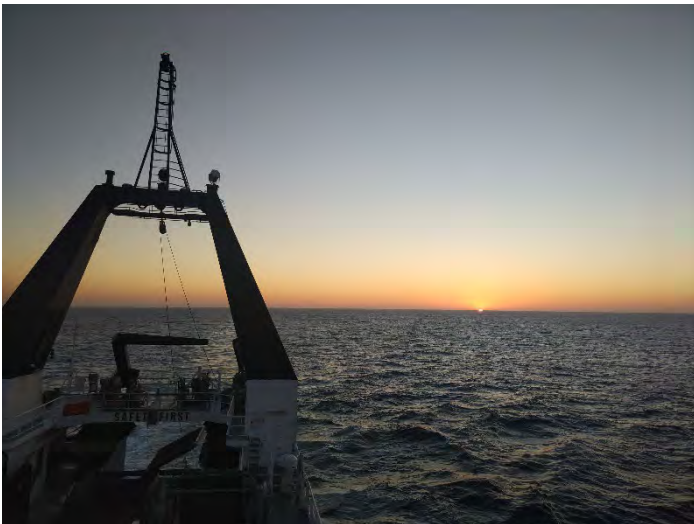


# Seismic hazards from earthquakes in the locked zone offshore

Martha Kane Savage<sup>1</sup>, Emily Warren-Smith<sup>2</sup>, Katie Jacobs<sup>2</sup>, Laura Wallace<sup>2</sup>, Pascal Audet<sup>3</sup>, Mladen Nedimovic<sup>4</sup>, Graeme Cairns<sup>4</sup>, Katie Woods<sup>1</sup>, Rupert Sutherland<sup>1</sup> and Shao-Jinn Chin<sup>1</sup>

<sup>1</sup> School of Earth Sciences  
Victoria University of Wellington  
<sup>2</sup> GNS Science, New Zealand  
<sup>3</sup> University of Ottawa, Canada  
<sup>4</sup> Dalhousie University, Canada

Thanks to Funding Agencies EQC, NSF, NIED, ERI, MBIE, JSPS, Canadian Foundation for Innovation, Natural Science and Engineering Research Council of Canada



Photos credit Weiwei Wang

# Outline

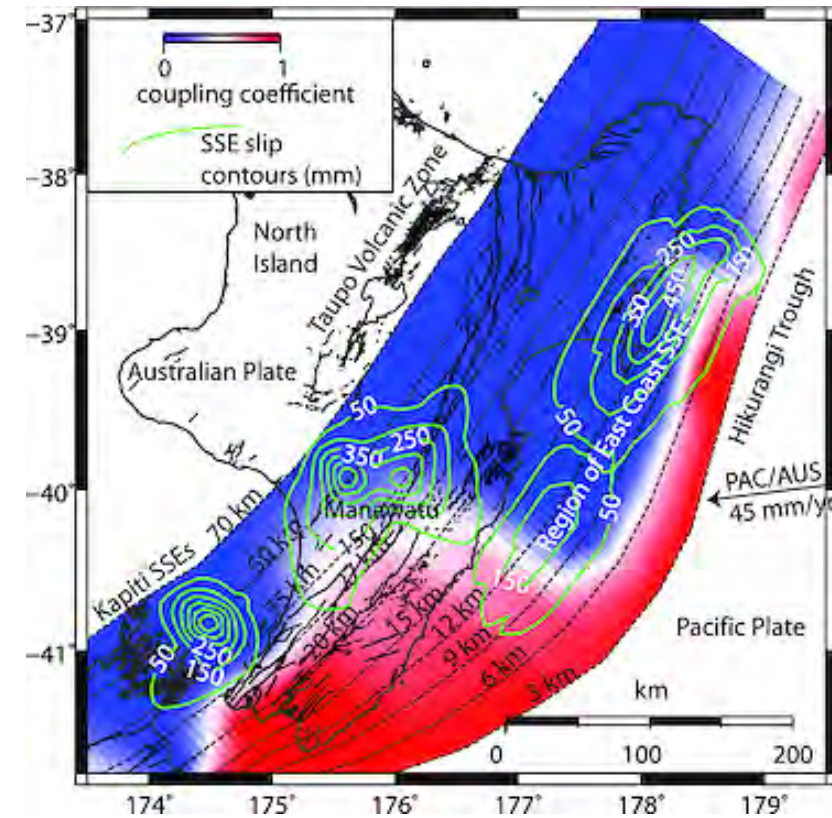
Recent work on earthquake locations on and offshore New Zealand

Plans for new deployment offshore Wellington

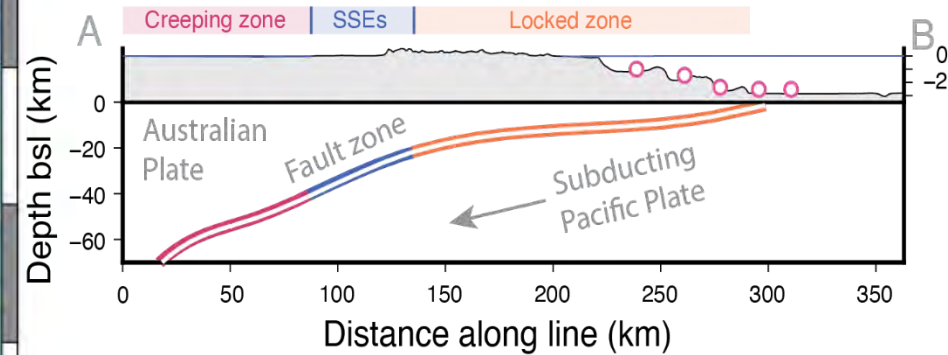
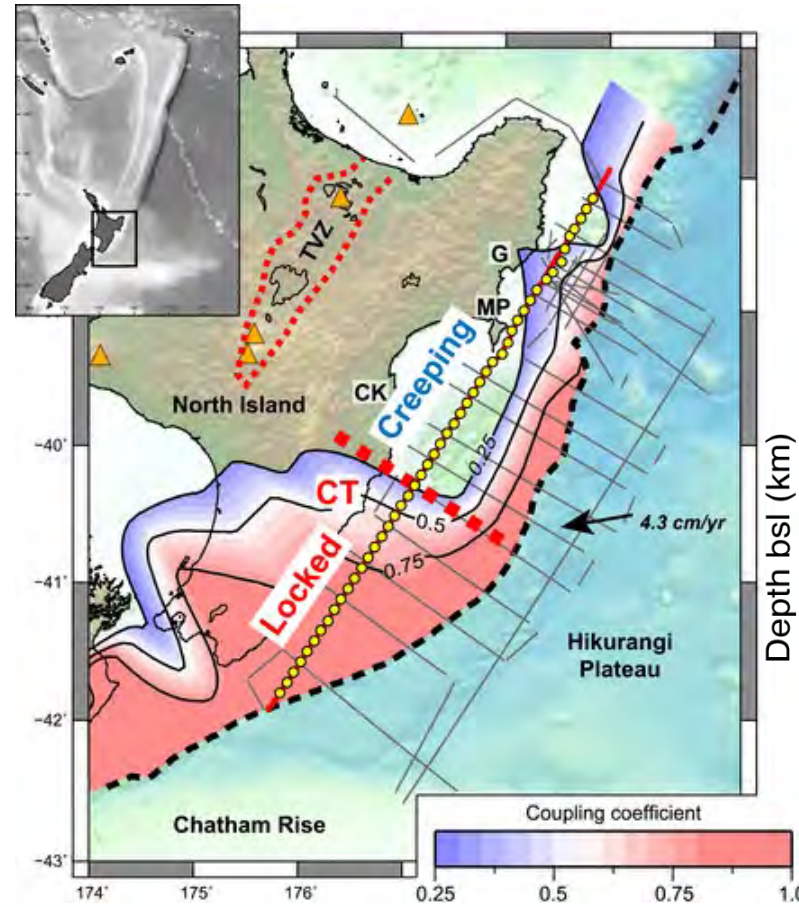
Example of expected methodology: Earthquake Hazards in New Caledonia



# SSEs on the Hikurangi Subduction Margin



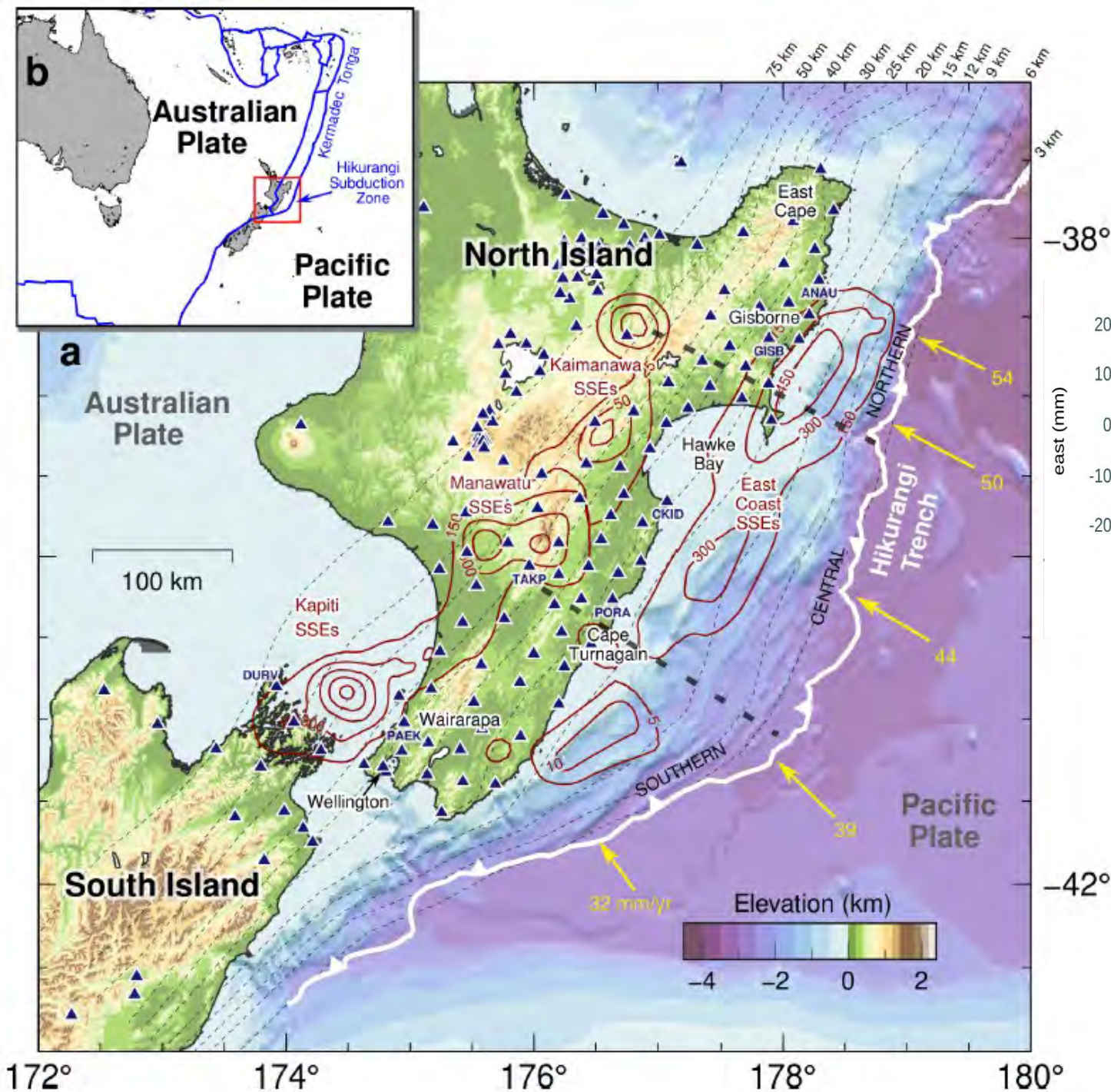
(Wallace, 2012)



(Schwartz and Rokosky, 2007)



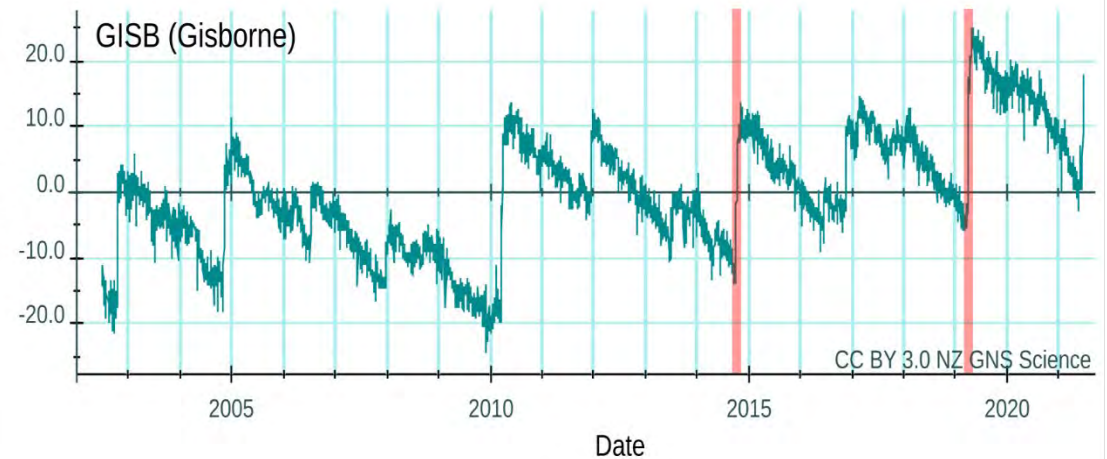
# Slow Slip



-38°

east (mm)

GISB (Gisborne)



-42°

From Wallace, 2020



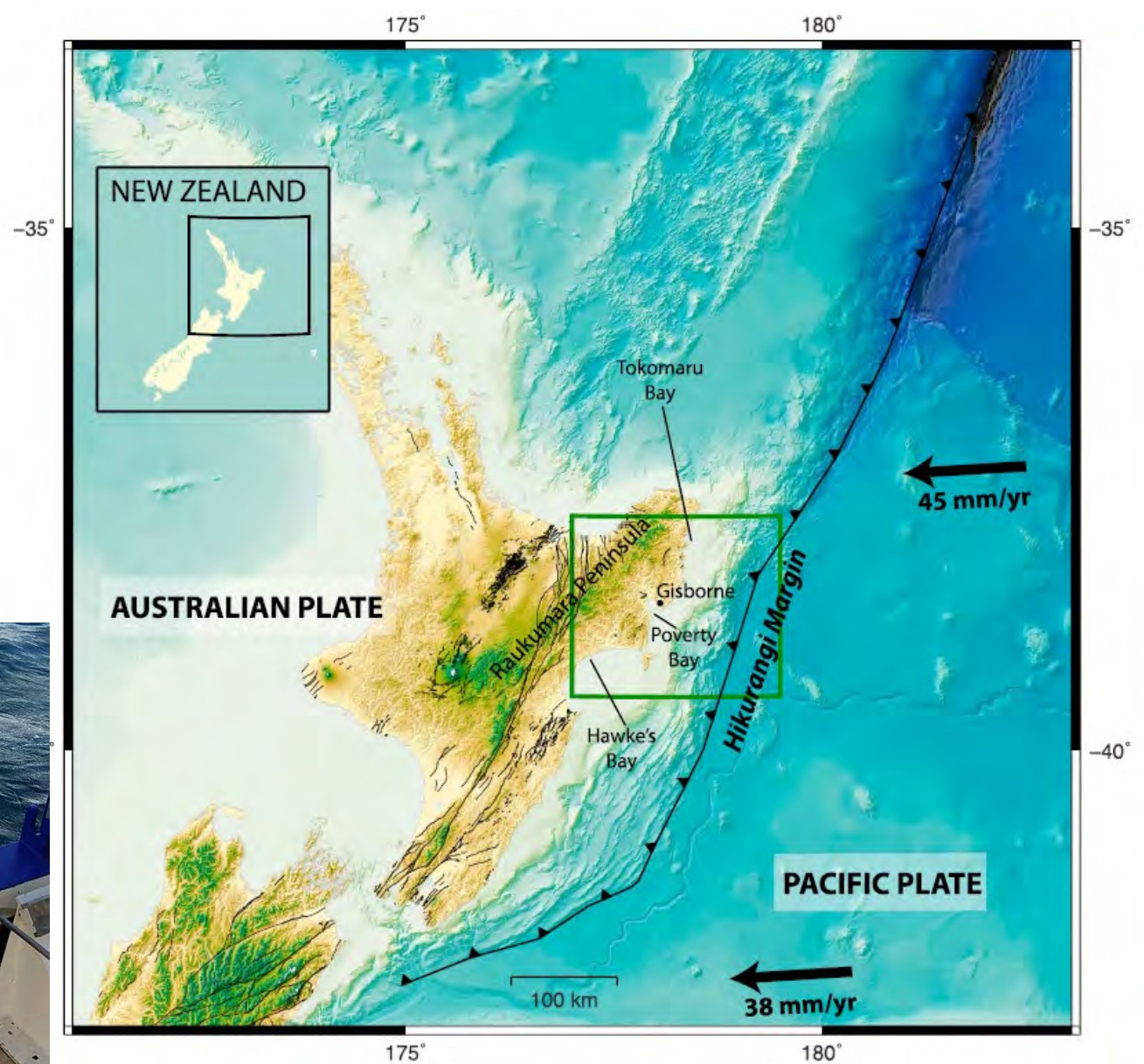
VICTORIA UNIVERSITY OF  
**WELLINGTON**  
TE HERENGA WAKA



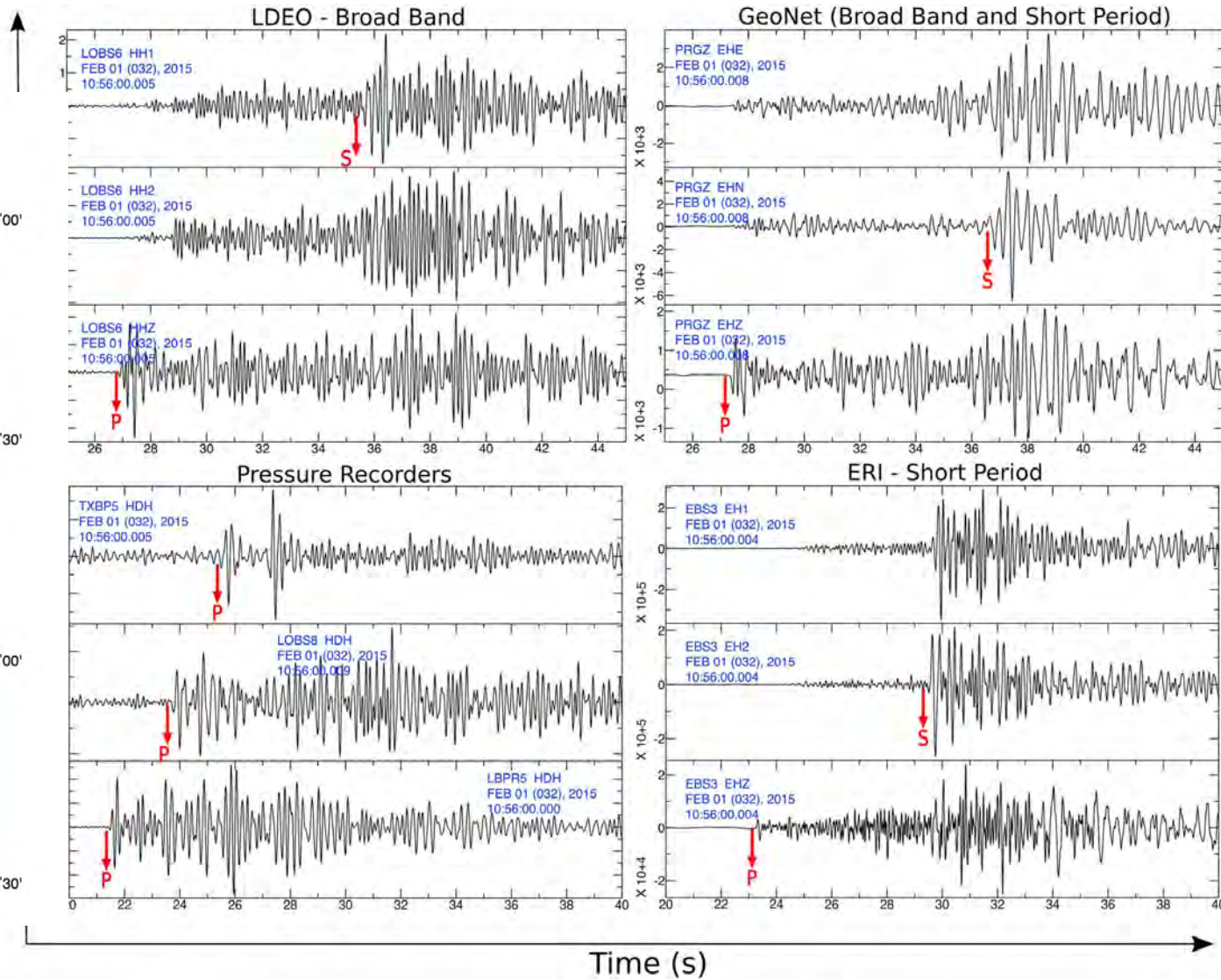
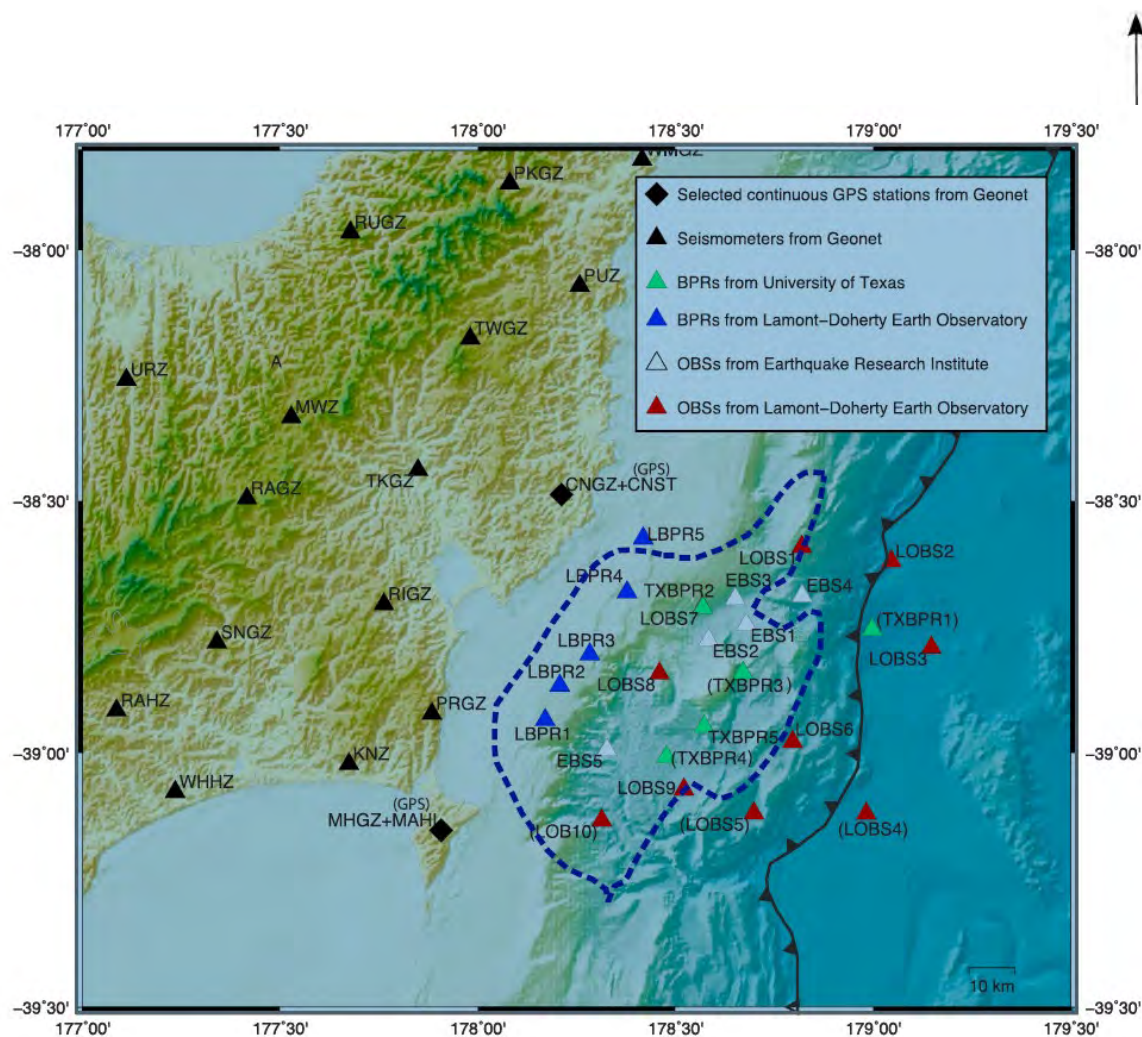
# Seismicity offshore North Island



Hikurangi Ocean  
Bottom Investigation  
of Tremor and Slow  
Slip-HOBITSS







# Traditional Workflow to find more earthquakes

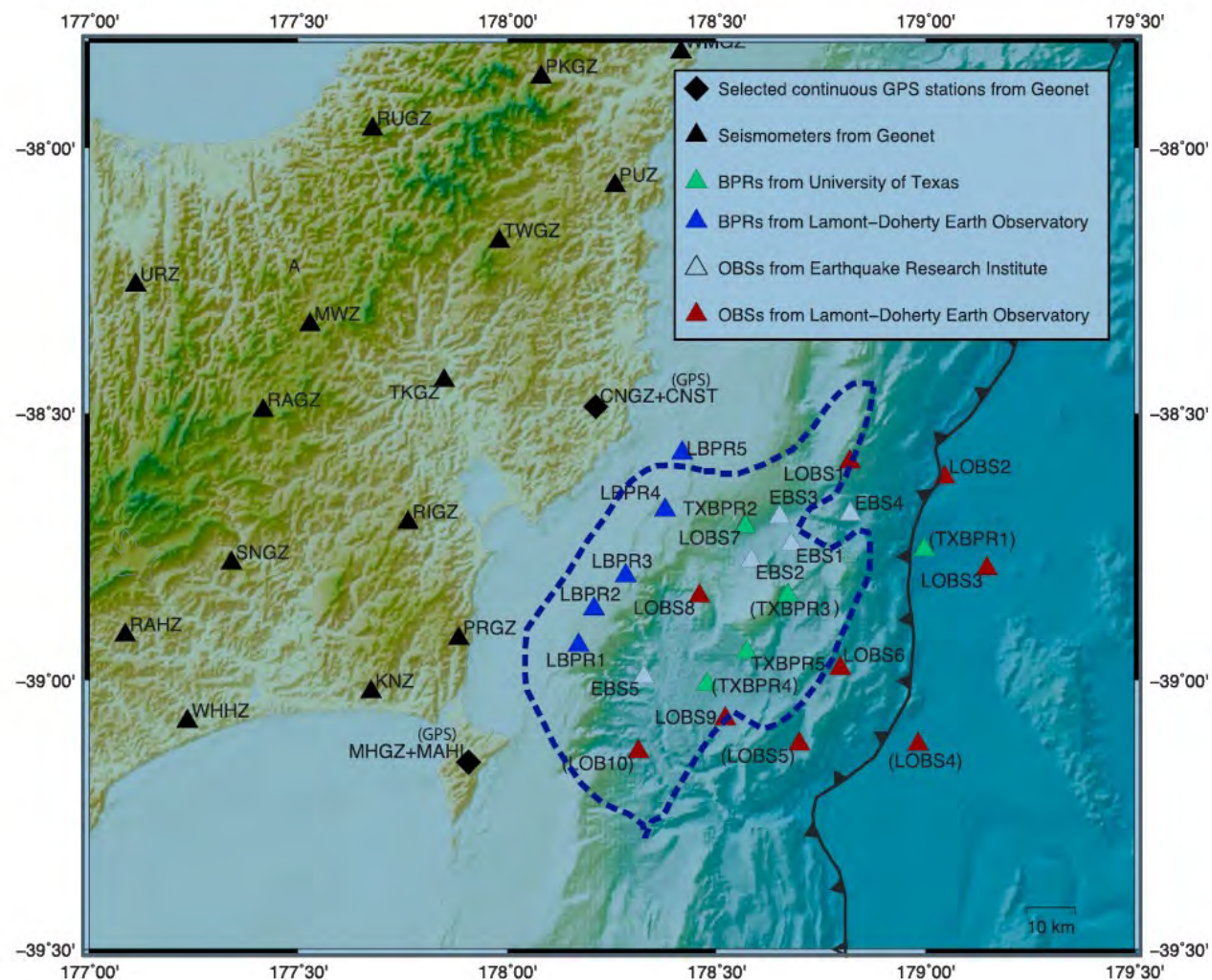
- ½) GeoNet only locates earthquakes that have arrivals on 10 or more stations. We have stations filling in gaps, so we can measure more, small earthquakes.

## Traditional way

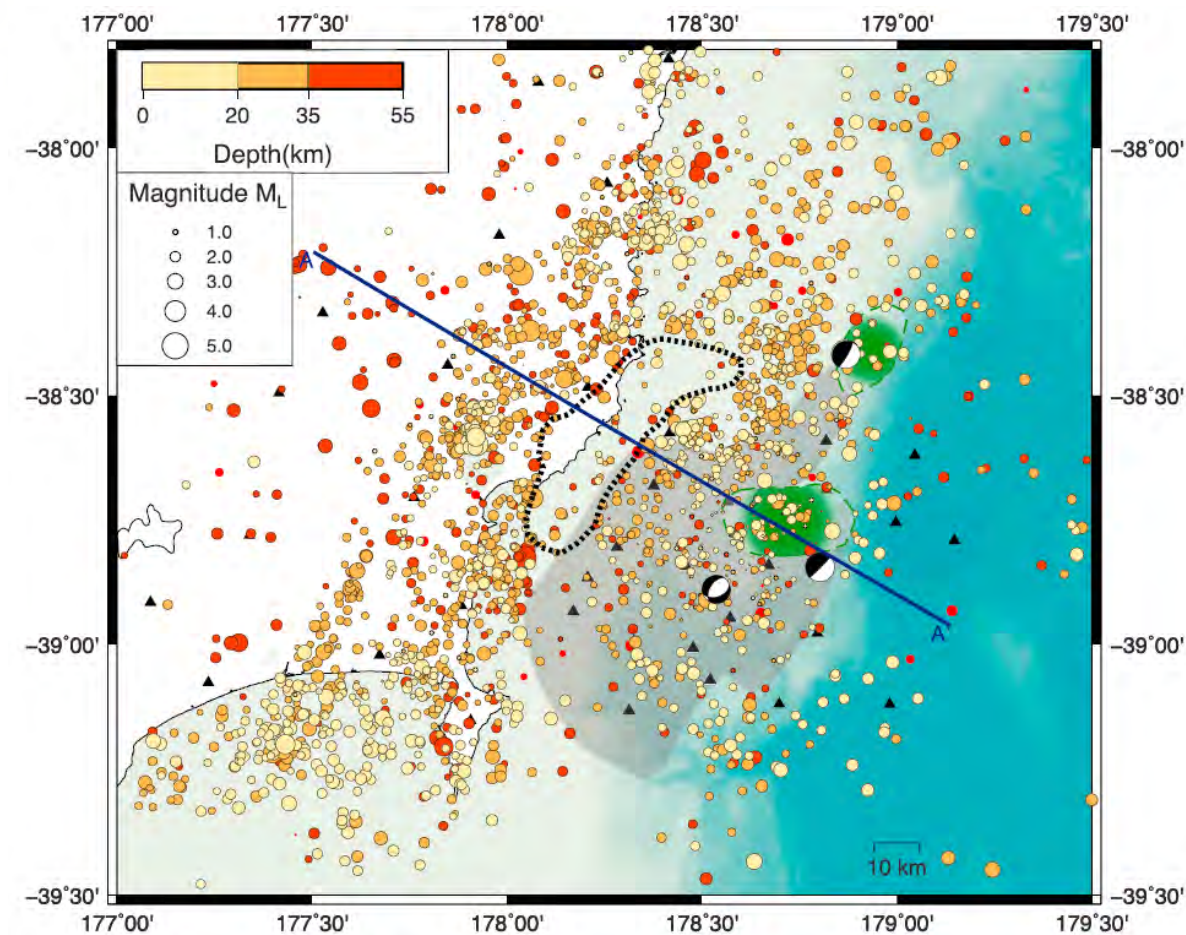
- 1) Start with GeoNet-located earthquakes to get an idea of larger earthquakes' seismicity and to get a set of earthquakes to test
- 2) Pick arrival times on our temporary seismometers, checking GeoNet stations and relocate, possibly get focal mechanisms
- 3) Start from waveforms of combined set of temporary and permanent stations to find earthquakes via the same method GeoNet uses, but will get new, smaller earthquakes. Location errors around 1 km or more.



## Deployment 2014-2015



2x more Eqs than GeoNet  
(~2000)

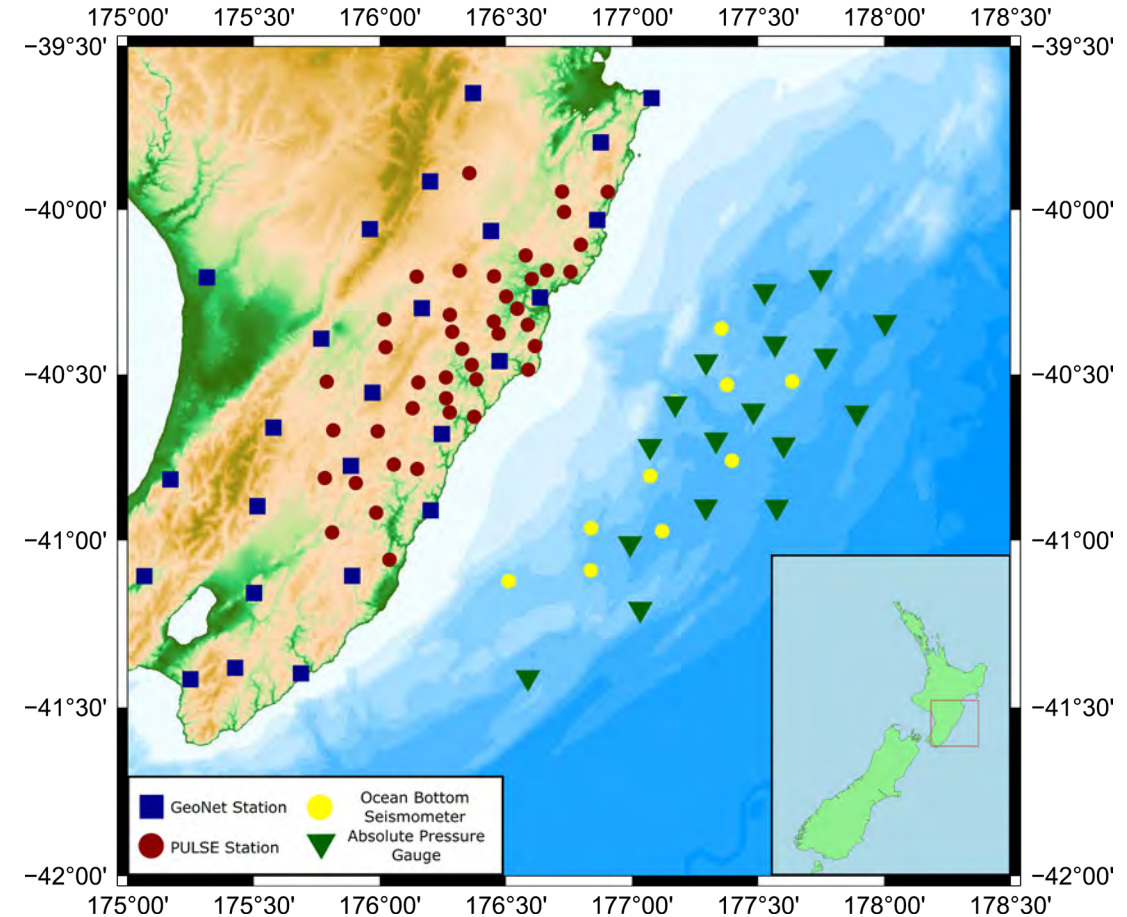


Dashed line encloses 2014 slow slip area



# The PULSE Network

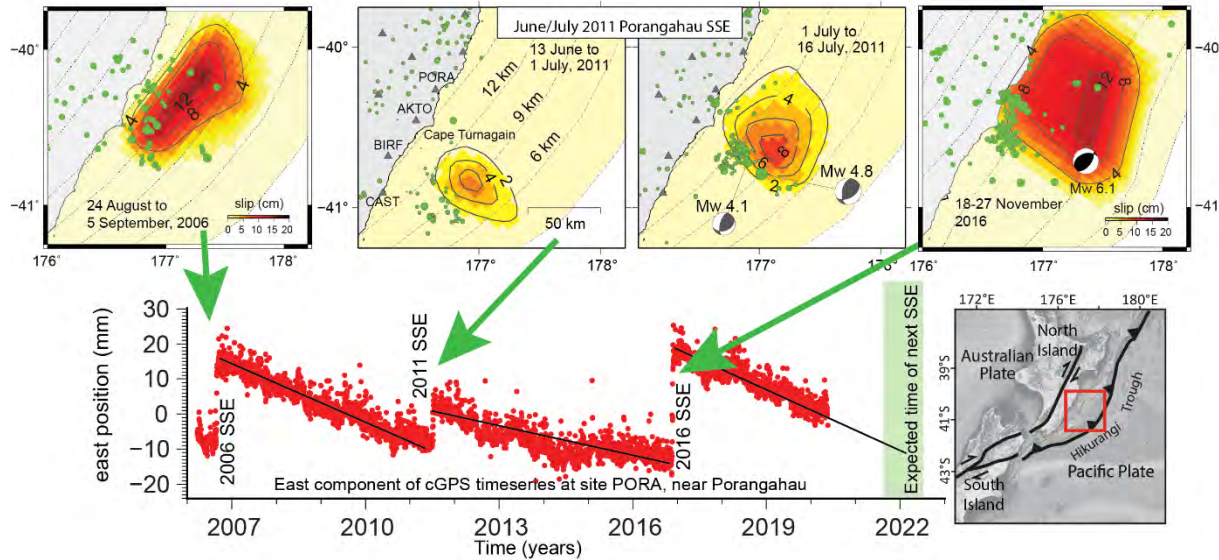
- 55 Onshore Stations
- 26 Offshore Stations
- Onshore: Deployed June 2021
- Offshore: Deployed October 2020





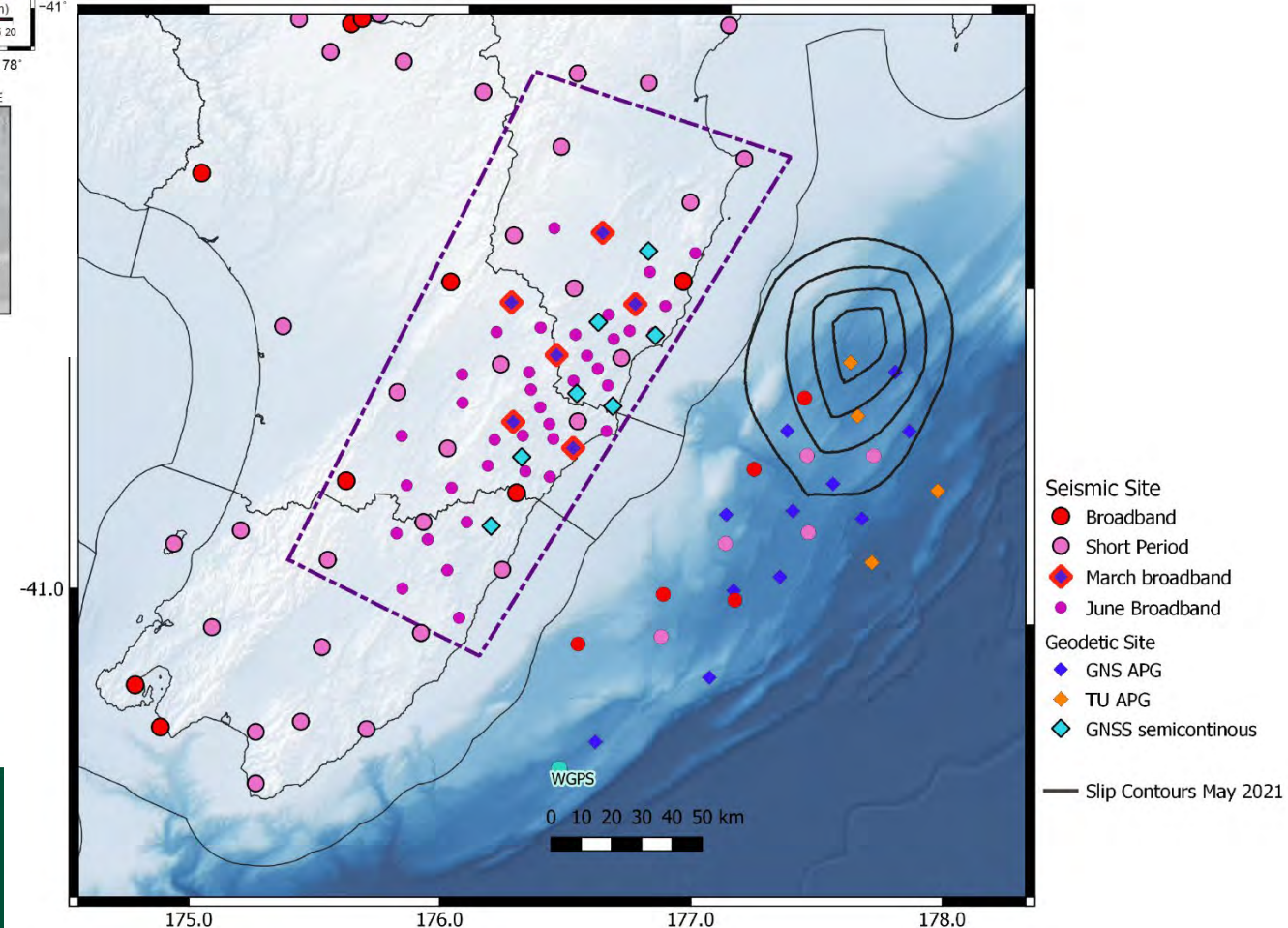
# Large central Hikurangi SSE in May 2021 captured with an amphibious geodetic and seismic network—SSEs occur here every ~5 years

L. Wallace, E. Warren-Smith, K. Jacobs, M. Savage, K. Mochizuki, Y. Yamashita, Y. Ito, R. Hino, S. Suzuki, Seismicity study now PhD student Stephen Kwong

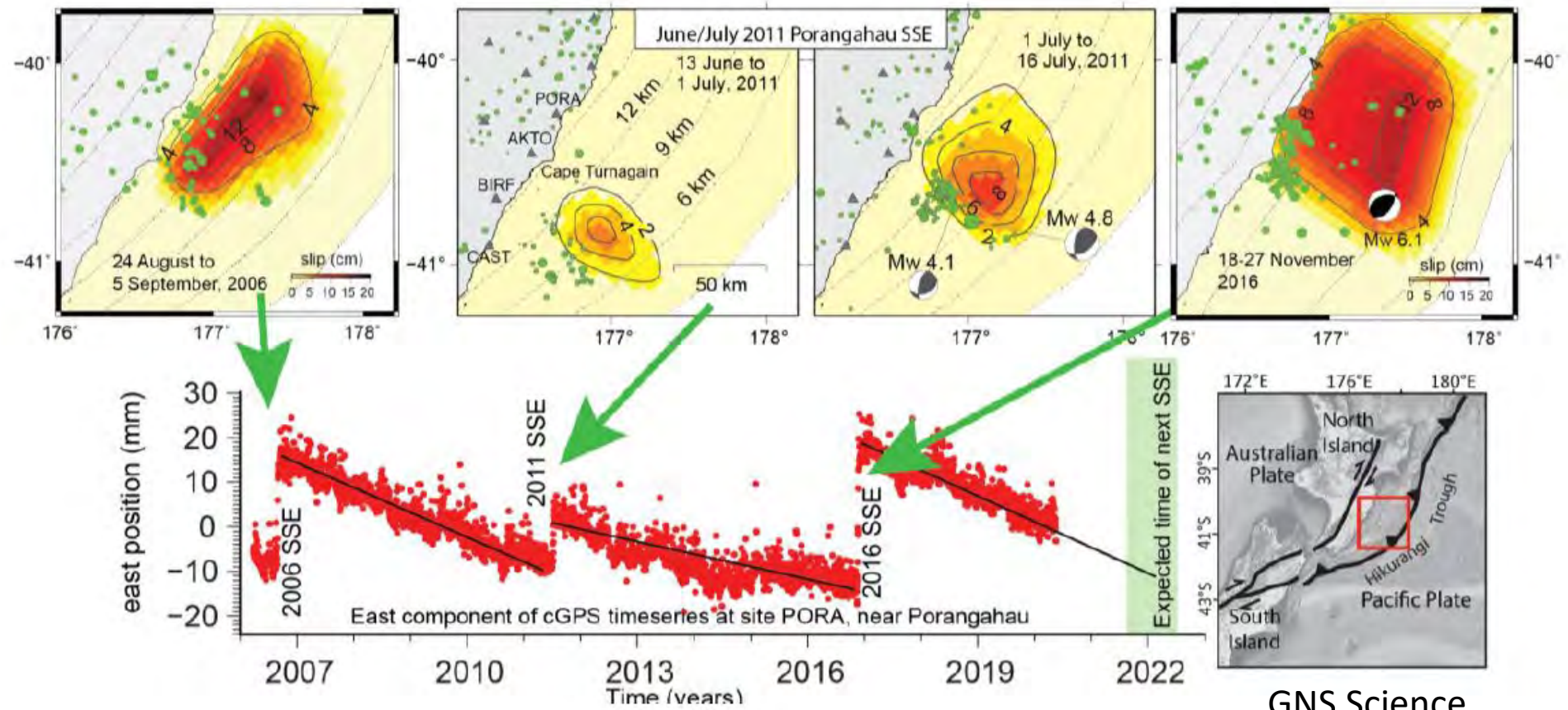


APG oceanographic reference sites in similar water depths (along-strike; e.g., Frederickson et al., 2019)

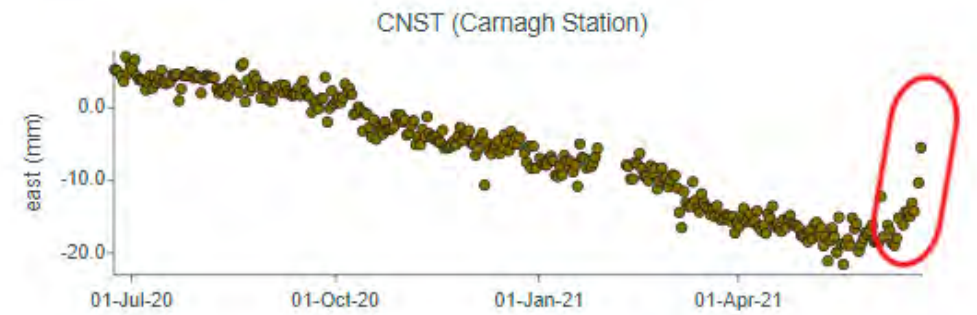
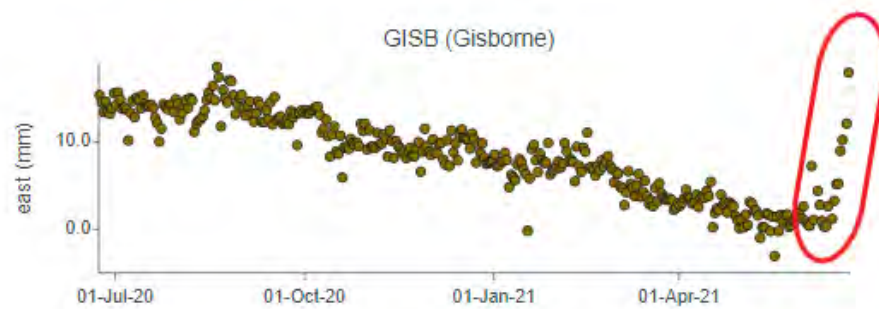
Collaborative project between New Zealand and Japan involving deployment of 10 OBS and 16 APGs, >40 onshore broadband seismic stations, and several temporary GNSS sites onshore.







GNS Science





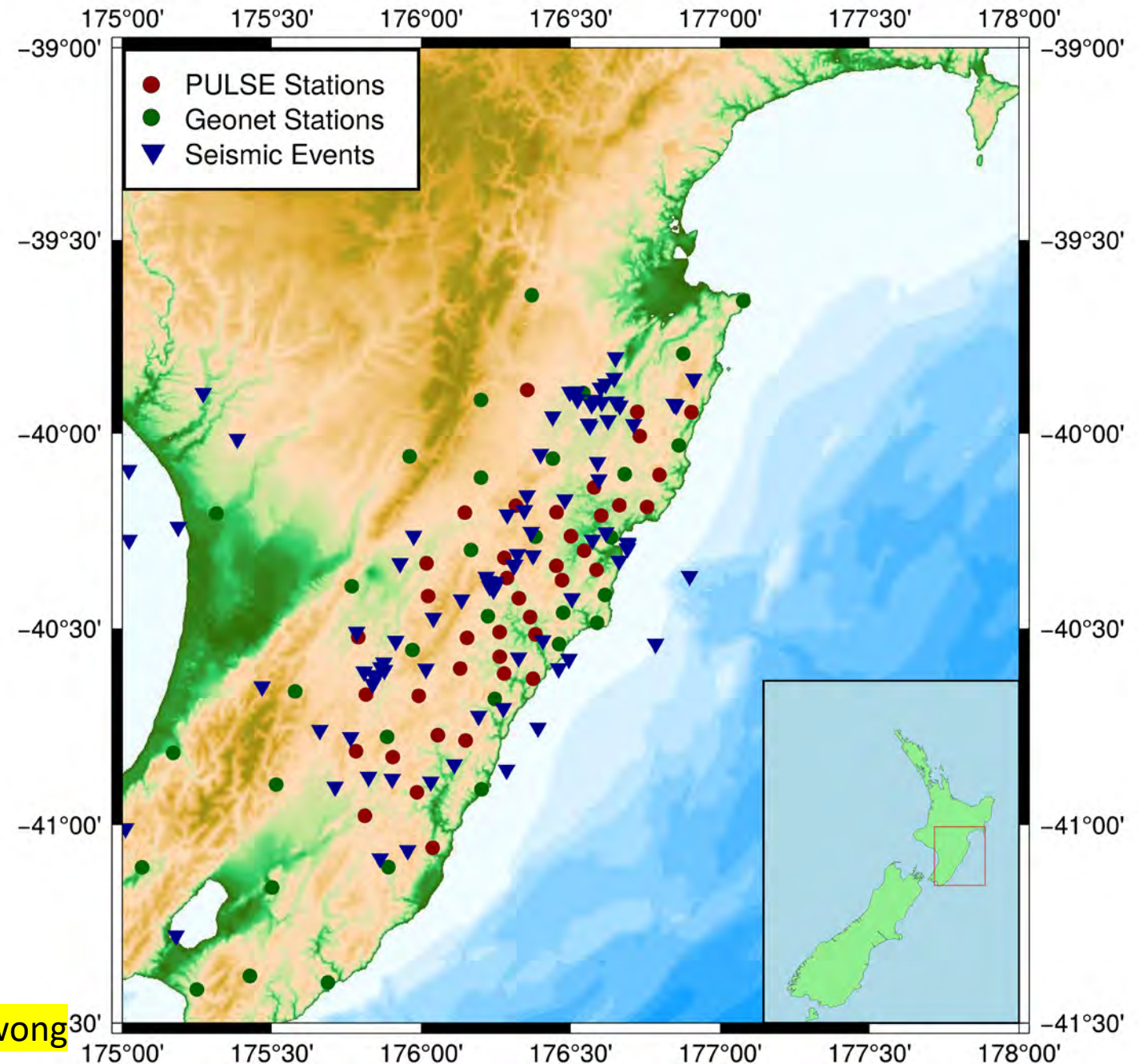
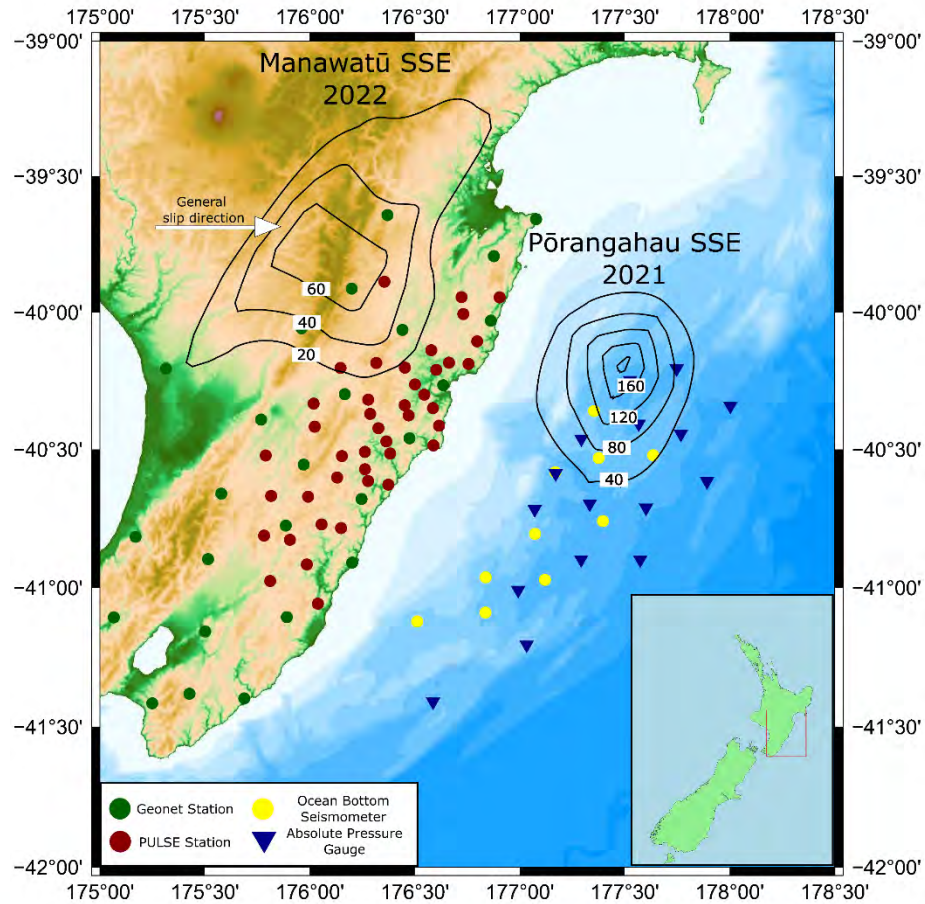
# New workflow to find more earthquakes

- **1) Use Artificial Intelligence pickers to pick P and S arrivals, comparing to traditional catalog to get parameters right.**
- **2) Locate newly picked earthquakes.**
- **3) Find a new velocity model for P and S waves**
- **4) Relocate earthquakes with new velocity model.**
- 5) Use best-located earthquakes as “templates” to find new, very small earthquakes, that have similar waveforms.
- 6) Locate templates with traditional methods or relative earthquake location methods—location errors 10’s to 100’s of meters. Tiny earthquakes allow faults to be delineated better.



# Earthquakes used for EQTransformer Testing

## The PULSE Network





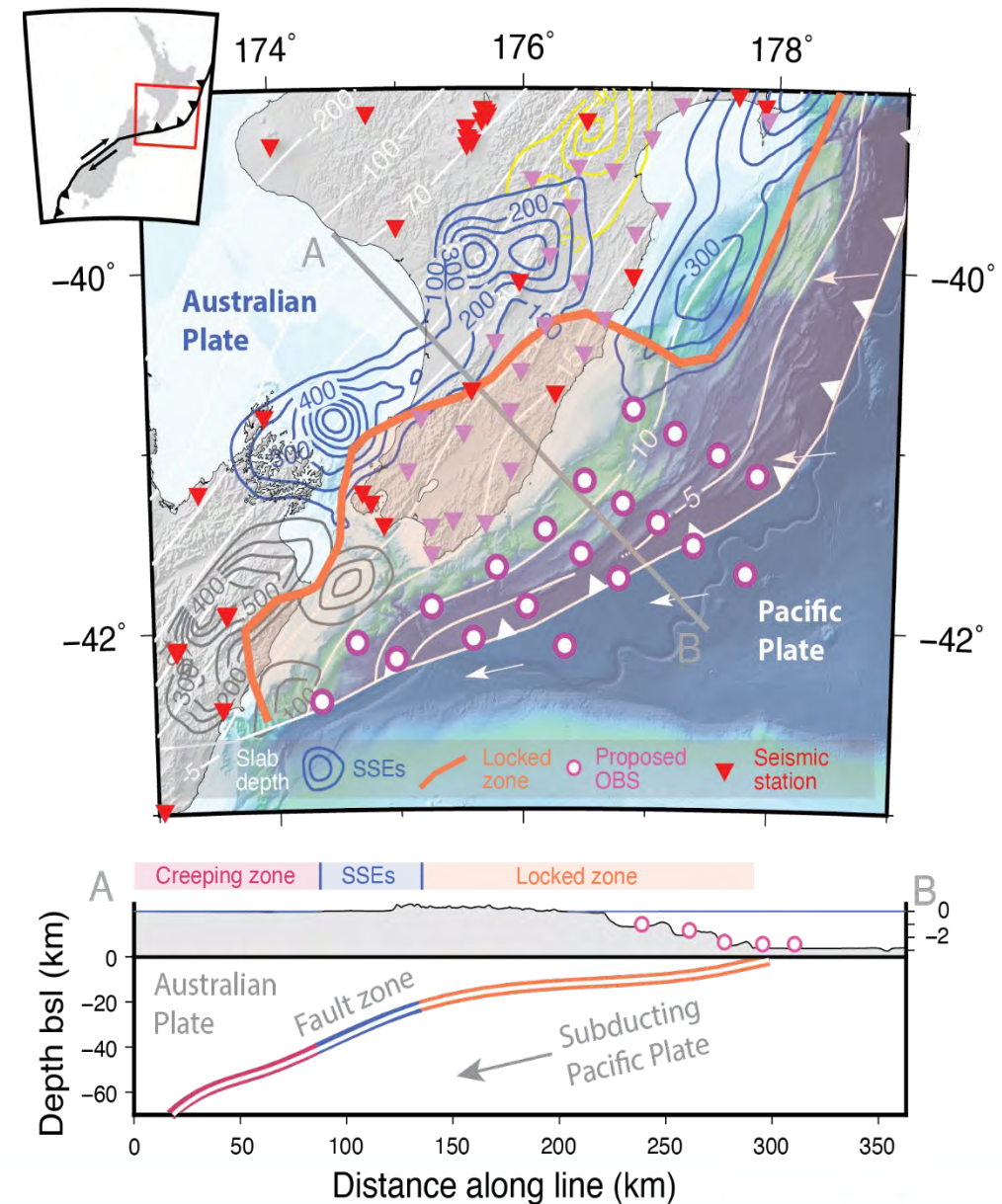
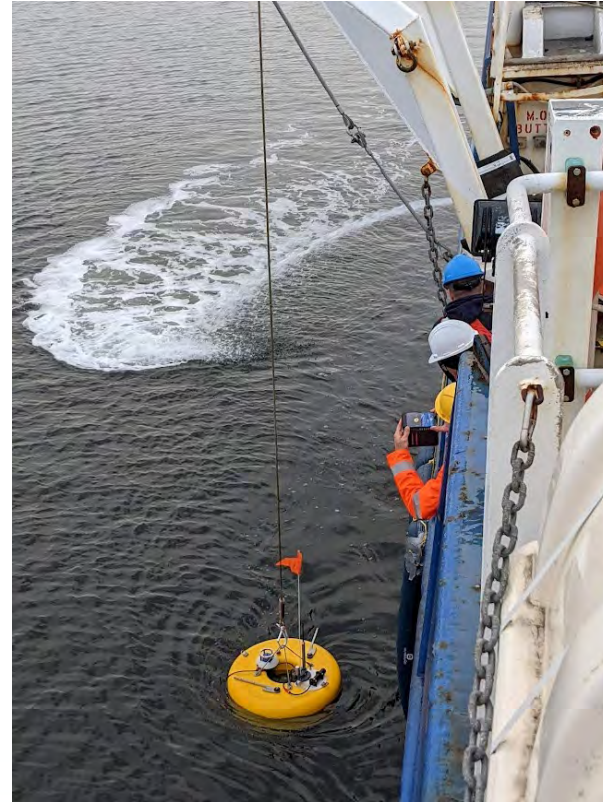
# Results

- Parameters chosen for preliminary onshore stations now being tested with HOBITSS (2014) OBS data.
- Those parameters seem to capture all the same events found previously
- They also find more events than were found before.
- Should give good parameters to use for both PULSE and new OBS deployment.



# Future Work

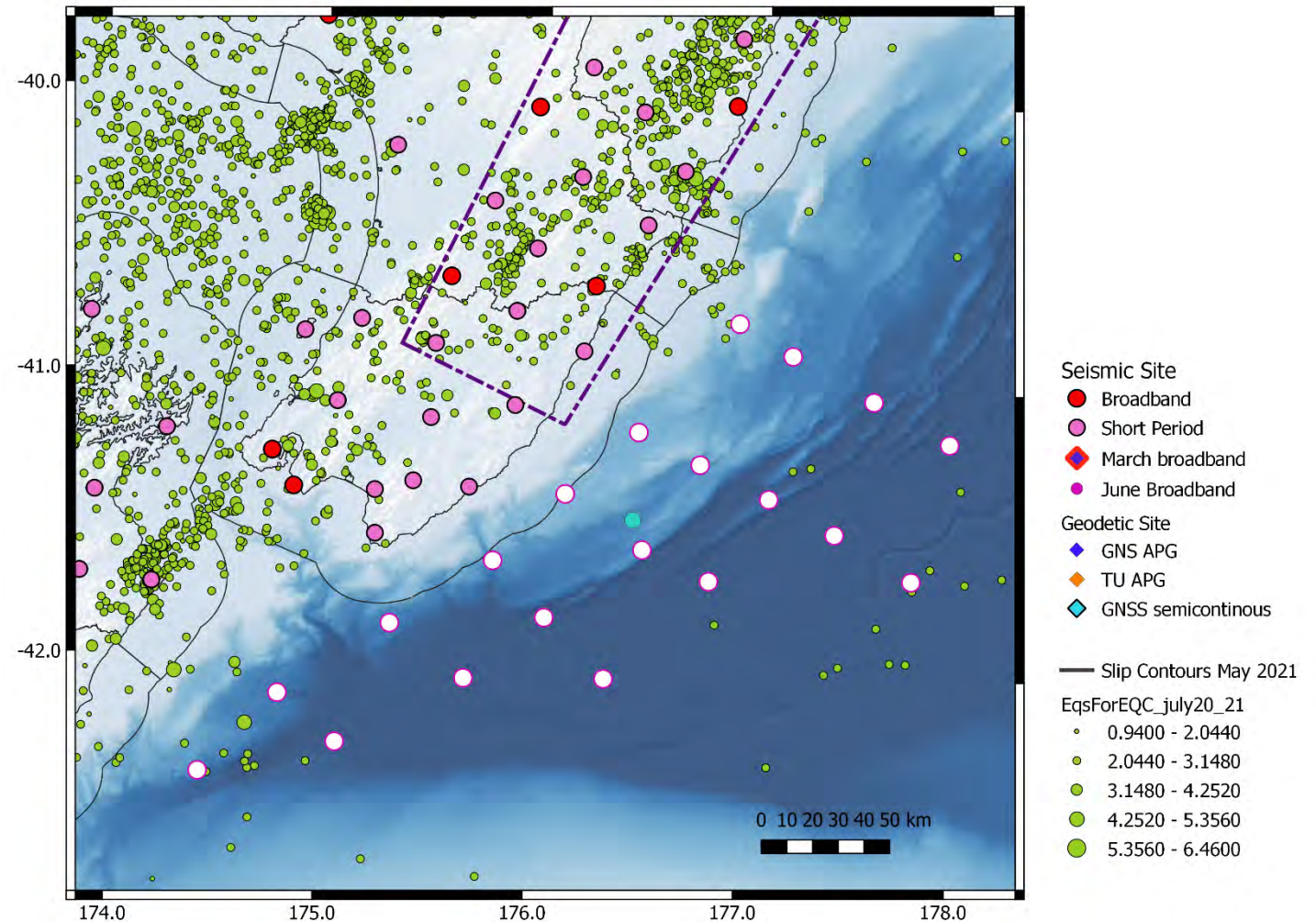
- Seismic Hazards from Earthquakes in the Locked Zone Offshore Wellington (2023-2024)





# Future Deployment and one year's earthquakes

Will find new earthquakes to determine future hazards (our new techniques can usually find 10x more earthquakes than standard methods)



# What if there really are no earthquakes?

- We will have some stations eastwards of trench to check for earthquakes responding to slab-bending in the “outer rise”
- We will get teleseismic (distant) earthquakes and seismic noise to get better seismic velocity structure to understand effect of properties on shaking from a large earthquake.



# Earthquakes in New Caledonia

- Shao-Jinn Chin-PhD student
- Rupert Sutherland
- Martha Savage
- John Townend
- Julien Collot
- Bernard Pelletier
- Olivier Monge
- Finnigan Illsley-Kemp



## Tectonic Setting

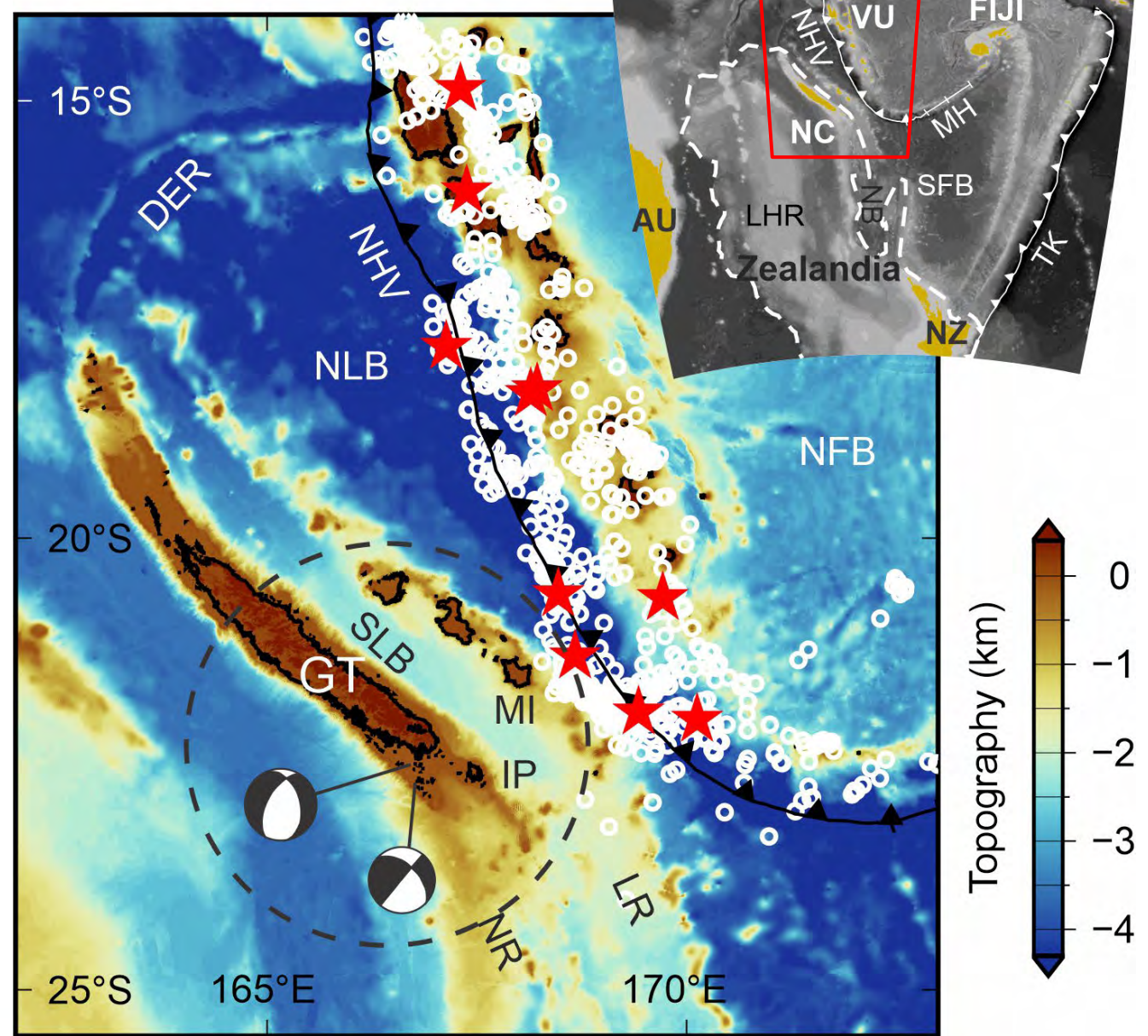
### New Caledonia

White circles =  $M > 5$  Earthquakes from USGS catalogue 2011-2020

Red stars =  $M > 7$

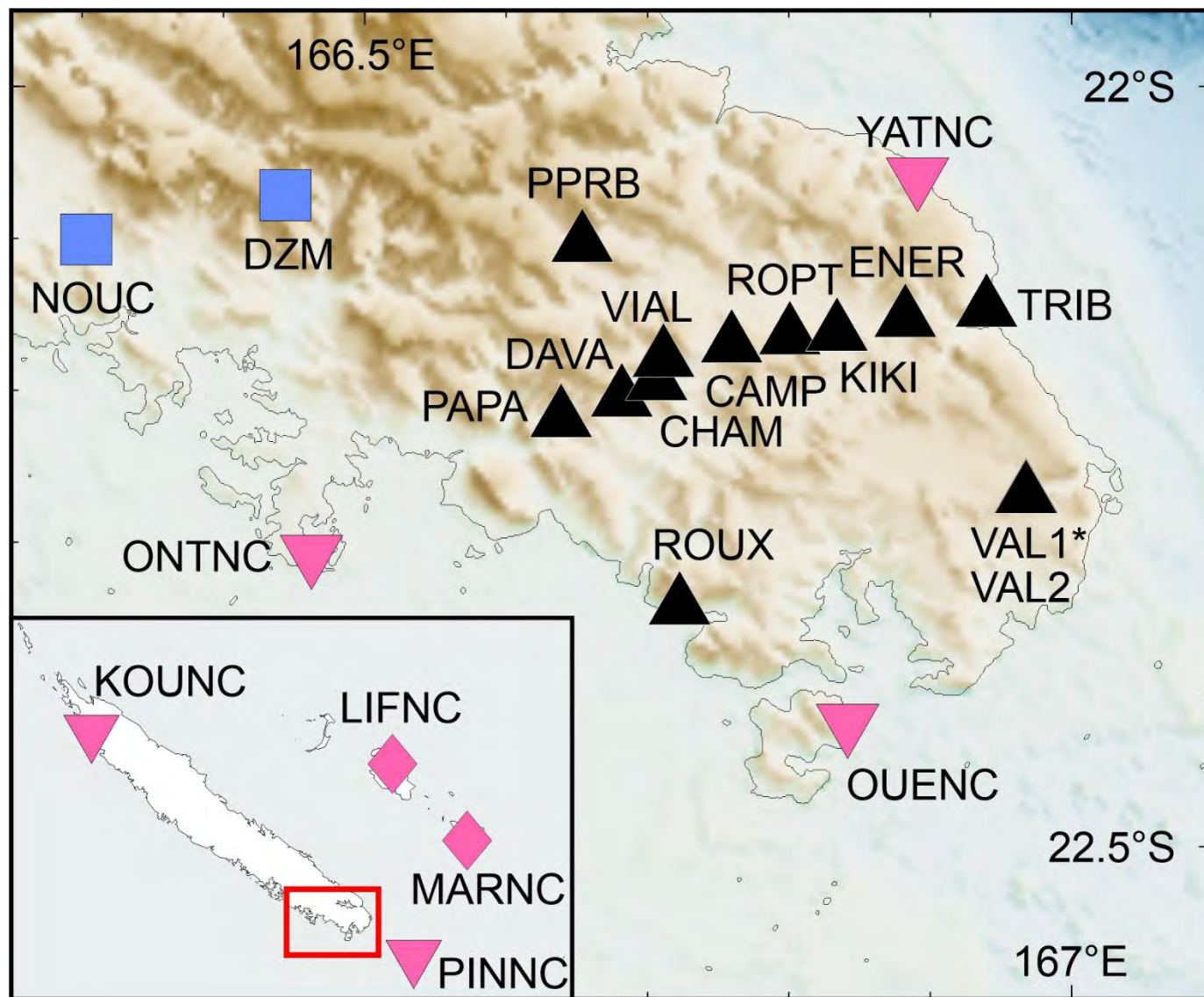
Deployed seismometers from 2018-2019 in “Investigating the Thickness of the Peridotite Nappe of New Caledonia (ITOPNC)” to understand the subduction zone and thickness of nickel layers for possible drilling

But first—we realised that there was very little known about earthquake hazards





# Seismic Stations on New Caledonia—Black Triangles = temporary



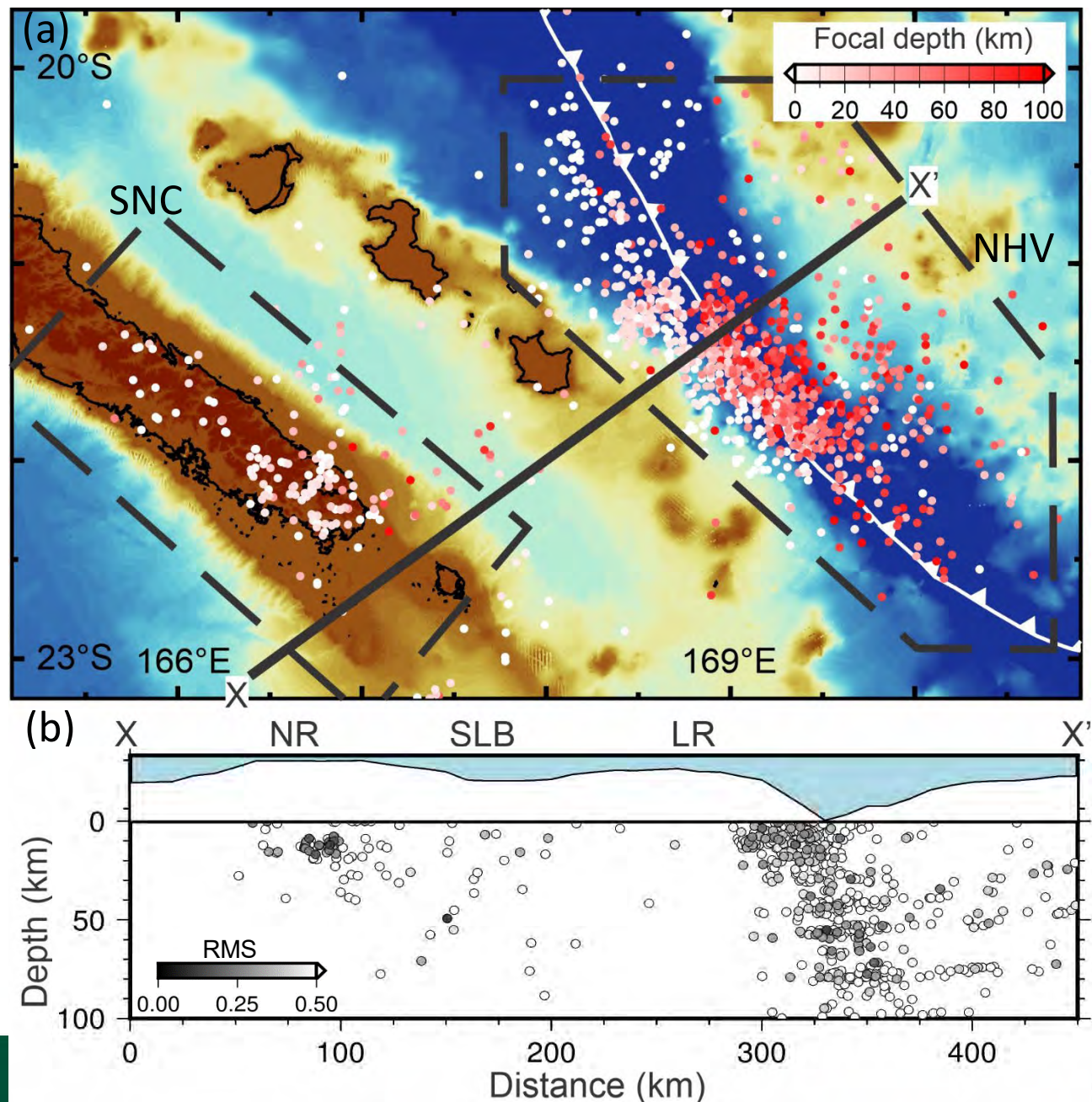


Earthquake Locations  
using combined  
network

Pick Arrival times and  
associate events using  
AI picker

Determine velocity  
model with “Velest”

Use “Nonlinloc”  
nonlinear inversion  
code to get 1374  
earthquake locations





## Magnitude Distribution

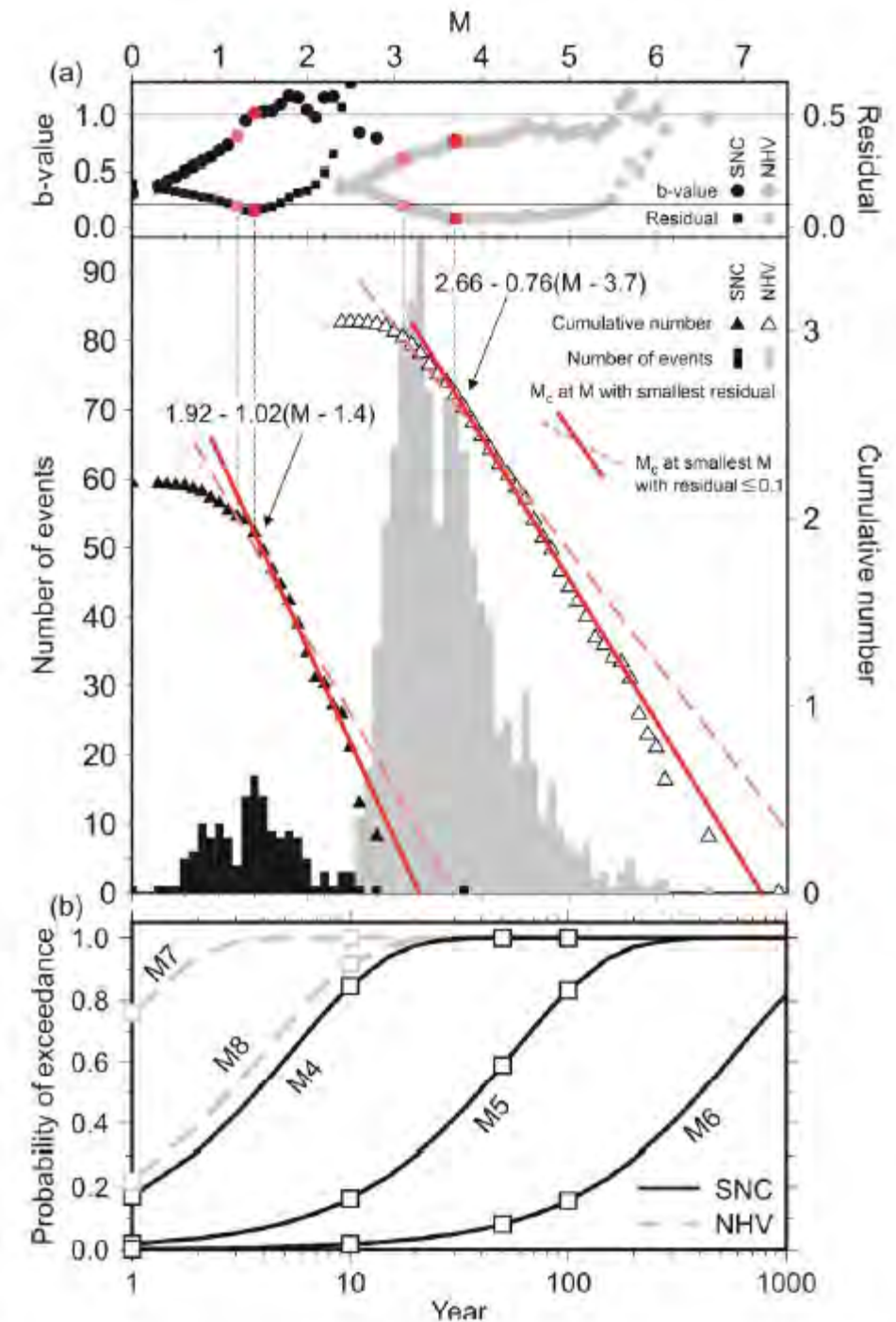
Determined local magnitude function from amplitudes

$$-\log(A_0) = 0.495 \log\left(\frac{r}{17}\right) + 0.003646(r - 17) + 2$$

Then determine number of events per magnitude

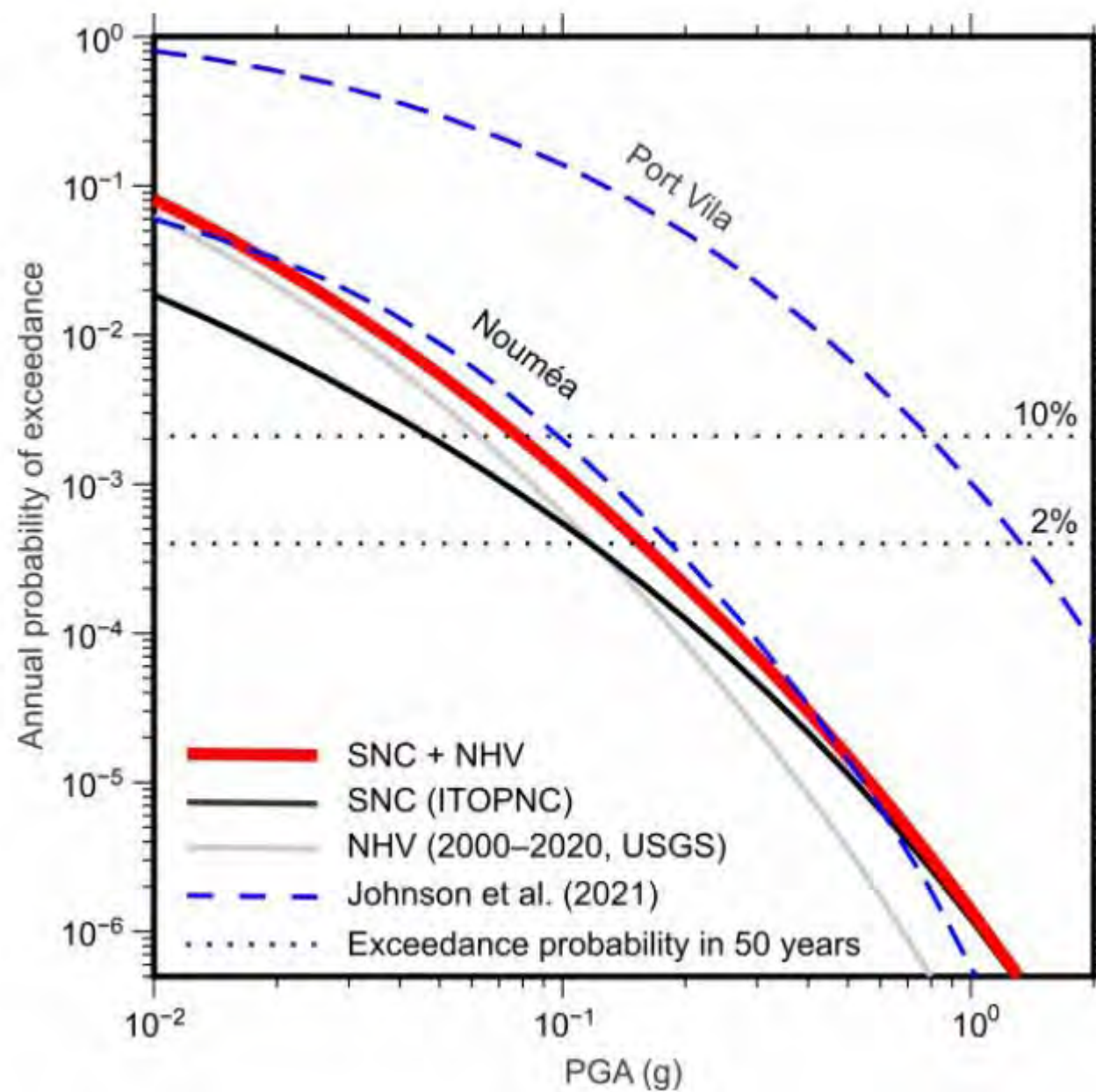
NC = New Caledonia eqs

NHV=New Hebrides-Vanuatu



Hazard Curves:  
Probability of exceedance

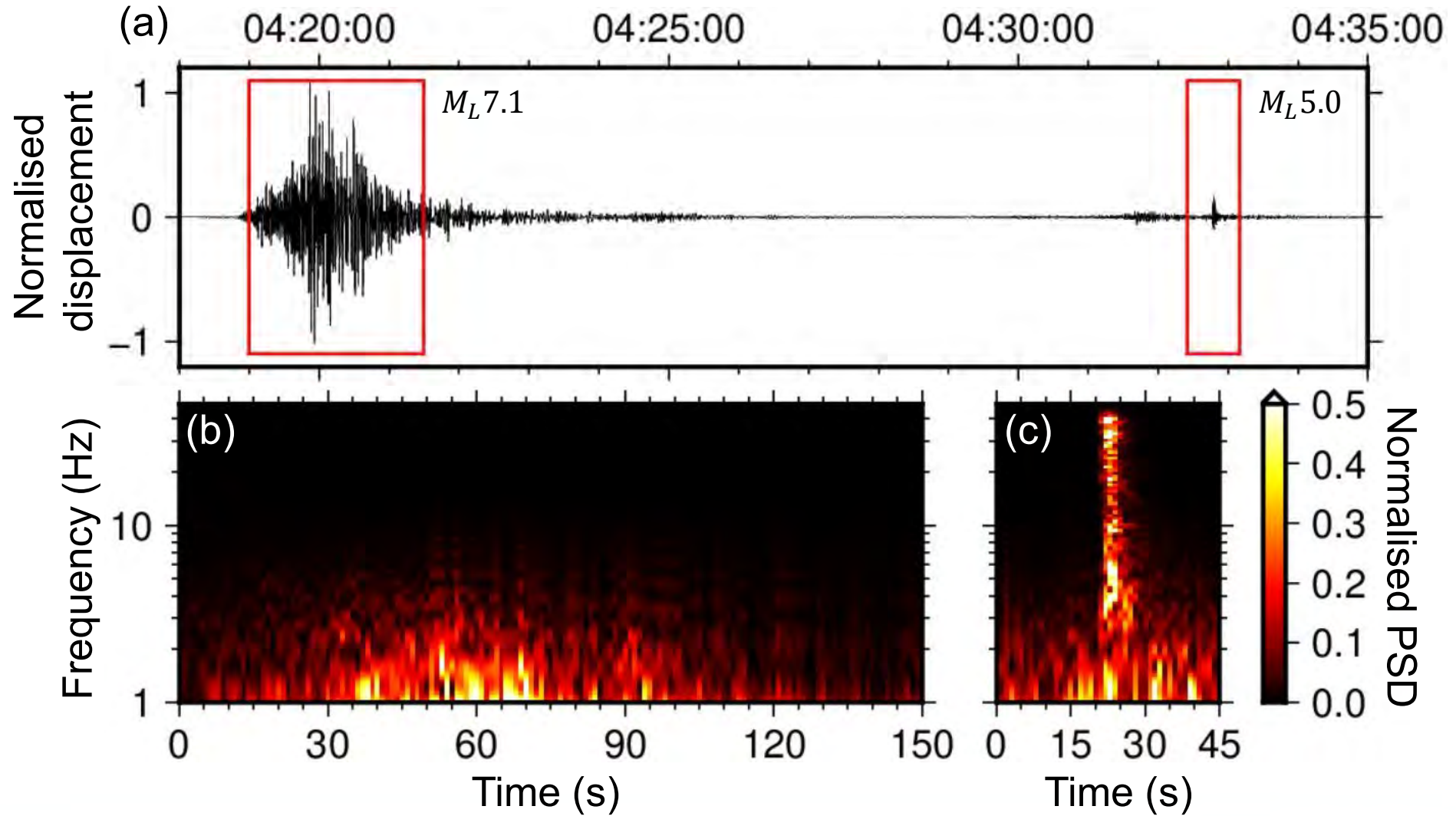
Red = our results



In 50 years



# Earthquake Triggering



# Summary

- More stations can find smaller earthquakes
- There have not been any stations offshore Wellington ever
- We don't know whether small earthquakes are happening
- New OBS deployment will help to test the NSHM model.



# Geophysics at Victoria University

- Uses Physics to study the Earth
- We accept 4<sup>th</sup> year students from a variety of quantitative majors and bridge them into geophysics
- Honours, MSc, PhD
- Seismology—Earthquake location, source properties, Earth structure imaging & tectonics
- Geodesy-slow earthquakes and tectonics and fast earthquakes
- Volcanology and Volcano Geophysics

# Some Current projects at VUW

- Alpine Fault Earthquakes—John Townend and Calum Chamberlain
- AI and earthquakes: Calum Chamberlain and Finn Illsley-Kemp
- Volcano seismology and eruption prediction: Finn Illsley-Kemp and Martha Savage
- Earthquake processes studied through laboratory measurements: Carolyn Boulton
- Earthquake Early Warning: Martha Savage (with Caroline Holden)
- Slow Slip Earthquakes: Martha Savage (with several others)
- Strain accumulation across the Wellington Fault: Simon Lamb