Statistical Characterization of Persistent Gravity Waves in the Mesosphere and Lower Thermosphere at McMurdo, Antarctica With a 2D Wavelet-Based Methodology

Ian Geraghty and Xinzhao Chu, University of Colorado Boulder

Introduction

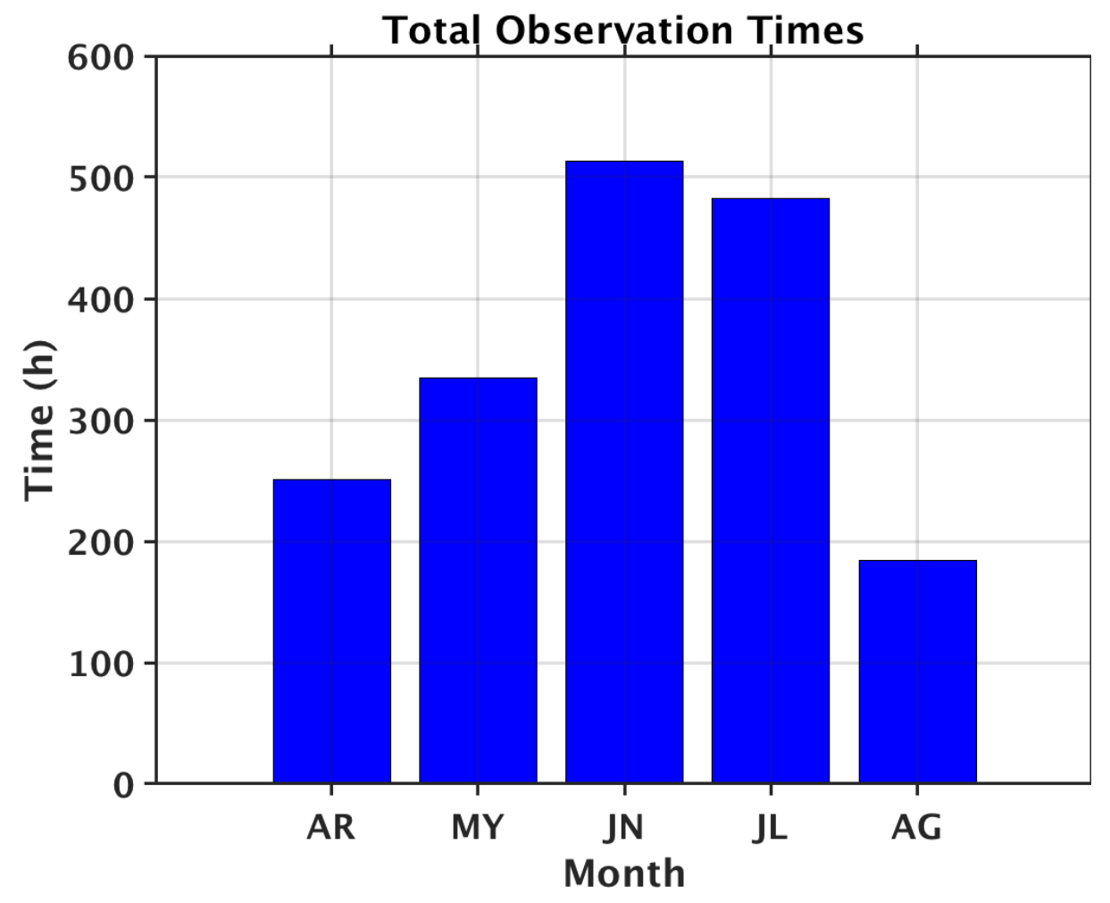
Aside from radiative and chemical forcing, the climatology of the upper atmosphere is largely determined by the dynamic forcing of atmospheric waves. Gravity waves (GWs) are primarily generated in the troposphere and exhibit significant spatial and temporal variability. Systematic and observational studies of GWs in the upper atmosphere are needed to:

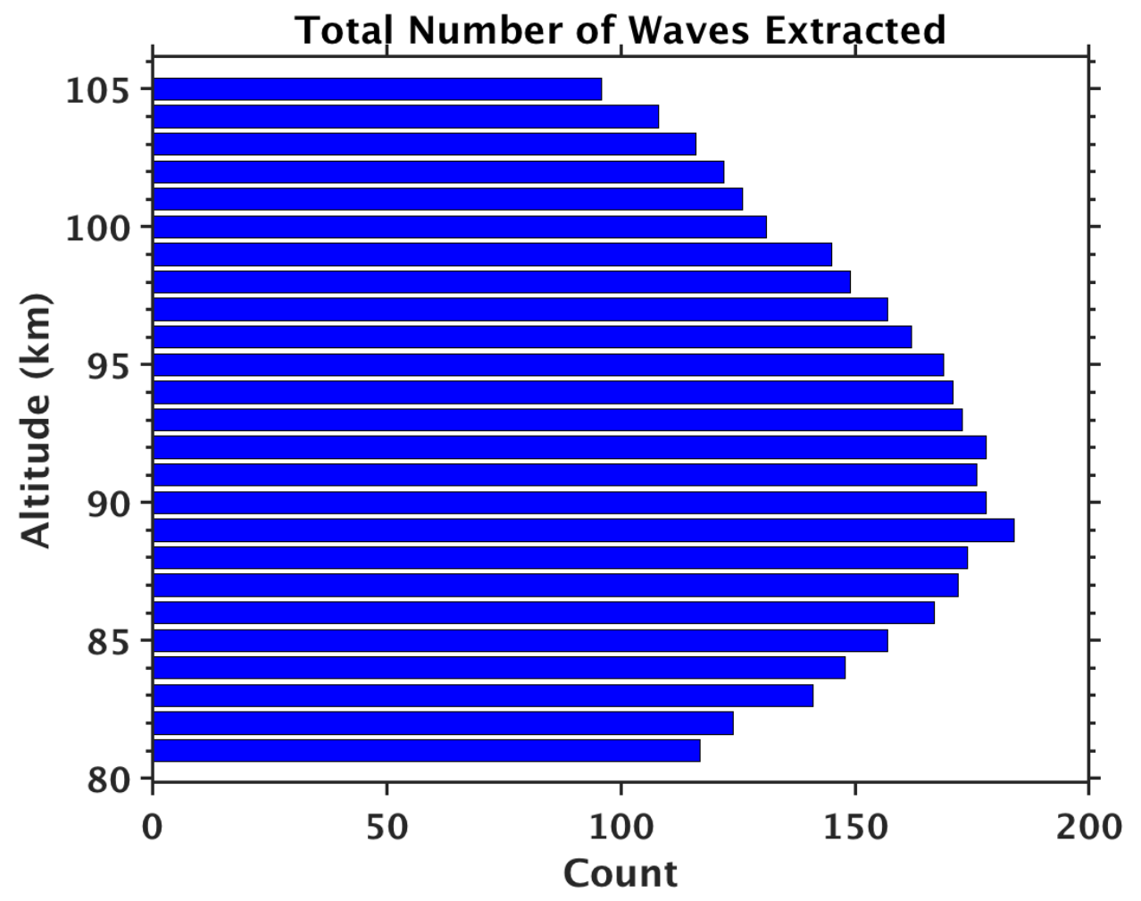
- Provide a baseline for the validation of general circulation models and inform GW parameterization schemes
- Determine the role of atmospheric waves in driving climate change in the upper atmosphere (dynamic variability vs. increasing concentration of CO2)
- Understand the vertical coupling function of GWs through the whole atmosphere
- Improve predictions of satellite drag higher in the thermosphere

Resonance fluorescence lidars are one of the few instruments that can make high-resolution measurements of temperature perturbations induced by GWs in the mesosphere and lower thermosphere (MLT). The Chu Research Group has been operating an Fe Boltzmann temperature lidar at McMurdo Station, Antarctica since 2010. During this campaign, a new class of persistent and high amplitude (~20 – 30 K) GWs were discovered in the MLT. The persistent nature of these waves indicate that they are capable of transporting significant amounts of energy and momentum, making them particularly interesting. This study utilizes a novel 2D wavelet analysis and 10 years of lidar data to statistically characterize the properties of GWs in the MLT at McMurdo. These results will fuel further research into of GW variability, dissipation mechanisms and wave sources.

Results

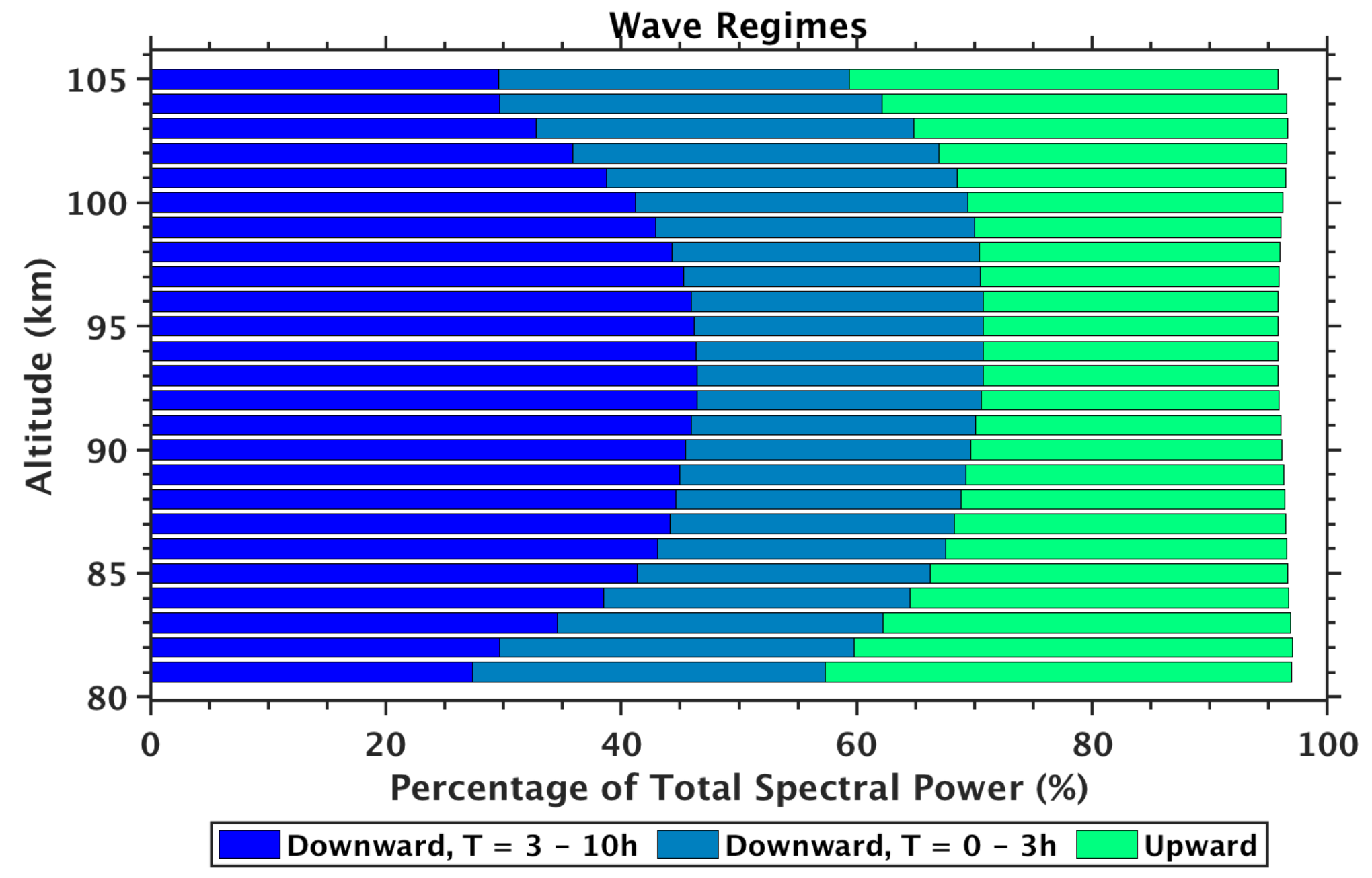
- Total of 226 wave packets extracted from 1765 hours of data
- Some waves persist for > 75 h



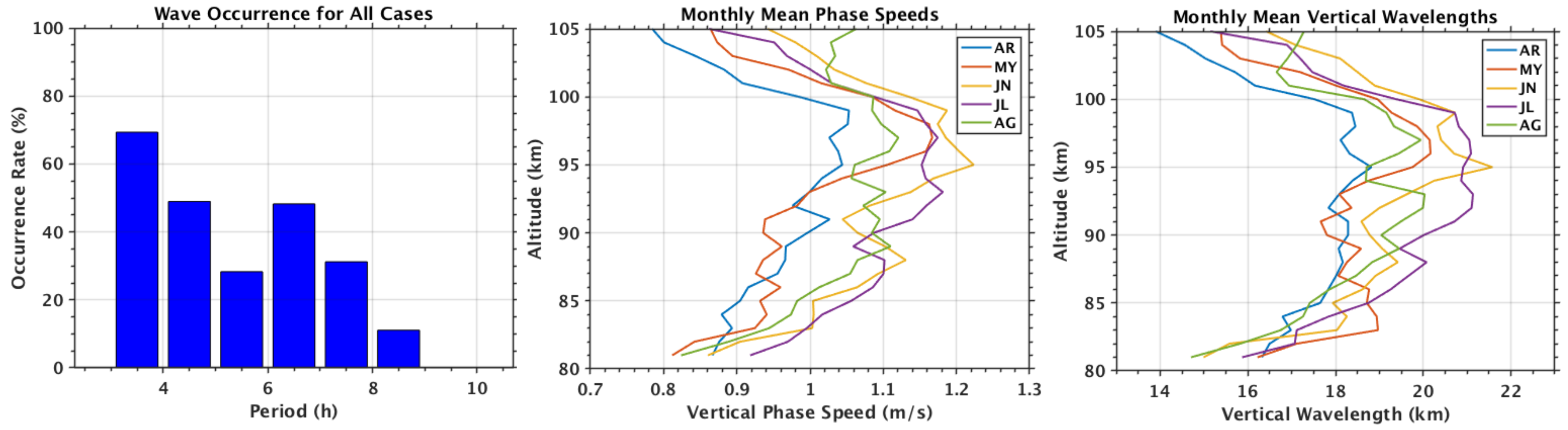


Significance of different wave regimes

- **Downward phase progressing waves occupy the majority of power spectrum**
- 3 – 10h downward phase waves dominate in the middle of the altitude range but are comparable to the other regimes at the top and bottom



Properties of Downward Phase Progressing Waves with T = 3 – 10h



No sign of significant seasonal variations in winter months

- Overall, shorter period waves occur more frequently
- **$\overline{c_z(z)}$ and $\overline{\lambda_z(z)}$ vary between ~ 0.8 – 1.2 m/s and ~15 – 20 km, respectively**
- Why do the vertical profiles increase with altitude and suddenly turn near the mesopause?

Wavelet Methodology

The wave packet extraction process can be broken down into the following steps:

1) Calculate density-scaled, relative temperature perturbations

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

2) Apply 2D wavelet transform and calculate power spectrum

3) Perform Monte Carlo simulation to determine spectral noise floor from lidar temperature errors

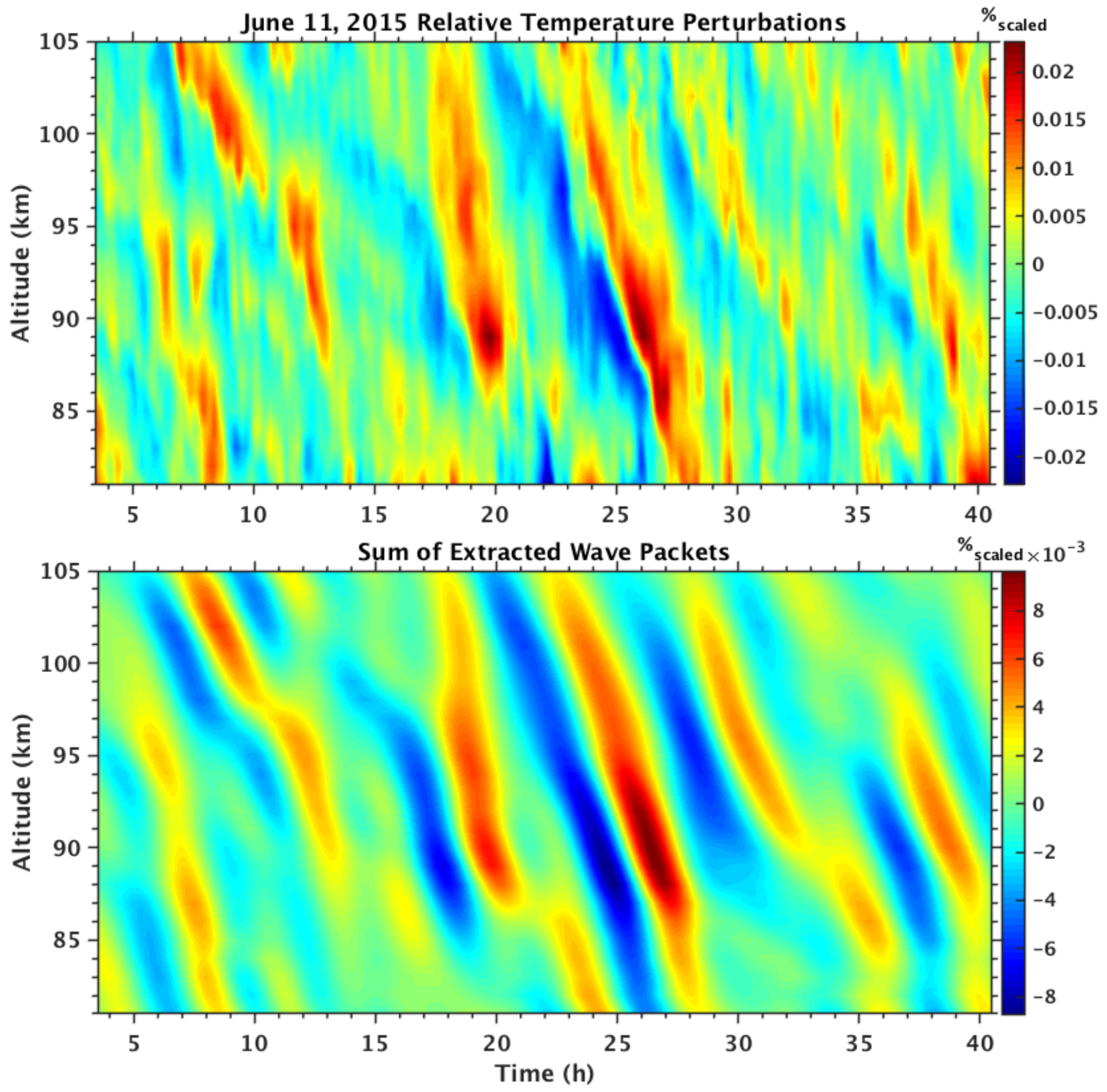
4) Identify peaks in the power spectrum and track peaks to the base of another peak or the noise floor level

5) For each identified peak

- Reconstruct wave packet by performing inverse transform to the localized portion of the power spectrum
- Track the two strongest phase lines over altitude
- Perform windowed, linear fitting to calculate vertical phase speed, $c_z(z)$
- Calculate vertical wavelength, $\lambda_z(z)$, assuming a constant period

$$c_z(z) = \frac{d\phi}{dz} \qquad \lambda_z(z) = \frac{T}{c_z(z)}$$

Example Case



Good agreement between input data and wavelet reconstructions

Conclusions

- **Downward phase progressing GWs with periods of 3 – 9 h and vertical wavelengths of 10 – 30 km dominate temperature perturbations in the MLT**
    - Downward phase progression implies upward energy transport, i.e., a wave source lower in the atmosphere, but depends on background winds.
- Possible wave sources include secondary/tertiary generation by the breaking of orographic GWs lower in the atmosphere, but **more work is needed to narrow down wave sources**.
- Results indicate that high-frequency (T < 3 h) and upward phase progressing waves are more prevalent near ~80 km and in the lower thermosphere than previously thought.

Future Work

- Expand study to include high-frequency and upward phase progressing wave statistics.
- Combine lidar data with co-located meteor radar wind data to derive intrinsic and horizontal wave properties.
- Calculate corresponding momentum fluxes and gravity wave drag **to quantify the impact of these waves on the general circulation of the MLT.**