UK Research and Innovation

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Global Realtime Early Assessment of Tsunami
GREAT

Usama Kadri
School of Mathematics, Cardiff University

19th Meeting of the ICG/IOTWMS Steering Group

17-19 June 2025

Jakarta, Indonesia

unesco
Intergovernmental Oceanographic Commission

United Nations Educational, Scientific and Cultural Organization

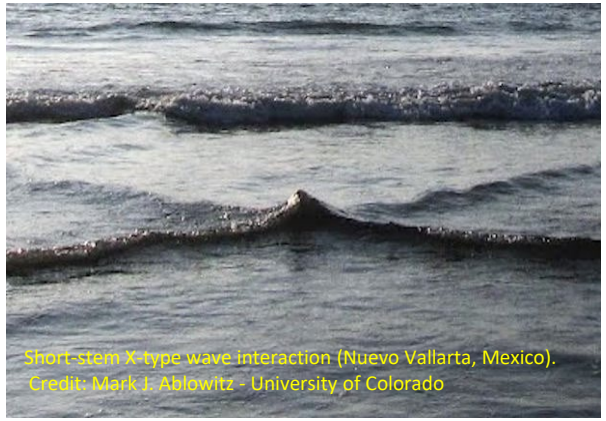
Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Acoustic-Gravity wave theory

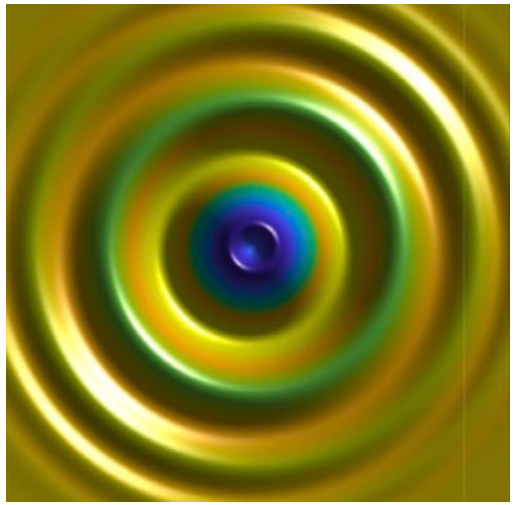
"an emerging field that is rapidly gaining popularity due to the broad utility in many disciplines"

Wave interaction & microseisms



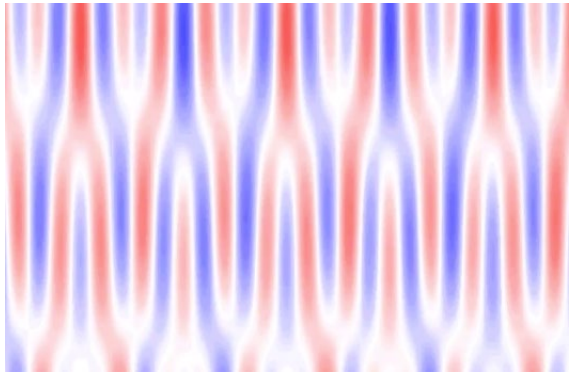
Real-time Tsunami detection

Remote sensing

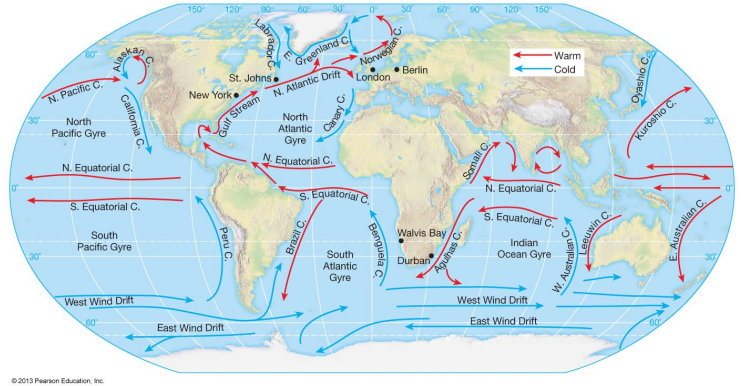


Quantum analogues
&Faraday Waves

Ocean energy harnessing



Deep water transportation



Atmospheric/ Ocean processes & circulation

Addressing most challenging questions with high impact on
Science & Society.

- **Gaza, occupied Palestine (2023, and ongoing)**
- Avoidable man-made destruction (by Israeli forces).
- Tsunami risk coastal area.

- **Palu, 2018 Sulawesi earthquake and tsunami**
- Unavoidable naturally made destruction.
- Tsunami risk coastal area.

Content

- Brief intro on Acoustic-Gravity Waves
- Early tsunami warning technology:

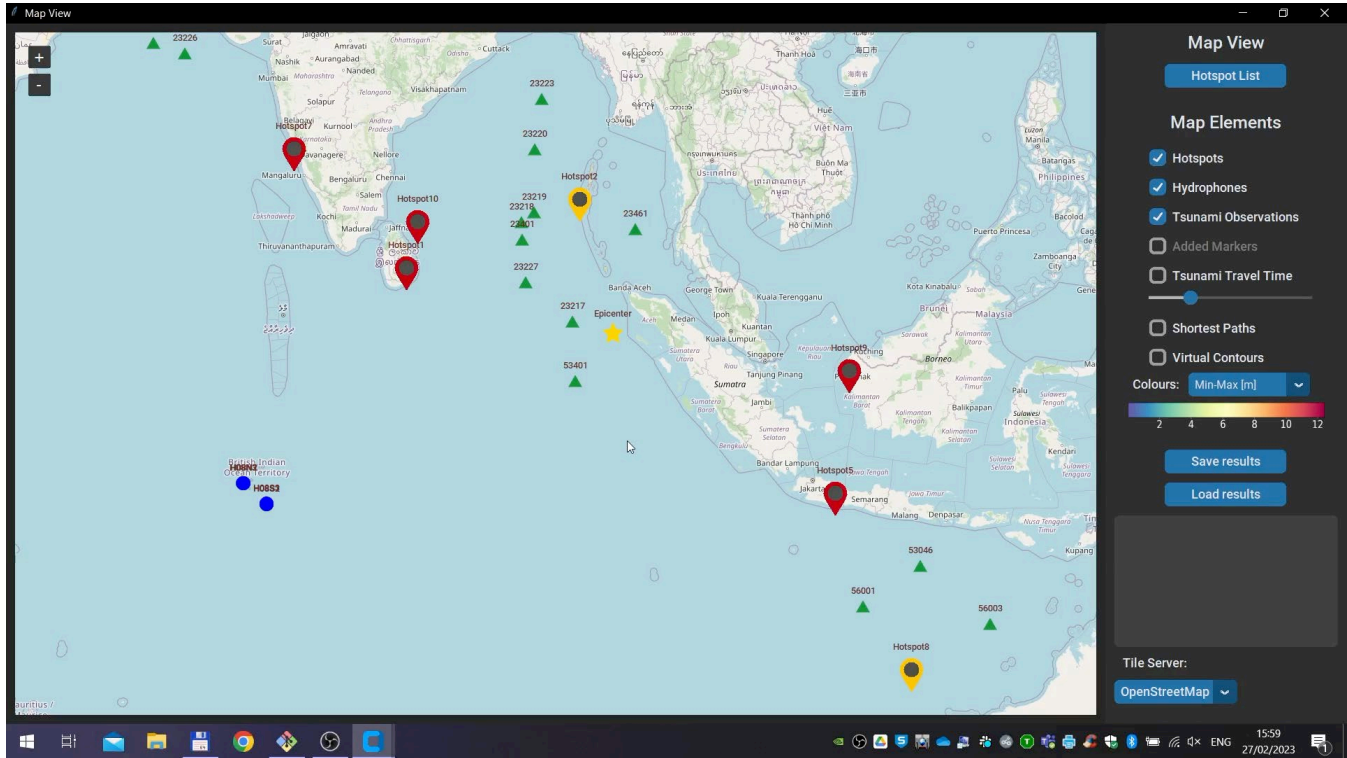
  - Global Real-time Early Assessment of Tsunami (GREAT)

  - Application to low-cost hydrophones

  - Success story / real-time assessment

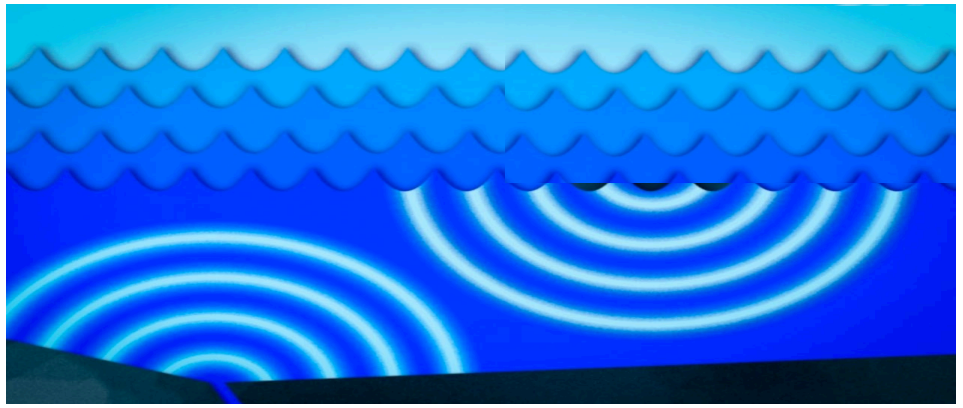
  - New features → optimisation

- Concluding remarks:
  challenges & opportunities



Surface waves are gravity waves
(neglect compressibility)

Acoustic waves are compression waves
(neglect gravity)



What are acoustic-gravity waves?

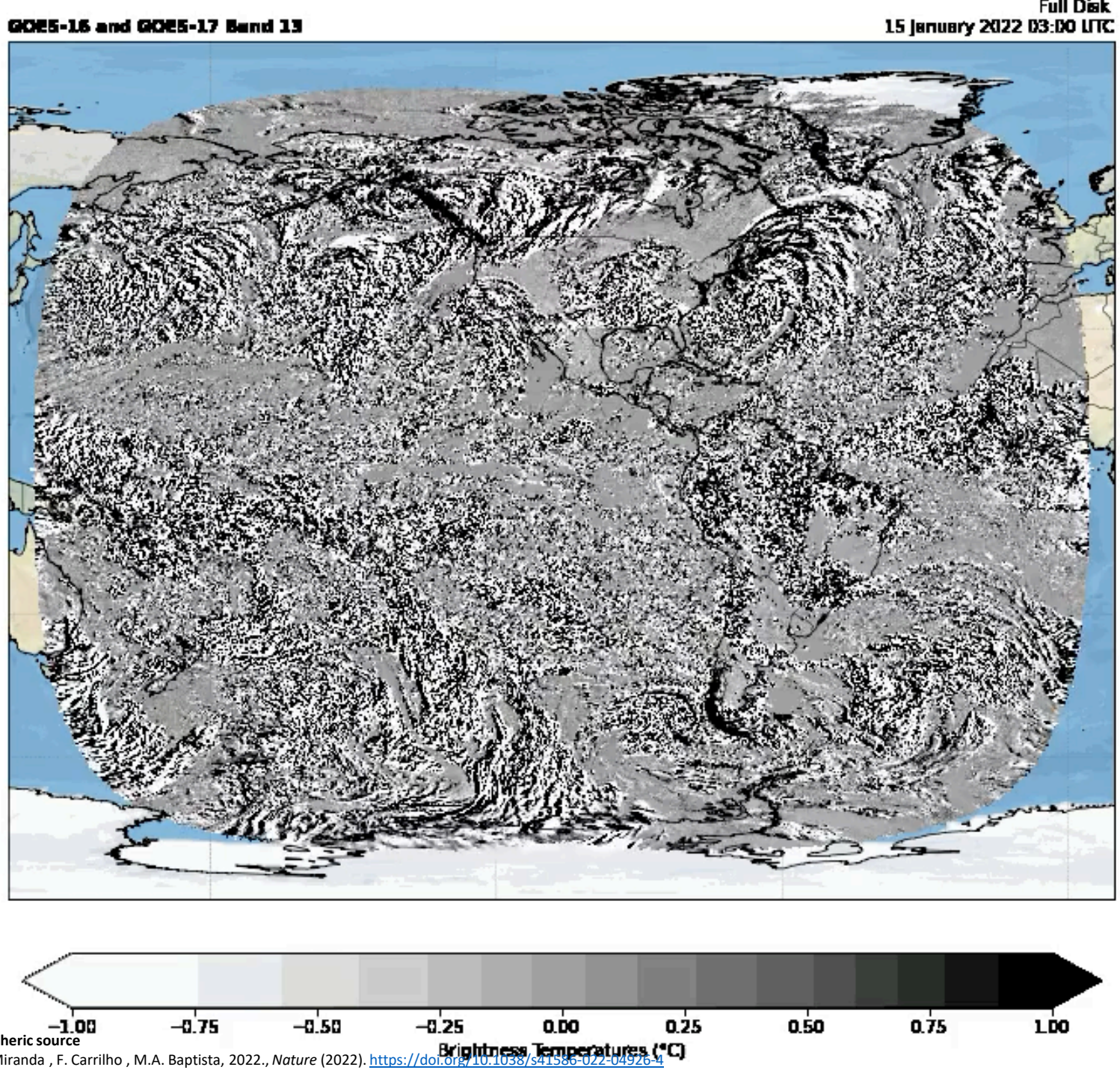
Compression-type waves travelling under the effects of gravity

Main properties:

- Low frequency (<10 Hz)
- High travelling speed (of sound in medium)
- Carry information on the source

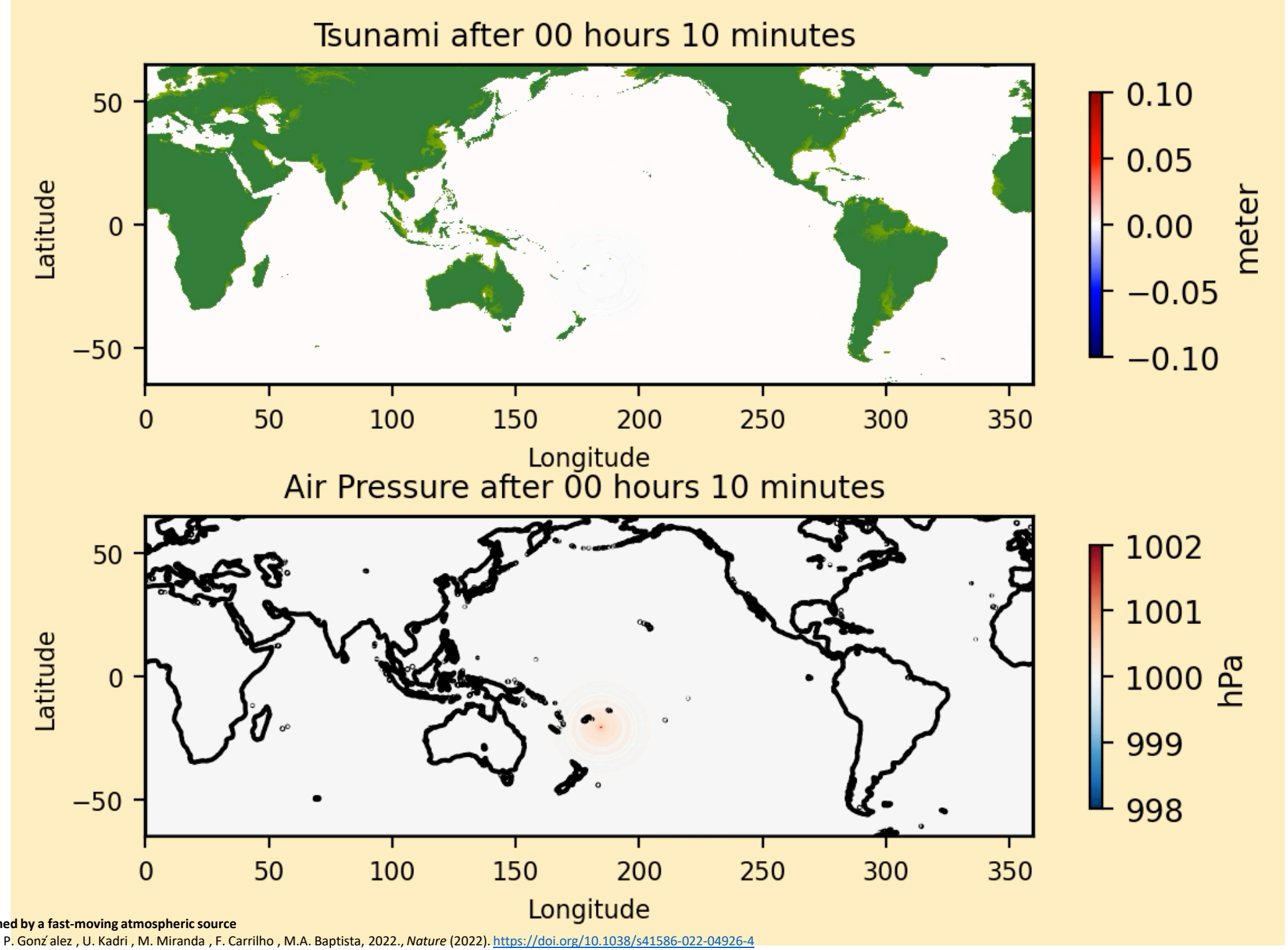
How do acoustic-gravity waves look like?

Hunga Tonga Hunga Ha’apai



Global Tonga tsunami explained by a fast-moving atmospheric source

R. Omira, R. Ramalho , J. Kim , P. Gonz´alez , U. Kadri , M. Miranda , F. Carrilho , M.A. Baptista, 2022., *Nature* (2022). https://doi.org/10.1038/s41586-022-04926-4



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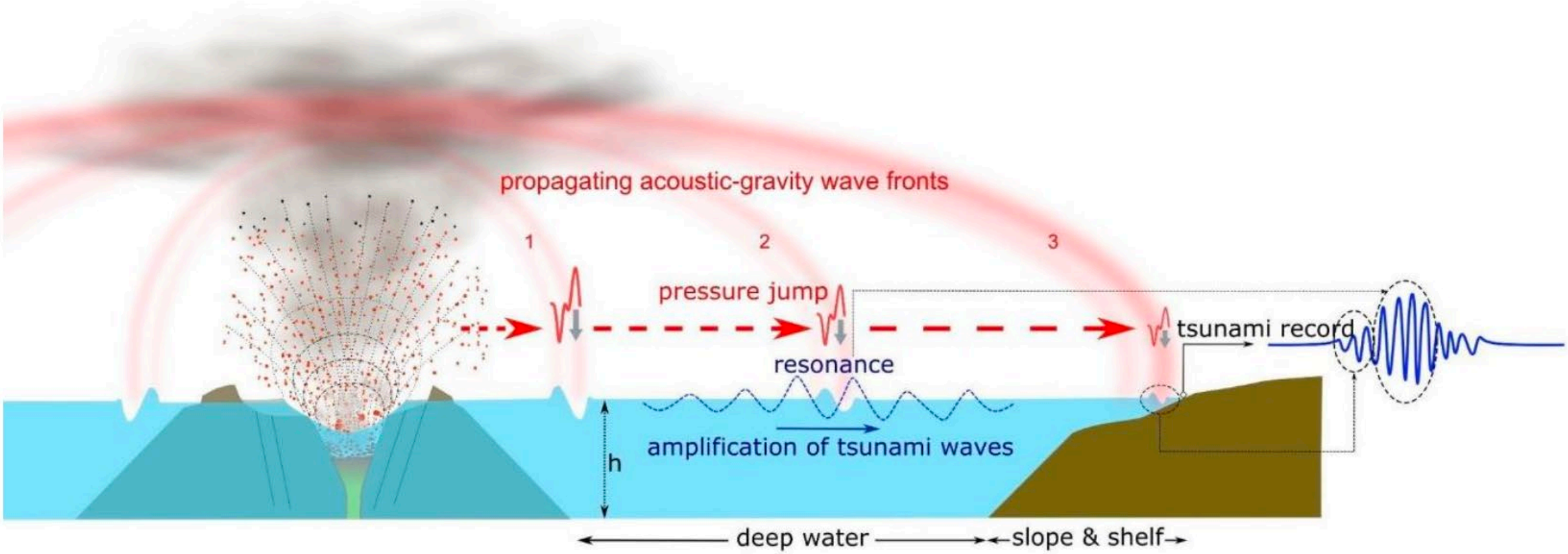
How are acoustic-gravity waves generated?

Generation of acoustic-gravity waves

Volcanic Eruption



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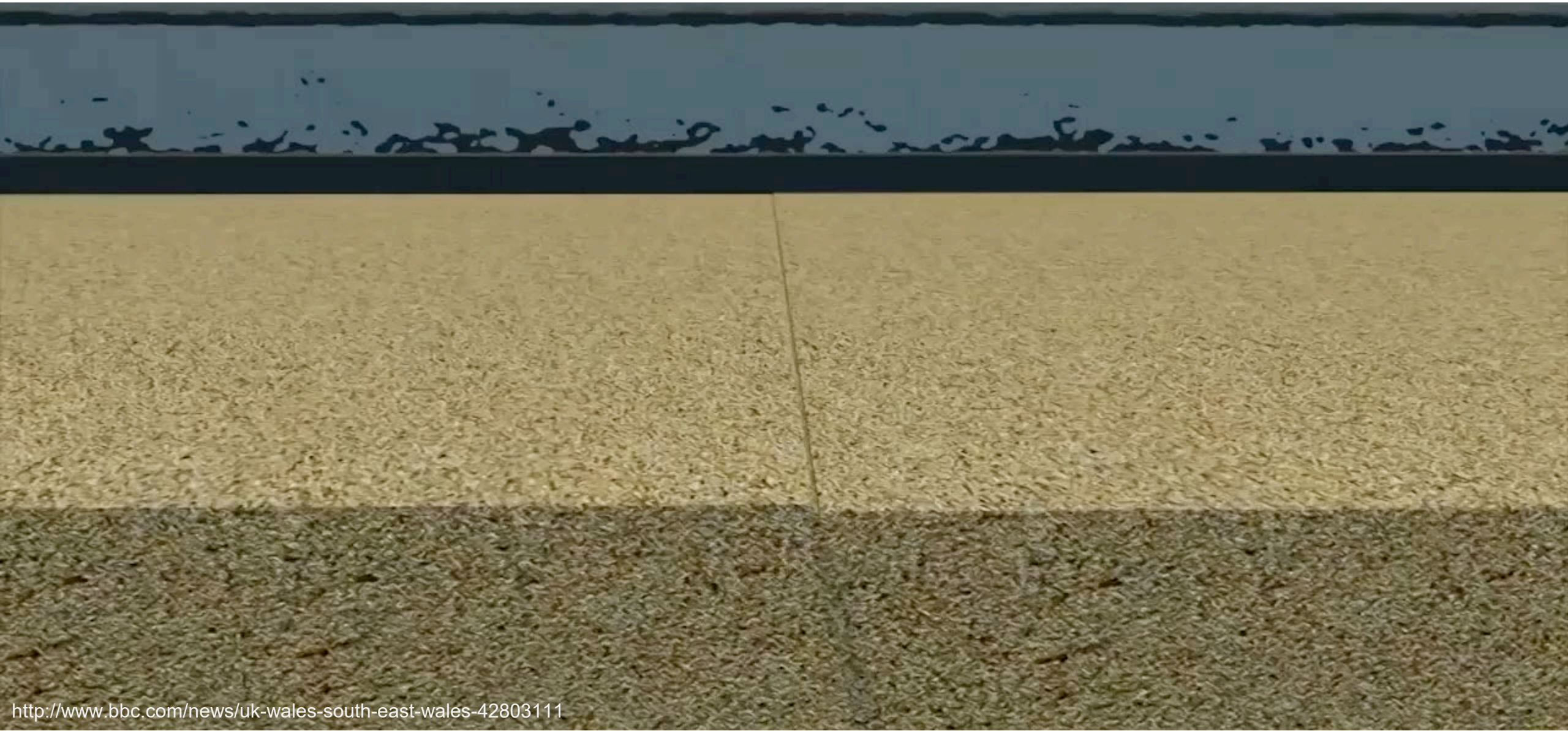
Generation of acoustic-gravity waves

Submarine Earthquake



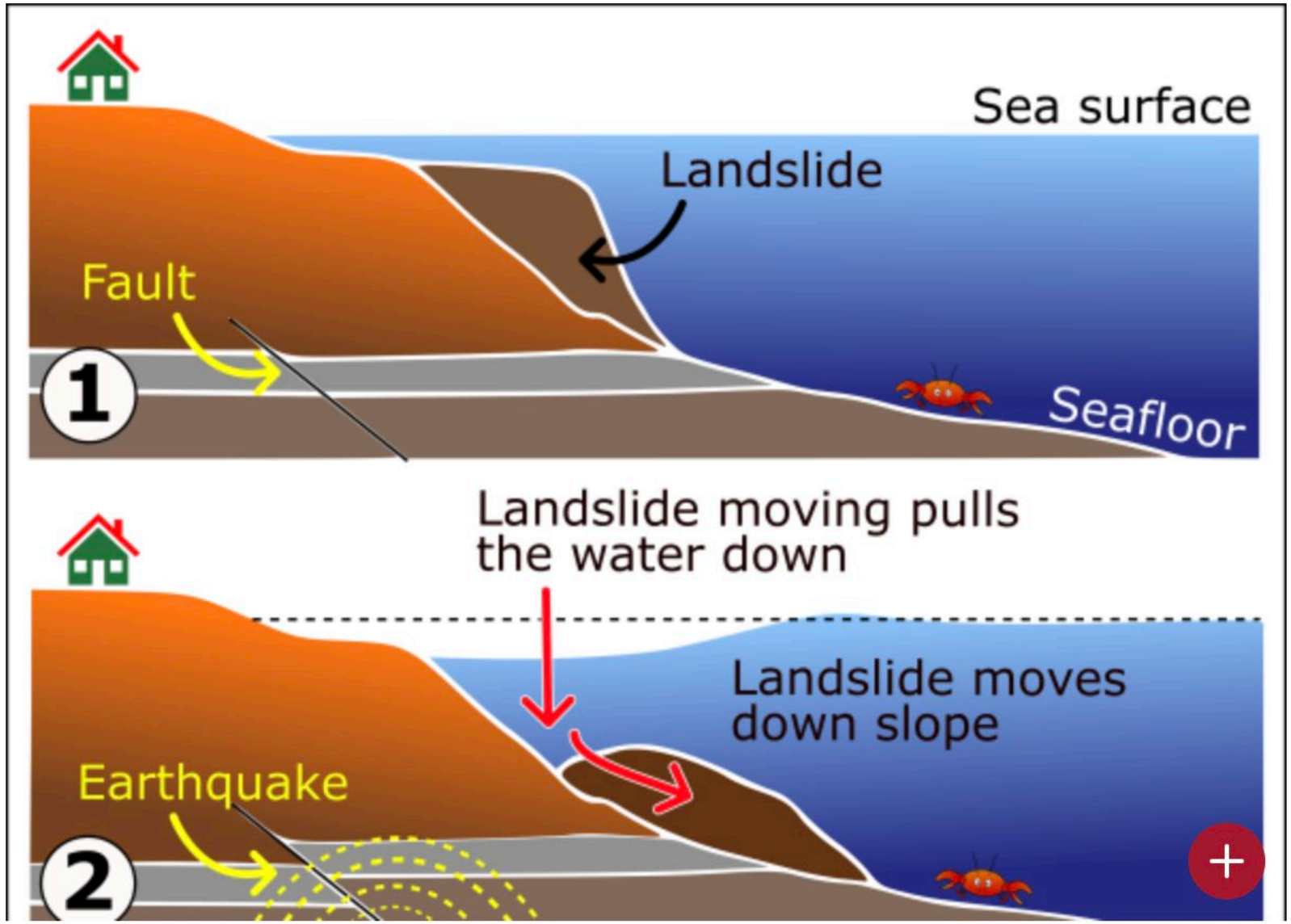
http://www.bbc.com/news/uk-wales-south-east-wales-42803111

Generation of acoustic-gravity waves

Impacting Objects

Generation of acoustic-gravity waves

Lanslides



Underwater landslides graphic

Early tsunami warning technology

Background

(with Ali Abdolali & Maxim Filimonov)

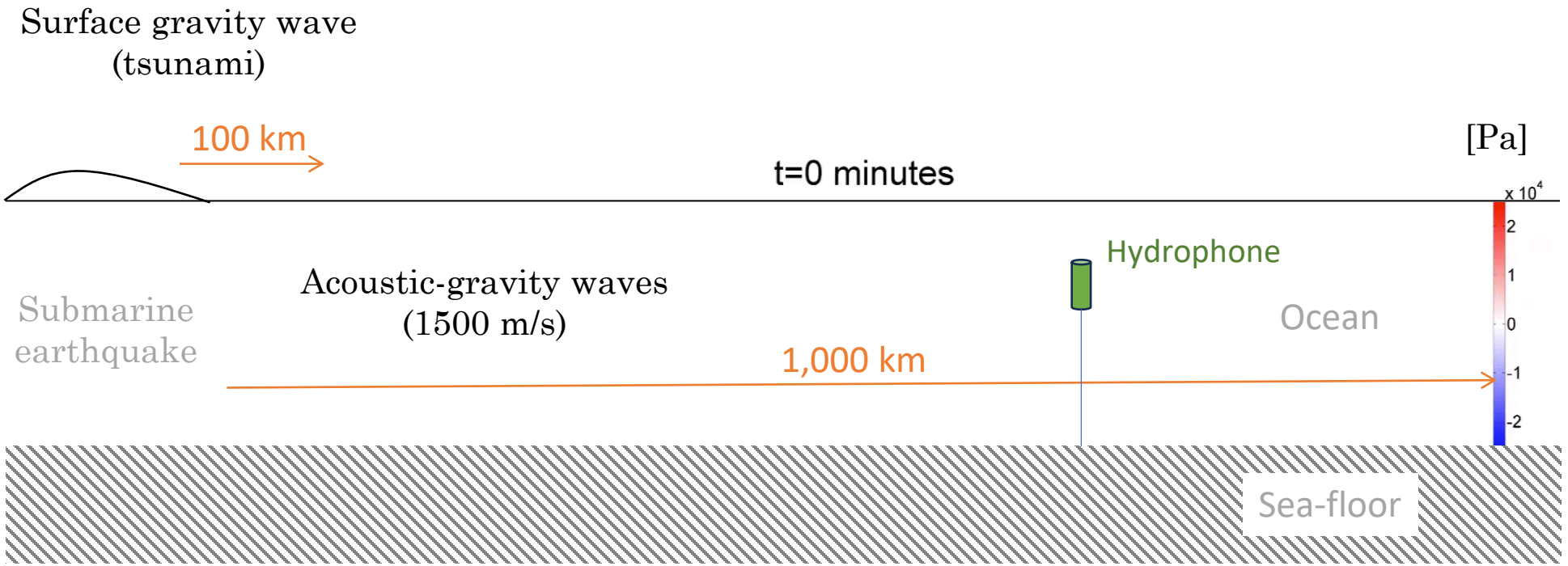
[2]Earth System Science Interdisciplinary Center, University of Maryland, US
[3]School of Computer Science, Cardiff University, UK

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

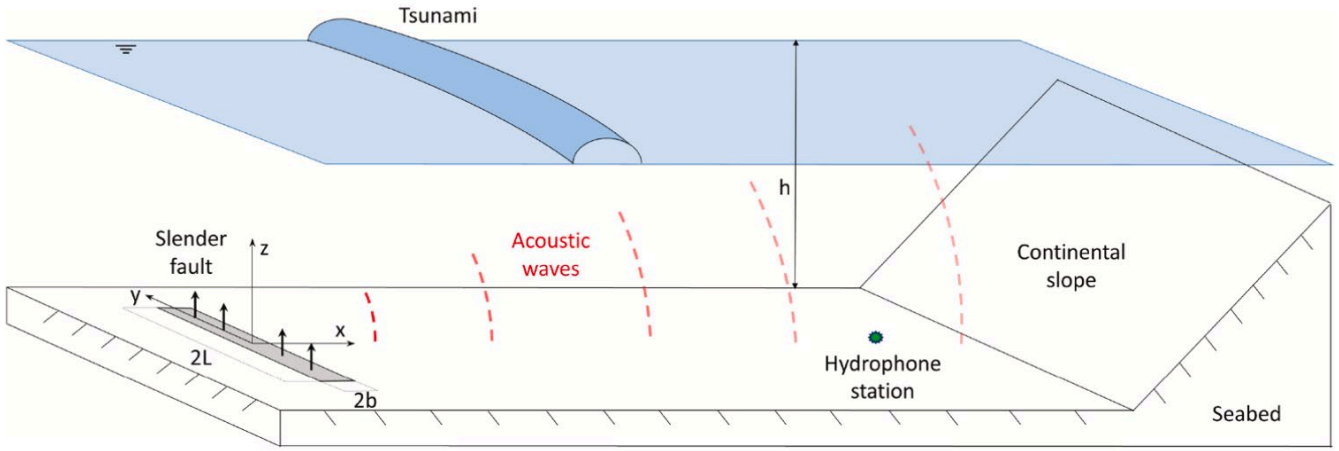
Kadri, U., Abdolali, A., and Filimonov, M.: GREAT v1.0: Global Real-time Early Assessment of Tsunamis, *Geosci. Model Dev. Discuss.* [preprint], https://doi.org/10.5194/gmd-2024-139 , (accepted), 2025.

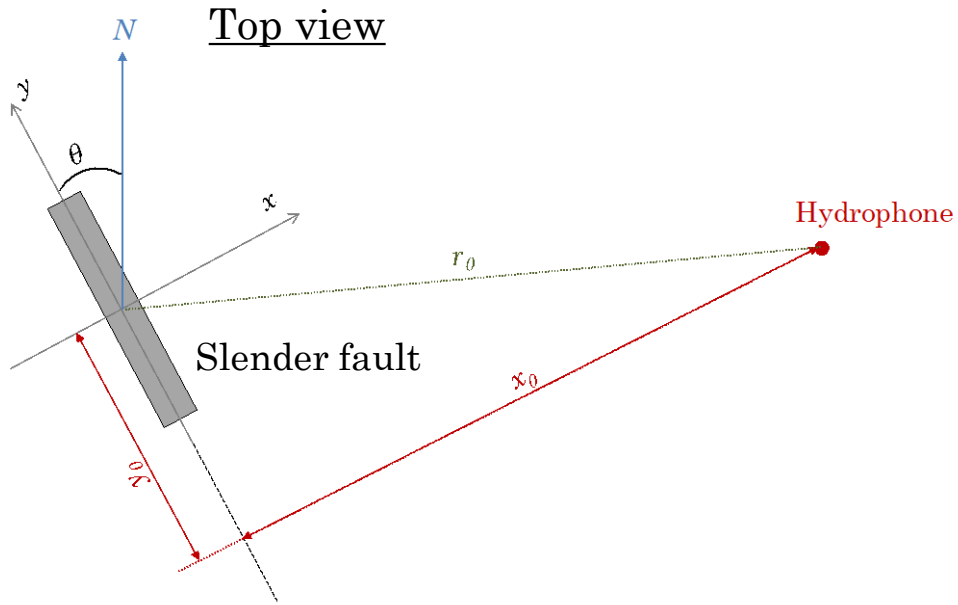
Real-time Tsunami Detection by Acoustic-Gravity Waves

Background



Analytical solution – simple & explicit





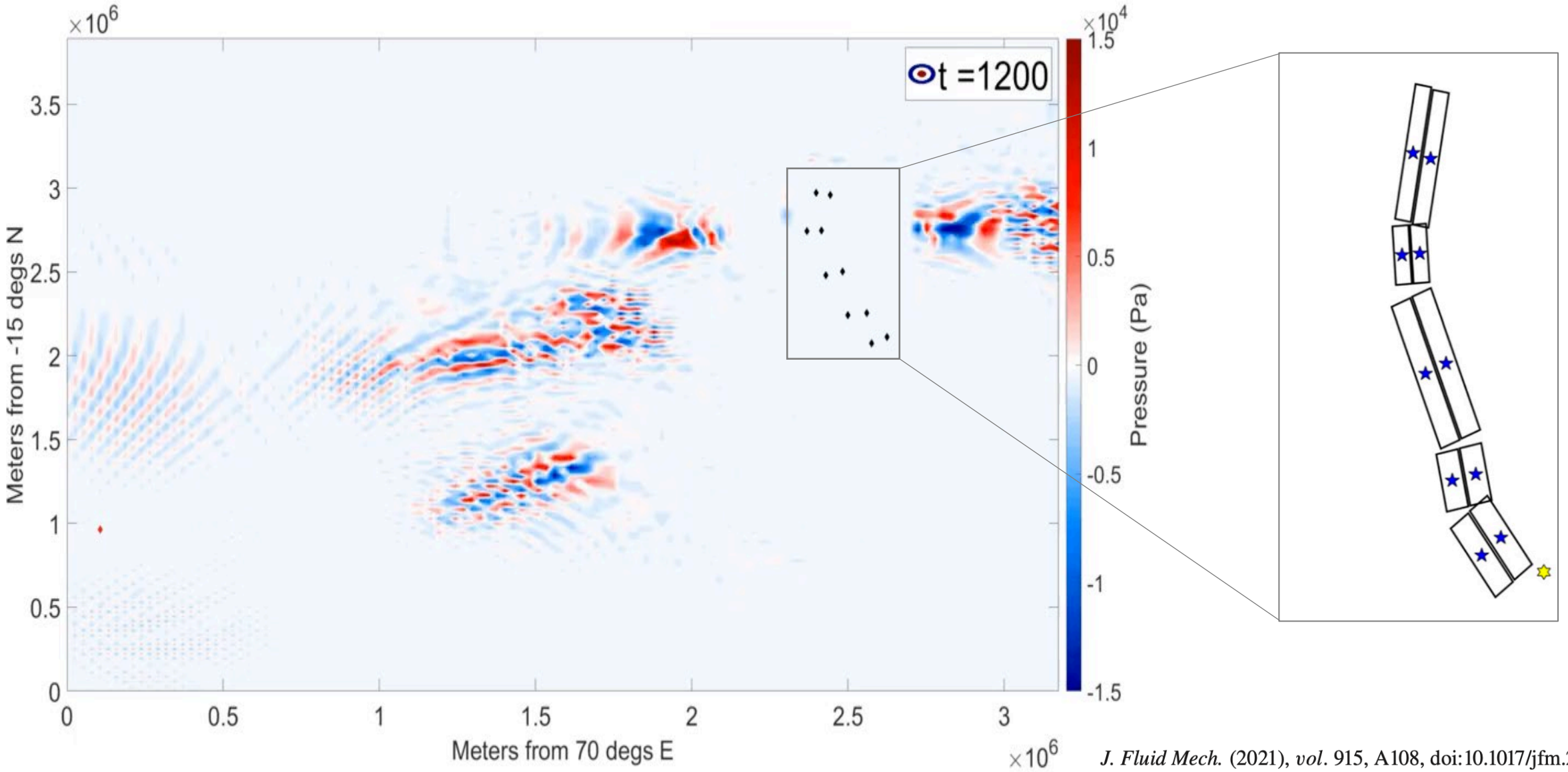
Tsunami origin	Earthquake duration (min)	Fault width (km)	Fault length (km)	Sea depth (km)
Chile (1960)	10	200	800	4
Alaska (1964)	10	100	700	4
Indian Ocean (2004)	10	200	1200	4
Tohoku (2011)	6	150	500	3.8

TABLE 1. Key data of some recent tsunamis. The sea depth is approximately 4 km in all cases above. From the lecture by Philip L.-F. Liu, in *Tsunami and storm surges*, Valparaiso, Chile, 2–13 January 2013.

$$\widehat{P}_1(\hat{t}_j) = \rho W_0 |A_1(K_1, X, Y)| \frac{2^{7/2} C}{\sqrt{\pi^3 x_0 k(\widehat{\Omega}_{\hat{t}_j})}} \sin[k(\widehat{\Omega}_{\hat{t}_j}) b] \sin(\widehat{\Omega}_{\hat{t}_j} T).$$

MEI, C.C. & KADRI, U. 2018 Sound signals of tsunamis from a slender fault. *J. Fluid Mech.* **836**, 352–373.

Analytical solution – multi-fault

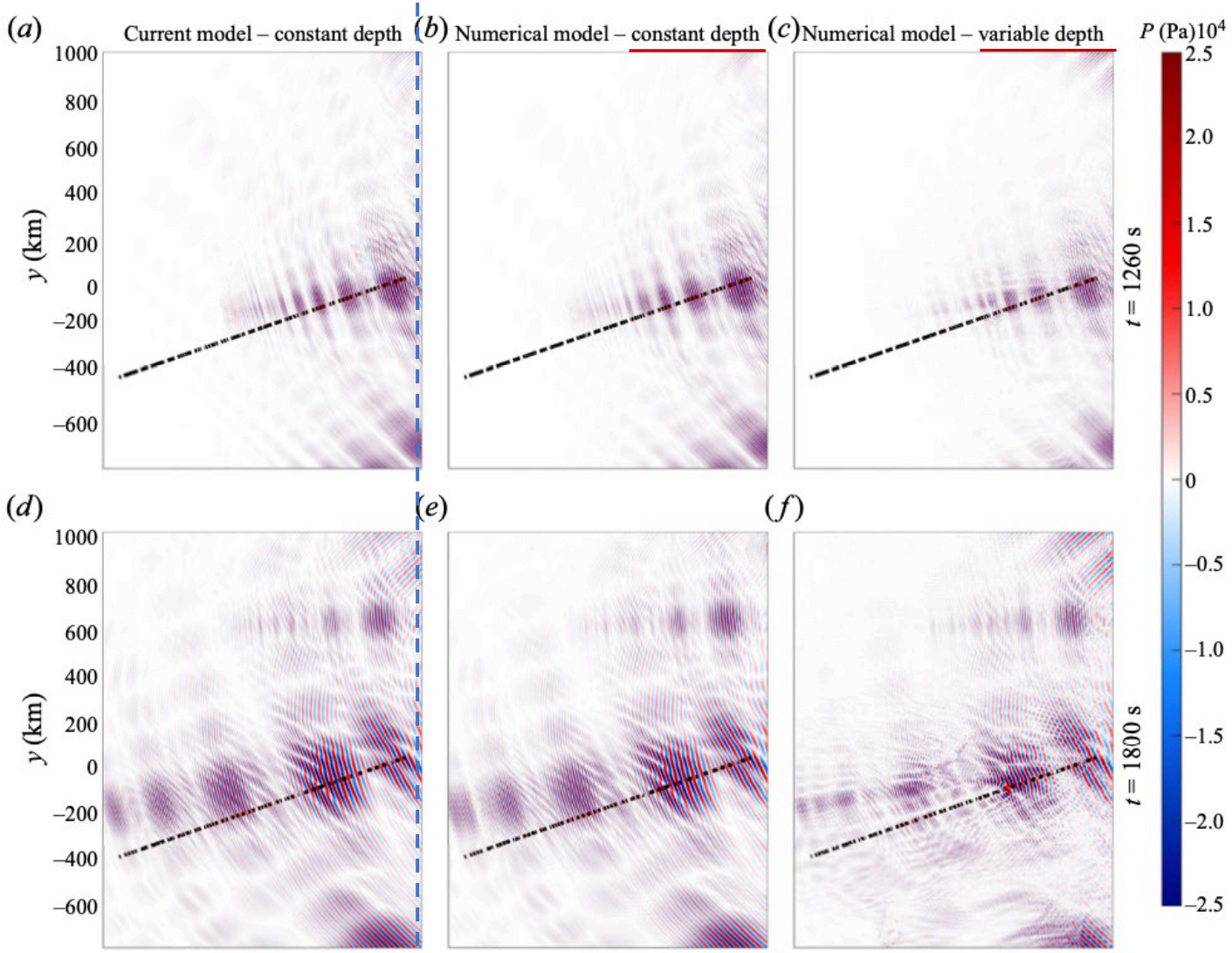


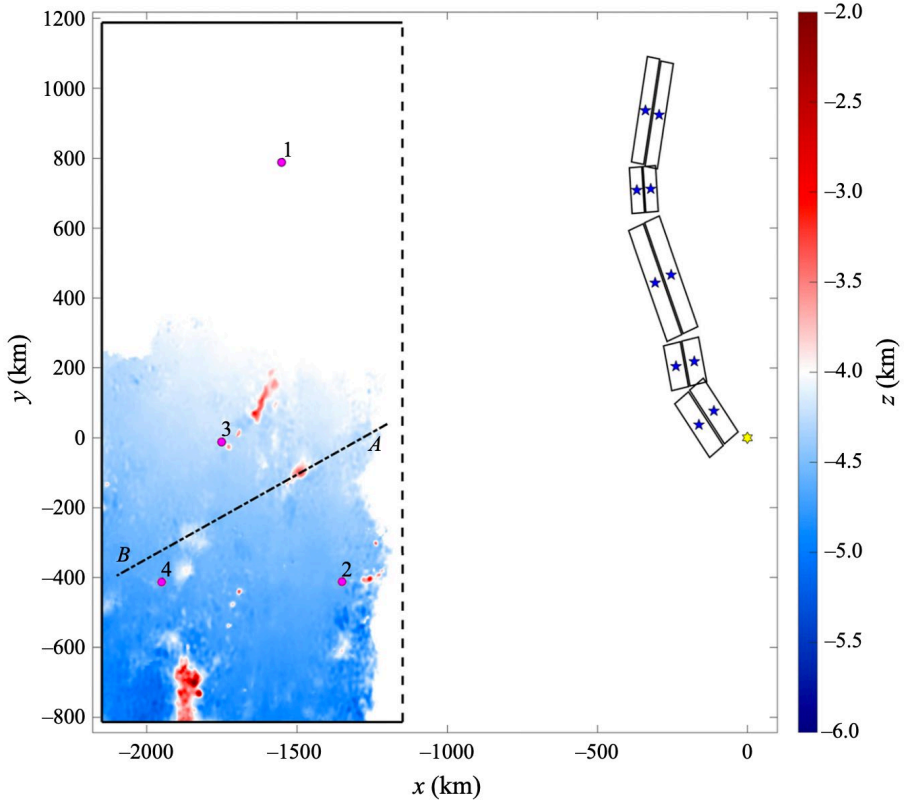
J. Fluid Mech. (2021), *vol.* 915, A108, doi:10.1017/jfm.2021.101

Analytical solution – very fast

Analytical

Numerical





J. Fluid Mech. (2021), *vol.* 915, A108, doi:10.1017/jfm.2021.101

Inverse Problem Model

$$\widehat{P}_1(\hat{t}_j) = \rho W_0 |A_1(K_1, X, Y)| \frac{2^{7/2} C}{\sqrt{\pi^3 x_0 k(\widehat{\Omega}_{\hat{t}_j})}} \sin[k(\widehat{\Omega}_{\hat{t}_j}) b] \sin(\widehat{\Omega}_{\hat{t}_j} T).$$

Speed

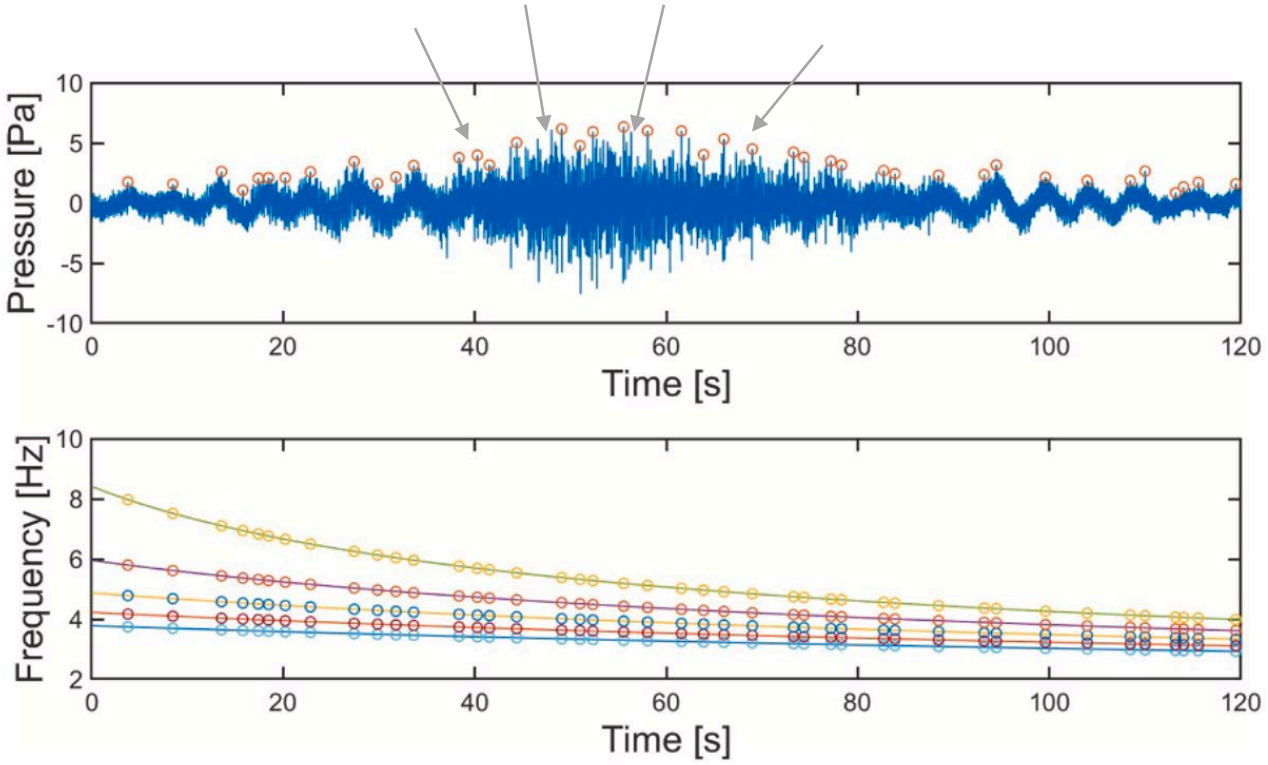
Length & location

Horizontal location

Width

Duration

UNKNOWNS



Appl. Ocean Res. **109**, 102557 (2021).

Sci. Rep. **11**, 23062 (2021)

Physics of Fluids **35** (4): 046113 (2023)
https://doi.org/10.1063/5.0144360

Machine Learning (ML) Model
Predicts *Surface Elevation* from *Acoustic Signals*

- The ML model uses pressure recordings, earthquake epicentre and locations features to:
  - **A) classify** whether the event is **tsunamigenic** or not;
  - **B) predict** earthquake magnitude & surface elevation globally.

- ML model was trained with **1,400 earthquake** events with magnitudes from 5.0 to 9.1. That includes **all recorded** earthquake events **from January 2000** with magnitudes **higher than 6.5.** All signals were downloaded from IMS/CTBTO, with a newly developed automatic script.

- GREAT software has new functionality to predict surface elevation at the shoreline contours and compare the results with the values calculated by the direct model.

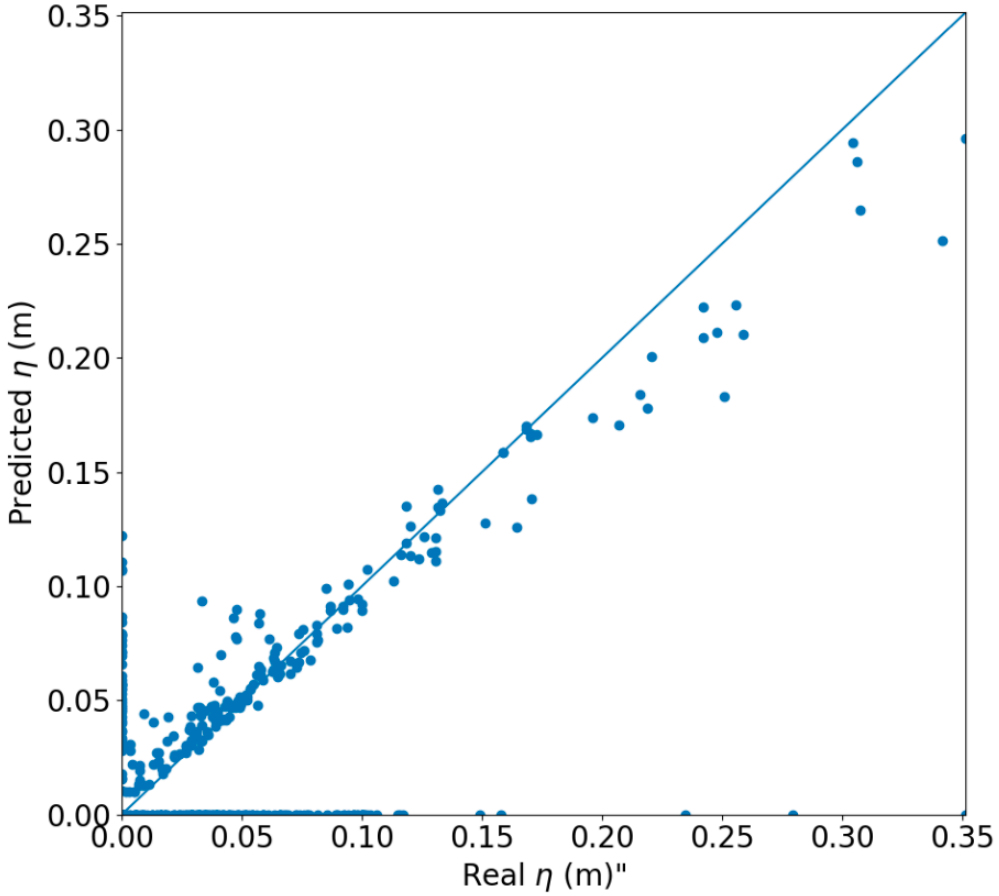
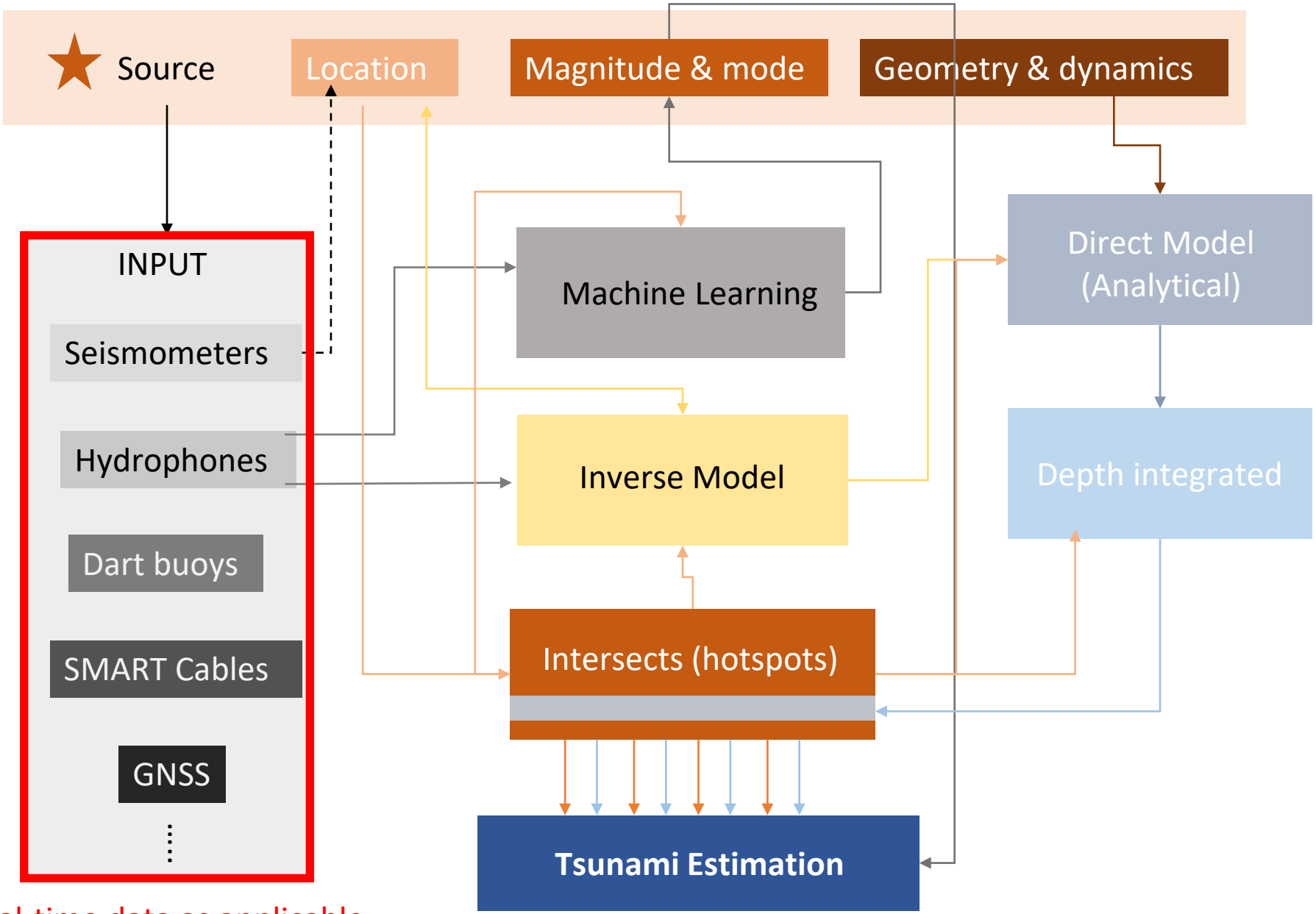


Figure 1 – Evaluation of surface elevation machine learning model



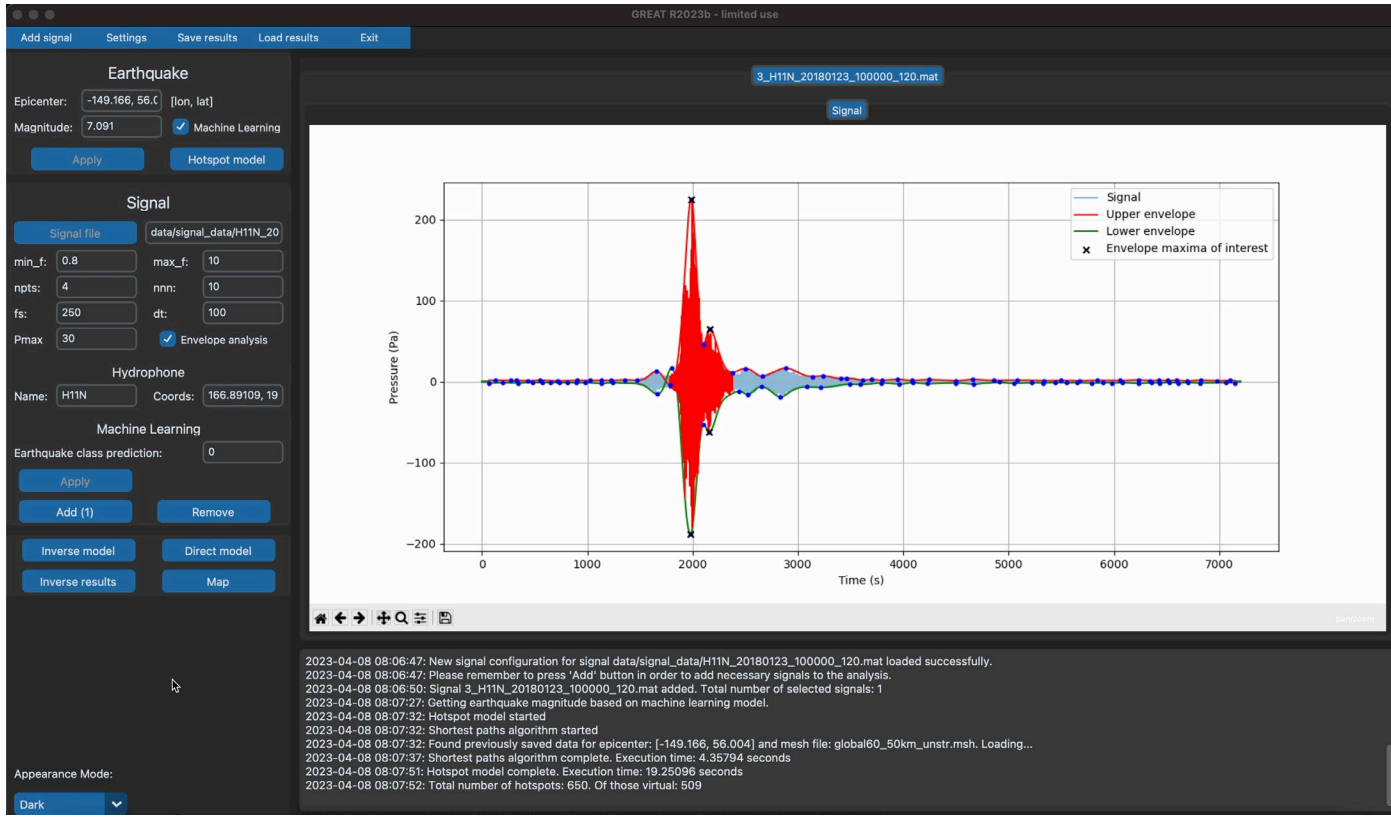
Please share real-time data as applicable

Operational Software: Global Real-time Early Assessment of Tsunami (GREAT)

Detection → Warning → Dissemination

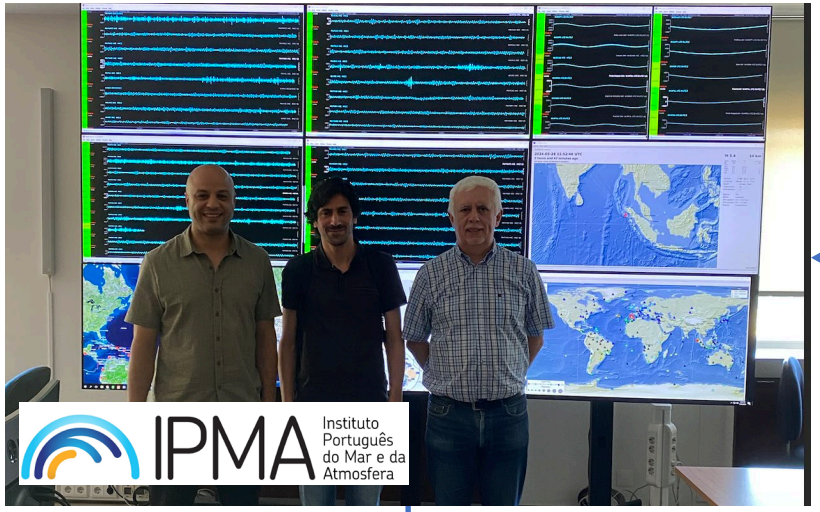
- Provides **initial assessment** based on EQ epicentre, sensors' locations, and required evacuation time.
- Detects signals; **categorises** earthquakes / events; **analyses** hydroacoustic data; calculates **tsunami size**
- Operates **automatically**, and **manually** (after training)
- Hydrophones & Tide-gauges data are already integrated; other data sources can be integrated, e.g., seismic/GNSS, SMART cables, …

M 7.9 - 2018 261 km SE of Chiniak, Alaska Earthquake 2018-01-23 09:31:40 (UTC)

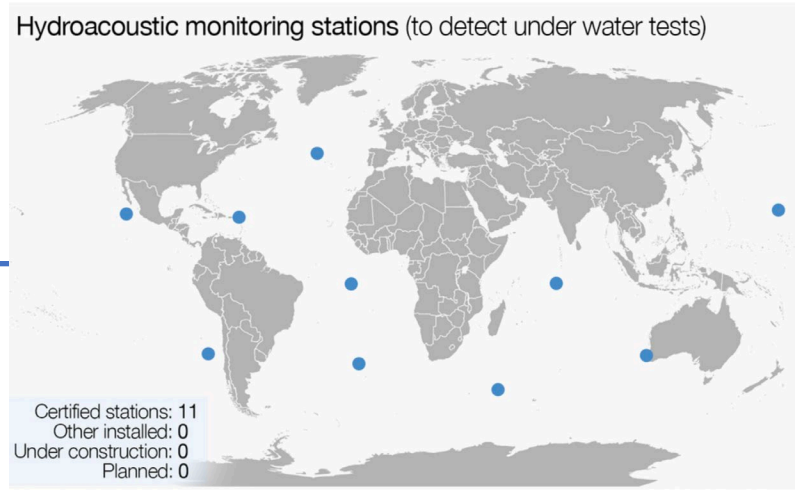


Access to IMS/CTBTO Real-Time Hydroacoustic Data

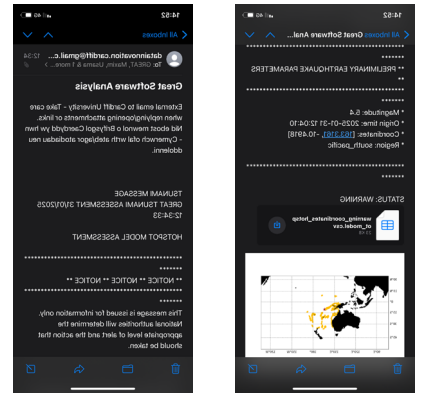
Software deployed at IPMA June 2024

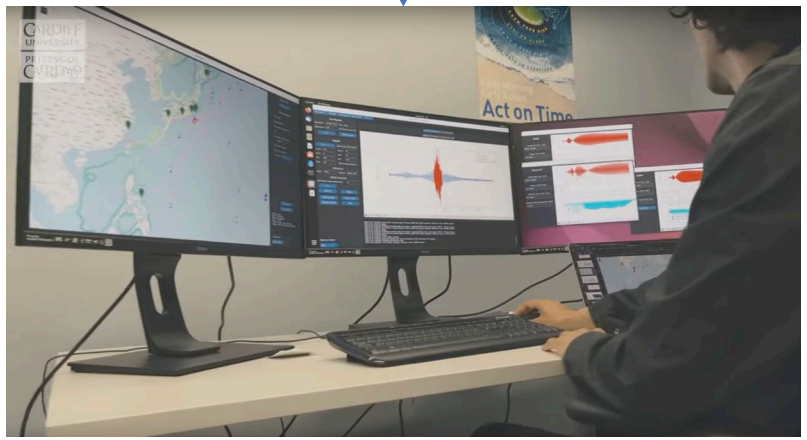


Real-time access

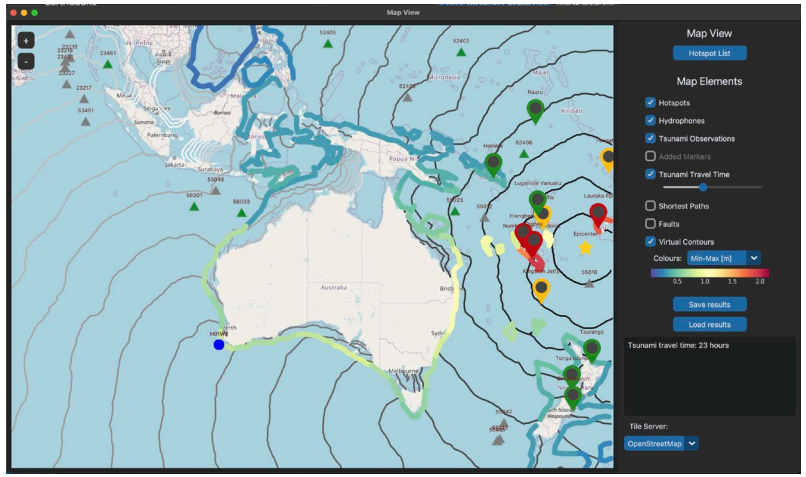


e-mail Alerts



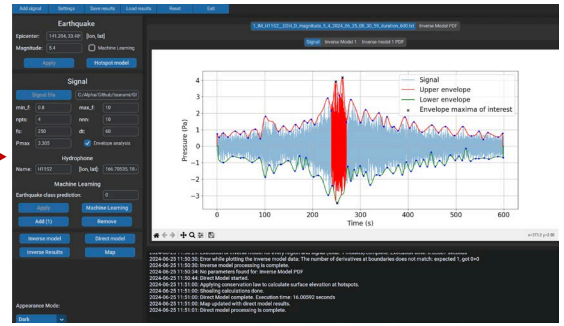


Cardiff University Tsunami Centre, UK



Assess Tsunami globally & benefits coastal communities, especially SIDS and LDCs

Live streaming



E-mail alerts: Message #1

GREAT TSUNAMI ALERT - MESSAGE 1
Global Real-time Early Assessment of Tsunami (GREAT) System
Issued by: GREAT Monitoring Center, Cardiff University, UK
Date and Time: 13/04/2025 20:14:26 UTC

IMPORTANT NOTICE
This alert is distributed solely for informational purposes to support the GREAT tsunami early assessment initiative. It is provided to assist national authorities in evaluating risk; each country should determine its own alert level and may supplement this message with additional local guidance.

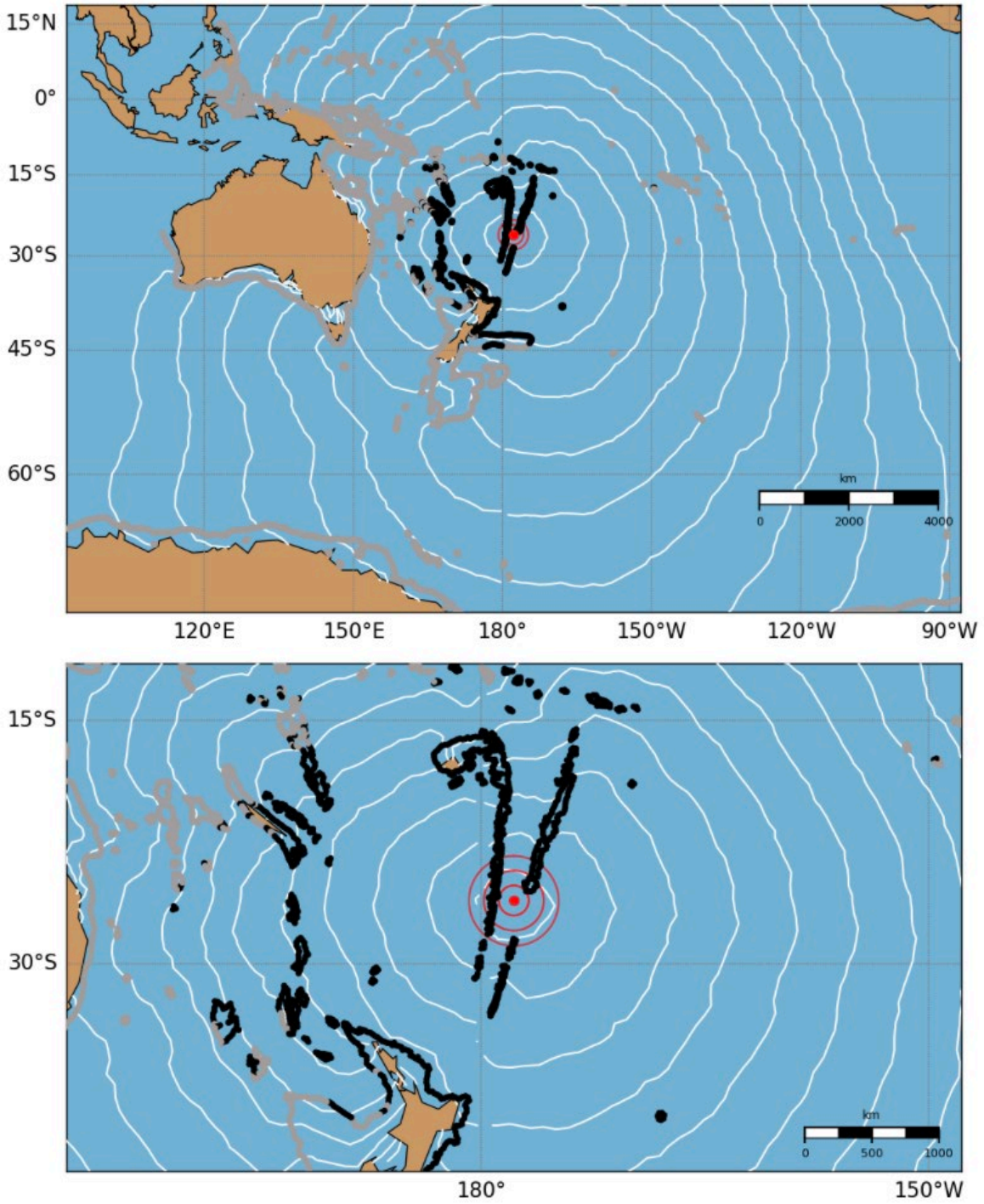
PRELIMINARY EARTHQUAKE DATA (Source: USGS)
* Magnitude: 6.5
* Event Date and Time: 2025-04-13 20:03:17 UTC
* Coordinates: 26.255° S, 177.805° W
* Location: South Pacific

CURRENT EVALUATION
A seismic event registering a preliminary magnitude of 6.5 was recorded in South Pacific region on date and time: 2025-04-13 20:03:17 .
==> Our preliminary HOTSPOT analysis indicates a tsunami risk associated with this event.

ADVICE TO AUTHORITIES
National authorities will determine the appropriate level of alert and the action that should be taken.

FUTURE UPDATES & ADDITIONAL INFORMATION
* Further update will be provided once more data becomes available.
* For authoritative earthquake details, please refer to the U.S. Geological Survey at earthquake.usgs.gov.
* Further tsunami-related updates are available at our GREAT website: [insert URL].

DISCLAIMER
The information provided in this alert is compiled from multiple data sources and is meant for early situational awareness only. GREAT does not guarantee the timeliness, accuracy, or completeness of this information. It is the responsibility of local and national agencies to verify details and disseminate warnings appropriately.
To unsubscribe from these notifications, please visit [unsubscribe link].



E-mail alerts: Message #2

GREAT TSUNAMI ALERT - MESSAGE 2
Global Real-time Early Assessment of Tsunami (GREAT) System
Issued by: GREAT Monitoring Center, Cardiff University, UK
Date and Time: 13/04/2025 21:23:45 UTC

IMPORTANT NOTICE
This alert is distributed solely for informational purposes to support the GREAT tsunami early assessment initiative. It is provided to assist national authorities in evaluating risk; each country should determine its own alert level and may supplement this message with additional local guidance.

PRELIMINARY EARTHQUAKE DATA (Source: USGS)
* Magnitude: 6.5
* Event Date and Time: 2025-04-13 20:03:17 UTC
* Coordinates: 26.255° S, 177.805° W
* Location: South Pacific

CURRENT EVALUATION
A seismic event registering a preliminary magnitude of 6.5 was recorded in South Pacific region on date and time: 2025-04-13 20:03:17 . Hydroacoustic data recorded at station H11S1 on 13/04/2025 at 21:01:22 UTC was analysed using GREAT.
==> Our MACHINE LEARNING analysis does not indicate an imminent tsunami risk associated with this event.
==> Our ANALYTICAL analysis does not indicate an imminent tsunami risk associated with this event.

ADVICE TO AUTHORITIES
No immediate action is required based on the available information.

FUTURE UPDATES & ADDITIONAL INFORMATION
* This notice is intended as the only update for this event unless further data suggest a change in conditions.
* For authoritative earthquake details, please refer to the U.S. Geological Survey at earthquake.usgs.gov.
* Further tsunami-related updates are available at our GREAT website: [insert URL].

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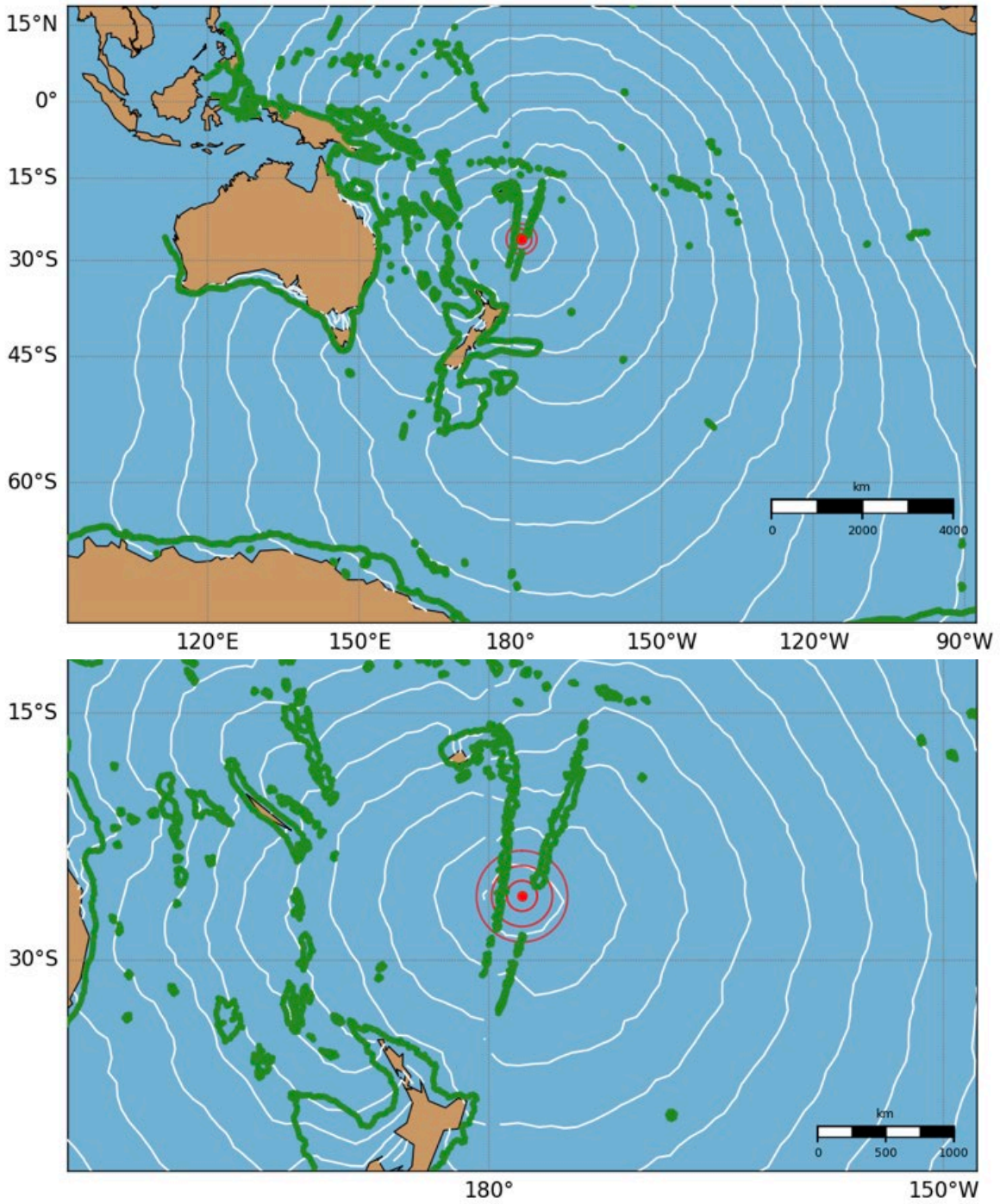
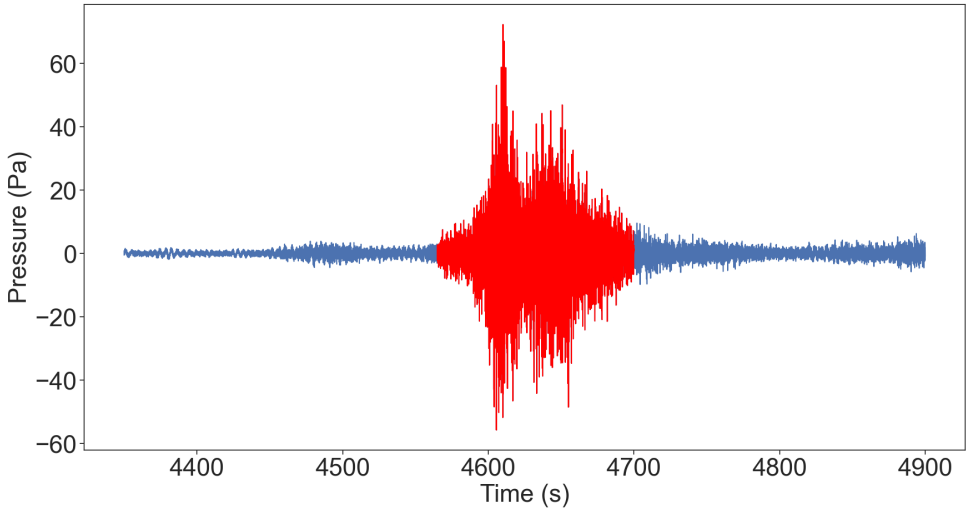


Cost-effective hydrophones

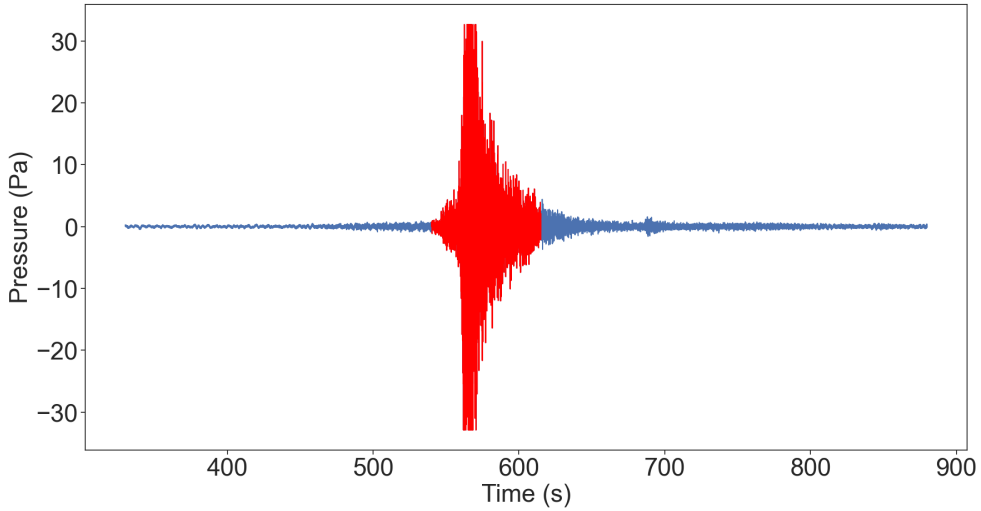
Potential exploitation of technology

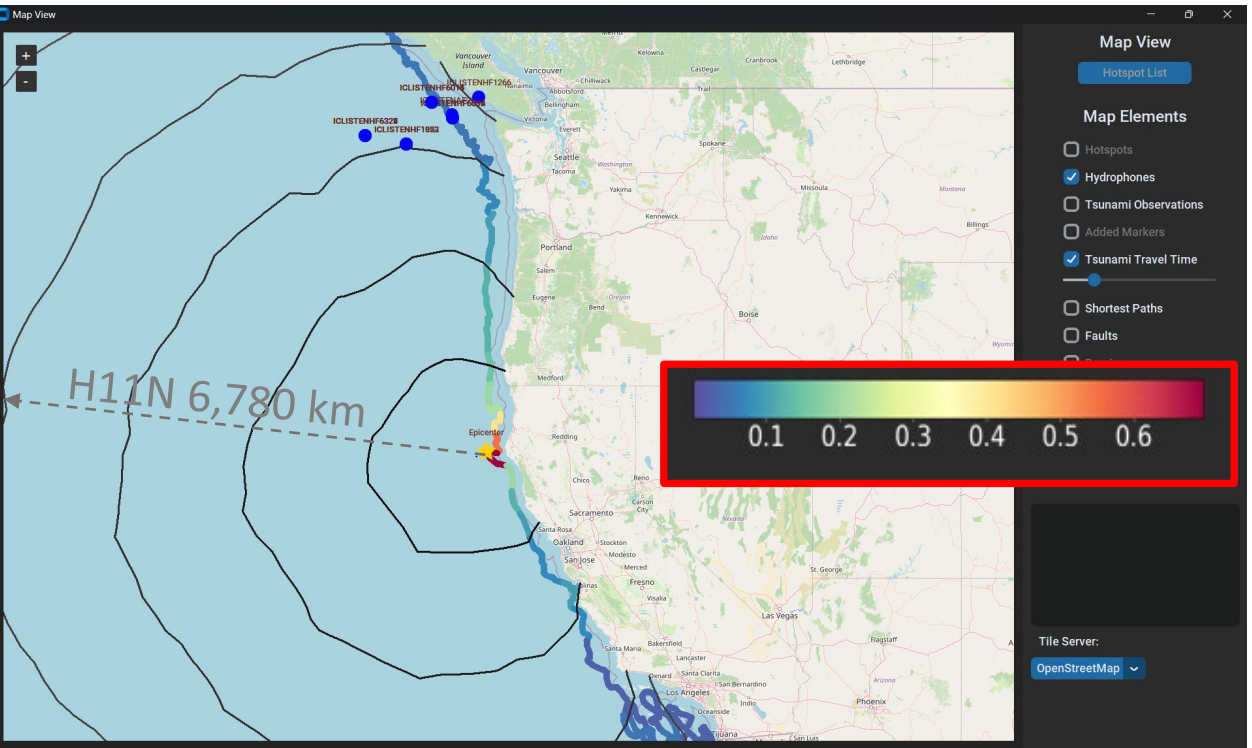
M 7.0 - 2024 Offshore Cape Mendocino, California Earthquake 2024-12-05 18:44:21 (UTC)

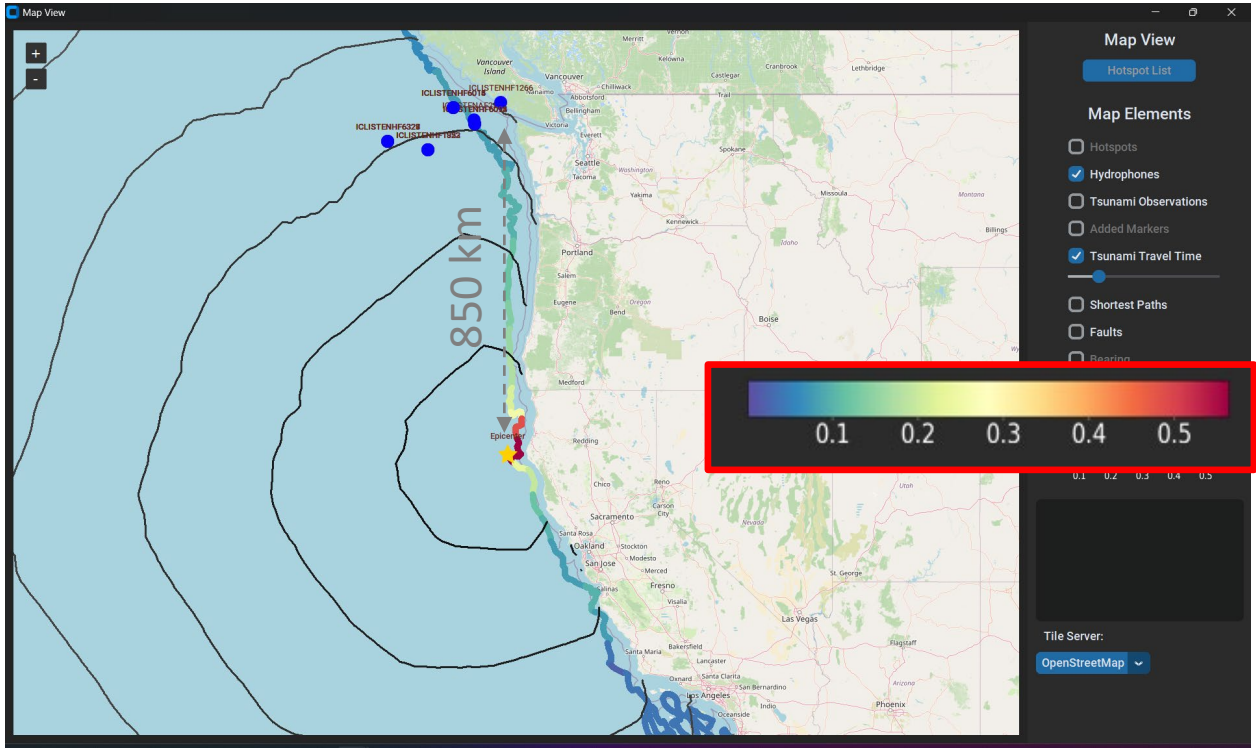
CTBTO (hydroacoustic station H11N)



Ocean Network Canada (icListen AF 2534)

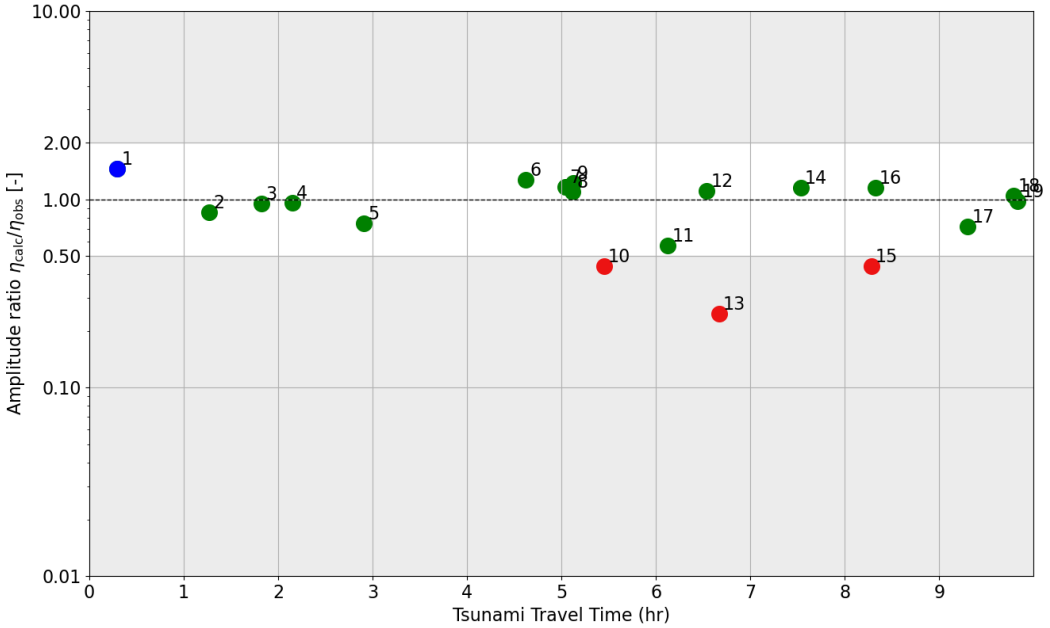


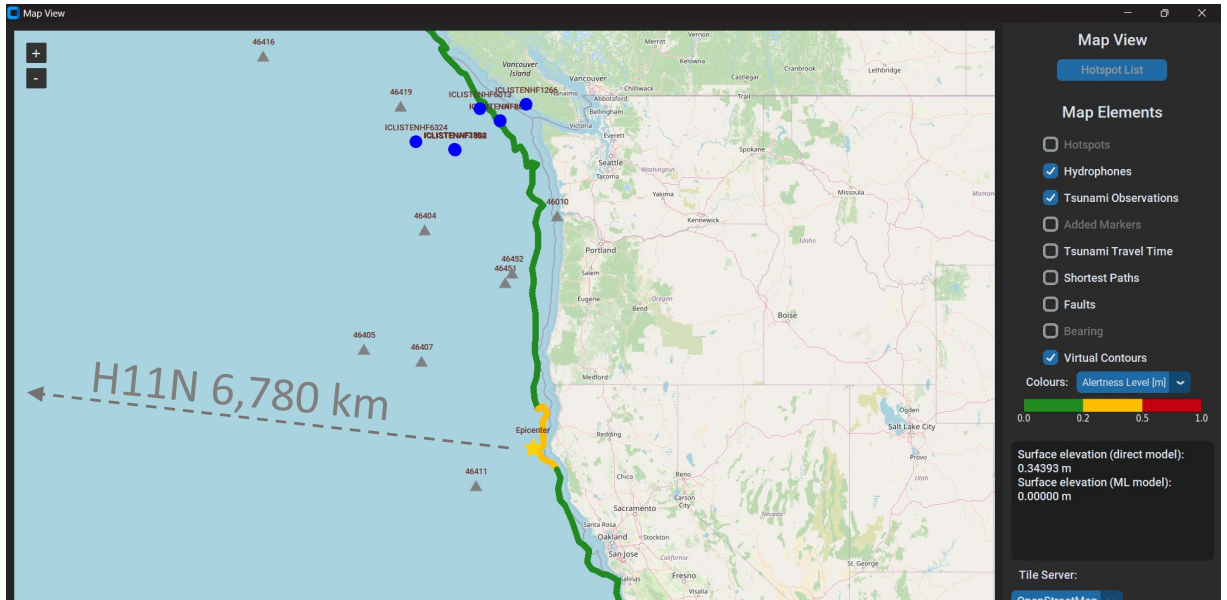




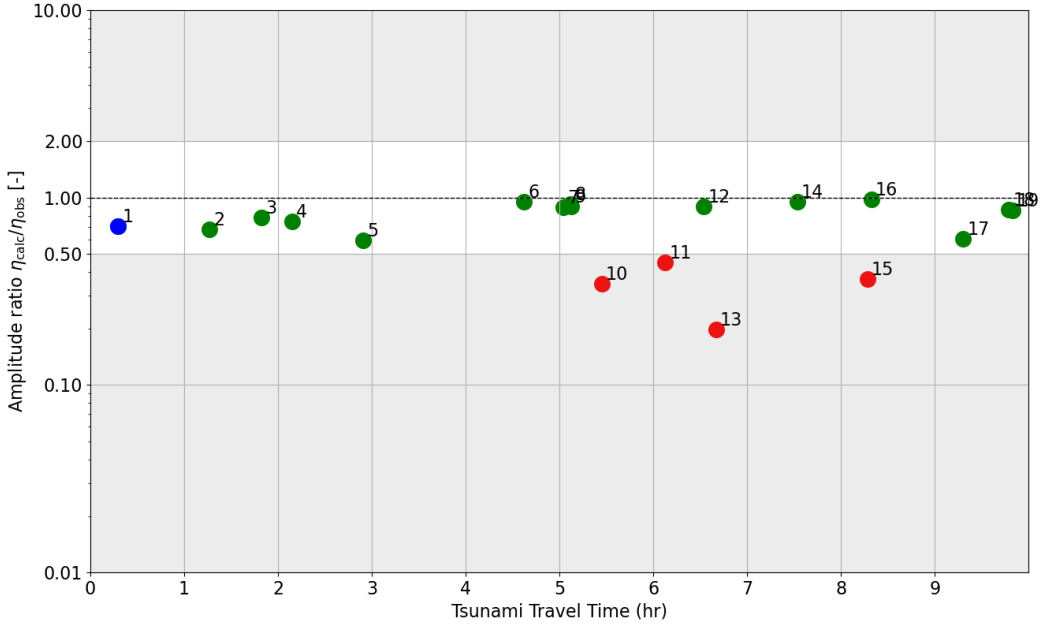
Comparison with Dart Buoy data

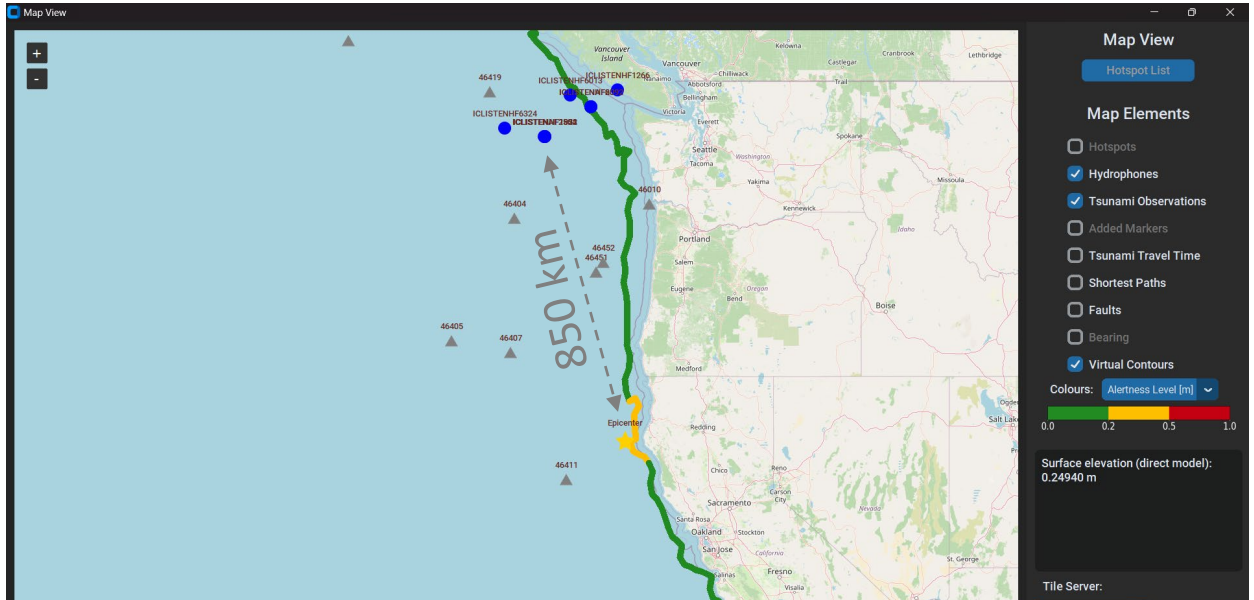
CTBTO (hydroacoustic station H11N)





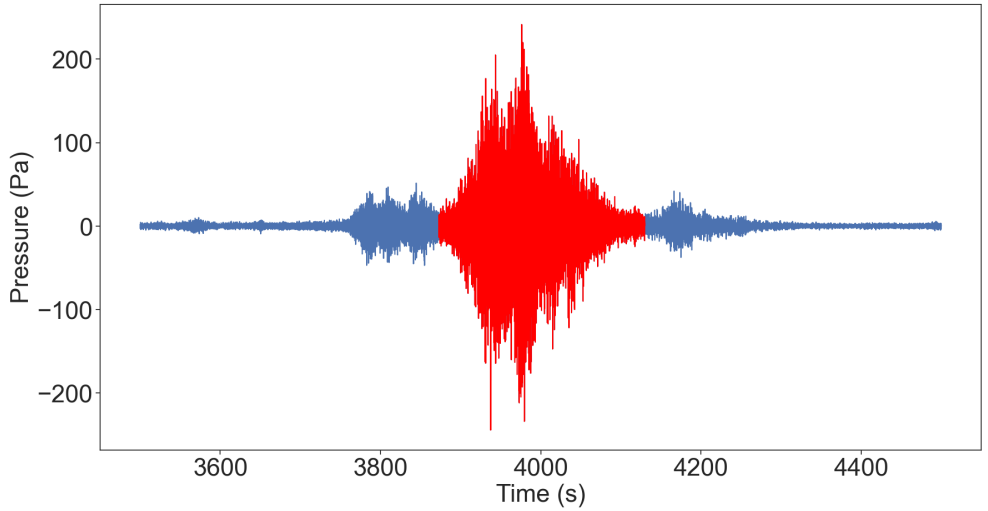
Ocean Network Canada (icListen AF 2534)



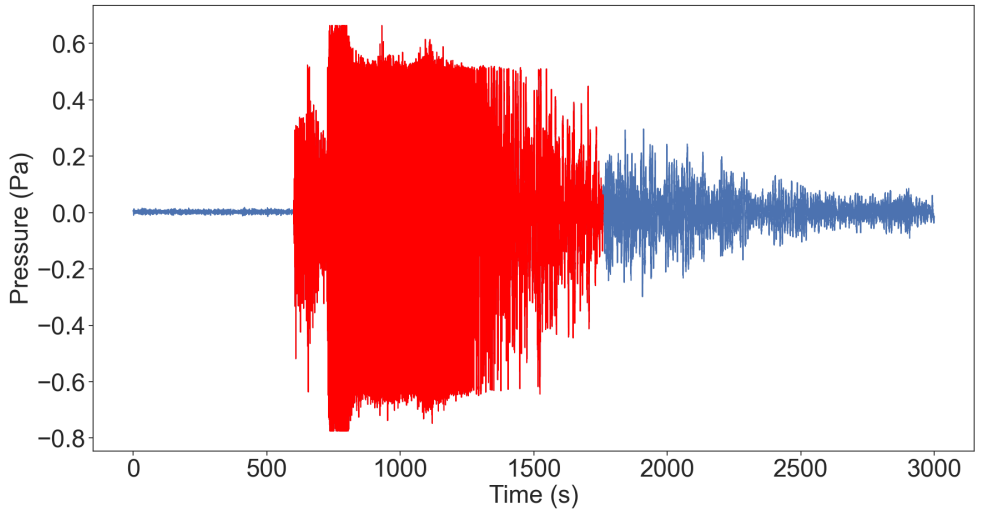


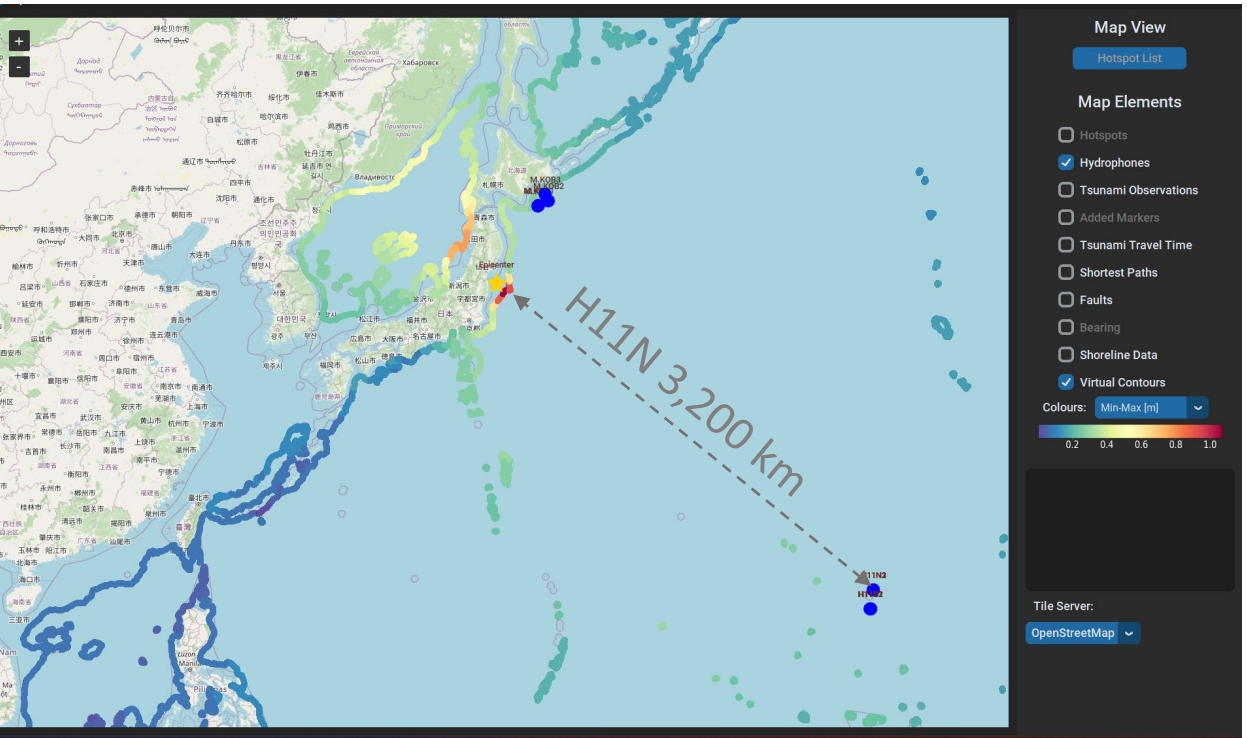
M 7.3 - 57 km ENE of Namie, Japan 2022-03-12 14:36:30 (UTC)

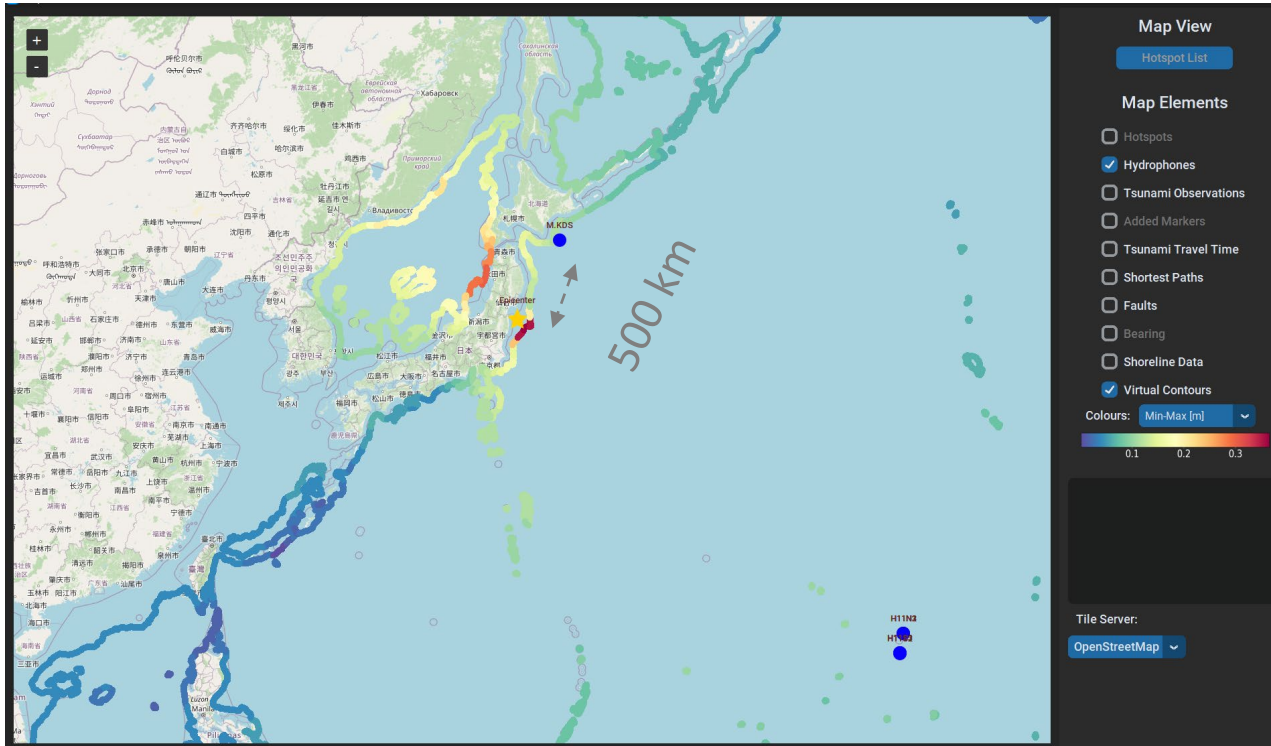
CTBTO (hydroacoustic station H11N)



JAMSTEC MKDS





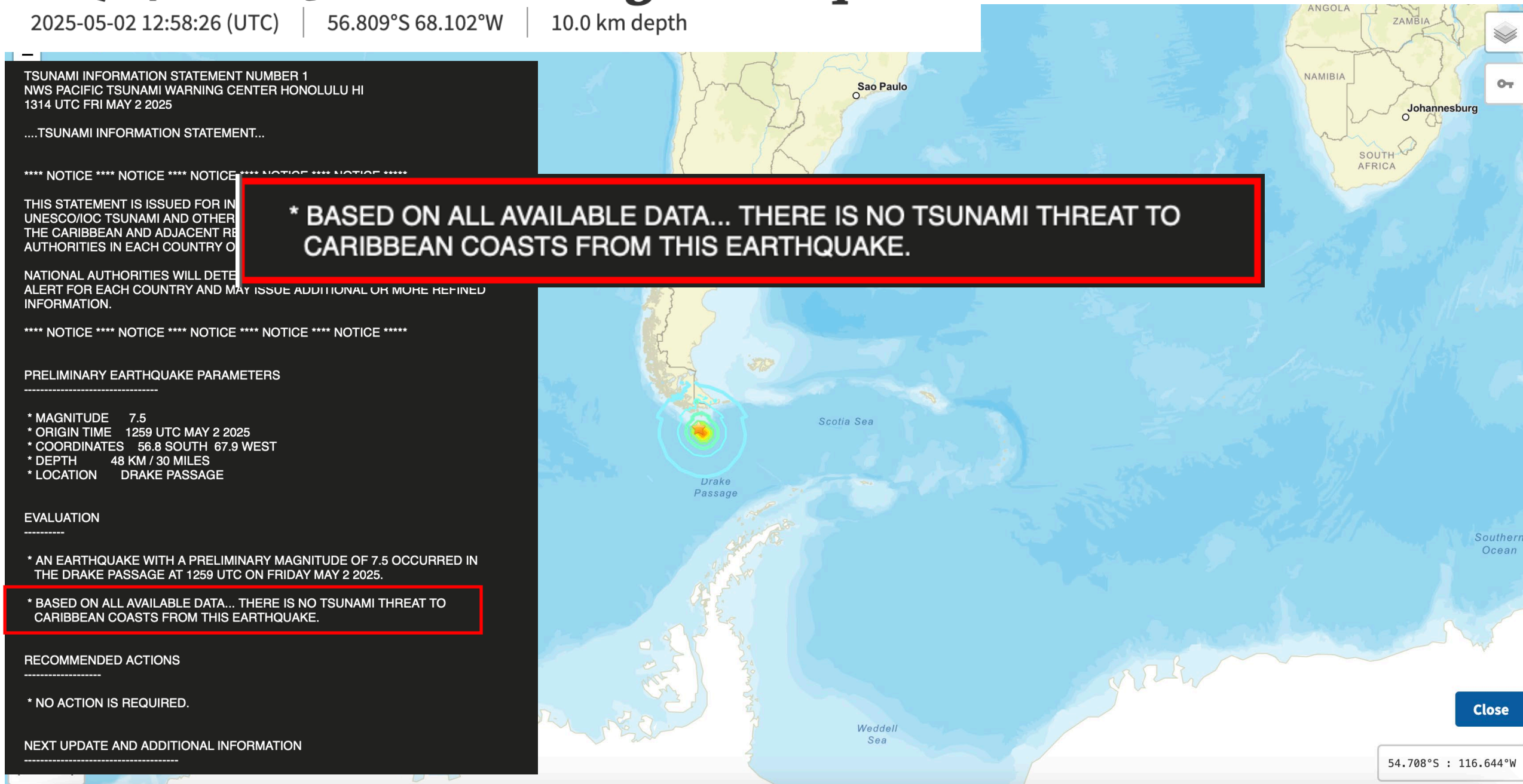


Real-time event example

Success story

M 7.4 - 2025 Drake Passage Earthquake

2025-05-02 12:58:26 (UTC) | 56.809°S 68.102°W | 10.0 km depth



M 7.4 - 2025 Drake Passage Earthquake

2025-05-02 12:58:26 (UTC) | 56.809°S 68.102°W | 10.0 km depth

**** NOTICE **** NOTICE **** NOTICE **** NOTICE **** NOTICE *****

THE TSUNAMI FORECAST IS UPDATED IN THIS MESSAGE.

PRELIMINARY EARTHQUAKE PARAMETERS

* MAGNITUDE 7.5
* ORIGIN TIME 1259 UTC MAY 2 2025
* COORDINATES 56.8 SOUTH 67.9 WEST
* DEPTH 48 KM / 30 MILES
* LOCATION DRAKE PASSAGE

EVALUATION

* AN EARTHQUAKE WITH A PRELIMINARY MAGNITUDE OF 7.5 OCCURRED IN THE DRAKE PASSAGE AT 1259 UTC ON FRIDAY MAY 2 2025.

* BASED ON ALL AVAILABLE DATA... HAZARDOUS TSUNAMI WAVES ARE FORECAST FOR SOME COASTS.

TSUNAMI THREAT FORECAST...UPDATED

* TSUNAMI WAVES REACHING 1 TO 3 METERS ABOVE THE TIDE LEVEL ARE POSSIBLE ALONG SOME COASTS OF

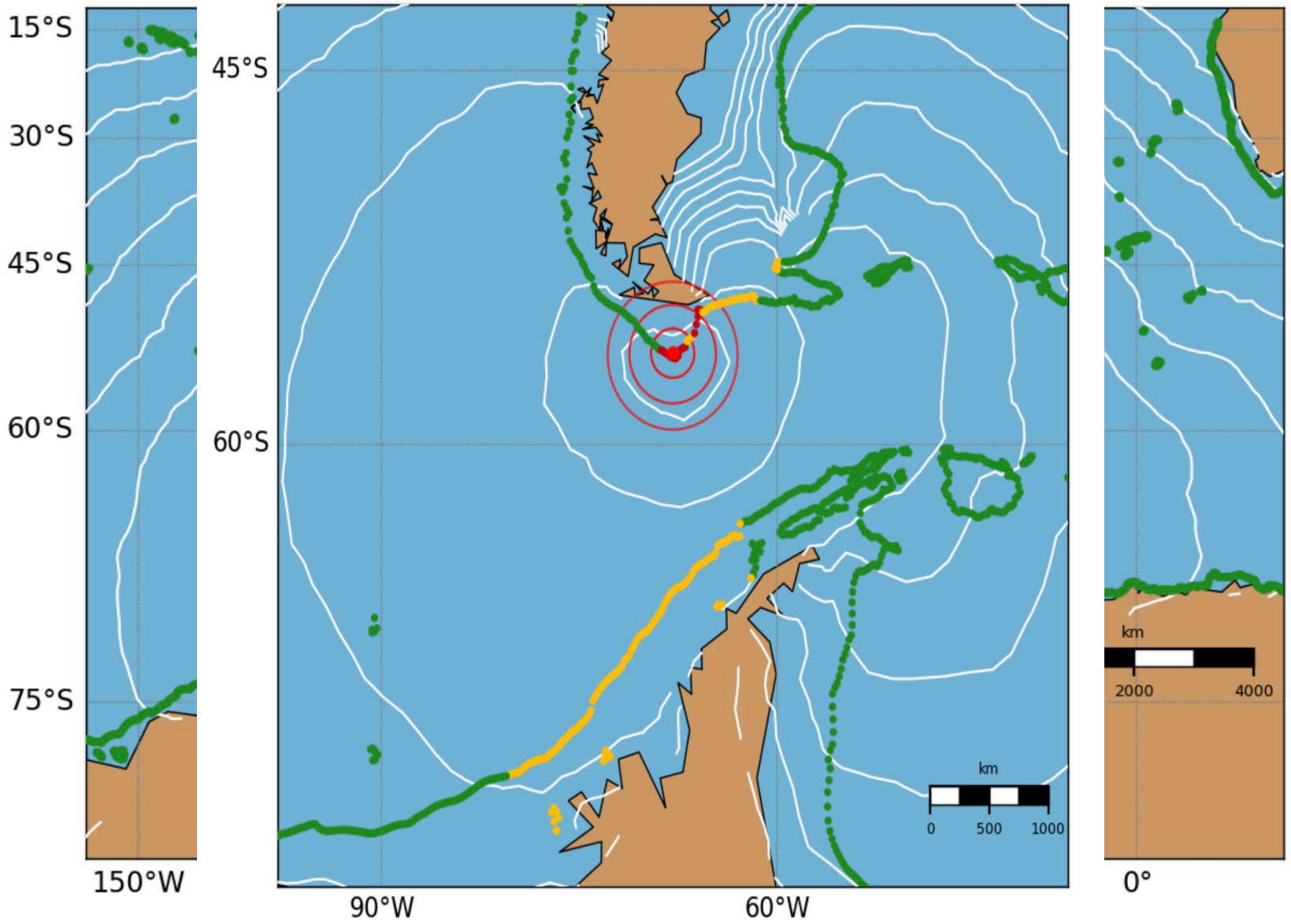
CHILE.

* TSUNAMI WAVES REACHING 0.3 TO 1 METERS ABOVE THE TIDE LEVEL ARE POSSIBLE FOR SOME COASTS OF

ANTARCTICA.

* ACTUAL AMPLITUDES AT THE COAST MAY VARY FROM FORECAST AMPLITUDES DUE TO UNCERTAINTIES IN THE FORECAST AND LOCAL FEATURES. IN PARTICULAR MAXIMUM TSUNAMI AMPLITUDES ON ATOLLS AND AT LOCATIONS WITH FRINGING OR BARRIER REEFS WILL LIKELY BE MUCH SMALLER THAN THE FORECAST INDICATES.

* FOR OTHER AREAS COVERED BY THIS PRODUCT A FORECAST HAS NOT YET BEEN COMPUTED. THE FORECAST WILL BE EXPANDED IF NECESSARY IN SUBSEQUENT PRODUCTS.



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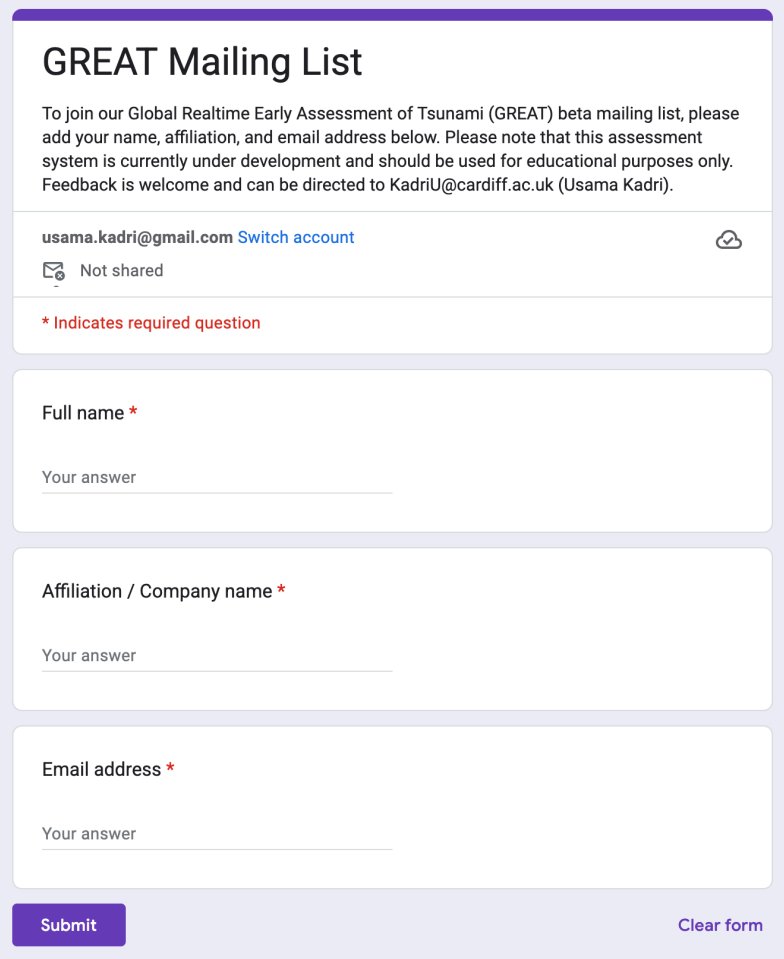
Scan the QR code or drop me an e-mail:
E-mail: KadriU@Cardiff.ac.uk



GREAT Mailing List

To join our Global Realtime Early Assessment of Tsunami (GREAT) beta mailing list, please add your name, affiliation, and email address below. Please note that this assessment system is currently under development and should be used for educational purposes only. Feedback is welcome and can be directed to KadriU@cardiff.ac.uk (Usama Kadri).

usama.kadri@gmail.com Switch account

Not shared

* Indicates required question

Full name *

Your answer

Affiliation / Company name *

Your answer

Email address *

Your answer

Submit

Clear form

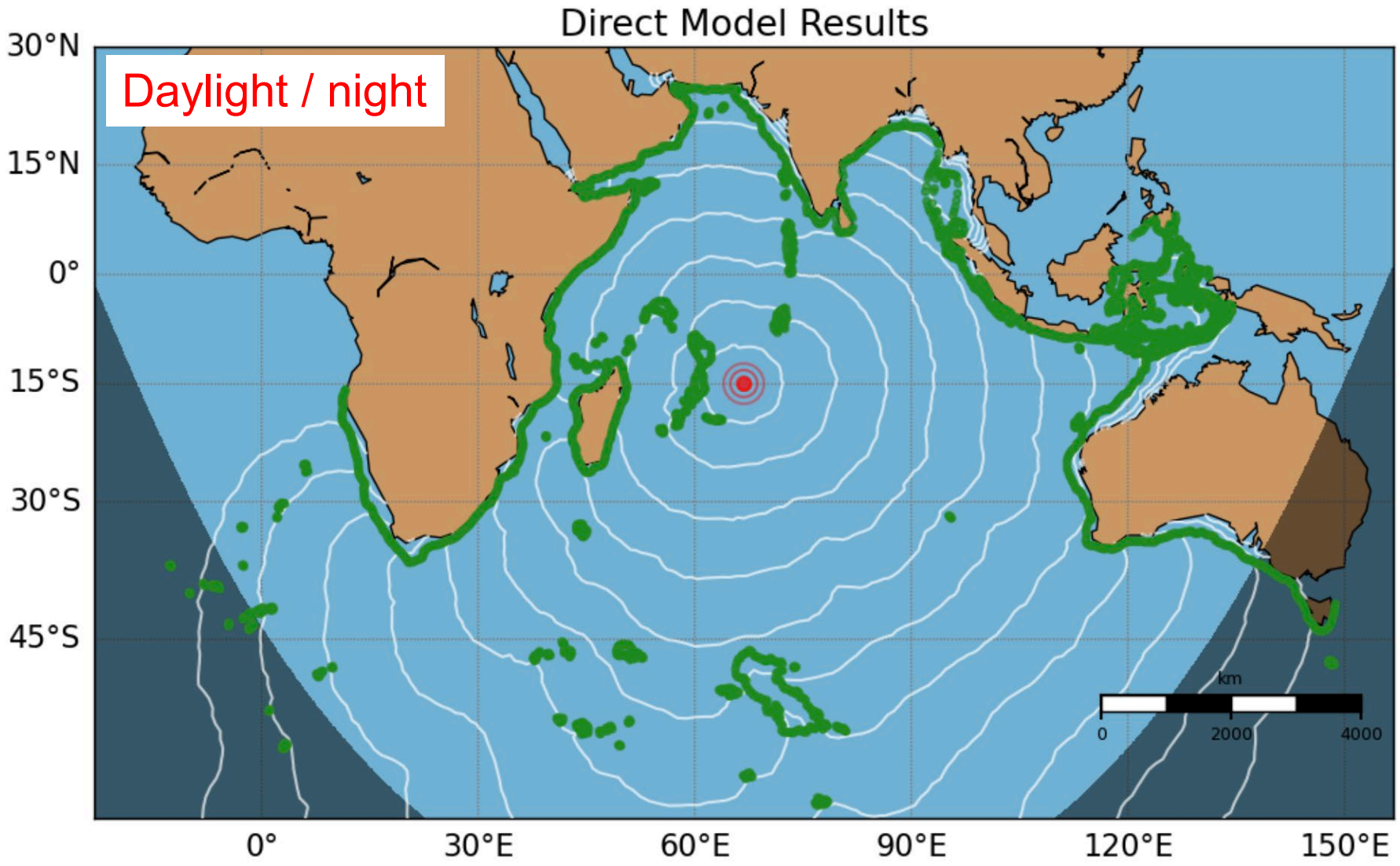
Google Form URL: https://forms.gle/uG62qoZcq3f6pana6

New features → evacuation optimisation

daylight | evacuation time | population | roads | tsunami risk

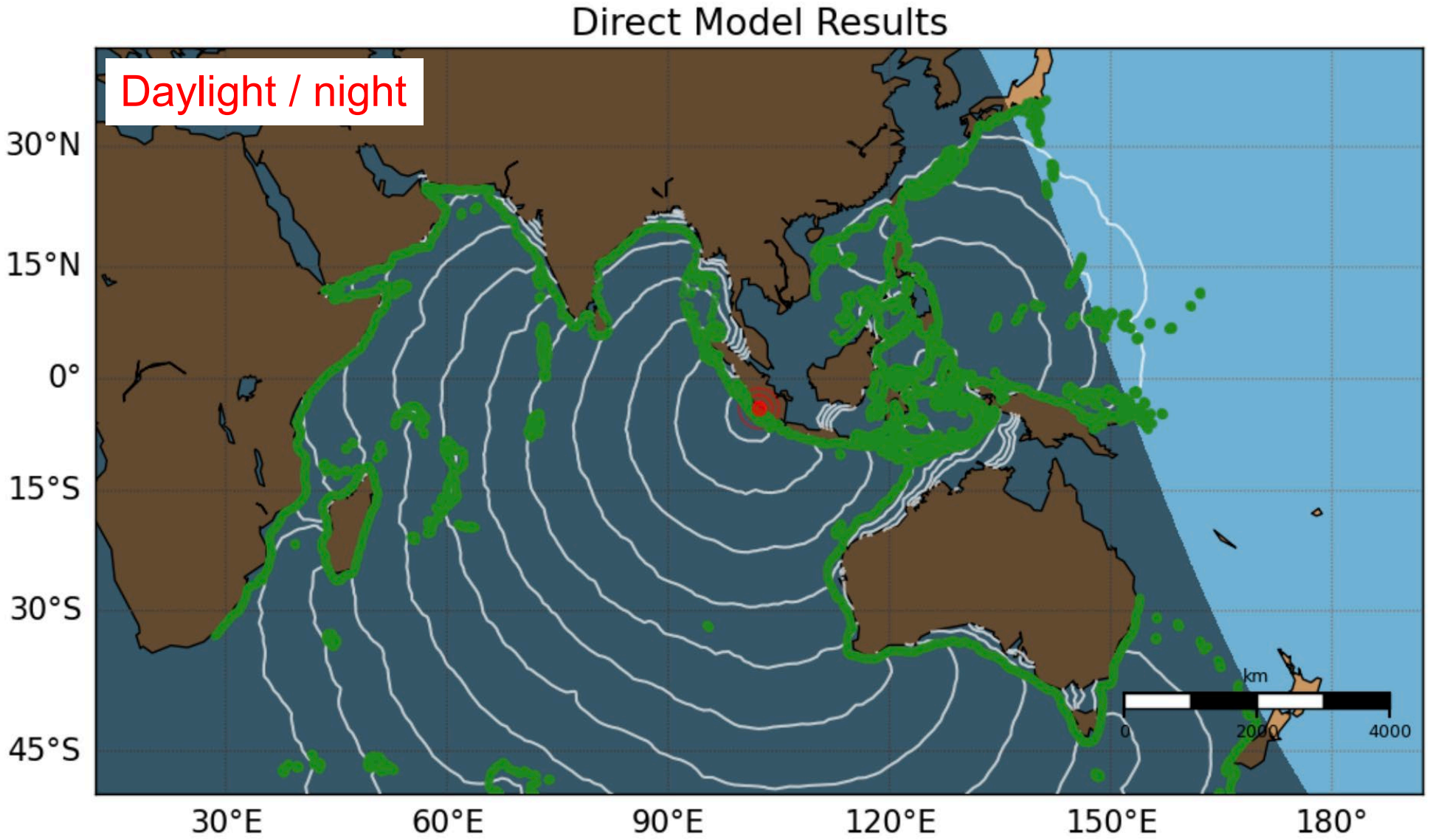
M 5.5 – Mid-Indian Ridge

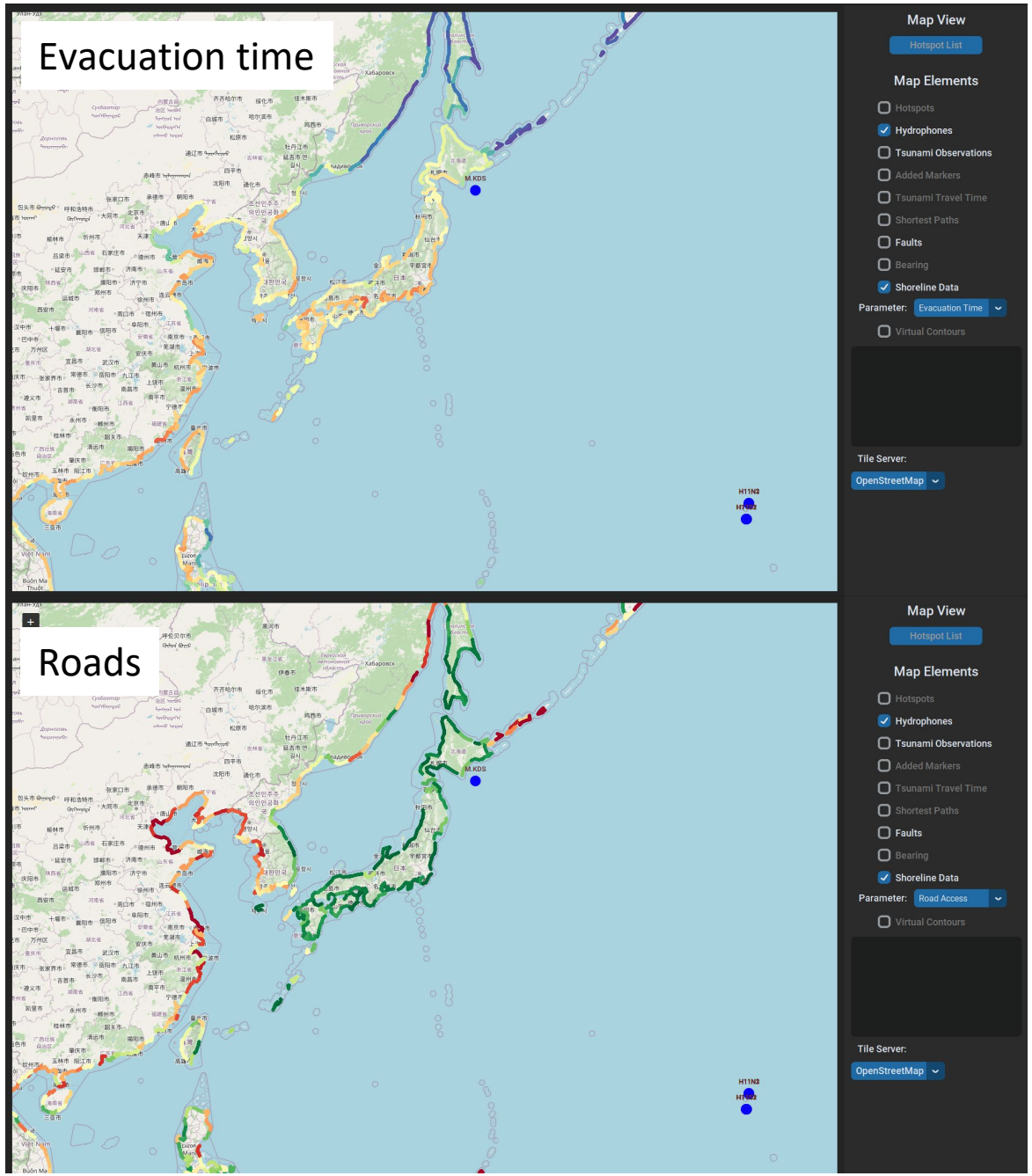
2025-06-07 07:33:40 (UTC) | 14.920°S 66.806°E | 10.0 km depth

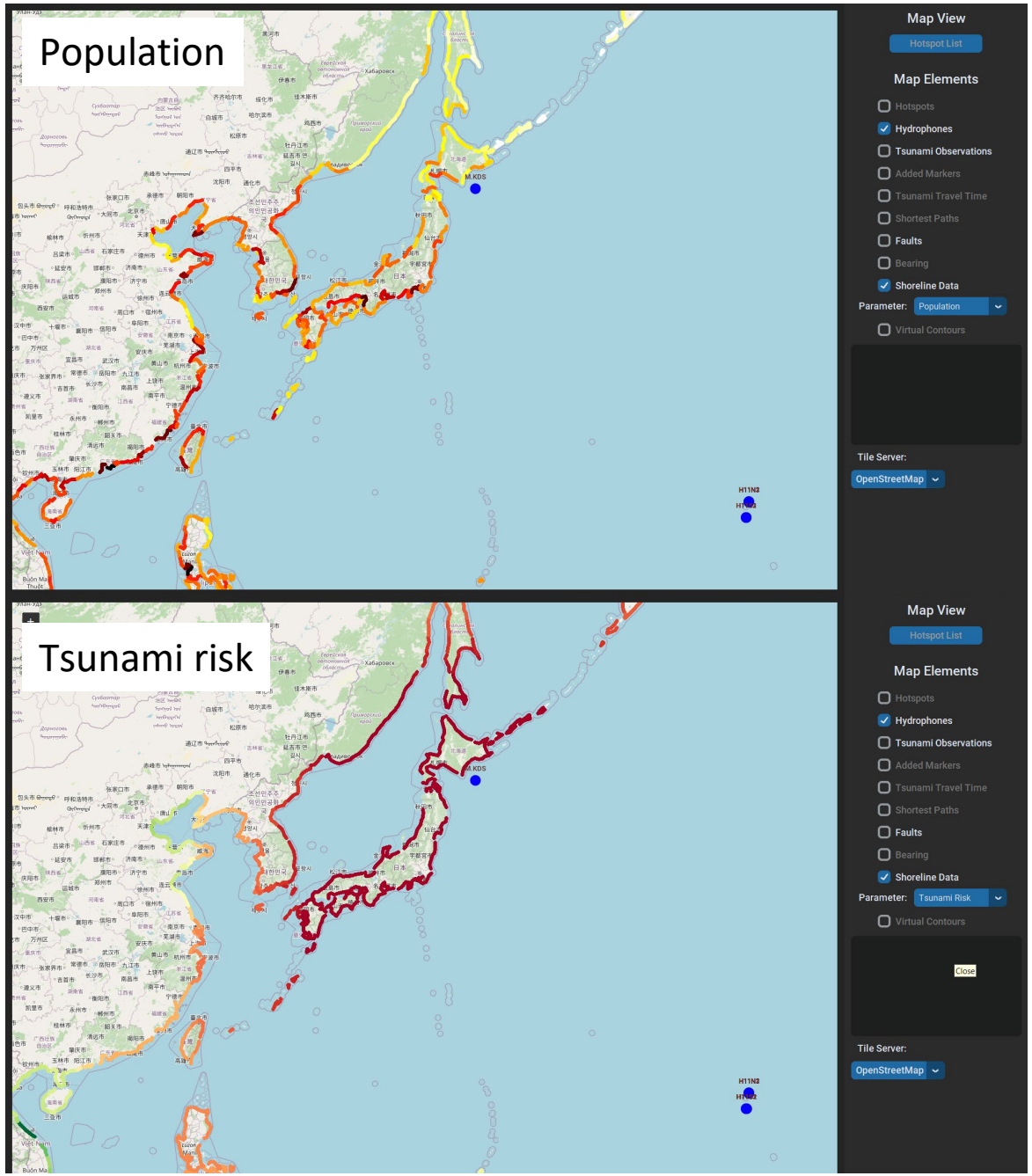


M 5.7 – 28 km SSW of Bengkulu, Indonesia

2025-05-22 19:52:36 (UTC) | 4.053°S 102.203°E | 47.0 km depth







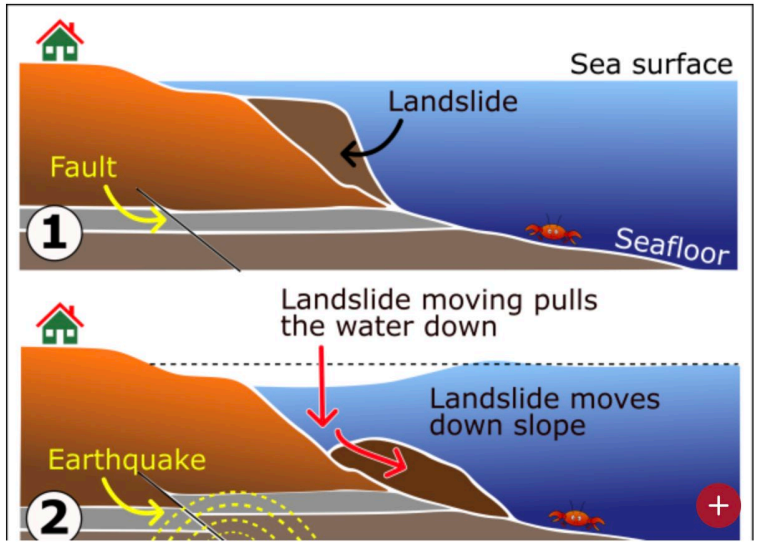
Athanasiou, P., van Dongeren, A., Pronk, M., Giardino, A., Vousdoukas, M., and Ranasinghe, R.: Global Coastal Characteristics (GCC): a global dataset of geophysical, hydrodynamic, and socioeconomic coastal indicators, *Earth Syst. Sci. Data*, **16**, 3433–3452, https://doi.org/10.5194/essd-16-3433-2024, 2024.

Non-seismic Tsunamis
& Global Protection

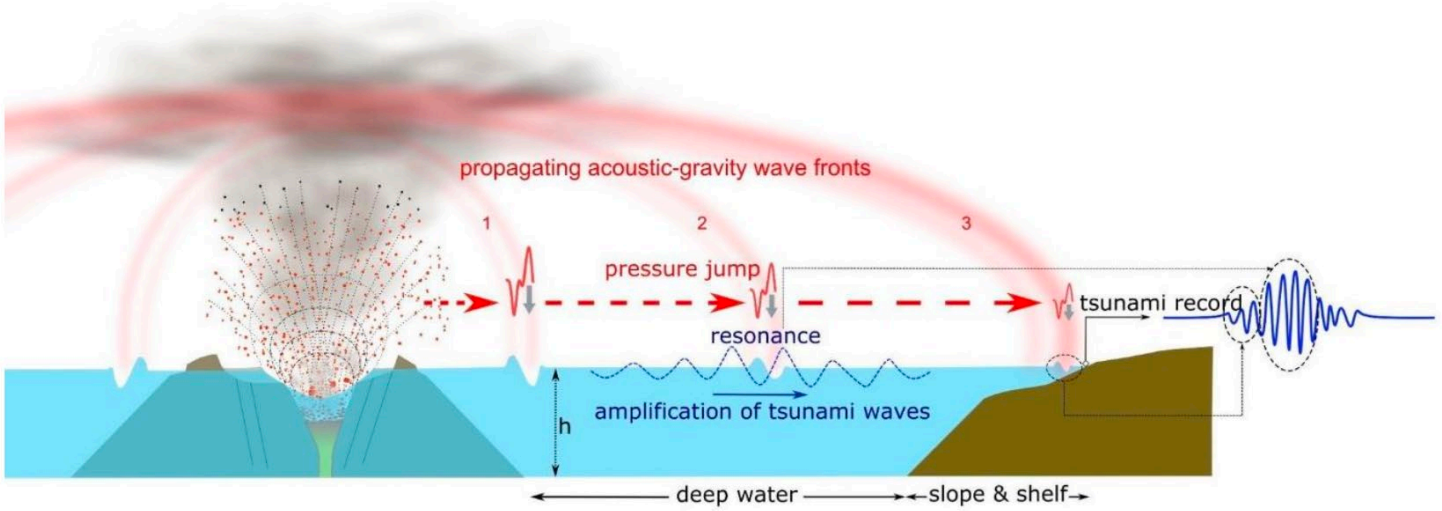
Non-seismic / multi-hazard

- Any tsunami should result in an acoustic signature.
  Is the inverse problem solvable in real-time?

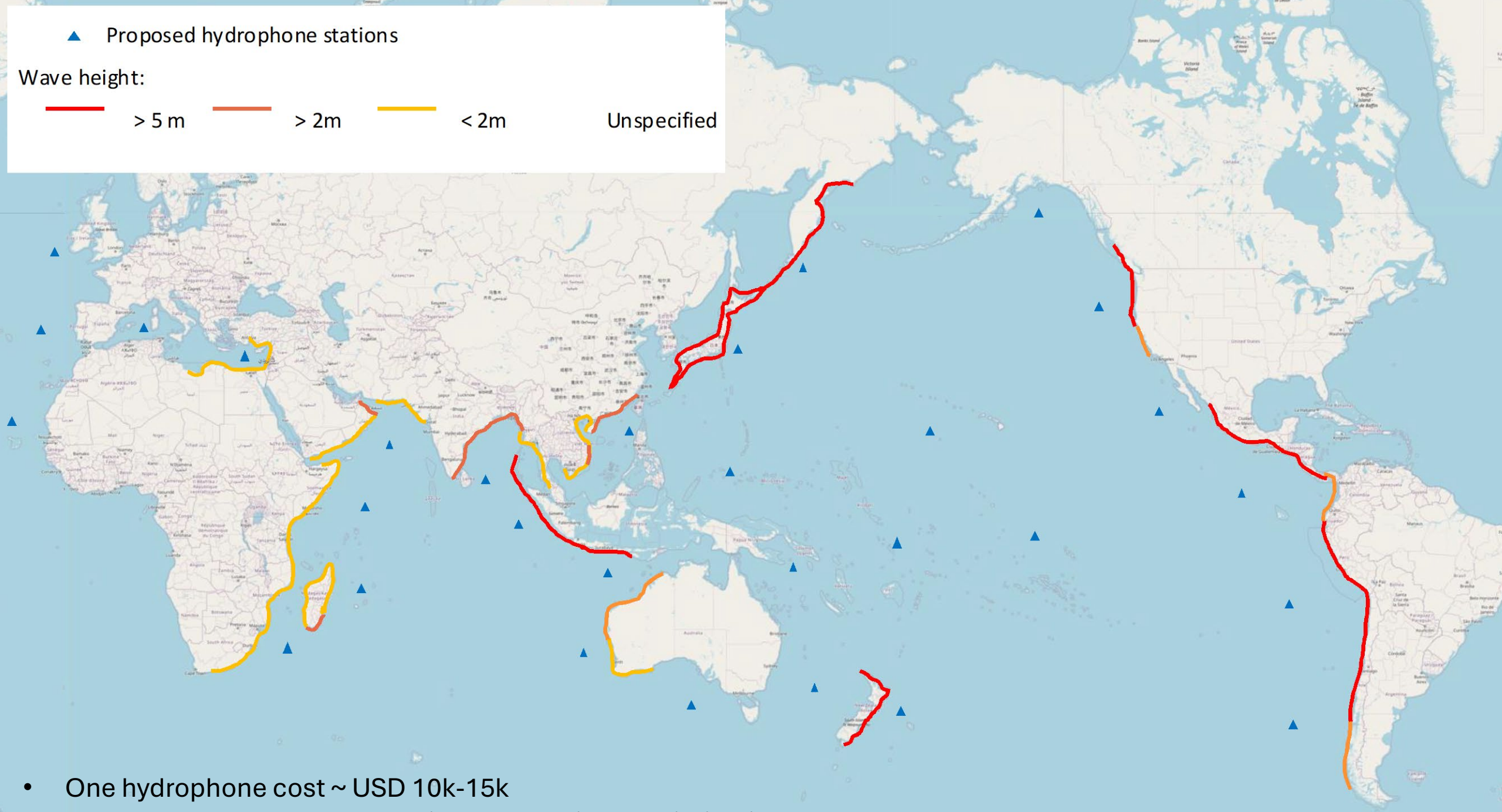
- A new IAA-SIF project (June-November 2025): focus on TGVE's (landslides & meteotsunamis)



Underwater landslides graphic



Global Tonga tsunami explained by a fast-moving atmospheric source
R. Omira, R. Ramalho , J. Kim , P. Gonźalez , U. Kadri , M. Miranda , F. Carrilho , M.A. Baptista, 2022., *Nature* (2022). https://doi.org/10.1038/s41586-022-04926-4



- One hydrophone cost ~ USD 10k-15k
- + deep deployment and associated costs (incl. optimisation) => total cost USD 70k-100k

Conclusions

- Our **operational software** (GREAT) has been running in real-time since June 2024.
- Assessment of real-time analysis are in good agreement with observations.

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Challenges

- More real-time hydroacoustic data sources is required.
- Dart-buoy data can be poor – complement data by other sources (e.g., satellite data).
- Secure funding to maintain R&D.

Opportunities

- The software can be deployed in more TWCs.
- Cost-effective hydrophones can exploit the real-time data significantly.
- Optimising evacuation.

Thank you