

The early postseismic phase of Tohoku-Oki earthquake (2011) from kinematics solutions: implication for subduction interface dynamics

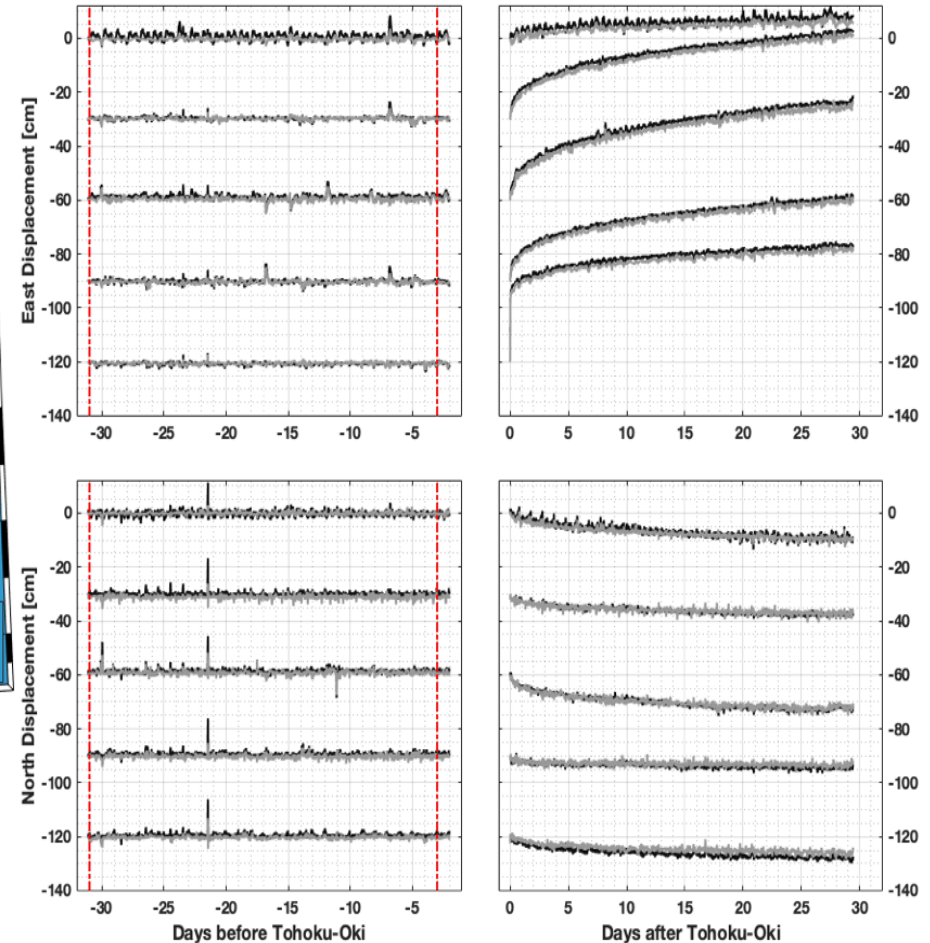
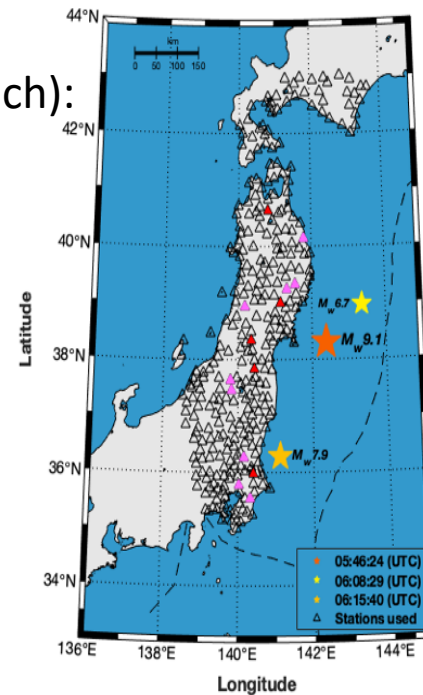
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Data Processing – GPS DATA

- ➔ GEONET network in Japan provides a large amount of GPS recordings for:
 - M_w 9.0 Tohoku-Oki (Mainshock)
 - M_w 6.7 Iwate-Oki and M_w 7.9 Ibaraki-Oki (Largest Aftershocks)
 - Postseismic Deformation

- ➔ Processing with GipsyX (Precise Point Positioning approach):
 - Computation of 30-s kinematic time series
 - Strategy used is based on [Twardzik et al 2019]

- ➔ Post-Processing steps:
 1. Removing Multipath Effect with the Sidereal Filter from [Twardzik et al 2019]
 2. Removing Common Modes with a stacking approach



Temporal Evolution – Different Models tested

➔ How to explain the displacement evolution of the postseismic deformation?

1. Viscoelastic Mechanism - Exponential decay

$$v_1(t) = e^{\frac{-t}{\tau}} \mid u_1(t) = A_1 (1 - e^{\frac{-t}{\tau}})$$

2-3. Frictional Interaction Afterslip

We tested the assumption: afterslip velocity is following an « Omori-like » relaxation.

$$v_i(t) = v_0 \frac{c}{(t+c)^p} \mid \text{Expressions depend on p-value:}$$

$$p=1 \rightarrow u_2(t) = v_0 c \log\left(1 + \frac{t}{c}\right)$$

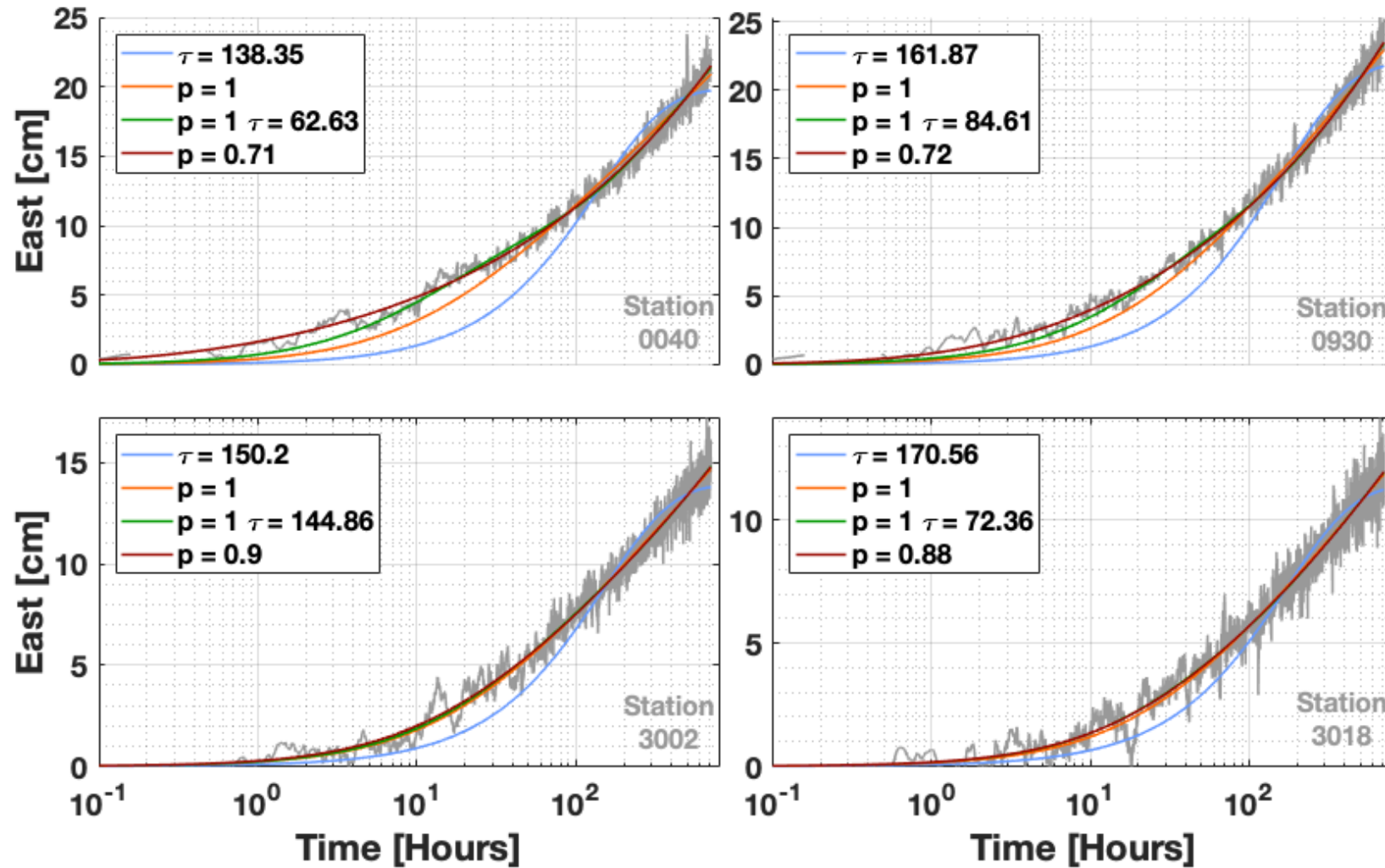
or

$$p \neq 1 \rightarrow u_3(t) = \frac{v_0 c}{1-p} \left(\left(1 + \frac{t}{c}\right)^{1-p} - 1 \right)$$

4. Combination of Afterslip and Viscoelastic Mechanism

Temporal Evolution – Fits and Residuals

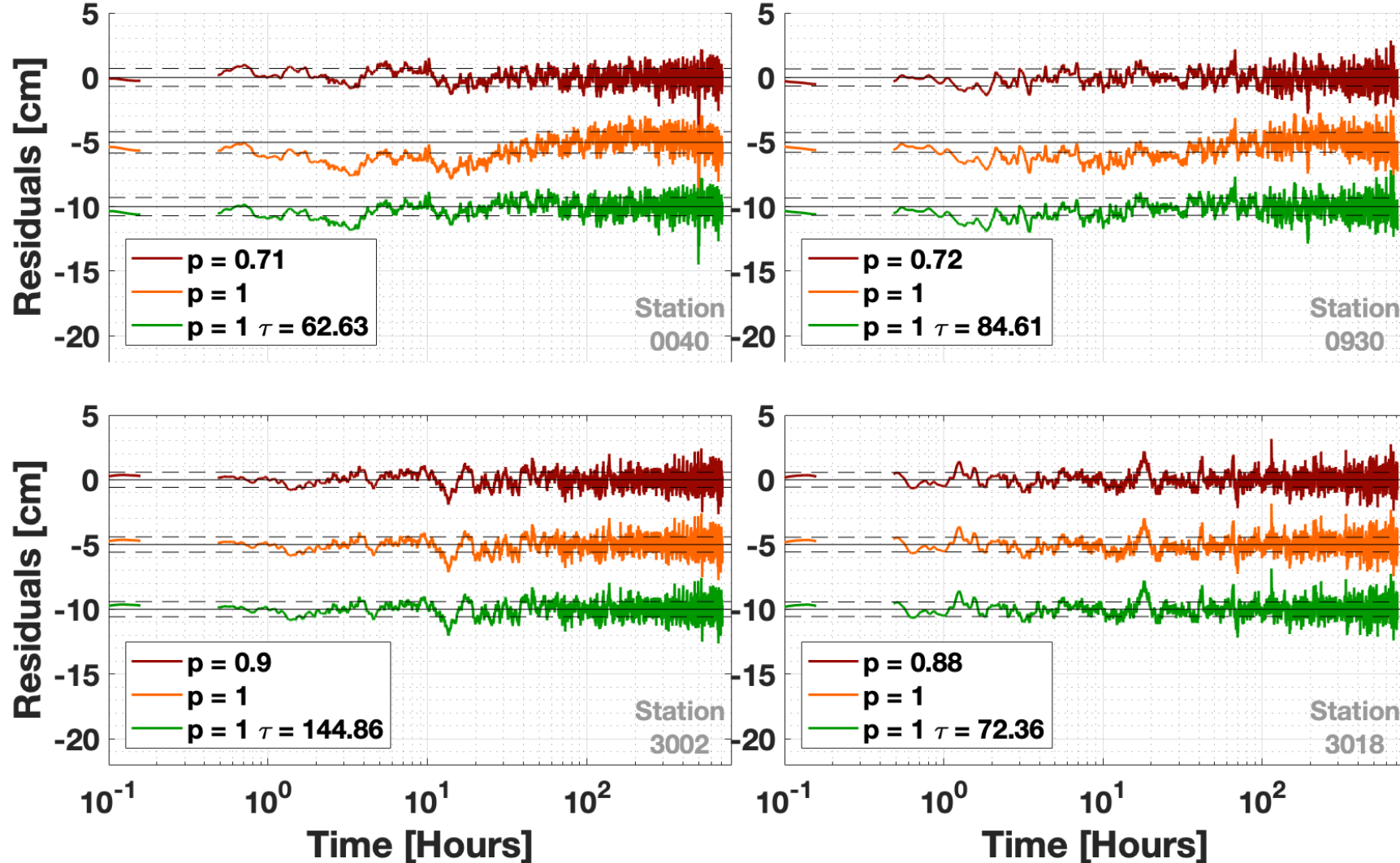
→ Non-Linear least squares inversions to estimate parameters



→ Exponential Decay is not working (purely viscoelastic mechanism excluded)

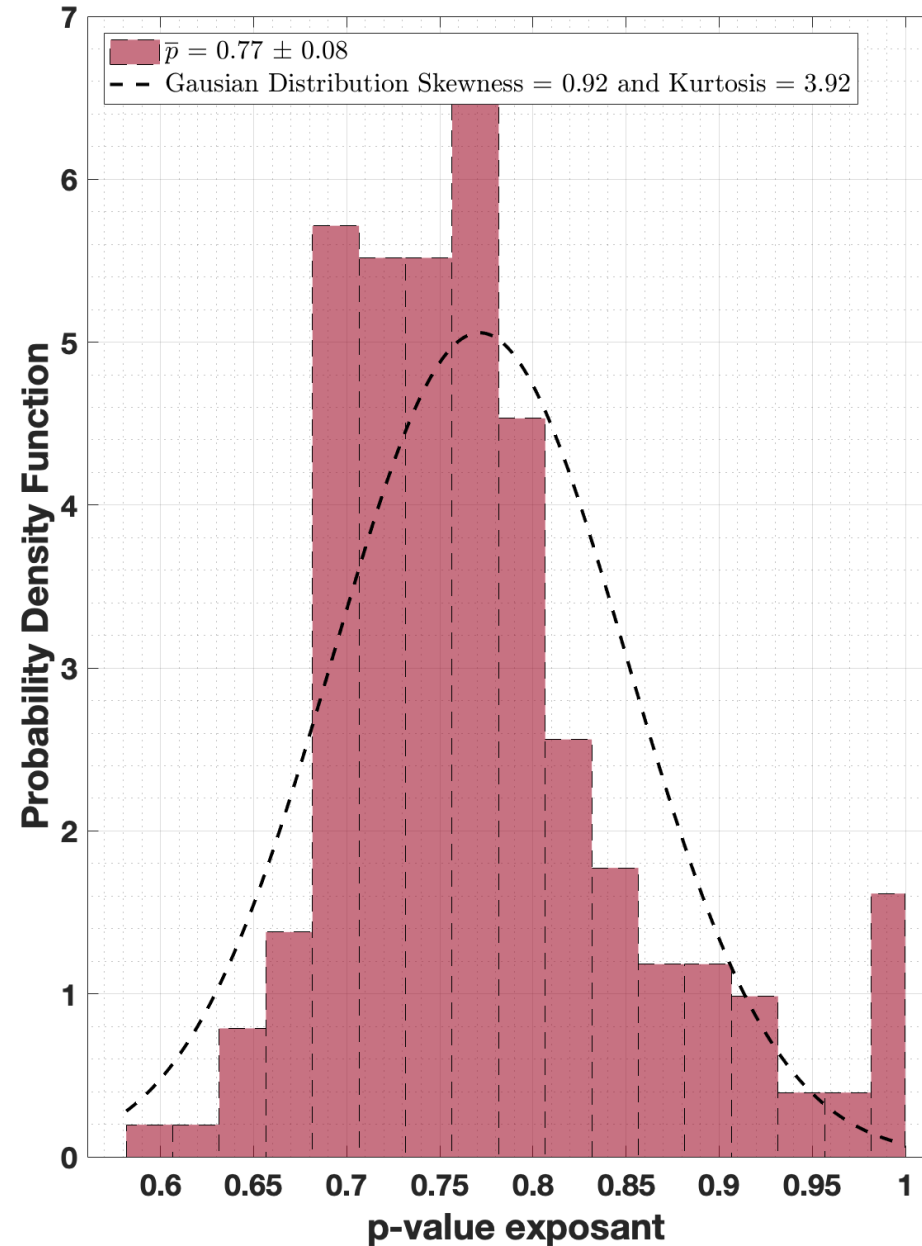
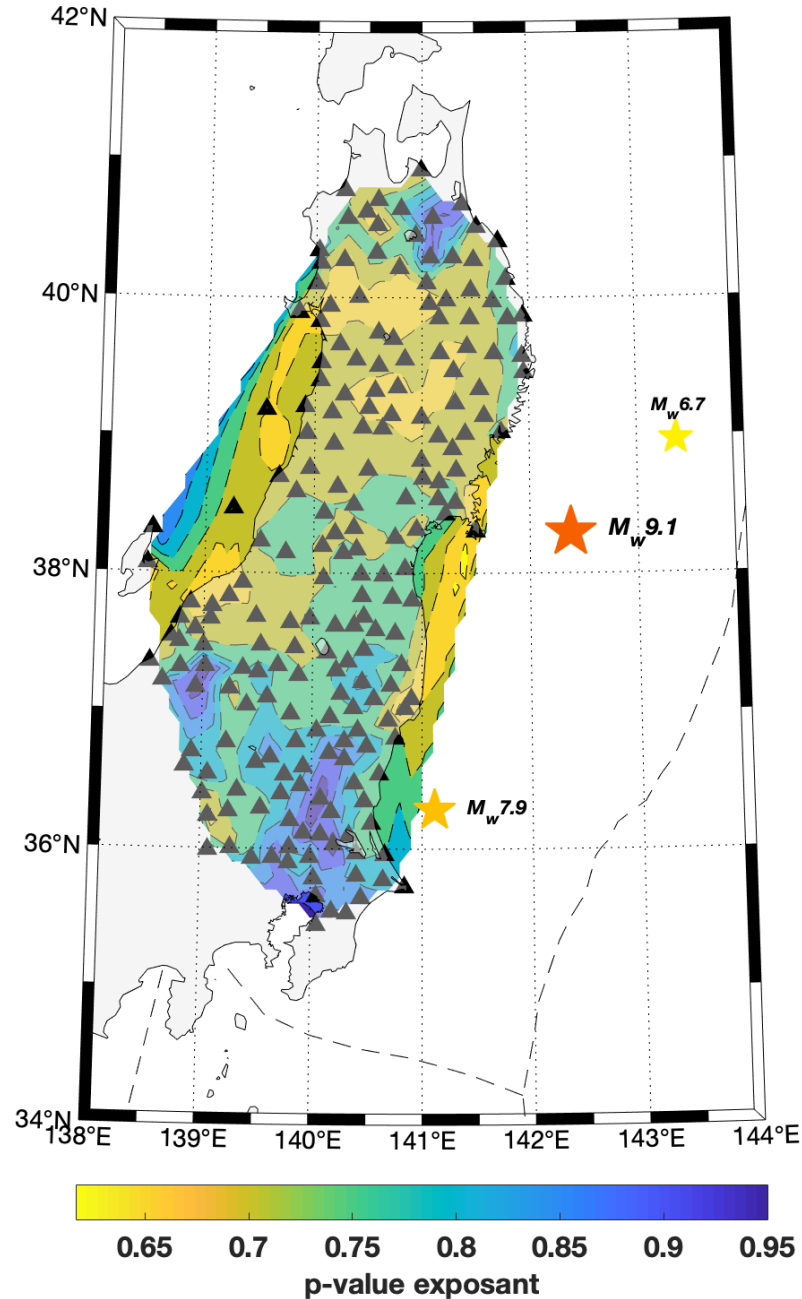
→ Logarithmic Decay is not working for the first ~40 hours (Afterslip with an Omori-like with $p=1$ assumption excluded)

Temporal Evolution – Fits and Residuals



- ➔ Based on residuals analysis Afterslip with an Omori-like relaxation with $p \neq 1$ explained the data and even the first ~40 hours of the deformation
- ➔ Combination of logarithmic and exponential decay also explained the data (more parameters involved)

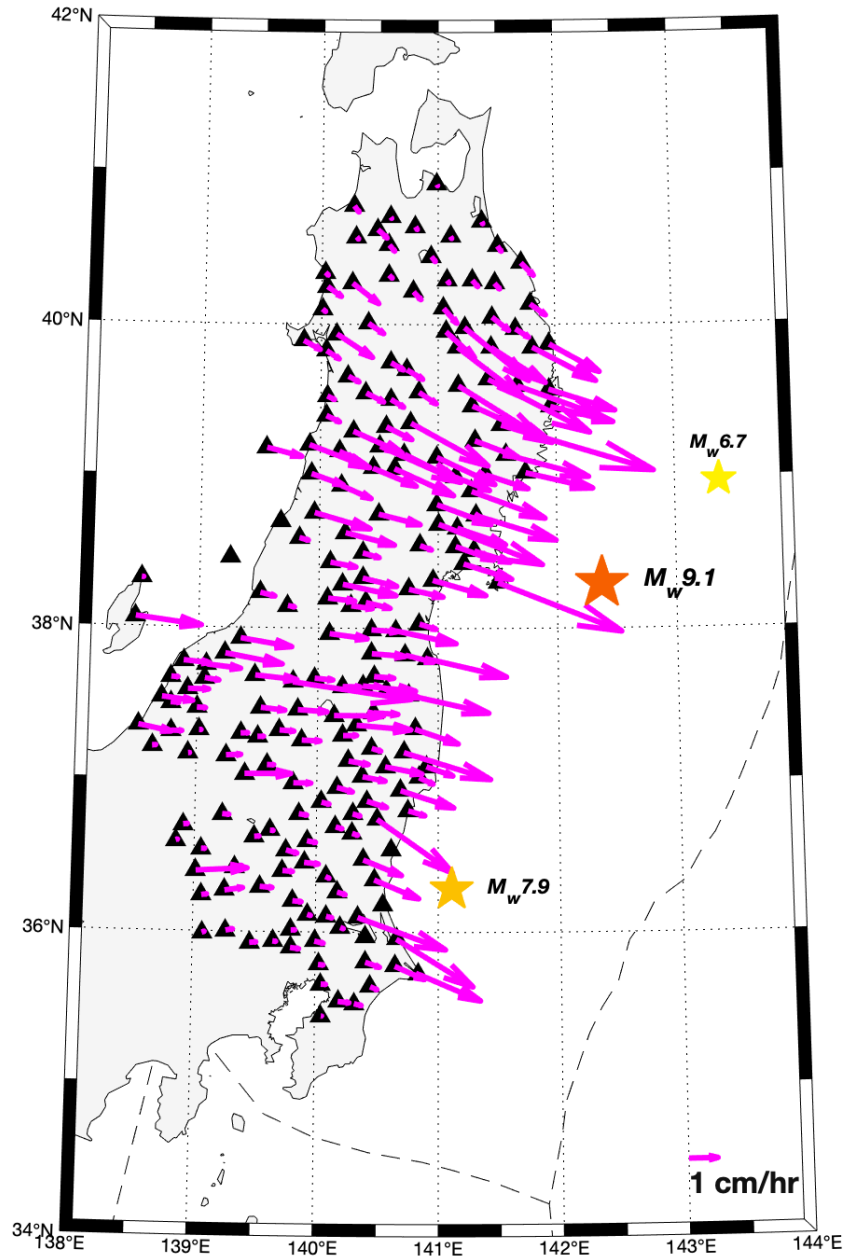
Temporal Evolution – Spatial Variations of $p \neq 1$



→ $p \sim 0.7$ seems to explain postseismic data

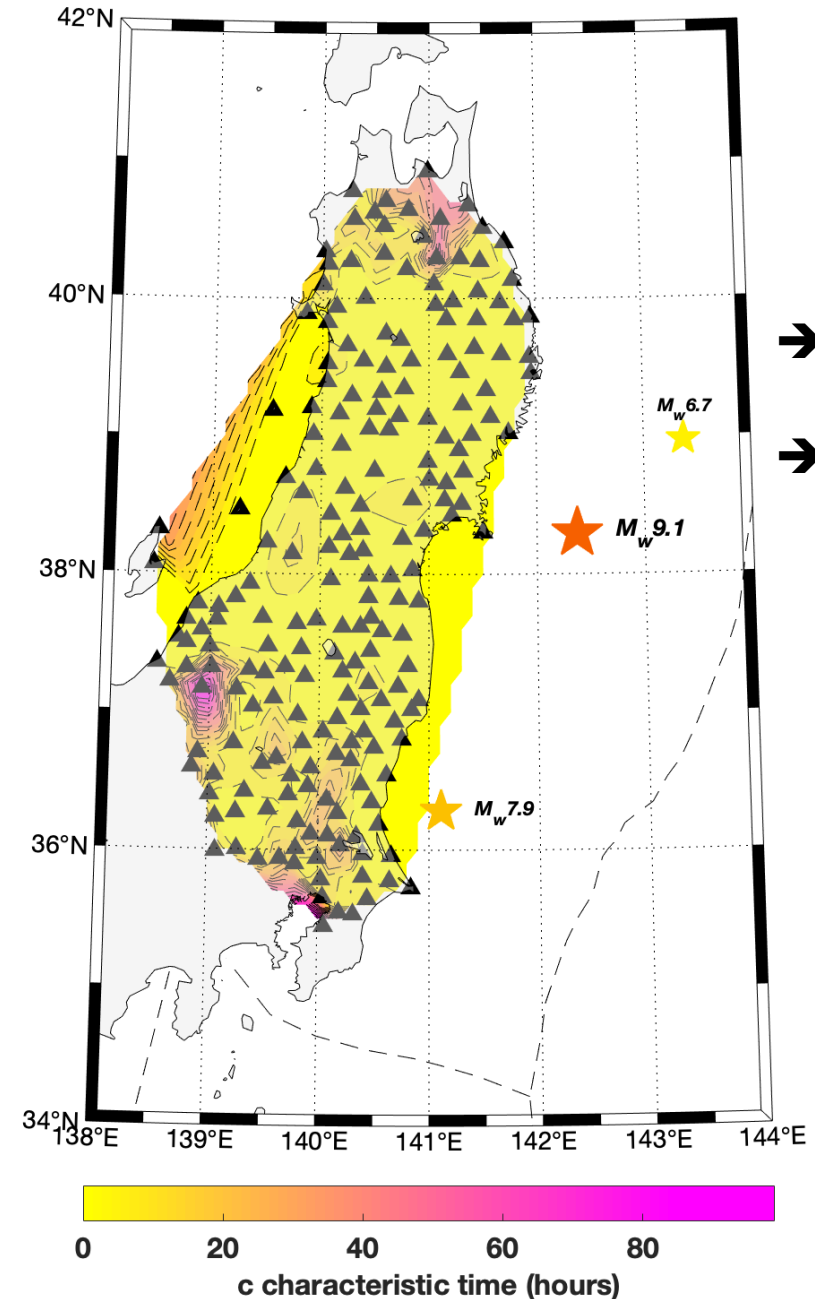
→ Except for a small region near Ibaraki-Oki aftershock location where p-values are close to 1.

Temporal Evolution – Spatial Variations of v_0 and c



→ v_0 initial velocities are higher near the coast.

→ cm/hr signal

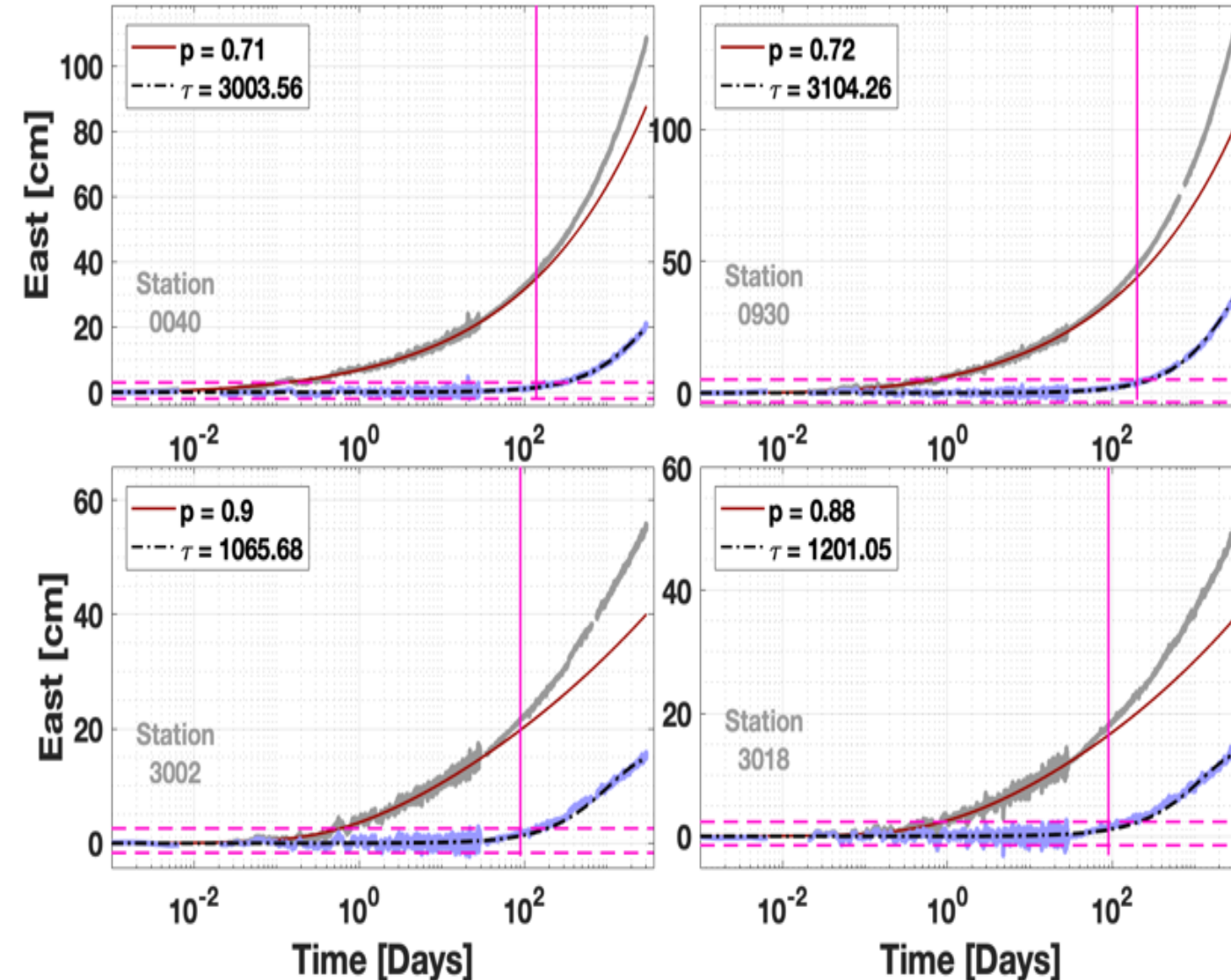


→ c characteristic time

→ C -values are < 10 hours

Temporal Evolution – For a larger time scale

- We extended our 30-s time series of the first month with daily solutions until ~7 years after the mainshock.
- We detrended our Time Series with Interseismic Velocities.
- We checked the $p \neq 1$ model acceptability for a larger time scale and we improved it



→ Red curves are model obtained for the first month

→ The model doesn't fit the data after some years.

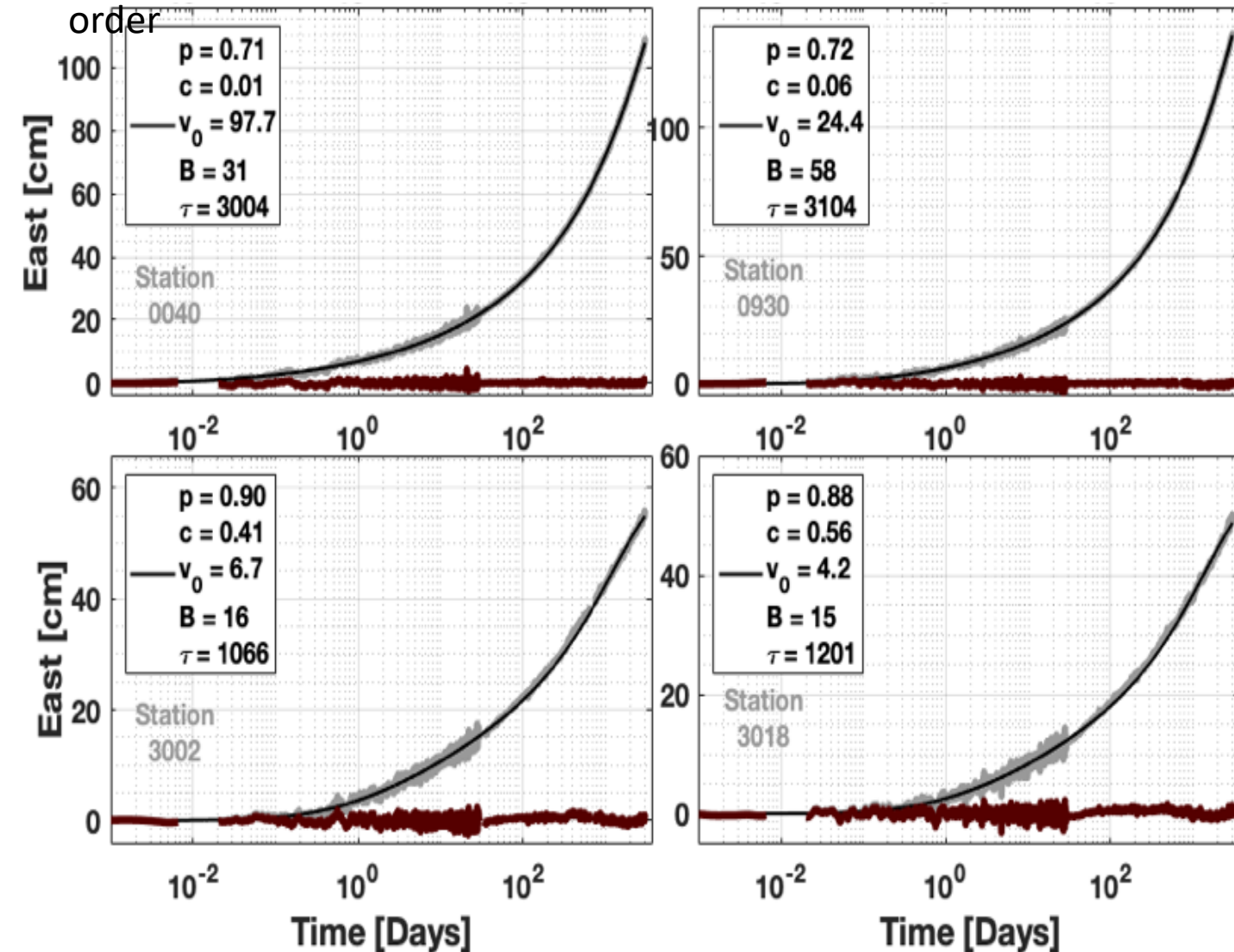
→ Blue curves are residuals computed.

→ We tried to model our residuals with an exponential decay.

Temporal Evolution – For a larger time scale

→ To explain completely the data (flat brown residuals), combination of:

- Afterslip ruled by an Omori-like relaxation with $p \neq 1$.
- Viscoelastic mechanism with τ characteristic times value of ~ 9 years, corresponding to a η viscosity of $1.0e+19$ Pa.s



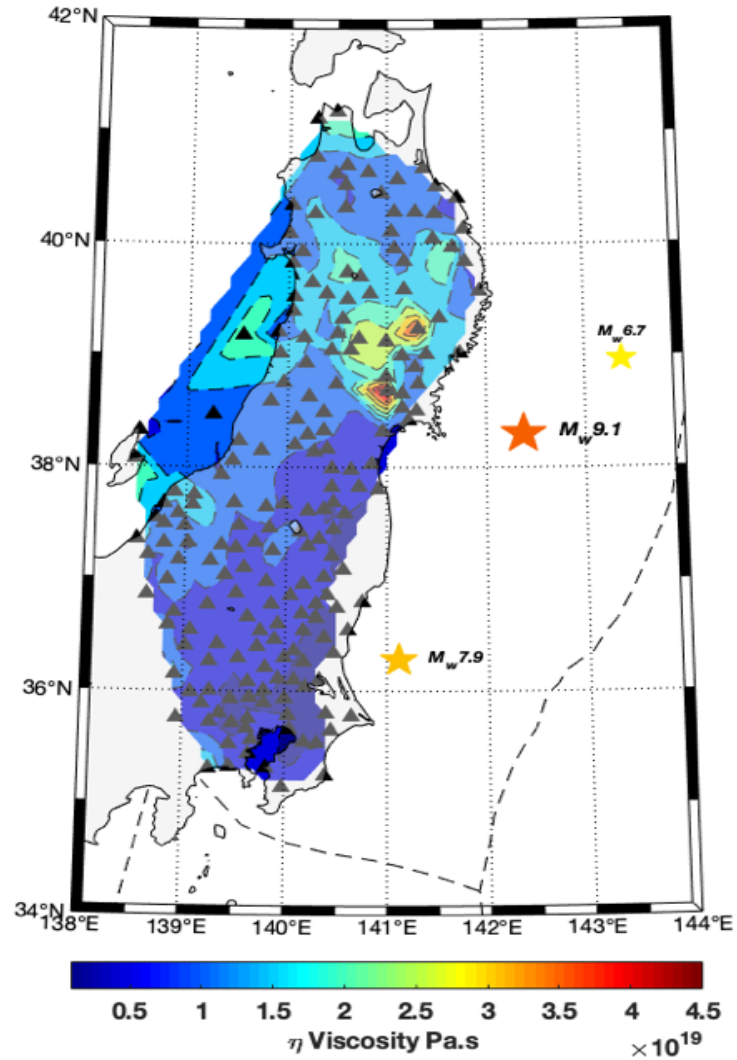
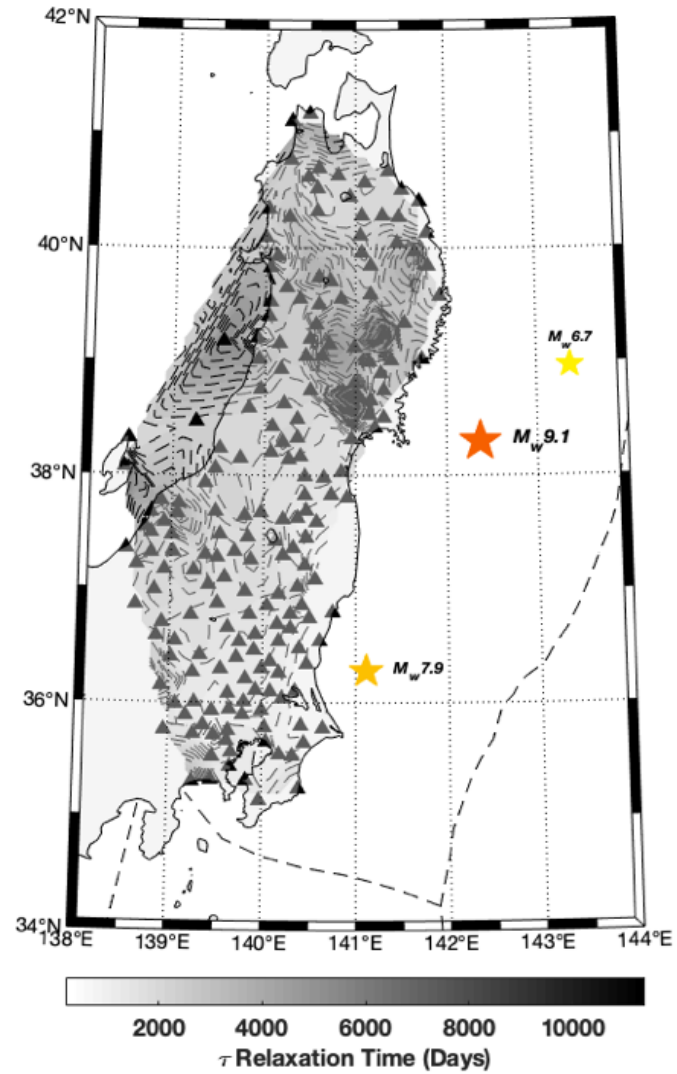
$$\rightarrow u(t) = u_1(t) + u_3(t)$$

$$\rightarrow u(t) = A_1 \left(1 - e^{\frac{-t}{\tau}}\right) + \frac{v_0 c}{1-p} \left(\left(1 + \frac{t}{c}\right)^{1-p} - 1 \right)$$

→ We concluded with a prevalency of afterslip in the early postseismic deformation of Tohoku-Oki earthquake.

→ A viscoelastic mechanism is necessary to explain the data for a larger time scale.

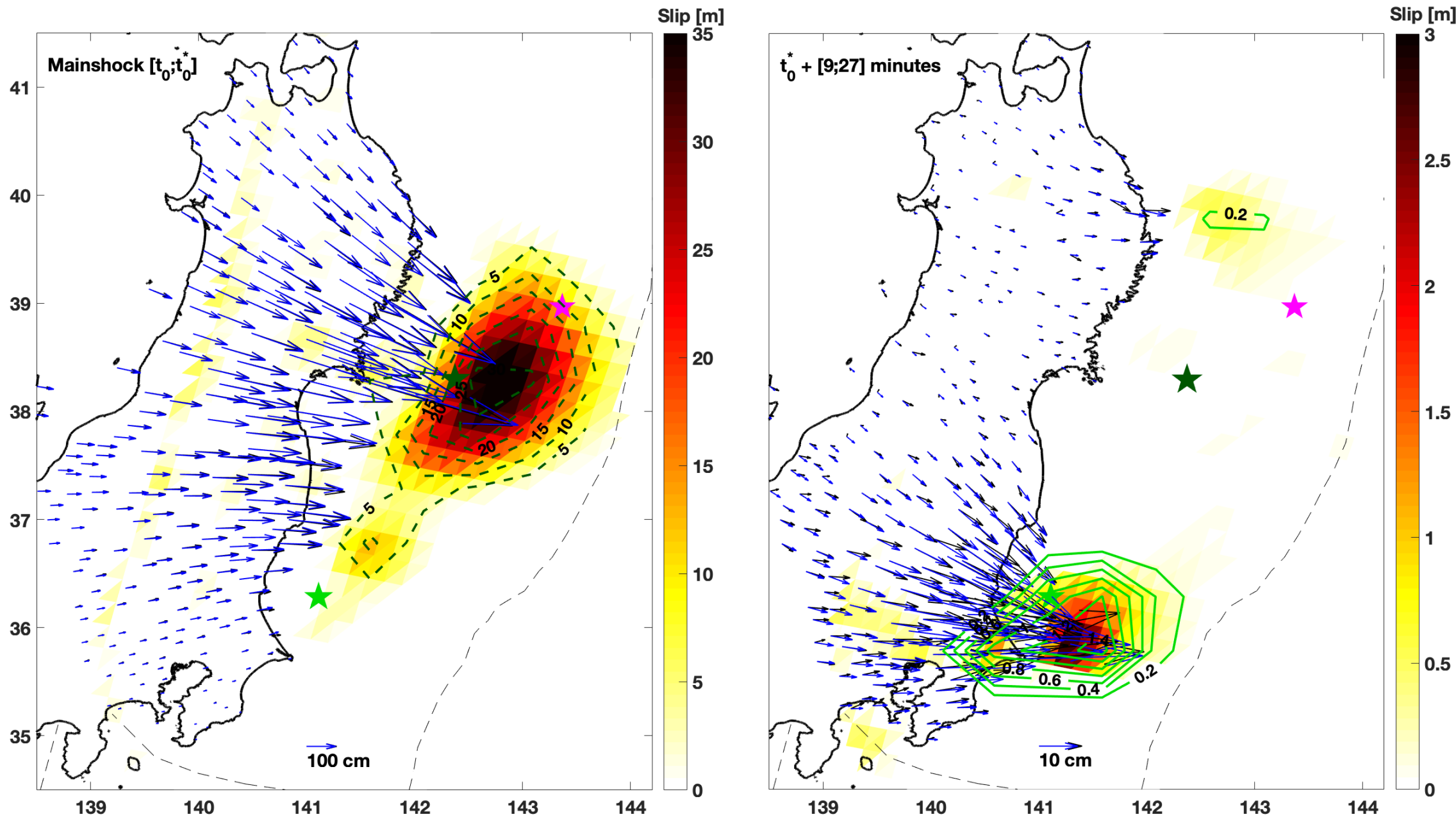
Temporal Evolution – Spatial Variations τ and η



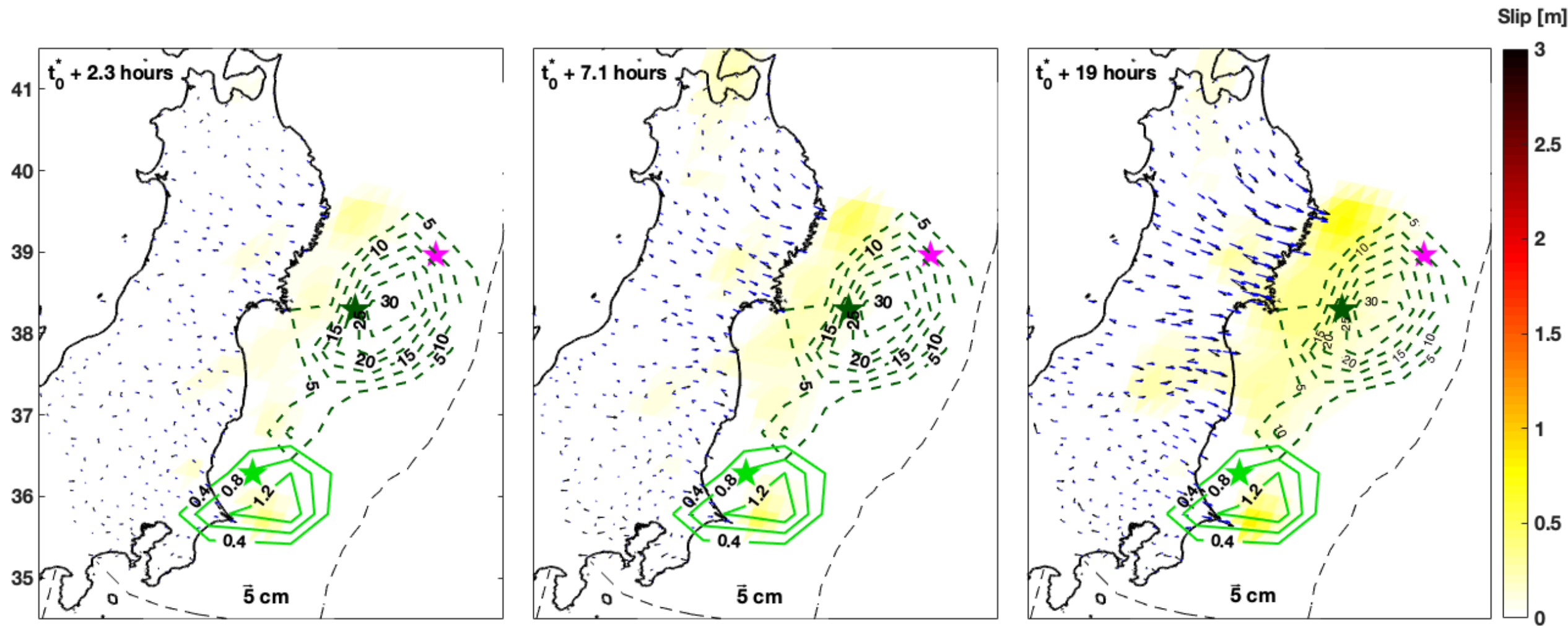
Spatial Distribution – How to analyze the data?

1. Estimation of coseismic from M_w 7.9 Ibaraki-Oki aftershock (~30 minutes after the mainshock)
2. TS are corrected from the aftershock displacement
3. For the postseismic study we select time windows of increasing durations, each corresponding to the same displacement values (obtained on a witness station) ➔ 12 Time Windows obtained
4. The coseismic offsets, and each time windows are inverted for slip on the subduction interface using a regularized least-square inversion.
5. Greens functions are computed for a 3D plate interface assuming an elastic half space (Okada 1995)

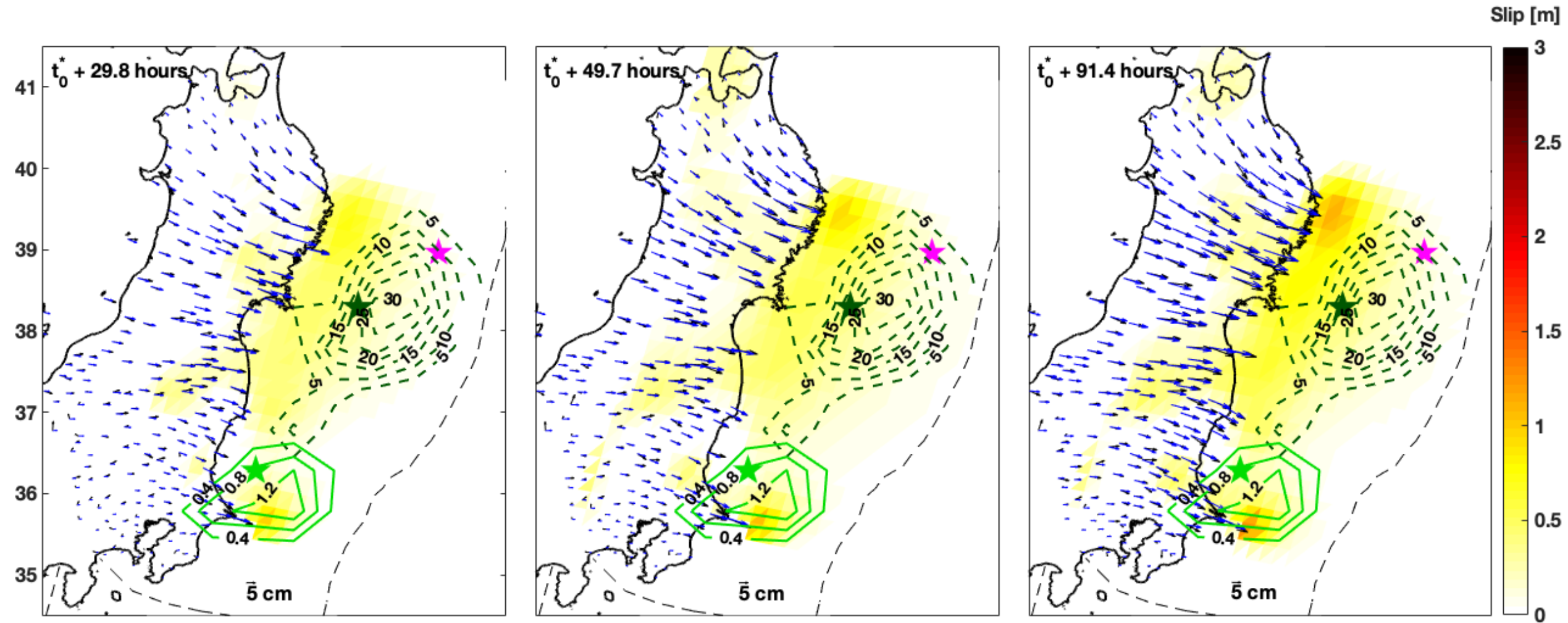
Spatial Distribution – Mainshock and Aftershock Slip



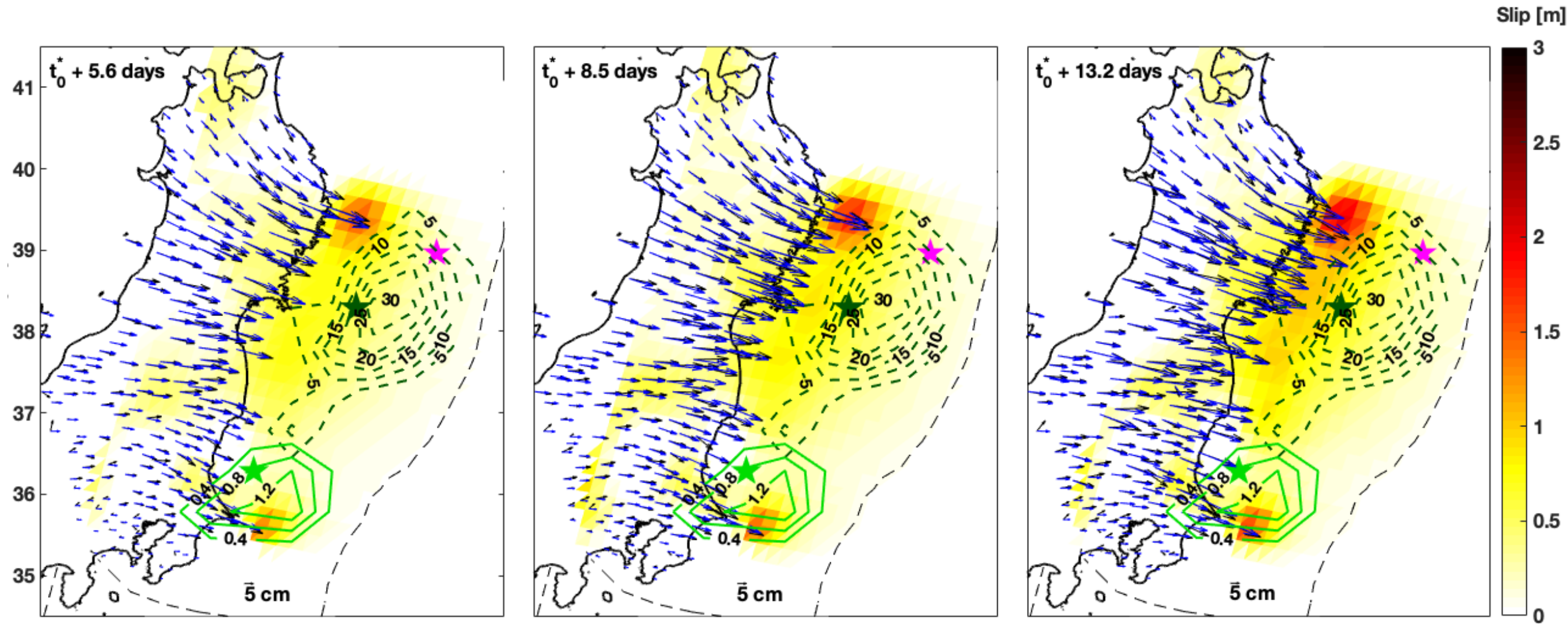
Spatial Distribution – + 2.3, + 7.1 and + 19 hours postseismic slip



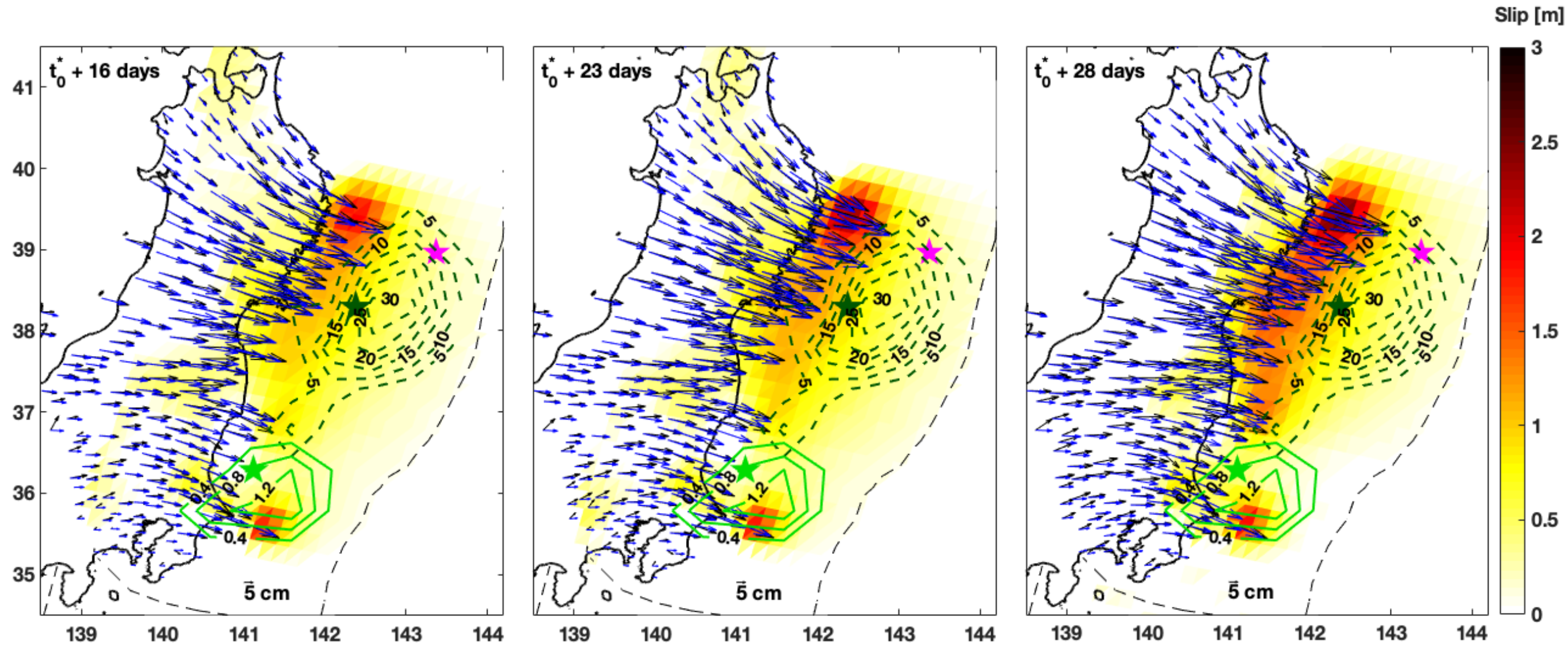
Spatial Distribution – +29.8, + 49.7 and + 91.4 hours postseismic slip



Spatial Distribution – +5.6, + +8.5 and + 13.2 days postseismic slip

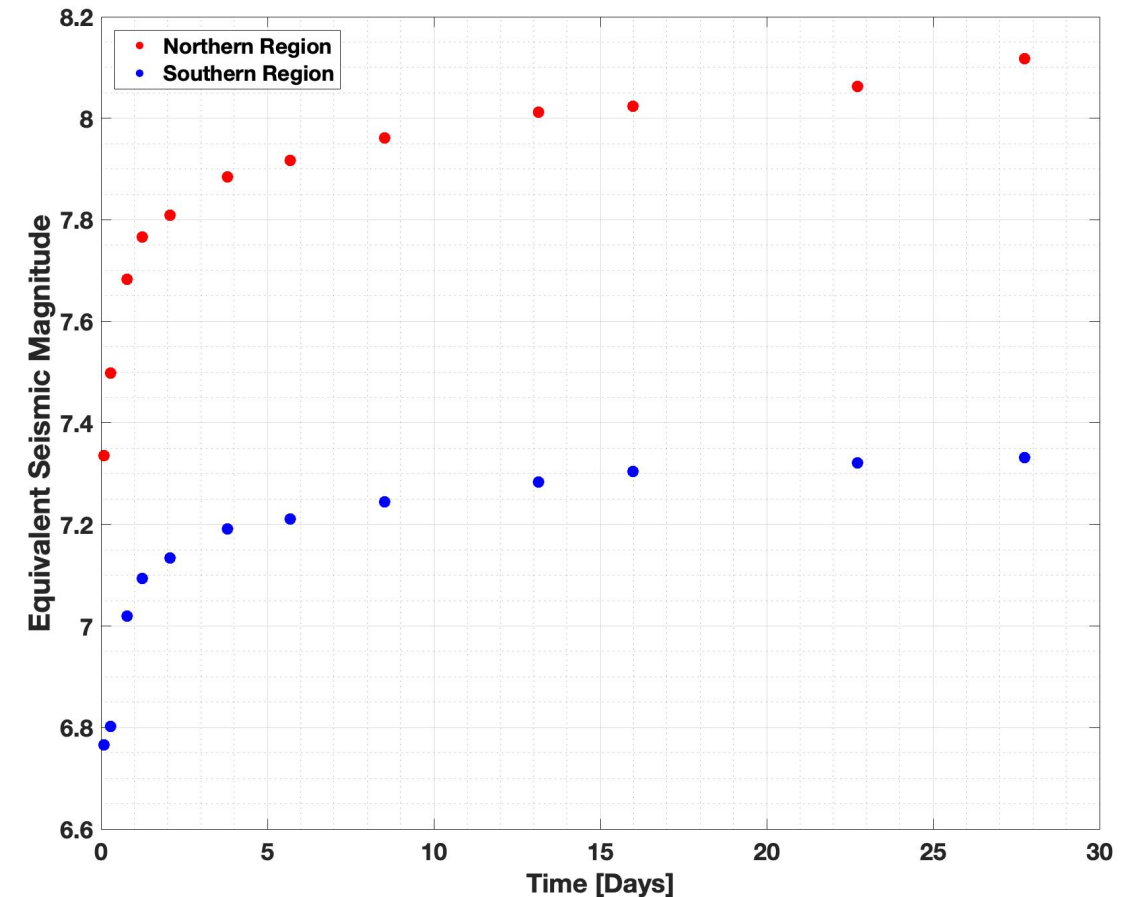


Spatial Distribution – + 16, + 23 and + 28 days postseismic slip



Conclusions

1. Kinematic Processing allows us to obtain 30-s high-rates solutions
 - ➔ Observations of the details of the early postseismic phase of Tohoku-Oki and the largest Ibaraki-Oki aftershock which occurred ~30 minutes after the mainshock in GPS Time Series
 - ➔ Computation of slip distribution of the mainshock and the M_w 7.9 Ibaraki-Oki aftershock
 - ➔ Computation of slip distribution of the postseismic slip
 - northern region with an equivalent magnitude $M_w \sim 7.7$ after ~20 hours and $M_w \sim 8.1$ after one month.
 - Southern region with an equivalent magnitude $M_w \sim 7.05$ after ~20 hours and $M_w \sim 7.3$



2. Modelling of temporal evolution
 - ➔ The early postseismic displacement can be explained with an Omori-like model:
 - $p \sim 0.7$ in the northern region where we identify afterslip from the mainshock
 - $p = 1$ in the southern region, corresponding to the afterslip region of the Ibaraki-Oki aftershock
 - ➔ On the long-term, additional mechanism as viscoelasticity have to be considered to explain the postseismic displacement evolution.