Investigating Short-Term Variability of Mesospheric Gravity Waves Over Antarctica

Kenneth Zia[1], Mike Taylor[1], Yucheng Zhao[1], Dominique Pautet[1], Masaru Kogure[2], Takuji Nakamura[2]
Utah State University Department of Physics & Center for Atmospheric and Space Science[1], National Institute for Polar Research Japan[2]
E-mail: kennethzia@gmail.com

ANtarctic
Gravity
Wave
Instrument
Network

ANGWIN

Introduction

Short-period (<1 hr) atmospheric gravity waves (GWs) are known to transport large amounts of the energy and momentum into the Upper Mesosphere Lower Thermosphere region (MLT ~80-100 km). Atmospheric Imaging Lab (AIL) at Utah State University (USU) uses selected OH emissions lines (~87 km) to quantify the temperature amplitudes of these waves.

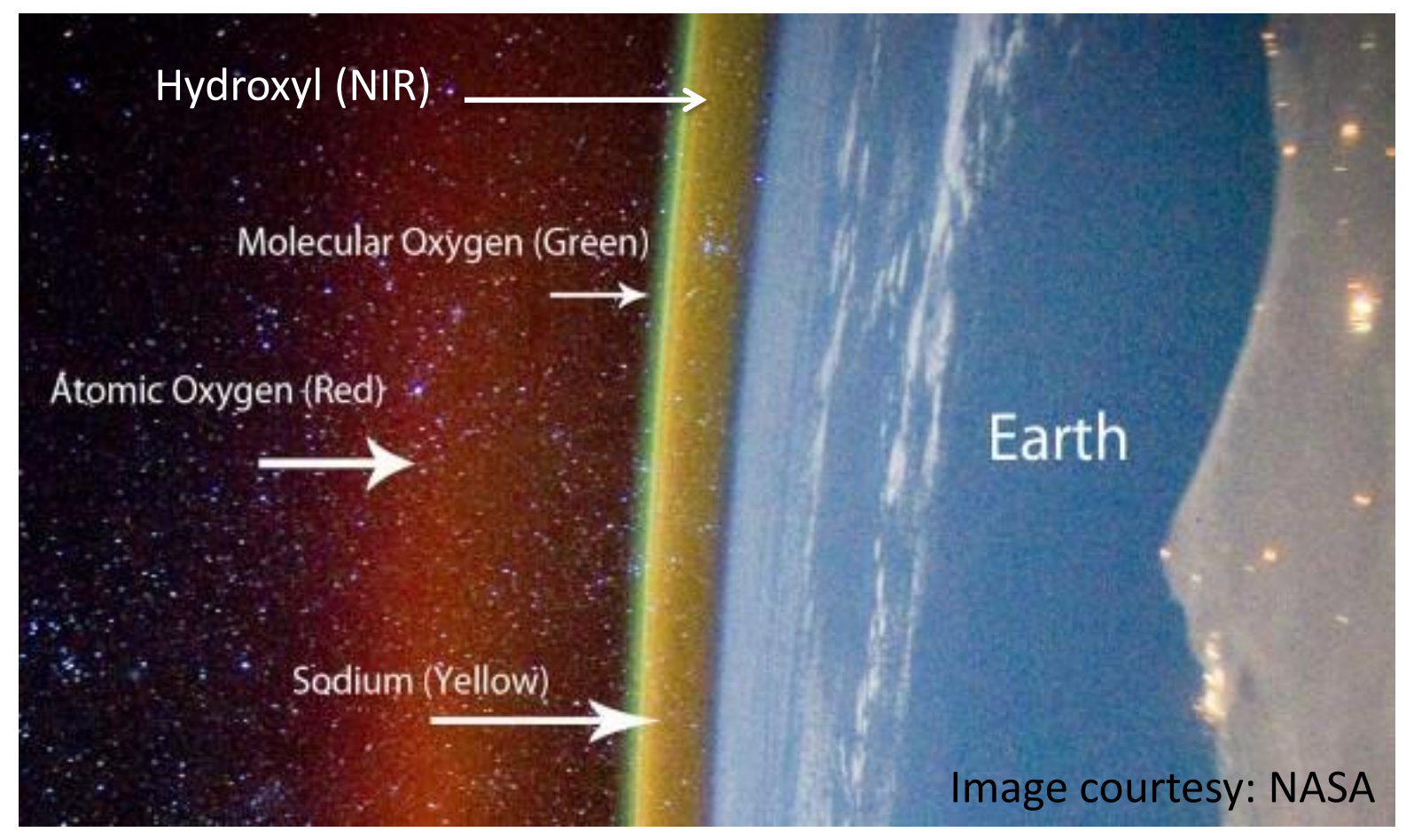
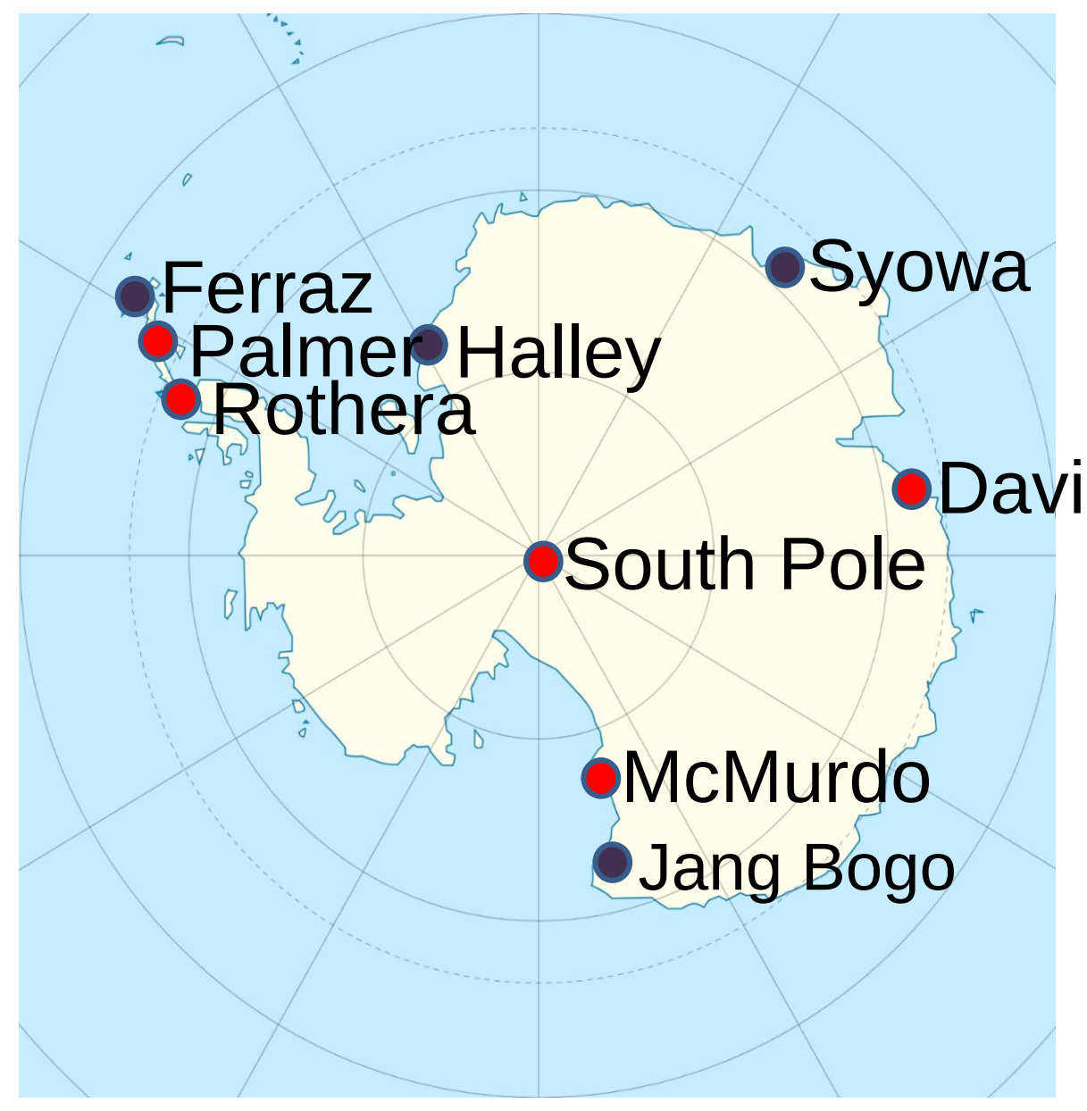


Image courtesy: NASA

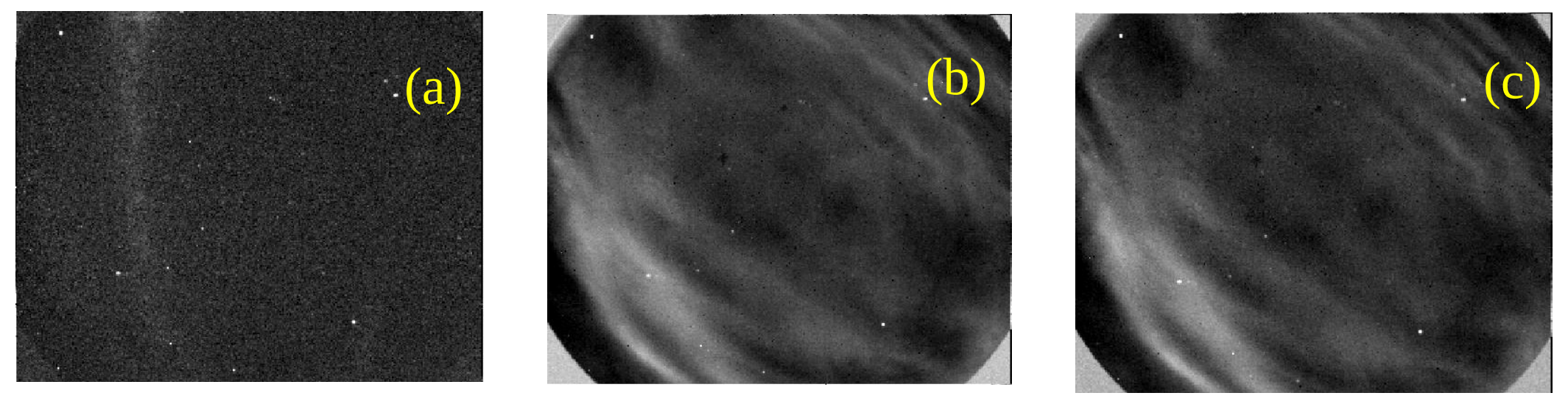


The ANtarctic Gravity Wave Instrument Network (ANGWIN) is an international collaboration program geared to studying the properties and dynamics of trans-Antarctic gravity waves in the MLT region. As part of this collaboration, a 3D-FFT technique originally developed to analyze all-sky airglow imagers at NIPR, Japan,, has recently been adapted to analyze GW temperature maps obtained by the USU Advanced Mesospheric Temperature Mapper (AMTM). This poster presents an initial spectral analysis of OH GW temperature maps over McMurdo station, Antarctica.

Advanced Mesospheric Temperature Mapper (AMTM)

(Left) AMTM mounted at Arrival Heights Observatory, McMurdo station, Antarctica (78°, 167°).

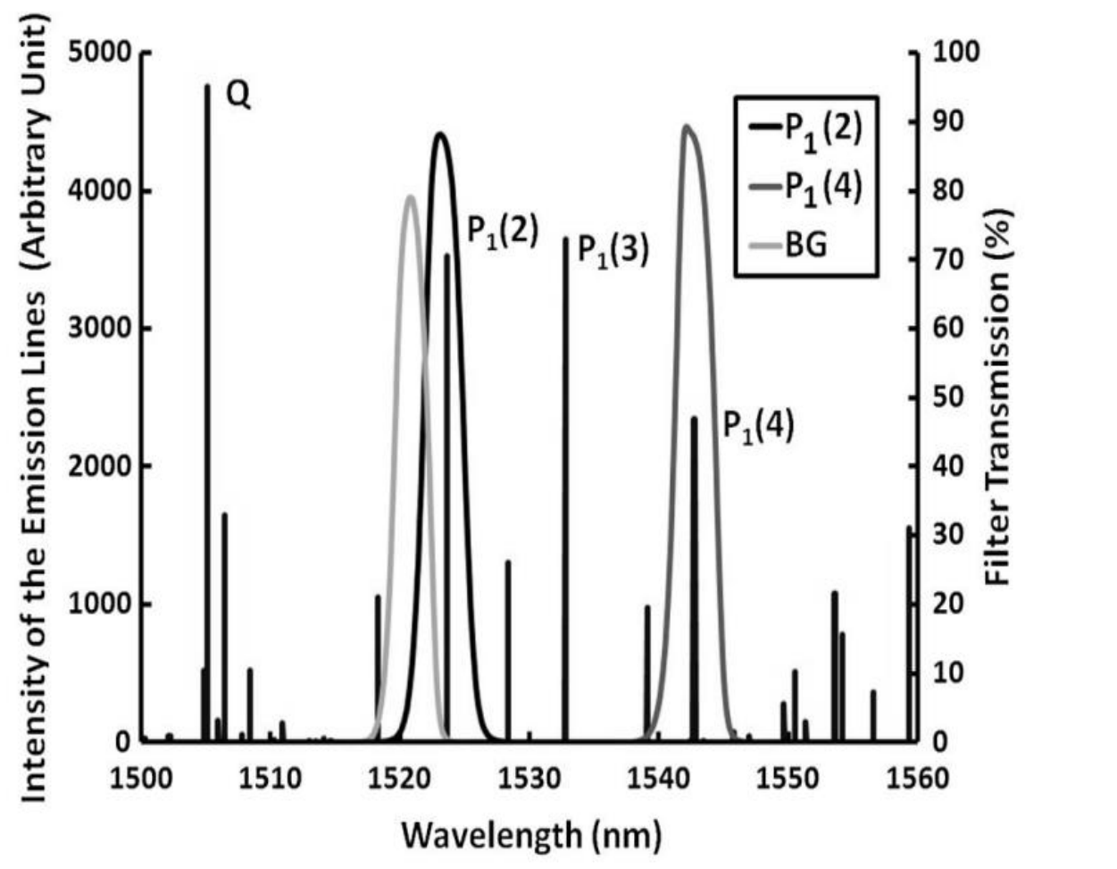
The AMTM measures the intensity of the $P_1(2)$ and $P_1(4)$ lines of the OH (3,1) band (integration time 10 s each line for T map ~30 s) , as well as a nearby background (BG), to derive MLT temperature maps (Pautet et al., 2014).



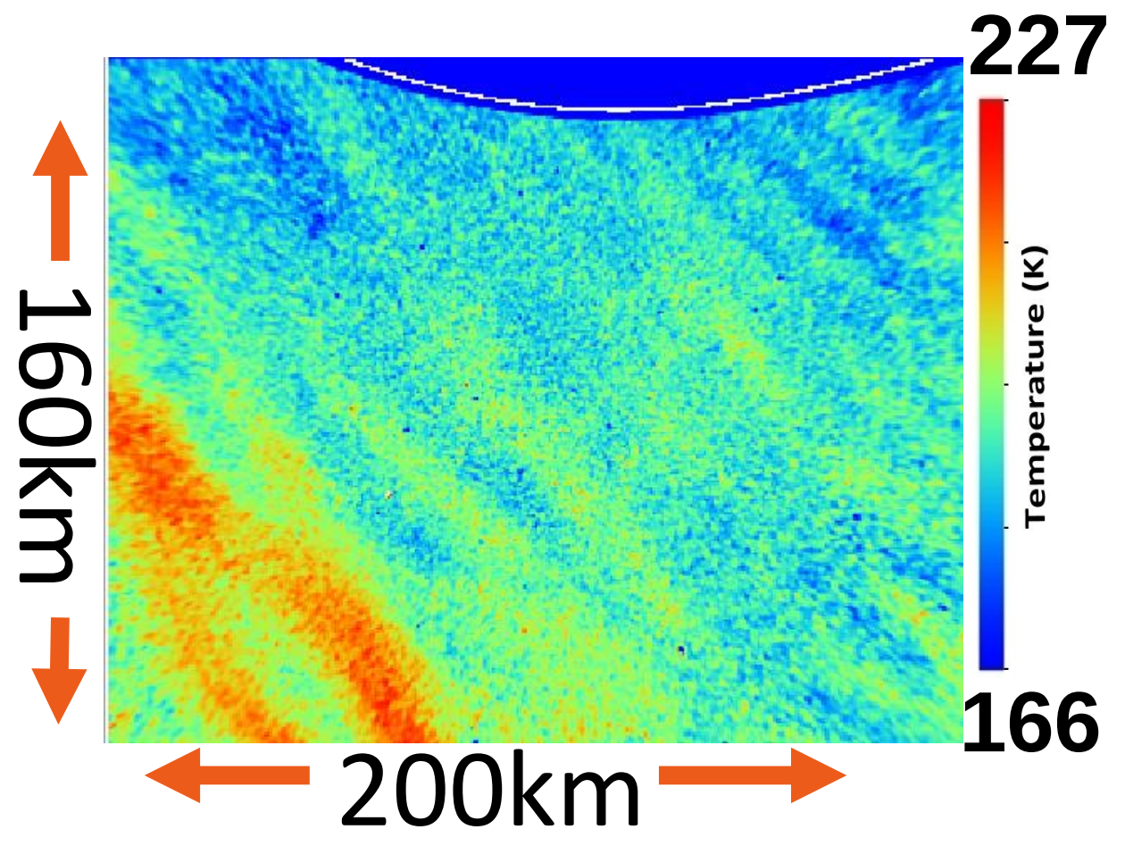
Flat-fielded, calibrated, and star-removed intensity images for (a) BG, (b) $P_1(2)$, and (c) $P_1(4)$ emissions filters.

The OH (3,1) band rotational temperature T_r is determined using the ratio R of the background-removed $P_1(2)$ and $P_1(4)$ bands in the following equation (Meriwether 1975):

$$T_r = \frac{259.58}{\ln(2.644R)}$$



OH (3,1) band spectrum and the narrow band filters used to isolate selected emission lines.

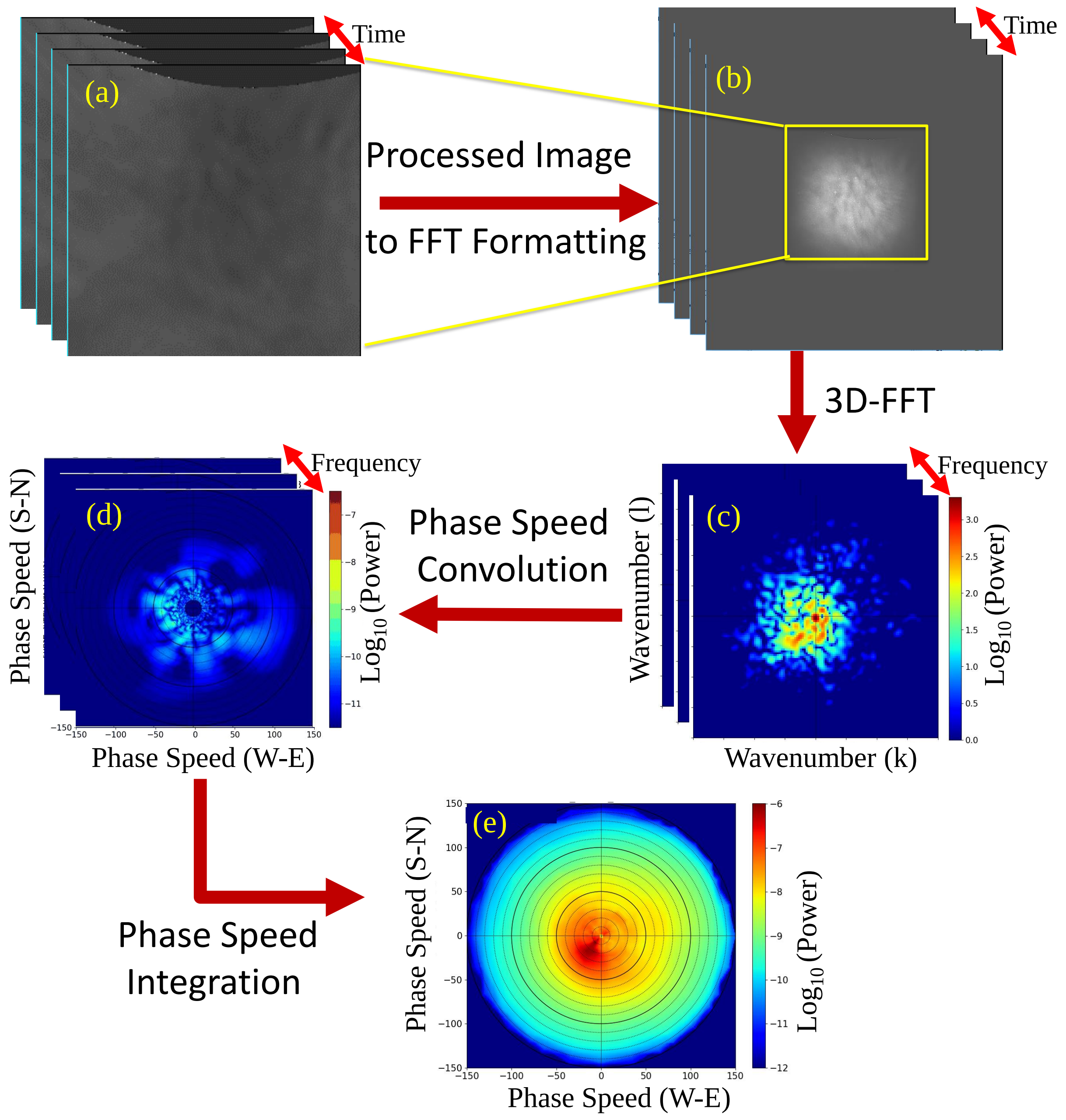


Example of coherent small gravity wave event in the OH temperature map taken from McMurdo on June 28th, 2017.

3D-FFT Technique (Adapted from Matsuda et al. 2014)

3D-FFT

a) Remove the mean from the temperature maps (256x320), and crop to 256x256 pixels.
b) Add zero padding and Hanning filter in x, y, and t. Then perform the 3D-FFT.
c) Select small scale frequency: 10 to 60 min, and wavelength 5 to 100 km.
d) Convolve the power spectrum density (PSD) to phase speed domain at each frequency.
e) Integrate the PSD for all frequencies to obtain a complete phase speed diagram to show total wave direction, speed, and power intensity.



Processed Image to FFT Formatting

3D-FFT

Phase Speed Convolution

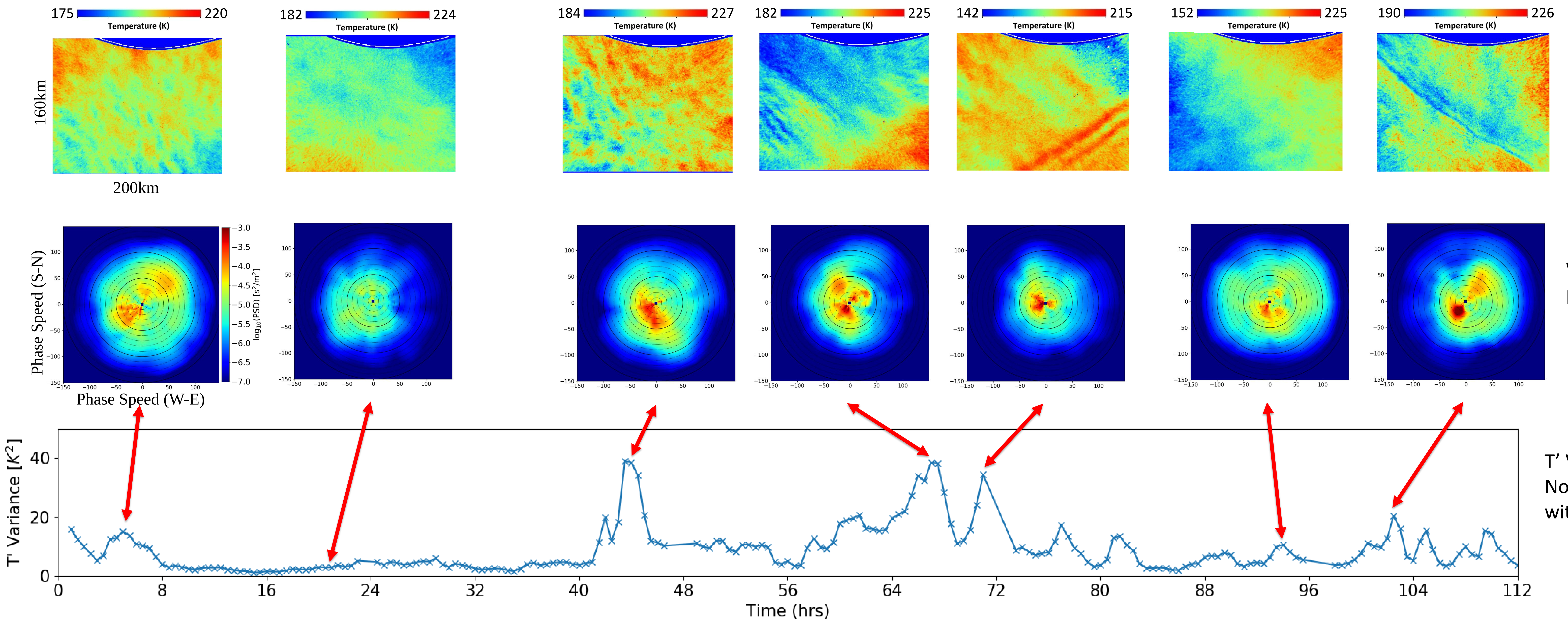
Phase Speed Integration

AMTM Analysis

Data:
Nearly 5 days (112 Hours) of clear-sky observations used to create a continuous series of temperature maps during austral winter 2017 (June 26-30) from McMurdo station , Antarctica (78°S).

Analysis:
- Uses a 2-hour window of data, stepped by 30 min throughout this period.
- Removed the mean (T_0) of each temperature map (T) to determine $T'=T-T_0$ and calculate the Power Spectrum Density (PSD) as a function of variance of T'.

Results:
- High variance peaks are corresponding to and strong phase speed PSD.
- Spectral variance and phase speed PSD are related to strong temperature perturbations (top row).



Mesospheric gravity waves imaged in OH temperature maps.

Well defined Phase speed PSD.

T' Variance.
Note high correlation with phase speed PSD

Summary

Results:
- First quantitative application of 3D-FFT to OH temperature maps.
- Novel analysis of intra-hour gravity wave spectral variability.
- Initial results show short-time scale wave energies increases clearly correlated to strong wave events in the temperature maps (and hence associated momentum fluxes).
- Phase speed power identifies sustained (~5days) overall preference for Southwestward propagation, but with individual events exhibiting a broad range of wave headings.

Future Work:
This method will be applied to existing winter season data obtained by two AMTMs sited at McMurdo (2017-ongoing) and South Pole stations (2012-ongoing) to investigate the intra-seasonal and inter-annual variability of mesospheric small-scale GWs across Antarctica.

References & Acknowledgements

Matsuda T. S., T. Nakamura, M. K. Ejiri, M. Tsutsumi, and K. Shiokawa. New statistical analysis of the horizontal phase velocity distribution of gravity waves observed by airglow imaging. *Journal of Geophysical Research: Atmospheres*, **119** (16):9707-9718, 2014.

Pautet P.-D., M. J. Taylor, W. R. Pendleton Jr, Y. Zhao, T. Yuan, R. Esplin, and D. McLain. Advanced mesospheric temperature mapper for high-latitude airglow studies. *Applied optics*, **53** (26):5934-5943, 2014.

Meriwether, J. W. High latitude airglow observations of correlated short-term fluctuations in the hydroxyl Meinel 8-3 band intensity and rotational temperature. *Planetary and Space Science*, *23*(8), 1211-1221,1975.

The first AMTM instrument was designed and developed under an Air Force DURIP grant F49620-02-1-0258. The AMTM operated at McMurdo station was supported under the NSF OPP grant 1143587. The authors would like to thank Dr. Takuji Nakamura (director of NIPR) for supporting K. Zia's 3- month research fellowship (2018) and sharing their new analyses with us. Also, thanks to the USAP personnel at McMurdo station for their help in maintaining and operating our instruments, especially the research assistants: Liz Widen, Graham Tilbury, and Neal Scheibe.