Improvement of the realtime tsunami prediction system using DONET and its implementation

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ABSTRACT

Coastal areas along the Nankai Trough were damaged repeatedly by large earthquakes and tsunamis. And, these areas are relatively close to the trough axis comparing with the Japan Trench area. Therefore, it is very important to understand tsunami distribution for disaster prevention around local residents. We developed a realtime tsunami prediction system using the Dense Oceanfloor Network for Earthquakes and Tsunamis (DONET), which is installed in rupture areas of Tonankai and Nankai earthquakes. The principle of this prediction system is based on the tsunami amplification, which corresponds to correlation between the pressure data at the DONET stations and the coastal tsunami height. Although previous system used average of absolute pressure gauge data of 20 DONET stations, we developed the prediction system by optimized selection of fault models from the tsunami database. We introduced selection method of the fault models based on tsunami trigger pattern of the DONET stations and the dynamic selection of the DONET stations used for the prediction. In particular, the dynamic selection depends on the tsunami propagation, therefore, the used DONET stations for realtime tsunami prediction on each coastal position are revised every second. We also revised processing of pressure gauge data for calculation of average of absolute values and use peak hold value of the pressure data as input data into the prediction system. The accuracy of the tsunami prediction was improved than previous system, and it is implemented in the a few local governments. We introduce the developed tsunami prediction system using a few fault models of Tonankai and Nankai earthquakes.

CONCEPT

DONET has ability of early detection of earthquakes related to the plate subduction and their tsunamis. In particular, the Nankai Trough area is very near the rupture zone and there are few time for local residents to evacuate tsunami. Therefore, our aims are to inform the tsunami information as soon as possible, and to construct the simplest system to be able to confirm tsunami situation in realtime for the local governments. Our realtime tsunami prediction system is focused on the local government, which plays a role as headquarter for real disaster prevention for each local area.

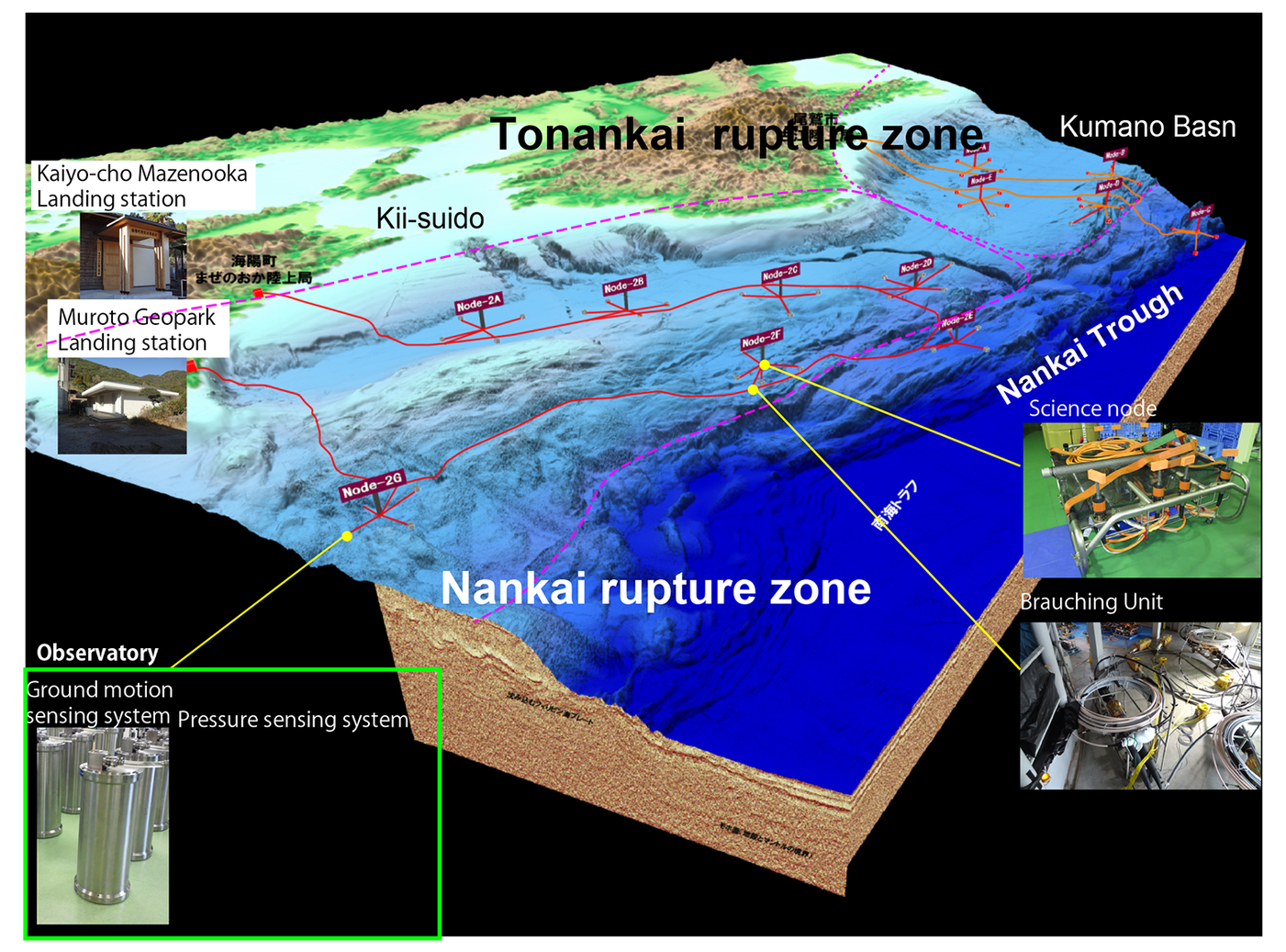


Figure 1 Map view of DONET. DONET covers the western Tonankai rupture area in the Kumano basin and the eastern Nankai rupture area of off Kii-suido. All DONET stations have seismometers and pressure gauges and the covered area extends to the trough axis area. Therefore, DONET has large superiority on the early detection of tsunami

PRINCIPAL

It is well known that tsunami become large near the coastal line, because the tsunami speed depends on the water depth. We adopted this principal to predict tsunami in realtime, and process of tsunami height during the tsunami propagation is monitored using DONET stations.

We only see the tsunami height on each DONET station, and this system is not identified the tsunami source. Because the seafloor landslides could be occurred at input of strong motions and because it could make occur huge tsunami. It is important to catch tsunami with appropriate DONET stations for each tsunami prediction point.

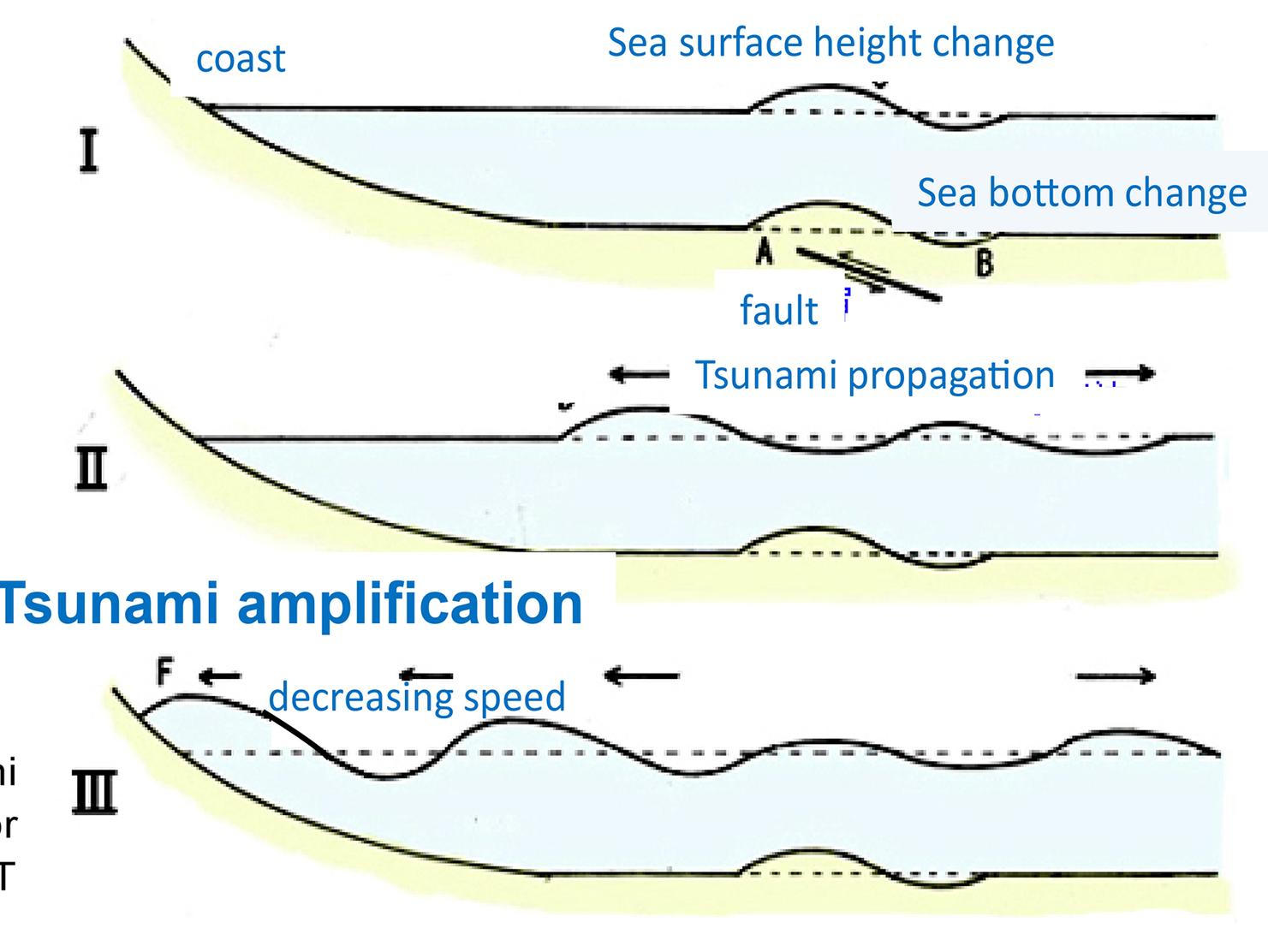


Figure 2 Principal of our realtime tsunami prediction system. It is important to monitor tsunami height recorded on the DONET stations along the tsunami propagation.

DATABASE

Tsunami database was constructed in advance and the tsunami prediction is done by extraction of appropriate fault modes according to appropriate condition. This database is composed of 1506 fault models and each maximum tsunami height on the DONET stations, predicted points, tide gauge stations of Japan Meteorological Agency and the local government, and so on. We gave some variations of the fault models on the magnitude (7.6 to 8.5), the depth (5 km to 20 km), and the fault angle (5 degree to 25 degree). Each model is linked to each inundation map for all prediction points. In the database, the correlation map is constructed between the amplitude of the pressure gauges on DONET stations as input and maximum tsunami height of each predicted point. The input data is calculated by moving absolute average with short time windows for DONET stations, and the average of the moving absolute average is calculated using some DONET stations, which is selected by appropriate methods as shown by next frame. Baba et al. (2014) adopted average for all extracted models, and we adopted the worst case to avoid underestimation of tsunami height. In this example (Figure 3c), the gray-colored bar indicates input data of approximately one meter and the predicted tsunami is approximate eight meters as output.

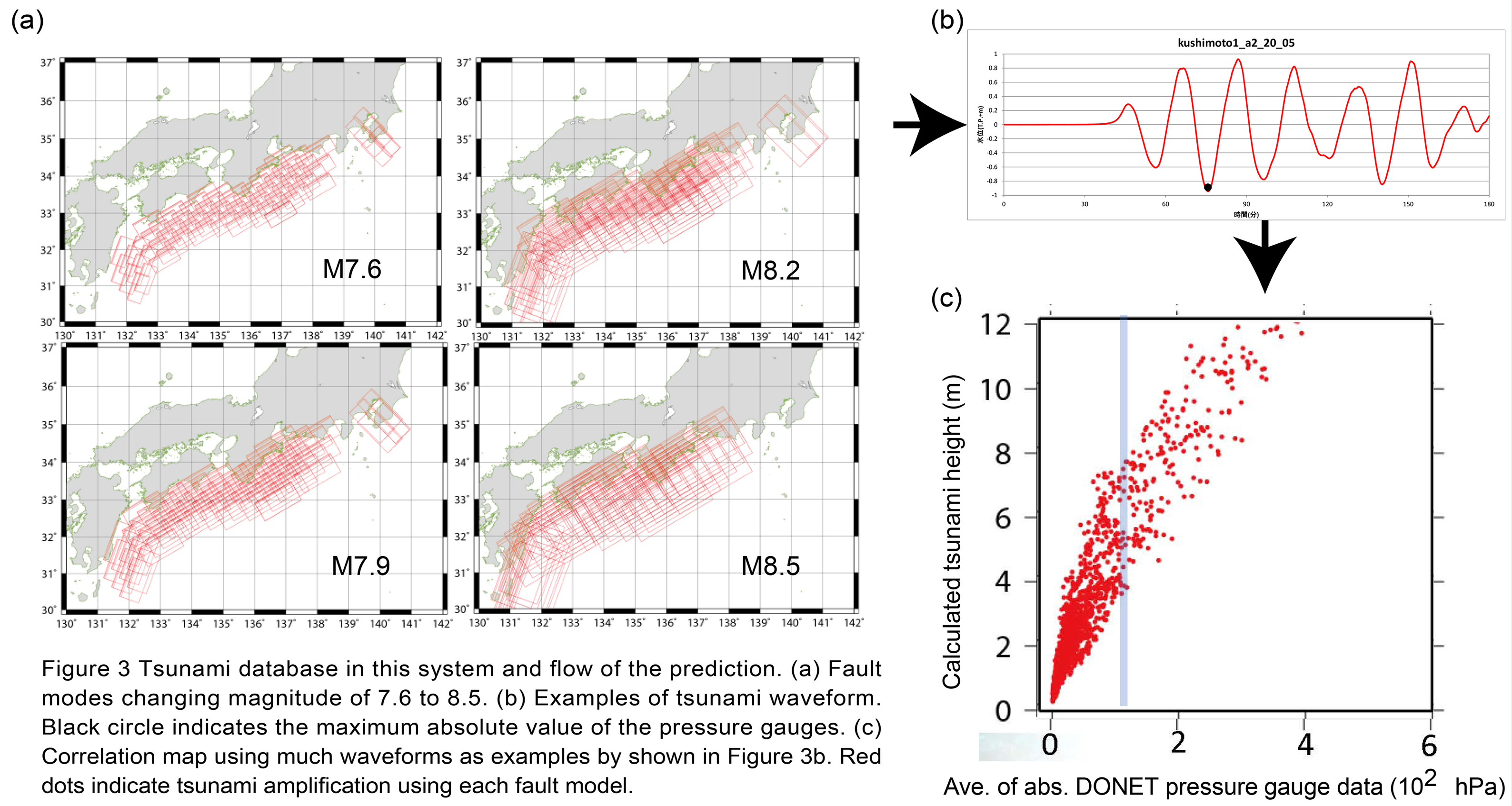


Figure 3 Tsunami database in this system and flow of the prediction. (a) Fault modes changing magnitude of 7.6 to 8.5. (b) Examples of tsunami waveform. Black circle indicates the maximum absolute value of the pressure gauges. (c) Correlation map using much waveforms as examples by shown in Figure 3b. Red dots indicate tsunami amplification using each fault model.

TRIGGER OF TSUNAMI

It is indispensable to trigger tsunami, because the trigger should be starting signal of this prediction system. On the other hand, wrong trigger is linked to wrong prediction, therefore, the trigger logic should be determined carefully. We used tsunami records of 2011 off Tohoku earthquake with a magnitude 9 for determination of the trigger condition. Tohoku university deployed ocean bottom pressure gauges in the rupture zone, and they got clear tsunami signals (Figure 4). To avoid short period signals like seismic signals, we introduced double moving average with long and short time windows, and determined the parameters by trial and error. And we used the ratio of the both to trigger tsunami signals.

We use peak hold values after calculation of average for absolute pressure gauge data to avoid effects of differences of tsunami phases.

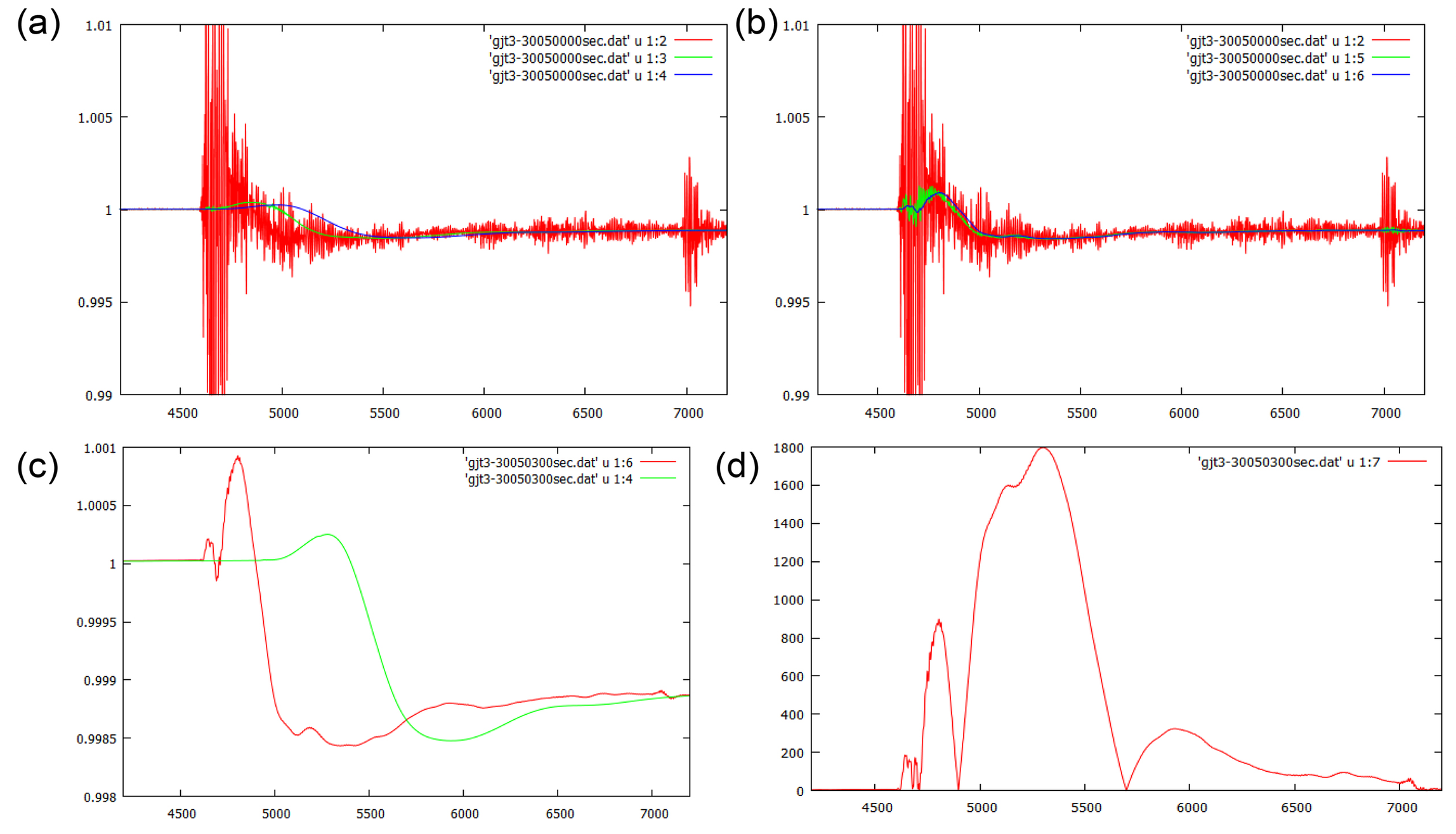


Figure 4 Examples of tsunami signals of 2011 off Tohoku earthquake. (a) Test for moving average using long time window (LTA). Red, green, blue lines are raw data, a moving average, and double moving average, respectively. (b) Test using short time window (STA). (c) Comparison between LTA and STA. (d) Waveform of the ratio of STA/LTA.

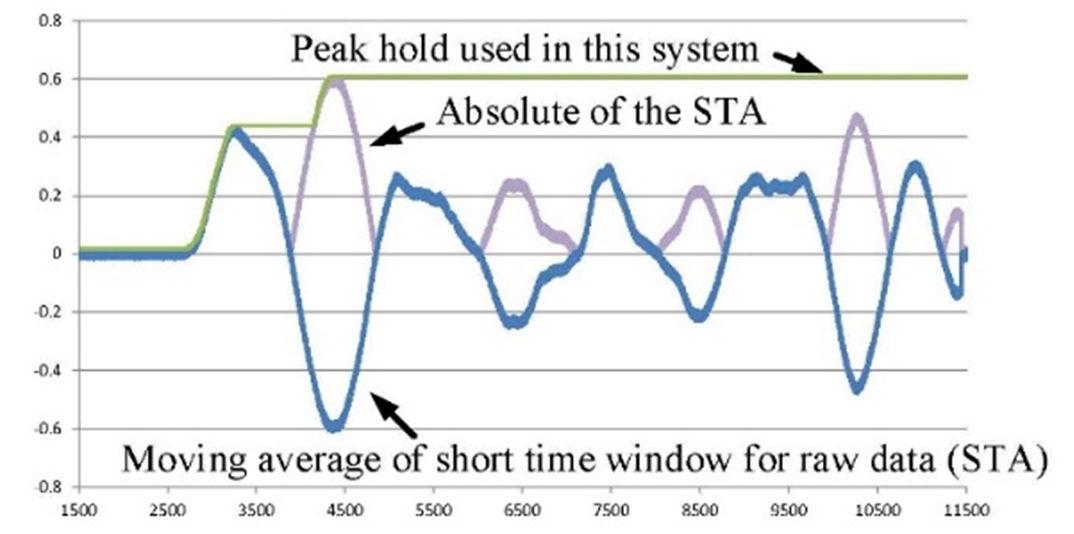


Figure 5 Processing of input data. Blue, purple, green lines are original, absolute value and peak hold value, respectively. We use green line as input data for the prediction system.

EXTRACTION OF TSUNAMI MODELS

The accuracy of this tsunami prediction depends on the variation of the correlation between pressure values of DONET stations and maximum tsunami height of the prediction points as shown in Figure 3c. It is important to select stations along the tsunami propagation for prediction of tsunami height as shown in PRINCIPAL section. Therefore, it is effective to select dynamically the fault models and DONET stations along the tsunami propagation for improvement of the accuracy for tsunami prediction.

First one is selection of fault models. The fault models are selected using seismic signals. As shown in Figure 6, we comparison traveltimes of seismic signals between much pair among the DONET stations, and identify the direction of the source. If there are no differences, the selection of the fault model will not be carried out. Next, we focus fault models using pattern of the tsunami trigger on the DONET stations (Figure 7). On the other hand, locations of asperity producing strong motion and tsunami source are not always consistent with each other. Therefore, we select fault models for the prediction by union of the selections using traveltimes difference of seismic signals and pattern of the tsunami trigger (Figure 8).

Second one is selection of DONET stations. To select DONET stations on the line between the tsunami source and the prediction points, we monitor process of the tsunami trigger and do not use the tsunami data going away (Figure 9). The tsunami prediction is revised when the new predicted tsunami height is higher than older one or when all stations used for the prediction change as DONET stations trigger.

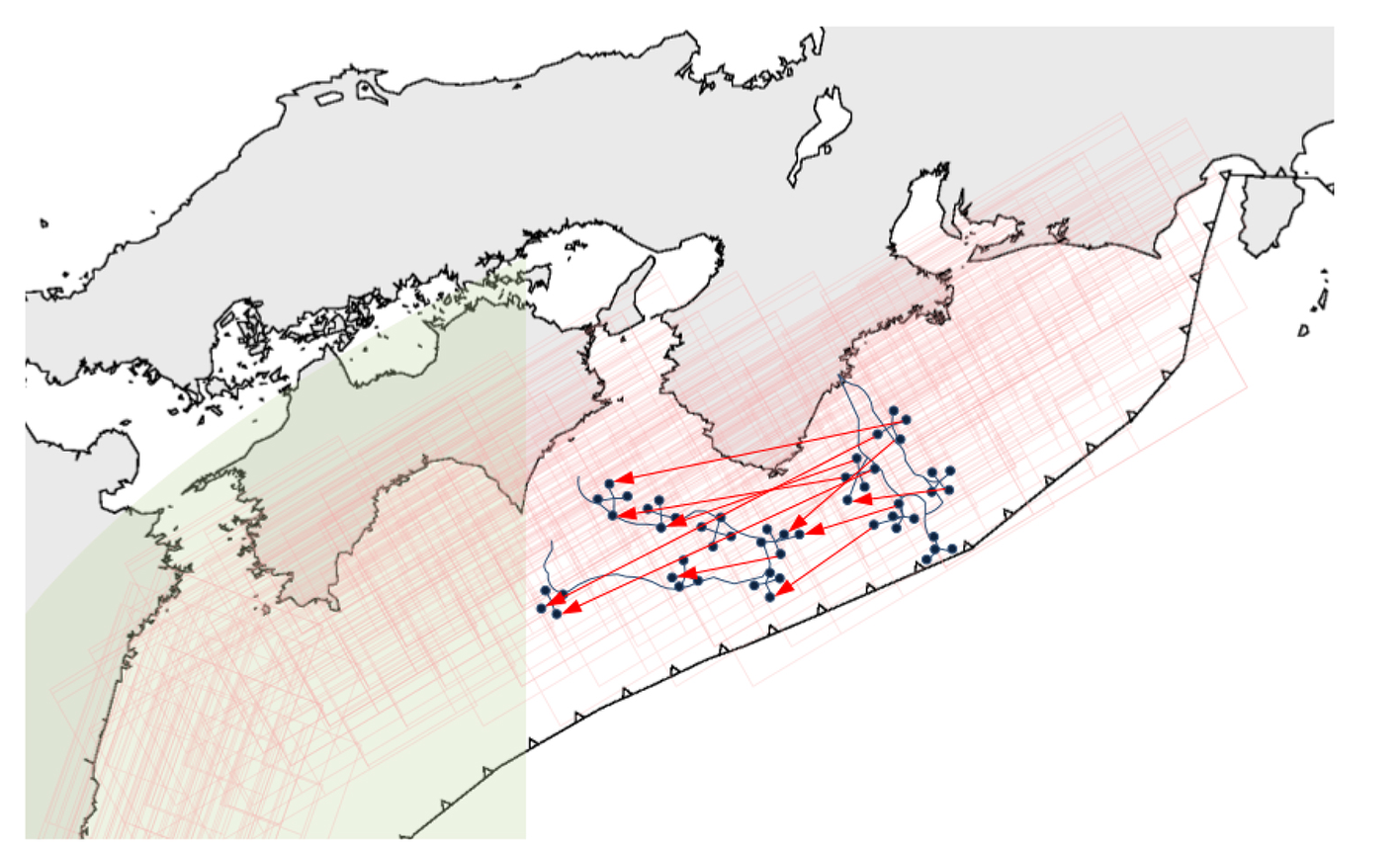


Figure 6 Schematic figure for identification of direction for the source. In this example, traveltimes of seismic signals recorded on the western stations of the DONET are faster than the eastern part, fault models within the gray-colored area is selected.

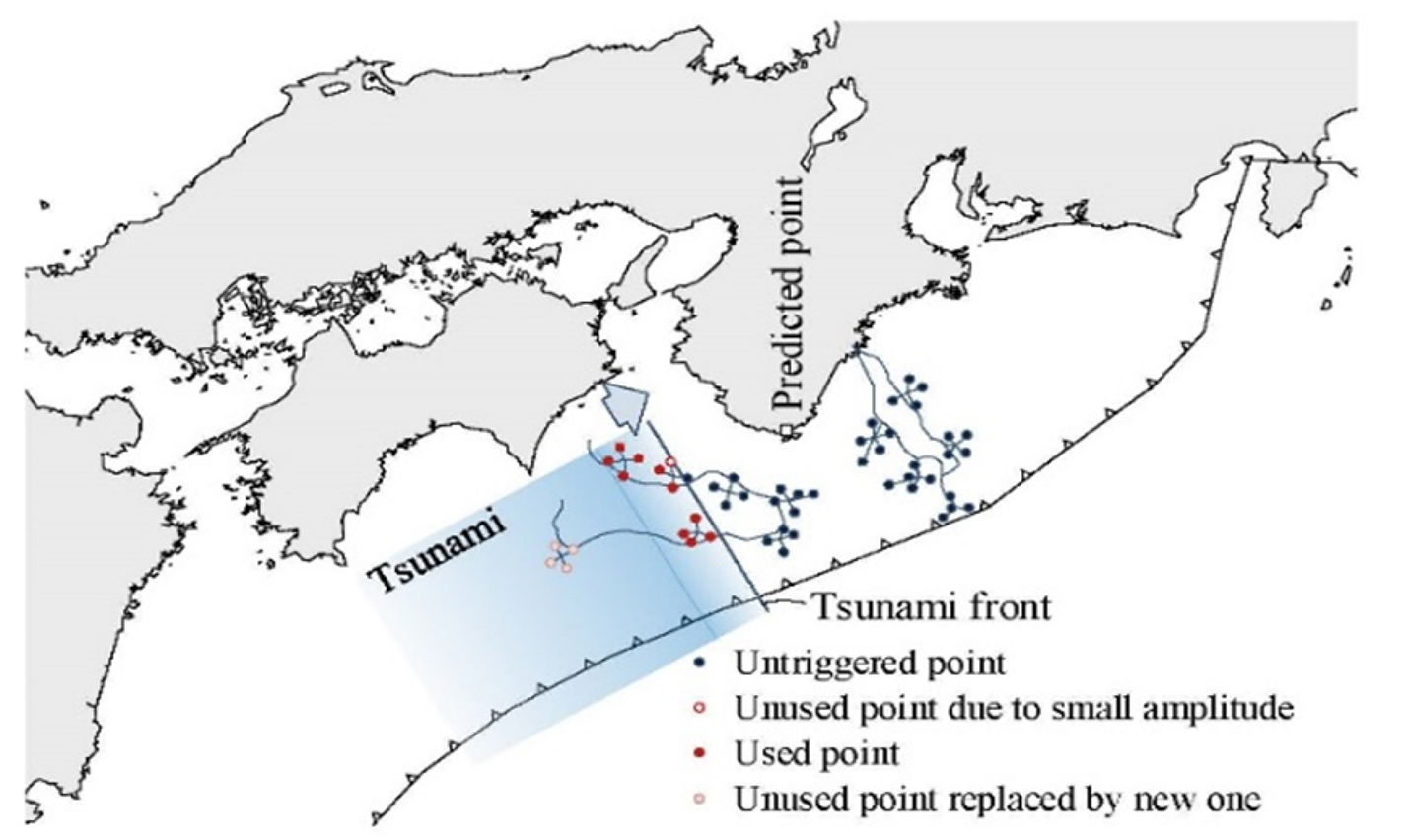

Predicted point
Tsunami
Tsunami front
● Untriggered point
○ Unused point due to small amplitude
● Used point
○ Unused point replaced by new one

Figure 7 Schematic figure for identification of direction for the tsunami source. In this example, order of tsunami trigger is from the western station to the eastern, fault models in the western Nankai trough are selected.

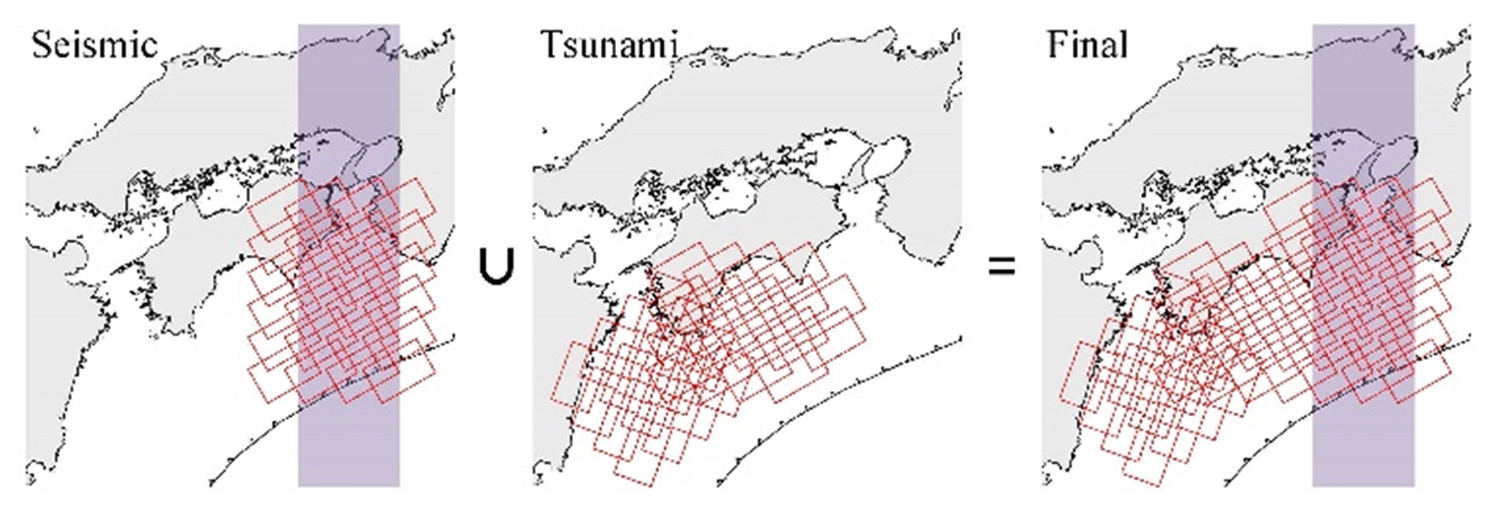


Figure 8 Schematic figure for final selection of fault models. The prediction system adopts fault models by union of models selected by seismic and tsunami pattern.

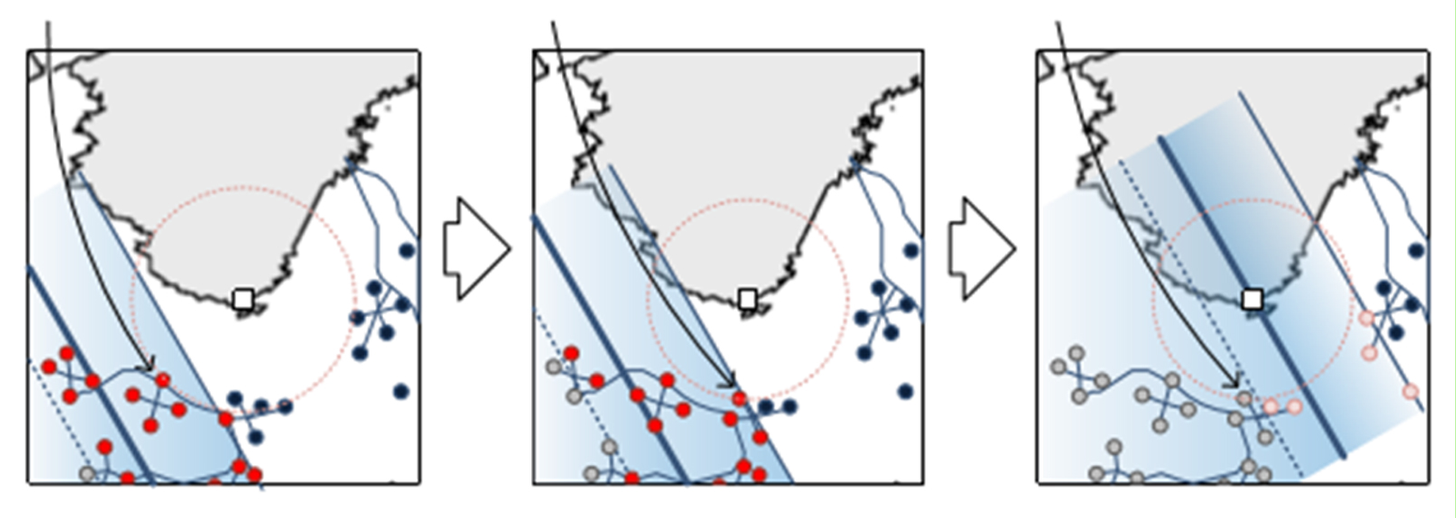
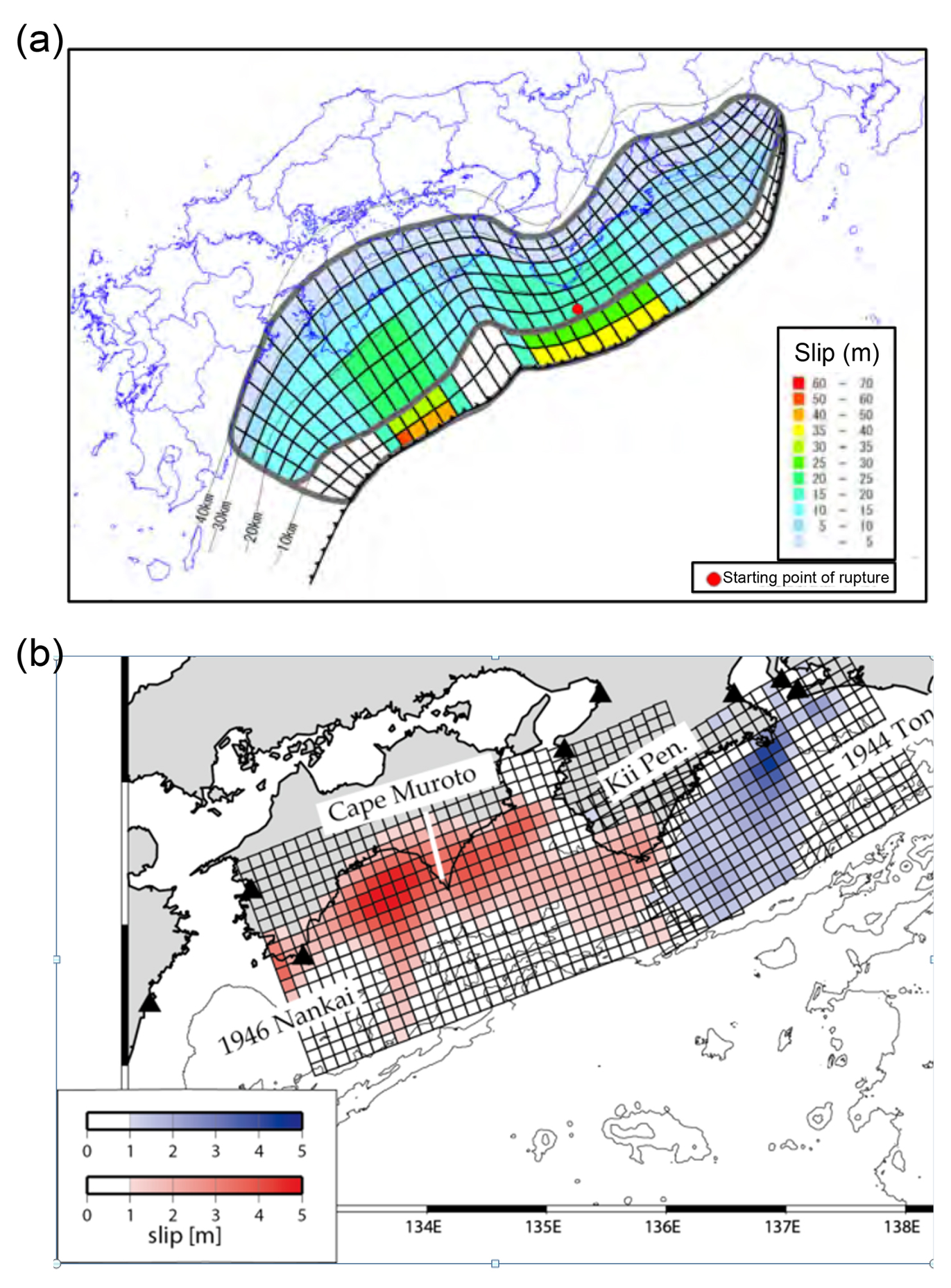


Figure 9 Schematic figure for selection of the DONET station. Red solid and open circles are triggered station and no use station, respectively. Open square indicates the prediction point. Tsunami data going away for the predicted point is not used.

VERIFICATION

We compared predicted maximum tsunami height with synthetic tsunami height calculated using Case 10 proposed by Japan Cabinet Office (JCO) (JCO, 2012) and 1946 Nankai earthquake model (Baba et al., 2005). We calculated maximum tsunami height using these fault models, introduced the calculated tsunami waveforms to the prediction system, and compared them. This system picks maximum tsunami height within narrow grayed colored area in Figure 3c to avoid underestimation, although Baba et al. (2014) adopted the average. The predicted tsunami height is larger than the calculated at some hamlets in this verification, but it is expected and we regard these results as reasonable one.

Although tsunami database does not include fault models with a magnitude nine, the effect of the large slip on the maximum tsunami height is within the variation brought by variation of the fault depths and angles. In other words, this system has robustness to predict tsunami with large slip. Even if seafloor landslide occurs and if local tsunami is brought by it, this system will show the tsunami including the effects of local anomaly.



(c)

	Hamlet	JCO Case 10 Calculation (m)	JCO Case 10 Prediction (m)	1946 Nankai Calculation (m)	1946 Nankai Prediction (m)
Western coast of Kii Peninsula	Yamauchi	5.17	8.67	1.67	4.24
	Shiba	5.70	8.89	1.70	4.24
	Haya	5.07	8.89	1.52	3.73
	Mera	4.98	8.93	1.54	3.73
	Tenjinzaki	4.51	6.62	1.35	2.40
	Suehiro-cho	5.21	7.36	1.48	2.44
	Mori	5.39	8.51	1.55	2.67
	Shinjo1	5.51	8.17	1.76	2.48
	Shinjo2	5.85	9.05	1.89	3.36
	Higashi-Shirahama	5.80	8.29	1.60	2.56
	Seto	4.42	6.94	1.72	3.07
	Shirarahama	4.39	6.16	1.54	2.83
Southern coast of Kii Peninsula	Arida	7.08	10.19	0.68	1.72
	Takatomi	9.17	11.70	1.66	3.01
	Kushimoto1	9.95	12.45	1.74	3.14
	Kushimoto2	7.91	10.17	1.52	1.65
	Kushimoto3	6.67	11.07	1.57	1.56
	Hime	12.41	11.71	0.76	1.30
	O-shima	5.15	9.53	1.32	1.47
Eastern coast of Kii Peninsula	Uragami	5.49	9.48	1.01	1.29
	Shimozato	7.47	8.74	0.54	1.23
	Taiji1	4.33	8.68	0.54	0.83
	Taiji2	7.44	8.86	0.41	0.76
	Johdo	4.10	9.54	0.77	1.26
	Moriura	6.60	11.09	0.93	1.56
	Nikoh	4.89	10.49	1.04	1.52
	Tsukiji	4.13	9.70	0.82	1.55
	Katsuura	8.49	9.36	0.59	1.21
	Tenma	10.79	10.60	0.96	1.80
	Hamanomiya	10.59	11.54	1.01	2.02

Figure 10 Verification of the tsunami prediction system. (a) Fault model of case 10 proposed by Japan Cabinet Office (JCO) in 2012 (JCO, 2012). (b) Fault model of 1946 Nankai earthquake tsunami (Baba et al., 2005). Red and blue areas are 1946 Nankai and 1944 Tonankai earthquakes, respectively. In this test, we used slip rate colored by red. (c) Comparisons with calculated and predicted tsunami heights using fault models of the case 10 and 1946 Nankai earthquake. These hamlets are coastal village in the Wakayama prefecture. Top 12 villages are located at the western Kii Peninsula, and next seven villages are in the south in Kushimoto town, and 11 villages are located at the east.

IMPLIMENTATION

We designed the visualization to show the tsunami prediction, considering that local government distribute the result to disaster division of cities and towns. Therefore, it is planed that the division people of the cities and towns can monitor tsunami prediction of only each city or town without any operations, which are expected arrival time, thenami height, realtime pressure gauge data of DONET stations, inundation area, and calculated tsunami waveform for the prediction point using extracted fault models from the database in this system (Figure 11). During shaking by string motion, it is possible to be cut seafloor cable and be lost data. In this system, the DONET stations with troubles like lack of data will not used automatically. However, it is very important to understand healthy of the entire system for users, and we recommend that user should monitor DONET data sent to the local government in realtime. As described above, the processes of this system are receiving data, processing input data, management of the tsunami database, and control of the visualization for two monitors. We aimed simple system using only one server to implement it easily with low cost (Figure 12). This system was already introduced on Wakayama and Mie prefectures, Owase city, and Chubu electrical power, and implemented it there.

DONET data is sent to Japan Meteorological Agency (JMA) for early warning of earthquakes and Tsunami. JMA plays a role to inform the warning to the entire Japan and all Japanese people. On the other hand, local government and companies use DONET data for special process for their disaster prevention. The information of tsunami prediction is useful for early decision of their disaster prevention with realtime understanding the entire damages.

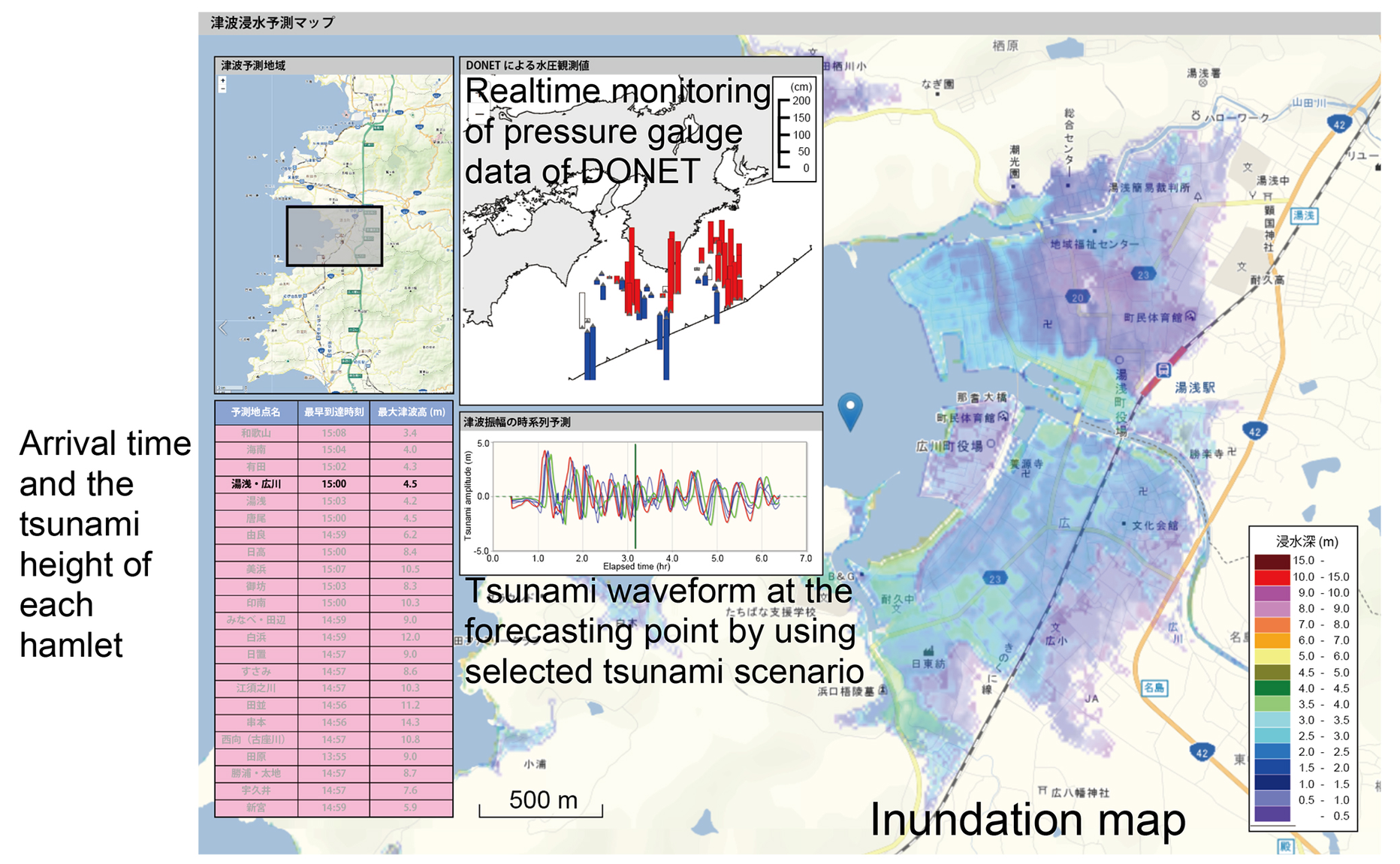

津波浸水予測マップ
Realtime monitoring of pressure gauge data of DONET
Arrival time and the tsunami height of each hamlet
Tsunami waveform at the forecasting point by using selected tsunami scenario
500 m
Inundation map
浸水深 (m)

Figure 11 An example of the interface for the tsunami prediction system.

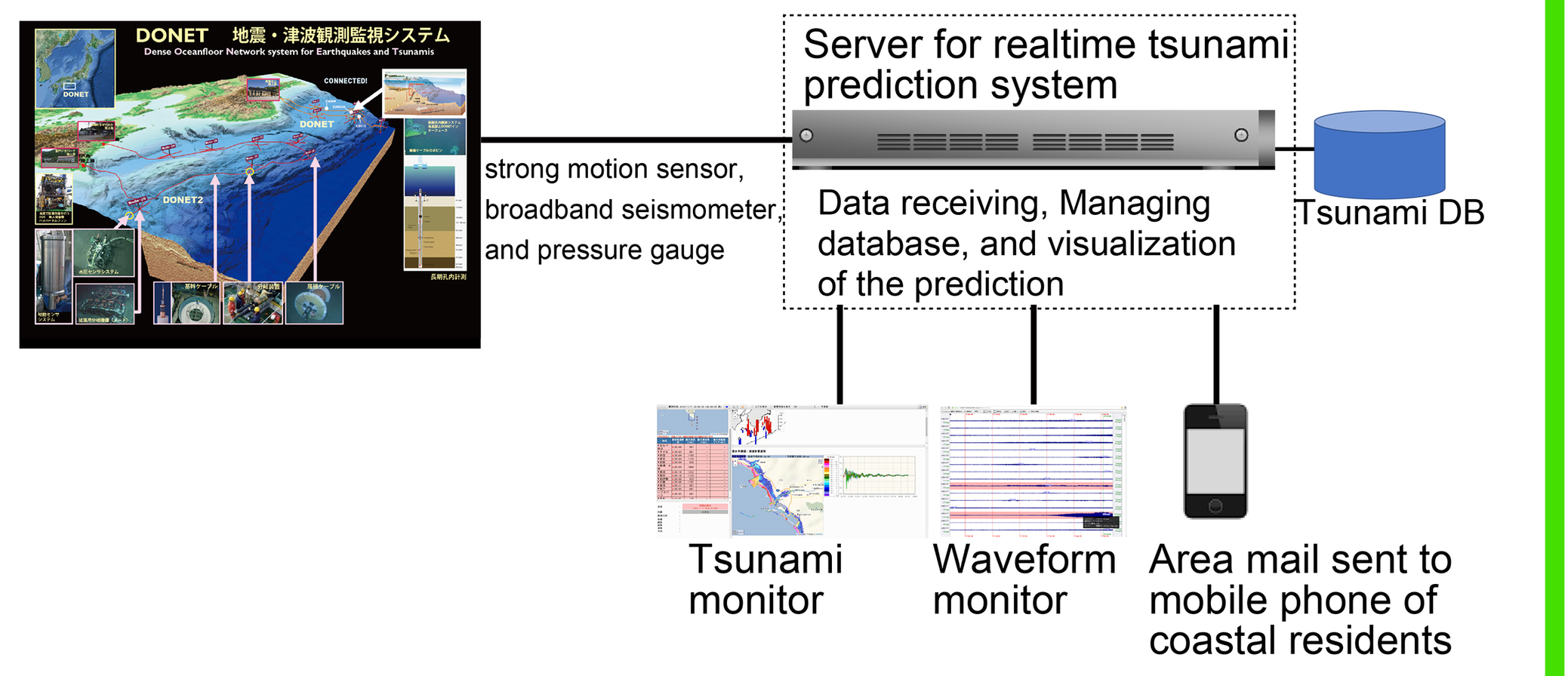

DONET 地震・津波観測監視システム
strong motion sensor, broadband seismometer, and pressure gauge
Server for realtime tsunami prediction system
Data receiving, Managing database, and visualization of the prediction
Tsunami DB
Tsunami monitor
Waveform monitor
Area mail sent to mobile phone of coastal residents

Figure 12 Data flow and outline of our realtime tsunami prediction system. A server plays a role for all process. Realtime information related to tsunami detection and growing up of the amplitude are sent to mobile phones of coastal residents.

SUMMARY AND FUTURE PLAN

We developed a realtime tsunami prediction system using DONET to inform expected tsunami arrival time, the height, inundation area, and calculated tsunami waveform of the prediction point using extracted fault models, installed on Wakayama and Mie prefectures, Owase city and Chubu electrical power, and implemented it there (Figure 13). The principal of the prediction is based on the tsunami amplification along the tsunami propagation using database. To improve accuracy of the prediction, it is important to select fault models and DONET stations for each prediction point. We will disseminate it to other local government.

As the future plan, we are working on preparation to apply for far field tsunami. Far field tsunami could have lower frequency comparing with near field. If so, the far field tsunami could have broader inundation area than near field tsunami under condition of similar tsunami height. We are investigating applicability of this system for far field tsunami. Another plan is to develop for realtime damage prediction. We experienced many types of tsunami damages, for example, tsunami fire and so on, at the 2011 off Tohoku tsunami. Though the evaluation of these risks in advance, we try to develop realtime tsunami damage prediction.

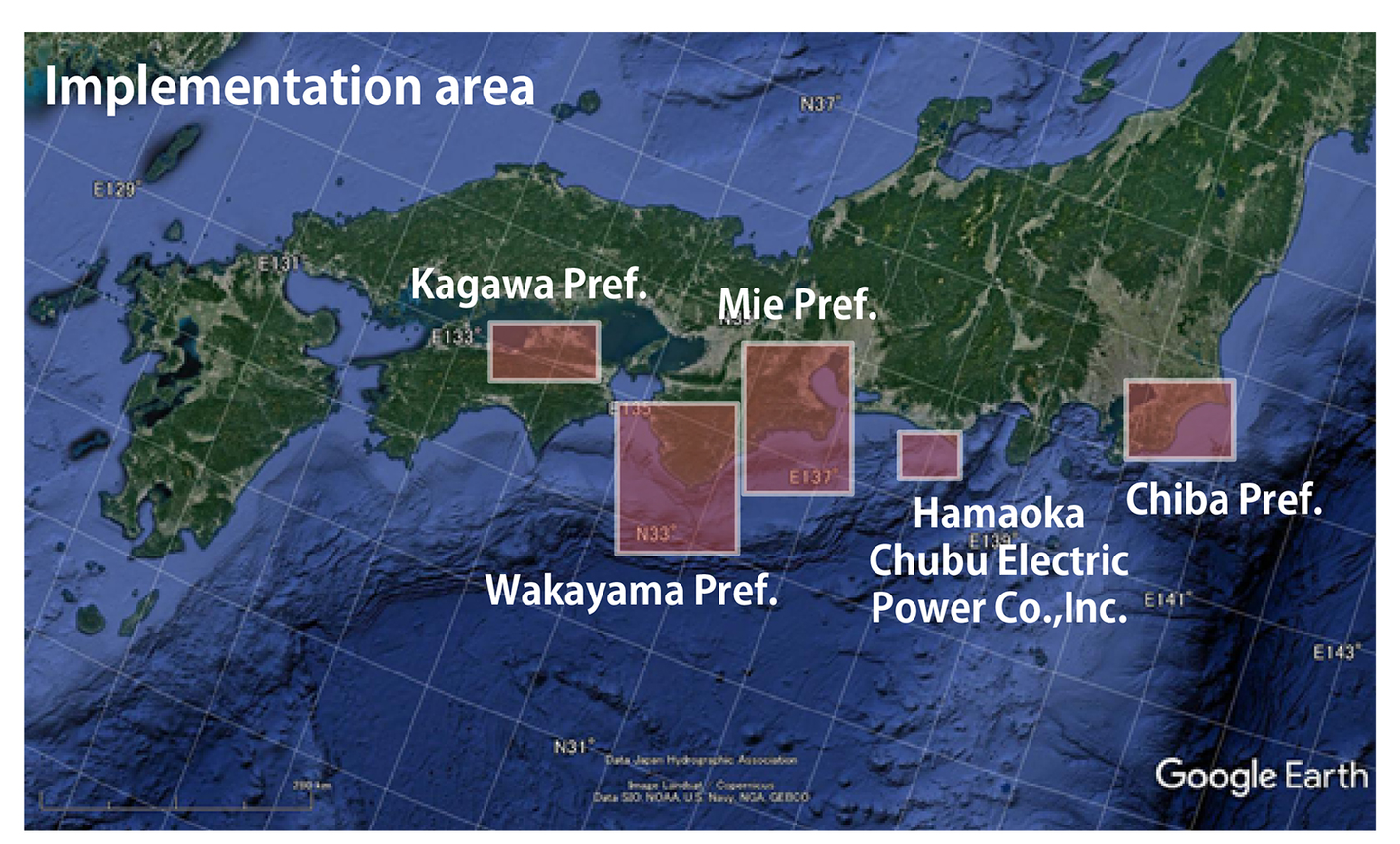


Figure 13 Map of the tsunami prediction area .