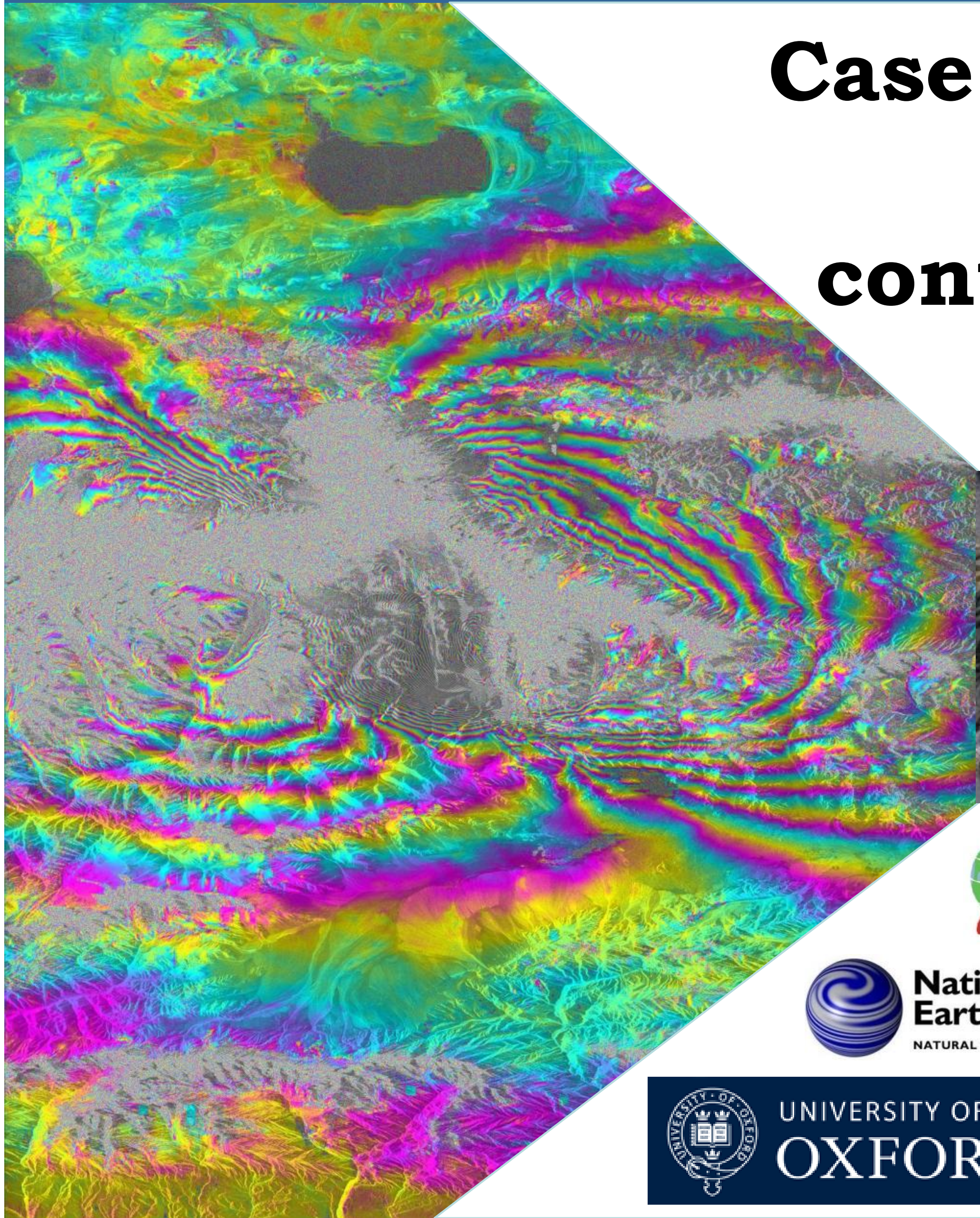
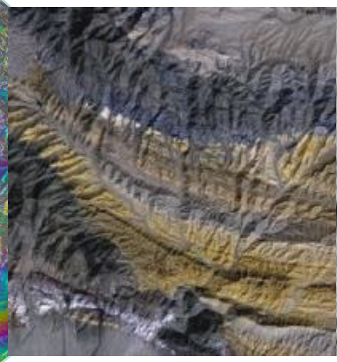
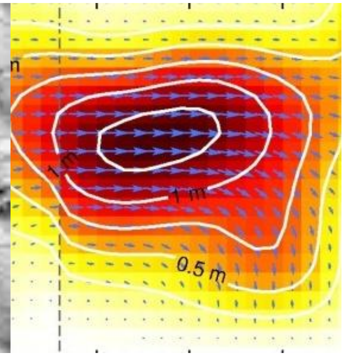


Case studies of coseismic deformation from continental earthquakes





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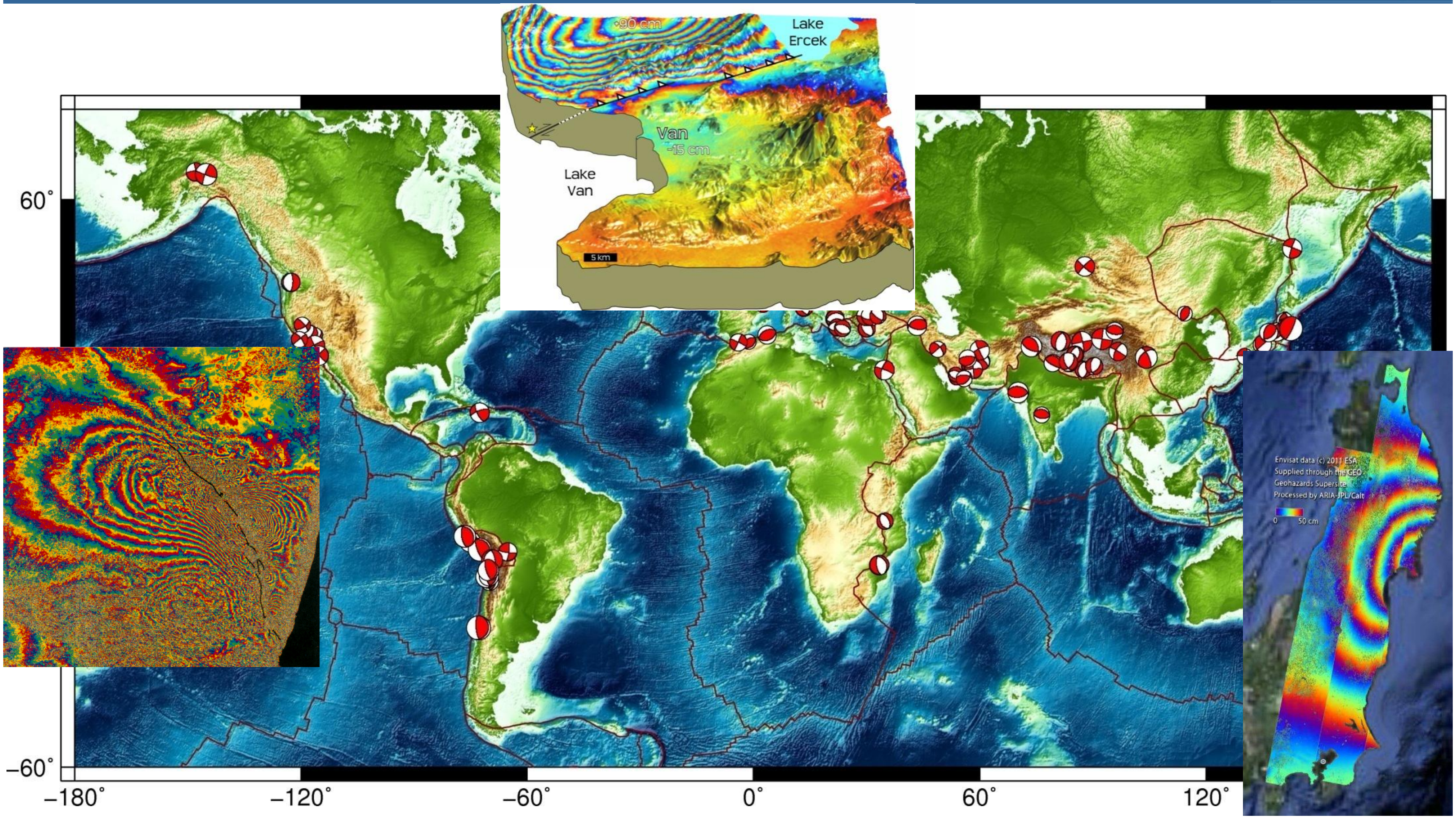
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF OXFORD

Introduction

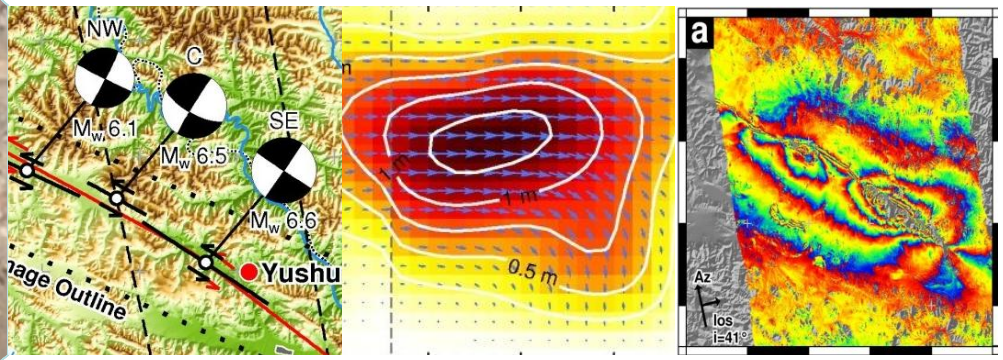
- I will present static slip models for a pair of recent continental Mw 7 earthquakes (Yushu, China and Darfield, New Zealand) constrained primarily by InSAR phase observations.
- Other observations such as field measurements of surface slip, SAR pixel offsets, remote imagery, DEMs and seismology were used to inform our choice of fault geometry.
- Good constraints on fault geometry and slip distributions are required for further work on
  - fault rupture and propagation, postseismic analysis, accommodation of strain in the continental lithosphere, characterising fault evolution and scaling, calculation of stress changes and assessment of future seismic hazard.

InSAR Coseismic Observations



Over 91 Earthquakes studied with InSAR, in a twenty year period 1992-2012

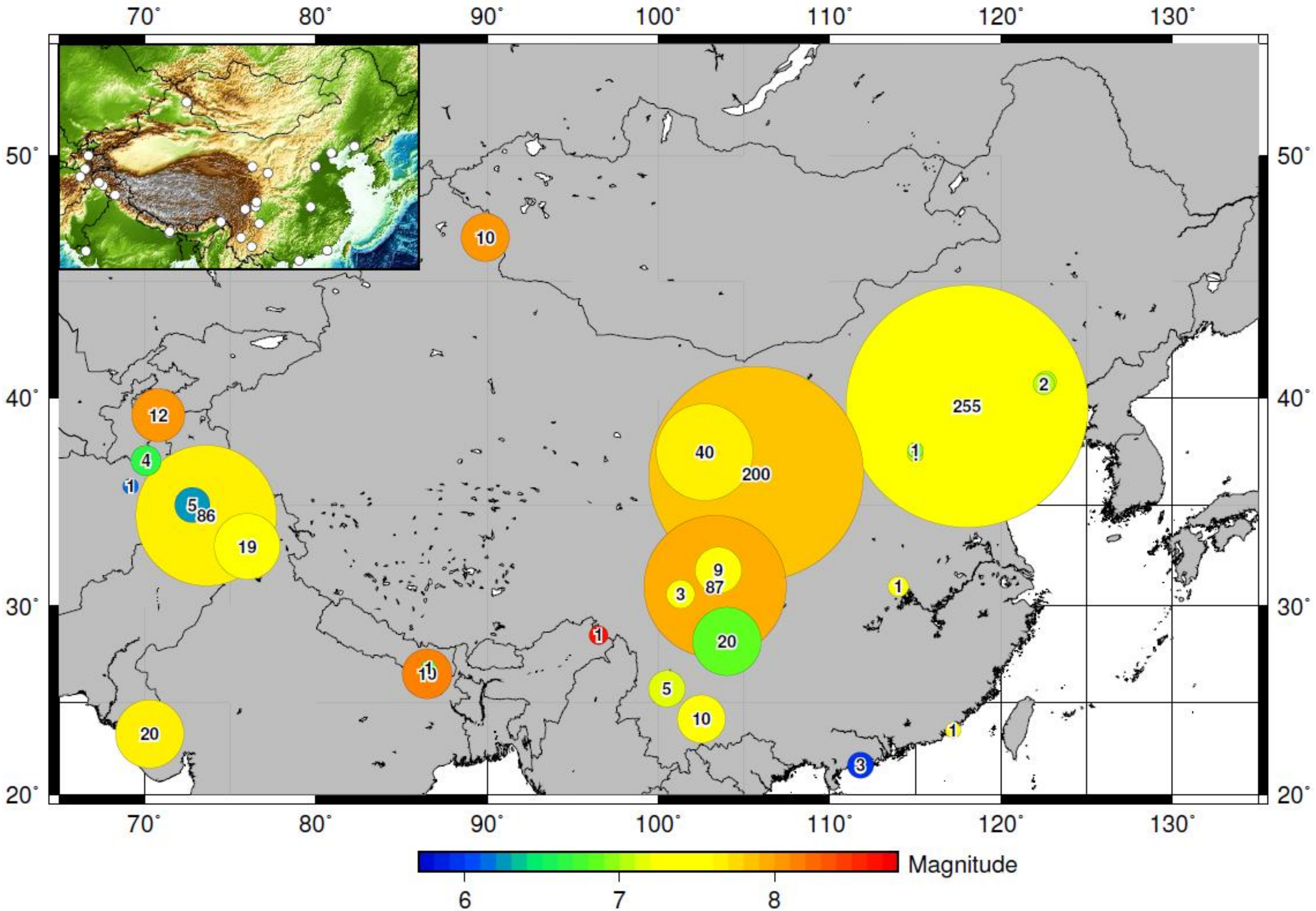
2010 Yushu (China) M_w 6.8 Strike-Slip Earthquake



Li, Elliott et al. JGR (2011)
doi:10.1029/2011JB008358

Wanpeng Feng, James Jackson,
Barry Parsons, Richard Walters

Asian Continental Earthquakes



Yushu, China

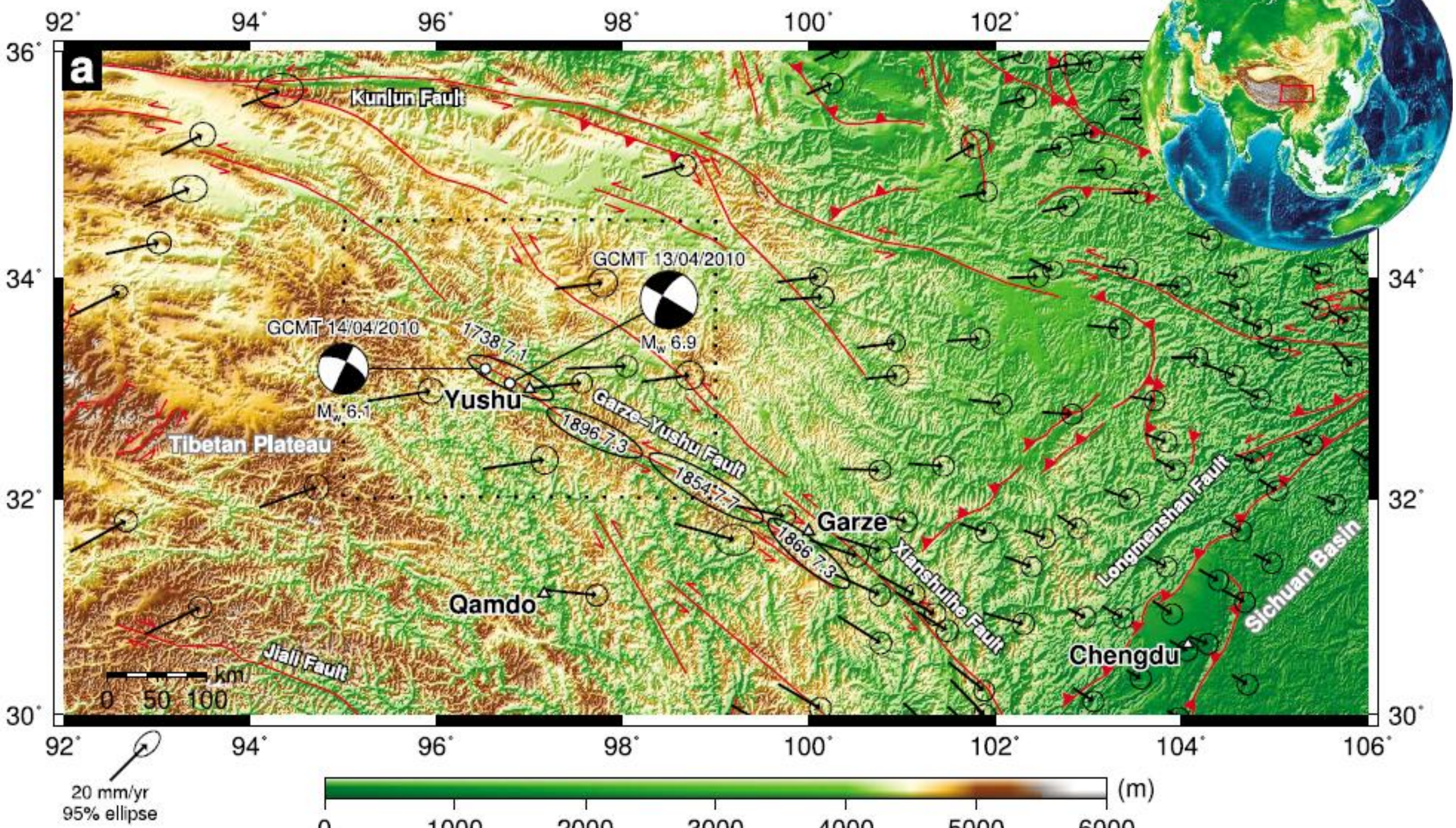
Earthquake Fatality Rates

Table 1 List of recent earthquakes for which a Prompt Assessment of Global Earthquakes for Response (PAGER) estimate of the number of people exposed to VIII+ shaking on the Modified Mercalli Intensity (MMI) scale is given. An estimate of the fatality rate from this severe shaking is given by dividing the number of fatalities by the population exposed to at least this level of shaking

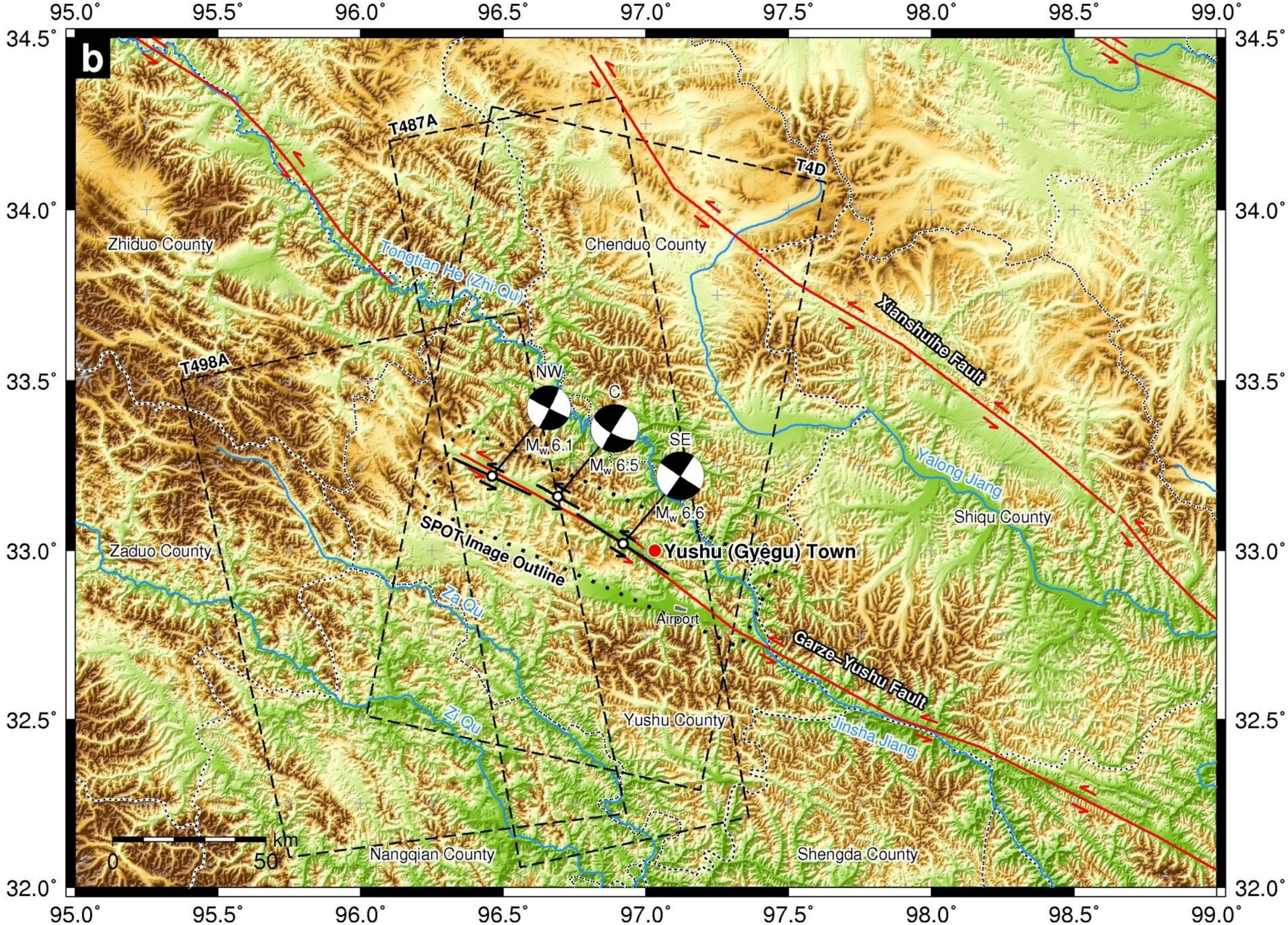
Earthquake	Magnitude	Date	Facilities	VIII+ shaking	Fatality rate (%)
Tohuku, Japan	9.0	11 March 2011	20 350	6 073 000	0.34
Christchurch, New Zealand	6.3	21 February 2011	181	320 000	0.06
Darfield, New Zealand	7.1	3 September 2010	0	22 000	0.00
Yushu, China	6.9	13 April 2010	2700	12 000	22.50
Baja, Mexico	7.2	4 April 2010	2	801 038	0.00
Maule, Chile	8.8	27 February 2010	521	3 649 000	0.01
Haiti	7.0	12 January 2010	46 000–316 000	3 056 000	1.5–10
L'Aquila, Italy	6.3	6 June 2009	287	10 000	2.87
Wenchuan, China	7.9	12 May 2008	88 000	1 775 000	4.96

Crowley & Elliott 2012

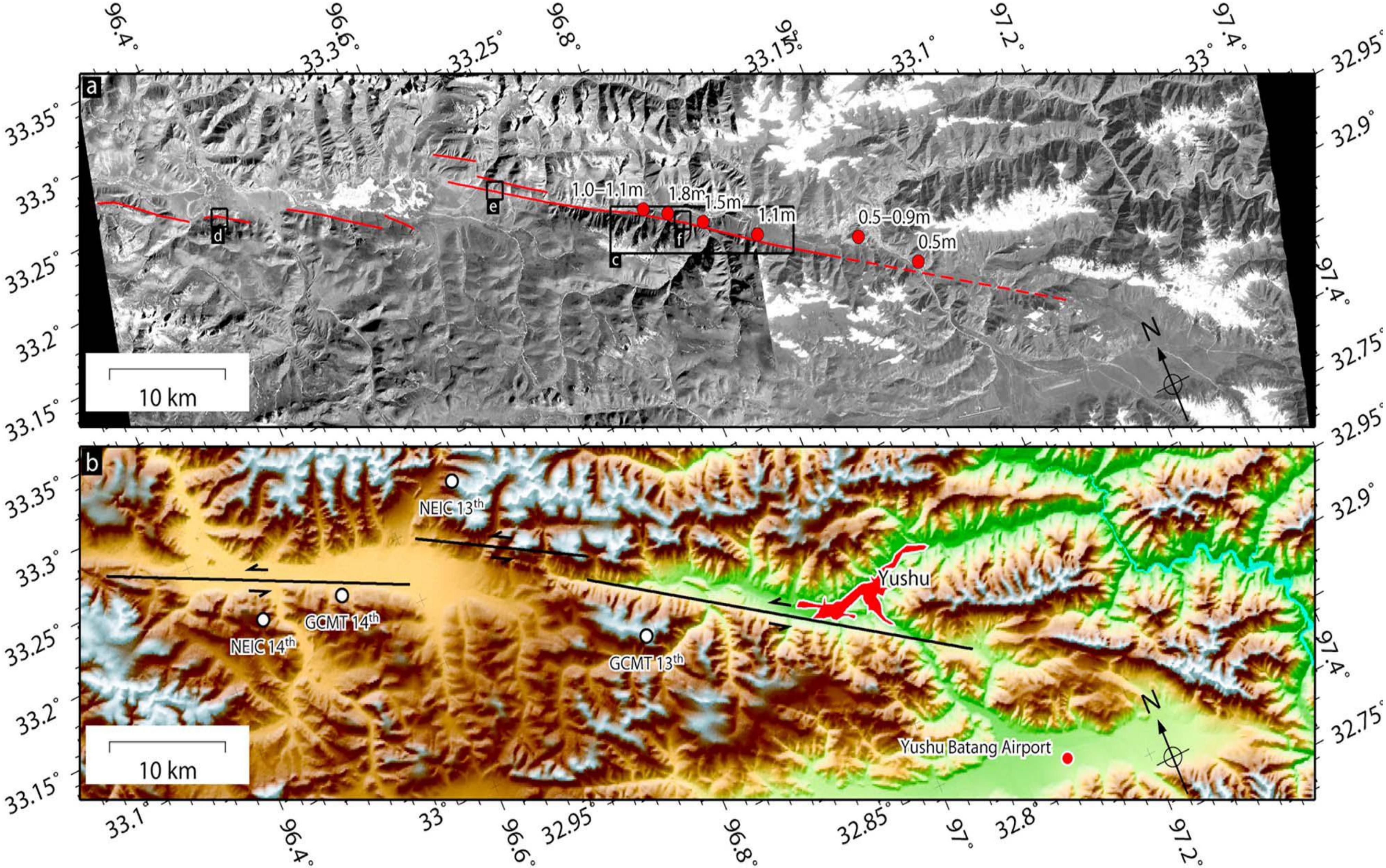
Eastern Tibetan Faulting



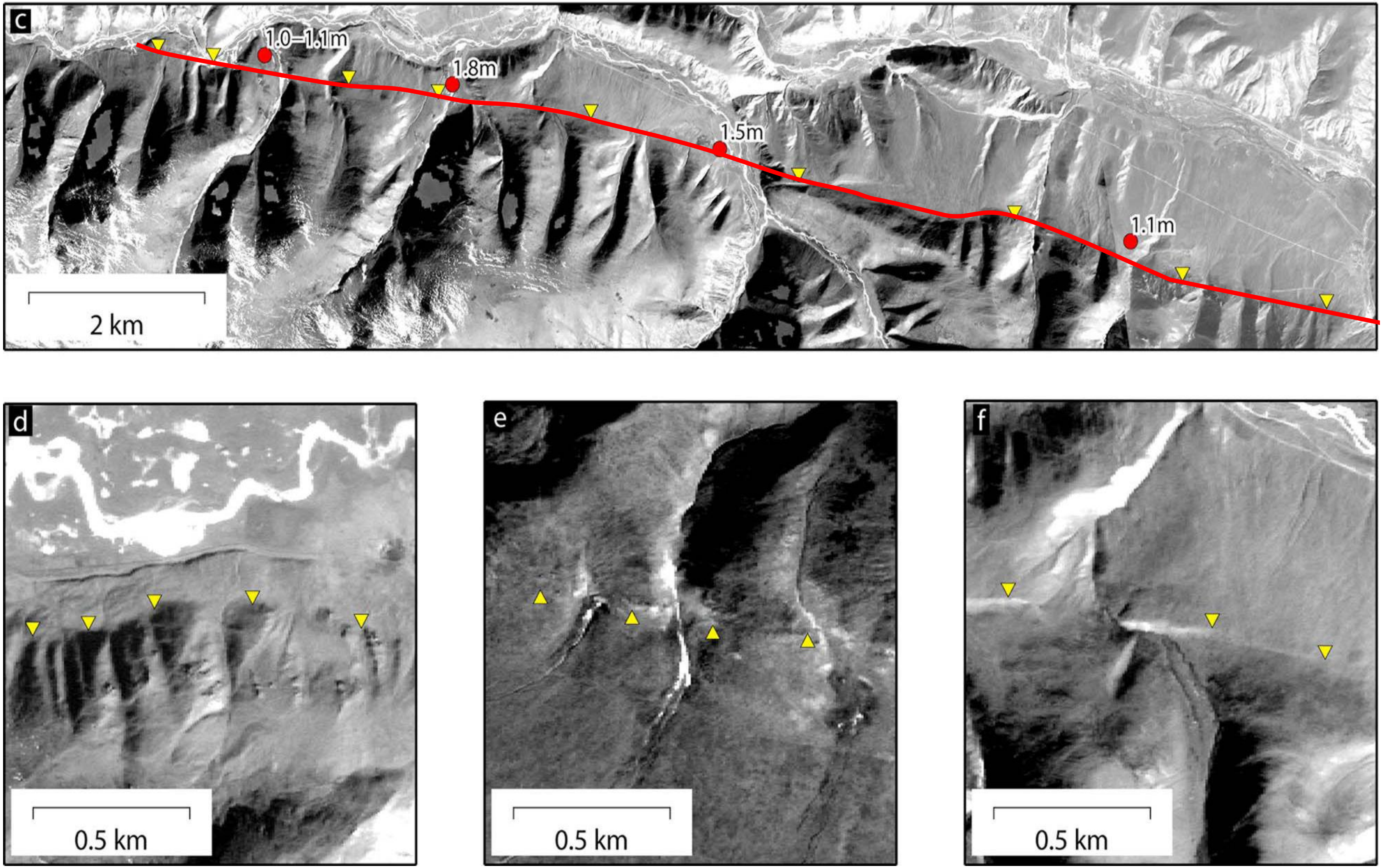
Yushu Earthquake



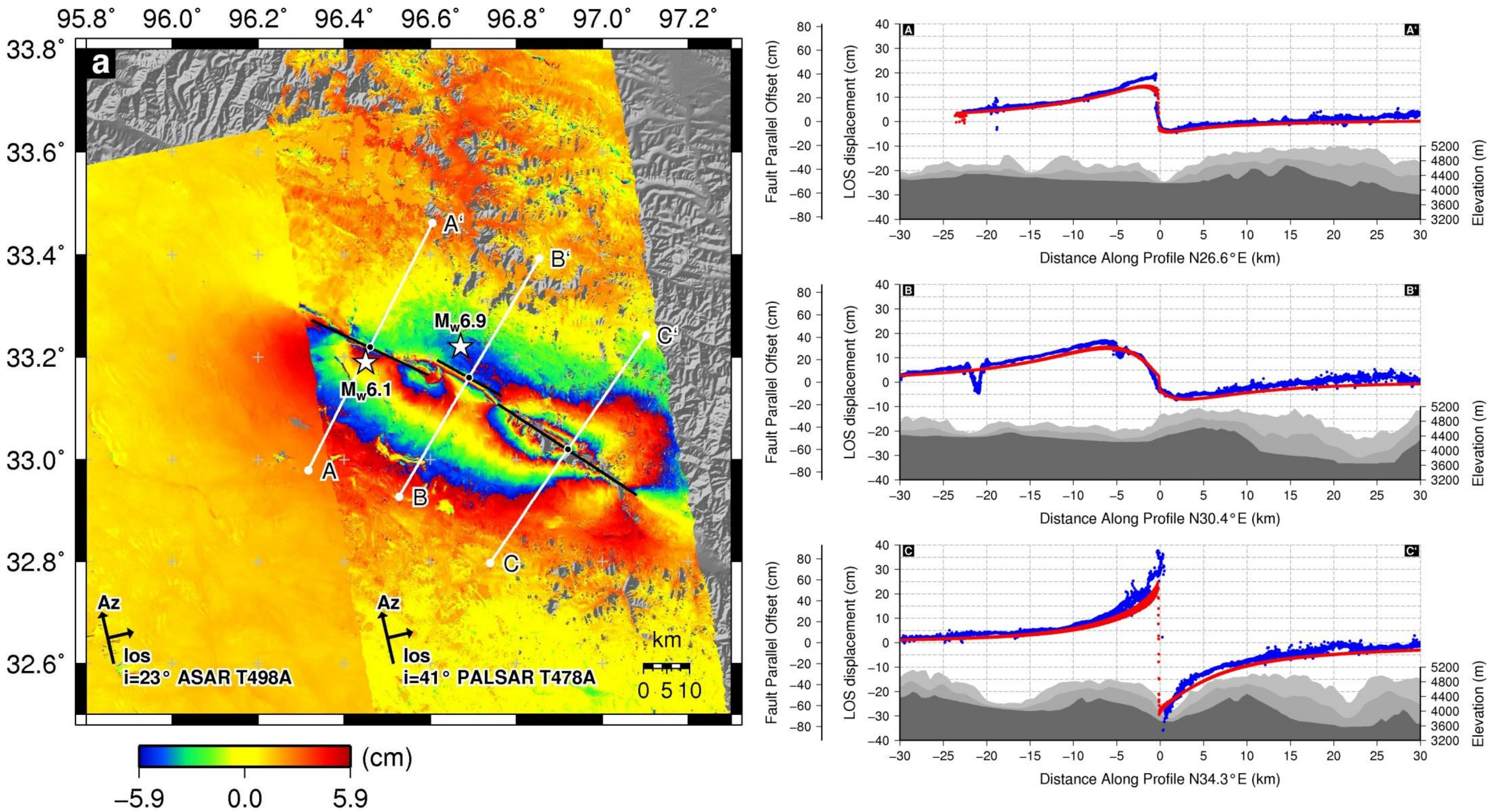
Surface Fault Trace



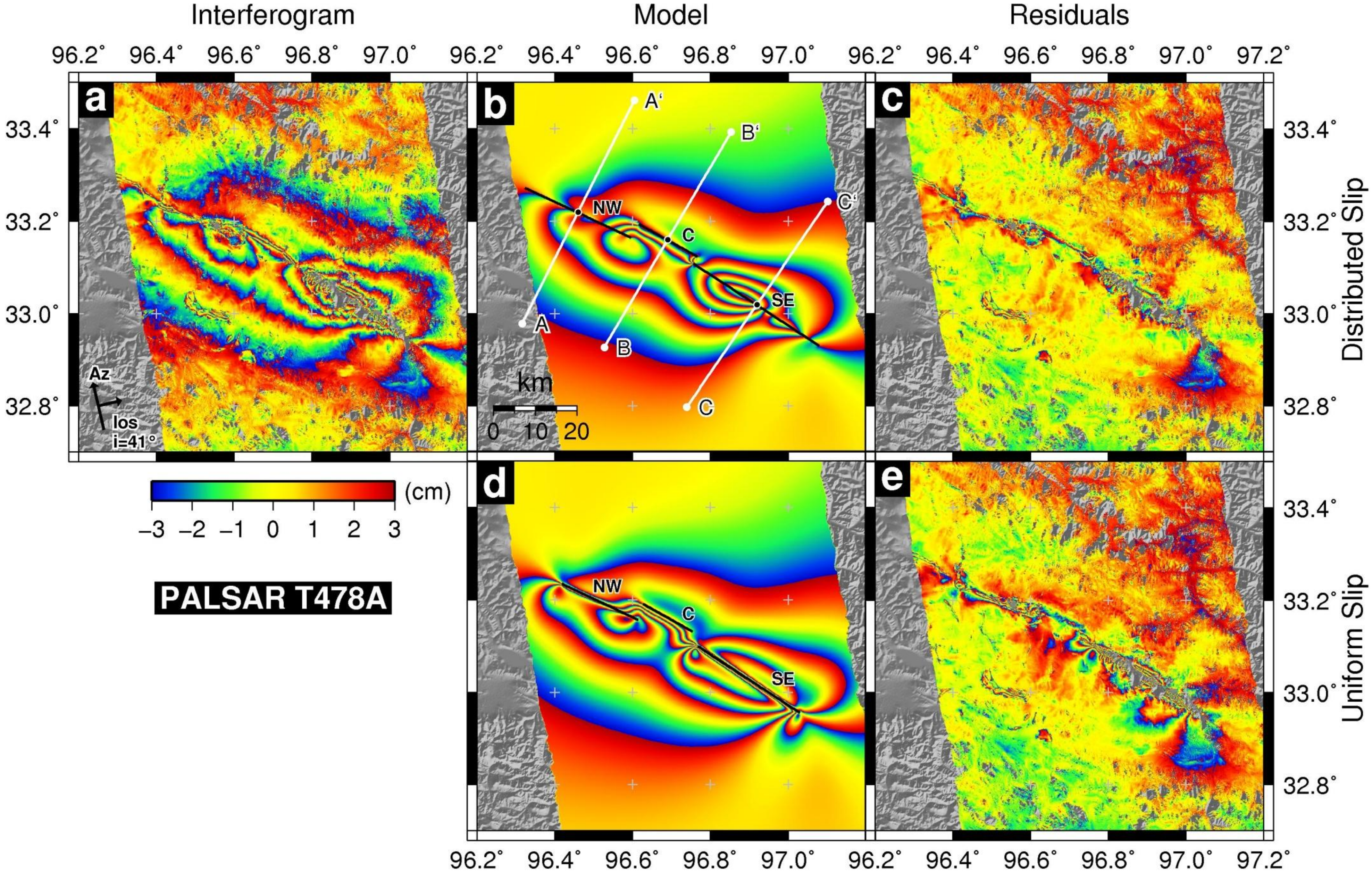
Surface Fault Trace



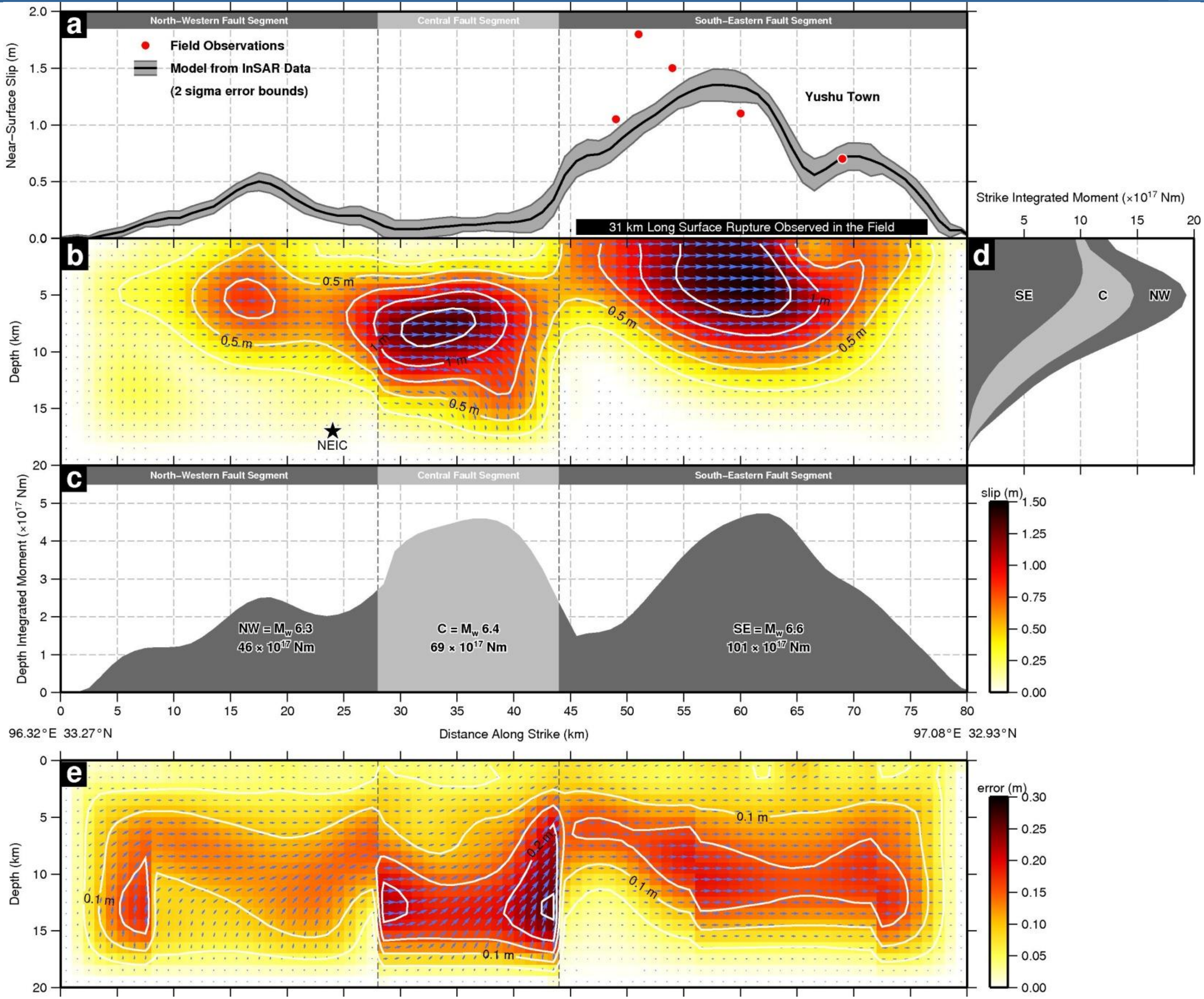
Earthquake Surface Offsets



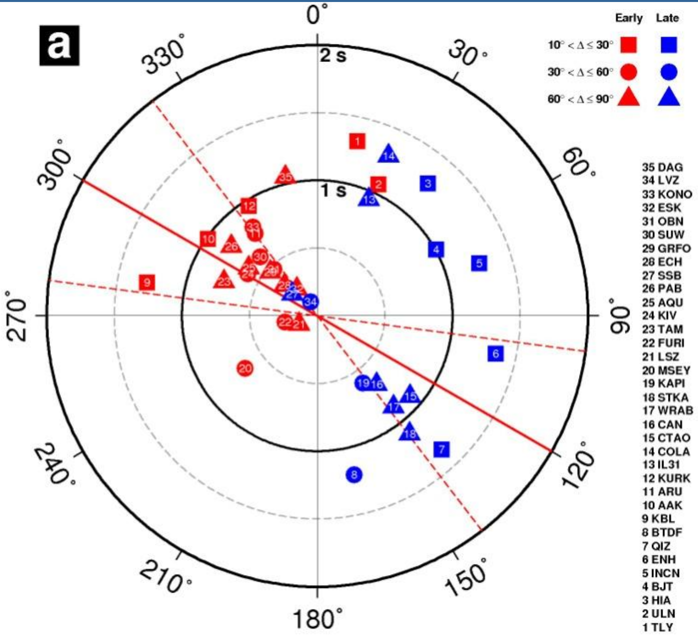
InSAR Constrained Models

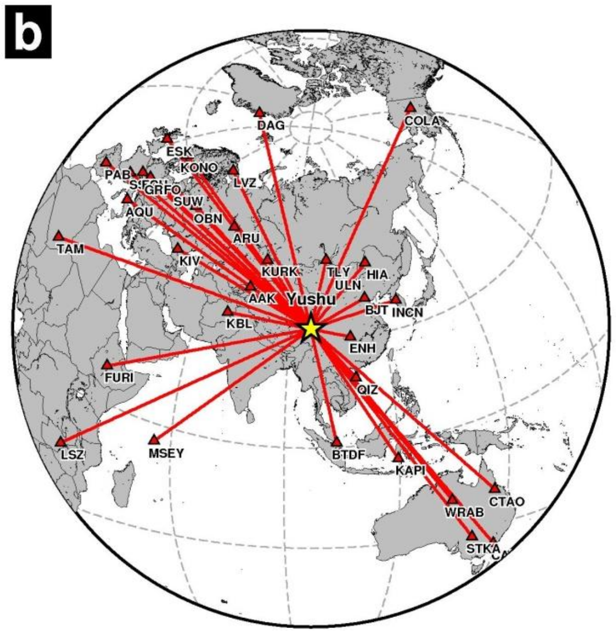


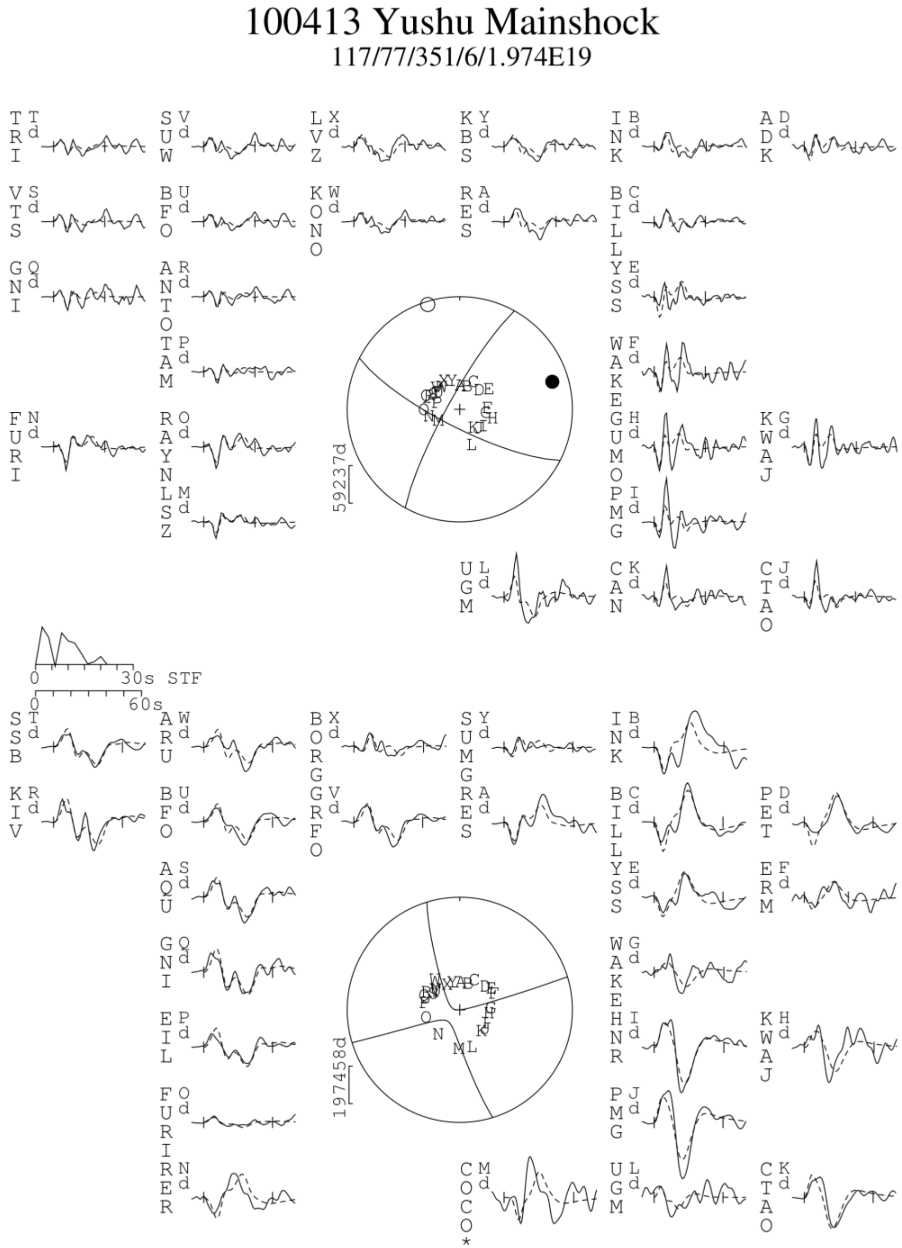
Sub Surface Slip Distributions



Seismological Observations





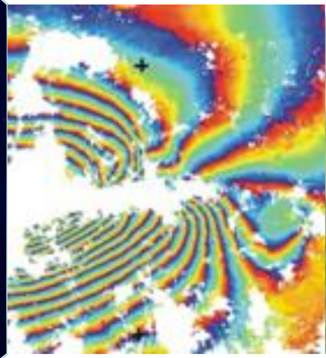


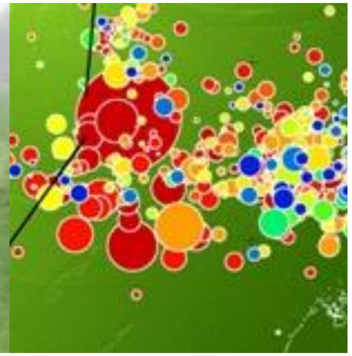
Summary

- Nearly pure left-lateral slip has occurred on three segments of the Yushu fault over a distance of nearly 80 km, with maximum slip of 1.5 m on the 30 km long southeastern segment
- The slip on the northwestern segment is probably due to the Mw 6.1 aftershock that occurred just under 2 hours after the main shock
- Almost eighty per cent of the moment release occurred for depths less than 10 km. The mean slip over the combined 50 km length of the central and south-eastern segments is 1.1 m
- The considerable building damage can be accounted for by the fact that the rupture in the main shock propagated at a speed of ~3 km/s toward the town of Yushu located at the end of the south-eastern segment of the fault. Strain accumulation since the last earthquake on the continuation of the fault beyond Yushu has the potential to produce an Mw 6.5 event.

Li, Elliott et al. JGR (2011)

Slip in the 2010-2011 Canterbury Earthquakes, New Zealand





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Elliott et al. JGR (2012)
doi:10.1029/2011JB008868

Ed Nissen, Philip England
James Jackson, Simon Lamb,
Zhenhong Li, Mike Oehlers,
Barry Parsons

Introduction

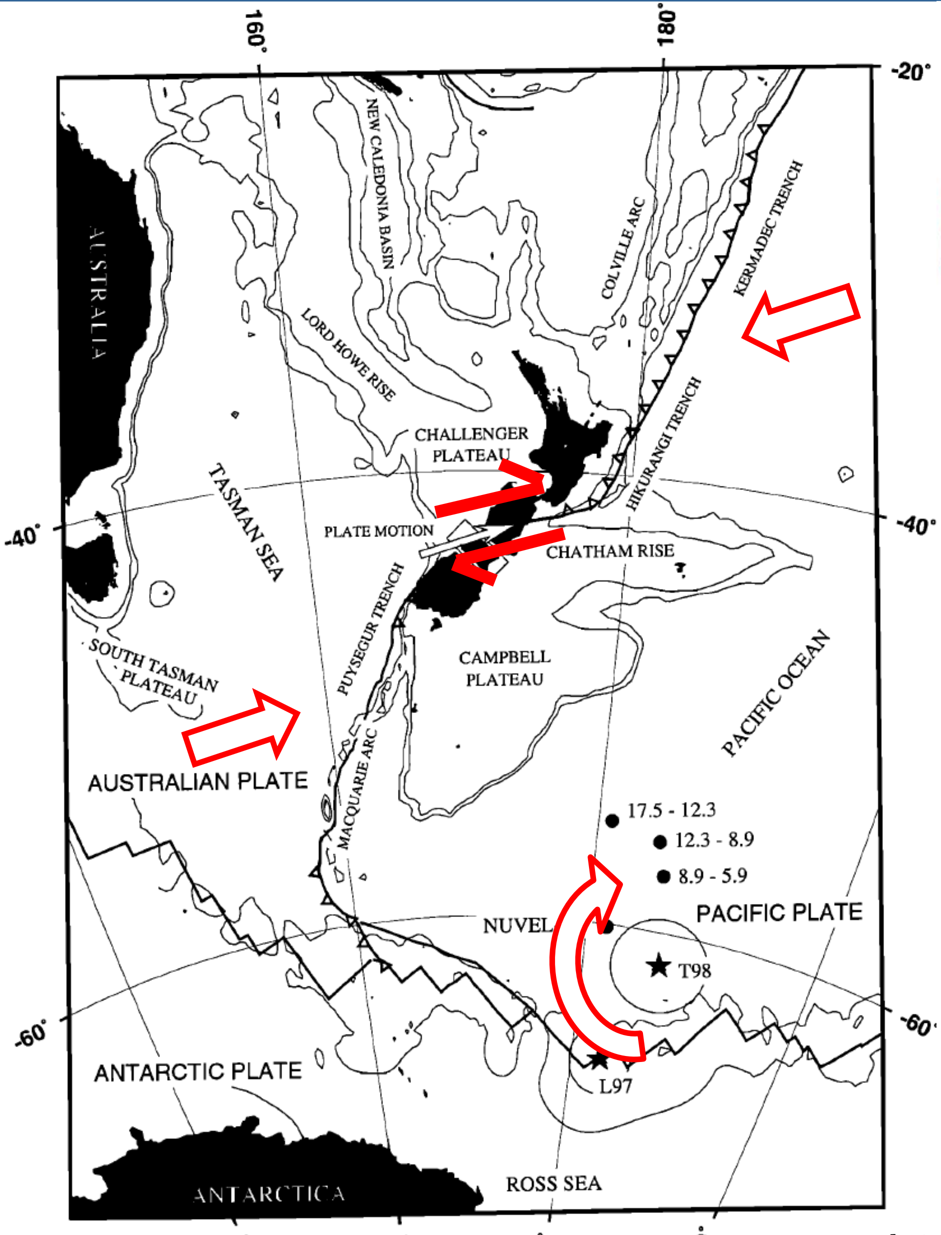
- A large M_w 7 strike-slip faulting earthquake struck in the Canterbury plains, with the epicentre 40 km west of Christchurch (pop. 330,000) in September 2010 with no fatalities

- Less than 6 months later a M_w 6.3 thrust earthquake occurred right beneath the city of Christchurch, killing almost 200.

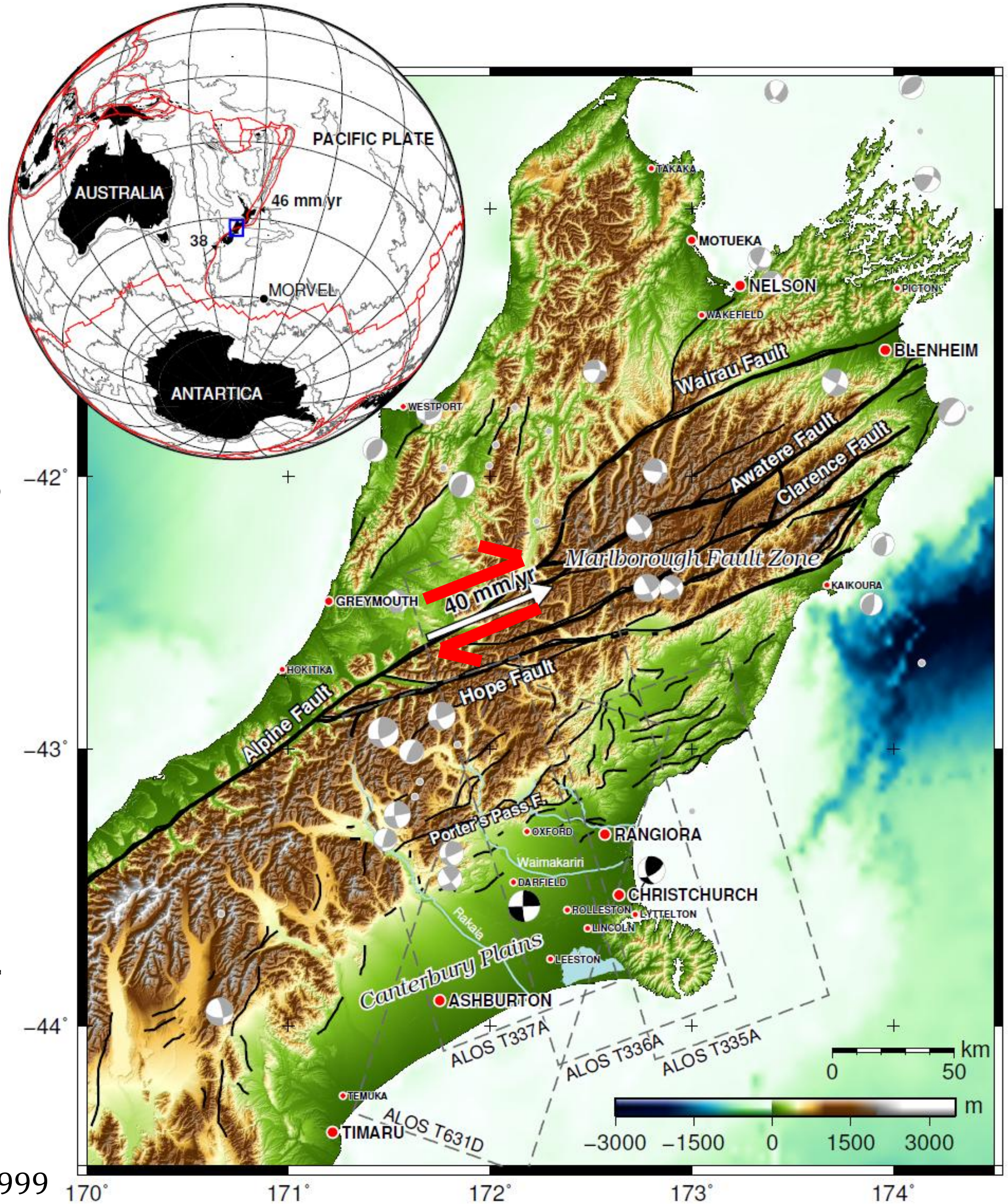
- We combine Earth Observations from InSAR and optical satellite imagery with aerial photographs, a LiDAR DEM, field observations and seismology to characterise the faulting in this event.

- Fault models reveal a complex pattern of faulting and a gap in the slip distribution that potentially poses a risk to the SW of the city.

Introduction

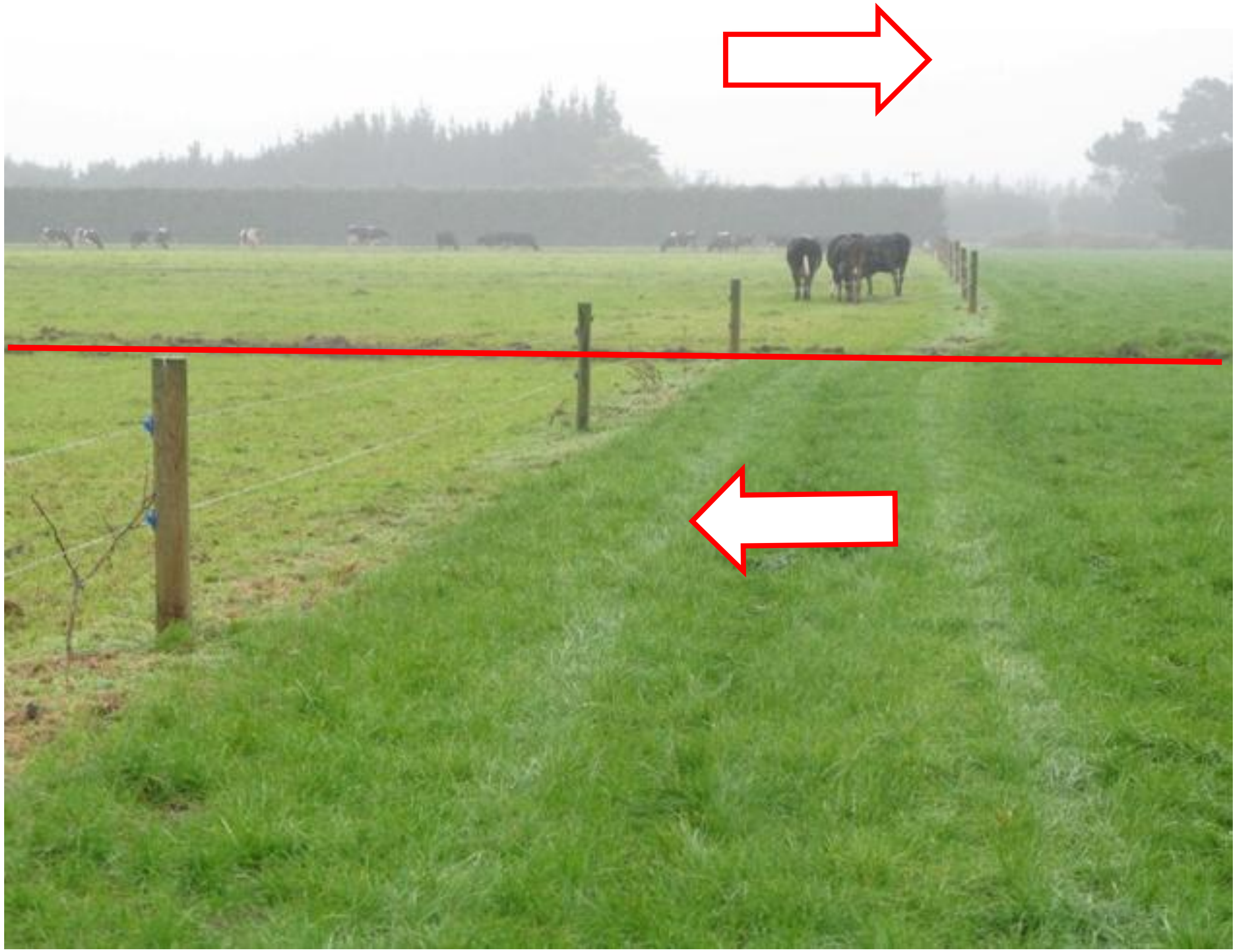


Beavan et al, 1999



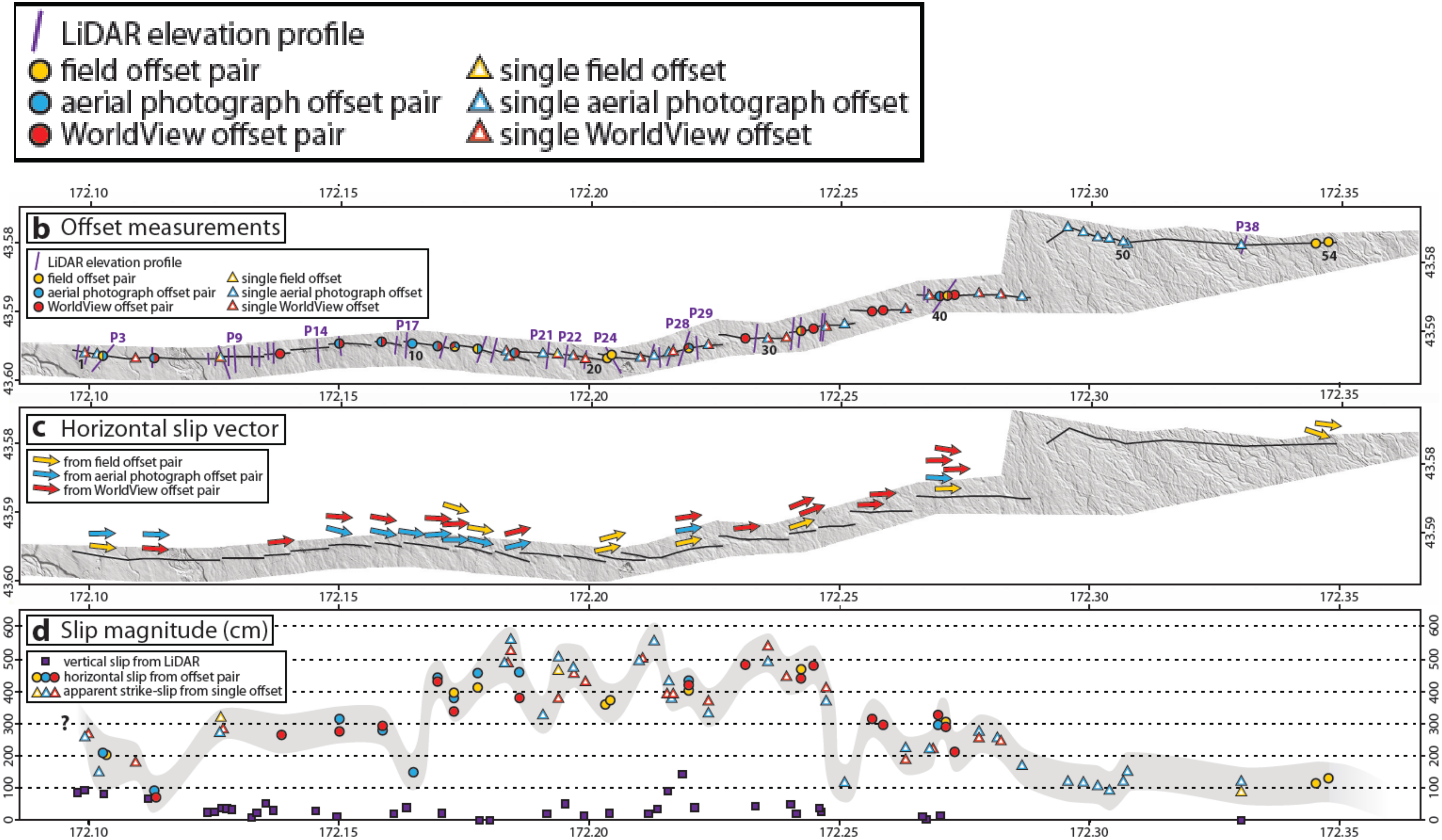
Field Observations

- Simon Lamb made field measurements in the days after the earthquake
- Over four metres of displacement was measured at several localities
- Rupture and slip vectors were mapped for 20 km



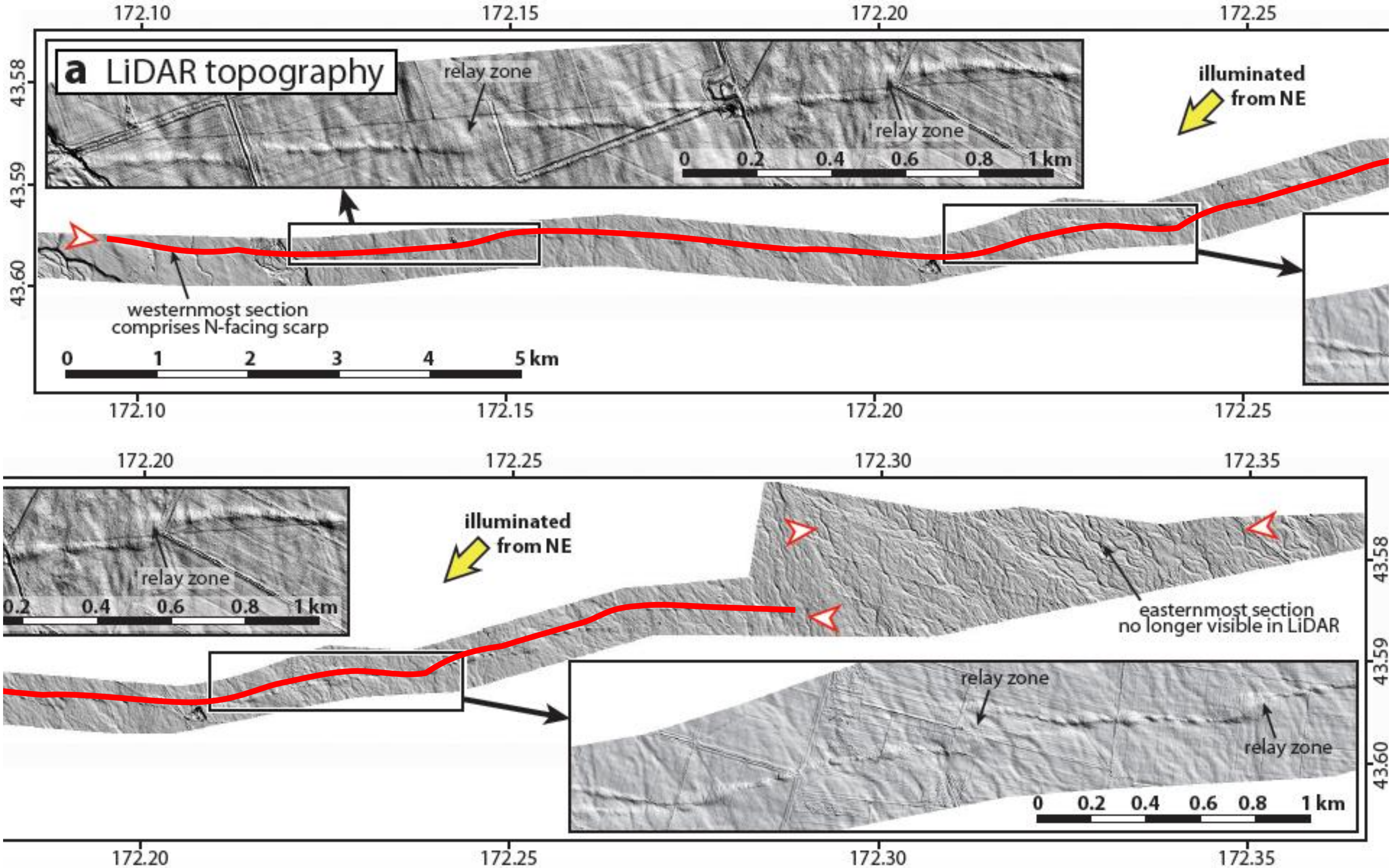
Satellite Imagery

Fault Trace Offsets



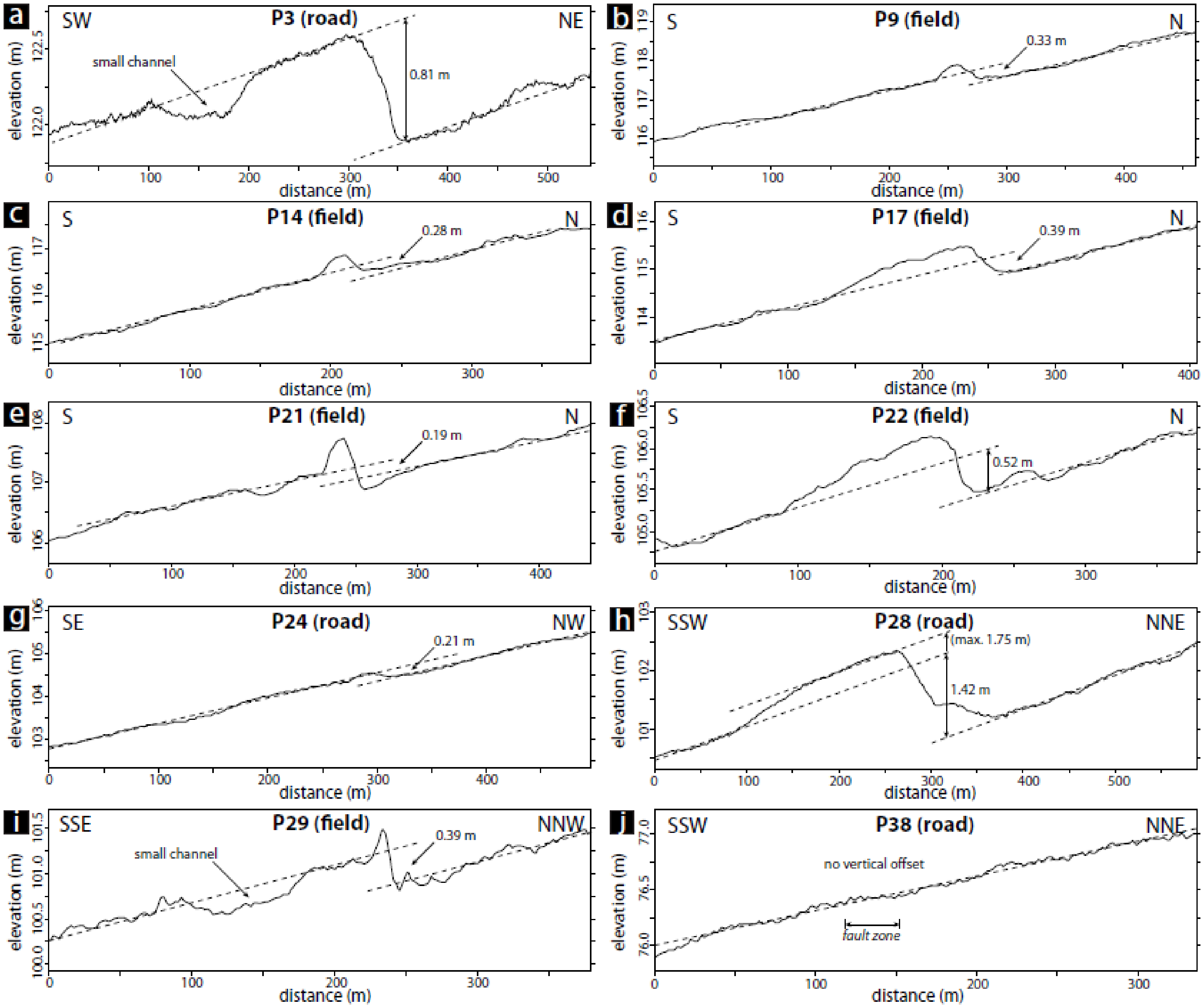
LiDAR DEM courtesy of Environment Canterbury

LiDAR DEM



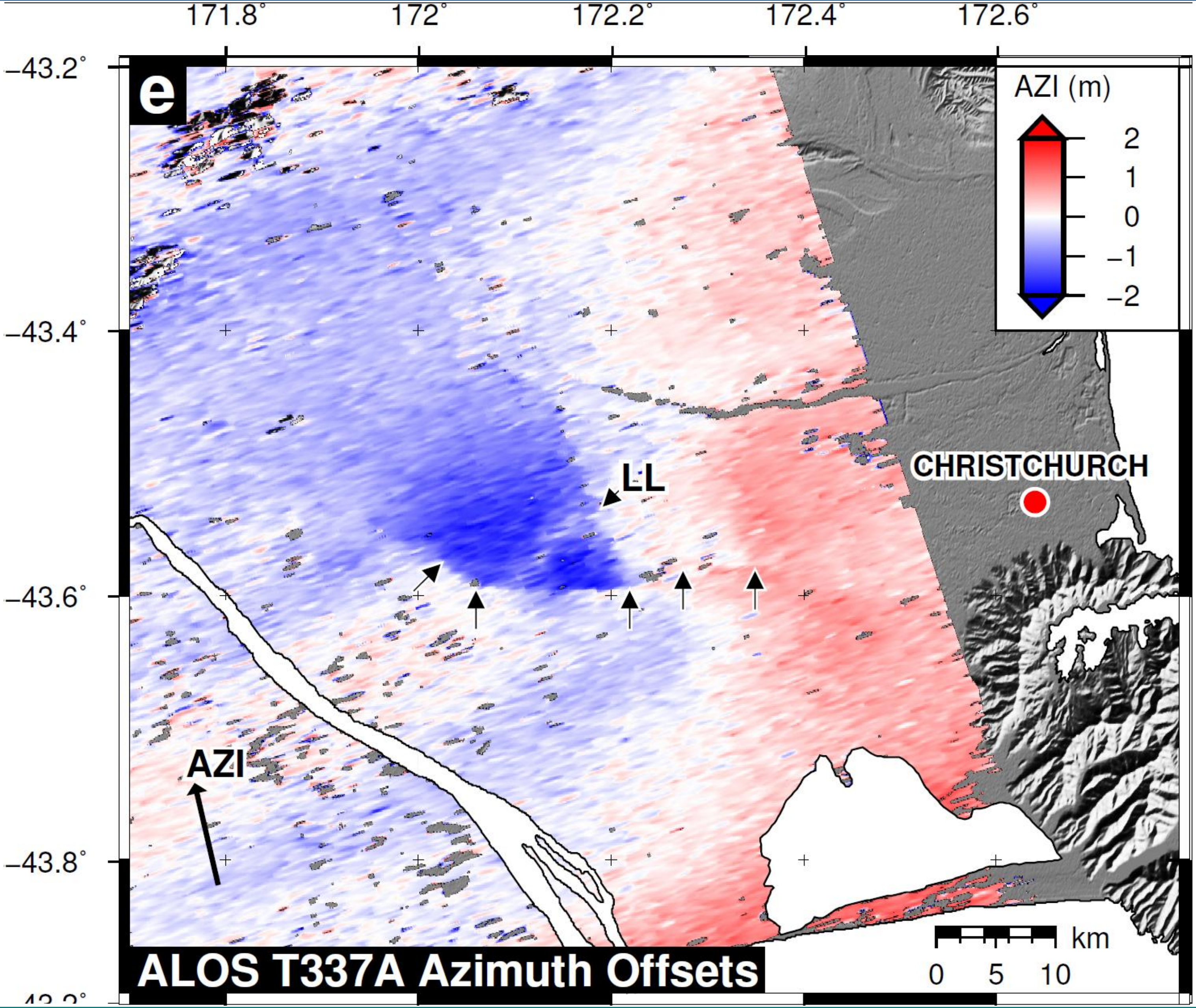
a LiDAR topography
relay zone
relay zone
0 0.2 0.4 0.6 0.8 1 km
illuminated from NE
westernmost section comprises N-facing scarp
0 1 2 3 4 5 km
172.10
172.15
172.20
172.25
43.58
43.59
43.60
relay zone
0.2 0.4 0.6 0.8 1 km
illuminated from NE
easternmost section no longer visible in LiDAR
relay zone
relay zone
0 0.2 0.4 0.6 0.8 1 km
172.20
172.25
172.30
172.35
43.58
43.59
43.60

LiDAR DEM

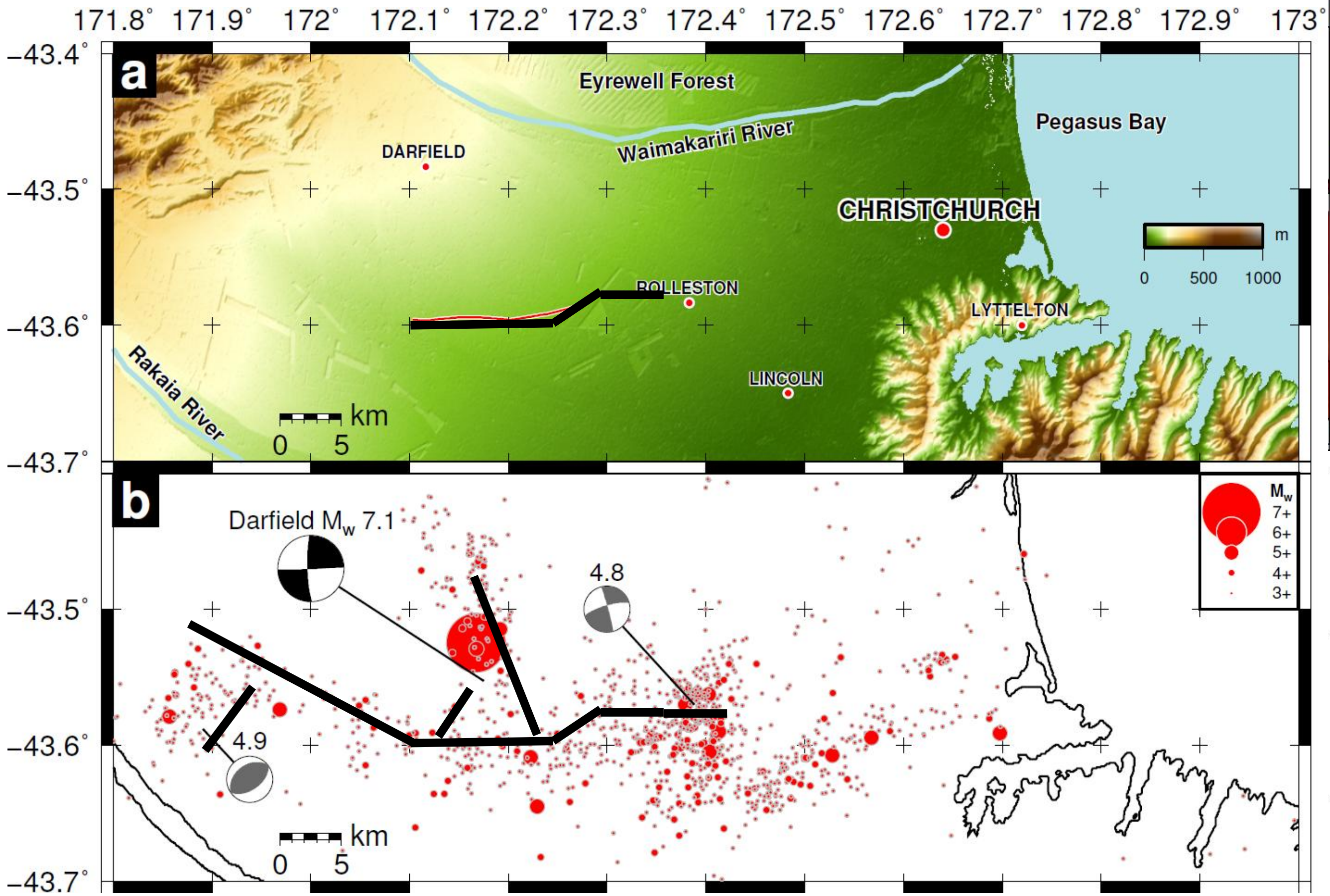


a
SW
P3 (road)
NE
small channel
0.81 m
elevation (m)
distance (m)
b
S
P9 (field)
N
0.33 m
c
S
P14 (field)
N
0.28 m
d
S
P17 (field)
N
0.39 m
e
S
P21 (field)
N
0.19 m
f
S
P22 (field)
N
0.52 m
g
SE
P24 (road)
NW
0.21 m
h
SSW
P28 (road)
NNE
(max. 1.75 m)
1.42 m
i
SSE
P29 (field)
NNW
small channel
0.39 m
j
SSW
P38 (road)
NNE
no vertical offset
fault zone

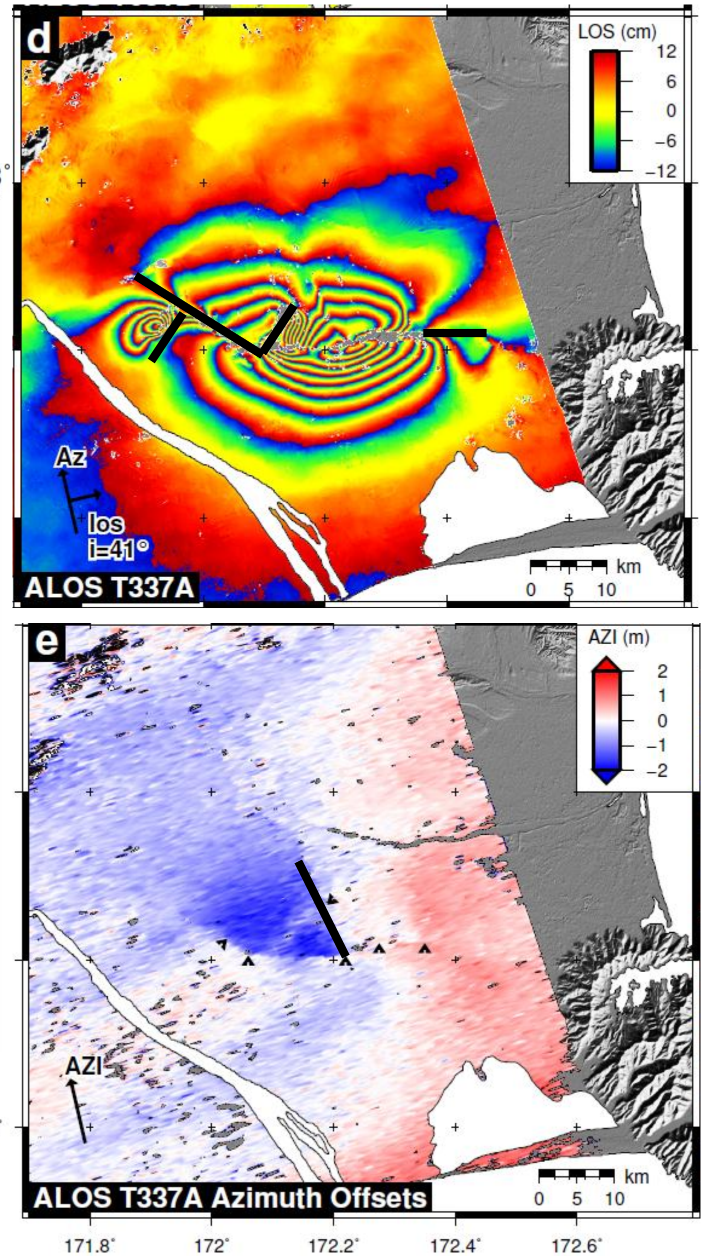
Ground Deformation



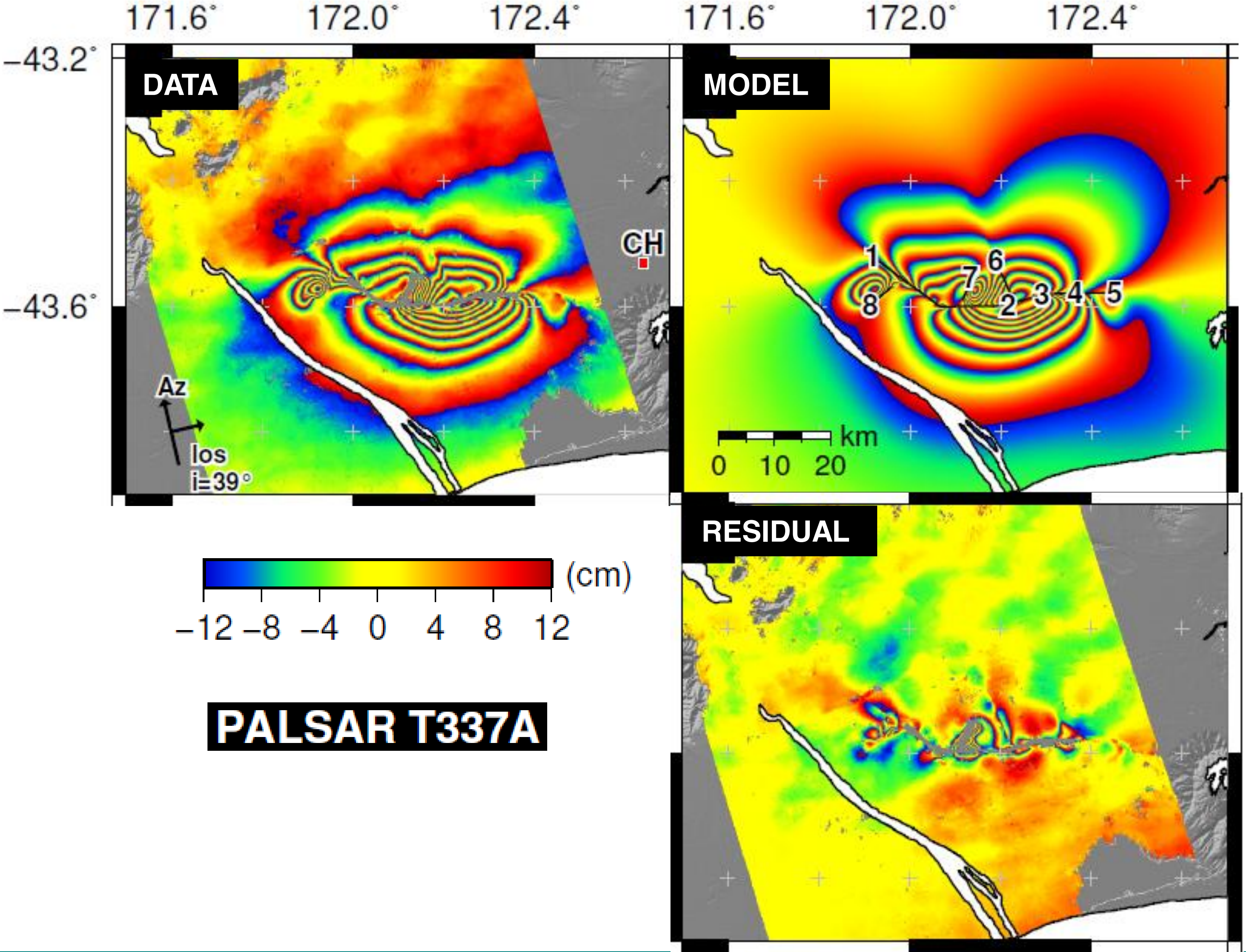
Complex Fault Segmentation



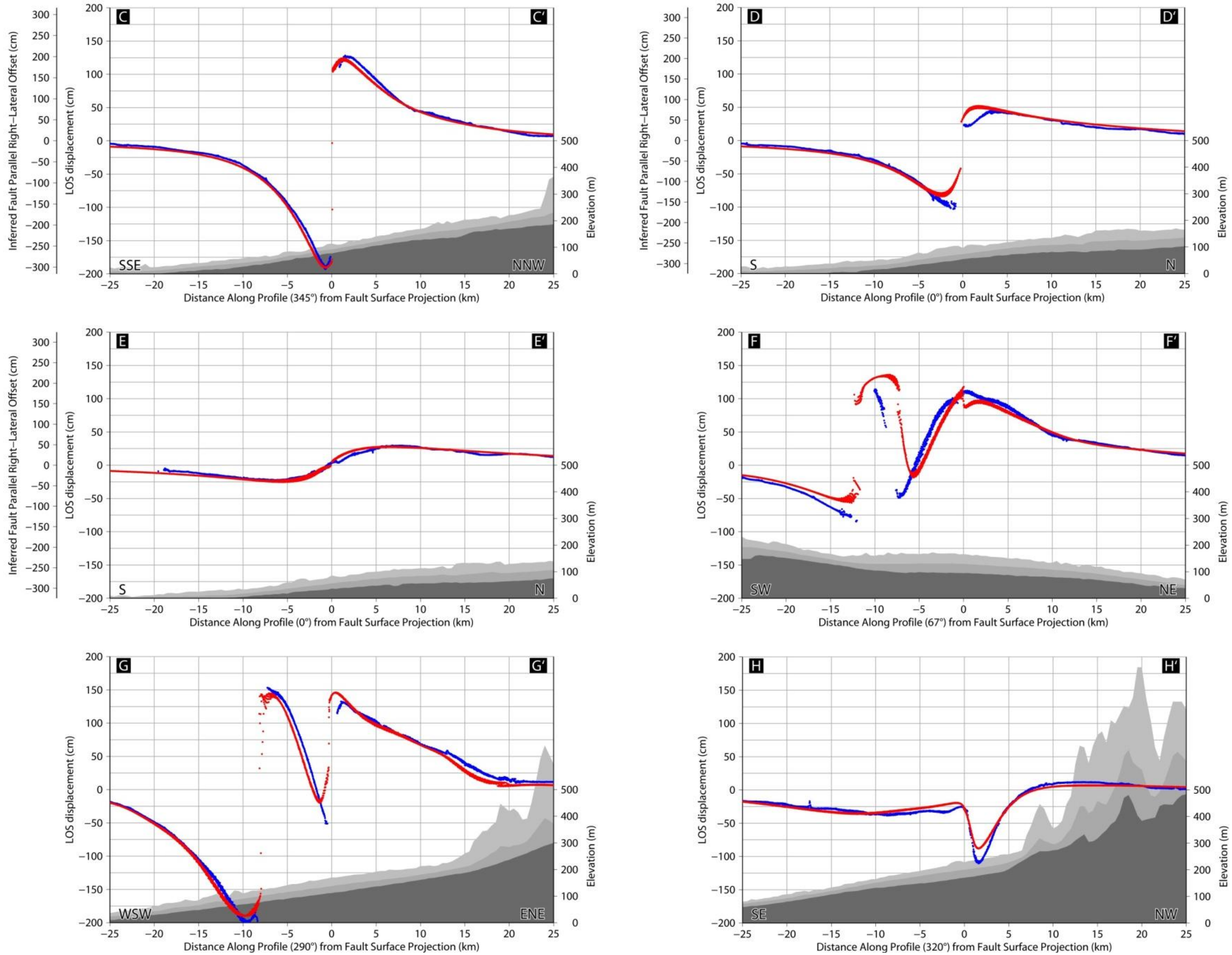
Aftershocks from GNS GeoNet



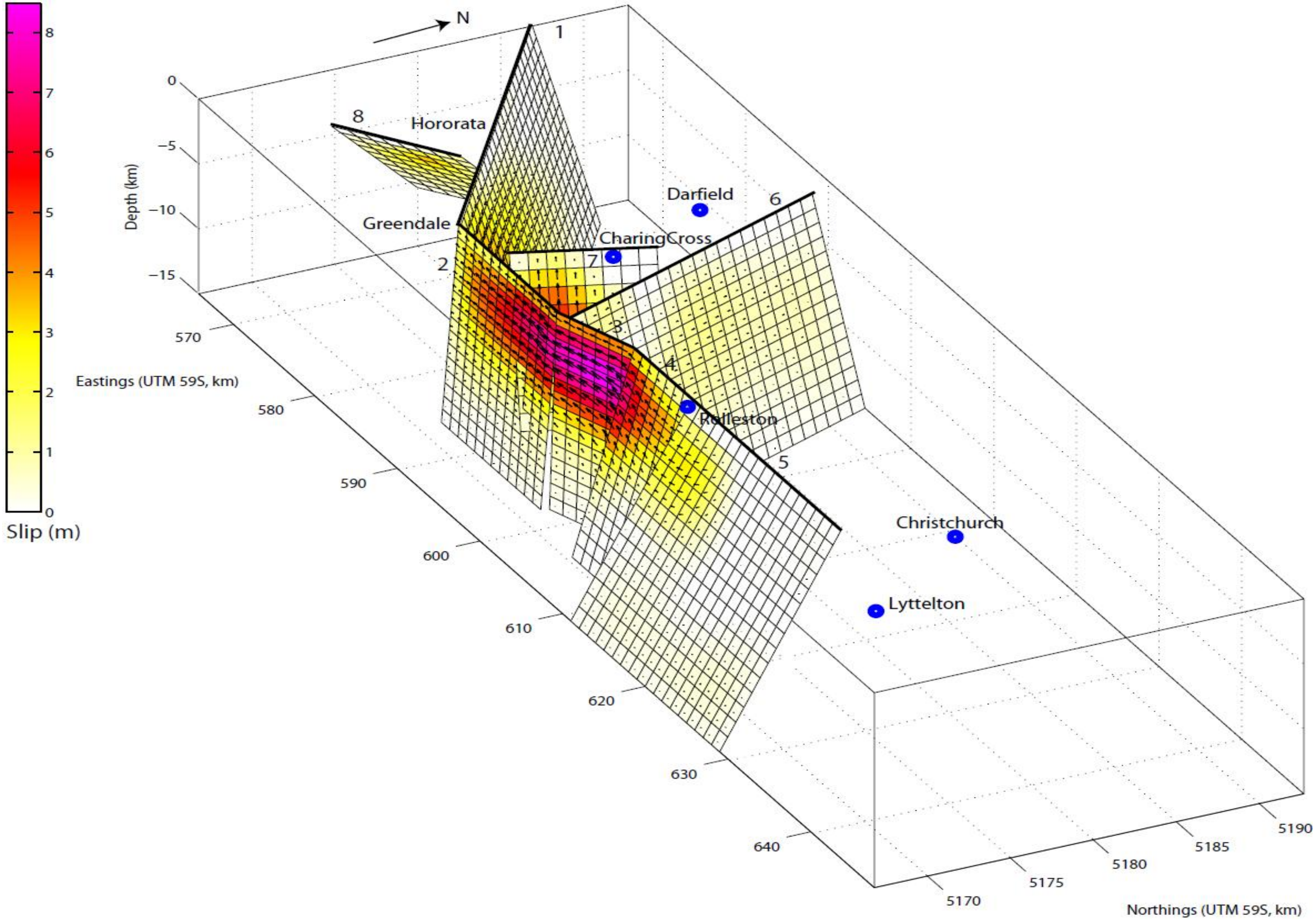
Fault Modelling



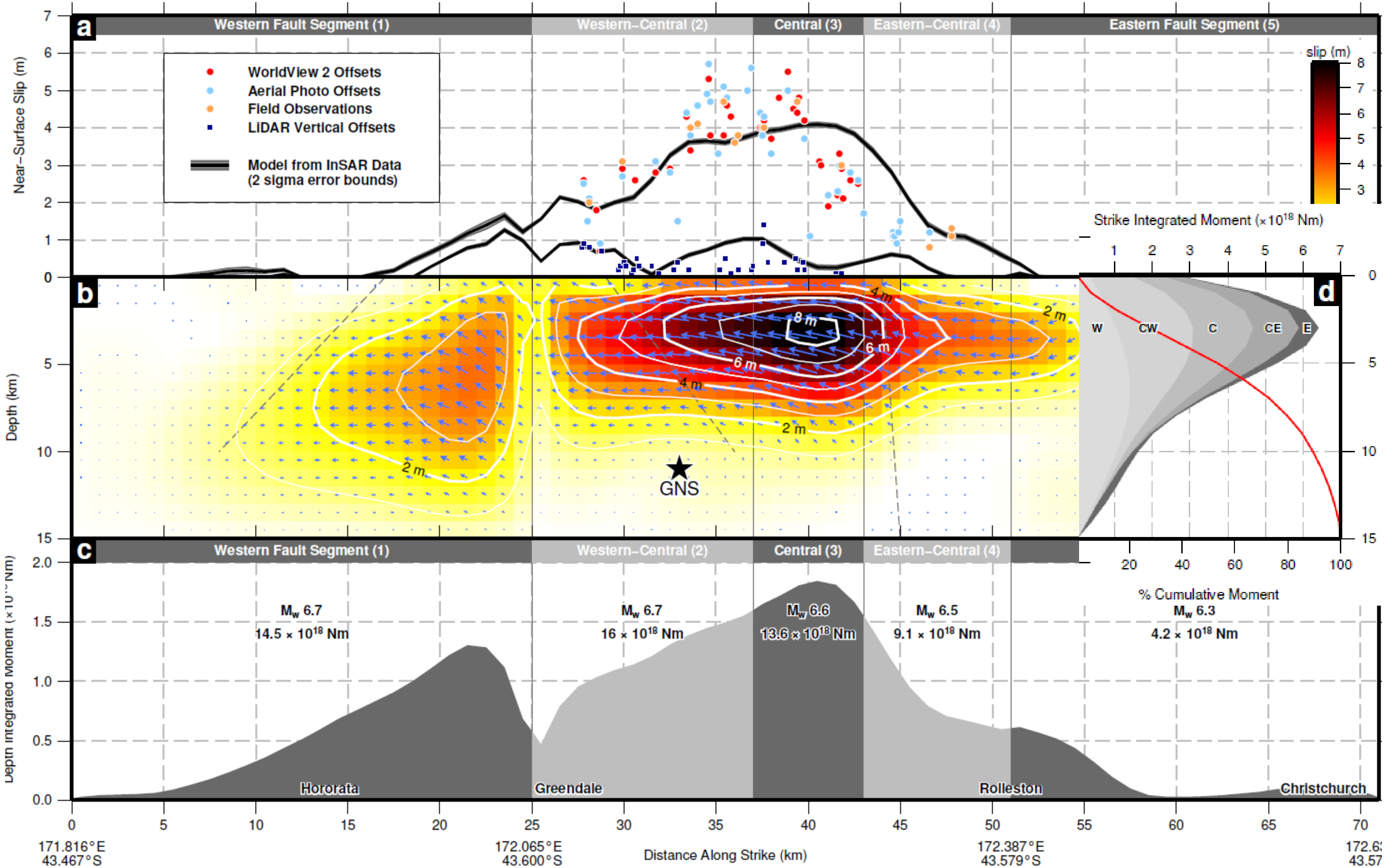
Fault Perpendicular Profiles



Distributed Slip Model

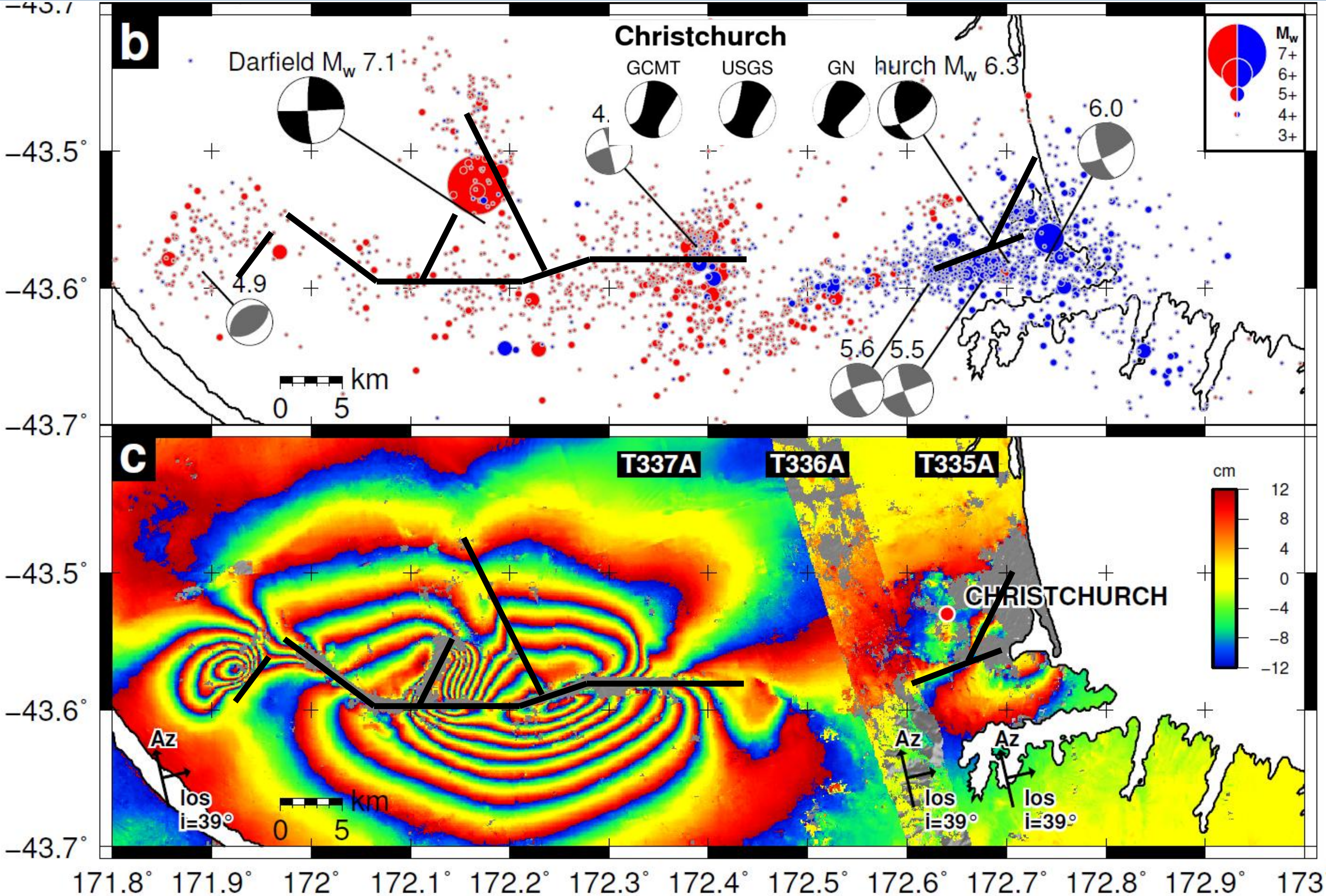


Comparison with Surface Observations

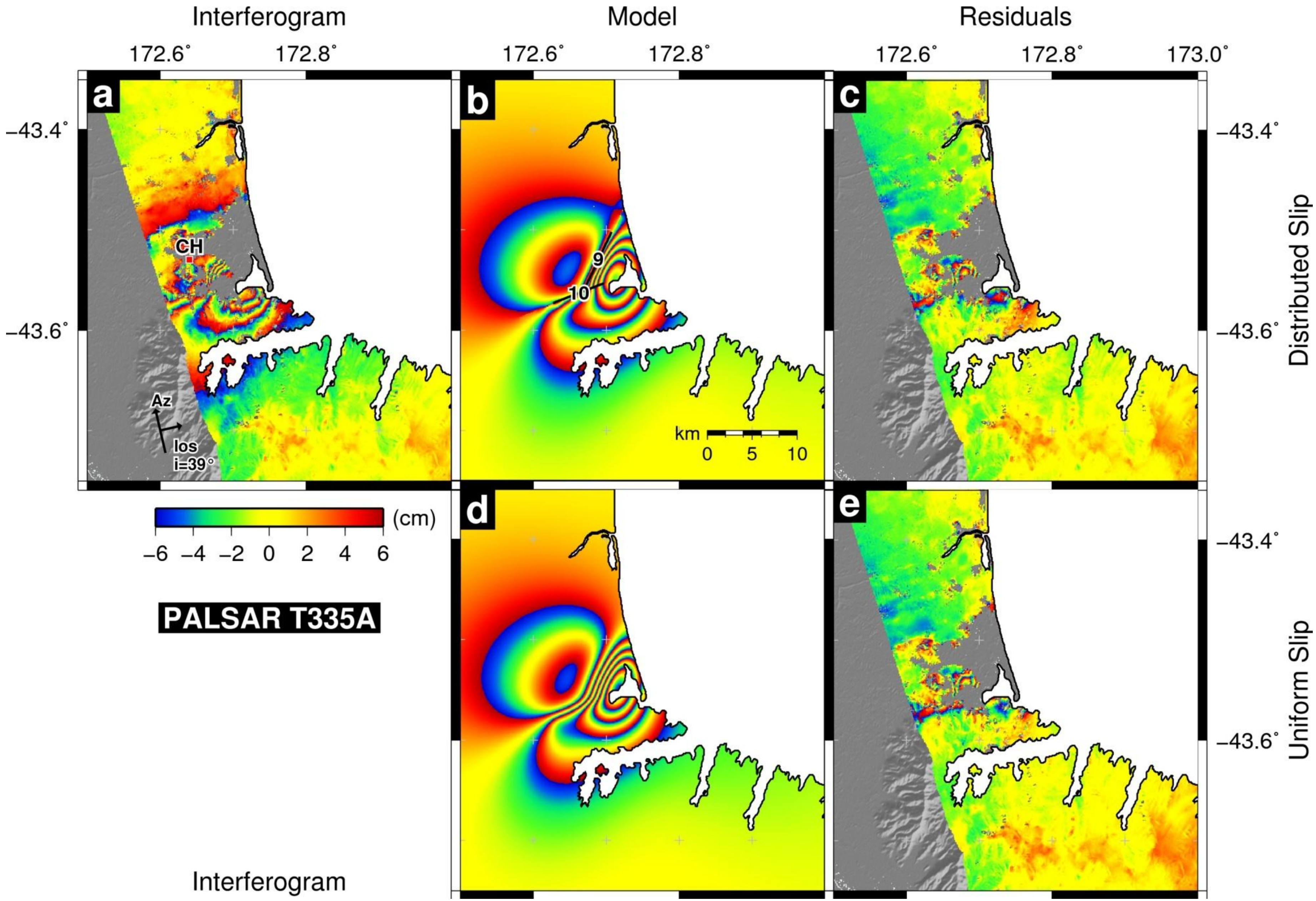



2011, Christchurch, New Zealand

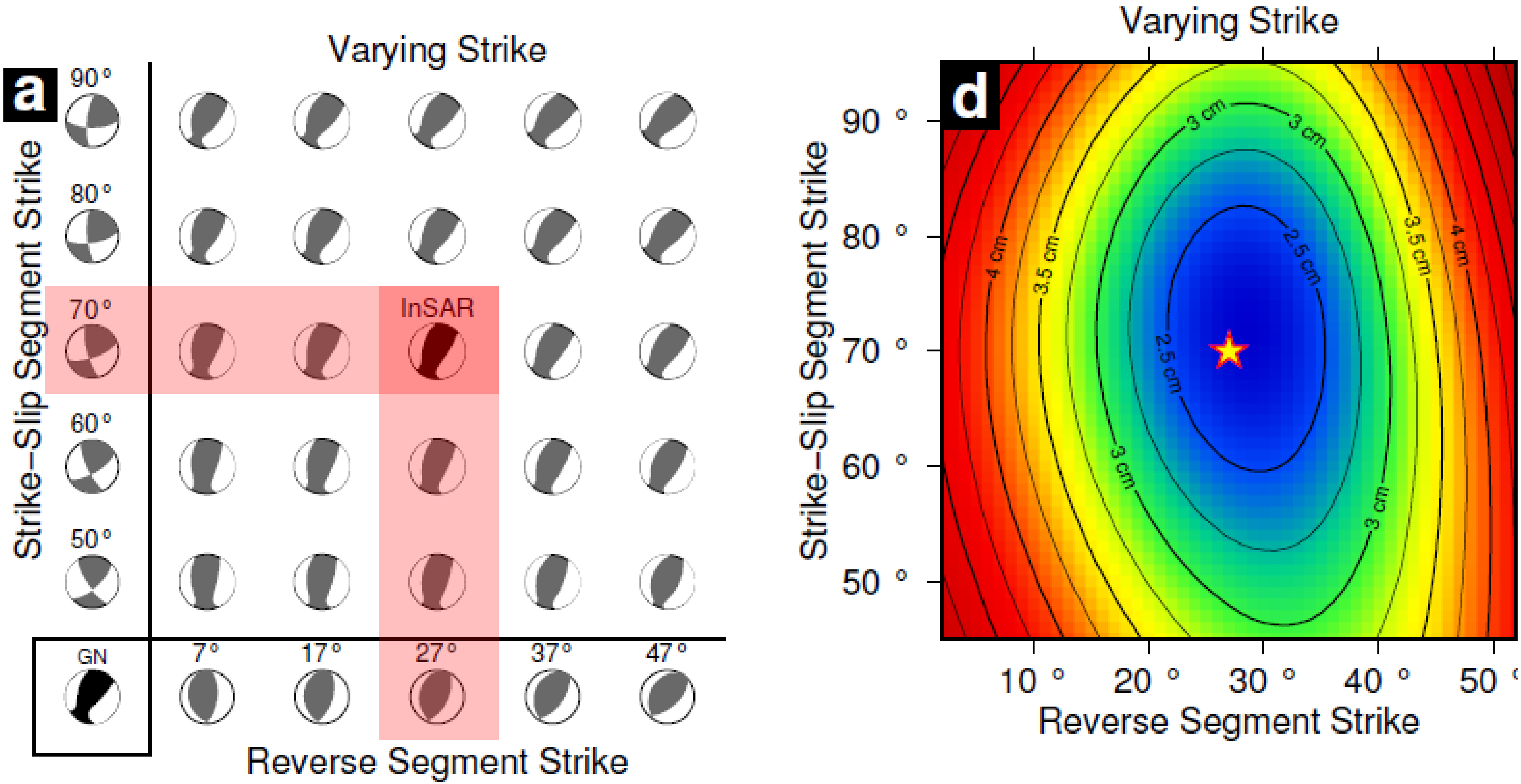
Christchurch Earthquake



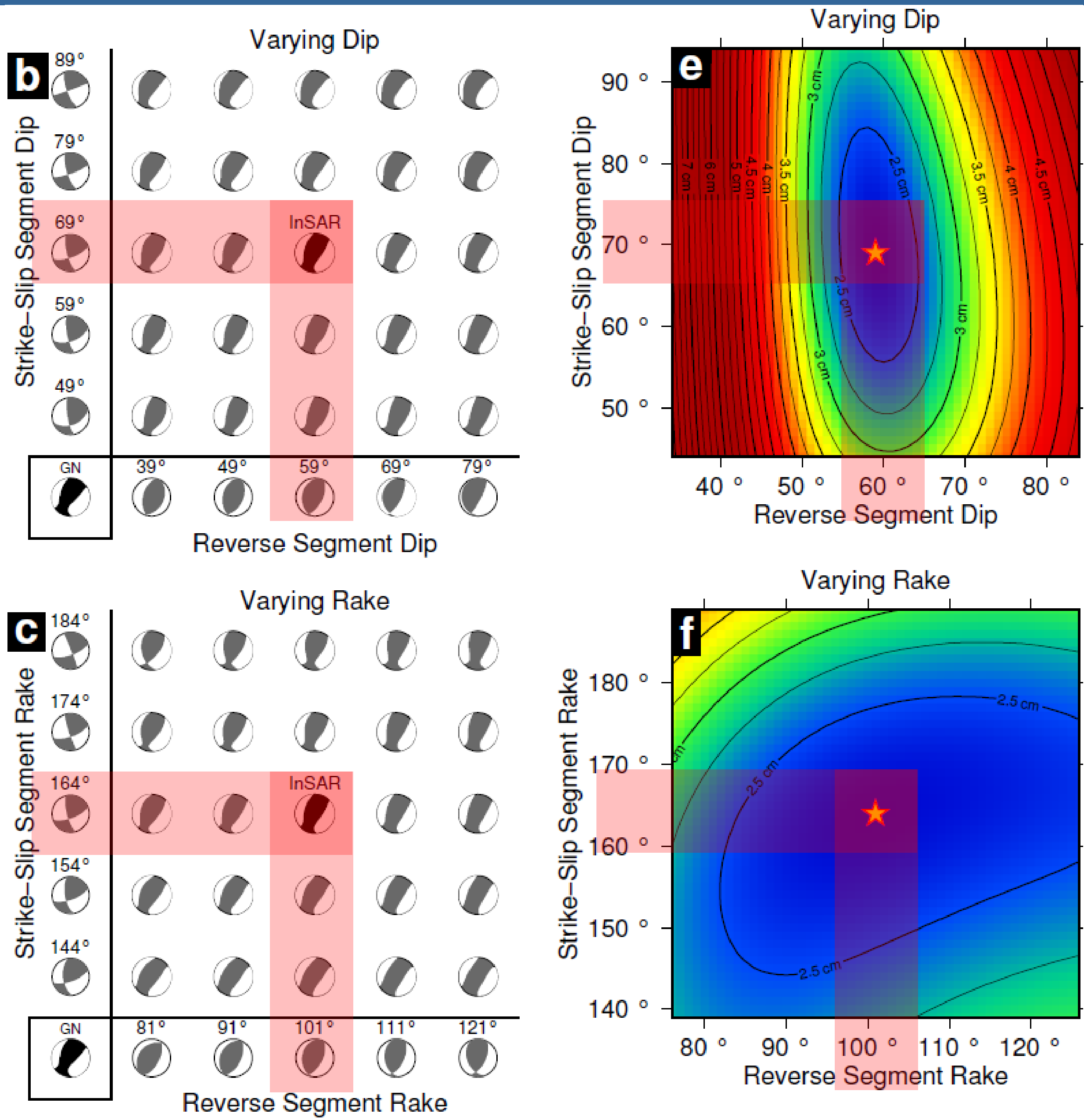
Fault Modelling



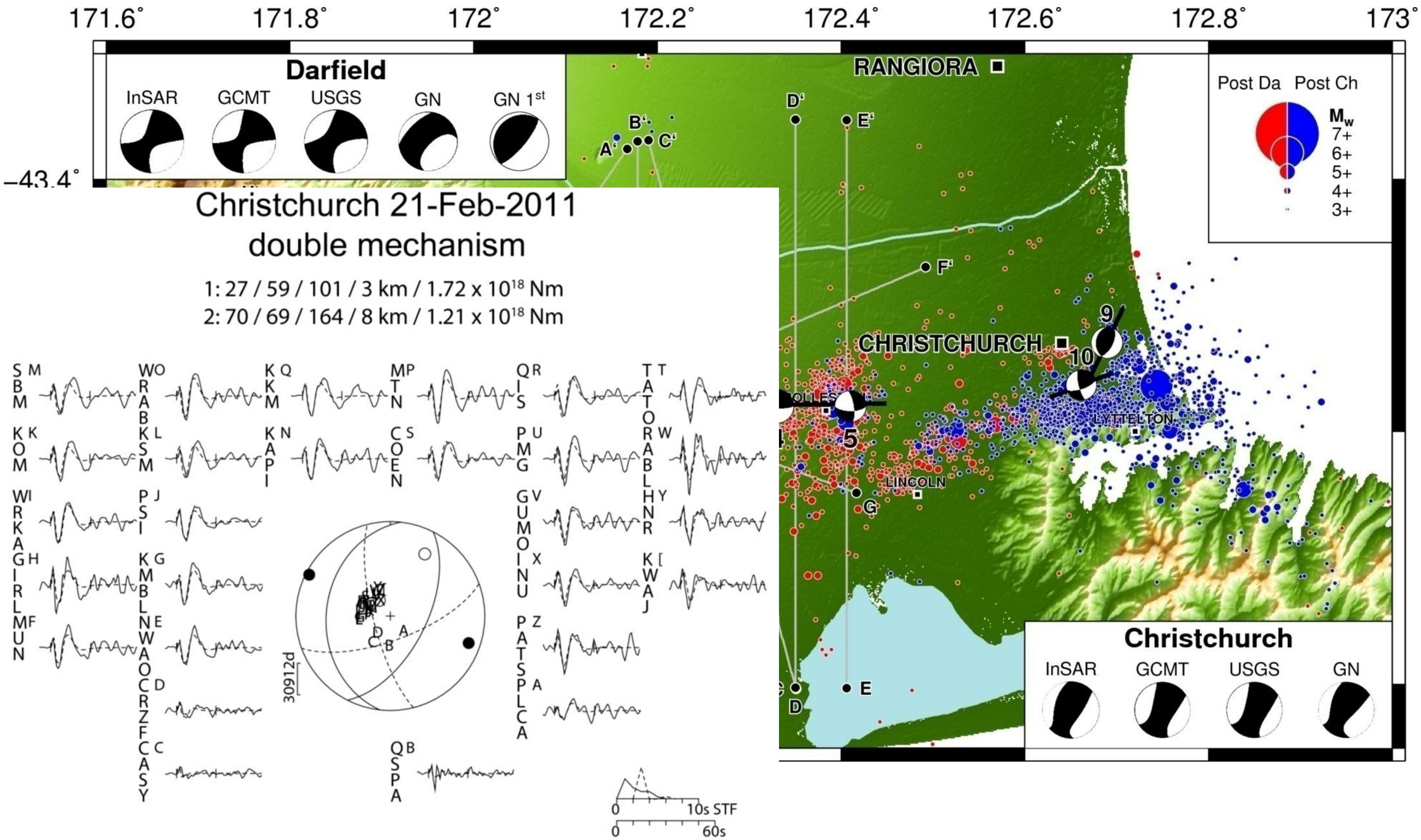
Moment Tensor Summation



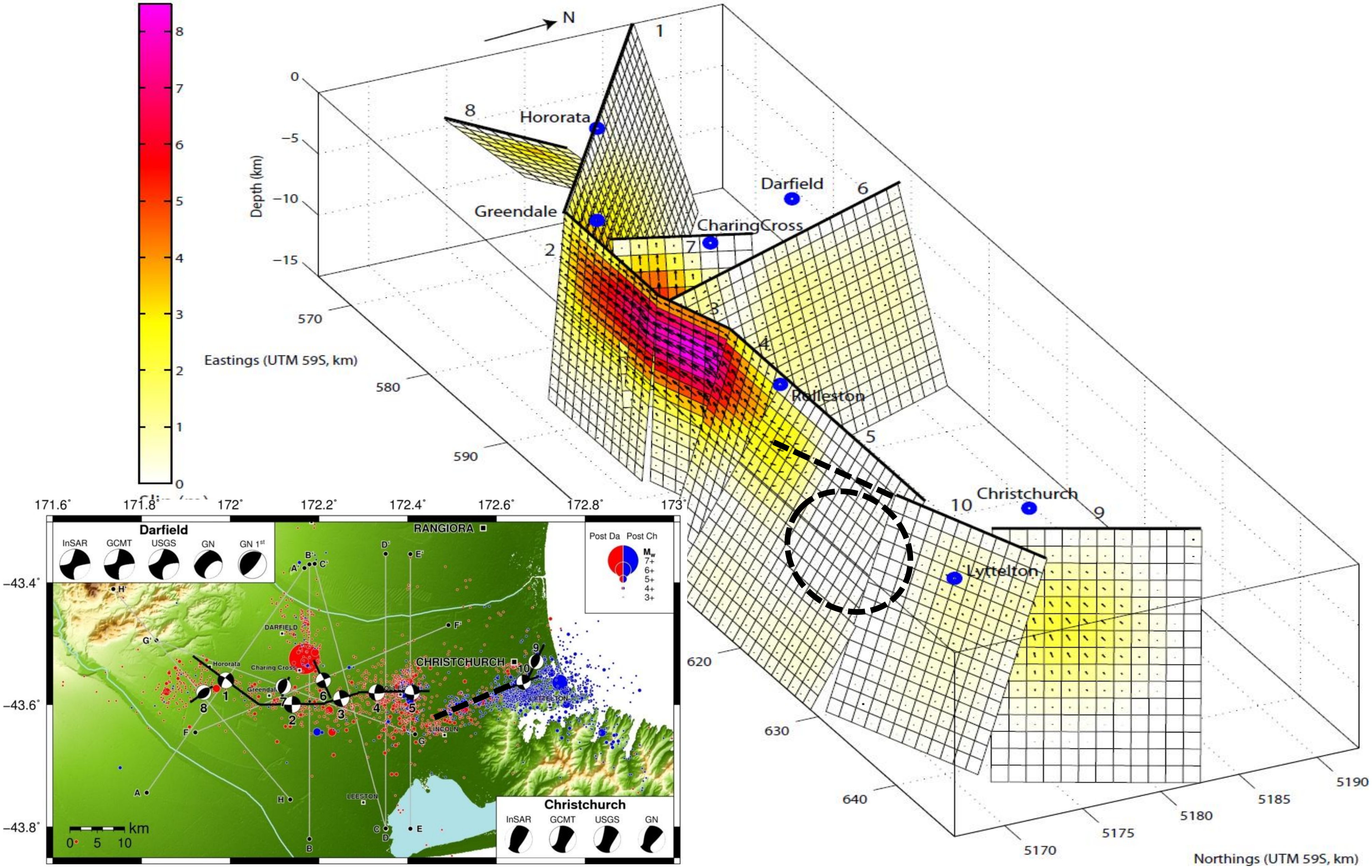
Moment Tensor Summation



Darfield-Christchurch Fault Segmentation

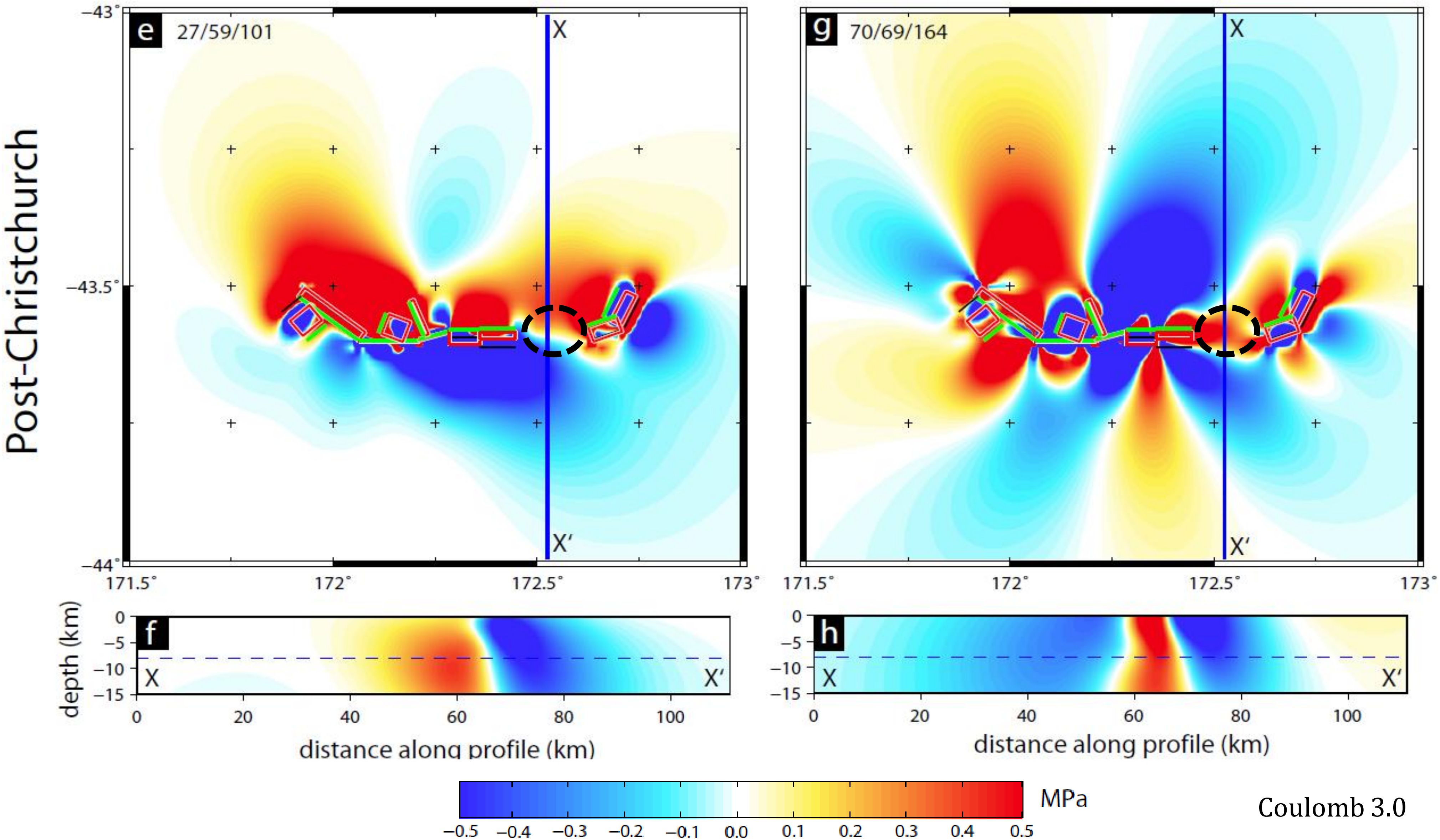


Distributed Slip Model



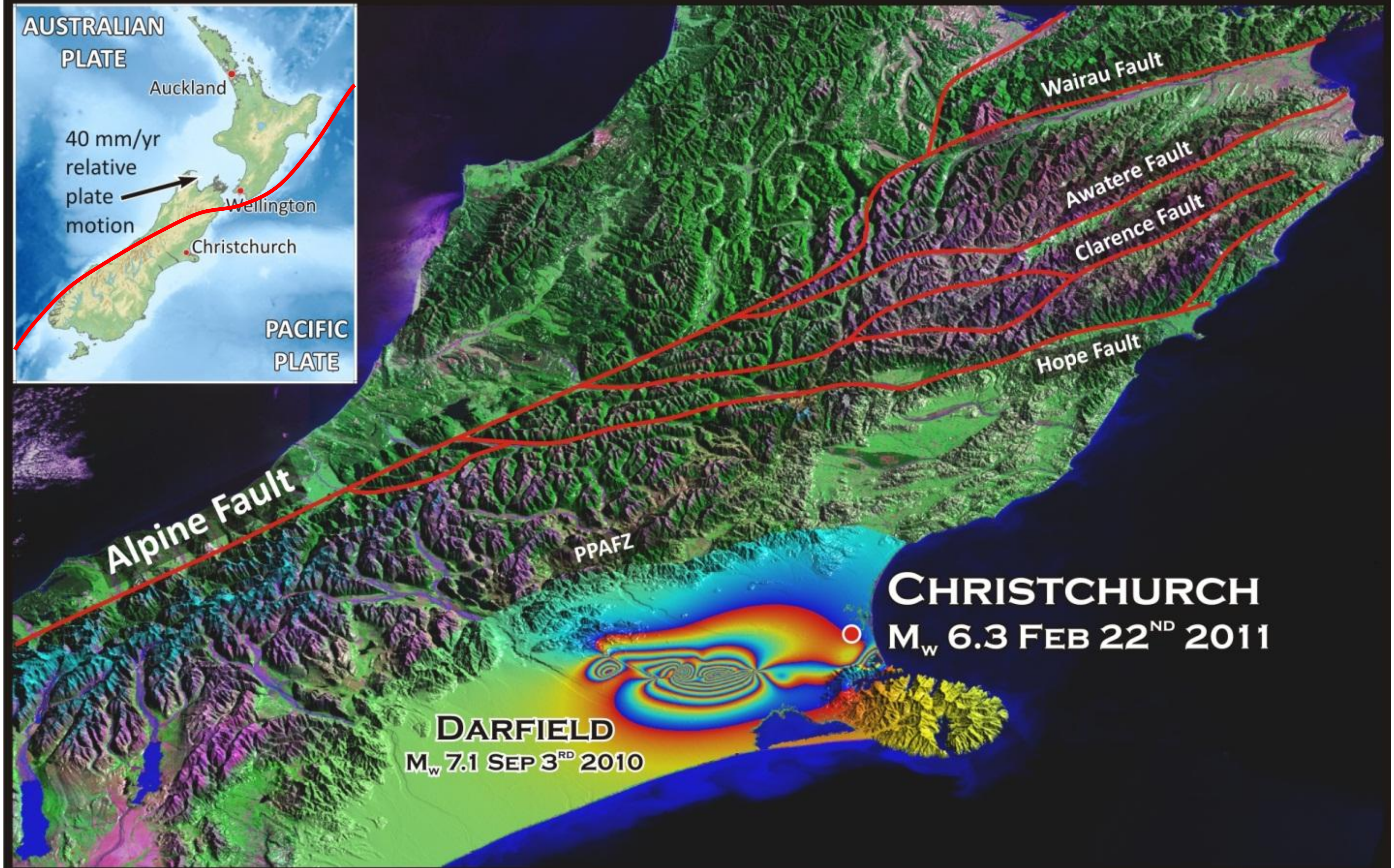
Coulomb Stress Model

Reverse Orientation | Strike-Slip Orientation



Coulomb 3.0

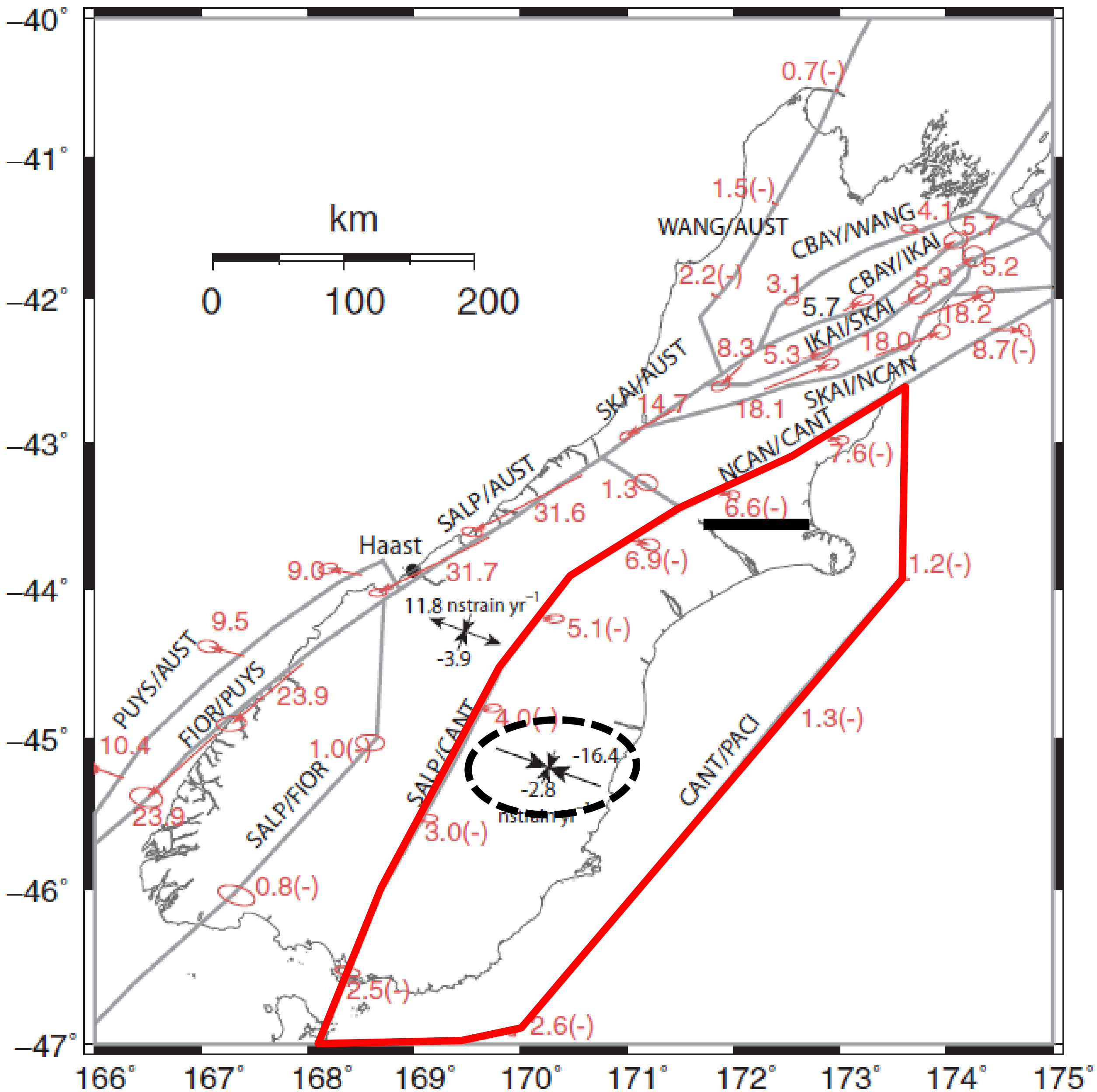
New Zealand Earthquakes



Regional Strain Field

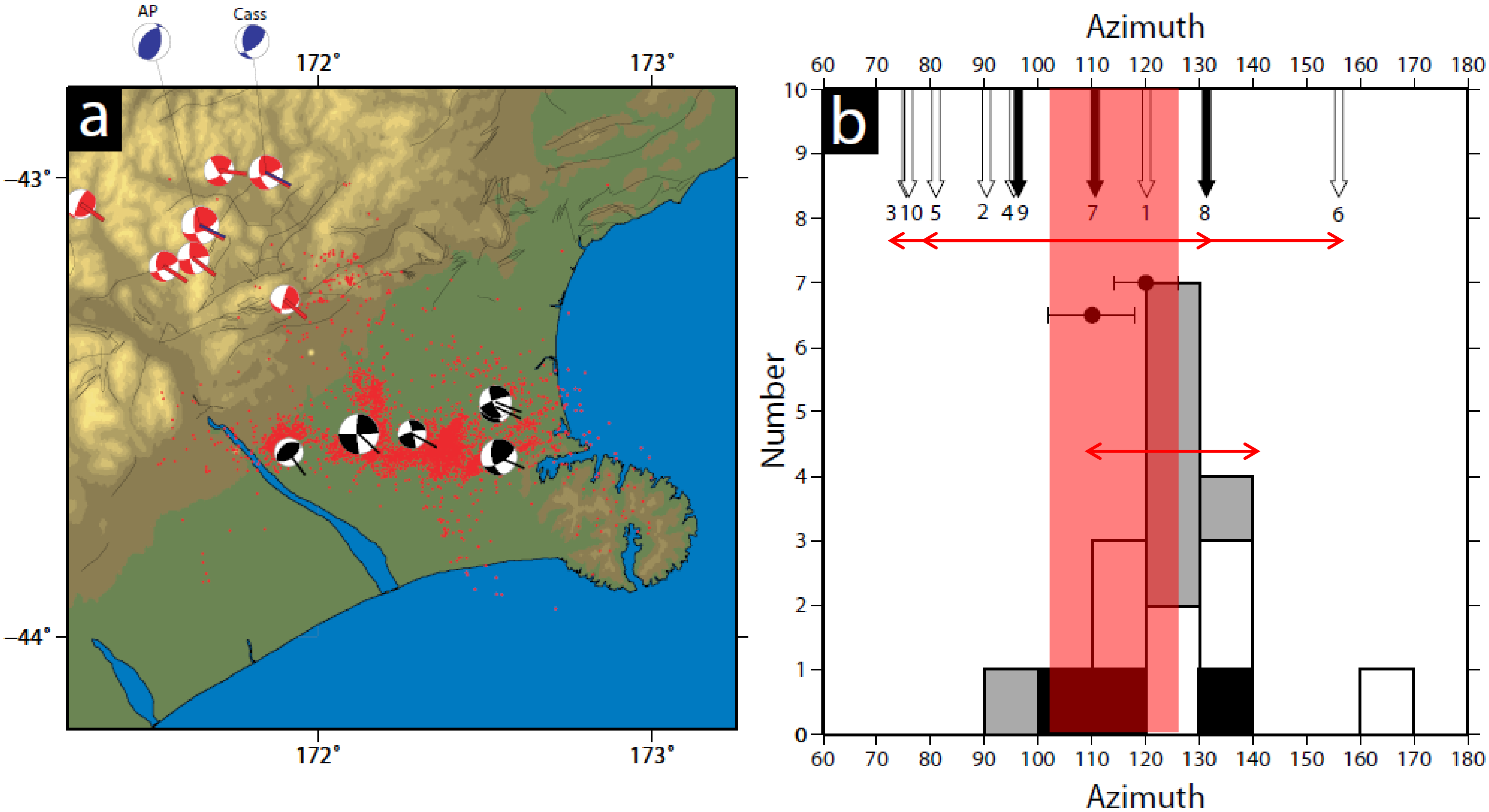
The Darfield and Christchurch Earthquakes occurred within a region which was previously modelled as a block and where the earthquakes where only expected to occur around the edges.

However, significant strain is accumulating in this block.



Wallace et al. (2007)

Regional Strain Field



The slip vector is significantly different from that expected from the plate boundary and there is significant shortening parallel to the mountain range.

Conclusions

- The Darfield earthquake involved a complex series of ruptures, that would not have been revealed with field mapping alone.

- How complex a fault model is useful and justifiable when presented with high resolution LiDAR and InSAR measurements of the near fault surface deformation? - datasets that are increasingly available for present earthquakes.

- Both earthquakes initiated on reverse faults before proceeding onto a strike-slip segment, resulting in significant dextral slip only in the Darfield event.

- The gap between faulting SW of Christchurch in an area with delineated aftershocks is a potential concern regarding future seismic hazard.

Conclusions

- Continental earthquakes exhibit a distributed pattern of faulting – plate tectonics does not work here.
- Locations of future earthquakes are not always on the obvious faults.
  - Corollary: historical earthquakes are probably mis-attributed to the known largest faults in the region.
- Small Strains Matter – mapping on the continental scale with satellite geodesy is becoming possible.
- Combine historical seismicity, strain accumulation & fault geomorphology to better characterise hazard.