UNIVERSITÉ SAVOIE MONT BLANC

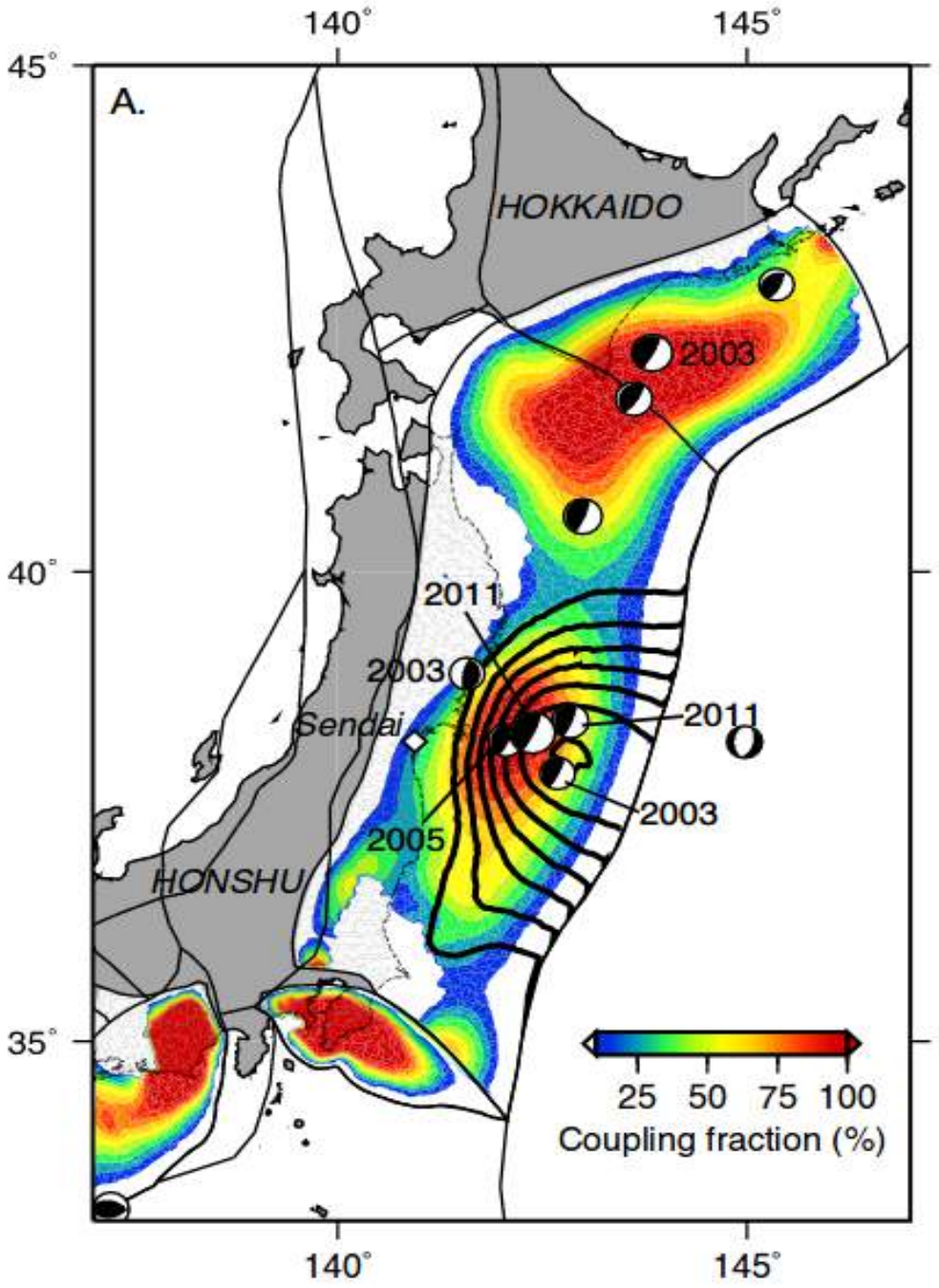
ISTerre
Institut des Sciences de la Terre

Long and short term nucleation of the 2011 Tohoku-Oki earthquake

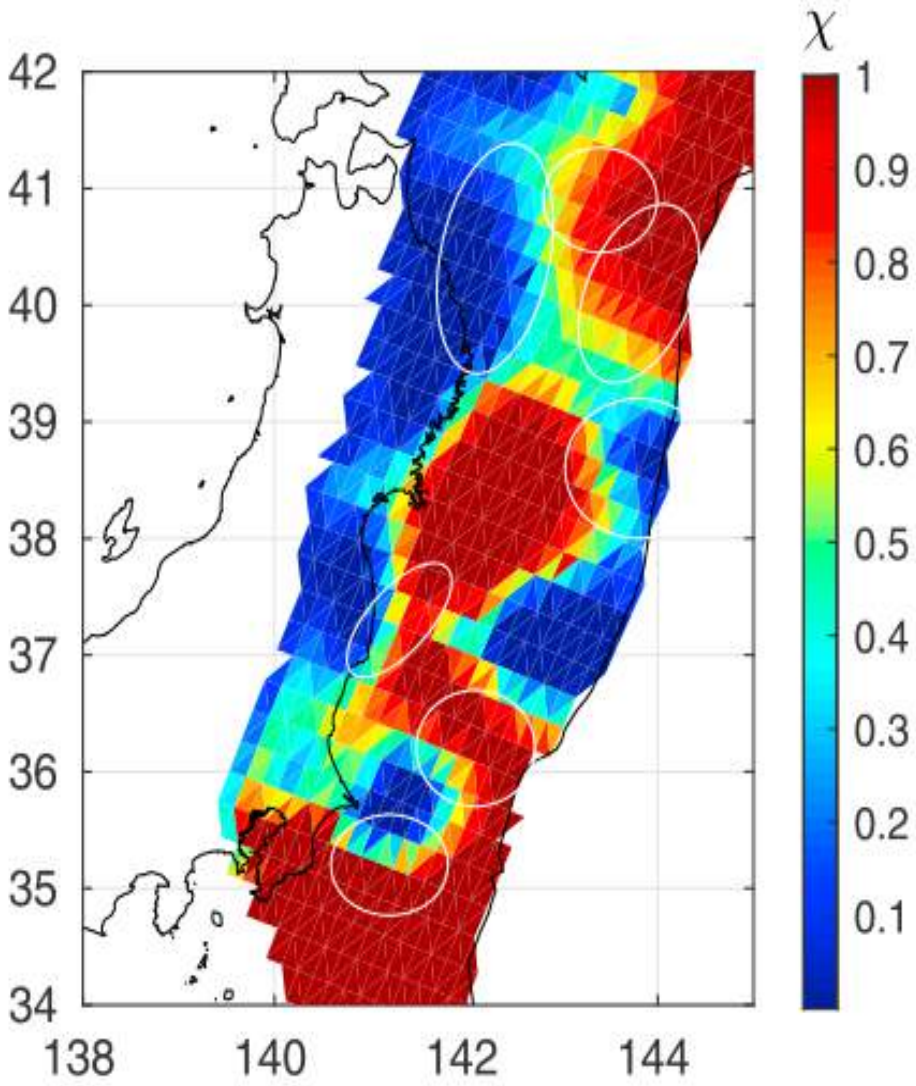
D. Marsan, B. Enescu, B. Gardonio, M. Bouchon, T. Reverso, A. Socquet, A. Helmstetter, H. Perfettini

Precursory activity prior to the 2011 M9.0 Tohoku earthquake :

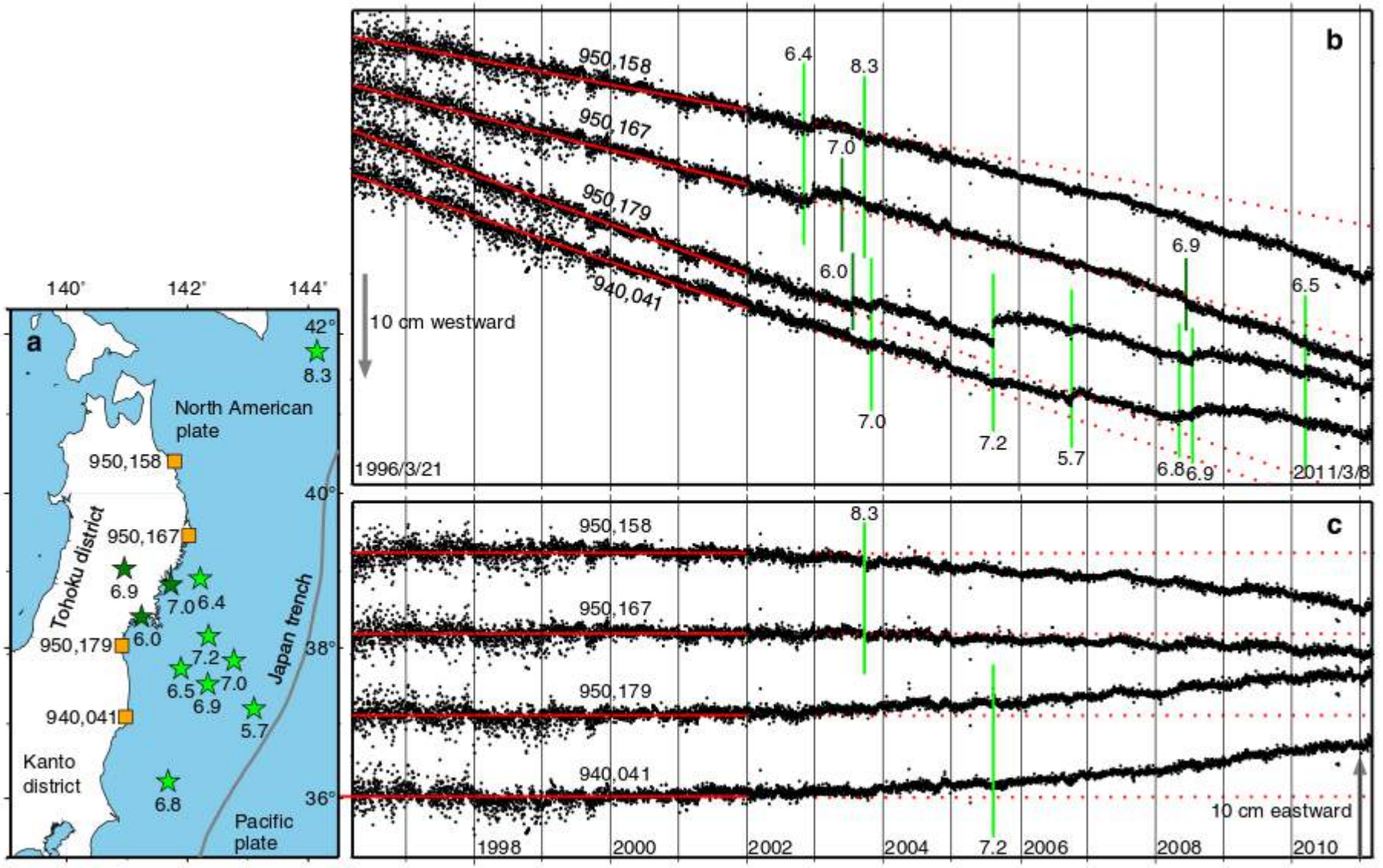
- Long term (> years) changes in slip deficit rate
- Swarm activity (months)
- M7.3 foreshock with co & post-seismic slip (days)
- But no immediate precursory slip (hours - minutes)



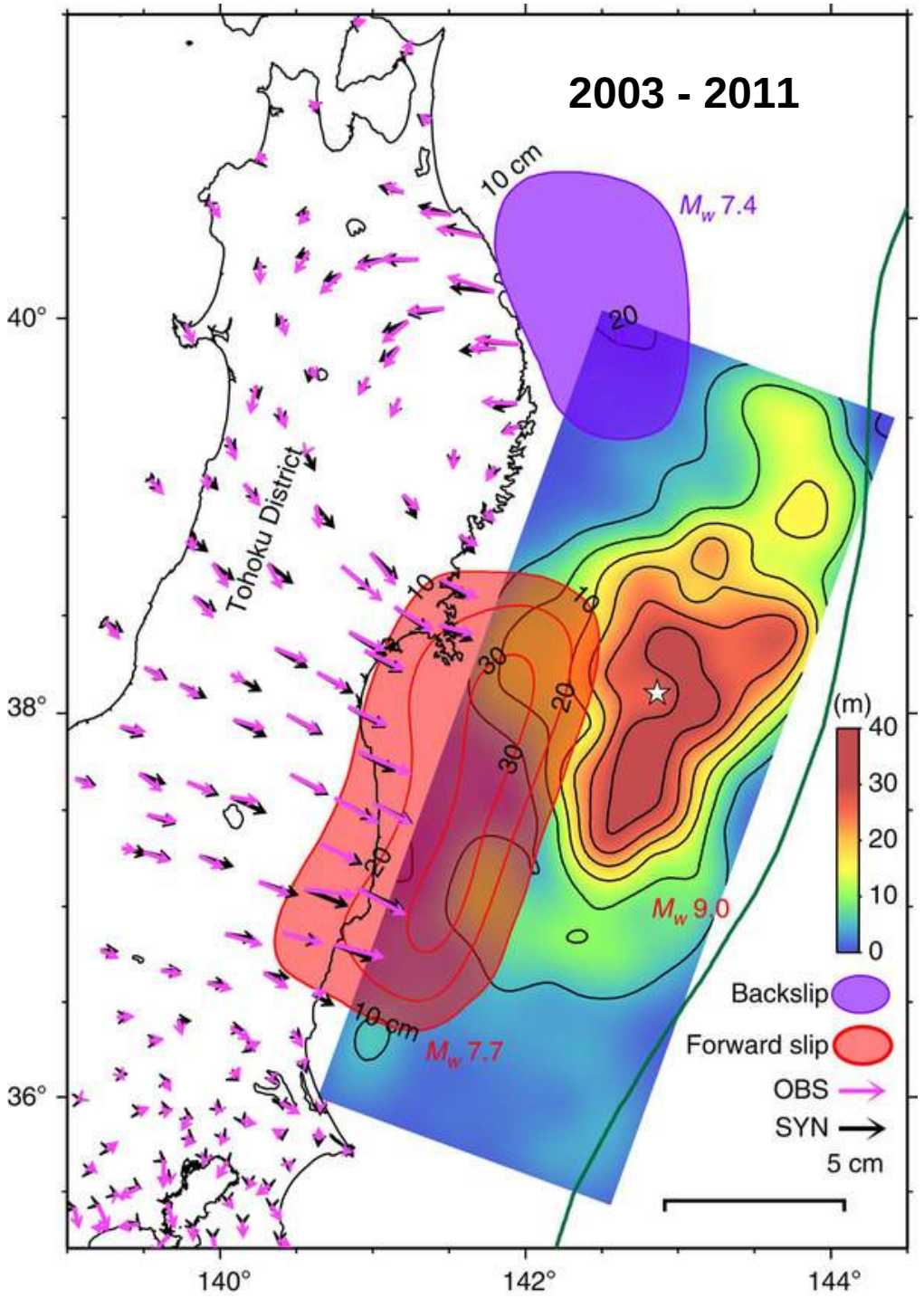
Loveless and Meade (2011)



Cubas et al. (2015)

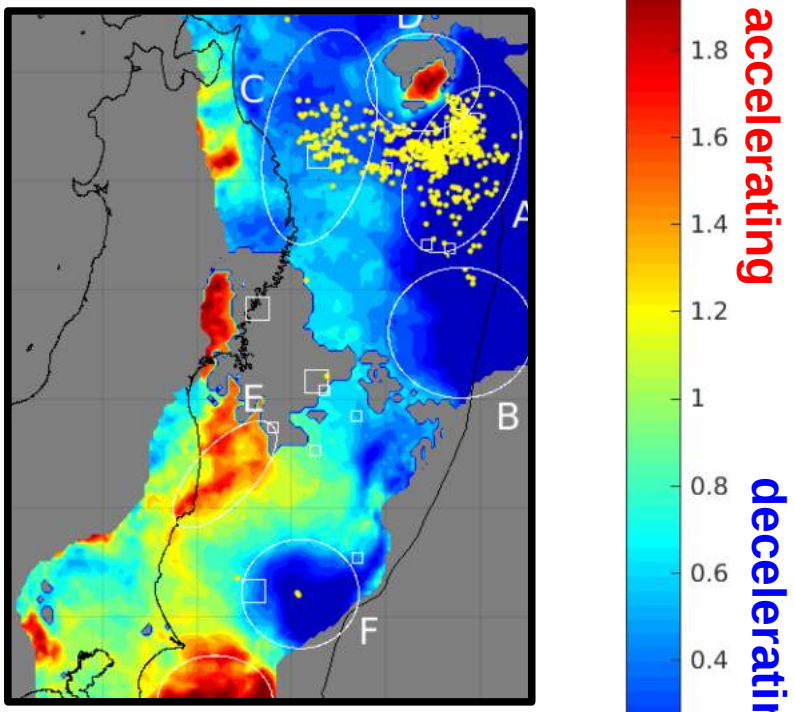


Yokota and Koketsu
(Nat. Comm., 2015)

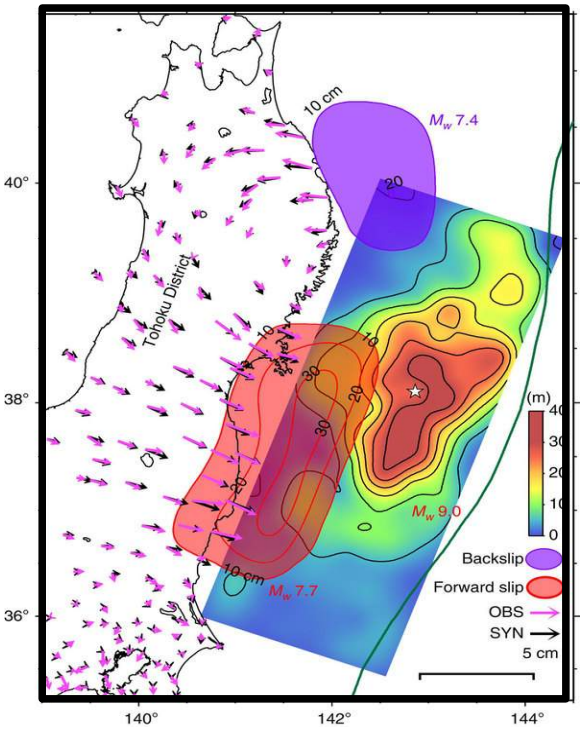


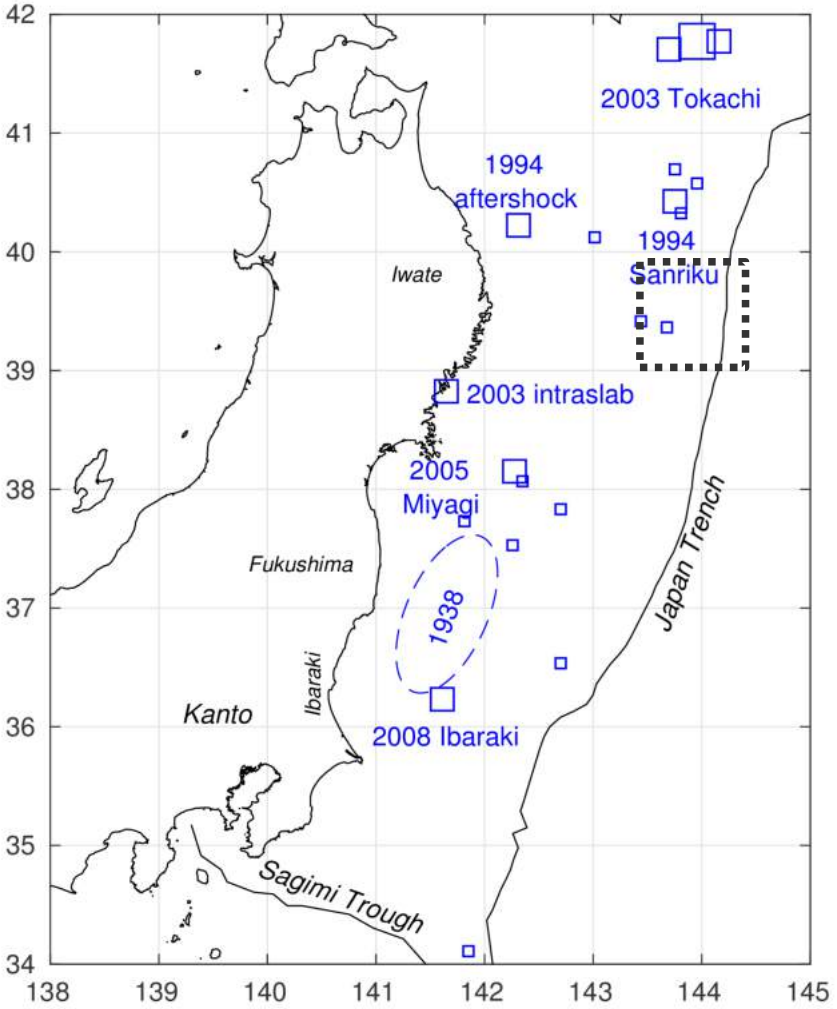
Yokota and Koketsu
(Nat. Comm., 2015)

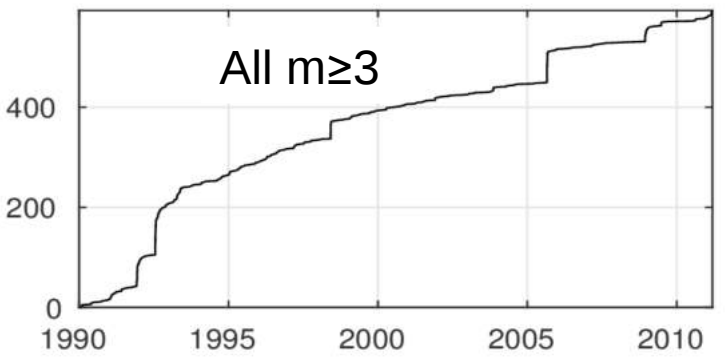
Change of background rate
1990 – 2011

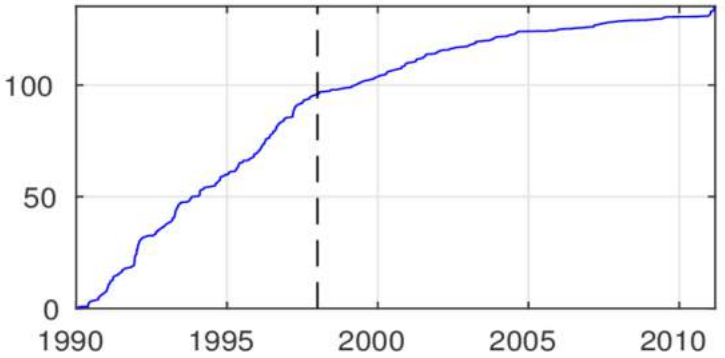


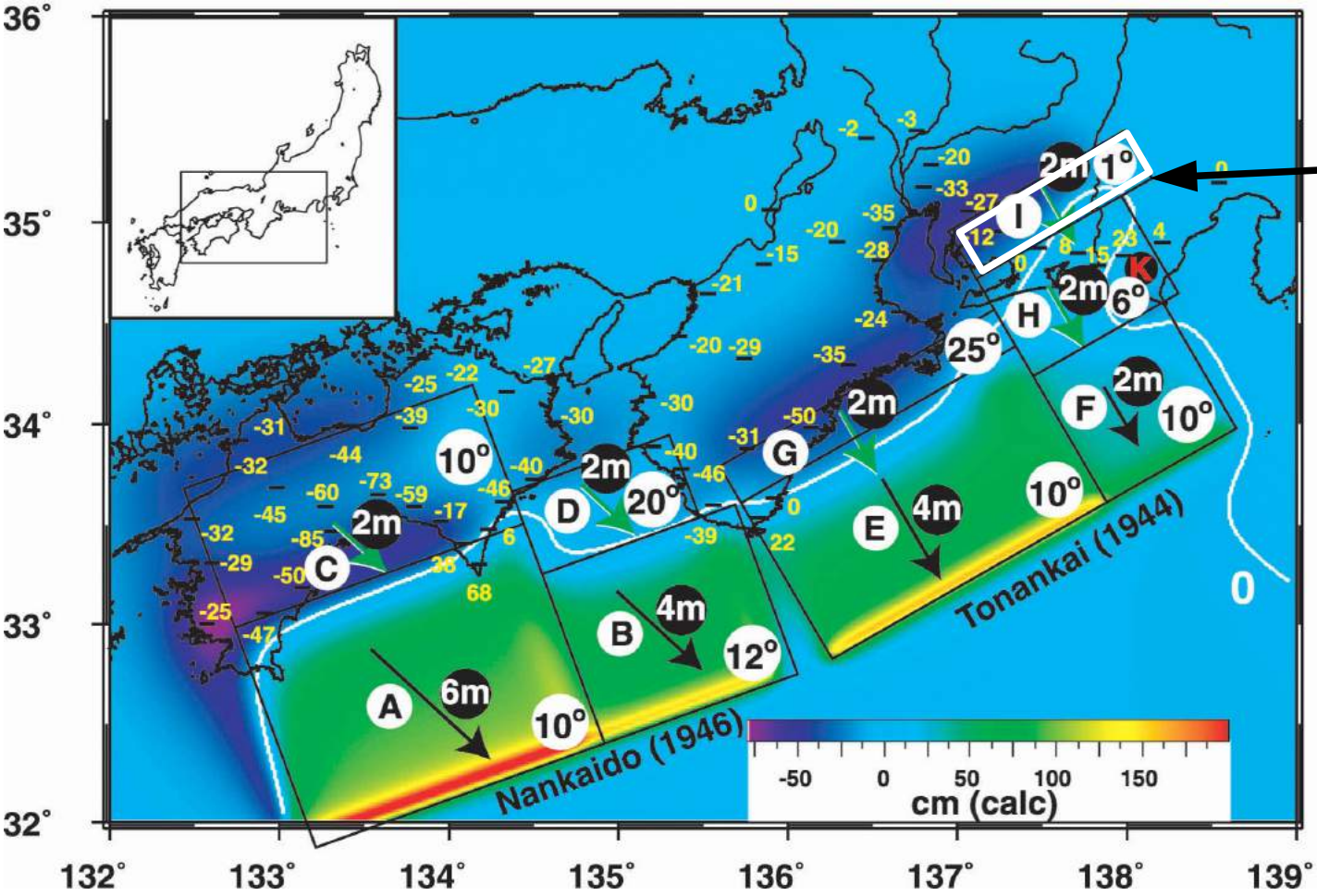
Change of slip-deficit rate
2003 - 2011




2003 Tokachi
1994
aftershock
1994
Sanriku
Iwate
2003 intraslab
2005
Miyagi
Fukushima
1938
Japan Trench
Ibaraki
Kanto
2008 Ibaraki
Sagimi Trough
42
41
40
39
38
37
36
35
34
138
139
140
141
142
143
144
145

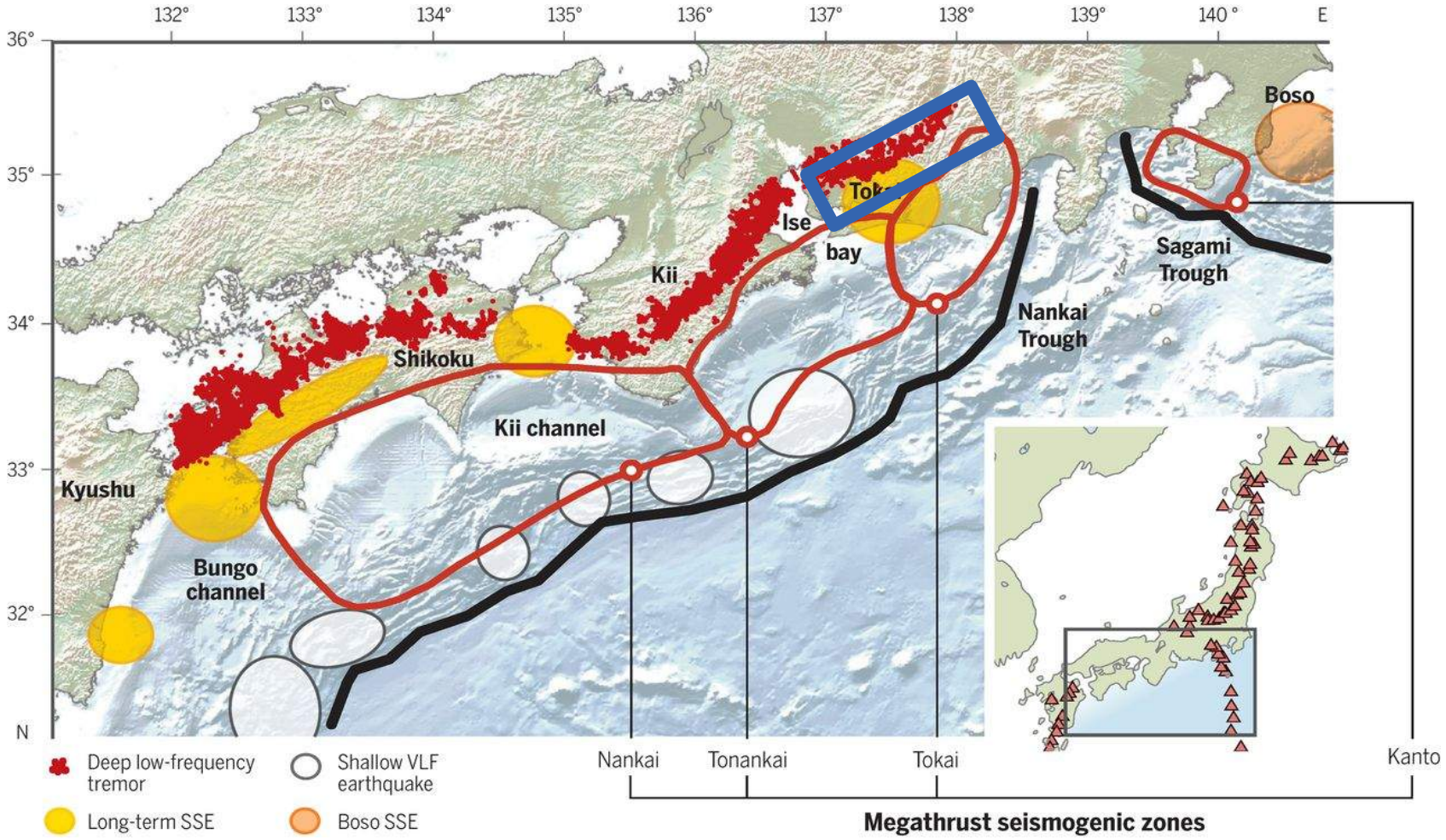

All m≥3
400
200
0
1990
1995
2000
2005
2010


100
50
0
1990
1995
2000
2005
2010

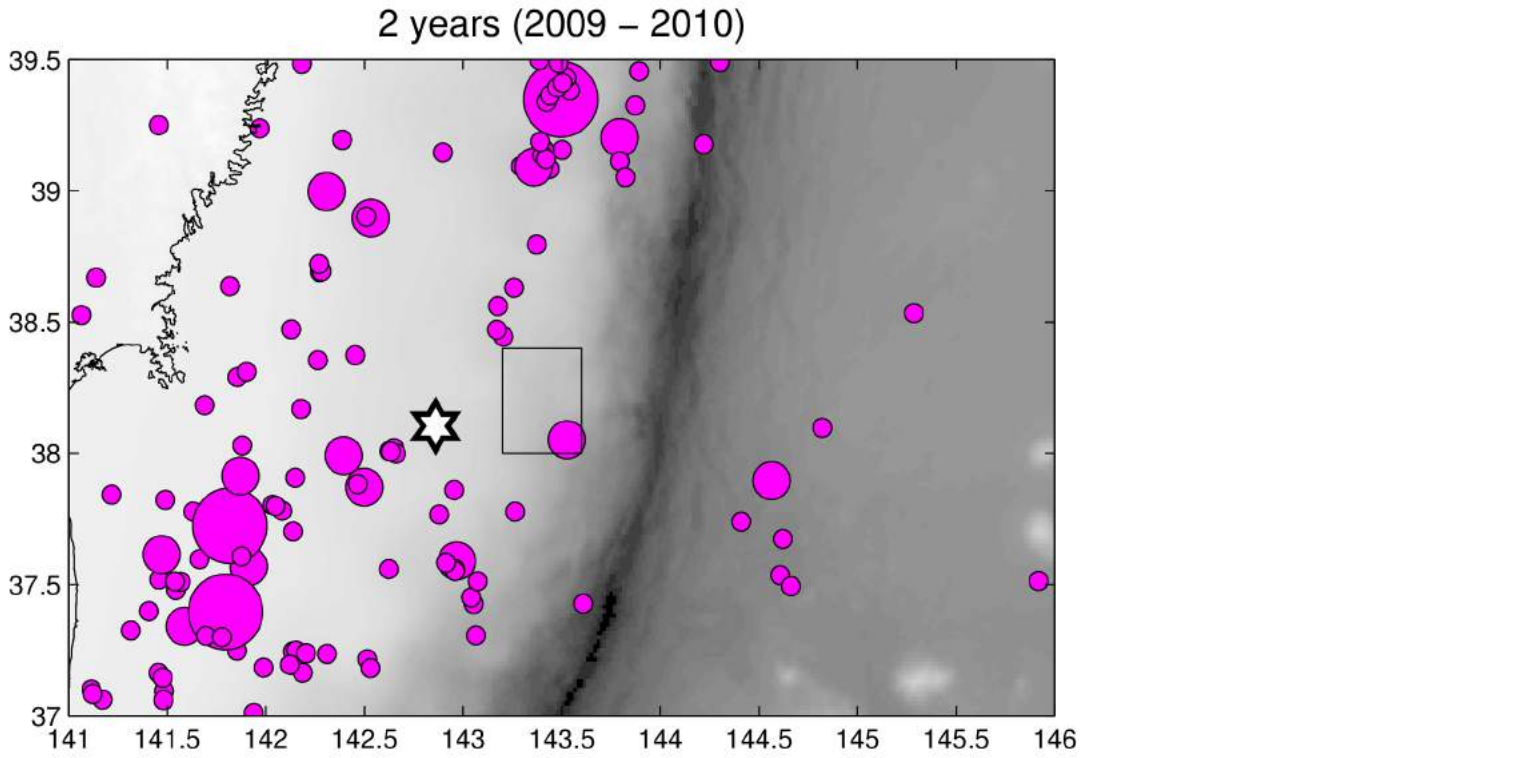


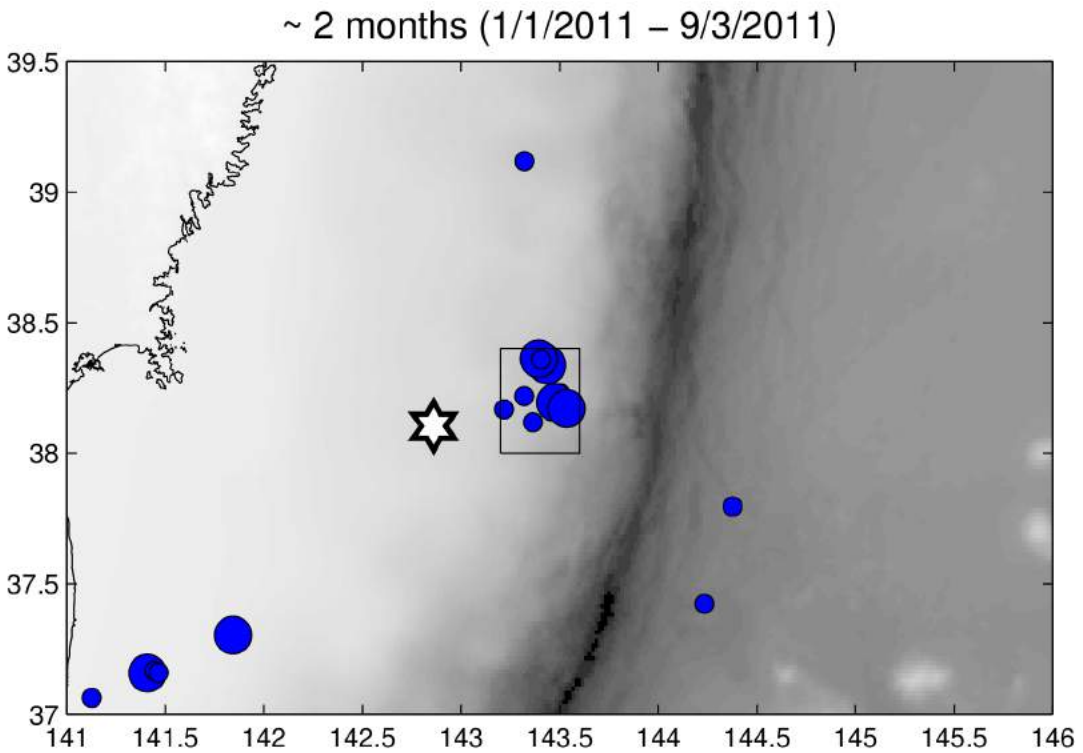
2 m in < 12 hrs

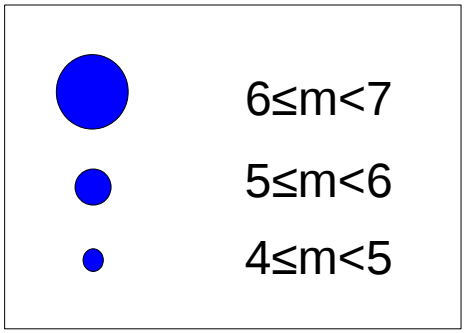
Linde and Sacks (2002)



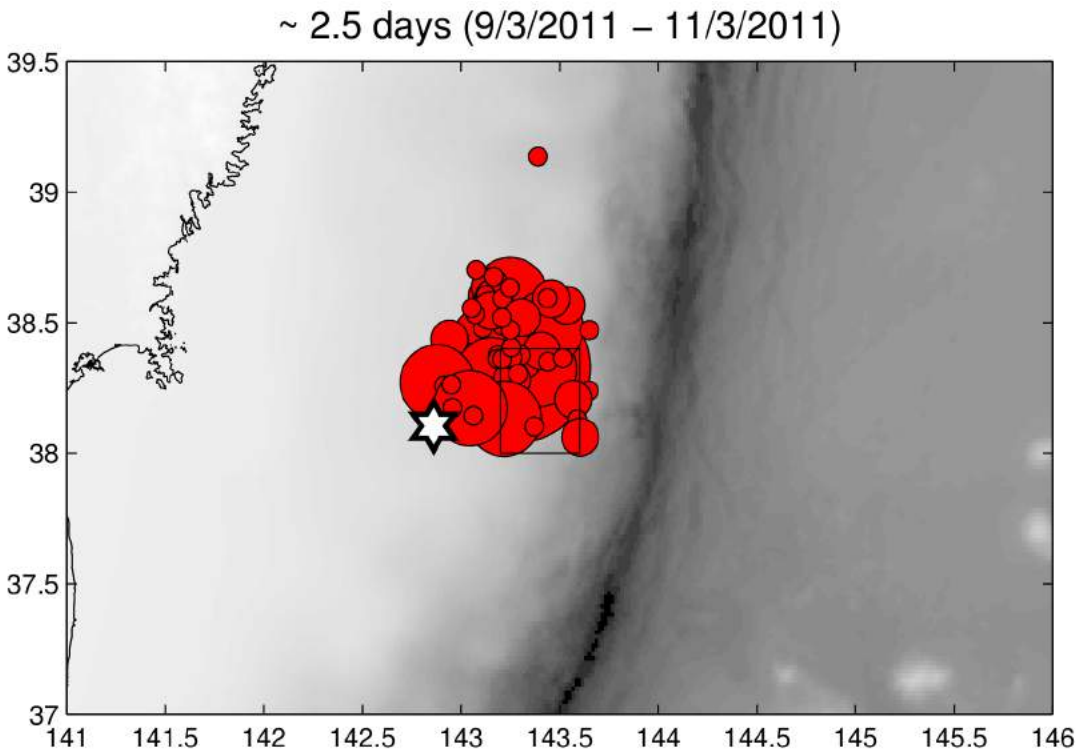
Obara & Kato (2016)


6≤m<7
5≤m<6
4≤m<5
2 years (2009 – 2010)
39.5
39
38.5
38
37.5
37
141
141.5
142
142.5
143
143.5
144
144.5
145
145.5
146

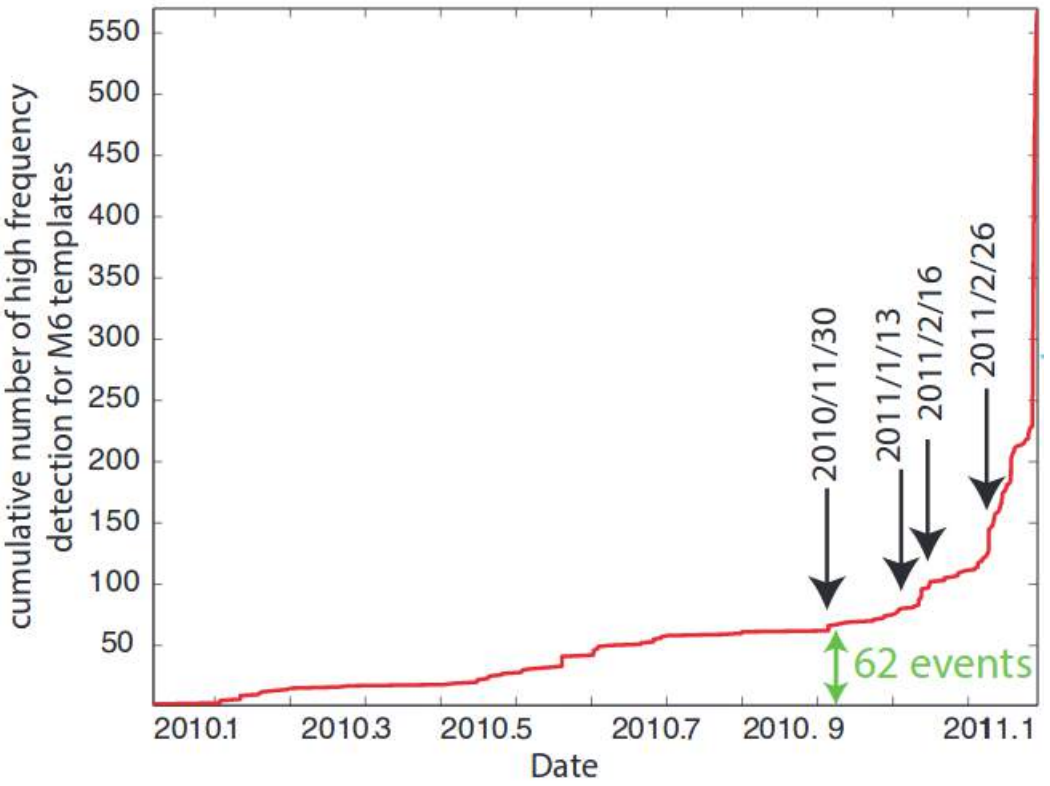




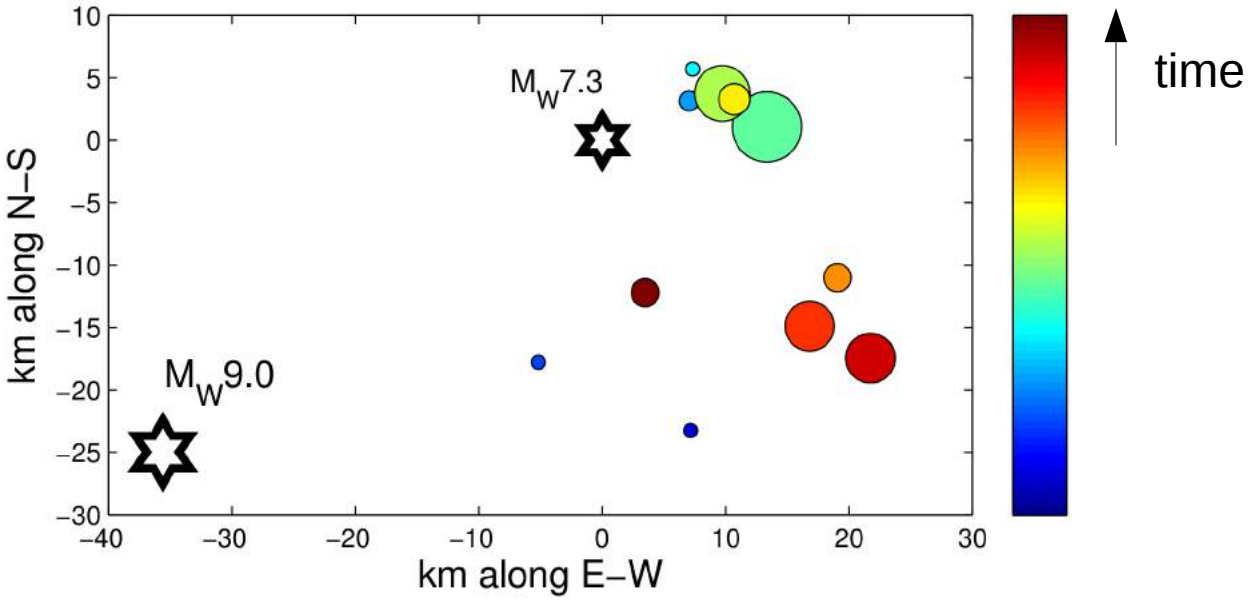
1st PHASE (2 months)



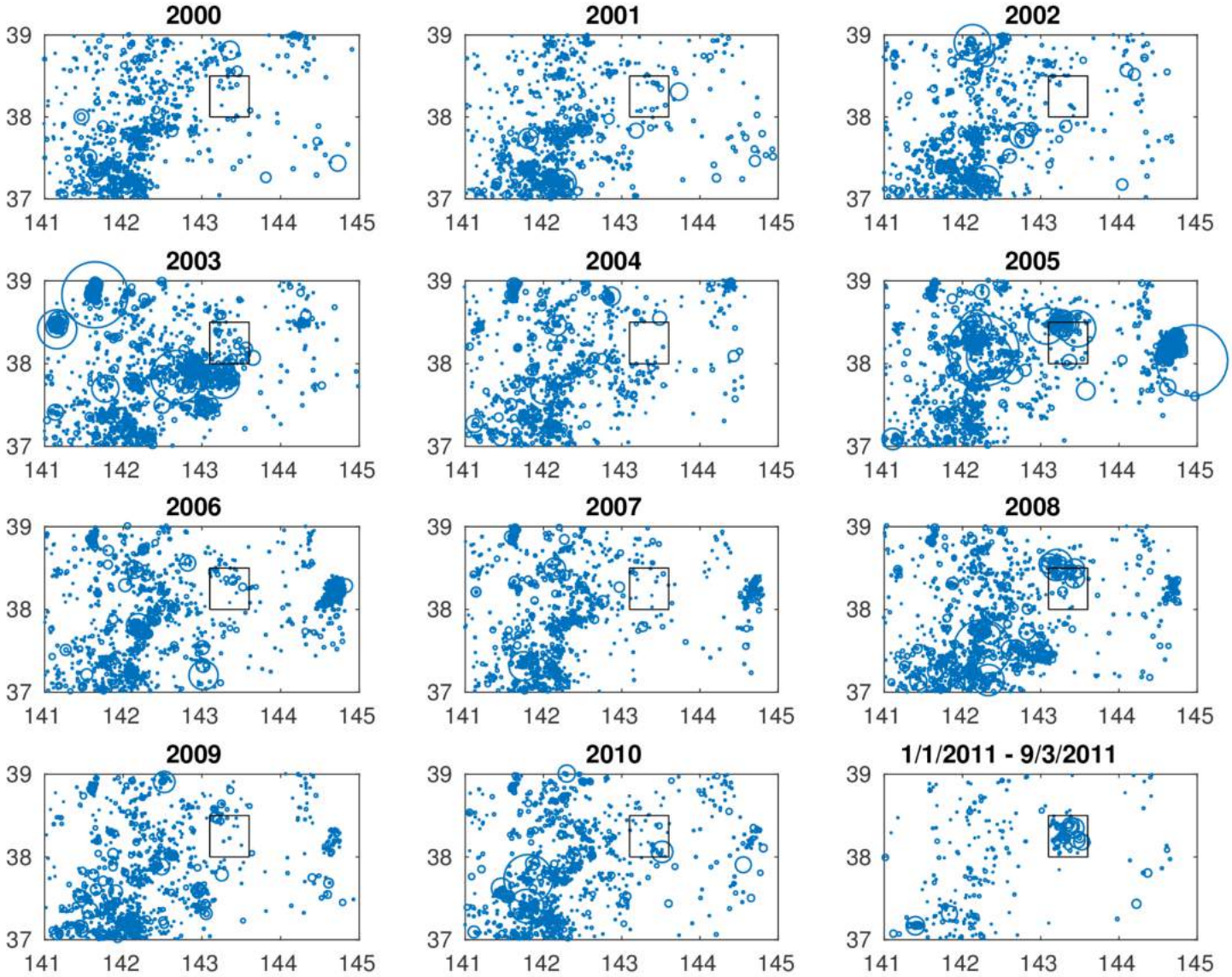
2nd PHASE (2.5 days)

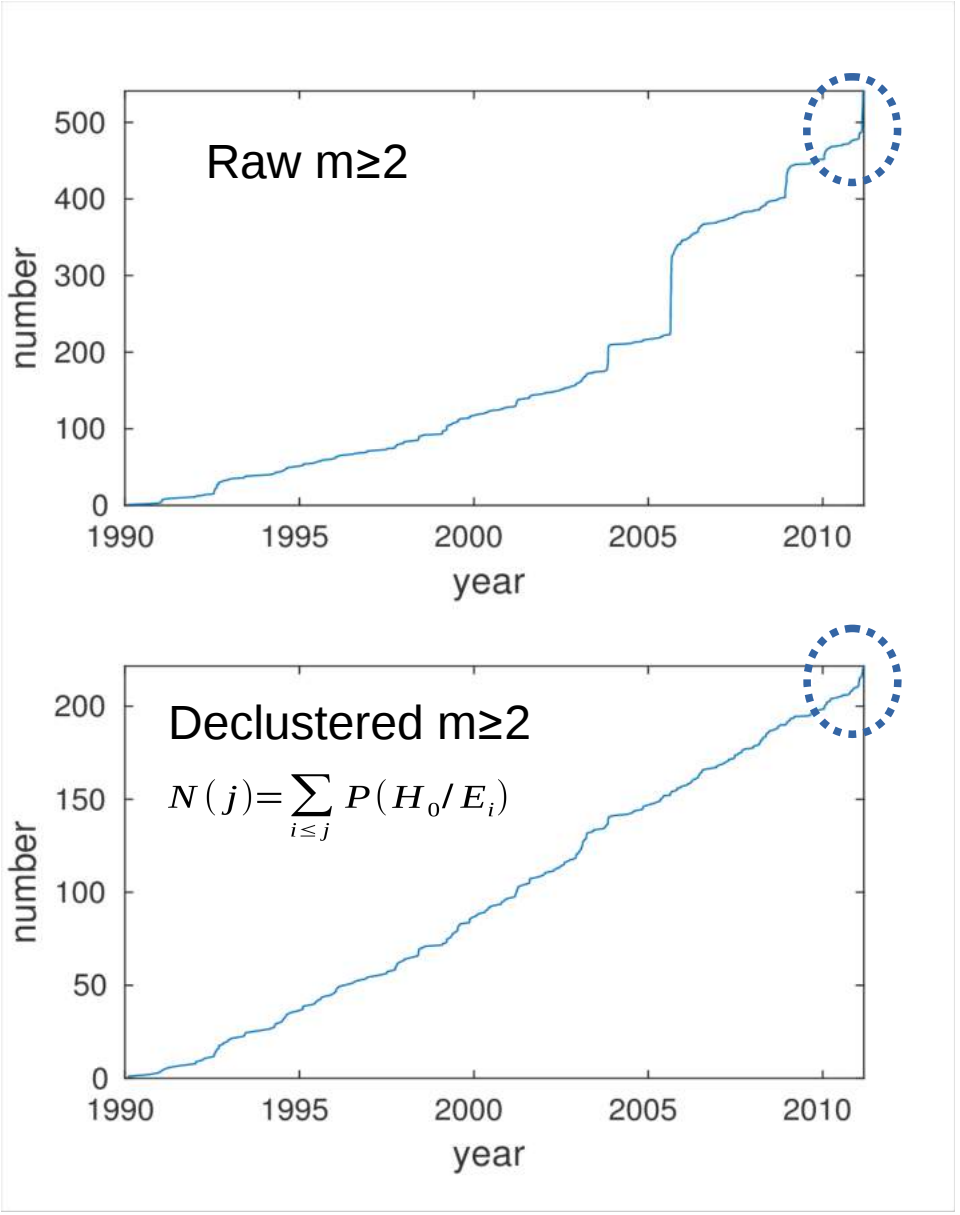


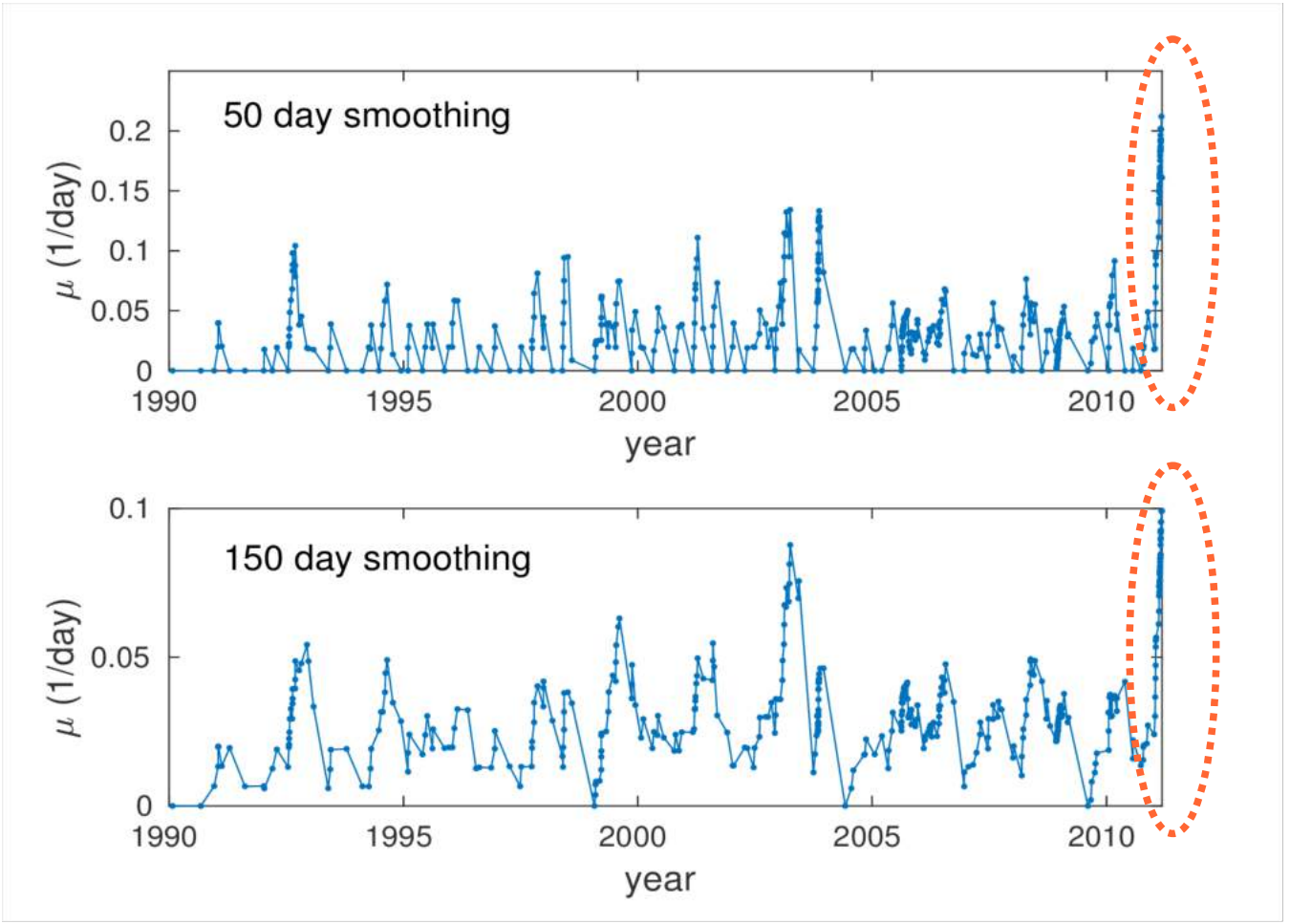
Gardonio et al. (submitted)



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

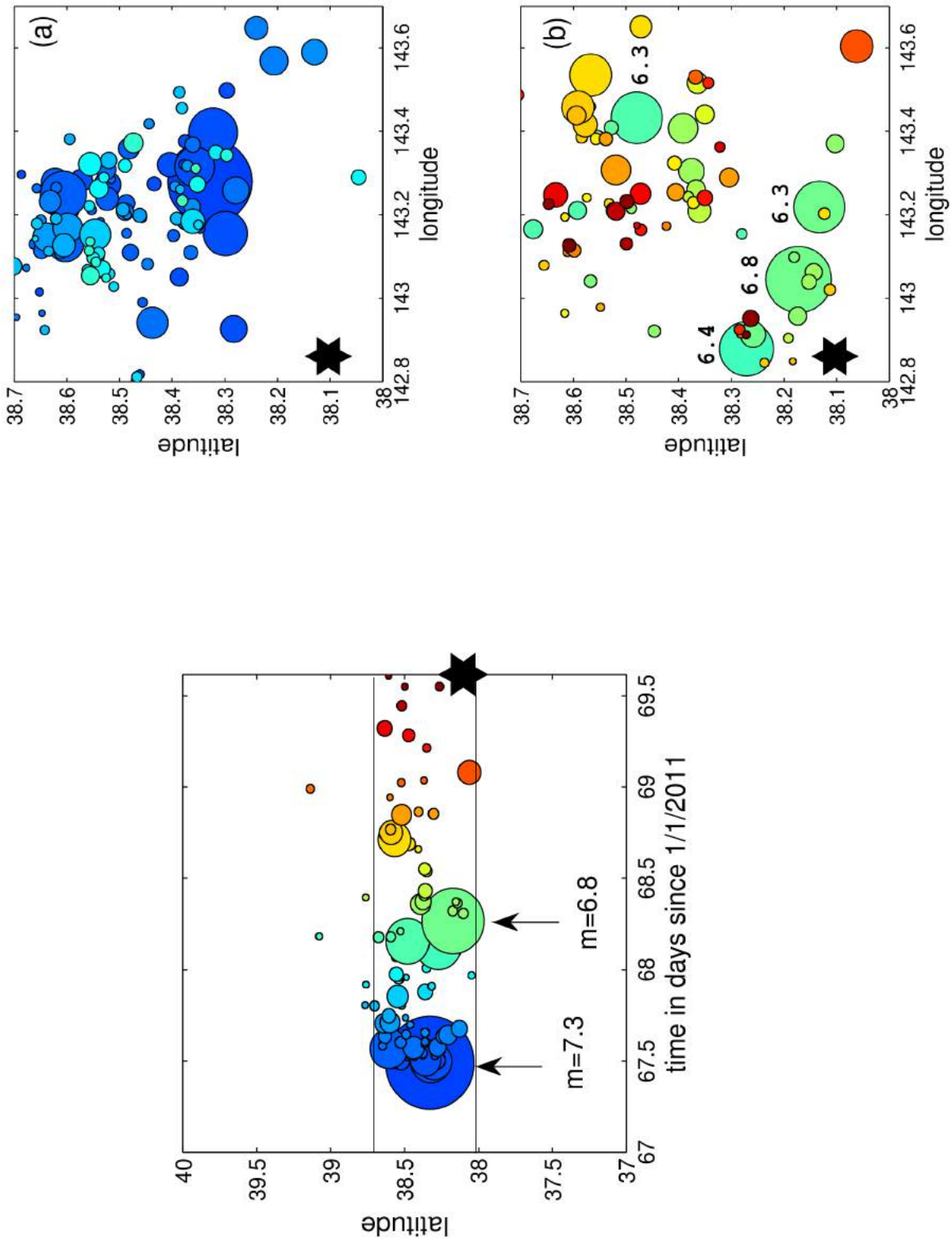

2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
1/1/2011 - 9/3/2011
39
38
37
141
142
143
144
145


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

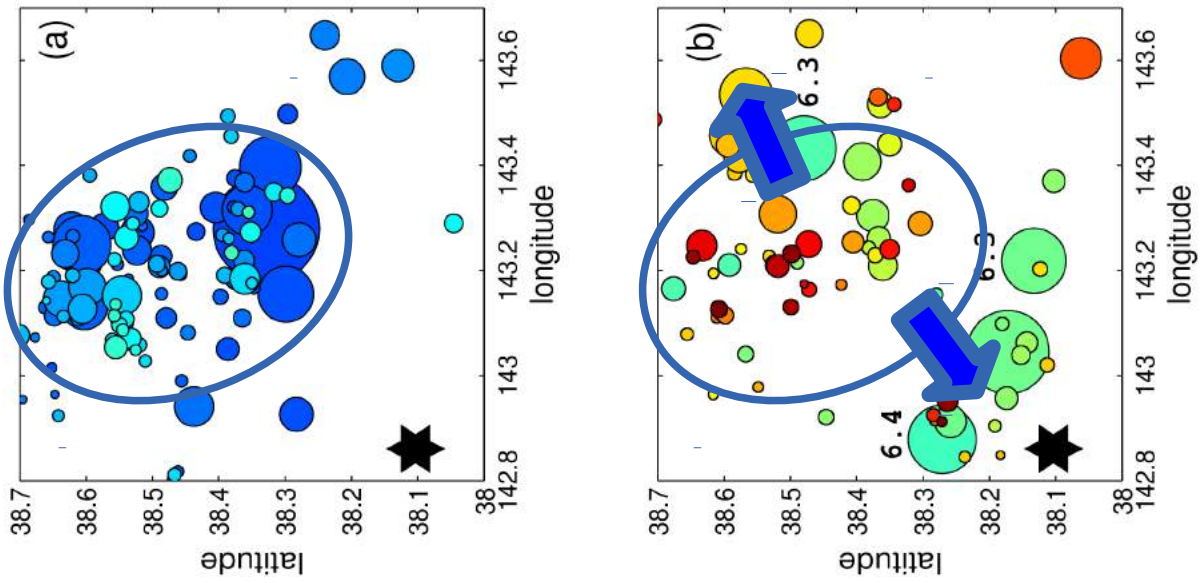
First day after M7.3

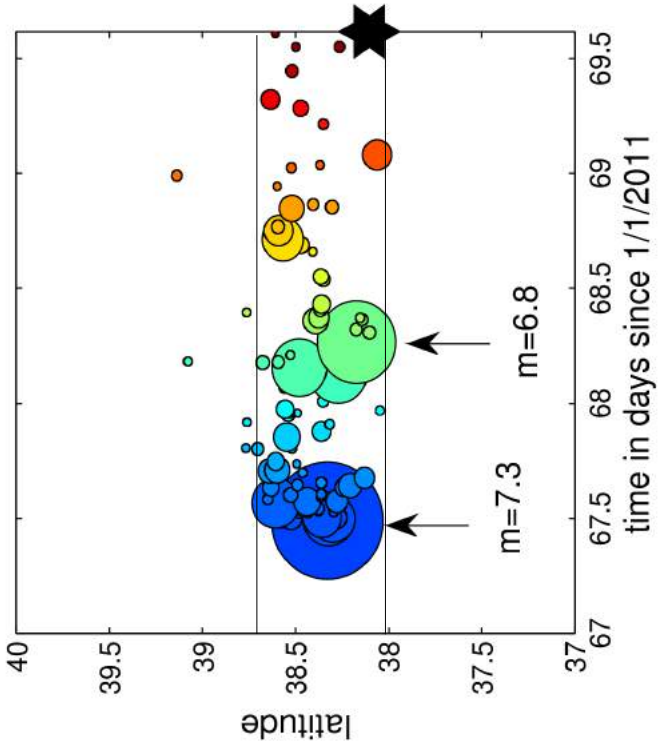
Second day after M7.3

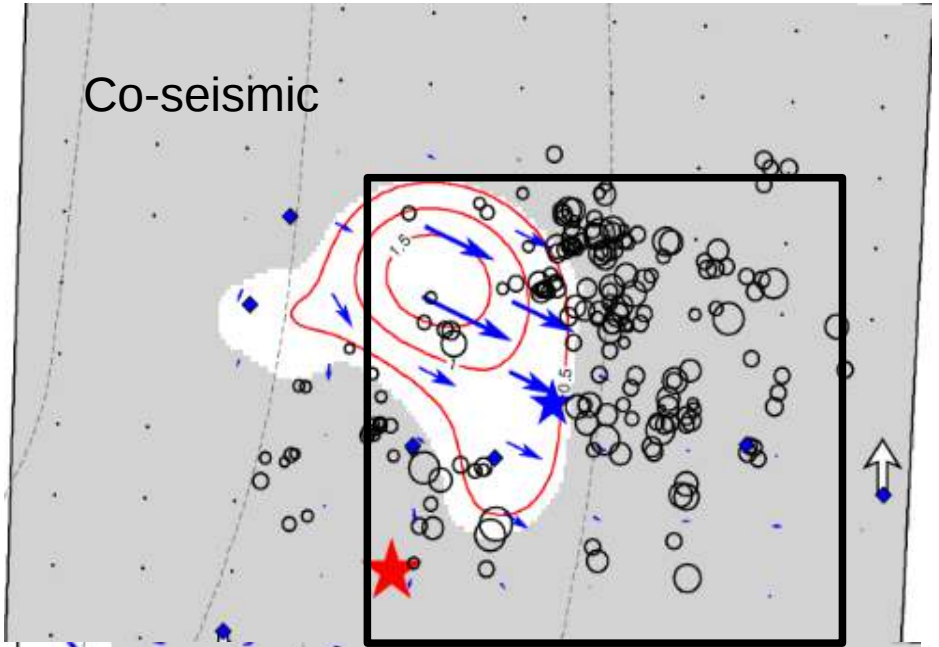


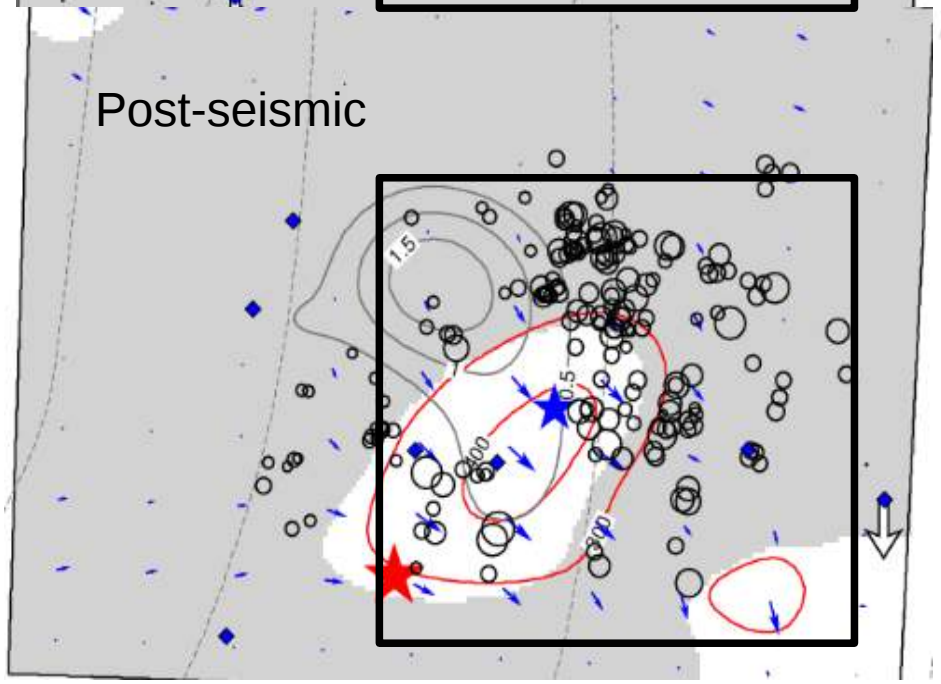
First day after M7.3

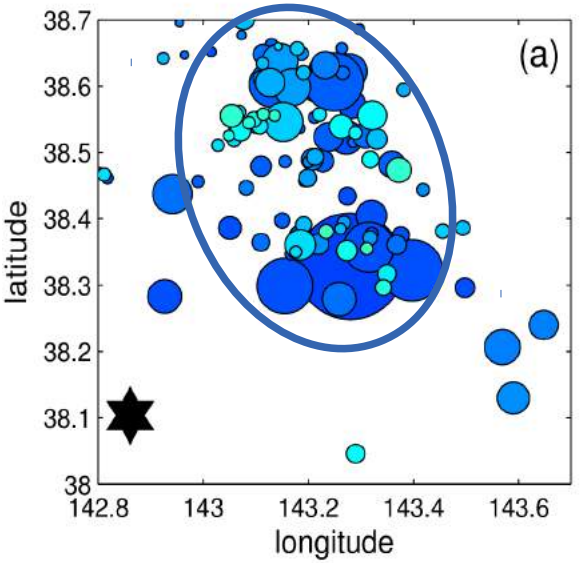
Second day after M7.3



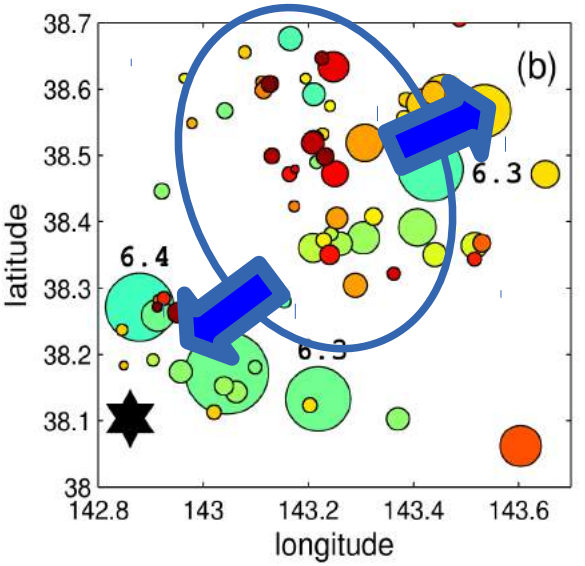








First day after M7.3



Second day after M7.3

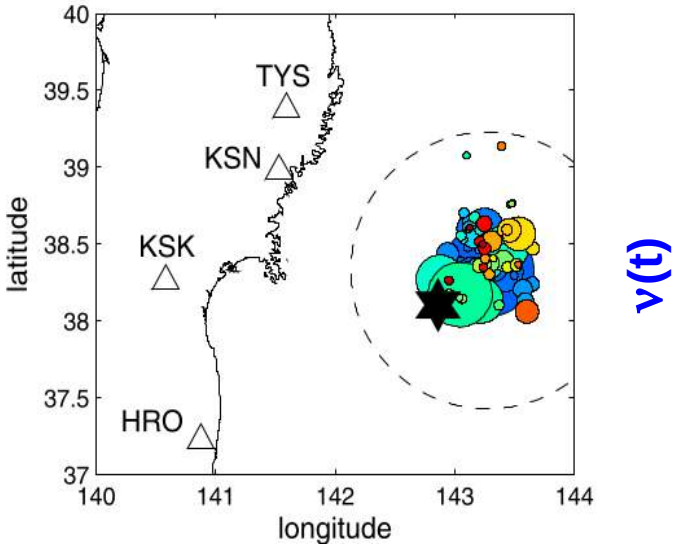
Ohta et al. (2012)

Completeness M_c = 4.2 for these 2.5 days

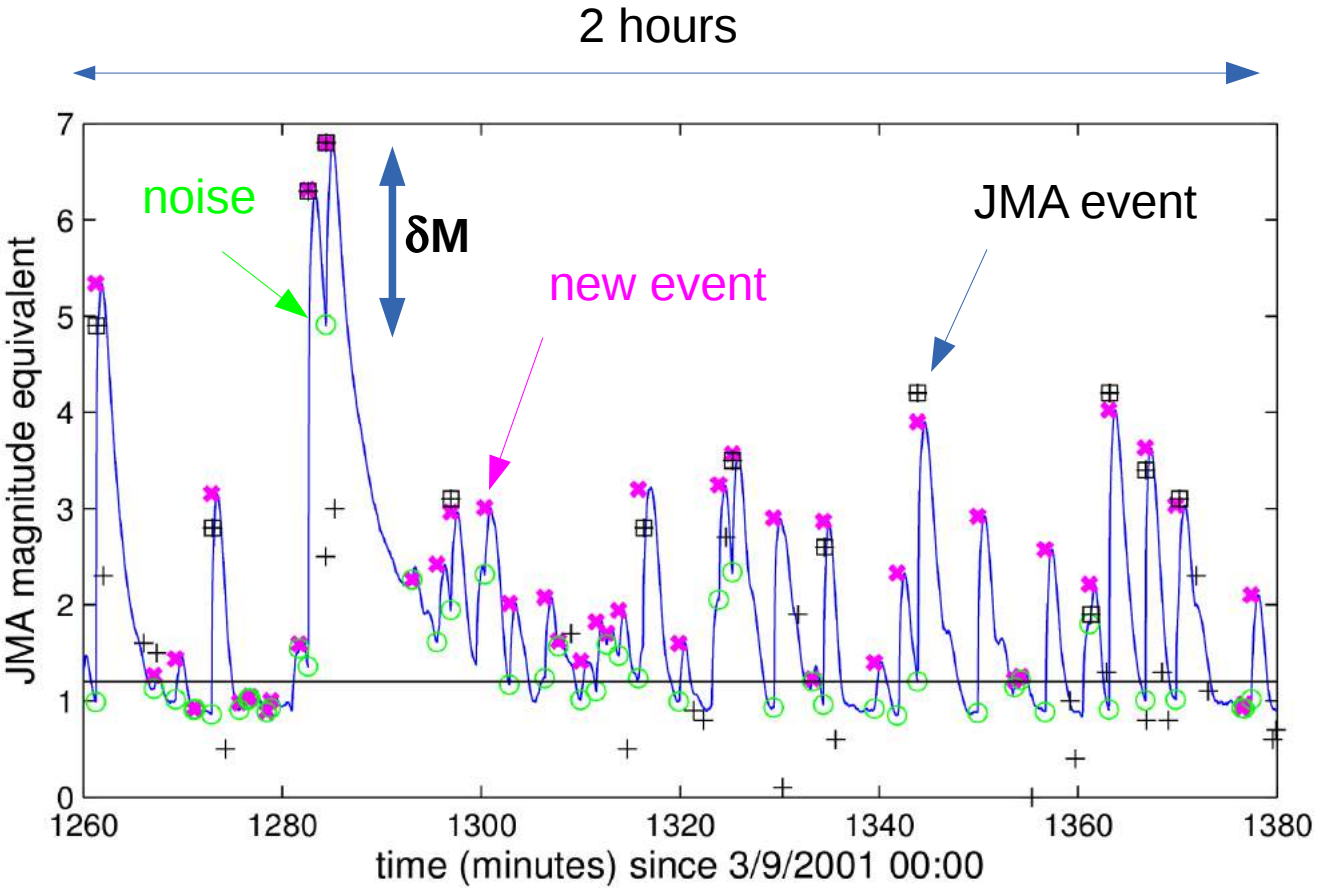
Changes in magnitude of completness (many large shocks):

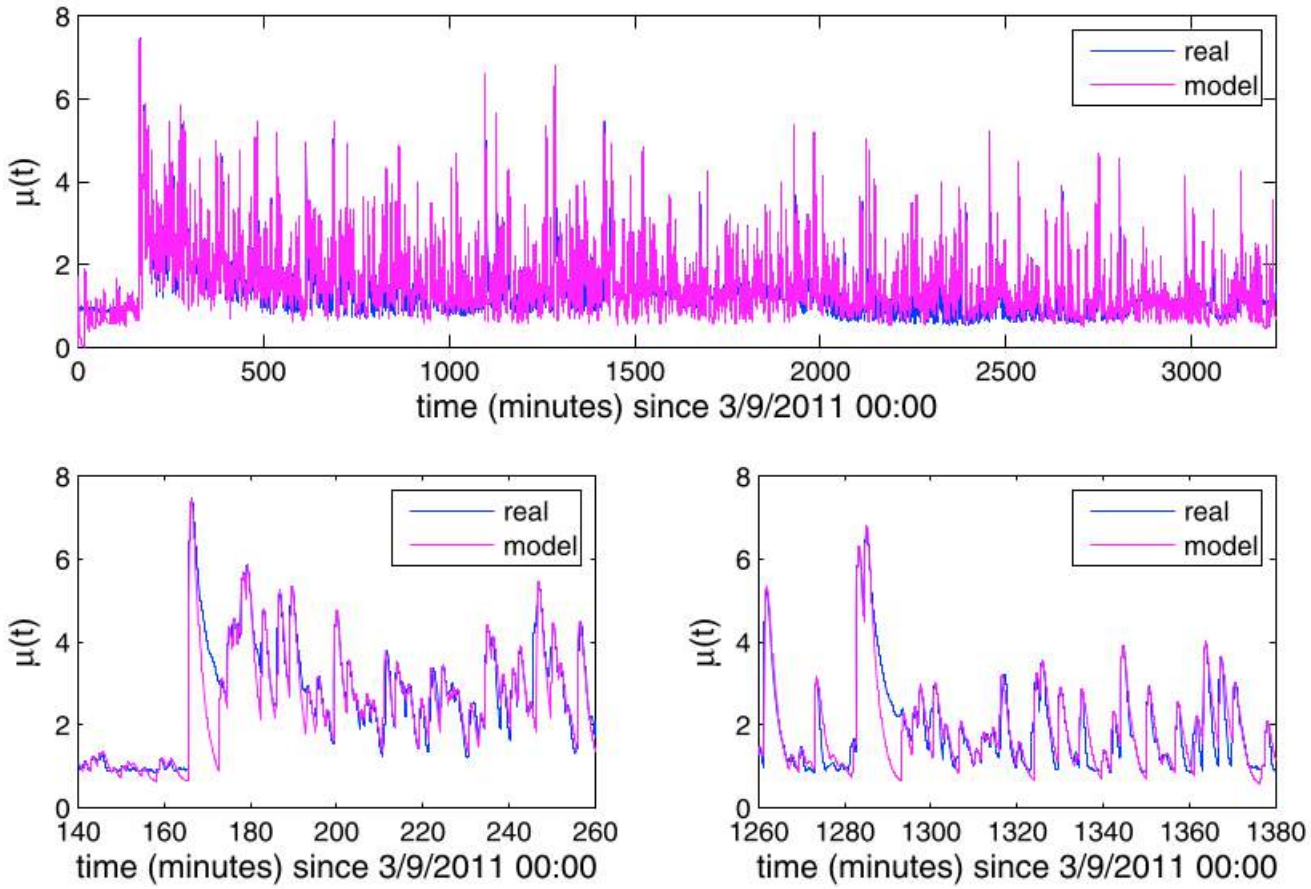
Following Peng et al. (JGR, 2007):

- We detect new, small earthquakes in the continuous broad-band recordings
- We quantify the level of noise at all time and prior to all JMA and new earthquakes
  v(t) = log of stacked envelopes (4 closest F-net stations),f>20 Hz, smoothed at 100s



v(t)





ETAS model + (non-linear) convolution by enveloppe function

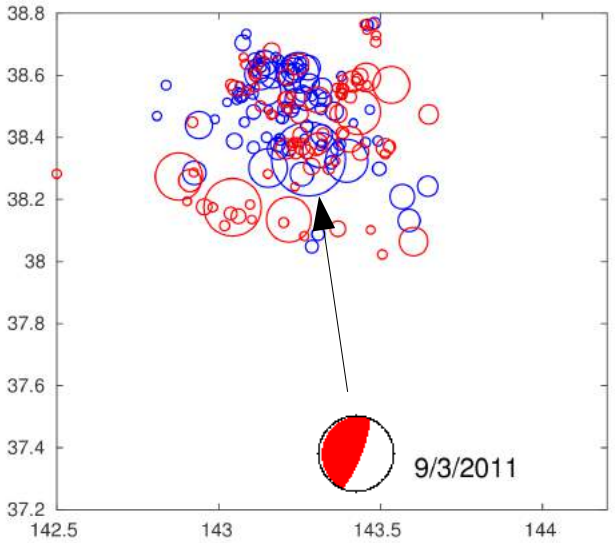
Time series is simply one of a « normal » aftershock sequence

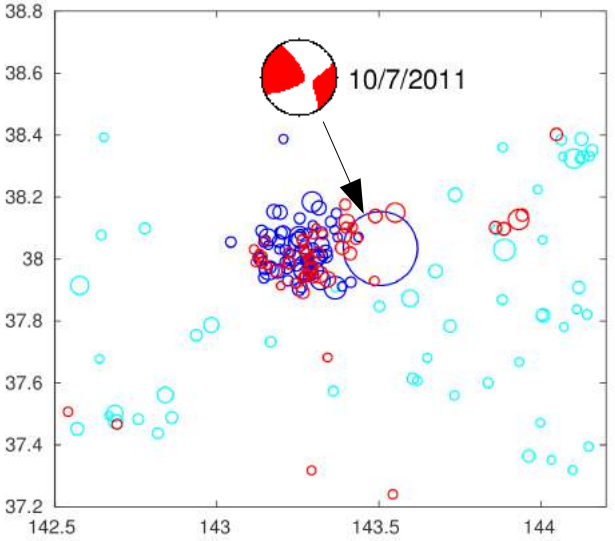
Marsan and Enescu (2012)

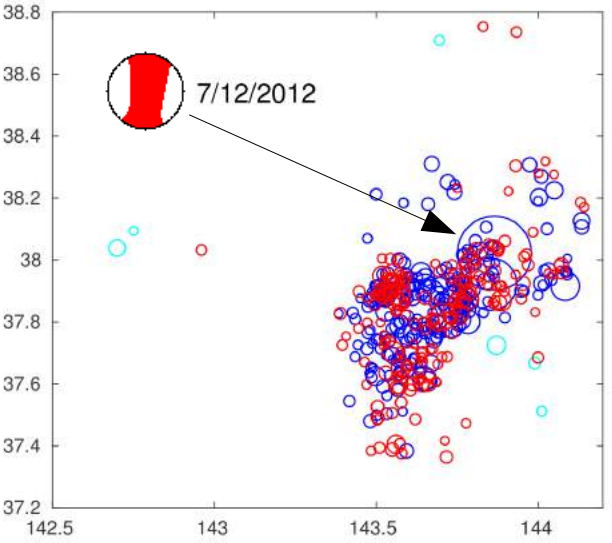
10 days before mainshock

0 - 0.5 days after mainshock

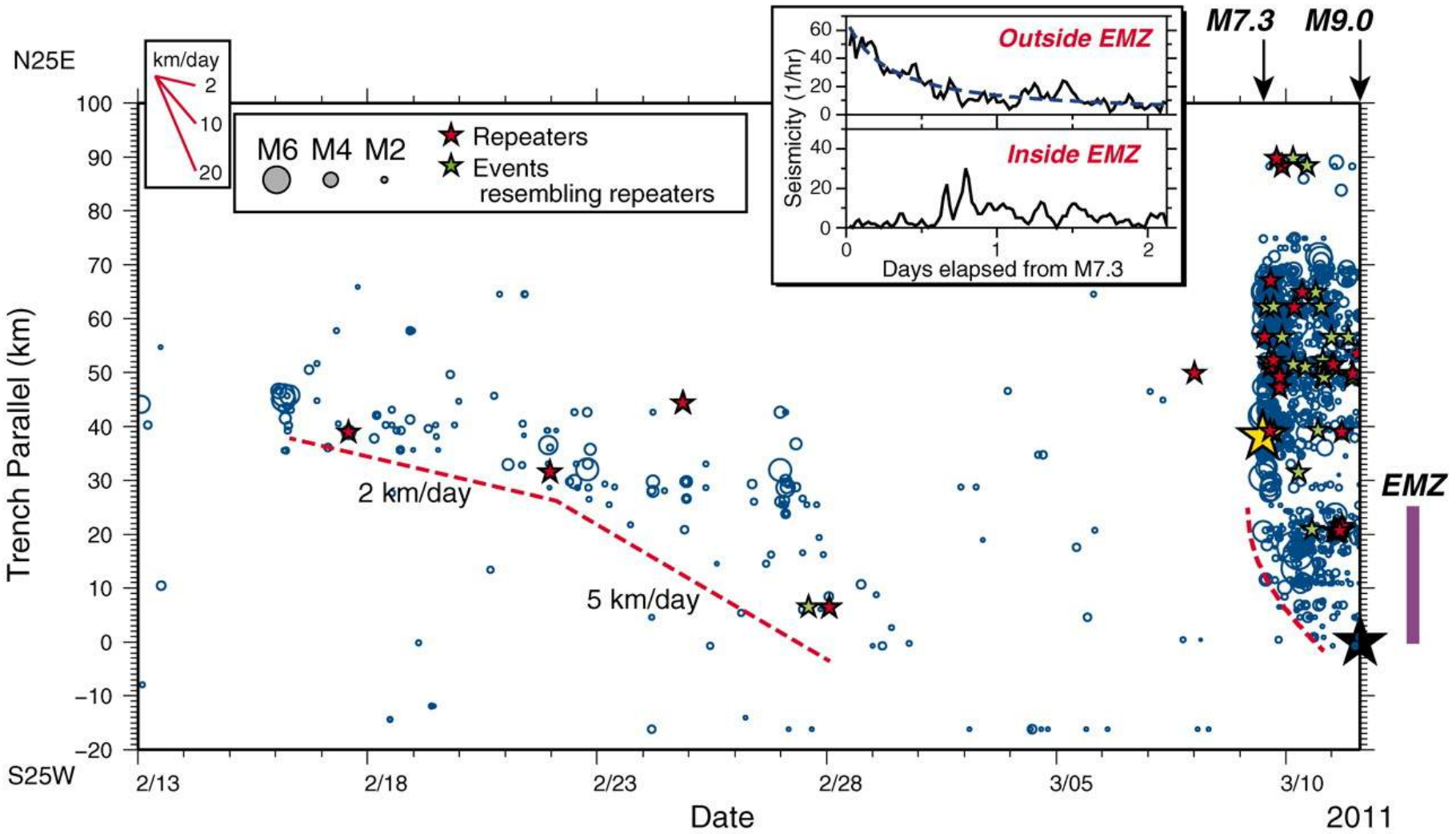
0.5 - 2 days after mainshock



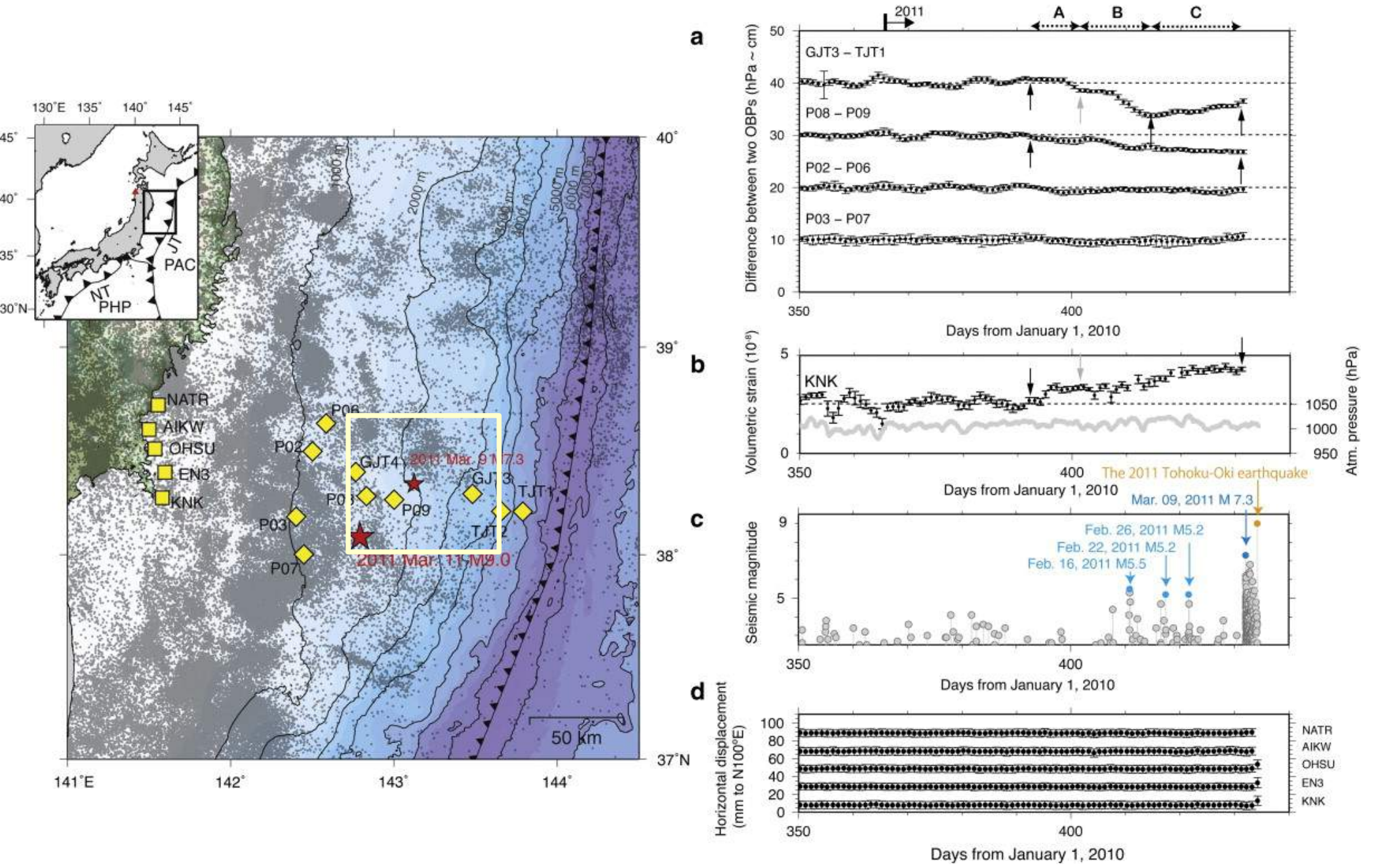




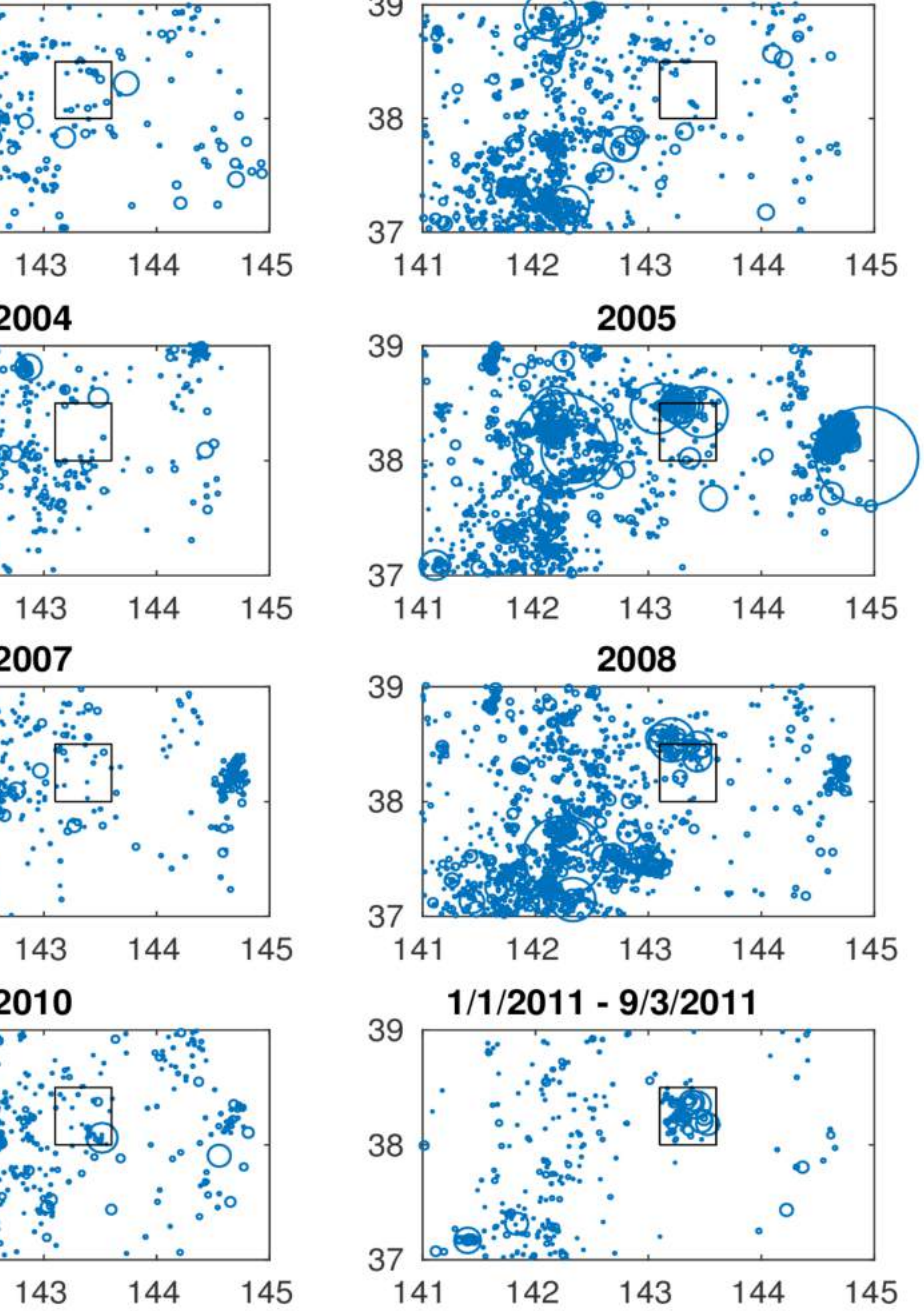
Three M7.3 mainshocks in the same zone (2011 – 2012)

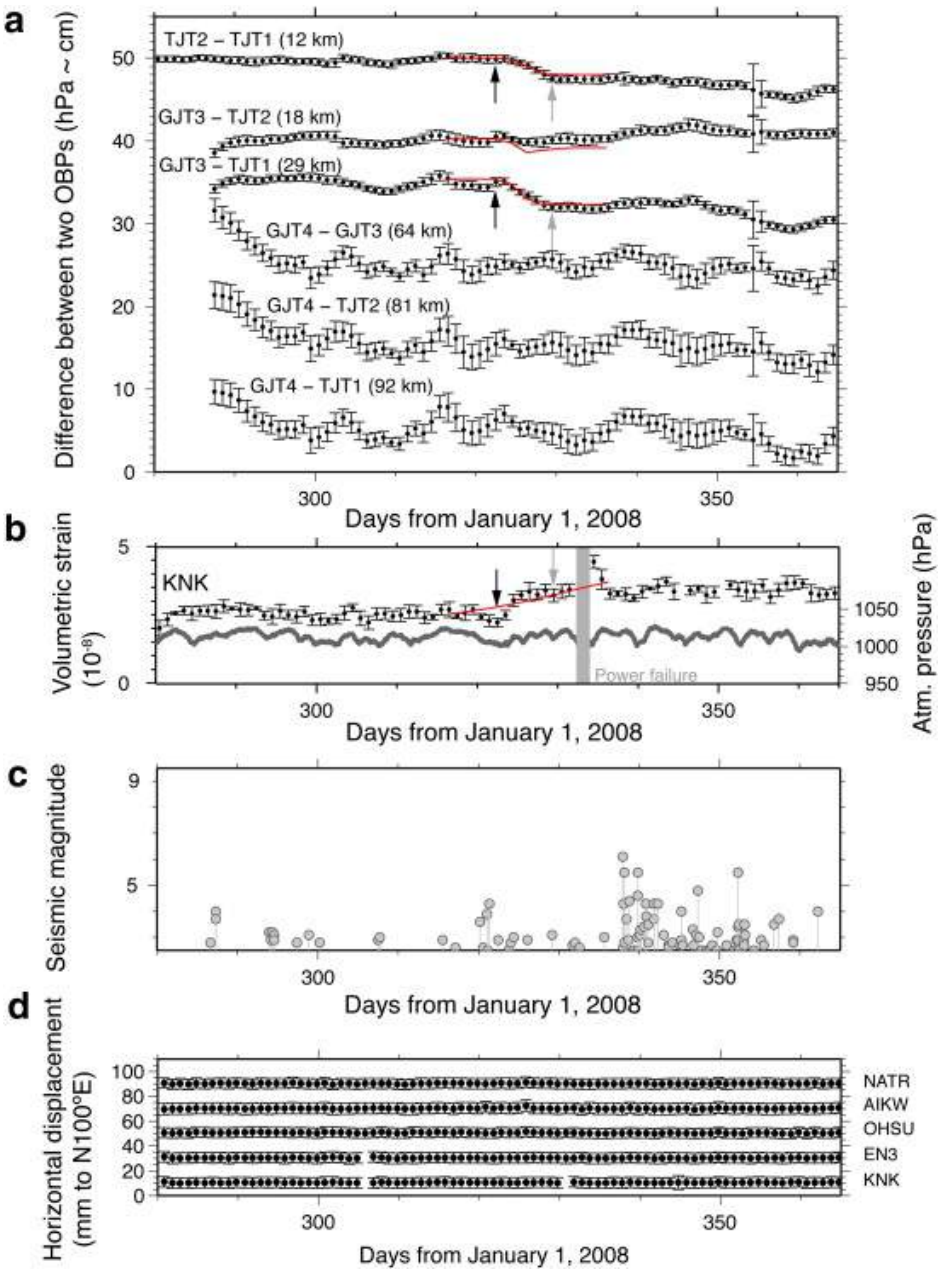


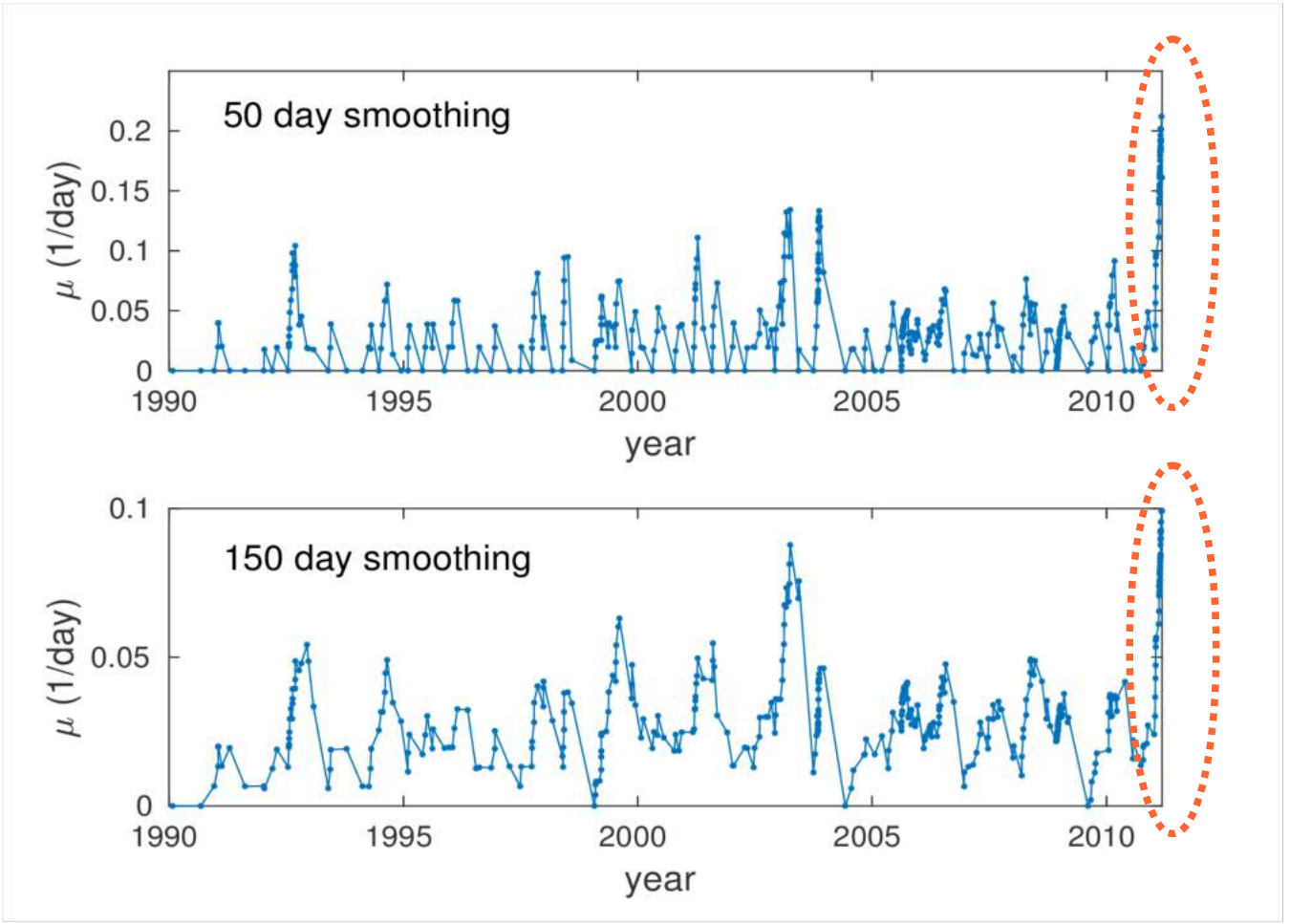
Kato et al. (2012)



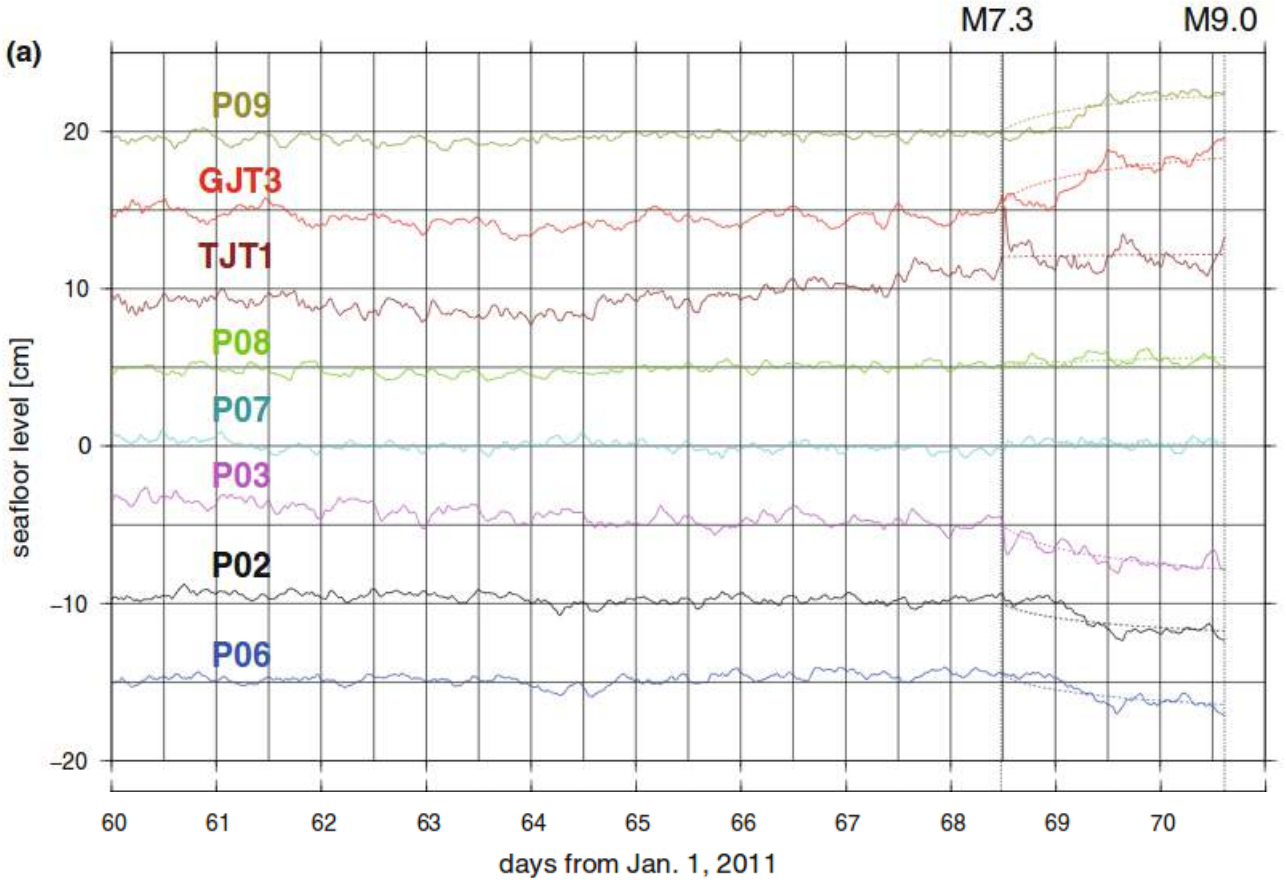
Ito et al. (2013)

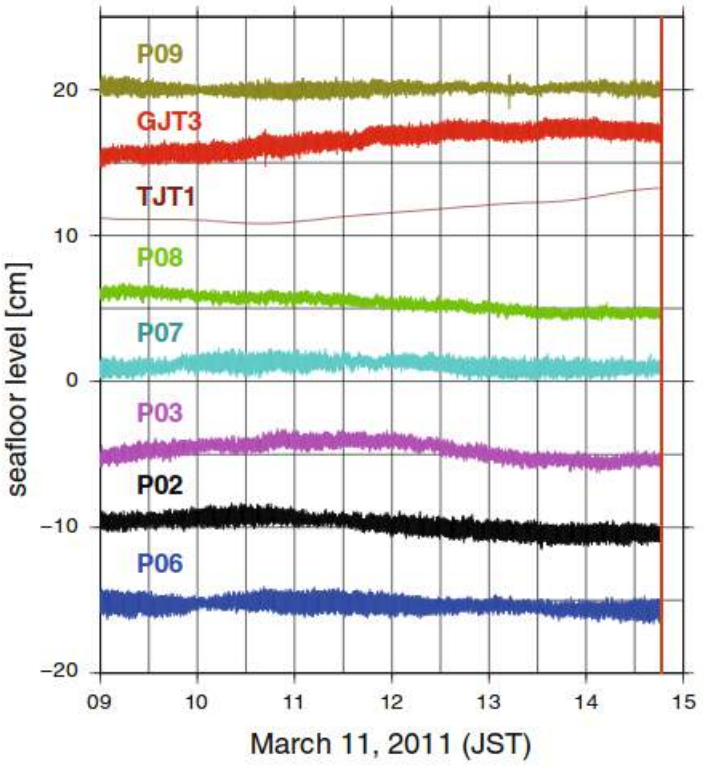

2004
2005
2007
2008
2010
1/1/2011 - 9/3/2011
39
38
37
143
144
145
141
142


a
TJT2 – TJT1 (12 km)
GJT3 – TJT2 (18 km)
GJT3 – TJT1 (29 km)
GJT4 – GJT3 (64 km)
GJT4 – TJT2 (81 km)
GJT4 – TJT1 (92 km)
Difference between two OBPs (hPa ~ cm)
Days from January 1, 2008
b
KNK
Volumetric strain (10⁻⁸)
Power failure
Atm. pressure (hPa)
c
Seismic magnitude
d
Horizontal displacement (mm to N100°E)
NATR
AIKW
OHSU
EN3
KNK


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

No immediate pre-slip (resolved at Mw6.0 – 6.2)





(6 hours)

Hino et al. (2014)

Seismic moment of slow slip ?

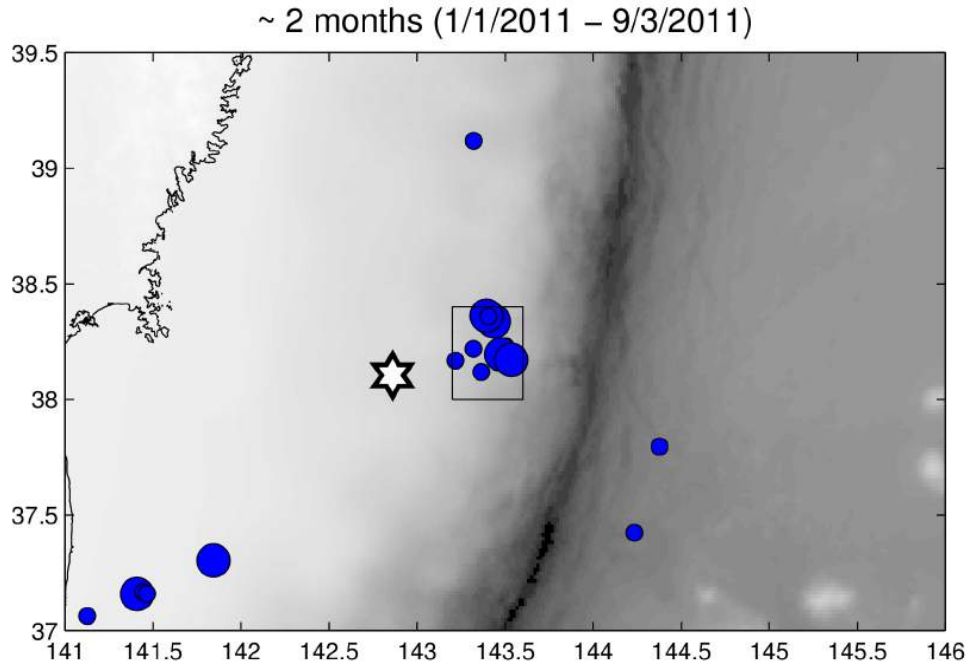
If seismicity only relaxes 1% of total moment

- Total seismic moment (1 month) ➡ M_w=5.7 ◄► *6.7* ◄► *7.0*

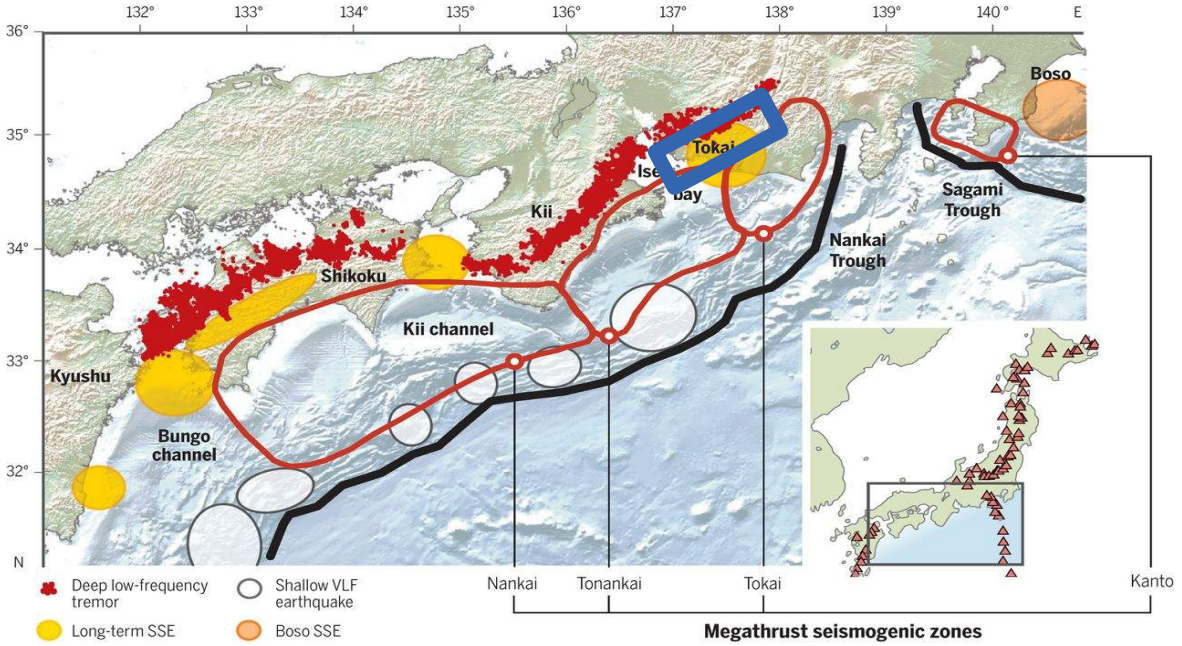
If seismicity only relaxes 3% of total moment

- Repeating earthquakes (1 month) ➡ M_w=7.1 (Kato et al. 2012)

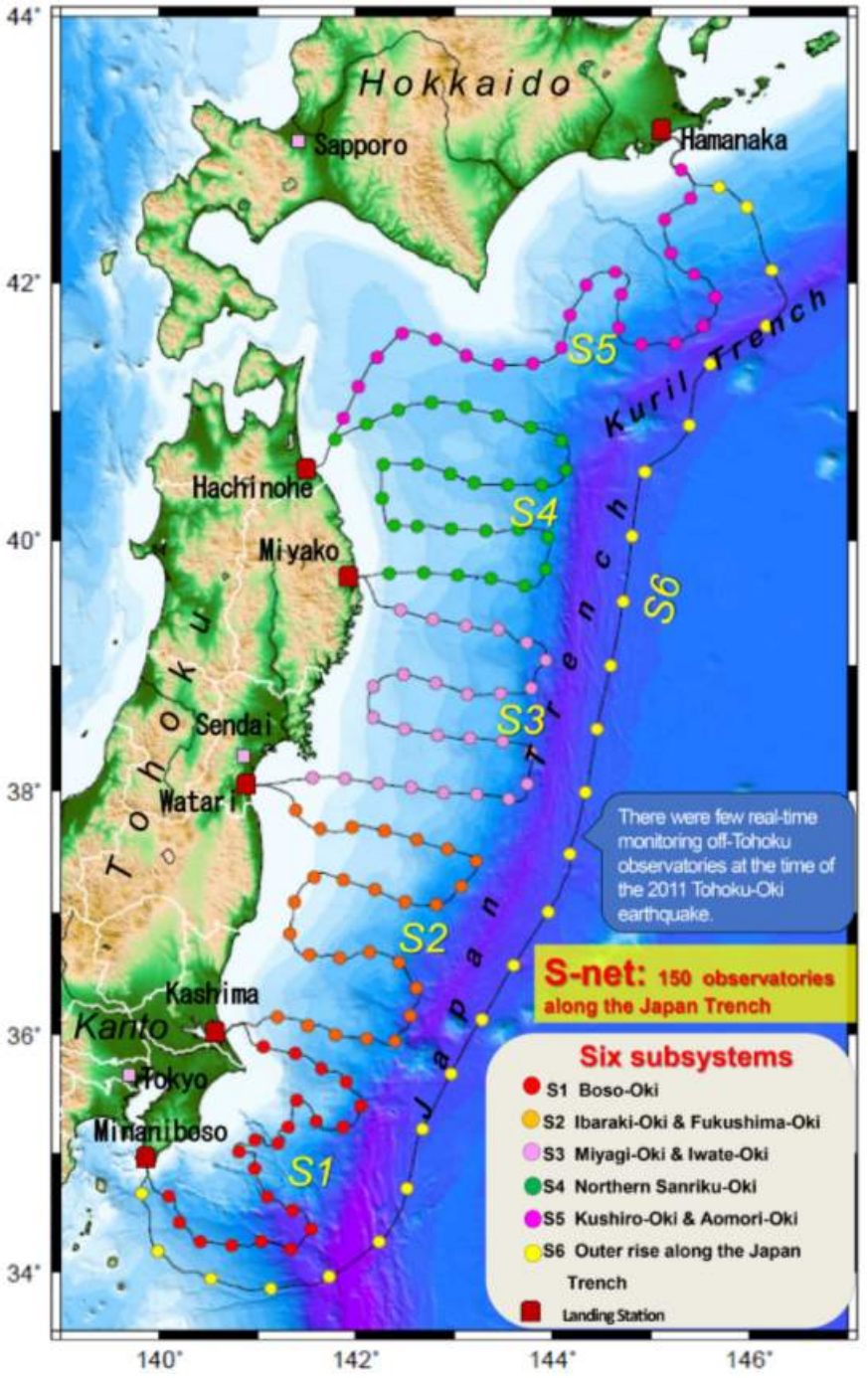
- Pressure gauges ➡ M_w=7.0 (Ito et al. 2013)



M_w = 6.7 – 7.1
in 1 week to 1 month



M_w=7.8 in 1 day
(Linde & Sacks 2002)

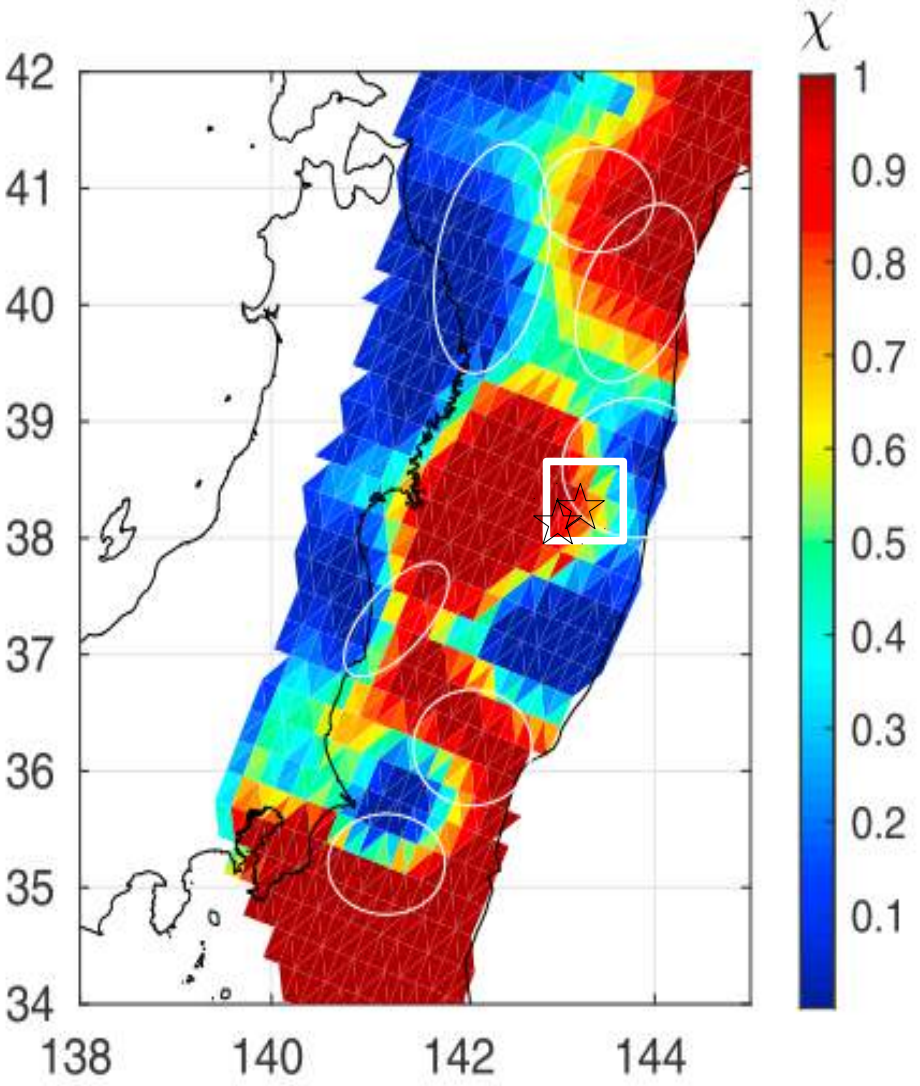

Hokkaido
Sapporo
Hamanaka
Hachinohe
Miyako
Sendai
Watari
Tohoku
Kashima
Kanto
Tokyo
Minamiboso
S1
S2
S3
S4
S5
S6
Kuril Trench
Japan Trench
44°
42°
40°
38°
36°
34°
140°
142°
144°
146°
There were few real-time monitoring off-Tohoku observatories at the time of the 2011 Tohoku-Oki earthquake.
S-net: 150 observatories along the Japan Trench
Six subsystems
S1 Boso-Oki
S2 Ibaraki-Oki & Fukushima-Oki
S3 Miyagi-Oki & Iwate-Oki
S4 Northern Sanriku-Oki
S5 Kushiro-Oki & Aomori-Oki
S6 Outer rise along the Japan Trench
Landing Station

Kinematics

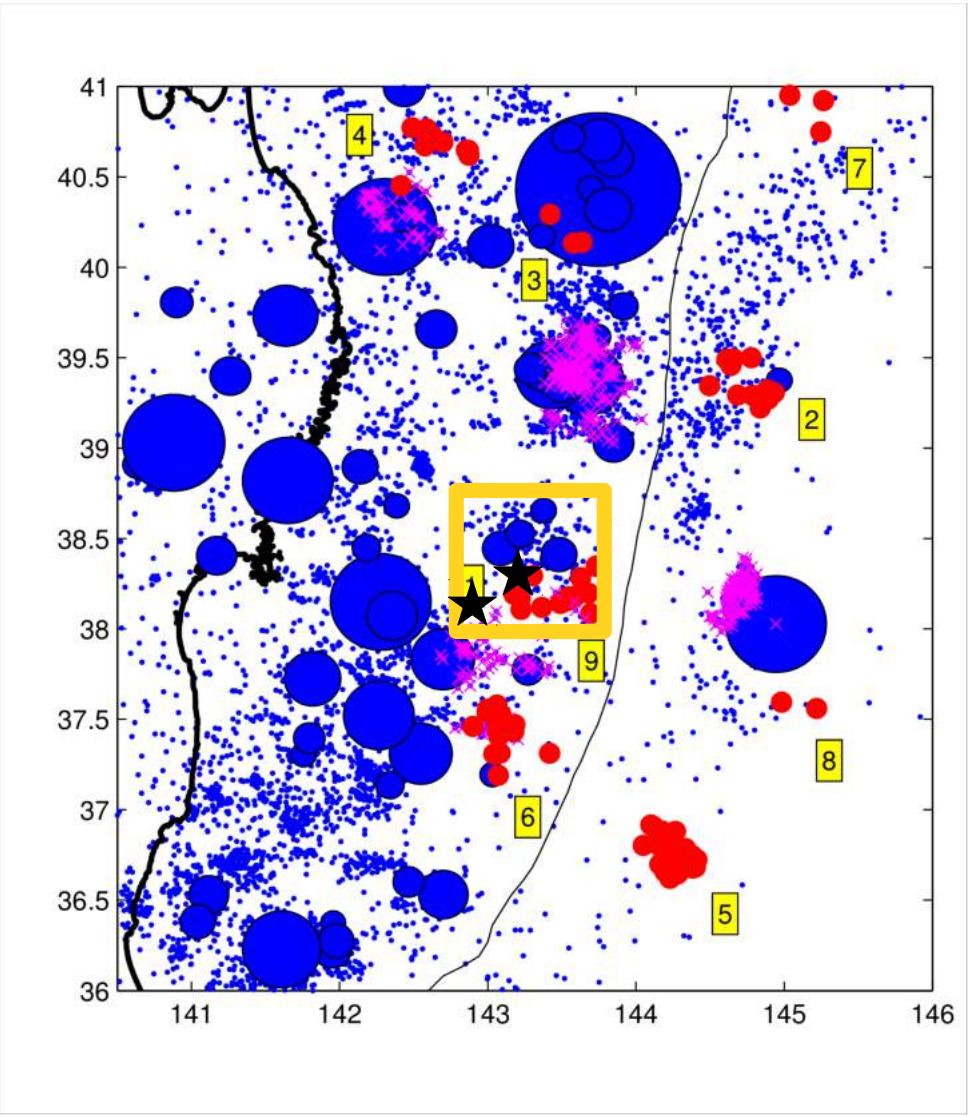
Slow slip can be **identified** & **characterized**
(using seismicity + GPS + deformation data)

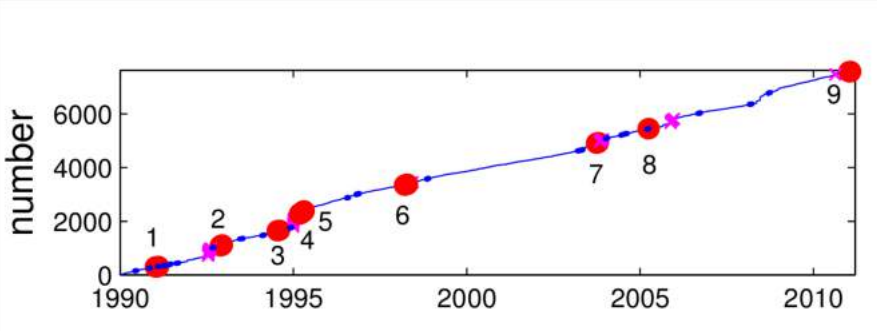
Dynamics

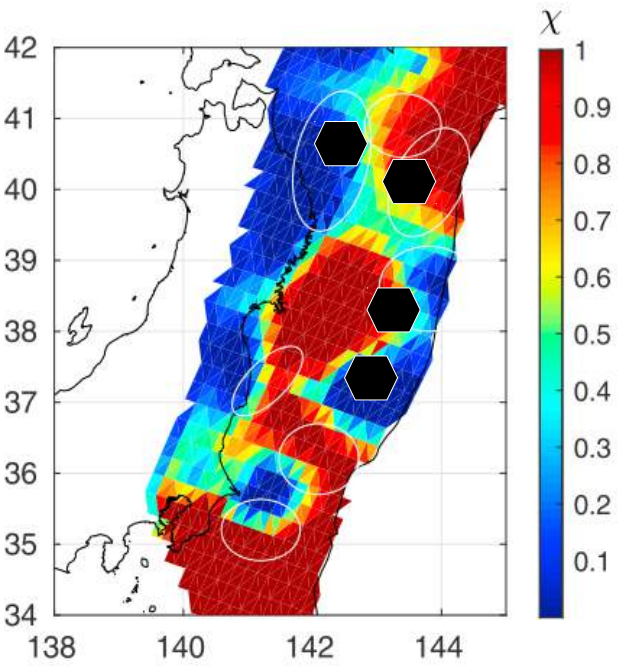
What causes this transient slow slip ?



Cubas et al. (2015)



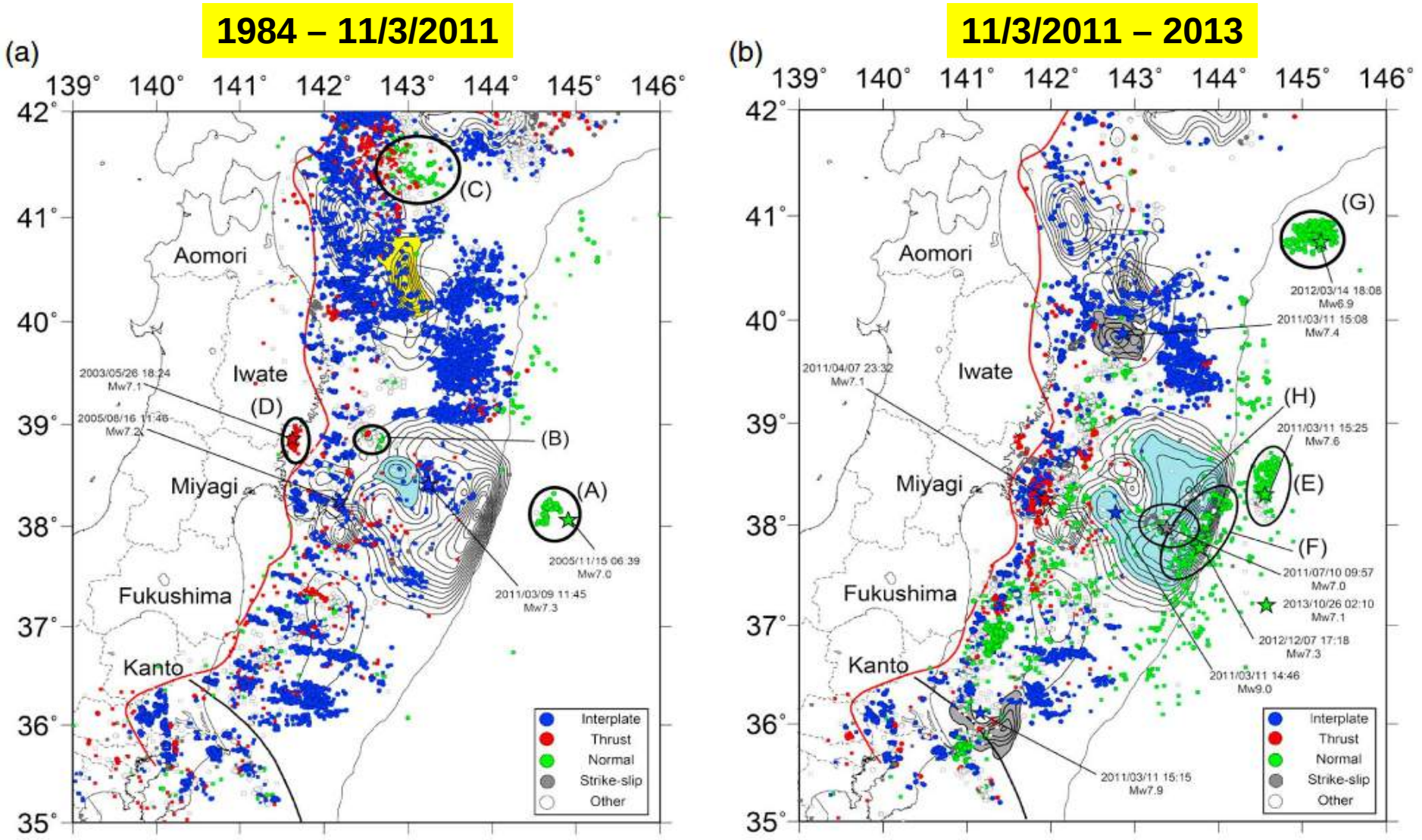




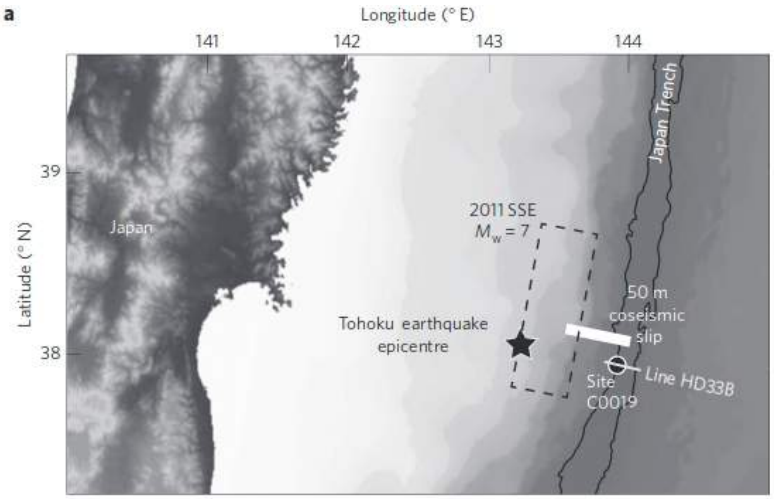
Swarms of Marsan et al. (2013)
(excluding the outer-rise swarms)

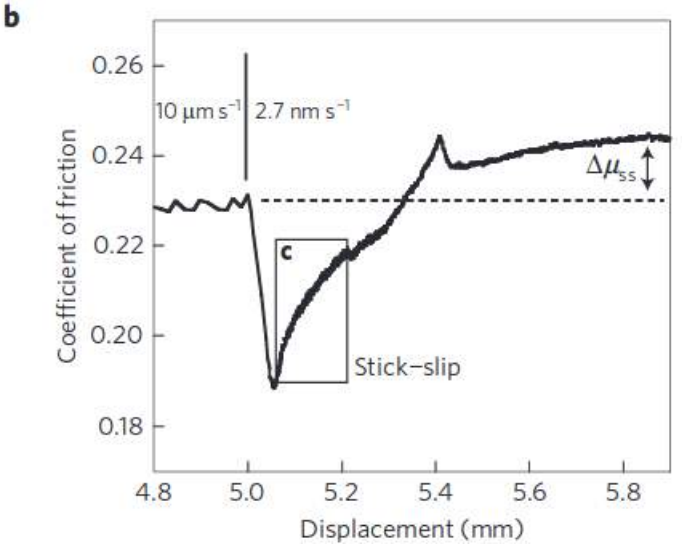
Marsan et al. (2013)

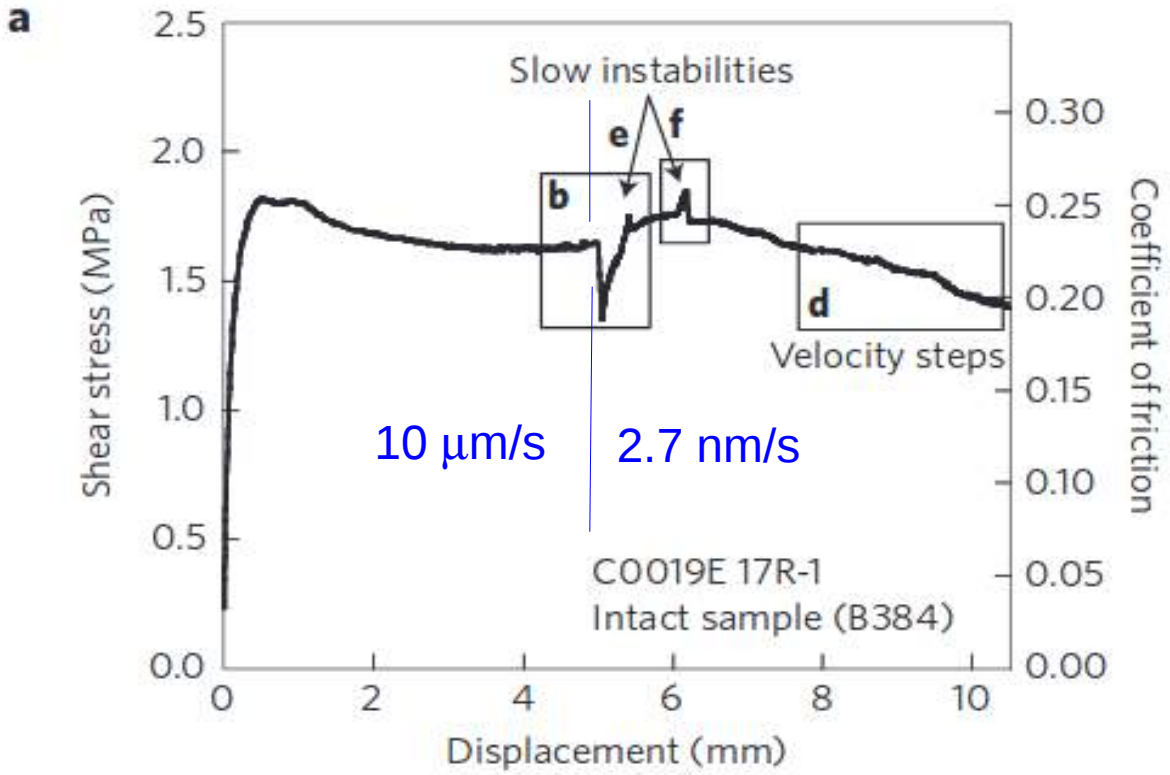
Nakamura et al. (2016)

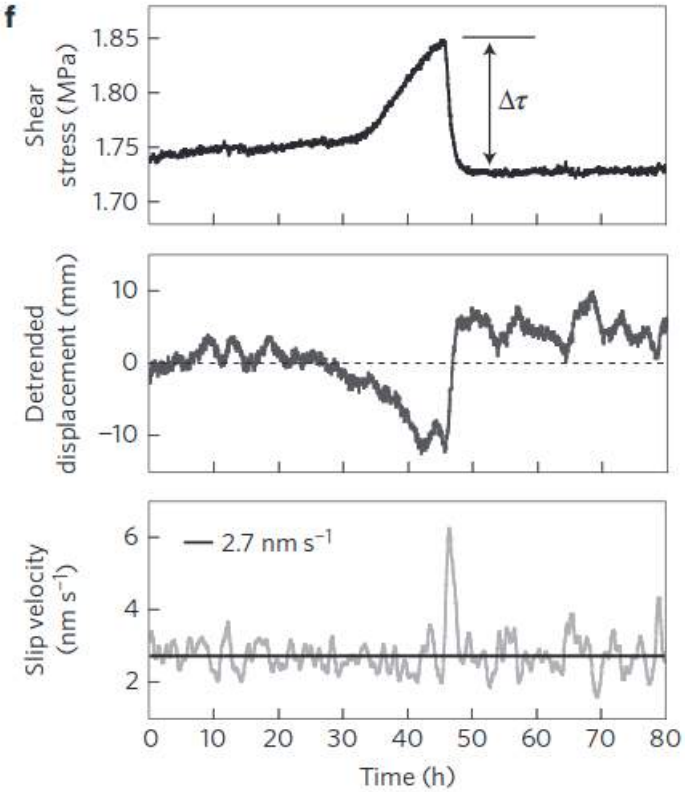


Large co-seismic slip, large stress drop









Ikari et al. (2015)

Slow slip at shallow depth in subduction zones :

- Trigger swarms
- Can repeat over many years
- Near large coupling gradients
- Can trigger intermediate (M7.3) and megathrust (M9.0) earthquakes
- Could mark low friction zones (➡ high tsunamigenic hazard)