Modeling Tsunami Inundation for Hazard Assessment of Aneityum, the Republic of Vanuatu

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Study Phases

1. DEM Merging/Grid Generation

2. Model Validation/Source Definition

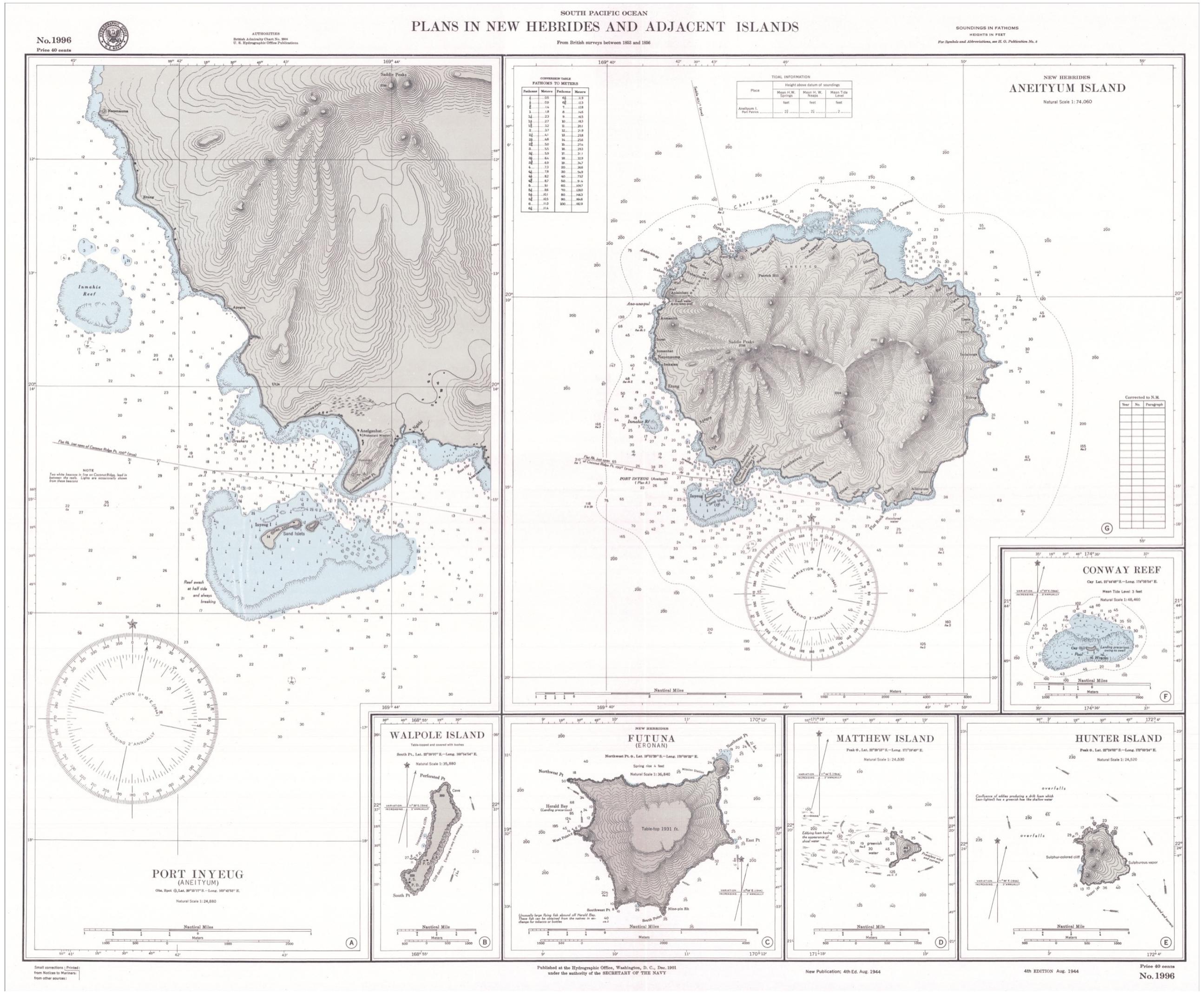
3. Modeling Results and Products

Bathymetry and topography data

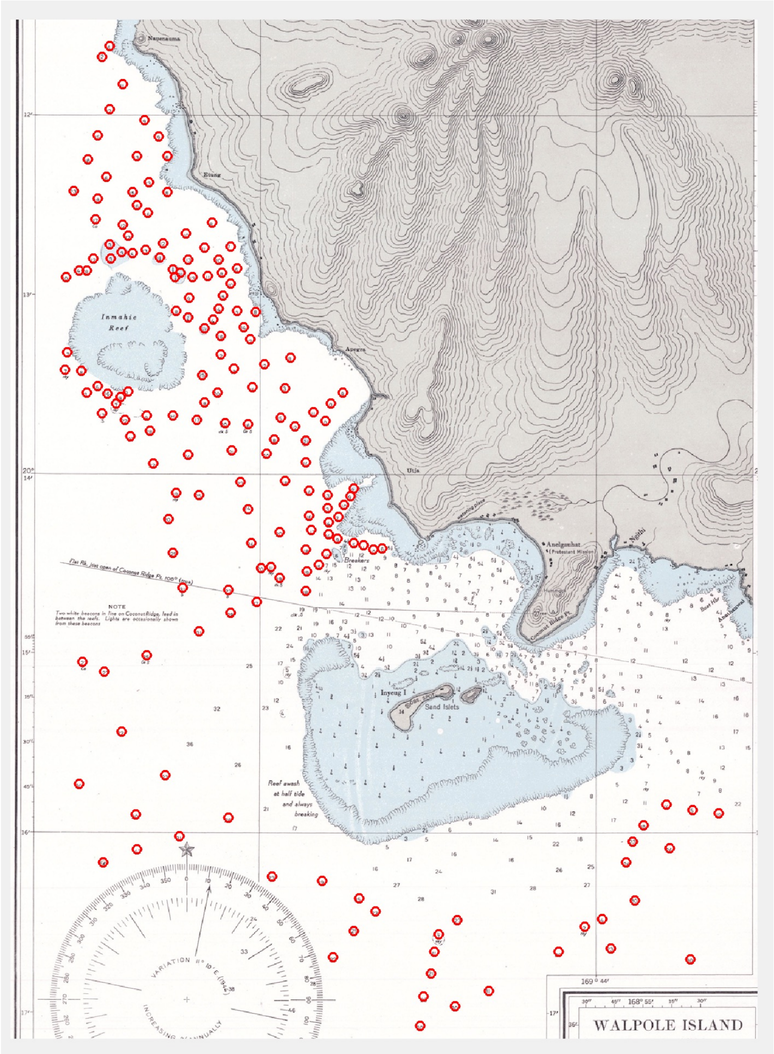
Datasets used for the composite Aneityum DEM:

Number	Bathy/topo	Location	Name (Nickname)	Source	Type	Resolution
1)	Bathy	Reefs, shallow water area around the island	Allen Coral Atlas	Allen Coral Atlas	Satellite	10 m
2)	Bathy	Area around Aneityum	Nautical Charts	United States Hydrographic Office, 1901	Lead-line soundings	15.9 – 829.43 m
3)	Bathy and topo	Deeper area (> 25 m) around Aneityum	AusBathyTopo	Beaman, 2023	Single beam, multi-beam	250 m
4)	Topo	Aneityum land	FABDEM V1-2	Neal and Hawker, 2023	Satellite	1 arc sec
5)	Bathy and topo	Deep ocean area around Aneityum	GEBCO 2024	GEBCO 2024 (GEBCO,2024)	Single beam, multi-beam, satellite	15 arcsec

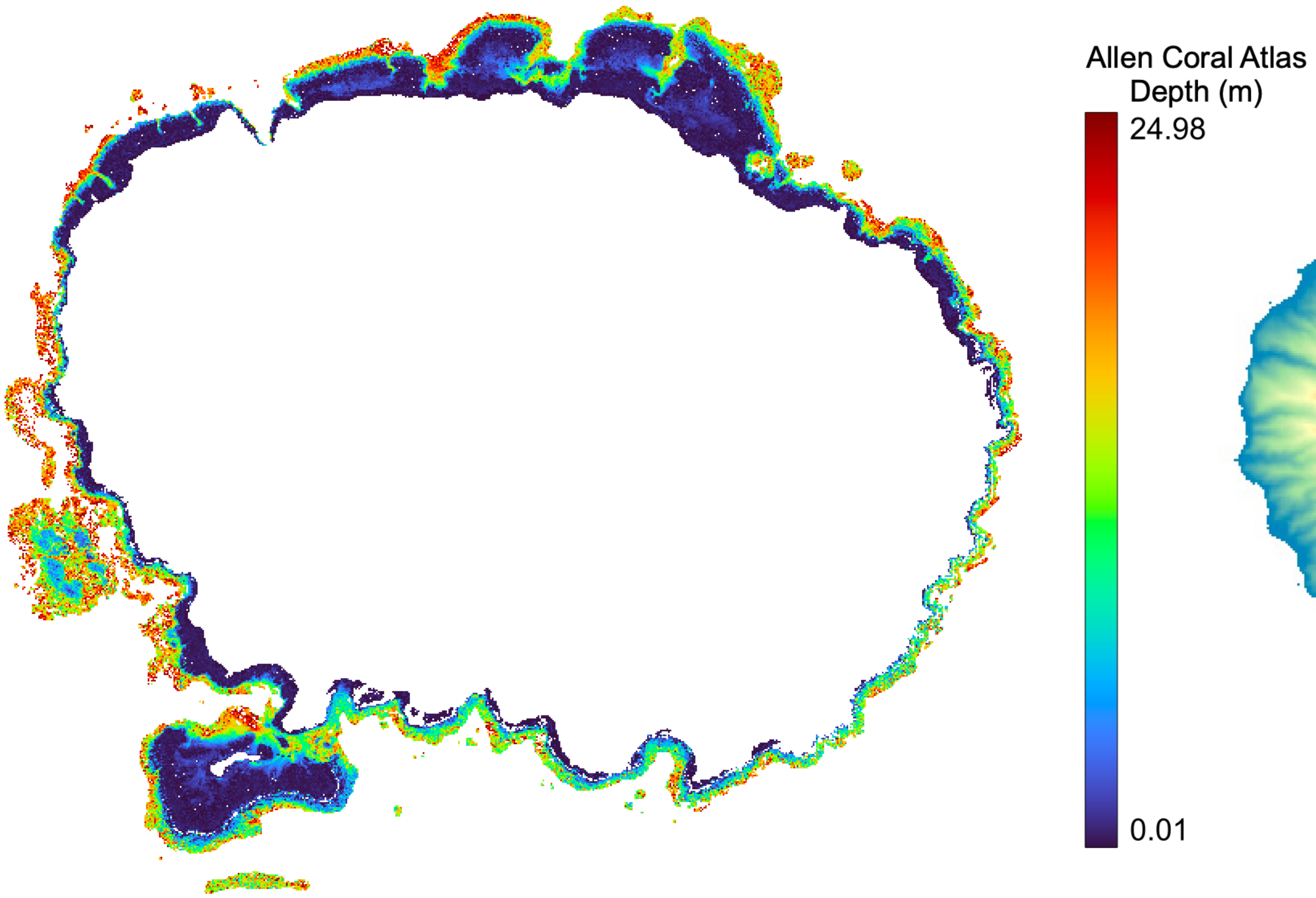
Bathymetry and topography data



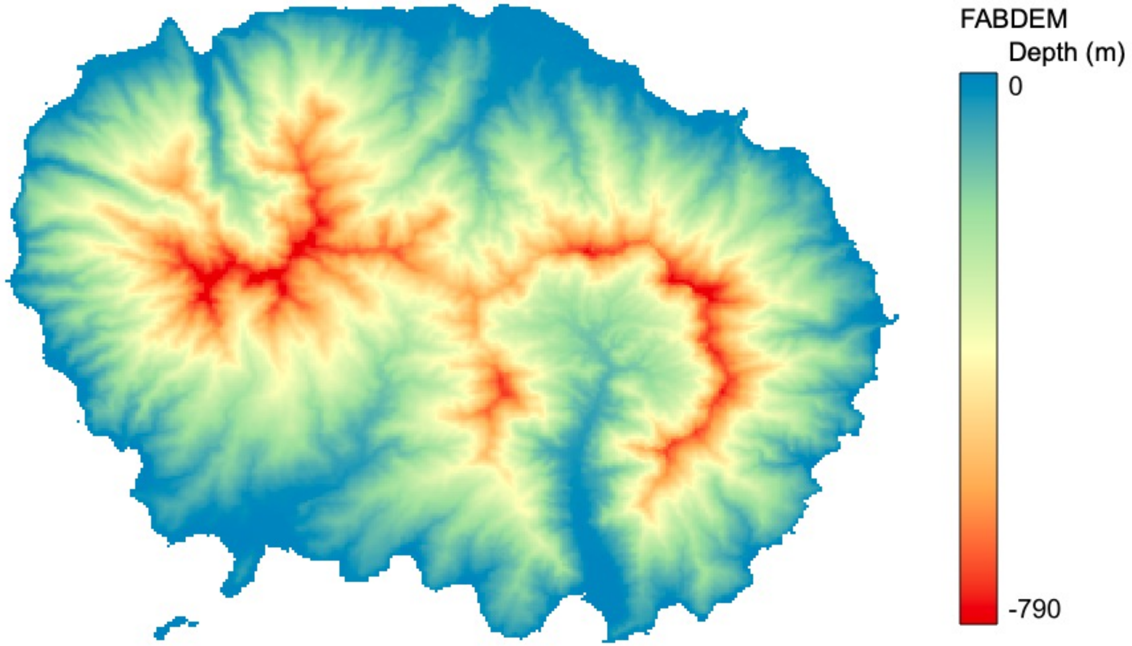
Nautical charts published by the United States Hydrographic Office in 1901, based on British surveys conducted between 1853 and 1856. Grid resolution ranges from 15.9 to 829.43 m.



The process of manually digitizing nautical charts using MATLAB: circled numbers indicate data already recorded, while encircled numbers indicate data to be recorded.



Allen Coral Atlas, 2020. Imagery, maps and monitoring of the world's tropical coral reefs. Grid resolution: 10 m.



FABDEM V1-2 (Forest and Buildings removed Copernicus DEM). Grid resolution: ~30 m (1 arc-second).

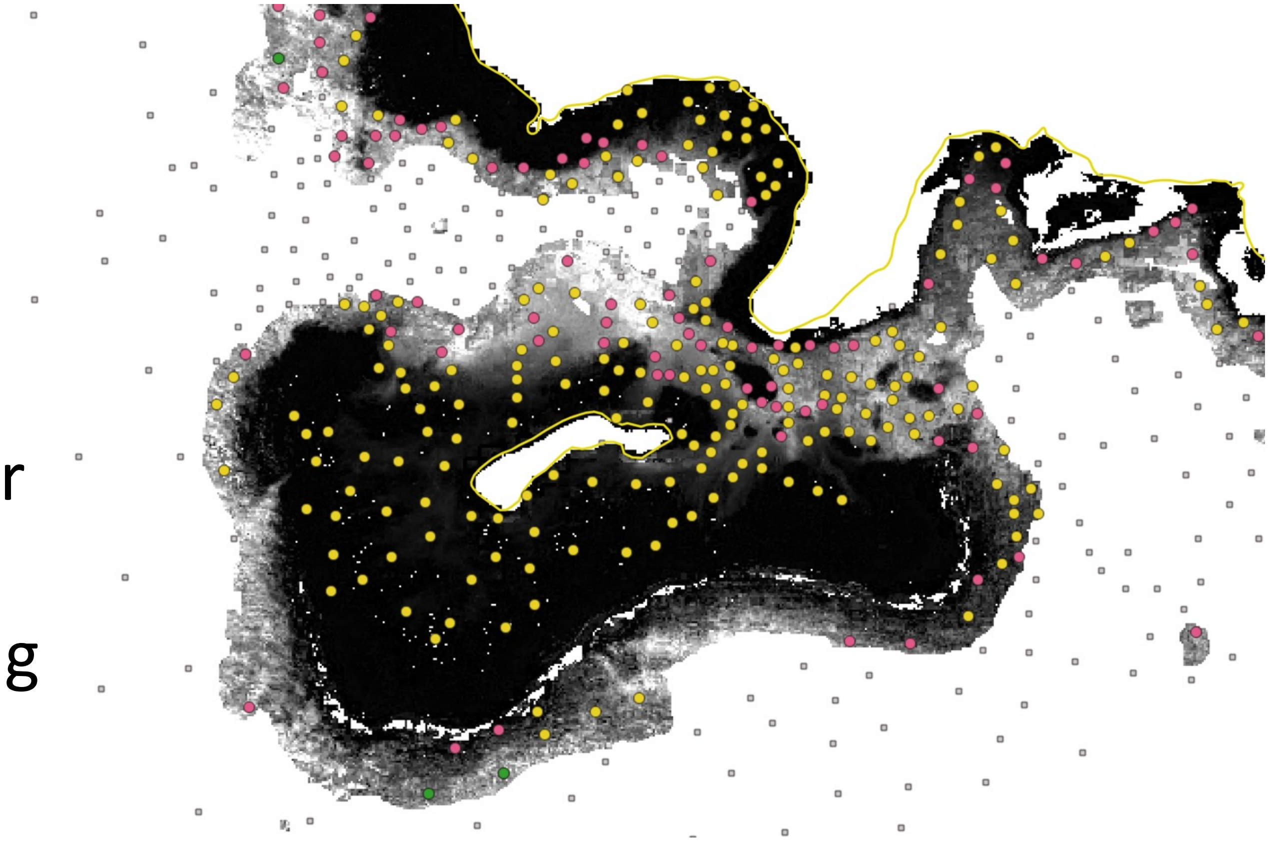
Questions:

- Should old nautical chart data be adjusted for sea-level rise?

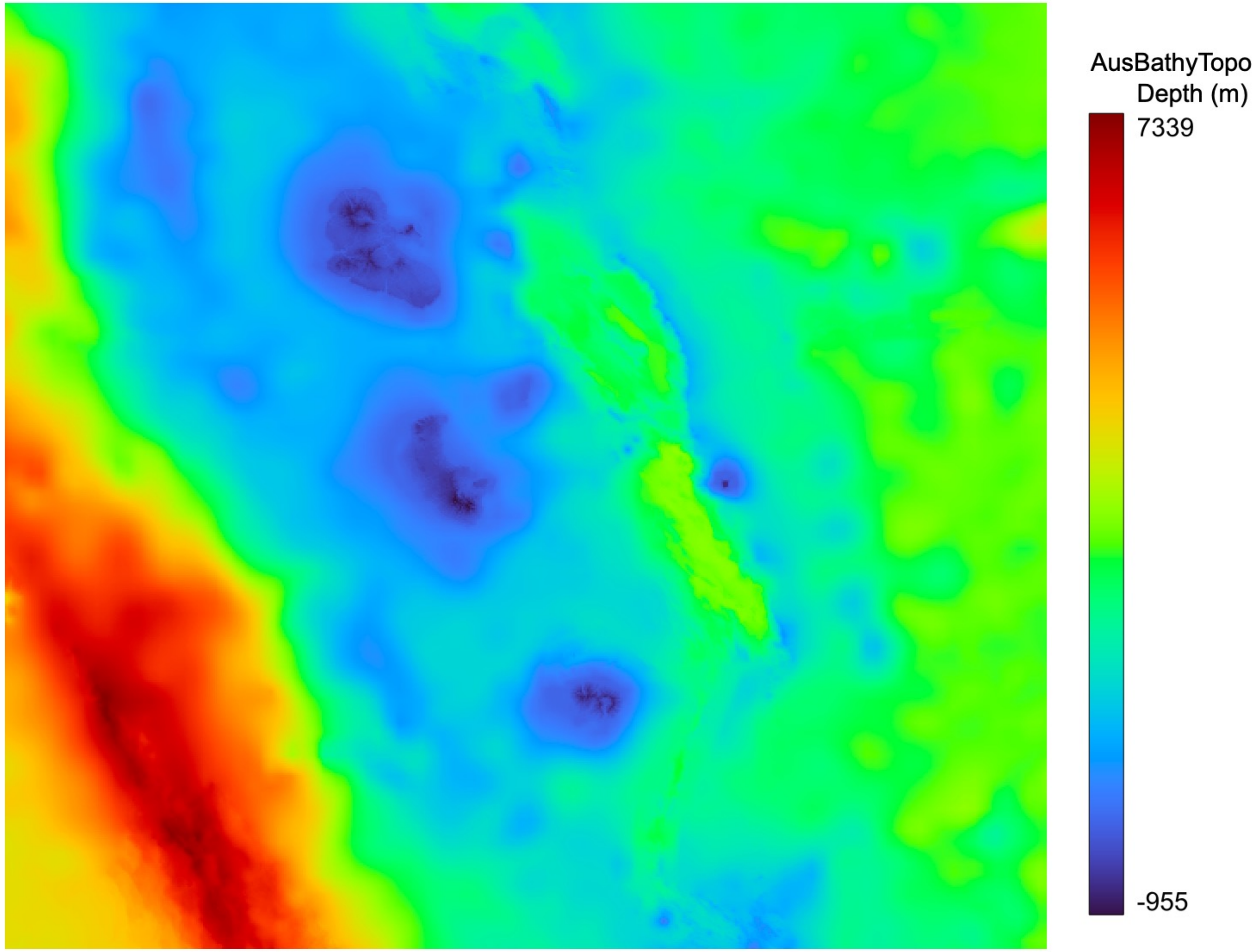
  No — the data are in good agreement with the Allen Coral Atlas, so a sea-level adjustment isn't necessary.

- Which dataset should we prioritize where the Allen Coral Atlas and nautical charts overlap?

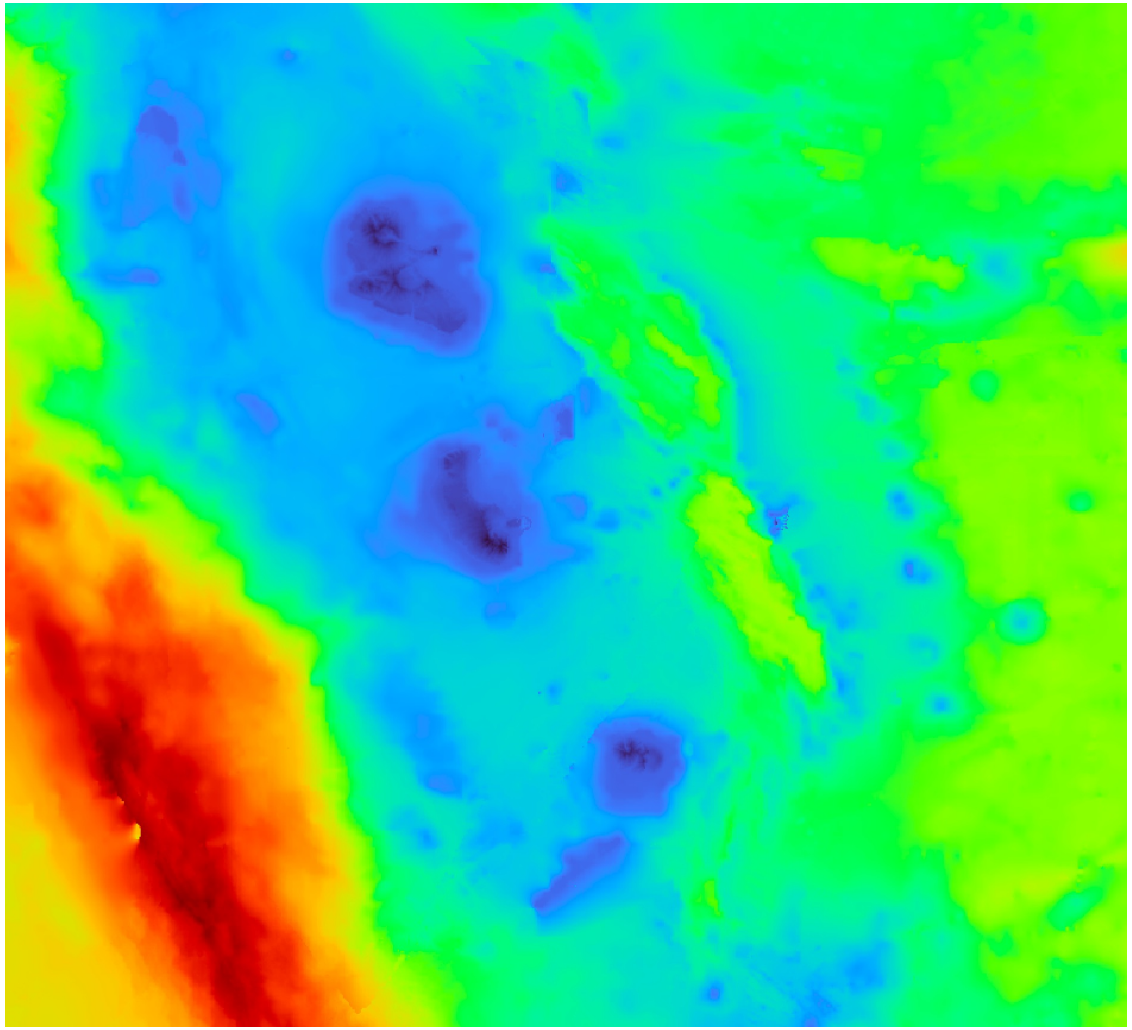
  Larger discrepancies (pink dots) occur on outer reef edges where rapid depth changes and historical sampling limitations make chart values less reliable.



Depth difference between charts and satellite data.

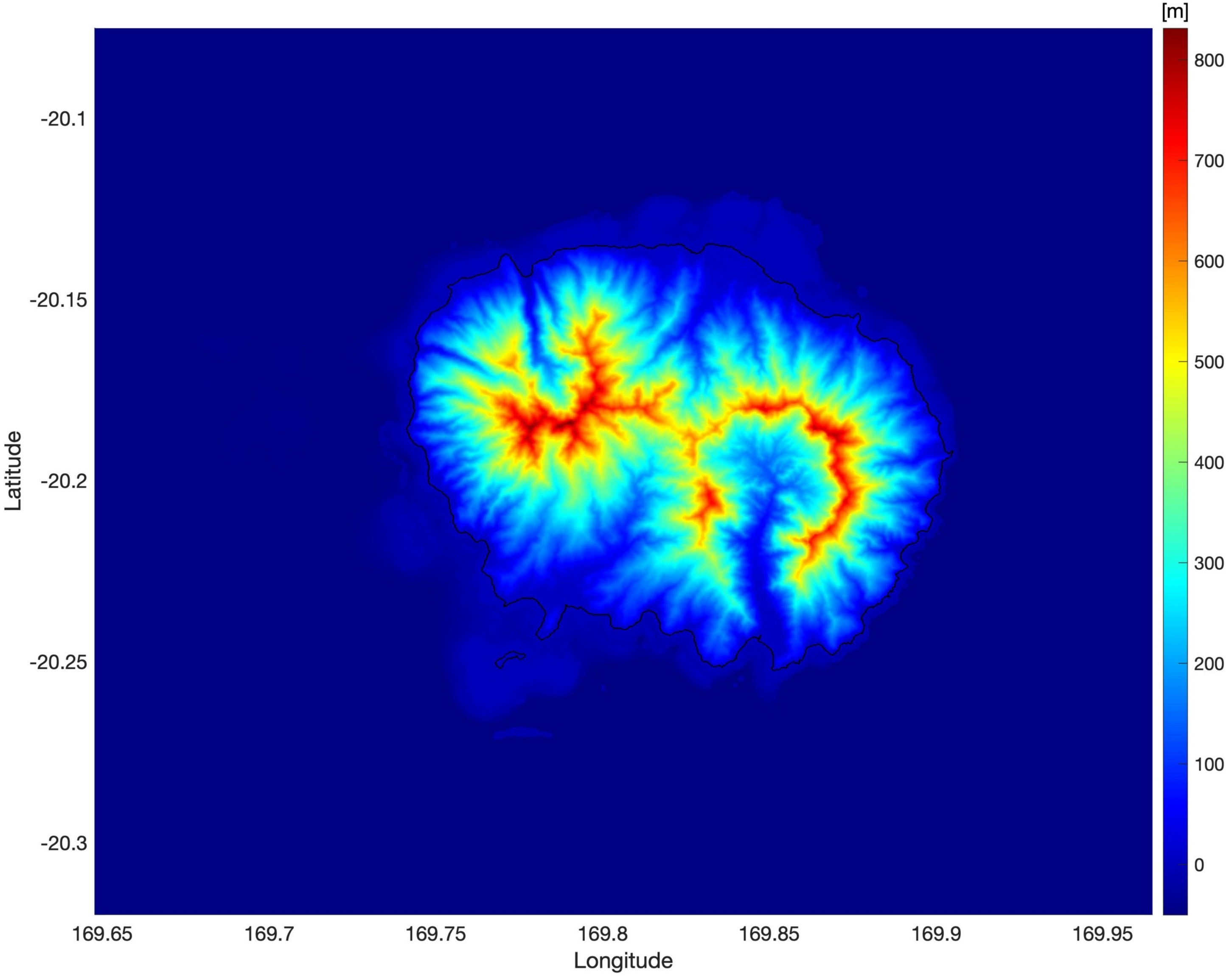


AusBathyTopo (Australia), 2023. A regional-scale depth model. Commonwealth of Australia (Geoscience Australia). Grid resolution: 250 m.



GEBCO Compilation Group, 2021. GEBCO 2021 Grid. Grid resolution: ~445 m (15 arc-seconds).

The resulting composite DEM



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Tsunami Model and Grid Development

- The HySEA model – approved by the US Tsunami Hazard Mitigation Program – was selected for high-resolution island modeling.
- This tsunami model code has been designed to numerically solve the non-linear shallow water equations and utilizes GPU graphics cards for parallelization, making it suitable for very large, very high-resolution grids.
- The nested grids are implemented in the HySea model keeping the accuracy-speed balance. Three levels of larger grids contain these highest-resolution grid, in increasing size and resolution.

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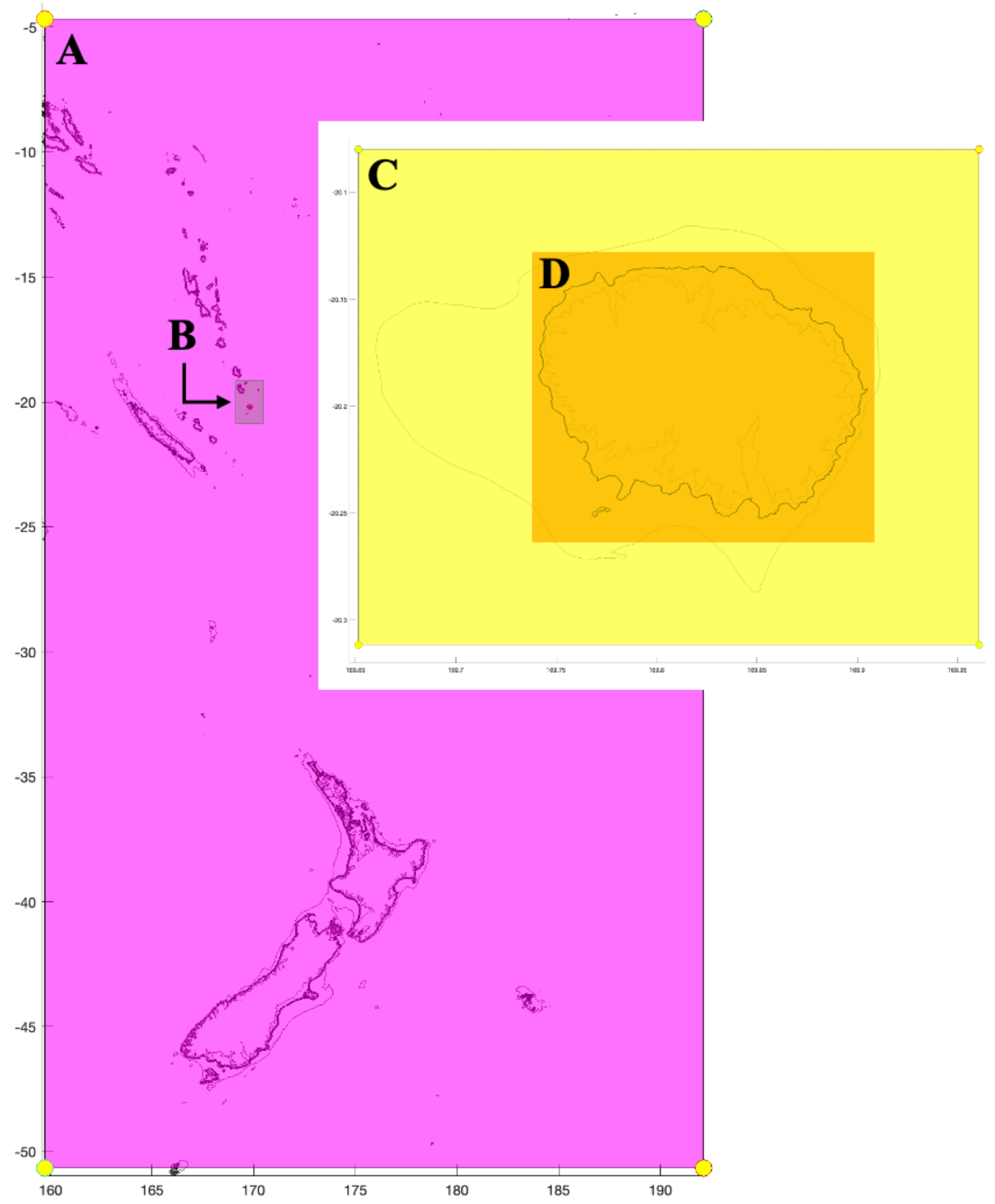
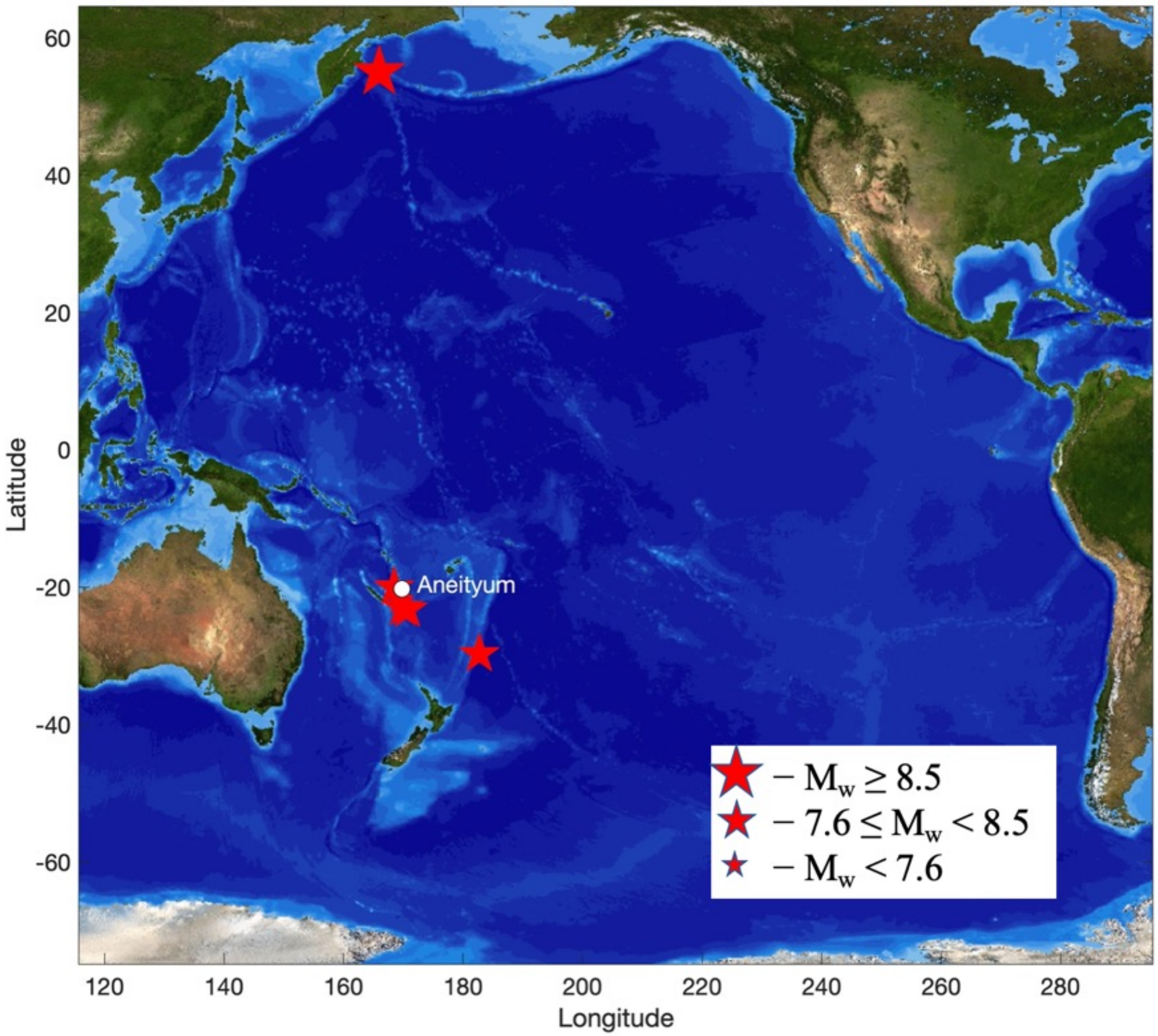


Extents of the grids: outermost (A) encompasses the nearby SZs and all inner grids, regional (B) includes Aneityum and Tanna islands, the next level – intermediate (C) includes Aneityum and the deep-water area around it, and the innermost grids (D) includes Aneityum island and shallow water area around it.

Historic Earthquake-Generated Tsunamis That Have Affected Aneityum

NOAA National Centers for Environmental Information Global Historical Tsunami Database (NCEI, 2024)



- Six tsunami events have affected Aneityum.
- Tsunami originated from the SZ: Vanuatu (4), Tonga-Kermadec (1), Kuril-Kamchatka (1).
- The largest tsunami runup of 8 m was observed during the 16 May 1995 Mw 7.7 Loyalty Islands event.
- The database is likely incomplete because of the absence of instrumental recordings (no tide gauge on the island) and tsunami deposit surveys.

Historic Earthquake-Generated Tsunamis That Have Affected Aneityum

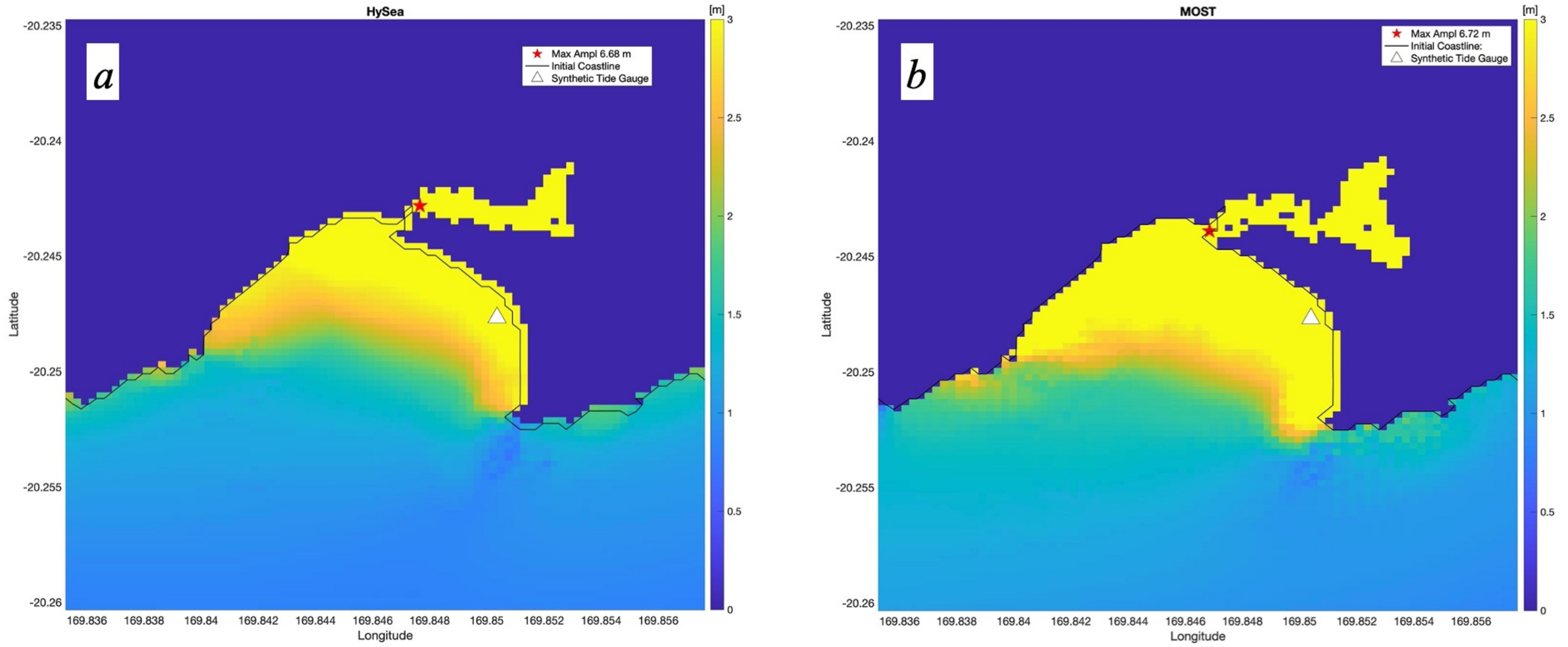
Table 1: Historical tsunami events that affected Aneityum (NCEI, 2024).

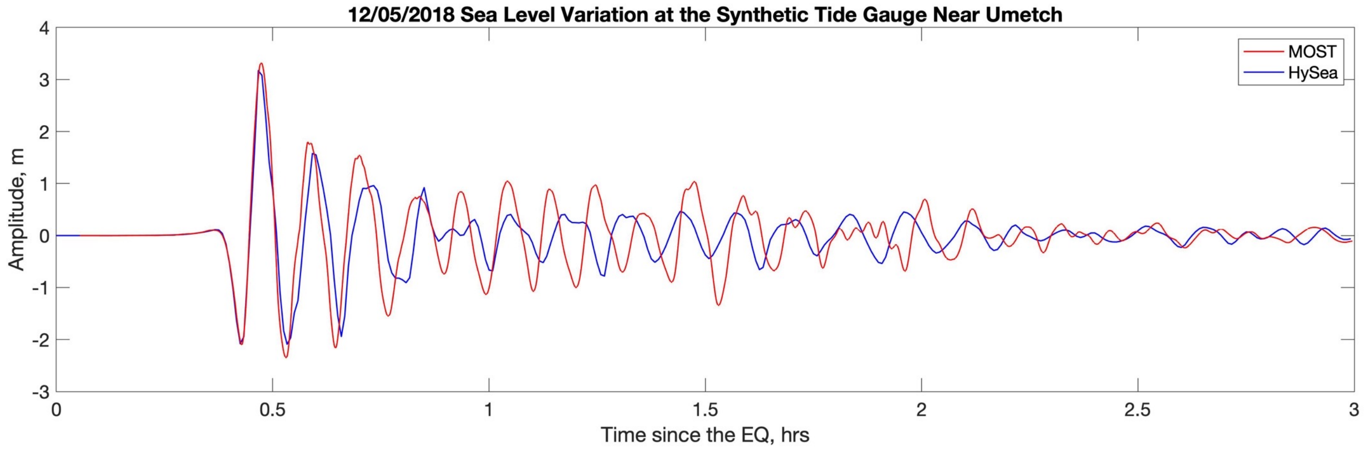
Date	Date	Source Location/Country	Source Longitude	Source Latitude	M_w	Runup
1	5/19/2023	Loyalty Islands, New Caledonia	170.694	-23.229	7.7	
2	3/4/2021	South of Raoul Island, Kermadec Islands, New Zealand	-177.267	-29.74	8.1	
3	12/5/2018	Loyalty Islands, New Caledonia	169.427	-21.95	7.5	Umetch ~4 m, Anelgauhat ~2 m
4	5/16/1995	Loyalty Islands, New Caledonia	169.9	-23.008	7.7	8 m
5	3/28/1875	Lifou Islands, Loyalty Islands, New Caledonia	168.5	-20.0	8	3 m
6	9/29/1849	Kamchatka, Russia	166.0	55.0		

Location and consequences of the 6 December 2018 tsunami impact on Umetch (Vanuatu), adapted from Roger et al. (2021).

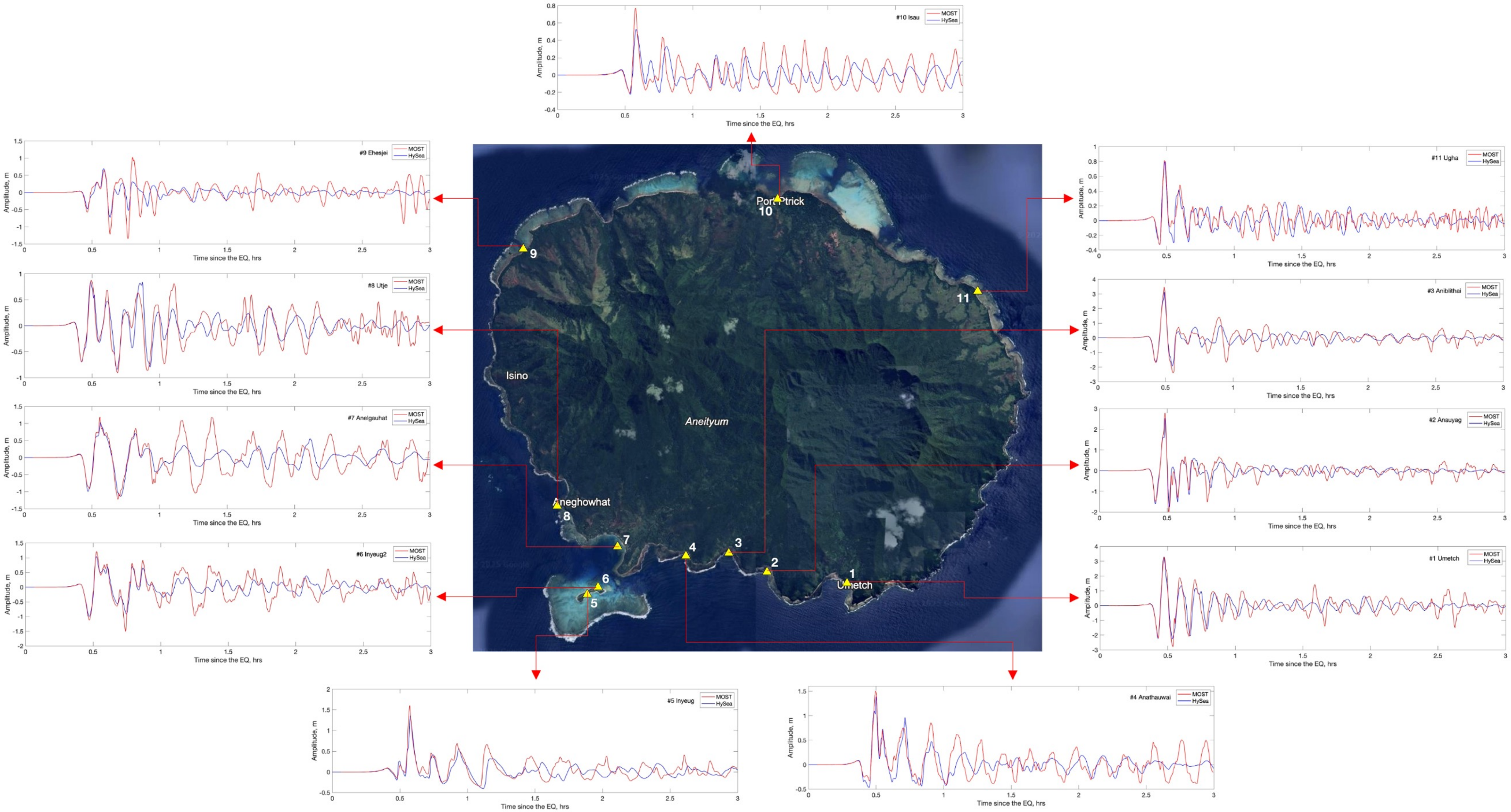
Roger, J., et al., 2021. The Mw 7.5 Tadine (Maré, Loyalty Islands) earthquake and related tsunami of 5 December 2018: Seismotectonic context and numerical modeling. Nat. Hazards Earth Syst. Sci., 21, 3489–3512. https://doi.org/10.5194/nhess-21-3489-2021

Model Validation. Comparison of modeled maximum wave amplitudes and inundation in Umetch from the **5 December 2018** event, simulated with HySEA (a) and MOST (b).

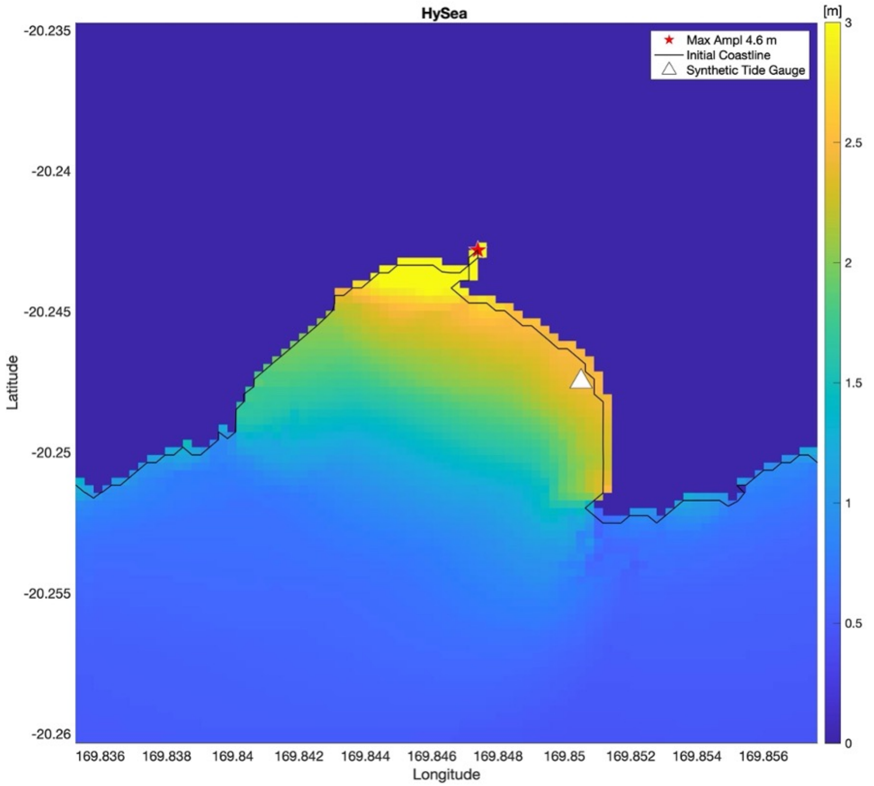


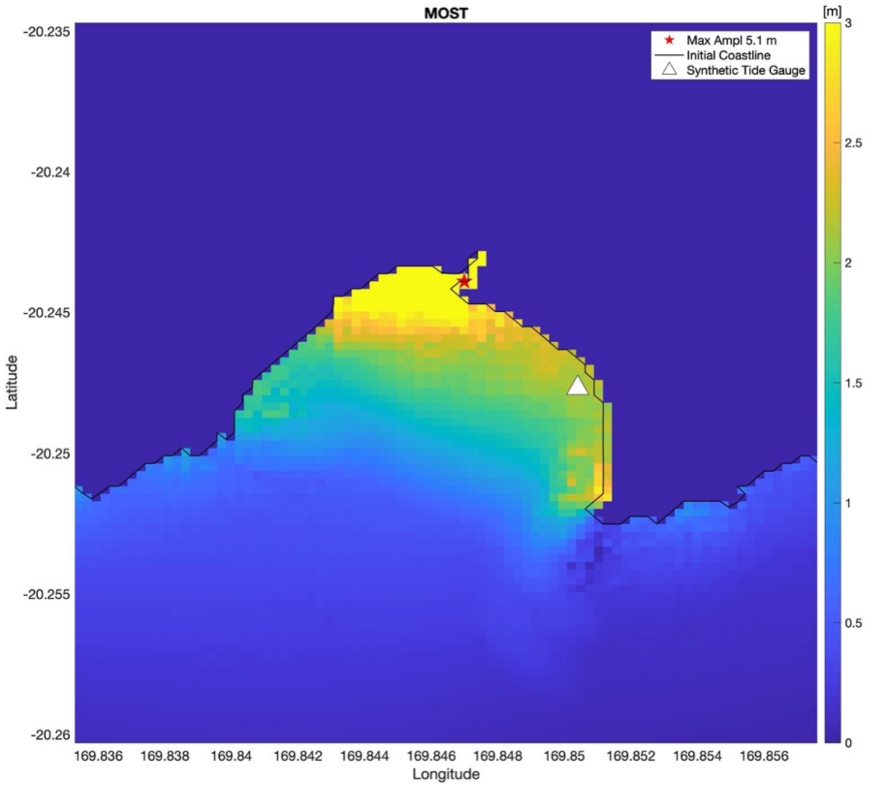


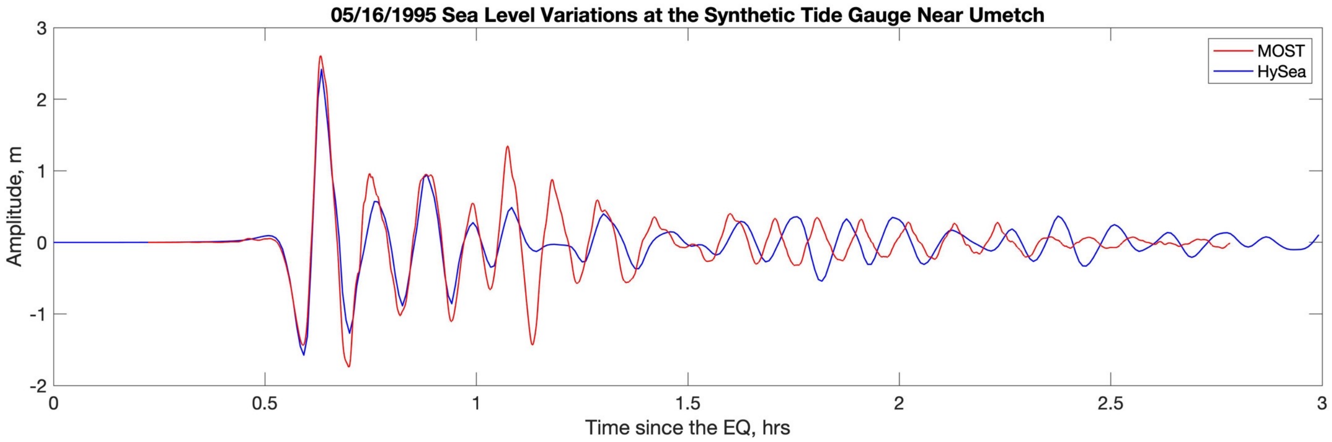
Comparison of modeled sea-level variations from the HySEA and MOST models at 11 synthetic tide gauges around Aneityum for the Mw 7.5 Loyalty Islands event of 5 December 2018.



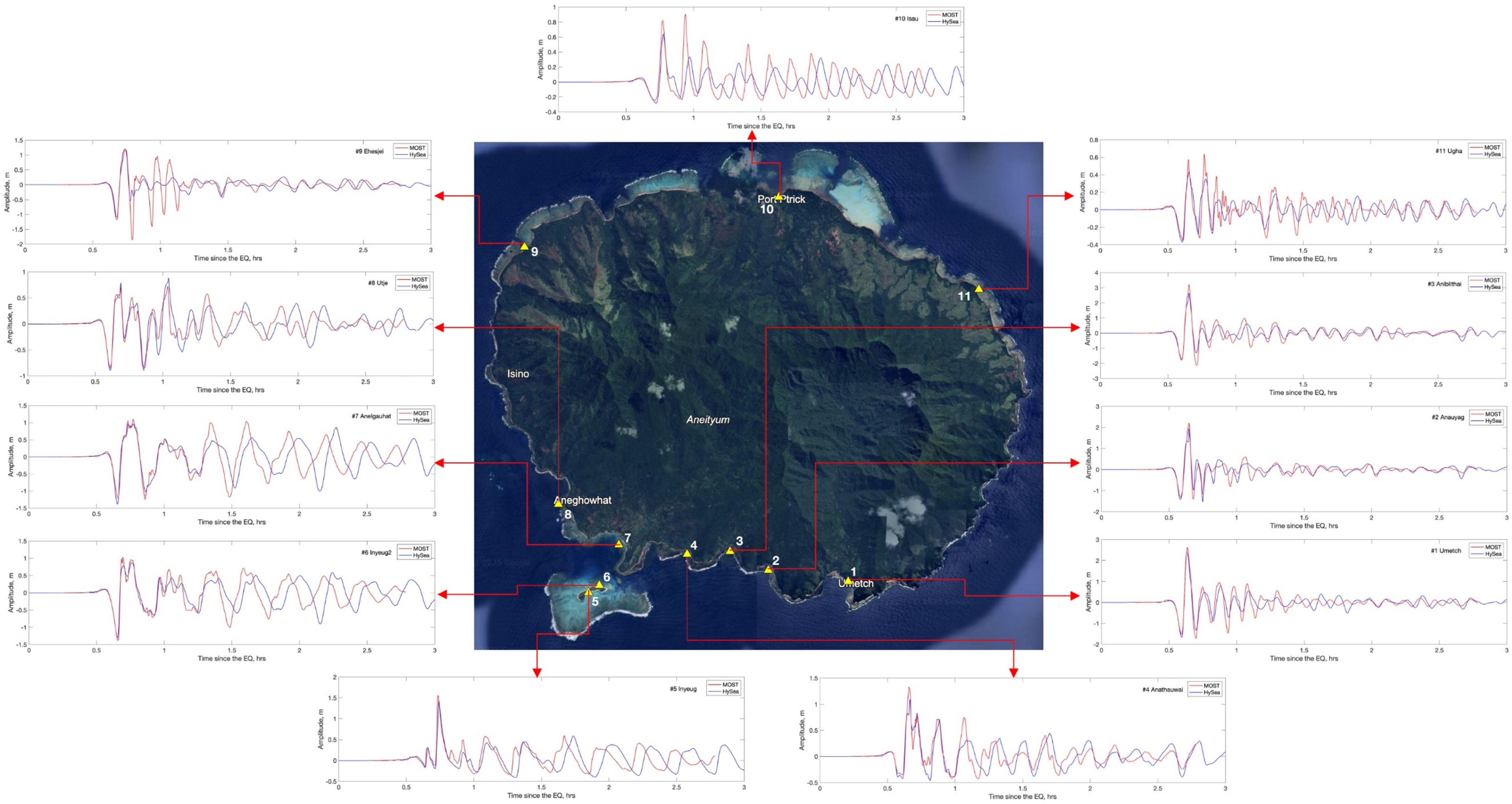
Model Validation. Comparison of modeled maximum wave amplitudes and inundation in Umetch from the **16 May 1995** event, simulated with HySEA (a) and MOST (b).





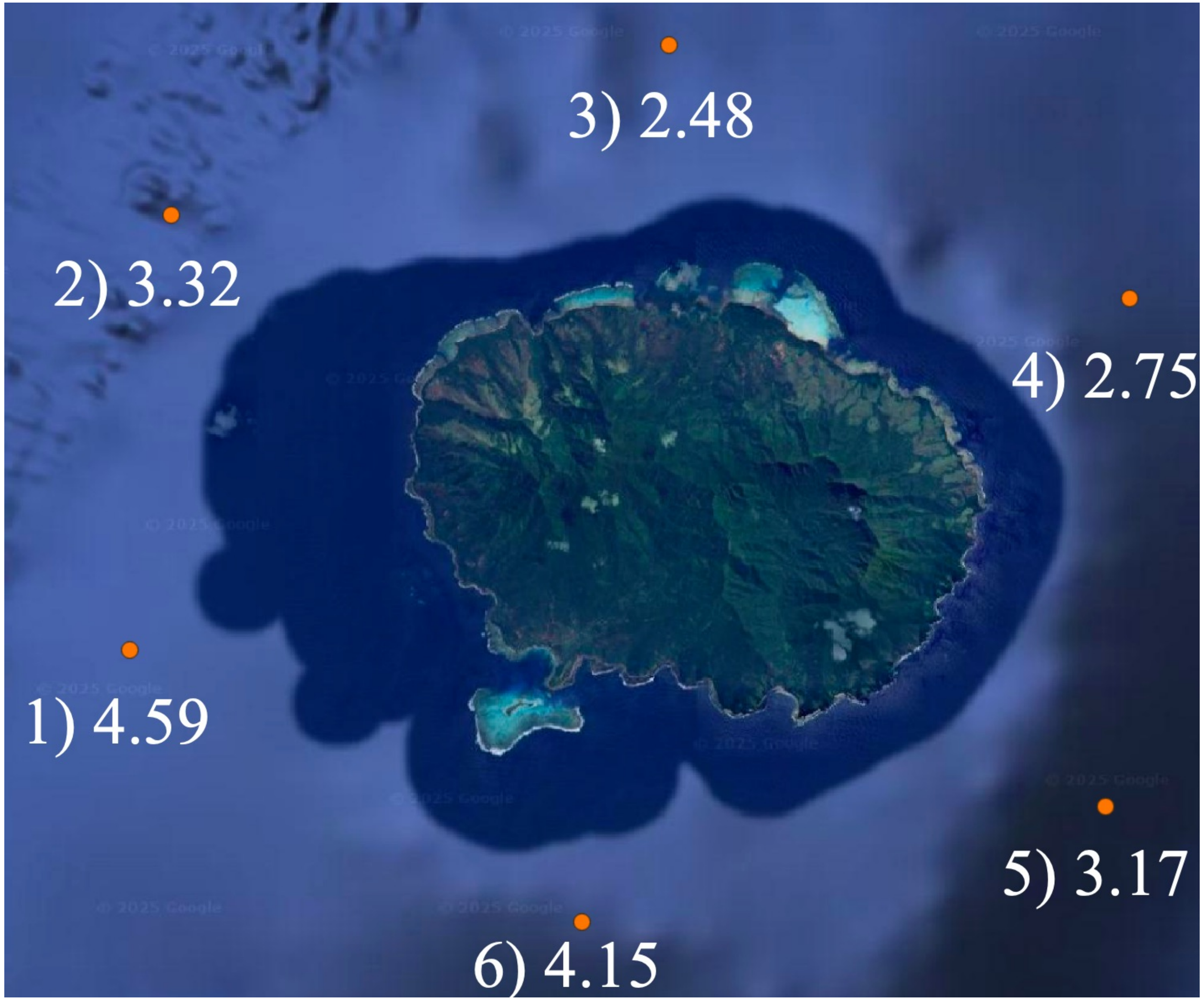


Comparison of modeled sea-level variations from the HySEA and MOST models at 11 synthetic tide gauges around Aneityum for the Mw 7.7 Loyalty Islands event of 16 May 1995.



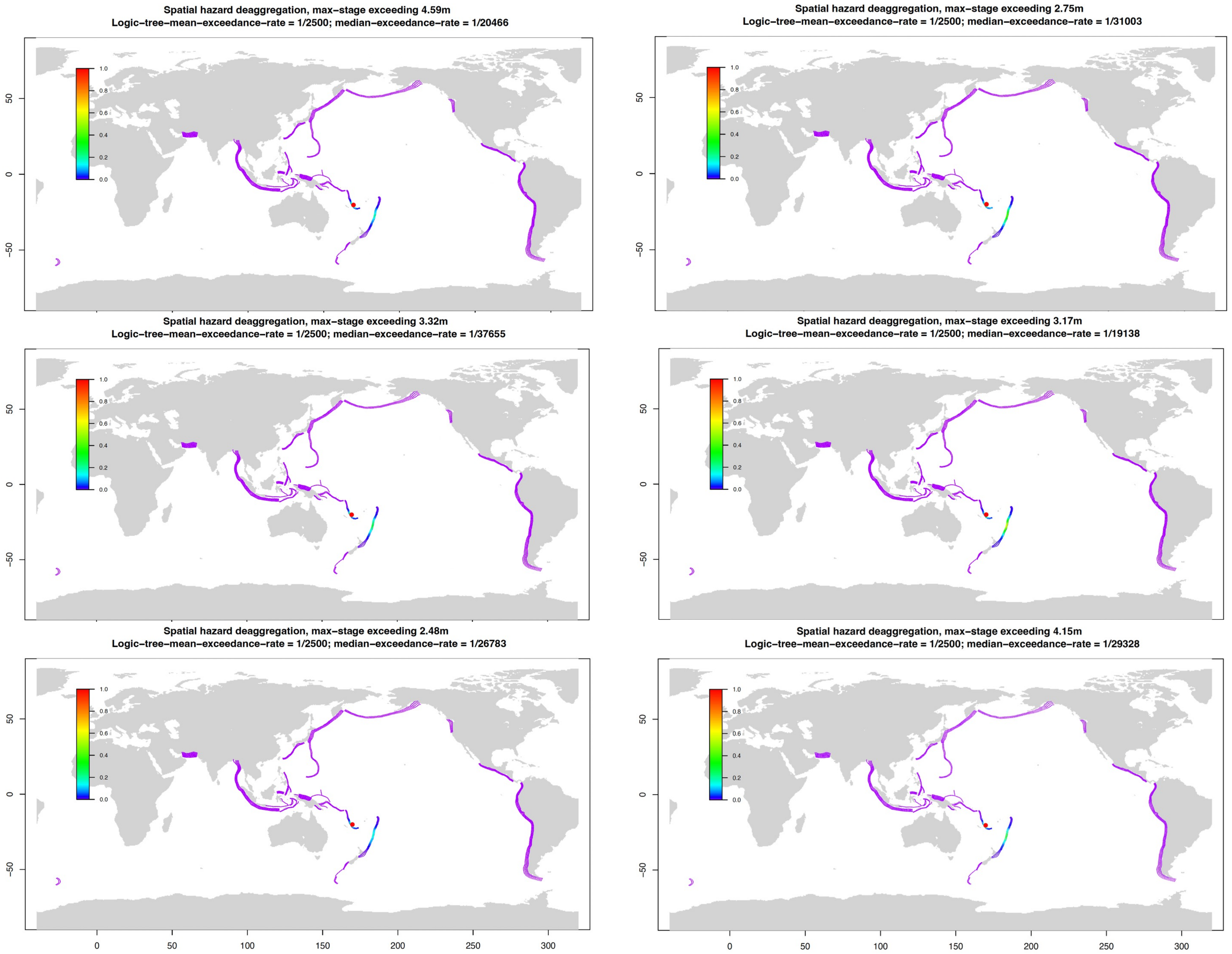
Selection of Tsunami Source Scenarios

We used a scenario-based assessment technique that combines the Probabilistic Tsunami Hazard Assessment (PTHA18) with the credible worst-case scenario.



Aneityum and the six nearest PTHA18 hazard points, showing maximum tsunami heights (m) for a 2,500-year return period.

Spatial hazard deaggregation plots for the six hazard points closest to Aneityum, corresponding to a 2,500-year mean recurrence interval.



Source Selection

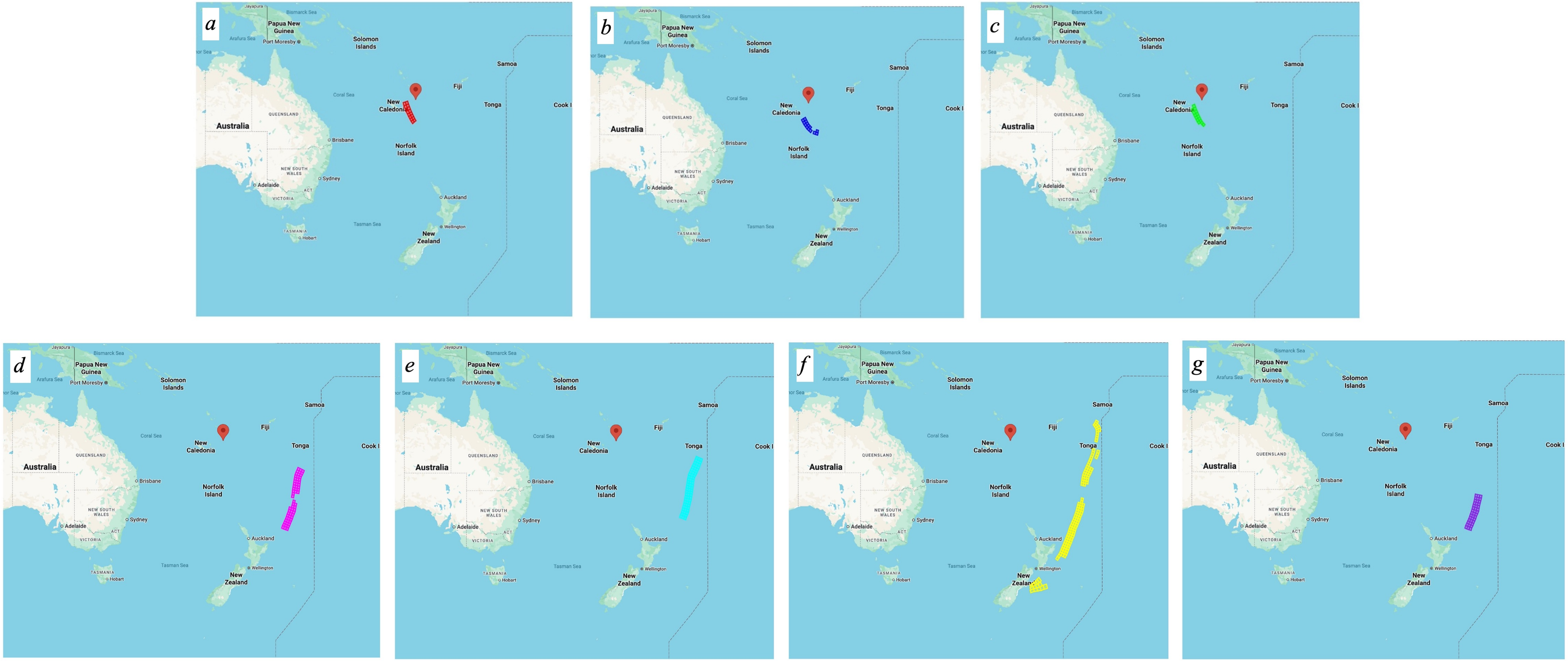
We applied **two criteria** to select the most potentially hazardous sources for Aneityum from the PTHA18 database for the Vanuatu and Tonga-Kermadec subduction zones (SZs). **First**, sources with the maximum expert-estimated moment magnitude (Mw) for each SZ were selected (UNESCI/IOC, 2020, 2024). **Second**, following ASCE (2022) guidelines, a source was chosen for full-scale modeling if:

- The maximum wave amplitude at each of the six hazard points nearest the island exceeded 80% of the maximum offshore tsunami stage for the 2,500-year return period, and

- The mean amplitude at all six points was equal to or greater than the mean maximum offshore tsunami stage for the 2,500-year return period.

American Society of Civil Engineers, 2022. Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-22). Reston, VA: ASCE.
UNESCO/IOC, 2020. Expert meeting on tsunami sources, hazards, risk and uncertainties associated with the Tonga-Kermadec Subduction Zone, Wellington, New Zealand, 29 October–3 November 2018. IOC Working Report 289.
UNESCO-IOC, 2025. Expert Meeting on Tsunami Sources, Hazards, Risk and Uncertainties Associated with Vanuatu, San Cristobal and New Britain Subduction Zones, Port Vila, Vanuatu, 14–17 May 2024. IOC-WR-315.

Sources selected for full-scale modeling:
(a) V1, (b) V2, (c) V3, (d) TK1, (e) TK2, (f) TK3, and (g) TK4.
The red marker indicates the location of Aneityum.



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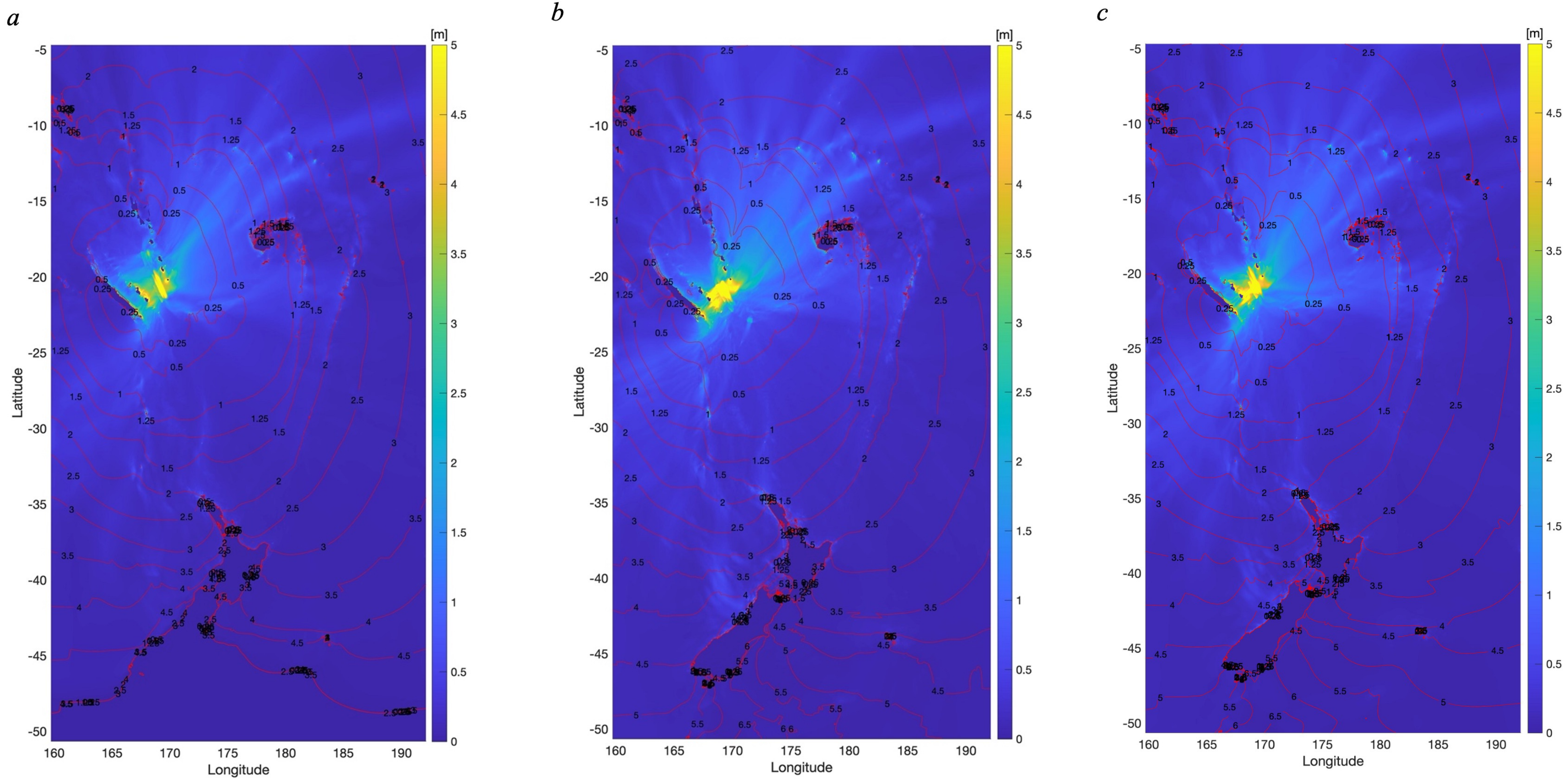
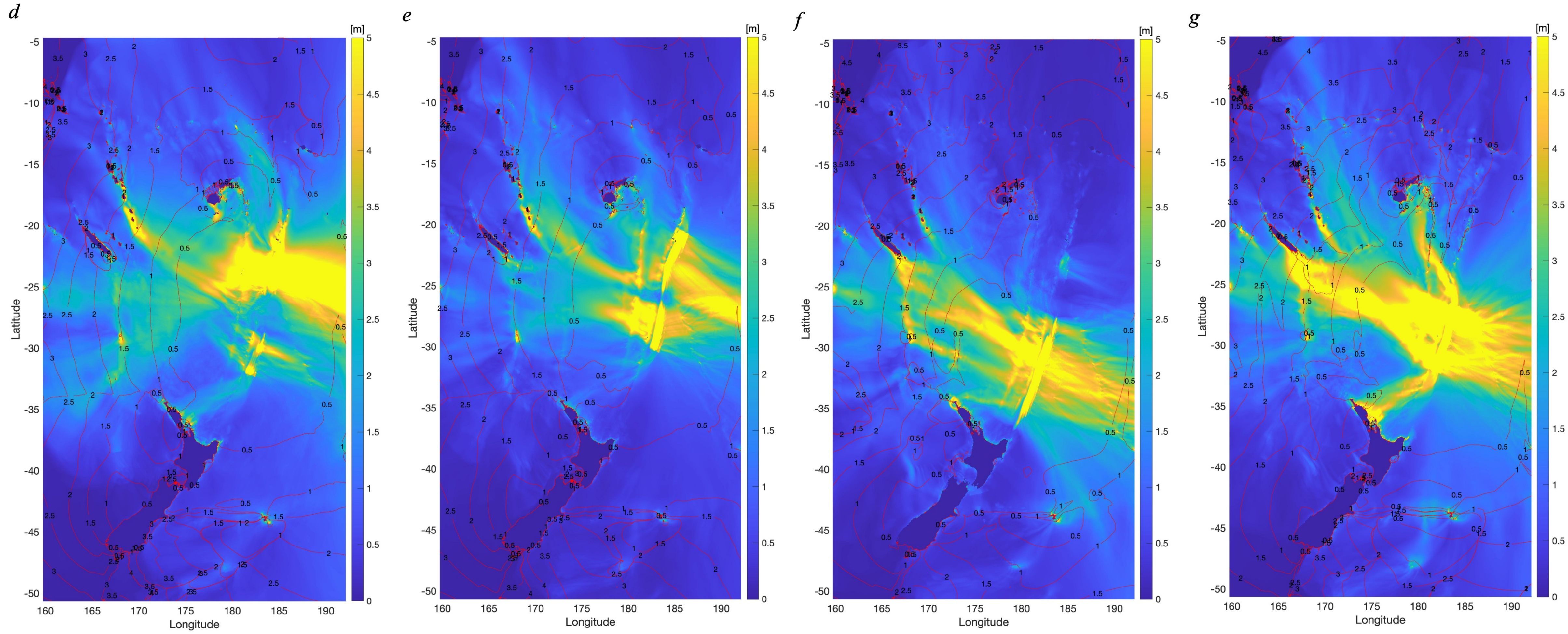
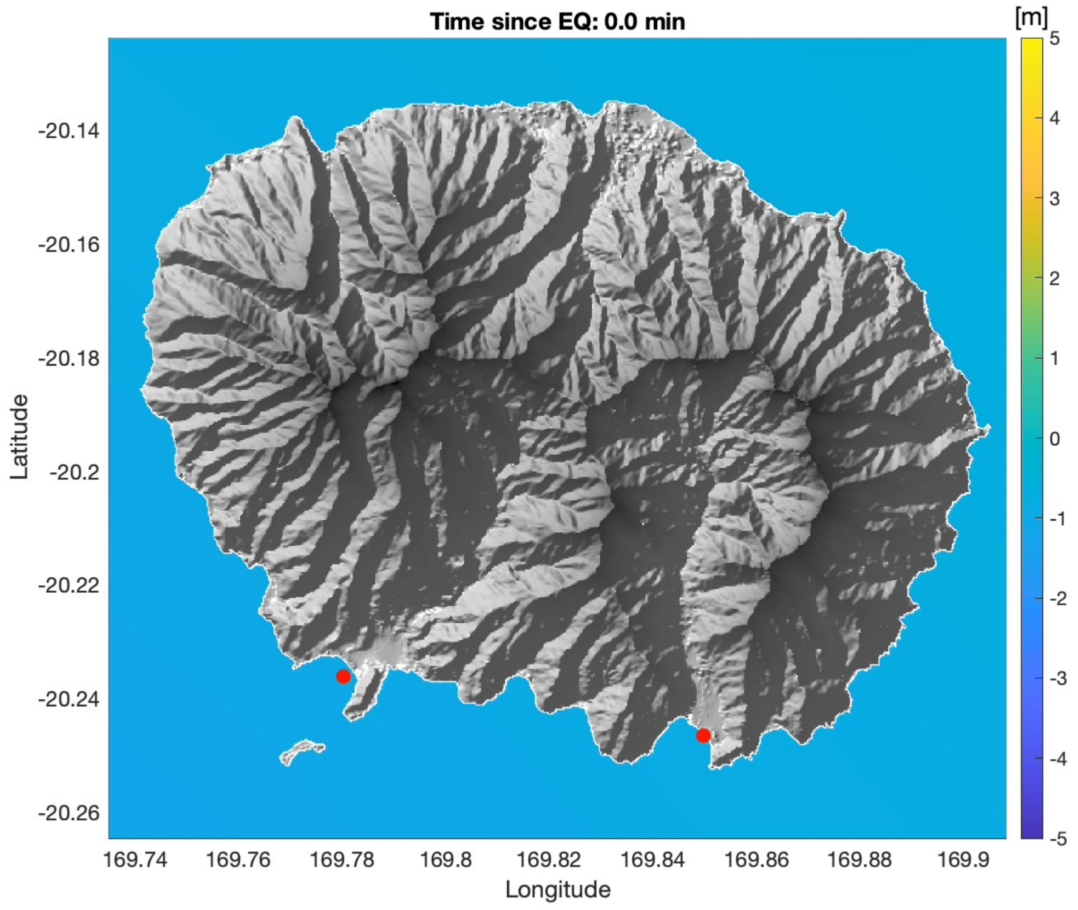
Source locations, arrival times, and maximum deep-ocean wave amplitudes from sources V1 (a), V2 (b), V3 (c).

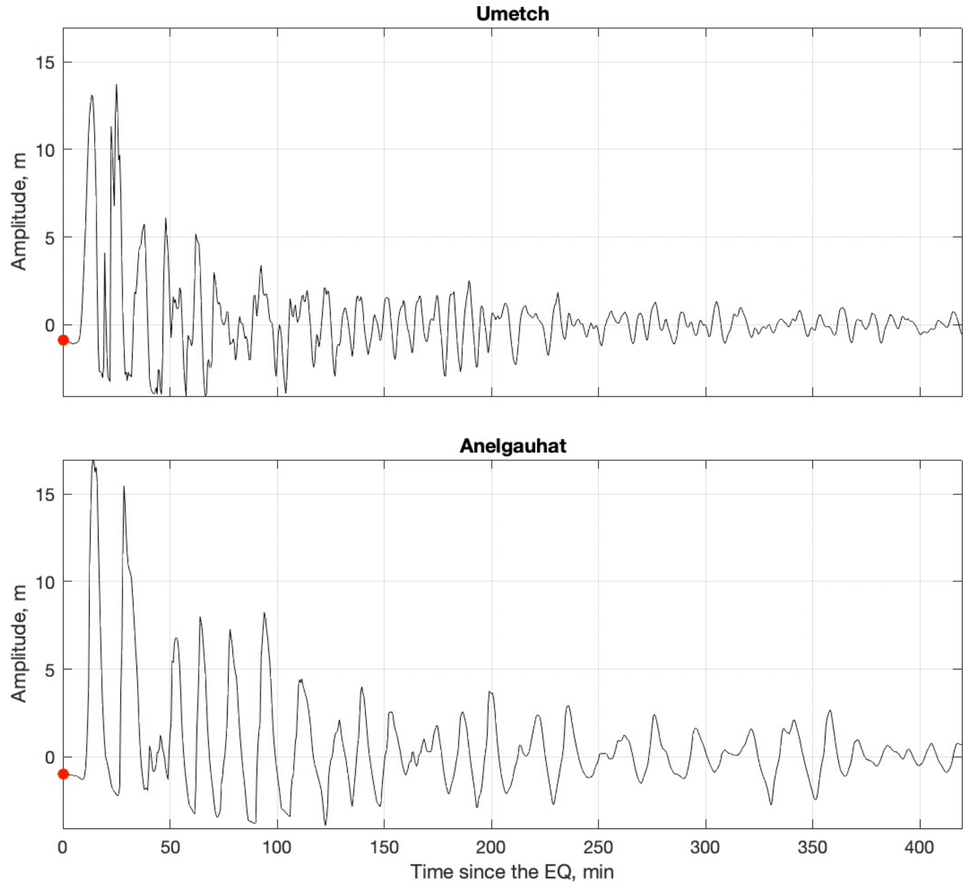


Source locations, arrival times, and maximum deep-ocean wave amplitudes from sources TK1 (d), TK2 (e), TK3 (f), and TK4 (g).

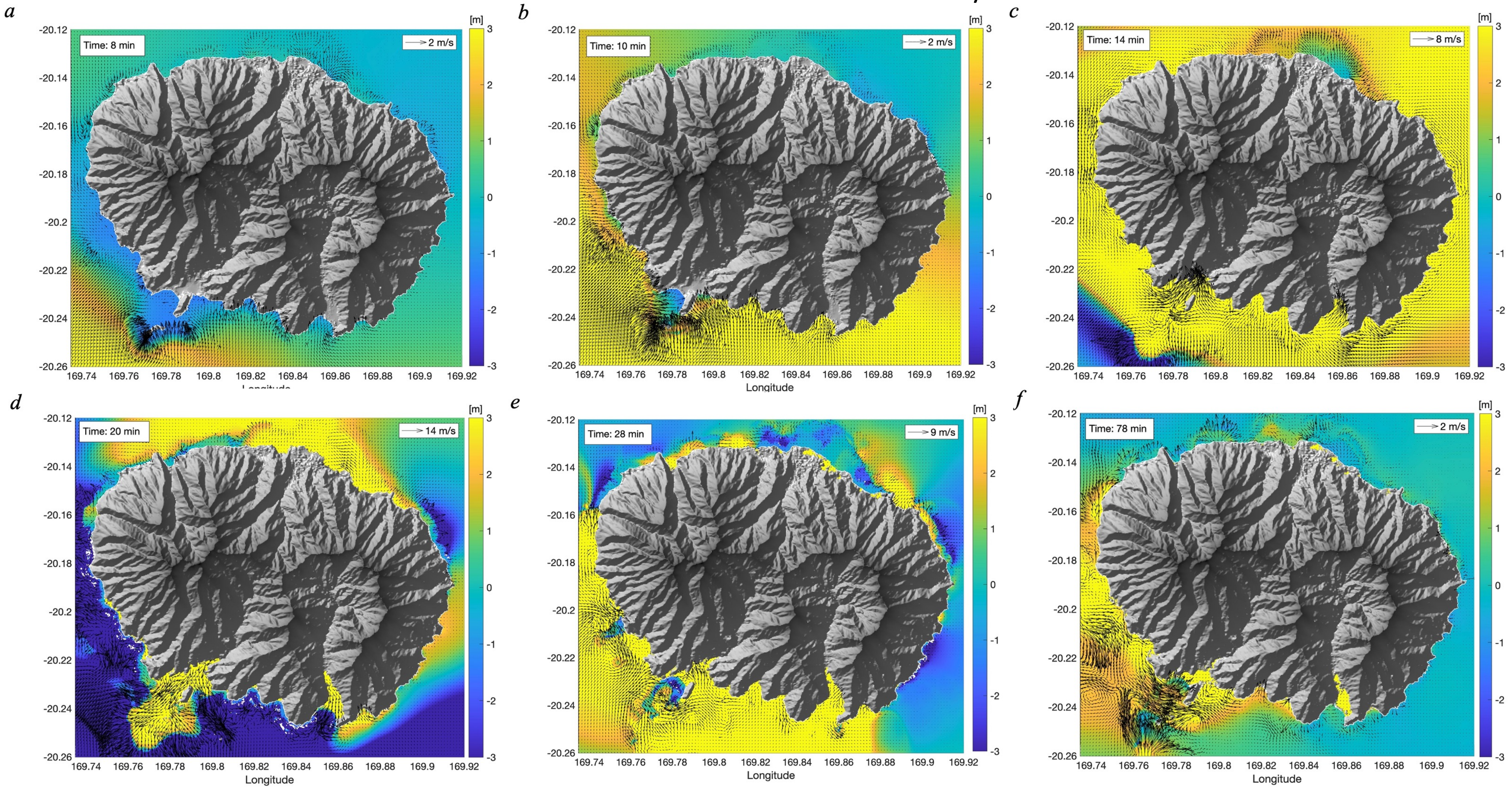


Propagation of tsunami waves from the V2 source, identified as the most hazardous for Aneityum.

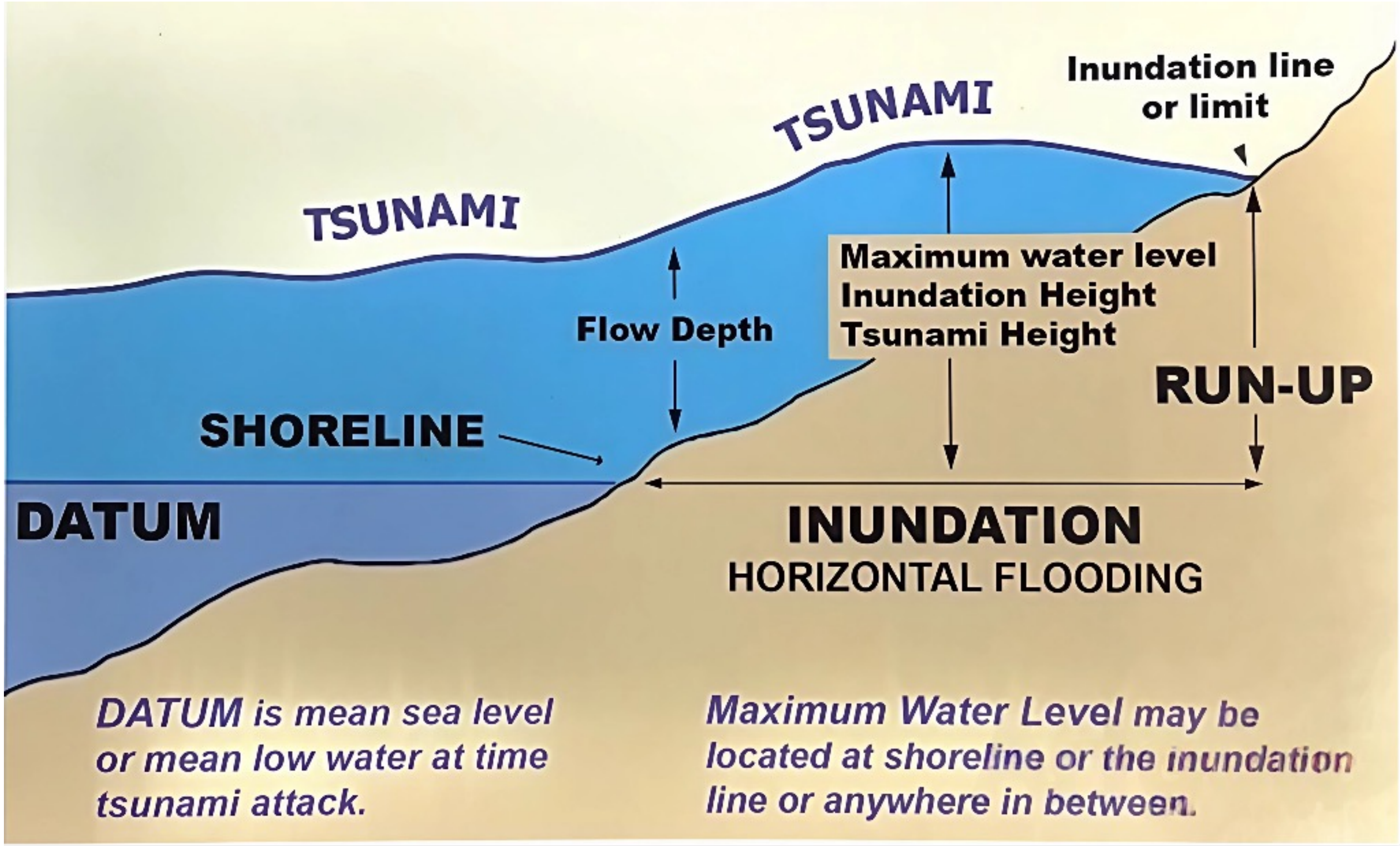




Offshore wave amplitudes, onshore tsunami heights, and currents (black vectors) at different times after the earthquake (times shown in the figures) from the V2 source—the most hazardous for Aneityum.

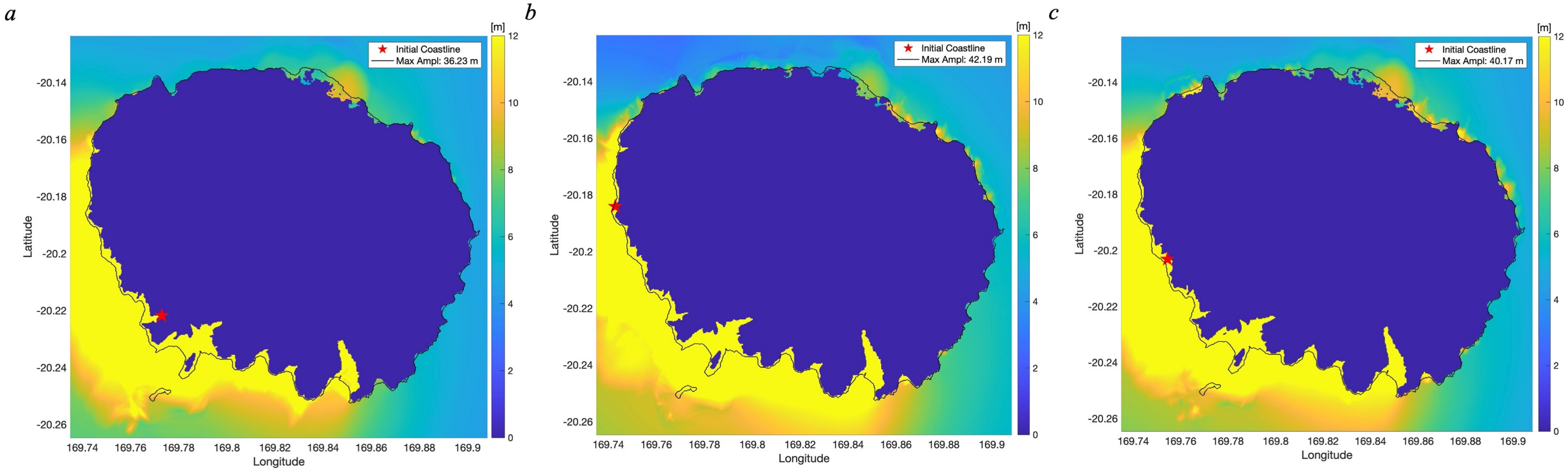


Tsunami Inundation Terms
(Intergovernmental Oceanographic Commission, 2019)



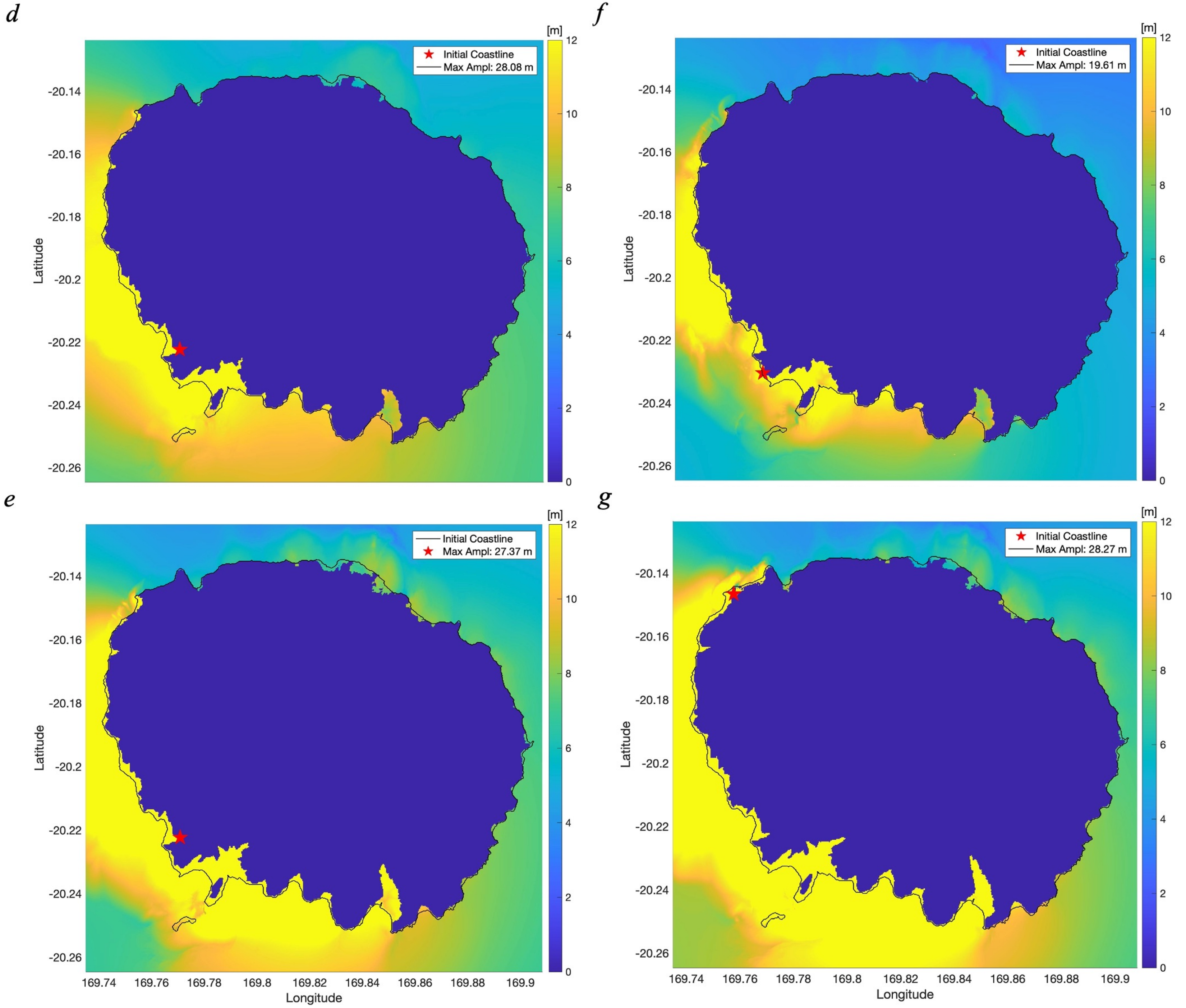
Maximum tsunami heights and inundation from Vanuatu sources V1 (a), V2 (b) and V3 (c).

Red triangle: overall grid maximum; black curve: initial coastline.

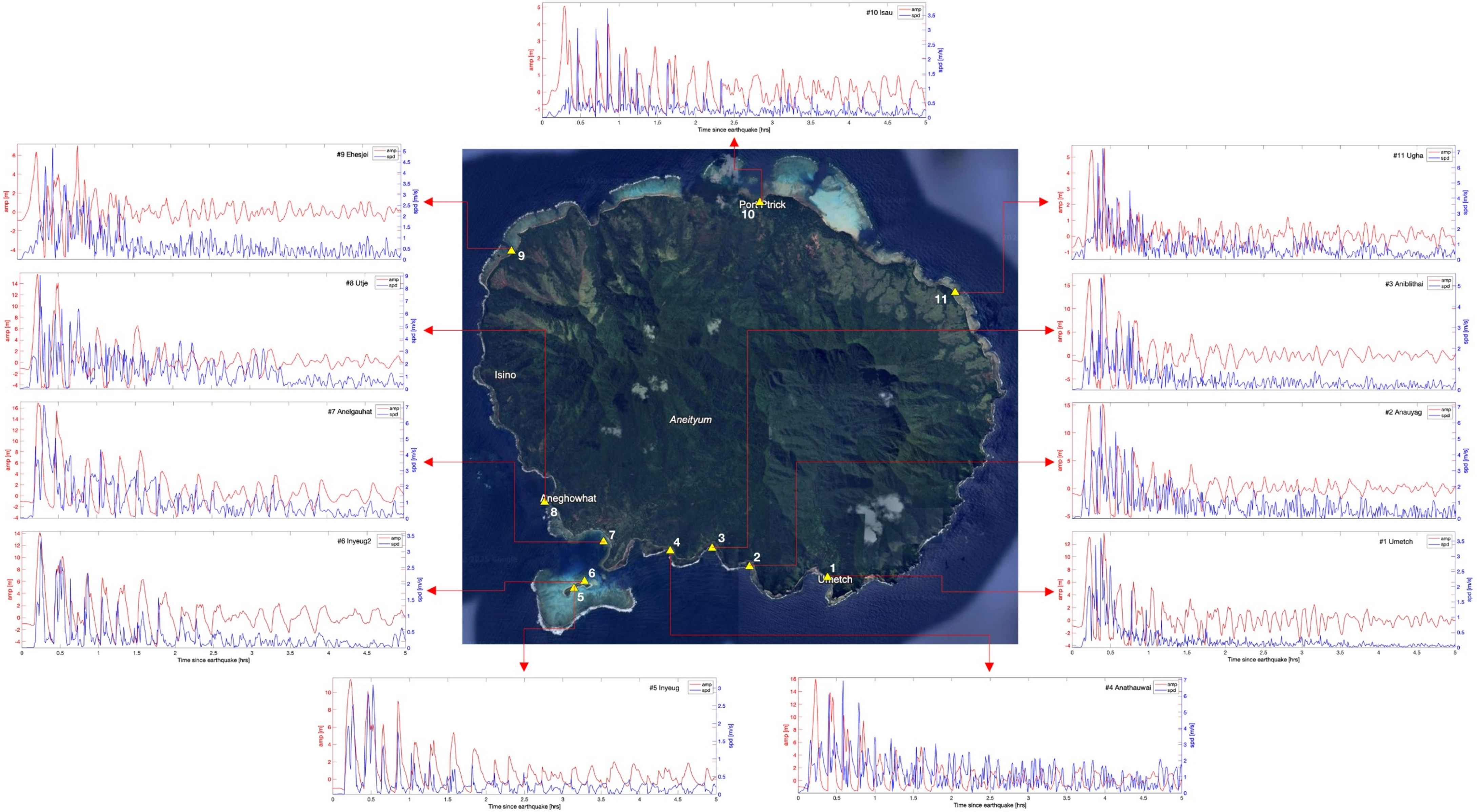


Maximum tsunami heights and inundation from Tonga-Kermadec sources TK1 (d), TK2 (e), TK3 (f) and TK4 (g).

Red triangle: overall grid maximum; black curve: initial coastline.

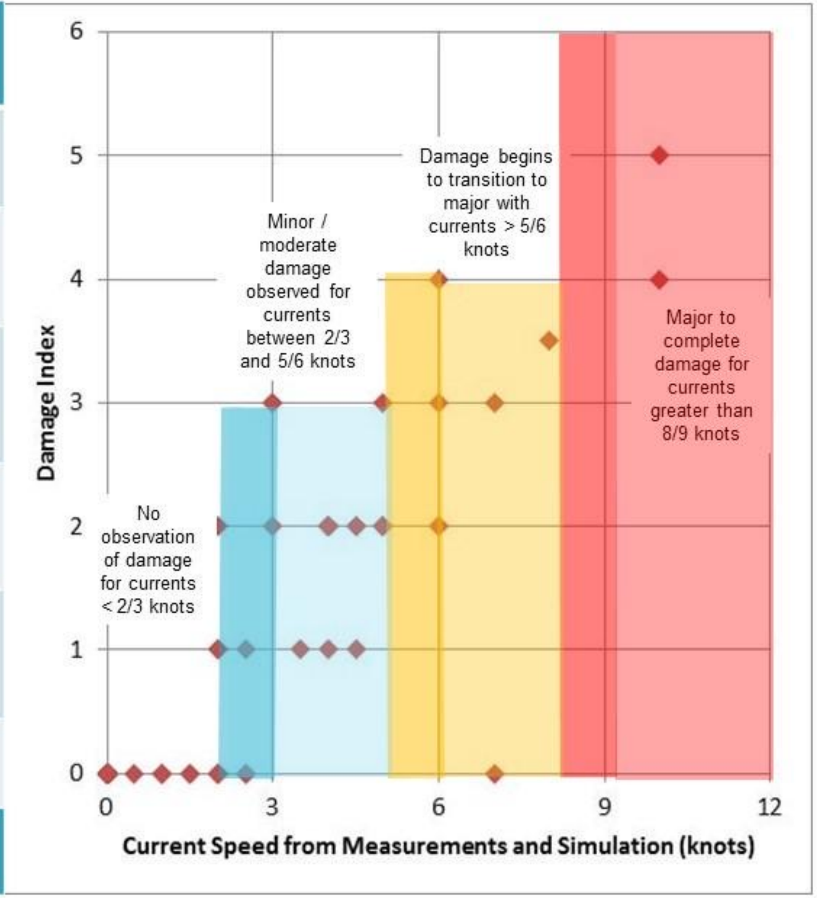


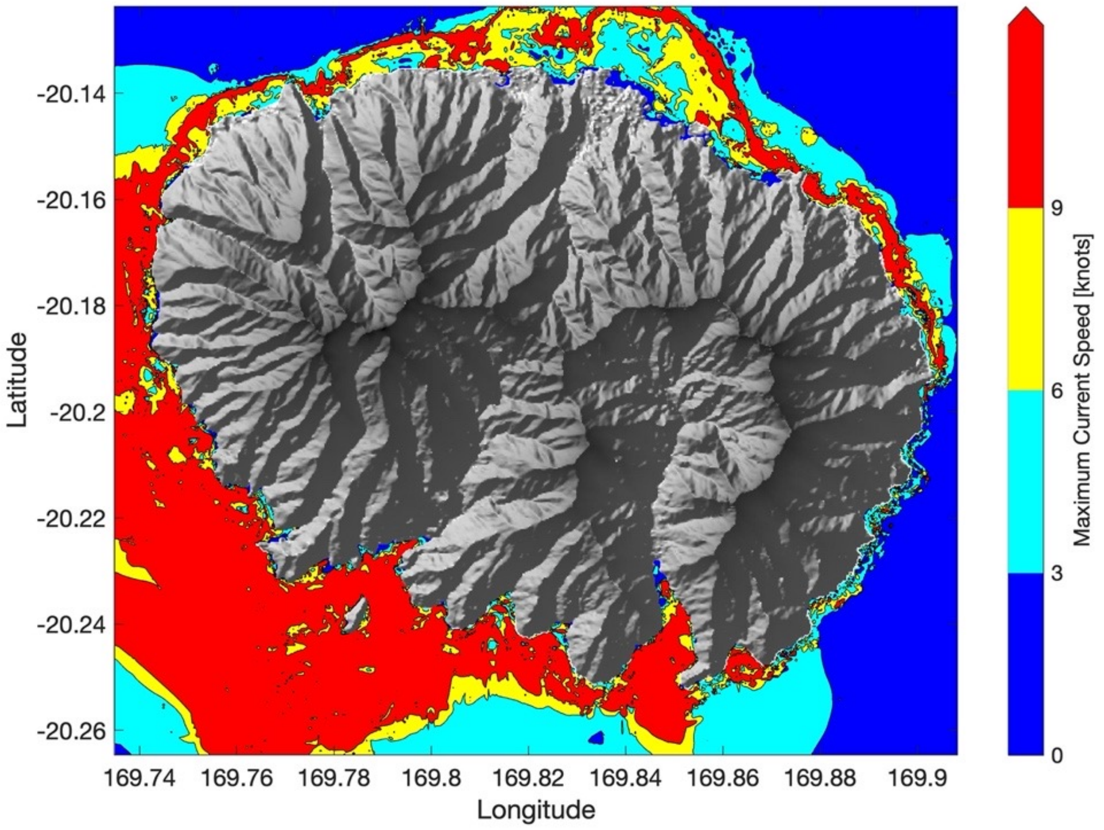
Time series of wave amplitude (red) and current speed (blue) forced by the V2 source at 11 synthetic tide gauges around Aneityum.



Maximum current speeds around Aneityum from the V2 source.

Damage Index	Damage Type
5	Complete destruction
4	Major dock/boat damage, large vessels off moorings
3	Moderate dock/boat damage, mid-sized vessels off moorings
2	1-2 docks/small boats damaged, large buoys moved
1	Small buoys moved
0	No damage

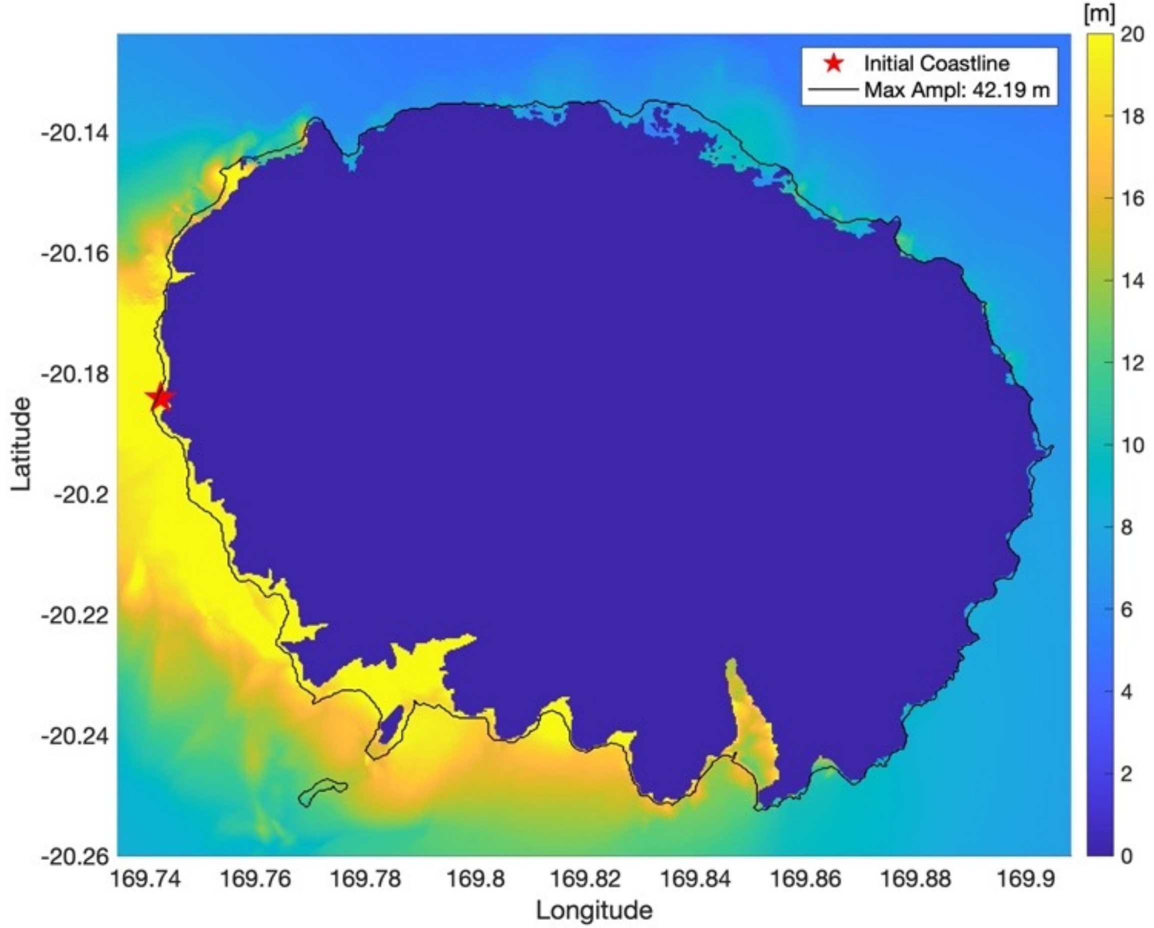


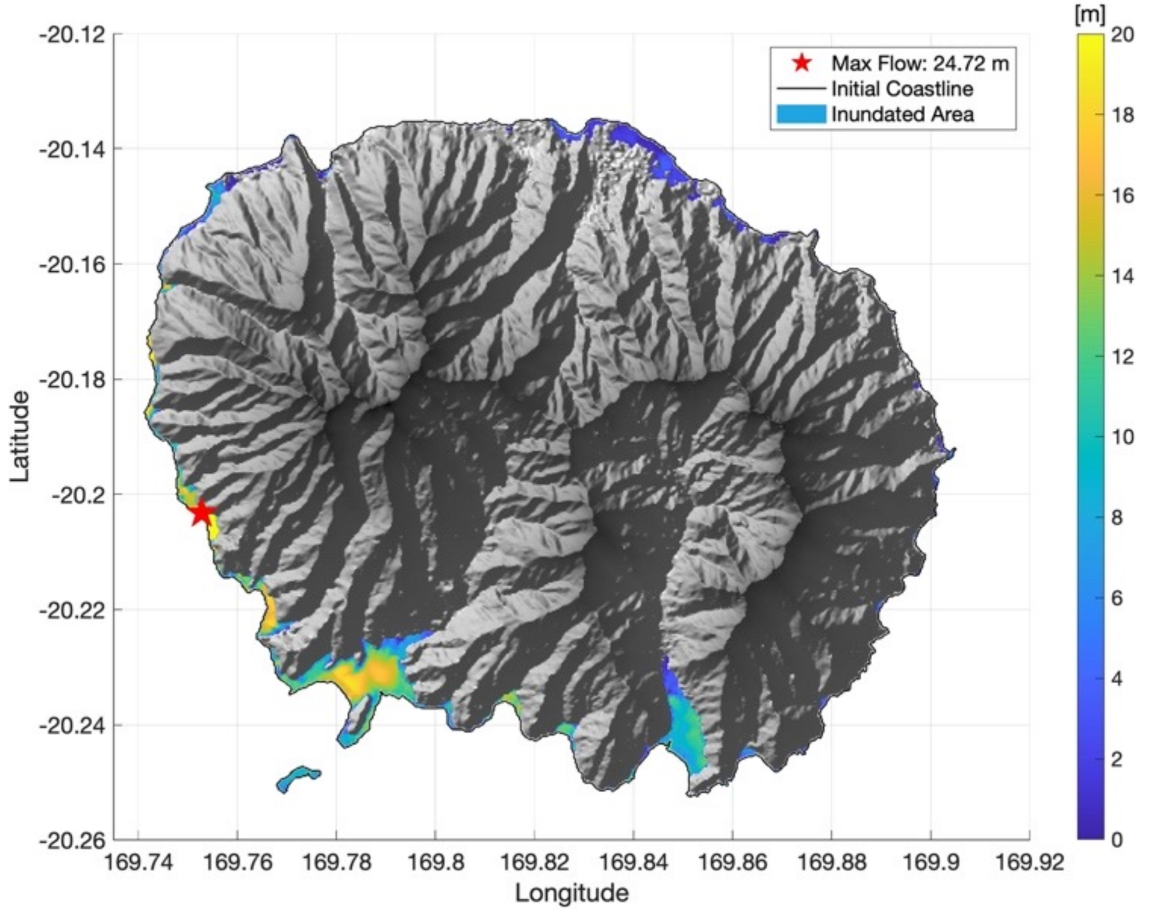


Scatter plot of observed damage indices versus their corresponding tsunami-induced currents, with potential damage descriptions adapted from Lynett et al. (2014)

Lynett, P., Borrero, J., Son, S., Wilson, R., Miller, K., 2014. Assessment of the tsunami-induced current hazard. Geophys. Res. Lett., 41, 2048–2055. https://doi.org/10.1002/2013GL058680

Composite maximum tsunami heights and flow depths at Aneityum.





Thank you!