Exploring Gravity Wave Dynamics, Sources, and Predictability in DeepWave

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

James D. Doyle[1], P. Alex Reinecke[1], Carolyn A. Reynolds[1], Qingfang Jiang[1], Eric Hendricks[1], Stephen D. Eckermann[2], David C. Fritts[3], Ronald B. Smith[4], Mike Taylor[5]

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

NRL-Monterey DeepWave Objectives

Dynamics, Sources, Predictability

- **NRL-MRY DeepWave Objectives:**
  - **Dynamics:**
    - Influence of horizontal and vertical shear on gravity waves
    - Characterizing gravity wave sources (mountains, jet stream, convection etc.)
    - Tropopause effects (stability jump and shear)
    - Gravity wave characteristics (momentum flux, energy flux, launching conditions)
  - **Modeling Issues:**
    - Gravity wave drag parameterizations (especially non-local parameterizations)
    - Verification of explicit gravity wave simulations (and breaking)
  - **Predictability:**
    - Quantify initial condition sensitivity and predictability of wave launching and deep propagating gravity waves using ensemble and adjoint approaches
    - Links between stratospheric gravity wave predictability and tropospheric storms
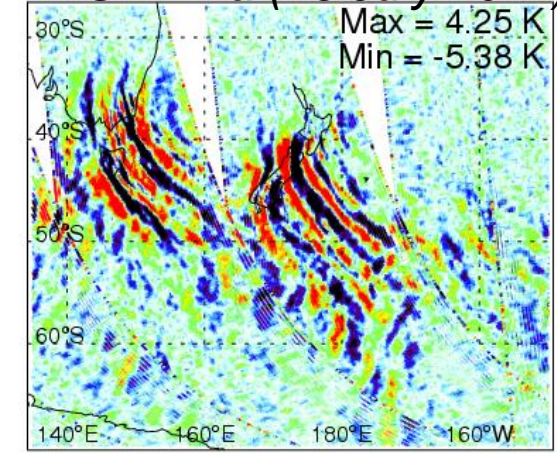- **Facilities**
  - NCAR GV: in situ, dropwindsondes (data assim., predict.), remote sensing
  - DLR Falcon: in situ, wind lidar
  - ISS: characterization of upstream conditions (predictability)
  - Satellite observations (e.g., AIRS), conventional radiosondes, surface obs.
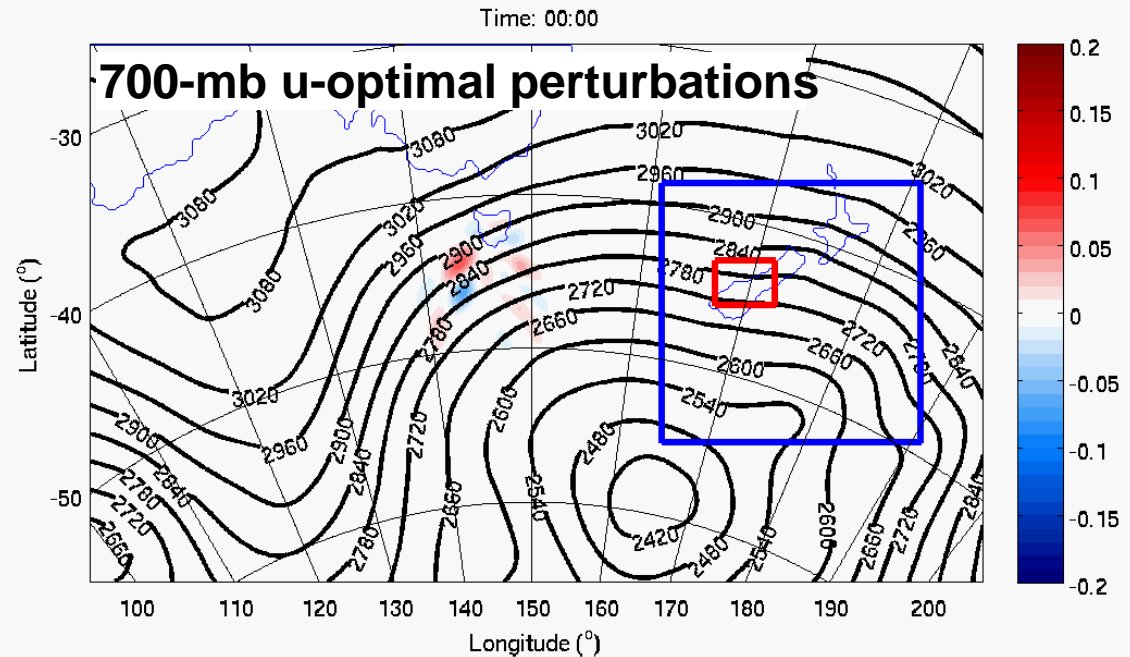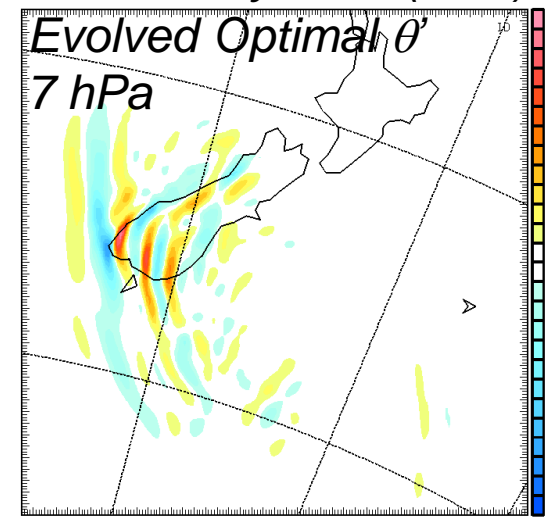
Predictability of Deep Propagating GWs

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)

Max = 4.25 K
Min = -5.38 K

12Z 13 July 2011 (24 h)

*Evolved Optimal θ'
7 hPa*

700-mb u-optimal perturbations

Time: 00:00

- Adjoint is used to diagnose sensitivity using a kinetic energy response function (lowest 1 km)
- Sensitivity located ~1200 km upstream (in coarse mesh over 24 h) near 700 hPa shortwave.
- Adjoint optimal perturbations lead to strong wave propagation (refracted waves south of NZ)

3

Predictability of Deep Propagating GWs

June-July 2010-2011 Mean for $U_{700\ hPa} > 10\ m\ s^{-1}$

Total Energy of Adjoint Optimal Pert. (0h)

600 nm
1200 nm
1800 nm
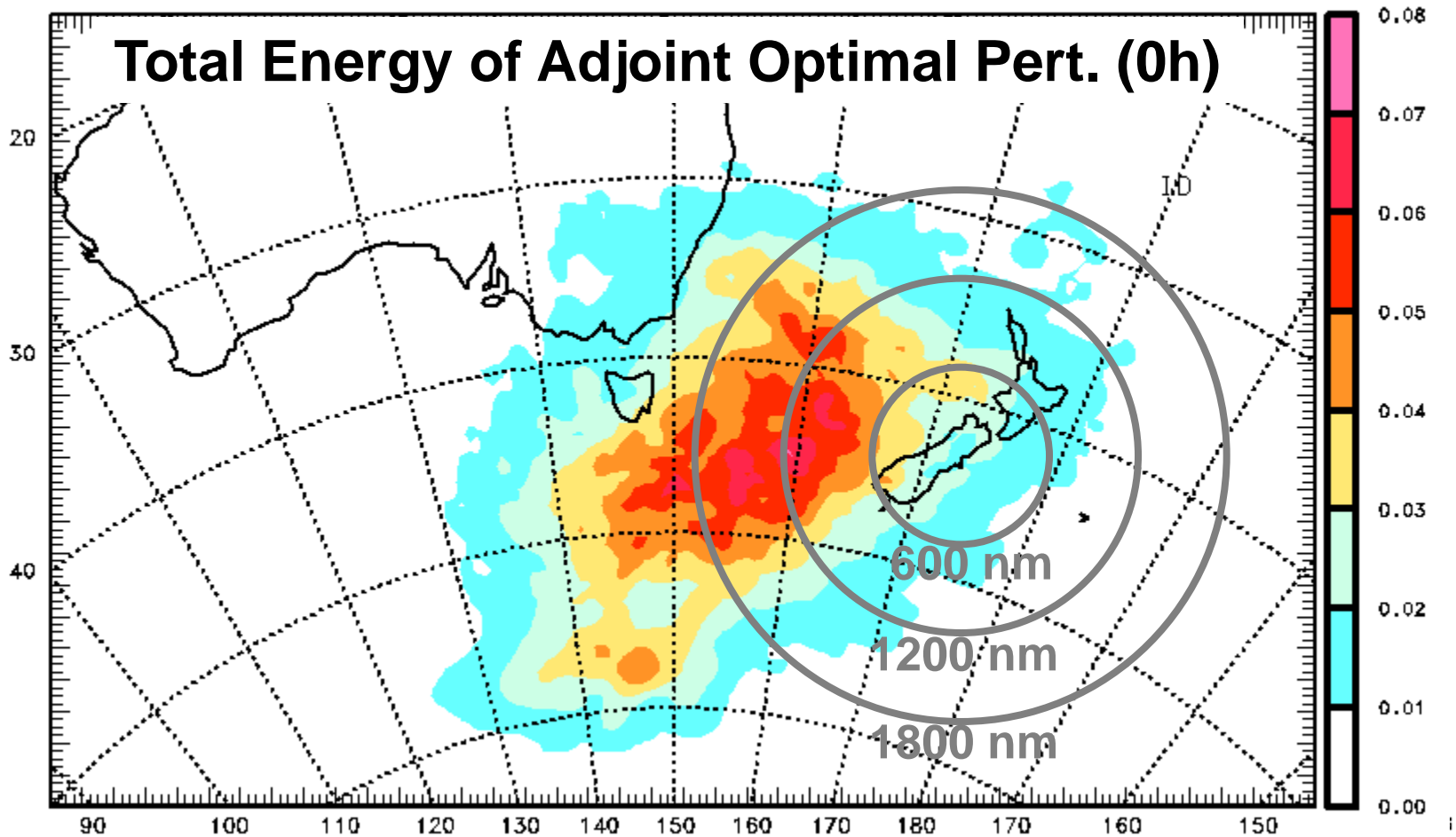
Mean 700-hPa sensitivity is location over the Tasman Sea to the west of New Zealand and very accessible for G-V (dropsondes) and Falcon (wind lidar) to perform targeted observing.
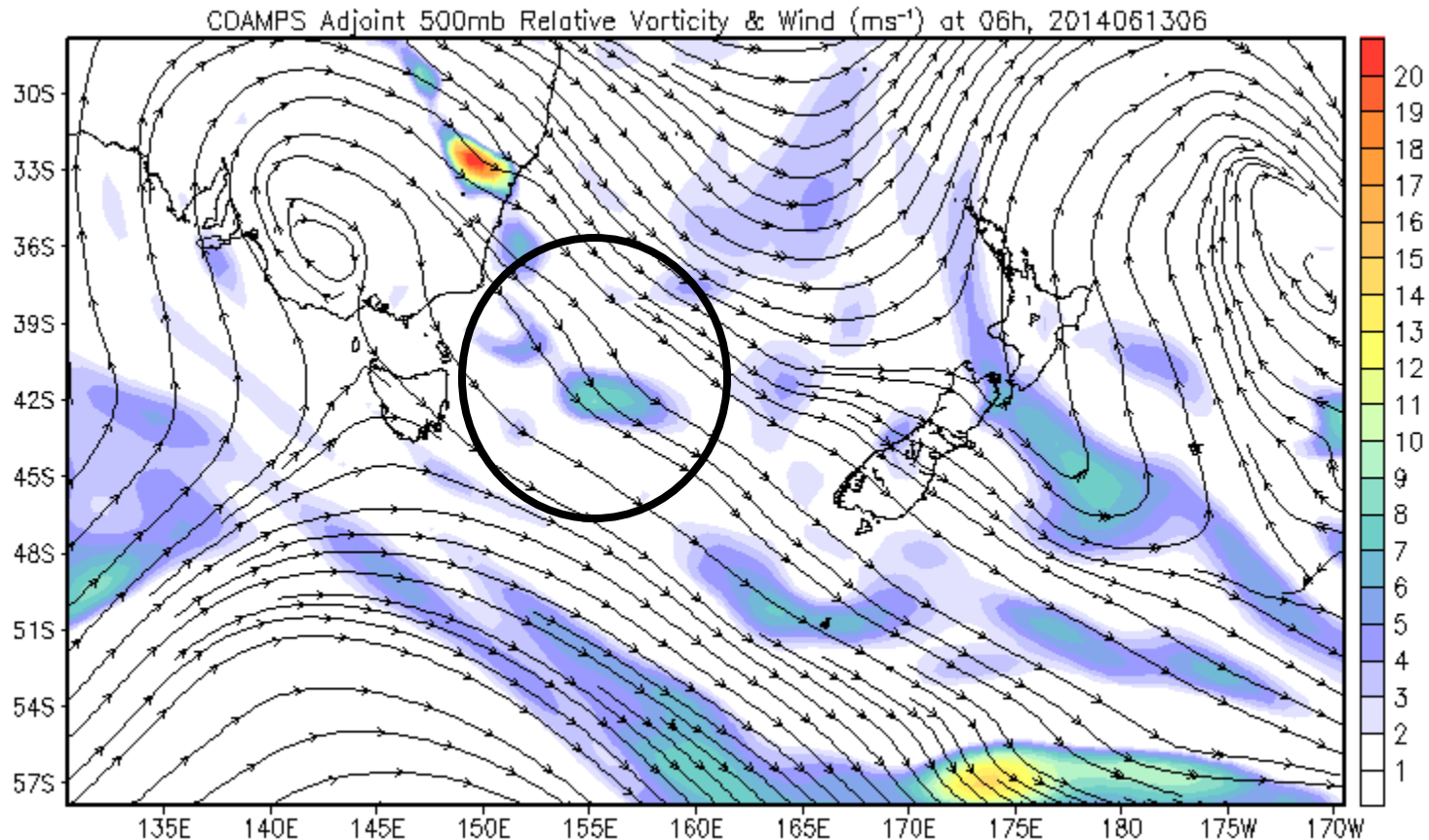
RF03 (IOP 3 Flight 1)

Summary

Objectives:

- **To sample a region of adjoint sensitivity upstream of the S. Alps prior to a GW event.**
- **To gain experience with predictability missions.**
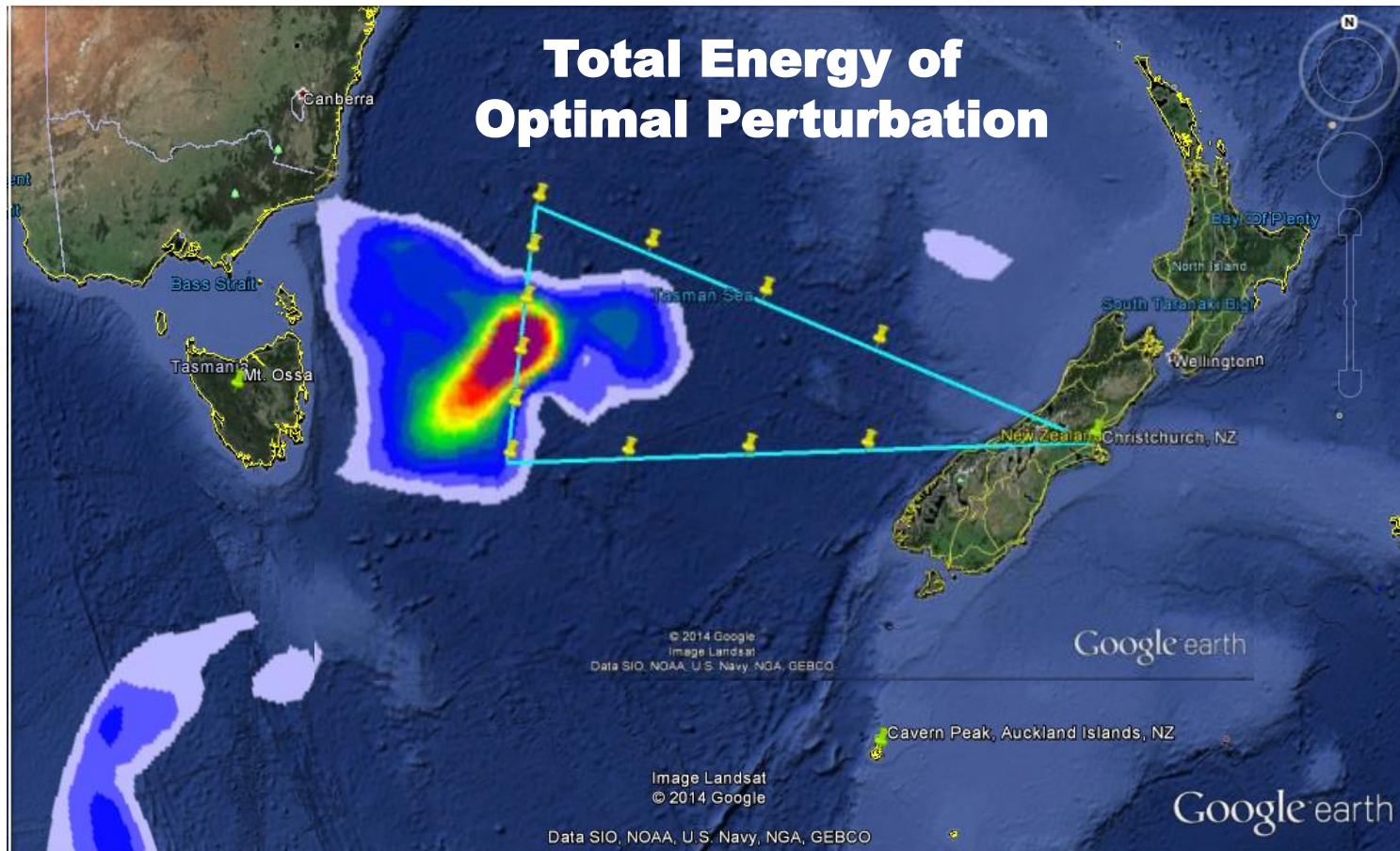
Total Energy of Optimal Perturbation

RF03 (IOP 3 Flight 1)
Preliminary Analysis

- **Sensitivity maximum located near *shortwave* at 700 and 500 hPa. Enhanced cloud shield near sensitive region.**
- **Low-level jet within sensitive regions.**
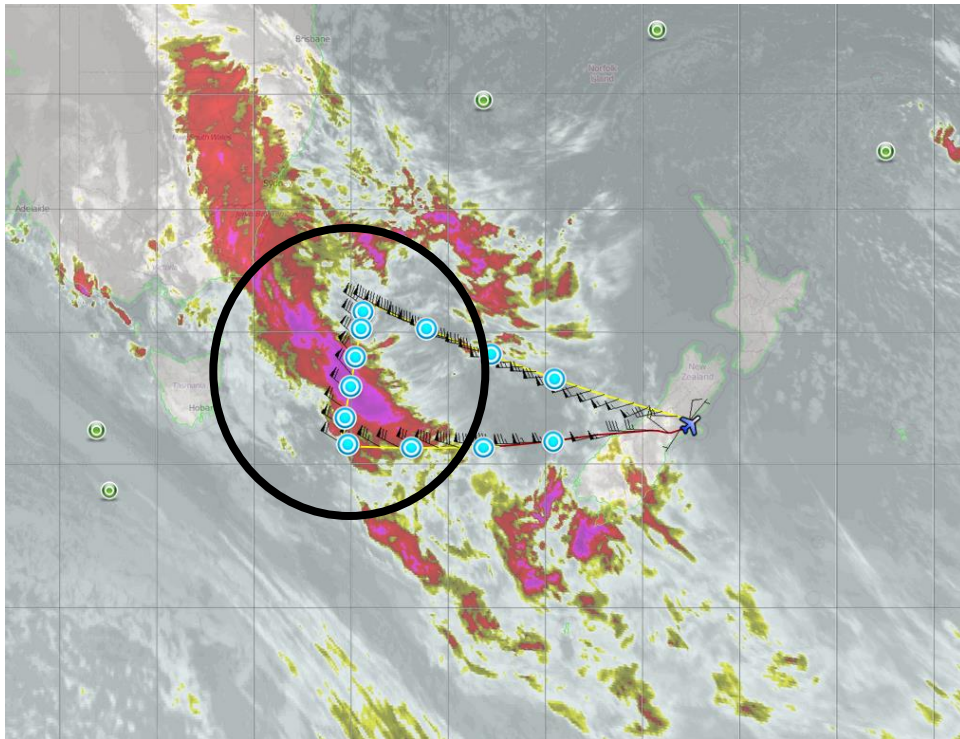- **Targeted dropsondes successfully observed this feature well.**

COAMPS Adjoint 500mb Relative Vorticity & Wind (ms⁻¹) at 06h, 2014061306
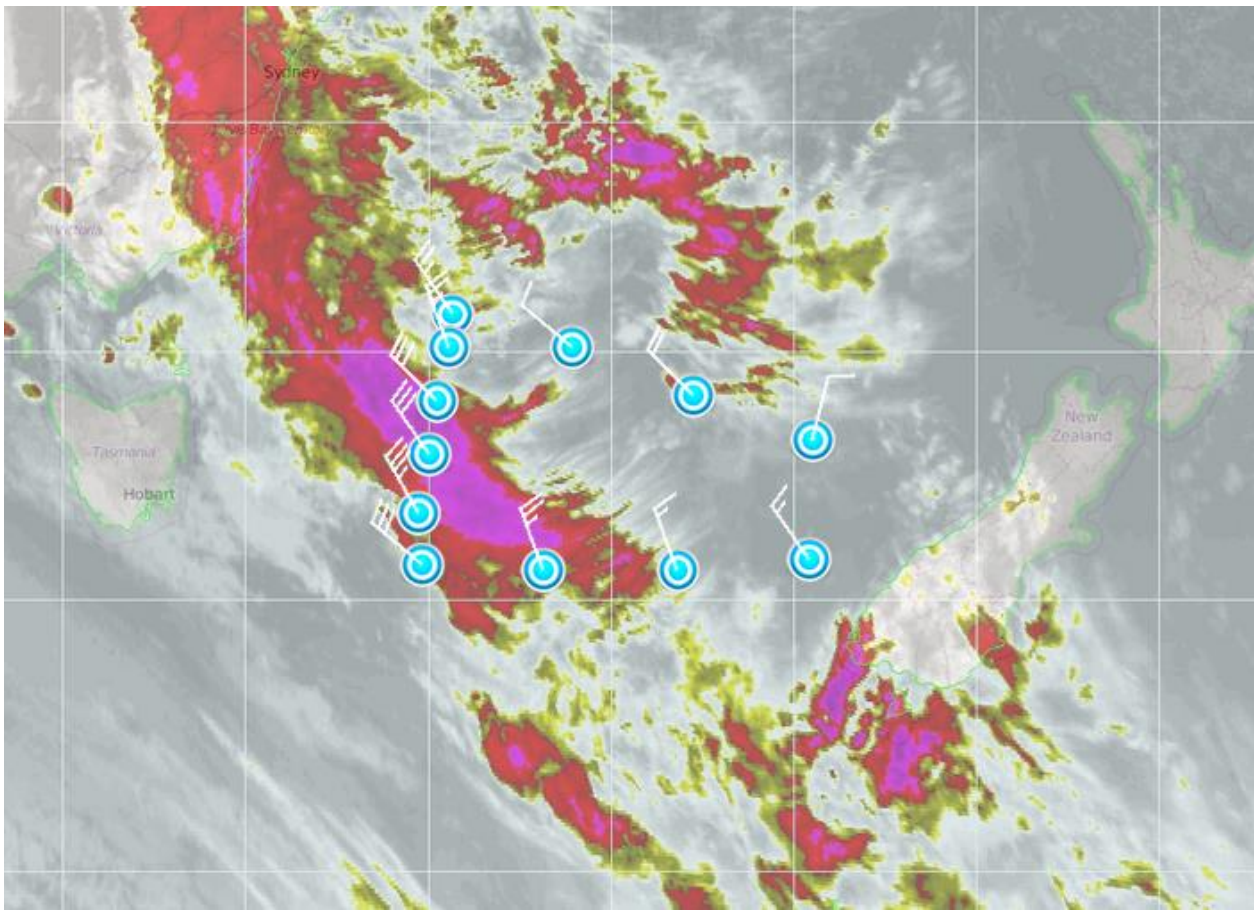
RF03 (IOP 3 Flight 1)
Preliminary Analysis

- Sensitivity maximum located near shortwave at 700 and 500 mb. Enhanced cloud shield near sensitive region.
- Low-level jet within sensitive regions.
- Targeted dropsondes successfully observed this feature well.

Flight level winds and IR

700-mb Droposonde Winds

RF03 (IOP 3 Flight 1)

Preliminary Analysis

- **Sensitivity maximum located near shortwave at 700 and 500 mb. Enhanced cloud shield near sensitive region.**
- **Low-level jet within sensitive regions.**
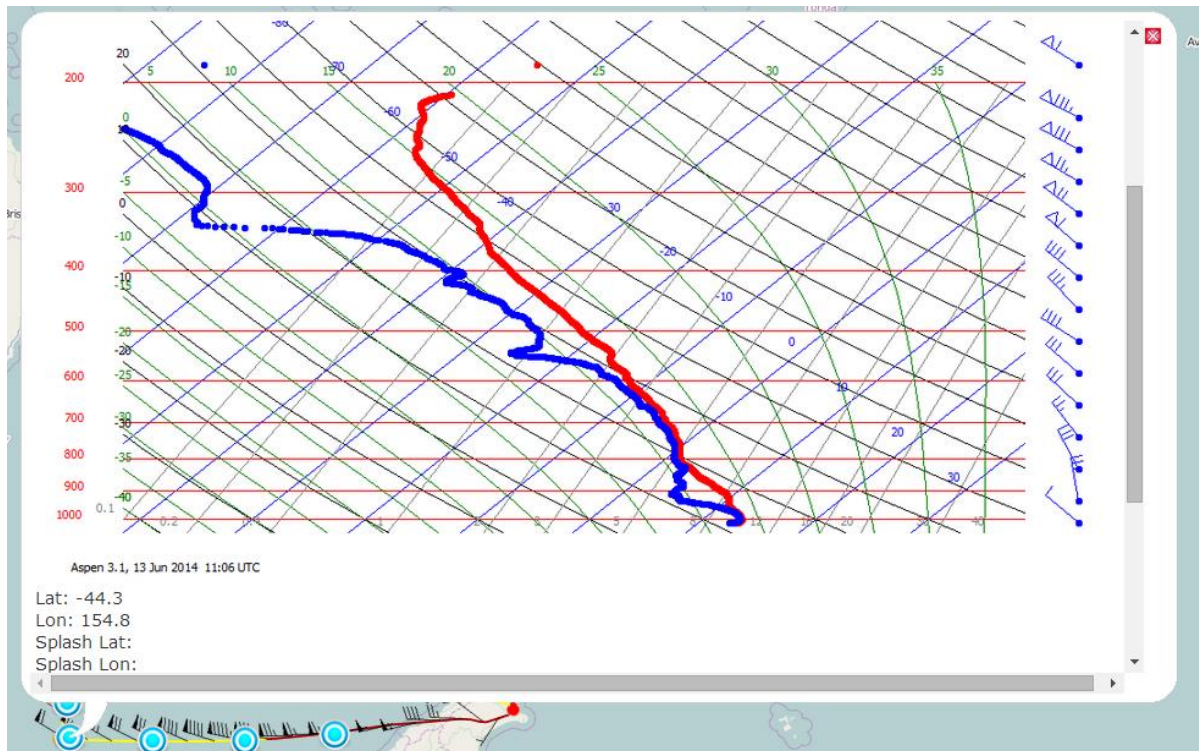- **Targeted dropsondes successfully observed this feature well.**

700-mb Droposonde Winds and IR

Preliminary Analysis

- **Some of the dropsondes near the shortwave indicated some shallow convection with moist layer up to 550 hPa**
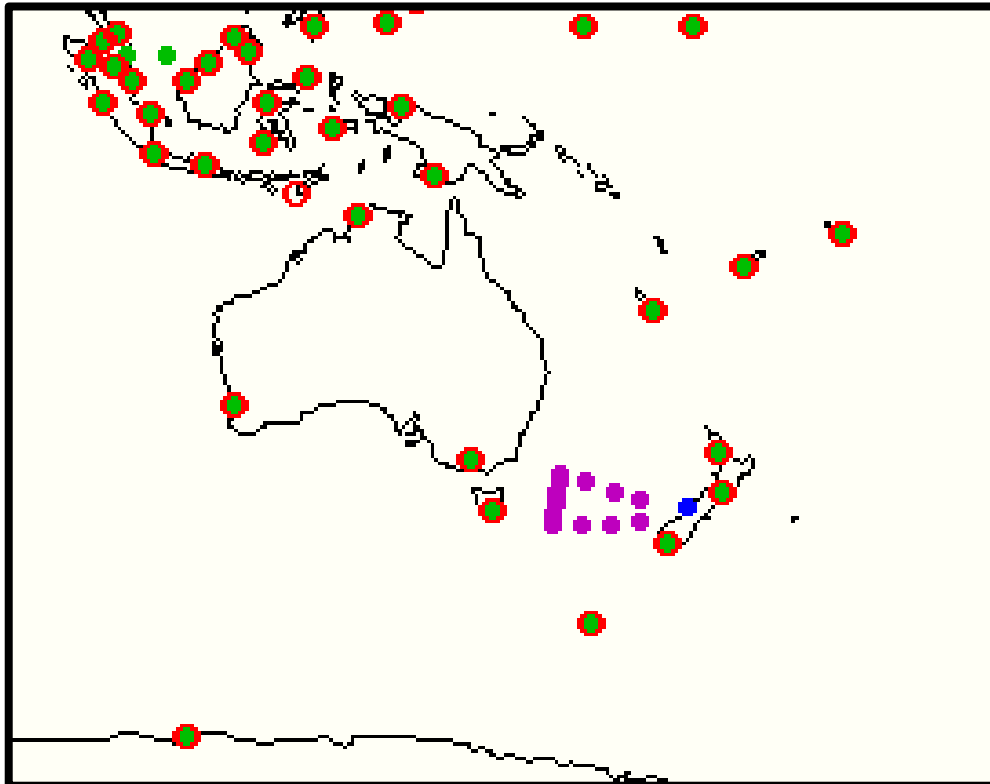
Dropsonde near SW way point

Aspen 3.1, 13 Jun 2014 11:06 UTC

Lat: -44.3
Lon: 154.8
Splash Lat:
Splash Lon:

RF03 (IOP 3 Flight 1)
Preliminary Analysis

- **Dropsondes were successfully ingested into the FNMOC (Navy) and ECMWF systems.**
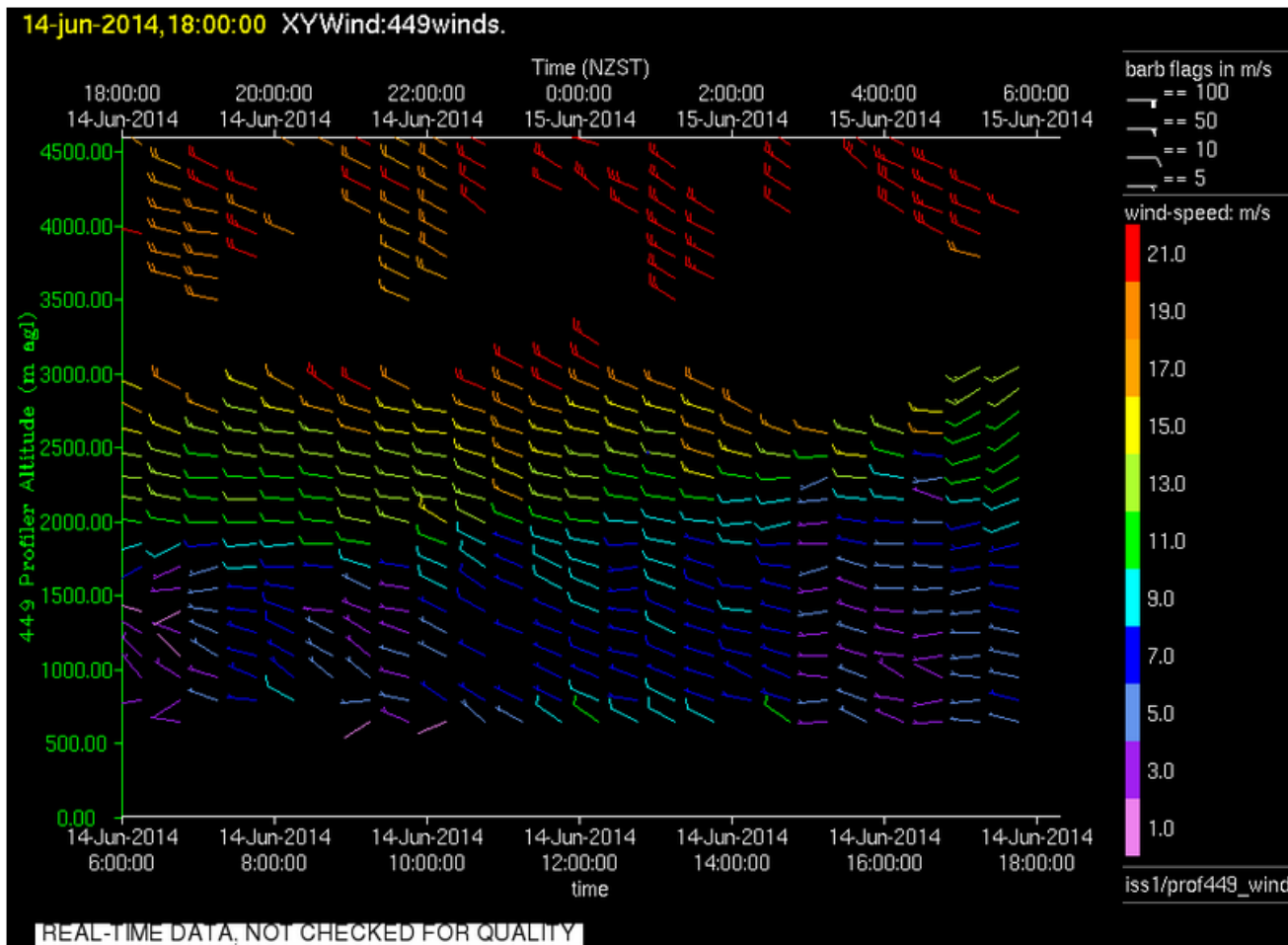- **Data were passed through the QC system and were assimilated in the operational systems.**

Droposonde Coverage for FNMOC

RF03 (IOP 3 Flight 1)
Winds at Final Time

- **Dropsondes were deployed at 0700-1500 UTC June 13**
- **Objectives were to improve the initial conditions for the model forecasts valid at 1200 UTC June 14.**
- **ISS shows the moderate westerly flow present**

RF04 (IOP 3 Flight 2)
Gravity Waves at Final Time

- Companion "verification flight" on 14 June was conducted (RF04).
- Questions remain regarding the degree to which the gravity wave forecasts for 14 June are improved through the assimilation of the additional dropsondes.
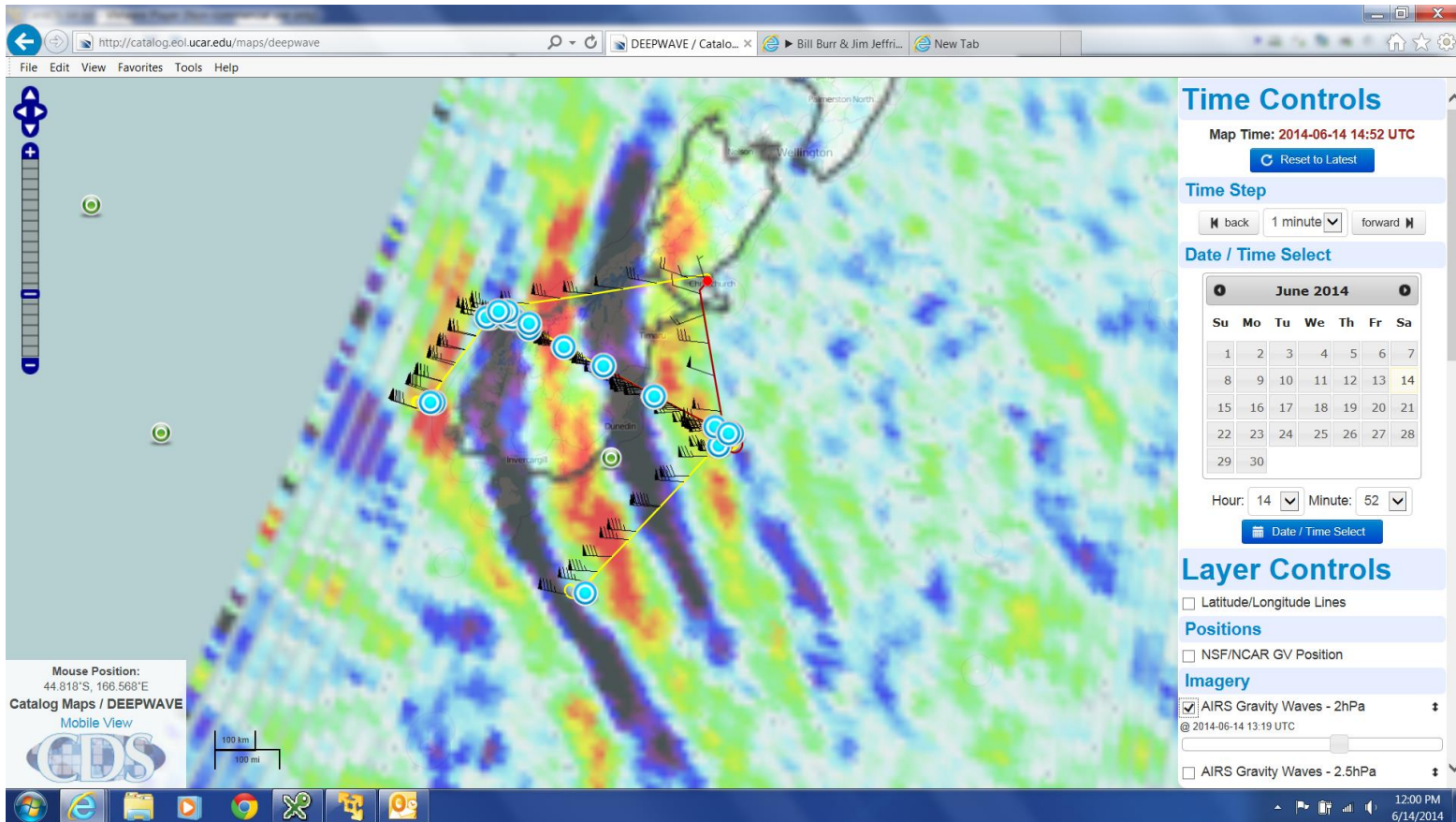
Summary for Predictability Objective

- **Predictability Flights**
  - Carried out a successful predictability mission in tandem with a gravity wave mission the following day.
  - Sensitive regions were in a physically meaningful location near a shortwave trough

- **Data impact studies**
  - Data denial studies need to be carried out to assess the impact of the sondes on the forecasts for the gravity wave event
  - Links between tropospheric predictability and the upper atmosphere?
  - Can targeted observing be used to improve the prediction of GWs?

- **Sources of stratospheric GWs**
  - Terrain-forcing, spontaneous GW emission from baroclinic waves & jets
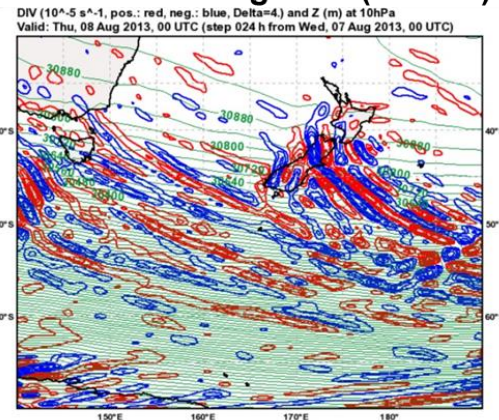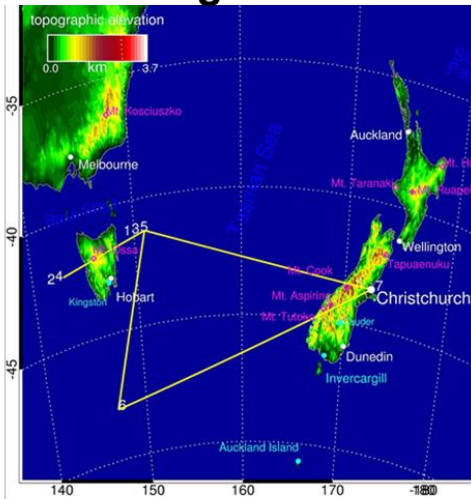 - Adjoint could provide important tool

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

Gravity Wave Sources Test Cases

New Zealand Flight
8 August 2013
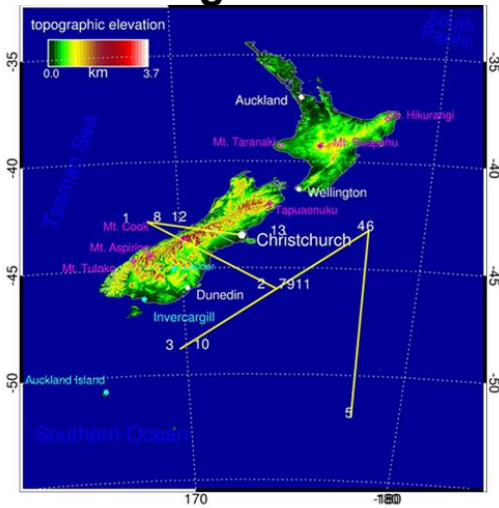
Tasmania Flight
10 August 2013

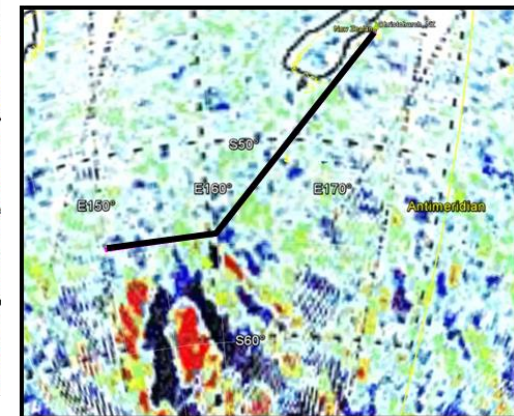**S. Ocean Flight**
15 August 2013

ECMWF Divergence (3 hPa)

ECMWF Divergence (10 hPa)
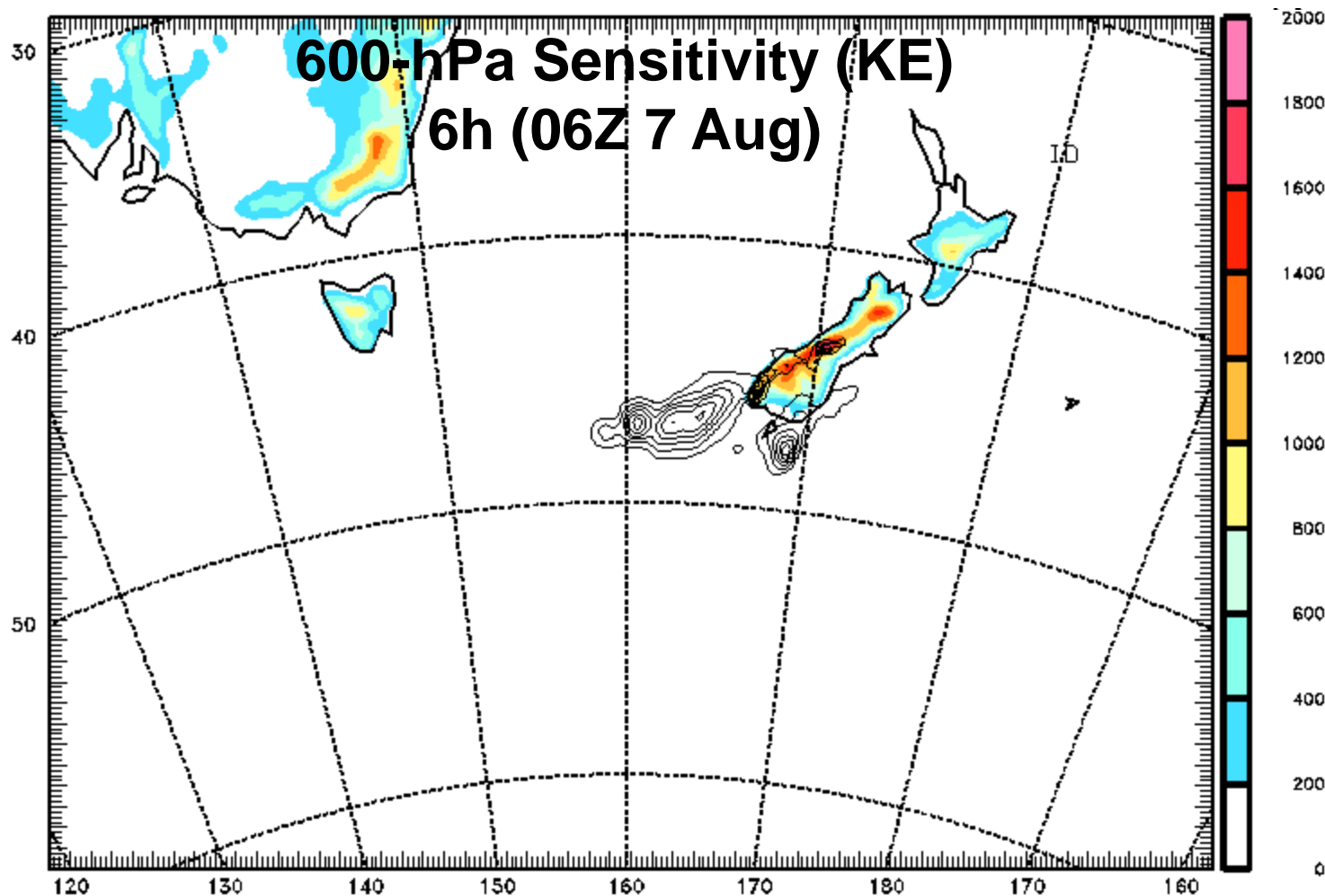
ECMWF Divergence (10 hPa)
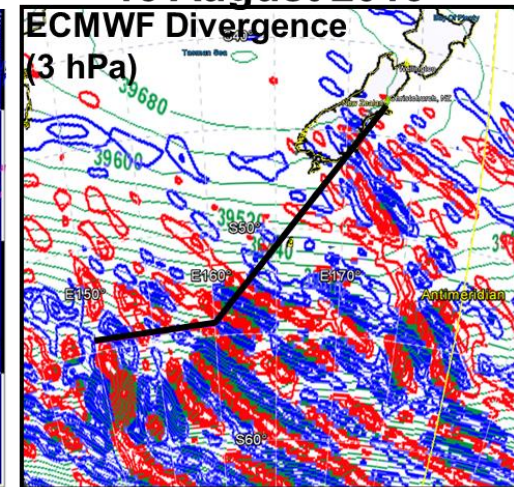
AIRS Radiances (3 hPa)

- Dry run exercise (5-15 August 2013) examples examined, with a focus on 8 August (New Zealand GWs) and 15 August (S. Ocean GWs) cases.
- What are the gravity wave sources and characteristics?

Gravity Wave Source Identification

Orographic Wave Case (7-8 August 2013)



600-hPa Sensitivity (KE)
6h (06Z 7 Aug)

- Adjoint identifies most sensitive portion of the Alps for wave launching.
- Bands located to SE of NZ are linked with GW launching from the N. Alps.
- Bands located to S of NZ are linked with S. Alps and nonorographic forcing?

Gravity Wave Source Identification

Non-Orographic Gravity Wave Case (14-15 August 2013)
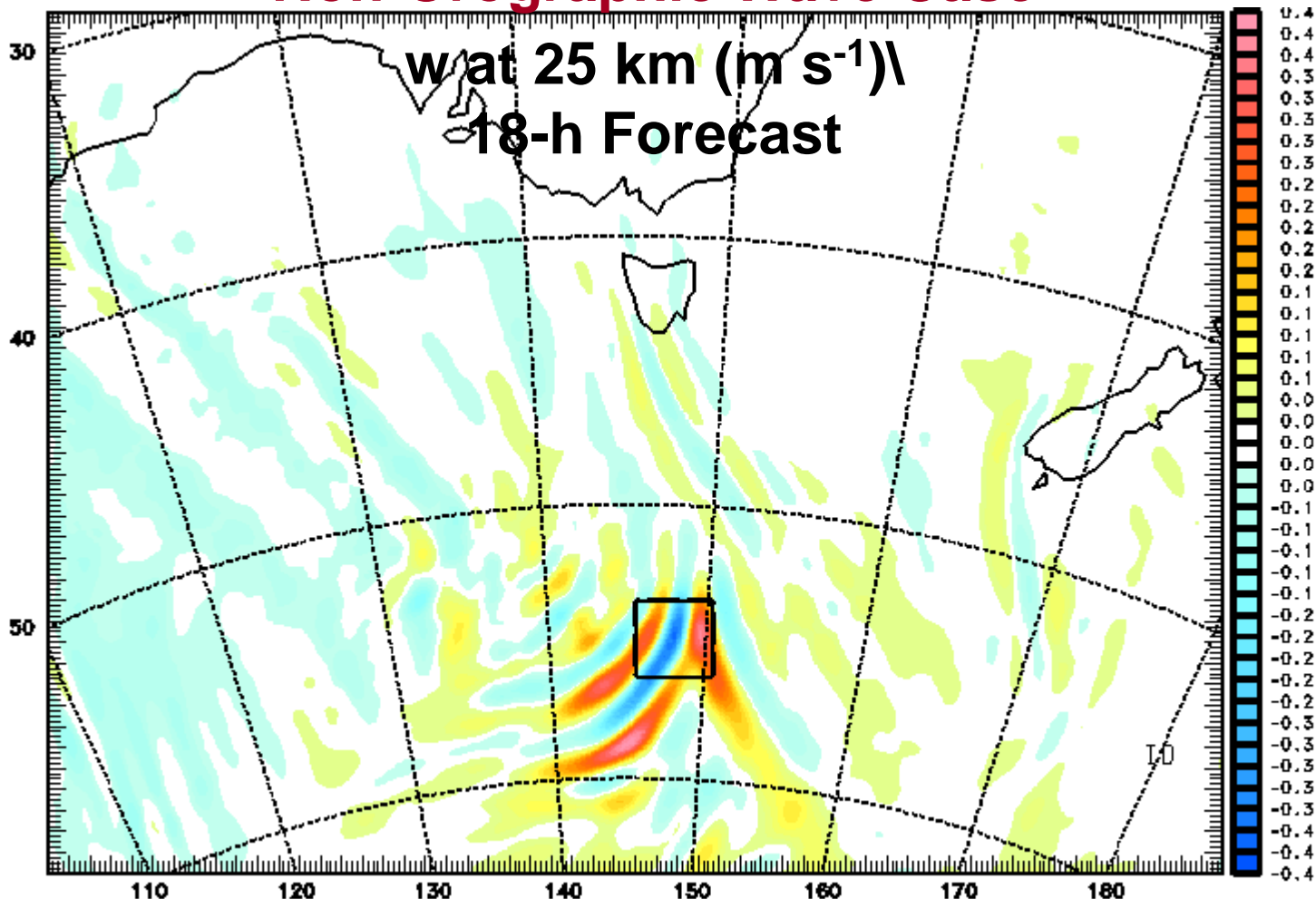
AIRS (3 mb)

ECMWF Divergence (3 mb)
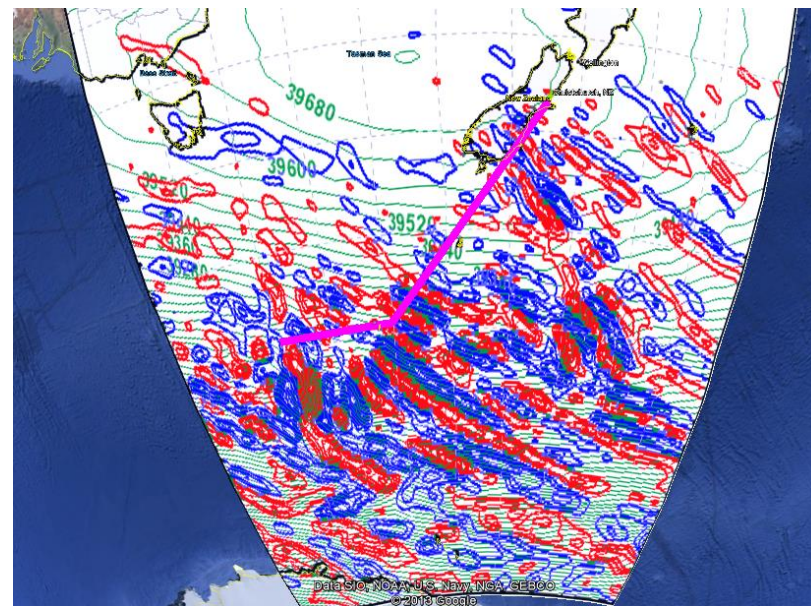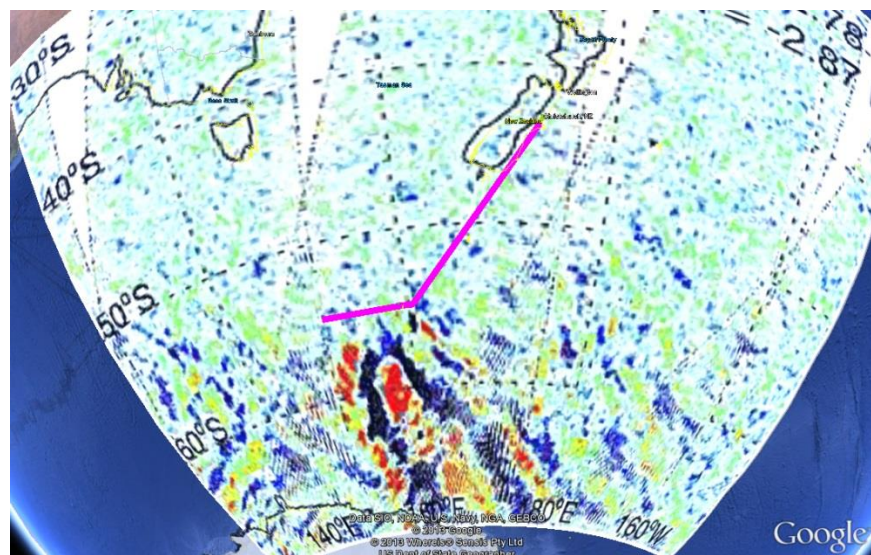
- Focus on a possible non-orographic gravity wave case from the DeepWave dry run on 14-15 August 2013.
- Gravity waves observed by AIRS located well to the south of New Zealand and in a region with no topography.

Gravity Wave Source Identification
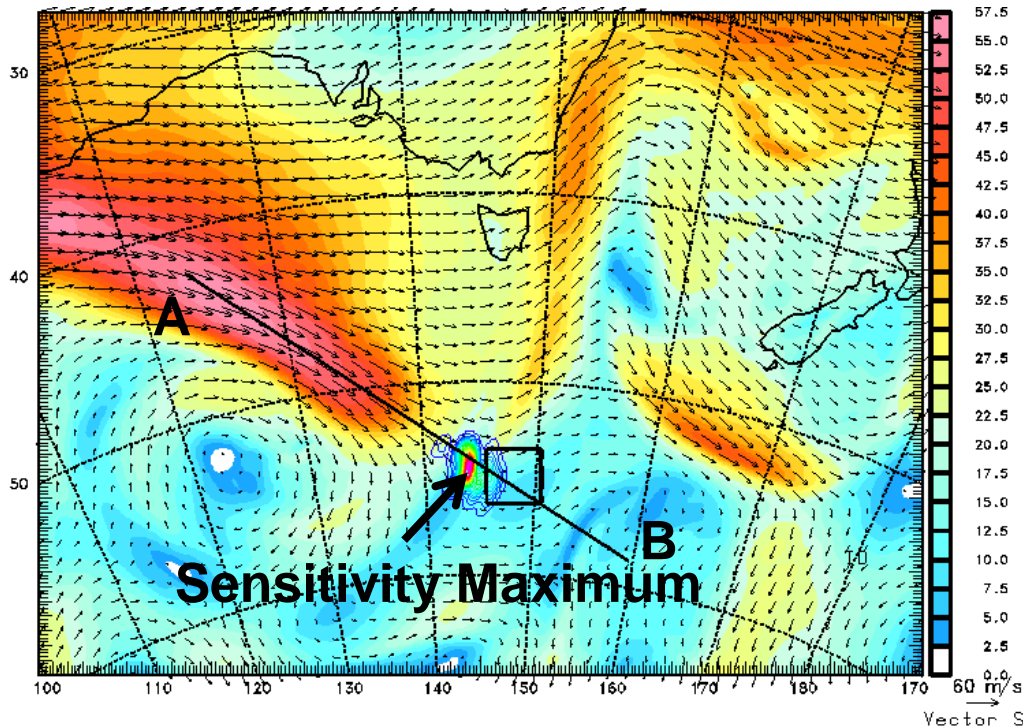
Non-Orographic Wave Case

w at 25 km (m s^{-1})\
18-h Forecast

COAMPS model appears to capture the characteristics of the stratospheric gravity waves fairly well.
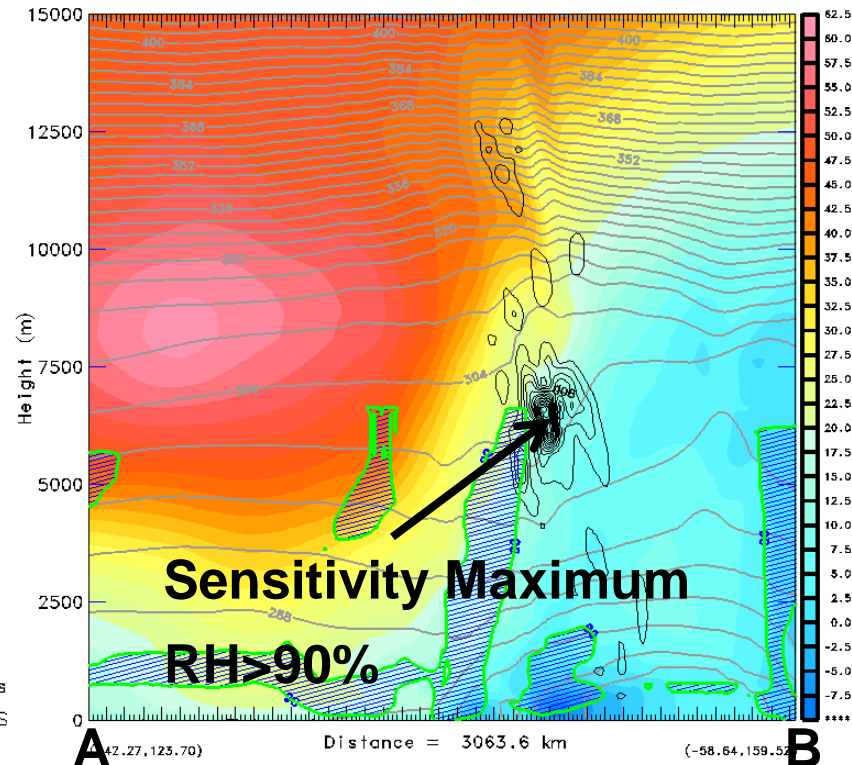
Gravity Wave Source Identification

Non-Orographic Wave Case

**400 hPa wind speed (m s⁻¹)**
Optimal Perturbation KE (6 h)

Along section wind speed (m s⁻¹)
Optimal Perturbation KE (6 h)

Sensitivity maximum is locations upstream of the response function near the exit region of a very strong jet and near 7 km near the top of a region of saturated rising motion (e.g., grid scale precipitation).

Gravity Wave Source Identification

Non-Orographic Wave Case

w at 25 km (m s^{-1})
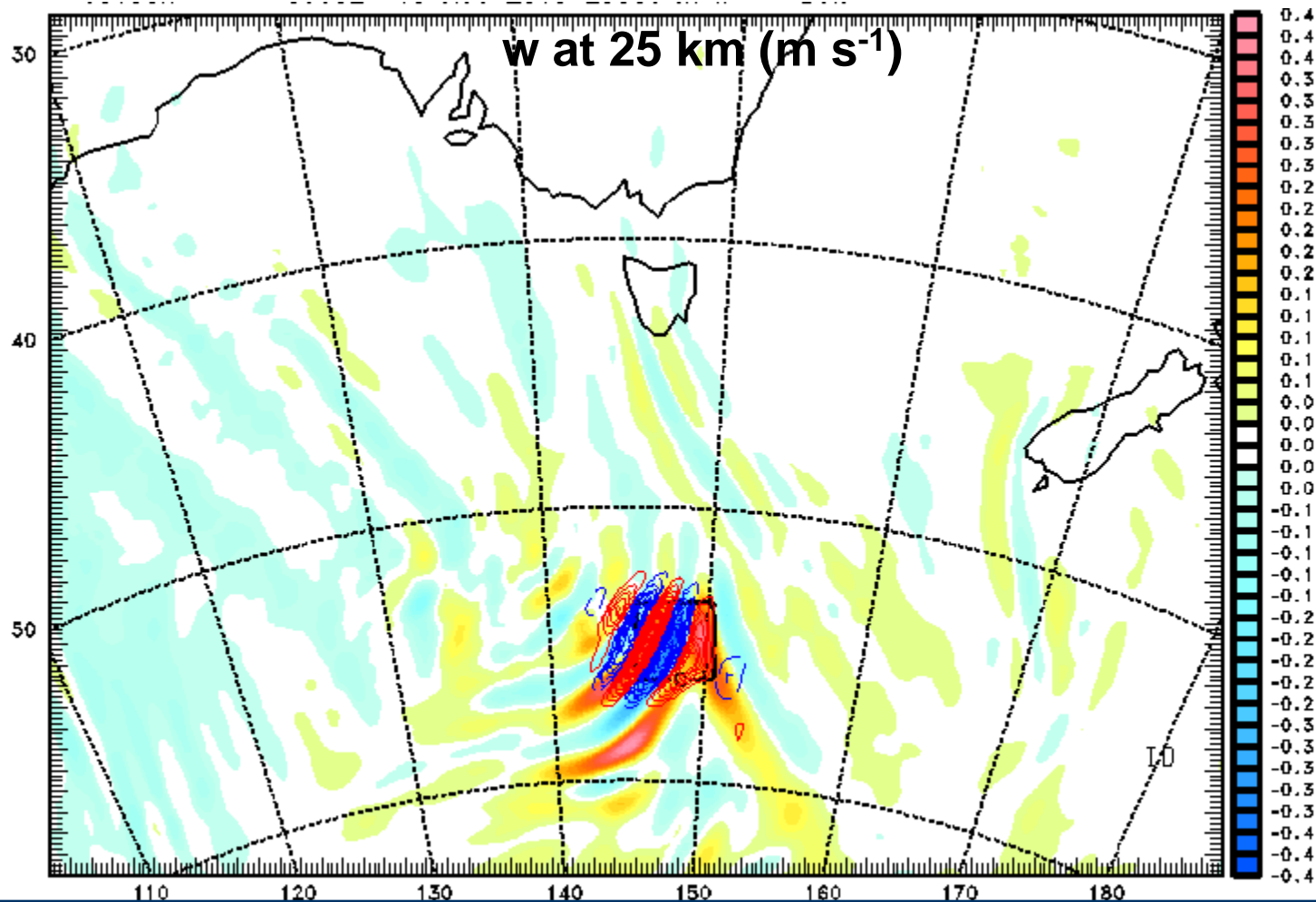
Adjoint optimal perturbation project on to the gravity wave packet generated by the exit region of the jet and precipitation processes, demonstrating the physical significance of the adjoint sensitivity.