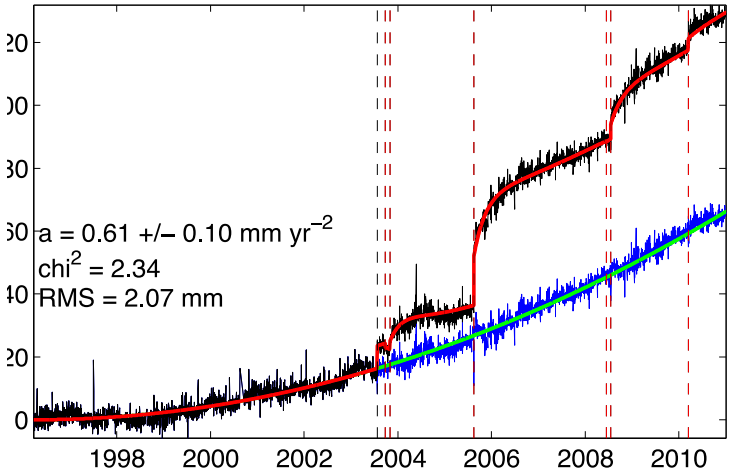
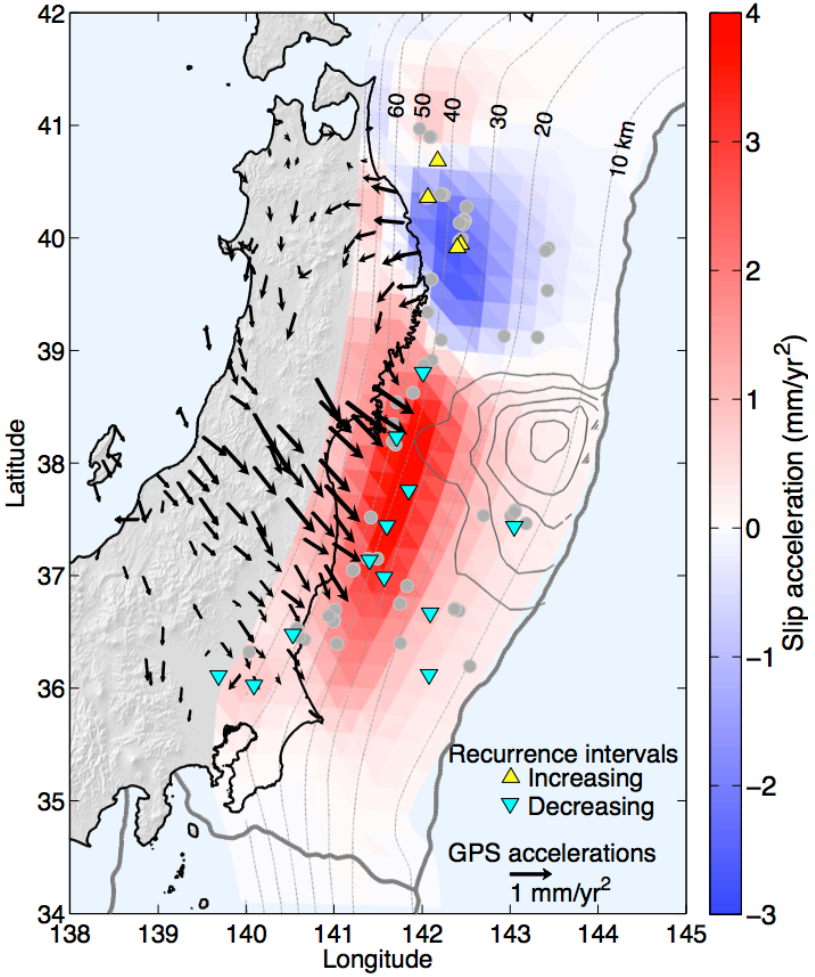
Long Term Transient Deformation Prior to the 2011 Magnitude 9 Tohoku-oki Earthquake

Paul Segall[1], Andreas P. Mavrommatis[1], Kaj M. Johnson[2], Camilla Cattania[1]

[1] *Department of Geophysics, Stanford University*

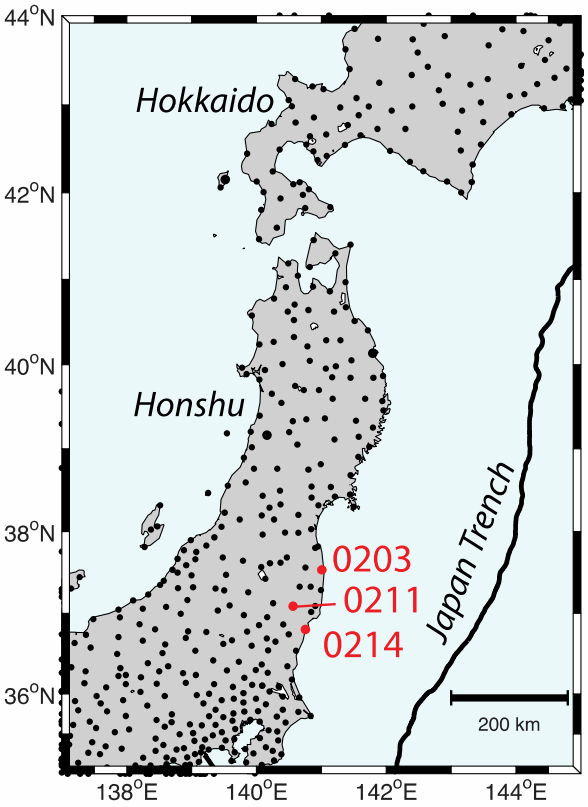
[2] *Department of Geological Sciences, Indiana University*

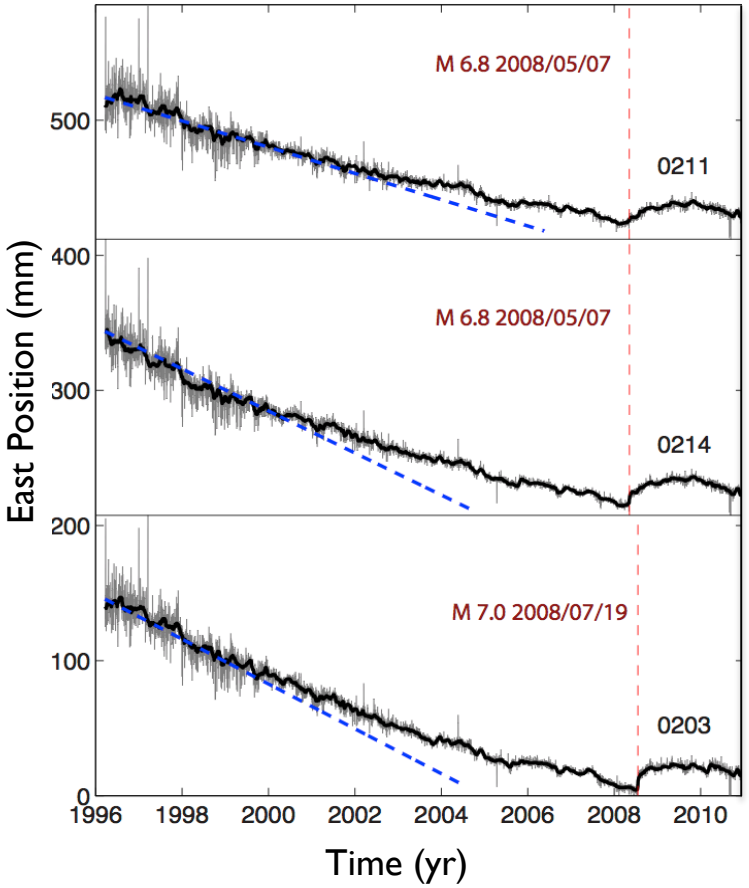




Mavrommatis et al. (2016)

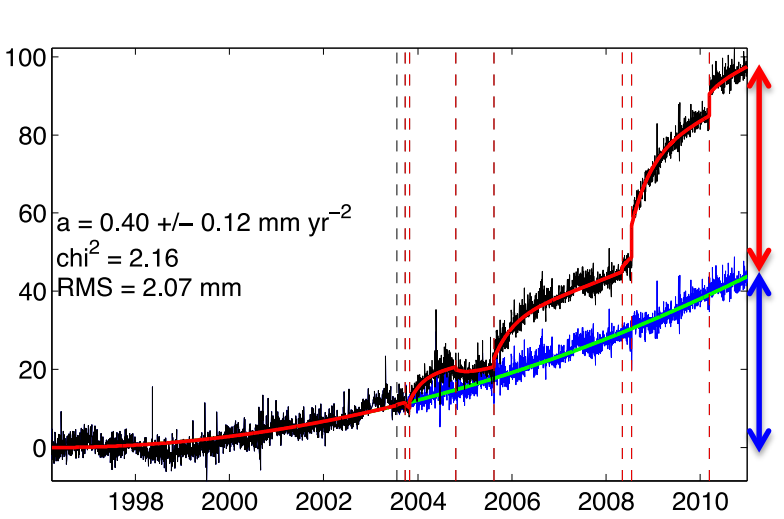
Apparent Rate Change in GPS Prior to 2011 M 9 Tohoku-oki





- Reference frame artifact? **No**, sites in SW Japan show linear trend.
- Processing artifact? **Not completely**, independent processing exhibits similar behavior.
- Transient deformation due to past earthquakes? Partially

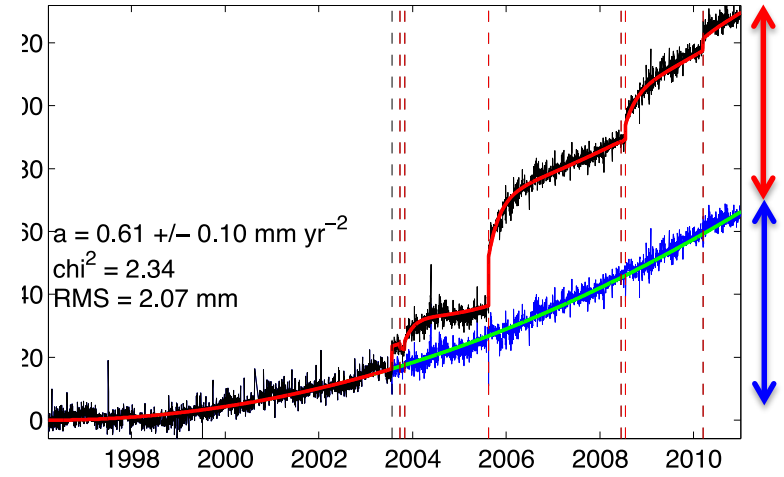
Correction for Post-seismic transients



postseismic transients

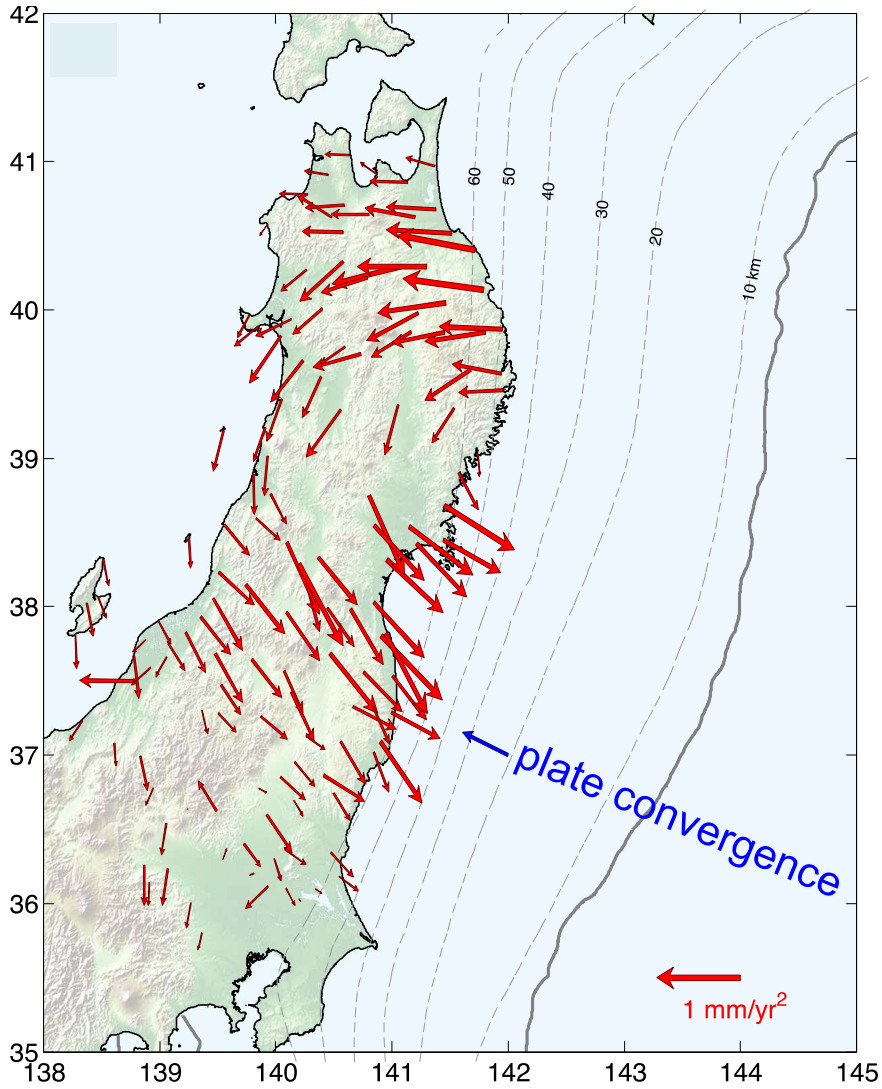
residual transient

$$x(t) = x_0 + v_0 t + \frac{1}{2} a t^2$$



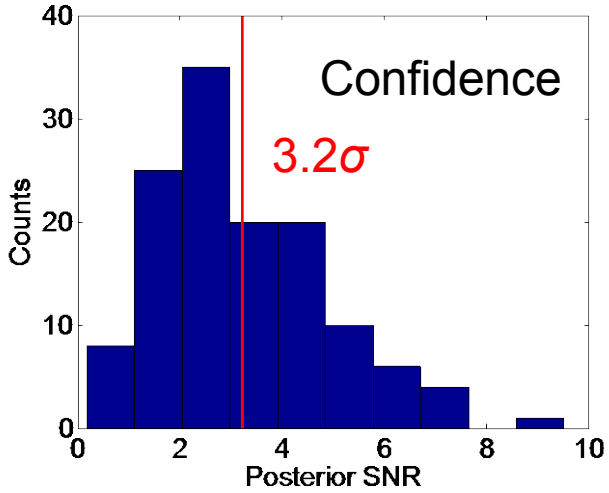
Mavrommatis et al. (2014)

Spatially coherent acceleration



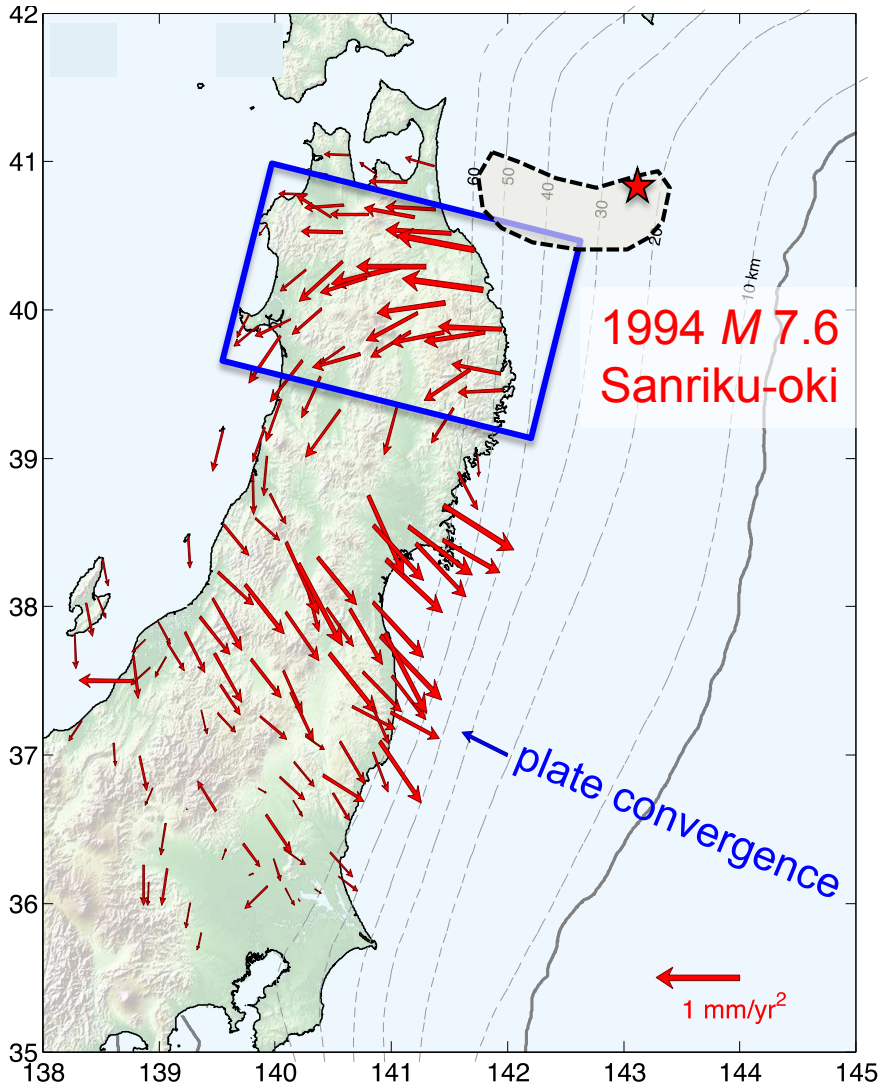
Corrected for:

- Reference-frame errors
- Postseismic effects of $M > 6.3$ (1996—2011)



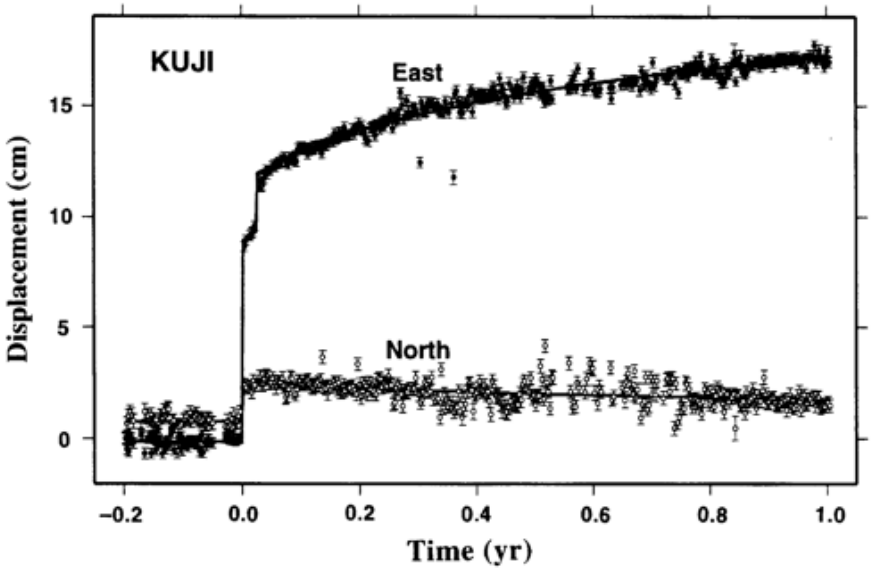
Mavrommatis et al. (2014)

Postseismic Signal from 1994 Sanriku Quake

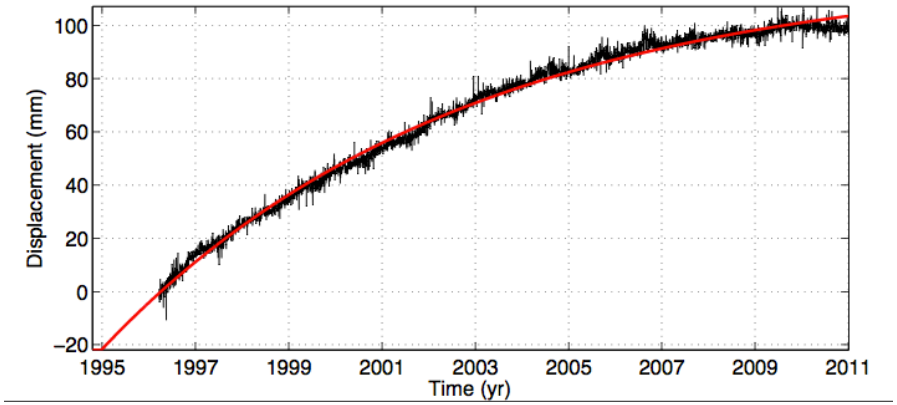


Mavrommatis et al. (2014)

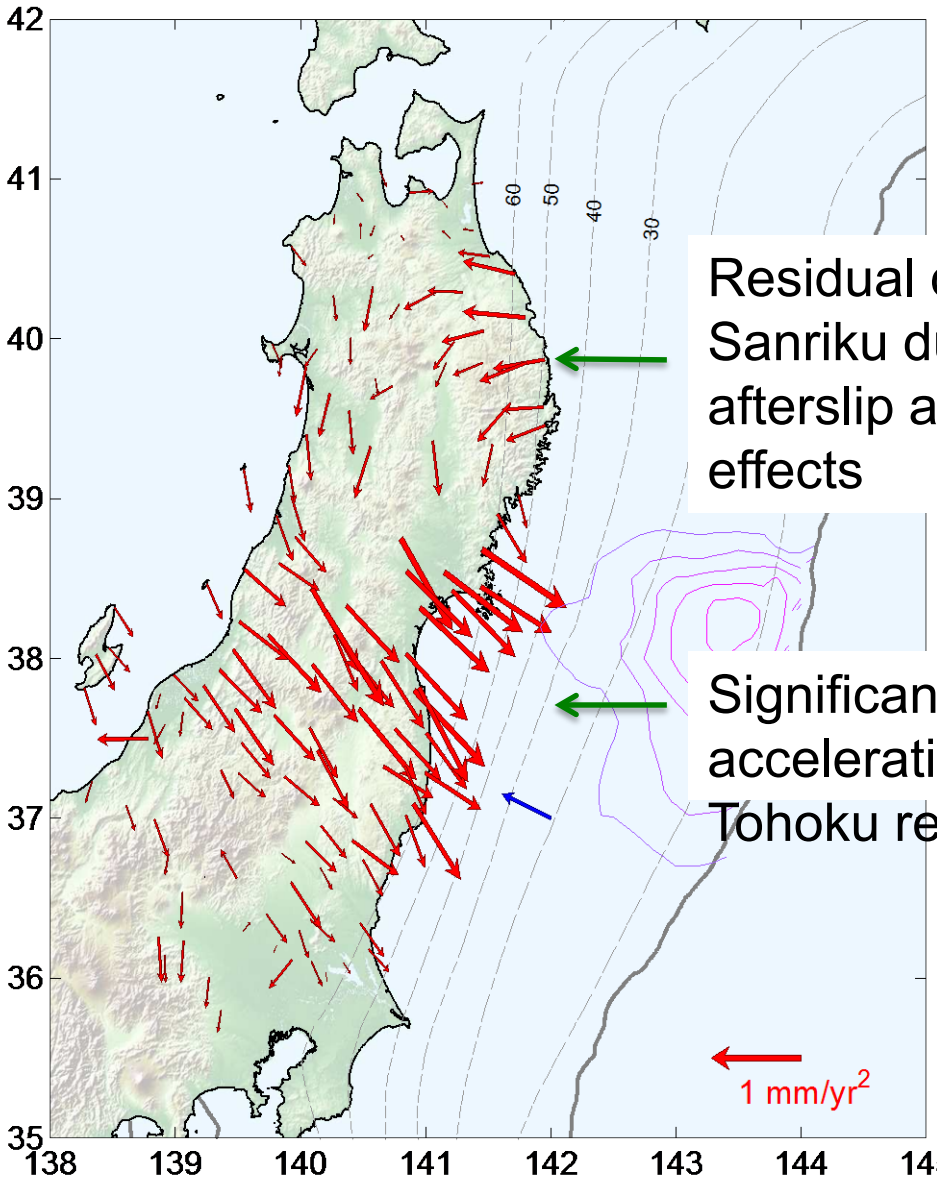
Heki et al. (1997)



Prediction from Heki 1997



‘Corrected’ acceleration field

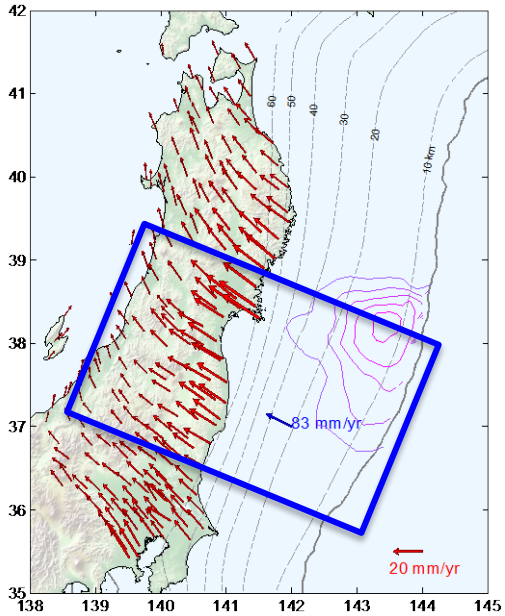


Residual deceleration in Sanriku due to unmodeled afterslip and/or viscoelastic effects

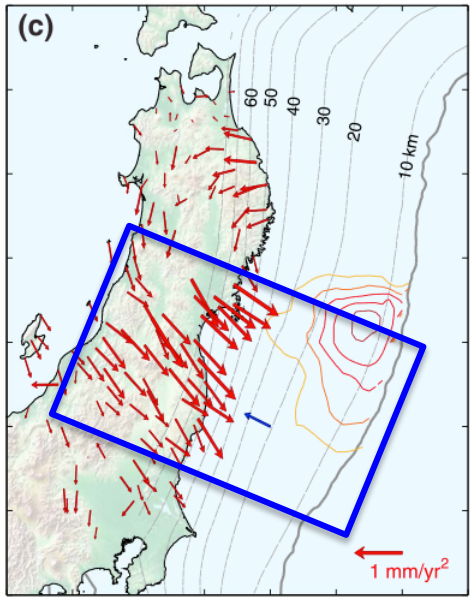
Significant residual acceleration in southern Tohoku region

Change in Strain-Rate

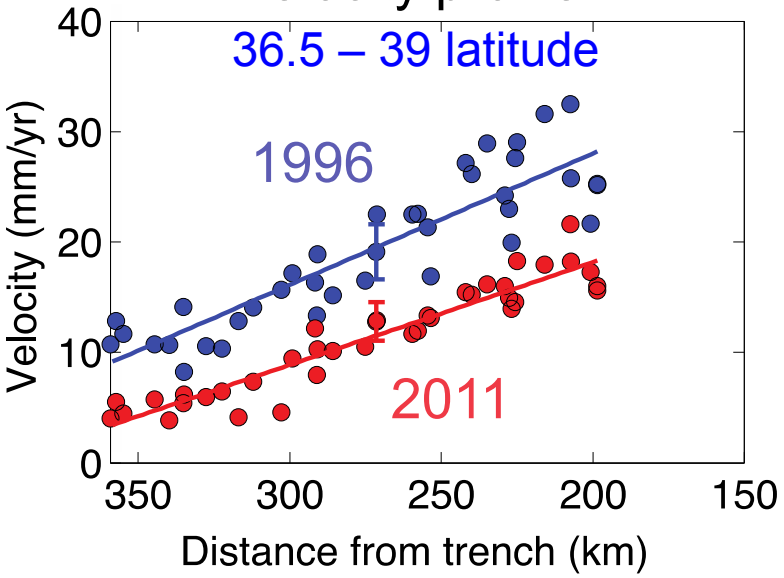
Velocity



Acceleration



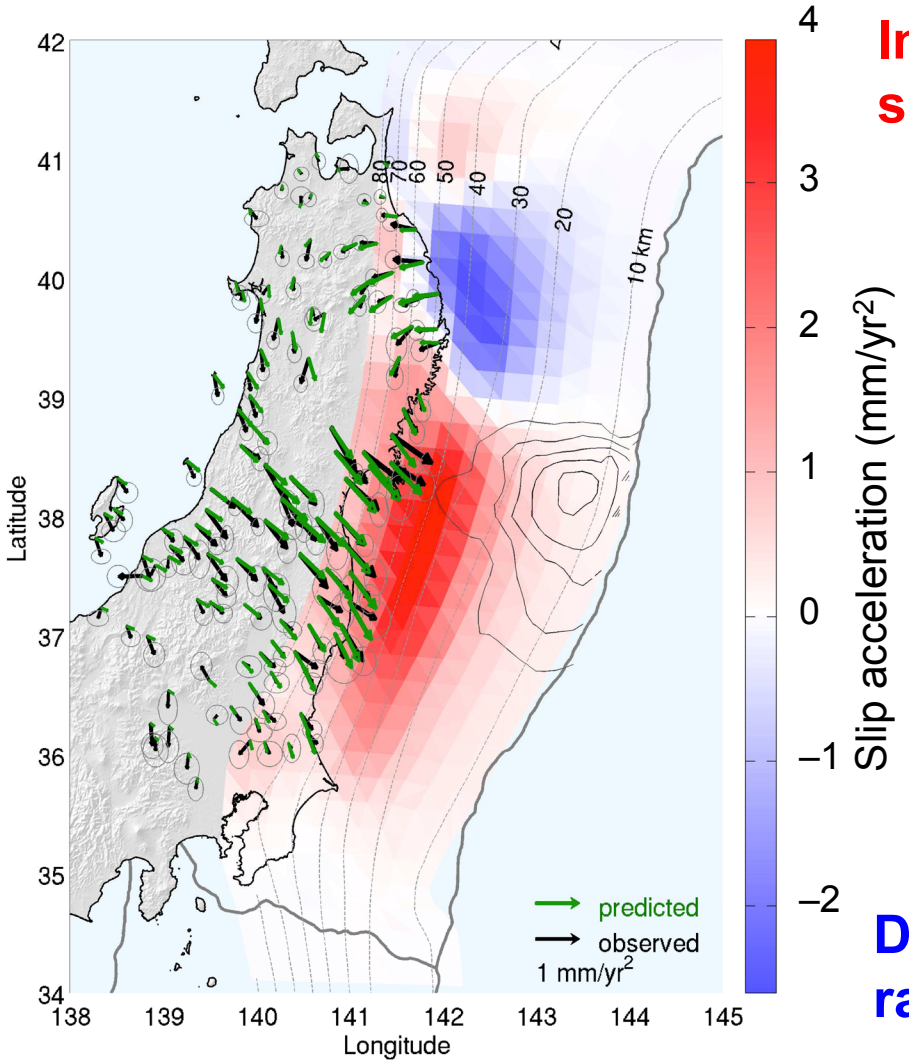
Velocity profile



- 1996—2011: Decrease in average strain rate by 1/3 in 15 years
- Acceleration correlates with velocity suggesting similar source

Mavrommatis et al. (2014)

Slip acceleration on plate interface



Increasing slip rate

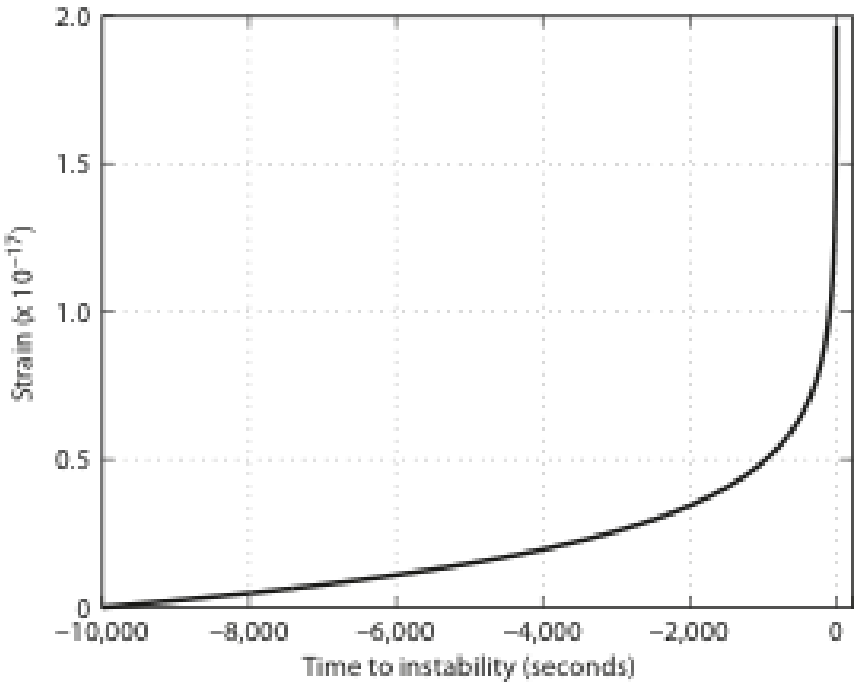
Decreasing slip rate

Mavrommatis et al. (2014)

$$min\ ||a - G\ddot{s}|| + \lambda^2||\ddot{s}||$$

Transient **Not** Like Expected Nucleation

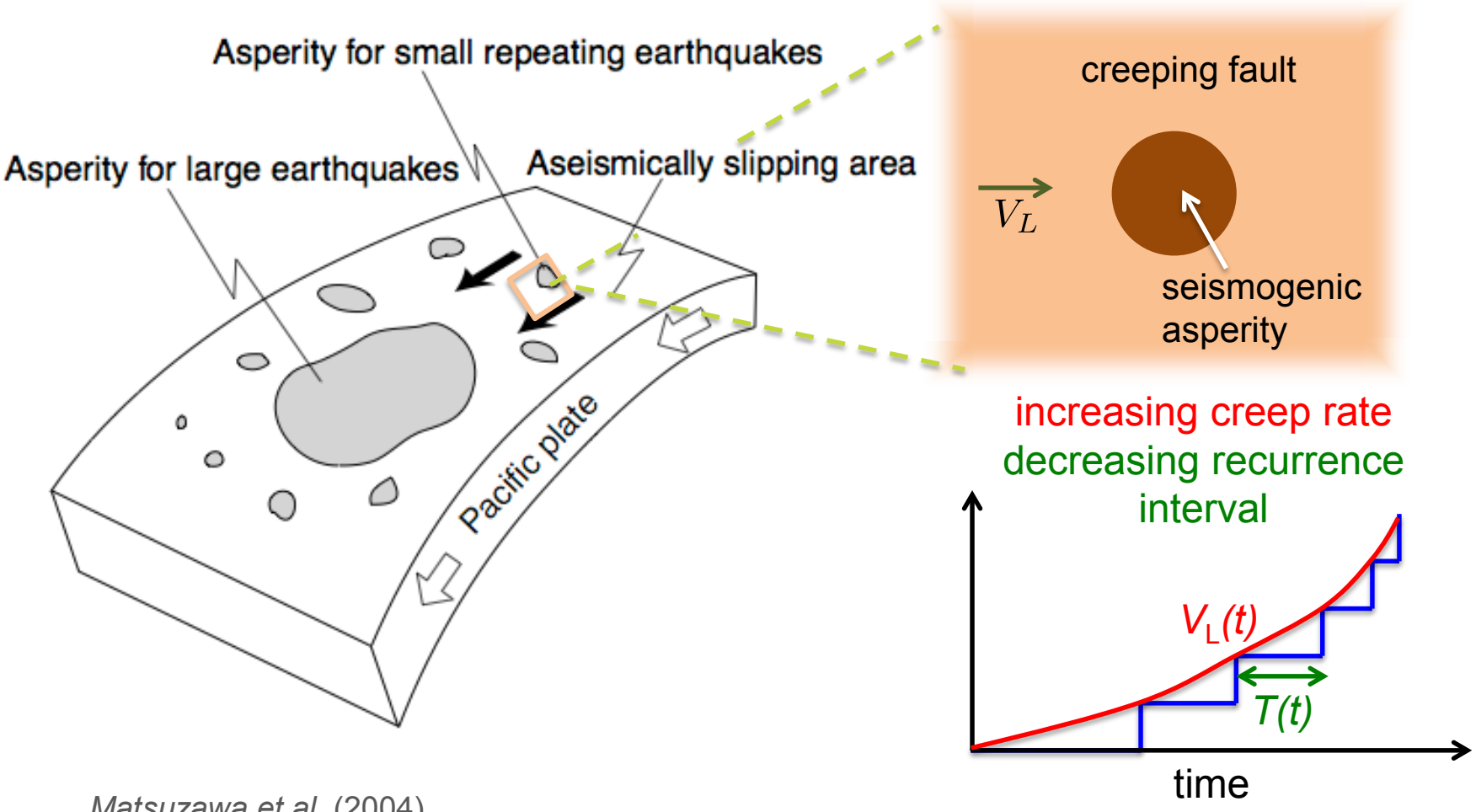
- Accelerating slip does not localize toward hypocenter
- Constant curvature, not accelerating toward an instability



Segall, 2010

Predicted acceleration not observed $v(t) \sim 1/(1- t/t_c)$

Repeating earthquakes

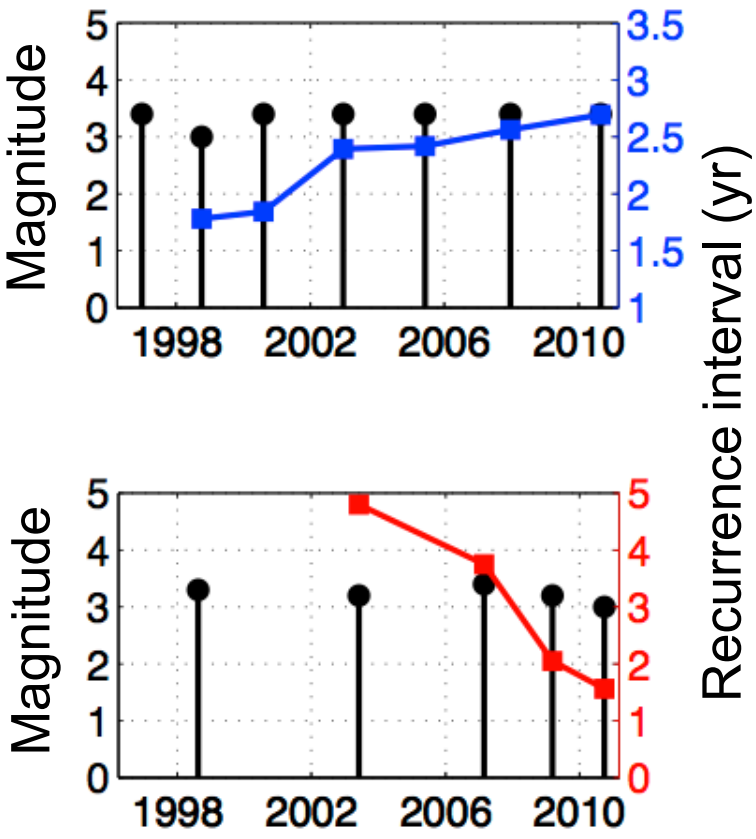


Matsuzawa et al. (2004)

Test: Look for significant **changes in recurrence interval**

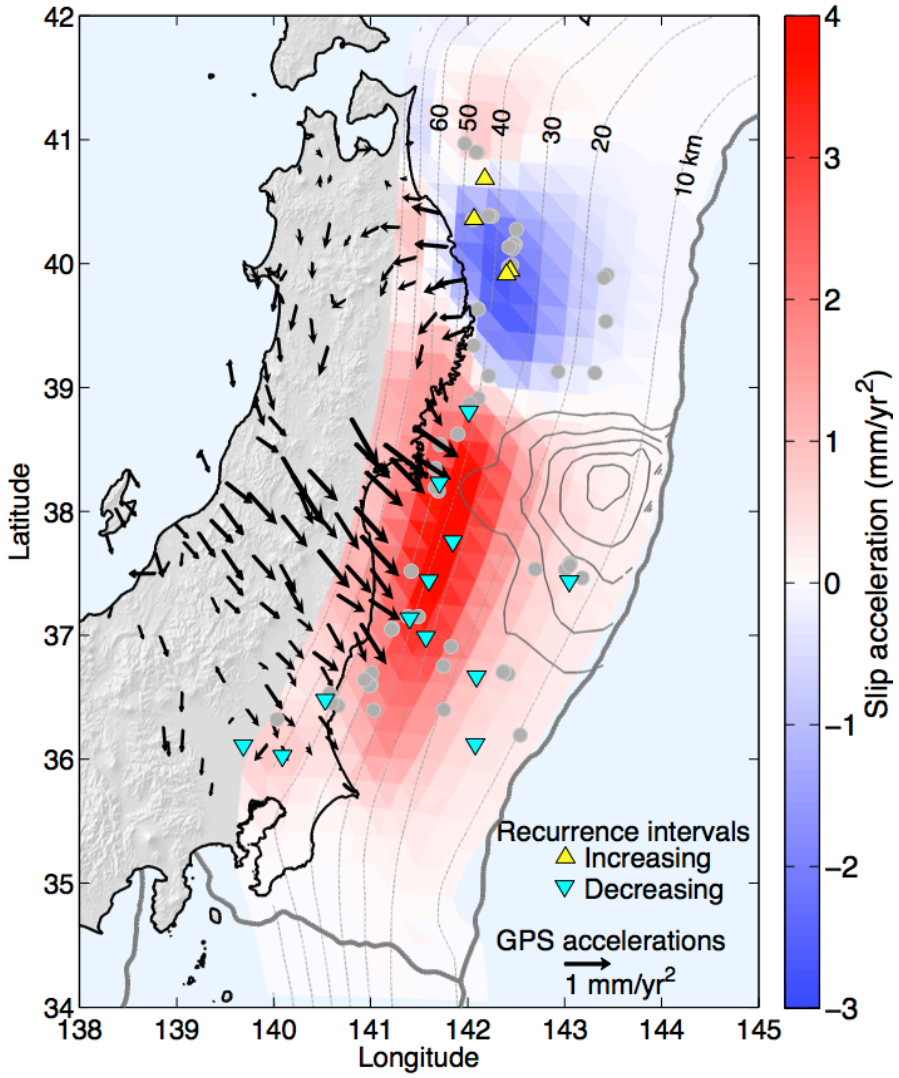
Trend detection: Mann-Kendall test

- Mann-Kendall test
  - H_0: no monotonic trend
  - H_a: monotonic trend is present
- Observations: recurrence interval in a given sequence
- Test H_0 against upward or downward monotonic trend



Repeating Eqs & GPS

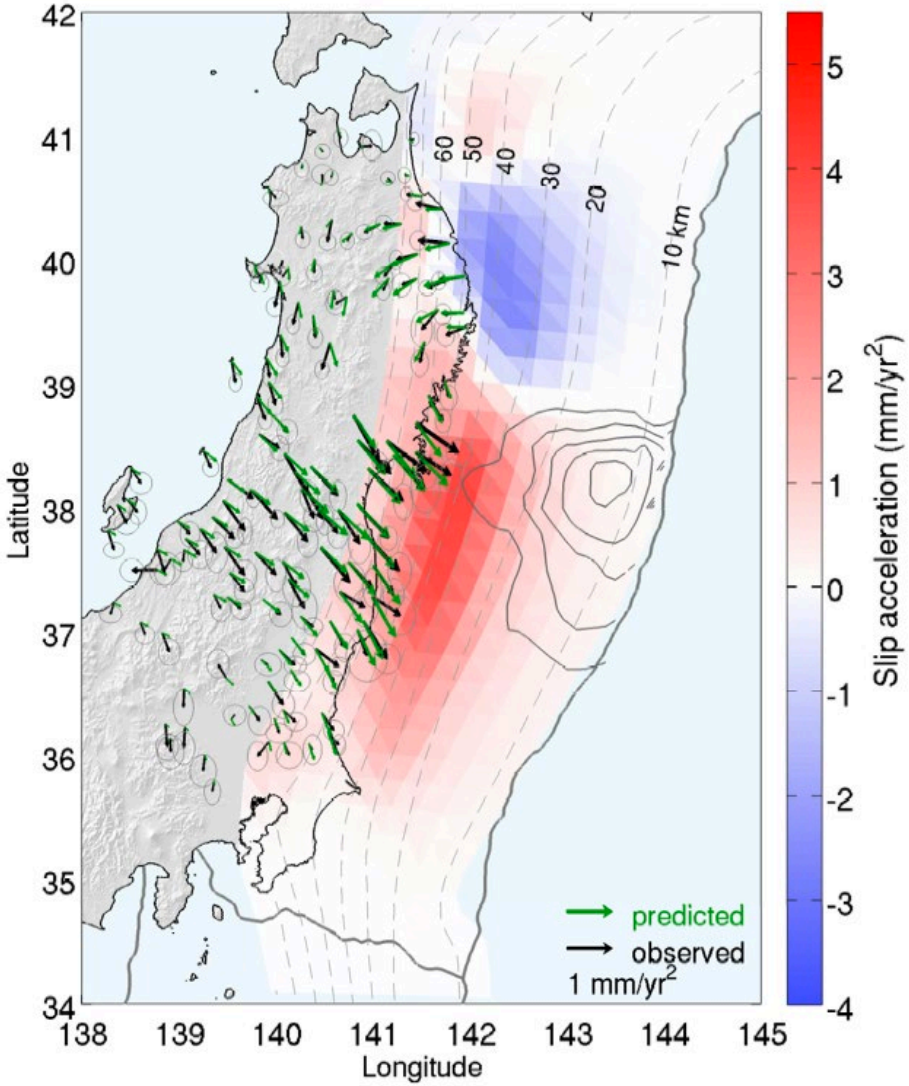
- North:
  - increasing recurrence intervals (△)
  - decelerating creep
- South-central:
  - decreasing recurrence intervals (▽)
  - accelerating creep

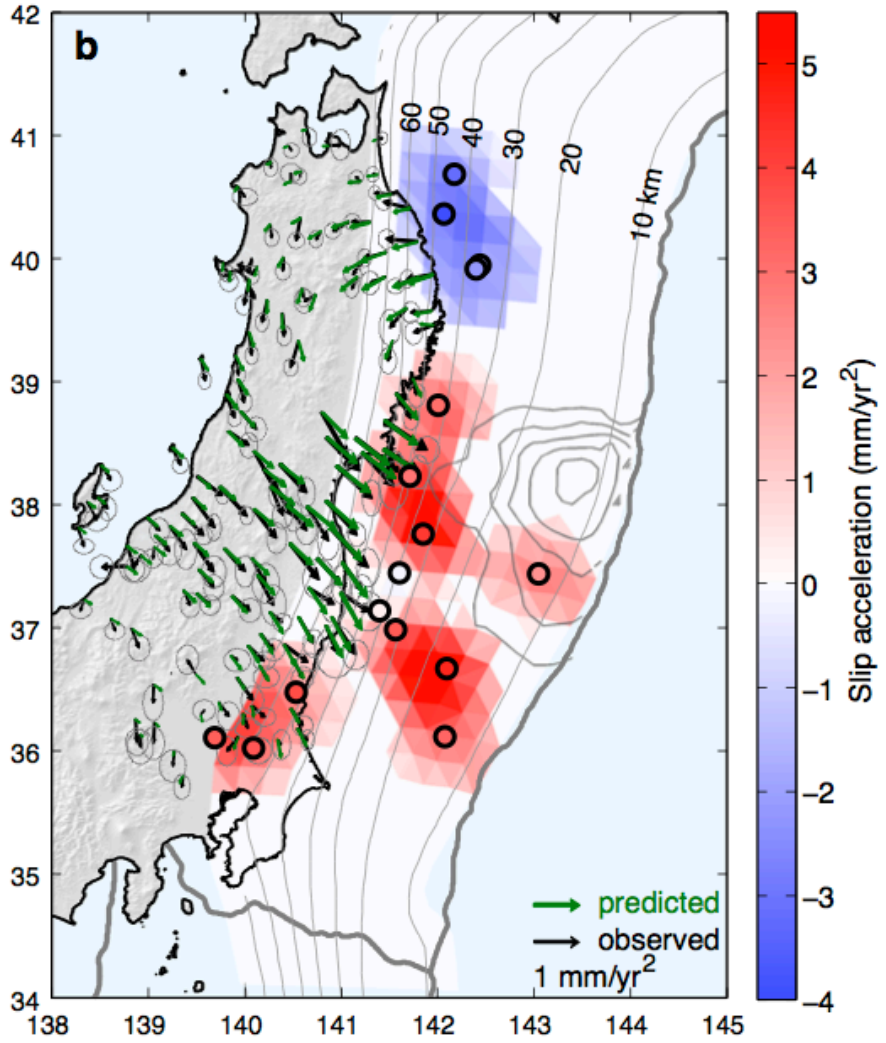


Mavrommatis et al. (2016)

GPS only

GPS + repeating earthquakes

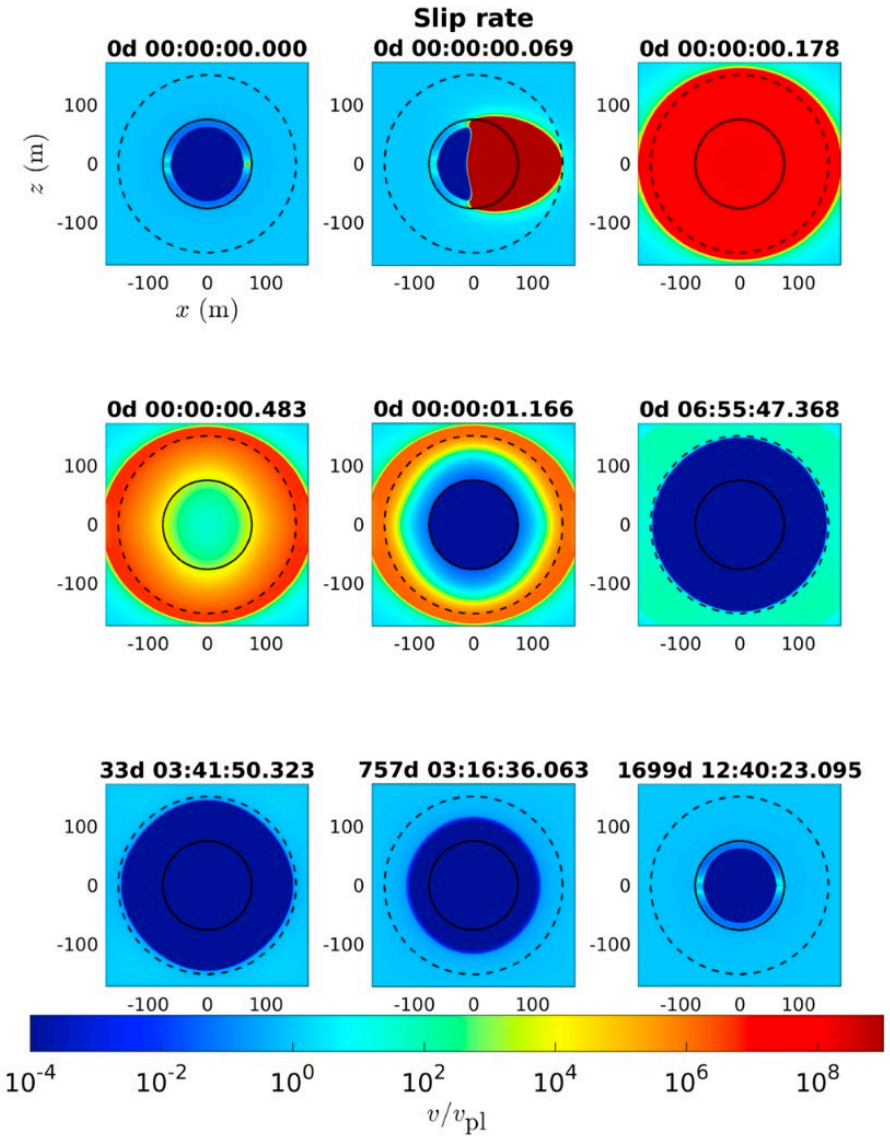




(r = 50 km)

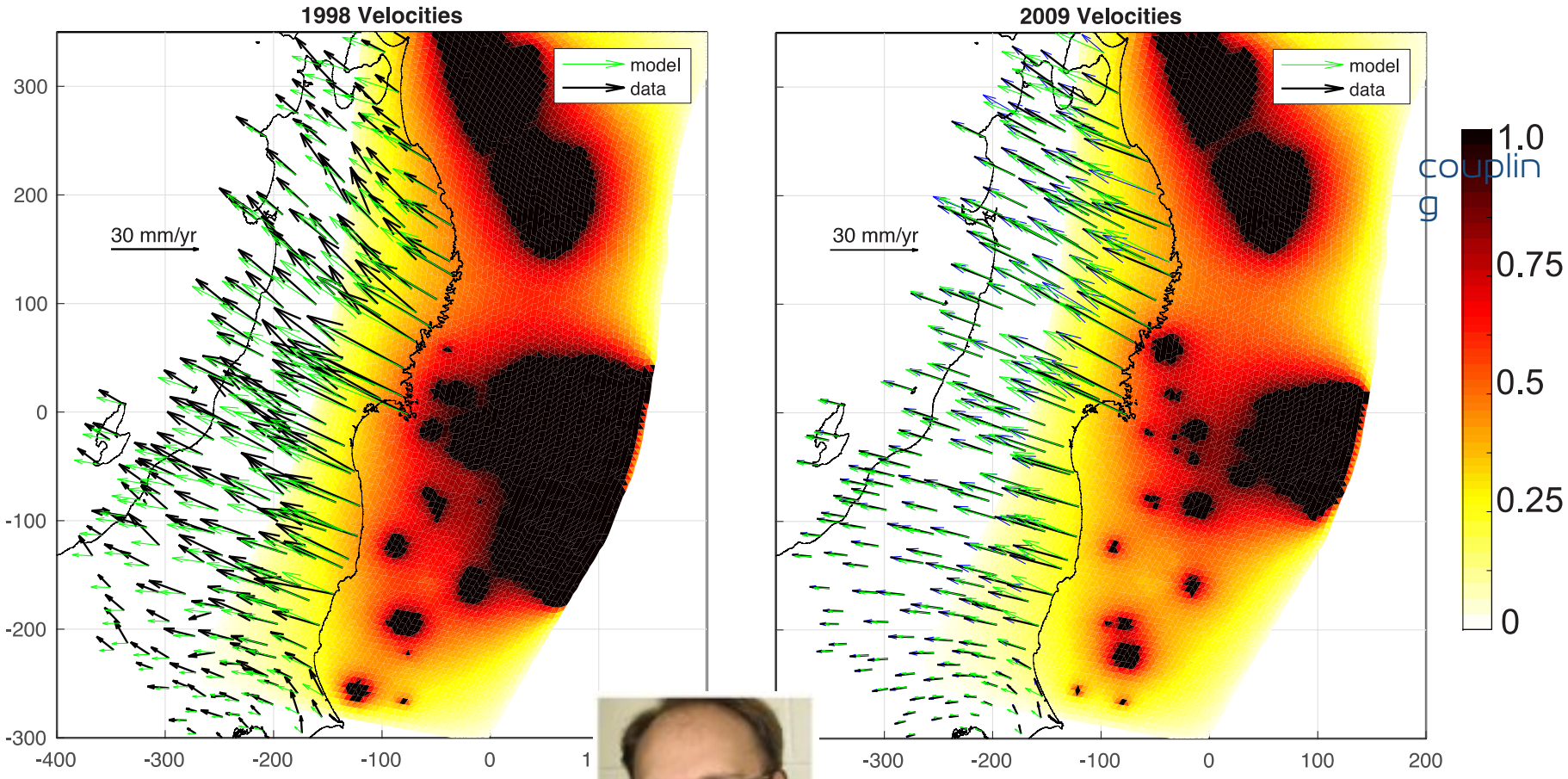
Mavrommatis et al. (2016) Accelerations from repeaters **model dependent**

Asperity Erosion



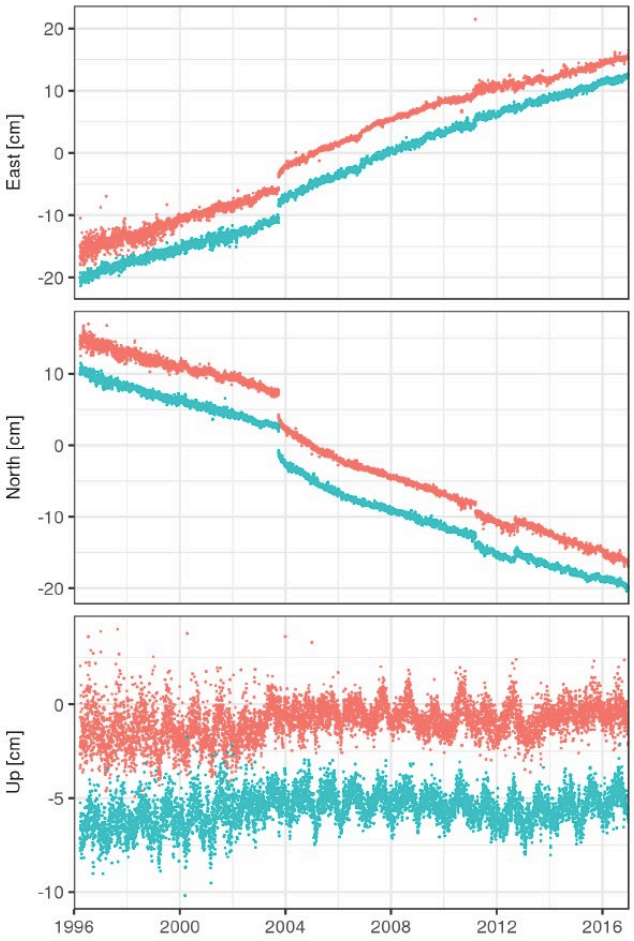
- Ruptures extend into velocity strengthening region due to dynamic weakening
- Creeps inward until next event nucleates
- Coupling is time dependent

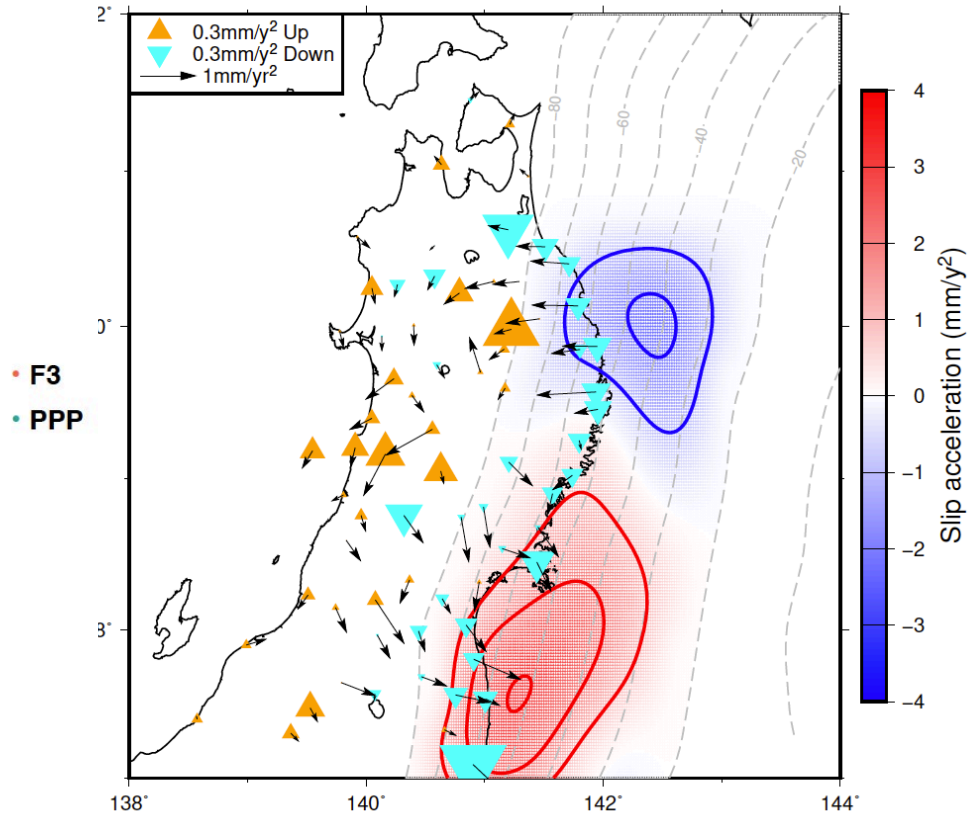
Result – Fit to GPS Velocities



Kaj Johnson et al, in progress

Independent GPS Analysis



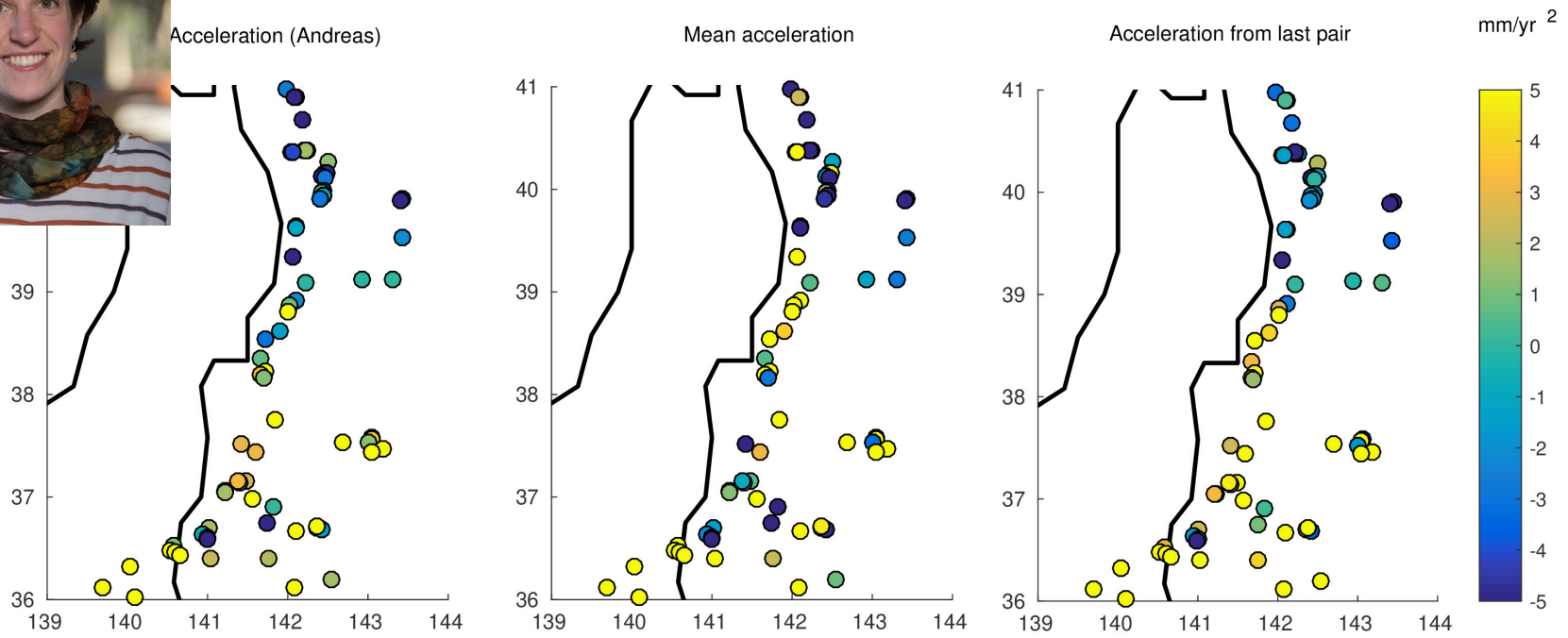


Kawashima and Sagiya: PPP solutions using ephemerides, satellite clock errors and Earth orientation parameters (EOP) data produced by the Geo-ForschungsZentrum (GFZ)

Independent Repeating Quake Analysis

$$Tr \sim M_0^{1/6}/V$$

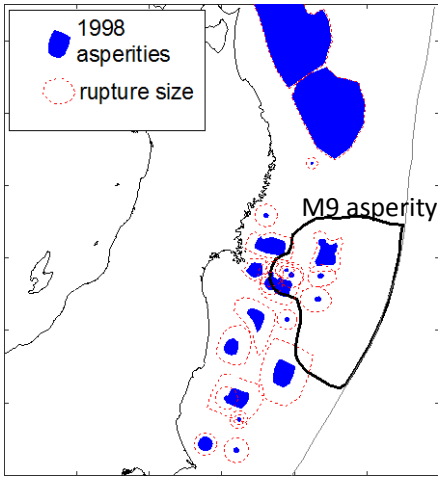
$$\frac{V_2 - V_1}{\Delta t} = \frac{(V_2/V_1) - 1}{\Delta t} V_1$$

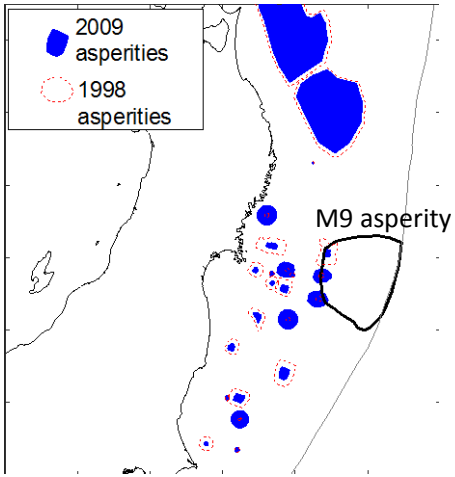


Other Relevant Observations

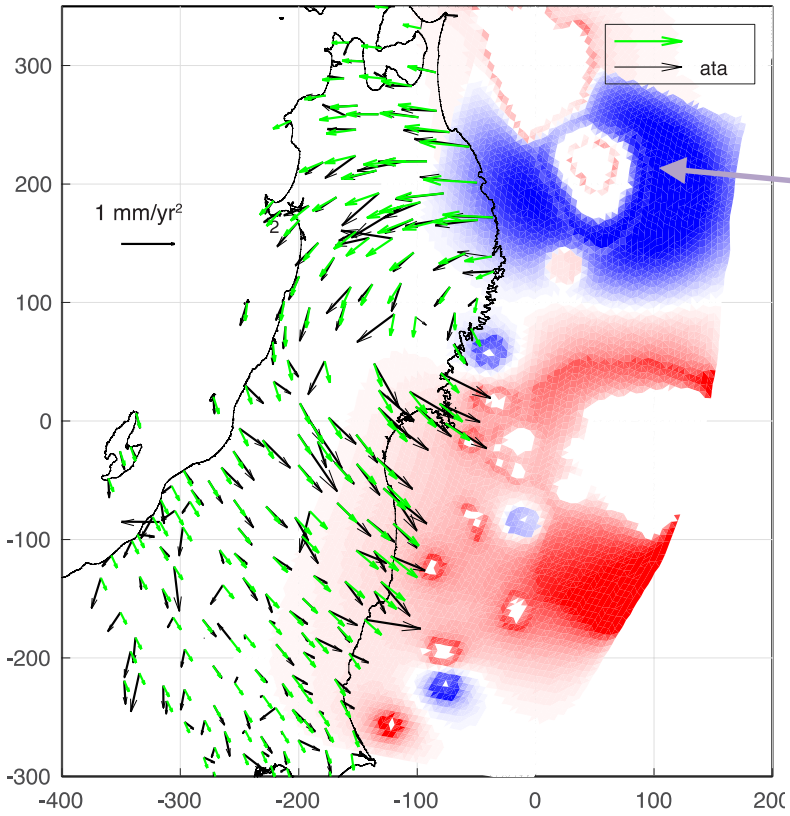
- M 6.5+ earthquakes in Tohoku exhibit anomalous post-seismic transients (Suito et al,2011). Geographic or temporal feature?
- M 7.3 Foreshock had highly anomalous after-slip, M 7.0 equivalent in 50 hours prior to mainshock (Miyazaki, McGuire, Segall, 2011)
- Transient signals on pressure gauges one month prior to mainshock (Ito et al, 2012).

Result – Fit to GPS Accelerations

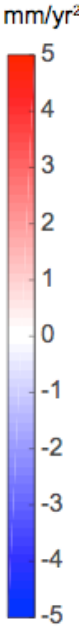




1996-2011 accelerations

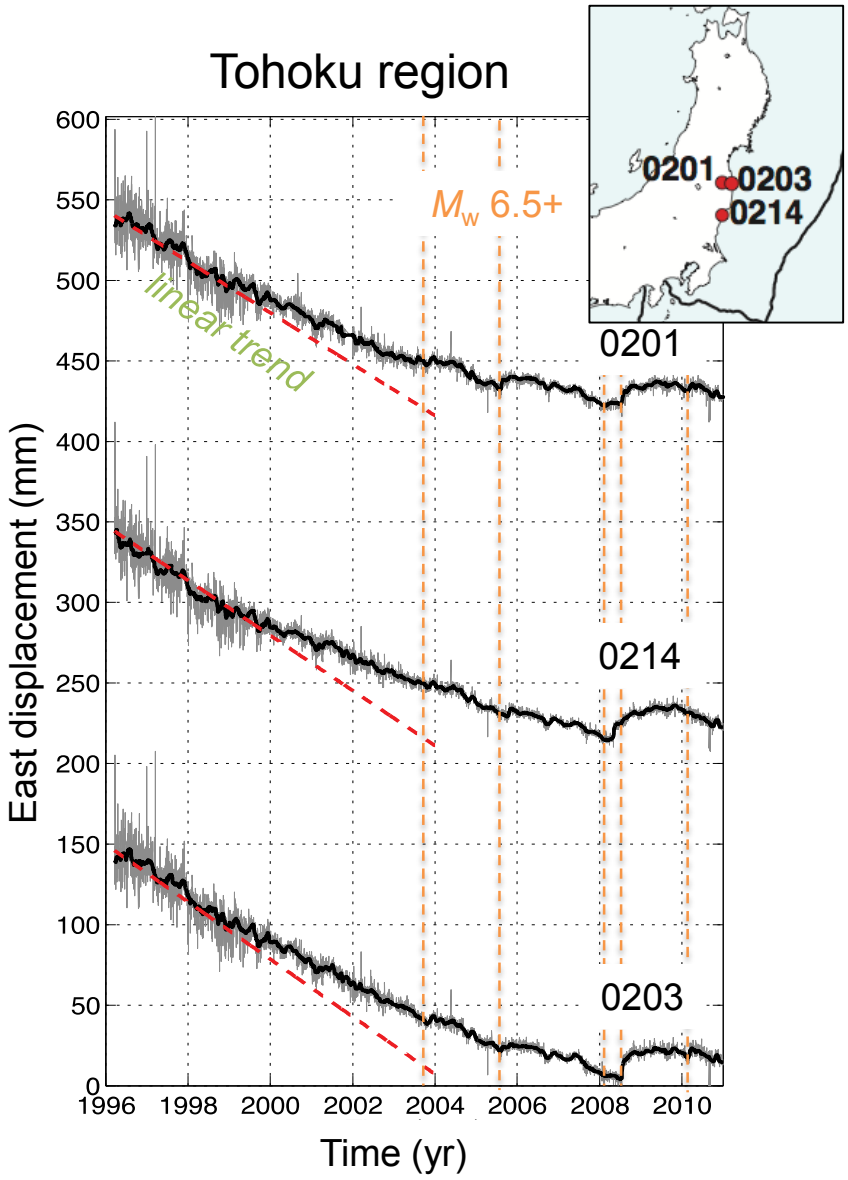


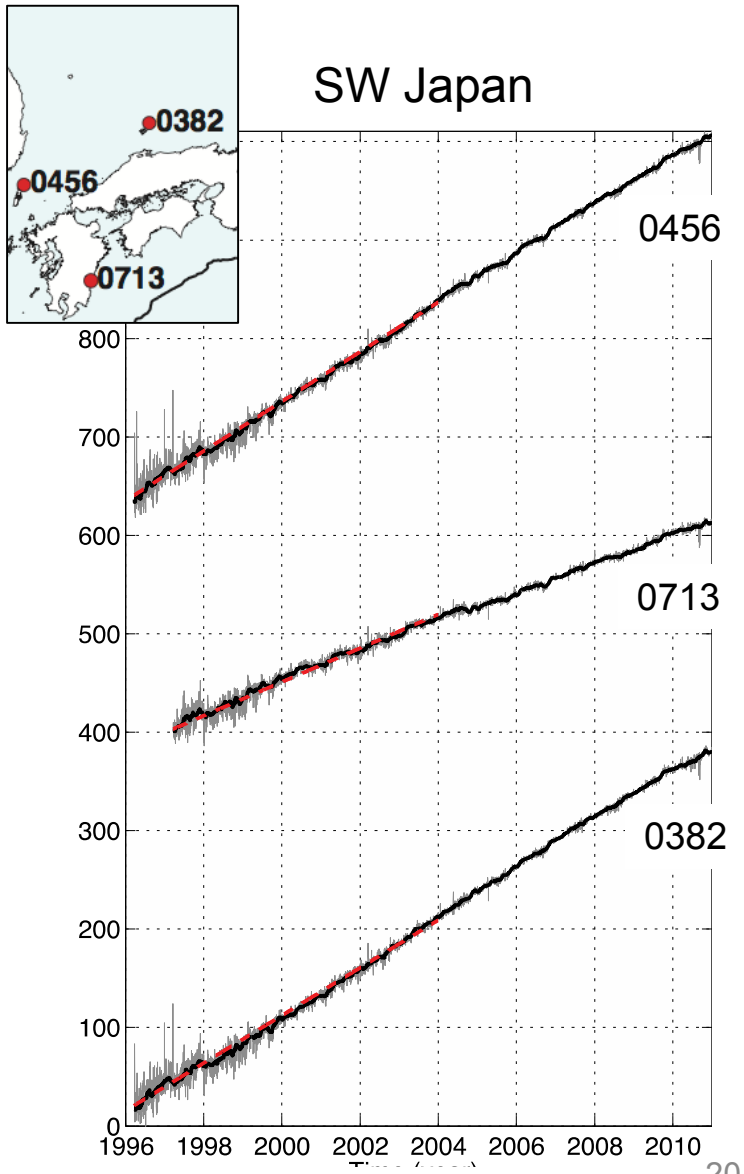
1994 Sanriku afterslip

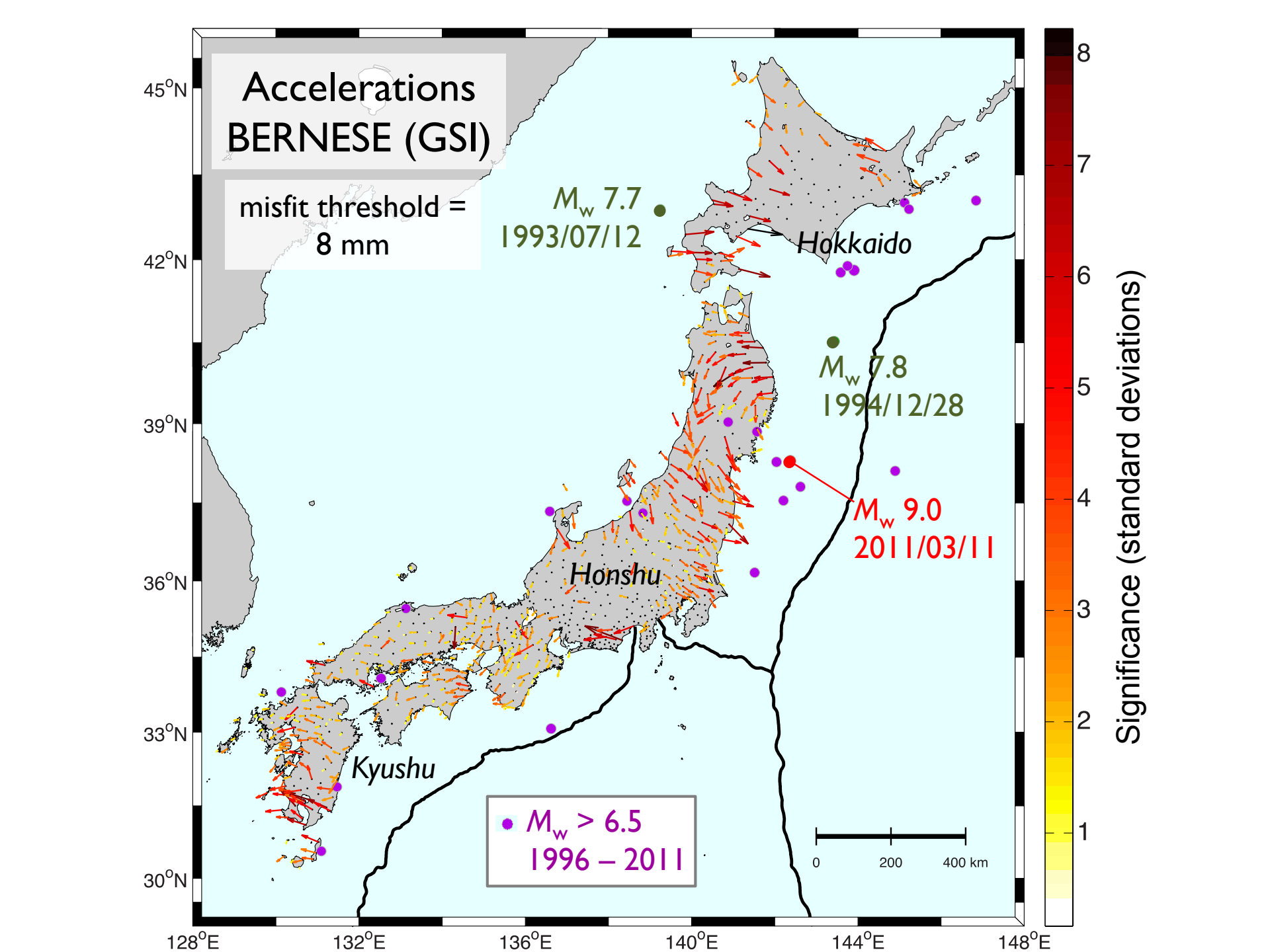


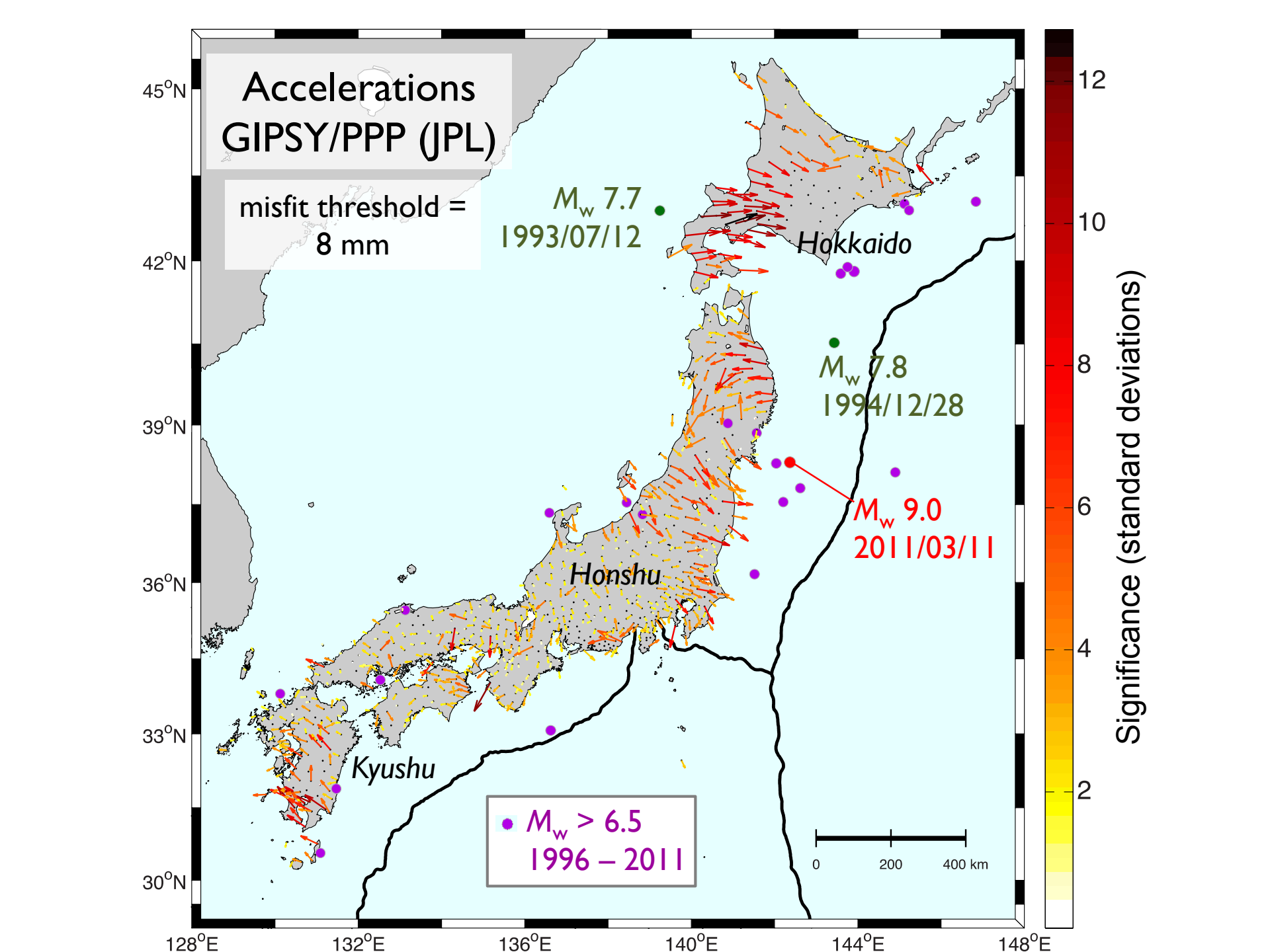
Kaj Johnson et al, in progress

Non-steady deformation in Tohoku region



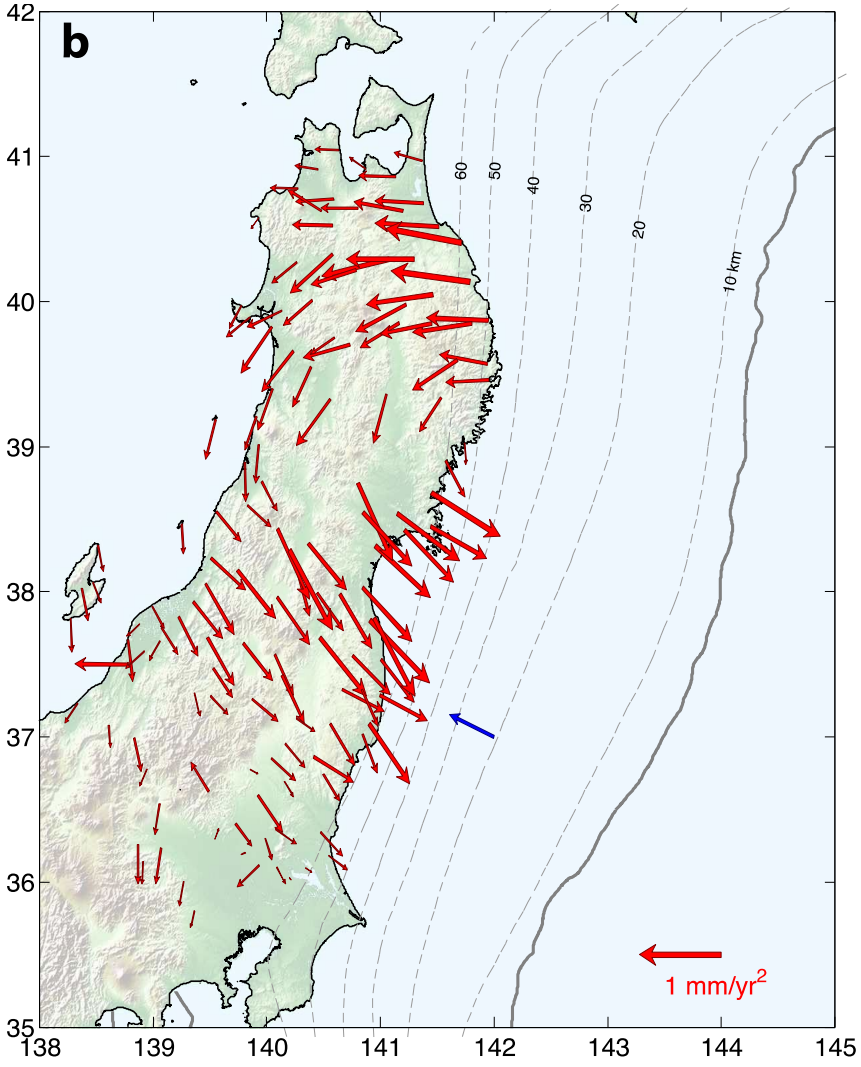



Accelerations
BERNESE (GSI)
misfit threshold =
8 mm
M_w 7.7
1993/07/12
M_w 7.8
1994/12/28
M_w 9.0
2011/03/11
Hokkaido
Honshu
Kyushu
M_w > 6.5
1996 – 2011
0
200
400 km
45°N
42°N
39°N
36°N
33°N
30°N
128°E
132°E
136°E
140°E
144°E
148°E
Significance (standard deviations)
1
2
3
4
5
6
7
8

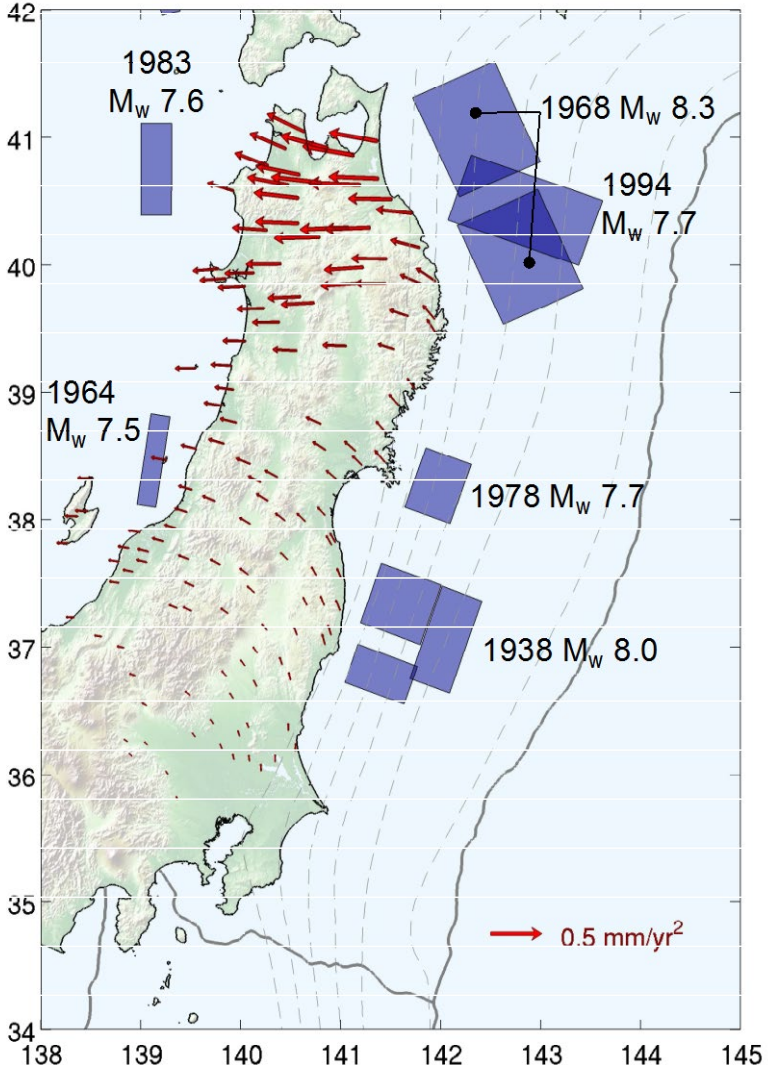

Accelerations
GIPSY/PPP (JPL)
misfit threshold =
8 mm
M_w 7.7
1993/07/12
M_w 7.8
1994/12/28
M_w 9.0
2011/03/11
Hokkaido
Honshu
Kyushu
M_w > 6.5
1996 – 2011
0
200
400 km
45°N
42°N
39°N
36°N
33°N
30°N
128°E
132°E
136°E
140°E
144°E
148°E
Significance (standard deviations)
12
10
8
6
4
2

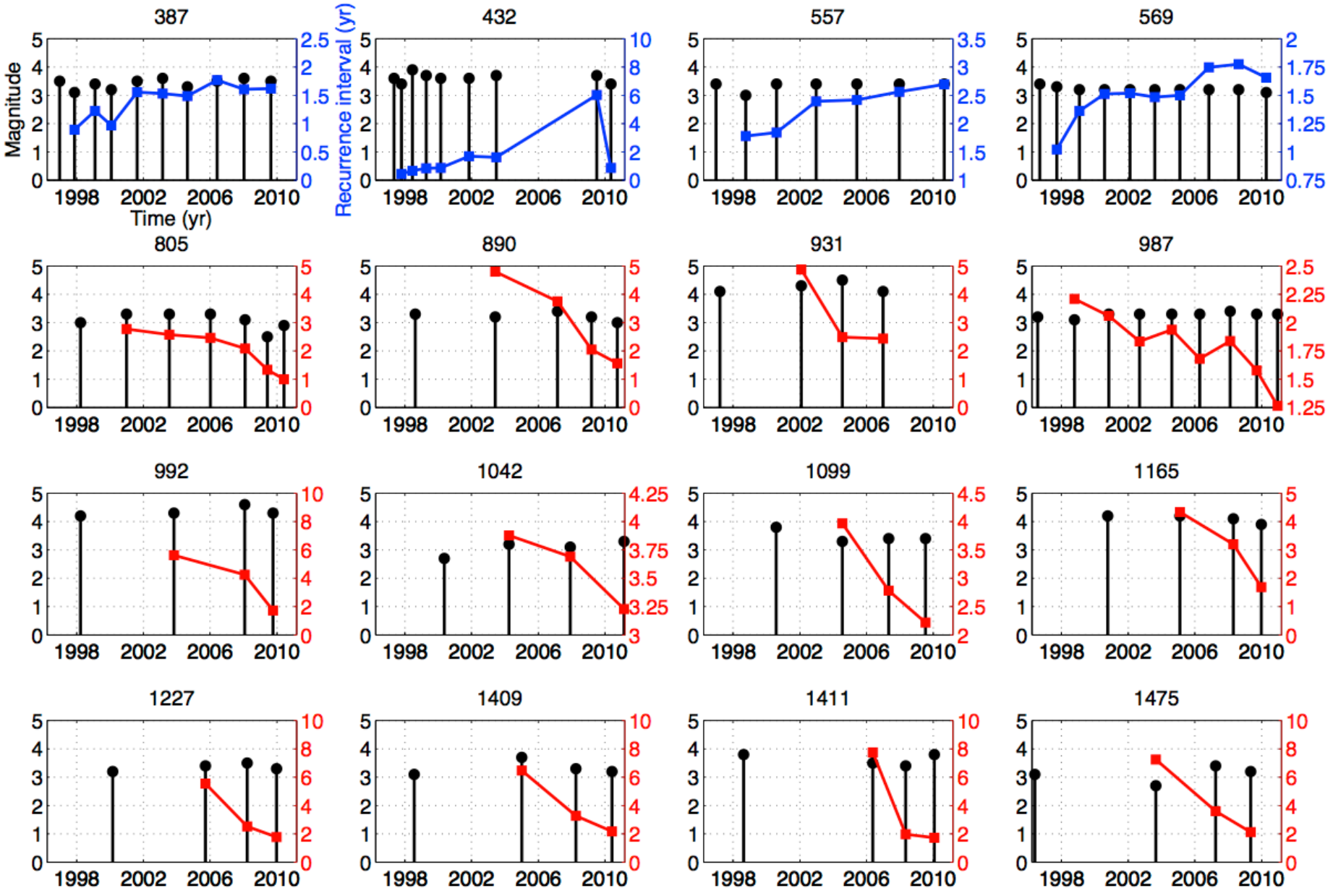
Viscoelastic Modeling

Observed accelerations



Modeled accelerations





Mavrommatis et al., in prep.