Landslides and sediment cascade triggered by the 14 November 2016, M_W 7.8 Earthquake, Kaikoura, New Zealand

Phaedra Upton[1]
Summarizing work of many including:
Chris Massey[1], Jamie Howarth[2], Dimitri Lague[3], GNS and GeoNet Landslide Response Team
[1]GNS Science, [2]Victoria University of Wellington, [3]Rennes University

GNS SCIENCE TE PŪ AO

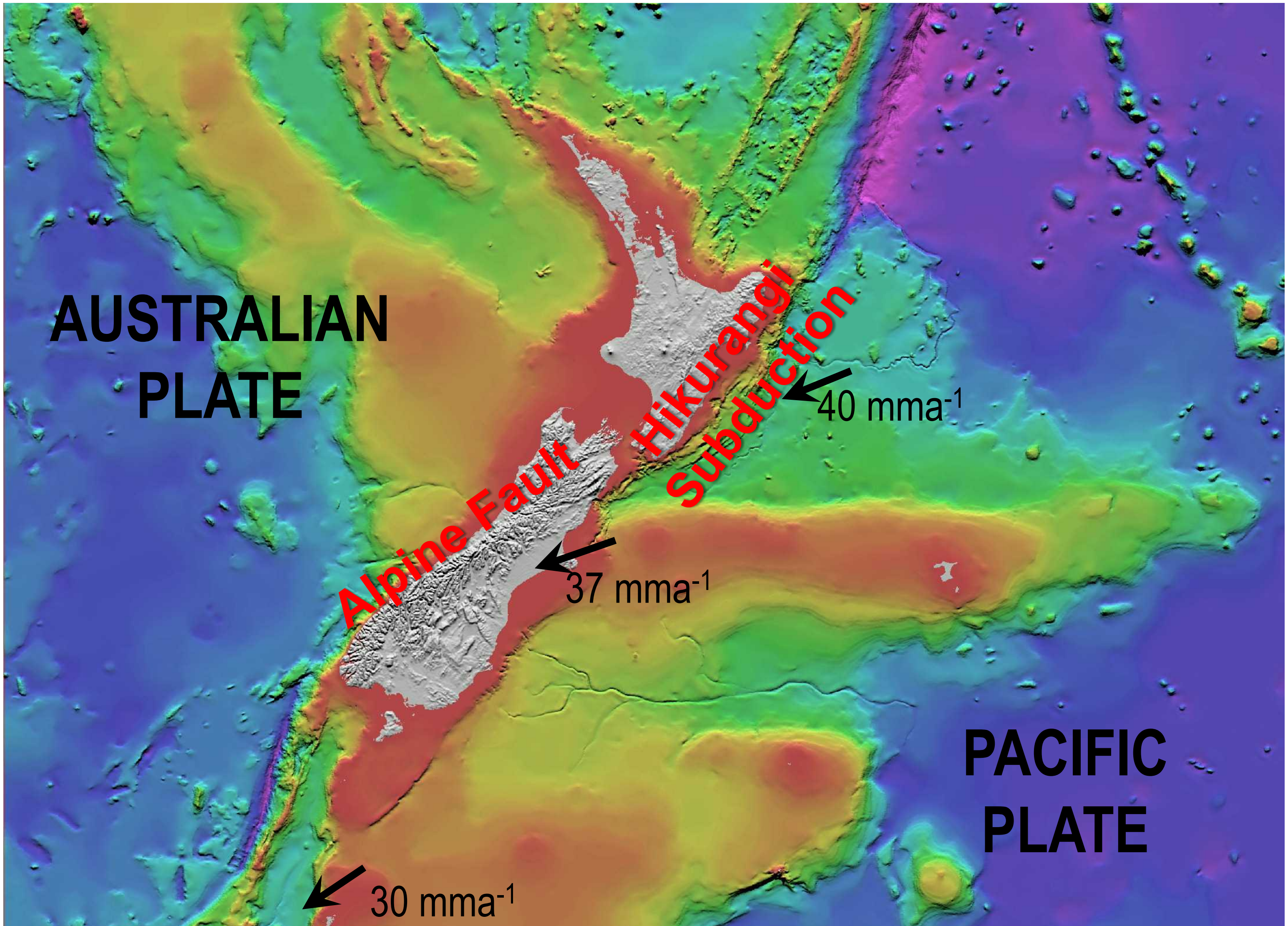
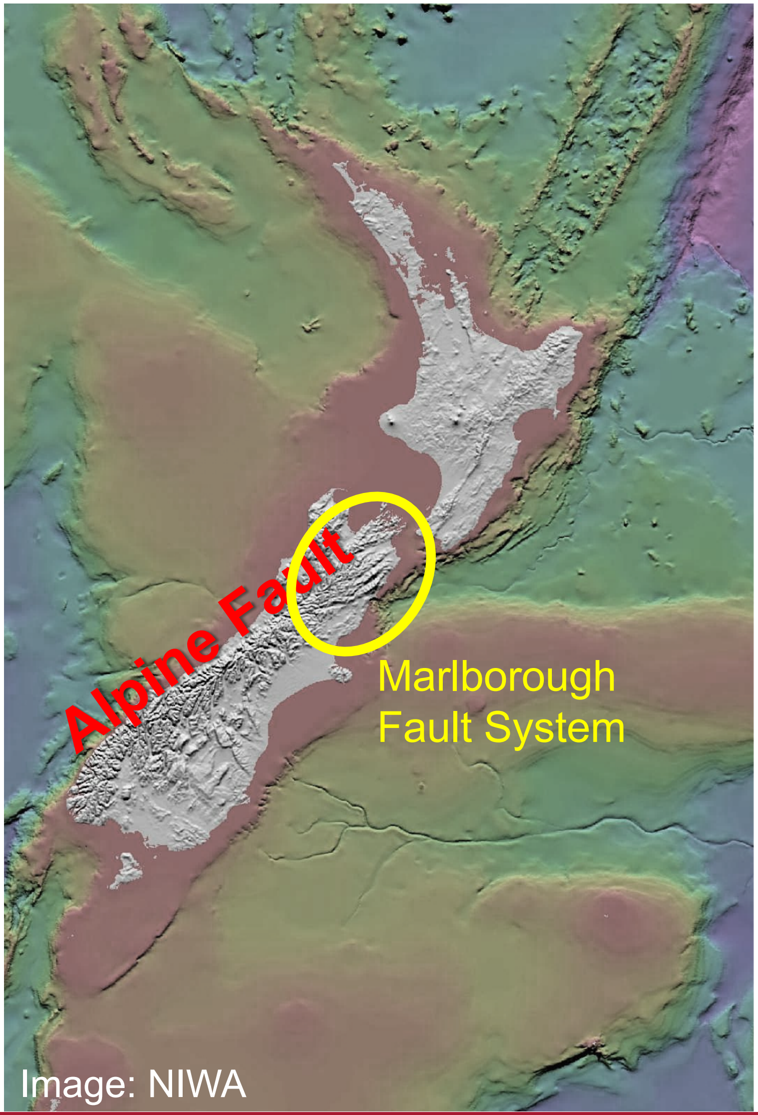
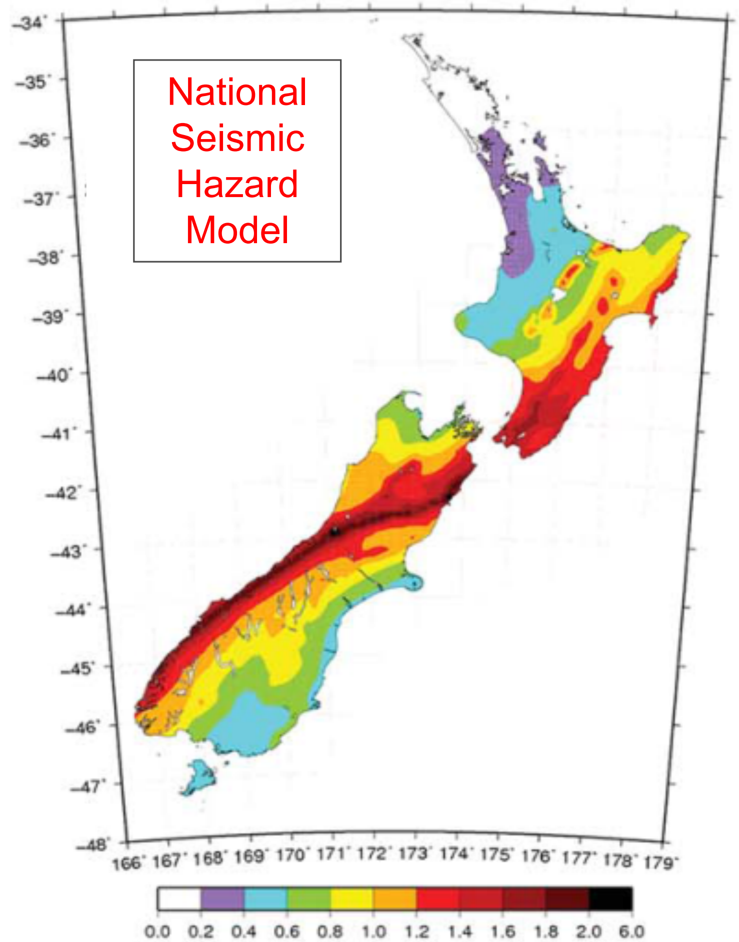
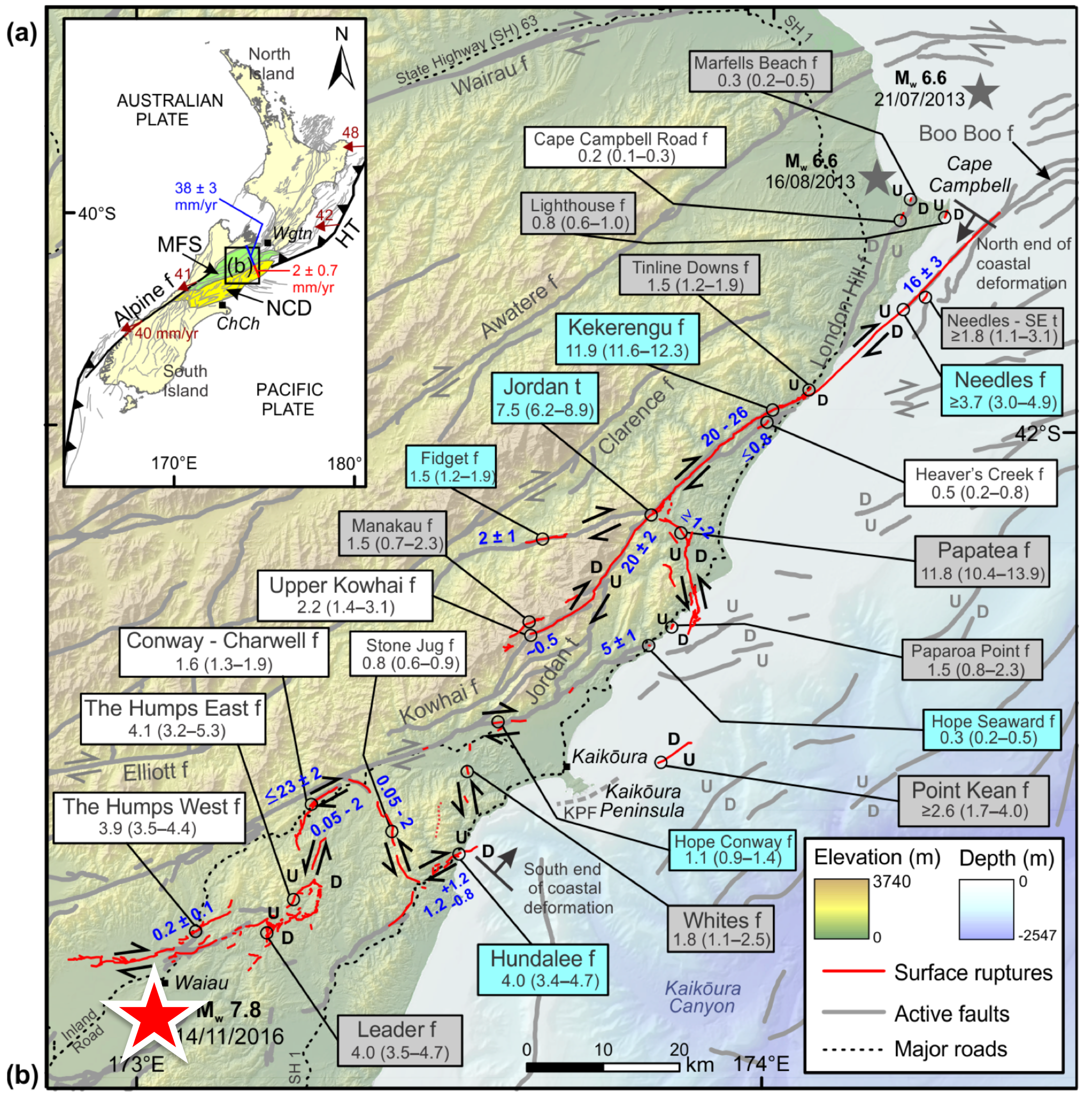

AUSTRALIAN PLATE
PACIFIC PLATE
Alpine Fault
Hikurangi Subduction
40 mma-1
37 mma-1
30 mma-1

Image: NIWA

Image: NIWA


Alpine Fault
Marlborough
Fault System
Image: NIWA


National
Seismic
Hazard
Model
-34° -35° -36° -37° -38° -39° -40° -41° -42° -43° -44° -45° -46° -47° -48°
166° 167° 168° 169° 170° 171° 172° 173° 174° 175° 176° 177° 178° 179°
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 6.0



Kaikōura Earthquake

Magnitude: M_w 7.8

Duration:
Shaking lasted 2-3 minutes depending on location

Effects on the landscape

Surface fault rupture

- ~180 km rupture length, up to 12 metre offsets
- multiple faults broke ~21

Coastal uplift

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

Tsunami

- Local run-up up to ~7 m, low tide,

Landslides

- Tens of thousands
- Many landslide dams

Liquefaction

- Locally significant

Surface Fault Ruptures


Photo: Julian Thomson

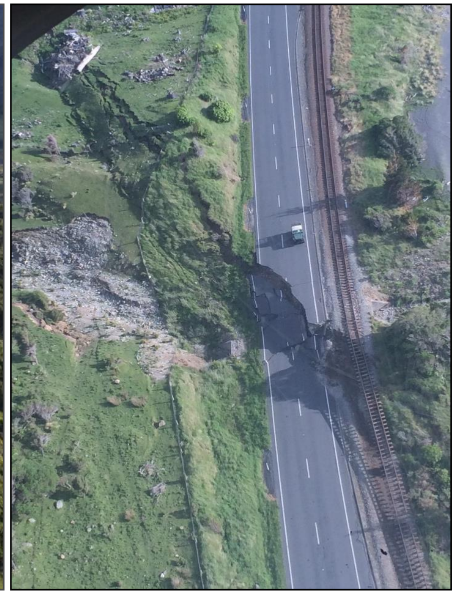



Photo: Tim Little


Photo: Kate Pedley


~8 m

Papatea Fault

Rupture crosses the Clarence River in several places

Photo: Julie Rowland


1 m
Needles F.
3 m
Kekerengu F.
Papatea F.
3 m
5.5 m
Point Kean F.
1 m
2.5 m
Hundalee F.
2016 coastal deformation
6 m
0 m


Waipapa, Papatea Fault popup block, 4 days post-EQ, 4.5 m uplift.

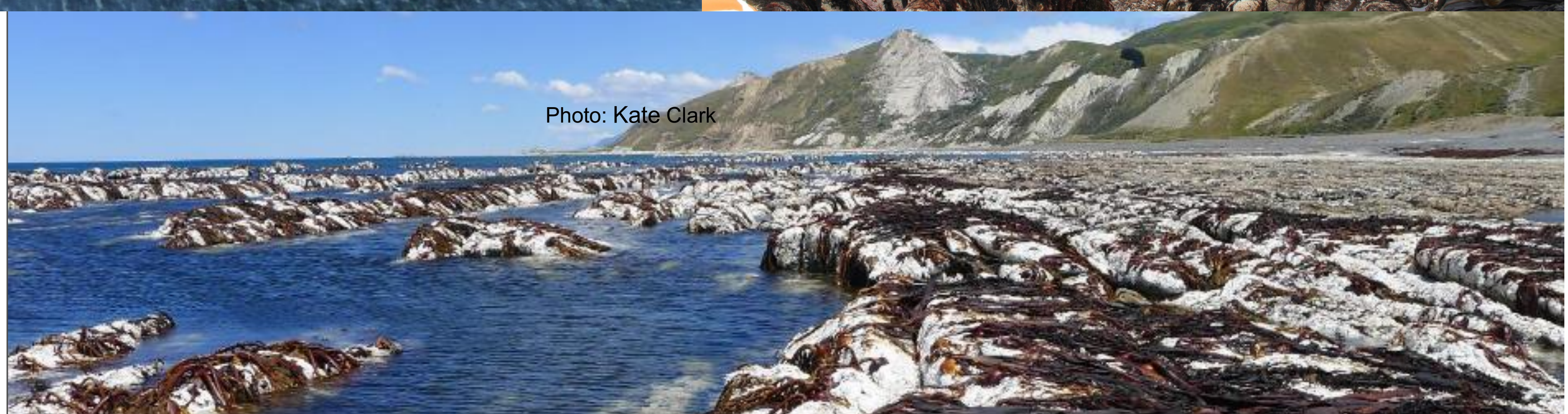
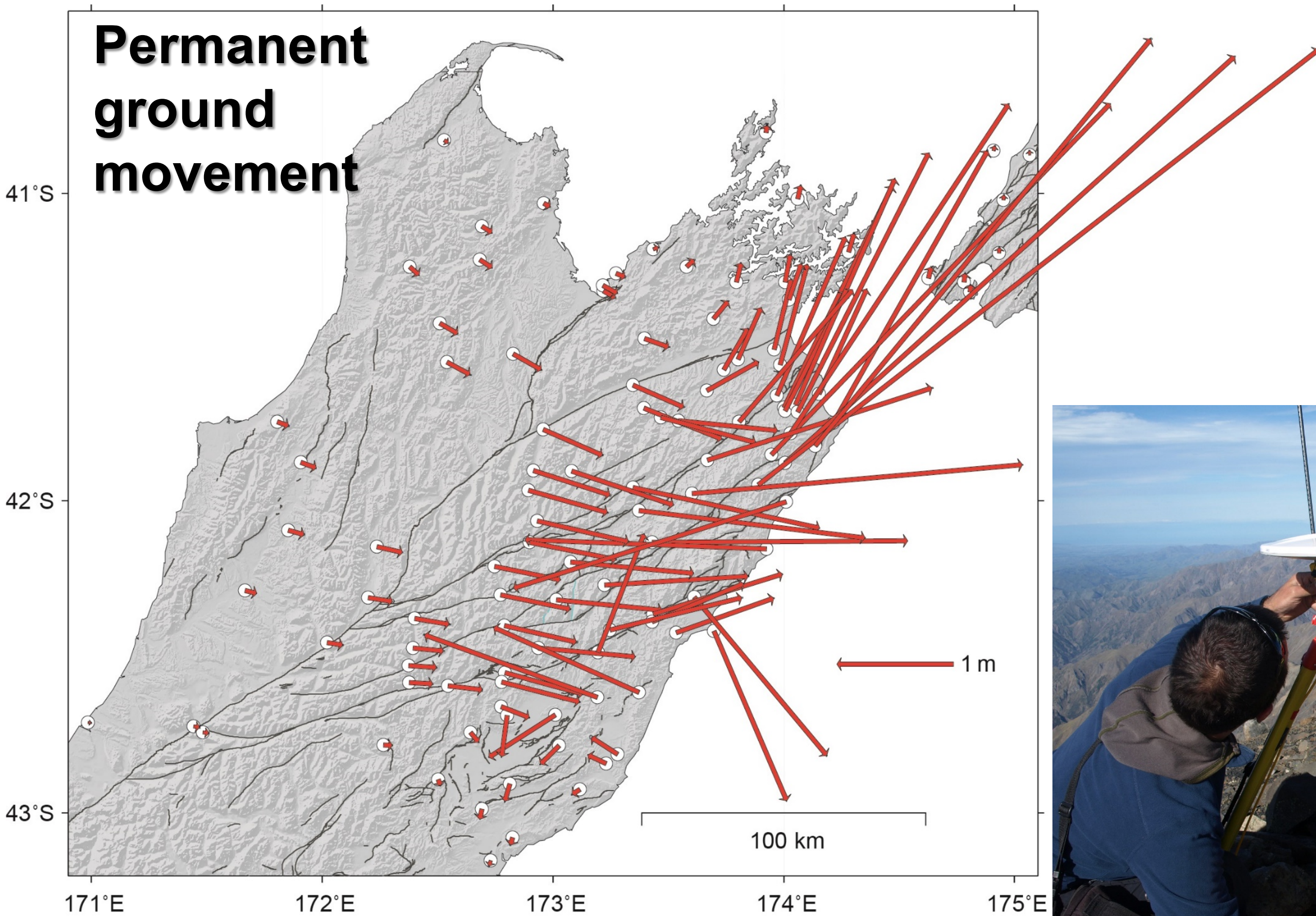


Photo: Kate Clark



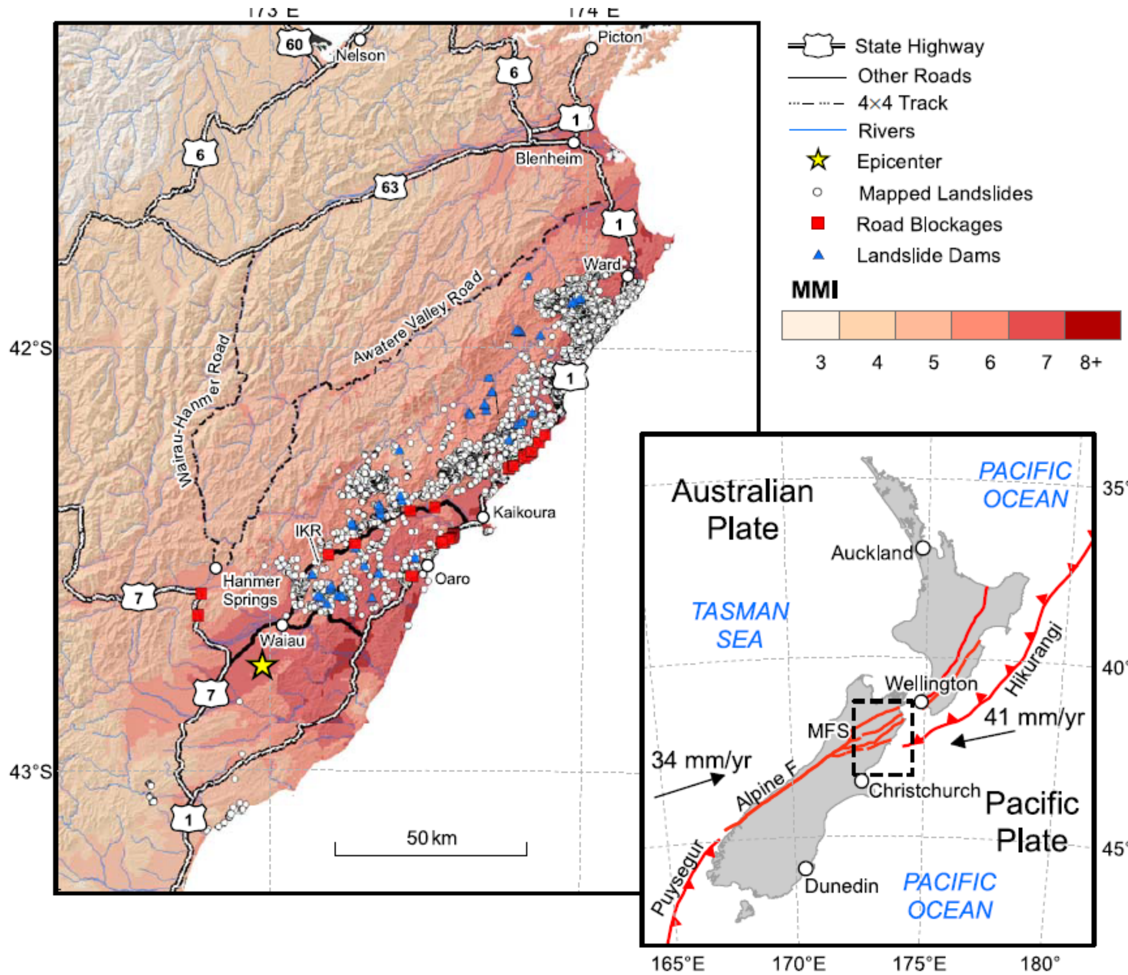
(credit: Sigrun Hreinsdottir, GNS Science)

Photo: Phaedra Upton

GNS Science

Landslides – Earthquake response phase

- Immediately obvious that landslides were going to be a major issue
- Many seen on initial reconnaissance flights by scientists and the media
- Concern over the potential for landslides dams and their breaching, especially as it was wet in the days following the earthquake
- Groups out of Durham and the USGS with GNS, U Canterbury, Otago attempted to model landslide extent in real-time



Landslides – Earthquake response phase

Bulletin of the Seismological Society of America, Vol. XX, No. XX, pp. –, – 2018, doi: 10.1785/0120170234

Near-Real-Time Modeling of Landslide Impacts to Inform Rapid Response: An Example from the 2016 Kaikoura, New Zealand, Earthquake

by Tom R. Robinson, Nick J. Rosser, Tim R.H. Davies, Thomas M. Wilson, and Caroline Orchiston

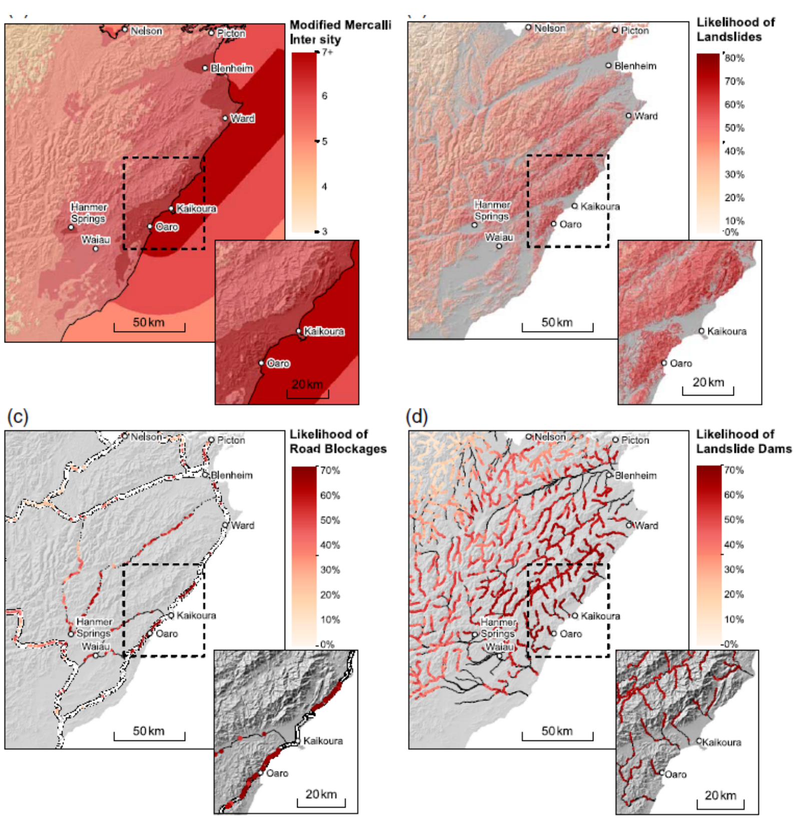
Bulletin of the Seismological Society of America, Vol. 108, No. 3B, pp. –, June 2018, doi: 10.1785/0120170297

Improving Near-Real-Time Coseismic Landslide Models: Lessons Learned from the 2016 Kaikoura, New Zealand, Earthquake

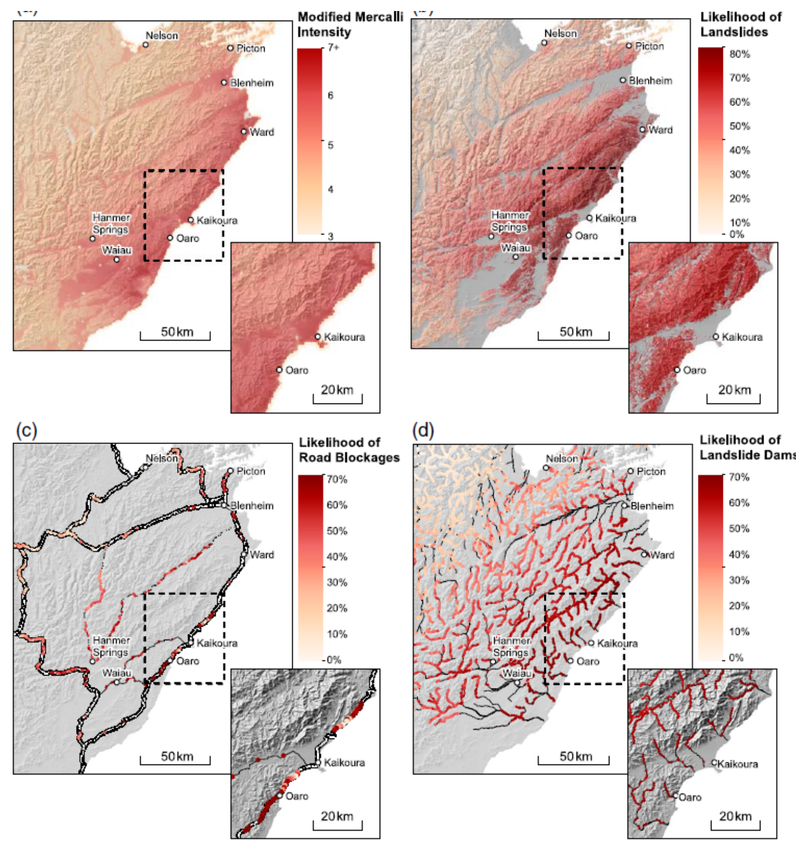
by Kate E. Allstadt, Randall W. Jibson, Eric M. Thompson, Chris I. Massey, David J. Wald, Jonathan W. Godt, and Francis K. Rengers

Landslides – Earthquake response phase

Model 1 – USGS ShakeMap v.1, 21 hrs after EQ



Model 2 – GeoNet ShakeMap v.1, 72 hrs after EQ

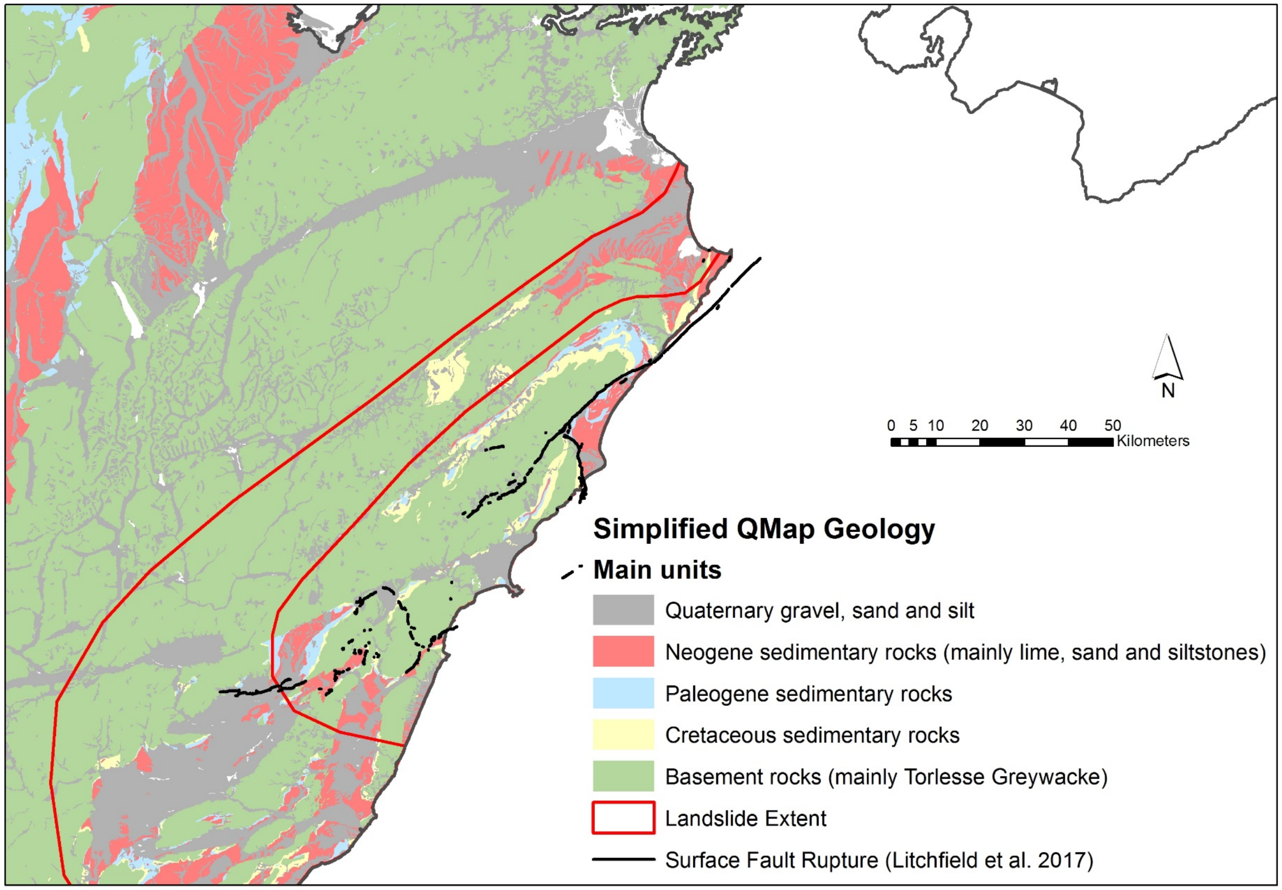


Landslides – Earthquake response phase

- All models highlighted the expectation that landsliding would be widespread
- Impacts to roads meant that Kaikōura would likely be cut off from surroundings (as seen on the first day by flights)
- Results were used by responders to formulate aerial reconnaissance flight paths
- Model verification showed that while models captured a large percentage of the landslides, the outputs were overpredicted
- Modification of model and automation are needed to increase utility and speed of modelling for future events

Landslides – geology and relationship to faults

- **Main rock types**
  - Quaternary gravels, sands and silts forming alluvial fans and terrace deposits
  - Neogene (and Paleogene) sand, lime and silt stones
  - Basement sandstones, mainly greywacke (Lower Cretaceous)



Landslides – geology and relationship to faults

Two distinct rock types:

1. Neogene sedimentary rocks, generally soft rocks plus limestones
2. Carboniferous to Cretaceous Torlesse greywacke, moderate strength

Two distinct landslide geomorphology groups:

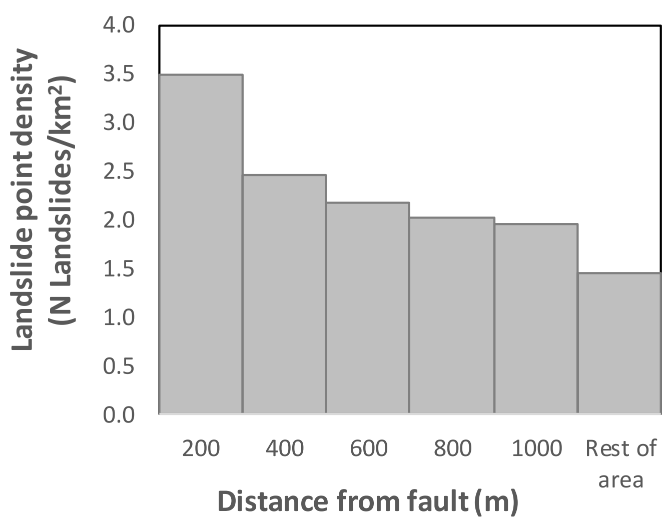
1. Slumps and rock block slides; and
2. Rock-fall, disrupted rock slides and rock avalanches.

Landslides – geology and relationship to faults

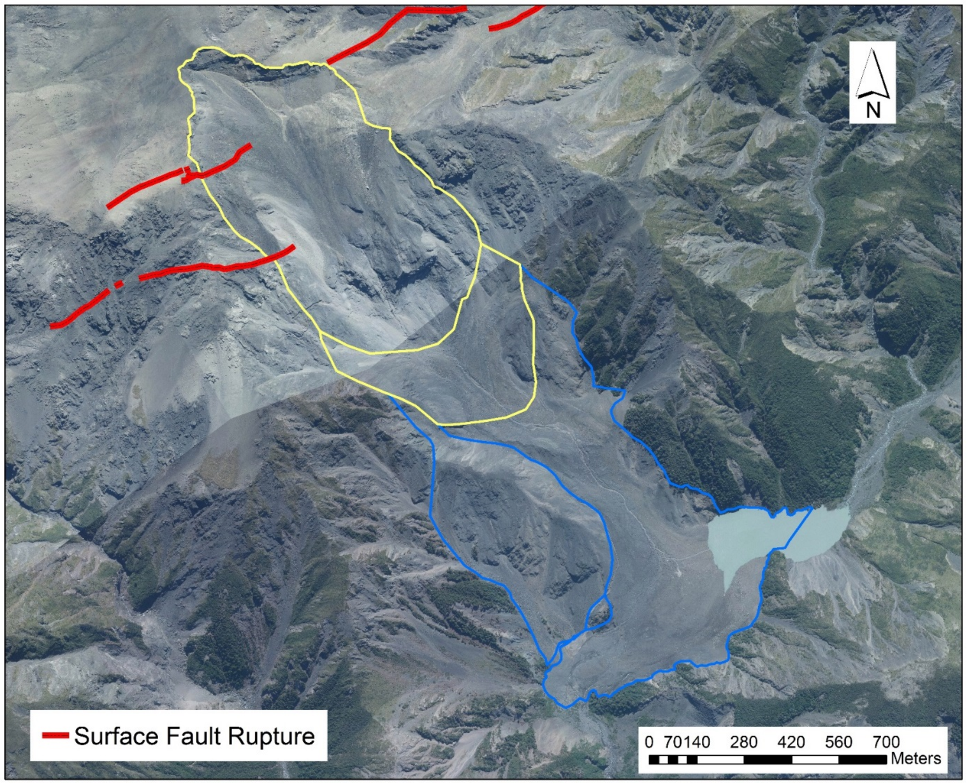
- **Most landslides occurred on:**
  - Coastal slopes; and
  - Close to faults that ruptured to the surface
- **Coastal landslides in predominately greywacke along the coast, blocked SH1 and the railway line**
- **Rail reopened to freight only Sept 2017**
- **Road reopened (several 1-way sections) Dec 2017**

Landslides – geology and relationship to faults

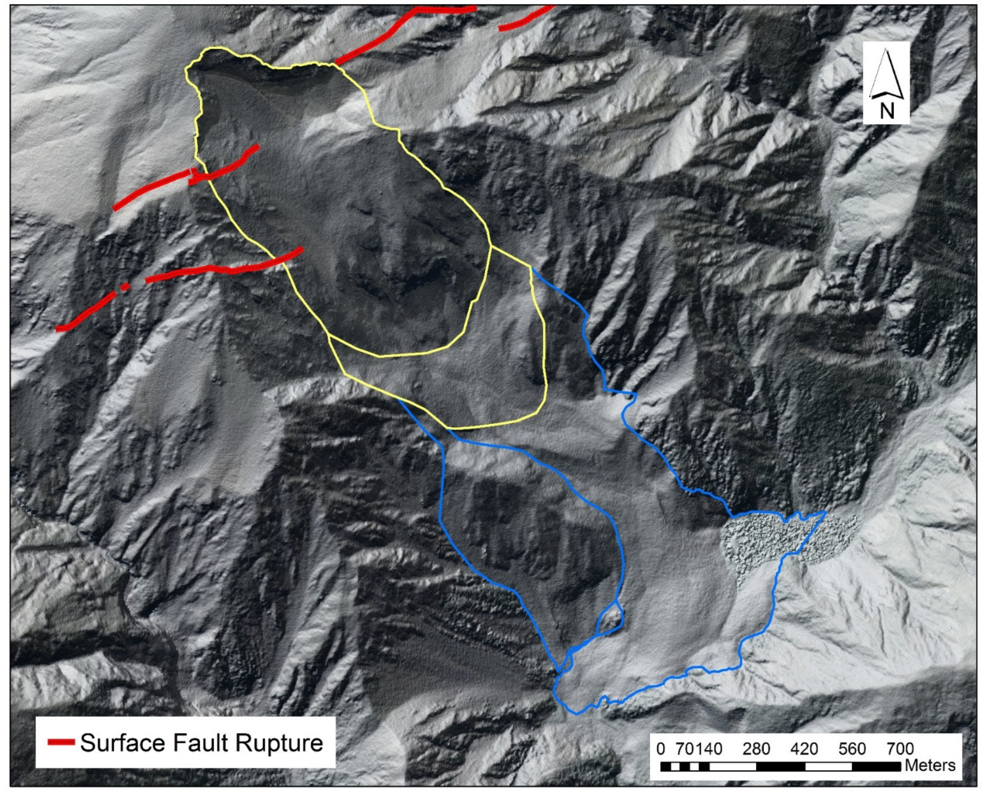
- **Most landslides occurred on:**
  - Coastal slopes; and
  - Close to faults that ruptured to the surface
- **The five largest landslides all had surface fault ruptures either pass through their source areas or very close (<200m) to them**



Large landslides – Hapuku rock avalanche



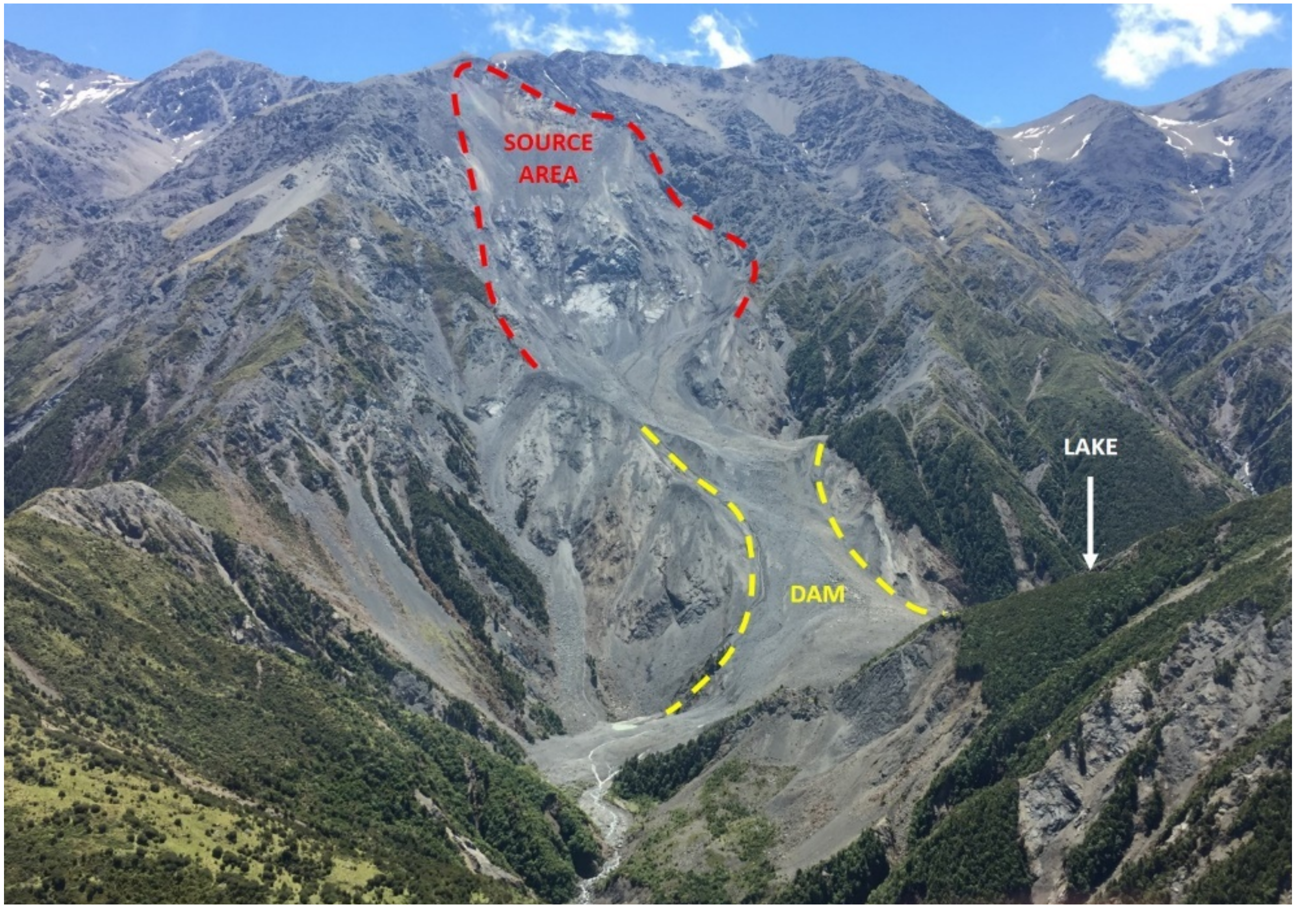
Post EQ ortho image



Post EQ Digital Surface Model

Large landslides – Hapuku rock avalanche

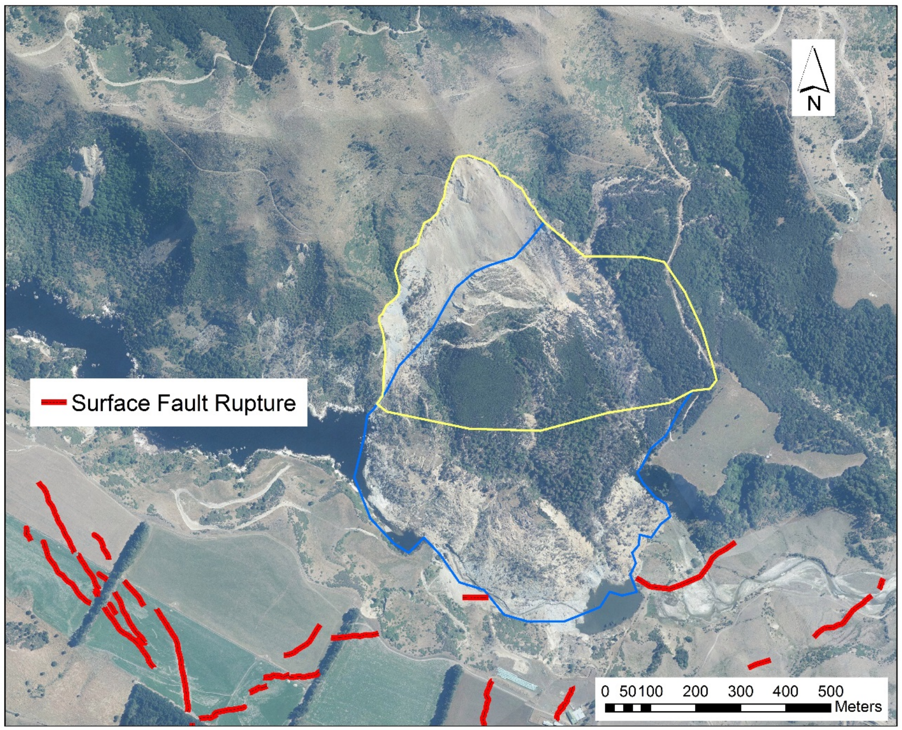
- Several fault ruptures in source – source area discontinuity controlled in greywacke
- Largest mapped landslide
- Dammed the Hapuku River
- Vol. ero: 20 (±2) M m^3
- Vol. dep: 13 (±2) M m^3
- Runout about 2.7 km



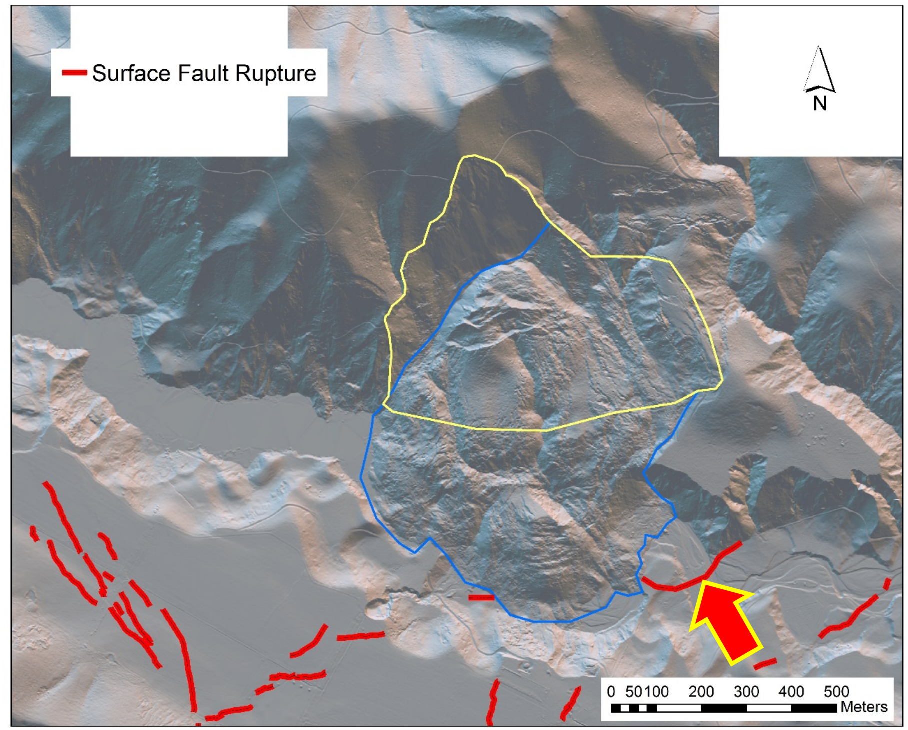
Large landslides – Leader rock slide/slump

- Dominant material: Neogene Limestone
- Failure surface: Bedding, Several surface fault ruptures pass through valley bottom
- Setting: Canterbury high country
- Volume range: 7-10M m^3
- Runout up to 1 km

Large landslides – Leader rock slide/slump



Post EQ ortho image



Post EQ Digital Surface Model

Post earthquake landsliding (Cyclone Debbie 2017)

- Hapuku dam overtopped and eroded
- Many debris flows from the cracked terraces at the crests of the coastal cliffs
- Many blocked SH1 again

Post earthquake landsliding (Ex-Cyclone Gita 2018)

- **Rainfall highly localised on coast**
- **Kaikoura 270 mm in 12 hours**
- **Estimated 300000m^3 debris covered road and rail**
- **Most occurred in locations where the slope had been damaged by the EQ**
  - Remobilisation of debris
  - Enlargement of the source areas
  - Remobilisation of debris in streams
- **Many blocked SH1 for > week**

Post earthquake landsliding
(Ex-Cyclone Gita 2018)

Photo: Chris Massey

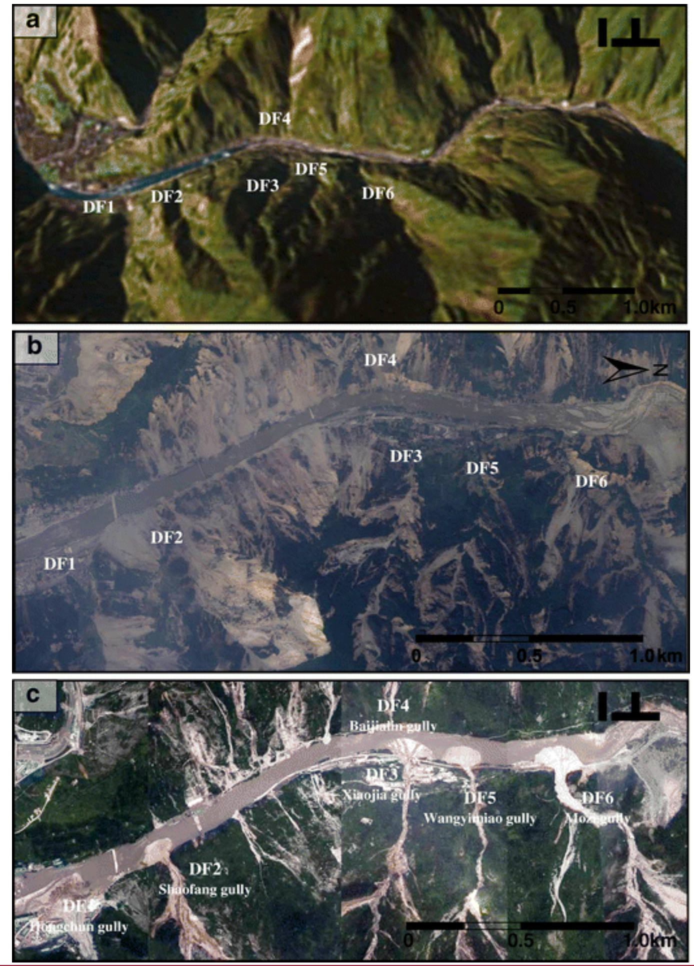
Sediment cascade – Hillslope to sea

Long-term effects:

- Debris moves downstream toward the sea
- Poses a risk to agriculture, aquaculture and infrastructure
- These hazards will persist for years or possible decades

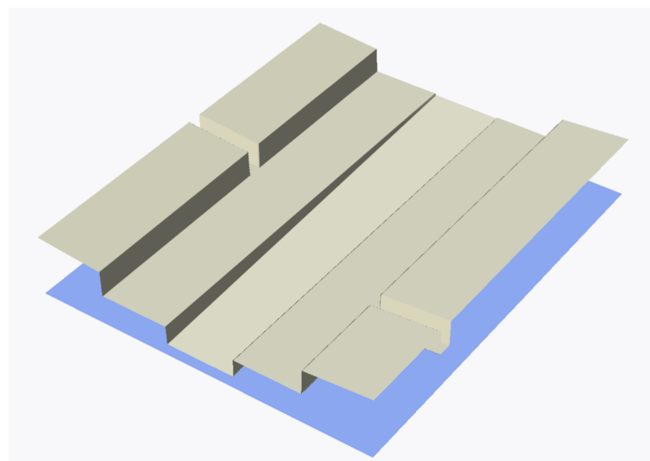
Monitoring and modelling:

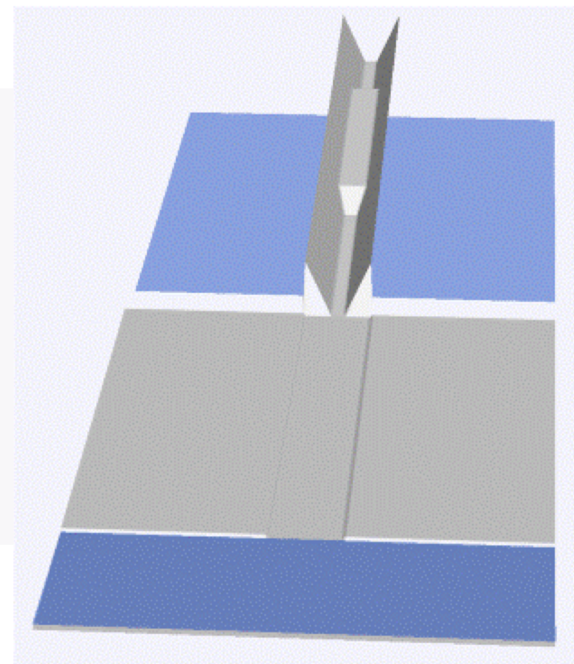
- LiDAR, Structure for Motion, rainfall
- EROS modelling
- Working with communities and stakeholders



EROS

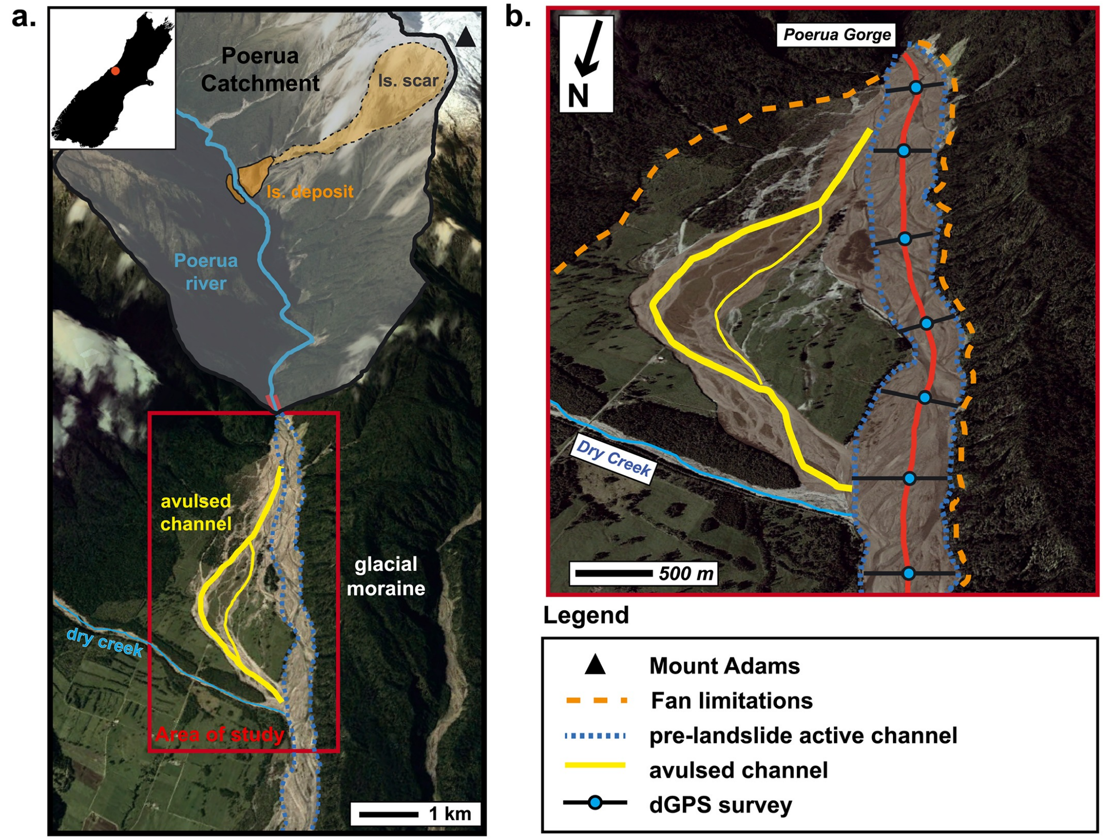
- **2D morphodynamic model using Floodos**
  - Adds erosion, transport, deposition
  - Lateral erosion
  - Non-local sediment transport
  - Can be used on high resolution topographies



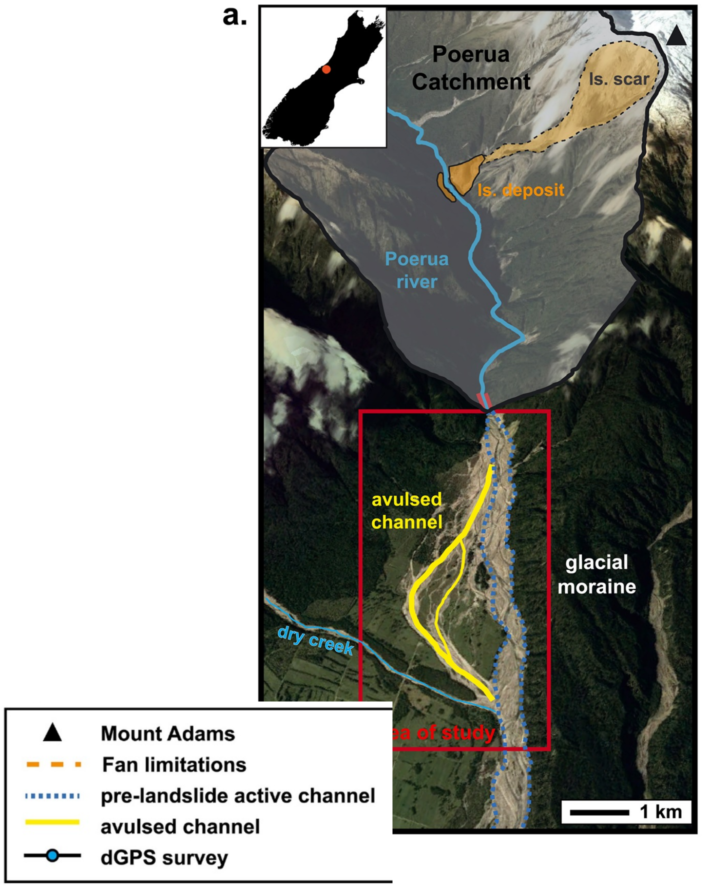


EROS

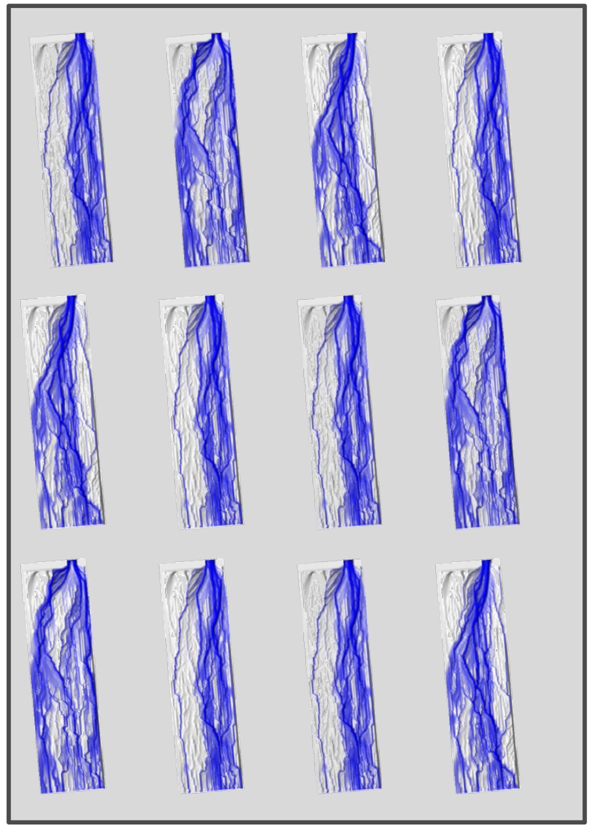
- **2D morphodynamic model using Floodos**
  - Adds erosion, transport, deposition
  - Lateral erosion
  - Non-local sediment transport
  - Can be used on high resolution topographies
- **Calibrated against Mt Adams landslide, Southern Alps, NZ**



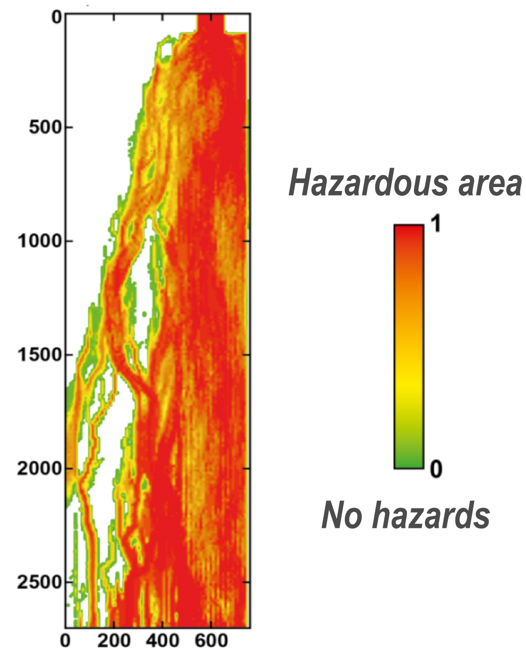
Alluvial fan hydro-sedimentary hazards prediction



Ensemble modeling



Probability of cell flooding



Alpine Fault: >50% change of an M8 in next 50 yrs

- Record of past events now goes back 8000 years in places
- ~400km rupture along edge of steep mountains with rapid erosion
- Post-seismic response lasts 40-60 years