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Earthquake and tsunami scenarios constructed based on mechanical modeling: The Nankai Trough, southwestern Japan

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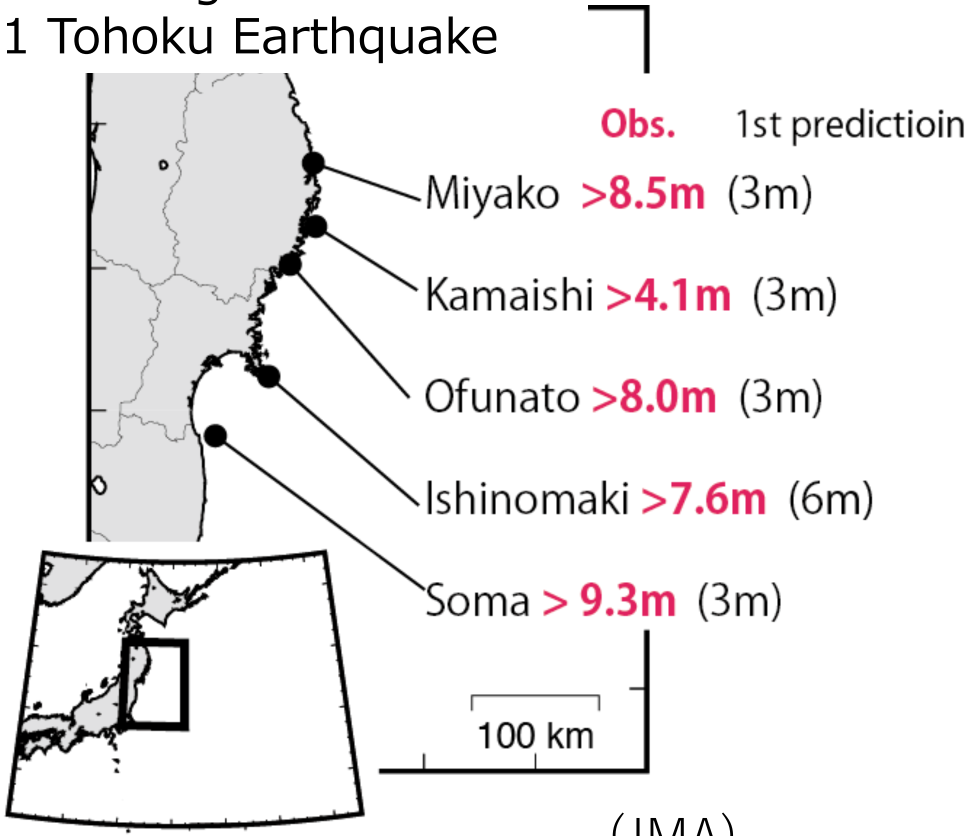
Outline

1. Background and issues
2. Objectives
2. How to make rupture scenarios (energy conservation laws)
3. How to create the synthetics of observable records (elastic-fluid dynamics)
4. Summary

Background and Issues

At the 2011 Tohoku tsunami, we underestimated coastal tsunami height.

Tsunami heights at the
2011 Tohoku Earthquake



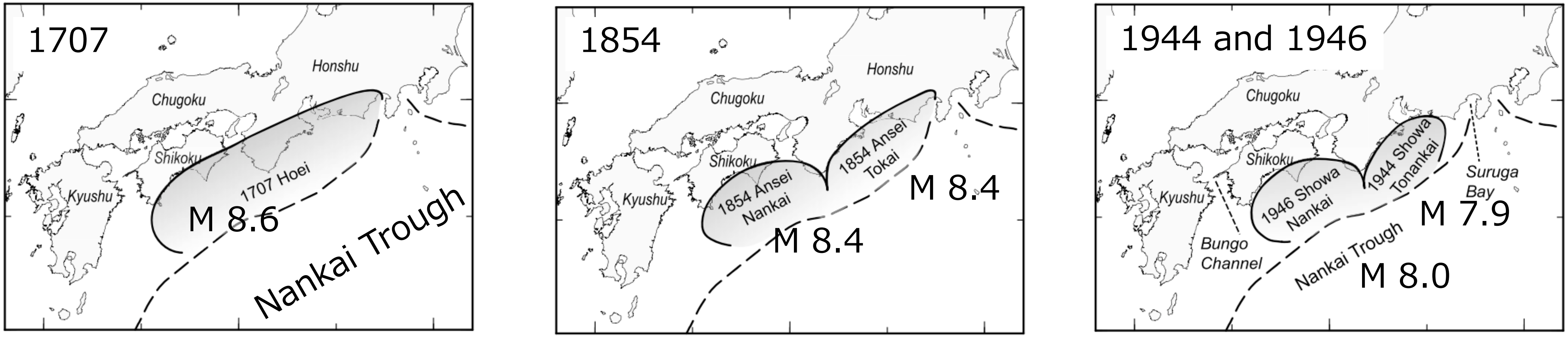
(JMA)

We **did not suppose M9 earthquakes** in this region before 2011.

We overestimated our tsunami monitoring ability for M9 earthquakes.

It is important to create various earthquake scenarios and to correctly evaluate our monitoring ability using synthetics of scenarios.

Our target: The Nankai Trough, huge earthquakes repeatedly occurred



Furumura et al. 2011 JGR

Objectives

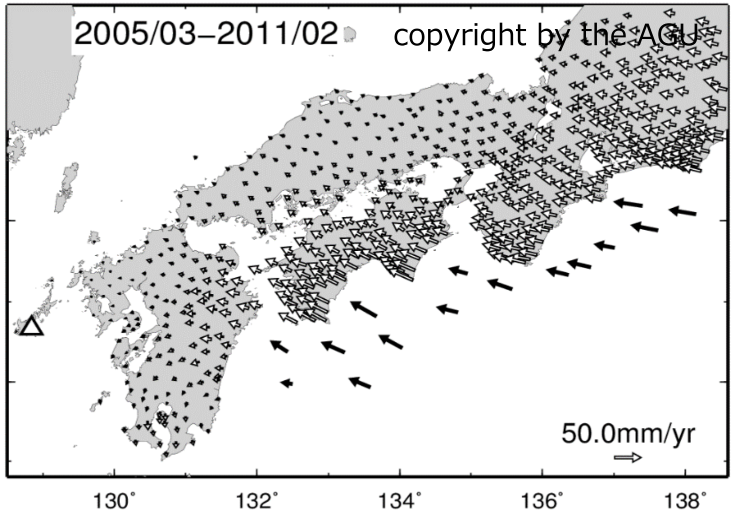
- Construct various rupture scenarios using slip deficits and an energy conservation law
- Create synthetics of observable tsunami records using elastic-fluid dynamic wave propagation simulation

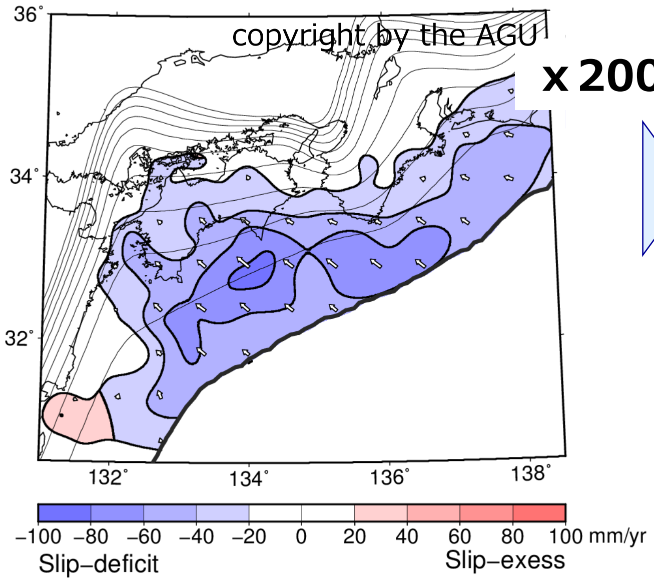
Stress accumulation along the Nankai Trough

Displacement rate data (GNSS・GPS-Acoustic)

Slip deficit-rate distribution

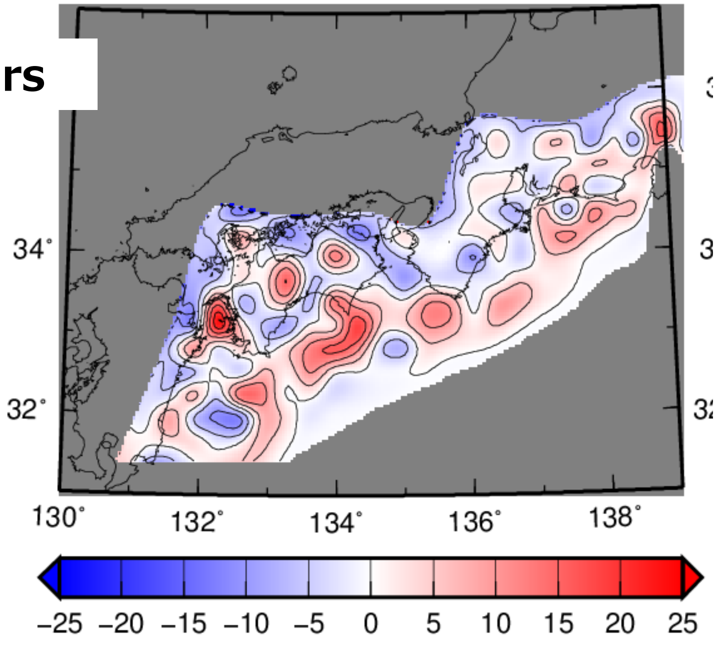
Shear stress distribution





Noda et al. (2018 JGR)

x 200 years



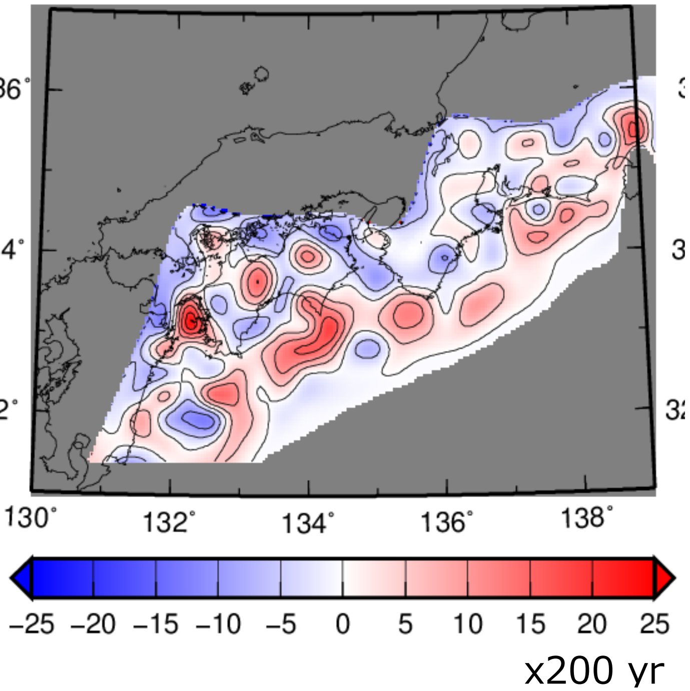
Shear stress (kPa)

We estimated the shear stress accumulation based on the slip deficit-rate distribution assuming the time interval of 200 years.

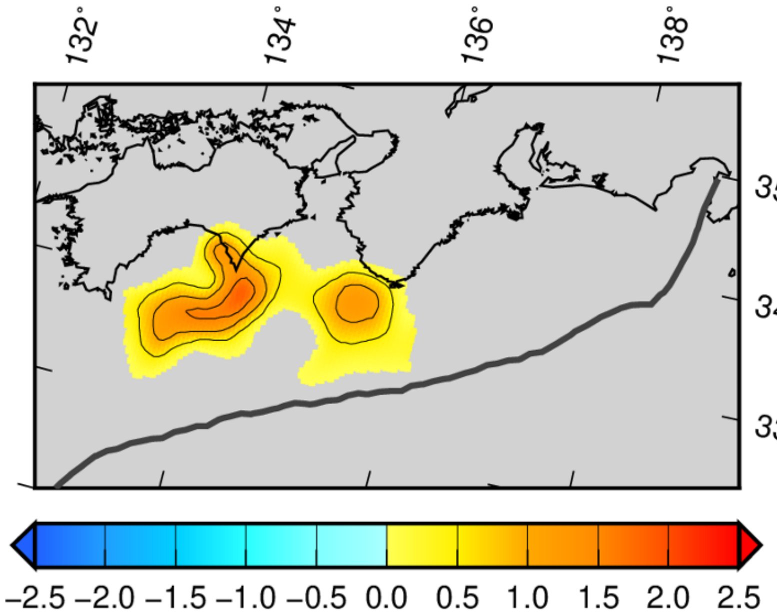
1854 Ansei Nankai earthquakes (M 8.4 and 8.4) occurred.

A method for creating a rupture scenario

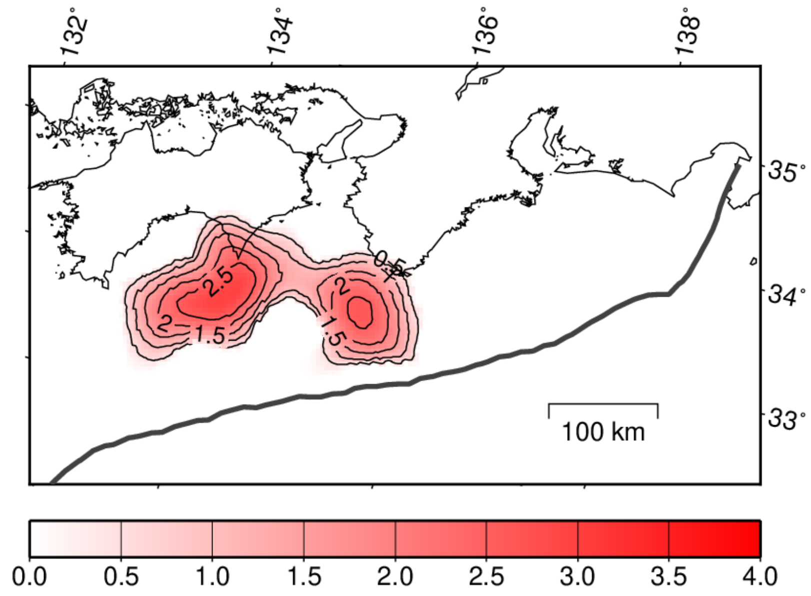
Shear stress accumulation → **Set rupture areas** → **Slip distribution estimated from shear stress release**



Shear stress [kPa]



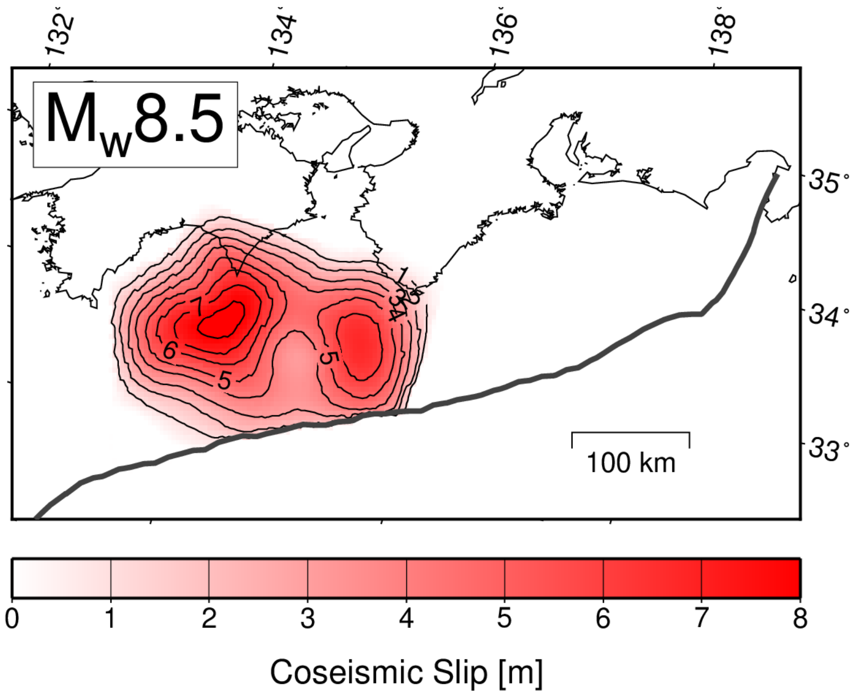
Coseismic stress drop [MPa]



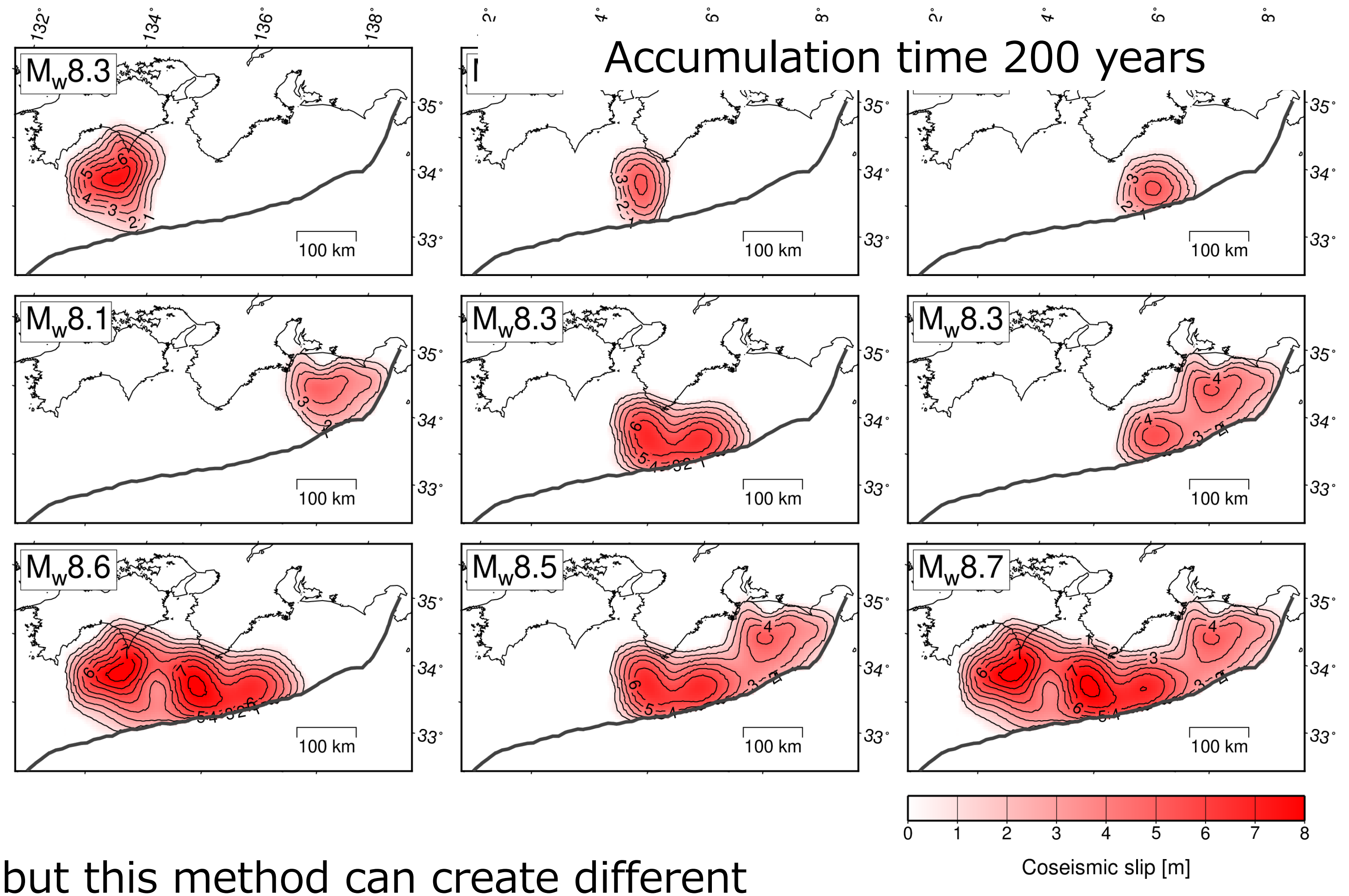
Coseismic slip [m]

Rupture scenarios

Rupture senarios based on earthquake mechanics and GNSS observations



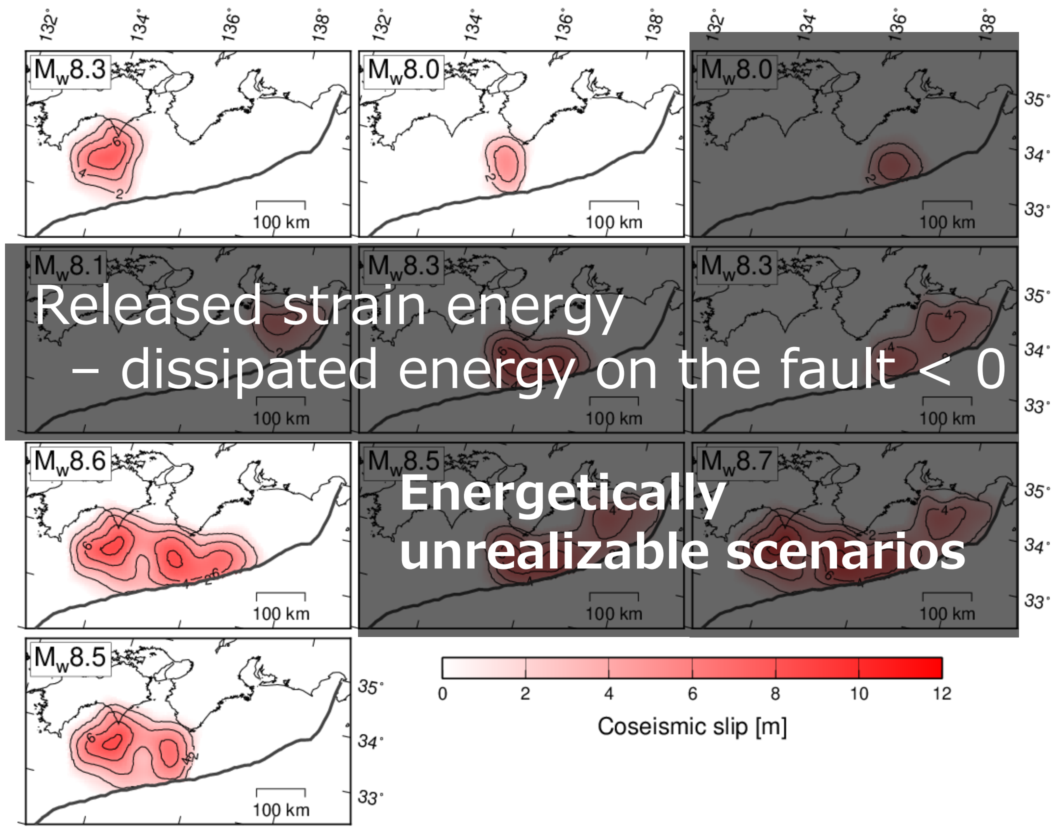
Accumulation time 200 years



Historical-earthquake data are limited but this method can create different scenarios reasonaly based on earthquake mechanics using GNSS records.

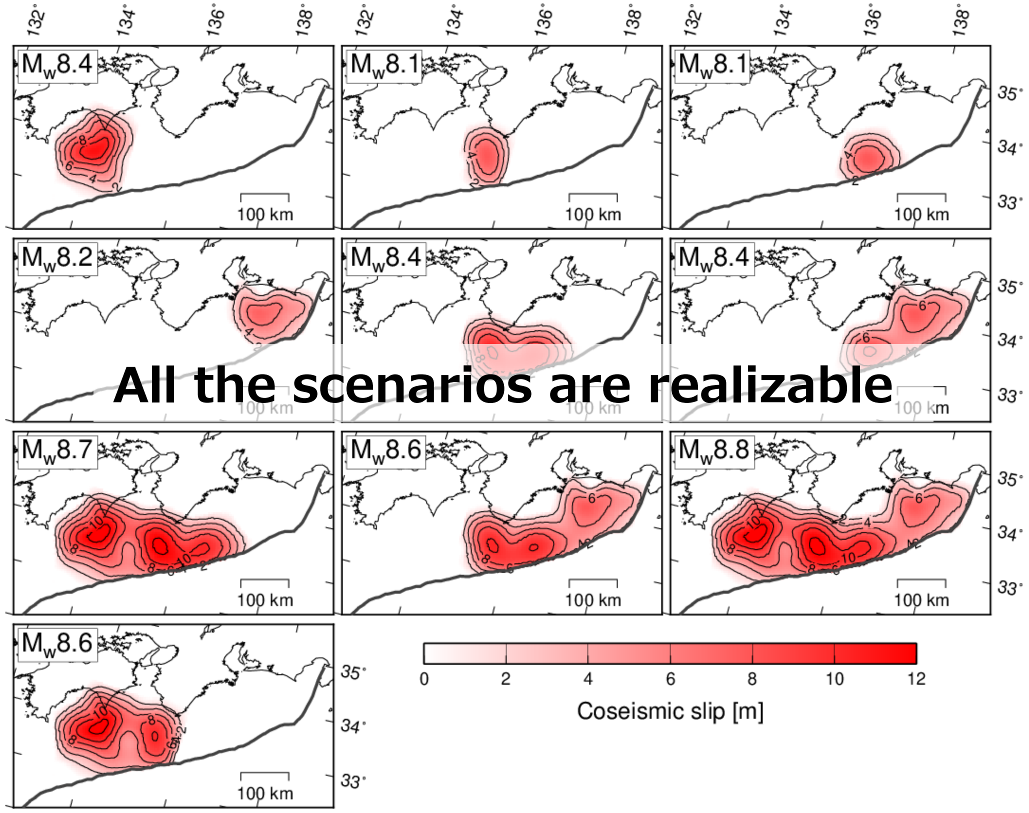
Possibility of each rupture scenario

Accumulation time: 200 years



Even though there is slip deficit, multi-segment ruptures are not realizable because strain energy is too small.

Accumulation time: 300 years



When the strain energy is stored enough, multi-segment ruptures can occur.

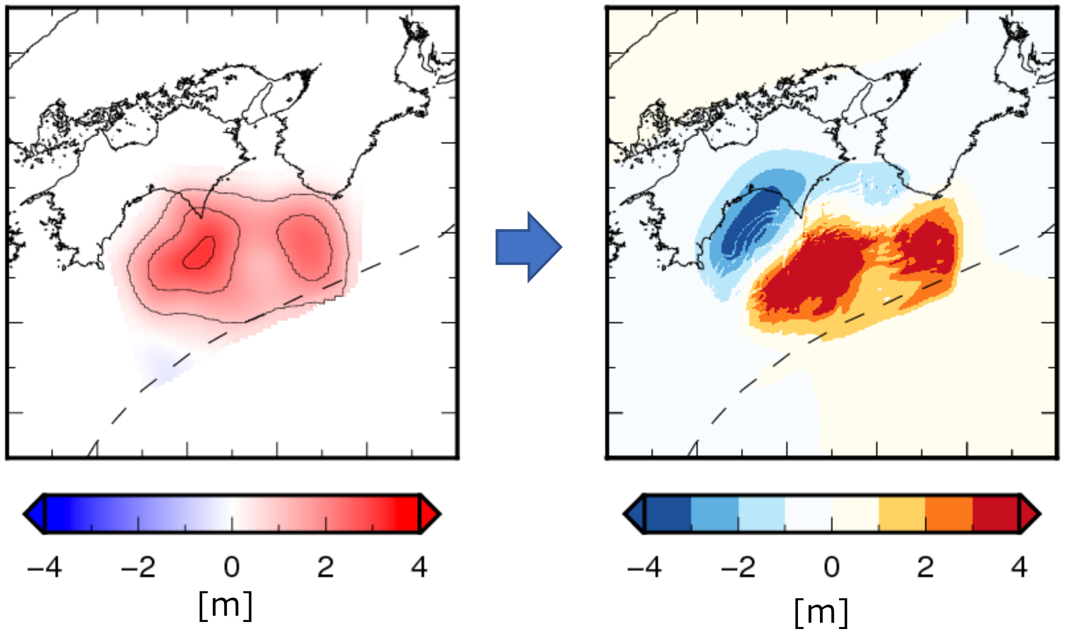
Noda et al. (EGU2020-12581)

Tsunami simulations: Generation

Numerically calculate the vertical displacement by the finite difference simulation.

Slip distribution

Vertical displacement at the sea surface $u_z(x, y, z_{sur}, t = \infty)$



Equations of seismic waves

$$\rho \frac{\partial v_i(\mathbf{x}, t)}{\partial t} = \tau_{ij,j}$$

$$\frac{\partial \tau_{ij}}{\partial t} = \lambda \delta_{ij} v_{k,k} + 2\mu\left(v_{i,j} + v_{j,i}\right)$$

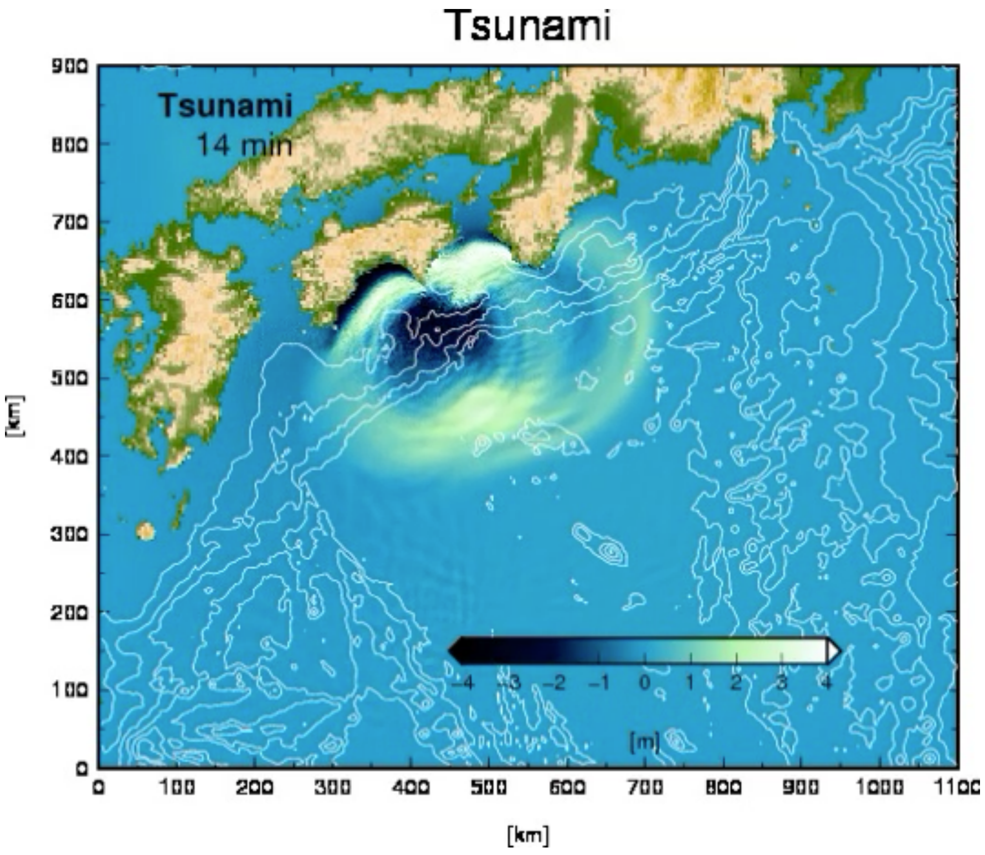
Finite Difference Simulation
dx = 0.5 km, dz = 0.25 km,
dt = 0.01 s

The permanent vertical displacements $u_z(x, y, z_{sur}, t = \infty)$ at the sea surface work as an initial tsunami height distribution

$$\eta_0(x, y) = u_z(x, y, z_{sur}, t = \infty)$$

Tsunami simulations: Propagation

Initial height distribution -> Tsunami propagation



Time-dependent initial tsunami height distribution

$$\Delta\eta_0(x, y, t) = \Delta u_z(x, y, z_{sur}, t)$$

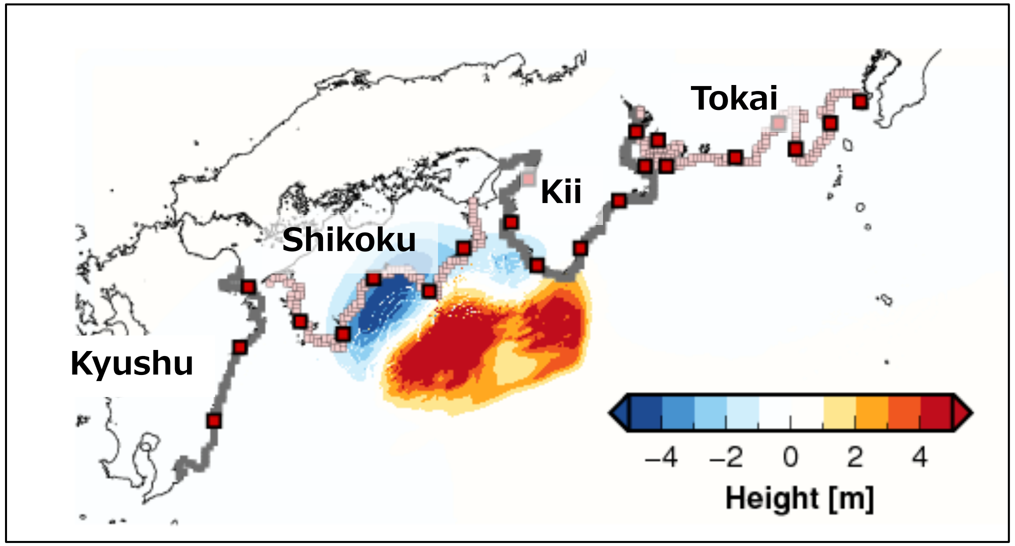
2-D dispersive tsunami propagation equations

$$\frac{\partial v_i^{\text{av}}(x, y, t)}{\partial t} + g_0 \frac{\partial \eta}{\partial x_i} = \frac{h}{3} \frac{\partial}{\partial t} \frac{\partial}{\partial x_i} \left(\frac{\partial}{\partial x_k} (h v_k^{\text{av}}) \right)$$

$$\frac{\partial \eta(x, y, t)}{\partial t} + \frac{\partial}{\partial x_k} [h v_k^{\text{av}}(x, y, t)] = 0$$

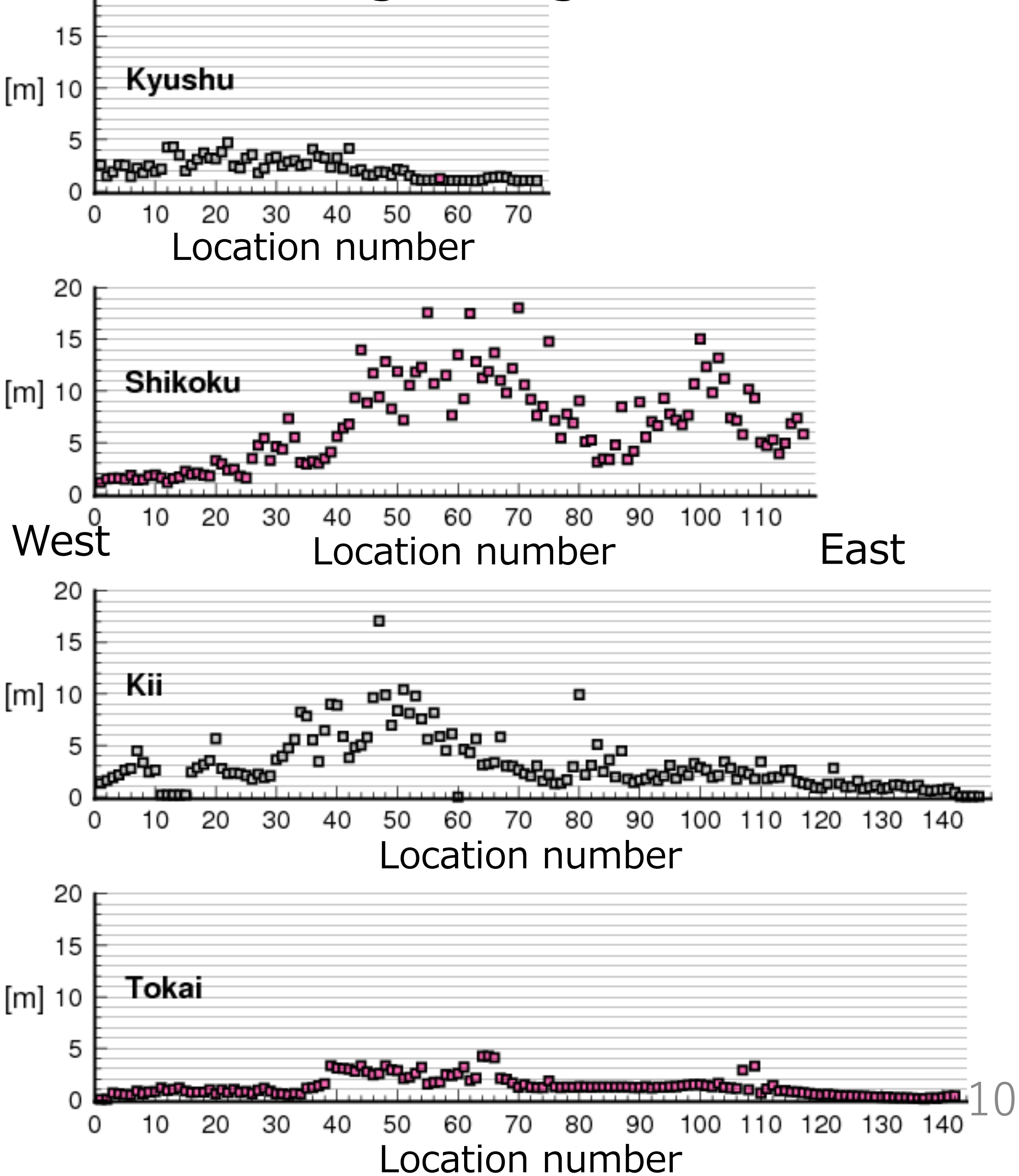
Finite Difference Simulation
$\Delta x = 500$ m, $\Delta t = 1.0$s

Tsunami simulations



This result is preliminary.
High-resolution simulations (50 m) are planned.

Tsunami height along coasts



Synthetics of ocean-bottom pressure change

1st step: Seismic-wave simulation
Input: **kinematic rupture model**
output: At the sea bottom: velocity v_z^{bot},
displacement u_z^{bot}, and pressure σ_{zz}^{bot}
At the sea surface: velocity v_z^{sur}

2nd step: Tsunami simulation
Input: velocity v_z^{sur} at the sea surface
output: tsunami height η

Calculation of the sea bottom pressure change

$p_e = p_{static} + p_{dynamic}$

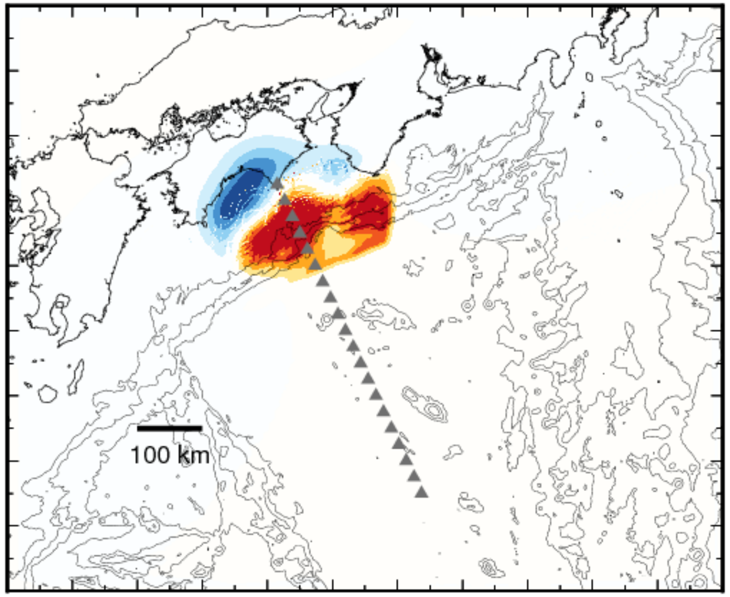
$\sim \rho_0 g_0(\eta - u_z^{bot}) + \sigma_{zz}^{bot}$

Static pressure change originates from **gravity**

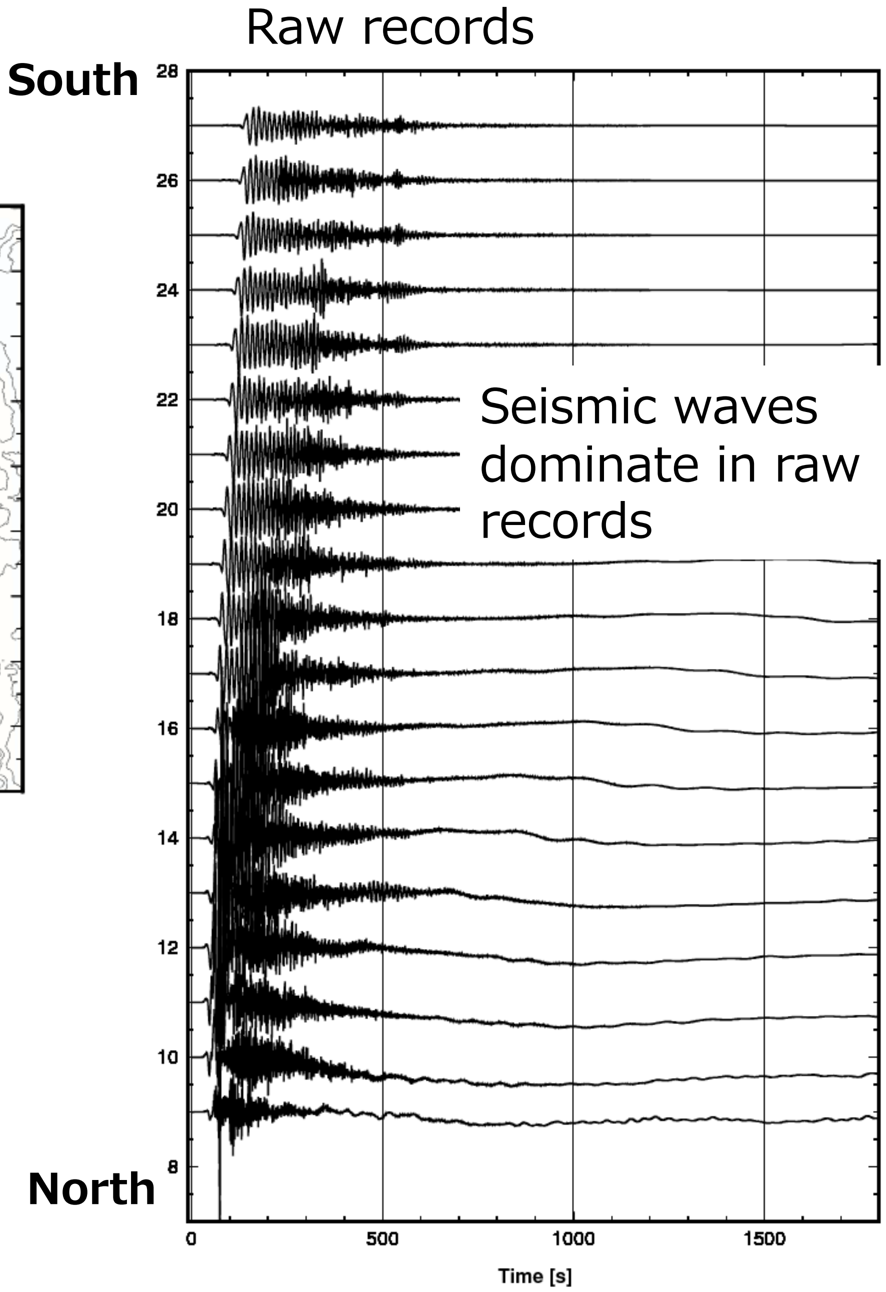
Dynamic pressure change is **independent of gravity**

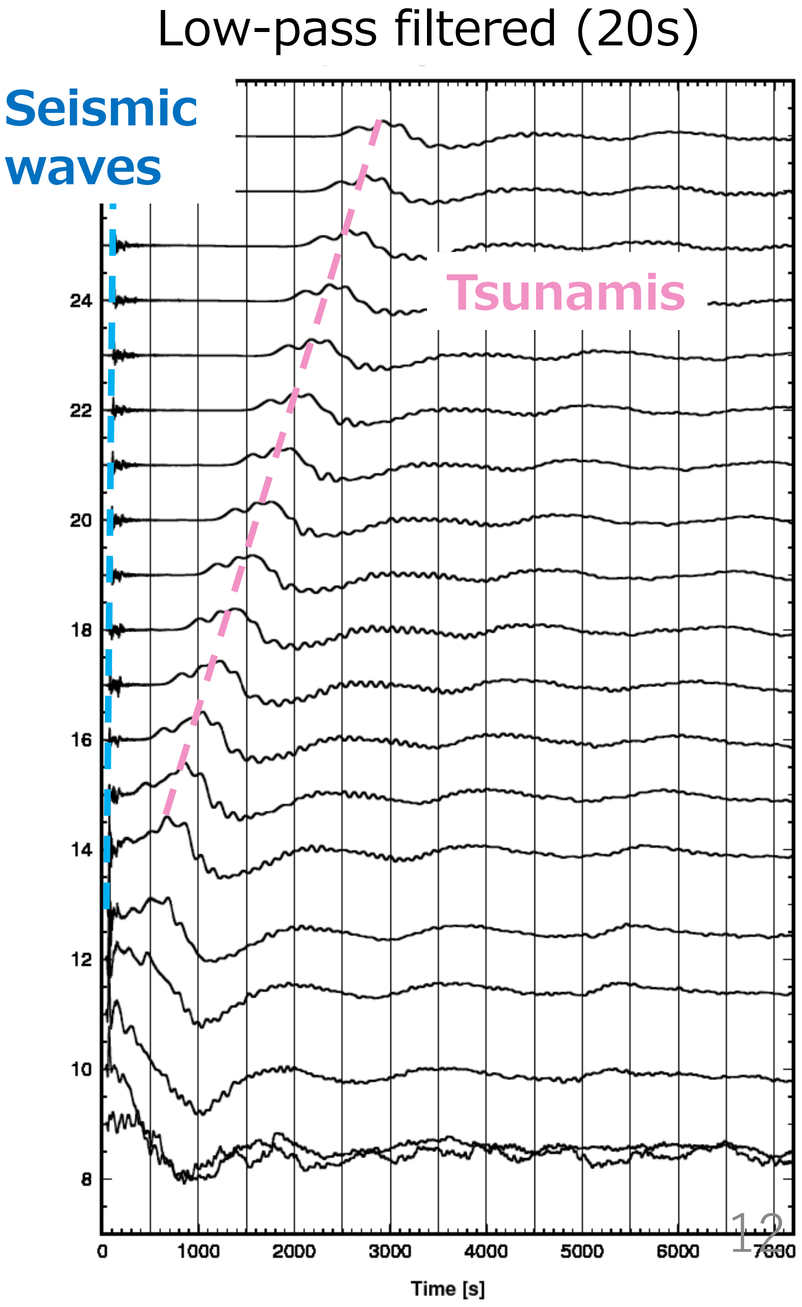
e.g. Saito (2019 Tsunami Generation and Propagation, Springer), Saito and Kubota (2020 Annual. Rev. Earth. Planet.)

Synthetics of ocean-bottom pressure change



Our synthetics include both seismic waves and tsunamis

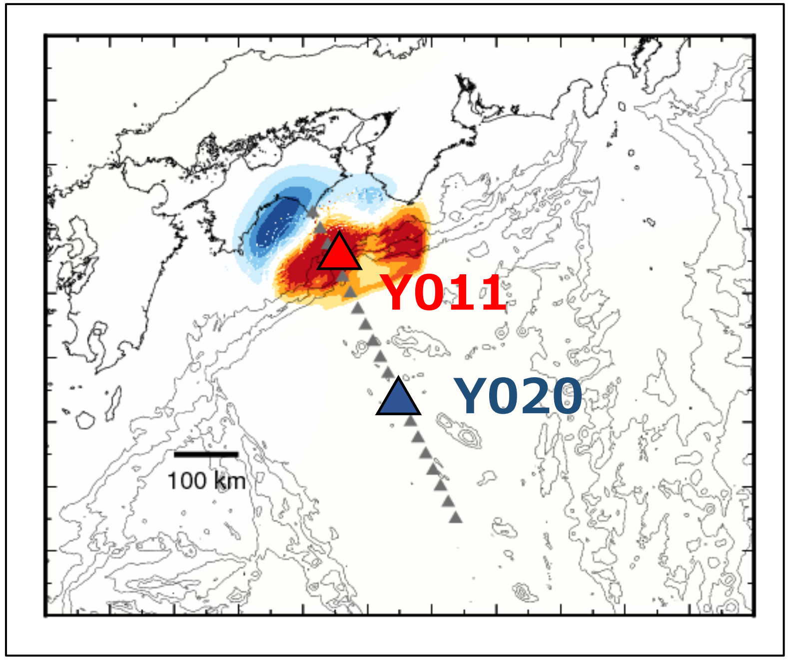


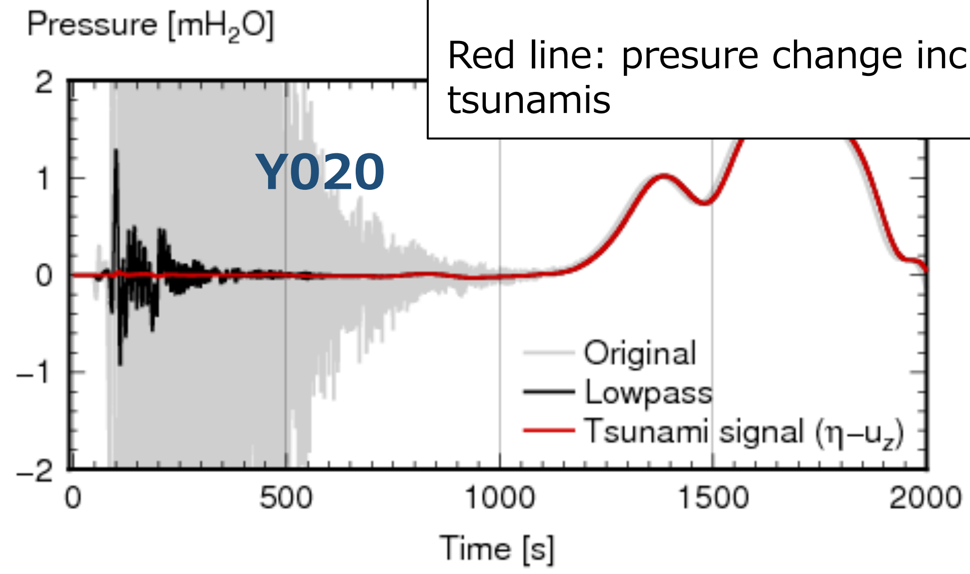


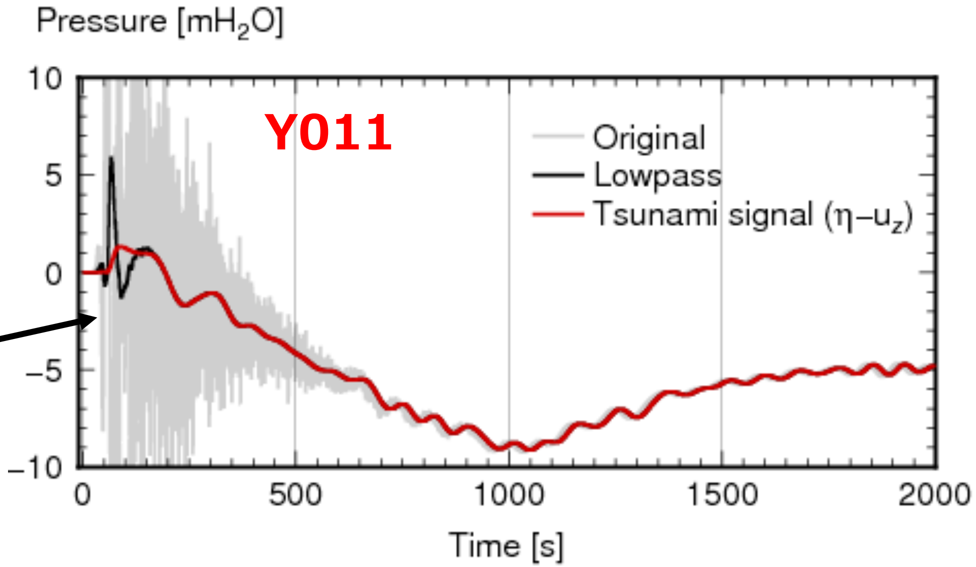
Synthetics of ocean-bottom pressure change

Black line: pressure change including both seismic waves and tsunamis

Red line: presure change including only tsunamis







When a station is inside the focal area, seismic waves overlap tsunami signals (elapsed time < ~200s).

A lowpass filter cannot completely remove the seismic waves.

Summary

A method for constructing earthquake-tsunami scenarios based on mechanics of multi-segment ruptures and elastic-fluid dynamics of wave propagation

We made rupture scenarios for huge earthquakes in the Nankai Trough, Japan, based on the observed shear-stress accumulation rate on the plate boundary.

Based on an energetic consideration, we evaluated the possibility of the multi-segment ruptures (the details found in Noda et al. EGU2020-12581). If the accumulation time is longer, multi-segment ruptures can occur.

We evaluated the tsunami height along the coasts for rupture scenarios and also simulated observable records (pressure change) including both seismic waves and tsunamis.

Basically, a low-pass filter could not completely remove the seismic waves in the records of pressure gauge sensors. The seismic waves can be noise for tsunami signals.

In order to evaluate our tsunami monitoring ability, the synthetics created in this study are useful.