WASEDA UNIVERSITY

PIANC Asian Seminar 2021

Recent Coastal Disasters over the World

Tomoya Shibayama

Professor, Department of Civil and Environmental Engineering

Frequent attacks by tsunamis and storm surges

① Field Surveys ⇨ New Findings ⇨ New Analysis ⇨ Mitigation

Analysis of Mechanism →

②Hydraulic Laboratory Experiment,

③Numerical Models (Tsunami Flooding Model, Weather-Storm Surge Model)

④Mitigation Methods (Evacuation Model, Cost-Benefit Analysis)

Supported by the Grant to Support Private Universities for Building up their Foundation of Strategic Research by MEXT, Japanese Government

Formation of International Platform of Disaster Reduction Research

Principal Researcher: Tomoya Shibayama
22 Japanese and 23 International Members

Tsunami, Storm Surge, High Wave (Coastal Erosion), Earthquake, Fire, Flood, Liquefaction, Drought, Landslide, Eruption：Field Survey and Proposal for Disaster Reduction

① Field Survey＋Numerical Simulation＋Hydraulic Experiment
Creation of Real Image of Disaster
Common Images with Local Residents
② Variety of different scenarios of disaster
It is necessary to decipher the social context of disasters,
to prepare disaster reduction scenarios, and
to work with local government staffs and local residents.

International Platform for Disaster Research In Waseda University

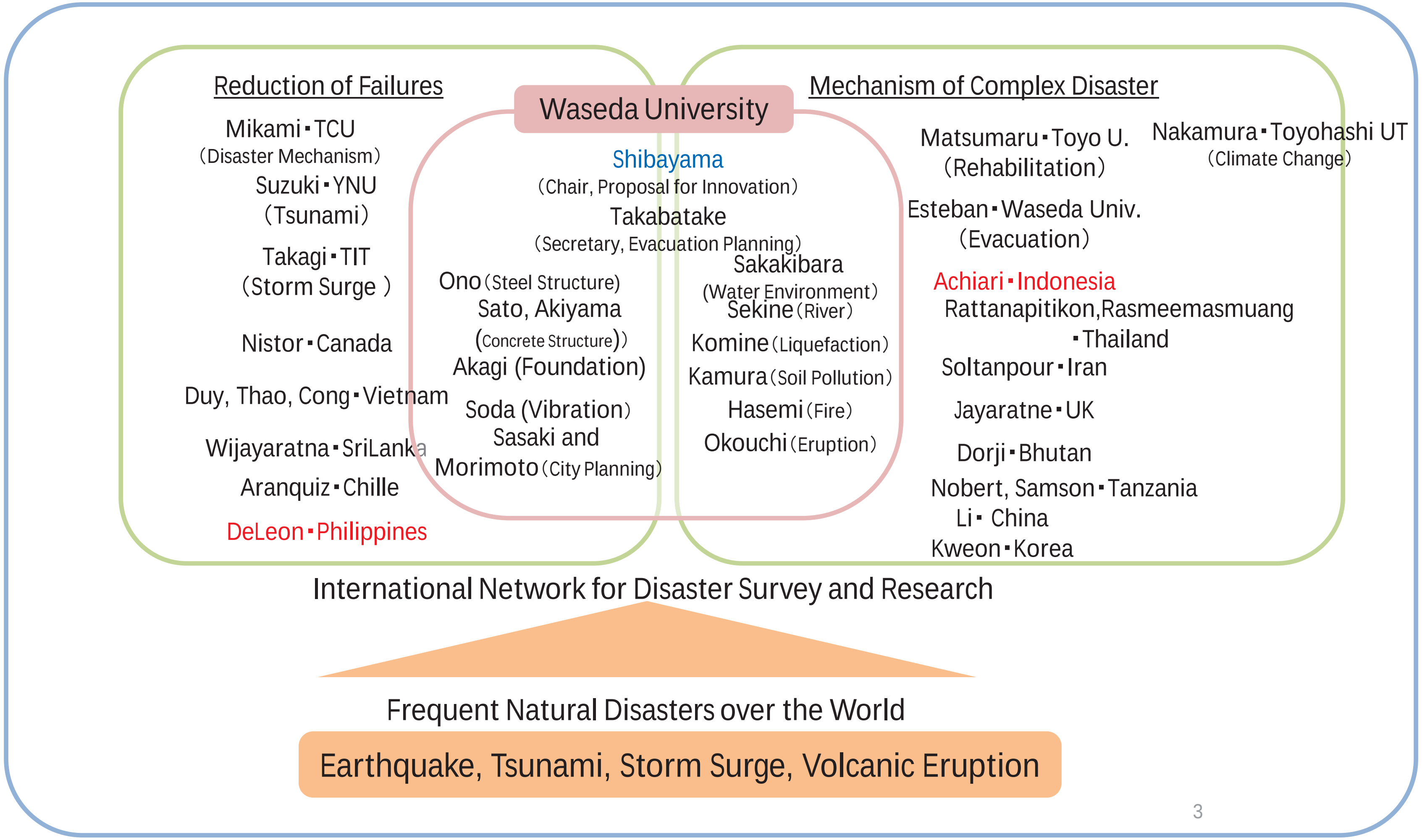


Figure: Study Team

Frequent Attacks of Tsunamis and Storm Surges

"un-predicted" and "far greater than predicted"

Recent Field Surveys of my own

Number of Losses and Unknowns

2004 Indian Ocean Tsunami Sri Lanka, Indonesia,Thailand 220,000
2005 Storm Surge by Hurricane Katrina, USA 1,200
2006 Java Tsunami, Indonesia 668
2007 Storm Surge by Cyclone Sidr, Bangladesh 5,100
1970: 400,000 1991: 140,000 (Construction of Cyclone Shelters)
2008 Storm Surge by Cyclone Nargis, Myanmar 138,000
2009 Tsunami in Samoa Islands, Samoa 183
2010 Chile Tsunami, Chile 500
2010 Tsunami in Mentawai islands, Indonesia 500
2011 Tohoku Tsunami, Japan Death15,782 Unknown 4,086
2012 Storm Surge by Hurricane Sandy, USA (New York City) 170 (USA80)
2013 Storm Surge by Typhoon Yolanda, Phillipines4,011+1,602
2014 Volcanic Eruption in Ontake Mountain, Japan, 58+8
2014 Storm Surge in Nemuro, Hokkaido Island, Japan, 0
2017 Volcanic Eruption in Shinmoe Mountain, Japan, 0
2018 Volcanic Eruption in Shirane Mountain, Japan, 1
2018 Tsunami in Sulawesi Islands, Indonesia, Death 2,081 Unknowns 1,309
2018 Tsunami in Sunda Strait, Indonesia, Death 426 Unknowns 29
2019 Storm Surge and High Waves by Typhoon Faxai, Japan, 3

Storm Surge Survey Team in the Philippines (2013)

Tsunami Survey Team in Palu, Indonesia (2018)

Institute of Future Sustainable Society, Waseda University (2018 ~)

（Program Officer） Tomoya Shibayama, Professor

March, 1977	B. E. in Civil Engineering, University of Tokyo
March, 1985	Dr. of Engineering, University of Tokyo
May, 1985	Lecturer, University of Tokyo
March, 1986	Associate Professor, University of Tokyo
April, 1987	Associate Professor, Yokohama National University (YNU)
August, 1997	Professor, Yokohama National University
April, 2009	Professor, Waseda University Emeritus Professor, YNU

Professor Tomoya Shibayama is one of the top technical experts of tsunami and storm surge disaster mitigation in Japan. He performs hydraulic laboratory experiments, field surveys and numerical simulations for his mitigation study. He served as a team leader of all major tsunami and storm surge events in Japan and overseas over the last fifteen years.

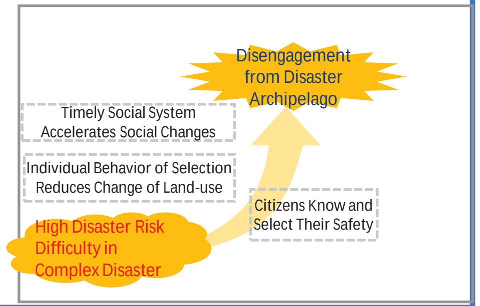
Remarkable Innovation

✓ **Breakthrough**

✓ **Limitation of Existing Technology:**
- Residents continue to live in the same area.
- Risk is not reduced.

✓ **How to exceed the limitation?**
- Individual risk is quantified.

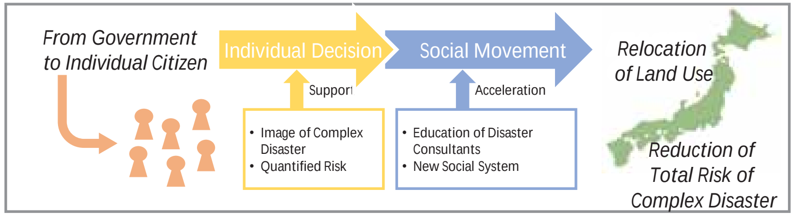
✓ **Final Goal:**
- No loss of lives due to disasters.



Challenges and Possible Impact to Society

✓ **Background**
- Japanese islands are so-called "Disaster Islands".
- There is no concrete national strategy and procedure for protection of residents.

✓ **Impact on Society**
- Change viewpoints from the government to individual resident.
- Quantify complex risk ay citizen's level.
- Disaster risk is added to individual's needs such as selection of residents, properties, schools, super markets etc.
- Change the future land-use based on the individual selection
- Based on above implications, Japanese people gradually withdraw from high-risk areas in next 100 years.
- New social system is proposed for gradual change to conquer local vulnerability by relocating citizens, based on Japanese social changes including declining birthrate and aging.



Scenario for Success and Goal

✓ **Approach to Success**
- Based on the most advanced research results of disaster studies in Japan, we will establish a concept of complex disaster. Individual disaster such as Earthquake, Tsunami, Storm Surge are re-organized to time history of a complex disaster such as, (1) Earthquake, Fire, Liquefaction, Tsunami, (2) Typhoon, Strong Wind, Heavy Rain, Storm Surge, Flood or (3) Earthquake, Volcanic Eruption, Volcanic Ash Distribution , Flood.
- We organize co-operative research system and promote joint research in project group.

✓ **Management Strategy**
- A part of the project will be planned based on public offering.
- Every year, we examine members of the project and will change the members. New members will be invited if necessary.
- The Program Officer participate weekly research group meeting and make all information open to all members.
- Project members have individual consultation with the Program Officer every 2 weeks and deliver presentation of progress report to all members every one month. These accelerate development speed and harmonize the cooperation of members.

✓ **Final Goal**
- Final Judgement Scale: Completeness and Practicality of the Package of New Risk Evaluation System of Complex Disaster and Social System.
- Required Level：High Level Quantification to Change Individual Decision Making Process.

✓ **Risk of Project :** It is necessary to quantify different risks in the same level of accuracy.

What should you do if a Tsunami was coming to your area in 40 minutes?

Take our first edX course
Study the mechanisms of coastal disasters
Plan for disaster evacuation

MOOC
(Massive Open Online Course)

2500 learners 120 countries
USA（19%）Japan（15%） India（6%） U.K.（4%） Chile（3%） Canada（3%） Spain（3%） Indonesia（3%） Netherland（2%） Philippines（2%）

Tsunamis and Storm Surges: Introduction to Coastal Disasters

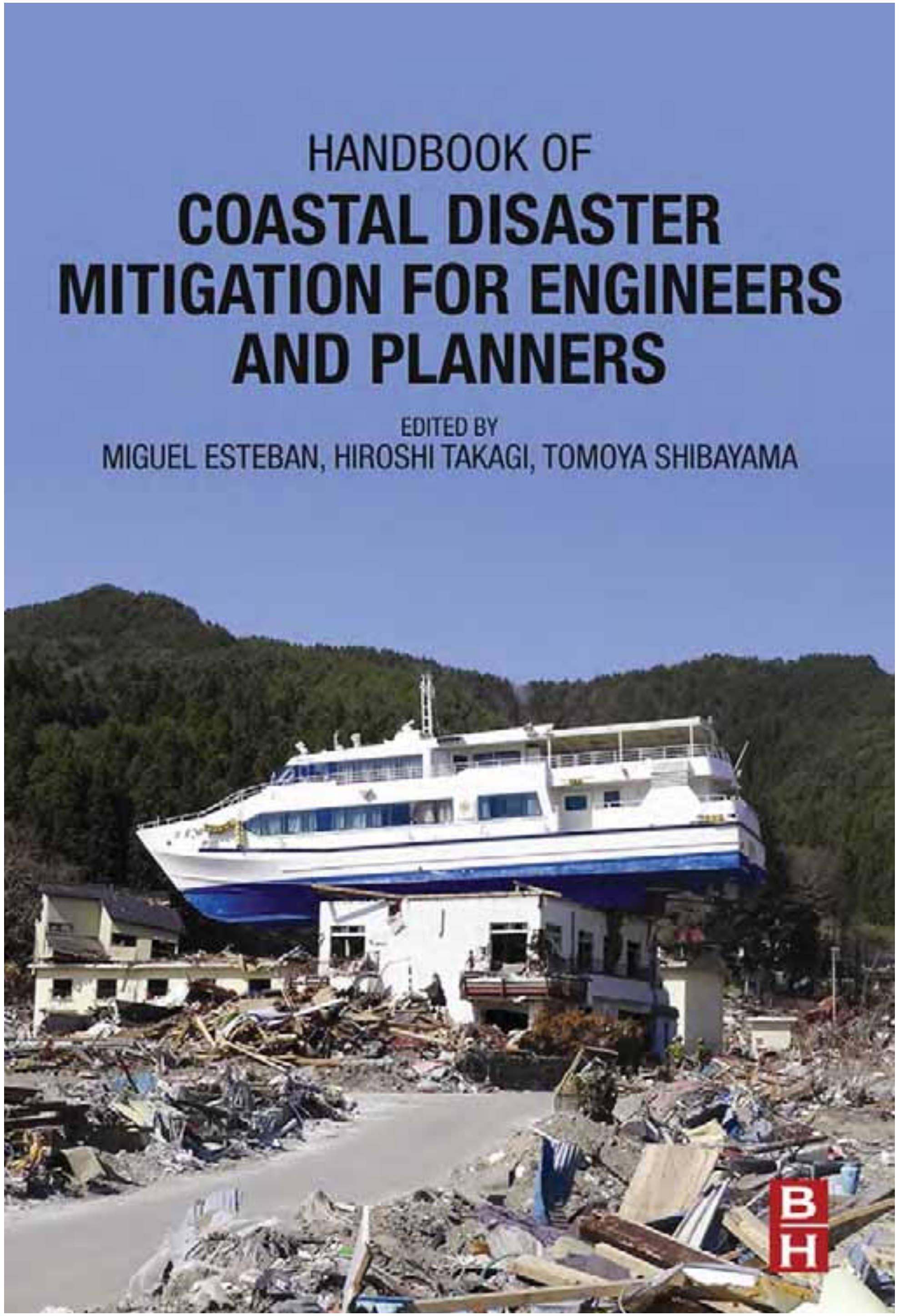
Prof. Tomoya Shibayama
A leading researcher of coastal disaster prevention and coastal engineering at Waseda University

Started January 18th, 2016
Take the course for free
Started again as self-paced course on April 2021

edX
早稲田大学
WASEDA University
WasedaX

Enroll Now!

Waseda edX


HANDBOOK OF
COASTAL DISASTER
MITIGATION FOR ENGINEERS
AND PLANNERS
EDITED BY
MIGUEL ESTEBAN, HIROSHI TAKAGI, TOMOYA SHIBAYAMA
B
H

Advanced Series on Ocean Engineering — Volume 28

COASTAL PROCESSES

Concepts in Coastal Engineering and Their Applications to Multifarious Environments

This book provides us with important concepts in coastal engineering, their applications to coastal processes and disaster prevention works. It is designed for graduate students pursuing advanced studies in coastal processes and for engineers and managers of coastal zone management. The first part describes basic concepts of coastal engineering, dealing mainly with wave-induced physical problems in the field of coastal engineering and hydraulics. The second part consists of the author's results of 30 years of scientific research on the progress of coastal sediment transport and coastal disasters. In terms of sediment transport study, the book covers not only coastal zones but also sediment production in river basins and river sediment transport to understand the present reasons for coastal erosion. A number of case studies for various countries around the world are given, and from the descriptions provided, it is possible to understand the different problems and challenges facing each country.

ABOUT THE AUTHOR

Tomoya Shibayama is a Professor of Civil Engineering at Yokohama National University, Japan. He received his Doctorate degree in Engineering from the University of Tokyo. Formerly, he was an Associate Professor at the University of Tokyo and at Asian Institute of Technology. He has long experiences of survey of coastal processes and coastal disasters in developing countries including Asia and Africa. Presently he serves as the editor-in-chief of Coastal Engineering Journal (CEJ).

Cover Description: The original Ukiyoe (Japanese woodblock print in the Edo period) on the cover page was drawn by Hokusai Katsushika, titled "Kanagawa Oki Namiura", meaning "wave breaking off the coast of Kanagawa". Kanagawa refers to the Kanagawa Ward of Yokohama City, with Yokohama National University located less than four kilometers from this coastline in the direction of Mount Fuji.

World Scientific
www.worldscientific.com
6828 hc

ISBN-13 978-981-281-395-4
ISBN-10 981-281-395-0
9 789812 813954

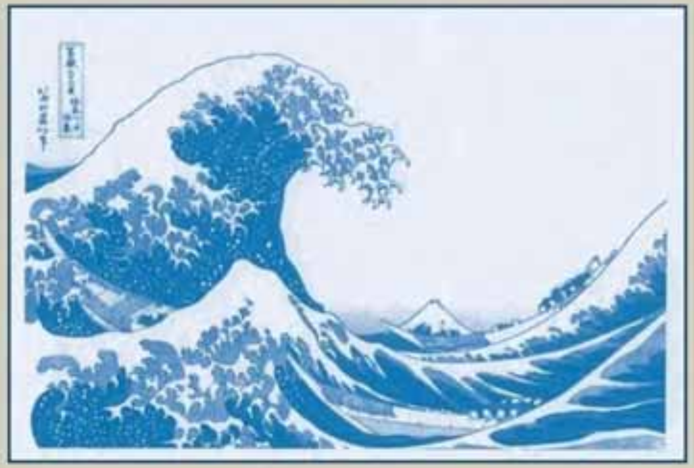
Shibayama

COASTAL PROCESSES

Advanced Series on Ocean Engineering — Volume 28

COASTAL PROCESSES

Concepts in Coastal Engineering and Their Applications to Multifarious Environments



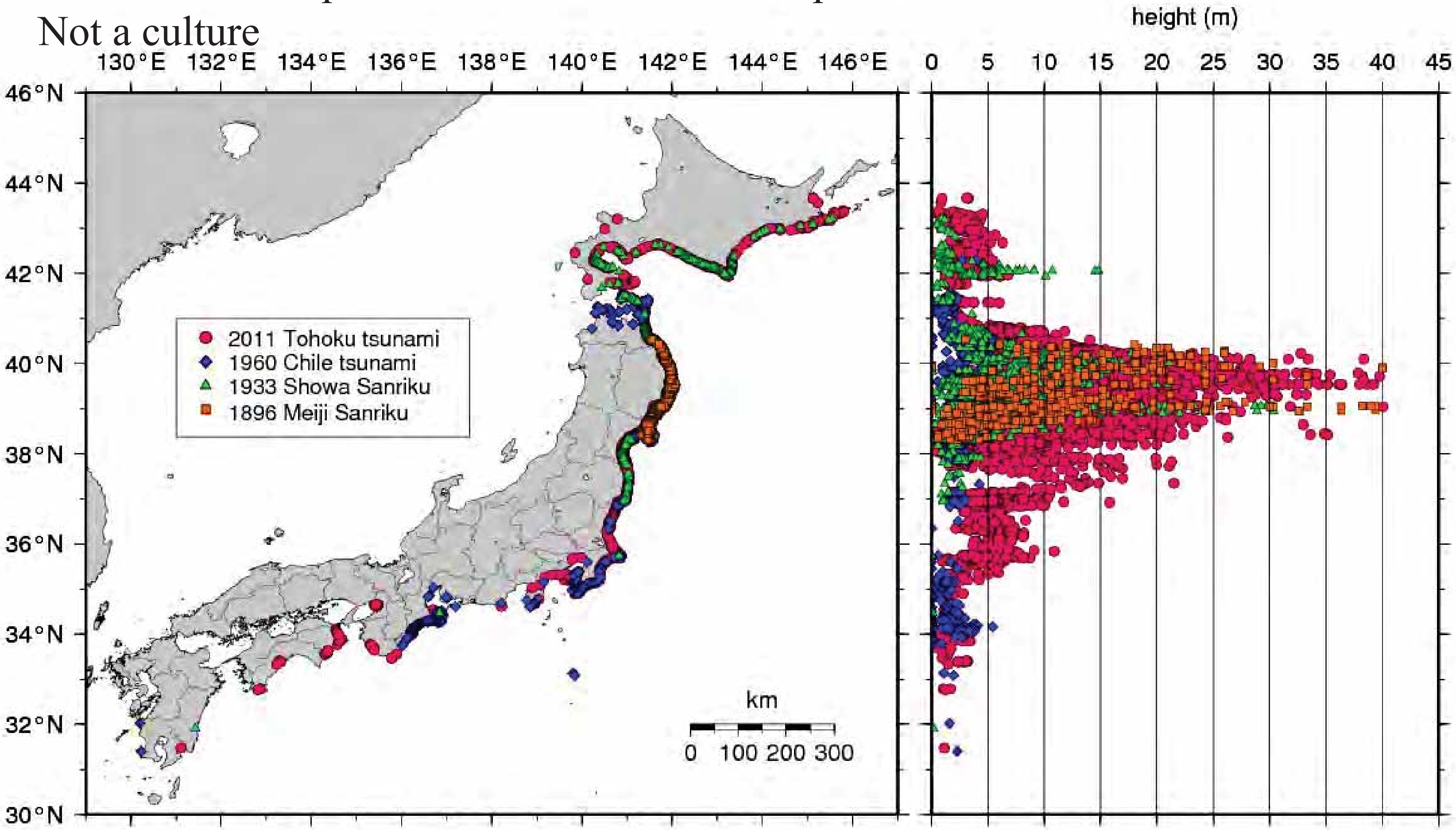
Tomoya Shibayama

World Scientific

Tsunami Height Distributions--Summary

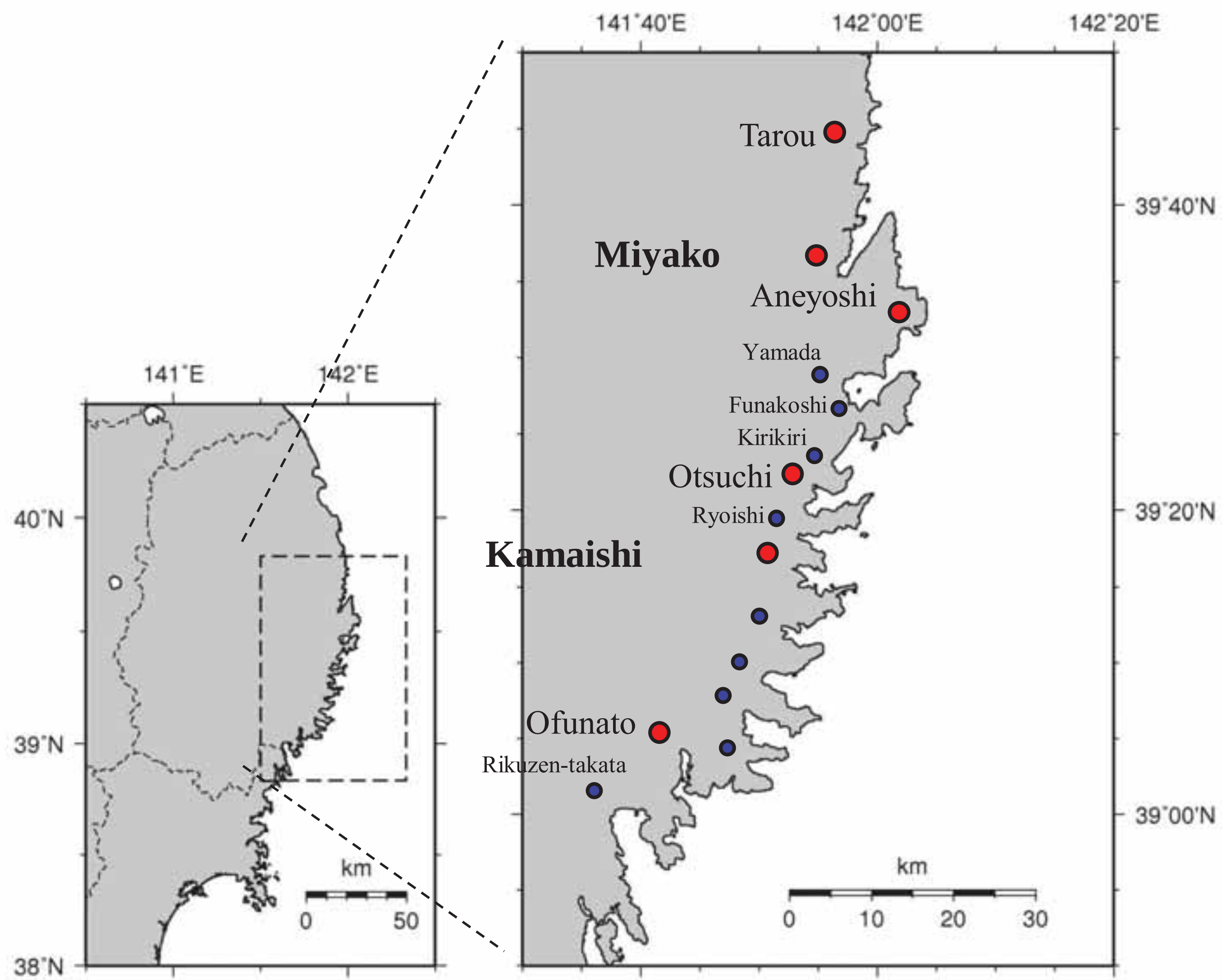
1.Wide Area from Hokkaido to Chiba
2. In Sanriku, two big tsunamis in these 115 years.
3. In Sendai plain, the biggest tsunami after Jogan tsunami in 869.

Difference of Experiences in north and south parts. → Difference of Future Selections.
Not a culture



United Japan Team for Tohoku Tsunami Survey including Waseda University

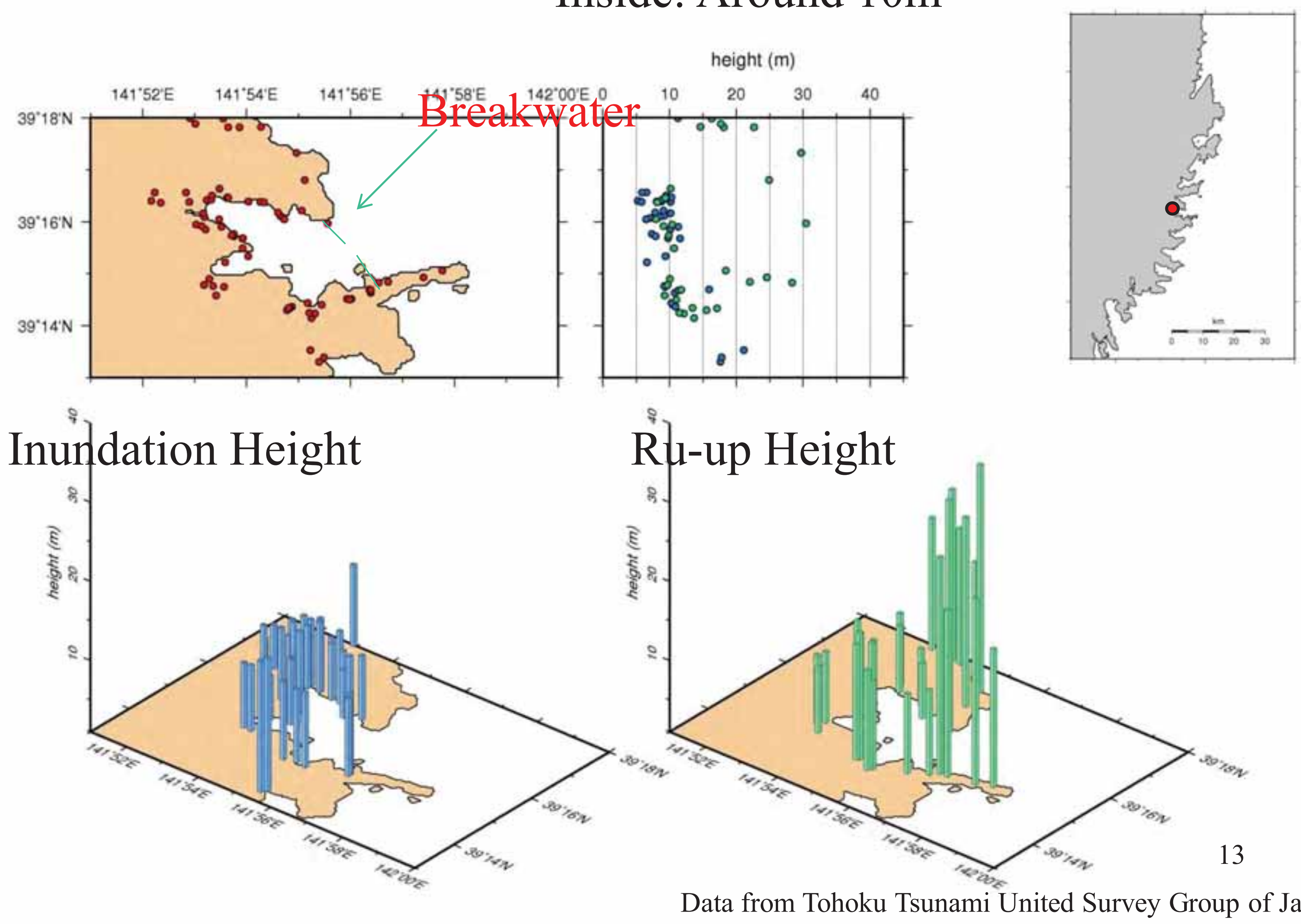
Major Survey Points in Iwate Prefecture



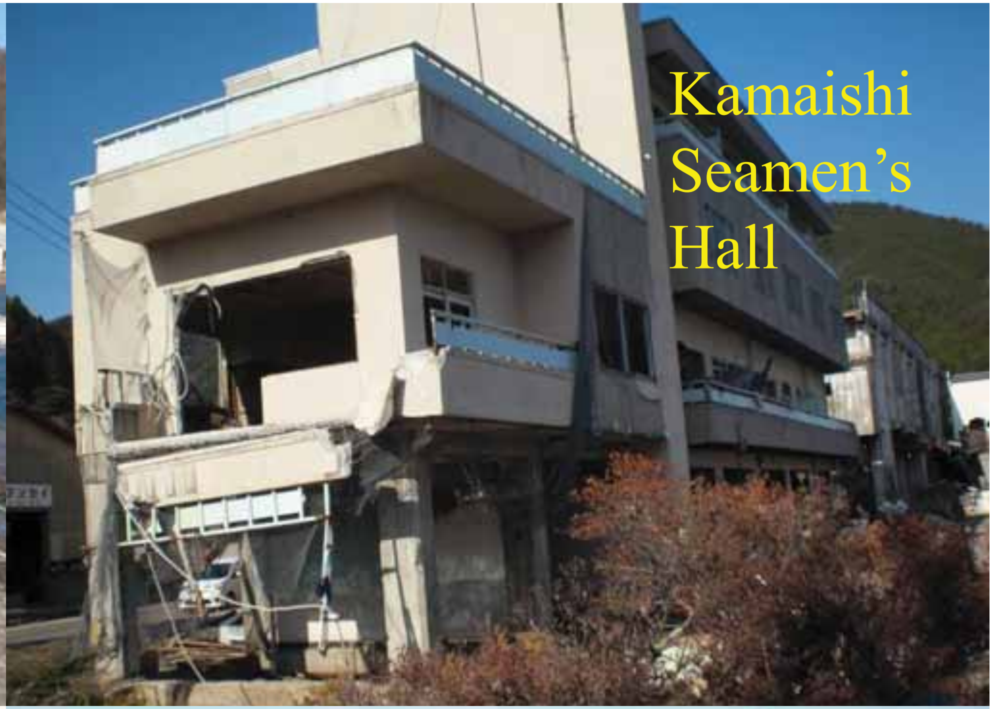
Kamaishi City

There were three defence lines

Bay-mouth Tsunami Breakwater
Outside : More than 30m run-up
Inside: Around 10m



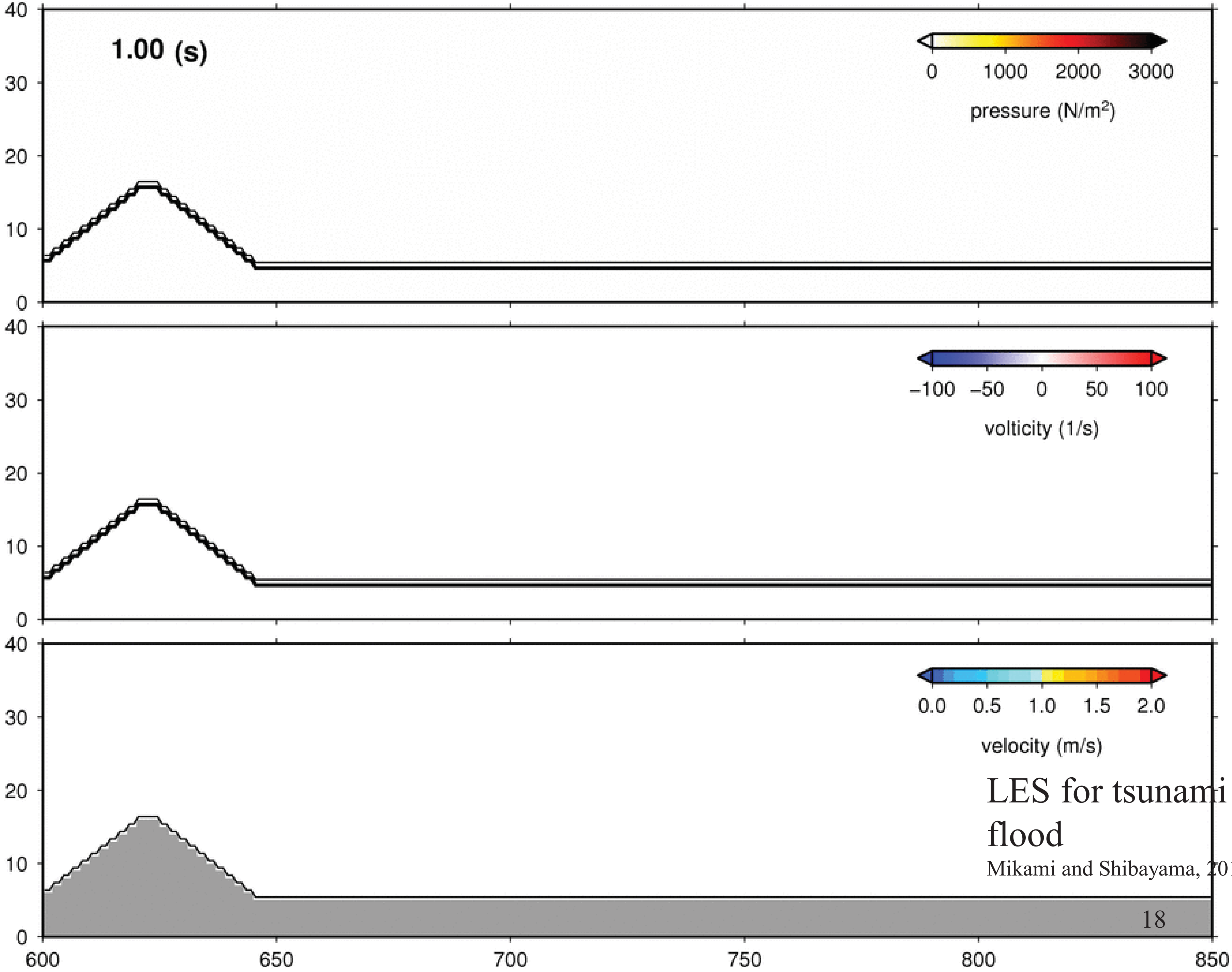
Data from Tohoku Tsunami United Survey Group of Japan


Kamaishi
Seamen's
Hall

Kamaishi after the tsunami

ASCE-JSCE Joint Work

Designated evacuation building



LES for tsunami flood

Mikami and Shibayama, 2012

Tohoku Tsunami: Japanese Debates on the Reconstruction Process

1) Balance of Soft and Hard Measures

The idea that hard measures can protect against the loss of life has been discarded.

Level I Tsunami Protection Height

1. The function of coastal structures would be to attempt to protect property or to help evacuation process against the more frequent but low-level events (typically with a return period of several decades to 150 years). "Once for 100 years" Coastal protection structures are designed for this tsunami height.

Level II Tsunami Evacuation Height

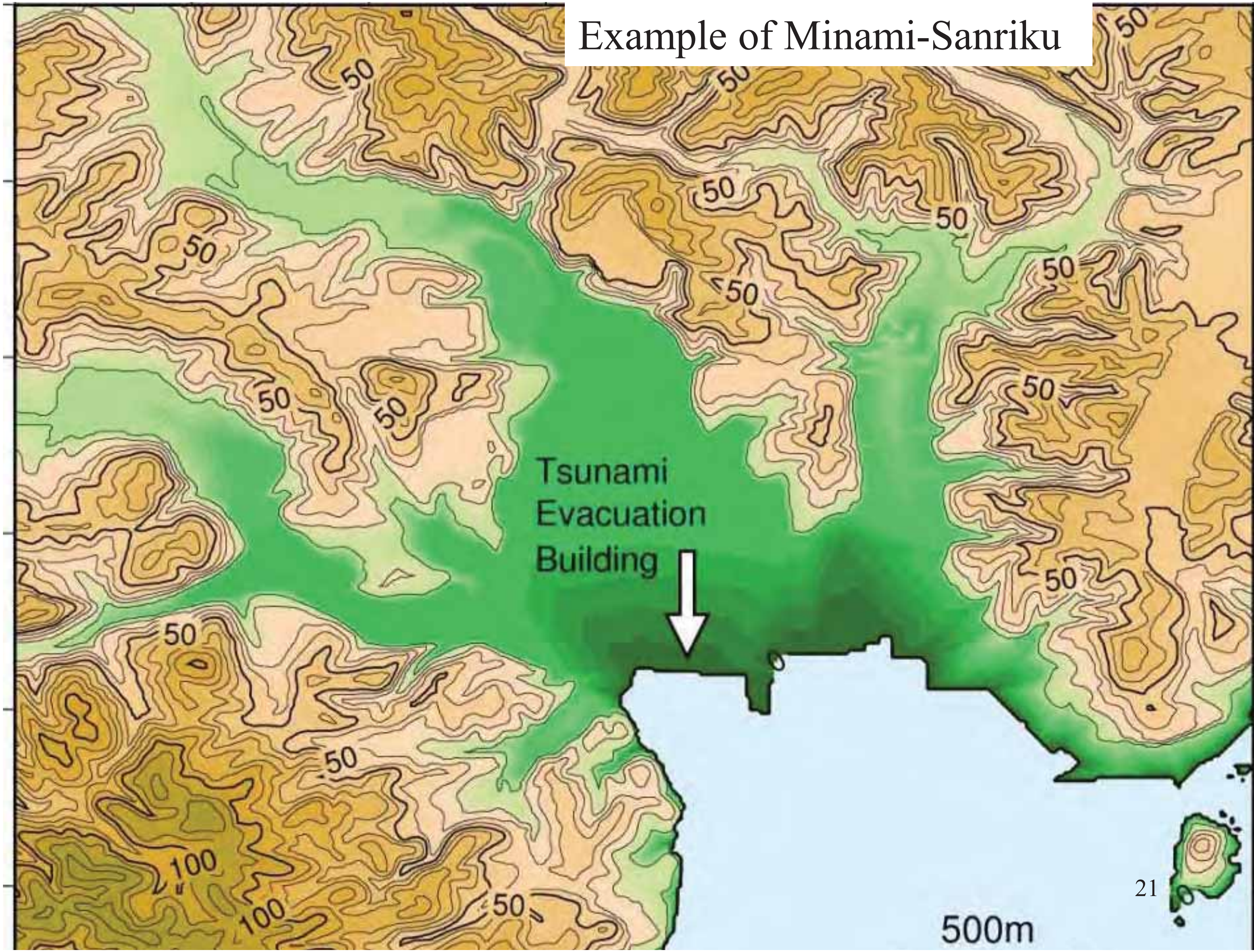
2. Soft measures (Evacuation), on the other hand, would be used to protect lives, and be designed with more infrequent higher level events (with much longer return periods, for example 1,000 years). "once for 1000 years"

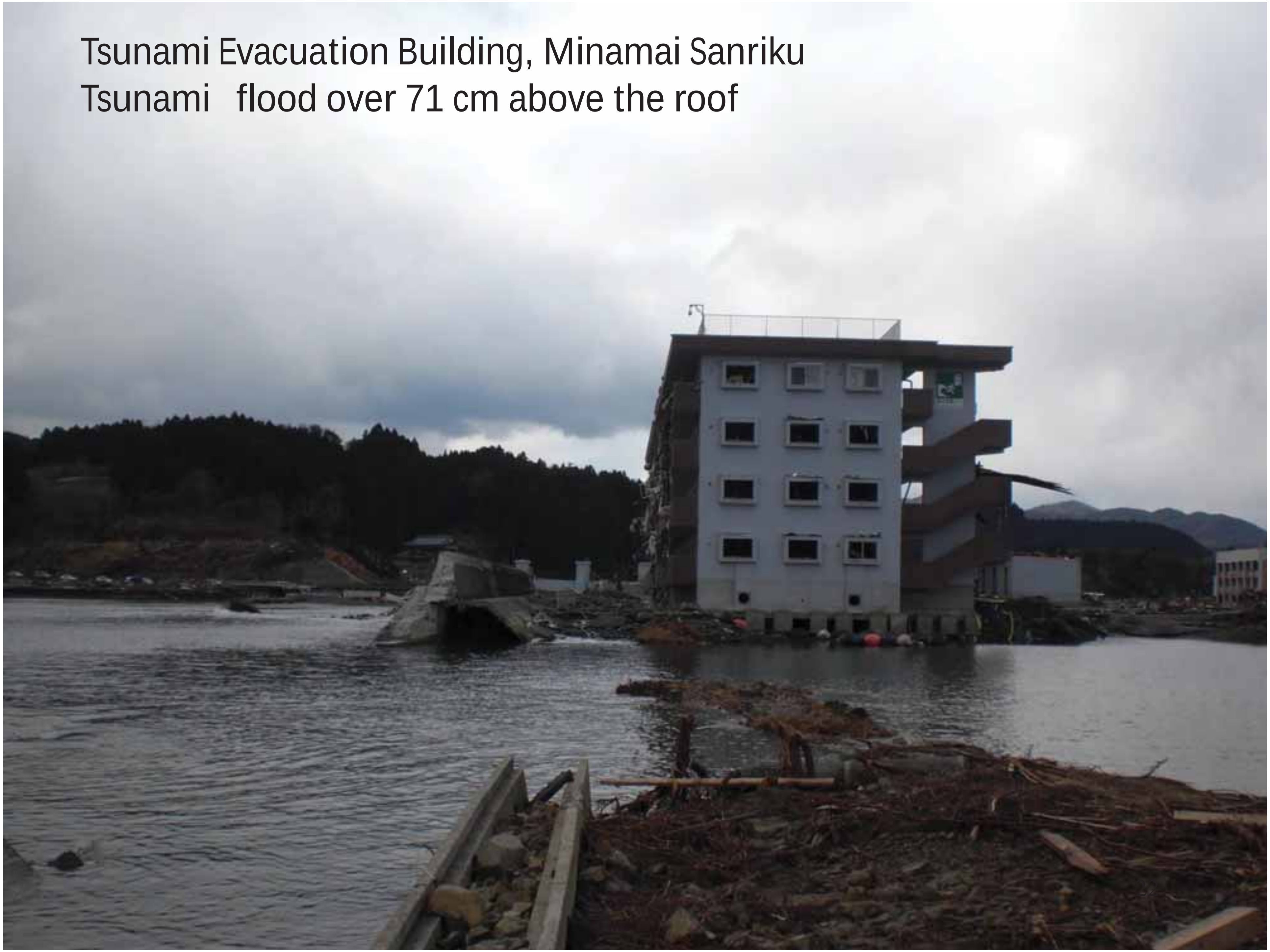
For Level II tsunami, structures are overflowed but are required not to be destructed. They are expected to reflect tsunami partially and will assist evacuation process by reducing tsunami height and delaying tsunami flood time.

Case of Minami-Sanriku

*http://zgate.gsi.go.jp/SaigaiShuyaku/20110525/index2.htm

Example of Minami-Sanriku





Tsunami Evacuation Building, Minamai Sanriku
Tsunami flood over 71 cm above the roof

The classification of evacuation points in Japan into three separate categories.

Category A: This category would include hills (higher terrain) that are adjacent to the coast but continue to increase in elevation for a long distance. These would not be isolated low hills, but those that form part of larger geographical features and have a higher hinterland region. Kamaishi, Tarou

Category B: This would include robust buildings that have 6 or more floors , or hills that are more than 20m in height. This category would have the inherent risk of being isolated during the worst tsunami, but would likely be safe for most events

Category C: This would include robust buildings that are over 4 floors high. This category, however, would have the risk of being overtopped during the worst tsunami events. Minami-Sanriku

○Guideline from the Central Government to Local Governments

How to make Scenarios? How to decide "Tsunami Design Height (Tsunami Protection Height), Level I"

→Recorded Old Tsunami Height ＋Numerical Simulation Results of Old Tsunamis ＋Numerical Tsunami Simulation Results of New Earthquake Scenario

→Drawing figure of year and tsunami heights data

→Selection of Level I tsunami Heights (Return Period around 100 years)

→Numerical Simulation of Tsunami Height at the Location of Coastal Tsunami Fence

→Drawing Distribution of the Simulated Height

→Decision of Tsunami Protection Height Corresponding to Level I

→Decision of Sturucture Height considering Multifarious Conditions such as Environment, Land Scape Design, Cost, Sustainability of the Local Society and so on. Consensus Formation Meetings in Local Society are necessary.

Analysis by A Local Government---An Example of Kanagawa Prefecture (Examination Committee chaired by Shibayama)

Kamakura, Yokohama and Tokyo Bay

1. Numerical Analysis:

Genroku Kanro Earthquake (1703)

Keicho Earthquake (1605)

Meiou Tokai Eartuquake (1498)

North Tokyo Bay Earthquake

Miura-Boso (Tokyo Bay Mouth) Earthquake

2. Analysis of Old Documents

Old Capital City—Kamakura (since 12 th Century)

3. Bowling for Tsunami Sediments Layer

Kamakura and Zushi

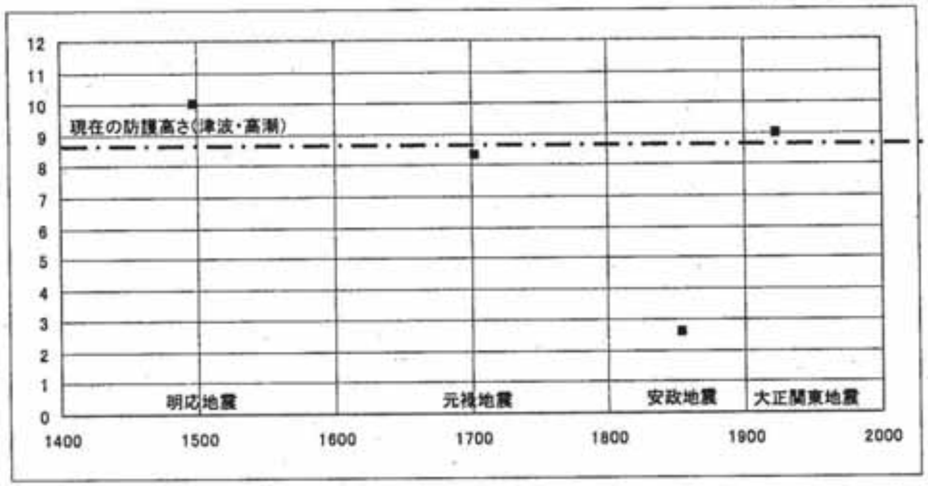
Evaluation of Tsunami Height

Kanagawa Prefectural Government, 2011

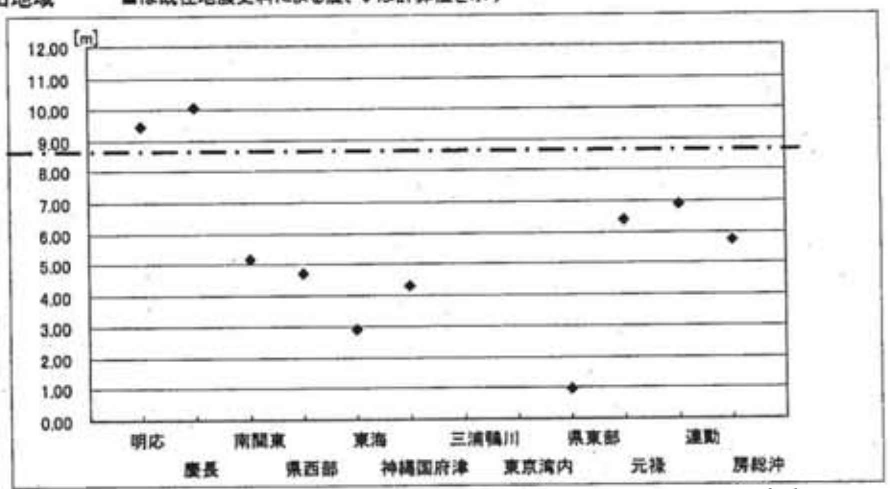
Historical Record

Numerical Simulation

鎌倉・逗子・葉山地域 ■は既往地震史料による値、◆は計算値を示す

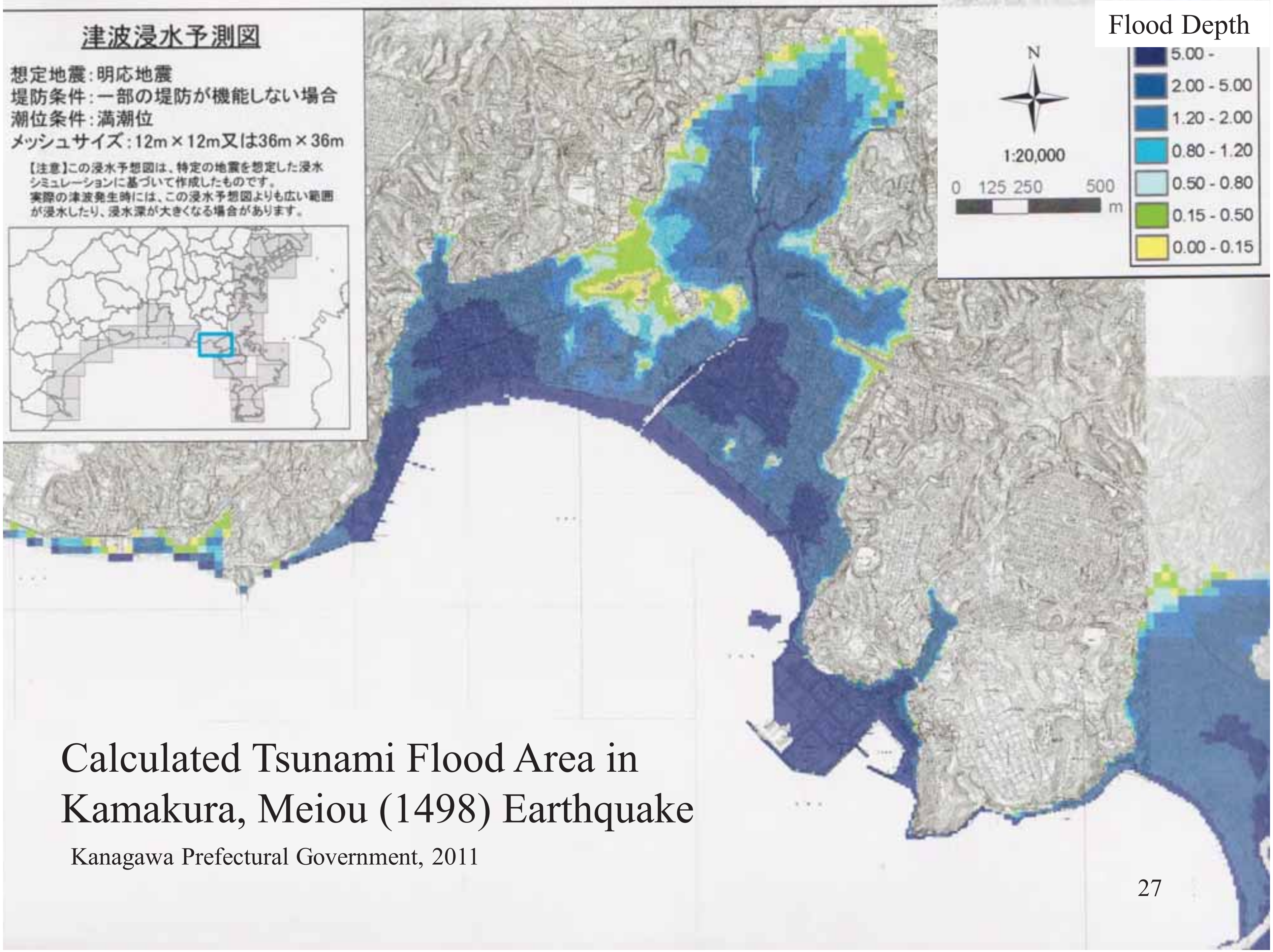


Year



Different Tsunami Types

15



Calculated Tsunami Flood Area in Kamakura, Meiou (1498) Earthquake

Kanagawa Prefectural Government, 2011

Introduction of Tokyo Bay

- Tokyo bay is a major political and economical hub in Japan.

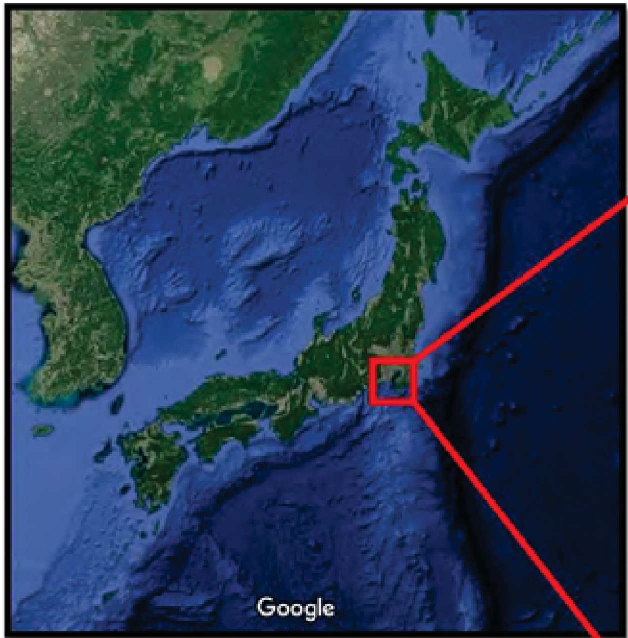
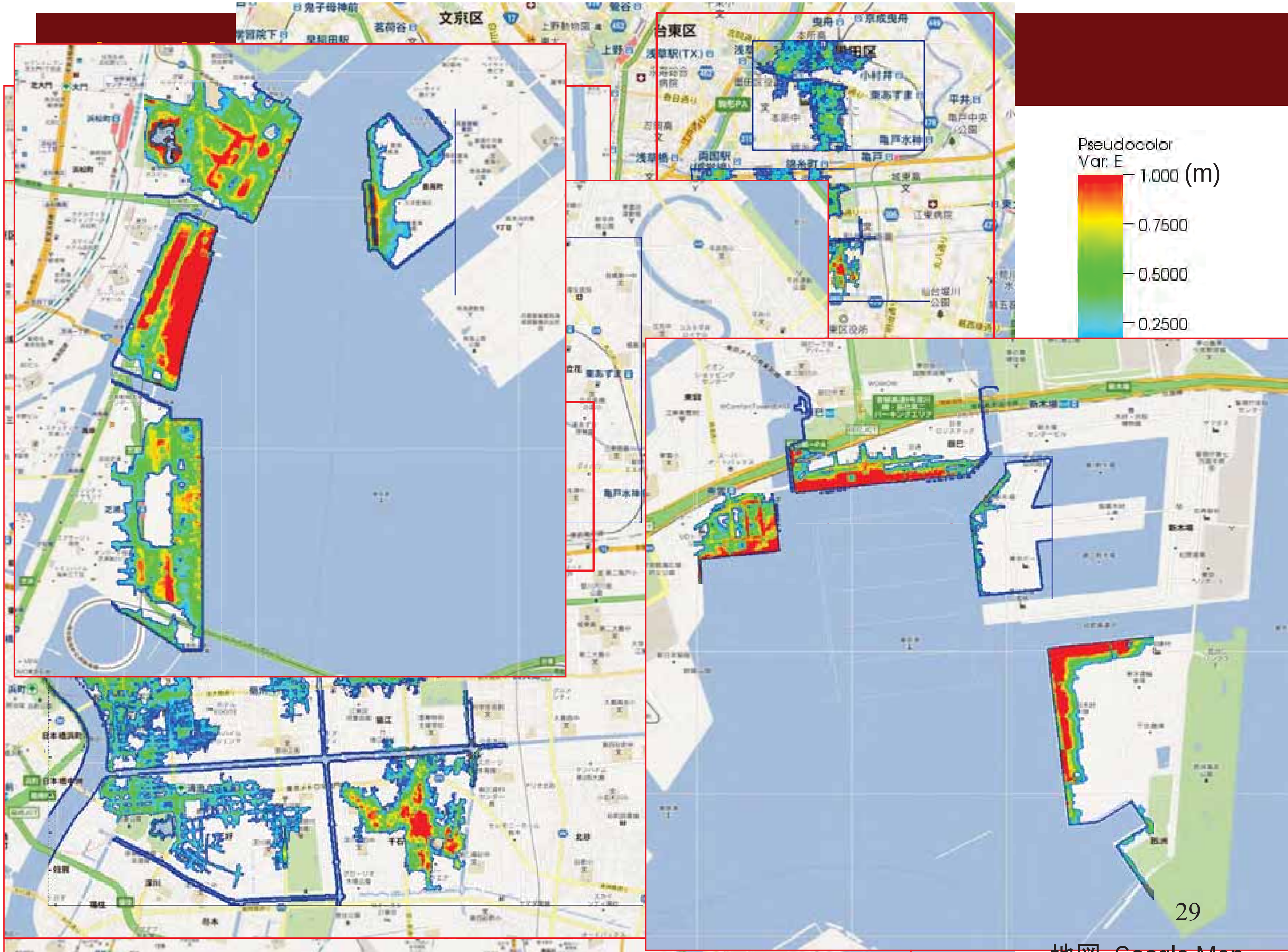


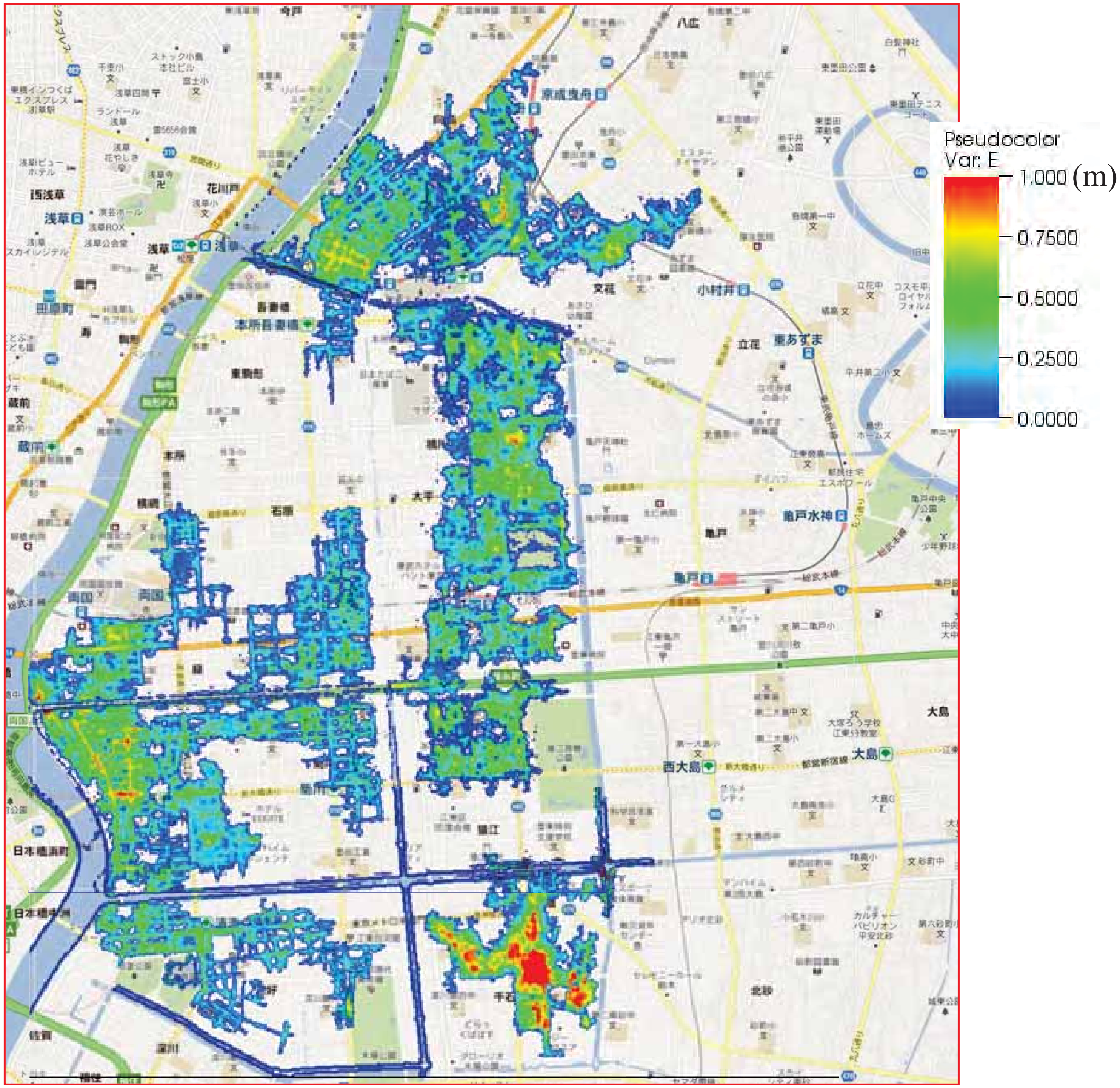
Fig. 1. Overview of Japan and sea.
(Google Map (Image: DATA SIO, NOAA, U.S. Navy, NGA, GEBCO, Landsat / Map Data : SK telecom, ZENRIN))

Fig. 2. Overview of Tokyo Bay.
(Google Map (Image : Landsat, DATA SIO, NOAA, U.S. Navy, NGA, GEBCO, Data Japan Hydrographic Association, Data LDEO-Columbia, NSF, NOAA / Map Data : ZENRIN))



地図：Google Map

Flood in Tokyo downtown, Koto ward , if storm surge barriers are destroyed by earthquake.



Ground subsidence in the Tokyo Bay region

Waseda University

■ A lot of ground water was pumped up to urbanize the Tokyo Bay region in the past. It caused the severe ground subsidence.

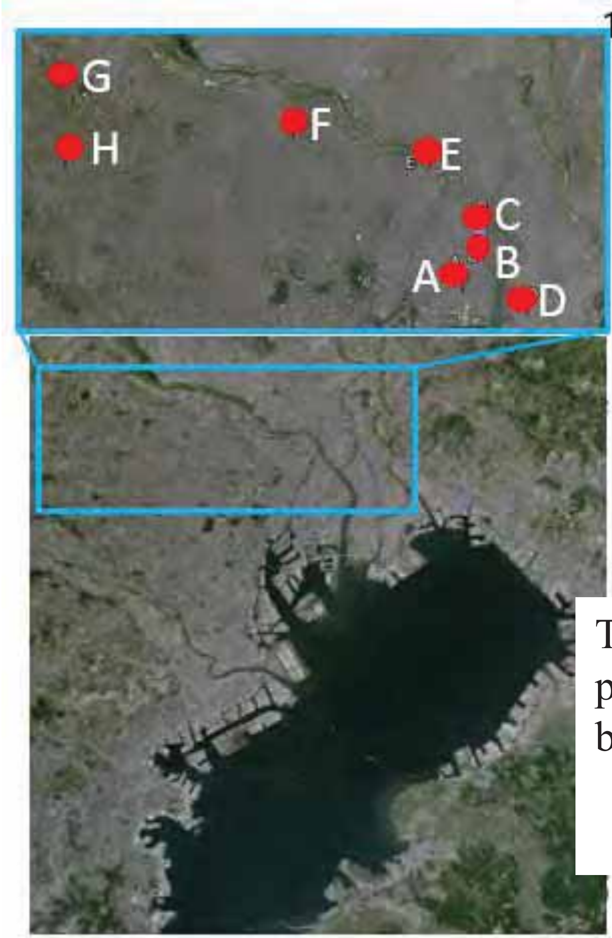


Fig. 4. Observation points of ground subsidence
(Source : Google Map (Image : Image Landsat, Data SIO, NOAA, U.S. Navy, NGA, GEBCO))

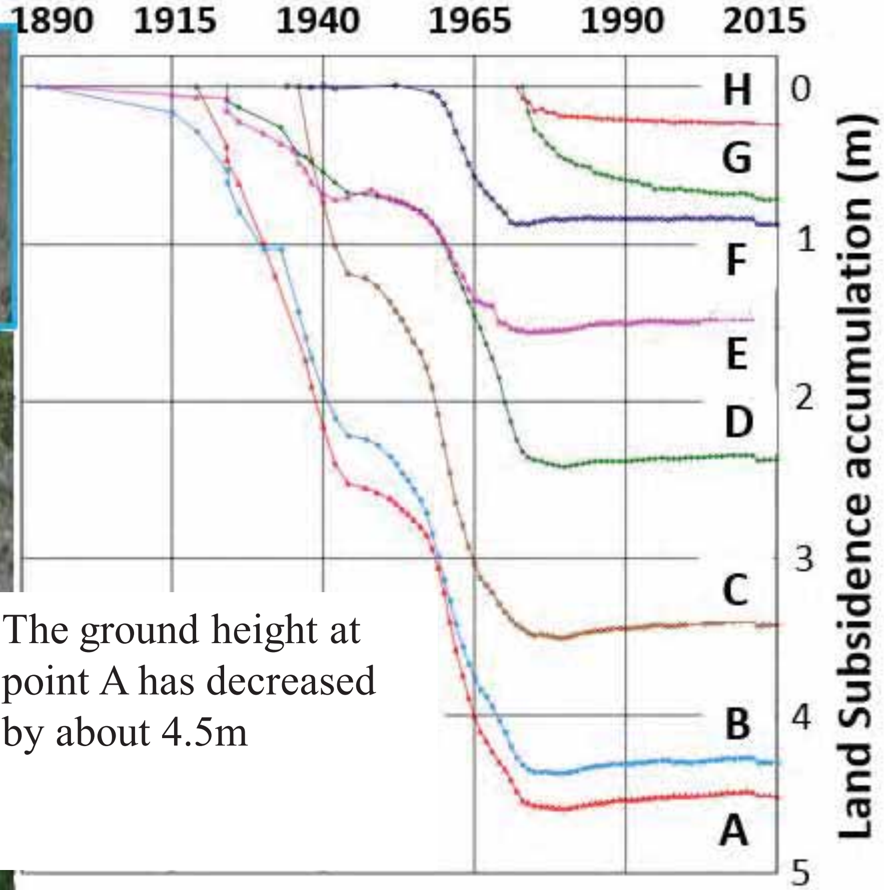


Fig.5. Time history of ground subsidence
(Civil Engineering Support and Training Center, Bureau of Construction, Tokyo Metropolitan Government, 2013)

Ground elevation in the Tokyo Bay region

Waseda University

■ As a result of the ground subsidence, low-lying areas, including below-sea-level areas, widely spread in the current Tokyo Bay region.

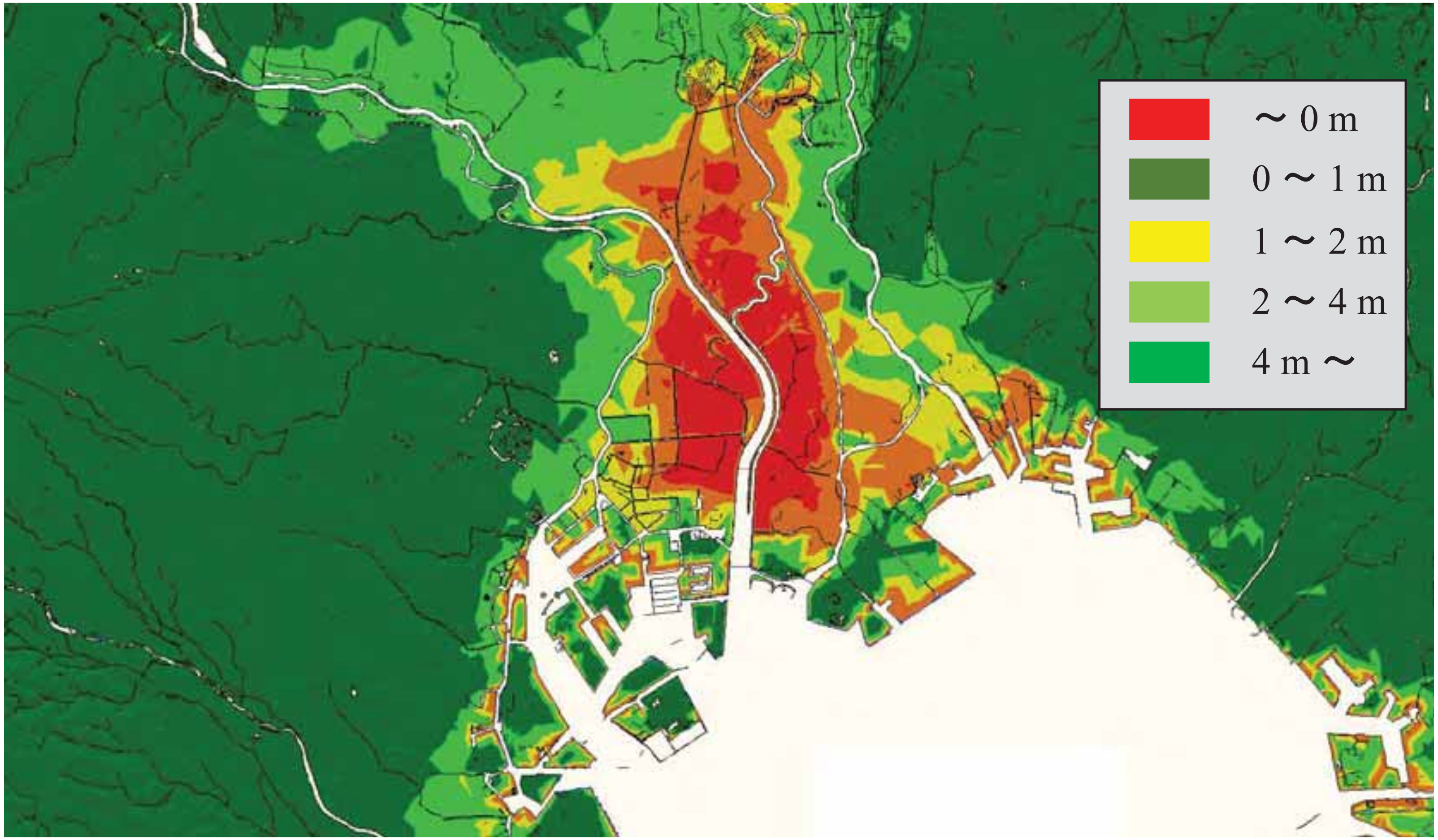


Fig. 6. Ground elevation in the Tokyo Bay region
(Geospatial Information Authority of Japan, 2016)

Flooding caused by the storm surge

Waseda University

■ The storm surge caused massive damage to the Tokyo Bay region and losses of 1,300 human lives.

Fig. 10. Kyobashi-city after flooding by the storm surge (Kitahara, 2007)

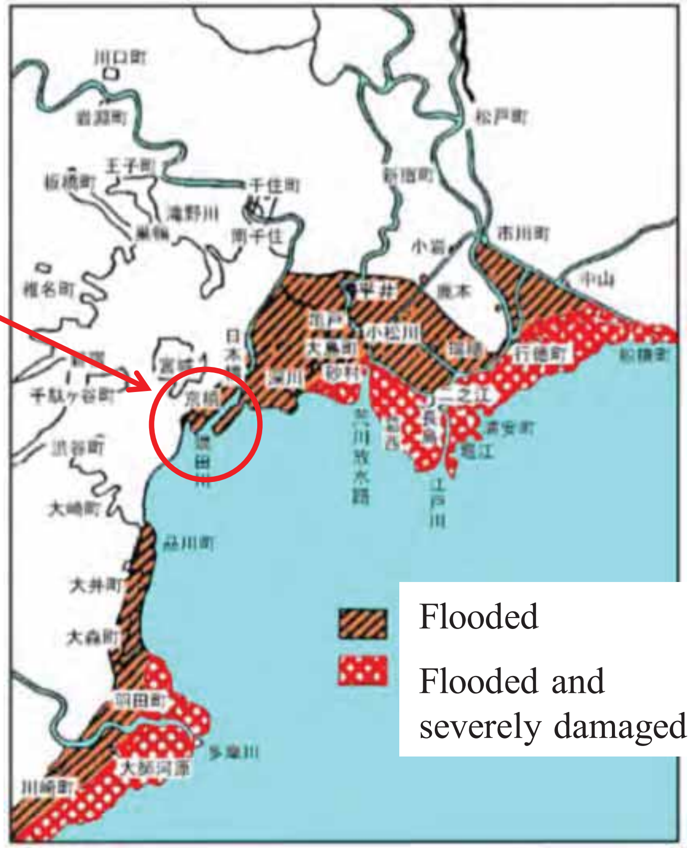


Fig. 11. Flooded area (Japan Meteorological Agency Technical Report)

Table. 3. Damage caused by the 1917 storm surge (Miyazaki, 2003)

Dead or missing	1,324
Wounded	2,022
Completely destroyed houses	36,459
Half destroyed houses	21,274
Flooded area	215km² (in Tokyo)

Reason of geographical changes in Tokyo Bay

Waseda University

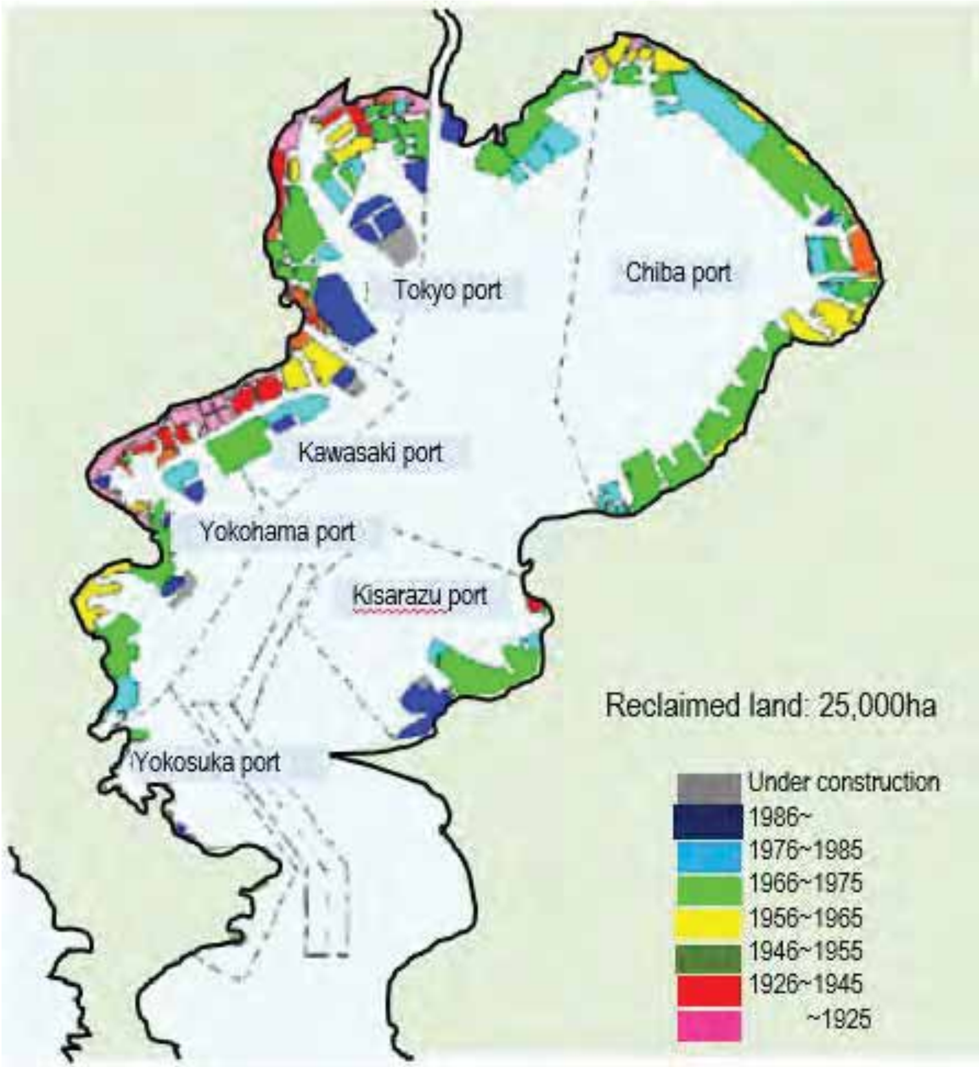


Fig. 16. Historical change of land reclamation in Tokyo Bay
(Ministry of Land, Infrastructure, Transport and Tourism, 2012)

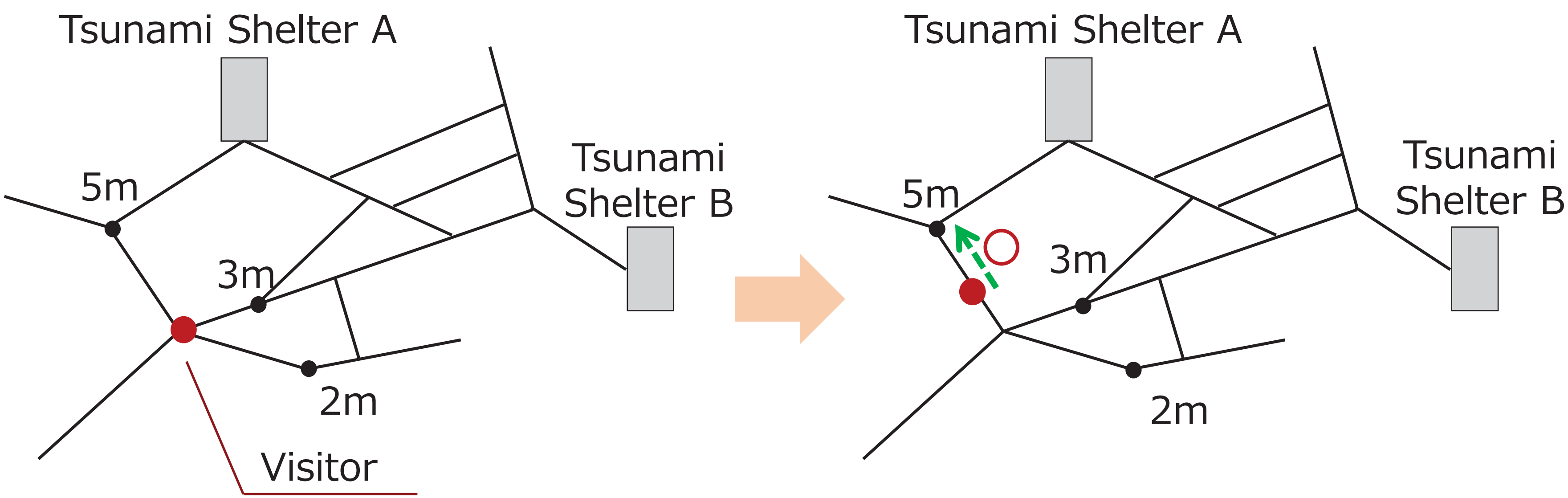
- A lot of reclaimed lands have been constructed in Tokyo Bay.
- The land reclamation in Tokyo Bay started in 1590 mainly to expand residential areas and increase waste disposal sites.

Evacuation Simulation Considering Local Residents and Visitors

Takabatake & Shibayama (2017)

Evacuation Simulation Model -Choices of Evacuation Routes-

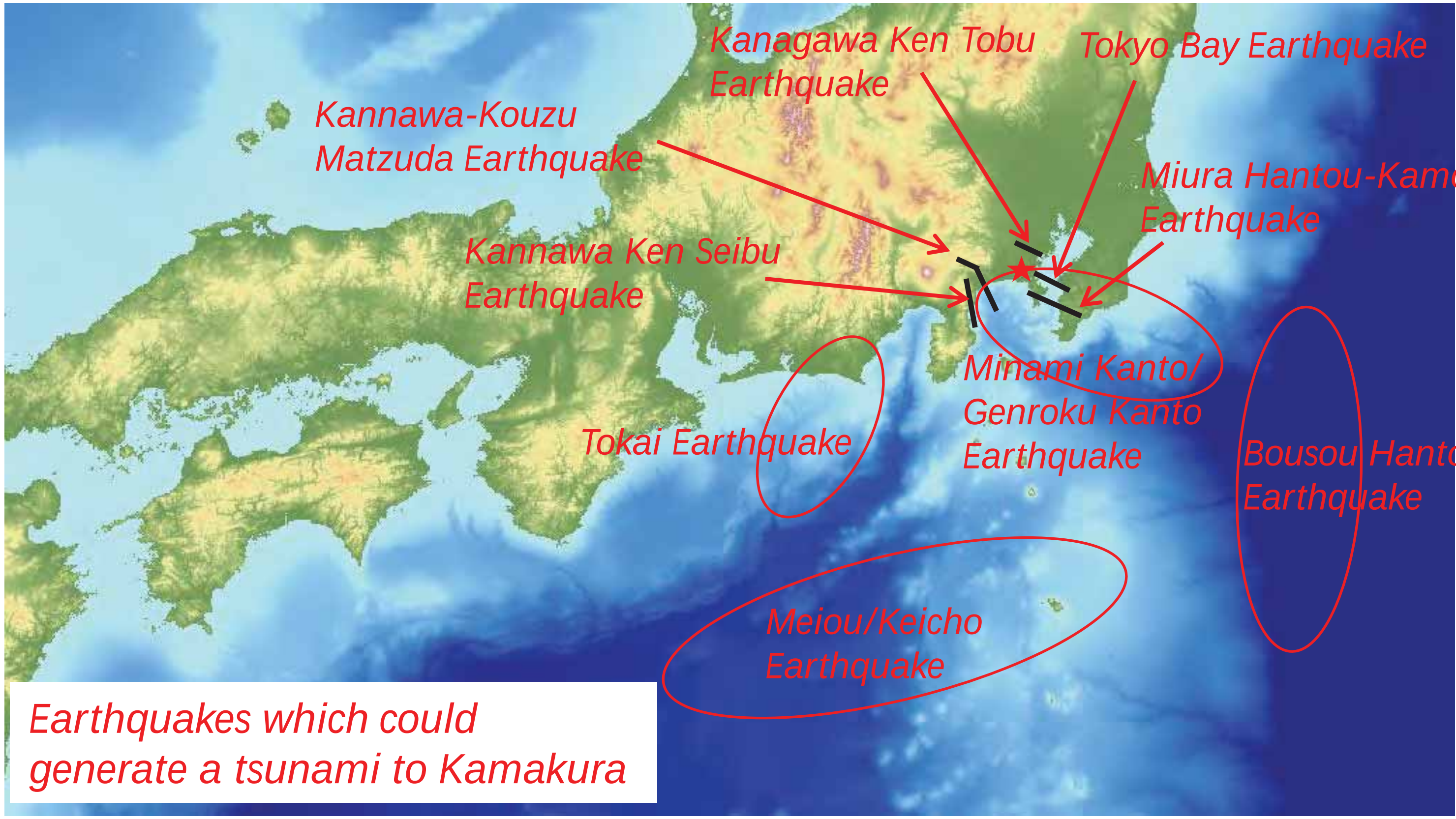
- **Local people** : Decide to go to the closest evacuation place and chose the shortest route, which is calculated by Dijkstra Method (Dijkstra, 1959).
- **Visitors** : (1) Choose a road where there are more evacuees. (2) Decide to go to higher places. / In order to consider uncertainties of visitor's behaviors, the probability for choosing either rule can be specified for each simulation.



(b) Behaviors of Visitors

Further Application : Casualty estimation for Kamakura tsunami

- Kamakura City is one of the most vulnerable coastal areas in Japan.
- There are around 175,000 local residents and around 22 million tourists visit it every year (Kamakura City Office, 2016).

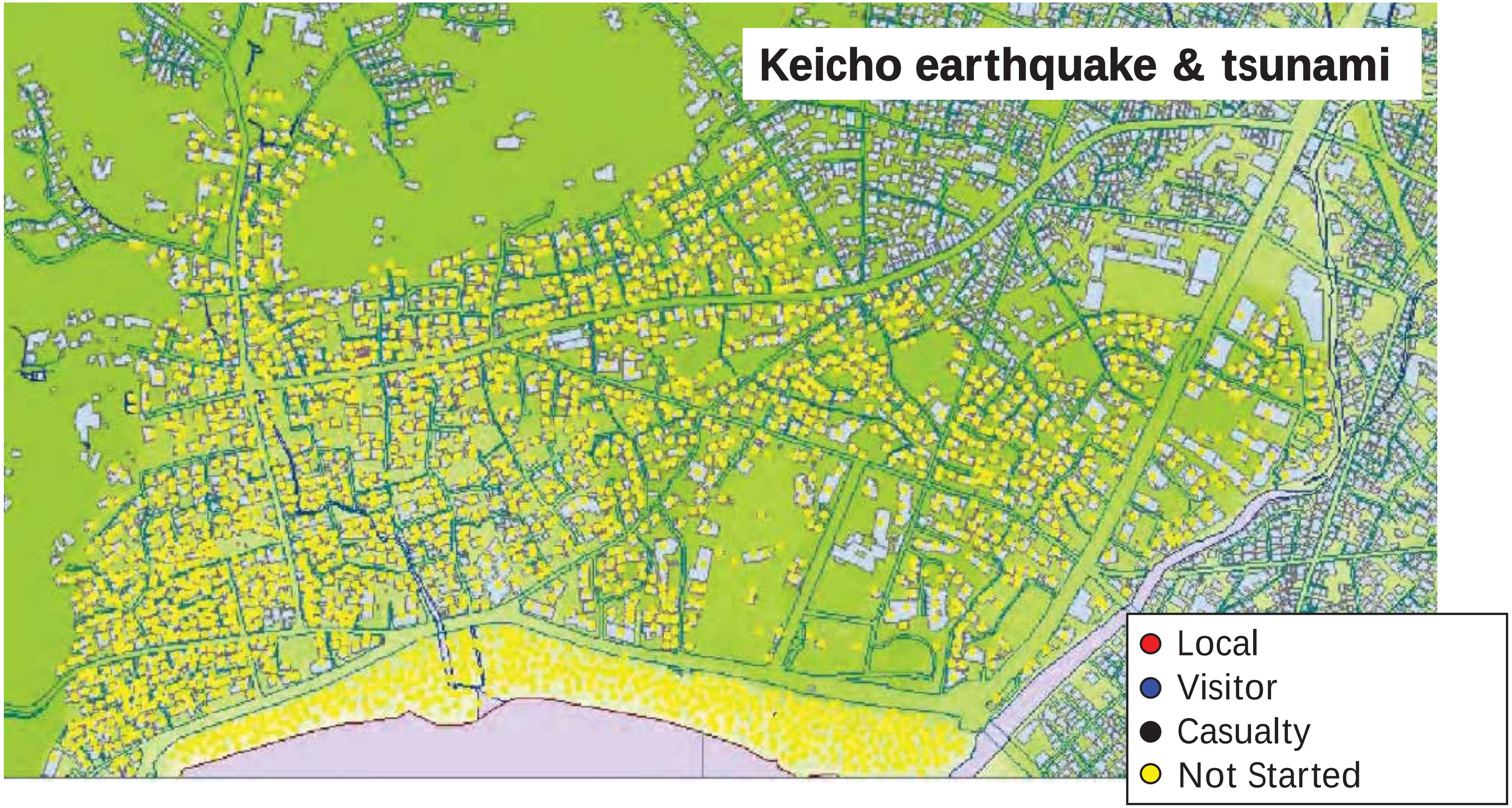


（Example of Fujisawa city)
Maximum Tsunami Height and its Travel Time

South Kanto Earthquake	8.09m	24min.
Genroku Kanto Earthquake	7.69m	21min.
Meiou-Toukai Earthquake	7.99m	52min.
Keicho Earthquake	9.47m	72min.

Decision for Evacuation:
Emergency Information Transmission
Quick decision

Results : Evacuation Simulation (Casualty Estimation)



Study on Tsunami Risks for Kamakura

Summary

- Using the developed evacuation simulation model, it is possible to estimate casualties for different scenarios. (e.g. different tsunamis / different situations (daytime/night, high season))
- It is also possible to evaluate the effectiveness of countermeasures for different scenarios.

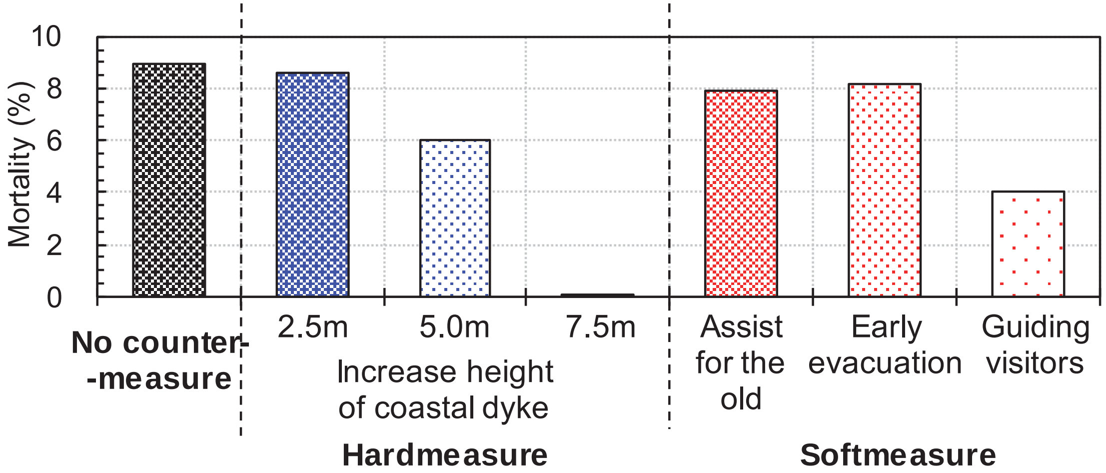


Fig. Effectiveness of countermeasure for Keicho tsunami

Increase height of coastal dyke

Effects of countermeasures can be compared form the viewpoints of casualties.

Tsunami Basin Experiment

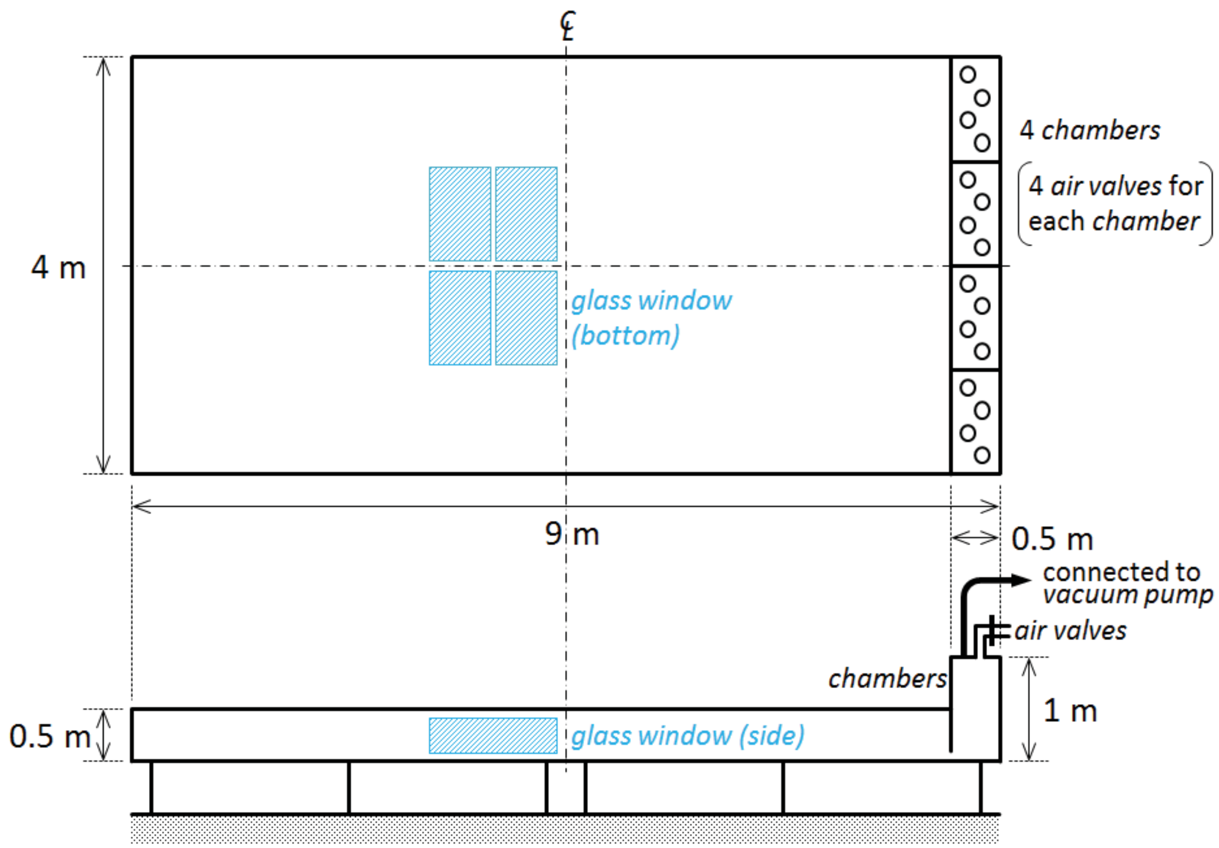


Fig. Plan and side views of the tsunami basin

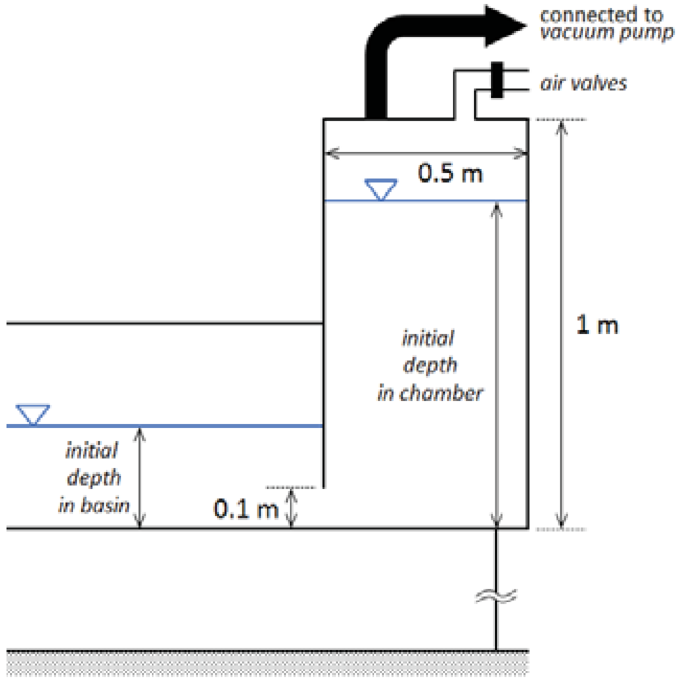
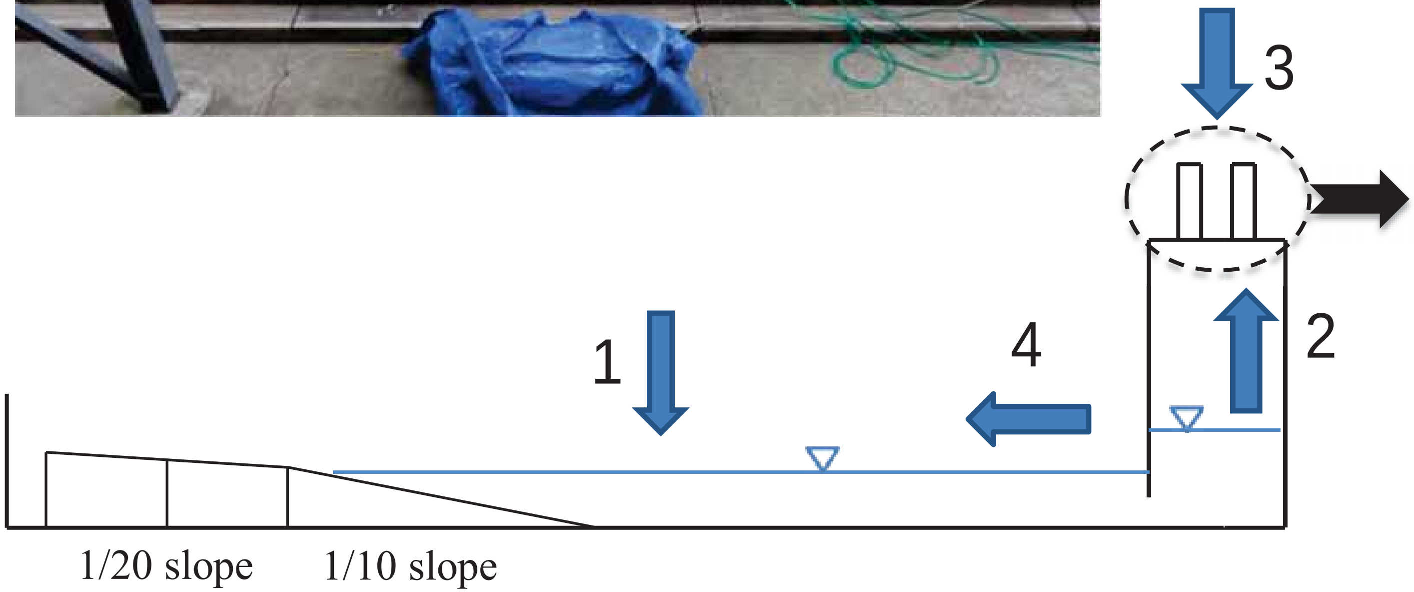


Fig. Side view of chamber

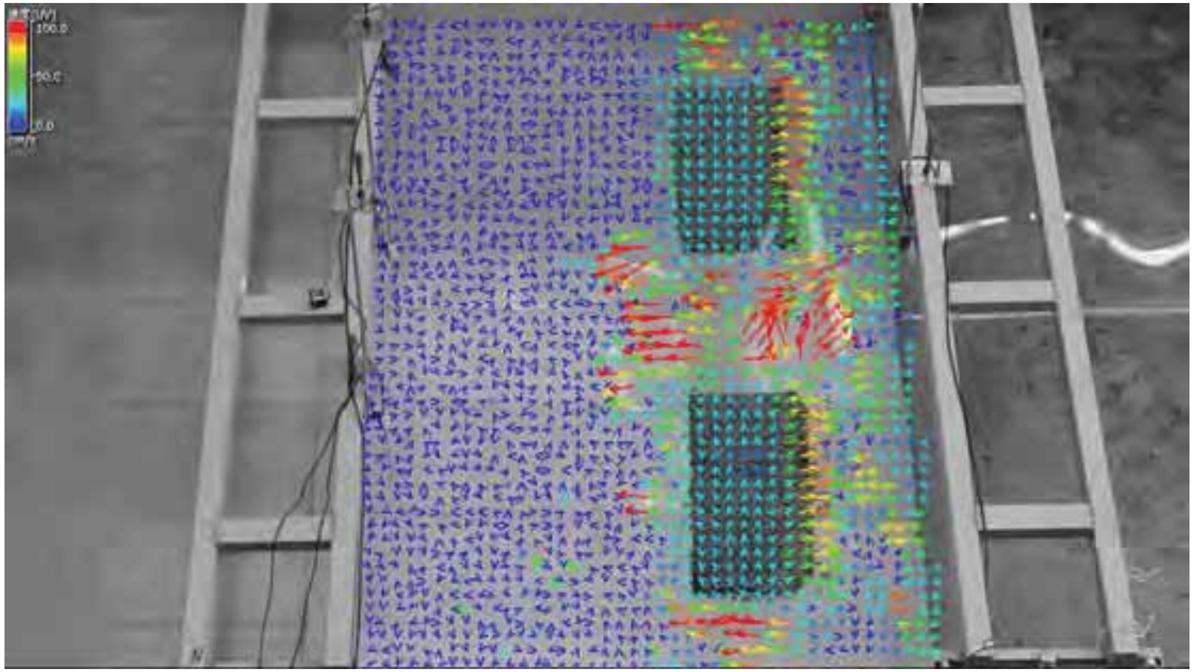
Generation of Tsunami Wave in Waseda Univeristy

1. store water
2. suck up water to chamber
3. select valves release phase
4. release water



Laboratory Experiment

- Apply PIV (Particle Image Velocimeter) to tsunami basin to visualize water movement.



Second Findings: Change of Storm Behaviors due to Climate Changes

Future Predictions-------Numerical Simulation

Nakamura, R., Shibayama, T., Ohira, K., Tasnim, M.K. (2014)

Rapid Development: Yolanda (2013), Nemuro (2014)
Route Change : Nargis (2008)

Components of Storm Surge

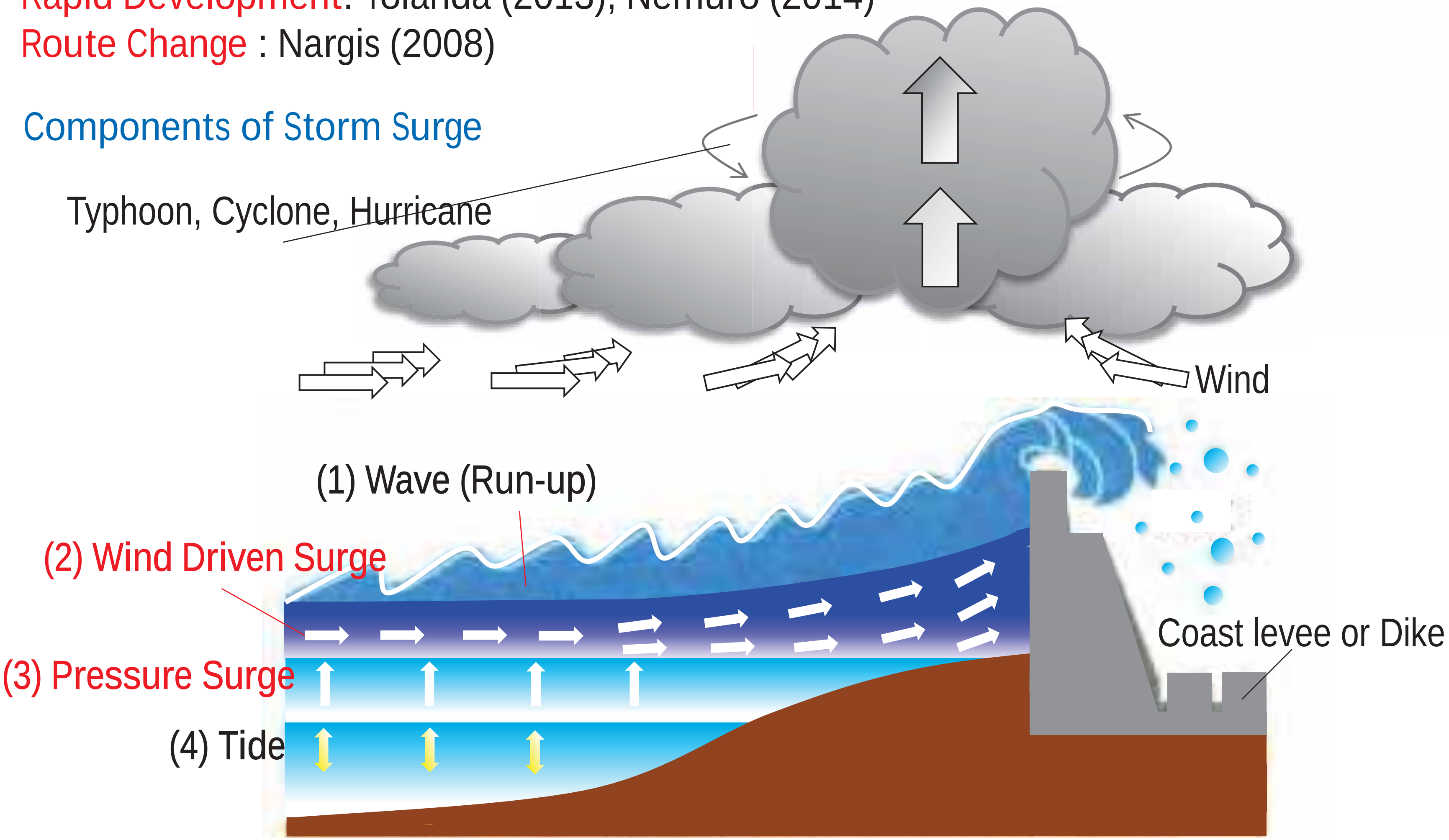
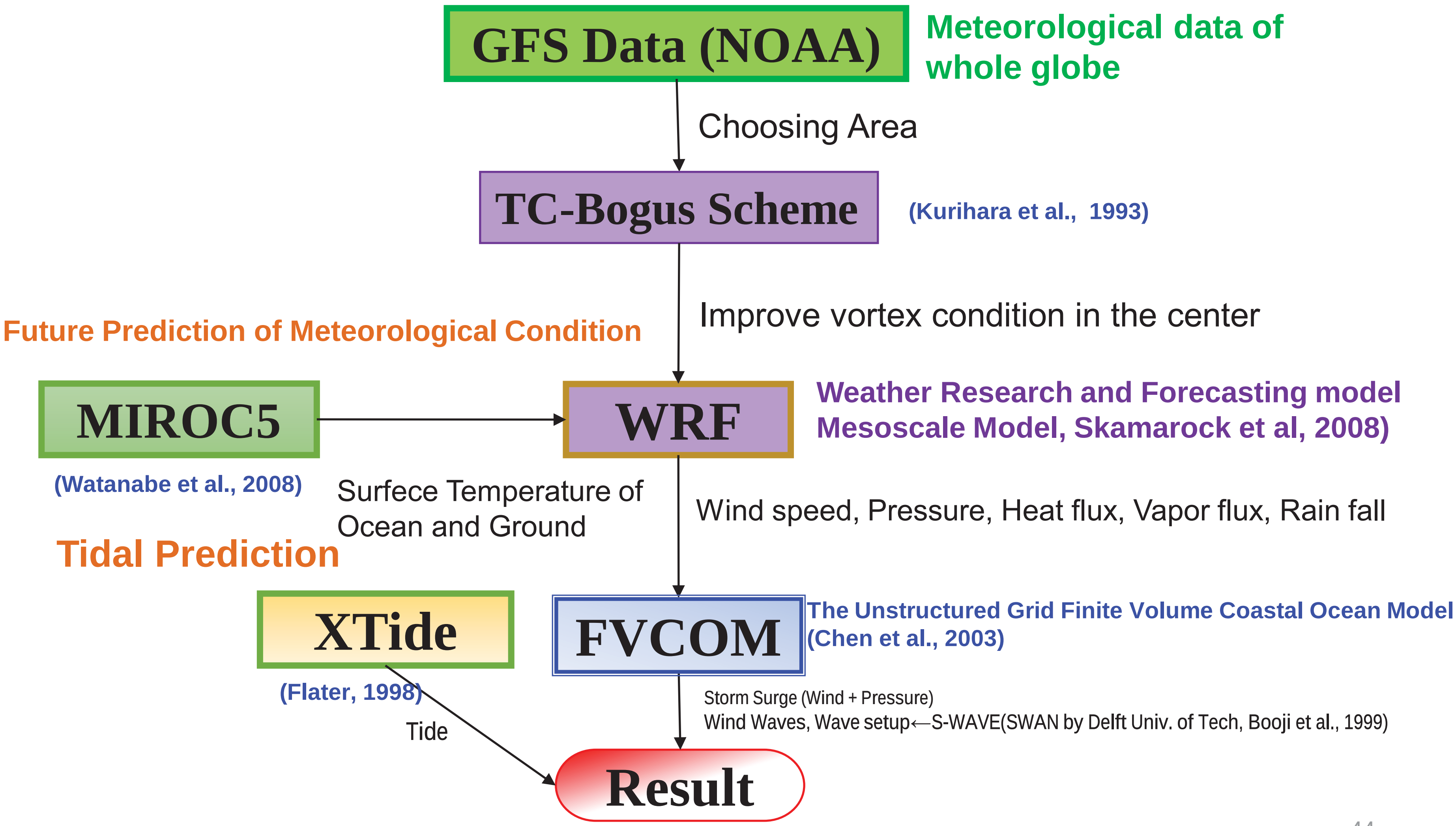


Fig. An image of phenomena when typhoon
*(2) + (3)= Storm Surge

Storm Surge Prediction Model (Nakamura and Shibayama, 2014)
Coupled Weather-Storm surge-wave-tide model
WRF-FVCOM-Xtide-MIROC5



Numerical modelling: A coupled top-down approach

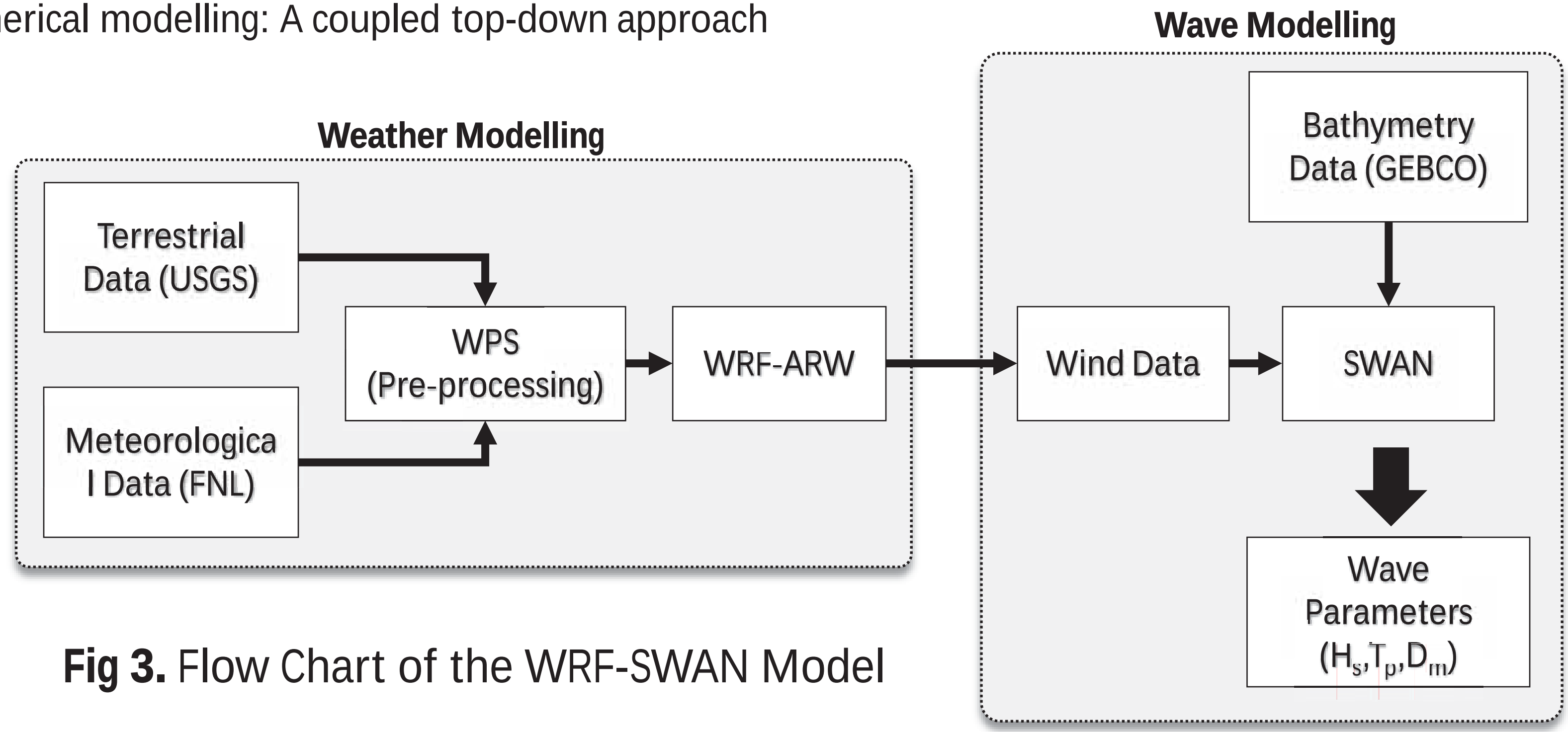


Fig 3. Flow Chart of the WRF-SWAN Model

METHODOLOGY:

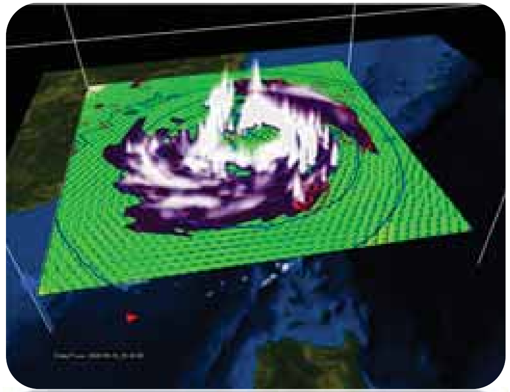
WRF : Weather Research and Forecasting model)
Skamarock et al, 2008)

Momentum Conservation

$$\frac{\partial U}{\partial t} + m\left[\frac{\partial}{\partial x}(Uu) + \frac{\partial}{\partial y}(Vu)\right] + \frac{\partial}{\partial \eta}(\Omega u) + \left(\mu_d \alpha \frac{\partial p'}{\partial x} + \mu_d \alpha' \frac{\partial \bar{p}}{\partial x}\right) + \left(\frac{\alpha}{\alpha_d}\right)\left(\mu_d \frac{\partial \phi'}{\partial x} + \frac{\partial p'}{\partial \eta}\frac{\partial \phi}{\partial x} - \mu_d \frac{\partial \phi}{\partial x}\right) = F_U$$

$$\frac{\partial V}{\partial t} + m\left[\frac{\partial}{\partial x}(Uv) + \frac{\partial}{\partial y}(Vv)\right] + \frac{\partial}{\partial \eta}(\Omega v) + \left(\mu_d \alpha \frac{\partial p'}{\partial x} + \mu_d \alpha' \frac{\partial \bar{p}}{\partial x}\right) + \left(\frac{\alpha}{\alpha_d}\right)\left(\mu_d \frac{\partial \phi'}{\partial y} + \frac{\partial p'}{\partial \eta}\frac{\partial \phi}{\partial y} - \mu_d \frac{\partial \phi}{\partial y}\right) = F_V$$

$$\frac{\partial W}{\partial t} + m\left[\frac{\partial}{\partial x}(Uw) + \frac{\partial}{\partial y}(Vw)\right] + \frac{\partial}{\partial \eta}(\Omega w) - m^{-1} g \left(\frac{\alpha}{\alpha_d}\right)\left(\frac{\partial p'}{\partial \eta} - \bar{\mu}_d (q_v + q_c + q_r)\right) + m^{-1}\mu_d' g = F_W$$



Mass Conservation

$$\frac{\partial \mu_d'}{\partial t} + m^2\left[\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}\right] + m\frac{\partial \Omega}{\partial \eta} = 0$$

Scaler Conservation

$$\frac{\partial Q_m}{\partial t} + m^2\left[\frac{\partial}{\partial x}(Uq_m) + \frac{\partial}{\partial y}(Vq_m)\right] + m\frac{\partial}{\partial \eta}(\Omega q_m) = F_{Q_m}$$

Potential Temperature

$$\frac{\partial \Theta}{\partial t} + m^2\left[\frac{\partial}{\partial x}(U\theta) + \frac{\partial}{\partial y}(V\theta)\right] + m\frac{\partial}{\partial \eta}(\Omega \theta) = F_\Theta$$

State Law

$$p = p_0\left(R_d \theta_m / p_0 \alpha_d\right)^\gamma$$

Geo-Potential

$$\frac{\partial \phi'}{\partial t} + \mu_d^{-1}\left[m^2\left(U\phi_x + U\phi_y\right) + mU\phi_\eta - gW\right] = 0$$

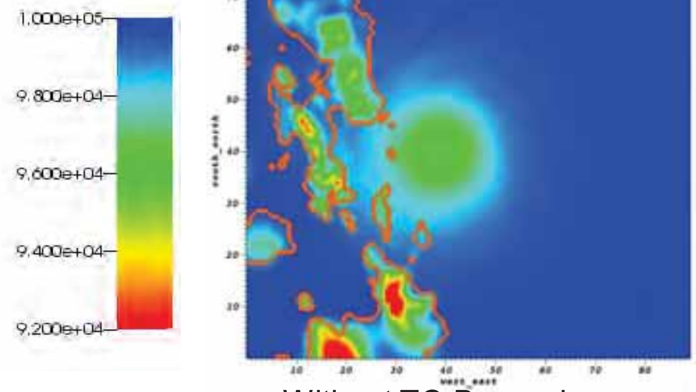
NCAR

METHODOLOGY: WRF

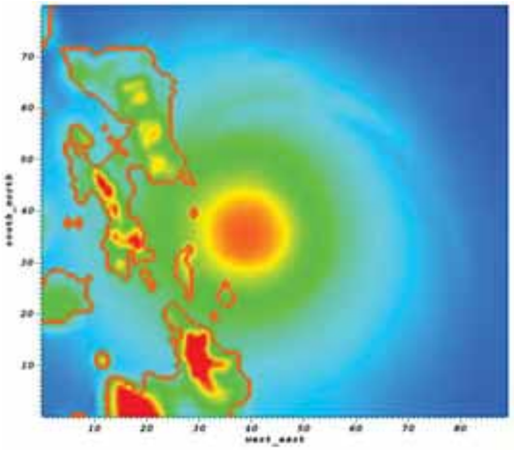
TC-Bogussing Scheme

◆Using artificial Rankin vortex for initial conditions

(Kurihara et al. 1993)



Without TC-Bogussing


With TC-Bogussing

<u>Rankin Vortex</u>

$$v = A[z]F[r]$$

$$F(r) = \frac{v_m}{r_m} r \qquad (r \leqq r_m)$$

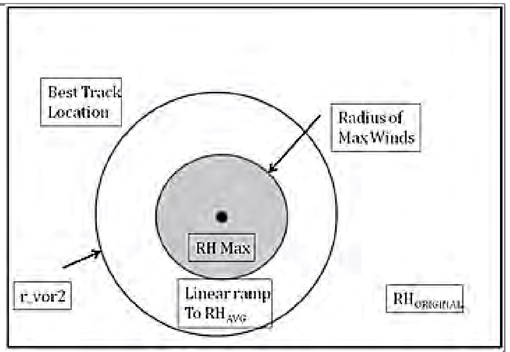
$$F(r) = \frac{v_m}{r_m{}^{\alpha}} r^{\alpha} \qquad (r > r_m)$$

v : Wind speed

v_m : Maximum velocity at the Max velocity diameter r_m

α : $Constant(\alpha = -0.75)$

$A[z]$: $Scale\ Factor\ depending\ on\ each\ typhoon, 0.90\ for\ this\ case.$



Concept of Rankin vortex

METHODOLOGY: OCEAN MODEL FVCOM (Chen et al. 2003)

FVCOM : The Unstructured Grid Finite Volume Coastal Ocean Model

Version 3.1.6 (2011)

FVCOM governing equations

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - fv = -\frac{1}{\rho_0}\frac{\partial(p_H + p_a)}{\partial x} - \frac{1}{\rho_0}\frac{\partial q}{\partial x} + \frac{\partial}{\partial z}(K_m\frac{\partial u}{\partial x}) + F_u$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + fu = -\frac{1}{\rho_0}\frac{\partial(p_H + p_a)}{\partial y} - \frac{1}{\rho_0}\frac{\partial q}{\partial y} + \frac{\partial}{\partial z}(K_m\frac{\partial v}{\partial x}) + F_v$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho_0}\frac{\partial q}{\partial z} + \frac{\partial}{\partial z}(K_m\frac{\partial w}{\partial x}) + F_w$$

Momentum Conservation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

Mass Conservation

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = \frac{\partial}{\partial z}(K_h\frac{\partial T}{\partial x}) + F_T$$

Potential Temperature

$$\frac{\partial S}{\partial t} + u\frac{\partial S}{\partial x} + v\frac{\partial S}{\partial y} + w\frac{\partial S}{\partial z} = \frac{\partial}{\partial z}(K_h\frac{\partial S}{\partial x}) + F_S$$

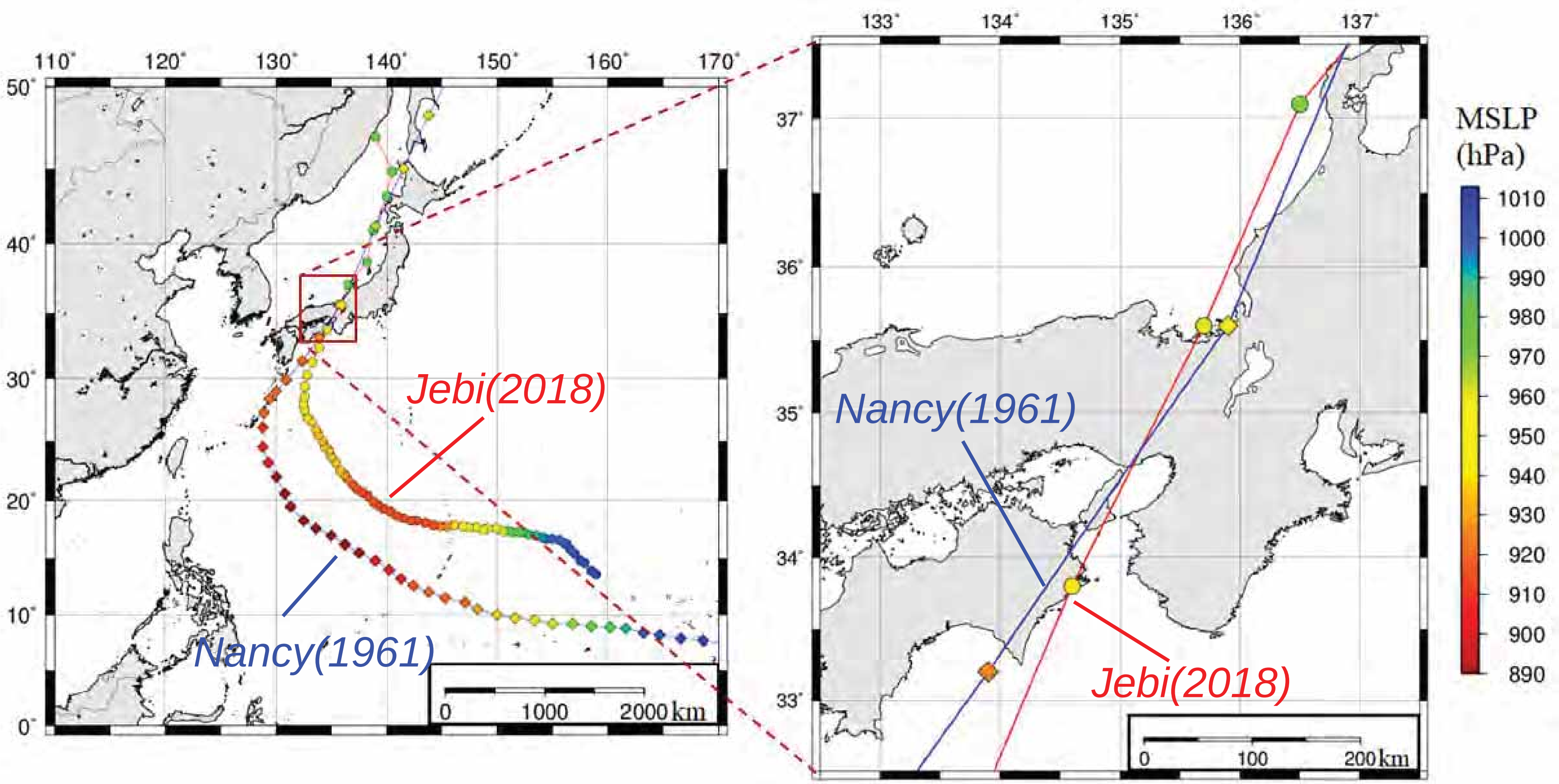
Salinity

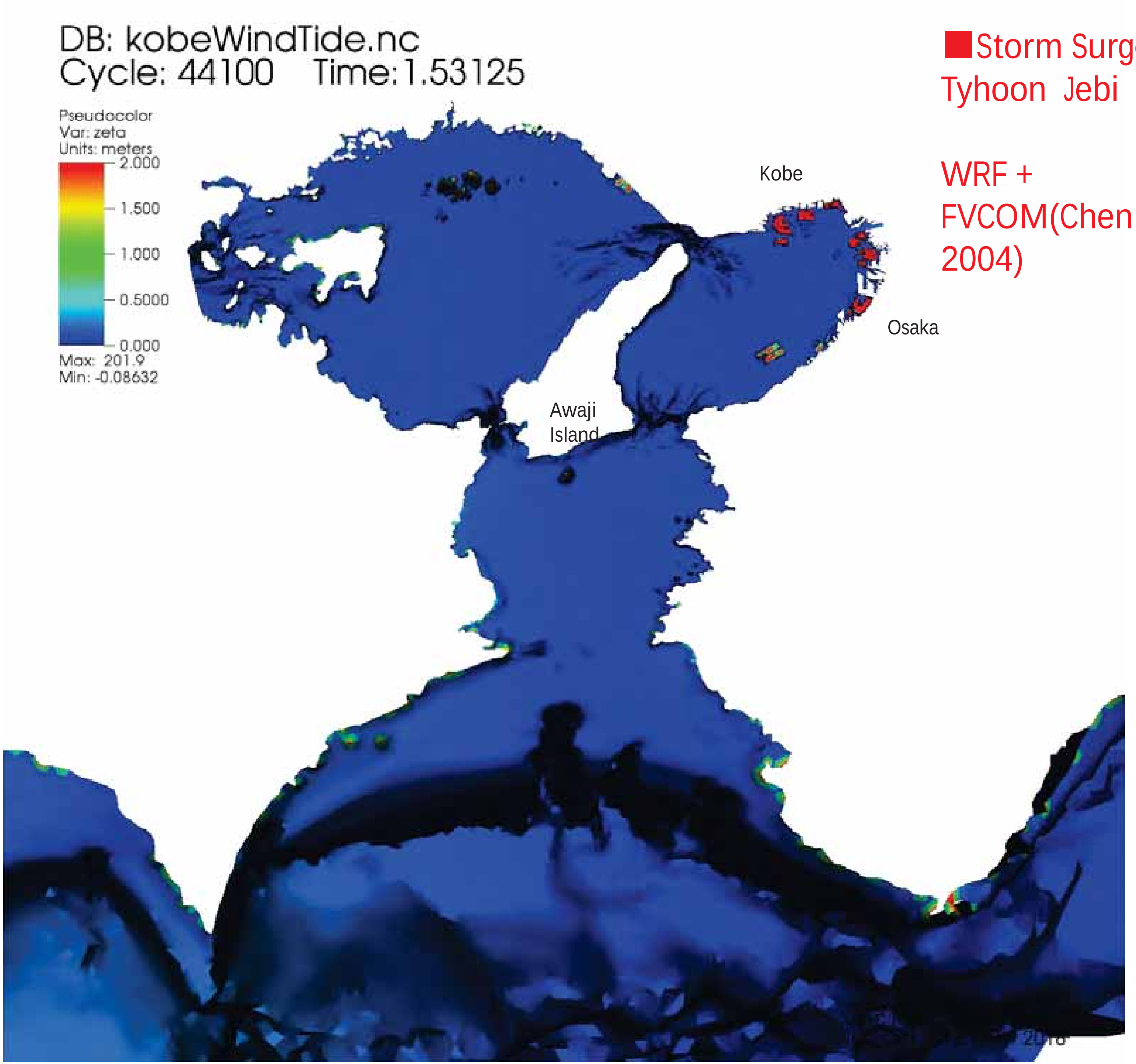
$$\rho = \rho(T, S, p)$$

Density

σ coordinate system and Cartesian coodinate system : Chen et al., 2011

Typhoon Jebi (2018)





■Storm Surge by Tyhoon Jebi

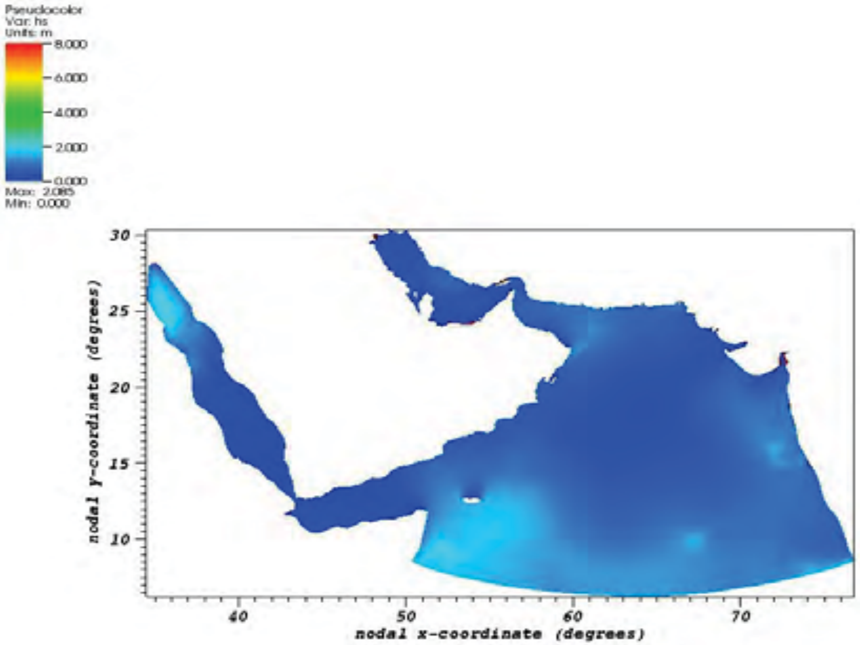
WRF + FVCOM(Chen et al., 2004)

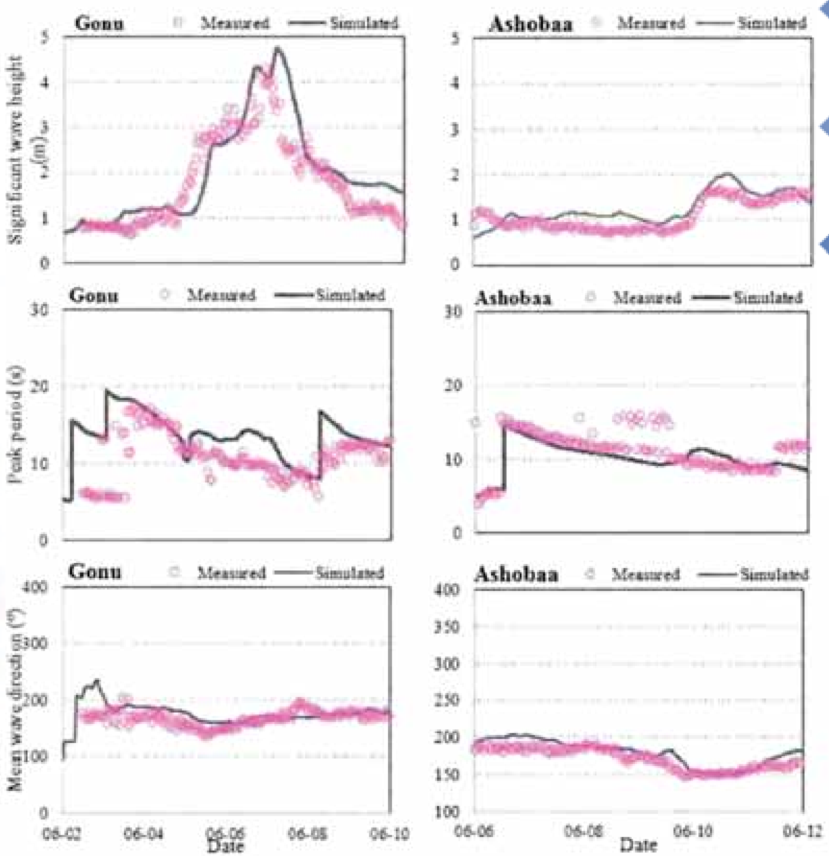
Target Cyclones

Gonu, 2007

Ashobaa, 2015

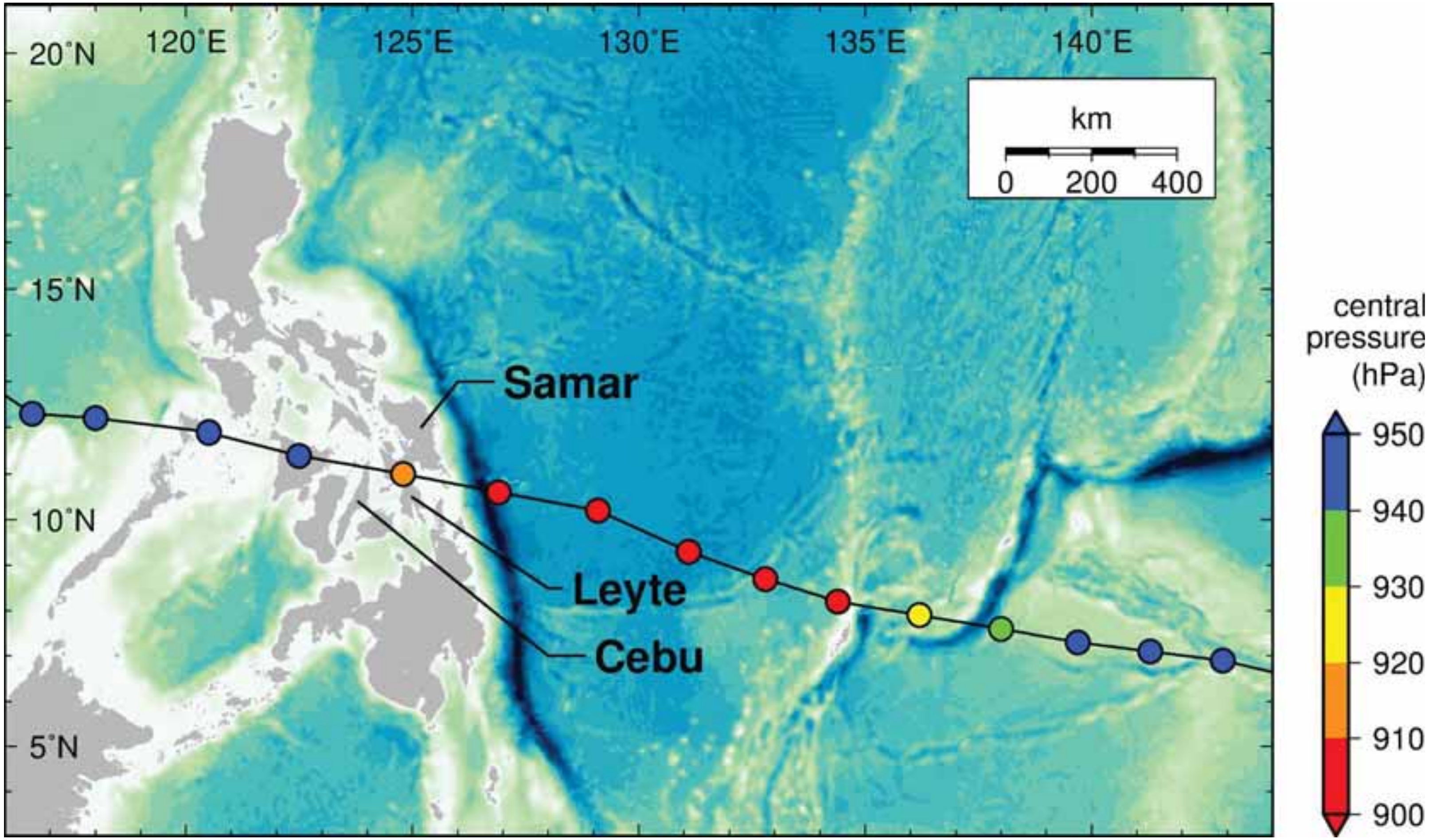
SWAN Model Results





Tyhoon Yolanda

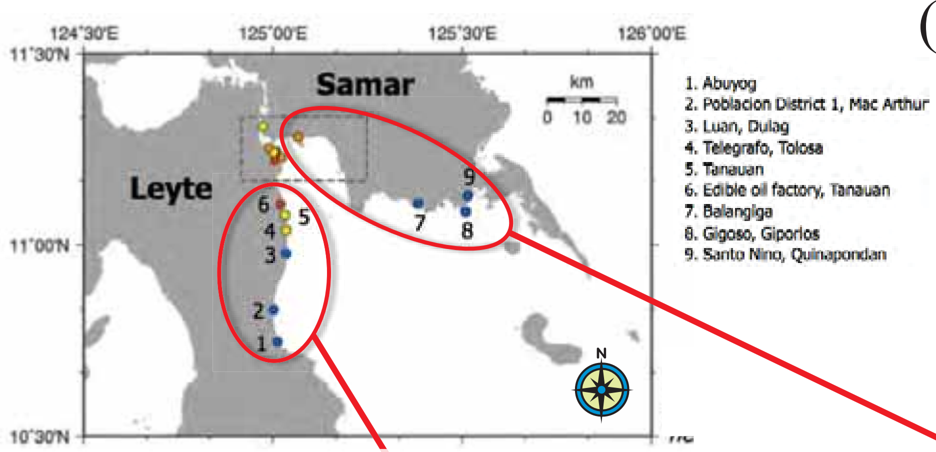
Time of Generation: 2013-11-04 00:00 UTC
Time of Disappearance: 2013-11-11 06:00 UTC
Duration: 174 hours
Minimum Pressure: 895 hPa
Maximum Wind Speed: 64.3 m/s
Number of Victims: 6201 (Jan. 14 in the Philippines)
Number of Unknowns: 1785(Jan. 14 in the Philippines)



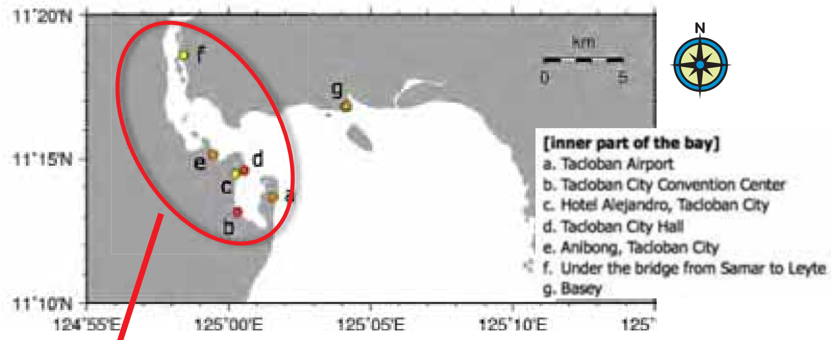
Track data: The Regional Specialized Meteorological Center (RSMC) Tokyo Best Track Data
http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/trackarchives.html

COMPARISONS OF WATER MARKS AND CALCULATION

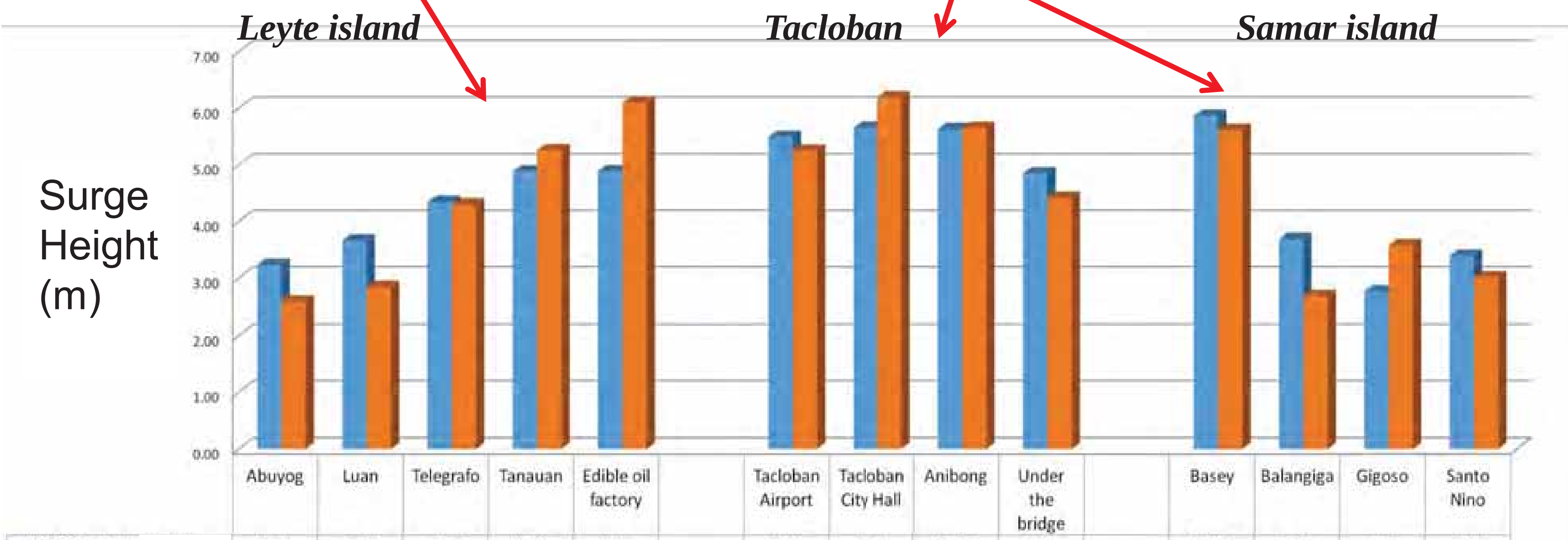
(Nakamura and Shibayama, 2014)



Observation points of Shibayama et al., 2013



Observation points near Tacloban



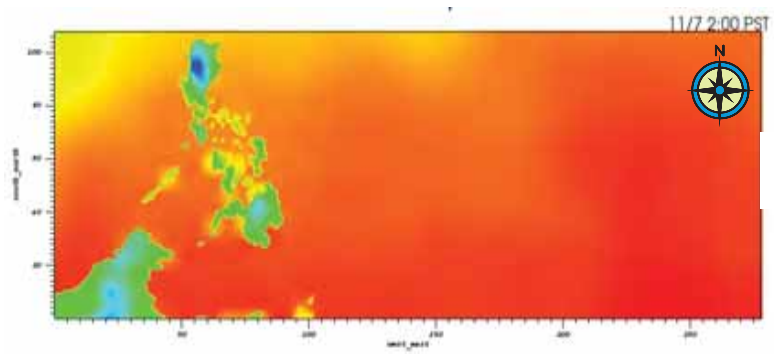
(m)	Abuyog	Luan	Telegrafo	Tanauan	Edible oil factory	Tacloban Airport	Tacloban City Hall	Anibong	Under the bridge	Basey	Balangiga	Gigoso	Santo Nino
FVCOM+setup	3.24	3.67	4.35	4.89	4.89	5.49	5.65	5.63	4.85	5.86	3.69	2.76	3.40
Measured	2.58	2.84	4.30	5.26	6.10	5.25	6.19	5.65	4.42	5.62	2.68	3.58	3.01

Comparison of water mark height and calculations in Reyte Bay

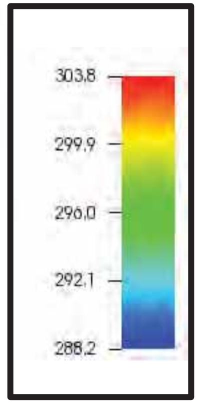
FUTURE PREDICTIONS

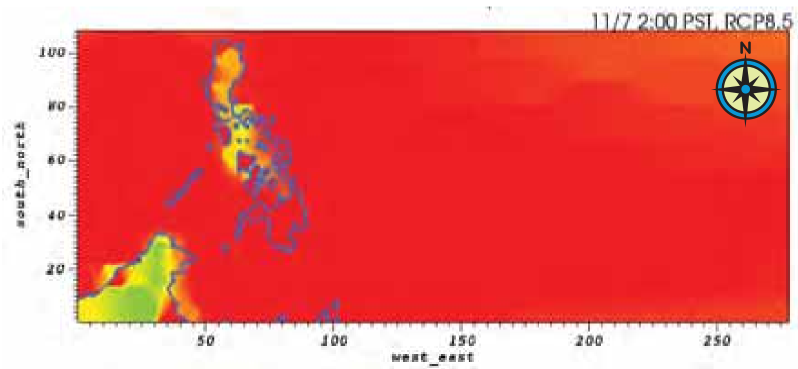
(Nakamura and Shibayama, 2014)

- MIROC5
  RCP8.5 scenario
  Surface temperature in 2100
- Increase of vapor flux results stronger typhoon



Surface temperature at 2:00, November 7, 2013 (PHT)

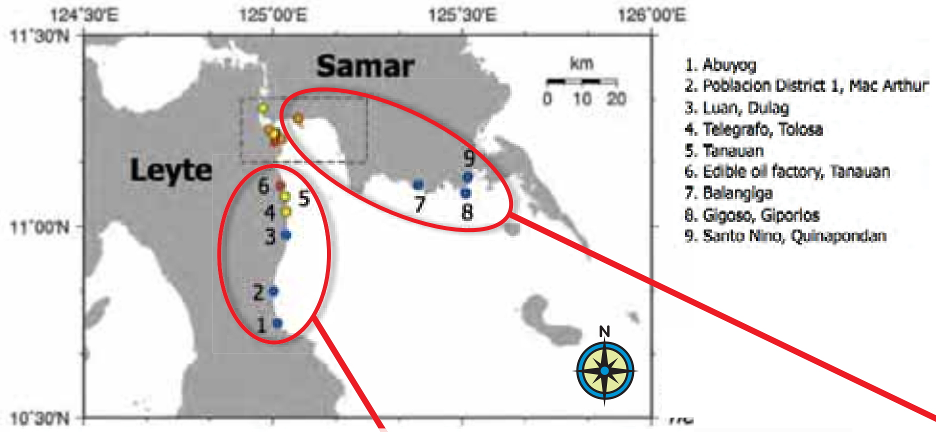




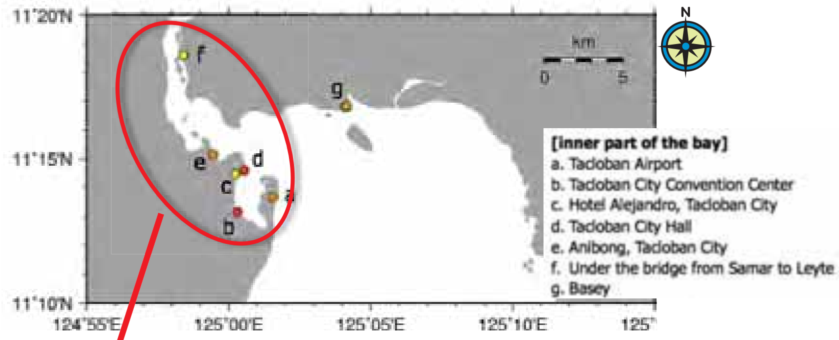
Surface temperature at 2:00, November 7, 2100 (PHT)
(IPCC AR5 RCP8.5 scenario, MIROC5)

CALCULATION OF EACH LOCATION UNDER THE CONDITION OF IN 2100

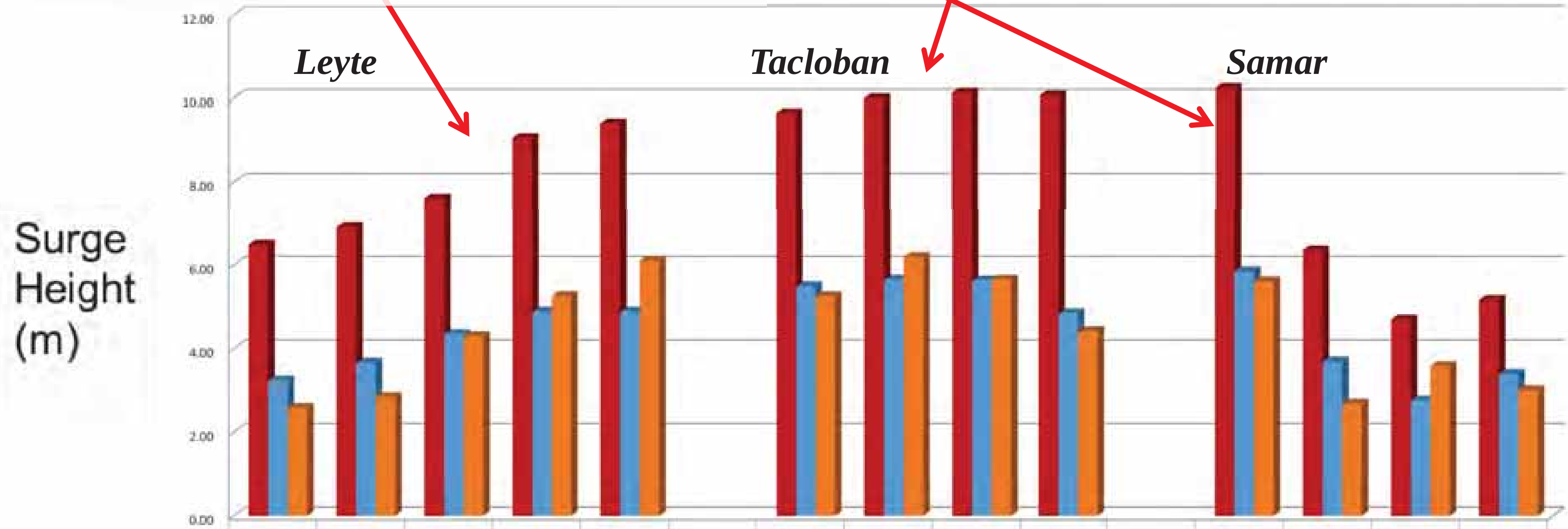
(Nakamura and Shibayama, 2014)



Observation points of Shibayama et al., 2013



Observation points near Tacloban



(m)	Abuyog	Luan	Telegrafo	Tanauan	Edible oil factory	Tacloban Airport	Tacloban City Hall	Anibong	Under the bridge	Basey	Balangiga	Gigoso	Santo Nino
FVCOM+setup 2100	6.49	6.91	7.60	9.05	9.40	9.64	9.99	10.12	10.06	10.24	6.35	4.69	5.16
FVCOM+setup (最高	3.24	3.67	4.35	4.89	4.89	5.49	5.65	5.63	4.85	5.86	3.69	2.76	3.40
Measured	2.58	2.84	4.30	5.26	6.10	5.25	6.19	5.65	4.42	5.62	2.68	3.58	3.01

Calculations for 2013, for 2100 and water marks.

Three different approaches

1. Construction of high coastal dike again and protection of low land area against the next tsunami attack. (Tarou)
2. Making artificial elevated area over old downtown in low land area by land fill. Use the elevated ground surface for residential area. (Rikuzentakata)
3. Movement to higher hill side and developing new residential area. (Onagawa)

Those methods are commonly used in part in these cities in Tohoku.

Tarou

Height of Tsunami Barrier wall is change

from 10m to 14.7m.

Rikuzentakata

Raise the Ground Level Elevation for 10-12m

There are selections for residents.

1) Natural Hill (45 ha)
2) New Artificial Hill (91 ha)

Onagawa

Change of Land-use:

Downtown in Low Land
→
No Residence, Open space

Construction of New Residence Area in Natural Hill

Arahama

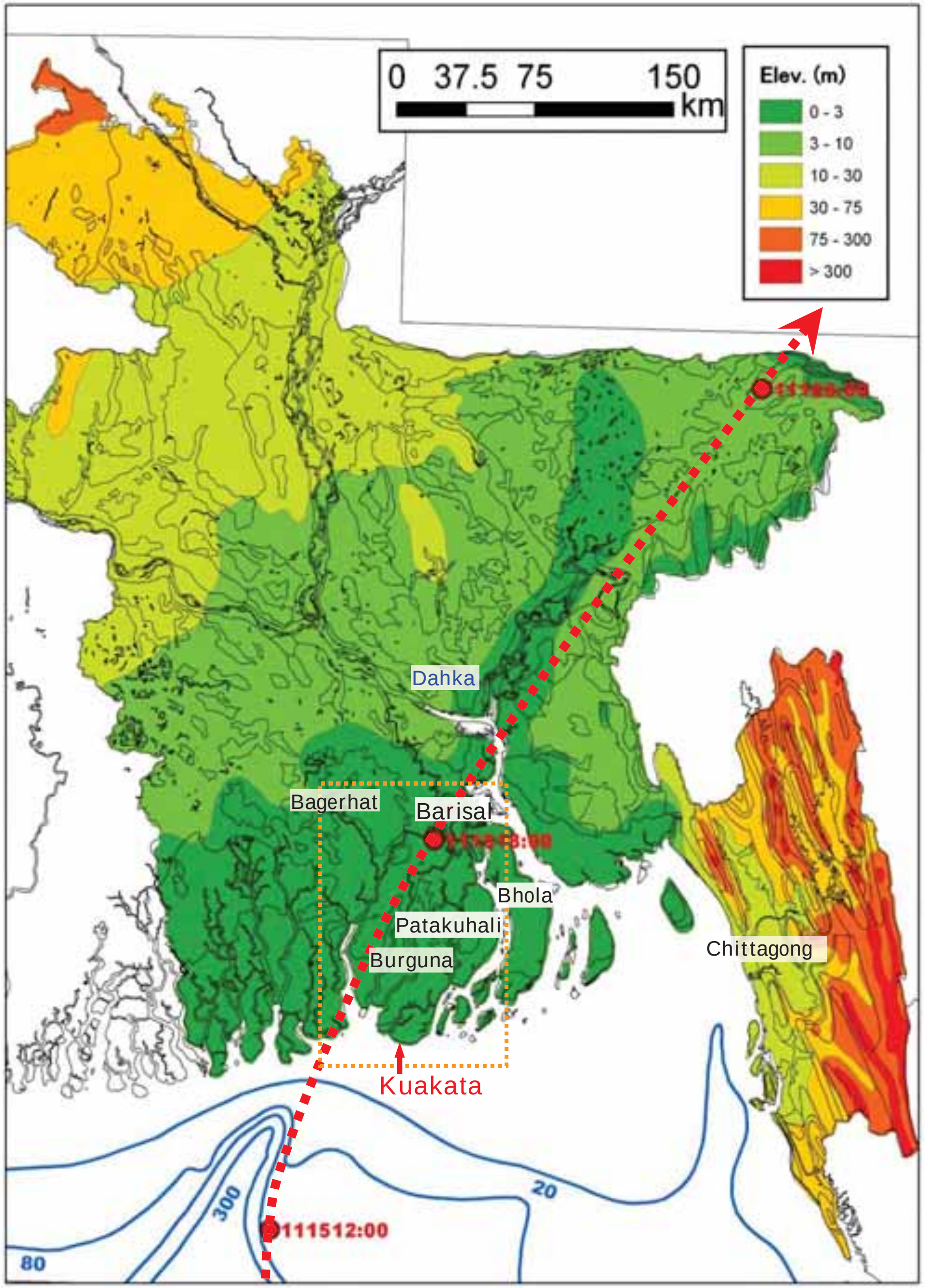
Movement

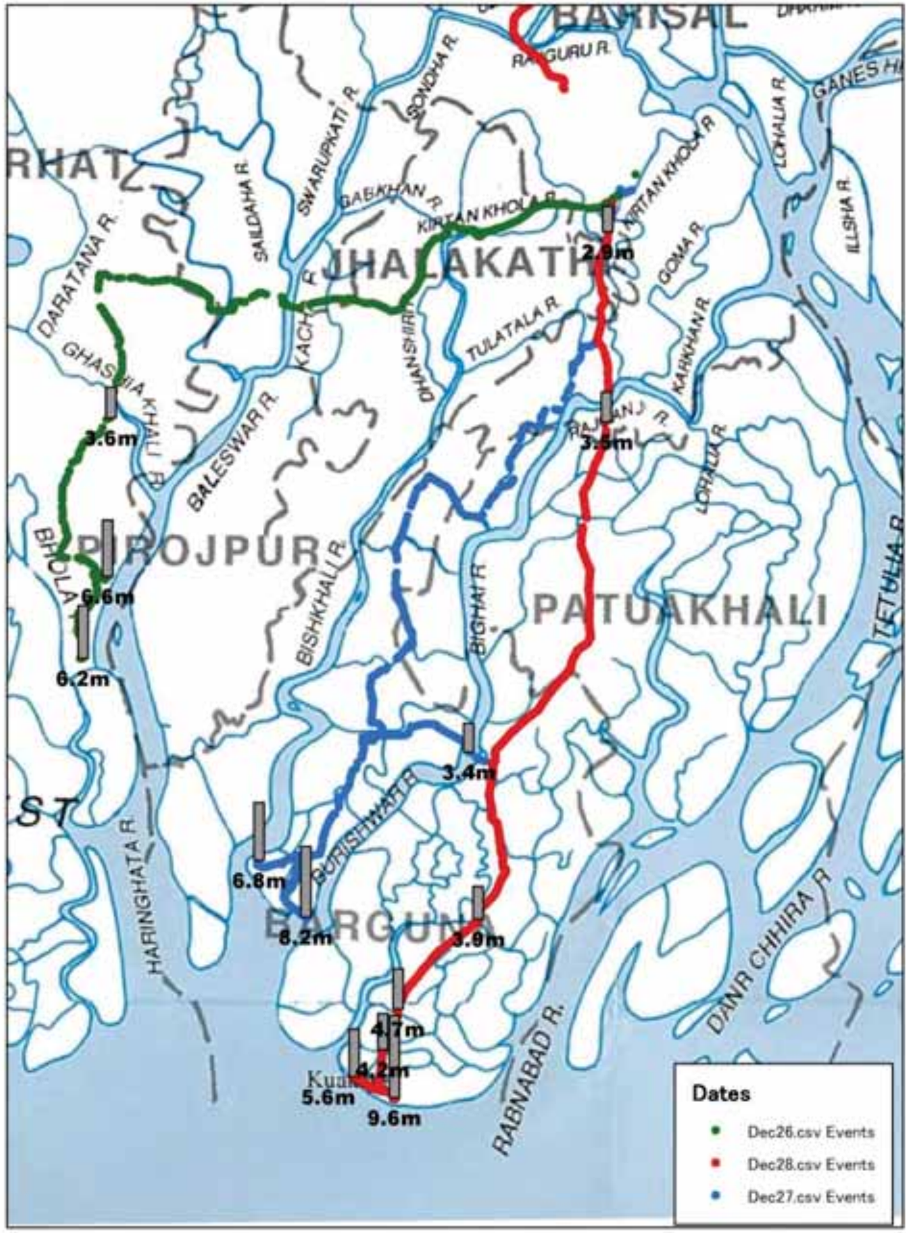
All residents moved to a new area in inland.

Field Survey of Storm Surge Disaster due to Cyclone Sydr in Bangladesh

Tomoya Shibayama, Yoshimitsu Tajima, Taro Kakinuma, Hisamichi Nobuoka, Tomohiro Yasuda
Raquib Ahsan, Mizanur Rahman, M. Shariful Islam





Topography of Bangladesh and Route of Sidr