Investigating the 21-22 June Mountain Wave Breaking Event

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DEEPWAVE Science Team Meeting, Naval Postgraduate School, Monterey, CA, December, 2015
449 MHz BL radar (NCAR)
radio sondes (NCAR, DLR)
MLT airglow imagers (BU)
MLT FPI (UW)
MLT AMTM (USU)
Na Rayleigh lidar (DLR)

Rayleigh lidar, meteor radar, and radiosondes at Kingston, Tasmania (AAD, ATRAD)

Hokitika
Haast
Mt. John
Lauder

Christchurch AC base
AMTM Installed at NIWA Lauder Observatory, 45°S, NZ, for Mission

AMTM:
- 180 x 200 km temperature and intensity maps of the OH layer (~87km), centered at the zenith, every ~30s
GV Advanced Mesospheric Temperature Mapper (AMTM)

- New High-resolution mesospheric gravity wave intensity and temperature mapping.
- IR imager (~1.55μm) OH (3,1) band, ~87 km.
- Medium format (80° x 60° FOV) fast (f/1) telecentric optics (120 km x 80 km FOV).
- Operates at very high 4 sec cadence, 15 sec for temperature map, precision ~2 K.

Temperature: ratio of $P_{1}(2)$ and $P_{1}(4)$ lines
Selected Ground Based Nights

- GB1*
  30/31 May  Propagating and MW

- GB2
  2/3 June  Excellent wave activity

- GB3
  18/19 June  MW and coincident RF 6

- GB4*
  21/22 June  Breaking MW and sharp temperature gradients

- 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 and RF 23 coincidence
Temperature Movie, Jun 21-22 (5hrs)
"Keogram" Technique to Study Broad Range of Wave Scales and Periods

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

Uses a sequence of temperature maps.
First AMTM Observations at Lauder, May 30-31

Propagating waves

Low velocity (MWs)
Breaking Mountain Waves, Jun 21-22
(No flight as forcing deemed to be insufficient)

Continuous small scale waves interrupted by MW outburst

(~10-13 UT)
P₁(2) Emission Evolution at 4 min Intervals (11:00-12:12 UT)
Development of instability Along Deep/Cold Troughs

(11:04-11:44 UT)

11:04 UT  11:12 UT  11:23 UT  11:36 UT  11:44 UT

Instability development  Cold trough development
Development of Fine-Scale Waves and Twisting (12:15-13:04UT)

Vortex-like fine scale waves
MW Persistence Phase
Secondary GW Generation

Region of overturning/intense GW breaking
AMTM Temperature and Intensity Structure
OH (3,1) Rotational Temperatures

200 km

160 km

11:00  11:30  12:00

12:30  13:00  13:30

Temperature (K)

175  225
OH (3,1) Band Intensity Showing Fine Scale Structuring (1 min intervals)
FPI Mesospheric Winds, June 21-22
Mt. John Observatory (MJO)

Zonal Wind speed (m/s)

UT Time

MW

Courtesy G. Hernandez, M, McCarthy, U.W)
June 21-22 – Momentum Flux Estimate

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

(Fritts et al., 2014)

\( \omega_i \), intrinsic frequency
\( N \), Brunt-Väisälä frequency (from Na lidar)
\( < T' > / T_0 \), temperature perturbation (from AMTM)

\( C^2 \), GW temperature variance reduction due to phase averaging for GW vertical wavelengths less than \(~\)twice the OH layer FWHM:

\[ C = \frac{< T' >}{T'(z_0)} = \exp \left( -3.56 \frac{Z_{\text{FWHM}}^2}{\lambda_z^2} \right) \]

\( dT \sim 10-15K \)
\( T \sim 208K \)
\( dT/T \sim 3-7\% \)

\[ < u'_h w' > = 60-300 \text{ m}^2/\text{s}^2 \]

- Wind speed \( \sim 50\text{m/s} \)
- \( \lambda_x \sim 55\text{km} \)
- Direction \( \sim 95^\circ \)
- Observed horizontal phase speed \( \sim 0 \text{ m/s} \)
- \( dT/T \sim 3-7\% \)
- \( -\lambda_z \sim 17\text{km} \)
June 21-22 – COAMPS Winds at 850mb
June 21-22 – Cross-Track Model Forecasts

COAMPS vertical wind velocity

ECMWF vertical wind velocity
ECMWF Vertical Winds

ECMWF T1279/L137 operational analyses (6 h) and 1 hourly high-resolution IFS predictions $w/\text{ms}^{-1}$
ECMWF Vertical Winds & Strong MW Events

ECMWF T1279/L137 operational analyses (6 h) and 1 hourly high-resolution IFS predictions

$w/\text{ms}^{-1}$
Mountain Waves over Lauder

Summary: Lauder AMTM GW/MW Observations:

51 consecutive nights of observations from May 30\textsuperscript{th} to July 21\textsuperscript{th}:

- 15 clear nights
- 25 partially cloudy nights
- 11 nights totally cloudy

Amongst the 40 data nights:

- 28 nights with mountain (standing) waves (>100 hrs)
  (with durations from ~1-14 hrs).
- 12 nights with only propagating GWs
Keogram Examples of Extended Mountain Waves

June 26/27

June 27/28

July 14/15
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Dominant GWs Over Lauder – June 2014

MW=16/24 nights
Dominant GWs Over Lauder – July 2014

MW = 12/17 nights
Summary AMTM Ground Observations

- 53 nights of observations, 20 cloudy
- 33 nights with GW structure (partially cloudy)
- 19 nights with extended MW activity
  Total ~100 hrs of mountain wave activity

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End
June 21-22 – Secondary GW Generation
June 21-22 – Secondary GW Generation
Secondary GW Generation, July 07-08
Intermittent MW over ~10 hours, June 01-02

NS aligned low velocity waves appear as quasi-horizontal stripes in WE Keograms
Strong MW, June 02-03

MW, Low velocity waves

Tropospheric cloud
Intensity Movie, Jun 21-22 (~10hrs)

200 km

160 km

09:00
Secondary Wave Generation?
Jun 21-22

15:00

200 km

160 km
Rayleigh Lidar, July 07-08 (RF 18)
June 21-22 – Cross-Track Model Forecasts

COAMPS vertical wind velocity

ECMWF vertical wind velocity
Temperature Movie - May 30-31
First Night!
Summary (to date)

- T-Mapper instrument suite worked very well. Enabled detailed measurements of the characteristics and dynamics of GW from the GV (lateral spatial coverage up to ~1000 km).
- Vast amount of data acquired! Currently in data reduction and geographic mapping phase....
- Coordinated measurements at Lauder indicate Mountain Wave activity on multiple nights...not always during strong forcing!
- Dominique to show data “nuggets”......
Used to make slices
spare