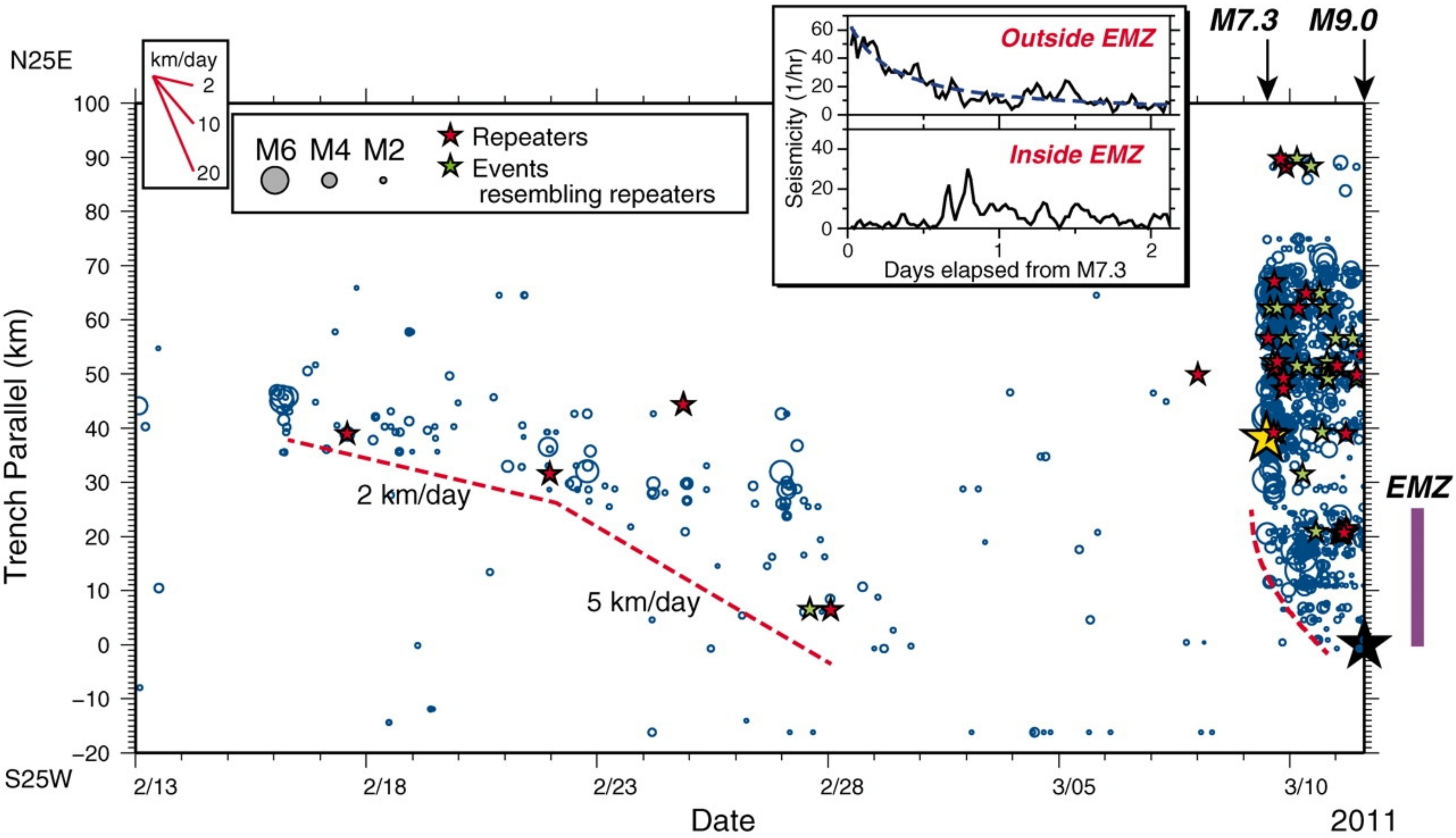
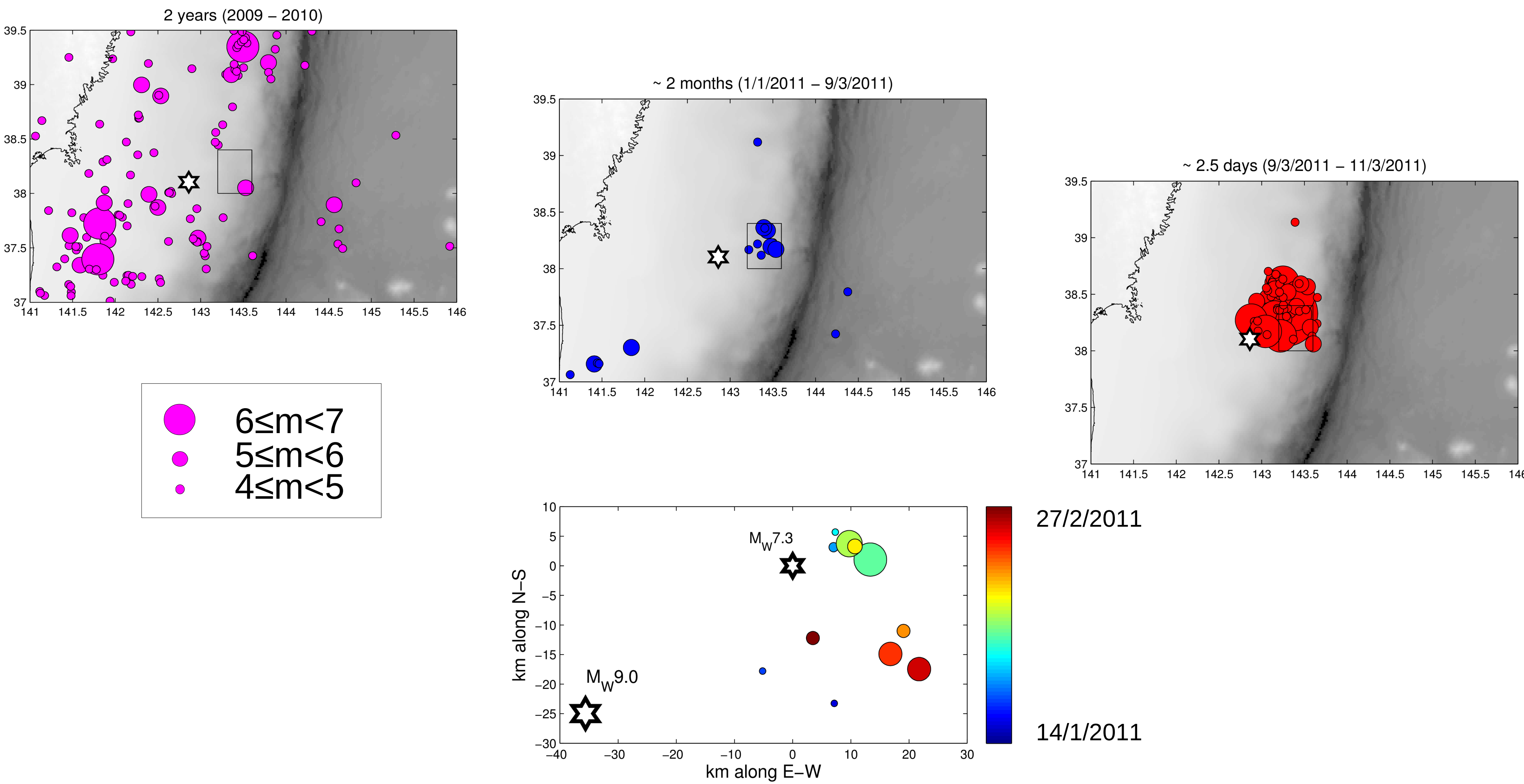
Foreshocks of M9.0 Tohoku earthquake

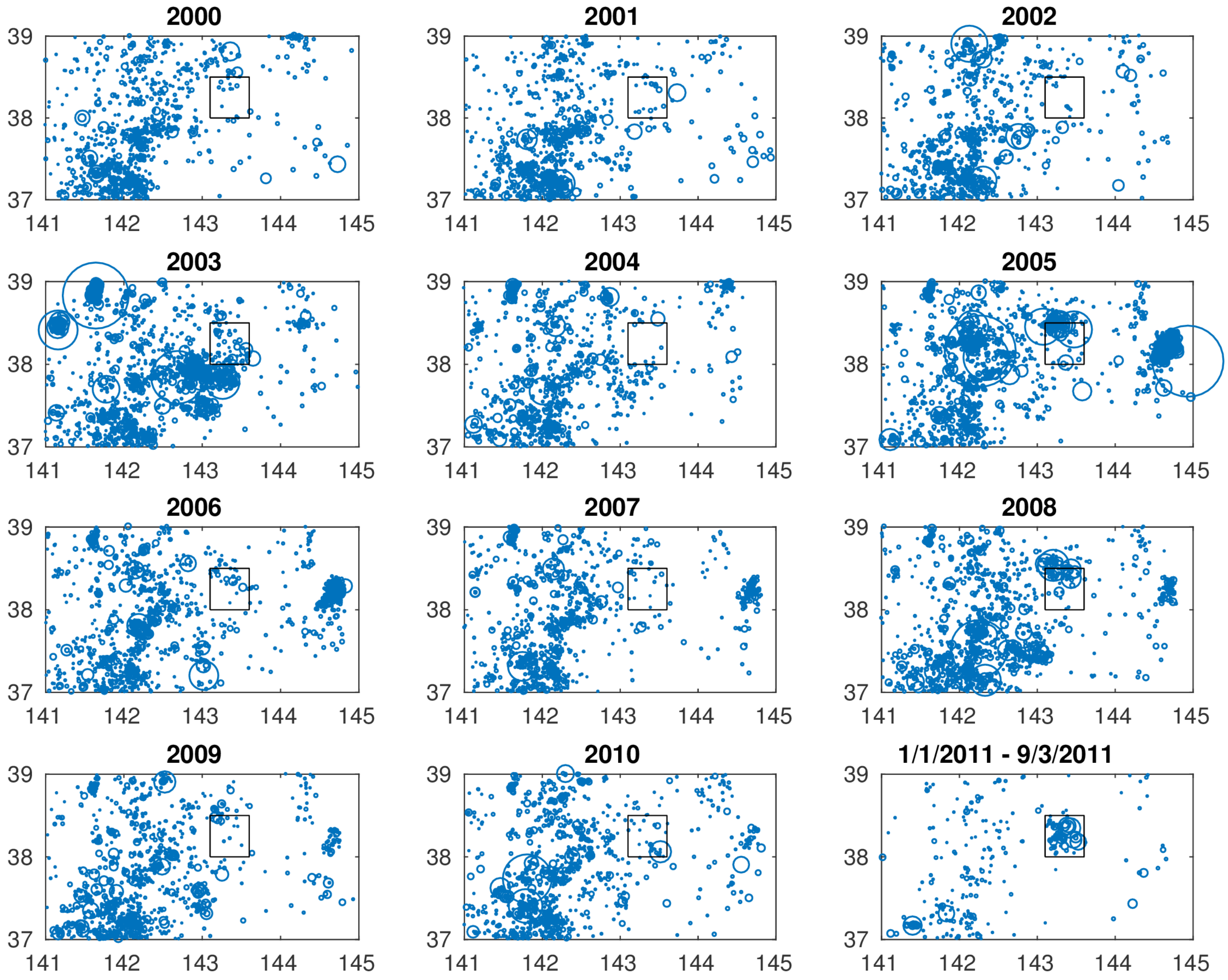


Kato et al. (Science 2012)

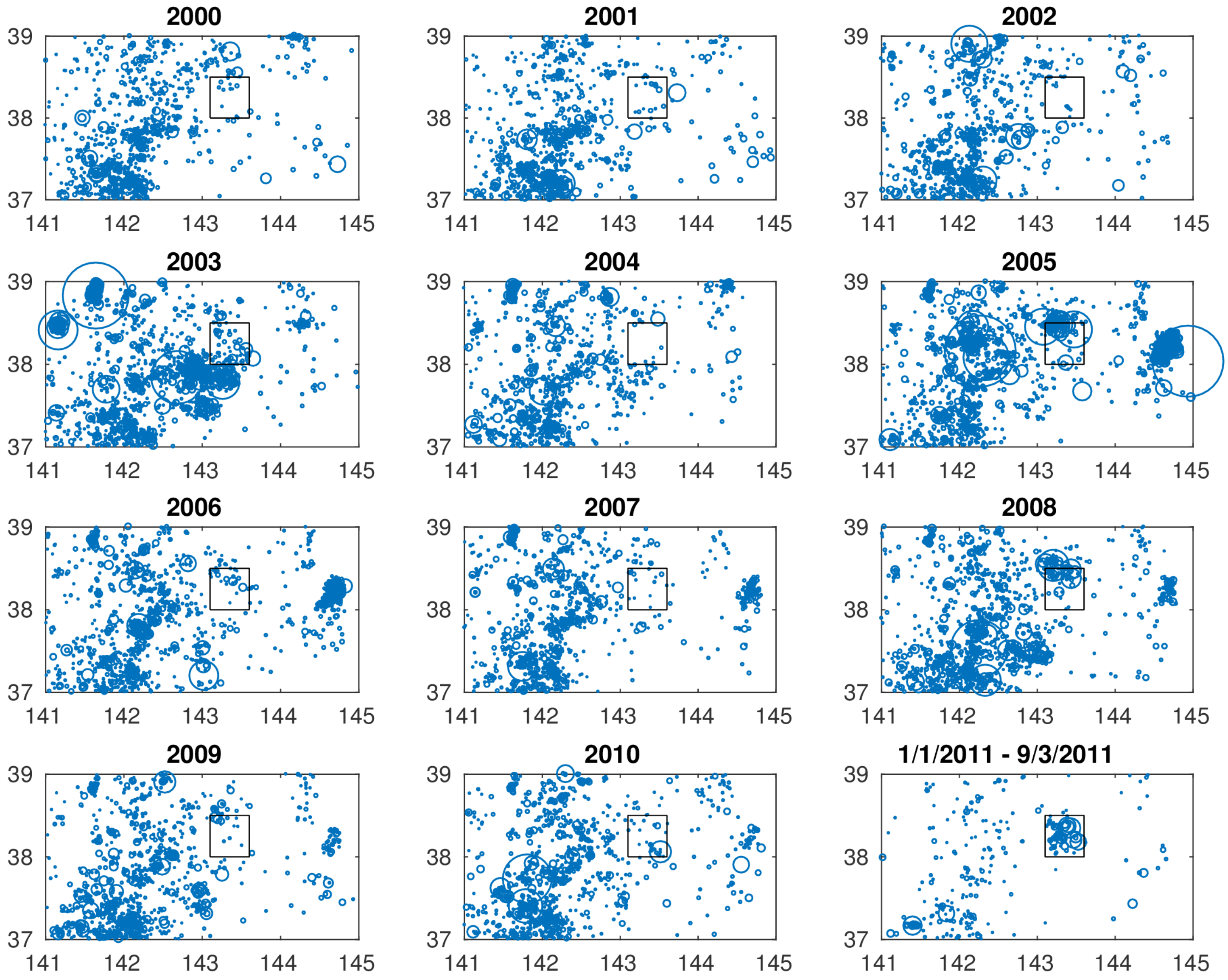
Foreshocks of M9.0 Tohoku earthquake



Eleven 4.0 ≤ m ≤ 5.5 earthquakes between 14/1/2011 and 27/2/2011

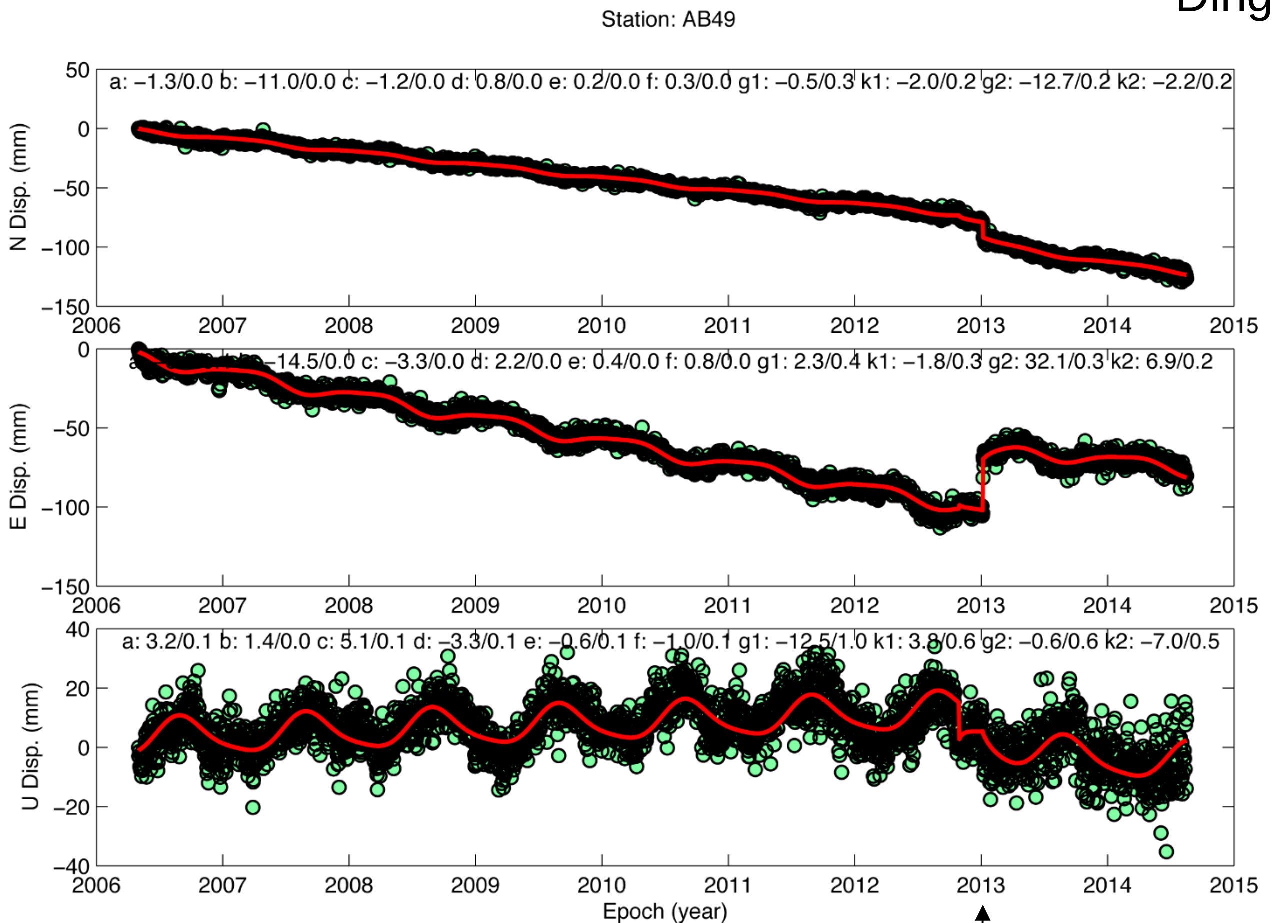


2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
1/1/2011 - 9/3/2011
39
38
37
141
142
143
144
145



Is this activity in early 2011 anomalous?

Ding et al. BSSA 2015



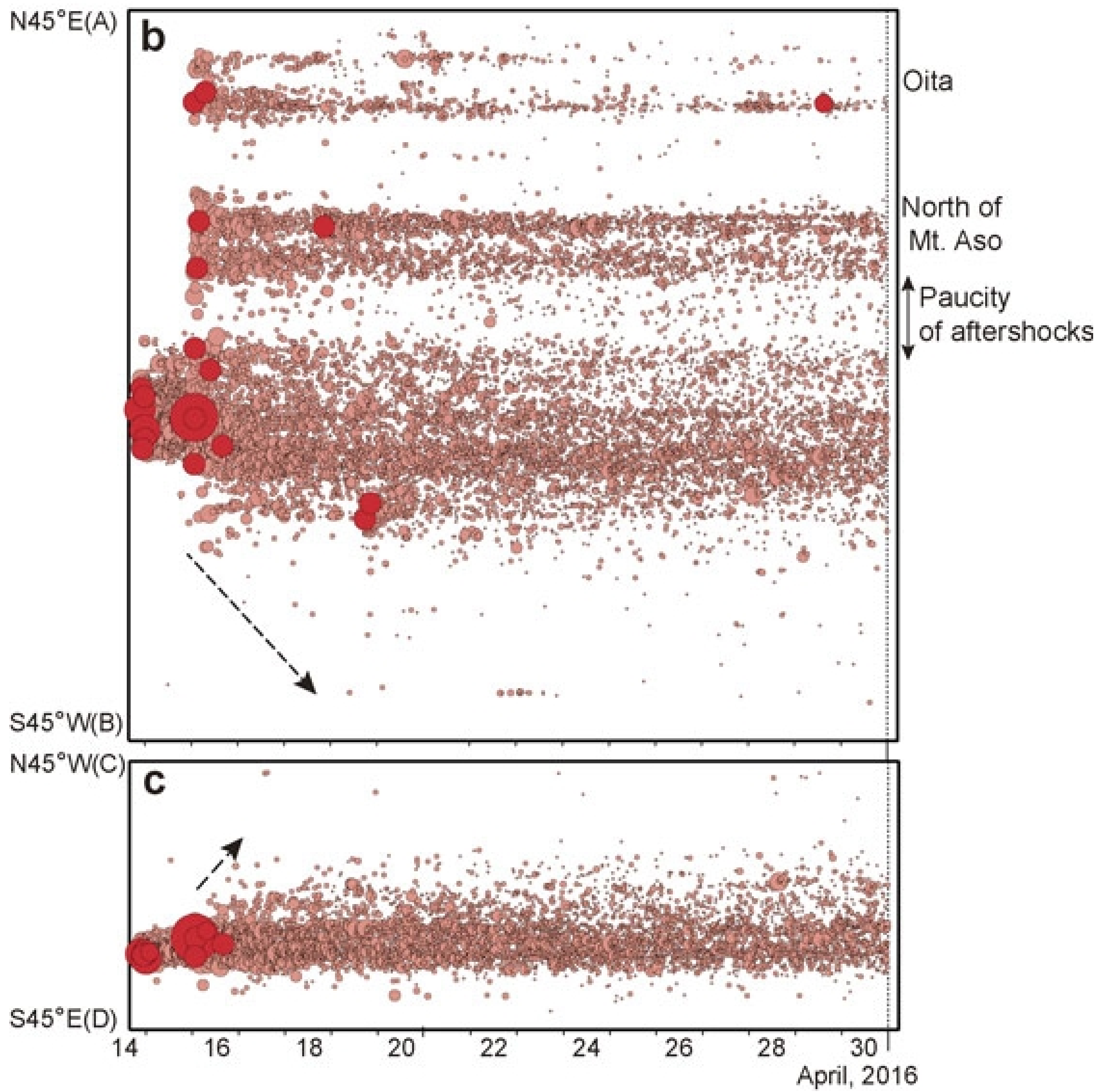
Craig earthquake (Alaska)

$$y(t) = a + bt + c\sin(2\pi t) + d\cos(2\pi t) + e\sin(4\pi t) + f\cos(4\pi t) + g\,H(t-t_0) + k\log\left(1+\frac{t-t_0}{\tau}\right)H(t-t_0)$$

secular annual + semi-annual coseismic postseismic

Far–field co-seismic:

$$\begin{cases} y(t) = g\,H(t - t_0) \\ g \sim \dfrac{M_0}{r} \end{cases}$$

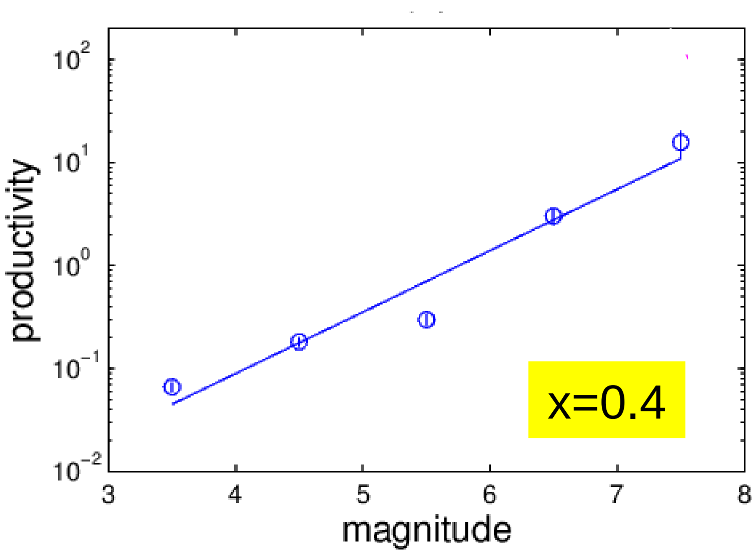


Kato et al. (Proc. Jap. Acad.) 2017

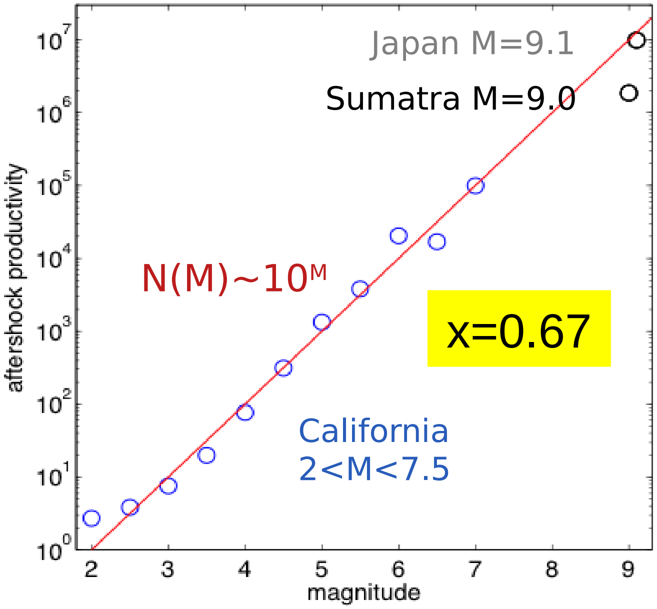
Far–field co-seismic (GPS):

$$\begin{cases} y(t) = g\, H(t - t_0) \\ g \sim \dfrac{M_0}{r} \end{cases}$$

Aftershock triggering: $N(M_o) \sim {M_o}^{x}$ **with 0.3 < *x* < 0.7**



Marsan and Lengliné 2008



Helmstetter 2014

GPS:

$$y(t) = a + bt + c\sin(2\pi t + \varphi) + d\sin(4\pi t + \psi) + \sum_i g_i H(t - t_i) + k_i \log\left(1 + \frac{t - t_i}{\tau_i}\right) H(t - t_i)$$

Only the largest shocks

Seismicity:

$$N(t) = secular + triggered(aftershocks)$$

CORSSA

HOME ARTICLES GLOSSARY CONTACT

www.corssa.org

CORSSA: the Community Online Resource for Statistical Seismicity Analysis

D. Vere-Jones, M. Naylor, K. Orfanogiannaki, D. Harte, S. Husen, J. Hardebeck, A. Mignan, J. Woessner, L. Gulia, S. Wiemer, M. Wyss, E. Hauksson, J. Zhuang, M. Werner, S. Hainzl, S. Zhou, S. Steacy, D. Marsan, T. Iwata, T. van Stiphout, S. Touati, J. D. Zechar

CORSSA articles in Theme IV

- Earthquake location accuracy
- Completeness magnitude in earthquake catalogs
- Catalog artifacts and quality control
- What is an instrumental seismicity catalog?

CORSSA articles in Theme V

- Basic models of seismicity: temporal models
- Basic models of seismicity: spatiotemporal models
- Seismicity models based on Coulomb stress calculations
- Earthquake triggering caused by the external oscillation of stress/strain changes
- Seismicity rate changes
- Seismicity declustering
- Stochastic simulation of earthquake catalogs

CORSSA articles in Theme VI

- Evaluating earthquake predictions and earthquake forecasts: a guide for students and new researchers

Declustering

=

Removing aftershocks

=

For mainshock H, find its aftershocks

Gardner and Knopoff BSSA 1974
Reasenberg JGR 1985

Declustering

=

Removing aftershocks

=

For earthquake E, find its trigger *among all previous shocks* H_i

- **Single link clusters** (Davis and Frohlich, GJI, 1991)
- **Stochastic declustering** (Zhuang et al., JASA, 2002)

For earthquake E, find its trigger
among all previous shocks H_i

Bayes

$$P(H_i|E) = \frac{P(E|H_i)}{\sum_i P(E|H_i)}$$

$P(E|H_i) =$ Probability 1 earthquake E in { volume [$\underline{x}$,$\underline{x}$+d$\underline{x}$], interval [t, t+dt], interval [m, m+dm] } knowing H_i is the trigger

$$P(E|H_i) = \lambda_i \, d\underline{x} \, dt \, dm \quad \Rightarrow \quad P(H_i|E) = \frac{\lambda_i}{\sum_i \lambda_i}$$

For earthquake E, find its trigger *among all previous shocks H_i*

An earthquake can also occur **spontaneously**: it is not the aftershock of a (known) previous mainshock

H_0 = no seismic trigger

$$P(E|H_0) = \mu\, d\underline{x}\, dt\, dm$$

$$P(H_0|E) = \frac{\mu}{\mu + \sum_i \lambda_i}$$

$$P(H_i|E) = \frac{\lambda_i}{\mu + \sum_i \lambda_i}$$

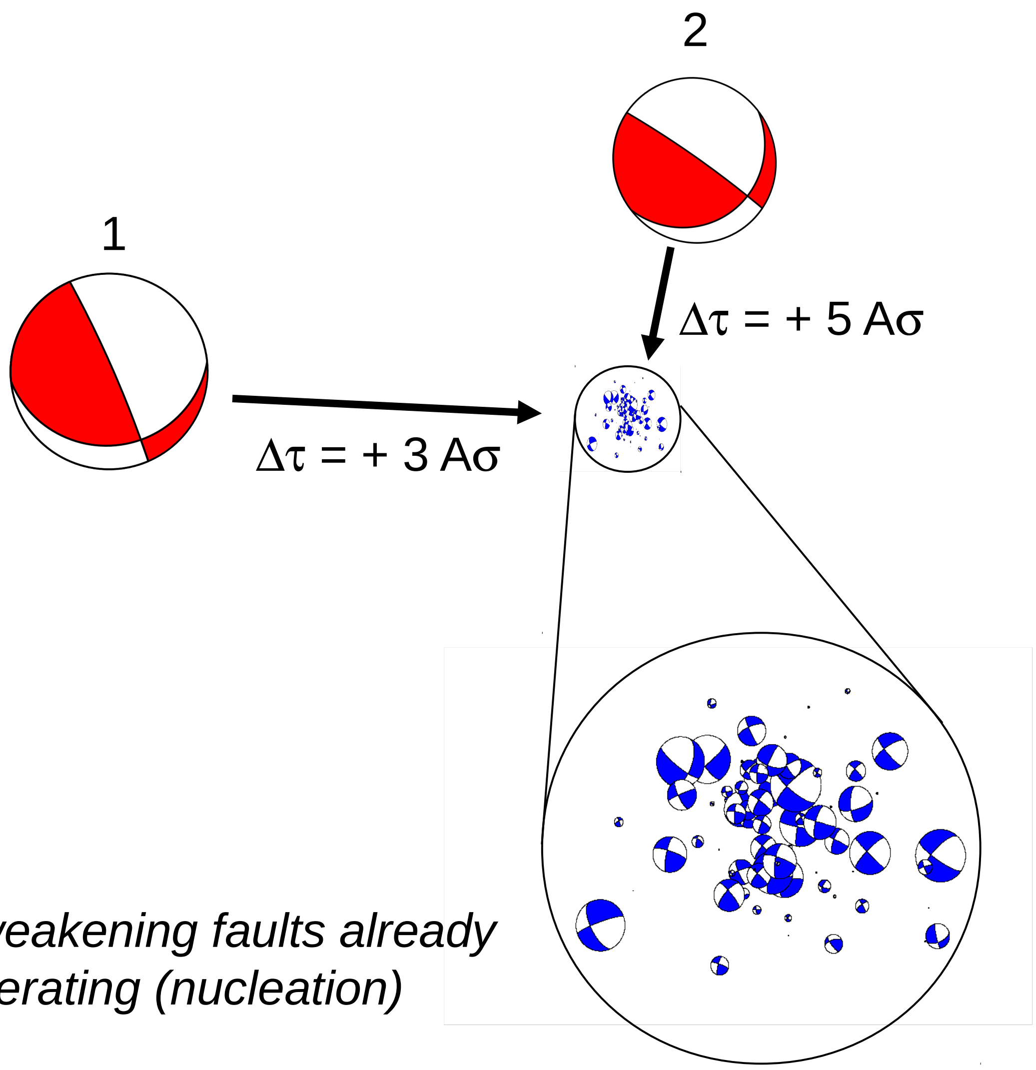
For earthquake E, find its trigger *among all previous shocks* H_i

$$P(E) = P(E|H_1)P(H_1) + P(E|H_2)P(H_2)$$

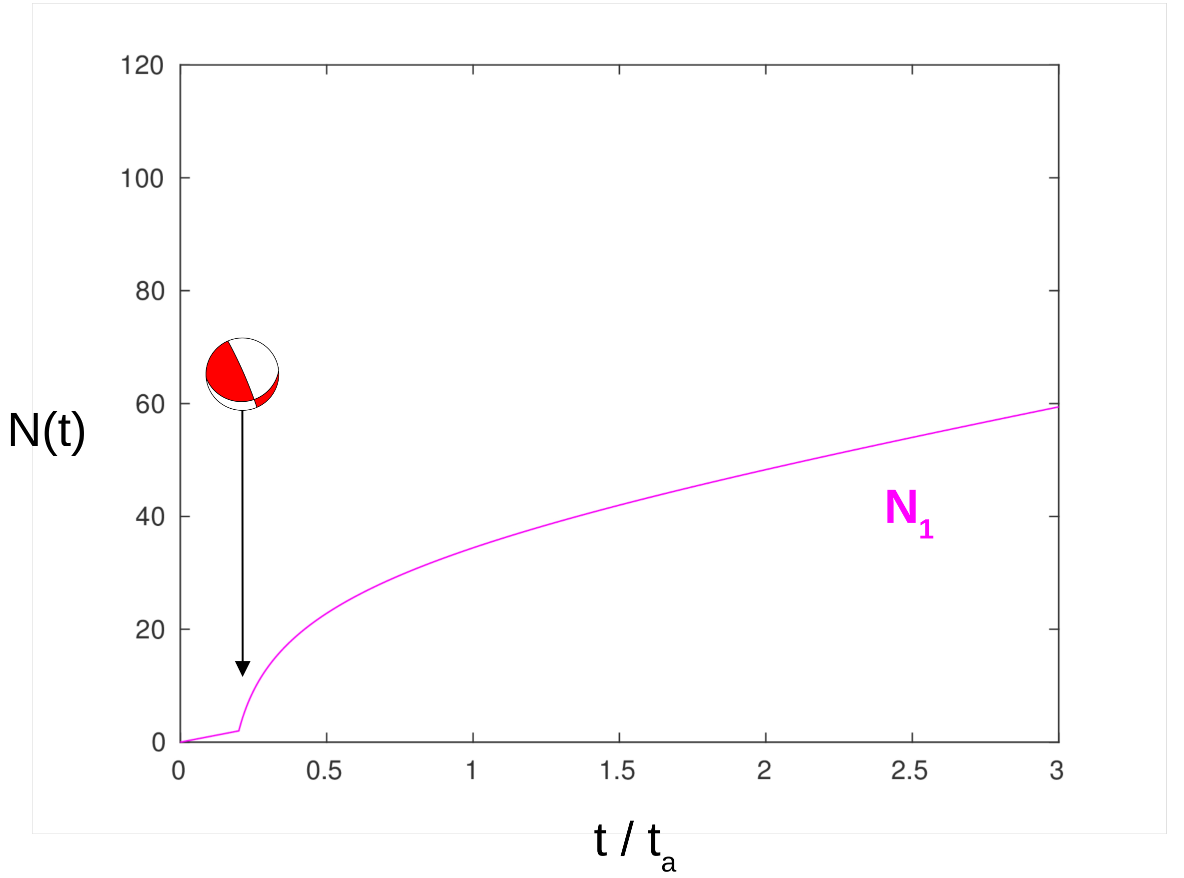
only if H_1 and H_2 are **independent**

Is this the case?

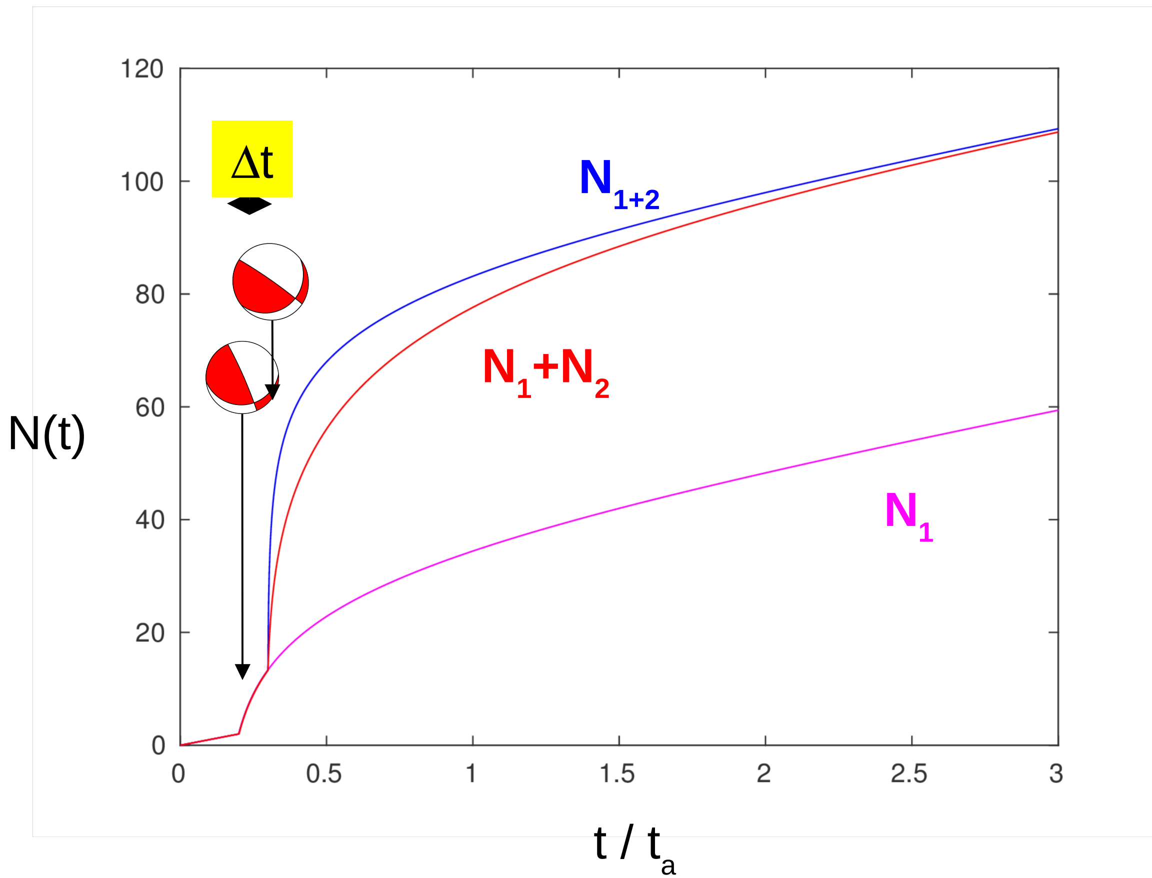
Triggering according to rate-and-state friction

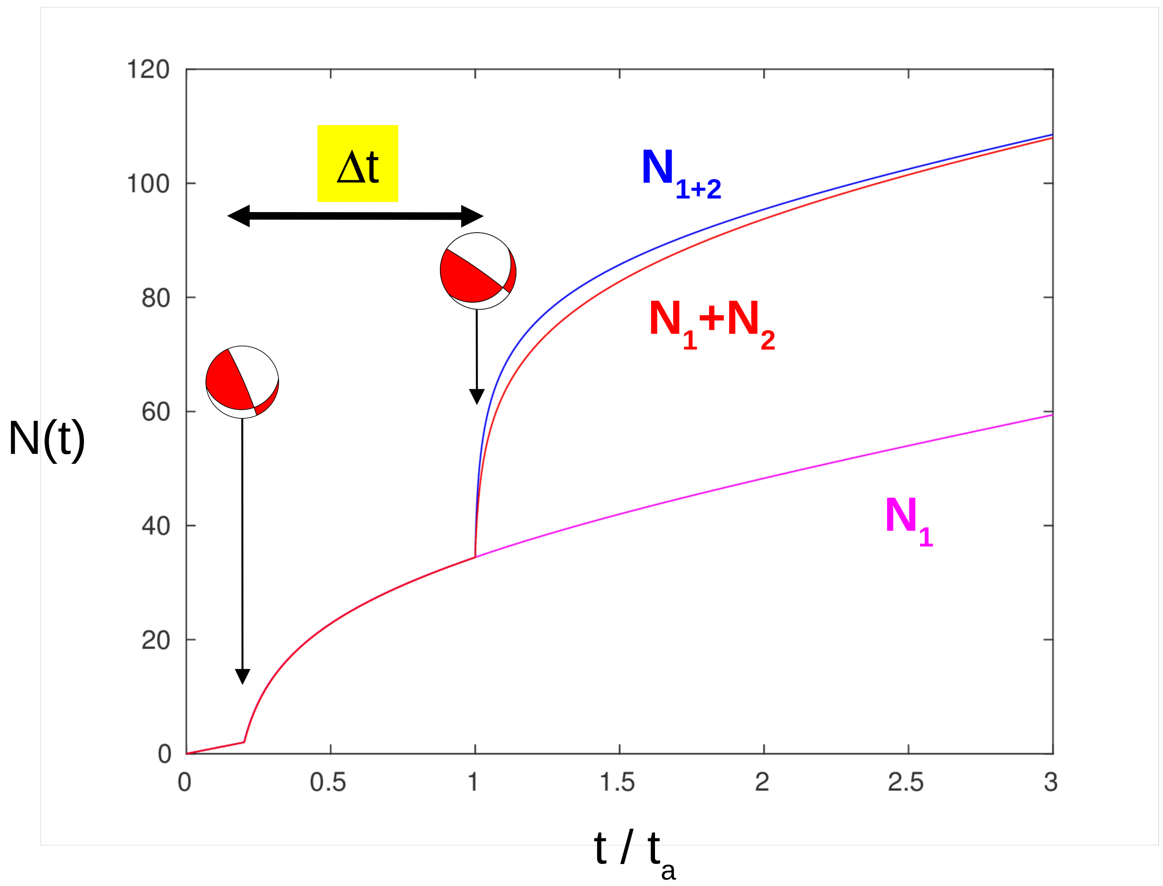


Velocity weakening faults already accelerating (nucleation)

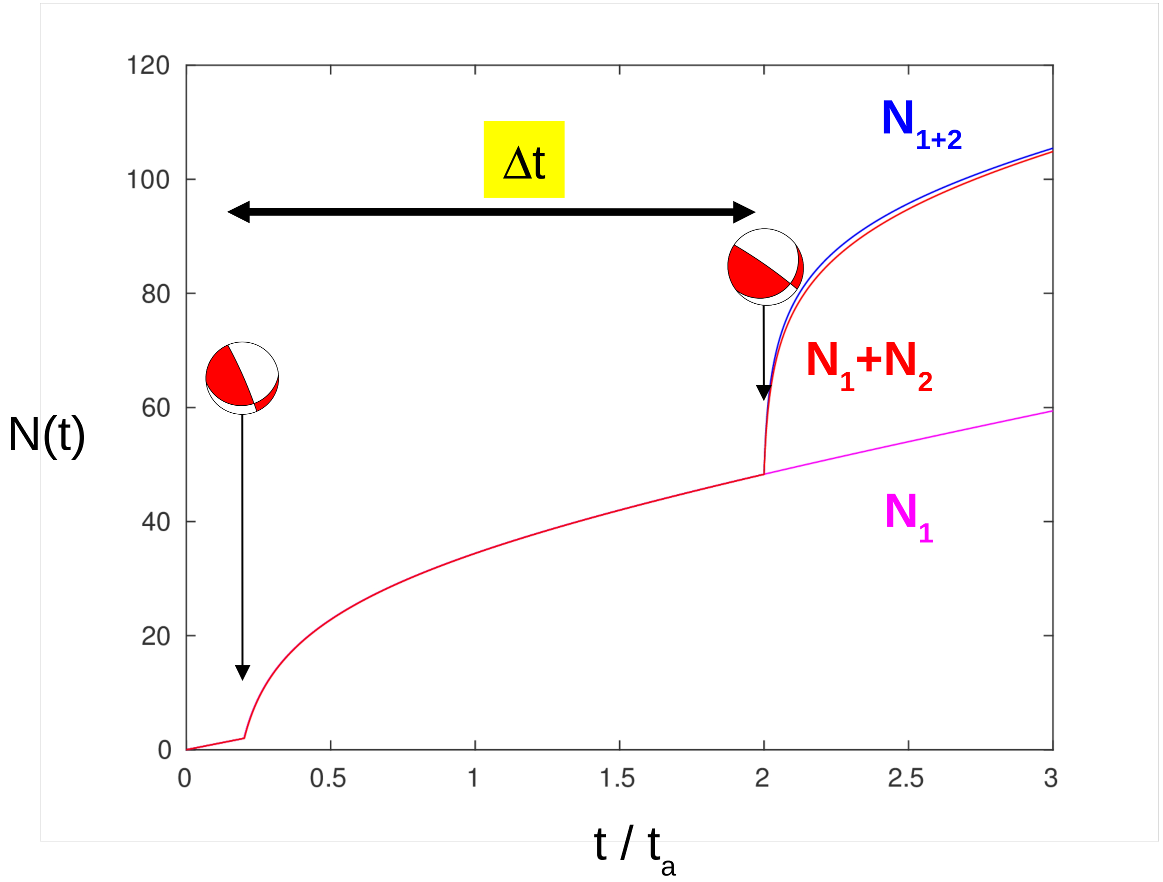


N(t)
t / t_a
N_1
0
20
40
60
80
100
120
0
0.5
1
1.5
2
2.5
3


120
100
80
60
40
20
0
N(t)
Δt
N1+2
N1+N2
N1
0
0.5
1
1.5
2
2.5
3
t / ta



N(t)
t / t_a
Δt
N_{1+2}
N_1+N_2
N_1
0
20
40
60
80
100
120
0
0.5
1
1.5
2
2.5
3



120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
N(t)
t / t_a
Δt
N_{1+2}
N_1+N_2
N_1

For earthquake E, find its trigger
among all previous shocks H_i

$$P(E) = P(E|H_1)P(H_1) + P(E|H_2)P(H_2)$$

only if H_1 and H_2 are **independent**

Is this the case?

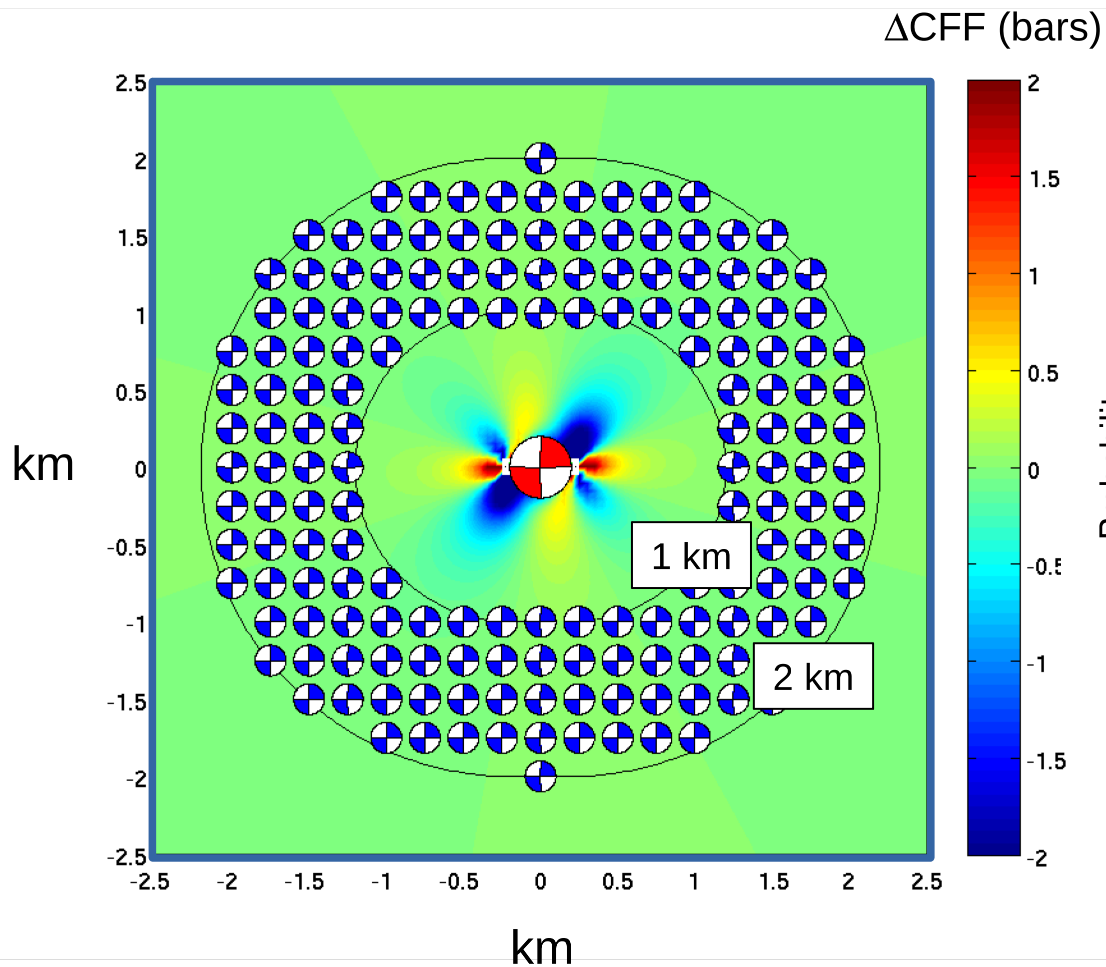
No according to rate-and-state

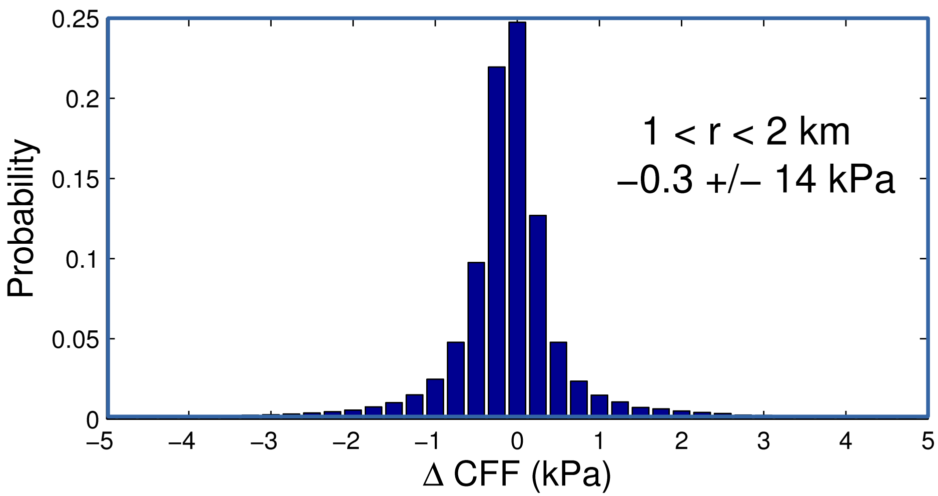
But :

- Departure is only significant at short time scales
- Departure vanishes when $\Delta t \to \infty$
- Total N is linear

Static stress triggering with rate-and-state

M = 3 earthquake (L = 400 m, u = 1 cm)





Marsan and Lengliné (JGR) 2010

Rate-and-state friction

n = # of direct aftershocks in time $[0, t]$ and distance $[R_1, R_2]$

$$n = \mu(R_1, R_2)\; t_a \left\{ \ln\left(e^{t/t_a} + e^{-\Delta CFF/A\sigma} - 1 \right) + \frac{\Delta CFF}{A\sigma} - \frac{t}{t_a} \right\}$$

Dieterich (JGR) 1994

Rate-and-state friction

n = # of direct aftershocks in time $[0,t]$ and distance $[R_1,R_2]$

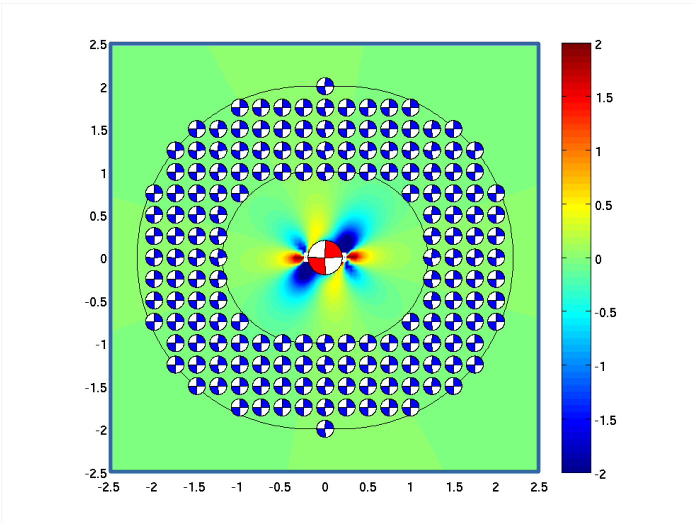
$$n = \mu(R_1,R_2)\; t_a \left\{ \ln\left(e^{t/t_a} + e^{-\Delta CFF/A\sigma} - 1 \right) + \frac{\Delta CFF}{A\sigma} - \frac{t}{t_a} \right\}$$

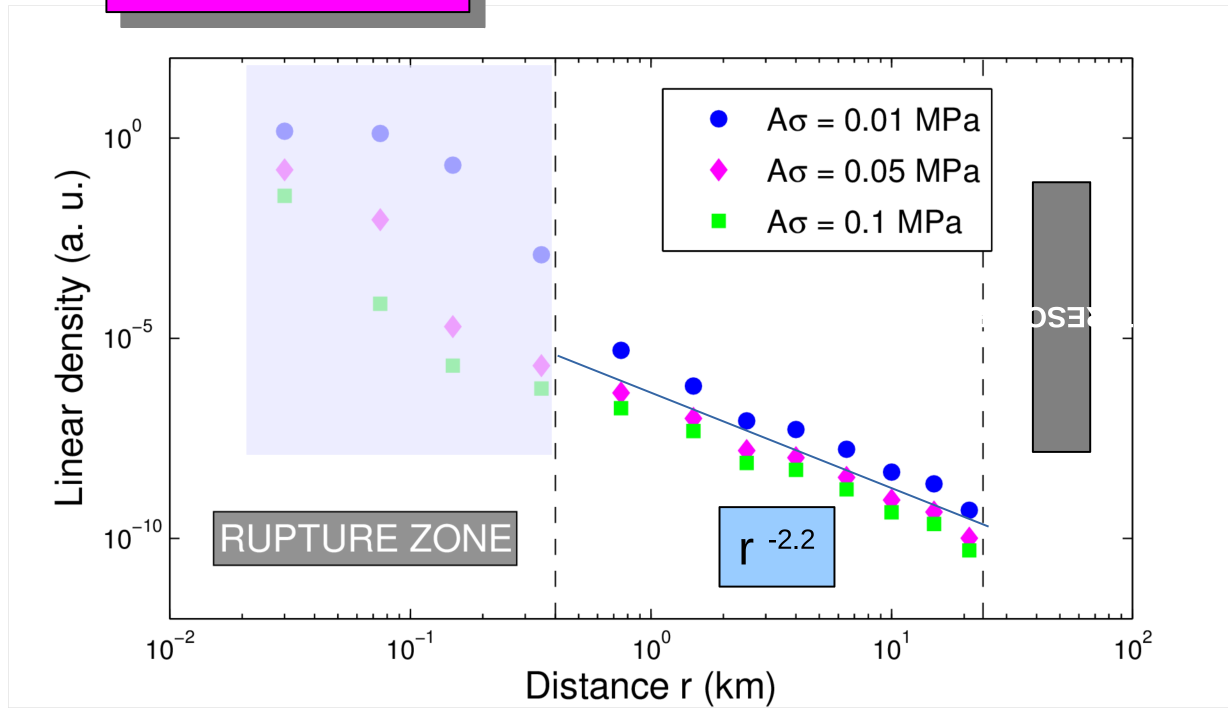
Background density

$\mu(R) \sim R^{1.65}$

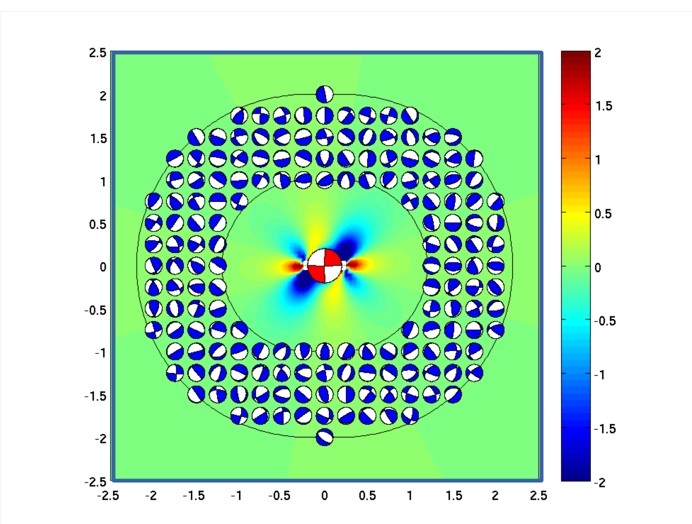
Total number N grows in $L^{1.65} \sim M_o^{0.55}$

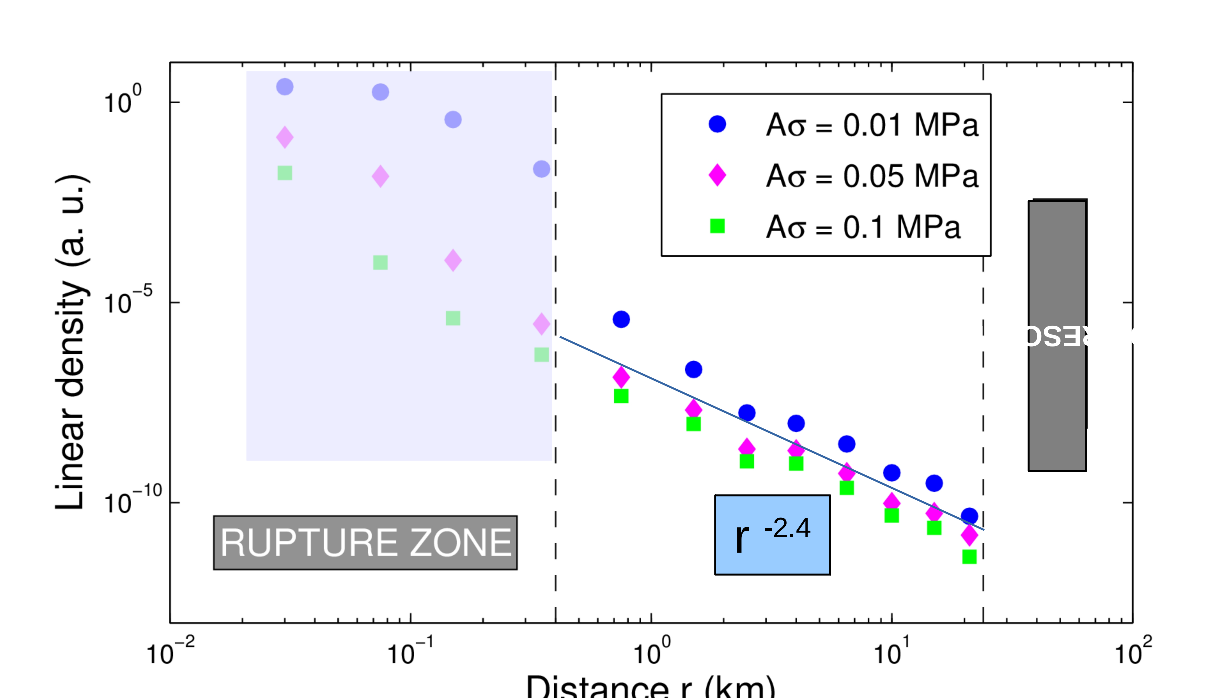
0<t<1 hour





Linear density (a. u.)
Distance r (km)
Aσ = 0.01 MPa
Aσ = 0.05 MPa
Aσ = 0.1 MPa
RUPTURE ZONE
r -2.2





Linear density (a. u.)
Distance r (km)
Aσ = 0.01 MPa
Aσ = 0.05 MPa
Aσ = 0.1 MPa
RUPTURE ZONE
r -2.4

For earthquake E, find its trigger *among all previous shocks H_i*

$$P(E) = P(E|H_1)P(H_1) + P(E|H_2)P(H_2)$$

only if H_1 and H_2 are **independent**

Is this the case?

No according to rate-and-state

But :

- Departure is only significant at short time scales
- Departure vanishes when $\Delta t \rightarrow \infty$
- Total N is linear
- **Rate decays in t^{-1}**
- **Rate decays in $r^{-\gamma}$ ($\gamma \approx 2$)**
- **Total N grows in M_o^x ($x \approx 0.5$)**

For earthquake E, find its trigger *among all previous shocks H_i*

ETAS (space-time) models :

- N is linear
- Rate decays in t^{-p}
- Rate decays in $r^{-\gamma}$
- Total N grows in M_o^x

Ogata (Ann. Inst. Stat. Math.) 1988

$$P(E|H_i) = \lambda_i \, d\underline{x} \, dt \, dm$$

$$P(H_i|E) = \frac{\lambda_i}{\sum_i \lambda_i}$$

$$\lambda_i = \frac{Ke^{\alpha m}}{(t+c)^p} (r+L_m)^{-\gamma}$$

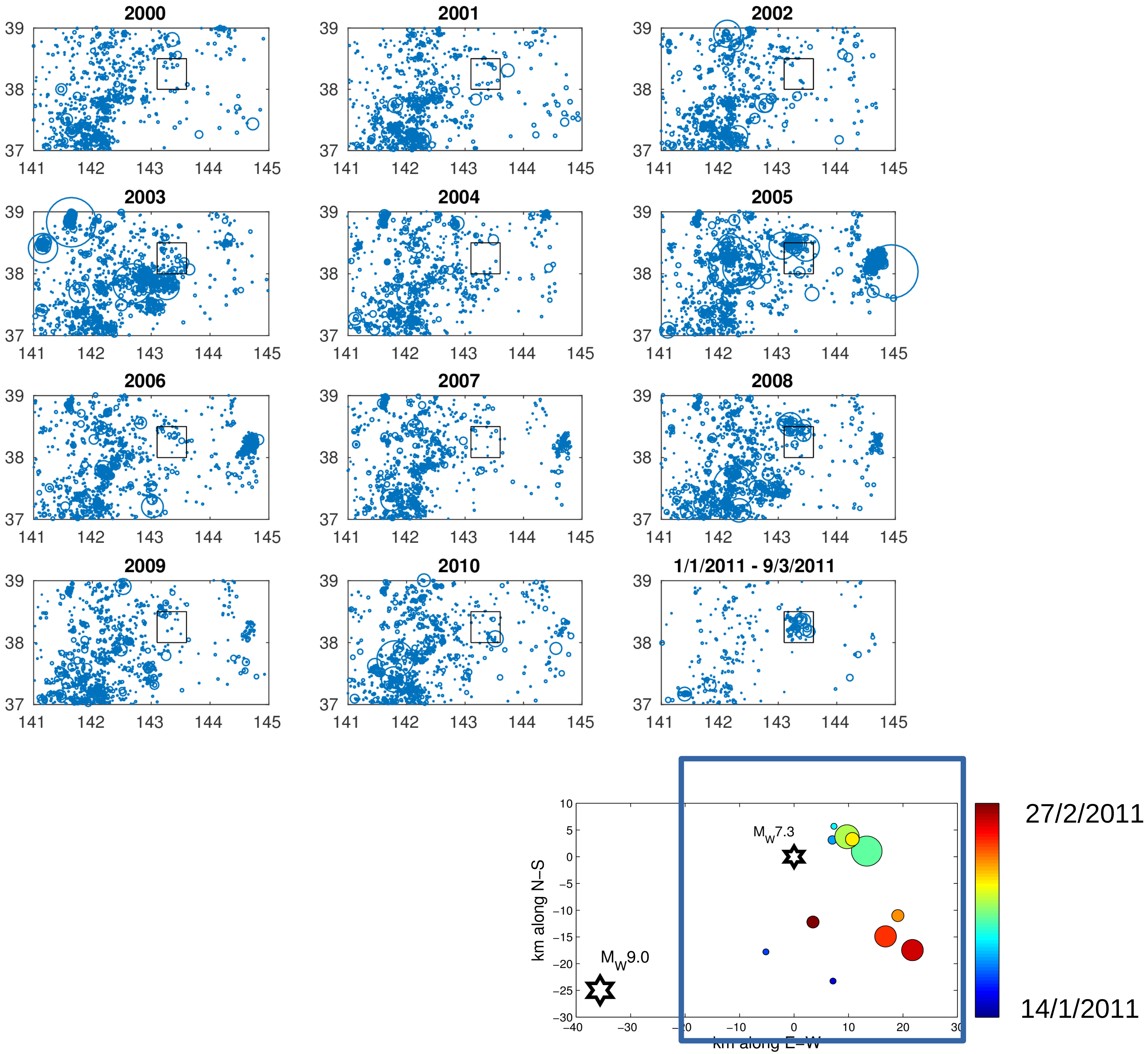
For earthquake E, find its trigger *among all previous shocks H_i*

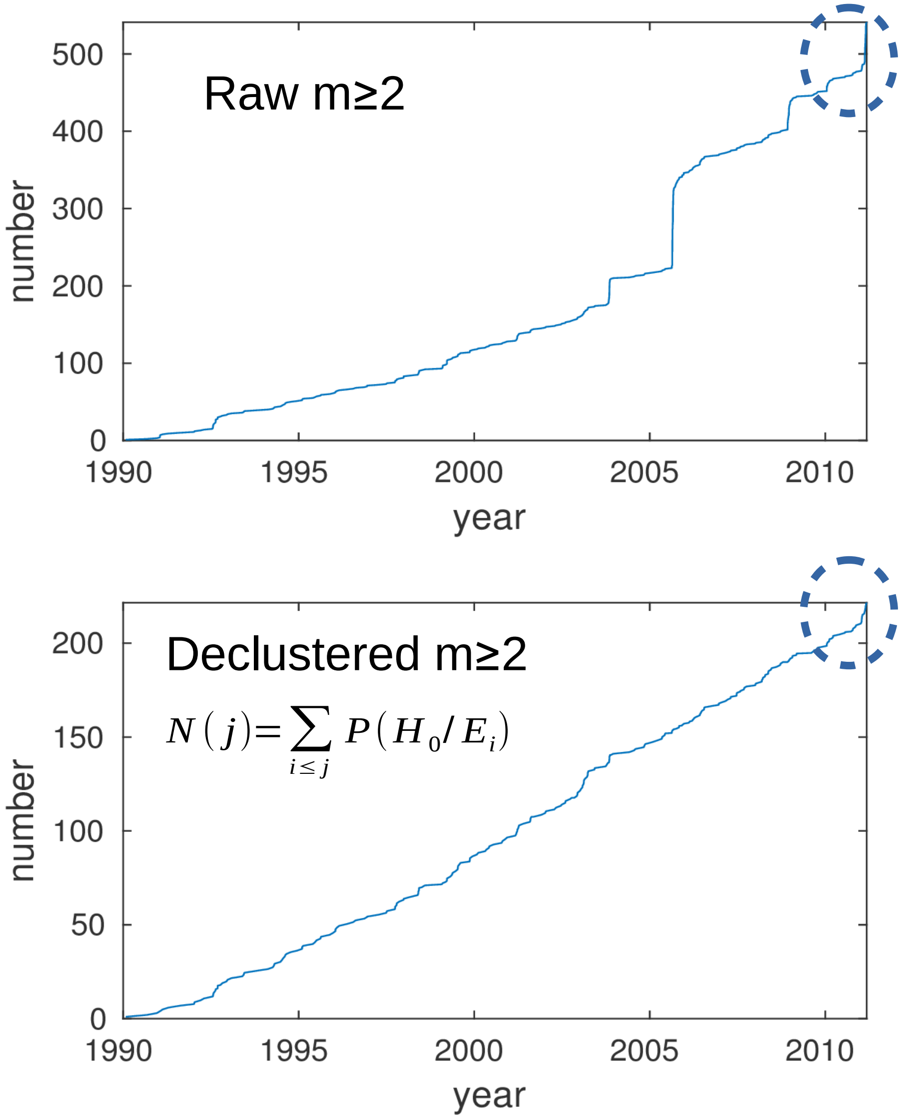
$$P(H_0|E) = \frac{\mu}{\mu + \sum_i \lambda_i}$$

$$P(H_i|E) = \frac{\lambda_i}{\mu + \sum_i \lambda_i}$$

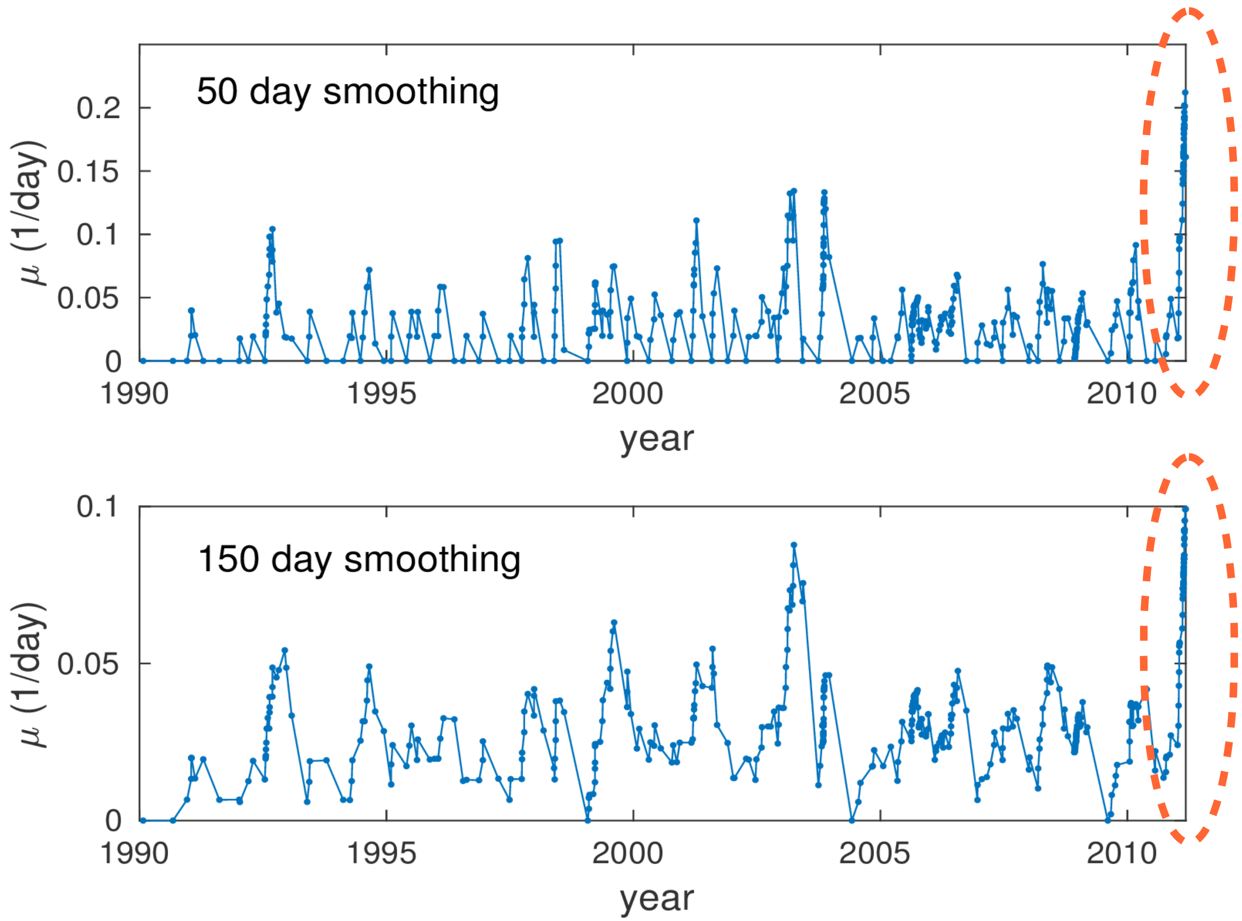
$$\lambda_i = \frac{Ke^{\alpha m}}{(t+c)^p}(r+L_m)^{-\gamma}$$

- Compute $P(H_i|E)$ and $P(H_0|E)$ for all earthquakes E
- Smooth $P(H_0|E)$ in space and time → ***$\mu(x,y,t)$***
- Iterate until convergence

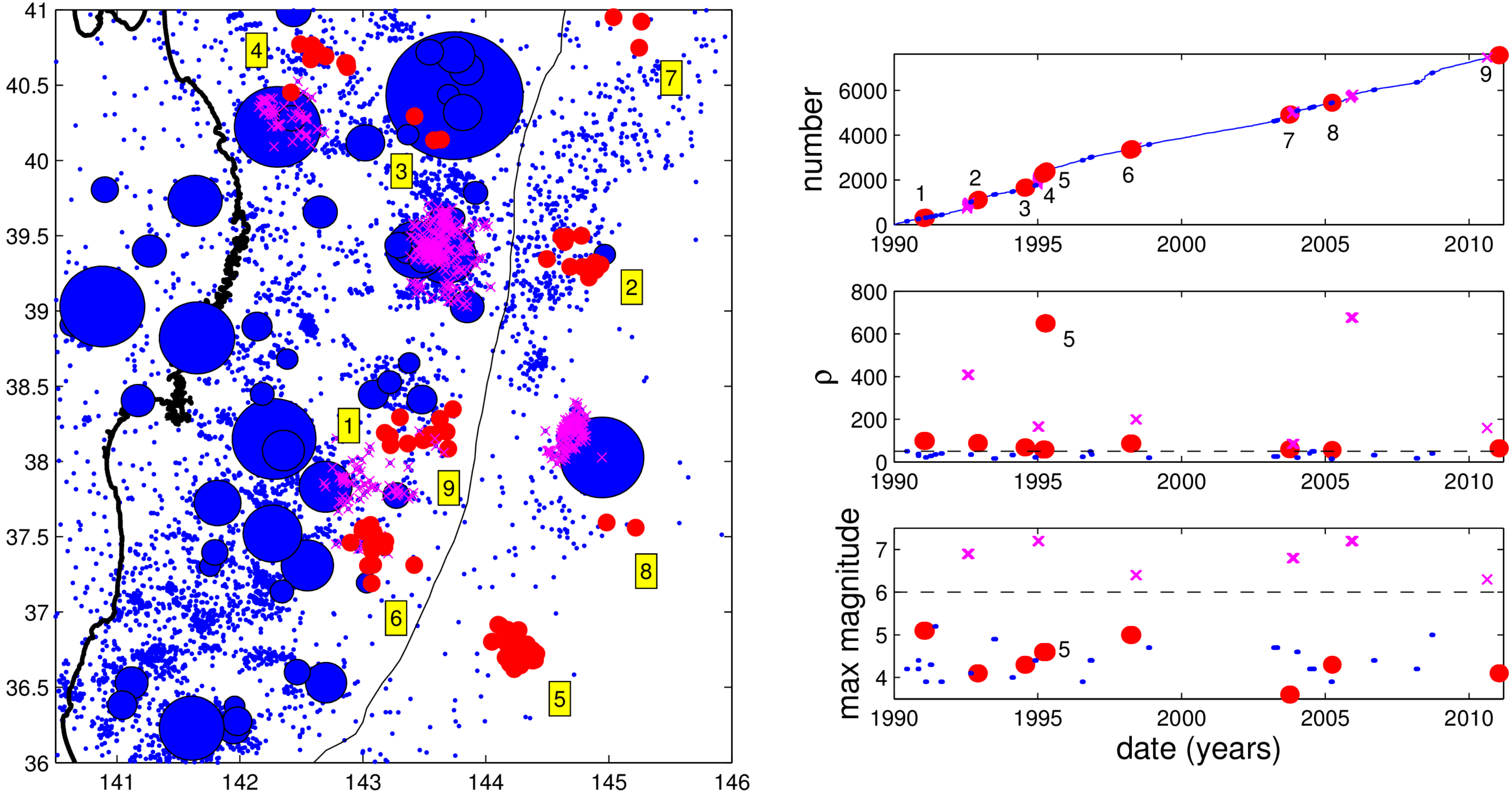

2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
1/1/2011 - 9/3/2011
km along N–S
km along E–W
M_W7.3
M_W9.0
27/2/2011
14/1/2011



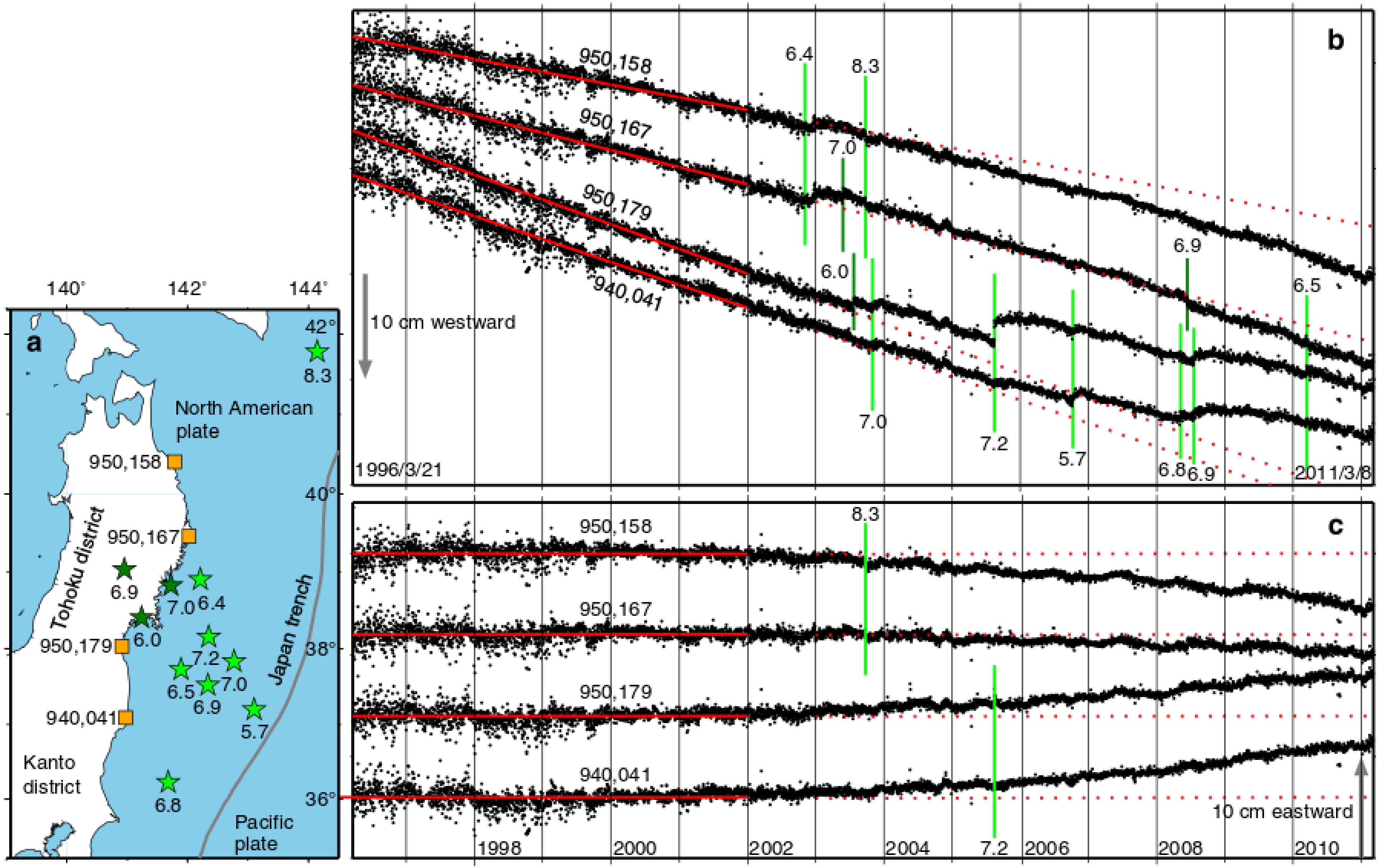
Raw m≥2
number
year
0
100
200
300
400
500
1990
1995
2000
2005
2010
Declustered m≥2
$N(j)=\sum_{i \le j} P(H_0/E_i)$
number
year
0
50
100
150
200
1990
1995
2000
2005
2010


50 day smoothing
0.2
0.15
0.1
0.05
0
μ (1/day)
1990
1995
2000
2005
2010
year
150 day smoothing
0.1
0.05
0
μ (1/day)
1990
1995
2000
2005
2010
year

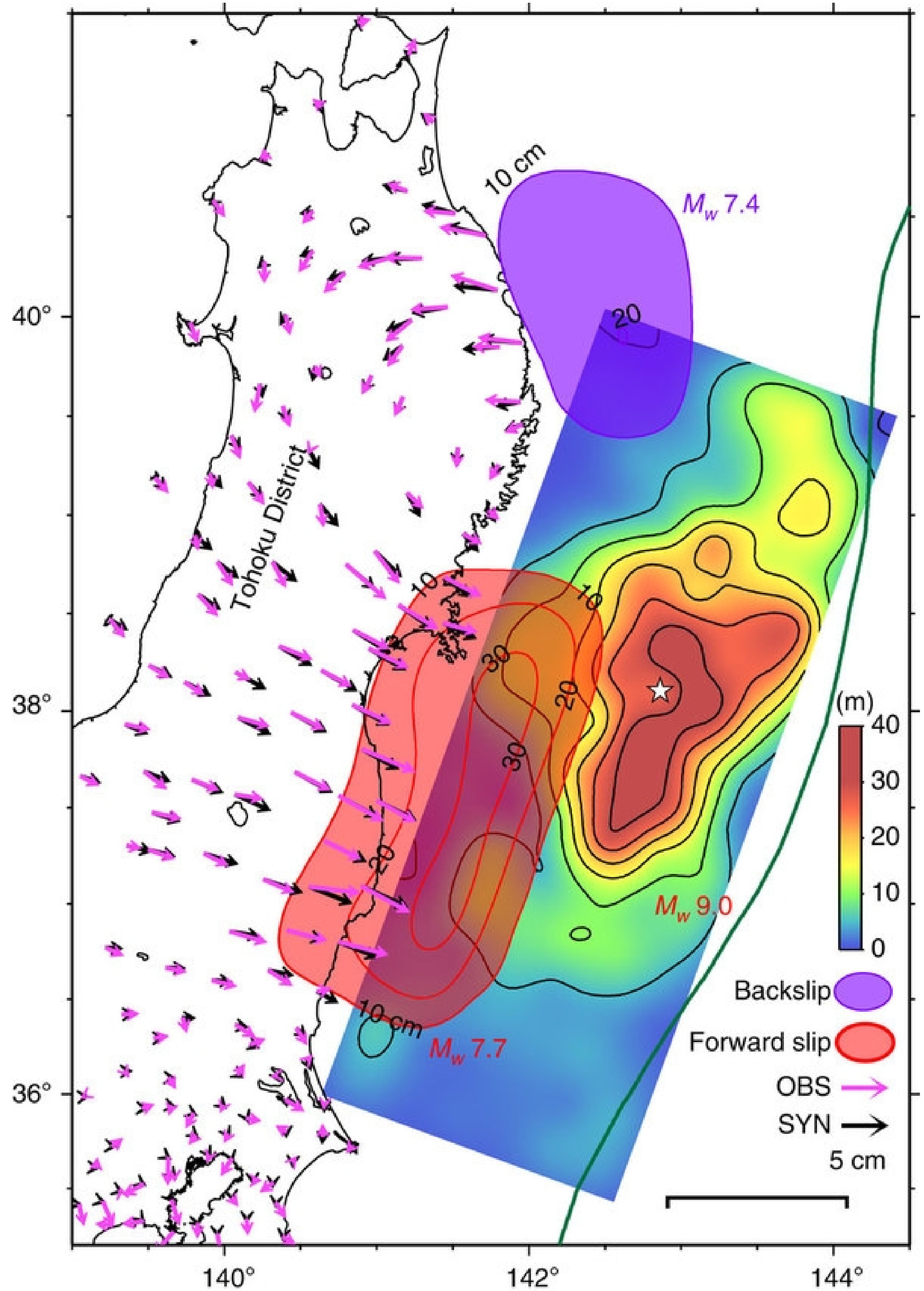
Small scale transients: ℓ = 20 km, τ = 40 days



Marsan et al. JGR 2013



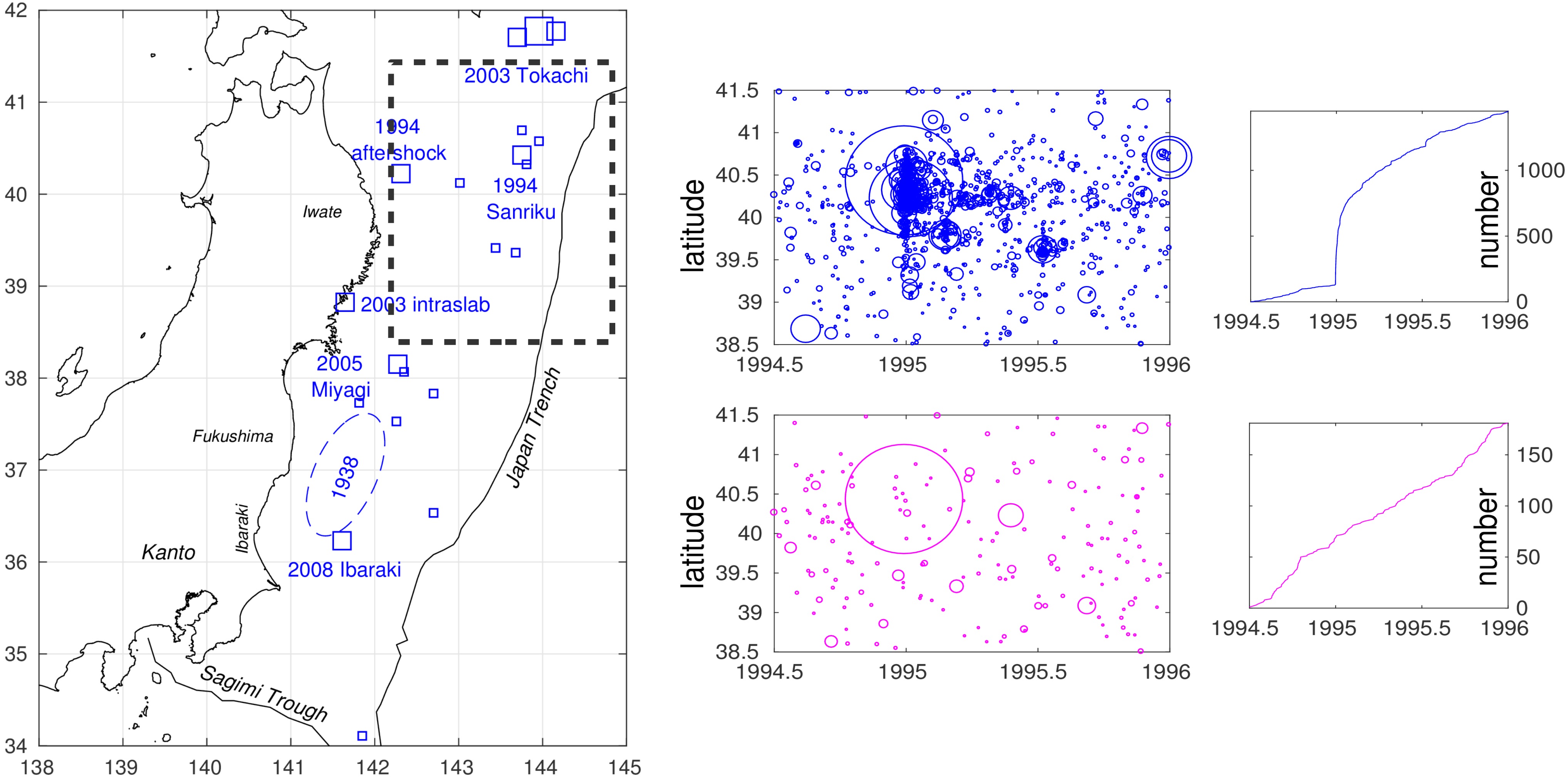
Yokota and Koketsu
(Nat. Comm., 2015)



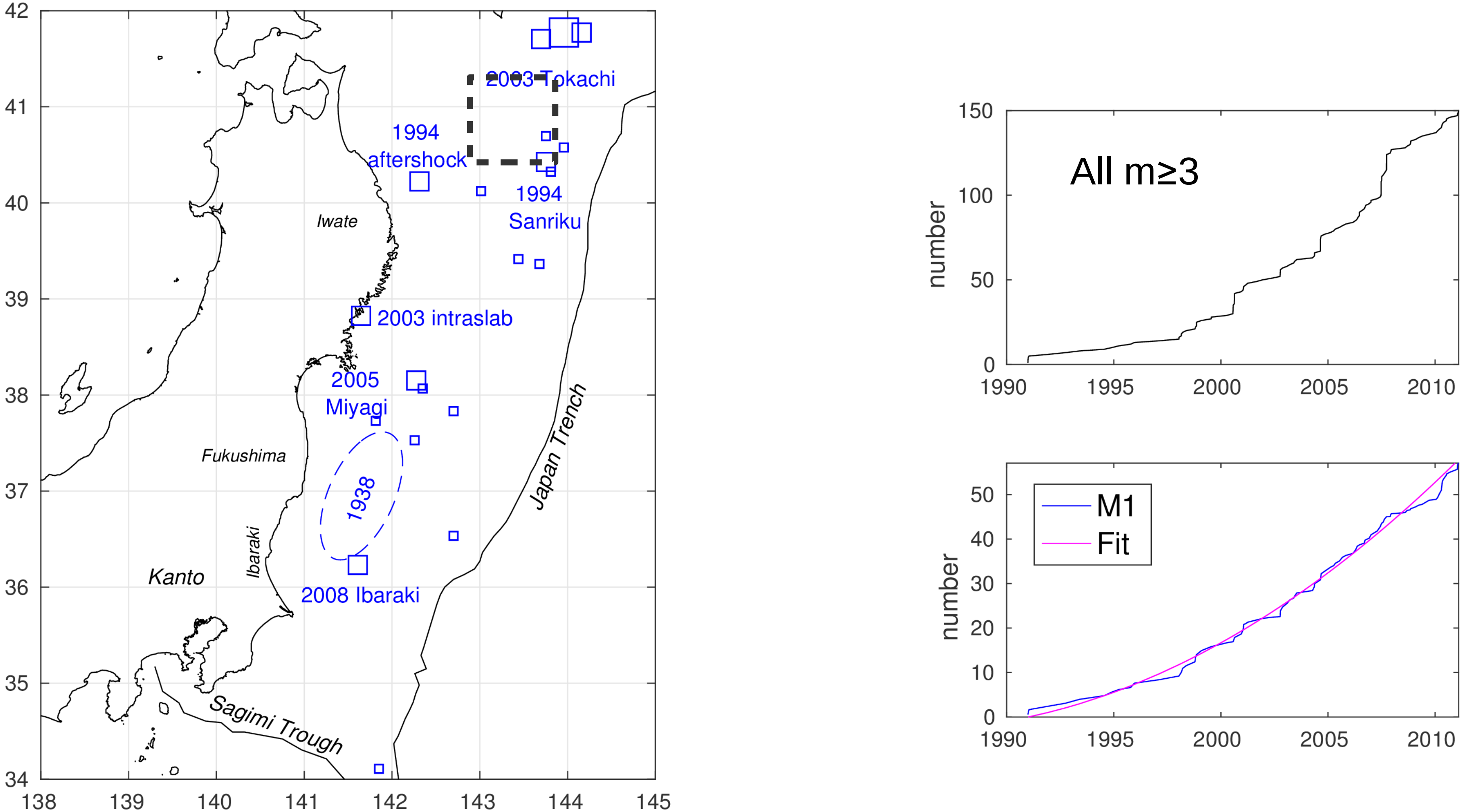
Yokota and Koketsu
(Nat. Comm., 2015)

Mavrommatis et al. (GRL 2014)

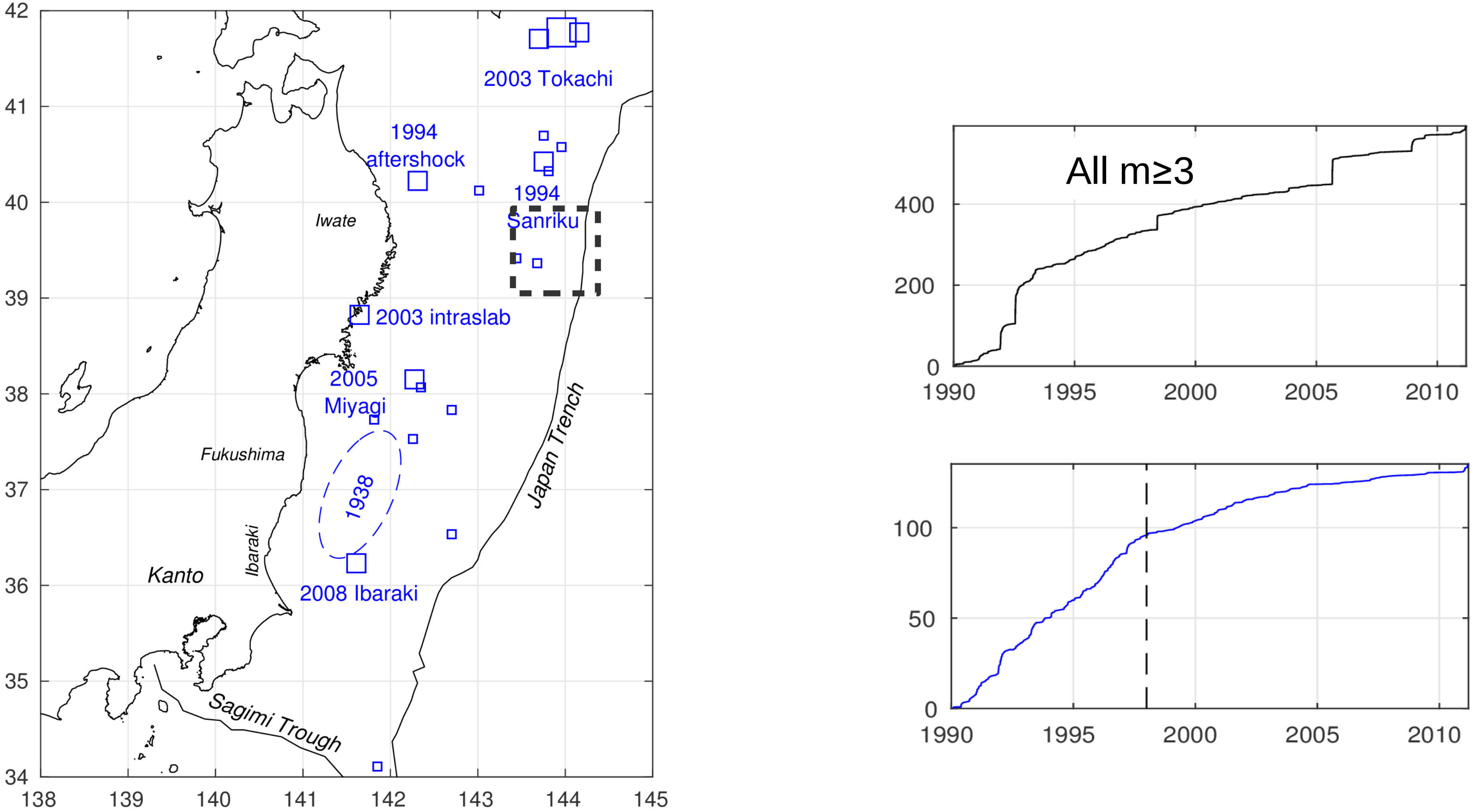
Heki and Mitsui (EPSL 2013)



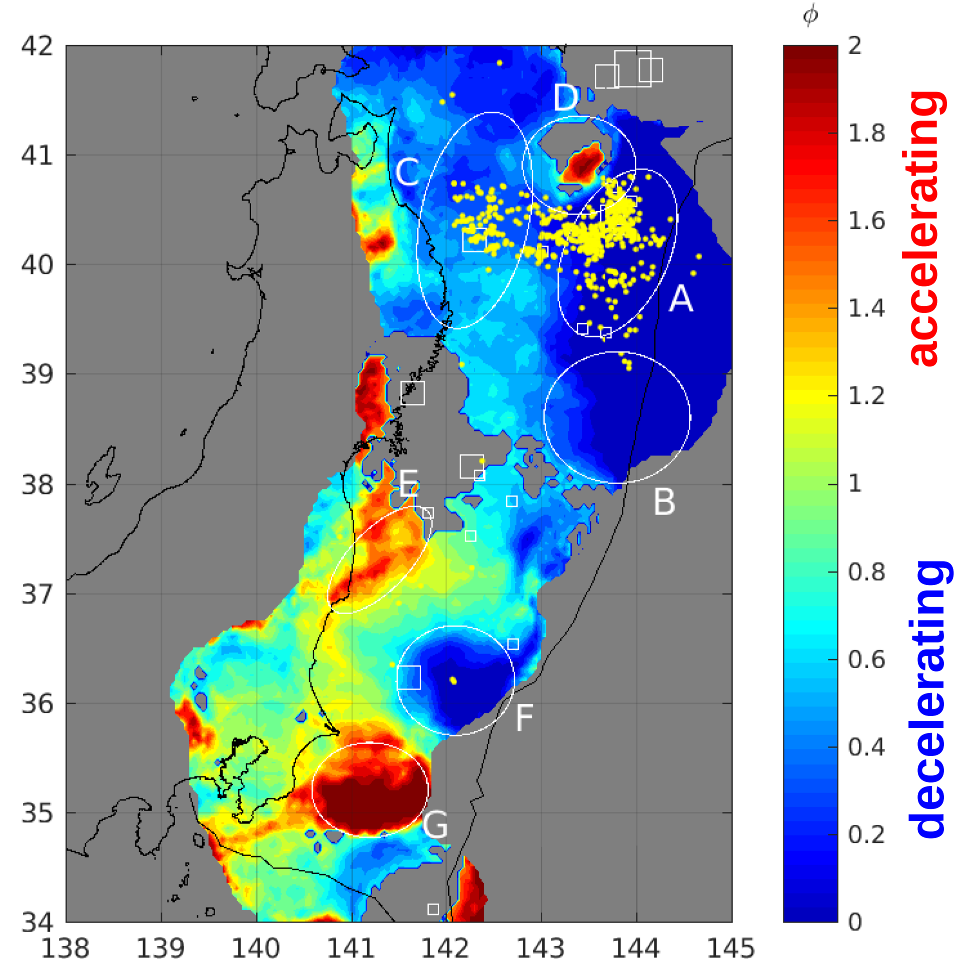
2003 Tokachi
1994 aftershock
1994 Sanriku
2003 intraslab
2005 Miyagi
1938
2008 Ibaraki
Iwate
Fukushima
Ibaraki
Kanto
Japan Trench
Sagimi Trough
latitude
number

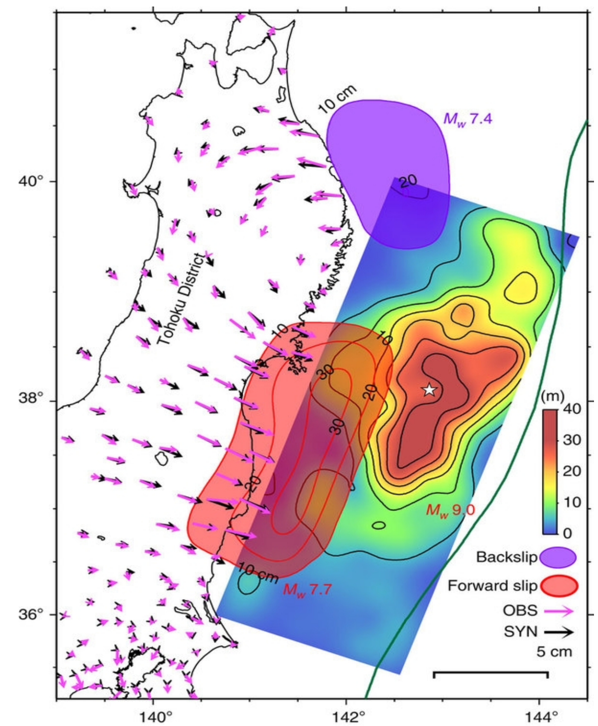


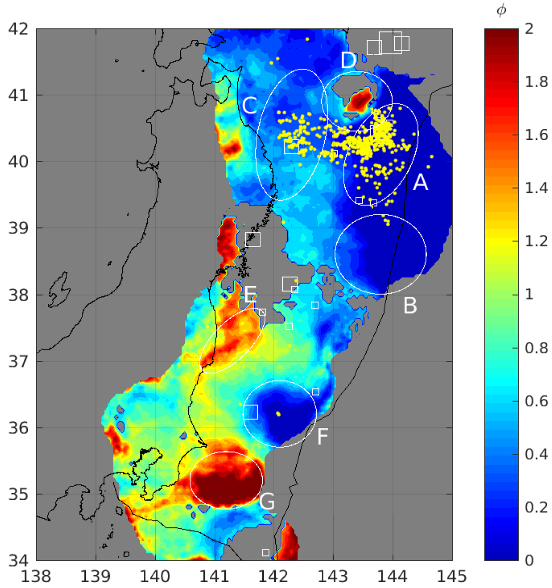
2003 Tokachi
1994
aftershock
1994
Sanriku
Iwate
2003 intraslab
2005
Miyagi
Fukushima
1938
Japan Trench
Ibaraki
Kanto
2008 Ibaraki
Sagimi Trough
All m≥3
number
M1
Fit

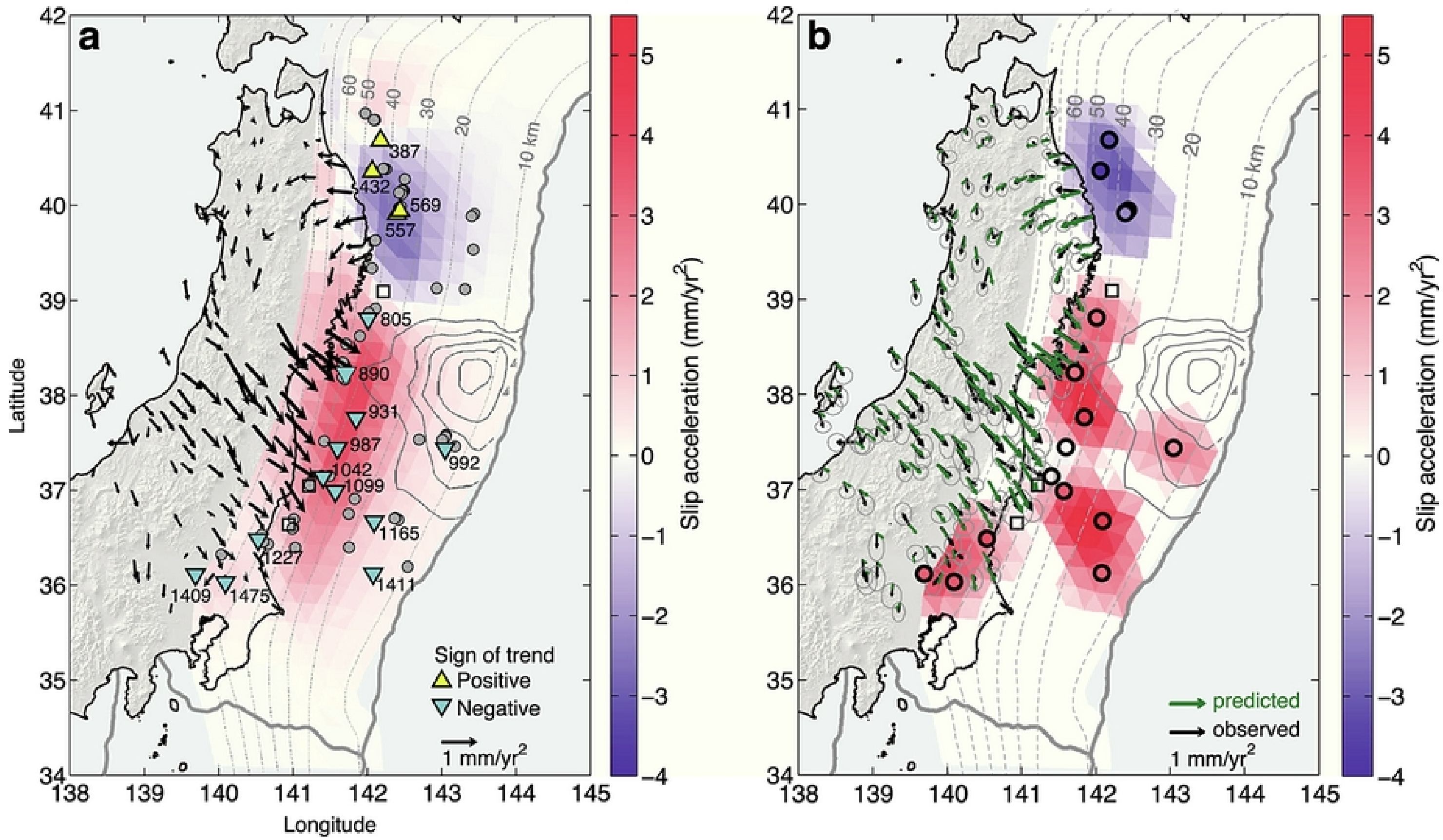

2003 Tokachi
1994
aftershock
1994
Sanriku
Iwate
2003 intraslab
2005
Miyagi
Fukushima
1938
Japan Trench
Ibaraki
Kanto
2008 Ibaraki
Sagimi Trough
All m≥3

Rate change of background activity 1990 – 2011

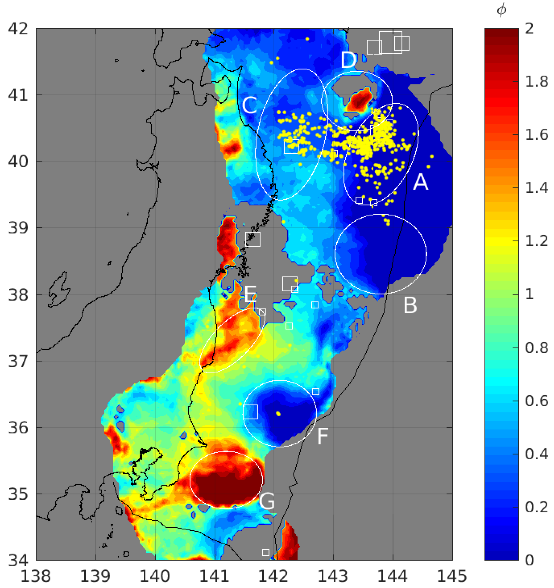




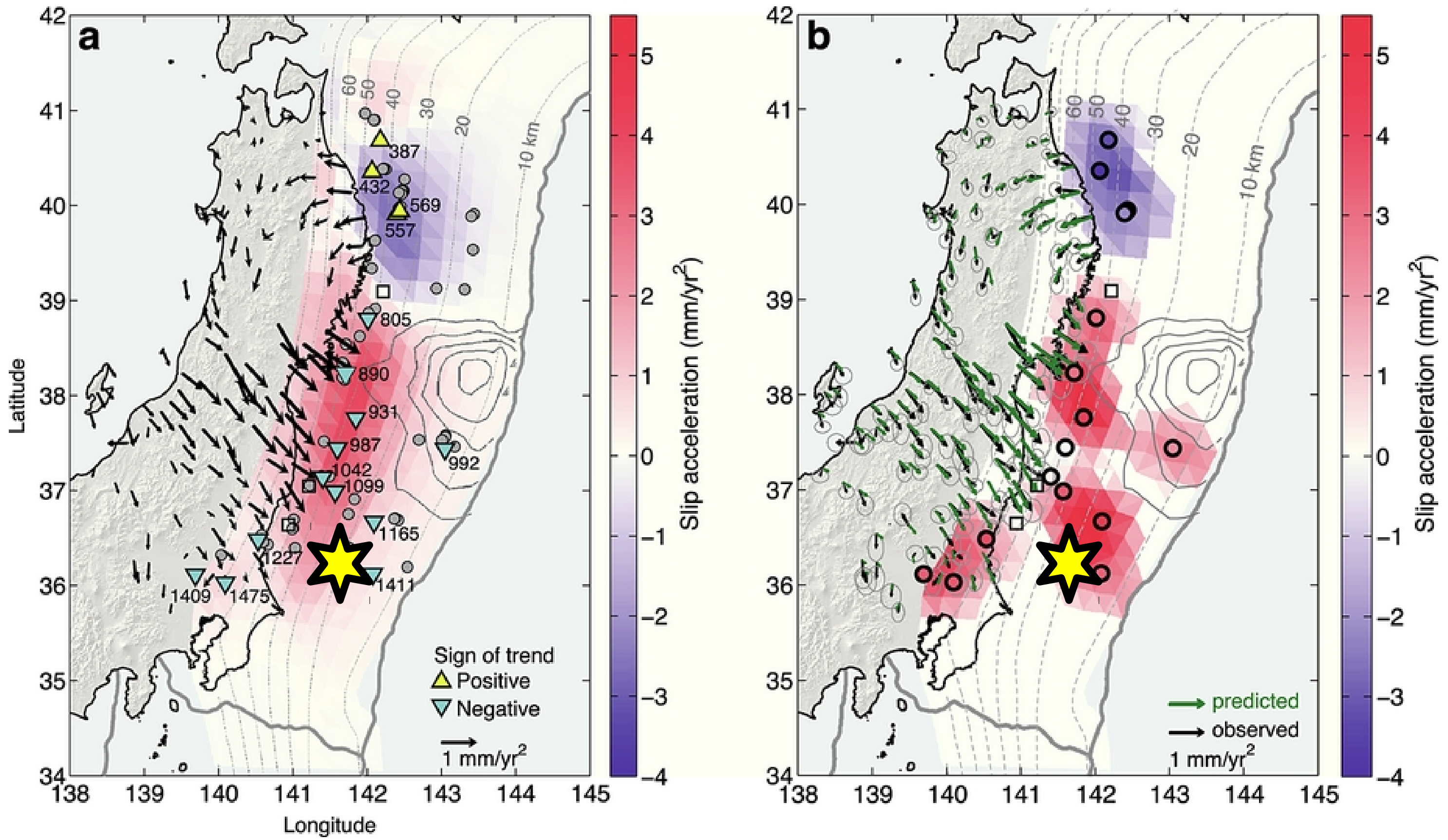




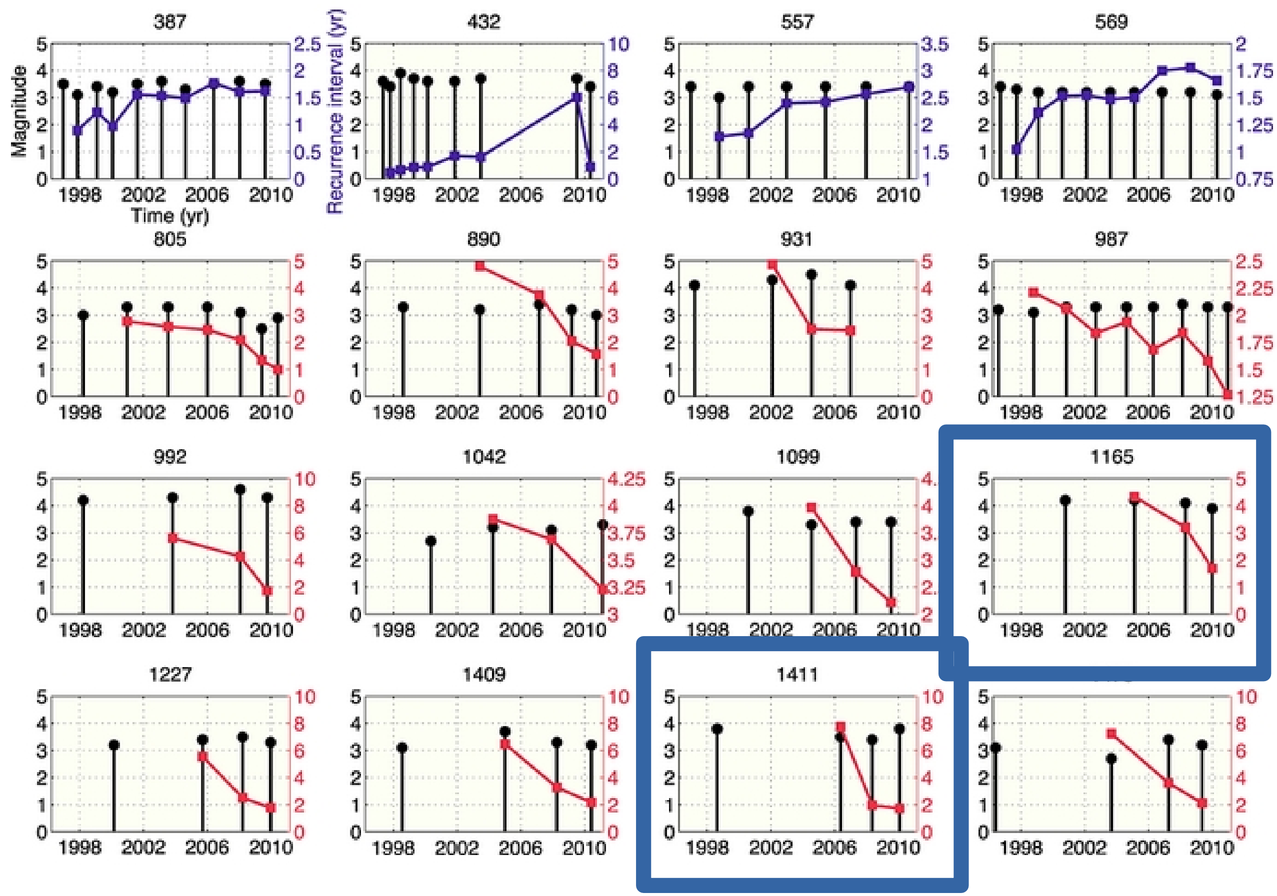
Mavrommatis et al. (GRL) 2015



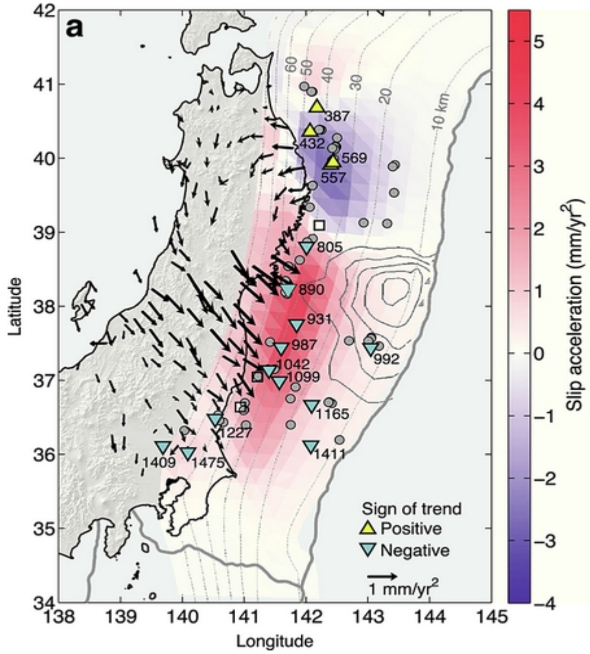
2008 M7.0 Ibaraki earthquake



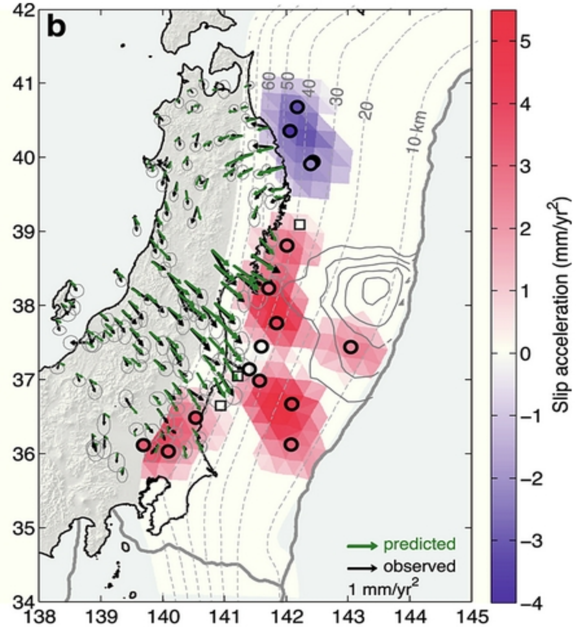
Mavrommatis et al. (GRL) 2015


387
432
557
569
805
890
931
987
992
1042
1099
1165
1227
1409
1411
Magnitude
Recurrence interval (yr)
Time (yr)
1998
2002
2006
2010

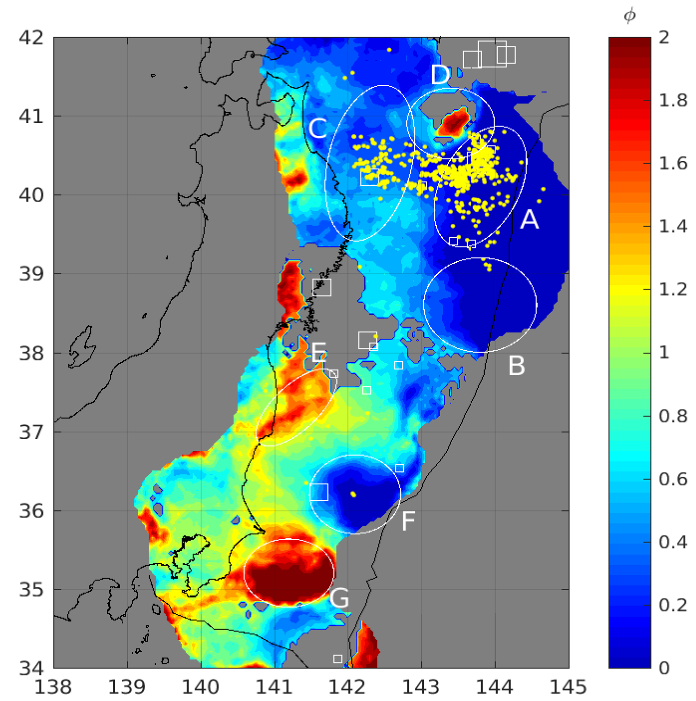
GPS



Repeaters



Seismicity



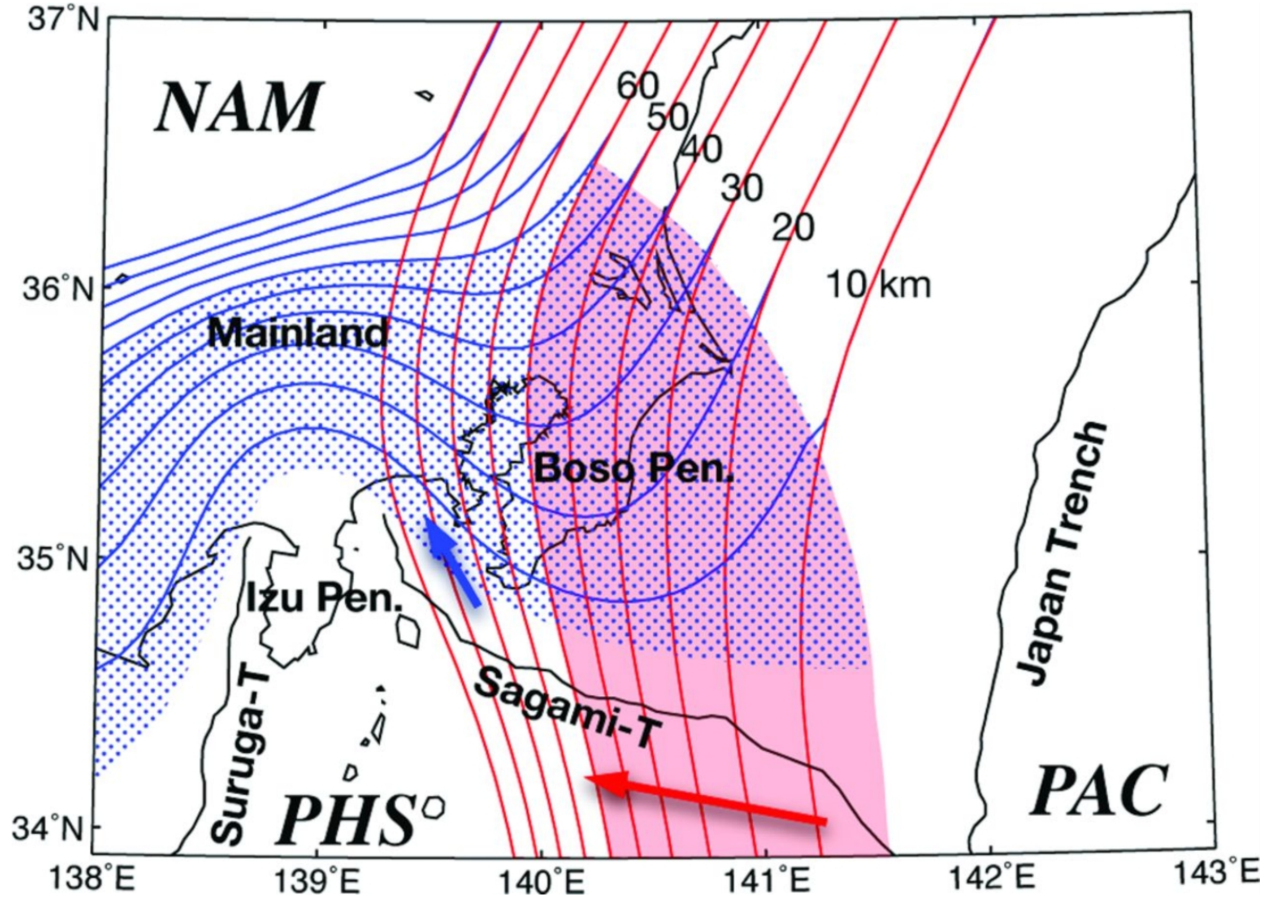
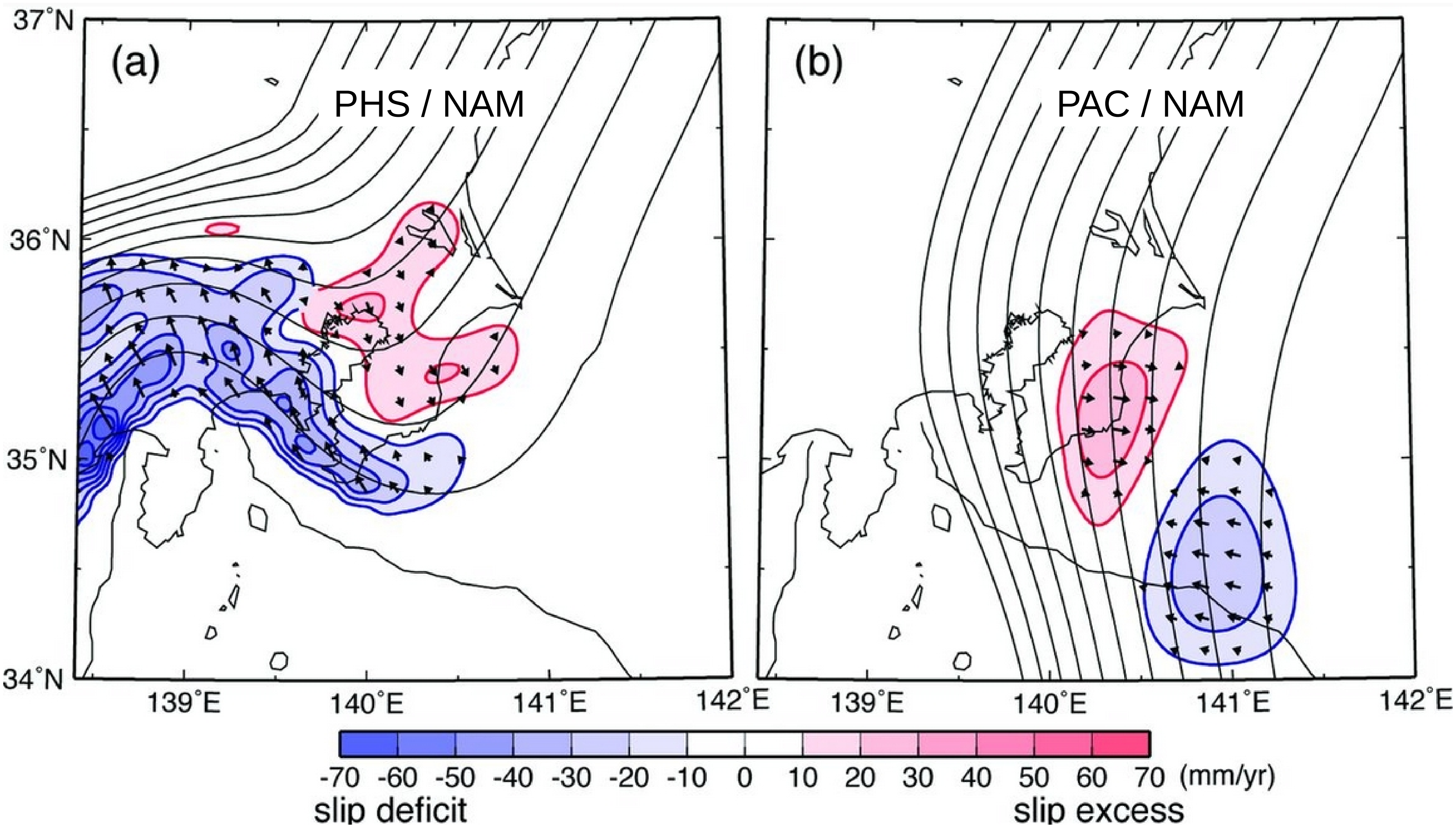


Plate interface geometry in the Kanto region and model setting. The blue and red iso-depth contours (10-km intervals) represent the NAM-PHS and NAM/PHS-PAC plate interfaces, respectively. The blue-stippled portion of the NAM-PHS plate interface and the pink-coloured portion of the PHS-PAC plate interface show the model regions for inversion analysis. The blue and red arrows indicate the steady slip vectors at the NAM-PHS and PHS-PAC plate interfaces, respectively. NAM, North American plate; PHS, Philippine Sea plate; PAC, Pacific plate. Noda et al. 2013.



Noda et al. 2013

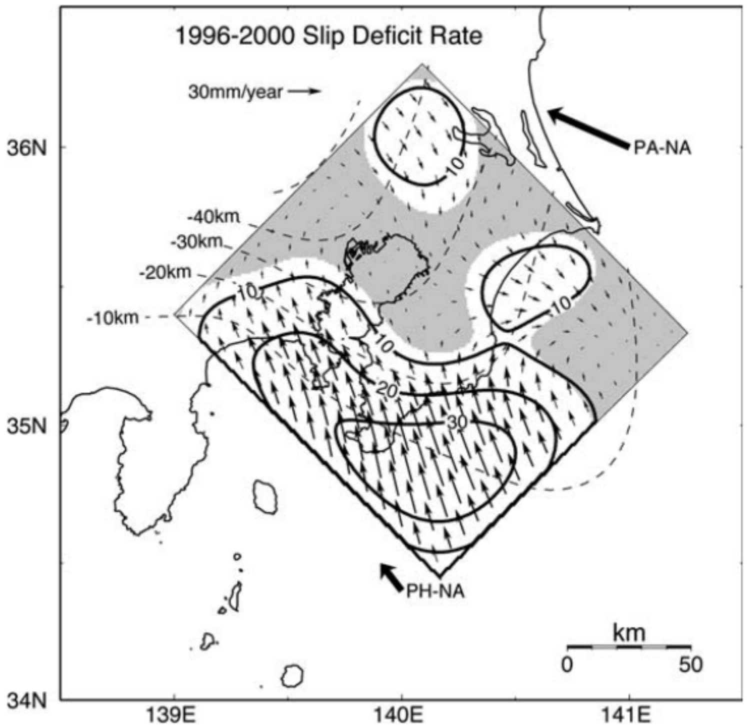


Figure 3
Slip deficit distribution on the Philippine Sea slab deduced from the GPS velocity data in Figure 2. Solid contours show magnitudes of slip deficit vectors. Dashed contours denote the configuration of the Philippine Sea slab. Thick arrows indicate relative plate motion of the Pacific plate (PA-NA) and the Philippine Sea plate (PH-NA) with respect to the North American plate.

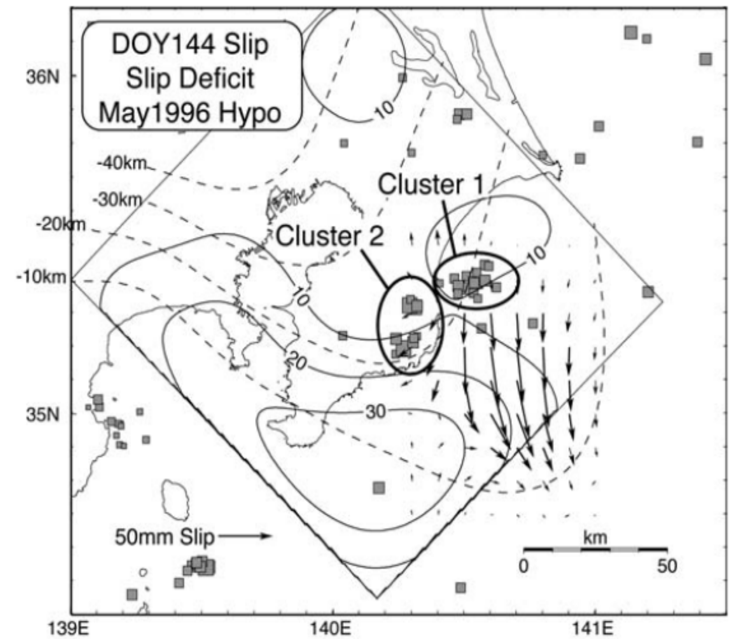
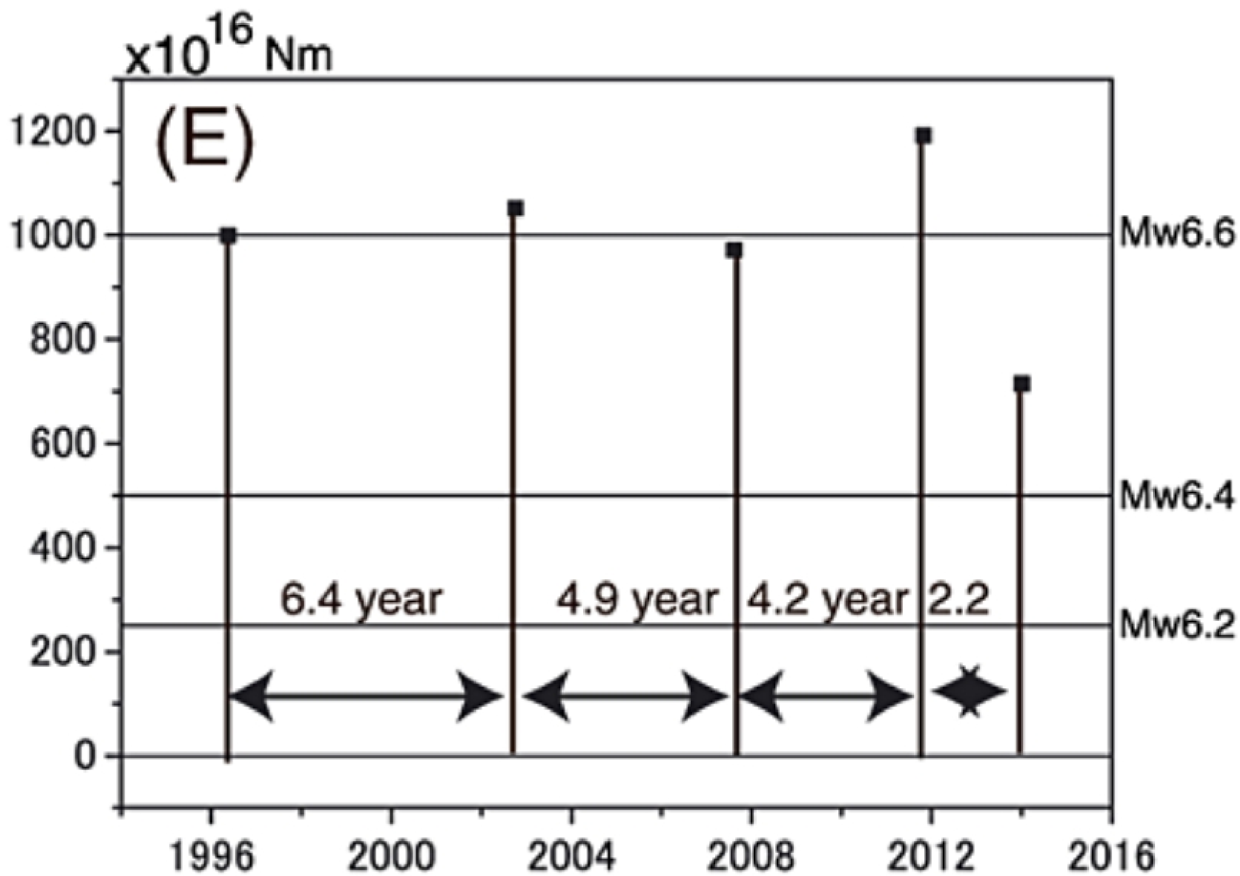


Figure 6
Comparison of the slip distribution of the 1996 Boso silent earthquake (DOY 144), the slip deficit distribution in Figure 3, and the plate configuration (dashed contours). Squares denote hypocenters of shallow (depth < 50 km) earthquakes during DOY 136–144 of 1996. Clusters 1 and 2 are seismicity associated with the silent earthquake.

Sagiya PAGEOPH 2004



Ozawa GRL 2014

Reverso et al. GRL 2016

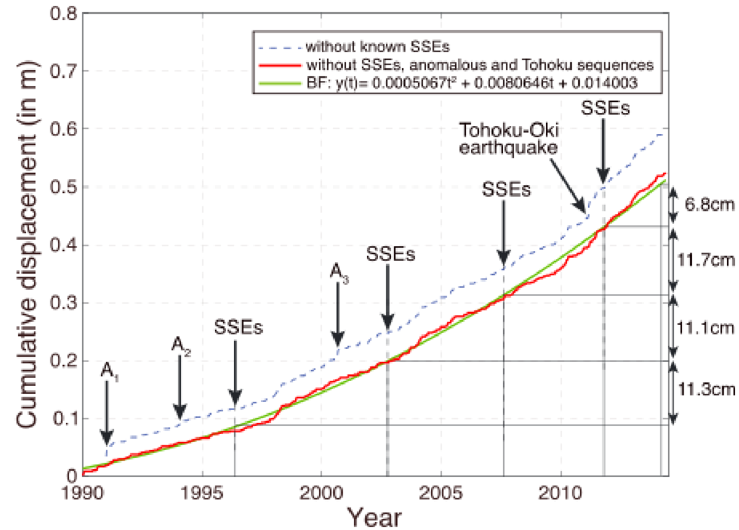


Figure 4. Inferred displacement at Boso, using our estimated background rate, and the relationship of Figure 3. The dashed curve is obtained after removing the SSEs; the thick curve has also the transients A_1-A_3 and the direct effect of the 2011 Tohoku-Oki earthquake removed. The best quadratic polynomial fit is shown. It yields a fixed displacement of 11.4 cm between the 1996, 2002, 2007 and 2011 SSEs.

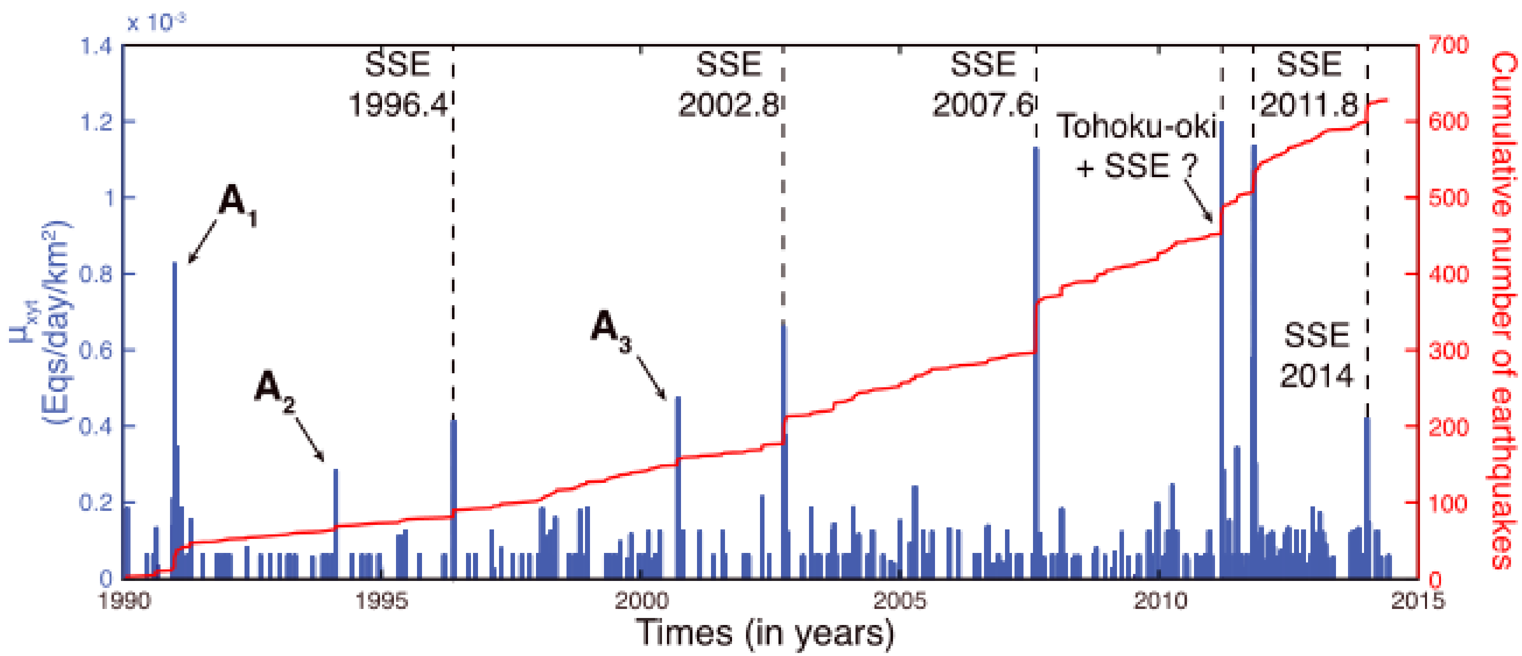
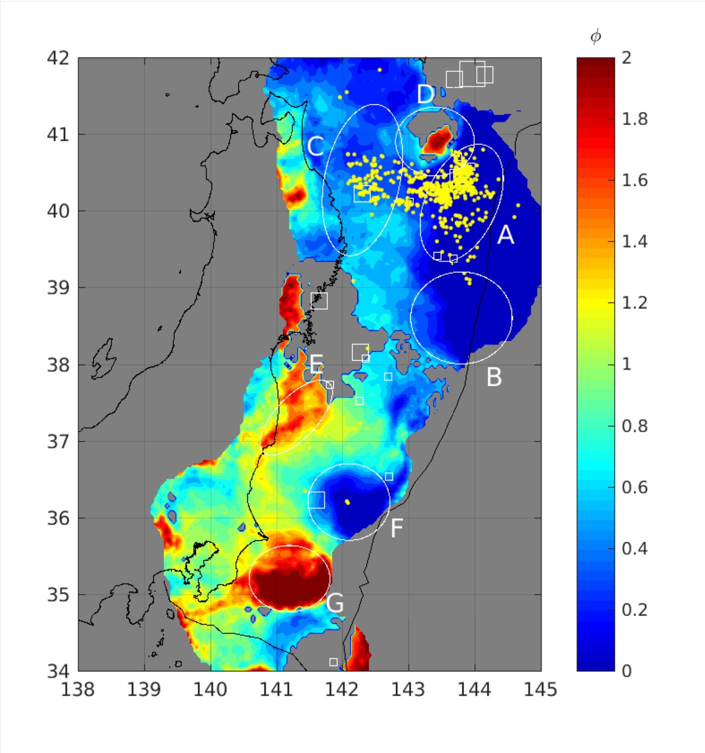
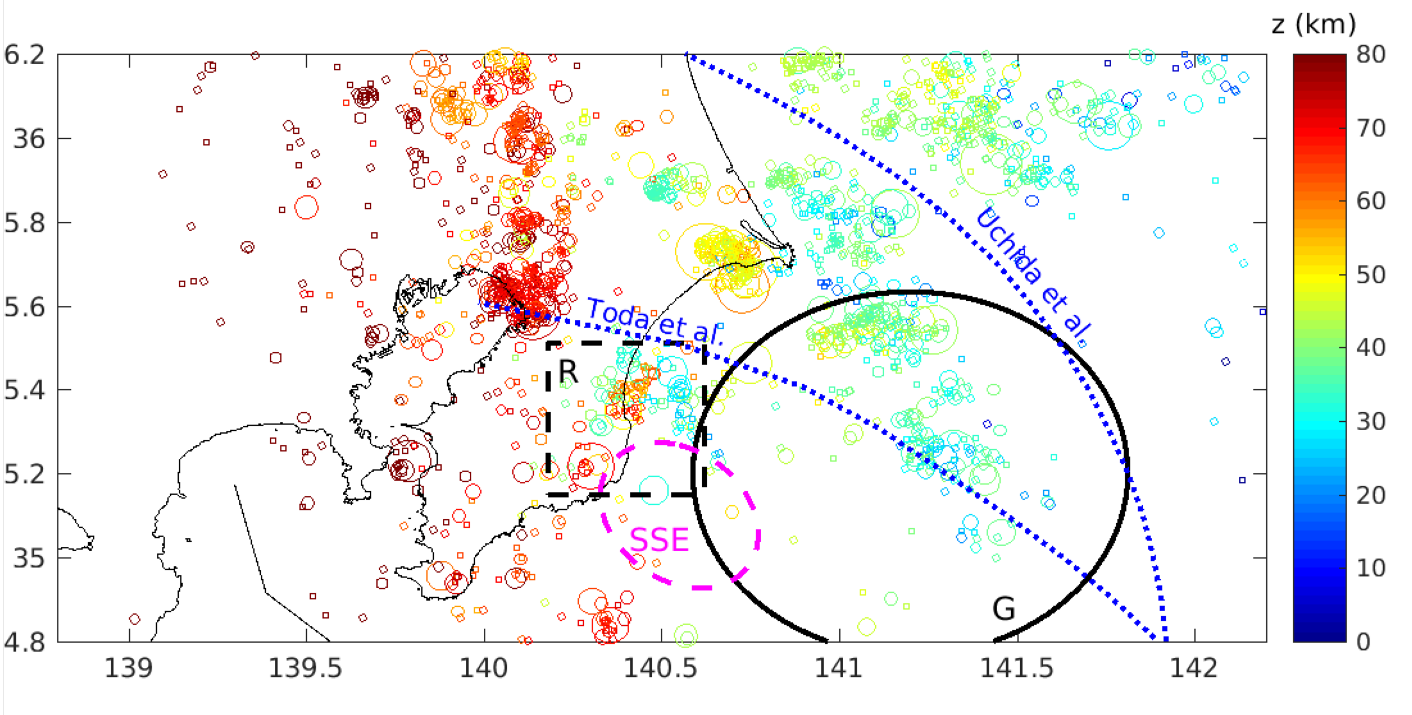
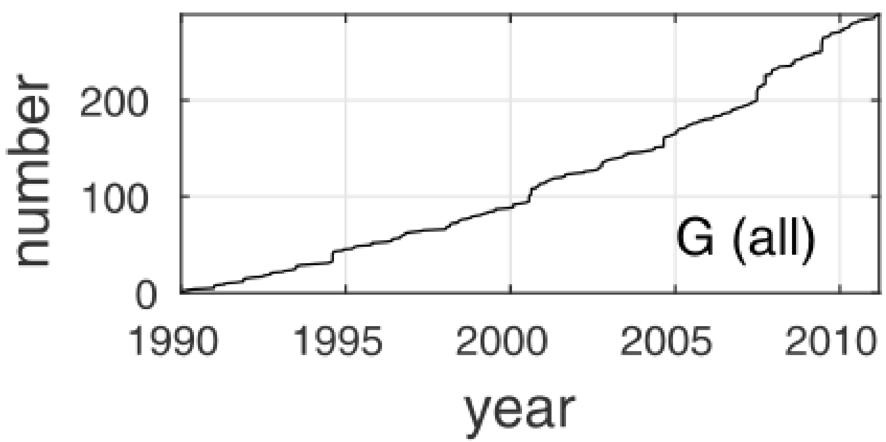
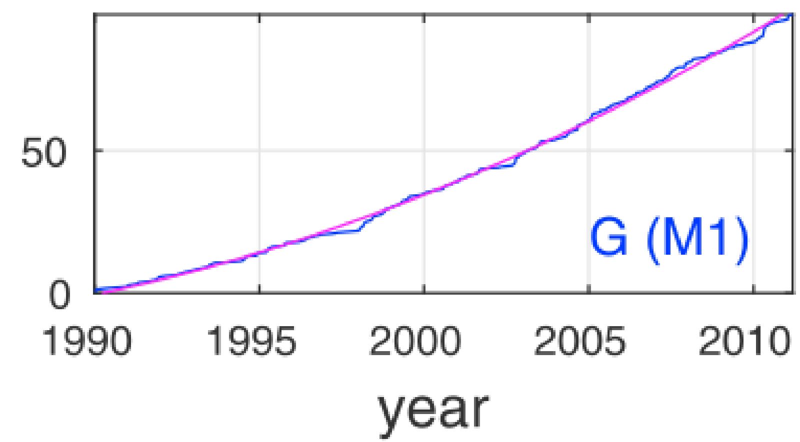


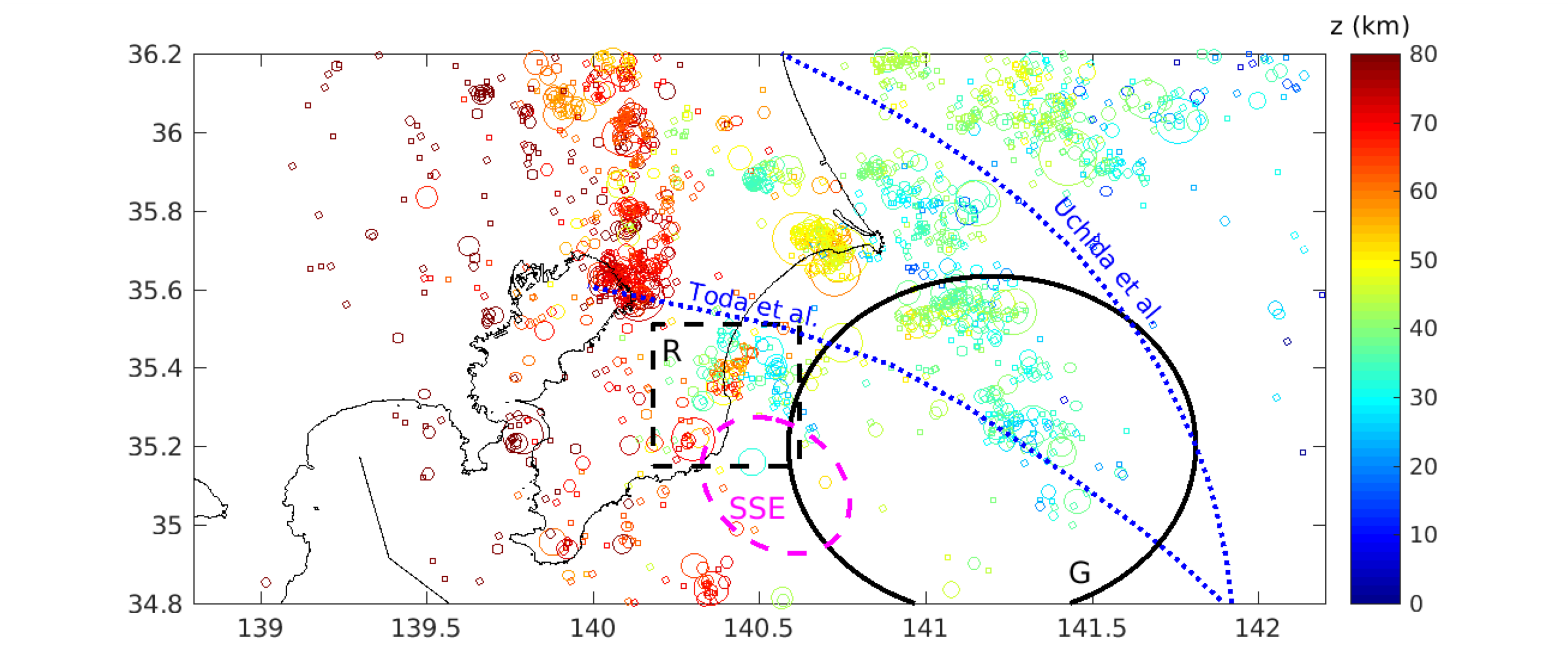
Figure 2. Cumulative number of earthquakes (in red) and time series of the background seismicity rate μ_{xyt} (in blue) for the Boso area. The three transients occurring outside the five known SSEs are labeled A_1, A_2, and A_3.

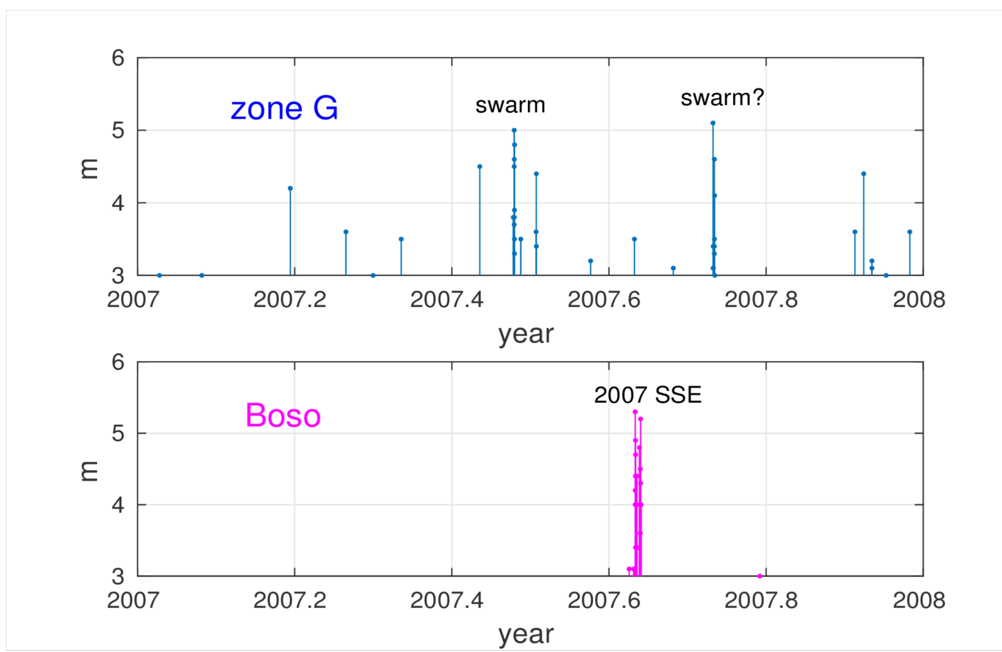

ϕ
A
B
C
D
E
F
G
138
139
140
141
142
143
144
145
34
35
36
37
38
39
40
41
42
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


z (km)
R
SSE
G
Toda et al.
Uchida et al.
6.2
36
5.8
5.6
5.4
5.2
35
4.8
139
139.5
140
140.5
141
141.5
142
0
10
20
30
40
50
60
70
80


number
year
G (all)
0
100
200
1990
1995
2000
2005
2010


year
G (M1)
0
50
1990
1995
2000
2005
2010


z (km)
80
70
60
50
40
30
20
10
0
36.2
36
35.8
35.6
35.4
35.2
35
34.8
139
139.5
140
140.5
141
141.5
142
Toda et al.
Uchida et al.
R
SSE
G


zone G
swarm
swarm?
m
year
2007
2007.2
2007.4
2007.6
2007.8
2008
Boso
2007 SSE
m
year

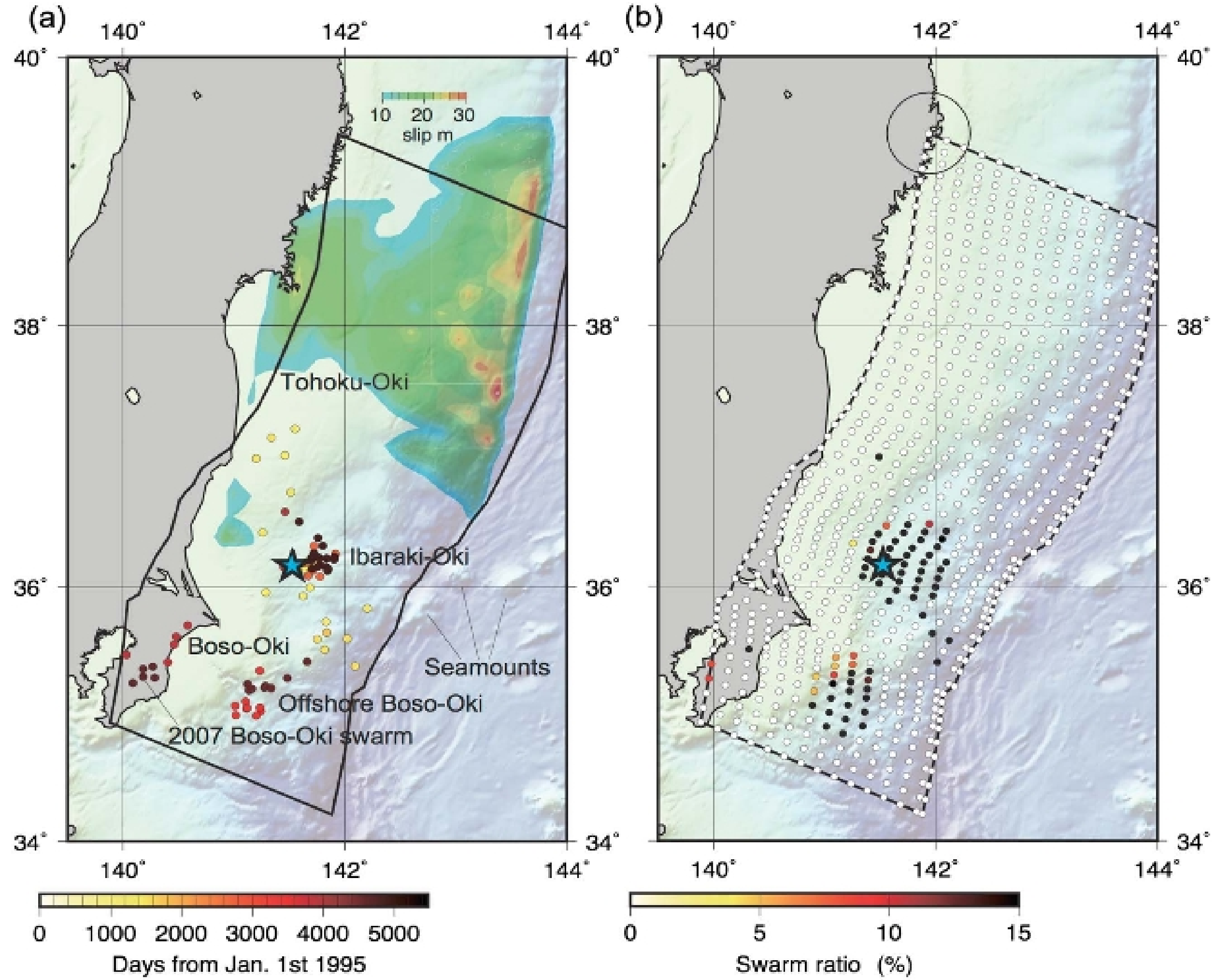
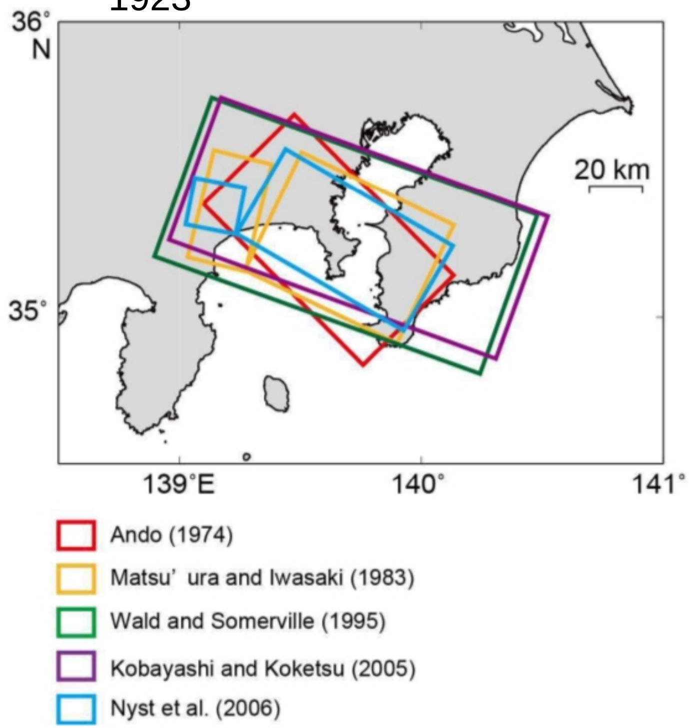
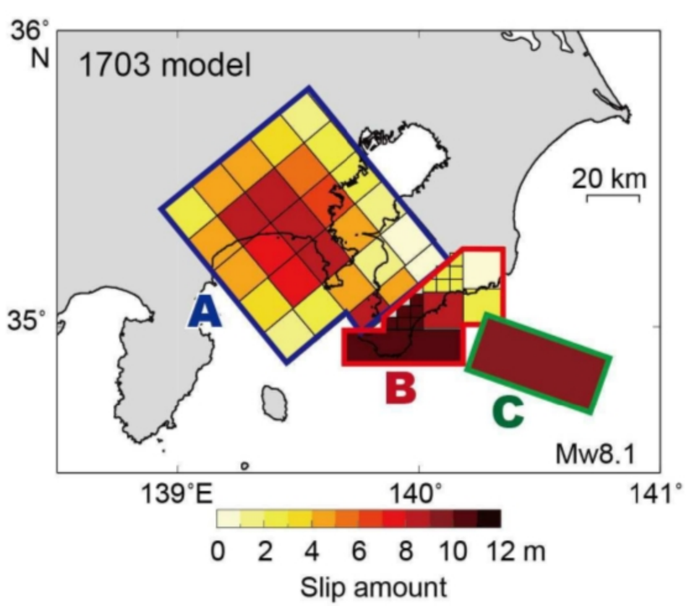


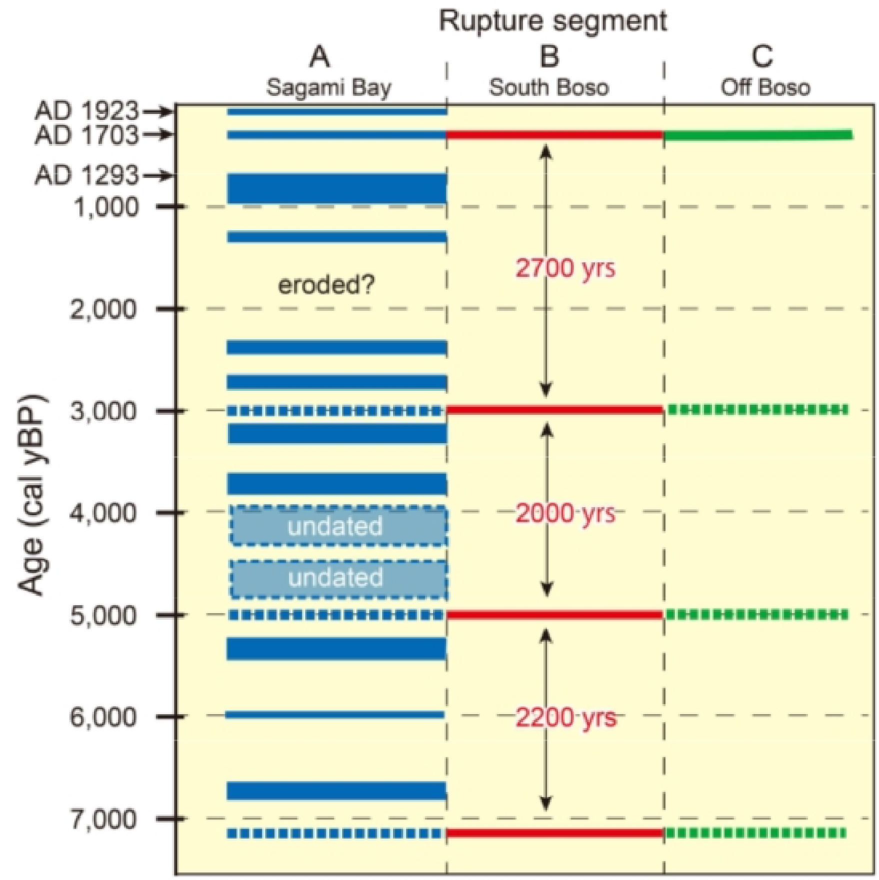
Figure 3. Detected swarms and swarm ratios in the southern Japan Trench. (a) Hypocenters of swarms detected by our analysis. Hypocenters of detected swarms are shown as small circles and colored according to their occurrence time. The hypocenter of the 2008 *M* 6.9 Ibaraki-Oki earthquake is indicated by the blue star. The color shading denotes areas where more than 10 m of slip occurred during the 2011 Tohoku earthquake [*Ide et al.*, 2011]. (b) Swarm ratios calculated for each detection circle. The large circle is an example of a detection circle of radius 30 km; the small circles indicate the center of each detection circle and are colored according to the computed swarm ratio.

Nishikawa & Ide JGR 2017

1923







12 m / 2000 years = **0.6 cm / year** only

(instead of 2 to 3 cm / year)

Shishikura 2014

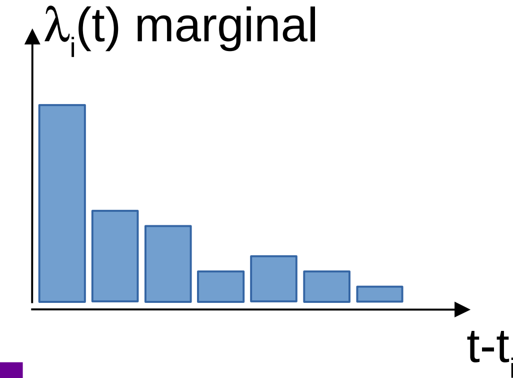
$$\lambda_i = \frac{K e^{\alpha m}}{(t+c)^p} (r + L_m)^{-\gamma}$$

- OK for aftershocks
- But not for other processes, eg LFE during SSE

Contribution from #i $\quad \lambda_i(x,y,t) = \lambda(x-x_i, y-y_i)\ \lambda(t-t_i)$

Distance from #i

Time since t_i



Only assume **linearity** and search for a **mean-field** solution

Marsan and Lengliné 2008

Contribution from #i

$$\lambda_i\left(\underline{x},t\right)=\lambda_{j,k,l}$$

Distance from #i to $\underline{x}$

Time t-t_i

Magnitude m_i

(Maximization)

$$\lambda_{j,k,l}=\frac{n_{j,k,l}}{n_l\ \ \delta t_k\ \ \delta V_j}$$

window duration

shell volume

Predictive policing

CHICAGO DATA PORTAL

Browse | Tutorial | Feedback | Sign In

Crimes - 2001 to present

This dataset reflects reported incidents of crime (with the exception of murders where data exists for

Manage | More Views | Filter | Visualize | Export | Discuss | Embed | About

Find in this Dataset

	ID	Case Number	Date	Block	IUCR	Primary Type	Description
34	11094312	JA439983	09/20/2017 10:57:00 PM	047XX W VAN BUREN ST	143A	WEAPONS VIOLATION	UNLAWFUL POSS OF HANDGUN
35	11094322	JA439945	09/20/2017 10:56:00 PM	069XX S WOODLAWN AVE	041A	BATTERY	AGGRAVATED: HANDGUN
36	11094330	JA439951	09/20/2017 10:55:00 PM	004XX E 79TH ST	031A	ROBBERY	ARMED: HANDGUN
37	11094268	JA439941	09/20/2017 10:53:00 PM	040XX W GLADYS AVE	0486	BATTERY	DOMESTIC BATTERY SIMPLE
38	11094257	JA439991	09/20/2017 10:51:00 PM	080XX S COTTAGE GROVE A	5111	OTHER OFFENSE	GUN OFFENDER: ANNUAL REGIS
39	11094286	JA439940	09/20/2017 10:50:00 PM	067XX S RIDGELAND AVE	1310	CRIMINAL DAMAGE	TO PROPERTY
40	11094289	JA439956	09/20/2017 10:41:00 PM	040XX W DIVISION ST	0530	ASSAULT	AGGRAVATED: OTHER DANG WEA
41	11094244	JA439935	09/20/2017 10:37:00 PM	034XX W MADISON ST	1661	GAMBLING	GAME/DICE
42	11094265	JA439933	09/20/2017 10:36:00 PM	038XX W COLUMBUS AVE	0486	BATTERY	DOMESTIC BATTERY SIMPLE
43	11094521	JA440195	09/20/2017 10:30:00 PM	092XX S FOREST AVE	0920	MOTOR VEHICLE THEFT	ATT: AUTOMOBILE
44	11094255	JA439930	09/20/2017 10:30:00 PM	012XX N LAVERGNE AVE	0630	BURGLARY	ATTEMPT FORCIBLE ENTRY
45	11095035	JA440798	09/20/2017 10:30:00 PM	062XX S KILPATRICK AVE	0820	THEFT	$500 AND UNDER
46	11094295	JA439965	09/20/2017 10:30:00 PM	069XX S HONORE ST	0810	THEFT	OVER $500
47	11094288	JA439967	09/20/2017 10:30:00 PM	011XX S DELANO CT E	1310	CRIMINAL DAMAGE	TO PROPERTY
48	11094296	JA439939	09/20/2017 10:28:00 PM	071XX S VINCENNES AVE	0460	BATTERY	SIMPLE
49	11094333	JA439962	09/20/2017 10:21:00 PM	014XX N CLEVELAND AVE	0460	BATTERY	SIMPLE
50	11094263	JA439943	09/20/2017 10:17:00 PM	034XX S DR MARTIN LUTHE	0860	THEFT	RETAIL THEFT
51	11094254	JA439894	09/20/2017 10:17:00 PM	056XX W FULTON ST	1365	CRIMINAL TRESPASS	TO RESIDENCE
52	11094337	JA440028	09/20/2017 10:15:00 PM	021XX E 100TH ST	0486	BATTERY	DOMESTIC BATTERY SIMPLE
53	11095768	JA439925	09/20/2017 10:15:00 PM	028XX N LEAVITT ST	0320	ROBBERY	STRONGARM - NO WEAPON
54	11094666	JA440331	09/20/2017 10:15:00 PM	045XX N ASHLAND AVE	0820	THEFT	$500 AND UNDER
55	11094232	JA439922	09/20/2017 10:09:00 PM	003XX E 35TH ST	2024	NARCOTICS	POSS: HEROIN(WHITE)
Totals		6438416					

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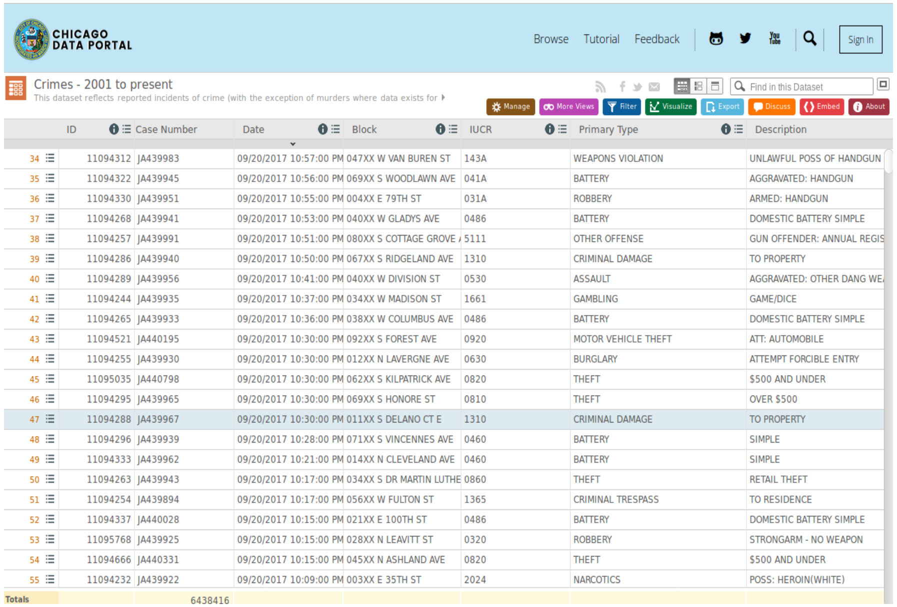
The Predictive Policing Company



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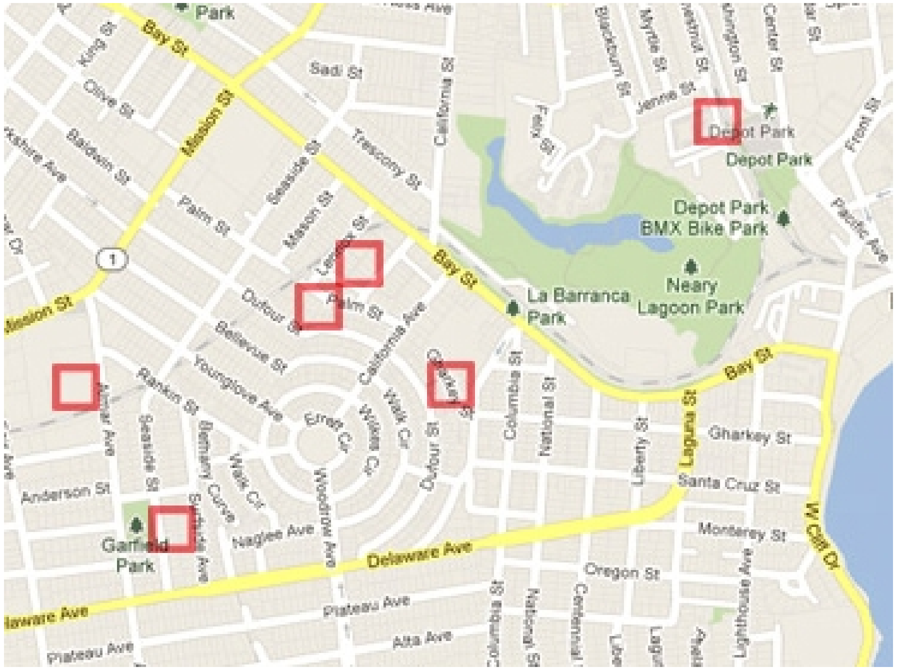
55	11094232	JA439922	09/20/2017 10:09:00 PM	003XX E 35TH ST	2024	NARCOTICS	POSS: HEROIN(WHITE)
Totals		6438416					



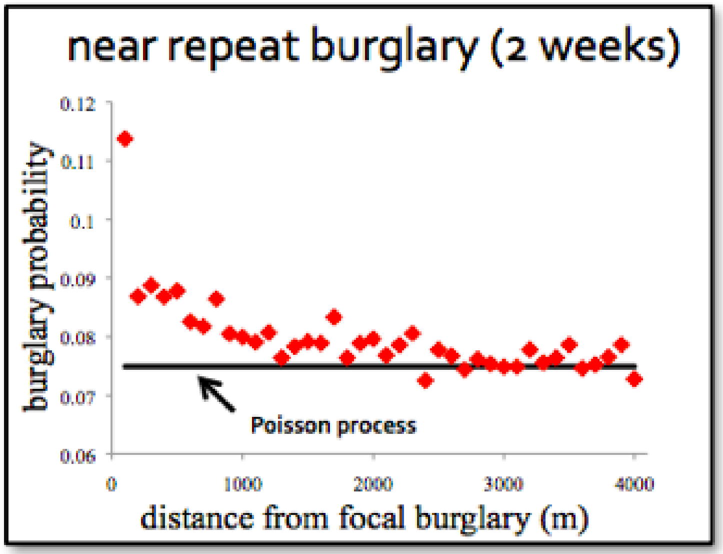
Predpol software is based on exactly the same algorithm as used for stochastic earthquake declustering

Contribution from #i

$$\lambda_i(\underline{x}, t) = \lambda_{j,k}$$

Distance from #i to $\underline{x}$

Time $t\text{-}t_i$



(Maximization)

$$\lambda_{j,k} = \frac{n_{j,k}}{n_l \; \delta t_k \; \delta V_j}$$

window duration

shell surface

Mohler et al JASA 2011

3. A SELF–EXCITING POINT PROCESS MODEL OF BURGLARY

For the purpose of modeling burglary we consider an unmarked self-exciting model for the conditional intensity of the form

$$\lambda(t, x, y) = \nu(t)\mu(x, y) + \sum_{\{k: t_k < t\}} g(t - t_k, x - x_k, y - y_k). \qquad (10)$$

Mohler et al JASA 2011

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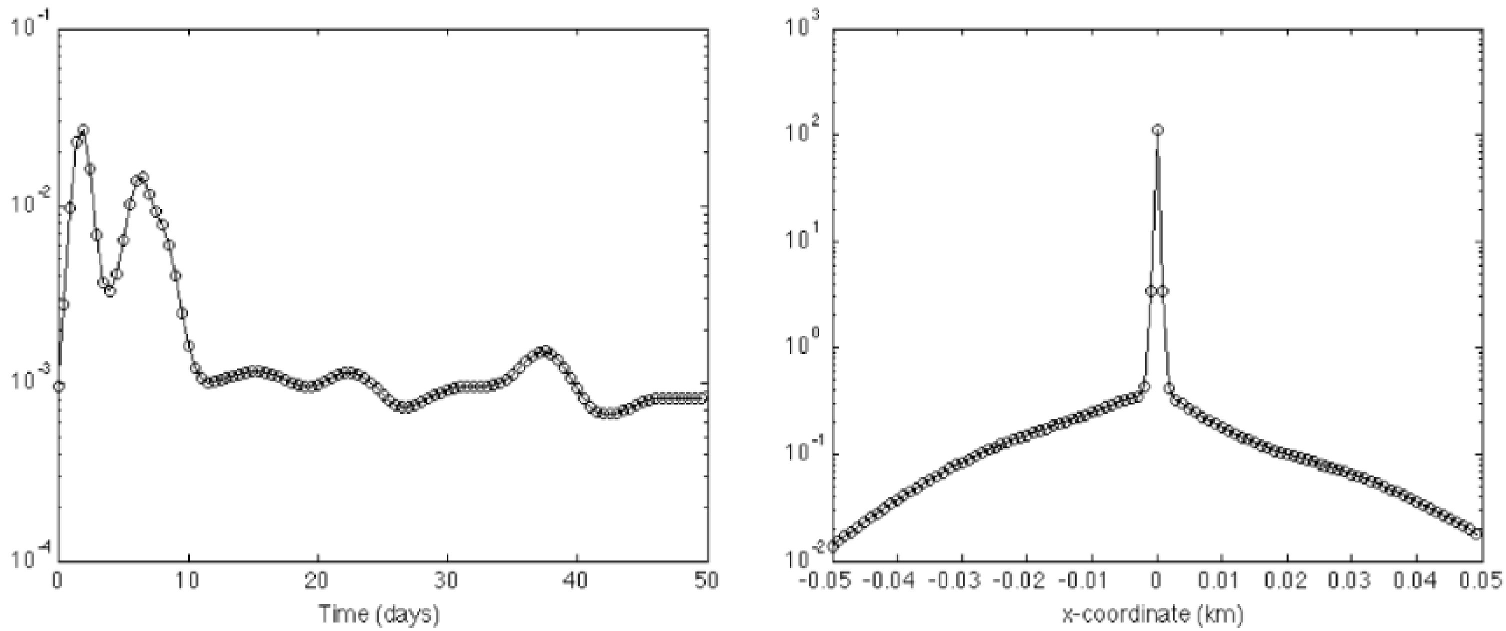
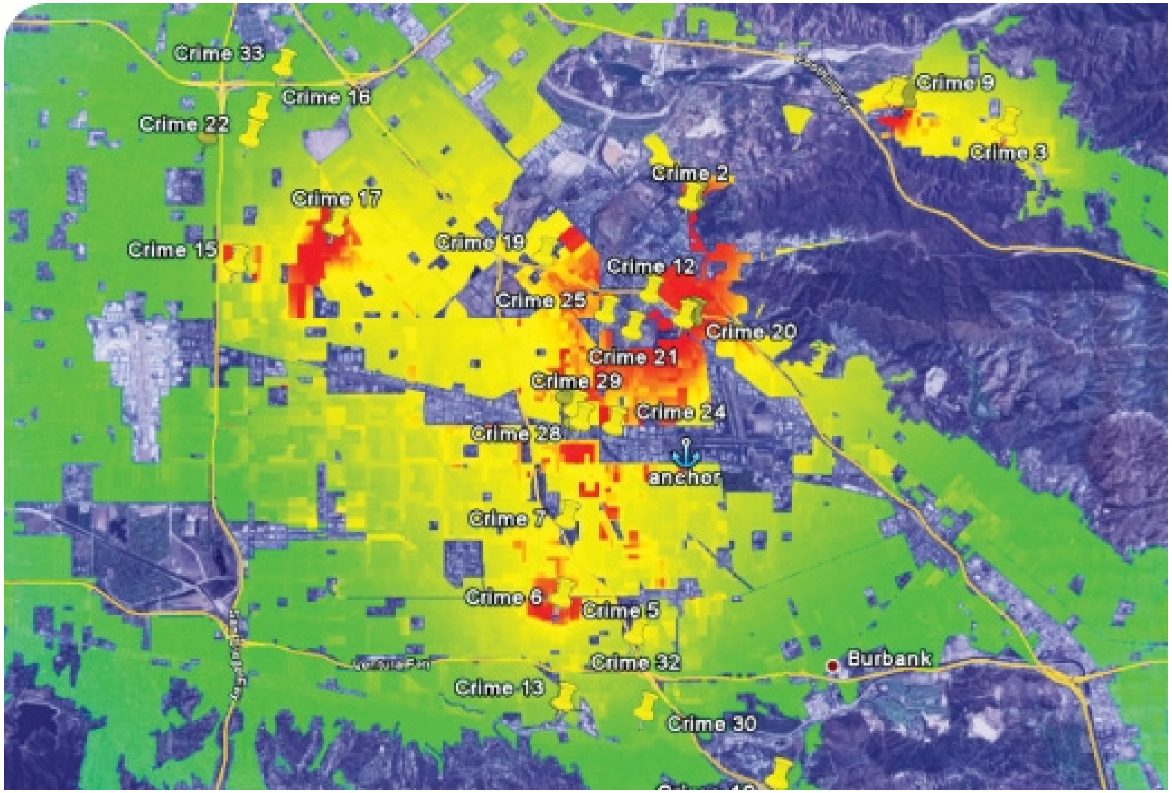


Figure 4. Marginal $g_{75}(t)$ (left) and marginal $g_{75}(x)$ (right) estimated using KDE based upon offspring/parent interpoint distances sampled from P_{75}.



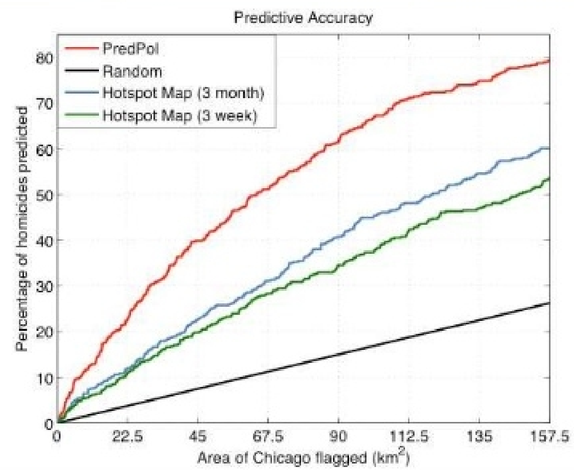
Flag the N spots with highest μ values

PREDICTIVE POLICING®

The Predictive Policing Company.

Prediction Results

PredPol predicts a greater number of gun homicides using its unique prediction methodology compared with alternative approaches.



Percentage of crime occurring within flagged areas vs. total area of Chicago flagged with predictions using 2011 historical data.

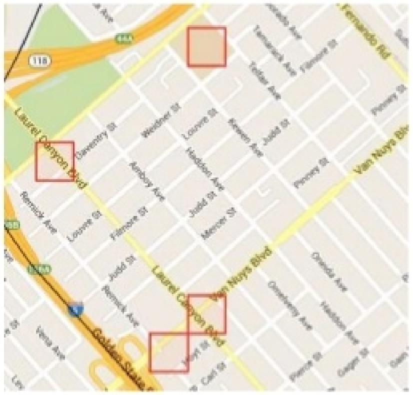
www.predpol.com

PREDPOL

Track Record
Third Year In L.A. Still Having An Effect

-20%

Foothill Division Property Crime
Jan'14-June'14
(year over year)



Source: LAPD's Capt. Sean Malinowski, July 2014

www.predpol.com

PREDPOL

Expanding and Starting CSEP Natural Laboratories

D. Schorlemmer[1], J. D. Zechar[1], and T. H. Jordan[1]
[1] University of Southern California, Los Angeles, USA.

SCEC an NSF + USGS center

USC UNIVERSITY OF SOUTHERN CALIFORNIA

Abstract

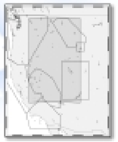
Natural laboratories are a key concept in the Collaboratory for the Study of Earthquake Predictability (CSEP). They define regions in which earthquake generation models are tested and the rules of these tests. Defining natural laboratories require profound knowledge about available data sources, e.g., earthquake catalogs. This includes knowledge about data generation, uncertainties, and derived properties, e.g., completeness of catalogs. CSEP employs working groups for data, test, and model standards to develop guidelines for natural laboratory developments. We present the already implemented natural laboratory of California and the efforts in establishing laboratories in New Zealand, Italy, the Basin & Range region, the Western Pacific region, and for global testing.

Basin & Range Natural Laboratory

Data stream
ANSS catalog?

Area
Covering many authoritative regions of ANSS

Models
?

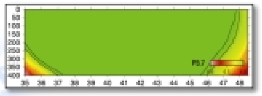


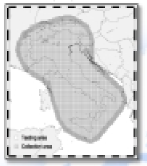
Italy Natural Laboratory

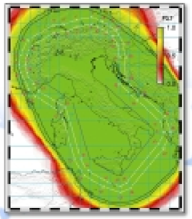
Data Stream
INGV catalog
Completeness at M=3.7

Area
Mainland Italy and Sicily

Tests
RELM Tests (N-, L-, and R-Test)







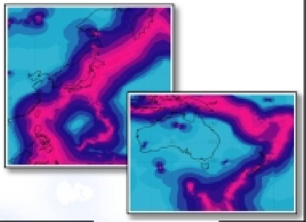
Western Pacific Natural Laboratory

Data stream
Harvard CMT catalog

Area
NW: 110E-170E/0N-60N
SW: 110E-170W/60S-0N

Tests
L-Test

Model
2 long-term models



Zürich

Roma

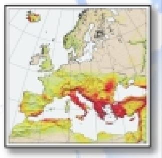
Los Angeles

Euro-Med Natural Laboratory

Data stream
EMSC catalog?

Area
All of Europe/Mediterranean region

Models
1 long-term (SESAME)



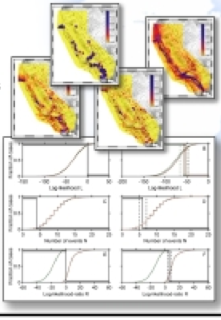
California Natural Laboratory

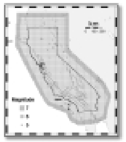
Data stream
ANSS catalog including location parameter uncertainties
Assumed overall completeness at M=3.7
Declustering (Reasenberg including parameter uncertainties

Area
Testing area = California + 1deg (0-30km)
Collection area = Testing area + 0.5deg

Tests
RELM Tests (N-, L-, and R-Test)

Models
19 long-term (5-year) models
2 short-term (1-day) models





Summary

These examples indicate a few of the interesting challenges of defining a natural laboratory:

- Identifying the appropriate earthquake catalog(s)
- Working with regions containing multiple 'authoritative sources' (e.g., California)
- Working with regions where no authoratative source has been identified (e.g., Basin and Range)
- Testing forecasts that transcend geographical boundaries (e.g., Italy)
- Working in regions with subduction zones (e.g., New Zealand)

All of these issues arise from the simplest form of observation: seismicity catalogs. As CSEP extends the experiment space to include other data such as GPS or fault models, careful consideration should be given to the process of defining the natural laboratories.

New Zealand Natural Laboratory

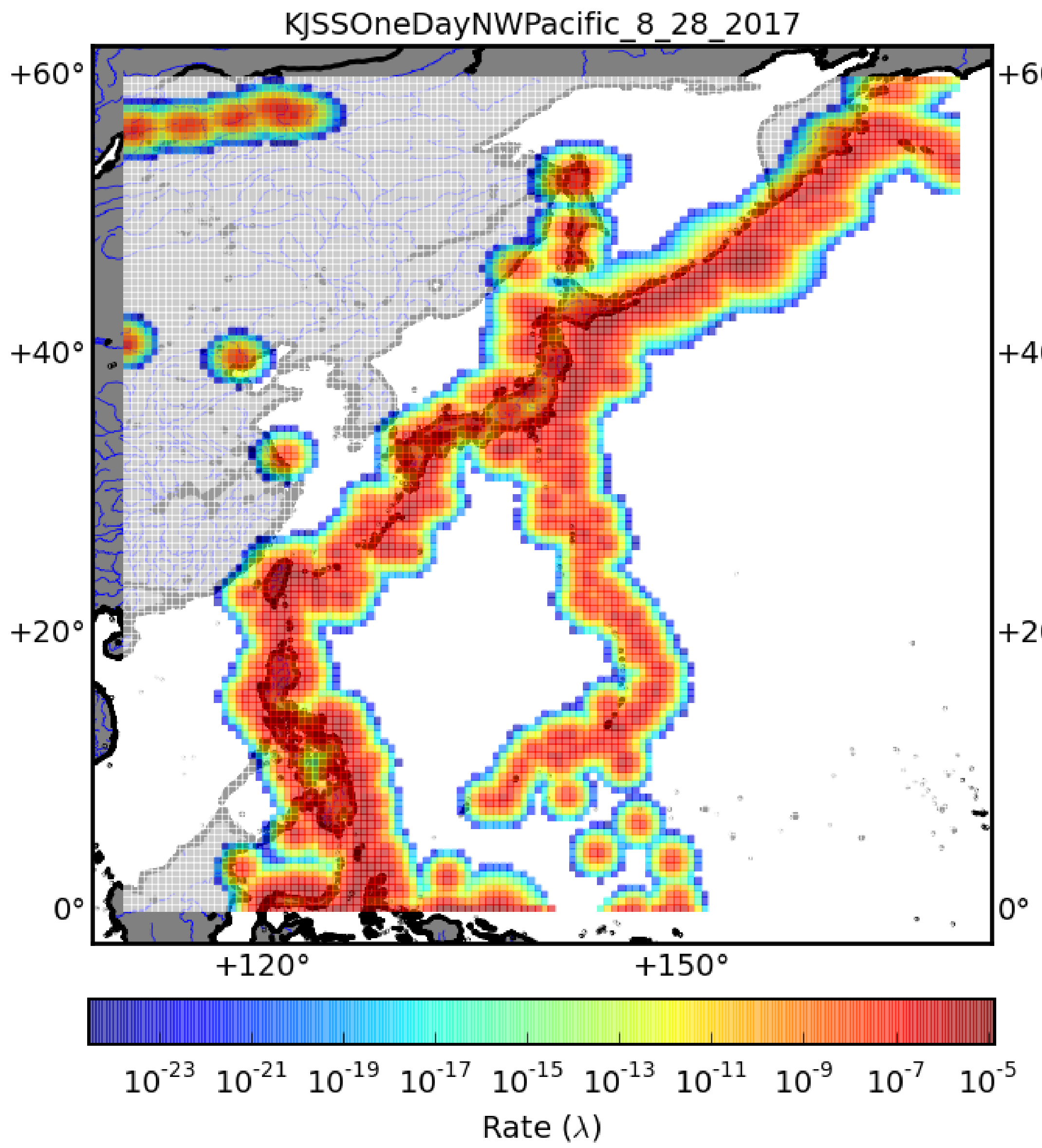
Data stream
Catalog including location parameter uncertainties
Assumed overall completeness at M=4
Declustering (same method as used in national hazard assessment)

Area
Testing area = New Zealand + 100km
Depth = 0-40km

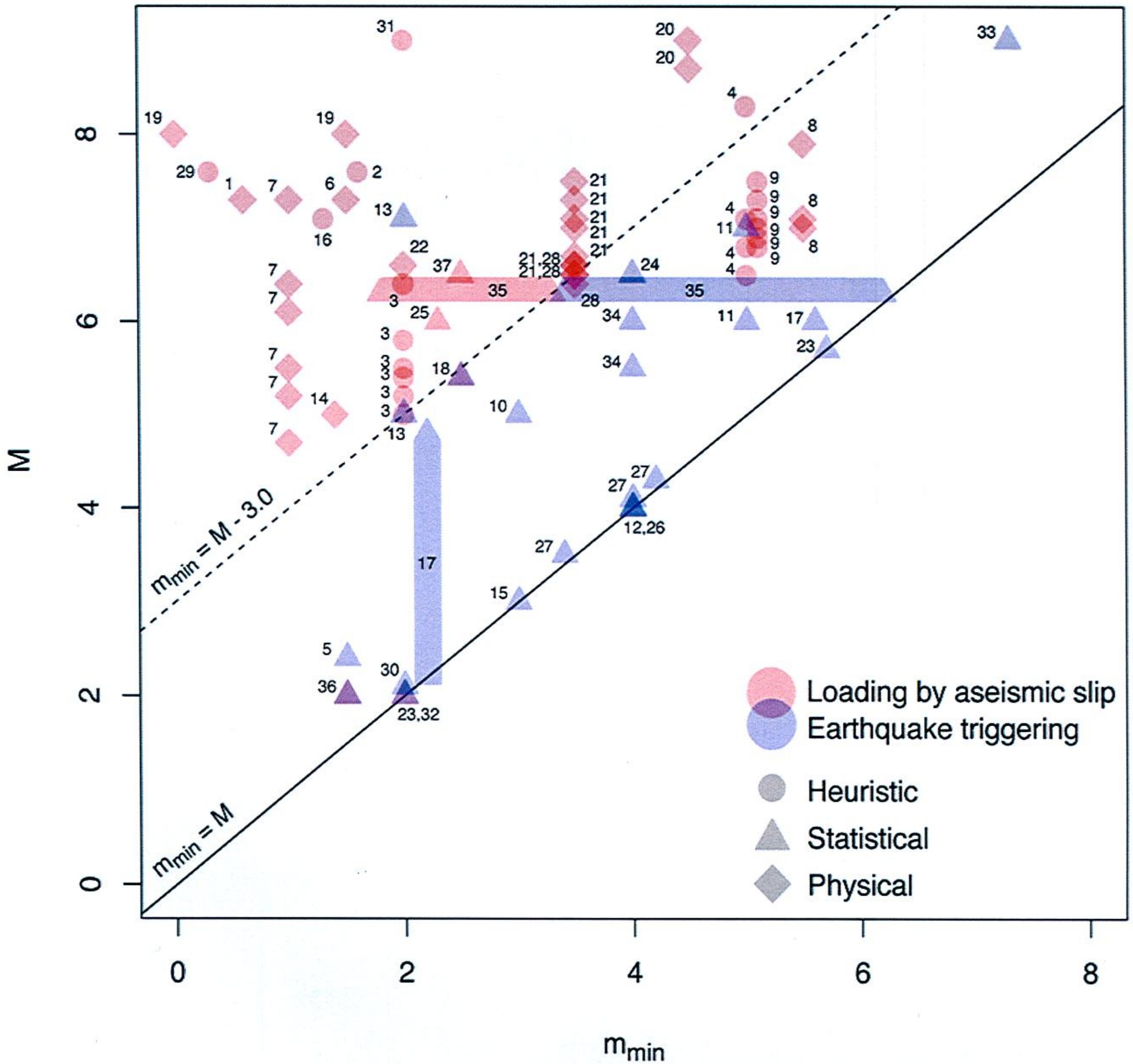
Tests
RELM Tests (N-, L-, and R-Test)
New tests under development

Models
4 5-year models, 4 3-month models, and 4 1-day models

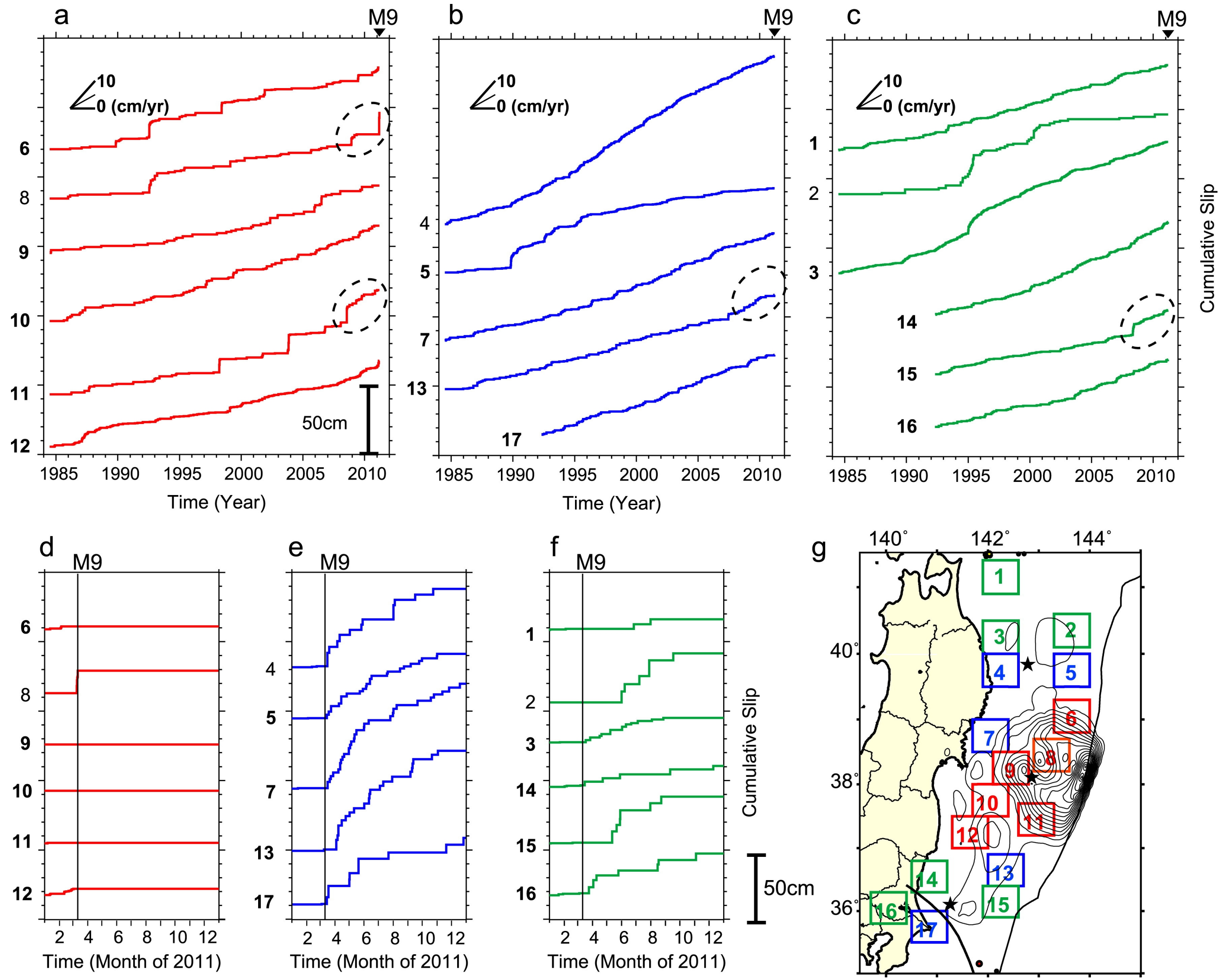
Wellington



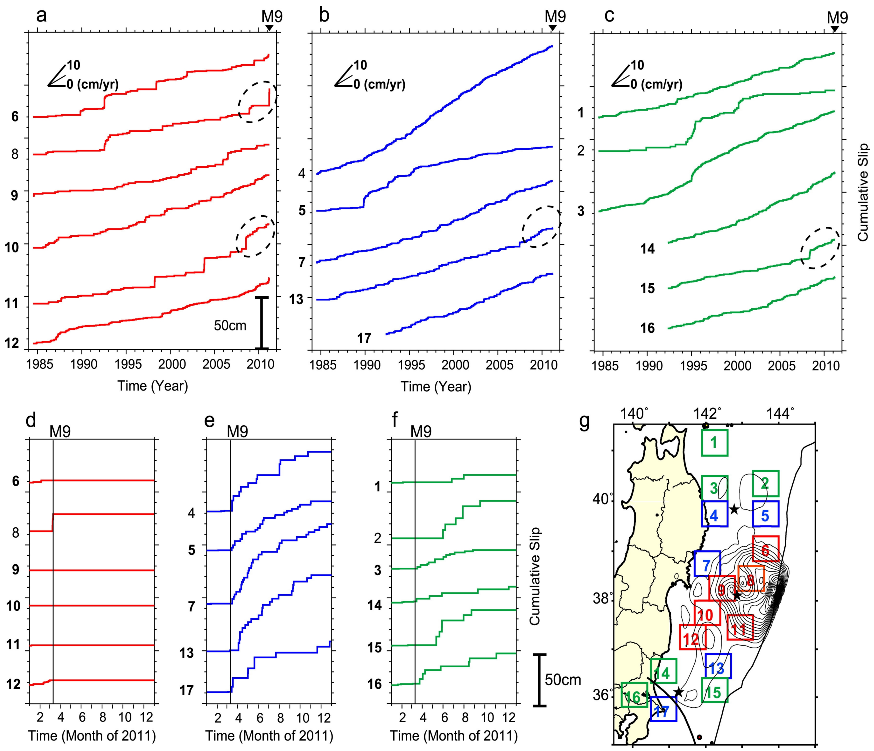
KJSSOneDayNWPacific_8_28_2017
+60°
+40°
+20°
0°
+60°
+40°
+20°
0°
+120°
+150°
10^-23 10^-21 10^-19 10^-17 10^-15 10^-13 10^-11 10^-9 10^-7 10^-5
Rate (λ)

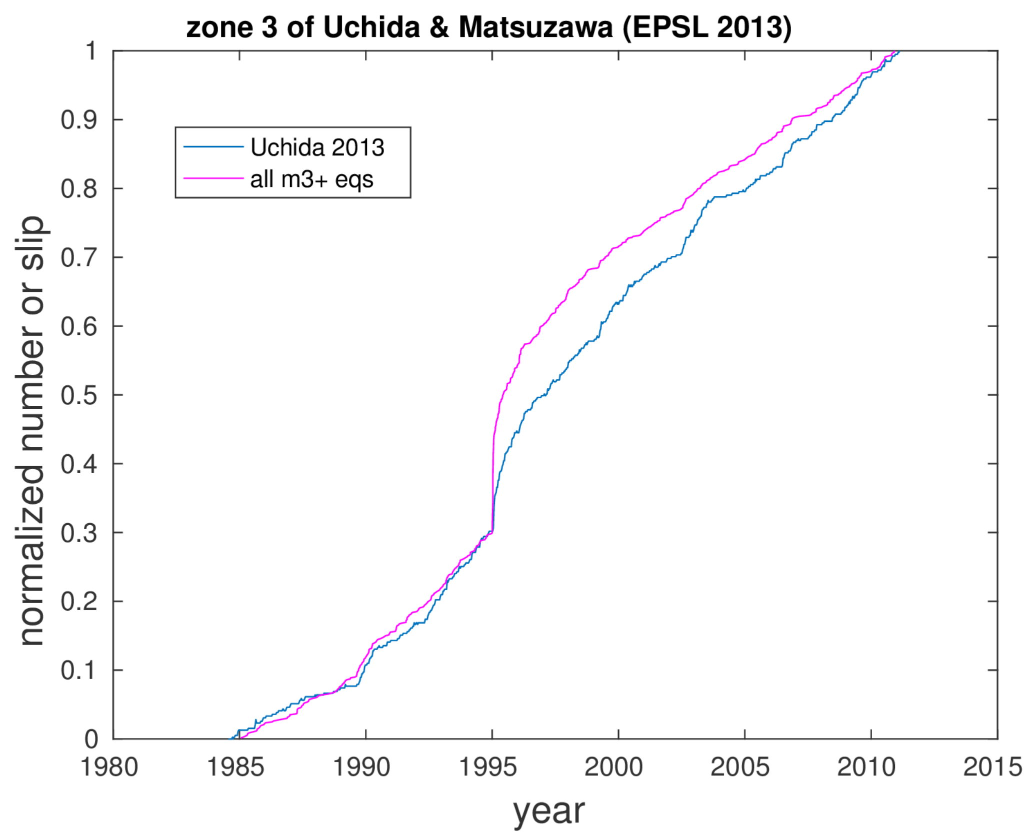


Mignan (Sci. Rep.) 2014



Uchida and Matsuzawa (EPSL) 2013





RE time series show clustering just as well as « normal » seismicity