Long-period ground motion simulation of great Nankai Trough, Japan, earthquakes

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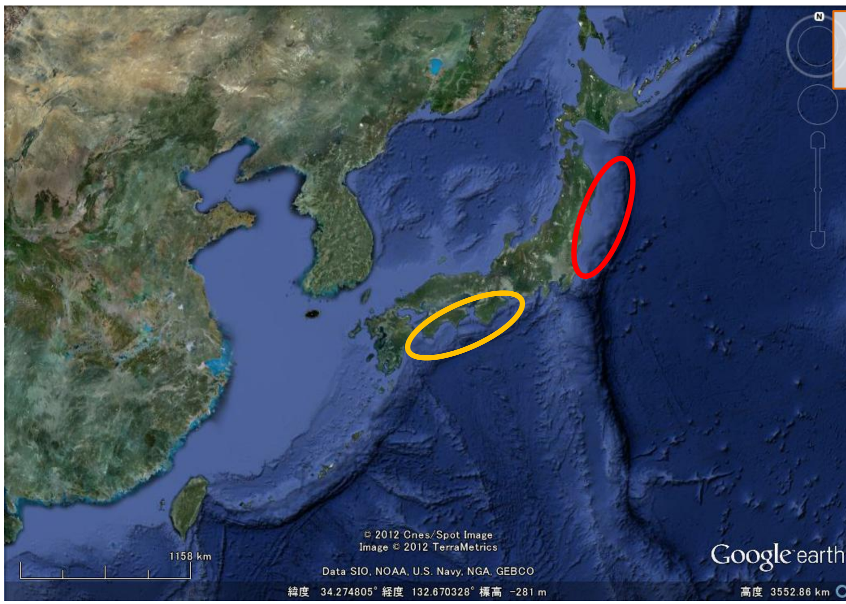
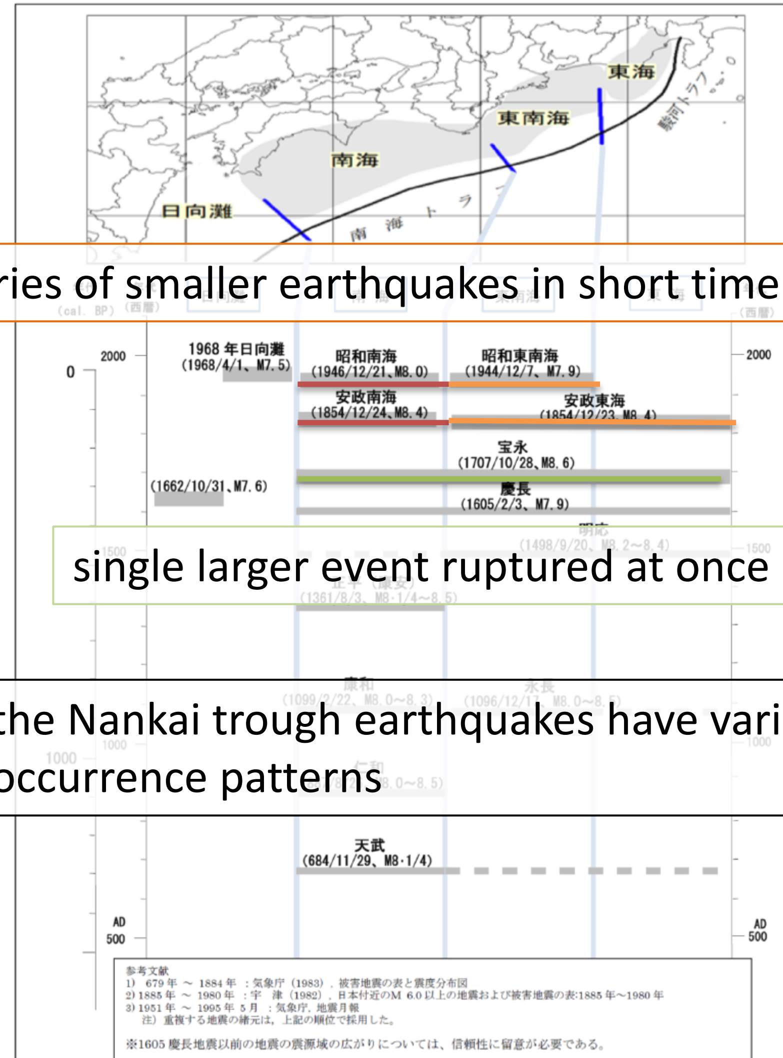
(NIED)

The Nankai trough earthquakes





series of smaller earthquakes in short time period

single larger event ruptured at once

the Nankai trough earthquakes have various occurrence patterns

Central Disaster Prevention Council (2011)

Long period ground motion

- The long-period ground motions cause damage to high-rise and large-scale structures.
  - 1985 Michoacan, Mexico earthquake M8.0
  - 2003 Tokachi-oki, Japan earthquake (Mw8.3)
  - 2011 Tohoku, Japan earthquake (Mw9.0)

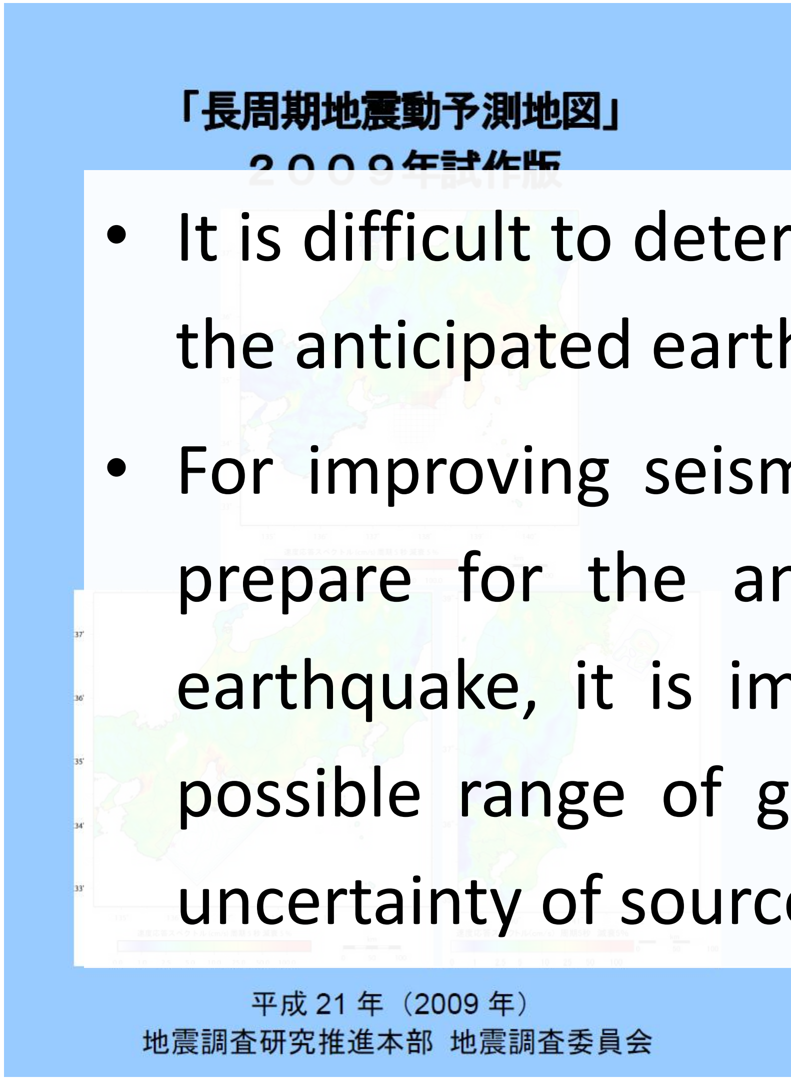
(USGS)

(Sapporo Fire Bureau)

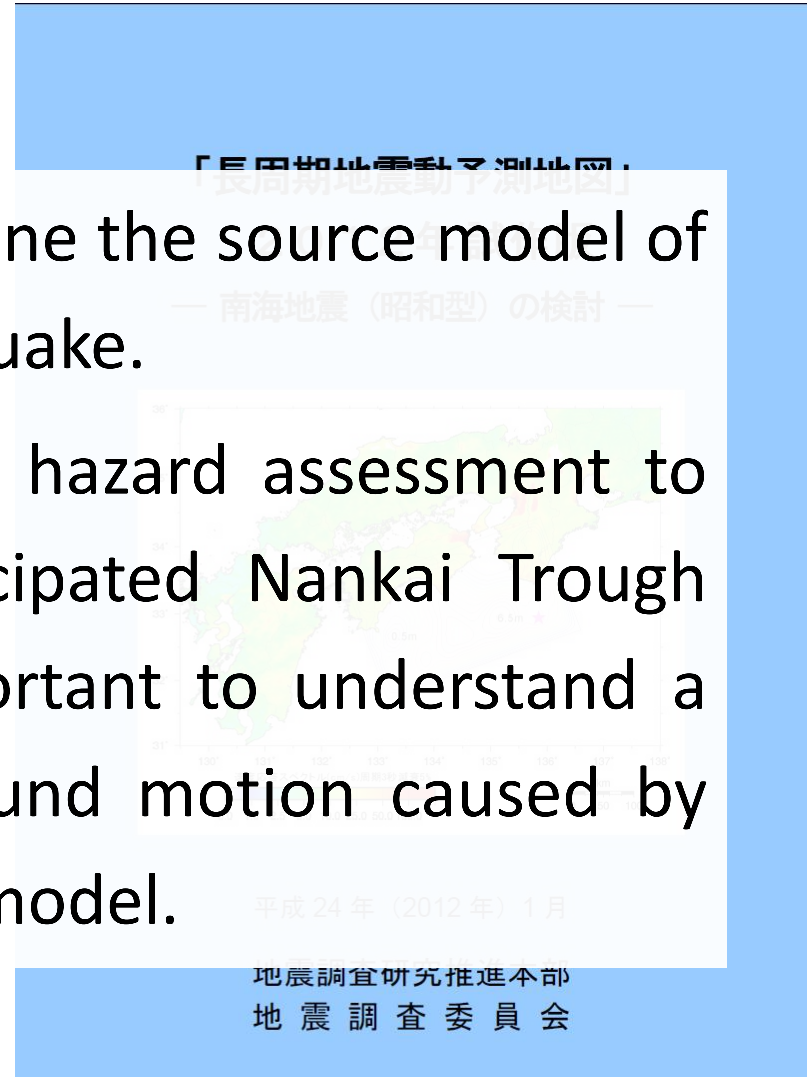
(youtube)

Long-Period Ground Motion Hazard Maps

- It is difficult to determine the source model of the anticipated earthquake.
- For improving seismic hazard assessment to prepare for the anticipated Nankai Trough earthquake, it is important to understand a possible range of ground motion caused by uncertainty of source model.



Earthquake Research Committee (2009)



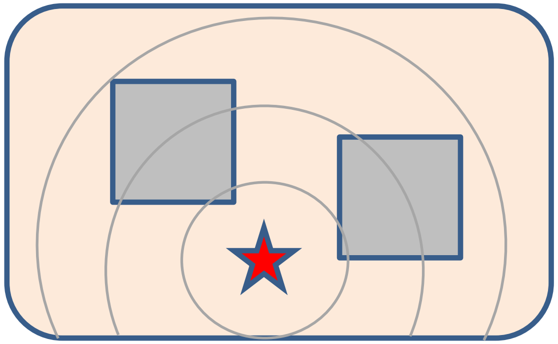
Earthquake Research Committee (2012)

Objective

- Simulate long-period ground motions for anticipated Nankai Trough earthquake (M8-9) using various source models and analyze a variability of predicted long-period ground motions.
- For selecting source models,
  - Assuming various source parameters: rupture area, asperity (area of large slip) location, and hypocenter.
  - Assuming the large slip near the trough following the lesson from the 2011 Tohoku earthquake.
- The long-period ground motions are simulated by the finite difference method using characterized source model and recently developed three-dimensional velocity structure model.

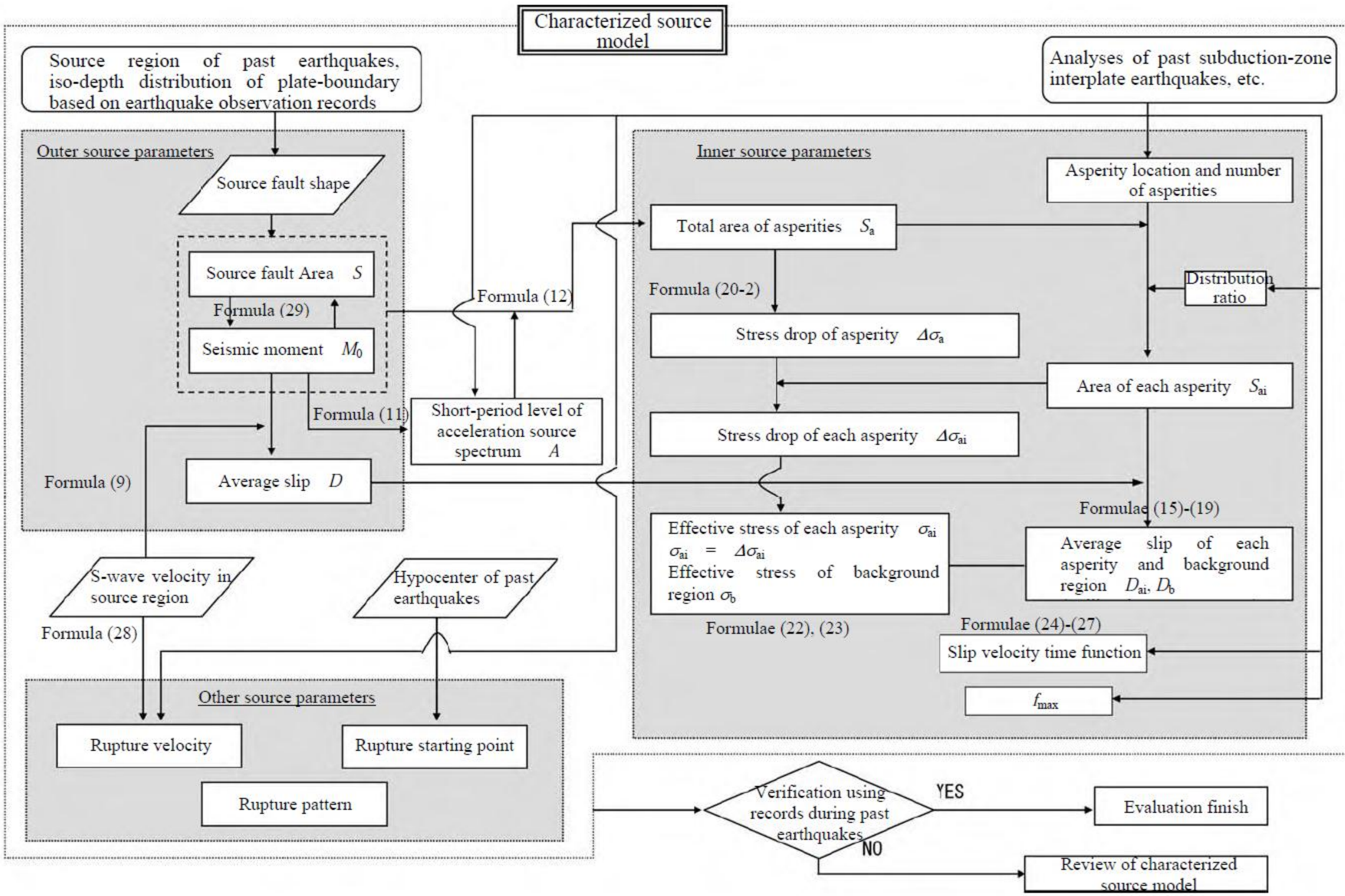
Characterized source model

- The characterized source model is used in the long-period ground motion simulation.
- Three kinds of parameters
  - Outer source parameters
    - Shape and area of the whole fault
  - Inner source parameters
    - Heterogeneity of the source fault
  - Other source parameters
    - Rupture process



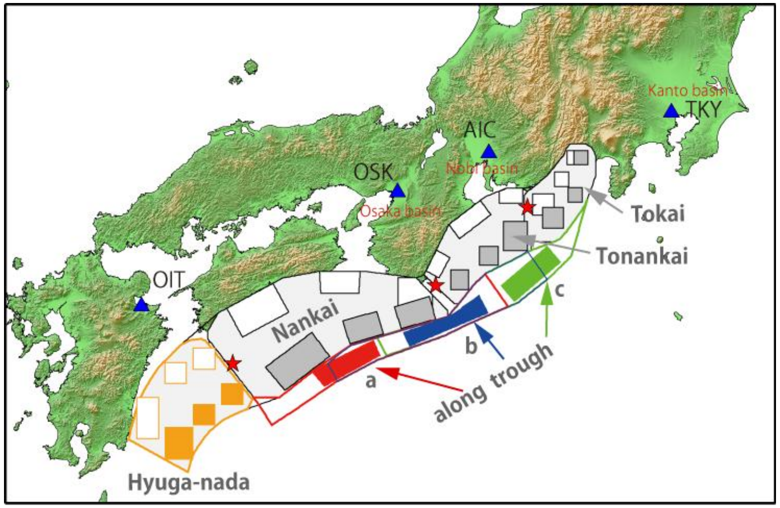
- These parameters are determined based on a ‘recipe’ for predicting strong ground motion (Irikura and Miyake, 2001)

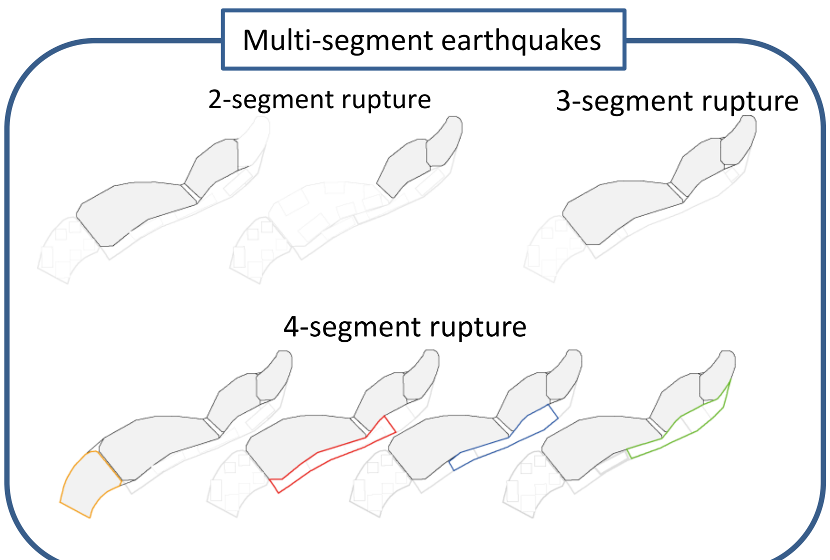
Flowchart of determination of source parameters for subduction-zone interplate earthquakes



Earthquake Research Committee (2009); Fujiwara et al. (2009)

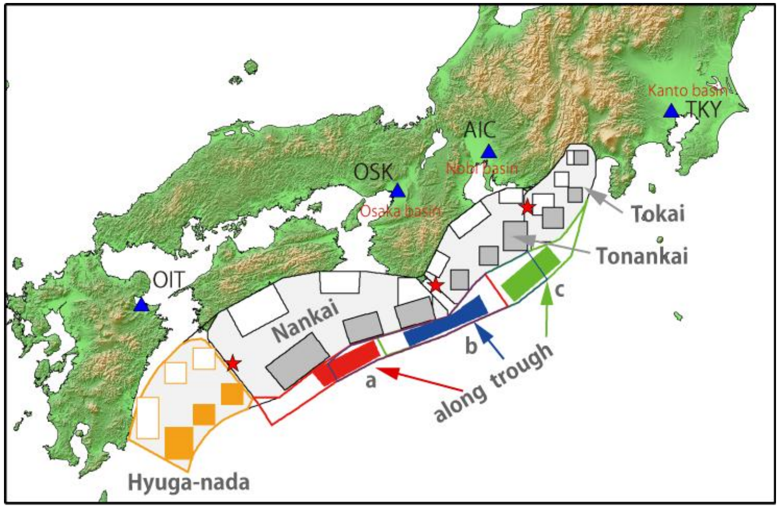
Characterized source model for the Nankai trough earthquakes

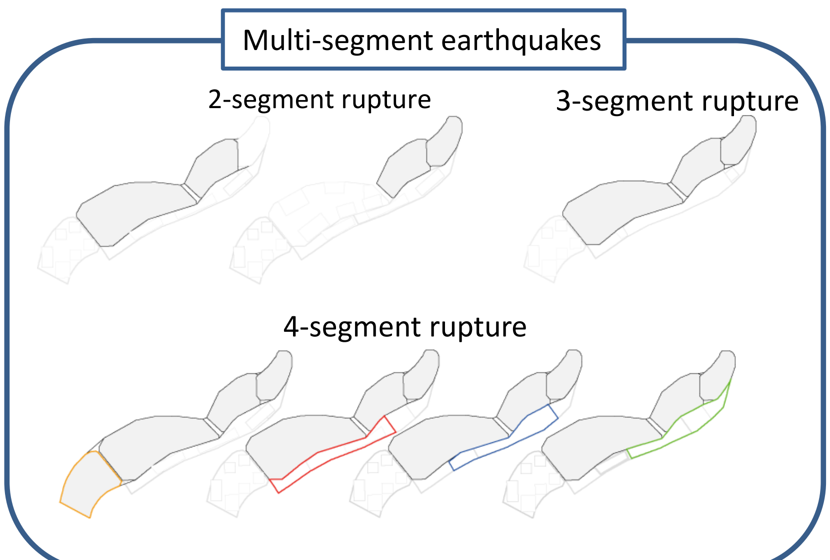




- Source areas (14 cases)
  - Single-segment earthquake
    - Nankai (ANNKI: Mw 8.5), Tonankai (ATNKI: Mw 8.2), Tokai (ATOKI: Mw 8.0), Hyuga-nada (AHGND: Mw 8.3), and along the trough (ATRGH: Mw 8.1)
    - Along the trough area has 3 cases (a, b, c).
  - Multi-segment earthquake (simultaneous rupture of multi segment)
  - 2-segment rupture
    - Nankai + Tonankai (ANNI1: Mw 8.7)
    - Tonankai + Tokai (ANNI2: Mw 8.4)
  - 3-segment rupture
    - Nankai + Tonankai + Tokai (ANNI3: Mw 8.8)
  - 4-segment rupture
    - 3-segment + along the trough (ANNI4: Mw 8.9)
    - 3-segment + Hyuga-nada (ANNI5: Mw 8.9)
  - Seismic moment are calculated using scaling model

Characterized source model for the Nankai trough earthquakes

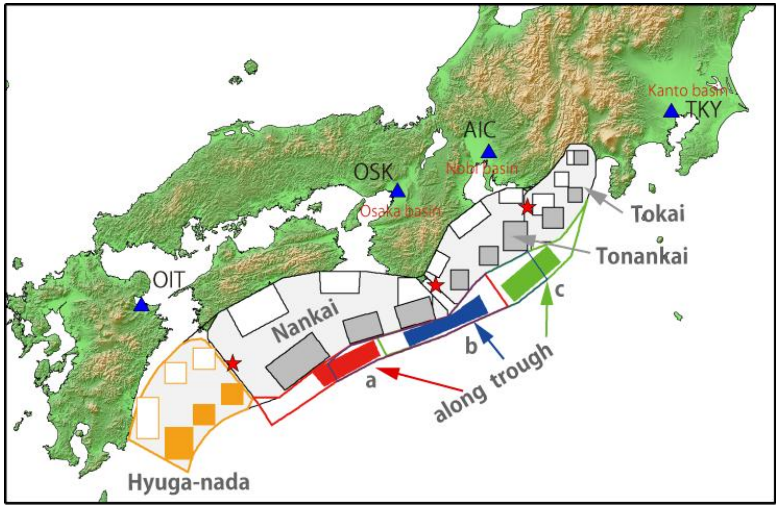




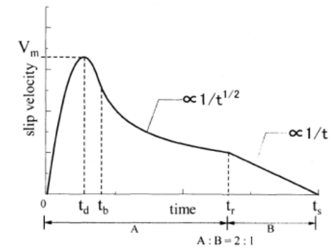
- Hypocenter (3 cases)
  - West: boundary of Hyuda-nada and Nankai
  - Center: boundary of Nankai and Tonankai
  - East: boundary of Tonankai and Tokai
- Asperity (2 cases)
  - Deeper and shallower cases
  - Total area of asperities is 20 % of source fault area (Murotani et al., 2008)
  - The number of asperity is one for along the trough, and three (area ratio is 2:1:1) for Nankai, Tonankai, Tokai and Hyuga-nada.

55 scenarios

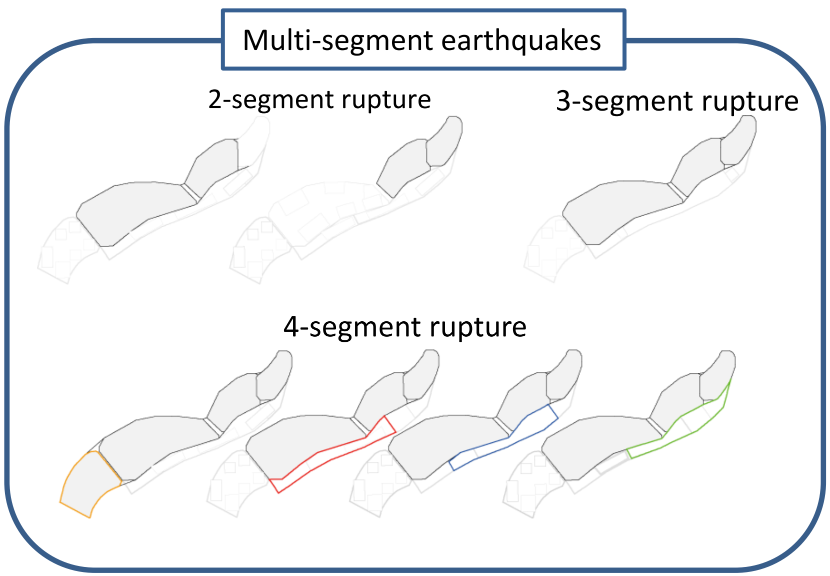
Characterized source model for the Nankai trough earthquakes



- Source time function
  - Kostrov-like slip velocity time function : Nakamura & Miyatake (2000)



- Rupture velocity
  - 2.7 km/ s

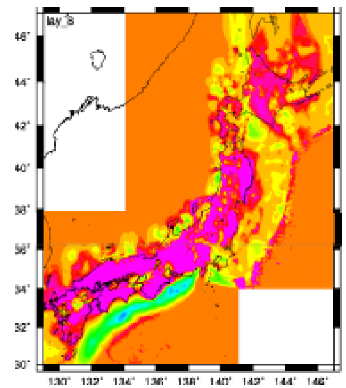


Velocity structure model

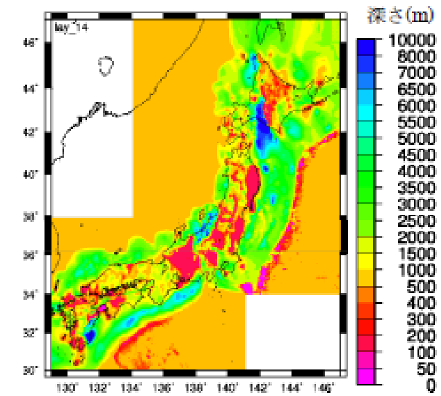
- Japan Integrated Velocity Structure Model

Layer	Vp(km/s)	Vs(km/s)	ρ (g/cm^3)	Qp	Qs
1	1.7	0.35	1.80	119	70
2	1.8	0.5	1.95	170	100
3	2.0	0.6	2.00	204	120
4	2.1	0.7	2.05	238	140
5	2.2	0.8	2.07	272	160
6	2.3	0.9	2.10	306	180
7	2.4	1.0	2.15	340	200
8	2.7	1.3	2.20	442	260
9	3.0	1.5	2.25	510	300
10	3.2	1.7	2.30	578	340
11	3.5	2.0	2.35	680	400
12	4.2	2.4	2.45	680	400
13	5.0	2.9	2.60	680	400
14	5.5	3.2	2.65	680	400
15	5.8	3.4	2.70	680	400
16	6.4	3.8	2.80	680	400
17	7.5	4.5	3.20	850	500
18	5.0	2.9	2.40	340	200
19	6.8	4.0	2.90	510	300
20	8.0	4.7	3.20	850	500
21	5.4	2.8	2.60	340	200
22	6.5	3.5	2.80	510	300
23	8.1	4.6	3.40	850	500

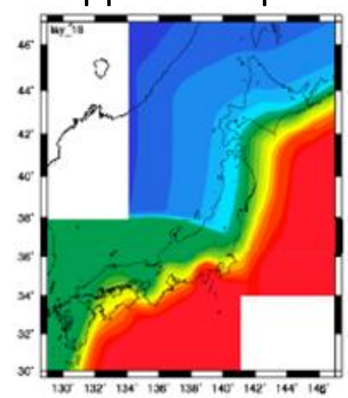
7th layer lower surface
: sedimentary wedge



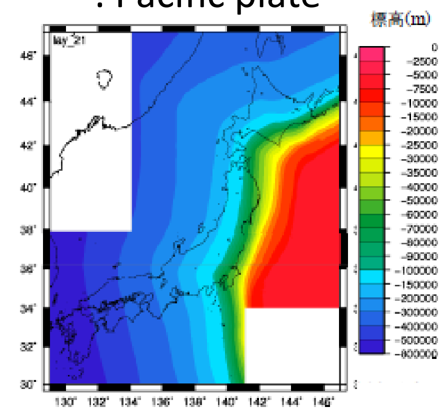
17th layer upper surface
: Moho discontinuity



18th layer upper surface
: Philippine Sea plate



21th layer upper surface
: Pacific plate



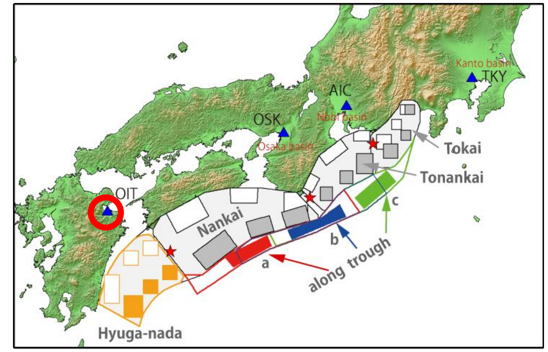
Earthquake Research Committee (2012)

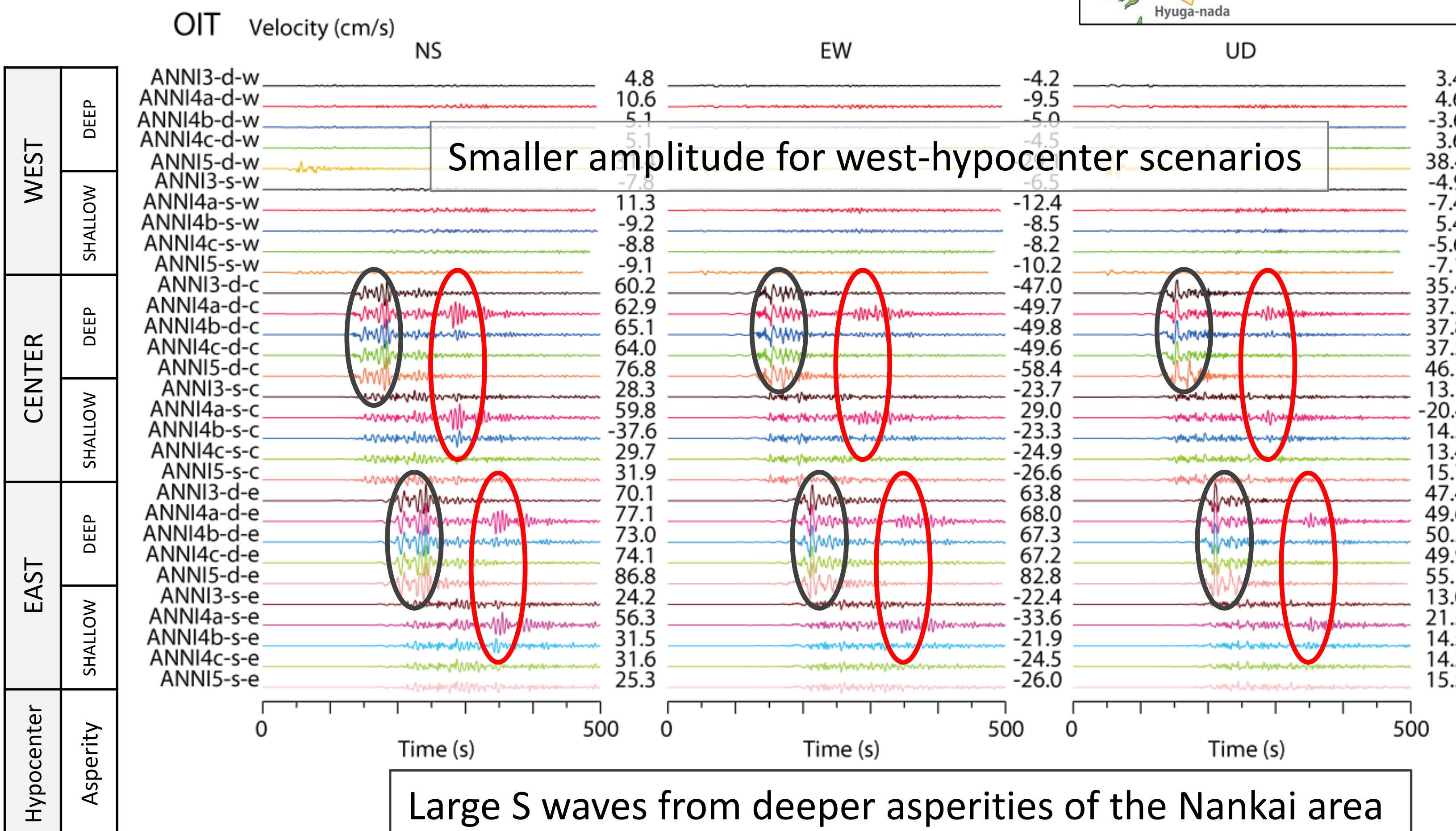
Finite difference method

- 3-D finite difference (FD) simulation with discontinuous grids (Aoi and Fujiwara, 1999)
- Grid spacing
  - 200m in horizontal, 100m in vertical (shallower than 8km)
  - 600m in horizontal, 300m in vertical (8km – 70km)
- Area of the 3-D simulation
  - 1100 km x 700 km x 70 km (The total number of grid points = 2 billion)
- Inelastic attenuation (Graves, 1996) : reference period of 5 sec
- Valid period of the FD simulation : more than about 5 second
  - Since the characterized source model does not include short-wavelength heterogeneity.
- Computation time
  - 36 hours/ 1 scenario
    - 60000 steps (120 Hz)
    - Itanium 1.66GHz × 256Core
    - Memory 130 GB

Velocity waveforms @ OIT

Simultaneous rupture of 3 and 4 segments (30 scenarios)

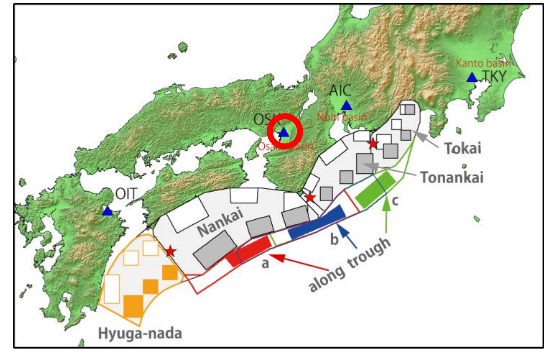


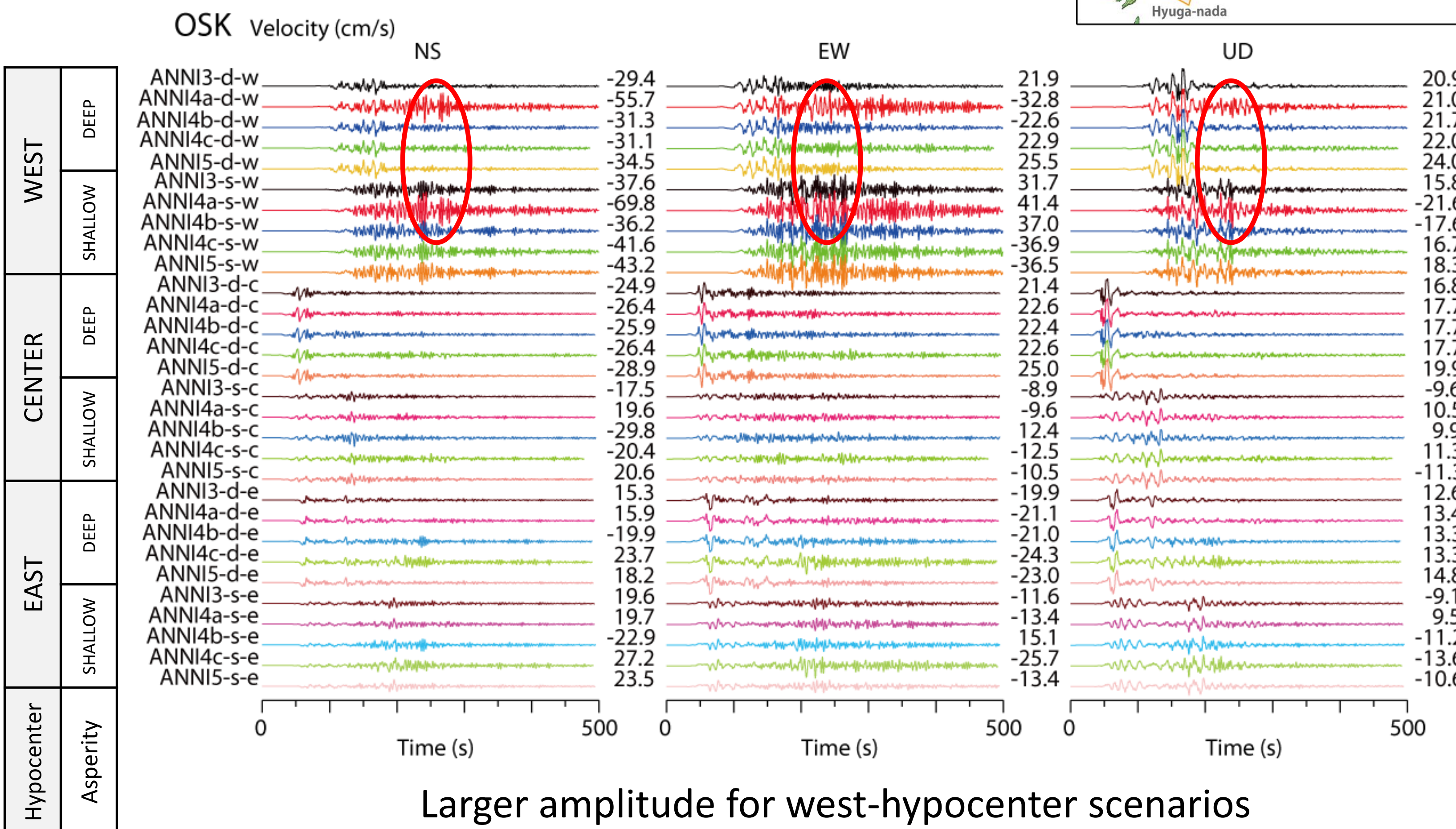


Later phases from the along trough ‘a’ area

Velocity waveforms @ OSK

Simultaneous rupture of 3 and 4 segments (30 scenarios)



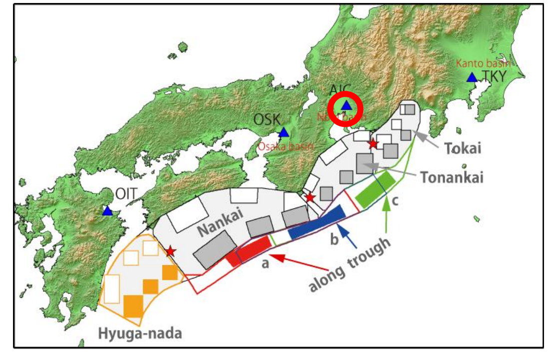


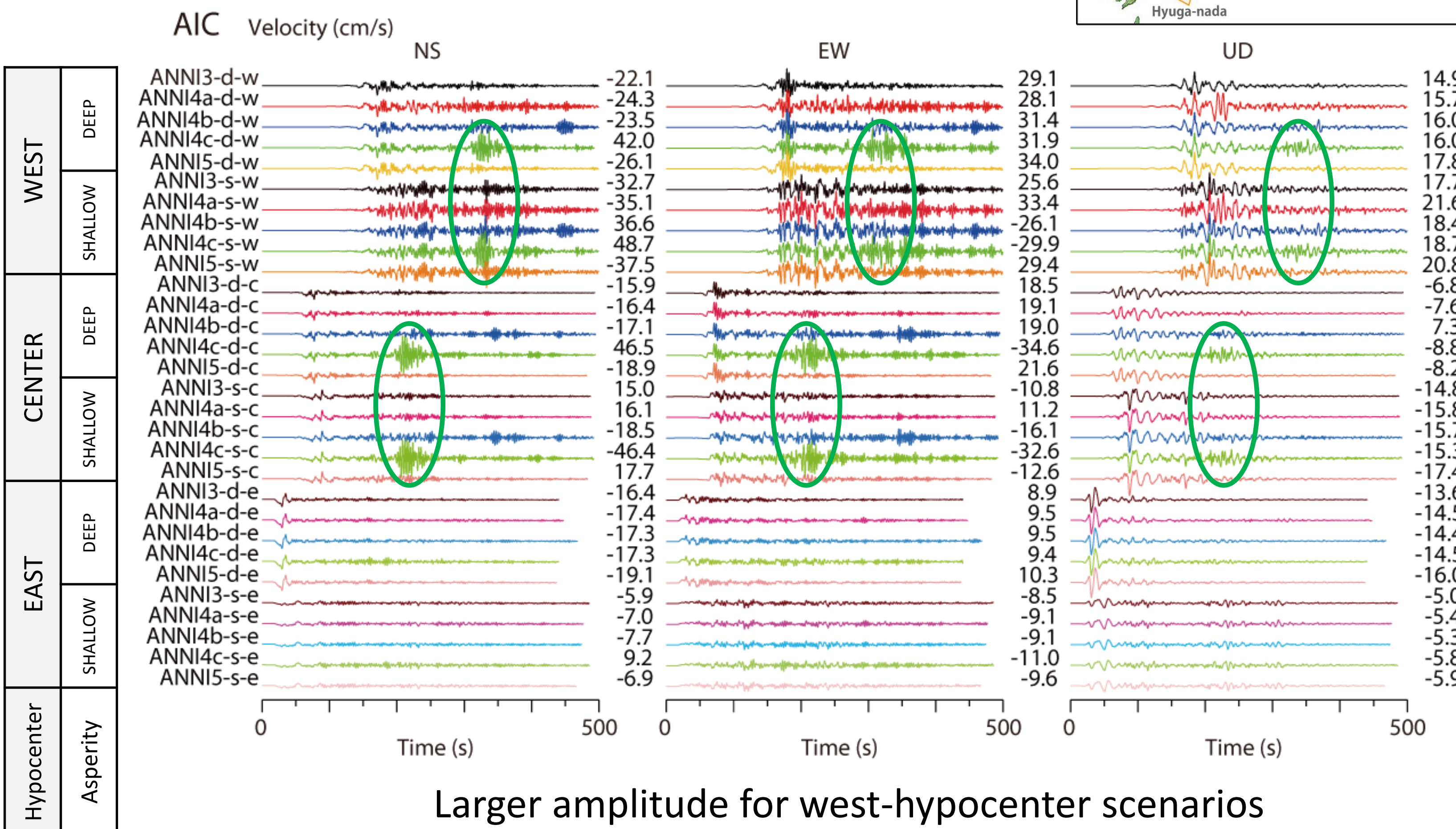
Larger amplitude for west-hypocenter scenarios

Later phases from the along trough 'a' area

Velocity waveforms @ AIC

Simultaneous rupture of 3 and 4 segments (30 scenarios)



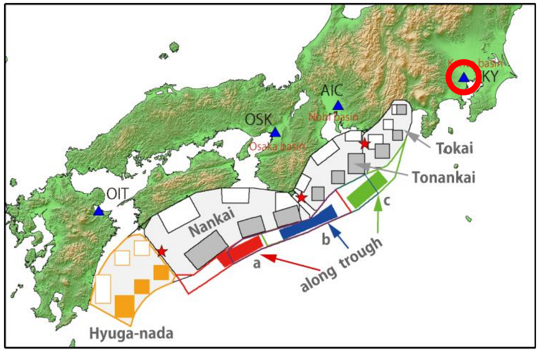


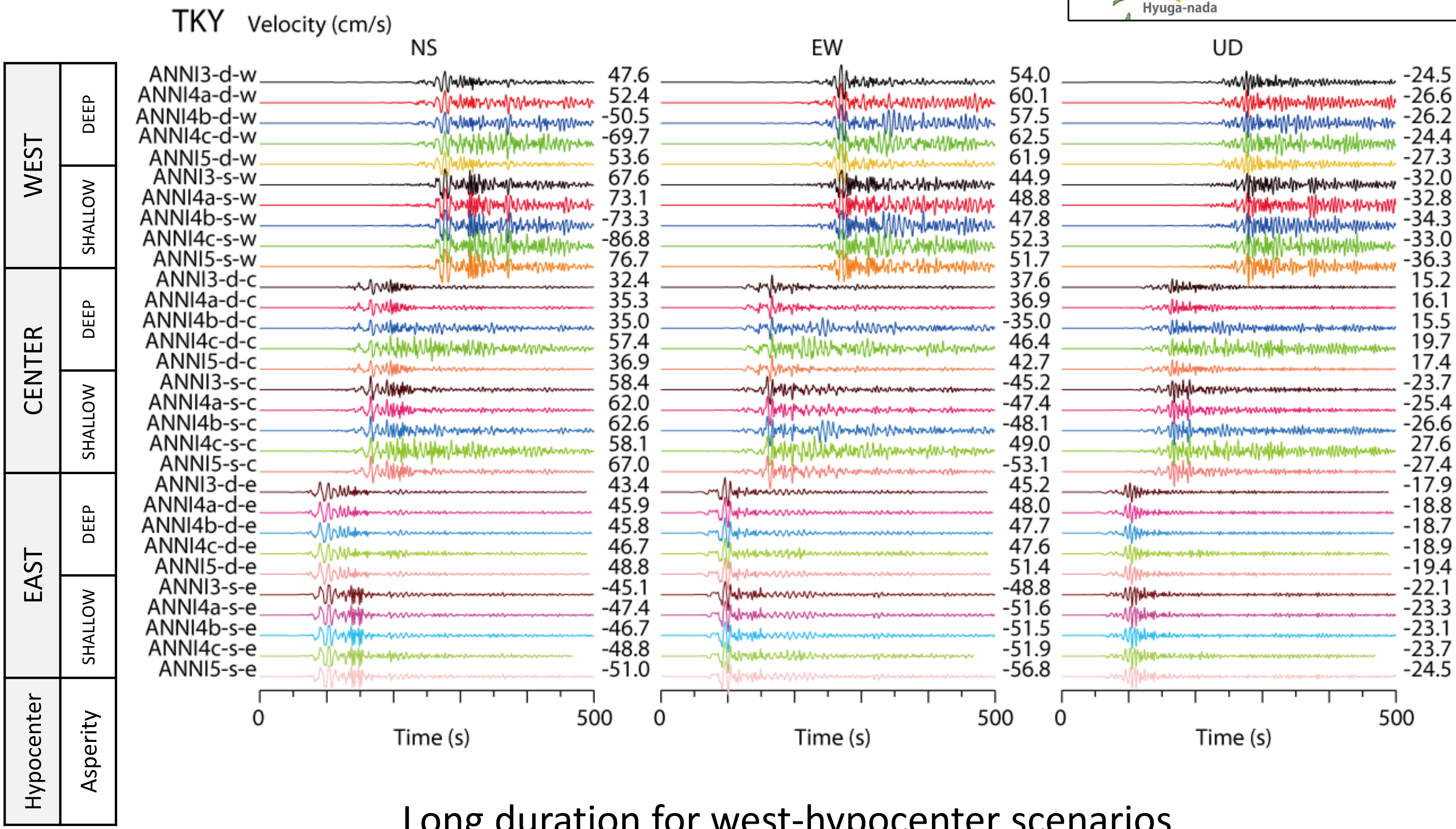
Larger amplitude for west-hypocenter scenarios

Later phases from the along trough ‘c’ area

Velocity waveforms @ TKY

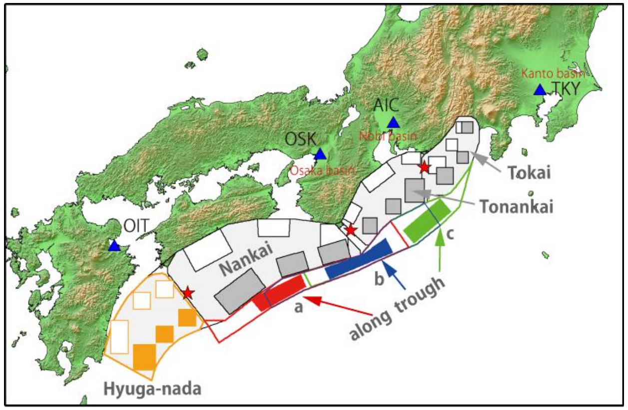
Simultaneous rupture of 3 and 4 segments (30 scenarios)





Long duration for west-hypocenter scenarios

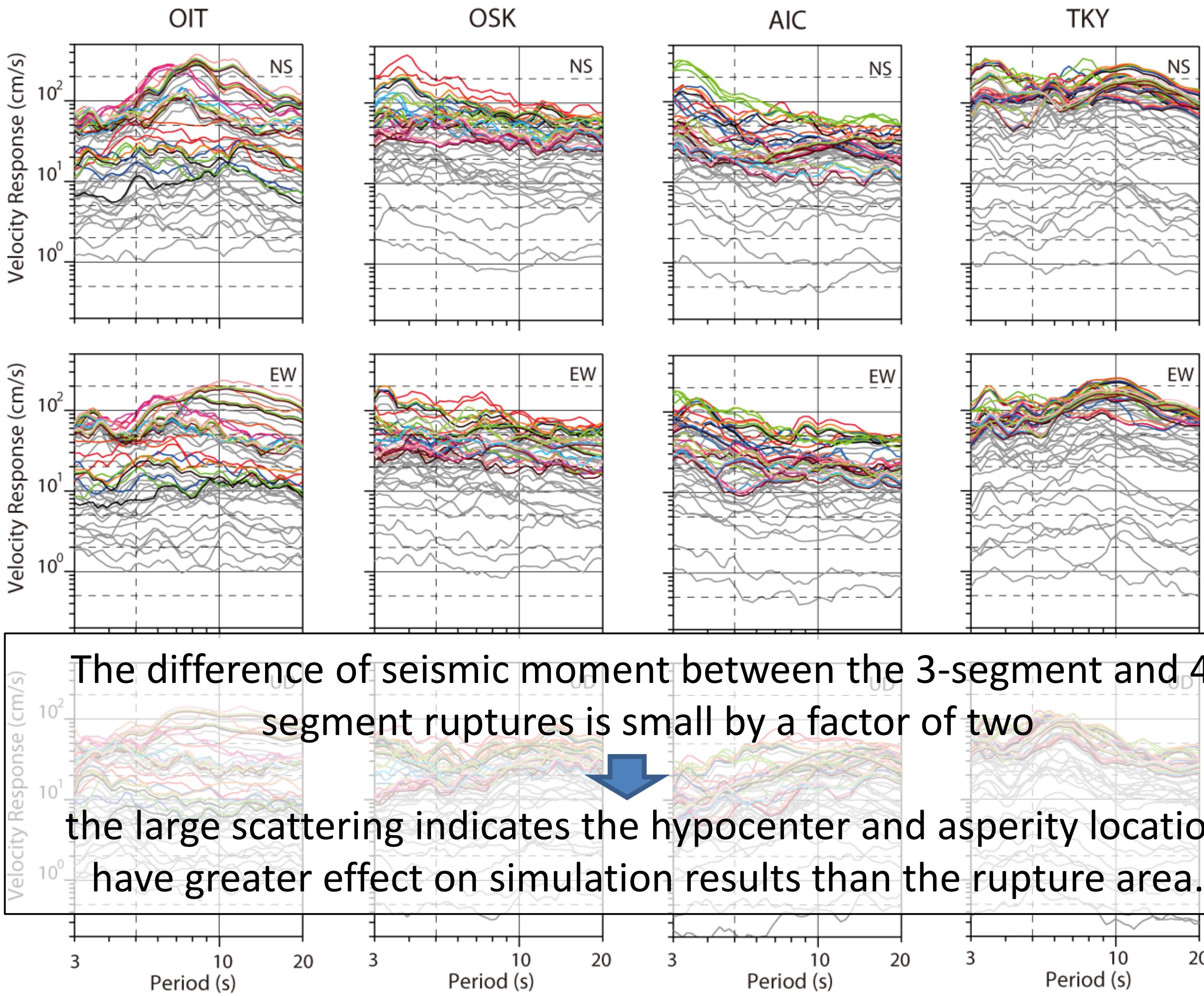
Character of the waveforms



OIT	• Smaller amplitude for <u>west-hypocenter</u> scenarios • S waves from deeper asperities of the Nankai area • Later phases from the along trough ‘a’ area
OSK	• Larger amplitude for <u>west-hypocenter</u> scenarios • Later phases from the along trough ‘a’ area
AIC	• Larger amplitude for <u>west-hypocenter</u> scenarios • Later phases from the along trough ‘c’ area
TKY	• Long duration for <u>west-hypocenter</u> scenarios

The hypocenter location tends to have a greater impact on long-period ground motions than the asperities location and the rupture areas.

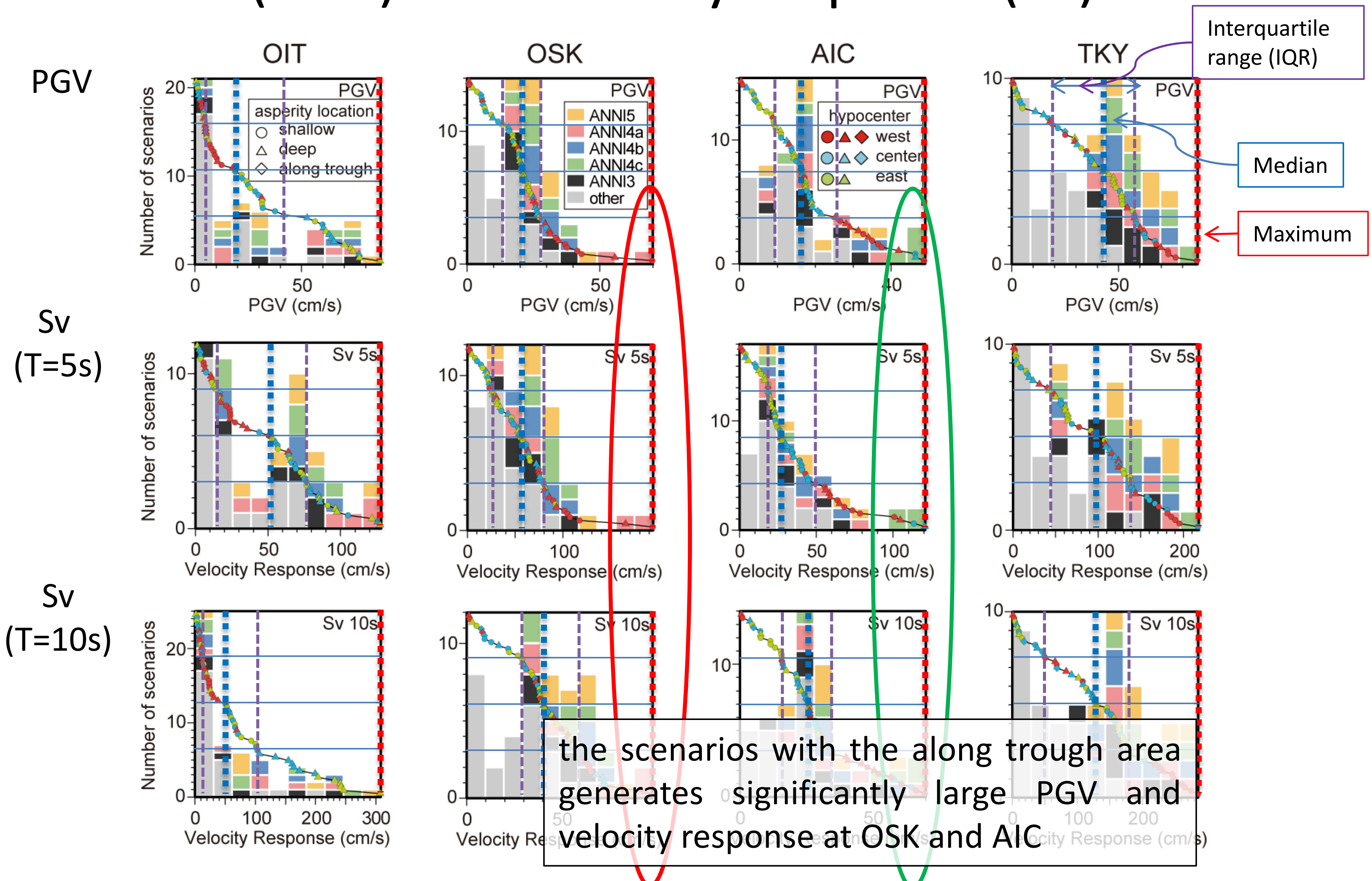
Velocity response (damping factor of 5%)



The difference of seismic moment between the 3-segment and 4-segment ruptures is small by a factor of two

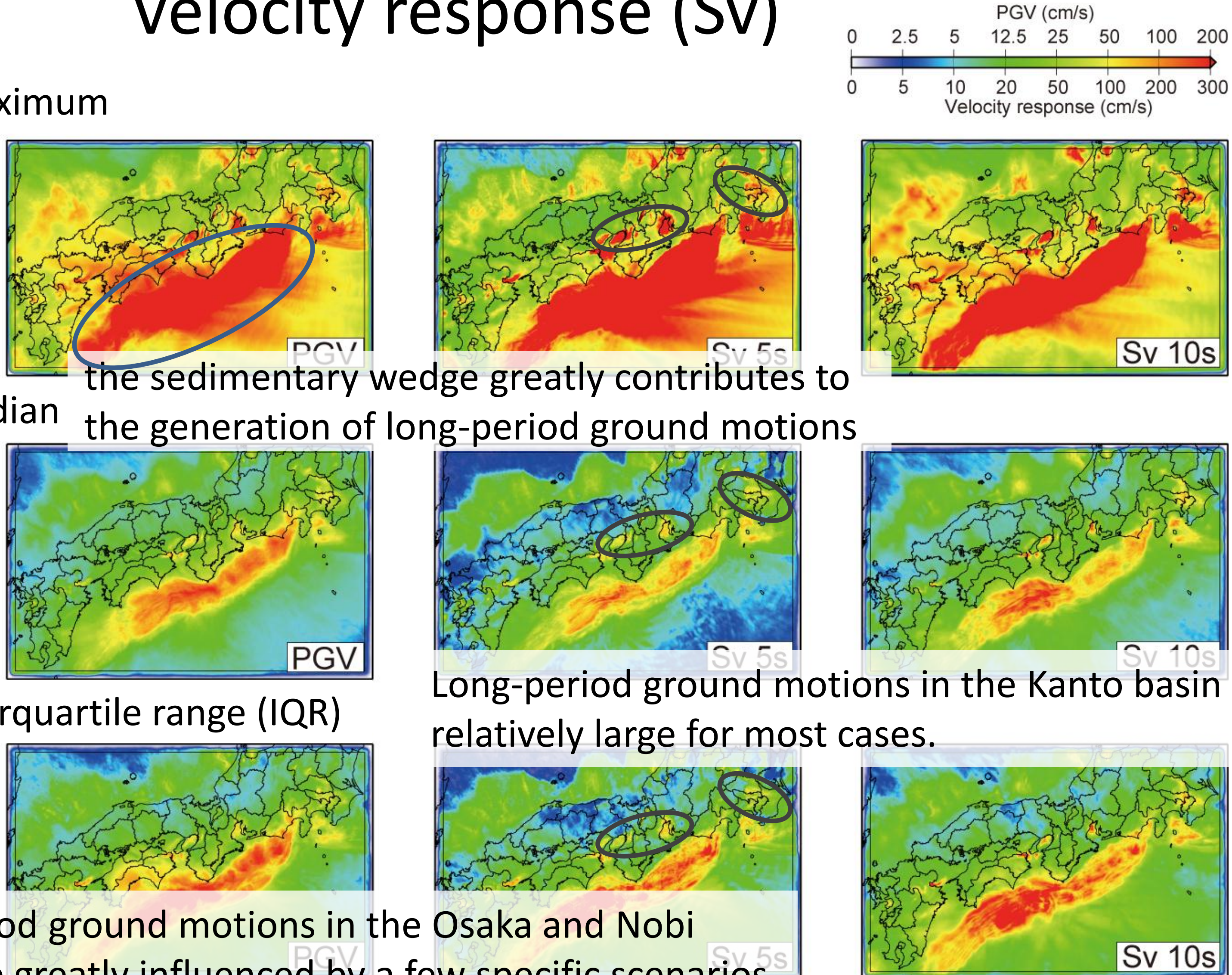
the large scattering indicates the hypocenter and asperity location have greater effect on simulation results than the rupture area.

Frequency distribution of Peak ground velocity (PGV) and Velocity response (Sv)



the scenarios with the along trough area generates significantly large PGV and velocity response at OSK and AIC

Maps of Peak ground velocity (PGV) and Velocity response (Sv)



Maximum

the sedimentary wedge greatly contributes to the generation of long-period ground motions

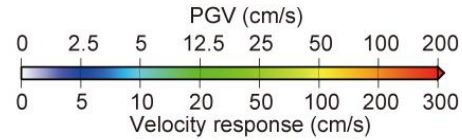
Median

Long-period ground motions in the Kanto basin are relatively large for most cases.

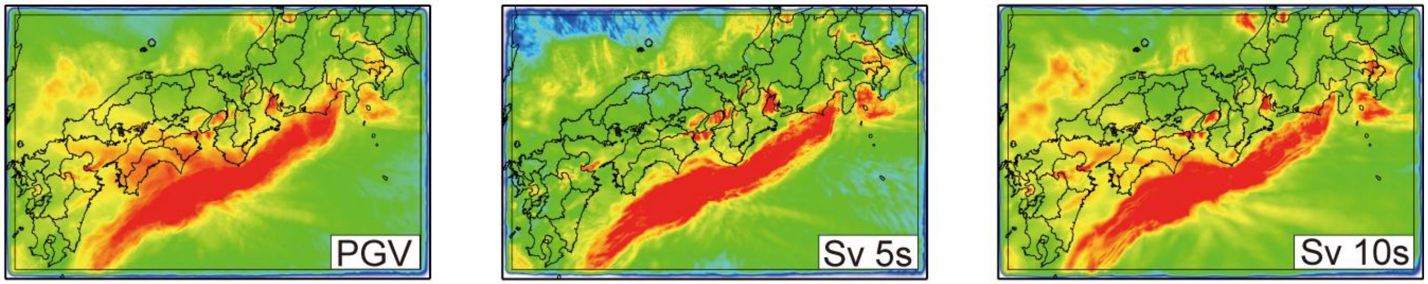
Interquartile range (IQR)

Long-period ground motions in the Osaka and Nobi basins are greatly influenced by a few specific scenarios.

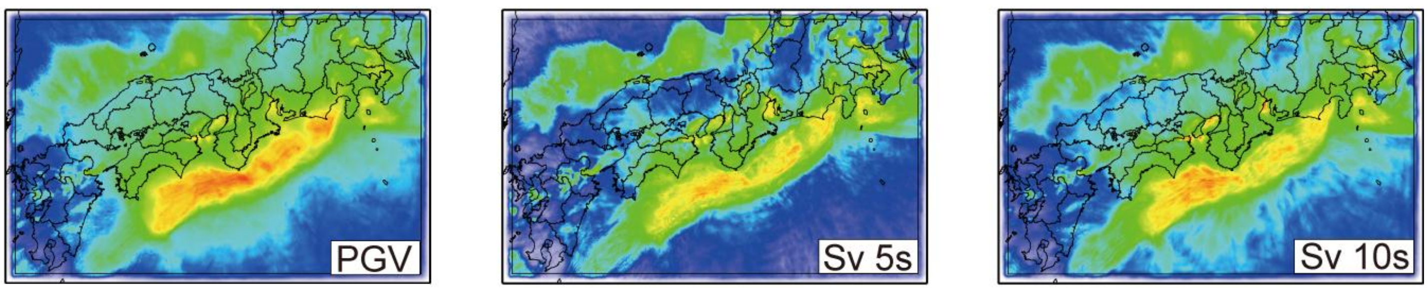
Maps of PGV and Sv (without 4-segment scenarios)



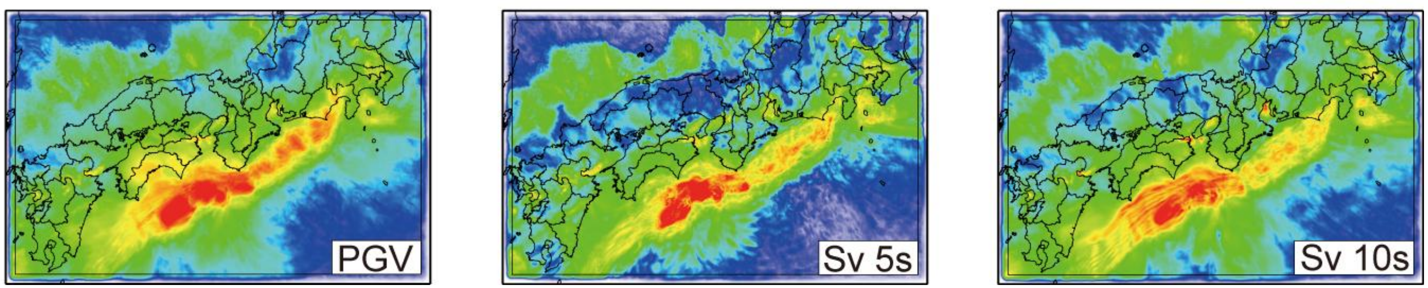
Maximum



Median

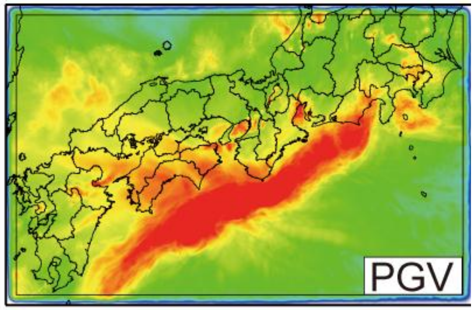


Interquartile range (IQR)

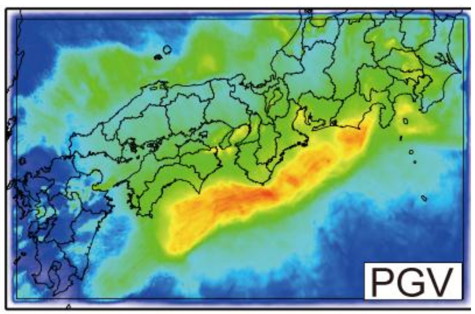


Maps of PGV and Sv
(before and after applying new findings)

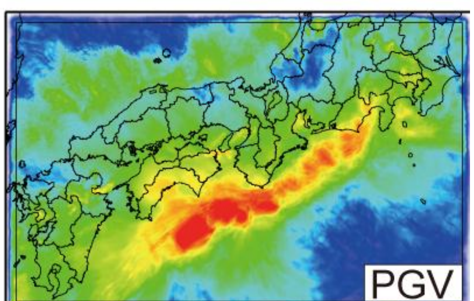
Maximum



Median

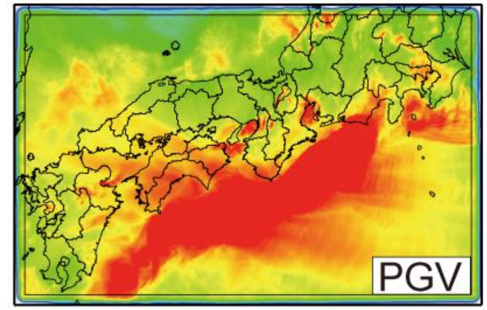


Interquartile range

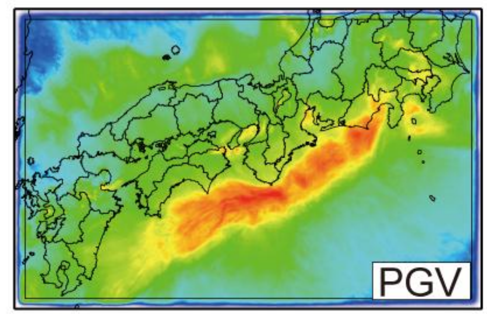


New findings
- Hyuga-nada
- Along the trough

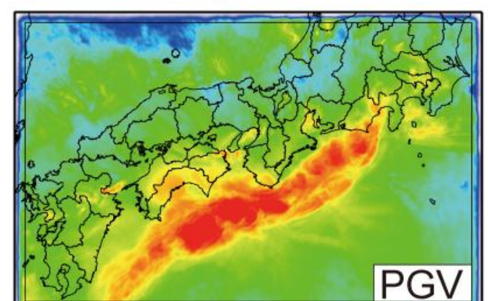
Maximum



Median



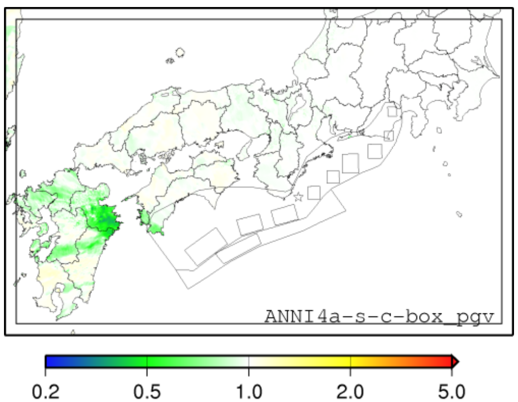
Interquartile range



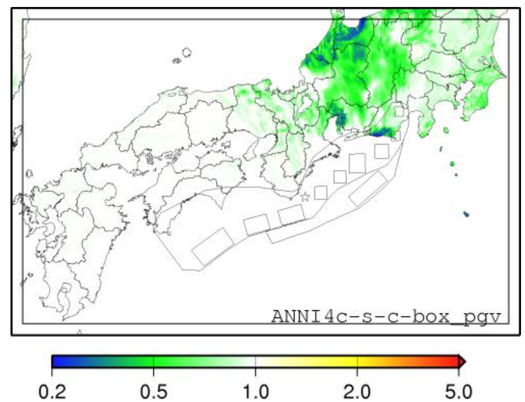
Effect of slip velocity function

- Change the slip velocity function for along the trough area
  - Kostrov-like slip velocity time function (Nakamura and Miyatake, 2000)
  - Boxcar-like slip velocity time function

PGV ratio (Boxcar / Kostrov)



PGV ratio



PGV ratio

- ➢ PGV values decrease by a factor of two locally.
- ➢ Selection of appropriate source time function is important.

Summaries

- We simulated long-period ground motion of the Nankai trough earthquakes using 55 scenarios with various possible source parameters.
- The hypocenter location (rupture start point) tends to have a greater impact on long-period ground motions than the asperities and the rupture areas.
- Long-period ground motions in the Osaka and Nobi basins are greatly influenced by a few specific scenarios including the along trough area.
- Long-period ground motions in the Kanto basin are relatively large for most cases.
- New findings will change the possible range of long-period ground motion.

Future tasks

- Selection of appropriate source time function for the along trough area.
- Improvement of source model, velocity structure model, and simulation method.
  - Introducing some kind of heterogeneity into the characterized source model.
  - Modeling shallow lower velocity layers.
  - etc...