Effect of Coseismic Stress Changes from the 1999 Chi-Chi and 2024 Hualien Earthquakes on the Ambient Stress Field

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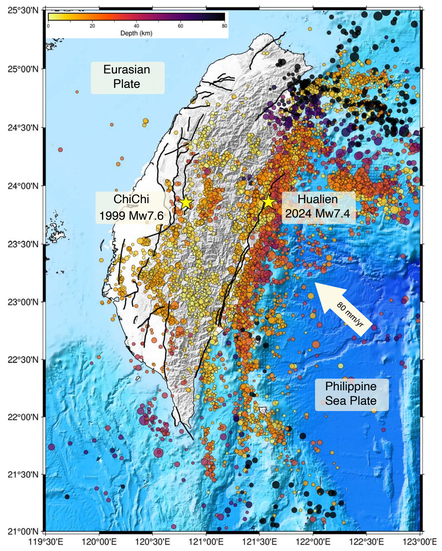
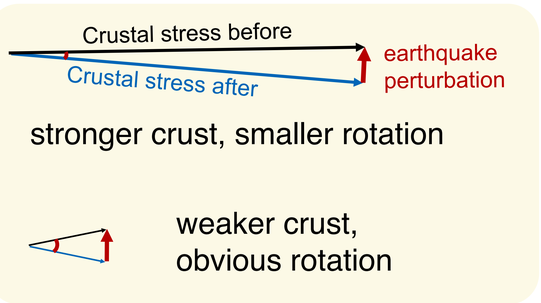
Question

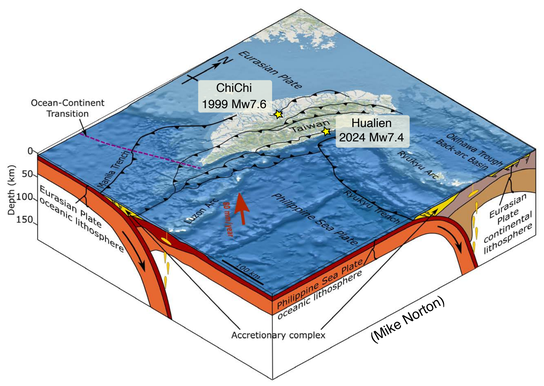
Can Mw 7+ earthquakes measurably reorient the ambient crustal stress field?

Taiwan is a natural laboratory: Chi-Chi ruptured the western fold-and-thrust belt, while Hualien ruptured the eastern plate-boundary system.

If coseismic stress rotates the stress orientation, ambient deviatoric stress cannot be much larger than the earthquake perturbation.





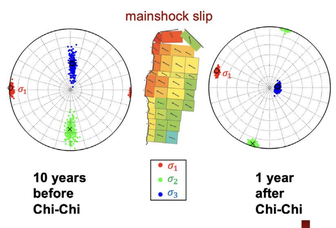


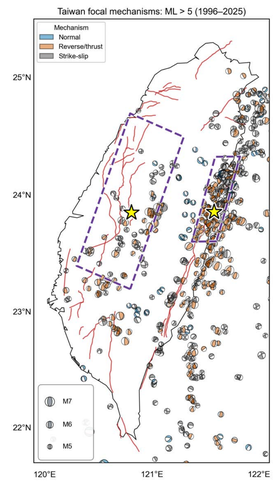
How we measure stress orientation and amplitude

Three-step approach

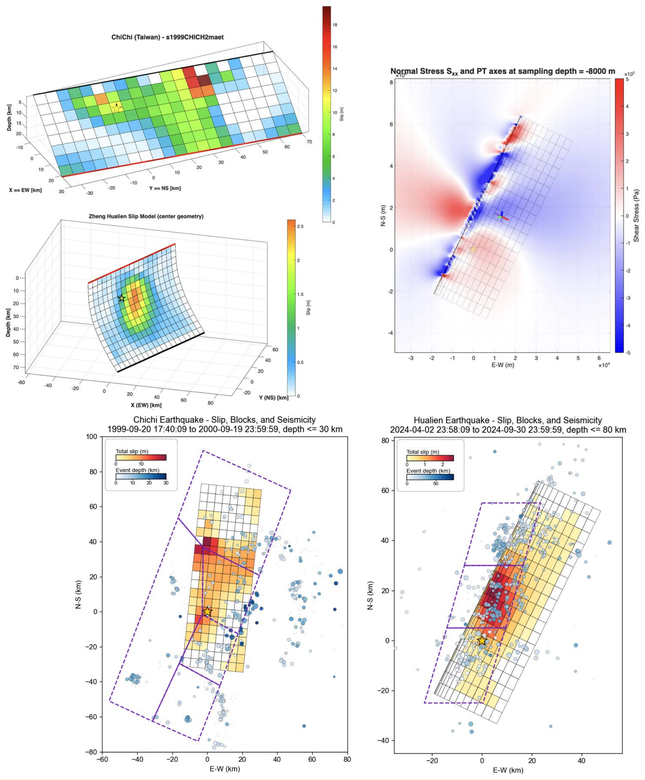
1. Stress inversion
Invert focal mechanisms for orientations of stress principal axes, and shape ratio $R=(\sigma_1 - \sigma_2)/(\sigma_1 - \sigma_3)$.
Compare pre- and post-mainshock stress states in regional blocks. (Vavrycuk, 2014)
normalized deviatoric stress tensor τ before & after

Focal Mechanism Catalogs
- First motion polarities (Wu et al., 2010)
- Full-waveform inversion AutoBATS (Jian et al., 2018)





2. Coseismic static stress change
Slip models are converted into static stress perturbations using Okada elastic dislocations.
3D coseismic stress changes $\Delta\sigma$



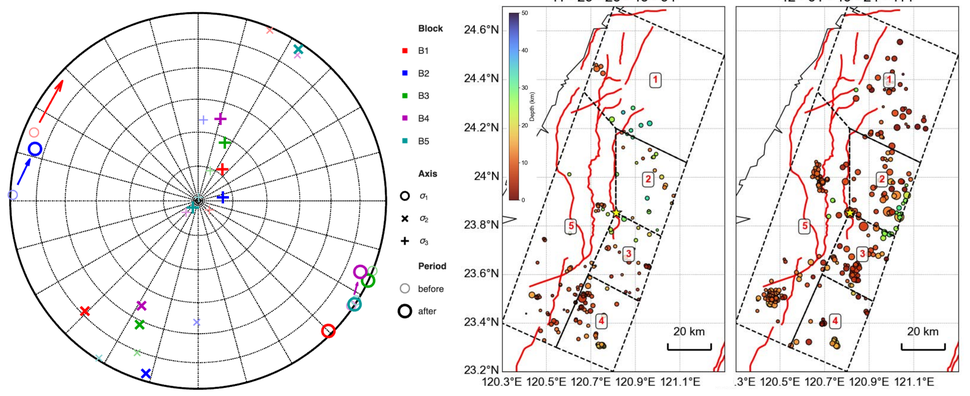
3. Amplitude inversion
Scale the normalized before- and after-mainshock stress tensors so that their difference matches the modeled 3-D coseismic stress change.
Estimate absolute deviatoric stresses c before and after.

$$\Delta\sigma \approx c_{after}\,\tau_{after} - c_{before}\,\tau_{before}$$

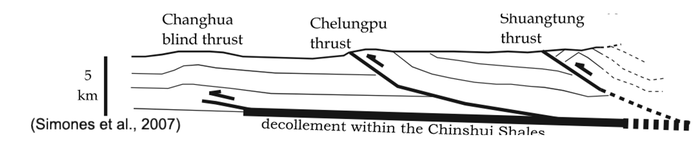
Result 1: Chi-Chi Rotated the Western Stress Field

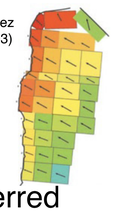
Selected blocks in the western fold-and-thrust belt show principal-axis rotations of roughly 20° or more after the 1999 earthquake.

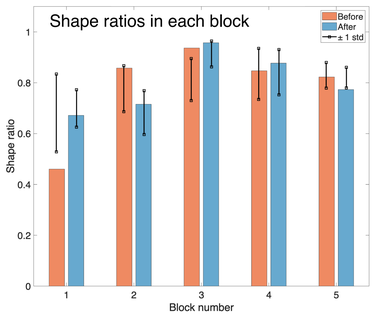
The largest changes occur in block 2 near major coseismic slip.



The rotation sense broadly follows the mainshock slip direction.

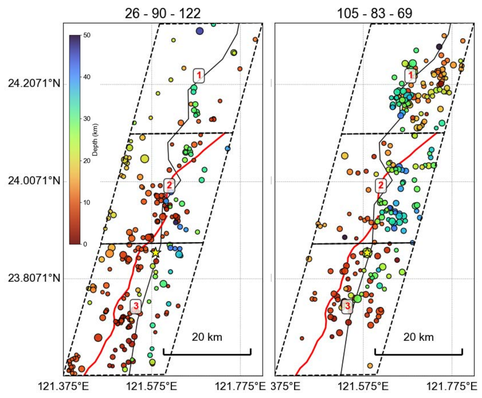






If a earthquake-induced stress change can rotate the inferred stress field this much, that implies ambient deviatoric stress is not greatly more than the earthquake-induced perturbation.

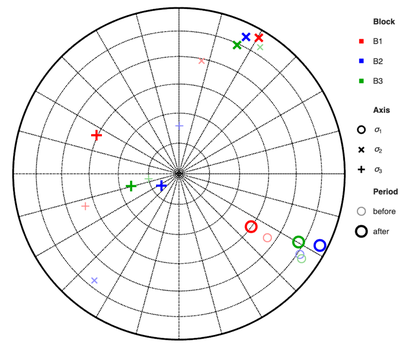
Result 2: Hualien Shows Smaller Rotation and R Changes

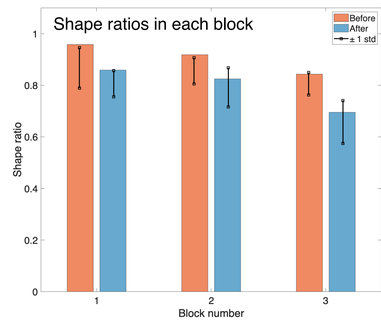


Hualien produces a different response: rotations are modest, but R decreases across the tested eastern blocks.

Shape ratio
$R = (\sigma_1 - \sigma_2)/(\sigma_1 - \sigma_3)$

Block	Before	After
1	0.96	0.86
2	0.92	0.83
3	0.84	0.70



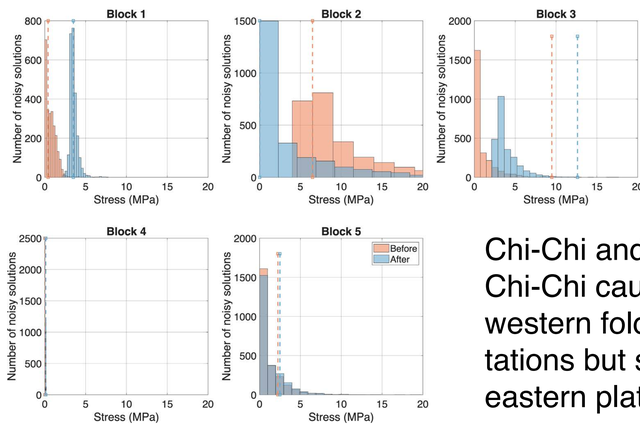


Eastern Taiwan may respond through stress-state reshaping rather than large rotation.

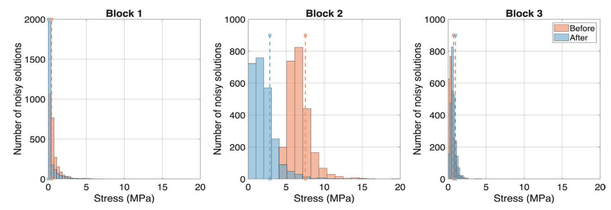
Preliminary Amplitudes

Initial amplitude inversions indicate stresses of a few MPa, but exact values remain sensitive to sampling location, slip model, and distance from finite-fault patches. We therefore consider these amplitudes as preliminary and do not yet report a preferred numerical range.

1999 Mw 7.6 Chi-Chi



2024 Mw 7.4 Hualien



Chi-Chi and Hualien produce different stress responses. Chi-Chi caused the clearest directional rotation in the western fold-and-thrust belt. Hualien produced smaller rotations but systematic changes in stress shape in the eastern plate-boundary system.

The contrast suggests that earthquake-induced stress changes can depend on fault geometry, tectonic setting, and the pre-existing stress state.

Take-home message: **Large earthquakes measurably reshape Taiwan's crustal stress field.** Chi-Chi strongly rotated stress axes in the west, whereas Hualien produced a smaller, shape-changing response in the east, consistent with stress release.