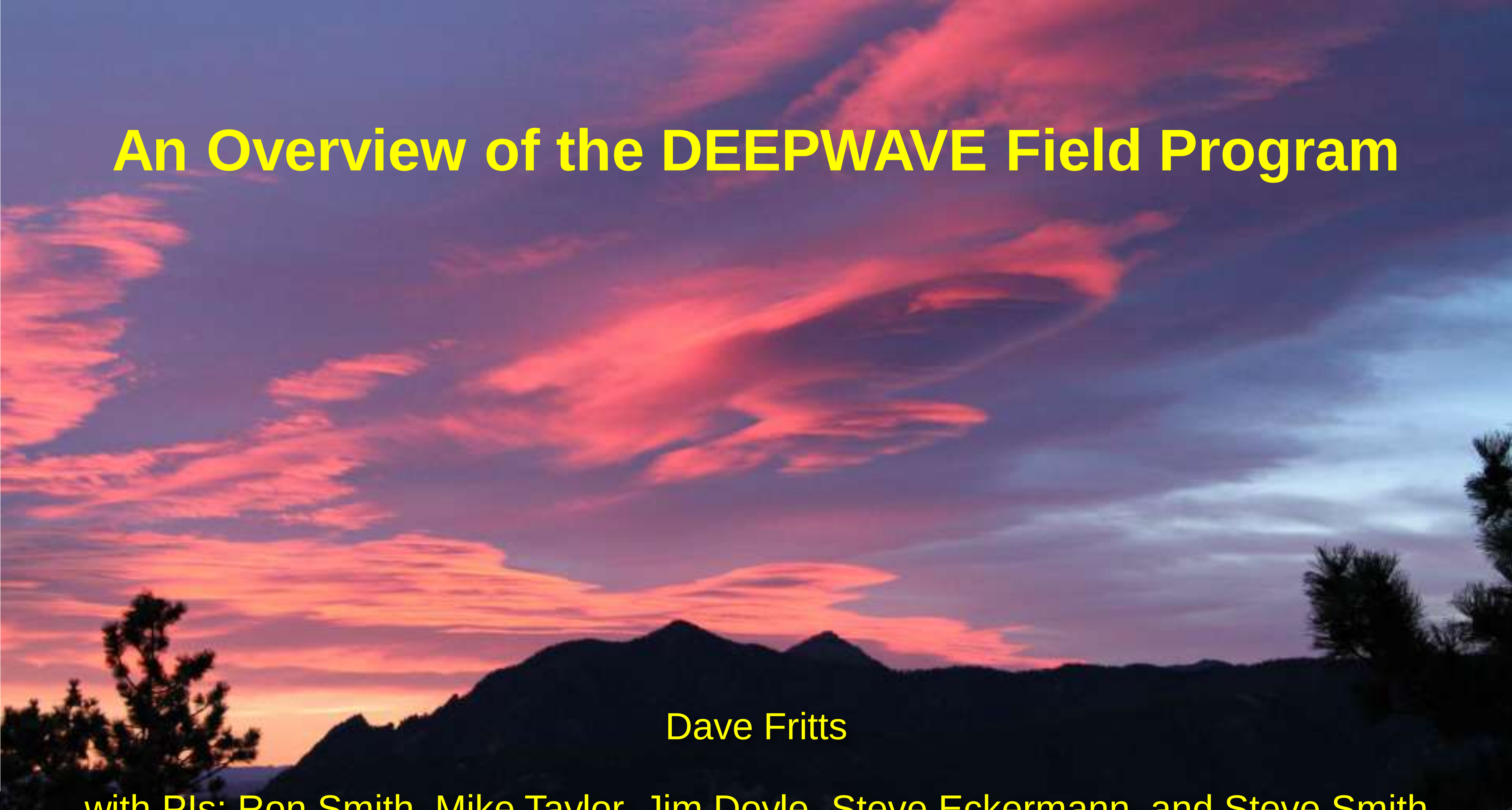


An Overview of the DEEPWAVE Field Program

Dave Fritts

with PIs: Ron Smith, Mike Taylor, Jim Doyle, Steve Eckermann, and Steve Smith

Co-Is:

Biff Williams, Dominique Pautet, Markus Rapp, Andreas Dörnbrack, Bernd Kaifler, Johannes Wagner, Katrina Bossert, Damian Murphy, Iain Reid, and Andrew Klekociuk

and many other participants at NCAR, NRL, Yale, USU, DLR, and elsewhere

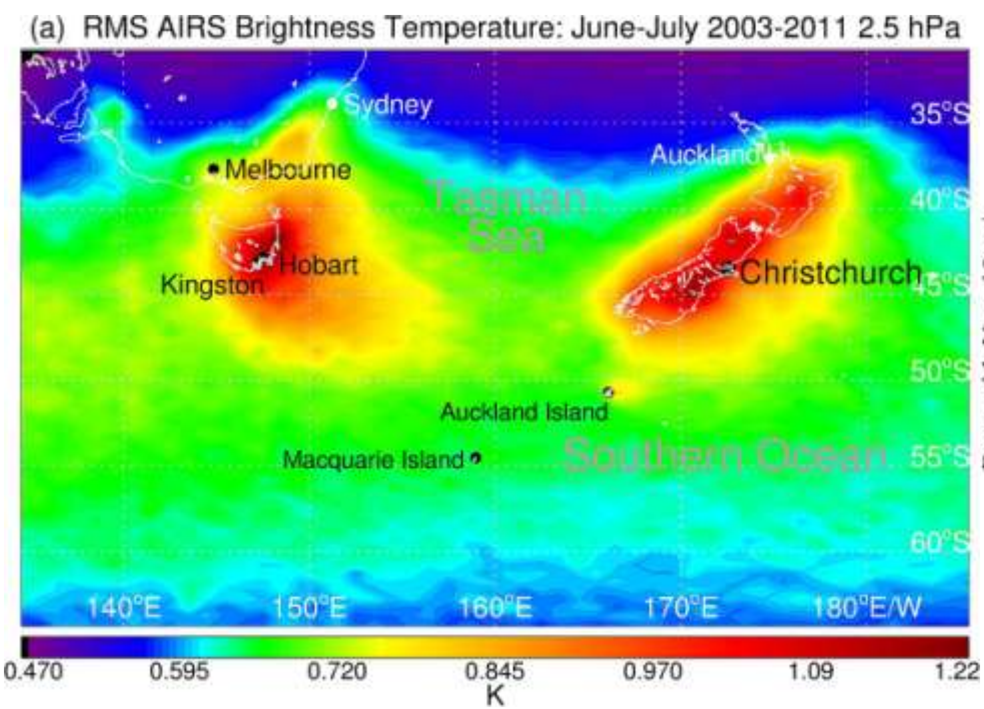
DEEPWAVE "Region of Airborne Operations" (RAO) is the 2nd largest GW hotspot in the S. Hemisphere

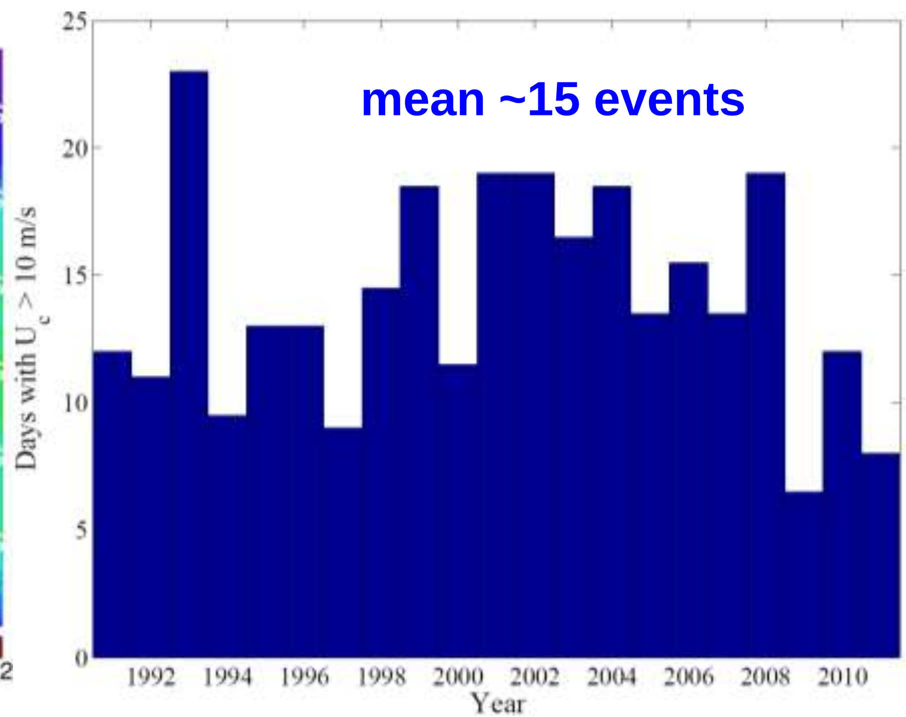
major GW sources include:

- topography (NZ, Tasmania, islands)
- circumpolar jet (Southern Ocean)
- frontal systems and convection

Frequency of 700 hPa winds >10 m s^{-1} at Invercargill, New Zealand

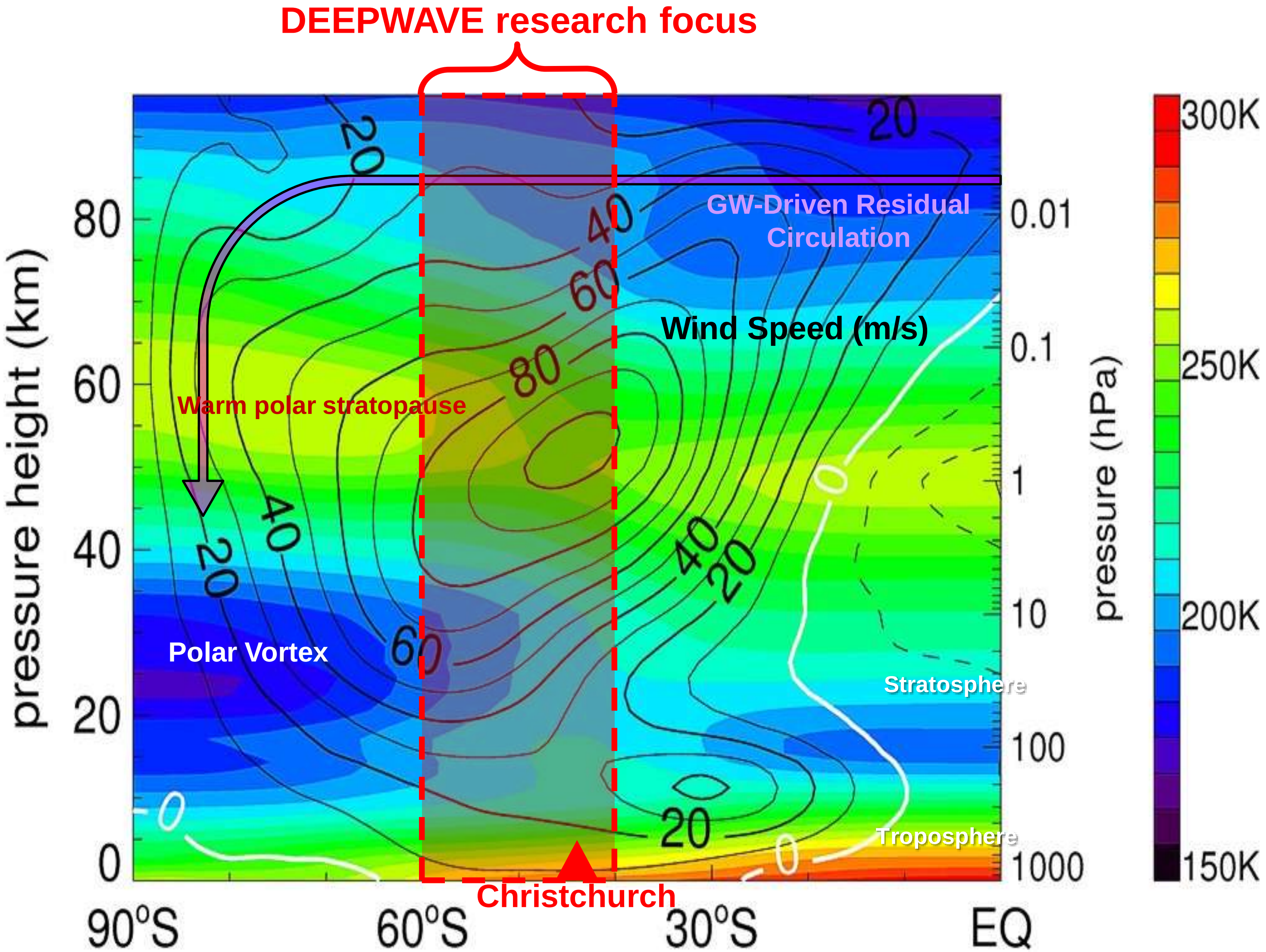
(July 1991-2011)





Austral Winter provides a stronger zonal jet and strong propagation channel enabling MWs to penetrate to very high altitudes

- *an ideal natural laboratory*



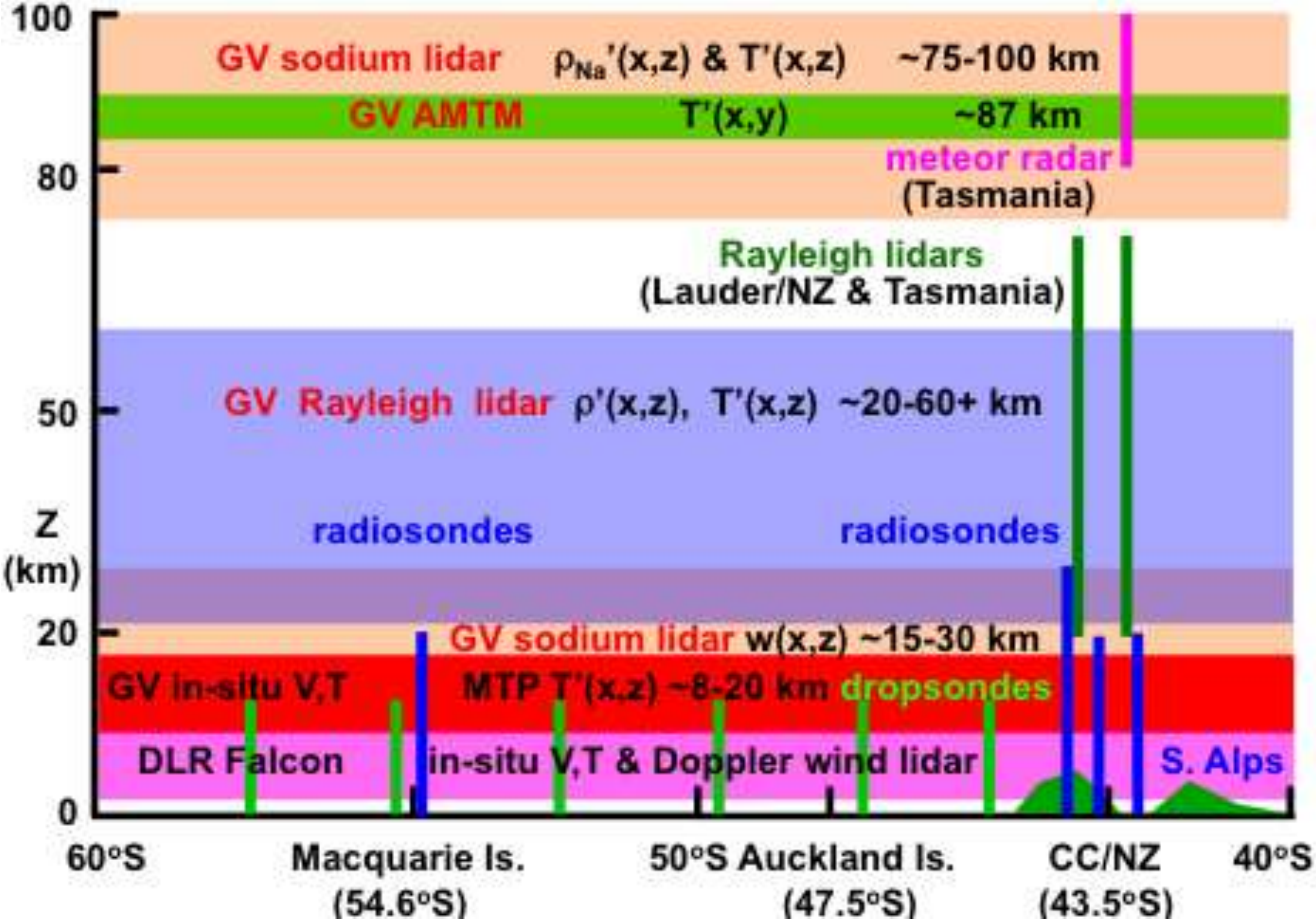
DEEPWAVE Approach:

- Perform measurements in a region that contains the major GW sources
- Expand GV measurement capabilities to address altitudes from ~0-100 km
- Bring additional U.S. and int'l. resources to enhance the research benefits
- Include extensive forecasting and modeling activities for better flight targeting, improved understanding, and GW parameterization guidance

NSF/NCAR Gulfstream V (GV) with new lidars and an AMTM

DLR Falcon with Doppler lidar

DEEPWAVE measurement capabilities



GV sodium and UV lidars

Na lidar: ~0.2 W beam, 9.8 W

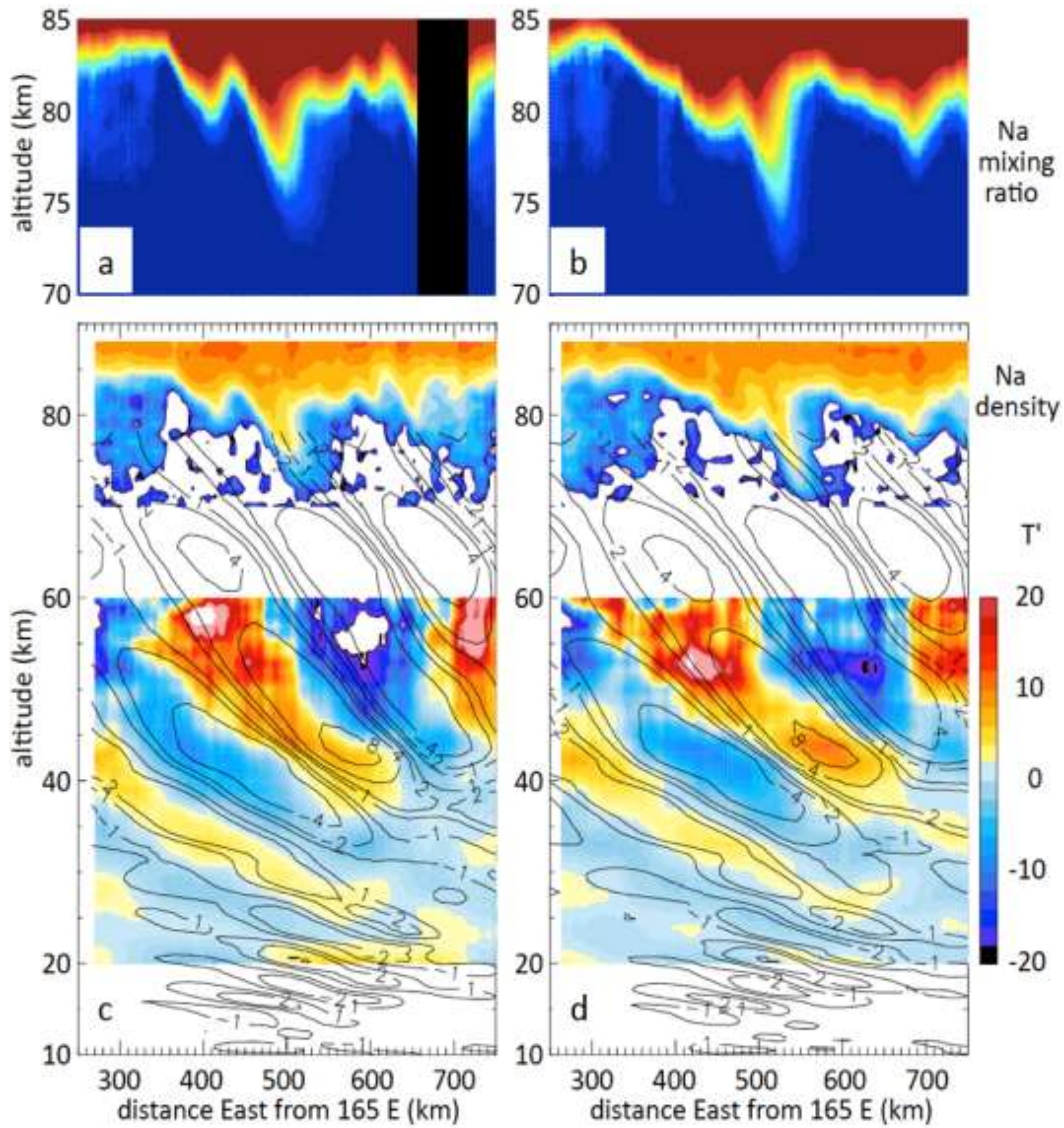
– $\rho_{Na}(z)$ and T(z) ~75-105 km

UV lidar: ~5 W pulsed

– densities & temperatures ~20-60 km

Research Flight 22 (13 July 2014)

– weak MW forcing, but very large MWs, 2ndary waves extending to >100 km (Bossert et al. poster)



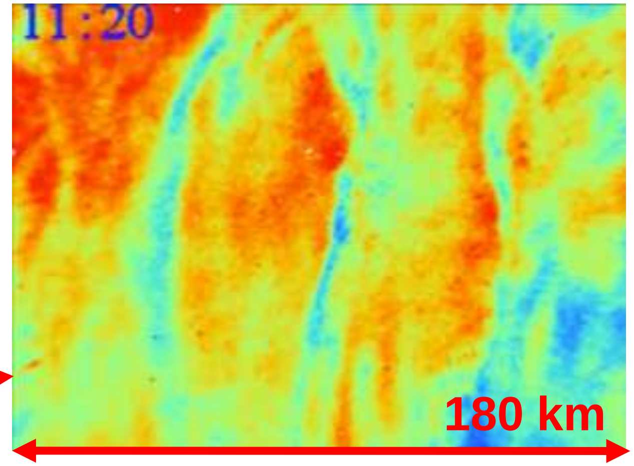
USU GW Imaging

Mapping MLT GWs in OH (~87 km) intensity and temperature

GV: AMTM and 2 side viewing GW imagers for large spatial coverage (~900 km cross track)

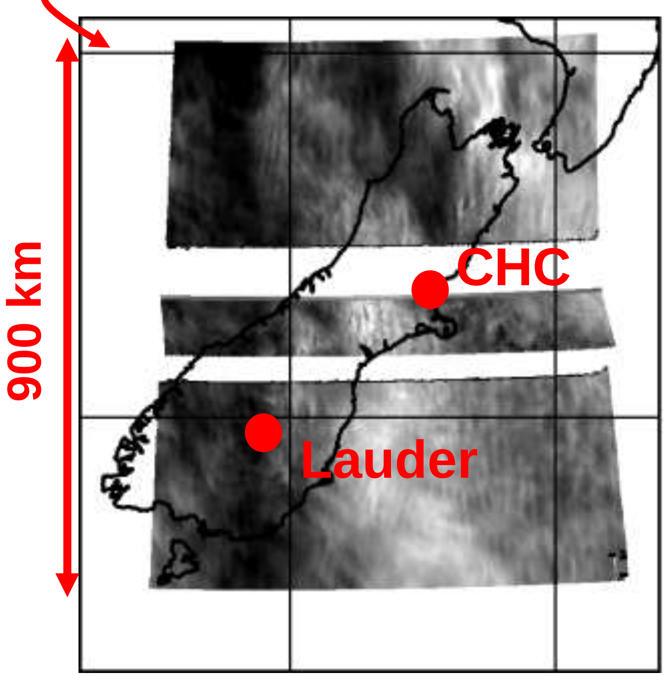
Lauder: second AMTM with 33 clear nights of GW & MW data

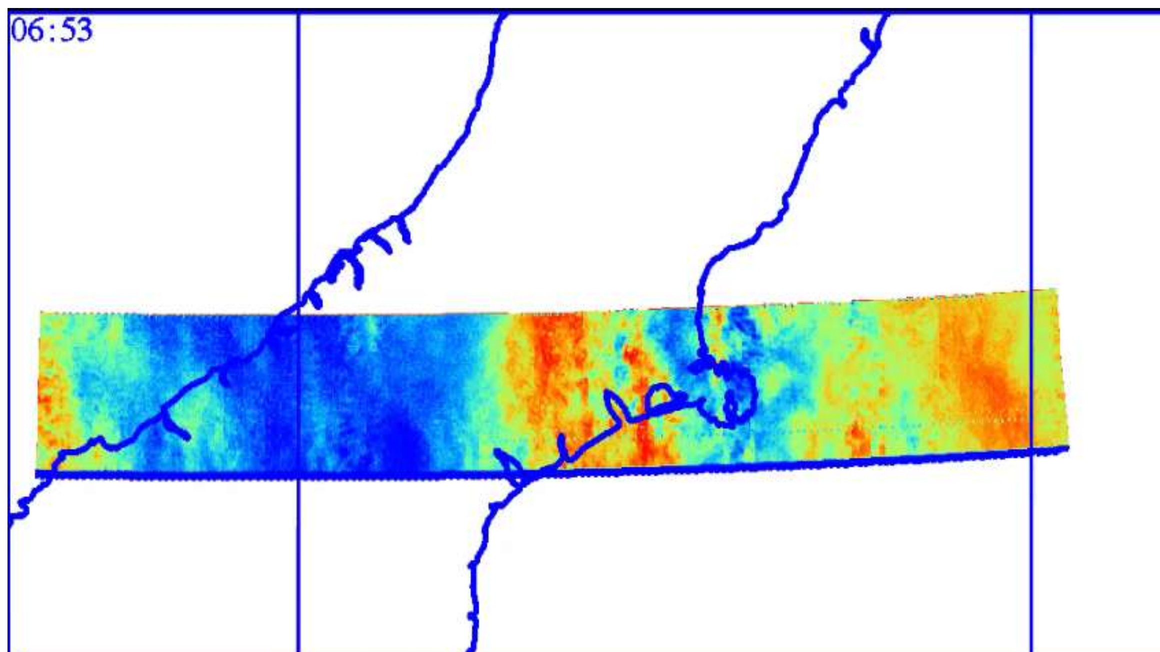
21 June @ Lauder



AMTM instrument suite

RF22 – 13 July 2014 with weak orographic forcing

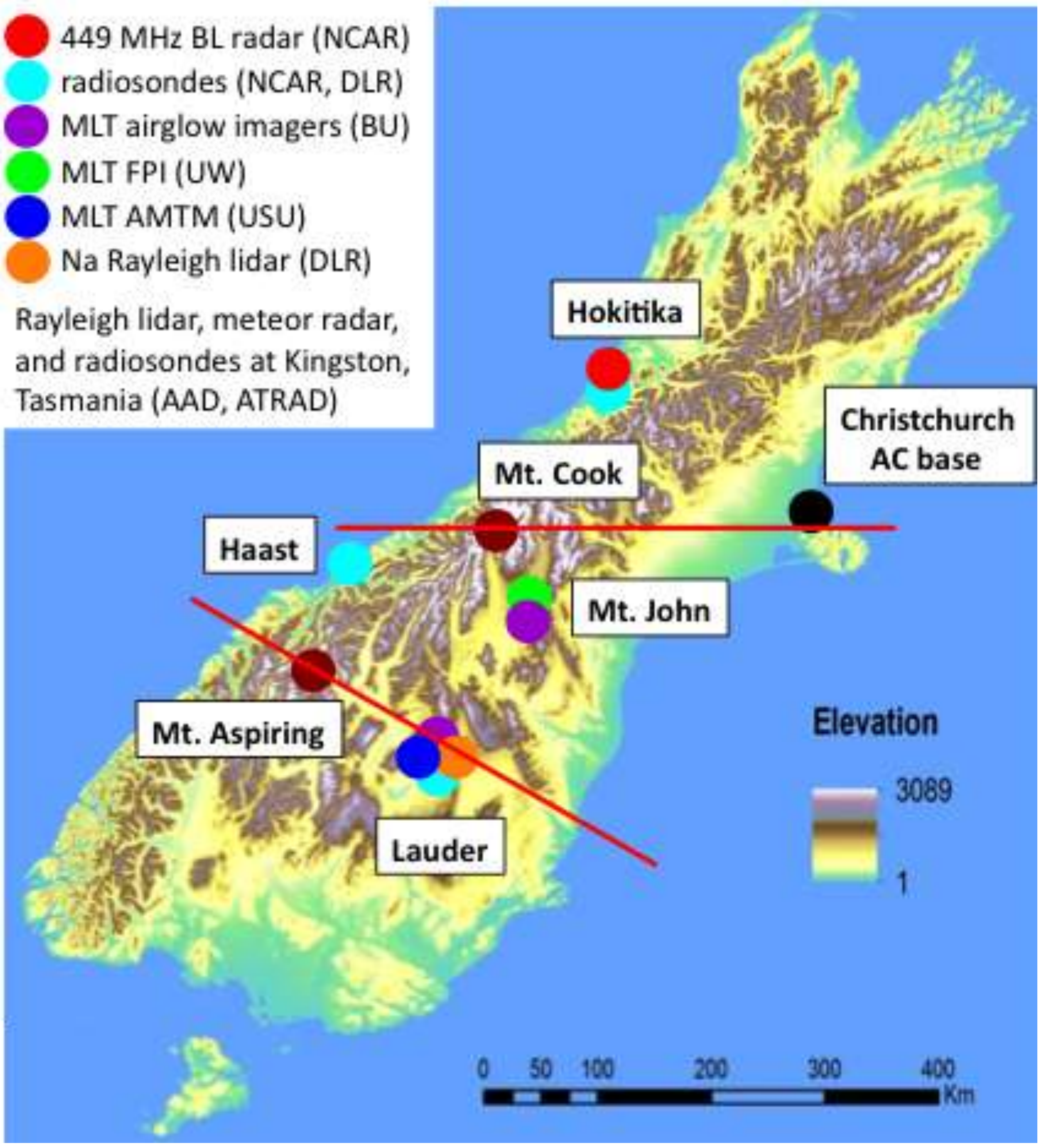




DEEPWAVE also employed extensive GB instrumentation

primary instrumentation on NZ South Island

also new Rayleigh lidar and meteor radar on Tasmania specifically to support DEEPWAVE



DEEPWAVE has extensive forecasting/modeling support by global NWP and regional models

DEEPWAVE Forecasting and Research Models

model	type, application	resolution	altitudes
ECMWF IFS	global, forecasting	16 km	0-60 km
NCEP GFS	global, forecasting/research	16 km	0-60 km
NIWA/UKMO	global, forecasting/research	2 & 6 km	0-40 km
NAVGEM	global, forecasting/research	36 km	0-100 km
NAVGEM (high altitude)	global, assimilation/research	130 km	0-120 km
COAMPS Adjoint	regional, forecasting/research	35 km	0-30 km
COAMPS	regional, forecasting/research	5 & 15 km	0-80 km
WRF (various)	regional, forecasting/research	2 & 6 km	0-40 km
Fourier-ray linear	local, forecasting/research	any	0-100 km
Finite-volume DNS	local, research	30m - 1km	0-400 km
Spectral DNS	local, research	3-10 m	$\delta z \sim 10$ km

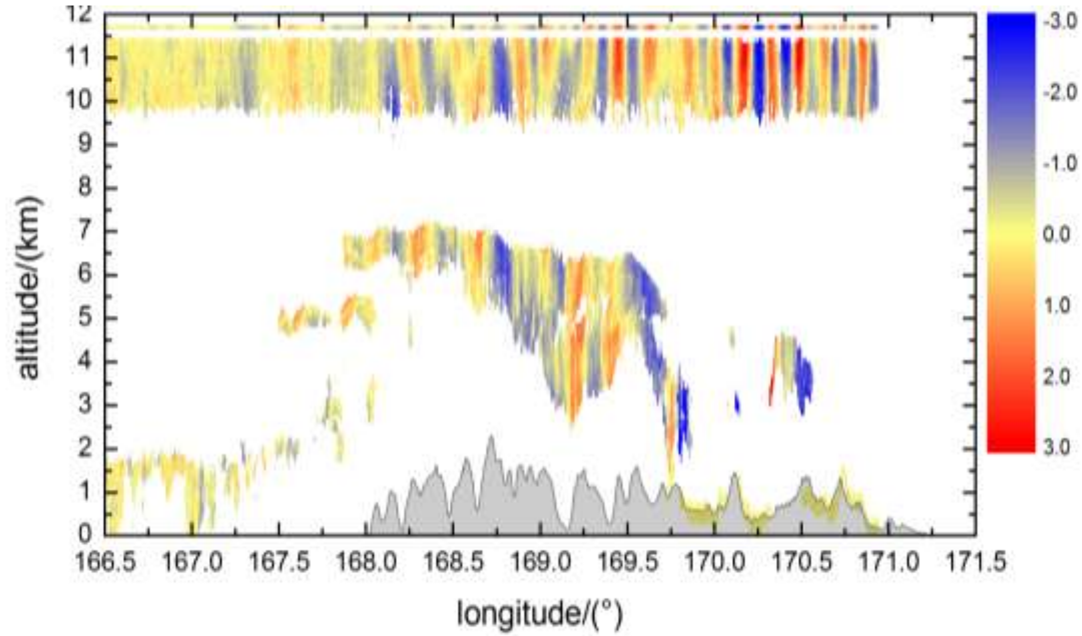
Research efforts will include:

- forecasts and re-analyses of measurement environments
- aiding interpretation of observations
- assessments of model performance
- improvements of GW drag descriptions

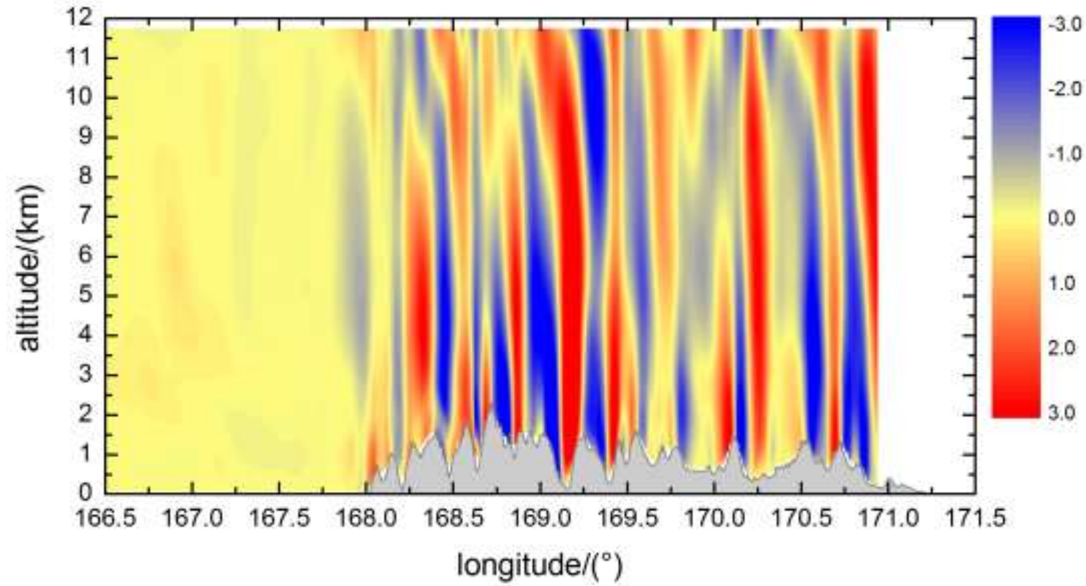
Comparisons of Observations and Modeling

DLR Falcon Doppler Lidar measurements of w'

Lidar w'



2-km WRF model

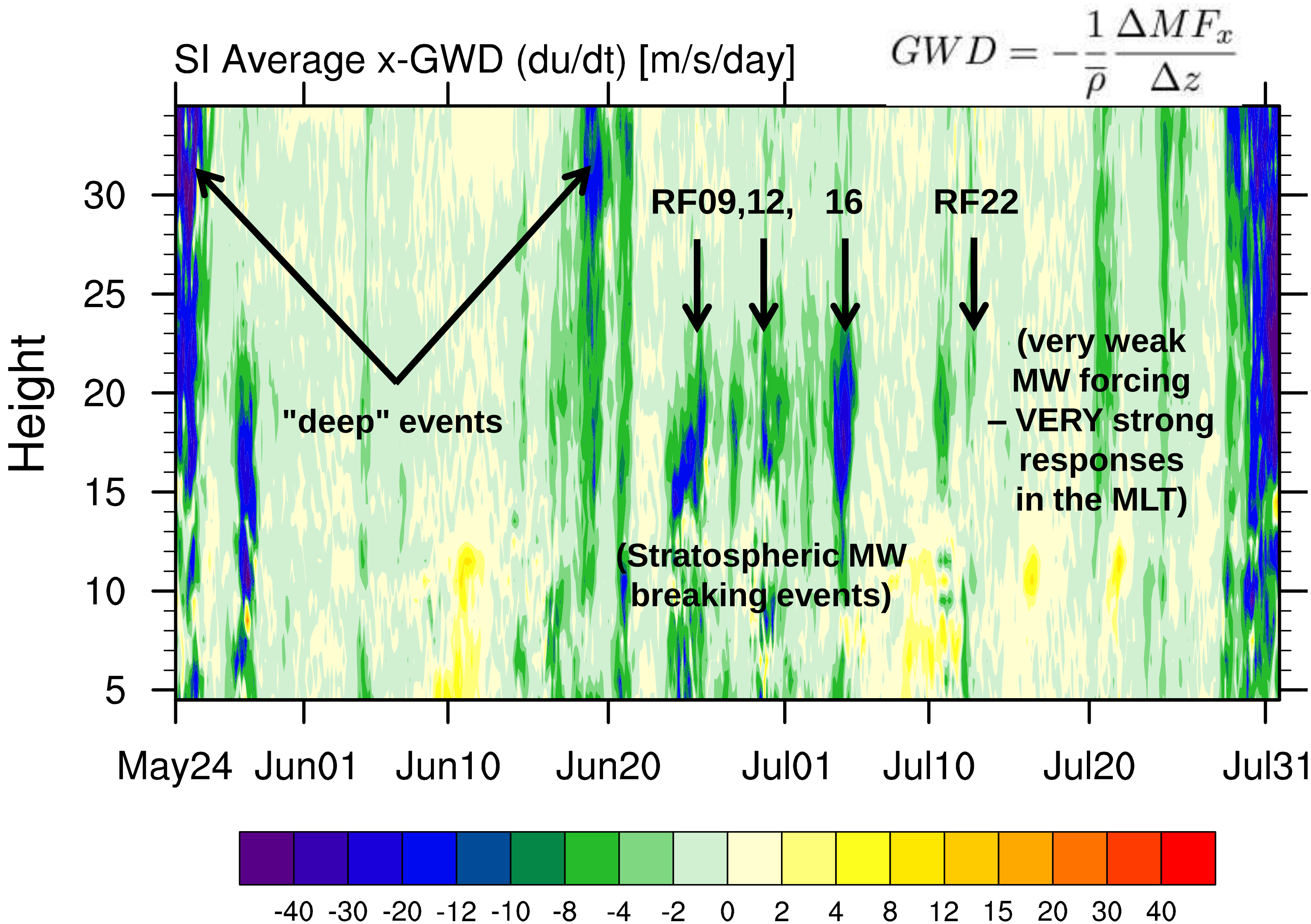


Observations indicate that higher WRF resolution is required for trapped MWs

South Island average GWD – 6-km WRF model

Kruse and Smith (2015)

6-km WRF forecast of OGWD with ECMWF boundary conditions



RF16 (04 July)

– strong MW forcing, restricted penetration

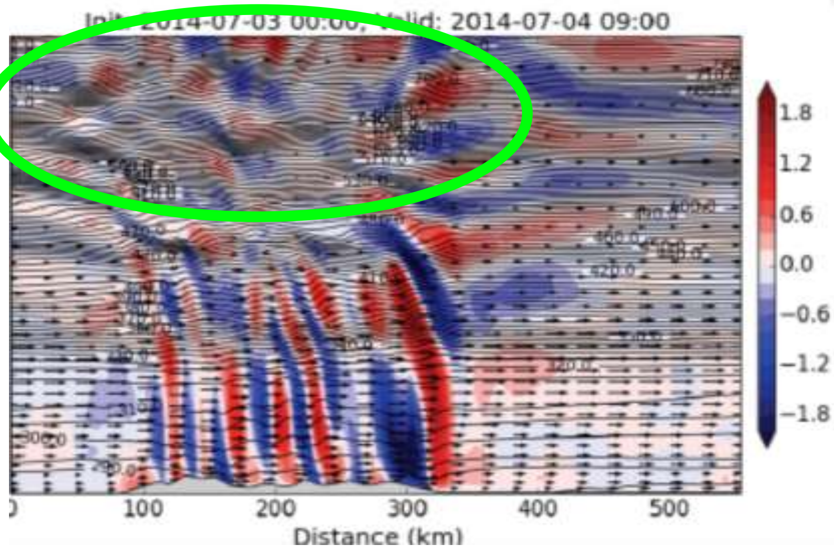
6-km WRF forecast suggested MW dissipation in weak stratospheric flow, radiation of secondary GWs to higher altitudes

WRF w(x,z) forecast

30

km

0



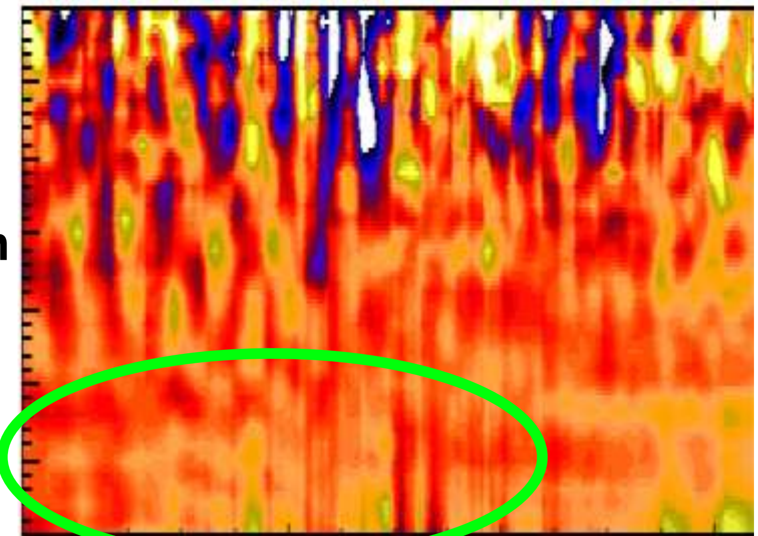
W Mountains E

Rayleigh lidar T' (x,z), ±15 K, RF seg. 3

55

km

20



168 170 172 174

longitude

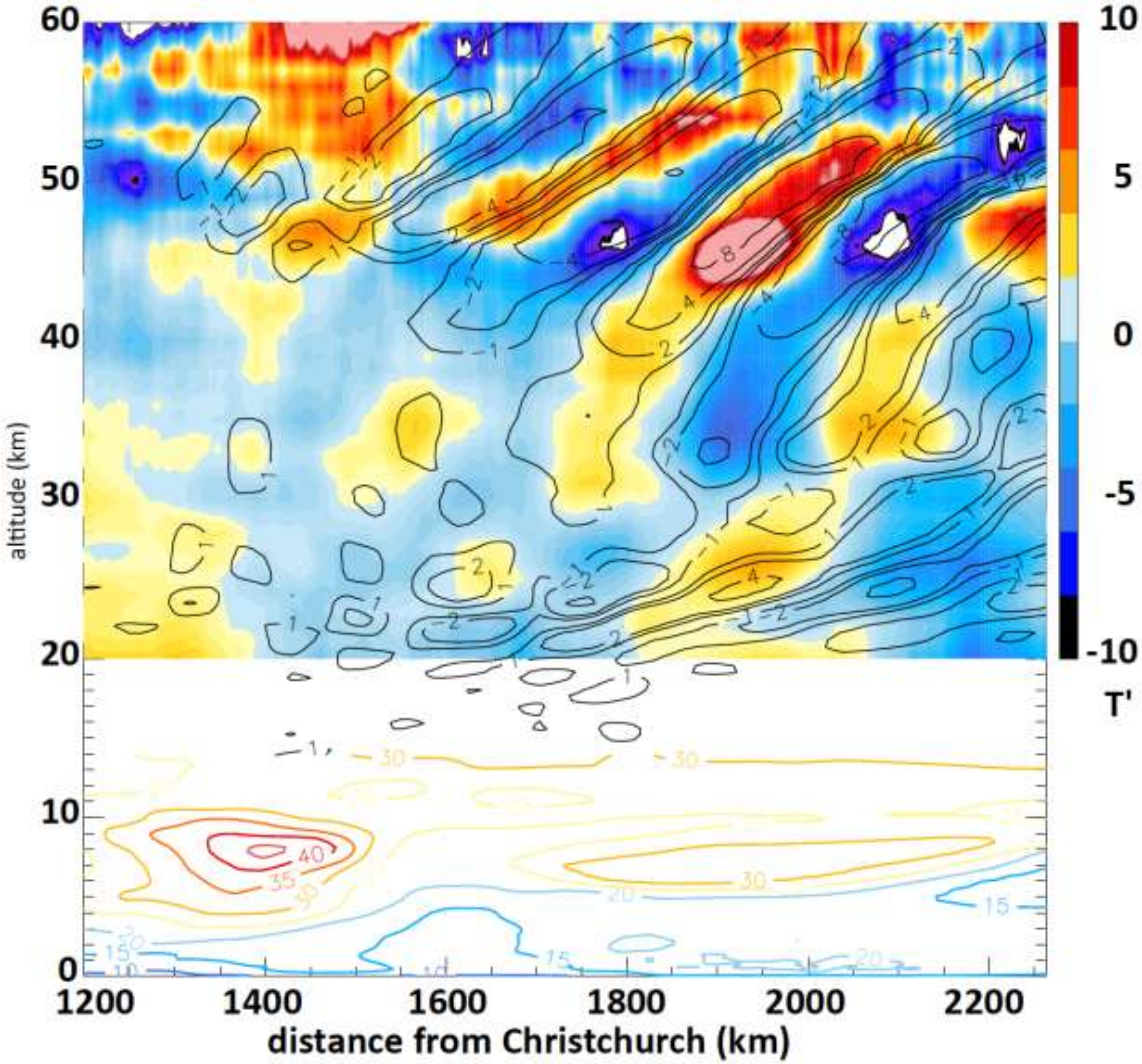
W Mountains E

lidar reveals:

1. weak GWs at ~20-30 km
2. increasing amps. >30 km
3. both westward and eastward prop. localized over terrain

RF25 – UV lidar T'(y,z) and ECMWF global model comparison

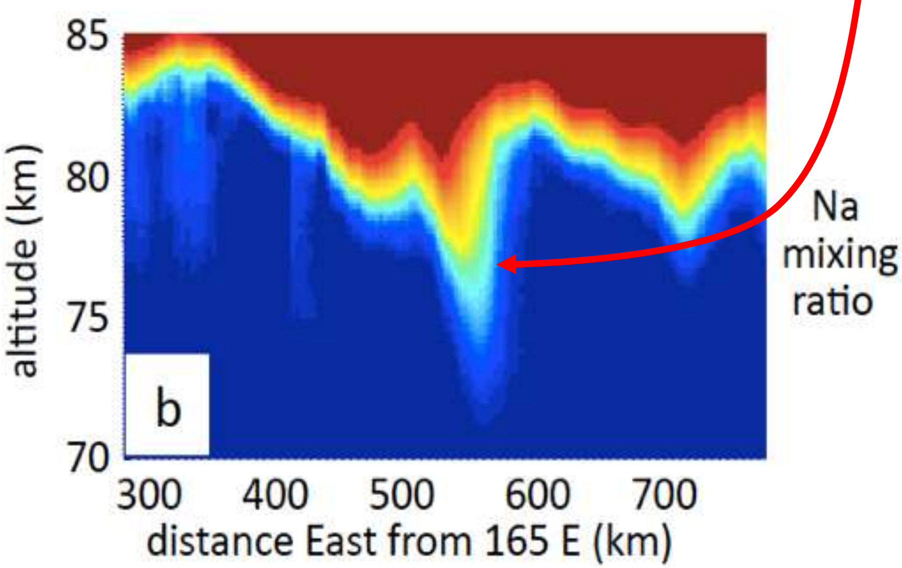
- EC model does well describing GW scales & location from a SO jet stream
- but under-estimates amplitude by ~2 times or more

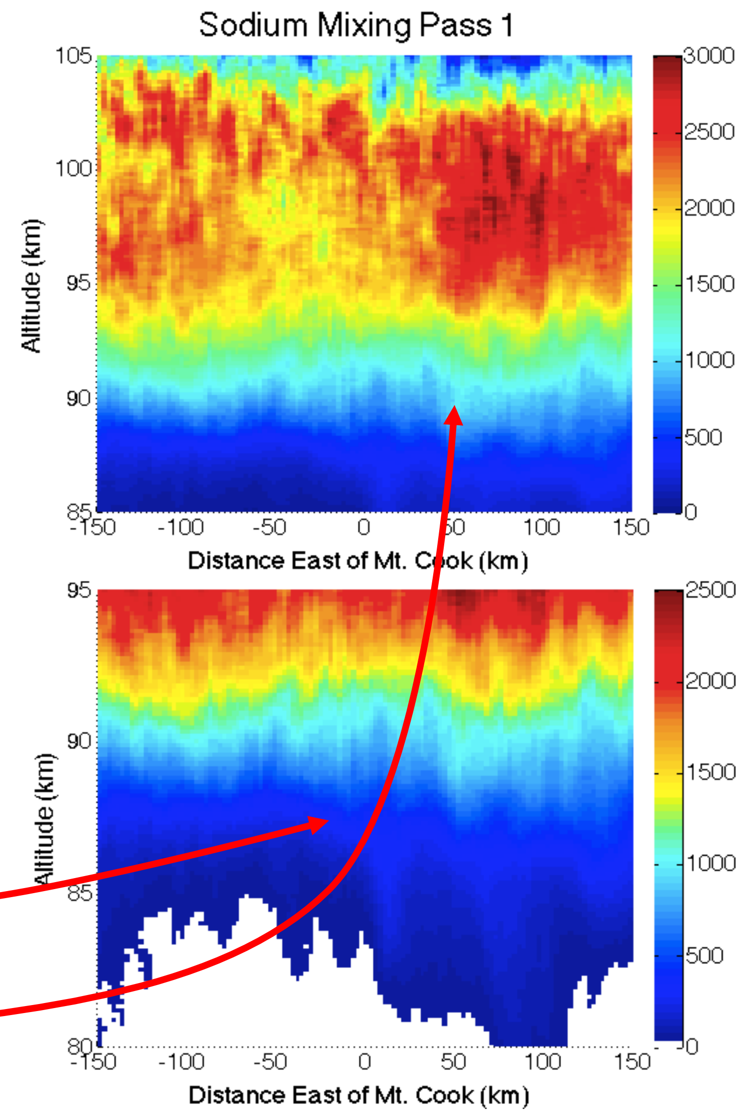


Mountain Wave Dynamics in the MLT

- RF22 (13 July) MWs had λ_h ~80-240 km, λ_z decreasing strongly in altitude
- strong dissipation approaching critical level, 2ndary GW generation

large-amplitude MWs have peak-peak δz ~8 km, exhibit breaking at ~75-85 km



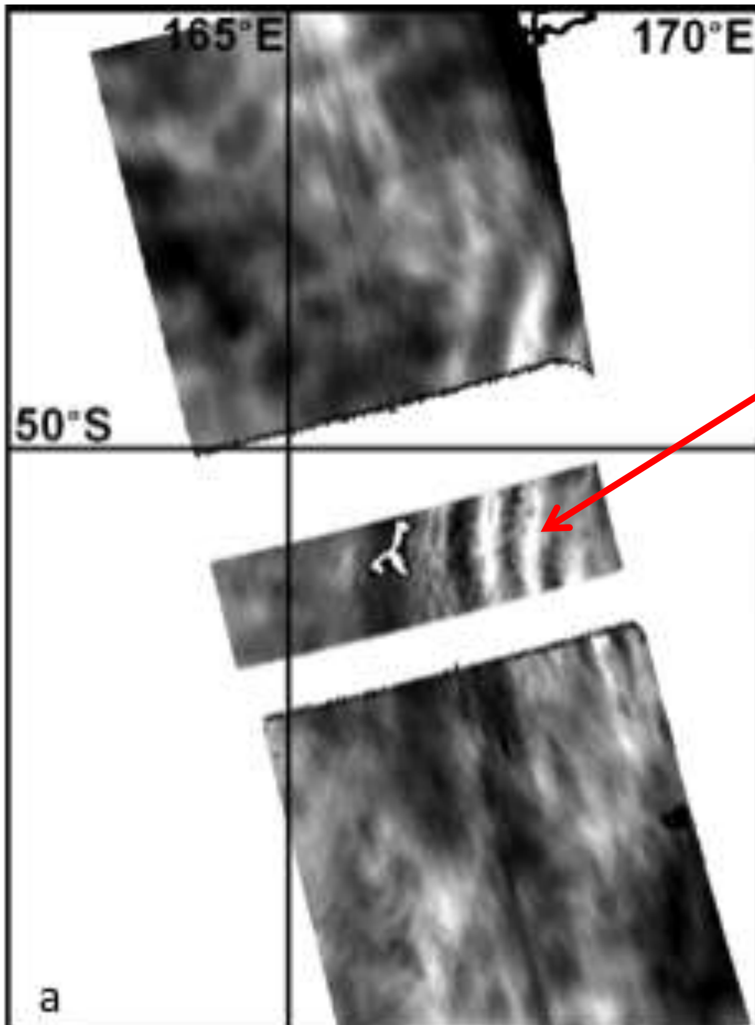


MW breaking strongly reduces MW amplitude below ~87 km,
causes 2ndary GW generation at multiple scales that penetrate to higher altitude

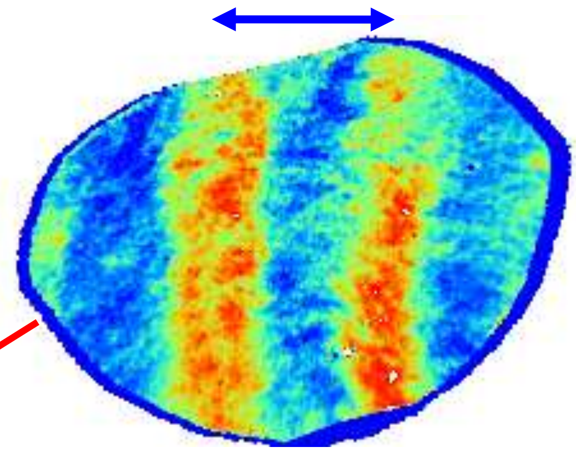
Auckland Island MWs on RF23 (14 July)

- clear "ship-wave" response at ~85 km

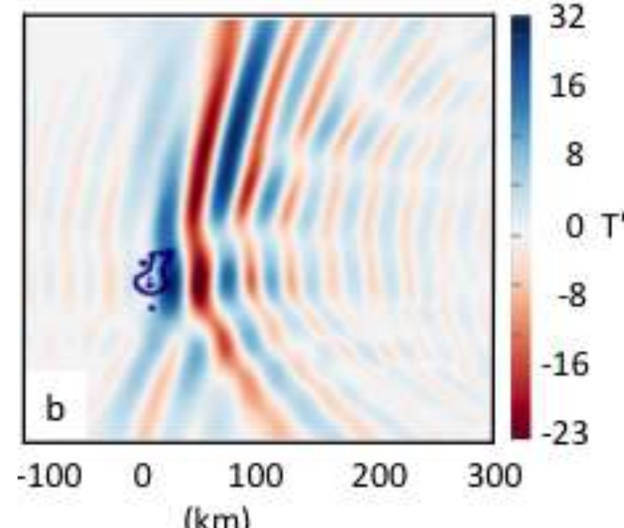
AMTM and wing camera OH airglow brightness at ~87 km



λ_z ~ 40 km, T' ~10 K



Fourier-ray model captures form, scales, and T'

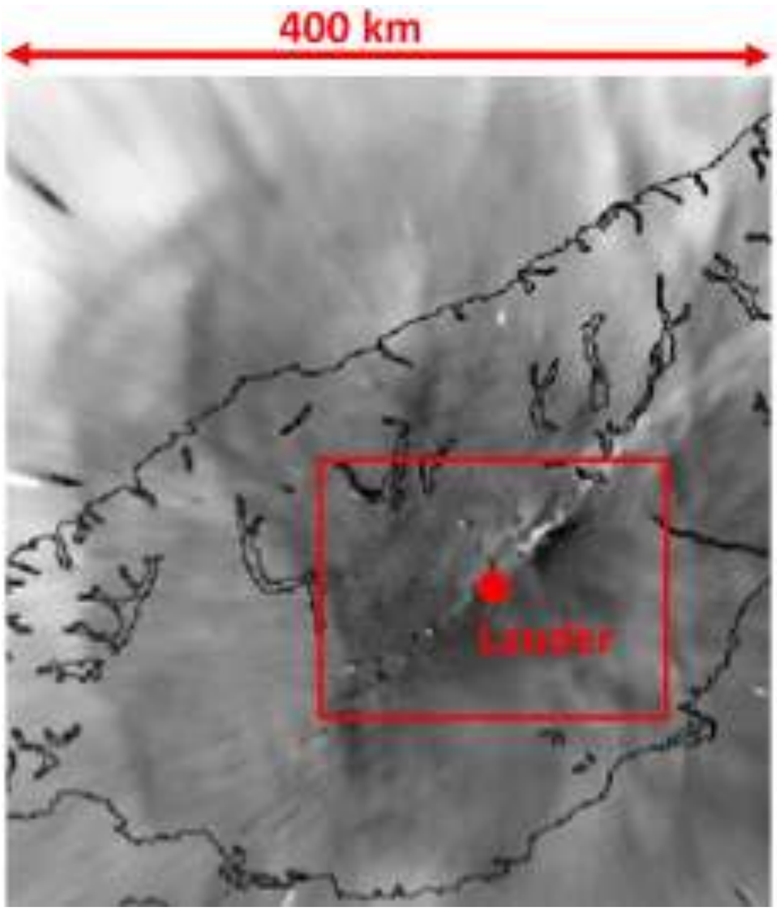


Ground-based imaging at Lauder and Mt. John – 21 June

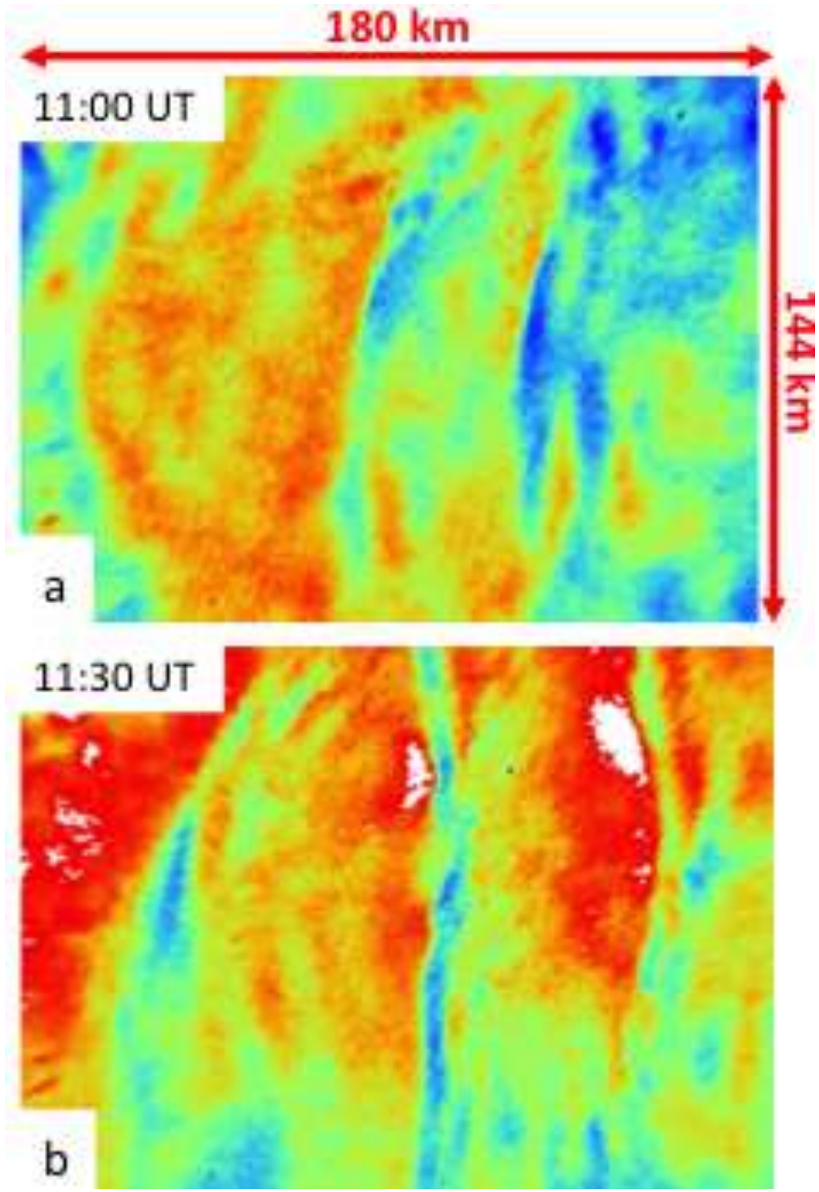
Forecast conditions judged "too weak" for significant MW responses

- but those seen at 87 km were the largest seen anywhere to date

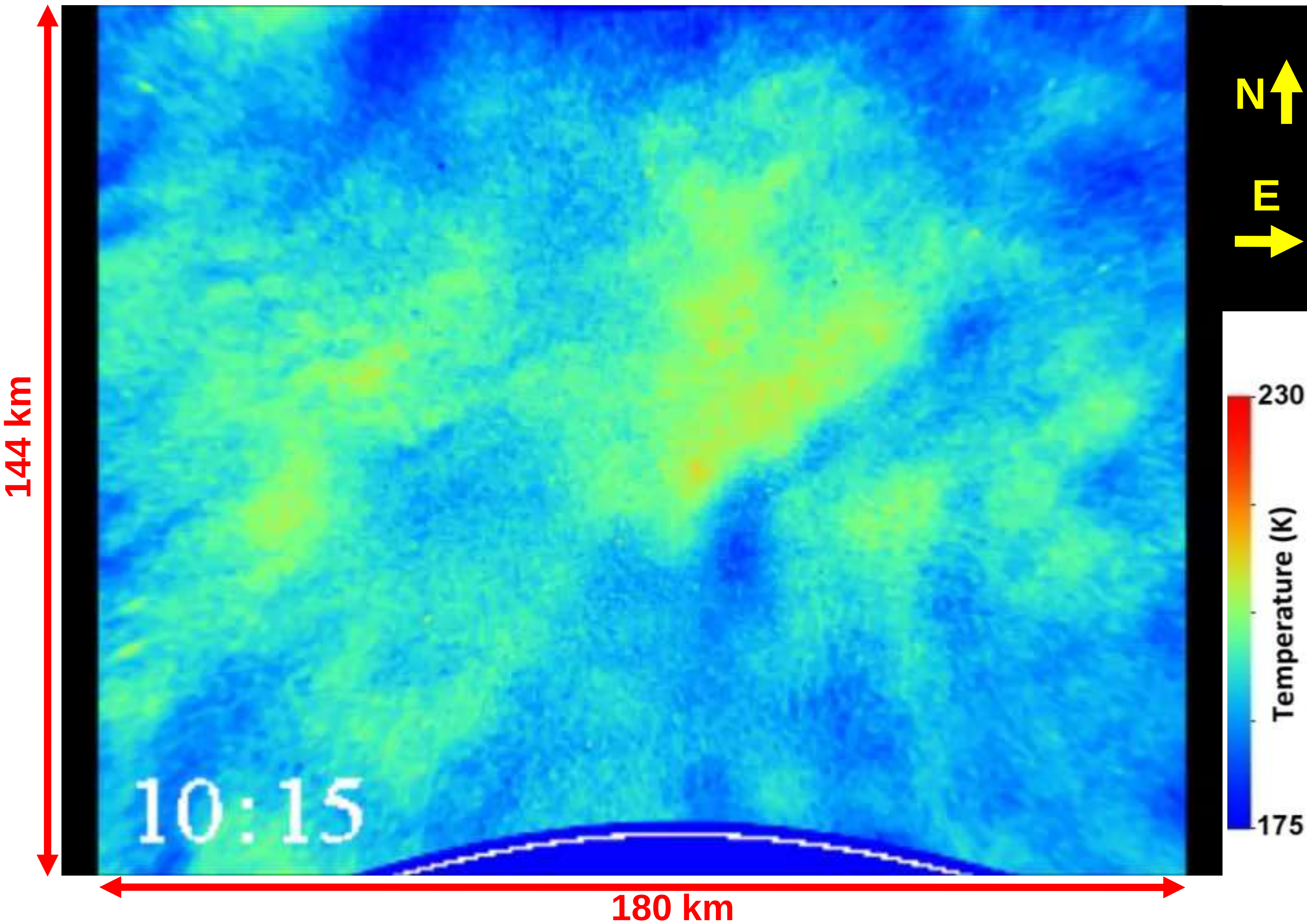
Mt. John all-sky imager



Lauder AMTM



21 June Lauder AMTM – MWs at ~87 km, λ_h ~12-80 km



Summary

- DEEPWAVE observations & modeling are quantifying GW scales, propagation, and dynamics from their sources to ~100 km

- MWs achieved the largest responses in the stratosphere and MLT:
  - weak forcing enables "linear" propagation, large amplitudes in the MLT
  - linear MWs having λ_h ~12-250 km readily penetrate into the MLT
  - large MW amplitudes at smaller scales yield larger momentum fluxes
  - MW breaking (stratosphere or MLT) yields strong 2ndary GW generation
  - large-scale MWs with small c_{gz} easily refract into the polar vortex

- GWs from jet streams & fronts have larger λ_h and penetrate to high altitudes

- larger-scale GWs often modulate the propagation of smaller-scale GWs

- high-resolution global and regional models often do a good job of predicting the gross features of the observed responses

- our field team of researchers and support staff did a spectacular job!