

Tsunami waveform inversion of the 2021 Loyalty Islands earthquake and implications for tsunami forecasting for New Zealand



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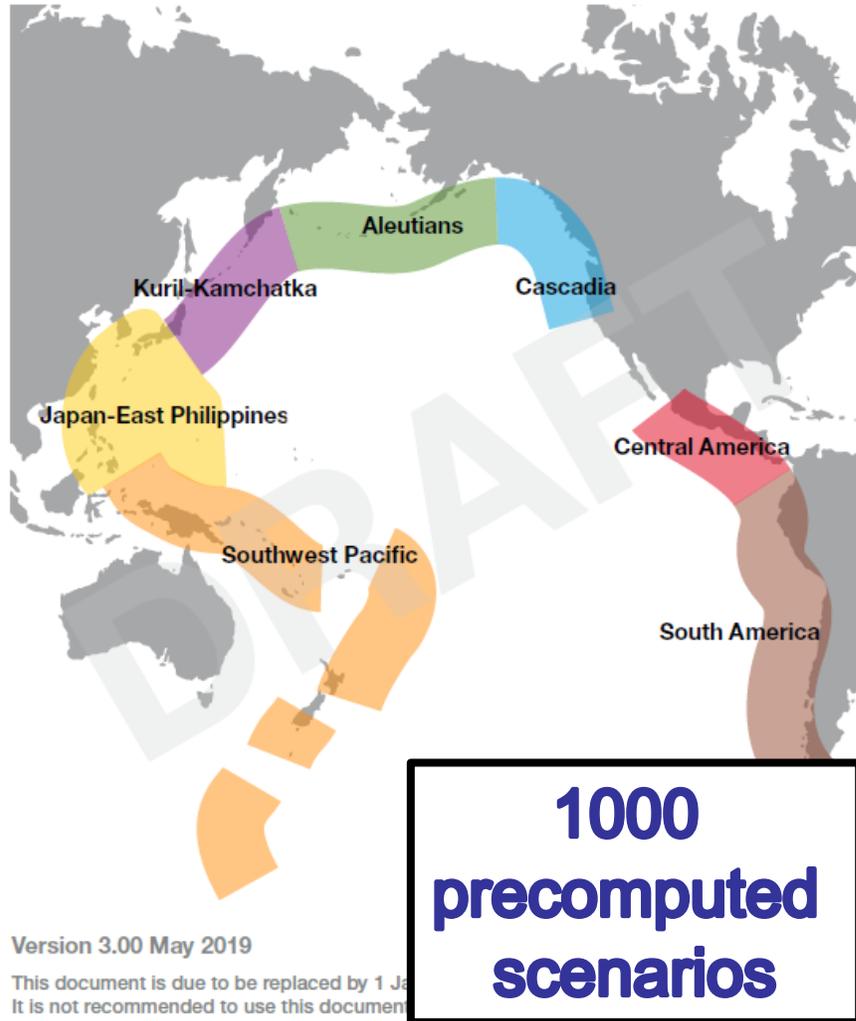


Introduction

- Precomputed tsunami database for tsunami forecasting in New Zealand
- New Zealand DART buoy (NOAA) network
- Earthquake source modeling of the 2021 Loyalty Islands earthquake using tsunami waveforms
- Evaluation of our tsunami forecasting techniques using data from the 2021 Loyalty Islands earthquake



TSUNAMI SCENARIO DATABASE



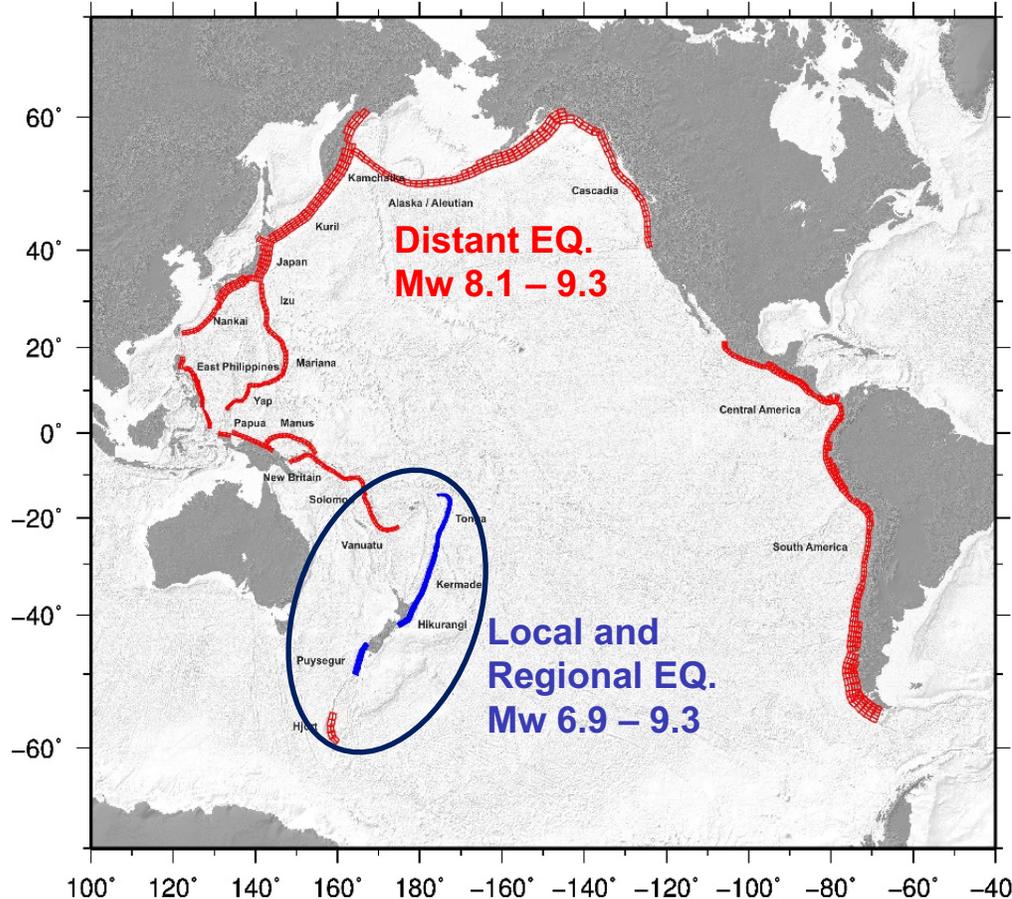
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User Guidelines

Fault patches used for the scenarios



Pre-computed scenarios Distant sources

- The fault size is 100 km x 50 km.
- Earthquake magnitudes: 8.1 – 9.3 (interval of 0.2)
- Space: 300 km

Regional sources

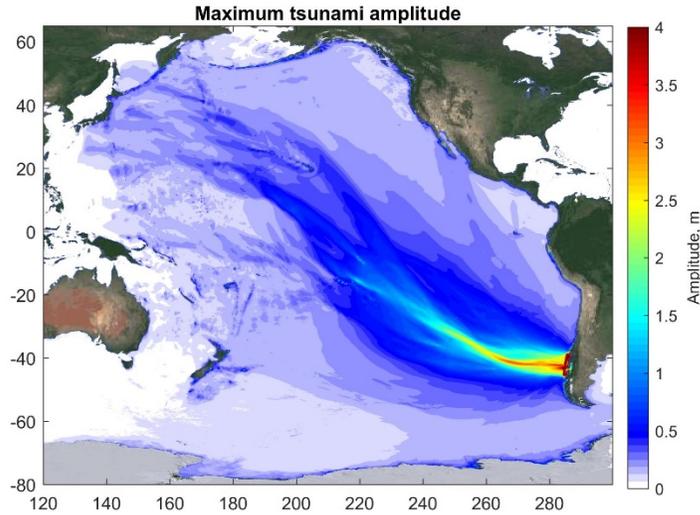
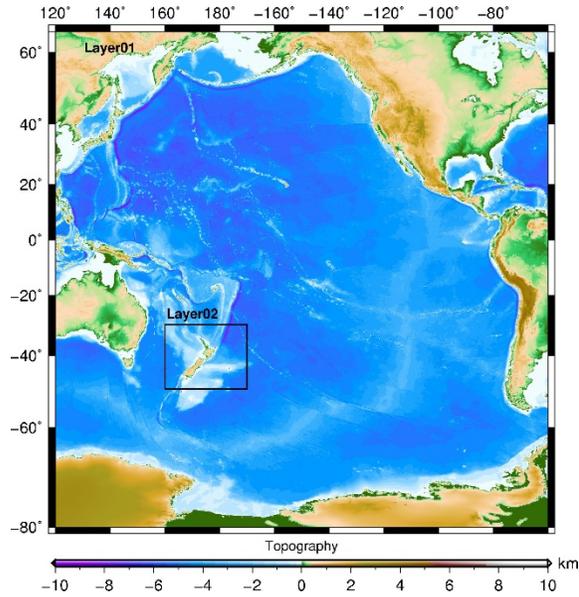
- The fault size is 50 km x 25 km.
- Earthquake magnitudes: 6.9 – 9.3 (interval of 0.2)
- Space: 100-150km

Fault Patches

- Fault patches are based on subduction interface models of NOAA, Scherwatch et al. (2018), Williams et al. (2013), and Power et al. (2012).

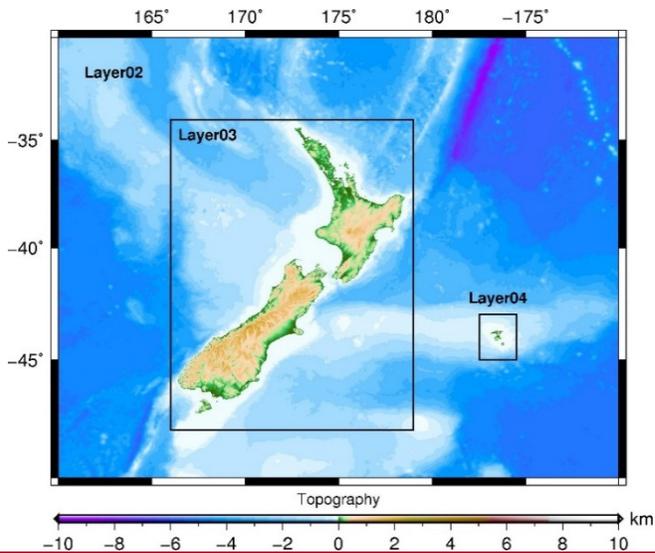


Tsunami Simulation

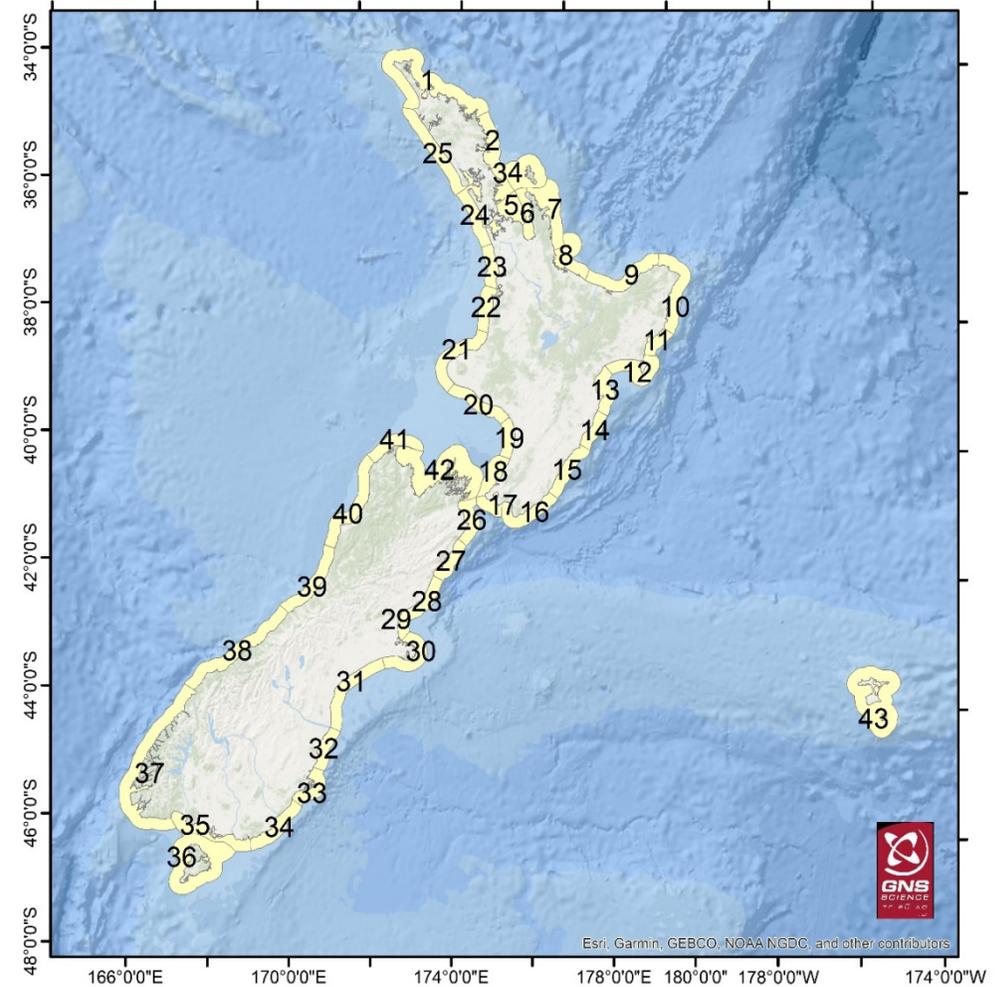


Tsunami Threat Level Calculation

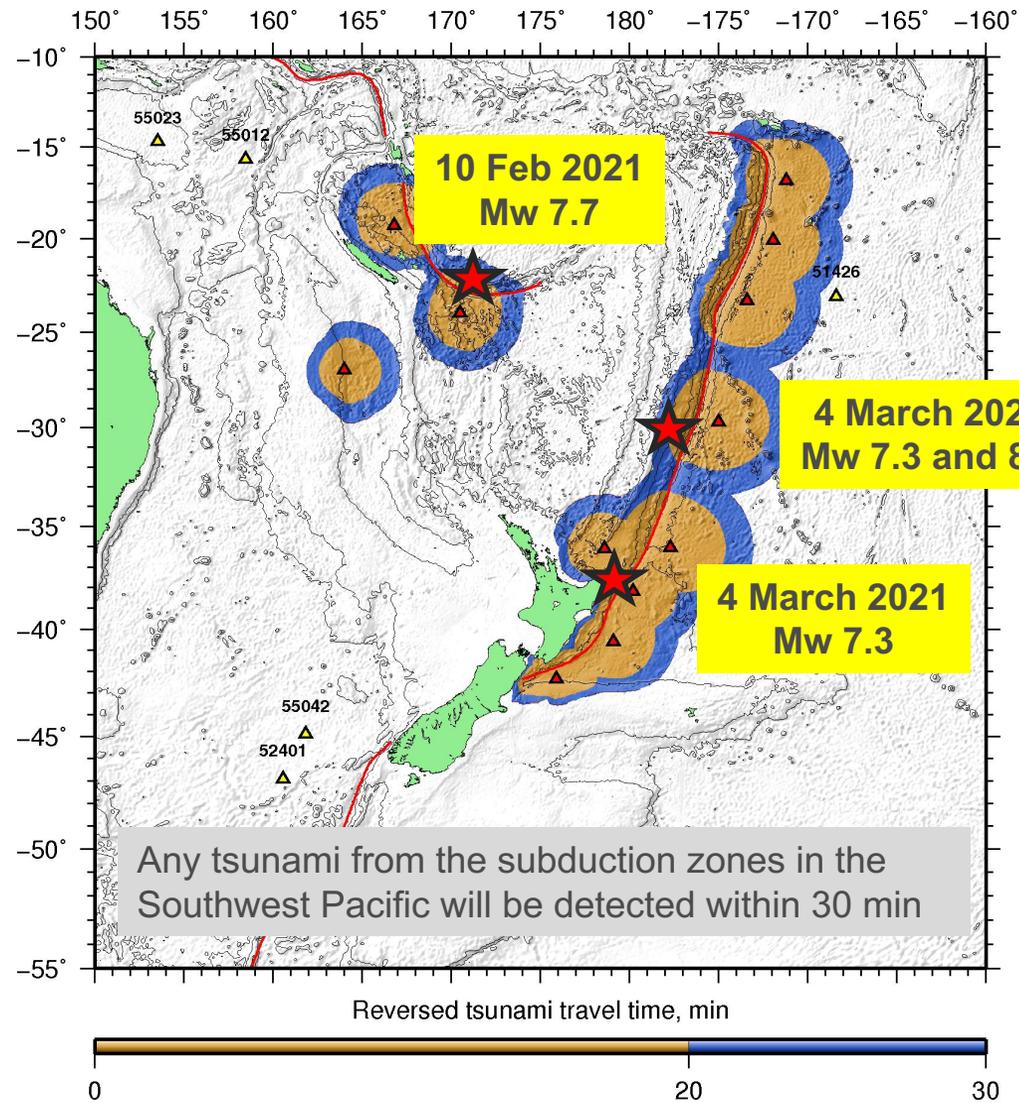
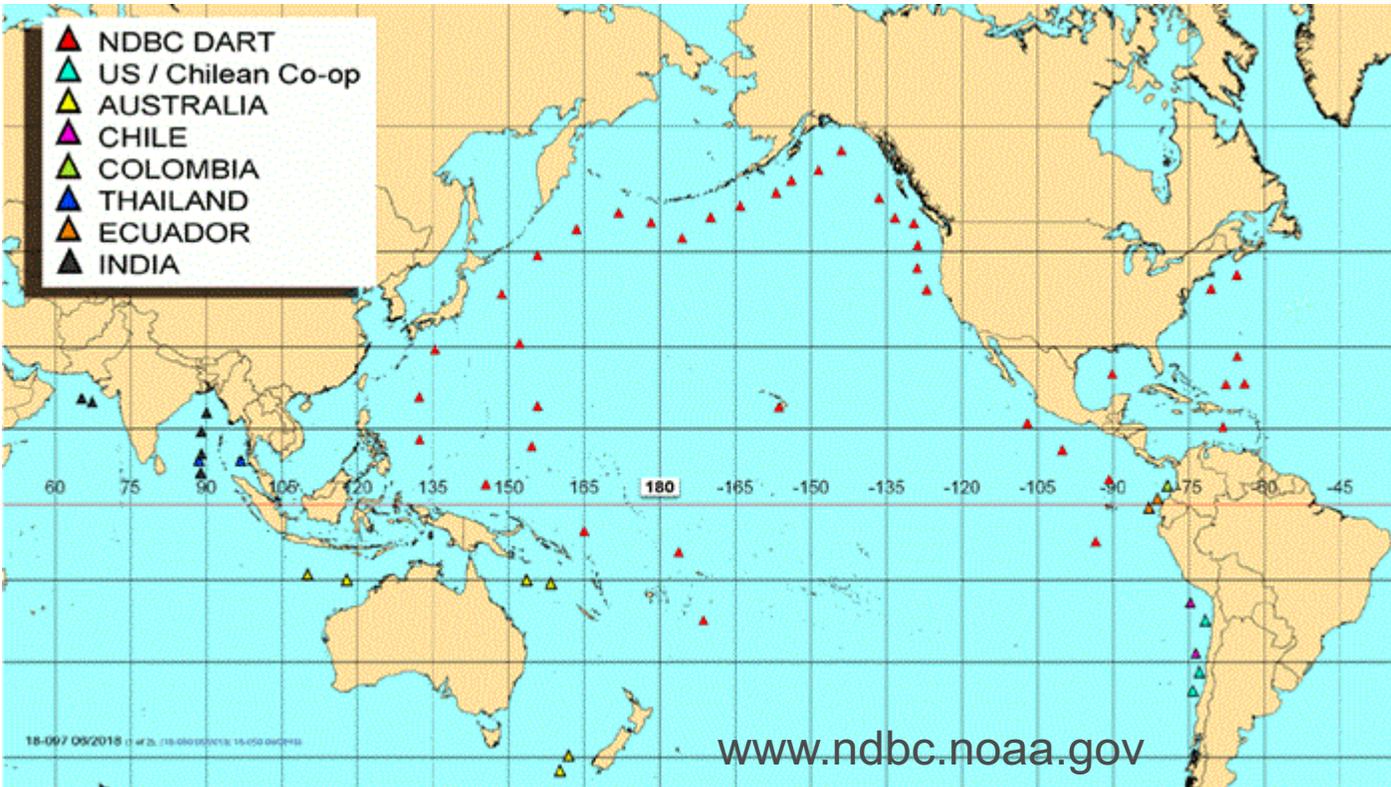
- Nonlinear shallow water equations with coastal wall boundary condition.
- Modelling grids: 4 arc-min, 2 arc-min, and 15 arc-second.
- We use NeSI for the computation
- 43 Warning Regions
- Threat level is based on the 99th percentile of the simulated coastal height within the warning region.



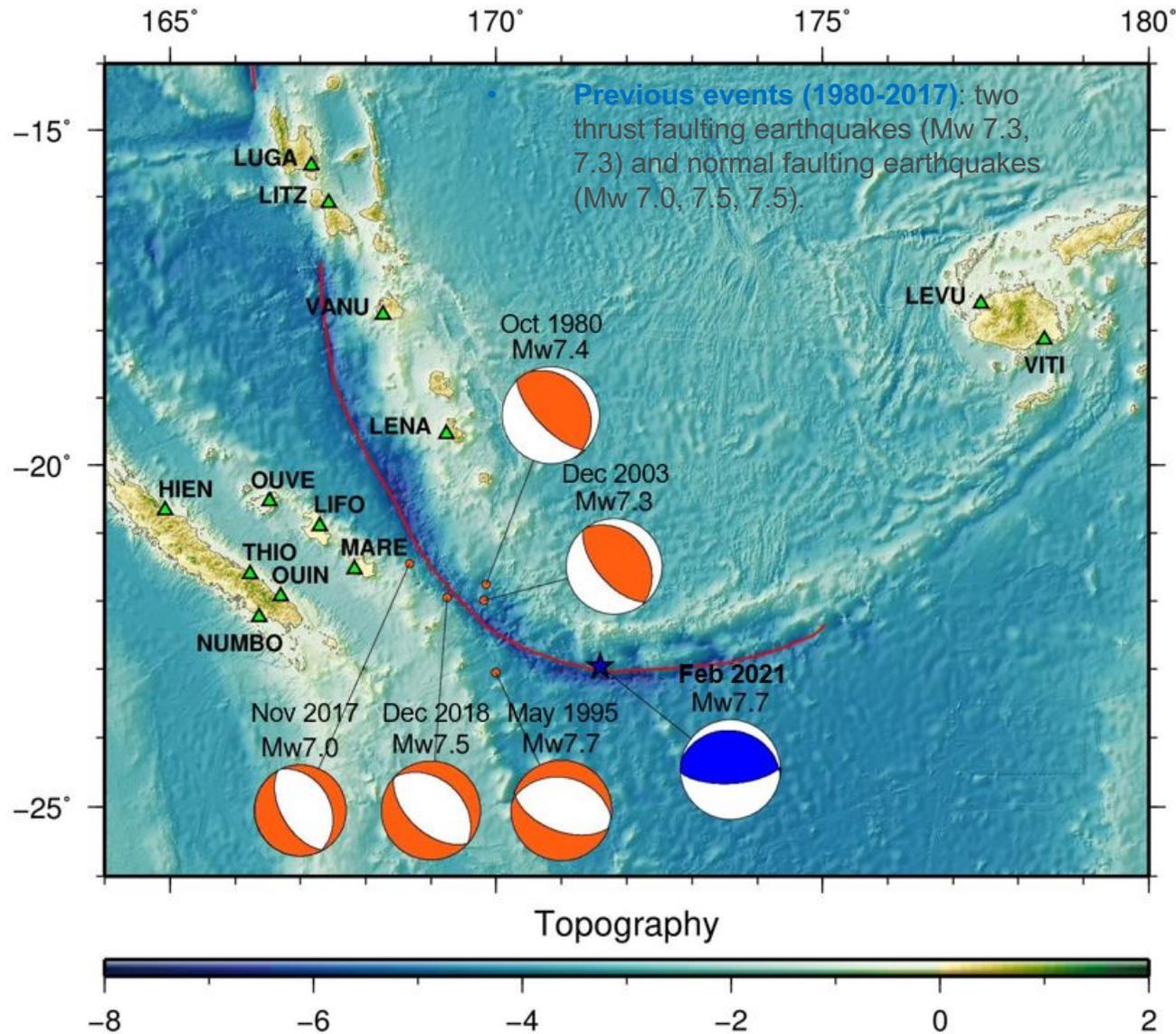
NEMA Tsunami Warning Regions



DART buoy network for tsunami detection



The 2021 Loyalty Islands Earthquake



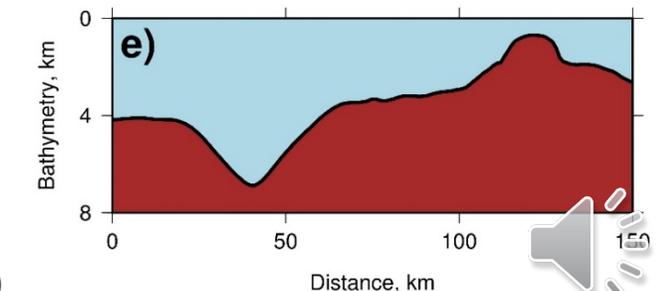
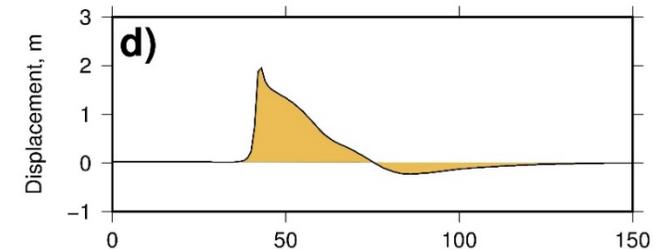
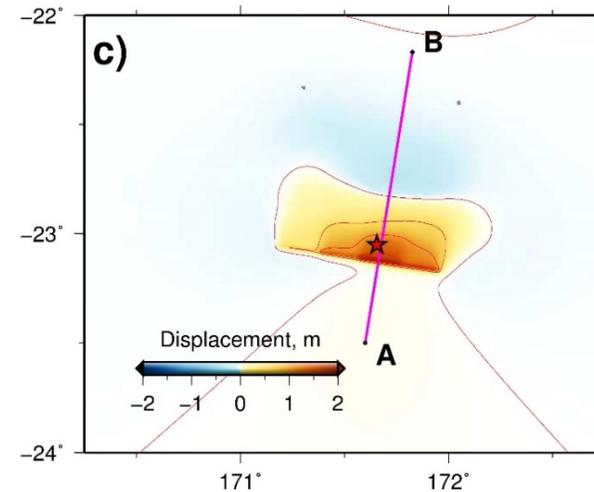
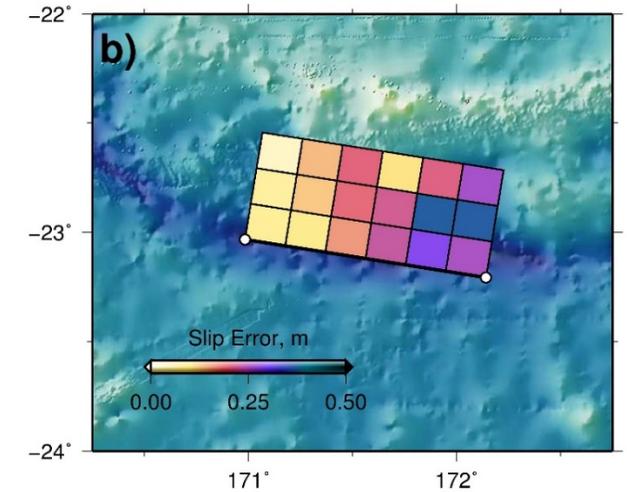
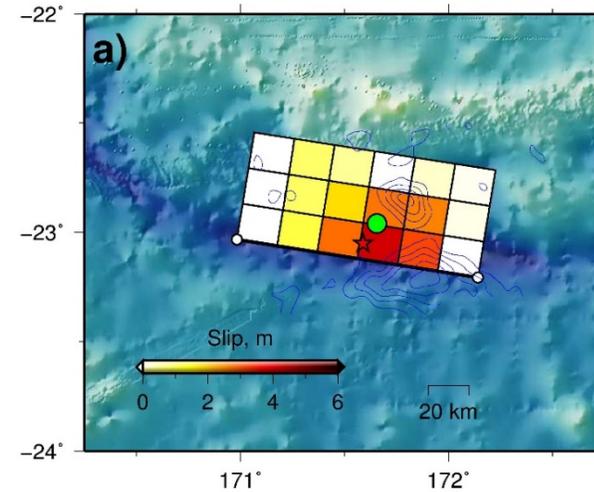
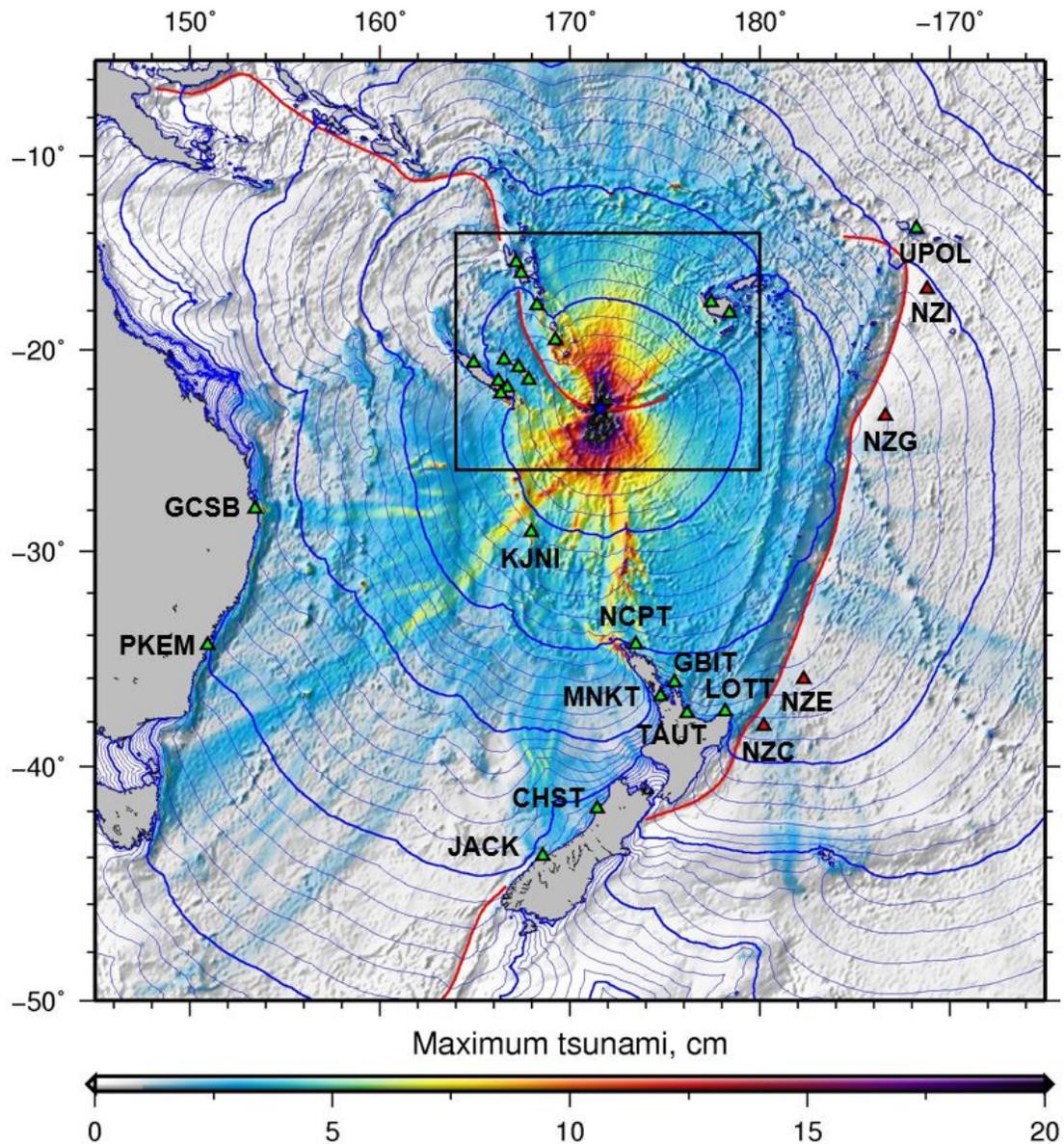
The 2021 Loyalty Islands Earthquake	
Date	2021-02-10
Time	13:19:55 UTC
Epicenter	23.051°S - 171.657°E
Depth	10 km
Mw	7.7
USGS WMT	4.36×10^{20} Nm

- Located in the southern part of **Vanuatu (New Hebrides) subduction zone**.
- The tsunami was recorded at **24 coastal gauges** and **4 DART stations**
- **Tsunami waveform inversion** (Satake 1995) to estimate the **fault slip distribution**
- **Source model validation** using **seismic data**



Slip distribution model

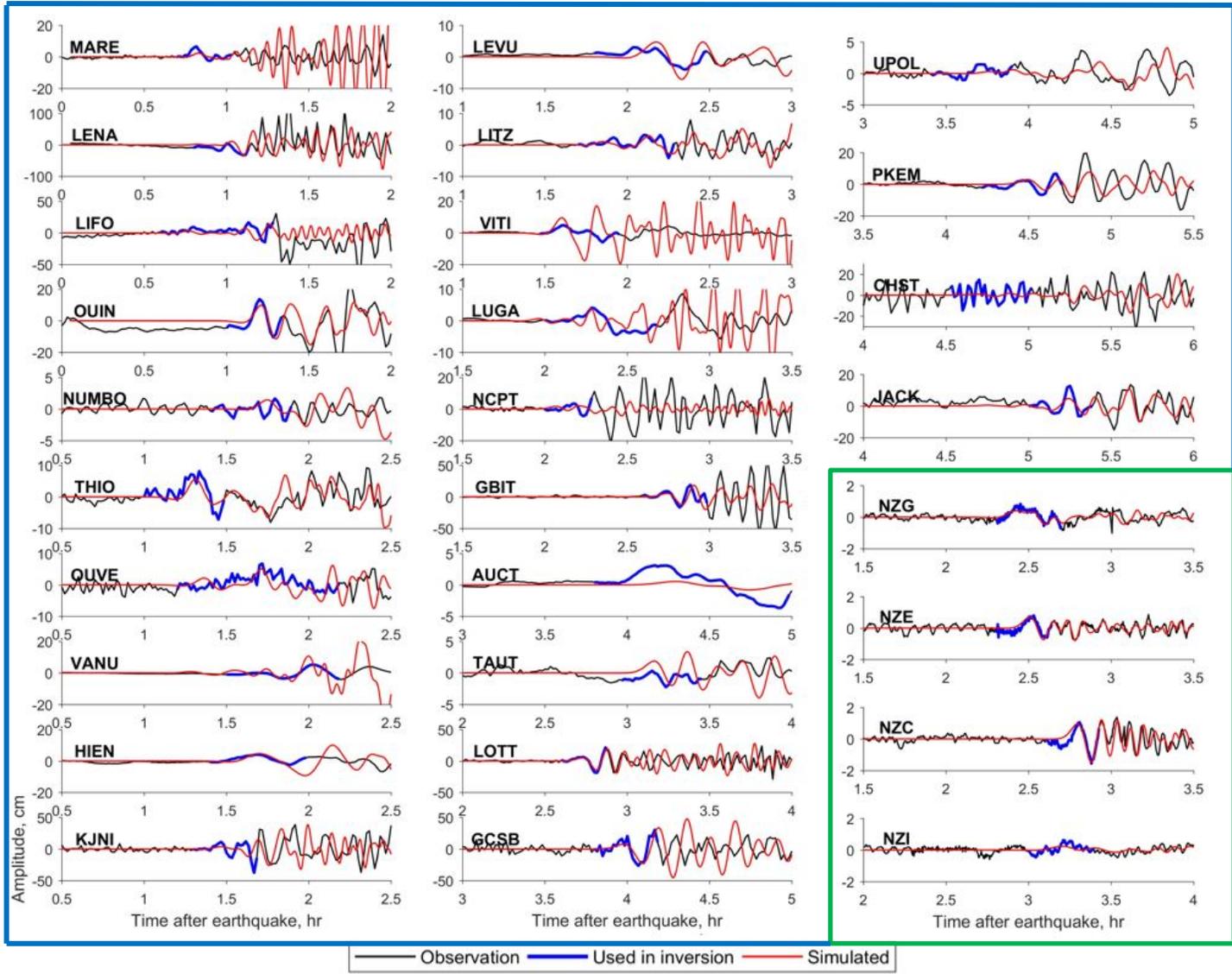
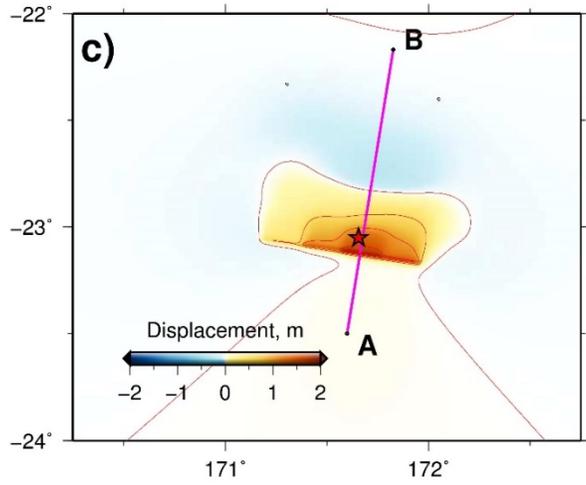
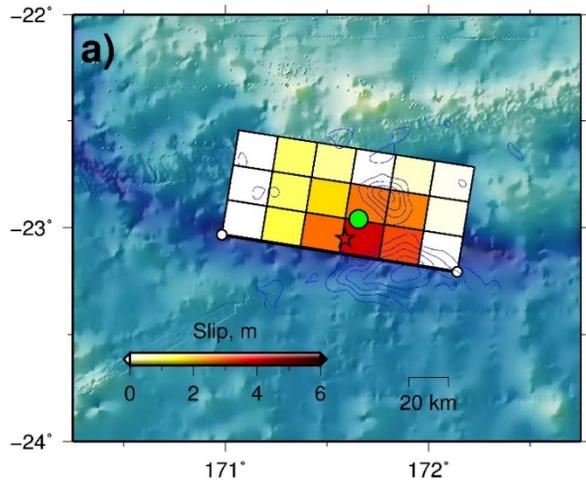
- Slip up to 4.1 m near the trench
- Seismic moment: 3.39×10^{20} Nm (Mw 7.65)
- Tsunami energy potential from the sea surface displacement model: 7.87×10^{12} J



Gusman et al. (JGR, submitted)

Tsunami waveform comparison

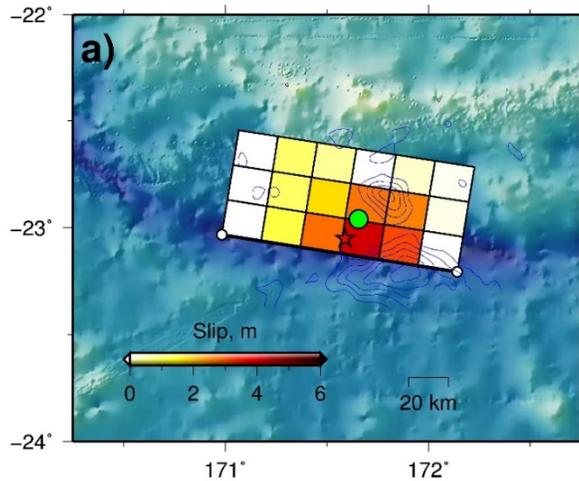
24 coastal gauges
4 DART buoys



Gusman et al. (JGR, submitted)



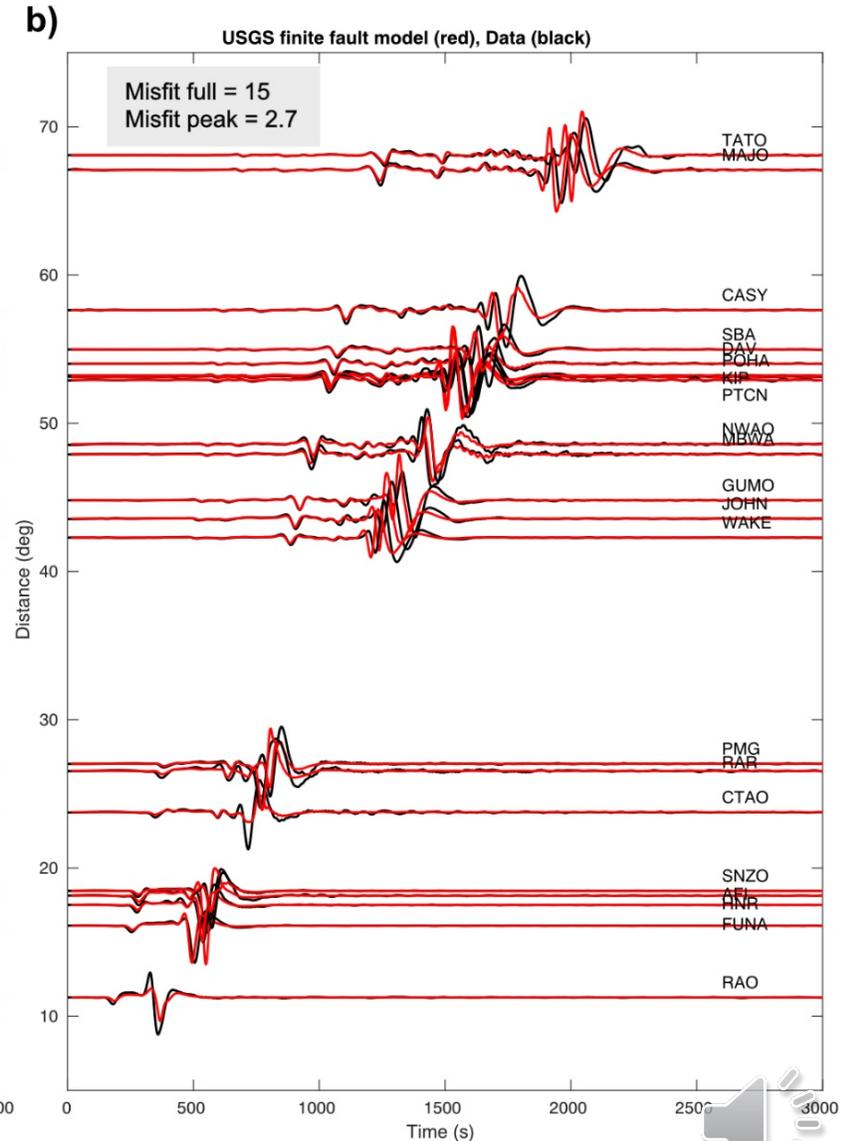
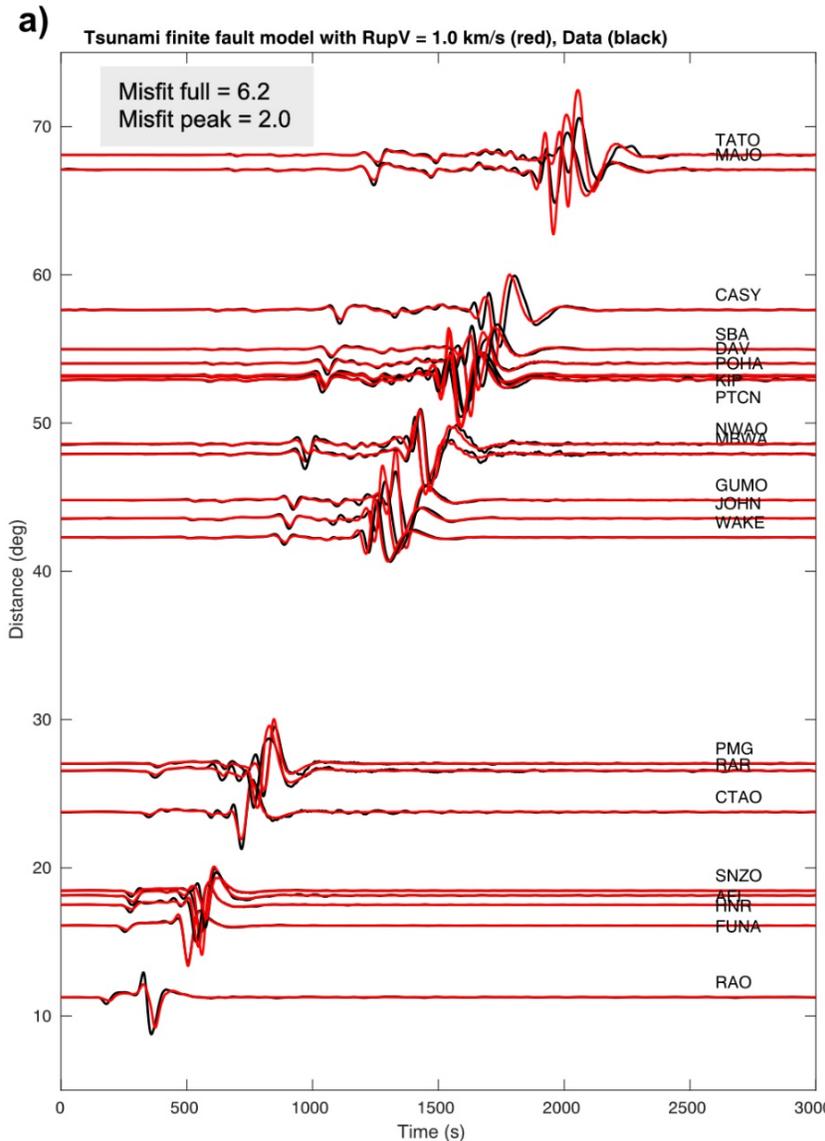
Seismic wave simulation



- Specfem3D Globe which is a spectral element wave propagation code (Komatitsch and Tromp, 2002a, b).
- Assumed rupture velocity of 1.0 km/s (1.5 and 2.0 km/s were also tested).
- Rise time based on the half duration (Ekstrom et al., 2012)

$$hdur = 1.05 \times 10^{-8} \times (M_0 \times 10^7)^{1/3}$$

- The simulated seismic waves were compared within the observations within a period band of 50 – 500 s.

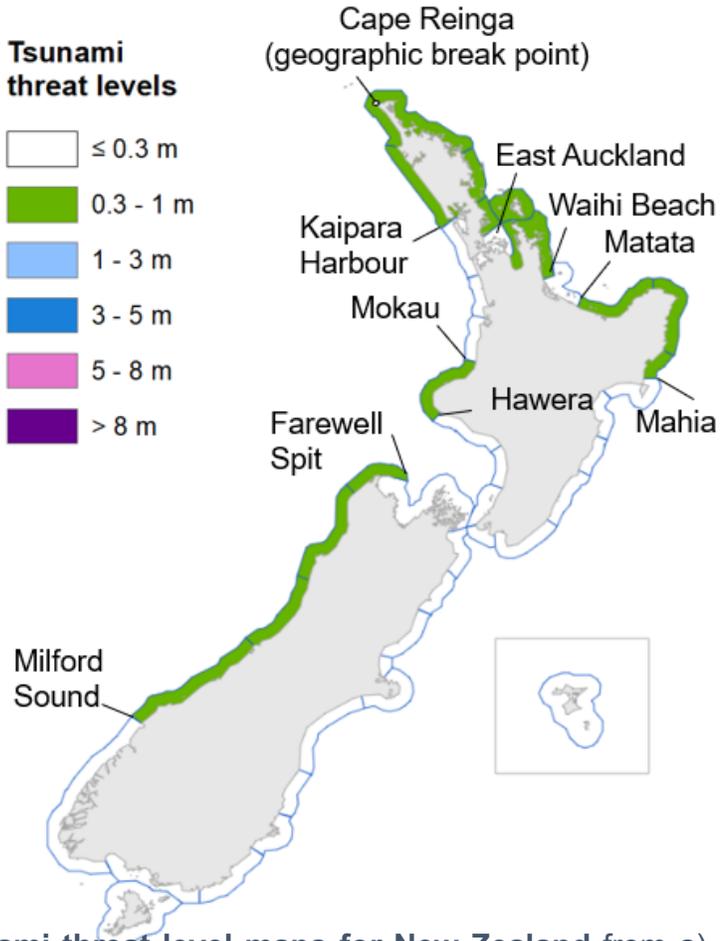
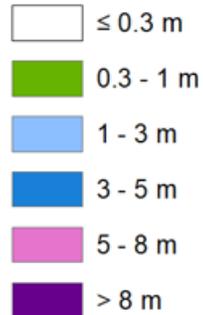


Tsunami threat level map

A **Reference** threat level map was obtained from the source model of the 2021 Loyalty Islands earthquake (Mw 7.7)

a) Fault slip distribution

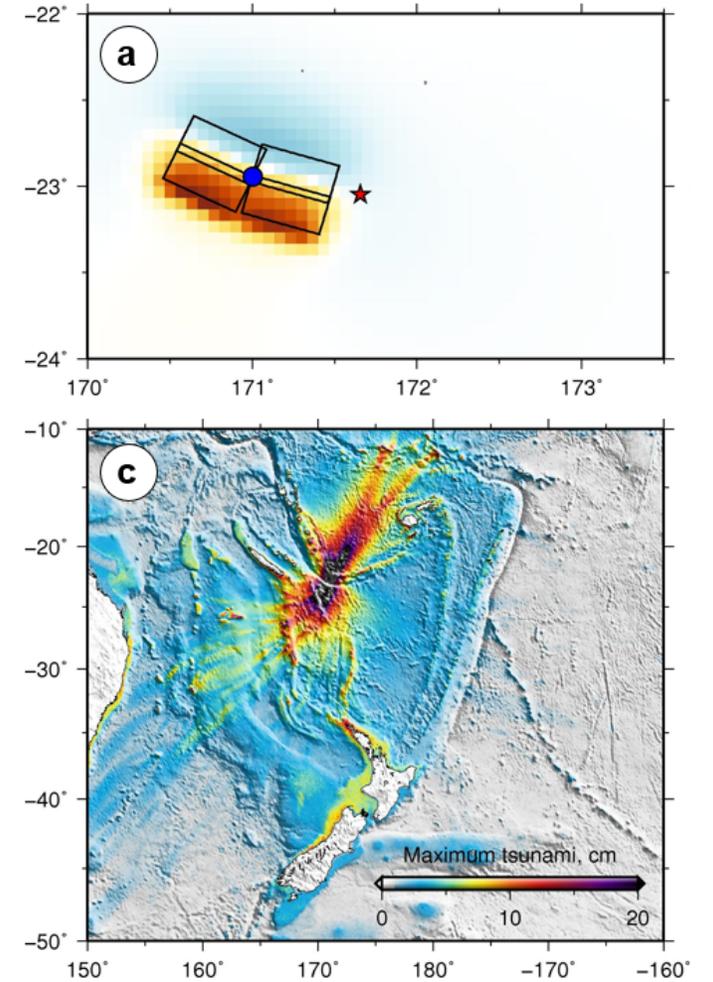
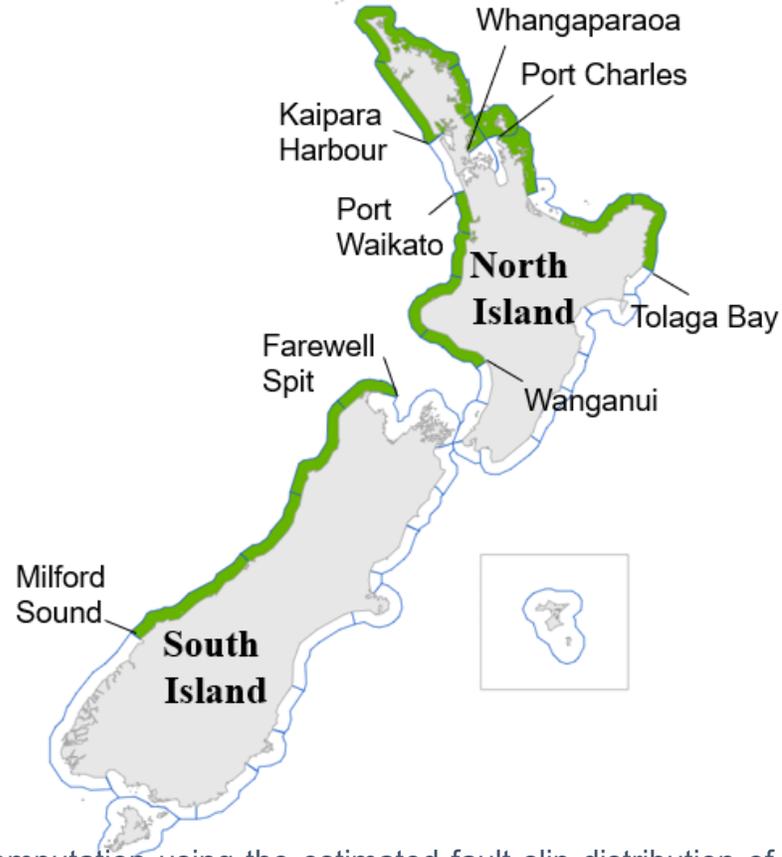
Tsunami threat levels



38 matches
2 underestimations
3 overestimations

b) Pre-computed scenario

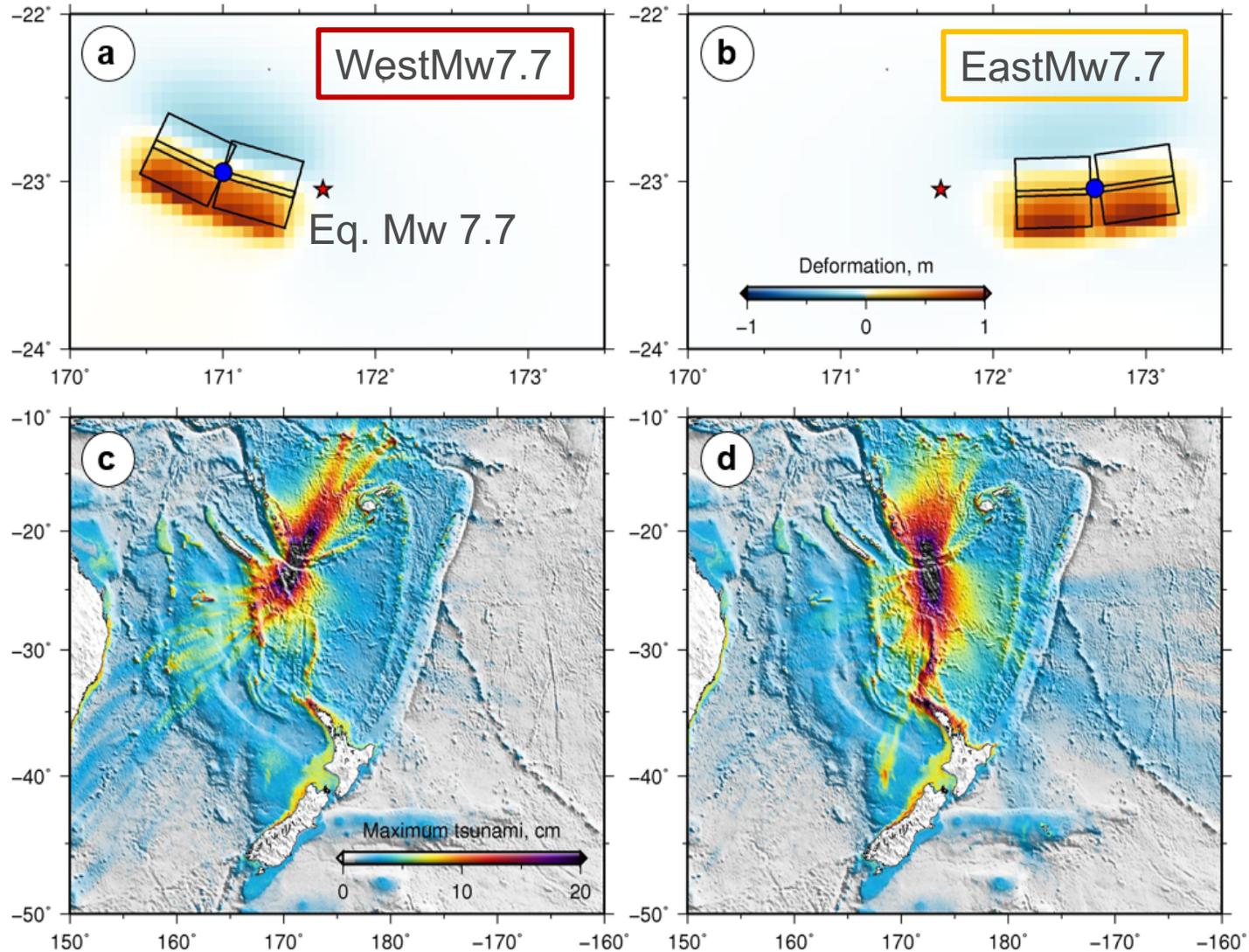
Standard operating procedure (SOP):
 Nearest scenario



Tsunami threat level maps for New Zealand from a) a computation using the estimated fault slip distribution of the 2021 earthquake and b) a pre-computed earthquake scenario (Mw 7.7) that best matches the epicentre and magnitude of the earthquake.



Tsunami threat level interpolation

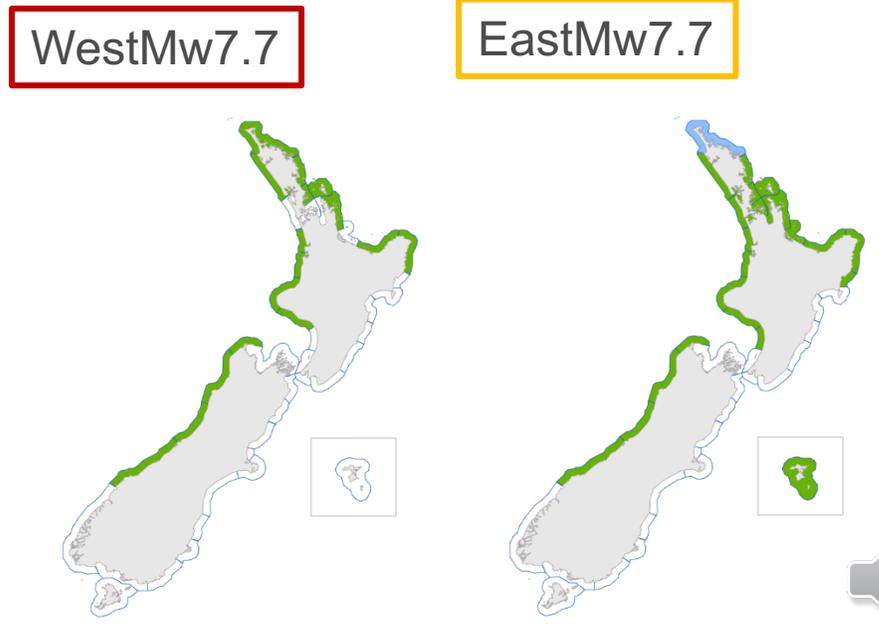


Gusman et al. (JGR, submitted)

A general way of finding an interpolated tsunami threat level (f_i) in the 43 warning regions ($i = 1, 2, \dots, 43$) for a given epicentre based on pre-computed tsunami threat level in the database $f_{i,j}$ for $j = 1, 2, \dots, N_s$

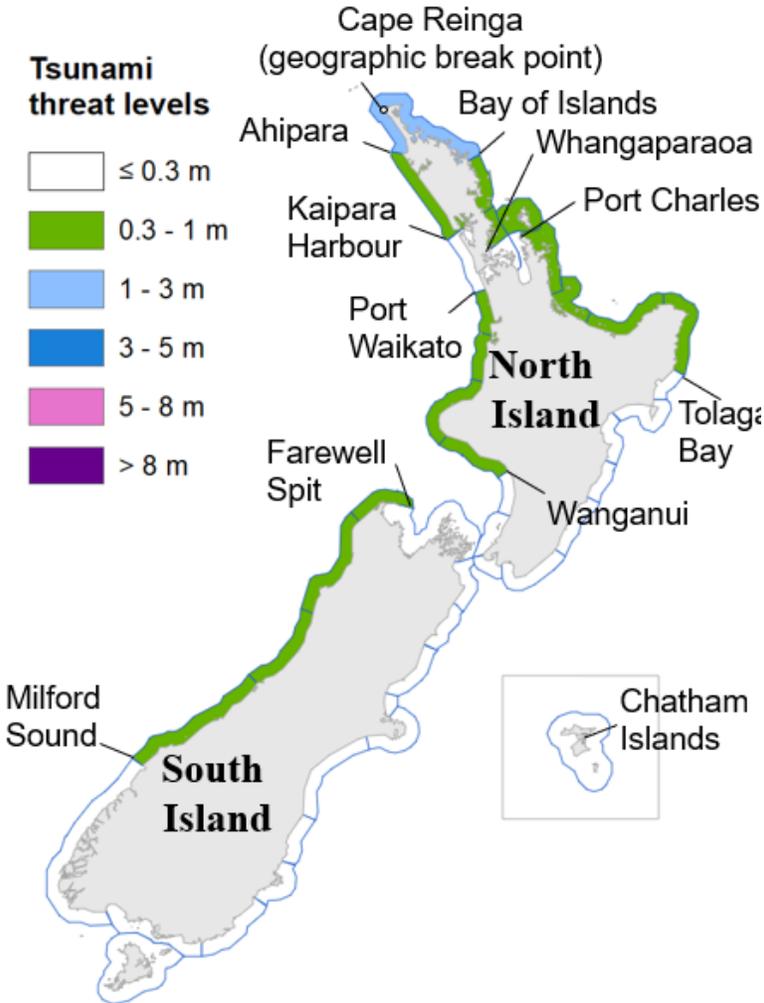
$$f_i = \begin{cases} \frac{\sum_{j=1}^{N_s} w_j \cdot f_{i,j}}{\sum_{j=1}^{N_s} w_j}, & \text{if } d \neq 0 \text{ for all } j, \\ f_{i,j}, & \text{if } d = 0 \text{ for some } j, \end{cases}$$

$$w_j = \frac{1}{d^p}$$



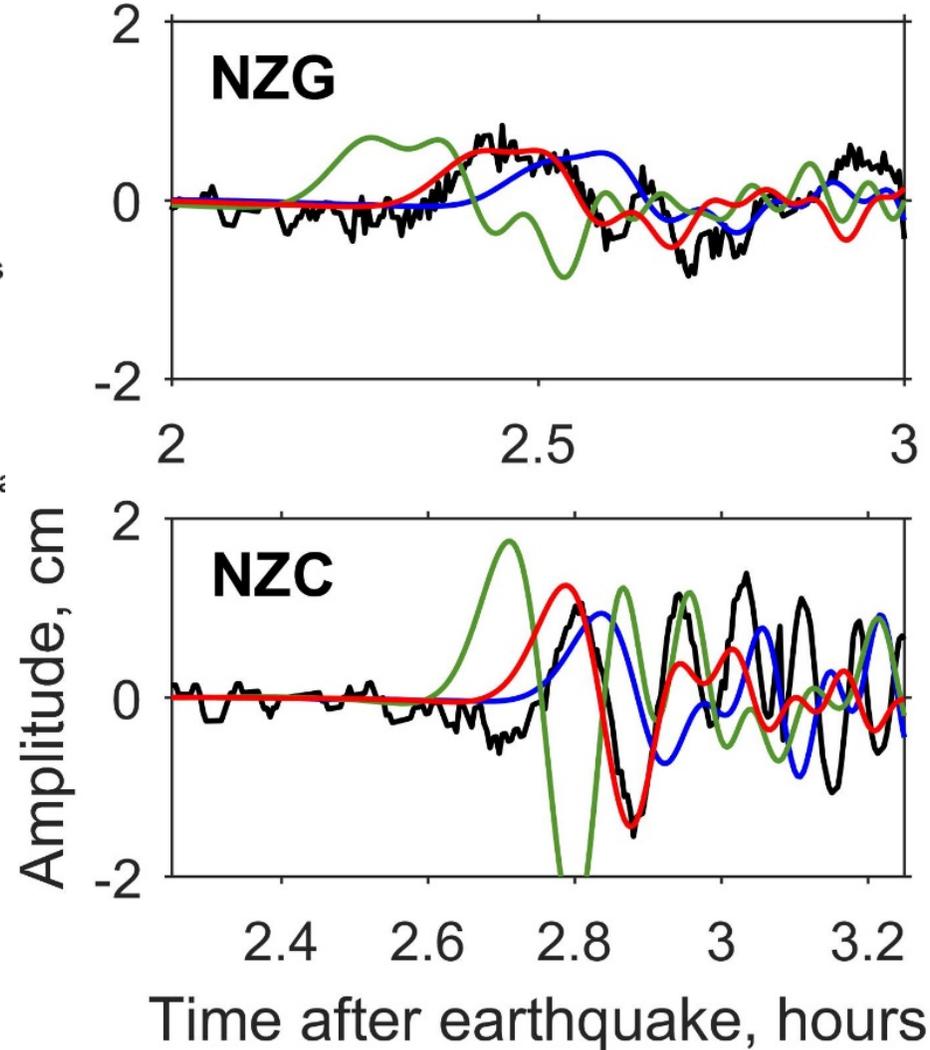
Interpolated tsunami threat levels and waveforms

a) Interpolated threat levels

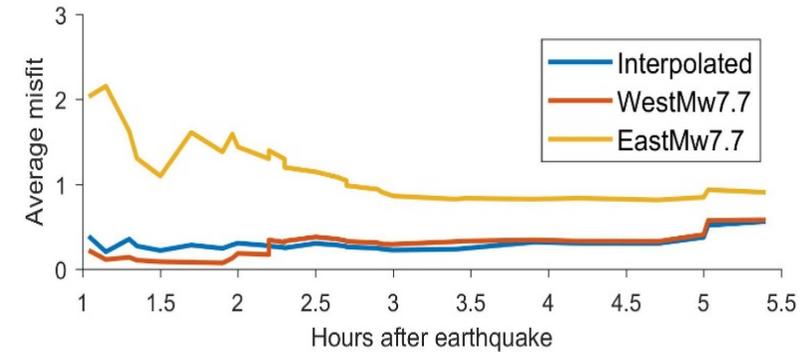
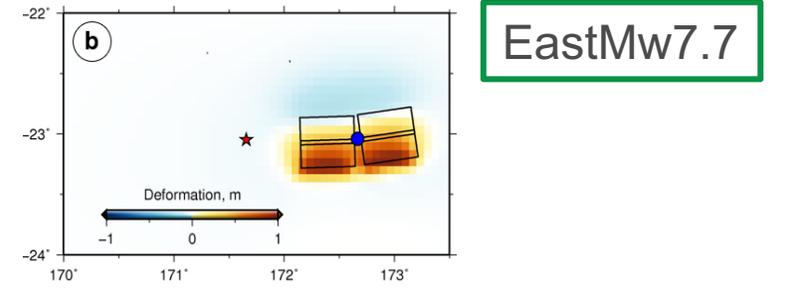
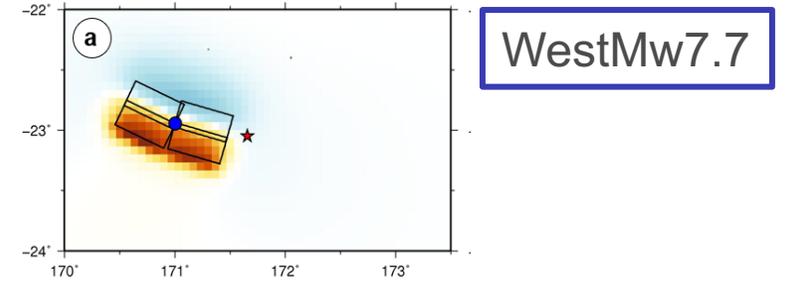


Gusman et al. (JGR, submitted)

Waveform interpolation method based on the Huygens-Fresnel principle in optics: Wang et al. (GRL, 2019)



— Data — West Mw7.7 — East Mw7.7 — Interpolated



Misfit and average misfit of tsunami amplitude at observation stations from the interpolated, WestMw7.7, EastMw7.7 scenarios.



Summary

- We have created tsunami threat level map database for tsunami early warning purposes in New Zealand.
- The source model of the 2021 Loyalty Islands earthquake was estimated using tsunami data. The model can reproduce well the seismic data.
- We presented two methods to produce the tsunami threat maps
 - Nearest scenario (current SOP)
 - Scenario interpolation
- The tsunami records at DART buoys are very useful to verify and update the tsunami forecast.

