# The Kaikoura, New Zealand Earthquake $M_w$ 7.8 , 14 November 2016

### "The Earthquake of Landslides"



### **Preliminary Report**

15 November 2016

### George GAZETAS and Evangelia GARINI

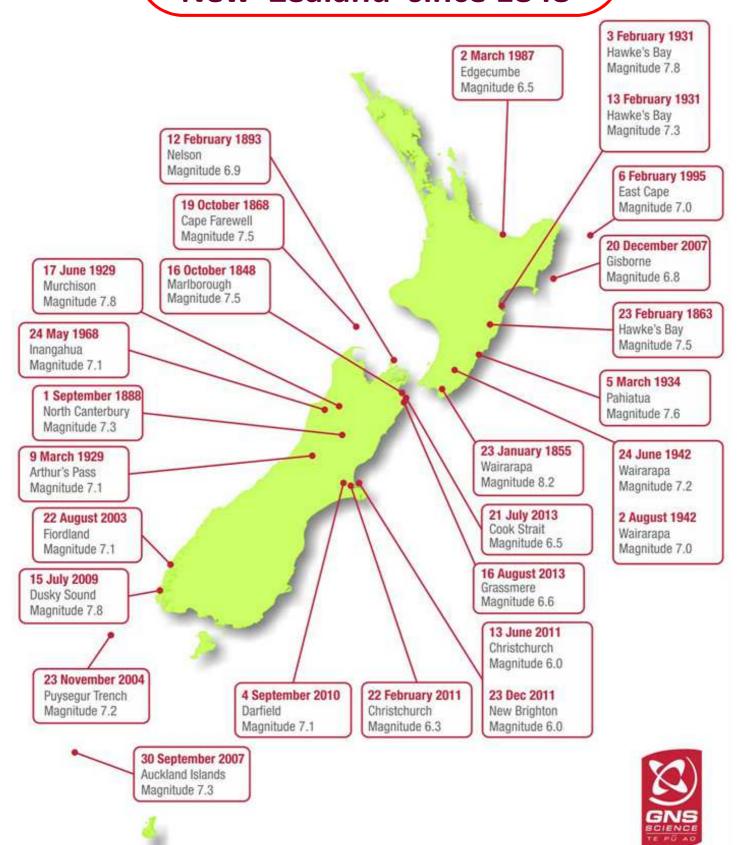
National Technical University of Athens, Greece



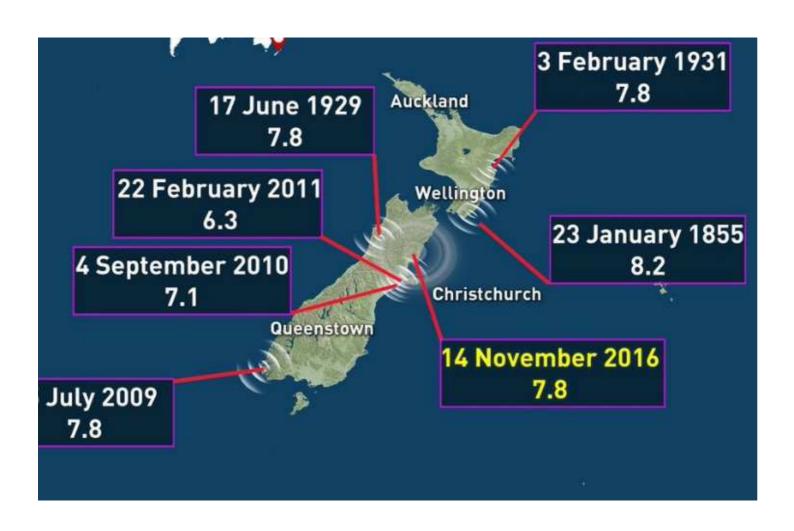
Two people have died. One when a Kaikoura homestead collapsed, the second in a property in Mt Lyford, southwest of Kaikoura.

Of course it is not known whether any cars traveled at that time (12:02 midnight) on the devastated from landslides Highway SH1. It is not impossible that were victims on that road (see in the sequel the extent of landslide damage on SH1). [GG + EG]

## Historic Earthquakes in New Zealand since 1848



# The November earthquake and some of the historic EQs



**Source: The Weather Network** 

## Two earthquakes of a combined magnitude 7.8

#### Two earthquakes, not one

There were two separate but related ruptures. The combination of these two quakes lasted 2 minutes, with the most severe shaking at around 50 seconds. It was widely felt throughout both the North and South Islands. It looks like one was a strike-slip and the other was a thrust (reverse) fault.

#### Multiple ruptures

Rapid field reconnaissance indicates that multiple faults have ruptured: ALL RELATED TO THE MAIN SUBDUCTION TRENCH THAT CROSSES THE TOP OF THE SOUTH NZ ISLAND (FROM N-E to S-W).

- •Kekerengu Fault at the coast appears to have had up to 10m of slip
- Newly identified fault at Waipapa Bay
- •Hope Fault seaward segment minor movement
- Hundalee Fault



severe

Region intensity 2 severe

NZDT Mon, Nov 14 2016, 12:02:56 am

Depth 15 km

Magnitude 7.8

Location 15 km north-east of Culverden

Felt it?

quake details...



Intensity

severe

Region intensity 2 severe

NZDT Mon, Nov 14 2016, 12:52:44 am

Depth 32 km

Magnitude 6.2

Location 25 km north of Kaikoura

Felt it?

quake details...



Intensity 2

severe

Region intensity 2 severe

NZDT Mon, Nov 14 2016, 12:32:06 am

Depth 29 km

Magnitude 6.2

Location 15 km north of Kaikoura

Felt it?

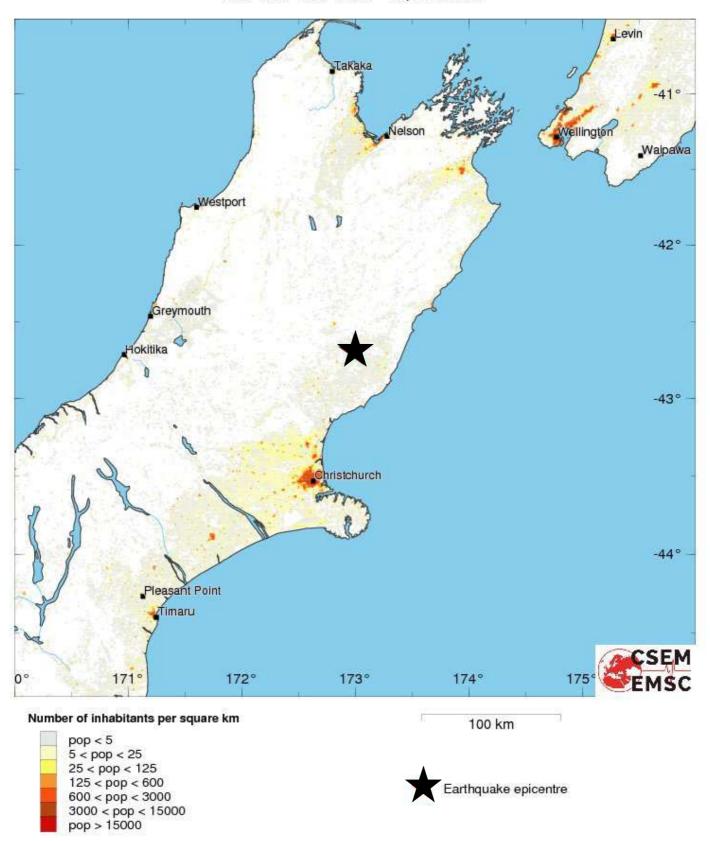
quake details...

**Source: GeoNet** 

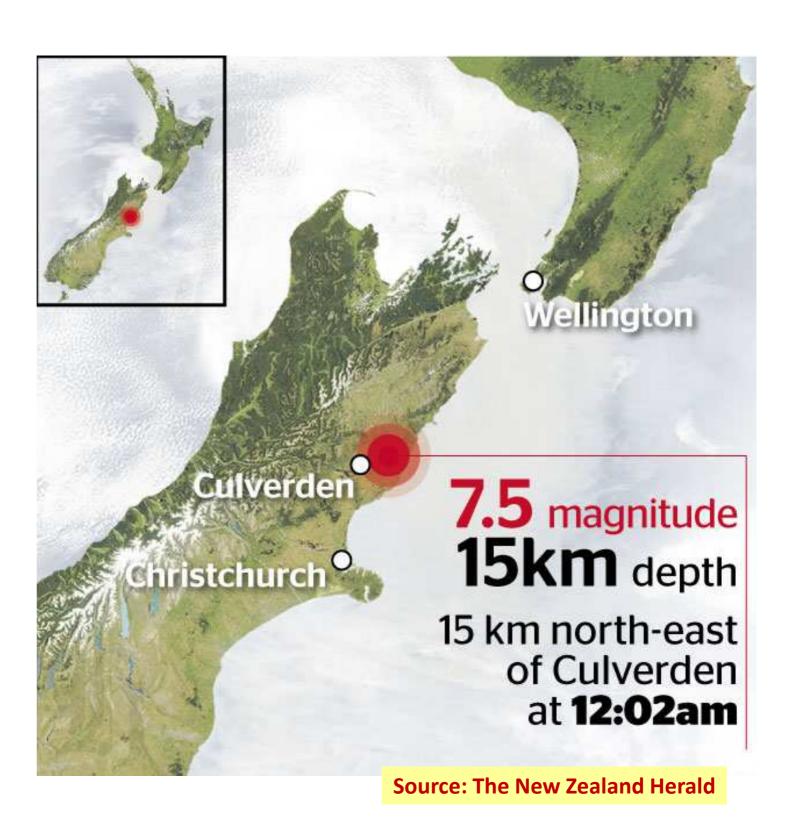


### **POPULATION DENSITY**

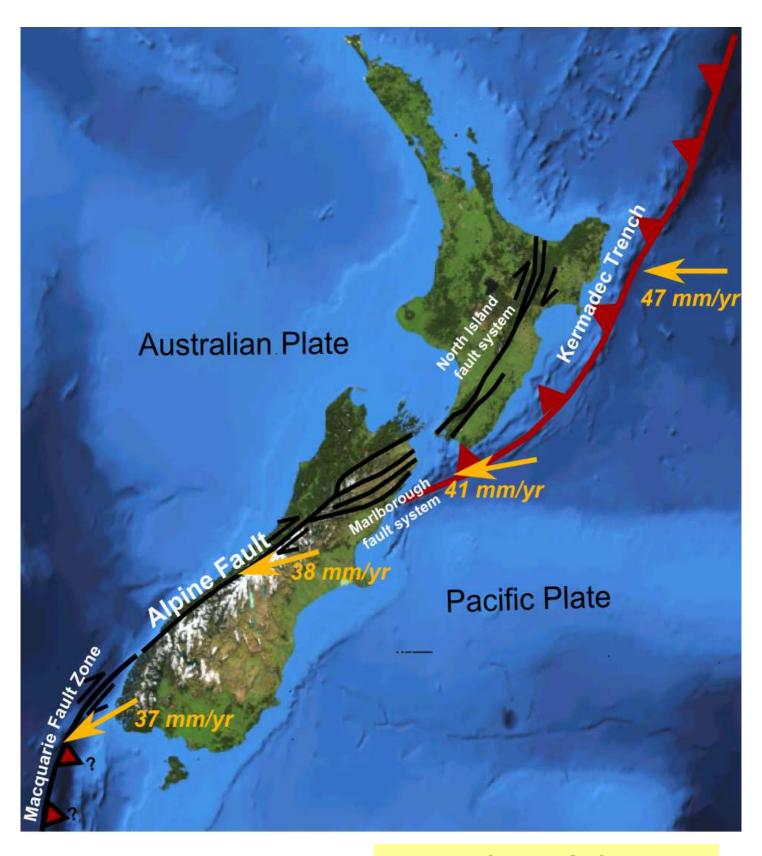
Population in the epicentral area Mag 7.9 2016/11/13 - 11:02:58 UTC Lat: -42.70 Lon: 172.99 Depth: 10.0 km



### **Seismological Data**

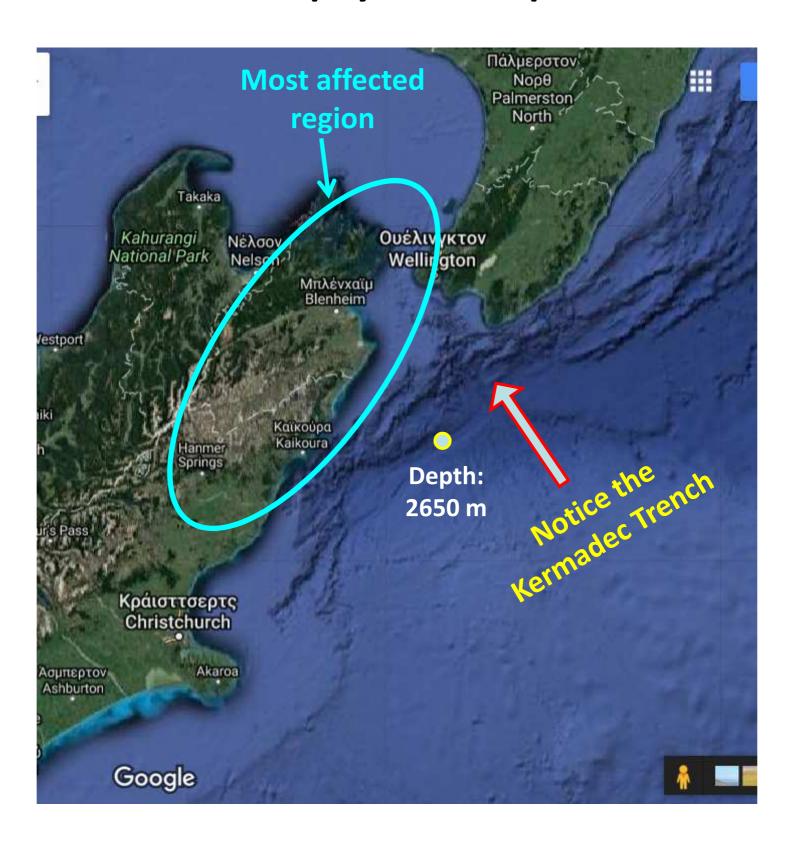


The latest revised magnitude M<sub>W</sub> estimate is 7.8, not 7.5!

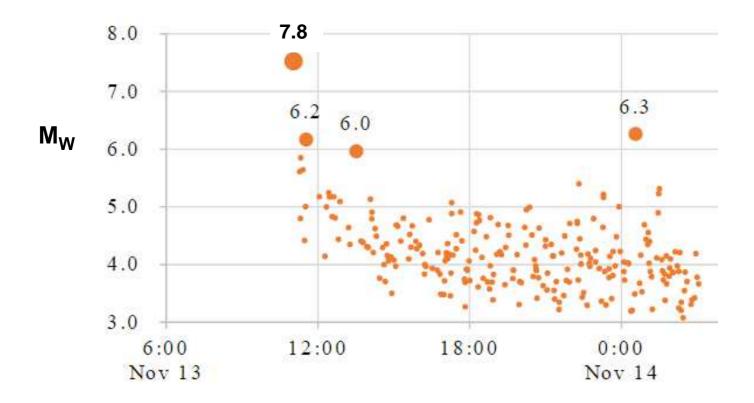


**Source: GNS** 

### **Geophysical Map**



### **Mainshock and Aftershocks versus time**



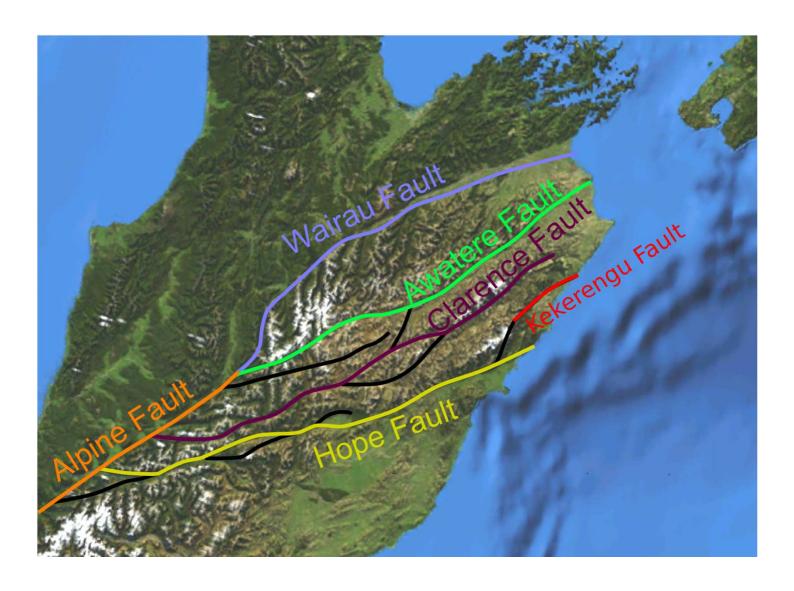
**Source: GEONET** 

### **Tectonic Summary**

The M 7.8 earthquake in New Zealand occurred as the result of shallow oblique-reverse faulting on or near the boundary between the Pacific and Australia plates in South Island. At that location, the Pacific plate moves to the west-southwest with respect to the Australia plate at a rate of approximately 40 mm/yr. The epicenter of the earthquake is about 30-45 km south-southeast of the main surface expression of the plate boundary in the region—the Hope Fault, part of the Marlborough Fault system that connects a subduction zone (the Hikurangi Trough) to the primary plate boundary in the South Island—the Alpine Fault. The plate boundary in the region of the earthquake is complex, involving a transition from subduction to transform faulting through the South Island. Part of the complexity of the event stems from the delayed release (by about 40 s) of the main energy.

The size, depth (~25 km), and faulting orientation of the November 13 event suggest a larger, subduction-related structure, though the subduction zone interface is not thought to extend this far to the south of the Alpine fault system. **Reverse-faulting** events of this size are typically about **120 x 50** km (length x width).

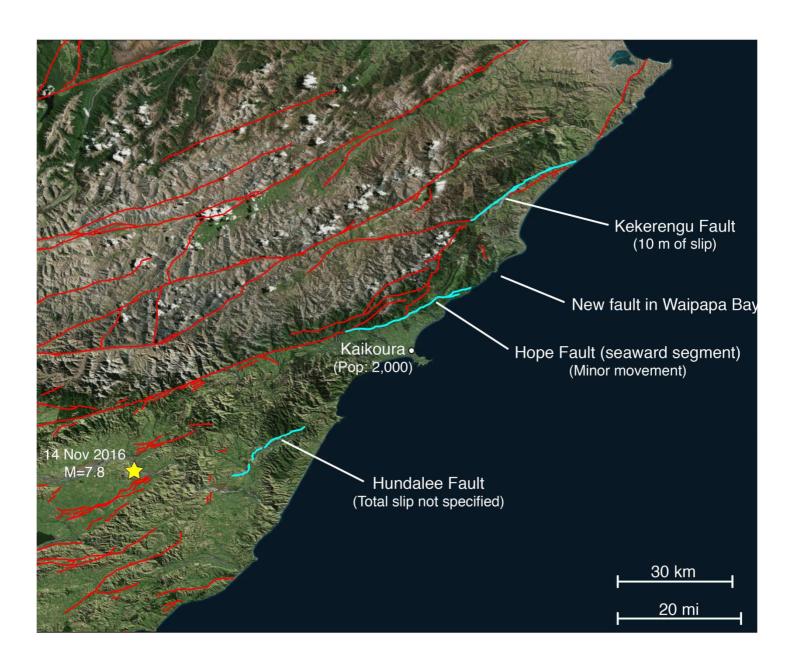
**Source: USGS** 



Initial surveys indicate motion on the **Kekerengu Fault** of up to **10 m**, movement on the **Hundalee fault**, a newly identified fault in Waipapa Bay, as well as minor motion on the Seaward segment of the Hope Fault.

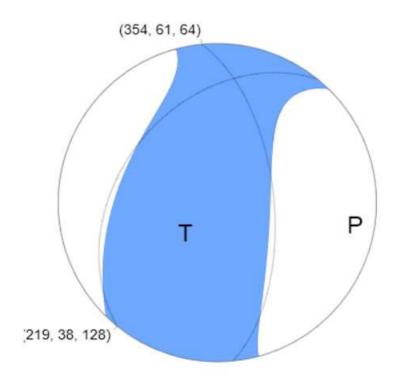
**Source: Wikipedia** 

### A more detailed map of the activated fault segments



**Source: Templor** 

### **Moment Tensor**



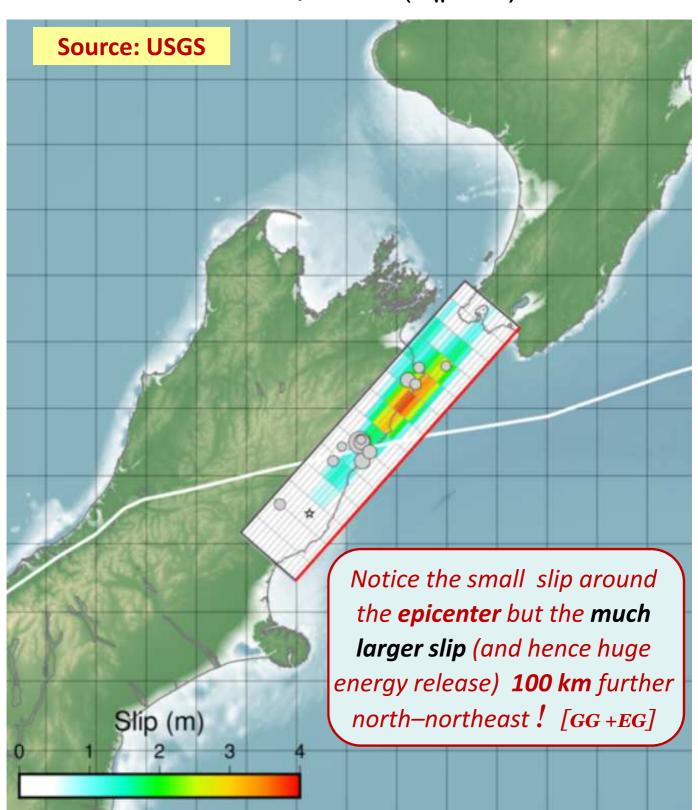
### **Nodal Planes**

Plane	Strike	Dip	Rake
NP1	219°	38°	128°
NP2	354°	61°	64°

**Source: USGS** 

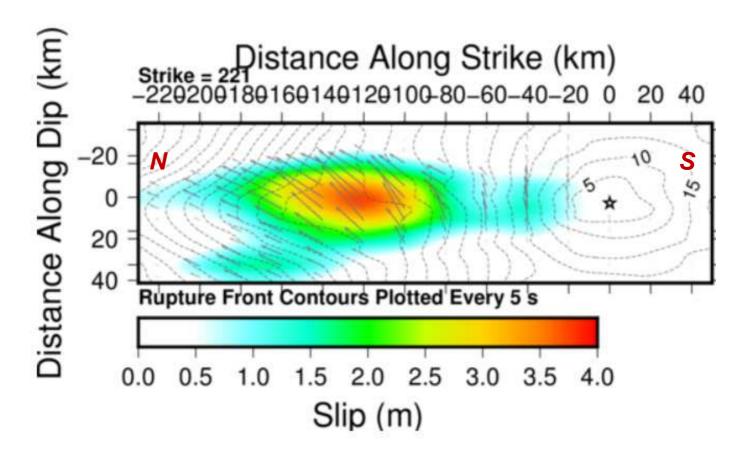
### FINITE FAULT MODEL

The seismic moment release based upon the fault plane is 7.4e+27 dyne.cm  $(M_W = 7.8)$ 



### FINITE FAULT MODEL

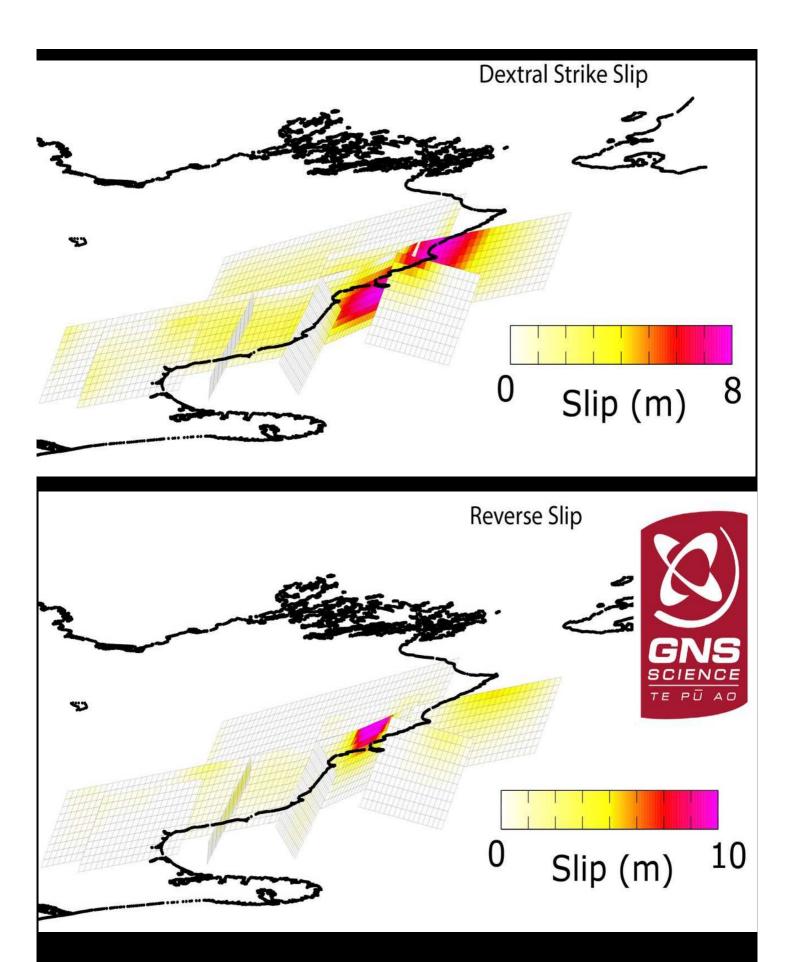
(Looking from the West)



Cross-section of slip distribution. The strike direction is indicated above each fault plane and the hypocenter location is denoted by a star. Slip amplitude is shown in color and the motion direction of the hanging wall relative to the footwall (rake angle) is indicated with arrows. Contours show the rupture initiation time in seconds.

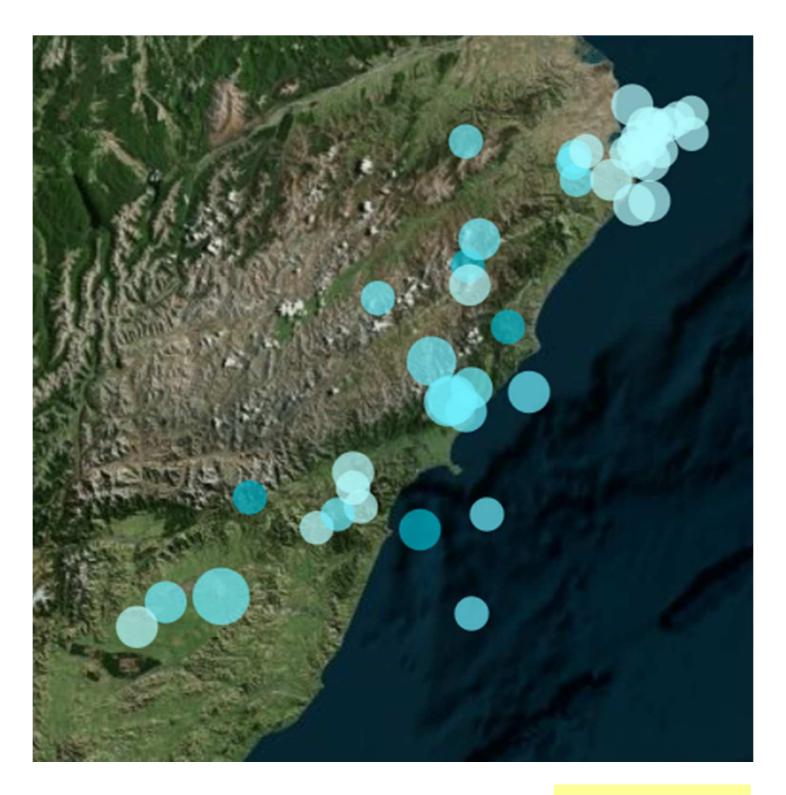
**Source: USGS** 

But notice an inconsistency with the observed 10 m ground-surface dislocation (see below) ![GG+EG]



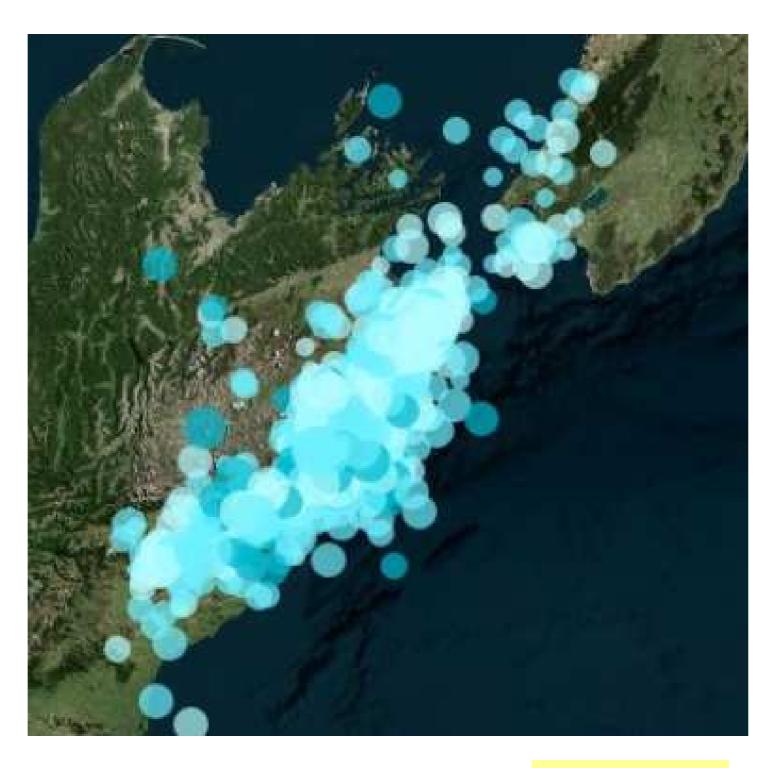
Fault rupture slip model based on the Sentinel-1 and GPS data

# Aftershocks recorded in the first 3 hours since the 7.8 mainshock.



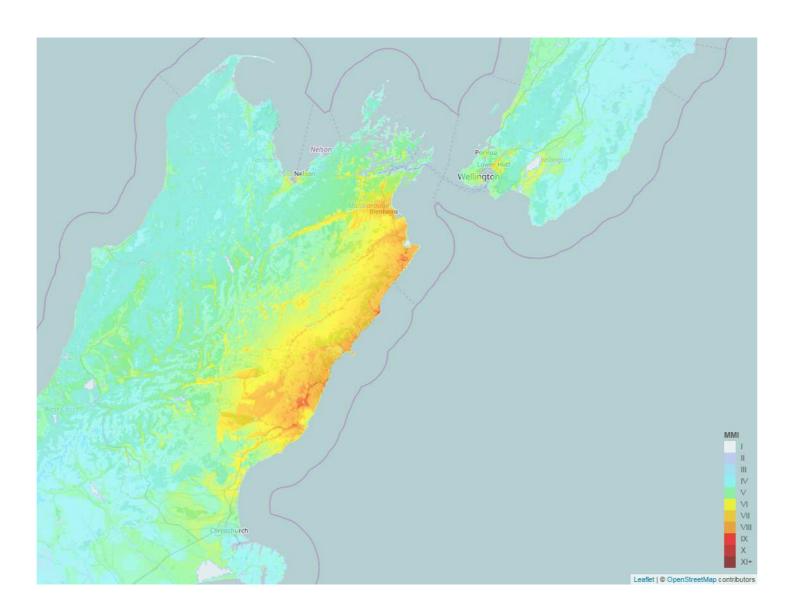
**Source: GEONET** 

# Aftershocks recorded during the first 2 days since the 7.8 mainshock.



**Source: GEONET** 

### ShakeMap of the M7.8 Kaikoura earthquake of November 13, 2016



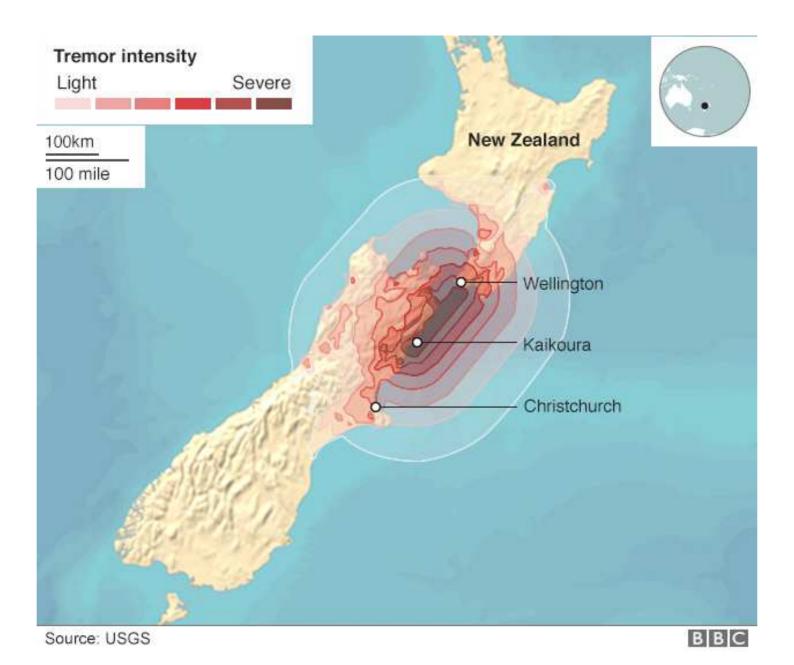
**Source: GeoNet** 

### **Ground Motions**

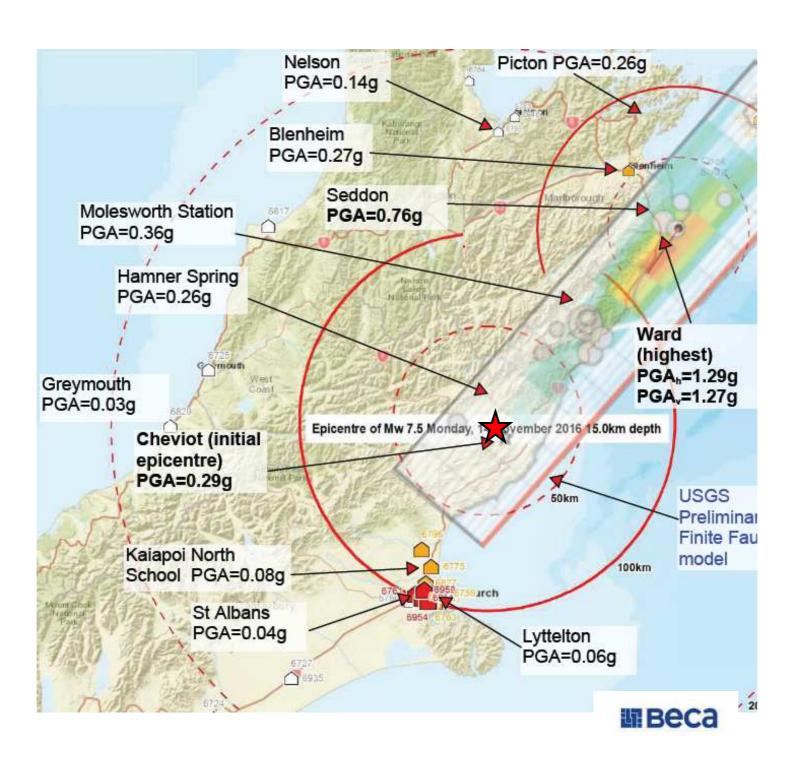
The epicentral distances that are reported for each accelerograph station below are as accurate as the location of the epicenter (i.e., nearly exact).

The much more significant distances from the fault are only our own crude estimates. But as you can see, these distances are the ones that can explain the different recorded motion intensities.

### Intensity Map of the M7.8 NZ earthquake



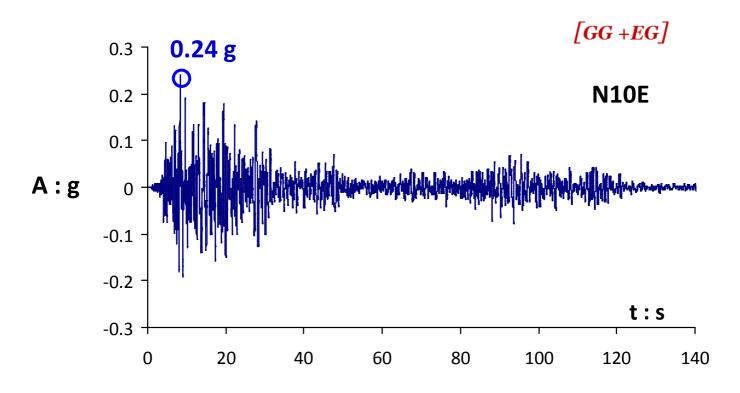
### **Peak Recorded Accelerations**

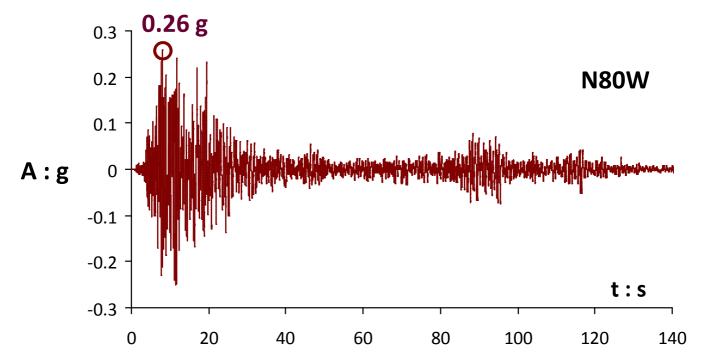


### **HSES: Hanmer Springs Emergency Centre**

**Epicentral Distance: 25 km (according to GNS)** 

Distance from seismogenic fault:  $\simeq 30-40 \text{ km}$  (our estimate)

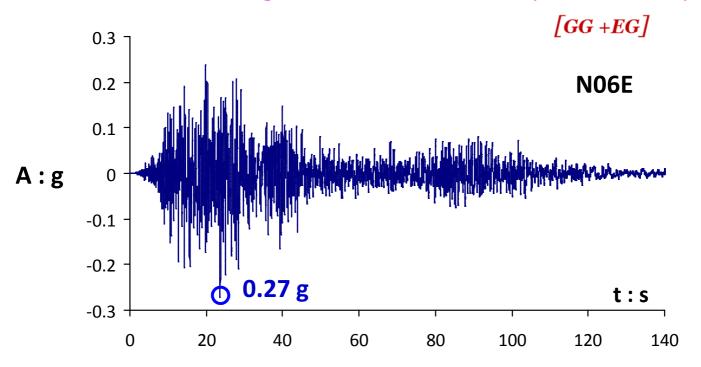


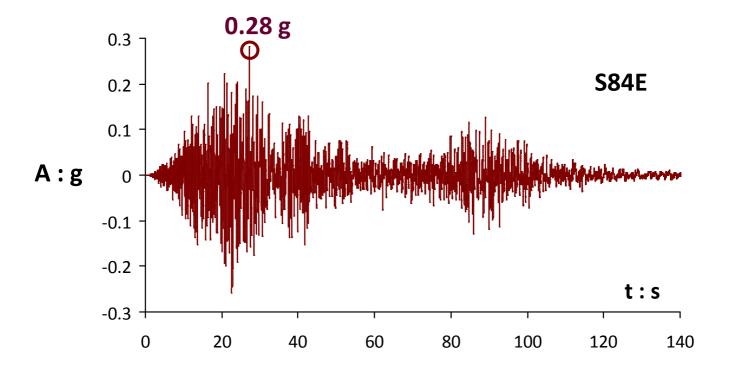


### **CECS: Cheviot Emergency Centre**

**Epicentral Distance: 25 km (according to GNS)** 

Distance from seismogenic fault:  $\simeq 40-50$  km (our estimate)

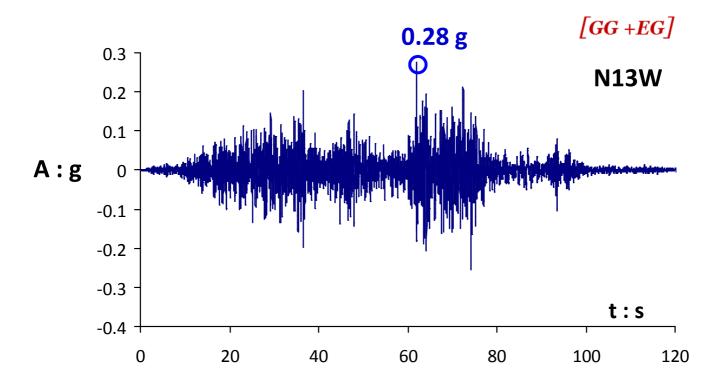


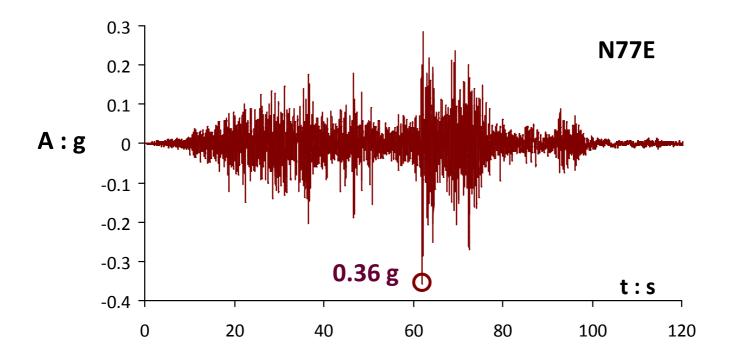


### **MOLS: Molesworth Station**

**Epicentral Distance: 70 km (according to GNS)** 

Distance from the seismogenic fault:  $\approx$  30 km (our estimate)

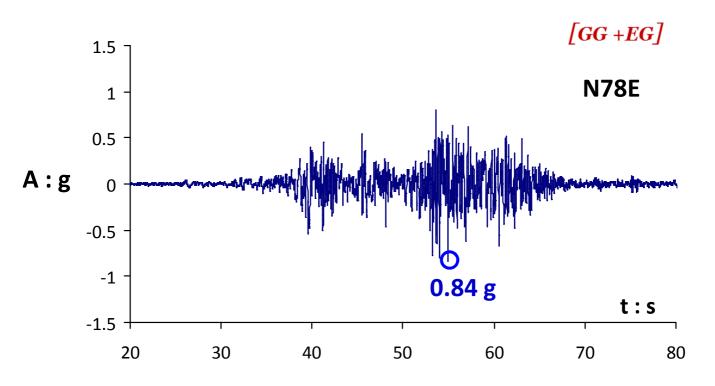


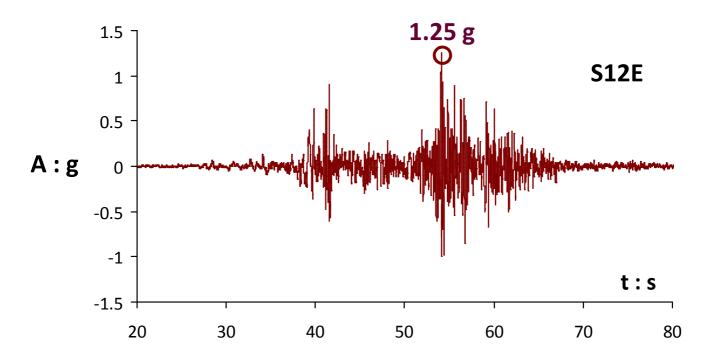


#### **WDFS: Ward Fire Station**

**Epicentral Distance: 133 km (according to GNS)** 

### **Distance from the seismogenic fault:** < 5 km (our estimate)

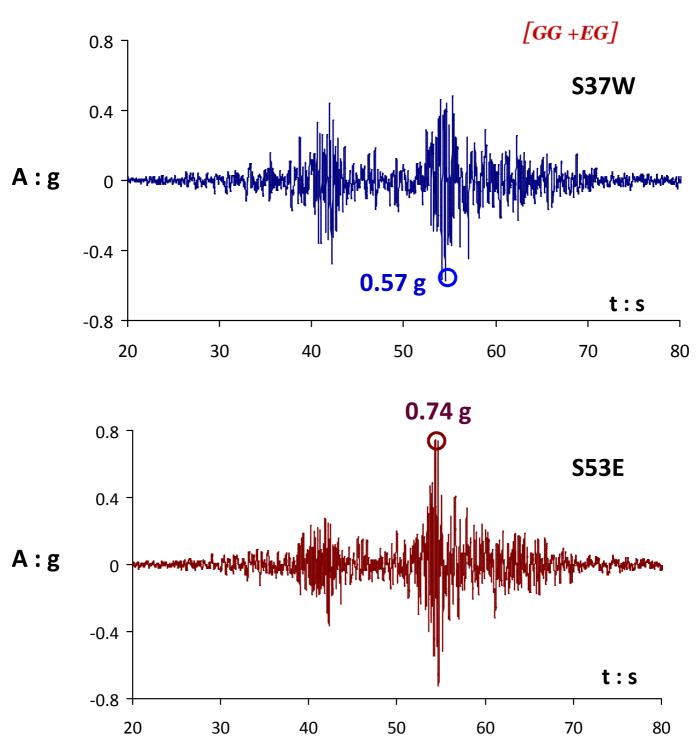




#### **CEDS: Seddon Fire Station**

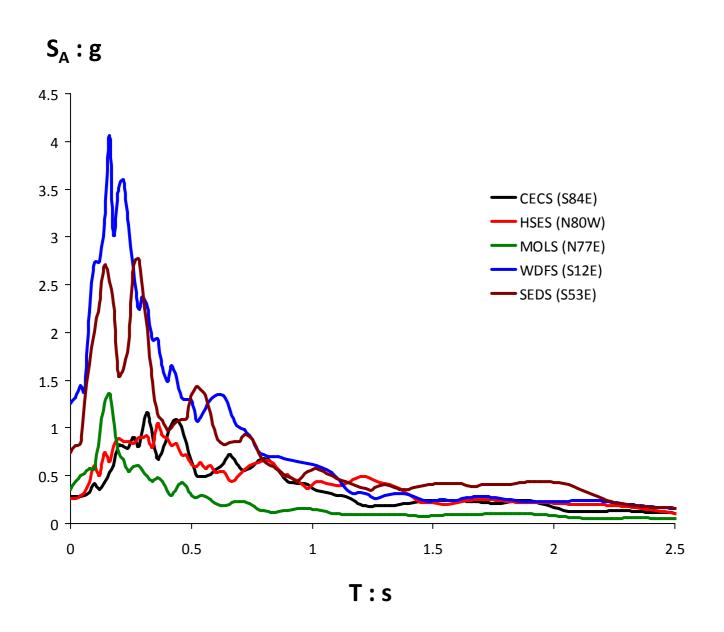
**Epicentral Distance: 143 km (according to GNS)** 

Distance from seismogenic fault:  $\simeq$  10 km (our estimate)



### Comparison of 5% damped response acceleration spectra of the

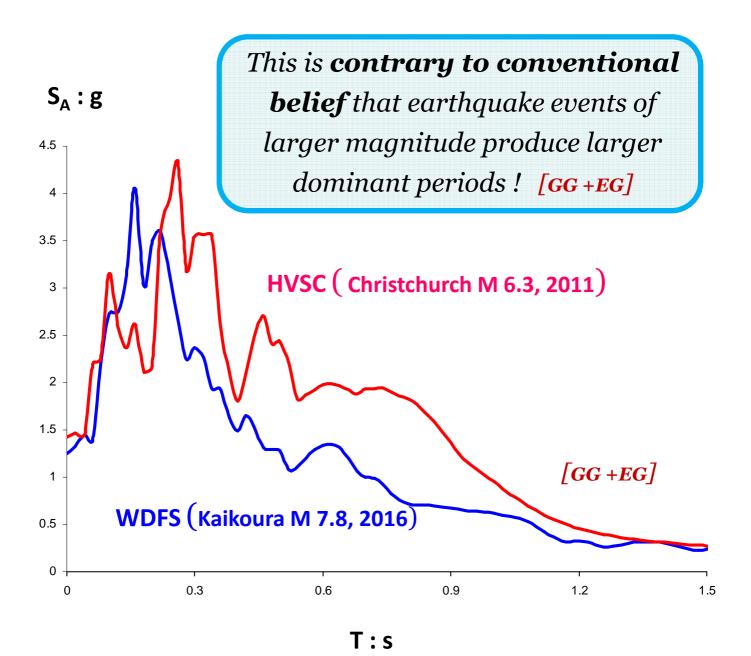
M<sub>w</sub> 7.8 Kaikoura EQ



[GG + EG]

### Comparison of acceleration spectra between

the  $M_{\rm w}$  7.8, 2016 Kaikoura and  $M_{\rm w}$  6.3, 2010 Christchurch EQs



Both records at a distance of 2–5 km from their seismogenic fault

It is interesting to compare the frequency content of the recorded motions in Christchurch in this 2016 earthquake and in the 2011 fatal event.

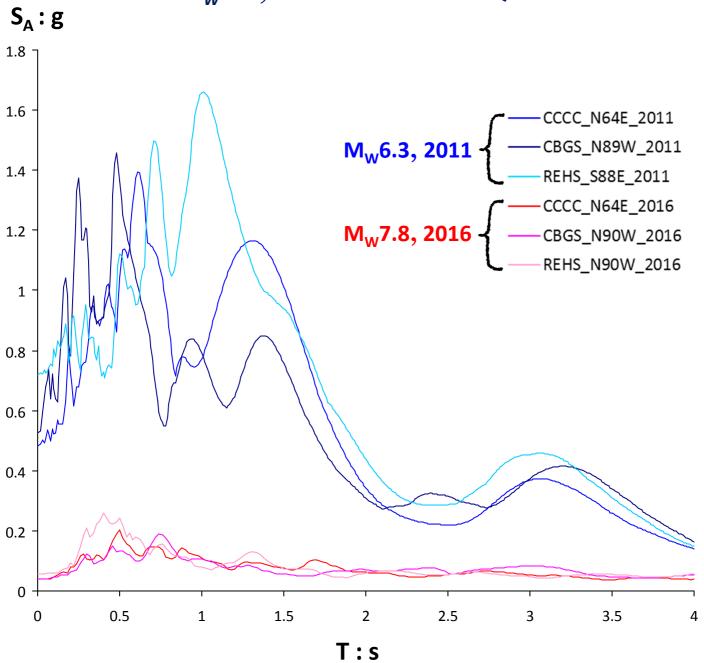
Obviously, the latest motions in Christchurch were very weak, as excepted in view of the 100 km distance from the epicenter and the even greater distance from the "center" of the main fault activity. So, the response spectra of 2016 earthquake motions in three CBD stations are much lower than the corresponding spectra of the 2011 motions (as shown in the plots of the next page).

However, when (in the subsequent page) all these spectra are normalised with their respective PGA, it is revealed that at  $T \approx 3$  s both earthquakes have produced significant humps; and in fact those of the recent event are stronger. A plausible hypothesis is that the weaker incident waves have now led to greater soil amplification at this long-period range. (see Refs.)

### Comparison of Christchurch acceleration response spectra between

M<sub>w</sub> 7.8, 2016 Kaikoura, and

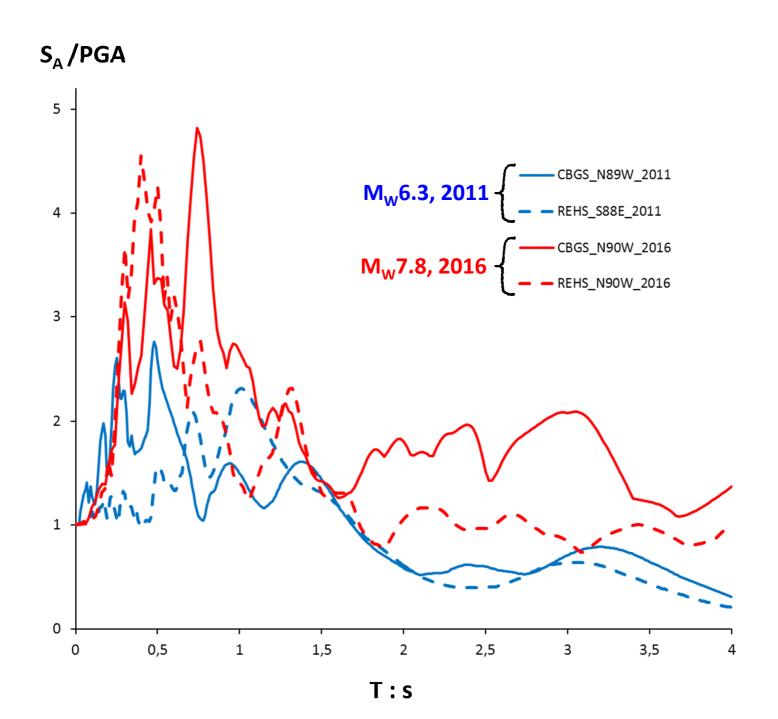
M<sub>w</sub> 6.3, 2011 Christchurch EQs



### Comparison of Christchurch acceleration response spectra

### normalised with PGA, between

 $M_W$  7.8, 2016 Kaikoura, and  $M_W$  6.3, 2011 Christchurch EQs



# Emergence of Fault Rupture on the Ground Surface



A house at Bluff Station btw Blenheim & Kaikoura. Right on top of the Kekerengu fault line.

**Source: Temblor** 

## In detail the right-lateral strike-slip fault rupture

**Source: Temblor** 



House moved and heavily damaged, but the cylindrical barn (or tank?) seems to have escaped damage (perhaps by fault "diversion"??)

#### **Kekerengu Fault rupture crossing a house**



Thrust-Fault Rupture directly under the middle of a single-storey house (about 32km north-east of Kaikoura).

**Source: GeoNet** 



Notice the courageous attitude of the young mother!

**Source: 1 NEWS** 

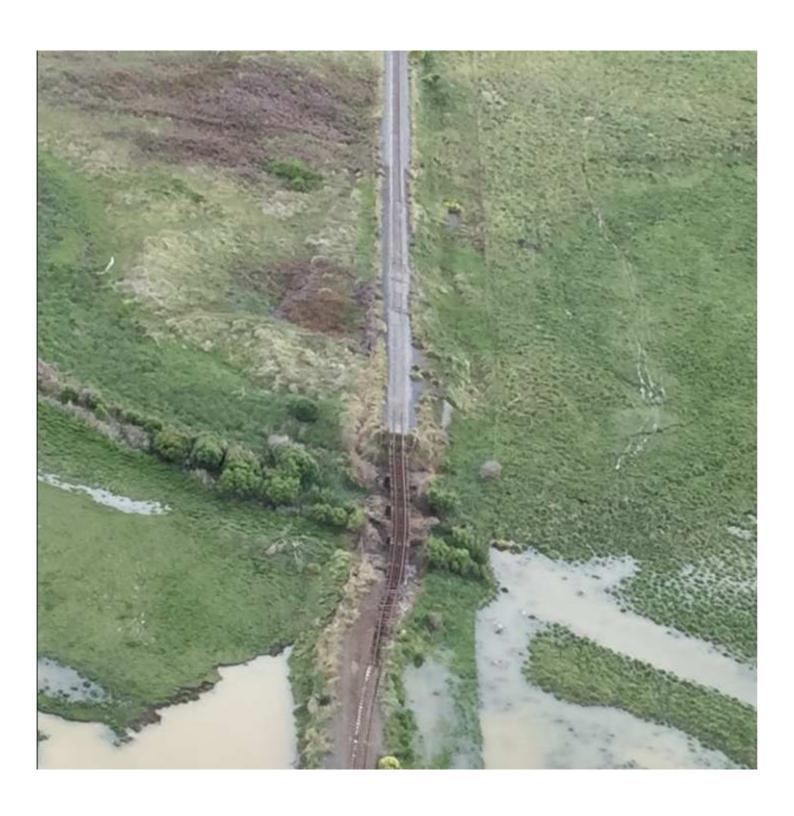


Straddling the Fault:

Not too bad

for some close neighbors!

[GG + EG]



Kekerengu fault - very clear rupture here.

**Source: Alex Perrottet** 





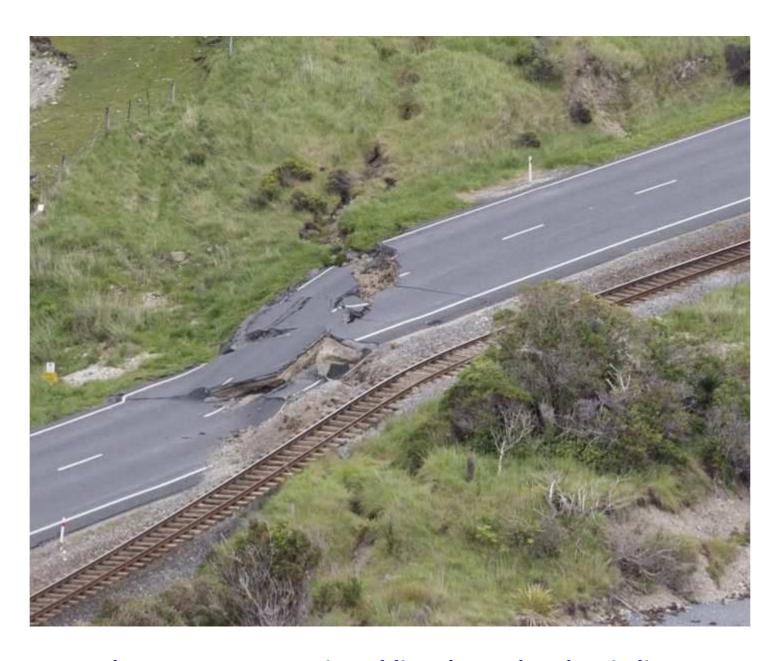
Near Kaikoura coast.

[WESTPAC RESCUE HELICOPTER]



Right-Lateral Strike-Slip Fault rupture of the ground surface (\*near Kaikoura)

[NZ Defense Force]

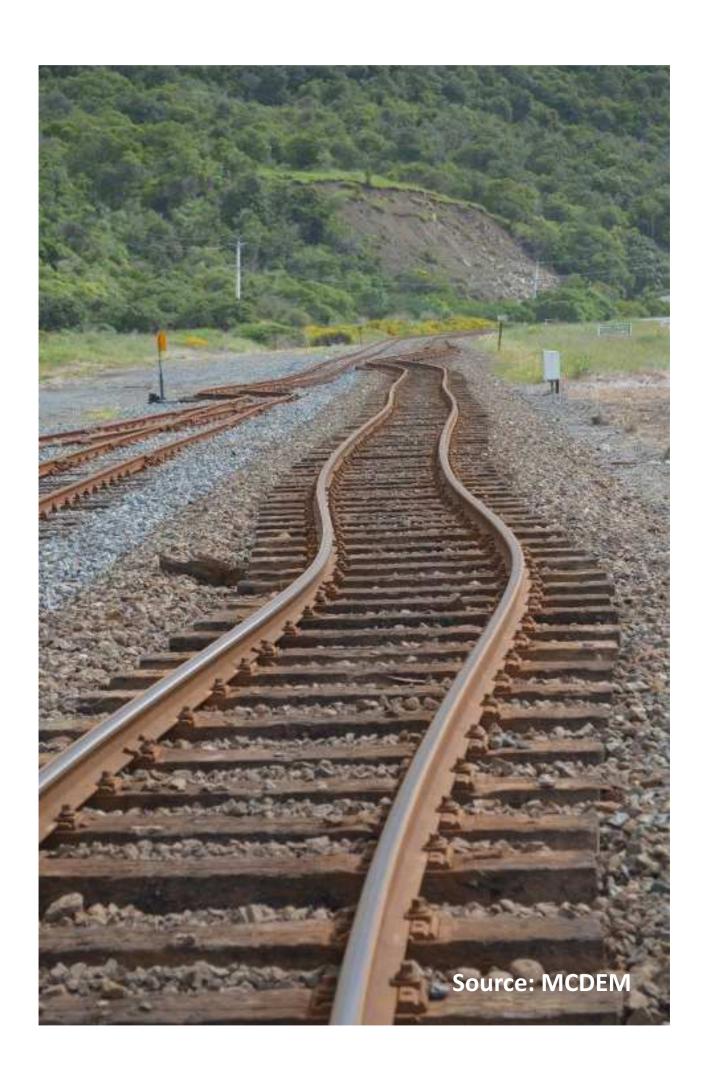


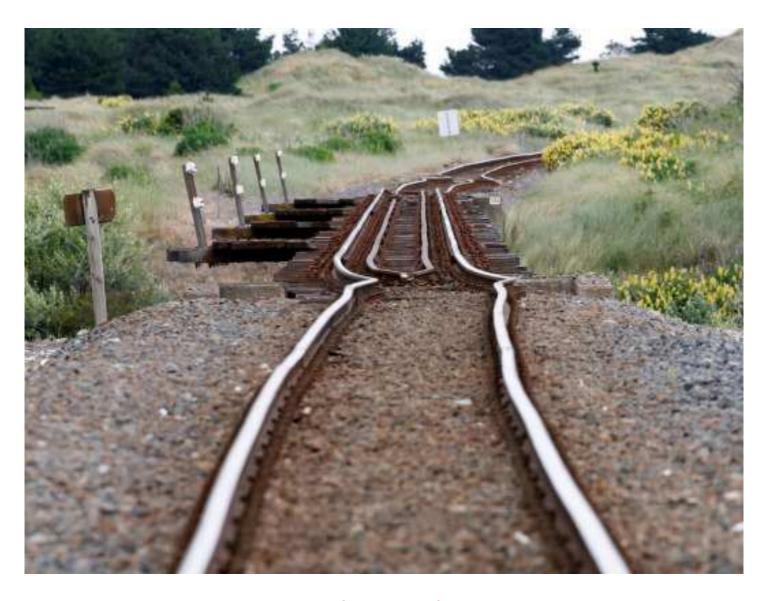
Thrust Rupture crossing obliquely road and train lines

**Source: Getty Images** 









A railway line damaged (perhaps) by an emerging fault rupture. (Exact mechanism cannot be identified from this photo alone.)

(Near Tirohanga stream south of Blenheim.)

**Photo: ANTHONY PHELPS/REUTERS** 



Strike-slip (?) Rupture hits obliquely the road

Photo: Stuff.co.nz



Rupture of the Hundalee Fault displacing SH1 and the railway line.

(Strike-Slip with a Thrust component ??)

**Source: GeoNet** 

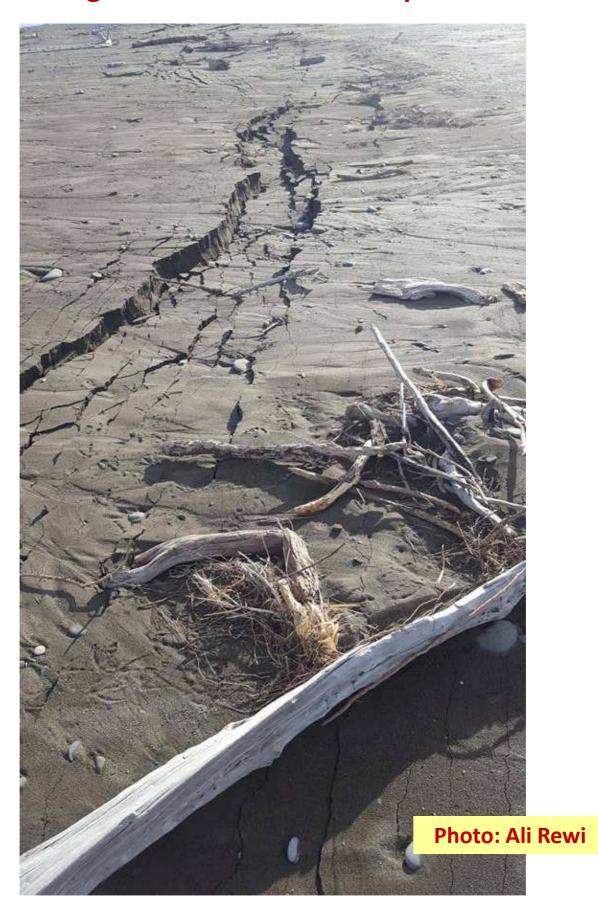


Lines damages on road close to Waiau

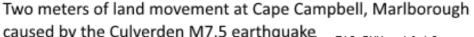
Interesting, but exact cause unknown

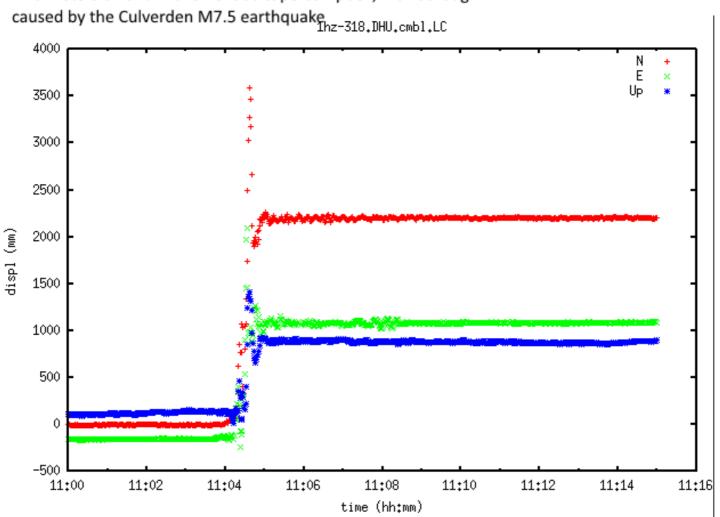
**Source: RZN/Conan Young** 

#### Rangitukia beach after the quake



#### 2 meters of land movement recorded on the Cape Campbell (Marlborough) GPS station.

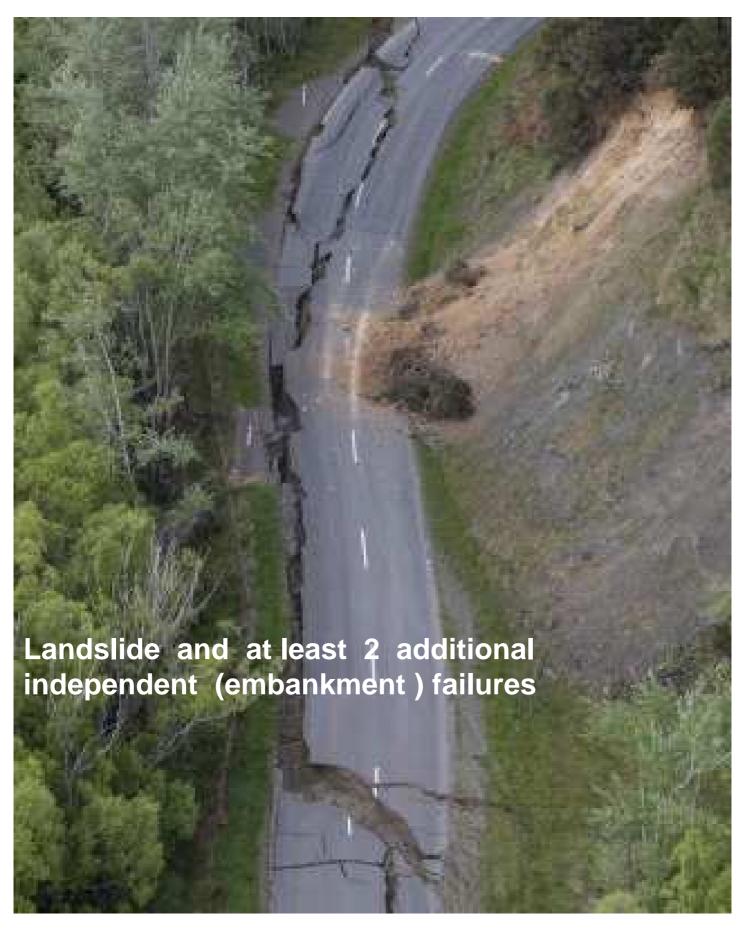




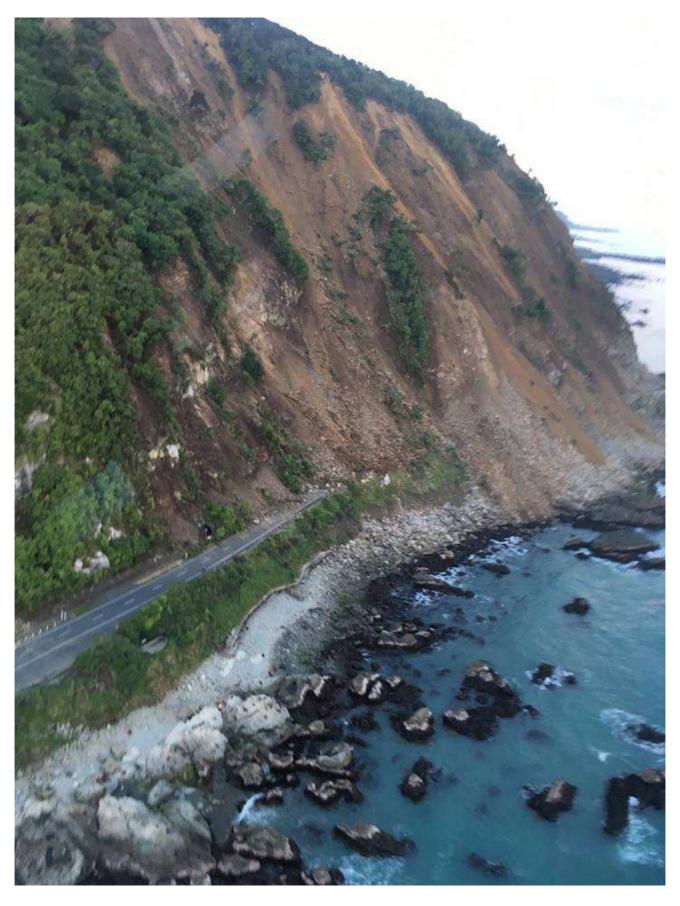
**Source: GEONET** 

### **LANDSLIDES**

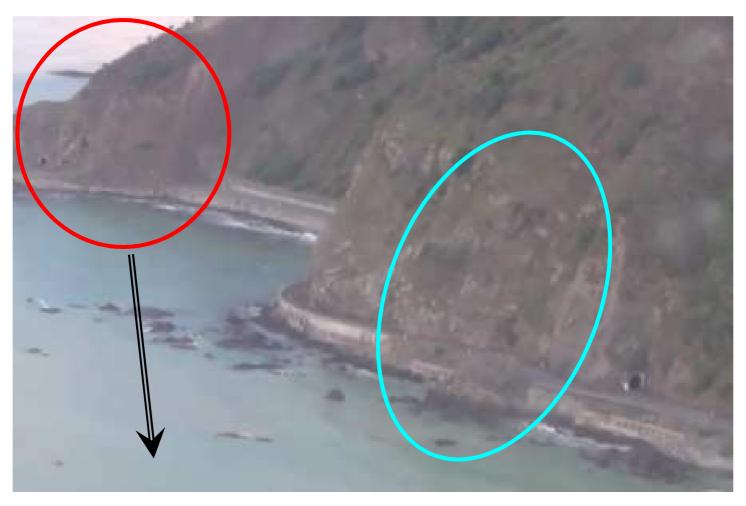
GeoNet estimates (from reconnaissance flights) that there may have been from 80 000 to 100 000 landslides!!!



Major road damage near Mt Lyford. [AIN MCGREGOR/FAIRFAX]



SH1: from precarious equilibrium to landslide



• Kaikoura and other South Island towns have been cut off, with the famous SH1 road and rail tunnels blocked by landslides



[Photograph: David Alexander/AP]



Tunnel entrances buried and distorted

[Photograph: David Alexander/AP]





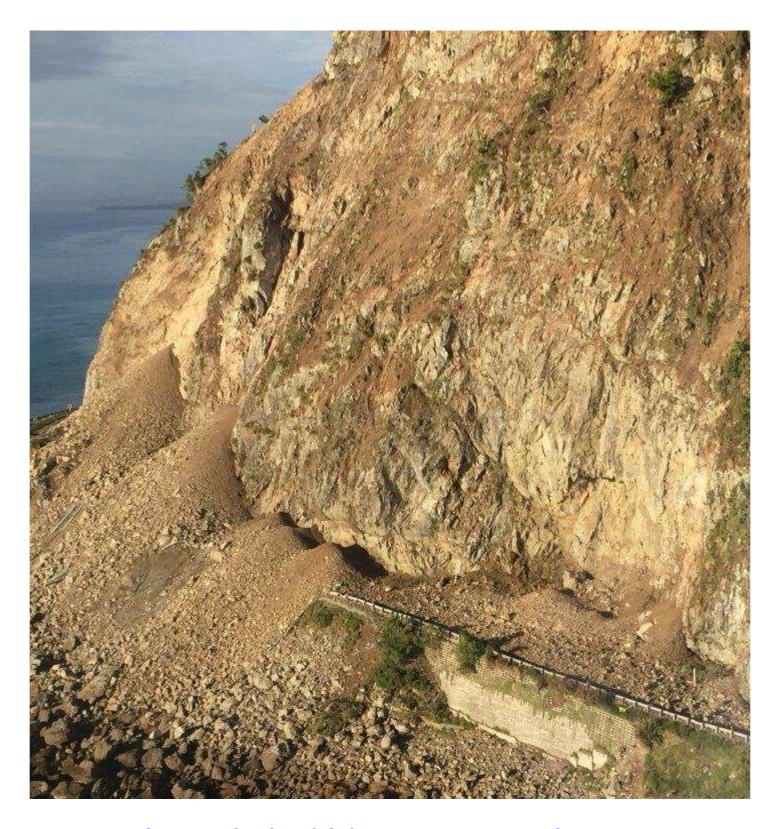
no comments











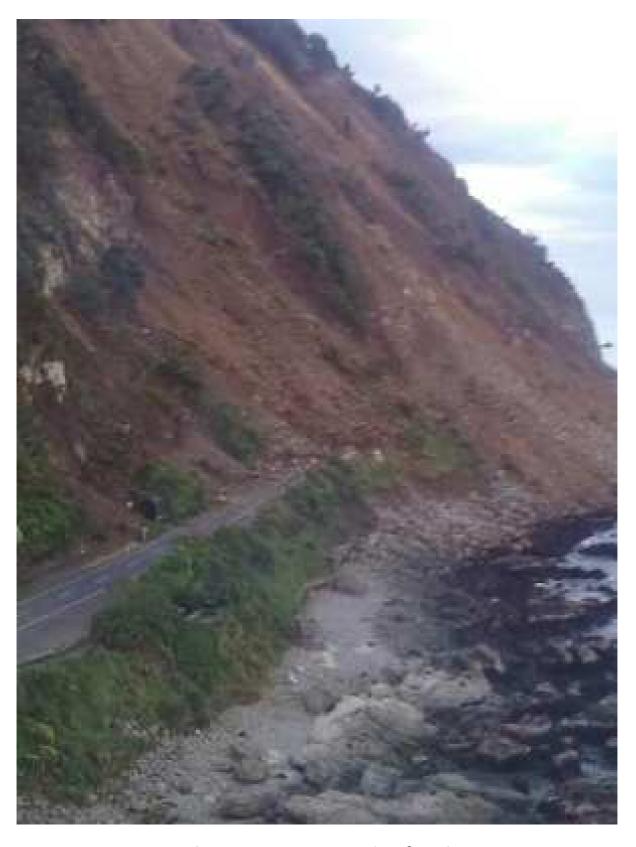
Another similar landslide on SH1, near Kaikoura

**Source: Marlborough Emergency** 



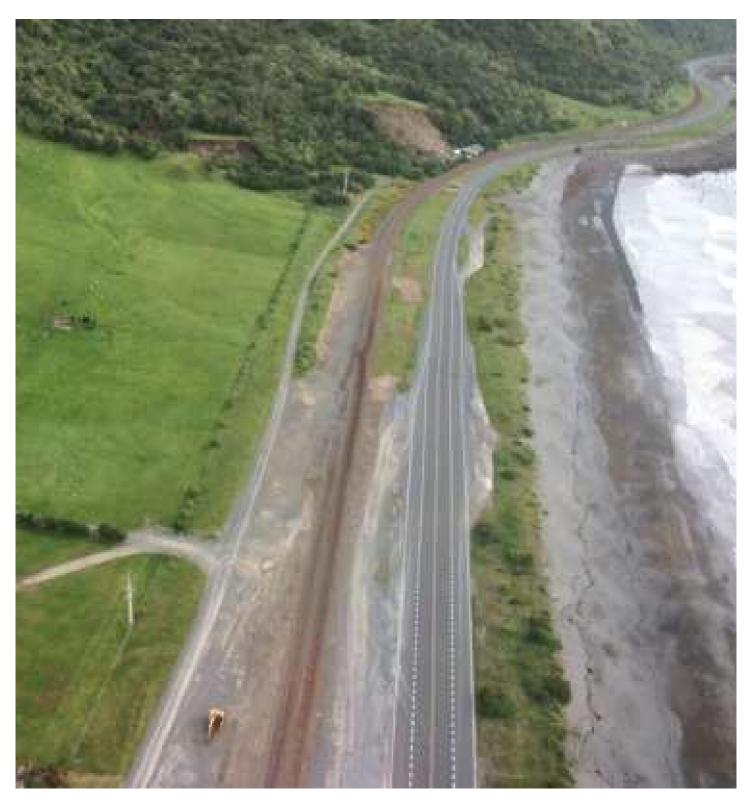
**Landslide blocked the State Highway 70** 

**Photo: Sam Smith** 



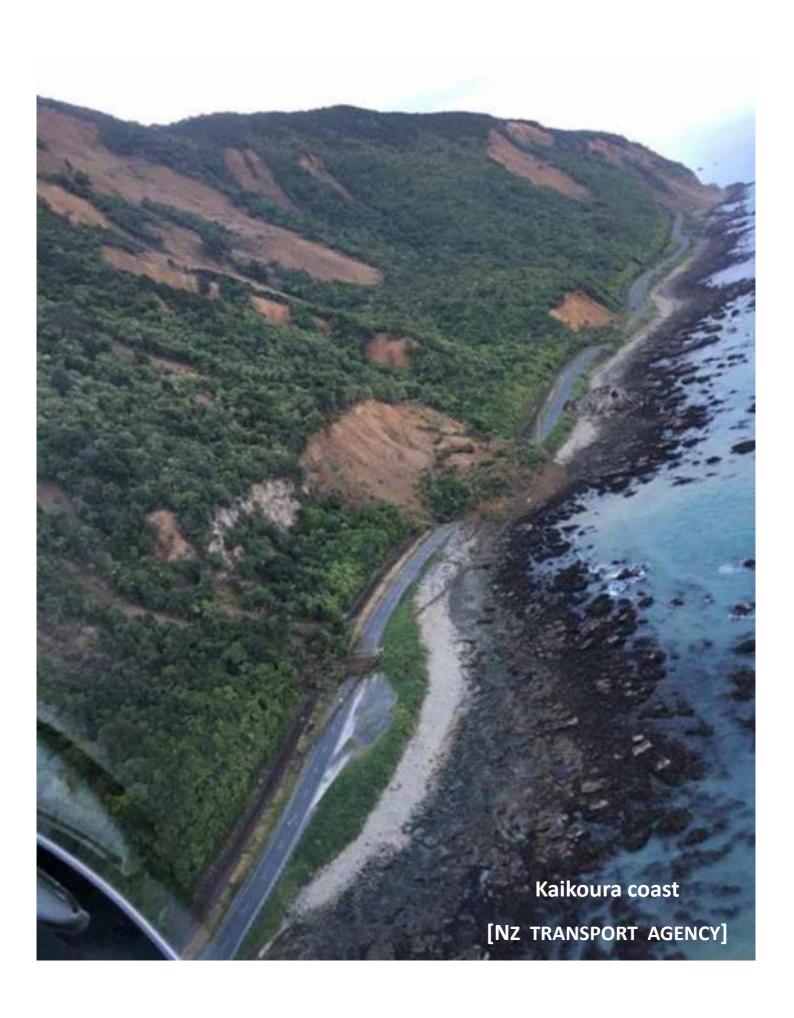
Oahu Point, SH1 north of Kaikoura.

[NZ TRANSPORT AGENCY]



Slip near SH1 south of Kaikoura. [WESTPAC RESCUE HELICOPTER]

Several Failure Mechanisms can be seen (even if barely) in this photo ! [GG+EG]





Landslide affecting house in Kaikoura.

[NZ Defense Force]

House appears severely damaged, but it did not collapse [GG+EG]



Photo: Stuff.co.nz

#### The railway displaced (max 100 m) from landslide



Photo: Stuff.co.nz

#### ...another view...

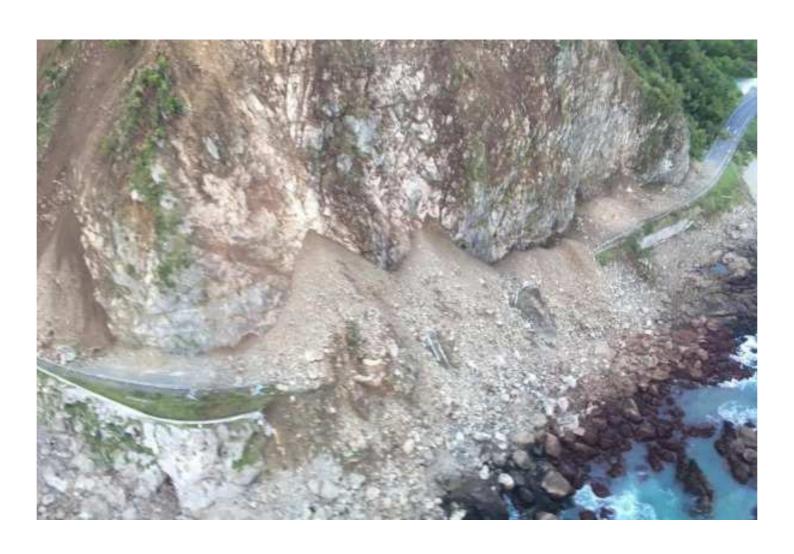


Photo: Thespinoff.co.nz



State Highway 1 (SH1).

**Photo:** Nelson Marlborough Rescue Helicopter



State Highway 1

**Photo:** Nelson Marlborough Rescue Helicopter



Clarence River, which flows from the Southern Alps, is blocked by landslide mass



Huge landslide on SH1 near Kaikoura.

**New Zealand Defense Force** 



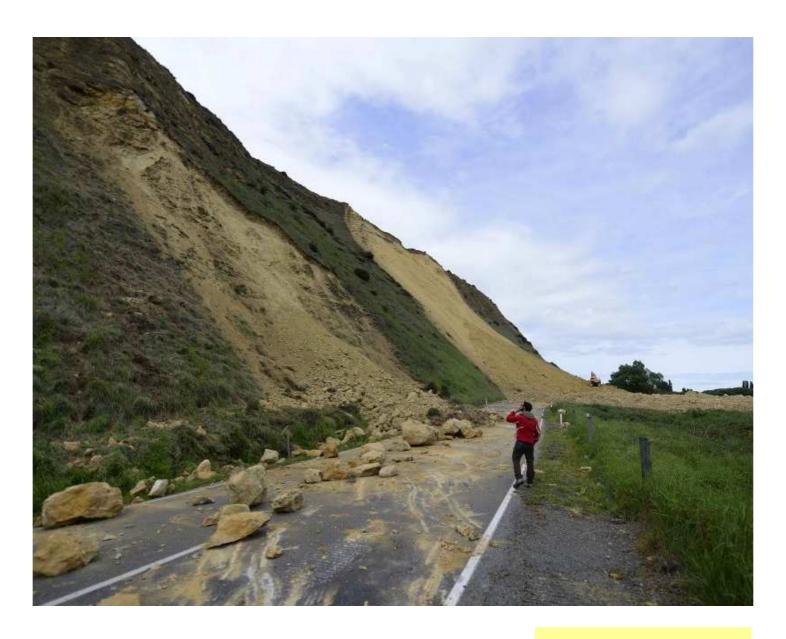
Extreme **retrogressive** landslide in Kaikoura.

Source: Ross Giblin/Fairfax NZ



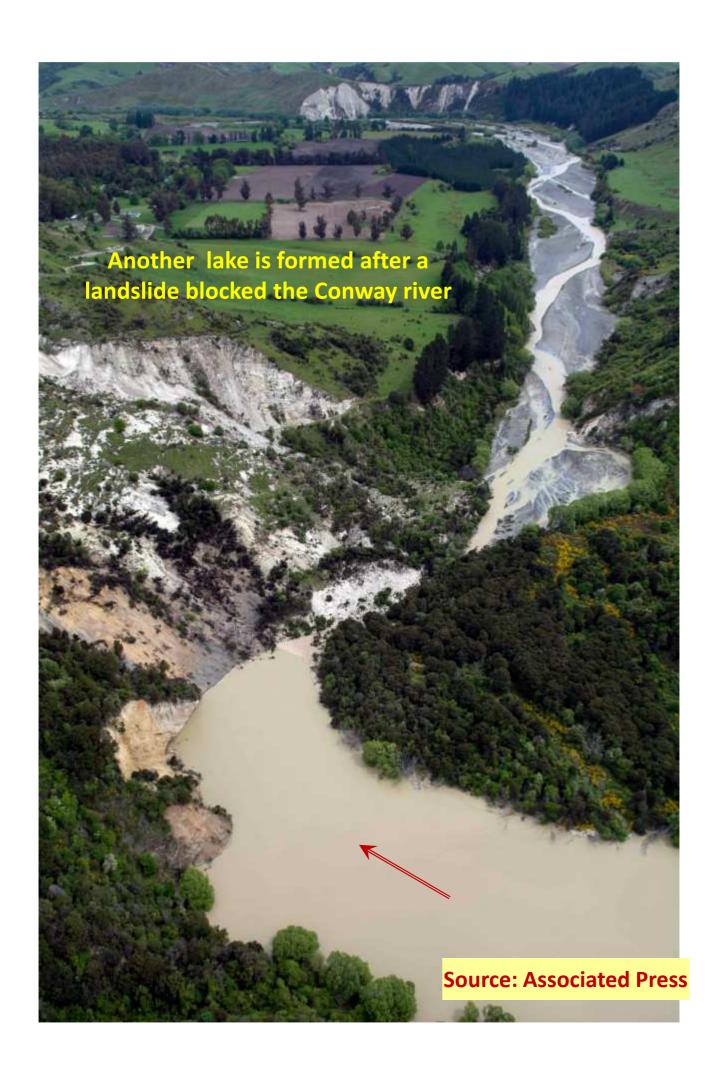
SH1 near Kaikoura.

Source: IAIN MCGREGOR/FAIRFAX NZ



**Source: Getty Images** 

Notice the precarious situation (very steep slope next to a highway) that led to disaster





Damage to Rotherham Road near Waiau town, some 90 kms to the south of Kaikoura. [Photograph: Matias Delacroix]

**Source: Getty Images** 

Again, a very steep slope consisting of soft clay-like material next to the highway!



Damaged road from local slide (between Kaikoura and Mt Lyford)

**Source: RZN/Rebekah Parsons** 

# Uplift of Seabed Due to Thrust Faulting



The seabed uplift north of Kaikoura – estimated between 2–2.5 m.



The purple-tinted areas represent the uplift.

[Photos: Tonkin+Taylor]





The seabed rose up to 2.5 metres in places.

[Photos: Tonkin+Taylor]

Before After





Aerial view of Waipapa Bay showing the uplift of the shore.

Source: Tonkin & Taylor

# Road & Embankment Damage



Road closures due to earthquake damage, according to the NZ Transport Agency.



Several possible mechanisms... None obvious





**Damage along Leader Road** 



Trucks parked up on State Highway 1 north of Ward



Damage to "Needles" Bridge Abutment (?) north of Ward.



Kaikoura MP Stuart Smith stands in destroyed road *embankment* 



Damaged Road in the Clarence Valley, Hanmer Springs. [Photo: Tara Manson]

**Source: NZ Herald** 

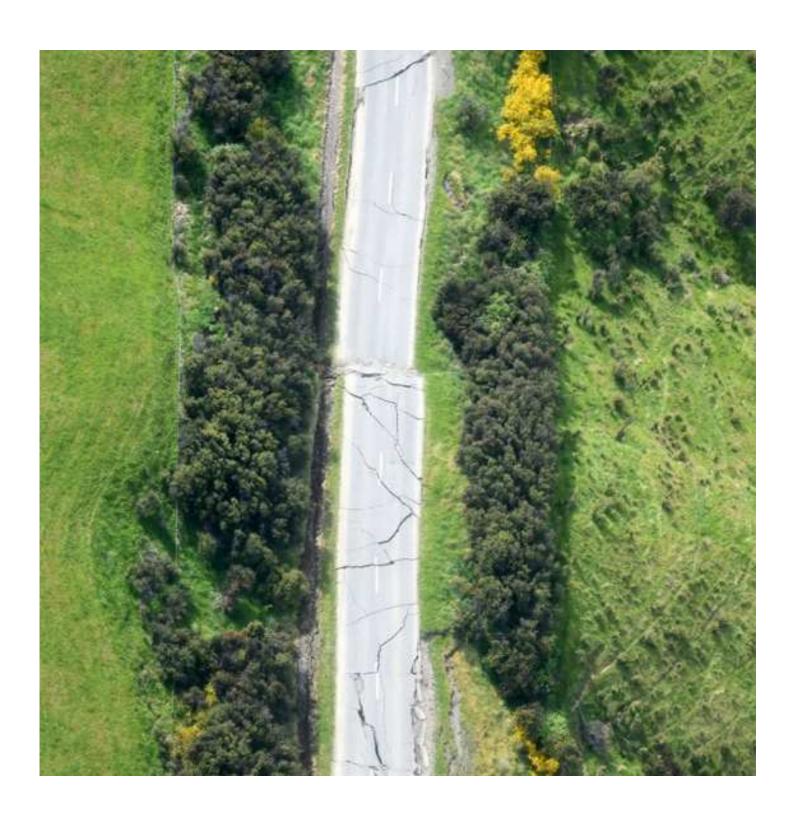




Major road damage near Mt Lyford. [AIN MCGREGOR/FAIRFAX]



A slip near Mt Lyford. [AIN MCGREGOR/FAIRFAX]



Road damage in the Kaikoura area .

[NZ Defense Force]



Source: Stuff.co.nz



Local residents look at damage along State Highway 1 near the town of Ward.

**Photo: ANTHONY PHELPS/REUTERS** 



Photo: Stuff.co.nz



Damage along State Highway 1.

Source: Stuff.co.nz

### **Structural Damage**

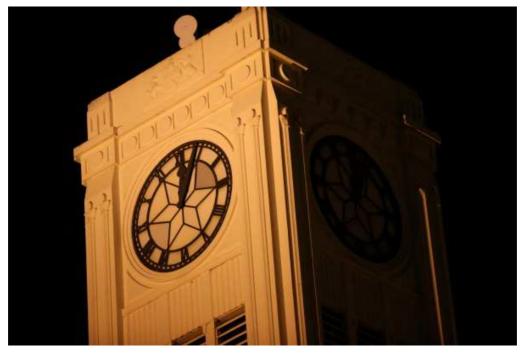
Fortunately of limited extent thanks to the thinly populated (mountainous) area



Culverden and Kaikoura are thought to be the worst affected areas



Builing damage on Picton's High St



The Timaru town clock stopped after the major earthquake just after midnight



Debris from buildings are seen on a sidewalk past a cordon line in Wellington early on November 14, 2016 following an earthquake centred some 90 kilometres (57 miles) north of New Zealand's South Island city of Christchurch © Marty Melville / AFP

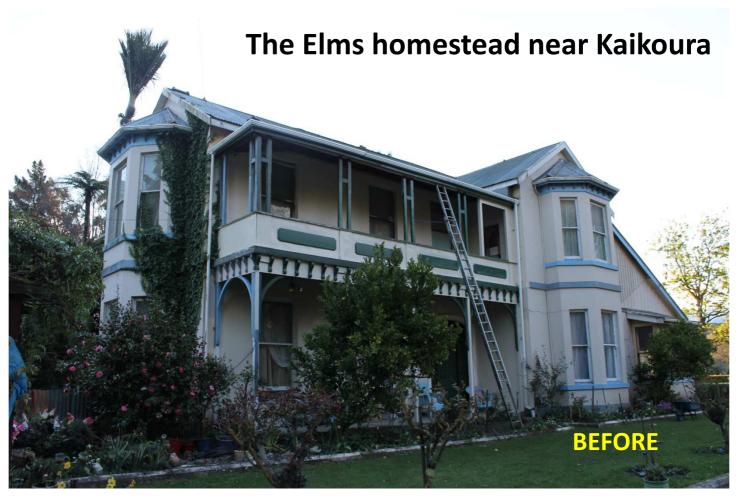


Rock slip blocking 100 metres of Inland Kaikoura Road, north of Cheviot

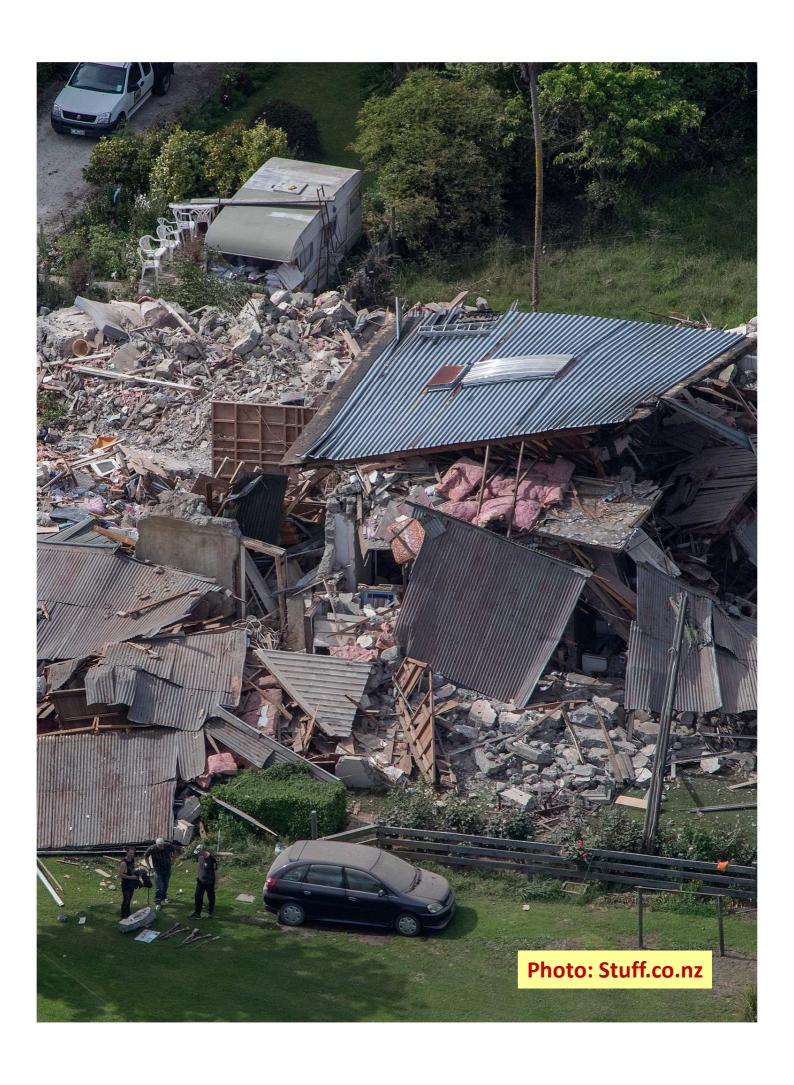


Destruction of *UMR house* in Kaikoura

Photo: Stuff.co.nz

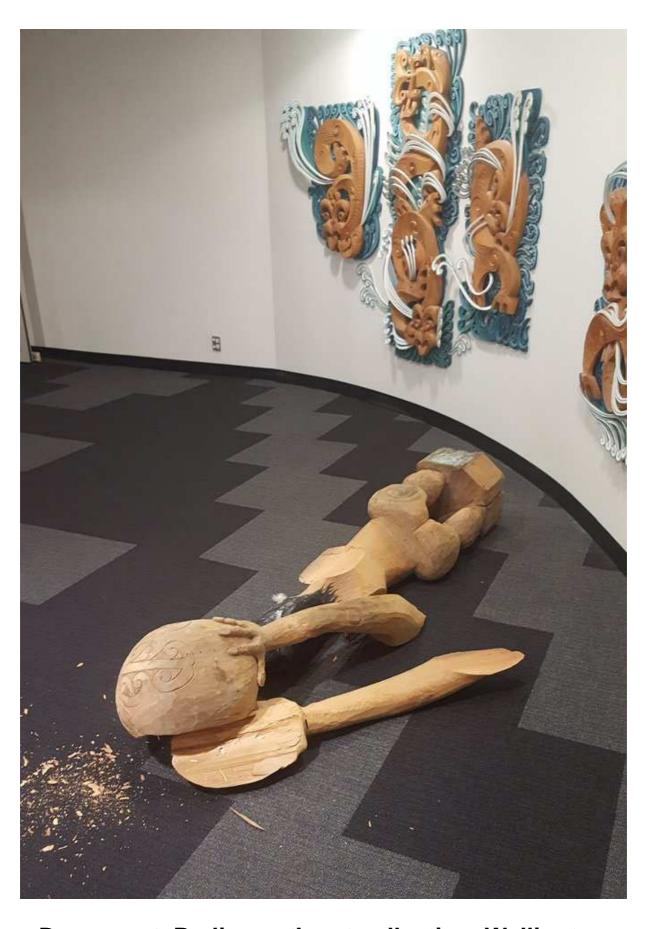




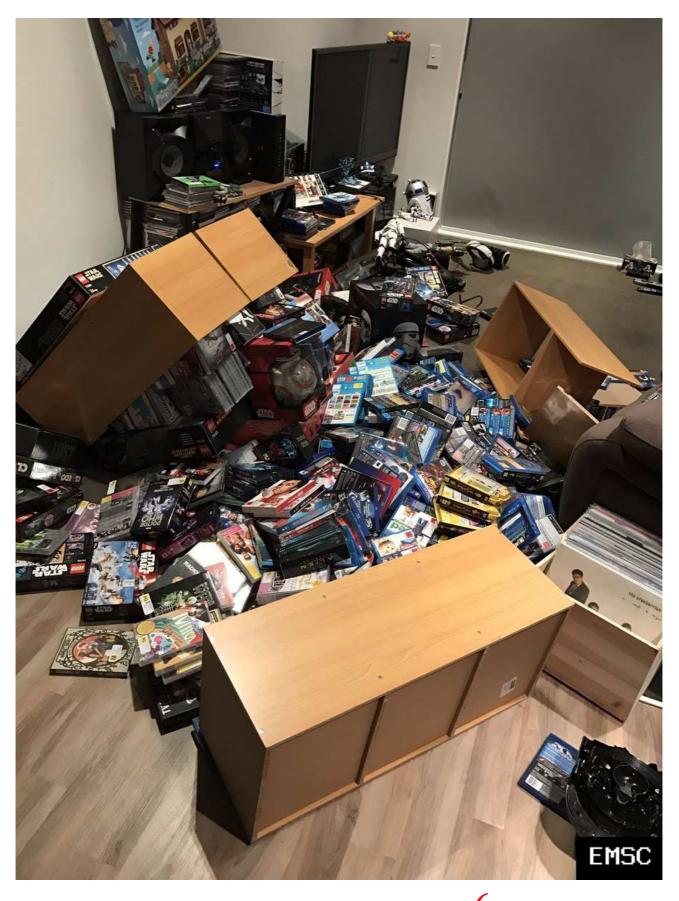




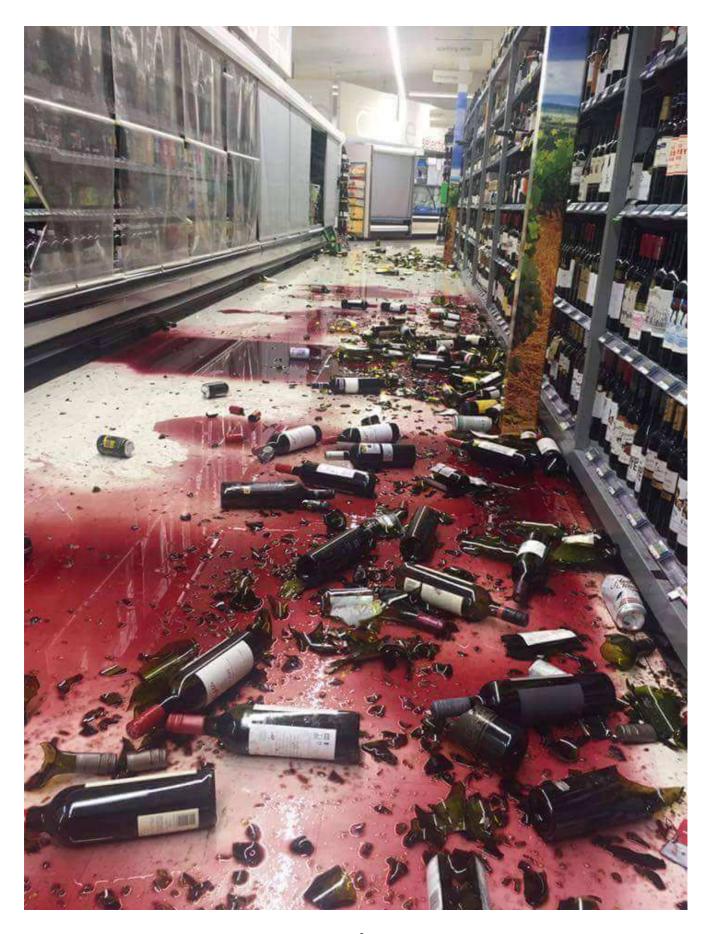
Damage in Parnassus, south of Kaikoura



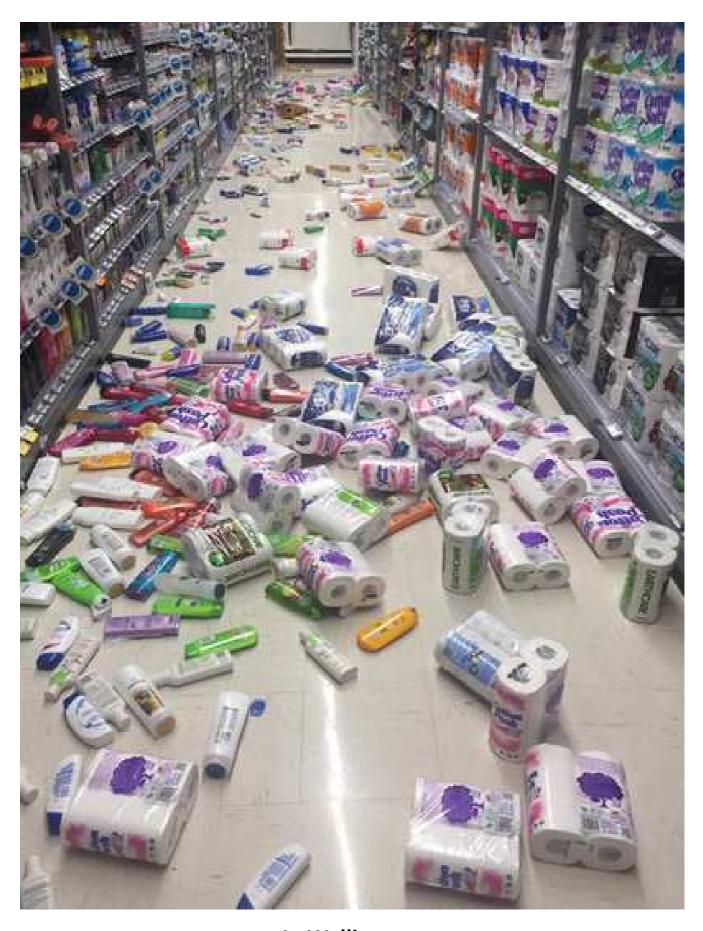
Damage at Parliament's art collection, Wellington



In Wellington, Distance to epicenter: 255 km (but much closer to the ruptured fault ! [GG + EG])

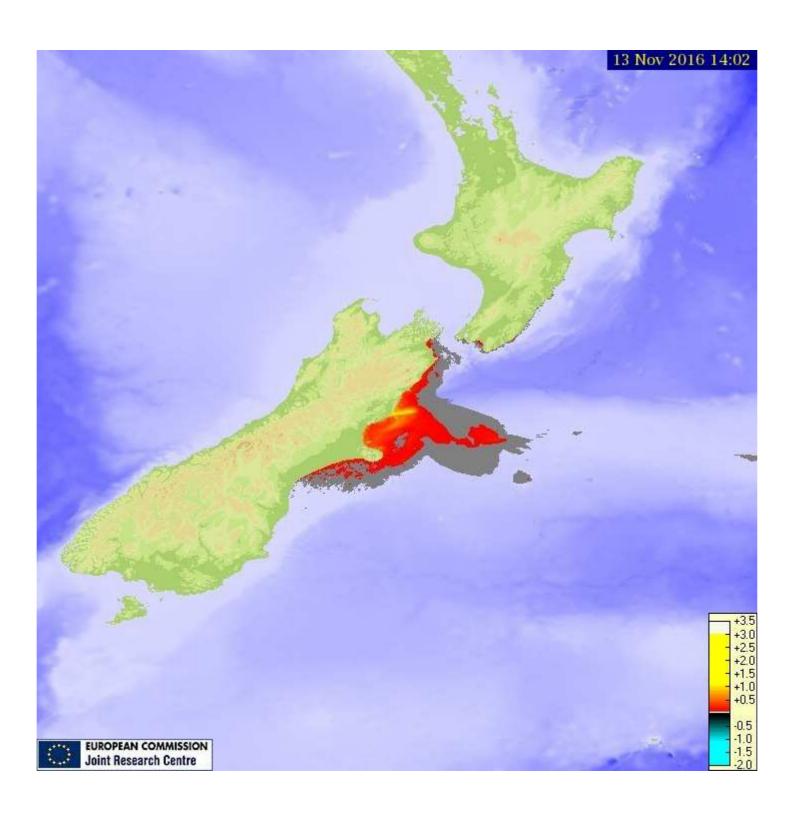


In Nelson



In Wellington

### Tsunami



Based on pre-calculated scenarios, the maximum tsunami wave height near the coast of New Zealand will be 2 m **Source: GDACS** 

# The sea level gauges in Kaikoura and Wellington





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#### Sources/References

**GEONET** (http://www.geonet.org.nz/) **GNS** (https://www.gns.cri.nz/) **USGS** (http://earthquake.usgs.gov/) **BECA** (http://www.beca.com/) EMSC-CSEM (http://www.emsc-csem.org/) Marlborough District Council (http://www.marlborough.govt.nz/) **Antonopoulos I. , Coffee, NZ** (Personal communication) **NZ Transport Agency** (https://www.nzta.govt.nz/) **Stuff** (http://www.stuff.co.nz/) Ministry of Civil Defense + Emergency Mgnt (http://www.civildefence.govt.nz/) **The Guardian** (https://www.theguardian.com) **NZ Herald** (http://www.nzherald.co.nz/) **Temblor** (http://temblor.net) **Tonkin & Taylor** (http://www.tonkintaylor.co.nz/) Wikipedia (https://en.wikipedia.org/wiki/2016 Kaikoura earthquake) **Scoop** (http://www.scoop.co.nz/) **The Mirror** (http://www.mirror.co.uk/) BBC (http://www.bbc.com/news/world-asia-37970775) **Associated Press** (www.ap.org) Earthquake-Report.com (http://earthquake-report.com/2016/11/13/massiveearthquake-culverden-on-november-13-2016/) Google Maps (https://maps.google.com/) **The Spinoff** (http://thespinoff.co.nz) **Getty Images** (www.gettyimages.com)

**Gazetas G., Garini E., Berill J.B., Apostolou M.** "Sliding and Overturning Potential of the Christchurch 2011 Earthquake Records", *Earthquake Engineering and Structural Dynamics*, Vol. 41(14), pp. 1921-1944, 2012.

## New Zealand: be strong

