth references for GW-resolving models. Lidars are powerful observational tools for the study of atmospheric waves because of their capability to probe large altitude ranges at high resolutions for long durations of time. This study presents statistics of GW properties in the mesosphere and lower thermosphere (MLT) derived from spectral analysis of 10 years of data collected by an Fe Boltzmann lidar at McMurdo Station, Antarctica. This lidar has revealed an extremely rich environment in the MLT above McMurdo, which is dominated by a class of strong, persistent GWs and characteristically different than the wave field in the stratosphere. The looming question is: **What is the source of the strong wave activity in the MLT?**

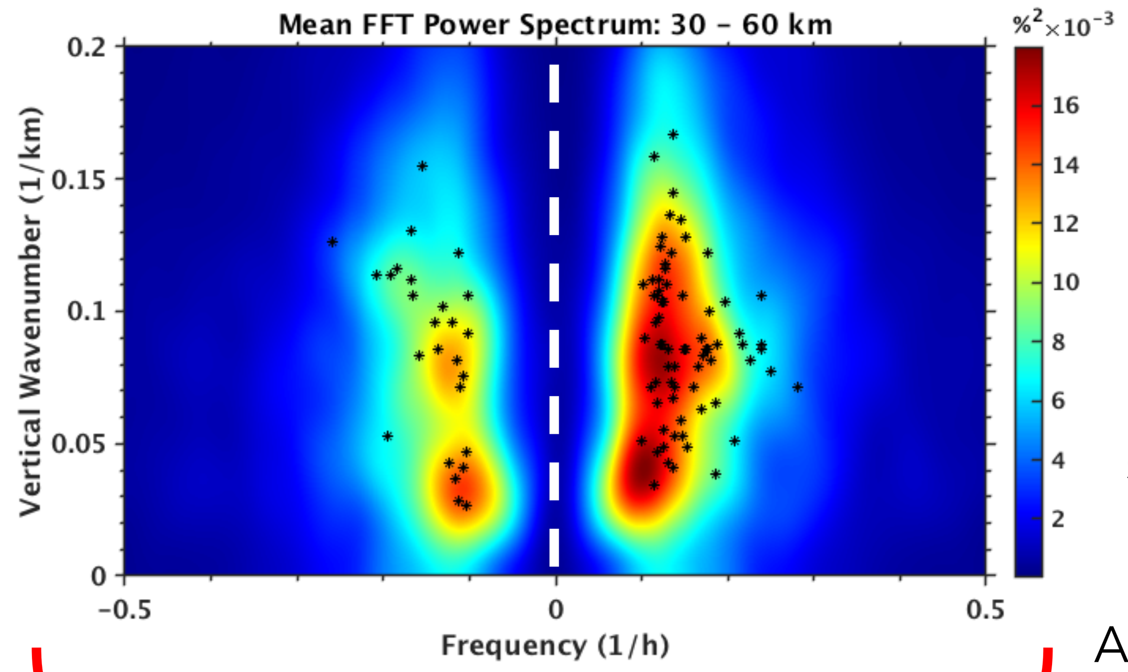
These GW observations helped drive the formation of the multistep vertical coupling concept and Vadas and Becker (2018) used the Kühlungsborn Mechanistic general Circulation Model (KMCM) to conclude that the majority of GWs in the MLT above McMurdo were secondary waves. Armed with a more complete assessment of the MLT GWs, we are now in a position to start evaluating possible wave sources from an observational standpoint, in conjunction with modeling efforts.



Examples of raw Fe Boltzmann lidar temperature measurements made at McMurdo in June

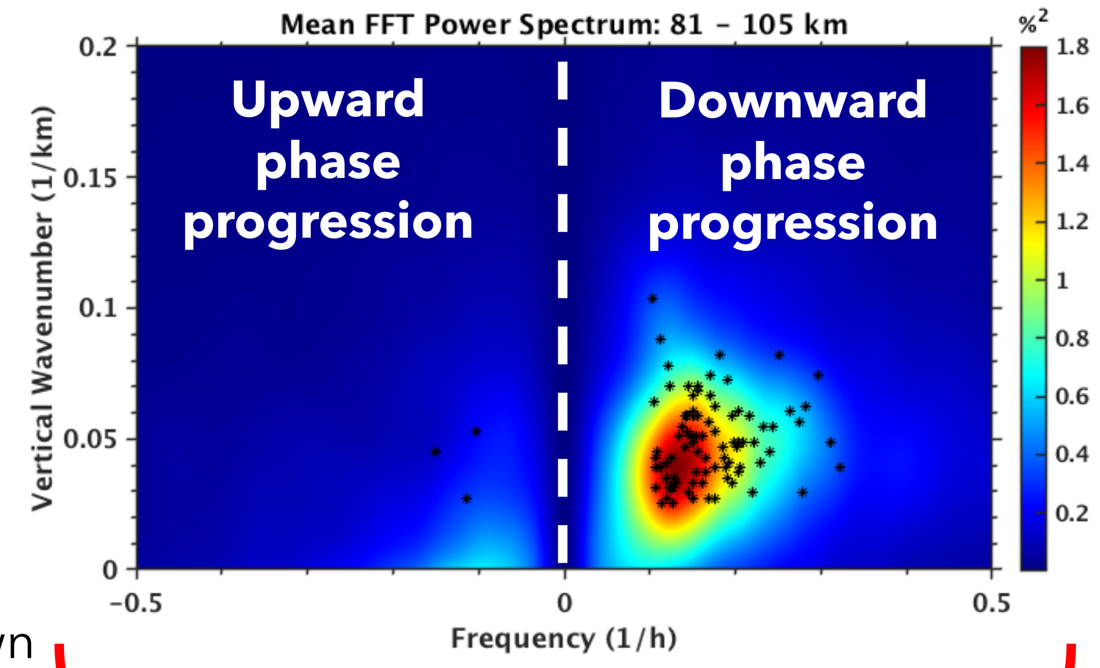
Stratosphere vs MLT wave spectrum as shown by 2D FFT:
Winter mean spectra of the 30 – 60 km and 81 – 105 km ranges show striking differences.

1) Distinct lack of upward phase progressing waves in the MLT compared to stratosphere
2) MLT is dominated by larger vertical wavelength waves in contrast to the stratosphere



How does the wave spectrum change so drastically between these two regions?

Black points mark the strongest wave signal from each lidar observation.
Average values are shown below.



Downward/ Upward	# of Waves	τ_{GB} (h)	λ_z (km)	c_z (m/s)
April	15 / 5	7.4 / 6.3	10.9 / 8.4	0.44 / 0.40
May	14 / 6	6.1 / 8.3	12.1 / 12.6	0.59 / 0.42
June	13 / 4	7.0 / 6.5	13.4 / 17.6	0.53 / 0.72
July	20 / 5	7.2 / 7.3	13.4 / 16.0	0.54 / 0.58
August	9 / 6	7.3 / 8.6	14.2 / 18.1	0.60 / 0.59
Total	71/ 26	7.0 / 7.5	12.7 / 14.5	0.54 / 0.53

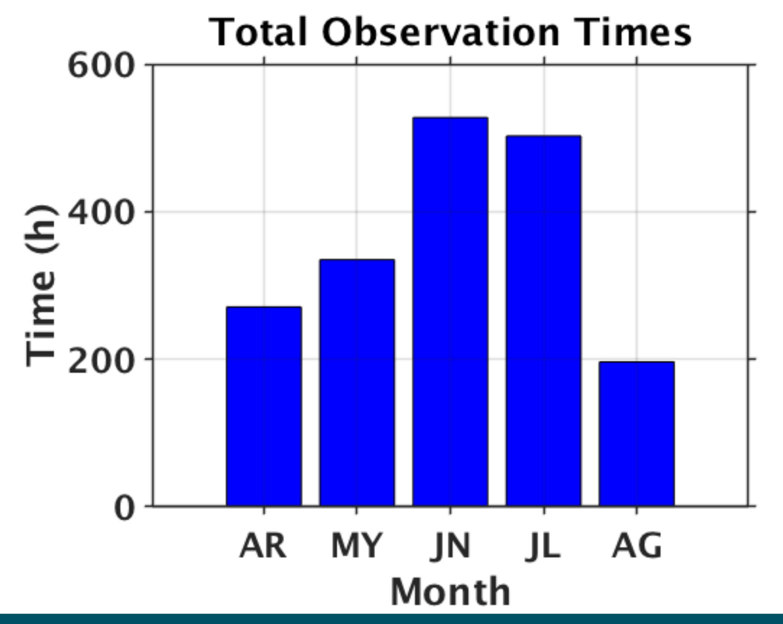
Just Downward	# of Waves	τ_{GB} (h)	λ_z (km)	c_z (m/s)
April	15	6.6	19.6	0.88
May	16	6.6	23.1	1.03
June	20	6.5	20.8	0.93
July	27	5.7	23.8	1.22
August	13	6.5	21.9	1.00
Total	91	6.3	22.1	1.04

Data:
Comprises ~1200 h of Fe Boltzmann lidar data collected between 2011 - 2020

- **MLT:** 0.5h x 1km resolution, 81 – 105 km range, unfiltered
- **Rayleigh:** 2h x 1km resolution, 30 – 60 km range, filtered with (1/11)h cutoff frequency to remove planetary waves and tides
  - **May still result in spectral leakage but these results are more demonstrative at this point**
- Spectral transforms are applied to relative temperature perturbations scaled by a normalized, mean atmospheric density profile from MSIS

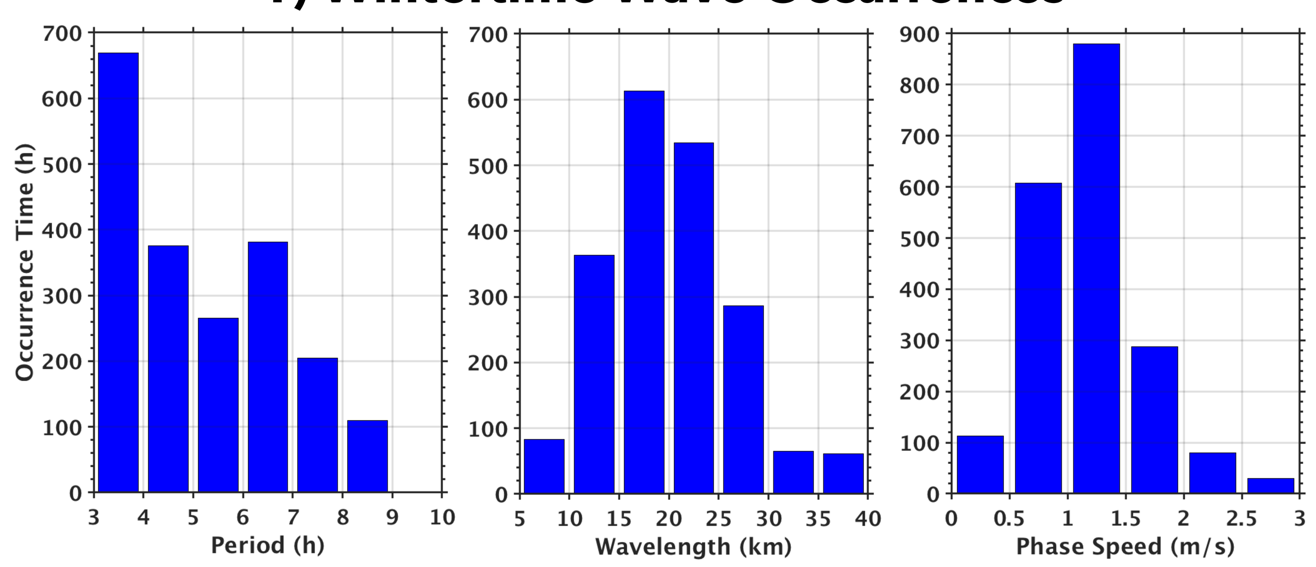
$$T'_{Rel}(t,z) = \sqrt{\frac{\rho(z)}{\rho(z_0)}} * \frac{T(t,z) - T_{mean}(z)}{T_{mean}(z)}$$

Study focuses on the wintertime when lidar data SNRs are highest



Deeper look into MLT GWs with a 2D wavelet-based methodology

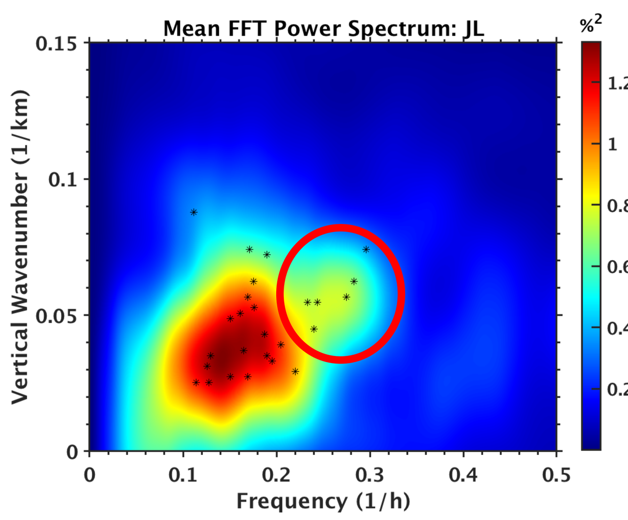
1) Wintertime Wave Occurrences

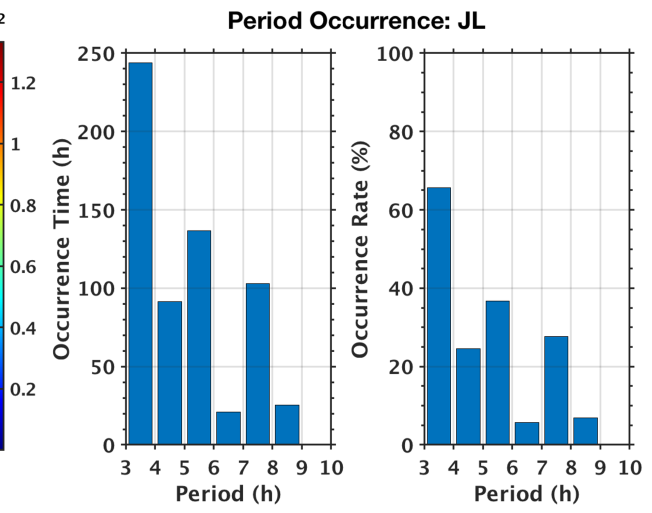


Ground-based period distribution shows various modes unlike the lognormal distribution Zhao et al., 2017 found in the stratosphere

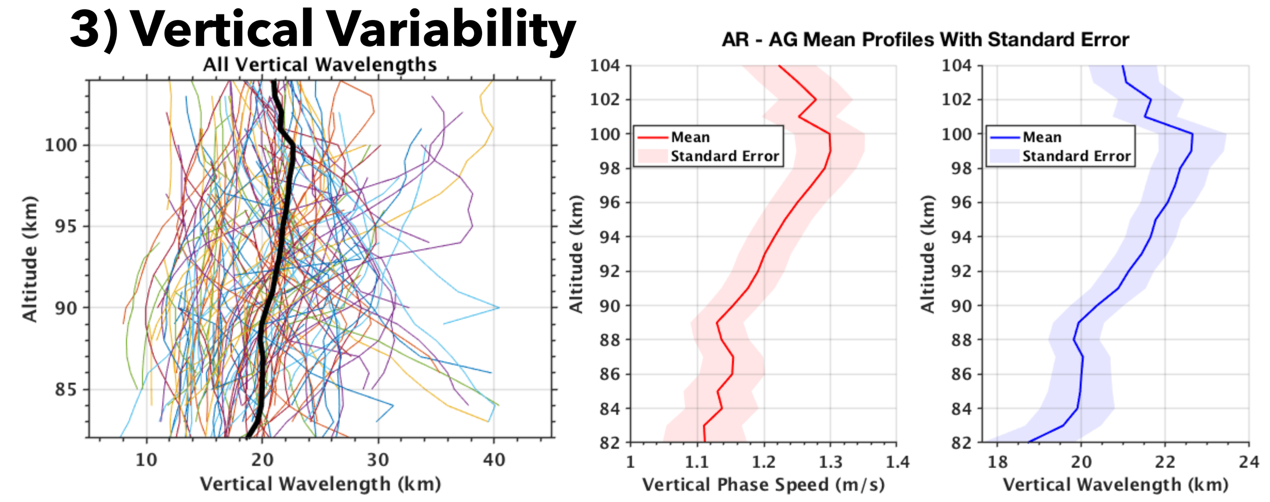
2) Signs of Seasonal Variability

FFT and wavelet results show that July experiences an exceptional amount of strong 3 – 4 h period waves that are uncharacteristic of the other months.





3) Vertical Variability



Turning point near 100 km in mean profiles may be a result of the wave spectrum changing or linked to Doppler shifting by the background winds. However, significant variability exists on a case by case basis.

Conclusions and Future Work

This work observationally characterizes the GWs in the MLT above McMurdo Station and further highlights the distinct differences between the MLT wave field and that of the stratosphere. The following results hint that the MLT GWs are largely secondary waves:

1) The larger vertical wavelengths and phase speeds of waves in the MLT relative to the stratospheric waves
2) The lack of upward phase propagating waves in the MLT, implying (not always the case) that their source is lower in the atmosphere

With this statistical baseline established, future work will involve looking further into the variability of these wave properties, as well as GW properties in the stratosphere and background atmospheric conditions, to gain more insight into possible wave sources. The main candidate for the MLT GW source is secondary wave generation, but more work is needed to provide supporting evidence from an observational standpoint and determine when other wave sources may be at play.

The McMurdo lidar projects were supported by the National Science Foundation (NSF) grants OPP-1246405, OPP-1443726, and OPP-0839091