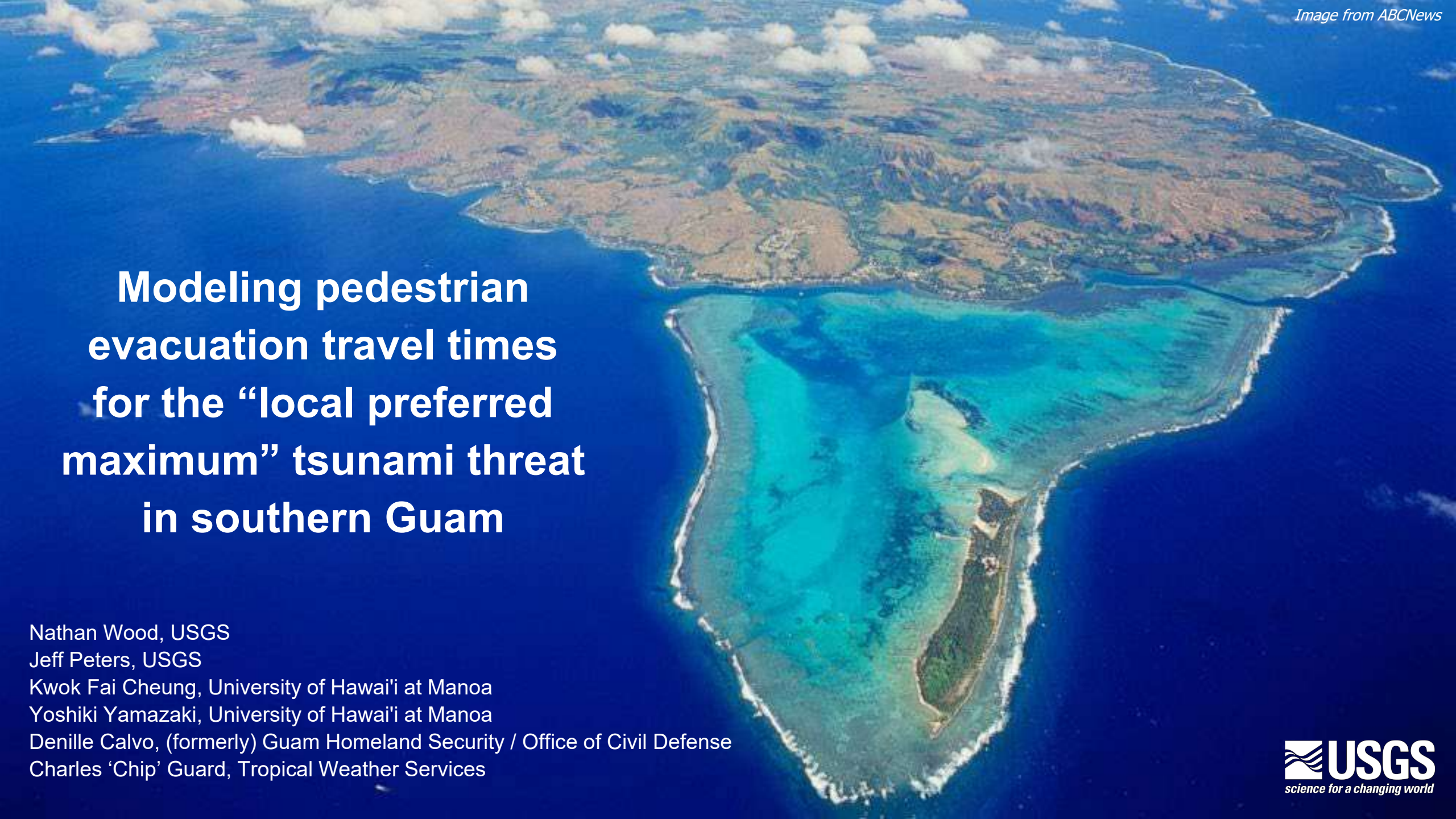

Modeling pedestrian evacuation travel times for the “local preferred maximum” tsunami threat in southern Guam

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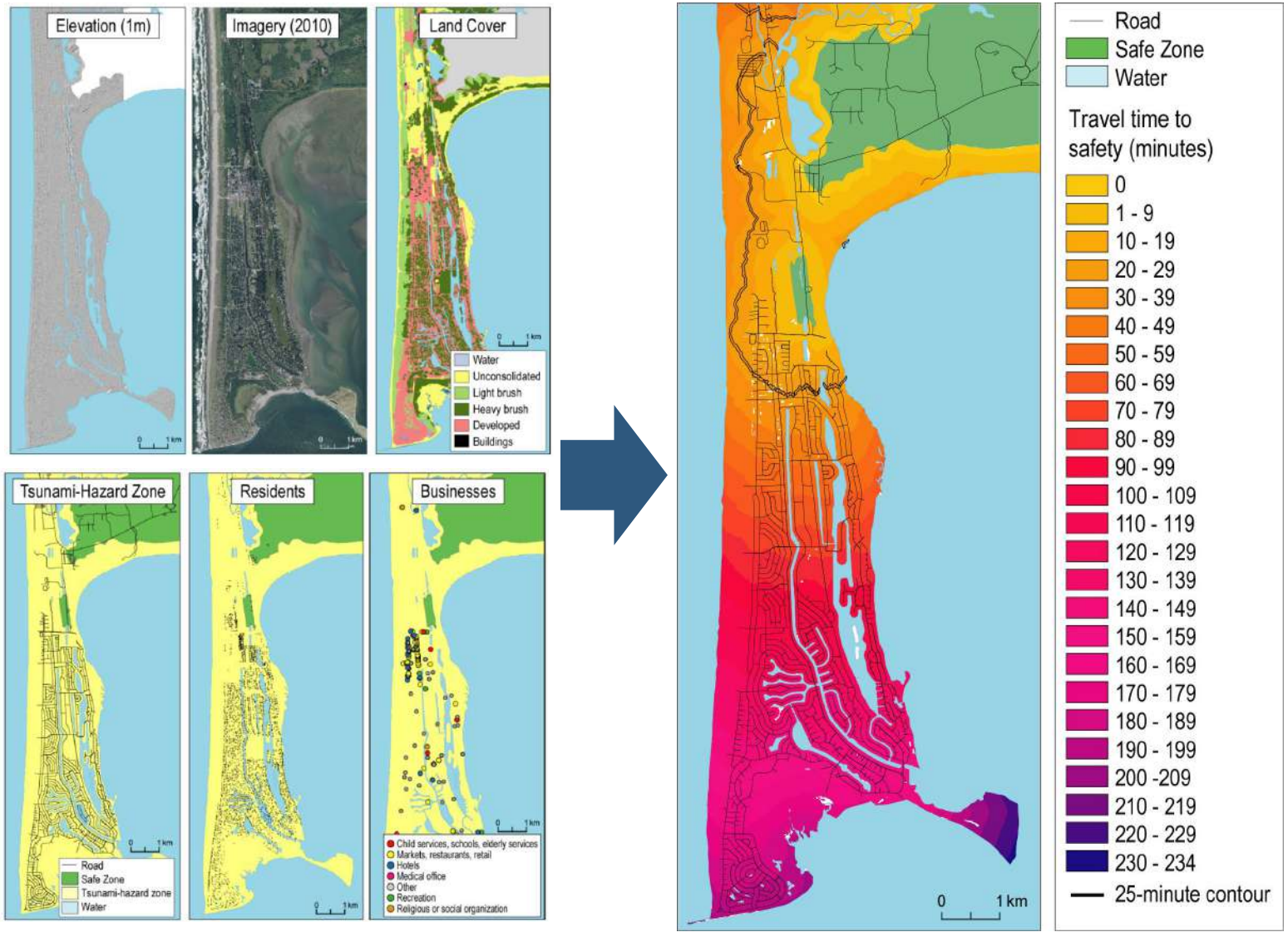
My Background

USGS representative to the U.S. National Tsunami Hazard Mitigation Program

USGS research geographer that specializes in research related to community vulnerability, including population hazard exposure and pedestrian evacuation modeling



Context for Study

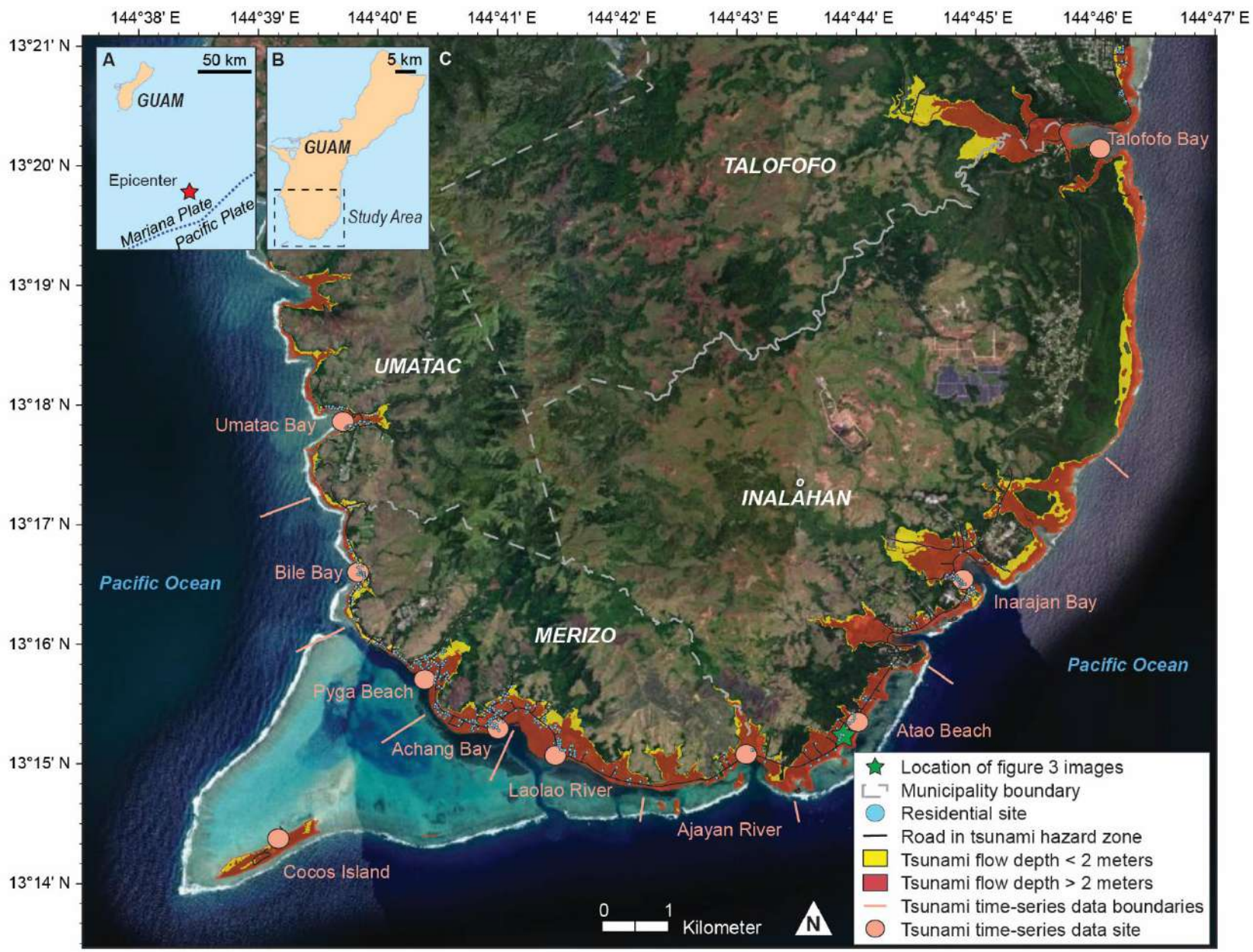
Guam is threatened by tsunamis that could arrive minutes after being created by a local earthquake

Mitigation strategies to save lives from local tsunamis used in other U.S. coastal communities, like vertical-evacuation structures, may not be necessary or feasible

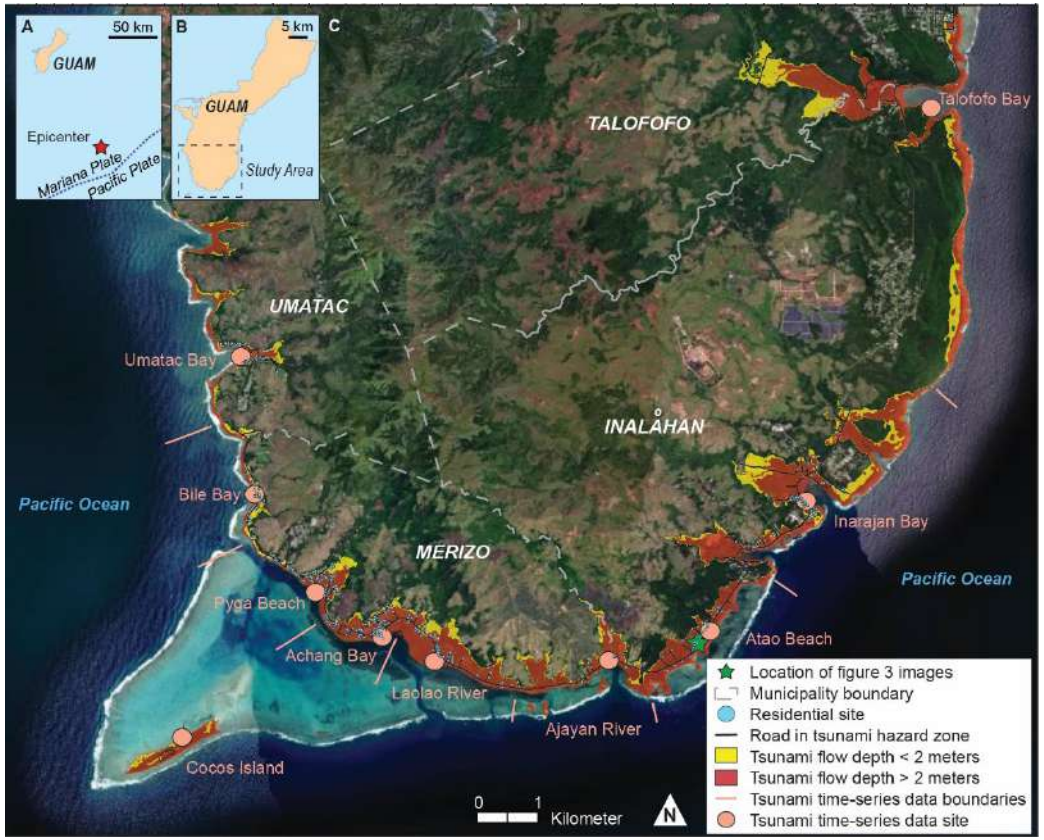
Guam coastal communities have far fewer numbers of at-risk people. High ground is very close, but may not be accessible due to vegetation

Study Overview

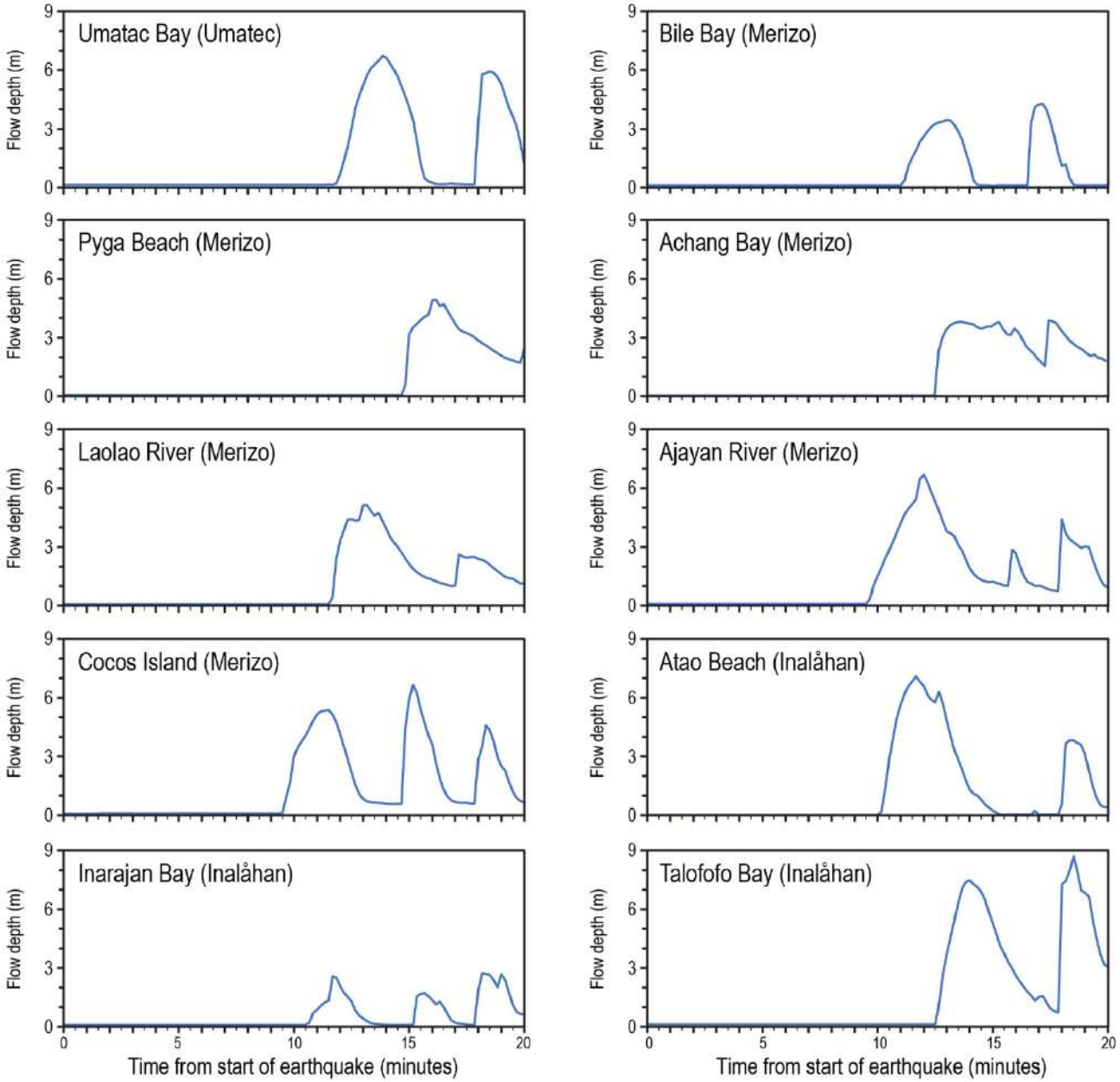
- Modeling pedestrian evacuations on southern coast of Guam to local tsunami threats associated with a Mariana subduction zone earthquake
- Based on new "**local preferred maximum**" tsunami-inundation maps completed by the University of Hawaii
- Evacuation modeling focused the number of saved lives based on:
  - Reducing departure delays
  - Increasing travel speeds
  - Creating new evacuation corridors through heavy brush



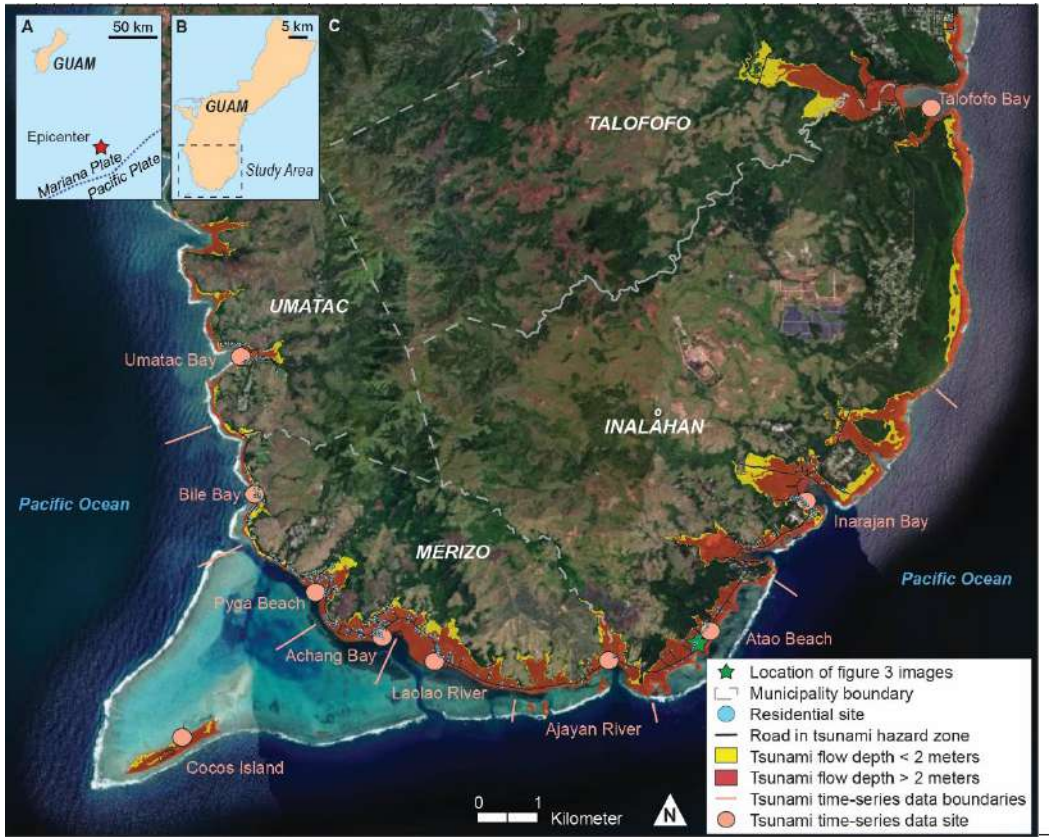
Wave-arrival time for various locations



***All graphs to the right are for locations on land and not for locations in the water.



Wave-arrival time for various locations



Original wave-arrival time

- When modeled flow depths reach 2 meters in height at **land** sites
- 2 meters is threshold for assuming 99% fatality in HAZUS

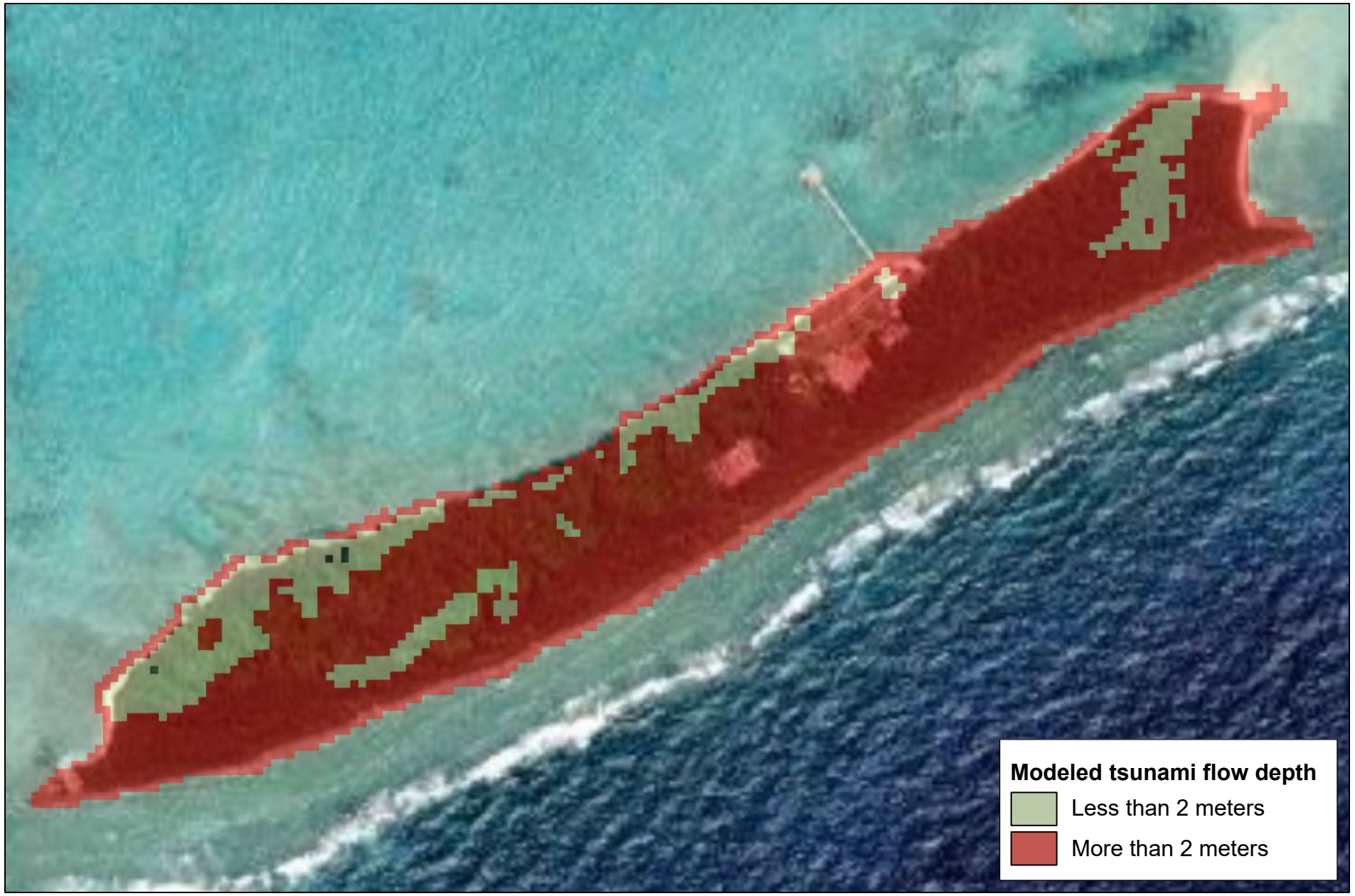
Further reduction of available time by 1.5 minutes

- May take ~15 s after earthquake start for ground shaking to reach Guam
- May be 25–30 s after that for strong shaking to develop
- Then additional 25–50 s for shaking to stop

Municipality	Nearby Geographic Name	Time (min) when flow depth >0 m	Time (min) when flow depth >2 m	Available evacuation time (min)	Time for peak flow depth (min)	Peak flow depth (m)
Umatac	Umatac Bay	11.8	12.3	10	13.8	6.7
Merizo	Bile Bay	11.2	11.8	10	17.2	4.2
Merizo	Pyga Beach	14.8	15	13	16.2	4.9
Merizo	Achang Bay	12.7	12.7	11	17.5	3.8
Merizo	Laolao River	11.7	11.8	10	13	5.1
Merizo	Ajayan River	9.7	10.3	8	12	6.7
Merizo	Cocos Island	9.7	10	8	15.2	6.6
Inalåhan	Atao Beach	10.2	10.5	9	11.7	7.1
Inalåhan	Inarajan Bay	10.7	11.7	10	18.2	2.7
Inalåhan	Talofofo Bay	12.7	12.8	11	18.5	8.7

Tsunami hazard zone on Cocos Island

- Modeled tsunami inundation covers all of Cocos Island
- Flow depths are primarily higher than 2 meters but isolated pockets of less than 2 meters
- No evacuation modeling done because no high ground available



Pedestrian Evacuation Modeling

- Used USGS Pedestrian Evacuation Analyst (least-cost distance model) developed by me and my team
- "Least cost distance models" determine the optimal path that results in the lowest "costs" based on the land that people are moving over (e.g., type of land and slope of land)
- Different scenarios

Travel speeds

- Impaired walk (~3 ft per second)
- Slow walk (~3.6 ft per second)
- Fast walk (~5 ft per second)

Departure delays:

- 0 minute
- 1 minute
- 3 minute
- 5 minute
- 10 minute

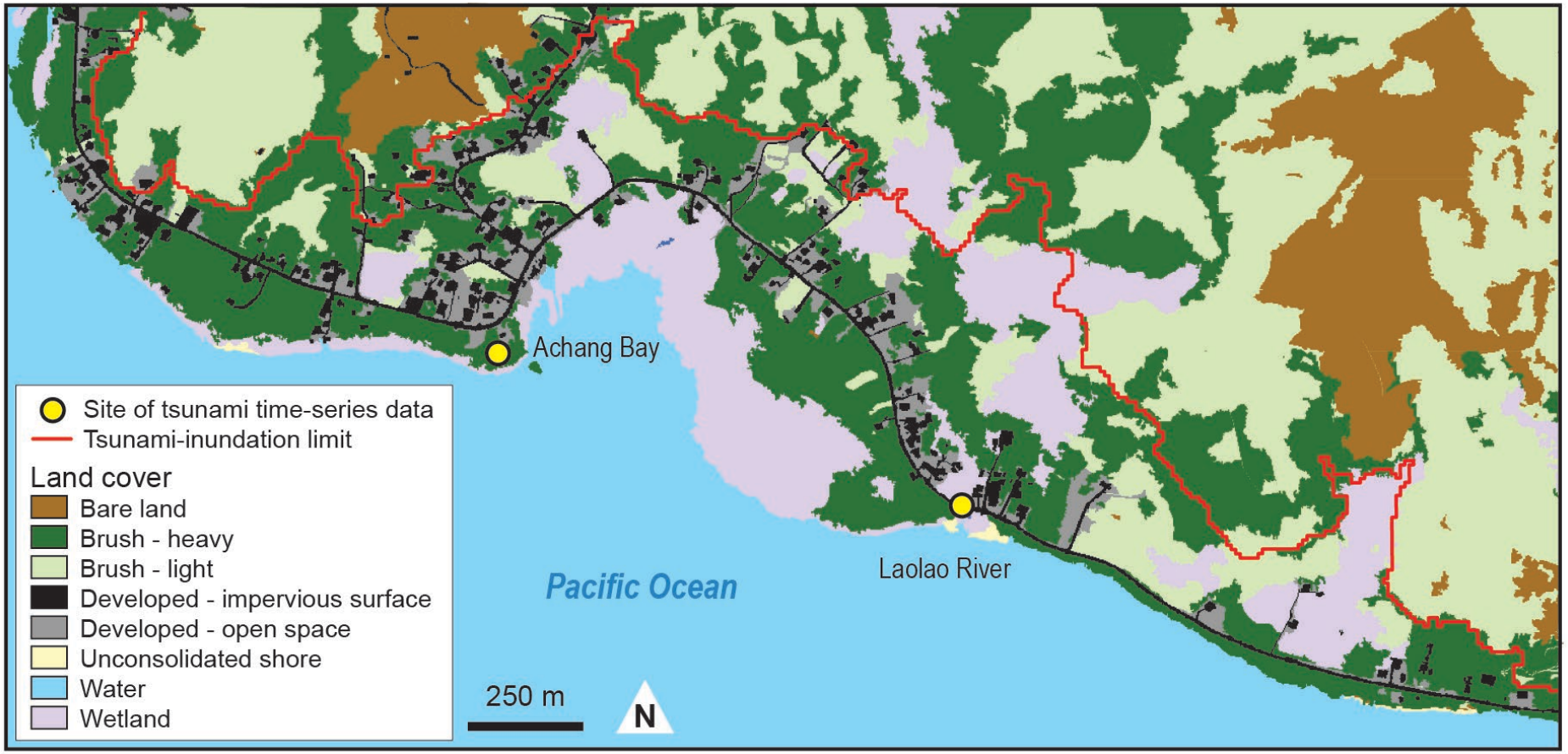
Changes in landcover assumption:

- "Heavy brush" treated impassable
- "Heavy brush" given values similar to gravel path

Pedestrian Evacuation Modeling – Modeling Inputs

- Slope based on 2020 1-m resolution, lidar-derived digital elevation model
- Types of land cover based on 2.4-m, 2016 NOAA C-CAP land-cover data
- Other land cover: roads, building footprints, and fences

- Residential points based on building footprints and 2010 Census blocks
- Business points based on purchased 2020 employee database from DataAxle and geolocated using Google View



Results of evacuation modeling

- Modeling creates maps of estimated travel times to safety out of the tsunami hazard zone
- We then estimate the number of locations where travel times are higher than wave arrival times
- We can change assumptions of pedestrian travel speeds and landscape conditions

*Assumes fast walk with no departure delay and inaccessible forests

Results of evacuation modeling – role of departure delays

Reducing departure delays had substantial impact of reducing the number of people with insufficient time

Municipality	Nearby Geographic Name	Residents in Hazard Zone	Number of residents with insufficient time to reach safety, given various departure-delay assumptions				
			No Delay	1 min	3 min	5 min	10 min
Umatac	Umatac Bay	156	0	0	0	0	144
Merizo	Bile Bay	124	2	2	2	4	124
Merizo	Pyga Beach	342	5	5	5	5	102
Merizo	Achang Bay	438	0	43	123	174	400
Merizo	Laolao River	280	157	162	202	230	270
Merizo	Ajayan River	21	0	0	6	8	21
Inalåhan	Ajayan River	18	0	7	7	7	18
Inalåhan	Atao Beach	101	40	48	62	79	101
Inalåhan	Inarajan Bay	281	0	0	14	14	259
Inalåhan	Talofofo Bay	8	0	0	0	0	0
Talofofo	Talofofo Bay	64	0	0	0	0	42
	Total	1835	204	266	421	522	1482

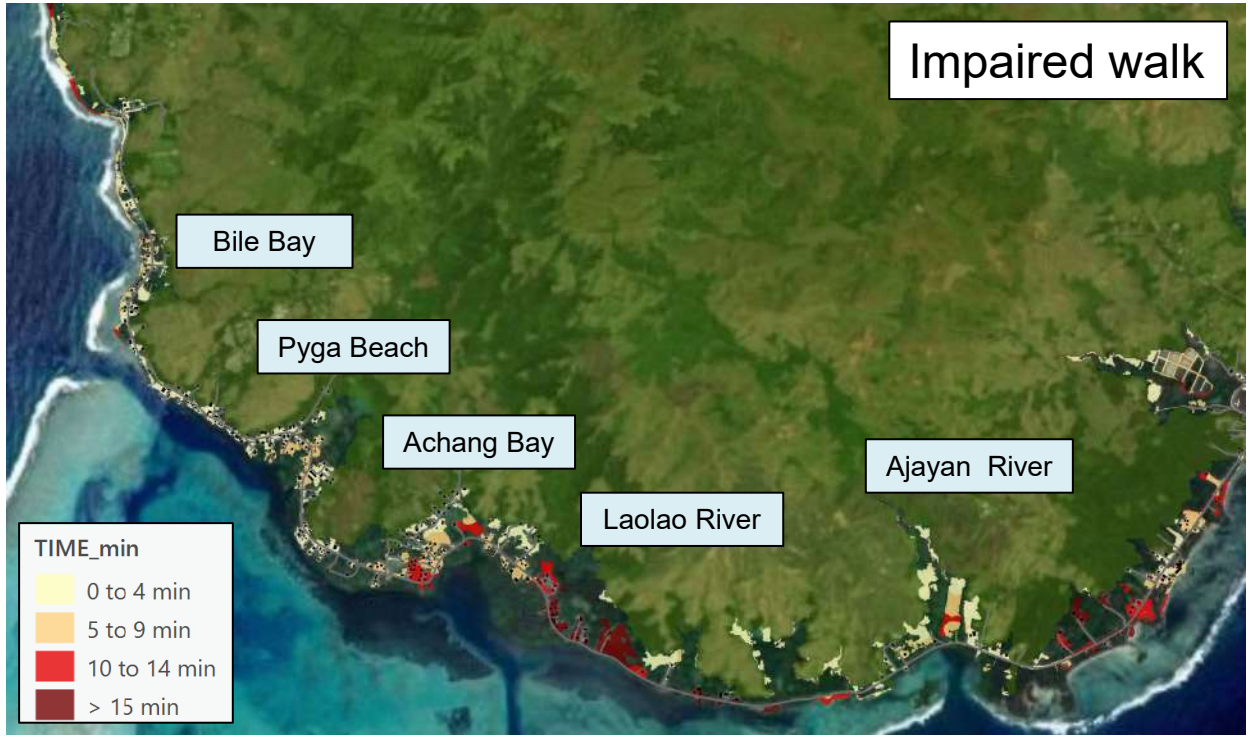
Results of evacuation modeling – Umatac/Humatak

- Estimated 156 residents in tsunami hazard zone
- Estimated available time to evacuate is 10 minutes
- Estimated travel times to safety are less than 4 minutes, even assuming “impaired walk” (~3 feet per sec.) and forested areas are inaccessible

Results of evacuation modeling – Merizo/Malesso

- Estimated 1,205 residents in tsunami zone
- Estimated available evacuation time is 8 minutes (Ajayan River) to 13 minutes (Pyga Beach)
- Travel time greater than wave arrival time for many near Laolao River

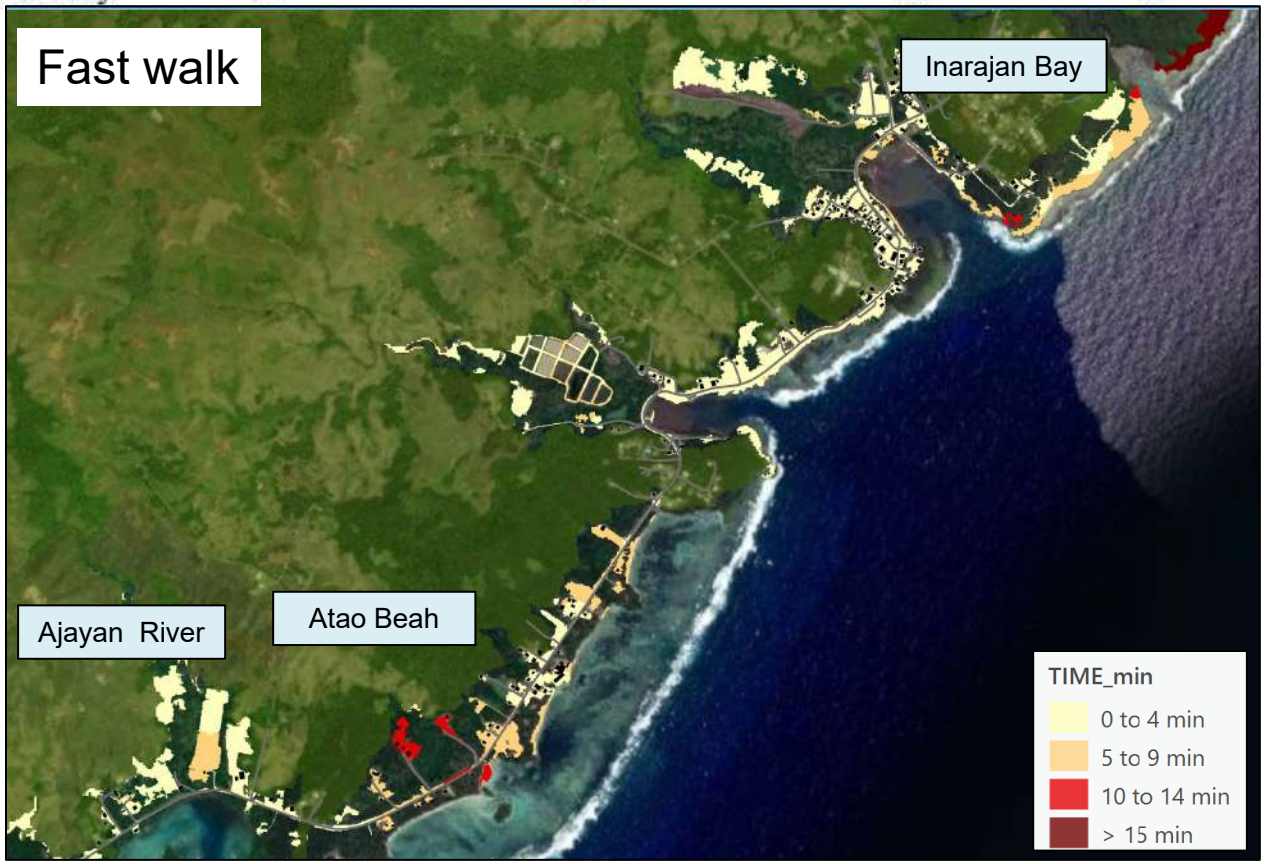
Nearby Geographic Name	Residents in Hazard Zone	Residents with insufficient time to evacuate assuming forest SCV = 0		
		Impaired Walk	Slow Walk	Fast Walk
Bile Bay	124	2	0	0
Pyga Beach	342	5	5	5
Achang Bay	438	0	0	0
Laolao River	280	157	142	75
Ajayan River	21	0	0	0



Results of evacuation modeling – Inalahan

- Estimated 408 residents in tsunami zone
- Estimated available evacuation time is 8 minutes (Ajayan River) to 11 minutes (Talofofo Bay)
- Travel time > wave arrival time near Atao Beach

Nearby Geographic Name	Residents in Hazard Zone	Residents with insufficient time to evacuate assuming forest SCV = 0		
		Impaired Walk	Slow Walk	Fast Walk
Ajayan River	18	0	0	0
Atao Beach	101	40	33	15
Inarajan Bay	281	0	0	0
Talofofo Bay	8	0	0	0



Results of evacuation modeling – Talofofo Bay

- Estimated 64 residents in tsunami zone
- Estimated travel time to safety (< 9 minutes) is less than wave arrival time (~11 minutes)

Nearby Geographic Name	Residents in Hazard Zone	Residents with insufficient time to evacuate assuming forest SCV = 0		
		Impaired Walk	Slow Walk	Fast Walk
Talofofo Bay	64	0	0	0

Results of evacuation modeling - role of new evacuation paths

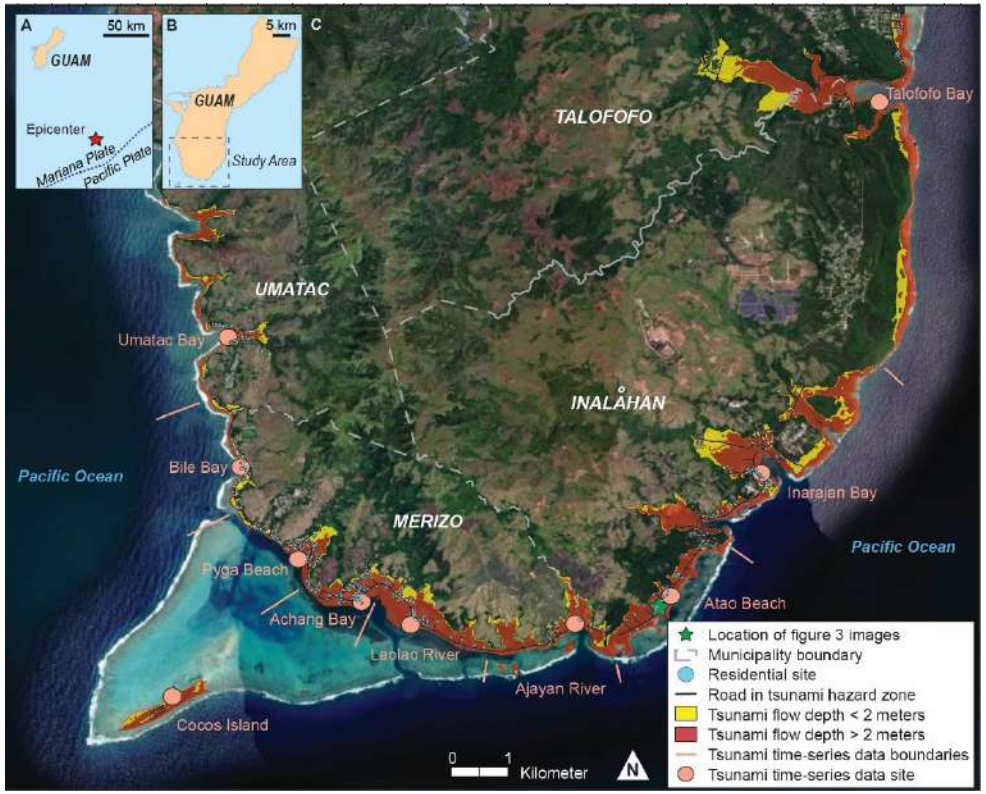
Travel times to safety are less than wave-arrival times for almost all at-risk individuals in the tsunami-hazard zone if one assumes faster travel speeds and new evacuation paths

Municipality	Nearby Geographic Name	Residents in Hazard Zone	Residents with insufficient time to evacuate assuming forest SCV = 0			Residents with insufficient time to evacuate assuming forest SCV = 0.9091		
			Impaired Walk	Slow Walk	Fast Walk	Impaired Walk	Slow Walk	Fast Walk
Umatac	Umatac Bay	156	0	0	0	0	0	0
Merizo	Bile Bay	124	2	0	0	0	0	0
Merizo	Pyga Beach	342	5	5	5	0	0	0
Merizo	Achang Bay	438	0	0	0	0	0	0
Merizo	Laolao River	280	157	142	75	53	14	0
Merizo	Ajayan River	21	0	0	0	0	0	0
Inalåhan	Ajayan River	18	0	0	0	0	0	0
Inalåhan	Atao Beach	101	40	33	15	7	0	0
Inalåhan	Inarajan Bay	281	0	0	0	0	0	0
Inalåhan	Talofofo Bay	8	0	0	0	0	0	0
Talofofo	Talofofo Bay	64	0	0	0	0	0	0
	Total	1835	204	179	95	60	14	0

Results of evacuation modeling – Creating Evacuation Paths

Municipality	Nearby Geographic Name	Residents in Hazard Zone	Residents with insufficient time to evacuate assuming forest SCV = 0			Residents with insufficient time to evacuate assuming forest SCV = 0.9091		
			Impaired Walk	Slow Walk	Fast Walk	Impaired Walk	Slow Walk	Fast Walk
Merizo	Laolao River	280	157	142	75	53	14	0
Inalåhan	Atao Beach	101	40	33	15	7	0	0

Results of evacuation modeling – Business exposure



- 28 nonresidential, business sites in the tsunami-hazard zone
- All sites except those with (*) are in areas with sufficient time to evacuate
- Government office in Pyga Beach has sufficient time if evacuation path created through forests
- People on Cocos Island wouldn't have sufficient time to evacuate out of mainland hazard zone

Municipality	Nearby Geographic Name	Cemetery	Entertainment	Government	Hotel	Religious Organization	Retail	Services	Total
Umatac	Umatac Bay						1		1
Merizo	Bile Bay				1	1	1		3
Merizo	Pyga Beach		3	1*		1	7	2	14
Merizo	Achang Bay						3		3
Merizo	Laolao River			1					1
Merizo	Cocos Island				1**			1**	2
Inalåhan	Inarajan Bay	1				2	1		4
	Total	1	3	2	2	4	13	3	28

Summary of study

1) There are an estimated 1,835 residents in the “local preferred maximum” tsunami hazard zone in the study area

2) At-risk people may not be able to see water level change before waves arrive because of thick vegetation and the brief amount of time before arrival

3) Reducing how long it takes people to start an evacuation to higher ground had the largest impact on reducing travel times to safety and the number of people with insufficient time before wave arrival

4) Creation of new evacuation trails through dense forested areas may save an estimated 144 people

5) All individuals at their homes and businesses have travel times to safety that are less than wave-arrival times **if** one assumes (a) little to no departure delays, (2) faster travel speeds, and (3) new evacuation paths through the forests in certain towns

6) The areas that could most benefit from evacuation training and creating maintained evacuation paths include the homes near Laolao River and Atao Beach.

Limitations of study

1) Modeled results suggest that people may have sufficient time to evacuate from a local MSZ-related tsunami; however, we assume at-risk individuals will immediately recognize the need to evacuate and will know where to go once they decide to move.

2) In the 2009 American Samoa tsunami, several studies indicated that many people did not evacuate until they observed the shoreline water levels drop; however, many people in southern Guam may not have a direct line of sight to the shoreline

3) Departure delays are common in other tsunami disasters and studies show that pre-disaster education and “wayfinding” strategies (e.g., signage, lighting) can be a critical factor in reducing these delays

4) Studies also suggest that including information about modeled evacuation times can help build confidence that it is worth to practice evacuation routes

5) If evacuation paths are created, then other things would help socialize them, such as signage, outreach, and creating assembly areas at the end of the uphill trail

Availability of journal article, data release, and software

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Modeling non-structural strategies to reduce pedestrian evacuation times for mitigating local tsunami threats in Guam

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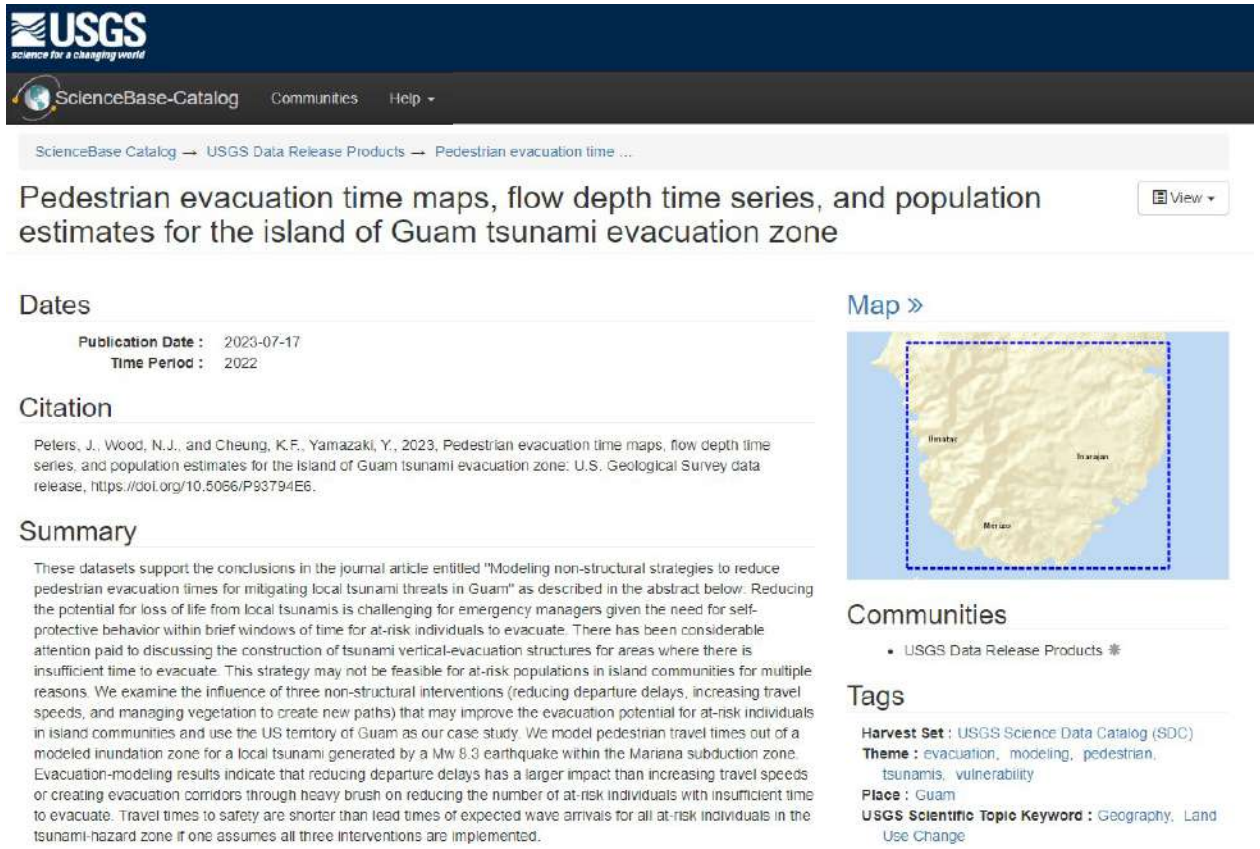
https://www.sciencedirect.com/science/article/abs/pii/S2212420923003394



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ScienceBase Catalog → USGS Data Release Products → Pedestrian evacuation time ...

Pedestrian evacuation time maps, flow depth time series, and population estimates for the island of Guam tsunami evacuation zone

View

Dates

Publication Date : 2023-07-17
Time Period : 2022

Citation

Peters, J., Wood, N.J., and Cheung, K.F., Yamazaki, Y., 2023, Pedestrian evacuation time maps, flow depth time series, and population estimates for the island of Guam tsunami evacuation zone: U.S. Geological Survey data release, https://doi.org/10.5066/P93794E6.

Summary

These datasets support the conclusions in the journal article entitled "Modeling non-structural strategies to reduce pedestrian evacuation times for mitigating local tsunami threats in Guam" as described in the abstract below: Reducing the potential for loss of life from local tsunamis is challenging for emergency managers given the need for self-protective behavior within brief windows of time for at-risk individuals to evacuate. There has been considerable attention paid to discussing the construction of tsunami vertical-evacuation structures for areas where there is insufficient time to evacuate. This strategy may not be feasible for at-risk populations in island communities for multiple reasons. We examine the influence of three non-structural interventions (reducing departure delays, increasing travel speeds, and managing vegetation to create new paths) that may improve the evacuation potential for at-risk individuals in island communities and use the US territory of Guam as our case study. We model pedestrian travel times out of a modeled inundation zone for a local tsunami generated by a Mw 8.3 earthquake within the Mariana subduction zone. Evacuation-modeling results indicate that reducing departure delays has a larger impact than increasing travel speeds or creating evacuation corridors through heavy brush on reducing the number of at-risk individuals with insufficient time to evacuate. Travel times to safety are shorter than lead times of expected wave arrivals for all at-risk individuals in the tsunami-hazard zone if one assumes all three interventions are implemented.

Map »

Communities

- USGS Data Release Products

Tags

Harvest Set : USGS Science Data Catalog (SDC)
Theme : evacuation, modeling, pedestrian, tsunamis, vulnerability
Place : Guam
USGS Scientific Topic Keyword : Geography, Land Use Change

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https://www.sciencebase.gov/catalog/item/638e5260d34ed907bf7bc838

**** Pedestrian Evacuation Analyst freely available from USGS and we can train people how to use it**