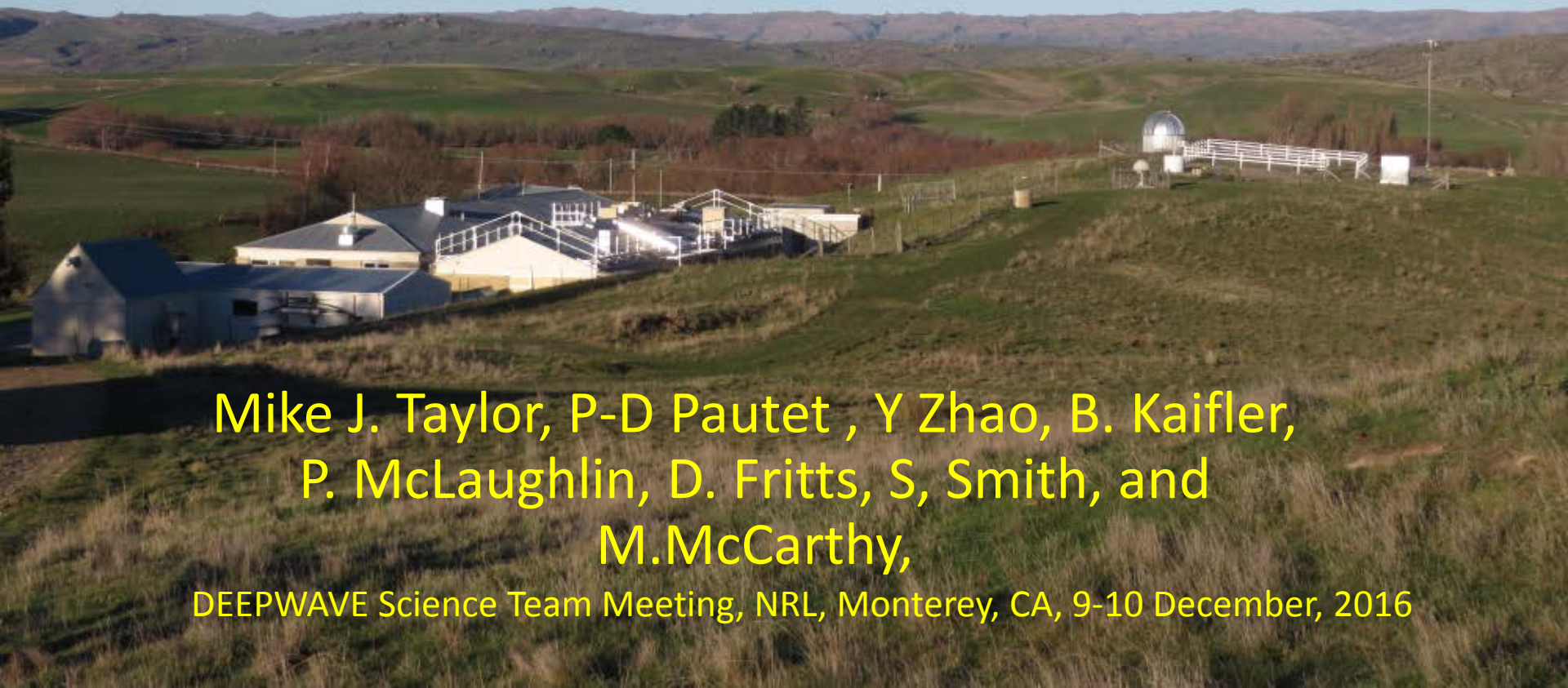
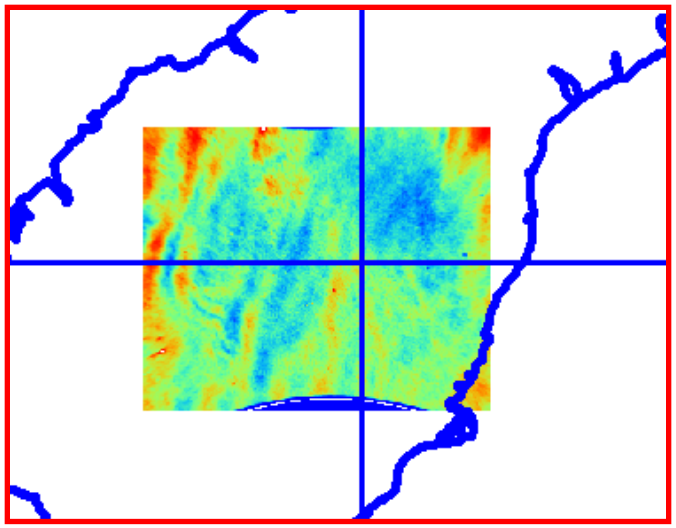
DEEPWAVE: Investigating Mesospheric Mountain Wave Activity and Properties Over Lauder, NZ.



Mike J. Taylor, P-D Pautet , Y Zhao, B. Kaifler, P. McLaughlin, D. Fritts, S, Smith, and M.McCarthy,

DEEPWAVE Science Team Meeting, NRL, Monterey, CA, 9-10 December, 2016

AMTM Installed at NIWA Lauder Observatory, 45°S, NZ, (May 30th- Jul 21st)



AMTM:

- 180 x 200 km temperature and intensity maps of the OH layer (~87km), centered at the zenith, every ~30s

Mountain Waves over Lauder

Summary: Lauder AMTM GW/MW Observations:

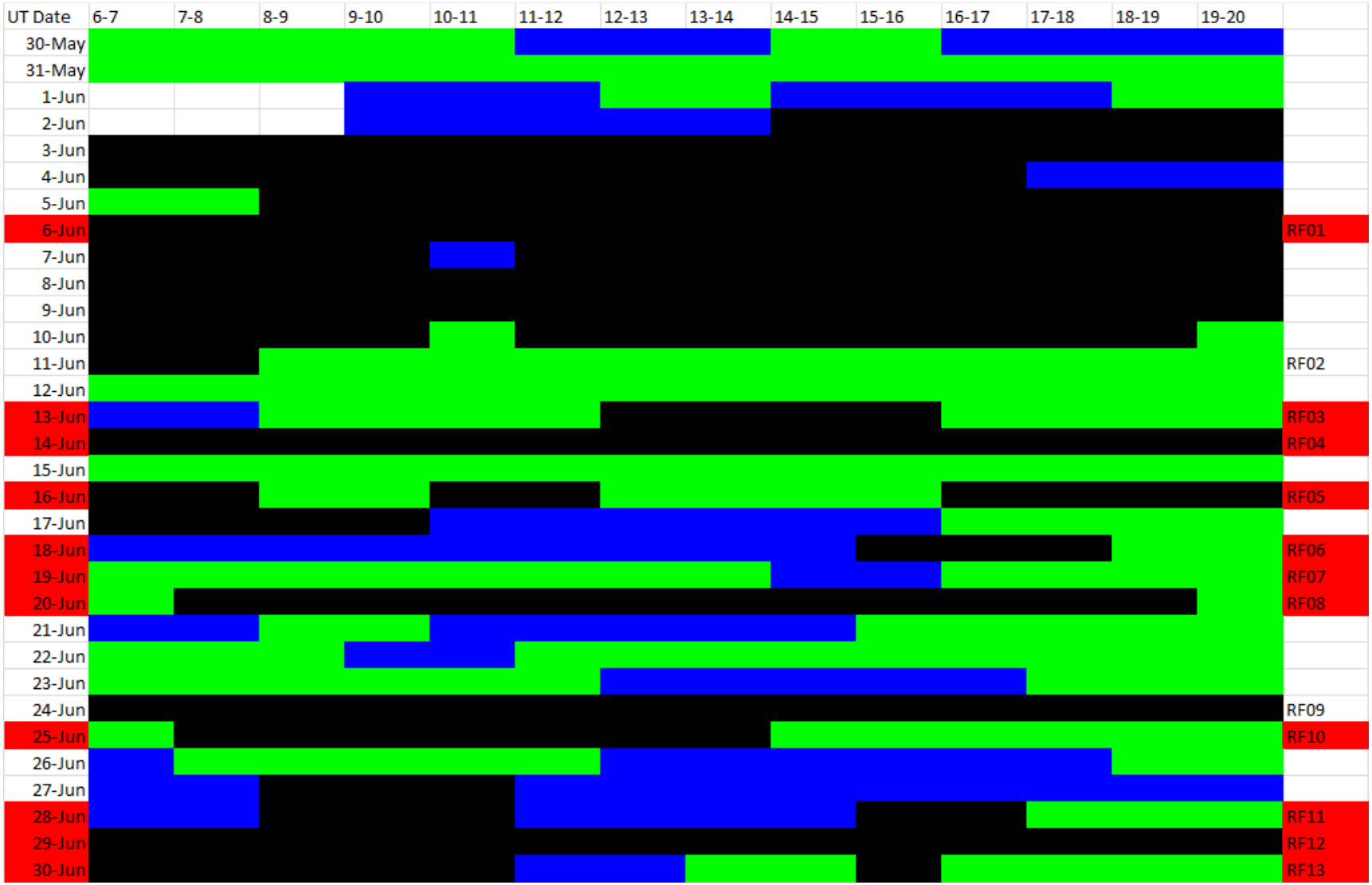
51 consecutive nights of observations from May 30th to July 21th:

- 15 clear nights
- 25 partially cloudy nights

Total of 40 data nights:

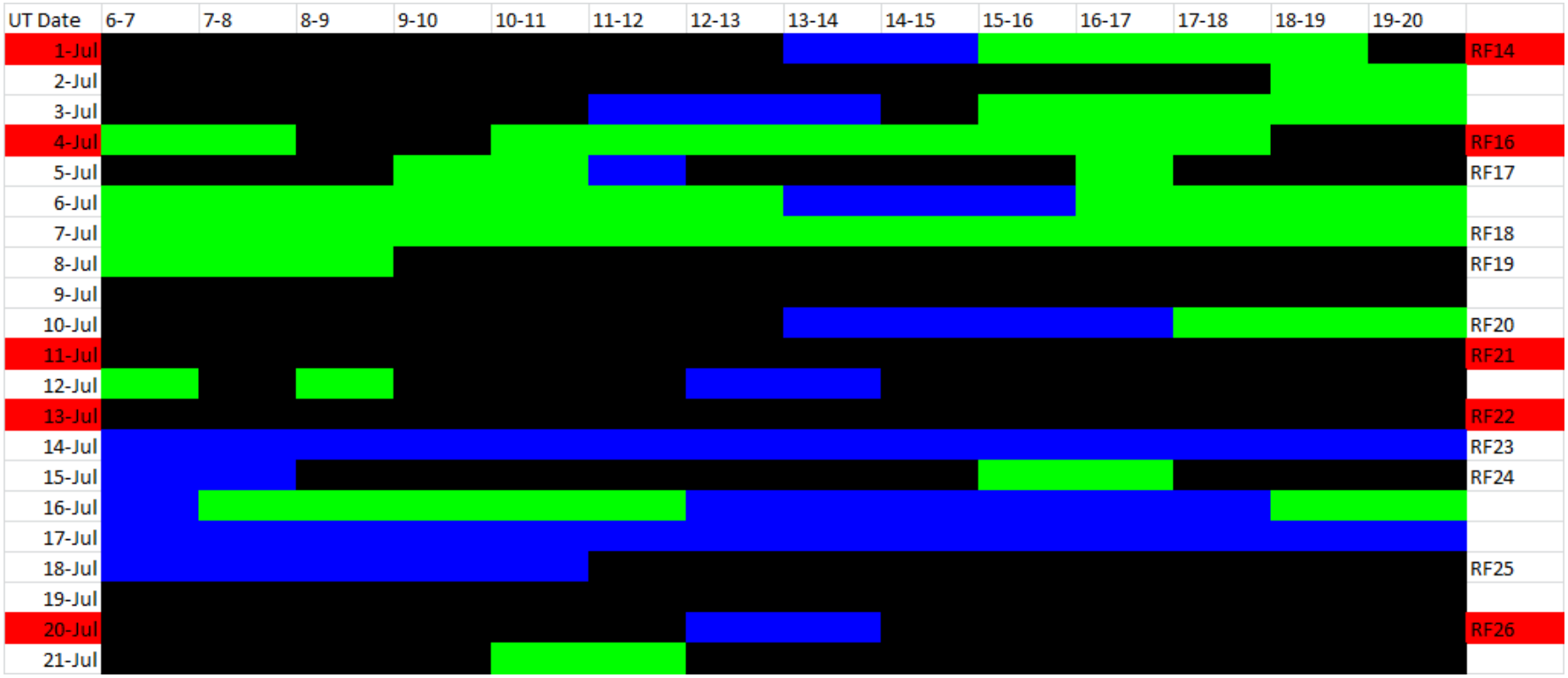
- **280 nights with mountain (standing) waves (>100 hrs)**
  (with durations from ~1-14 hrs).
- 12 nights with only propagating GWs

Dominant GWs Over Lauder – June 2014



MW=16/24 nights

Dominant GWs Over Lauder – July 2014



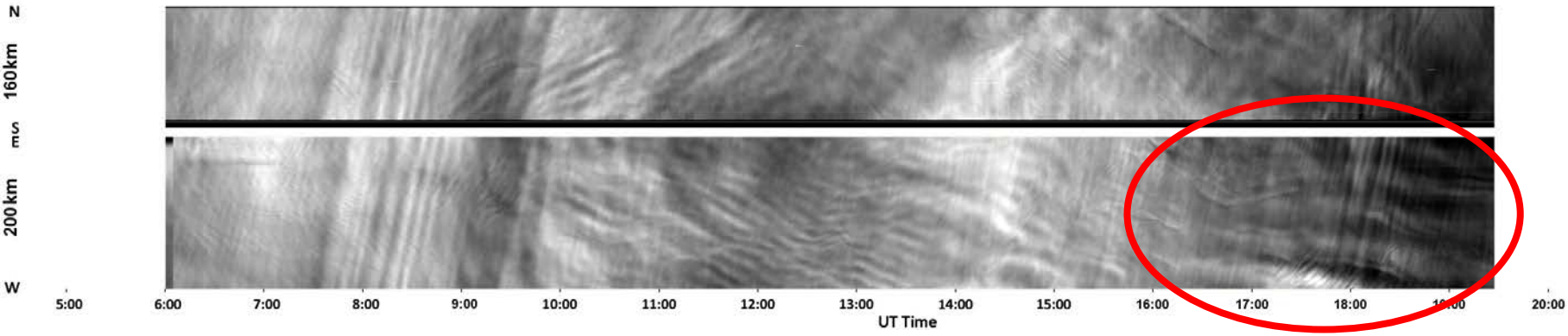
MW = 12/17 nights

Lauder: Selected Ground Based EventsNights

- GB1*
  30/31 May Numerous propagating and first MW event
- GB2
  2/3 June Excellent wave activity
- GB3
  18/19 June MW and coincident RF 6
- GB4*
  21/22 June Breaking MW, sharp temperature gradients, lidar
- GB5
  23/23 June Myriad small-scale and ducted waves
- GB6*
  26/27 June Good MW and instabilities
- GB7
  30/01 June good coordination with RF 13 MW data
- GB8*
  14/15 July Excellent MW, breaking , lidar and RF 23 coincidence

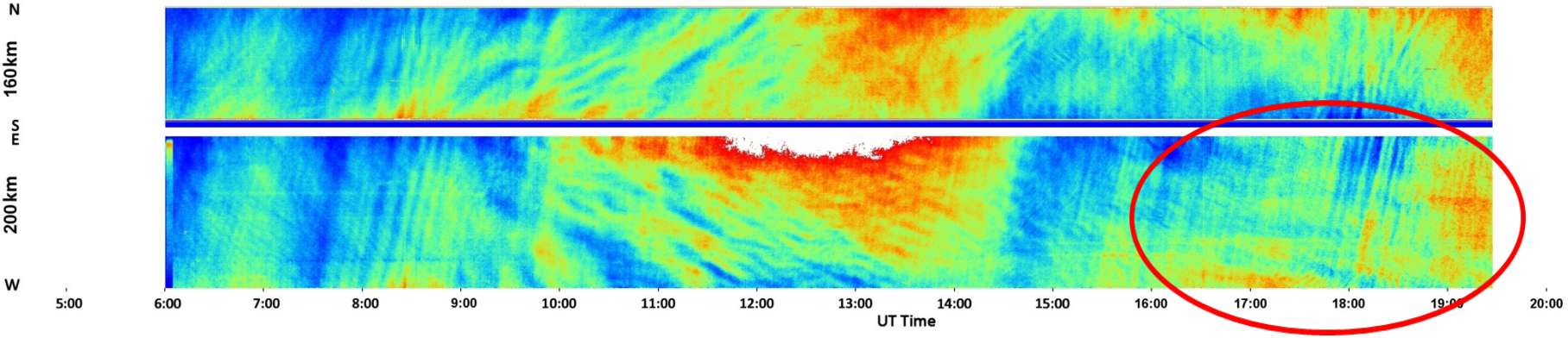
GB9 17/18July Long duration (>all night) MW event, Lidar

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



Propagating waves

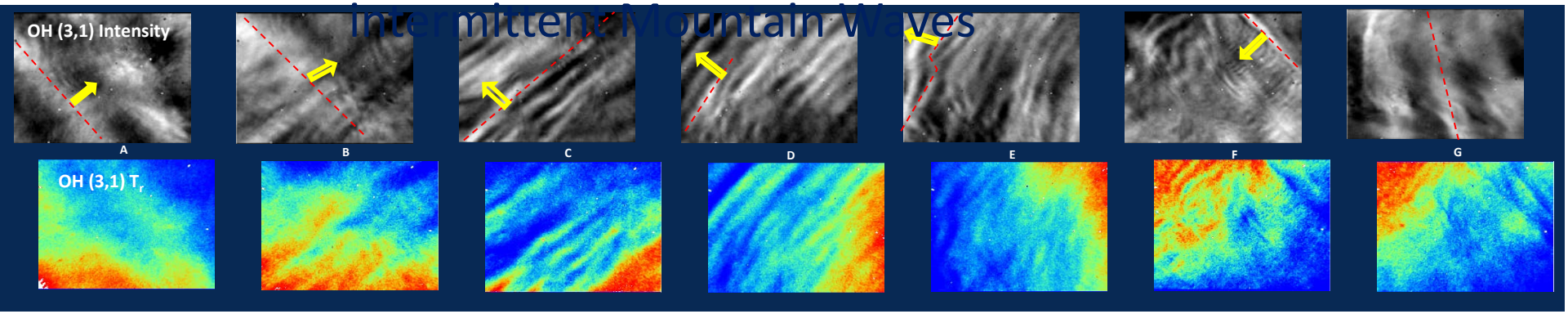
Mountain Waves



MW signature: near horizontal structures in E-W Keograms

Summary of the Rich GW Activity on the First Night of Data (May 30th)

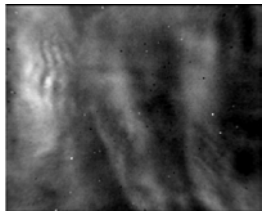
May 30th-7 hours of propagating, 4+ hours Intermittent Mountain Waves



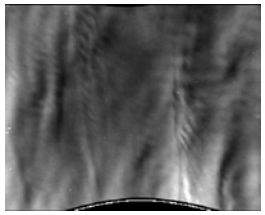
Event	Time	Wavelength [km]	Period [min]	ΔT [K]	Phase Velocity [m/s]	Θ [from North]	Duration [hours]
A	08:52 UT	46	6	~20	135 ± 3	52°	1.5
B	09:54 UT	57	9	~30	108 ± 2	49°	1
C	10:30UT	23	27	~ 20	14 ± 1	319°	1
D	12:05 UT	18	28	~25	11 ± 1	304°	4
E	13:19 UT	21	26	~25	13 ± 1	300°	1
F	15:48 UT	13	45	~20	5 ± 1	225°	1.5
G	18:02 UT	50	-----	~20	~ 0	-----	>4

(P. McLaughlin, CEDAR poster, 2016)

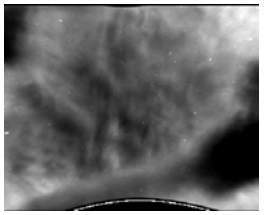
Summary of MW Events



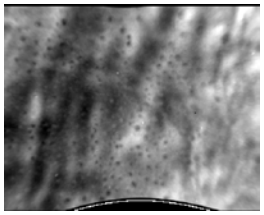
May 30-31
18:36 UT



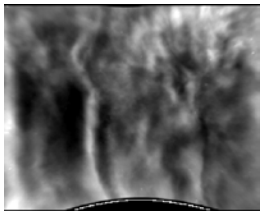
June 02-03
10:12



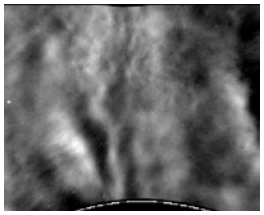
June 04-05
17:51



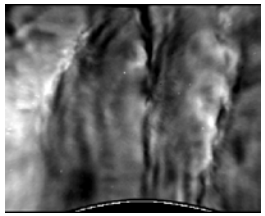
June 17-18
11:59



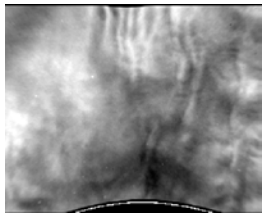
June 18-19
08:49



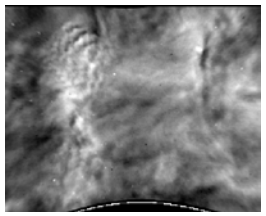
June 19-20
15:02



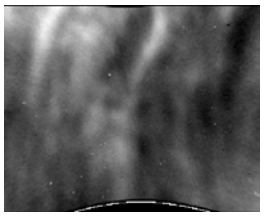
June 21-22
11:30



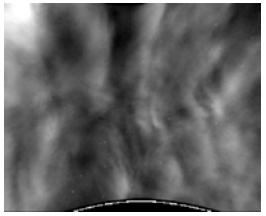
June 23-24
12:32



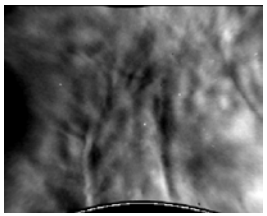
June 26-27
11:32



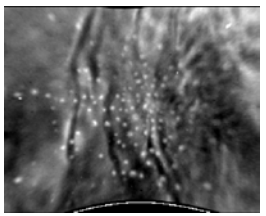
June 27-28
11:35



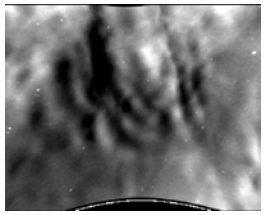
June 28-29
15:05



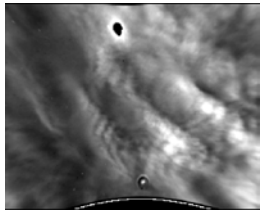
June 30-01
13:03



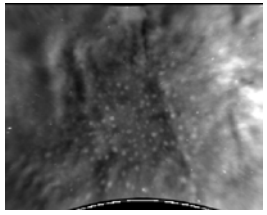
July 01-02
14:00



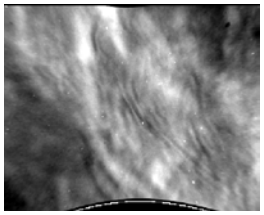
July 03-04
13:29



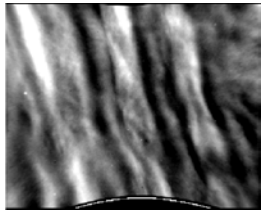
July 14-15
15:09



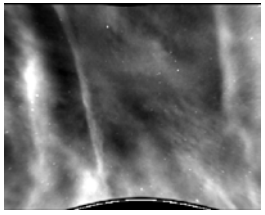
July 15-16
07:06



July 16-17
17:11



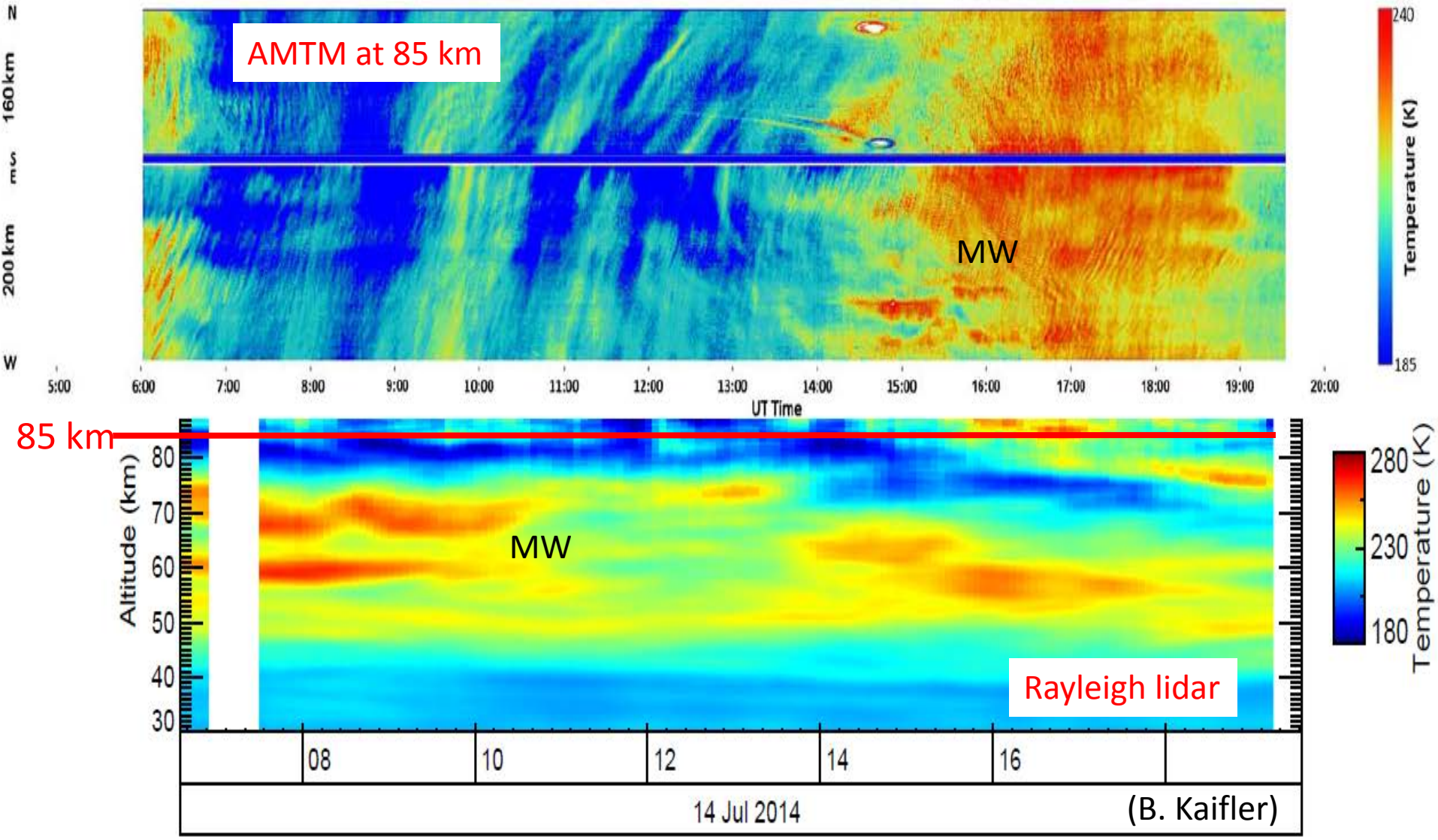
July 17-18
12:53



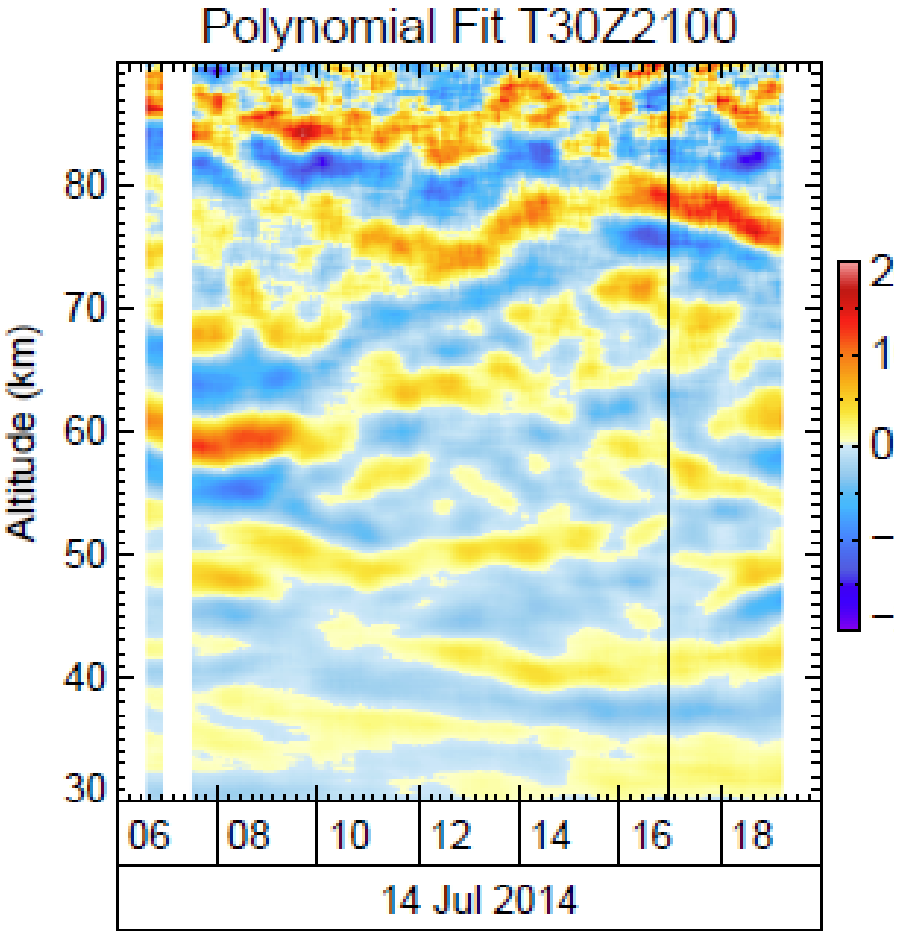
July 18-19
08:26

Wave breaking occurred on every night that MW were observed

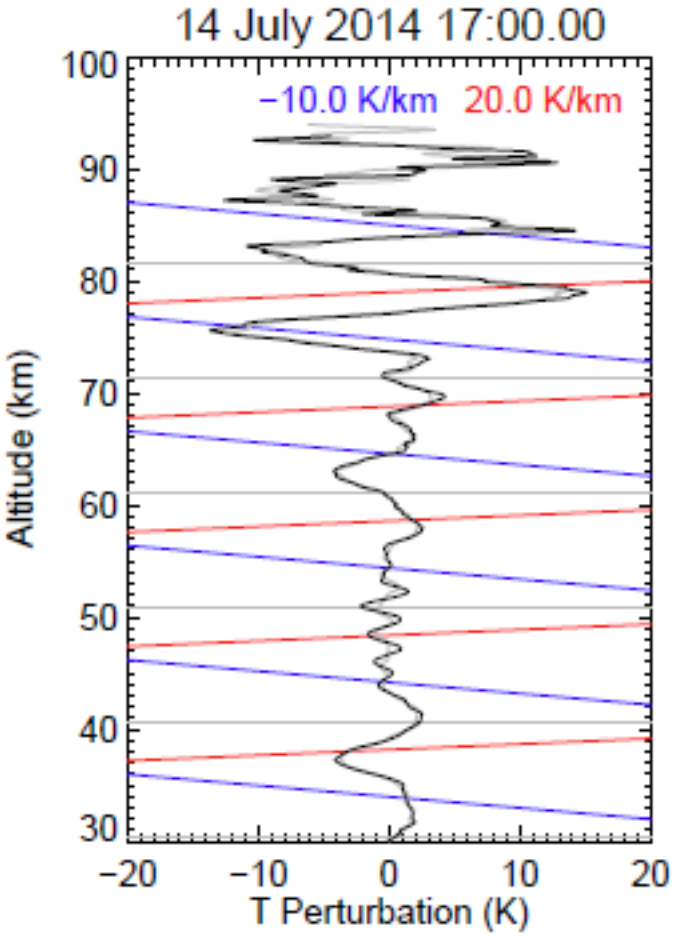
Comparison of AMTM and Rayleigh Lidar Data (July 14, 2014)



Rayleigh Lidar Mountain Waves (July 14, 2014)

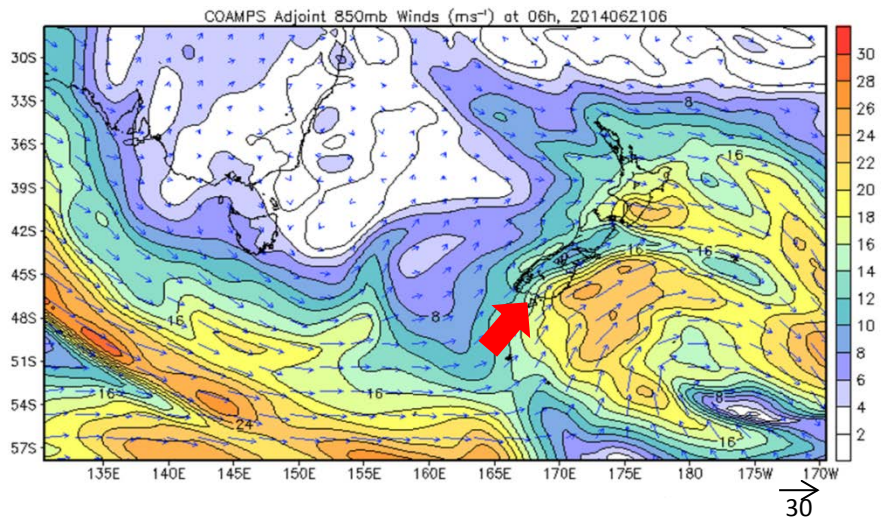


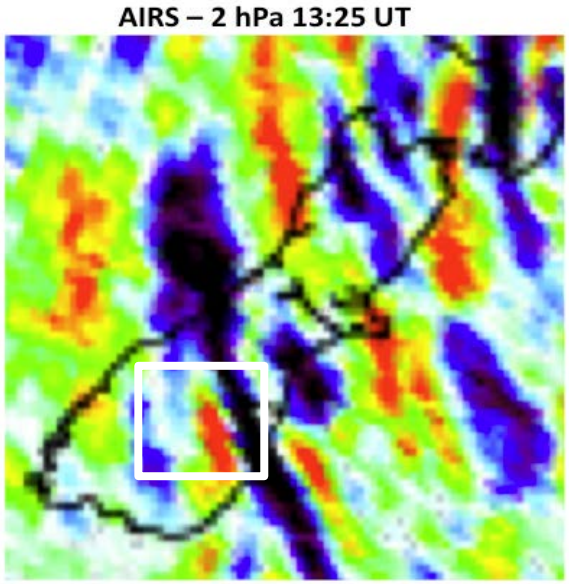
Temperature perturbations



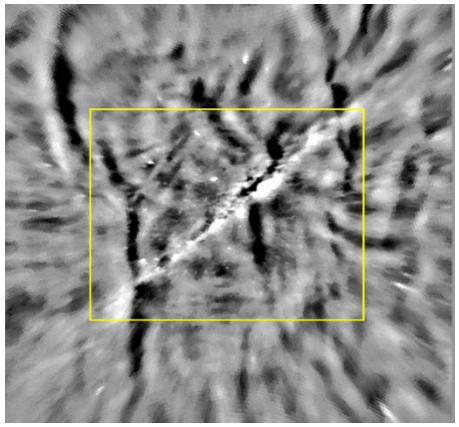
Strong (>10K amp.) MW detected in both Lidar and AMTM (16 -18UT)

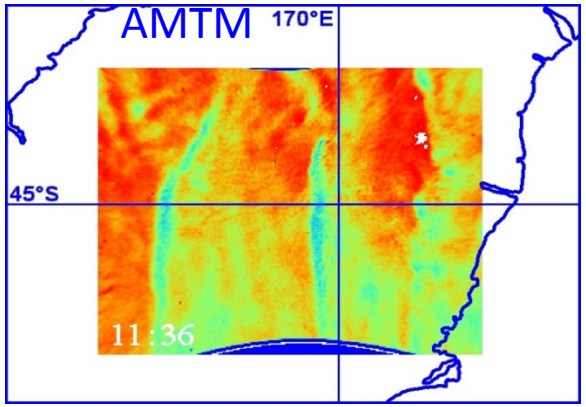
Overview of 21/22 June MW Event





All-sky OH Data

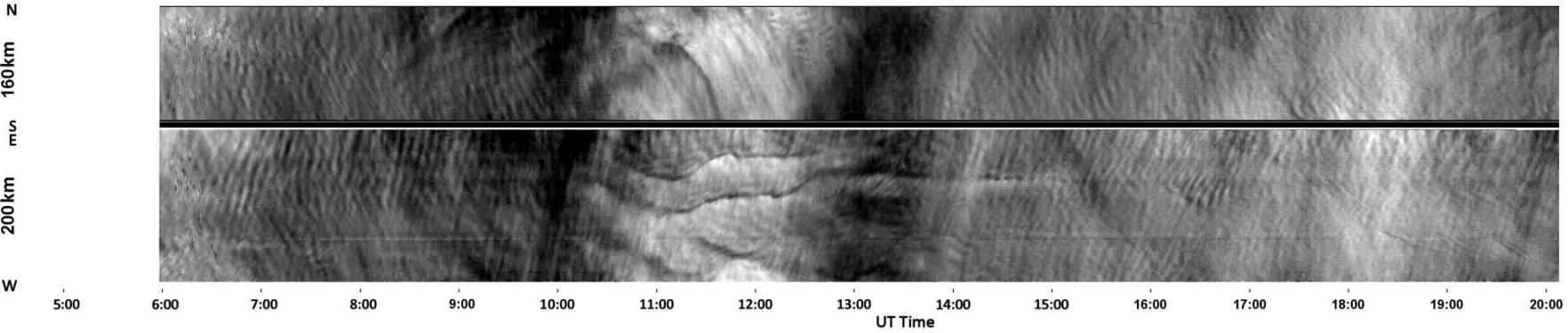




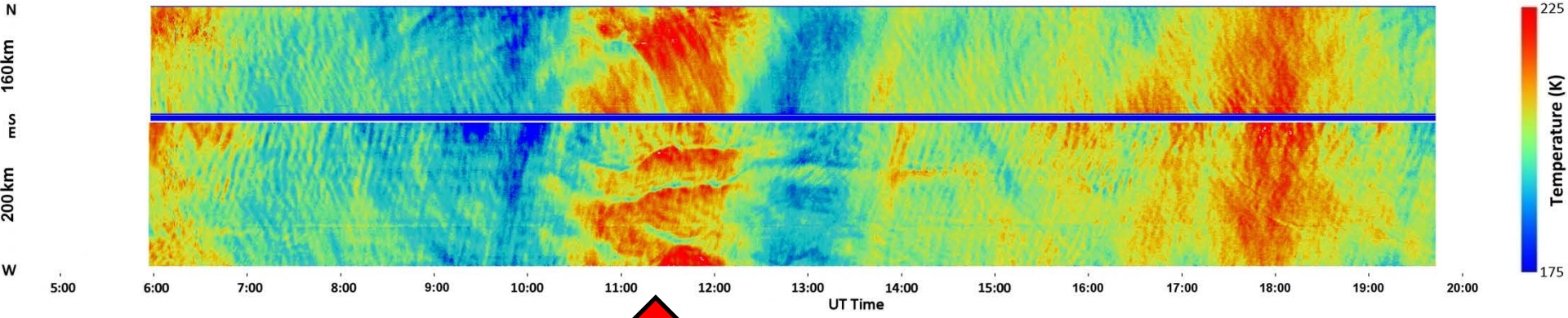
June 21-22 event: Prevailing tropospheric wind forcings over the Southern Alps and the resultant wave coupling into the stratosphere (AIRS data) and mesosphere (all-sky OH intensity and AMTM temperatures). Primary forcing was from the SW and the resulting MW where almost N-S aligned.

"Breaking" Mountain Wave Event, June 21/22

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



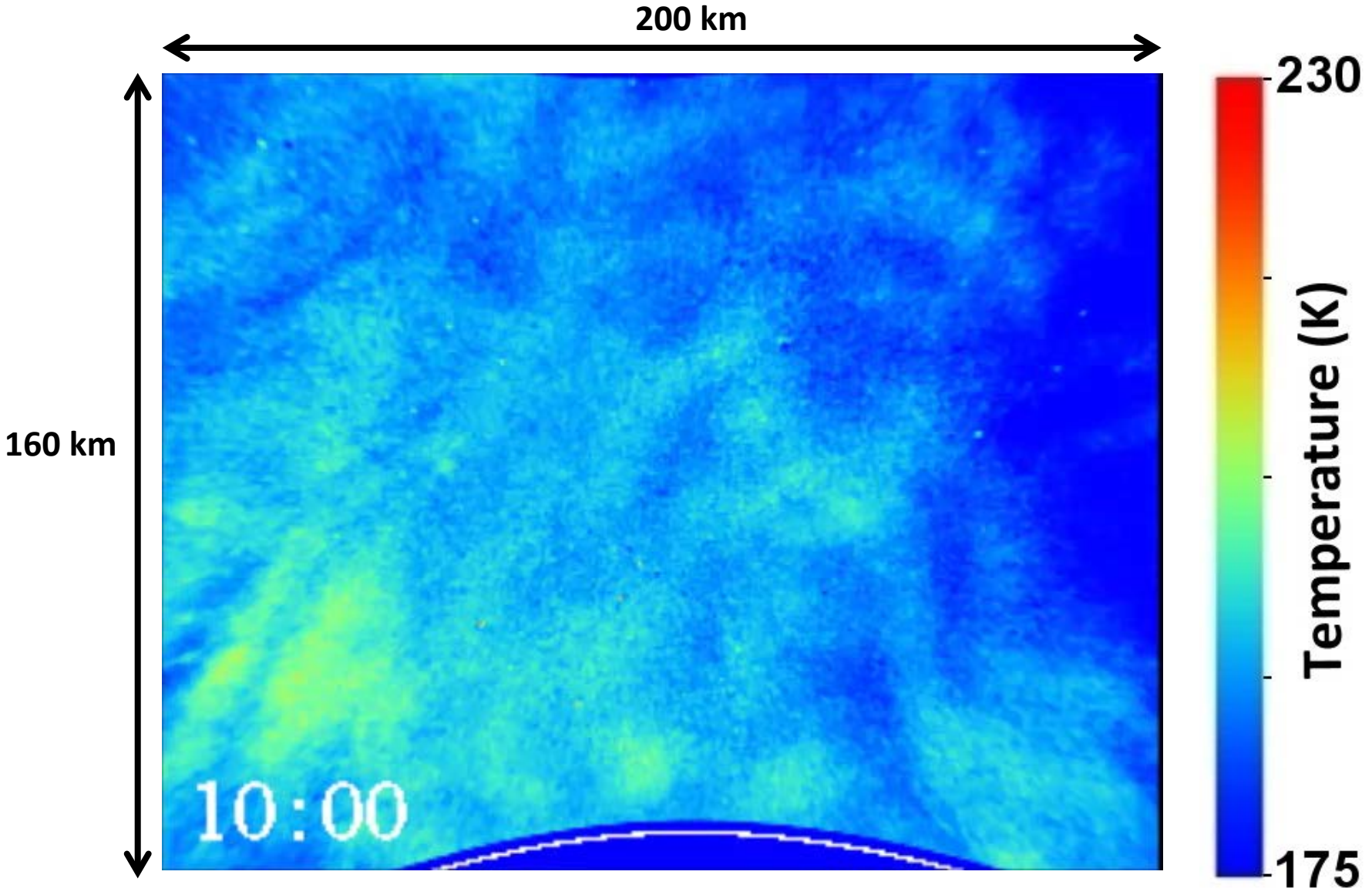
Continuous small-scale waves interrupted by MW outburst



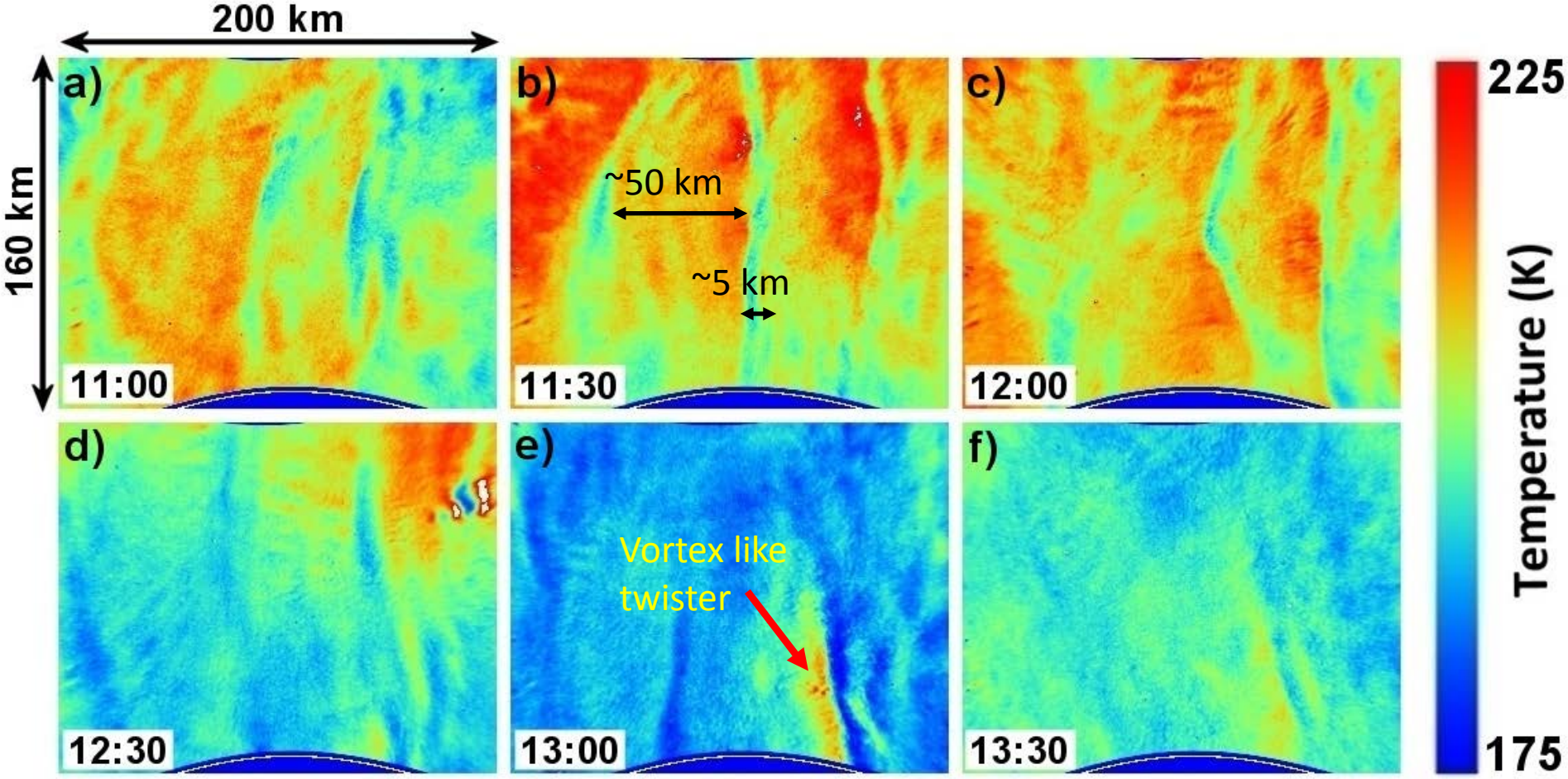
(MW Event ~10:30-13:30 UT)

OH Temperature "Mountain Waves" Movie

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

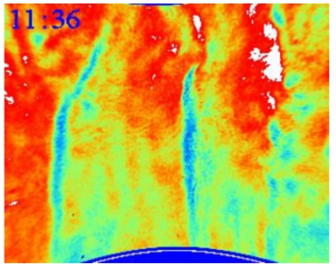


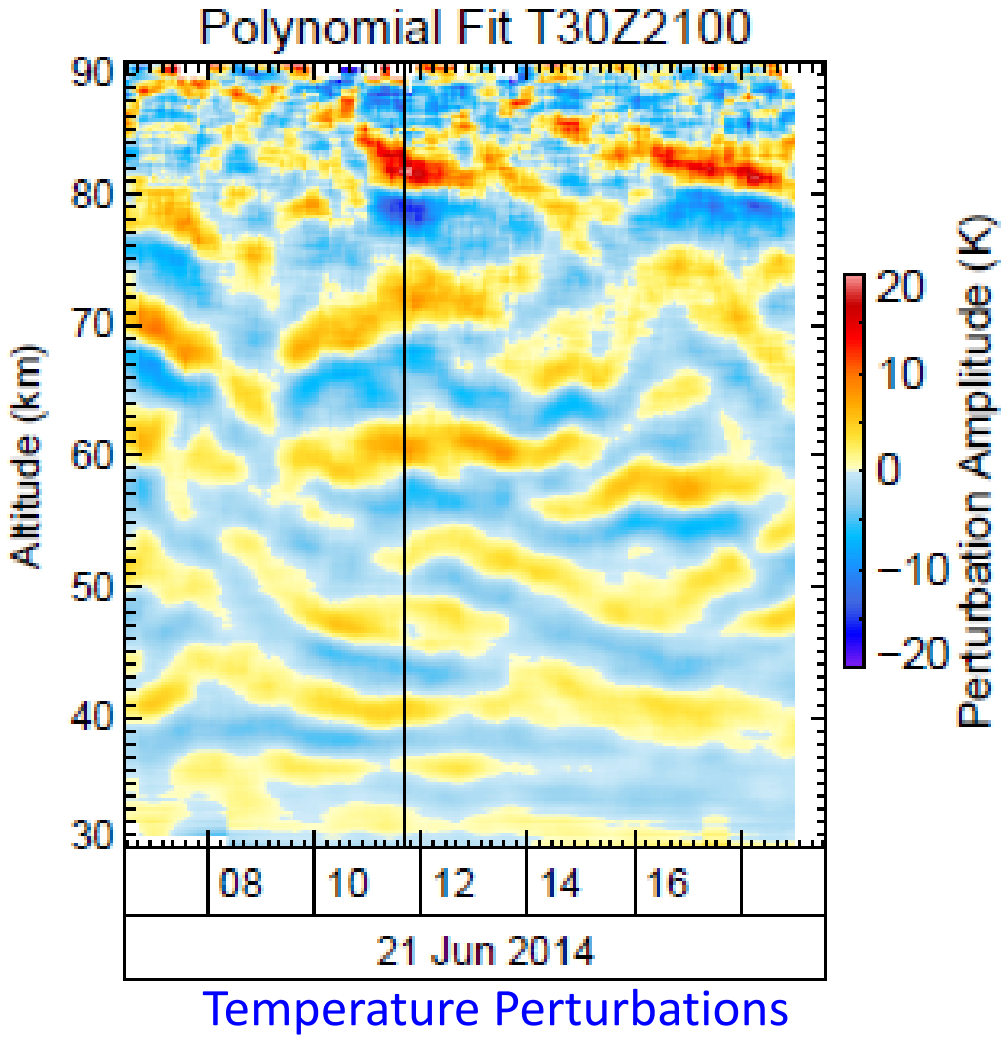
Snap-Shot Summary of MW Growth and Breaking Event (~2.5 hrs)



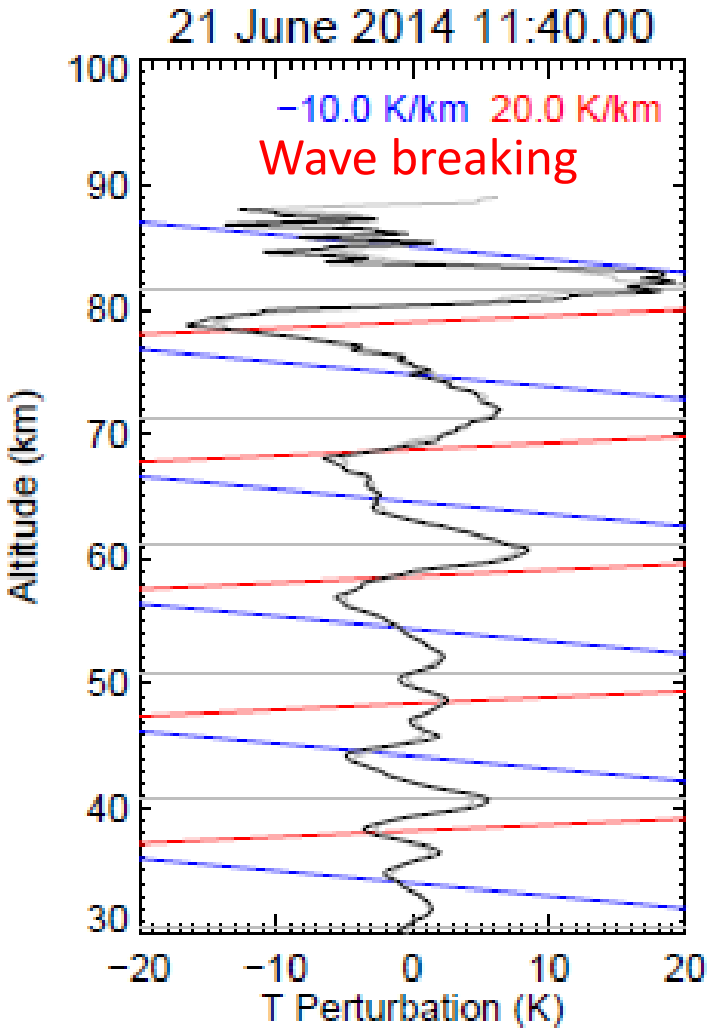
OH Temperature data, 21-22 June, 2014

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





Temperature Perturbations

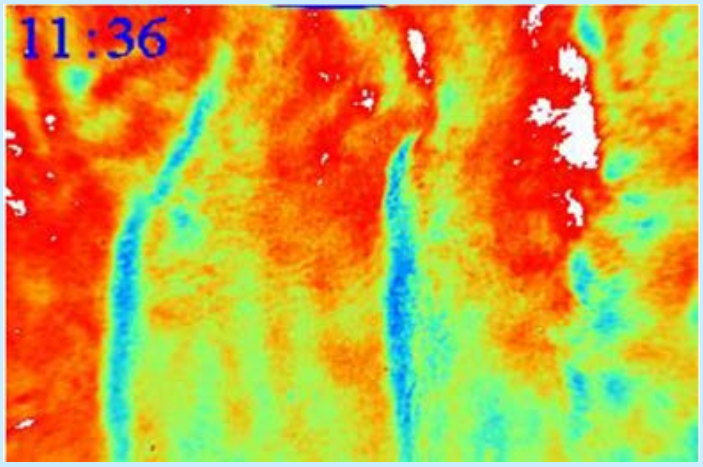


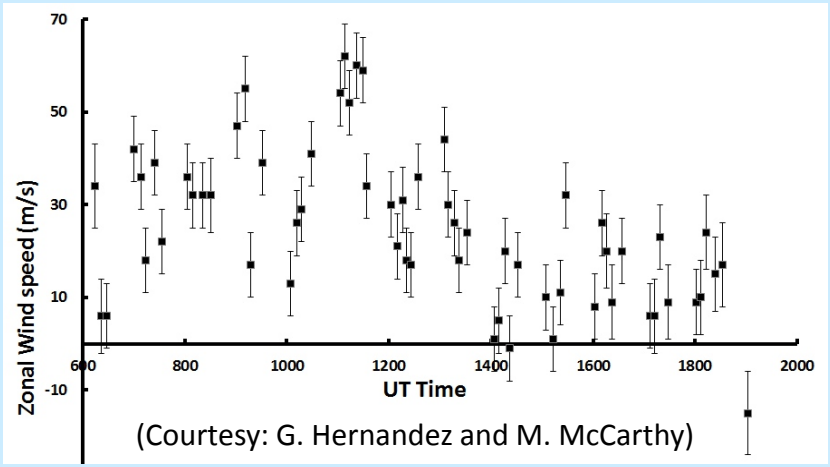
Large amplitude ~15K, breaking MW event, ~10:30-13:30 UT

Momentum Flux

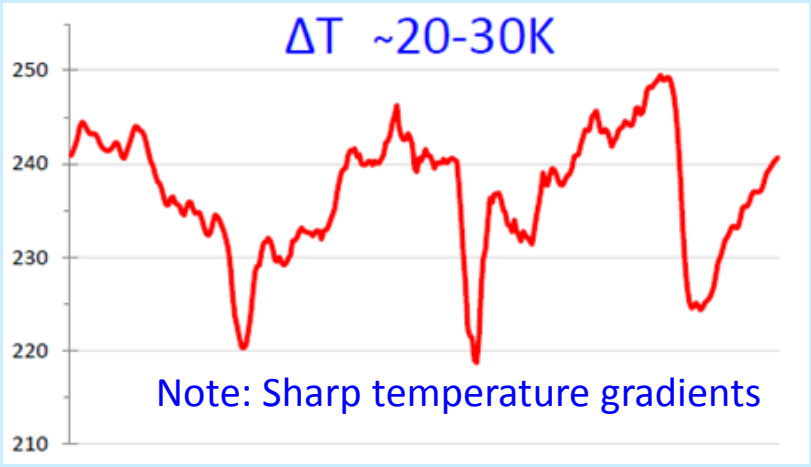
$$< u_h'w' >= \frac{g^2\omega_i}{2N^3}\sqrt{1-\frac{\omega_i^2}{N^2}}\left(\frac{< T' >}{T_0}\right)^2\frac{1}{C^2}$$

(Fritts et. al, 2014)





(Courtesy: G. Hernandez and M. McCarthy)



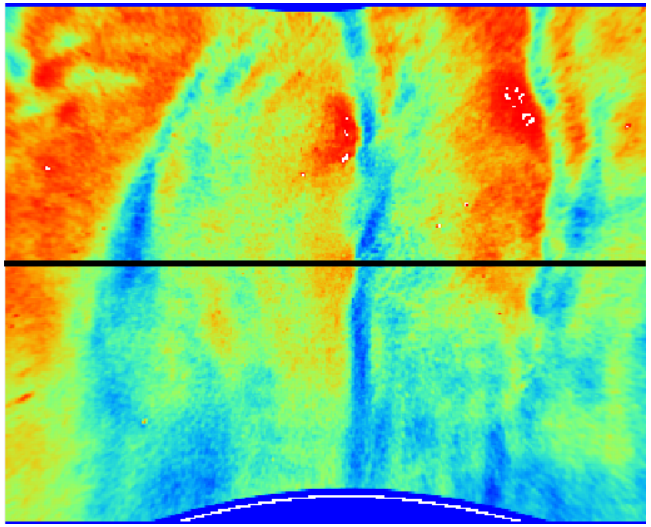
- Wind speed ~50m/s
- λ_x~55km
- Direction ~95°

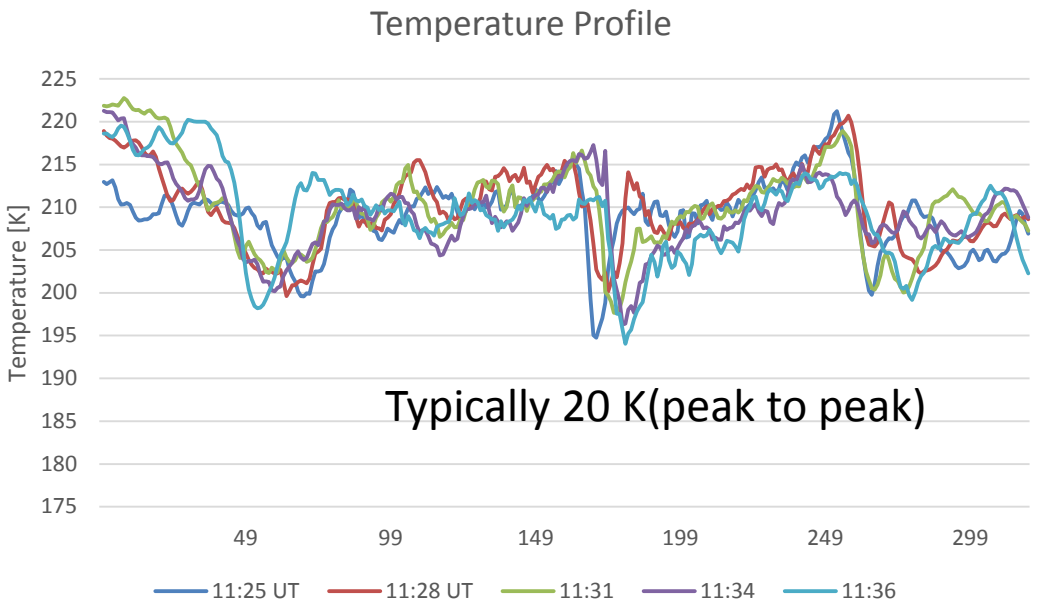
- Horiz. phase speed ~0 m/s
- $\Delta T/T$ ~3-7%
- λ_z ~17km

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

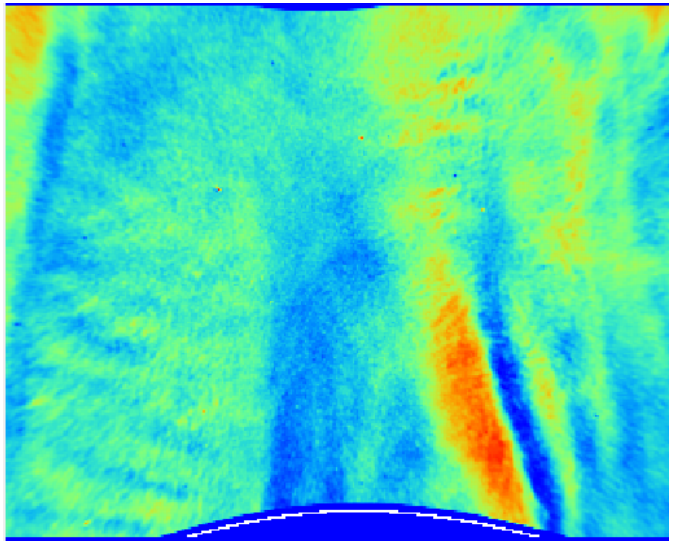
New Temperature Scans

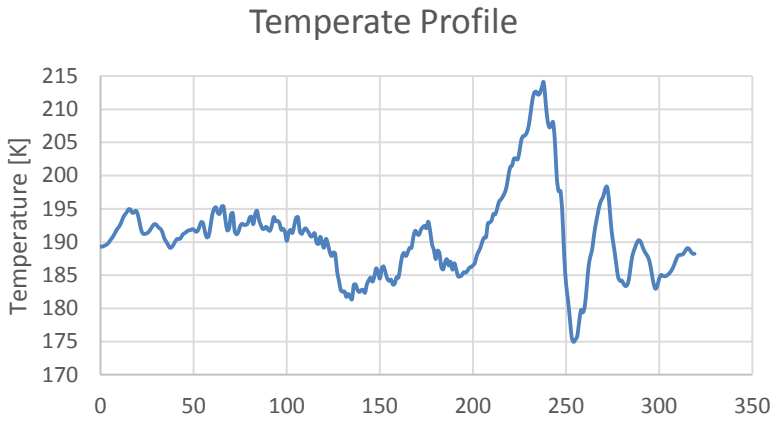
11.31 UT, June 21-22





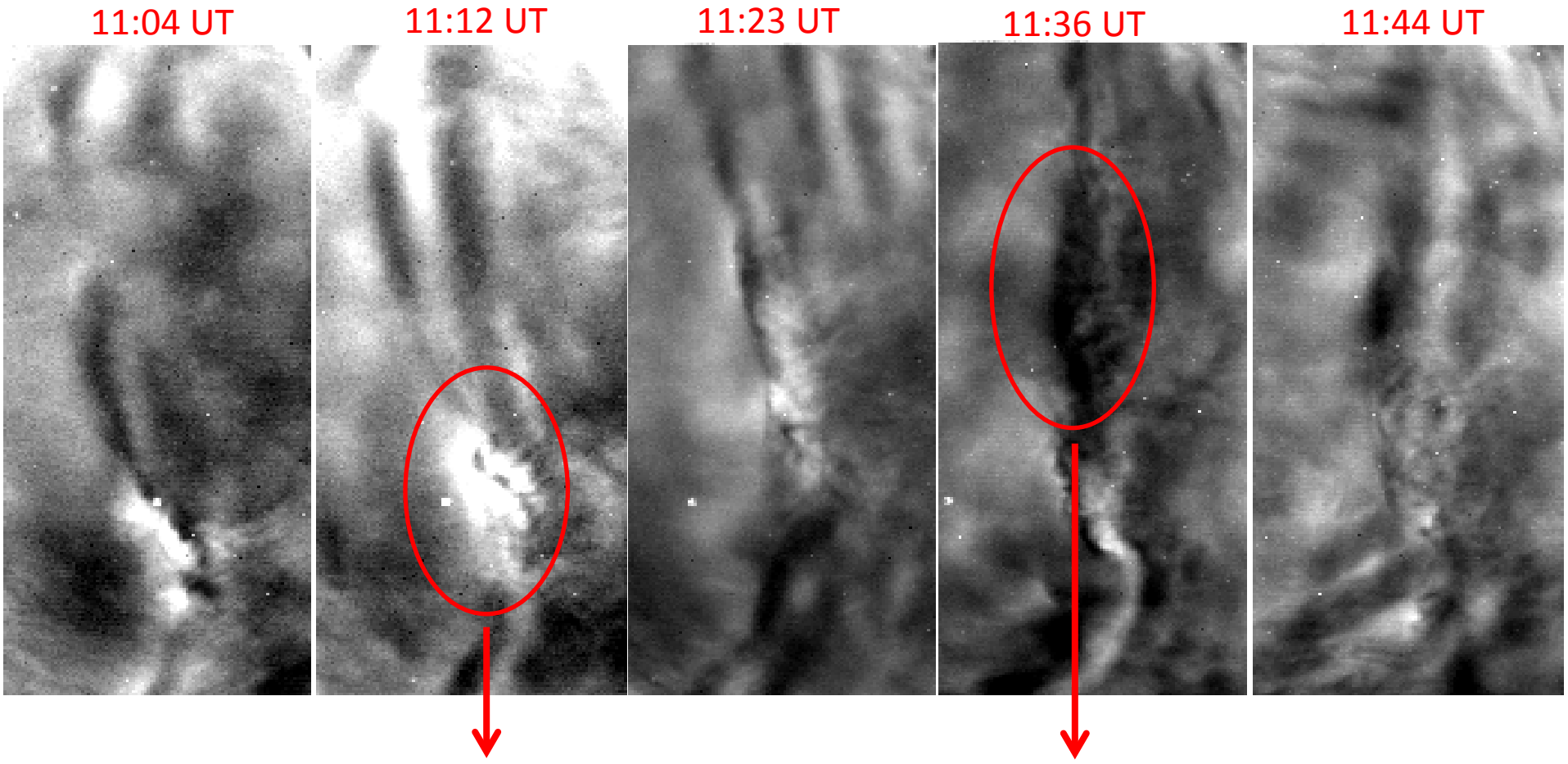
12:49 UT June 21-22





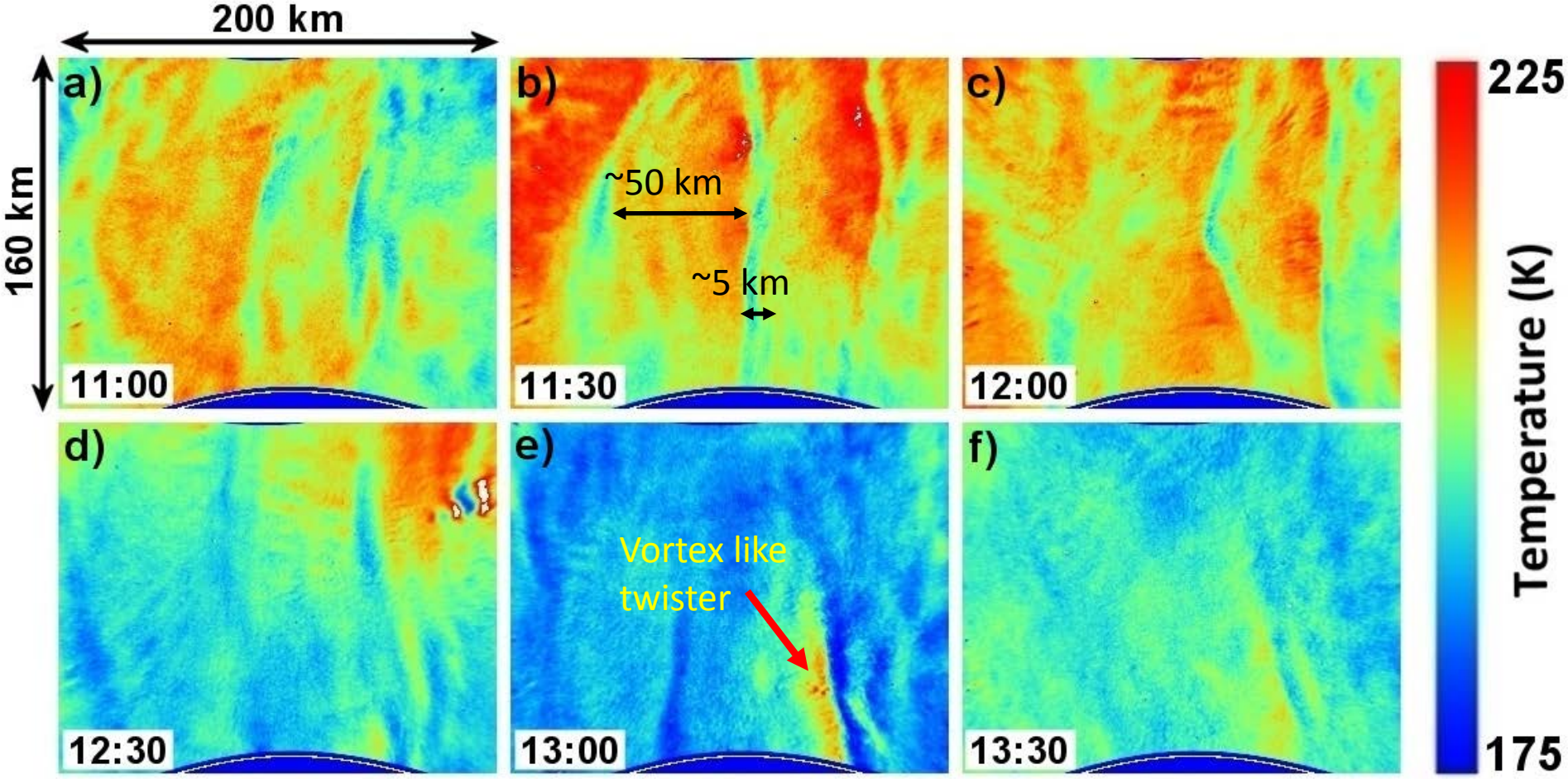
Maximum ~40K (peak to peak)

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



Basic characteristics of an MW breaking event-are they different to other GW?

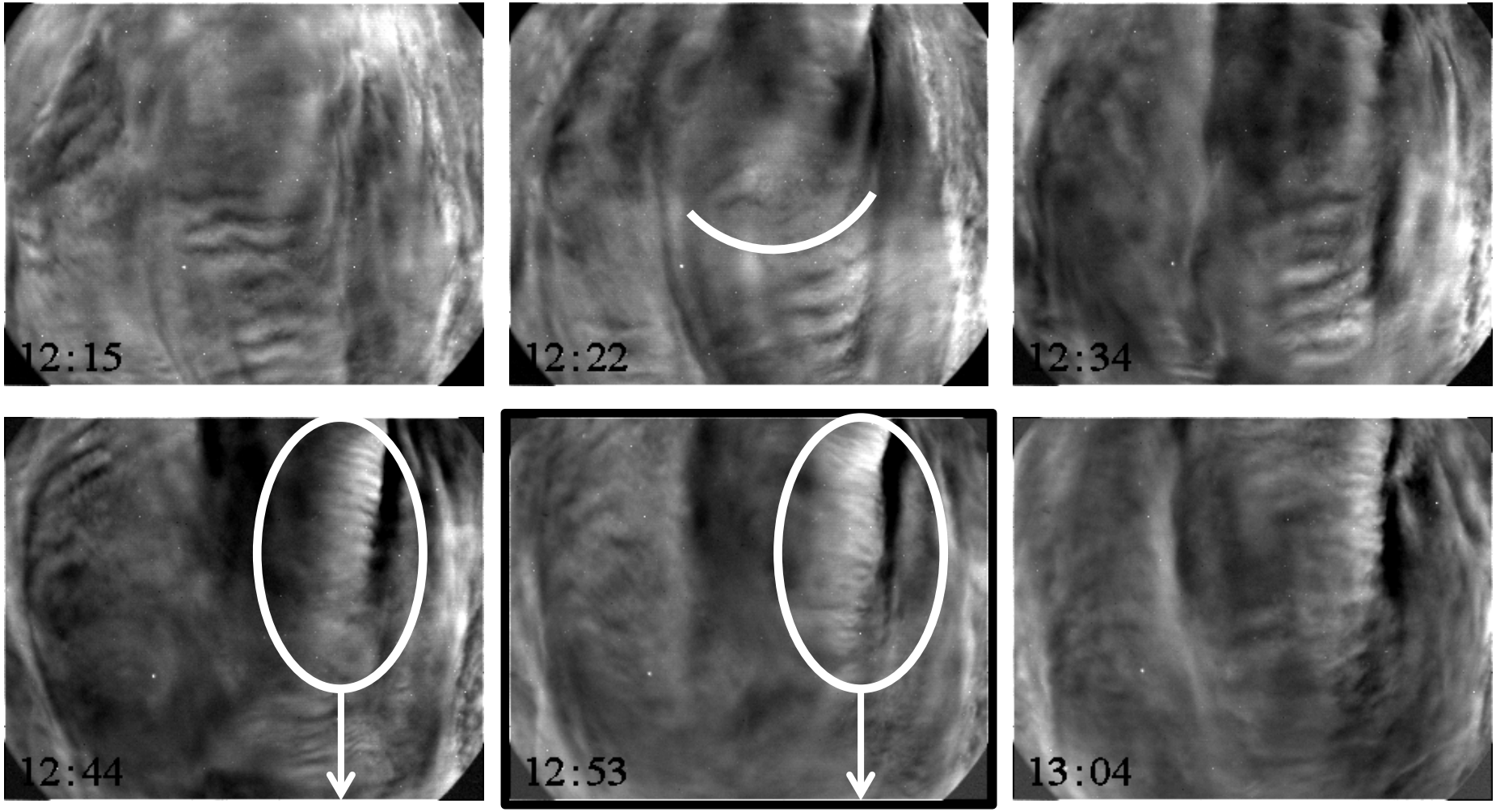
Snap-Shot Summary of MW Growth and Breaking Event (~2.5 hrs)



OH Temperature data, 21-22 June, 2014

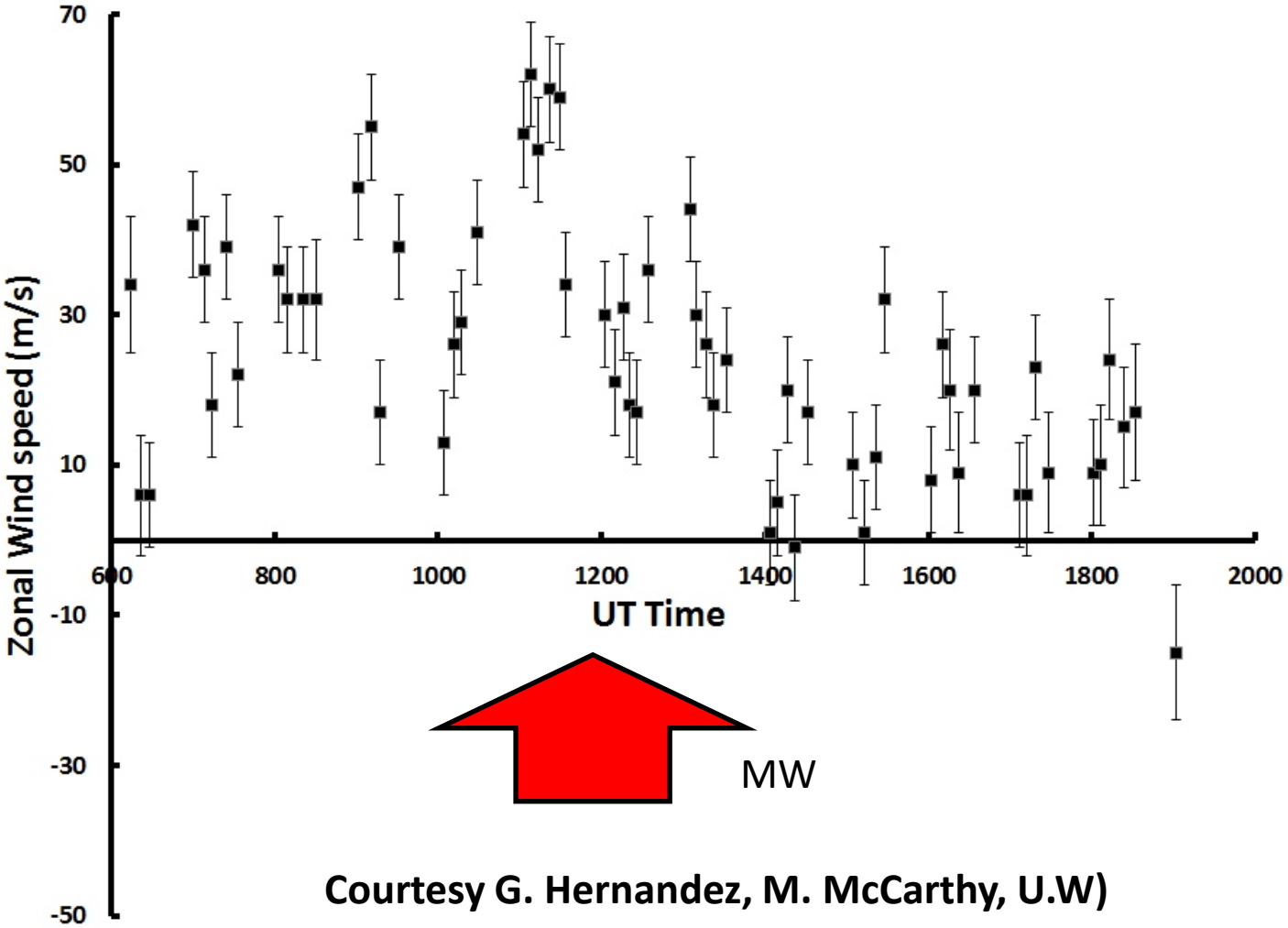
AMTM Development of Fine-Scale Waves and Twisting

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



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

FPI Mesospheric Winds, June 21-22
Mt. John Observatory (MJO)



Courtesy G. Hernandez, M. McCarthy, U.W)

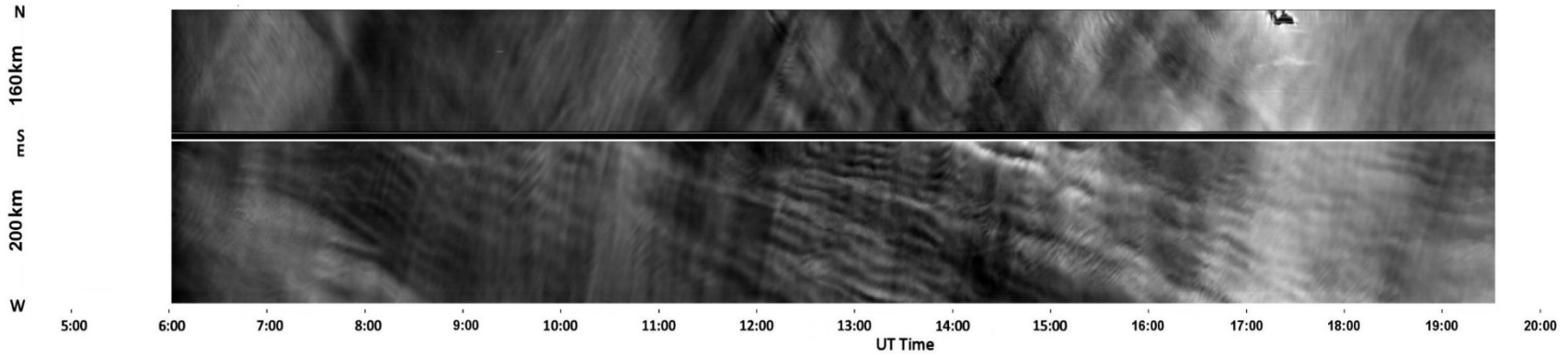
Summary of 21/22 June Event

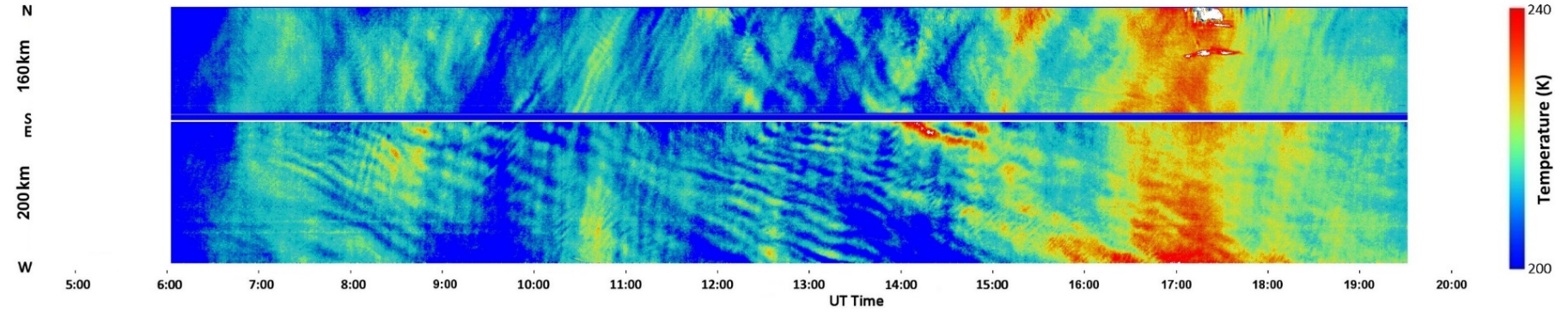
- This was a very dynamic night. The addition of the lidar results makes the MW interpretation clear. Lots of wave breaking going on all the time.

- 2 papers identified:
- Summary of the event capturing its scales and dynamics. Wave temperature amplitudes and momentum flux estimates.
- Modelling the instability features
- Possible 3rd paper on the larger scale dynamic leading up to this event (using Airs data)

- Qu: concerning the almost constant MW activity during the campaign and its relation to forcing?

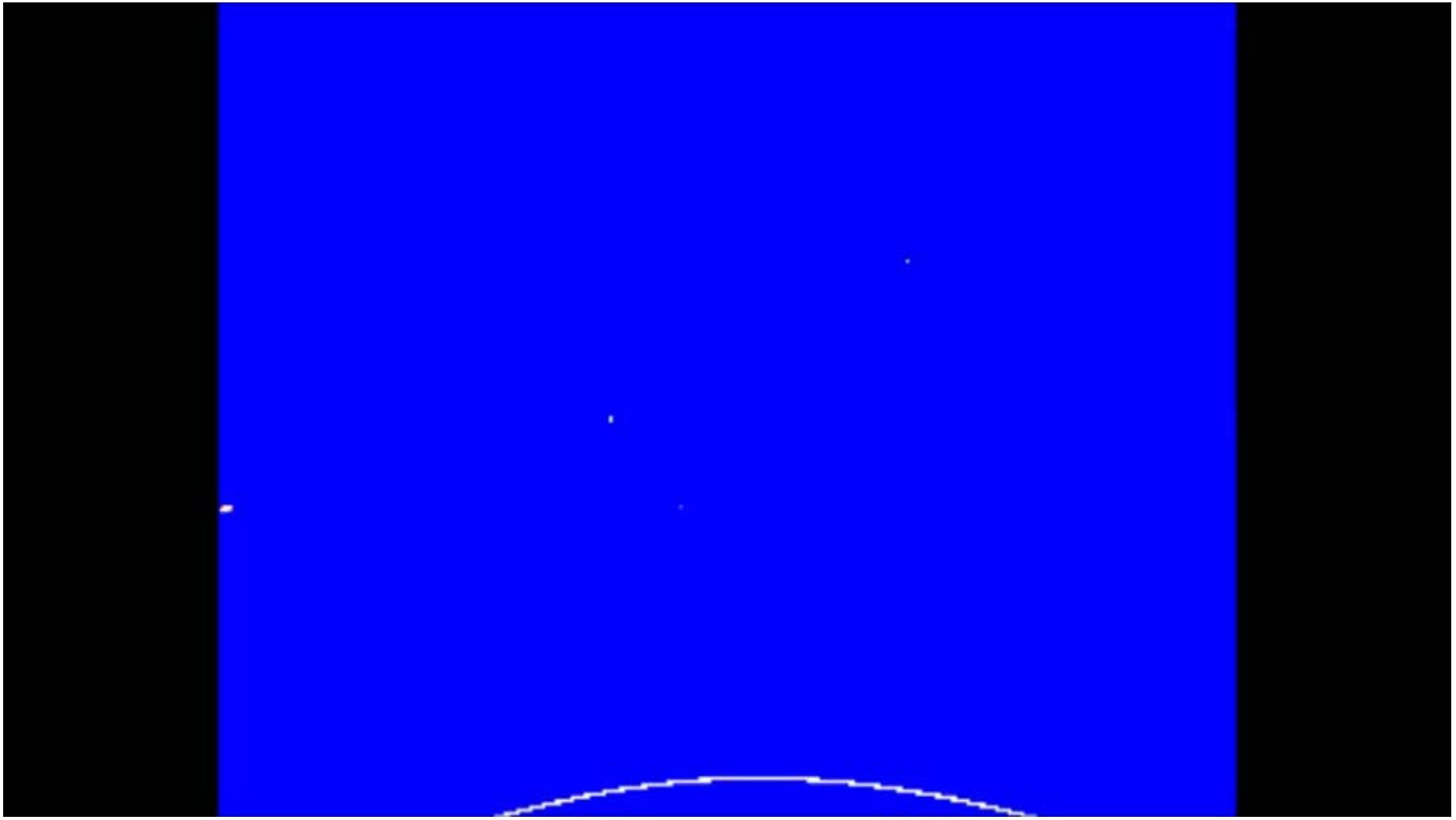
17 July Keogram





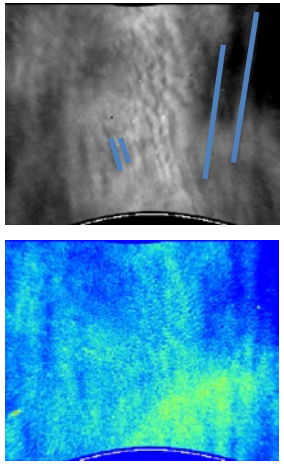
Constant fine scale MW activity all night

July 17-18 Movie
(Duration ~12 hrs)

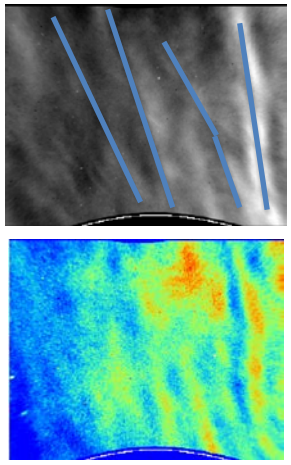


Snap-Shots of MW Activity

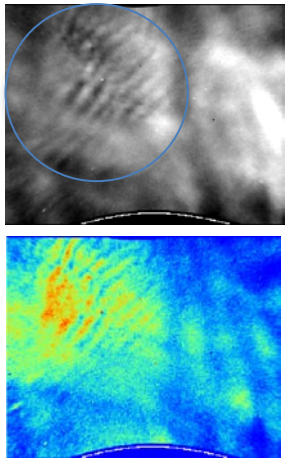
06:56



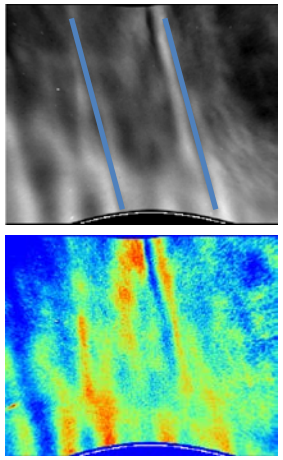
09:03



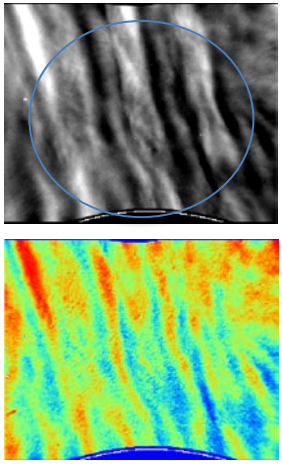
10:53



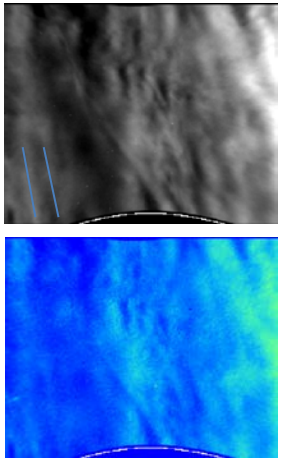
12:08



12:53

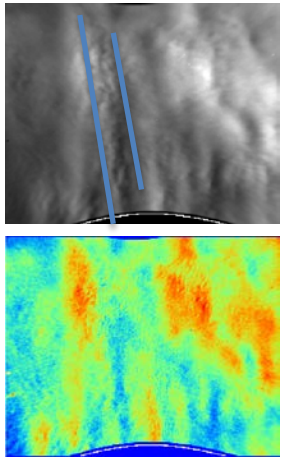


14:13

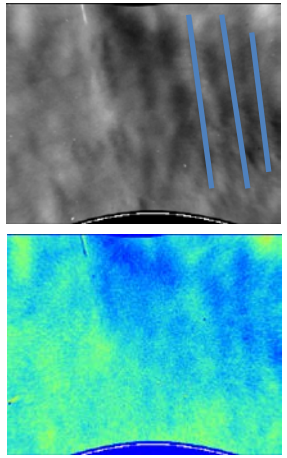


July 17-18

15:01

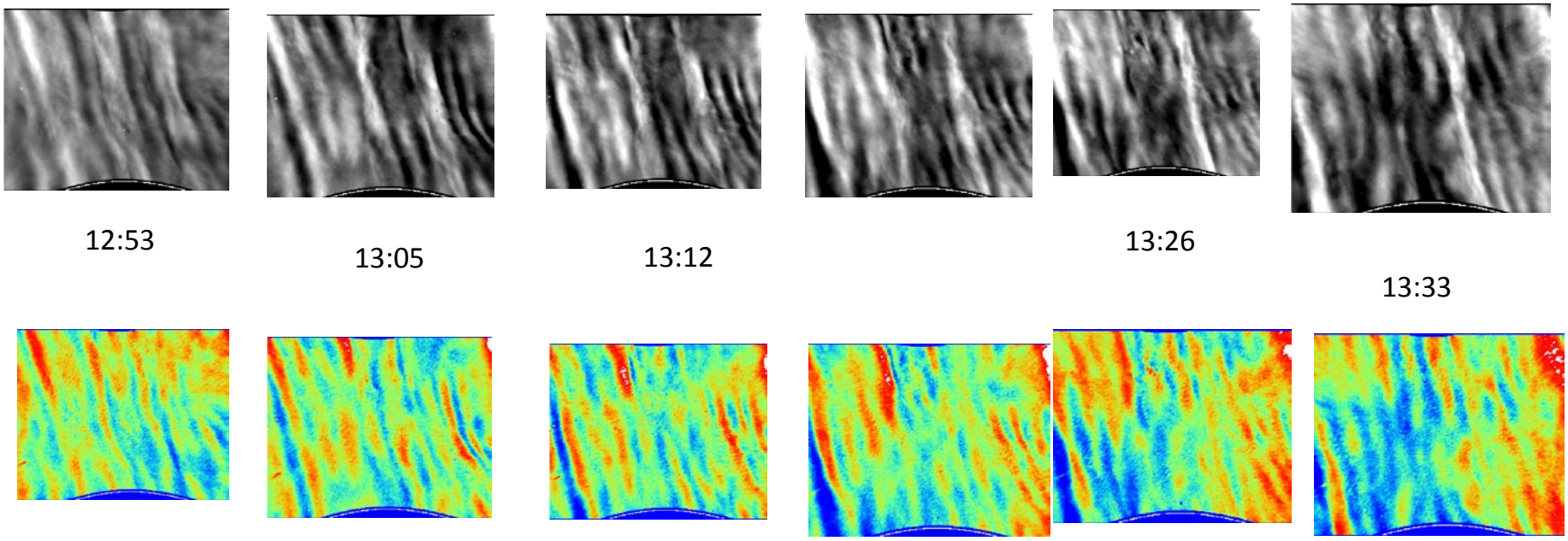


18:47



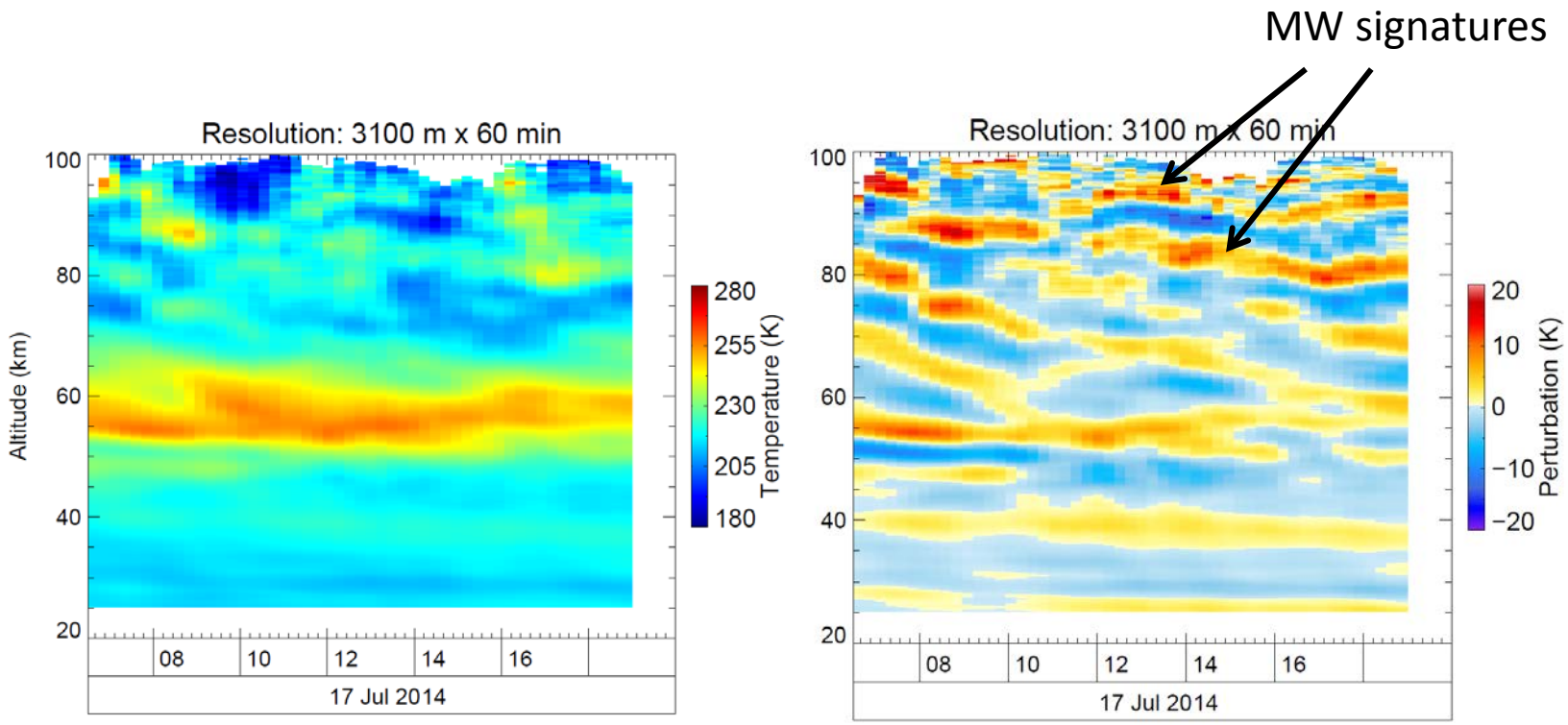
Continuous Narrow-Scale (~15km) MW Activity

July 17-18 from 12:53-13:33 UT

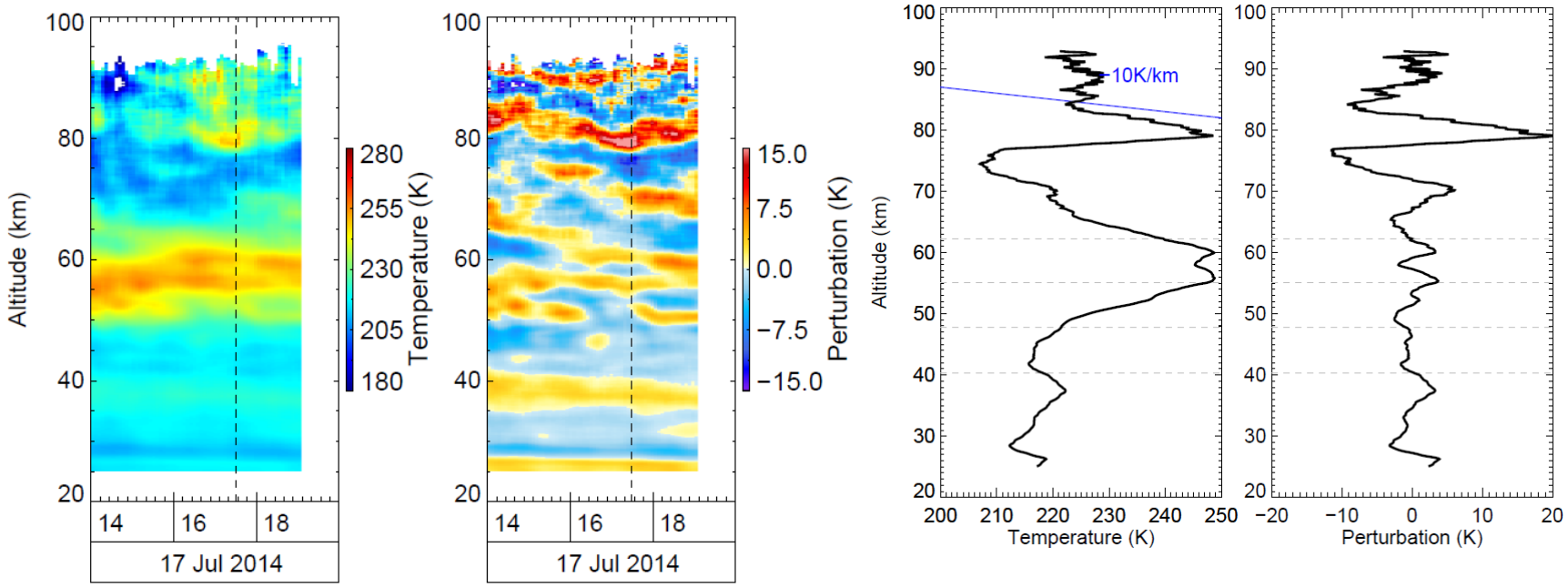


Time	Wavelength [km]	ΔT [K]
06:56	6, 19	~15
09:03	33 ,35	~20
10:53	8-12	~15
12:08	71.9	~25
12:53	15-25	~20
14:13	17.7	~30
15:01	29.2	~30
18:47	26.3,21.4	~20

Lidar at Lauder, 17 July 2014

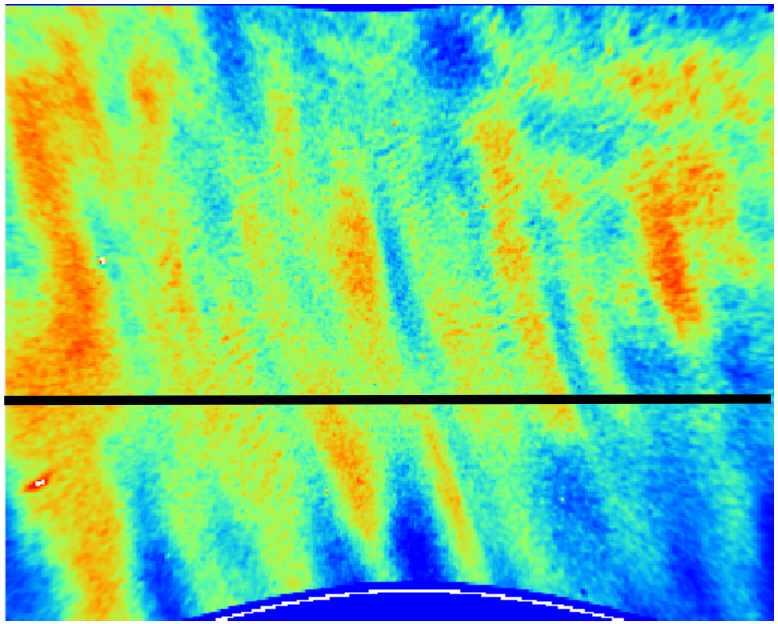


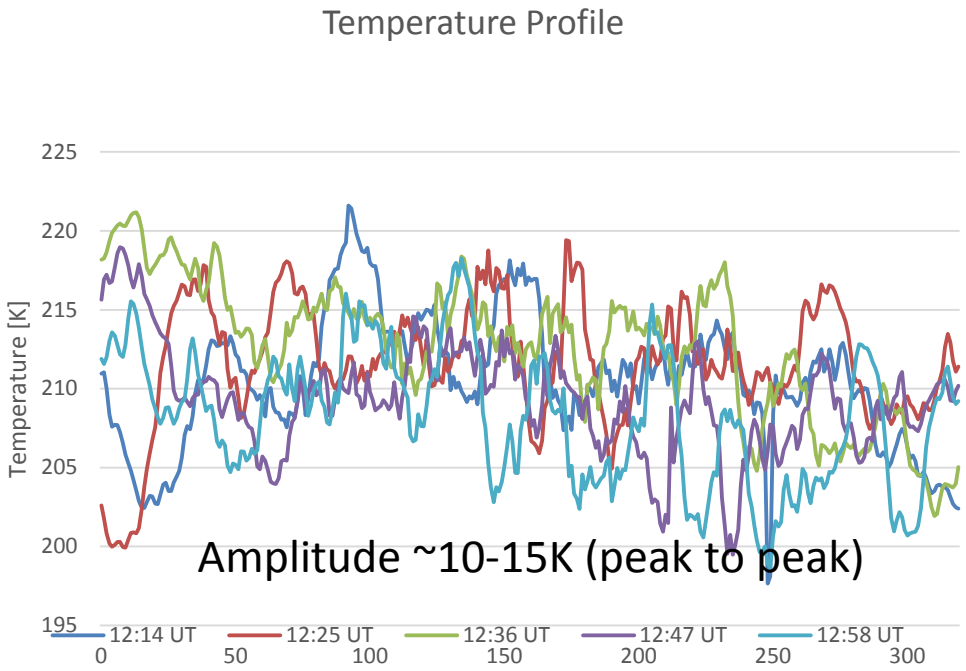
Lidar at Lauder, 17 July 2014



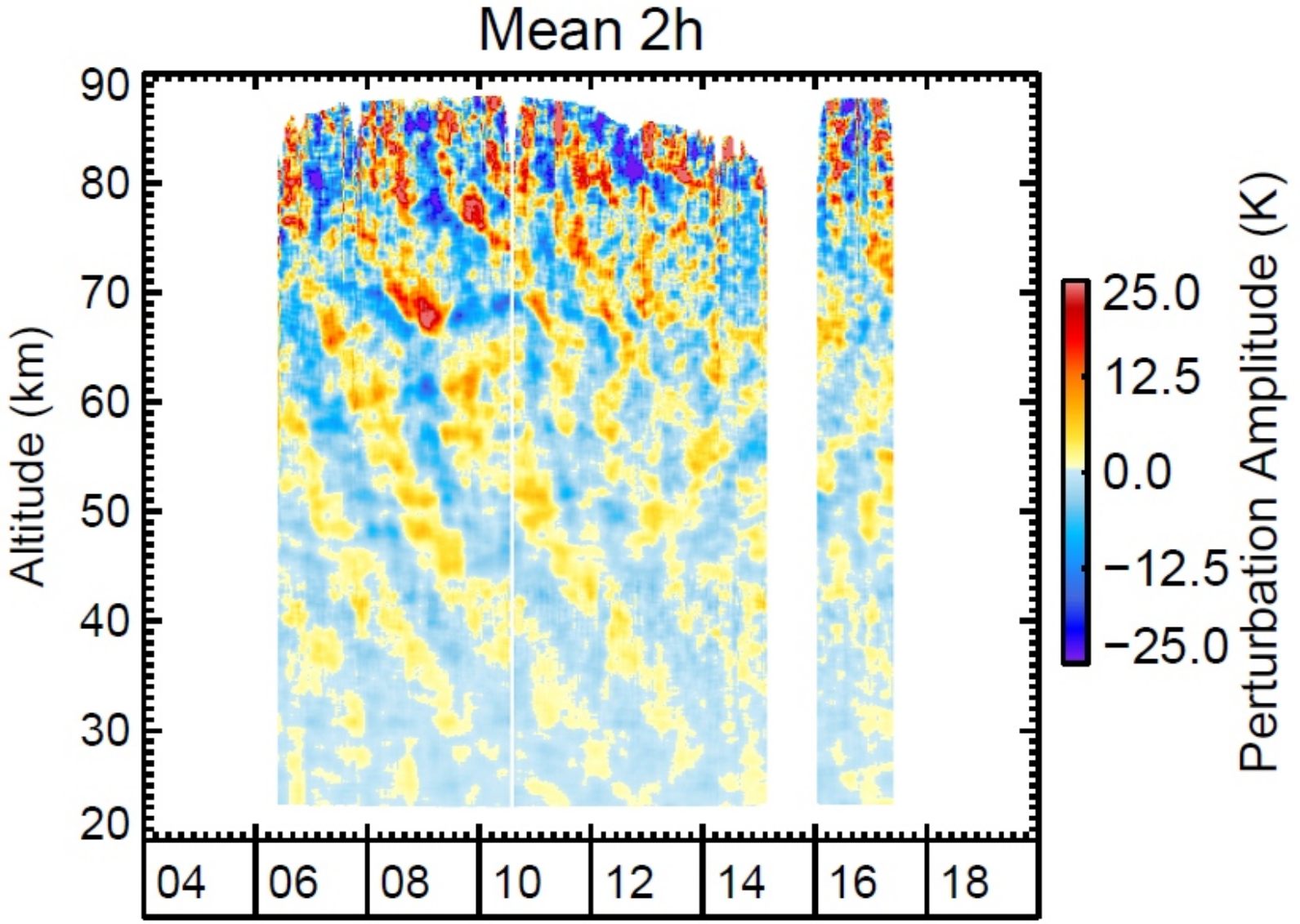
July 17, Temperature Scans

12:36





Rayleigh Lidar, July 07-08 (RF 18)



Summary (to date..)

- 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.

- So much wave breaking should have had a **significant effect on the state of the MLT region**. How to assess this?