National Science Challenges
RESILIENCE TO NATURE'S CHALLENGES
Kia manawaroa – Ngā Ākina o Te Ao Tūroa

EARTHQUAKE SIMULATOR RESEARCH – WEBINAR

9 March 2021

Presentation Outline

1) Why virtual earthquakes?
2) Virtual earthquake generation
3) Earthquake and fault interactions

UC
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

EQC
EARTHQUAKE COMMISSION
KŌMIHANA RŪWHENUA

NIWA
Taihoro Nukurangi

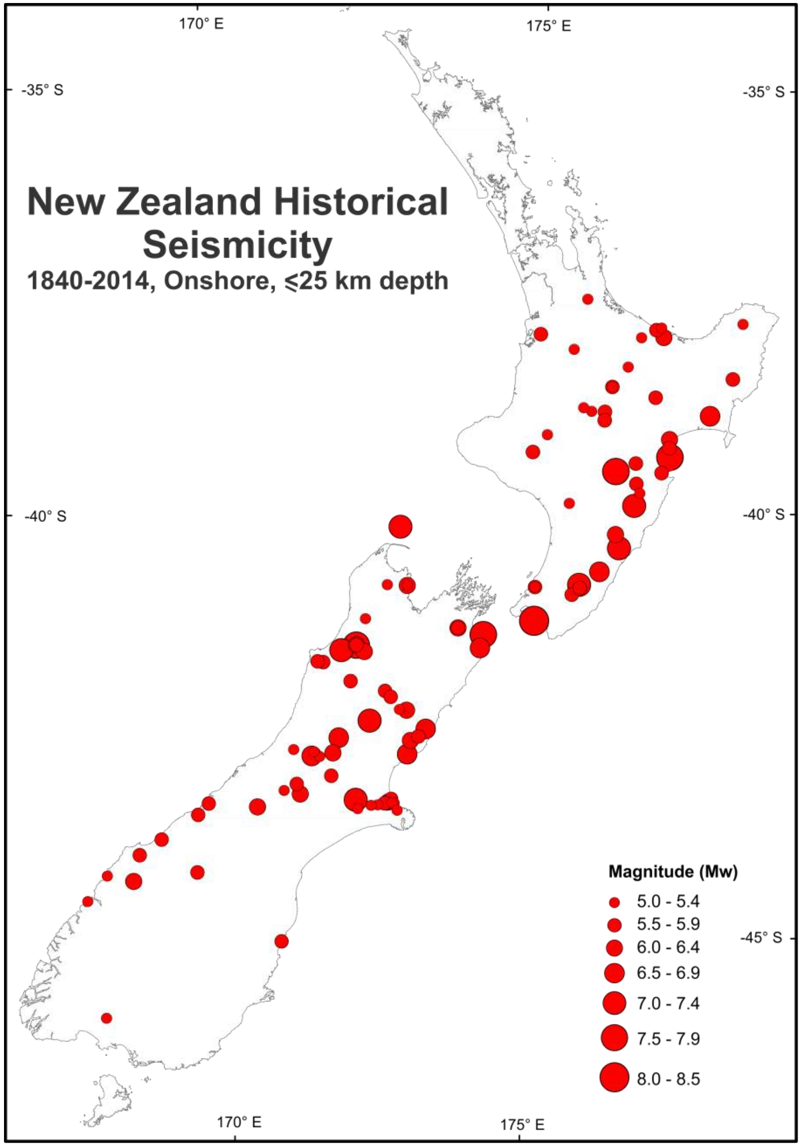
Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND
SAPERE AUDE

VICTORIA UNIVERSITY WELLINGTON
TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI

GNS SCIENCE
TE PŪ AO

The Earthquake Information Problem



Seismic hazard information is typically derived from historical and prehistorical earthquakes.

The NZ historical earthquake record of ~180 yrs is very short by geological standards.

~20 historical earthquakes > M7

We only have good prehistoric earthquake information for ~50 of ~900 known active faults (~5%).

200-300 prehistorical earthquake

NZ experienced 100,000-500,000 >M7 earthquakes in last 1 Myrs

National SCIENCE Challenges

RESILIENCE TO NATURE'S CHALLENGES

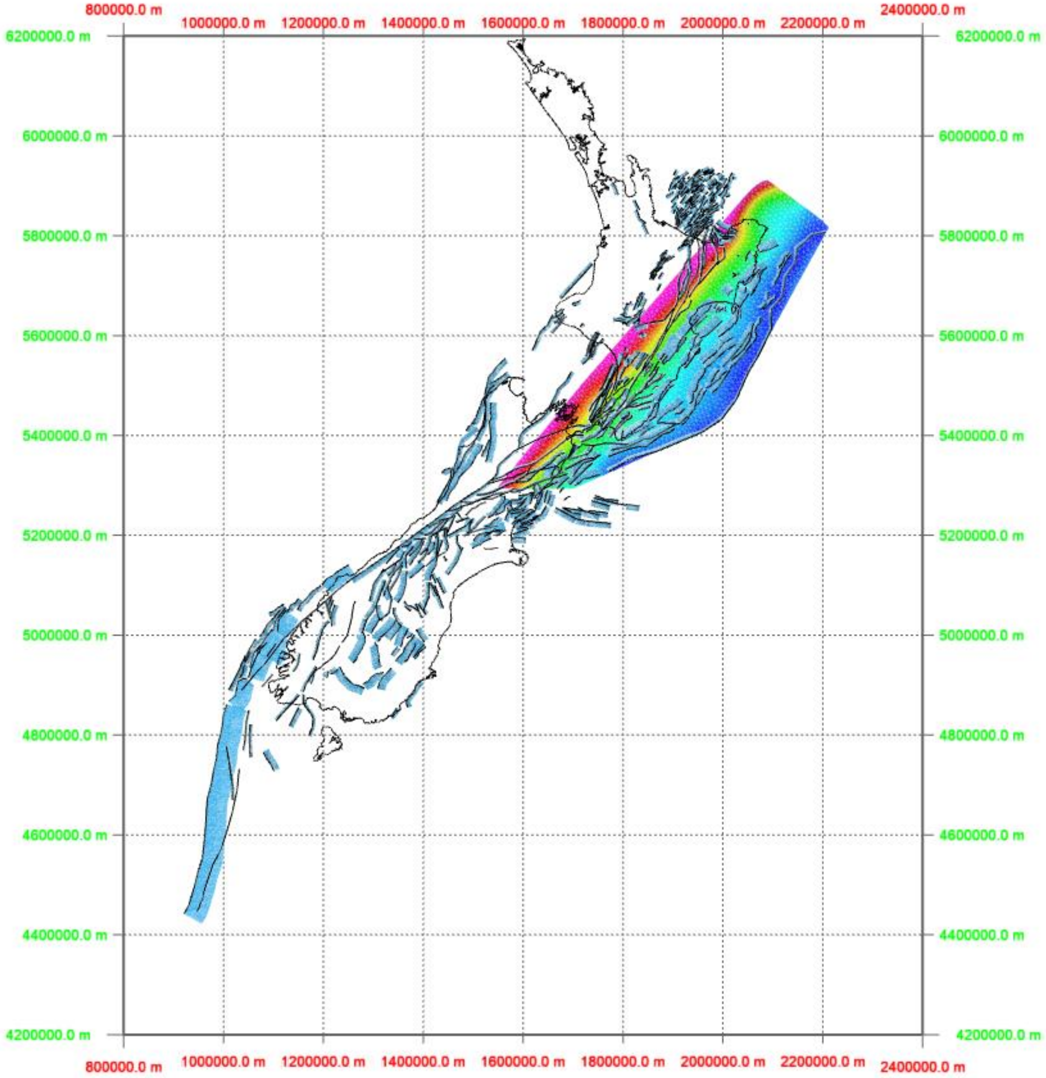
Kia manawaroa – Ngā Ākina o Te Ao Tūroa

Solving the earthquake information problem

Develop physics-based models of virtual earthquakes enabling new avenues of research to assess and forecast a range of earthquake-related hazards.

Kaikōura Earthquake fault rupture (photo Kate Pedley)

What is an Earthquake Simulator?



NZ Fault Source model (2020)

Physics-based computer model that approximates earthquake processes.

Uses information from known faults (e.g., location, size, slip rate).

Assign model rock and fault properties.

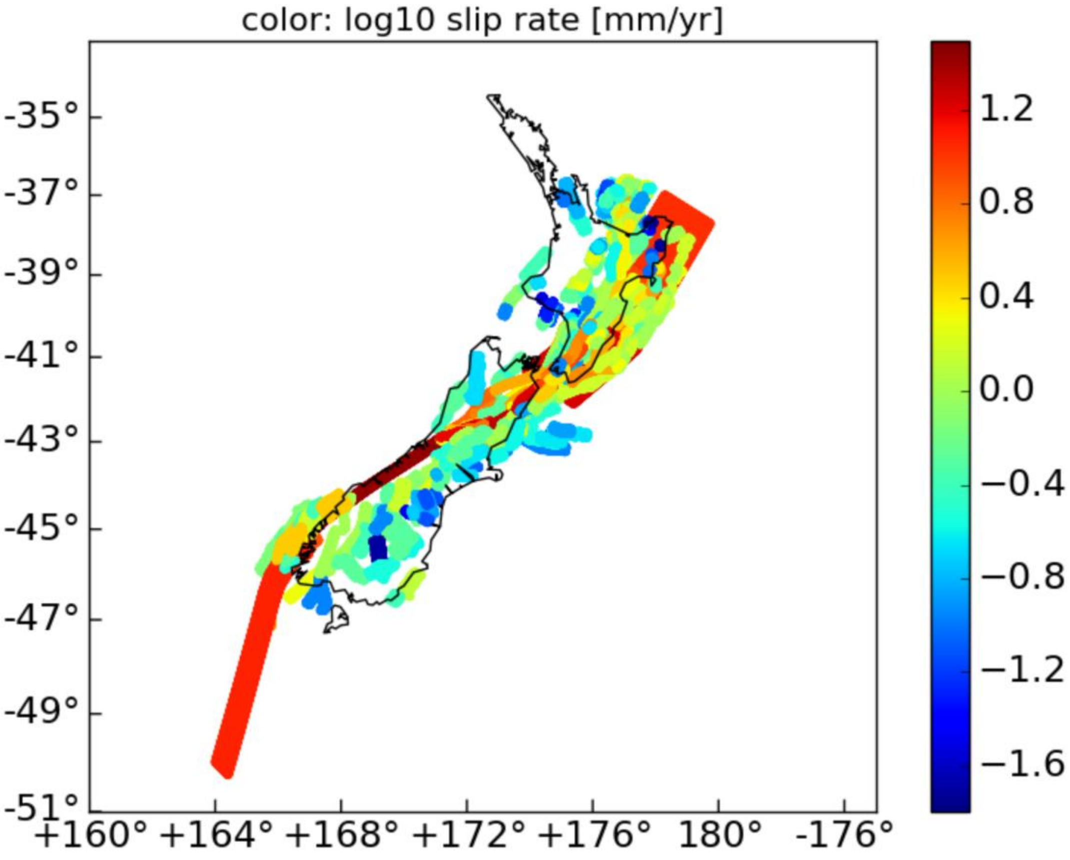
Model stresses faults and tracks resulting earthquakes.

Model can be used for 100s of faults and millions of years.

NZ model uses RSQSim software (Richards-Dinger & Dieterich, 2012).

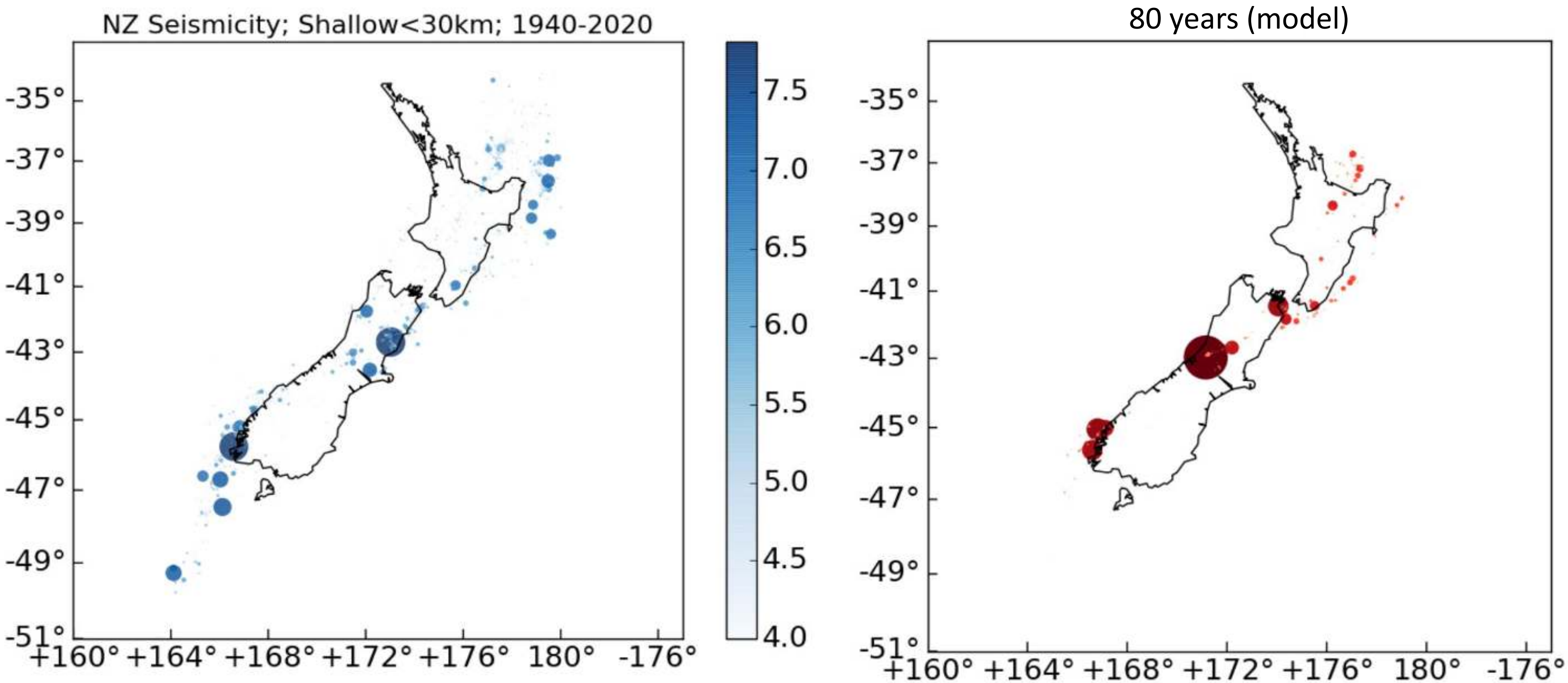
New Zealand Virtual Earthquake Model

- RSQSim model running for NZ (Shaw et al. preprint).
- Initial simulator model uses faults from Stirling et al. (2012).
- New Zealand fault model revised and updated (new model includes >900 faults – 70% increase from previous model).



Shaw et al. (preprint)

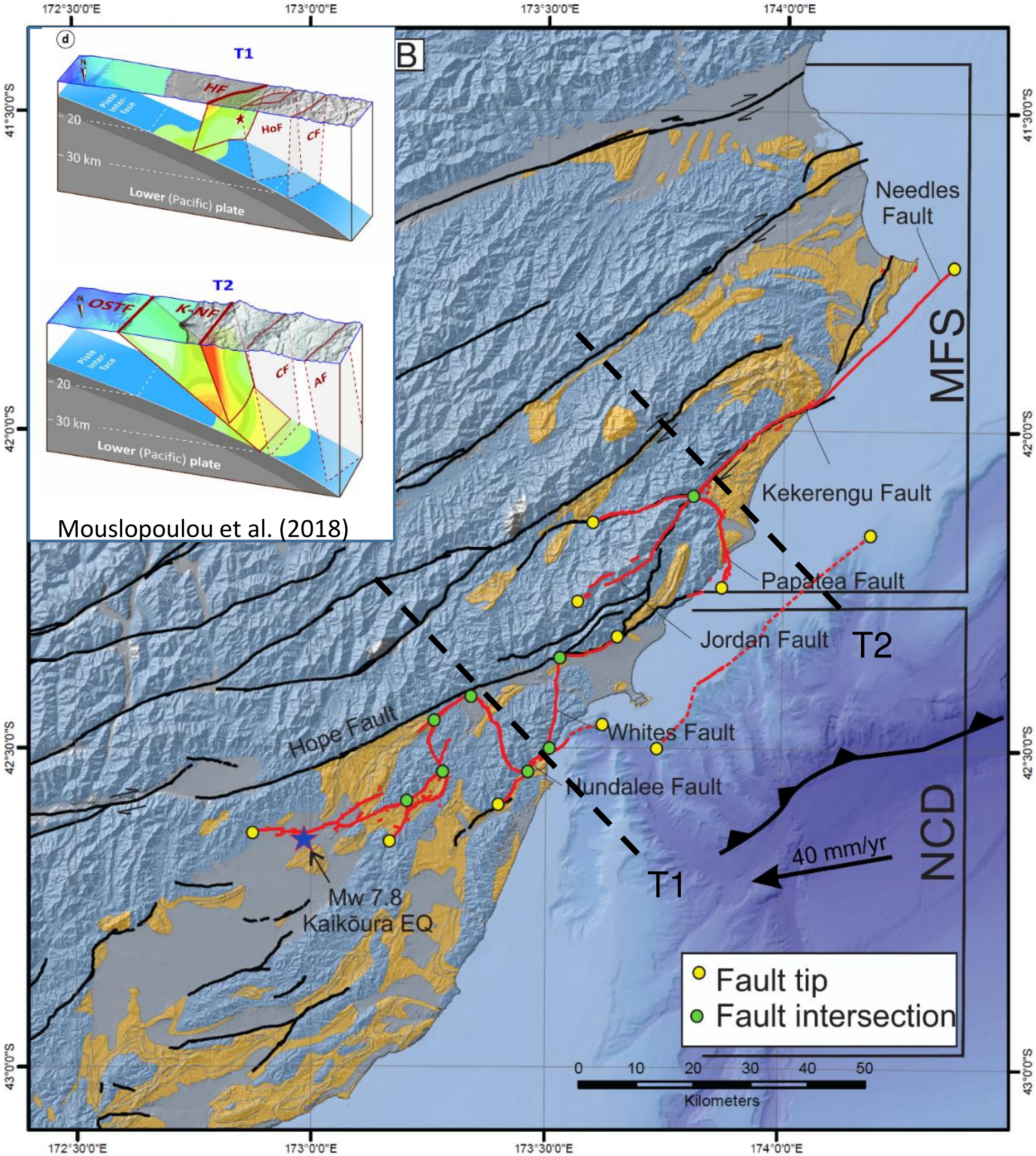
Comparison observations and model



Shaw et al. (preprint)

Broad earthquake patterns from simulator show many similarities to historical earthquakes.

Kaikōura Earthquake – multiple faults



Mouslopoulou et al. (2018)

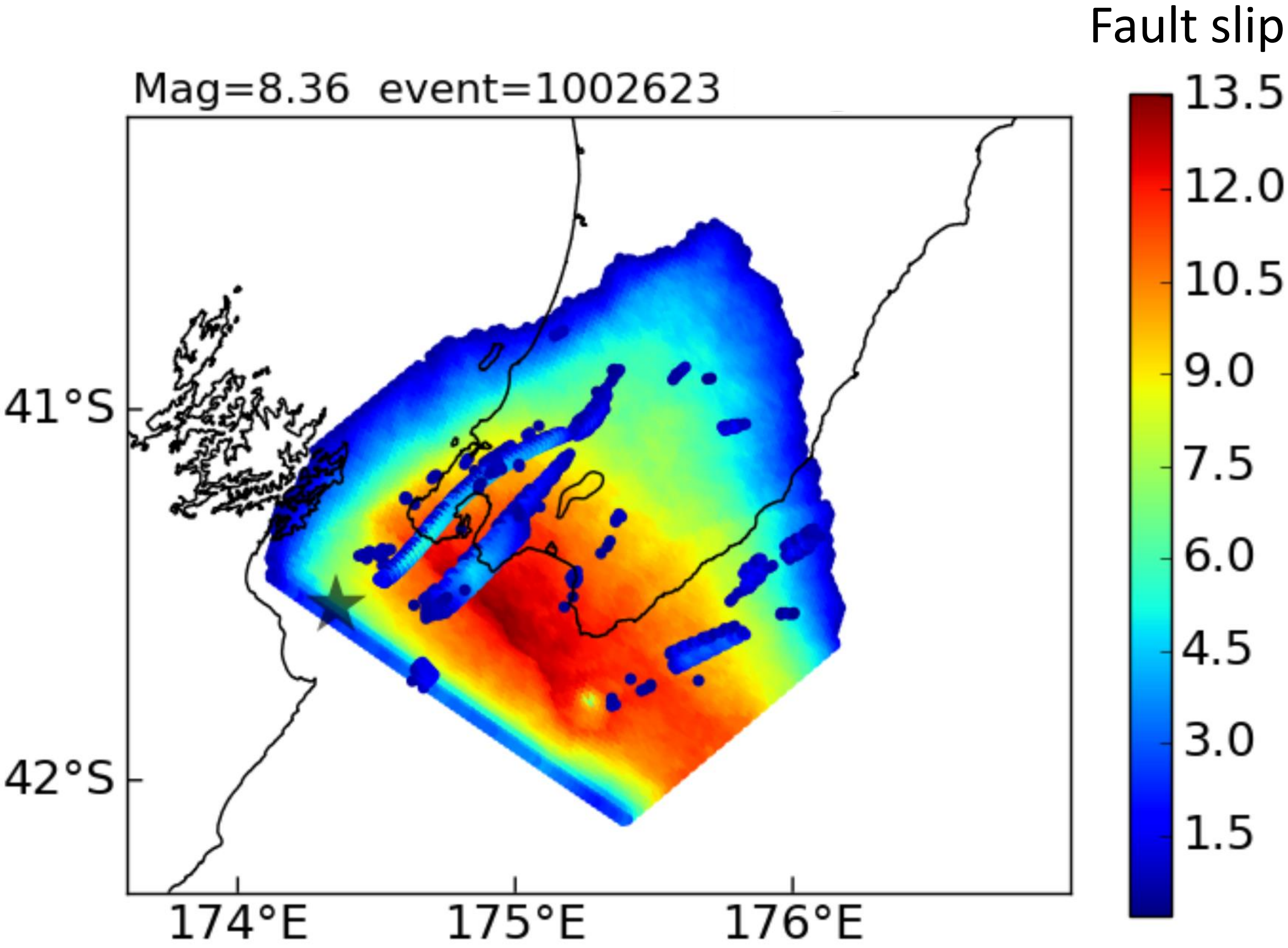
Modified from Nicol et al. (2018)

Multi-fault ruptures are common in the NZ historical earthquake record.

Are they common in our virtual earthquake record?

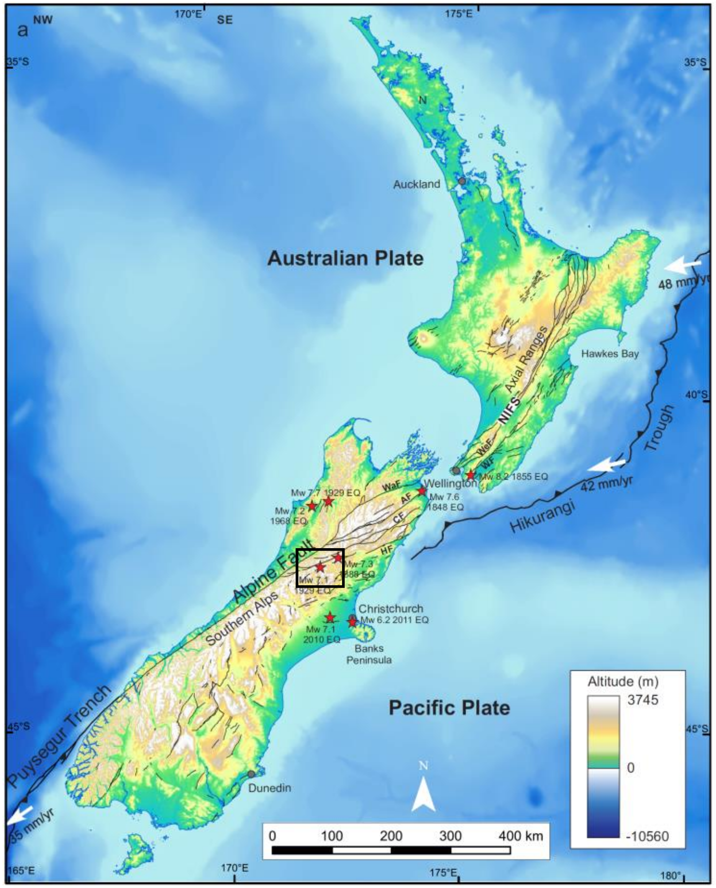
National SCIENCE Challenges
RESILIENCE TO NATURE'S CHALLENGES
Kia manawaroa – Ngā Ākina o Te Ao Tūroa

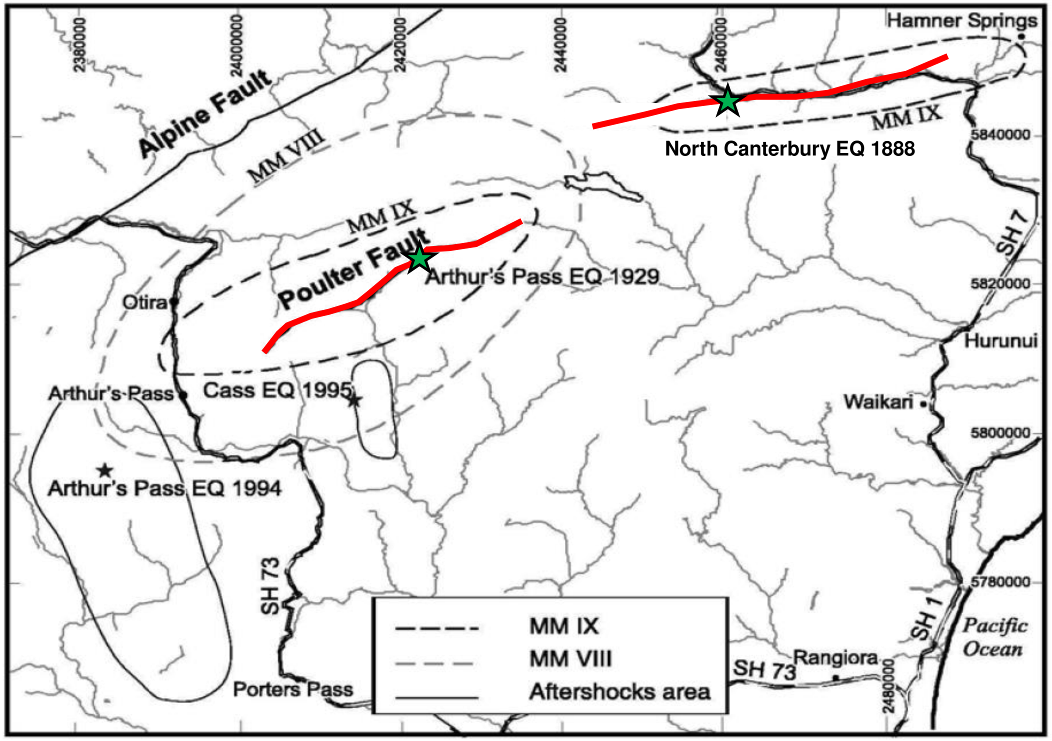
Multi-fault virtual earthquakes



Shaw et al. (preprint)

Earthquake triggering – Observations

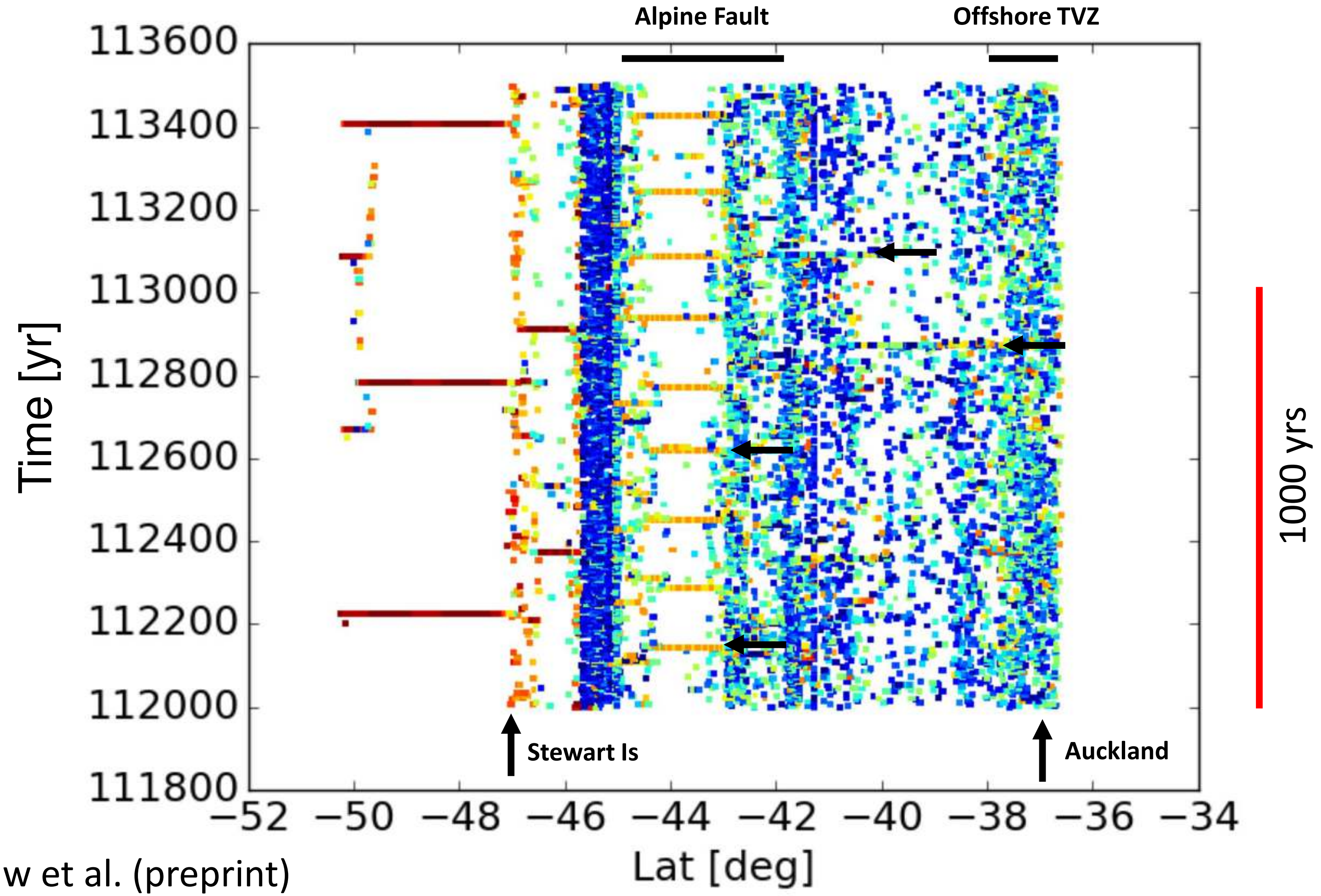




Modified from Berryman and Villamor (2004)

Some historical large magnitude earthquakes appear to have triggered large earthquakes.

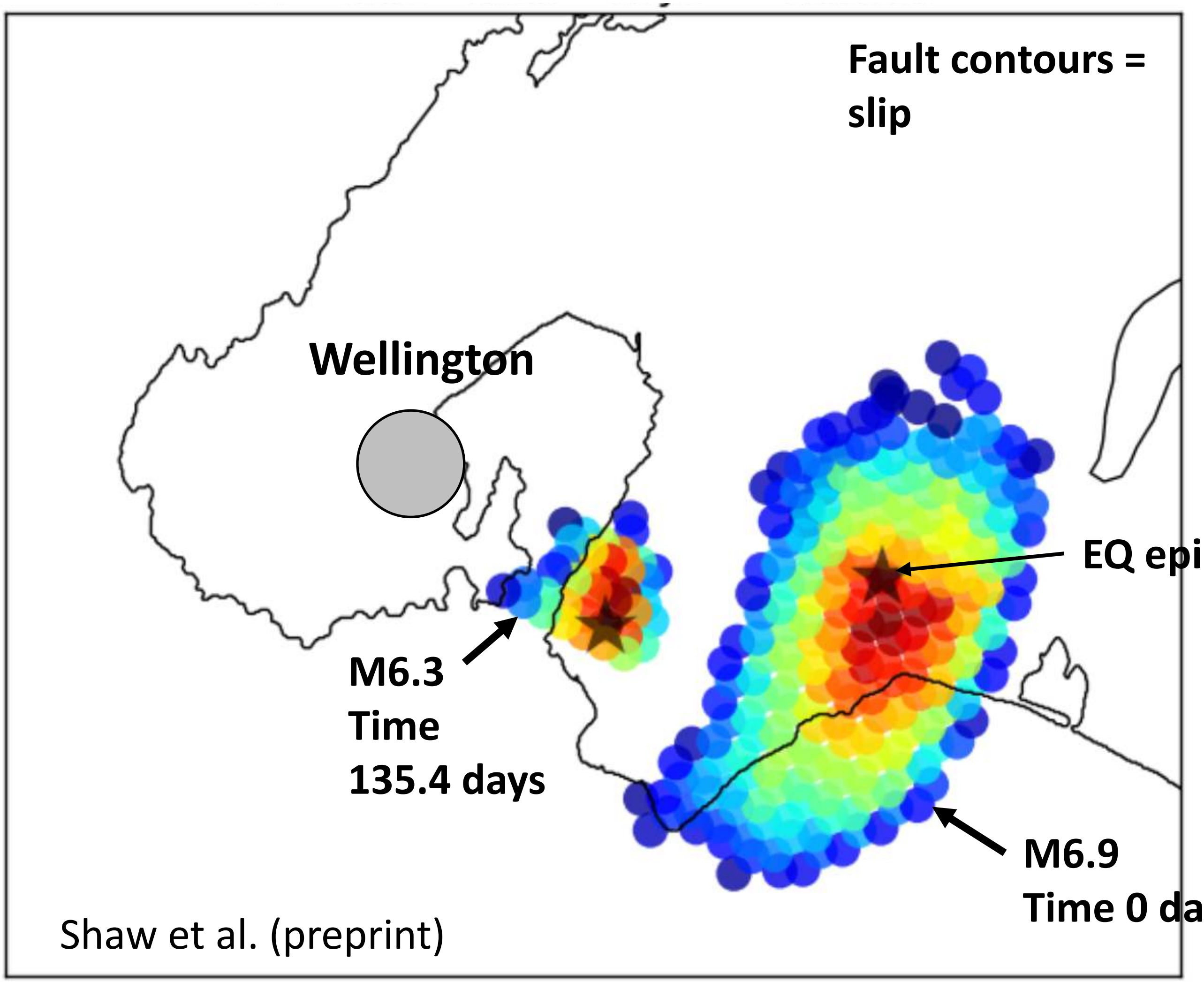
Earthquake triggering - Model



Shaw et al. (preprint)

Model shows some spatially stable earthquake activity
Horizontal alignment of events consistent with triggering

Earthquake triggering - Model



Shaw et al. (preprint)

Earthquake triggering common in the model.
Model can be interrogated to determine requirements for triggered events.

Concluding remarks

Initial RSQSim earthquake simulator model has been developed for NZ (Shaw et al. preprint).

Virtual earthquakes share many similarities with historical and prehistorical earthquakes.

Stress interactions for virtual earthquakes produce multi-fault ruptures and earthquake triggering.

Future work will examine what factors (e.g., stress conditions, earthquake magnitude, fault geometries) lead to multi-fault ruptures and triggered earthquakes.

Dr Bill Fry, GNS Science

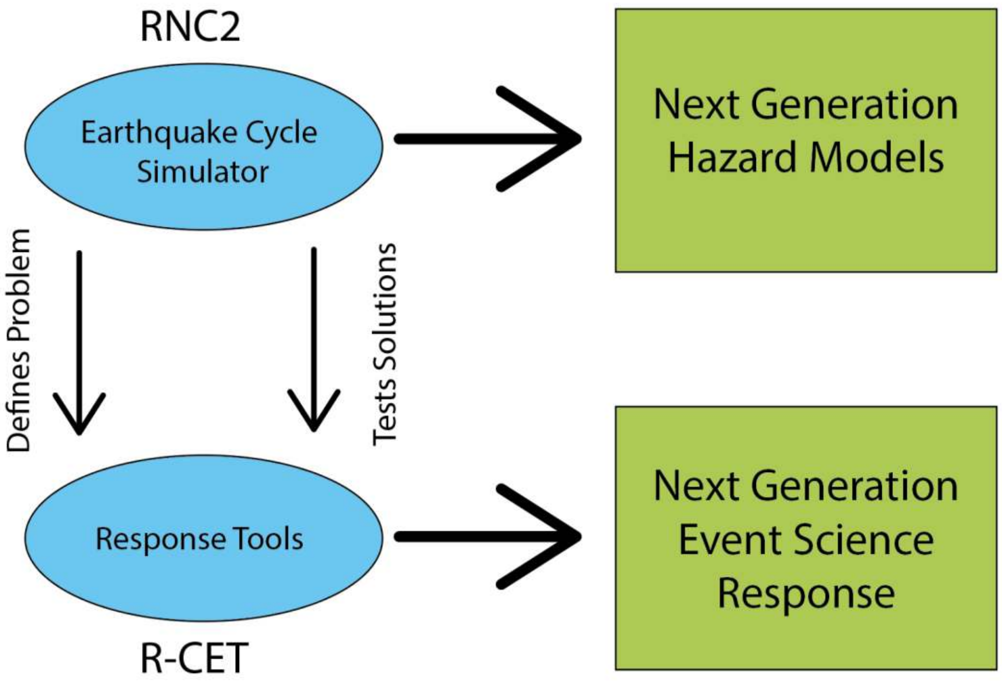
RNC2 synthetic catalogue applications

Big Fish (Think Blue whale – 27m)

- Next generation (physics-based) seismic hazard model
- Local-source tsunami hazard model

Medium Fish (Think tohorā – 18m)

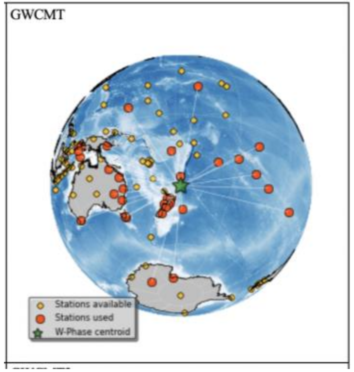
- Testing early warning (EEW and TEW)
- Improving ground motion estimates (e.g. topographic amplification)
- Improving forecasting of co- and post-seismic hazards (e.g. effects on groundwater)

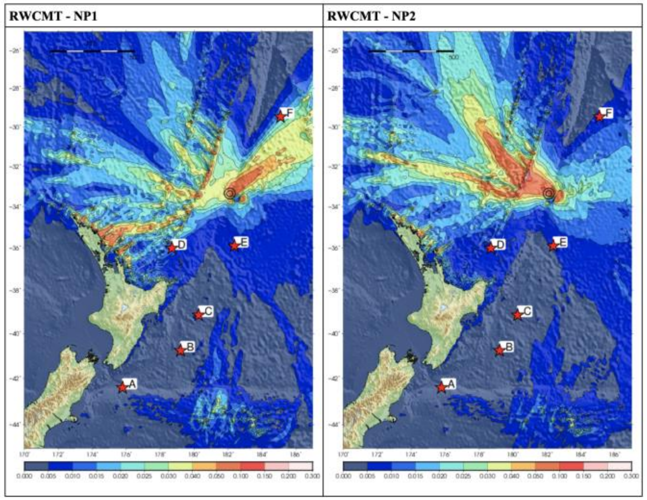


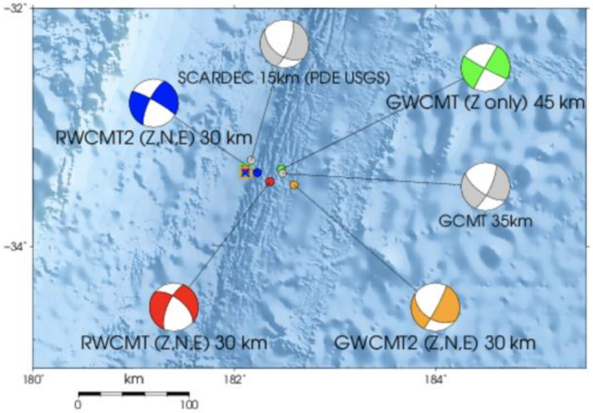
Let’s take a step back to understand TEW (Collaboration with C. Moore, D. Arcas, J. Borrero and A. Howell)

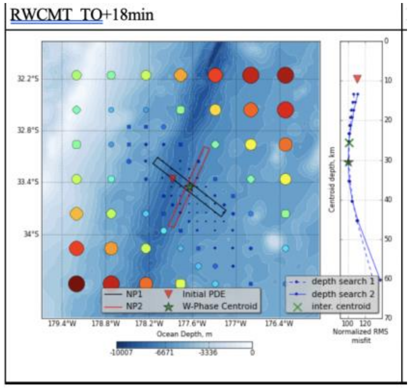
Seismic solutions provide information about the *earthquake* source. This information is not sufficient to unambiguously define the *tsunami* source.

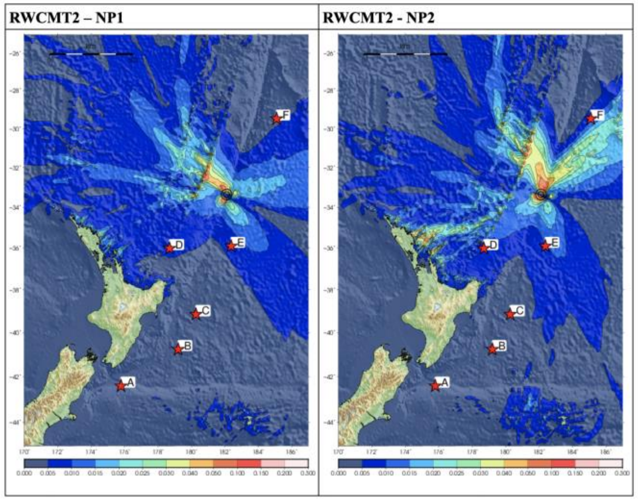
Challenge: Seismic info describes a non-unique tsunami model



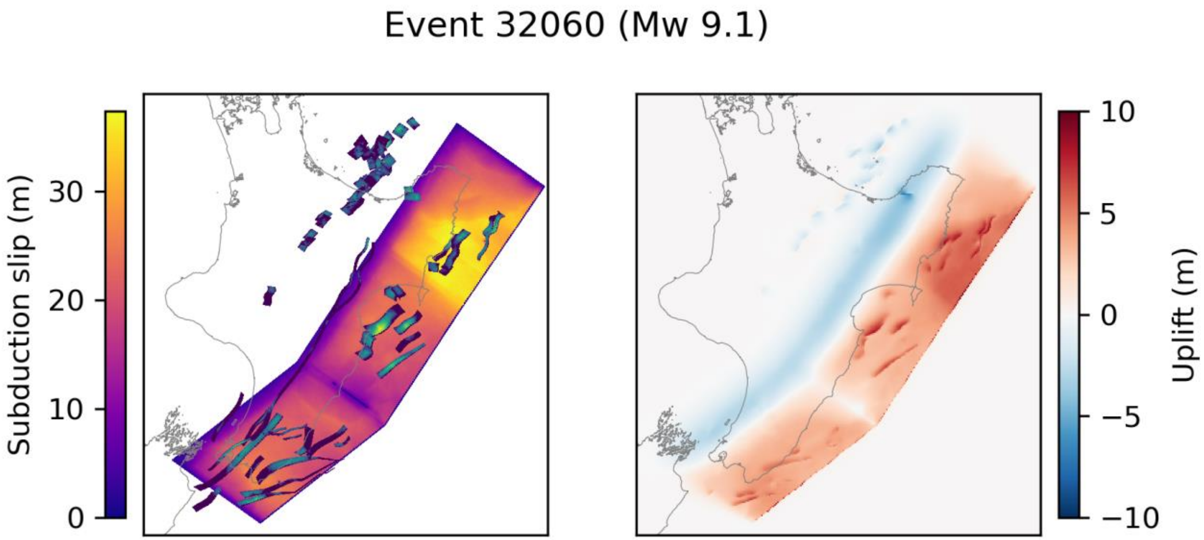


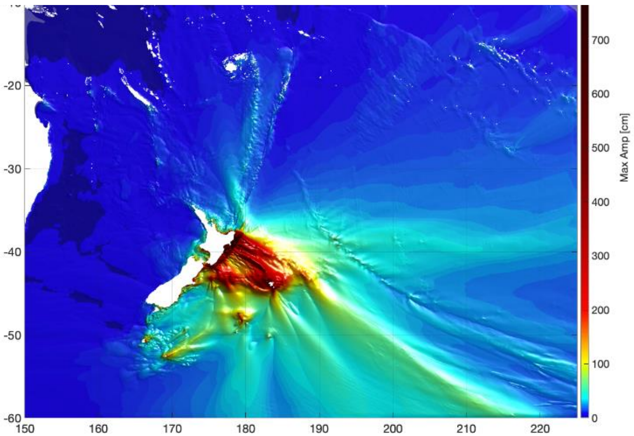


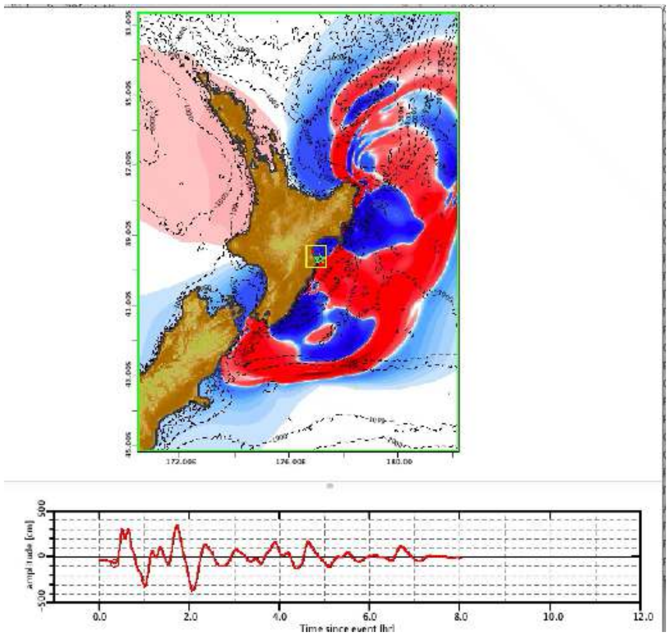


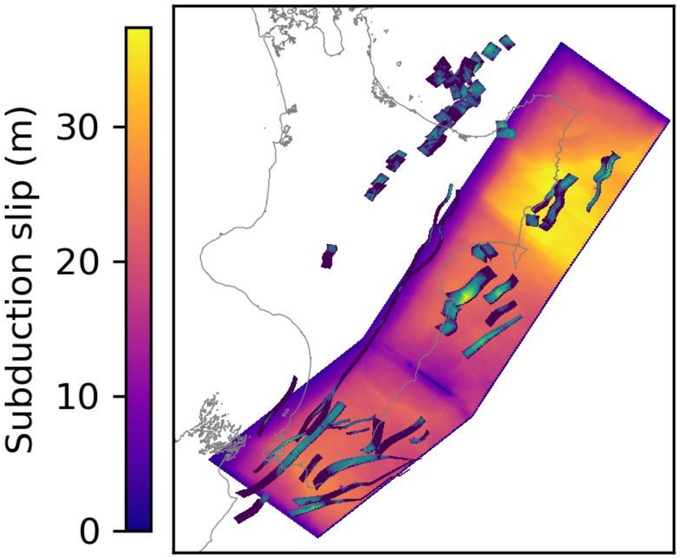


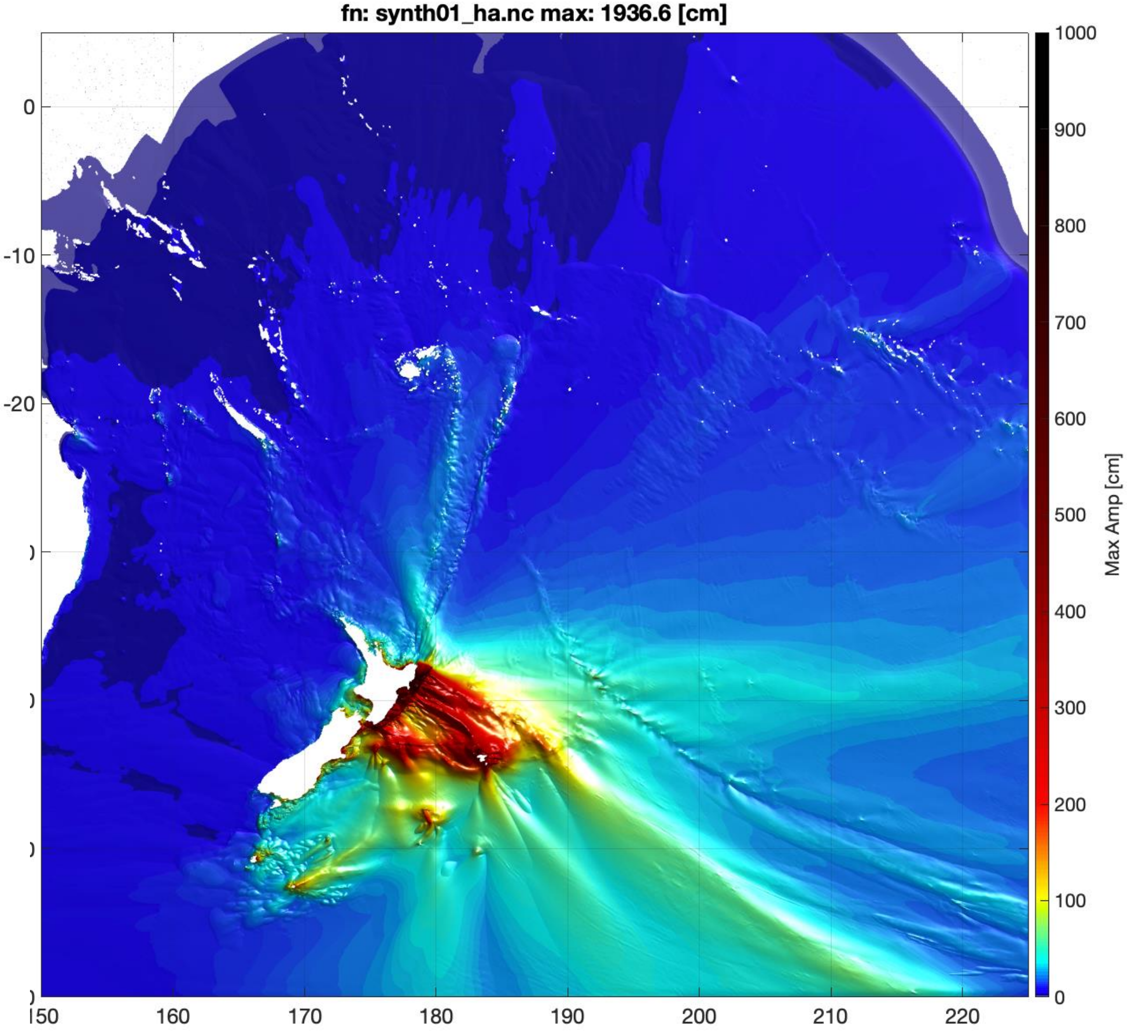
Testing TEW with a scenario event


Event 32060 (Mw 9.1)



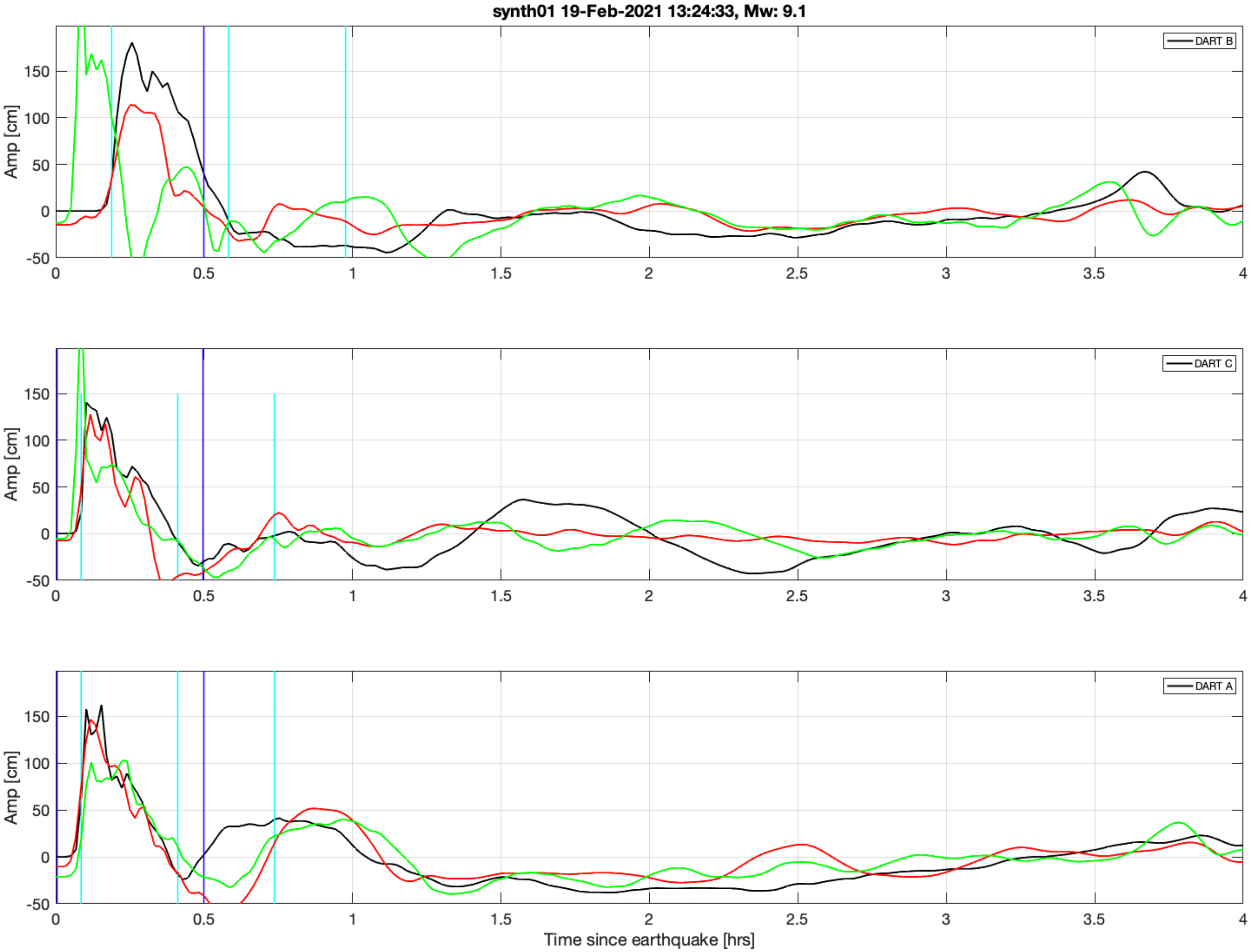



Subduction slip (m)
30
20
10
0

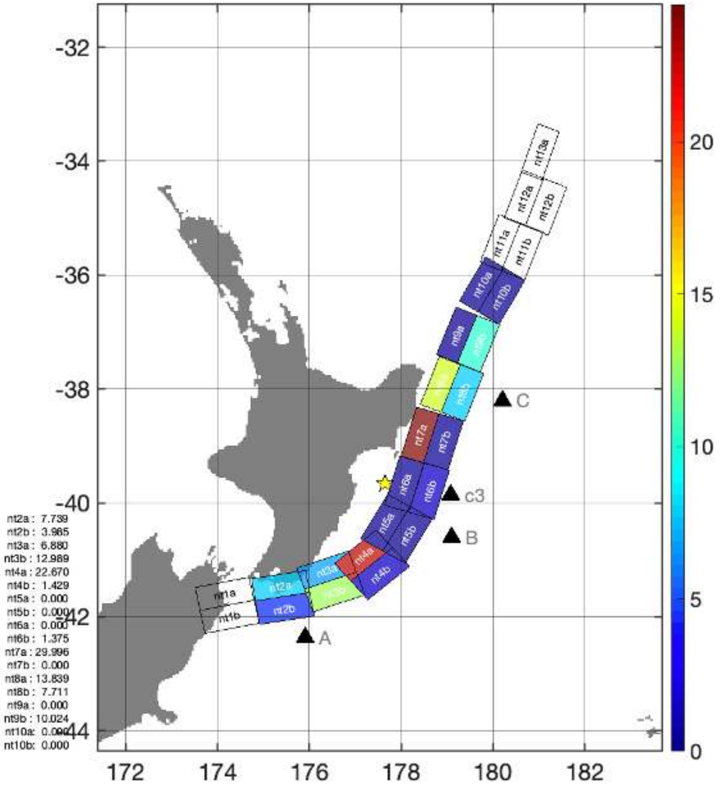

fn: synth01_ha.nc max: 1936.6 [cm]
0
-10
-20
150
160
170
180
190
200
210
220
1000
900
800
700
600
500
400
300
200
100
0
Max Amp [cm]

Inversion of DARTs

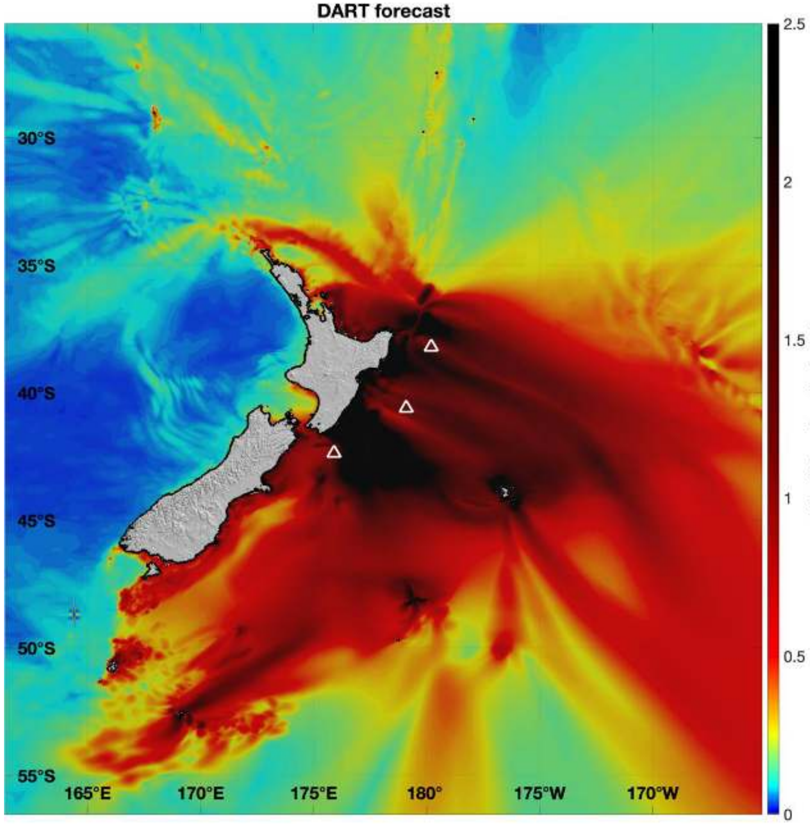
- Black: Input model
- Green: simplified model from homogeneous seismic source
- Red: inversion results



DART inversion



Forecast



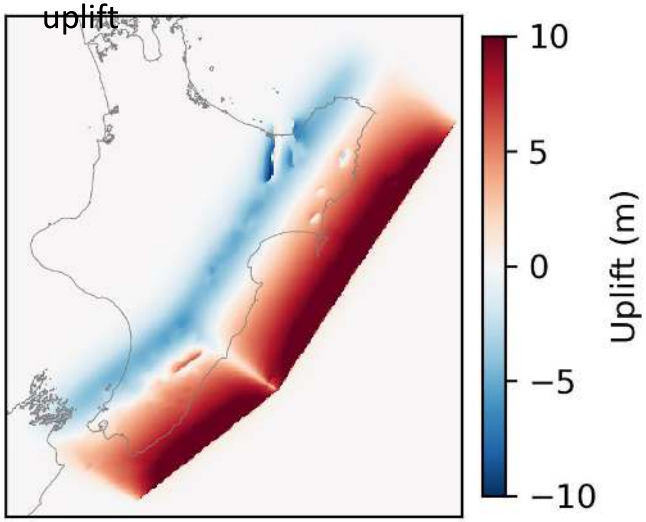
Now imagine repeating that exercise 10,000 times

- We can develop a statistical understanding of the efficacy of our early warning systems
- We can use that understanding to improve through network and algorithm adjustment

Now let's look at applications in co-seismic groundwater changes
(Collaboration with A. Howell,
P. Johnson and R. Westerhoff)

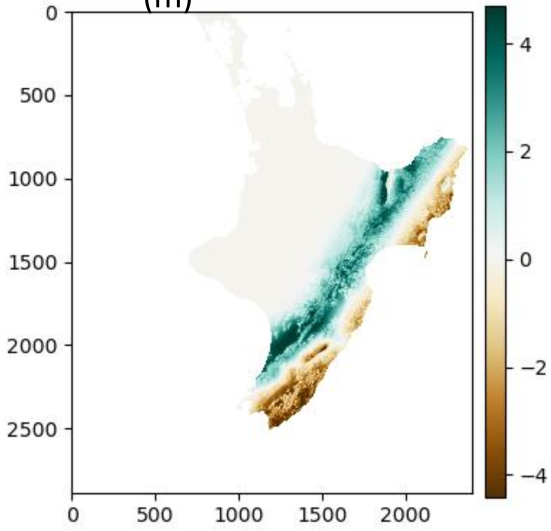
Change in water table depth: Event 588

Event 588 relative uplift



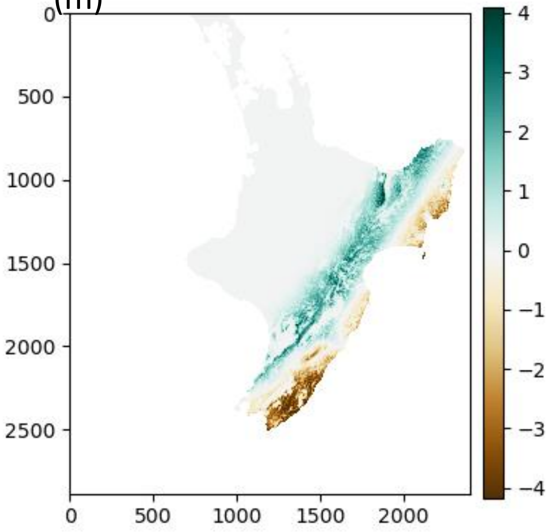
Red: uplift
Blue: subsidence

Change in head (m)



Positive value = increase in water table elevation

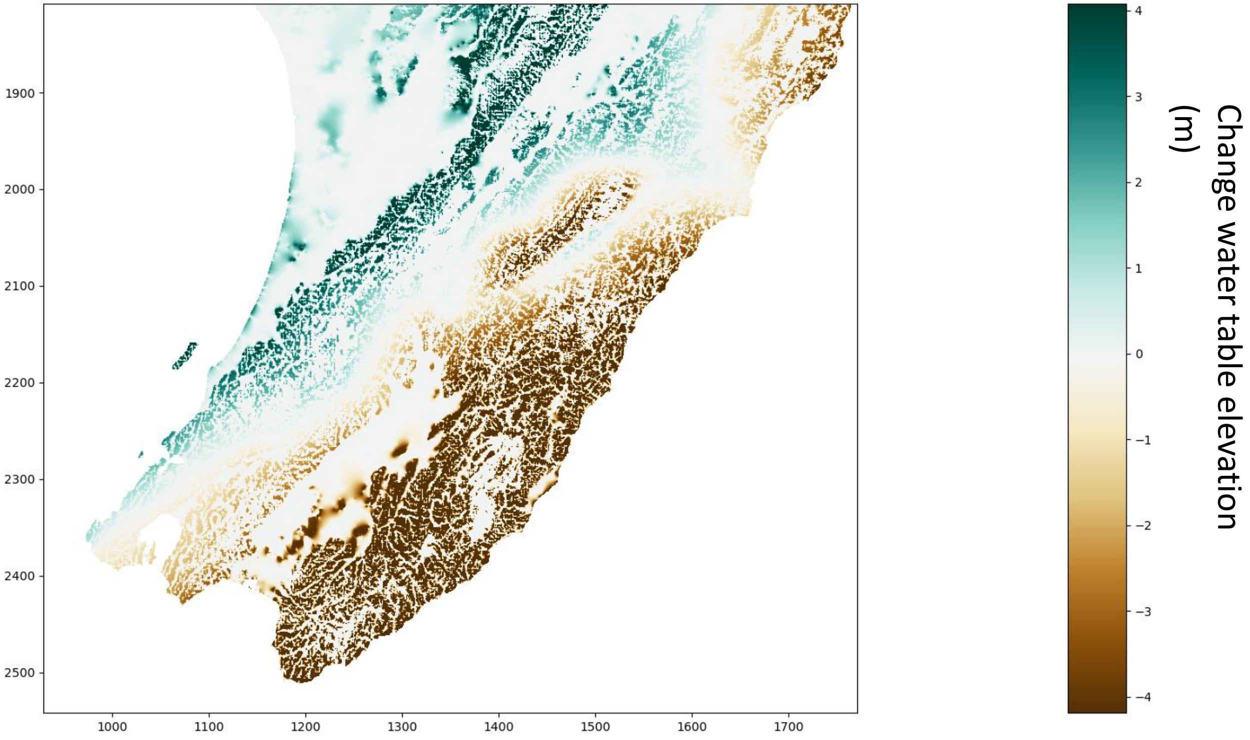
Relative rise of water table (m)



Positive value = shallower depth to water

All maps are on 250 m discretisation

Change in water table depth: zoom view

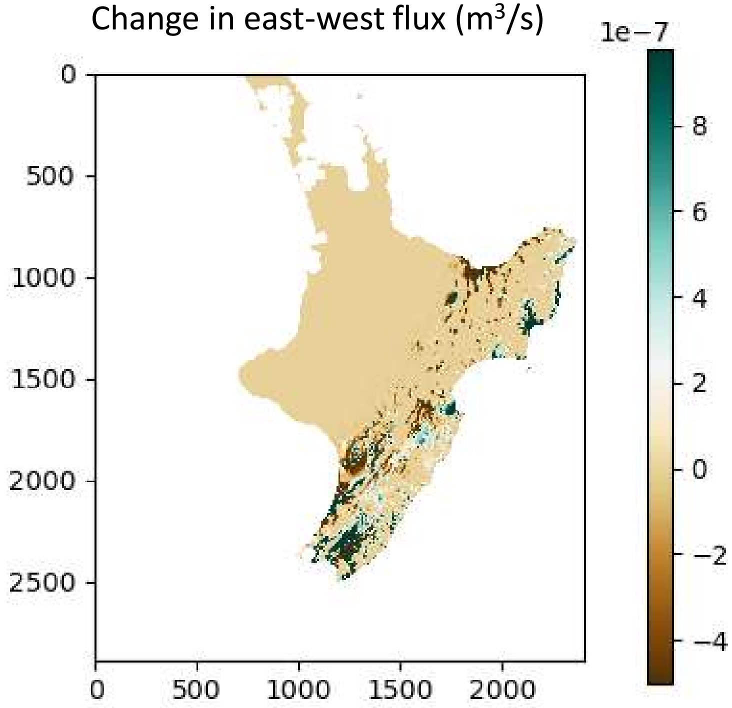


Green = water closer to land surface; possible inundation hazards, higher tendency towards flooding?

Brown: deeper to water, dry wells, reduced stream base flow

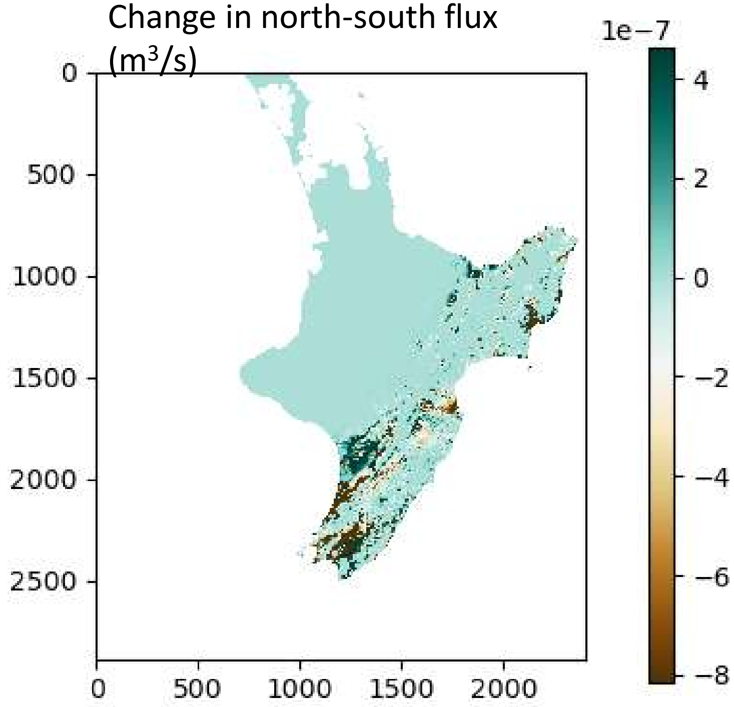
Change in groundwater flux

Change in east-west flux (m^3/s)



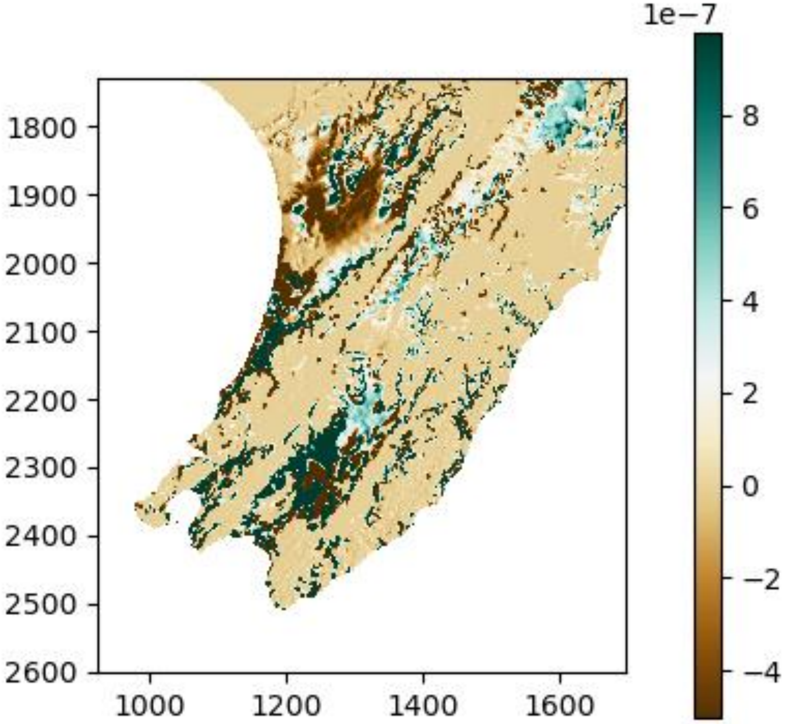
Positive values indicate increased flow to west (or reduced to east)

Change in north-south flux (m^3/s)



Positive values indicate increased flow to north (or reduced to south)

Change in E-W flux (zoom view)

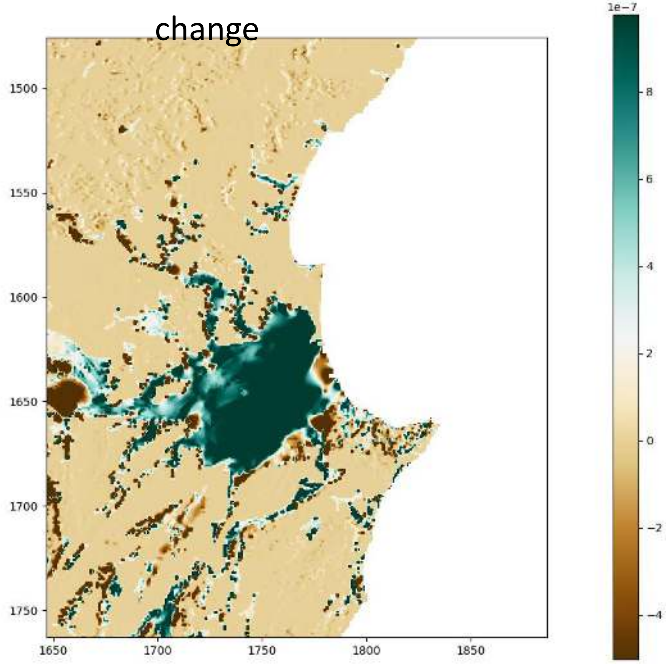


Green is greater flow to west (or reduced to east); brown opposite

Could effect:
- Contaminant arrival time
- Drawdown at wells with pumping

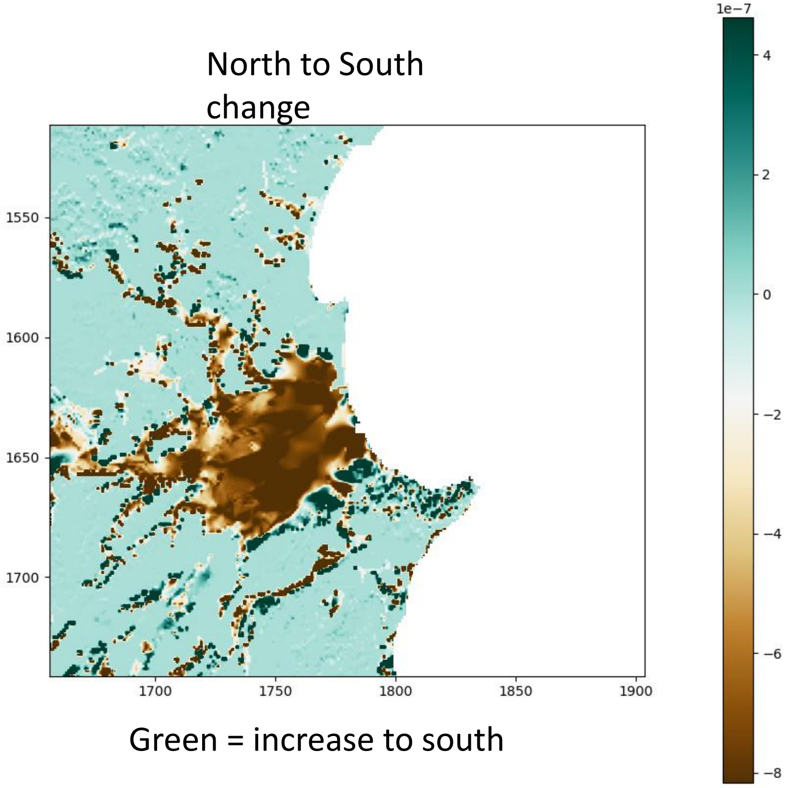
Flow change: Hawke’s Bay

East to West change



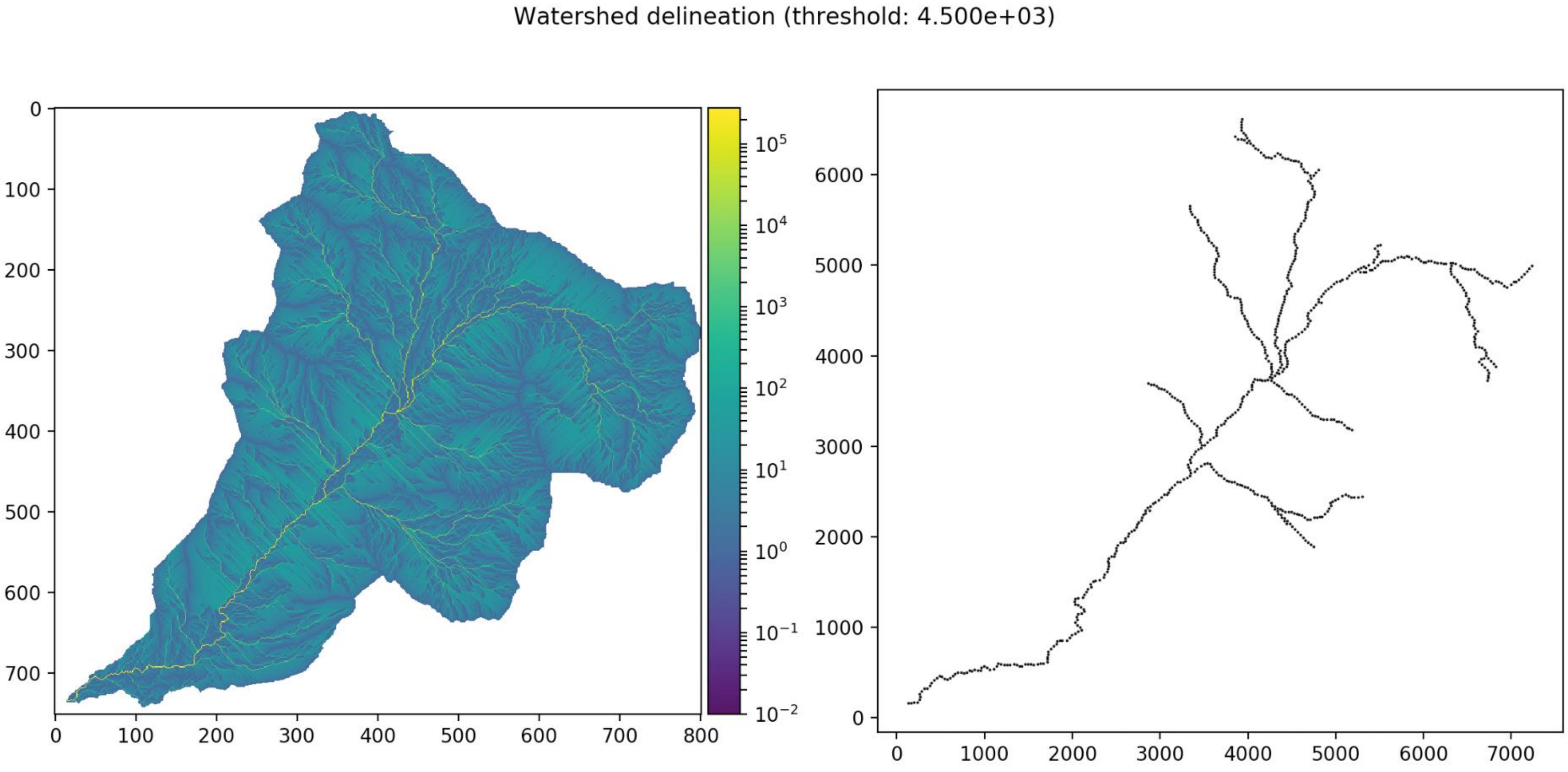
Green = increase to west

North to South change



Green = increase to south

Flow accumulation

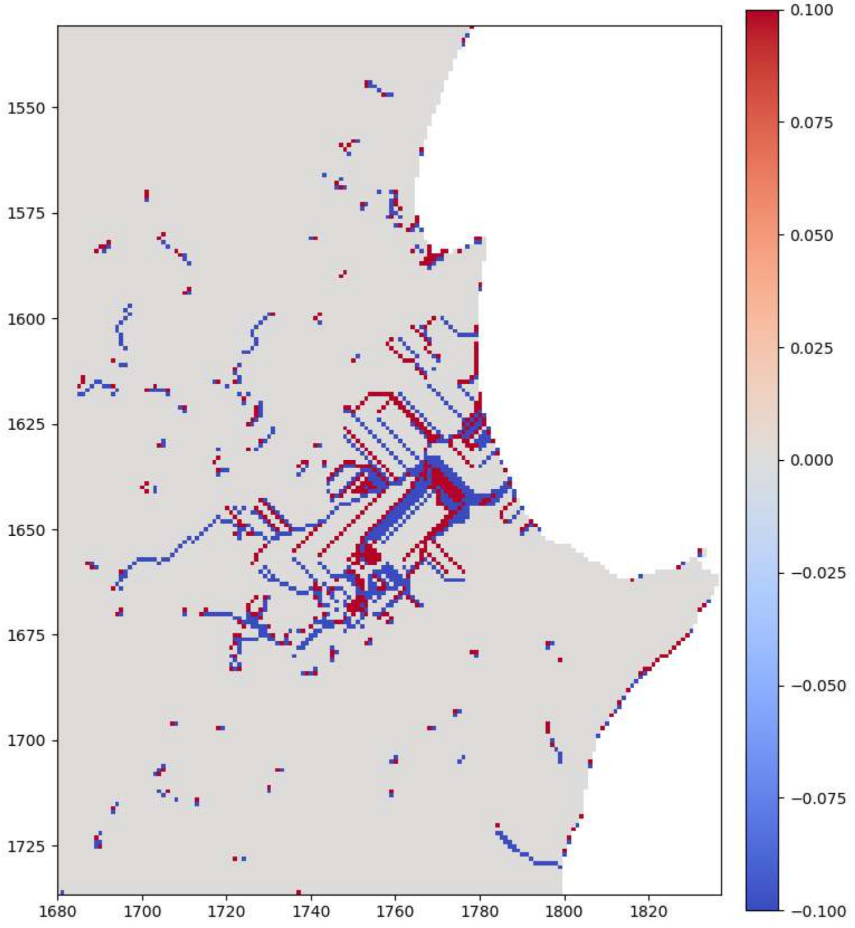


Watershed delineation (threshold: 4.500e+03)

River course change – Hawke’s Bay

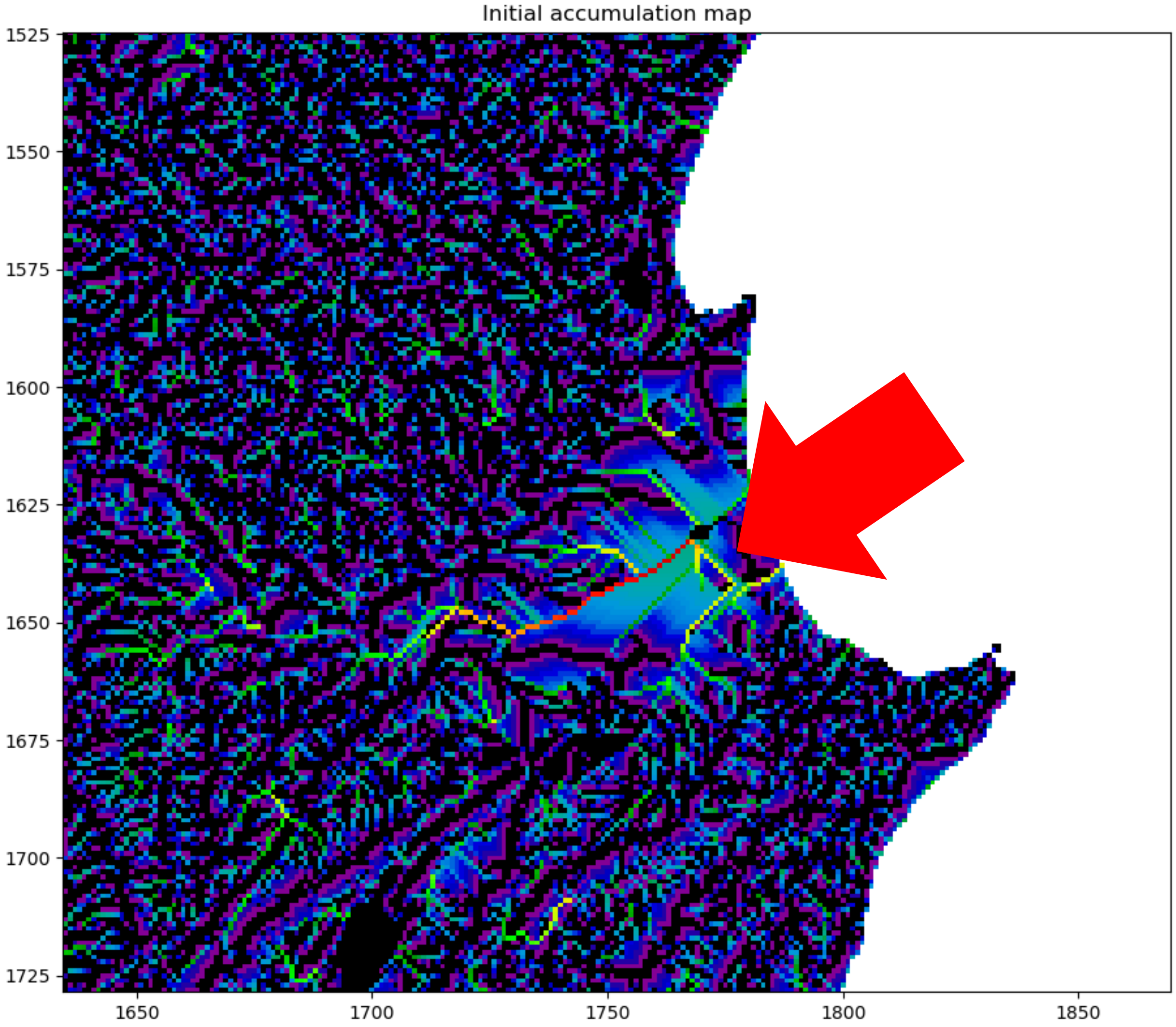
Red: More stream accumulation after deformation
Blue: Less stream accumulation after deformation

Where adjacent, stream course will tend to change from blue areas to red areas, presenting a possible hazard e.g. stress on levees, undercutting of infrastructure, increased flooding hazards, etc.

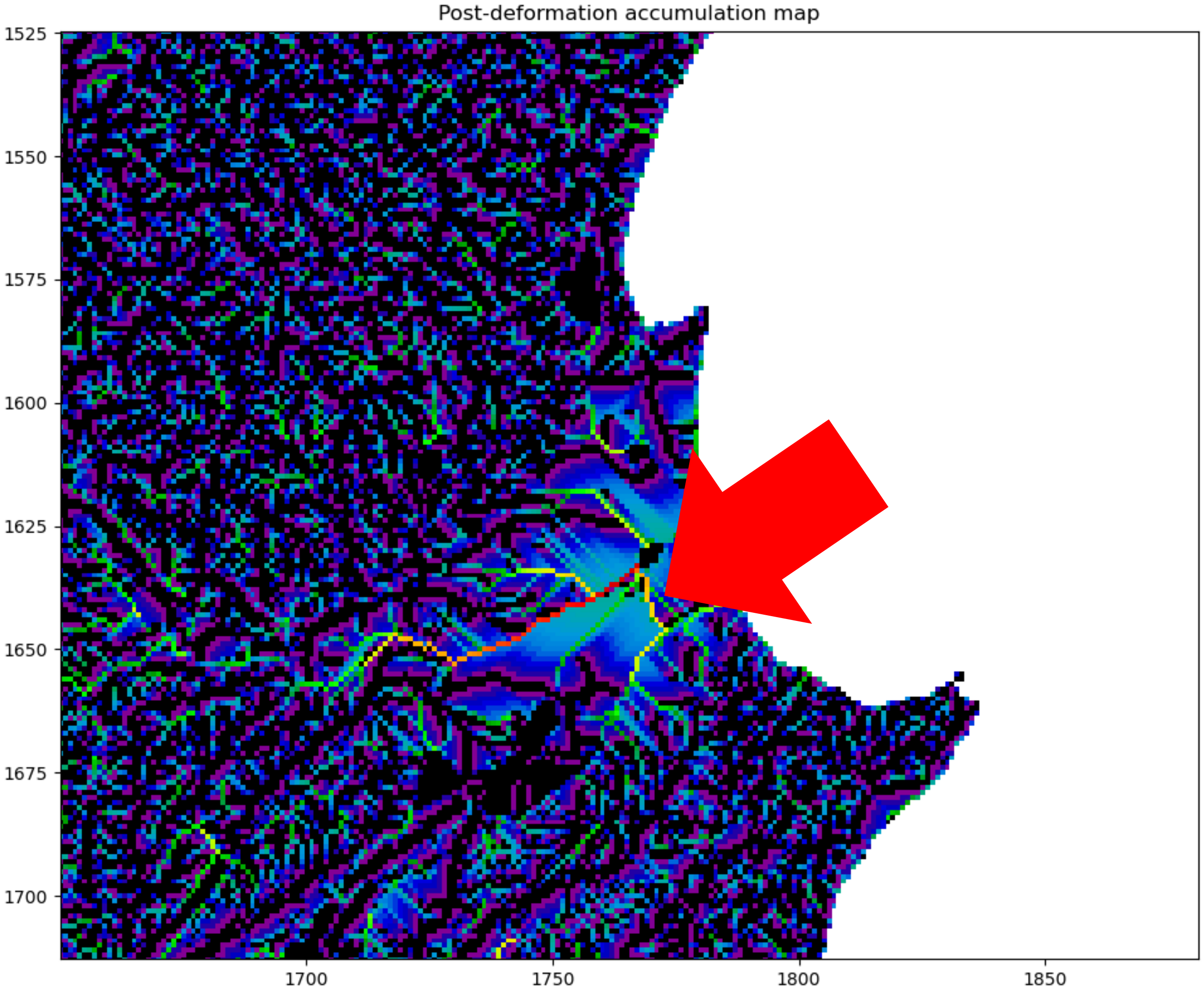


River course: Hawke's Bay

Flow accumulation: red colours indicate more drainage to that point (i.e., streams); purple/black less


Initial accumulation map

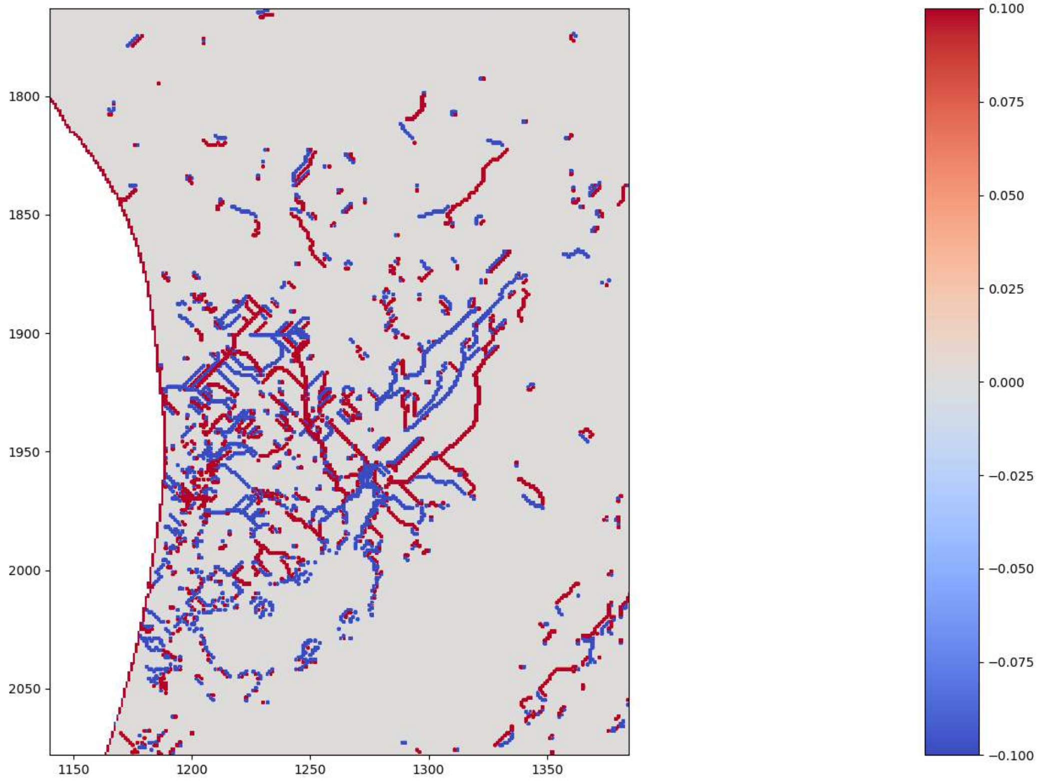
River course: Hawke's Bay



Kapiti Coast: Stream change

Red: More stream accumulation after deformation
Blue: Less stream accumulation after deformation

Numerous possible stream realignments



Bonus material!!!

- One challenging aspect of response was the accumulation of trapped energy in harbours because of multiple events!
- How often does this happen in the catalogue and the real world?

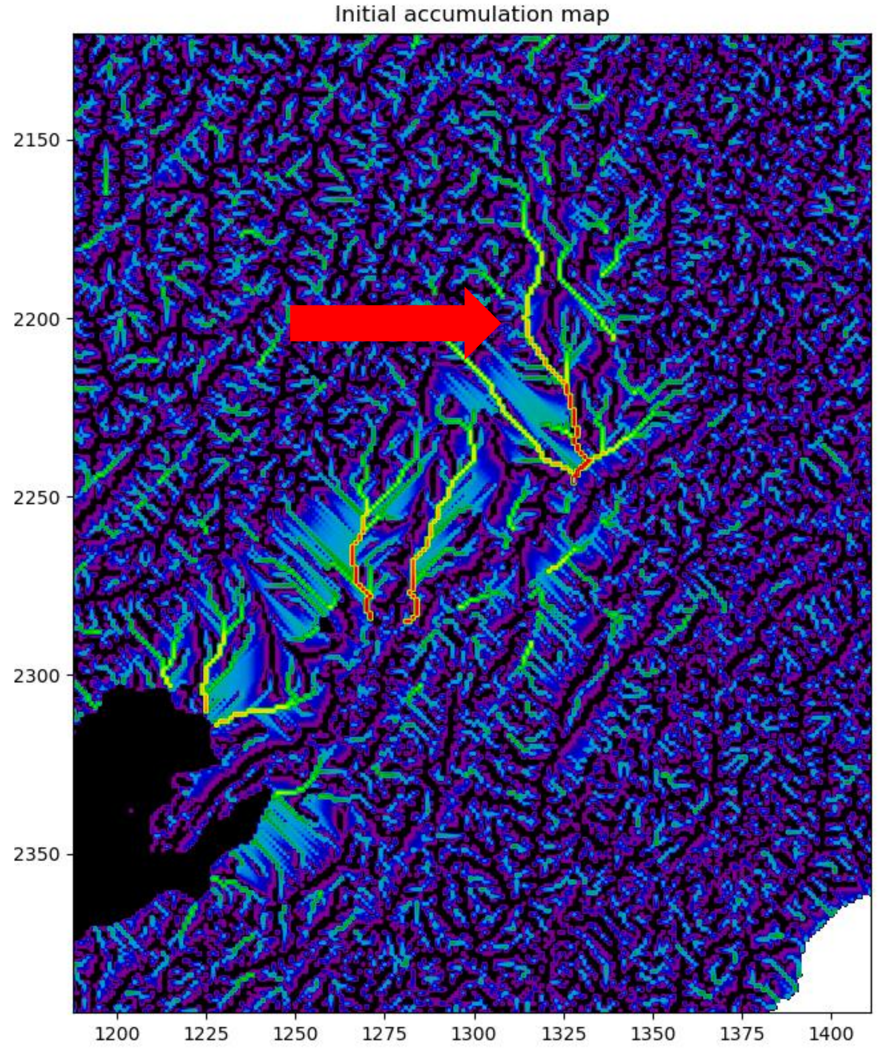
Friday 05 March 2021 - as of 09:35 AM NZDT

Magnitude 7 or greater earthquakes

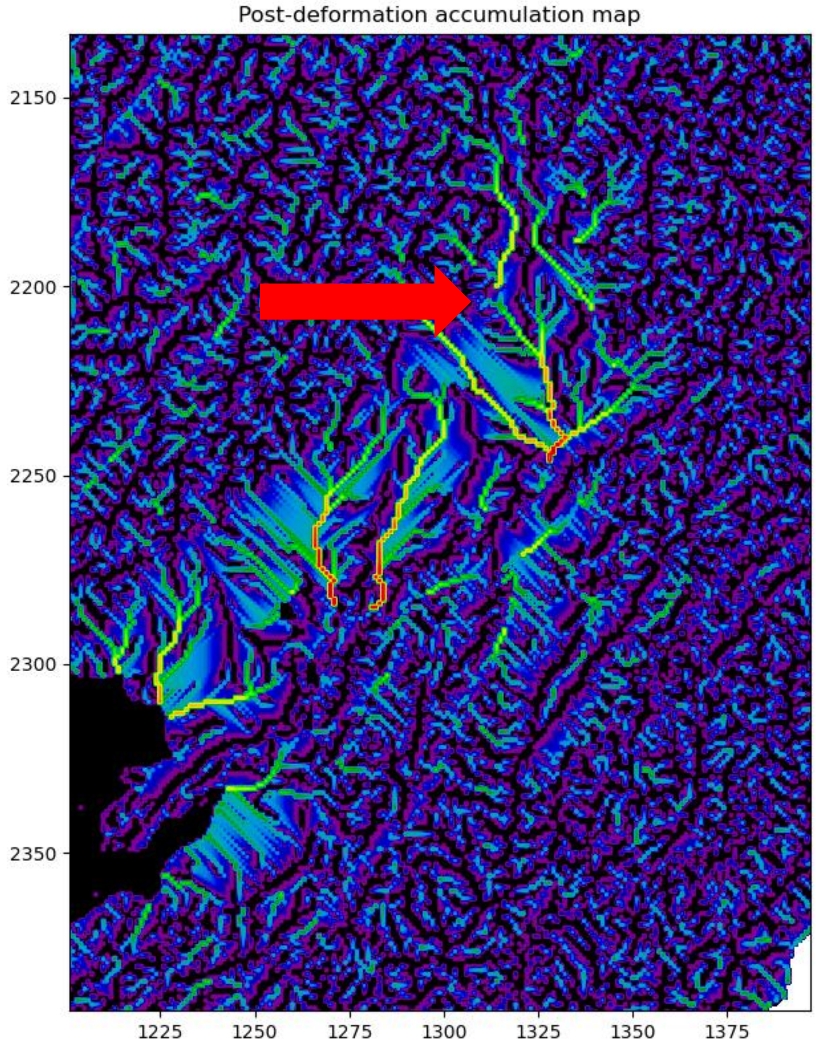
Summary

- Capturing the stochastic range of possible earthquakes opens up huge potential for improving resilience
- Watch this space for
  - Next generation seismic and tsunami hazard
  - Critical testing of early warning algorithms
  - Better understanding of earthquake clustering and multi-fault rupture
  - Better models of co-seismic impacts including
    - Topographic amplification of ground motion and its impacts on landslide models
    - Models of changes to surface and groundwater

Thanks for joining!

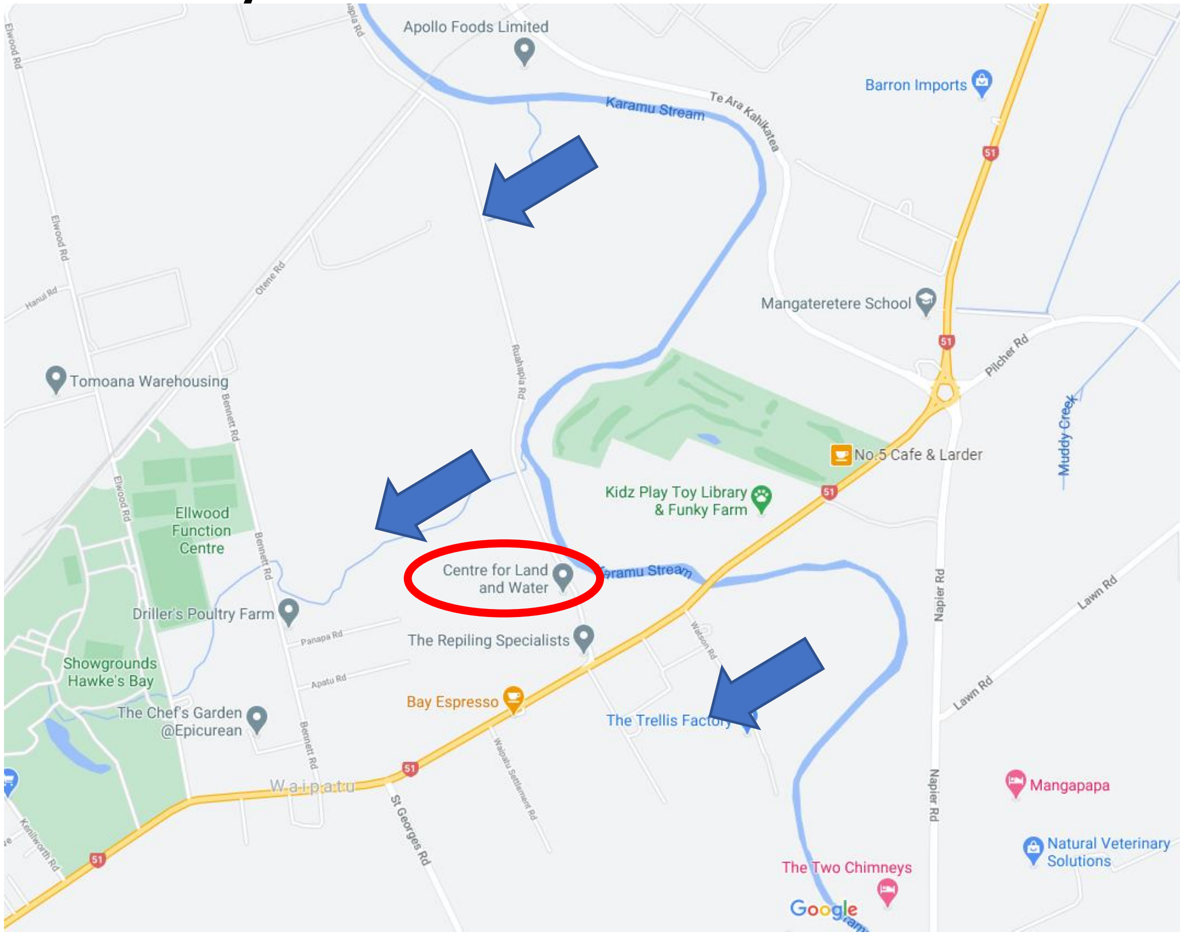


Initial accumulation map



Post-deformation accumulation map

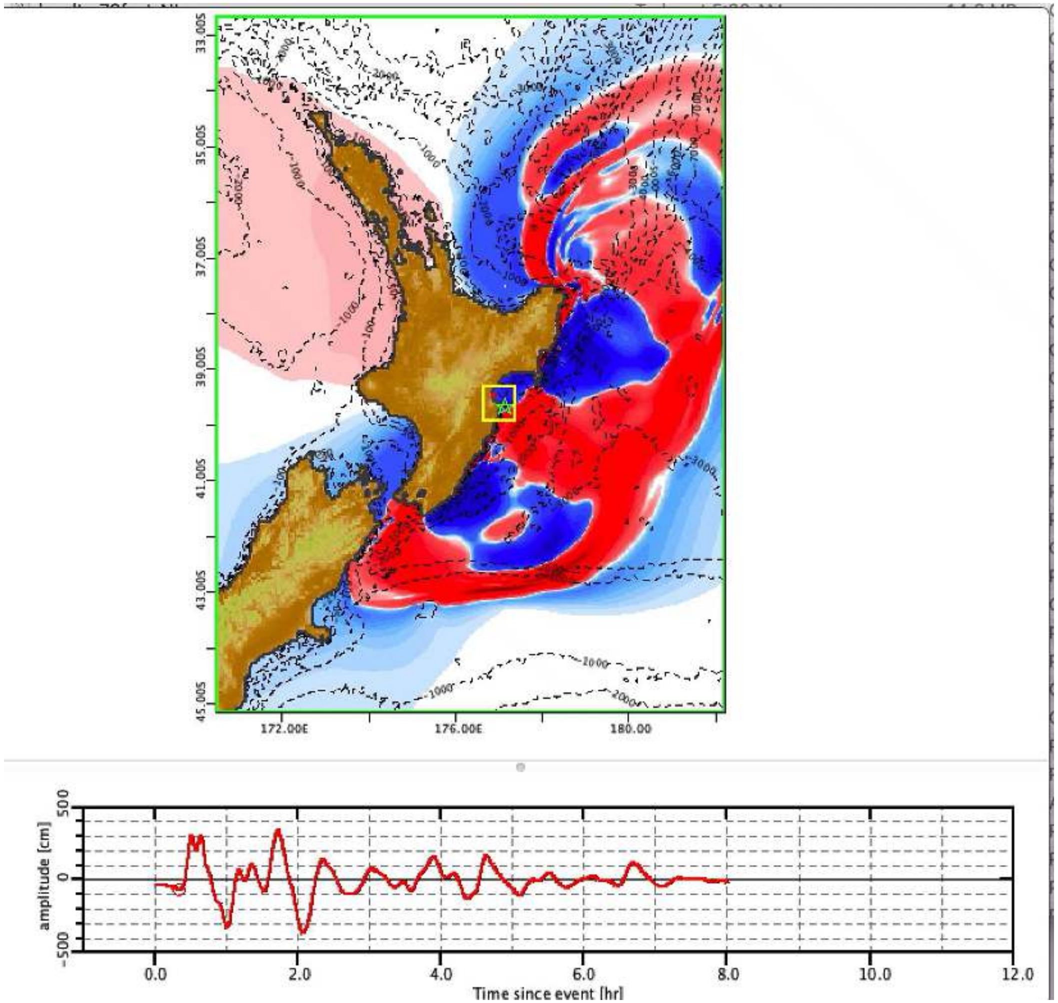
Hawke’s Bay


Apollo Foods Limited
Barron Imports
Karamu Stream
Te Ara Kahikatea
Mangateretere School
Tomoana Warehousing
No.5 Cafe & Larder
Kidz Play Toy Library & Funky Farm
Ellwood Function Centre
Centre for Land and Water
Driller's Poultry Farm
The Repiling Specialists
Showgrounds Hawke's Bay
The Chef's Garden @Epicurean
Bay Espresso
The Trellis Factory
Waipatu
Mangapapa
Natural Veterinary Solutions
The Two Chimneys
Napier Rd
Lawn Rd
Pilcher Rd
Muddy Creek
Ruahapia Rd
Bennett Rd
Elwood Rd
Otene Rd
St Georges Rd
Google

Supplemental slide on w-phase at short distances

Conclusions

- Purely from a monitoring perspective, instrumental cable would certainly help, but it’s impacts aren’t dramatic because of the (stream parallel) geometry
- Co-located sm and pressure sensors could probably help with removing seismic source contamination of tsunami measurements, subject to future work.



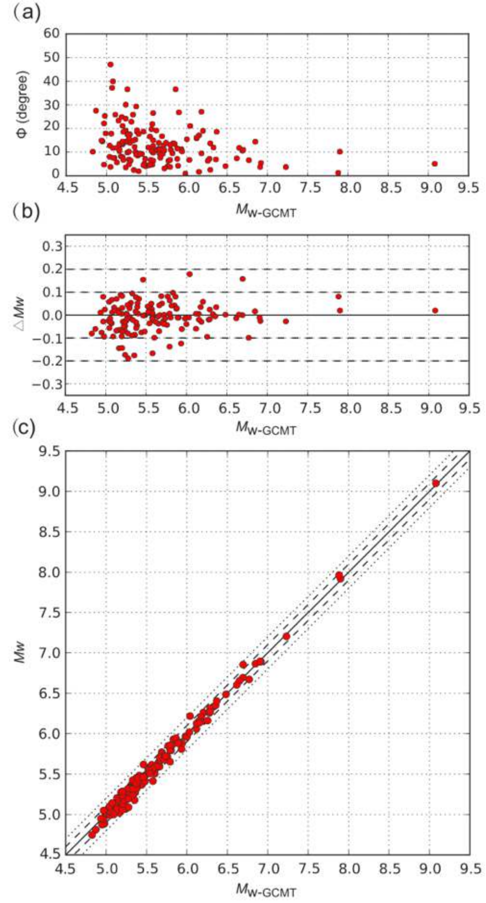
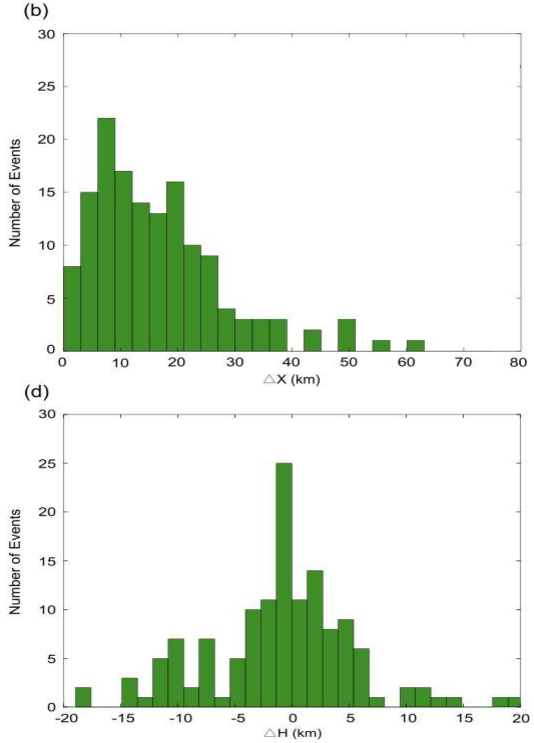


Figure 4. Comparison of W-phase and GCMT solutions obtained at T_0 + 7 min ($\Delta \leq 12°$). (a) Comparison between W-phase and GCMT focal mechanisms. Φ is the angular difference between W-phase and GCMT focal mechanisms (see equation (3)). (b) Magnitude difference $\Delta M_w = M_w - M_{w-\mathrm{GCMT}}$ between W-phase magnitude (M_w) and GCMT magnitude ($M_{w-\mathrm{GCMT}}$). (c) Comparison between W-phase (M_w) and GCMT magnitude ($M_{w-\mathrm{GCMT}}$).

- Left, the w-phase solution magnitudes available before 10 minutes compares really well with the global standard GCMT (within +/- Mw0.2).
- Right shows difference in epicentral locations between w-phase and GCMT. Difference in epicenter (top) and depth (bottom)
- Left and right plots based on 12 degrees of data (within 7 minutes). Table on bottom right shows what can be done with only 5degrees of data!



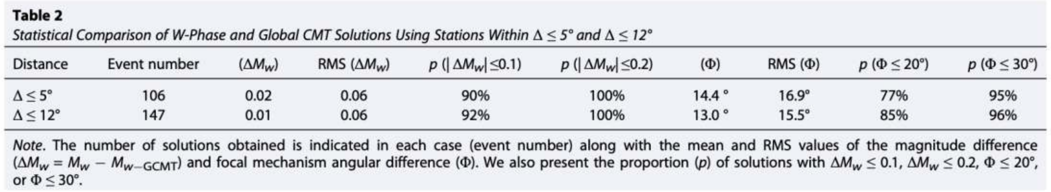


Table 2

Statistical Comparison of W-Phase and Global CMT Solutions Using Stations Within $\Delta \leq 5°$ and $\Delta \leq 12°$

Distance	Event number	(ΔM_w)	RMS (ΔM_w)	p ($\lvert\Delta M_w\rvert \leq 0.1$)	p ($\lvert\Delta M_w\rvert \leq 0.2$)	(Φ)	RMS (Φ)	p ($\Phi \leq 20°$)	p ($\Phi \leq 30°$)
$\Delta \leq 5°$	106	0.02	0.06	90%	100%	14.4 °	16.9°	77%	95%
$\Delta \leq 12°$	147	0.01	0.06	92%	100%	13.0 °	15.5°	85%	96%

Note. The number of solutions obtained is indicated in each case (event number) along with the mean and RMS values of the magnitude difference ($\Delta M_w = M_w - M_{w-\mathrm{GCMT}}$) and focal mechanism angular difference (Φ). We also present the proportion (p) of solutions with $\Delta M_w \leq 0.1$, $\Delta M_w \leq 0.2$, $\Phi \leq 20°$, or $\Phi \leq 30°$.

Zhao et al., 2017