Elucidation of Generation Mechanism of Tsunami due to Aseismic Slip

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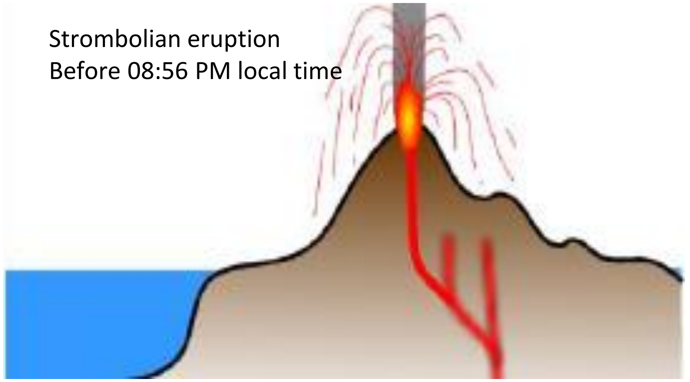
Goals

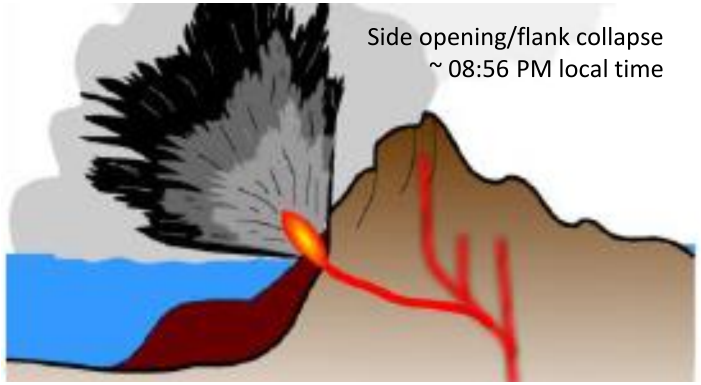
In the occurrence of the tsunami caused by the eruption of Krakatau volcano on 23rd December 2018, although the height of the tsunami was relatively small, there were many victims due to tsunamis. This tsunami seemed to be generated by the collapse of the mountain at the time of volcanic eruption, and it is speculated that the absence of warning system for such kind of tsunami led to the delay of tsunami evacuation and issued many victims. Therefore, in this research, we conduct the following three researches, elucidate the mechanism for the non-seismic tsunami, develop the detection system and propose the evacuation planning method.

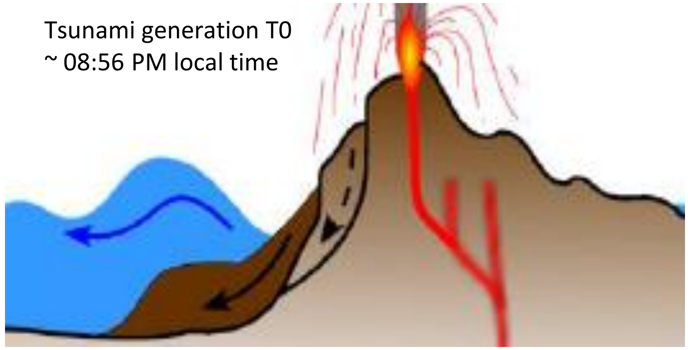
1) Measurement of seabed topography around Krakatau Island by a sonar
2) Verification of the possibility of sea level monitoring using video image
3) To propose the evacuation planning method by using the tsunami evacuation simulator

Background

- On December 23rd, 2018, a volcanic eruption triggered a tsunami between Indonesia's Java Island and Sumatra at 9:30 pm local time.
- The report indicated 24 minutes from the volcanic eruption to start of the tsunami inundation
- The authorities have no warning for a tsunami
- A total of 429 people died as a result of the tsunami, another 1,485 were injured and 154 were missing.



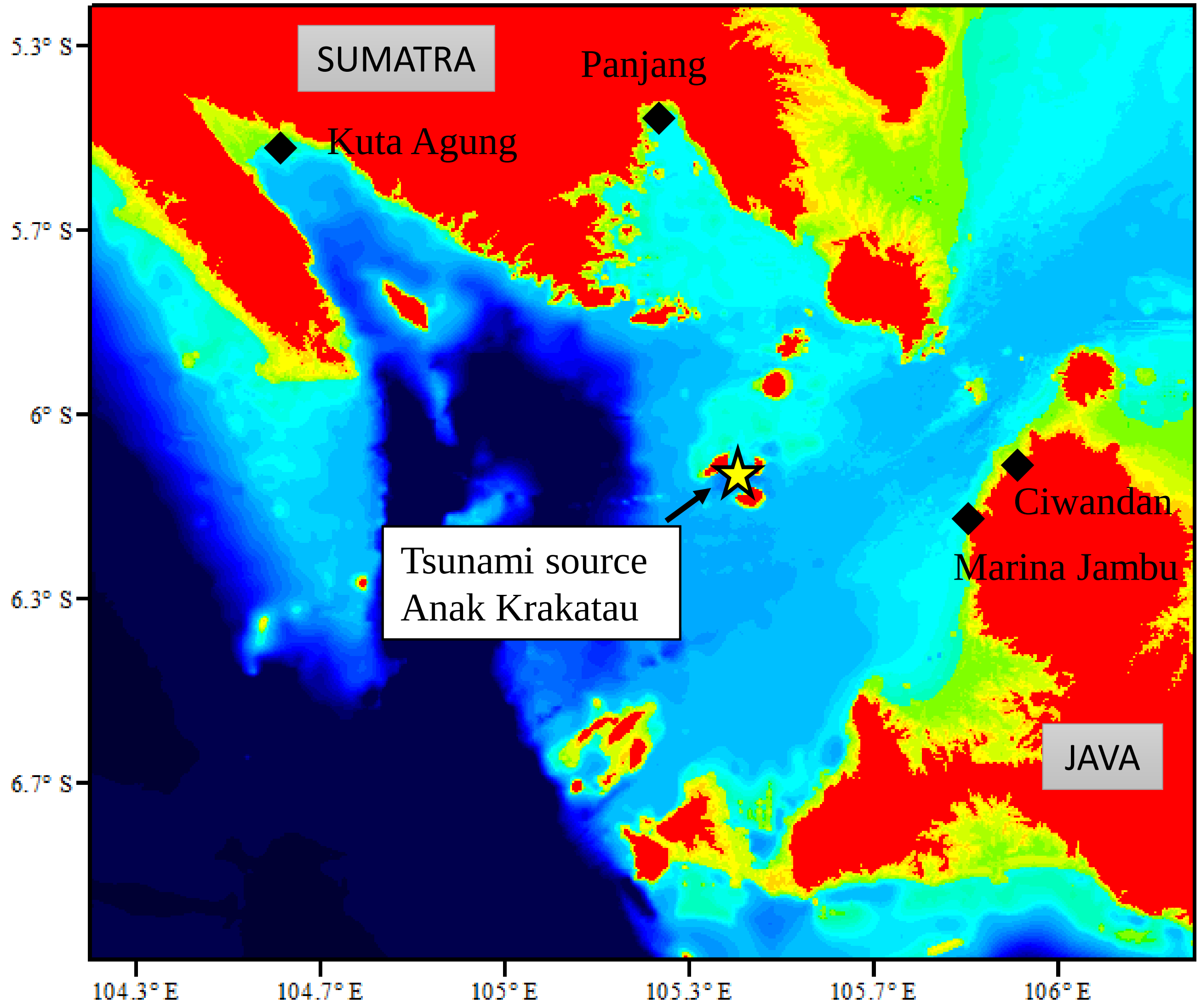




To clarify the mechanism of tsunami generation by submarine measurements

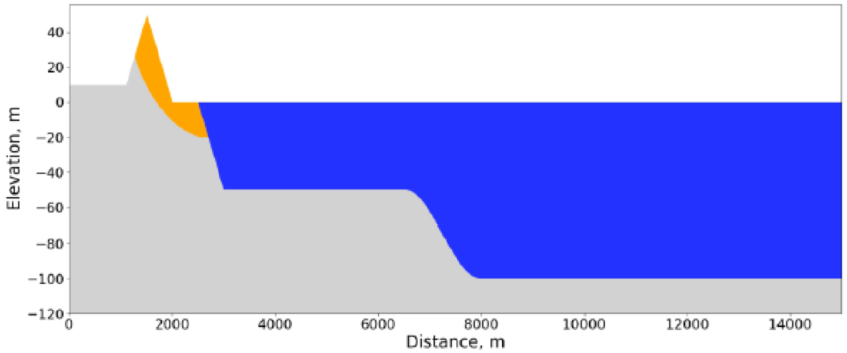
Calculation area (Pakoksung et al.,2019)

◆ Gauges position



Calculation condition

2-layer model



Parameter

Time step (sec)	0.005
Simulation time (min)	240
Print out (sec)	1
Soil density (kg/m^3)	1500
Stable slop of soil movement (m)	2.5
Change datum (m)	0.0

[Upper layer]

Continuity equation

$$\frac{\partial Z_1}{\partial t}+\frac{\partial Z_2}{\partial t}+\frac{\partial Q_{1x}}{\partial x}+\frac{\partial Q_{1y}}{\partial y}=0$$

Momentum equation

$$\frac{\partial Q_{1x}}{\partial t}+\frac{\partial \frac{Q_{1x}^2}{D_1}}{\partial x}+\frac{\partial \frac{Q_{1x}Q_{1y}}{D_1}}{\partial y}$$

$$+gD_1\frac{\partial Z_1}{\partial x}+gD_1\frac{\partial D_2}{\partial x}+\frac{\tau_{1x}}{\rho_1}=0$$

[Lower layer]

Continuity equation

$$\frac{\partial Z_2}{\partial t}+\frac{\partial Q_{2x}}{\partial x}+\frac{\partial Q_{2y}}{\partial y}=0$$

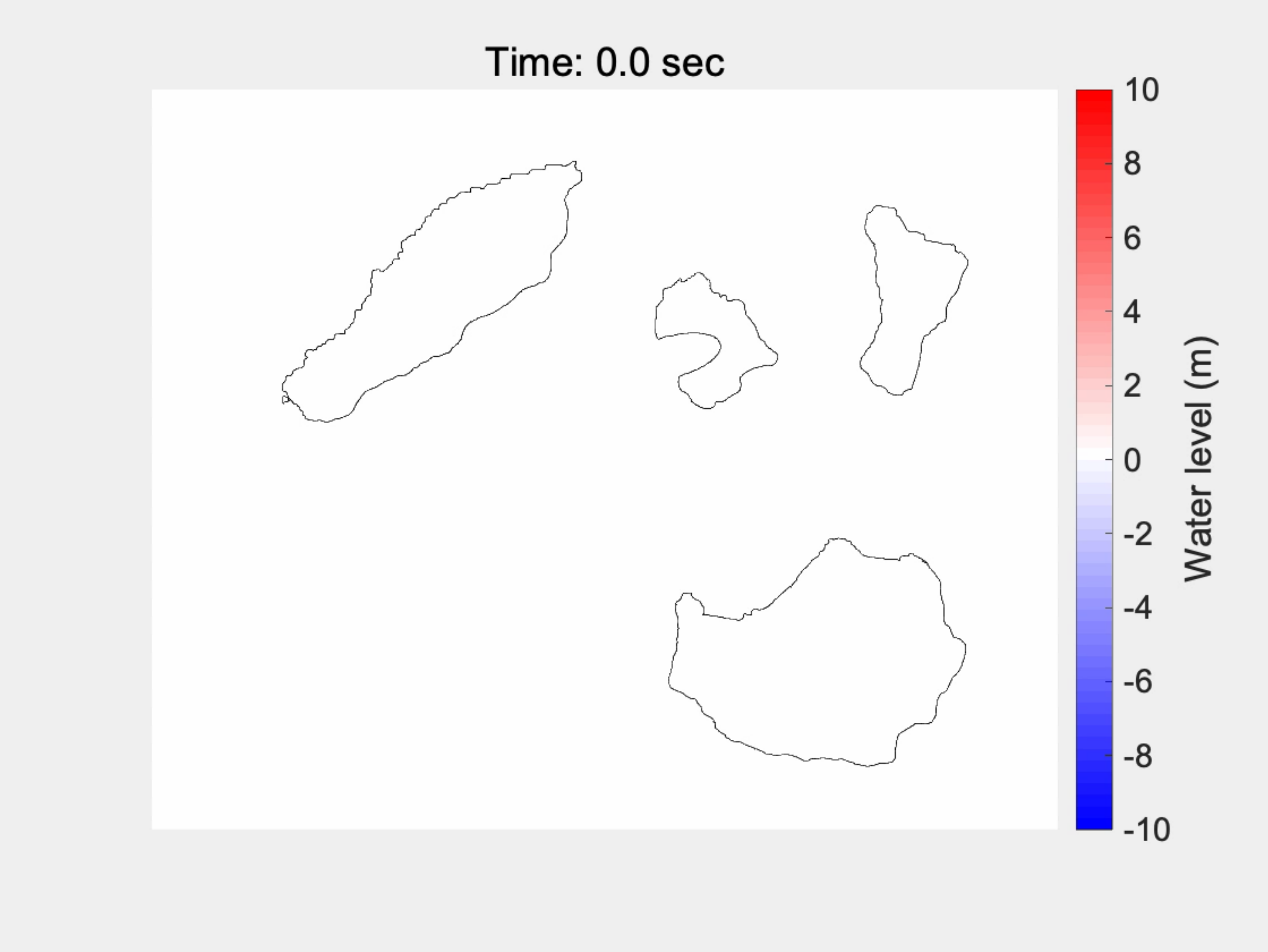
Momentum equation

$$\frac{\partial Q_{2x}}{\partial t}+\frac{\partial \frac{Q_{2x}^2}{D_2}}{\partial x}+\frac{\partial \frac{Q_{2x}Q_{2y}}{D_2}}{\partial y}$$

$$+gD_2\frac{\partial Z_2}{\partial x}+\mathrm{g}\frac{\rho_1}{\rho_2}D_2\frac{\partial D_1}{\partial x}+\frac{\tau_{2x}}{\rho_2}=0$$

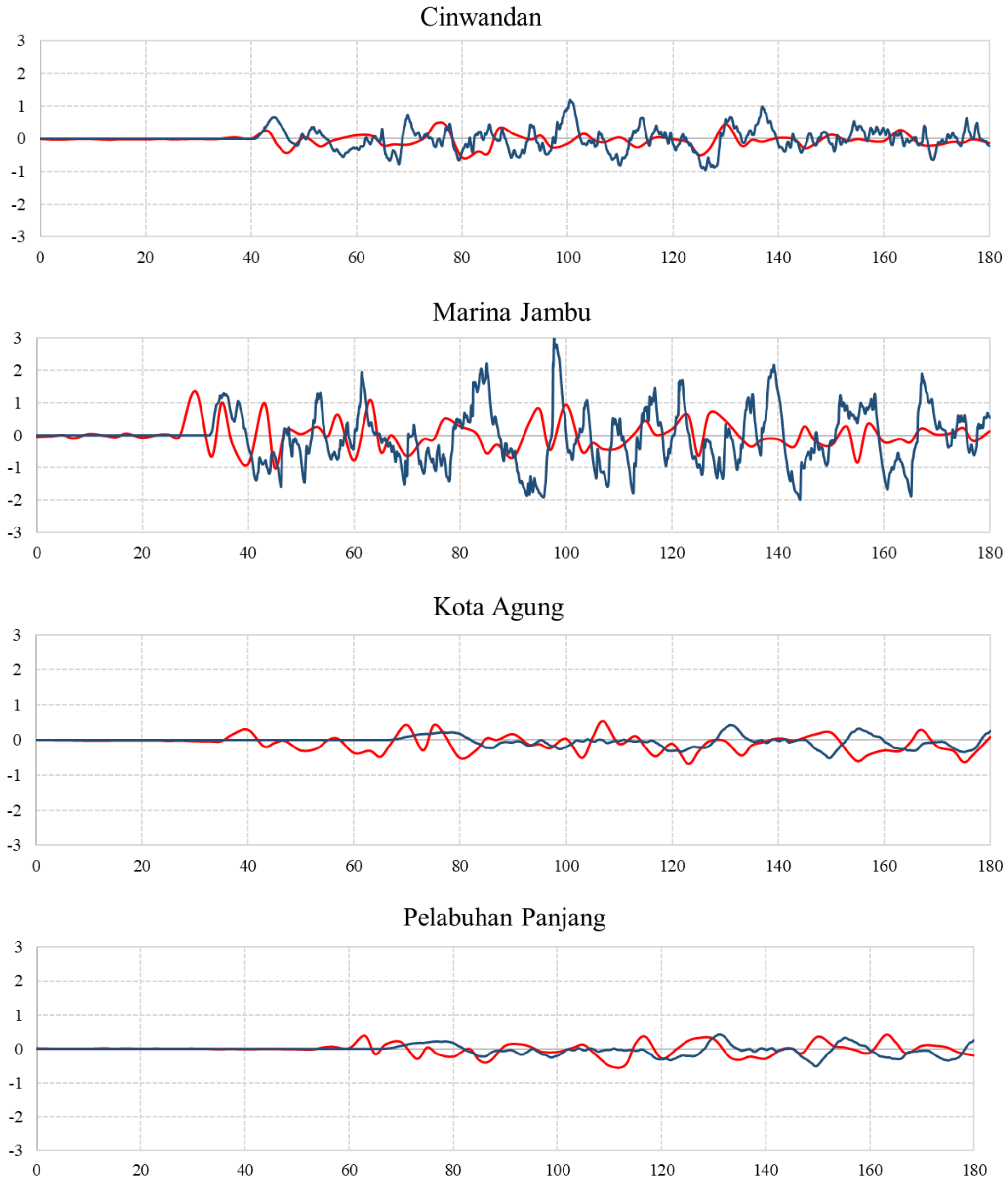
Index 1,2: upper layer and lower layer
Index x, y: x direction and y direction
Z_i: the level of the layer
Q_i: the vertically integrated discharge
g: the gravity acceleration
ρ_i: the density
τ_i: the bottom stress in each layer

Modeling results



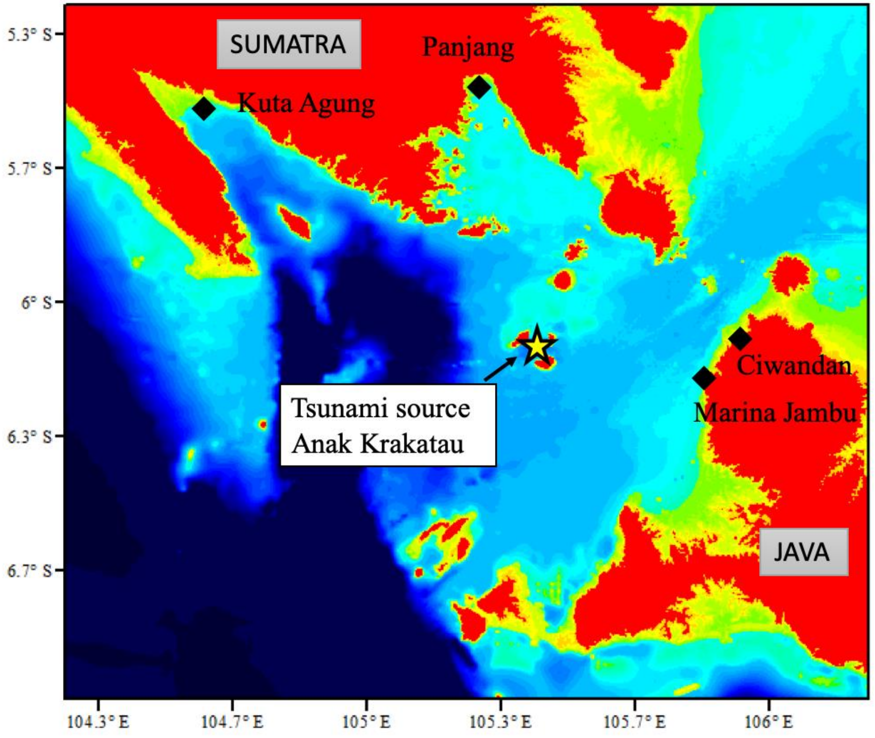
Modeling results

Comparison of simulation and observation

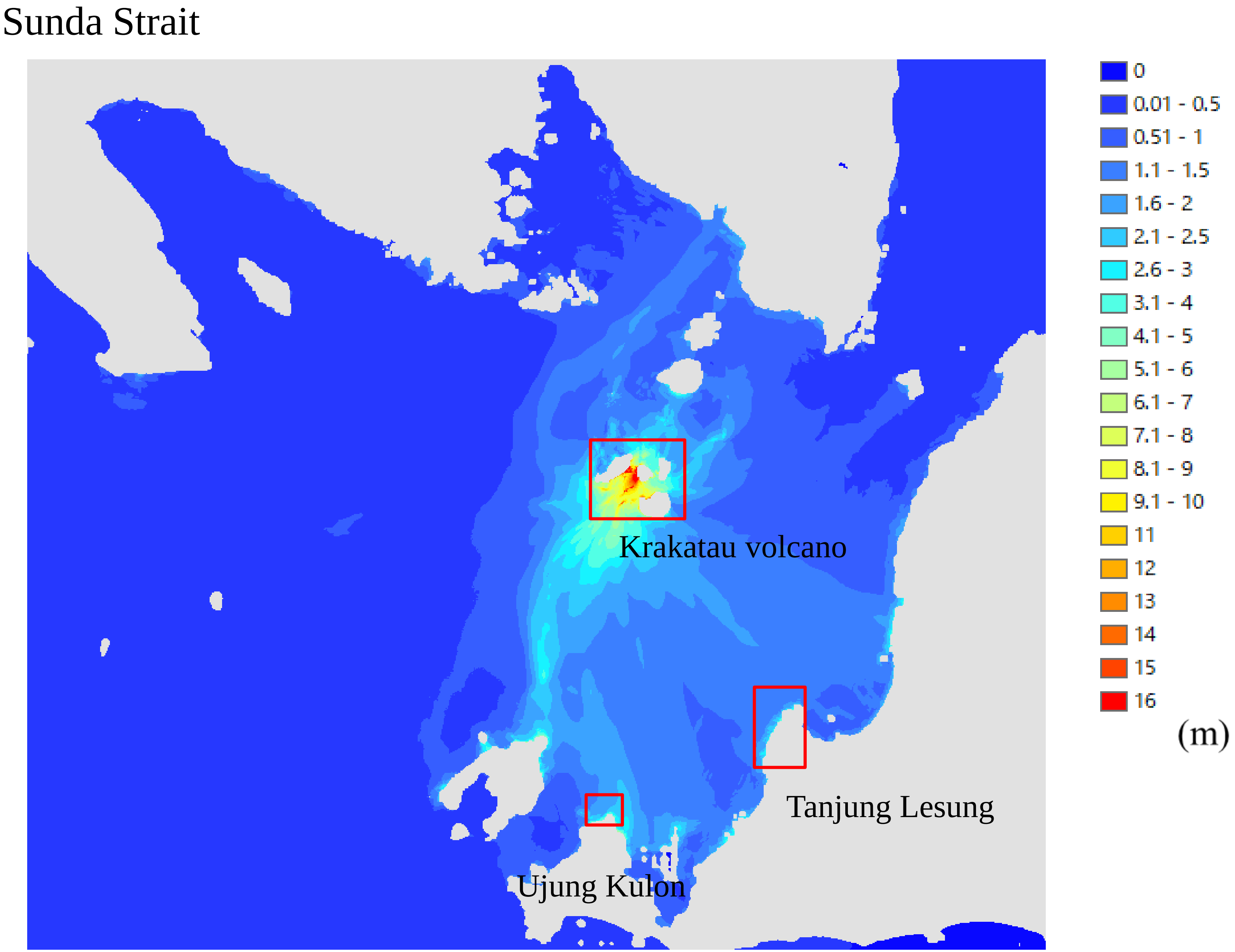


Obs point

	Lon	Lat
Cinwandan	105.95258	-6.017667
Marina Jambu	105.84	-6.189122
Pelabuhan Panjang	105.28306	-5.451667
Kota Agung	104.61936	-5.500444

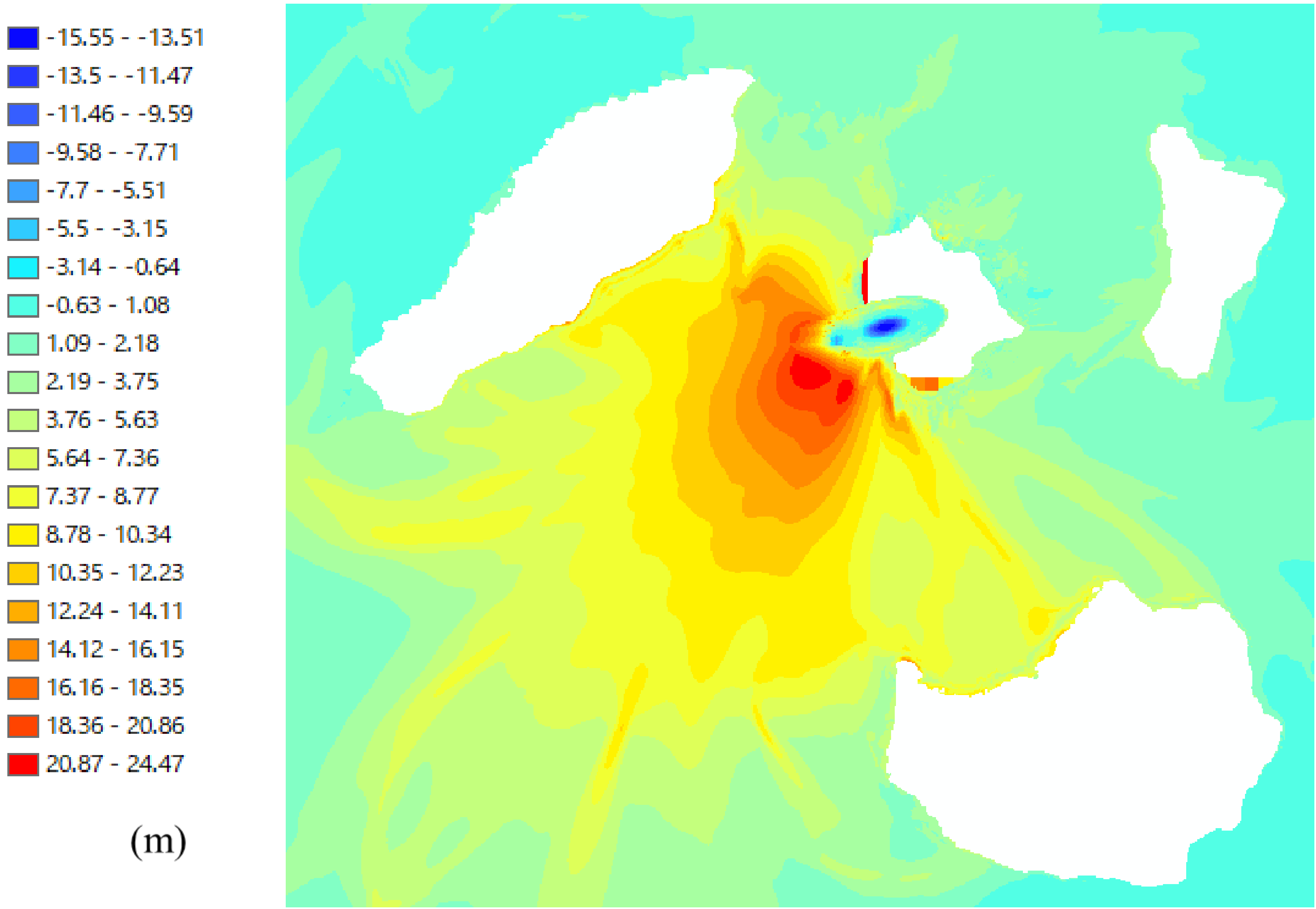


Maximum water elevation



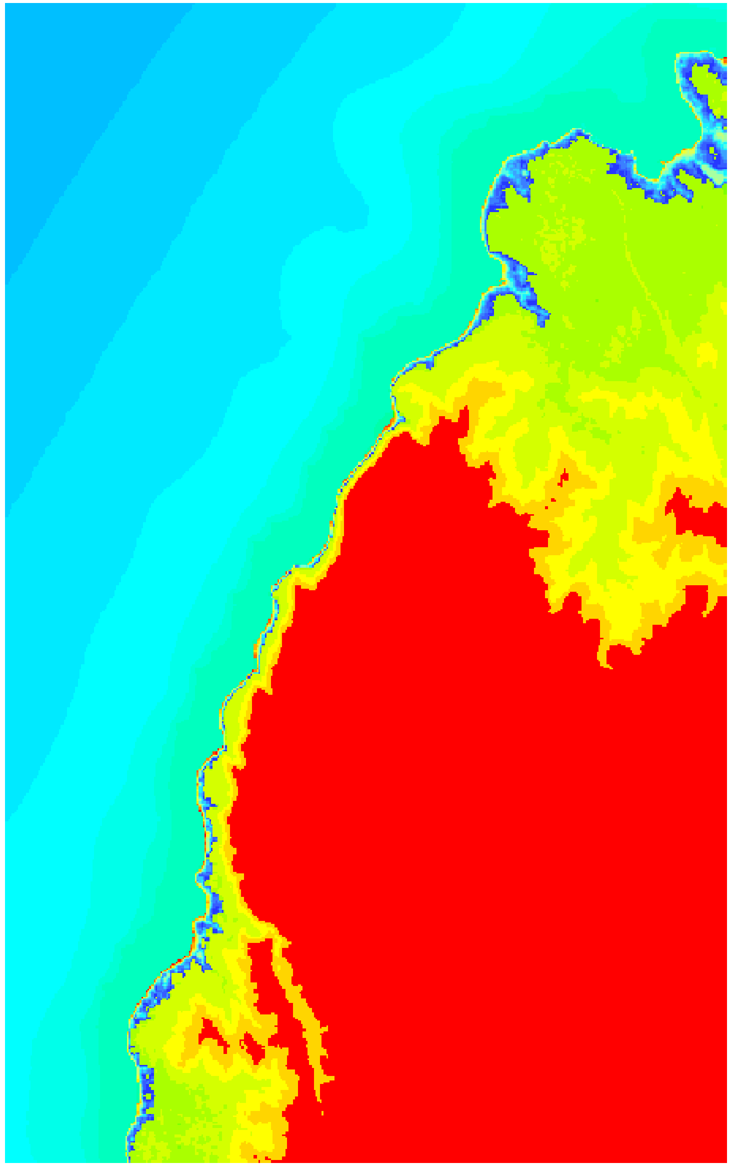
Maximum water elevation

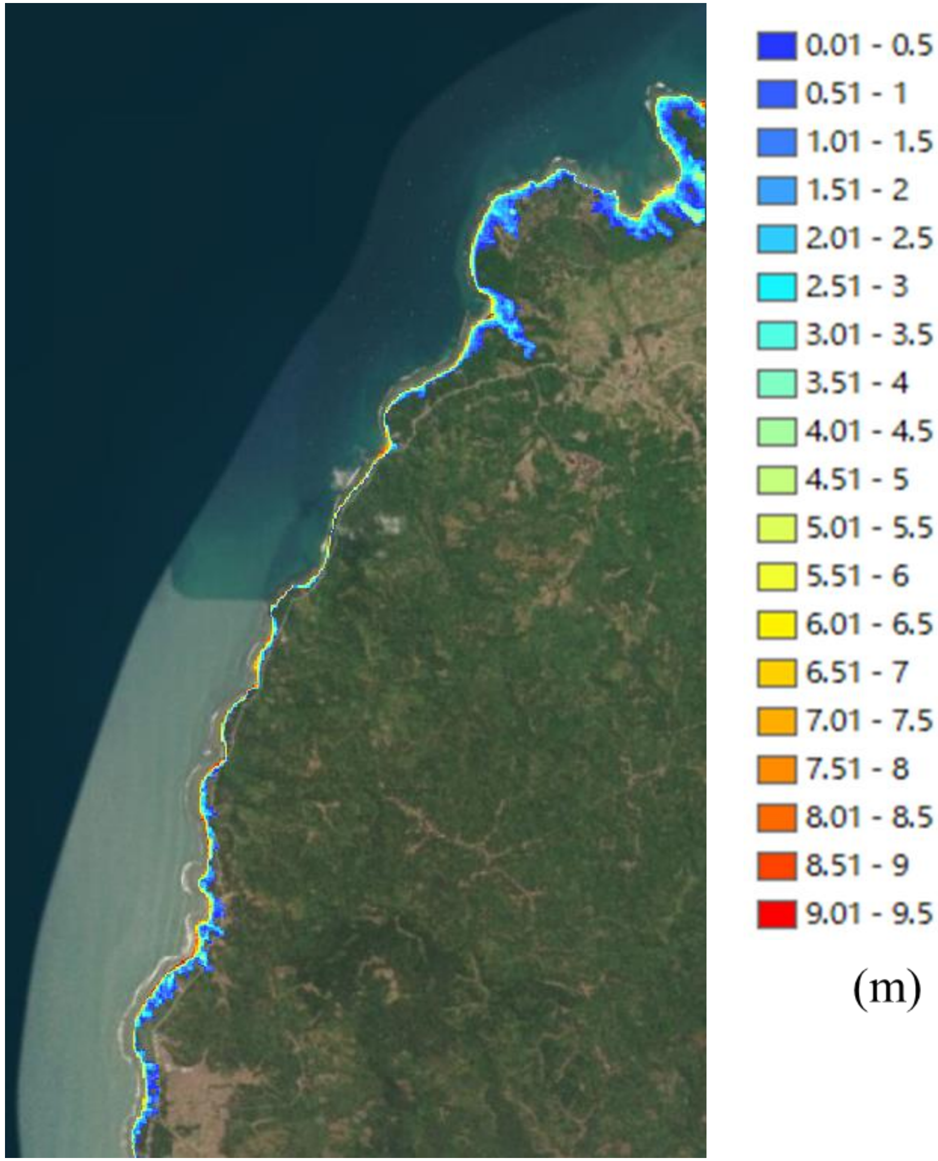
Krakatau volcano



Inundation area

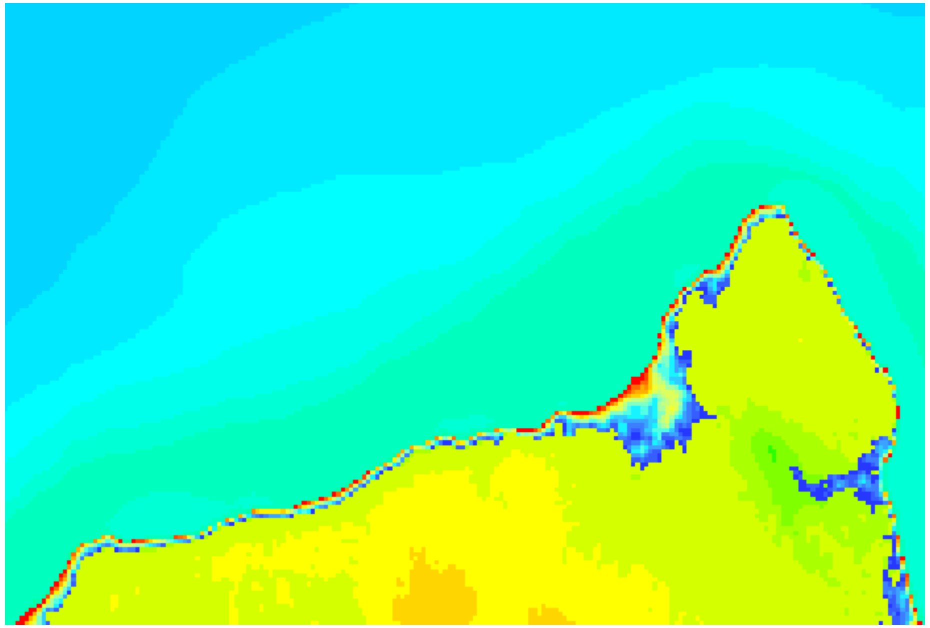
Tanjung Lesung

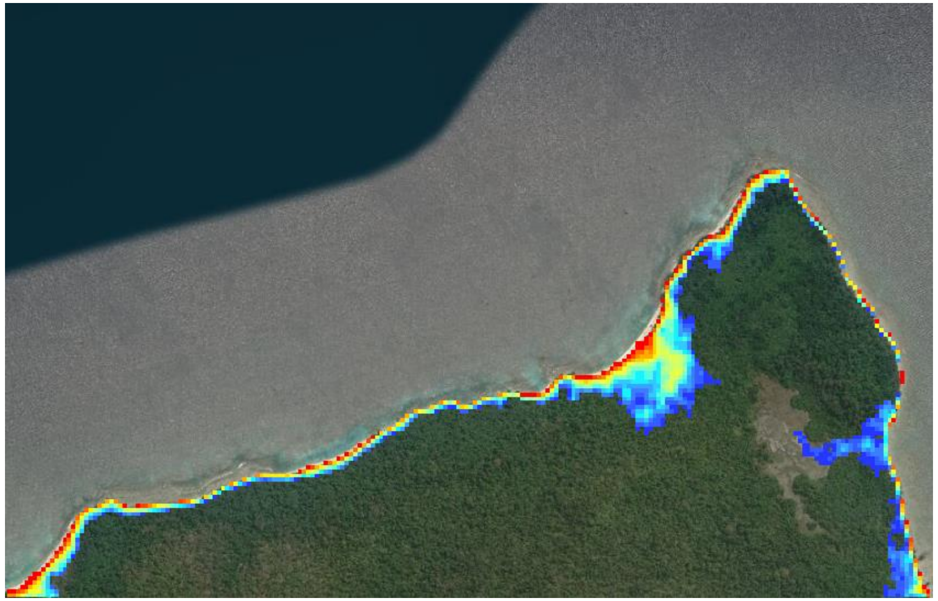




Inundation area

Ujung Kulon





To propose the evacuation planning method by using the tsunami evacuation simulator

Numerical Model

STOC-ML[1)](Storm surge and Tsunami simulator in Oceans and Coastal areas)

Quasi 3 dimensional model using hydrostatic approximation in z direction

Pass information of elevation, inundation,

Multi Agent simulator[2)]

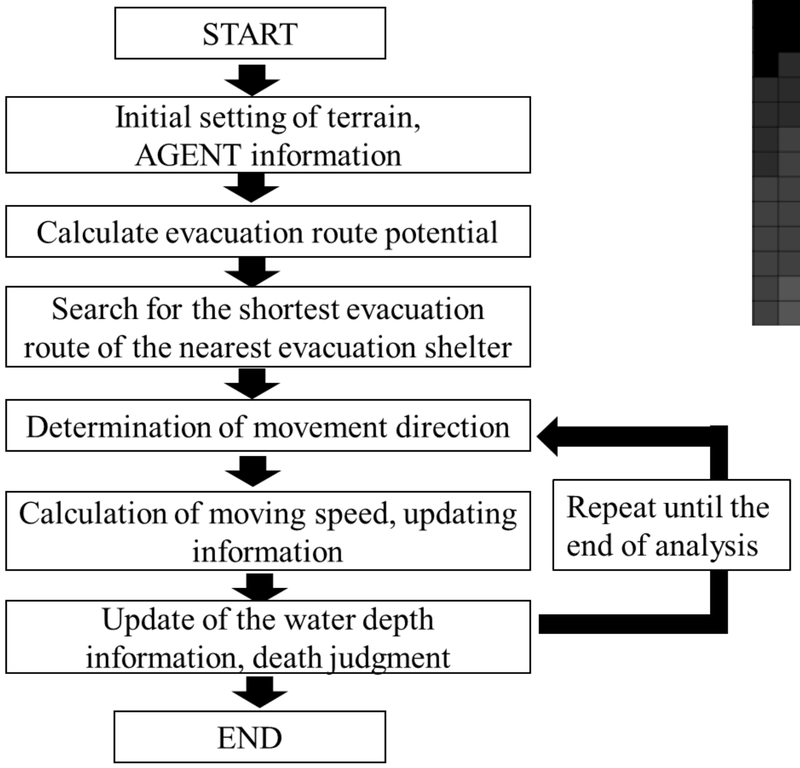
Evacuation simulator based on potential theory

1)Tomita et al. (2005) : Development of numerical simulator of seawater flow and Application to Tsunami Analysis
2)Arikawa・Oie (2015)：Study of Evacuation Behavior Characteristic using Evacuation Simulator Coupled with Numerical Wave Flume

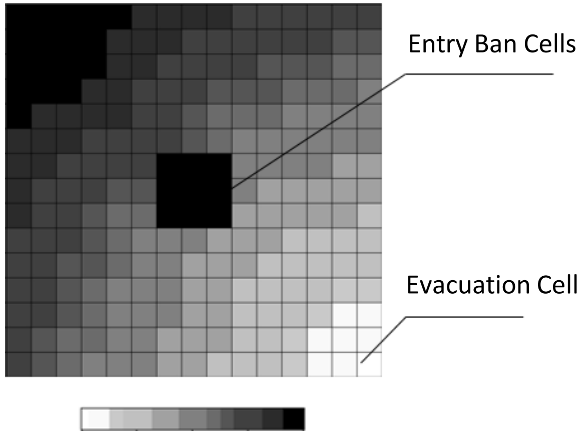
Numerical Model

A method to evacuate to the nearest shelter using the "potential theory"

Calculation flow



"Potential" calculation of evacuation route



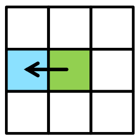
$$u_{shelter}(i, j) = -1 / r(i, j)$$

$u_{shelter}$: Evacuation route potential

$r(i, j)$: The shortest distance from the (i, j) cell to the nearest evacuation shelter

Determination of movement direction

Search 8 surrounding cells and move in the direction of minimum potential value

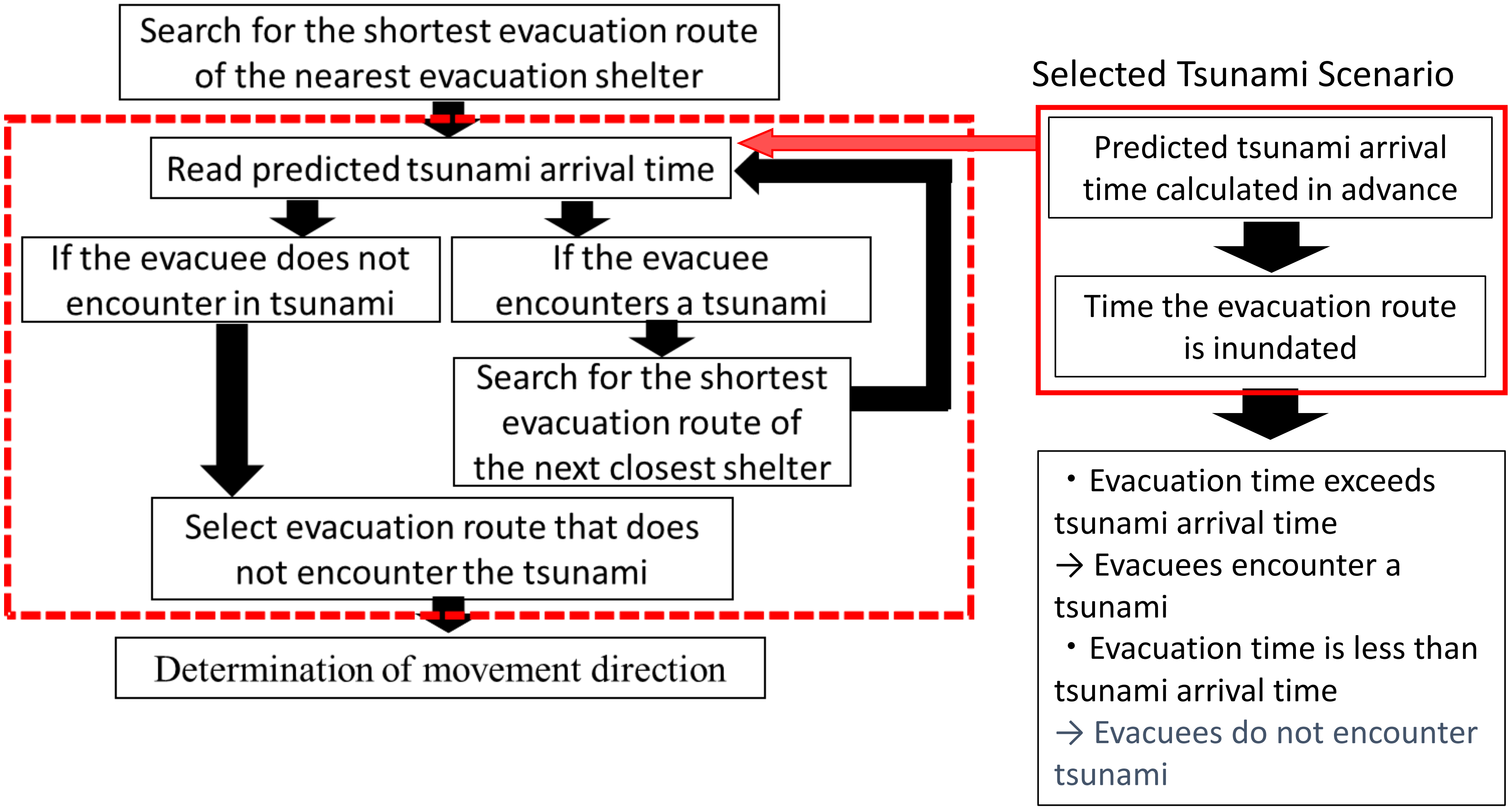


The current position of the evacuees

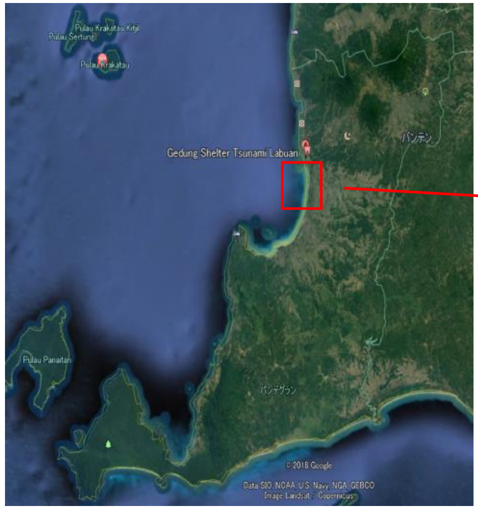
The cell of minimum potential value

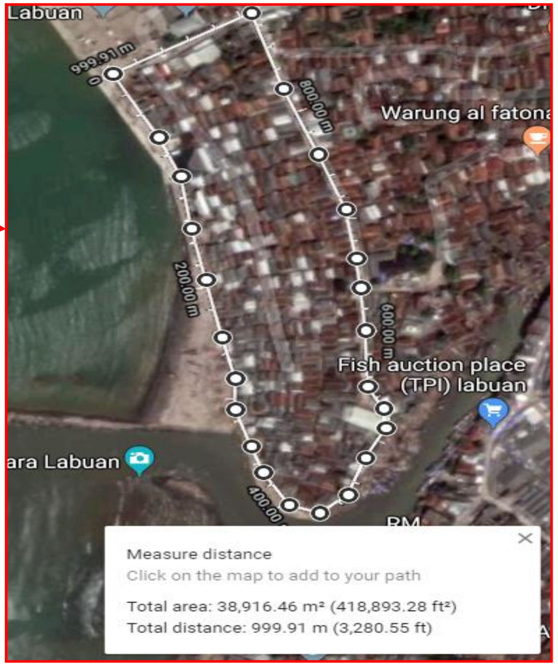
← Evacuee's moving direction

Evacuation Route Selection Method



Labuhan coastal area in western Java

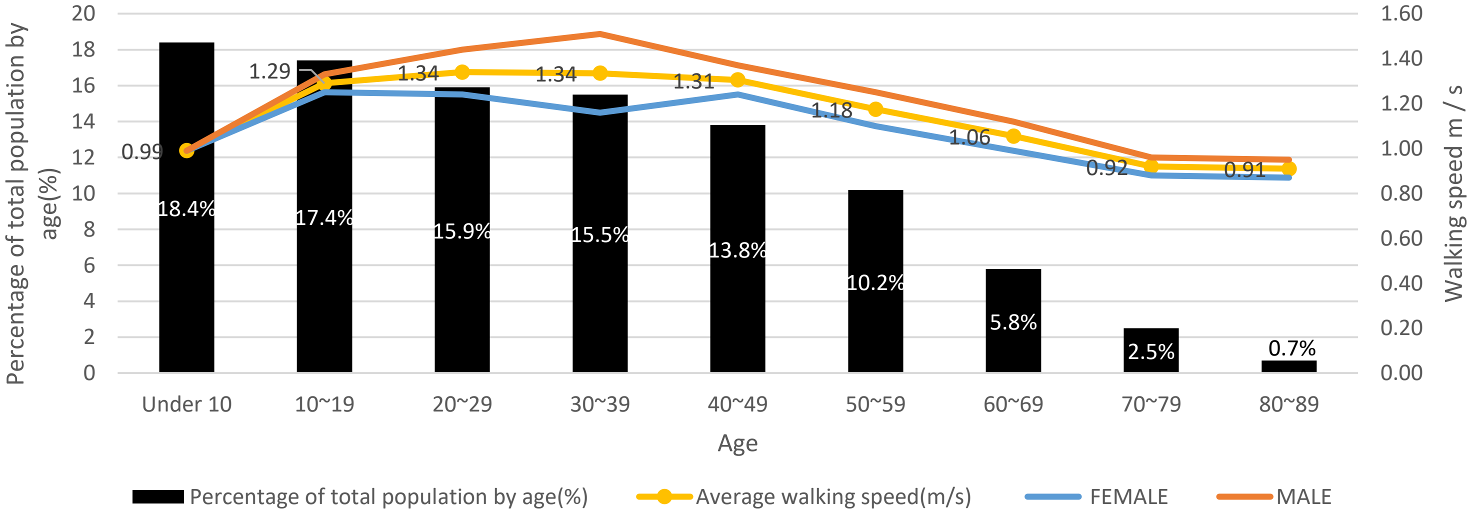




Area: 0.389165 square km

Density of population per unit of area : 1352 (persons per square km, in 2018)

Population ： 537



Field Application Calculation

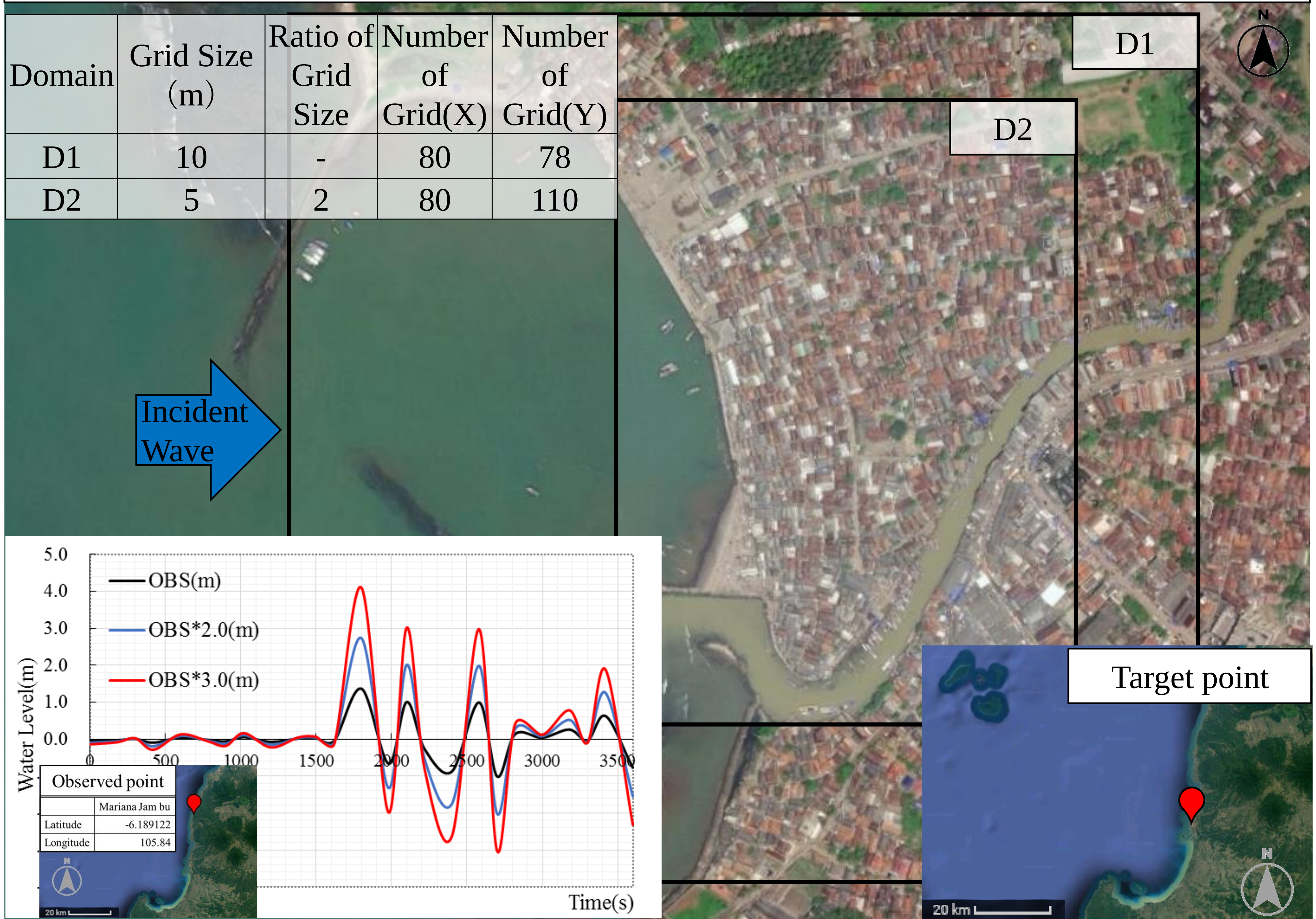

Evacuation Route and Evacuation Shelter

Calculation Condition for multi agent simulation

Article	Detail
Evacuation Root	
Evacuation Shelter	
Grid Size	1.0 m
Number of Grid	183×407
Time Step Interval	0.1 s
Calculation Time	3600 s
Evacuation Start Time	Every 100s Between 1060 s and 2060 s
Evacuee	537
Initial Placement of Evacuees	Random Set on Evacuation Route

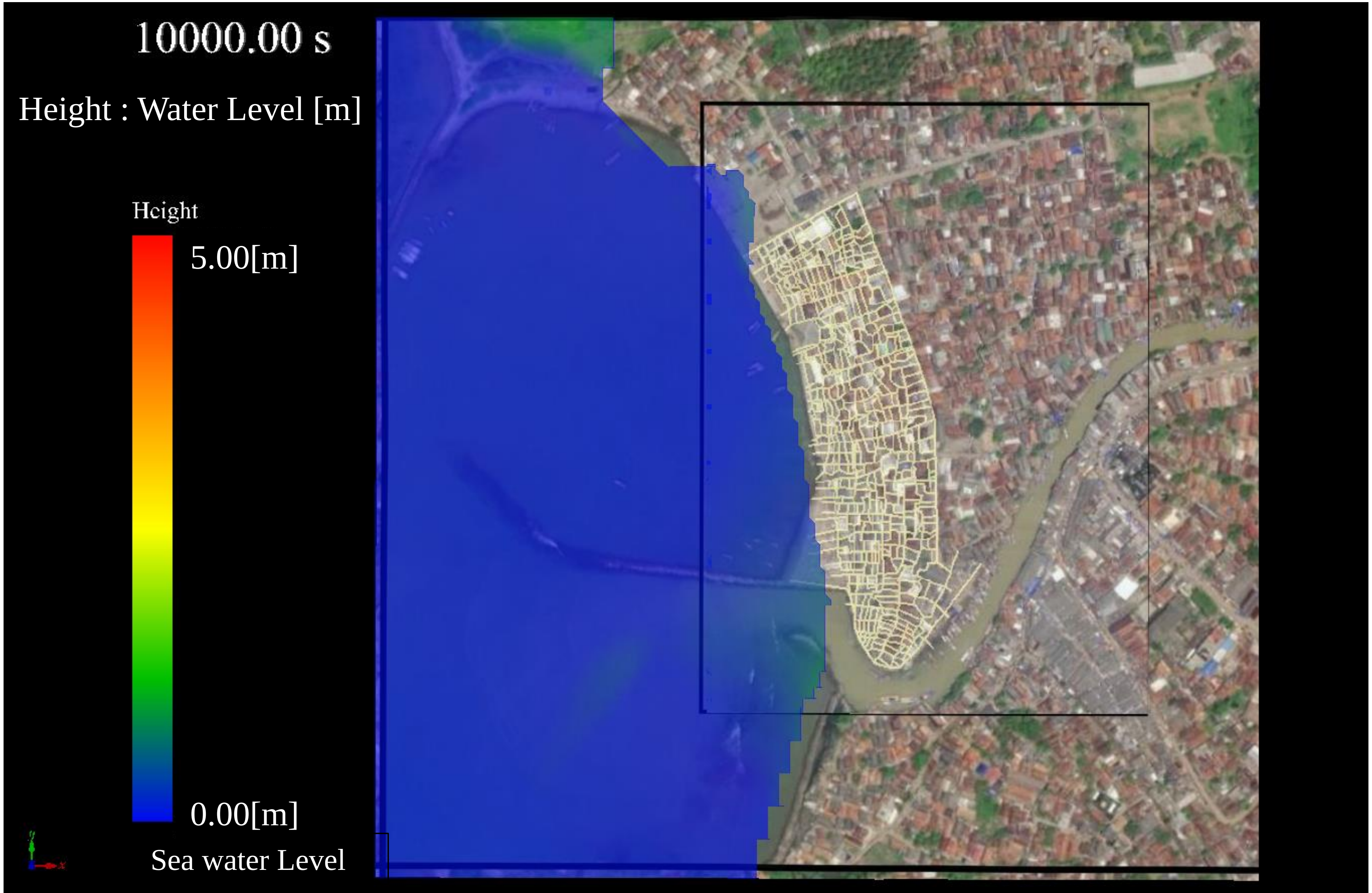
STOC-ML Calculation Condition(Labuhan)

Domain	Grid Size (m)	Ratio of Grid Size	Number of Grid(X)	Number of Grid(Y)
D1	10	-	80	78
D2	5	2	80	110



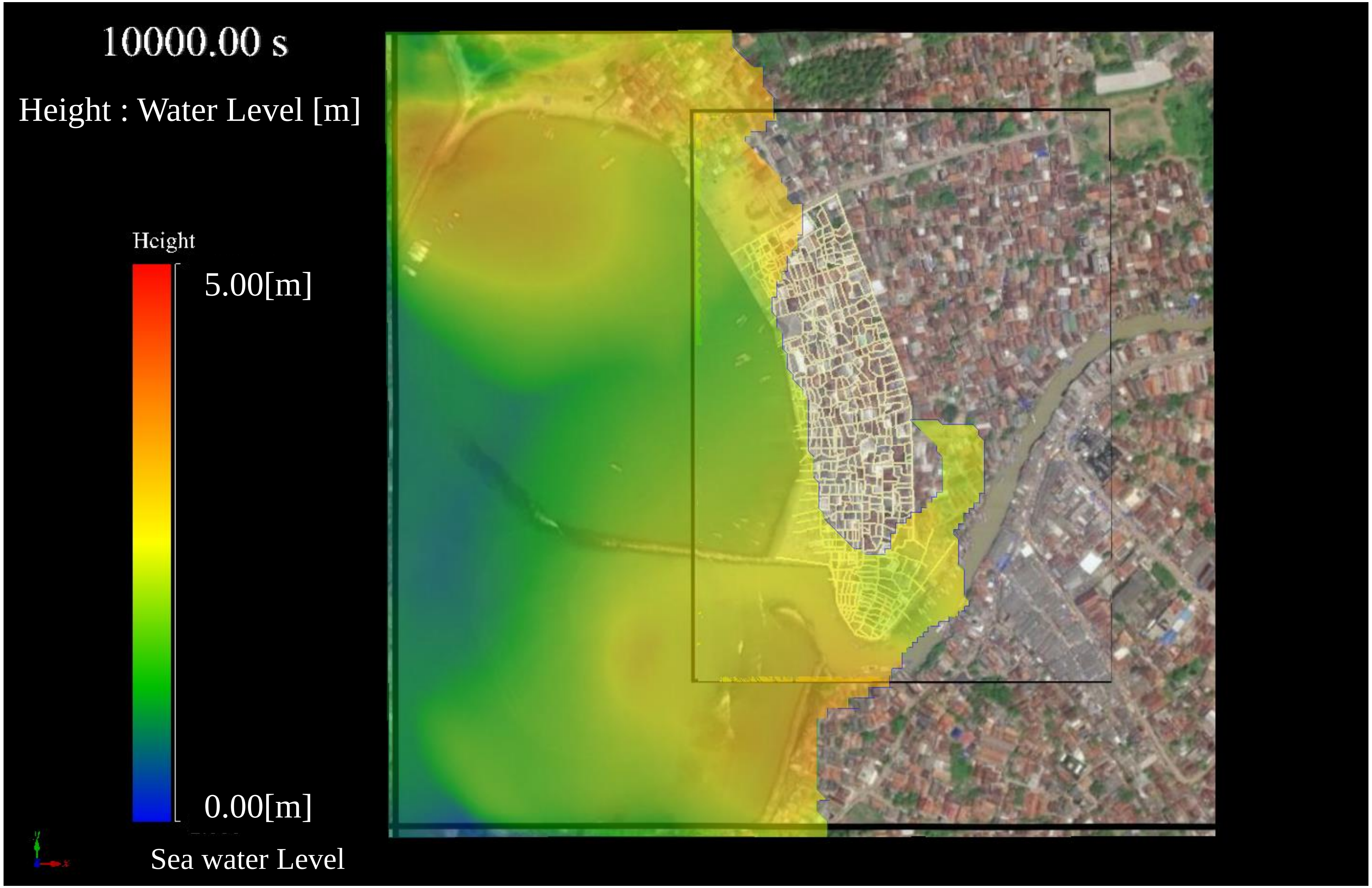
STOC-ML Calculation Result(Labuhan)

OBS*1.0_Inundation_Area



STOC-ML Calculation Result(Labuhan)

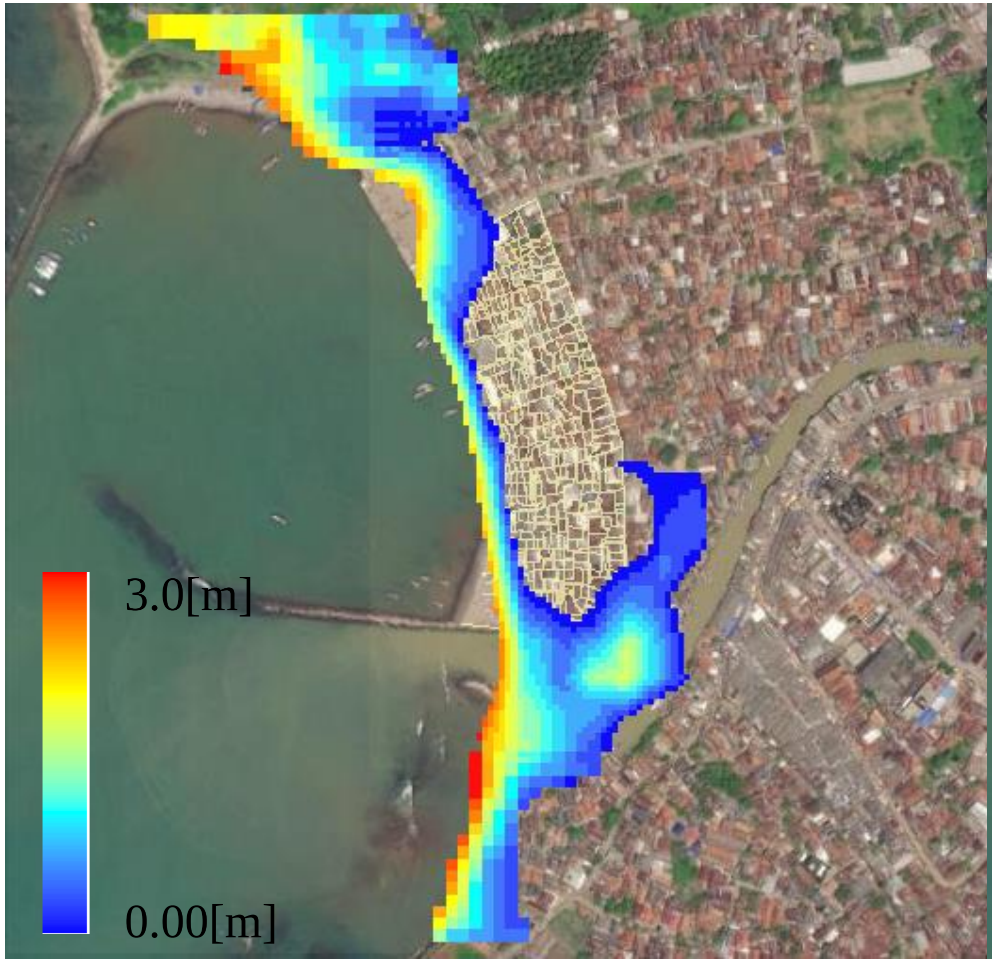
OBS*2.0_Inundation_Area



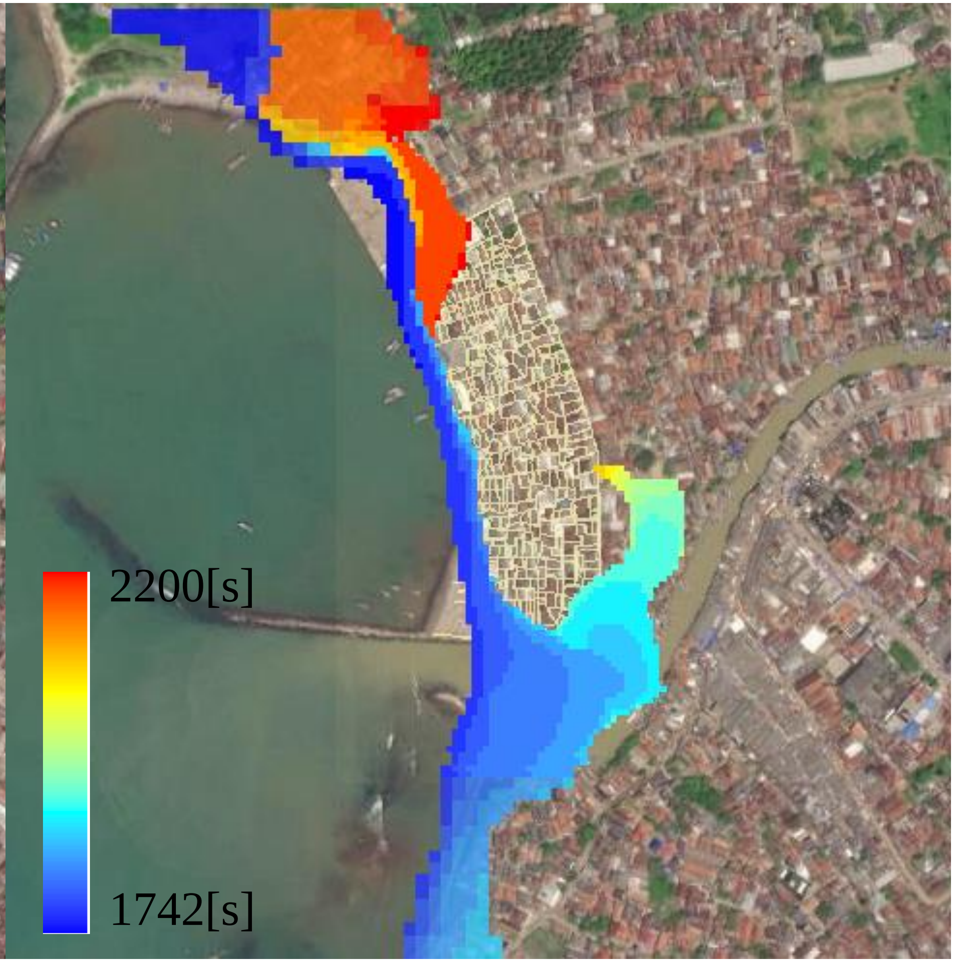
STOC-ML Calculation Result(Labuhan)

OBS*2.0

〇Inundation Depth

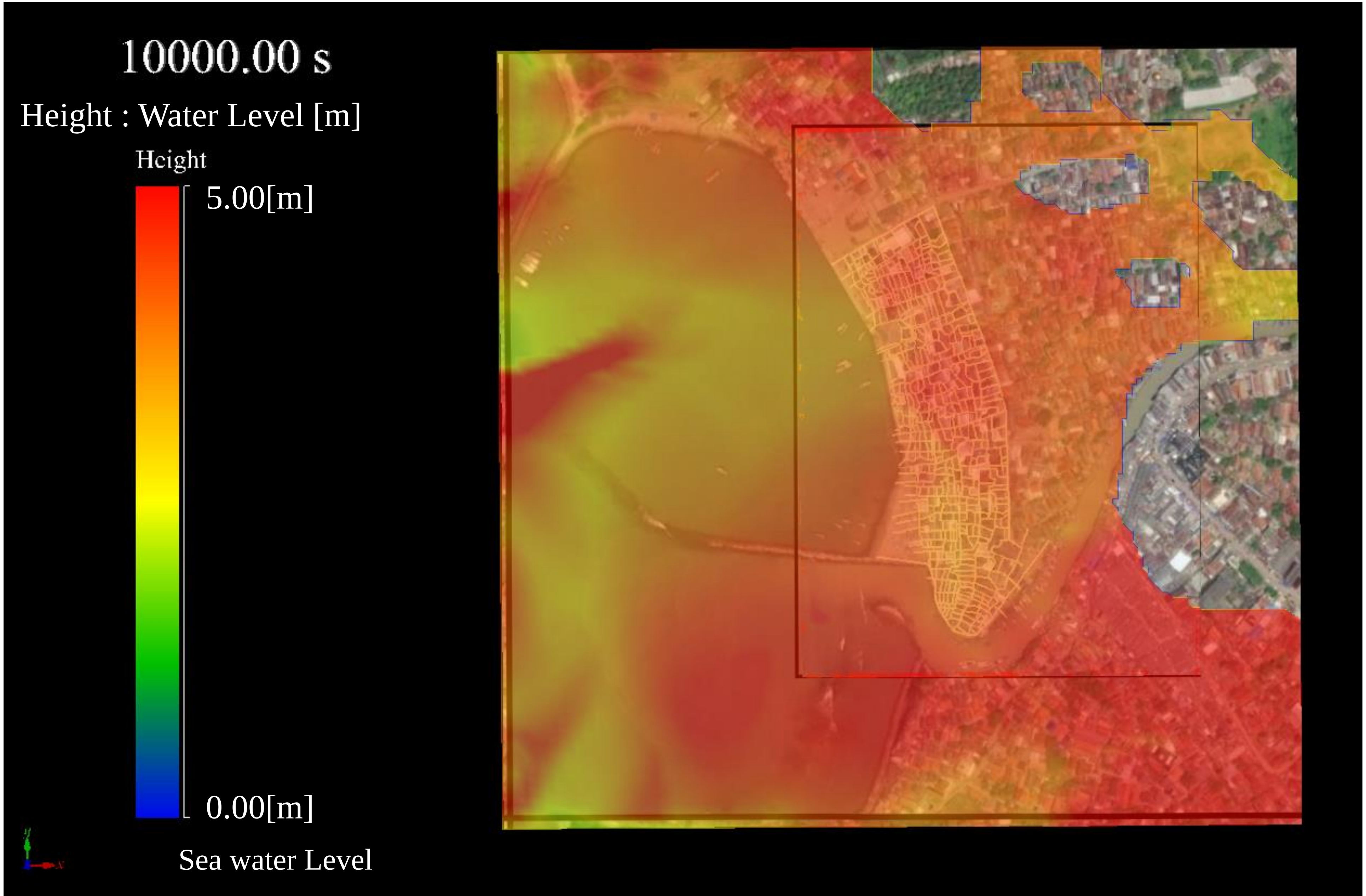


〇Tsunamiarrival time

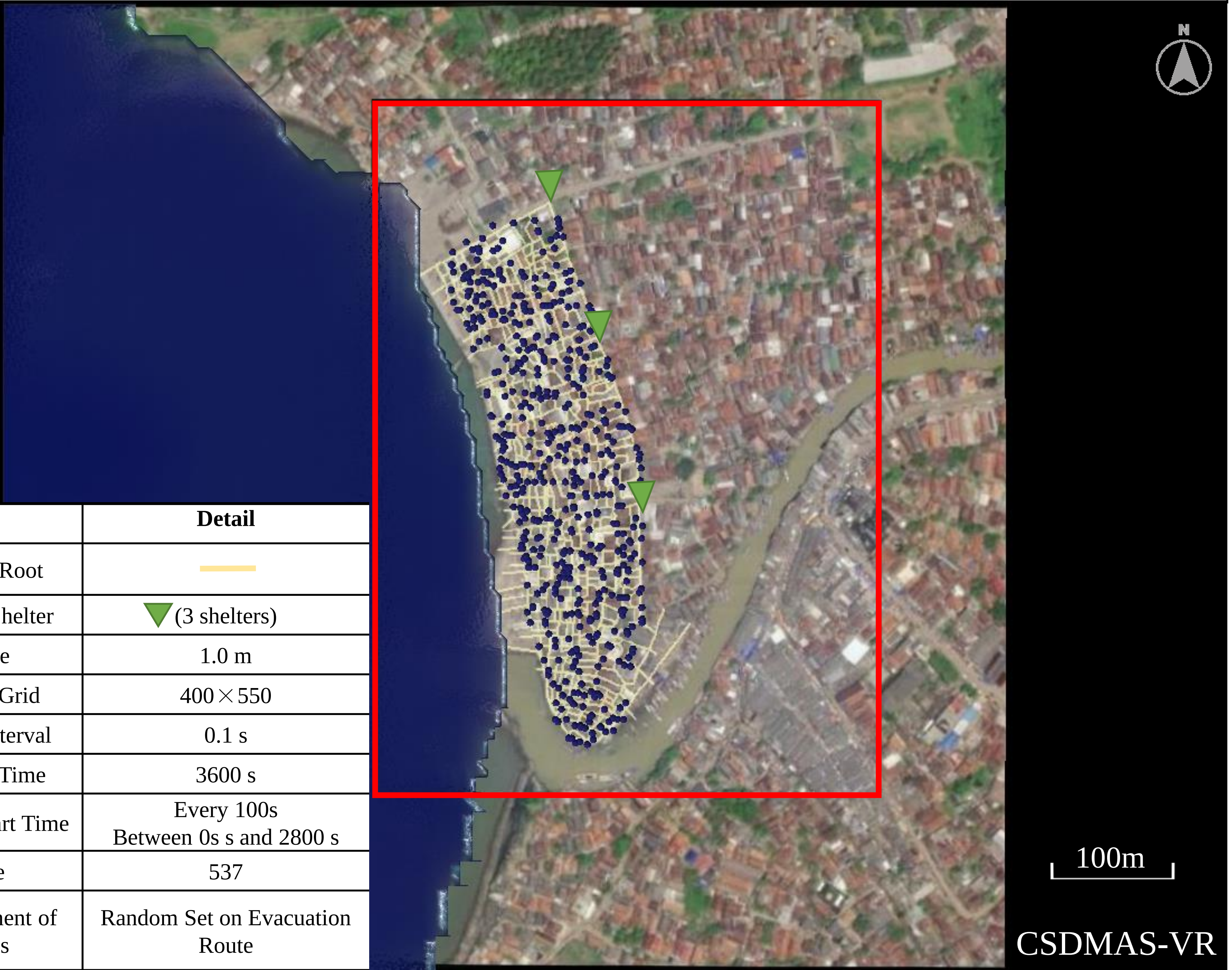


STOC-ML Calculation Result(Labuhan)

OBS*3.0_Inundation_Area

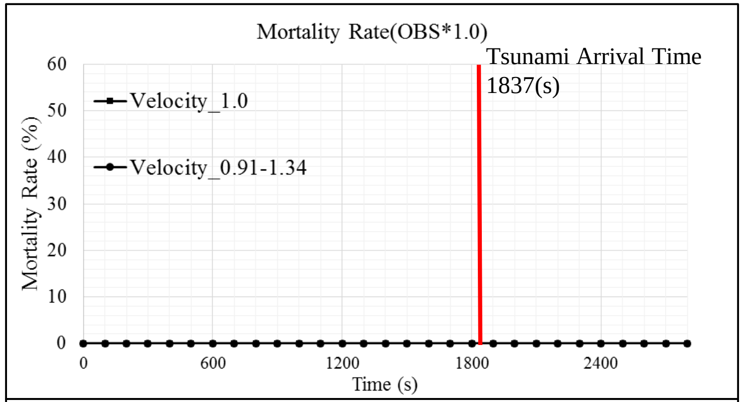


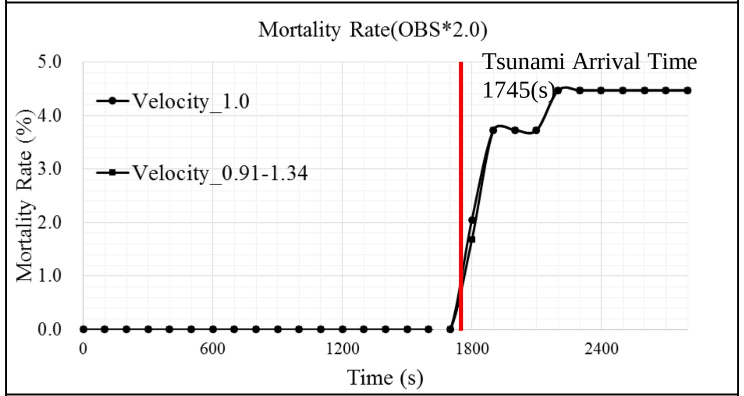
MAS Calculation Condition(Labuhan)

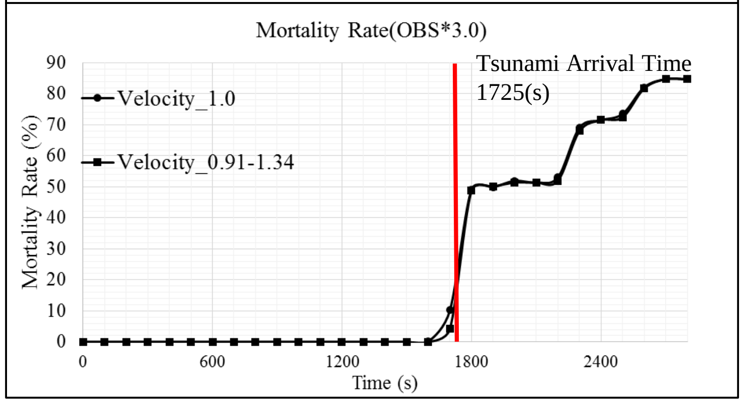


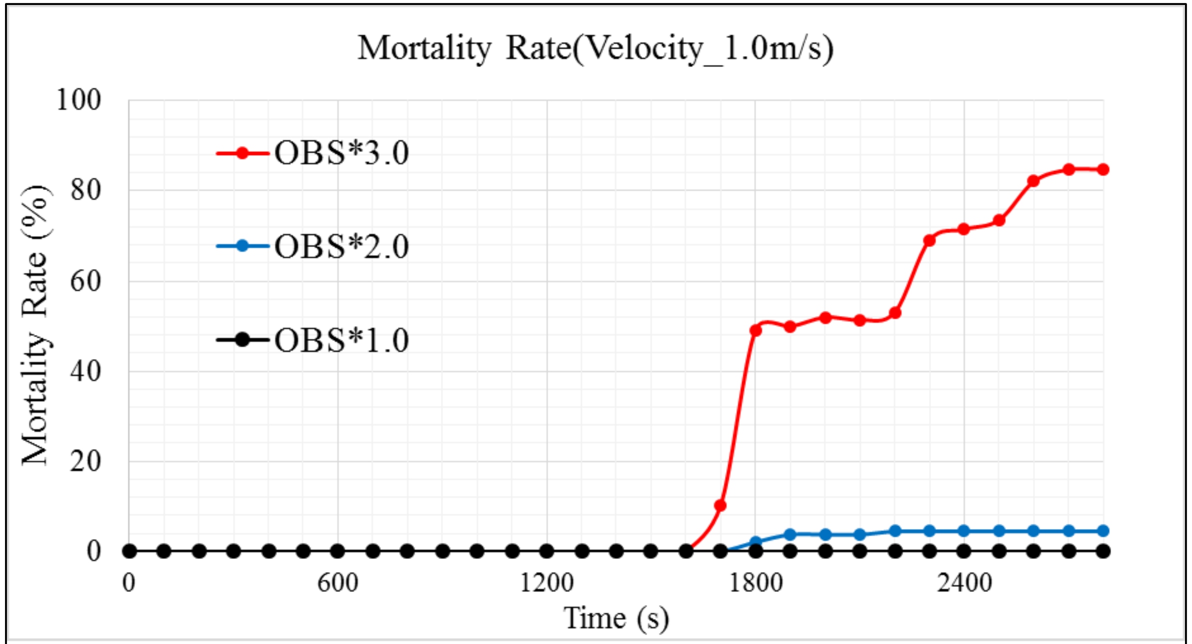
Article	Detail
Evacuation Root	
Evacuation Shelter	(3 shelters)
Grid Size	1.0 m
Number of Grid	400×550
Time Step Interval	0.1 s
Calculation Time	3600 s
Evacuation Start Time	Every 100s Between 0s s and 2800 s
Evacuee	537
Initial Placement of Evacuees	Random Set on Evacuation Route

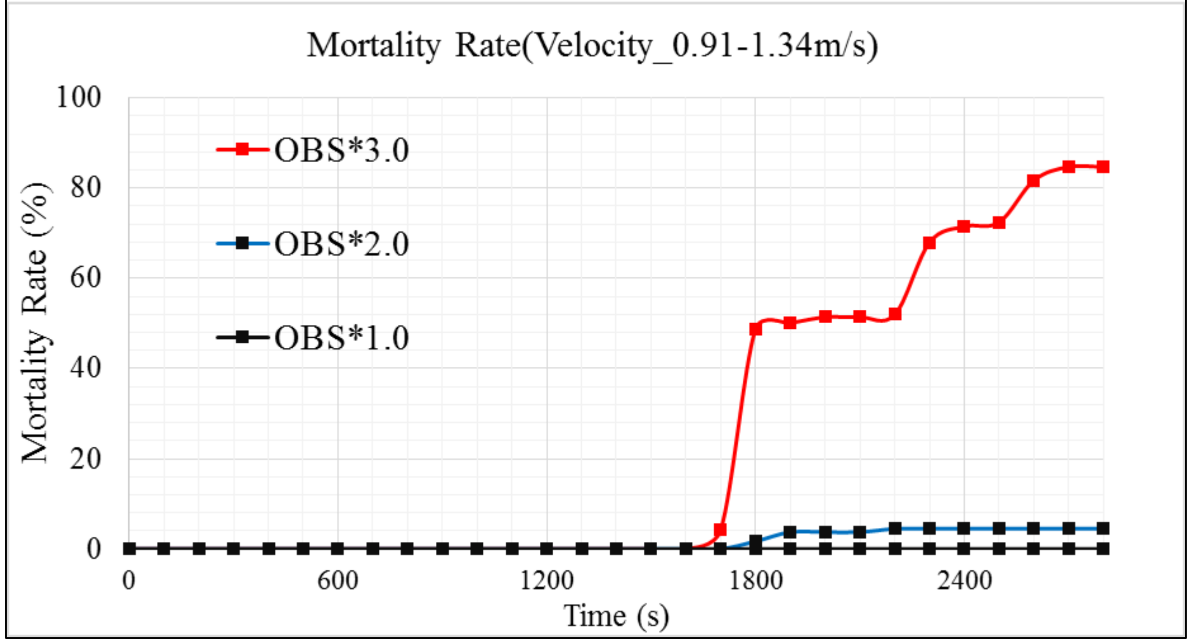
MAS Calculation Result(Labuhan)





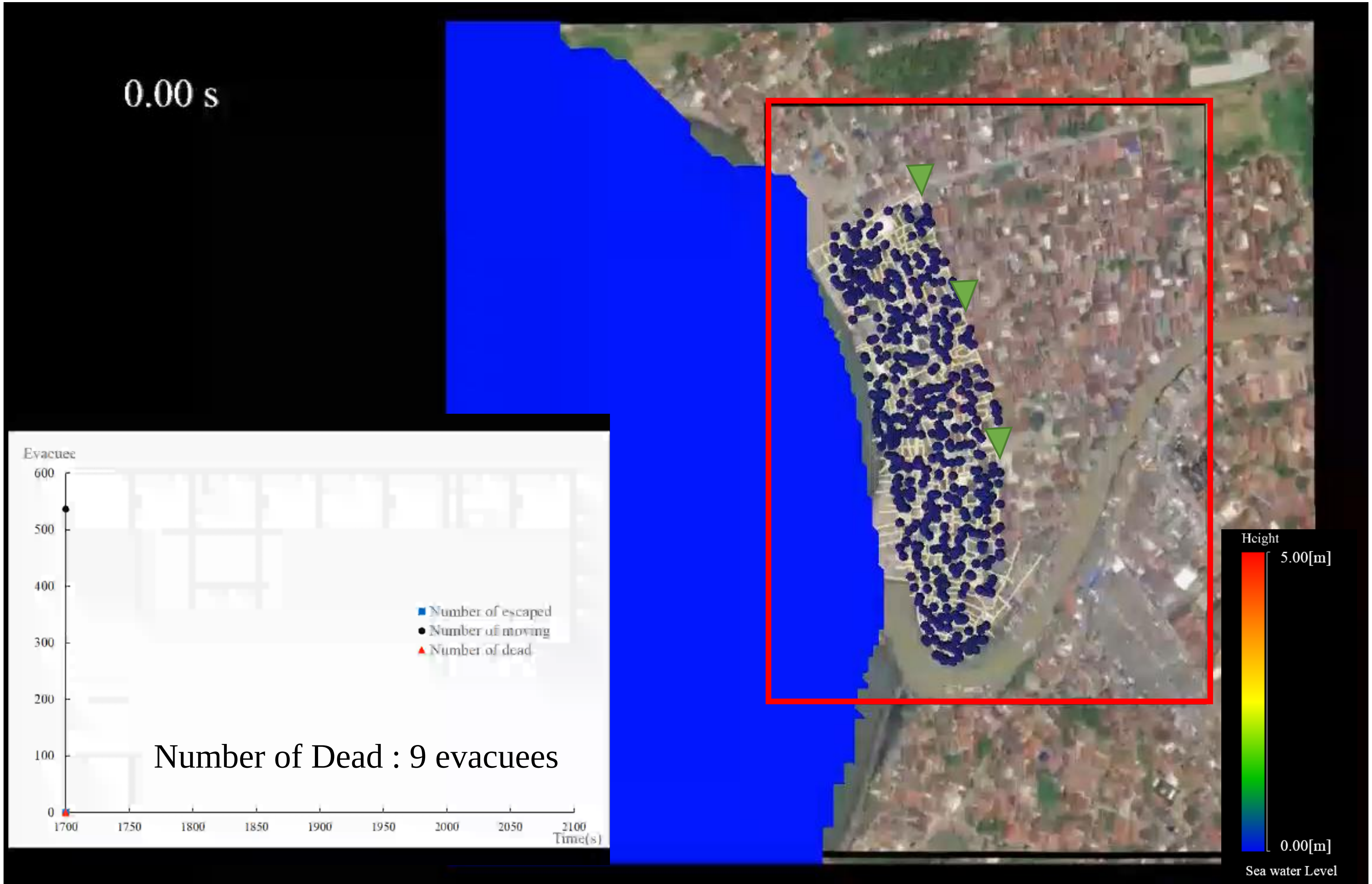






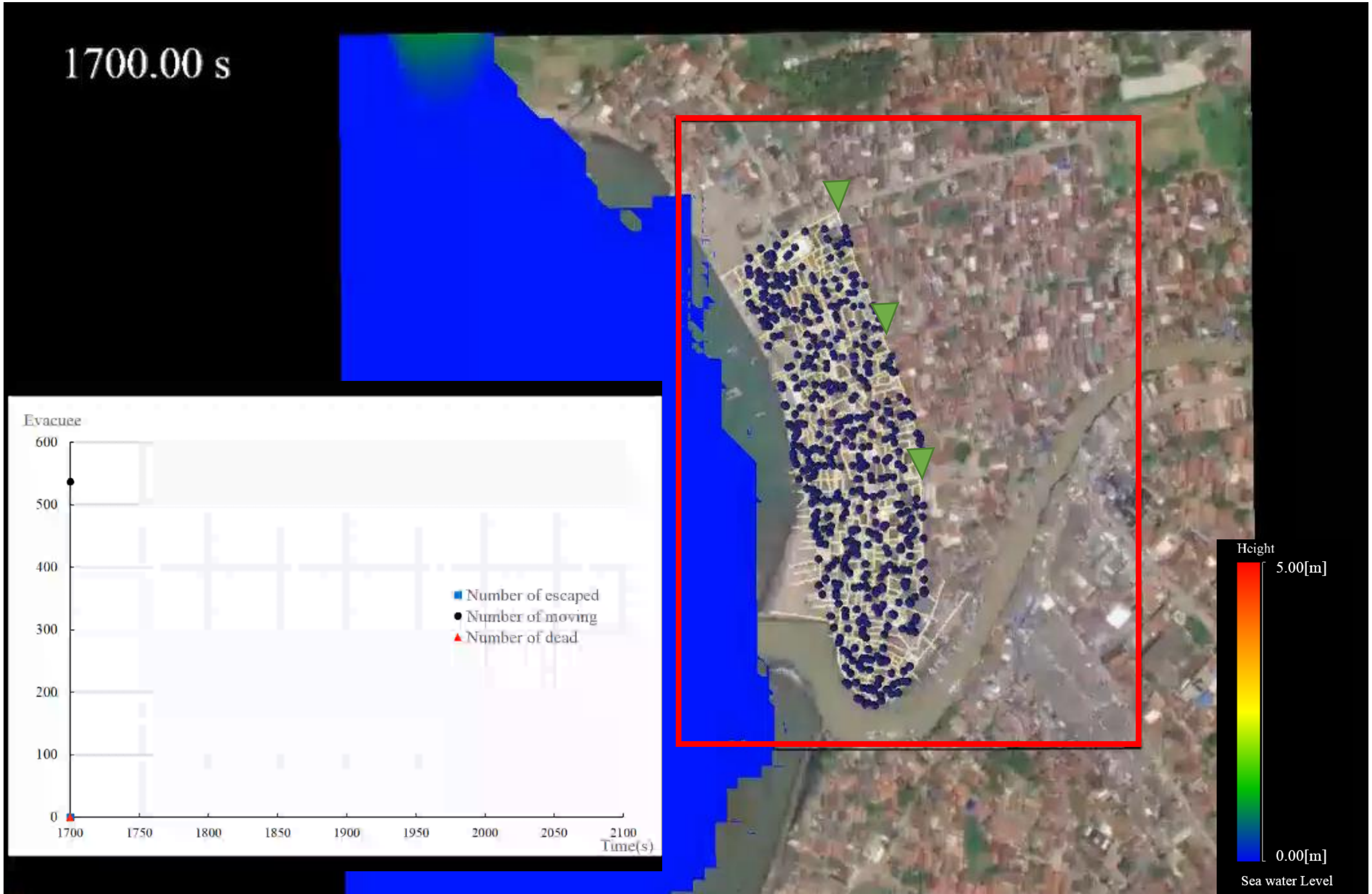
MAS Calculation Result(Labuhan)

OBS*2.0_Evacuation Start Time:1800s

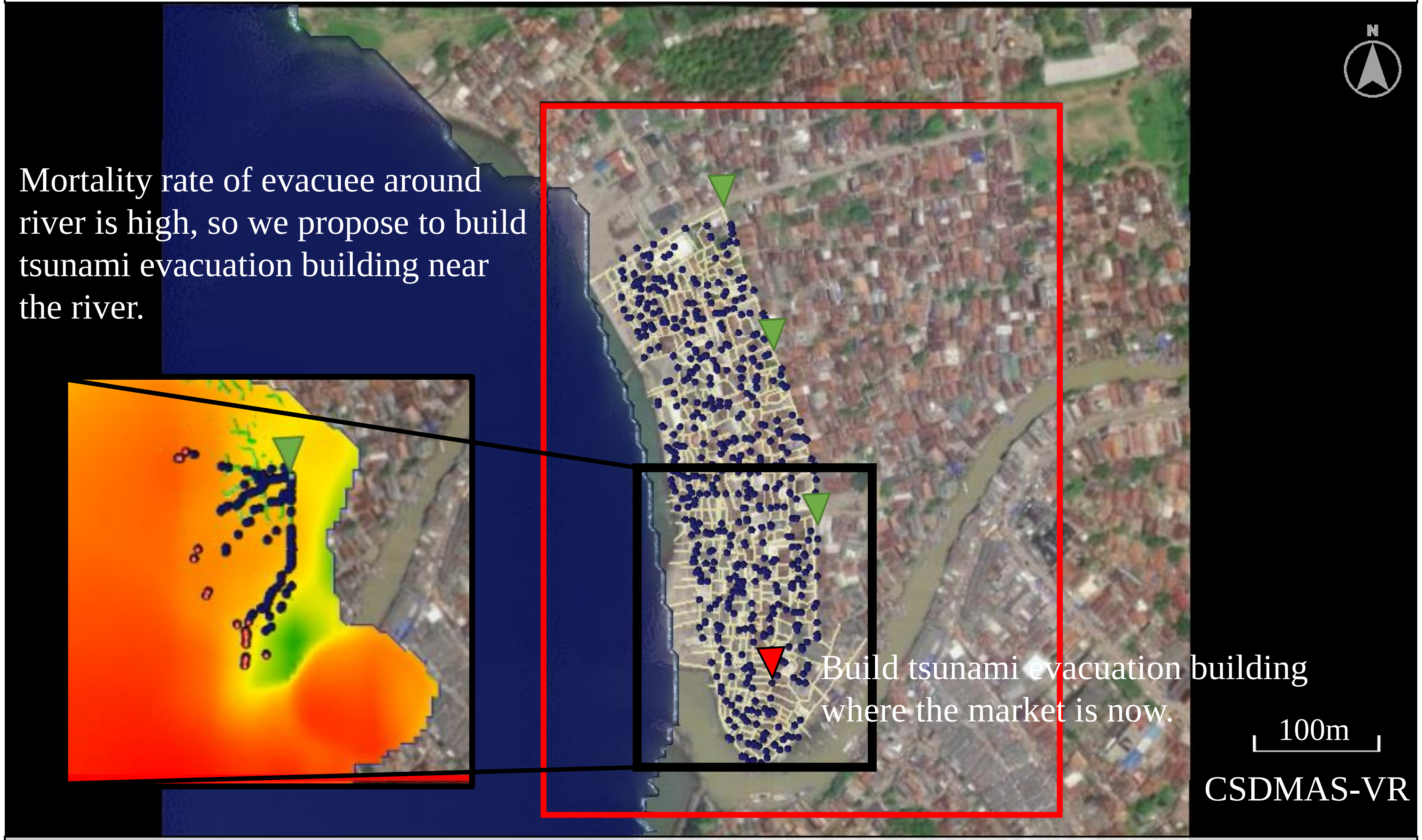


MAS Calculation Result(Labuhan)

OBS*3.0_Evacuation Start Time:1725s



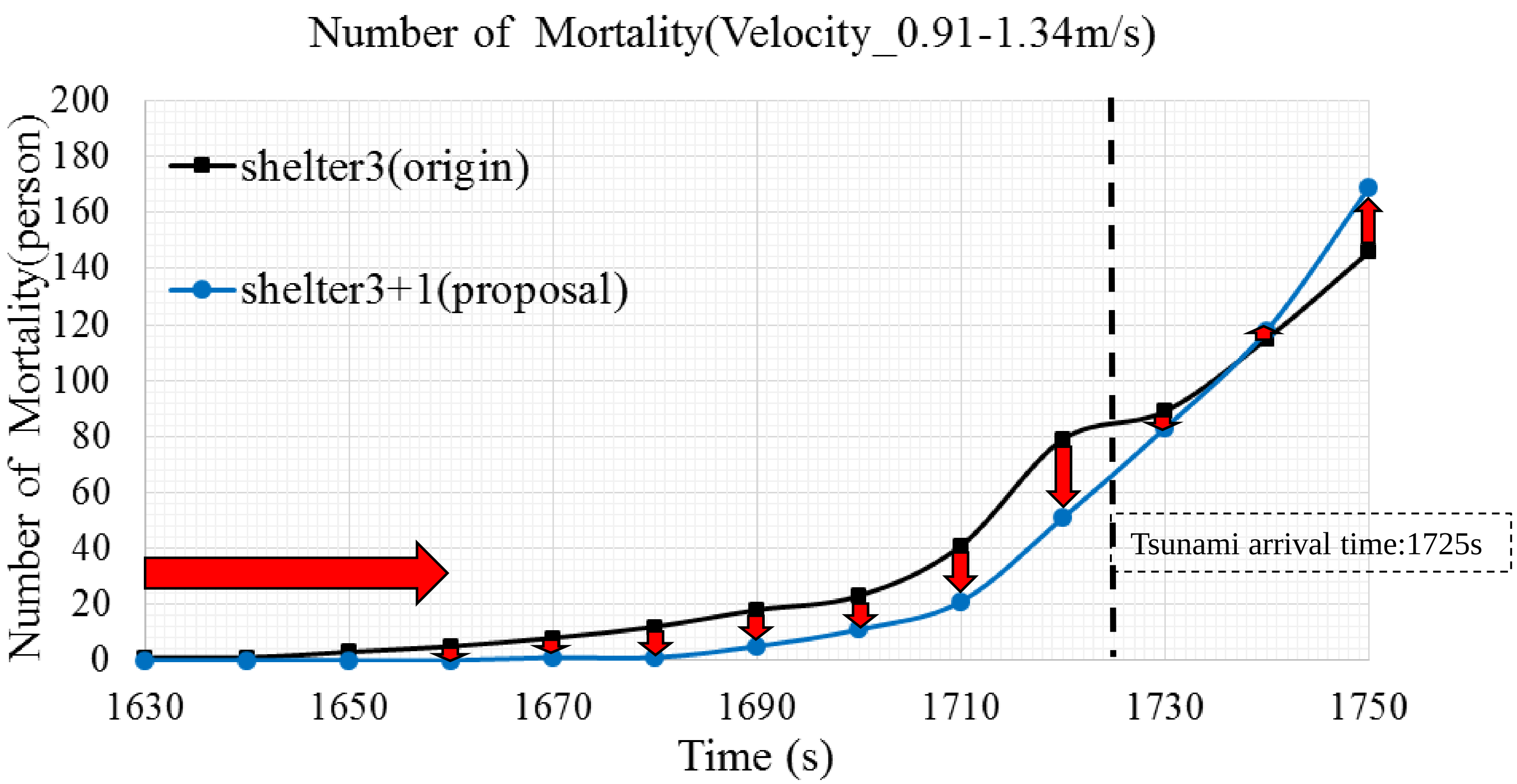
MAS Calculation Result(Labuhan)



Examine the impact on mortality of evacuee by tsunami evacuation buildings.

MAS Calculation Result(Labuhan)

OBS*3.0_Evacuation Start Time:1630~1750s

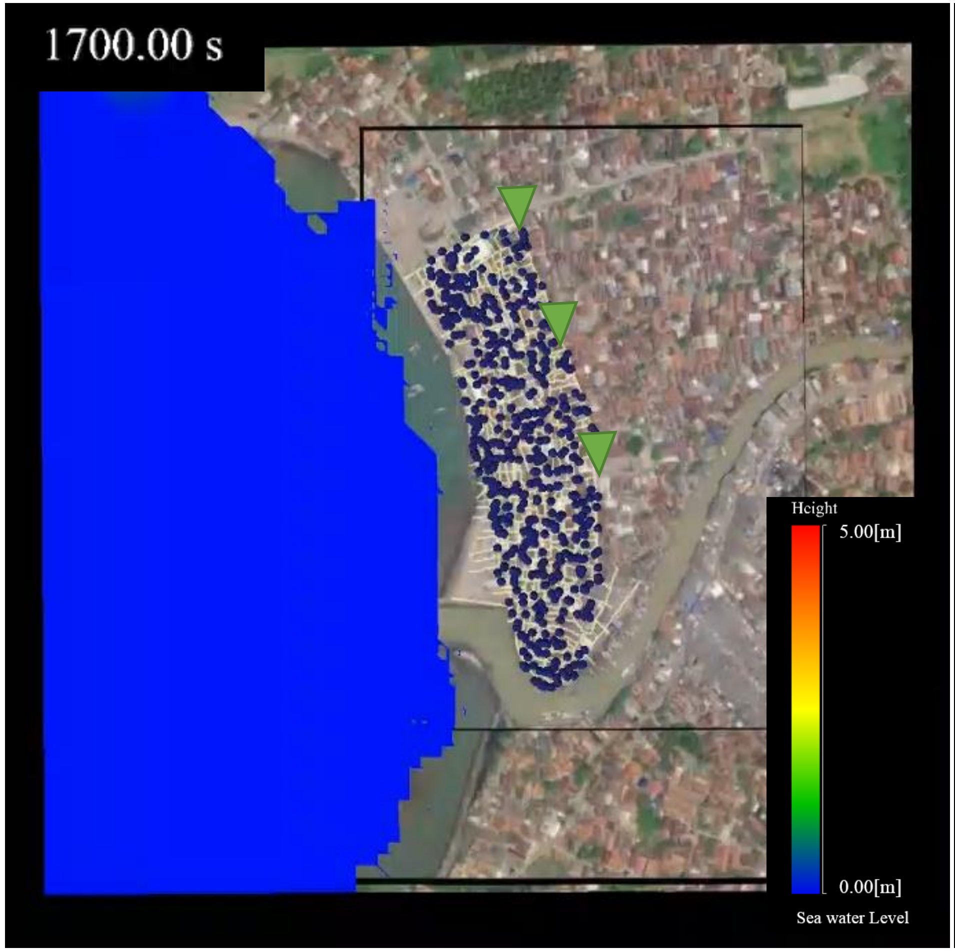


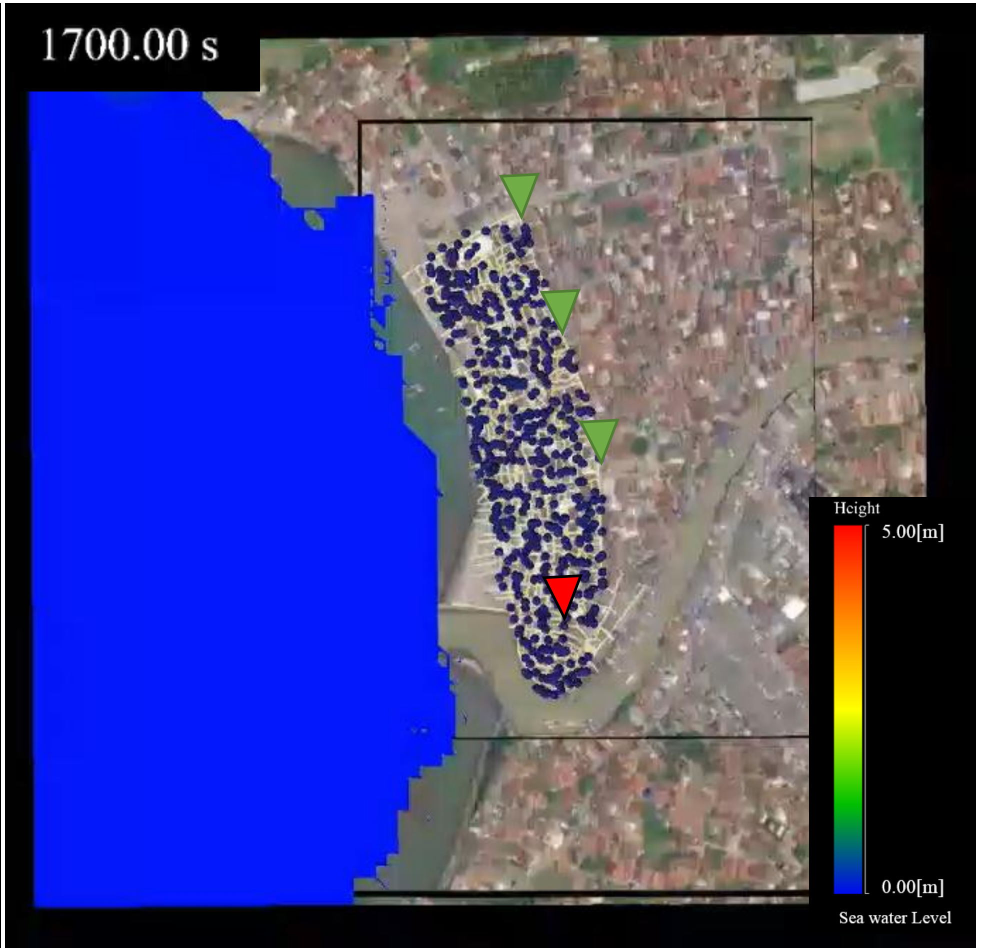
Extend the time limit for starting evacuation that mortality is zero. When evacuating before reaching the tsunami, the mortality rate is reduced.
On the other hand, after the arrival of the tsunami, the evacuation was based on the shortest route, so the evacuee evacuated in the direction of the tsunami, resulting in an increase in mortality.

MAS Calculation Result(Labuhan)

OBS*3.0_Evacuation Start Time:1720s

▼ Shelter
▼ Proposal Evacuation Building





Verification of the possibility of sea level monitoring using video image

Palu Tsunami on September 28, 2018

Many tsunami videos were recorded on SNS.

Such a landslide tsunami occurs very close to the coastline.

Locally, high tsunami arrives in a short time.

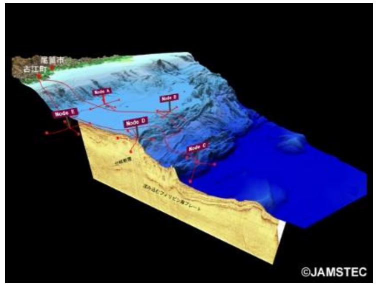
https://www.youtube.com/watch?v=61ItBglP-YM

Information required for evacuation

(1) Tsunami Warning System

Estimating the possibility of a tsunami based on the earthquake mechanism.

It cannot respond immediately to tsunami cased by submarine landslides or mountain collapse.



https://www.jamstec.go.jp/donet/j/donet/

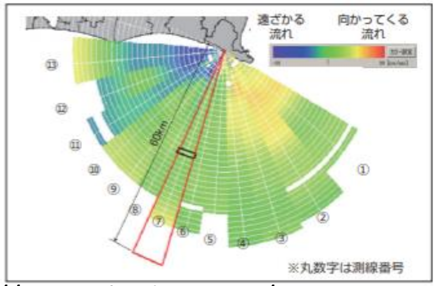
(2) Tsunami Monitoring System

(2-1) GPS Buoy, Submarine pressure gauge (expensive?)

They may be unaware of the tsunami that occurs near the coast and rises locally.

(2-2) HF radar

It may also be unaware of the tsunami that occurs near the coast and rises locally.



https://www.chuden.co.jp/resource/corporate/news_159_04.pdf

Submarine landslide tsunami

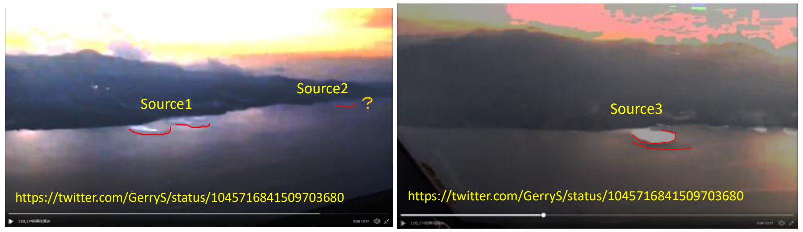
- There may be many places where it occurs(Steep slope, Estuary Delta, Soft sediment layer).
- It’s difficult to monitor those places with the current method alone(GPS buoy, Submarine pressure gauge, HR radar).

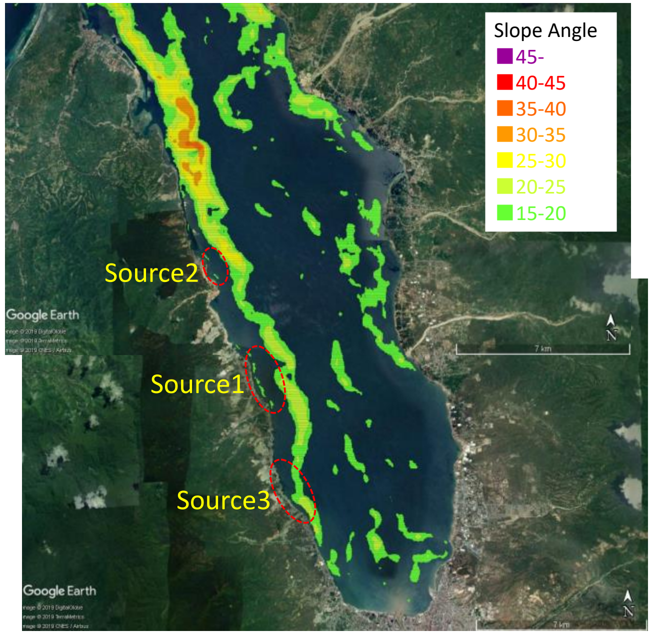
Use monitoring cameras to detect tsunamis

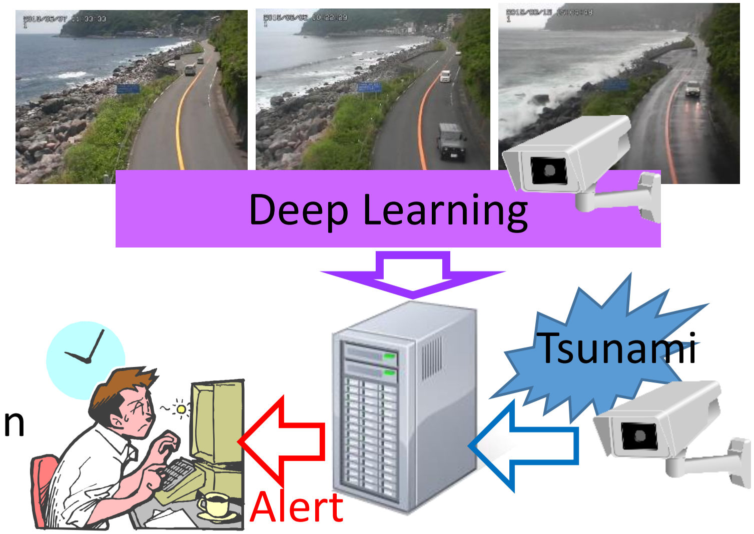
- Low cost of installation and operation(compared to current tsunami monitoring system).
- Therefore, many cameras can be installed.
- In addition, it can be used for purpose other than tsunami(for example, tourism and other safety).

Problems and challenges

- Who checks so many cameras? (around the clock)
- Apply artificial intelligence(deep learning method).
- An abnormal wave is detected from the image and an alert issued.

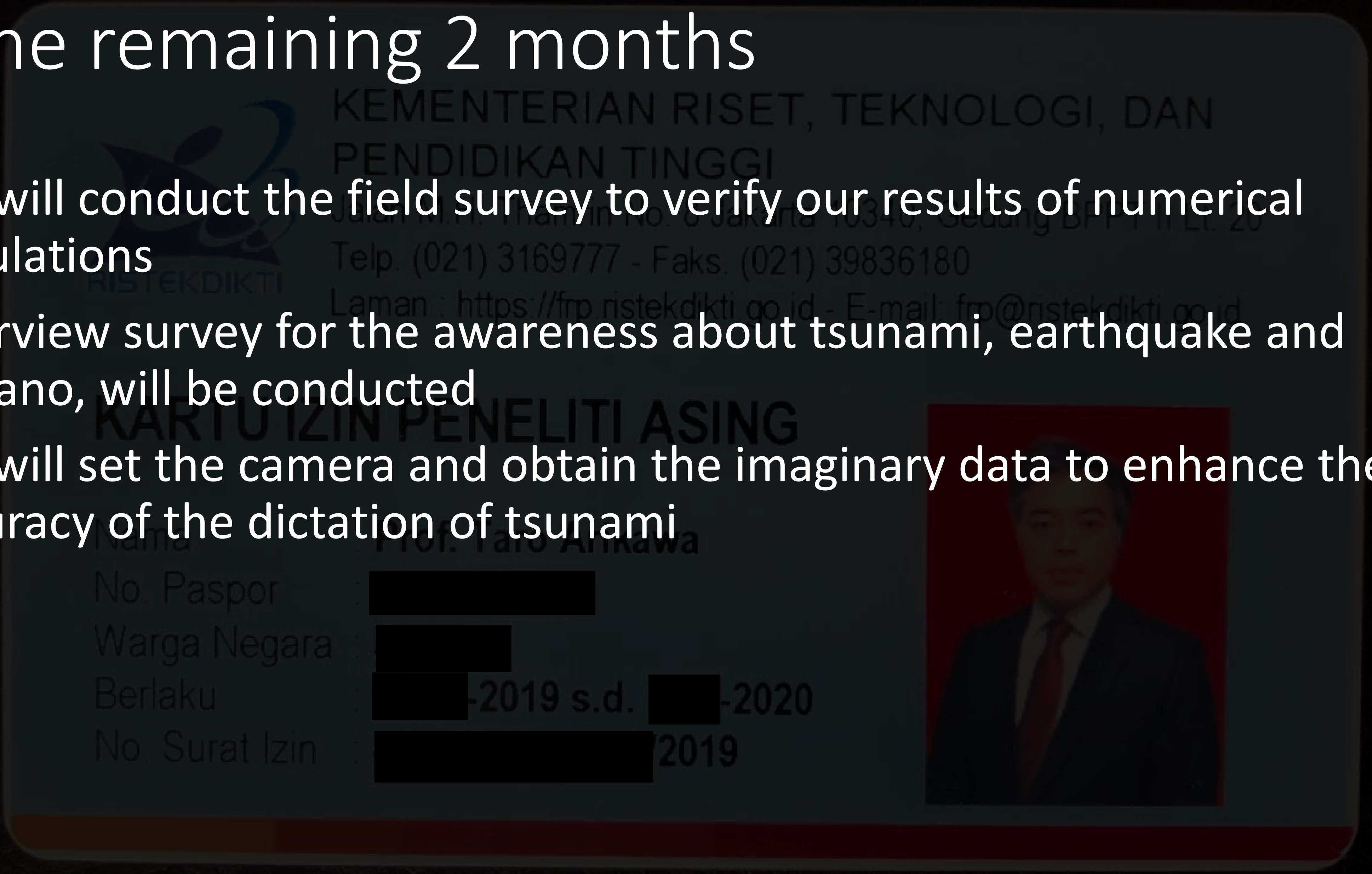






In the remaining 2 months

- We will conduct the field survey to verify our results of numerical simulations
- Interview survey for the awareness about tsunami, earthquake and volcano, will be conducted
- We will set the camera and obtain the imaginary data to enhance the accuracy of the dictation of tsunami




Thank you for your cooperations!