Geodetic inference on decadal afterslip following the 2011 Tohoku-oki earthquake

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What controls postseismic crustal uplift ?

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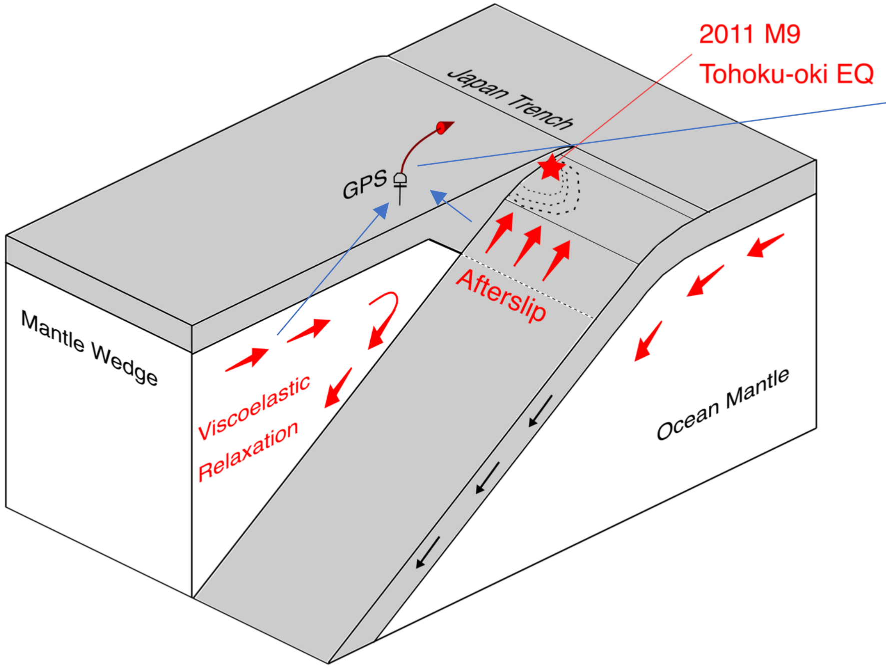
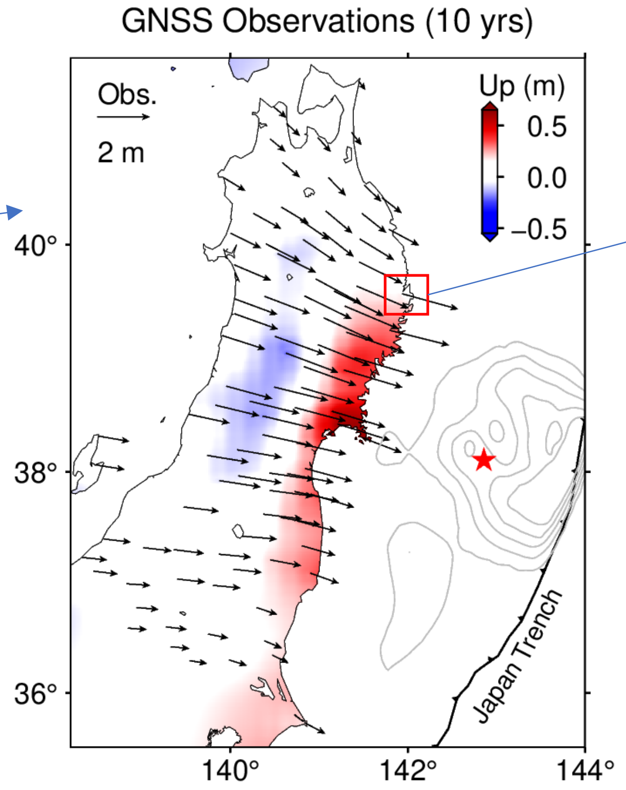
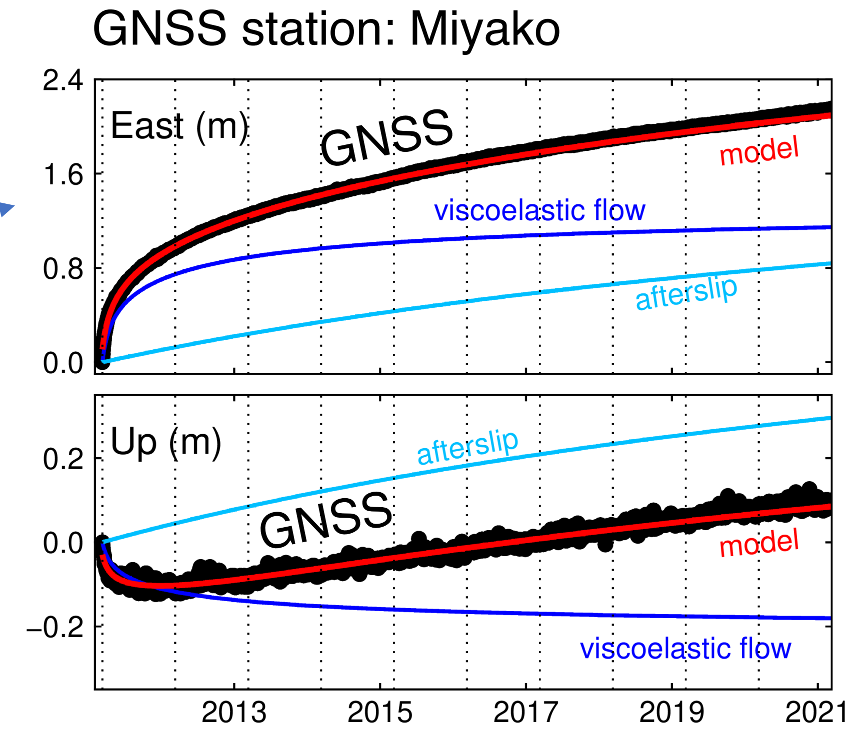
Subduction-zone earthquake



Schematic diagram for viscoelastic relaxation (in mantle) and afterslip (on megathrust)





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Standard approach (previous):

Physical model → Prediction of GNSS time series
(e.g., FEM)

New approach *(This study)*:

Designing analytical expression

Incorporates rheology
+
Predicts GNSS time series

GNSS Time series → Viscoelastic relaxation
→ Afterslip

Function model based on transient rheology

$$D(t) = C_1\left[2 - \left(1+\frac{t}{\tau_1}\right)^{-1/(n-1)} - \left(1+\frac{t}{\tau_2}\right)^{-1/(n-1)}\right] + C_2\left[1 - 2\lambda coth^{-1}\left(e^{\frac{2V_0G^*}{\lambda}t} coth\frac{1}{2\lambda}\right)\right] + C_3$$

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GNSS displacements

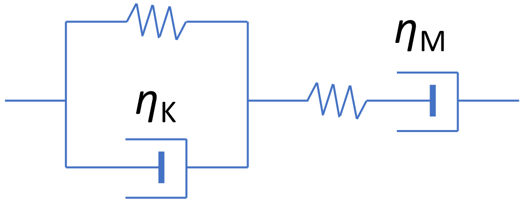
Relaxation timescale

Viscoelastic relaxation

Afterslip

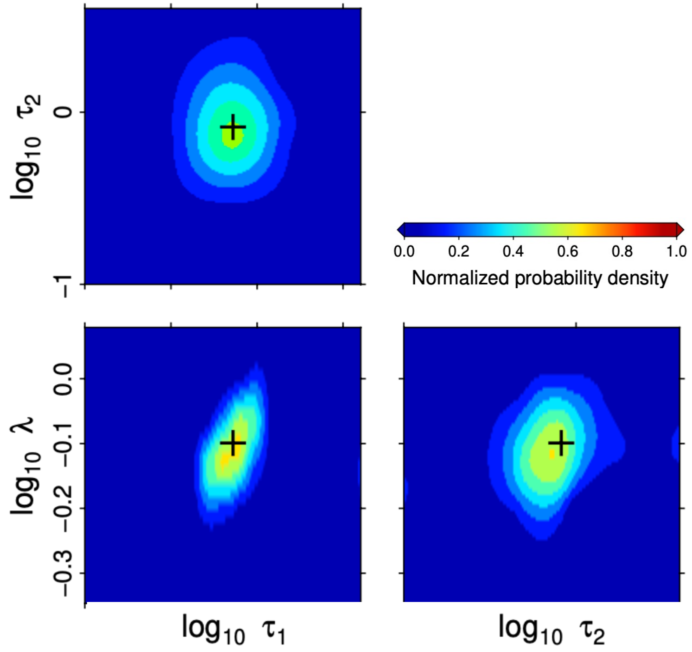
Frictional parameter

Rate-strengthening friction law
(Barbot et al. 2009, *JGR*)



Mimic the stress-response of
power-law Burgers rheology

(Muto et al. 2019 *Sci. adv.*;
Dhar et al. 2022 *GJI*
Barbot et al. 2009 *JGR*)



Bayesian search for model parameters
τ_1, τ_2, λ

Sampling method:
GP-UCB

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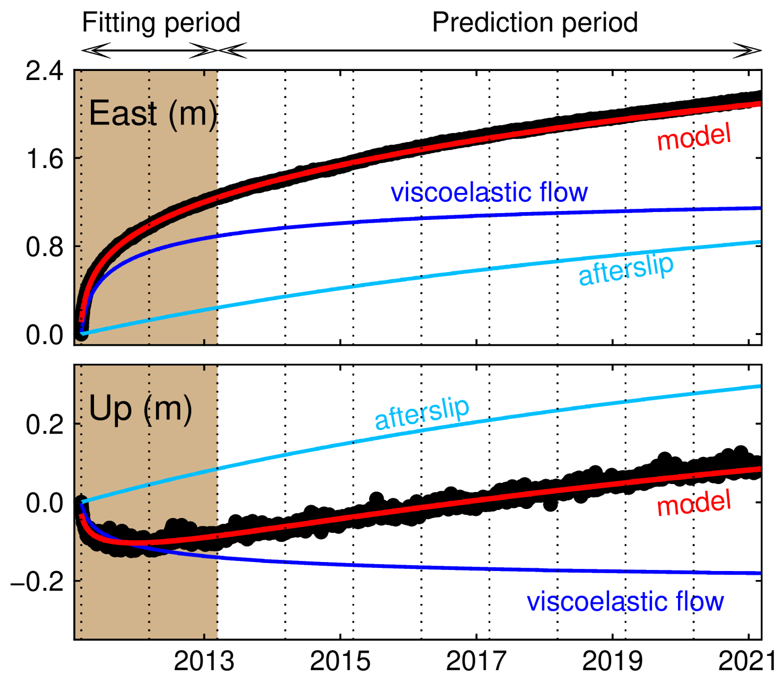
Function model and GNSS time series



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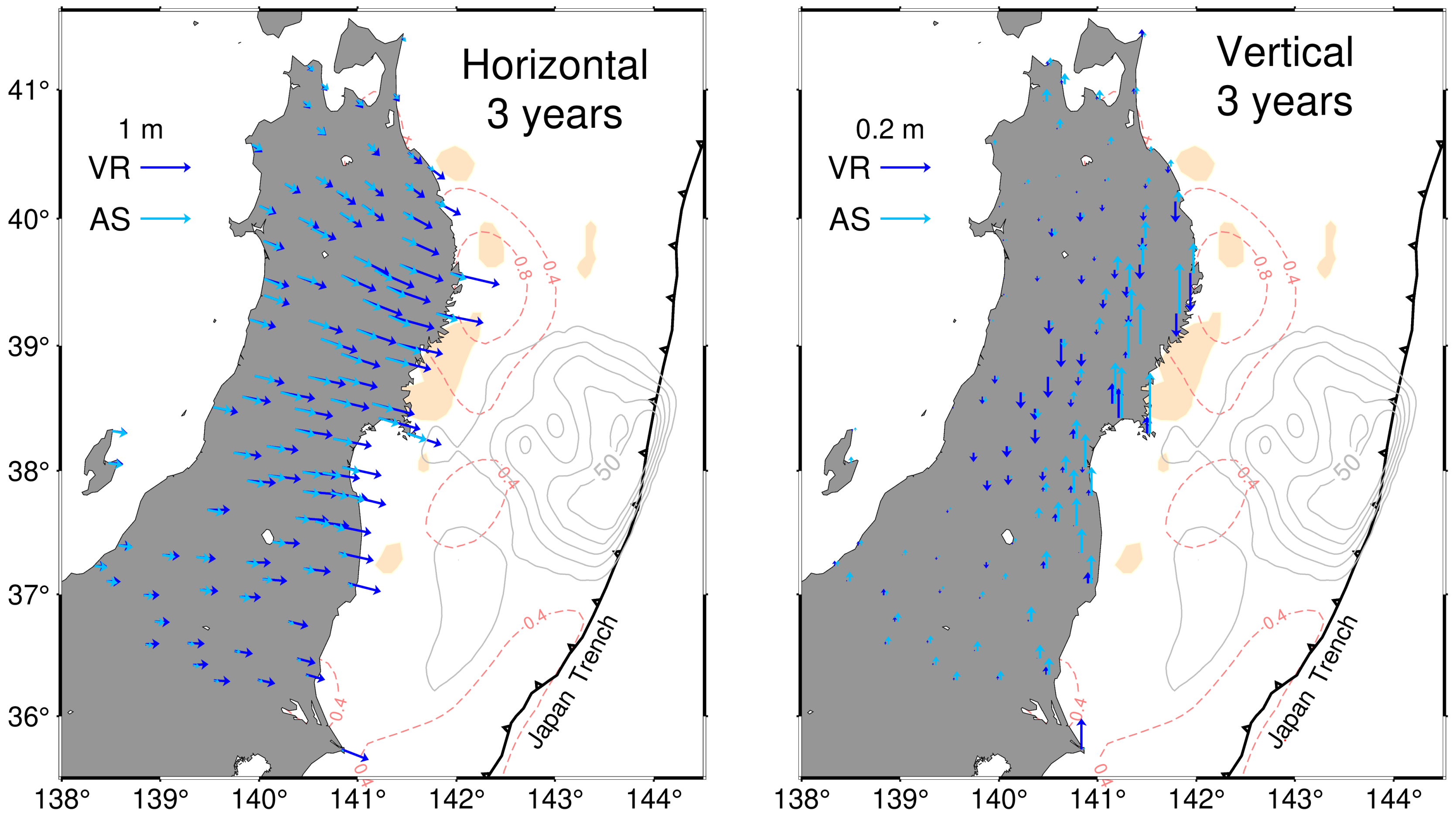
7 stations used to train the model
91 stations used for evaluation



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Spatial distribution of viscoelastic relaxation and afterslip contribution

Afterslip controls postseismic crustal uplift

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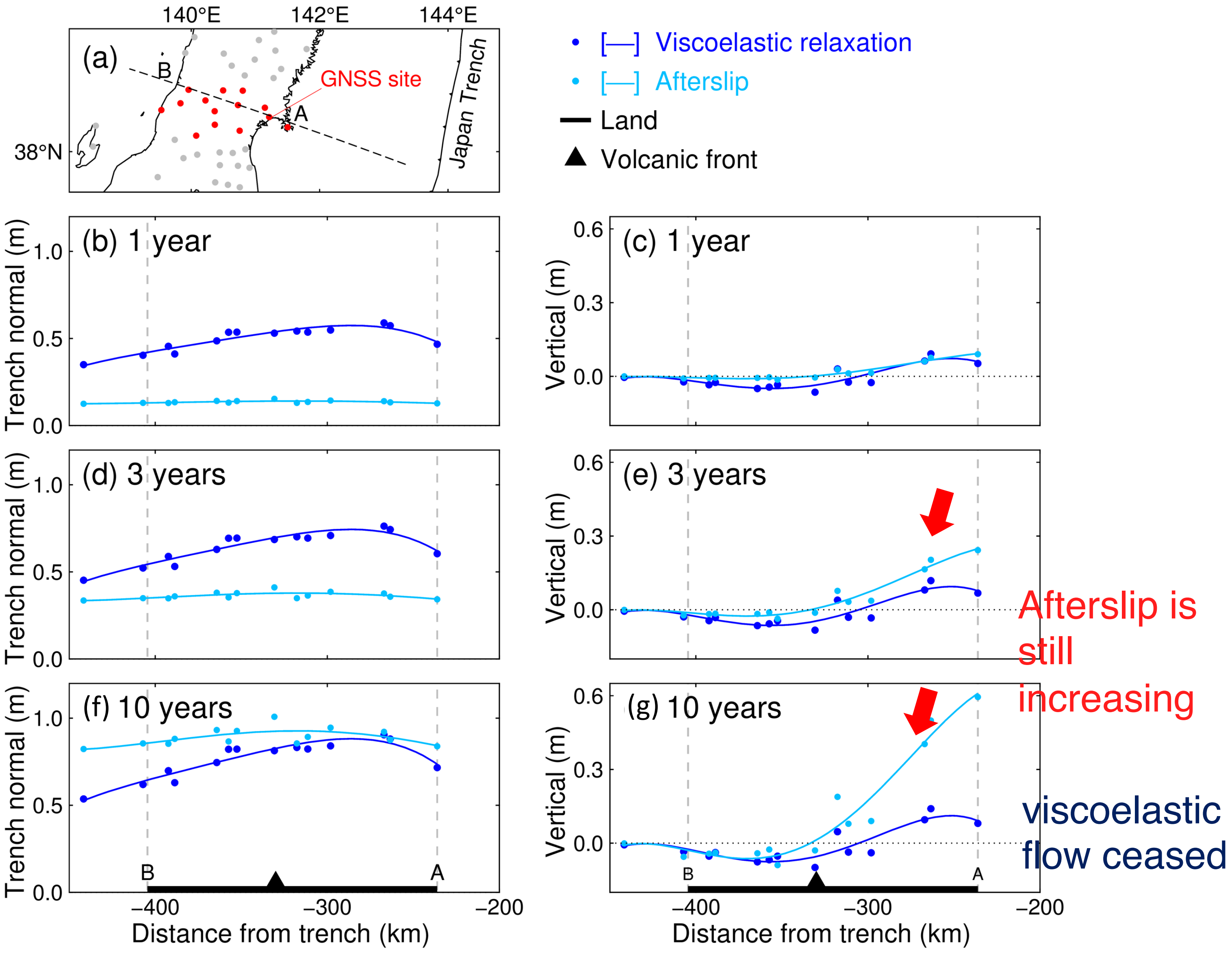
For horizontal compoent,

<u>Older consensus:</u>
Afterslip > viscoelastic flow

<u>New findings:</u>
Viscoelastic flow > Afterslip

[e.g.,
Sun et al. 2014 *Nature;*
Freed et al. 2017 *EPSL*;
Fukuda & Johnson 2021 *JGR*; Muto et al., 2019 *Sci. Adv.]*



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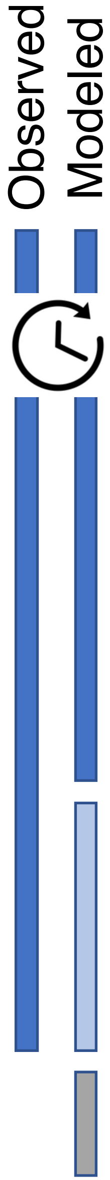

Consistent with previous physical models (0-7 yr)

This study (7-10 yr)

Future prediction (10-~30 yr)

Afterslip continues even after a decade

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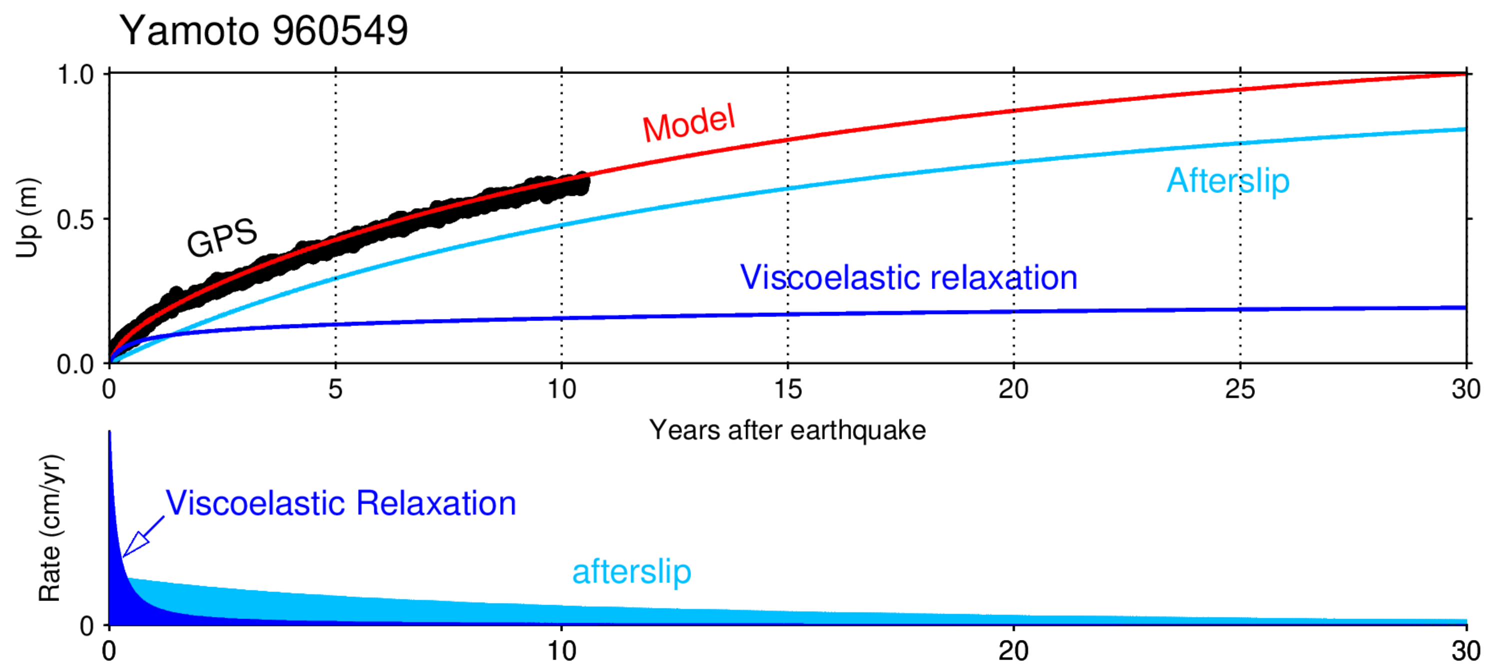
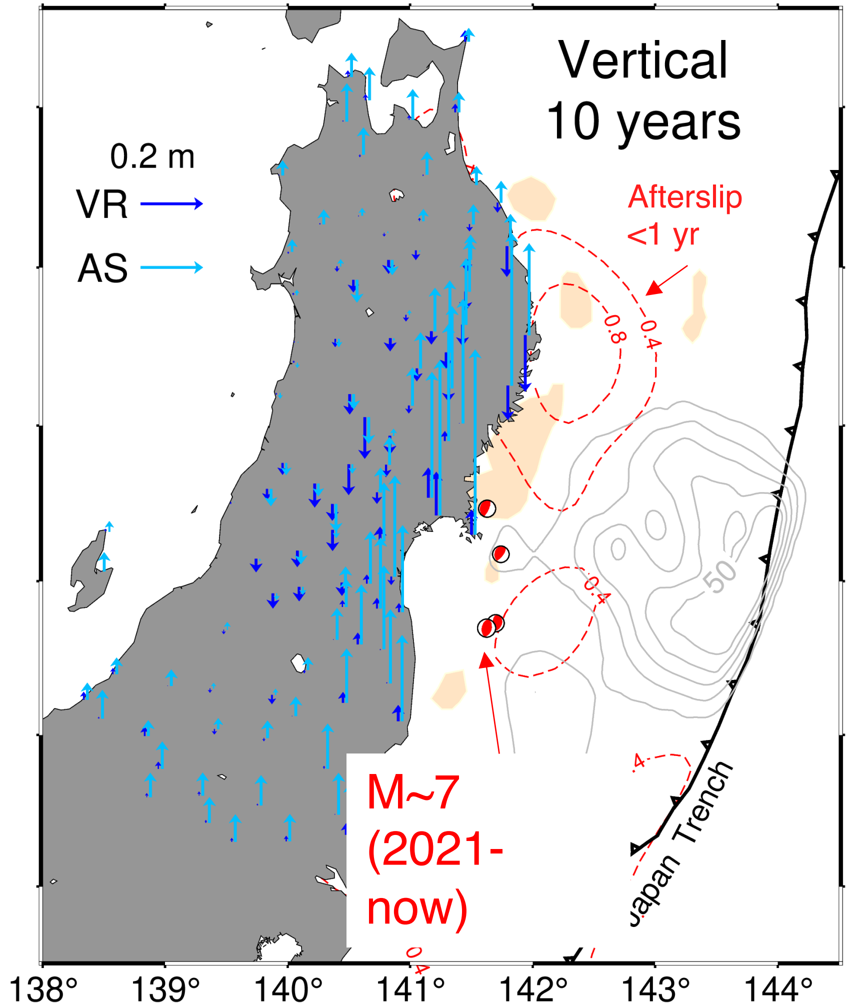


Afterslip triggers small repeating earthquakes and M~7 large earthquakes



- Decadal persistent of afterslip (~10-30 years) for forearc NE Japan
- Negligible contribution of viscoelastic relaxation at decadal scale

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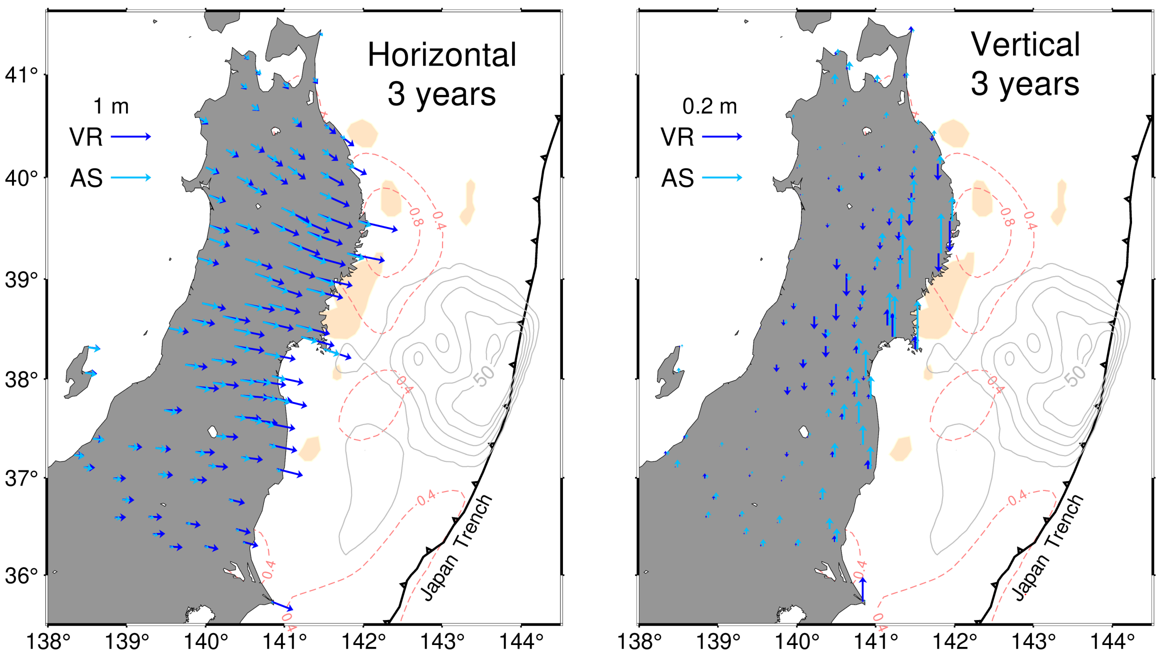
Take-home points

Breaking GNSS time series into viscoelastic relaxation and afterslip using only analytical expressions.

Q: What controls postseimsic crustal uplift at great subduction-zone earthquake?
Ans: Afterslip controls vertical motion at decadal timescale



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Thank you
for your attention!

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