Secondary Gravity Waves and Coupling from the Lower Atmosphere to the MLT

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NSF Postdoctoral Report

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Secondary Gravity Waves Overview

Linear Generation

Secondary GWs form due to the body force from breaking primary GWs [Vadas et al., 2003]

Nonlinear Generation

-Mechanism less understood

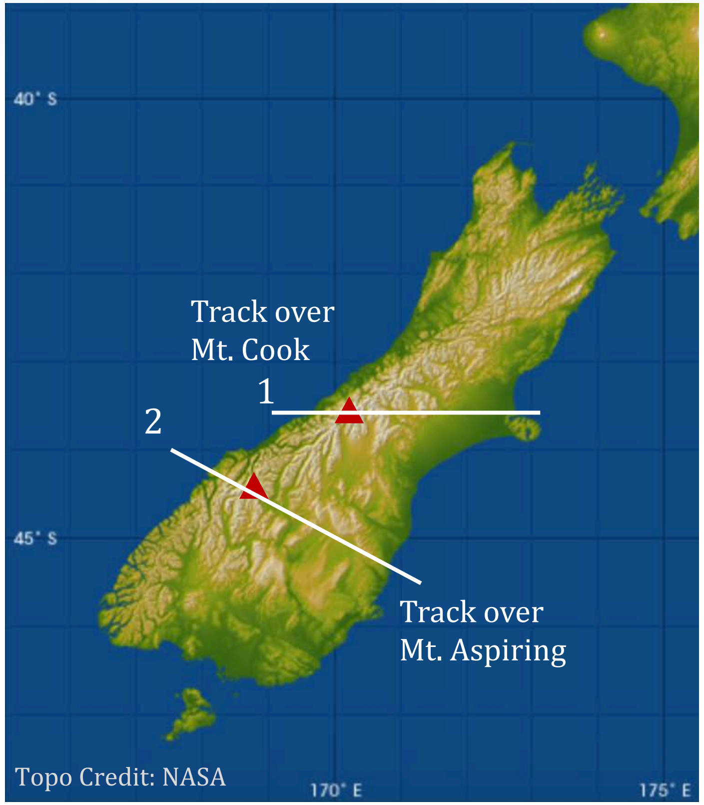
-modeling studies demonstrate smaller-scales than breaking GW

Importance in the Atmosphere

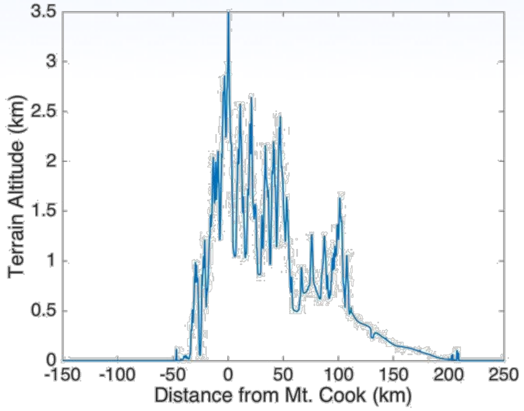
-GW spectra change throughout the atmosphere

-Secondary GWs largely unaccounted for in global scale parameterizations /difficult to resolve smaller scales

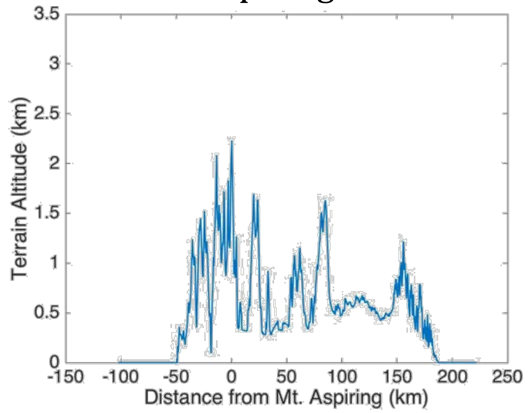
DEEPWAVE: Mountain Wave Generation Over NZ



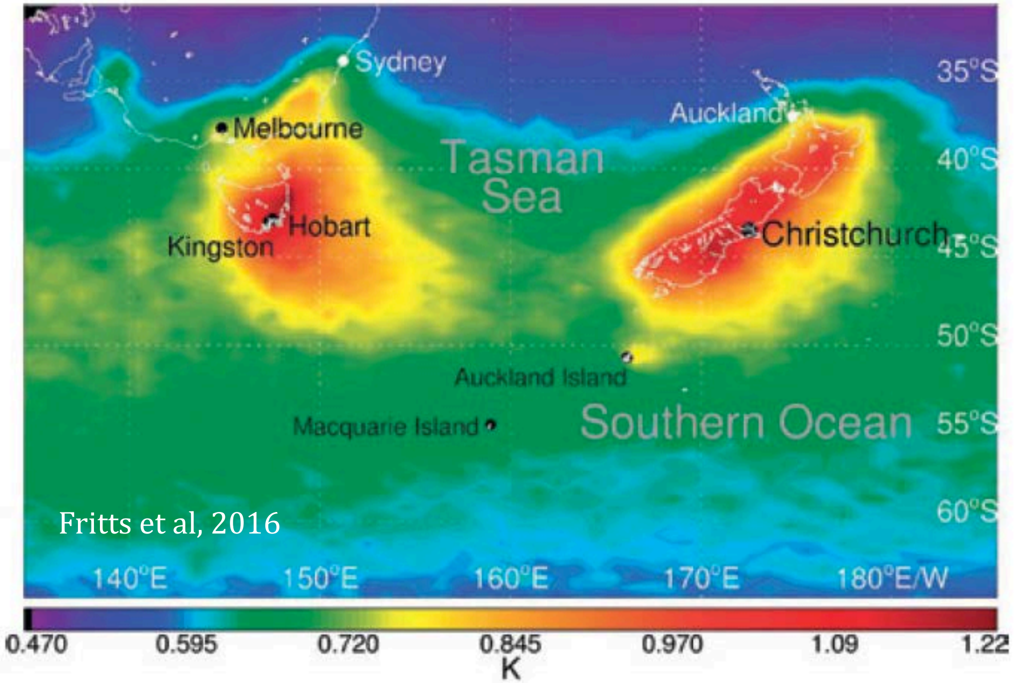
1. Mt. Cook Track



2. Mt. Aspiring Track



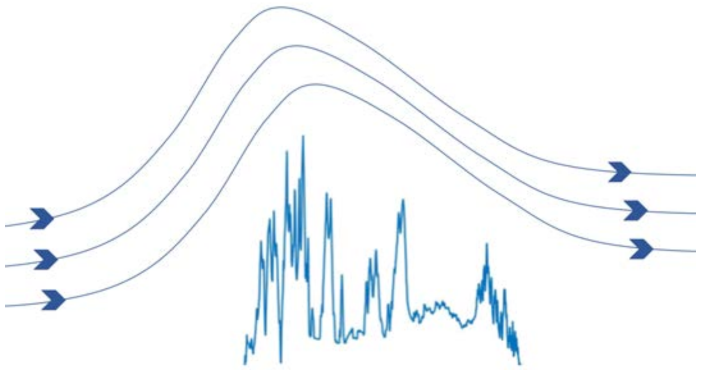
AIRS rms Temperature
Jun-Jul 2003-11 near ~35km



AIRS shows gravity wave hot spot over South Island of New Zealand

Mountain Wave (MW) Critical Levels

Mountain Wave Generation



- Vertically Propagating
- Stationary

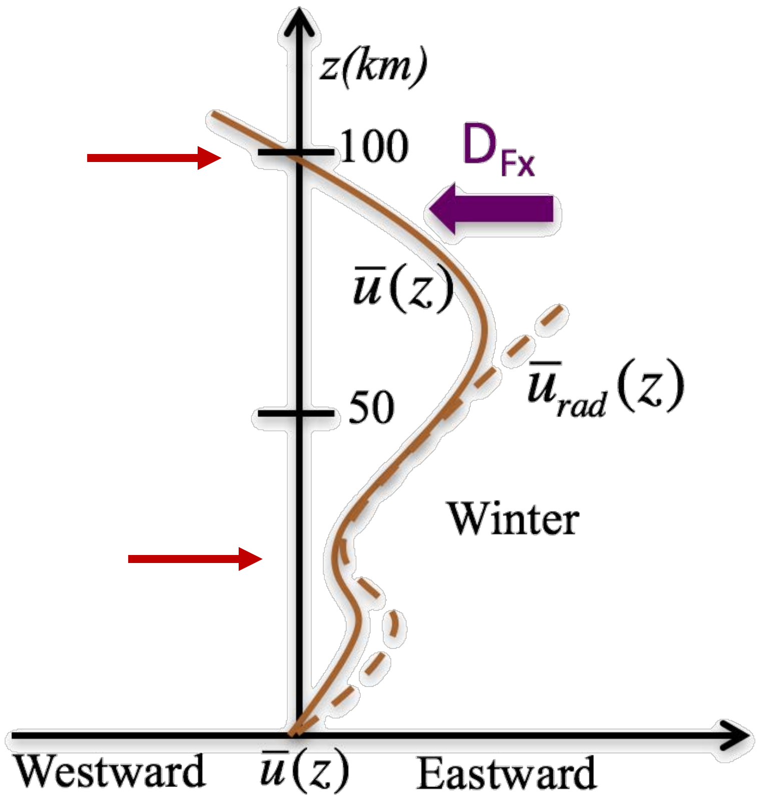
Mountain Wave Saturation

Horizontal wind perturbation is limited by the background wind.

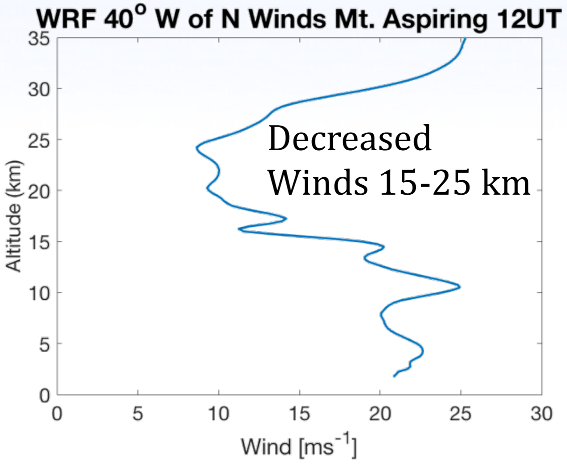
$$|u'_H| \leq |\bar{U}_H|$$

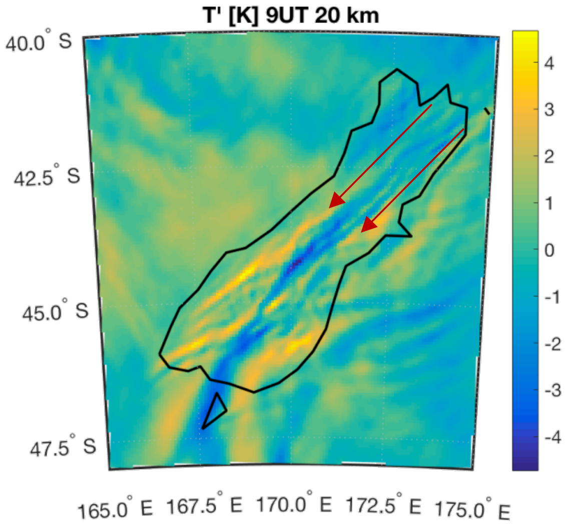
[Fritts, 1984]

Mountain Wave Critical Levels

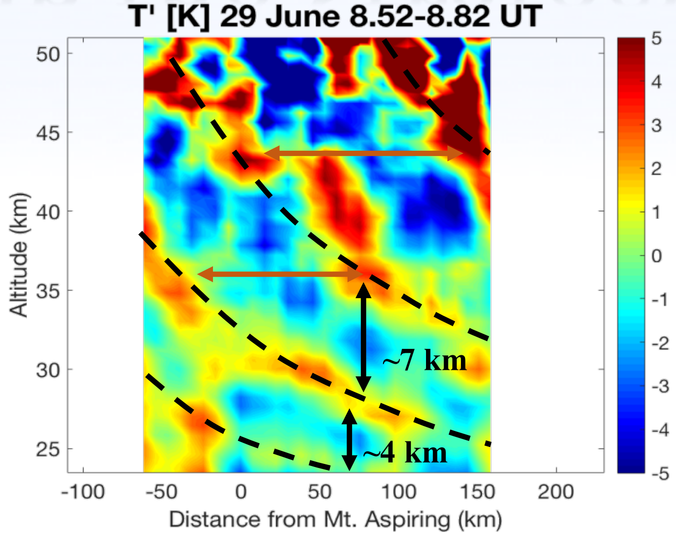


MW breaking in the Stratosphere



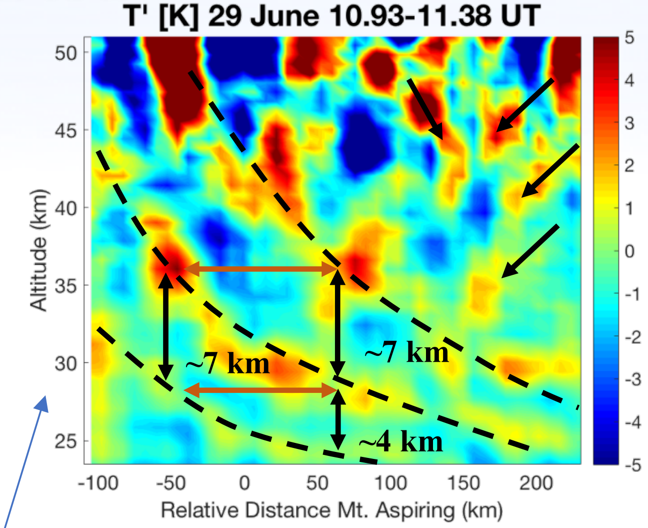


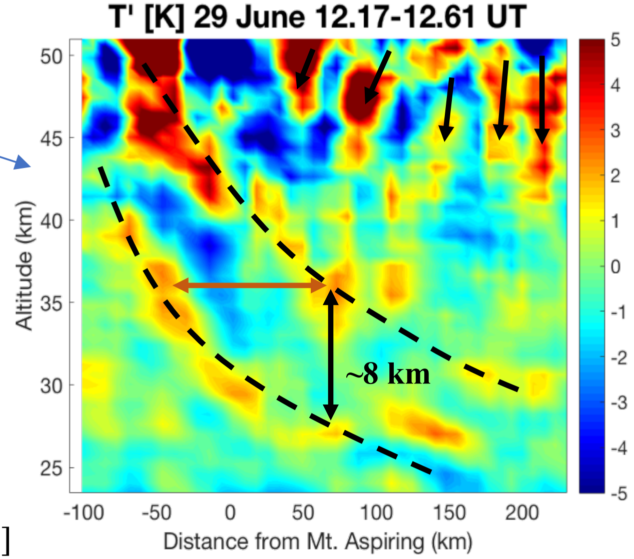
WRF shows presence of MW



Earliest flight pass shows MW intact up to 50km

Later flight passes with more breaking demonstrate small-scale GWs (black arrows) at higher altitudes



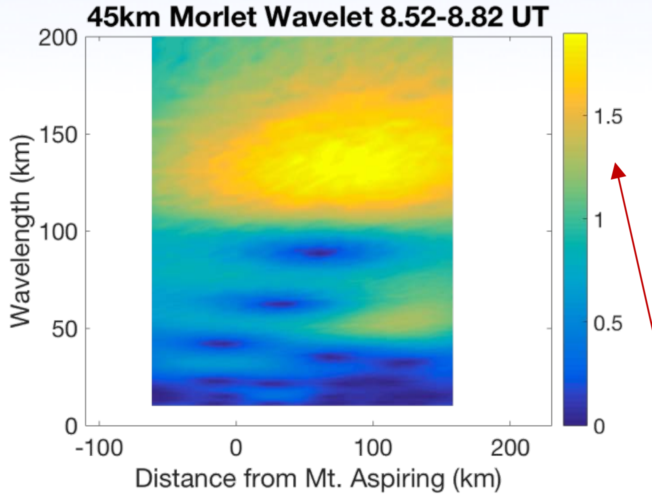


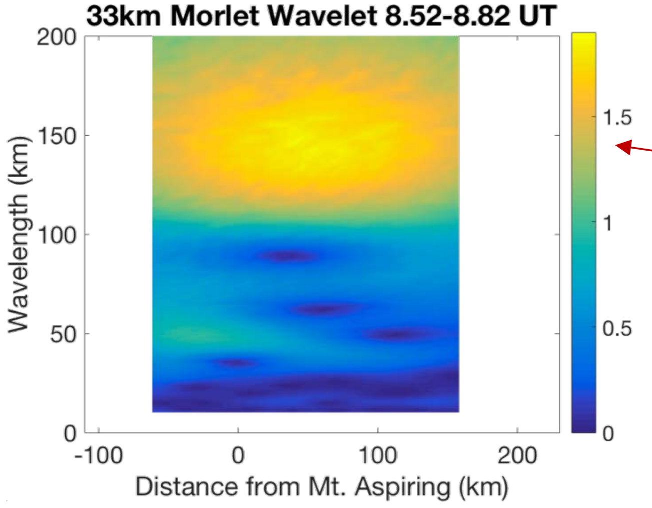
WRF model outputs validated in Kruse et al. [2016]

Figures from Bossert et al. [2017]

Wavelet analysis

MW visible up to 50 km (first pass)

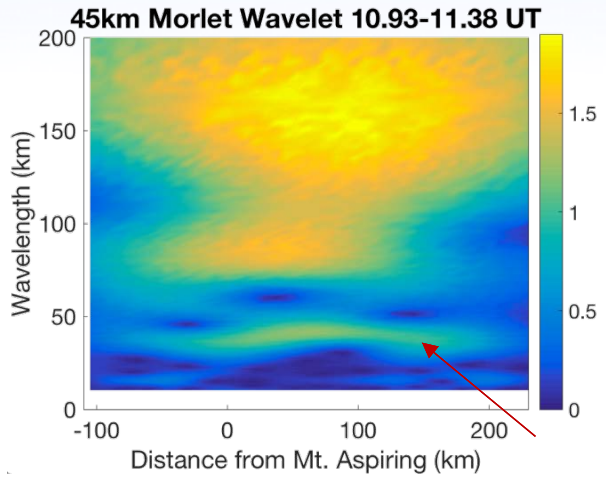


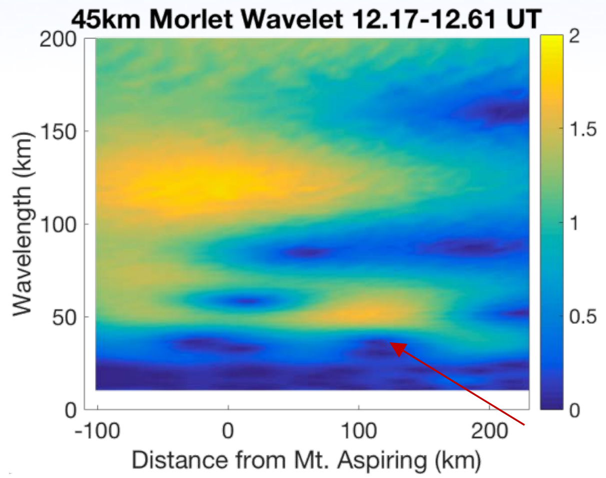


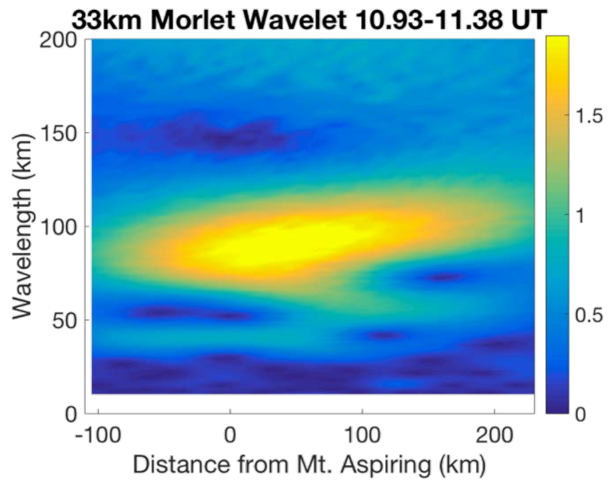
Spectral similarity at 33km and 45km

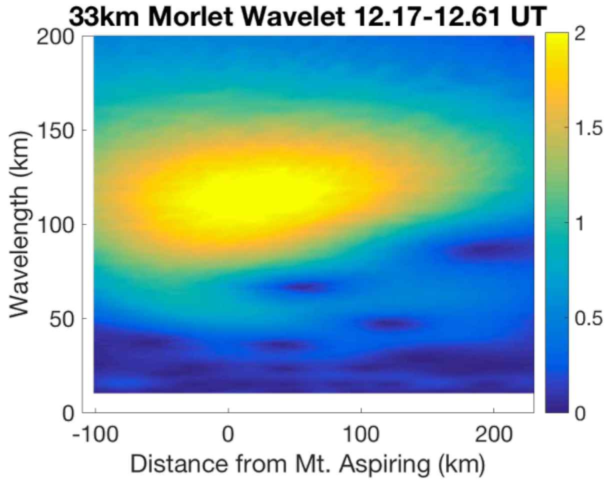
Figures from Bossert et al. [2017]

MW dissipation upstream of Mt. Aspiring (later passes)







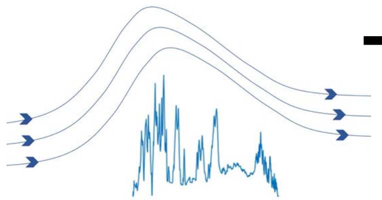


Data normalized for MW growth with altitude

45km:
- Primary MW spectrally diminished
- New spectral power at wavelengths <50km

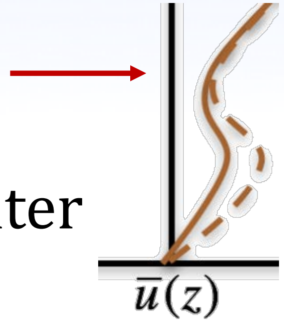
33km:
- Most spectral power in primary MW

MW Breaking in the Stratosphere: Overview



MW generation

MWs encounter "valve layer"



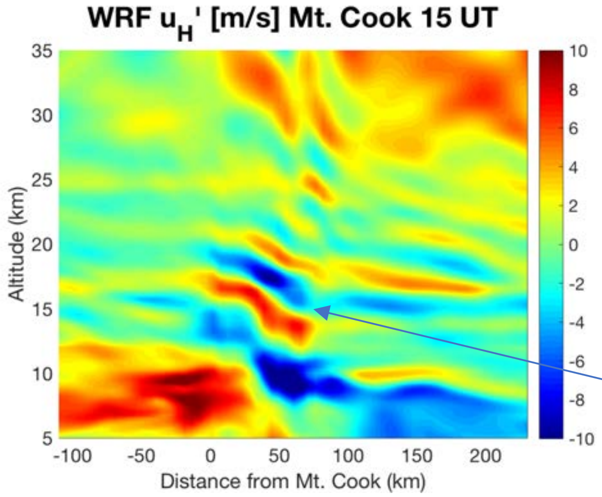
Saturation leads to some dissipation but not complete breaking

Nonlinear Secondary GW formation from partial MW breaking

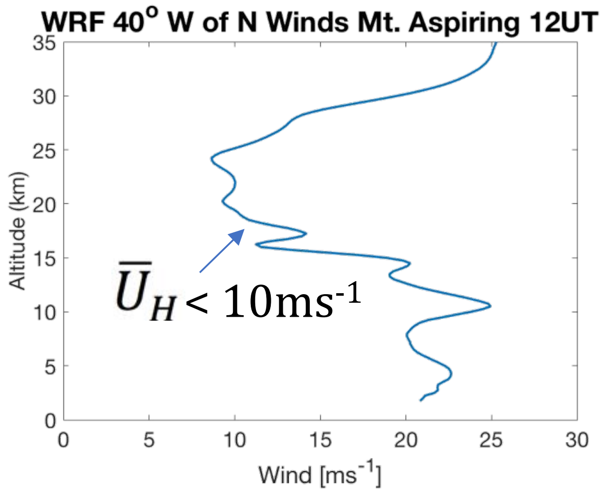
Expected amplitude growth with altitude

$$\sim e^{(z-z_o)/(2H)}$$

WRF shows decay from 15-25km



$u'_H \sim$ 9ms[-1]



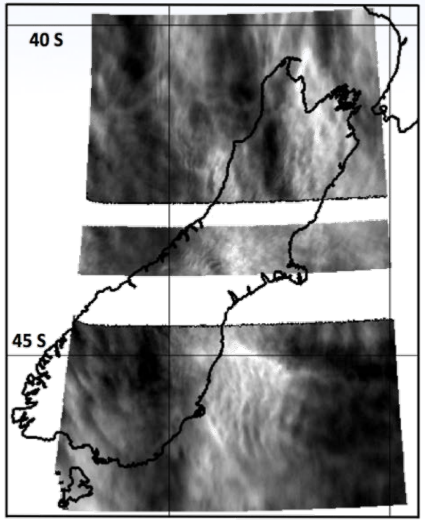
$\bar{U}_H < 10$ms[-1]

Saturation as

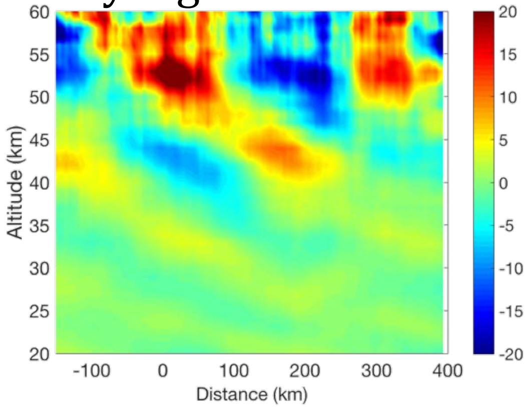
$u'_H/\bar{U}_H \rightarrow 1$

MW breaking in the MLT

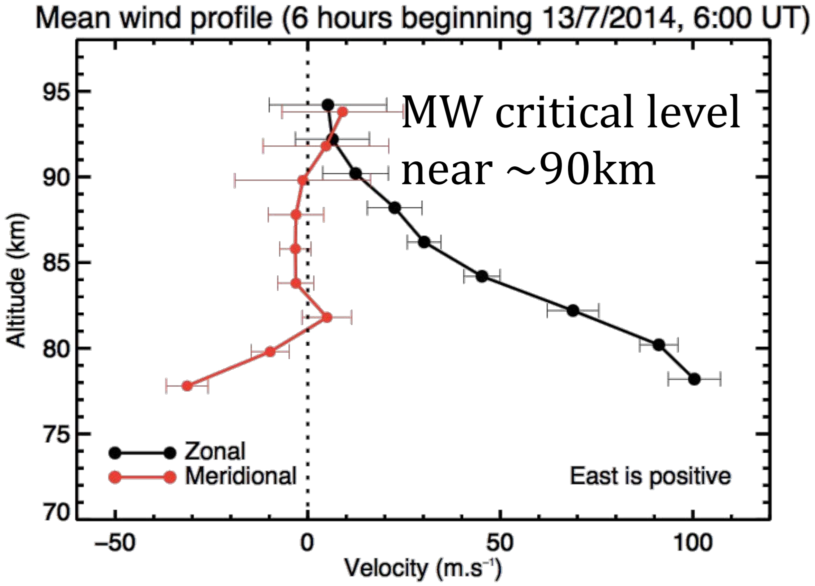
OH Airglow ~87km



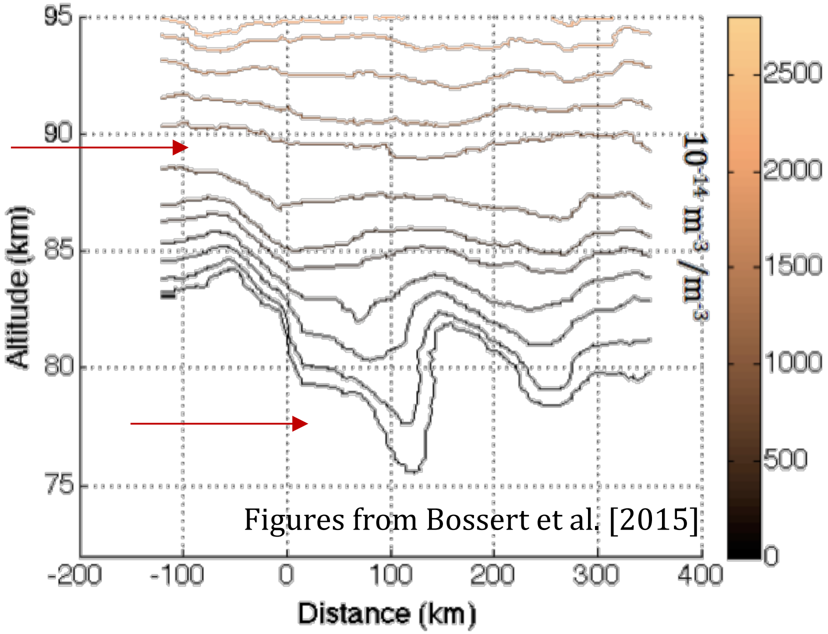
Rayleigh T' 20-60km



13 July 2014 ~240 km MW observed from 20– 87 km

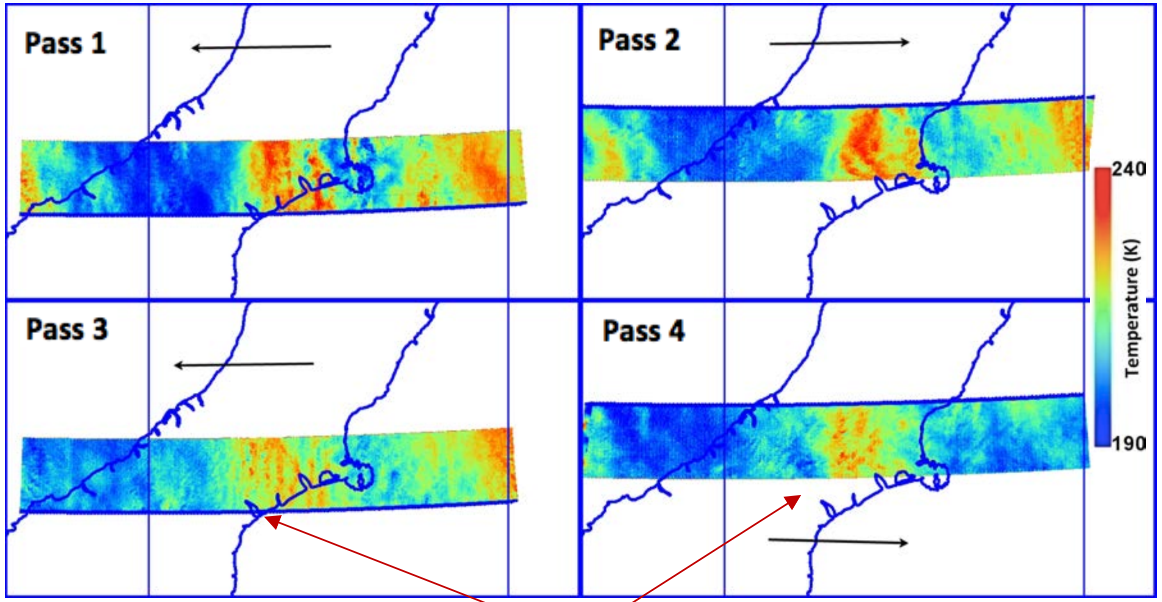


Sodium Mixing Ratio



Secondary GW Observations in the MLT

Advanced Mesospheric Temperature Mapper (AMTM)

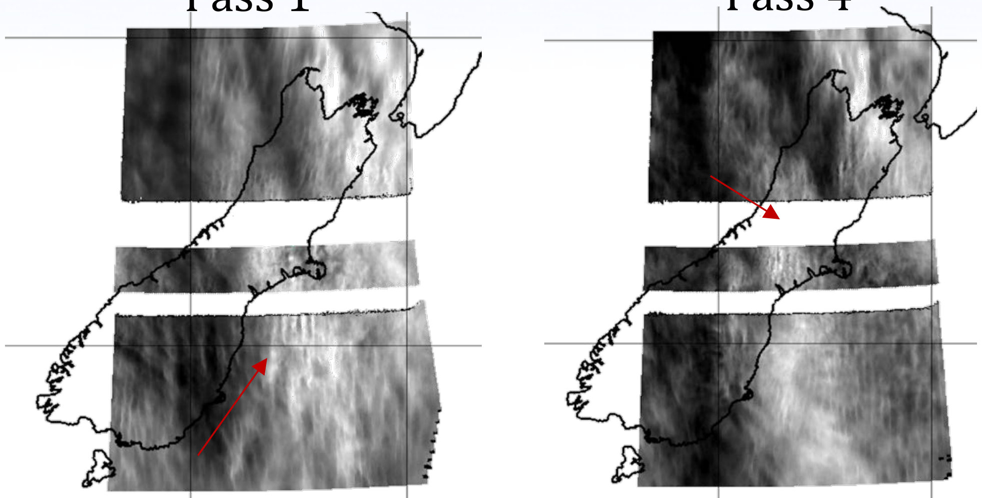


Small horizontal scale GWs in warm phase each pass

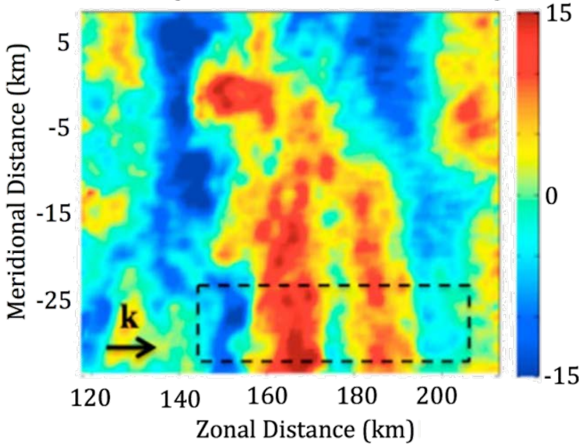
GW horizontal scales: 20-30km
Phase speeds: 0 to -135 m/s

OH Airglow Images

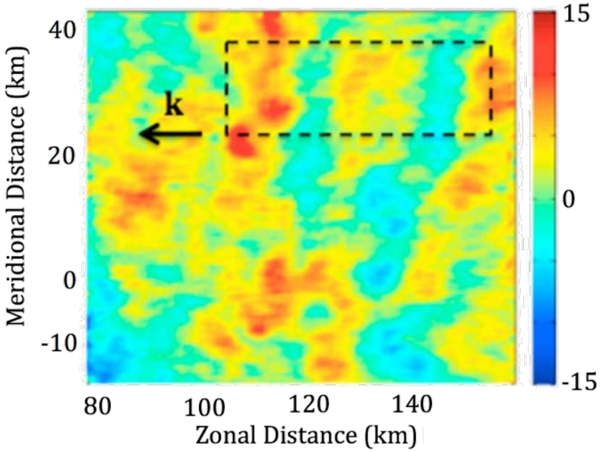
Pass 1 Pass 4



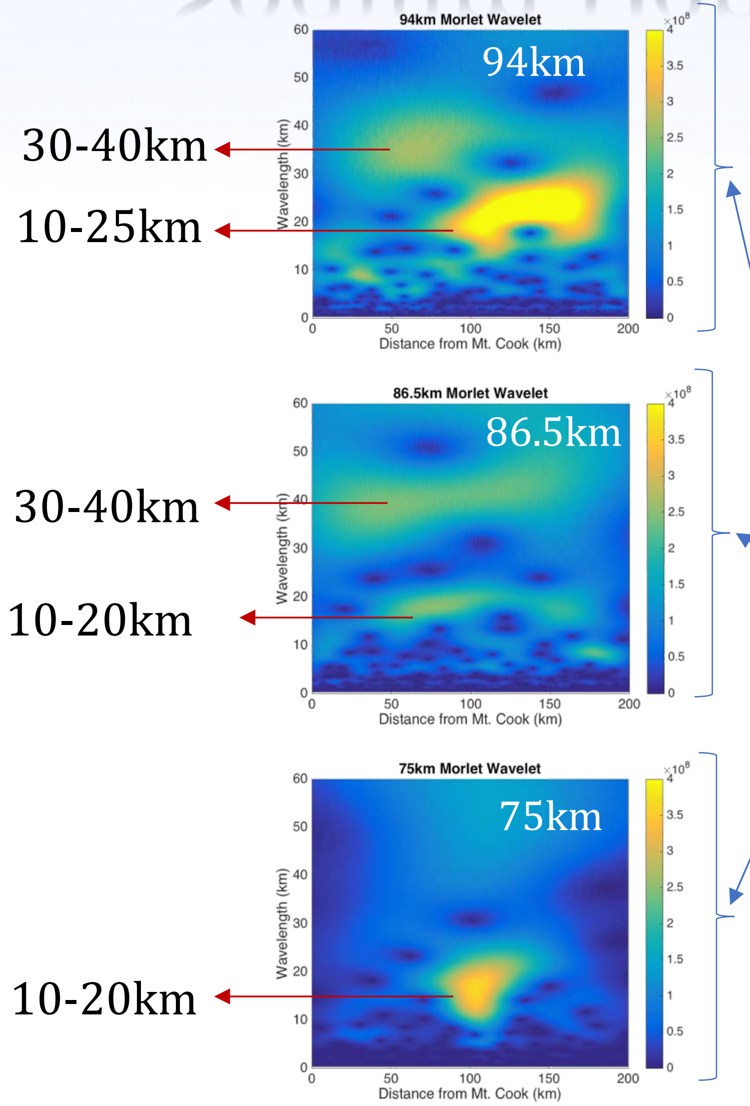
Pass 1 (173km East of Mt. Cook)



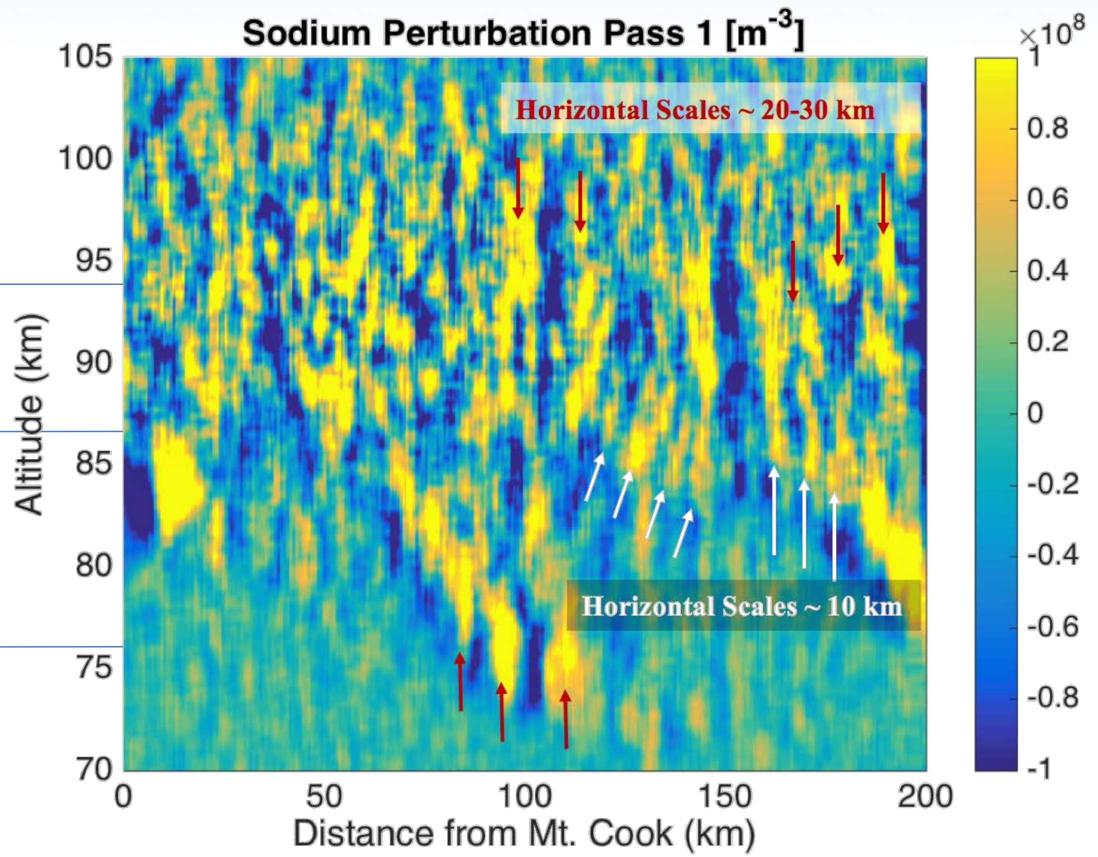
Pass 4 (111km East of Mt. Cook)



Sodium Density Perturbations



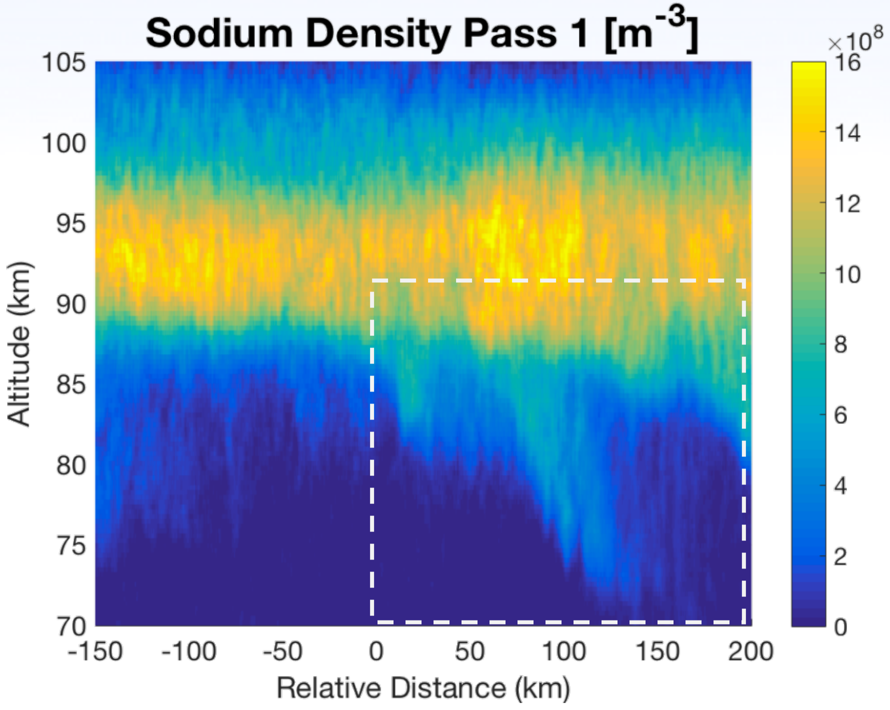
Wavelet Analysis

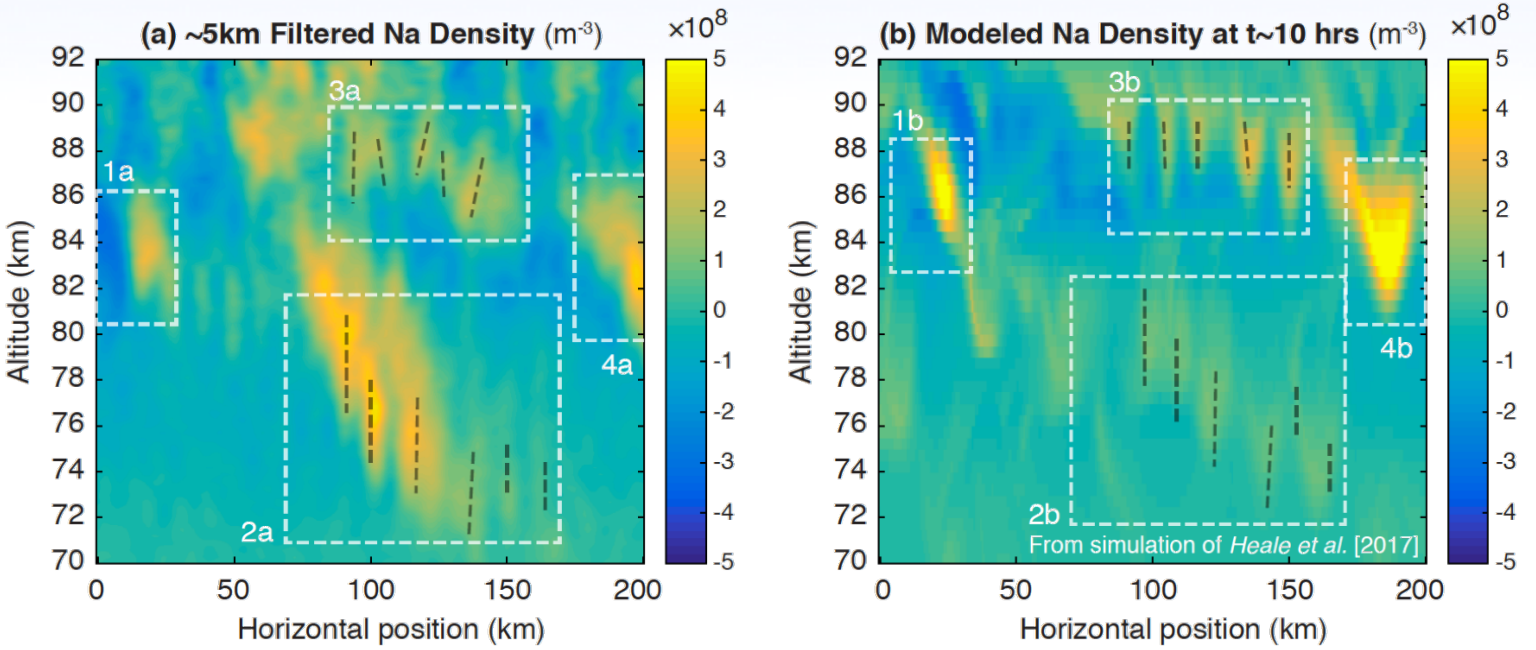


Multiple small horizontal scale perturbations observed in sodium densities

Phases aligned both upstream and downstream of the primary breaking MW

Secondary GW Observations and Modeling





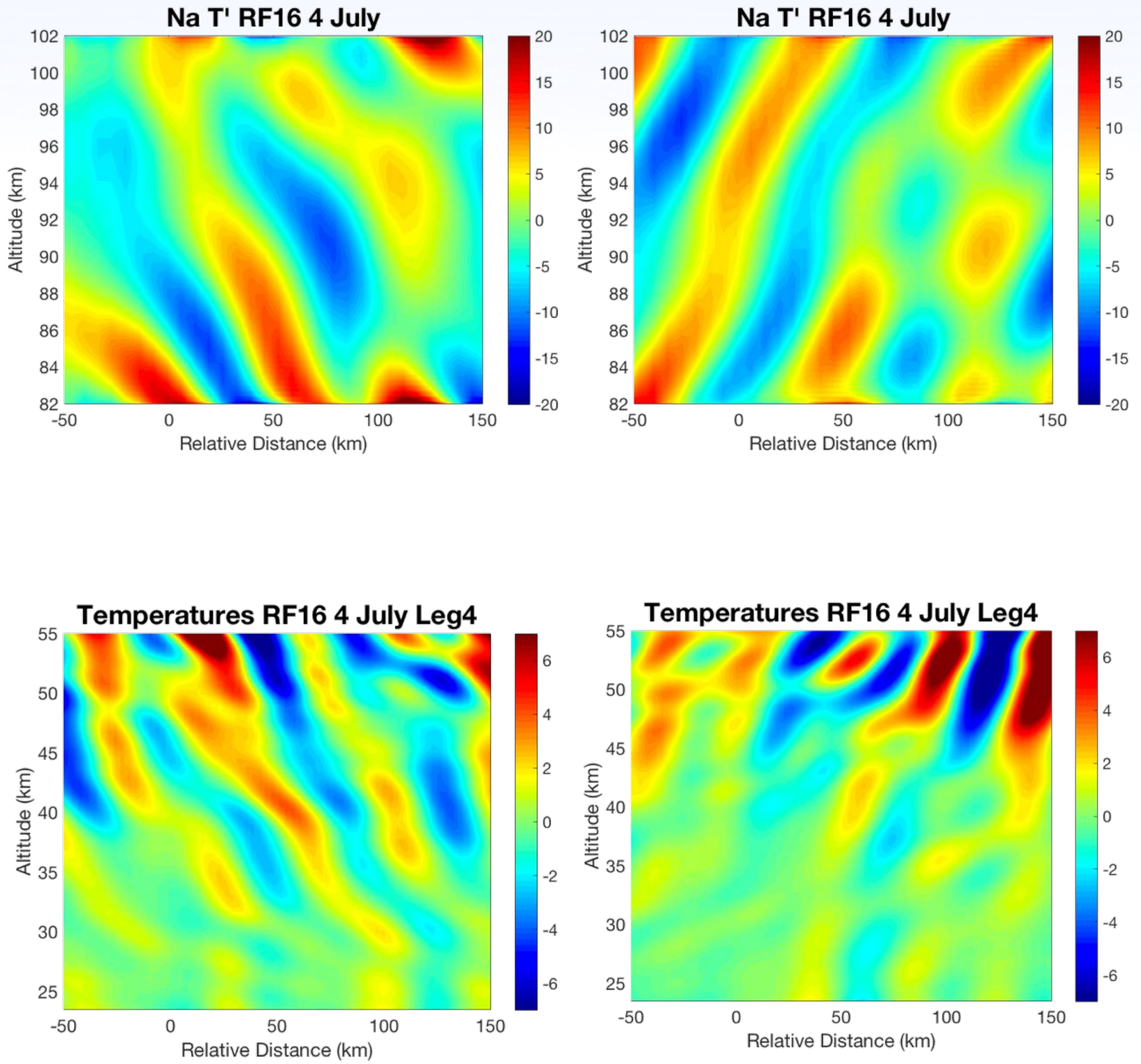
High-resolution sodium densities during first pass demonstrate small-scale features

Sodium densities in Bossert et al., 2017 demonstrate predicted secondary features arising from modeled 240 km MW breakdown in Heale et al., 2017

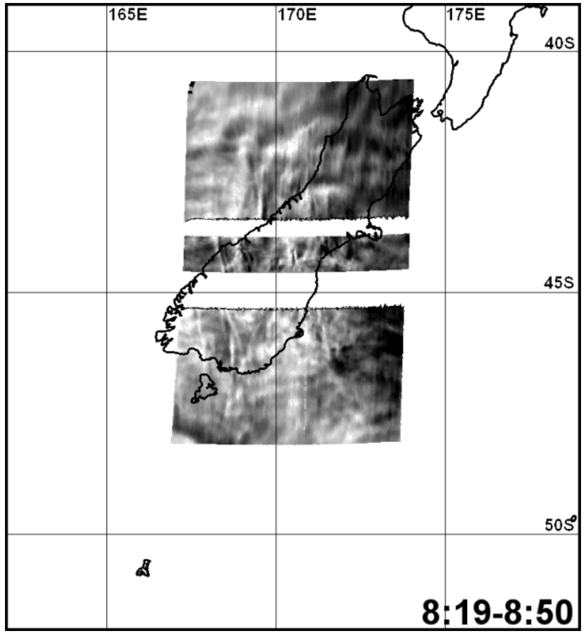
To be continued…

Other events of MWs, MW breaking, and GWs from the troposphere to the MLT

New analysis of MW propagation and breaking during the DEEPWAVE campaign, including temperature measuerments from the sodium lidar!



Today 13:30-15:30 in the *Collaborative Investigations of MLT* session.



Secondary Gravity Wave Summary

How do gravity wave hotspots in the lower and middle atmosphere have the potential to influence the upper atmosphere?

- Secondary GWs may contribute to larger vertical transport of horizontal momentum to higher altitudes above GW hotspot regions
- Secondary GWs observed at smaller or similar scales than the primary MW -> nonlinear generation mechanism
- Further studies needed on scales and spectra associated with nonlinear generation mechanisms

Acknowledgements and Collaborators

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NSF AGS-1338666

Thanks to DEEPWAVE Collaborators
and the dedicated NCAR team

Chris Heale is giving a talk later today on SGWs from the DEEPWAVE 13 July event in Collaborative Investigations of MLT (13:30-15:30)

GATS, inc. Collaborators:
Dr. Dave Fritts
Dr. Bifford Williams
Dr. Brian Laughman
Tyler Mixa

Yale Collaborators:
Chris Kruse

USU Collaborators:
Dr. Mike Taylor
Dr. Dominique Pauetet

ERAU Collaborators:
Dr. Chris Heale
Dr. Jonathan Snively

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Questions