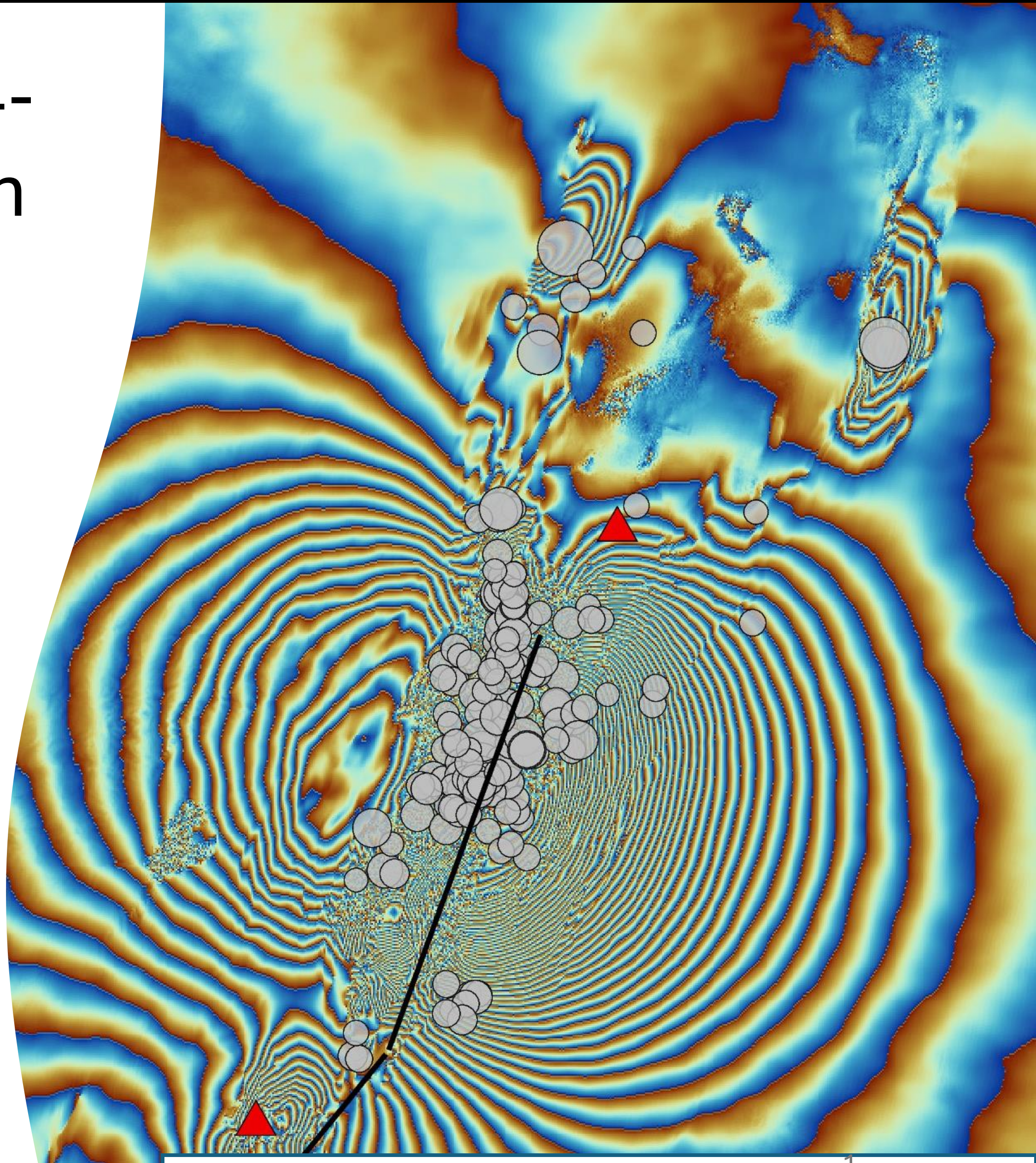
Investigating the fault motion at 2024-2025 Fentale-Dofen dike intrusions in Ethiopia, imaged by high-resolution InSAR observations

Simon Orrego[1], Juliet Biggs[1], Sam Wimpenny[1], Weiyu Zheng[1], Martin Vallée[2] ,Lin Way[1],, Raphaël Grandin[2], Tim Davis[1], Elias Lewi[3]

University of Bristol [1] IPGP [2] Addis Ababa University [3]



Sentinel-1 Descending track 20241229-20250110

Faulting during magma intrusions

Shallow crustal earthquakes associated with dyke intrusions

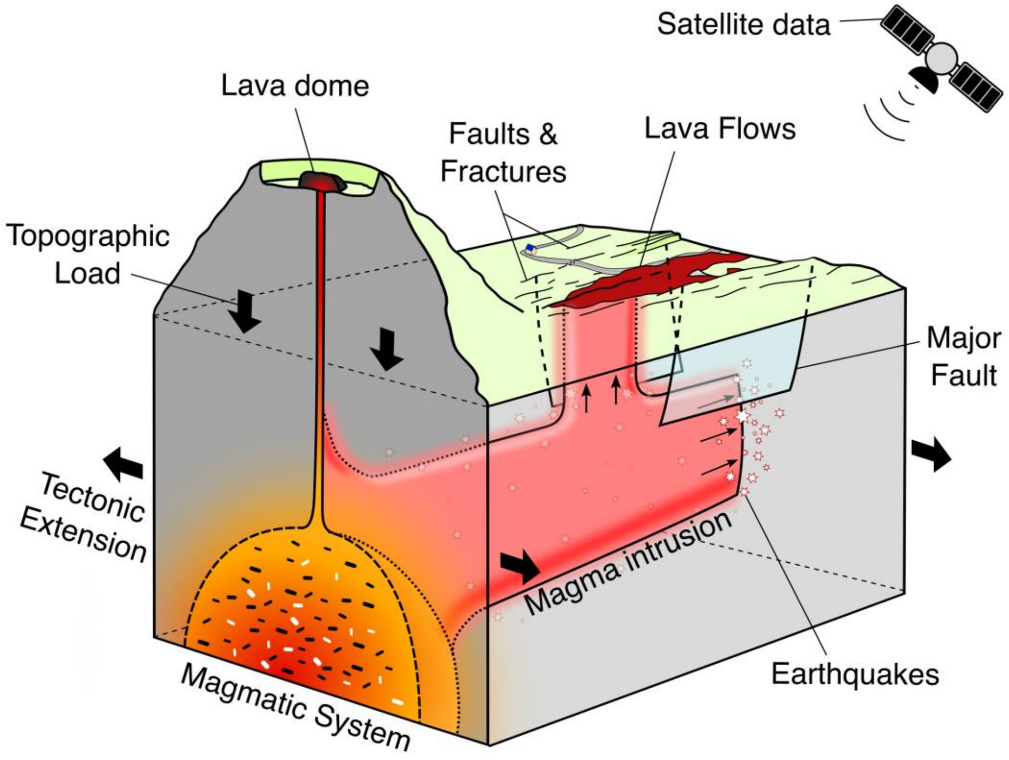
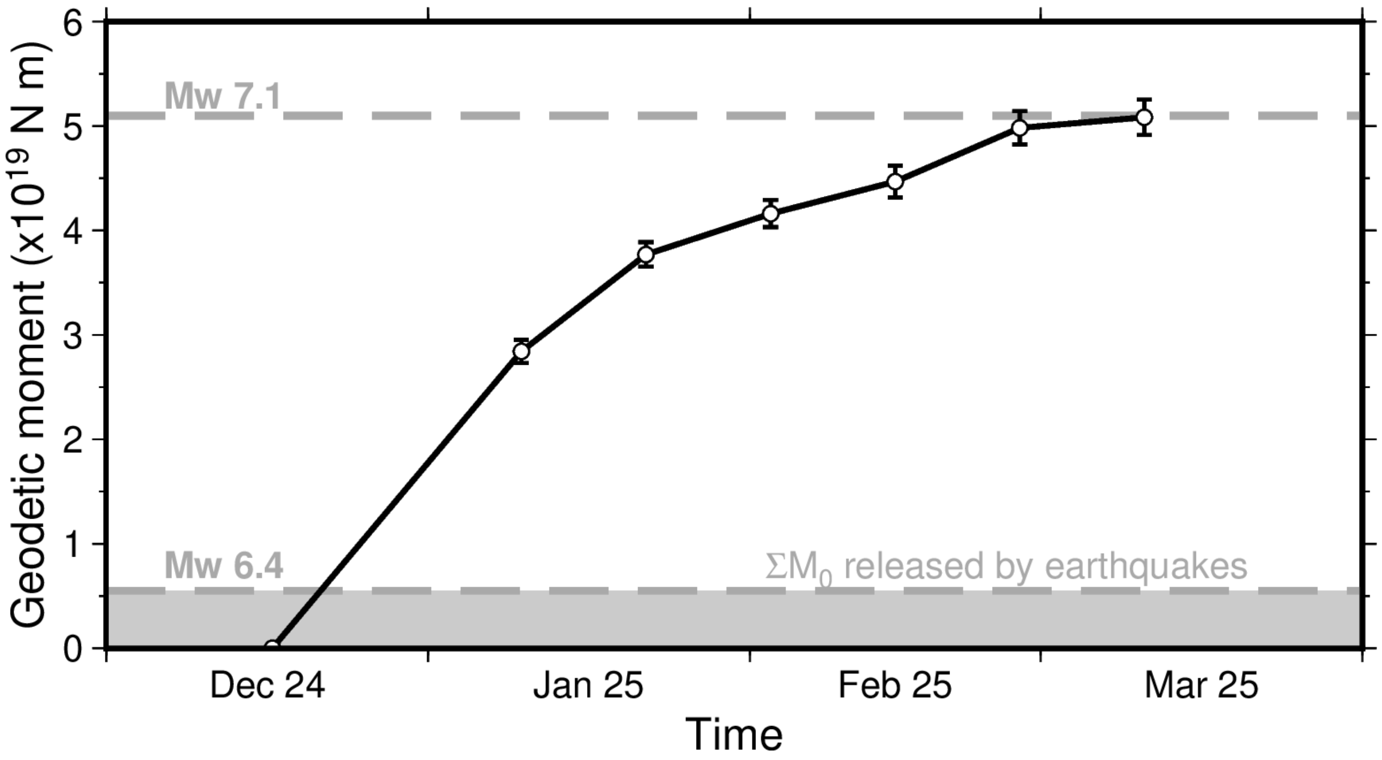


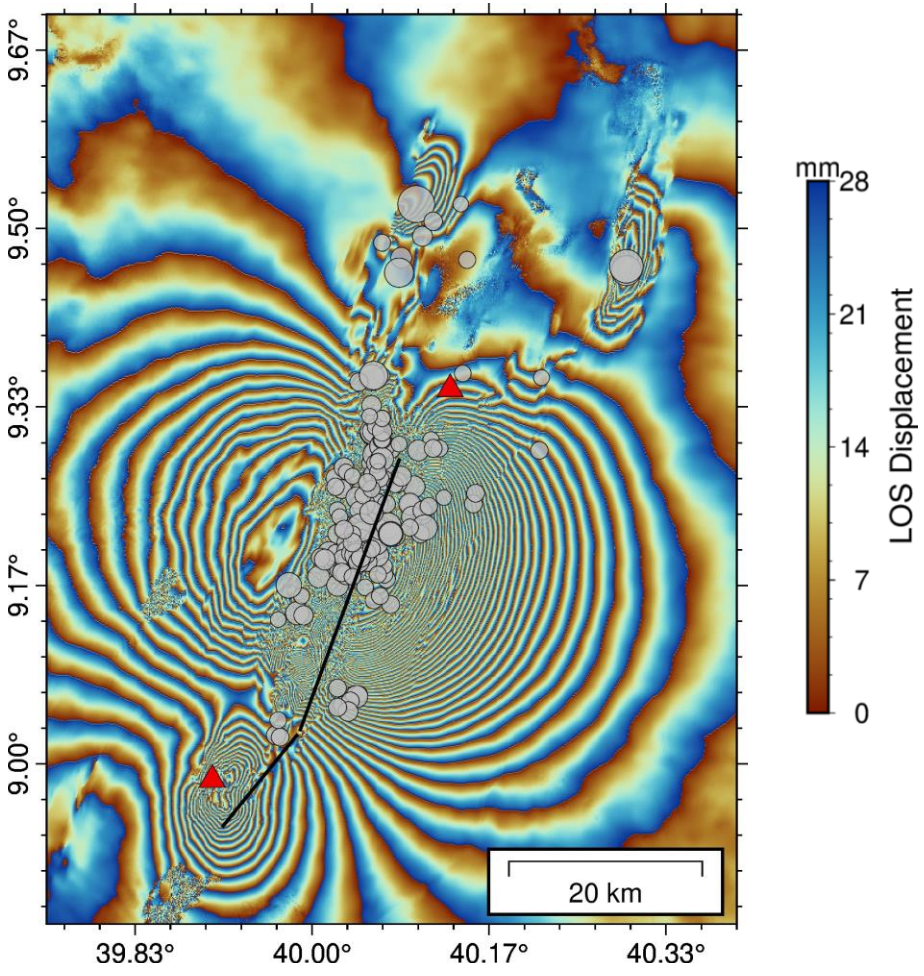
Figure by Edna Dualeh (U. of Bristol)

Geodetic moment released by Fentale-Dofen dyke intrusions (μV)



Seismicity associated

Catalogue > 150 relocated moderate-sized earthquakes (M4.5-6) using template matching



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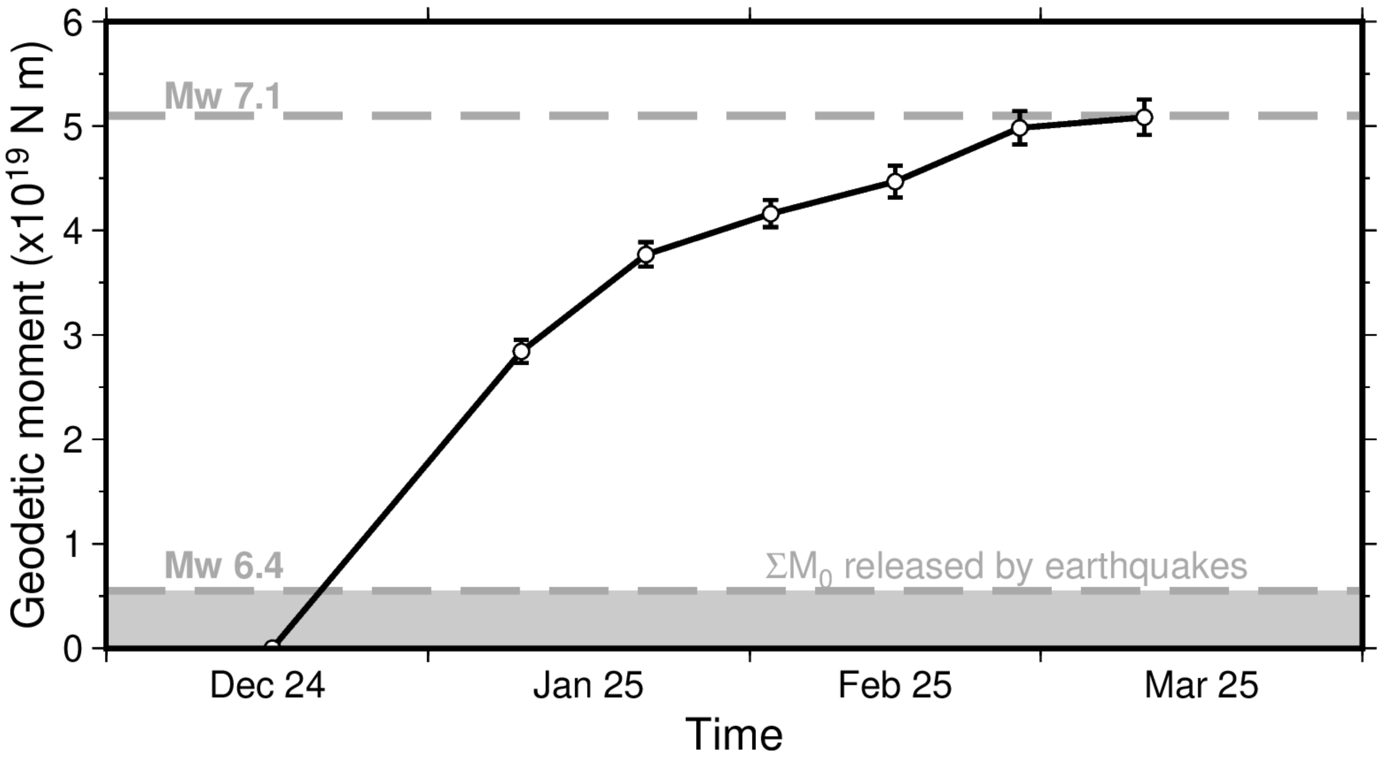

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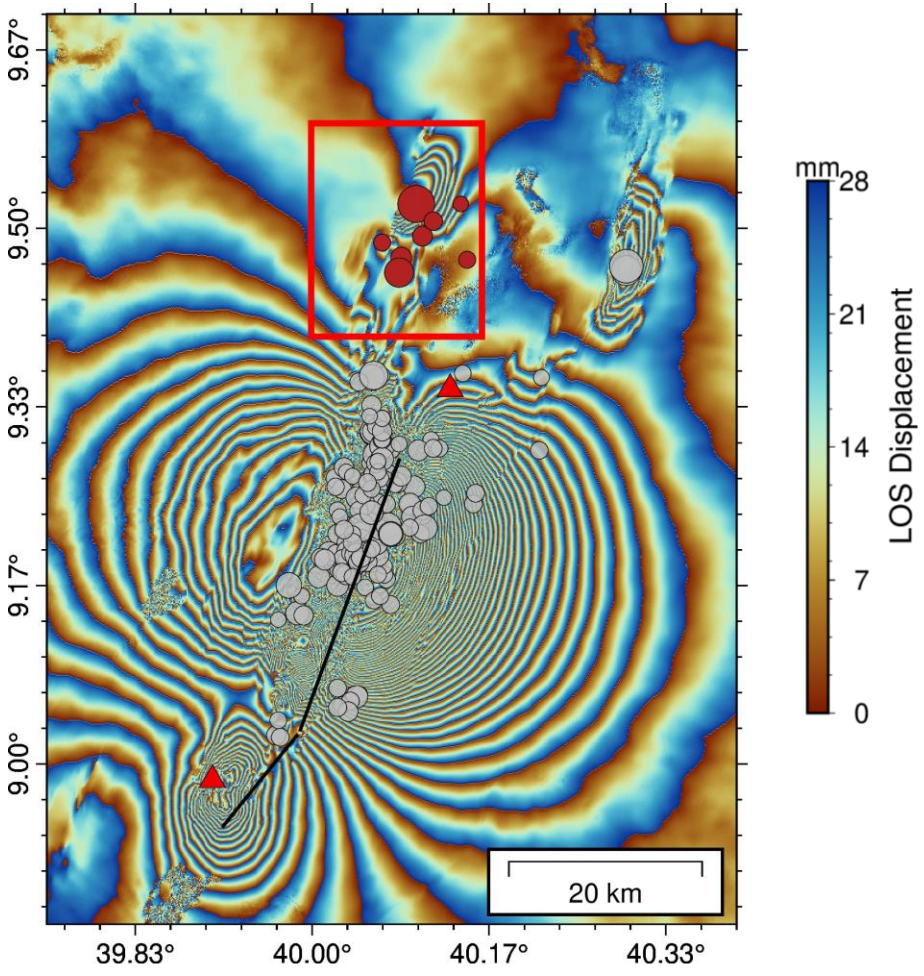

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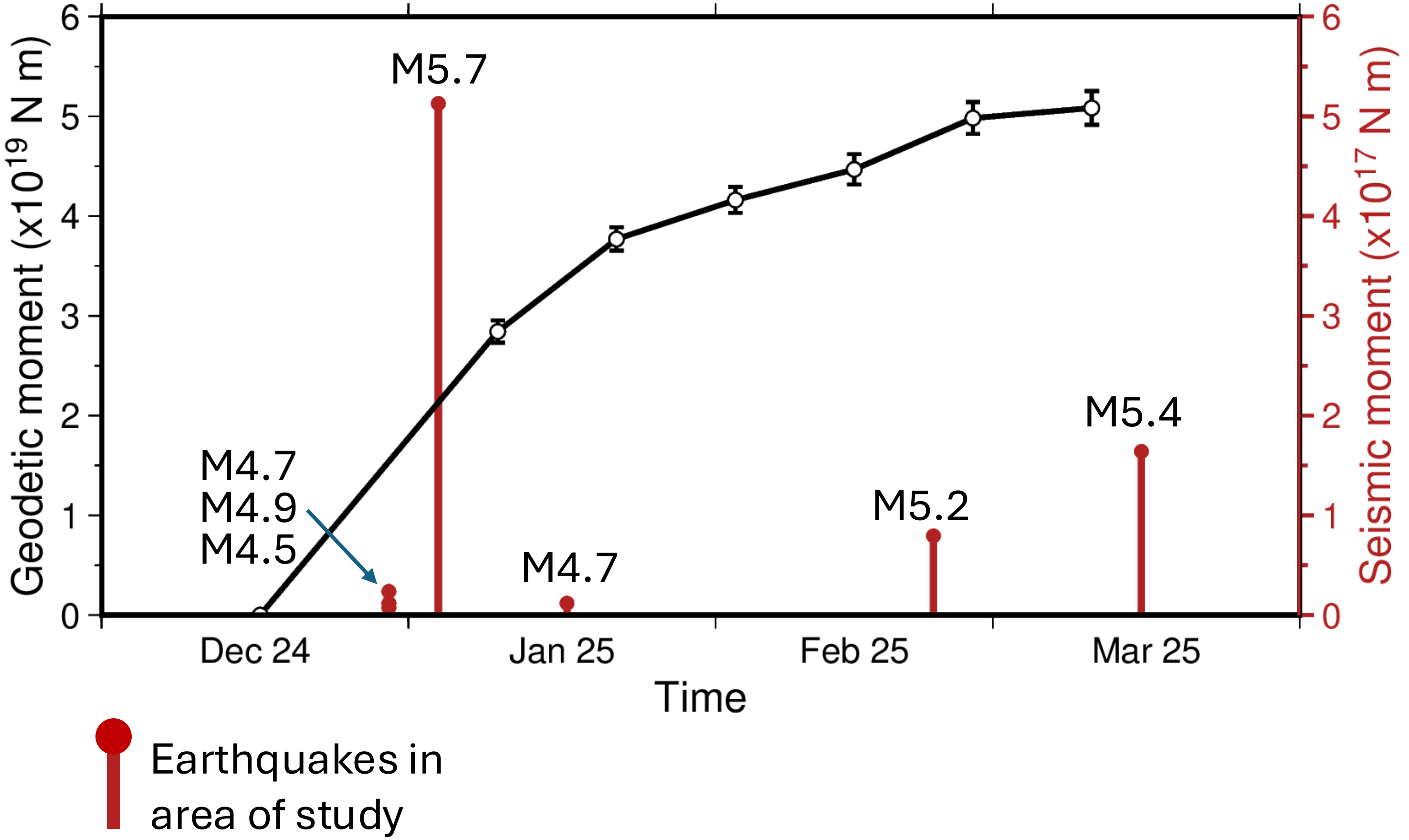
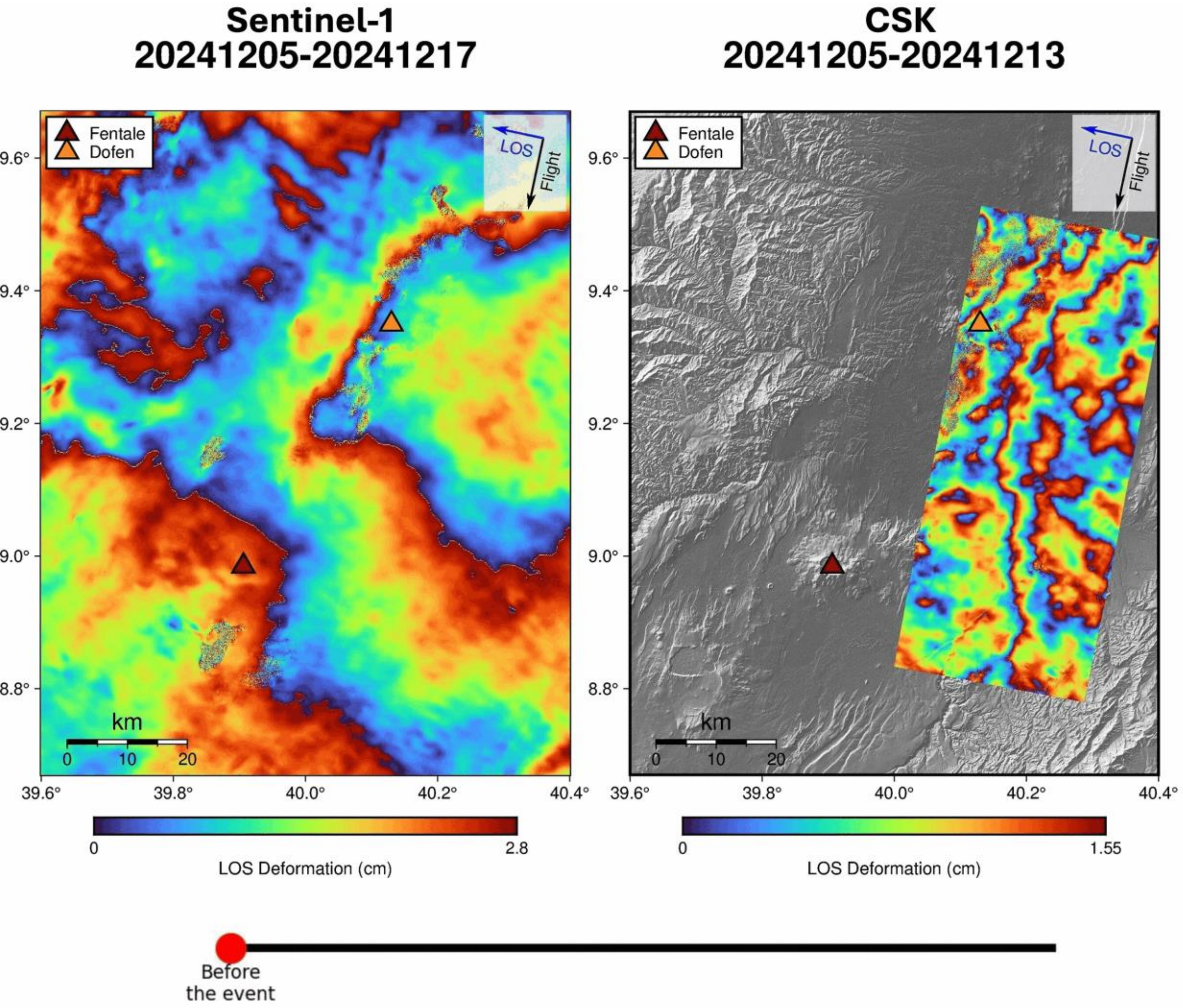


InSAR capability to track rapid evolving stress field



- High spatial and temporal resolutions for CSK data allows to separate co- and inter-seismic periods.

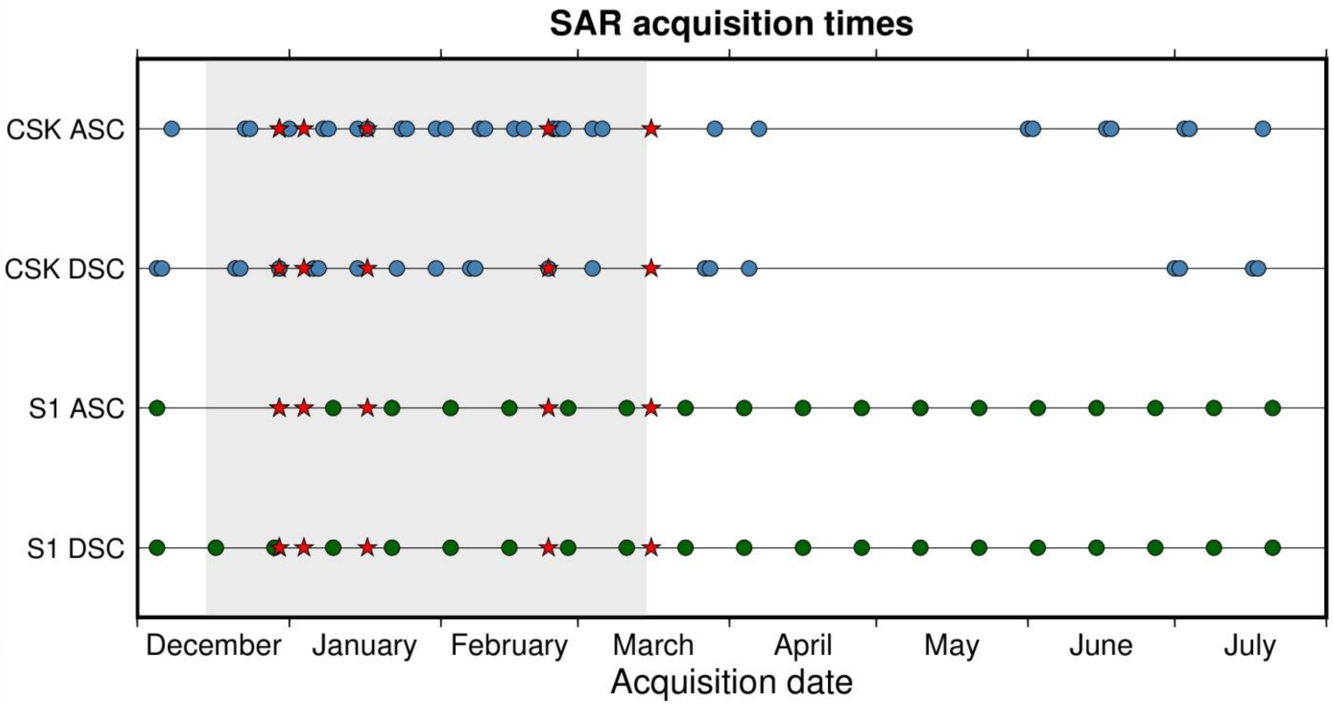


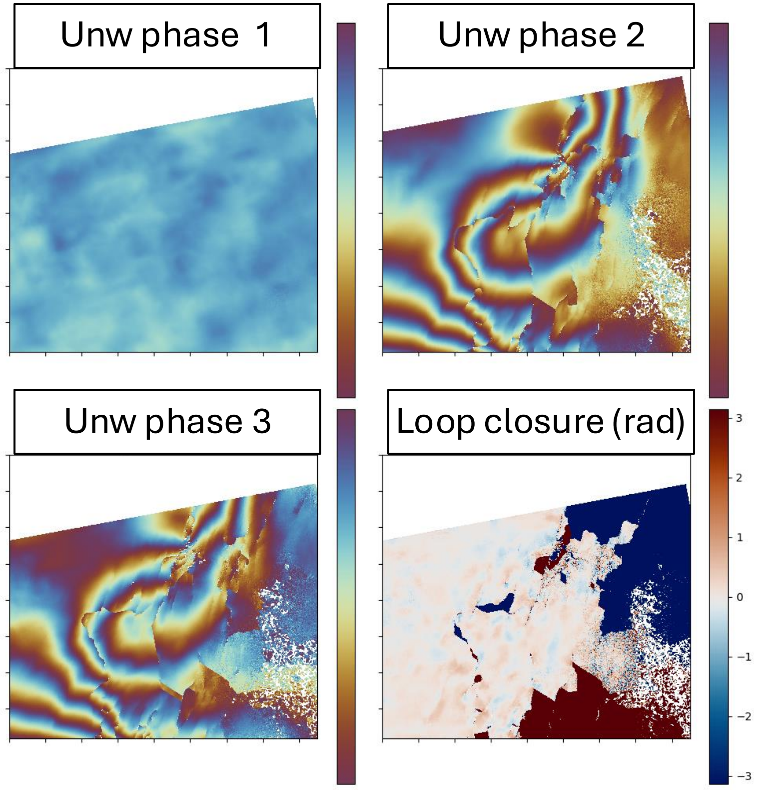
Figure by Weiyu Zheng (U. of Bristol)

InSAR unwrapping approach

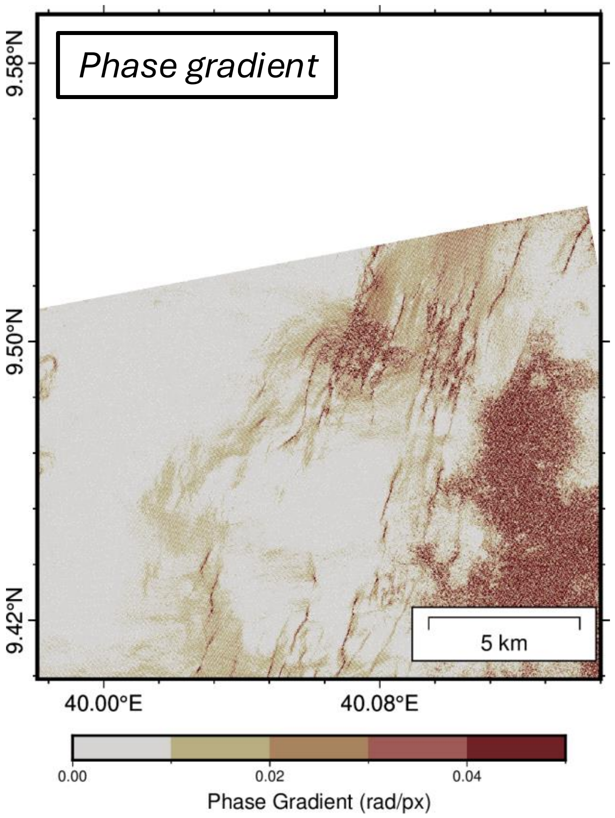
- Multiple phase discontinuities make the phase unwrapping challenging

Loop closure assessment:

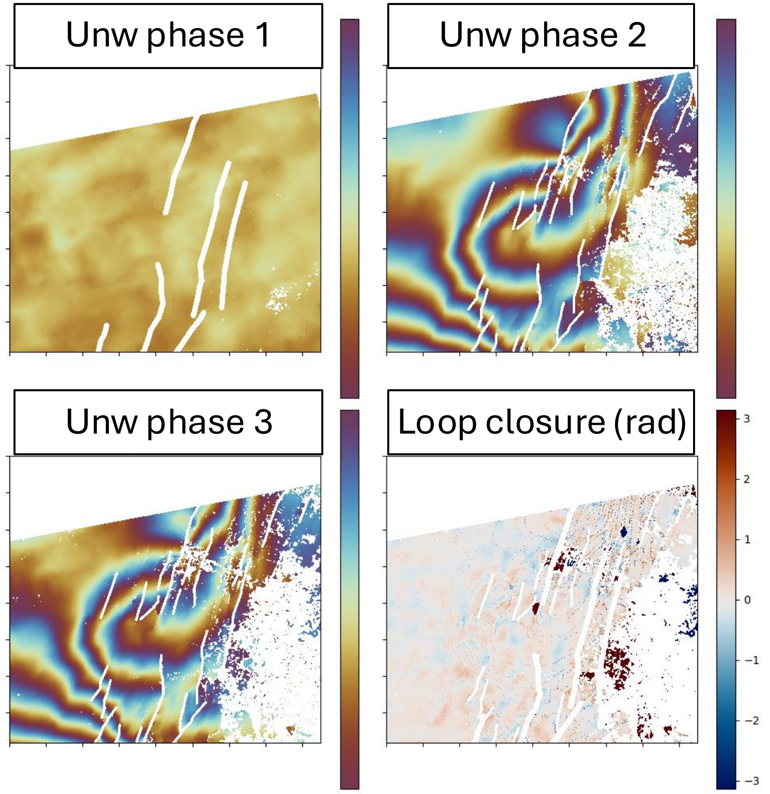
Standard phase unwrapping (snaphu)



Manually mask phase discontinuities (*Morishita, 2022 ; Xu et al., 2020)*



Corrected phase unwrapping (snaphu parameters tweaked)



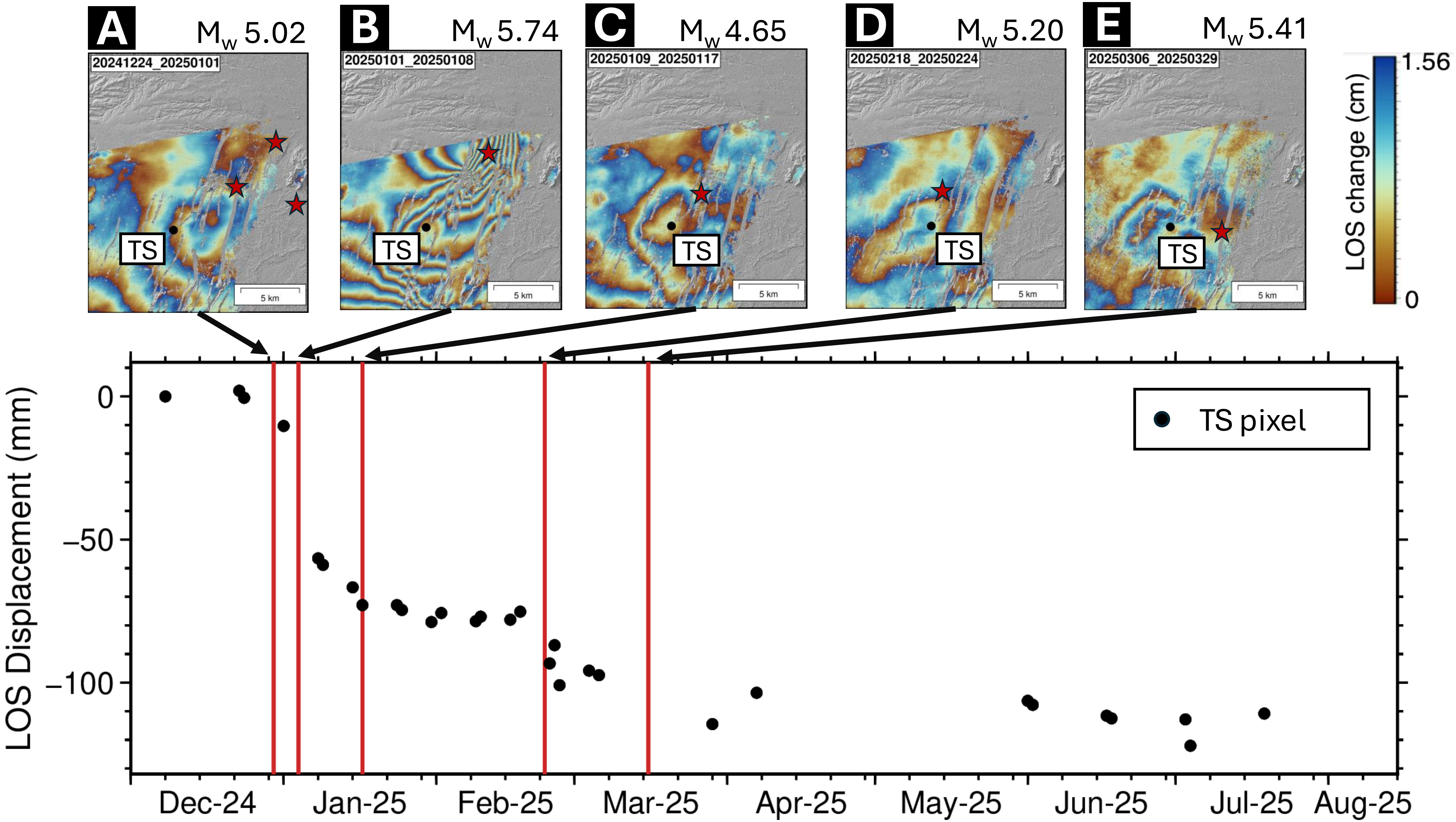
Loop closure Median RMS standard (170 triplets): 1.11 rad

Loop closure Median RMS corrected (170 triplets): 0.53 rad

Improvement: 52%

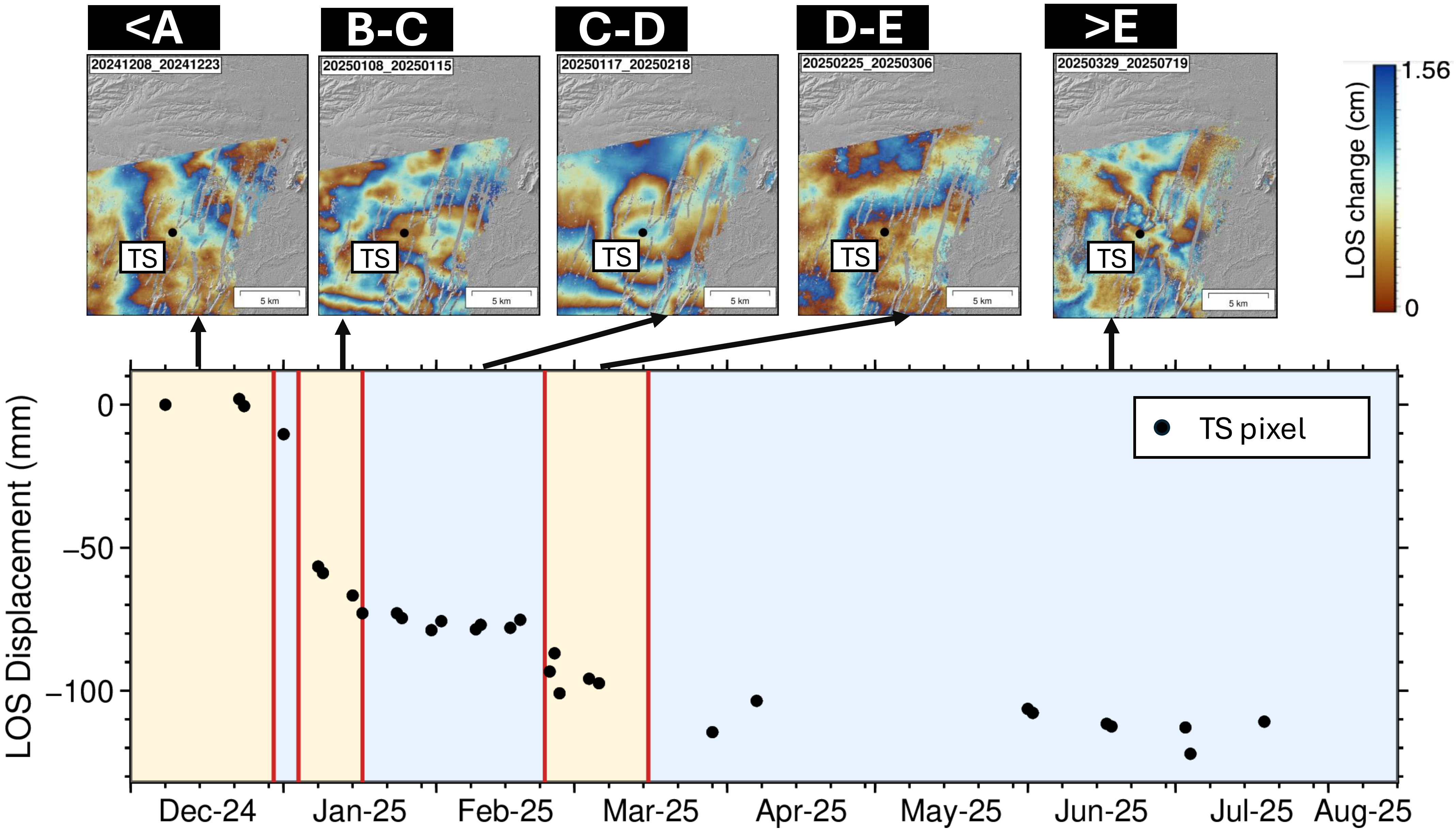
Deformation associated with earthquakes

InSAR COSMO-SkyMed time-series: **Coseismic displacement ascending data**



Deformation associated with interseismic periods

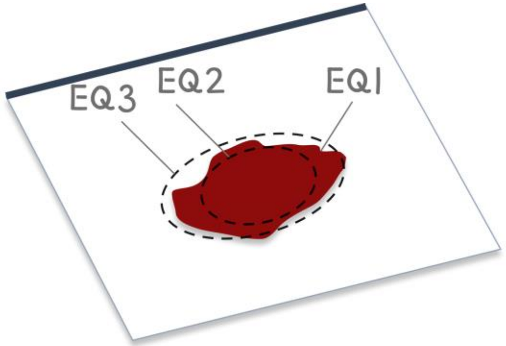
InSAR COSMO-SkyMed time-series: **Interseismic displacement ascending data**



How does fault slip respond to dike-induced stress changes?

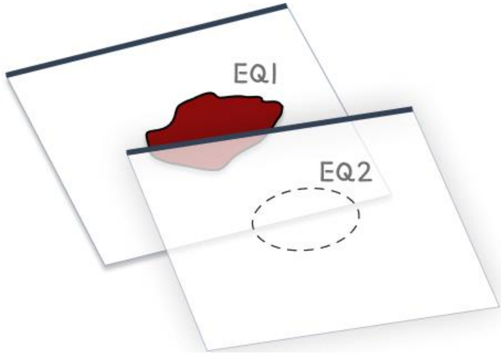
1 Repeated rupture of the same asperities

- Transient stress perturbations from magmatic intrusions.
- Fluid pressures changes reduce σ'_n



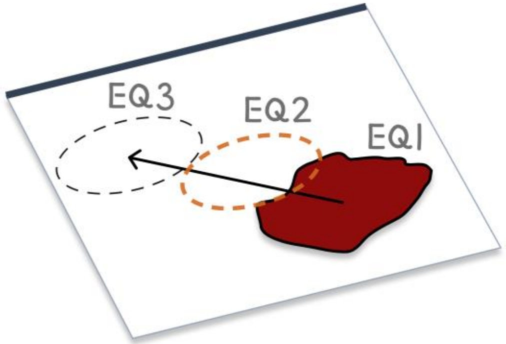
3 Slip partitioned across fault network

- Time-dependent stress perturbation from dike intrusion, static stress transfer from sub-parallel faults, and regional extension activates multiple pre-existing faults.



2 Slip migration

- Static stress transfer from adjacent fault patches.
- Dike-induced stresses along strike and/or downdip.

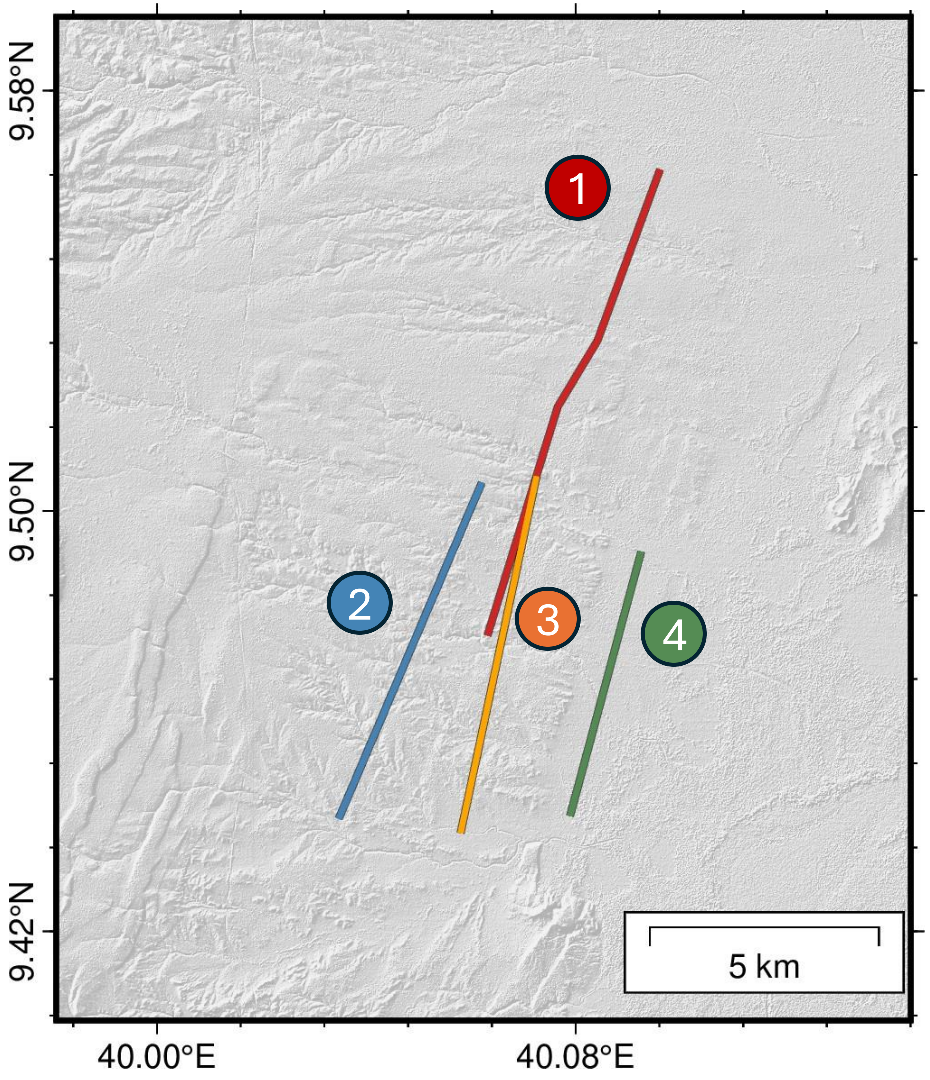


4 Aseismic slip

- Typical coseismic-afterslip behavior in faults that reach the failure due to dike-induced stresses.
- Stable sliding in velocity strengthening patches.

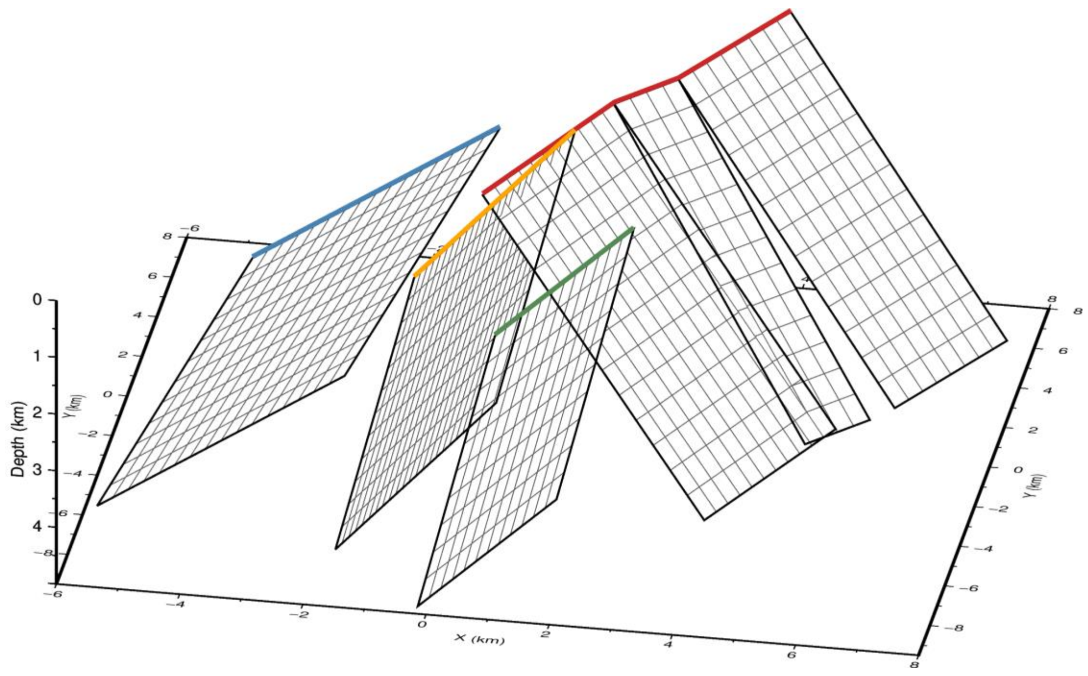
Slip partitioning across fault network

- Best-fit fault planes of the earthquakes modelled
- 4 fault planes constrained with elastic dislocation models



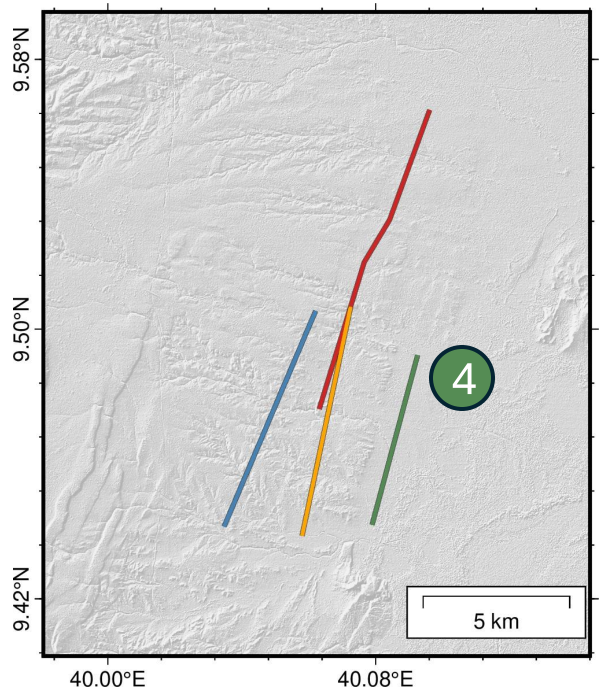
1 Main fault: Dipping towards the rift-axis

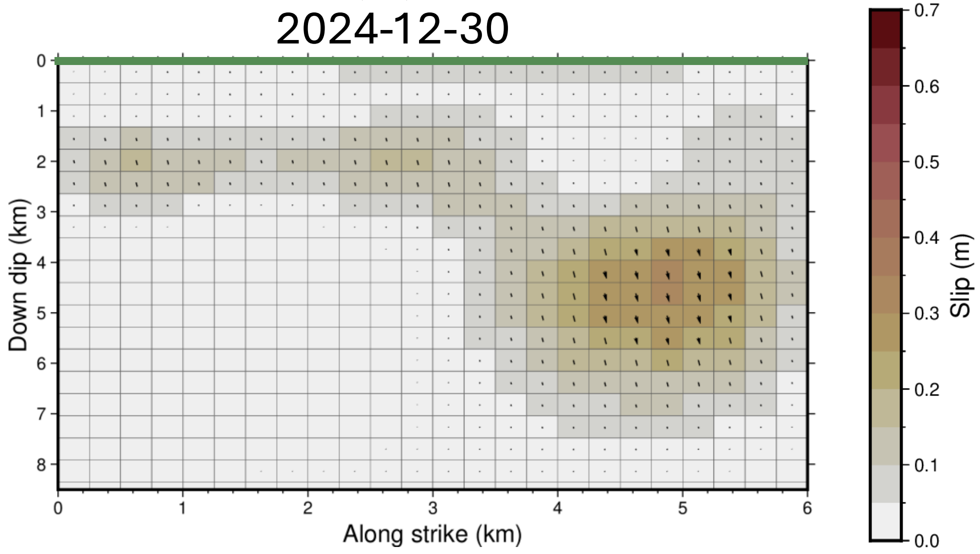
2 3 4 faults: Dipping away the rift-axis



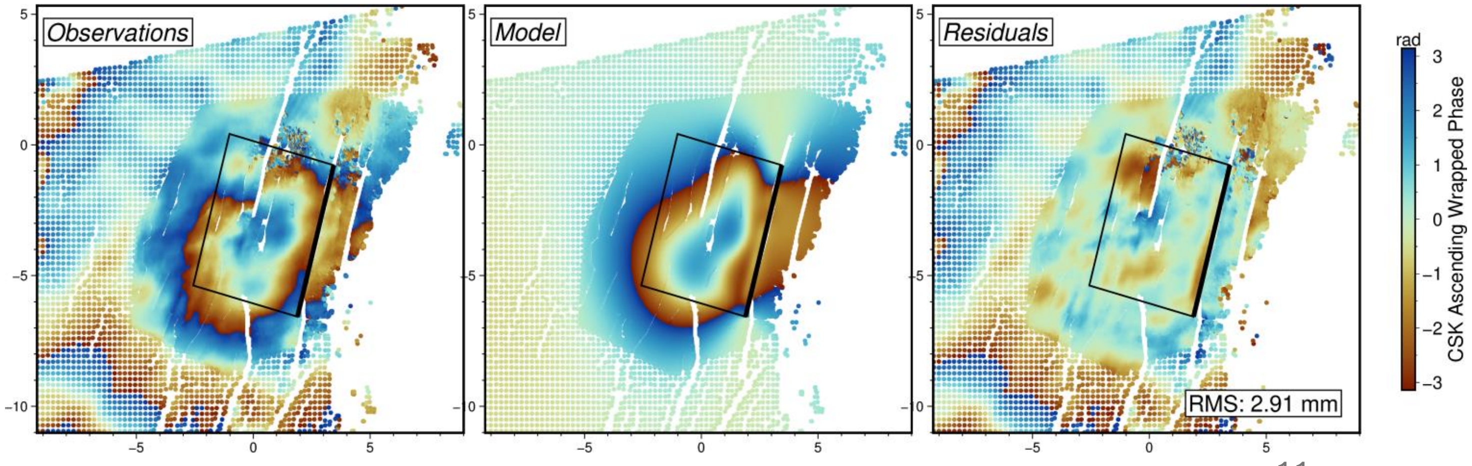
Coseismic slip history across fault network: Coseismic A

- First moderate-sized earthquakes in the sequence (**Coseismic A**) ruptured the segment 4 of the fault network.
- Geodetic moment released equivalent to a Mw 5.2



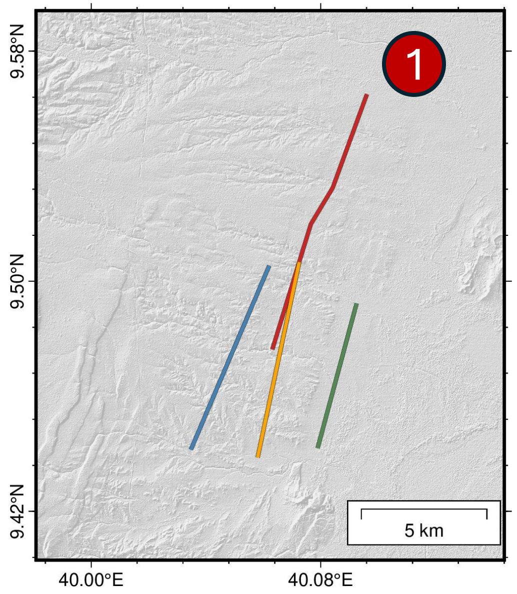


Ascending Model

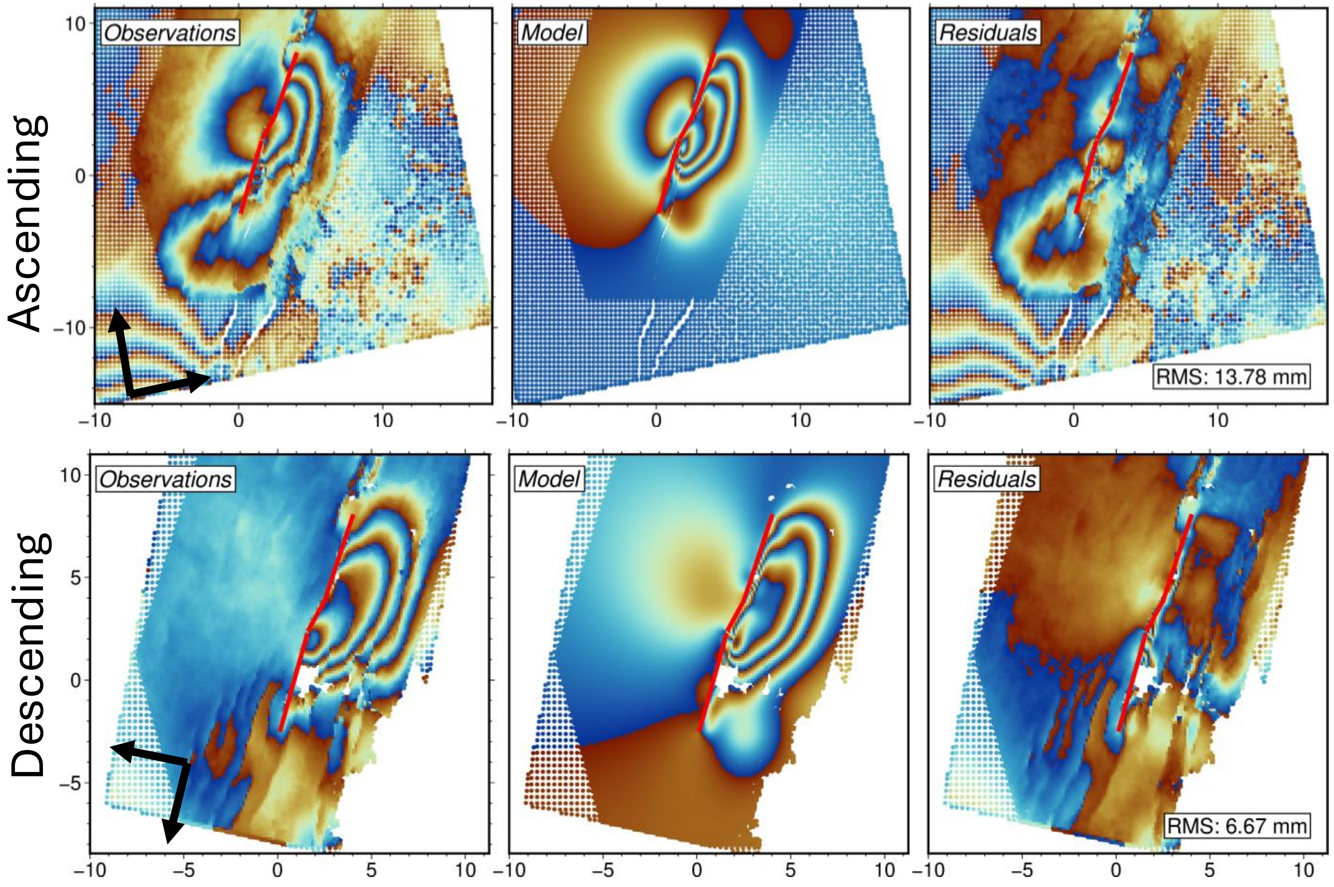


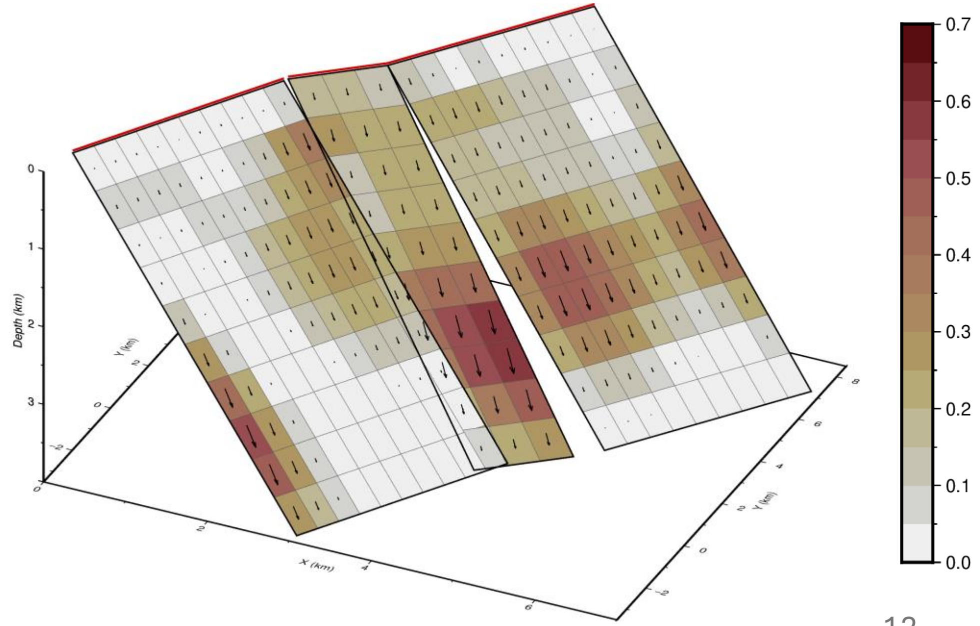
Coseismic slip history across fault network: Coseismic B

B 2025-01-04 Biggest earthquake recorded in the area



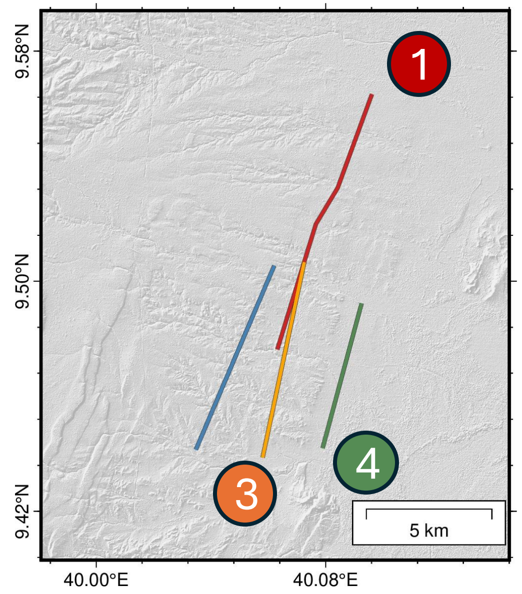
- More complexity is needed in the model for explaining residuals

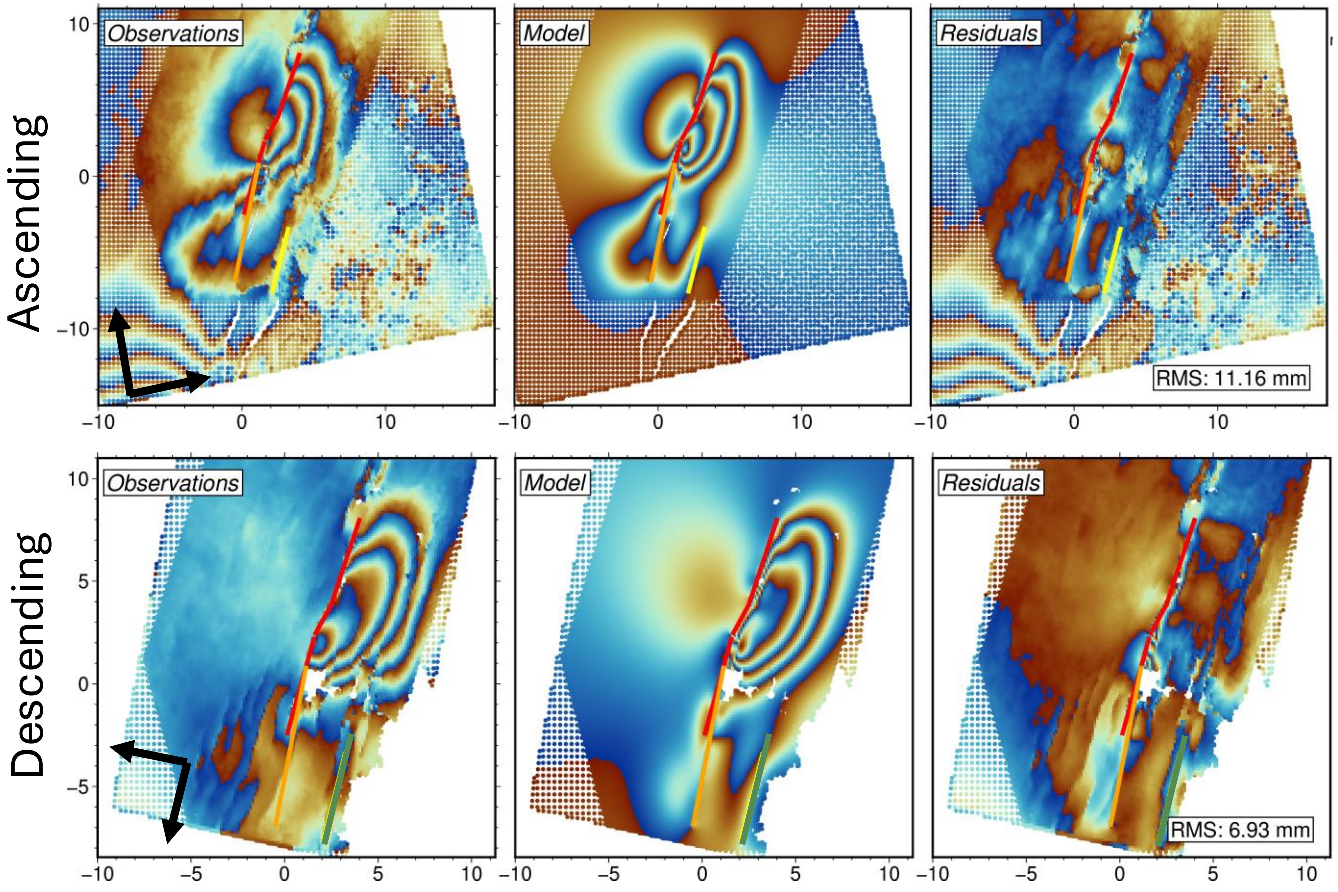


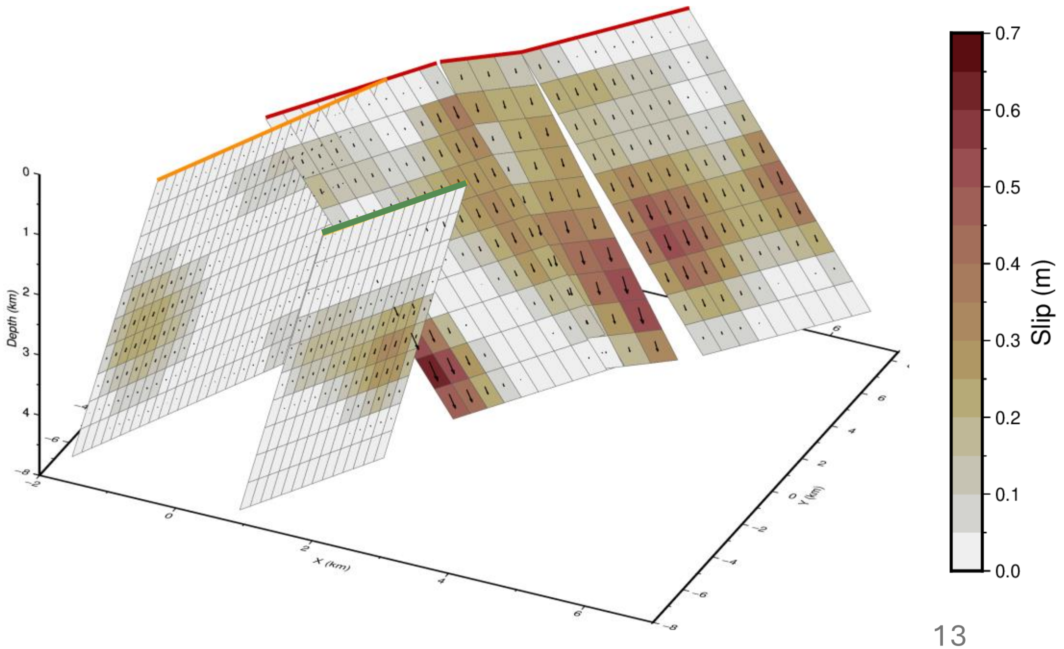


Coseismic slip history across fault network: Coseismic B

- ~73% of the total seismic moment is released by fault 1 (3 segments)
- Total seismic moment released, equivalent to Mw 5.72
- Fault 4 , previously ruptured, shows seismic slip again.



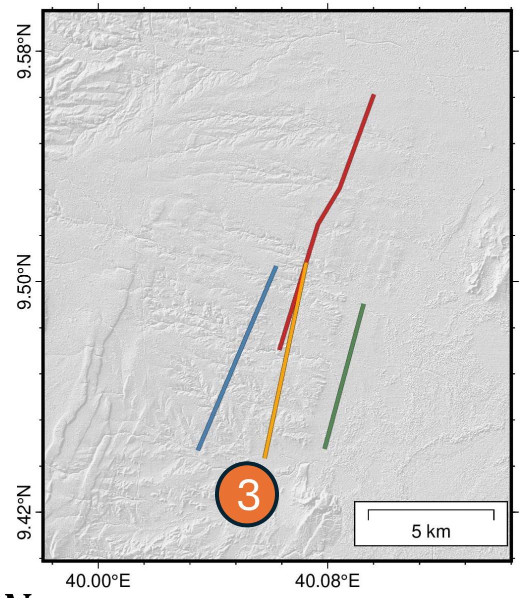




Coseismic slip history on same fault plane: Coseismic C and D

Elastic dislocation models of three earthquakes:

- Earthquakes rupturing same fault plane in 2 months.
- Slip migration on the fault plane -> progressive activation of patches downdip

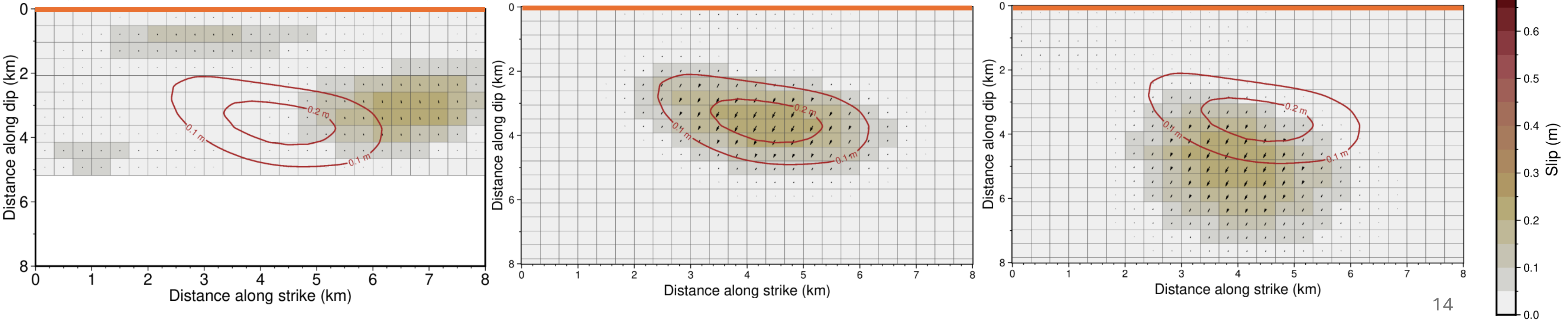


B
2025-01-04
M_0 $5.42 \times 10^{16} N\ m$

C
2025-01-17
M_0 $5.47 \times 10^{16} N\ m$

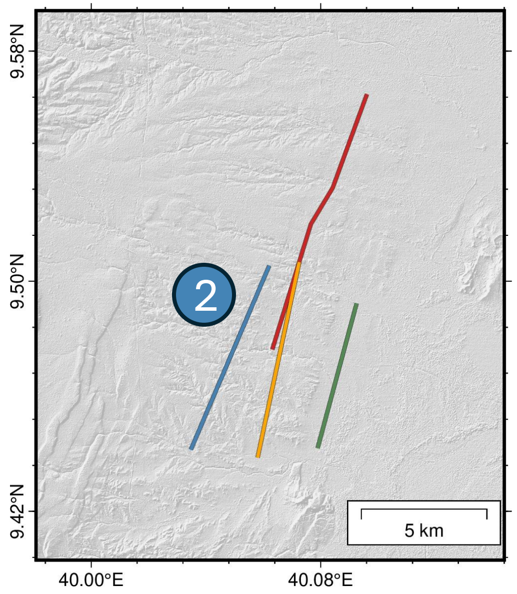
D
2025-02-23
M_0 $6.76 \times 10^{16} N\ m$

(Triggered slip in orange fault segment)



Coseismic slip history on new fault: Coseismic E

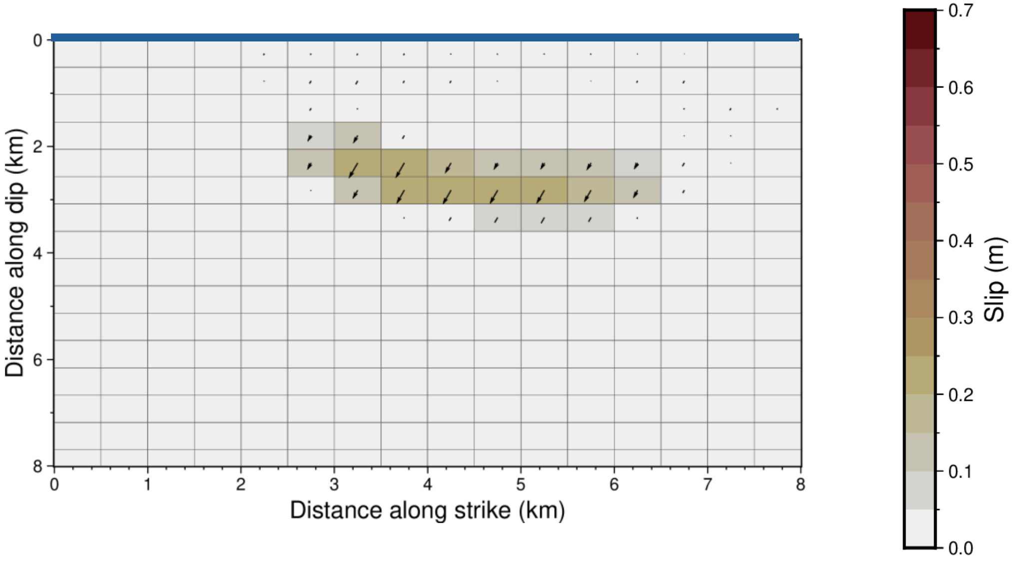
- New fault ruptured for the last earthquake in the sequence
- Geodetic moment released equivalent to a Mw 5.0



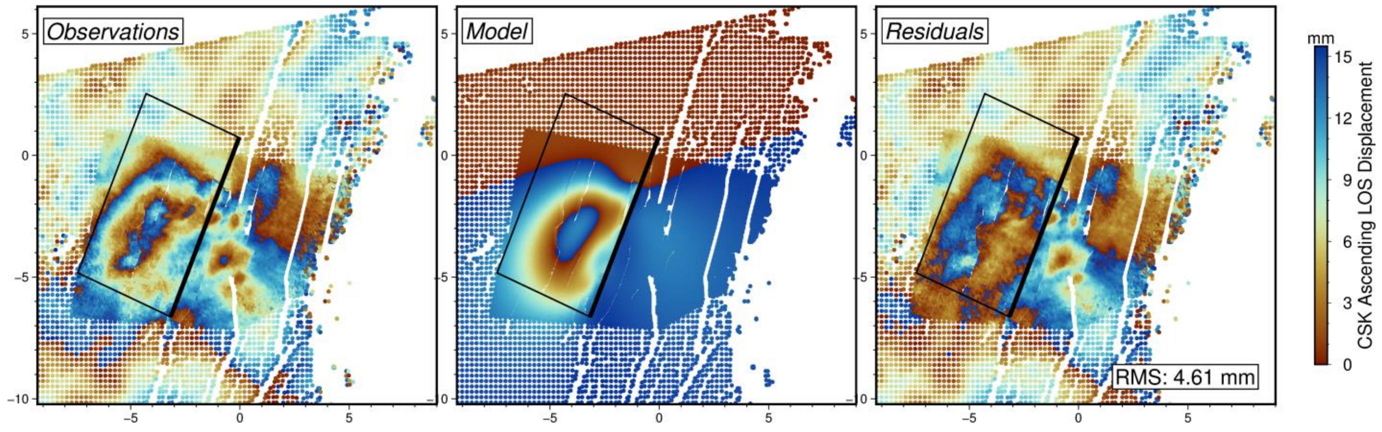
E

2025-03-16

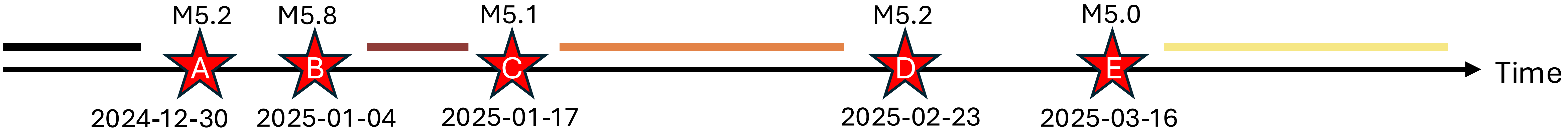
M_0 $3.45 \times 10^{16} N\ m$

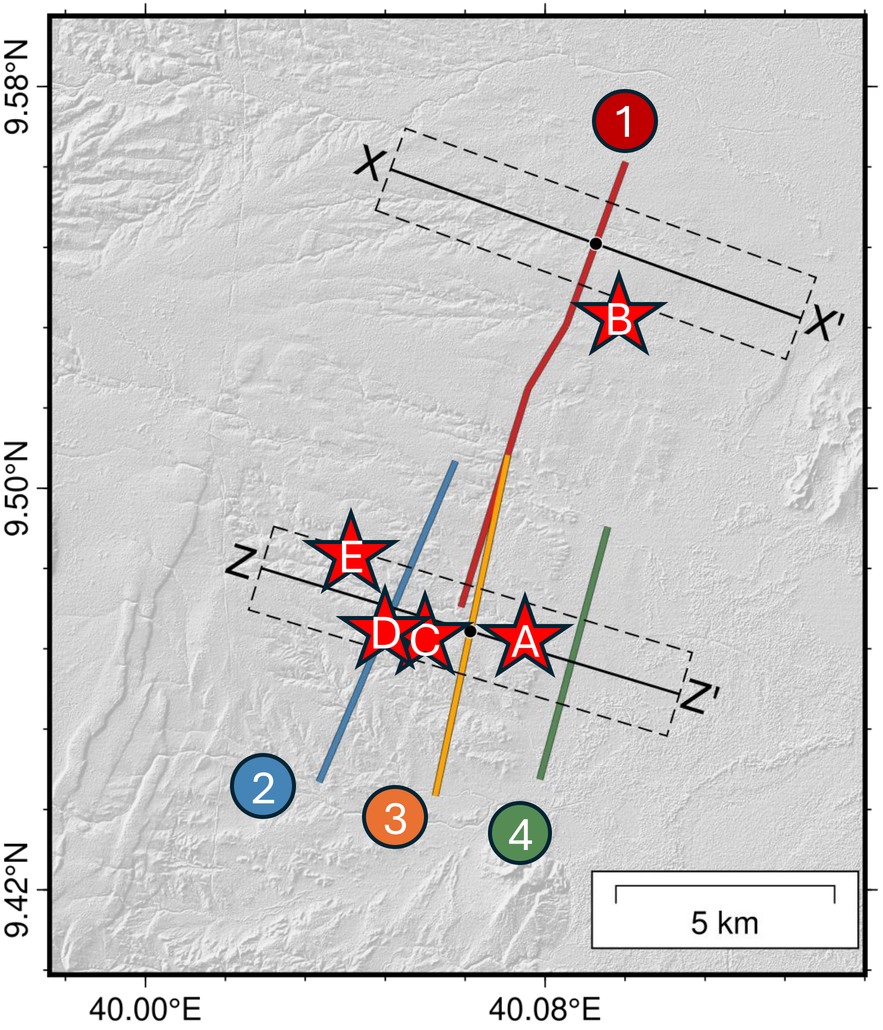


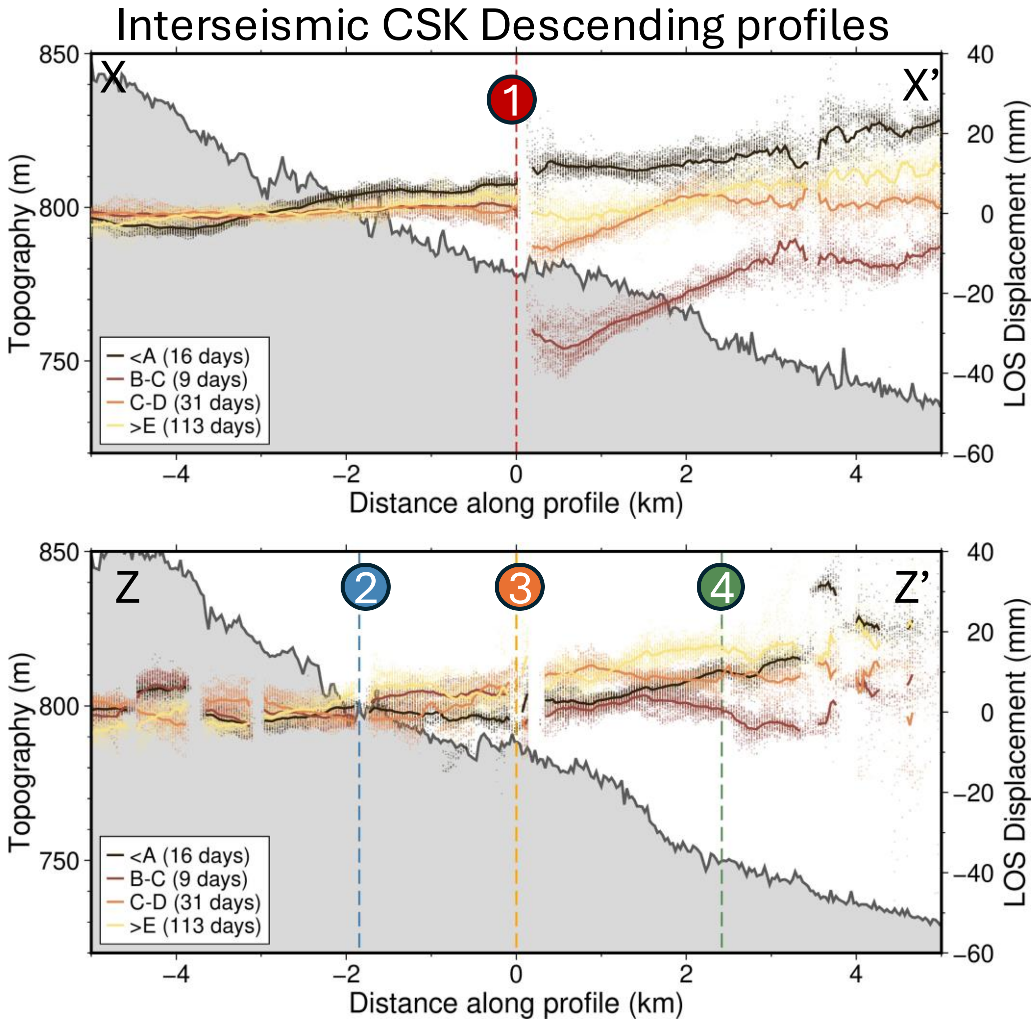
Ascending Model



Interseismic deformation

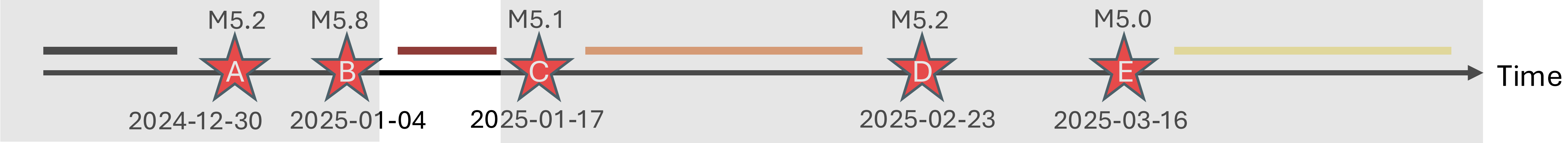


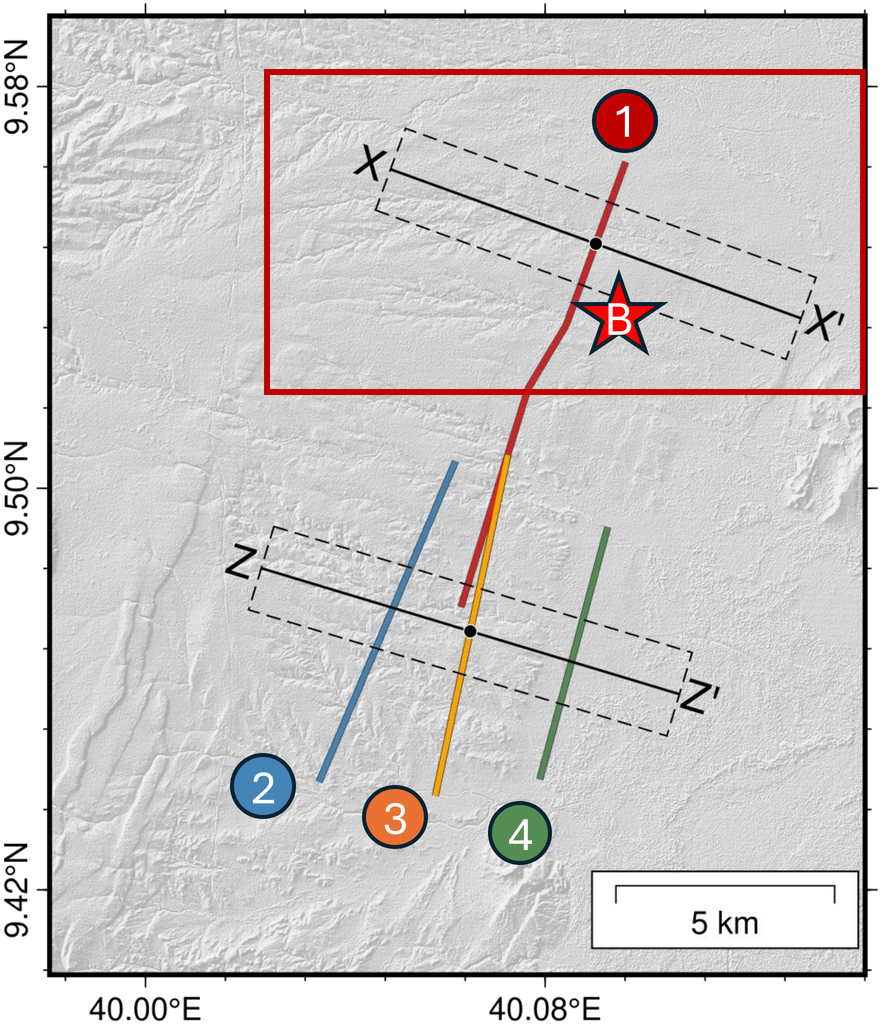


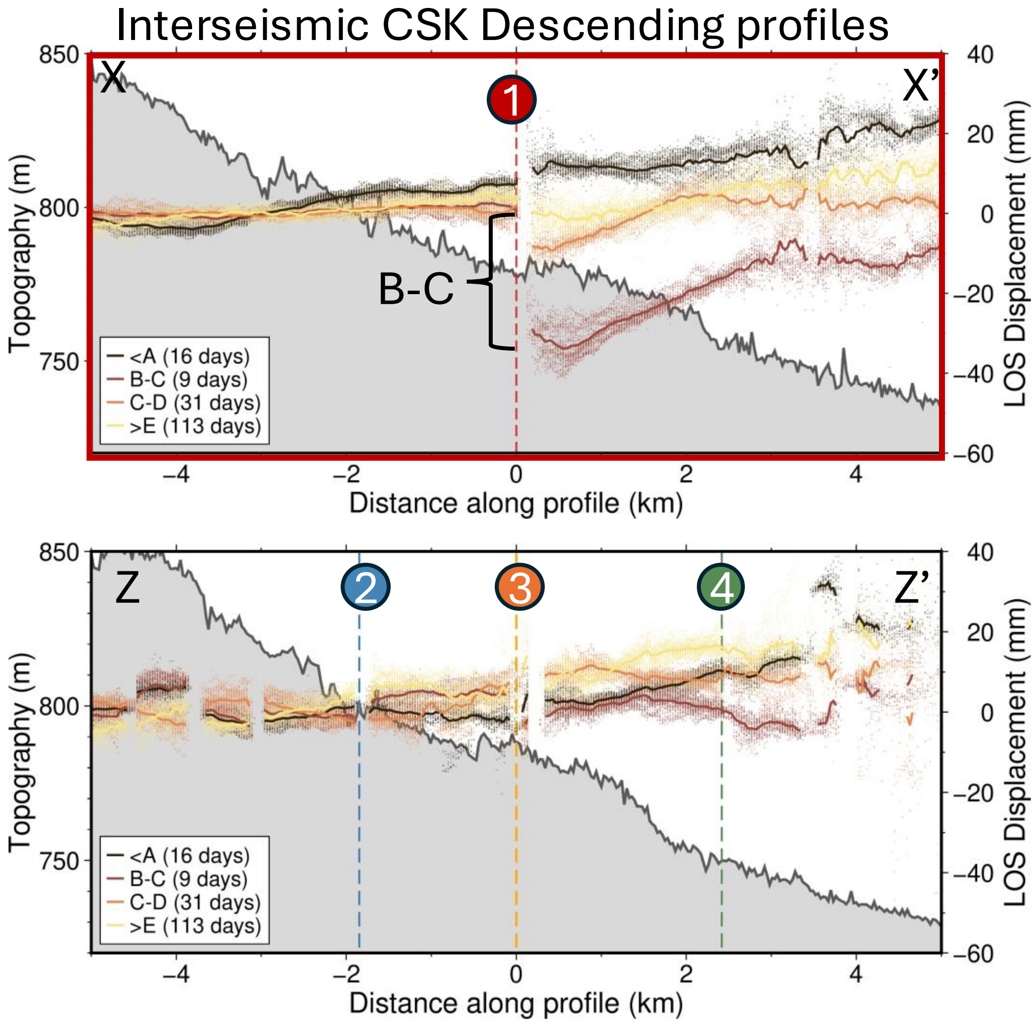


Distributed interseismic deformation across the fault network

Interseismic deformation

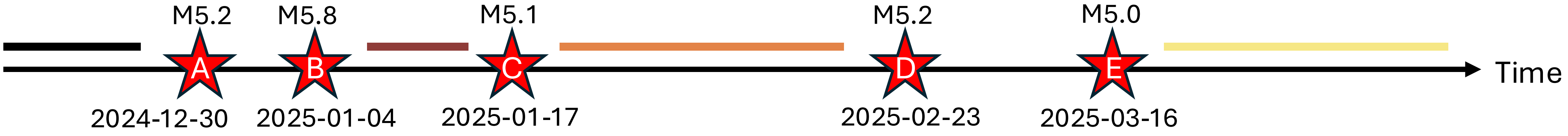


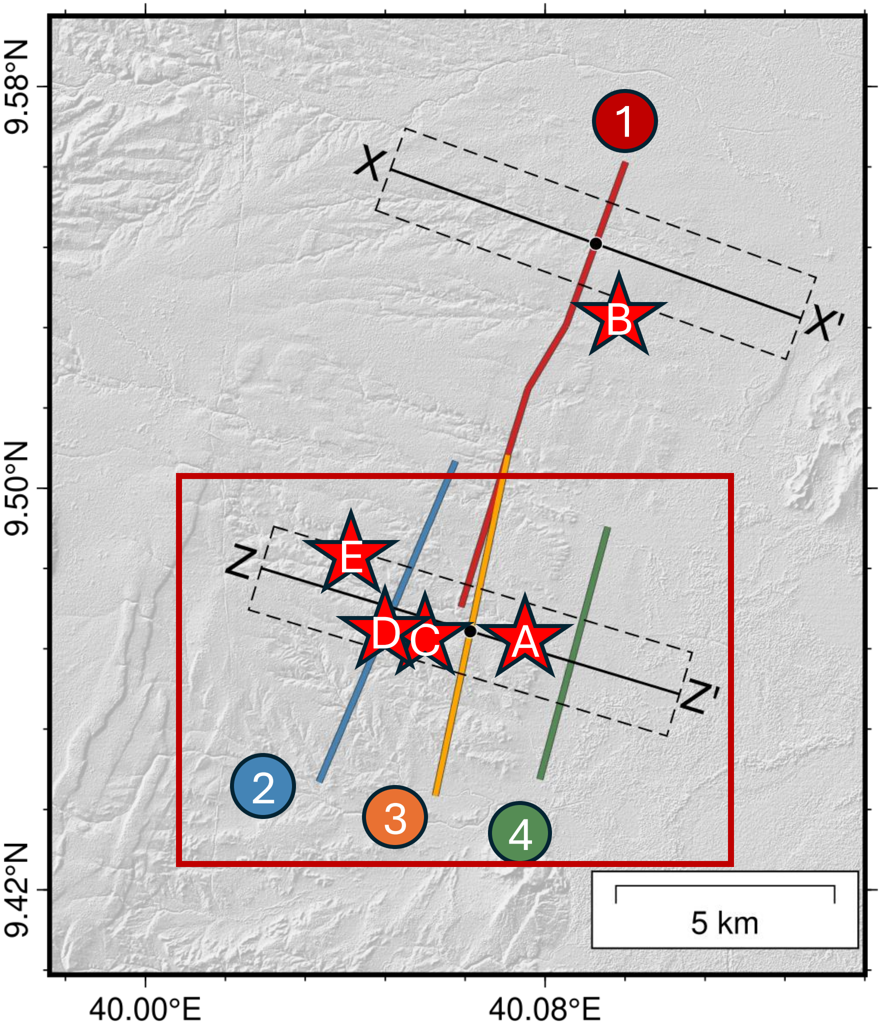


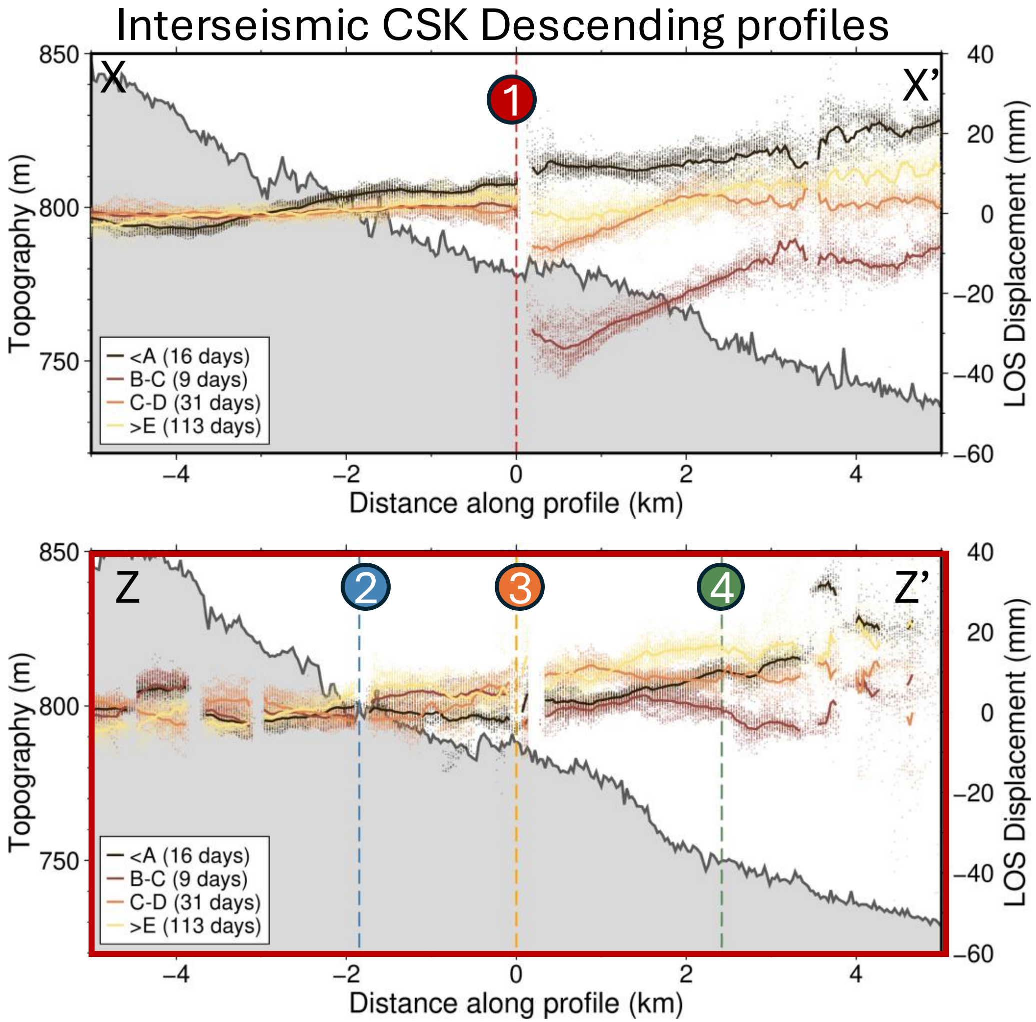


- Deformation showing a clear change towards the fault ruptured in earthquake B (Mw 5.7)
- Suggest **afterslip** occurring after the earthquake B.

Interseismic deformation







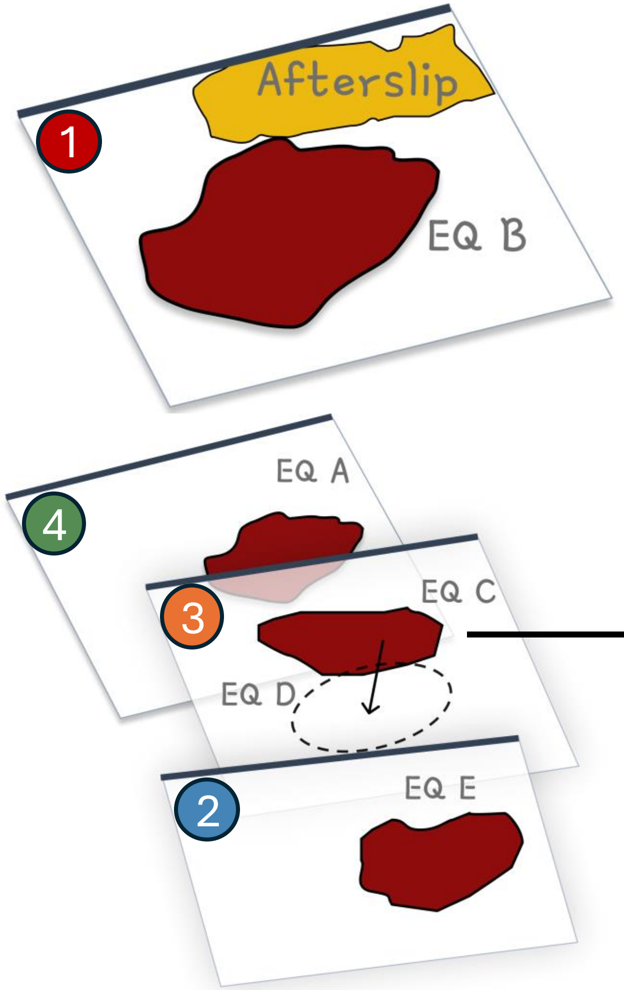
- Deformation shows no clear jumps across the modelled fault traces for earthquakes A, B, C, D, E.
- Suggest that afterslip does not dominate across the faults 2,3,4

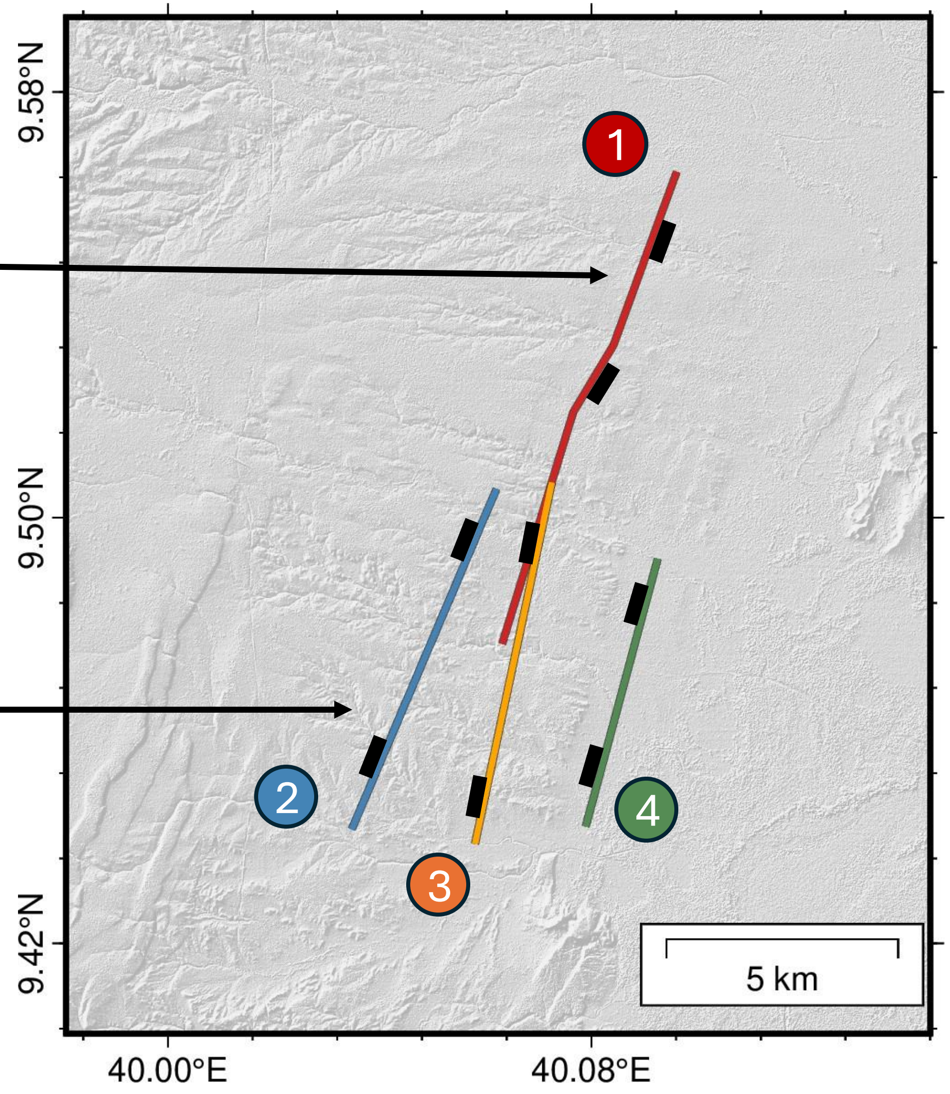
Possible explanation: heavily segmented faults with magmatic fluids going on.

Takeaways

1. Evidence of afterslip in fault 1

2. No clear evidence of afterslip between repeating earthquakes across fault network 2,3,4





- Evidence of different type of fault behavior:

- Heterogeneous fluid flow / material properties (hydrothermal alteration? clay-rich rocks?

Takeaways

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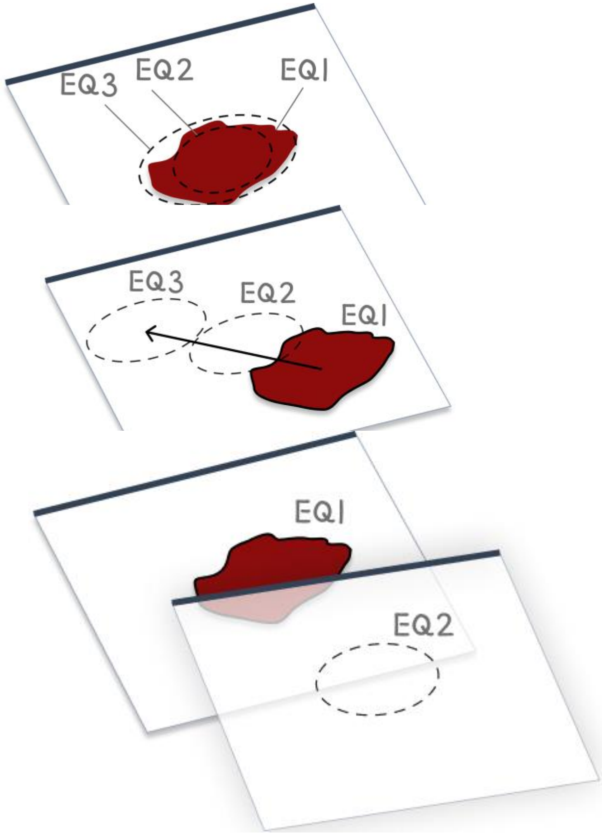
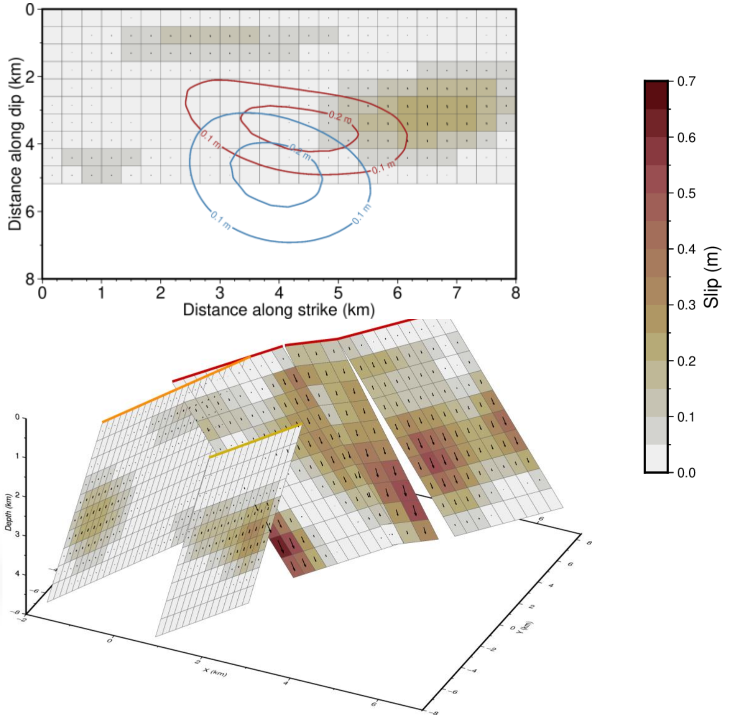
- Dyke intrusions provide an ideal opportunity to study cycles of seismic and aseismic slip driven by rapidly changing stress fields.

- High spatial and temporal resolution satellite data (e.g CSK) enable us to measure and model surface displacements associated with small, shallow earthquakes (M5-5.5).

1. ~~Repeated rupture of the same fault patch~~ →
2. Slip migration ✓ →
3. Slip partitioned across fault network ✓ →





Thank you for listening!

zy22448@bristol.ac.uk
simonst.orrego@gmail.com