Earthquake scenarios for the Hellenic Arc from 3D dynamic rupture modeling: implications for tsunami hazard

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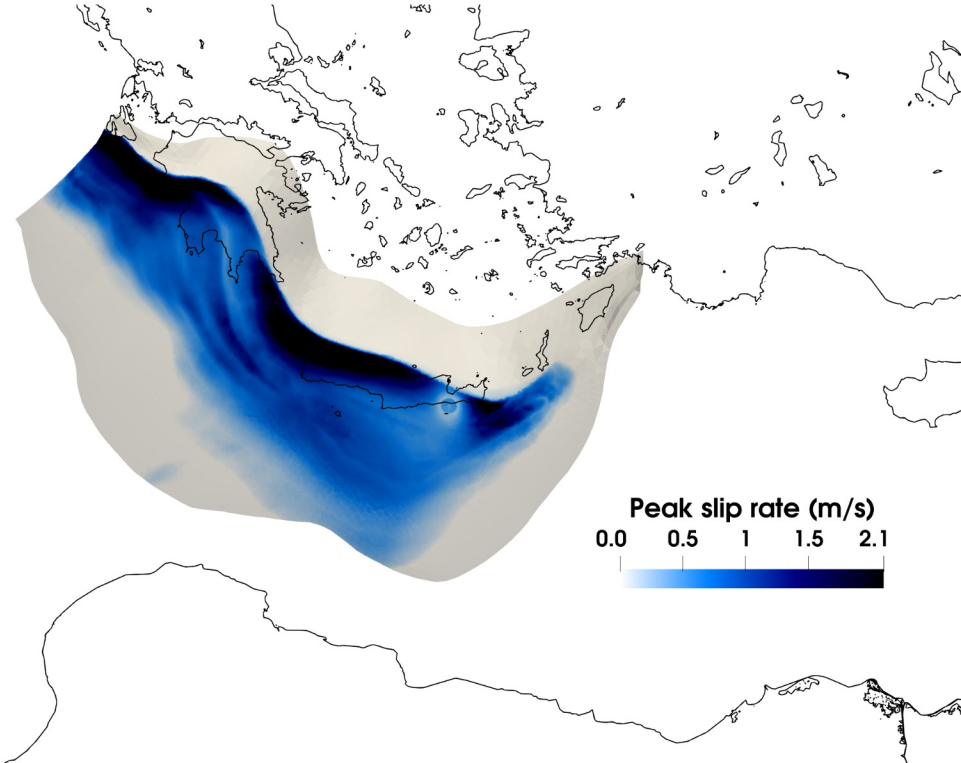
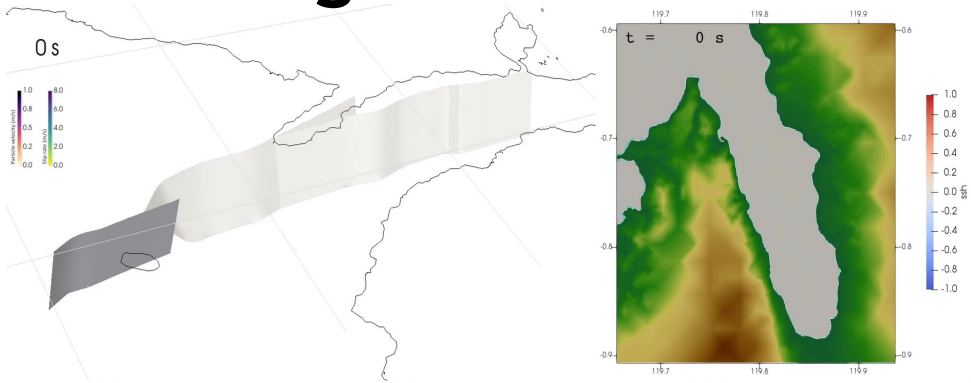
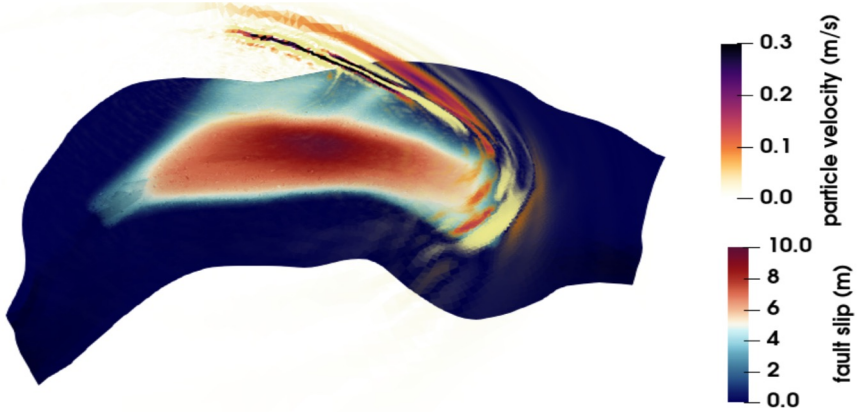


Earthquake scenarios for the Hellenic Arc from 3D dynamic rupture modeling

- Tsunami (probalistic) hazard studies commonly assume **instantaneous** and **static** displacement initial conditions to source tsunami, incl. when considering heterogeneous (stochastically distributed) slip patches
- **Physics-based dynamic rupture simulations** capture how faults yield and slide non-linearly coupled to seismic wave propagation and provide **time-dependent fault slip and seafloor displacement**
- Improve and complement tsunami hazard analyis by exploring earthquake mechanical viability and variability and earthquake-tsunami interaction



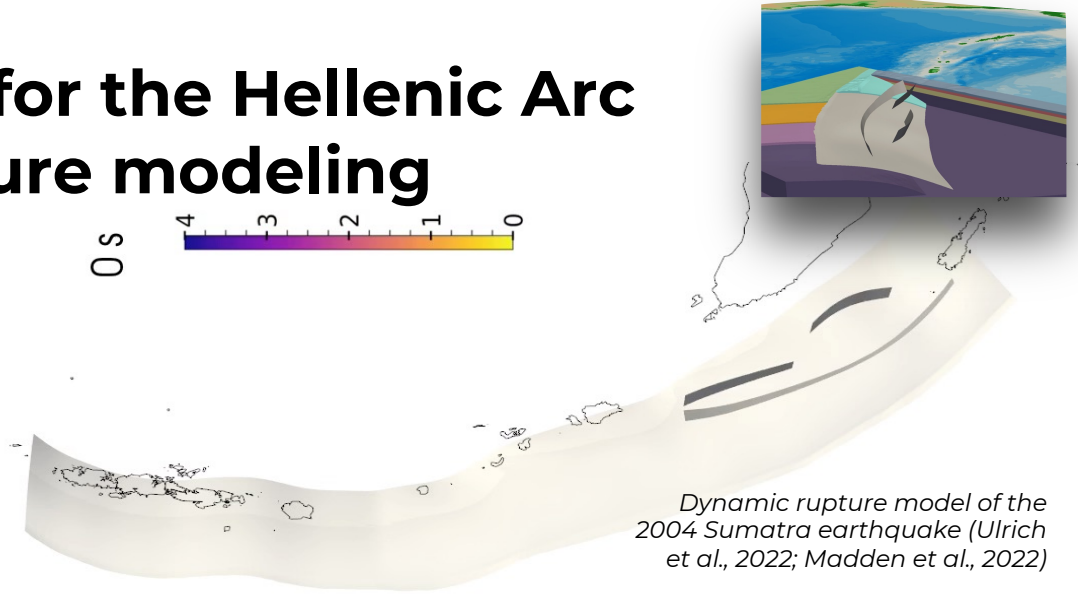
Dynamic rupture strike-slip induced local tsunami in Palu Bay (Ulrich et al., PAGeoph 2019)



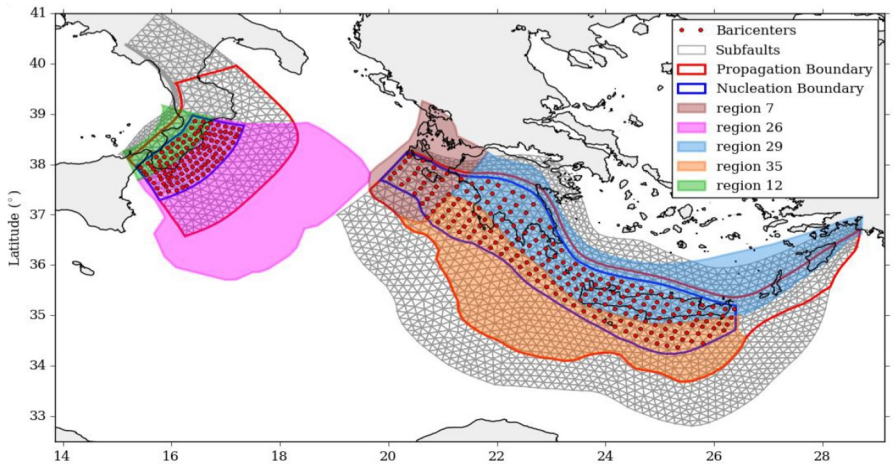
Earthquake scenarios for the Hellenic Arc from 3D dynamic rupture modeling

- **3D dynamic rupture models are now feasible on megathrust scales:** large space-time scales, cascading multi-physics and geometric complexity empowered by supercomputing

- Hellenic Arc model: 860.5km x 626.2km, depth=91.2km



Dynamic rupture model of the 2004 Sumatra earthquake (Ulrich et al., 2022; Madden et al., 2022)



Fault model by Selva et al. 2016:
Nucleation zone (blue): 17km - 50km depth
Propagation zone (red): 15km - 60km depth
(upper limit: "depth where shallow splay faults cutting through the accretionary wedge")

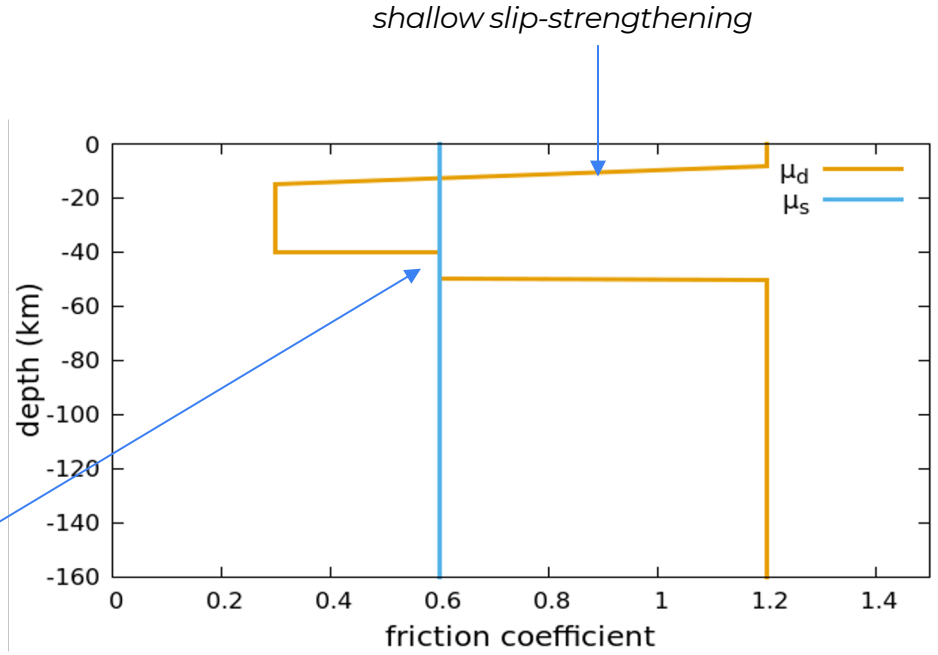
Frictional strength of the Hellenic Arc

- Much deformation of the Hellenic Arc may be **aseismic** (*Vernant et al., 2014; Selva et al., 2016*)
- Seismogenic zone potentially restricted to 15-45km depth (Laigle et al., 2004)
- **Linear slip-weakening friction** governing dynamic rupture:
  - 0-15km depth: slip strengthening
  - 15-40km depth: slip weakening
  - 40-50km depth: slip neutral
  - >50km depth: slip strengthening

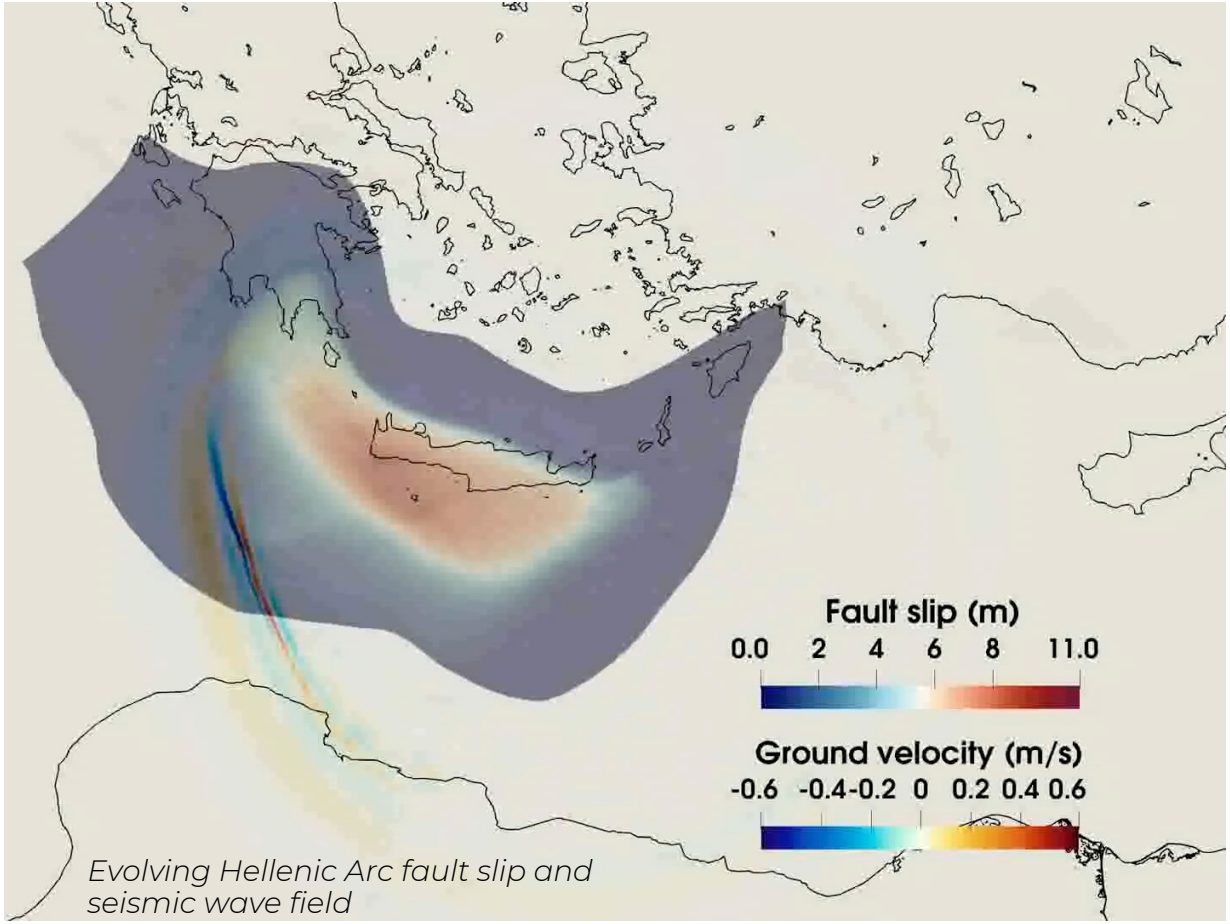
slip-neutral 'gap' as e.g. inferred for Cascadia, deep transition that separates ETS region from region that is conventionally considered to be locked (Gao & Wang, 2017; Ramos et al., 2019, 2021)

Assessing Margin-Wide Rupture Behaviors Along the Cascadia Megathrust With 3-D Dynamic Rupture Simulations

Marlon D. Ramos[1], Yihe Huang[1], Thomas Ulrich[2], Duo Li[2], Alice-Agnes Gabriel[2,3], and Amanda M. Thomas[4]

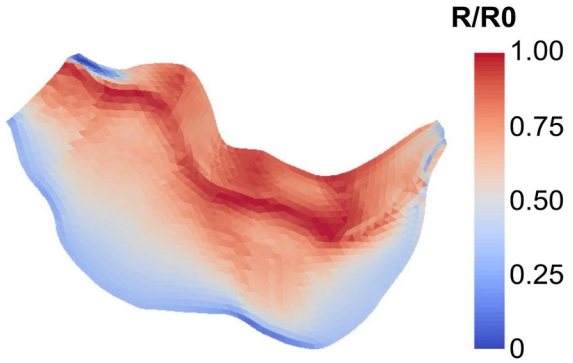


Margin-wide Hellenic Arc dynamic rupture model



Evolving Hellenic Arc fault slip and seismic wave field

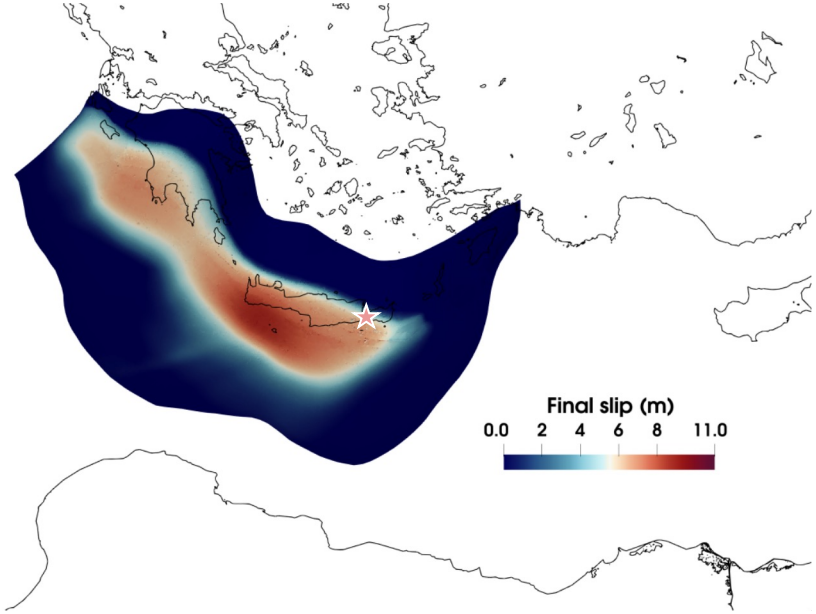
- **Pre-stress**: constrained from regional tectonics and stress inferences *(Ulrich et al., 2022)*
- **Margin-wide rupture scenario of earthquake spontaneously unzipping the whole length of the Hellenic Arc**

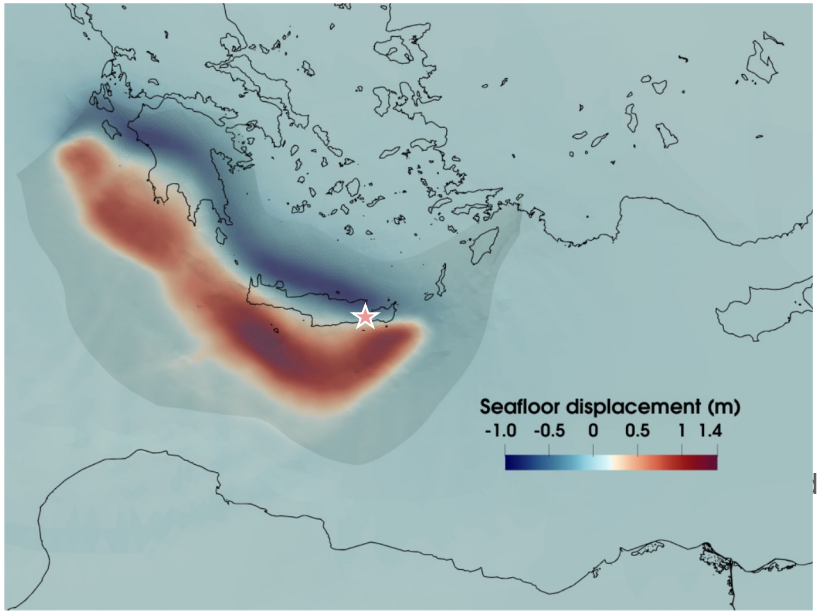


Normalized dynamic fault strength (stress drop/max. strength drop)

Margin-wide Hellenic Arc dynamic rupture model

- Magnitude Mw= 8.97
- max. **fault slip** 14.4 m, mean 4 m
- max. seafloor **uplift** above the megathrust 1.5 m
- max. **peak slip rate** 2.1 m/s (concentrated on steeply dipping fault segments)



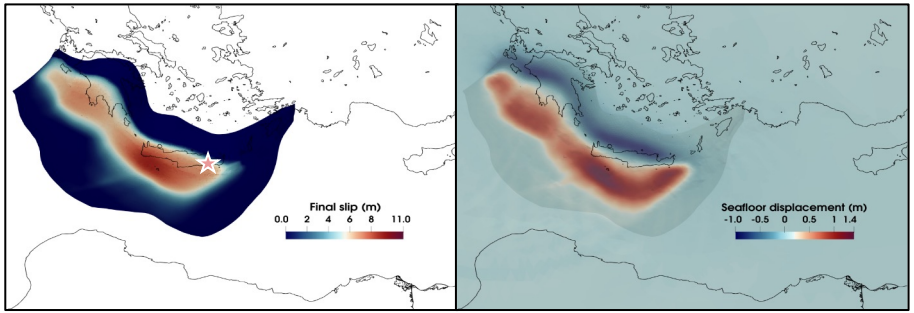


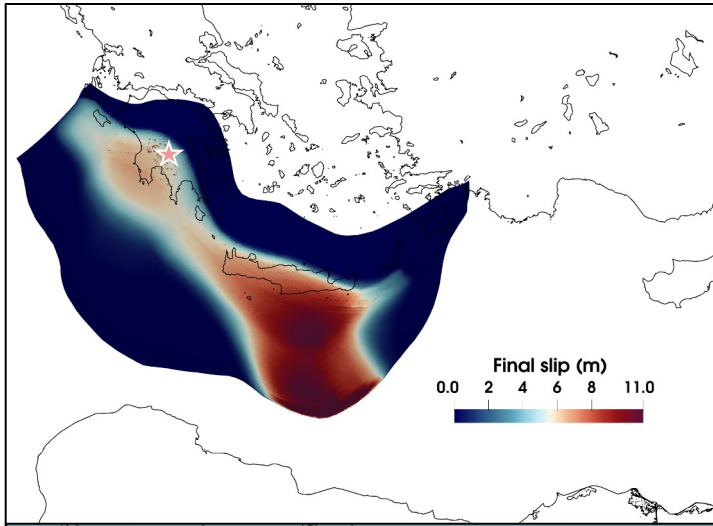
Directivity and shallow fault slip

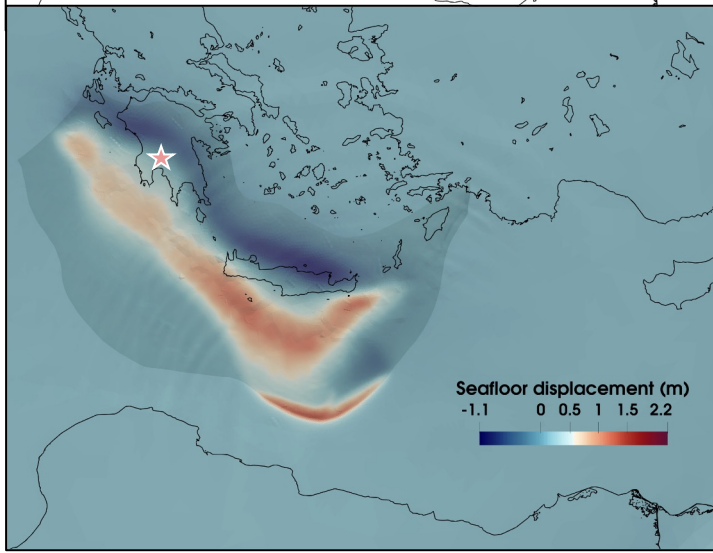
- Dynamic rupture can penetrate in **slip-strengthening region**
- Modulated by **directivity** and **slab geometry**
- Highest slip (18.2 m) occurs at shallow depth

→ Magnitude Mw 9.03
→ Average fault slip = 5.3 m
→ Peak slip rate = 3.3 m/s
→ max. seafloor uplift = 2.2 m

Fault slip and seafloor displacement of margin-wide model



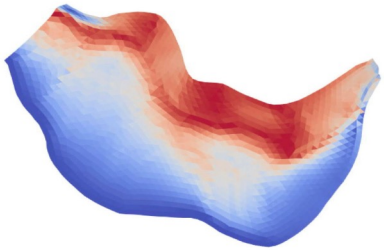


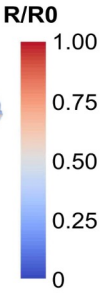


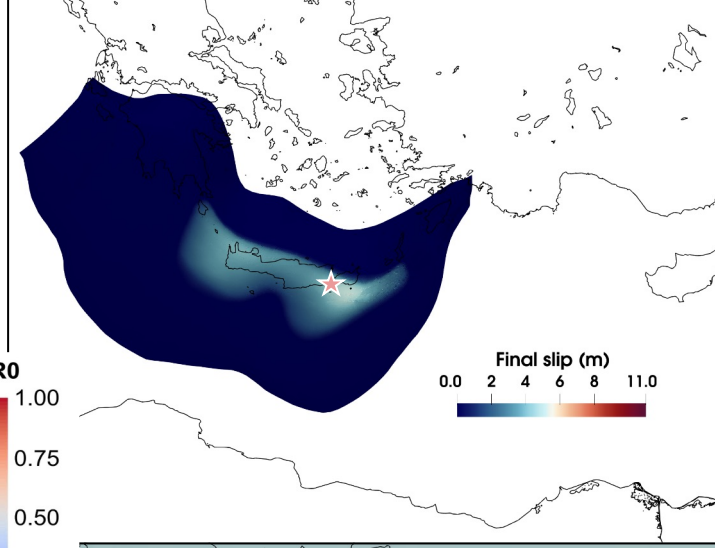
Non-optimally pre-stressed fault

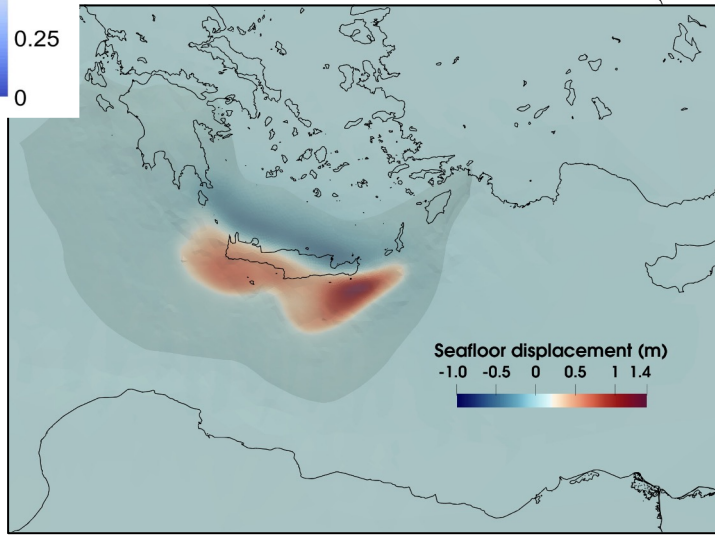
- Shallow segments not optimally pre-stressed
- Limits effectively spontenaous shallow rupture
- Rupture dynamically stopped by fault geometry

→ Magnitude Mw 8.53
→ Average fault slip = 2.3 m
→ Peak slip rate = 2.4 m/s
→ Seafloor displacement = 1.3 m

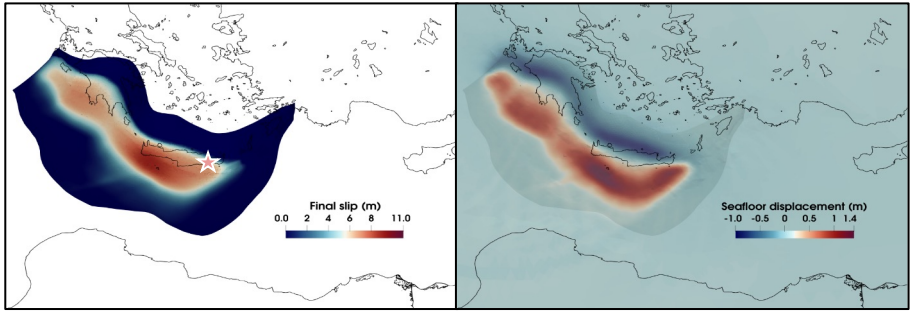








Fault slip and seafloor displacement of margin-wide model

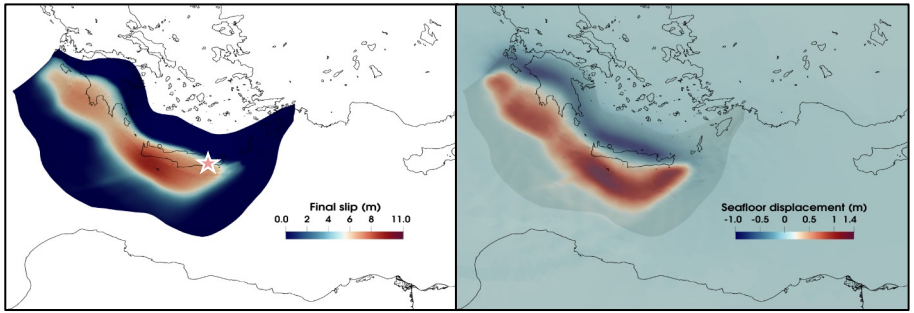


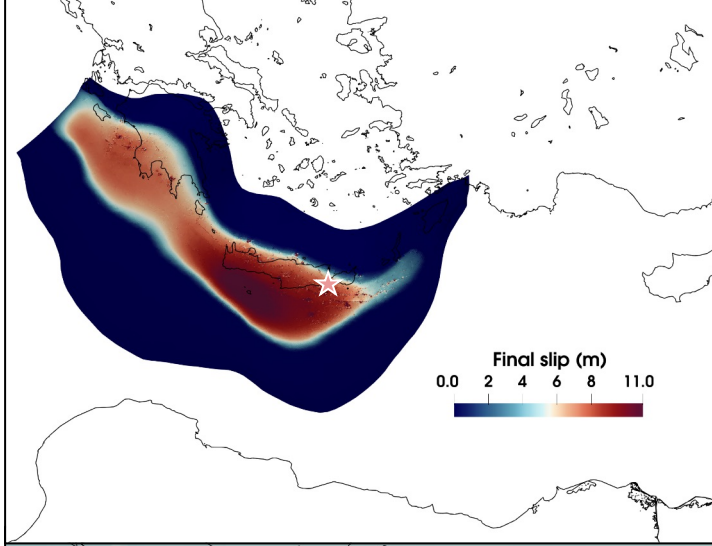
Off-fault plastic yielding

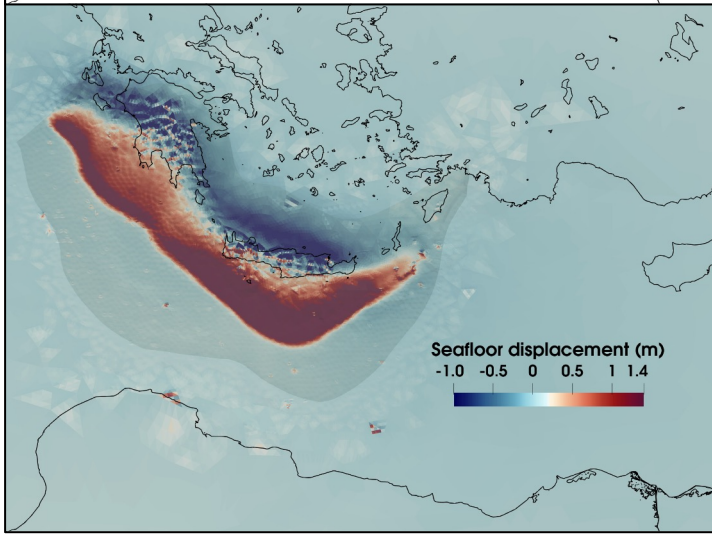
- Co-seismic **off-fault plastic deformation** leads to much larger vertical uplift and tsunami potential, limits slip to the trench
- Sediments: bulk cohesion is combination of constant term + depth-dependent term
- High plastic deformation near the **shallow portion of the megathrust**

→ Magnitude Mw 9.02
→ Average fault slip = 6.2 m
→ Peak slip rate = 4.7 m/s
→ **Seafloor displacement = 8.3 m**

Fault slip and seafloor displacement of margin-wide model

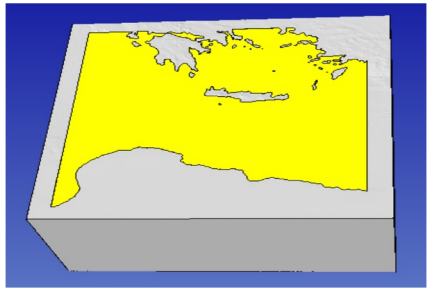






Conclusions

Outlook: CAD-model towards a fully-coupled earthquake-acoustic-tsunami model of the Hellenic-Arc (Krenz et al., SC'21)



- **Directivity and spontaneous rupture evolution important to constrain shallow fault slip**
- **Optimally pre-stressed fault → margin wide rupture → Mw ~ 9 (model 1)**
- **Rupture penetration into slip-strengthening region possible (model 2)**
- **Non-optimal pre-stressed fault → more realistic scenario → rupture spontaneously stopped by geometry → Mw 8.5 (model 3)**
- **Off-fault plastic yielding → rupture limited to deep fault (no shallow fault slip) → seafloor uplift ~7m higher (model 4)**