JST-NSF J-RAPID #16

Evaluation of the Potential of Large Aftershocks of the M9 Tohoku, Earthquake

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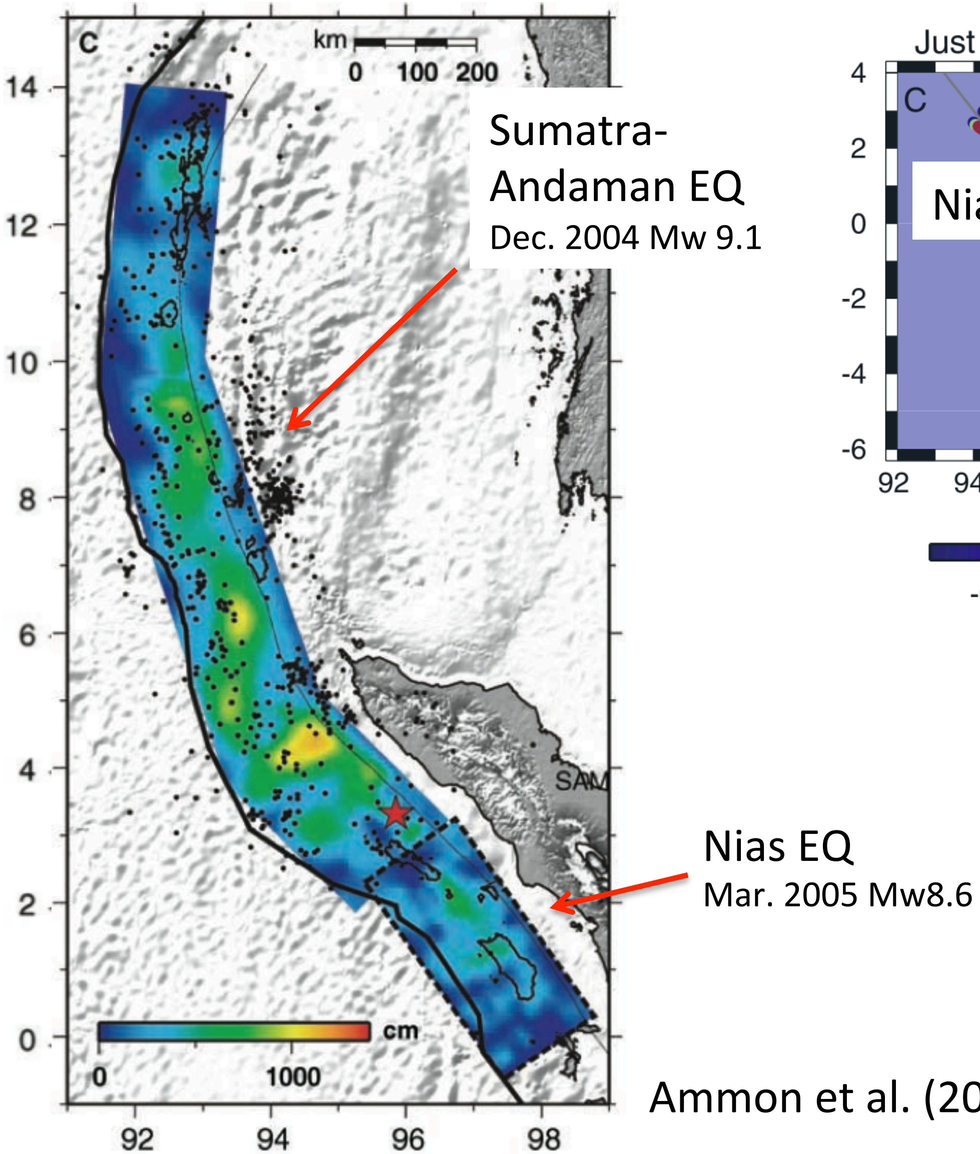
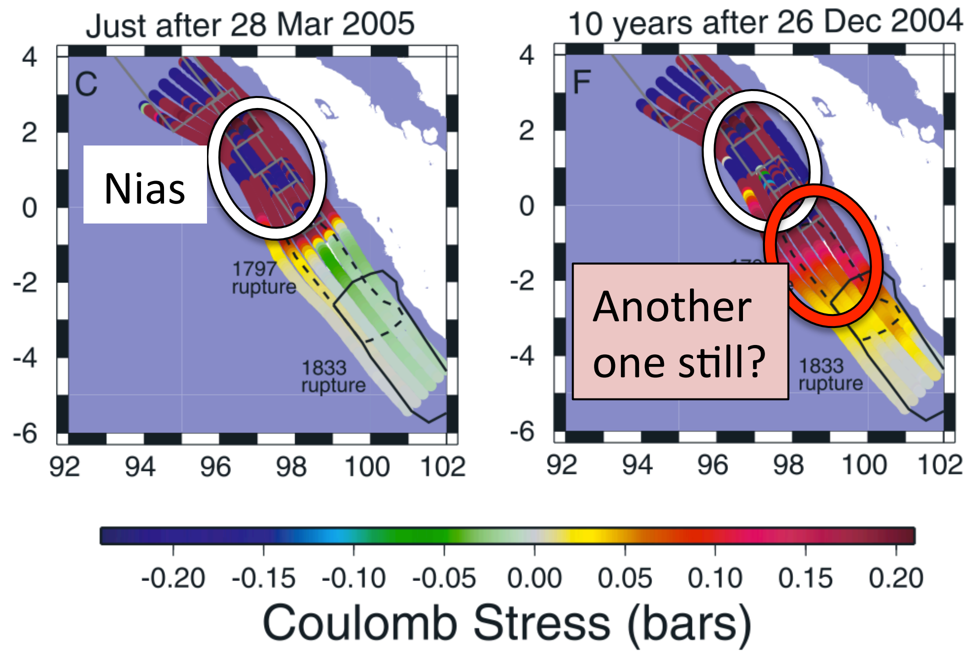
Acknowledgements:

This research uses the horizontal strain product derived from triangulation/trilateration data as well as the daily coordinate solutions, both made available by the Geospatial Information Authority of Japan (GSI).

Large EQs after megathrust events



Ammon et al. (2005)



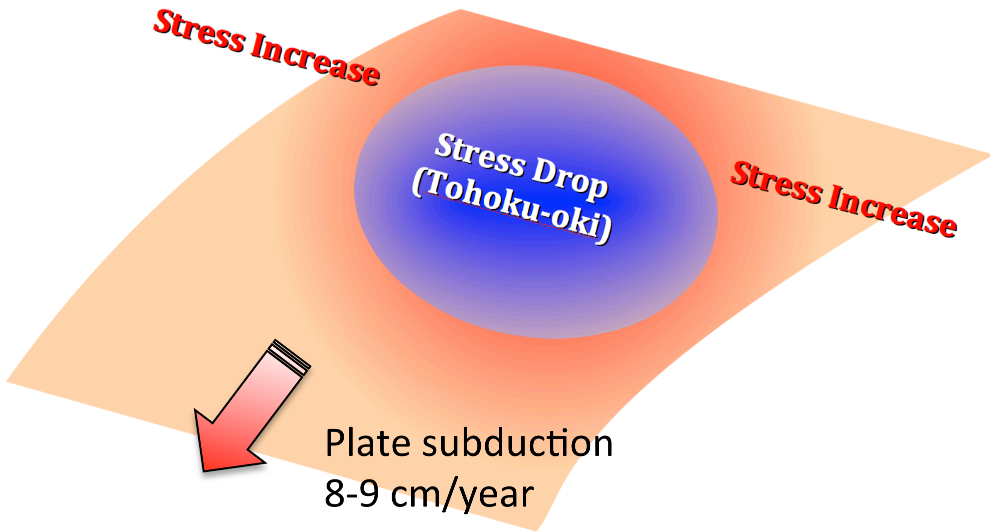
after Pollitz et al. (2006)

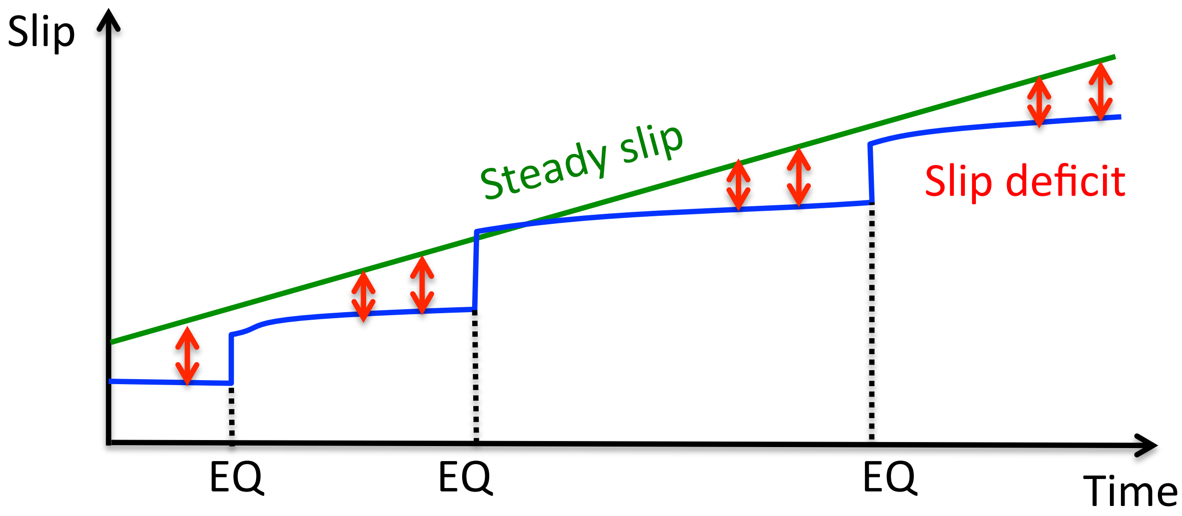
Basic Idea

- An EQ can trigger other EQs in the neighbor.
- This is possible if the slip deficit in the neighboring areas has already been built up.

↓

Examine the slip deficit on the fault to estimate the potential of future earthquakes.





Our Questions on Tohoku

1. How has slip deficit been built up over years? Are historical geodetic and recent GPS data consistent?
2. How do the slip deficit rate and slip compare?
3. What is the spatial distribution of the slip deficits as of today?

What we analyzed

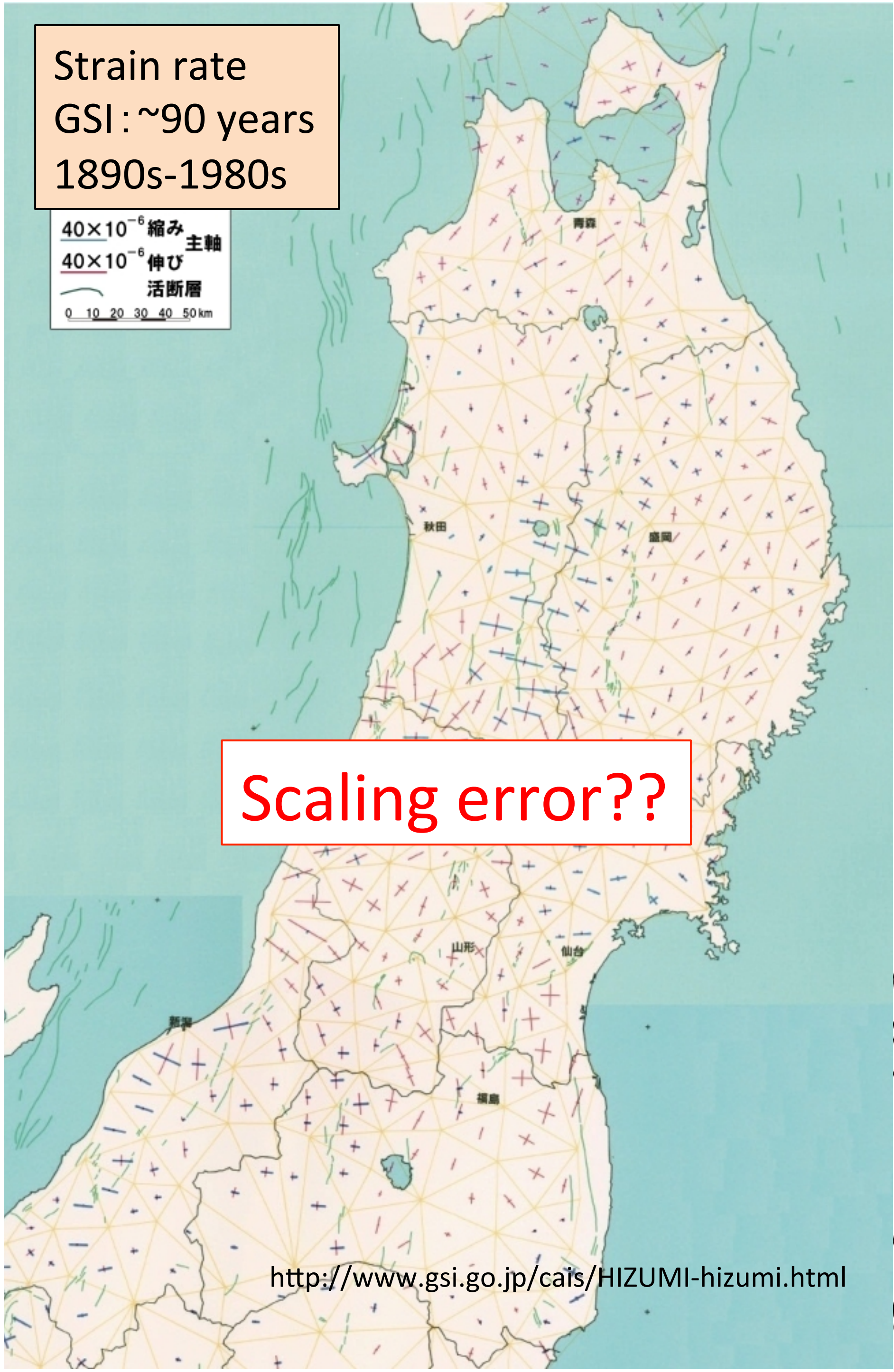
1. Horizontal strain rate of recent 120 years in Eastern Japan

2. Slip deficit rates, coseismic +postseismic slip from GPS displ.

1: Analysis of horizontal strain rate of recent 120 years in Eastern Japan

- Dataset #1: Horizontal strain rate derived from triangulation/trilateration surveys (1890s – 1980s)
- Dataset #2: Horizontal strain rate derived from GPS displacements (2000 - 2004)
- We compare a shear strain component (Υ_1) to avoid errors originated from baseline measurements.

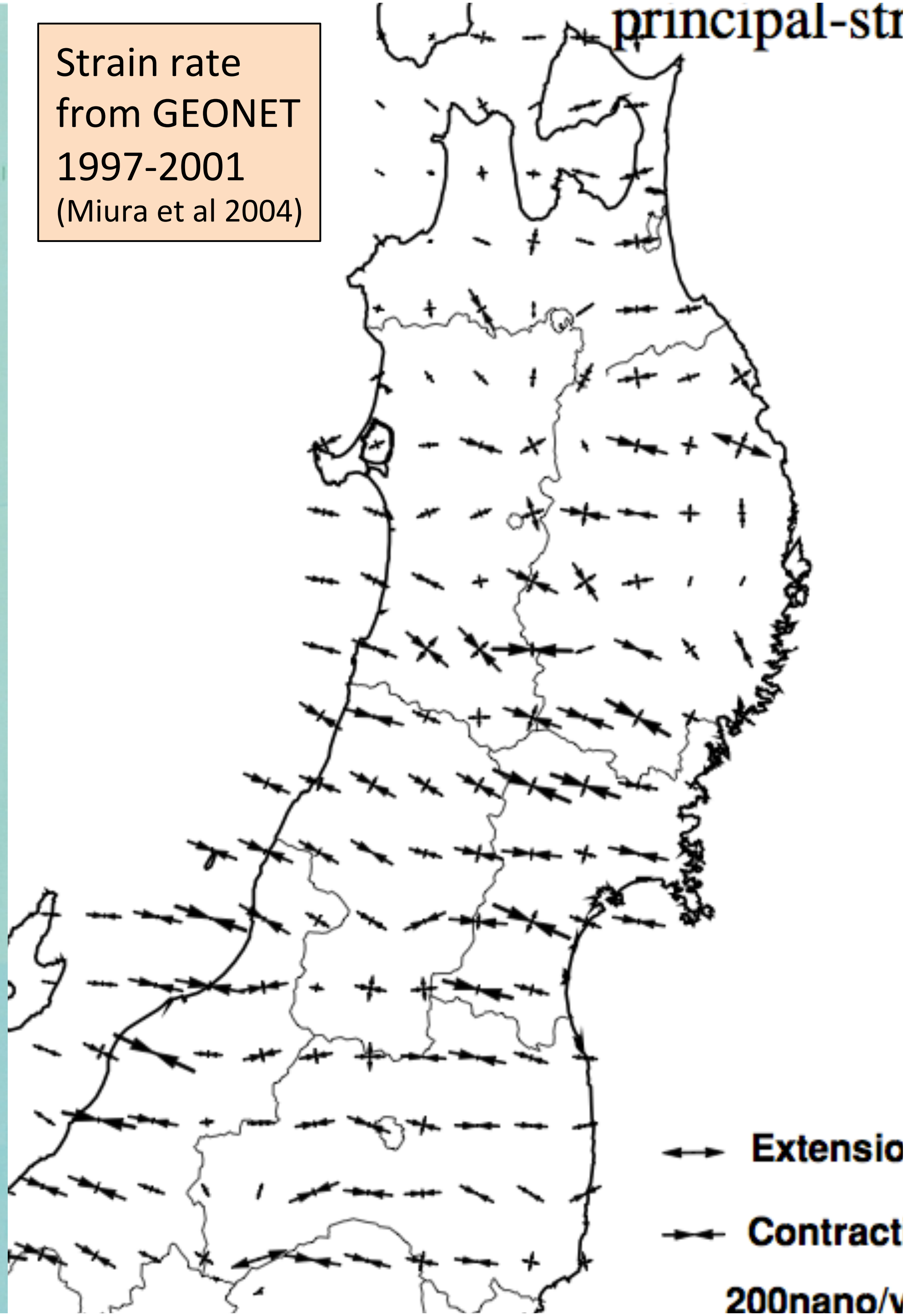
Strain rate
GSI : ~90 years
1890s-1980s



Scaling error??

http://www.gsi.go.jp/cais/HIZUMI-hizumi.html

Strain rate
from GEONET
1997-2001
(Miura et al 2004)



Υ_1 : a shear strain component

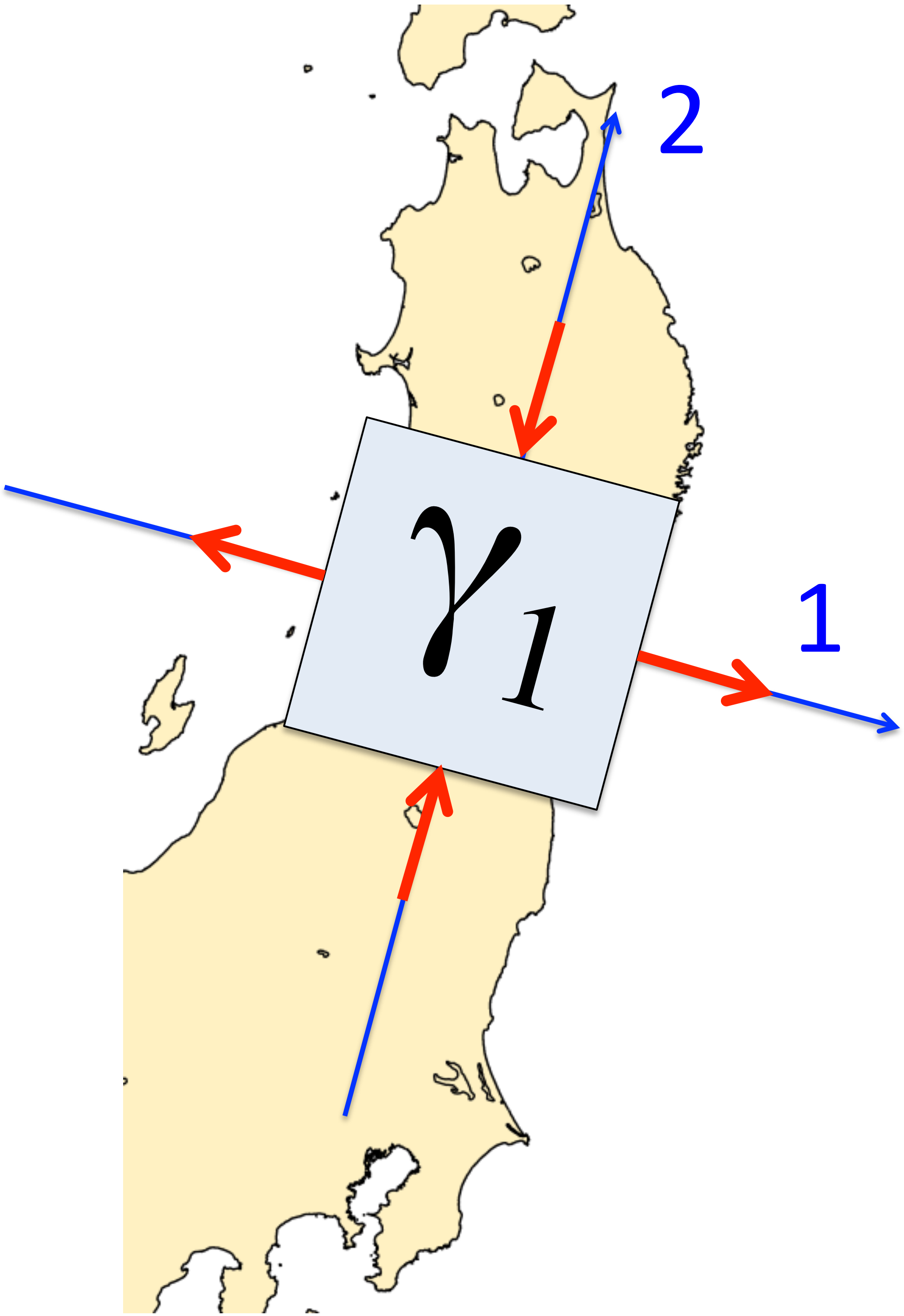
Bulletin of the Seismological Society of America. Vol. 56 No. 1, pp. 35–42. February, 1966

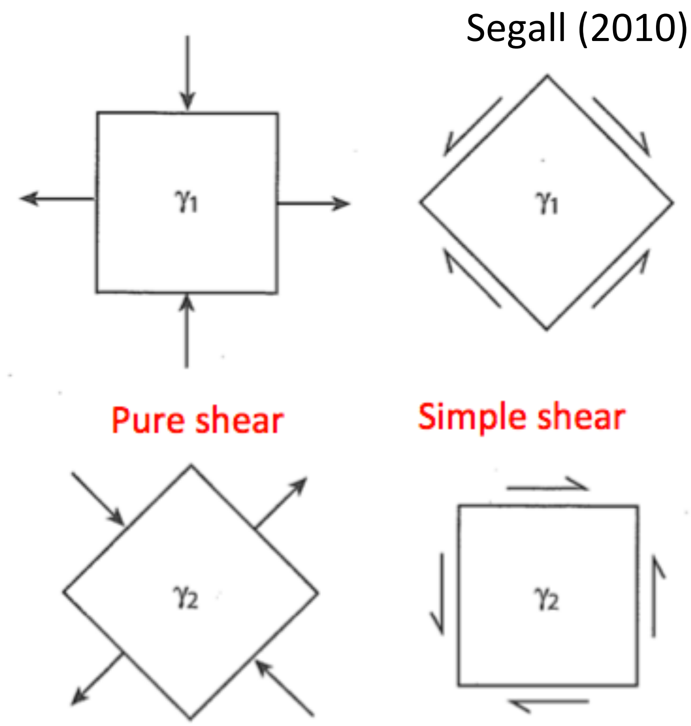
DEDUCTION OF EARTH STRAINS FROM SURVEY DATA

BY F. C. FRANK

ABSTRACT

In deducing earth strains from repeated triangulation surveys, it is advantageous to extract the shear components of strain $\gamma_1 = (\epsilon_{11} - \epsilon_{22})$ and $\gamma_2 = (\epsilon_{12} + \epsilon_{21})$ separately. Unlike the dilation and rotation components of strain, $\frac{1}{2}(\epsilon_{11} + \epsilon_{22})$ and $\frac{1}{2}(\epsilon_{12} - \epsilon_{21})$, these shear components can be determined locally, each triangle giving one measurement for γ_1 and γ_2, without requiring knowledge from adjoining areas. It follows that it should be possible to extract much more and better information about the shear strains from existing survey data than has been extracted hitherto.



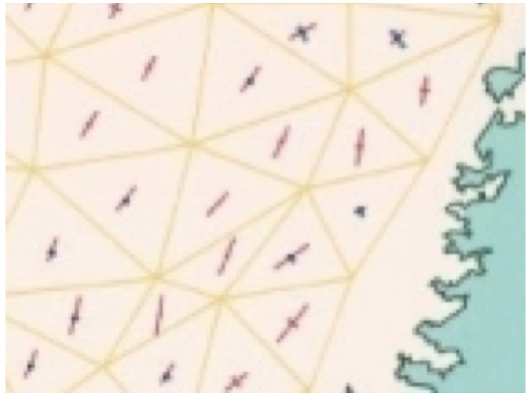


Since $\varepsilon_{11} >> \varepsilon_{22}$, $\Upsilon_1 \approx \varepsilon_{11}$.

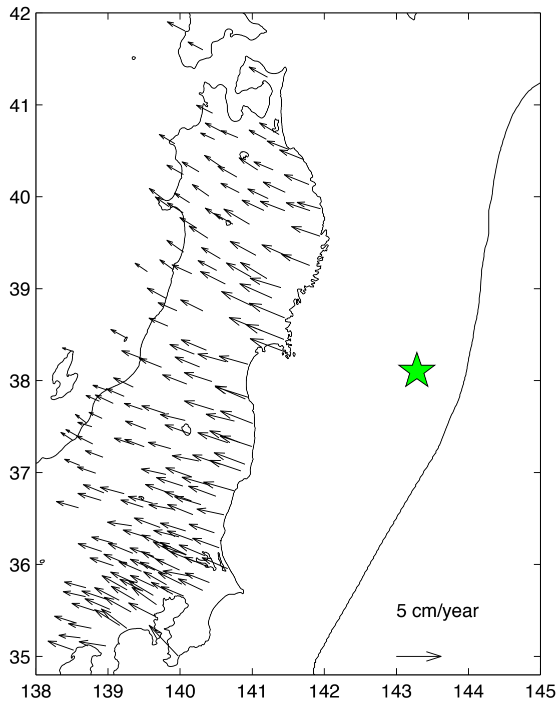
Υ_1 is useful to evaluate the degree of coupling between the subducting Pacific plate and the overriding plate.

Data Processing

- Triangulation/trilateration: For each triangle, calculate the Υ_1 rate by conversion from the lengths and directions of the principal strains and tensor rotation.

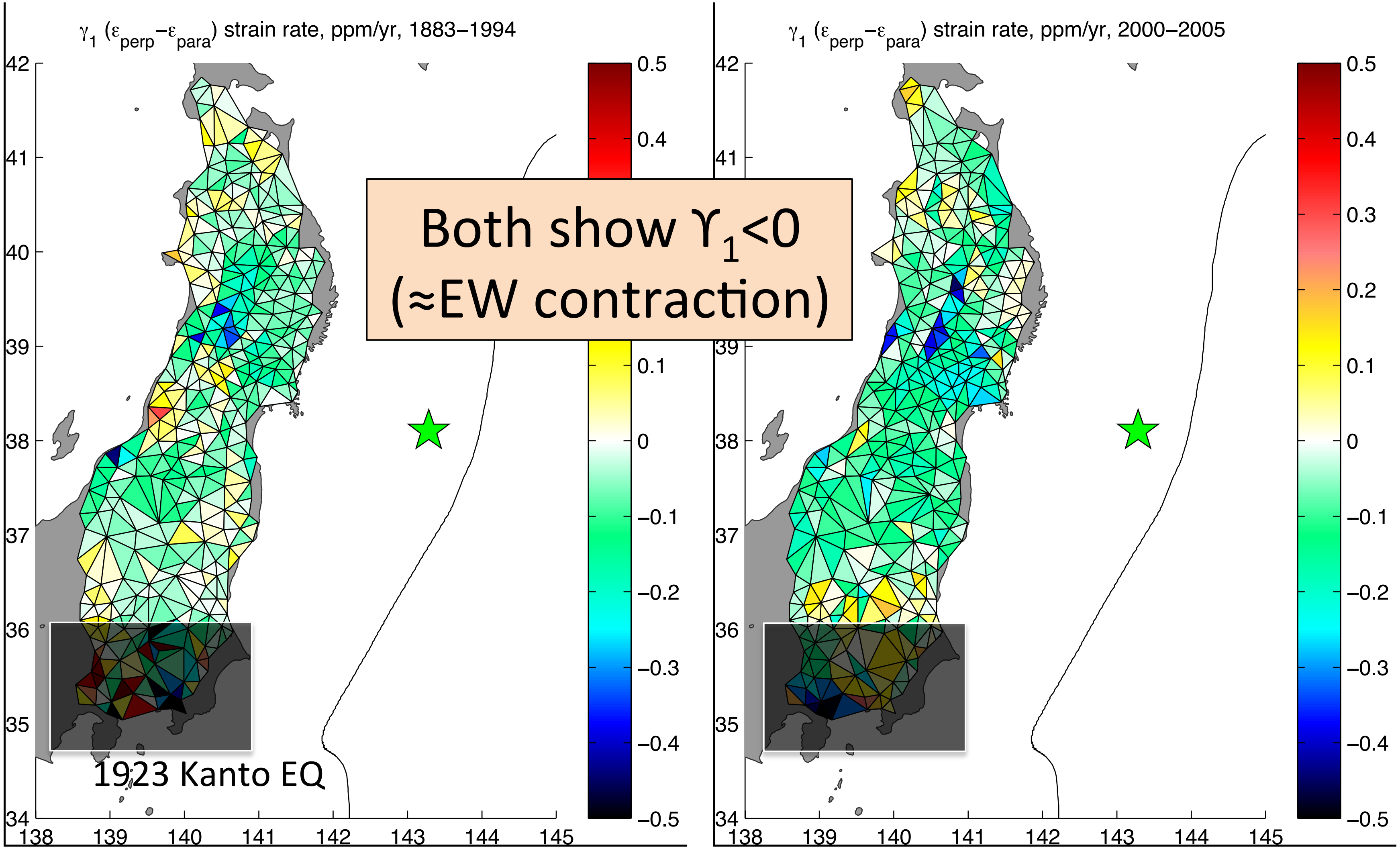


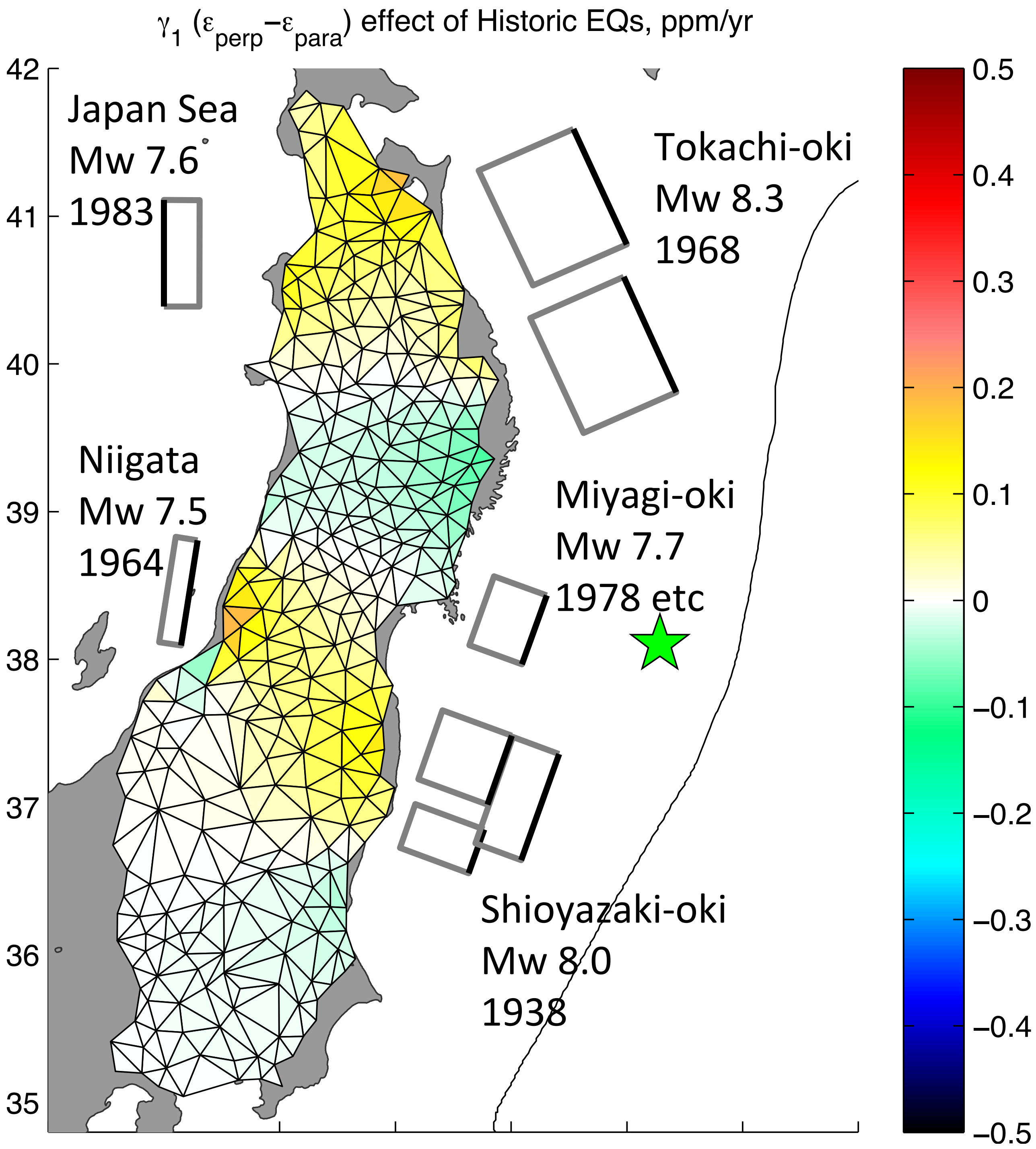
- GPS: Obtain the (constant) velocities from the daily coordinate solutions (GSI's F3 solution), interpolate the velocities to triangulation points, and compute the Υ_1 rate.



Comparison of ϒ$_1$ rate

Triang./Trilat. GPS

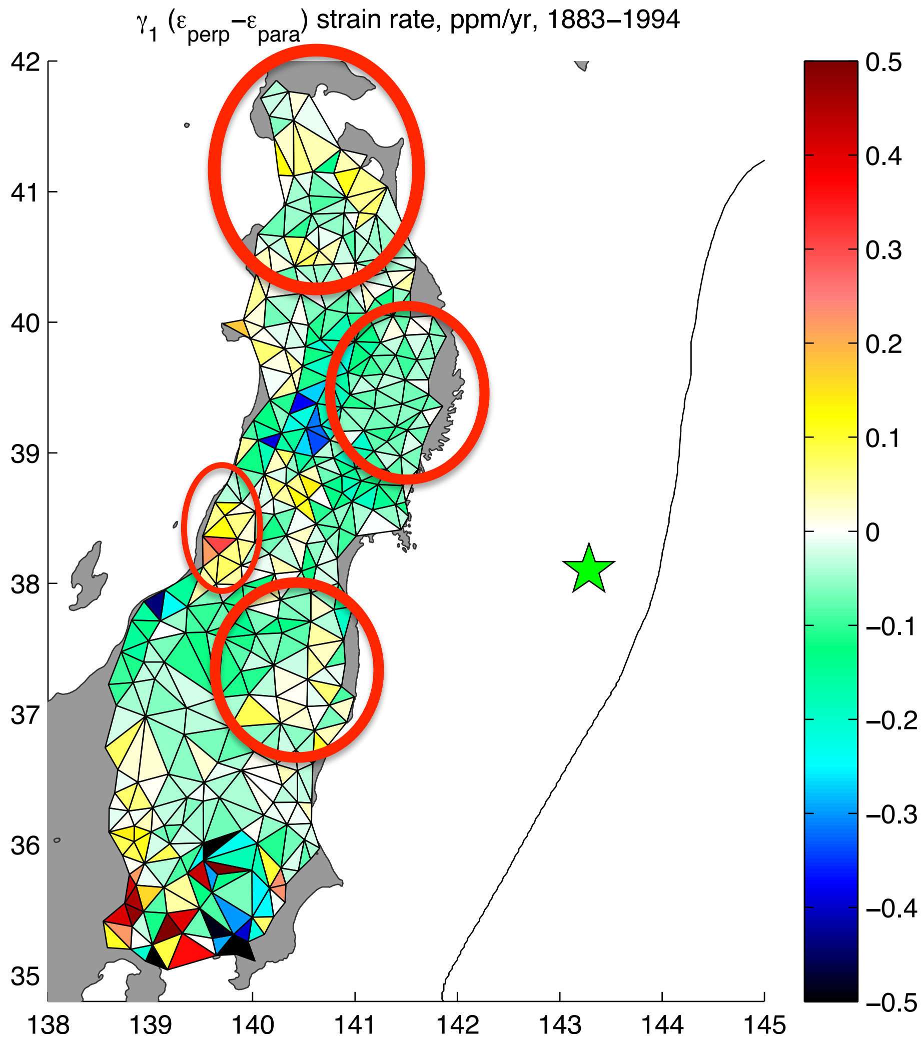




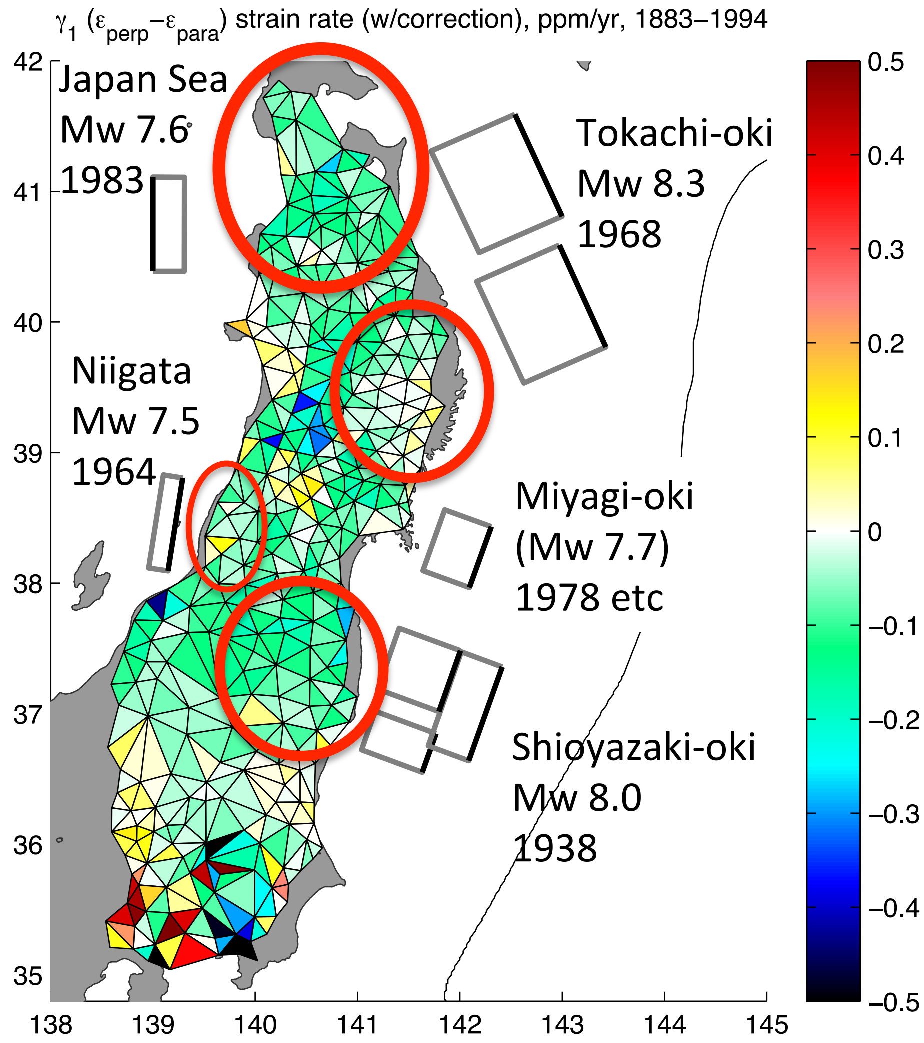
Corrections for the EQs that occurred in the triang./trilat. period

(Only the coseismic fault models were taken into account.)

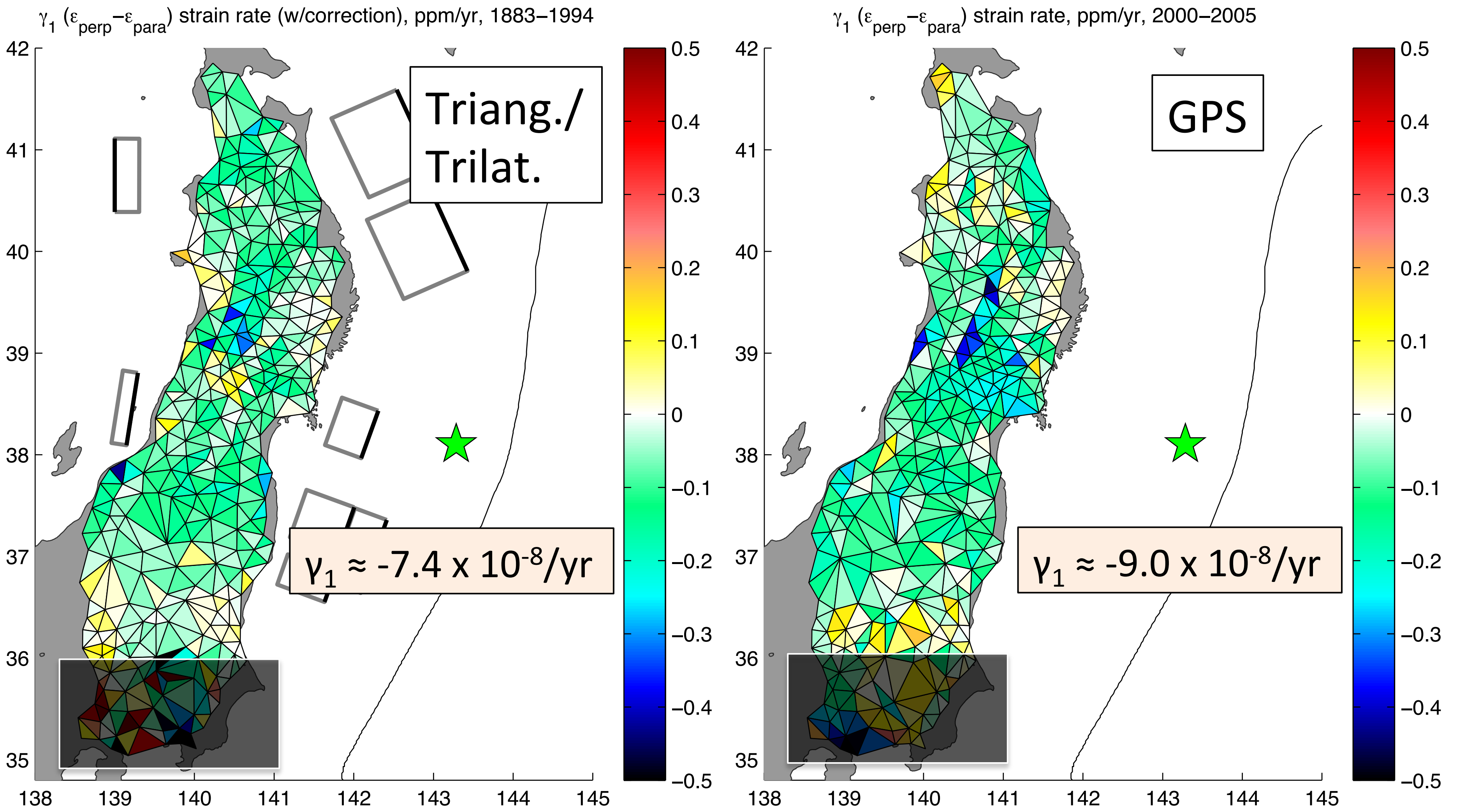
Before correction



After correction

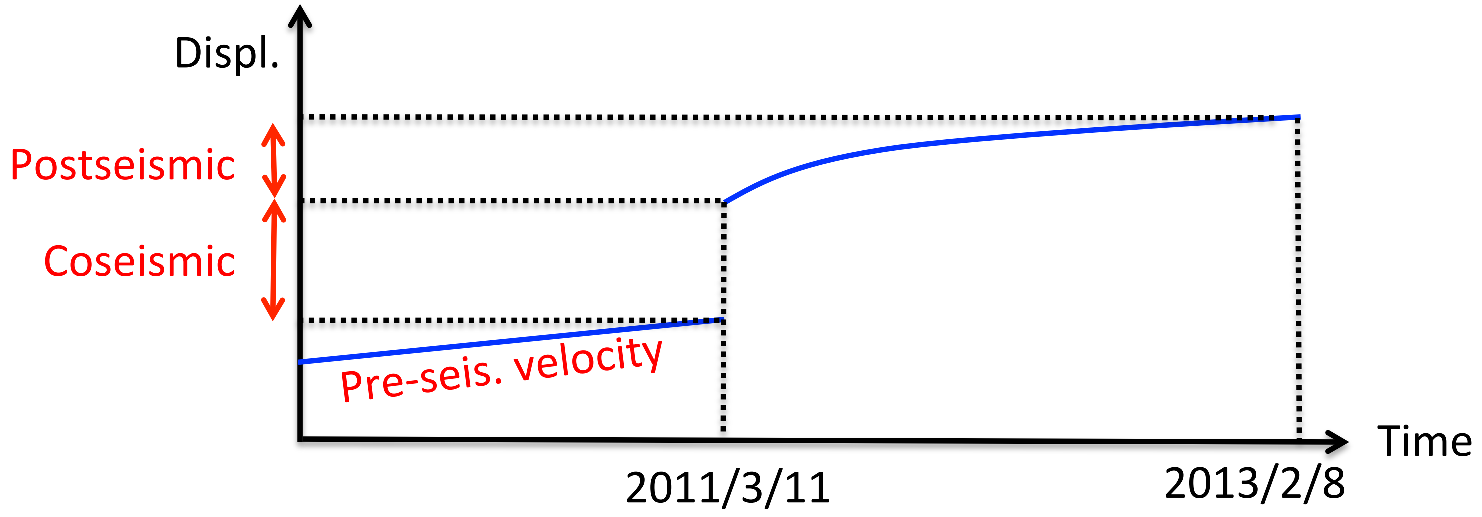


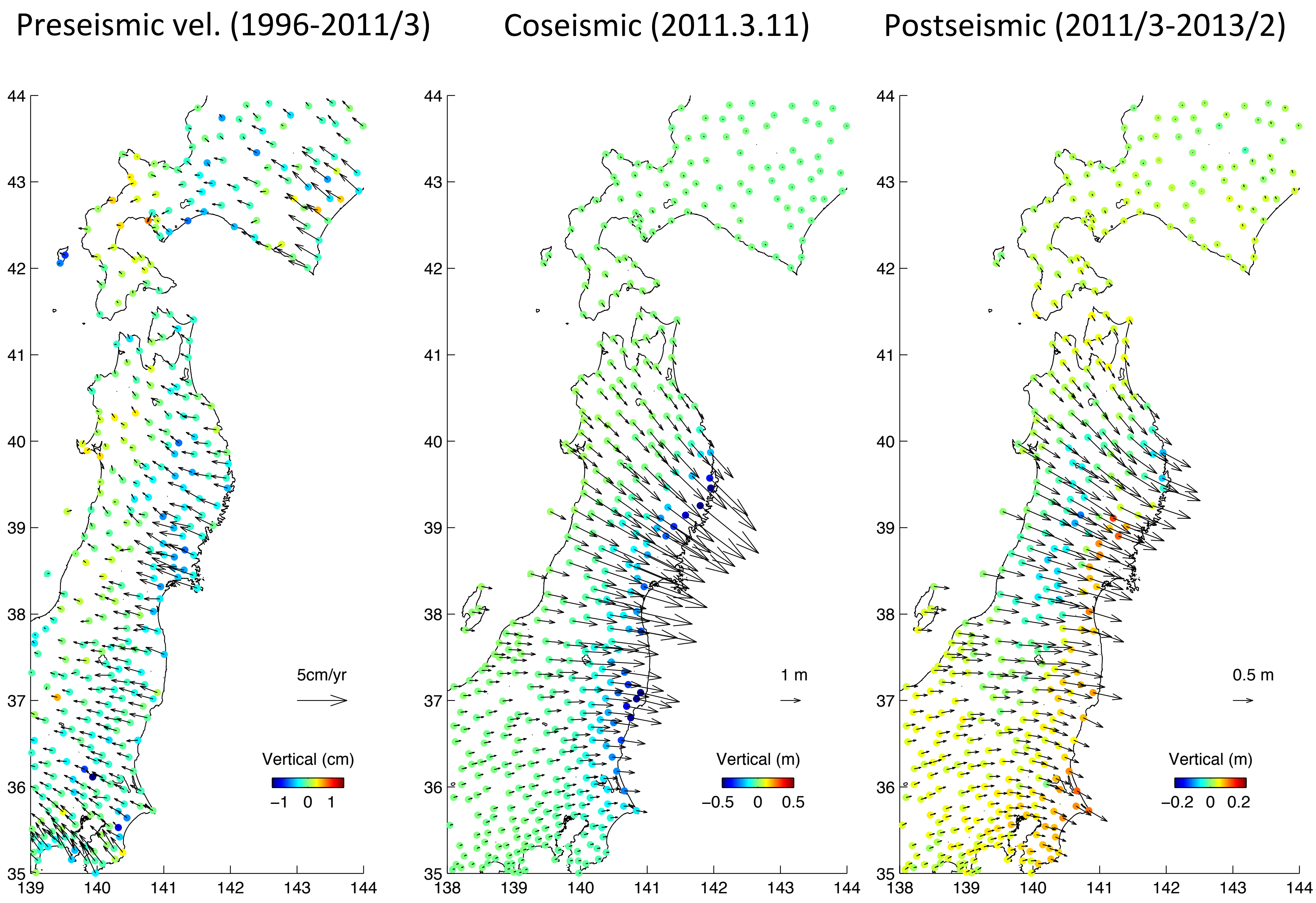
Conclusion from Part 1: The degree of coupling did not significantly change in 120 years.



2: Slip deficit rates, coseismic +postseismic slip from GPS displ.

- Pre-seismic (1996-2011): Obtain the constant velocity component at each station, by removing seasonal variations etc.
- Co- and post-seismic (2011-2013/2/8): Measure the displacement offsets.

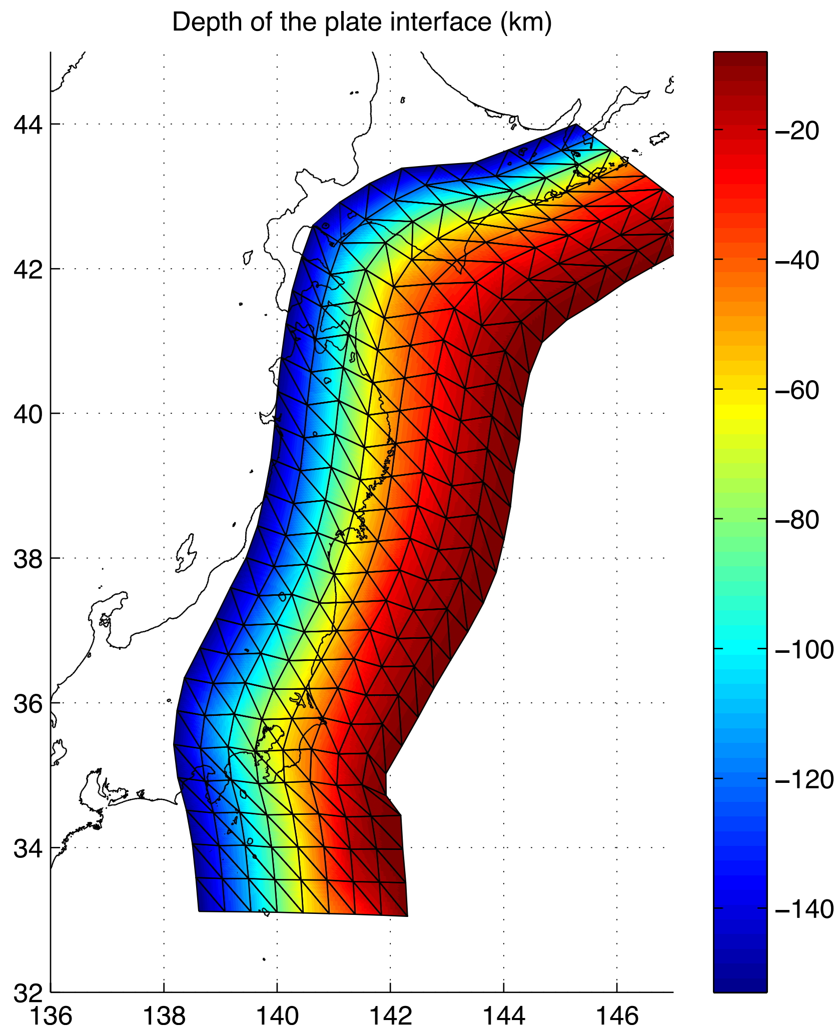




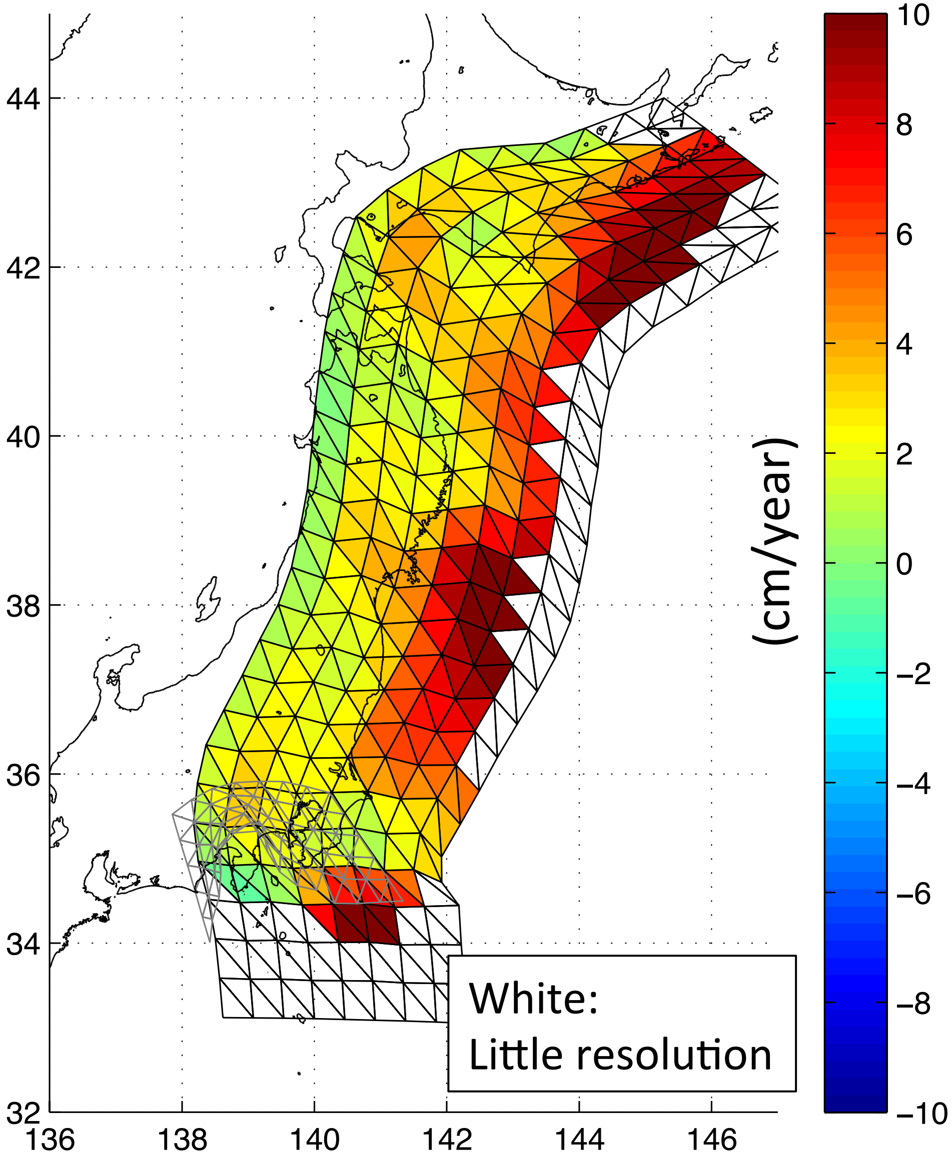
Preseismic vel. (1996-2011/3)
Coseismic (2011.3.11)
Postseismic (2011/3-2013/2)
5cm/yr
Vertical (cm)
−1 0 1
1 m
Vertical (m)
−0.5 0 0.5
0.5 m
Vertical (m)
−0.2 0 0.2

Analysis Method

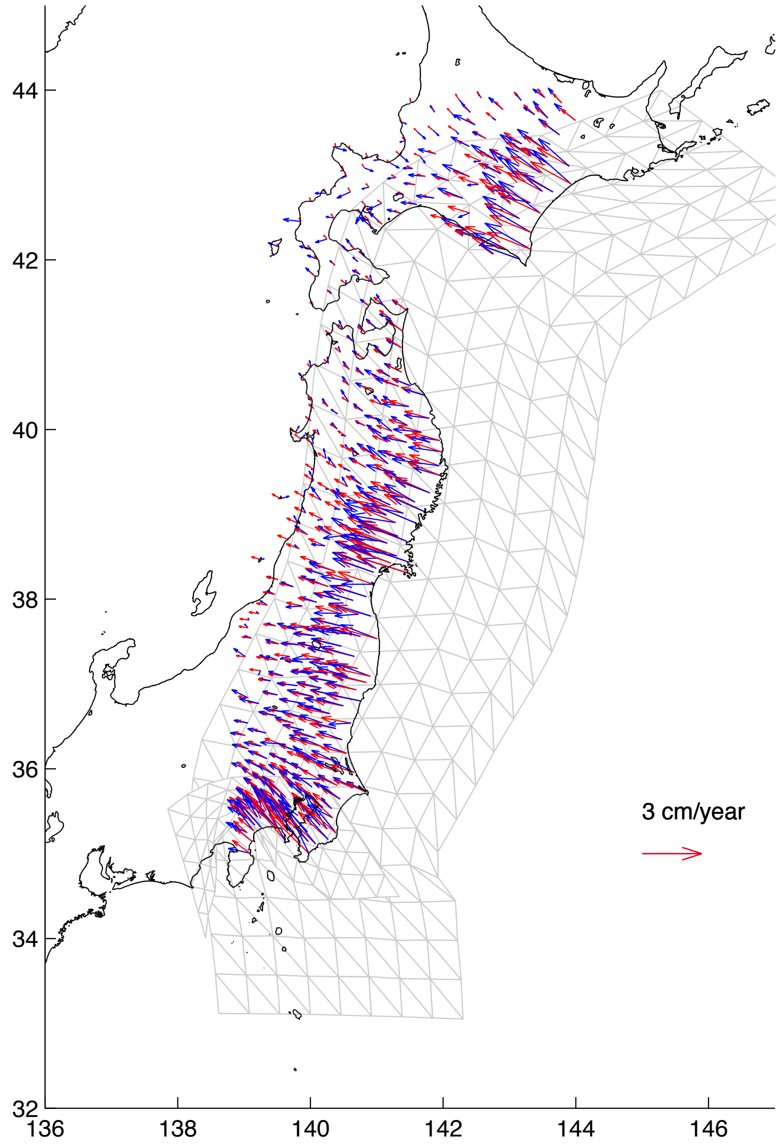
- Mesh the plate interface with triangles
- Solve for the distribution of slip deficits (pre-seismic) and slip (co- and post-seismic) on the mesh.
- Slip (deficit) is assumed to be in the plate convergence direction.
- Least-squares inversion with smoothing constraint. The weight of the smoothing is determined by the ABIC.



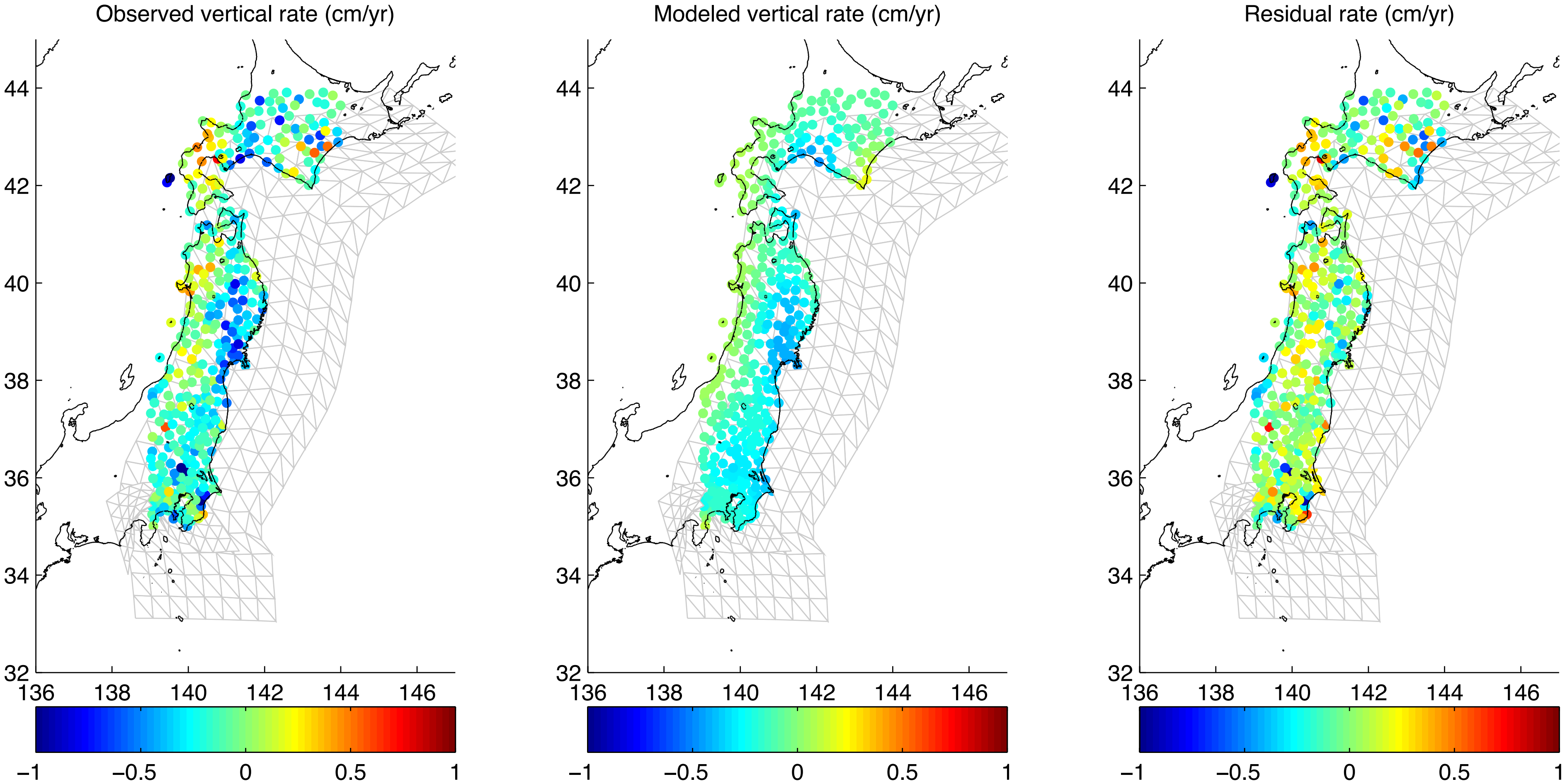
Slip deficit rate



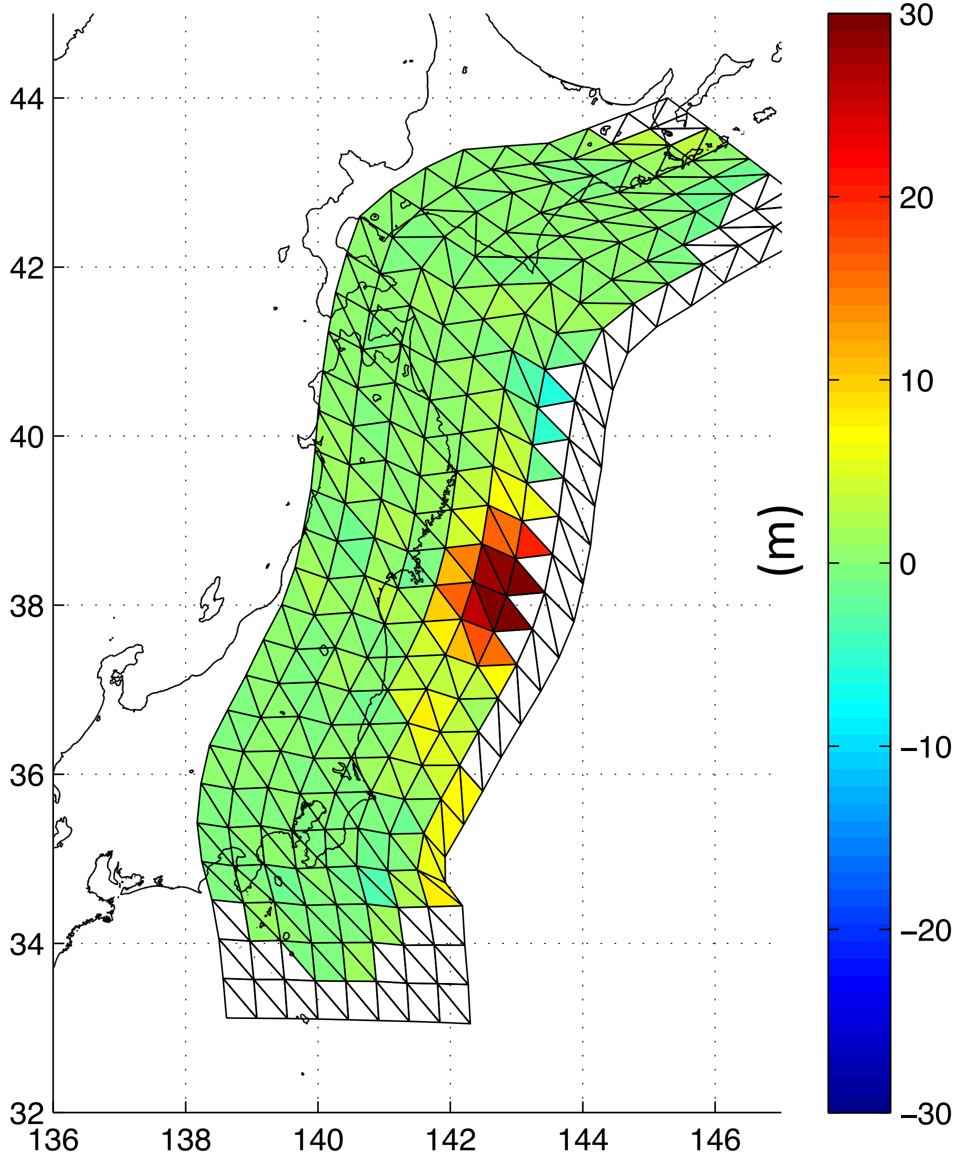
Goodness of fit (horiz.)



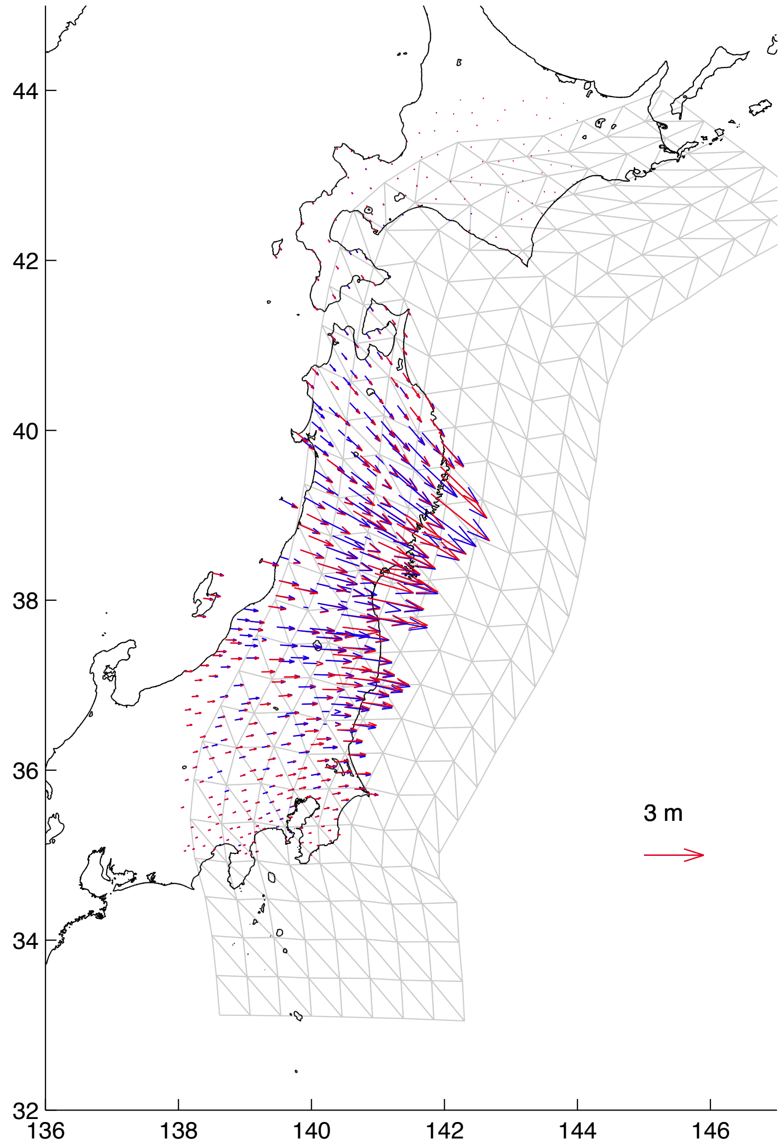
Goodness of fit (vertical)



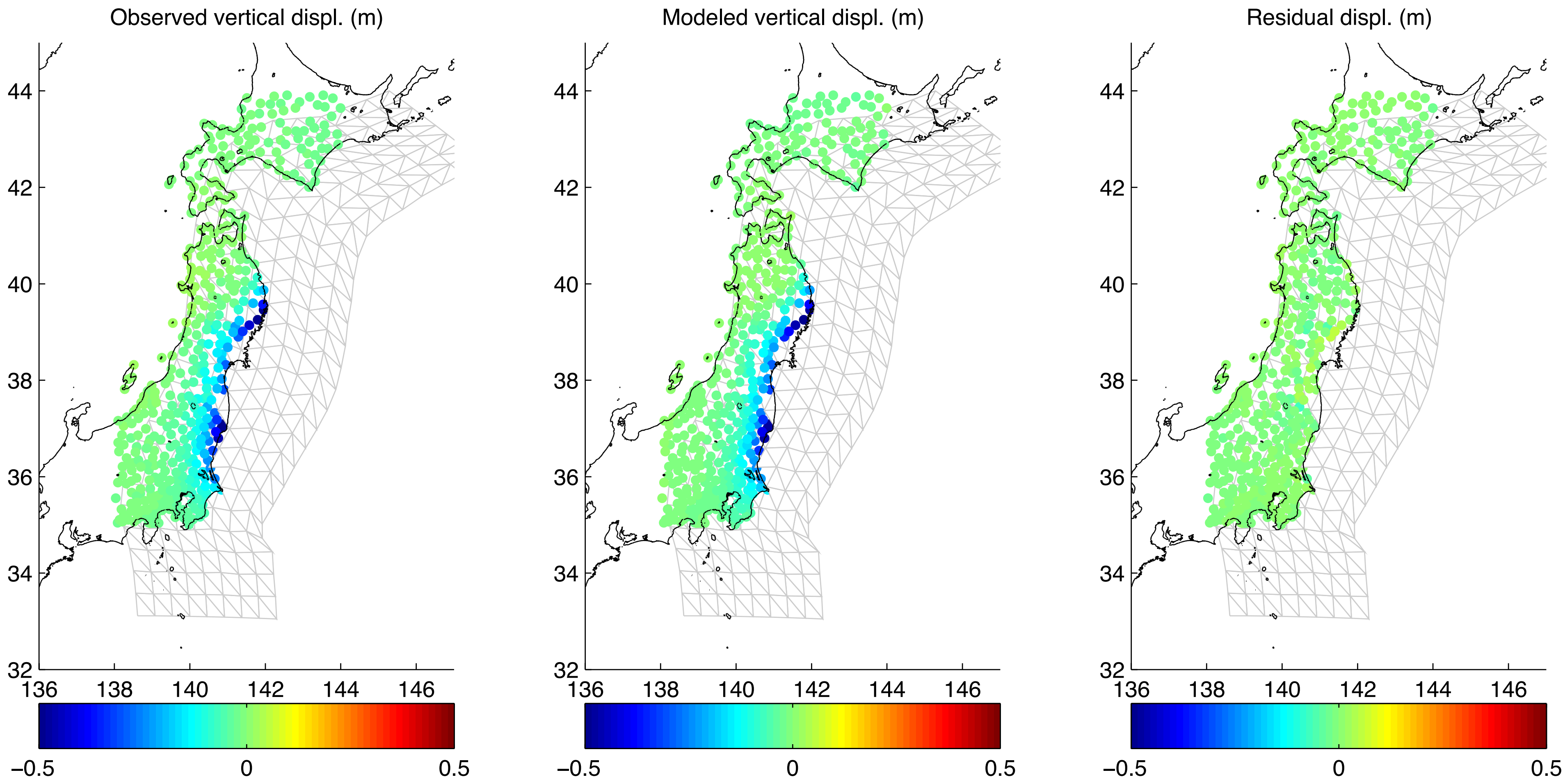
Coseismic slip



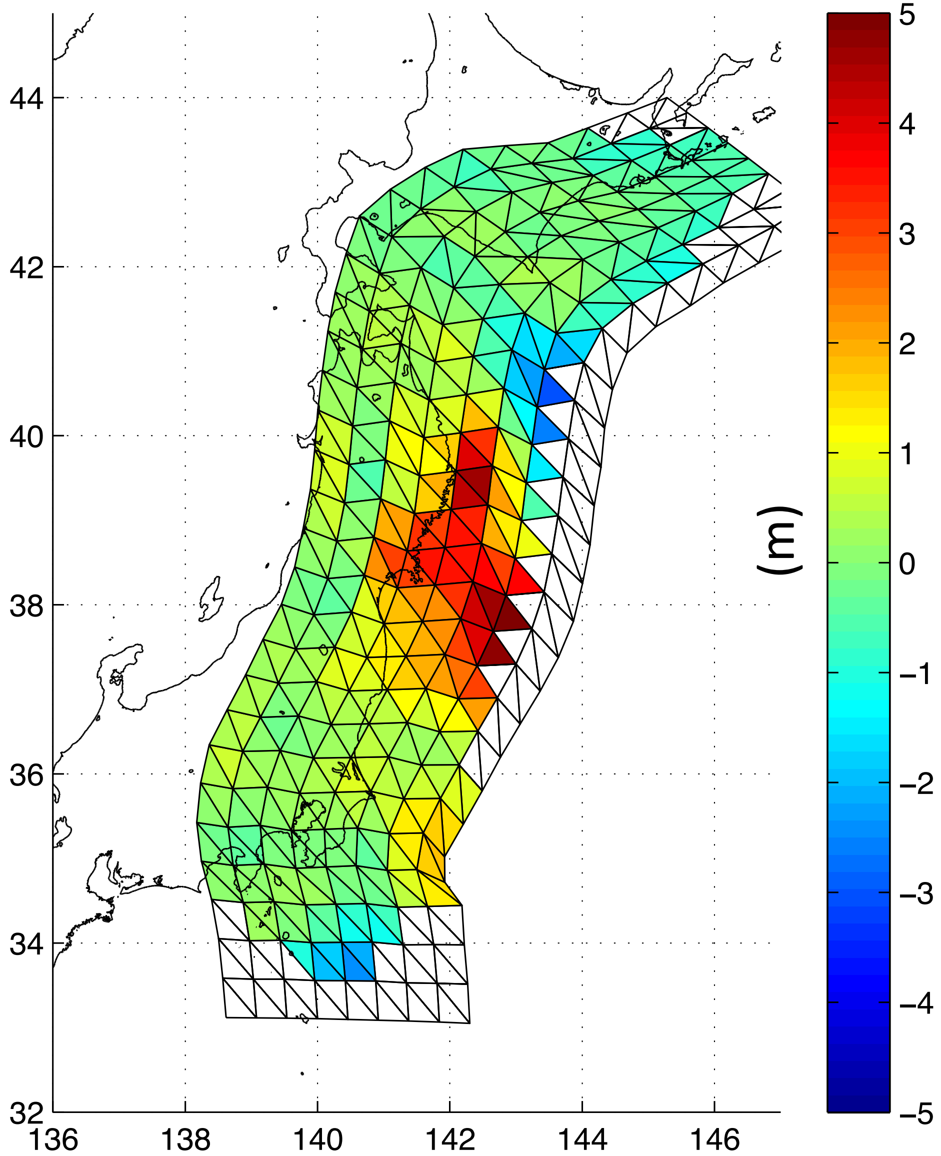
Goodness of fit (horiz.)



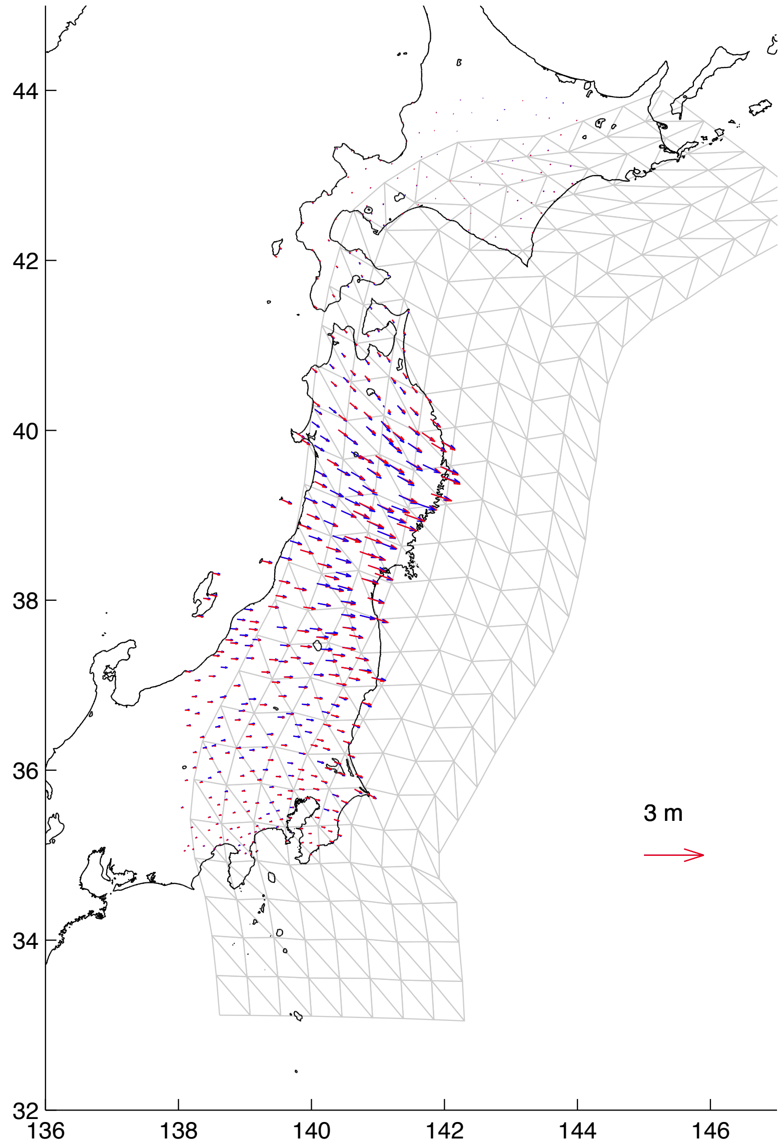
Goodness of fit (vertical)



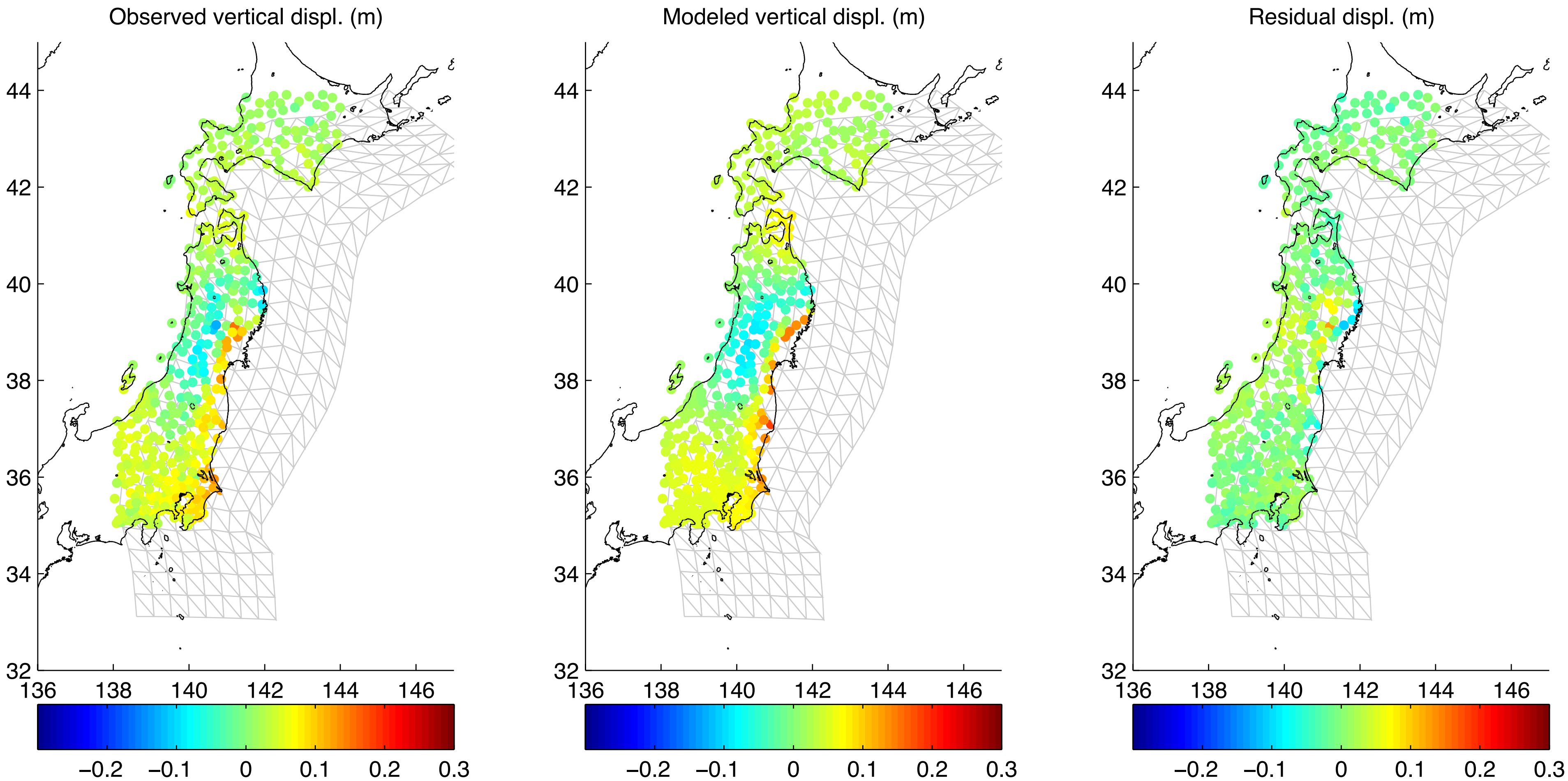
Postseismic slip



Goodness of fit (horiz.)



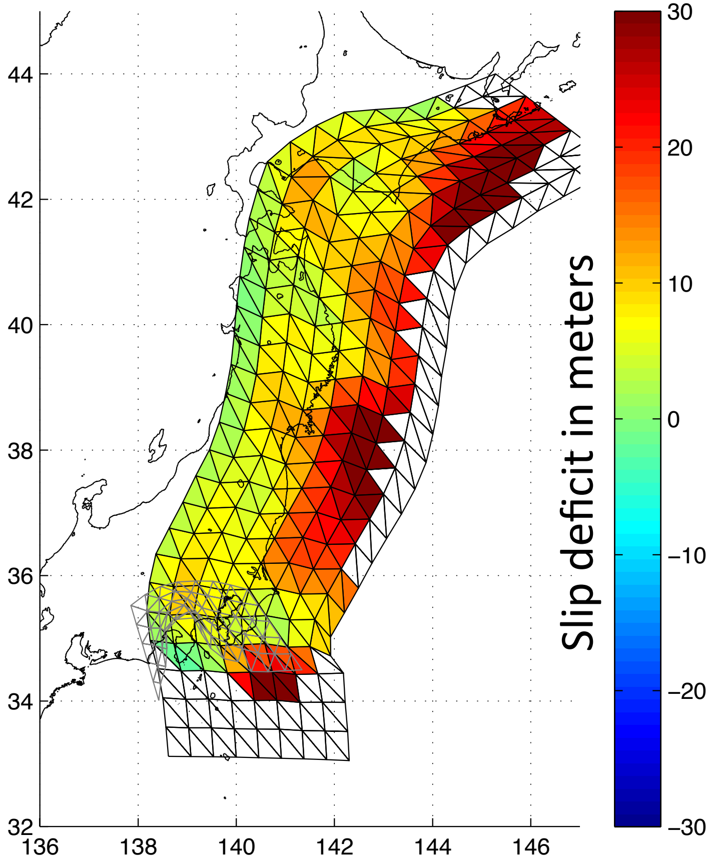
Goodness of fit (vertical)



The Slip Budget

From the analysis of the triang./trilat. data, we can extrapolate the slip deficit rate back in time…

Cumulative slip deficit in **300** yrs



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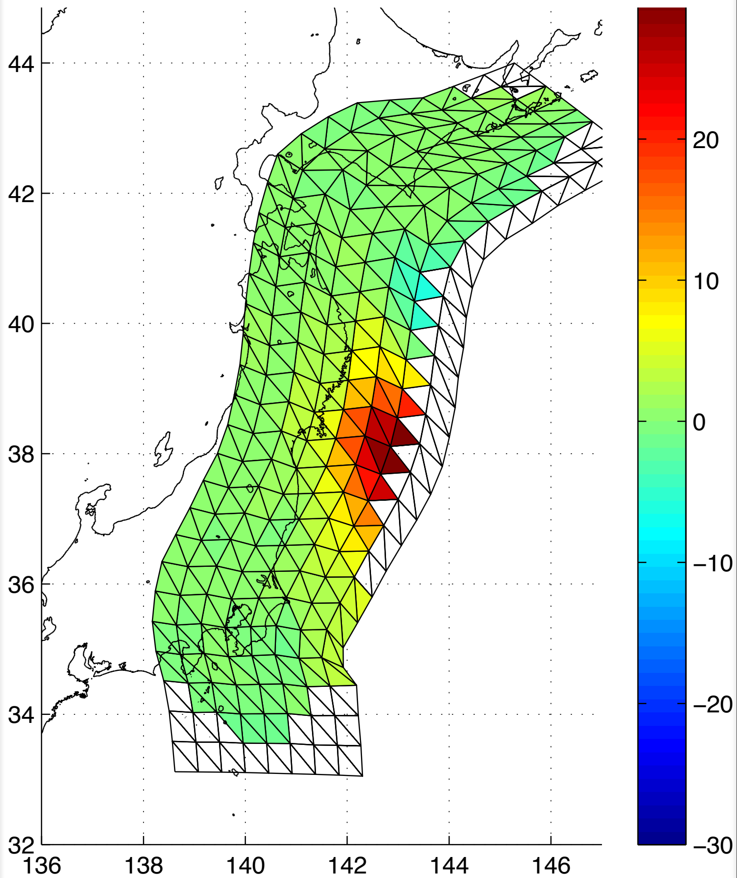
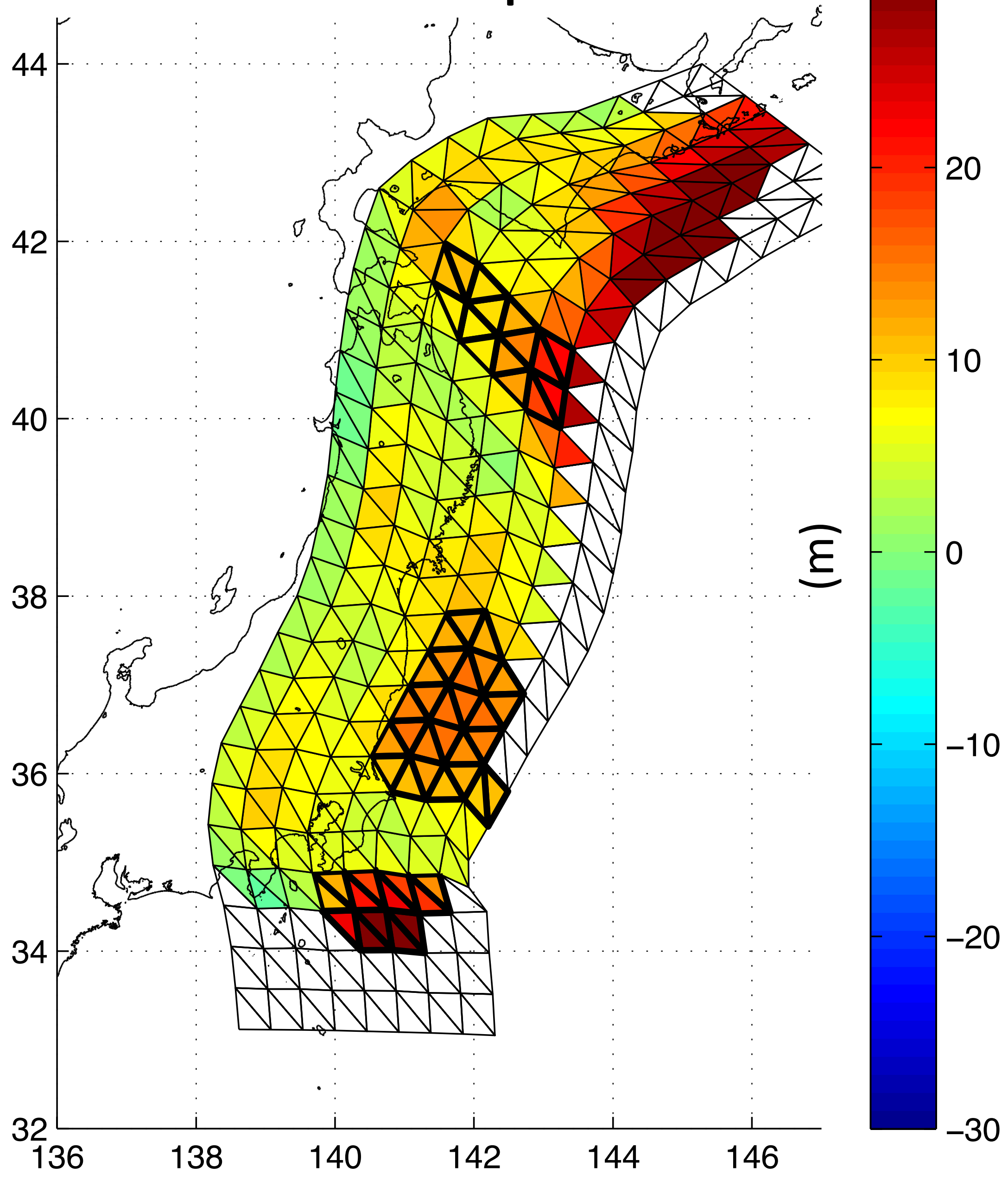
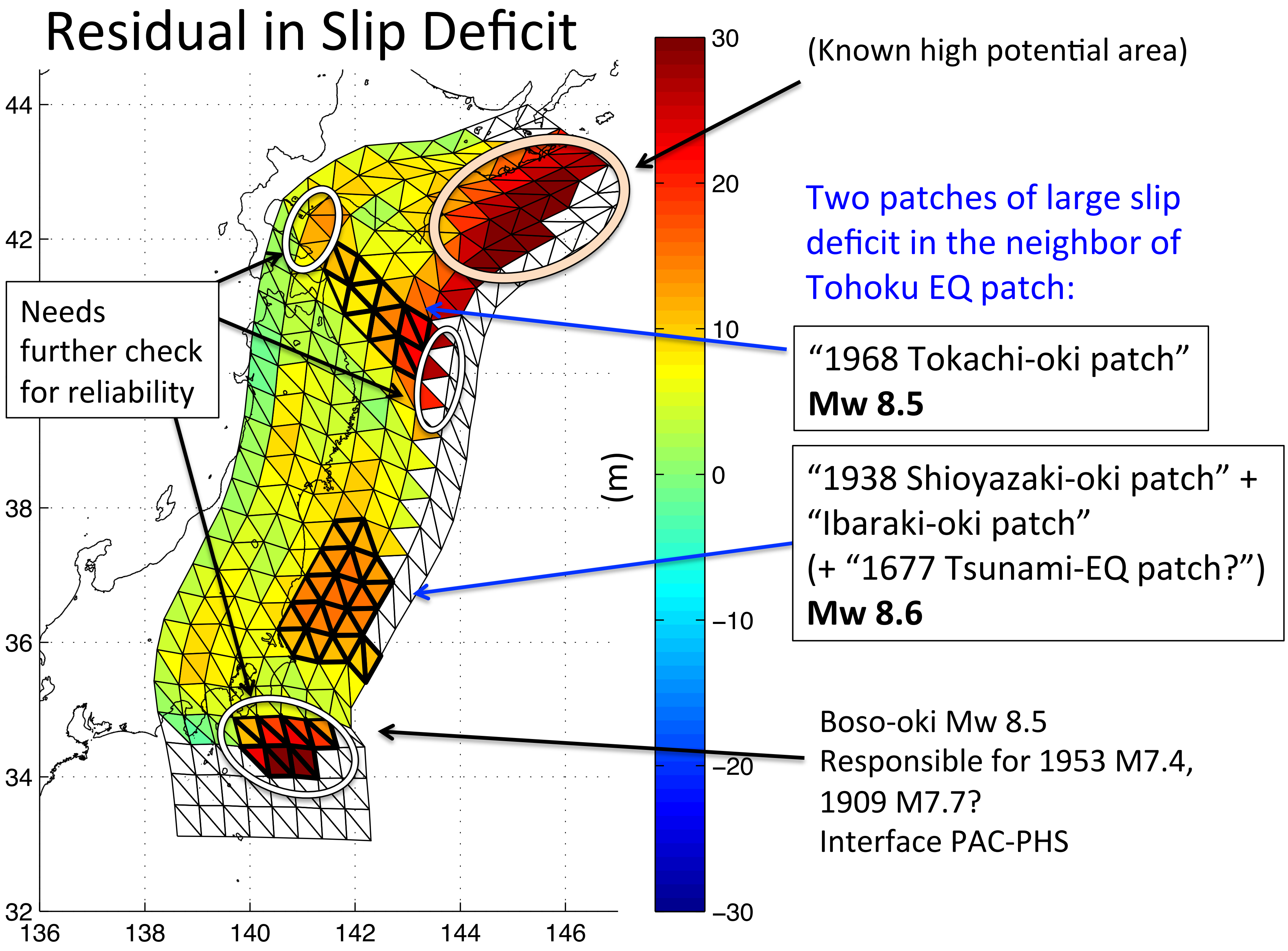
Coseis. + postseis. slip (released slip deficit) of Tohoku EQ



=?

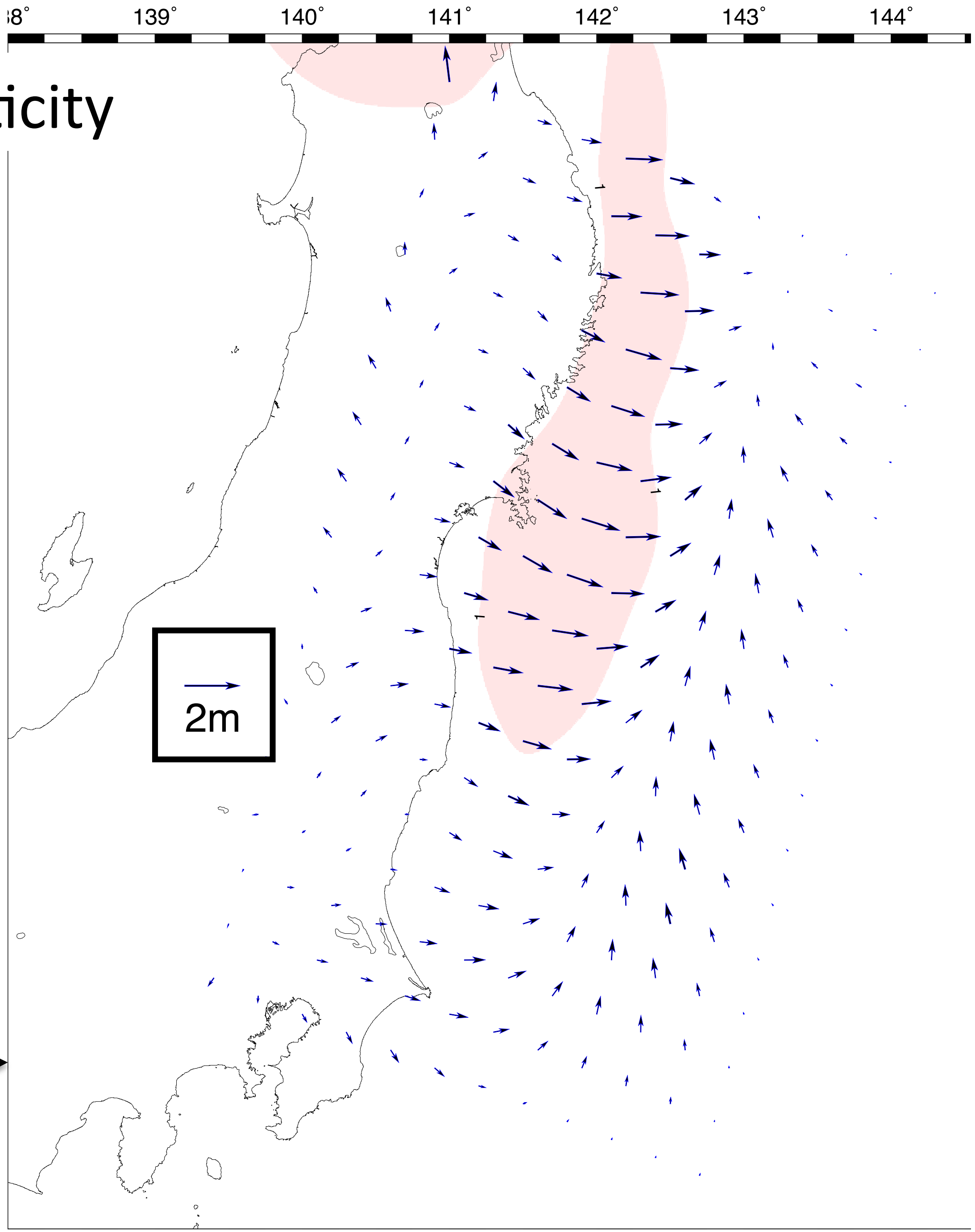
Residual in Slip Deficit




Residual in Slip Deficit
44
42
38
36
34
32
136
138
140
142
144
146
30
20
10
0
−10
−20
−30
(m)
(Known high potential area)
Two patches of large slip deficit in the neighbor of Tohoku EQ patch:
"1968 Tokachi-oki patch"
Mw 8.5
"1938 Shioyazaki-oki patch" + "Ibaraki-oki patch"
(+ "1677 Tsunami-EQ patch?")
Mw 8.6
Needs further check for reliability
Boso-oki Mw 8.5
Responsible for 1953 M7.4, 1909 M7.7?
Interface PAC-PHS

Importance of viscoelasticity

The estimations of slip deficit and afterslips could be much different when viscoelastic deformation is taken into account.



Afterslip in 50 days with viscoelasticity taken into account

Summary

1. How has slip deficit been built up over years? Are historical geodetic and recent GPS data consistent?

A. Triang./trilat. horizontal strain ≈ GPS horizontal strain.

2. How do the slip deficit rate and slip compare?

A. Area of large slip of Tohoku EQ had large slip deficit rates.

3. What is the spatial distribution of the slip deficits as of today?

A. The slip deficits continue to build up in the surrounding region of the Tohoku rupture area. To answer this question in more concrete manner, it is important to take into account the slip history associated with previous events in each area.