ECGS Workshop 2012: Earthquake source physics on various scales
Oct. 4, 2012 14:40-15:00
Alvisse Parc Hotel, Luxembourg

Modeling Scale-invariant Heterogeneity of Earthquakes

1: Fractal Patch Dynamic Rupture Model
2: The 2011 Tohoku-Oki Earthquake

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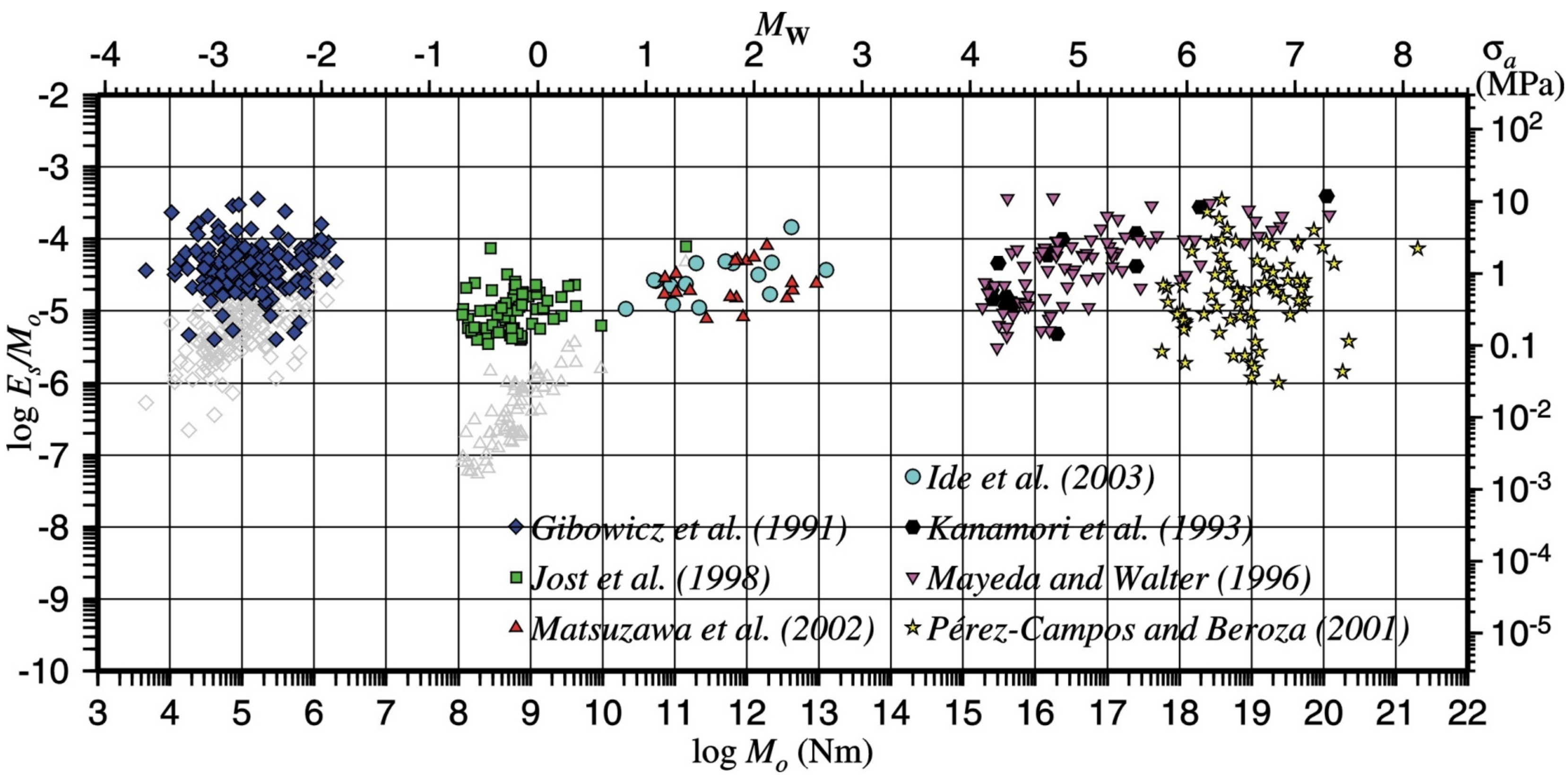
Scale invariance of earthquakes

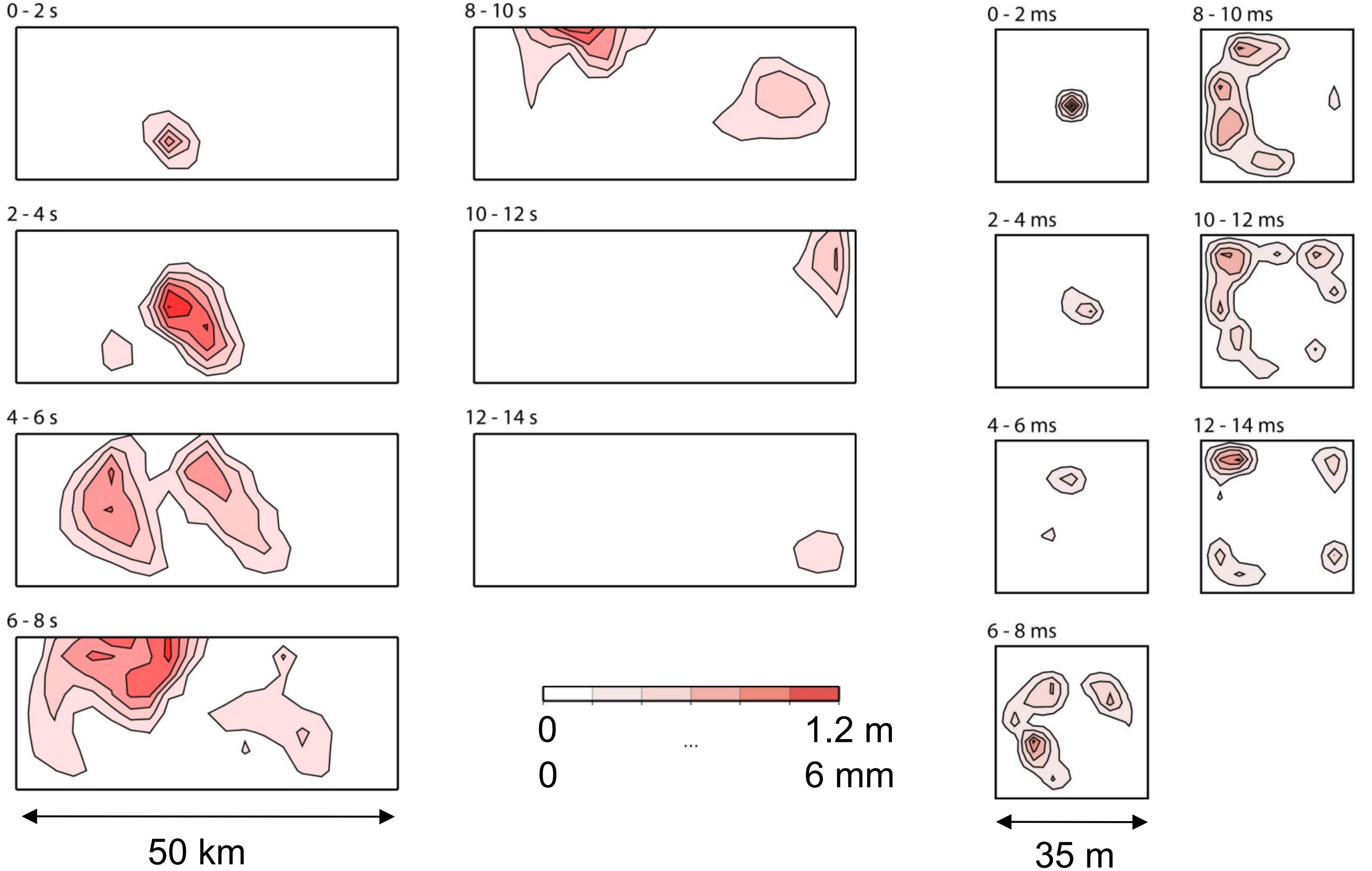
Between macroscopic parameters: Seismic energy vs. seismic moment



after Ide and Beroza (2001, GRL)

Scaling complexity of rupture

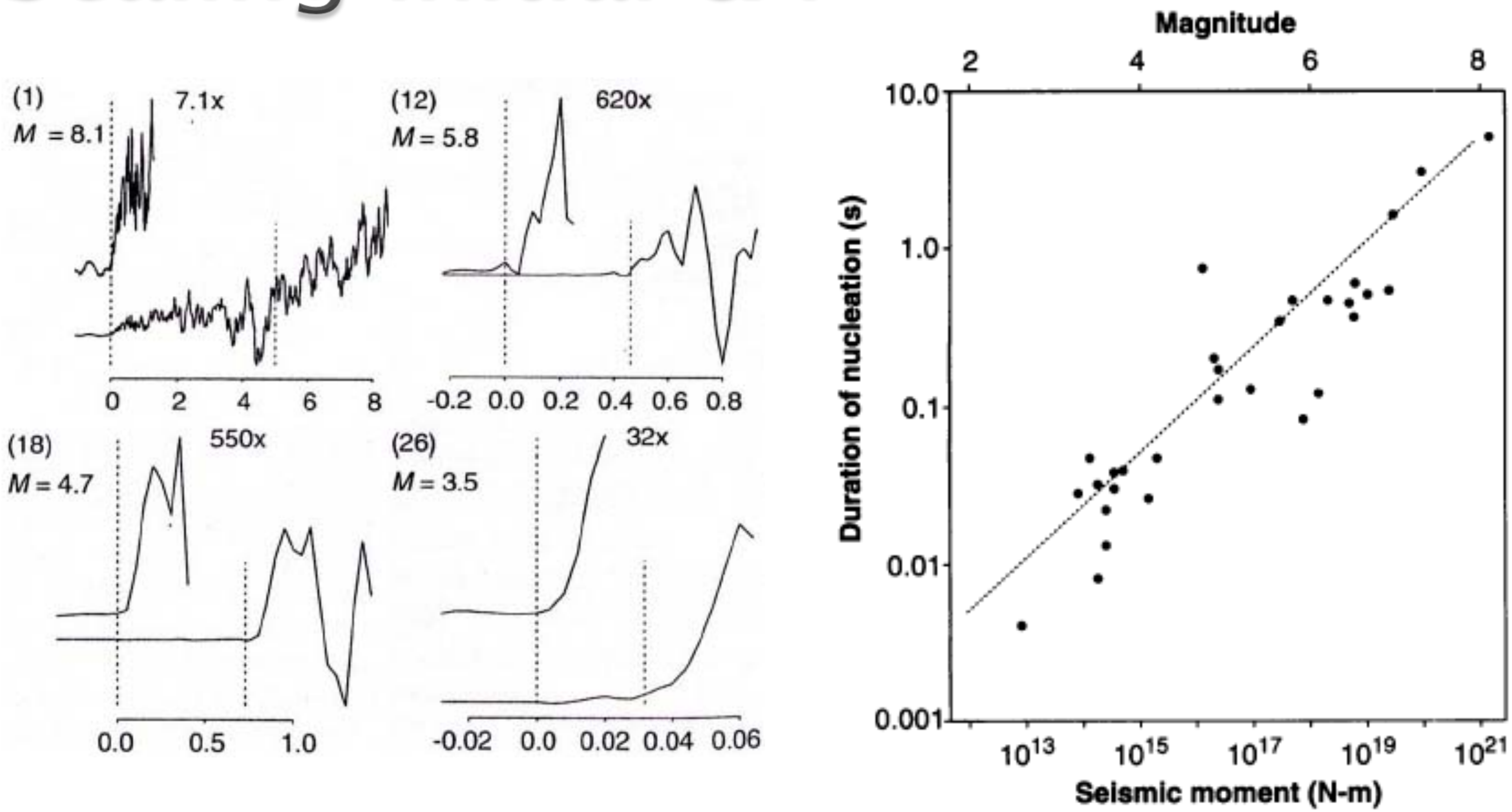
1995 Kobe Mw6.8 (Ide and Takeo 1997) SA mine Mw1.4 (Yamada et al., 2004)



Self-similarity in spatio-temporal slip pattern

Small earthquakes are not simple

Scaling initial & main processes



Scaling of “nucleation phase”

Ellsworth and Beroza (1995, Science)

Scaling heterogeneity of EQ

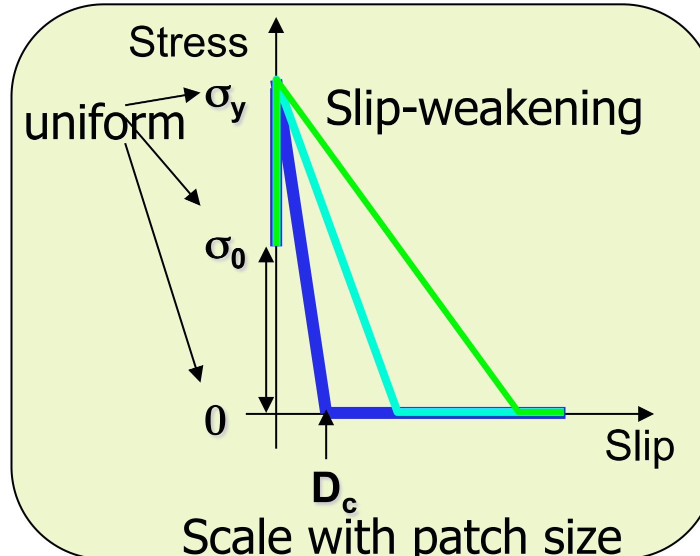
- Self-similarity between various macroscopic parameters
  - Length ∝ Width ∝ Final Slip ∝ Duration
  - Moment ∝ Energy
- Scale invariant properties
  - Stress (initial, maximum, dynamic, etc.) ~ MPa
  - Average rupture propagation velocity < Vs
- Complexity
  - Subevents, directivity, acceleration & delay of rupture
  - Initial (nucleation) phase ∝ source linear dimension

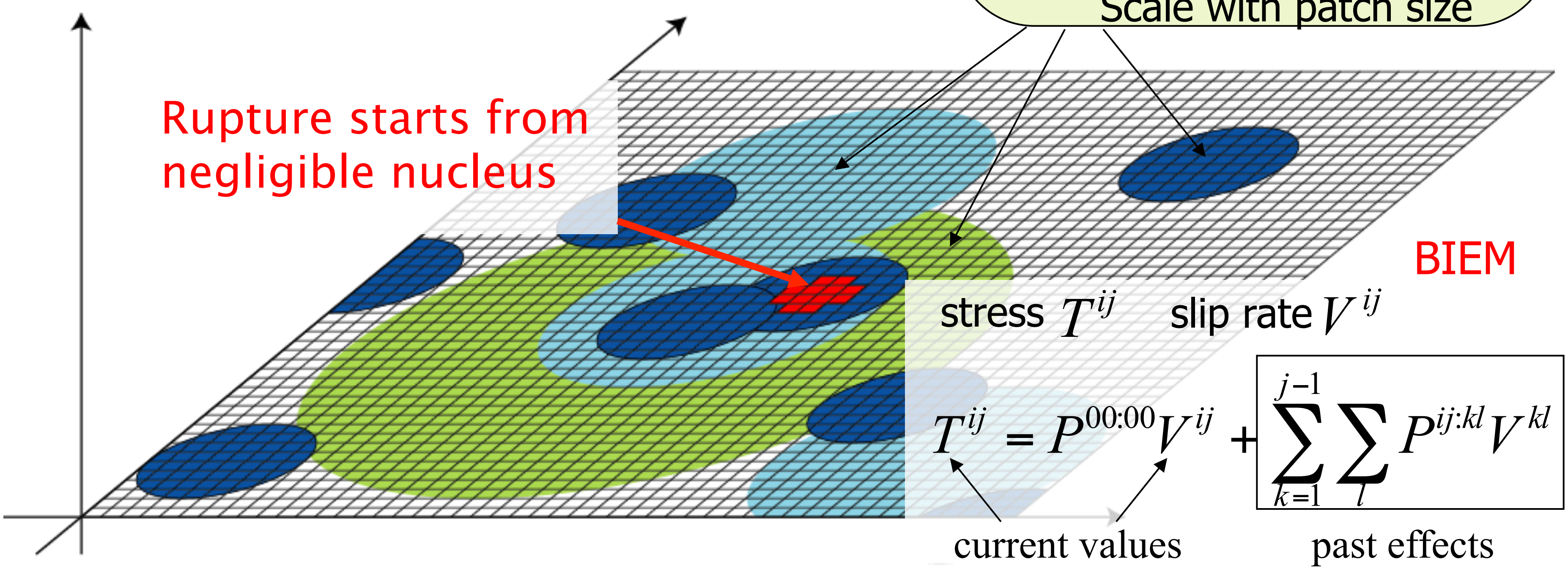
Fractal Patch Dynamic Rupture Model (Ide and Aochi, 2005)

3D Fractal Patch Model

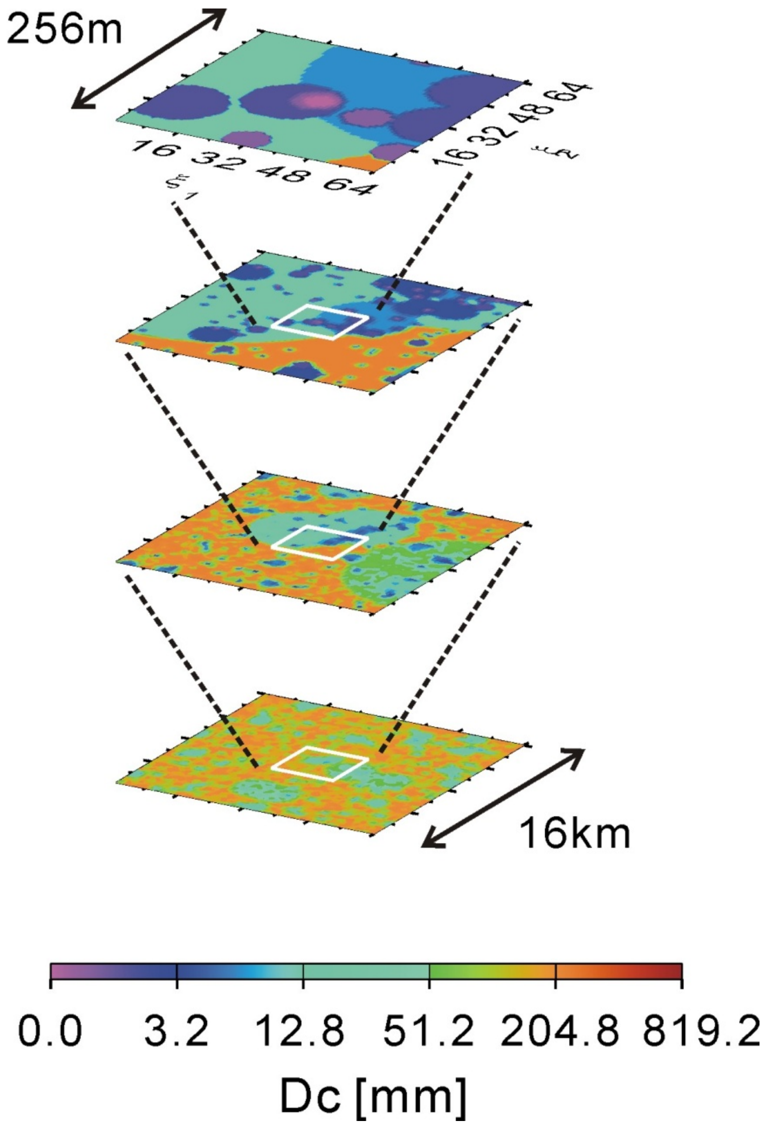
(Ide and Aochi, 2005)

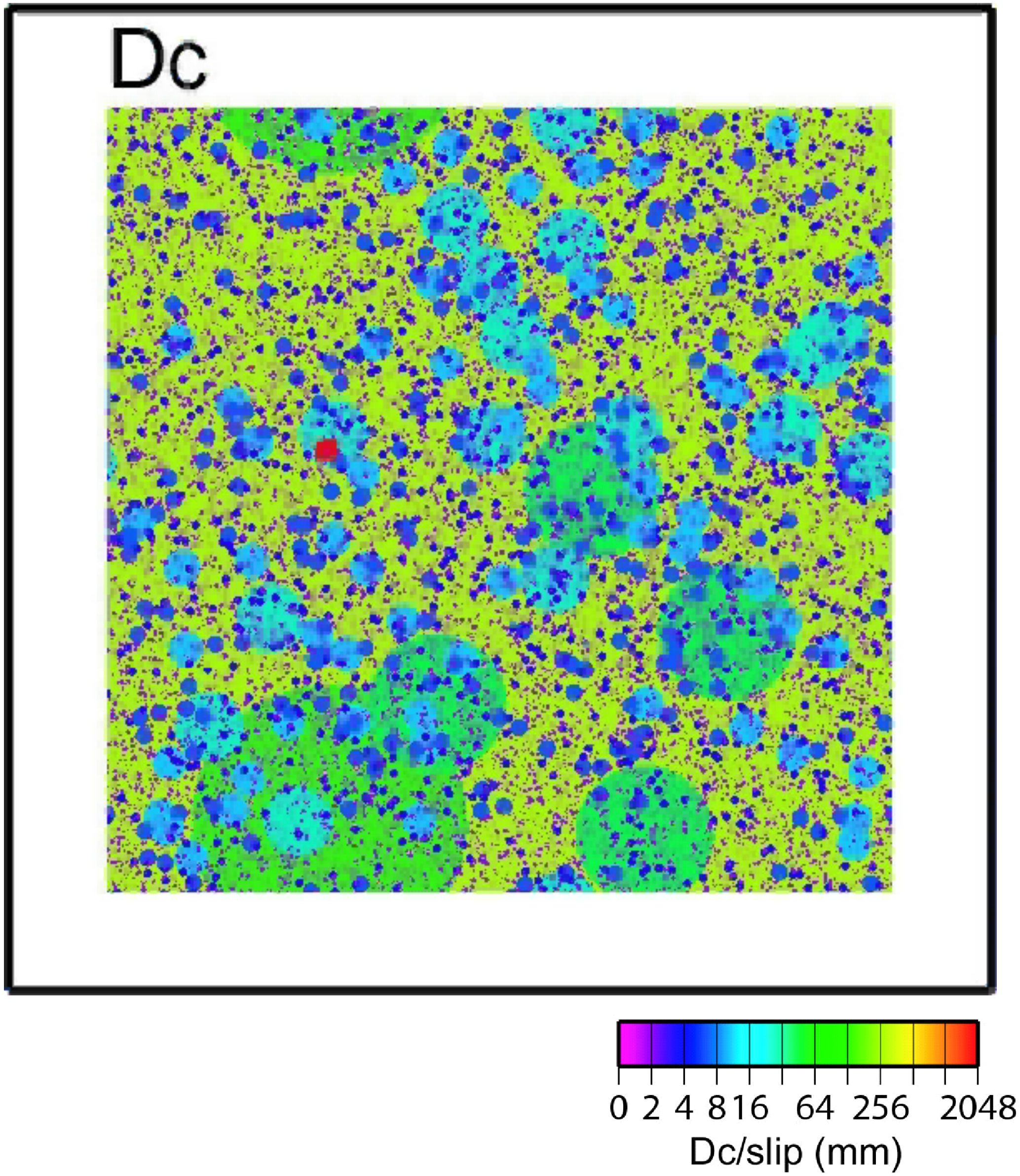
- Circular patch areas
  - A few large patches & many small patches (fractal)
  - Statistically self-similar
- Slip-weakening friction law
  - Dc ∝ patch radius
  - Homogeneous stress state



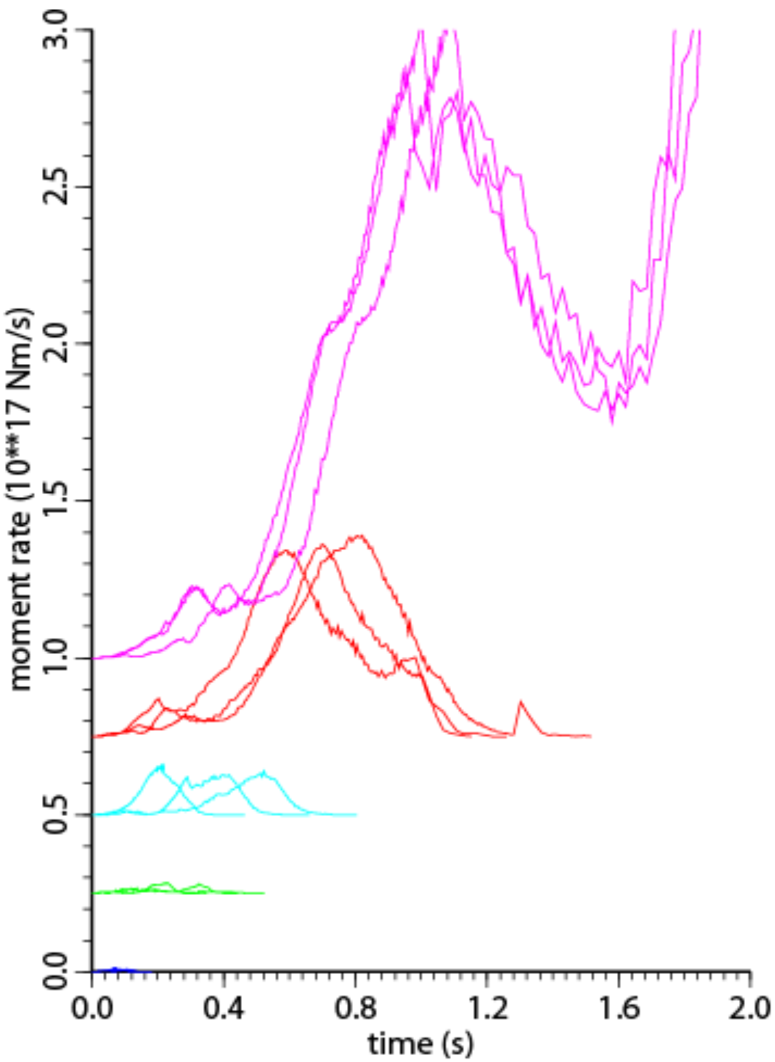


Example of dynamic rupture

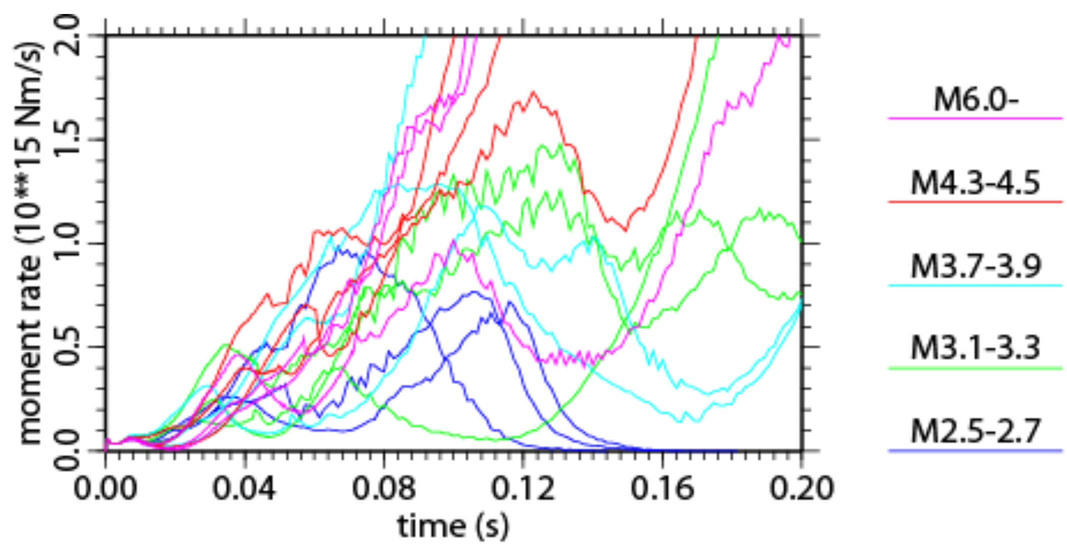




Seismic Waves (Moment rate functions)



- Irregular rupture growth
- Initial phase?
  Any moment rate function has some small irregular bumps before the 'main' phase



Ide and Aochi (2005, JGR)

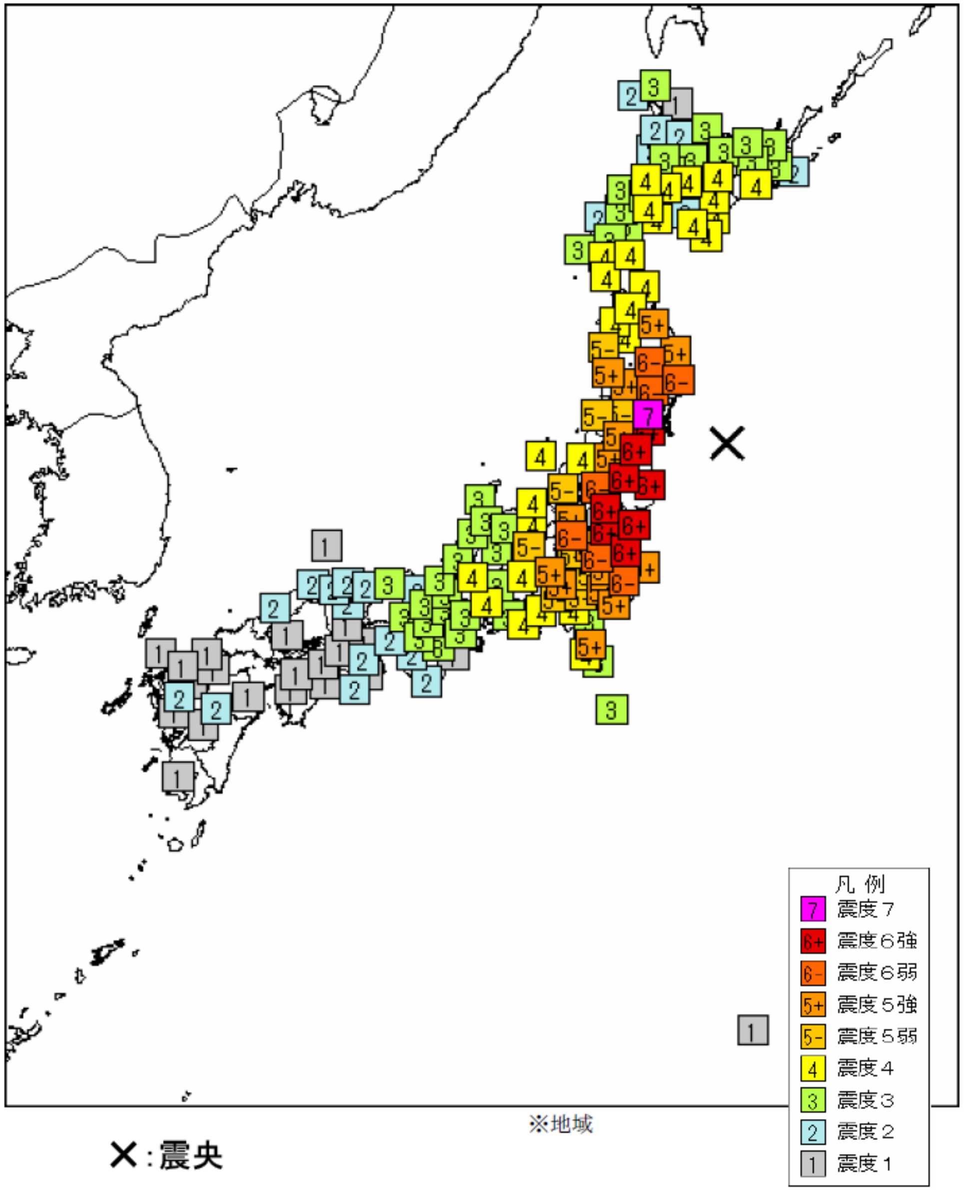
Fractal patch model Explains …

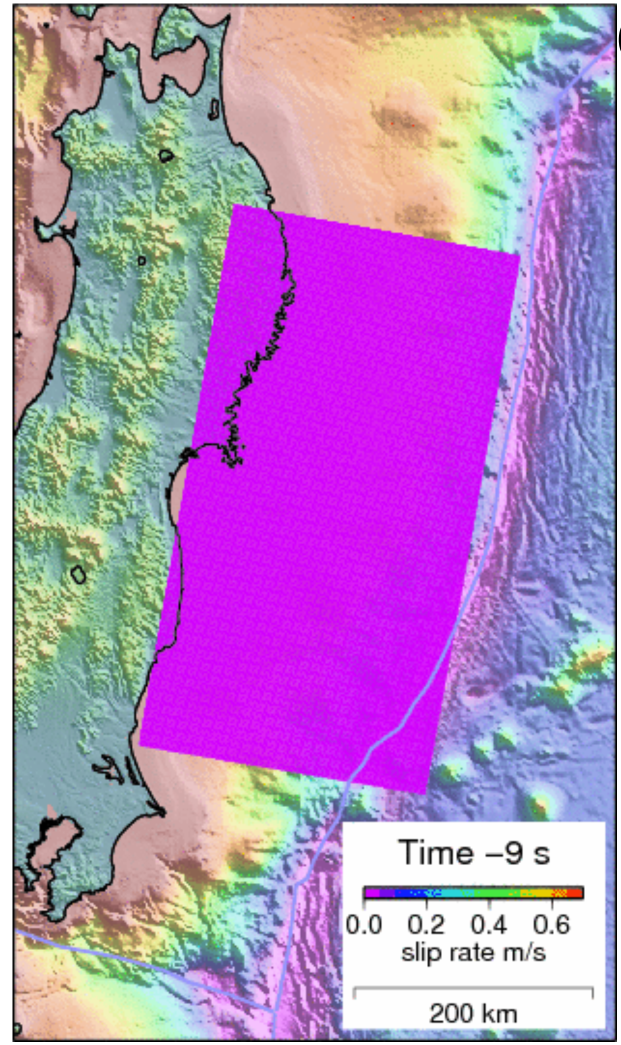
(Ide and Aochi, 2005)

- Self-similarity between various macroscopic parameters
  - Length $\propto$ Width $\propto$ Final Slip $\propto$ Duration
  - Moment $\propto$ Energy
- Scale invariant properties
  - Stress (initial, maximum, dynamic, etc.) ~ MPa
  - Average rupture propagation velocity $<$ Vs
- Complexity
  - Subevents, directivity, acceleration & delay of rupture
  - Initial (nucleation) phase $\propto$ source linear dimension

assumed

Tohoku-Oki earthquake





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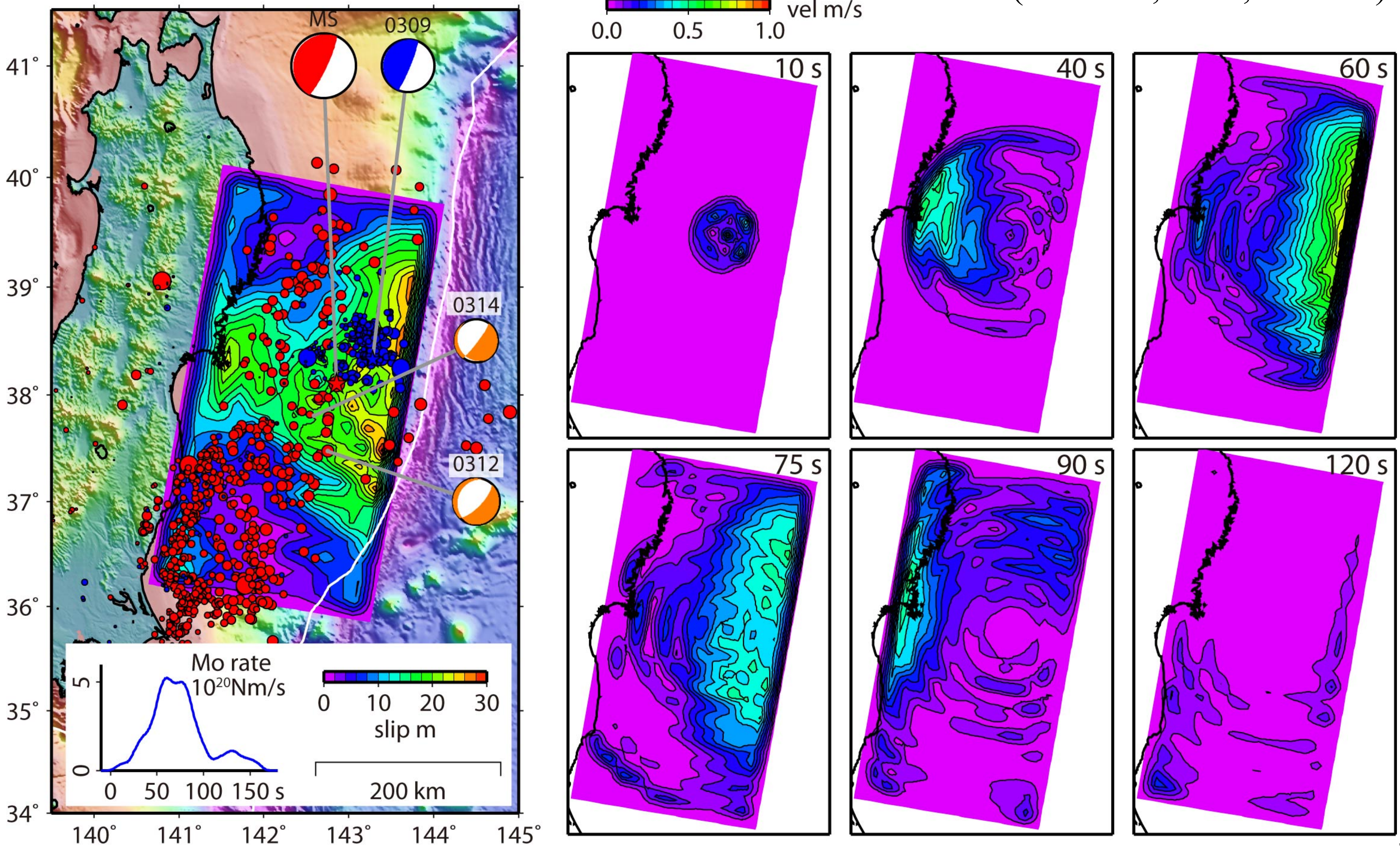
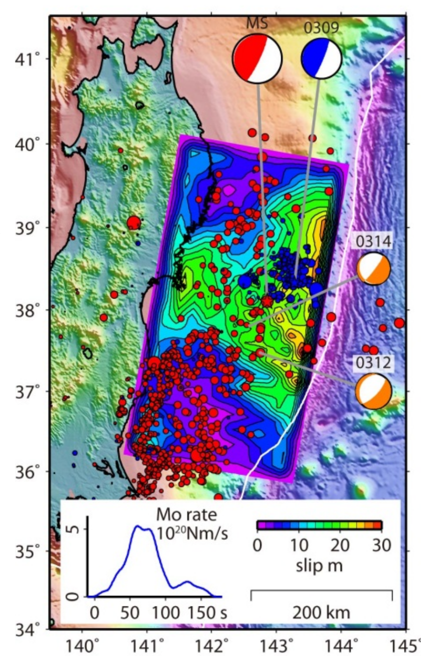
Tohoku-Oki Slip model

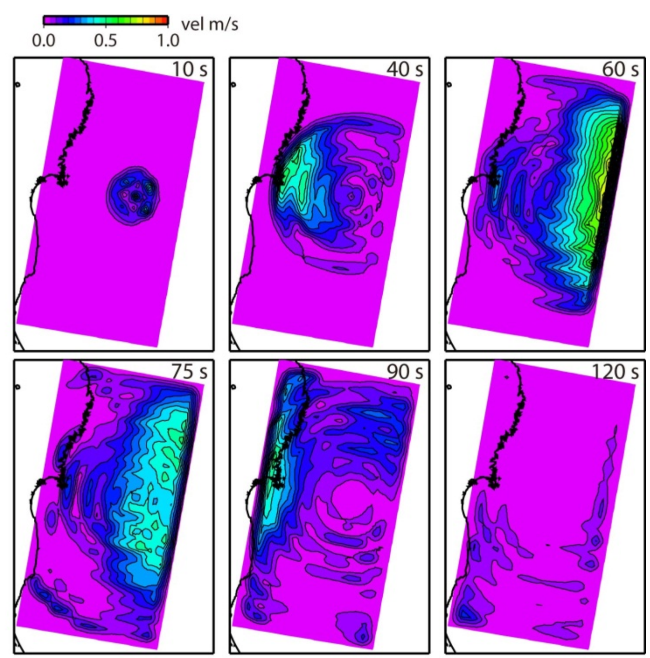
(Ide et al., 2011, Science)



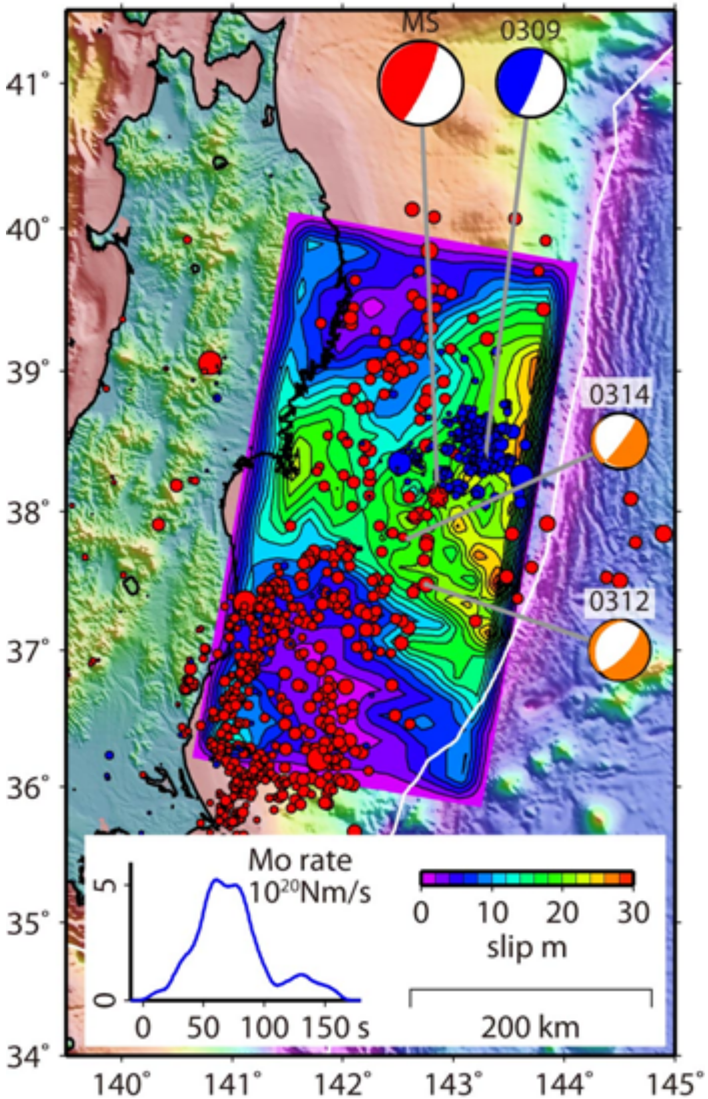
Questions

- What are responsible for:
  - Switchback rupture propagation
  - Delayed large slip near the trench (apparently slow rupture propagation)
  - Delayed slip in the southern region
- The role of the March 9 foreshock





Slip Model vs. Seismicity Catalog



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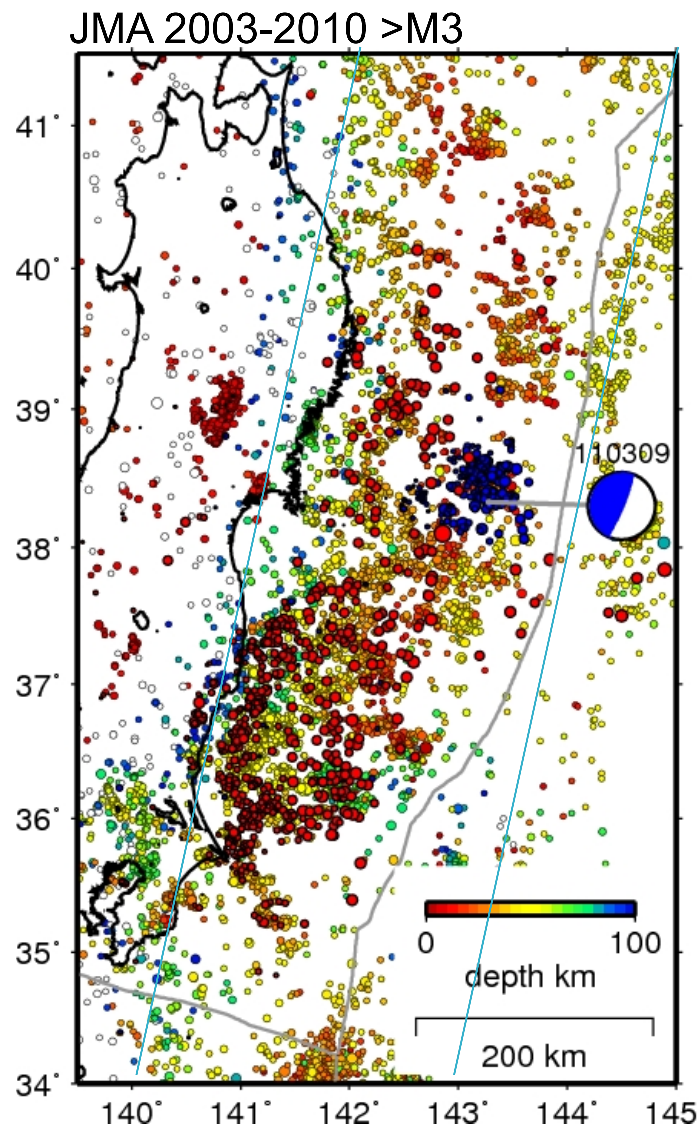
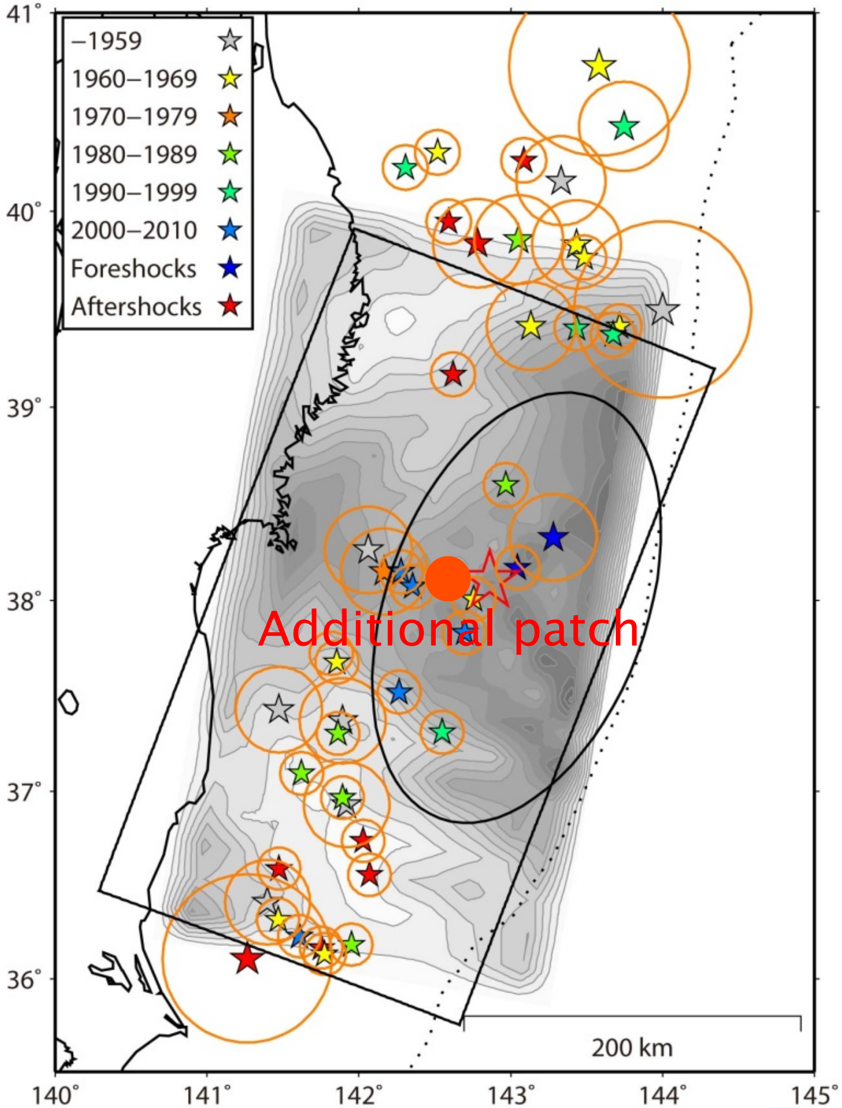


Hypocenters → Segments

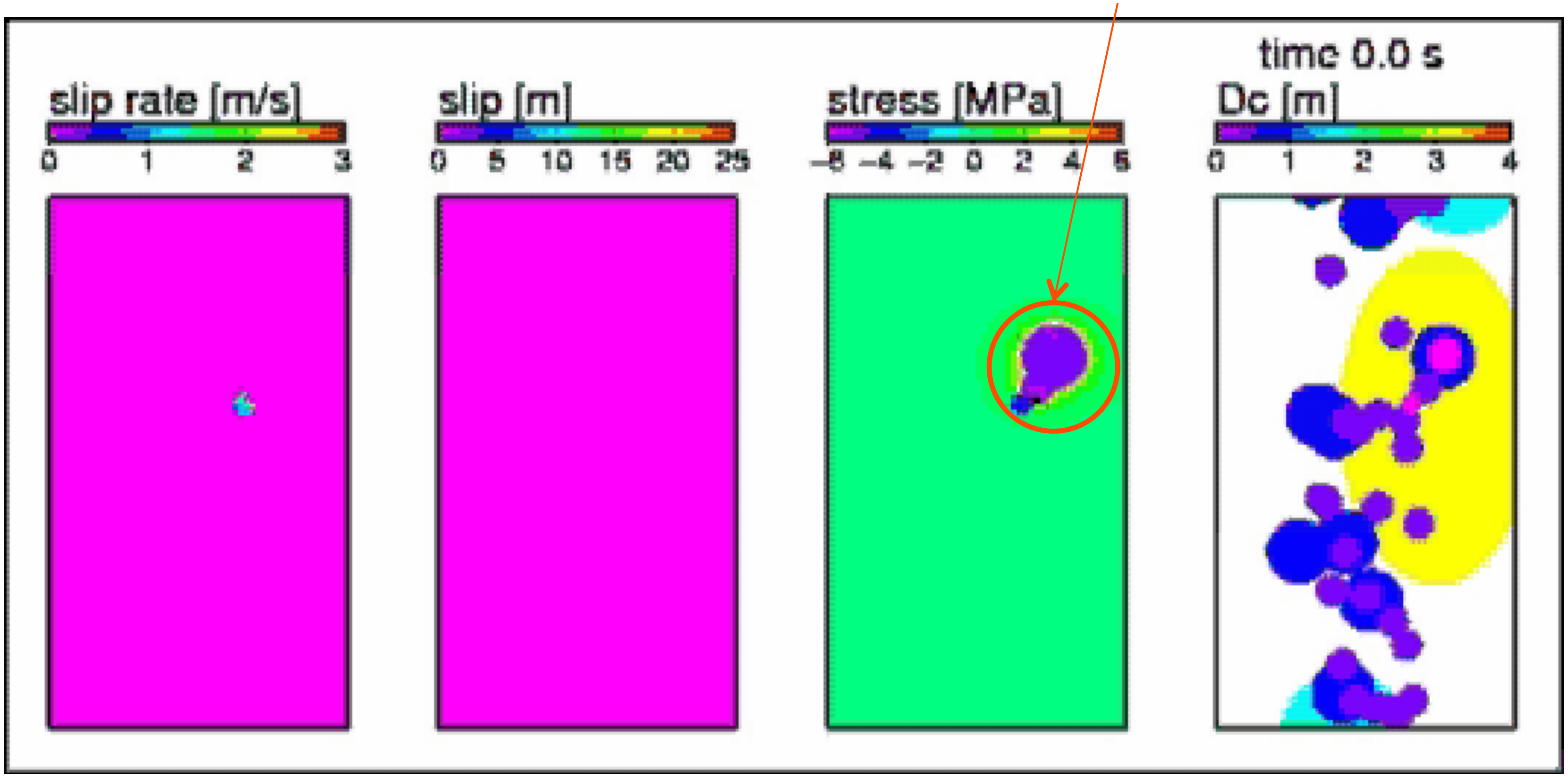


Level 1: 130 x 75 km^2
1 patch
Level 2: 100 km ~M8.0
3 patches
Level 3: 50 km ~M7.4
13 patches
Level 4: 25 km ~M6.8
30 patches

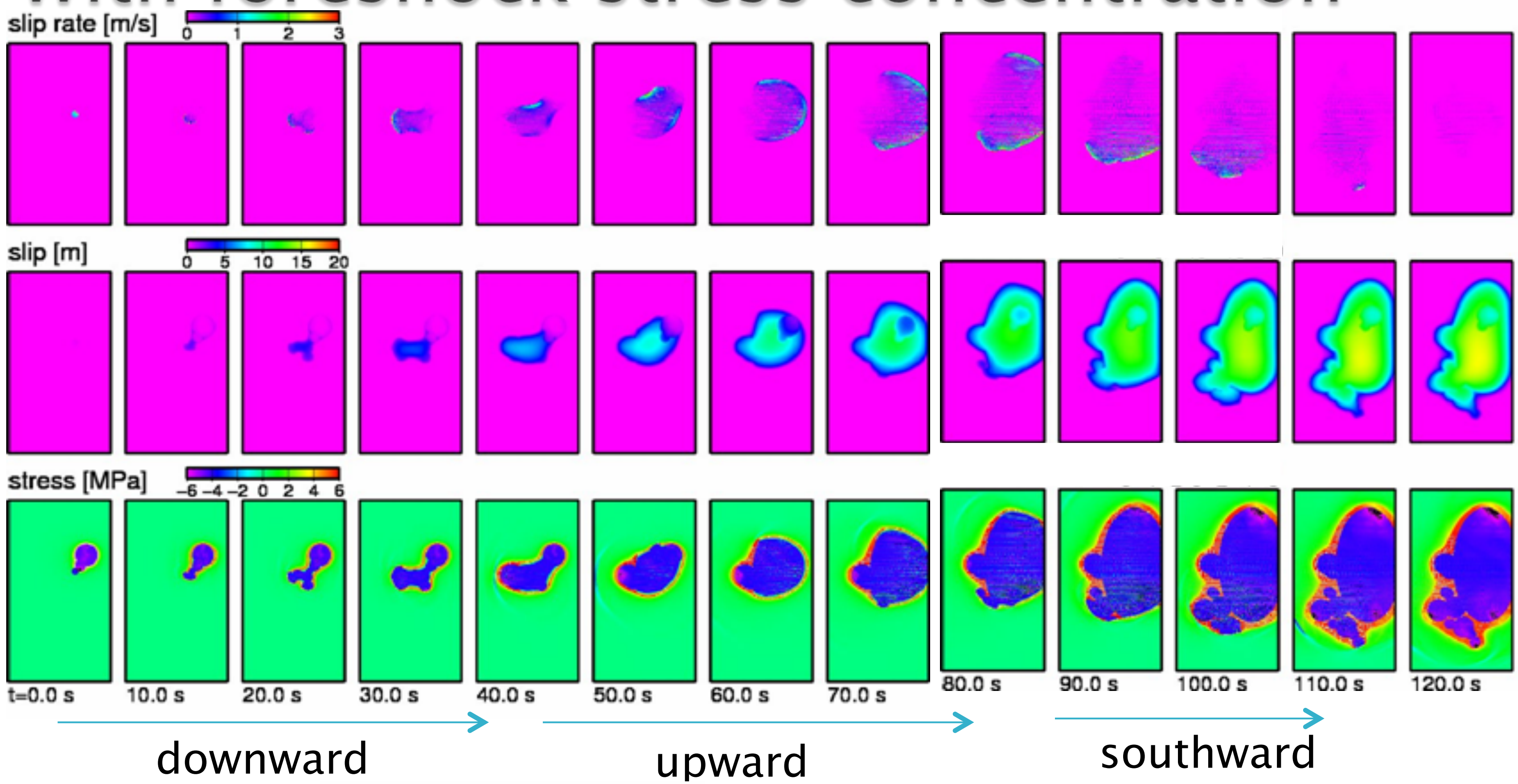
Assuming 4MPa stress drop
with 10 MPa strength drop

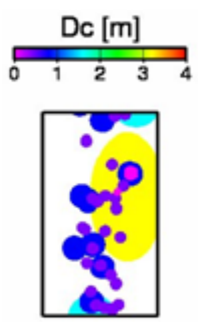
Dynamic rupture process

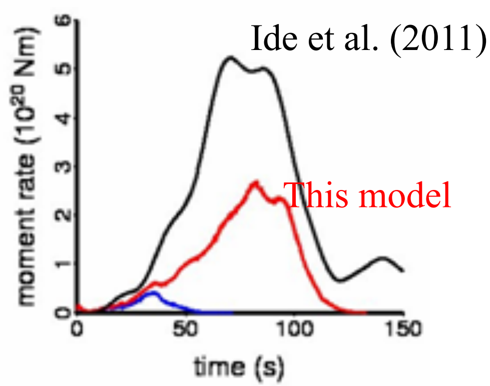
Stress concentration due to the foreshock



With foreshock stress concentration







Level 1 patch ruptured
100+s duration

Fractal patch model with Tohoku-Oki earthquake

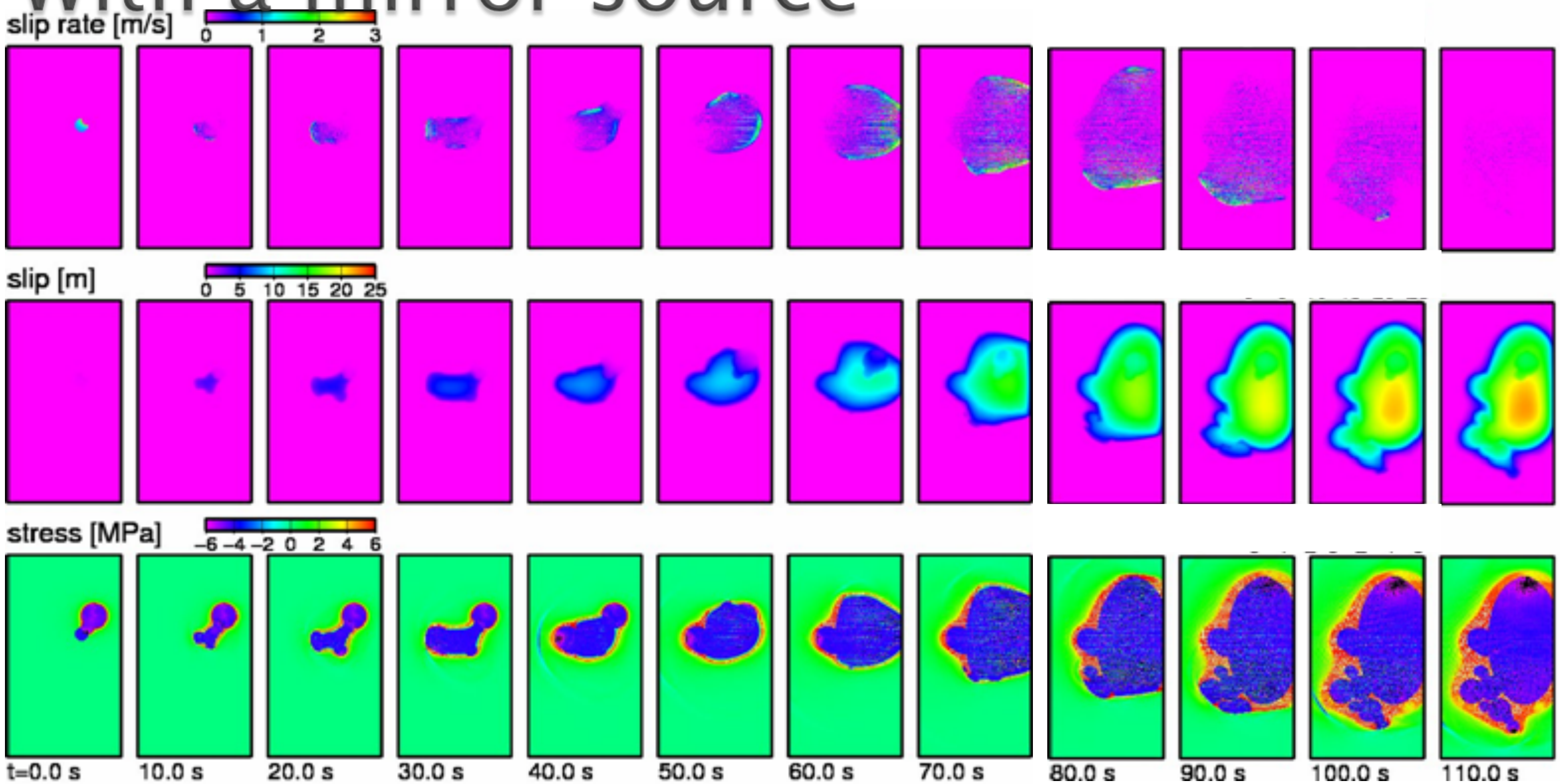
- Circular patch distribution assumed based on historical seismicity
  - 4 levels of patches (M6.8, M7.4, M8.0 + Main Slip)
  - Fracture energy & Dc proportional to patch radius
  - Uniform stress state with foreshock stress accumulation
- Features reproduced
  - Downward propagation up to 40 s
  - Large slip near the trench ~ 70 s
  - Delayed ruptures in the southern part
  - Aftershock patches remain unbroken
- Some problems

Conclusions

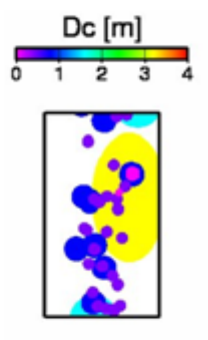
- Scaling of heterogeneity of earthquake source is well explained by a fractal patch dynamic rupture model
- A fractal patch model constructed based on historical seismicity can explain apparently strange rupture process of the 2011 Tohoku-Oki earthquake

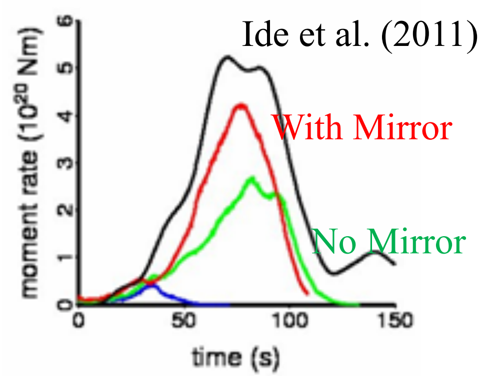
- One possible way to realize the scenarios of future earthquakes

With a mirror source



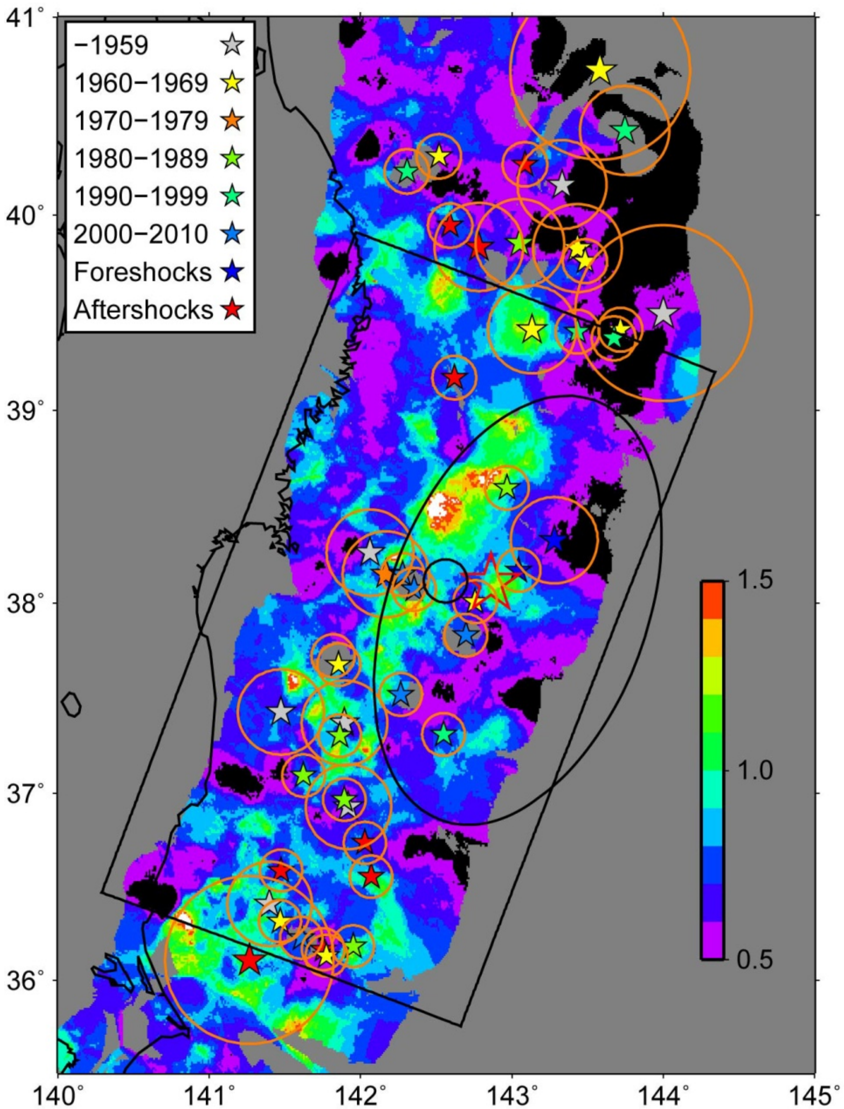
downward → upward → southward

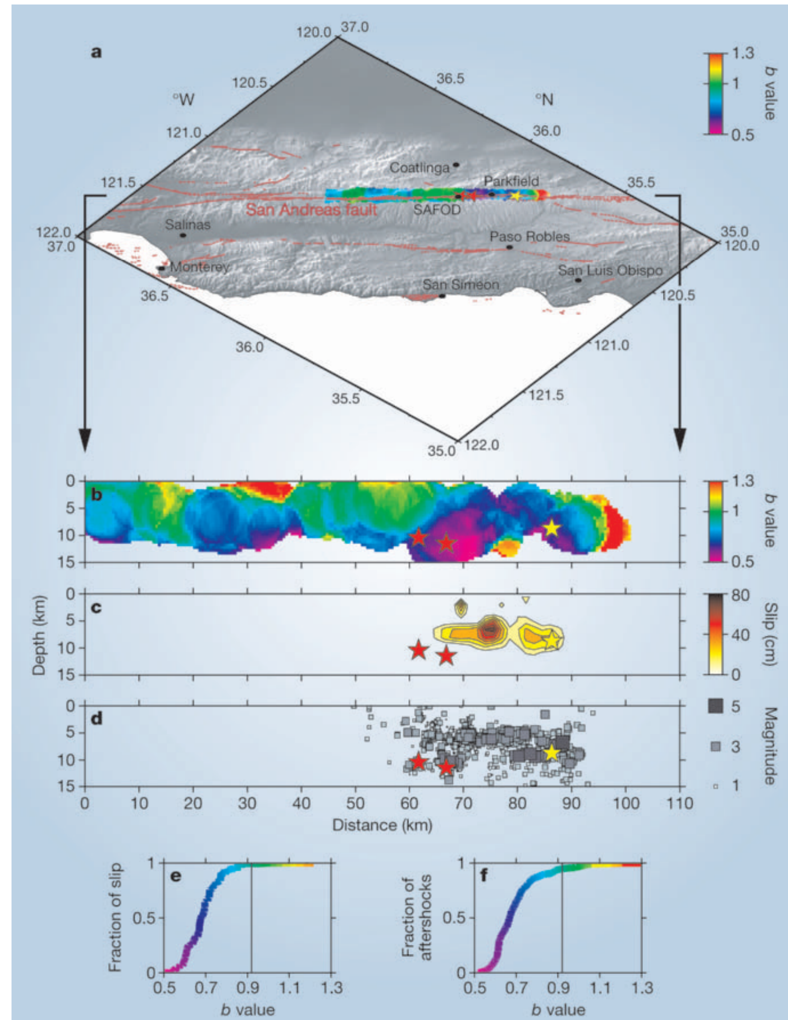




Level 1 patch ruptured
100+s duration
Similar Mo & Slip

GR b-value & patches





Schorlemmer and Wiemer (2005)