Shattering a plate boundary: the 2016 Mw 7.8 Kaikōura earthquake

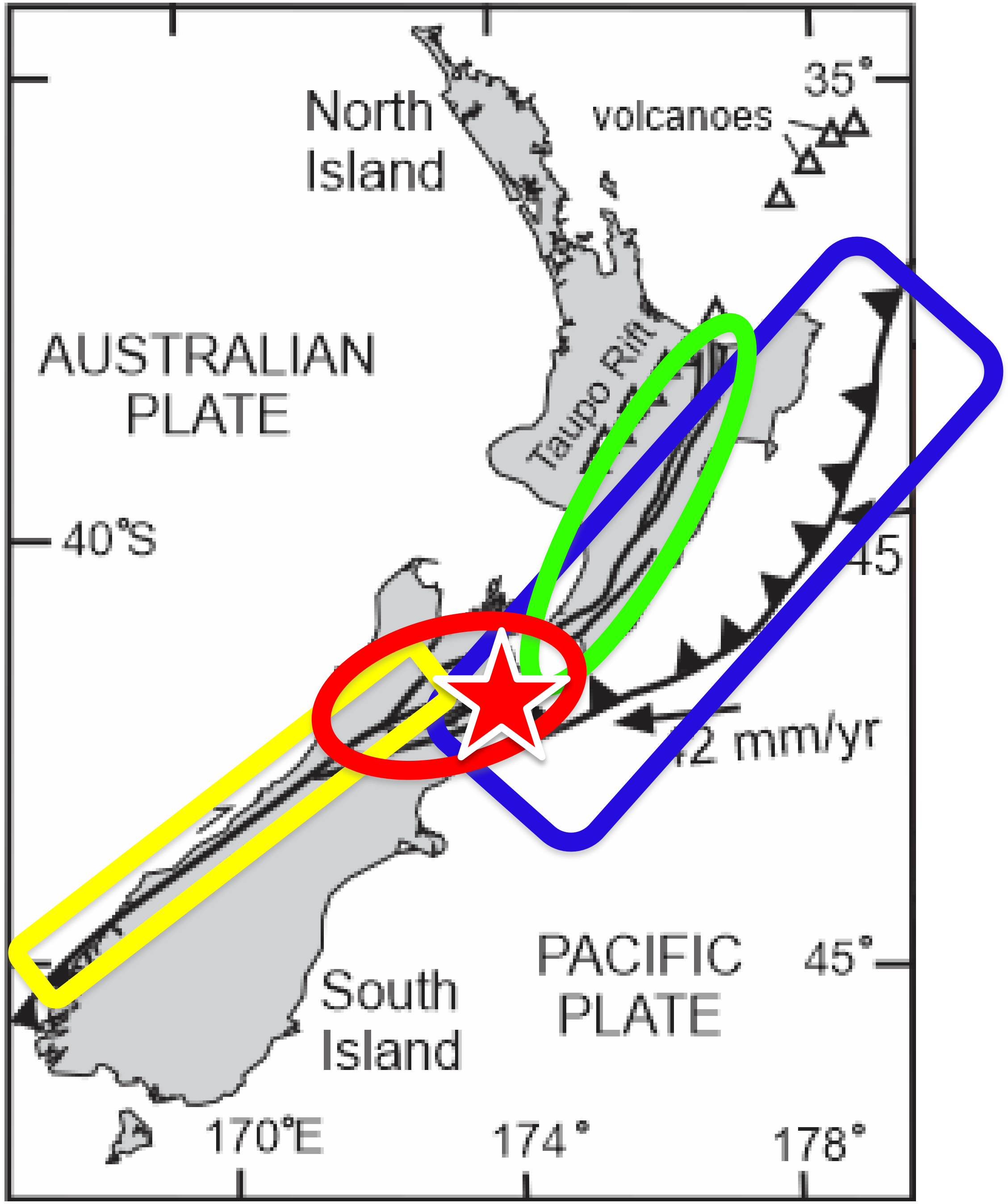
Presenter:
Pilar Villamor, GNS Science
On behalf of many, many others...

14 November 2016 Kaikōura Earthquake

This talk

- **Background**
- **During the Kaikōura Earthquake**
  - Seismicity
  - Surface Rupture, coastal deformation
  - InSAR and GNSS
  - Ground motions
  - Rupture model, energy release
  - Landslides, tsunami, liquefaction
- **After the Kaikōura Earthquake**
  - Postseismic deformation
  - Slow slip events

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

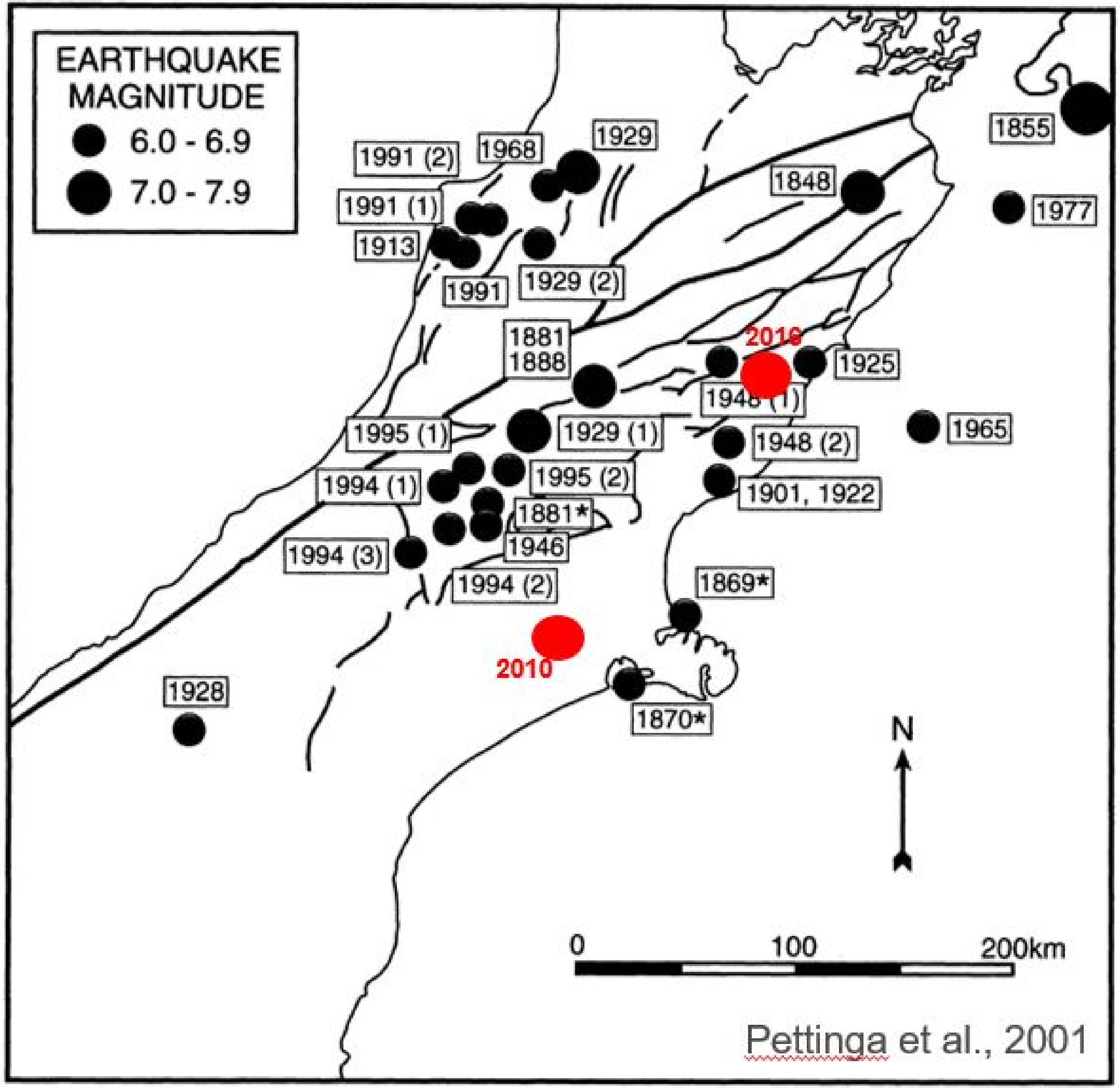


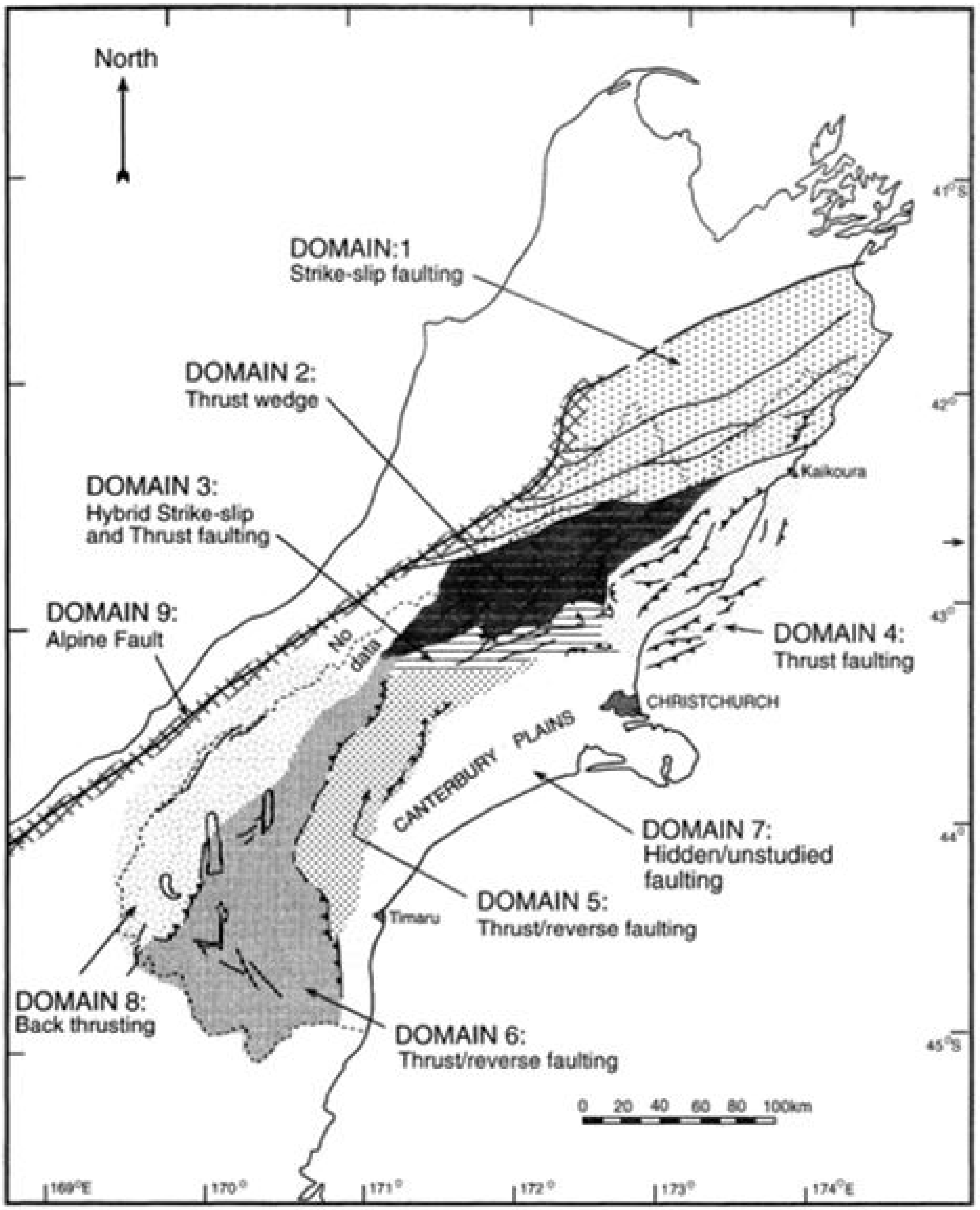
Background

- 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)

Major elements of New Zealand Plate Boundary

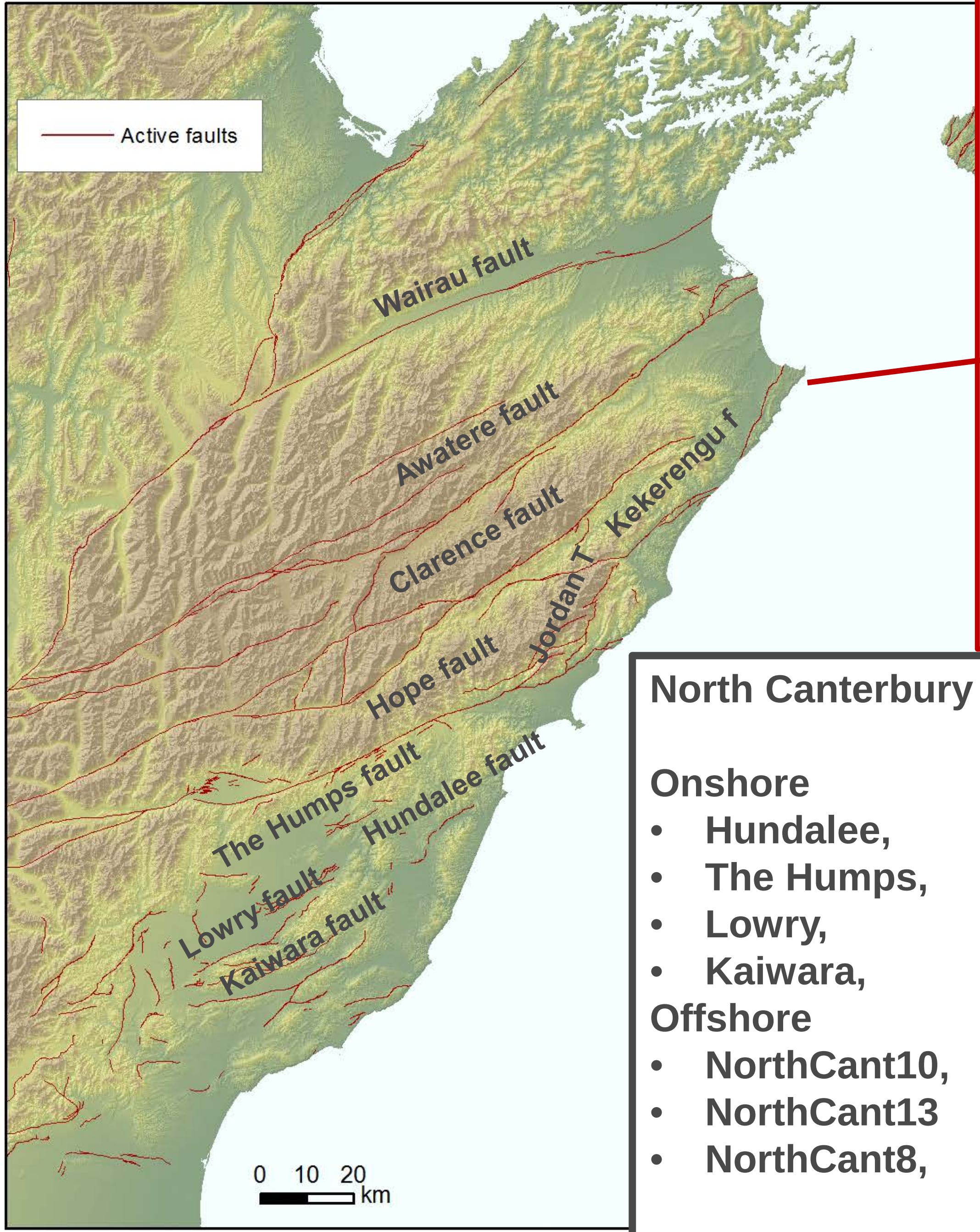
- Hikurangi Subduction Zone
- North Island Dextral Fault Belt
- Alpine Fault
- Marlborough Fault System

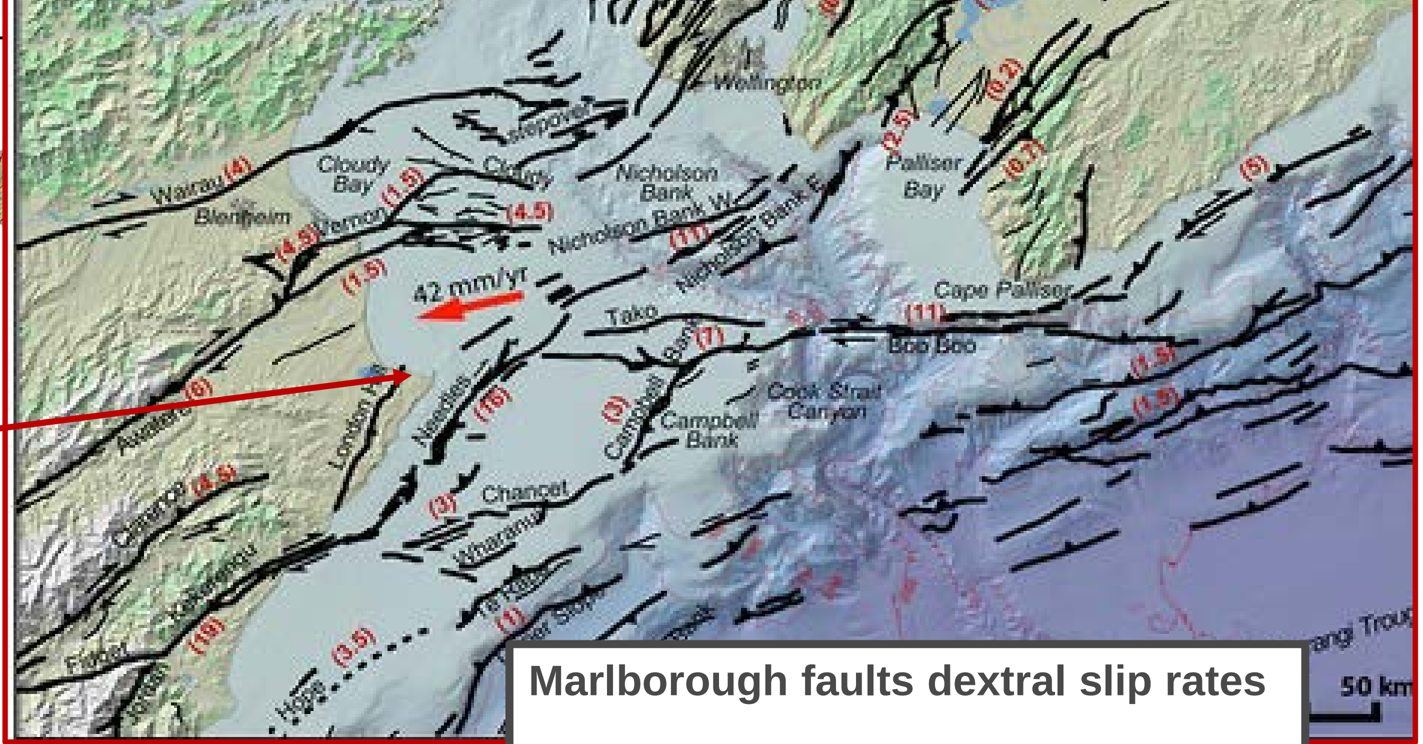




Historic Seismicity

Tectonic domains





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

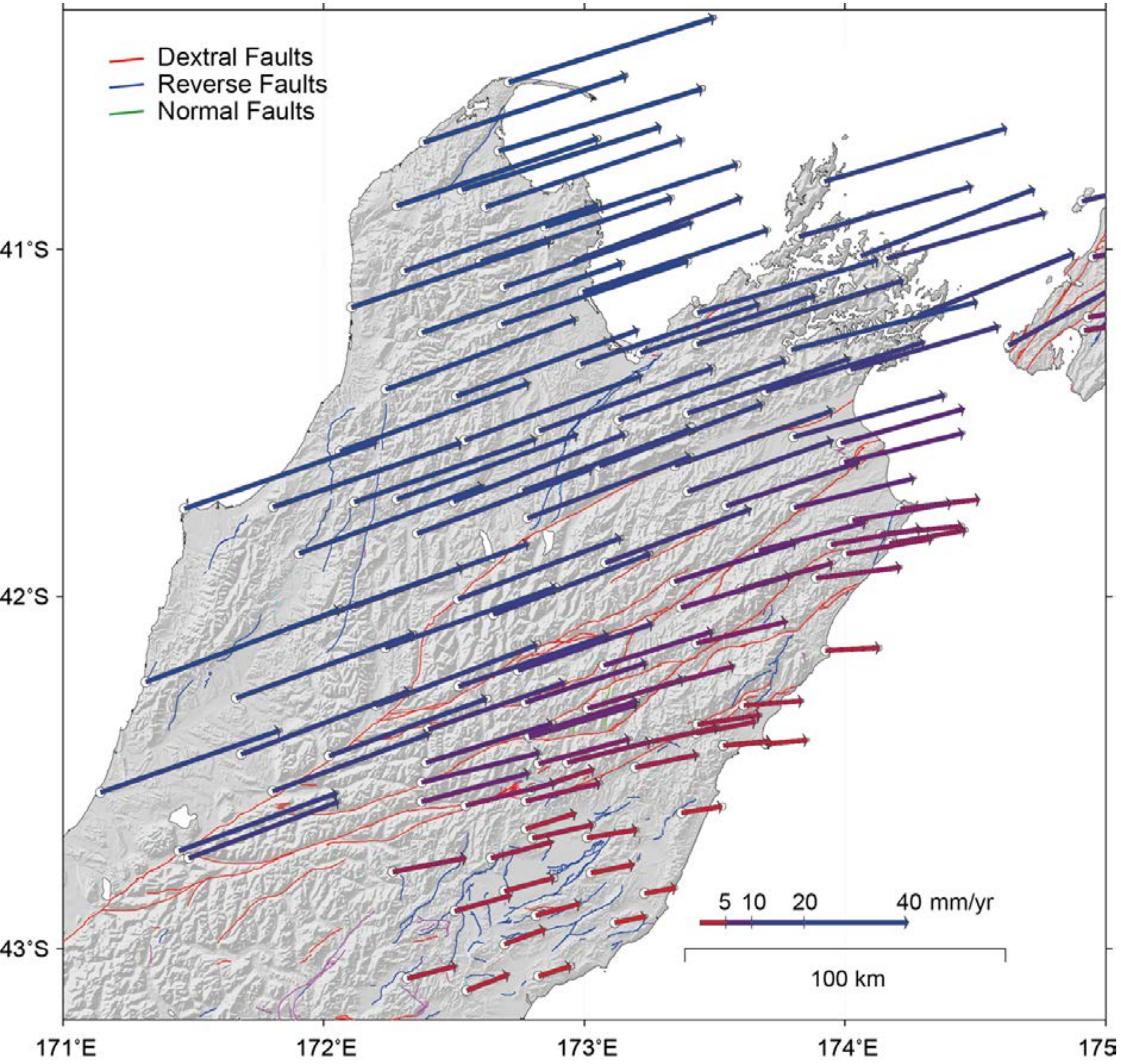
Offshore

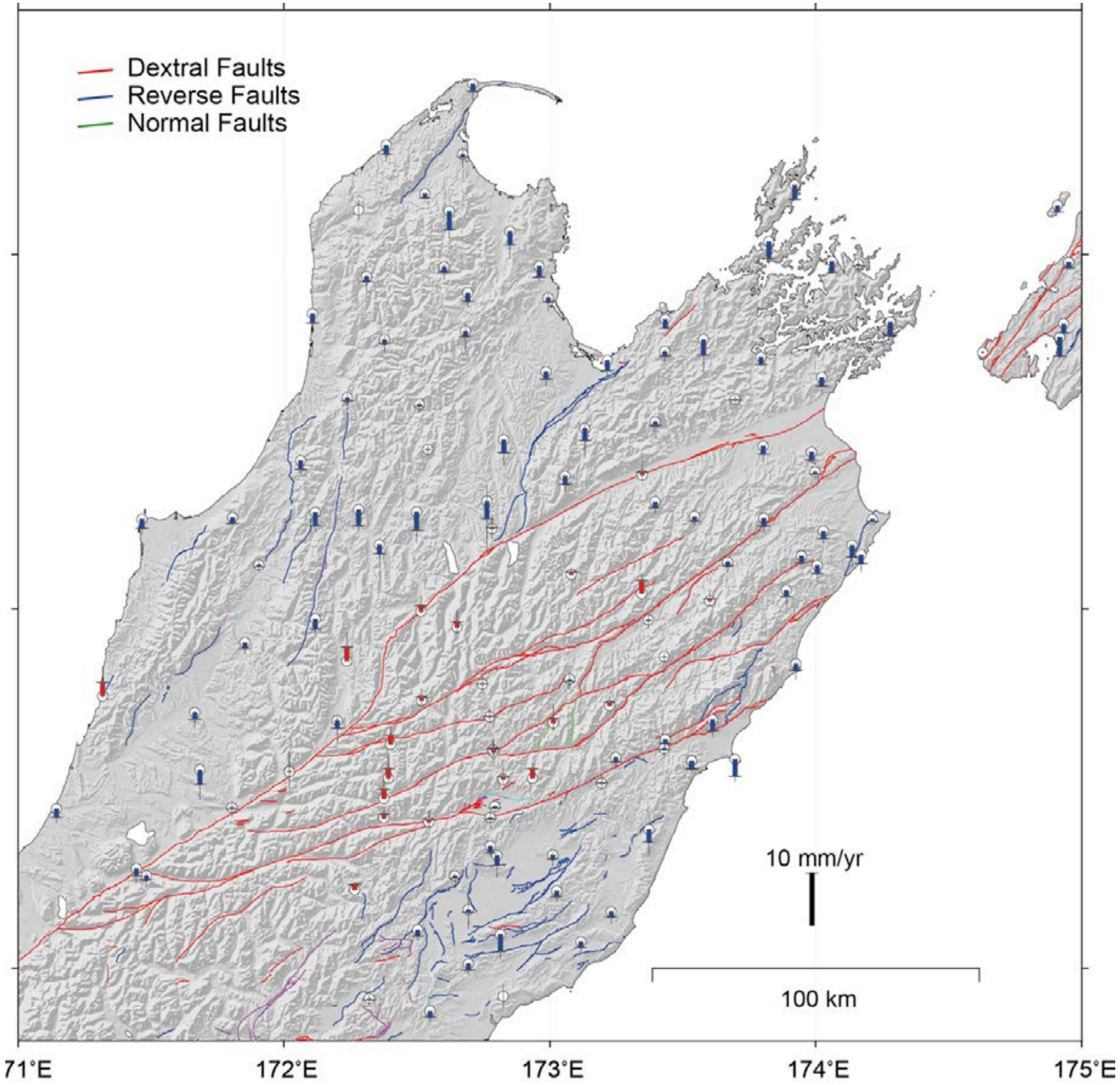
• Needles,	c. 16 mm/yr
• Chancet,	c. 3 mm/yr
• Vernon,	c. 4.5 mm/yr
• Nicholson B.,	c. 11 mm/yr
• Boo Boo,	c. 11 mm/yr

Known active faults and rates

GNSS: Interseismic velocity from data spanning 1998 – 2016

Sigrun Hreinsdottir et al 2017



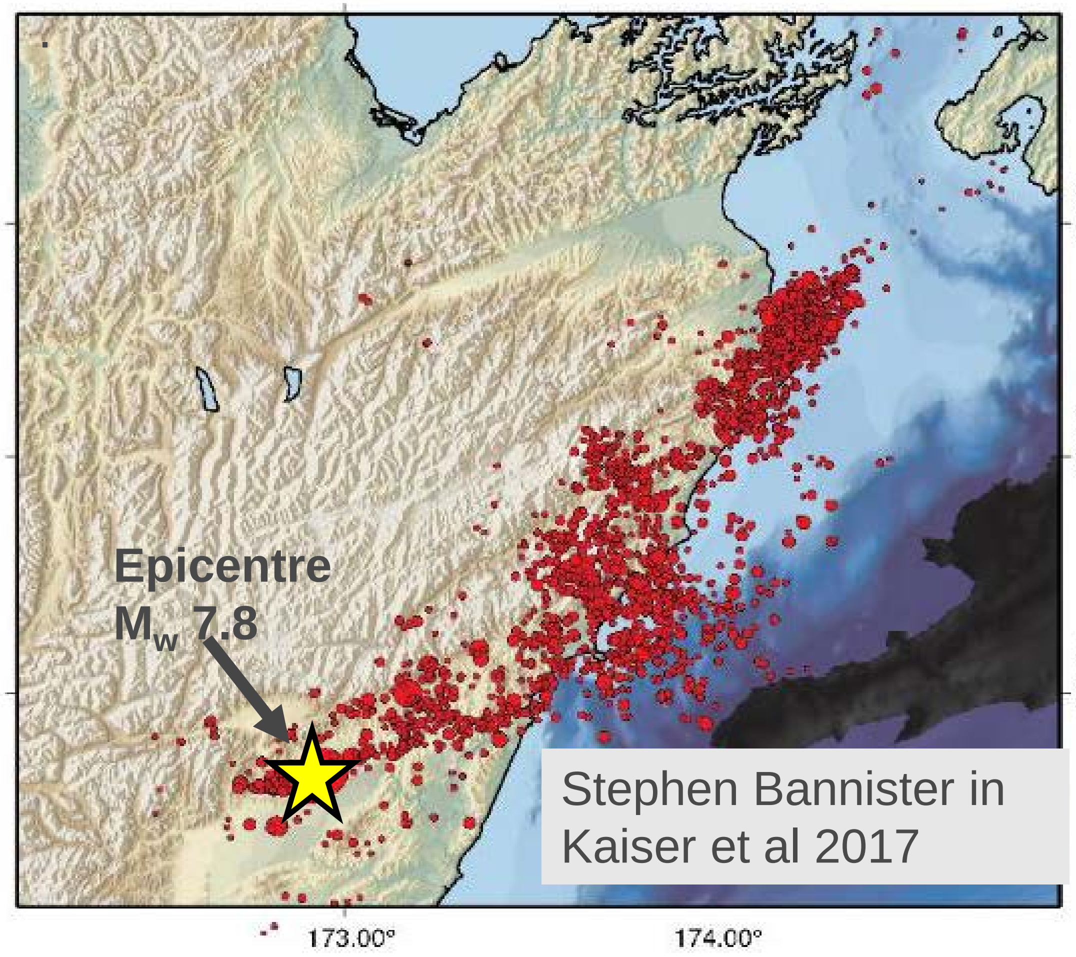


Faults from NZ active fault database; Velocities in ITRF14-Pacific plate fixed reference frame

The 14 November 2016 Mw 7.8 Kaikōura Earthquake

Location and aftershocks

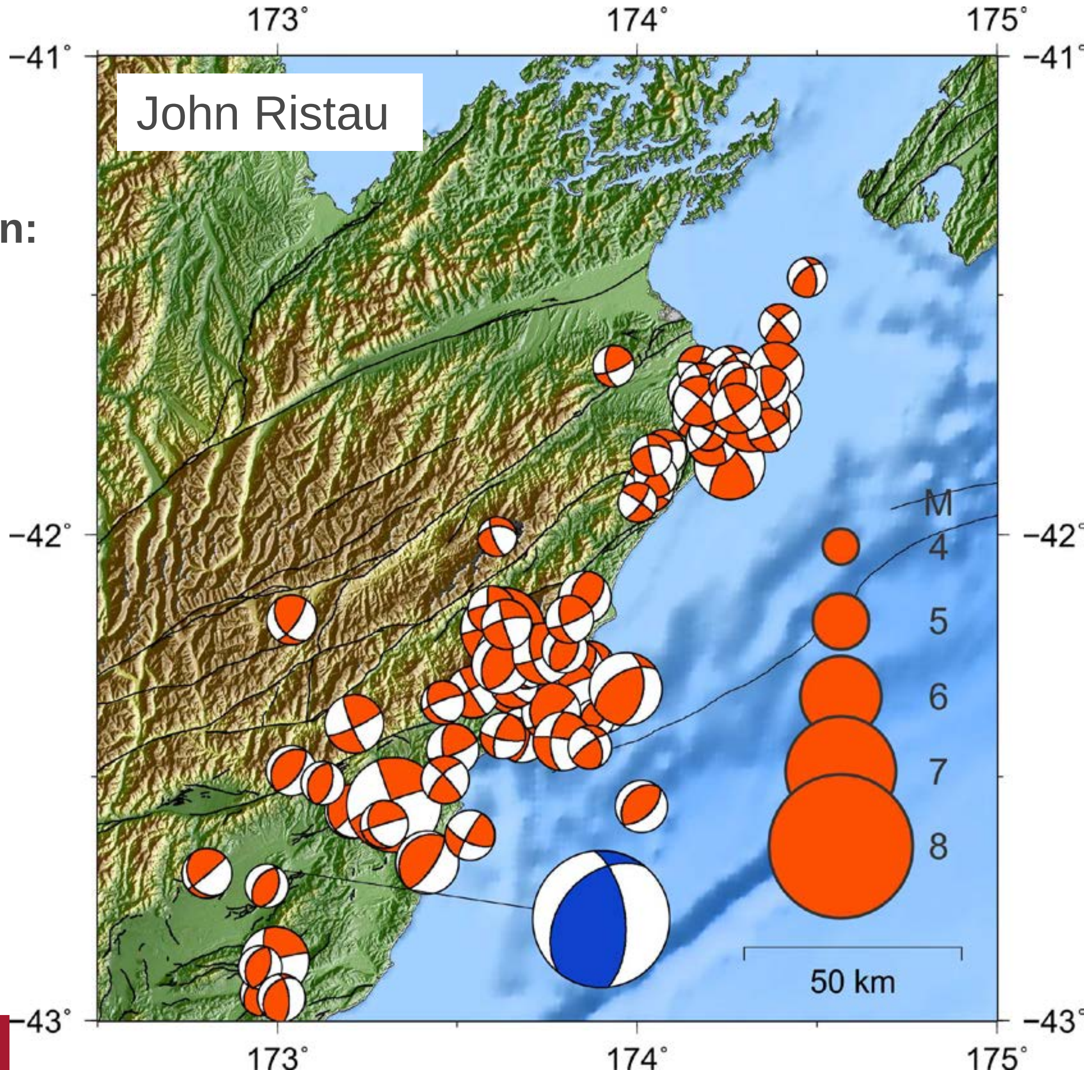
Duration: Shaking lasted about 2 minutes
Total of 17,492 earthquakes
549 of those earthquakes were M4-4.9
61 were M5-5.9
5 have been M6.0 or greater.

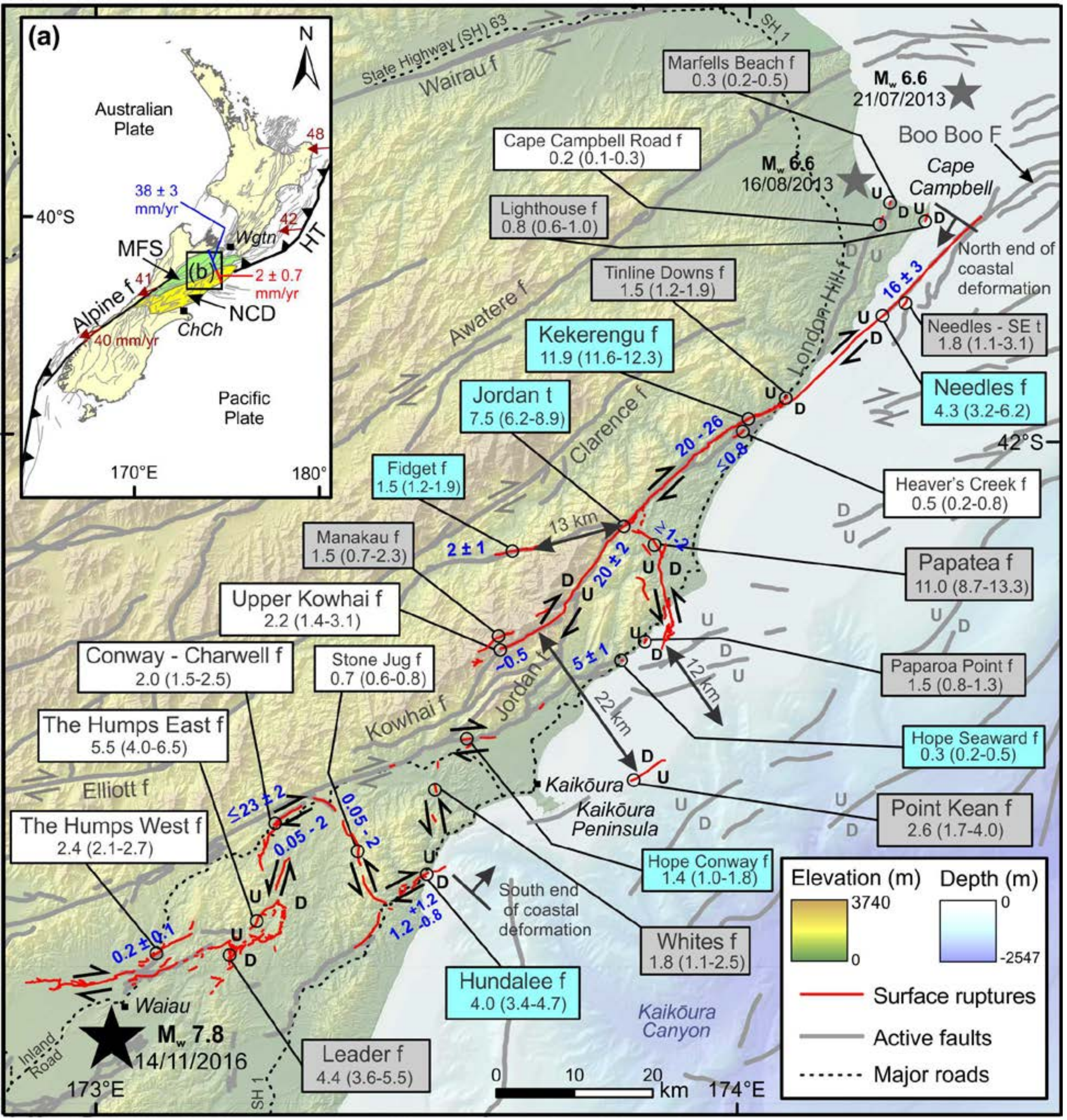


Epicentre location:
- ~100 km from Christchurch
- ~200 km from Wellington
- Near Waiau

Focal Mechanisms

Mainshock thrust mechanism
Aftershock mechanisms thrust and strike-slip





Effects on the landscape

Surface fault rupture
- Over a dozen major faults
- ~180 km rupture length
- up to ~12 m of displacement

Coastal uplift
- ~100 km of coast uplifted
- Variable, up to ~5 m

Tsunami
- Local run-up up to ~7 m

Landslides
- Tens of thousands
- Many landslide dams

Liquefaction
- Locally significant, but
- Nothing approaching severity of liquefaction in Christchurch during the 2010-2011 Canterbury EQ sequence

21 faults, 180 km of surface rupture Litchfield et al., in review

Hundalee Fault

NE trend thrust , ~ 1m vertical

E-W trend thrust , cumulative ~ 2m vertical

Leader Fault

The
Woodchester Wall

Narges et al ., 2017; Nicol et al., in prep.

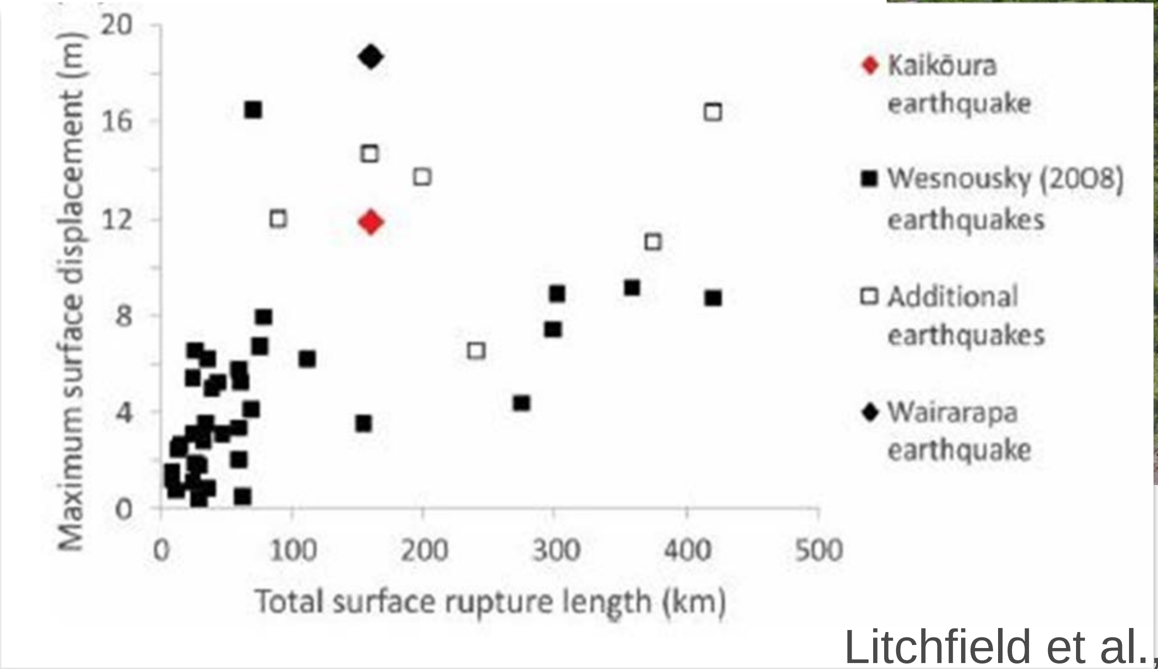
Kekeregu fault
12 m max

Kearse et al ., 2017 and submitted
Little et al., 2017 and submitted

Papatea Fault

Eastern coastal trace (left-lateral, reverse)

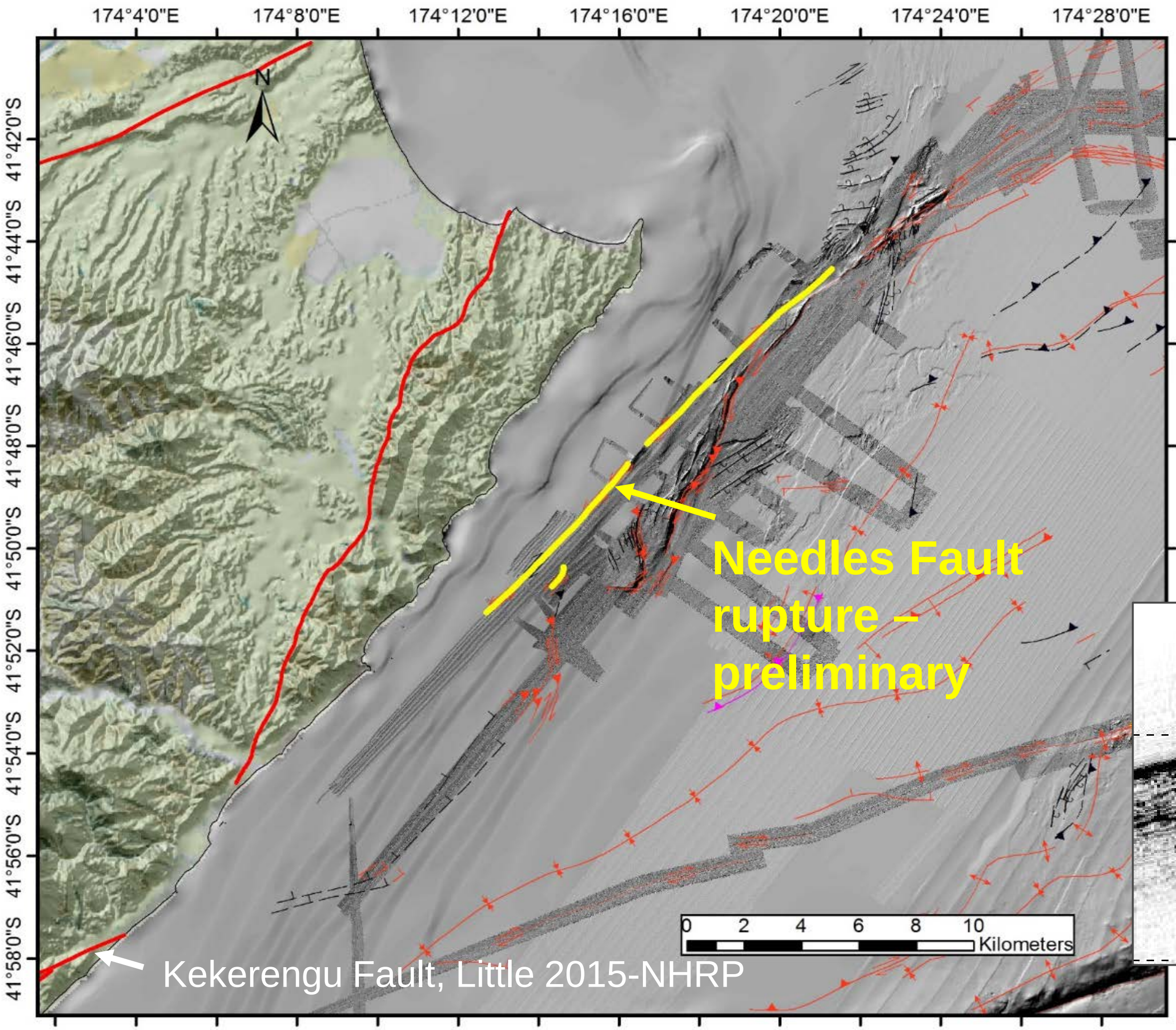
NZ faults tend to have large SEDs for rupture length



Litchfield et al., 2017, in review

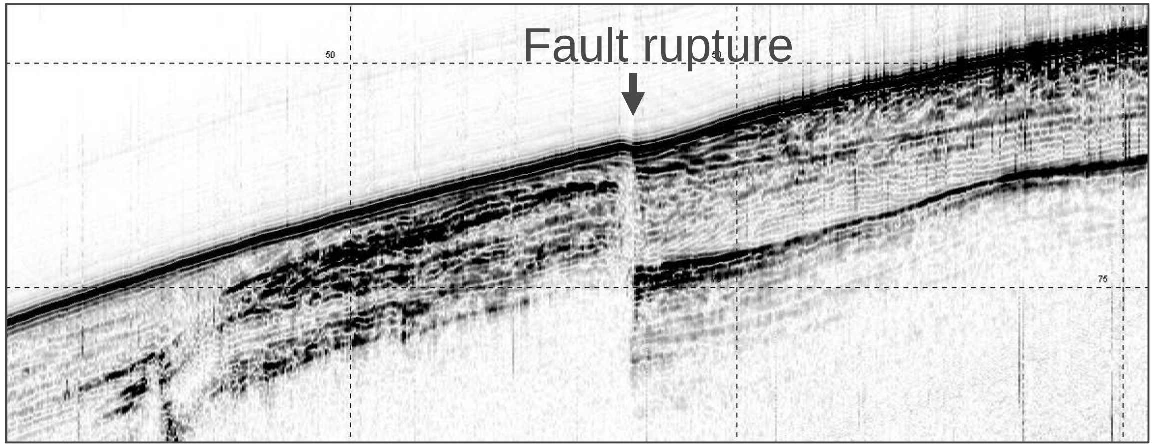
Lagridge et al., 2017, in review

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

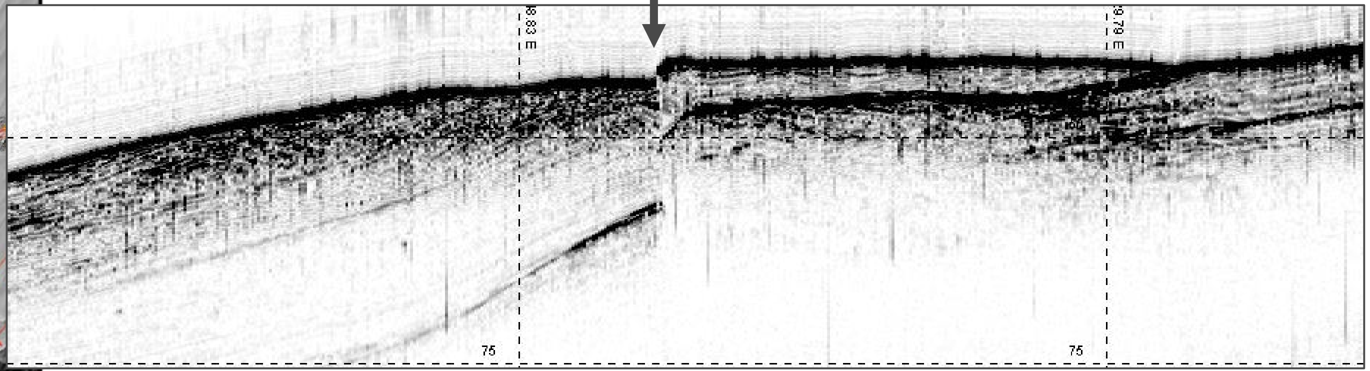


TOPAS PS18 Sub-bottom Profiles

Fault rupture

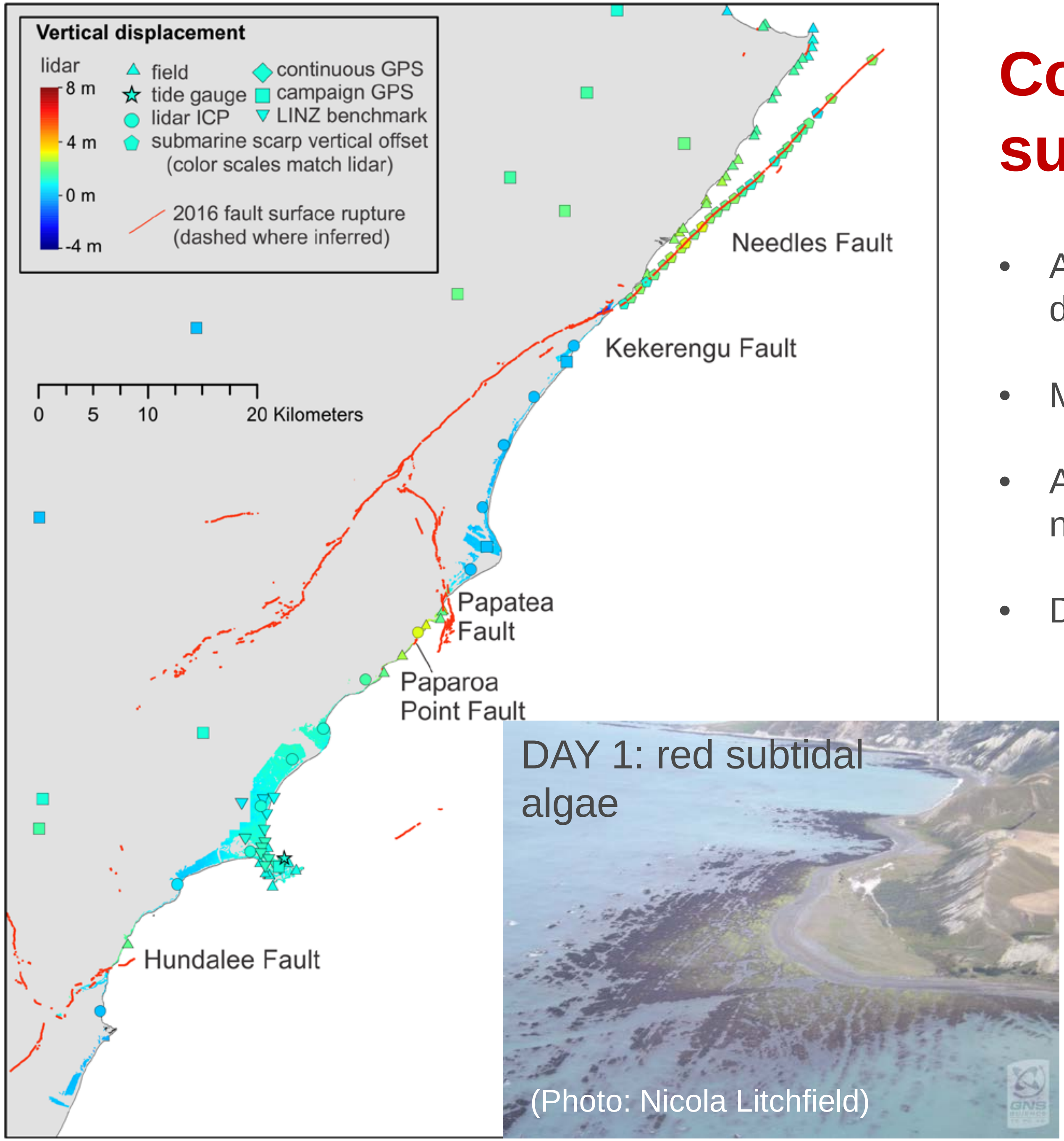


Fault rupture



Vertical offset up to 1.4 m up to NW

Kearse et al., in review



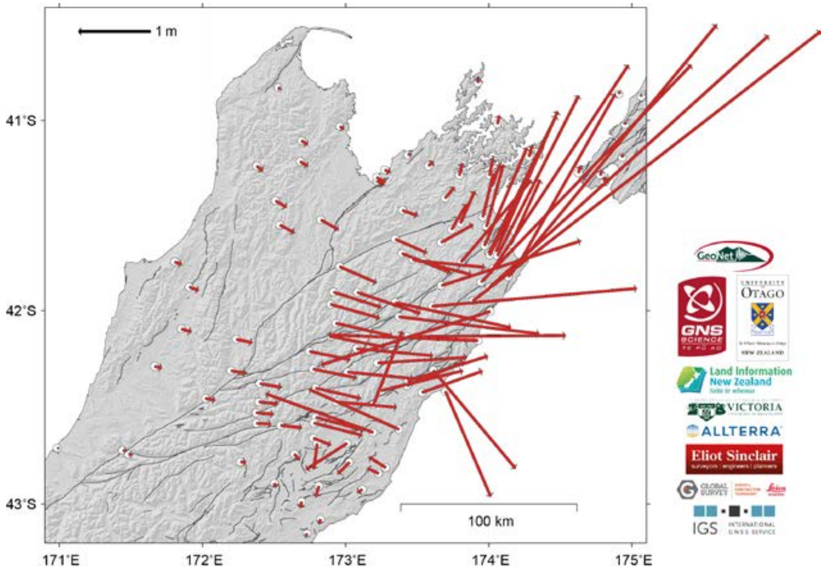
Coastal deformation: uplift and subsidence

- Approximately 110 km of the coastline underwent deformation
- Most areas went up, and by a substantial amount
- A significant stretch of low amplitude coastal subsidence north of the Clarence River
- Deformation characterised by high variability
    - Sharp changes around fault ruptures
    - 3 major & 5 minor fault ruptures across coast
    - Broad uplift around Kaikoura Peninsula & northwards related to an offshore fault

Clark et al., 2017

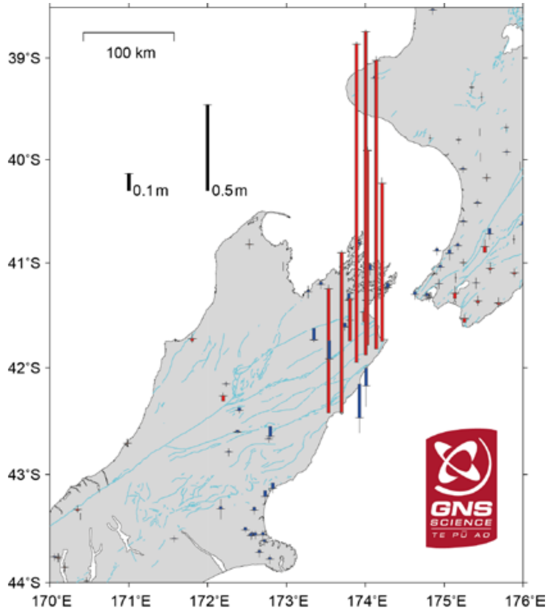
Surface coseismic deformation: GNSS and INSAR

GNSS horizontal



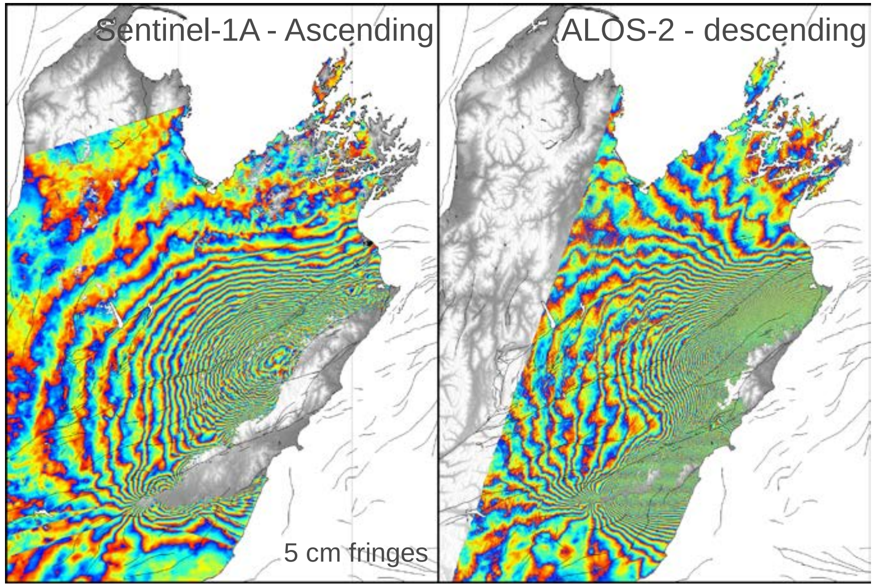
Sigrun Hreinsdottir

GNSS vertical



Sigrun Hreinsdottir

Satellite interferograms



03/11/16 – 15/11/2016

18/10/16 – 16/11/2016

Hmax: 6m; Vmax: 2m

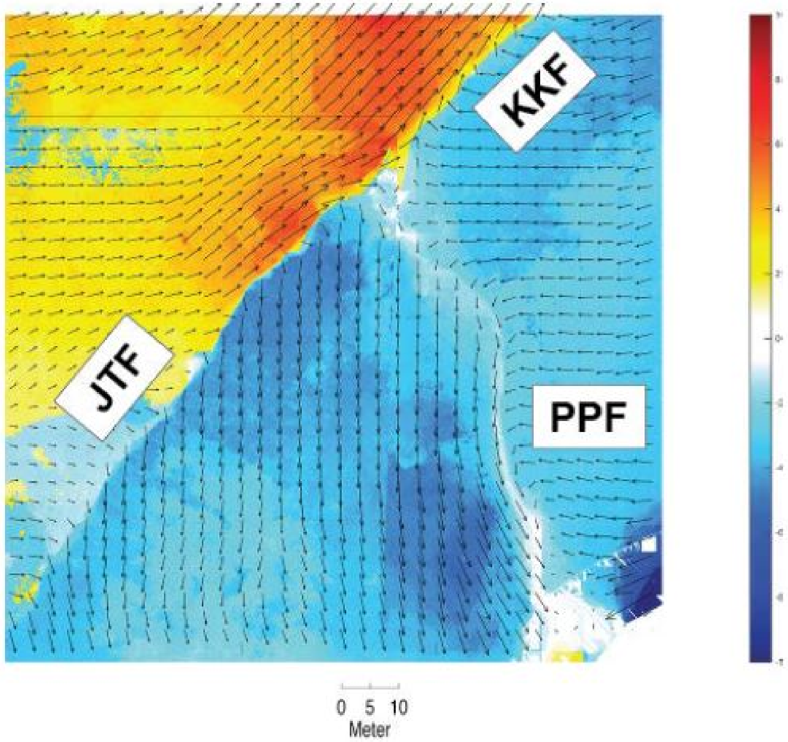
Next slide

Hamling et al. (2017)

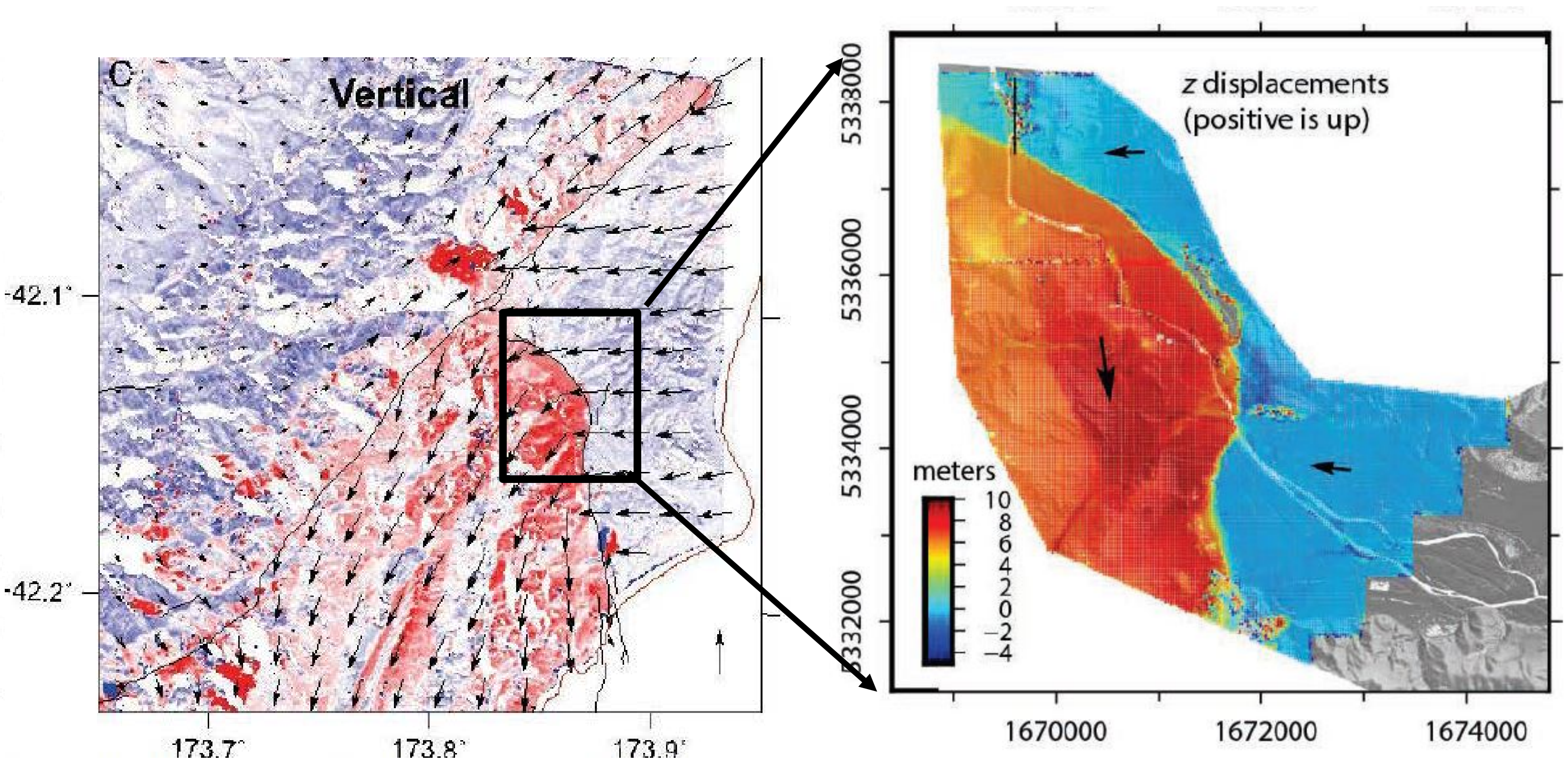
Surface deformation: new techniques.. Slightly different results

- Optical pixel tracking using various types of satellite images, orthophotos, etc.
- 3D differential analysis on satellite images and lidar data; Different 3D differential codes

The Papatea Fault



Klinger et al ., 2017 (PATA Days)

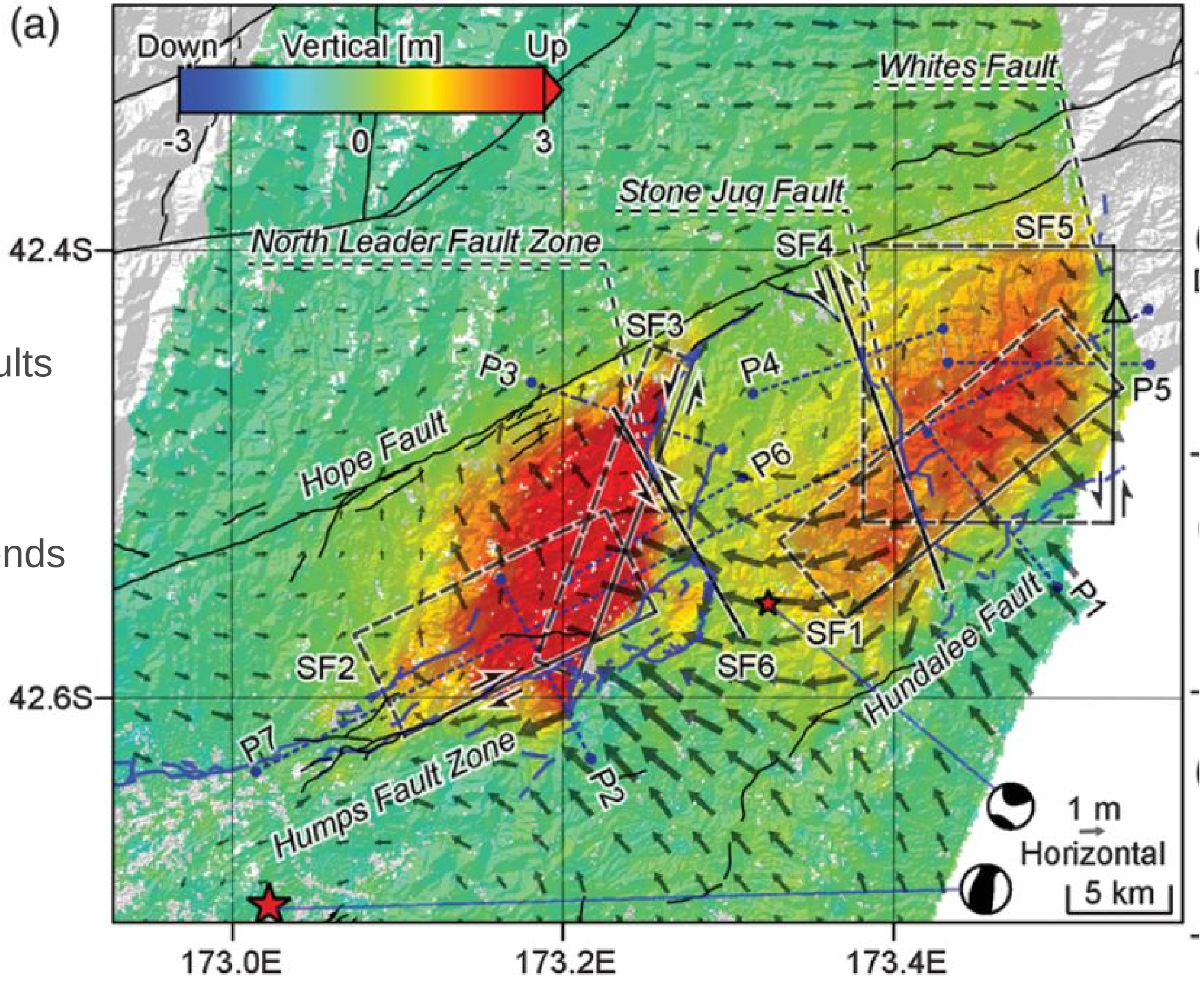


Mckenzie et al ., 2017 (PATA Days)   Nissen et al ., 2017 (PATA Days)

We are starting to have a much better understanding of co-seismic kinematics, rather that assuming typical half-space elastic dislocations, e.g, Papatea Bock

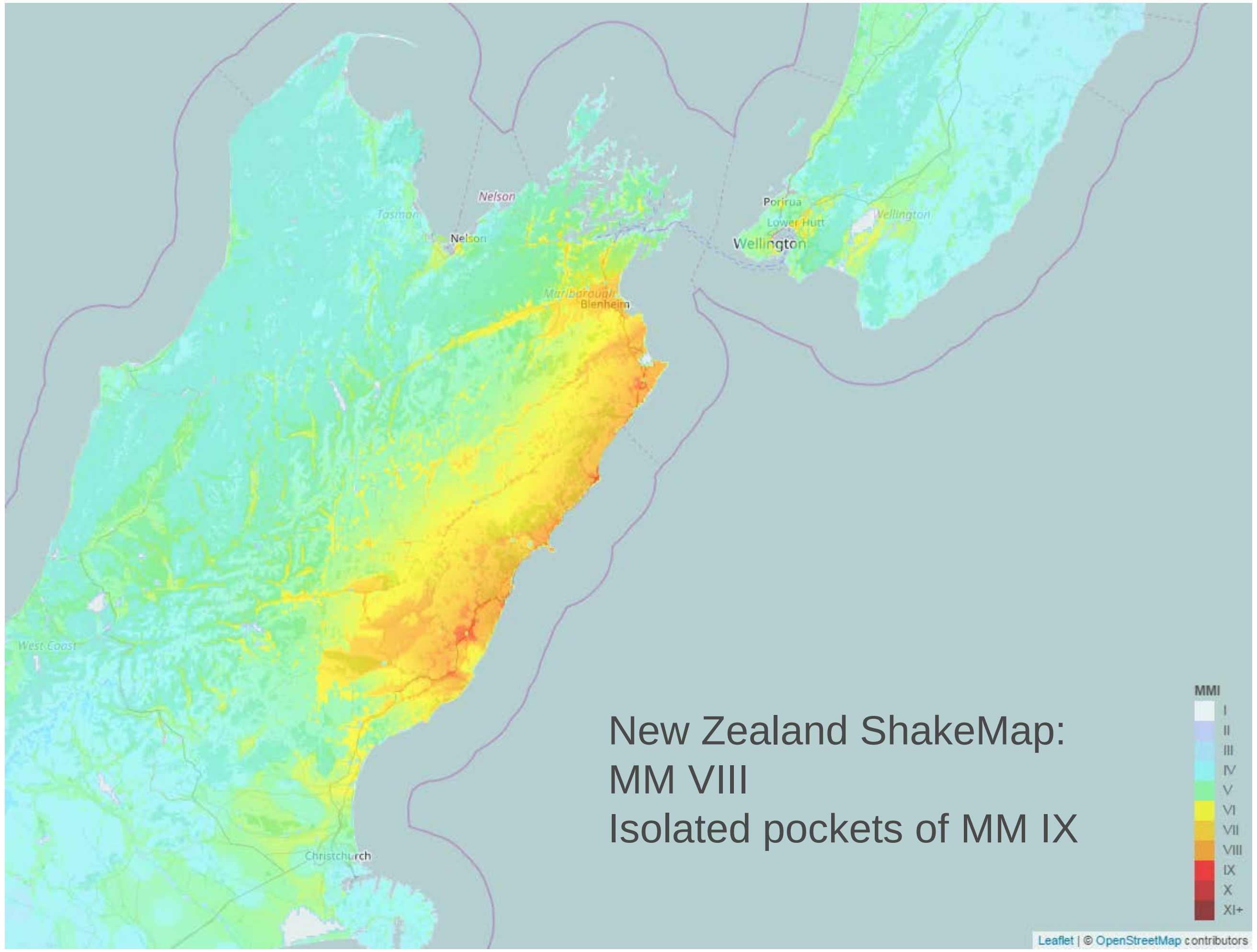
Fault ruptures in the North Canterbury contractional domain

- Beautiful example of rupture on non-mature faults
- Dextral and sinistral strike-slip , reverse
- N-S trends are along Mesozoic fabric , NW trends current tectonic regime,

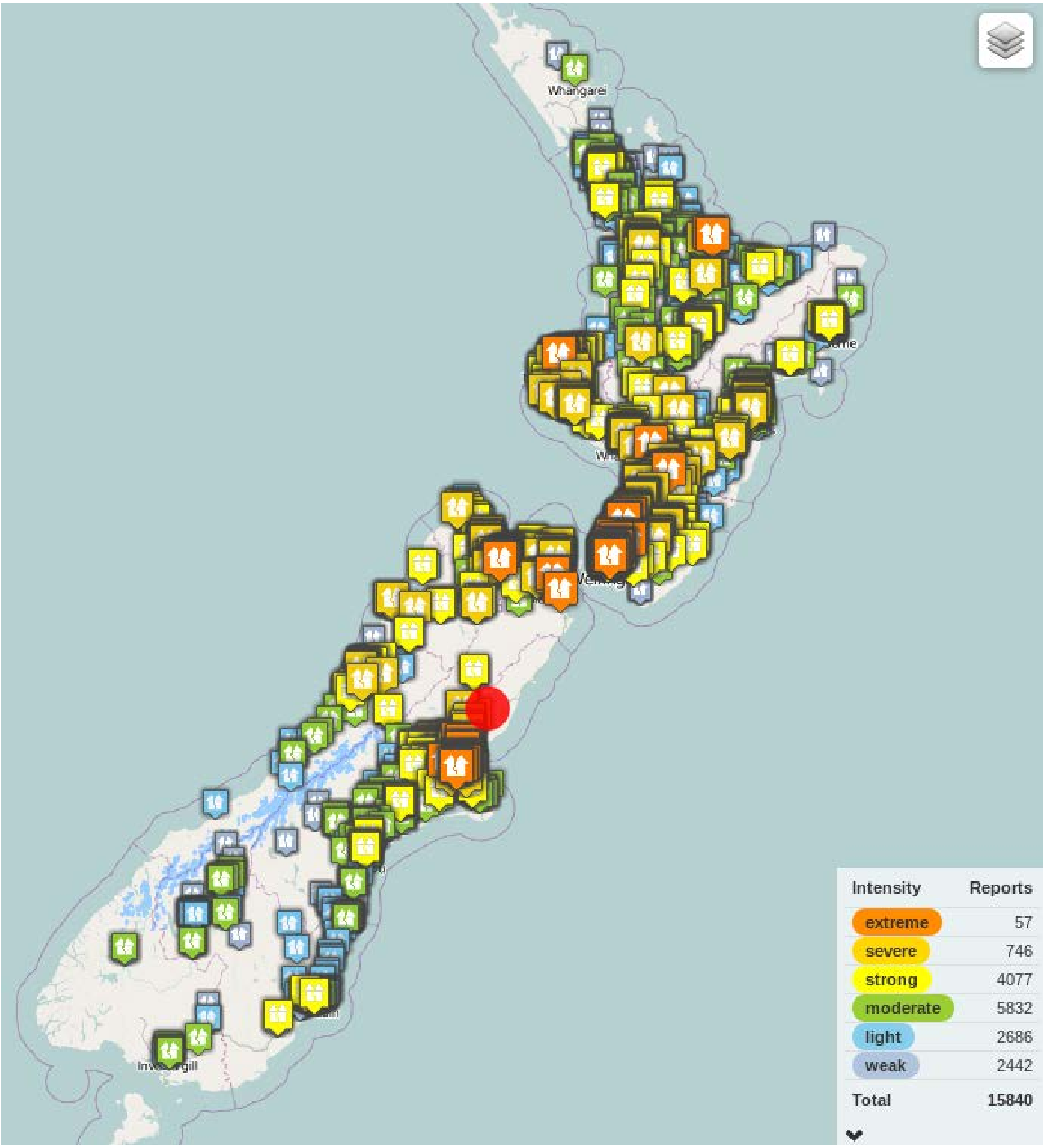


Moroshita et al ., 2017

Ground Motions: Intensity

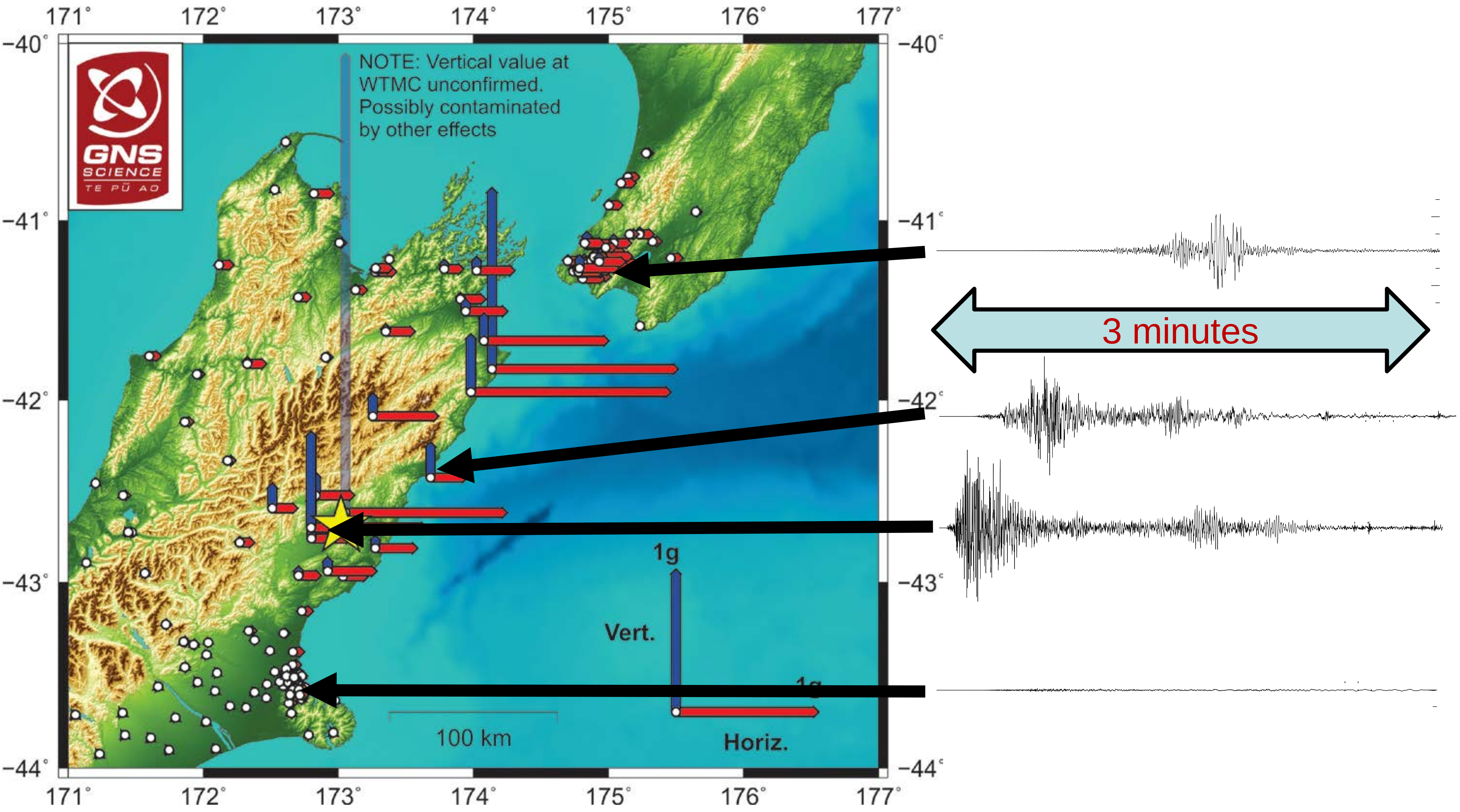


Nick Horspool



GeoNet, 15000+ felt reports

Ground Motion: Large Peak Ground Acceleration

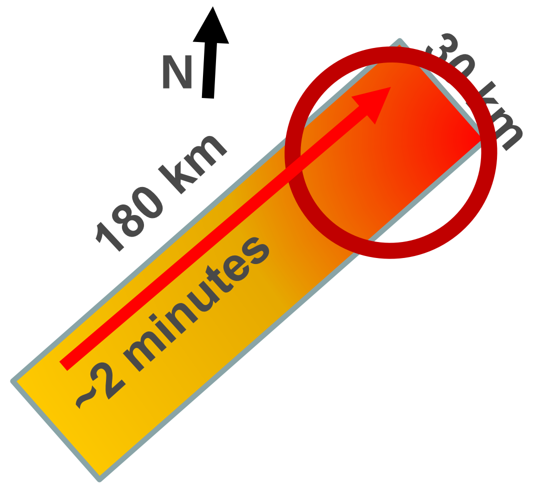


Anna Kaiser

- 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

When and where was the energy released?

Video Yoshi Kaneko & Julian Thomson;
https://www.youtube.com/watch?v=1DybzjUsjN0



Numerous fault source models

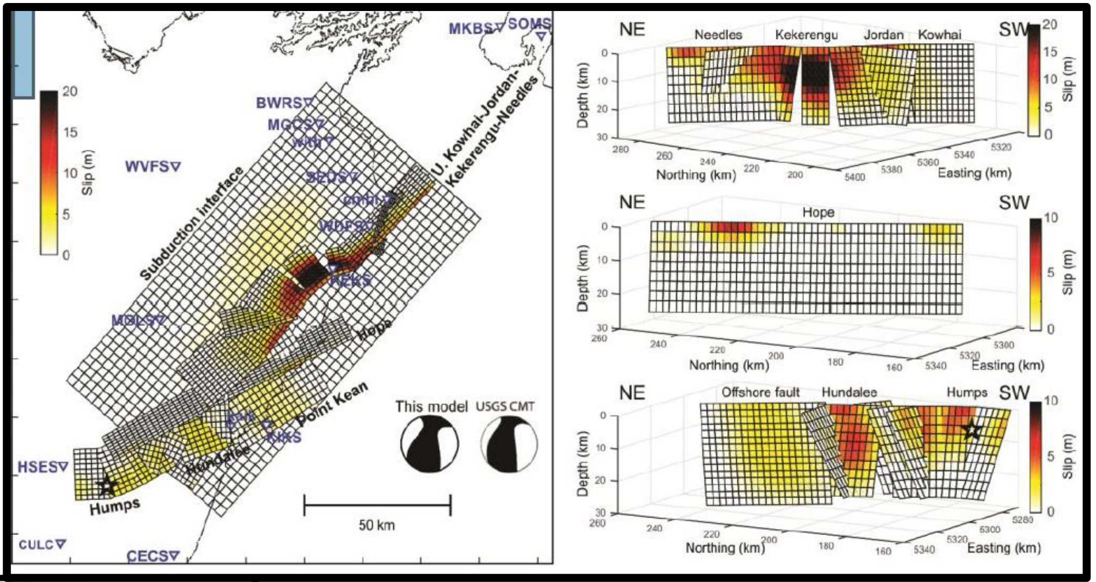
Using one or various of:

- surface deformation from satellite images
- near field seismology
- teleseismic data

Source models unknown: rupture of the Kekerengu fault

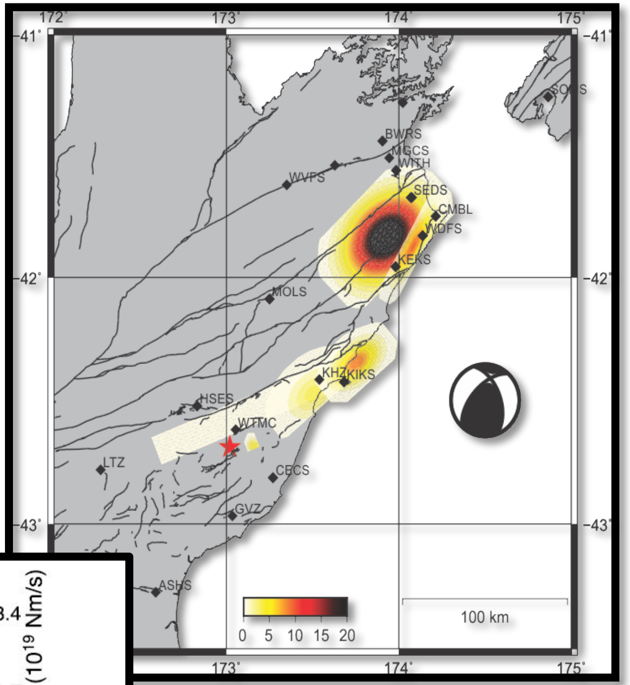
Clark et al ., 2017; Hamling et al., 2017

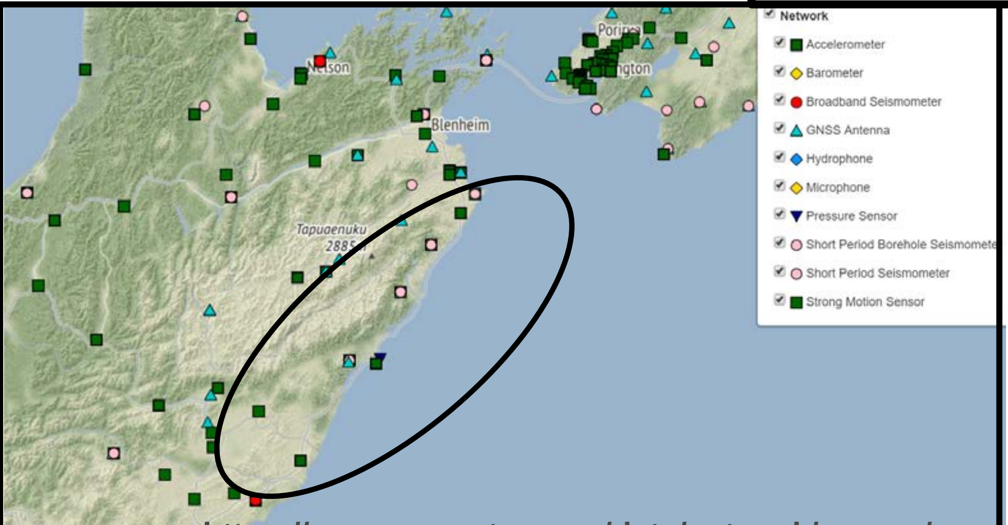
Double displacement in depth



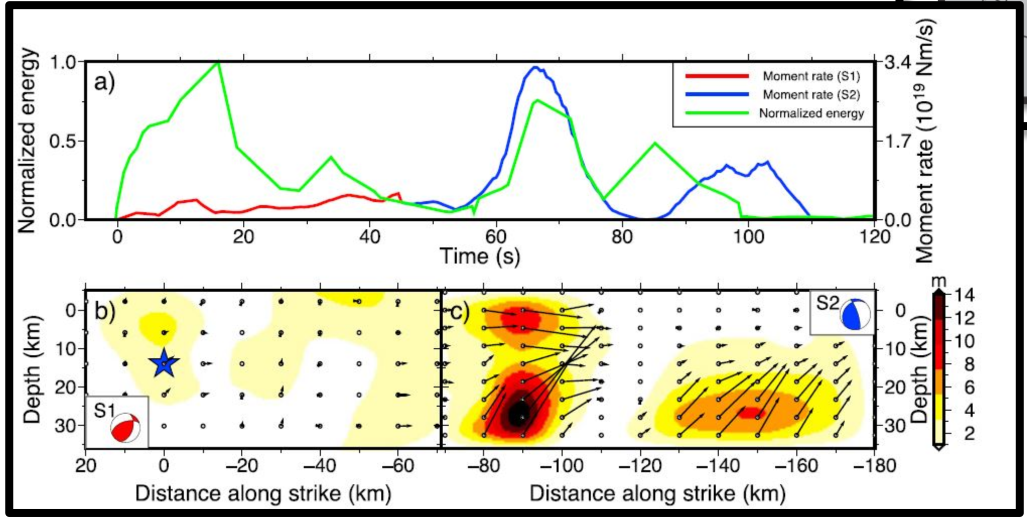
Holden et al., accepted

Fault ruptured twice





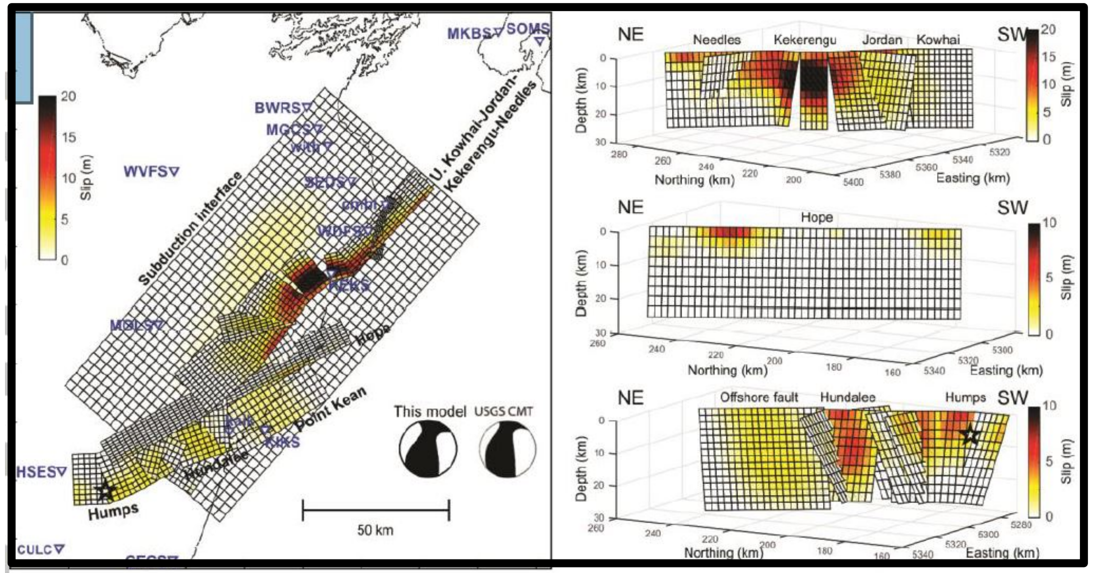
https://www.geonet.org.nz/data/network/sensor/map



Zhang et al., 2017

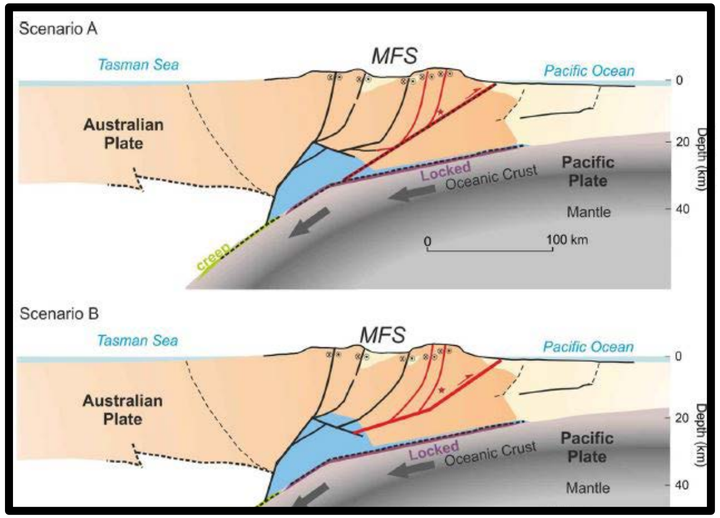
Different fault rupture mode in depth

Source models unknowns: role of the subduction interface (interface or shallow dipping crustal plane)

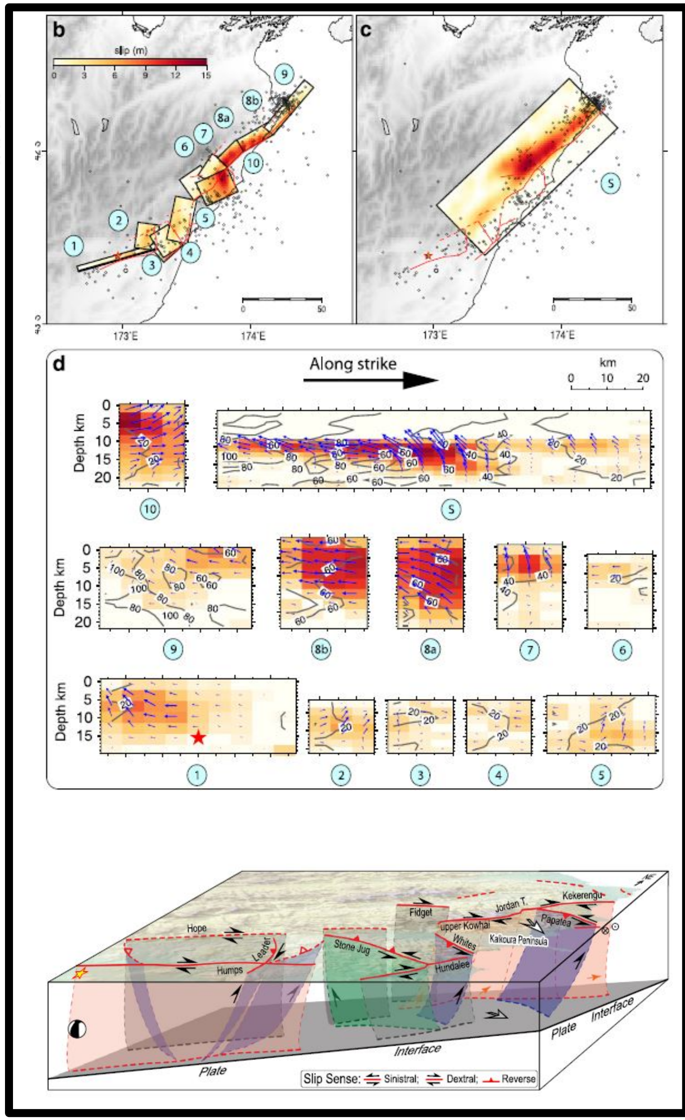


Clark et al ., 2017; Hamling et al., 2017

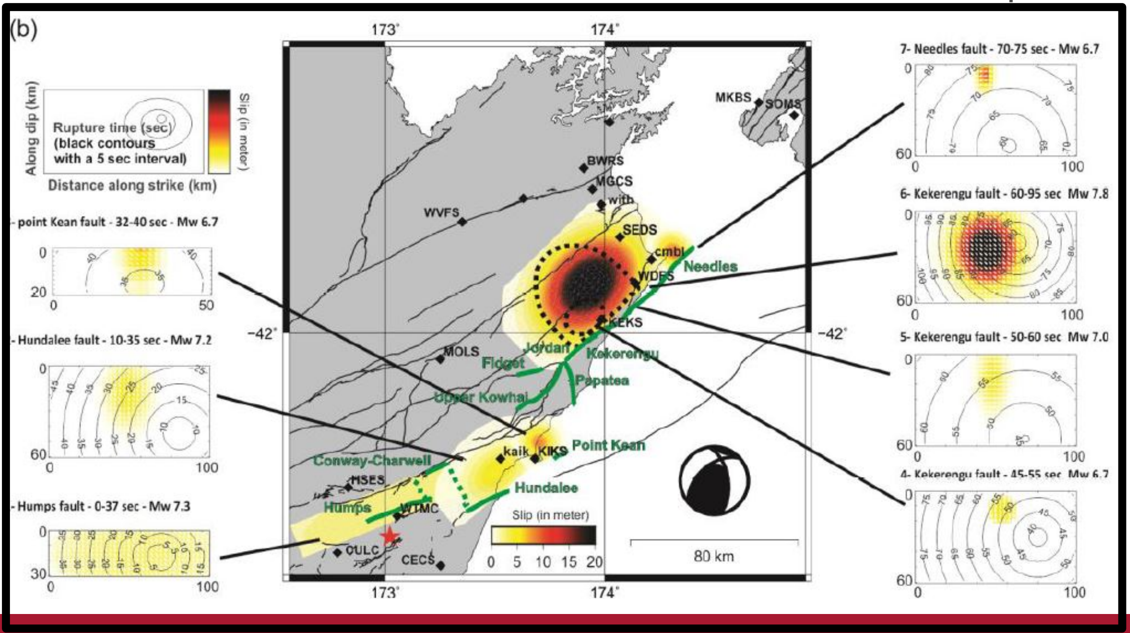
Cesca et al., 2017



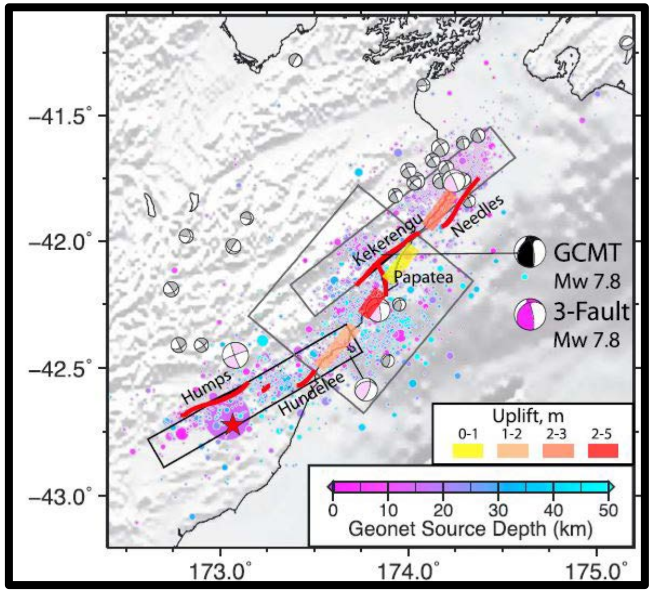
Wang et al., 2017



Holden et al., accepted

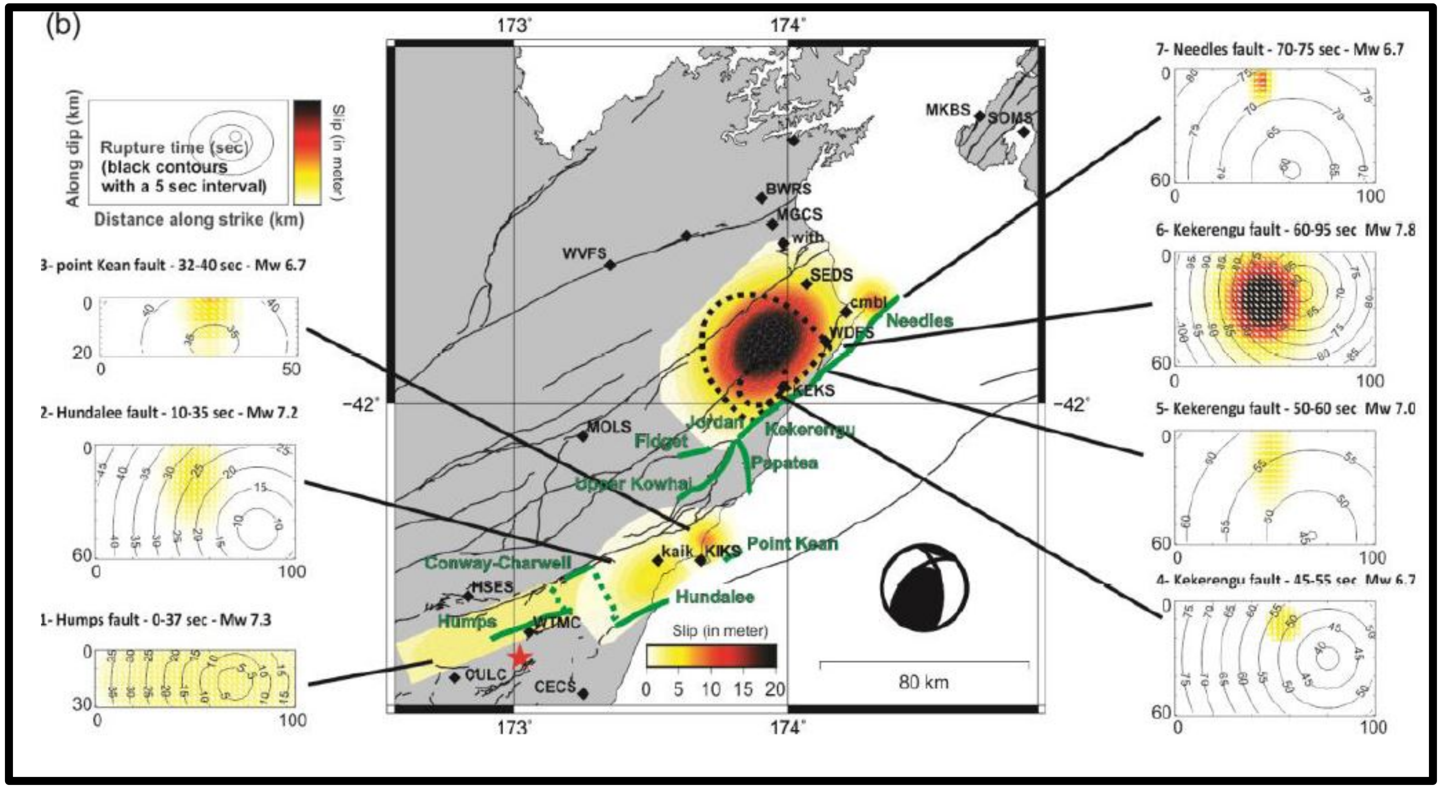


Bai et al., 2017



Source models unknowns: role of the Papatea fault

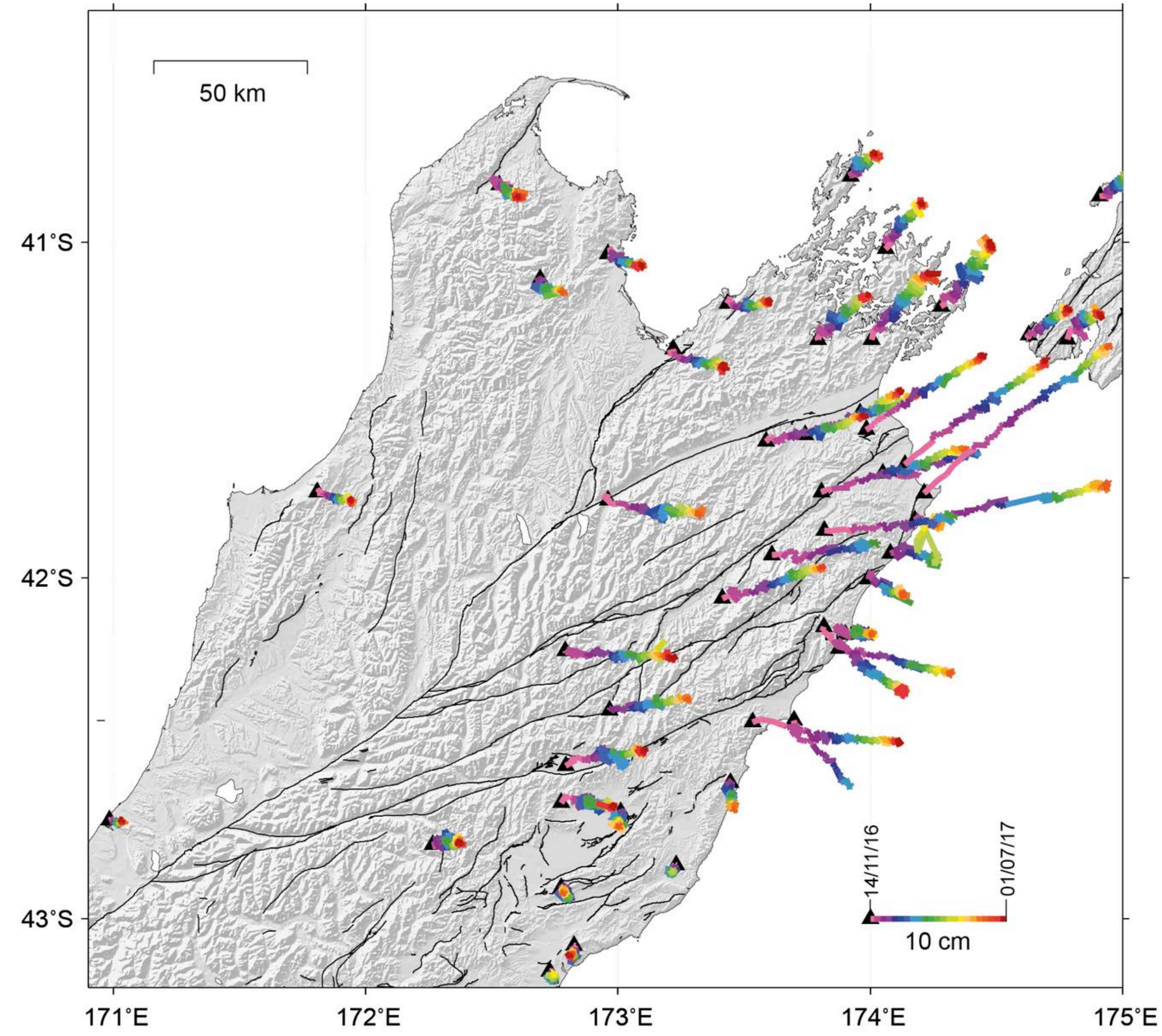
Papatea: energy released?



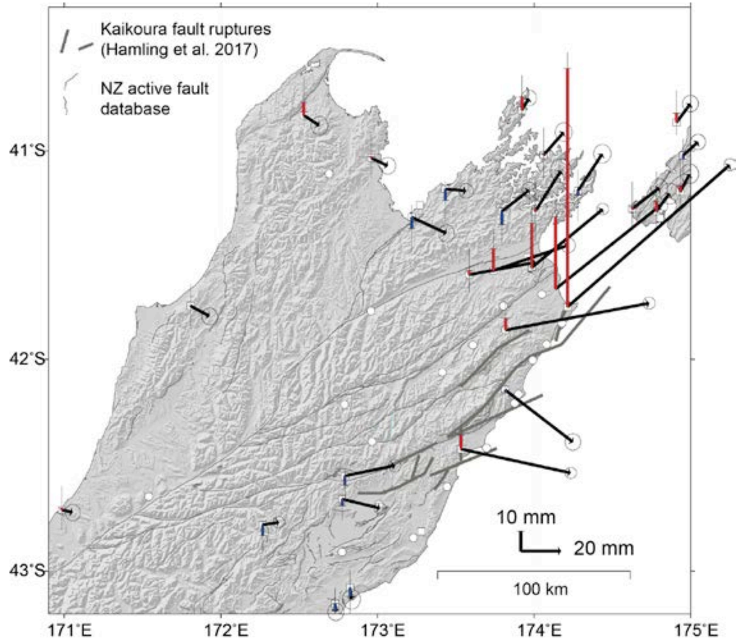
Holden et al., accepted

Benites et al in prep.: Modelling the near field strong ground motion . Papatea Fault breaks with Mw = 6.9
Non-double couple at Papatea

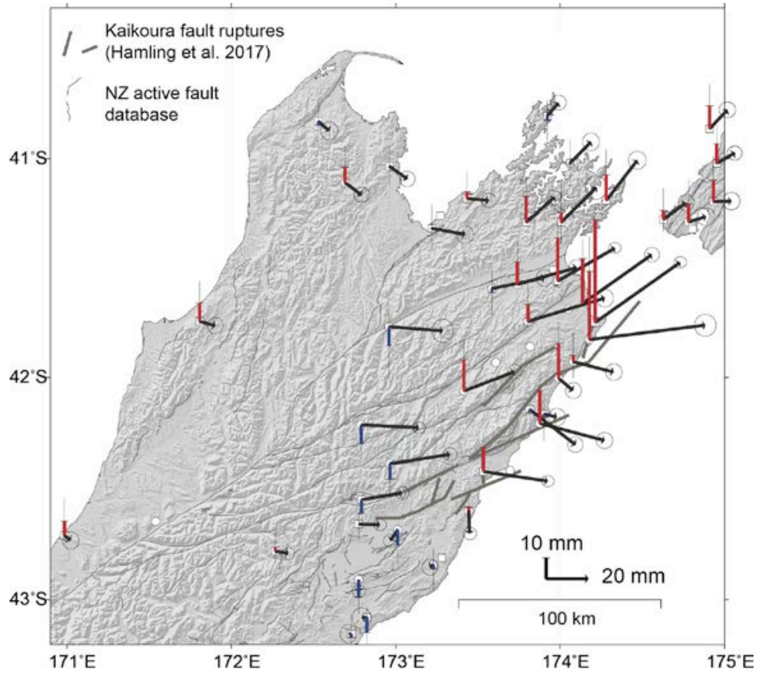
Postseismic slip



16 Nov 2016 – 16 Dec 2016

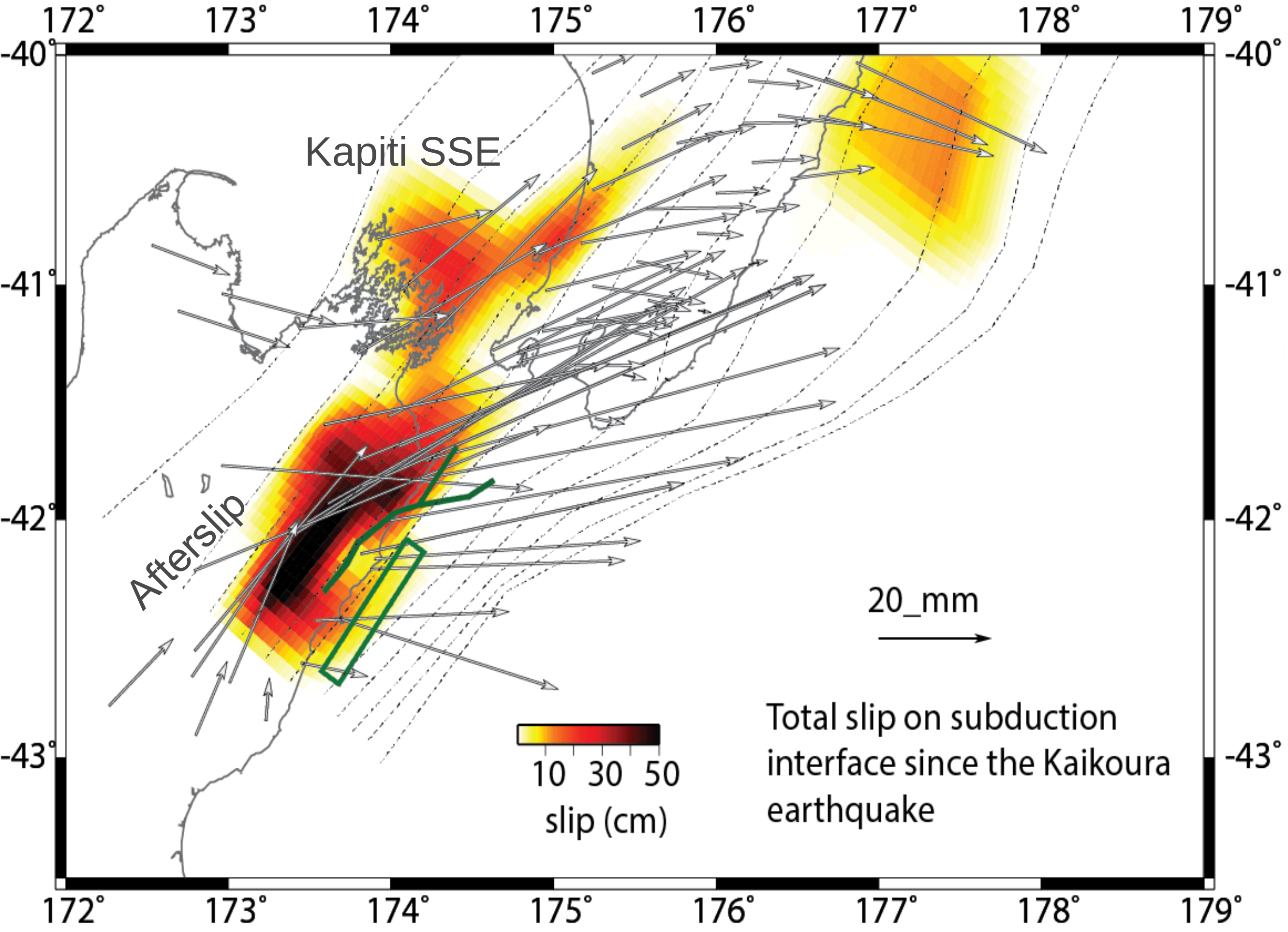


16 Dec 2016 – 26 Feb 2017

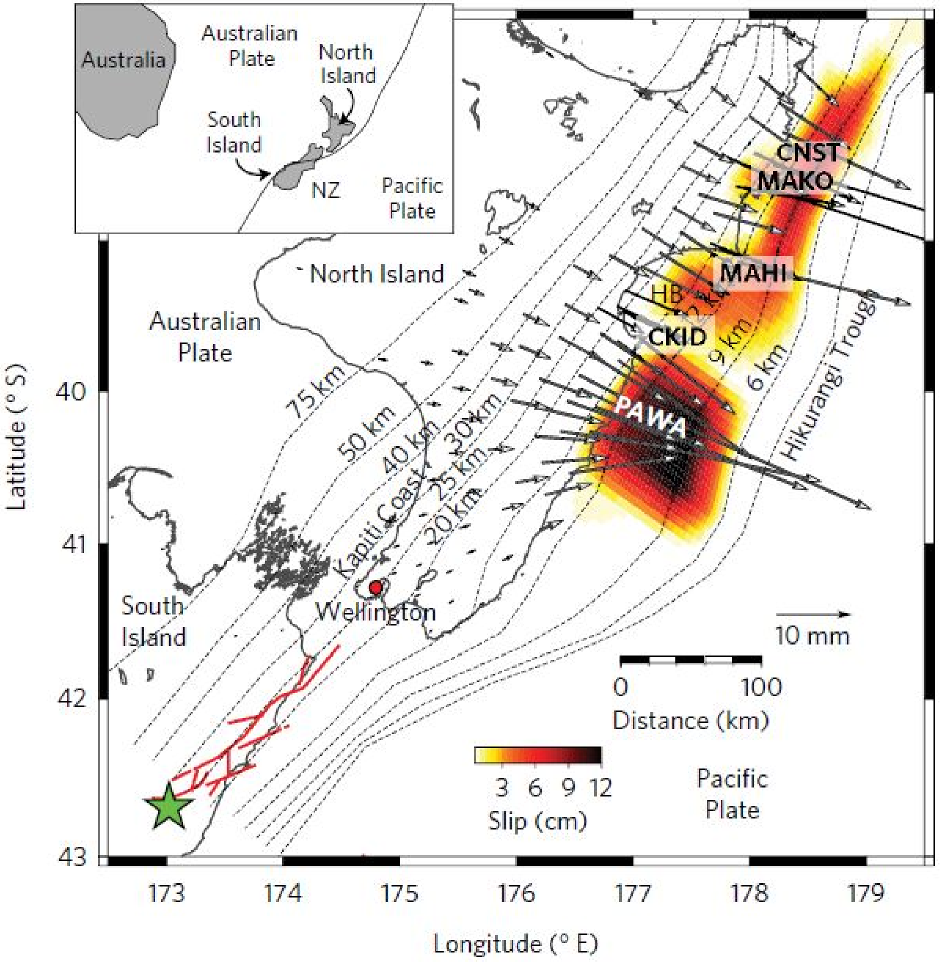


AFTER SLIP & SLOW SLIP EVENTS Time-dependent geodetic inversions (cGPS and InSAR) done with TDefnode.

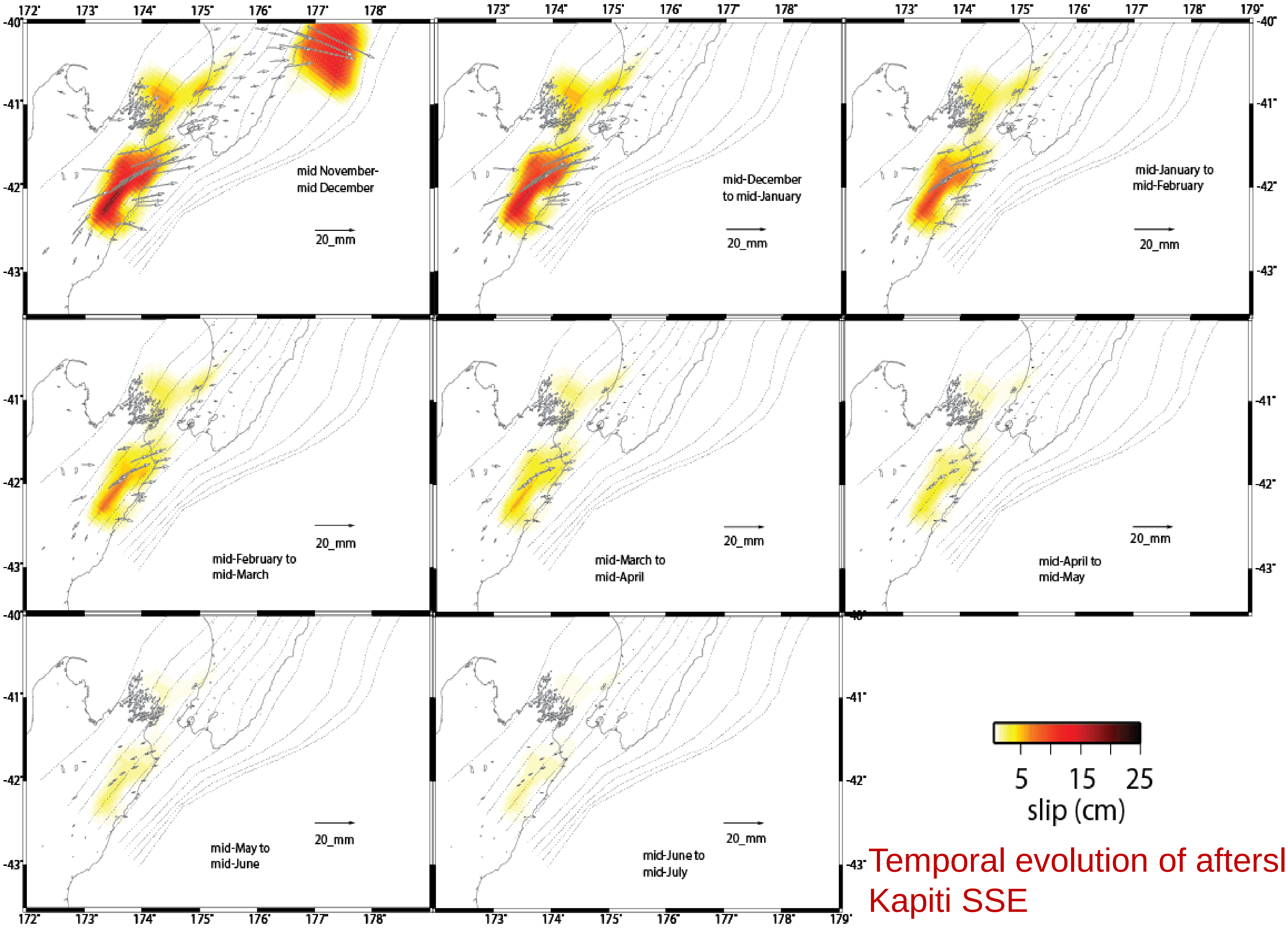
- Kapiti slow slip event and afterslip beneath northern South Island still ongoing. Afterslip = Mw 7.3, Kapiti SSE = Mw 7.1
- Slip on interface beneath northern SI required by a large uplift/subsidence pair in northern South Island, and eastward motion of sites east of Kekerengu/Jordan Thrust



Wallace, Hreinsdottir in prep.



Wallace et al., 2017 Nature



Temporal evolution of afterslip on the plate interface and Kapiti SSE

Insights……thoughts for discussion

Hazards assessment challenges:

- Multi-fault ruptures: How can we account for this complexity in seismic hazard model? Do we need to allow for multiple-segments if we cannot rule out that scenario? (E.g, JordaN-Kek-Needles)

- - How much complexity have we missed in historic events that had no INSAR, GNSS, dense seismic instrumentation? In paleo-events? Are earthquakes complex by nature?

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

- Coseismic coastal uplift… how would have we interpreted this event as a prehistoric one? A subduction event? Separate crustal events?

- What other tectonic environments can this complexity be predicted?

Fault mechanics/ fault slip models

- Dynamic and static triggering. Connection between co-seismically rupturing faults (why did the Hope Fault not rupture)? - direct impact on how we model fault sources for hazard

- Multidisciplinary approach to better understand fault slip models: we are doing really well but nature is continuously challenging us. Data type and quality, and an oversimplified crustal rheology can account for variety in the models.

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Victoria University of Wellington

EQC
Earthquake Commission
Kōmihana Rūwhenua

Natural Hazards Research Platform

QuakeCoRE
NZ Centre for Earthquake Resilience

The University of Auckland New Zealand

UC University of Canterbury
Te Whare Wānanga o Waitaha
Christchurch New Zealand

University of Otago
Te Whare Wānanga o Otāgo
New Zealand

Massey University
Te Kunenga ki Pūrehuroa
University of New Zealand

Humboldt State University

University of Michigan

Texas
The University of Texas at Austin

USC University of Southern California

University of Victoria

ETH zürich

Harvard University

University of Leeds

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THANKS !!!!!