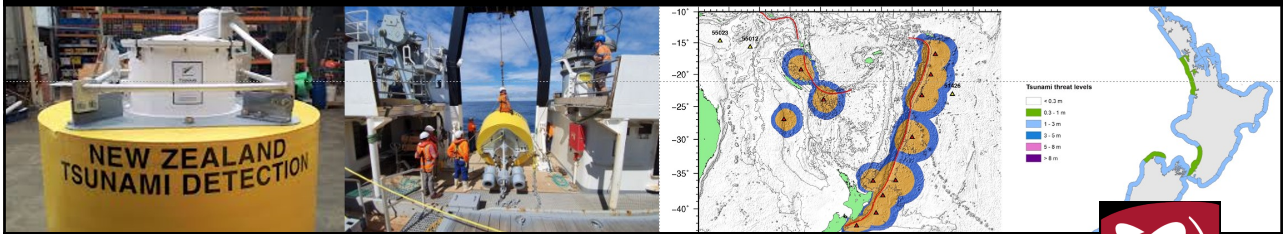
Volcanic Tsunami Threat Level Database: Pilot Phase



Aditya Gusman
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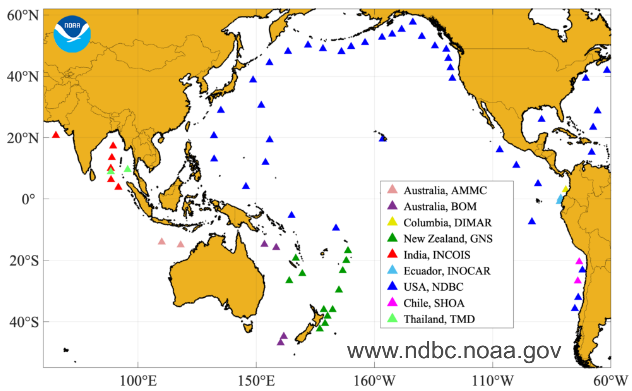
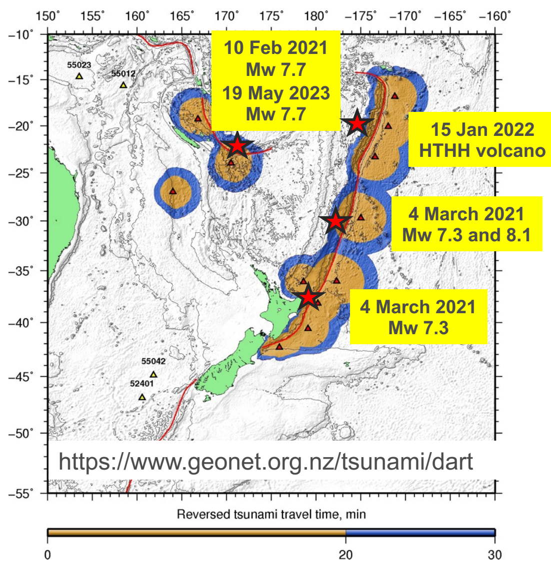
Earth Structure and Processes, GNS Science, New Zealand

1

DART buoy for tsunami detection





The use of DART buoys in monitoring and studying tsunamis is a crucial tool in our efforts to understand and mitigate the impacts of tsunamis

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The National Geohazards Monitoring Centre for New Zealand

Te Puna Mōrearea i te Rū

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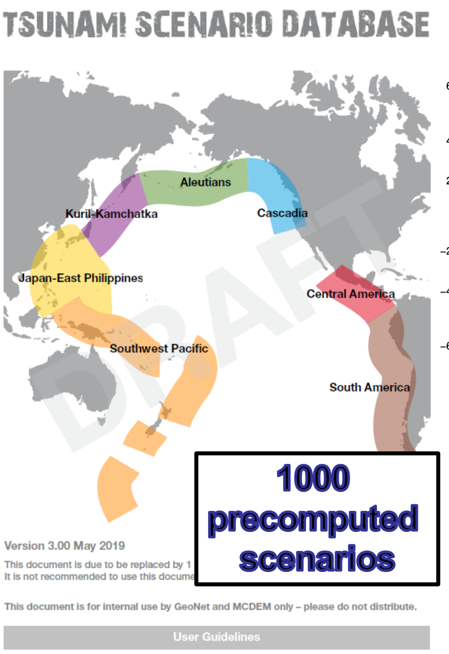
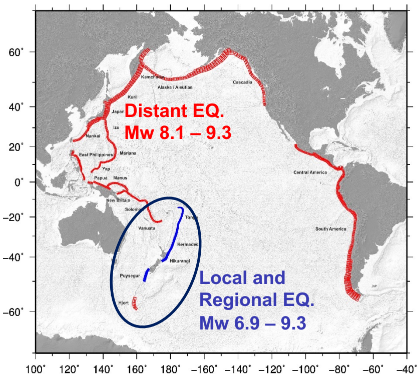


Fault patches used for the scenarios



Pre-computed scenarios

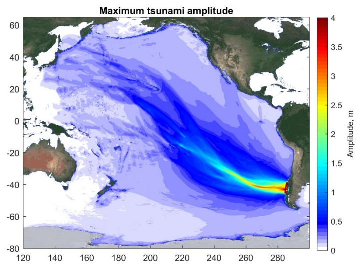
Distant sources

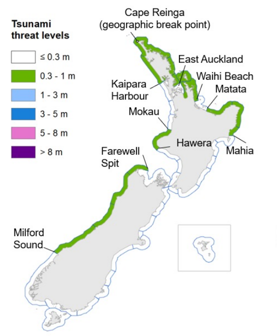
- The fault size is 100 km x 50 km.
- Earthquake magnitudes: 8.1 – 9.3 (interval of 0.2)
- Space: 300 km

Regional sources

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

Tsunami Threat Level





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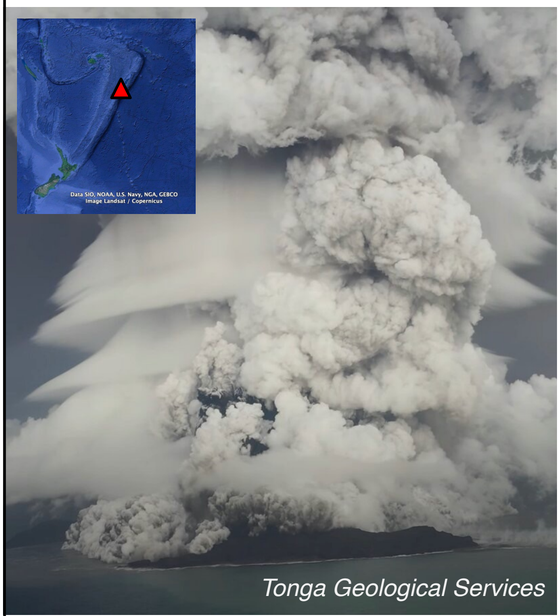
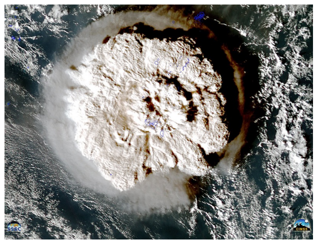
The 2022 HTHH tsunami



After the 14 January 2022 eruption

HIMAWARI-8
15 January 2022 eruption



After the 15 January 2022 eruption

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Tsunami Inundation Observations

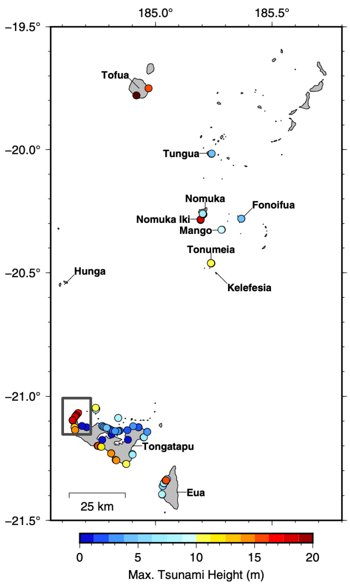
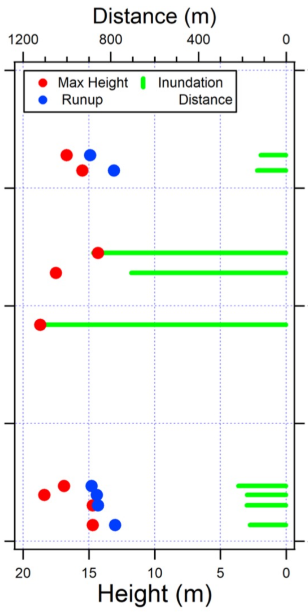
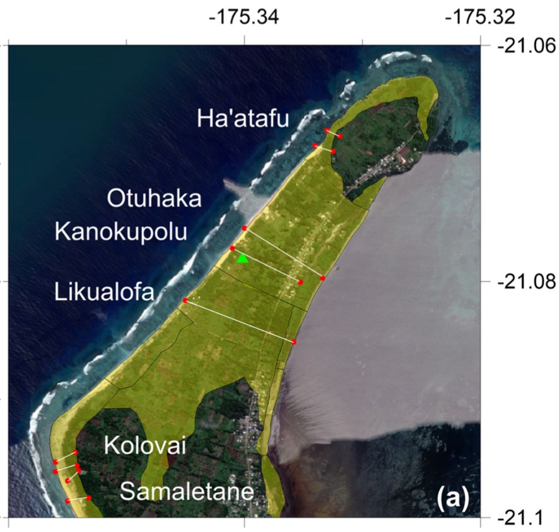


Figure 6
Summary data plots of maximum measured tsunami heights





Borrero et al. (2023)

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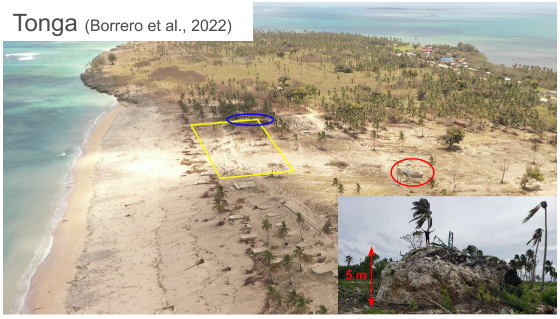
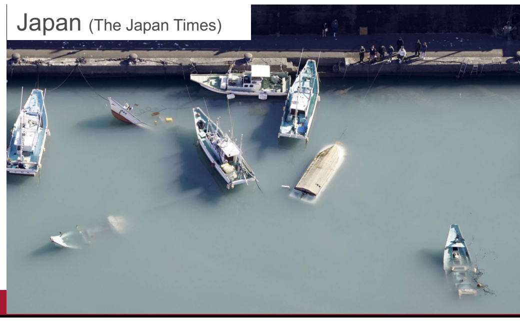
Tsunami Damages


Tonga (Borrero et al., 2022)

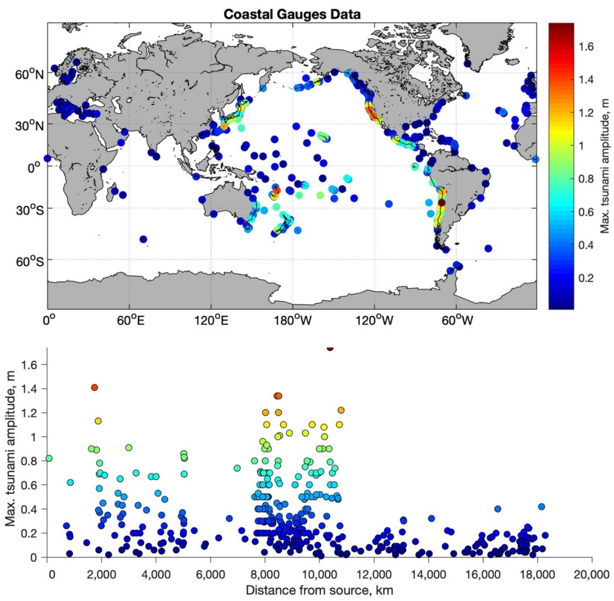

New Zealand (Stuff)


Peru (Merco Press)

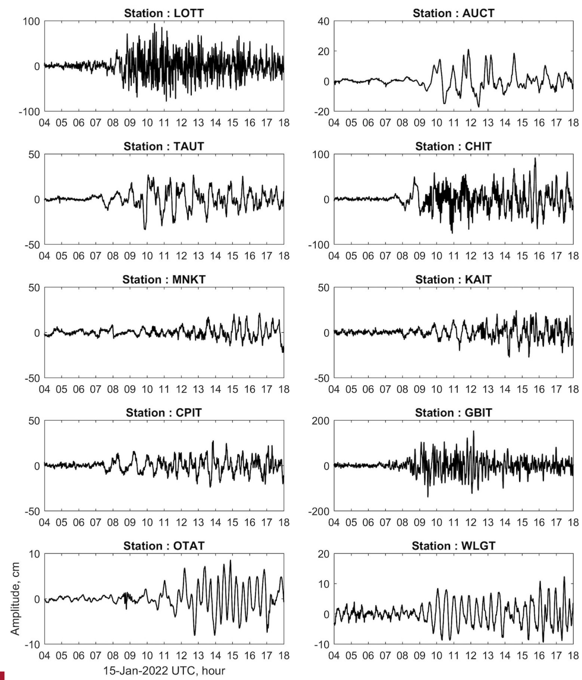

Japan (The Japan Times)

7

Coastal Gauges Data



Data source: Global Historical Tsunami Database (NOAA - NCEI)



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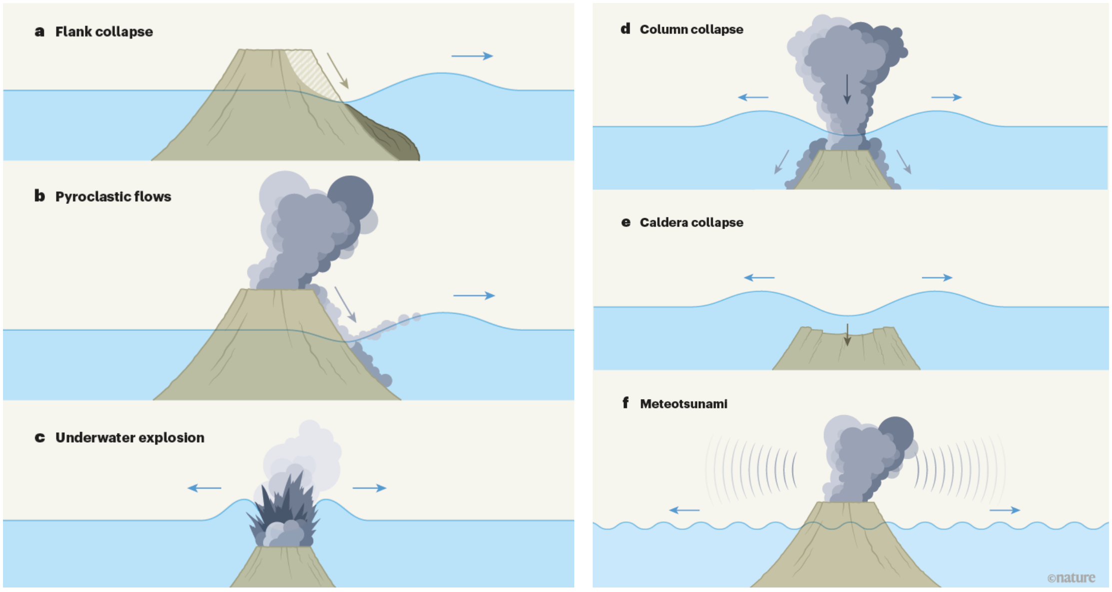
Volcanic Tsunami Source Mechanisms



Lane et al. (2022)

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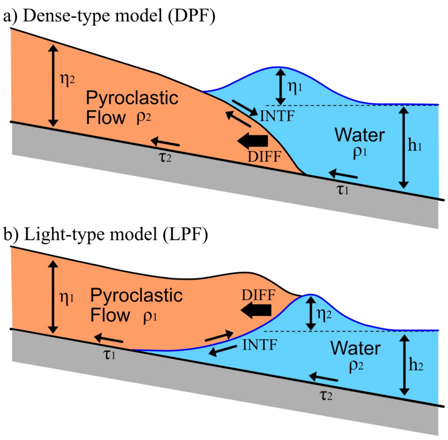
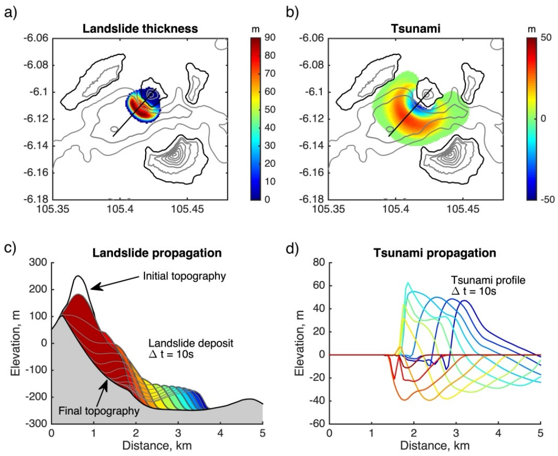
Pyroclastic Flow and Landslide Tsunami Sources





To calculate pyroclastic flows and tsunamis simultaneously, two types of two-layer shallow water models, a dense-type (DPF) model and a light-type (LPF) model were developed by Maeno and Imamura (2011).

The flank collapse model of the Anak Krakatau Volcano, which occurred during the eruption in 2018

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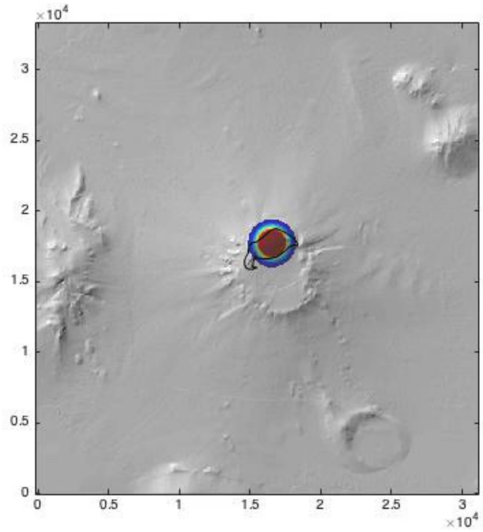
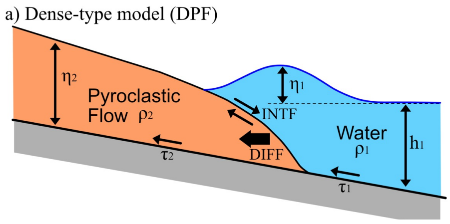
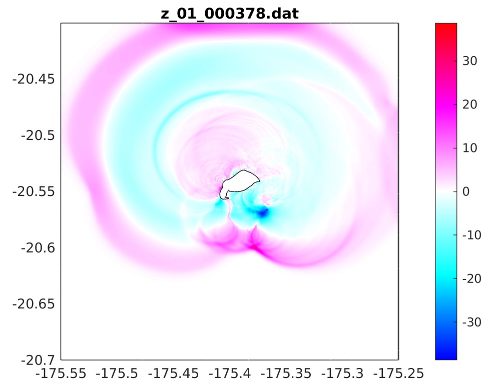
The 2022 HTHH Eruption: Pyroclastic Flow Tsunami Modeling



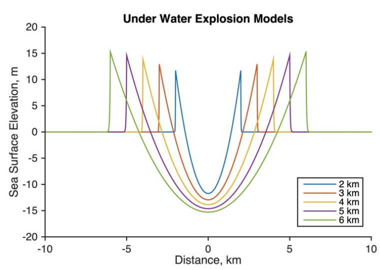


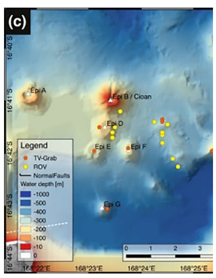


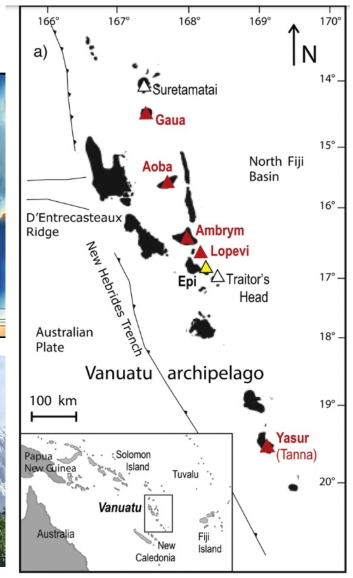
Under Water Explosion Model

A formula to estimate the initial water displacement model for underwater explosions has been proposed by Le Méhauté (1971). Some modification were made after ward (Torsvik et al., 2010).

$$\eta(r) = \begin{cases} \eta_0\left[2\left(\frac{r}{R}\right)^2 - 1\right], & if\ r \le R \\ \eta_0\left[2\left(\frac{r}{R}\right)^2 - 1\right] e^{P_r(1-r/R)}, & if\ R < r \le 2R \\ 0, & if\ r > 2R \end{cases}$$

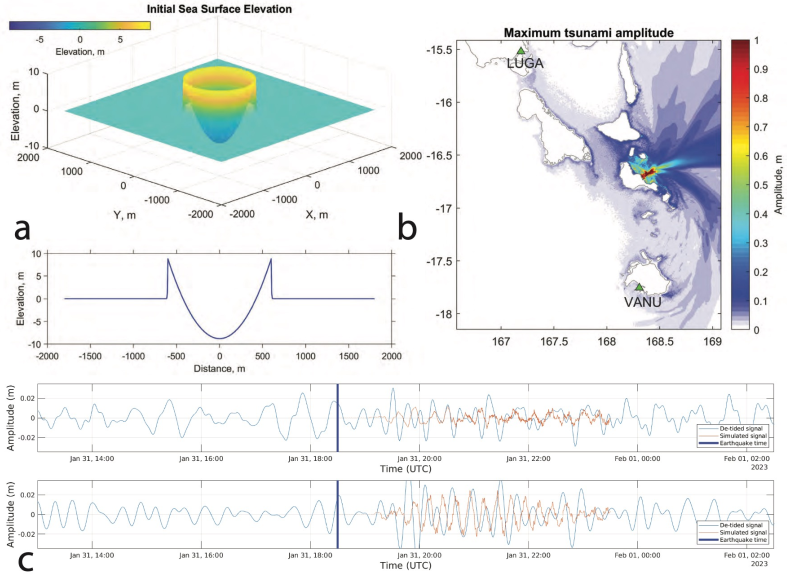






Epi Volcano eruption in December 2023 generated a small tsunami. The tsunami was simulated using an underwater explosion mode (Roger et al., under preparation) (Photo from: Vanuatu Meteorology and Geohazards Department)

The 2023 Epi Volcano Tsunami



AGU Fall meeting 2023 Poster (Roger et al., 2023)

Tsunami simulation: (a) Initial sea-surface deformation model (in meters); (b) Maximum wave amplitude map after 5 hours of tsunami propagation on a ~450-arcmin resolution grid ; (c) Comparison of the simulated waveforms (red curve) to the de-tided real recorded data (blue curve) at Lugan ville (LUGA) and Port-Vila (VANU) coastal gauges; the data were filterred using a passband filter to remove both tide signal and high-frequency background noise from the 1-minute sampling rate dataset (VLIZ/IOC, 2023).

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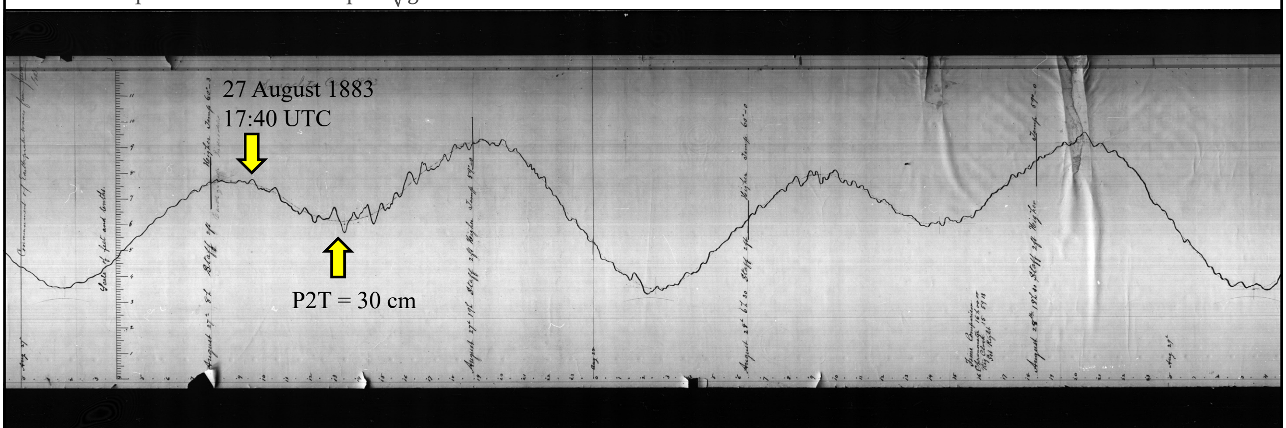
The 1883 Krakatau Tsunami

Largest eruption 27 August 1883 3:02 UTC
Distance from Krakatau to San Francisco 14,000 km
Arrival time: 27 August 1883 17:40 UTC
Wave speed: 266 m/s
Tsunami speed at 4 km water depth: $\sqrt{gd} = 200$ m/s
Tsunami speed at 1 km water depth: $\sqrt{gd} = 100$ m/s



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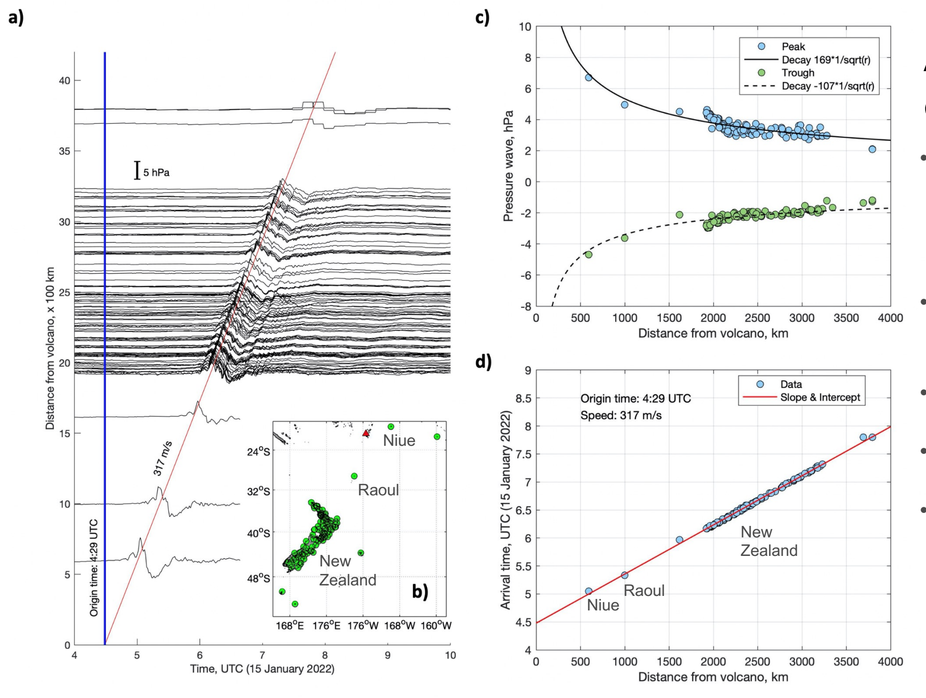

Air pressure observations

- Air pressure data at 94 stations (600 – 4000 km from HTHH volcano) were provided by MetService.
- Air-wave amplitude decays proportionately to $^{1}/_{\sqrt{r}}$.
- Estimated wave speed: **317 m/s**.
- Effective origin time: **4:29 UTC.**
- We used the above information to make a simple air pressure wave model.

Gusman et al. (2022)

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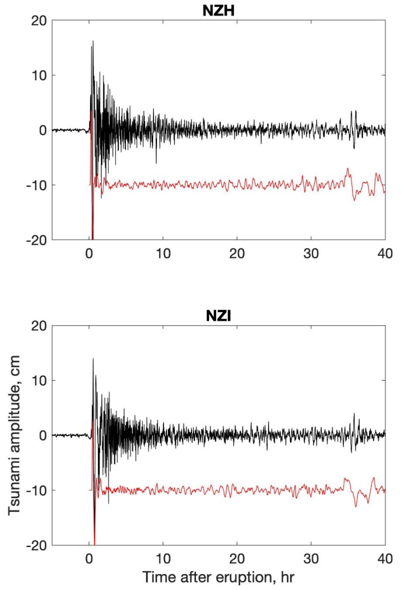
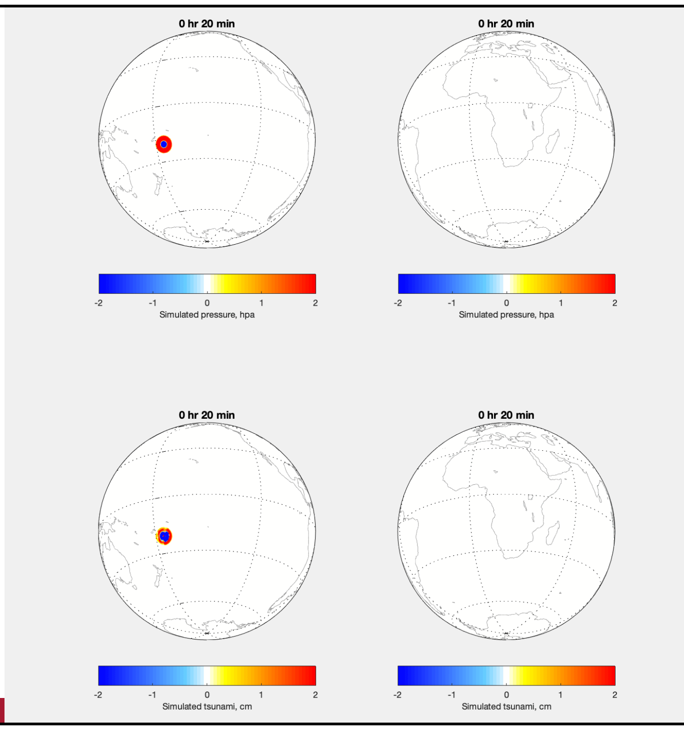
Global Tsunami Propagation (Lamb wave generated)





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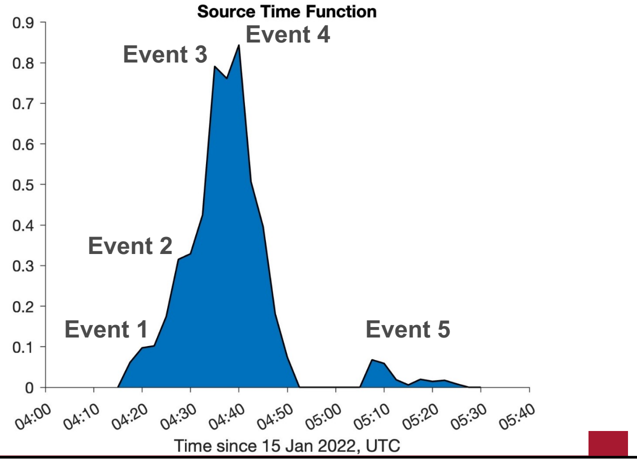
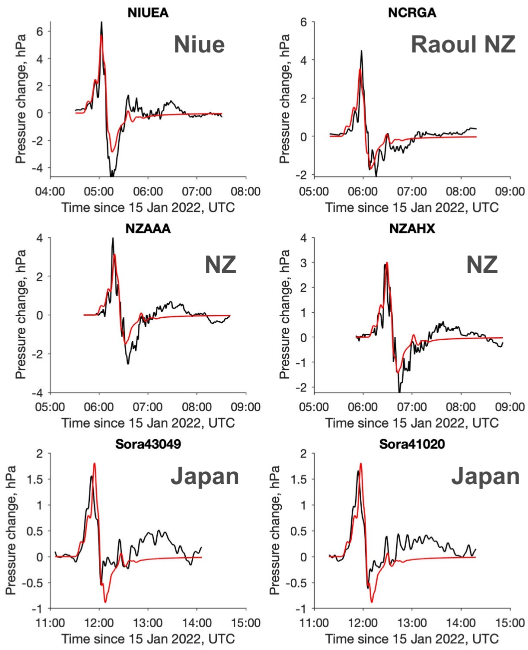
Lamb wave Inversion Results

- We estimated that five explosion events occurred based on the inversion.
- The largest event was estimated to have occurred at 4:40 UTC.
- The main source duration is 30 minutes.





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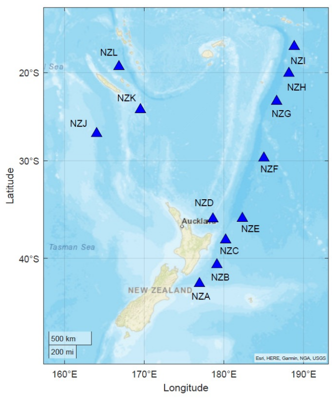
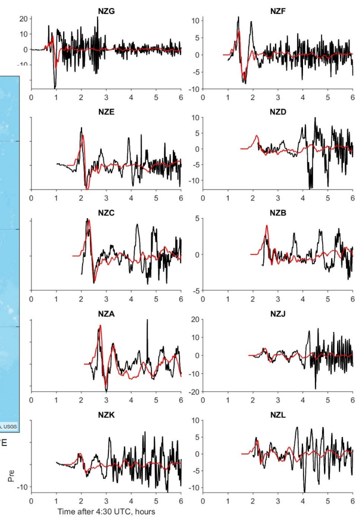
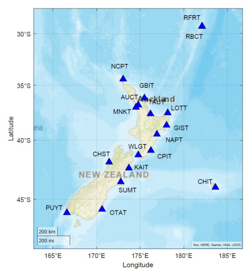
Tsunami prediction from source model

Waveform comparison between simulation and observation at **DART NZ stations**

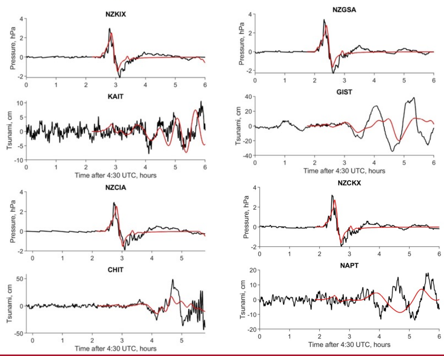




Bottom pressure gauge (DART): $p_{obs} = p_{atm} + p_{\eta}$



Waveform comparison between simulation and observation at **coastal gauge and the nearby weather station.**



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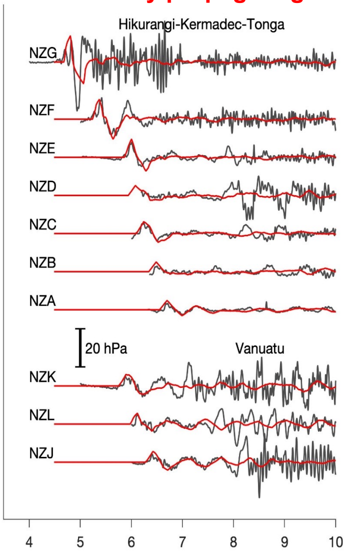
The 2022 HTHH Eruption Tsunami

Volcanic tsunami source mechanisms according to Paris et al. (2014):

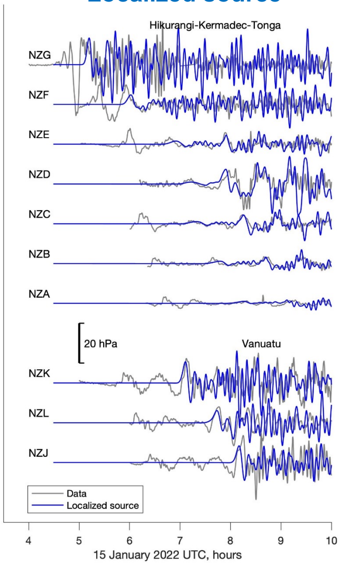
1. Underwater explosion
2. Air wave
3. Pyroclastic flow
4. Flank Failure
5. Caldera subsidence
6. Lahar
7. Earthquake

Localized source: A circular water uplift at the volcano with a characteristic diameter of 10 km and the same origin time as the air-wave

Air wave
Continuously propagating source



Water displacement
Localized source



Gusman et al. (2022)

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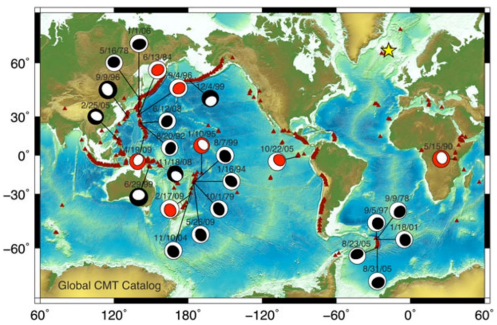
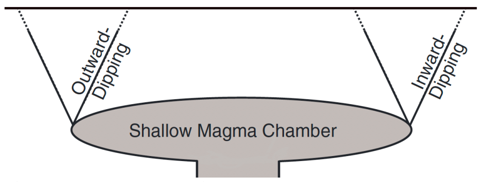
Vertical CLVD Earthquakes

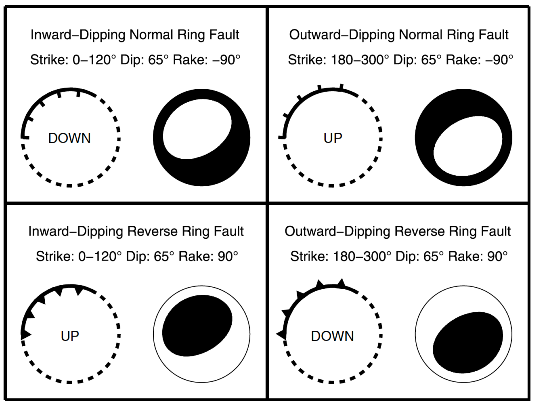
CLVD: Compensated Linear Vector Dipole



Vertical-CLVD earthquakes are predominantly associated with volcanic activities with most common source volcanoes are strato-volcanoes and submarine volcanoes with caldera structures (Shuler et al., 2013).



Schematic diagram for inward- and outward- dipping ring faults located above a shallow magma chamber



(Shuler et al., 2013)

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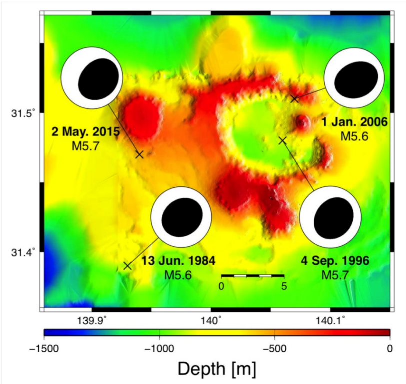
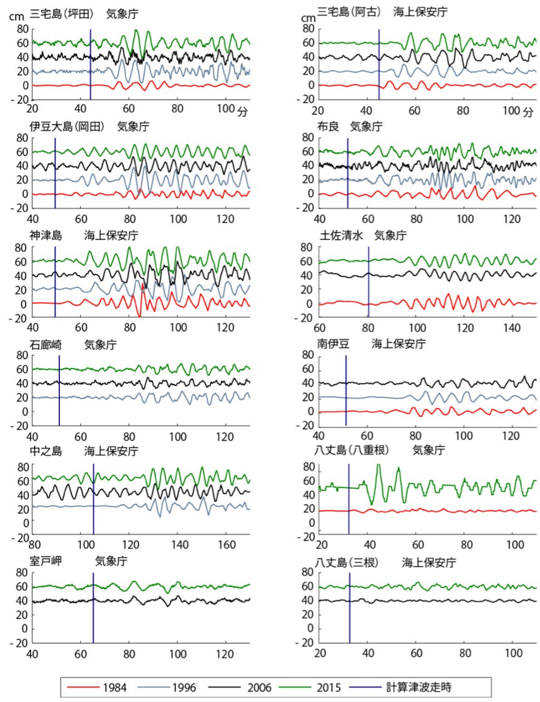
The Torishima Tsunami Earthquakes

13 June 1984 (M5.9)
5 September 1996 (M5.6)
1 January 2006 (M5.9)
3 May 2015 (M5.9)



(Satake and Gusman, 2015)



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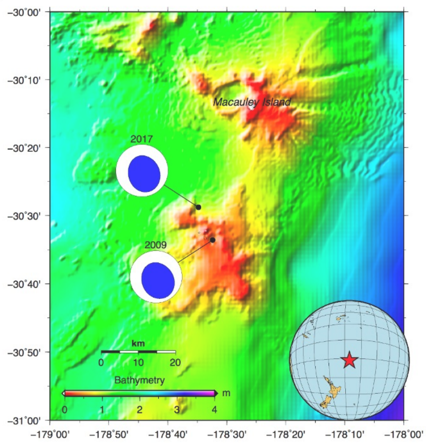
The Kermadec CLVD Earthquakes

The 2009 Earthquake

Date	2009-02-17
Time	03:30:53 UTC
Epicenter	30.724°S 178.617° W
Depth	13 km
Mw	5.8
Moment	7.29×10^{17} Nm

	NP 1	NP 2
Strike	319°	167°
Dip	47°	70°
Rake	46°	110°



Epicenter: USGS
Focal mechanism: Global CMT

The 2017 Earthquake

Date	2017-12-08
Time	02:09:57 UTC
Epicenter	30.555°S 178.492° W
Depth	12 km
Mw	5.8
Moment	6.44×10^{17} Nm

	NP 1	NP 2
Strike	327°	173°
Dip	43°	50°
Rake	70°	107°

Gusman et al. (GRL, 2020)

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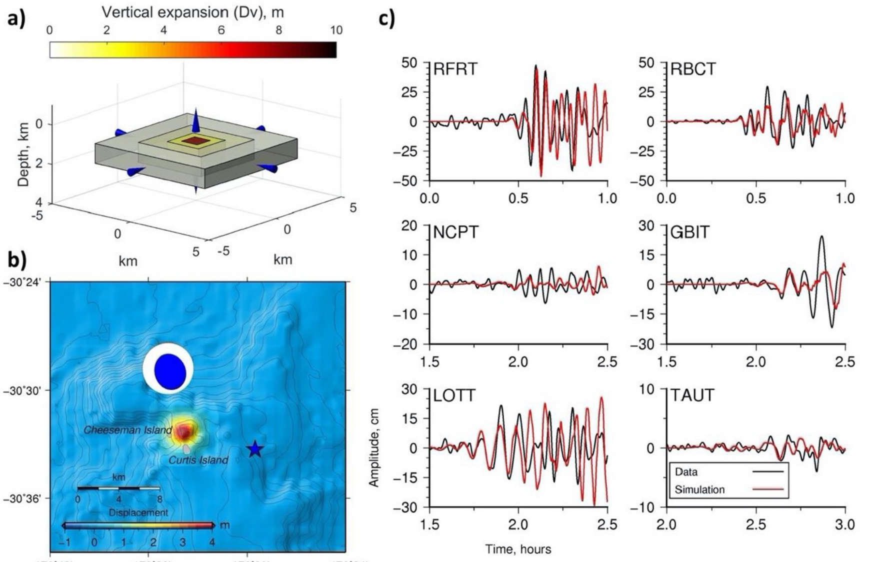
Source model for the CLVD earthquake and tsunami



Gusman et al. (GRL, 2020)

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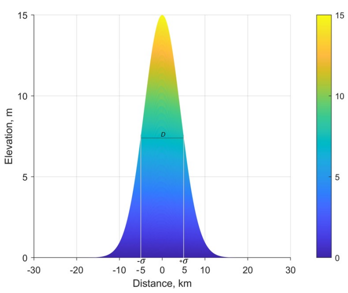
Volcanic Tsunami Threat Level Database

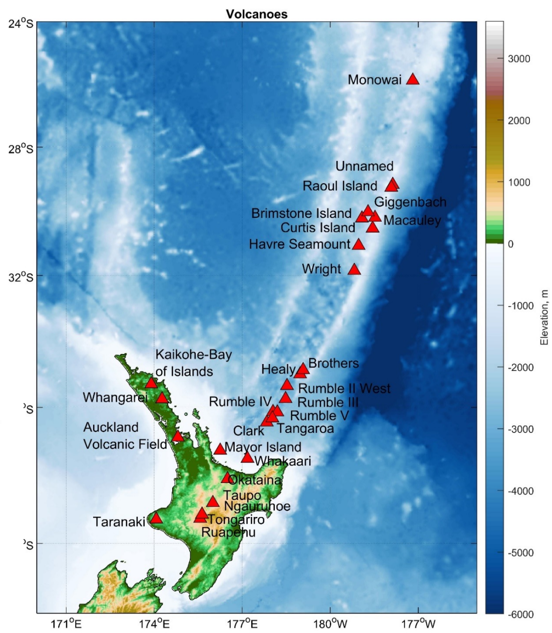
Selected Volcanoes

For this work, we selected 28 volcanoes located in New Zealand and the Kermadec ridge south of 25° S. These volcanoes include submarine volcanoes and volcanic islands from Monowai, a submarine volcano in Kermadec, to Whakaari/White Island, a volcanic island in the Bay of Plenty. Inland volcanoes are also evaluated, especially those located near the coast.

Source Model

We use a simple localized source model in which tsunami generation is approximated by an initial static sea surface displacement. The shape of the initial sea surface displacement is represented in simplified form by a three-dimensional Gaussian function with a characteristic diameter (D) of 10 km and maximum height (H) of 15.





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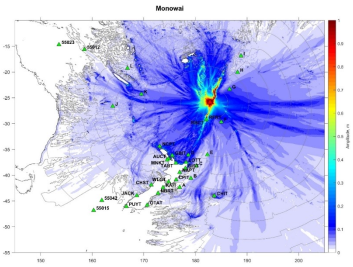
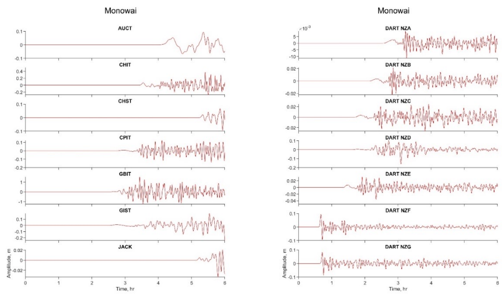
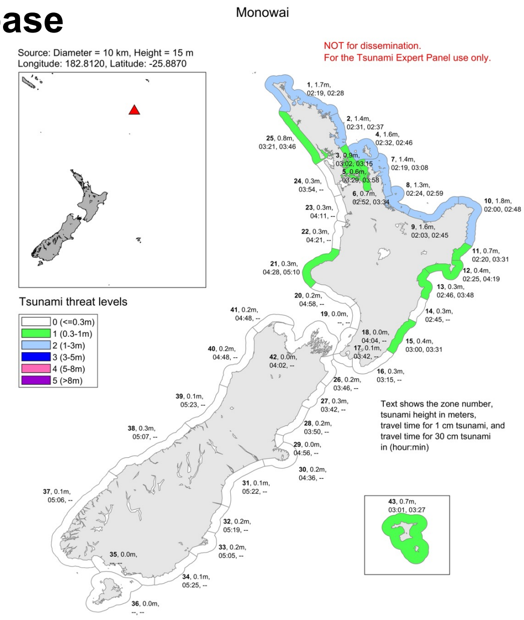
Volcanic Tsunami Threat Level Database







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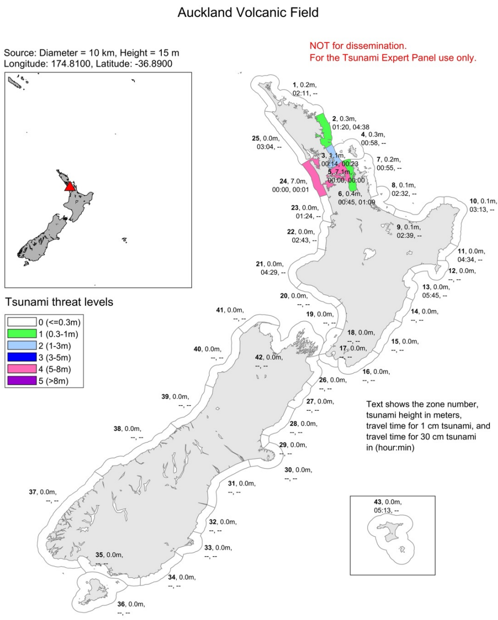

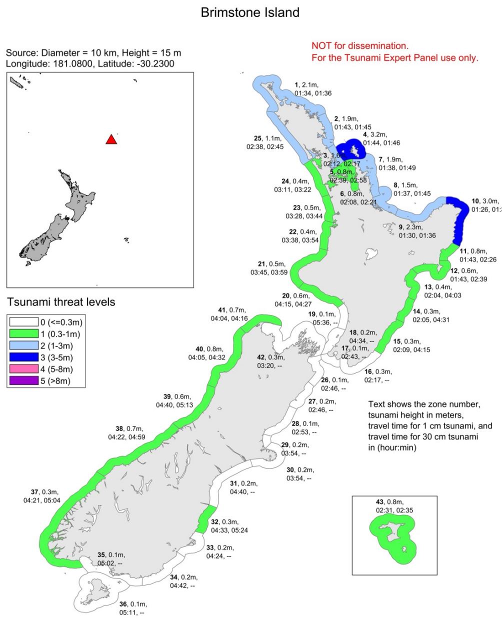

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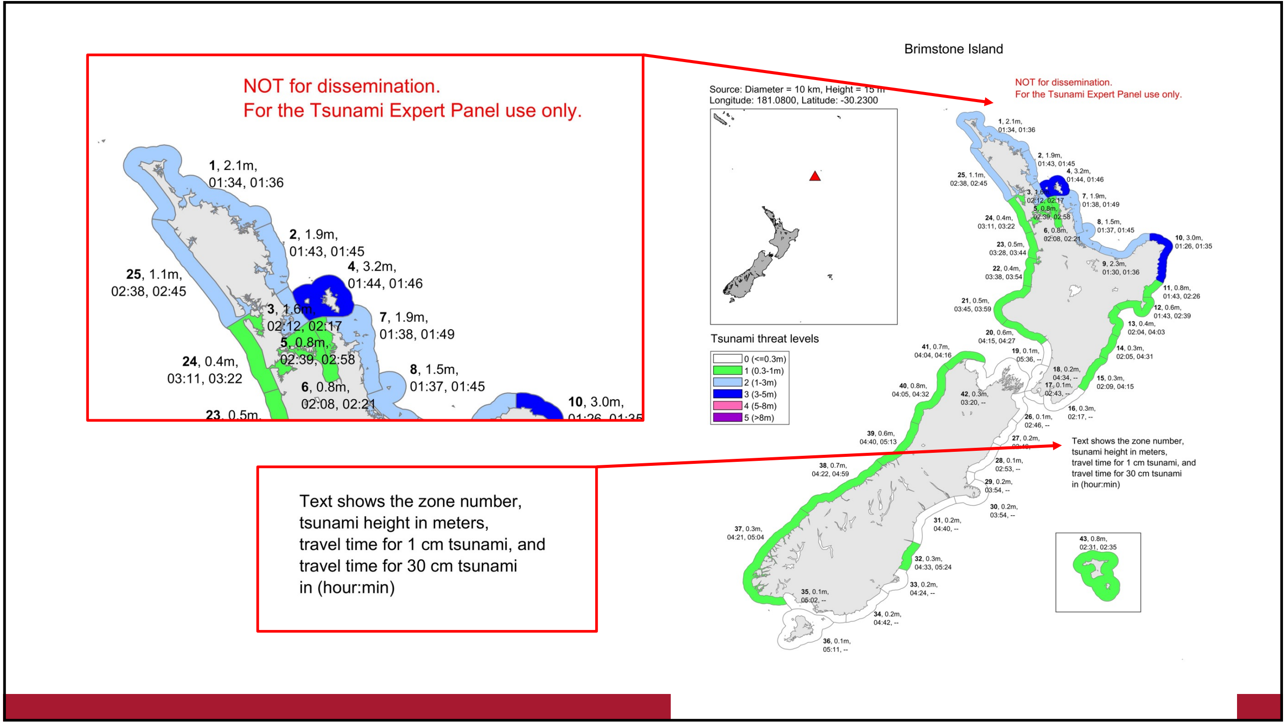

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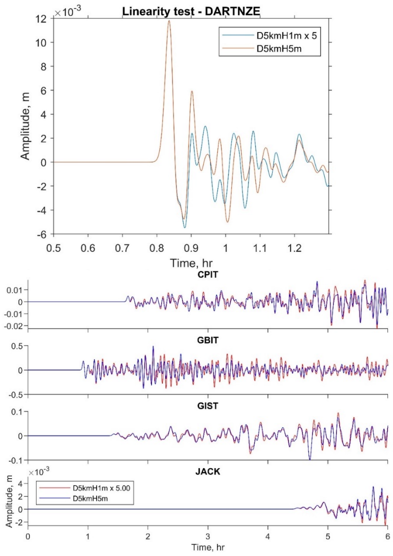
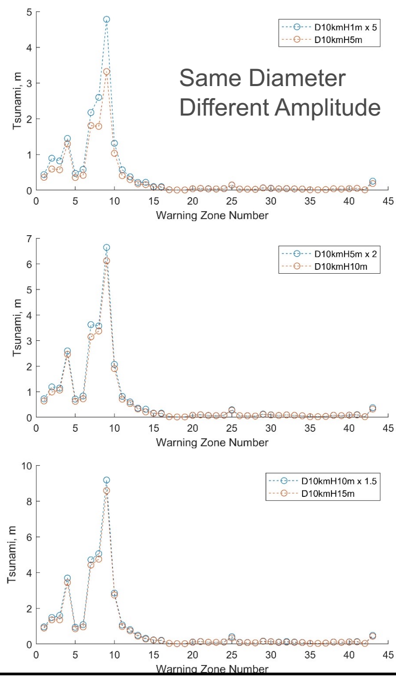
Is it possible to adjust/scaling the scenarios using the peak amplitudes recorded by DART?





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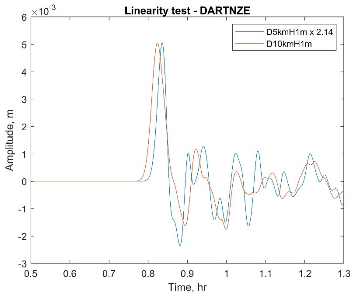
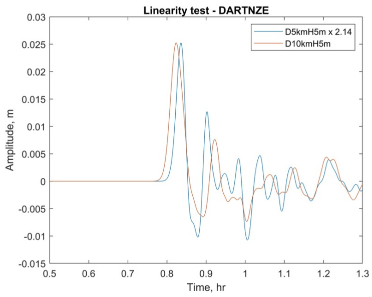
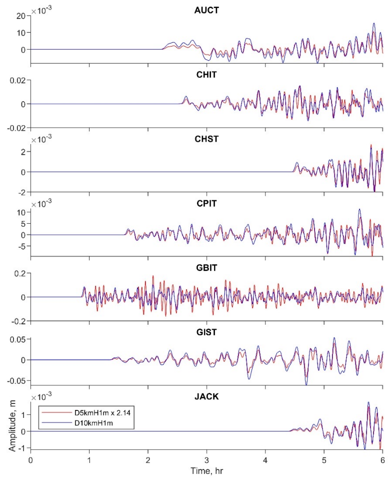
Is it possible to adjust/scaling the scenarios using the peak amplitudes recorded by DART?

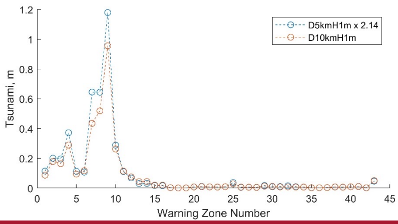
Same Amplitude
Different Diameter

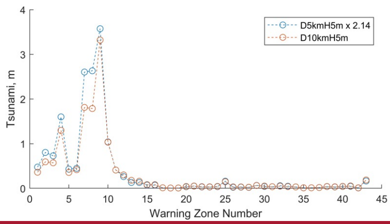




Whakaari







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