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Modeling Tsunami Inundation for Hazard Assessment of Majuro, Republic of the Marshall Islands

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Introduction

- The study presents the tsunami hazard assessment and subsequent tsunami inundation modeling for Majuro Atoll, the capital of The Republic of Marshall Islands conducted by the tsunami research group at the NOAA Pacific Marine Environmental Lab (PMEL) in Seattle, WA.
- Hazard assessment was conducted first by identifying records of historical events that impacted the island in the past and by then investigating the sensitivity of Majuro Atoll to tsunami impact from potential Mw 9.1 earthquake-triggered tsunami scenarios.
- The largest credible seismic scenarios that impinge on Majuro were identified and modeled with a fully non-linear shallow water wave model on 10 m resolution grid.
- Model results and especially products, including composite plots of maximum inundation and currents, provide the basis for The Republic of Marshall Islands to educate and engage the Majuro Atoll populations in development of evacuation maps and procedures to follow in the event of tsunami generation.

31 of 32 tsunami that have historically impacted the Marshall Islands following the NCEI Global Historical Tsunami Database [1] were originated from the Ring of Fire – a string of volcanoes and sites of seismic activity around the edges of the Pacific Ocean. We use a scenario-based assessment technique based on credible worst-case tsunami events. To identify the most potentially hazardous sources for Majuro we first conducted the sensitivity testing. Tsunami waves originating from 77 Mw 9.1 discrete earthquake sources along subduction zones throughout the Pacific were modeled using the NOAA Tsunami Forecast Propagation Database on optimized grid (**Figure 1**). Subsequent to the sensitivity study five earthquake scenarios along the most hazardous source segments: the New Britain, South Solomon-New Hebrides, Kuril-Japan-Izu subduction zones as identified in the sensitivity analysis, were selected and modeled at the highest possible resolution of 10 m (**Figure 2**).

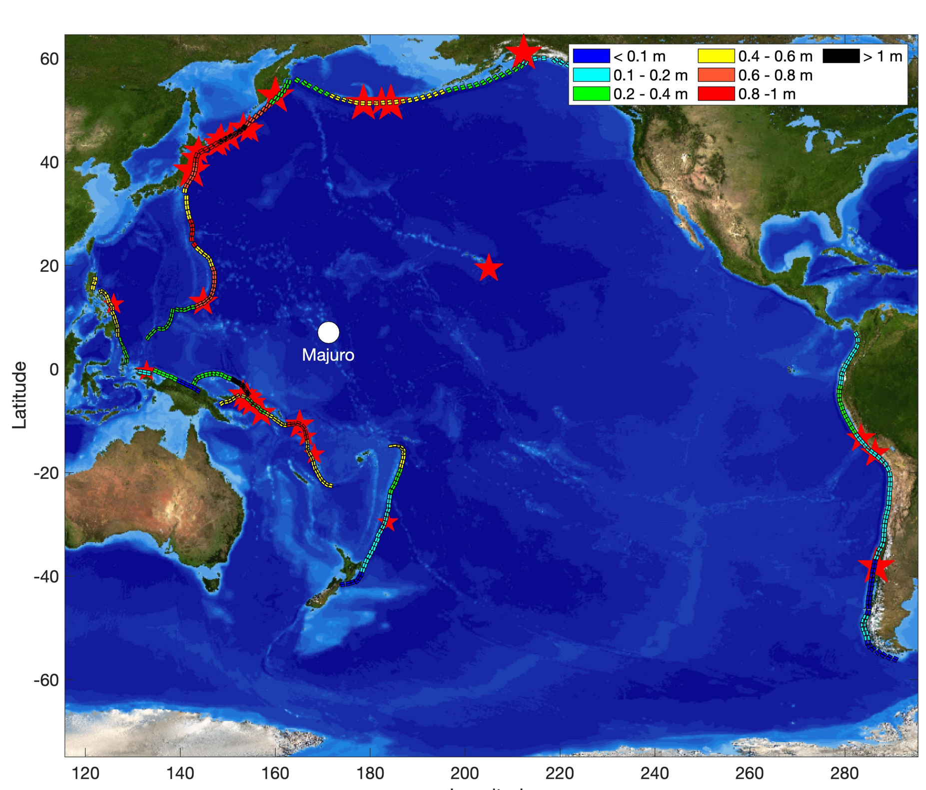


Figure 1: Maximum tsunami heights computed for Majuro from tsunamis triggered by synthetic Mw 9.1 earthquakes along Pacific Basin subduction zones. The red stars identify locations and size of the historical tsunami.

Light Detection and Radar (LiDAR) data at 10 m resolution (1/3 arc-second) were combined with multi-beam and other sourced data that together provided atoll-wide coverage of features off- and on-shore.

The US Tsunami Hazard Mitigation Program (NTHMP)-approved and benchmarked HySEA model [2] was selected to allow full-island modeling at full resolution, including all critical infrastructure. This model code has been designed to solve the non-linear shallow water equations and utilizes GPU graphics cards for parallelization.

This study provides a good first step toward assessing the effect of tsunamigenic earthquakes on Majuro. However, this study does not consider tsunami generating volcanic eruptions and landslides that may occur due to earthquakes or volcanic activity.

Modeling Results

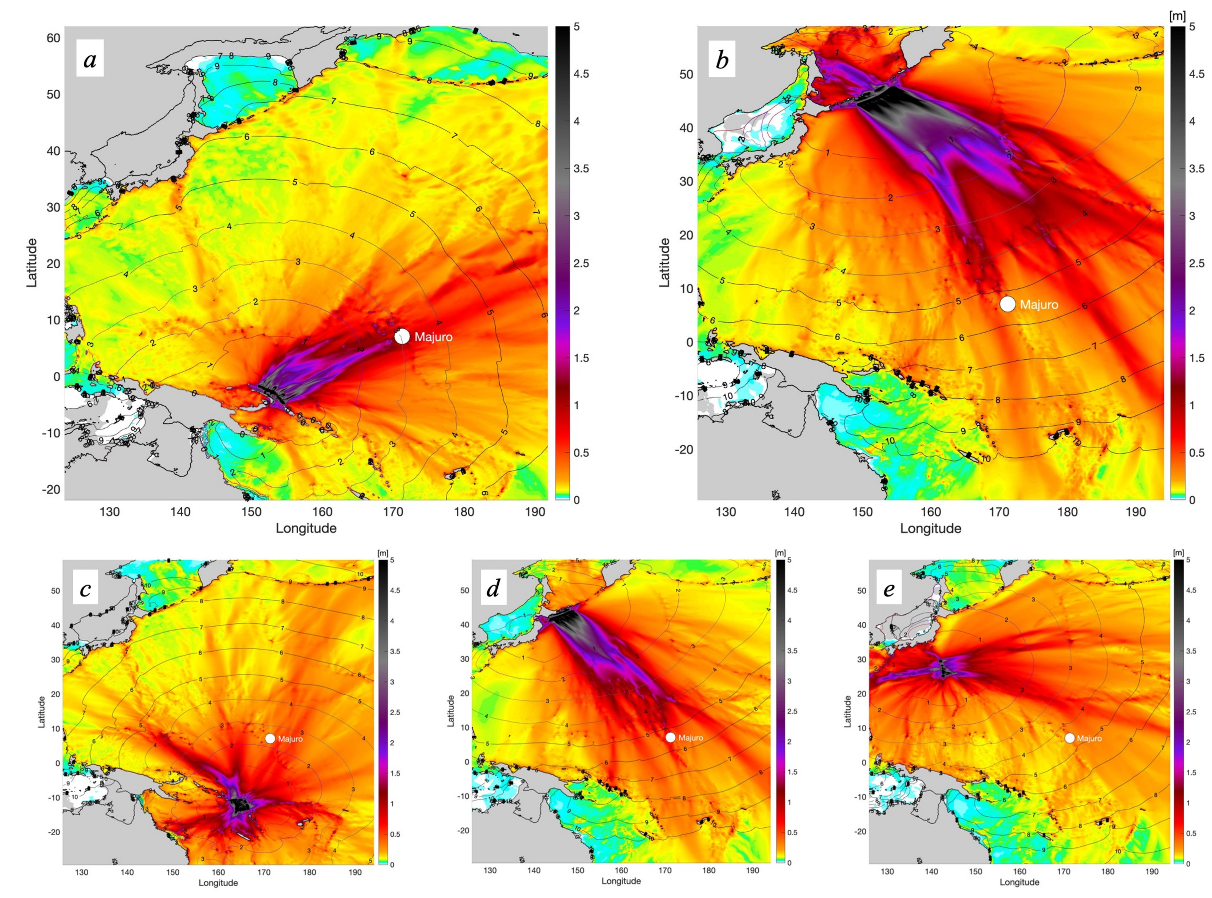


Figure 2: Source location, arrival times, and maximum wave amplitudes in deep ocean for the most hazardous sources: a) New Britain, b) Kuril, c) New Hebrides, d) Kuril-Japan, e) Izu-Bonin.

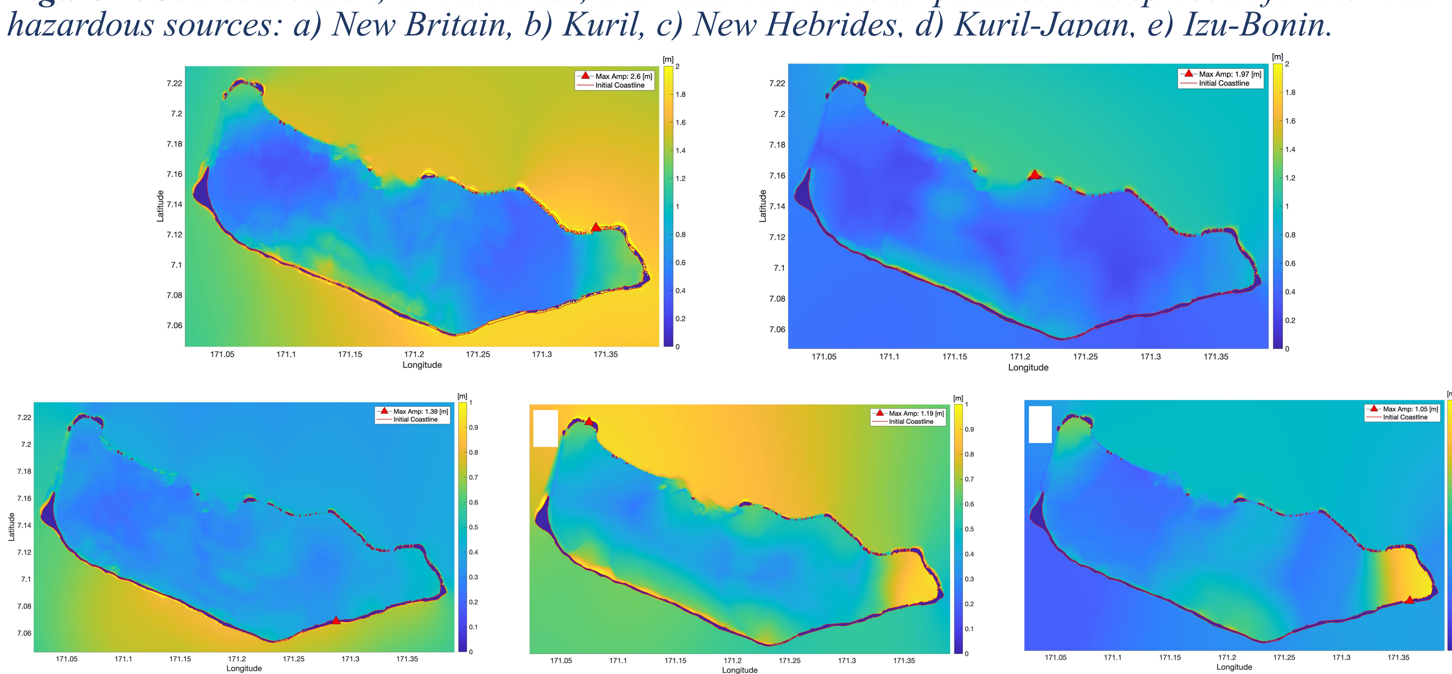


Figure 3: Maximum tsunami height and inundation for the a) New Britain, b) Kuril, c) New Hebrides, d) Kuril-Japan, e) Izu-Bonin sources. Red triangle marks the position of the overall grid maximum.

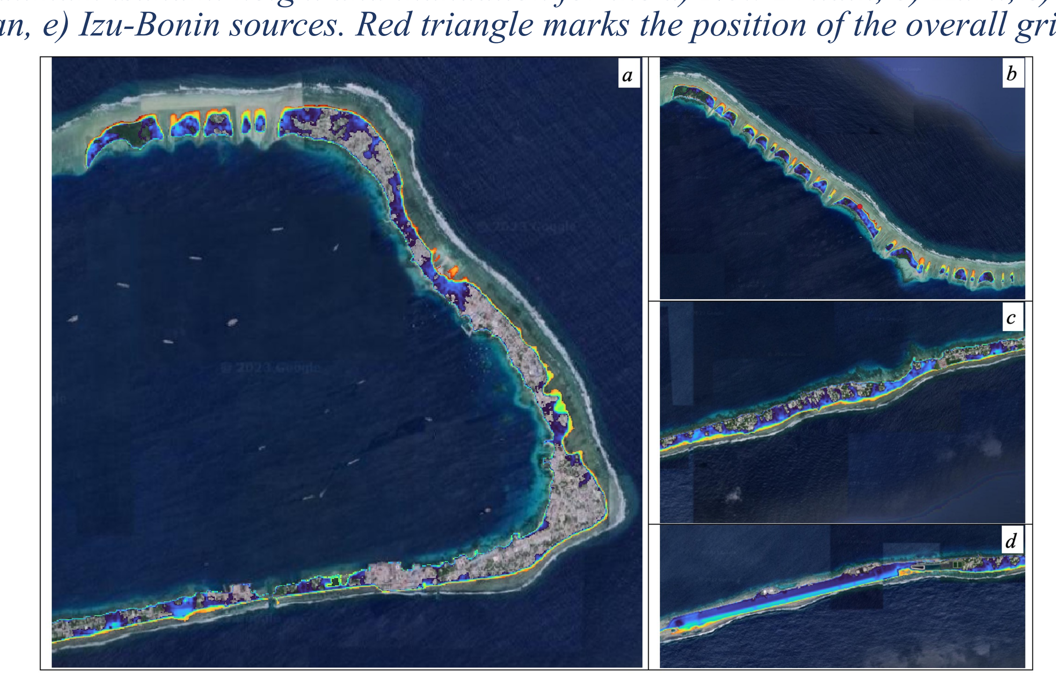
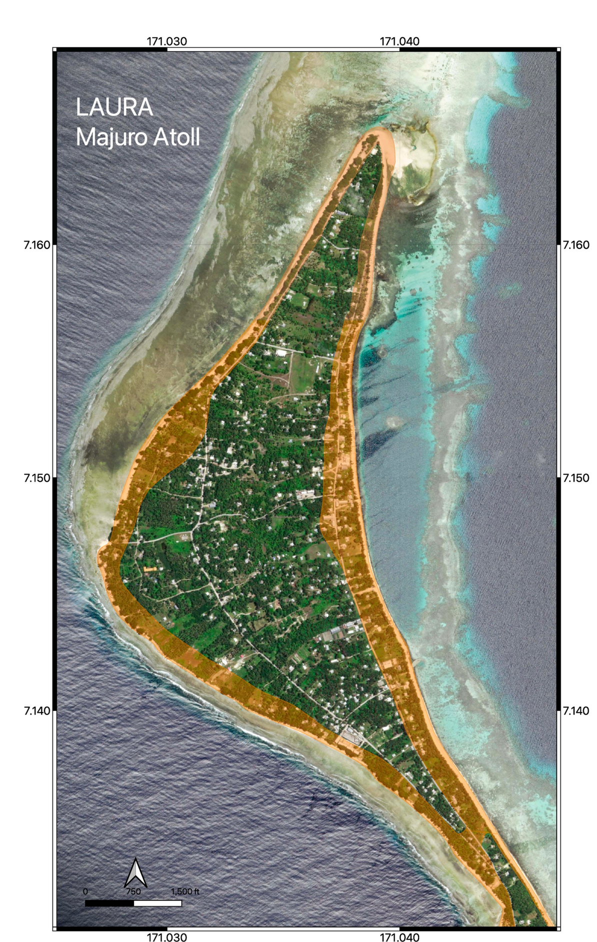


Figure 4: Maximum flow depth for the New Britain source with the areas of major concern ...Enigu islands, c – Rairik island, d – Amata Kabua ...tional Airport.



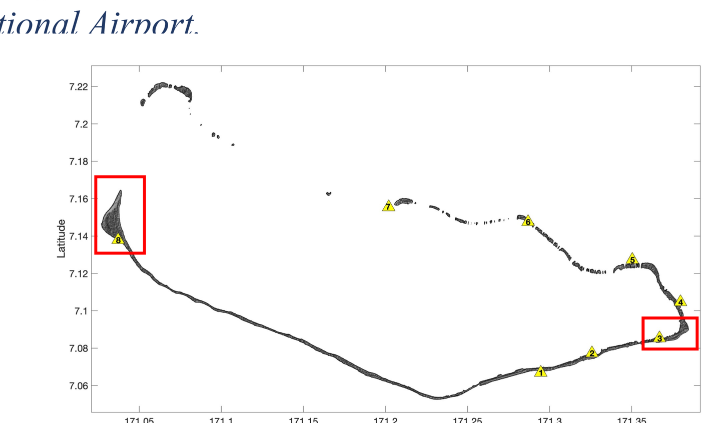


Figure 5: Locations of the synthetic tide gauges.

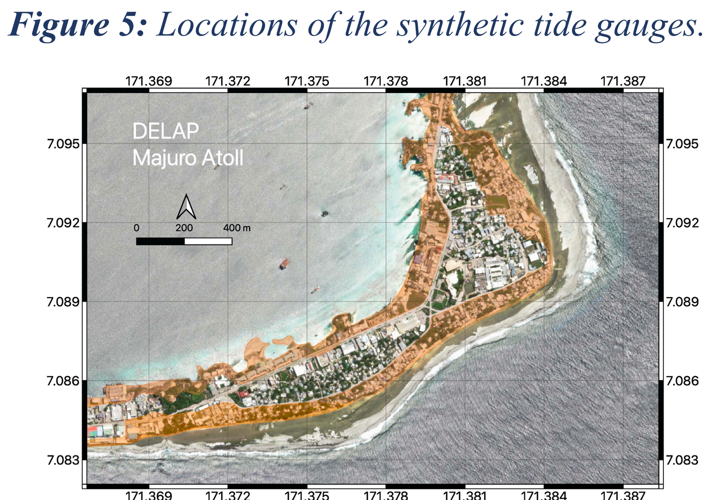


Figure 6: Tsunami evacuation maps for Laura and Delap.

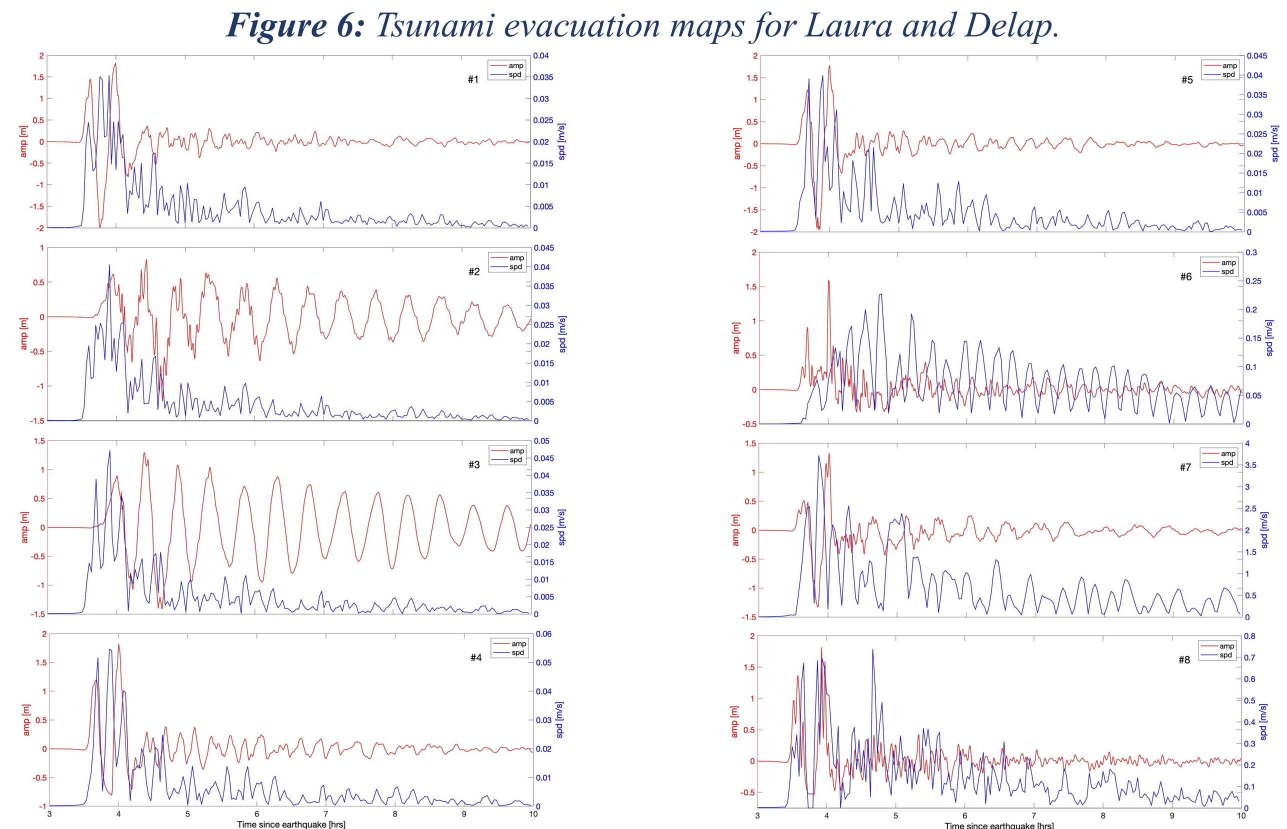


Figure 7: Time series of wave amplitude (red) and current speed (blue) forced with the New Britain source at eight synthetic tide gauges showed on Figure 5.

Discussion

- Sources New Britain and Kuril cause the largest amplitudes at Majuro (**Figure 2 a, b**). Source New Hebrides and New Britain have earlier arrival times near Majuro (≈ 2.5 – 3 hours) than more distant sources (**Figure 2 a, c**).
- The largest values for maximum tsunami height for two the most hazardous sources for Majuro, New Britain and Kuril, are 2.6 m and 1.97 m on the north part of Majuro in Arniel and Calalin islands respectively **(Figure 3 a, b)**.
- The inundation for the New Britain event is extensive. The low-lying south-eastern (Rairik with Amata Kabua International Airport) and north-eastern (islands between Djarrit and Calalin) parts of the atoll are almost fully inundated, the DUD areas between Djarrit-Uliga and Uliga-Delap are also significantly inundated **(Figure 4)**.
- Based on the modeling results the Majuro evacuation maps were developed **(Figure 6)**.
- The most dangerous for Majuro potential tsunami originated from the New Britain source arrives from the south-west starting with the rise of water (runup) and reaches its maximum tsunami height at Laura in 3 hours 35 minutes after the earthquake **(Figure 7, #8)** and about 4 minutes later at DUD **(Figure 7, #2 – 5)**. 20 minutes later after the first wave arrival, the second bigger wave hits Majuro. The wave refracts around the island and enters the lagoon center at the north through the Calalin Pass and other smaller passes **(Figure 7, #6 – 7)**. The second order seiches form in the lagoon with period of 30 min that continue many hours and attenuate slowly (**Figure 7, #2, #3**).
- The maximum tsunami heights around the atoll mostly vary within the range of 1.5 – 2.5 m exceeding these values at some points on the back side (in respect to the source location) next to Ronguron, Arniel and Djarrit islands.
- The outer reef serves as a barrier to the approaching tsunami. The maximum currents are getting bigger at the north part of the atoll (where are a lot of narrow passes) and exceed the 6-knot threshold between island and 9-knot threshold at the Calalin Pass and next to it between Eroj and Bokotana Islands. The 3-knot current attenuation times are the longest at the central pass to the lagoon – Calalin Pass and exceed two hours.

Conclusions

1. Arrival times for waves from the most hazardous source range from 3 hours 35 min – 3 hours 39 min. The maximum tsunami heights around the atoll mostly vary within the range of 1.5 – 2.5 m exceeding these values at some points on the back side.
2. The low-lying south-eastern (Rairik with Amata Kabua International Airport) and north-eastern (islands between Djarrit and Calalin) parts of the atoll are almost fully inundated, the DUD areas between Djarrit-Uliga and Uliga-Delap are also significantly inundated.
3. The large consistent currents exceeding the threshold of 9 knots form in the Calalin Pass (the main reef pass into the lagoon) due to the tsunami from the most hazardous source. The 3-knots attenuation time here is more than two hours.

References

1. NOAA National Centers for Environmental Information (NCEI), 2022, National Geophysical Data Center / World Data Service: NCEI/WDS Global Historical Tsunami Database. https://doi.org/10.7289/V5PN93H7
2. NTHMP, 2017, Proceedings and Results of the National Tsunami Hazard Mitigation Program 2015 Tsunami Current Modeling Workshop, February 9 – 10, 2015, Portland, Oregon: compiled by Patrick Lynett and Rick Wilson, 194 p.