Foreshocks and fault stress evolution: *from the lab to the field*

Patricia Martínez-Garzón, Sadegh Karimpouli, Grzegorz Kwiatek, Jiefang Song, Sebastian Núnez-Jara, Georg Dresen and Marco Bohnhoff

Schatzalp Workshop, 19-21 March 2025

GFZ Helmholtz Centre for Geosciences

HELMHOLTZ

Which methods and physical properties are best suited to detect fault proximity to failure?

A **Natural faults**

1. Evolution of kinematic attributes with (lab)fault loading

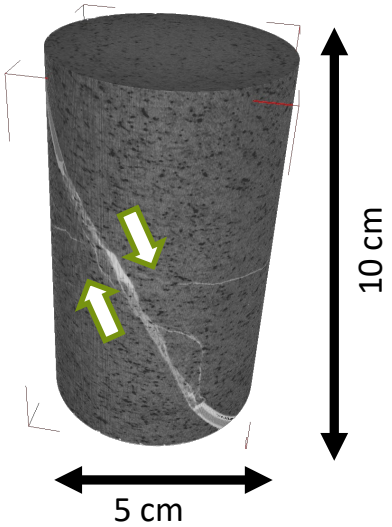
2. Identifying different stress levels on a (lab)fault

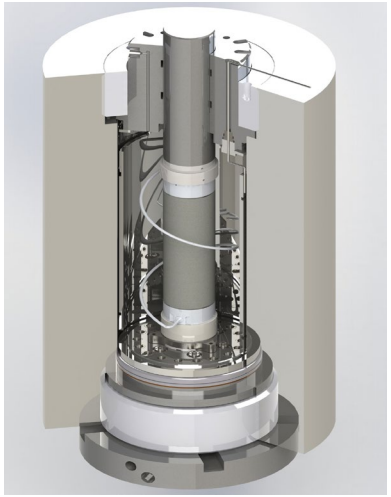
3. Insights into upscaling these methodologies to natural faults

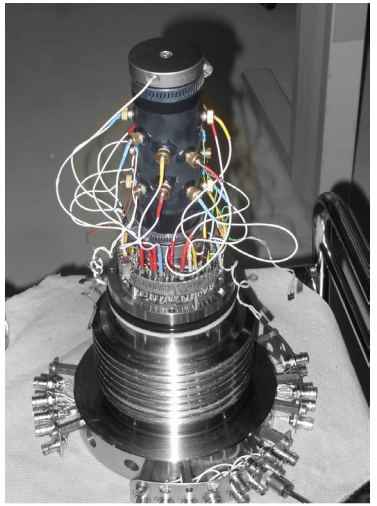
B **Lab faults**

Experimental procedure

Triaxial stick-slip as analog of repetitive rupture in the fault zone







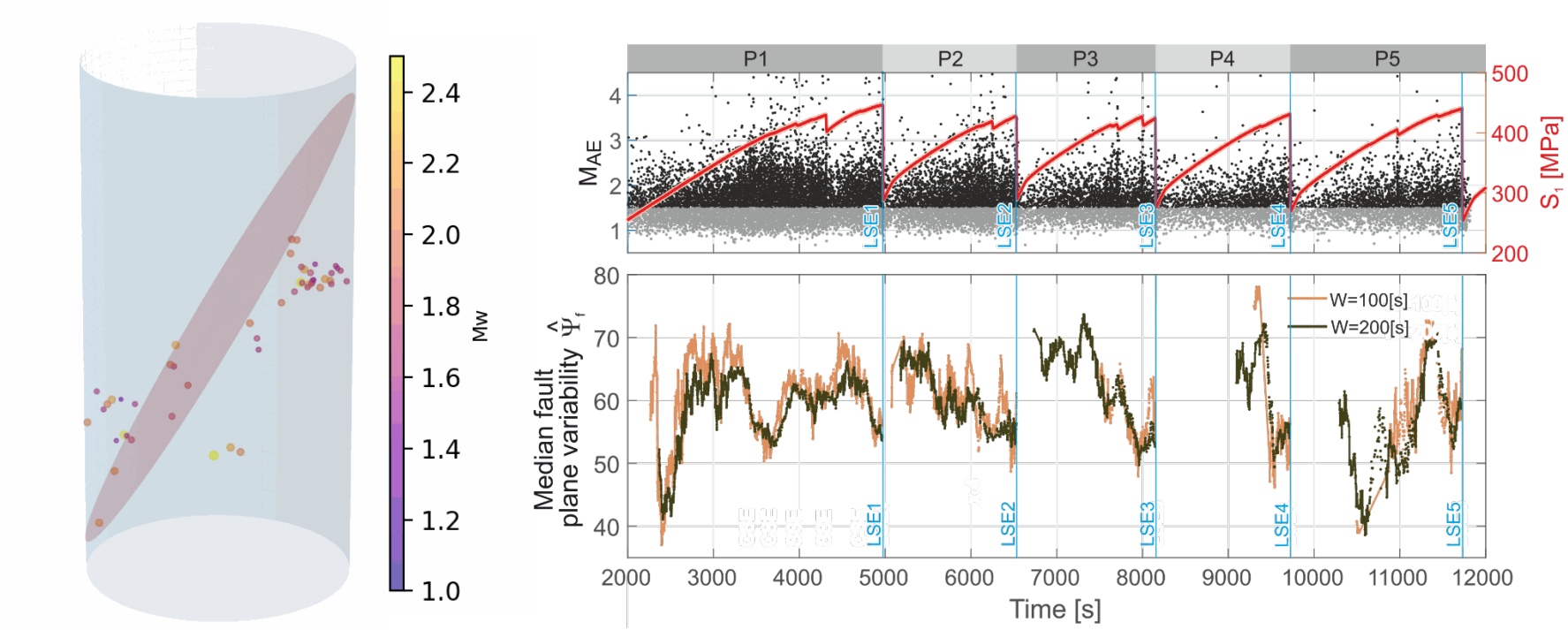
Stick-slip experiments on rough pre-fractured fault (westerly granite, sandstone)

Triaxial stress state (150 MPa, 35 MPa) Constant deformation rate along axial direction

Monitoring with 16 Acoustic Emission sensors and strain gauges

Experiments by T. Goebel, and L. Wang, see Goebel et al. (Geology, 2017)

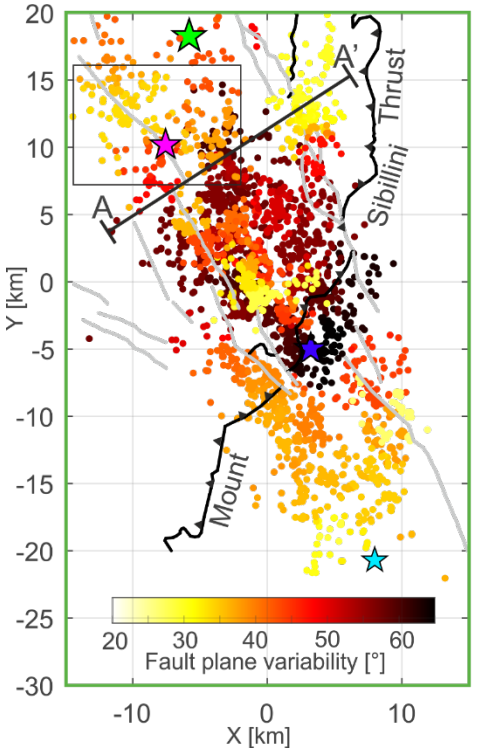
Monitoring multi-scale stress evolution using lab-quakes

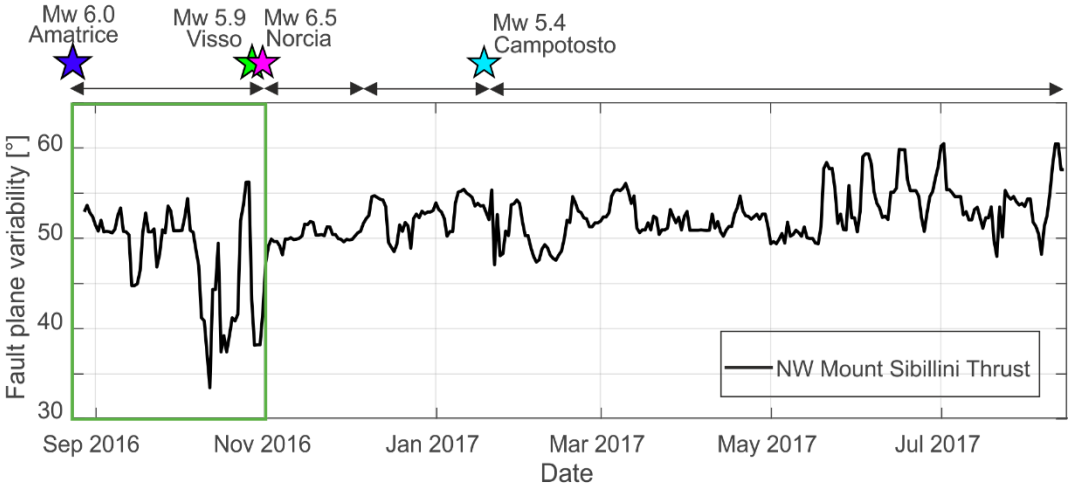


AE patterns reveal stress homogenization at local scale on the run-up to failure

Kwiatek et al. (JGR, 2024)

Stress homogeneization before 2016 M_W 6.5 Norcia





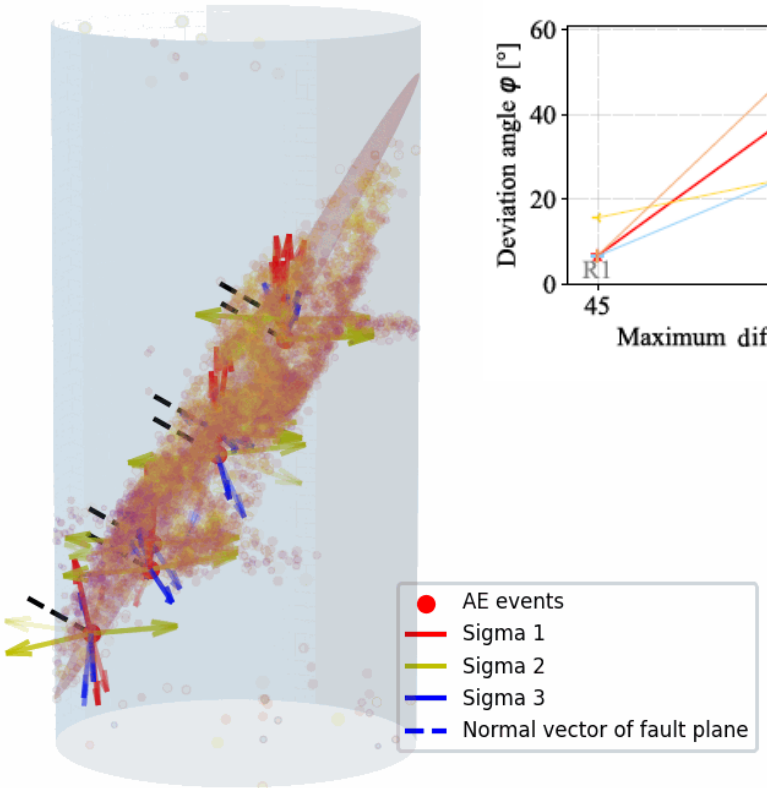
Deep-learning catalog ~40.000 focal mechanisms

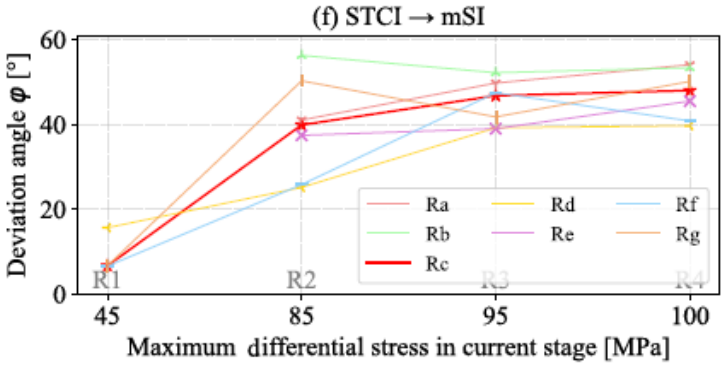
Meier, Lanza et al. (in prep)

Focal mechanism patterns reveal stress homogenization around M_W 6.5 Norcia epicenter

Martínez-Garzón, Meier et al. (in review)

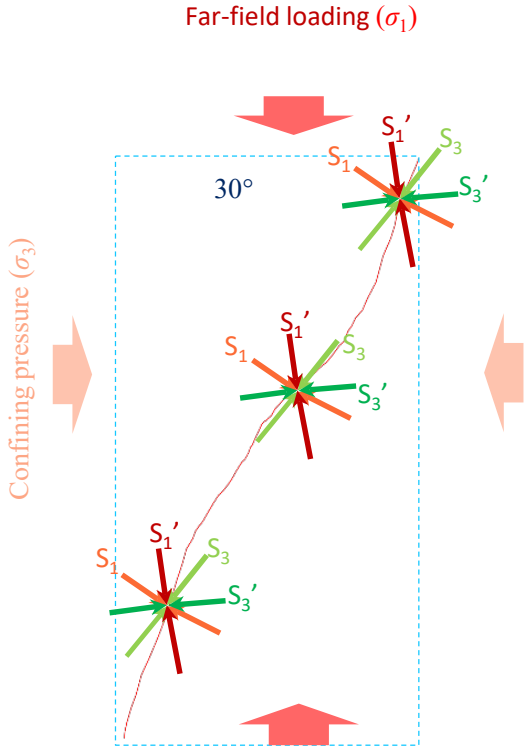
Evolution of principal stress orientations on a rough fault





Plunge S_1 gradually increases with loading

Inverted stresses evolve towards far-field stresses



Song et al. (GRL, 2024)

Identifying different stress states on a (lab)fault I

Input

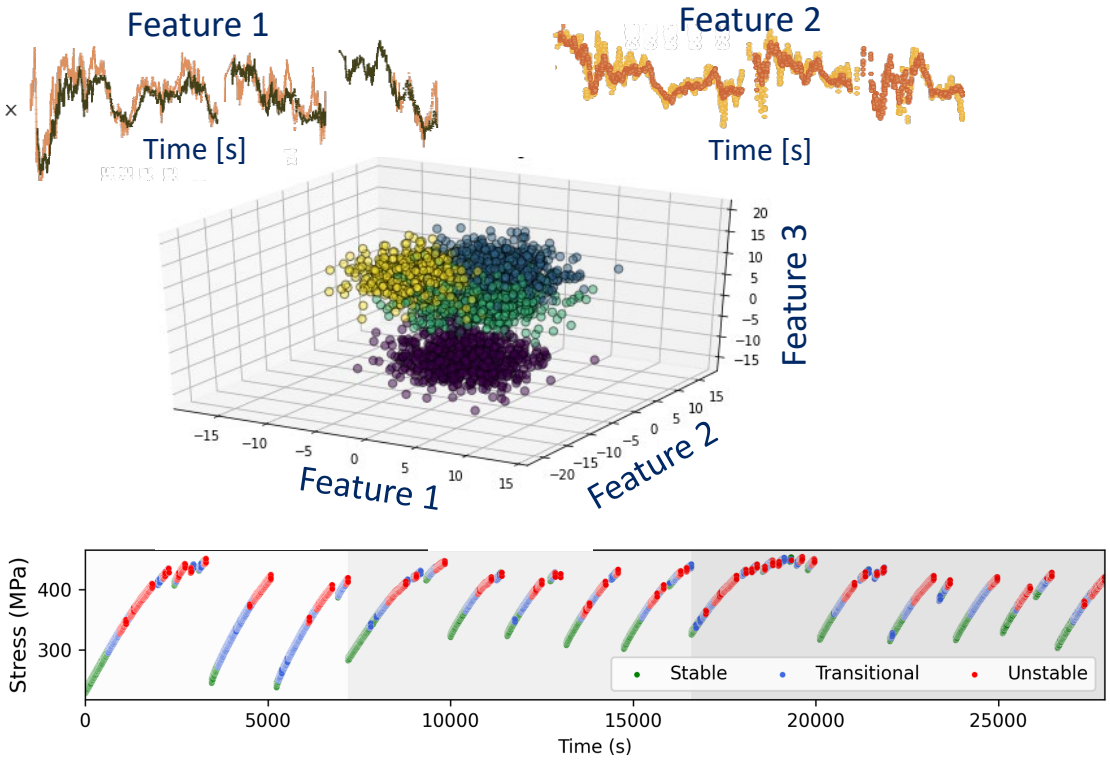
- Catalog-driven features (47 features with 1s interval)

ML method

- K-means clustering (k = 3)

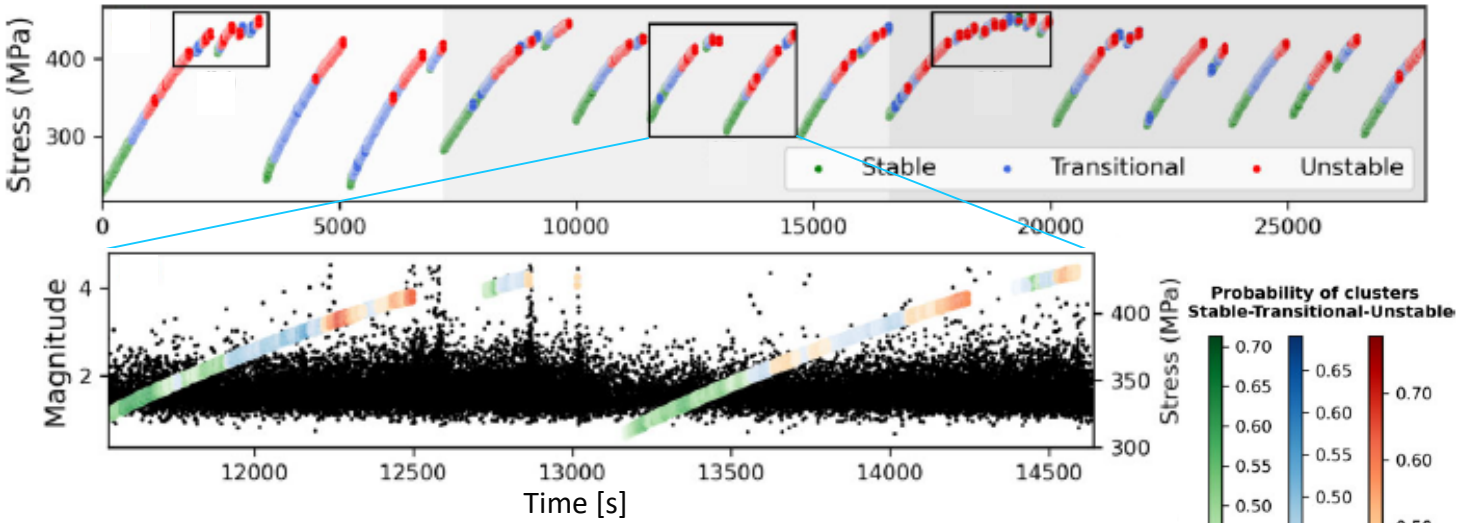
Output

- Stress state and evolution (Clustering problem)



(Karimpouli et al., GJI, 2024)

Identifying different stress states on a (lab)fault II



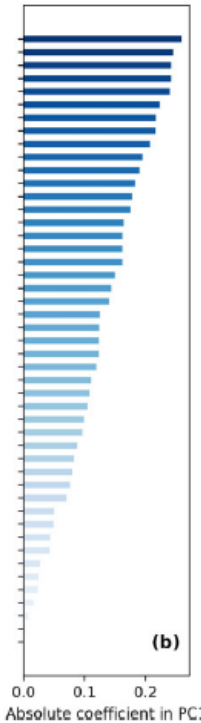
Top features

Event proximity

Event rate

Clustered background ratio

Correlation integral

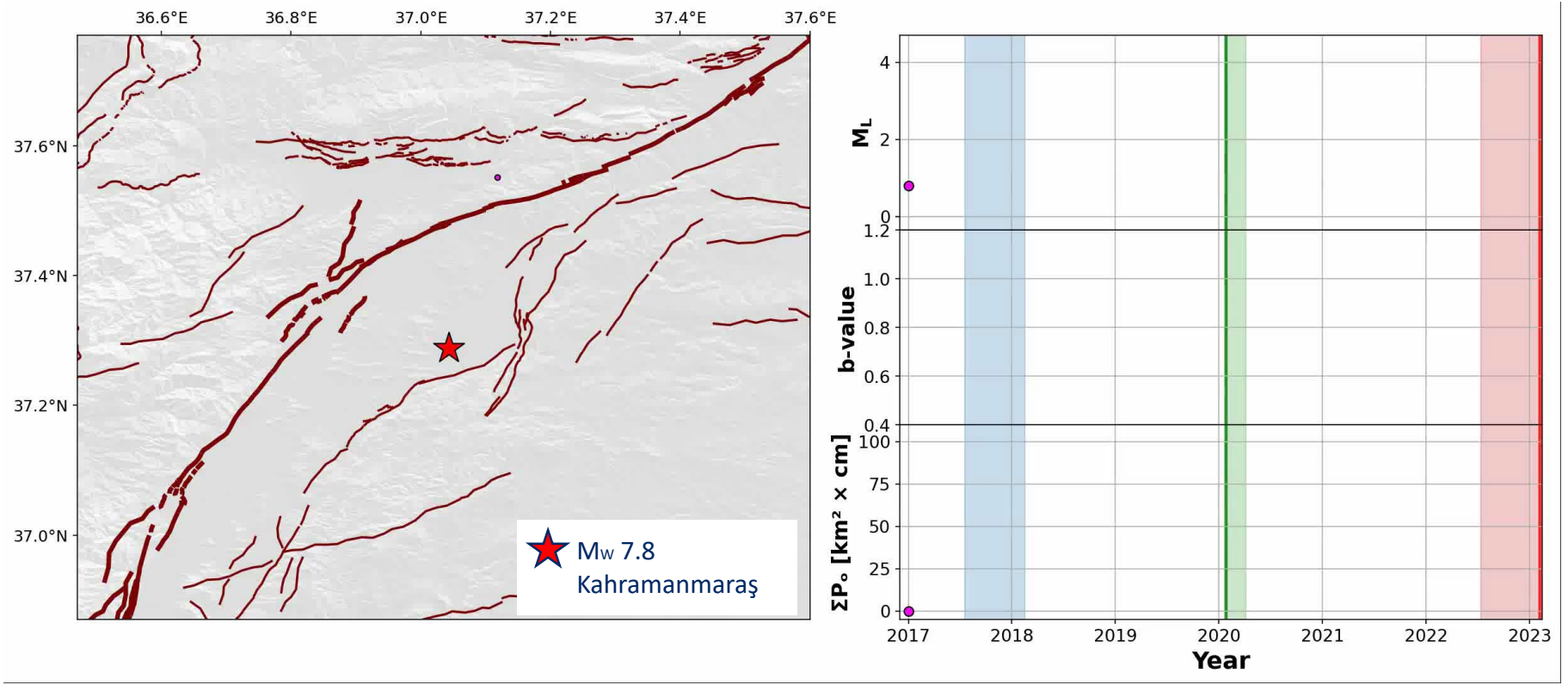


S. Karimpouli's talk on Thursday!

The three stages reproduce the temporal evolution of stress in the lab-fault

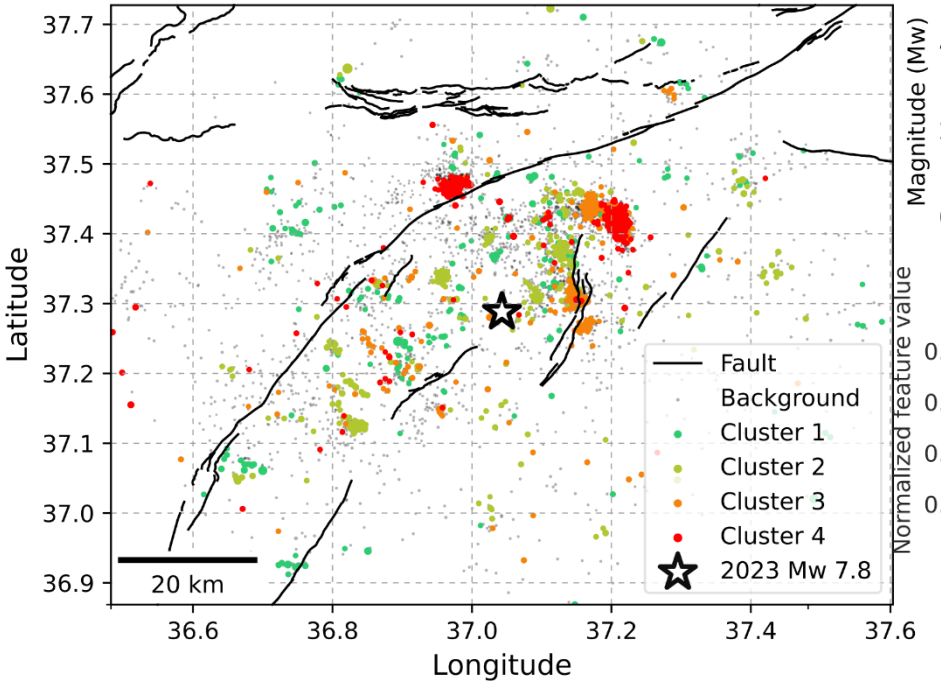
(Karimpouli et al., GJI, 2024)

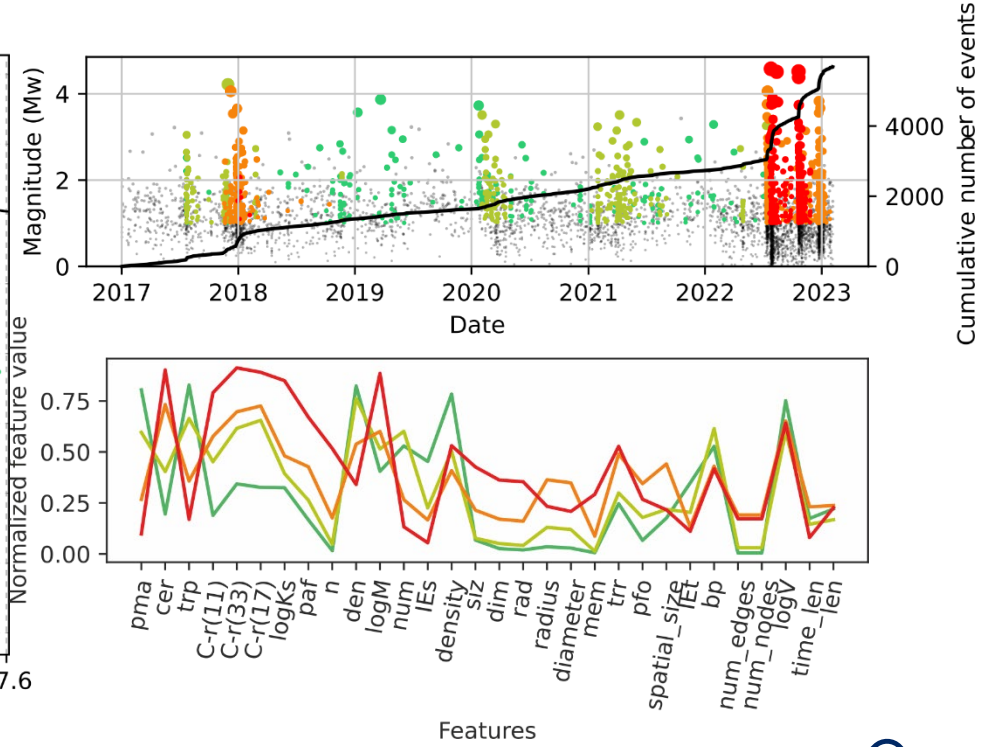
Upscaling to the field: 2023 M_w 7.8 Türkiye EQ



(Núnez-Jara et al., in review; Kwiatek et al., Nat Comm, 2023)

Identifying the 2023 M_W 7.8 Türkiye EQ preparatory phase



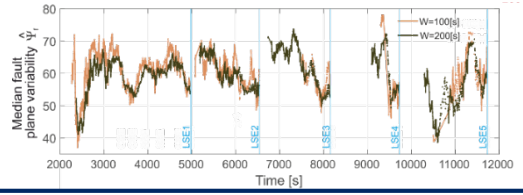


(Karimpouli et al., in prep)

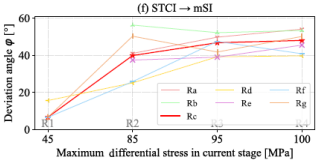
Summary

Thank you! Questions?

Large events can be preceded by lower focal mechanism variability, signifying stress homogenization.



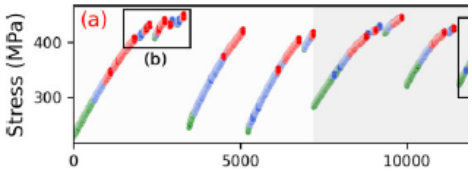
Kwiatek et al. (JGR, 2024)



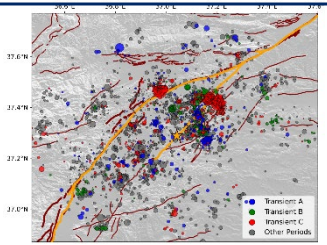
AEs reflect a stress evolution and alignment with far field stresses as sample approaches failure.

Song et al. (GRL, 2024)

Clustering methods applied to seismo-mechanical features of lab-quakes are able to track the stress level on lab-faults.



Karimpouli et al. (GJI, 2024)

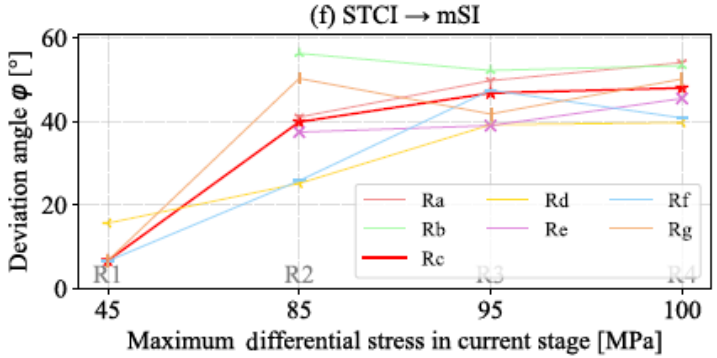


Upscaling the method to the field (2023 M_W 7.8 Kahramanmaraş) shows high potential to identify earthquake preparatory processes.

Nunez-Jara et al. (in review), Karimpouli et al. (in prep)

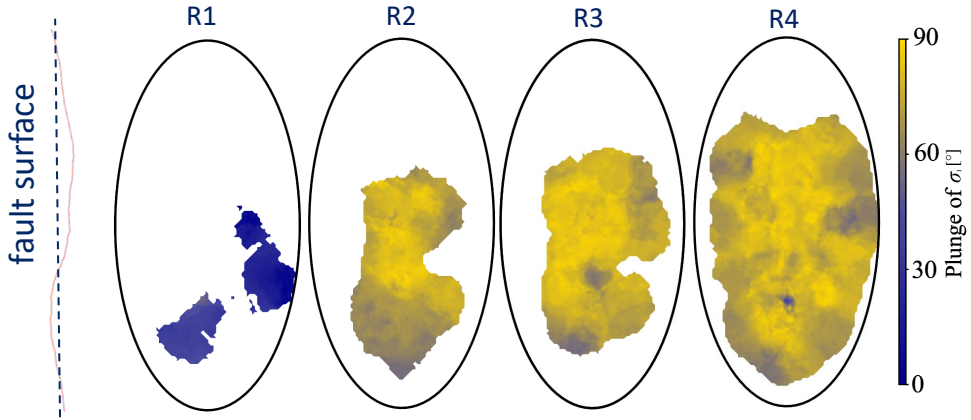
GFZ Helmholtz Centre for Geosciences

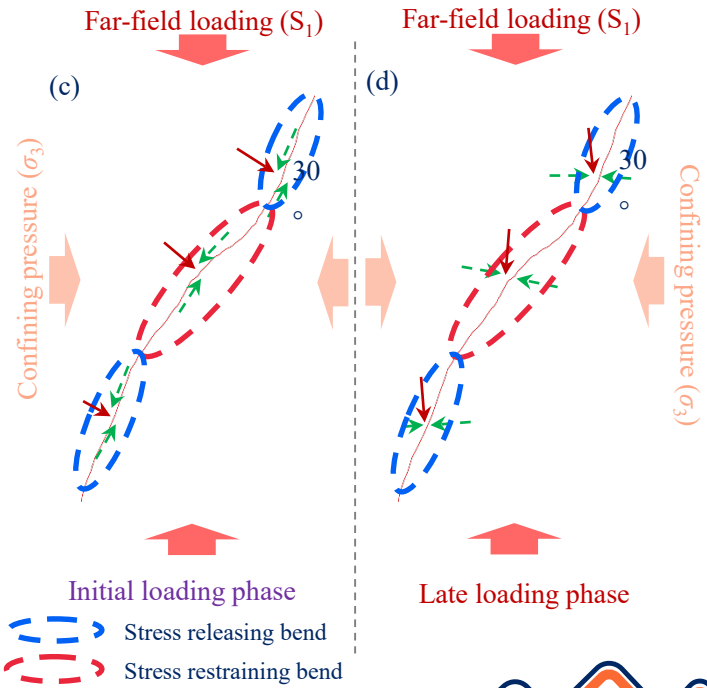
Progressive rotation of principal stresses with fault loading



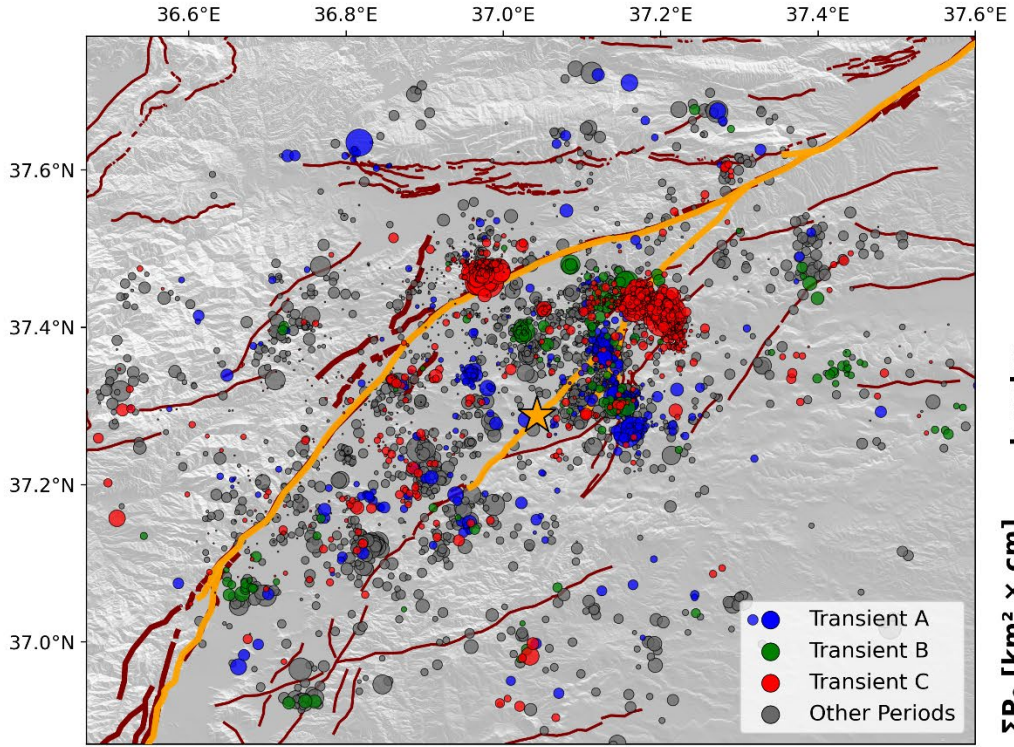
Larger ϕ with high stress concentrated

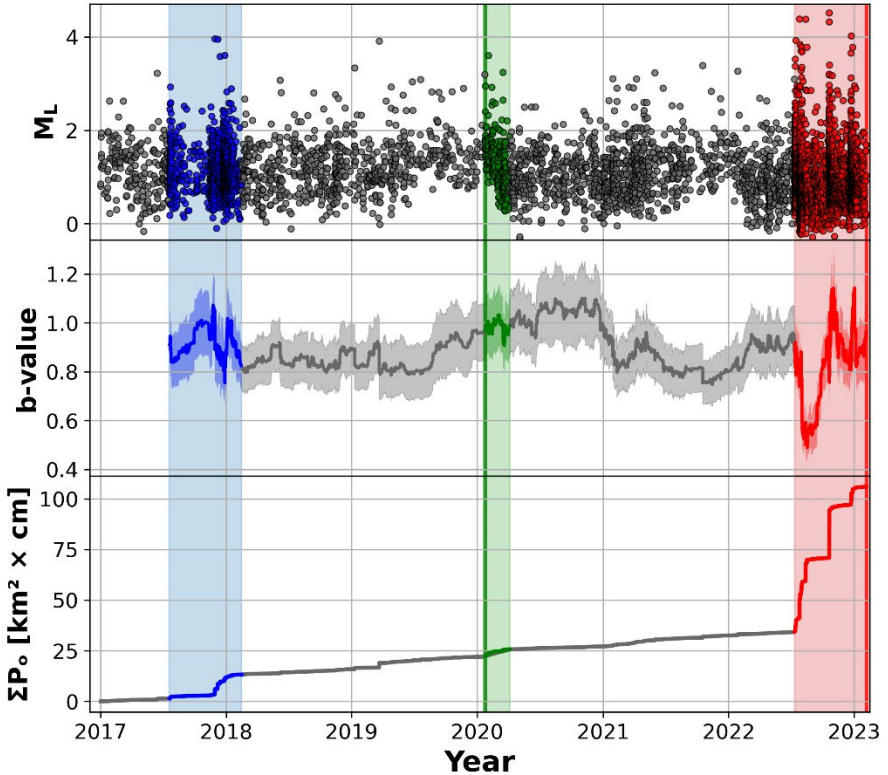
Plunge S1 gradually increases with loading





Upscaling to the field: 2023 M_w 7.8 Türkiye EQ





(Kwiatek et al., Nat Comm, 2023; Núnez-Jara et al., in review)