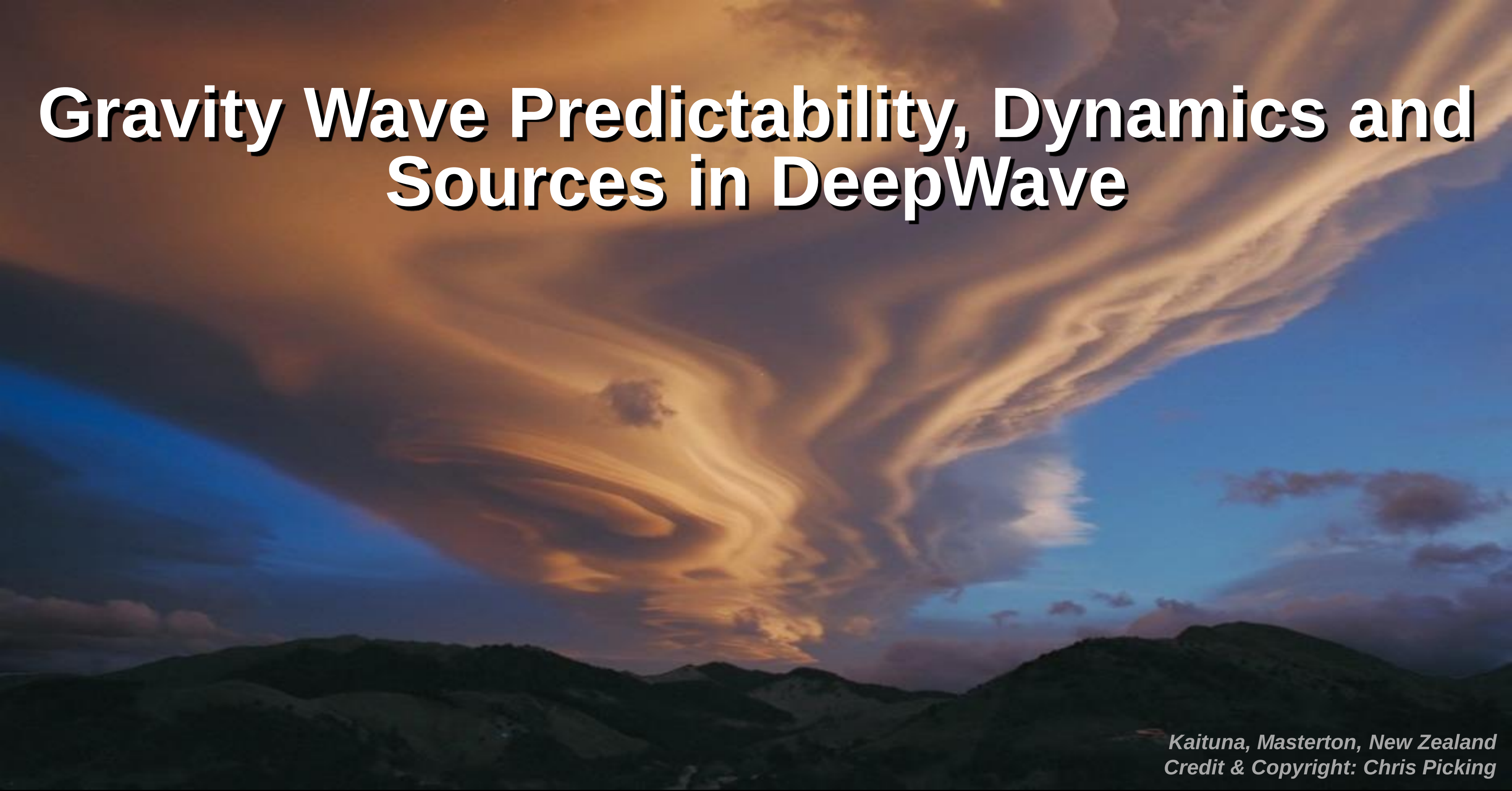
Gravity Wave Predictability, Dynamics and Sources in DeepWave



Kaituna, Masterton, New Zealand

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NRL-Monterey DeepWave Objectives

Dynamics, Sources, Predictability

- **Dynamics:**
  - Influence of horizontal and vertical shear on gravity waves
  - Characterizing gravity wave sources (mountains, jets, convection etc.)
  - Stochastic nature of gravity waves (fluxes)

- **Modeling Issues:**
  - Gravity wave drag parameterizations (stochastic, non-local etc.)
  - High-resolution (LES?) explicit gravity wave simulations (and breaking)

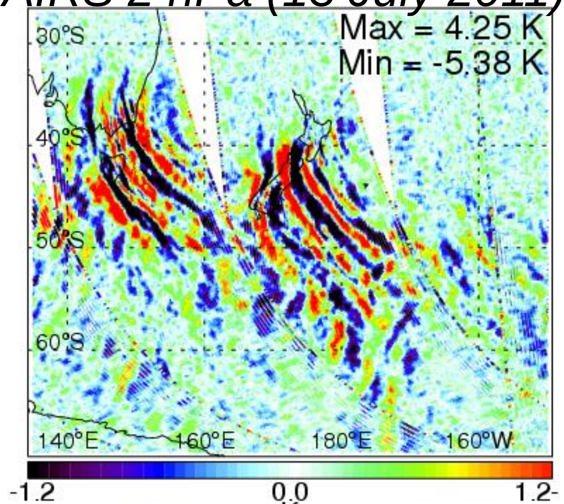
- **Predictability:**
  - Quantify initial condition sensitivity and predictability of wave launching and deep propagating gravity waves
  - Links between stratospheric GW predictability and tropospheric storms

Predictability of Deep Propagating GWs

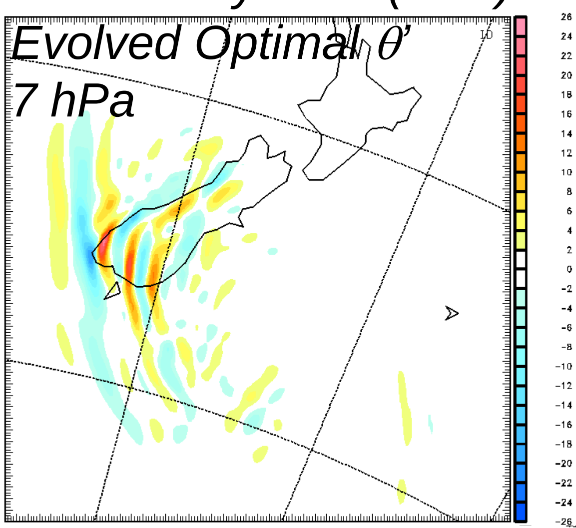
What are the predictability characteristics of deep propagating GWs?

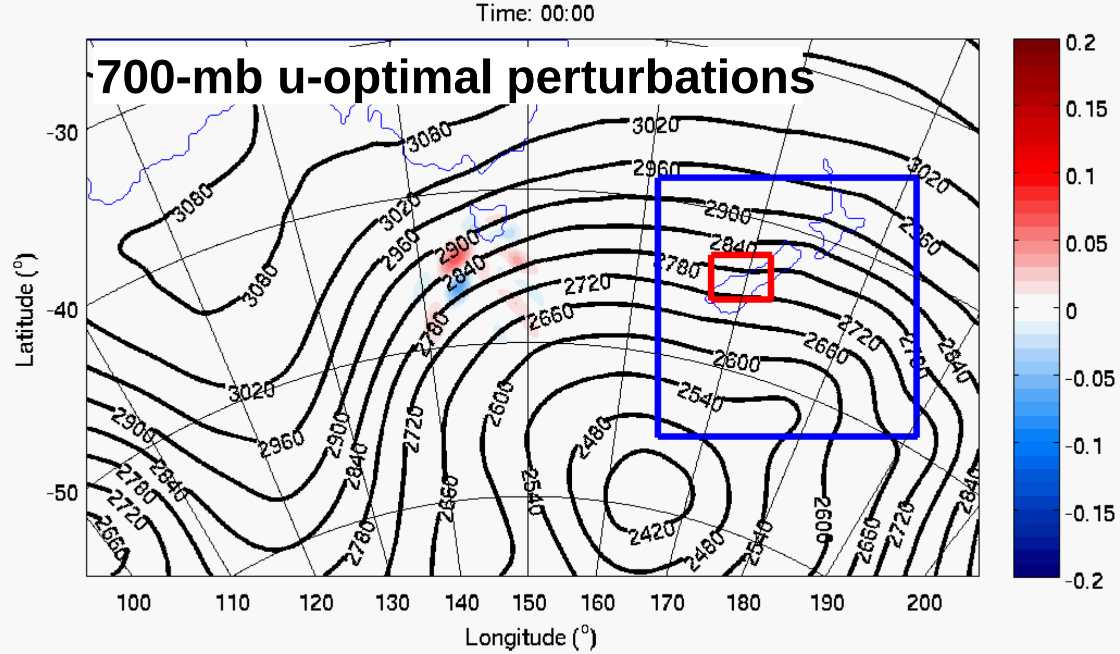
Adjoint allows for the mathematically rigorous calculation of forecast sensitivity of a response function to changes in the initial state

AIRS 2 hPa (13 July 2011)



12Z 13 July 2011 (24 h)

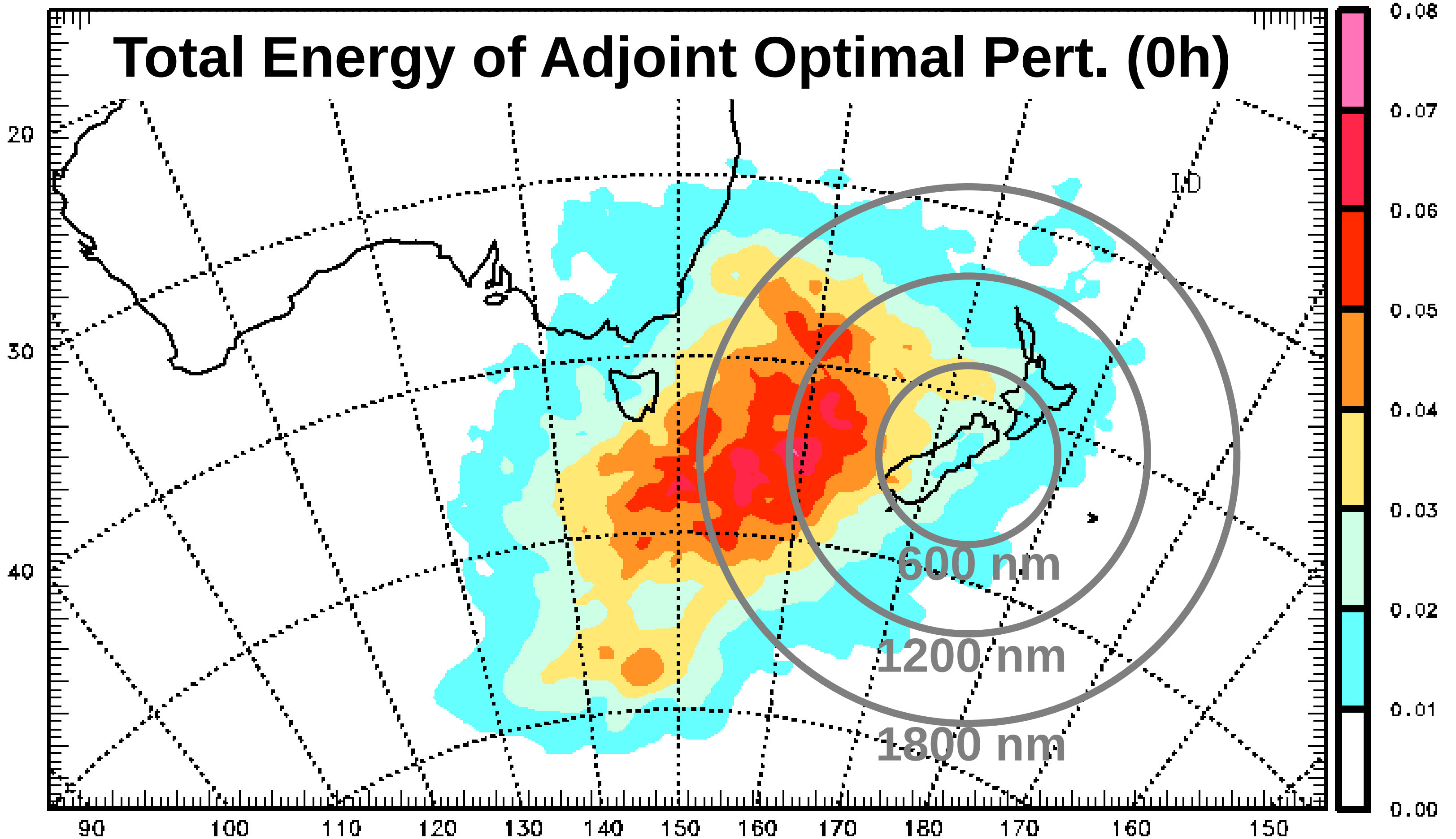




- Adjoint is used to diagnose sensitivity using a kinetic energy response function (lowest 1 km)
- Sensitivity located ~1200 km upstream (in coarse mesh over 24 h) near 700 hPa shortwave.
- Adjoint optimal perturbations lead to strong wave propagation (refracted waves south of NZ)

Predictability of Deep Propagating GWs

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

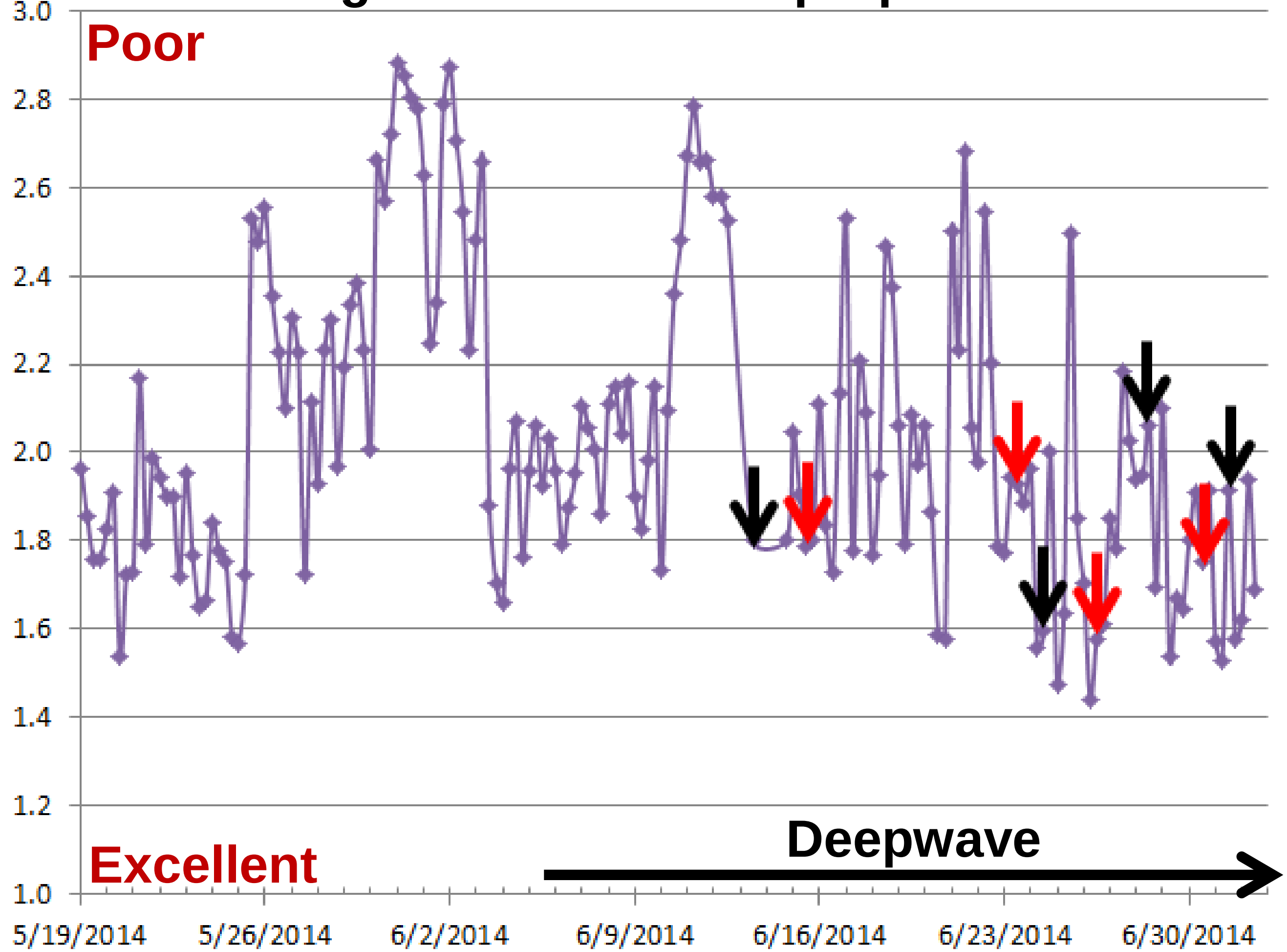


Mean 700-hPa sensitivity is location over the Tasman Sea to the west of New Zealand and very accessible for G-V (dropsondes) and Falcon (wind lidar) to perform targeted observing.

Summary of Predictability Scores

Total Objective Score - Lower number is better

(Black arrows-flights. Red arrows-proposed but not flown)



- Objective score based on: sensitivity, distance, area, speed at final time (D2)
- In general, predictability group is flying, observing, and proposing very good cases using the objective score as the main criteria.

Summary of Predictability Missions

RF	IOP	Date	Flight Type	Location	Length	Comments	Grade
3	3	6/13/ 2014	Predictability	Tasman Sea	4.5 h	Sampled short wave trough and LLJ	A
9	8	6/24/ 2014	Predictability and SI Mountain Waves	Tasman Sea and Cook 1b	8.25 h Includes 5 Cook transects	Sampled sensitivity associated with baroclinic wave, convection	B
-	-	6/25/ 2014	No flight, additional soundings from Hobart every 3h from 06Z-18Z	Hobart, Tasmania	0	Only partially sampled sensitive region.	C
11	9	6/28/ 2014	Predictability	Tasman Sea and Cook 1b	6 h Includes 2 Cook transects	Sampled areas of active convection, very strong jet.	B
14	9	7/01/ 2014	SI Mountain Waves with predictability dropsondes E of SI	Cook 1a and SE of SI.	0 h Trans-verse GW leg	Sampled frontal passage.	C

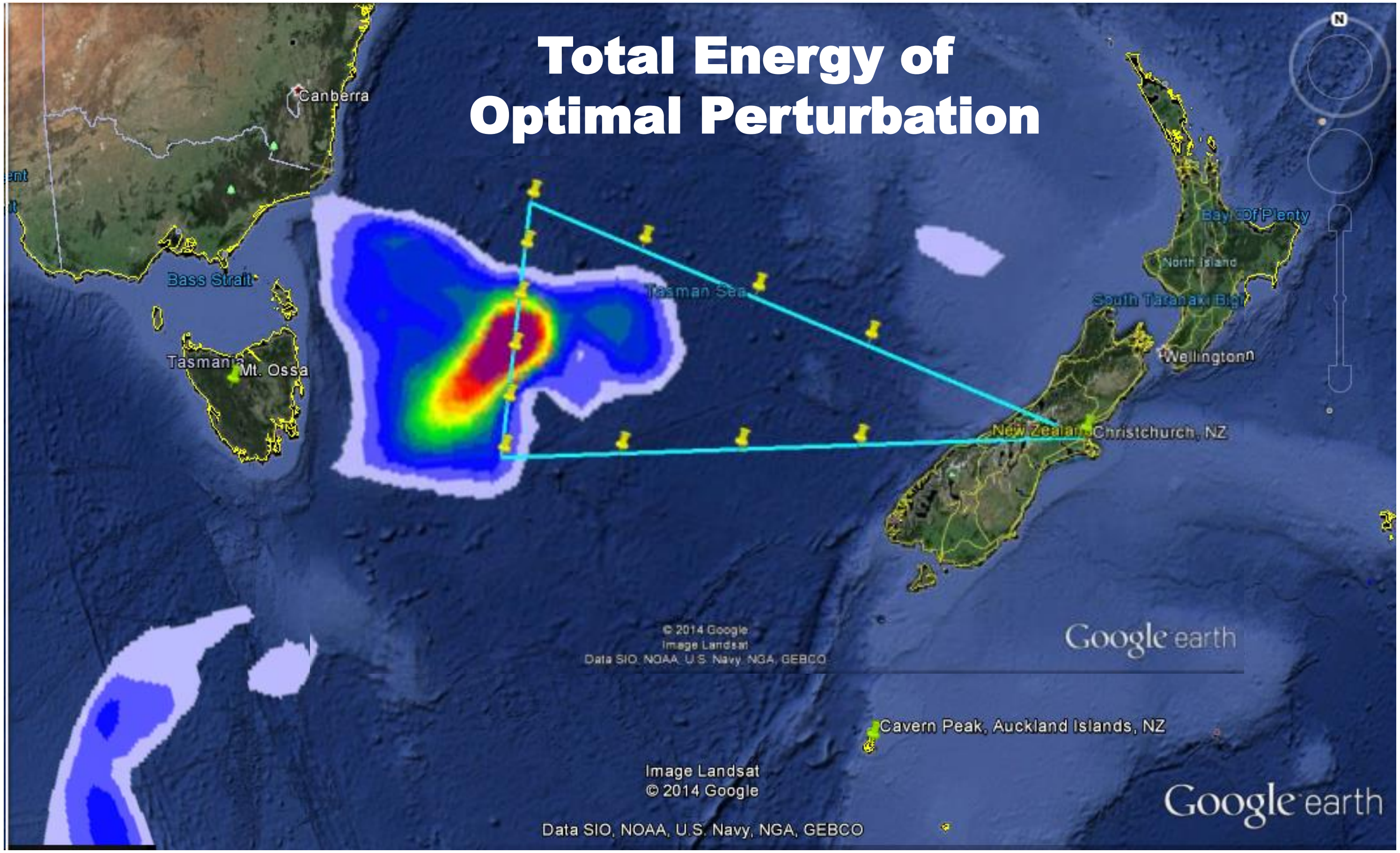
Summary of Predictability Proposals

Date	Proposed Flight	Reason not flown, comments
6/15	North Central Tasman	Nothing flown (not sure).
6/23	North Central Tasman Sea.	Nothing flown (down day)
6/26	Central Tasman (coupled with Tasmania flight)	Tasmania flight restrictions made this flight less appealing
6/29	Discussion of proposal for a Central Tasman Module (in conjunction with SI Mountain Wave study.	Mountain and trailing wave flight given priority. This was a very strong event.
6/30	Proposed Central Tasman Module (in conjunction with SI Mountain Wave study).	Mountain and trailing wave flight given priority. In retrospect, could have added module on readily.

RF03 (IOP 3 Flight 1)

Objectives:

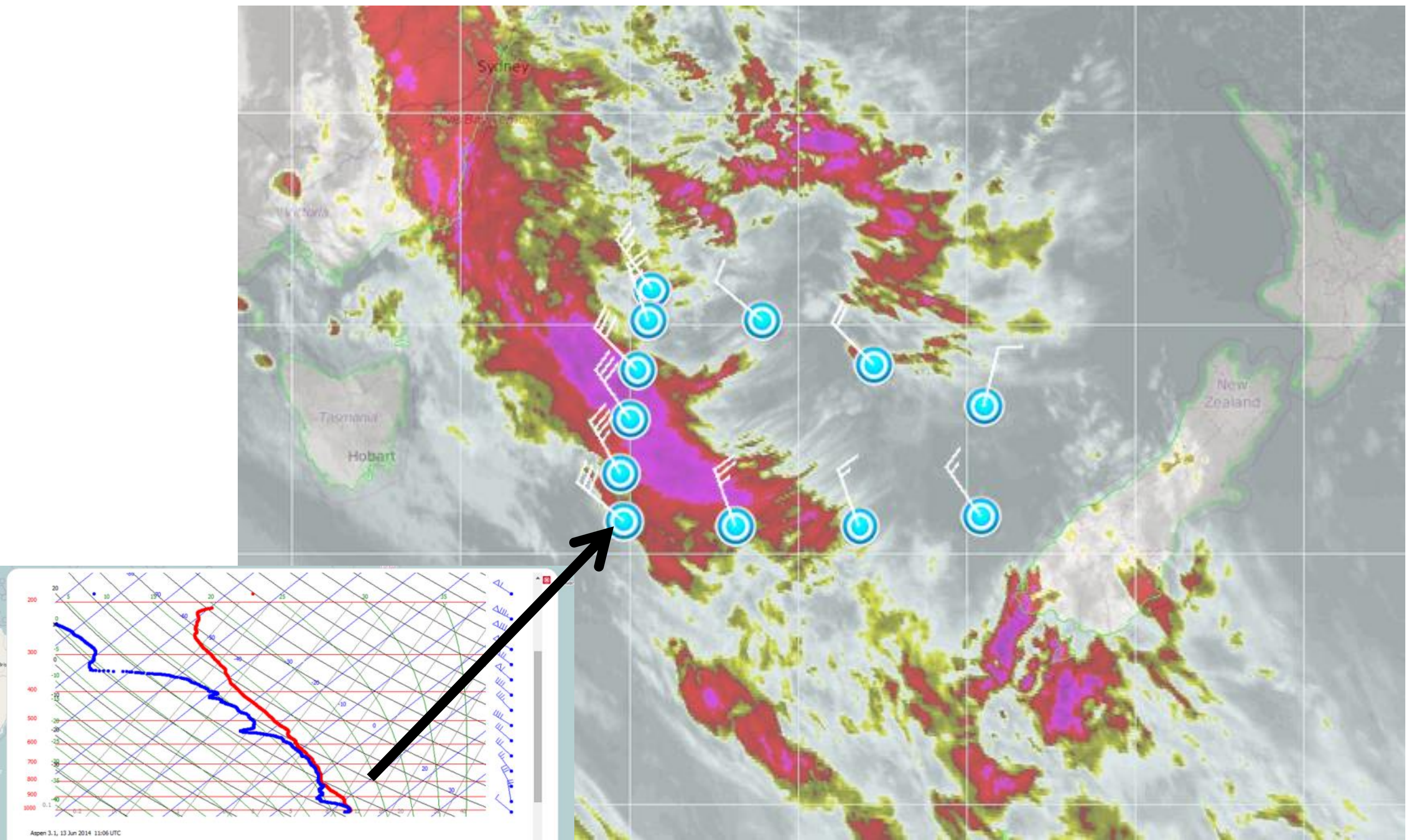
- To sample a region of adjoint sensitivity upstream of the S. Alps prior to a GW event.
- To gain experience with predictability missions.



RF03 (IOP 3 Flight 1)

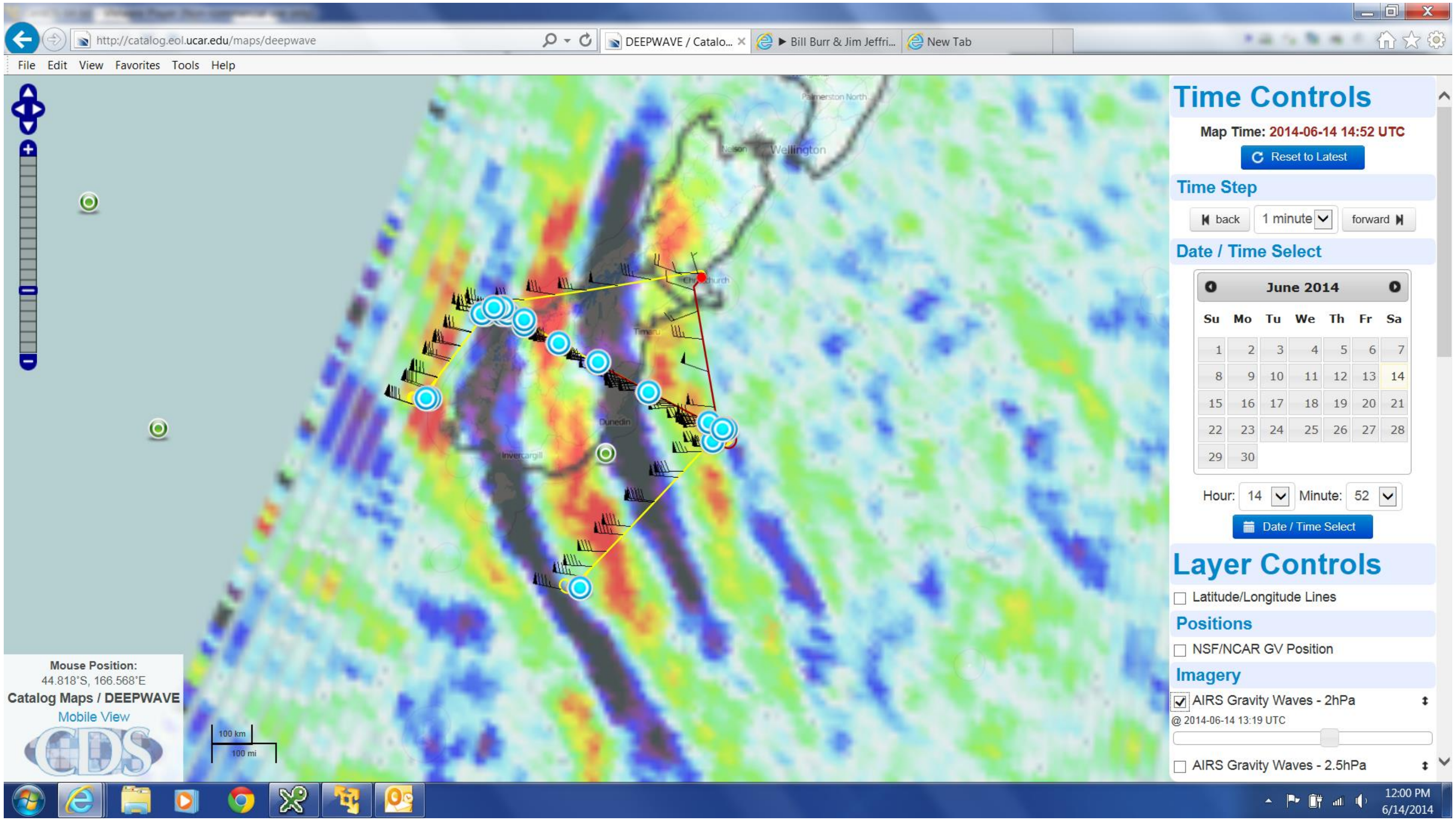
- **Sensitivity maximum located near shortwave at 700 and 500 mb. Enhanced cloud shield and low-level jet in sensitive region.**
- **Dropsondes indicated shallow convection with moist layer**
- **Targeted dropsondes successfully observed this feature well.**

700-mb Droposonde Winds and IR



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.

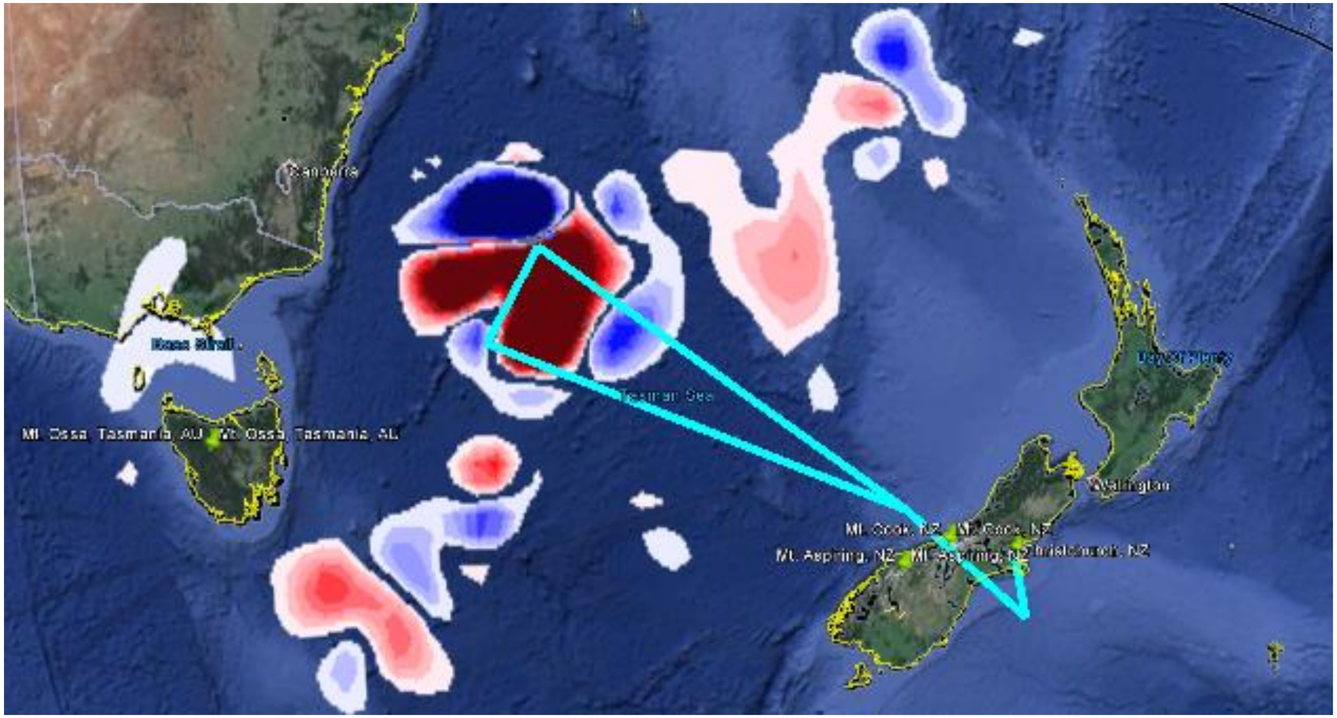


RF09 (IOP 8)

Objectives:

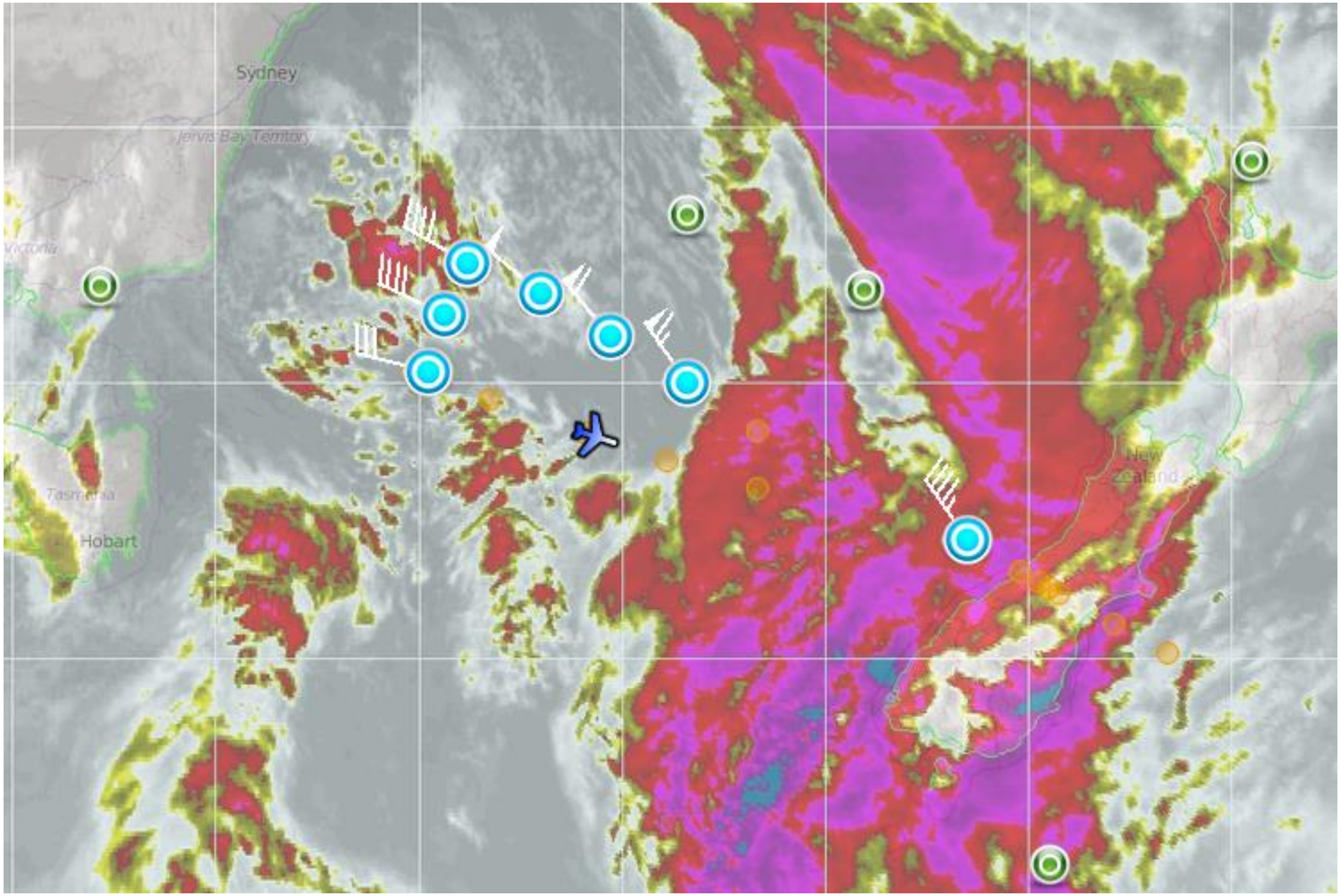
- **To sample a region of adjoint sensitivity upstream of the Southern Alps prior to a gravity wave event.**
- **Sample a dynamically active region that impacted the SI, generated GWs observed in RF10.**

700-mb Moisture Sensitivity at 12 UTC 24 June



RF09 (IOP 8)

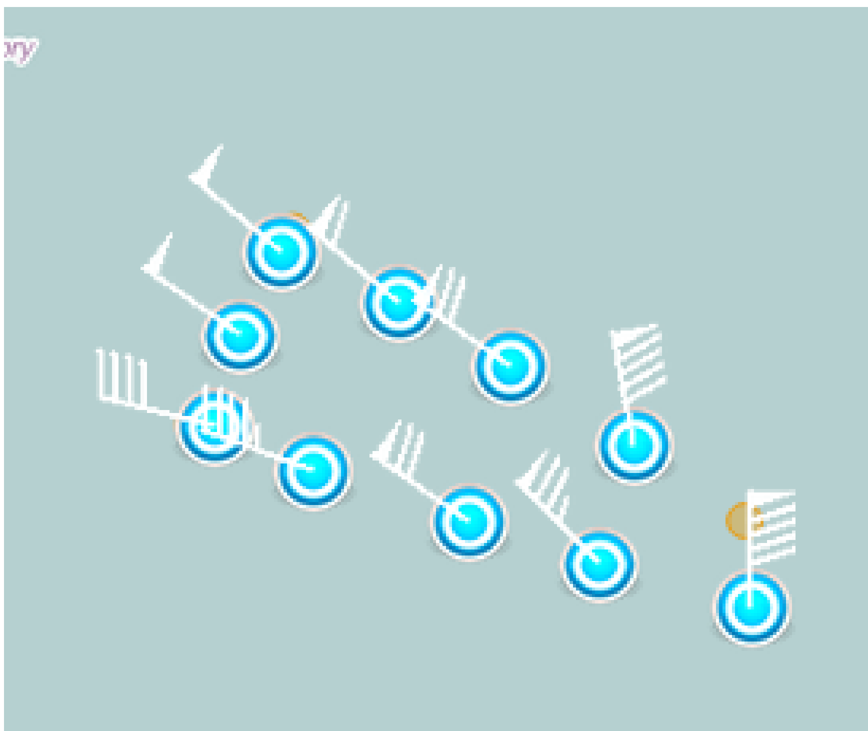
- **Sensitivity in a dynamically active region with convection and lightning**

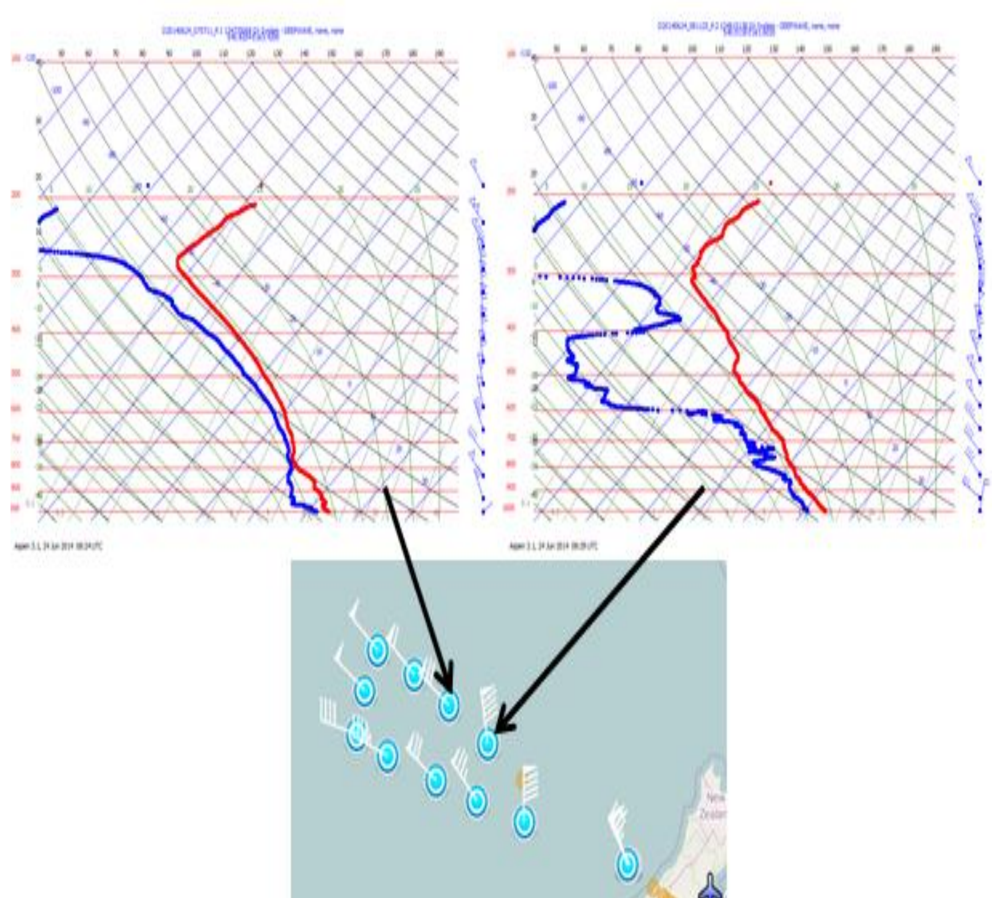


RF09 (IOP 8)

- **Region of strong horizontal shear**
- **Dropsondes show large horizontal moisture gradients in sensitive regions**

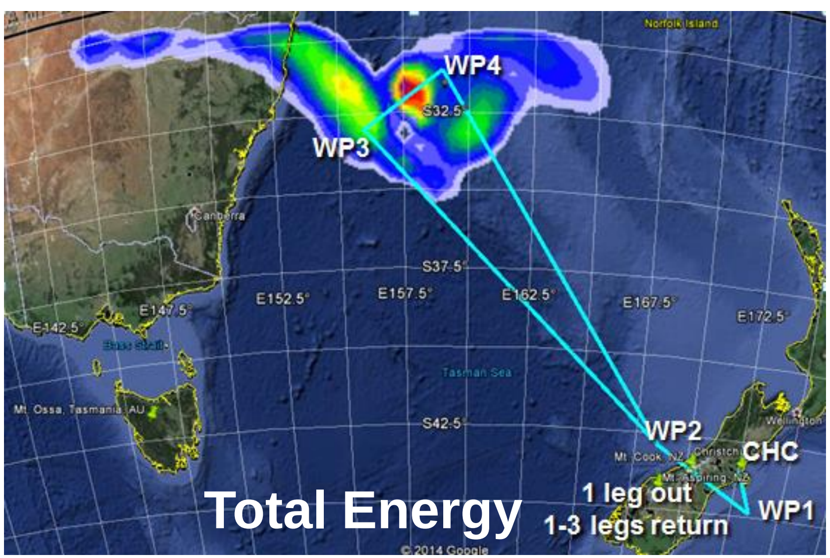
400 hPa Winds

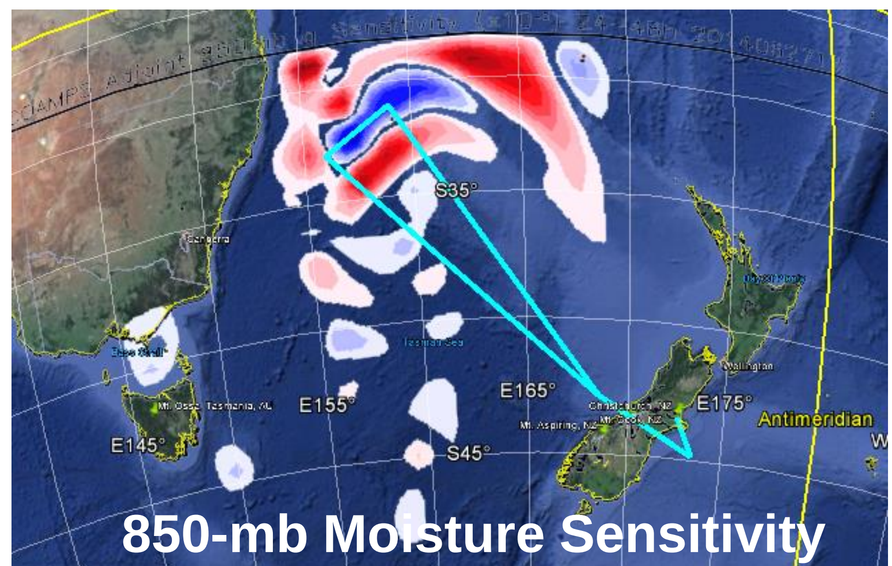




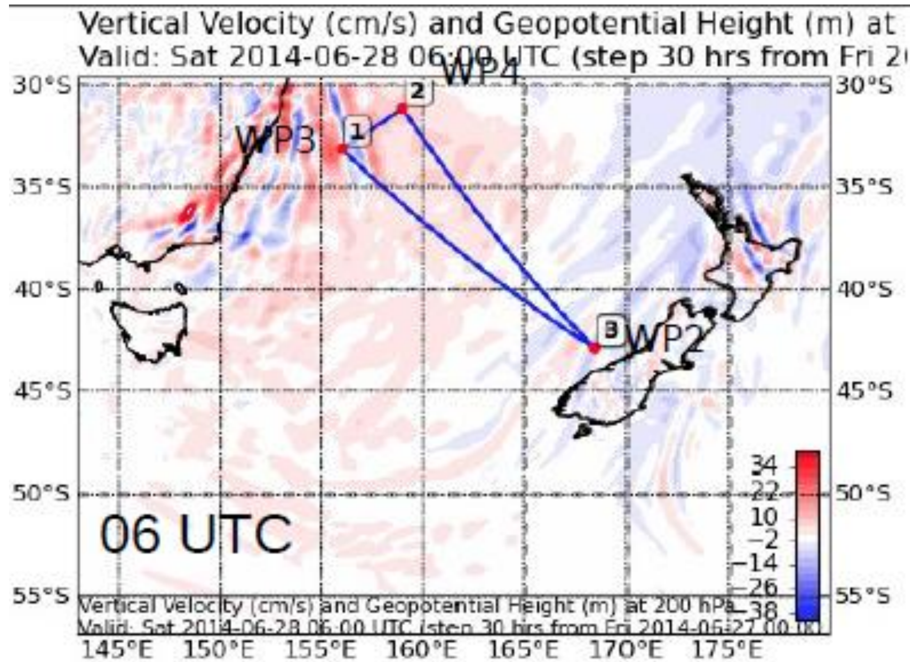
RF11 (IOP 9)

- **Predictability Objective**:
  - To sample a region of adjoint sensitivity in the **northern Tasman Sea** upstream of the Southern Alps prior to a gravity wave event on **Sunday**.
- **Gravity Wave Objective**:
  - To sample the Mt. Cook (1b) transect under weak flow (good baseline for fluxes).

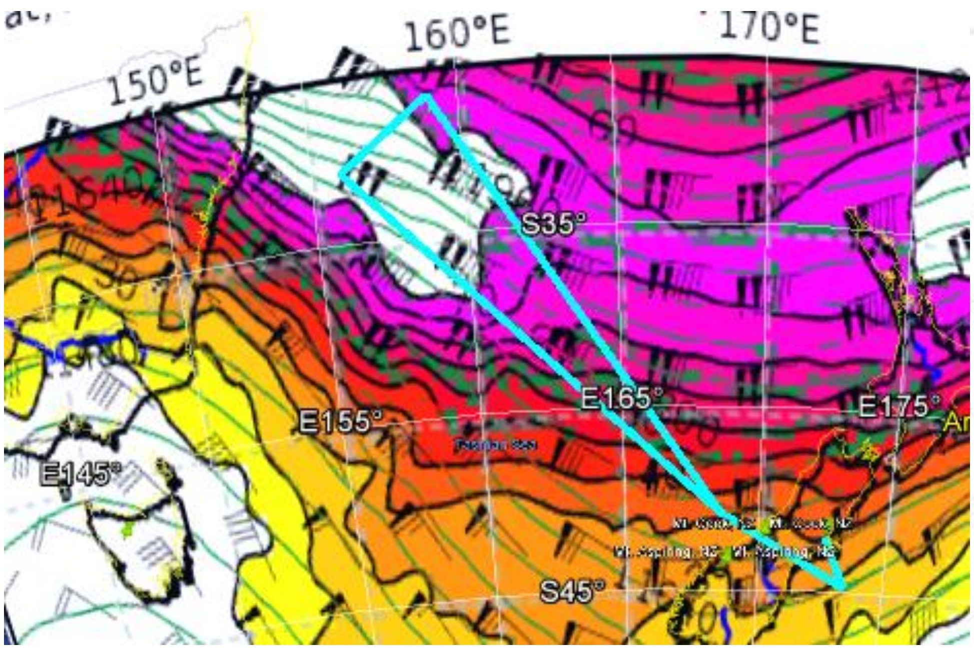


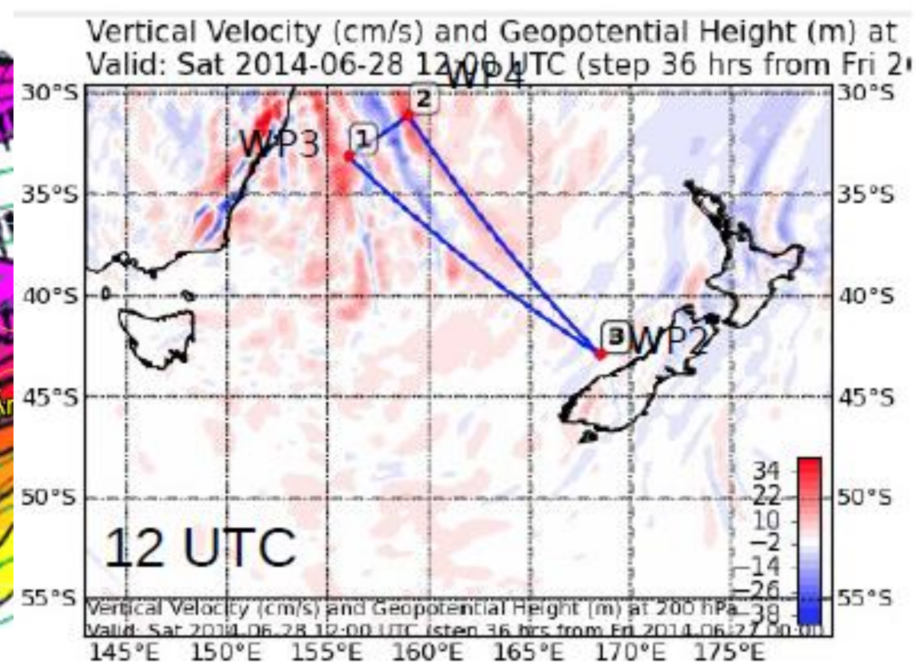


- **Sensitive region near a very strong jet stream (>75 m/s at flight level)**
- **WRF and ECMWF indicated non-orographic wave activity**



200-hPa Winds

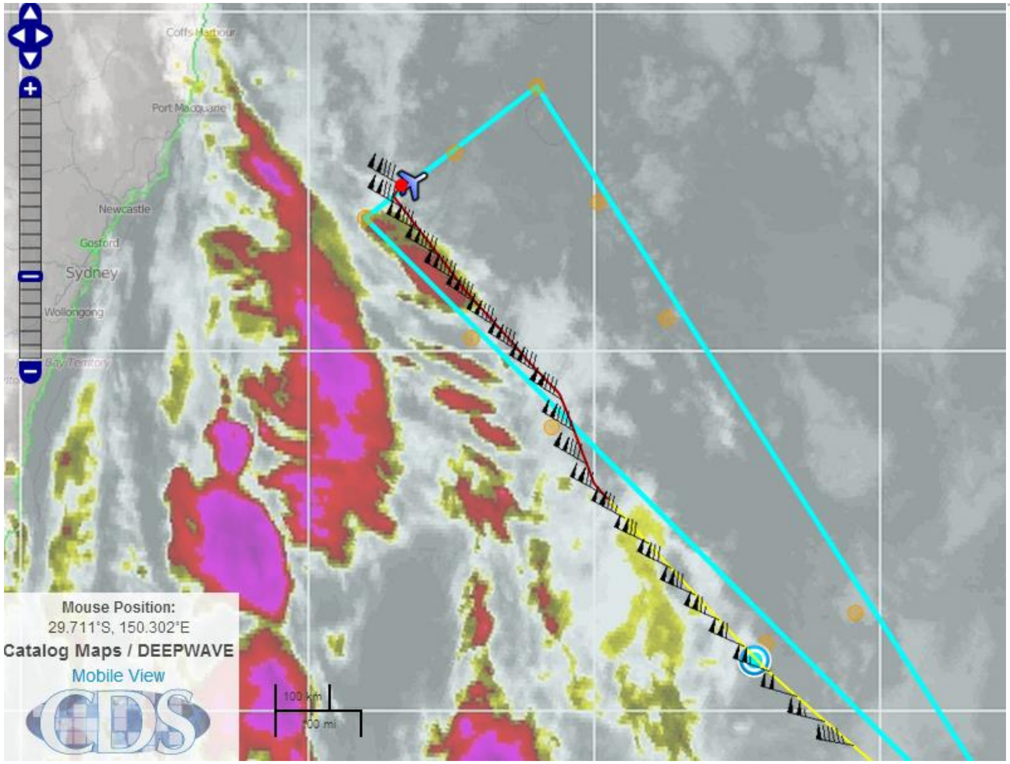




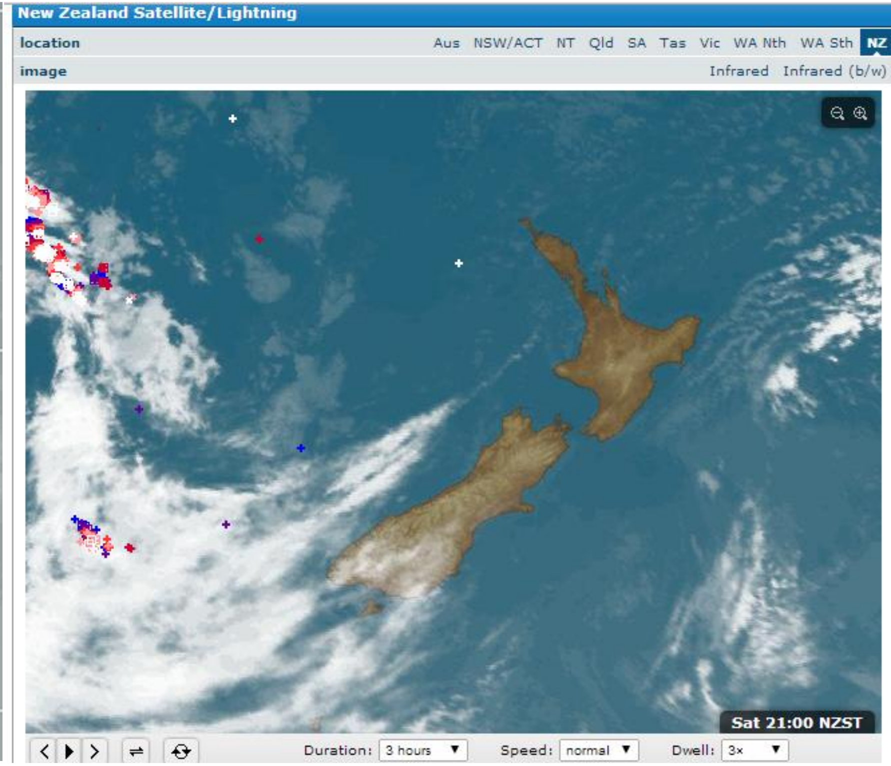
RF11 (IOP 9)

- Sensitive region near active convection with a large region of lightning
- GV deviated to north to avoid convection

IR (0832 UTC 28 June)

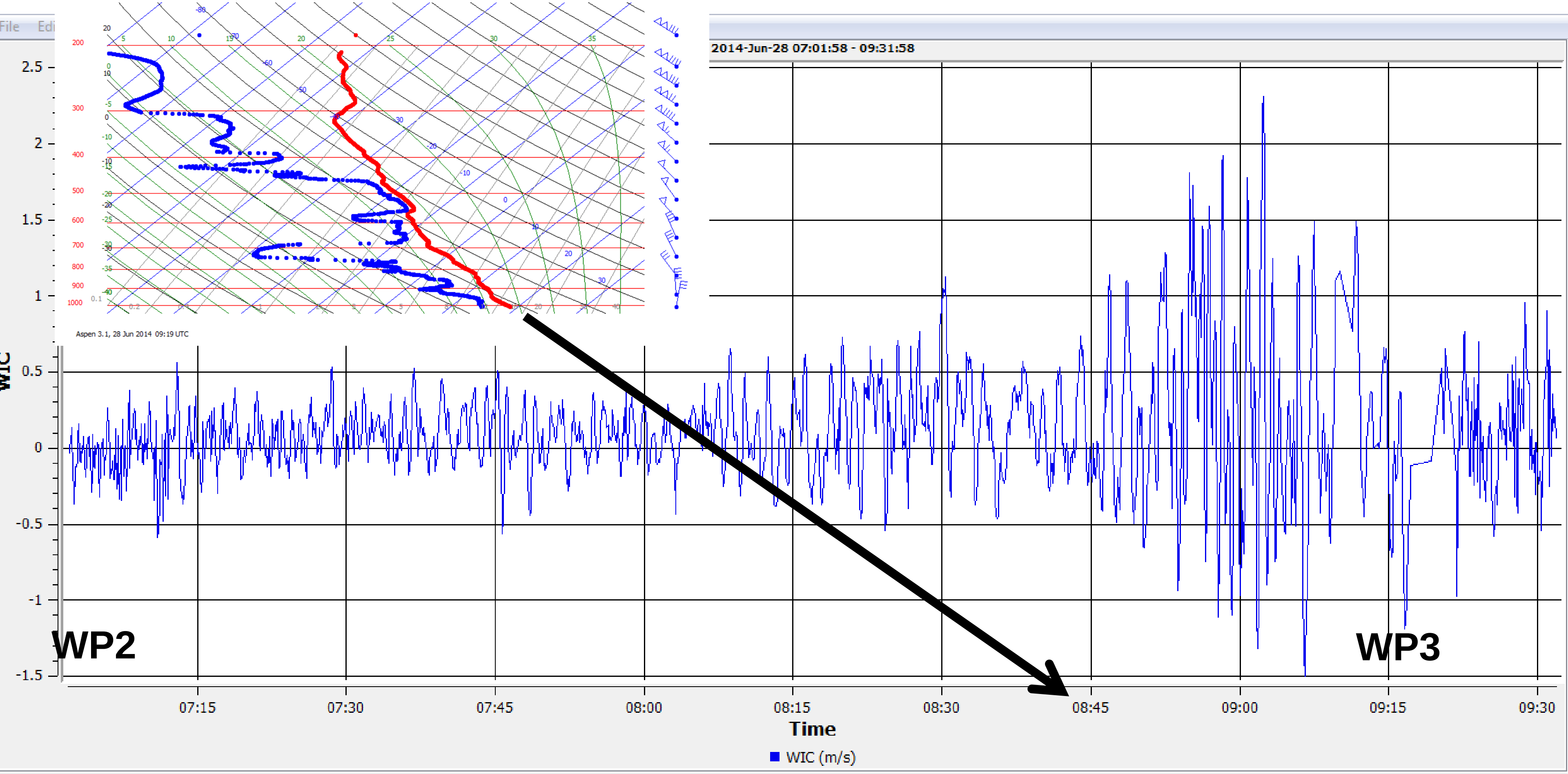


Lightning (0900 UTC 28 June)



RF11 (IOP 9)

- Strongest vertical velocity observed on top of the jet (>75 m/s) near WP3. Non-orographic wave source unclear (jet or convection or both?)
- Dropsondes contained large vertical shear and instability.



RF11 (IOP 9)

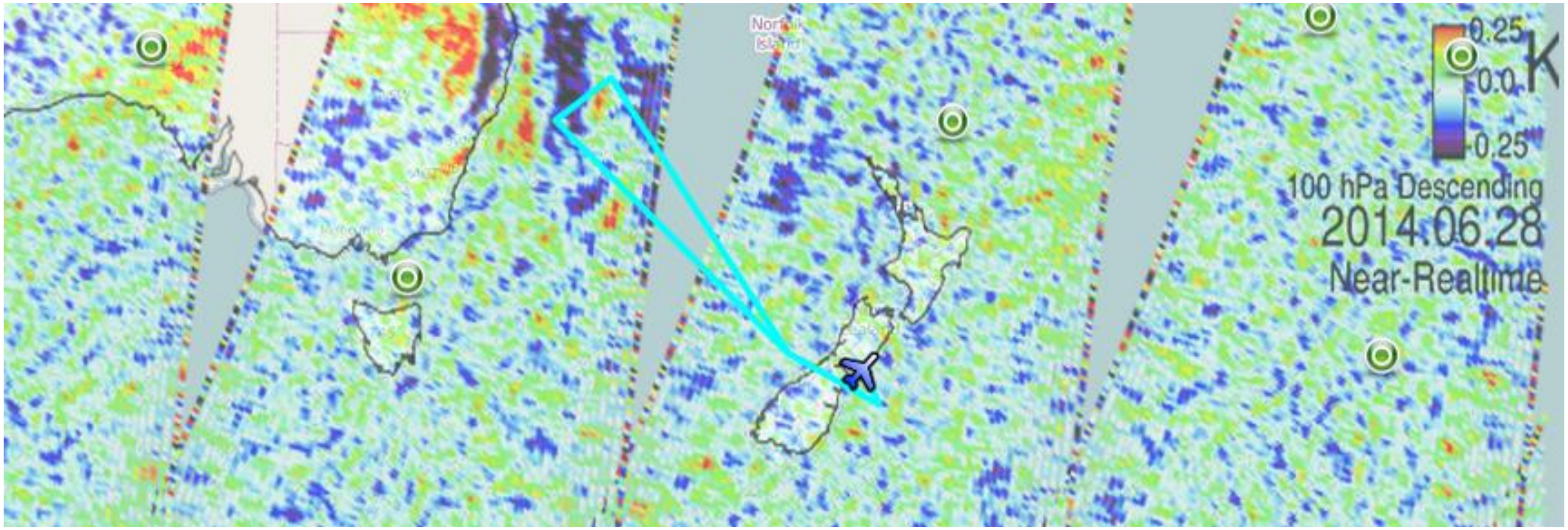
AMTM and Sodium Lidars Observed Rich Gravity Wave Activity in the Upper Levels

AMTM Imager (0642Z 28 June)

RF11 (IOP 9)

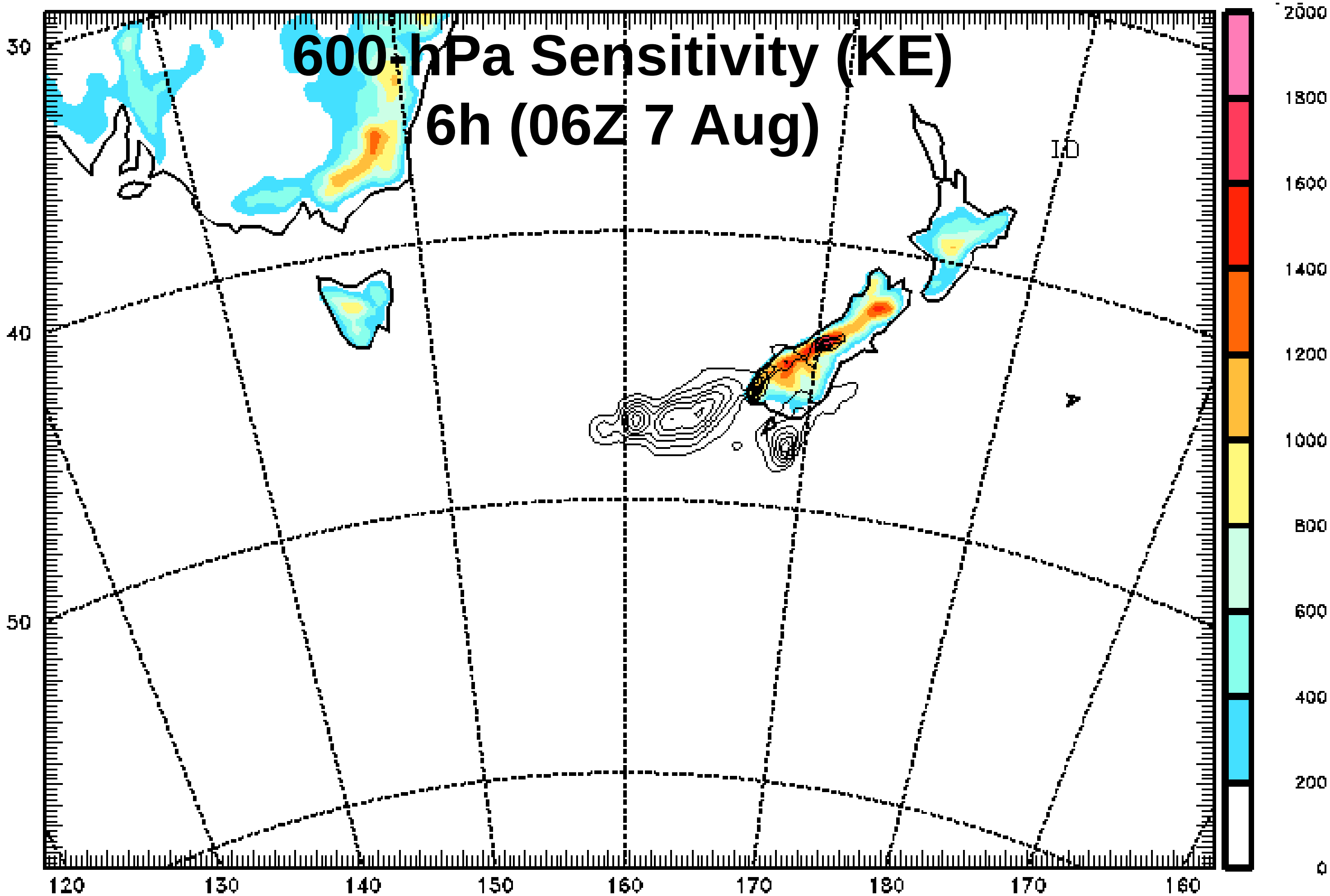
Large amplitude temperature perturbations apparent in the AIRS satellite observations near the time when the GV was flying.

AIRS at 100 hPa 1331Z 28 June



Gravity Wave Source Identification

Orographic Wave Case (7-8 August 2013)



- 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?

Summary for Predictability Objective

- **Predictability Flights**
  - Carried out 3 “complete” predictability missions, all in tandem with a gravity wave mission the following day.
  - Sensitive regions were in physically meaningful locations near: i) troughs, ii) jet streaks, iii) convection. What are the implications? Why?
  - Sensitive regions may be the “seeds” for the GWs and their characteristics
- **Data impact studies**
  - Data denial studies are underway to assess the impact of sonds on GWs.
  - Links between tropospheric predictability and the upper atmosphere?
  - Can targeted observing be used to improve the prediction of deep GWs?
- **Sources of stratospheric GWs**
  - Terrain-forced, spontaneous GW emission from baroclinic waves & jets
  - Adjoint could provide important tool to help with this (more demonstration work needed though)