Modeling short-term slow slip events and the associated low frequency earthquakes in the deeper parts of the Nankai subduction zone

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Friction for the transition zone
(Velocity weakening at low slip velocity and velocity strengthening at high slip velocity)

Relation between steady state friction and slip velocity

Dieterich/Ruina friction law with cut-off velocity

$$\mu = \mu_* + a\ln\left(\frac{v}{v_1}\right) + b\ln\left(\frac{v_2\theta}{D_c} + 1\right)$$

v_2 Cut-off velocity to an evolution effect

$$\frac{d\theta}{dt} = 1 - \frac{\theta v}{D_c}$$

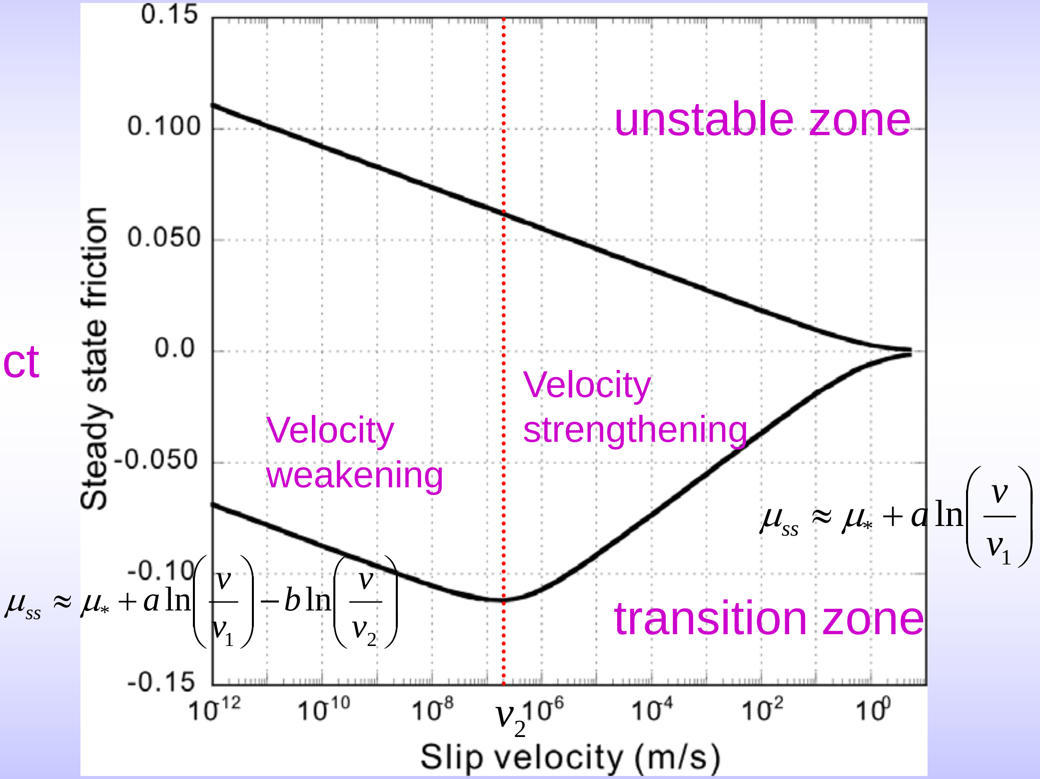
Steady state friction

$$v << v_2$$

$$\mu_{ss} \approx \mu_* + a\ln\left(\frac{v}{v_1}\right) - b\ln\left(\frac{v}{v_2}\right)$$

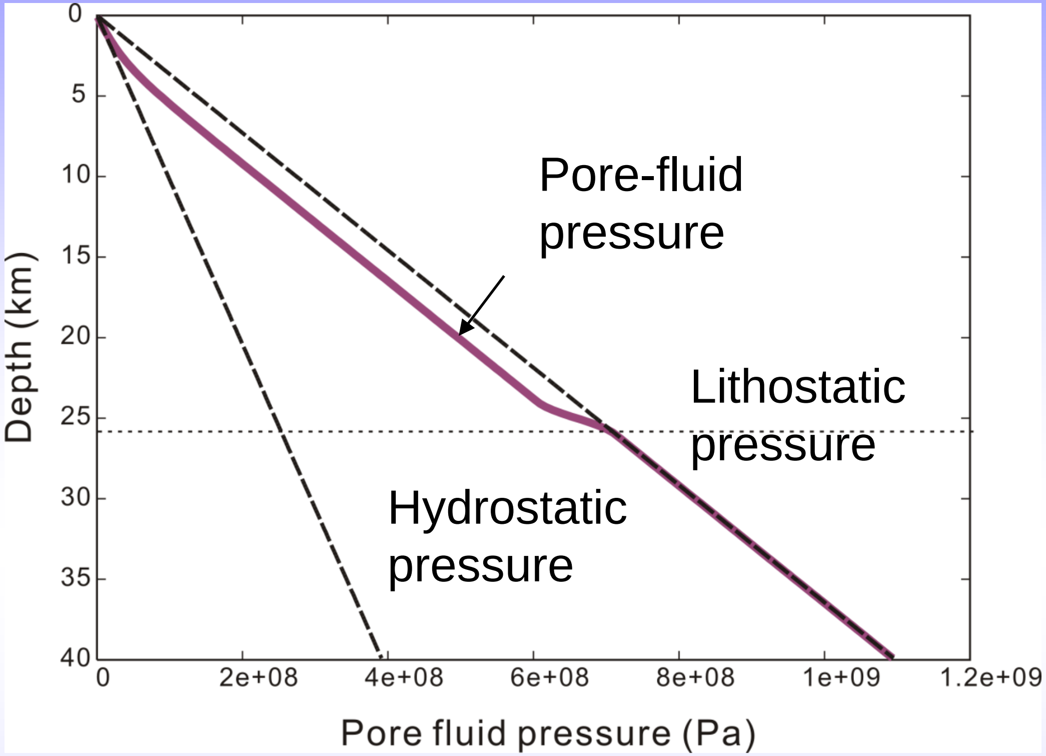
$$v >> v_2$$

$$\mu_{ss} \approx \mu_* + a\ln\left(\frac{v}{v_1}\right)$$



$$v_2 = 10^{-6.5}\, m/s$$

Pore fluid pressure distribution



Pore-fluid pressure is very high; the effective normal stress is low.
Seismological study: Shelly et al. (2006)
Petrological study: Kamaya and Katsumata (2004)

$$\sigma_n^{eff} = \sigma_n - P_f \approx 0.4\text{MPa}$$

The critical displacement is very small because of the small effective normal stress.

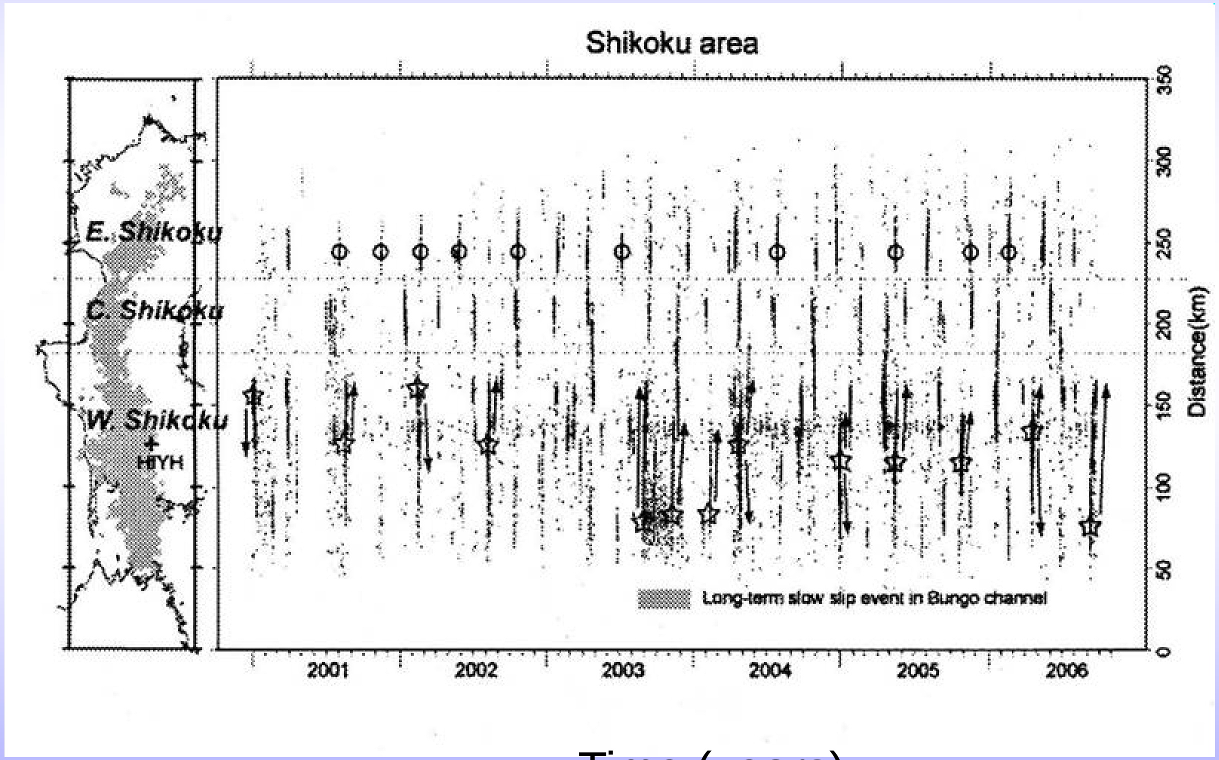
$$D_c \approx 0.3\text{mm}$$

Spatio-temporal distribution of low frequency tremors and SSEs beneath Shikoku

Obara (2007)

Three major segments

East



West

Time (years)

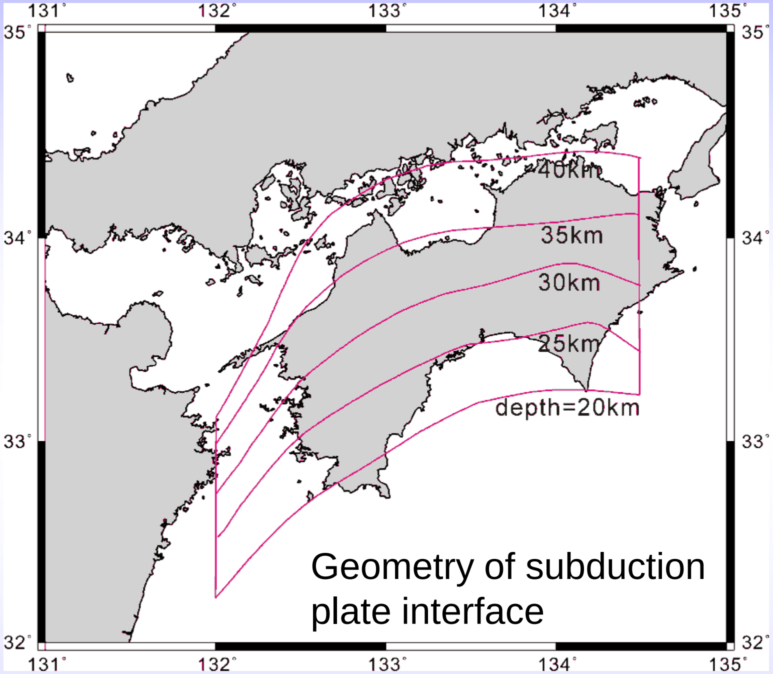
Eastern Shikoku
Length of segment: 20-30km
Recurrence interval: 3 month

Western Shikoku
Length of segment : 100km
Recurrence interval: 3-6 month

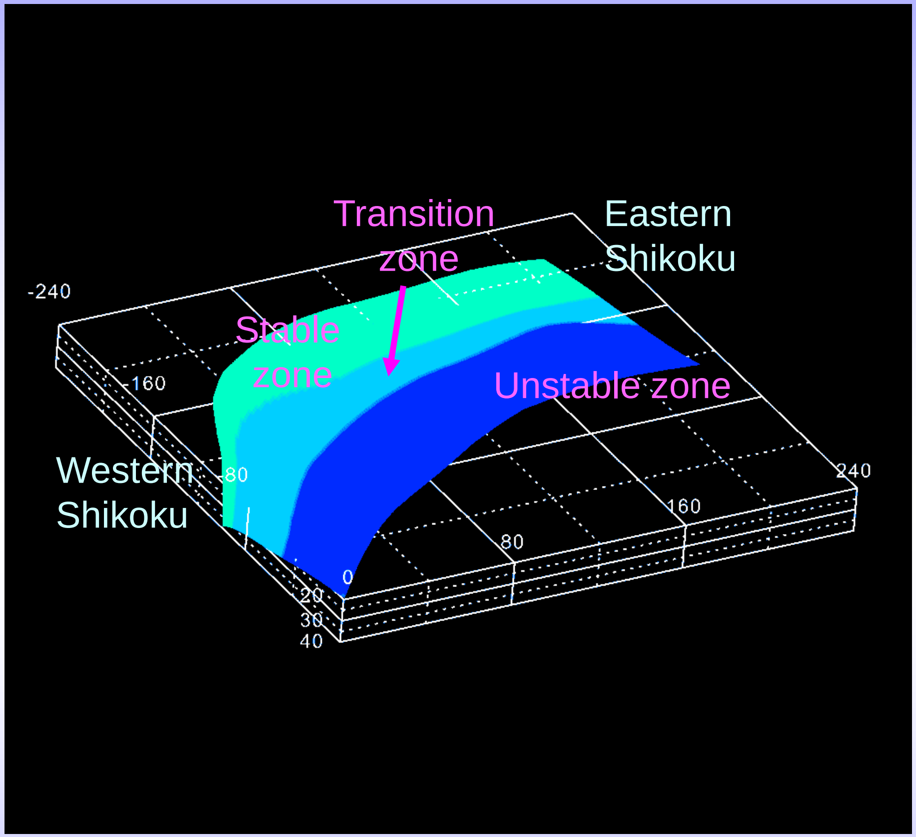
The width of the zone of the tremors beneath western Shikoku is more than that beneath eastern Shikoku.

3D Model for short-term SSEs beneath Shikoku

Assumed geometry of subduction plate boundary



Depth range of 25-45km



The generation zone of SSEs: wider beneath western Shikoku

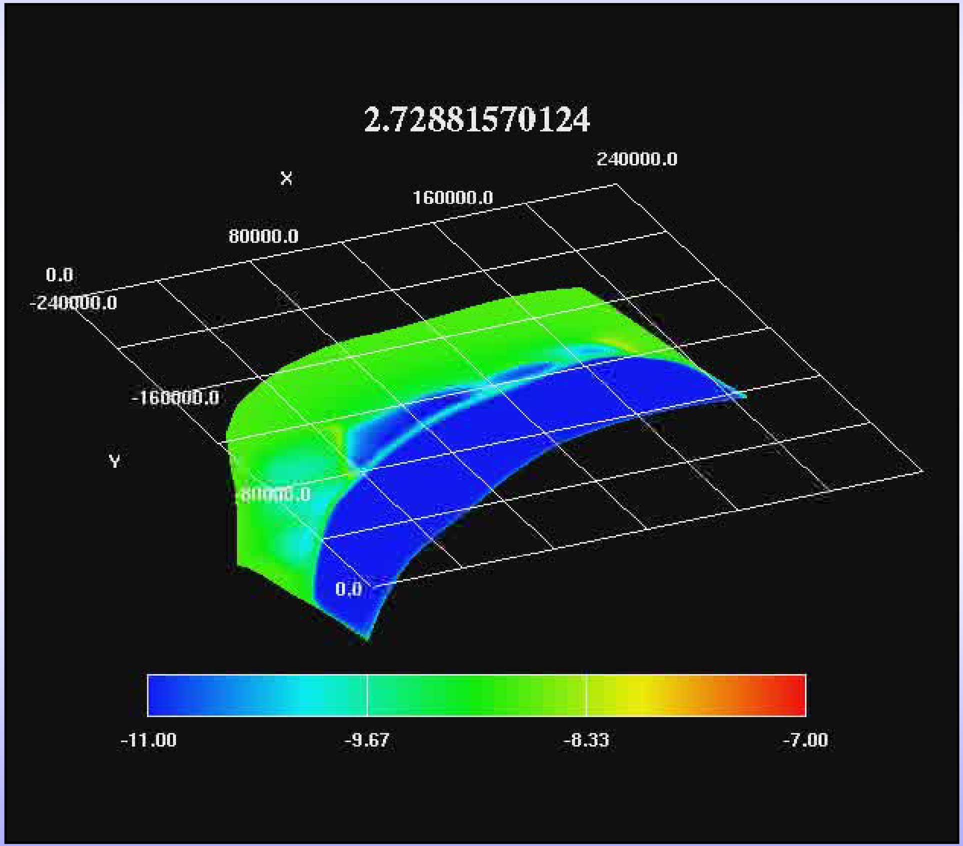
: narrower beneath eastern Shikoku

Stress is accumulated by the delay of the fault slip from relative plate motion

$$\tau_i = \sum k_{ij}(V_{pl}t - u_j) - \frac{G}{2\beta}\frac{du_i}{dt}$$

Slip velocity distribution with time

Elapsed time (years)

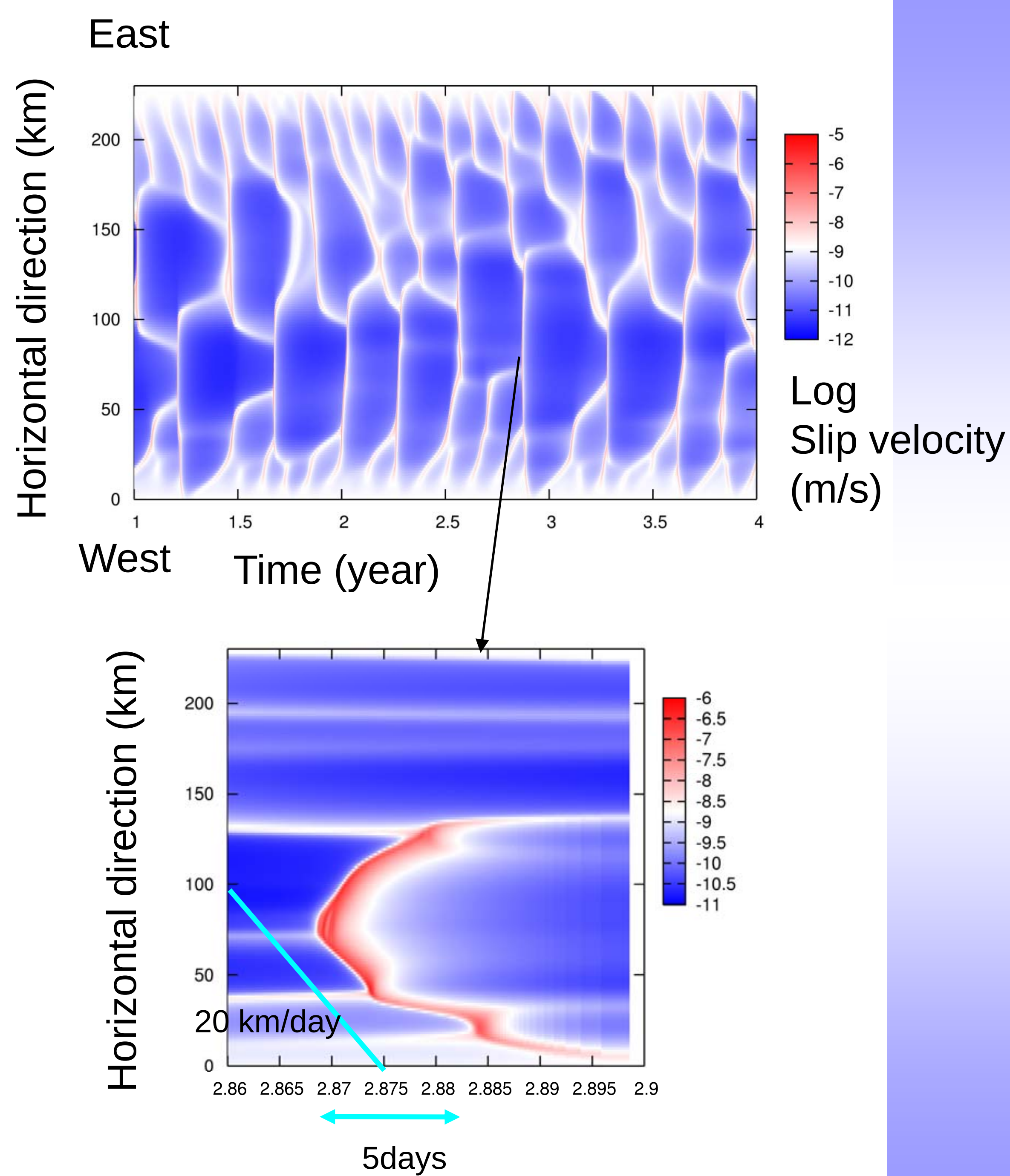


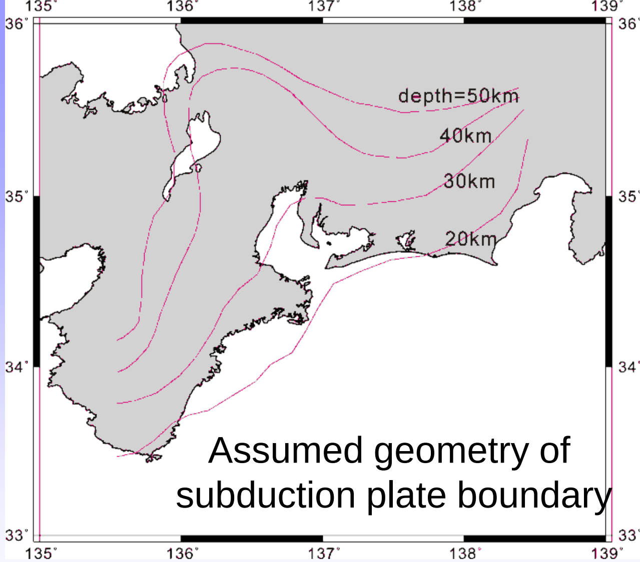
Log slip velocity (m/s)

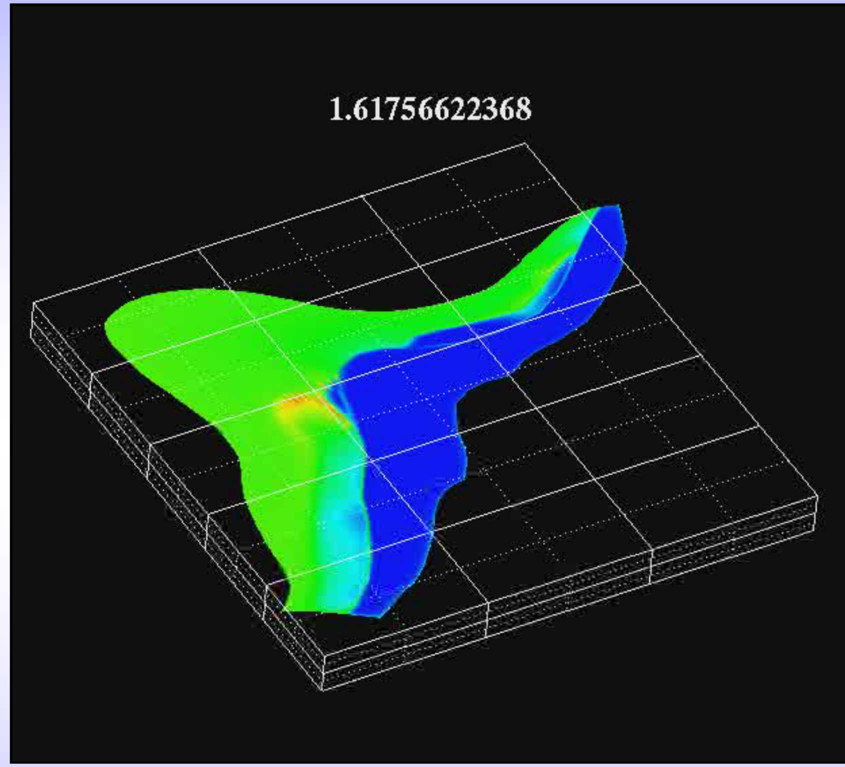
Slip velocity changes with time at the depth of 36 km

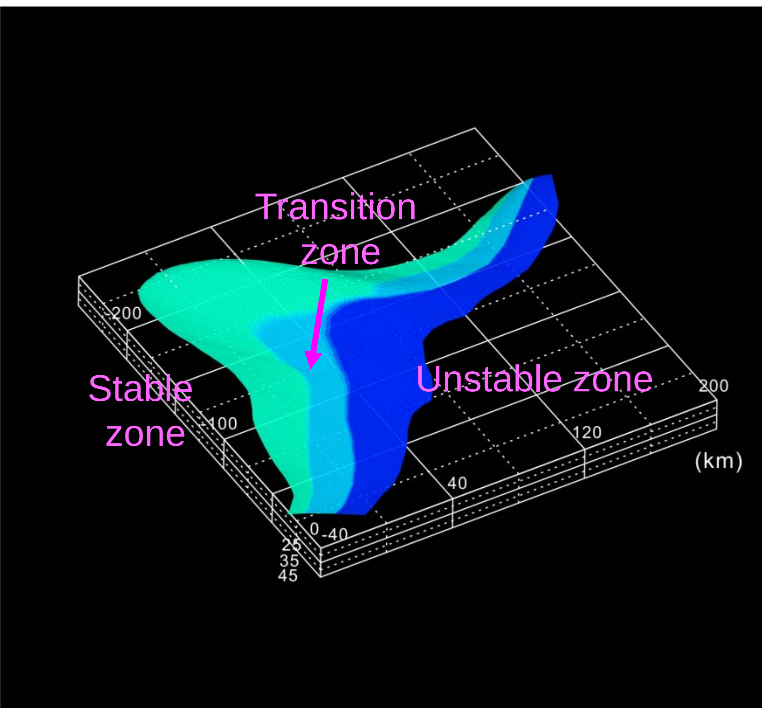
Eastern Shikoku:
Shorter length
Shorter recurrence interval

Western Shikoku:
Longer length
Longer recurrence interval




135°
136°
137°
138°
139°
36°
35°
34°
33°
depth=50km
40km
30km
20km
Assumed geometry of
subduction plate boundary


1.61756622368


Transition
zone
Stable
zone
Unstable zone
200
100
0
-40
40
120
200
(km)
25
35
45

Non-uniform frictional properties

- Very low frequency earthquakes are accompanied by short-term SSEs
  Ito et al. (2006)

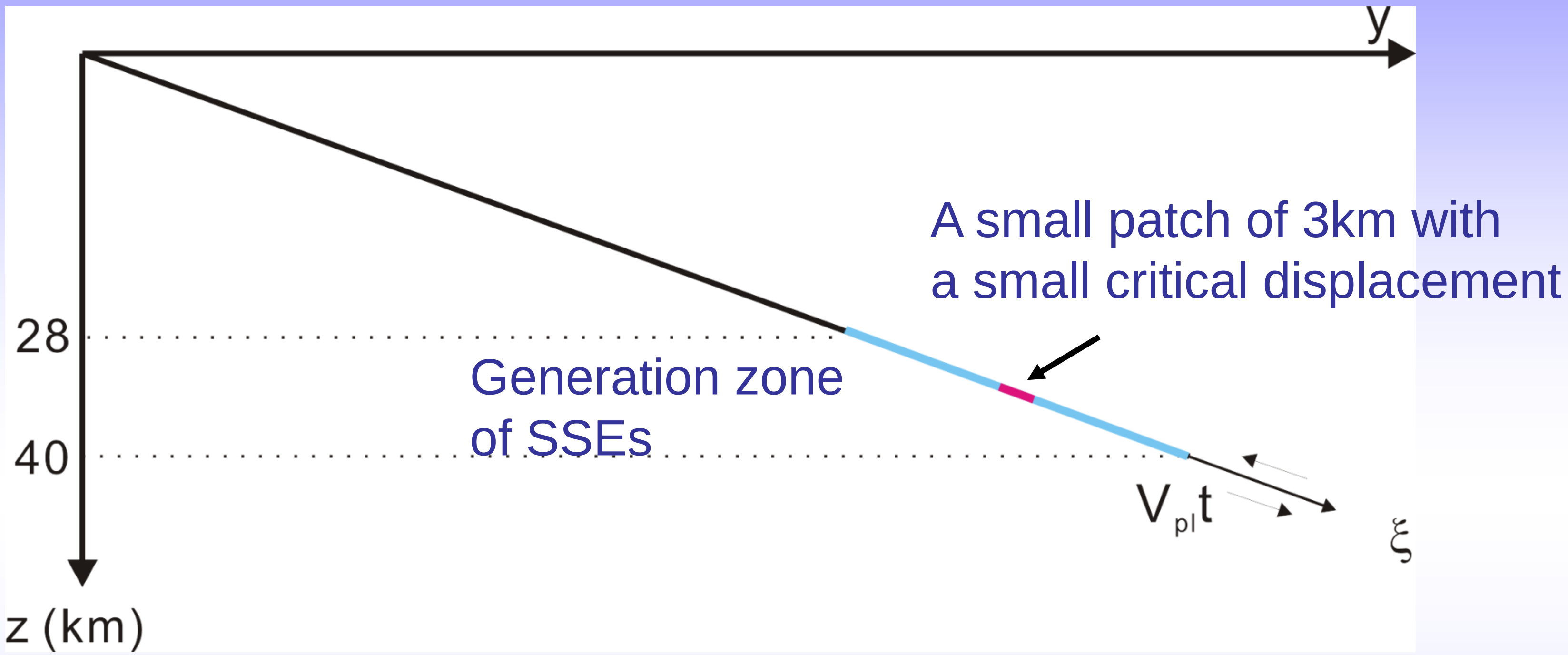
- Scaling law of slow earthquakes
  Ide et al. (2007)

  $M_0 \propto T$

  Propagation velocity $L/T \propto 1/L$ for diffusional constant-slip model
  $L/T \propto 1/L^2$ for constant stress drop model

The critical displacement is scaled with the size of the events.

2D model of low frequency earthquakes

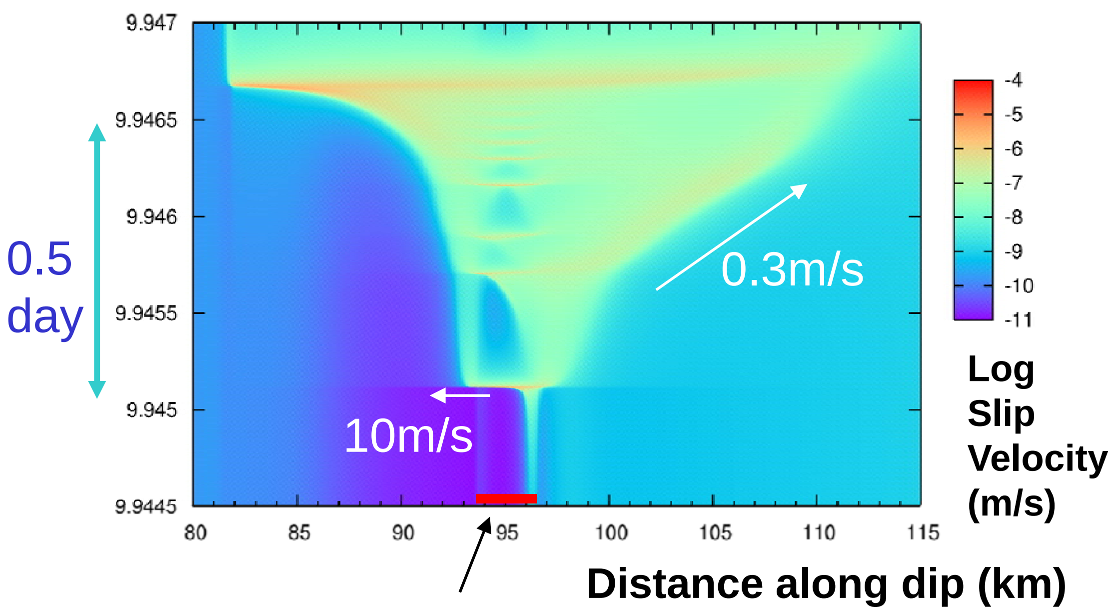


For slow events $D_c = 0.10\text{mm}$

For a patch of
low frequency events $D_c = 0.01\text{mm}$

2D model of low frequency earthquakes

Spatio-temporal development of slip velocity for a series of low frequency events

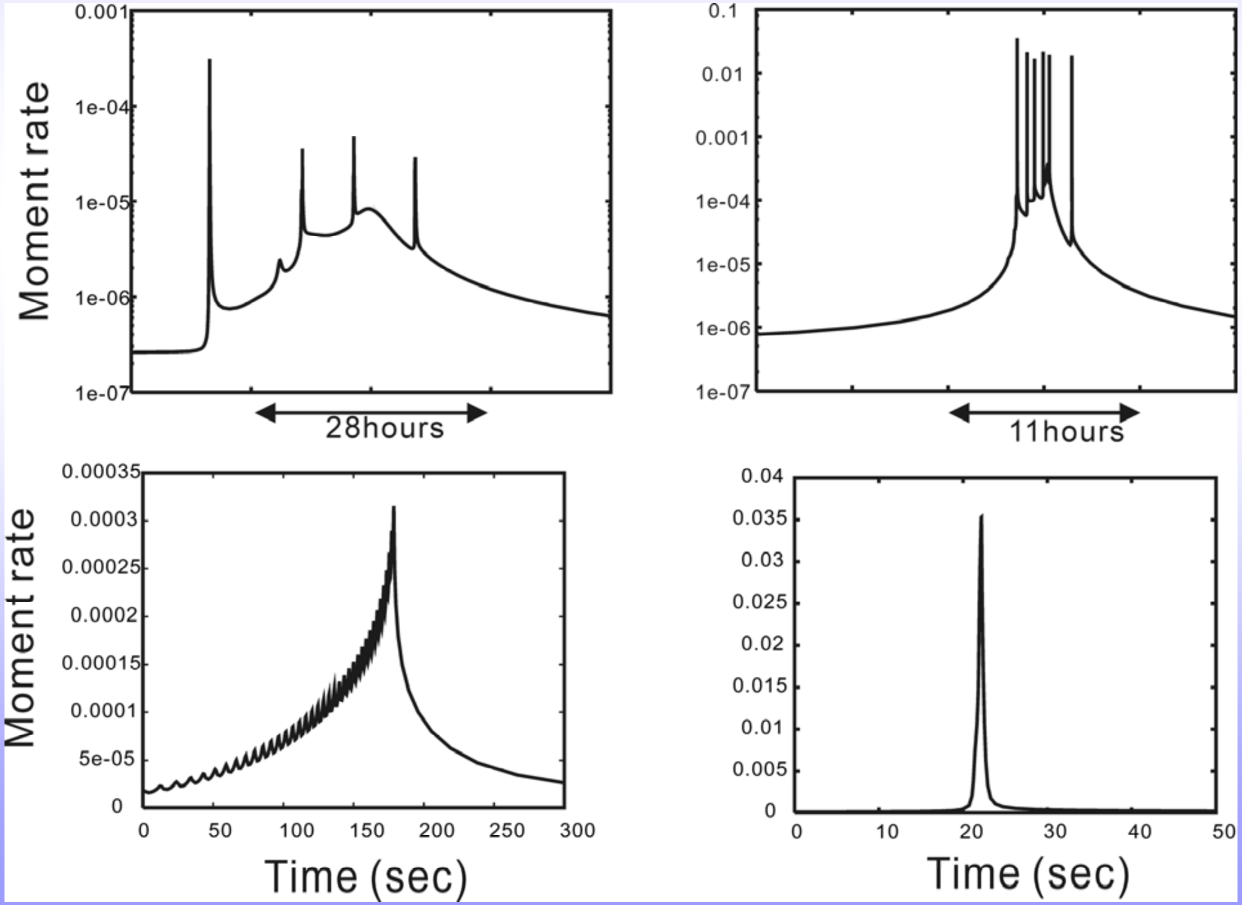


Small patch with
a small critical displacement

Moment rate function

Friction with velocity strengthening at high slip velocity

Friction with velocity weakening at high slip velocity



Summary

◆To reproduce short-term SSEs, we consider the frictional property at the unstable-stable transition regime. Short-term SSEs can be reproduced in a condition where pore fluid pressure is almost equal to the lithostatic pressure and critical displacement is very small.

◆By considering the 3D geometry of a fault plane and the horizontal variation in the width of the transition zone where SSEs occur, we can reproduce the segmentation of SSEs which are similar to the observed ones beneath Shikoku.

◆To reproduce low-frequency earthquakes, we considered a small patch that has a smaller critical displacement. Multiple slips were reproduced at the same location during one series of events. For the modeling of the low-frequency earthquakes, it would be necessary to consider the scaling property such that the critical weakening displacement is in proportion to the size of events.