Spatio-temporal variation in slip rate on the plate boundary off Sanriku, northeastern Japan, estimated from small repeating earthquakes

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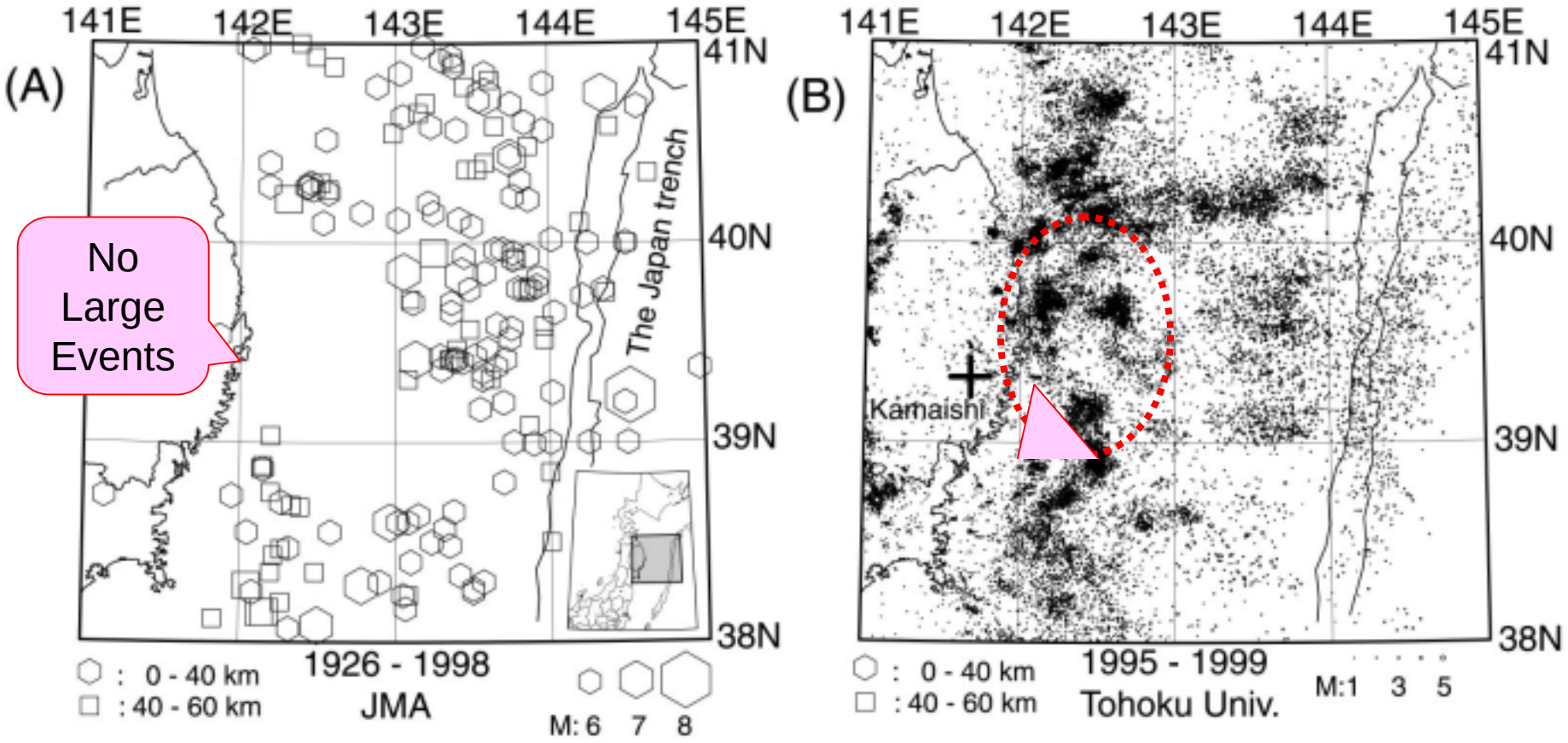
Small Repeating Earthquakes

- Have been found in transform fault type plate boundary regions in California.
  - Ellsworth, 1995; Nadeau and McEvilly, 1997.
  - In the regions, microearthquake activities are quite high.
- Question: Are they occurring in subduction zones also?

Repeaters off Kamaishi

- Location



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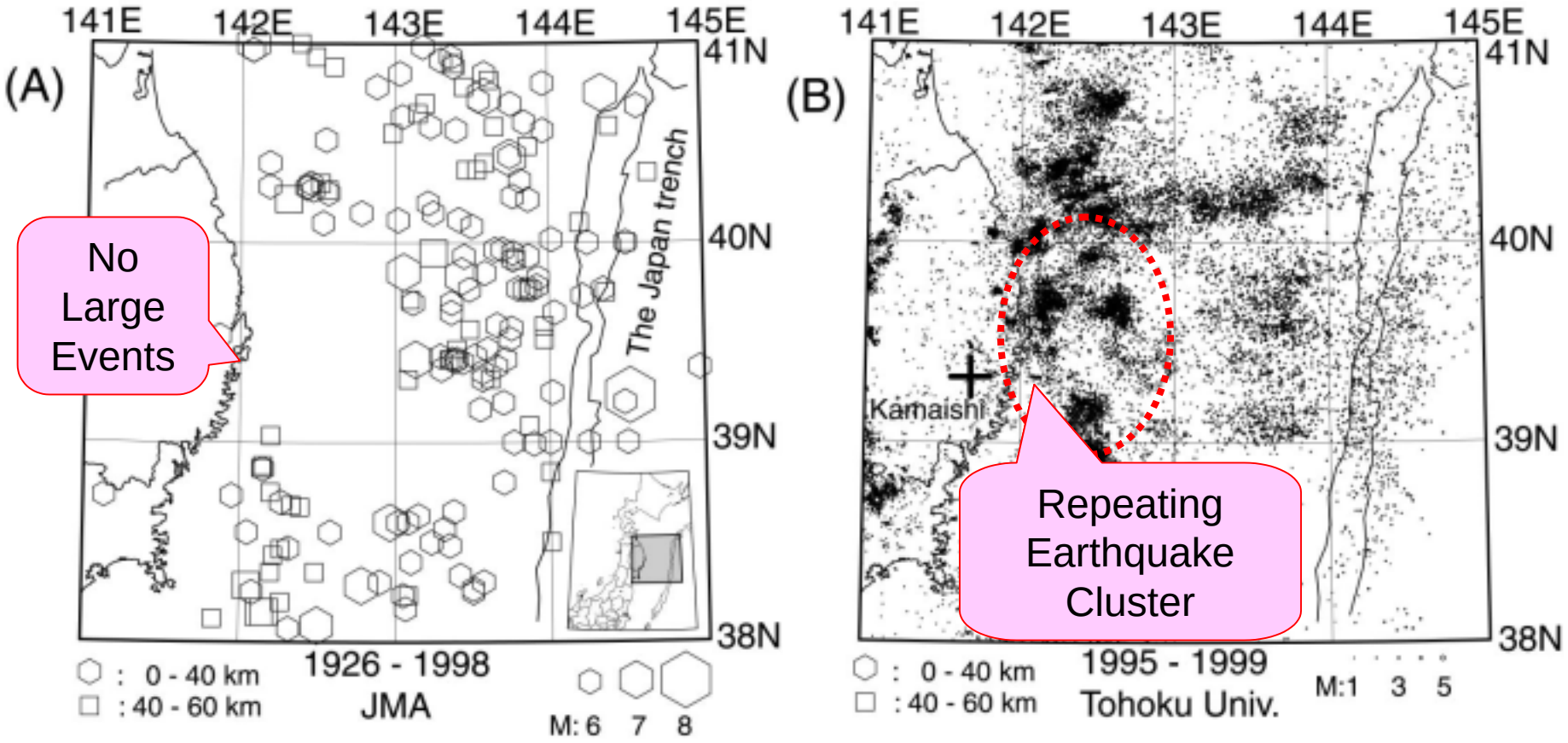

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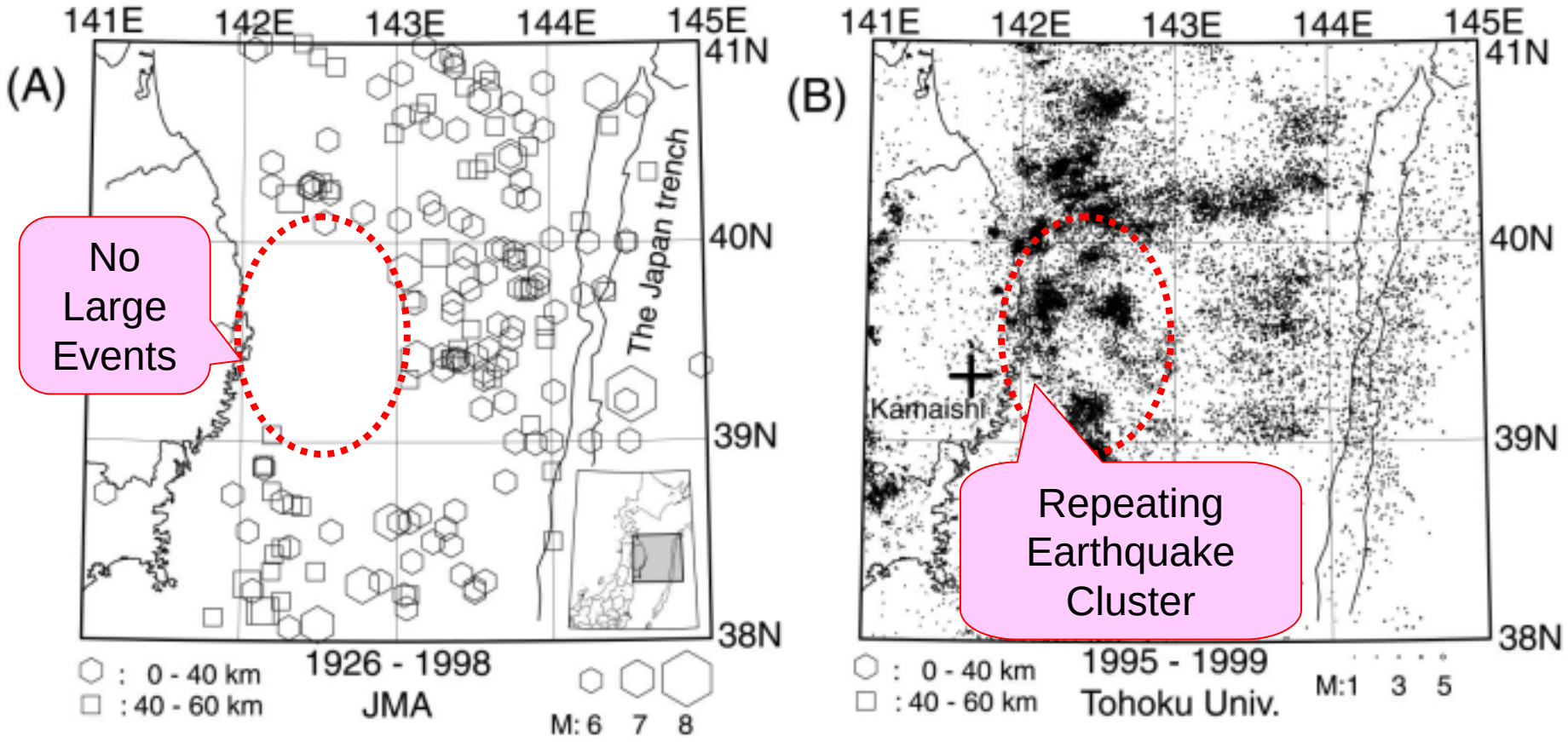


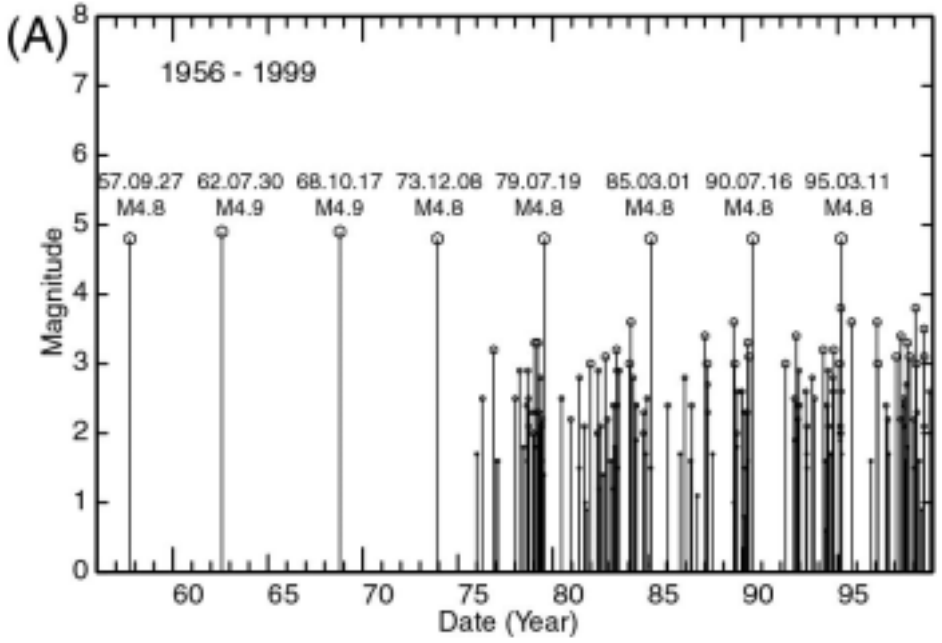
Repeaters off Kamaishi

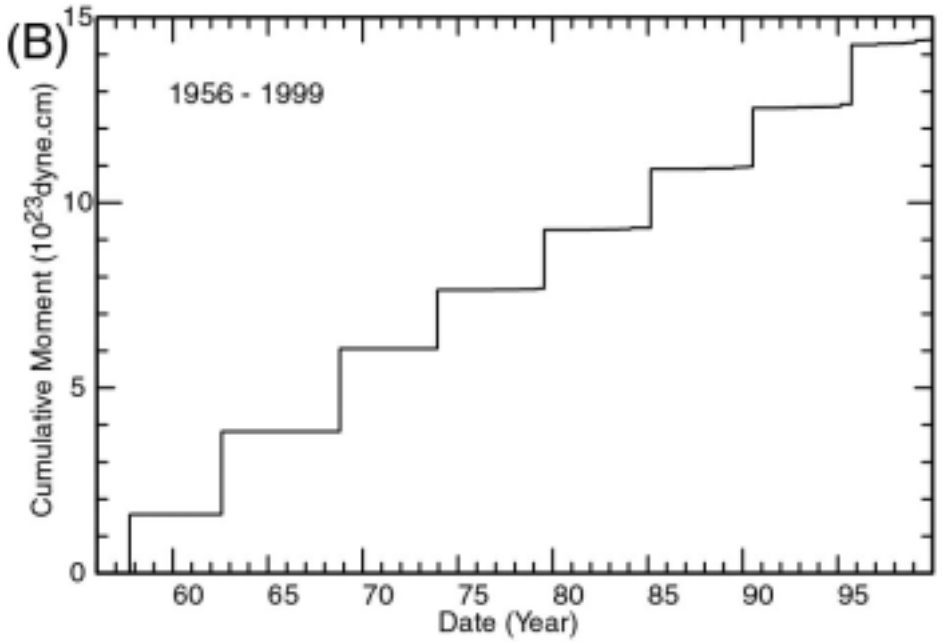
- History

M = 4.8 +/- 0.1

Repeating Interval

= 5.35 +/- 0.53 years



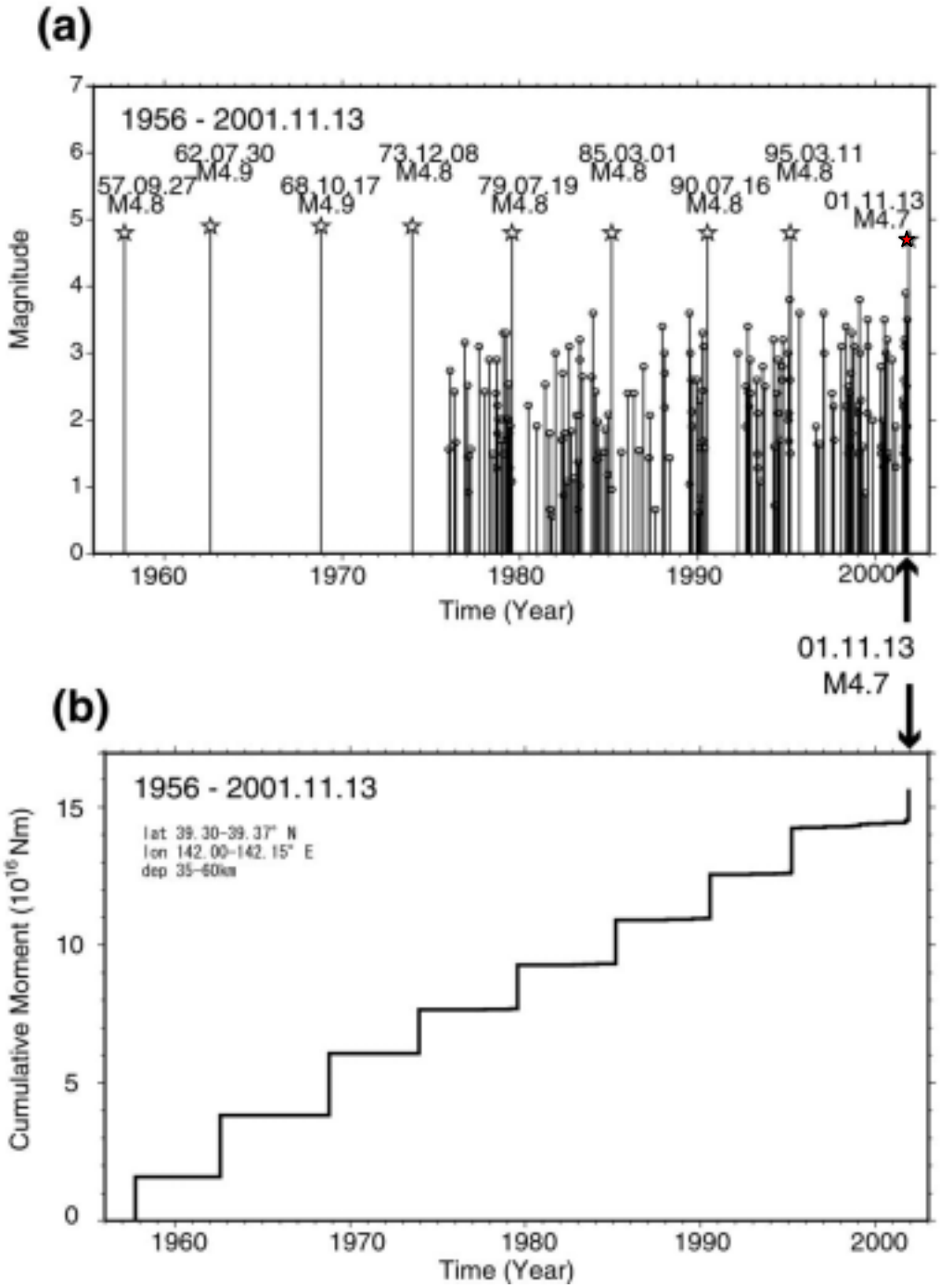


Repeaters off Kamaishi

- Predicted Event

Prediction: “Event with M4.8 +/- 0.1 will occur by the end of November 2001 with 99 % probability” (Matsuzawa et al., AGU fall meeting, 1999)

Actually, M4.7 event occurred on November 13, 2001.



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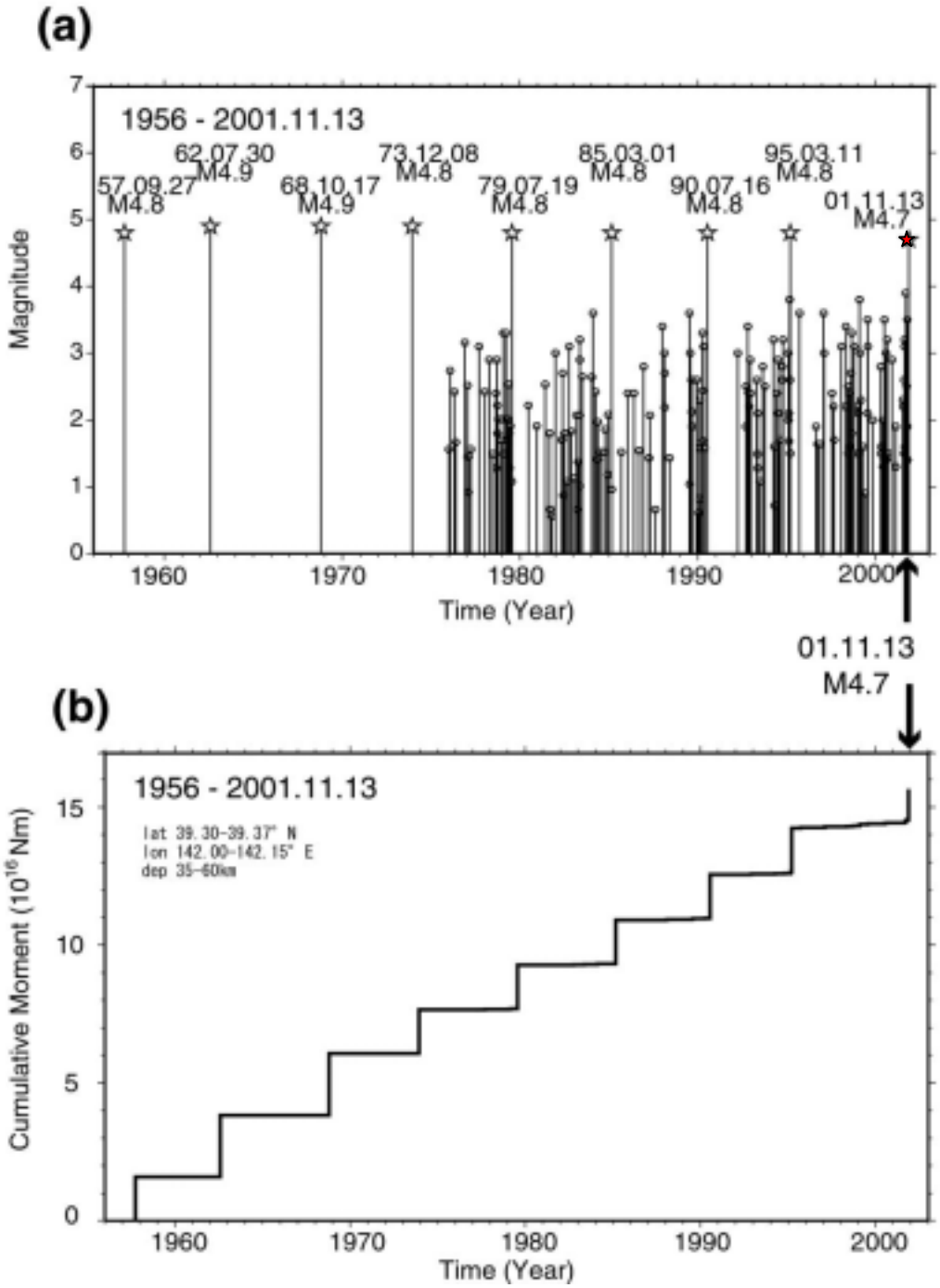
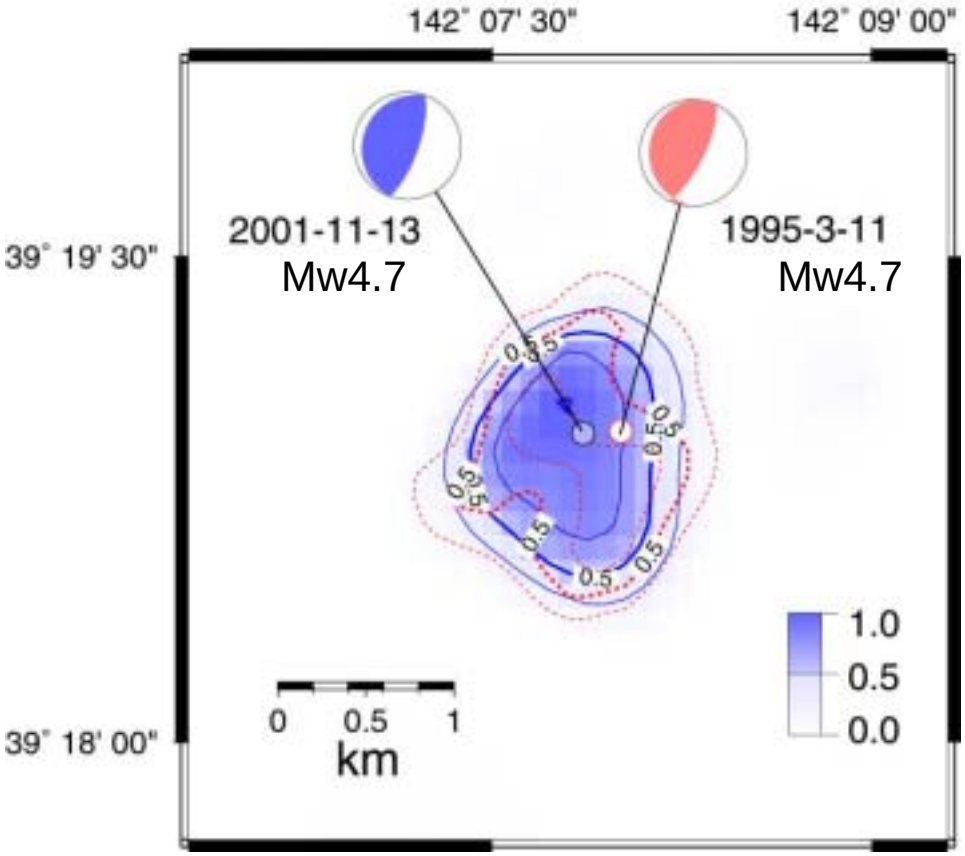
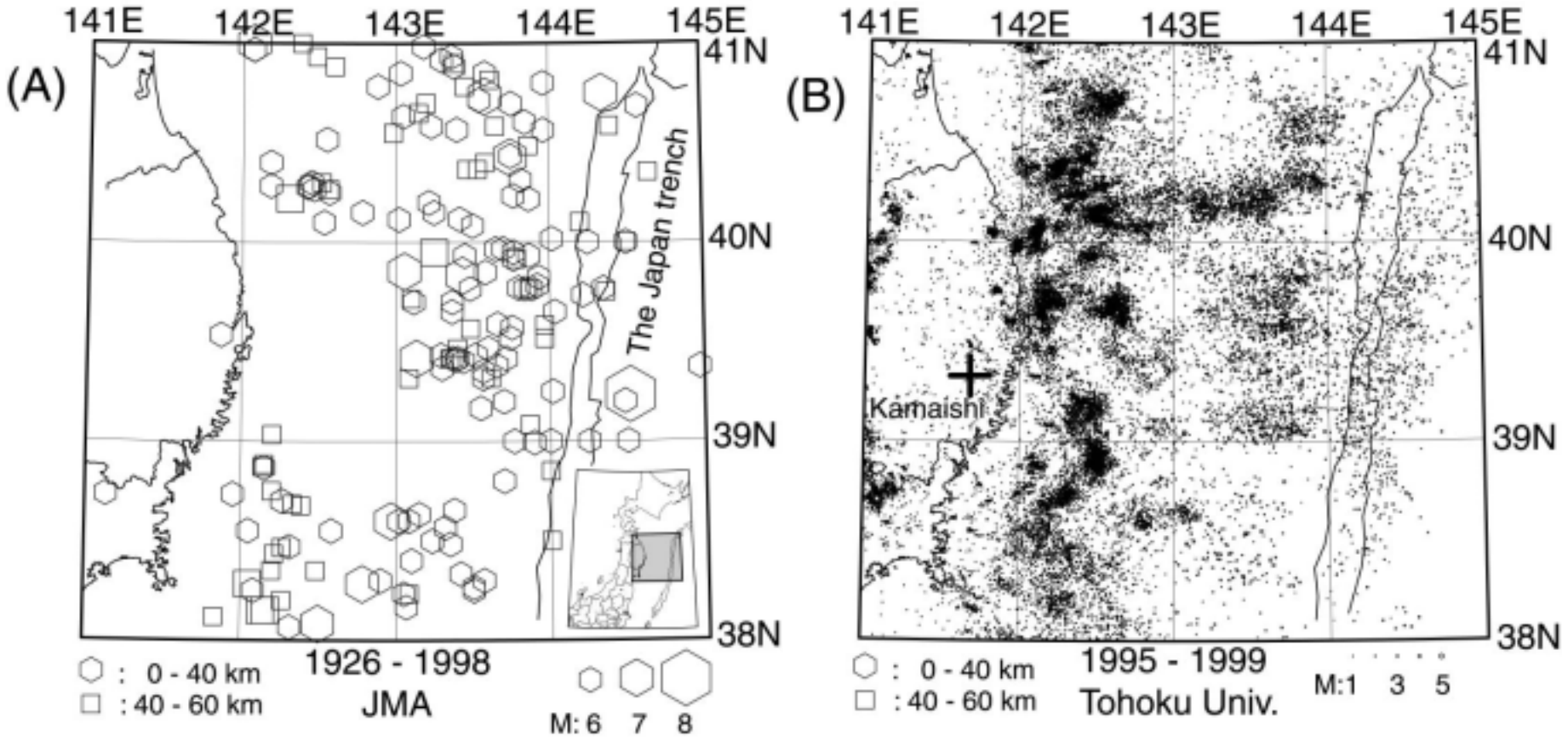


Repeaters off Kamaishi

- Moment Release Distribution (Okada et al., 2002)
  - Contour: relative moment release normalized by each maximum value



Repeaters off Miyagi Prefecture?



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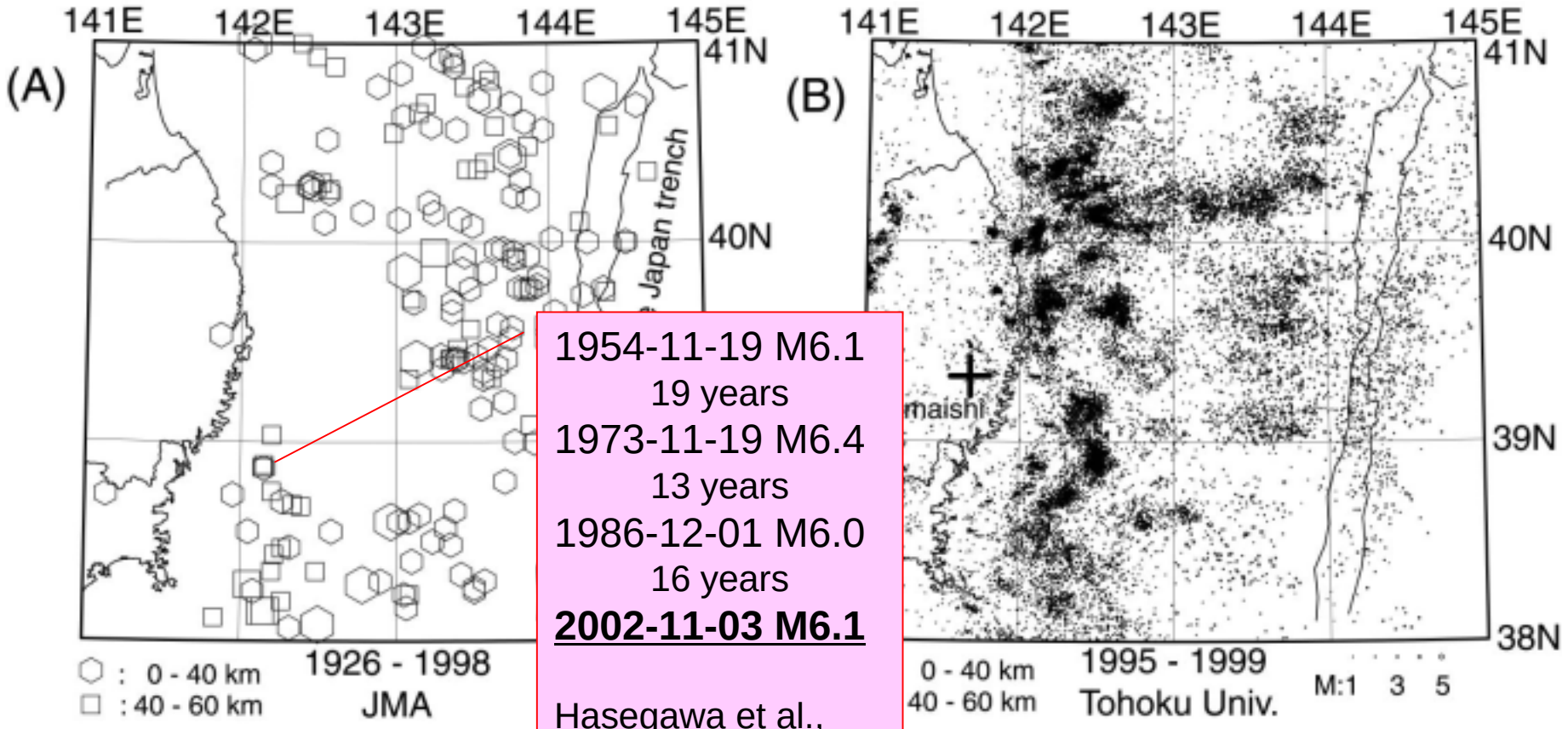

1954-11-19 M6.1
19 years
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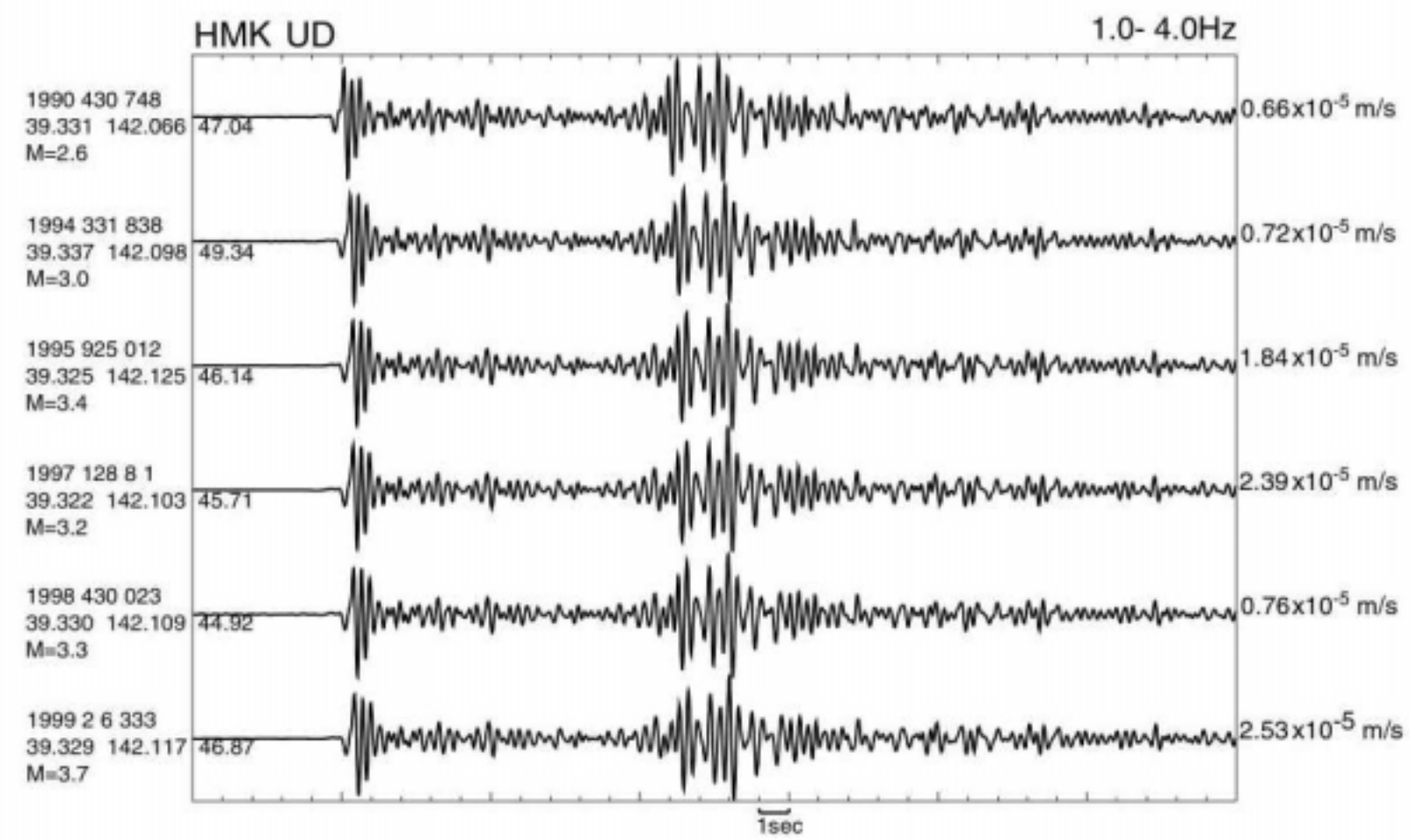
13 years
1986-12-01 M6.0
16 years
2002-11-03 M6.1

Hasegawa et al.,
SSJ Fall Meeting,
C36, 2002.

Small Repeaters in and around NE Honshu

- Waveform Similarity



Small Repeaters in and around NE Honshu

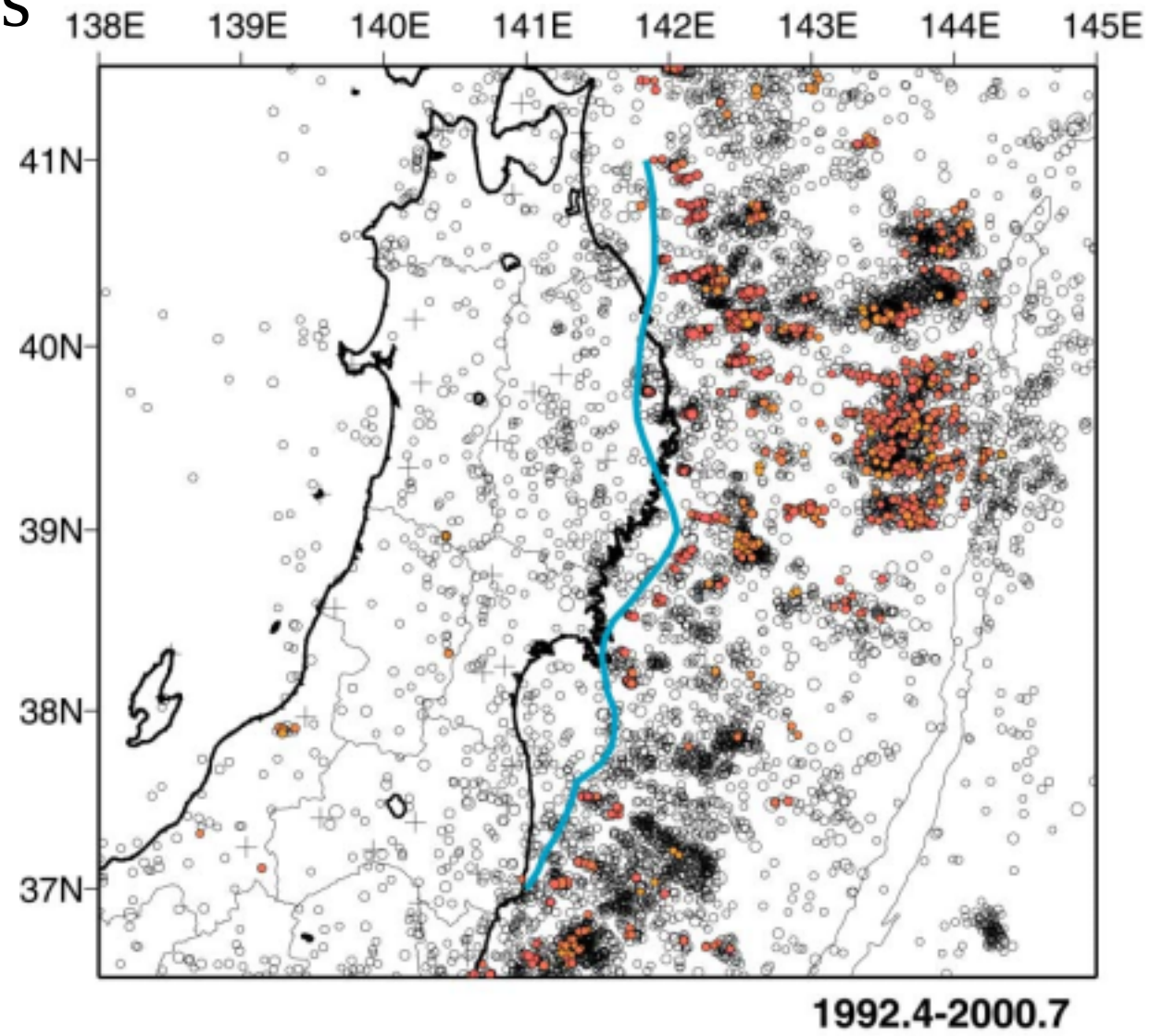
- Locations

M >= 3.0

Intermediate-Depth Events. and Events below the Pacific Ocean

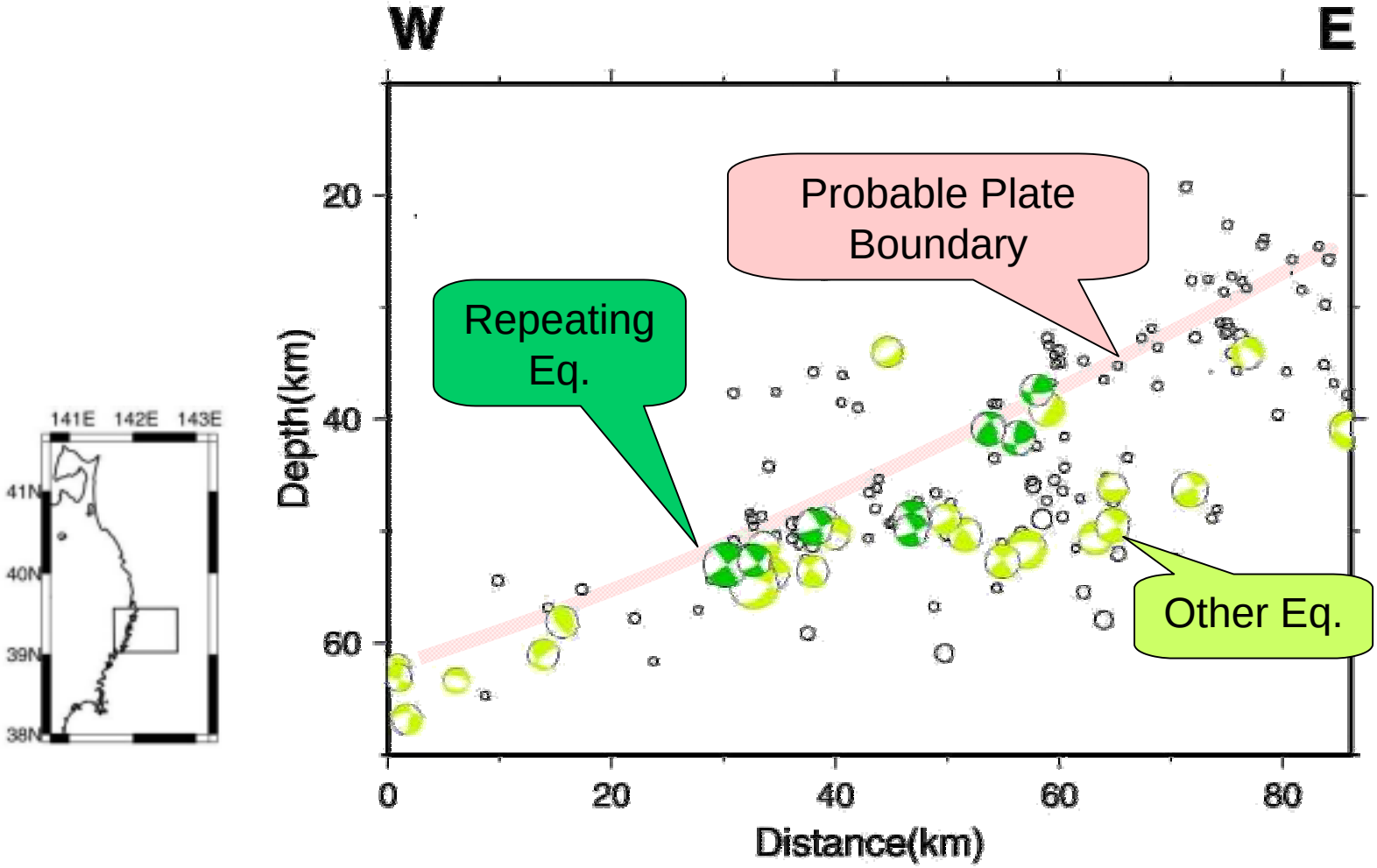
• : Repeating Eq.

: Western Limit of the Distribution of the Low-Angle Thrust Fault Type Events (Igarashi et al., 2001)



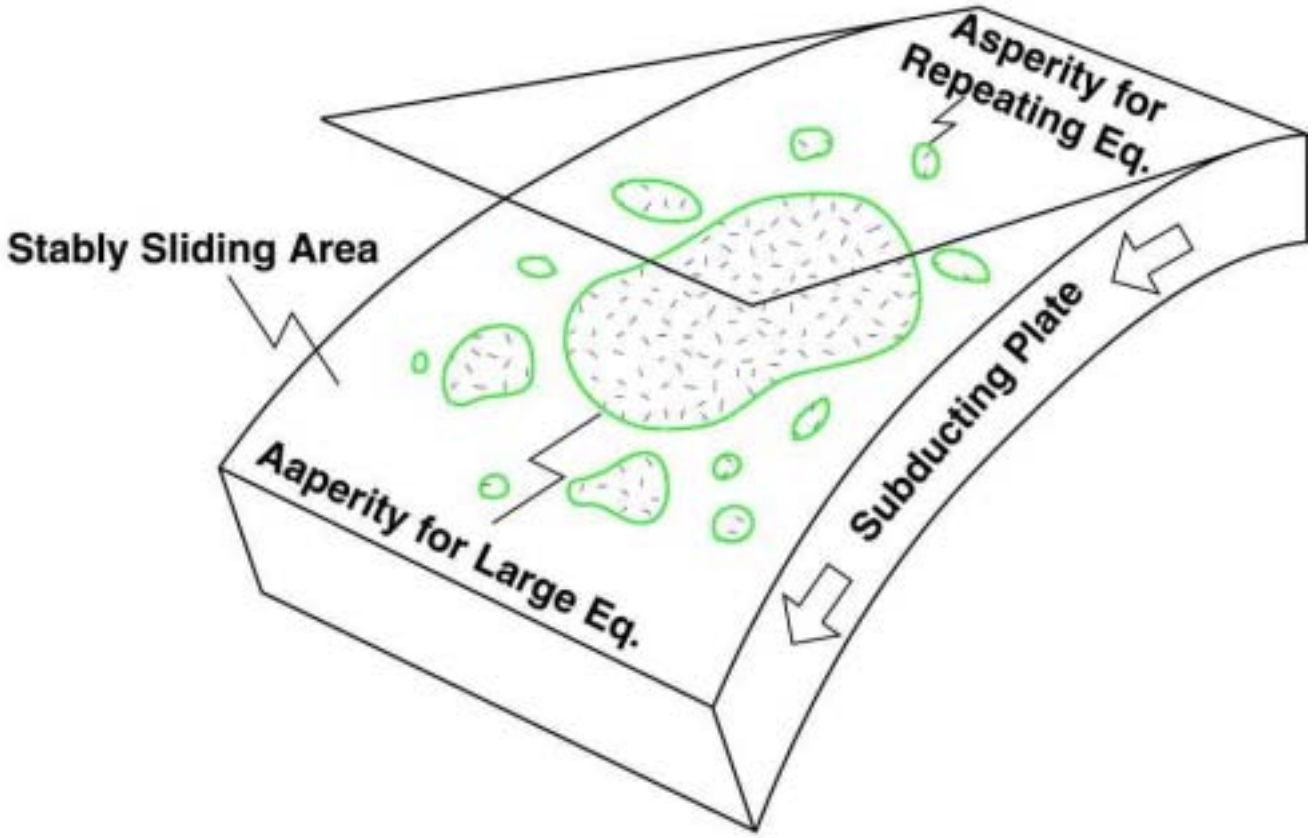
Small Repeaters in and around NE Honshu

- Vertical Cross-Section of Hypocenter Distributions and Focal Mechanisms



Small Repeaters in and around NE Honshu

- Model



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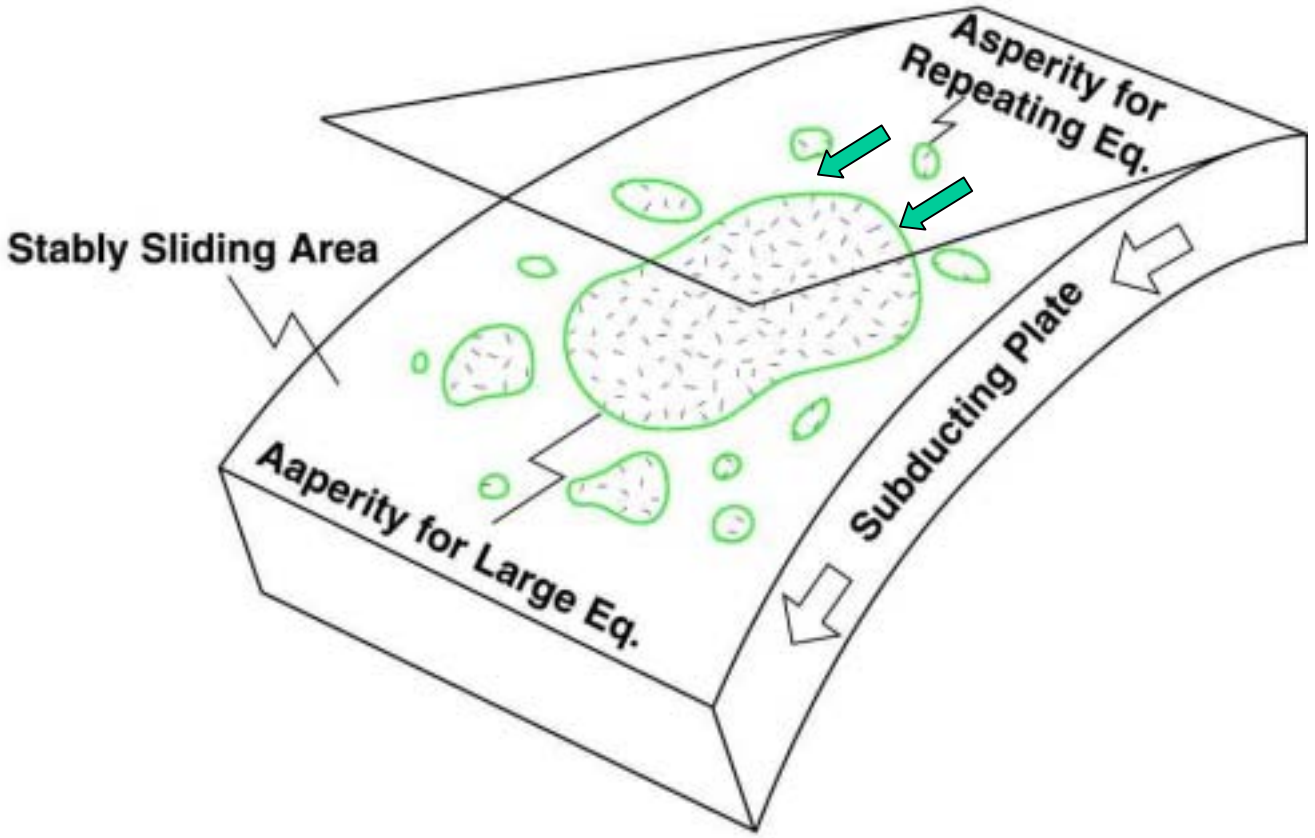

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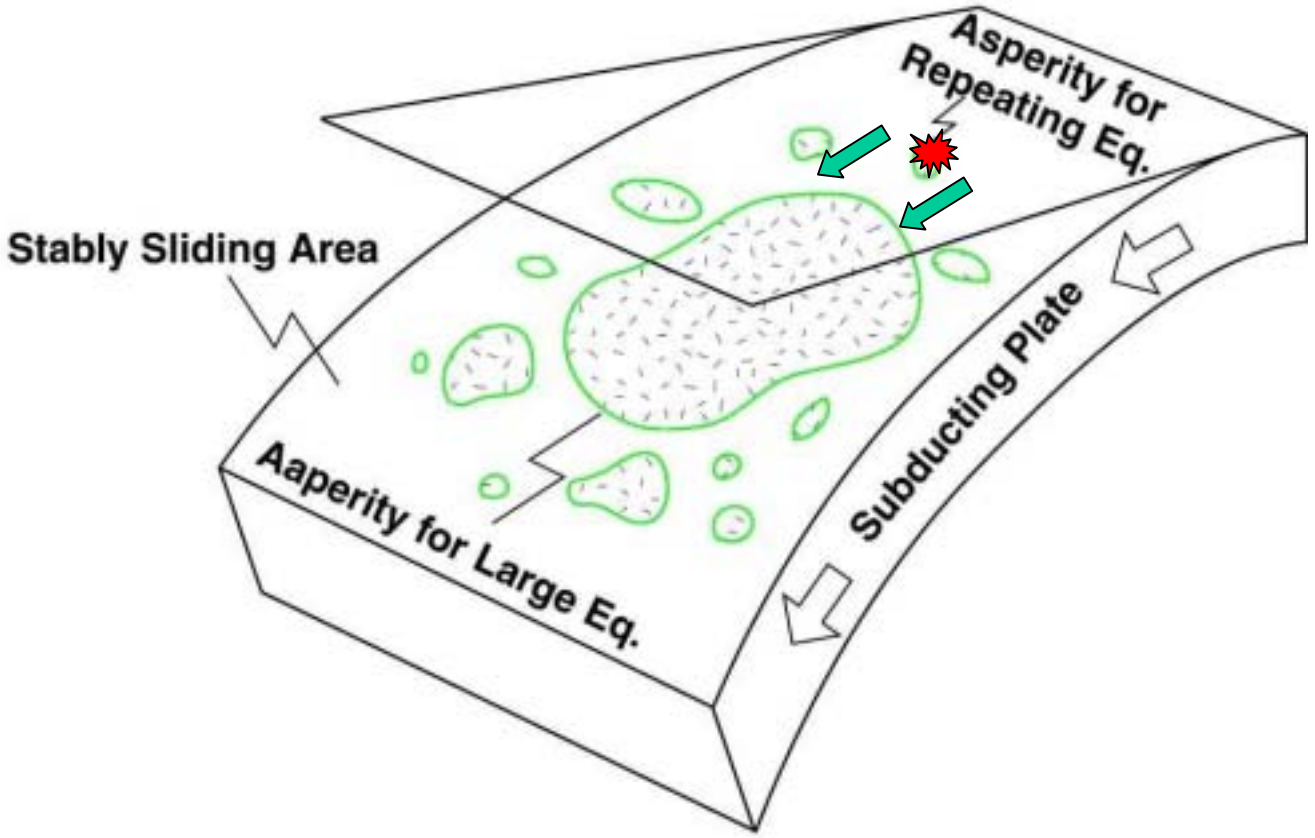

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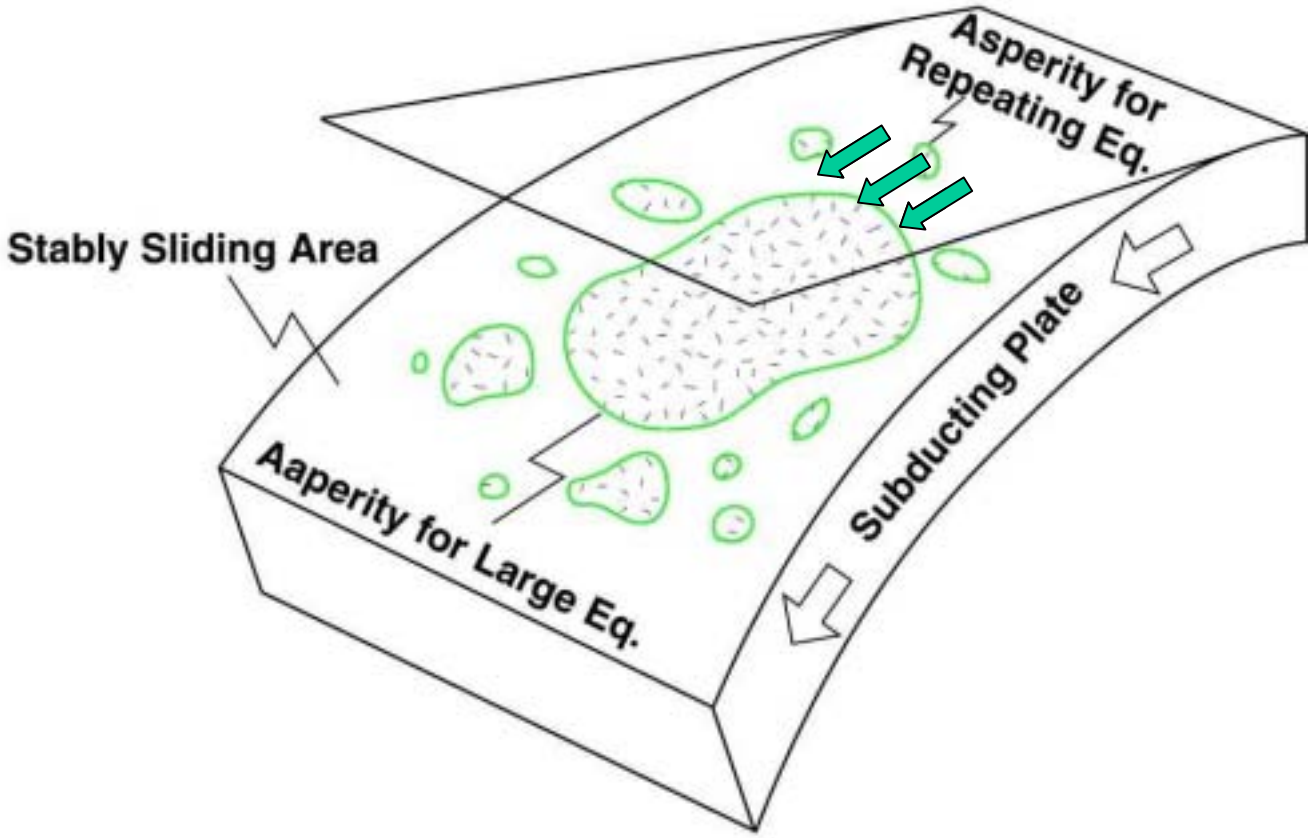
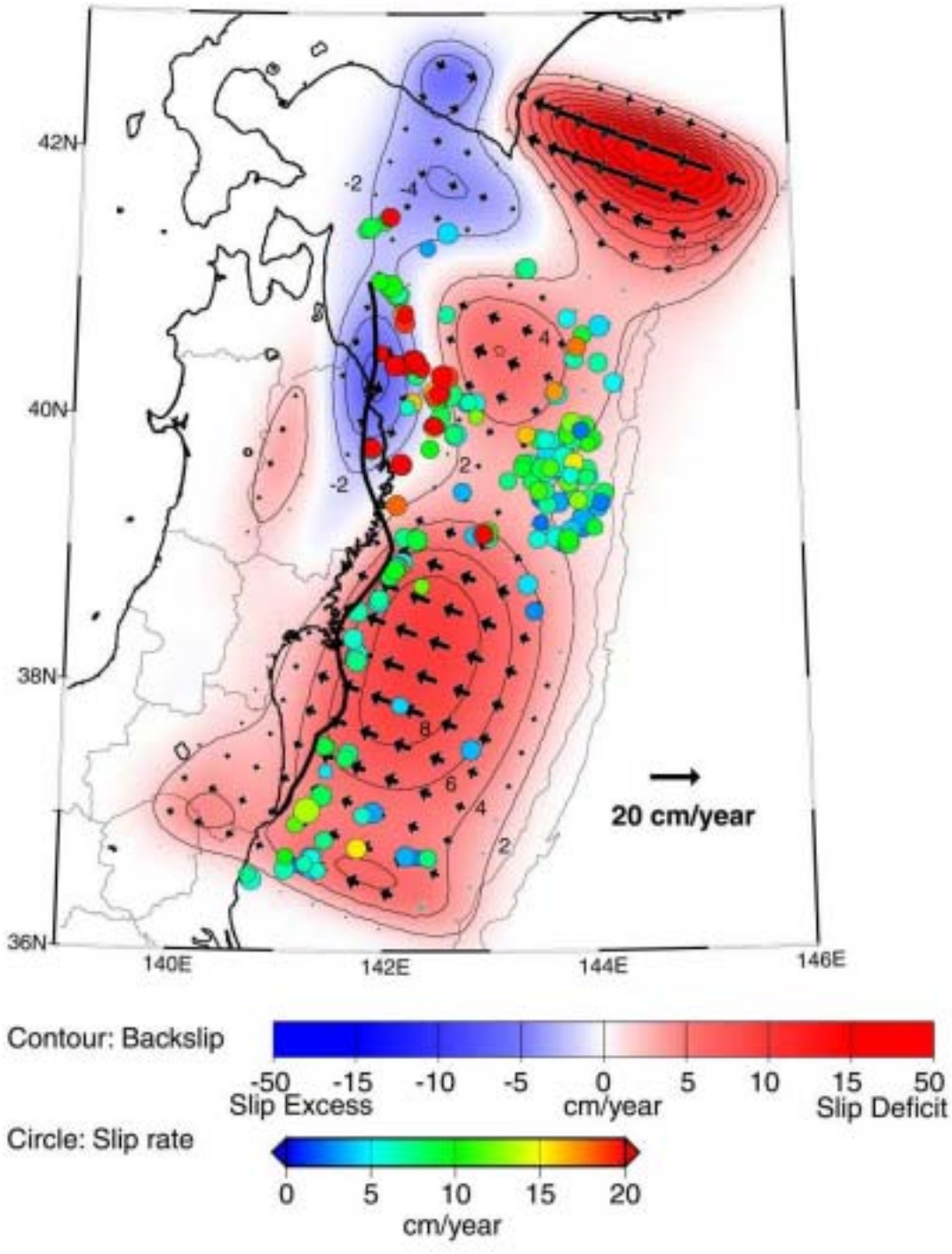


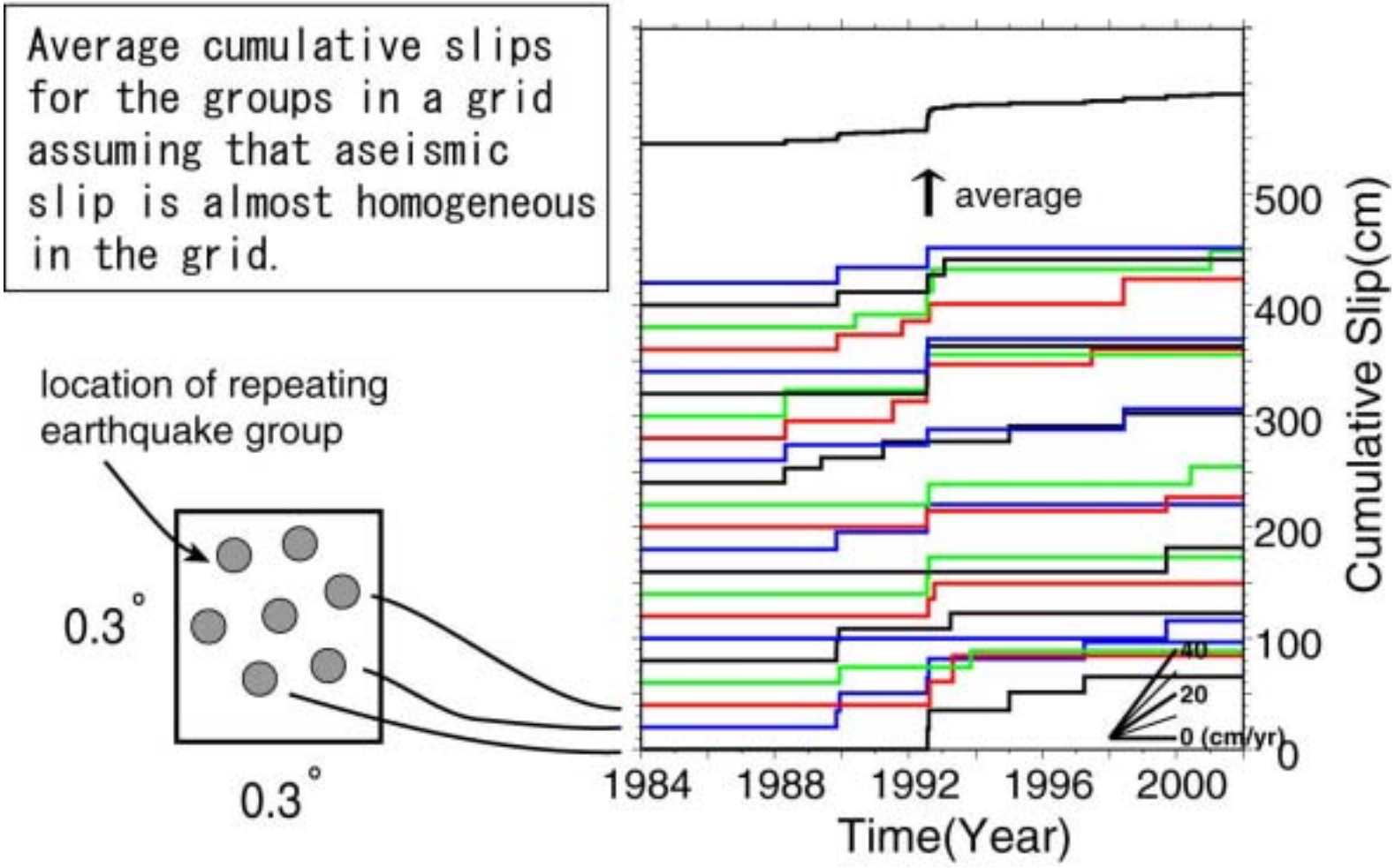
Small Repeaters in and around NE Honshu

- Slip Rate Distribution
  - Contour: Back Slip Rate Estimated from GPS (Nishimura, 2000)
  - Circle: Slip Rate Estimated from Repeater



Slip Rate Distribution off Sanriku

- Stacking of the Cumulative Slips



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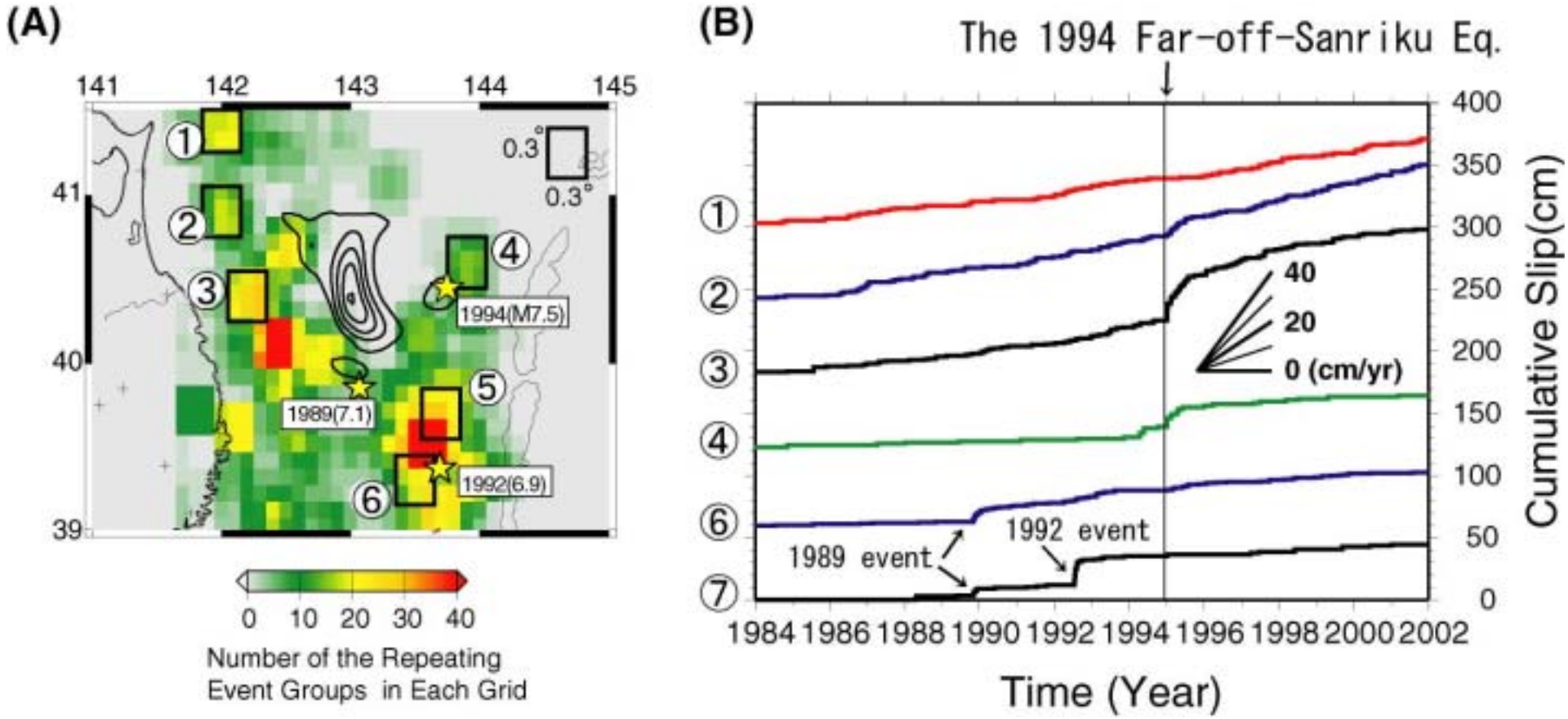
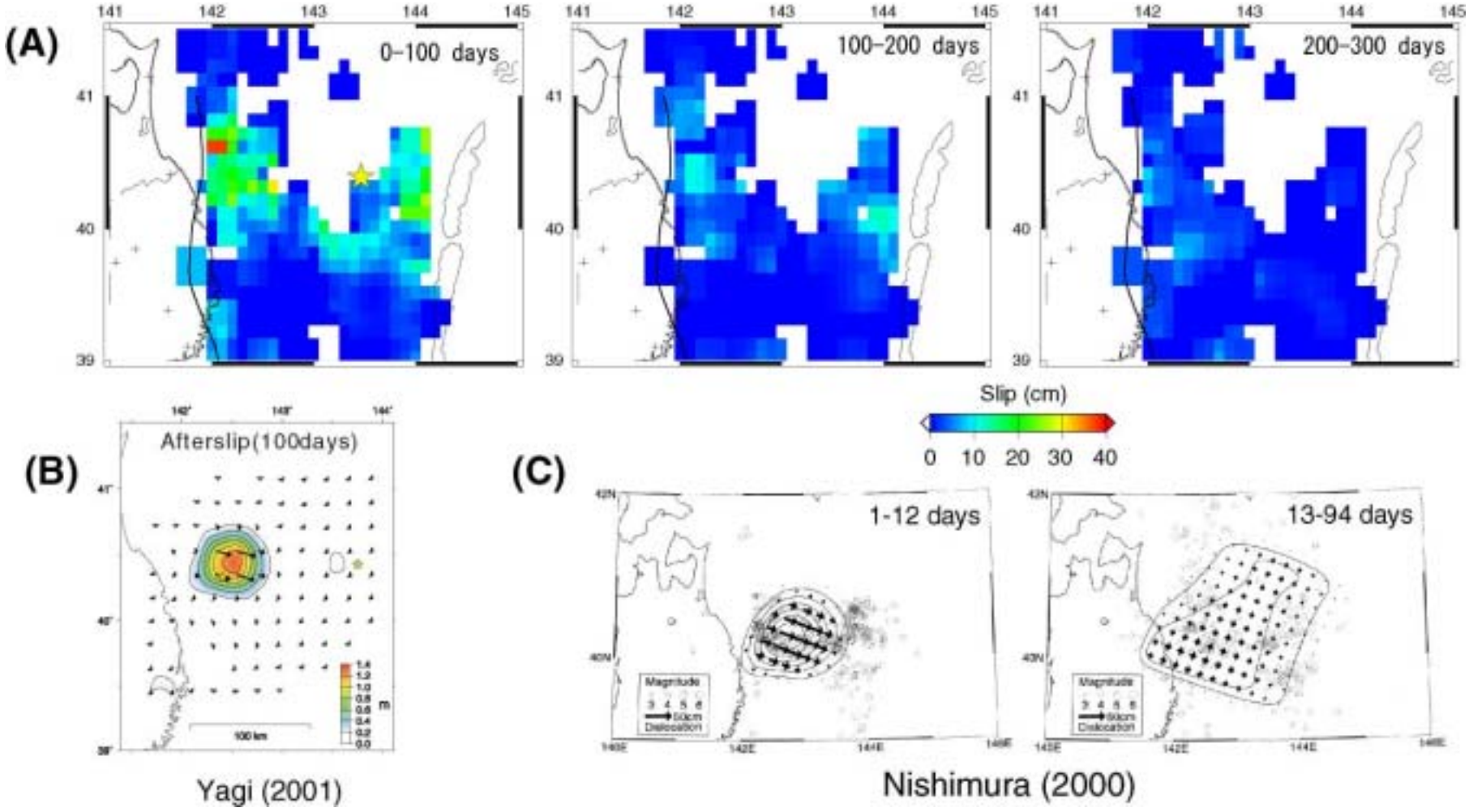


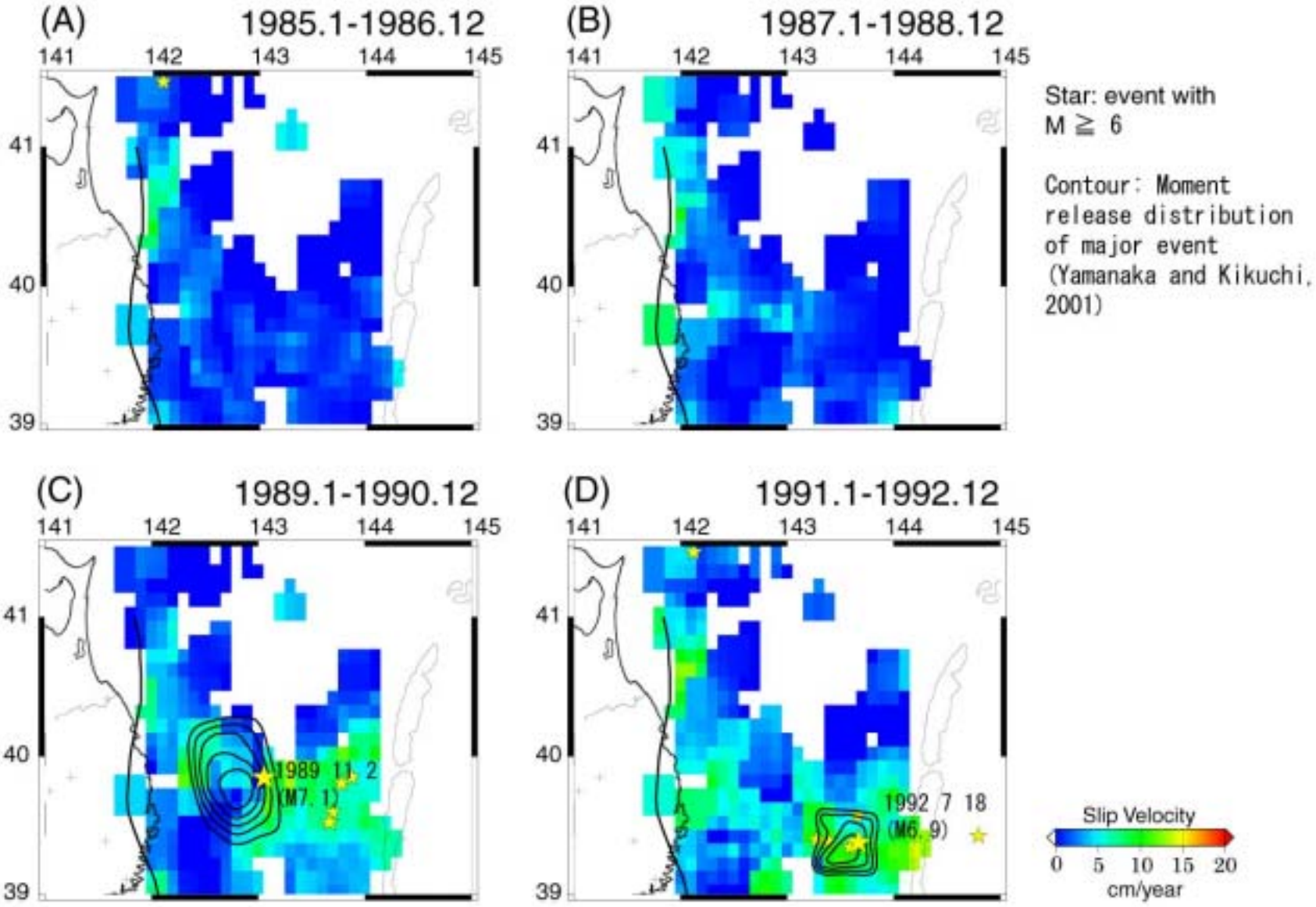
Slip Rate Distribution off Sanriku

- Afterslip Distribution of the 1994 Far-off Sanriku Eq.



Slip Rate Distribution off Sanriku

- Distribution for Every Two Years (1985-1992)



Slip Rate Distribution off Sanriku

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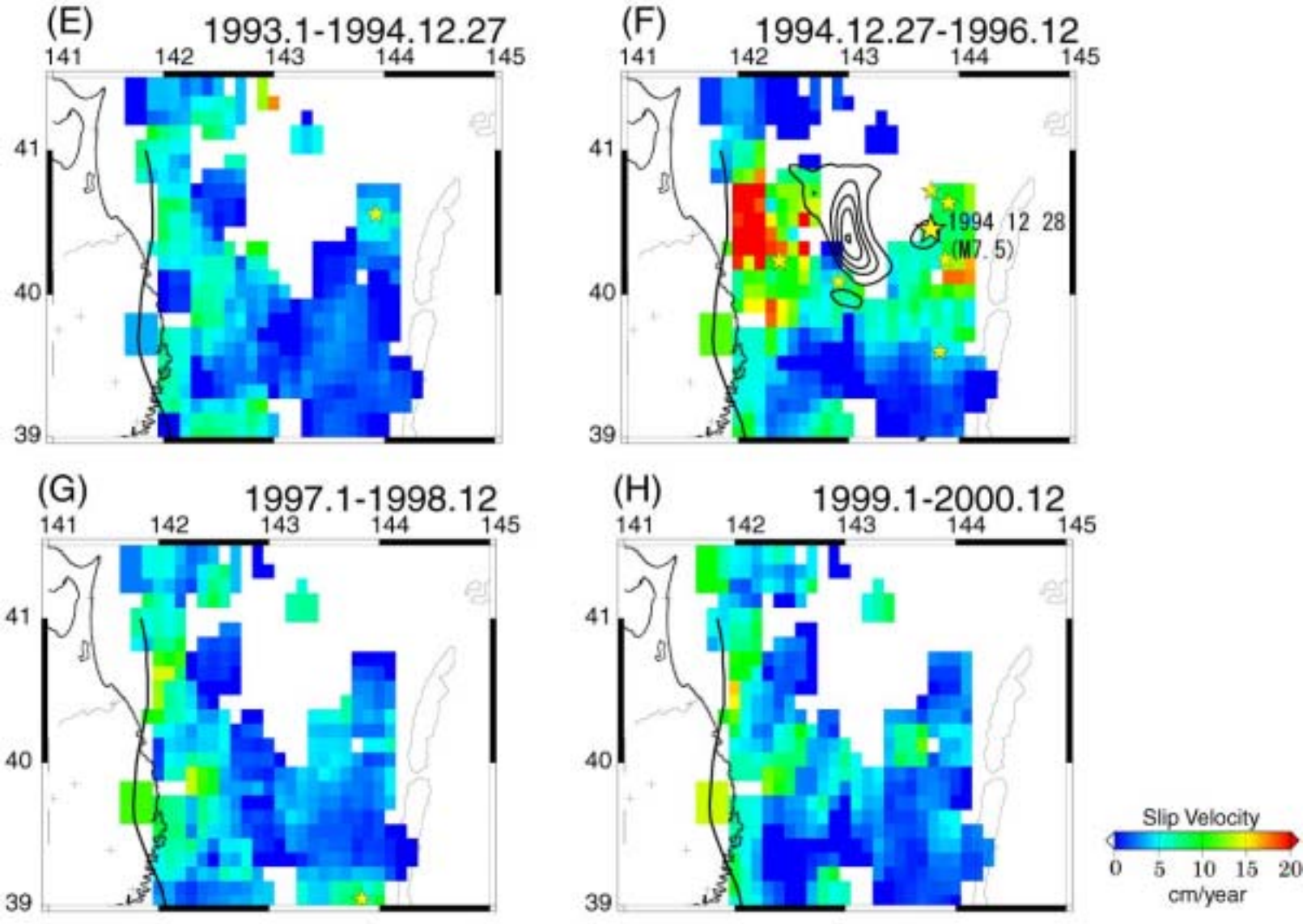
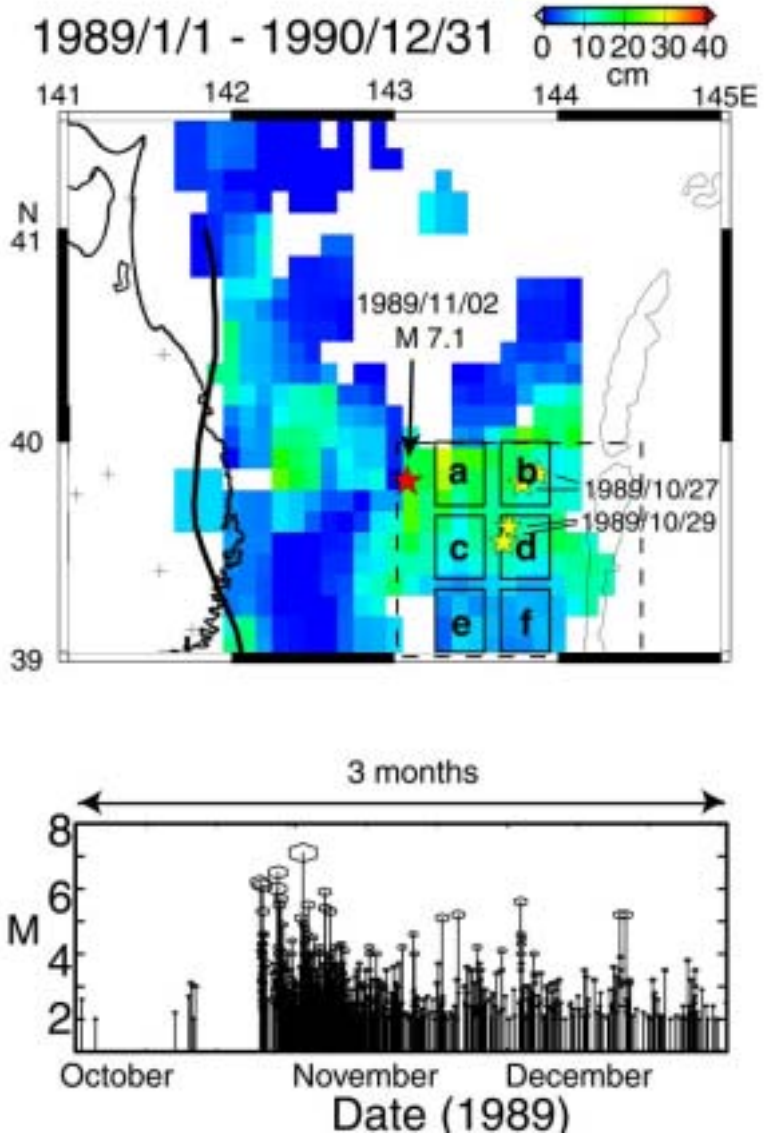
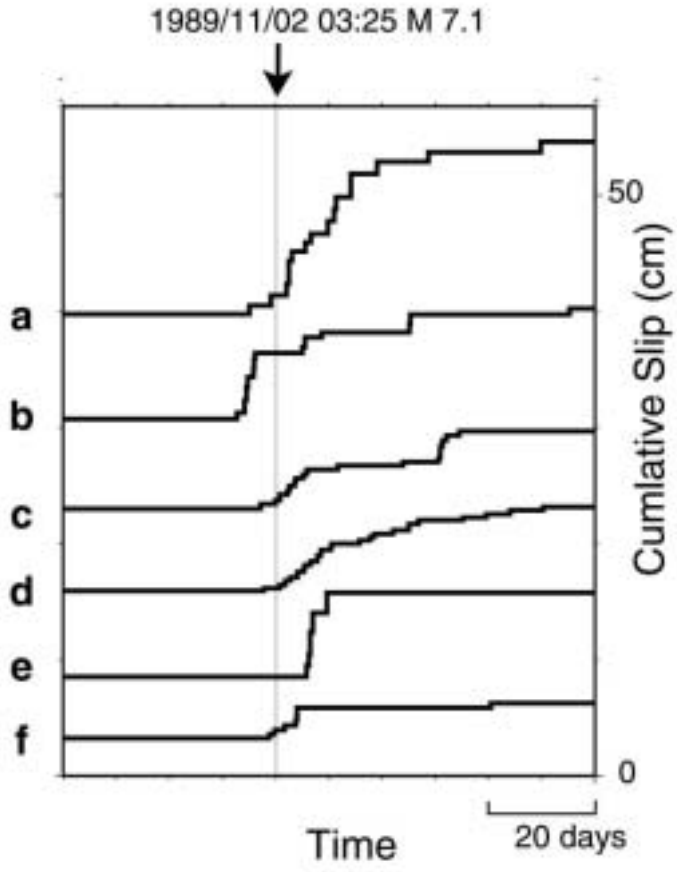


Slow Slip and Earthquake Swarm

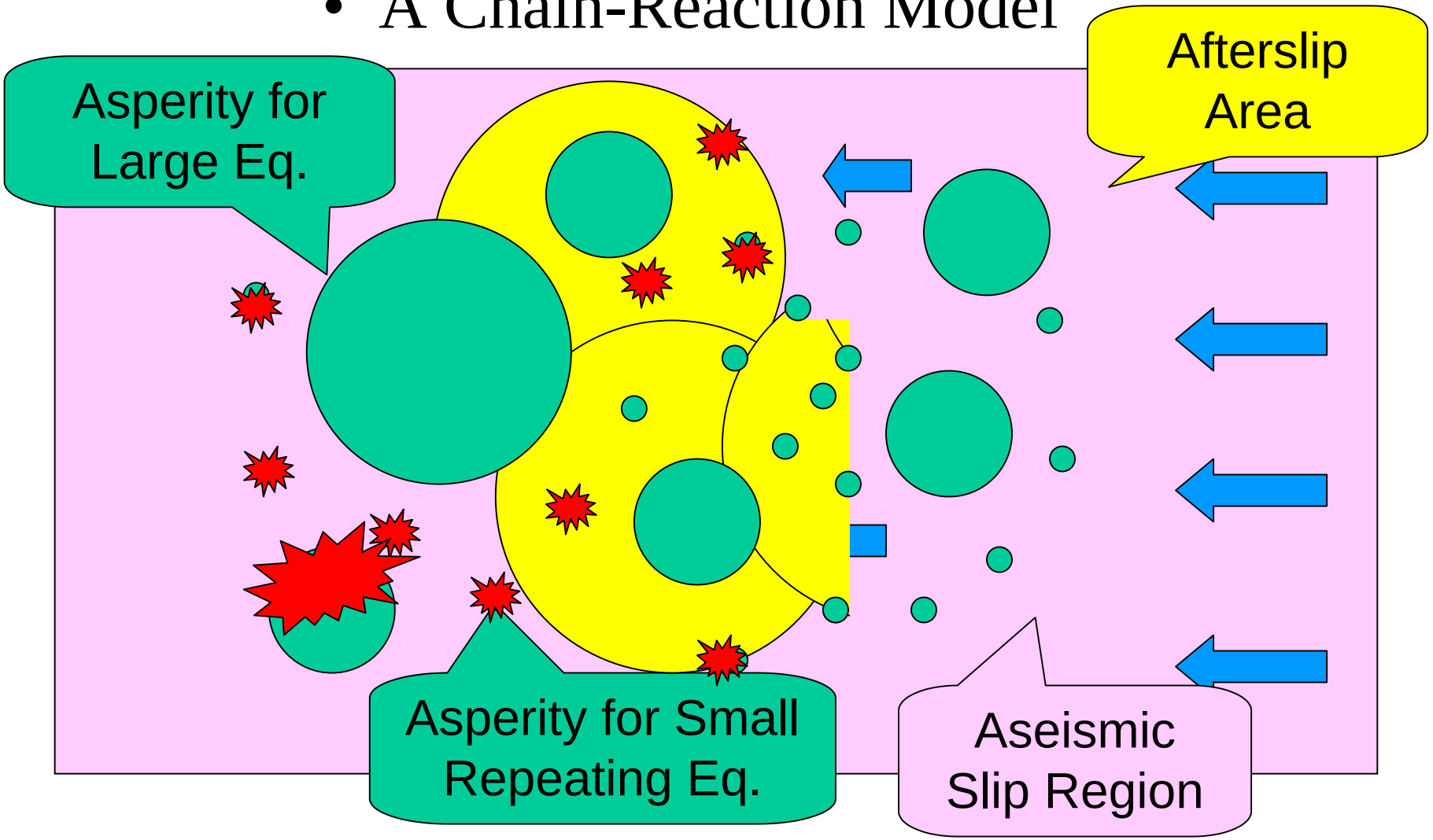
- The 1989 Swarm





Slow Slip and Earthquake Swarm

- A Chain-Reaction Model



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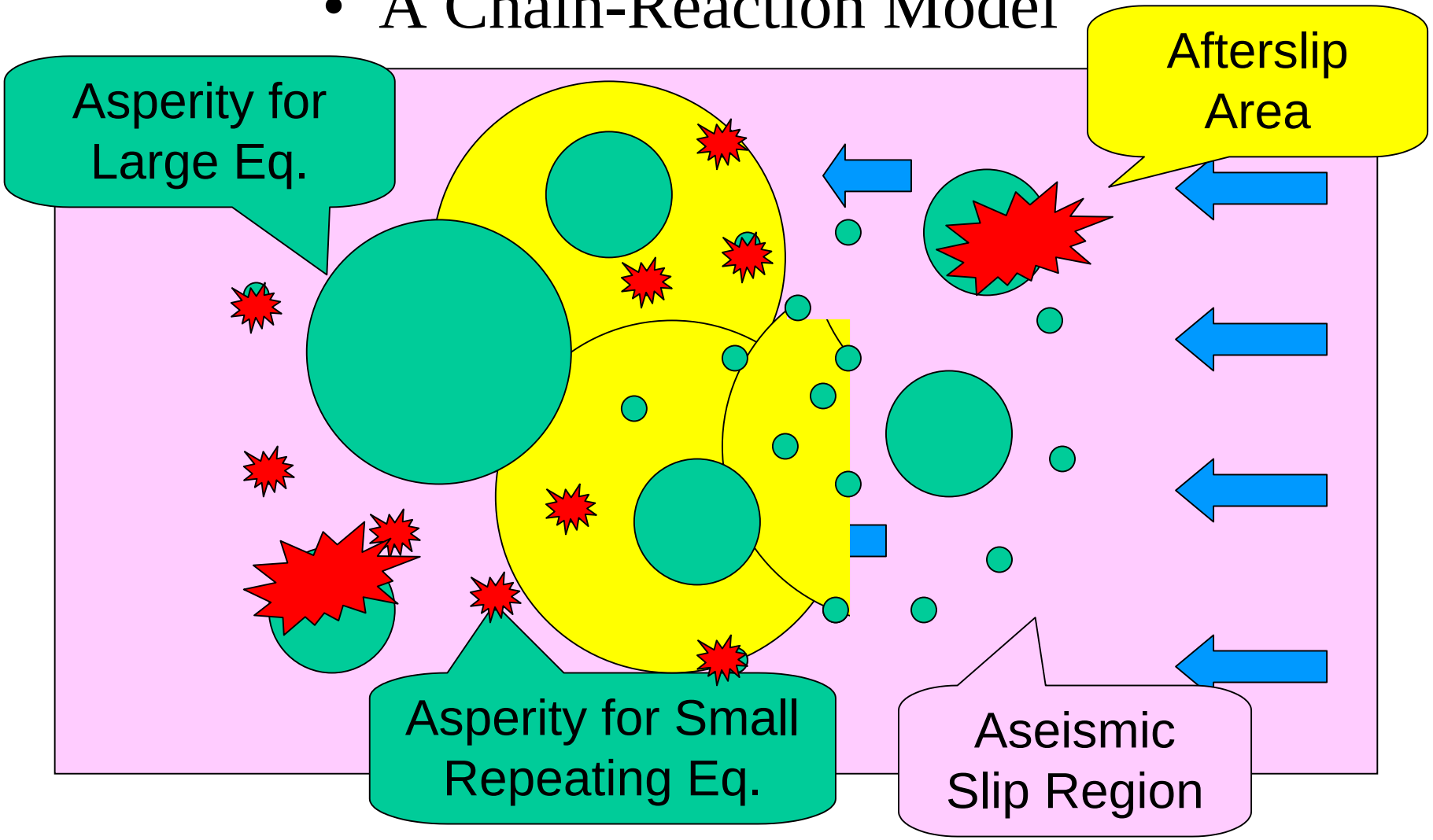

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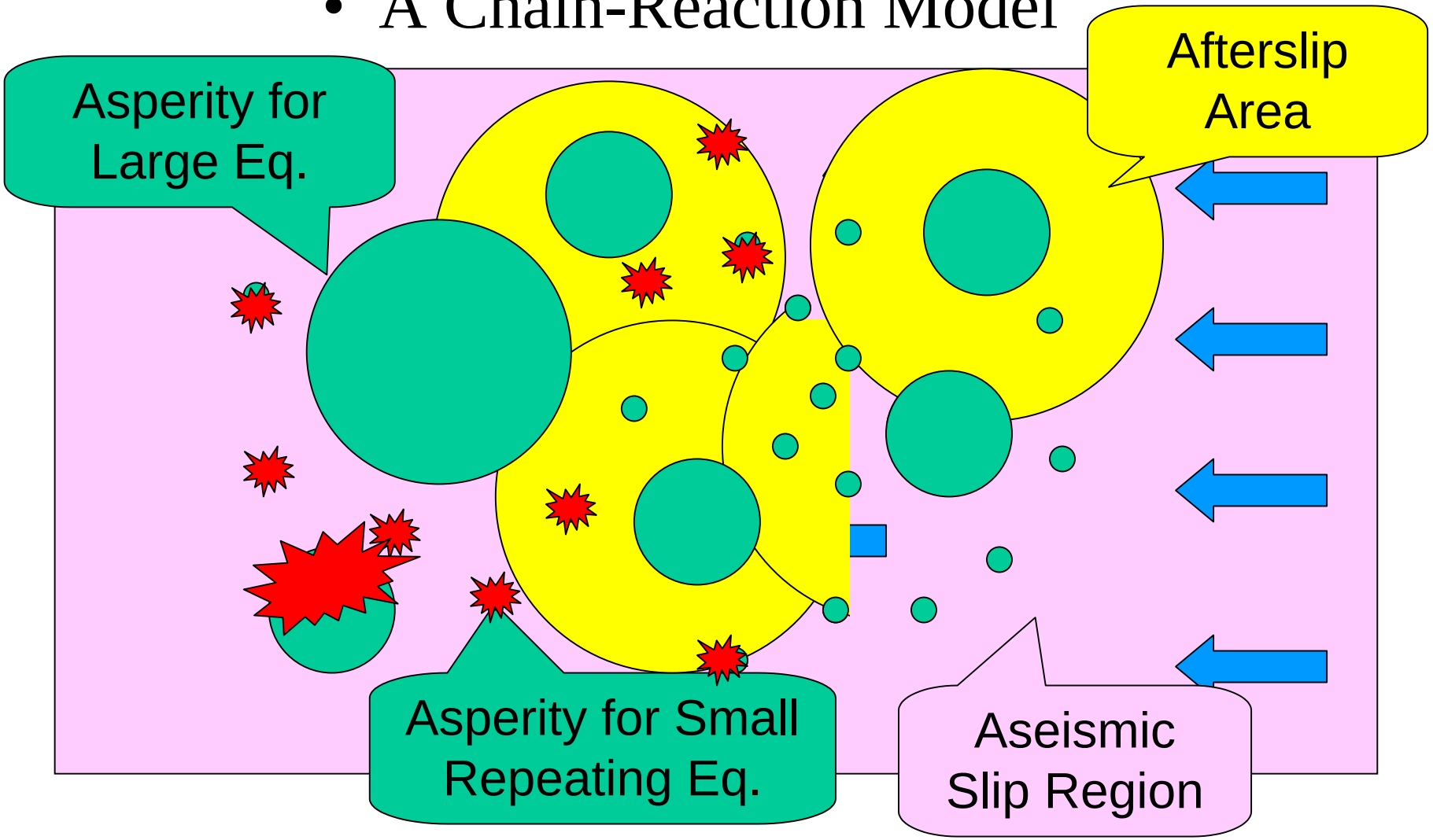

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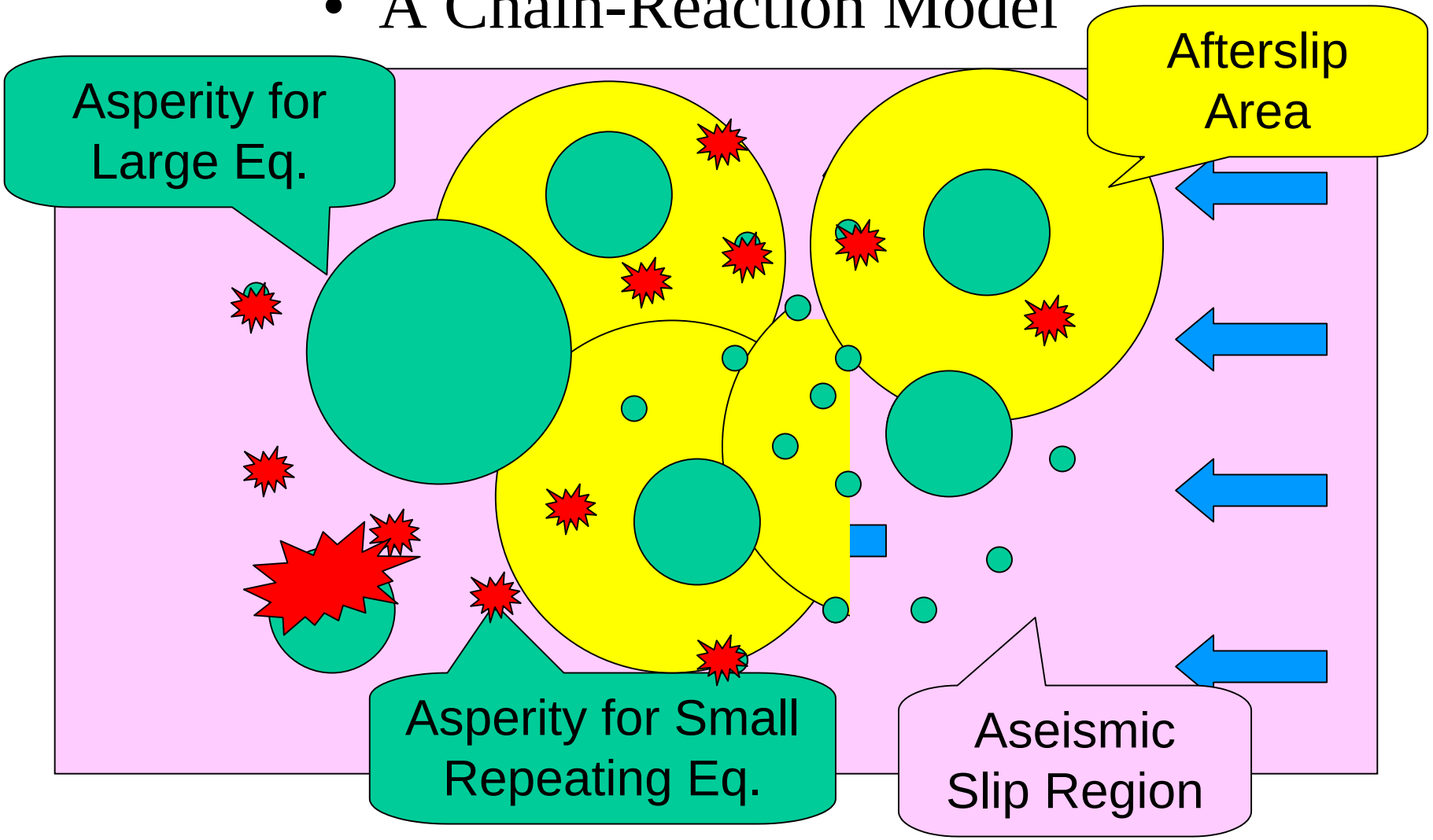

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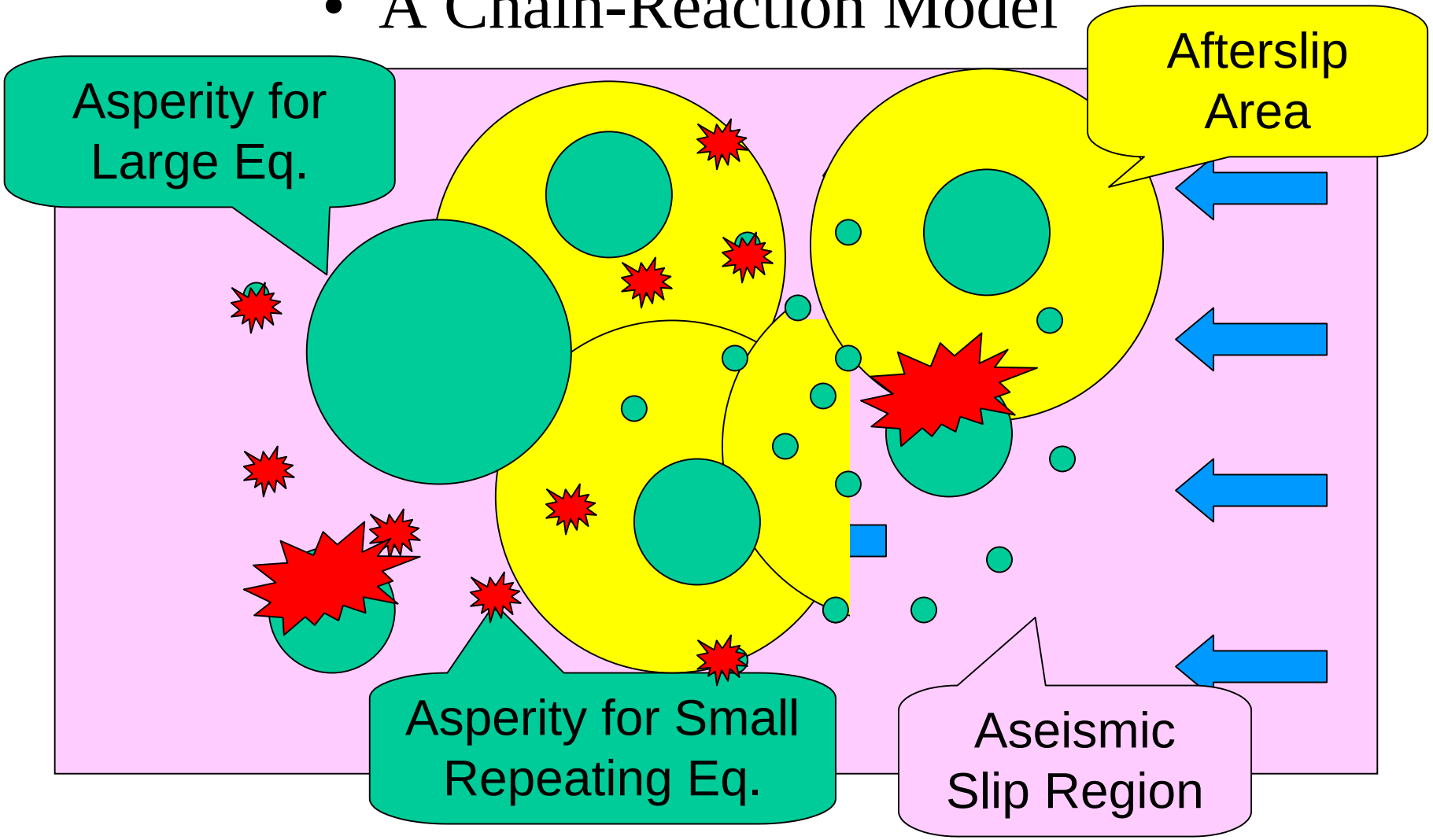

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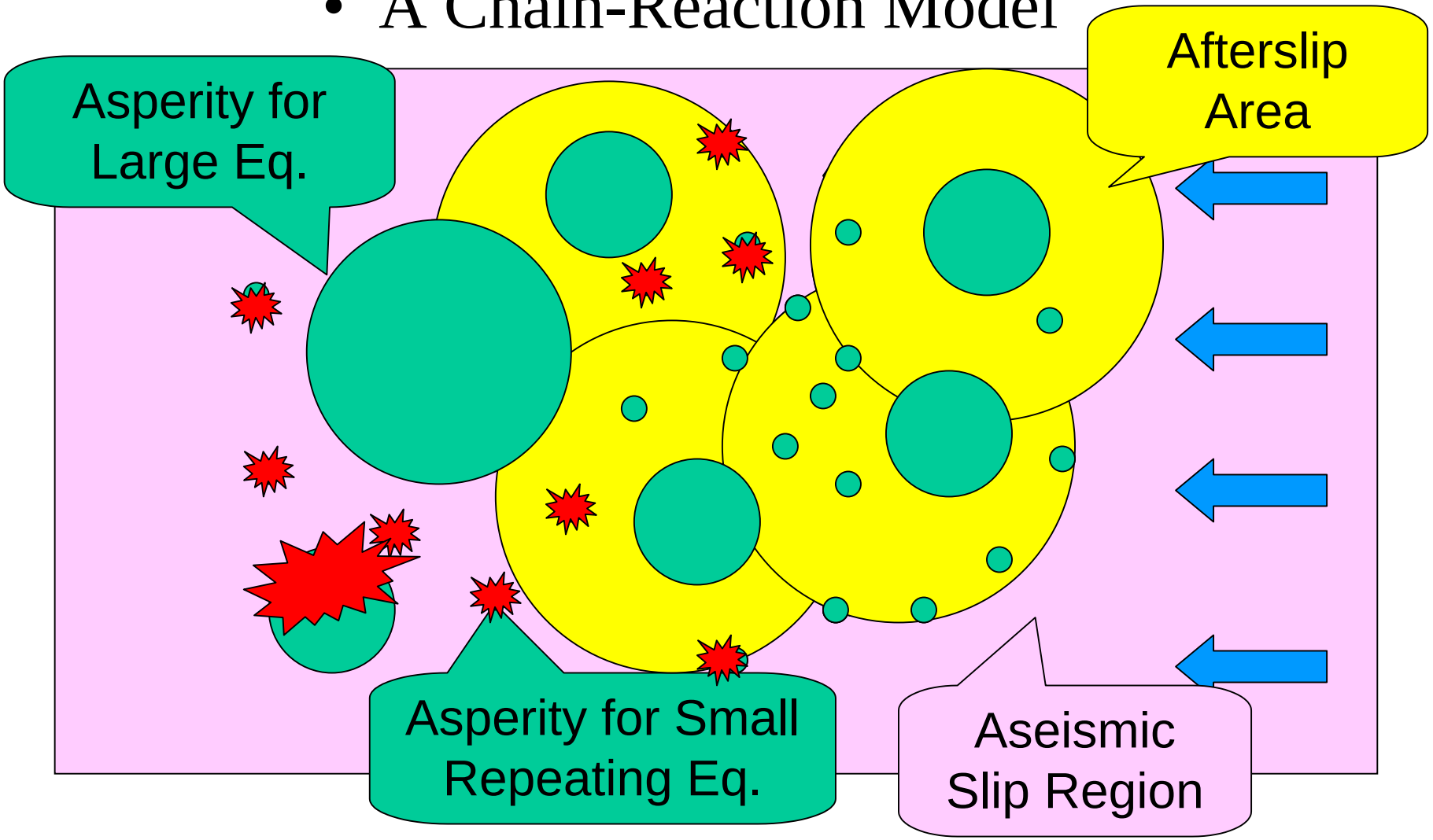

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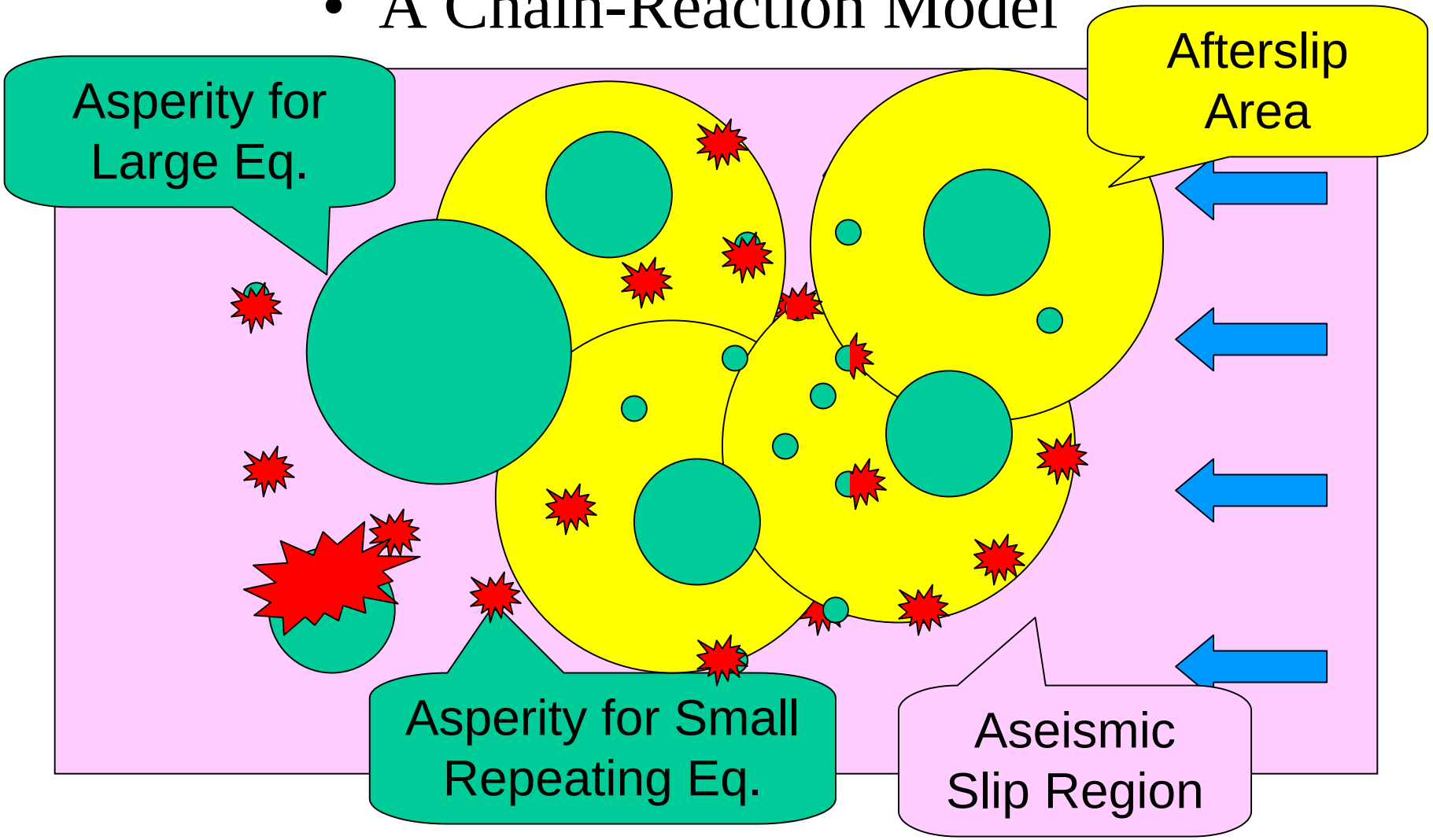

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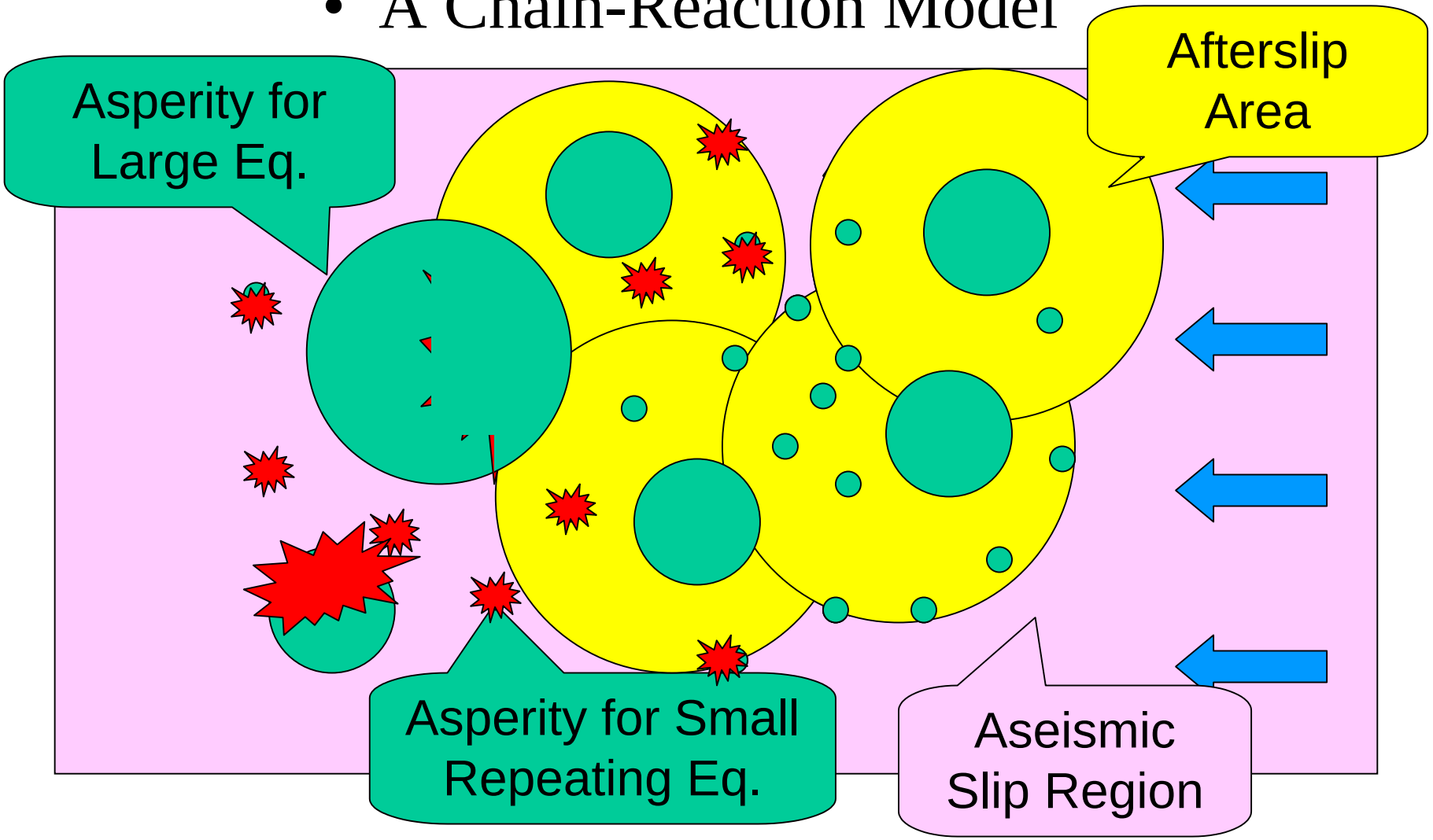

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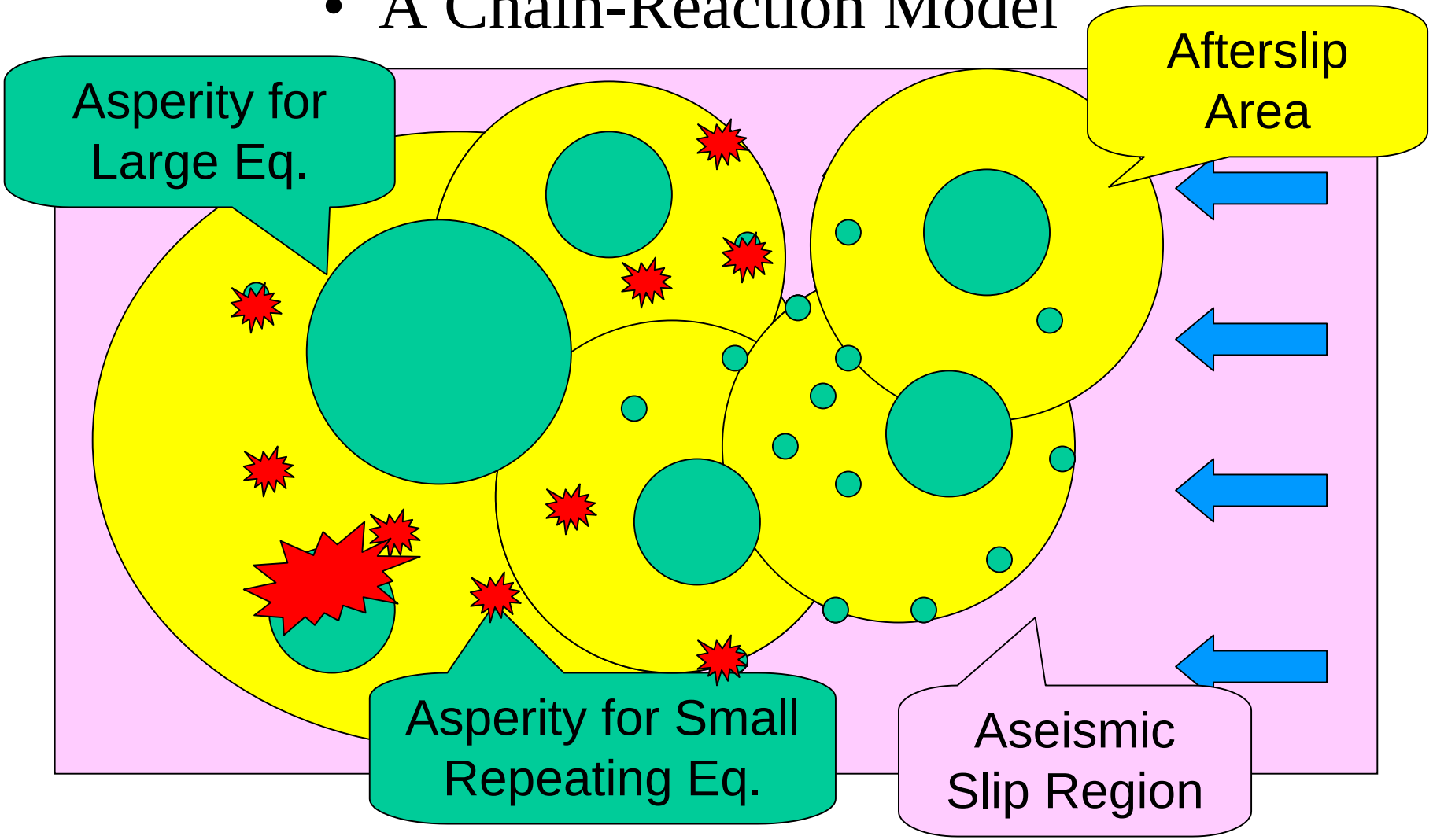

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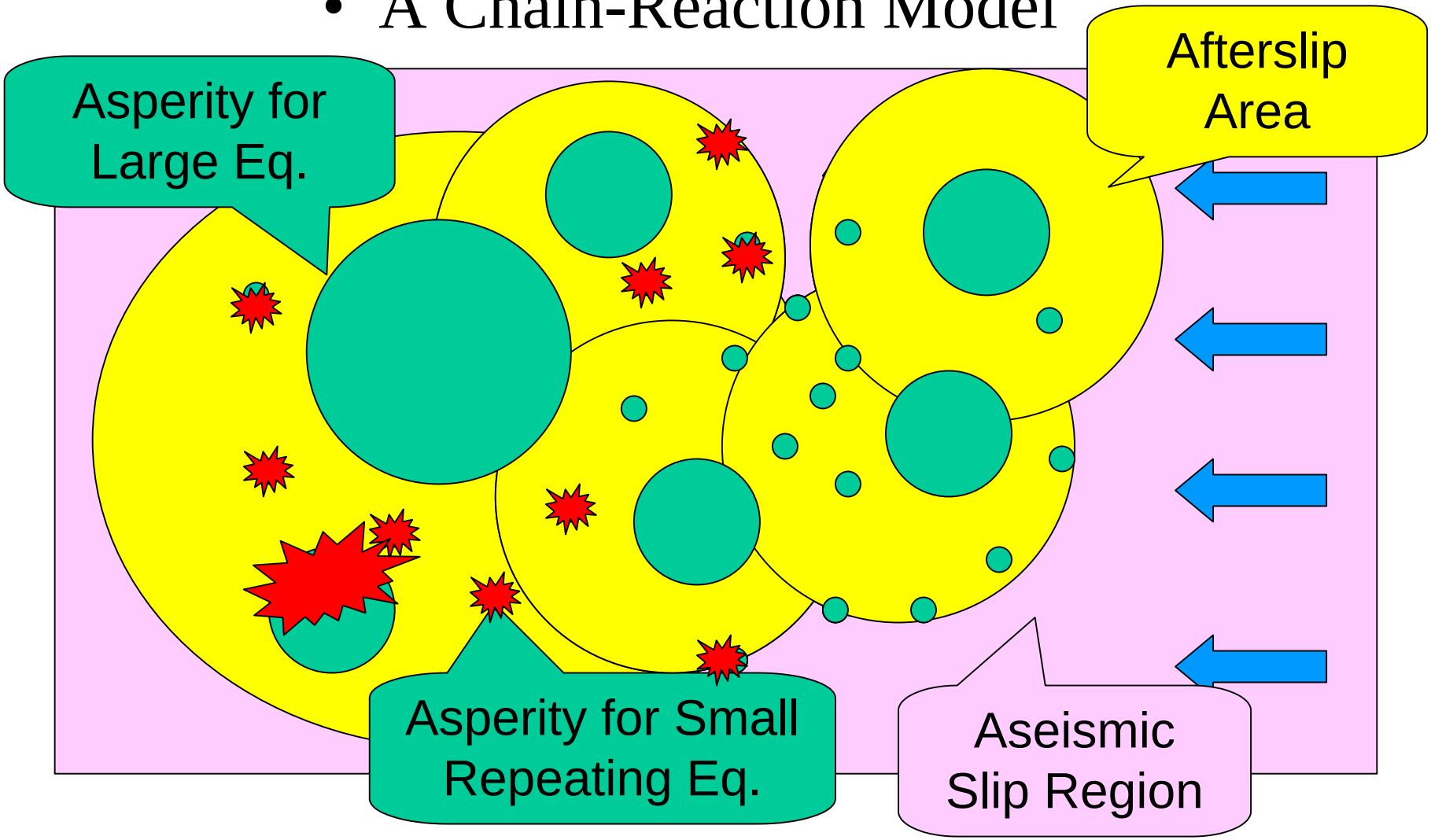


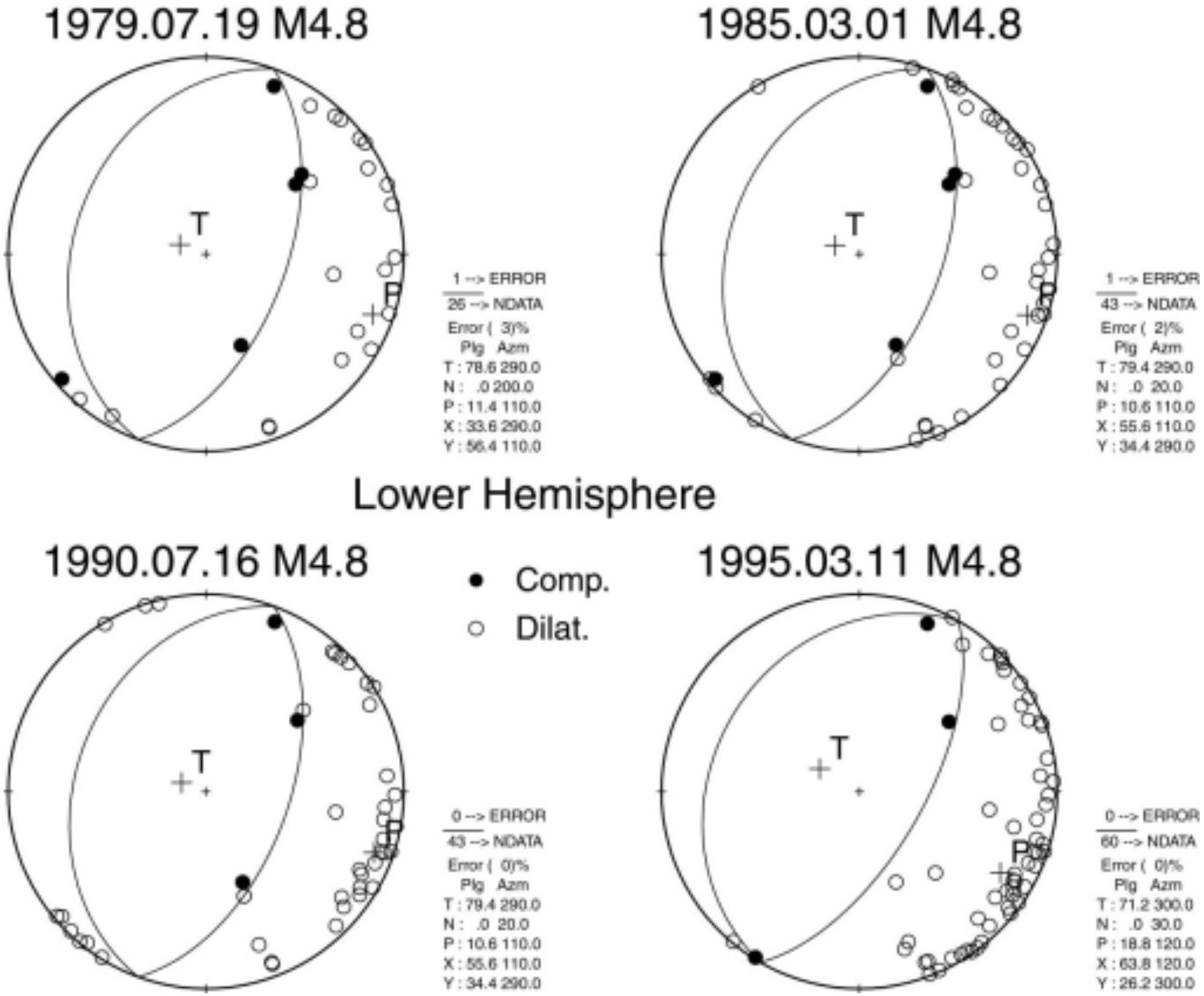
Question: Which Come First, Earthquake or Slow Slip?

Conclusions

- Many Small Repeaters Off Sanriku.
- Repeating Eq. = Repeated Rupture of Asperity.
- Cumulative Slip of Repeating Eq = Cumulative Slip of the Surrounding Aseismic Region
- Large Events (M>=6): Always Followed by Large Afterslips.
- Swam Activity: Probably Caused by the Chain-Reaction of Seismic Slip and Aseismic Slip.

Repeaters off Kamaishi

- Focal Mechanisms



Repeaters off Kamaishi

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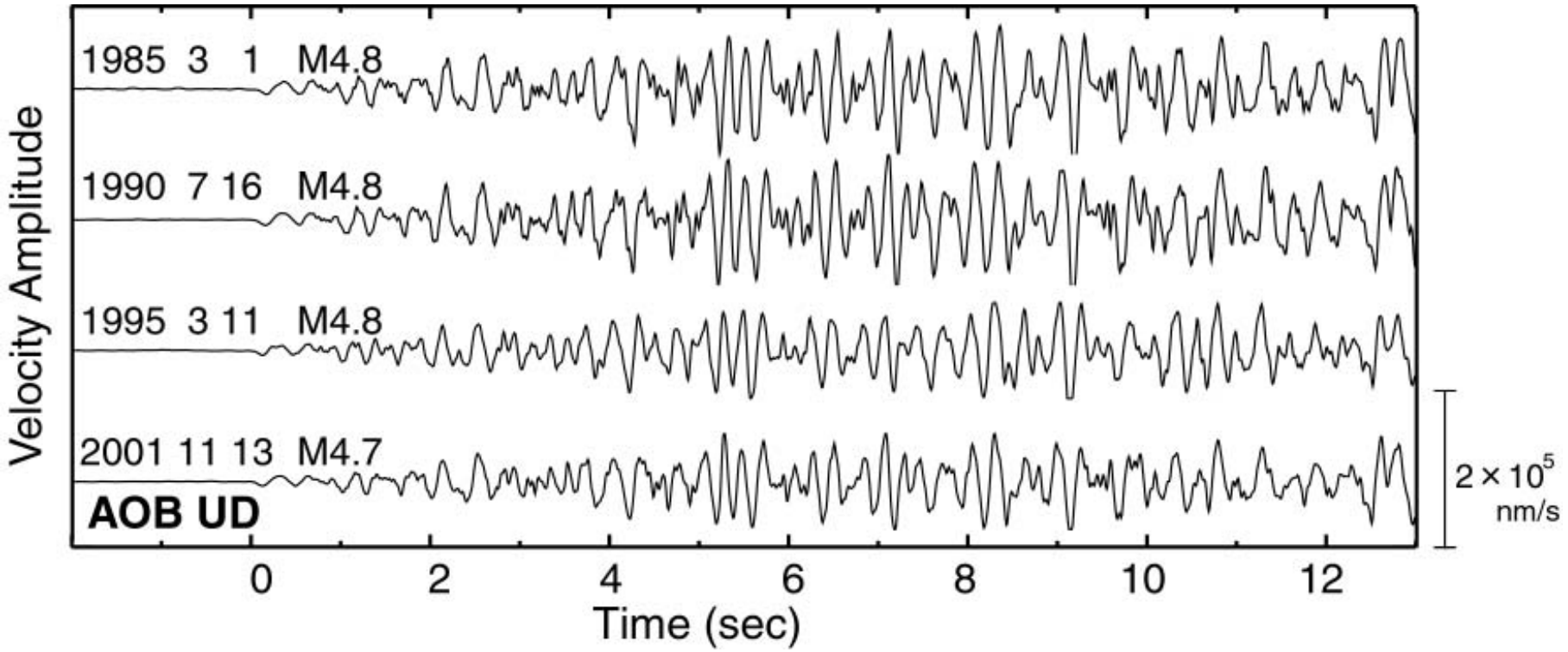
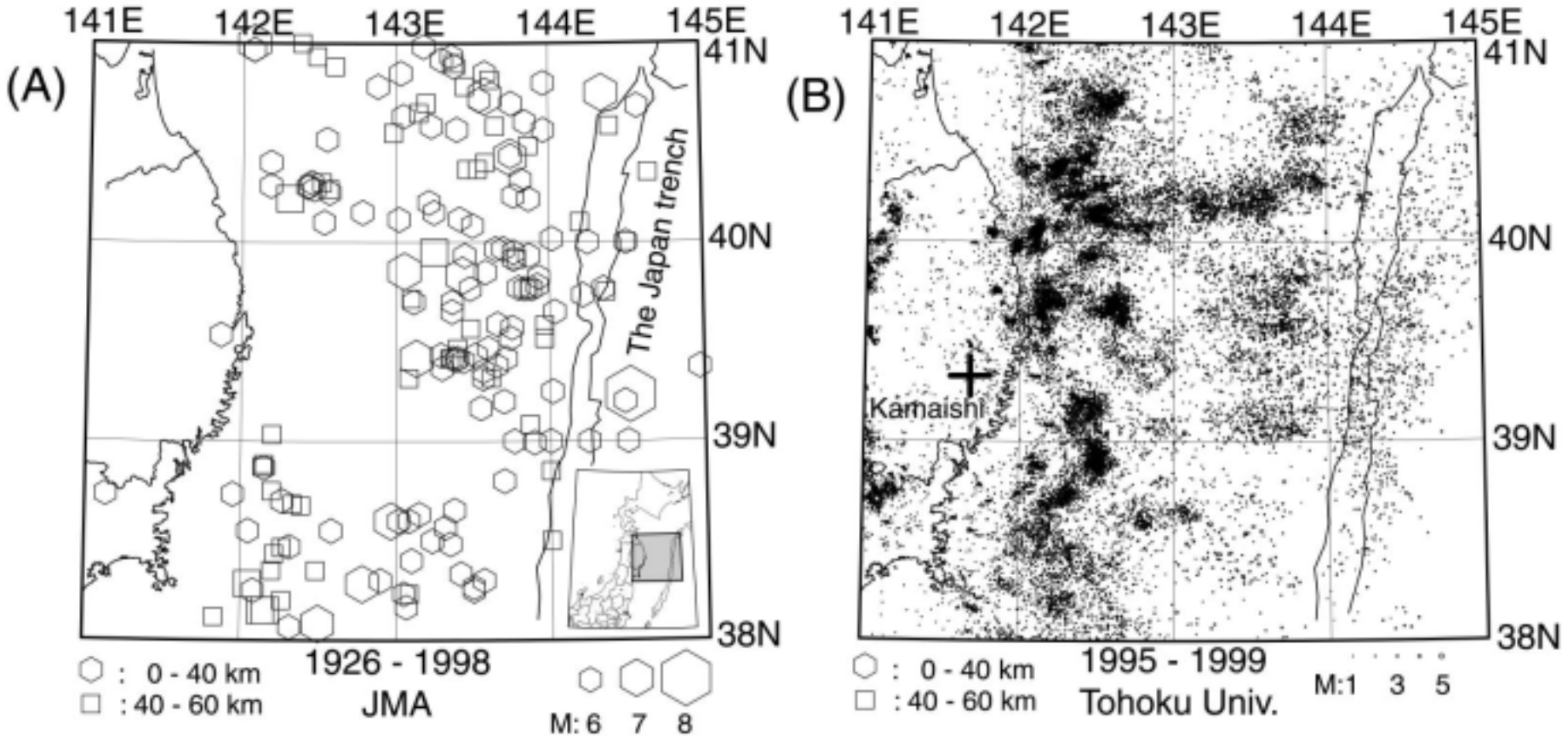


Repeaters off Miyagi Prefecture?



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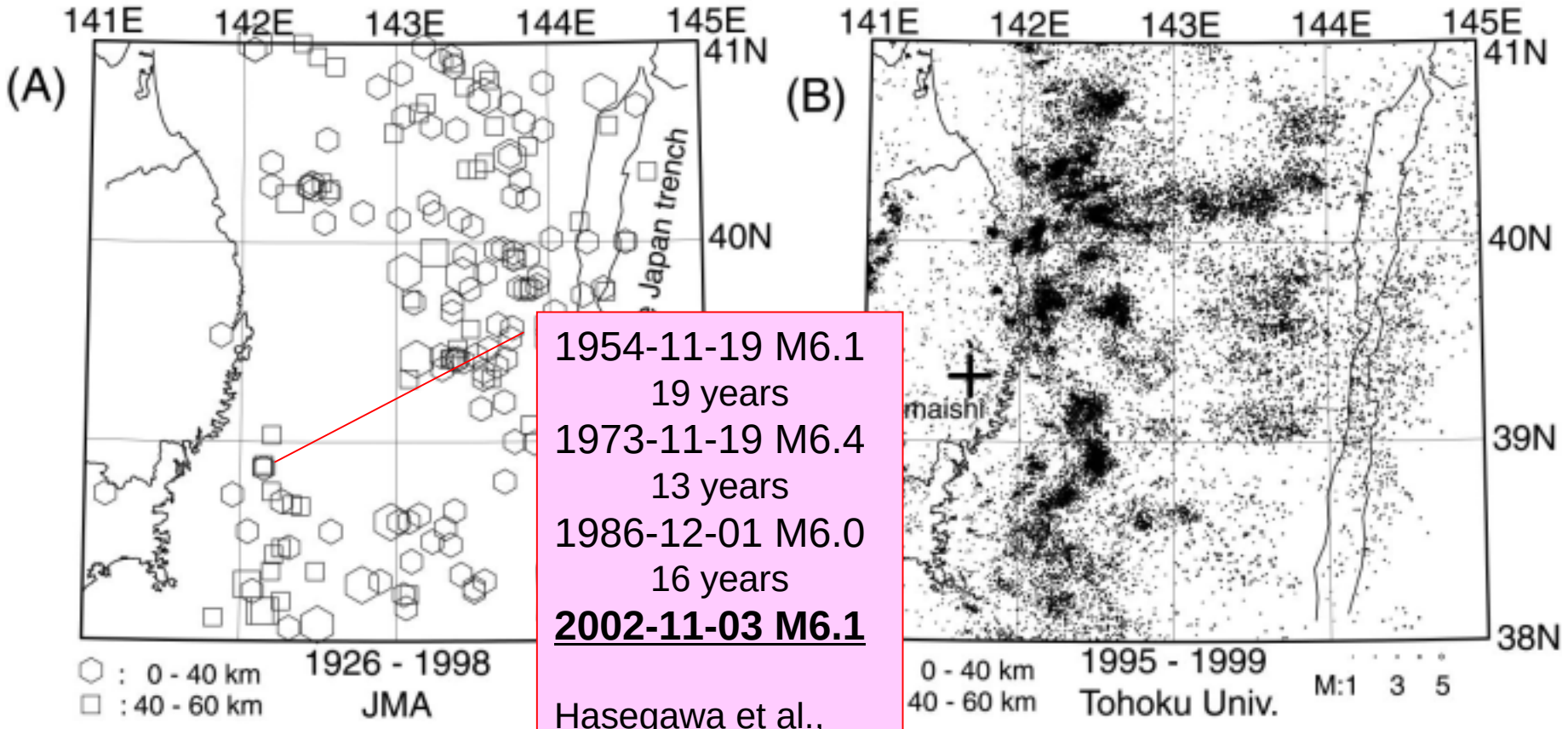

1954-11-19 M6.1
19 years
1973-11-19 M6.4
13 years
1986-12-01 M6.0
16 years
2002-11-03 M6.1

Hasegawa et al.,
SSJ Fall Meeting,
C36, 2002.

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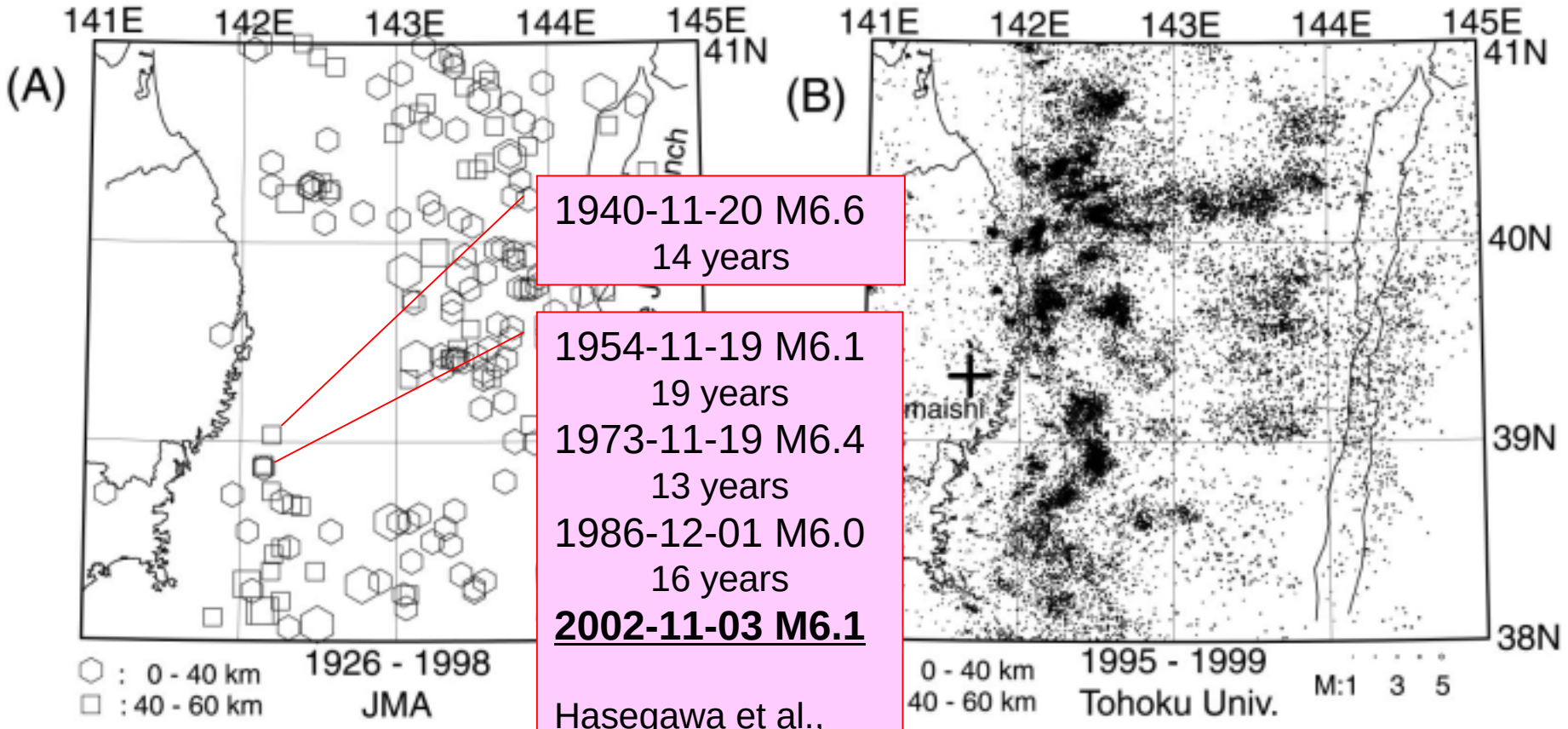

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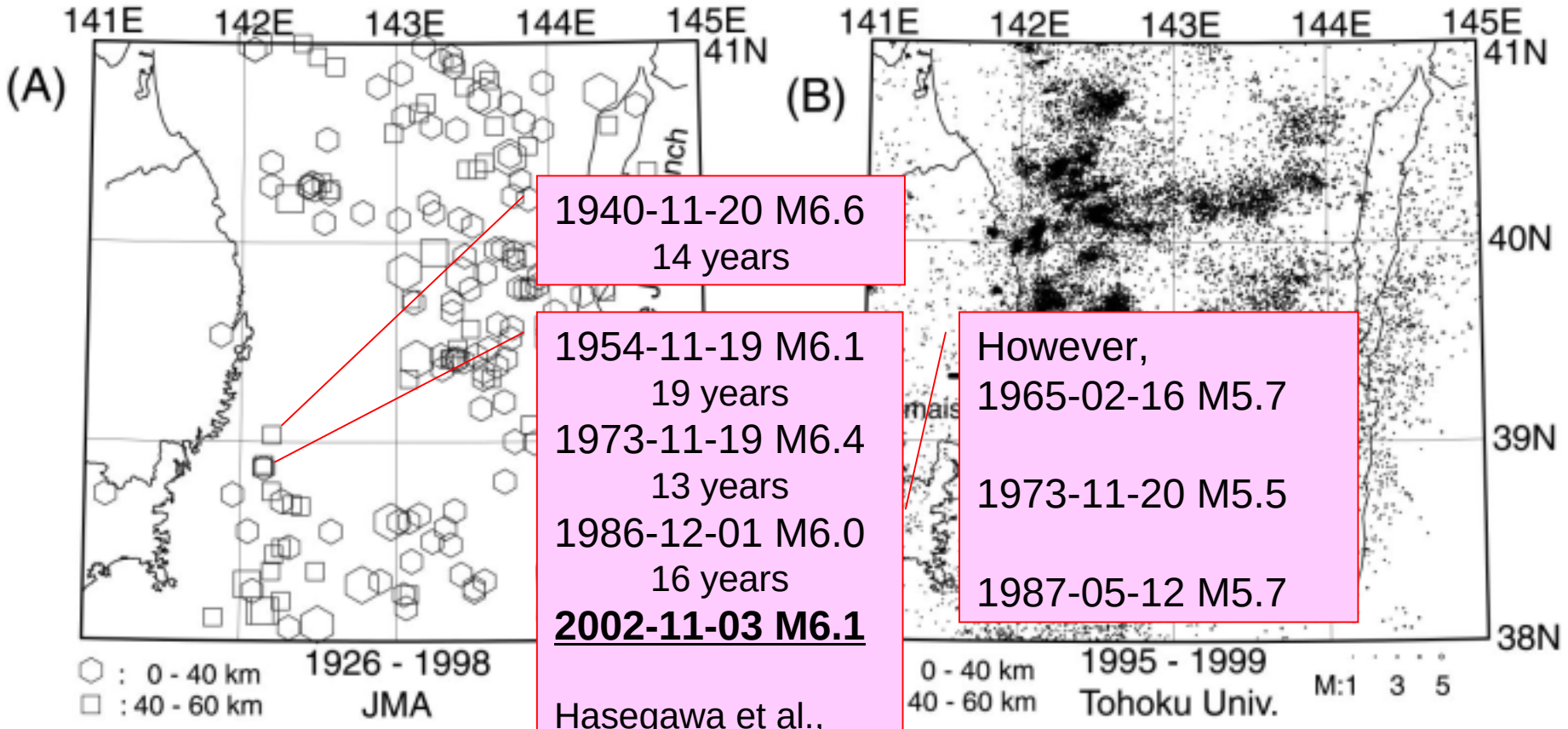


1940-11-20 M6.6
14 years

1954-11-19 M6.1
19 years
1973-11-19 M6.4
13 years
1986-12-01 M6.0
16 years
2002-11-03 M6.1

Hasegawa et al.,
SSJ Fall Meeting,
C36, 2002.

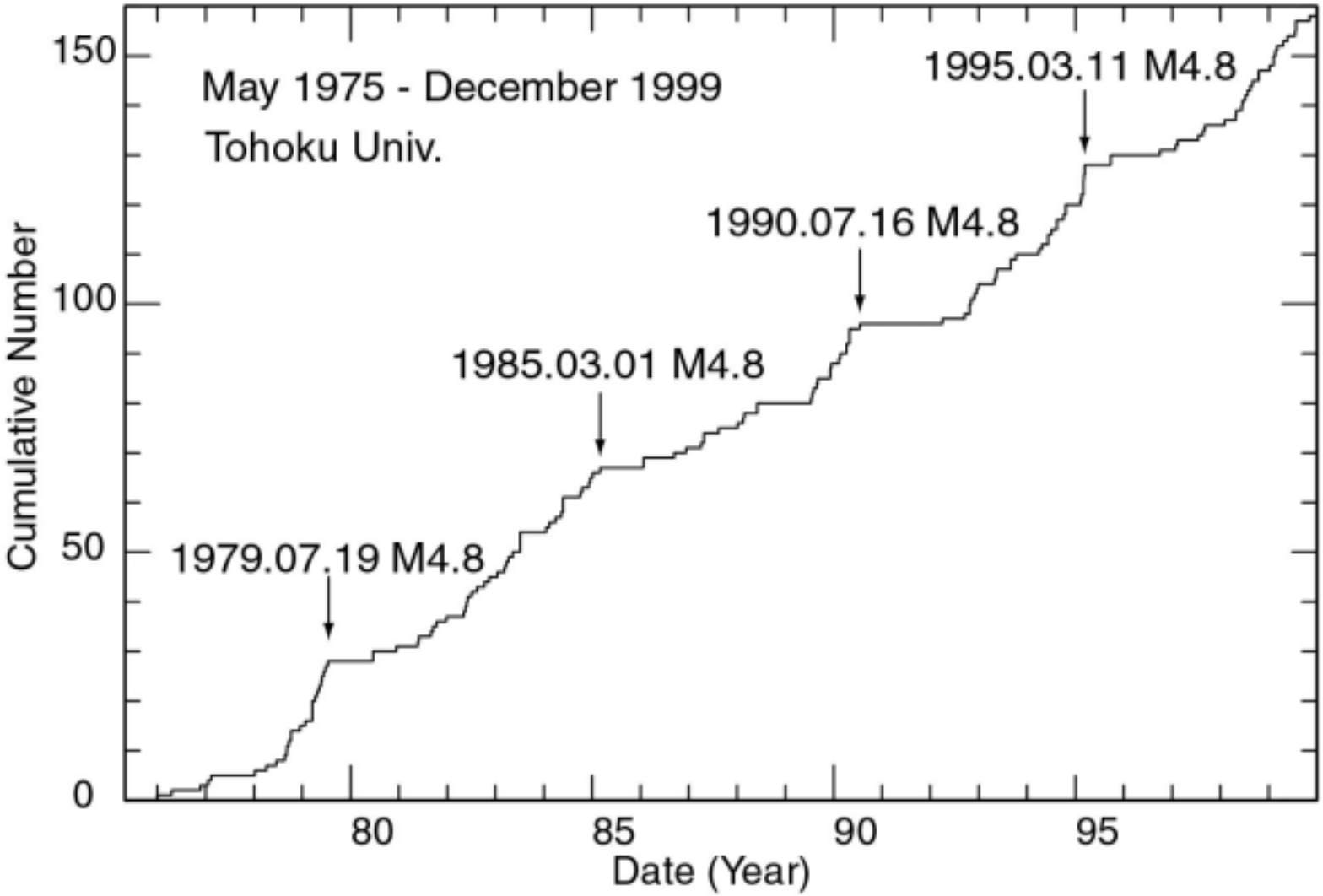
However,
1965-02-16 M5.7

1973-11-20 M5.5

1987-05-12 M5.7

Repeaters off Kamaishi

- Cumulative Number

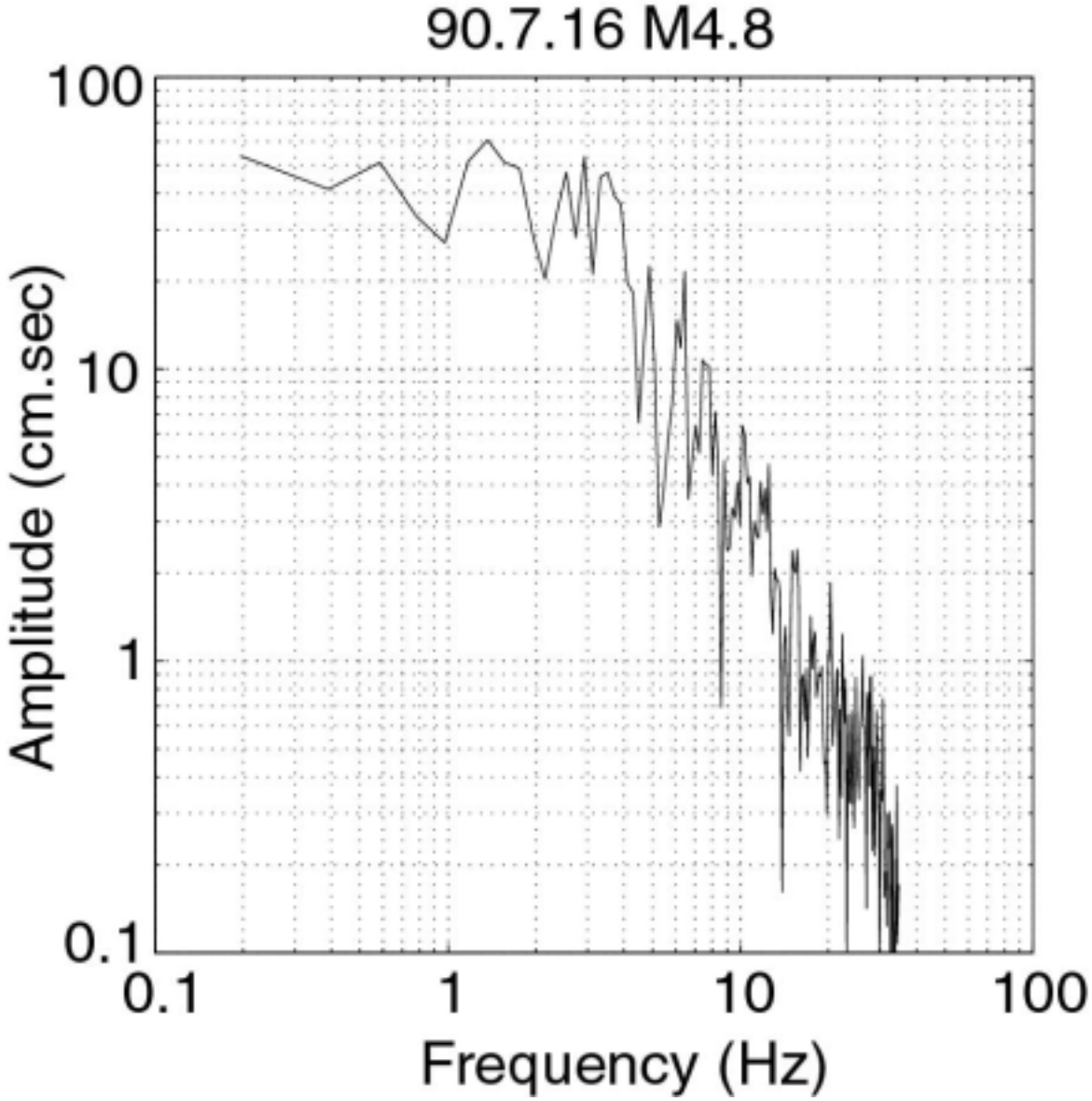


Repeaters off Kamaishi

- Displacement Amplitude Spectrum for S-wave

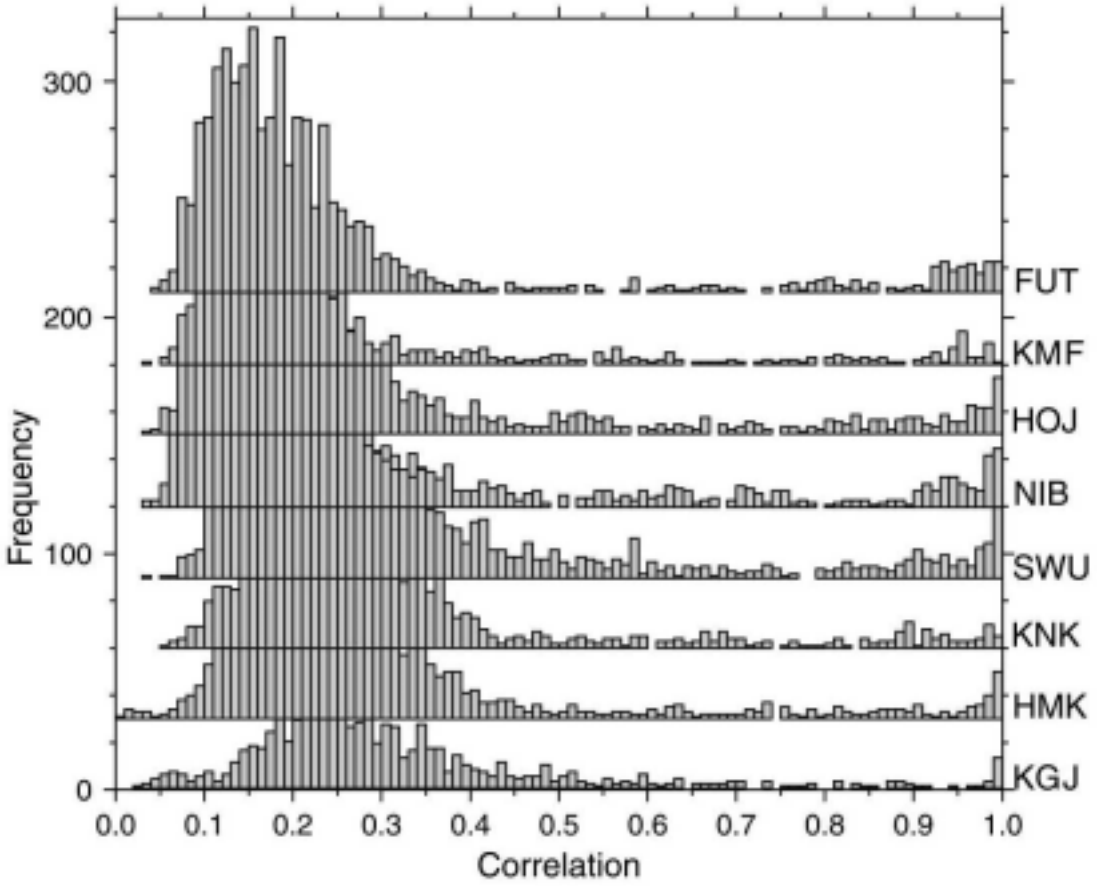
Fc = 3 - 4 Hz

L = 1- 2 km



Small Repeaters in and around NE Honshu

- Histogram of Cross-Correlation Coefficients of Waveforms Observed at Each Station

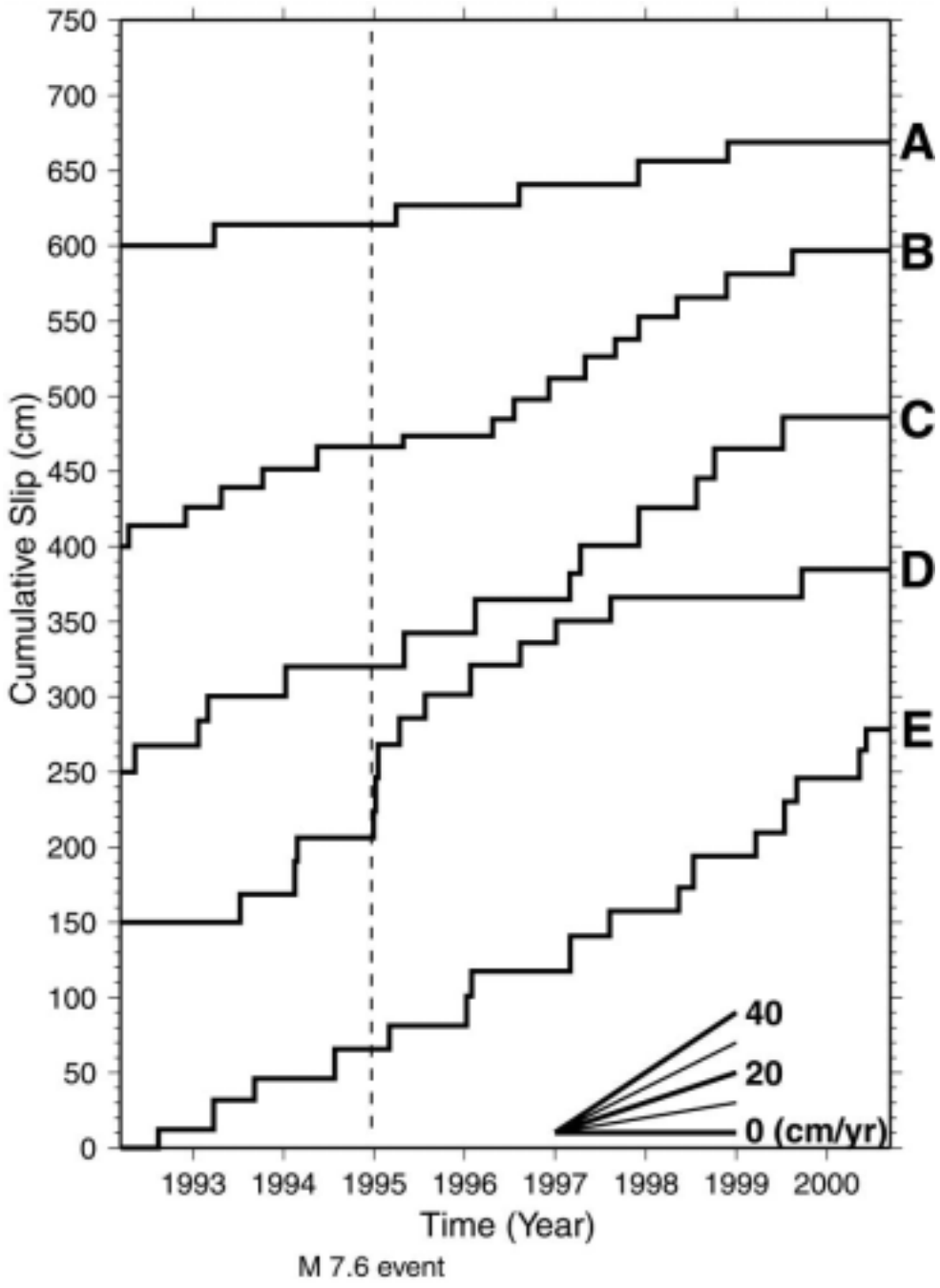


Small Repeaters in and around NE Honshu

- Method to Detect the Repeating Earthquakes
  - Select Event Pair
    - M>=3, Separation<30km
  - Filter the Seismograms
    - UD, 1-4Hz, Time-window=from P to 3sec. after S
  - Calculate Cross-Correlation Coefficients (CCC)
  - Judge
    - Criterion: CCC>0.95 at plural stations

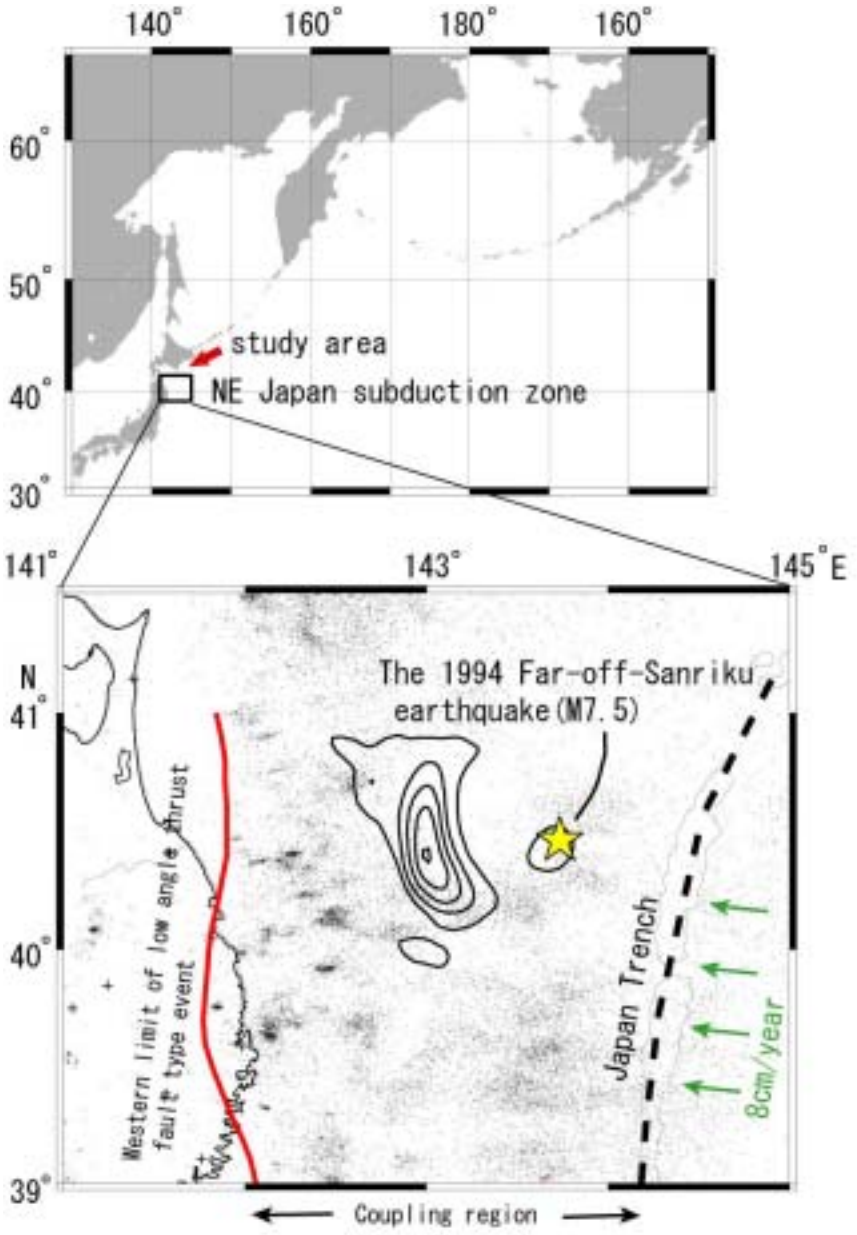
Small Repeaters in and around NE Honshu

- Cumulative Slip at Each Asperity



Slip Rate Distribution off Sanriku

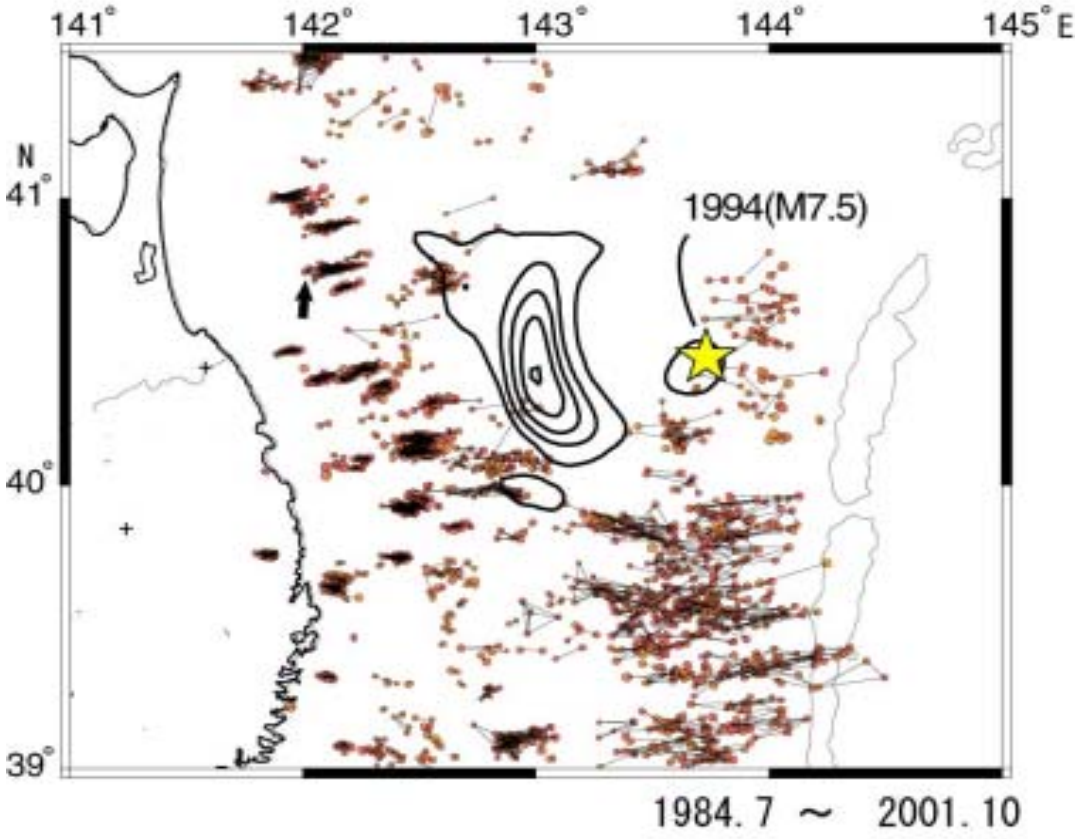
- Analyzed Area and Events



Epicenter map for the period from 1984 to 2001 (Depth ≦ 60km, M ≧ 2). Contours denote the moment release distribution of the 1994 M7.5 event (Yamanaka and Kikuchi, 2001)

Slip Rate Distribution off Sanriku

- Distribution of Repeating Eq.



Contour: Moment Release Distribution for the 1994 Far-Off Sanriku Eq. (Nagai et al., 2001)

Stations Used = 30

Events Checked ~ 30,000 (M>=2)

Event Pairs Checked ~ 36,000,000

Repeaters Detected = 2,509

Repeating Event Groups Detected = 600

Slip Rate Distribution off Sanriku

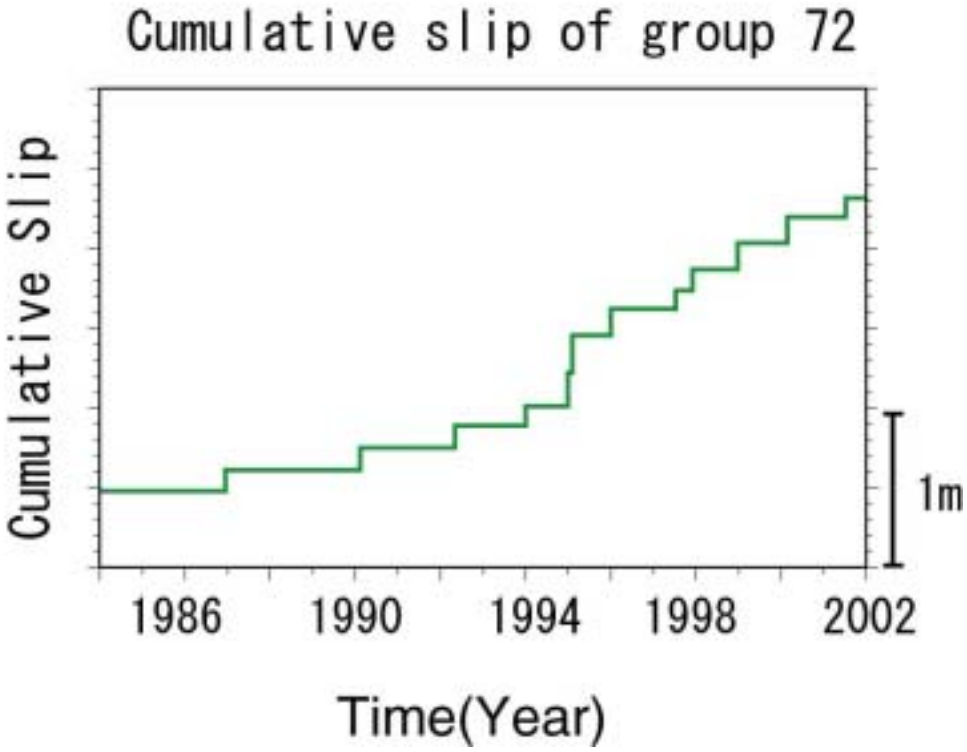
- Cumulative Slip

Estimation of Slip Amount

Moment(Mo)- slip(d) relation

$\log(d) = -2.36 + 0.17 \log(Mo)$

[Nadeau and Johnson(1998)]



Slow Slip and Earthquake Swarm

- The 1992 Swarm