The 14 Nov 2016 Mw 7.8 Kaikoura Earthquake: Surface rupture ... and much more

Pilar Villamor on behalf of the Earthquake Geology Response Team (54):

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The University of Auckland
GNS Science Te Pū Ao
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14 November Kaikoura Earthquake

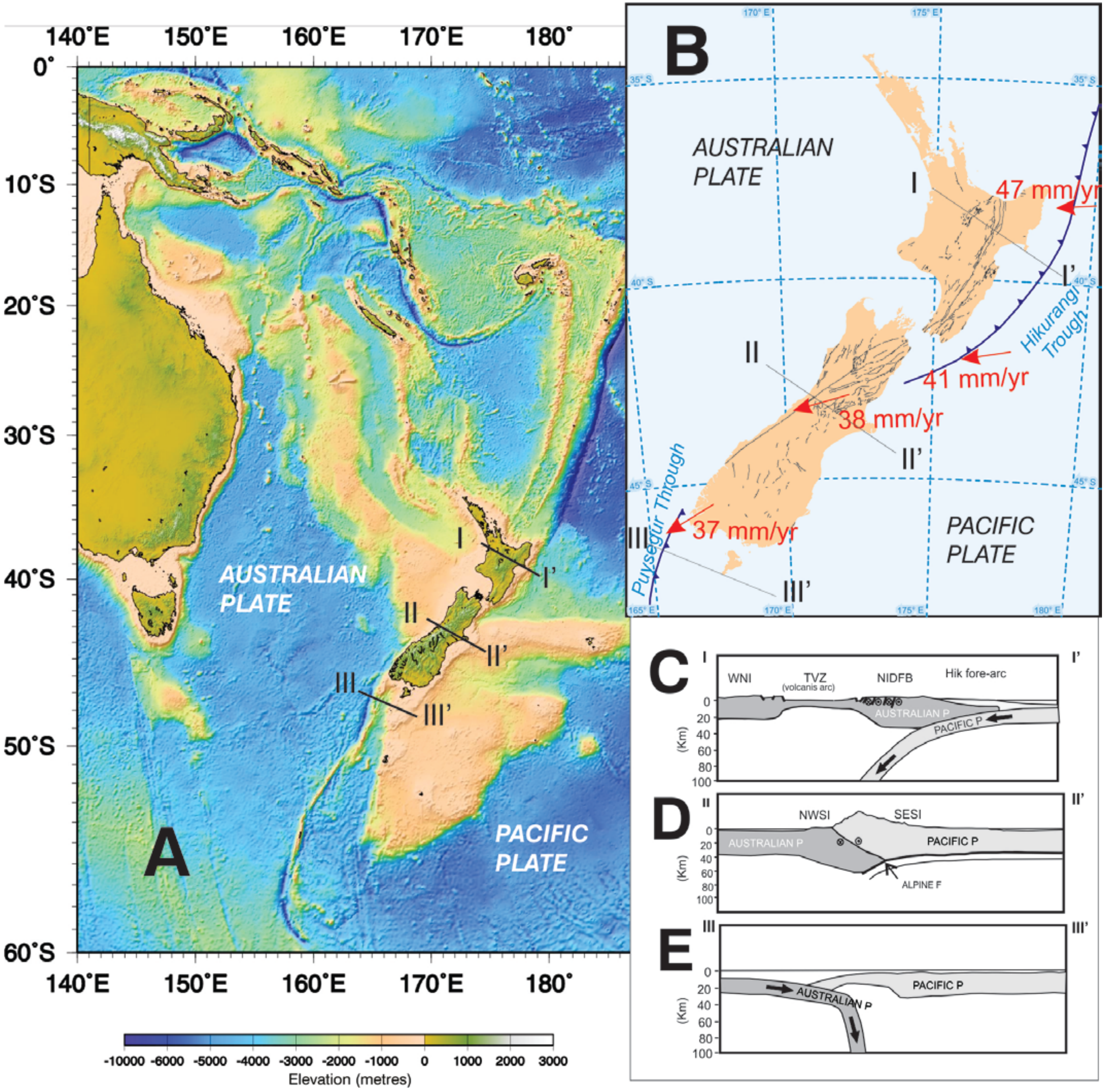
This talk

- **Background**
- **Kaikoura Earthquake**
  - Seismicity, ground motions
  - InSAR and GNSS
  - Preliminary rupture models
  - Surface Rupture
  - Tsunami, Landslides (if we have time..)

Surface rupture of the Papatea Fault displacing the coastal platform, road, railway and hill country.

Background

- The 14 Nov event occurred in the region between the Hikurangi subduction system of the North Island and the oblique collisional regime of the South Island (Alpine Fault)



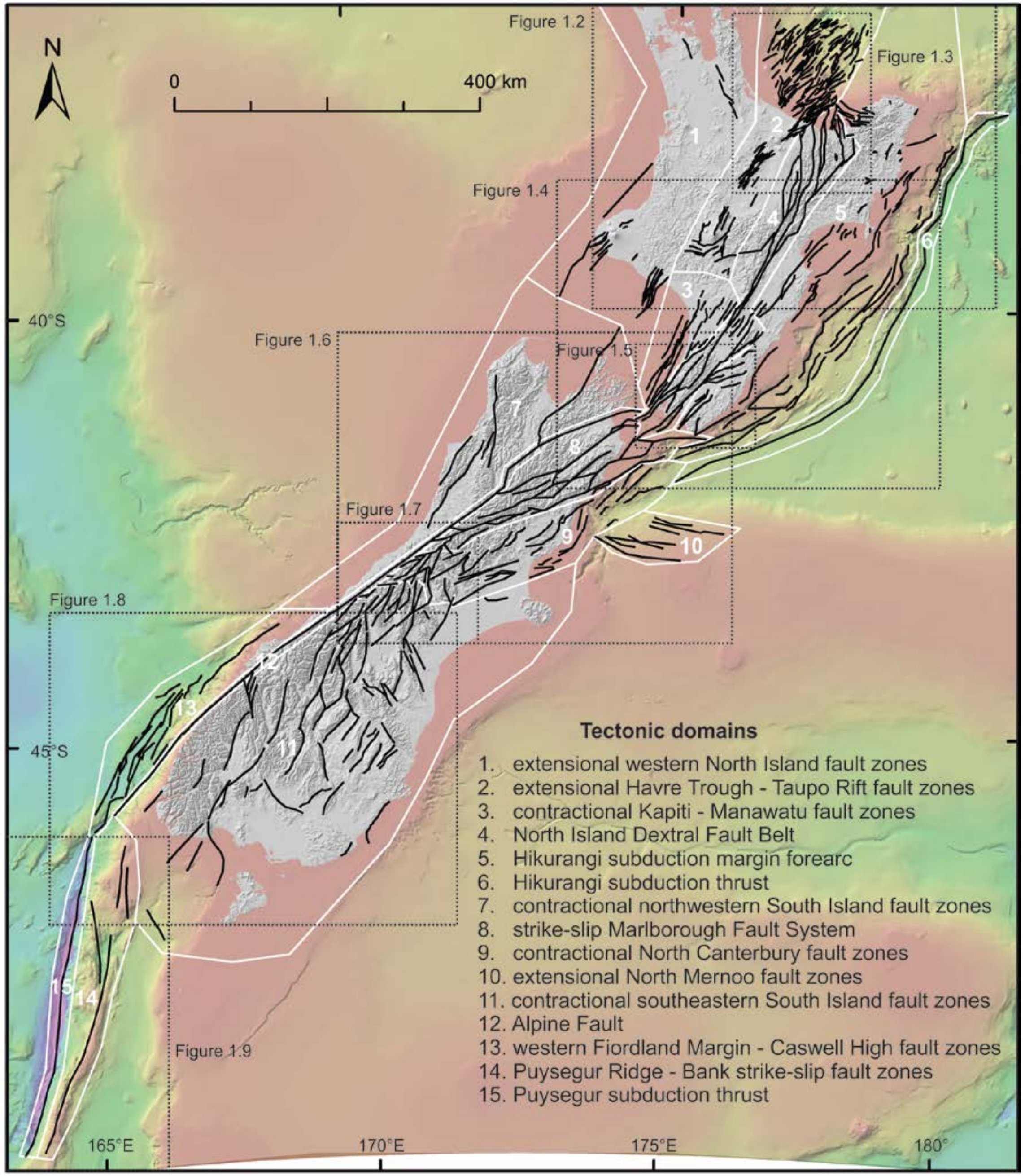
Background

- The 14 Nov event ruptured several faults that expand into different tectonic domains:

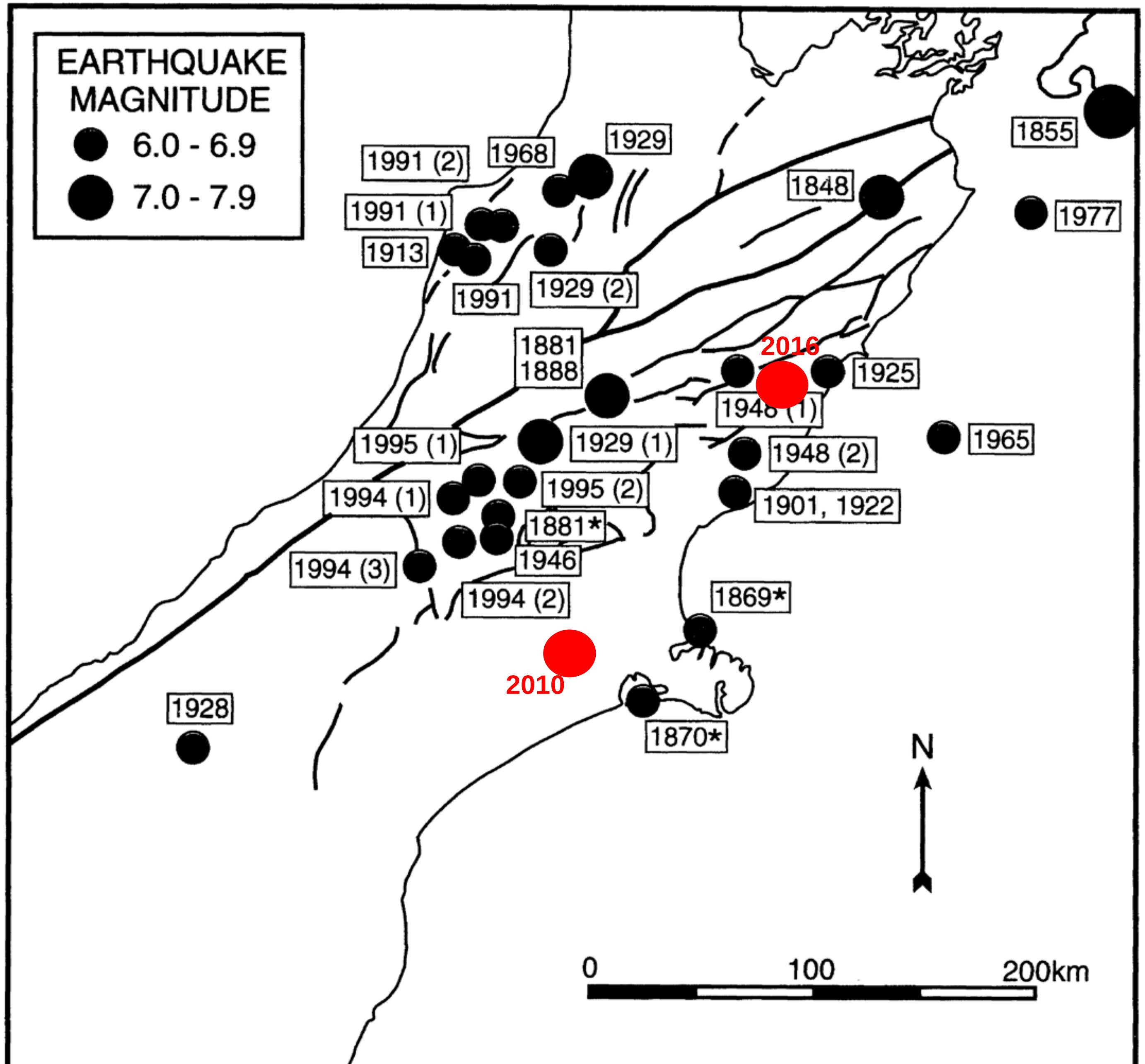
  - The **strike-slip Marlborough fault system** consists of a series of right lateral strike-slip faults, some with reverse component, that link to the Alpine fault on the west and to the subduction margin fore-arc to the east. Net fault slip rate varies from 0.1 to 25 mm/yr.

- The **contractional North Canterbury Fault Zone** has mixed fault orientations (northerly and easterly) and fault types (reverse faulting and folding and strike-slip). Net fault slip rate varies from 0.1 to 3.5 mm/yr (poorly constrained).

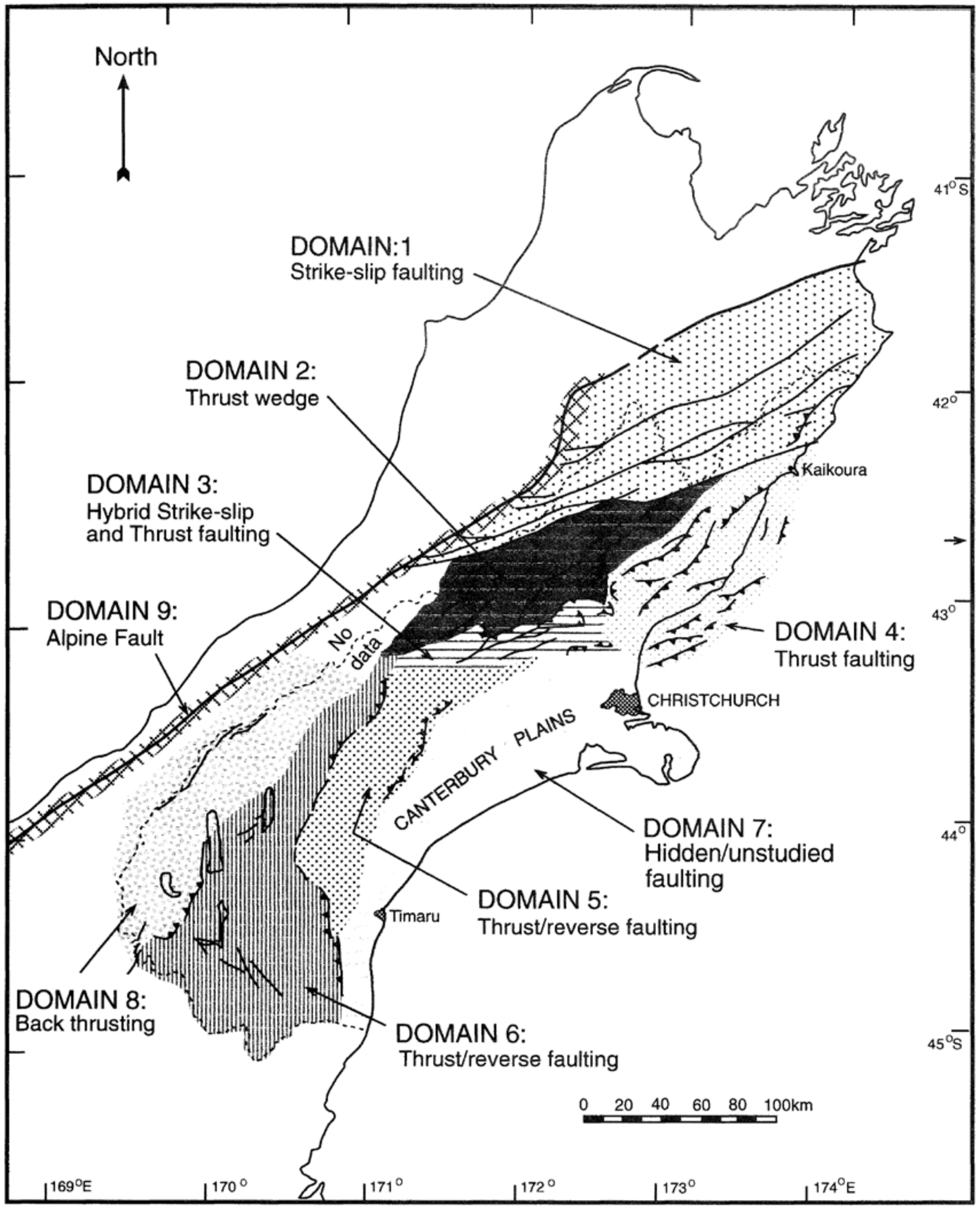
- The **subduction zone** terminates in close proximity to the area that ruptured during 14 Nov.



Litchfield et al 2014



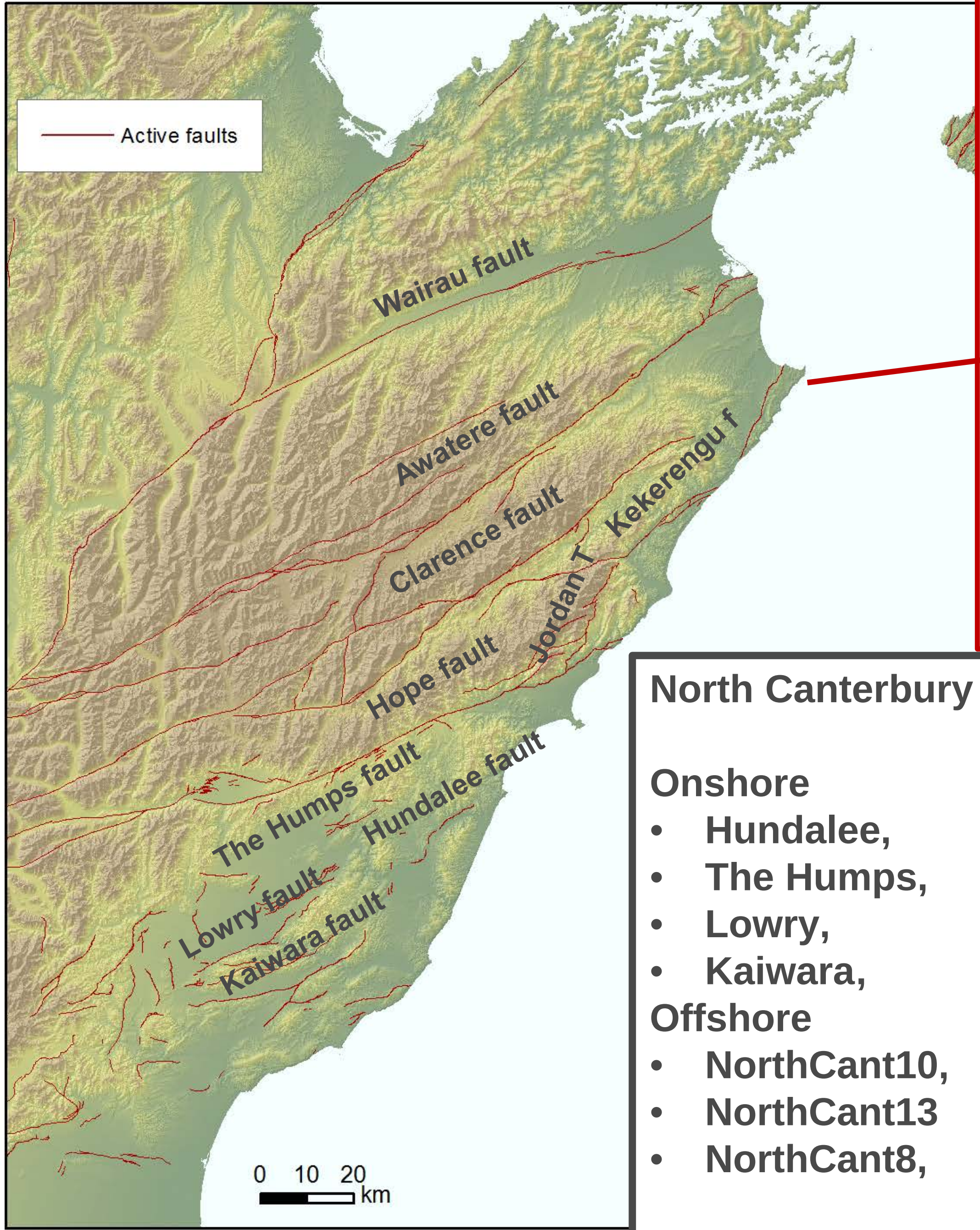
Pettinga et al., 2001

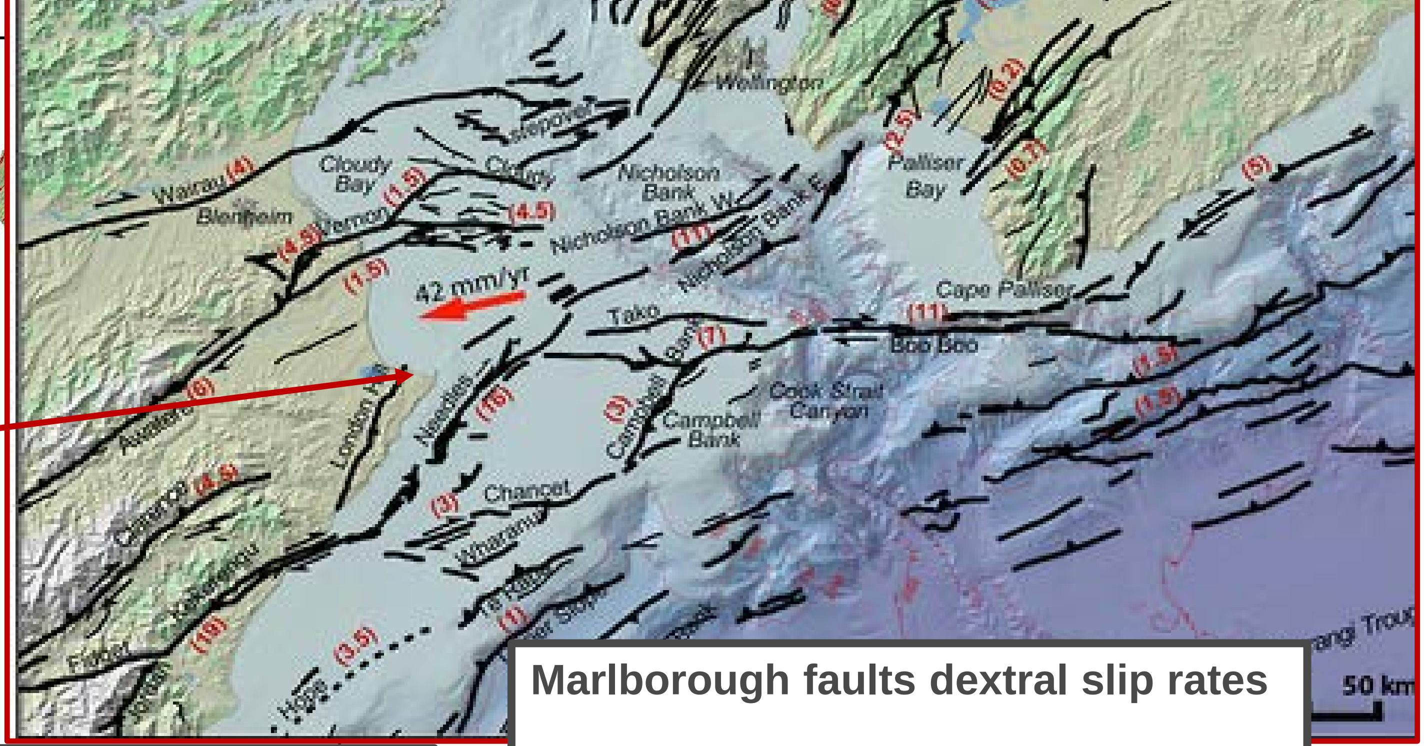


Historic Seismicity

Tectonic domains

GNS Science





North Canterbury faults

Onshore
- Hundalee, c. 0.5-1.5 mm/yr
- The Humps, ??
- Lowry, c. 0.5-1.5 mm/yr
- Kaiwara, c. 0.2-1.2 mm/yr

Offshore
- NorthCant10, c. 1-3
- NorthCant13 c. 0.3 mm/yr
- NorthCant8, c. 0.1-0.4 mm/yr

Marlborough faults dextral slip rates

Onshore
- Wairau, c. 3 mm/yr
- Awatere, c. 6 mm/yr
- Clarence, c. 3 mm/yr
- Hope Fault, c. 20 - 30 mm/yr
- Kekerengu, c. 20 - 26 mm/yr

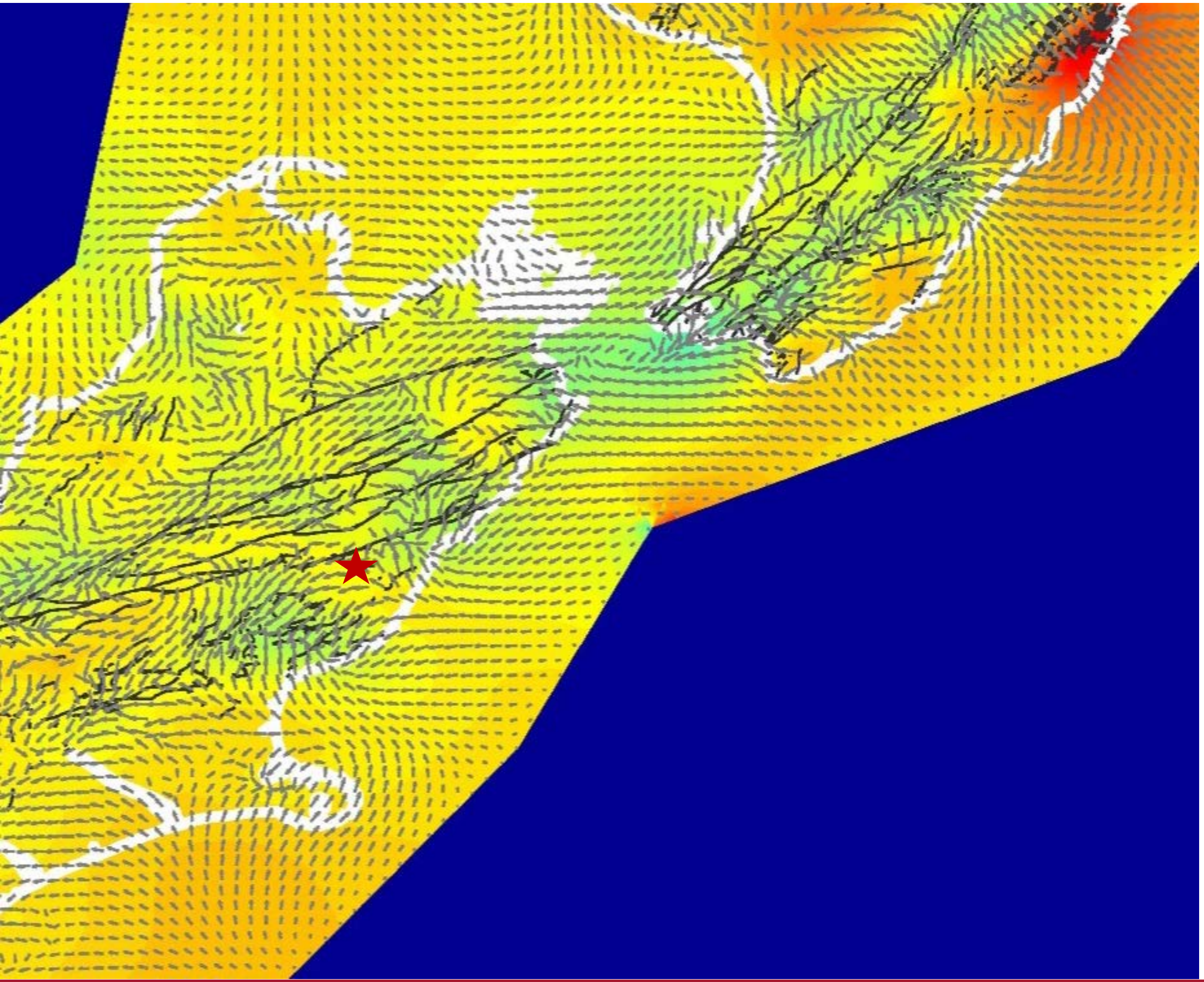
Offshore
- Needles, c. 16 mm/yr
- Chancet, c. 3 mm/yr
- Vernon, c. 4.5 mm/yr
- Nicholson B., c. 11 mm/yr
- Boo Boo, c. 11 mm/yr

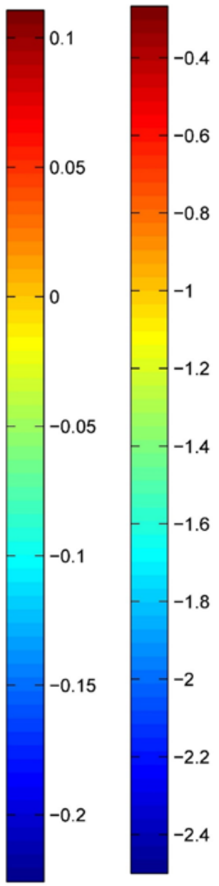
Known active faults and rates

Geodetic strain

Area Strain

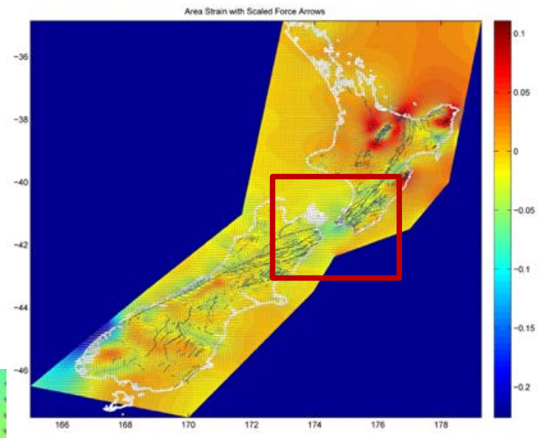
with Scaled Force Arrows

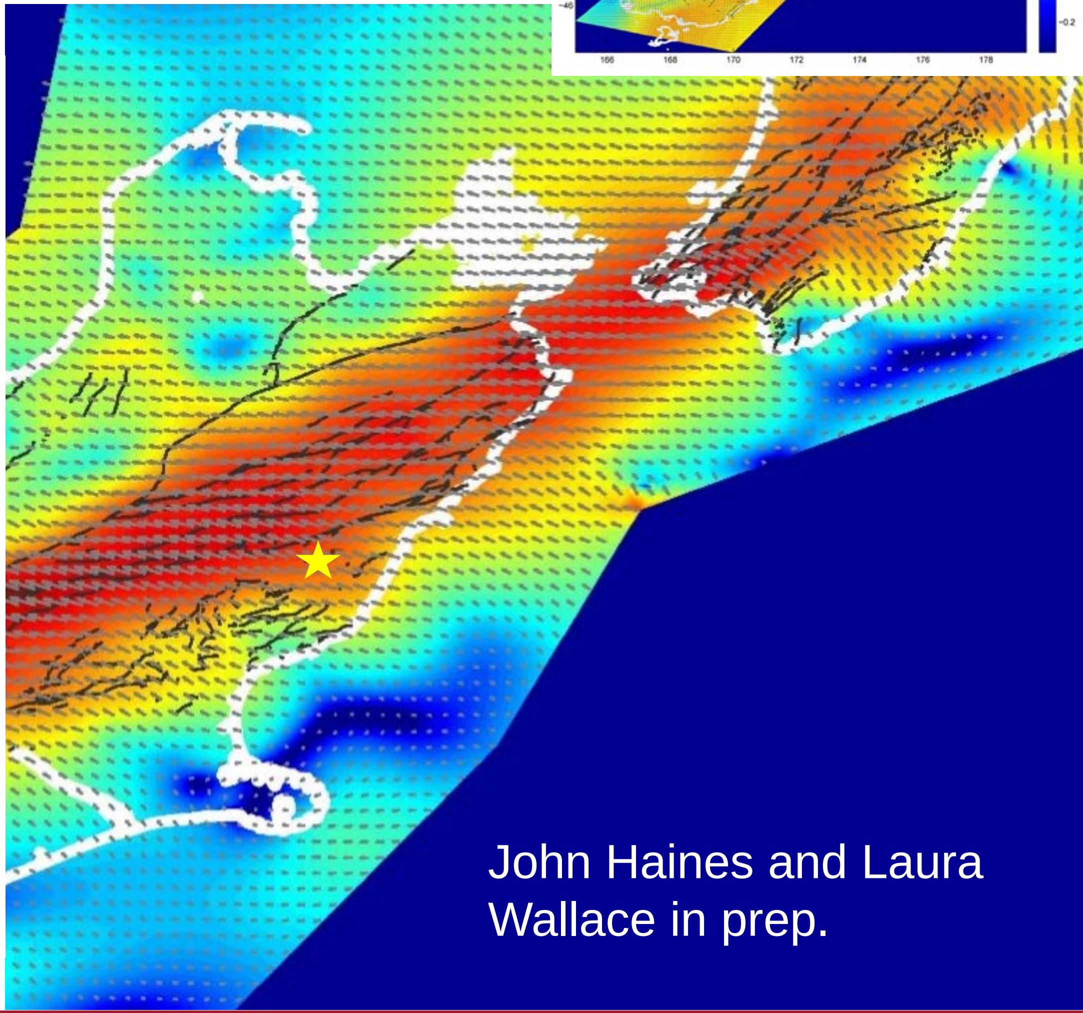




Log Shear Strain

max(-2.5,log10 (shear strain))-
with Principal Contraction
Directions



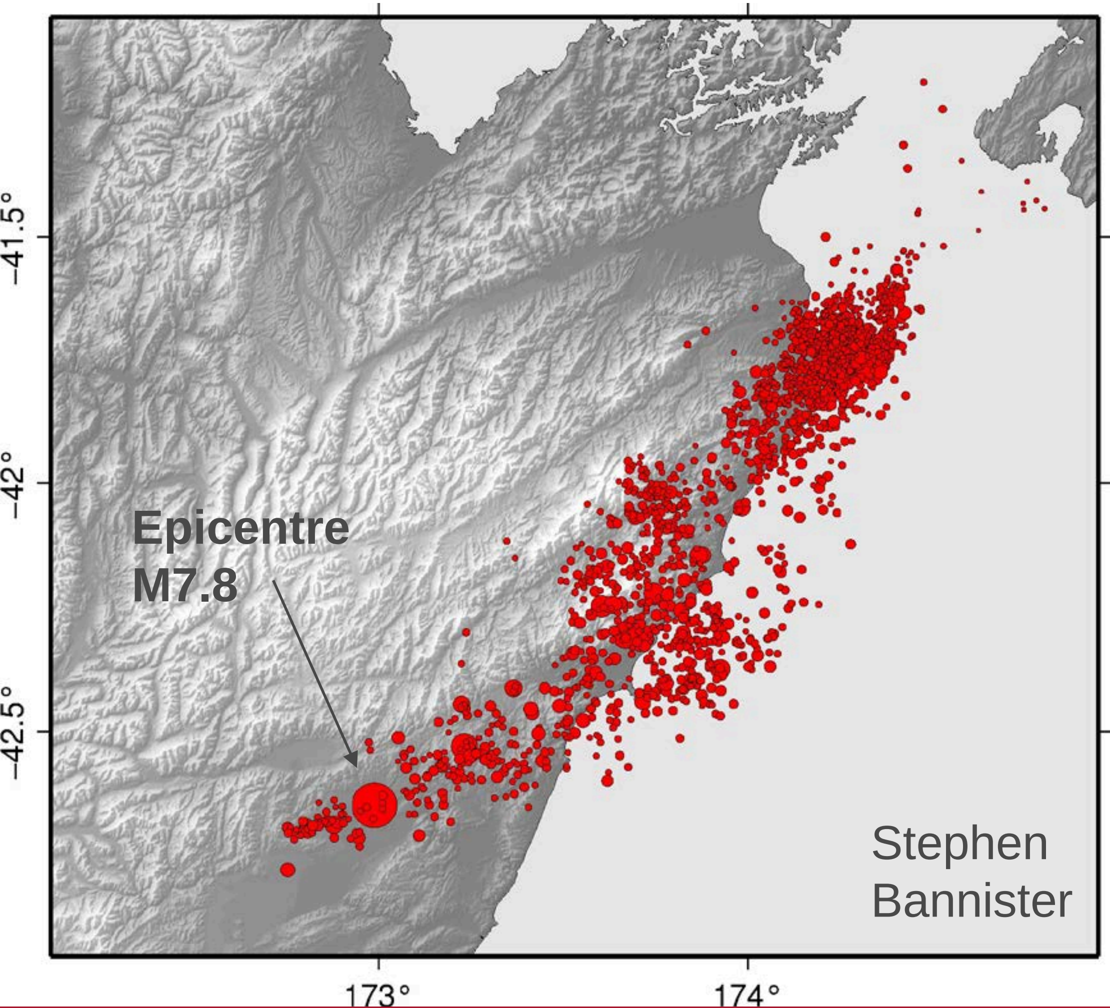


John Haines and Laura Wallace in prep.

The 14 November 2016 Mw 7.8 Earthquake

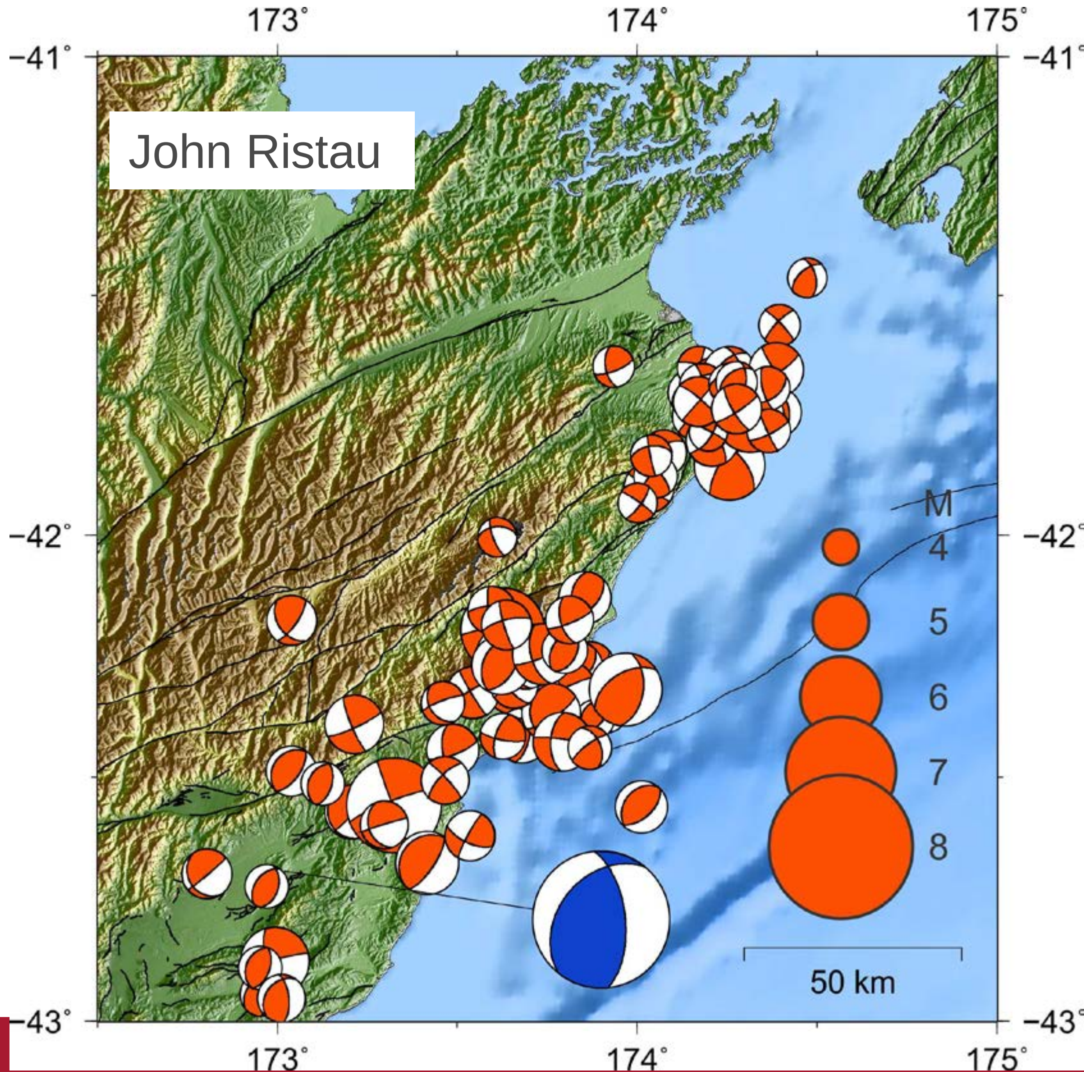
Location and aftershocks

Up to Friday 25th November
Two M6+ aftershocks (largest M6.3) occurred within two hours of the mainshock.

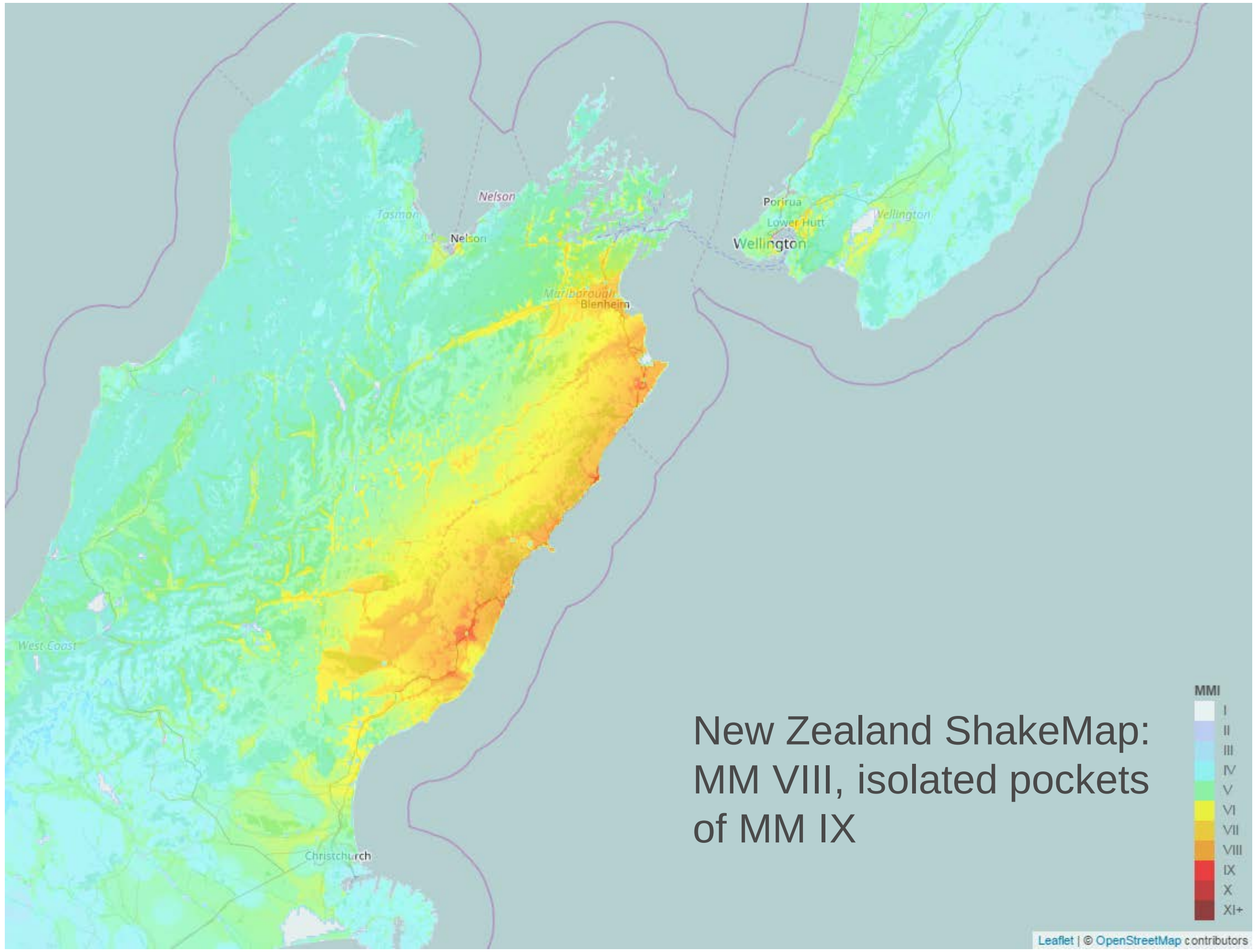


Focal Mechanisms

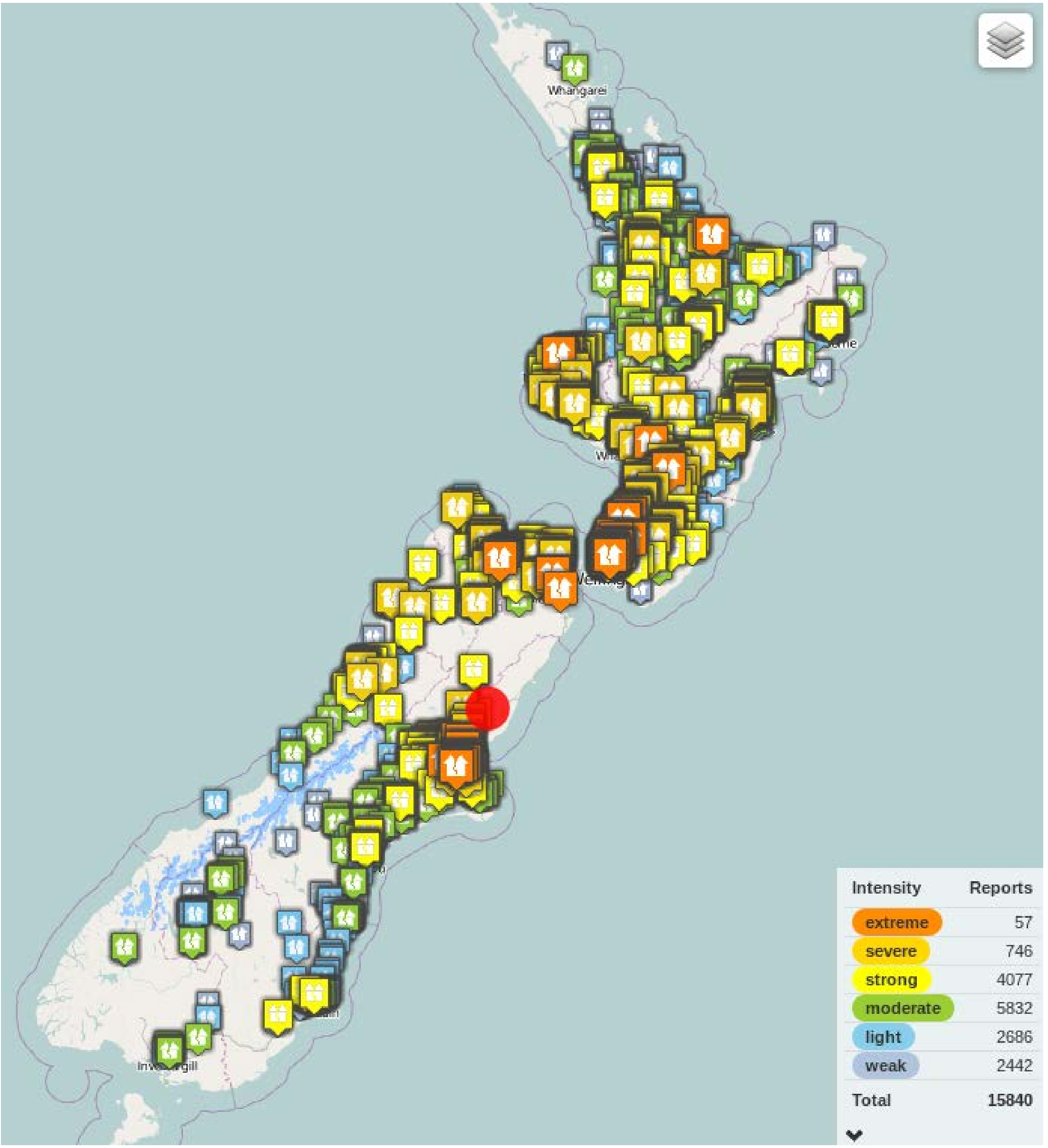
Mainshock thrust mechanism
Aftershock mechanisms thrust and strike-slip



Ground Motions: Intensity

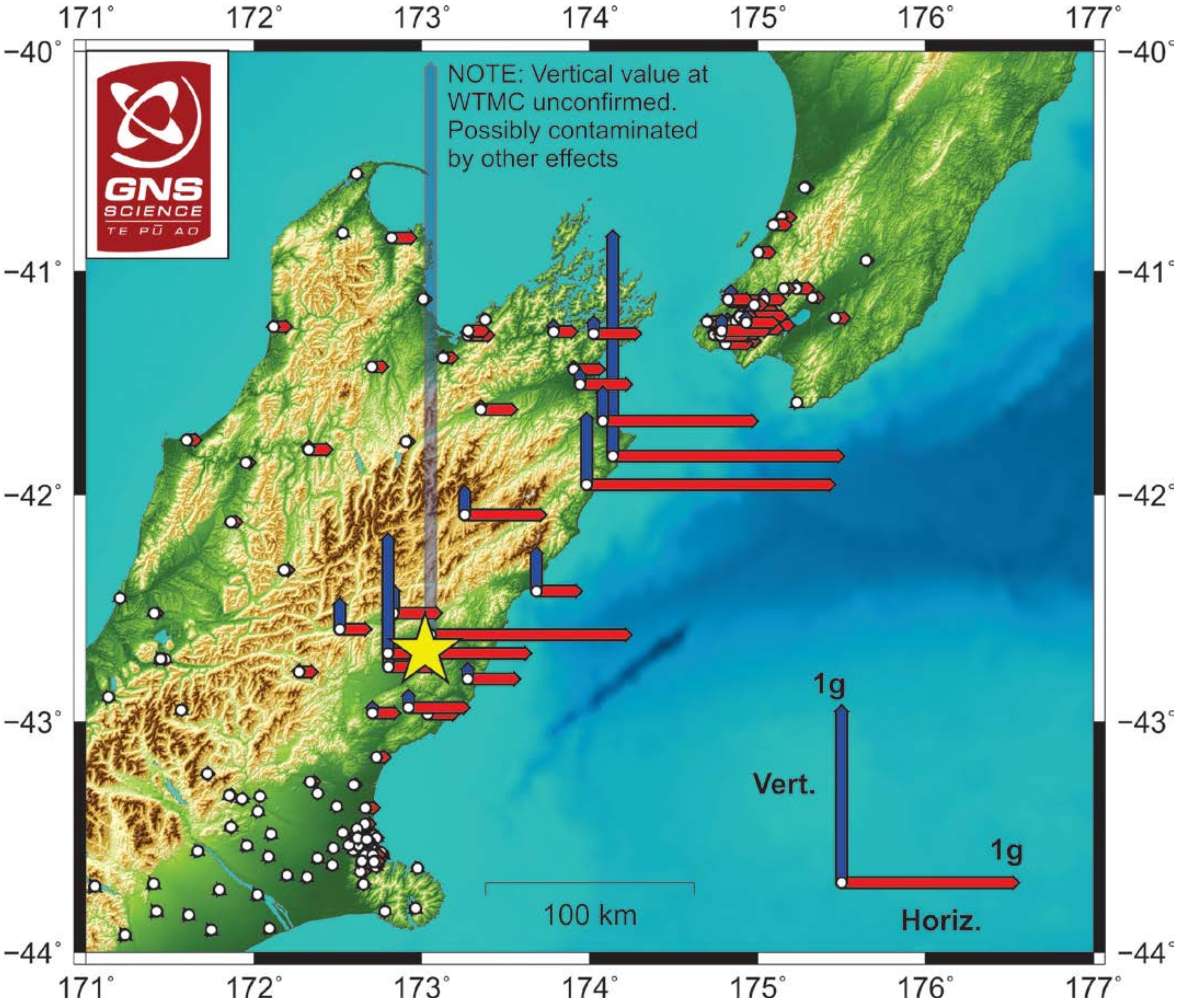


Nick Horspool



GeoNet, 15000+ felt reports

Ground Motions: Peak Ground Acceleration (PGA)



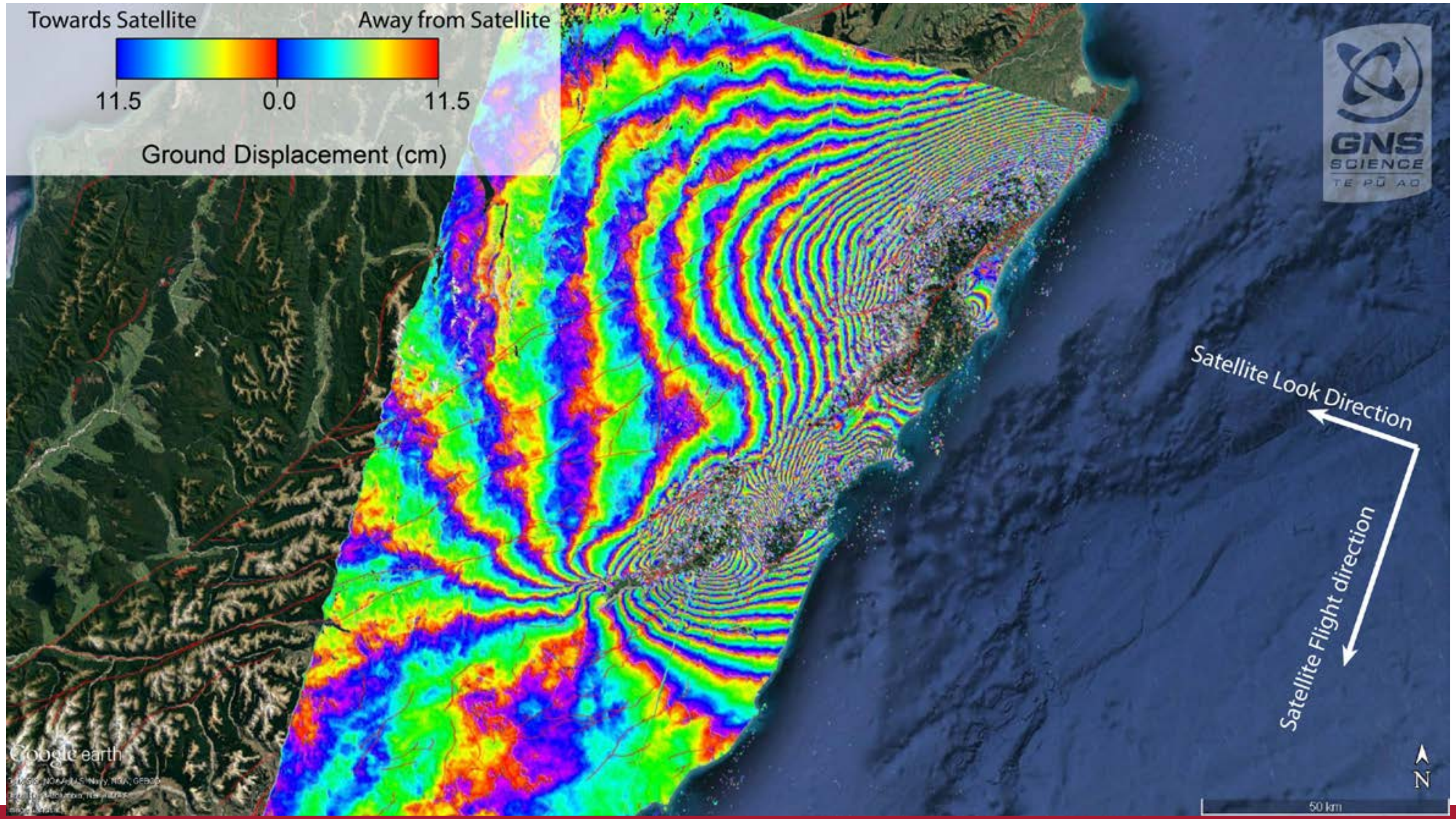
- PGA confirmed up to 1.3g (Ward station)
- Horizontal PGA > 1g recorded in the top of the South Island (Ward, Kekerengu) and the epicentral region (Waiau). Lower accelerations recorded in Kaikoura
- Ground shaking significantly lower in Christchurch than Wellington due to northward rupture from epicentre and distribution of fault slip

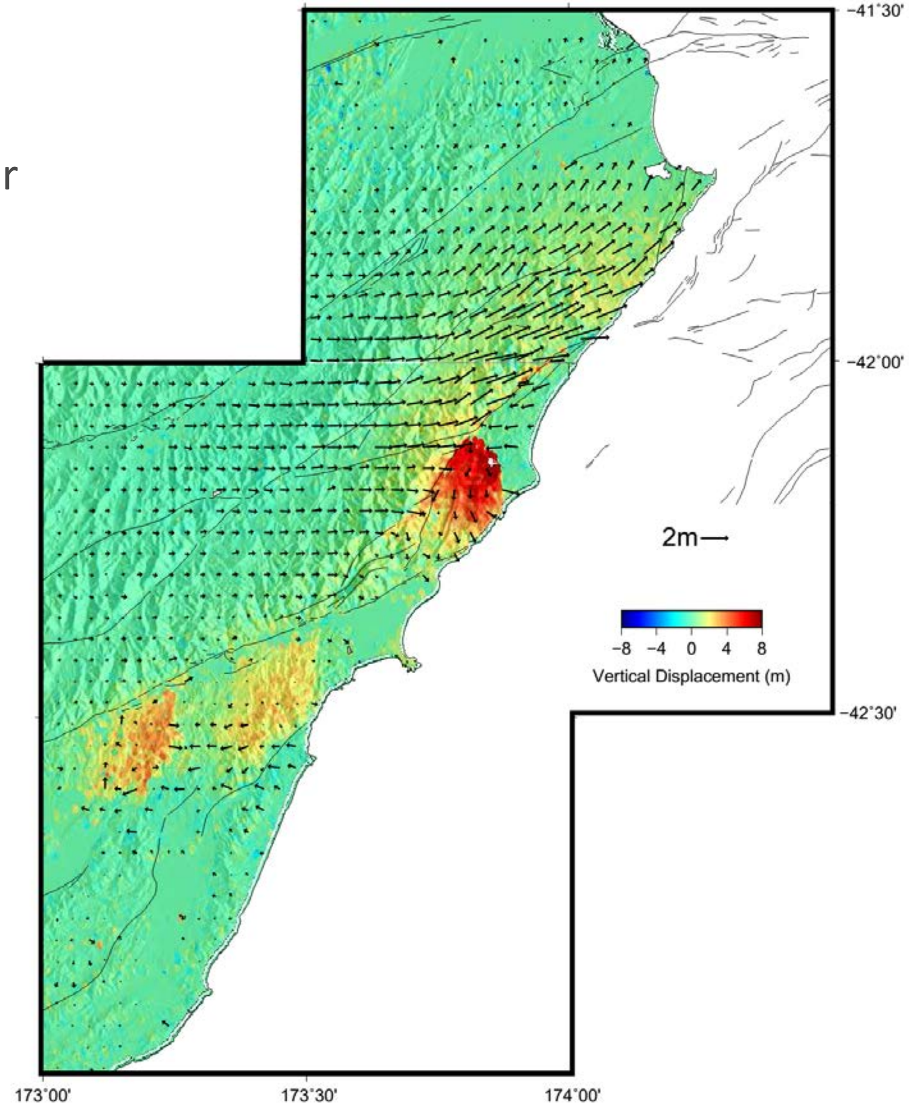
Anna Kaiser

InSAR observations from ALOS-2

Using radar satellites orbiting at 700 km we measure the displacement of the Earth’s surface by measuring the change in the path length between two radar acquisitions.

Each contour represents 11.5 cm of ground motion either towards or away from the satellite





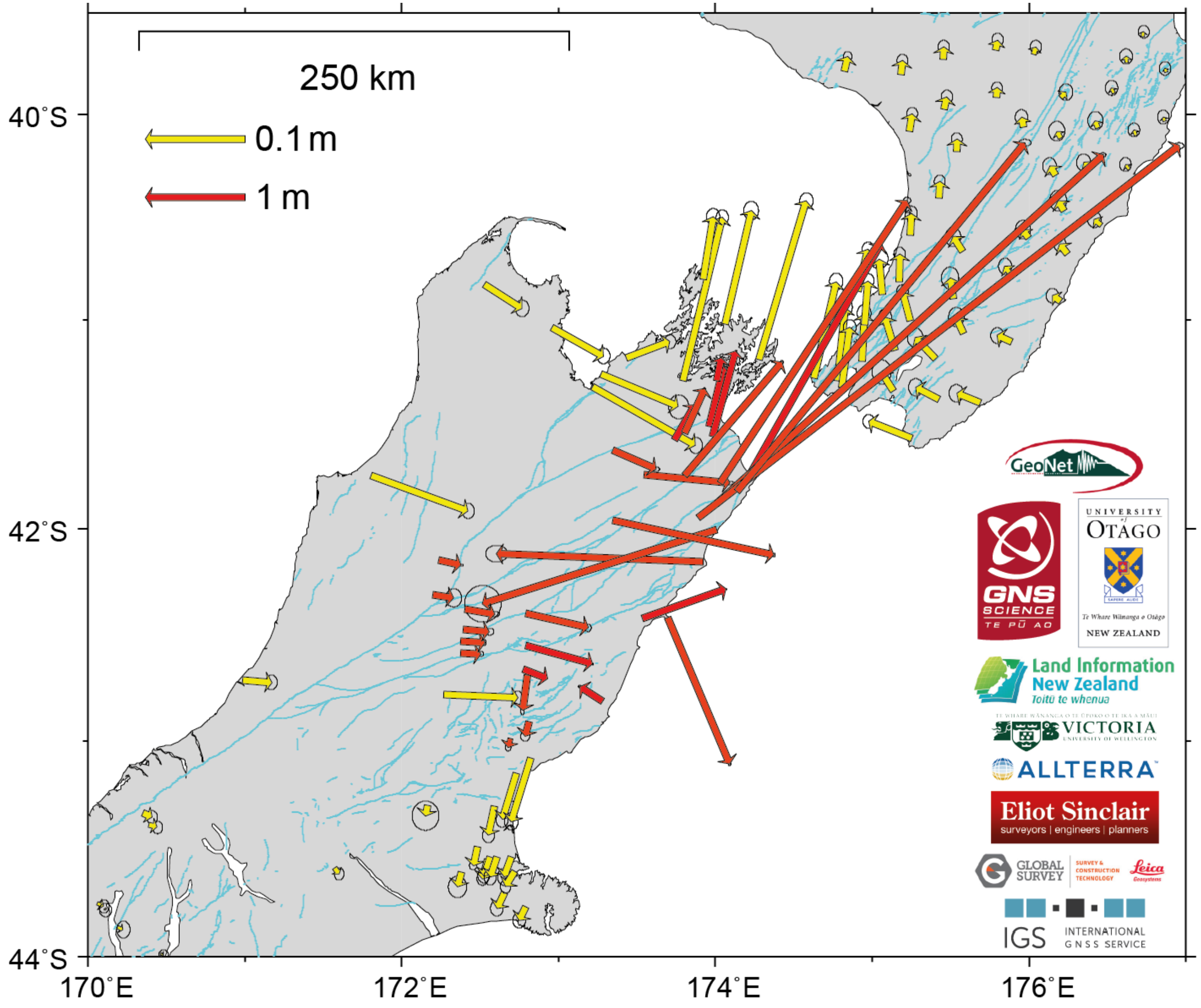
3D Displacement field derived from Sentinel-1 radar amplitude.

Ian Hamling

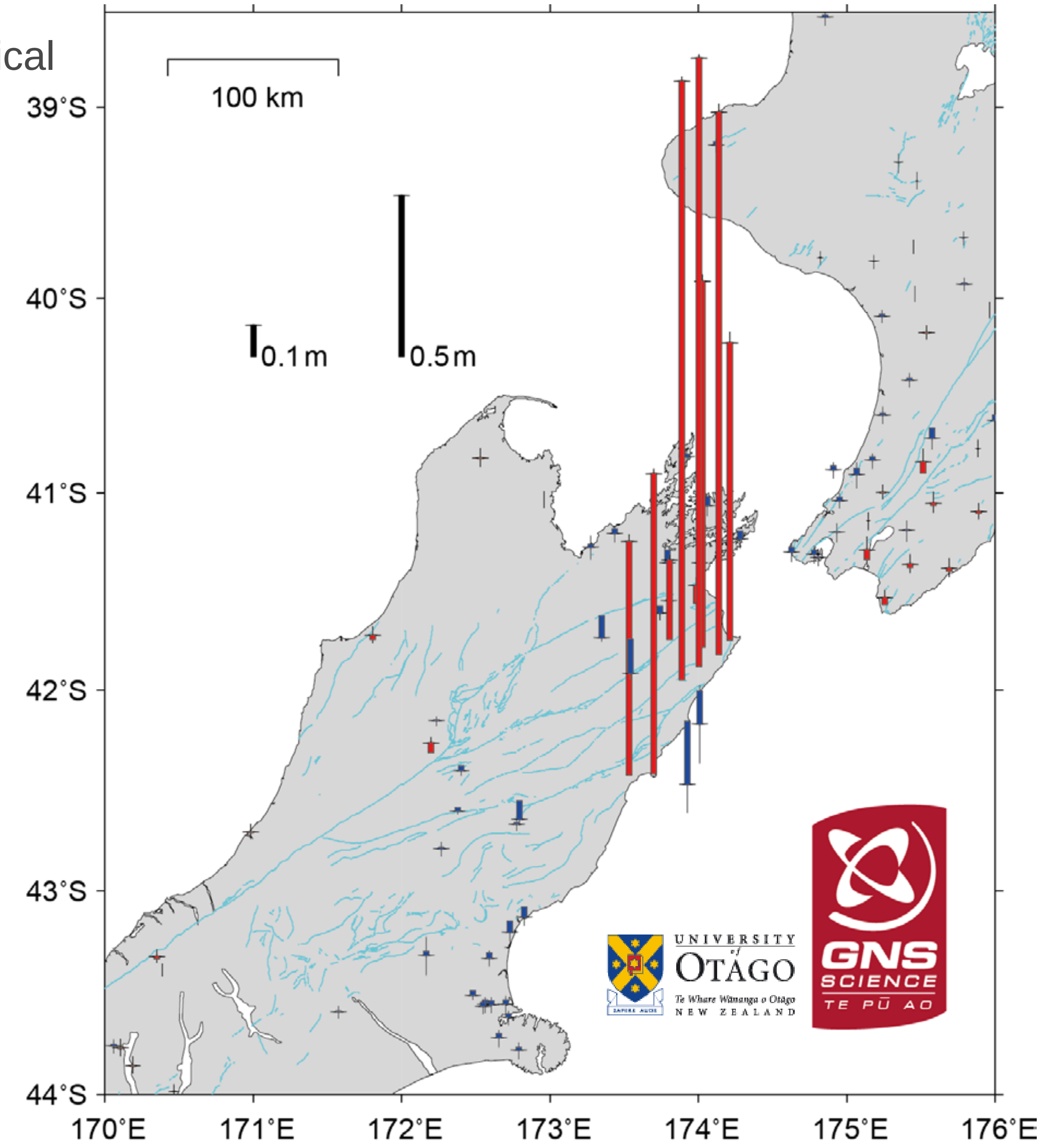
Coseismic geodetic measurements

Hmax: 6m; Vmax: 2m

Horizontal

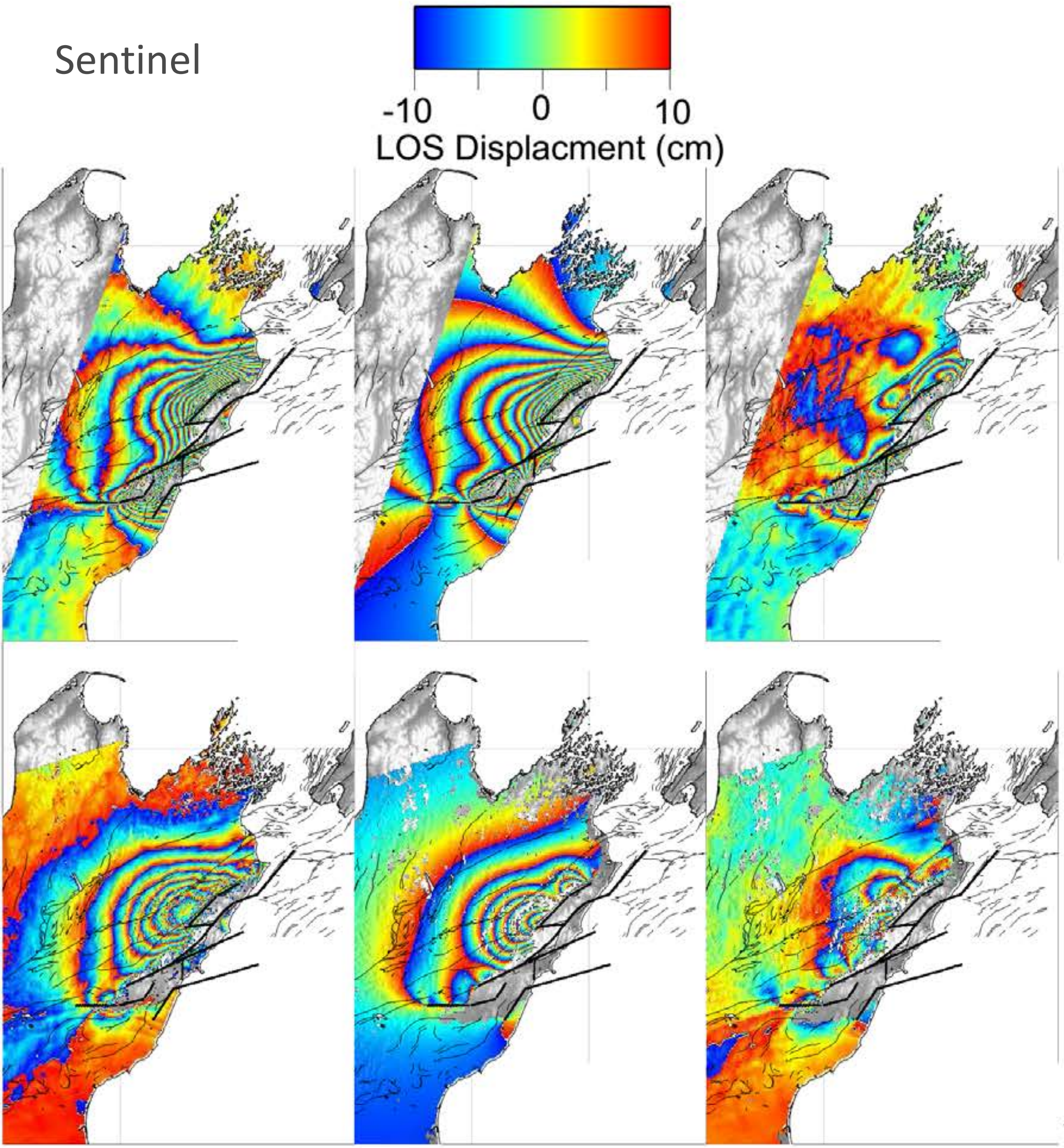


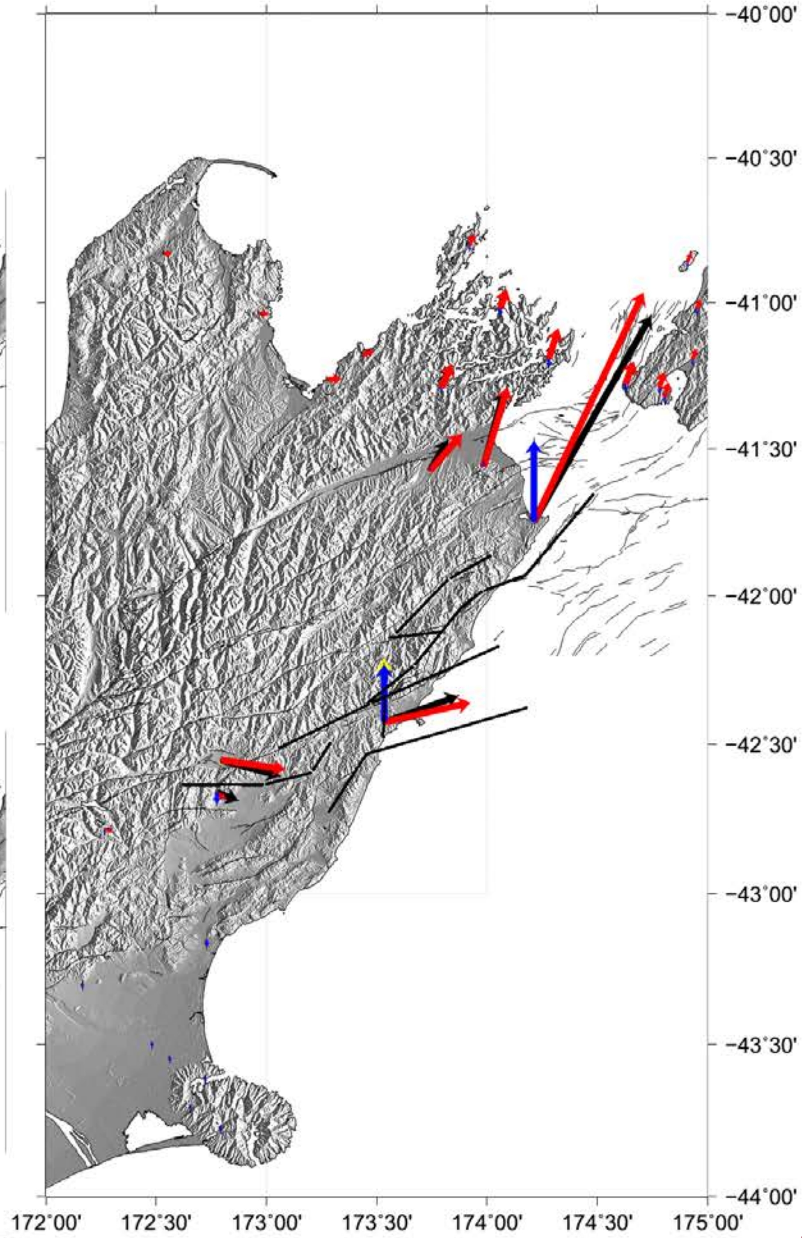
Vertical



Geodetic Fault Model

Sentinel



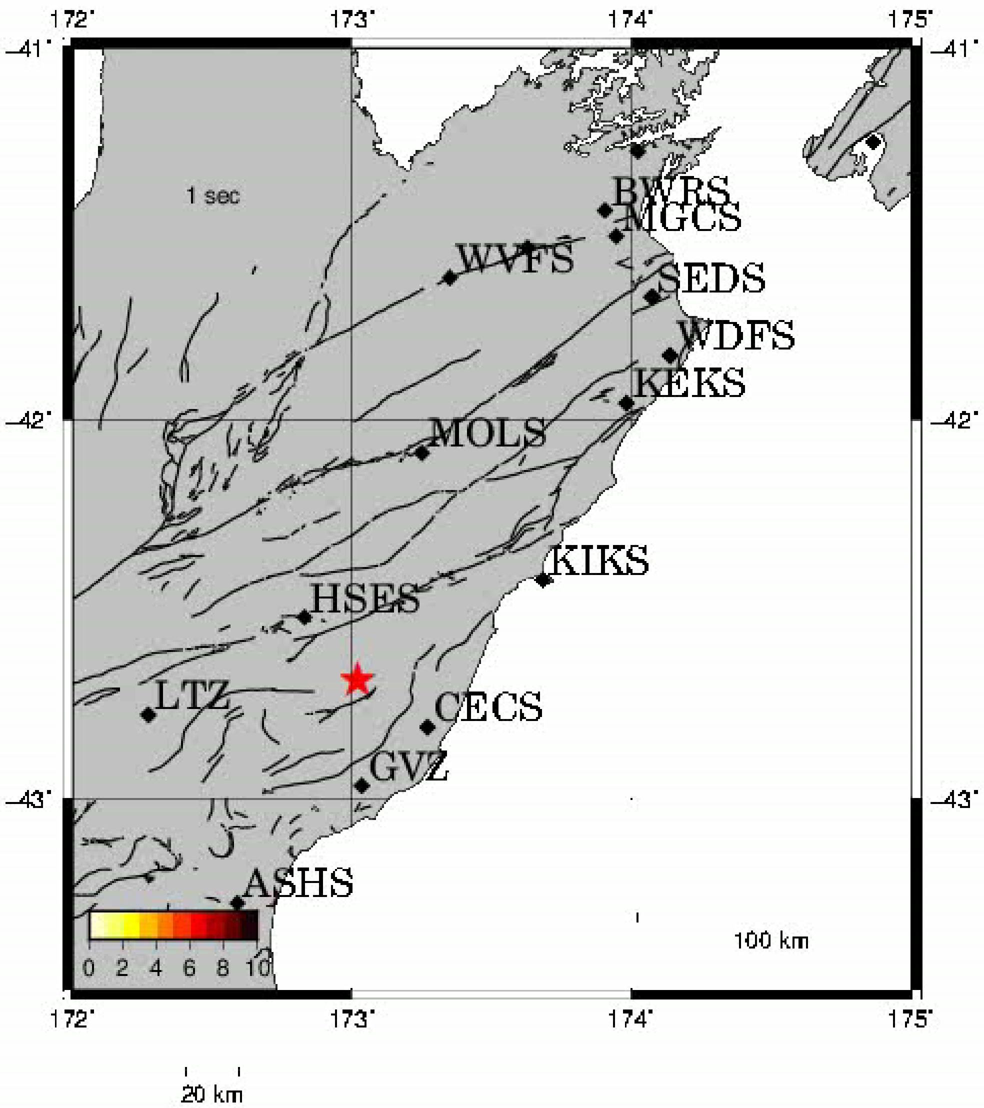


Preliminary slip model derived from InSAR and GPS data.

Despite the current model explaining 94% of the total data variance, significant residuals remain, further highlighting the complexity of the rupture.

Ian Hamling

Kinematic Fault Model (Preliminary)



Inversion of strong motion data for slip and timing of rupture on pre-defined fault segments (based on the preliminary geodetic fault model).

- South to North rupture across multiple fault segments

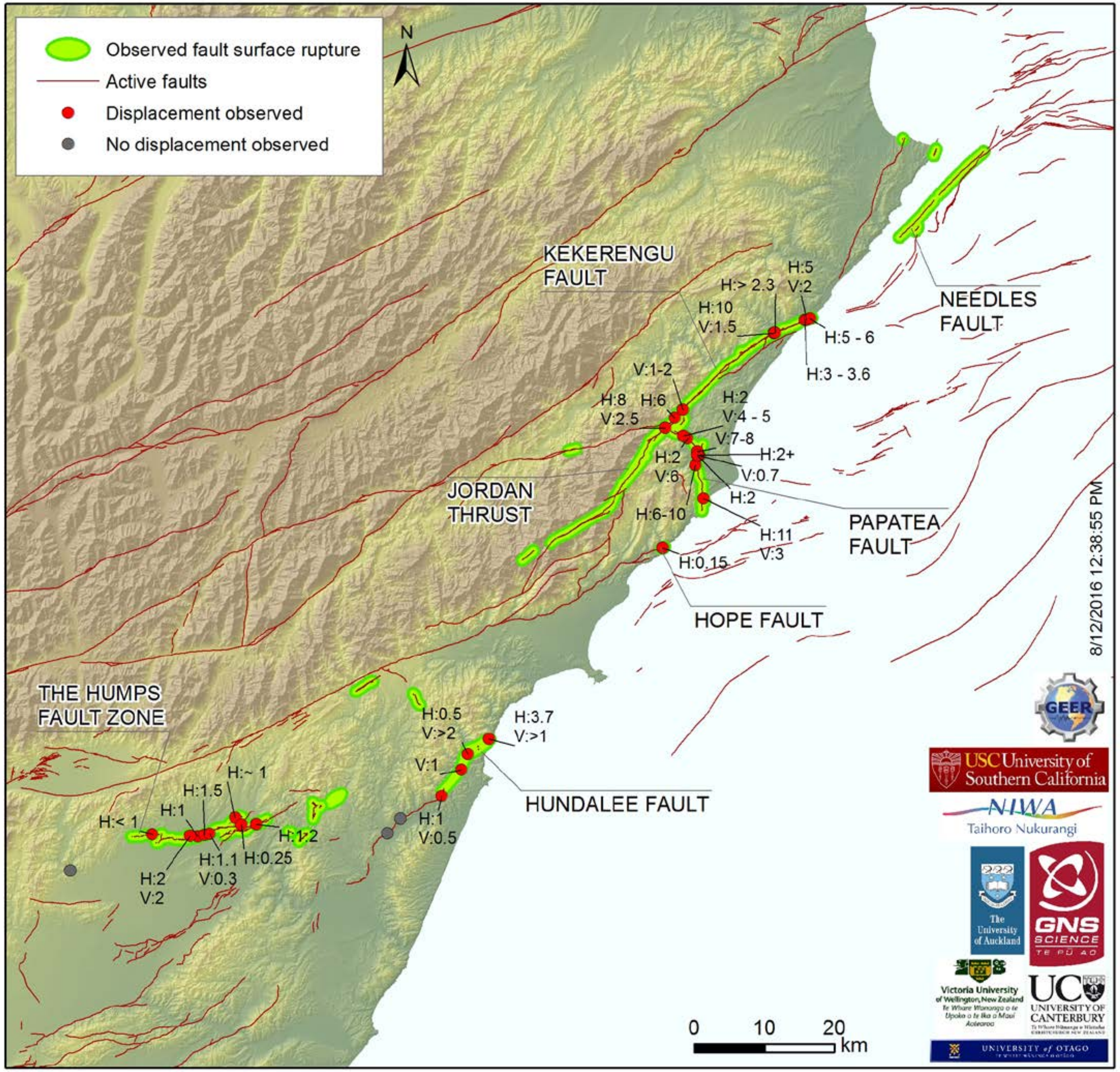
VIDEO

Caroline Holden

http://info.geonet.org.nz/display/quake/2016/11/23/Watching+the+M7.8+Kaikoura+Quake+Dominos+Fall+in+Real+Time

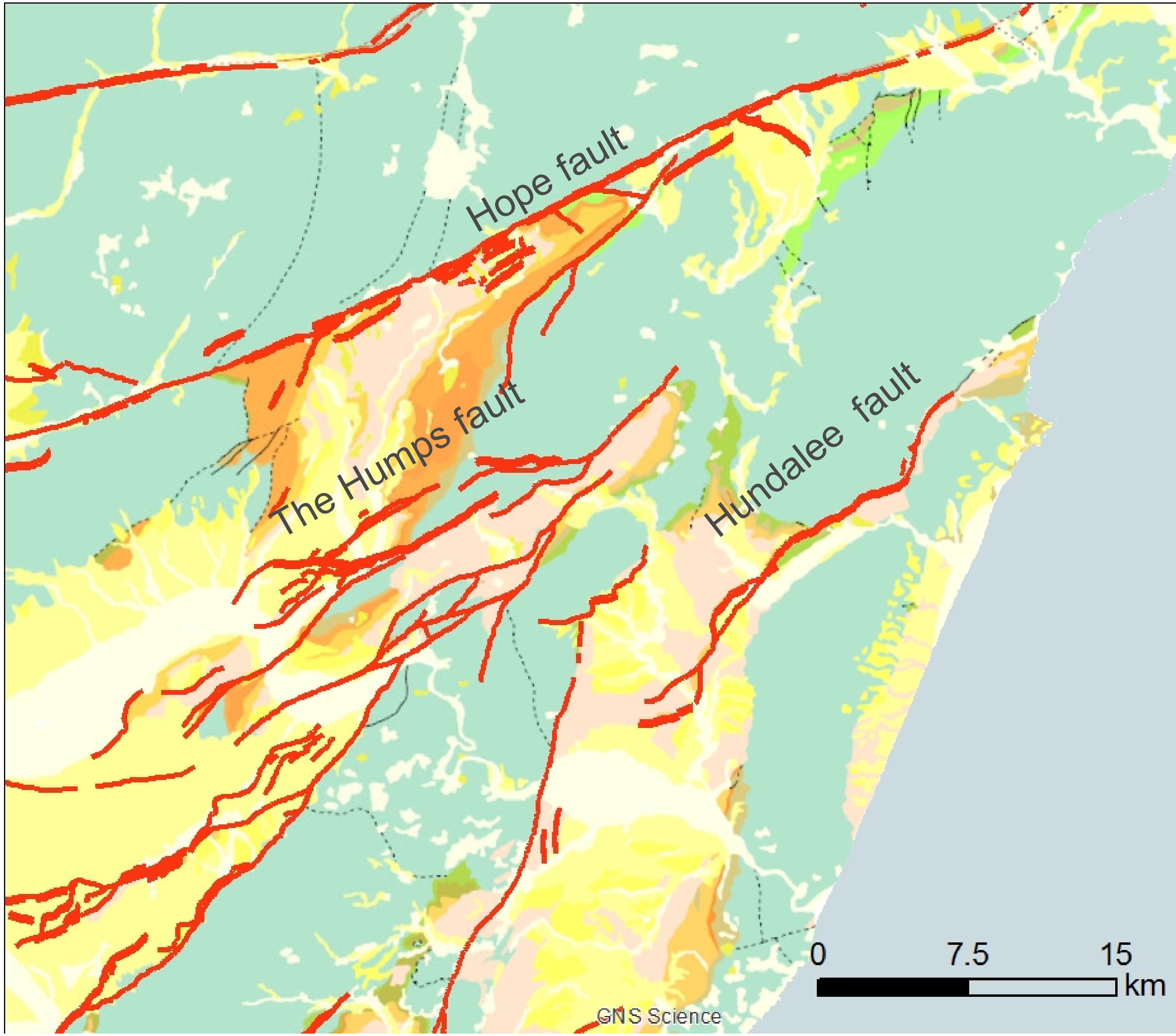
Observed fault ruptures and amount of displacement (m)

- The Humps fault zone- up to H:2 V:2
- Hundalee fault- up to H: 3.7 V: >2
- Hope fault – up to H: 0.5 V:0.5
- Papatea fault – up to H:5 & V:8
- Jordan Thrust- ?
- Kekerengu up to H: 10. V: 2.5
- Needles fault?
- Fidget fault?



The Humps-Leader Fault

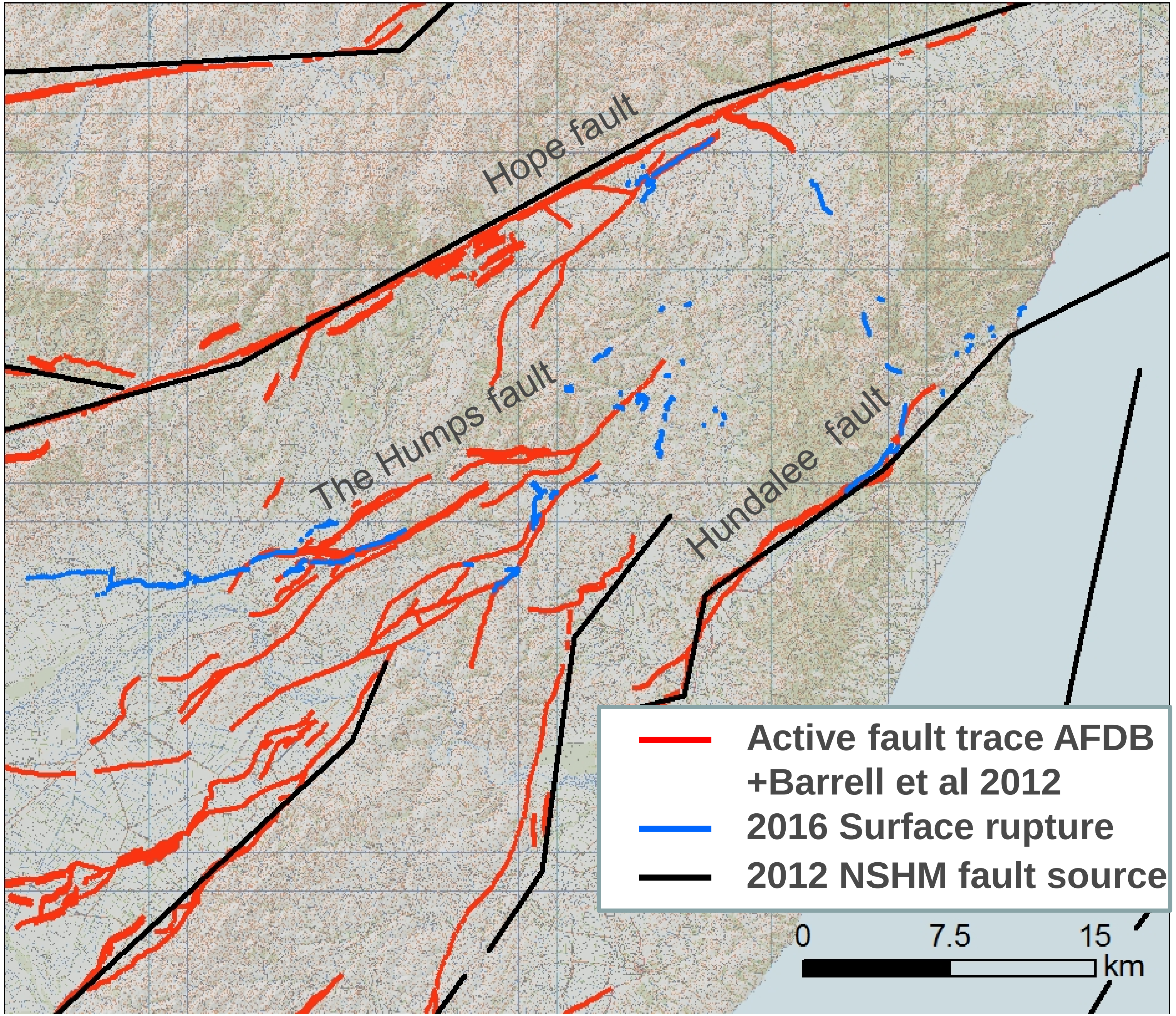
- **What did we know**
  - The Humps fault was mapped as active (AFDB), not included and a fault source in the NSHM (National Seismic Hazard Model) but Mmax for floating eq in this area in the Mw 7s
  - Faulting in the area is strike-slip and reverse

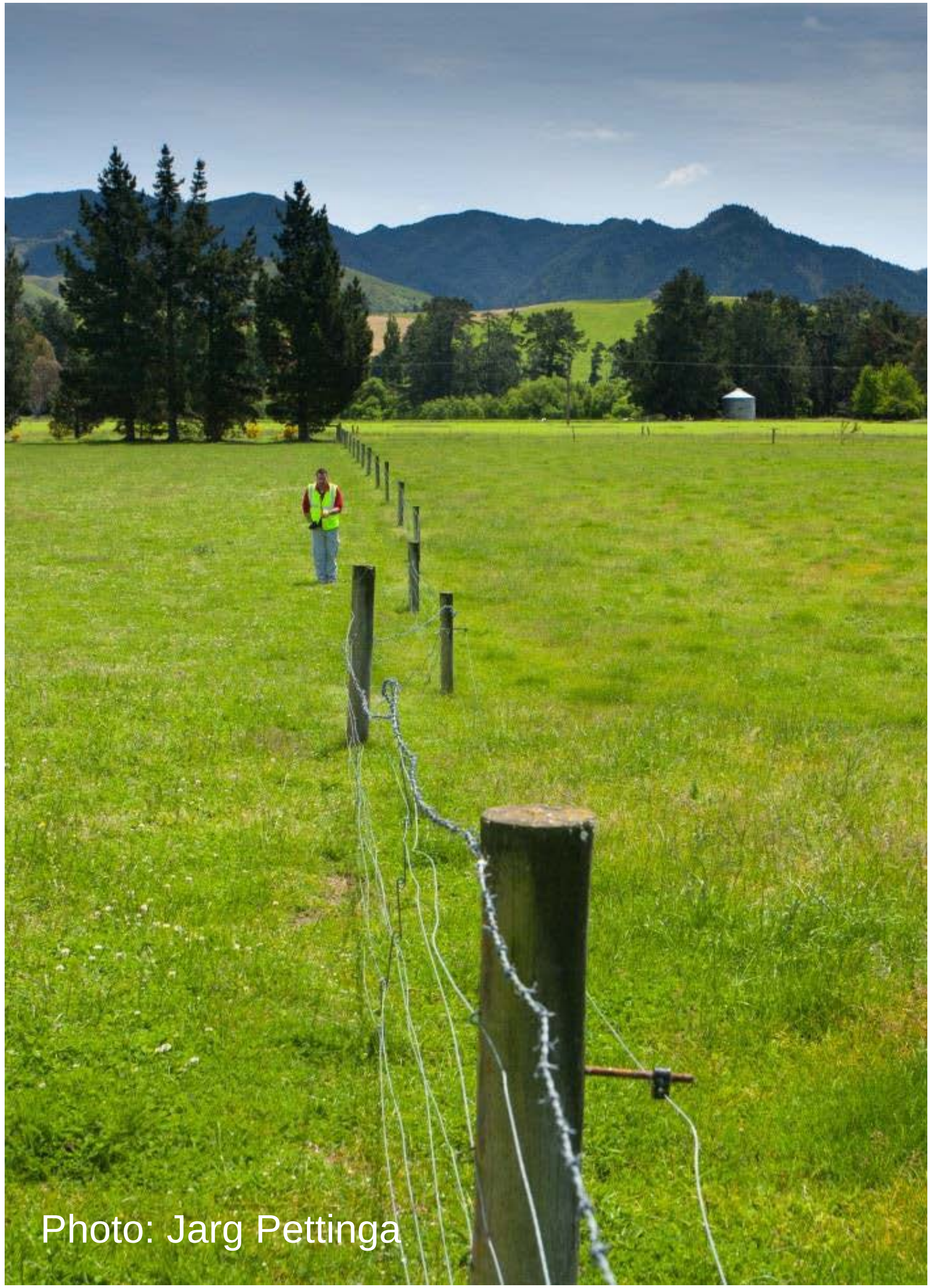


Active fault trace: AFDB (Active fault database) + Barrell et al 2012

The Humps-Leader Fault Fault

- **What we found**
  - Scattered small traces in areas where fault was mapped as well as other areas with no active flts
  - Fault displacement is oblique reverse with some oblique normal
  - NE strike = right lateral
  - N-S strike = left lateral; Large displacements also shown in INSAR





The Humps Fault ENE trend
Fault rupture west of Waiau township. Here the oblique dextral fault offset is further complicated by liquefaction and lateral spreading.

Segmented fault right lateral offset of ~1m, The Humps Fault Zone, ENE trend

Photo: Andy Nicol

Photo: Kate Pedley

Leader Fault Left lateral and reverse of ~1.5-2m (approximately equal values of each) Woodchester Station, N-S trend

Photo: Kate Pedley

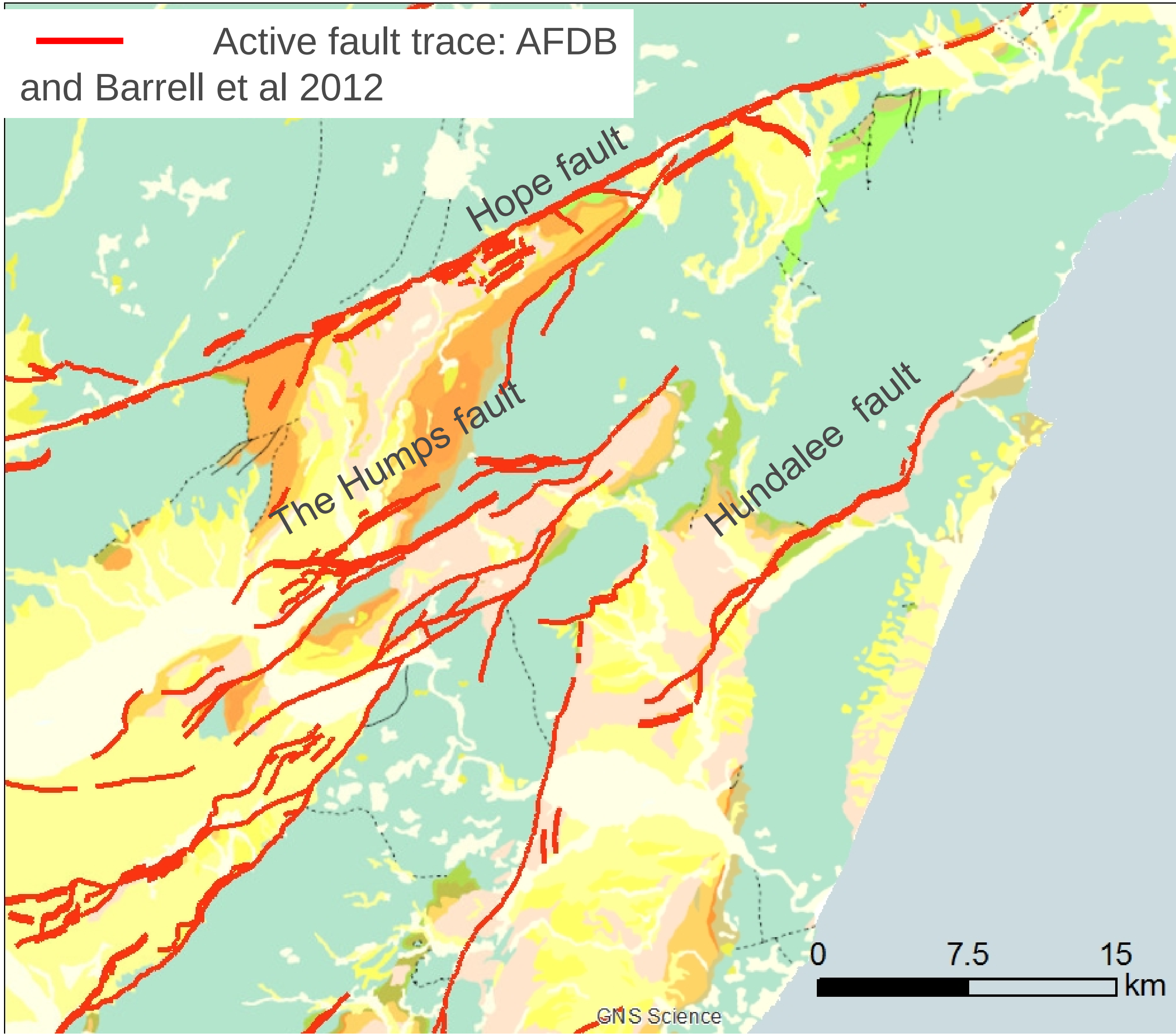
The Woodchester Wall

Leader Fault Left lateral and reverse of ~1.5-2m (approximately equal values of each) Woodchester Station.
N-S trend

Photo: Andy Nicol

The Hundalee fault

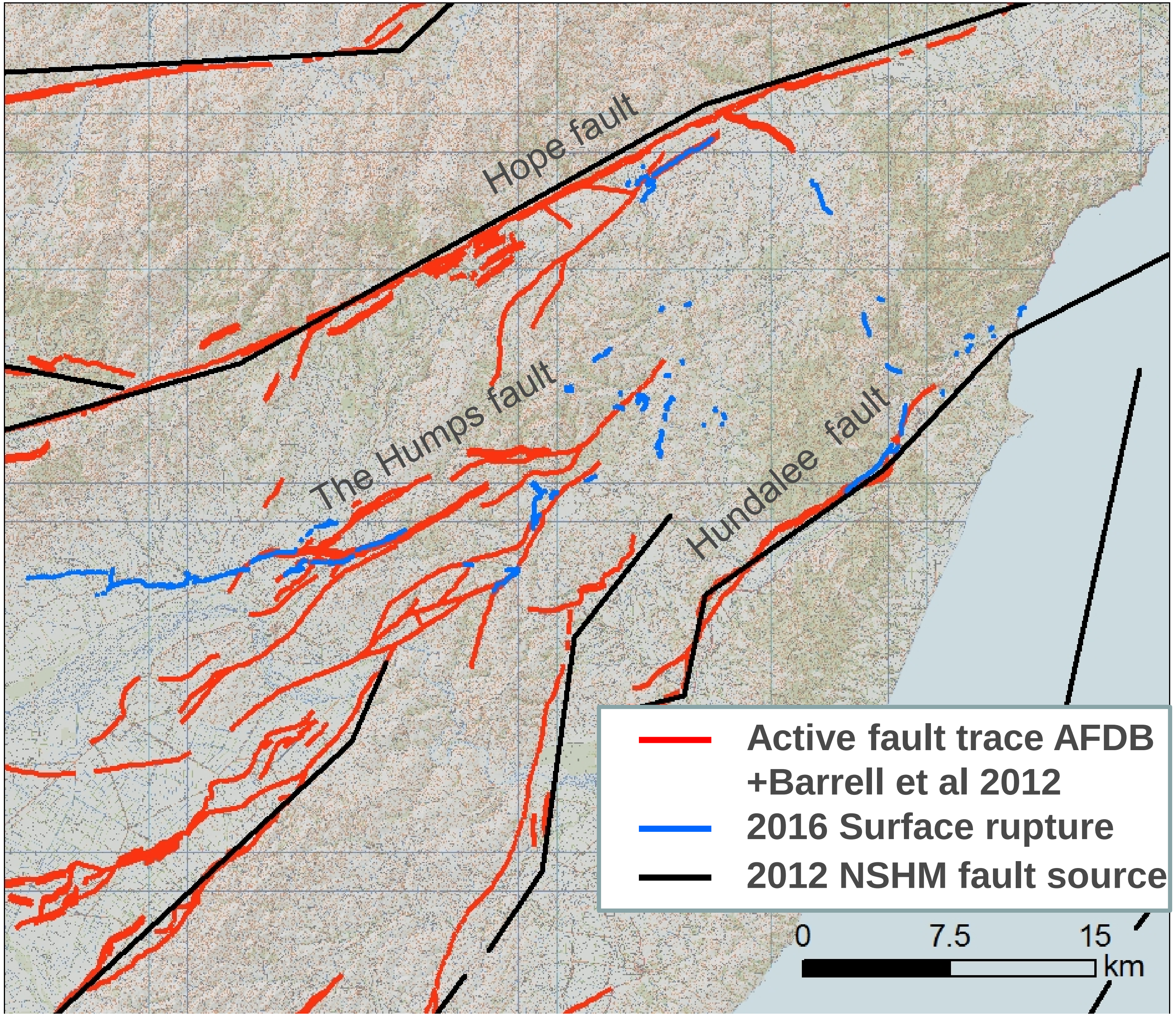
- **What did we know**
  - The Hundalee was mapped as an active fault onshore but no active traces found close to coast
  - It is a fault source in the NSHM but no field data exists. Derived parameters are: reverse (dextral); 0.4-1.5 (1.2) mm/yr slip rate; 53 km long; Last rupture < 10,000; RI 800-5000; Mw 7.3, SED 3.7 m
  - NSHM: Mapped extending offshore



The Hundalee Fault

What we found

- Scattered small traces in areas where fault was mapped as well as other areas not mapped
- Some traces mapped as active did not rupture
- Traces are NE, N-S and E-W
- Fault displacement is oblique reverse, or just reverse
- It extended offshore and could be responsible for uplift of Kaikoura Peninsula but no offshore mapping yet



NE trend thrust , ~ 1m vertical

E-W trend thrust , cumulative ~ 2m vertical

N20E, reverse ~ 0.5 m

N60E, RL strike slip ~1 m , reverse ~ 0.5 m

Hundalee fault

Displacement increases towards the coast

Photo: Julie Rowland

NE trend

3.7 m RL strike-slip (NSHM!!)

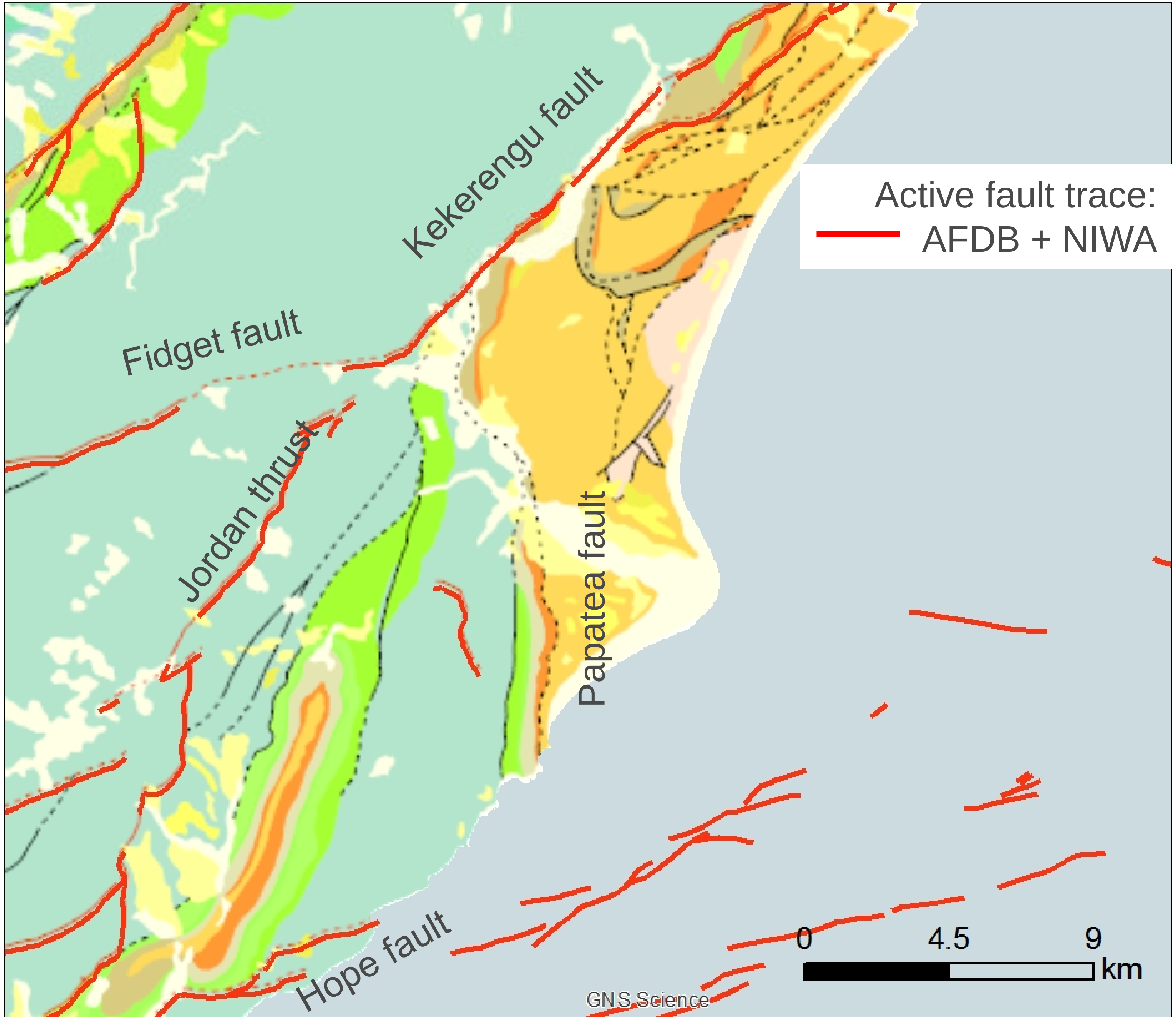
> 1m dip-slip

Photo: Julie Rowland

Photo: Julie Rowland

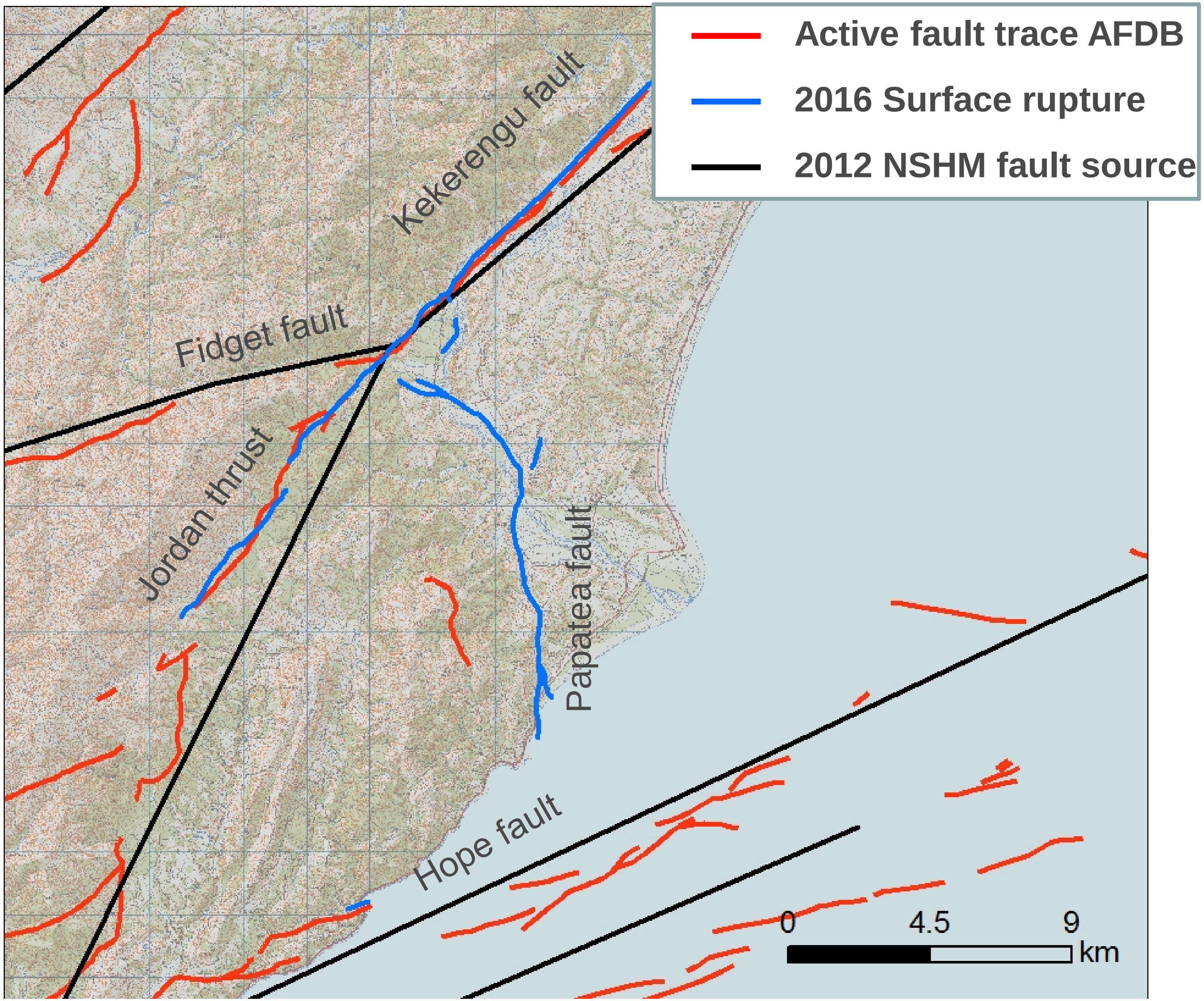
The Papatea Fault

- **What did we know?**
  - It was a mapped bedrock fault: boundary between Cretaceous and Miocene rocks.
  - It was a suspected active fault (pre-existing traces?
  - Not in the AFDB, not in the NSHM



The Papatea Fault

- **What we found**
  - Fault is active
  - Largest vertical offsets (8m) and quite large left lateral (11m)
  - Traces are mainly N-S with some WNW
  - Association with large landslides
  - Linkage with Kekerengu fault is complex
  - Some scarps difficult to detect (monoclines)



Papatea Fault - pop up between two faults at the coast

Western coastal trace (left-lateral, reverse)

Photo: Julian Thomson

Western coastal trace (left-lateral, reverse)

Papatea Fault-eastern coastal trace (left-lateral, reverse)

Papatea Fault- eastern coastal trace (left-lateral, reverse)

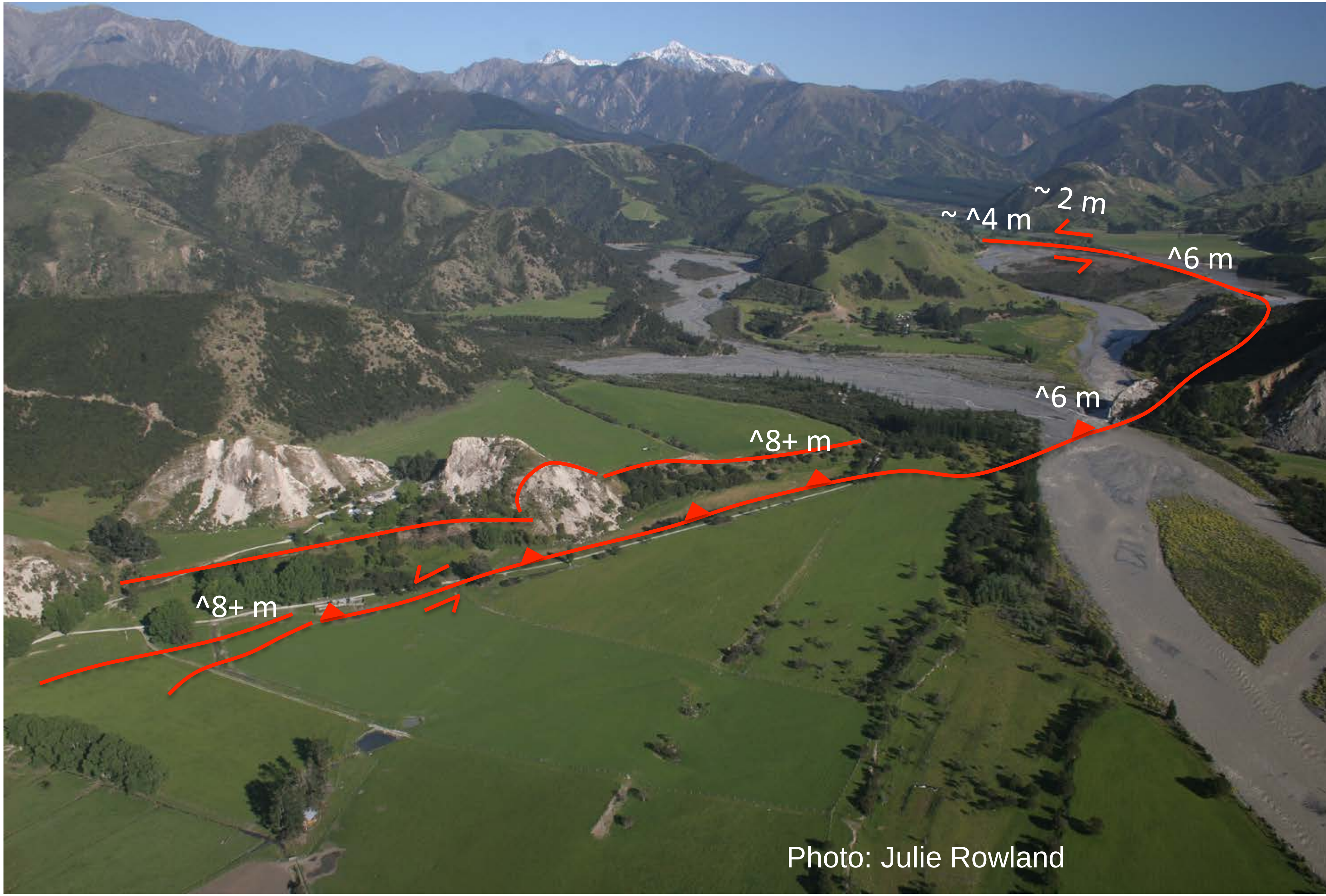
Association with huge landslides close to the coast


Photo: Robert Langridge/Julie Rowland

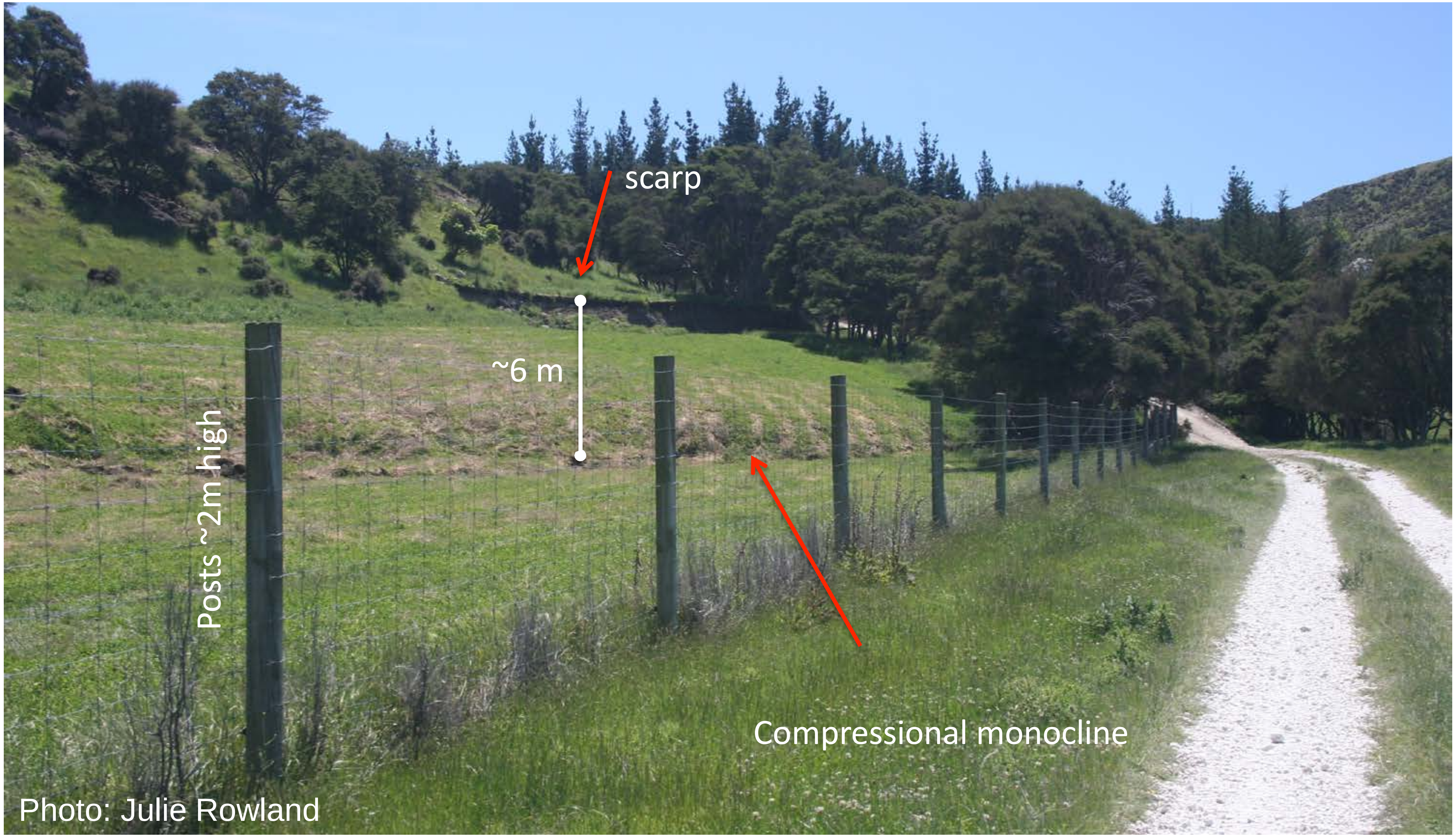

Photo: Robert Langridge/Julie Rowland

Seaward Landslide
(previously known as “cow island” or “stranded cow” landslide)

Papatea Fault- inland:



These measurements are approximate (sighted)– we are verifying with RTK GPS



Cumulative throw >6 m, perhaps ~8 m

Papatea Fault- inland: Partial avulsion Clarence River

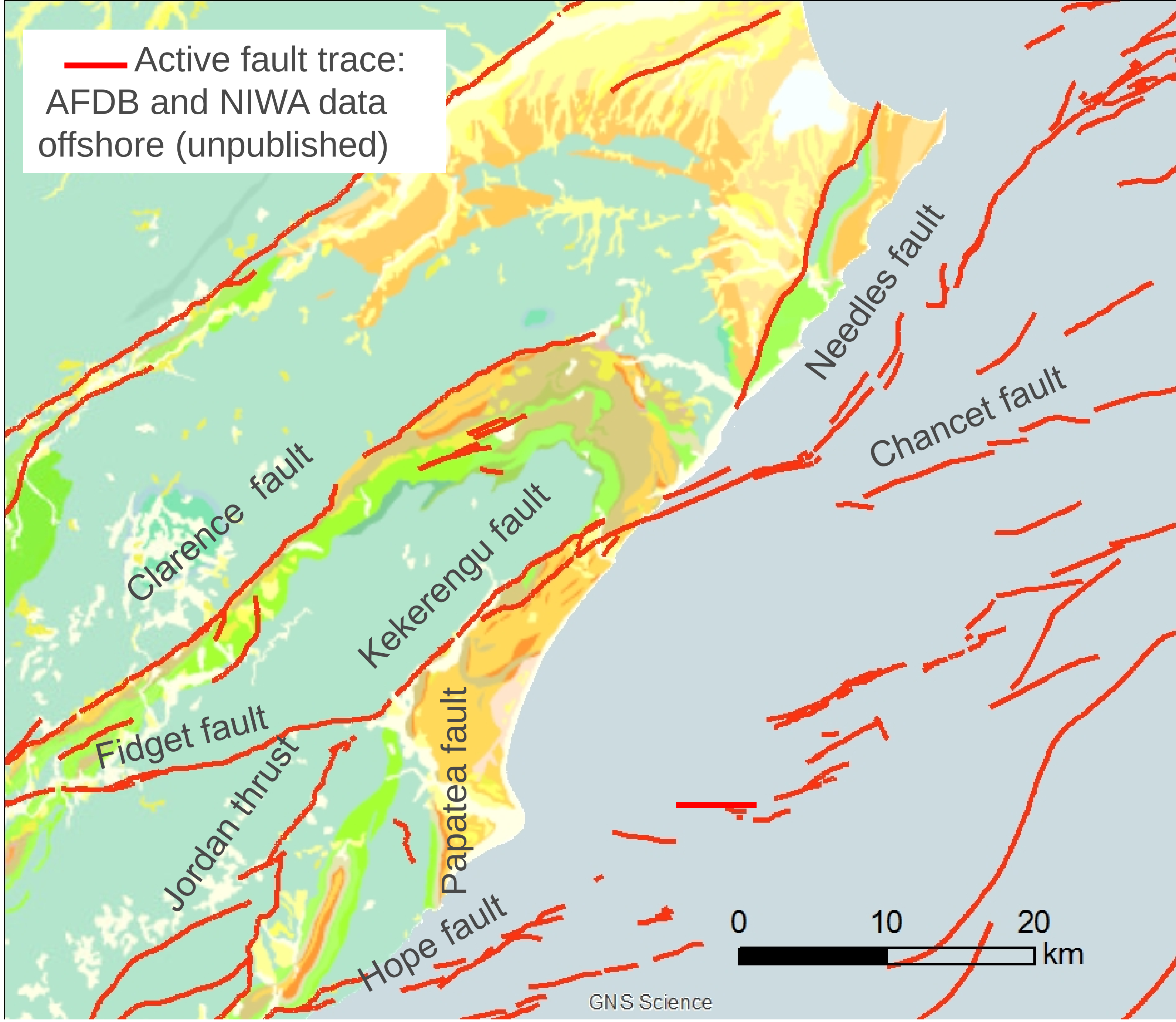

Photo: Robert Langridge


Photo: Julie Rowland /Robert Langridge

large (4 m) scarp formed
in Clarence River gravels

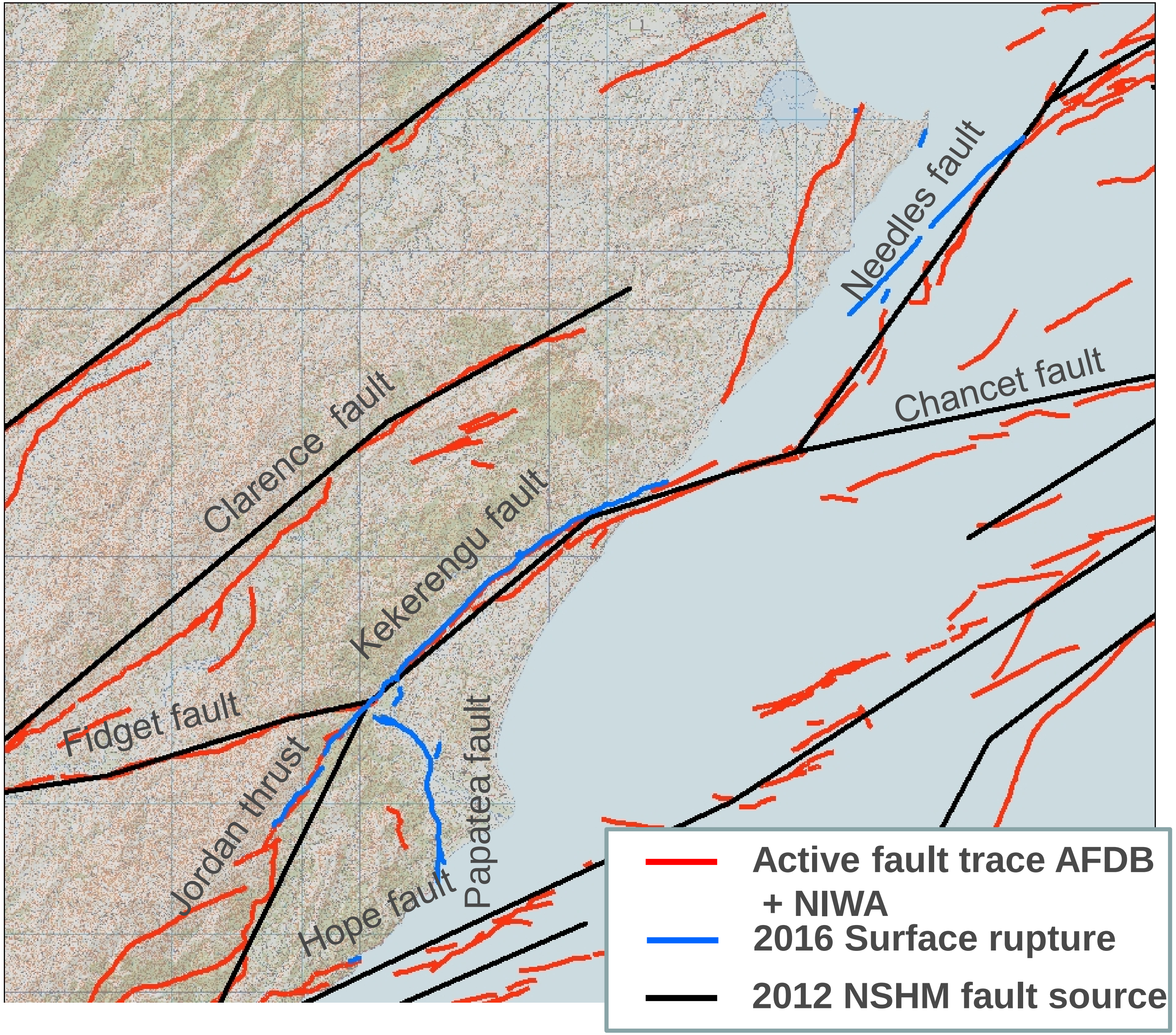
The Kekerengu Fault

- **What did we know?**
  - Well studied active fault
  - The second/third fastest fault in NZ: 20 - 26 mm/yr (Van Dissen et al, partially published)
  - 3 last events prior to 2016 (Little et al, unpublished):
    - 249-108 cal. yrs. B.P.;
    - 528-356 cal. yrs. B.P.:
    - 1248-903 cal. yrs. B.P.
  - NSHM fault source is modeled as a combined rupture with Jordan Thrust to SW and Needles Ft or Chancet fault (offshore)



The Kekerengu Fault

- **What we found**
  - Very large dextral offsets (max= 11+ m largest) They are still large (8+) close to the Fidget and Jordan faults.
  - ~ 5m strike -slip at the coast
  - Recent trenches: one displaced by 9 m, other not at all (most prominent scarp).



Fly over video

Trench 1, as of Nov 20, 2016 (looking NE)
Drone Photo Courtesy Julian Thomson, GNS


Photo: Tim Little

Photo: Tim Little/William Ries

Kekerengu Fault: very large dextral displacements

In excess of 10 m!

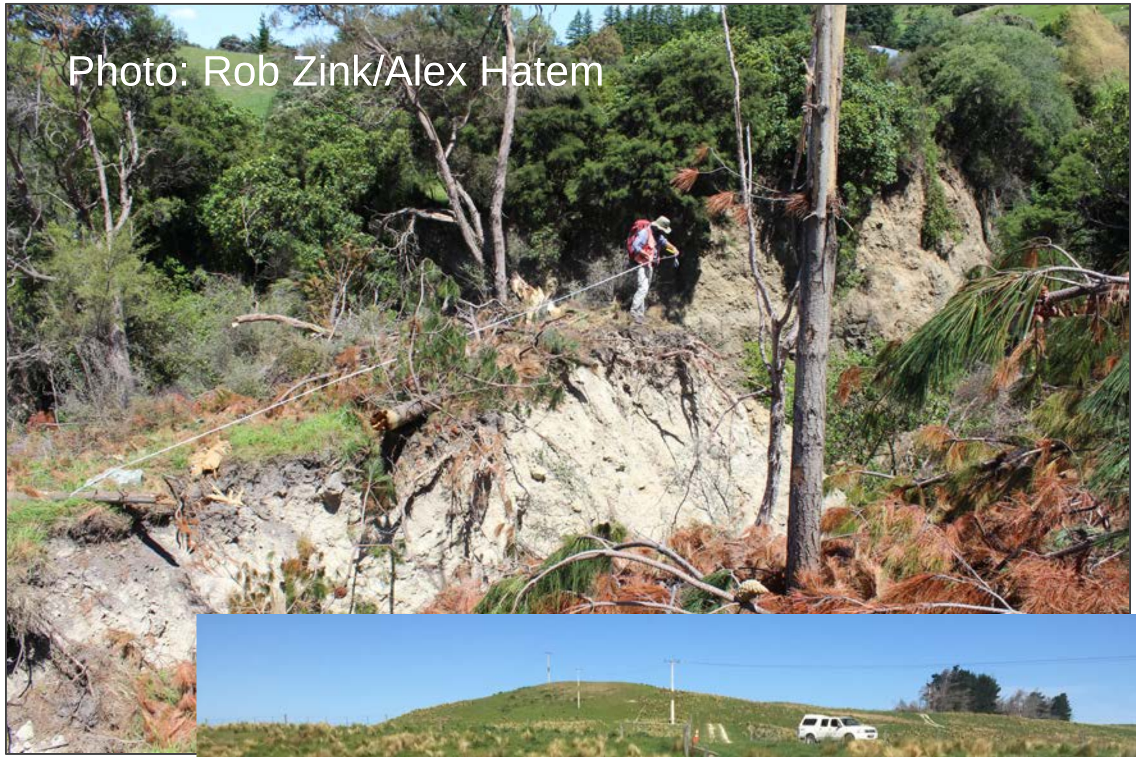


Photo: Rob Zink/Alex Hatem


Photo: Mark Hemphill-Haley


Photo: Rob Zink/Alex Hatem

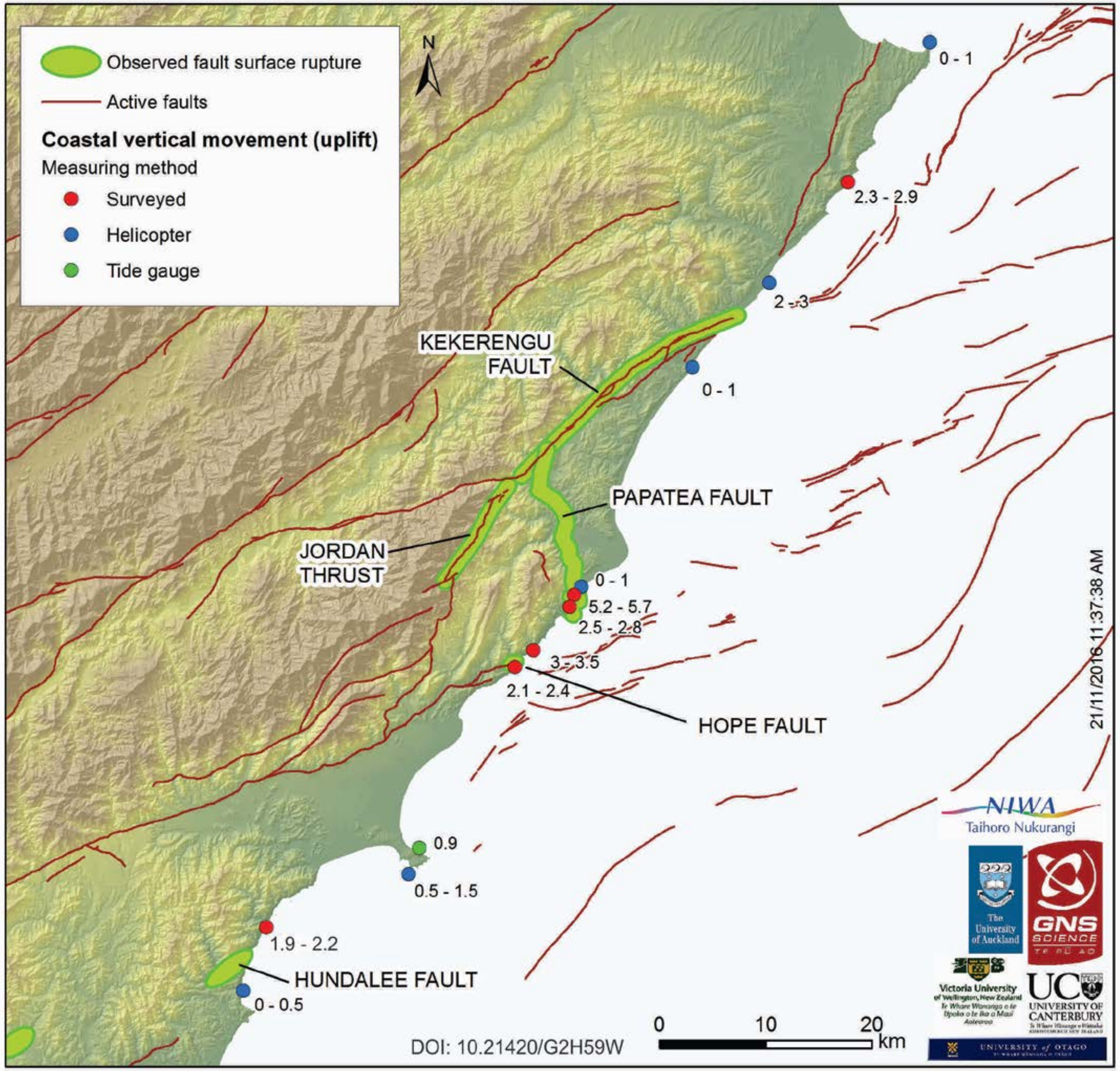

Photo: Julian Thomson

Coastal uplift

Coastal uplift reflects the uplift associated with fault movement during the 14 Nov event:

-major uplift associated with Papatea and Needles? faults

- Some offset across faults (or lack of) needs to be explained with offshore (near shore) faulting



High tide

Low tide tide: subtidal kelp exposed

(Photo: Pilar Villamor)

Seal snoozing in former subtidal zone

Stranded crayfish

(Photo: Kate Clark)

Low tide markers deteriorate fast!!

DAY 1: red subtidal algae

(Photo: Nicola Litchfield)

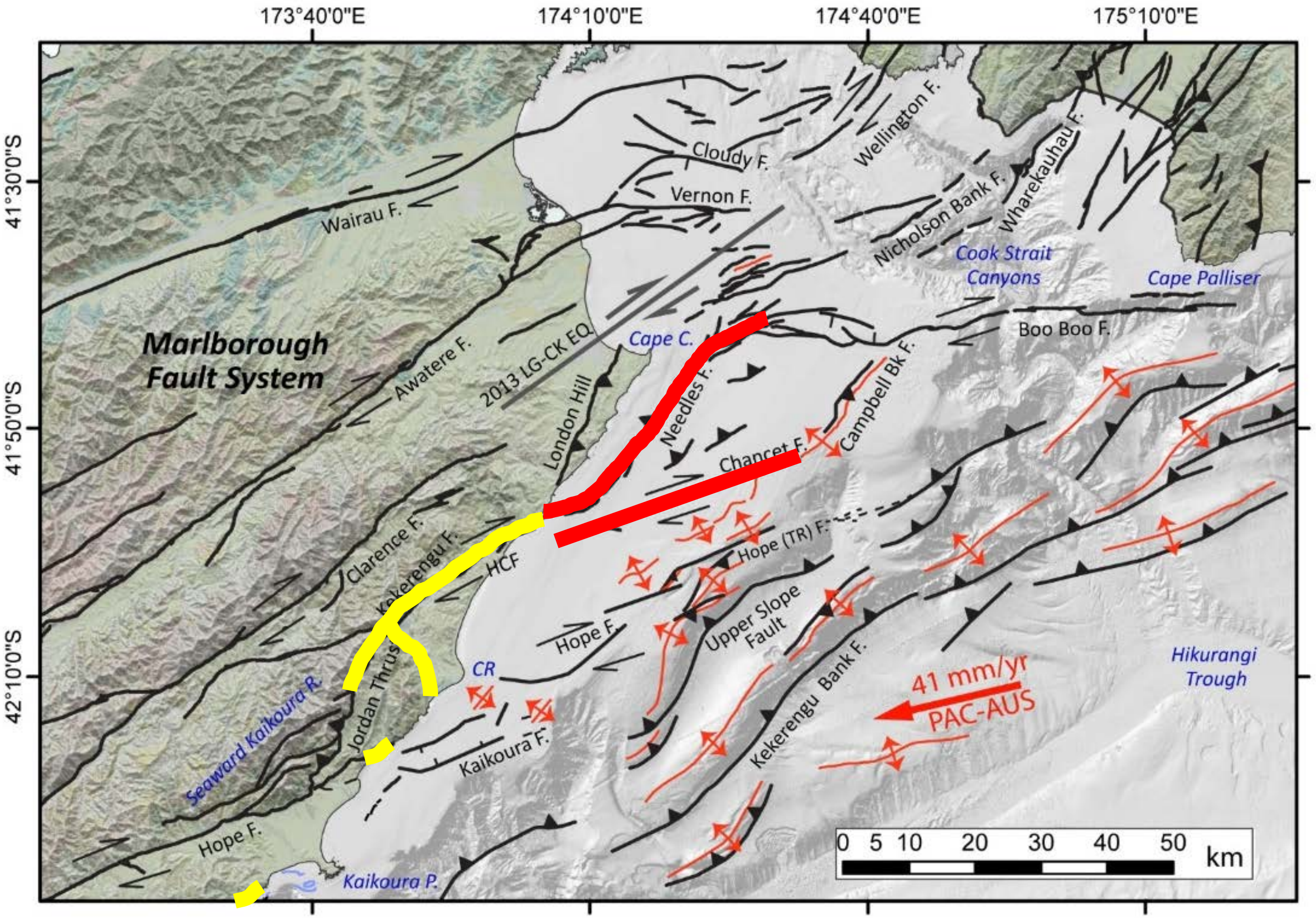
(Photo: Kate Clark)

DAY 5: red turning brown and white

(Photo: Pilar Villamor)

DAY 6: more and more white: uncertainty of marker increasing

Offshore rupture mapping

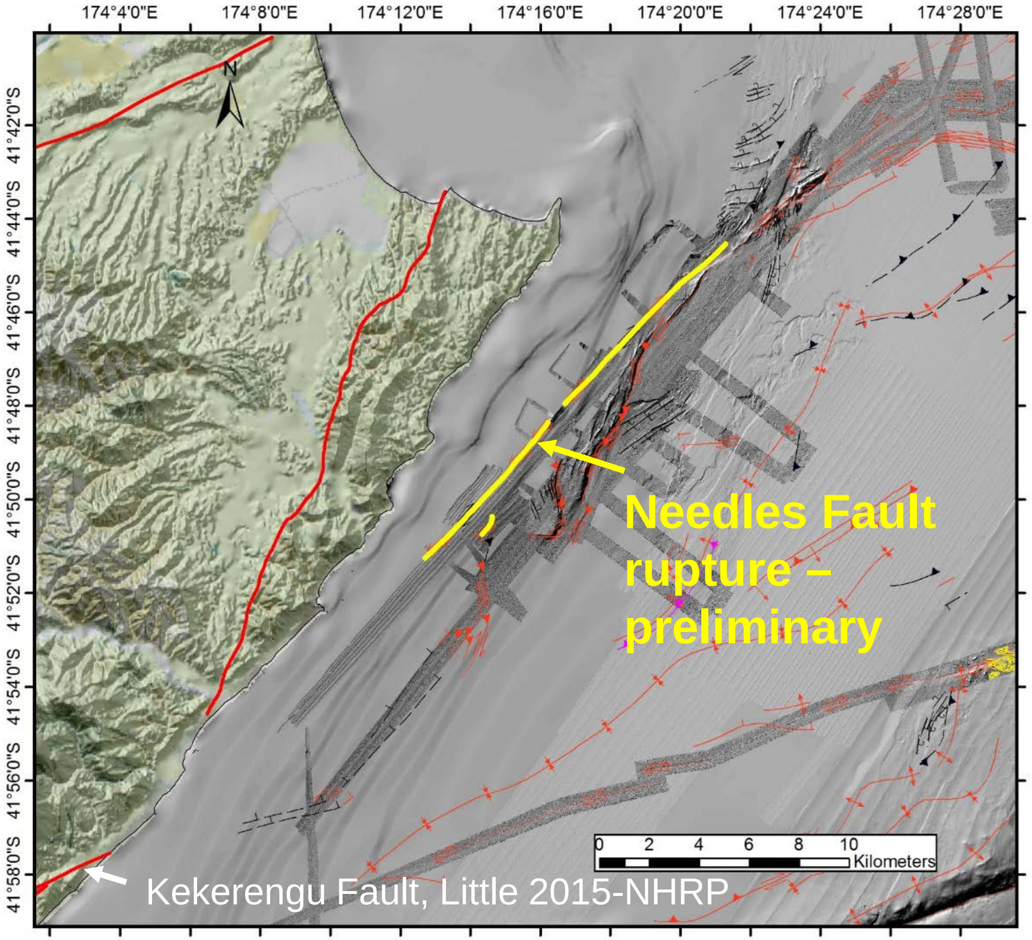


On Tangaroa - seafloor mapping and profiling of the Needles and Chancet faults, two major structures offshore of the Kekerengu Fault

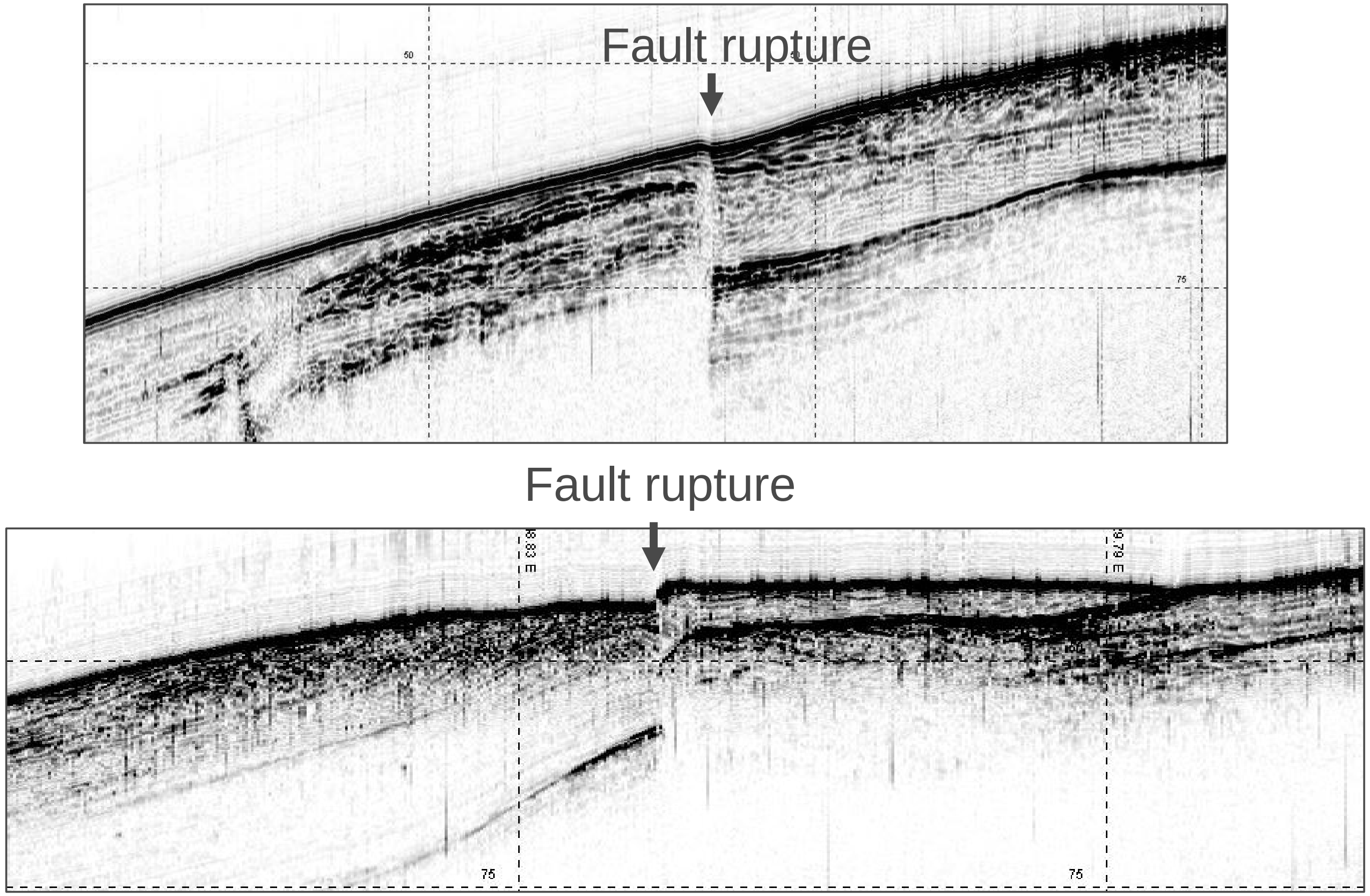
- Rupture of Kekerengu Ft ss confirmed
- Rupture of Kekerengu Ft rv possible
- No Rupture of Boo Boo Ft (northern limit of rupture)

Onshore fault breaks in Yellow, provided by onshore team

Post-Nov 14 multibeam mapping and sub-bottom profiling of the Needles and Chancet faults

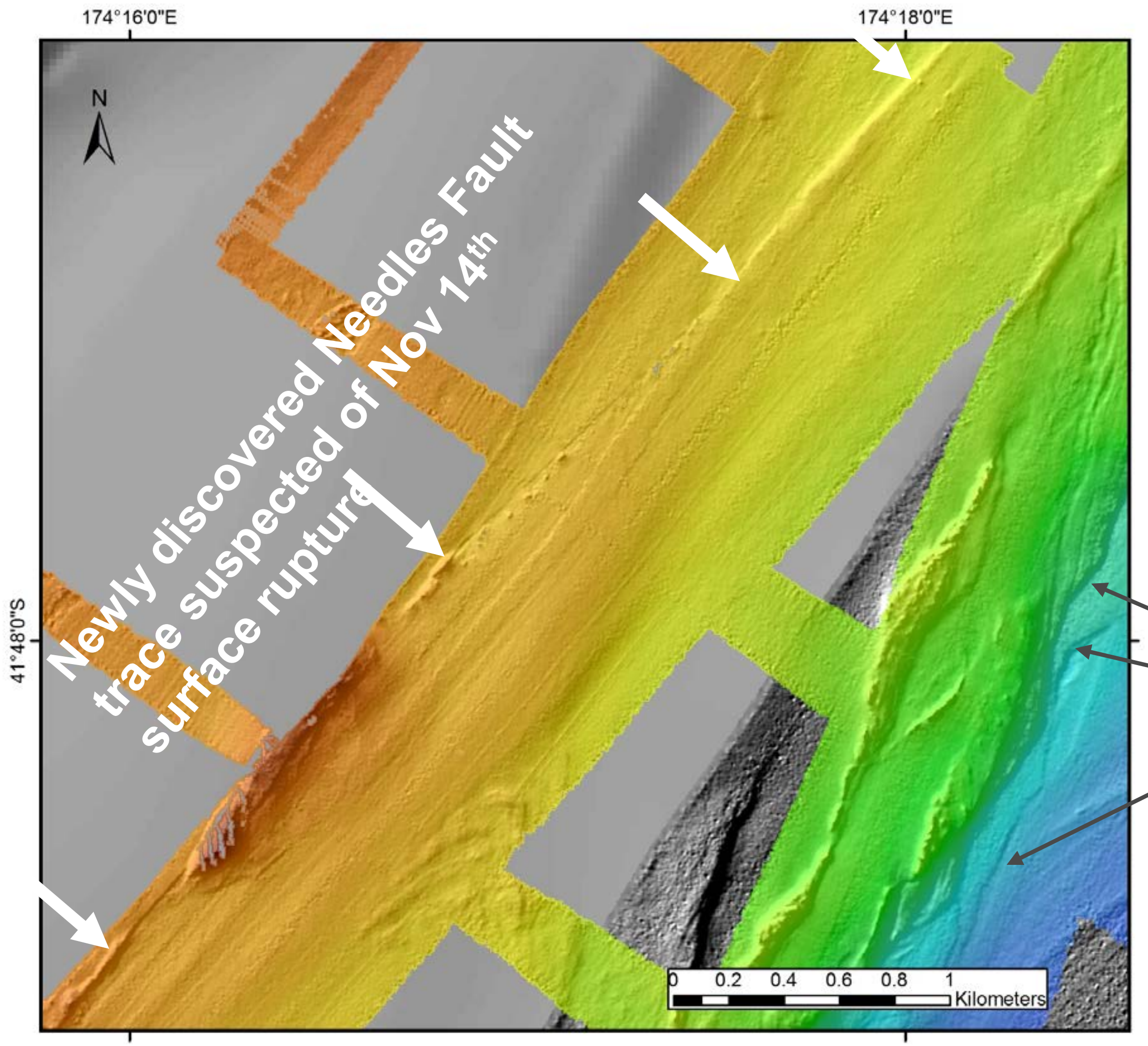


TOPAS PS18 Sub-bottom Profiles



Vertical offset up to 1.4 m up to NW

Example of newly mapped trace of the Needles Fault



Inferred oblique thrust components of the Needles Fault: Currently uncertain if involved in the Nov 14 Mw 7.8 earthquake

Earthquake Geology Insights……

(Not many yet sorry …as I am writing this last slide I have received the following email :

Tue 6/12/2016 12:35

Nicola Litchfield

new fault ruptures

To Pilar Villamor; Ian Hamling

Cc Sally Dellow

Had a text from Rob to say that in his and Russ's helicopter flight this morning they observed ruptures on the northern Jordan, central Fidget and an unnamed fault at the head scarp of the Hapuku landslide (possibly about to be named the Owerau Fault).
Will hopefully get another update later,
Nic

- Is this earthquake representative of the type of ruptures in this region or the odd event? (Papatea Ft)

- How does this earthquake inform surface displacement distribution? (fault per fault? Rupture as whole?)

- How can we account for this complexity in seismic hazard model and PDHA? (Eg what is secondary?; role of aftershocks)

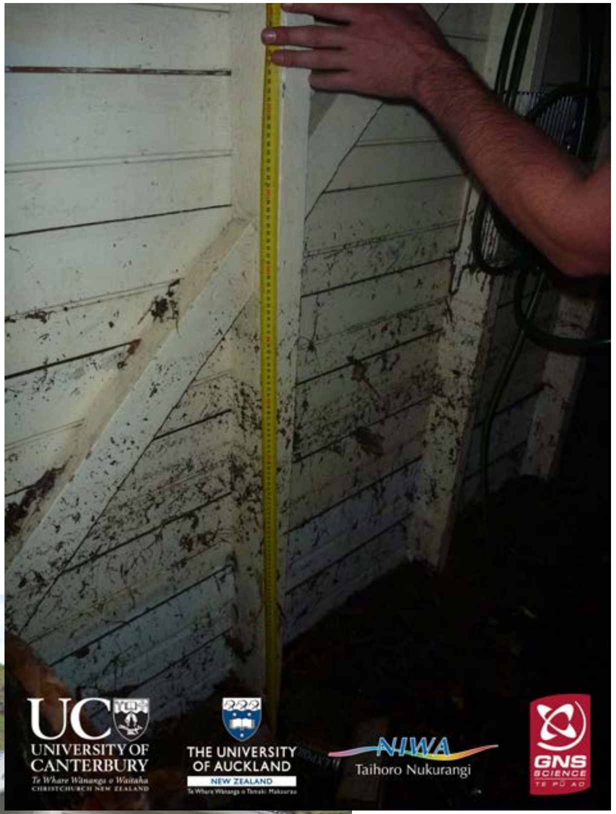
- How much complexity have we missed in historic events that had no INSAR, GNSS, dense seismic instrumentation ?
- Coseismic coastal uplift… how would have we interpreted this event as a prehistoric one?

Tsunami

~ 4 meters – Banks Peninsula (Christchurch)

~ 5 meters – Oaro (just south of Kaikoura)

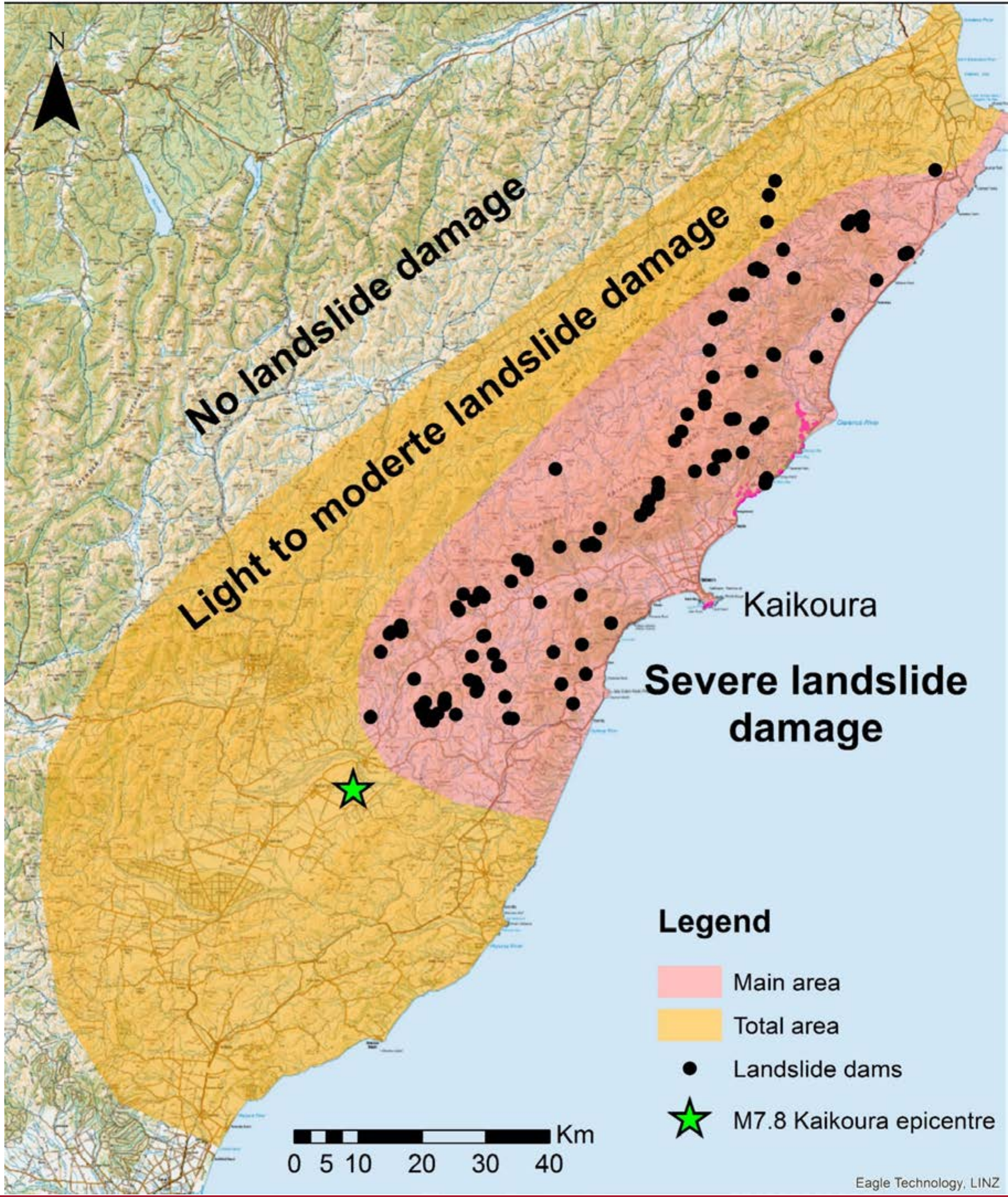
- Due to rugged coast with mainly gravel offshore and coseismic coastal uplift - No permanent tsunami deposit but stranded fish, crayfish and subtidal algae species.



Landslides Reconnaissance

- Initial estimates of 80,000 - 100,000 landslides triggered
  - ~5 >1,000,000 m^3
- Identified ~158 landslide dams

- Area of severe damage: 3,600 km^2
- Total area of landsliding: 10,000 km^2

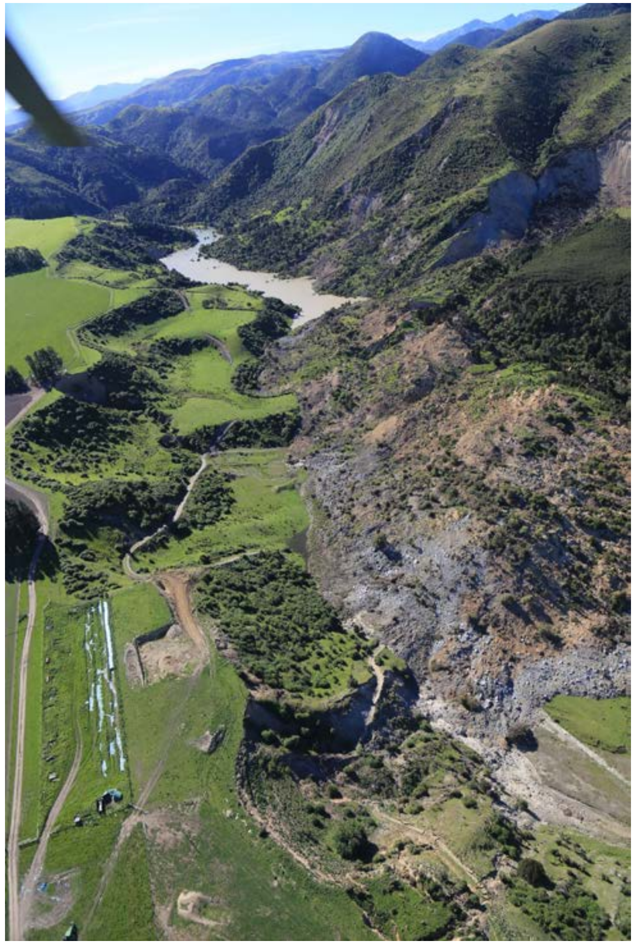


Landslide dams

- ~158 dams identified
  - Monitoring 11 dams
  - 4 possibly hazardous
- Daily helicopter reconnaissance
- River flow gauges
- Daily reports to Regional Council
- Modelling of possible dam breaks
- 80 people evacuated from Goose Bay due to risk of flooding if dam breached

Hapuku River

Medway River



Leader River

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