The Deep Propagating Gravity Wave Experiment (DEEPWAVE)

Science Overview and Approach

U.S. PIs: Dave Fritts[1], Ron Smith[2], Mike Taylor[3], Jim Doyle[4], Steve Eckermann[5], and Steve Smith[6]

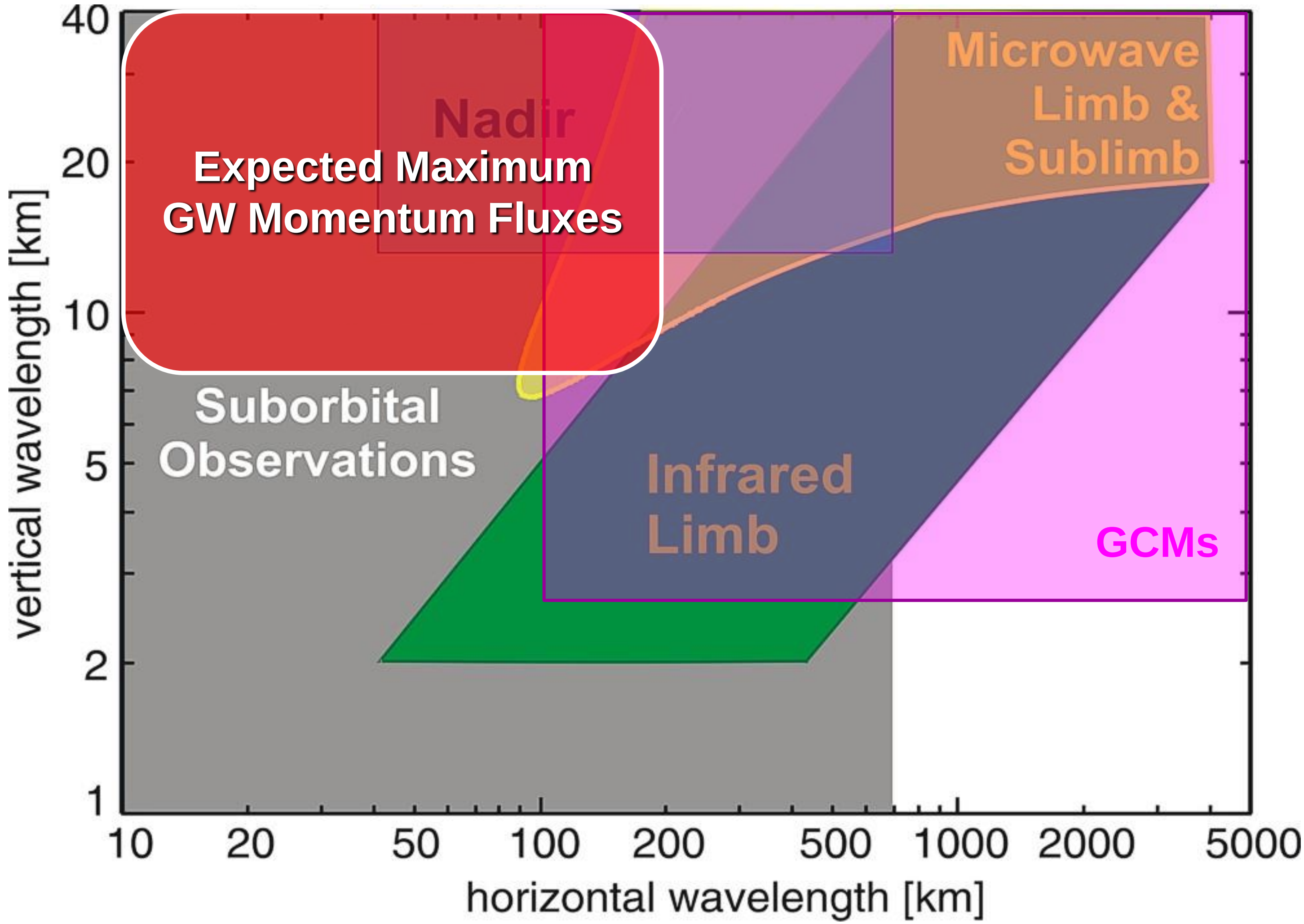
[1]GATS, Boulder, CO
[2]Yale University, New Haven, CT
[3]Utah State University, Logan, UT
[4]Naval Research Laboratory, Monterey, CA
[5]Naval Research Laboratory, Washington, DC
[6]Boston University, Boston, MA

DEEPWAVE Motivation:

Why are deep propagating GWs important?

- GWs account for primary vertical energy & momentum transport at all levels
- GCM parameterizations of GWs are known to be seriously deficient
- The important GWs are not resolved by satellite measurements or GCMs
- Better GW parameterizations require improved understanding, coordinated measurements and modeling studies

GW scale sensitivity and needs



- New measurements are needed to identify and quantify deep GW dynamics
- Efforts are needed to calibrate satellite measurement capabilities

DEEPWAVE Approach:

- **Perform comprehensive measurements at a location where these dynamics <u>have large responses</u> and <u>can be quantified with confidence</u>**

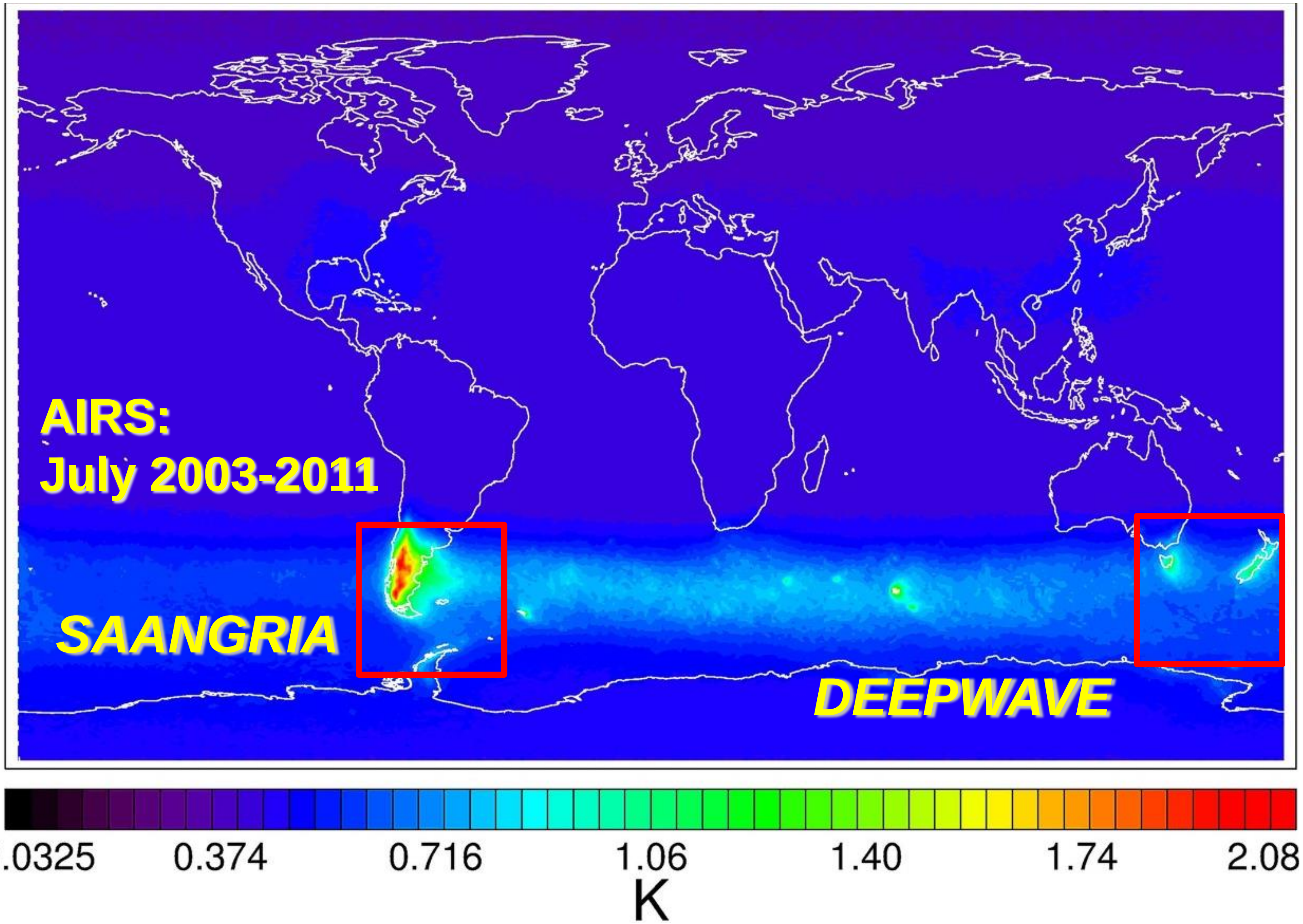
  - desire sensitivity to several major GW sources

- **Expand measurement capabilities to dramatically increase data accuracy and vertical extent – spanning altitudes of ~0-100 km**

- **Bring additional U.S. and international resources to enhance the value to the research community**

- **Include extensive forecasting and modeling activities for better understanding**

Site selection focused on Austral Winter GW “Hot Spots” (stronger responses, minimal SSW risk compared to N.H.)



GW sources with strong stratospheric responses include S. Andes, Antarctic Peninsula, New Zealand, and Tasmania

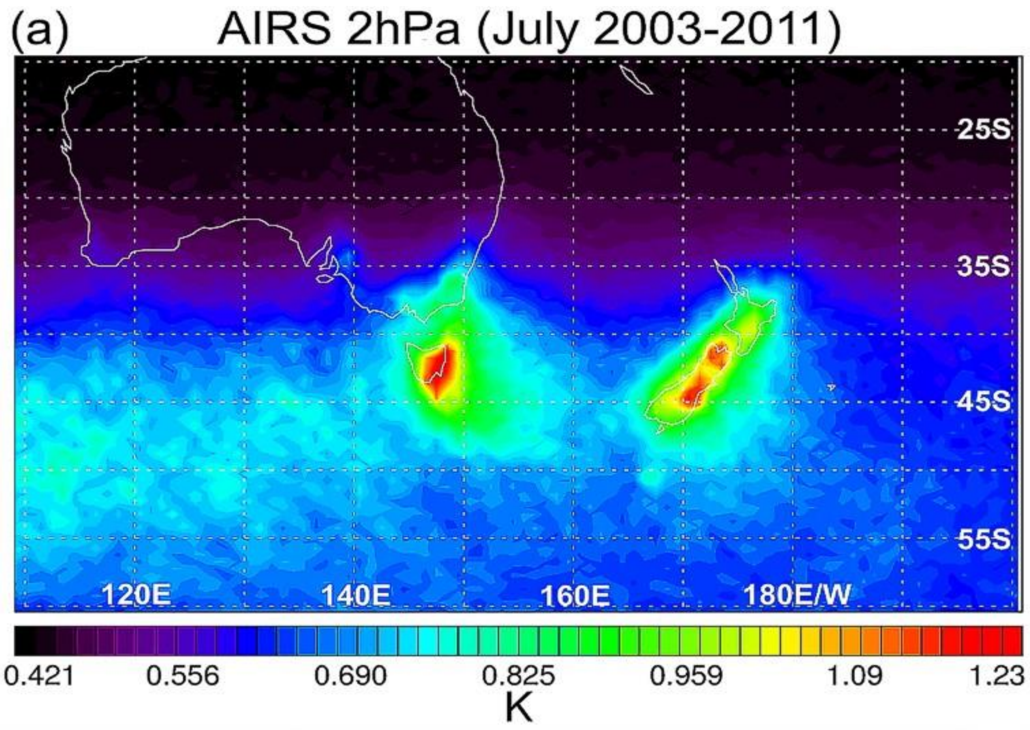
- S. Andes/AP (SAANGRIA) judged not feasible for NGV operations

DEEPWAVE "Region of Airborne Operations" (RAO) is the 2nd largest GW hotspot on Earth

major GW sources include:

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

New Zealand is a very good operational environment with good ground-based instrument support

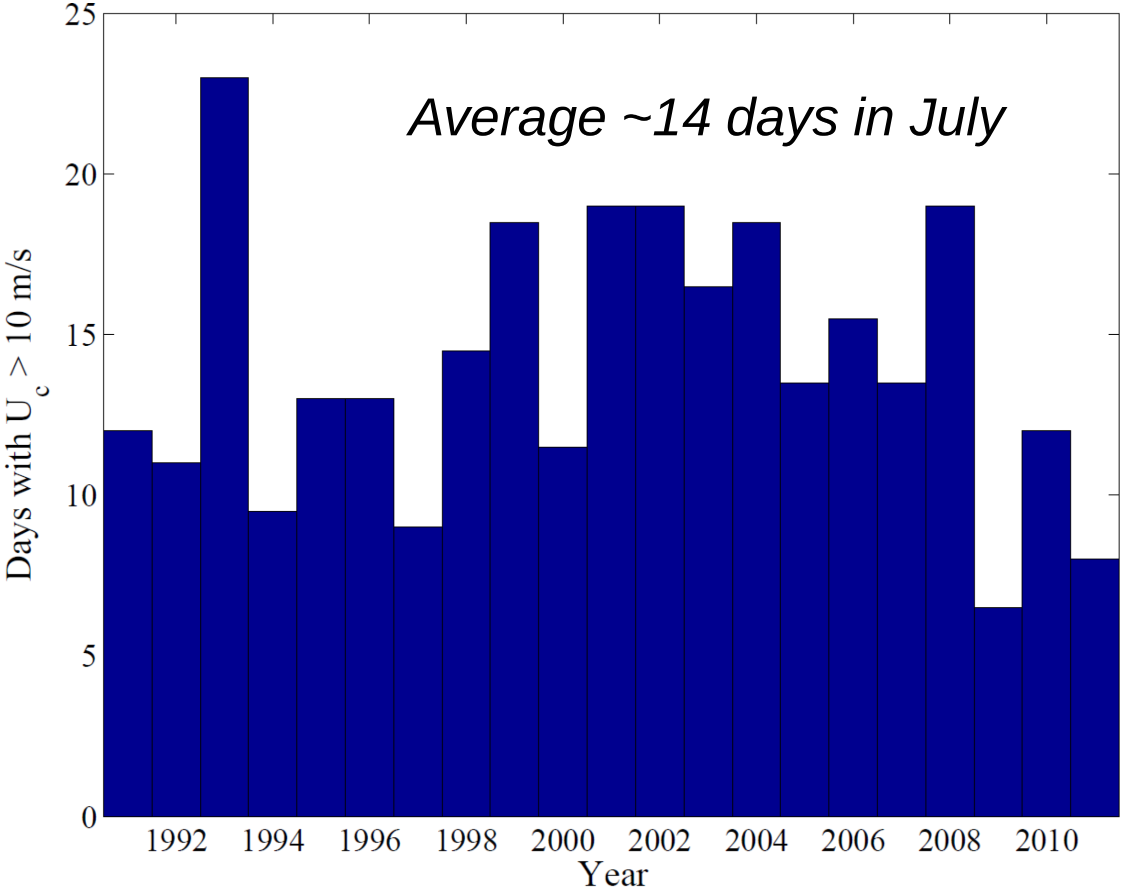


Deep GW Propagation over New Zealand

- high frequency of multi-day strong forcing events
- expect ~10 (minimum 3, maximum ~15) events with U > 15 ms^{-1} in 6-week campaign

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

ERA Reanalysis (July 1991-2011)

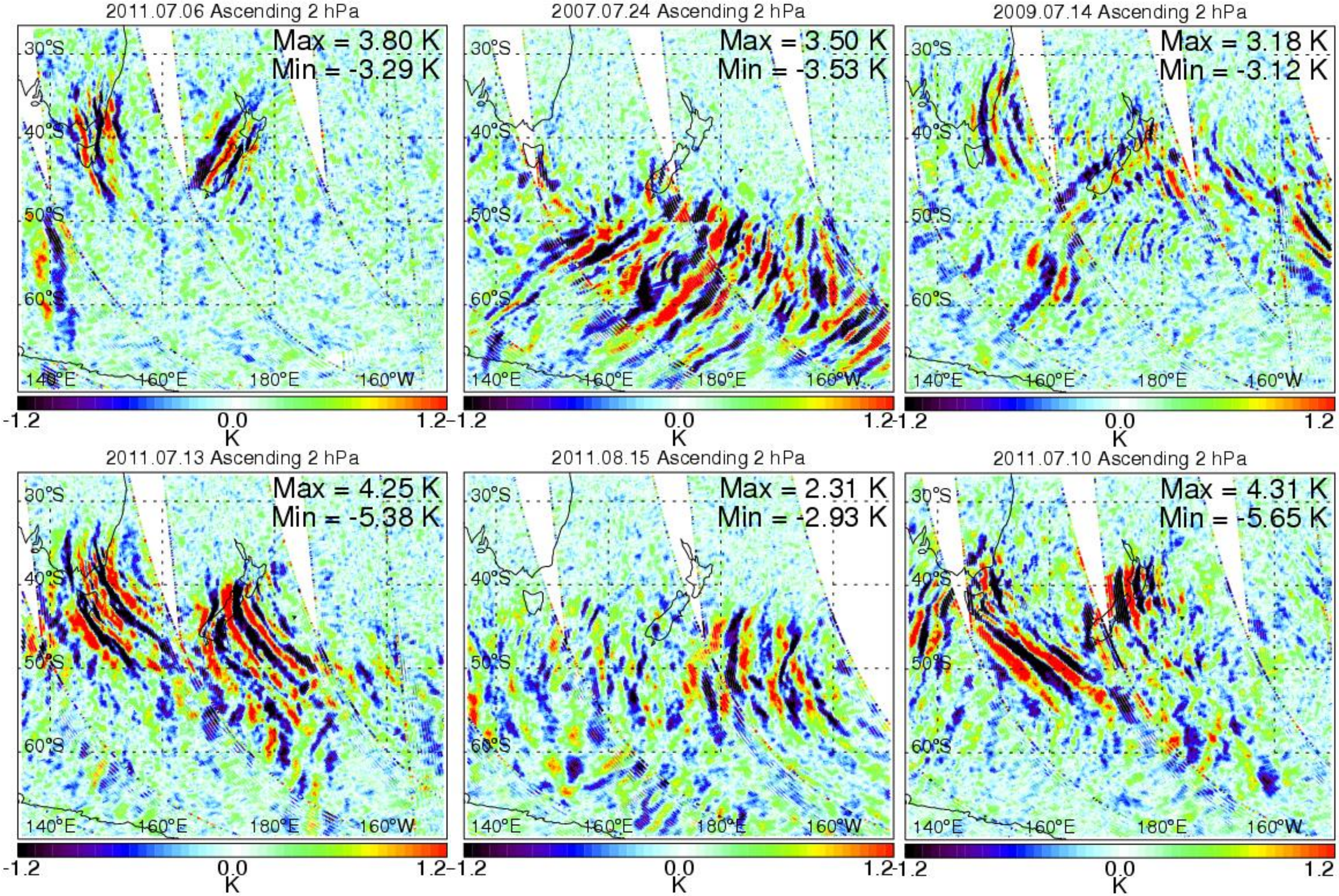


- Mountain wave propagation to high altitudes is common in S. Hemisphere
- Strong flows over New Zealand and Tasmania are prominent GW sources

GWs at ~41 km over New Zealand & the Southern Ocean

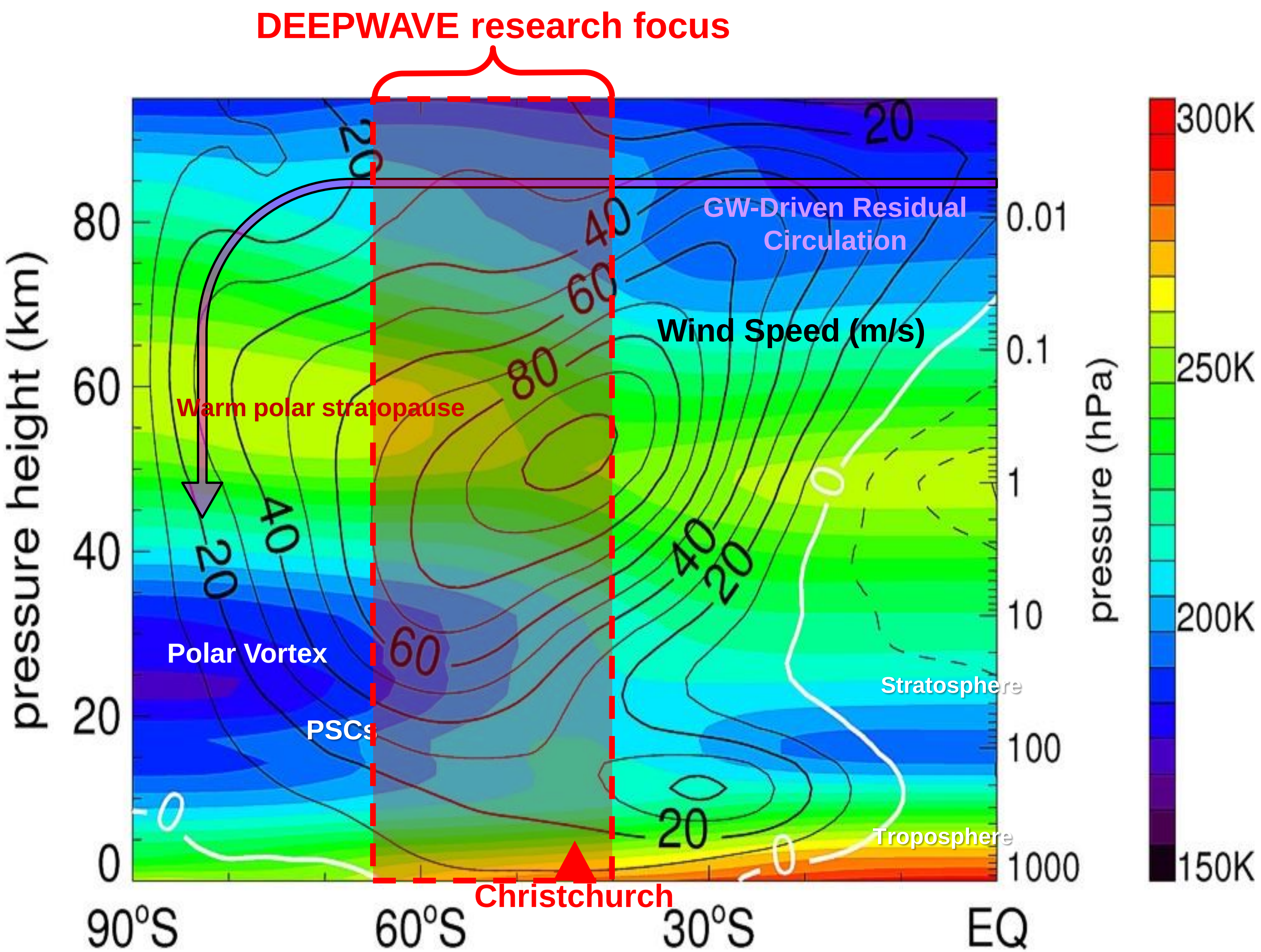
- rich sources of large-amplitude GWs

Mountain Waves | **Non-Orographic GWs** | **Multiple Sources**

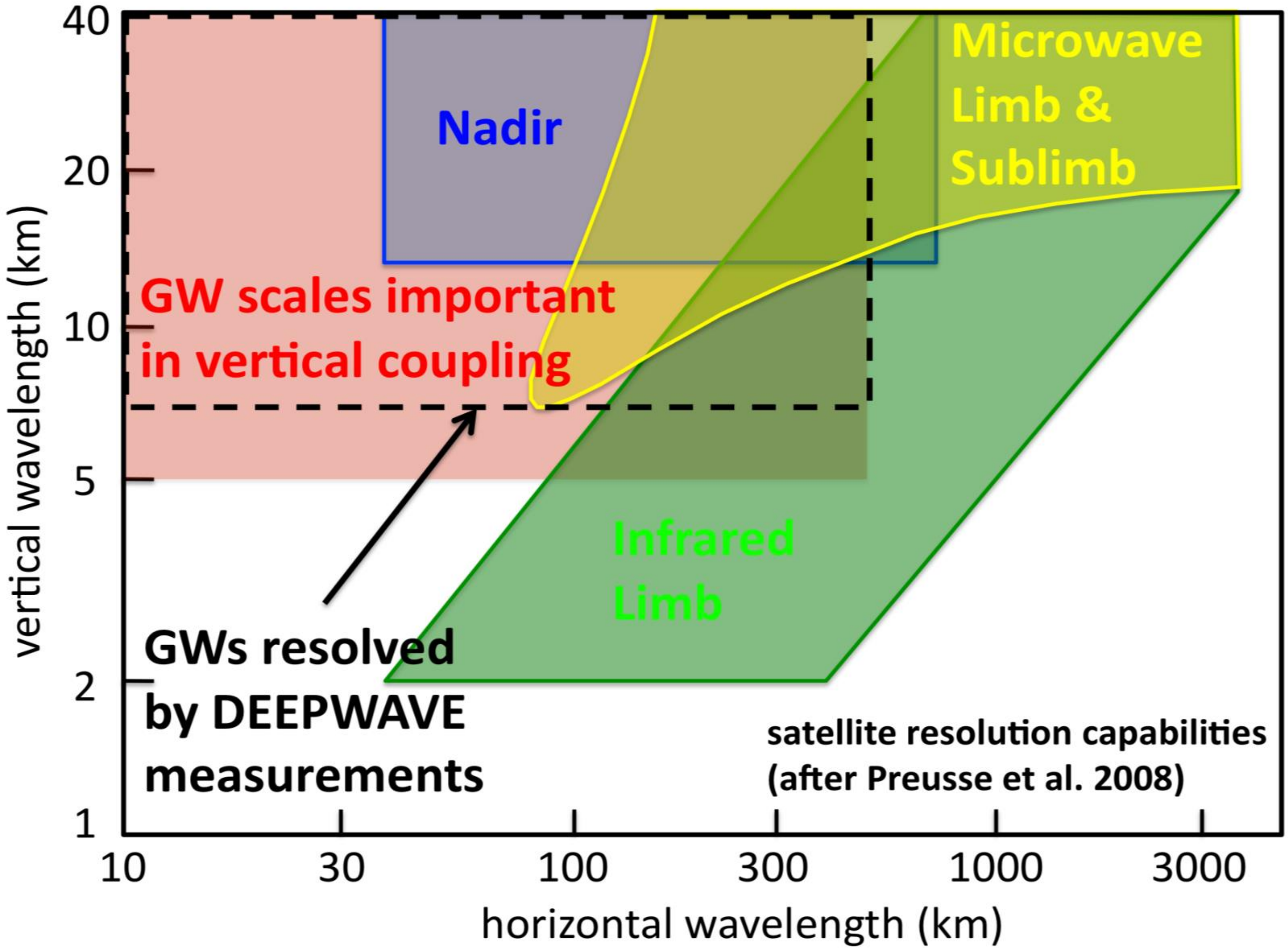


Austral Winter also provides a <u>stronger zonal jet and strong GW propagation channel</u> enabling GWs to penetrate to very high altitudes

- in an ideal natural laboratory



New DEEPWAVE instruments will provide sensitivity to the dominant GW scales relevant to quantifying GW influences and parameterization needs

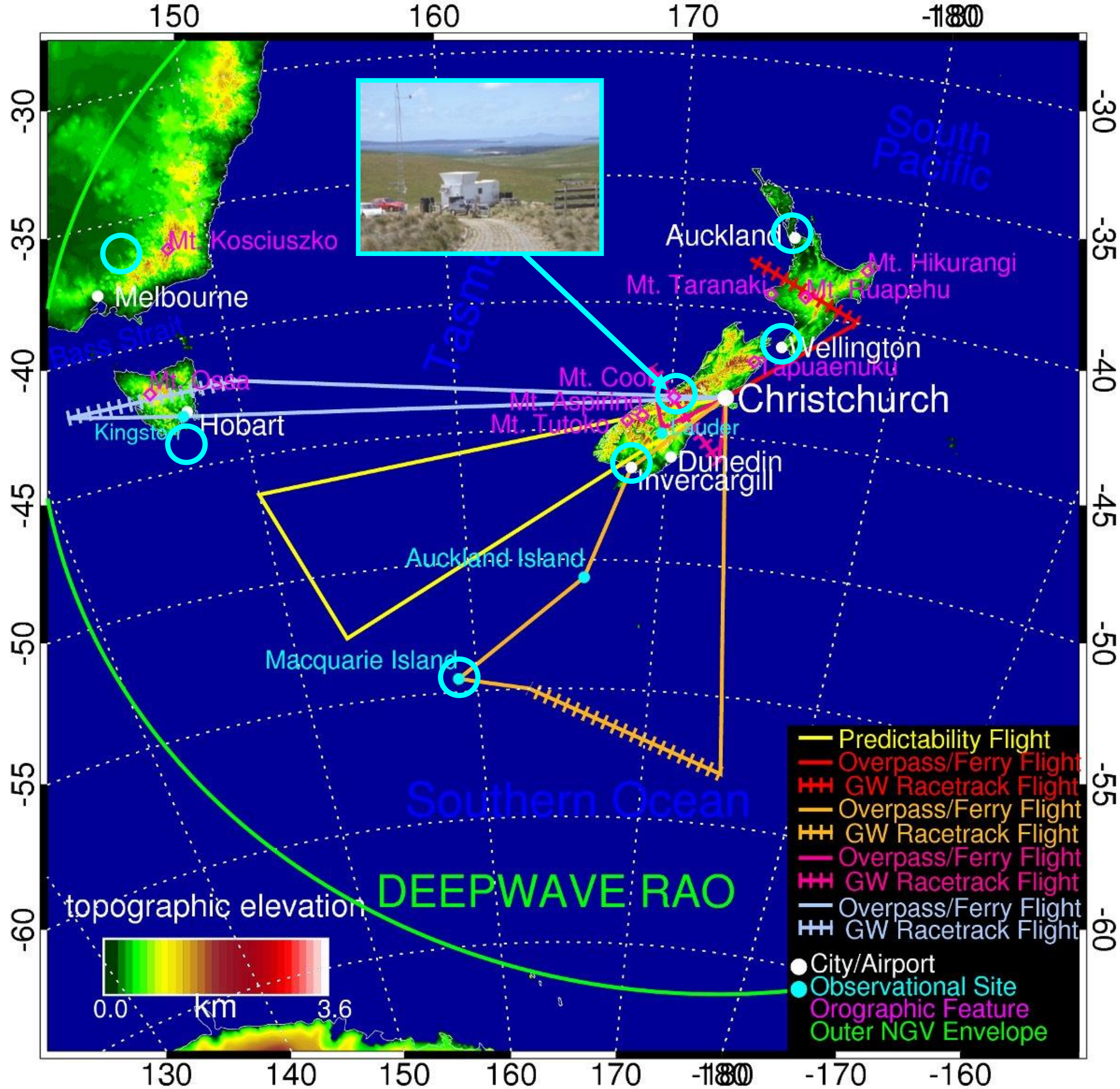


DEEPWAVE Field Campaign and Measurement Plans
- field program 5 June – 21 July 2014

NSF/NCAR Gulfstream V (NGV) with new lidars and MTM measuring from ~15 – 100 km

DLR Falcon with Doppler lidar measuring from ~0 – 11 km

DEEPWAVE "Region of airborne operations" (RAO)



DEEPWAVE Instrumentation
- all demonstrated in Feb. 2013 NGV test flights

Instrument	Parameters	Altitudes	Impact
***In situ* instruments** (gust probe, GPS..)	**Winds, temperature, O_3, aerosol, humidity** • 1-5 Hz (Δx~50-250 m)	Flight level (5-13 km)	Along-track hi-res GW & turbulence data
Dropsondes	**Wind & temperature profiles** • Δz~100 m	Below aircraft (0-13 km)	Flow environment, GW structure below flight level
Microwave Temperature Profiler (MTP)	**Temperature profiles** •±1-2 K, Δz~0.7-3 km, 10-15 s integration (Δx~2-4 km)	~5-20 km	GW structure above & below GV
Rayleigh lidar	**Temperature profiles** •±2-8 K, Δz~2 km, 20-s integration (Δx~4 km)	*T*~30-50+ km	GW structure GW-induced PSCs
Sodium (Na) **resonance lidar**	**Na densities, temperature** •±1-3 K, Δz~3-5 km, 20-s int. (Δx~4 km) **vertical wind** •±1-3 m/s, Δz~3-5 km, 20-s int. (Δx~5 km)	~15-30 km ~84-96 km	GW structure
Mesospheric Temperature Mapper (MTM)	**All sky OH airglow and temperature** •±2 K, 2-s integration/TDI (Δx~1 km)	~87 km	2D map of GW and instability structures, propagation directions

Existing Facility Instruments

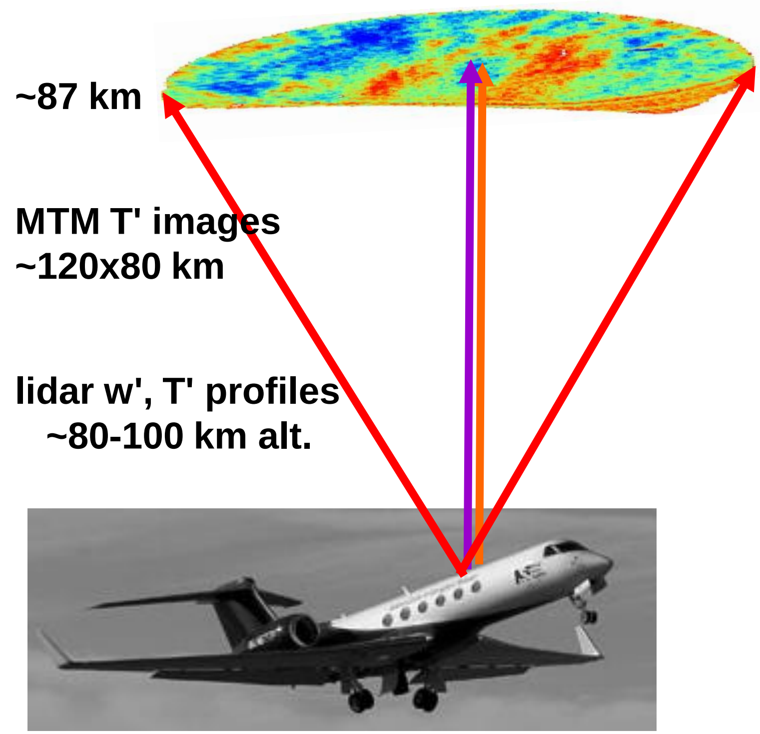
New Facility instruments recently developed for DEEPWAVE

DEEPWAVE PIs have developed 3 new NGV instruments to extend DEEPWAVE measurements from ~0 to 100 km

- Rayleigh lidar - T and T'(z,t) ~30 – 60 km
- Na resonance lidar - w' and T'(z,t) ~15-30 km and ~80-100 km)
- Mesosphere Temperature Mapper (MTM) - T and T'(x,y,t) ~87 km

Rayleigh and Na lidars (Biff Williams, GATS)

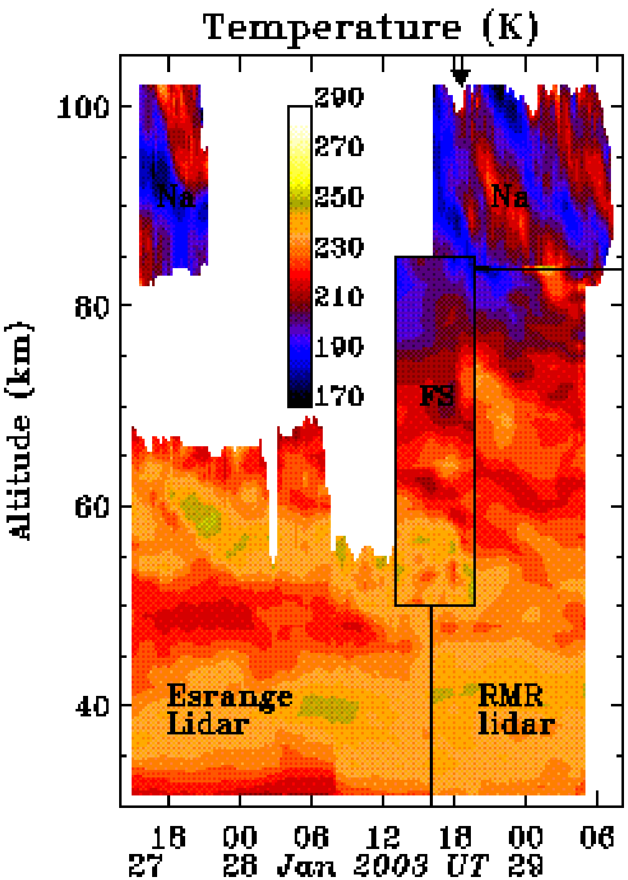
MTM (Mike Taylor, USU)



NGV UV and sodium lidar measurements

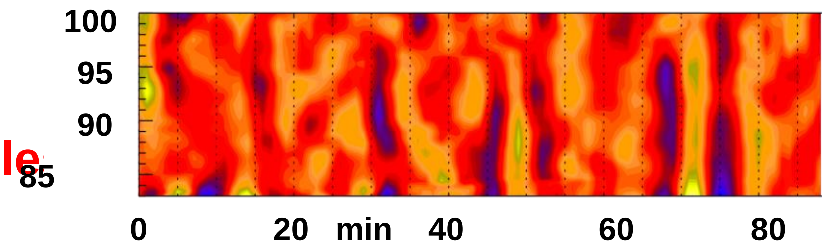
UV lidar: ~5 W pulsed
densities (temperatures) ~30-60 km

Na lidar: ~14 W CW, pulsed/32-channel scanned
vert. winds, temps. – double-edge filter, Na res.
~15 – 30 km, ~80 – 100 km

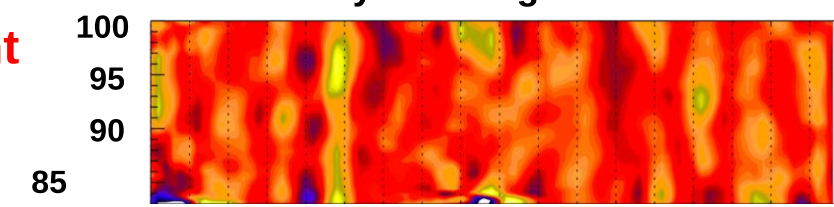


ALOMAR
Na lidar
dynamics example

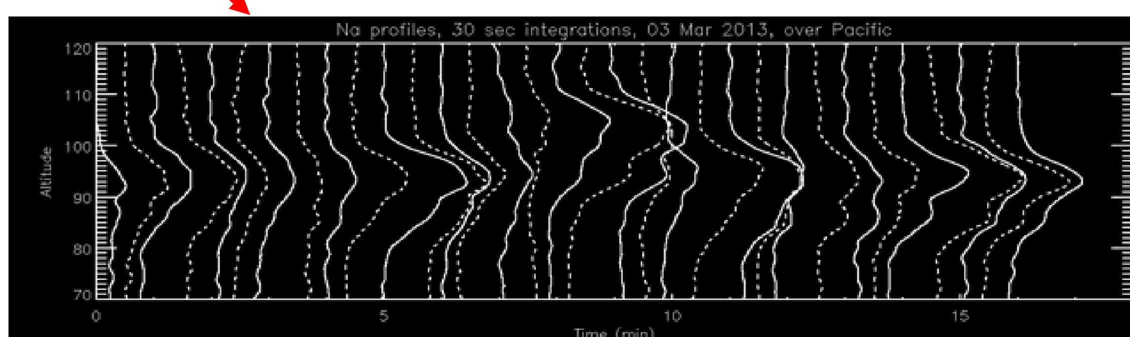
w' at Na layer as large as ± 1-20 ms^{-1}



T' at Na layer as large as ± 1-20 K



NGV test flight
Na profiles

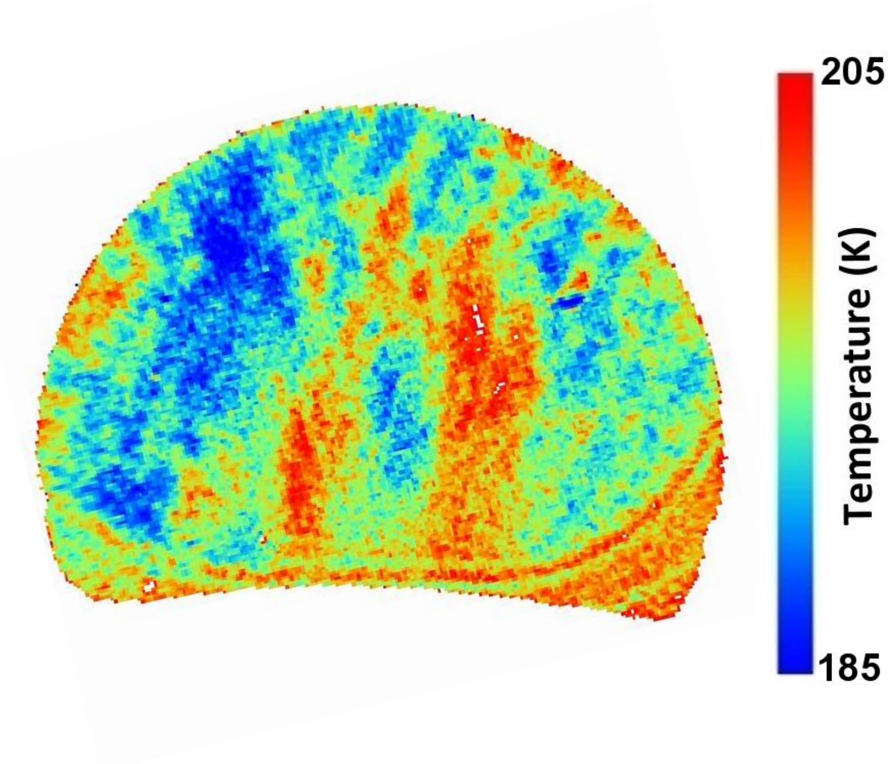


NGV MTM measurements ~87 km OH airglow

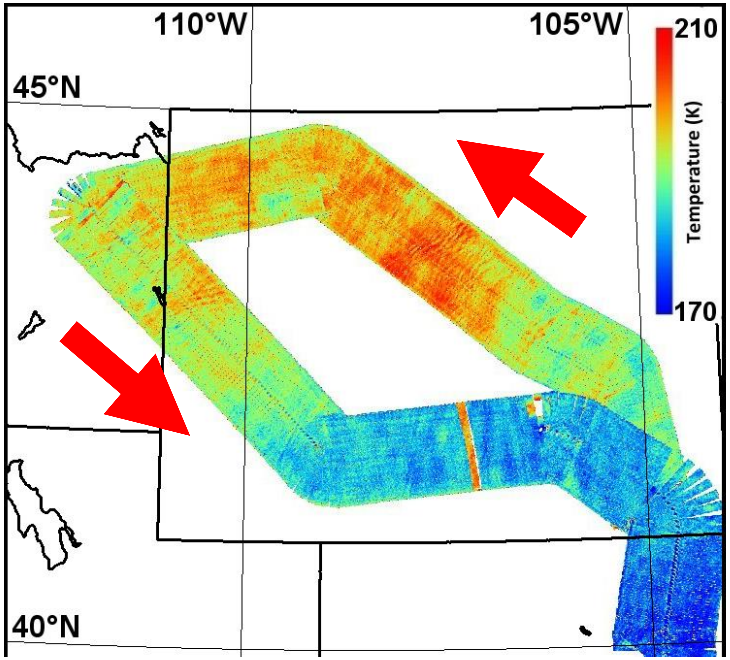
- continuous horizontal map of temperature: Δx, Δy ~0.5 km
  (~120 km along track, ~80 km cross track)

- temporal span ~10 min to track evolution of small-scale features

MTM temperatures

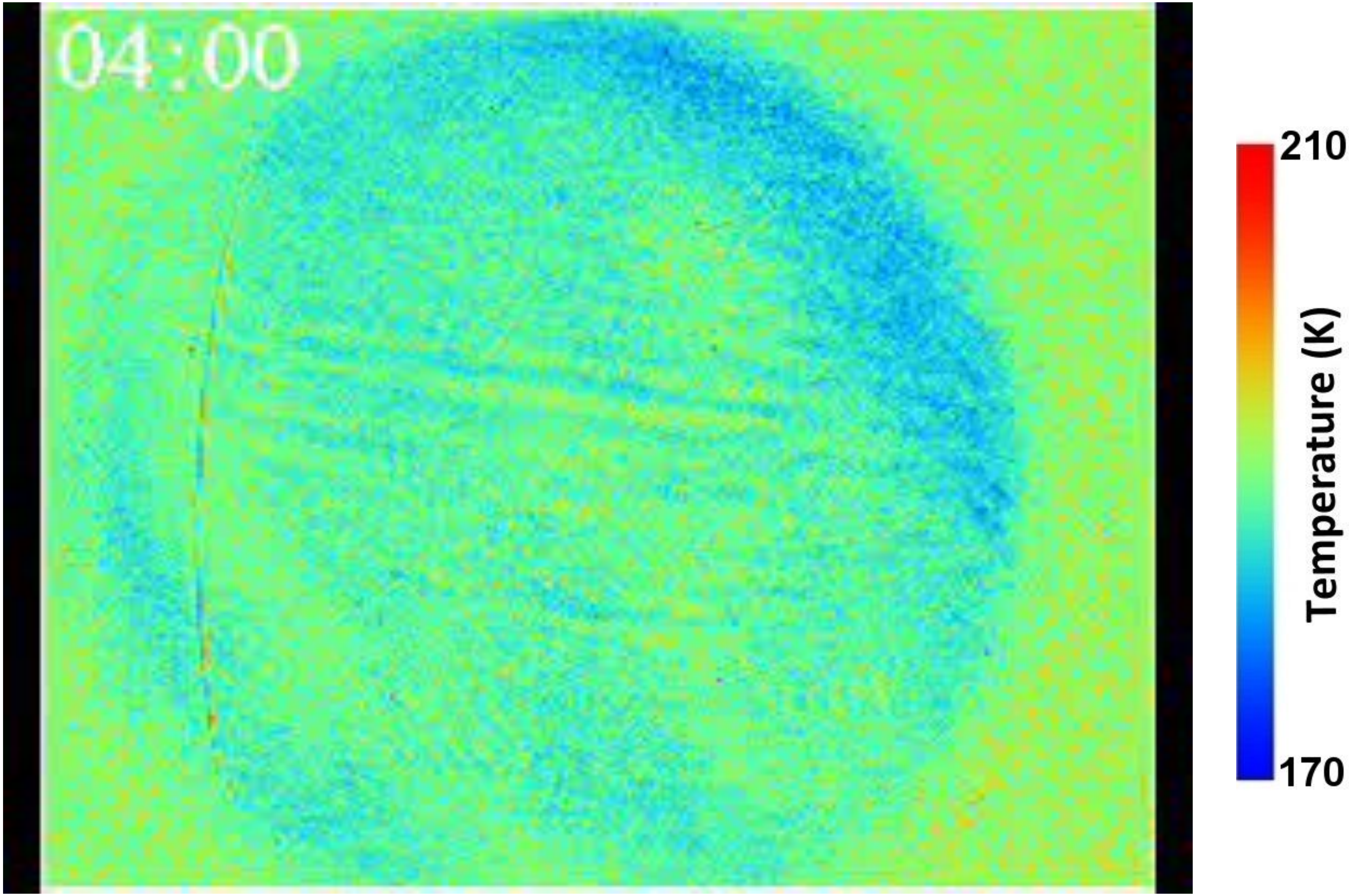


MTM along-track mapping



~6-hr test flight

Example MTM OH Temperature Movie



DEEPWAVE measurements will also be augmented through DLR participation with an airborne Doppler lidar, in-situ measurements, dropsondes, and a ground-based Na lidar

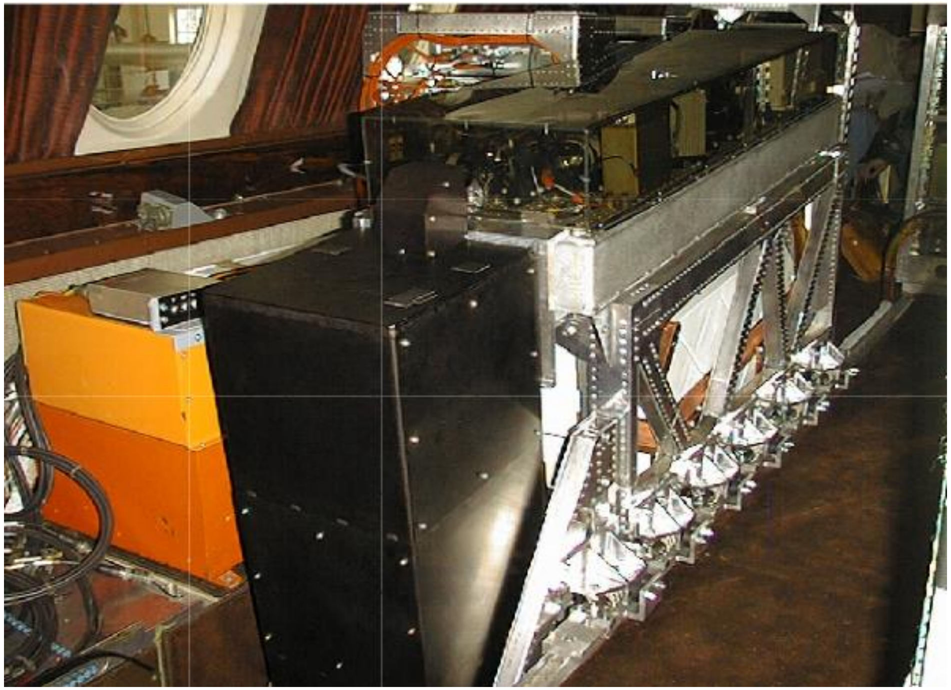
DLR Doppler lidar and dropsondes will yield:

- mean winds, GW structure, amplitudes, and momentum fluxes ~0 to 11 km

DLR ground-based Na lidar will yield:

- Rayleigh temperatures ~5-70 km

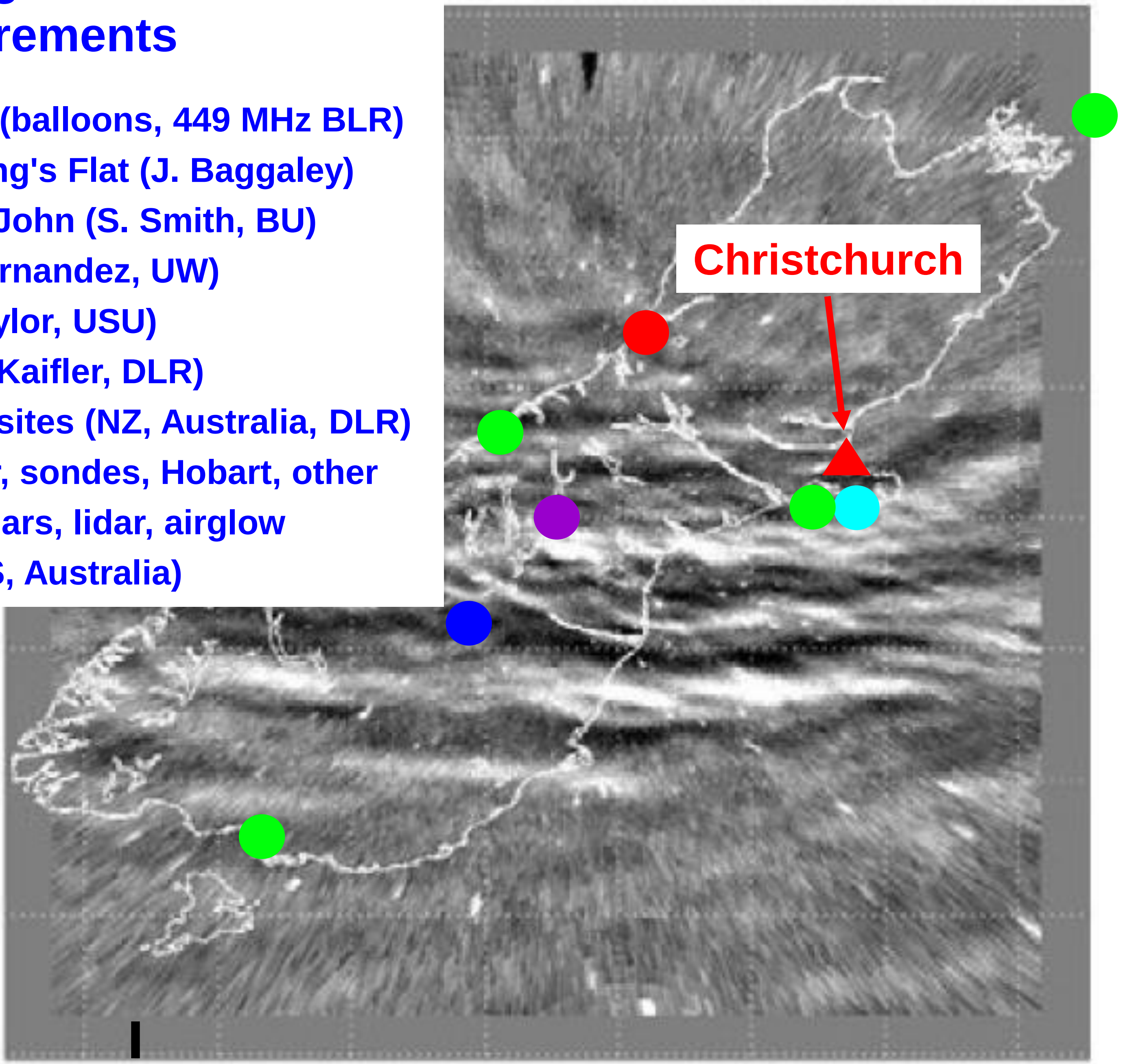
- radial winds ~80-105 km, if Na resonance capabilities are in place



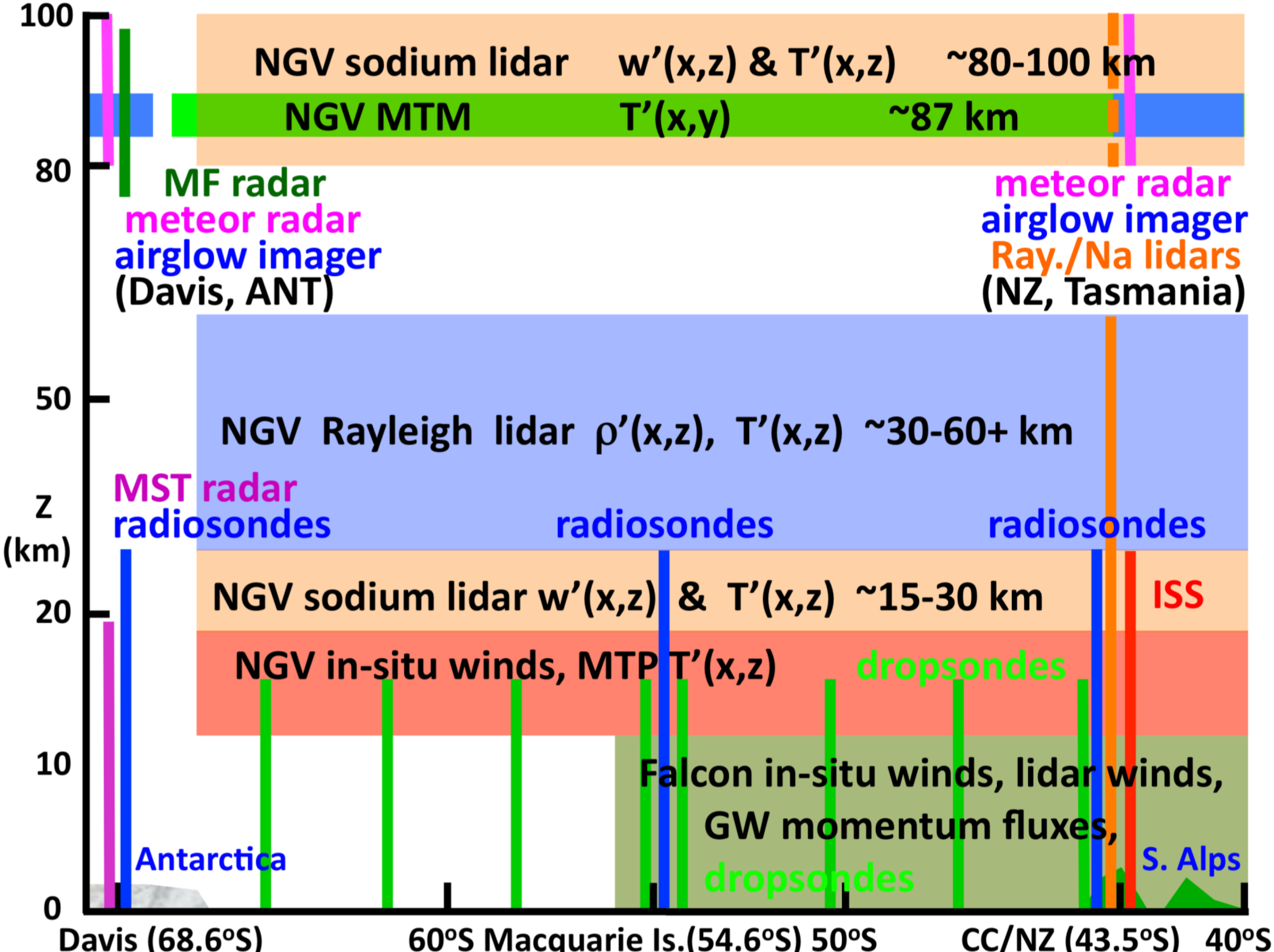
DEEPWAVE ground-based measurements

- NCAR ISS, Hokitika (balloons, 449 MHz BLR)
- meteor radar, Birdling's Flat (J. Baggaley)
- airglow imager, Mt. John (S. Smith, BU)
- FPI, Mt. John (G. Hernandez, UW)
- MTM, Lauder (M. Taylor, USU)
- Na lidar, Lauder (B. Kaifler, DLR)
- balloons at various sites (NZ, Australia, DLR)

AAD - Rayleigh lidar, sondes, Hobart, other
- Antarctic radars, lidar, airglow Davis (68.6ºS, Australia)



DEEPWAVE and correlative measurement capabilities



Forecasting and modeling support for DEEPWAVE

NOGAPS-ALPHA global (S. Eckermann, NRL)
- data assimilation, forecasting

COAMPS deep nested mesoscale (J. Doyle, NRL)
- data assimilation, forecasting, predictability

ECMWF forecasts (A. Dörnbrack, DLR)
- support for flight planning

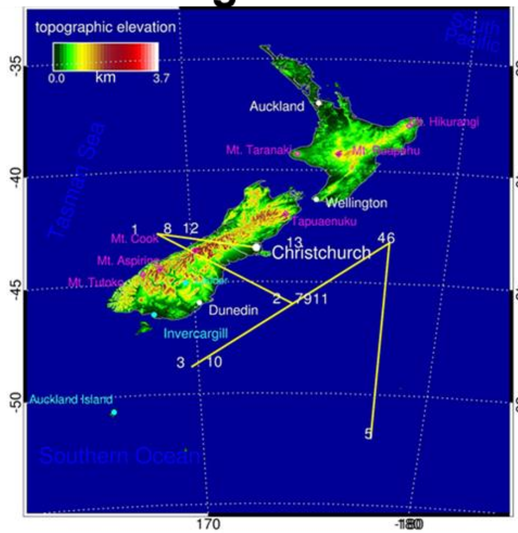
WRF (R. Smith, Yale, and A. Dörnbrack, DLR)
- orographic gravity wave forcing, lower altitudes

Finite-Volume regional (GATS, D. Fritts)
- compressible/anelastic, deep (~0-300 km) GW wave responses, interactions & instabilities

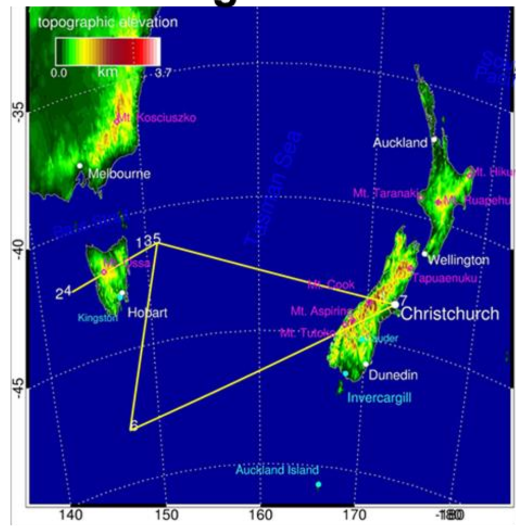
Spectral fine scale (GATS, D. Fritts)
- GW interactions, instabilities, and turbulence

DEEPWAVE Flight Forecasting
- successful "Dry Run" exercise 5-15 Aug. 2013
- major contributors – NOGAPS, COAMPS, ECMWF

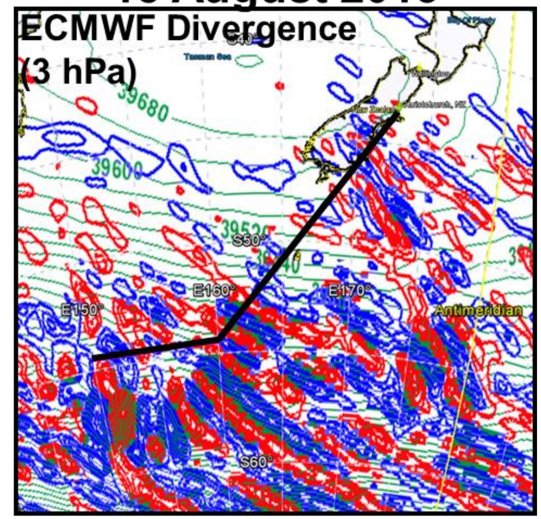
New Zealand Flight
8 August 2013



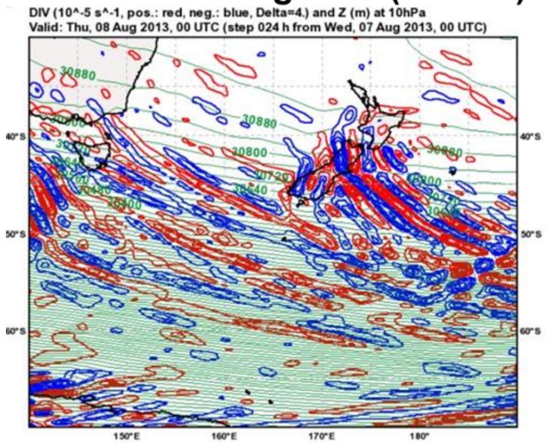
Tasmania Flight
10 August 2013



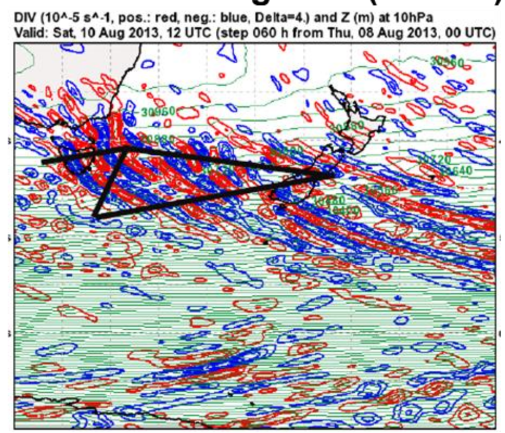
S. Ocean Flight
15 August 2013



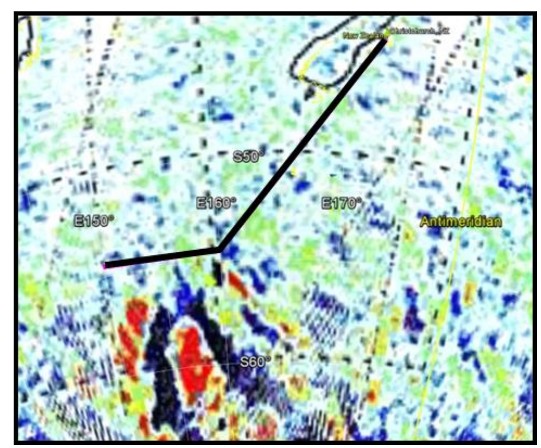
ECMWF Divergence (10 hPa)



ECMWF Divergence (10 hPa)



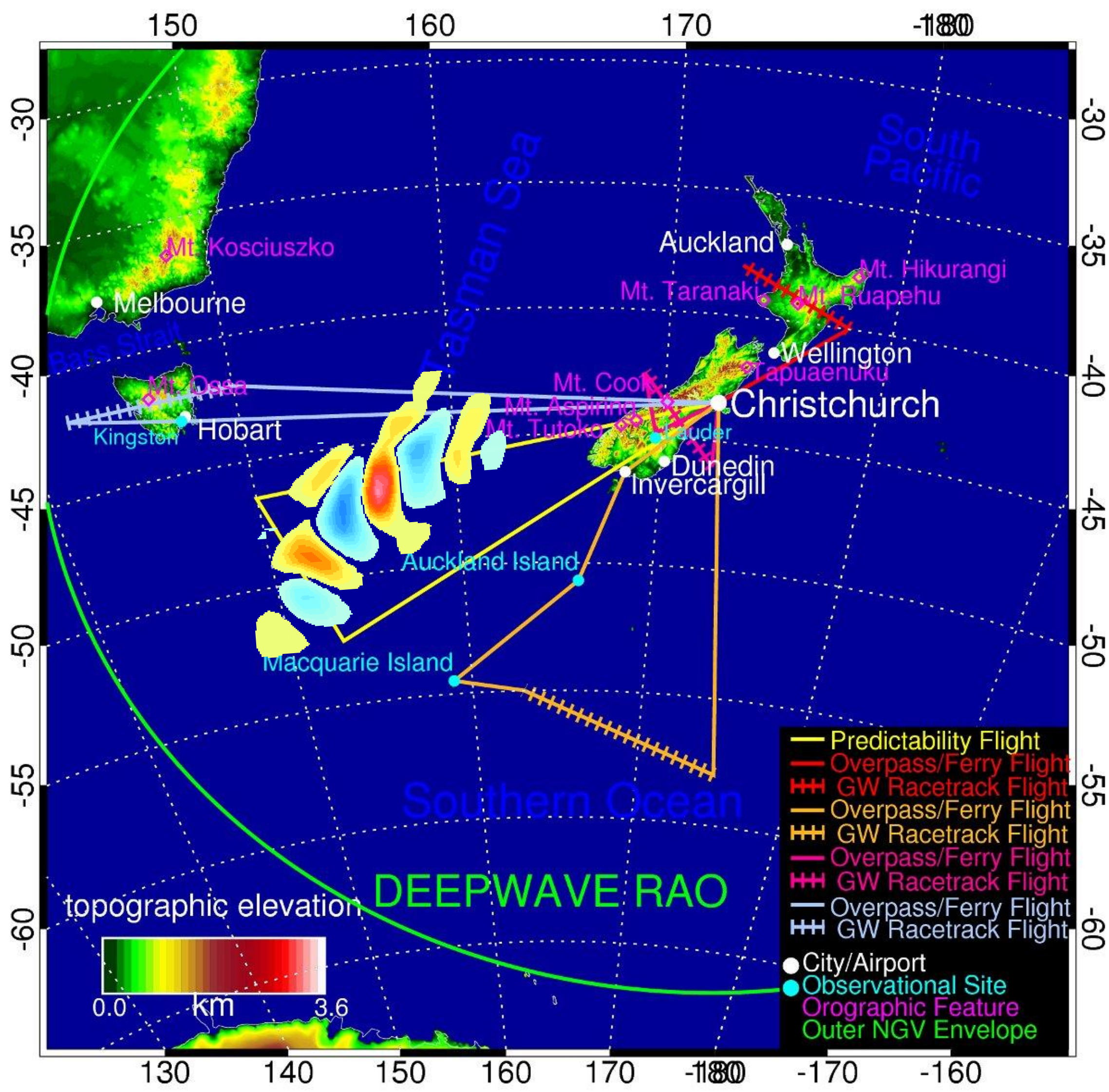
AIRS Radiances (3 hPa)



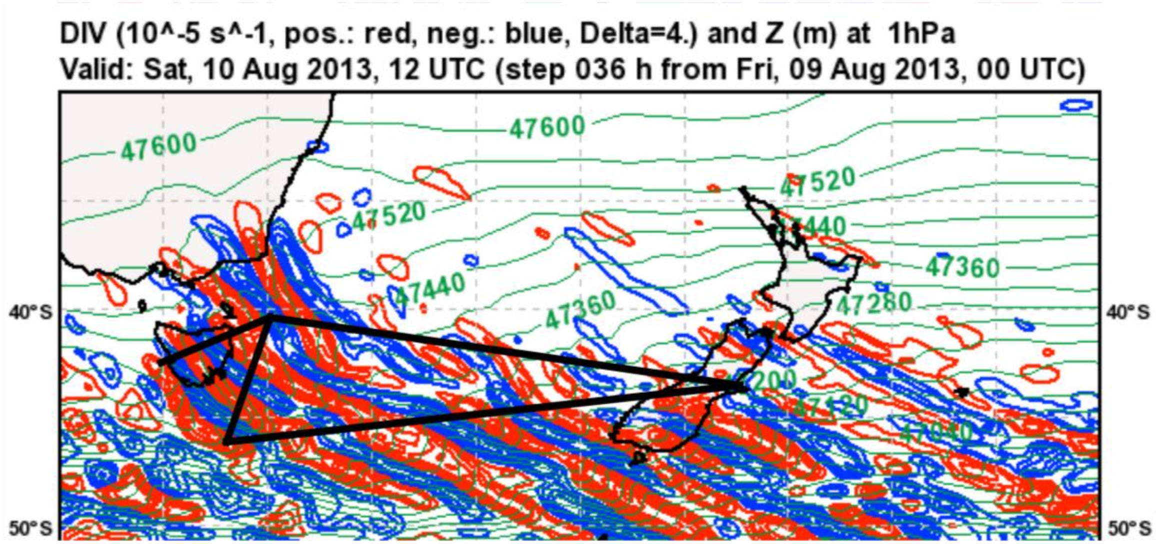
DEEPWAVE "upstream" predictability flights

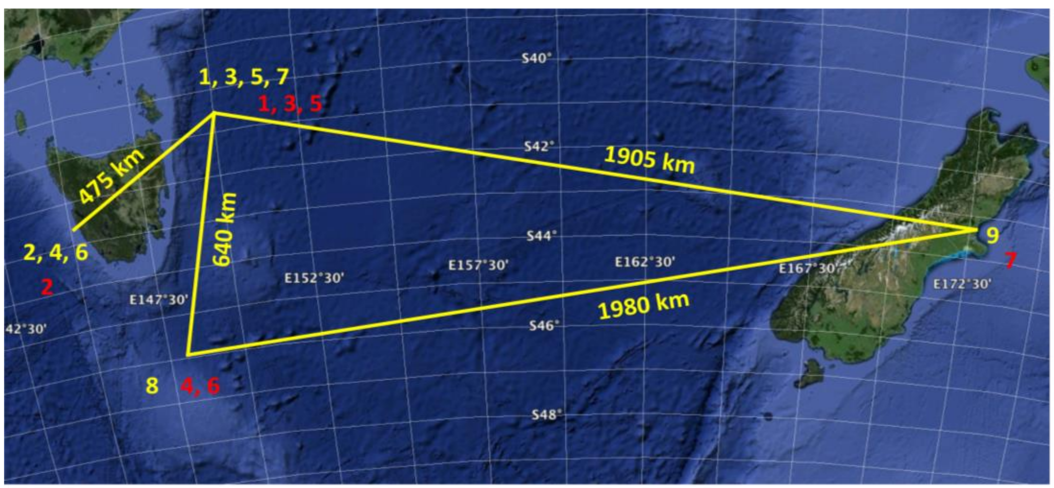
NGV "predictability" flights will target upstream sites anticipated to have structures that project strongly onto MW responses ~24-48 hr later

Subsequent MW flights will assess predictability skill



DEEPWAVE "mountain wave" flights





Waypoints:

1:	150E, 40.5S
2:	145E, 42.5S
8:	148E, 46S
9:	Christchurch

Yellow flight plan ~7375 km ~3982 nm
Red flight plan ~6755 km ~3648 nm

Flight altitudes:
- to WP1: max efficiency
- over TAS: staggered altitudes
- return from WP3: max efficiency

Dropsondes:
- upstream over TAS
- frequent sampl. on return from WP3

DEEPWAVE science (all)

We anticipate a wide range of collaborative studies involving:

- **analyses of DEEPWAVE measurements**
- **modeling of observed dynamics**
- **merging and comparisons of analyses, modeling, & satellite meas.**

COAMPS / WRF mesoscale modeling (Doyle, Smith, Dörnbrack)