Investigating Large Amplitude Mesospheric Mountain Wave Breaking Events and Oceanic Gravity Wave Signatures During DEEPWAVE

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SPARC, Gravity Wave Symposium, Penn State, 16-20 May, 2016,

NIWA Lauder Observatory (45˚S)

Special thanks to NIWA and EOL/ NCAR

NSF/NCAR GV Aircraft

Outline

Advanced Mesospheric Temperature Mapper (AMTM);

- Development of a high-performance infra-red imaging system for the NSF GV aircraft.
- Enabling high-resolution mapping of mesospheric gravity waves using the OH (3,1) band nightglow emission st ~85 km altitude.

DEEPWAVE Mission (June-July, 2014):

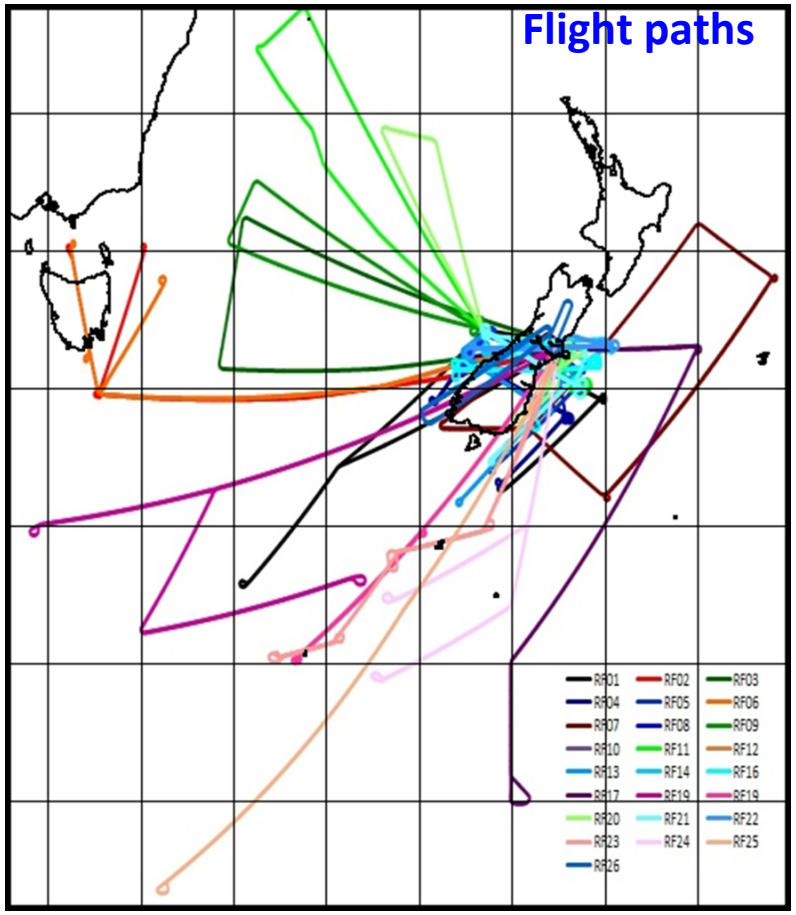
- Novel coordinated AMTM airborne and ground-based measurements of "Mesospheric Mountain Waves" over New Zealand, and extensive gravity waves observed over the surrounding oceans..

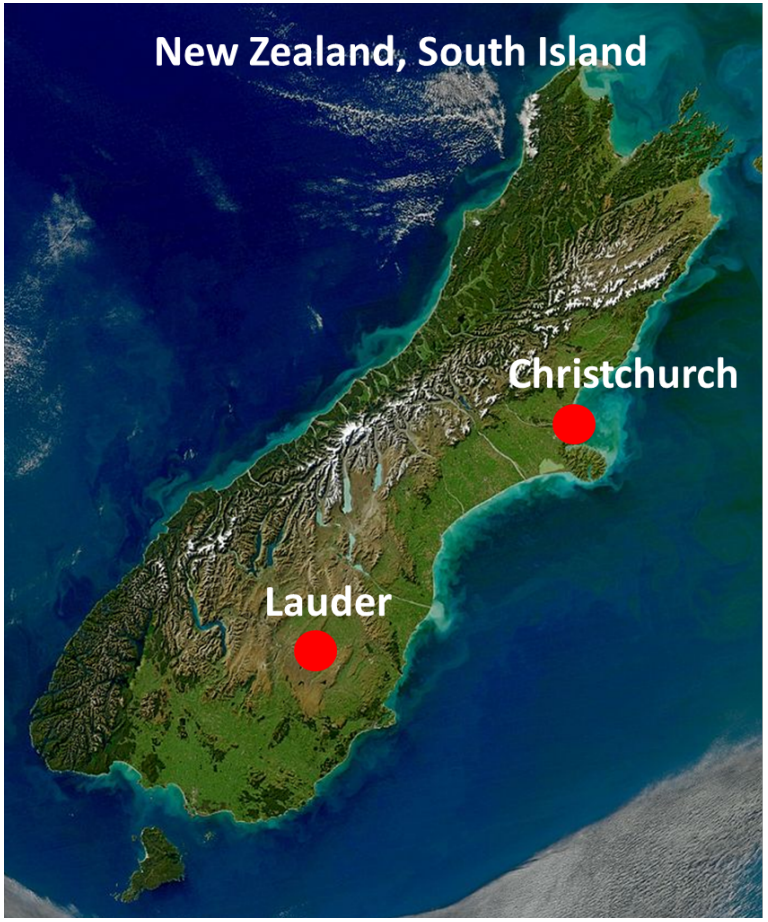
OH Airglow Layer:

~85 km altitude,

~8 km thick (FWHM)

DEEPWAVE: Airborne and Ground-Based Observations





Airborne: The 25 night-time flights:

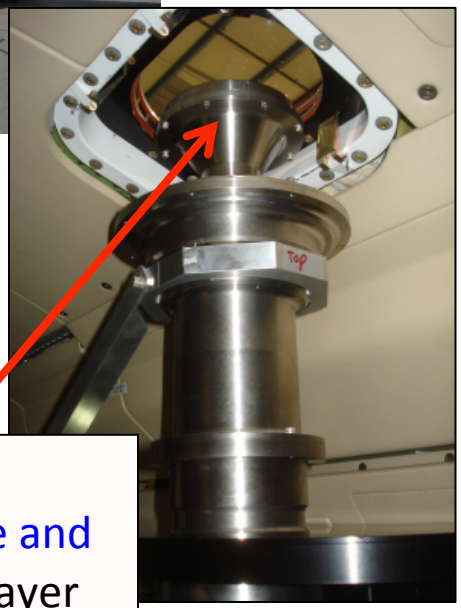
- 14 NZ South Island MW flights
- 11 extended ocean flights

Ground: 51 nights (May 30th- Jul 21st)

- 40 clear/partially clear nights
- Excellent complementary MW data

AMTM & IR Imagers on Gulfstream V Aircraft

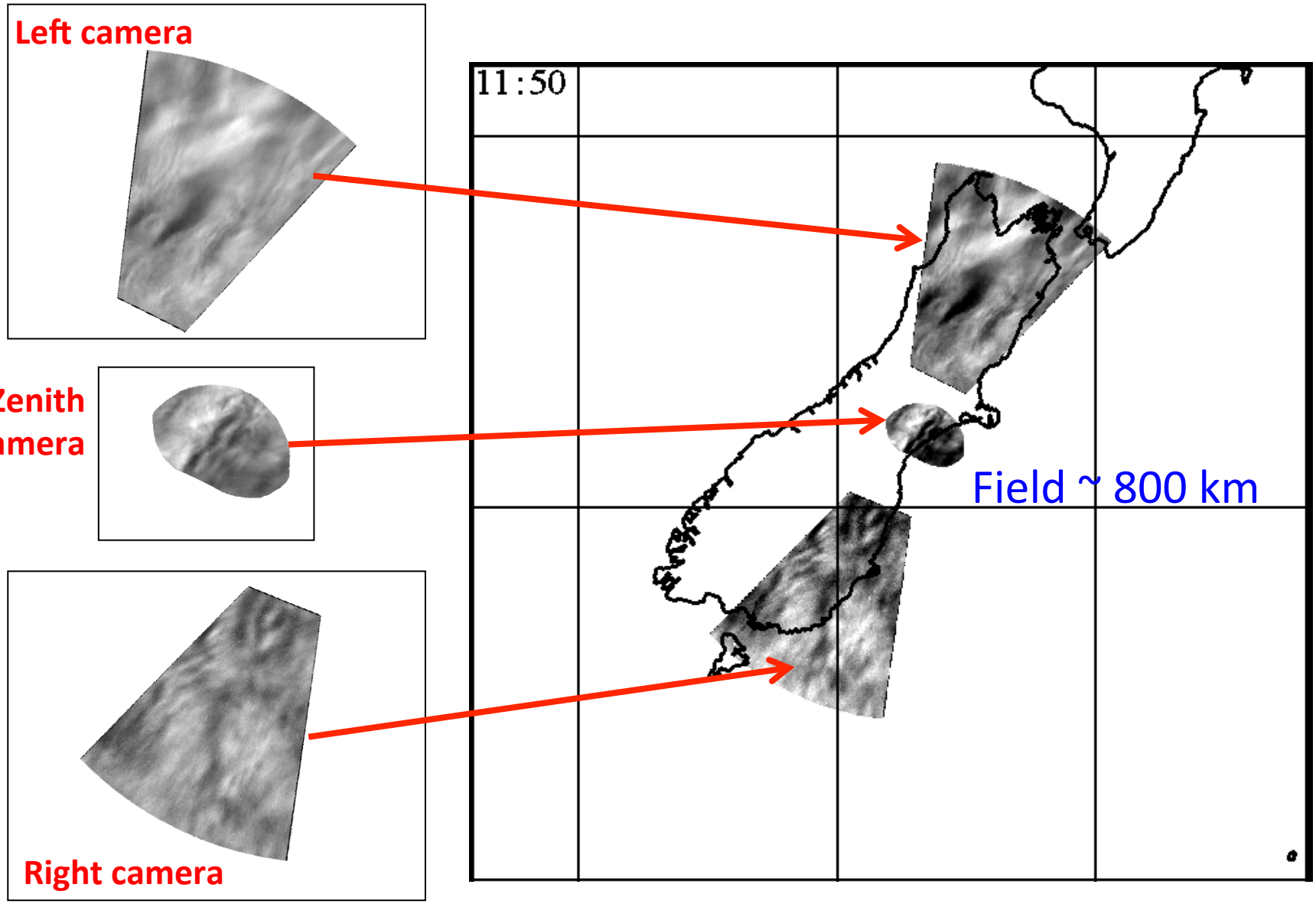
NSF/NCAR
GV Research Aircraft



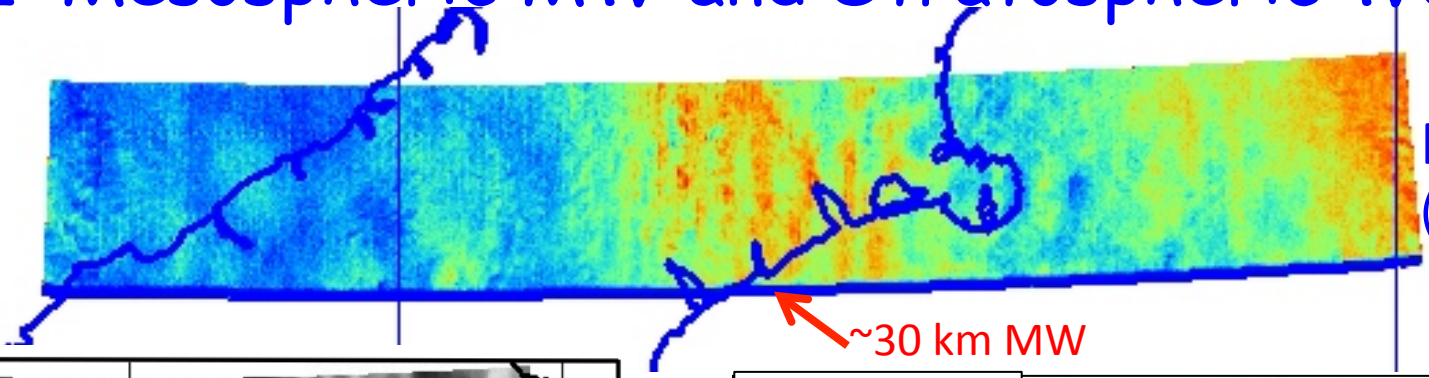
AMTM (80 x 60 ˚FOV):
- 120 x 80 km temperature and intensity maps of the OH layer (~85km), centered at the zenith, every ~15s (precision ~2K/pix)

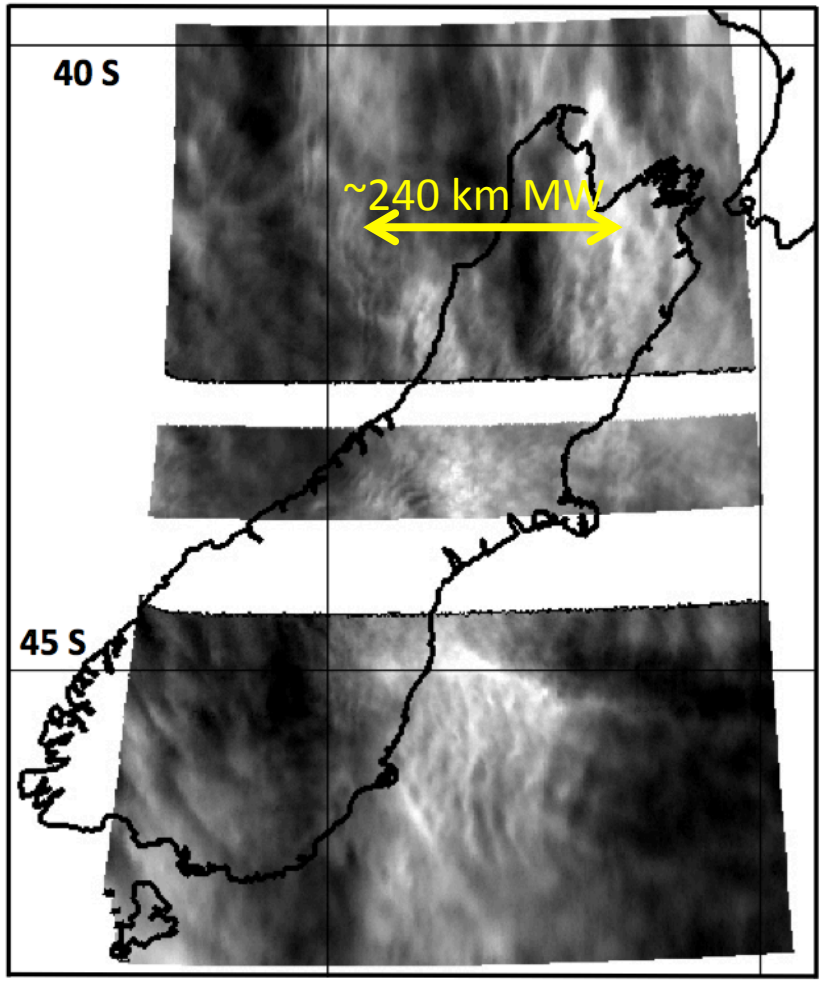
Two IR wide field-of-view side looking cameras:
- IR OH intensity GW maps over a large region (up to 400 km on each side of aircraft), every -4s.

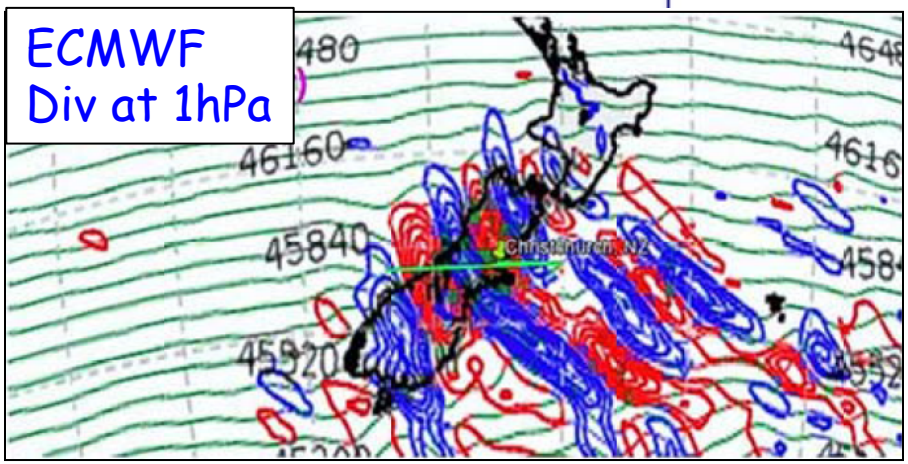
Camera Fields Projected onto a Geographical Map
(assuming 85 km altitude OH layer)



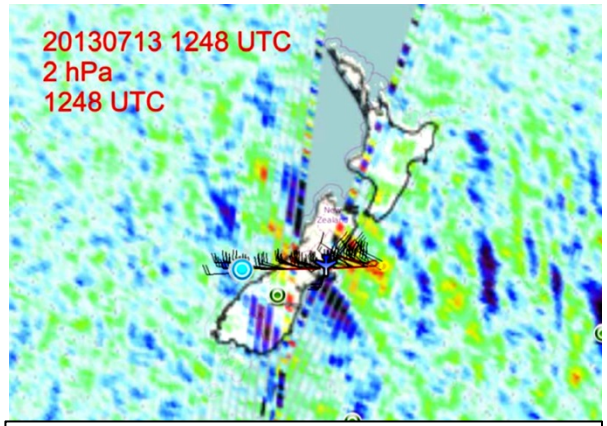
NZ: Mesospheric MW and Stratospheric Waves







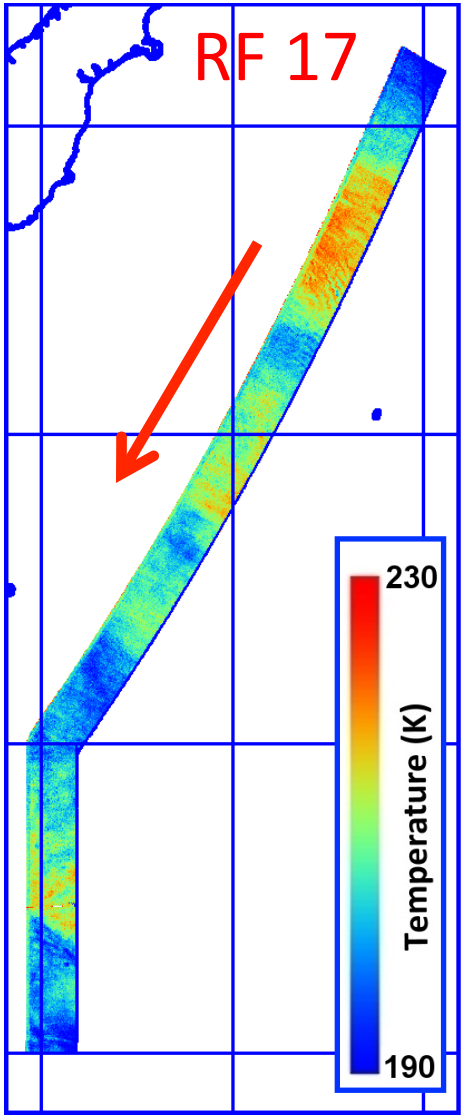
Note the strong similarities in large MW scales and orientation!

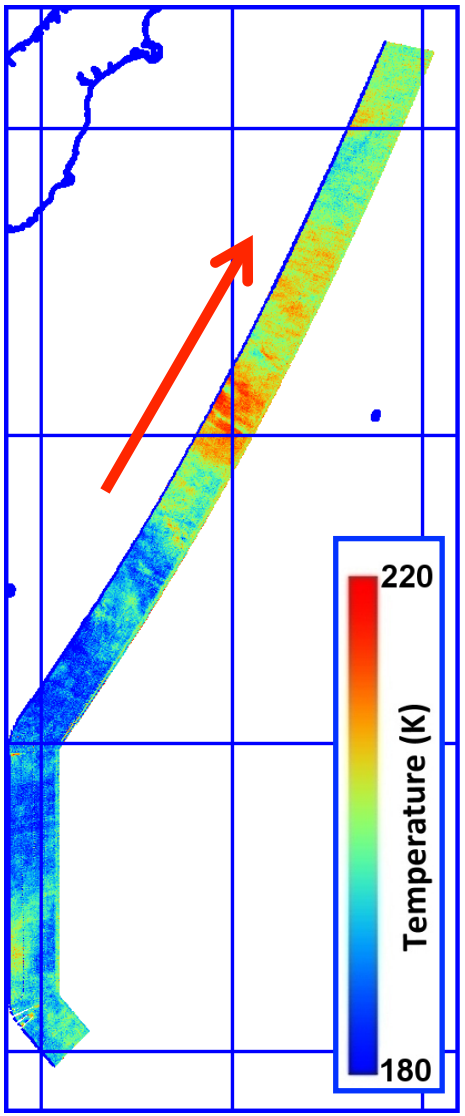


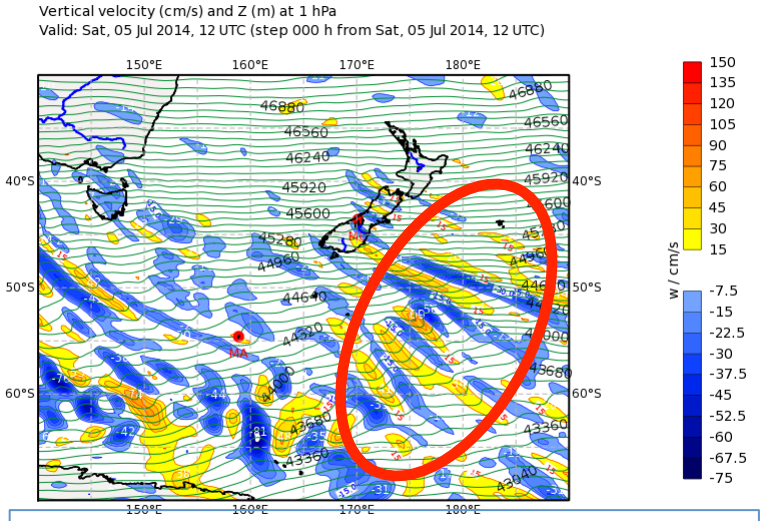
AIRS stratosphere Radiances

Extensive Southern Ocean GW: RF 17 (5/6 July)

(Comparison: OH Temperature (~85km) and ECMWF at 1hPa)

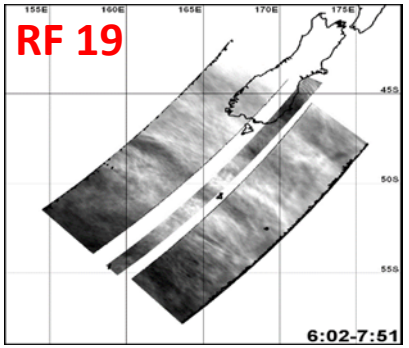




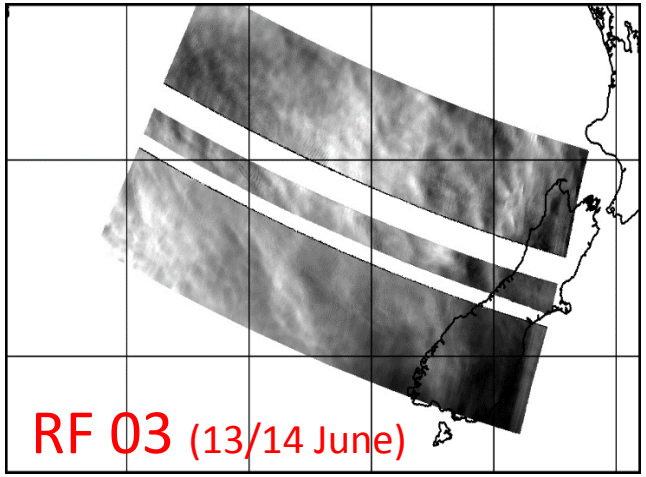


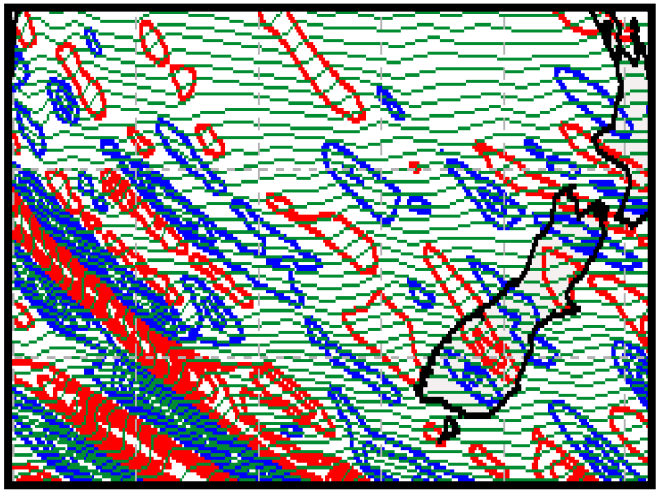
Coherent large-scale OH GW field and ECMWF vertical velocity at ~47 km exhibiting strikingly similar stratospheric and mesospheric wave patterns.

Below:similar GW activity on 8/9 July.

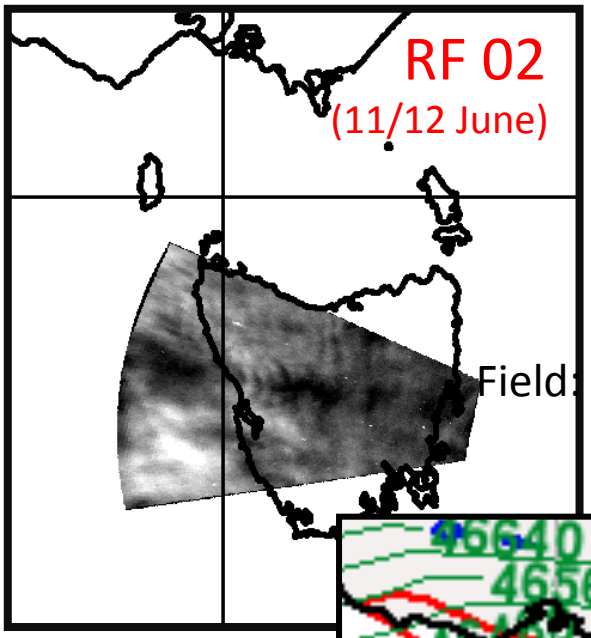


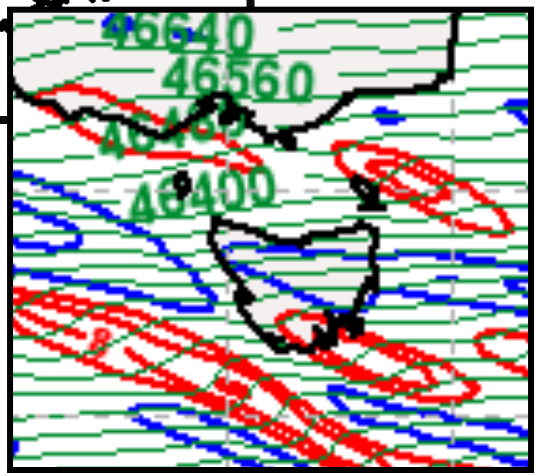
Comparative GW and ECMWF Over Tasman Sea





OH maps of extensive mesospheric GW over Tasman sea and ECMWF structure.



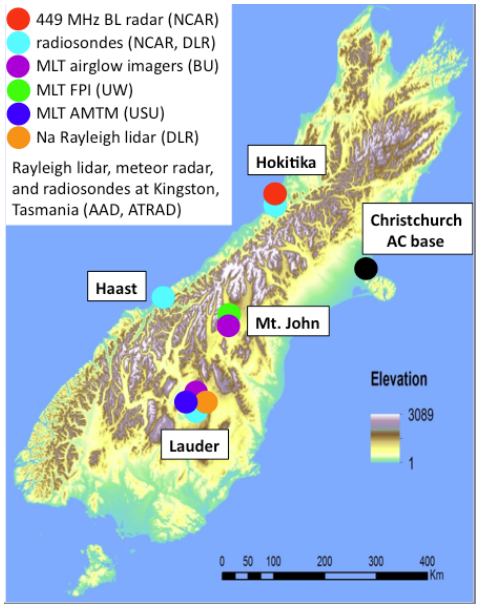


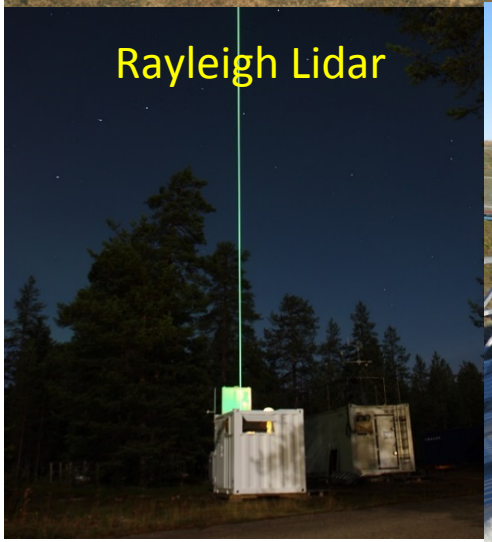
ECMWF Div.
1hPa, 12UT

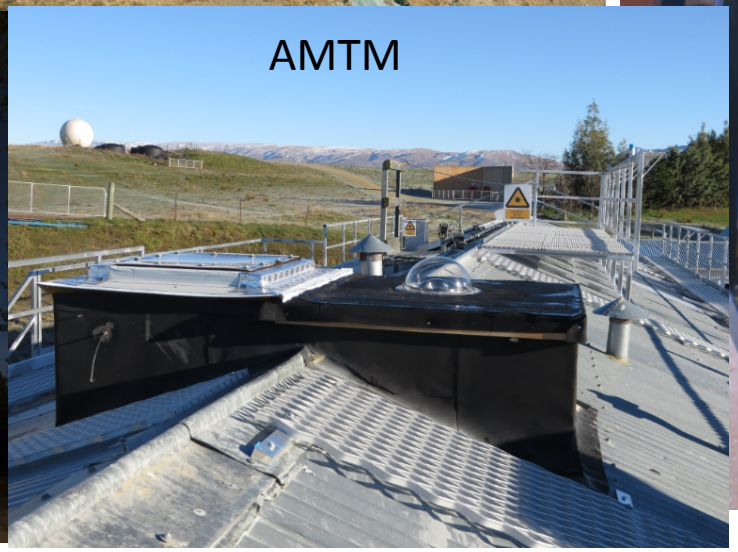
Snapshot OH image of mesospheric waves over Tasmania and stratospheric ECMWF.

Result: striking correlation between stratospheric models, AIRS data, and mesospheric gravity waves.

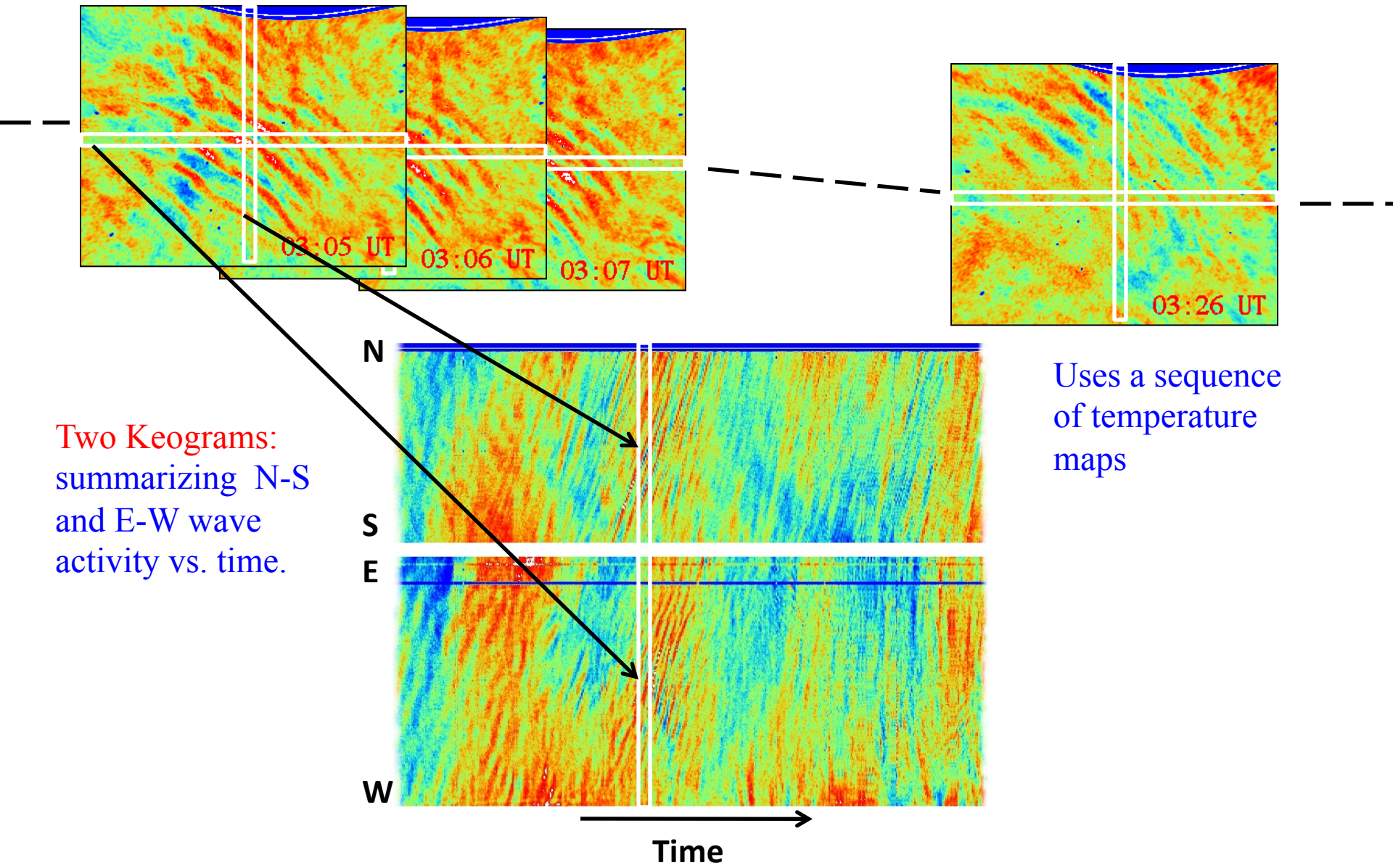
Ground-Based Observations at NIWA Station, Lauder (45°S)







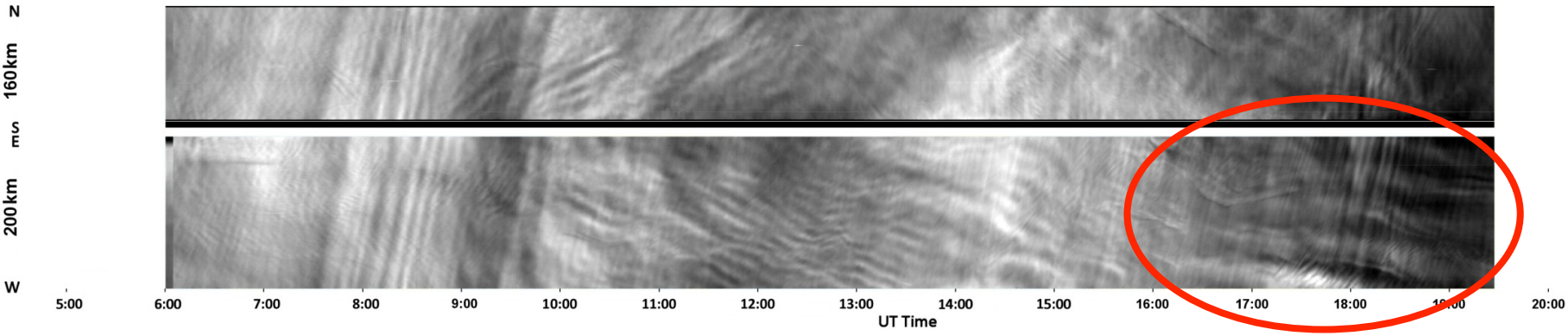
"Keogram" Technique to Study a Broad Range of Wave Events, Scales and Periods



Two Keograms: summarizing N-S and E-W wave activity vs. time.

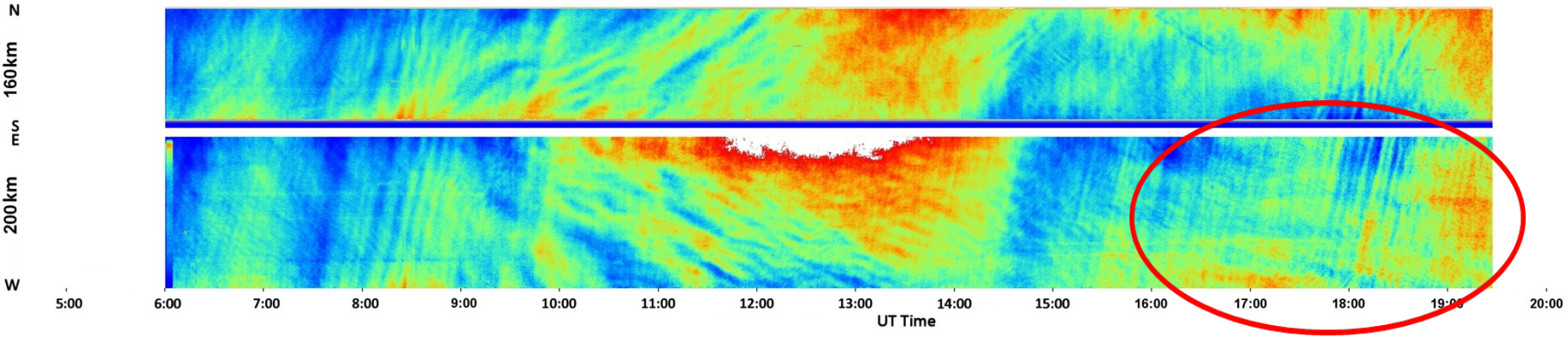
Uses a sequence of temperature maps

First AMTM Detection of Mesospheric Mountain Waves (Lauder, May 30-31, 2014)



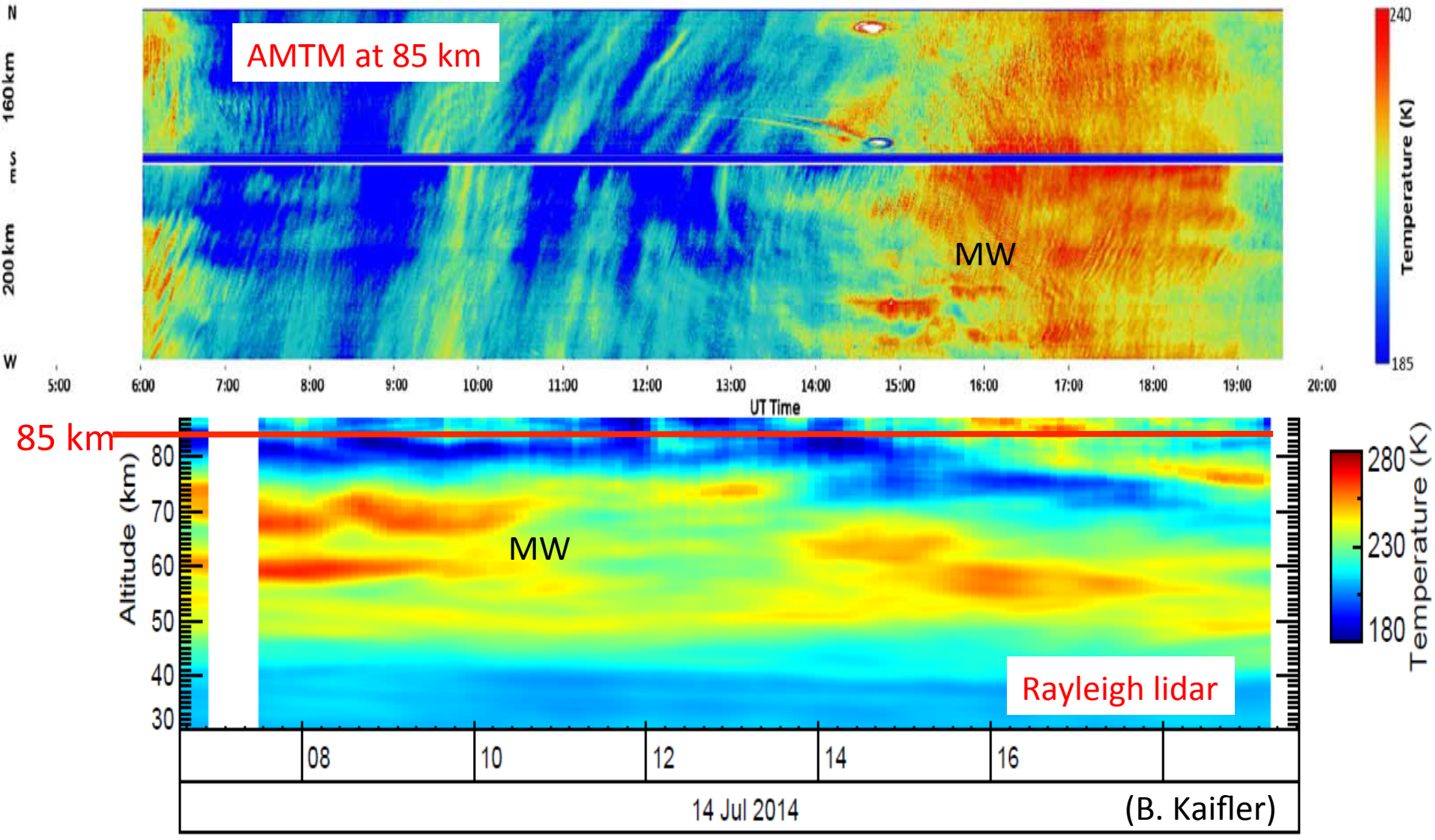
Propagating waves

Mountain Waves

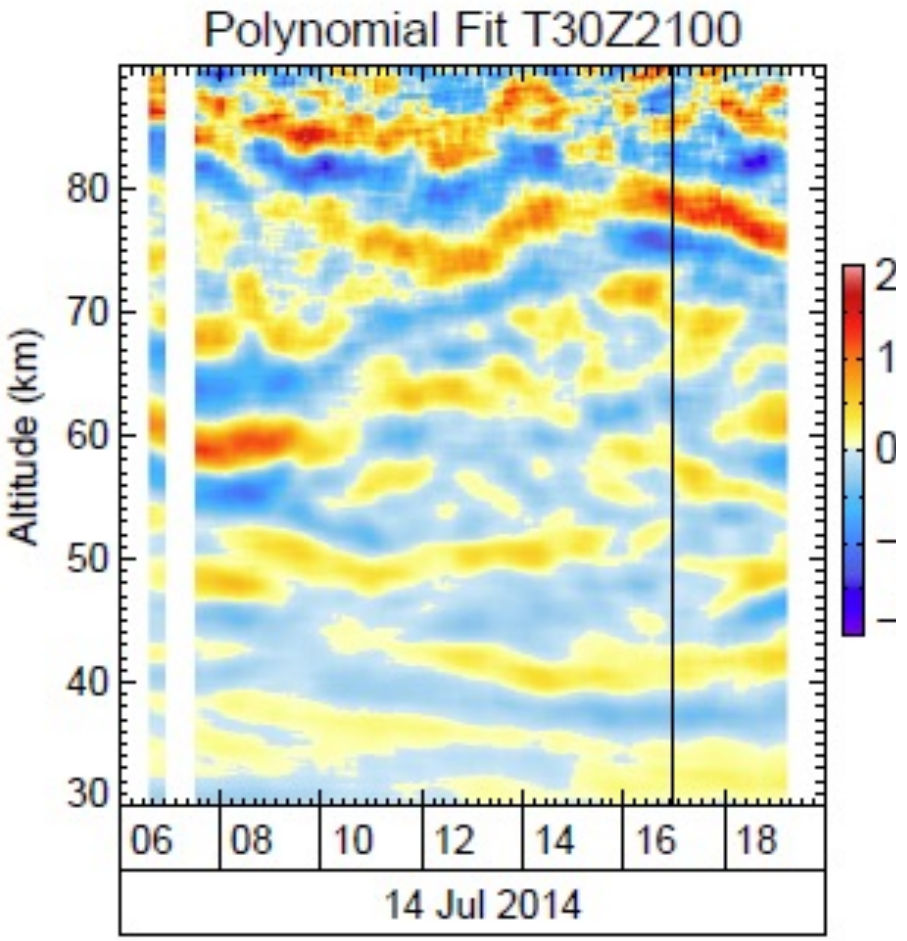


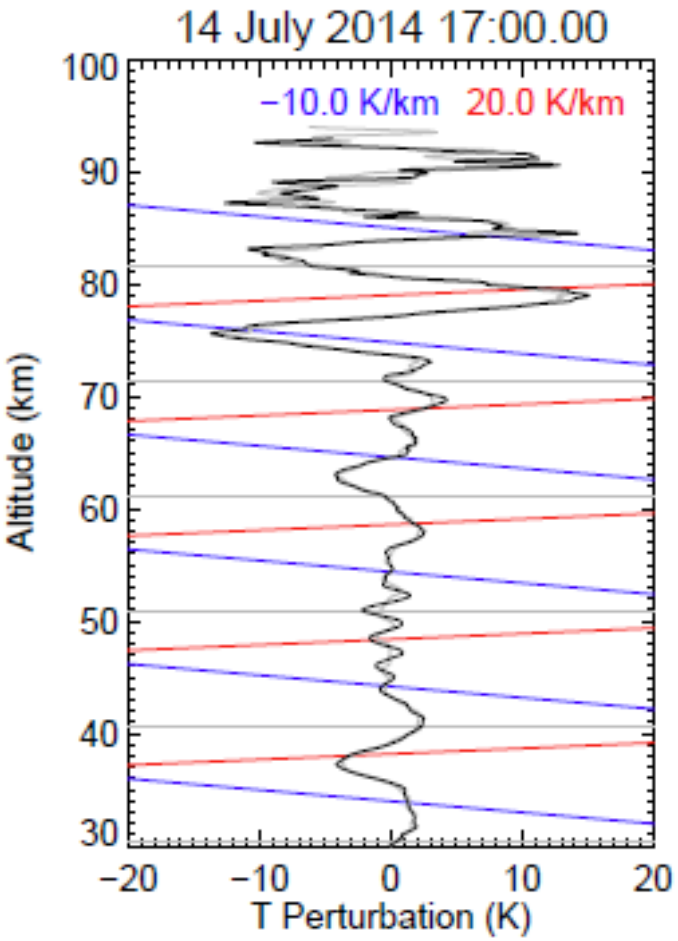
MW signature: near horizontal structures in E-W Keograms

Comparison of AMTM and Rayleigh Lidar Data (July 14, 2014)



Rayleigh Lidar Mountain Waves (July 14, 2014)



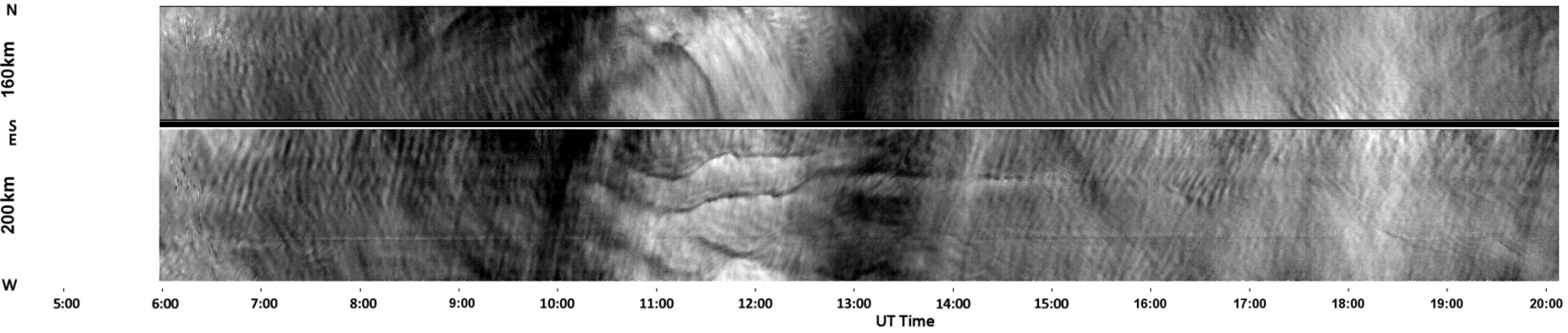


Temperature perturbations

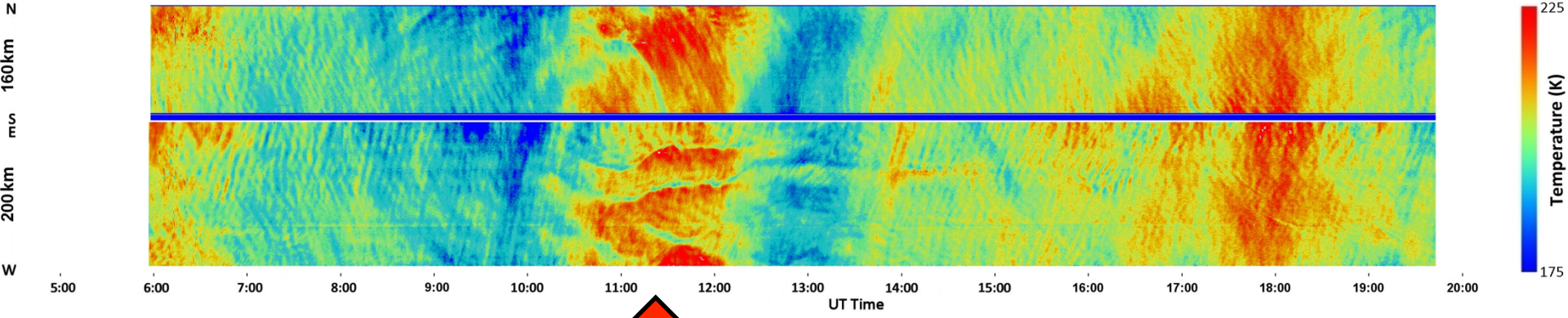
Strong (>10K amp.) MW detected in both Lidar and AMTM (16 -18UT)

"Breaking" Mountain Wave Event, June 21/22

(No flight this night as forcing deemed to be insufficient)

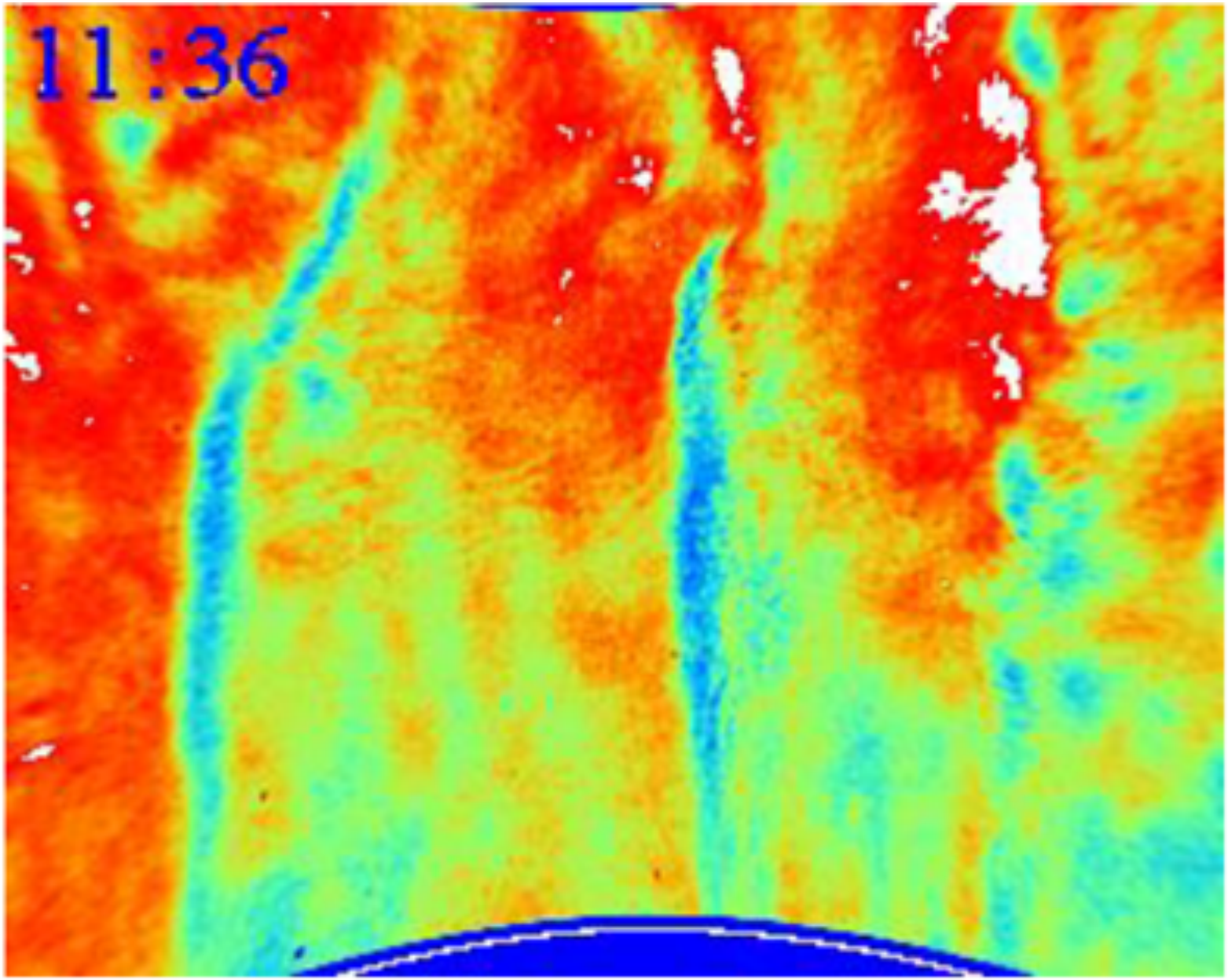


Continuous small-scale waves interrupted by MW outburst



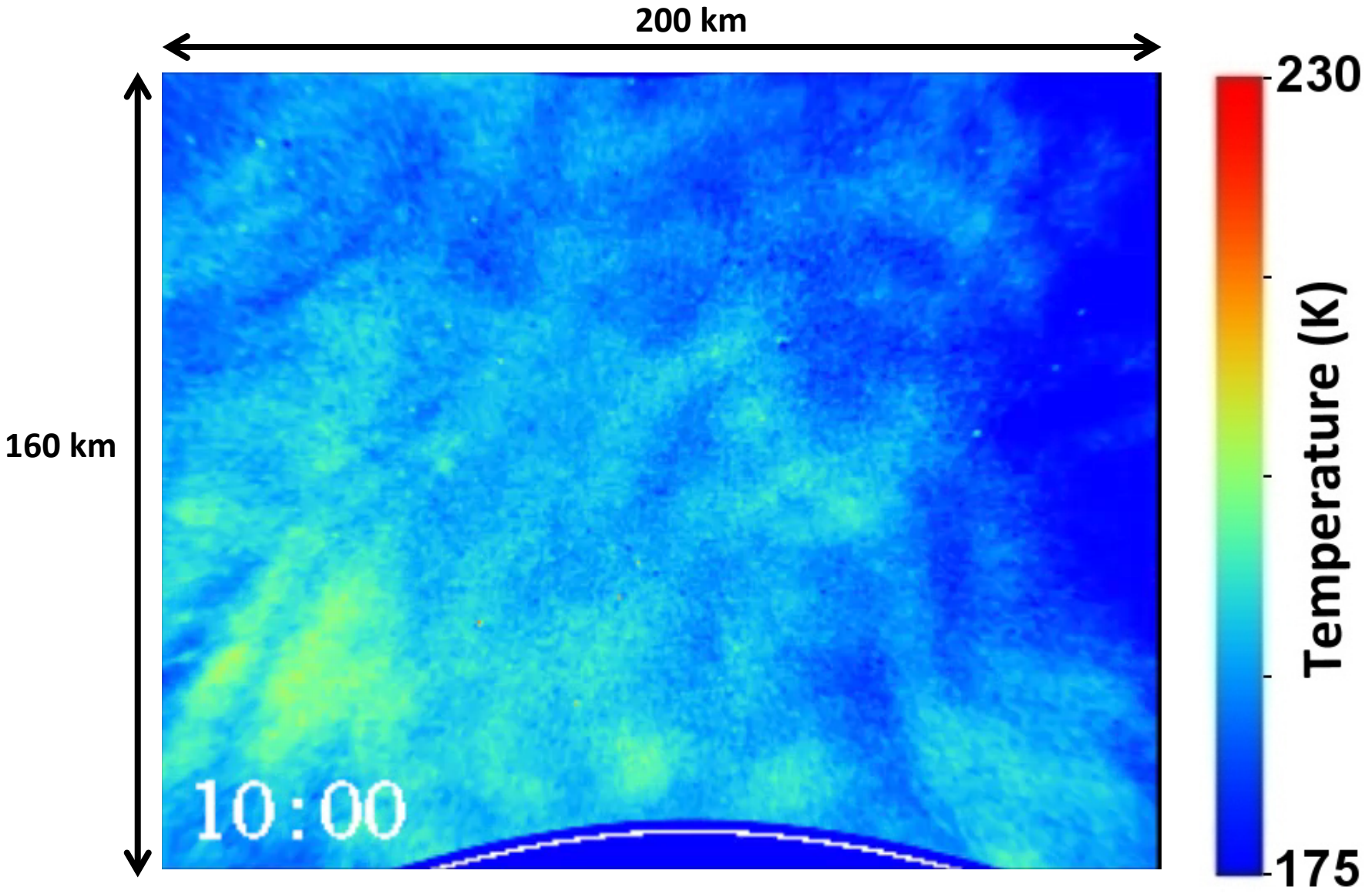
(MW Event ~10:30-13:30 UT)

AMTM: Complex MW Temperature Structure

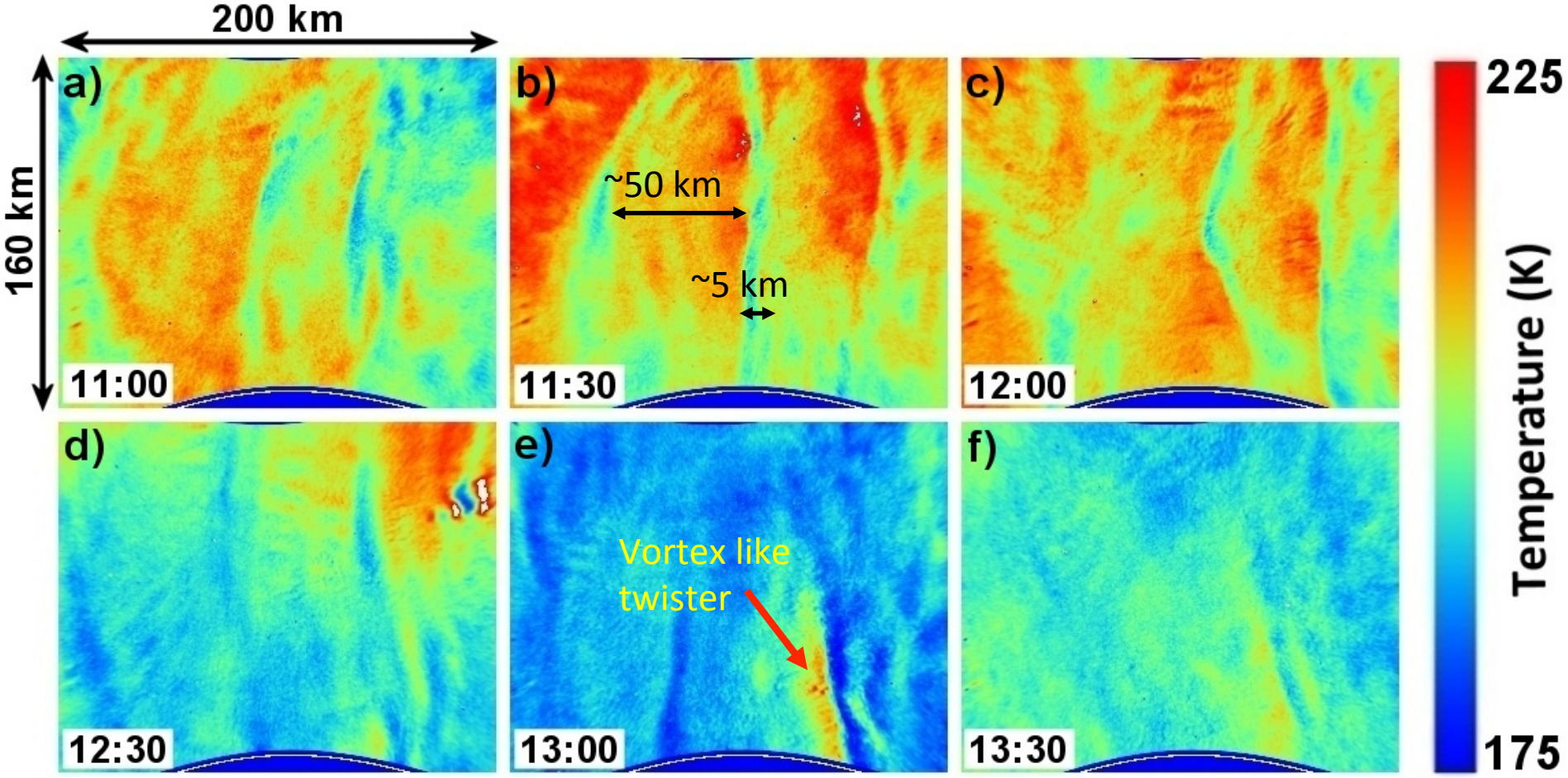


OH Temperature "Mountain Waves" Movie

(Lauder, June 21-22 - OH Temperature, ~5hrs)



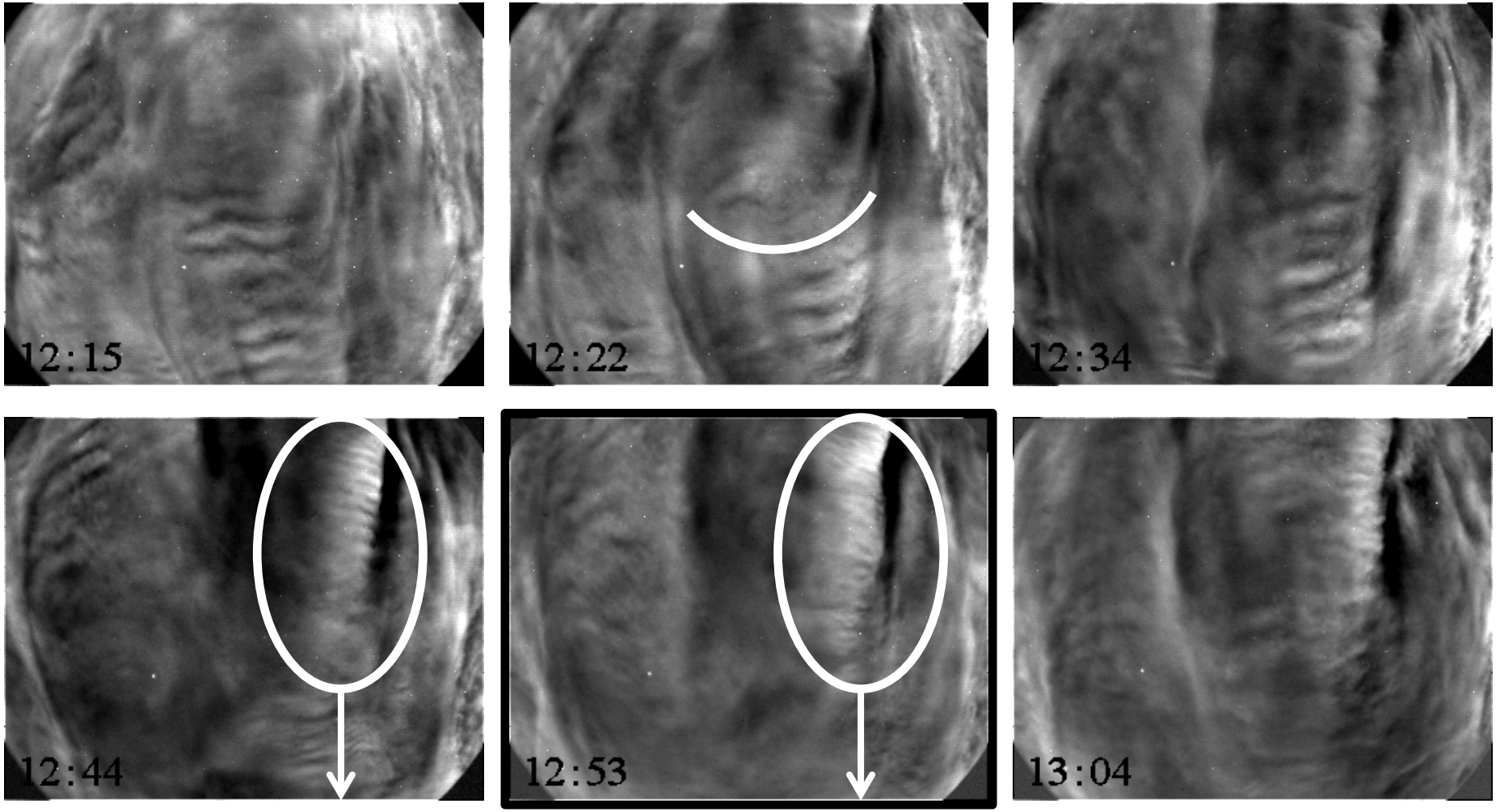
Snap-Shot Summary of MW Growth and Breaking Event (~2.5 hrs)



OH Temperature data, 21-22 June, 2014

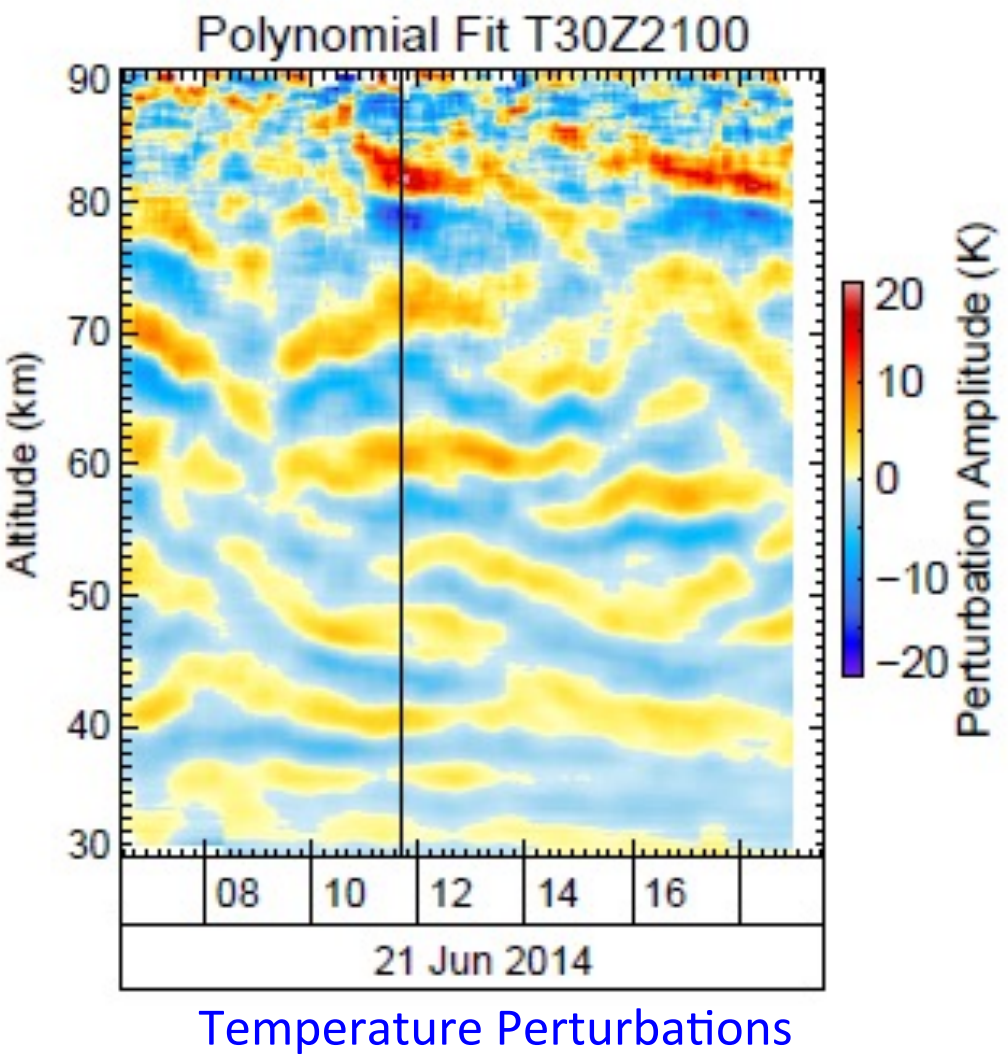
AMTM Development of Fine-Scale Waves and Twisting

Raw OH image data (12:15-13:04UT)

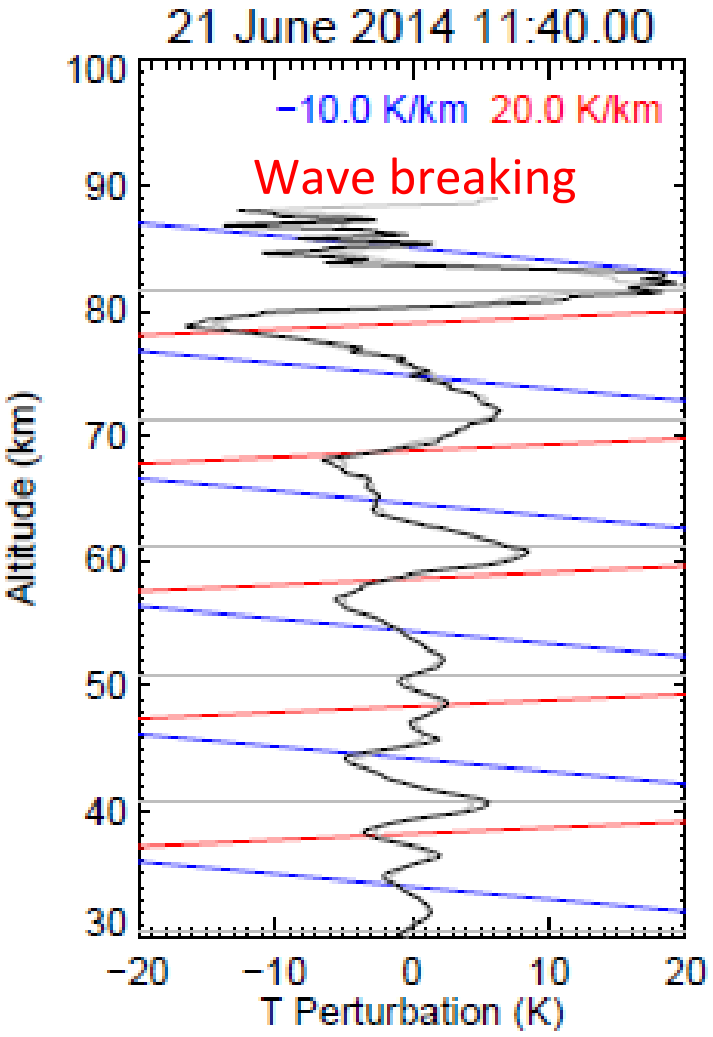


Growth of >12 “vortex-like” twisting fine-scale waves (~5 km)

Rayleigh Lidar: Breaking Mountain Waves
June 21/22. 2014



Temperature Perturbations

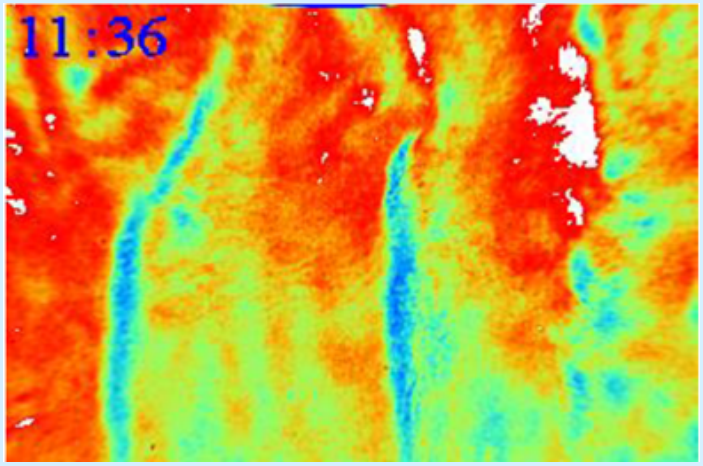


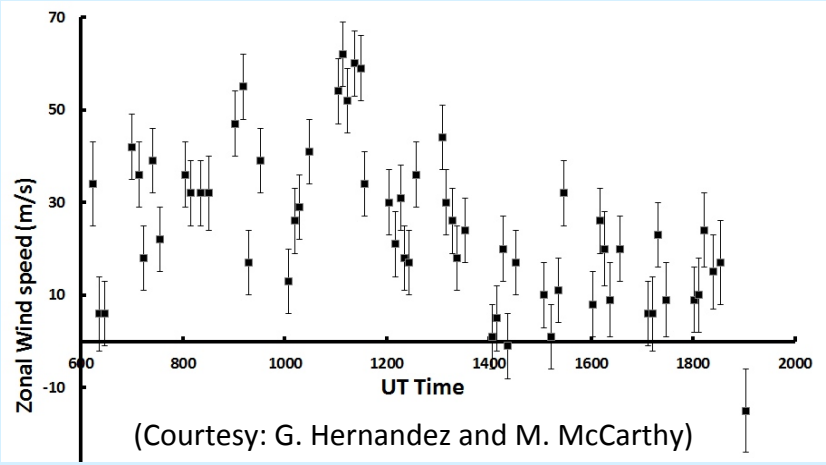
Large amplitude >15K, breaking MW event, ~10:30-13:30 UT

Momentum Flux

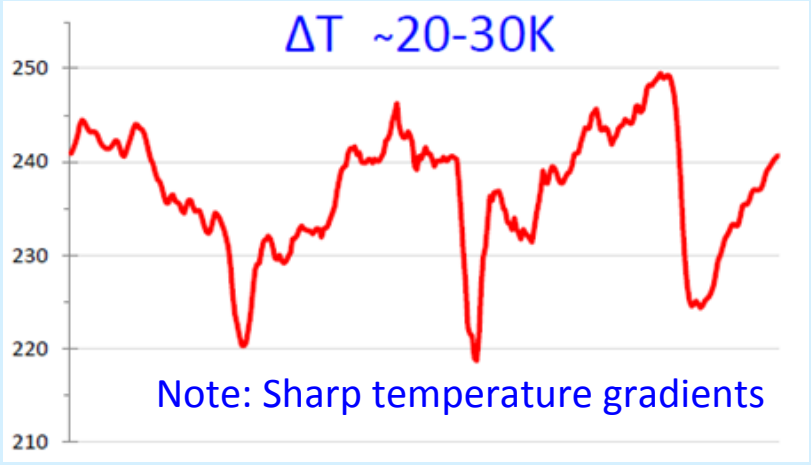
$$< u_h'w' >= \frac{g^2\omega_i}{2N^3}\sqrt{1-\frac{\omega_i^2}{N^2}}\left(\frac{< T' >}{T_0}\right)^2 \frac{1}{C^2}$$

(Fritts et. al, 2014)





(Courtesy: G. Hernandez and M. McCarthy)



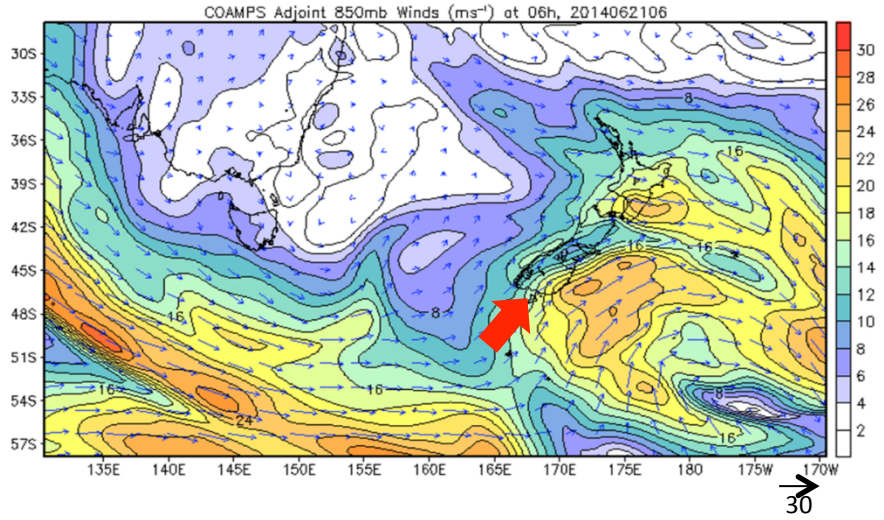
- Wind speed ~50m/s
- λ_x~55km
- Direction ~95°

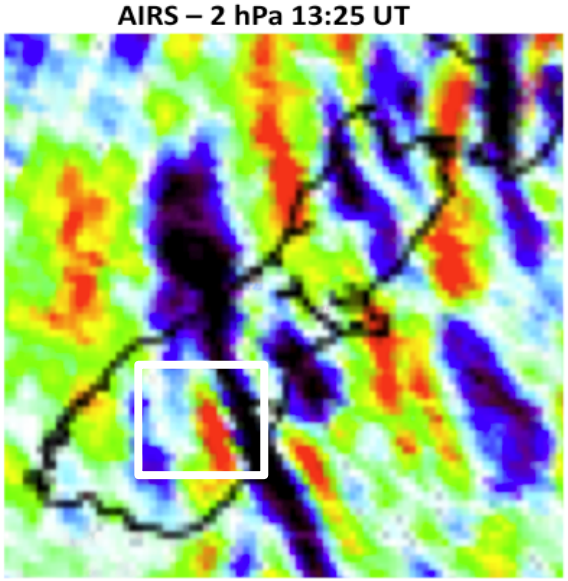
- Horiz. phase speed ~0 m/s
- $\Delta T/T$ ~3-7%
- λ_z ~17km

Estimated: $<u'_h w'> = 60\text{-}300\ m^2/s^2$

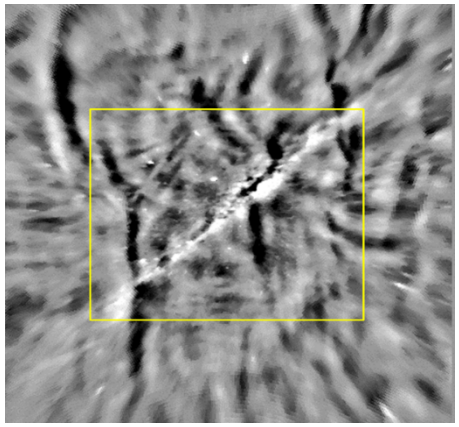
Summary (to date..)

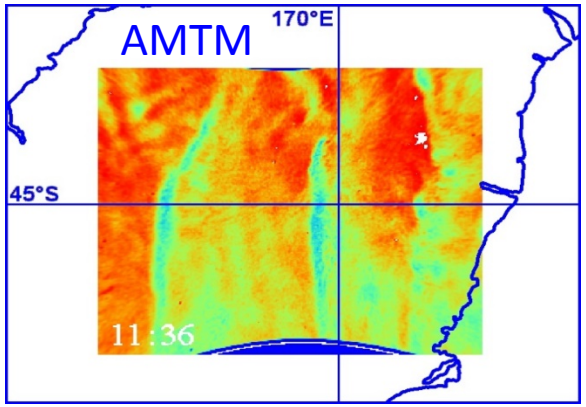
- Airborne and ground-based AMTM instruments succeeded in obtaining a wealth of high-quality mesospheric wave data during DEEPWAVE, capturing GW characteristics and variability over large mountainous and oceanic regions.
- On multiple occasions, **striking correlations** were determined between the stratospheric models and AIRS data, and the corresponding over **land and oceanic mesospheric waves.**
- AMTM measurements at Lauder indicated surprisingly large number (28) of nights with mesospheric MW activity, associated with weak to moderate wind forcing.
- Clear evidence for exceptionally **strong breaking MW events** were obtained on at least 4 occasions propagating into the mesosphere over the Southern Alps.





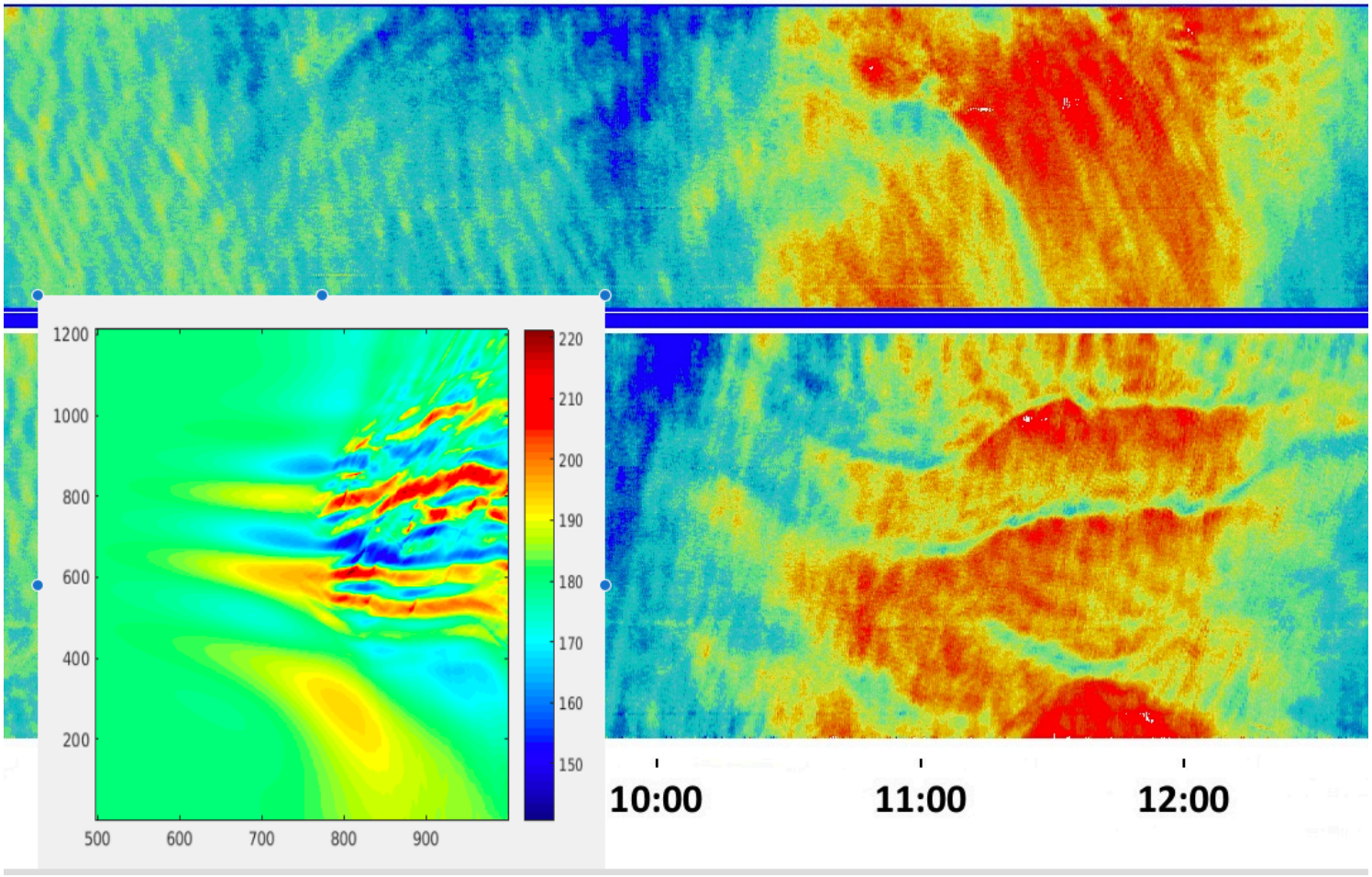
All-sky OH Data





June 21-22 event: Prevailing tropospheric wind forcings over the Southern Alps and the resultant wave coupling into the stratosphere (AIRS data) and mesosphere (all-sky OH intensity and AMTM temperatures). Primary forcing was from the SW and the resulting MW where almost N-S aligned. Boxes show the AMTM FOV

End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Development of Instabilities Along the Cold Troughs (40 min interval)