第59回自然災害科学総合シンポジウム
2022年9月26日　@オンライン、京都

【自然災害研究協議会突発災害調査報告】「トンガの噴火による非地震性津波に対する避難状況の確認の調査」

有川　太郎（中央大学理工学部都市環境学科）

どんな津波であったのか

参照した報告書（論文）

Tsunami Runup and Inundation in Tonga from the January 2022 eruption of Hunga Volcano

Submitted 8 September 2022

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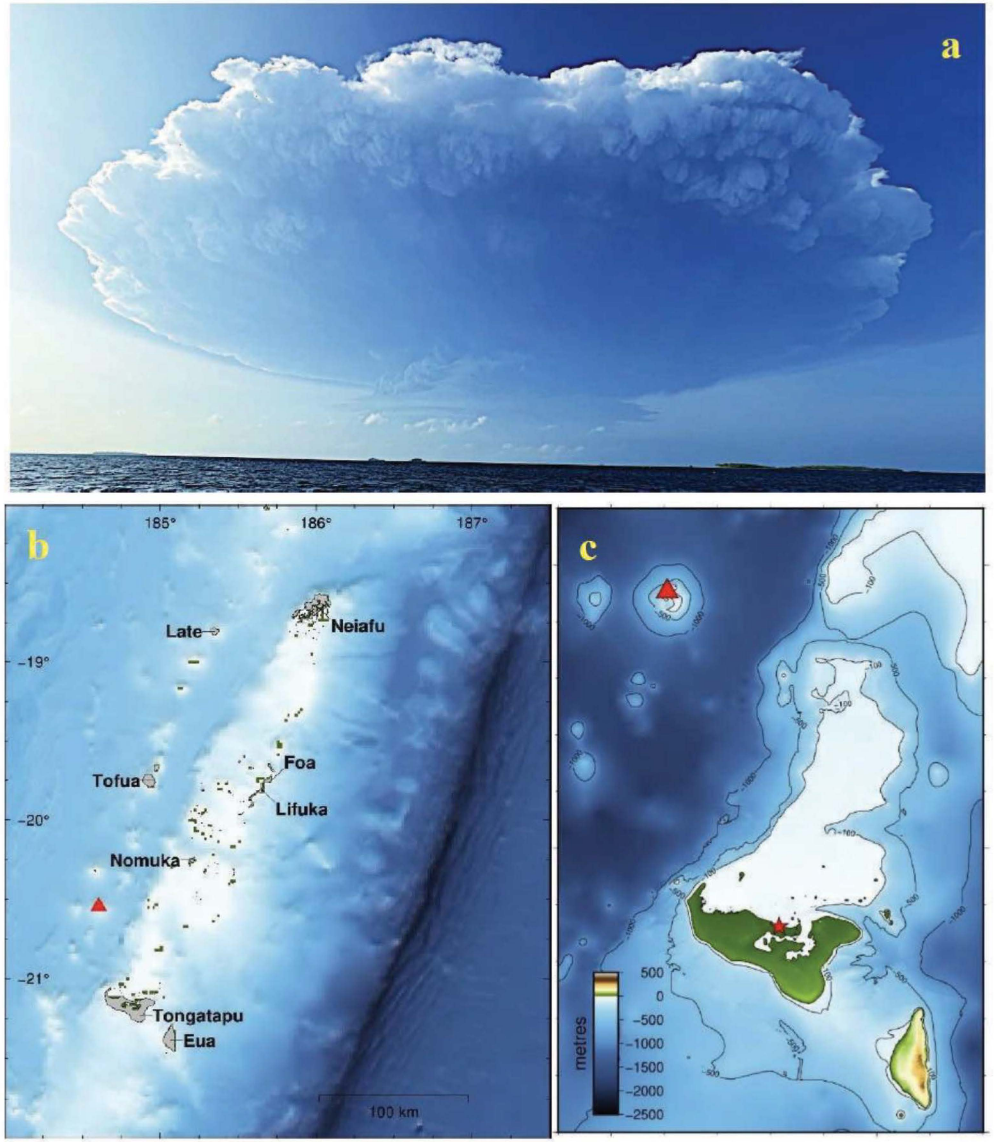
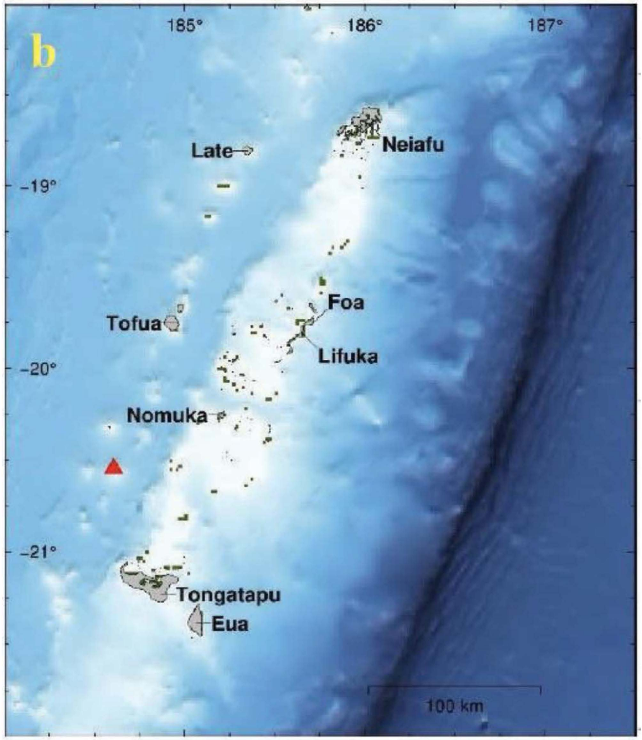


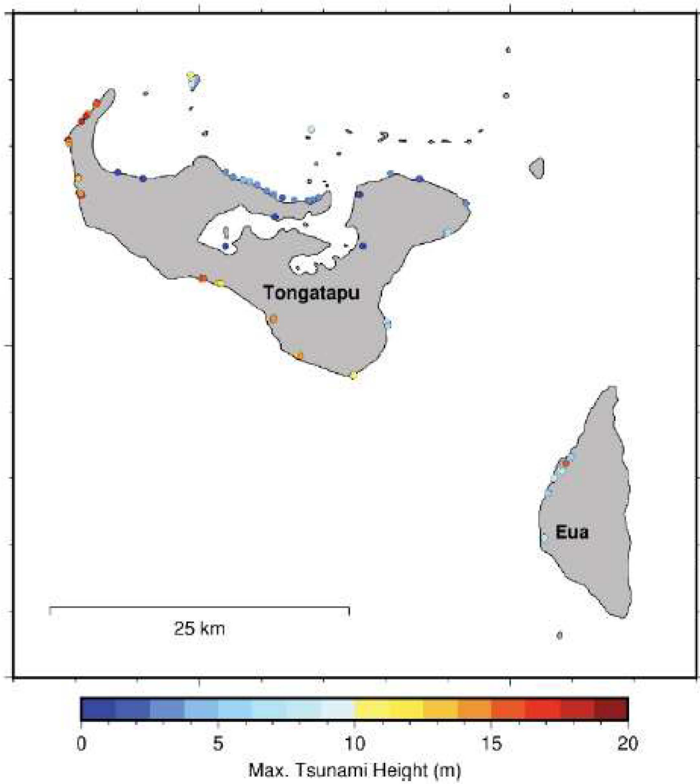
Fig. 1 (a) The eruption rising to its climax at 5.24 pm (0424 UTC) January 15th from ~10 km north of Tongatapu (Photo: Branko Sugar); the upper plume is already >100 km wide. (b) The location of major islands in the Kingdom of Tonga, with Hunga volcano indicated with a red triangle. (c) The bathymetry around Tongatapu and 'Eua islands

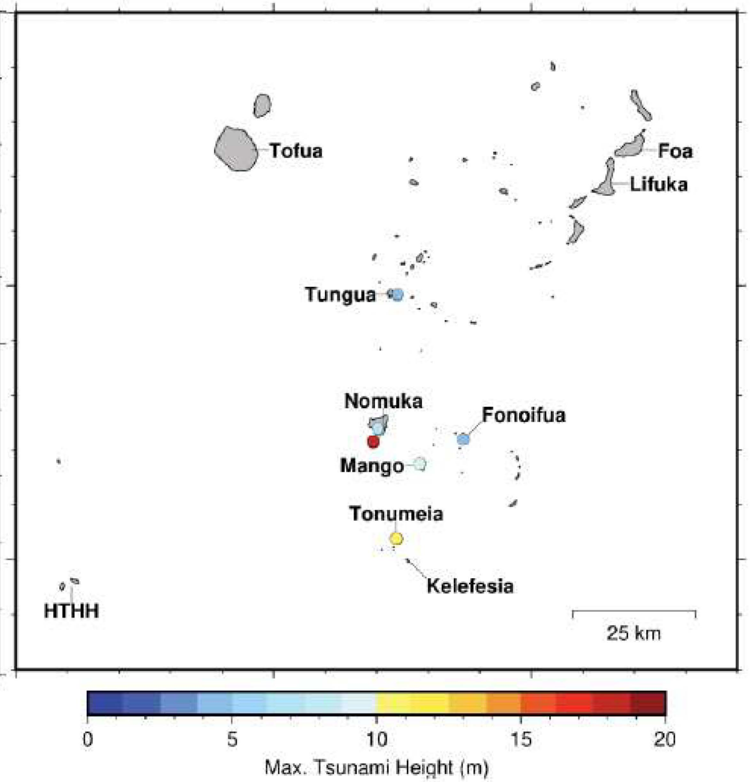
On January 15th, 2022, at approximately **4:47 pm local time** (0347 UTC), several weeks of heightened activity at Hunga volcano culminated in an 11-hour long violent eruption, 65 km northwest of the main populated island of Tongatapu in the Kingdom of Tonga (Fig. 1). Hunga is often referred to by the names of two small islands Hunga-Tonga and Hunga Ha'apai that are located on the submarine caldera's northern rim (Cronin et al., 2017), During the first 45 minutes of this eruption, a massive atmospheric pressure wave and a series of tsunamis were generated and observed around the world (Carvajal et al., 2022, Lynett et al., 2022).

2022年1月15日、現地時間午後4時47分（0347 UTC）頃、フンガ火山の数週間にわたる活発な活動は、トンガ王国の主要人口島トンガタプの北西65kmで11時間にわたる激しい噴火に至った（図1）。フンガは、海底カルデラの北縁に位置する2つの小島フンガ・トンガとフンガ・ハアパイの名前で呼ばれることが多く（Cronin et al., 2017）、この噴火の最初の45分間は、大規模な大気圧波と一連の津波が発生し世界中で観測された（Carvajal et al, 2022, Lynett et al, 2022）。
(DeepLによる翻訳)

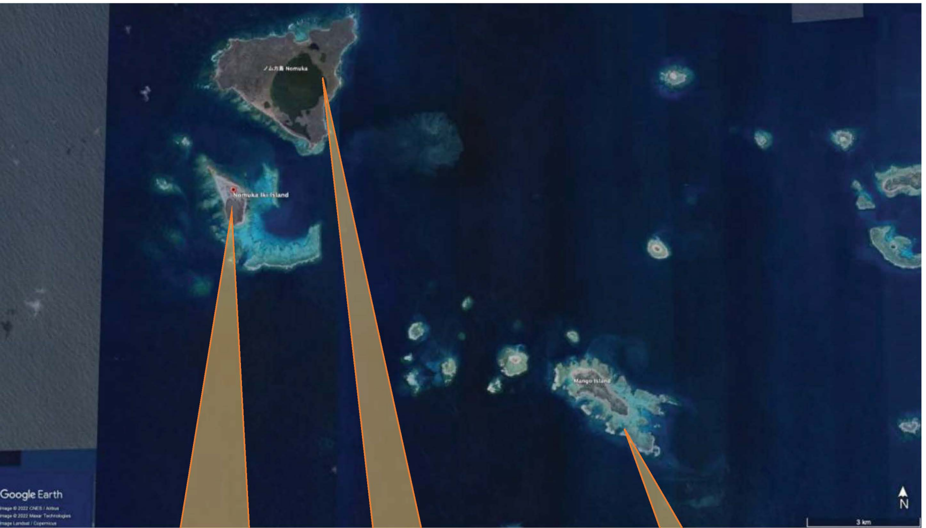
Summary data plots of maximum tsunami height for Tongatapu and 'Eua (left) and Ha'apai islands (right). HTHH = Hunga Tonga – Hunga Ha'apai Volcano







Nomuka iki island



Nomuka iki island

around 12.6- 20.0m on cliff

Runup height

Nomuka island

around 5.4 -10.0 m

Mango island

around 7.5m

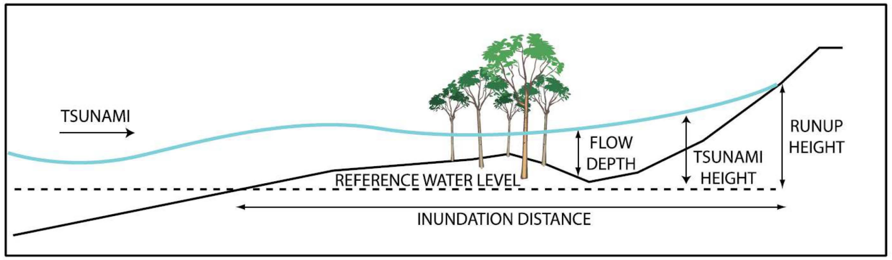
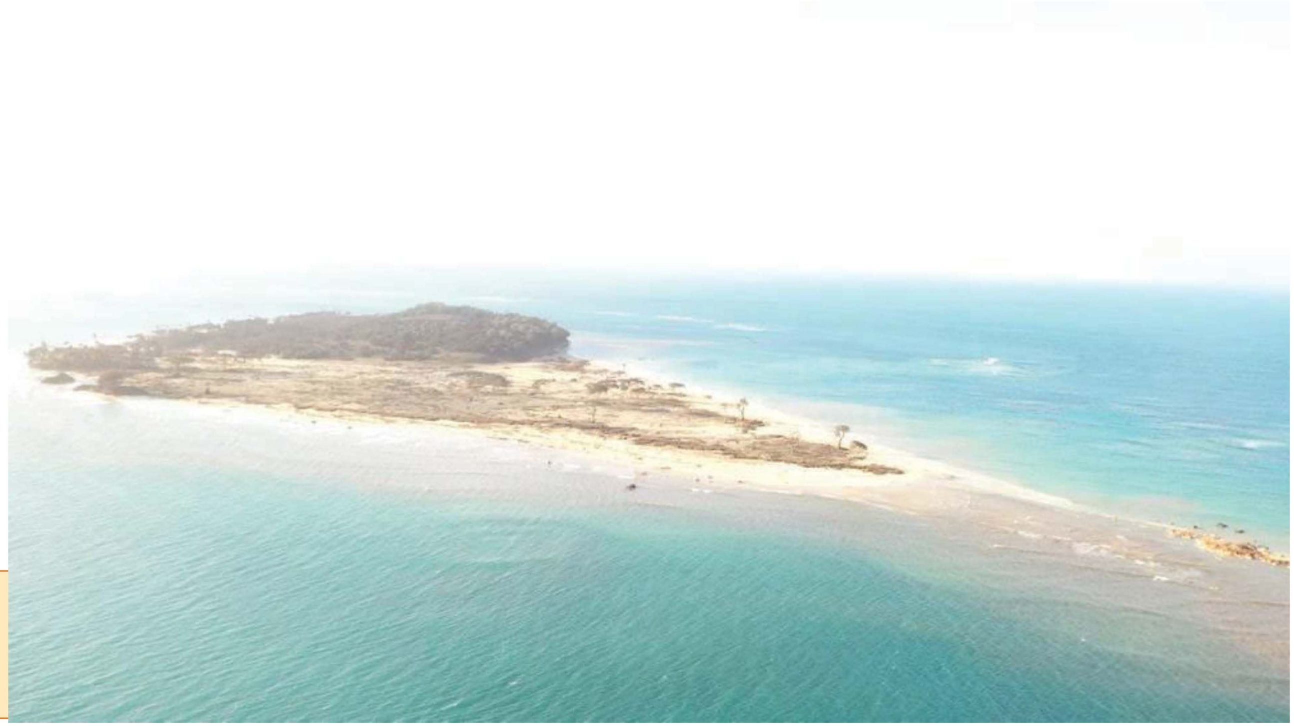
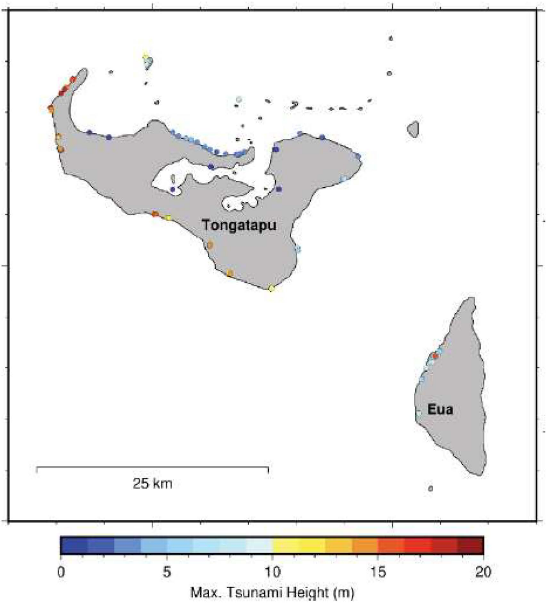


Figure 1.4 Definition sketch for tsunami flow terms.



video taken by TGS, 2022.01.19

Tongatapu island



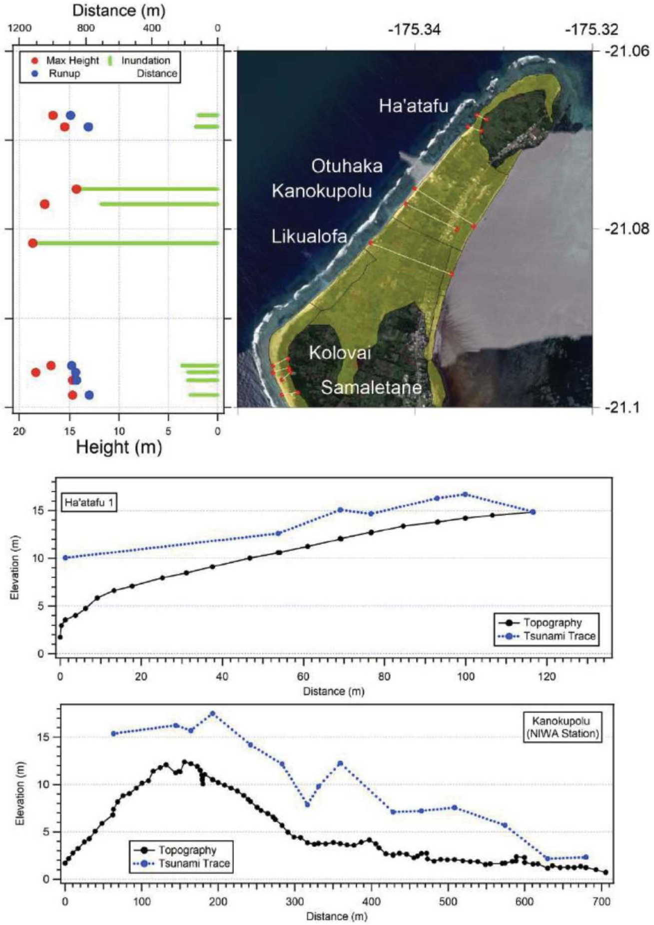


Fig. 7 Locations surveyed along the western coast of Tongatapu. The start and endpoints of each transect are indicated with the red dot. Green tringle indicates the location of the NIWA weather station. Yellow shaded area indicated extents of inundation. Left plot shows maximum tsunami trace height and maximum runup height along each transect, right plot shows maximum inundation distance.

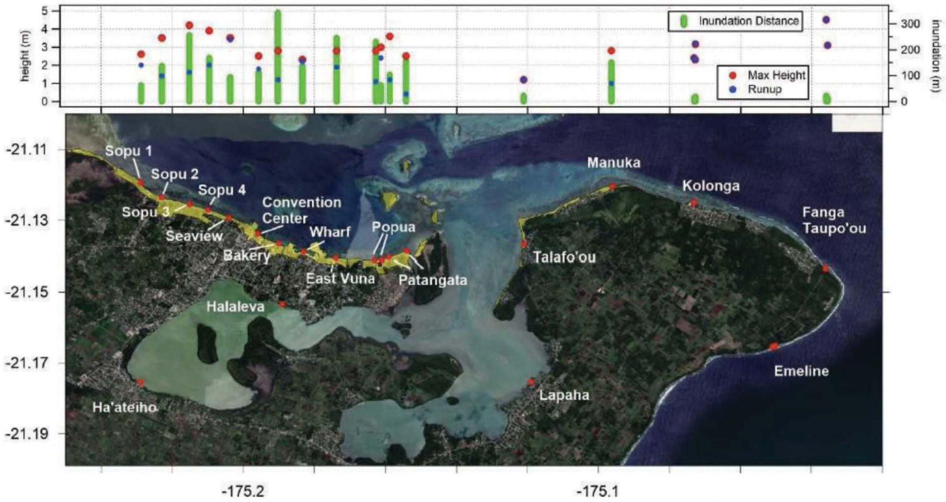


Fig. 9 Maximum tsunami trace elevation (red) and run up height (blue) along the north coast of Tongatapu.

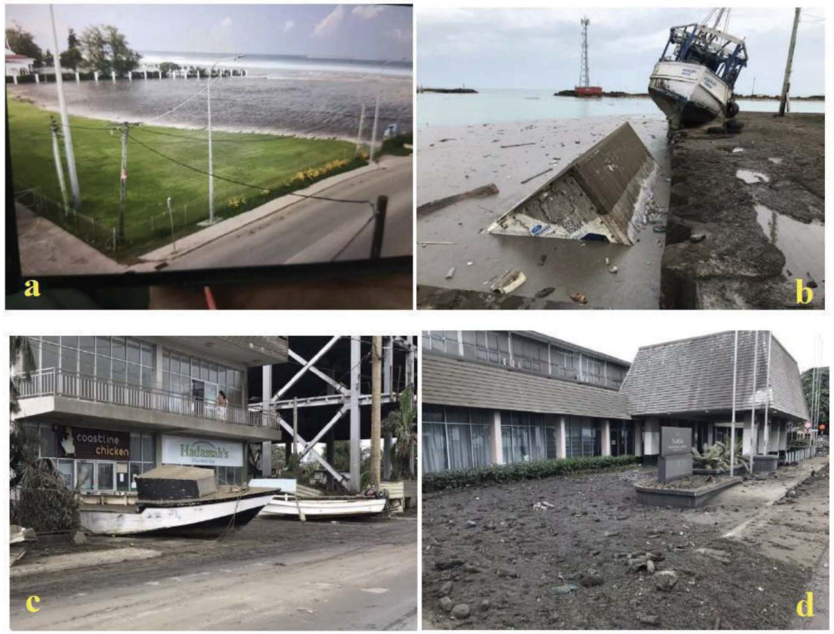
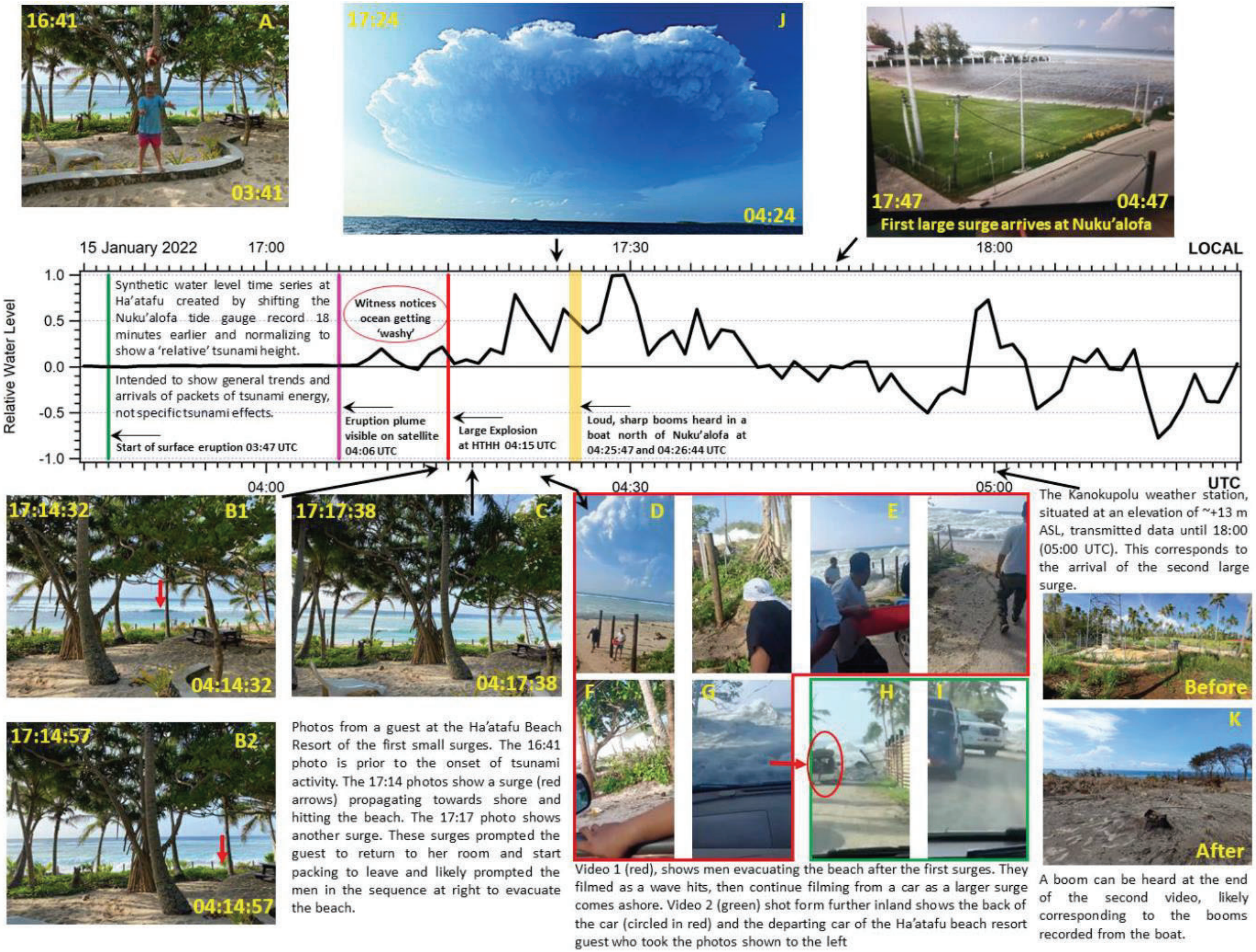


Fig. 10 Scenes from Nuku'alofa (a) tsunami surge coming ashore on the grounds of the Royal Palace at 17:47 local time (b, c) some smaller vessels were floated on to the wharf decks (d) inundation at the Tanoa Hotel along the waterfront.

Eruption, 2022.01.14

video taken by TGS, 2022.01.14

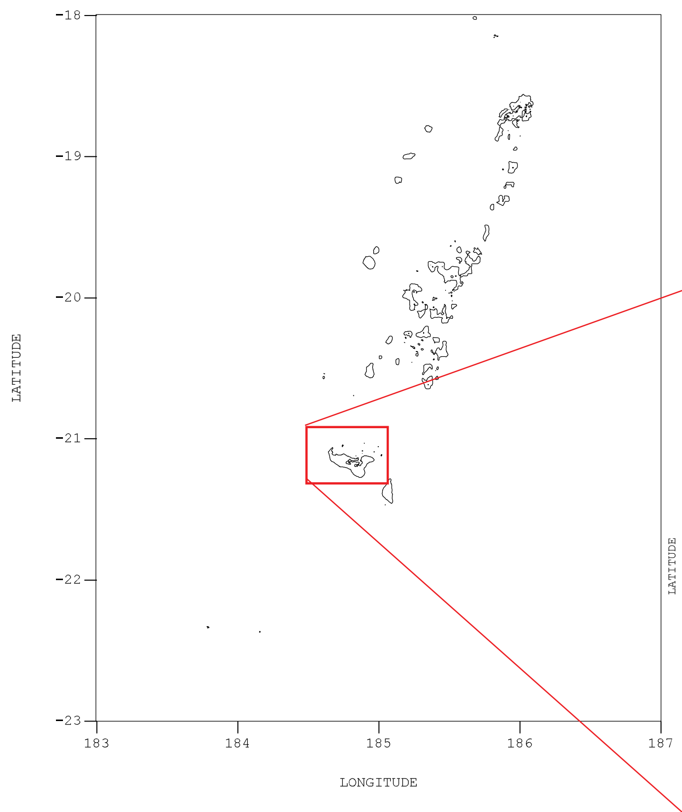
Tsunami arrival situation at Tongatap



数値シミュレーションではどうか

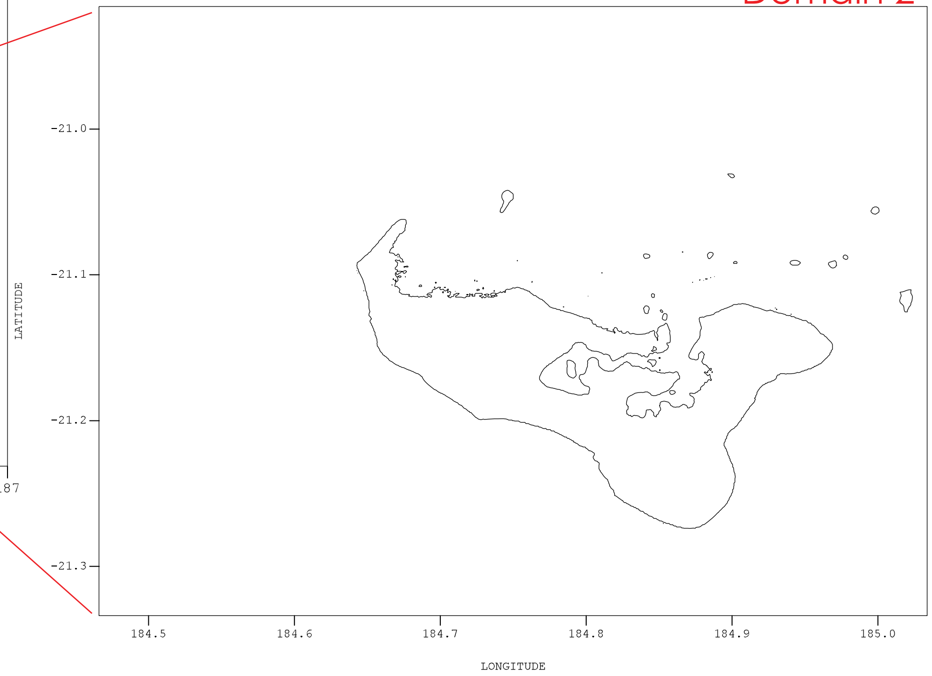
Calculation conditions

Domain 1

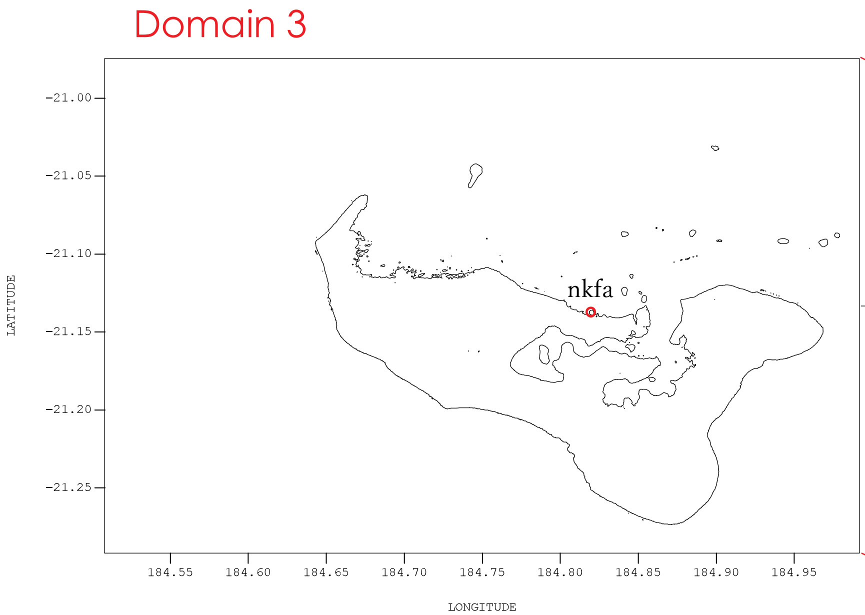


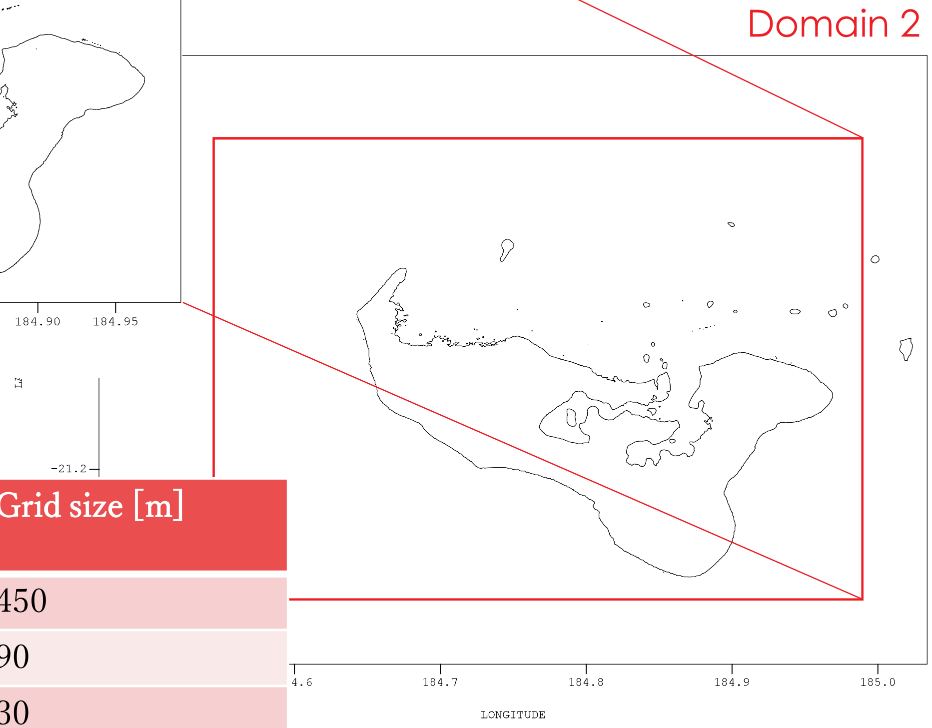
	Size Width x Height	Grid size [m]
Domain 1	960 x 1200	450
Domain 2	680 x 500	90
Domain 3	1740 x 1140	30

Domain 2



Calculation conditions

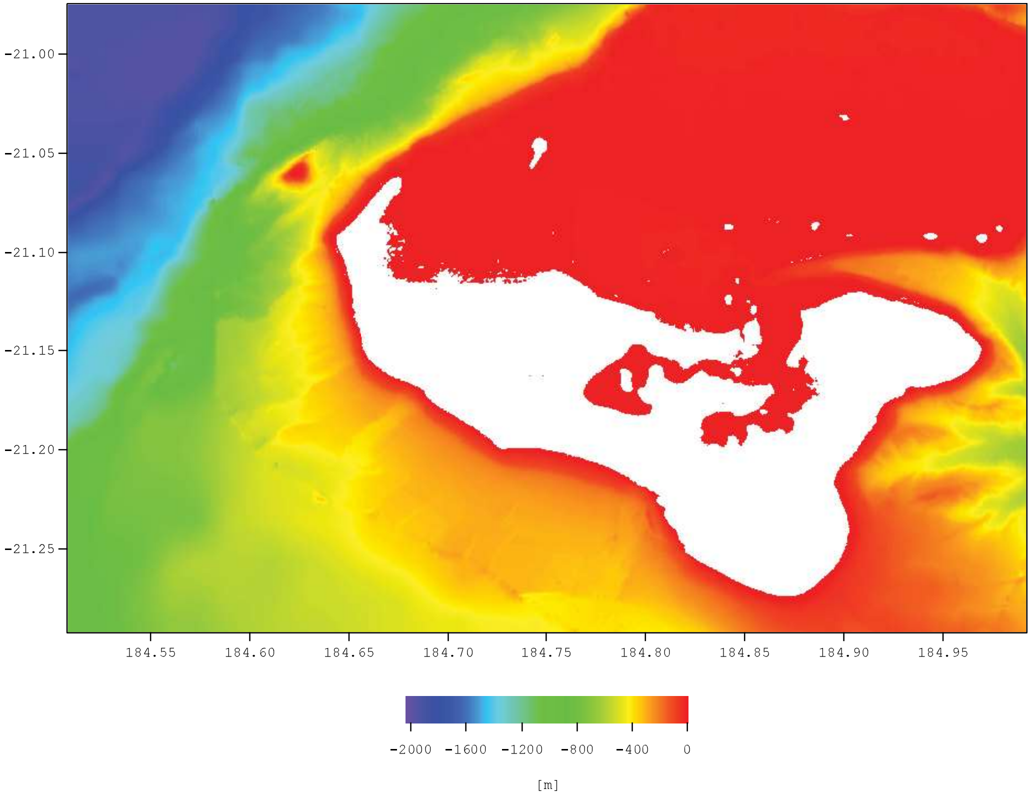




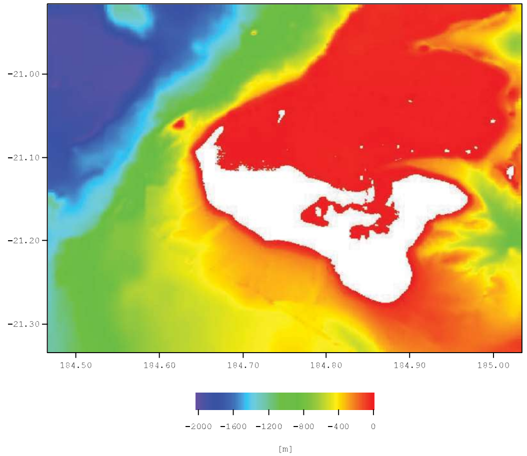
	Size Width x Height	Grid size [m]
Domain 1	960 x 1200	450
Domain 2	680 x 500	90
Domain 3	1740 x 1140	30

Topography

Domain 2

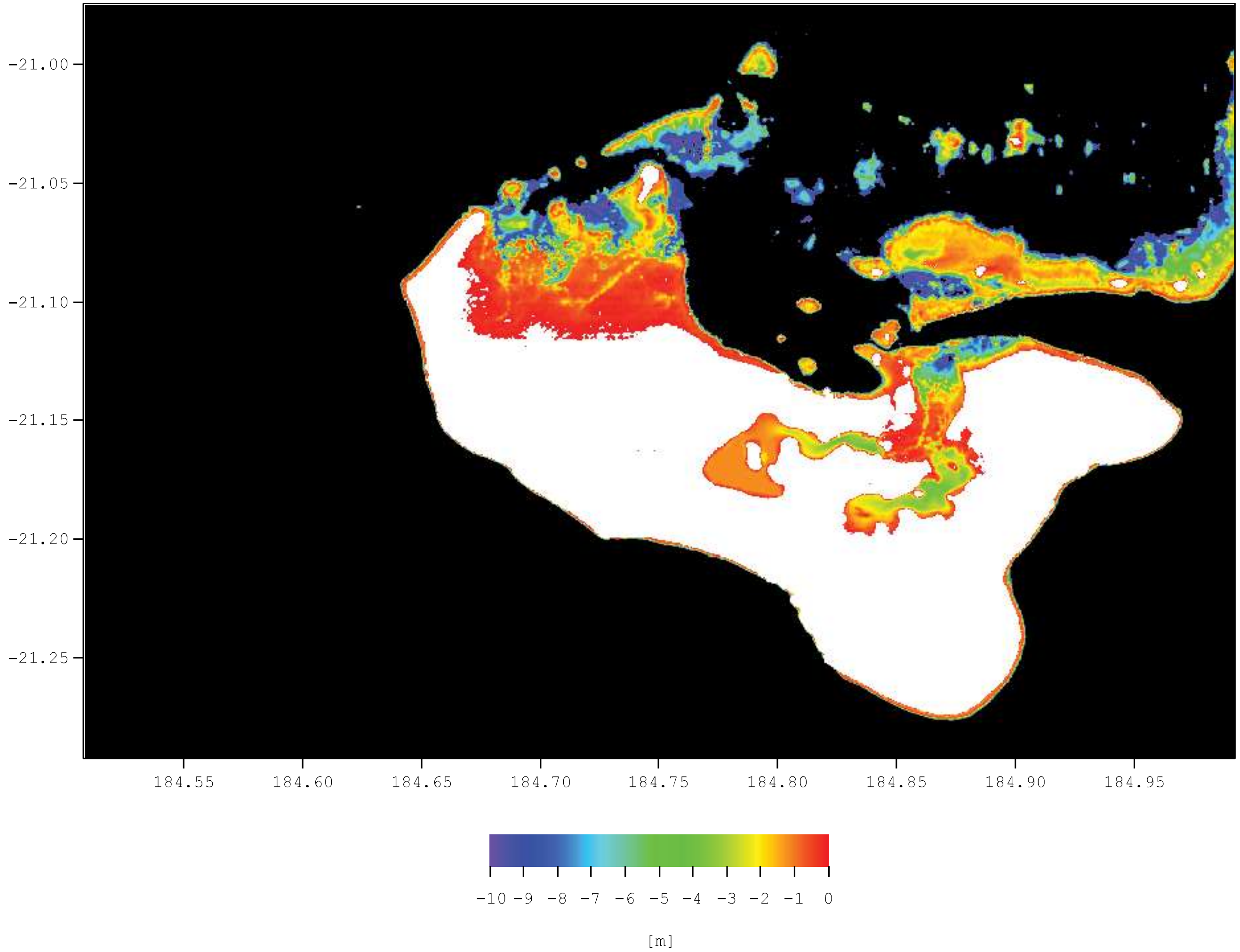


Domain 3



Topography

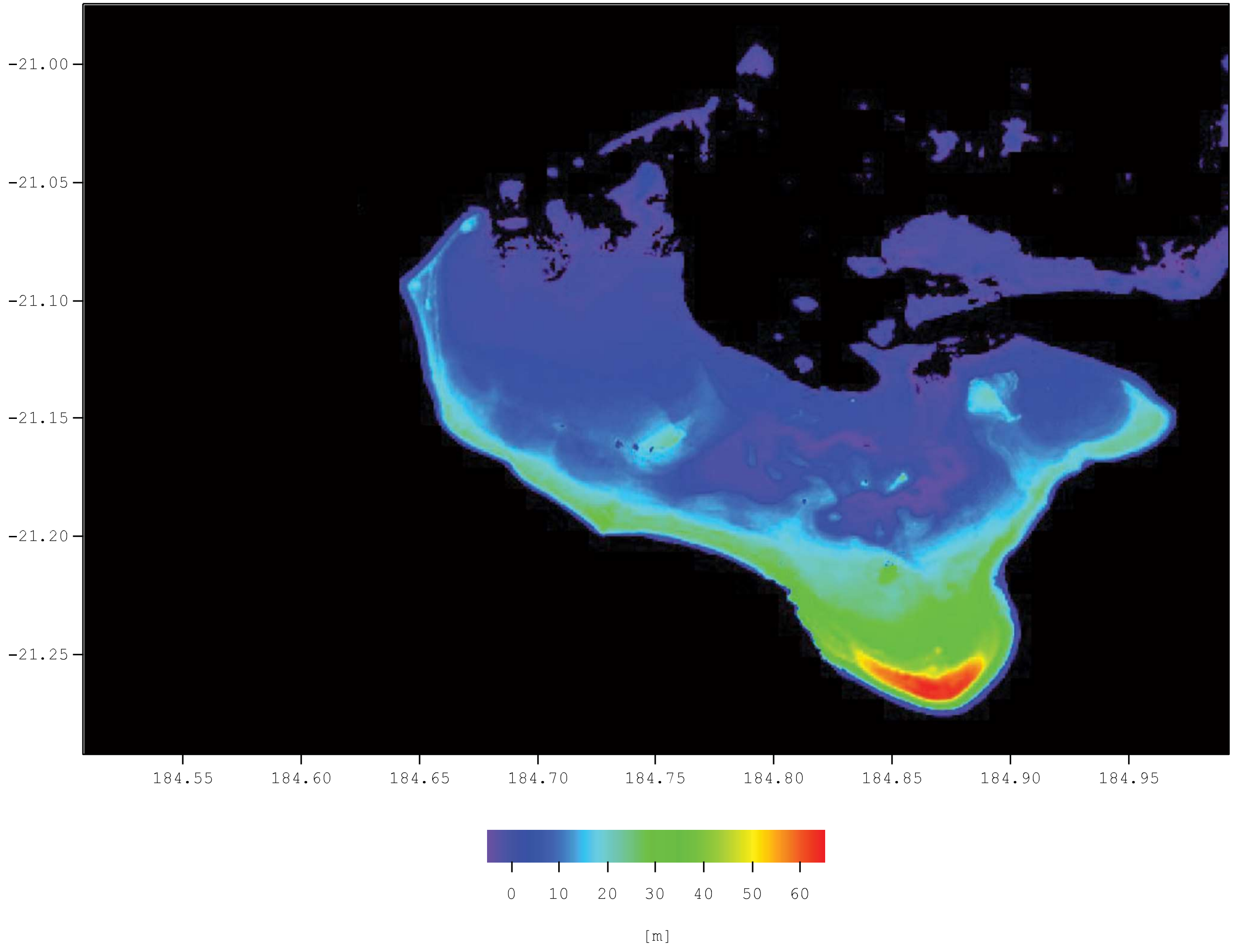
Domain 3



2022年8月13日　撮影

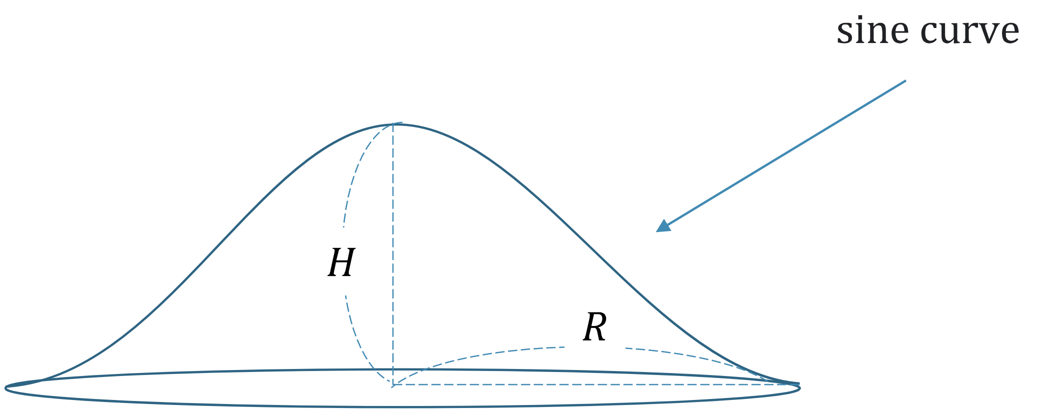
Topography

Domain 3



Calculation conditions

- Sea-level rise



R : distance from the burst center [m]

H : Maximum rise [m]

$R = 5000\text{m}, H = 45\text{m}$

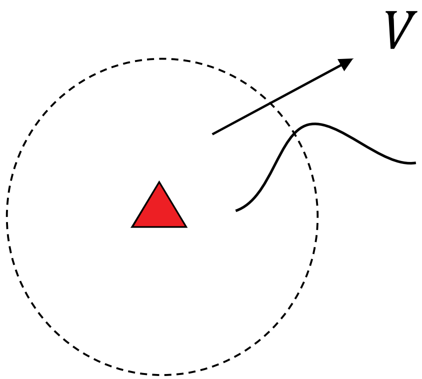
Calculation conditions

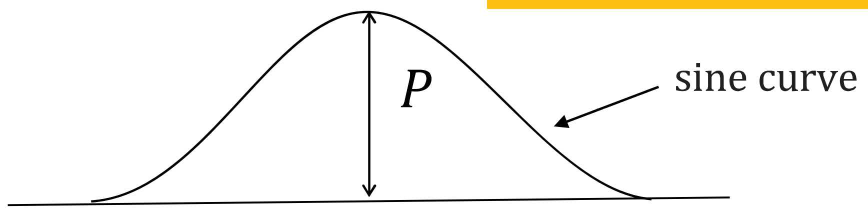
- Atmospheric pressure fluctuations

$$L = \begin{cases} \dfrac{L_1 - L_0}{P_1 - P_0}(\Delta P - P_0) + L_0, & L \le L_1 \\ L_1, & L > L_1 \end{cases}$$

$$L_0 = 2\,R\Big|_{\Delta P = P_0},\ L_1 = VT$$

L : wavelength, V : velocity, T : period

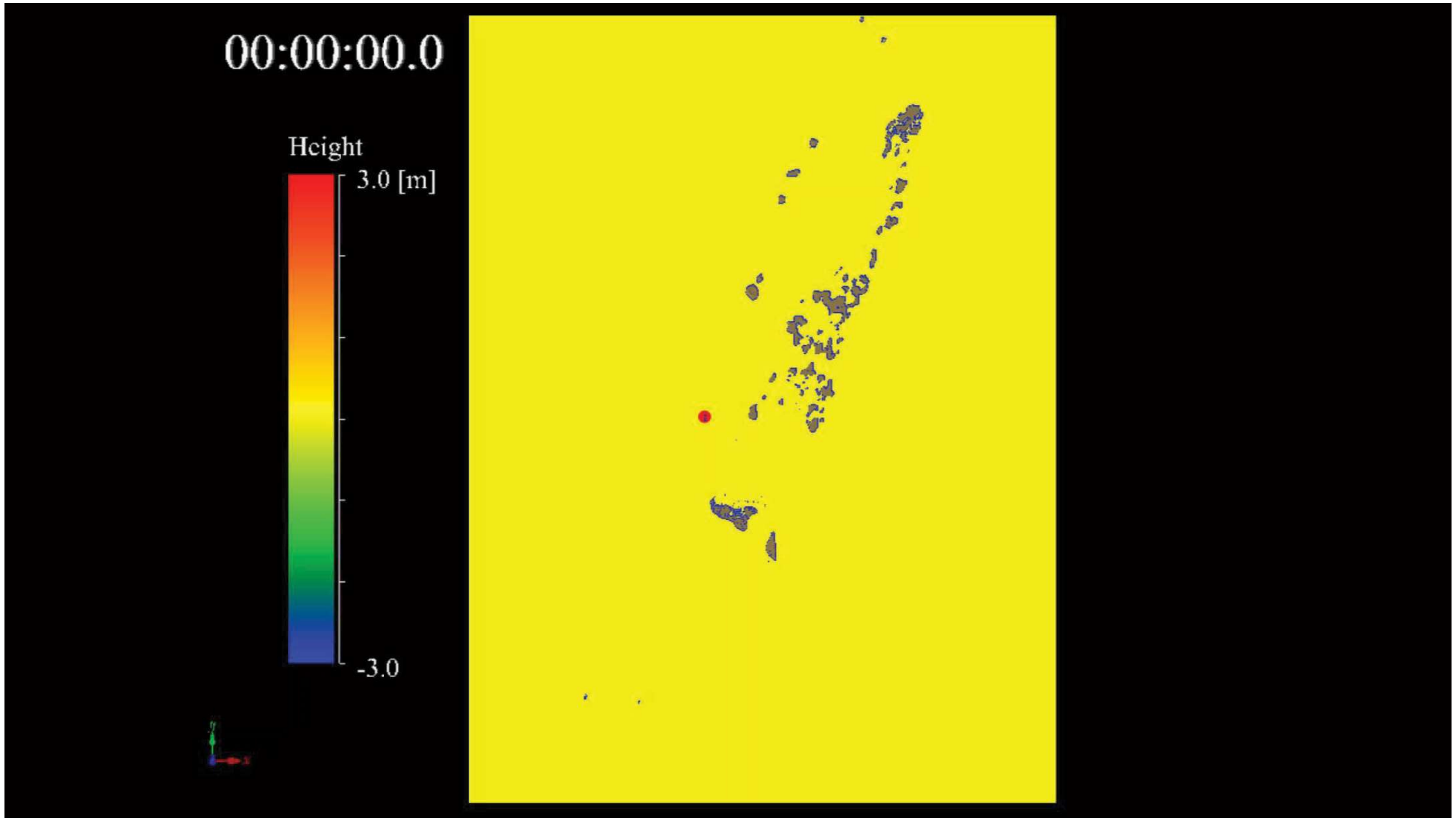




$P_0 = 500\text{hPa}, P_1 = 2\text{hPa}$
$T = 600\text{s}, V = 310\text{m/s}$

Result

Domain1

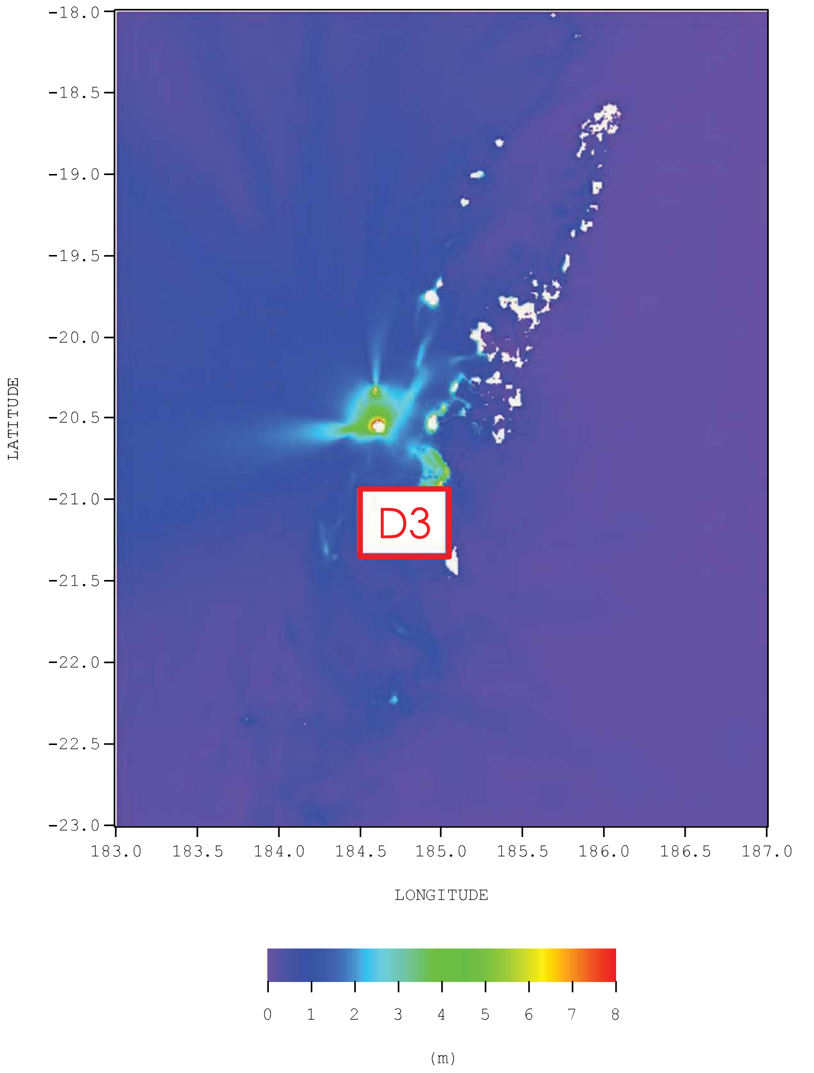


Result

Domain3

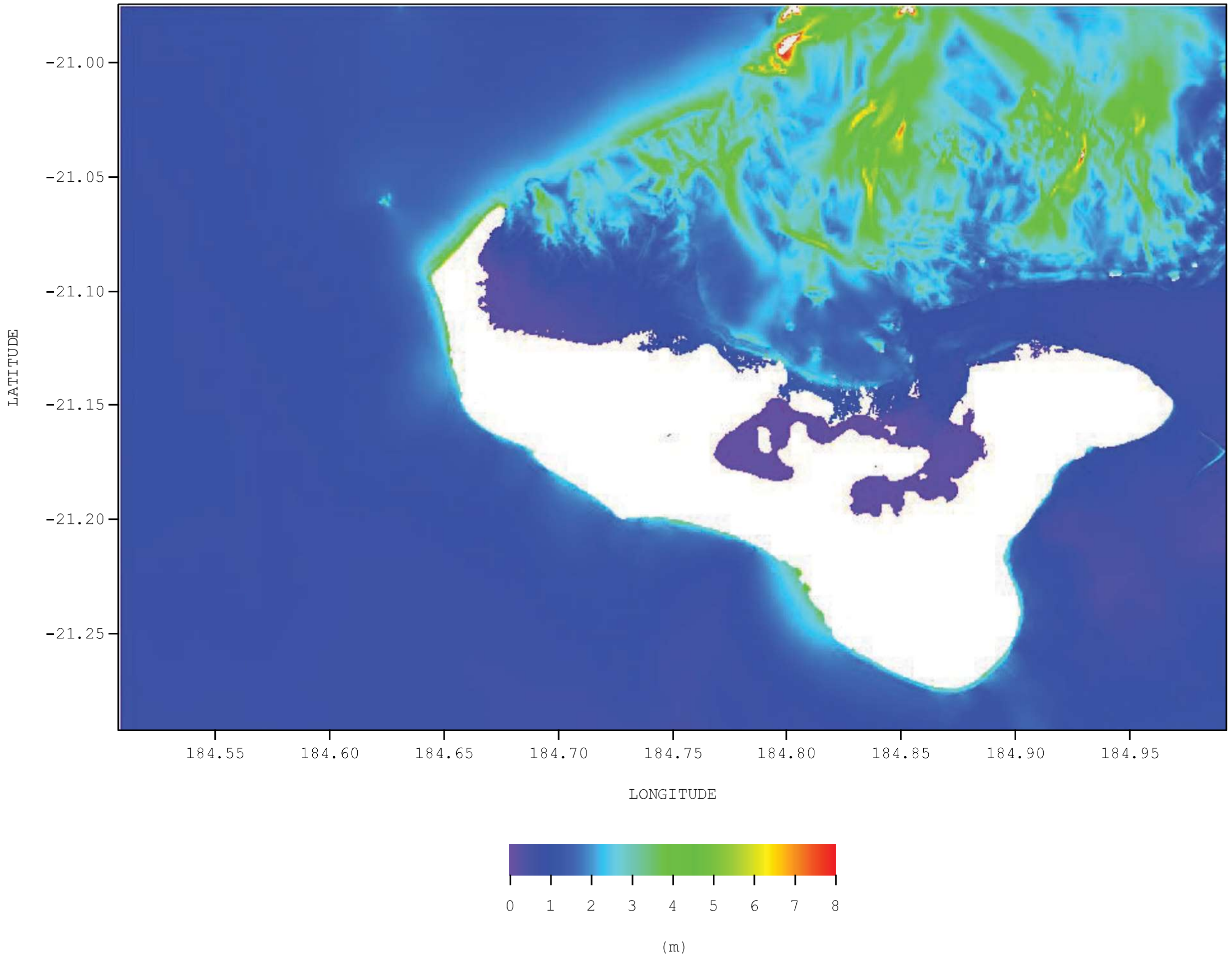
Maximum Water Level

Domain1

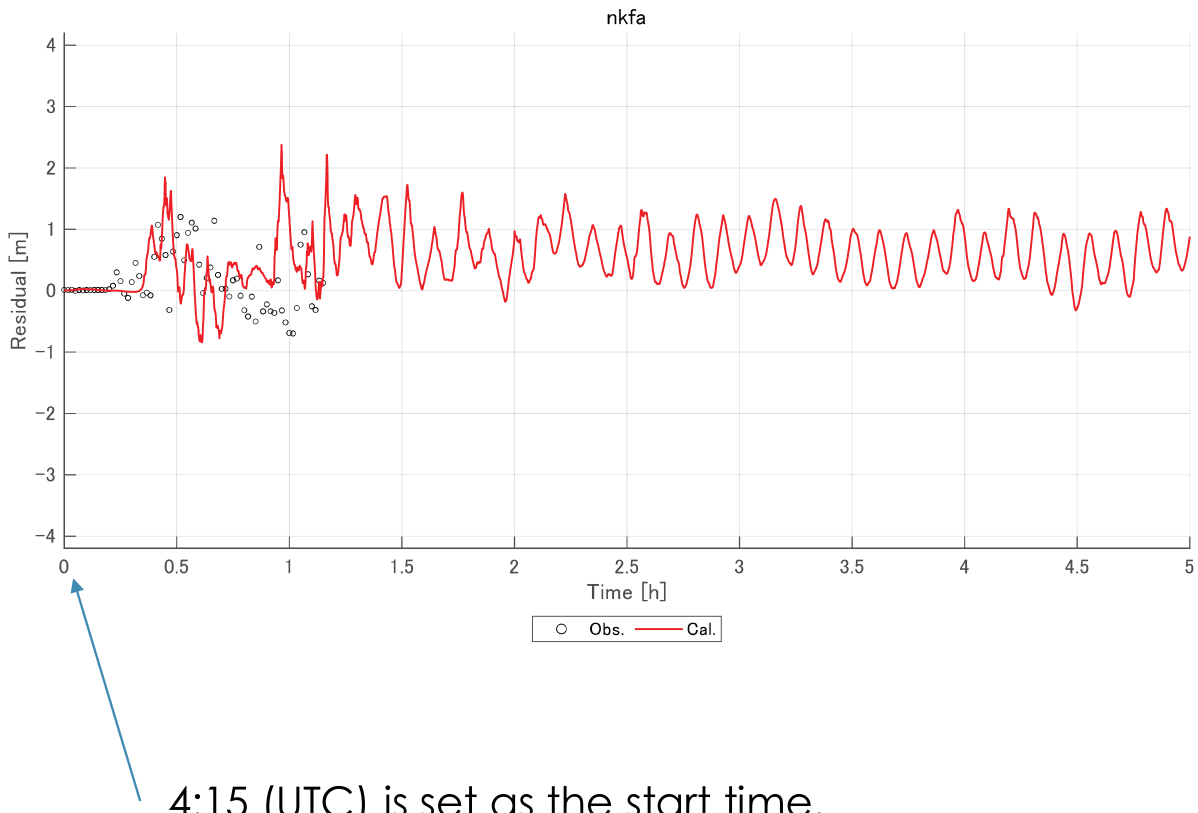


Maximum Water Level

Domain3

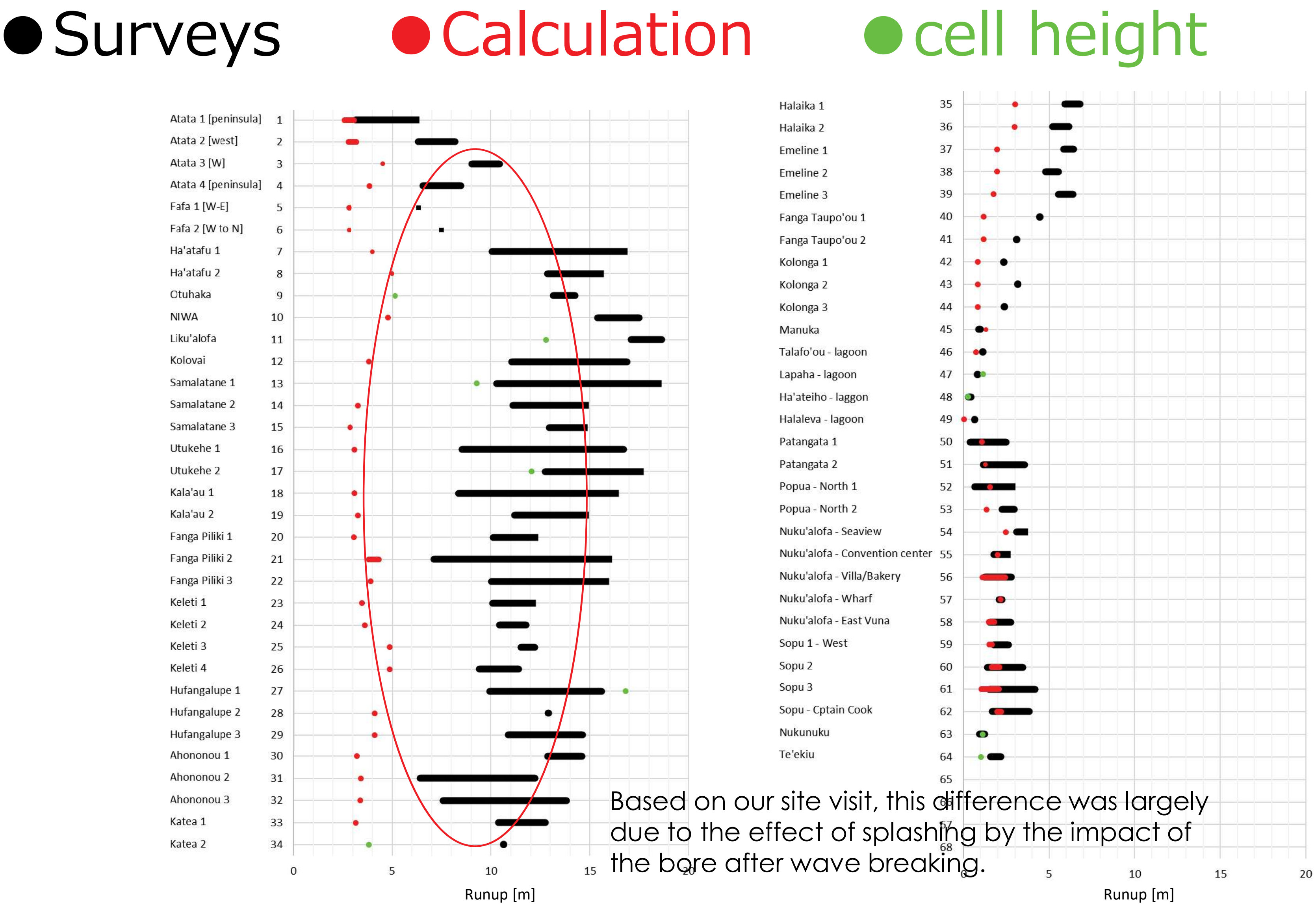


Result



4:15 (UTC) is set as the start time.

Survey Point from Prof. Cronin



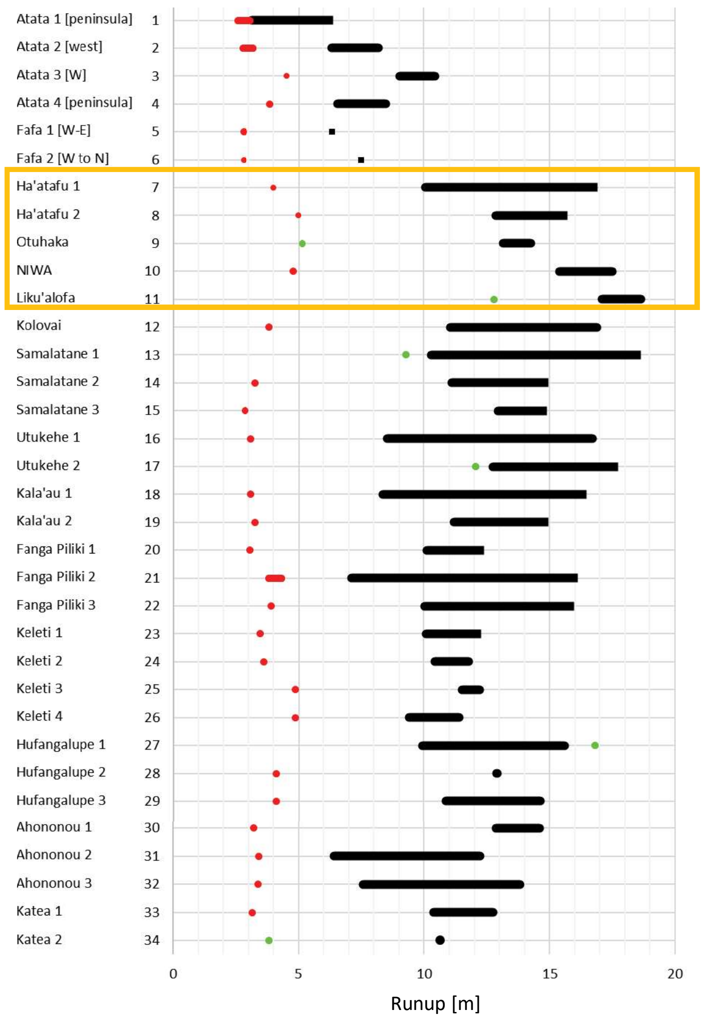
Based on our site visit, this difference was largely due to the effect of splashing by the impact of the bore after wave breaking.

Breaking（Kuji fishery port）

2011, Great East Japan Earthquake Tsunami

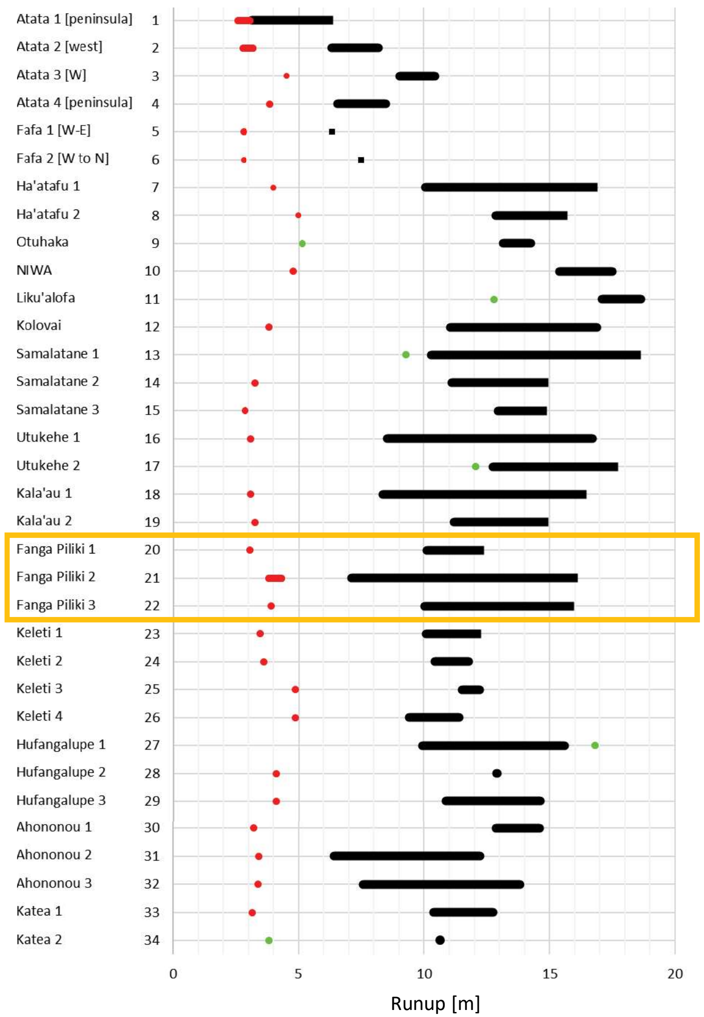
taken by a residence

● Surveys ● Calculation ● cell height

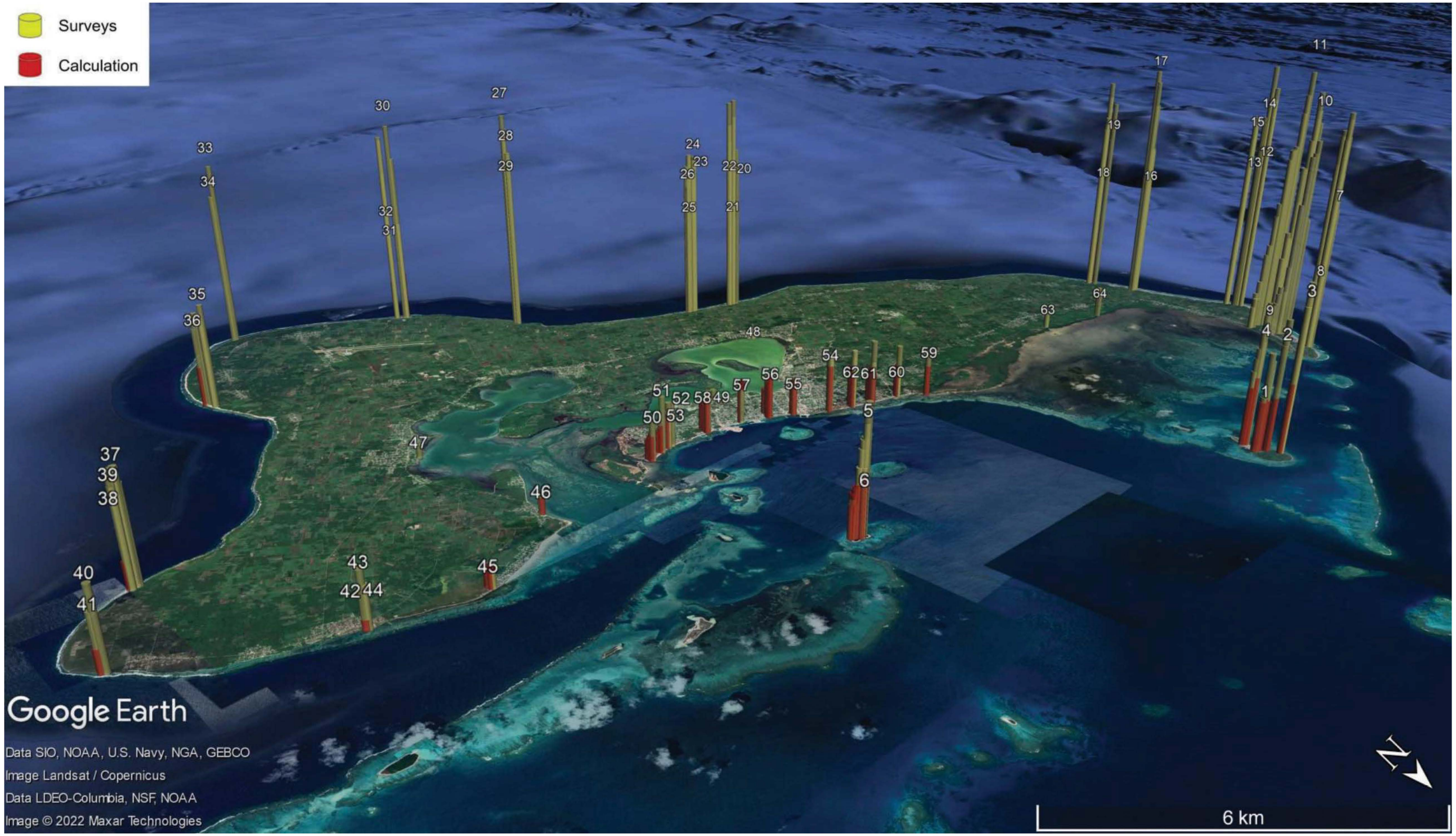



Here
12m
Shore line

● Surveys ● Calculation ● cell height



$$R = 5\text{km}, H = 45\text{m}$$



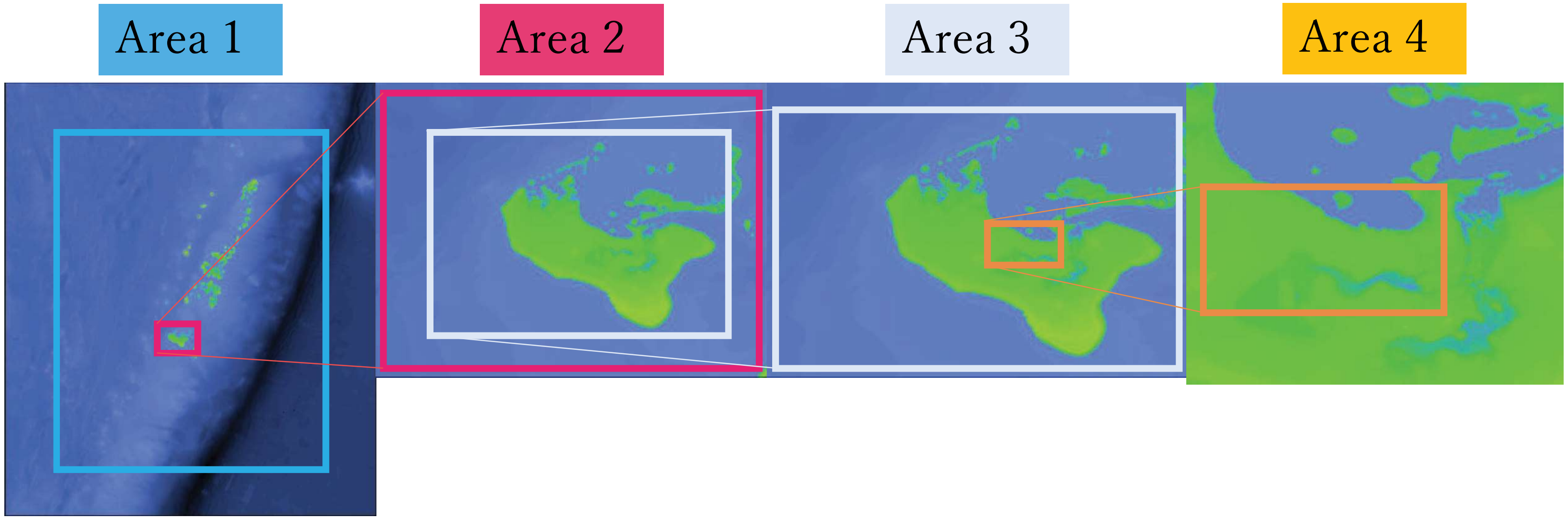
How should tsunami countermeasures be implemented on Tongatapu Island?

Tsunami sensitivity analysis

Calculation Conditions

Area	Size （x × y × z）	Grid size [m]
1	960×1200	450
2	680×500	90
3	1740×1140	30
4	1020×510	10

- Calculation Time : 7200s
- DT=AUTO(0.001~0.1s)

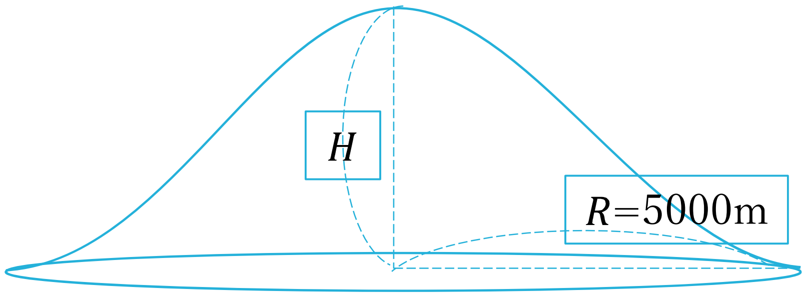


Tsunami sensitivity analysis

Wave Source

In this inundation simulation, the wave source from the eruption is given by sin wave concentrically from the position of the volcano.

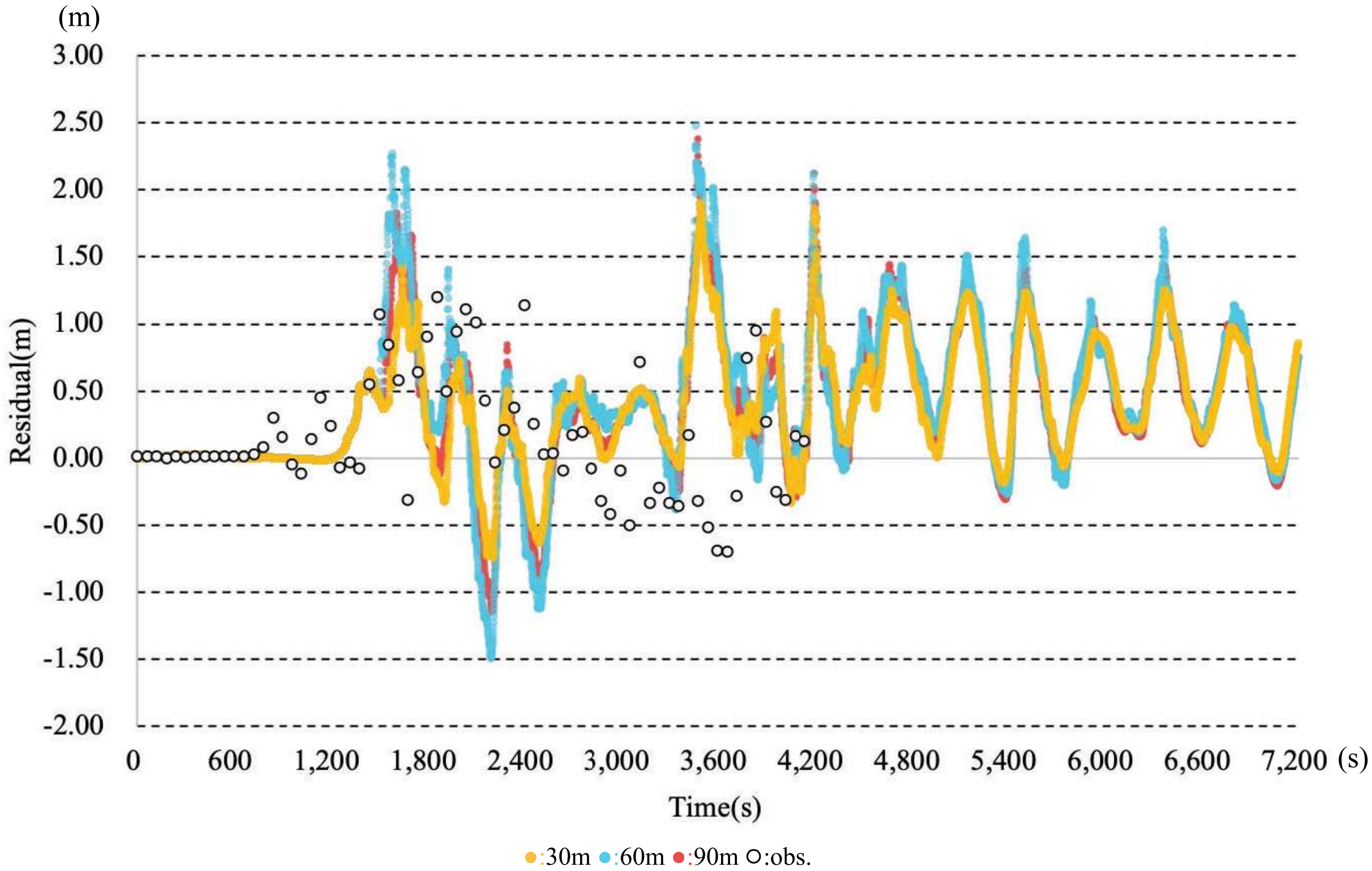
H= ①30m
②60m
③90m



R : distance from the burst center [m]
H : Maximum rise [m]

Tsunami sensitivity analysis

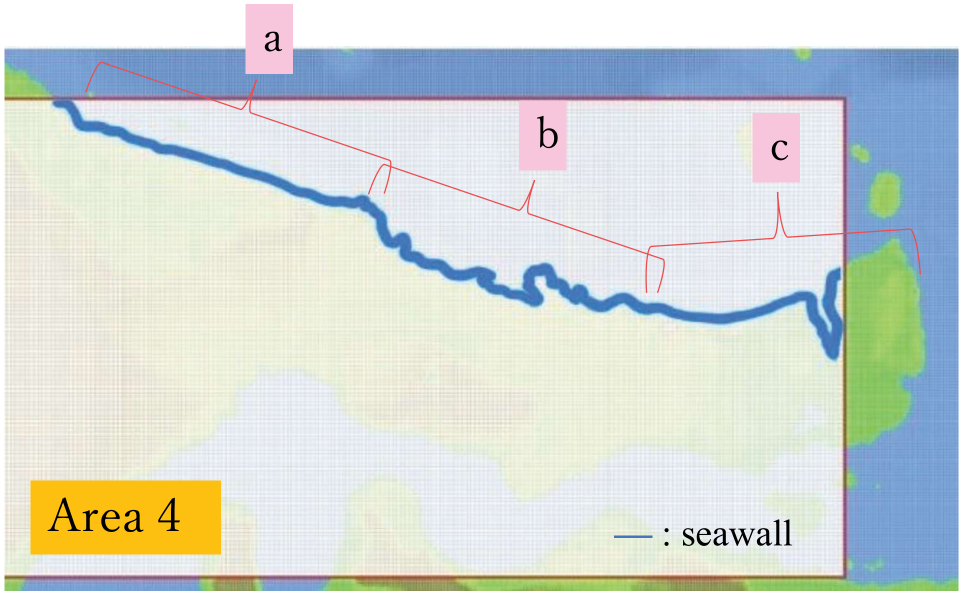
Comparison

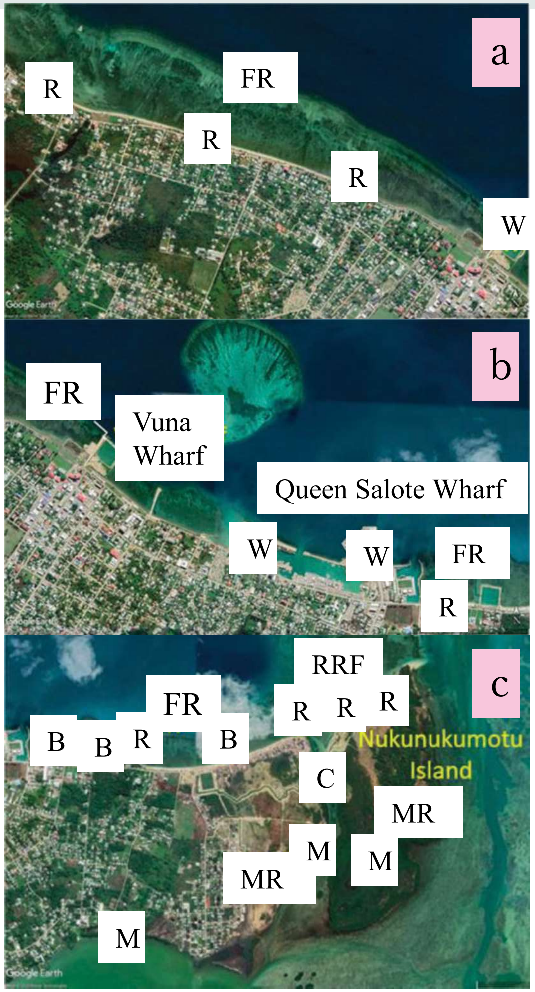


Tsunami sensitivity analysis

Seawall

①no seawall
②current seawall height(2.5m)
③seawall raised by 0.5m(3.0m)
④ seawall raised by 1.0m(3.5m)





FR=fringing reef, R=revetment, W=Wharf, C=channel, MR=mangrove removal, and M= mangroves, RRF=rocky reef flats, and B=breakwater

http://ccprojects.gsd.spc.int/wp-content/uploads/2021/03/Coastal-protection-along-the-north-coast-of-Tongatapu-Tonga_-CPS_20_140_Report-1_Rev1.pdf

Tsunami sensitivity analysis

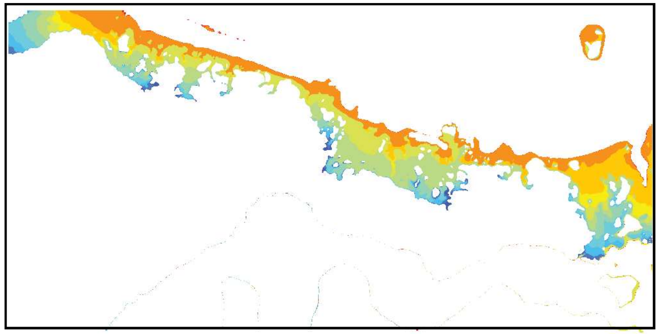
Arrival time of the first wave

Case name : R_seawall

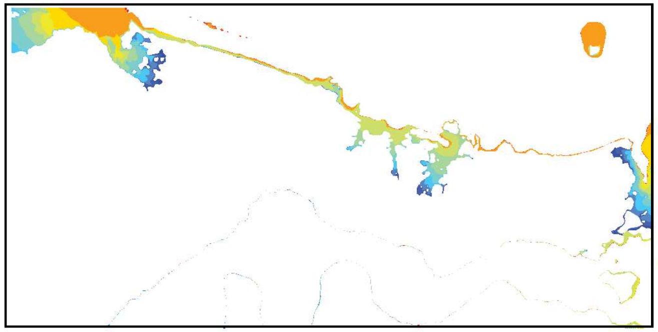
Ex) R=30m
no seawall } → 30m_no

- 0 - 600 (S)
- 600- 1,200
- 1,200 - 1,800
- 1,800 - 2,400
- 2,400 - 3,000
- 3,000 - 3,600
- 3,600 - 4,200
- 4,200 - 4,800
- 4,800 - 5,400
- 5,400 - 6,000
- 6,000 - 6,600
- 6,600 - 7,200

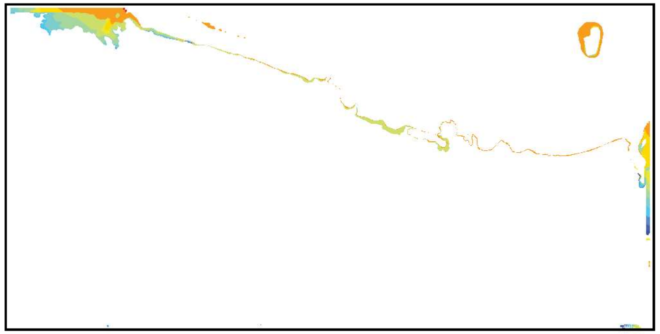
distance from the burst center : 30m



30m_no



30m_current

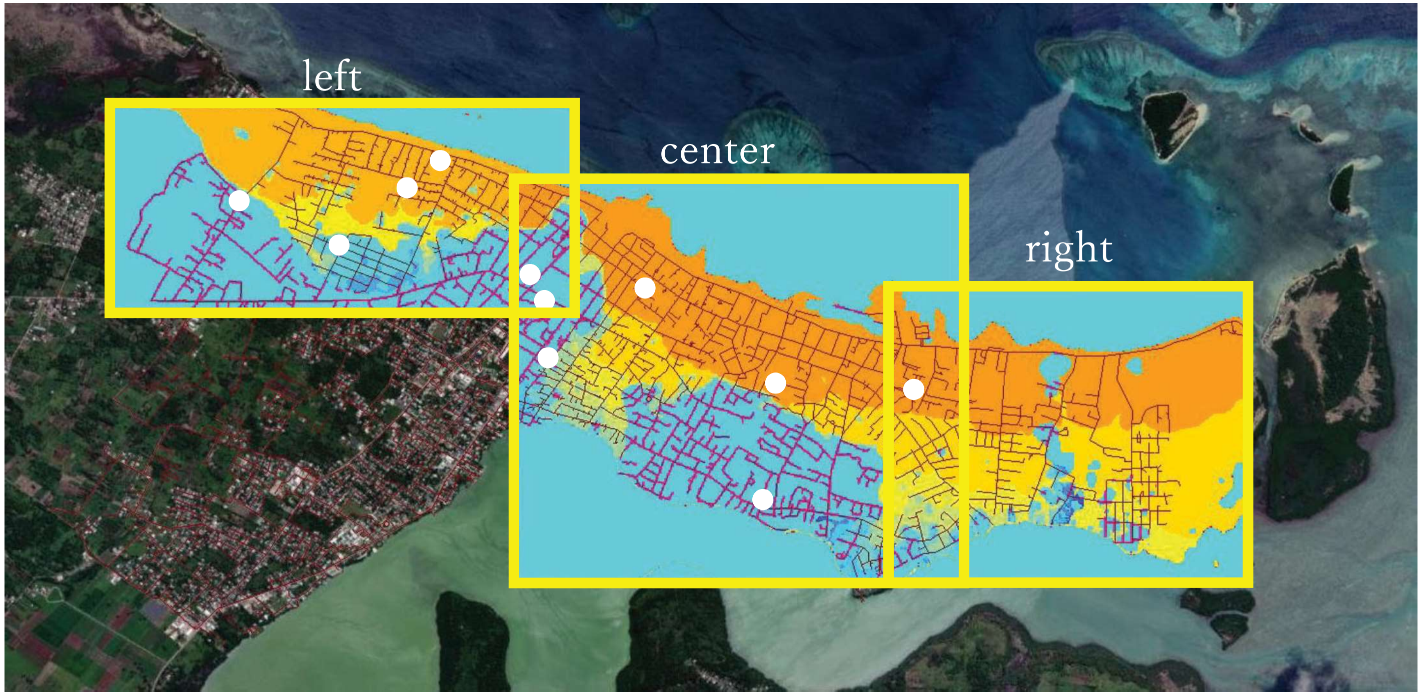


30m_+0.5m

30m_+1.0m

Evacuation simulations

Multi-agent based evacuation simulation (Arikawa and Oie, 2015)



Grid Interval	10m
Time Step Interval	10.0 s
Calculation Time	7200 s
Evacuation Start Time	0s,1400s,3000s,3300s,3600s,5400s
Evacuation Speed	1.0 m/s (initial velocity)
Number of Evacuees	5000 (random placement)
Tsunami Avoidance	On

Calculation Condition

11 Evacuation shelters :
School : 8/11
City hall : 1/11
Hill : 2/11

Location	left	center	right
Evacuation Center	6 locations	8 locations	1 location
Number of Grid	367 × 162	356 × 324	281 × 238

Discussion

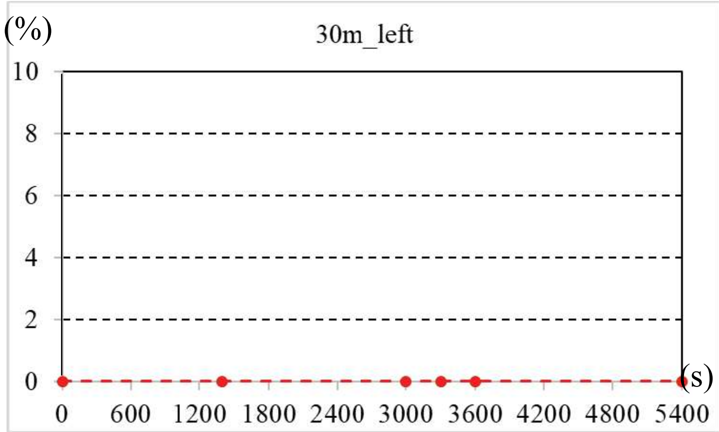
horizontal axis : Evacuation start time(s)

vertical axis : Percentage of affected people(%)

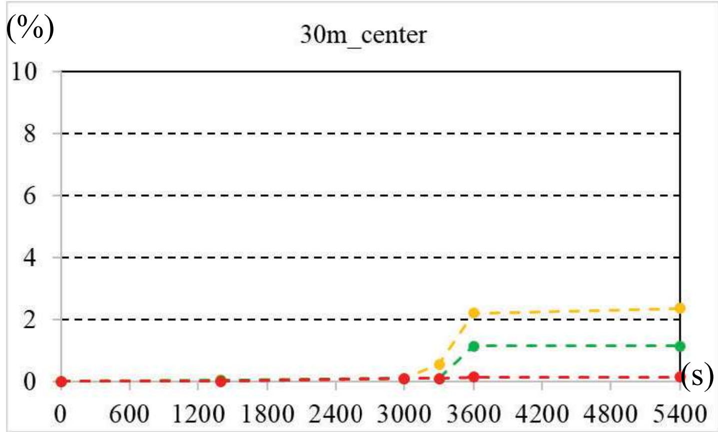
- no
- current
- +0.5m
- +1.0m

H=30m

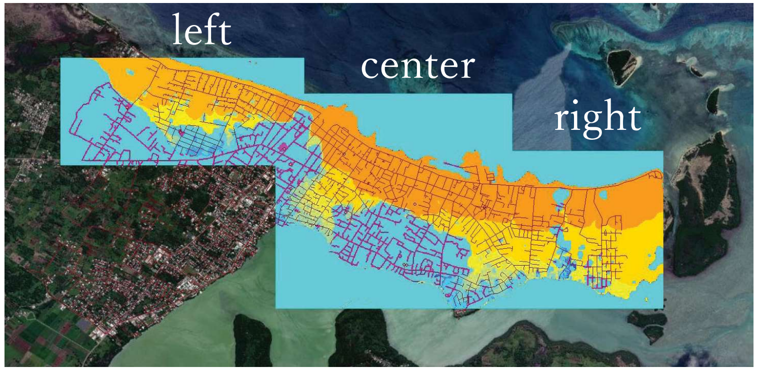
Left



Center



30m_+0.5

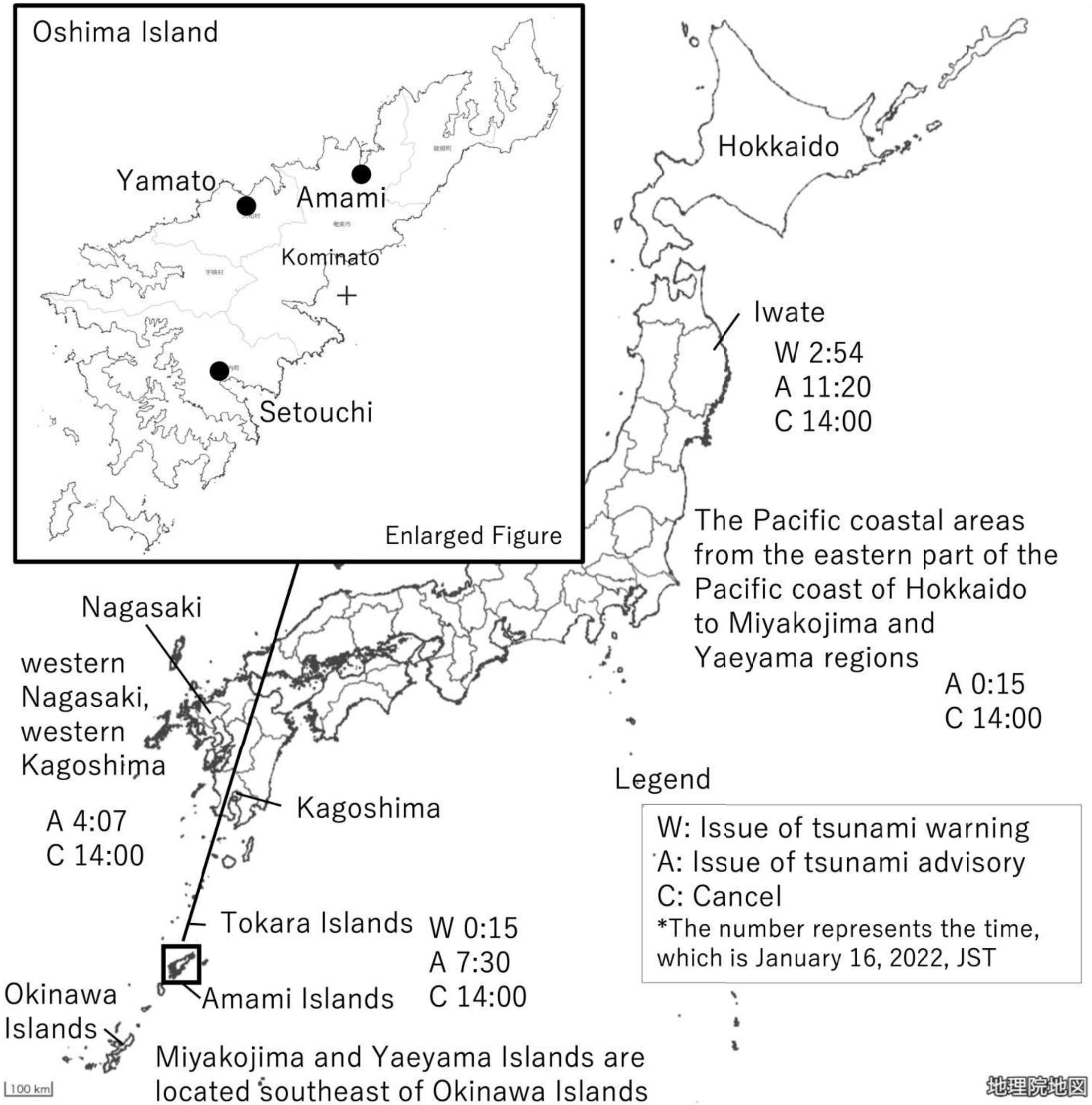


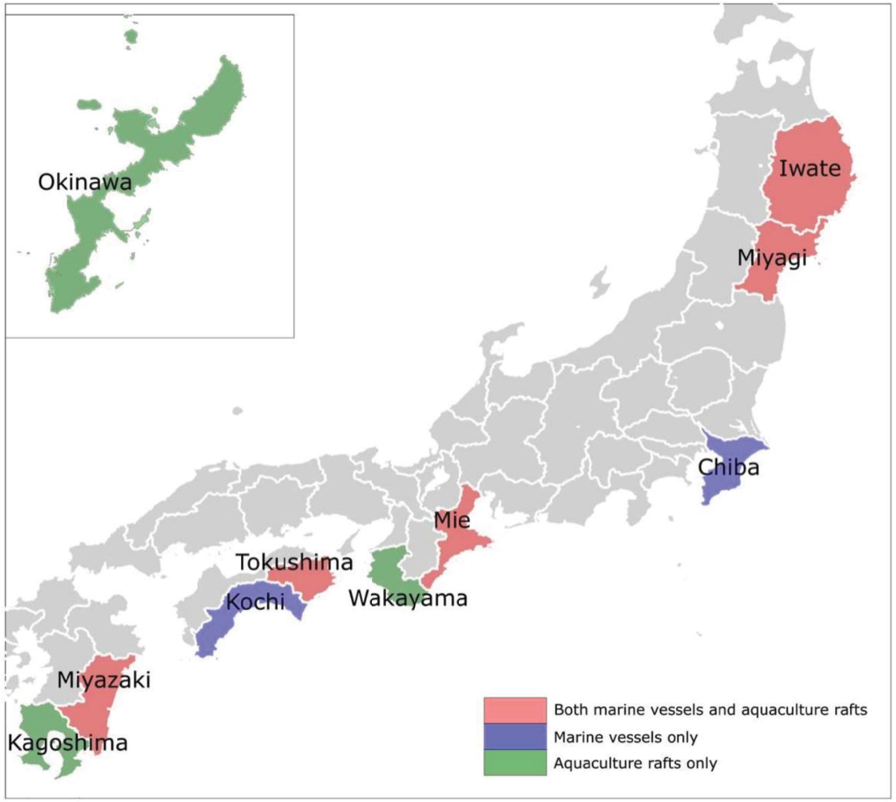
Evacuation Behavior

日本の避難行動は以下を参照

Imamura, F., Suppasri, A., Arikawa, T., Koshimura, S., Satake, K., & Tanioka, Y. (2022). Preliminary Observations and Impact in Japan of the Tsunami Caused by the Tonga Volcanic Eruption on January 15, 2022. Pure and Applied Geophysics, 179(5), 1549-1560. https://doi.org/10.1007/s00024-022-03058-0

Issue of tsunami warning





Major fishery damage along the coast of Japan

Evacuation behavior in Japan

- Amami Islands
  - In terms of the evacuation ratio, approximately 960 out of 1,400 people in Yamato Village evacuated, and most of those in Setouchi Town evacuated, including vertical evacuation to the 2nd and 3rd floors. In Amami City, government staff commented that the line of cars trapped in traffic started at 24:18 JST, 3 minutes after the warning was issued. This is proof that the evacuation started not only because of the evacuation order of the local government but also because of the JMA tsunami warning. We also found that quite a few people returned home after the alarm was cancelled.
  - There was a traffic jam that did not move for approximately one hour in Amami City
- Otsuchi Town
  - In Otsuchi Town, on the other hand, the evacuation rate was about 4%.

Evacuation behavior in Tongatapu

- Three people died
- From the interview with TGS, Tongans were aware that earthquakes and volcanoes can cause tsunamis, and they evacuated when they saw the signs of nature, rather than relying on alerts.
- In fact, on the west side of the coast, wh the restaurant owner saw the sea change he shouted to the people in the surround houses to run, and they evacuated inlanc
- There were witnesses on the north side who saw the tsunami and began to evacuate.

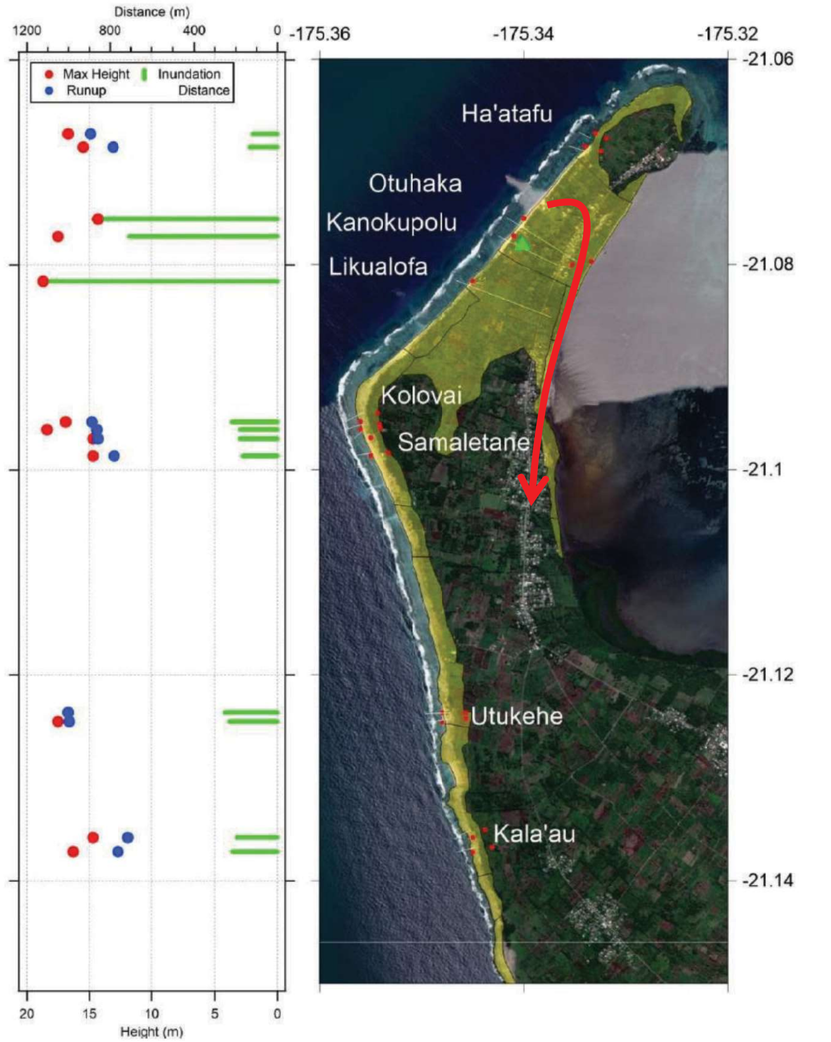
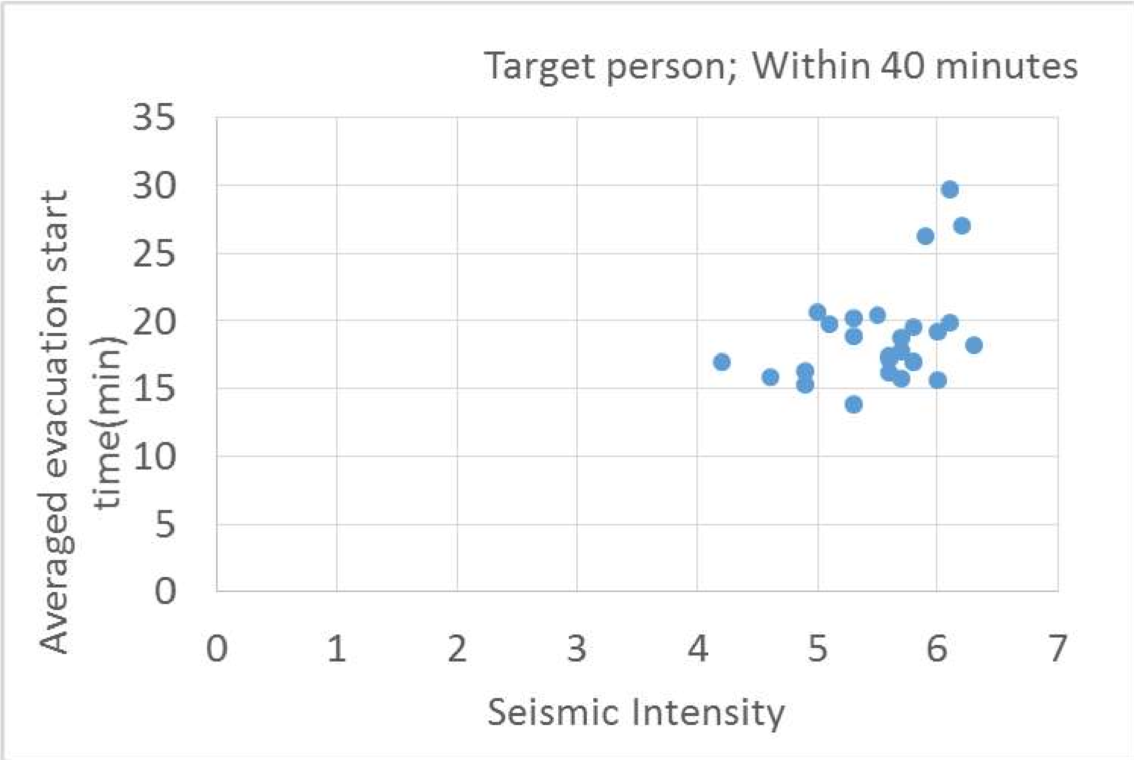


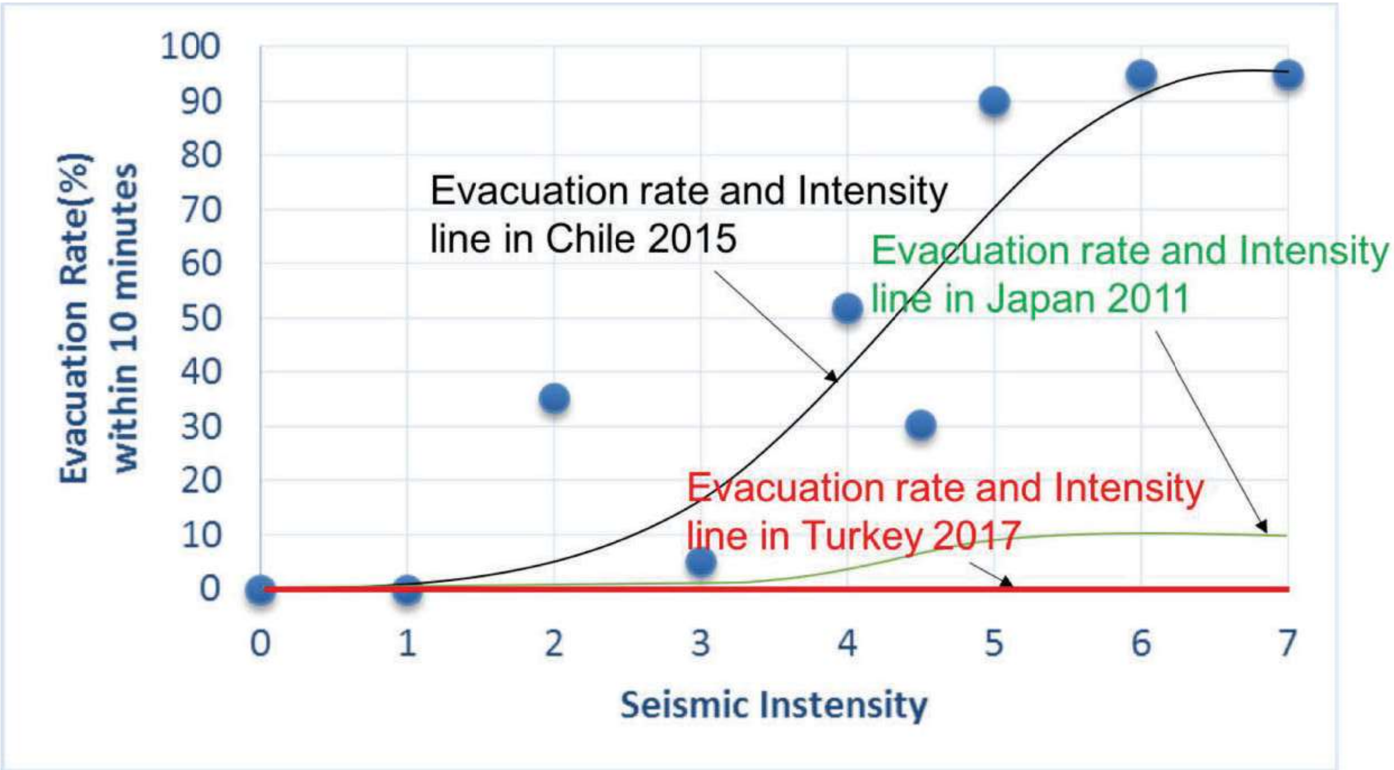
Figure 3.1 Locations surveyed along the western coast of Tongatapu. The start and endpoints of each transect are indicated with the red dot. Green tringle indicates the location of the NIWA weather station. Yellow shaded area indicated extents of inundation. Left plot shows maximum tsunami trace height and maximum runup height along each transect, right plot shows maximum inundation distance.

The relation between the Intensity of the shaking and evacuation rate in the 2011 Tohoku Earthquake



Data :archives for reconstruction support, http://fukkou.csis.u-tokyo.ac.jp/

Relation between seismic intensity and evacuation rate within 10 minutes in Turkey, Japan and Chile



Difference between country's preparation for tsunami disaster prevention and response to tsunami evacuation

	Protective facilities	Warning system	Tsunami education
Japan	◎	◎（within 3 min）	◎
Chile	×	○（after 2010）	◎
Turkey	×	×（the Med）	×

Japan・・・Waiting for information and do not depend on alert only. As a result, they do not evacuate until the limitation of their feeling
Chile・・・If the earthquake shakes, they run away quickly（do not depend on alert）
Turkey・・They evacuate properly against the earthquake. On the other hand, they do not recall the tsunami even strong earthquakes is occurred. As a result, after they see the tsunami, they would run away

Therefore, while it is important to enhance education and warnings, it is clear that visualization of the tsunami is important for immediate evacuation.

Case of the eruption tsunami in Tonga, 2022

	Protective facilities	Warning system	Tsunami education	Natural warning sign	Case
Japan	◎	◎（within 3 min）	◎		2011, 2022(tonga)
Chile	×	○（after 2010）	◎	Seismic intensity	2015
Turkey	×	×（the Med）	×		2017
Tonga	×	△(within 10 - 15min)	○	eruption	2022

- Visibility is important to the Tongan people. In other words, it is important to realize fear
- In the case of Japan, the height of the seawalls changed the resulting evacuation situation
- It suggests that "people did not evacuate because they felt safe that the tsunami would not inundate the area.“ (Height of seawall, Otsuchi 12m, Amami Islands less than 3m)

Conclusions

- トンガの被災の様子を示した。高いところでは20m近く遡上していることがわかる。また、トンガタプ島に来襲した津波の様子を示した。
- 津波のシミュレーション結果から、現状の堤防高さを50cm程度かさ上げすることで、今次津波の被害をおおよそ防ぐことができる。これは火山性津波の波長が比較的に短いことにも起因する
- 避難の様子は、日本では奄美大島と大槌町で異なり、奄美大島では、かなり多くの人が警報後即時避難した。一方で大槌町ではほとんど避難しなかった
- トンガにおいては、海の変化の様子を見た人が避難を率先した。火山により津波が生じることは知っていた。
- これらのことから、堤防の高さが安心感を助長しているという可能性が高く、今後のトンガの堤防の在り方や、日本における避難の在り方を議論することが重要であると考えられるものの、

Tsunami Boulder in Tongatapu

Photos

Video

Thank you for your attention