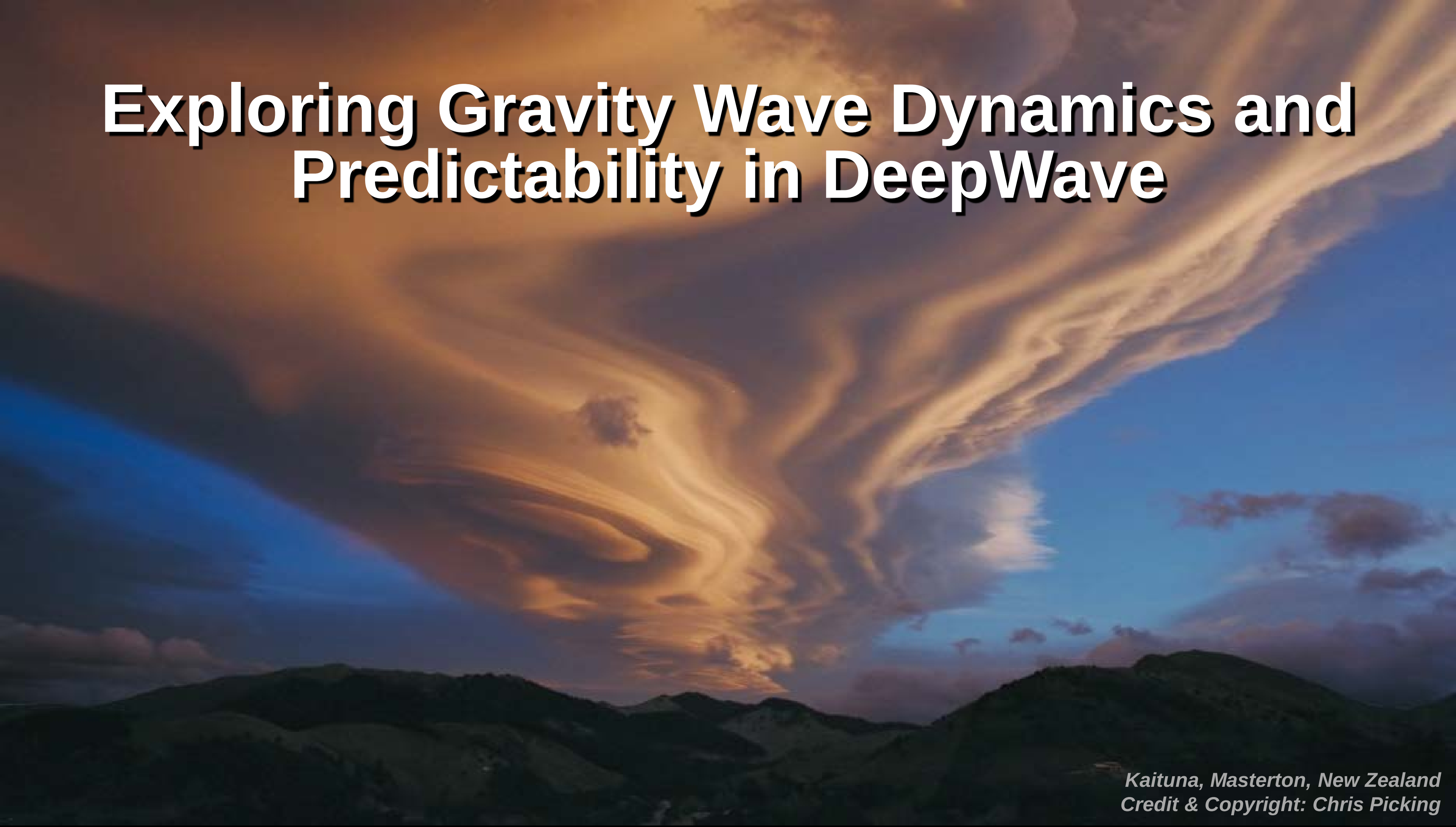
Exploring Gravity Wave Dynamics and Predictability in DeepWave



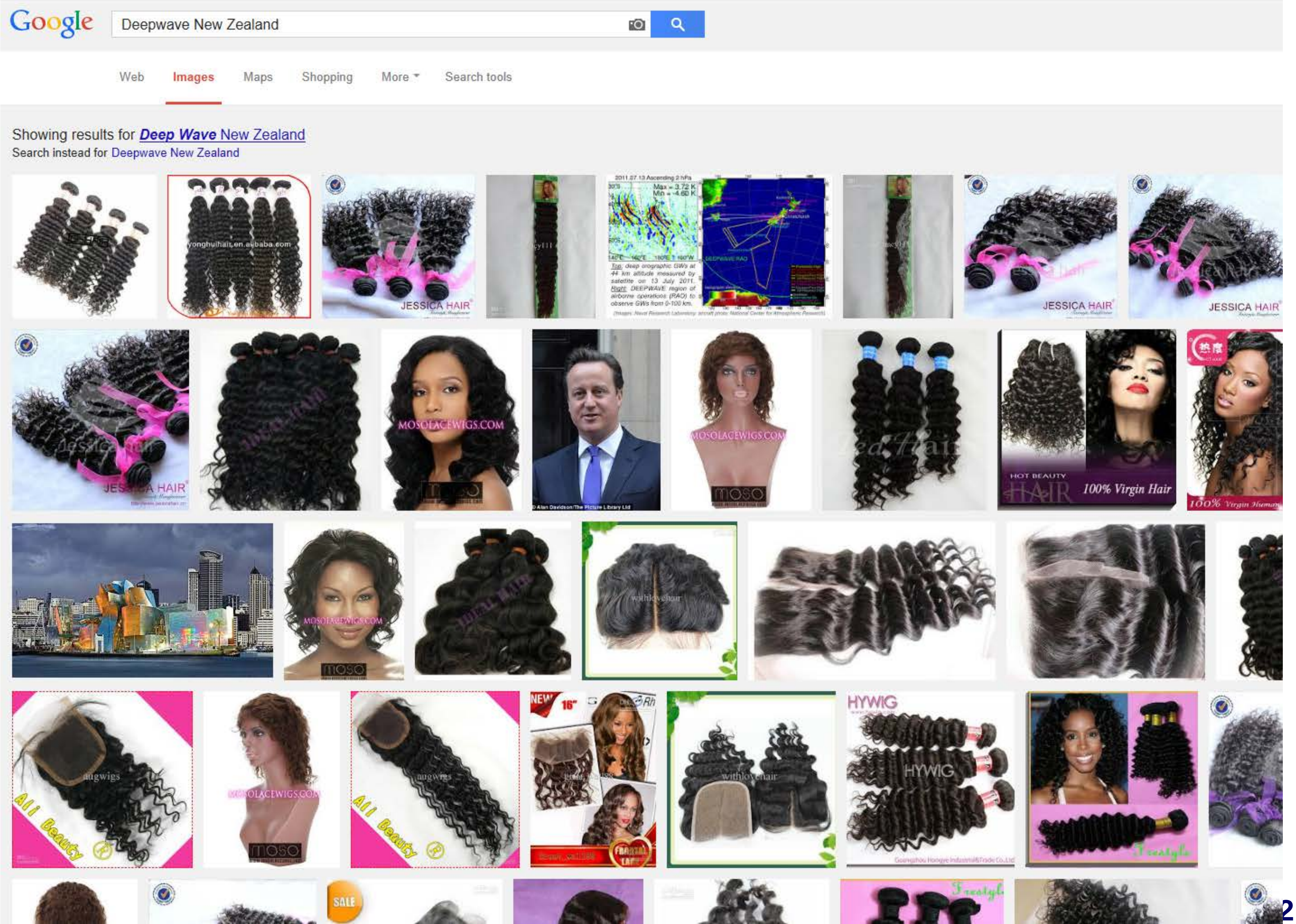
Kaituna, Masterton, New Zealand
Credit & Copyright: Chris Picking

James D. Doyle[1], David C. Fritts[2], Ronald B. Smith[3], Stephen D. Eckermann[4], Mike Taylor[5]

[1]Naval Research Laboratory, Monterey, CA
[2]GATS, [3]Yale, [4]NRL-Wash. DC, [5]Utah St.

Acknowledgements: NSF, NRL, NCAR, DeepWave Team

What is DeepWave?



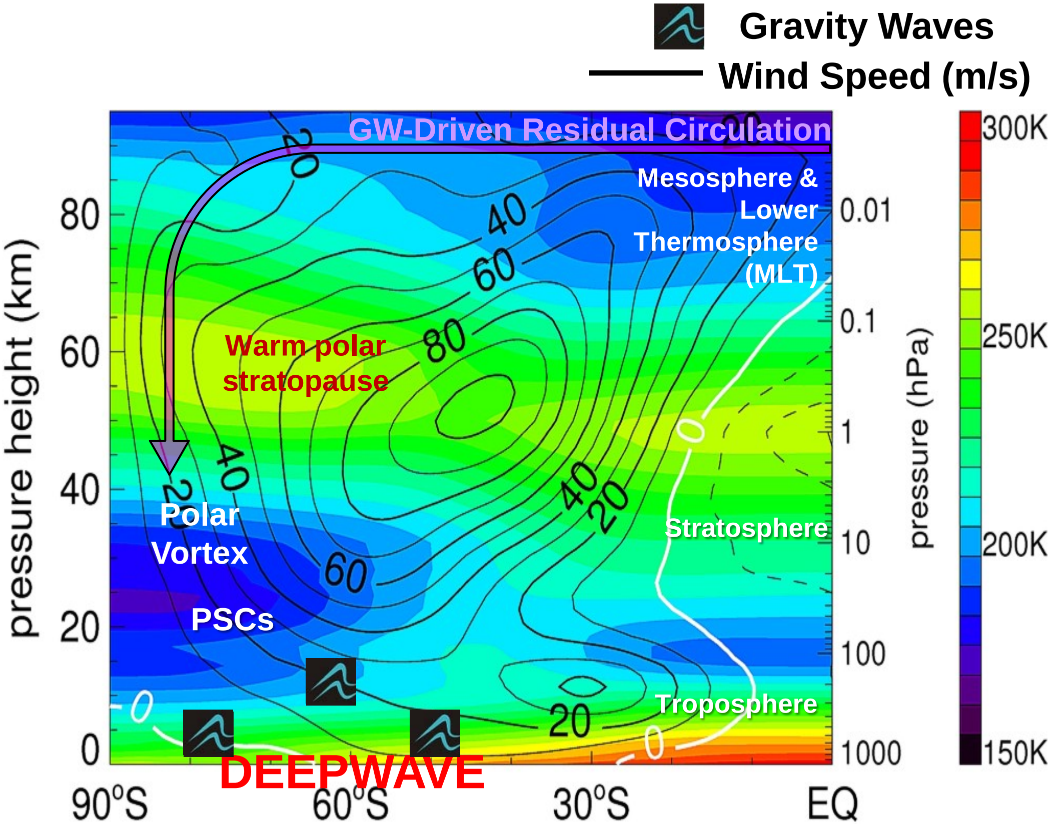
Showing results for ***Deep Wave*** New Zealand

Search instead for Deepwave New Zealand

What is DeepWave?

The DEEP propagating gravity WAVE (DEEPWAVE) initiative is a comprehensive, airborne and ground-based measurement and modeling program centered on New Zealand and focused on providing a new understanding of GW dynamics and impacts from the troposphere through the mesosphere and lower thermosphere (MLT).

DEEPWAVE will study these major GW influences on circulation, climate, variability, & predictability from 0-100 km altitude in an ideal natural laboratory



What is DeepWave?

- GWs account for main vertical energy & momentum transport at all levels
- The important GWs are not resolved by satellite measurements or GCMs
- GCM parameterizations of GWs are known to be seriously deficient
- Better GW parameterizations require improved understanding of complex GW dynamics via coordinated measurements and modeling
  - Lead to improved predictions of weather & climate

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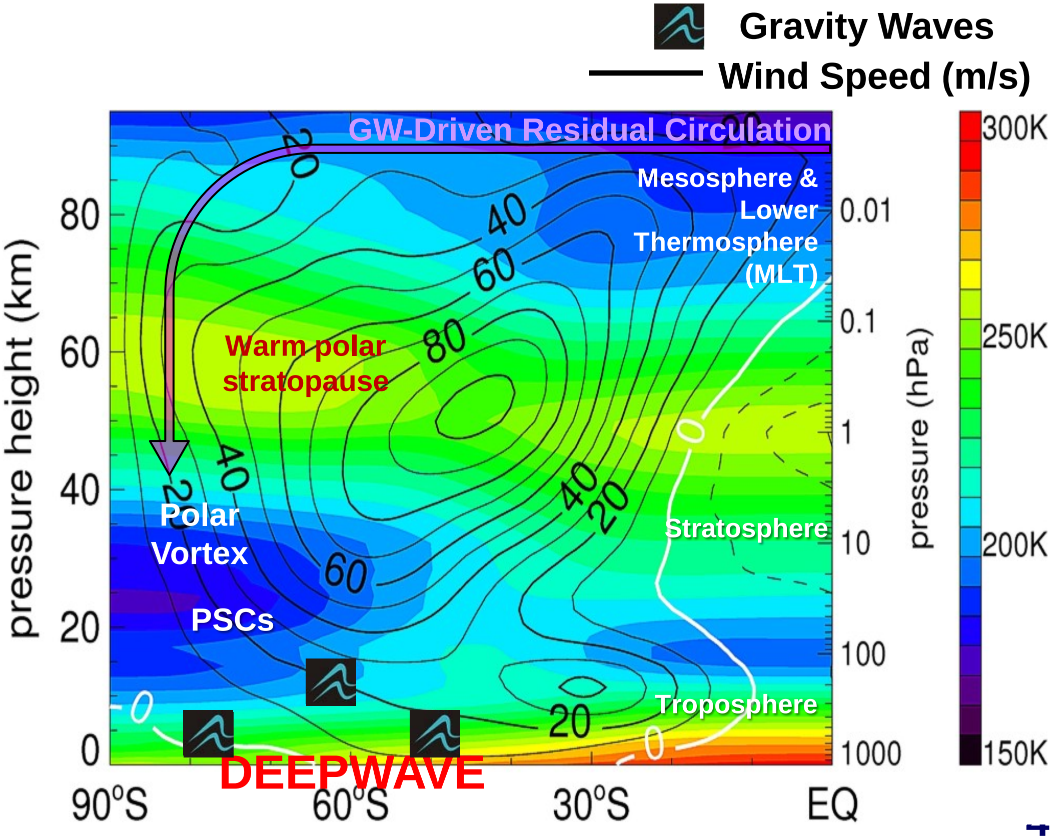

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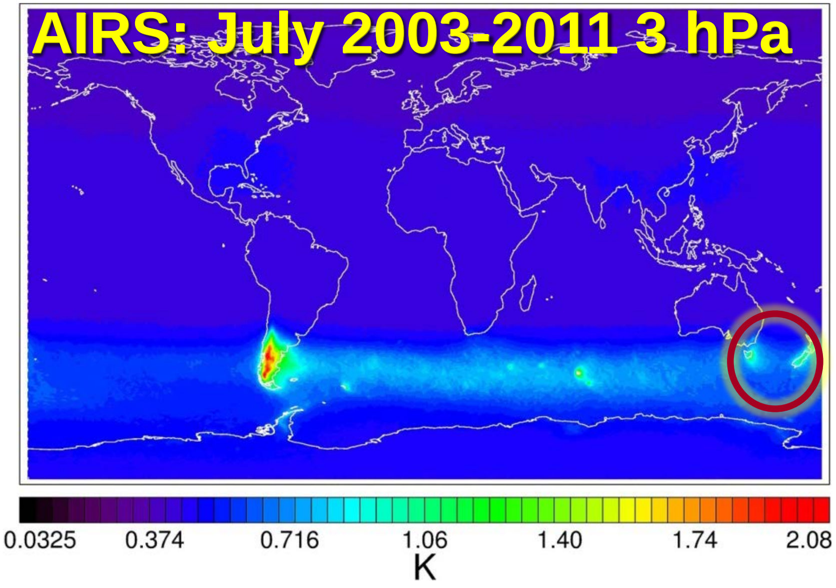

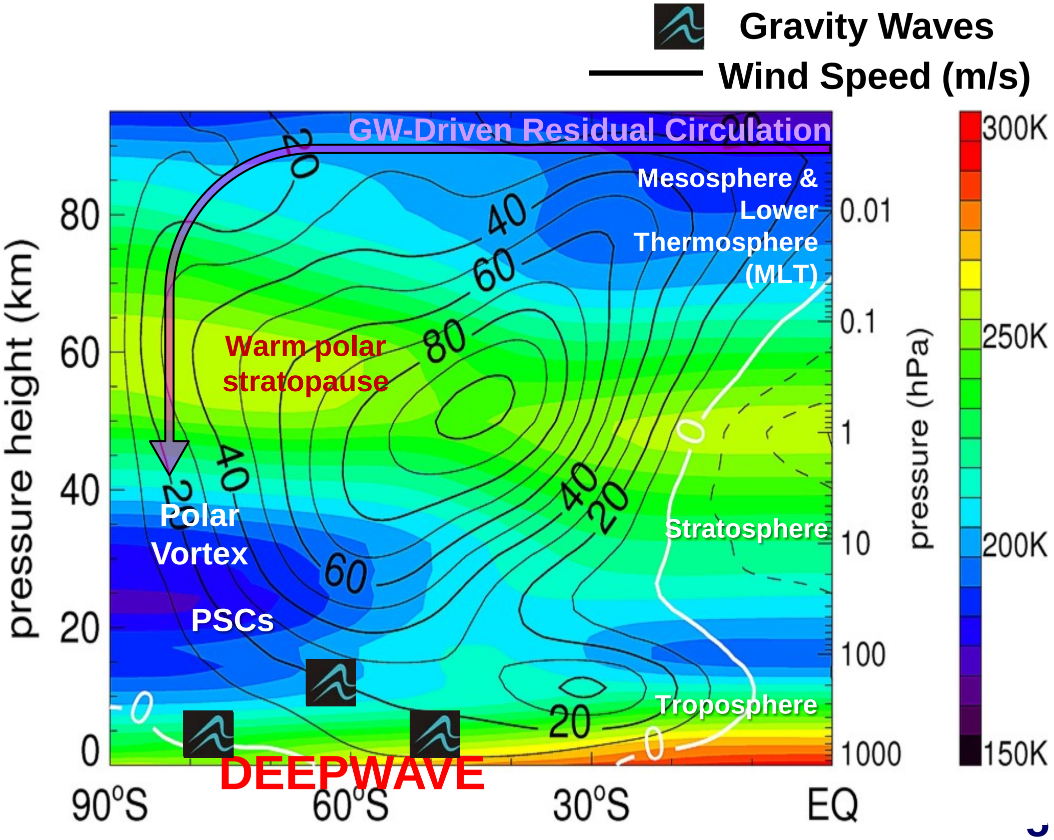

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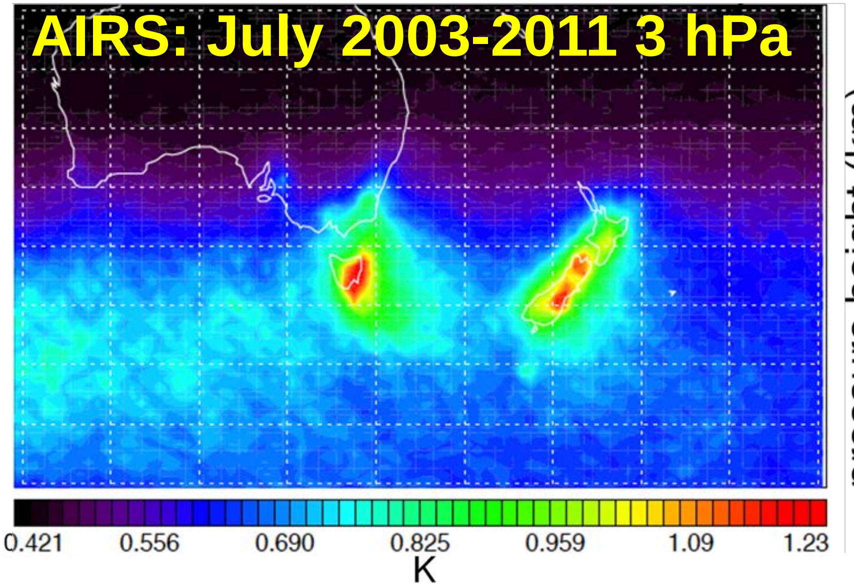
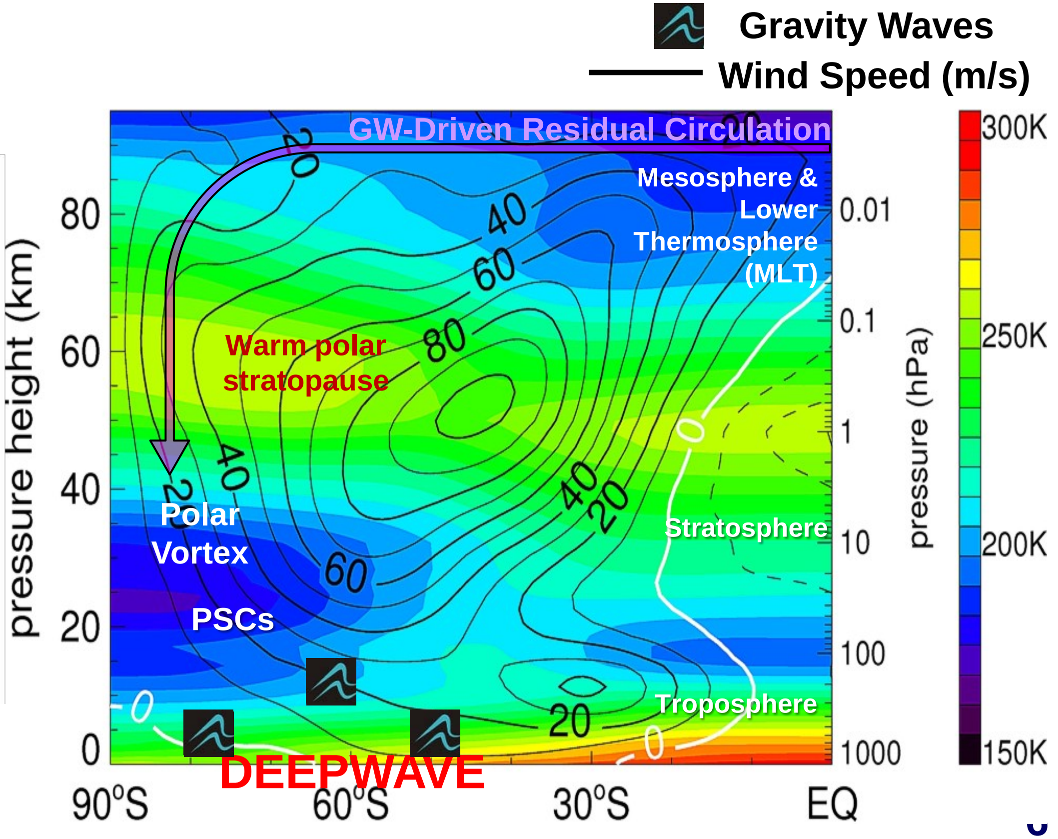
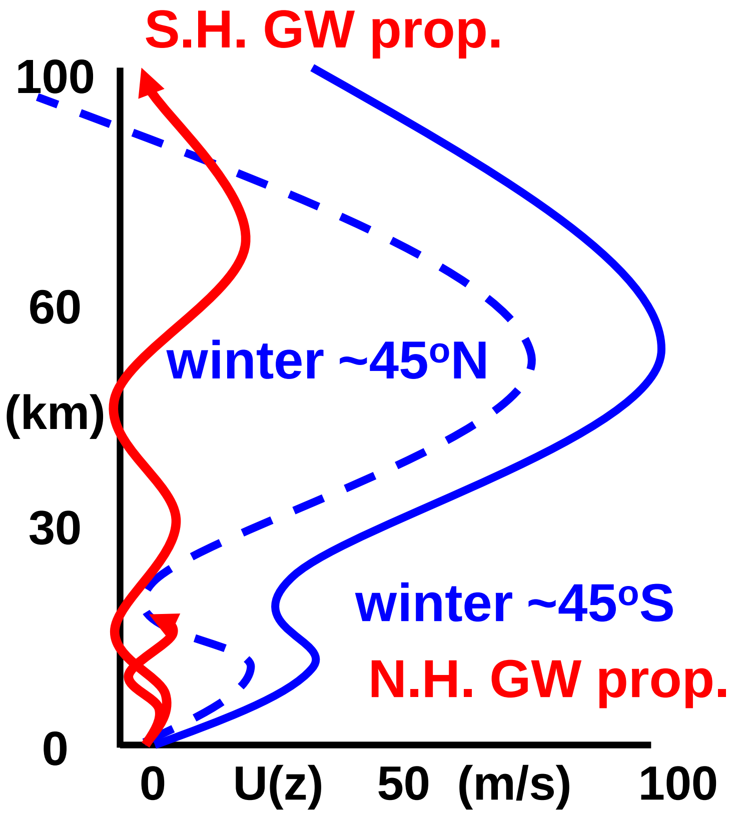




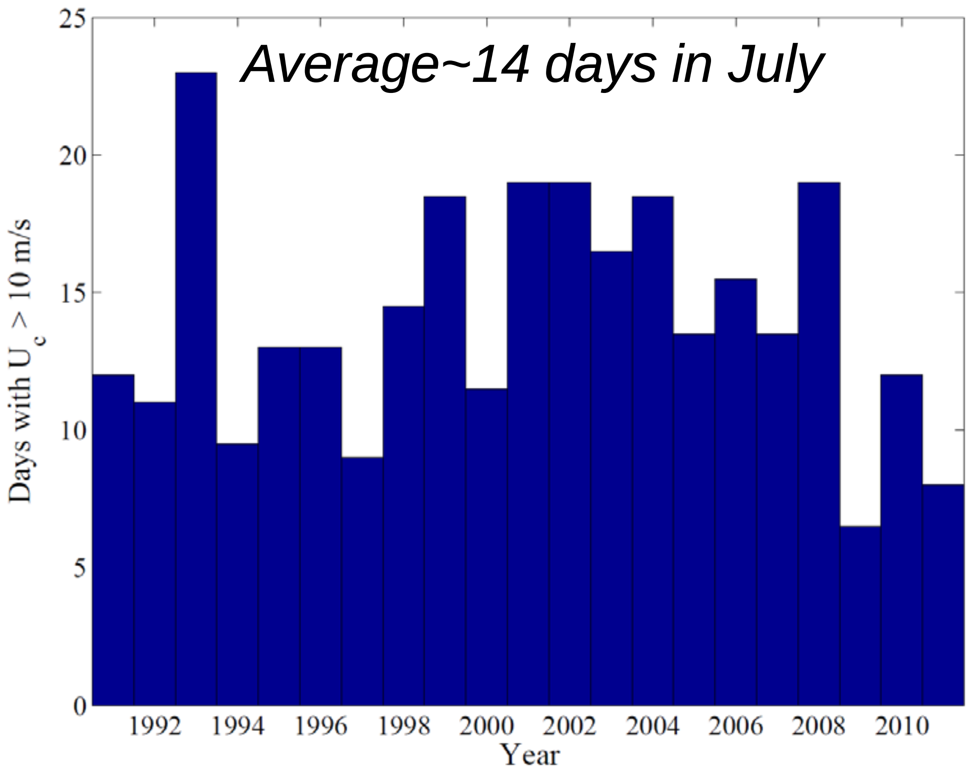
Deep GW Propagation over New Zealand

What Factors Enable GWs to Achieve Large Amplitudes in the Southern Hemisphere Stratosphere and Above (MLT)?

Zonal winds differ from Northern Hemisphere to S. Hemisphere



Frequency of 700 hPa U>10 m s^{-1}
Invercargill, New Zealand
ERA Reanalysis (July 1991-2011)



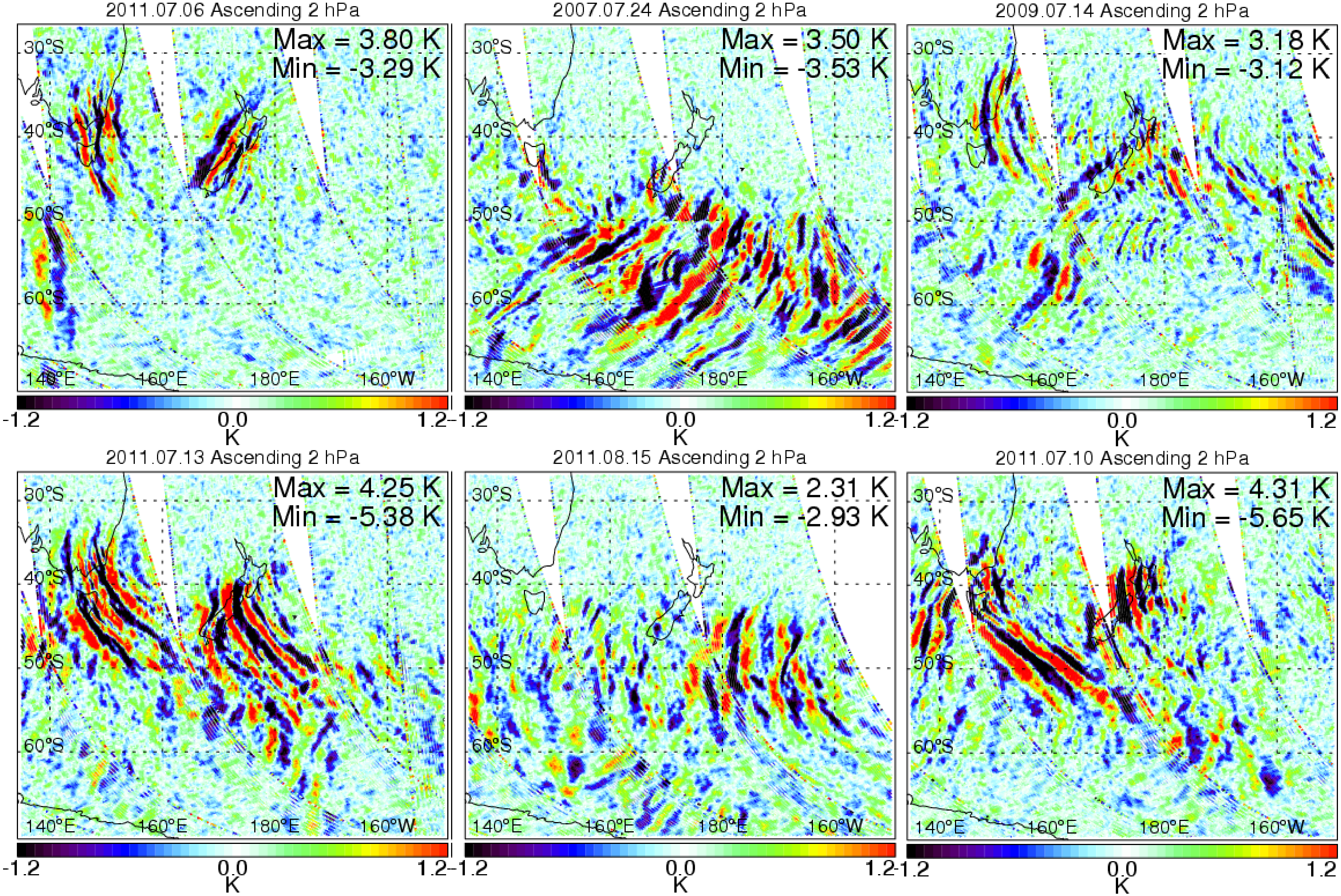
- Mountain wave propagation to high altitudes is common in S. Hemisphere.
- Strong flow over New Zealand (and Tasmania) is a prominent GW source.

Why the New Zealand & Southern Oceans?

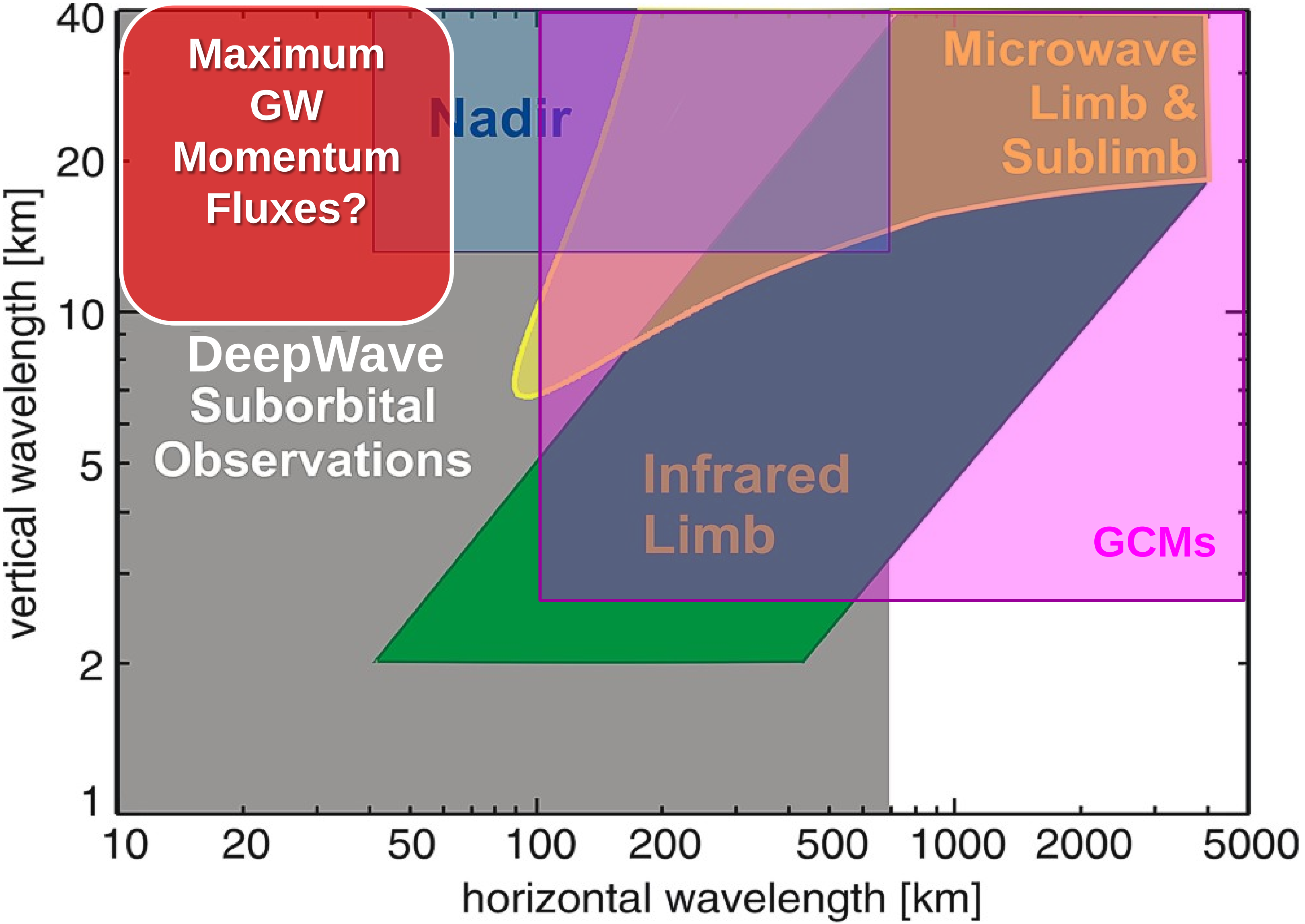
Rich Prevalent Large-Amplitude GW Structures

Examples from AIRS Radiances

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



Interrelating GWs Resolved by Satellite



- Which GWs are visible and invisible to different satellite remote sensors?
- What are the characteristics of stratospheric GWs and these “hotspots”?

DeepWave Instrumentation

NSF/NCAR GV Instrument Suite

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 hires GW & turbulence data
Dropsondes	**Wind & temperature profiles** • Δz~100 m	Below aircraft (0-13 km)	Flow environment, GW structure below flight
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 NGV
Rayleigh lidar	**Temperature profiles** • ±2-8 K, Δz~2 km, 20s integration (Δx~5 km) **aerosol** (PSC) **backscatter** • Δz~0.5-1 km	*T*~30-50 km *PSC* ~20-30 km	GW structure GW-induced PSCs
Sodium (Na) **resonance lidar**	**Na densities, temperature** • ±1-3 K, Δz~3-5 km, 20s int. (Δx~5 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, 5s integration (Δx~1 km)	~87 km	Two-dimensional GW structure, propagation directions

⬜ Existing Facility Instruments

🟧 New Facility Instruments being developed for DeepWave

DeepWave Instrumentation

NSF/NCAR GV Instrument Suite

Instrum	act
***In situ* instrum** (gust probe, GP	ires GW & ta
Dropsondes	ment, GW w flight
Microwave Temperature P (MTP)	above &
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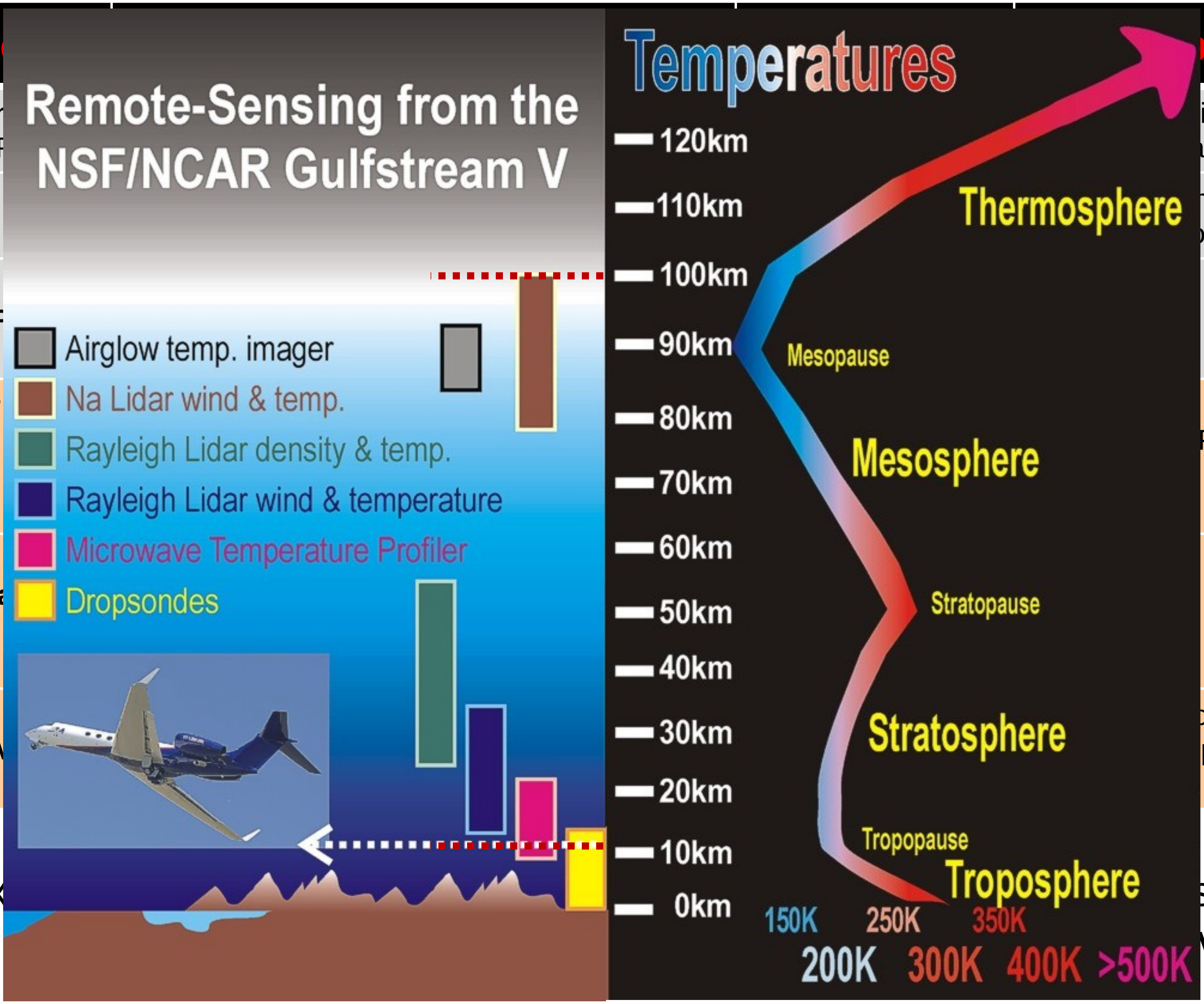


DeepWave Instrumentation

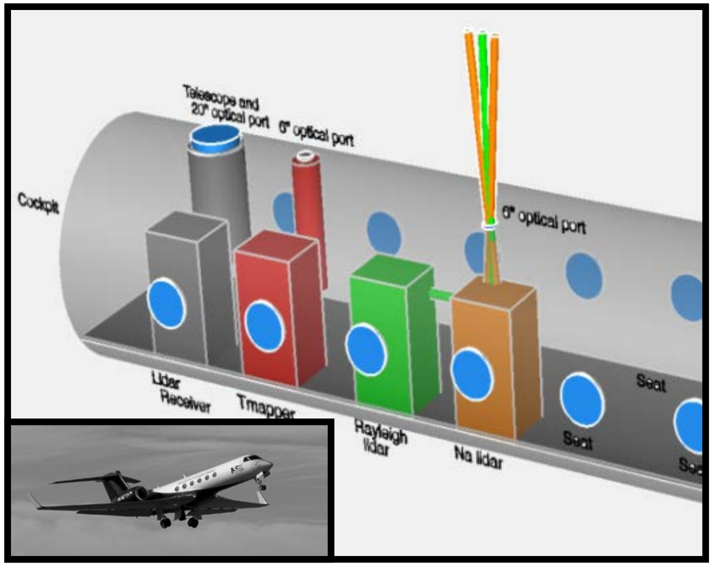
NSF/NCAR GV Instrument Test Flight (22-23 Feb 2013)

OH Intensity- Mesospheric Temperature Mapper (MTM) (Mike Taylor)

DeepWave Field Campaign

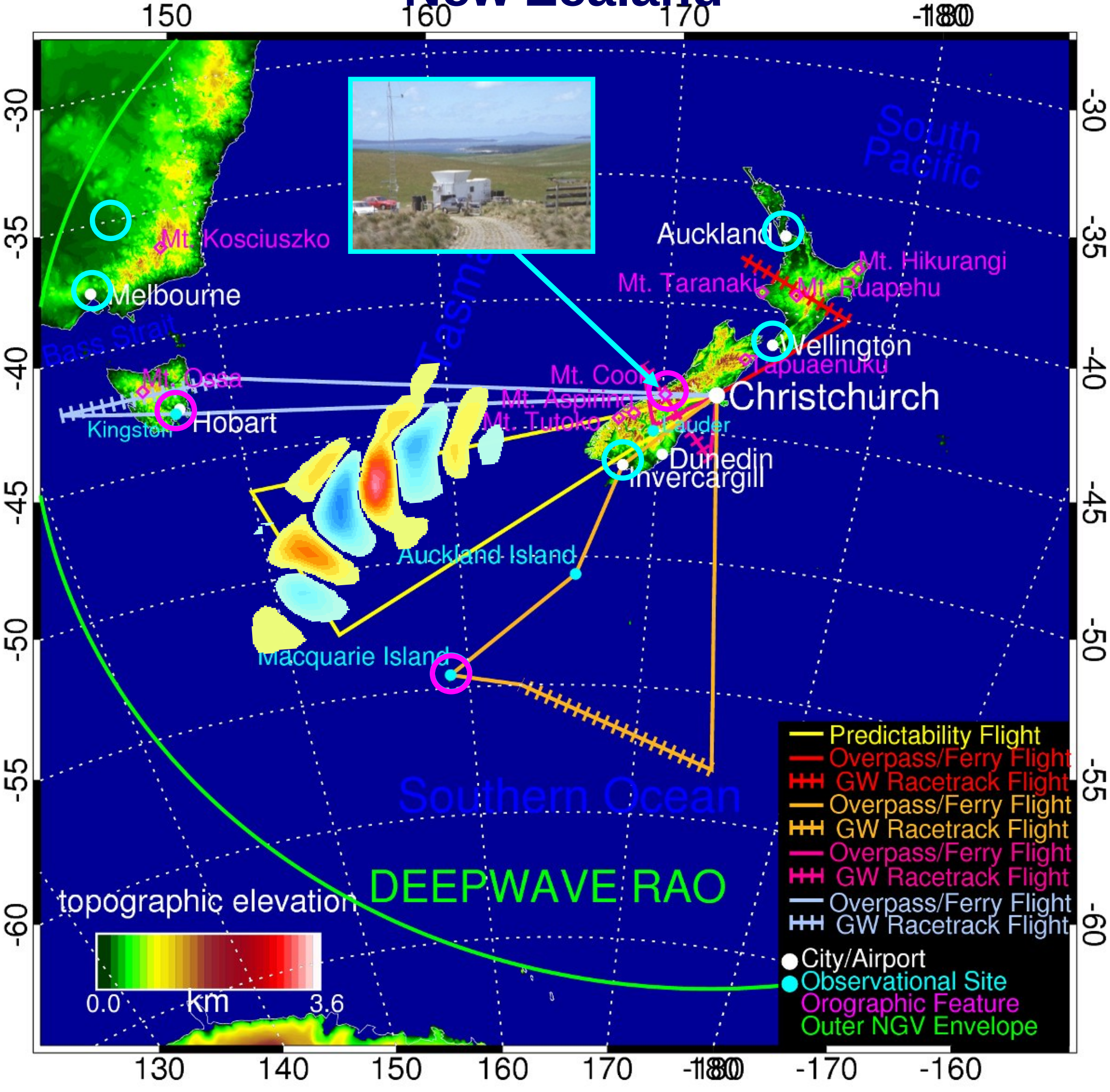
5 June – 21 July 2014

New NCAR-GV Up-looking Gravity Wave Instruments



DLR Falcon with Wind Lidar

Field Campaign in June-July 2014 New Zealand

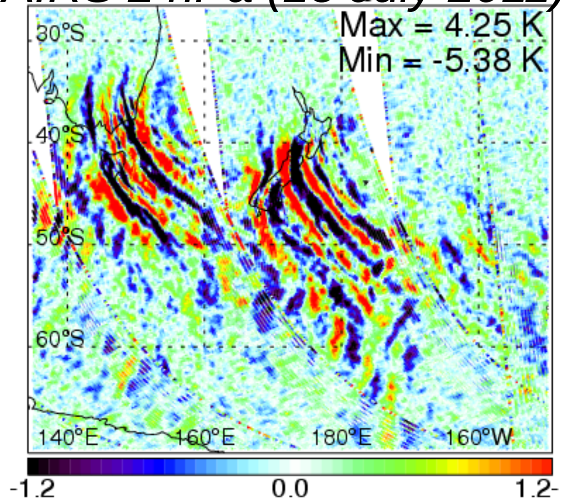


Predictability of Deep Propagating GWs

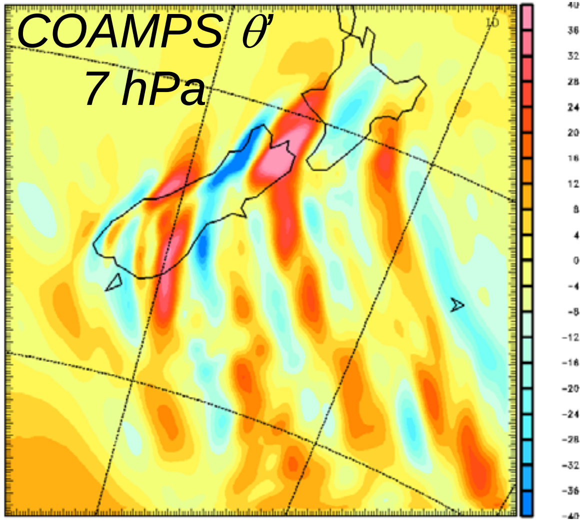
What are the predictability characteristics of deep propagating GWs?

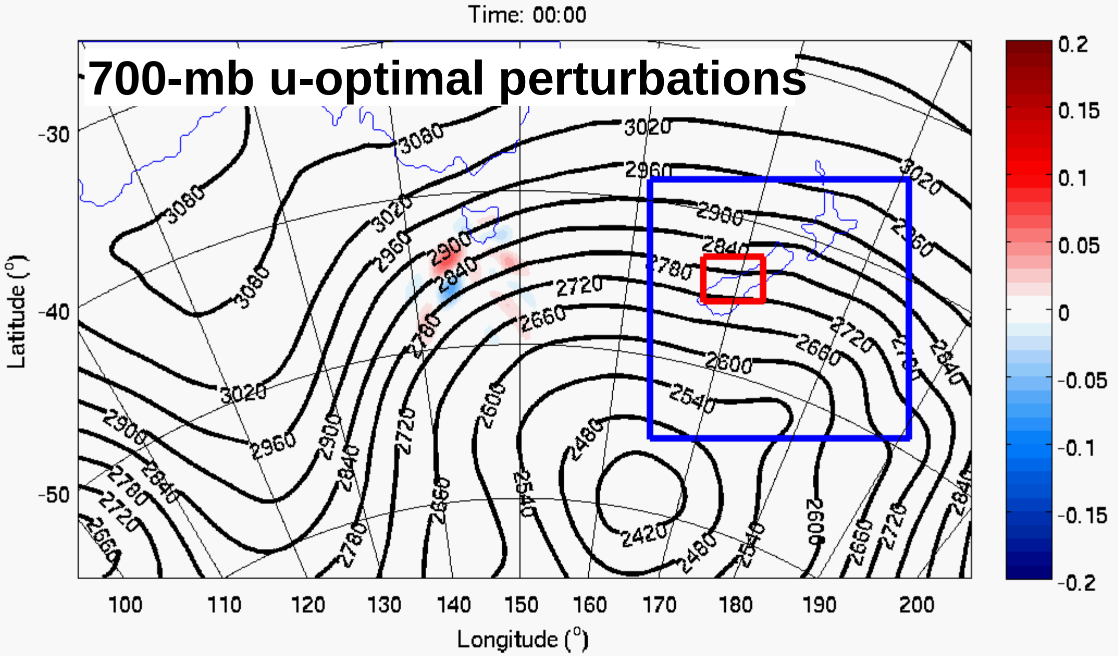
Adjoint allows for the mathematically rigorous calculation of forecast sensitivity of a response function to changes in the initial state

AIRS 2 hPa (13 July 2011)



12Z 13 July 2011 (24 h)

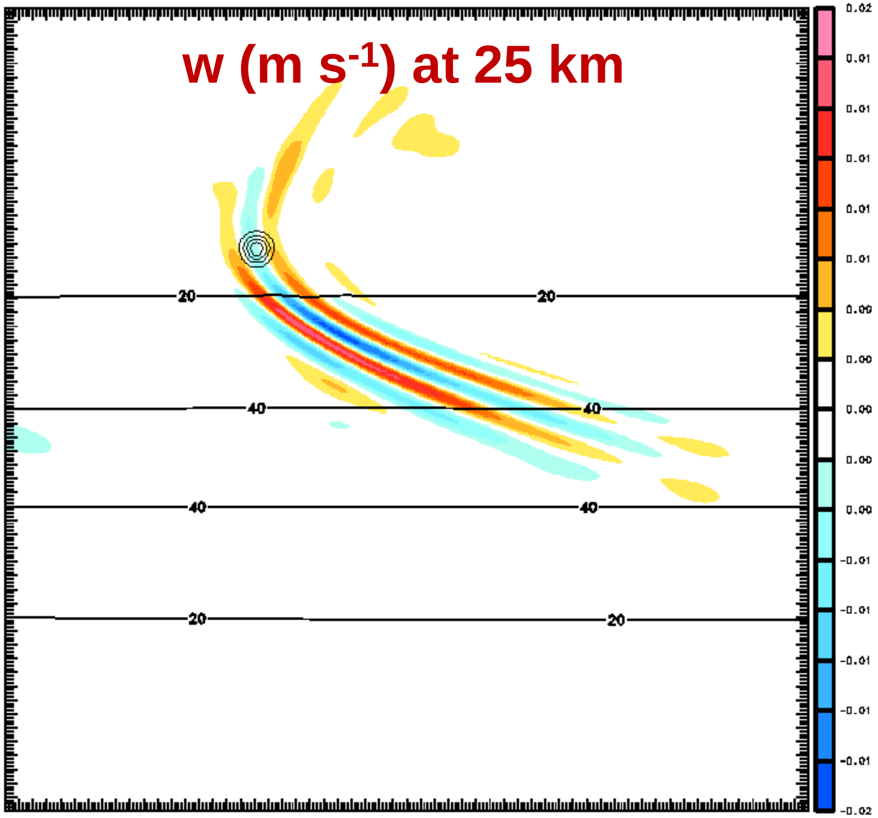


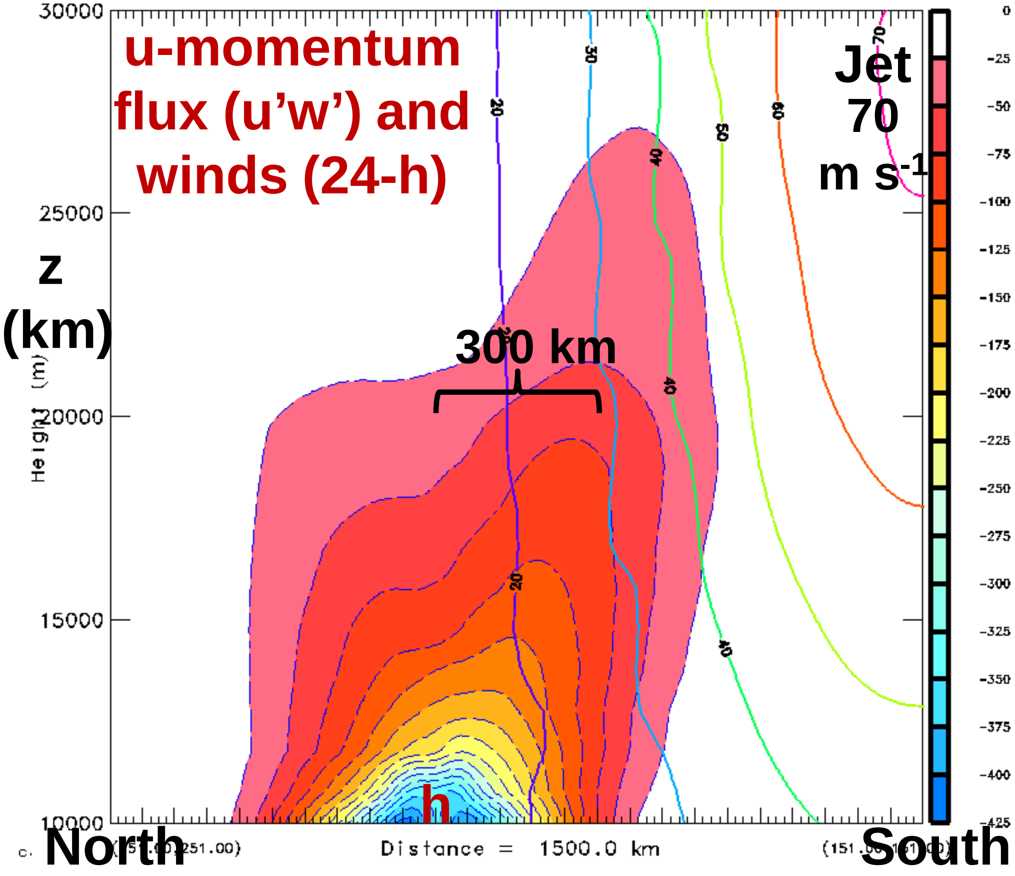


- Adjoint is used to diagnose sensitivity using a kinetic energy response function (1 km above mtn.)
- Sensitivity ~1200 km upstream near trough.
- Moisture & temp. are most sensitive variables.
- Adjoint optimal perturbations lead to strong wave propagation (refracted waves south of NZ)

Gravity Waves in Sheared Flow

Idealized Shear Experiments

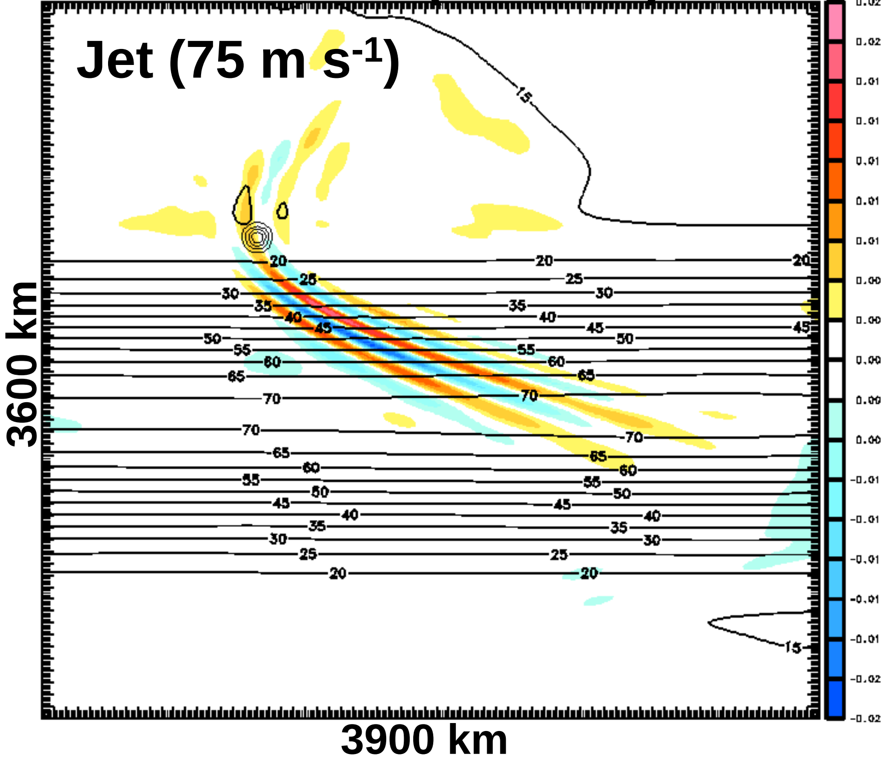




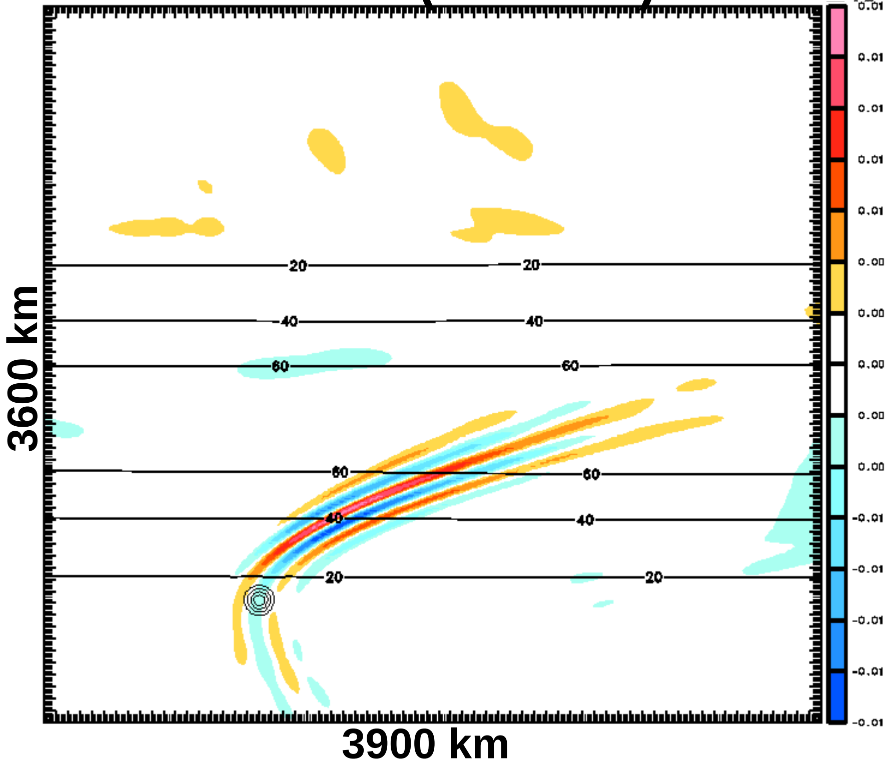
- Role of horizontal shear often is not considered in GW studies.
- Idealized simulations of gravity waves in balanced shear (Δx=15 km)
- Flow over Gaussian hill (north of jet) leads to vertically propagating waves that are refracted by the horizontal shear in the stratosphere.
- Zonal momentum flux in the stratosphere shows refraction due to shear.

Gravity Waves in Sheared Flow

Idealized Shear Experiments



Vertical Velocity
28 km (~10 hPa)

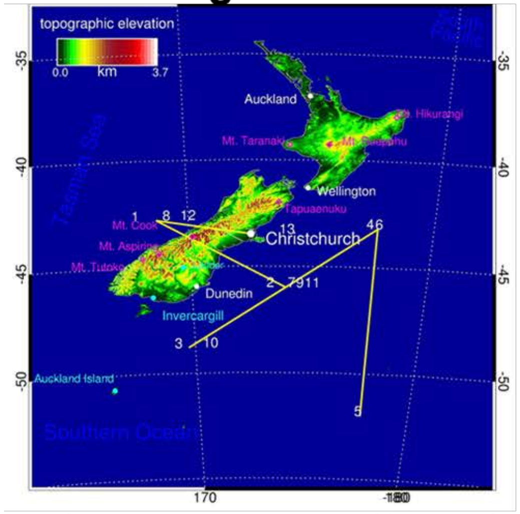


Vertical Velocity (65 m s^{-1} Jet)
28 km (~10 hPa)

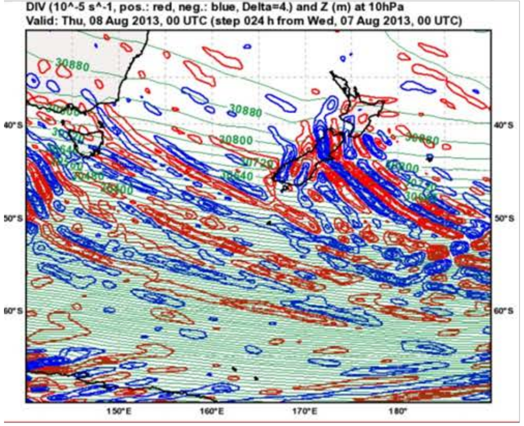
- Stronger shear leads to greater wave refraction and further propagation of the wave energy into the jet and downstream.
- Marked asymmetries are apparent in the waves due to the refraction into the jet and absorption at directional critical lines.
- None of these effects are included in wave drag parameterizations.

DeepWave Dry Run Exercise

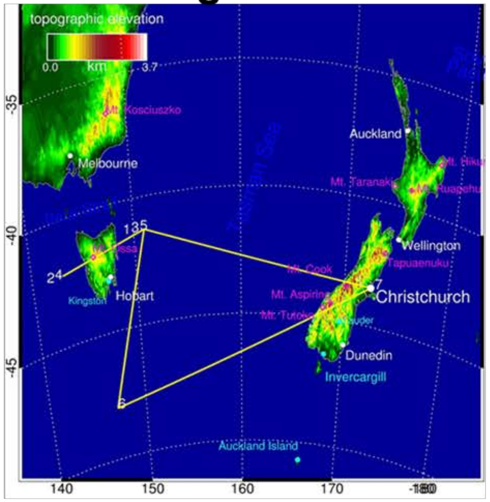
New Zealand Flight
8 August 2013



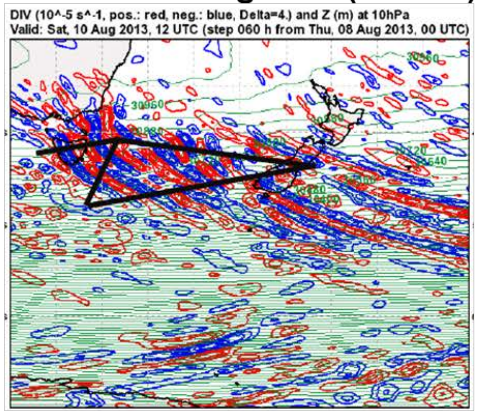
ECMWF Divergence (10 hPa)



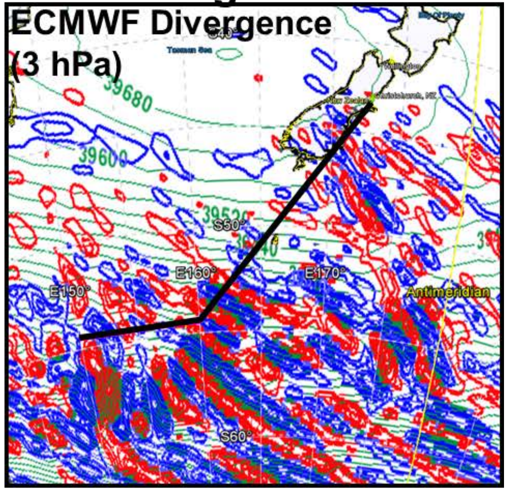
Tasmania Flight
10 August 2013



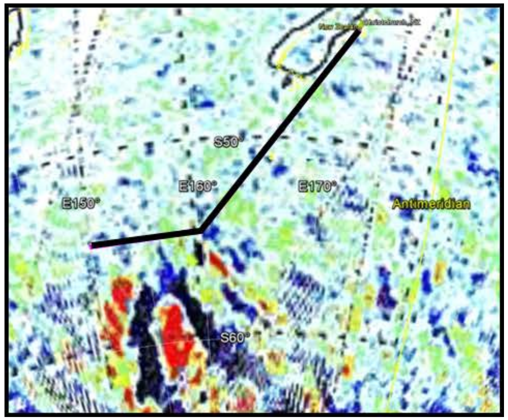
ECMWF Divergence (10 hPa)



S. Ocean Flight
15 August 2013



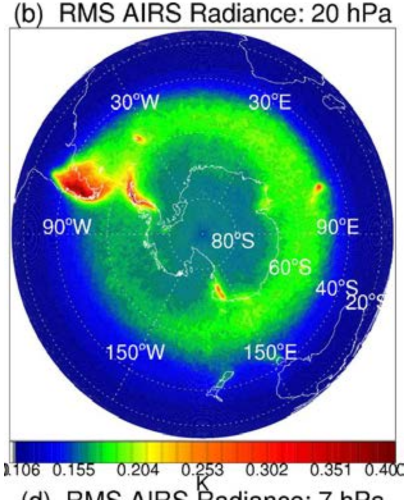
AIRS Radiances (3 hPa)

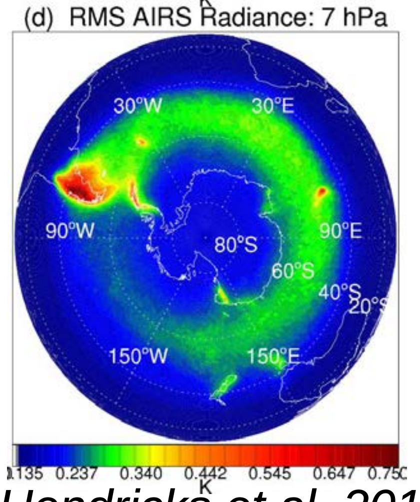


- Dry run exercise conducted from 5-15 August 2013.
- 5 “dry run flights” were proposed over NZ, Tasmania, and S. Ocean.
- Dry run was very useful to refine our observational strategy and procedures.

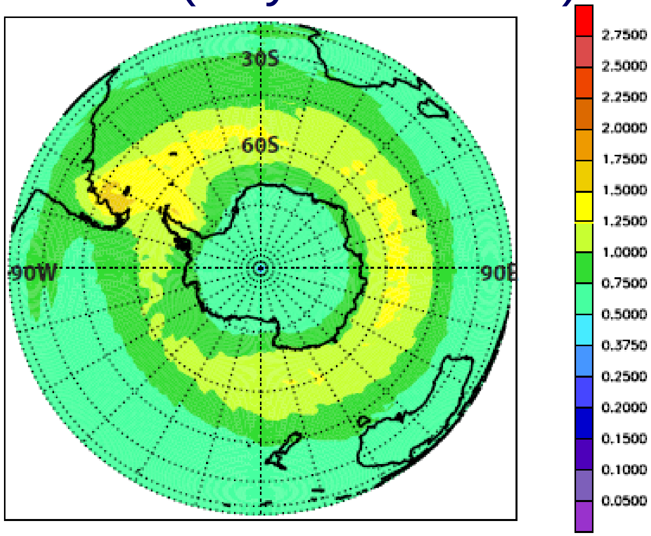
Gravity Wave Sources

AIRS Radiance (2003-2011)

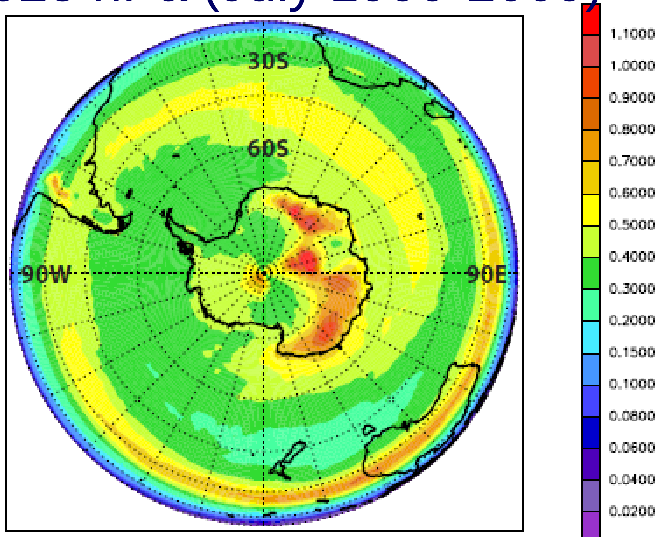

(b) RMS AIRS Radiance: 20 hPa


(d) RMS AIRS Radiance: 7 hPa

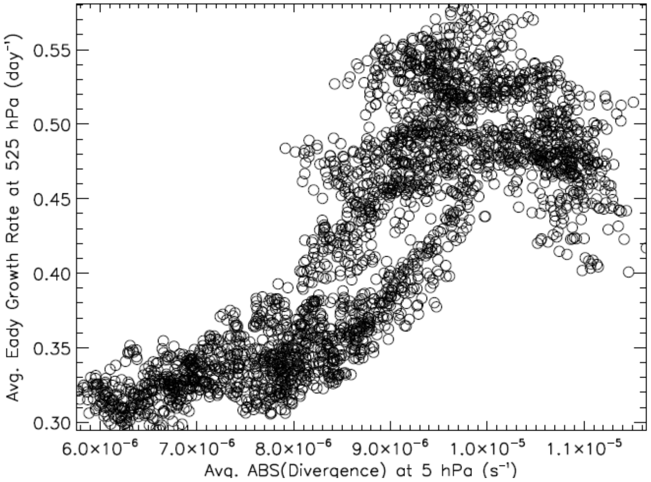
ERA divergence (10^{-5} s^{-1}) 5 hPa (July 1999-2009)



ERA Eady growth rate (day^{-1}) 525 hPa (July 1999-2009)



Correlation of the July average 5-hPa divergence with 525-hPa Eady growth rate (50-60°S)



Hendricks et al. 2014 (JAS)

- Eady growth rate and divergence (ECMWF reanalysis) correlation points to possible spontaneous GW emission sources from jets and baroclinic waves.
- What are the dominant sources that contribute to stratospheric GW activity?

Summary and Future Directions

- DeepWave will study, model, & parameterize GWs by observing and characterizing them over their *entire life cycle* (0-100 km) in a very active planetary “hot spot” (New Zealand, Tasmania, S. Ocean) [5 Jun–21 Jul ’14]
  - GW-resolving obs: NCAR GV, DLR Falcon, satellite, ISS, surface-based
  - Extensive forecast and post-analysis modeling & predictability component
- Horizontal shear fundamentally modifies stratospheric GW characteristics
  - Strong shear leads to GW ‘refraction’ and non-local GWD.
- Stratospheric GWs from multiple sources
  - Terrain-forcing and spontaneous GW emission from baroclinic waves & jets
- Predictability of stratospheric and MLT GWs is linked with tropospheric cyclones
  - Moisture and temperature perturbations lead to most rapid growth

Credit & Copyright: Chris Picking (Starry Night Skies Photography)