Multi-Year Survey of Persistent Gravity Wave Parameters in the Mesosphere and Lower Thermosphere at McMurdo (77.6 °S, 166.7 °E) , Antarctica

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Abstract

Internal gravity waves (IGWs) play a key role in distributing heat and momentum throughout the atmosphere. *Chen et al.* [2016] showed that during the month of June large amplitude gravity waves with periods of ~3 - 10 h and vertical wavelengths of ~20 - 30 km are dominant and persistent in the Mesosphere and Lower Thermosphere (MLT) above McMurdo (77.6 °S, 166.7 °E), Antarctica. These waves have been detected during every lidar observation, a phenomena that had not yet been documented. We present the preliminary results of a statistical study of IGW properties in the MLT above McMurdo. Ultimately, this study will characterize seasonal variations of MLT IGW properties using multiple years of iron temperature and density measurements. However, this poster focuses on the Antarctic winter months (May – August) in which IGW properties are extracted from iron temperature perturbations exclusively. An understanding of the seasonal variations of these waves is needed to fully understand the dynamics of the polar MLT region as well as provide clues of sources for persistent waves, which remain unknown. We hope that this analysis and comparison with IGW trends in the stratosphere provide clues as to dominant wave sources.

1. Data Overview

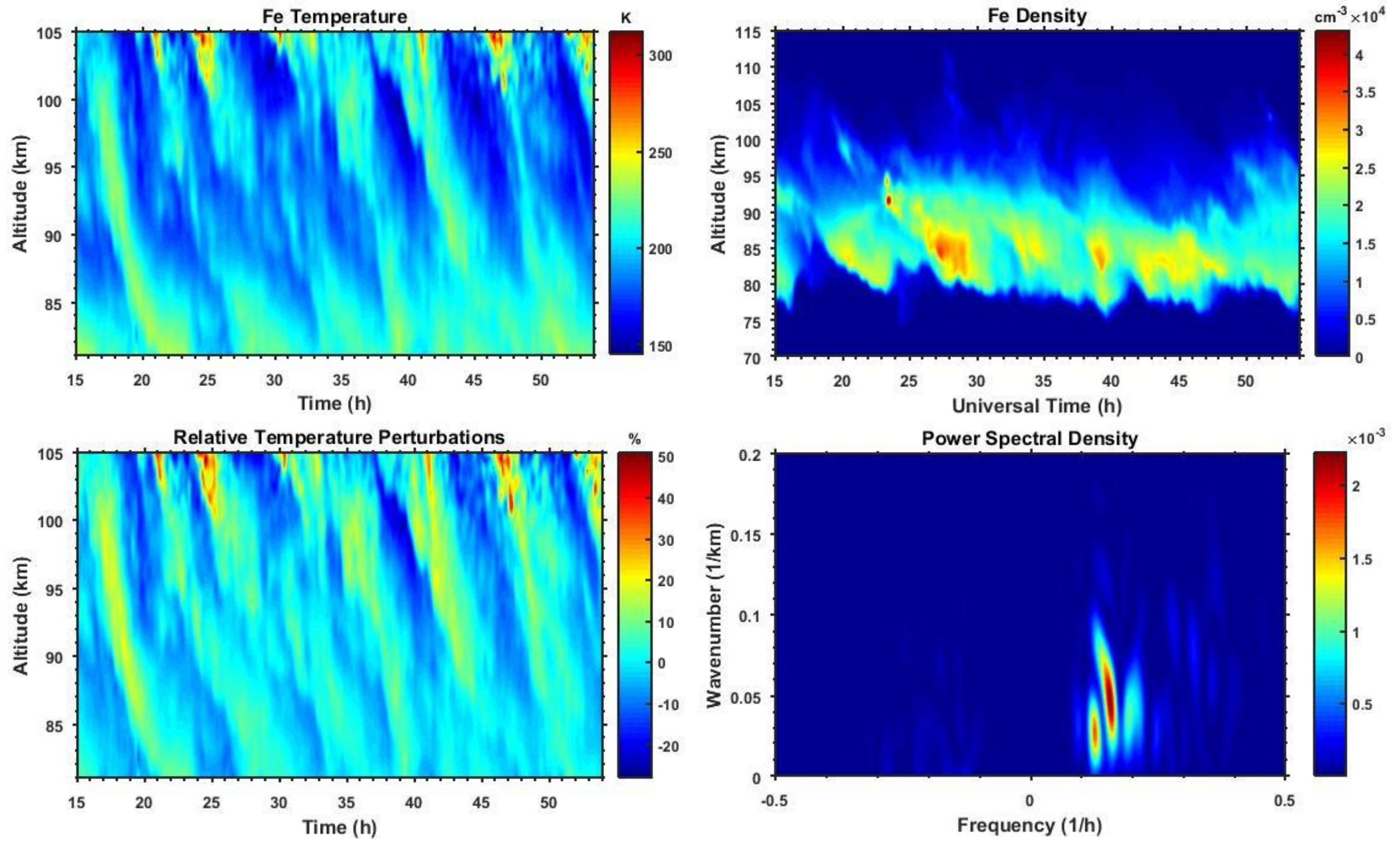
This study was enabled by the observations of an Fe Boltzmann lidar designed and operated by the University of Colorado lidar group. The resonance lidar measures the temperature of atmospheric iron with a vertical resolution of 0.5 km and a temporal resolution of 0.25 h. Four years of temperature measurements taken between 2011 and 2014 are incorporated in this study. An altitude range of 81 – 105 km is analyzed so that sufficient data is available throughout the year in spite of the seasonal changes in the height of the atmospheric iron layer. Following the procedure of *Zhao et al.* [2017], observations lasting less than 6 h are disregarded and observations lasting longer than 12 h are cut into 6 – 12 h segments.

2. Analysis Procedure

- Absolute temperature perturbations are calculated as follows where $T_0(z)$ is the temporal mean temperature:
$$\Delta T(z,t) = T(z,t) - T_0(z)$$
- $\Delta T(z,t)$ is filtered (to suppress effects of tidal and planetary waves) using a 6th order Butterworth filter with a cutoff frequency of $\frac{1}{11}\,h^{-1}$ which yields $\Delta T'(z,t)$
- Filtered relative temperature perturbations are calculated as follows:
$$T'_{rel}(z,t) = \frac{\Delta T'(z,t)}{T_0(z)}$$
- Two-dimensional Fast Fourier Transform is applied to $T'_{rel}(z,t)$ and the power spectral density (PSD) is calculated
- Monte Carlo simulation with 1000 iterations is used to estimate the spectral noise floor. For each iteration, temperature errors are multiplied by randomly generated numbers from a Gaussian distribution. These values are treated as $\Delta T(z,t)$ and subject to the same process outlined above to calculate the PSD. The resulting 1000 PSD's are averaged to get the spectral noise floor.
- The spectral noise floor is subtracted from the PSD and the 3 strongest peaks are included in the statistical analysis following the procedure of *Zhao et al.* [2017].

3. Results

3.1. Case Example – June 18, 2014



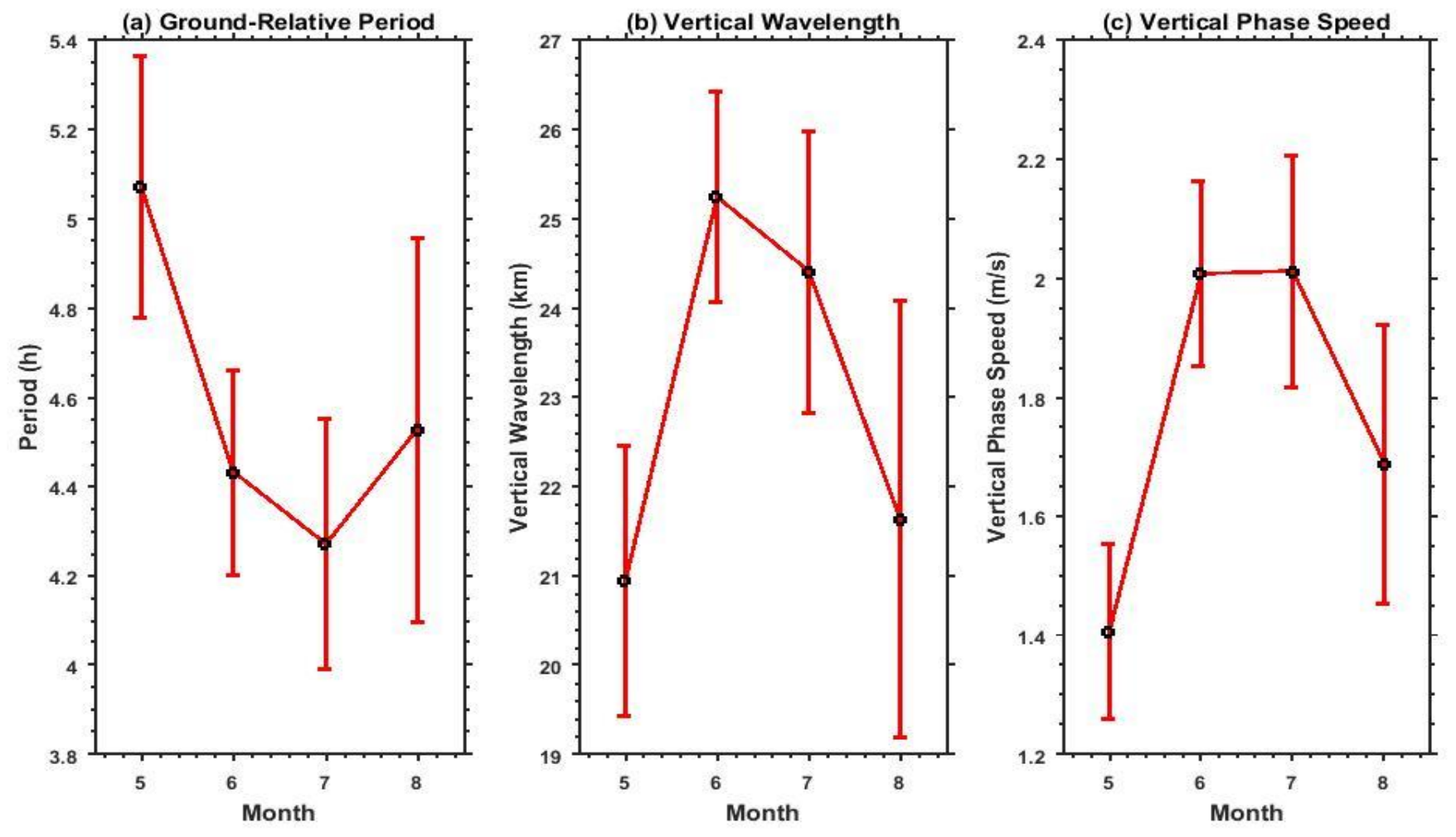
Challenges of analyzing iron density data include

1. Neglecting effects of polar mesospheric clouds
2. Neglecting chemical amplification effects at the atomic oxygen shelf

3.3. Monthly Average Parameters

Downward Phase Progression

*Upward phase progressing wave averages aren't shown because of the small amount detected



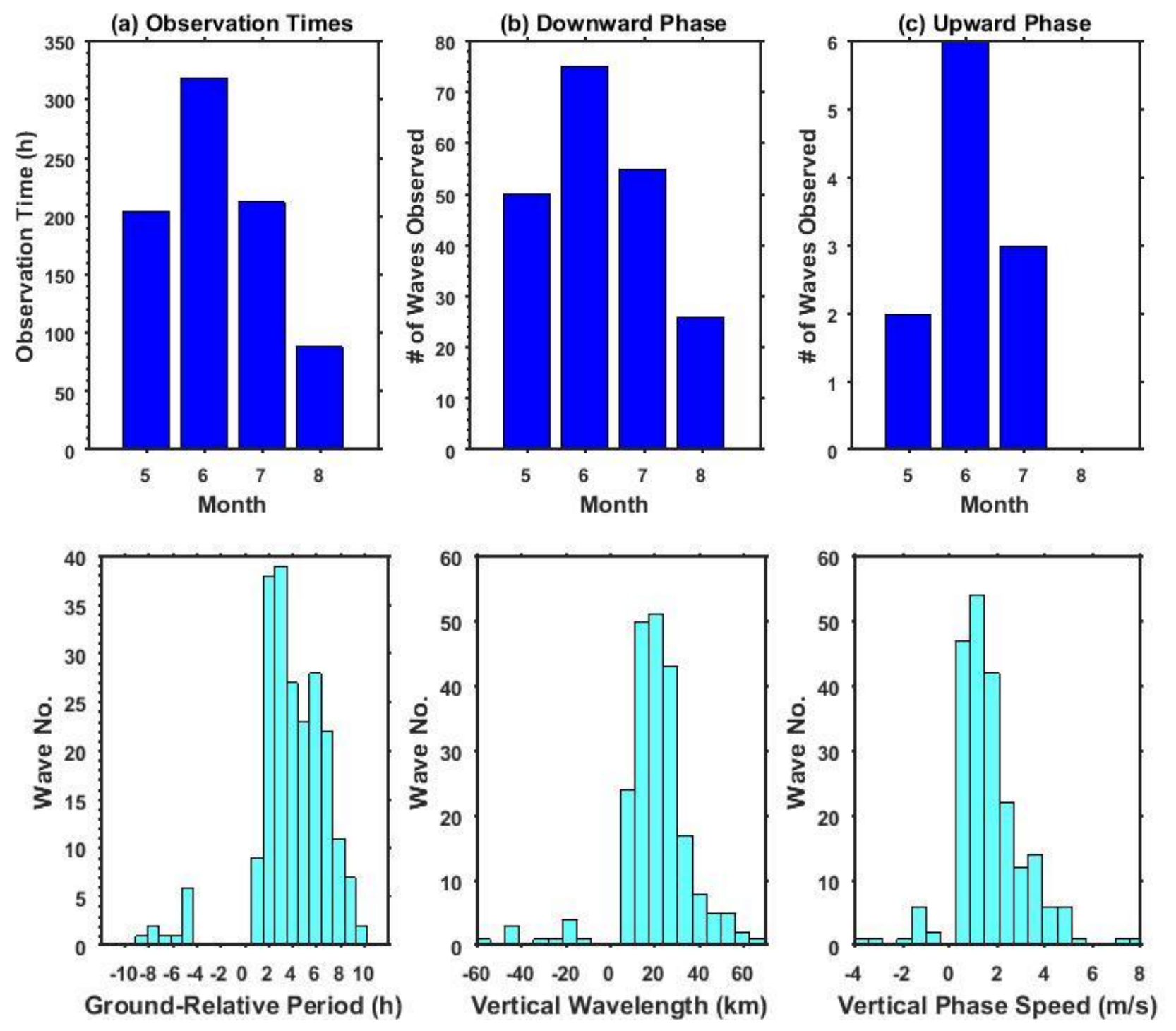
		Period (h)	Vertical Wavelength (km)	Vertical Phase Speed ($\frac{m}{s}$)
May	Mean ± Std of Mean	5.07 ± 0.29	20.95 ± 1.50	1.41 ± 0.15
	Std	2.07	10.64	1.04
	Median	4.90	19.06	1.08
June	Mean ± Std of Mean	4.43 ± 0.23	25.24 ± 1.18	2.01 ± 0.16
	Std	1.98	10.23	1.34
	Median	4.27	24.10	1.61
July	Mean ± Std of Mean	4.27 ± 0.28	24.40 ± 1.57	2.01 ± 0.19
	Std	2.07	11.68	1.44
	Median	4.10	22.76	1.62
August	Mean ± Std of Mean	4.50 ± 0.41	21.1 ± 2.29	1.65 ± 0.22
	Std	2.16	12.12	1.16
	Median	4.06	18.21	1.24

3.2. Statistical Results for Antarctic Winter

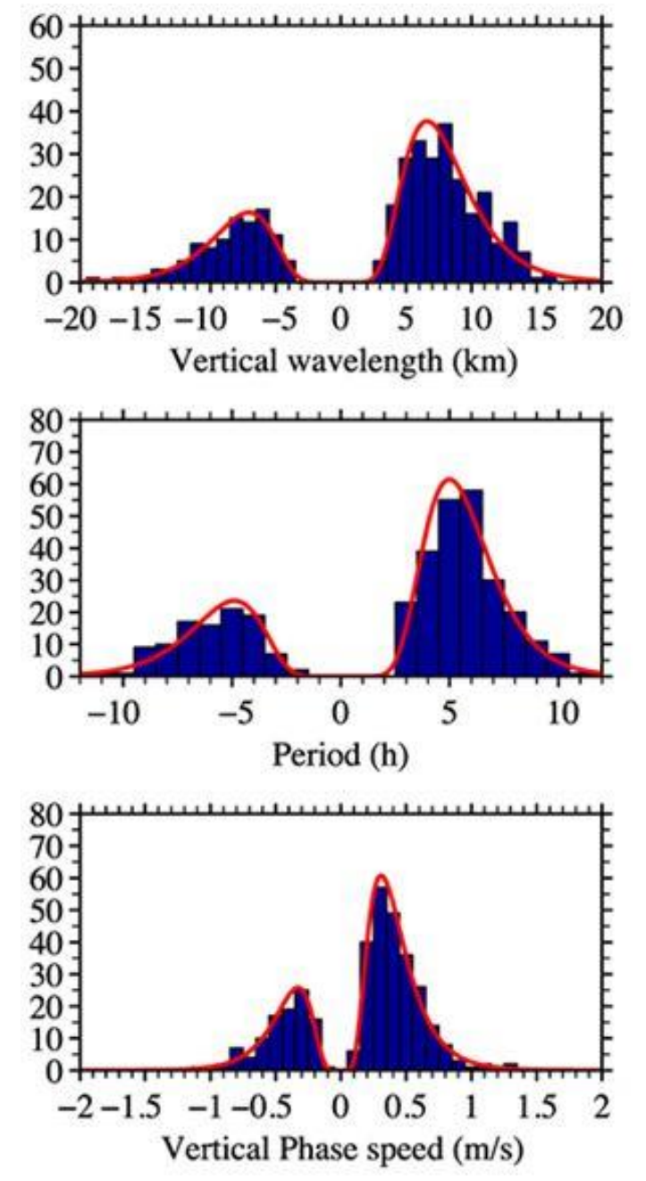
Results are shown next to those obtained by *Zhao et al.* [2017] for the stratosphere using the same methods (2D-FFT, 3 dominant waves). Negative values represent waves with upward phase progression.

* If 5 dominant waves are picked from the spectrum of each MLT observation the distributions begin to appear log normal as they are in the stratosphere.

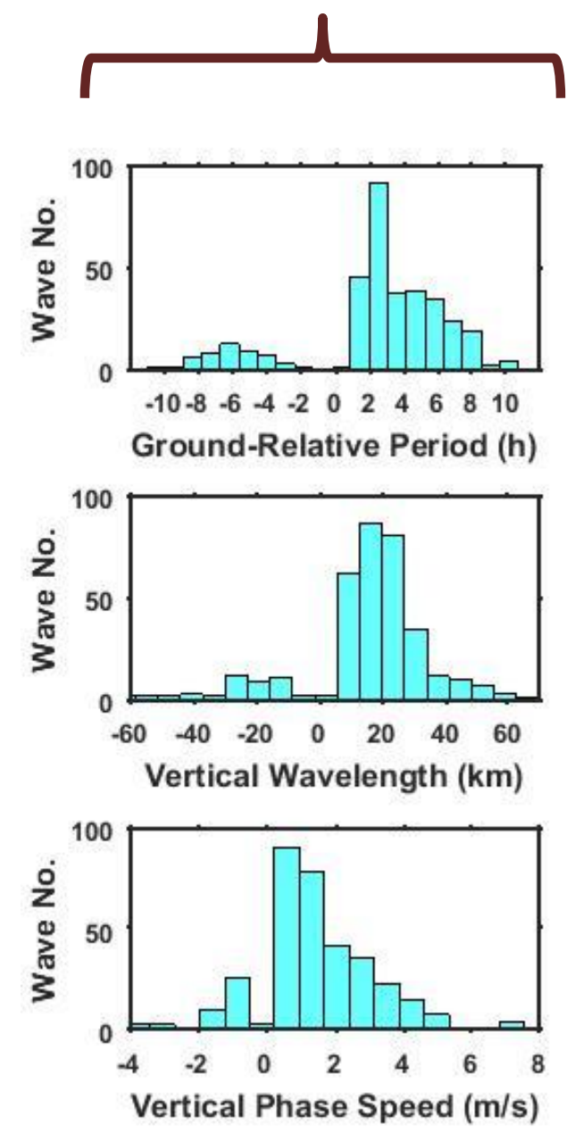
81 – 105 km



30 – 50 km



5 dominant waves



3.4. Potential Energy Density Study

$$E_{pm}(z) = \frac{1}{2}\frac{g^2}{\overline{N^2(z)}}\frac{T'_{GW}(z)^2}{T_{Bkg}(z)^2}$$

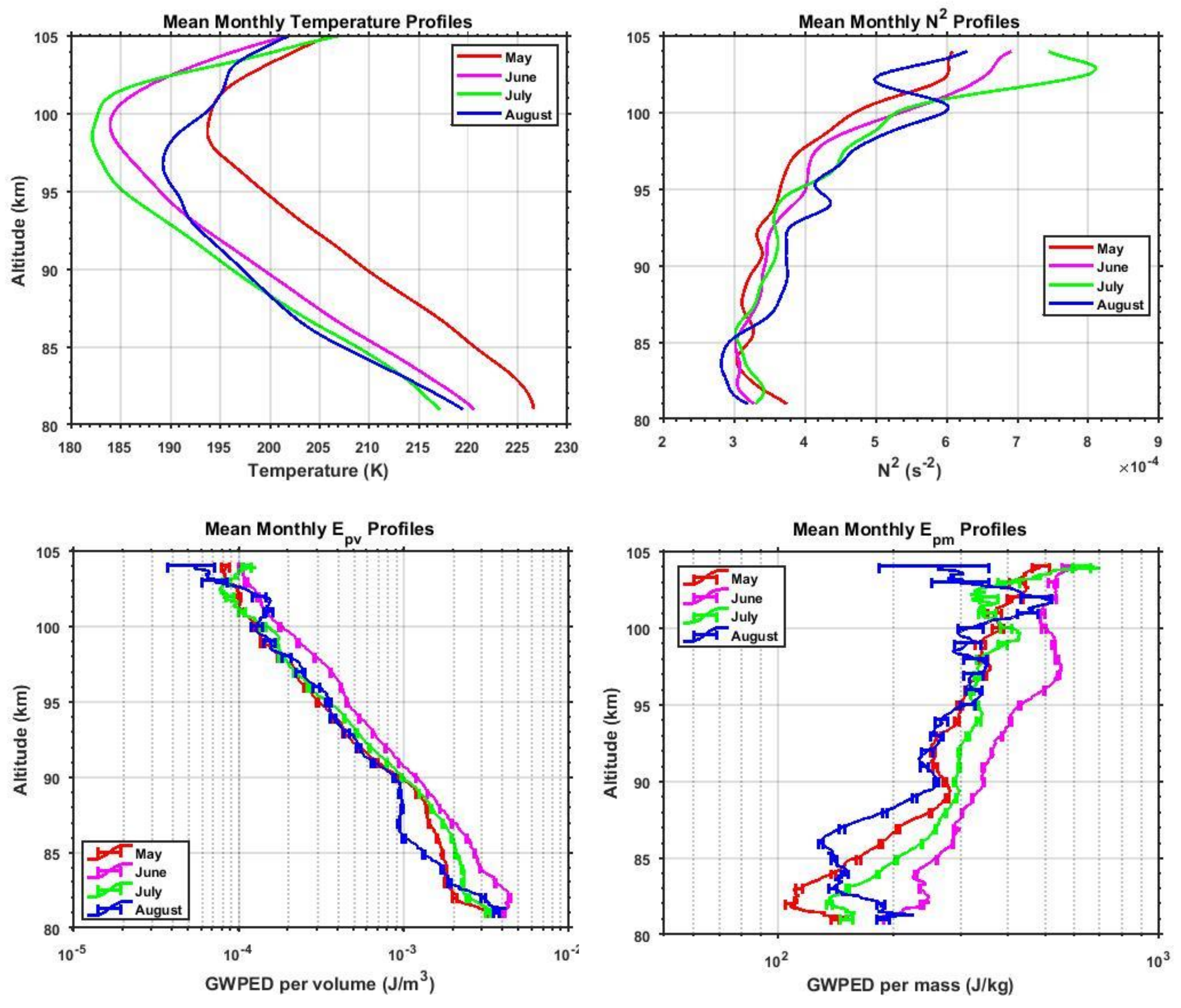
$$E_{pv}(z) = \rho_0(z)E_{pm}(z)$$

$$N^2(z) = \frac{g}{T_0(z)}\left(\frac{dT_0(z)}{dz} - \frac{g}{C_p}\right)$$

$$T'_{GW}(z)^2 = \overline{\Delta T'(z,t)^2} - \overline{\sigma_T(z,t)^2}$$

$$T_{Bkg}(z) = \frac{\sum_i^{N_p} w_i(z)T_{0,i}(z)}{\sum_i^{N_p} w_i(z)}$$

*w_i(z) is a weighting term equal to the amount of data points at each altitude after outlier removal of observation i where N_p is the number of observations in each respective month. This weighting was used for the calculation of the mean monthly $E_{pm}(z)$, $E_{pv}(z)$, and $N^2(z)$ profiles as well
*Mean $T_{Bkg}(z)$ and $N^2(z)$ profiles were Hamming smoothed with a window length of 1.5 km



Conclusions

1. Winter Wave Parameters

- Ground relative periods vary between 0.90 and 10.20 h with an average of 4.6 h
- Only ~8% of wave have periods < 2 h
- Vertical Wavelengths vary between 8.4 and 68.3 km with an average of 23.5 km
- Vertical phase speeds vary between 0.28 and 8.2 m/s with an average of 1.8
- Ratio of number of downward phase progressing waves to total number of waves detected is 95.4% (86% if 5 strongest waves are picked from each observation)
- IGWs are strongest in June (largest GWPED per unit mass)

2. Comparison with Winter Stratosphere IGW Trends

- Greater temperature perturbations and potential energy density per unit mass indicate that IGWs in the MLT are much stronger
- While the average ground-relative periods are similar (5.7 h for stratosphere), average vertical wavelength and phase speeds are significantly smaller (8.07 km and 0.43 m/s for stratosphere, respectively)
- Downward phase progressing waves are more dominant in the MLT (ratio of downward phase to total number of waves is 70.4% in the stratosphere)

3. Questions To Be Answered

- Why is downward phase progression so much more frequent than upward phase progression?
- If downward phase progression tends to correspond to upward energy propagation does this imply a stratospheric wave source? Would analysis of wind data reveal that the typical direction of energy propagation isn't upward?
- Due the IGW parameters in the MLT actually follow a log normal distribution as they do in the stratosphere? If so what does this imply?