LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

ChEESE

Center of Excellence for Exascale in Solid Earth

TS4.3 - Linking active faults and the earthquake cycle to Seismic Hazard Assessment: Onshore and Offshore Perspectives
Fri, 30 Apr, 15:45–15:47

Fabian Kutschera

Linking dynamic earthquake rupture to tsunami modeling for the Húsavík-Flatey transform fault system in North Iceland

Fabian Kutschera[1], Sara Aniko Wirp[1], Bo Li[1], Alice–Agnes Gabriel[1], Benedikt Halldórsson[2], Claudia Abril[2], and Leonhard Rannabauer[3]

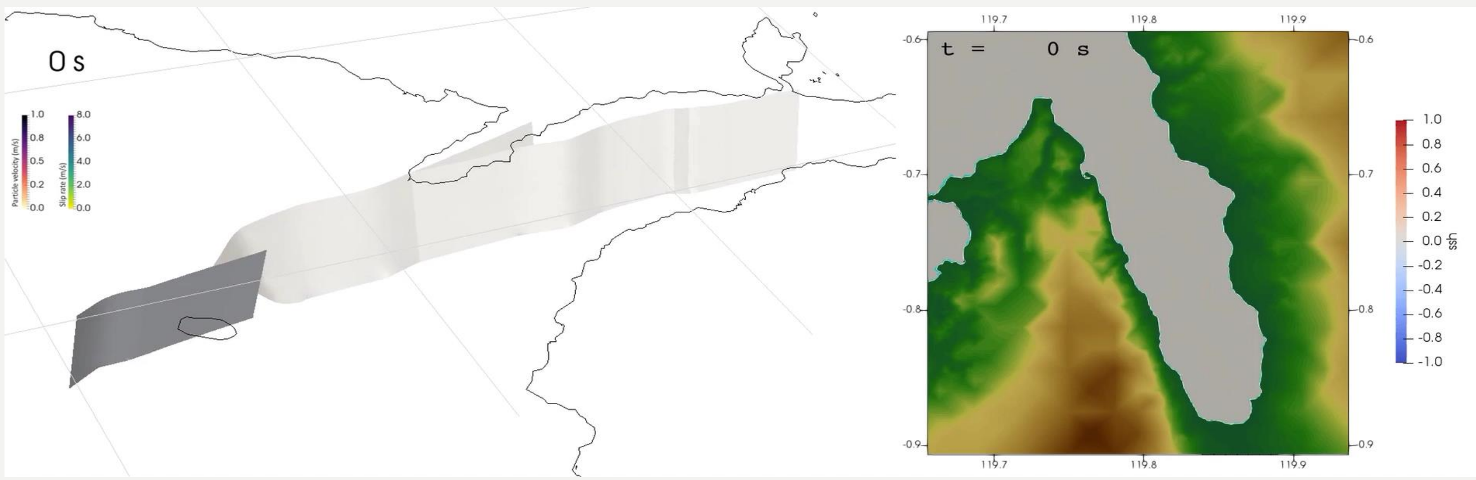
[1] Department of Earth and Environmental Sciences, Ludwig-Maximilians-University, Munich, Germany
[2] Division of Processing and Research, Icelandic Meteorological Office, Reykjavík, Iceland
[3] Department of Informatics, Technical University of Munich, Garching, Germany

- Palu Sulawesi Tsunami hit Palu Bay in September 2018 unexpected and caused severe destruction
- A $M_W 7.5$ earthquake occuring on a strike-slip fault system preceded the disaster

[Omira et al., 2019]

Motivation

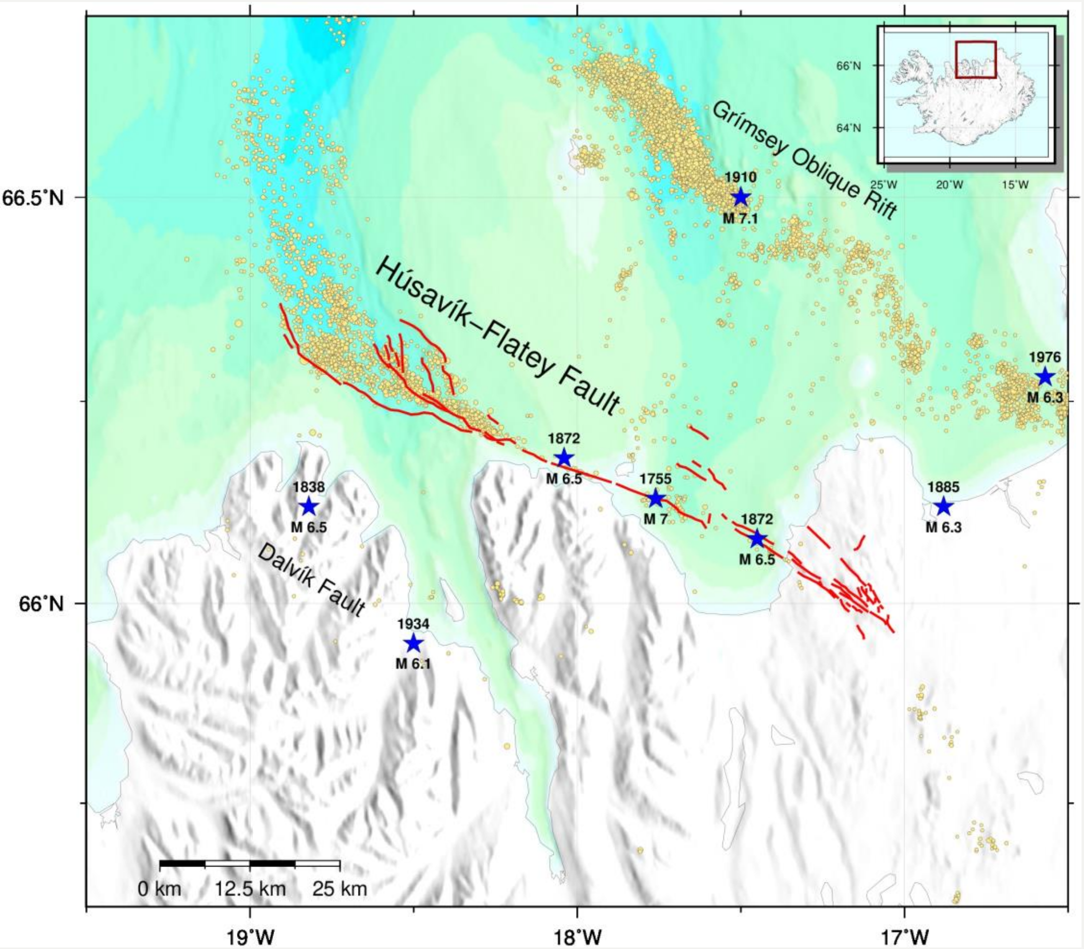
- Coseismic seafloor displacement during the Sulawesi earthquake in Indonesia likely involved in the subsequent tsunamigenesis *[Ulrich et al., 2019]*

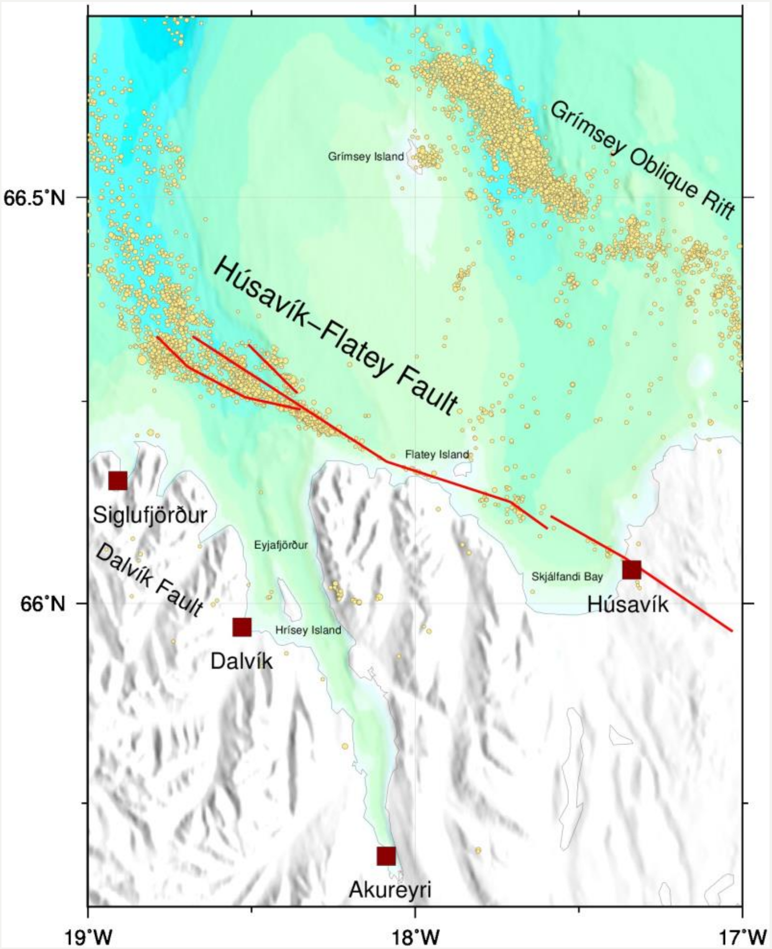


- No M>6 earthquakes on the HFF in the last 145 years
- Strain accumulation on locked HFF equivalent to a potential M_W 6.8±0.1 earthquake *[Metzger et al., 2013]*

Goal: Reassessment of tsunami potential of the HFF

Seismicity and fault geometries





Left: complex fault geometry and historic seismicity

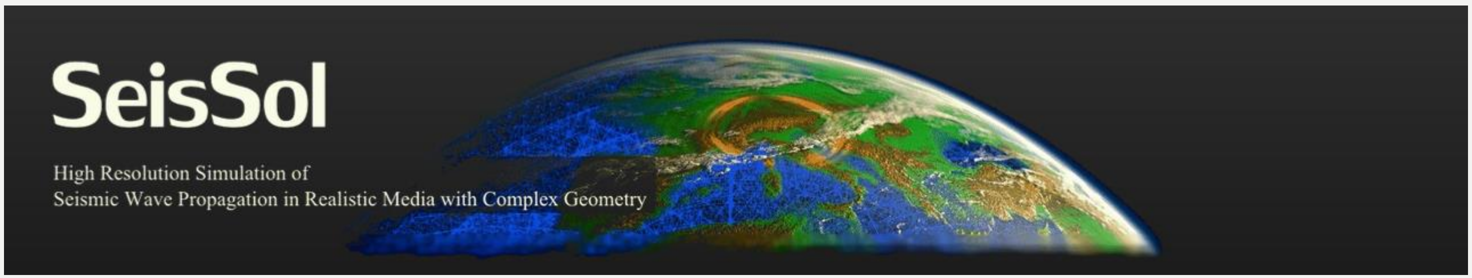
Right: simpler fault geometry and meaningful locations

Ingredients

- Bathymetry and topography of the area
  (www.geomapapp.org) [Ryan et al., 2009]
- 3-D subsurface structure *[Abril et al., 2020]*
- Newly inferred fault geometries *[Einarsson et al., 2019]*
- Primary stress orientations & stress shape ratio
  [Ziegler et al., 2016]
- Account for the contribution of horizontal ground deformation to the vertical displacement
  [Tanioka and Satake, 1996]

Modeling

- Dynamic earthquake rupture models (DR) simulated with SeisSol *(www.seissol.org) [Pelties et al., 2014]*

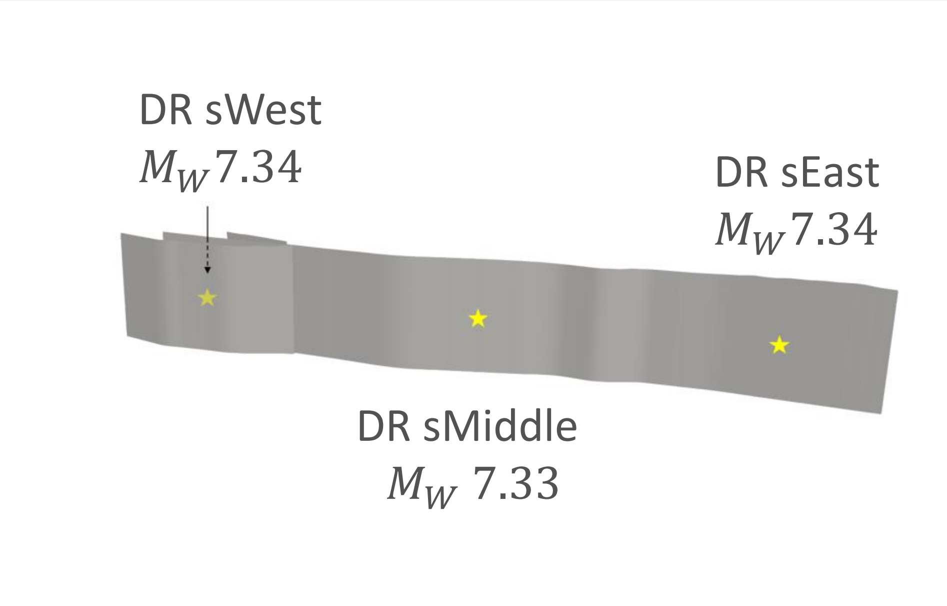


  - Discontinuous Galerkin (DG) scheme with Arbitrary high-order DERivative (ADER) time stepping on unstructured tetrahedral grids *[Dumbser and Käser, 2006]*
  - Modeling of spontaneous earthquake rupture across complex fault networks and seismic wave propagation

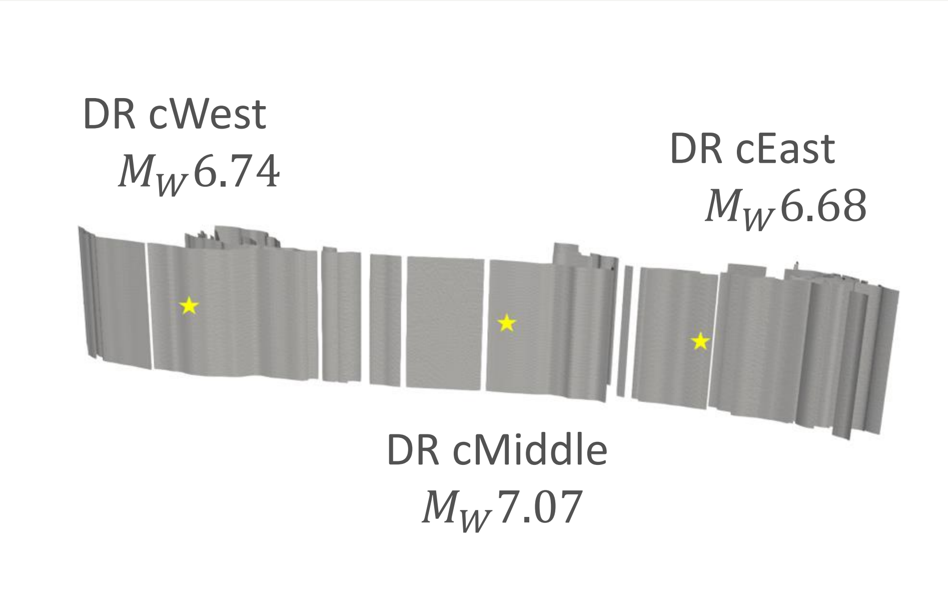
- Tsunami Simulations with sam(oa)²-flash *(https://gitlab.lrz.de/samoa/samoa) [Meister, 2016]*
  - Solving two dimensional depth-integrated hydrostatic nonlinear Shallow Water Equations (SWE)
  - Adaptive mesh refinement using Sierpinsky Space filling curve
  - Uses full spatio-temporal evolution of the seafloor displacement in the simulation

Note the different magnitudes between simple and complex

Simple



Complex

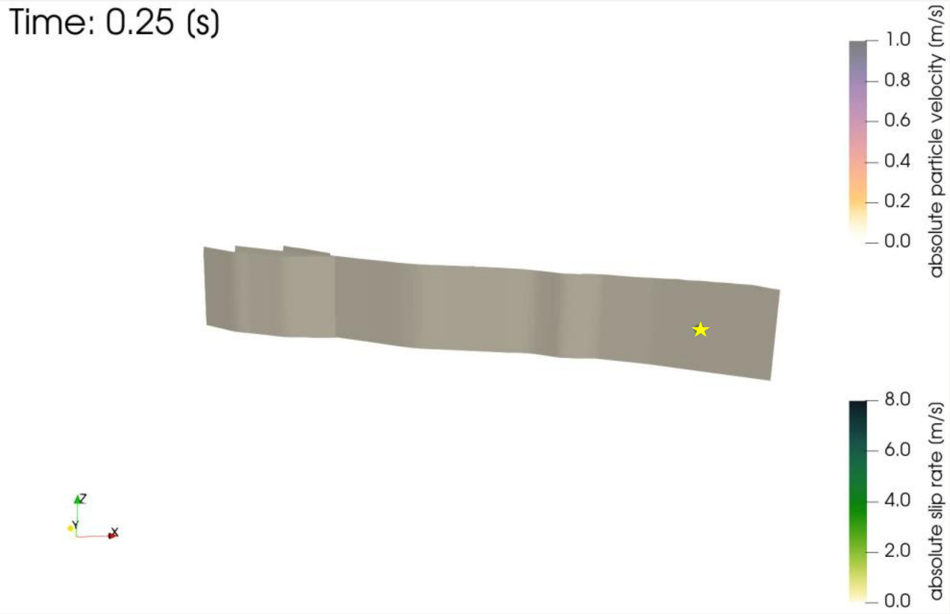


Hypocentre depths: 7km

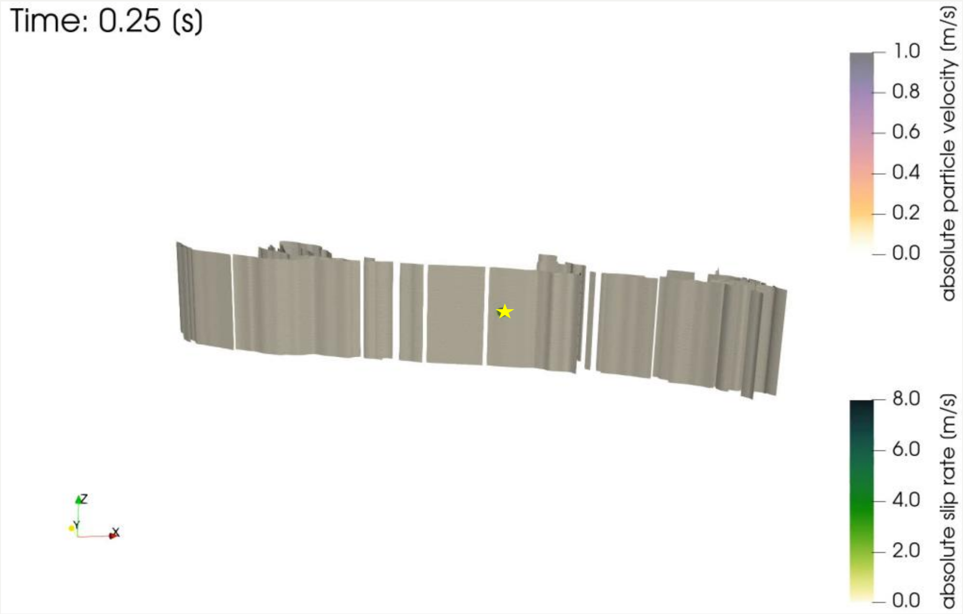
- Locking depth estimated between 6 and 10 km
  [Metzger and Jónsson, 2014]

Absolute slip rate and wavefield

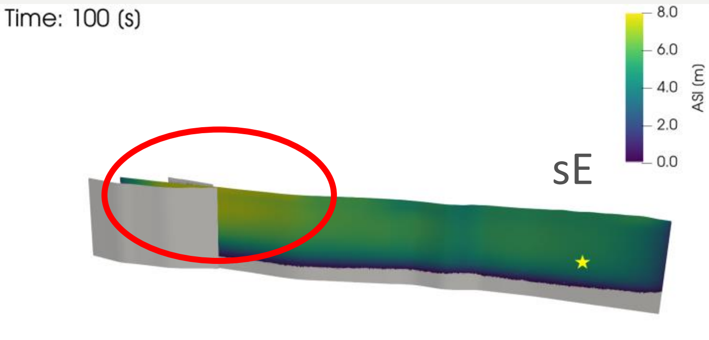
Simple East

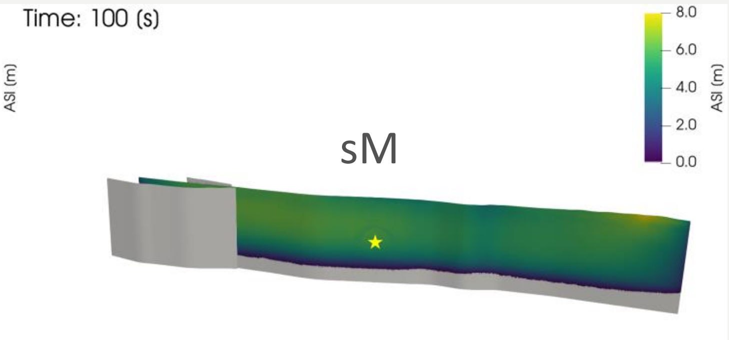


Complex Middle



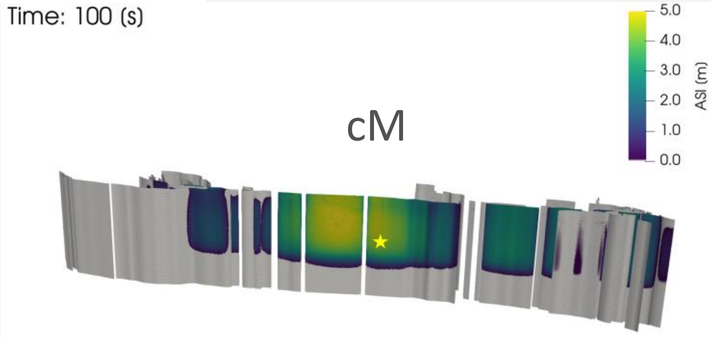
Absolute Slip – simple





Note the different scales between simple and complex scenarios

Absolute Slip – complex



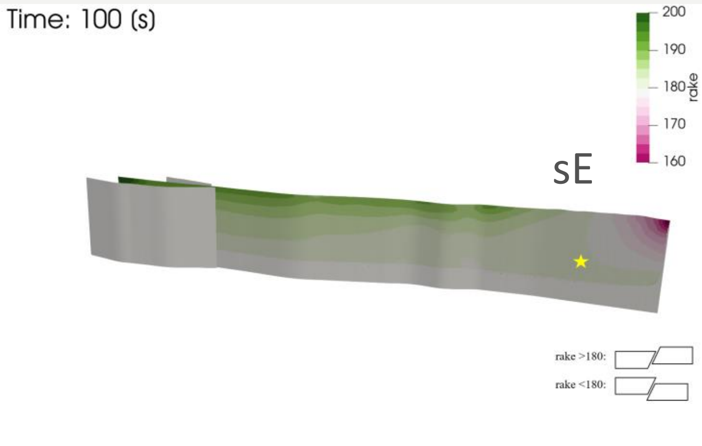
Simpler fault geometry

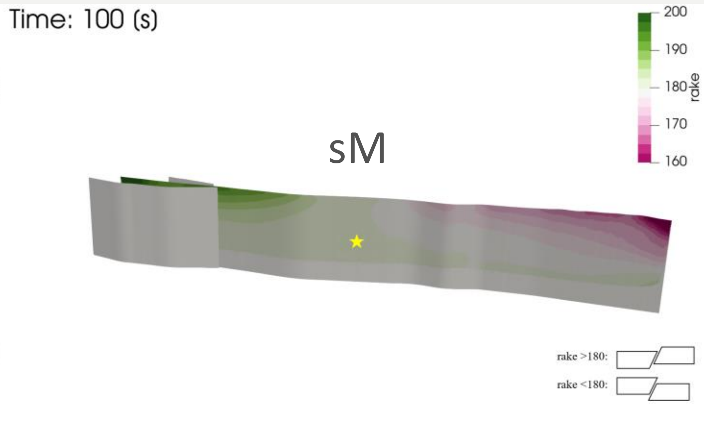
- Strong shallow fault slip for DR simple East (7.9 m)
- Rupture processes over entire main fault length

Complex fault geometry

- Smaller fault slip for all 3 DR Models,
  with highest ASI for complex Middle (5.2m)

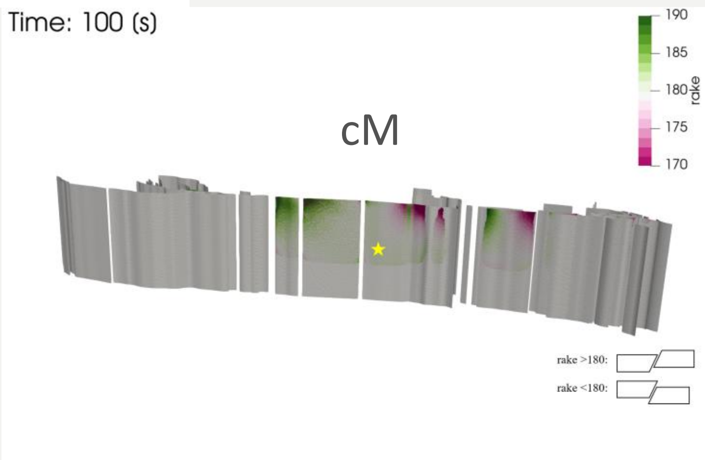
Rake – simple





Note the different scales between simple and complex scenarios

Rake – complex



Simpler fault geometry

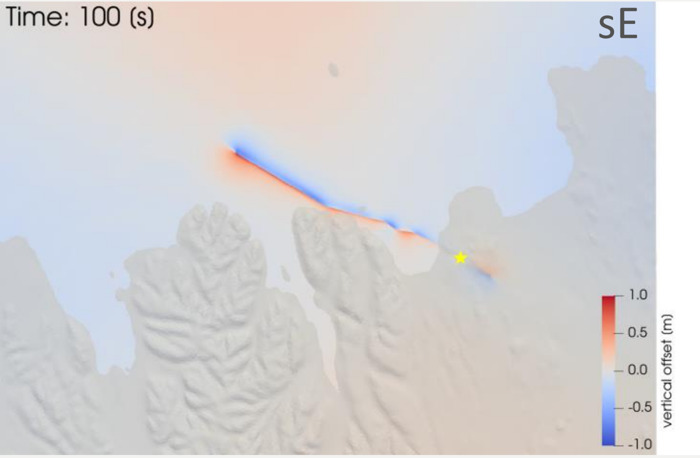
- Near-surface rake rotation of $\pm$ 20°

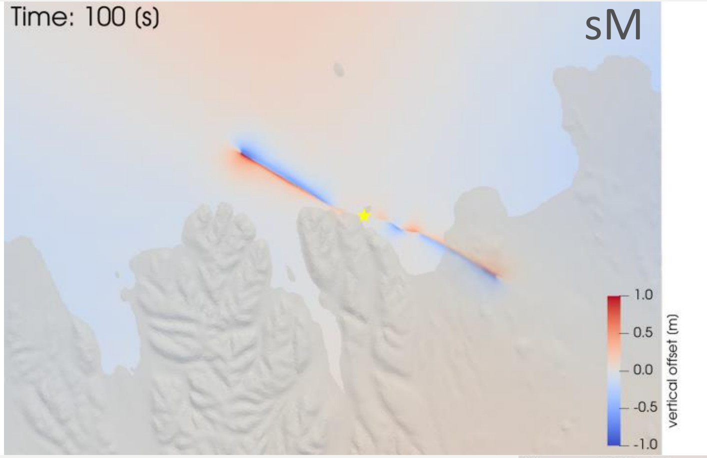
Complex fault geometry

- Near-surface rake rotation of $\pm$ 10°

Rake rotation can be observed in dynamic rupture models & can be seen in outcrops of surface-breaking earthquakes using slickenlines *[Kearse and Kaneko, 2020]*

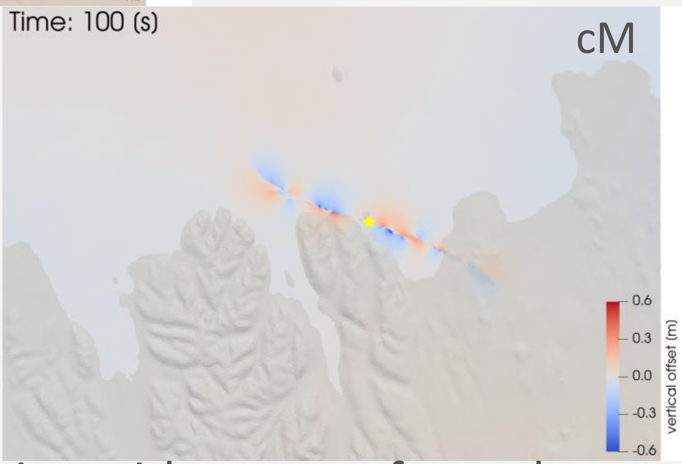
Vertical displacement – simple





Note the different scales between simple and complex scenarios

complex



Simpler fault geometry

- Seafloor uplift of up to 1 m for East and Middle

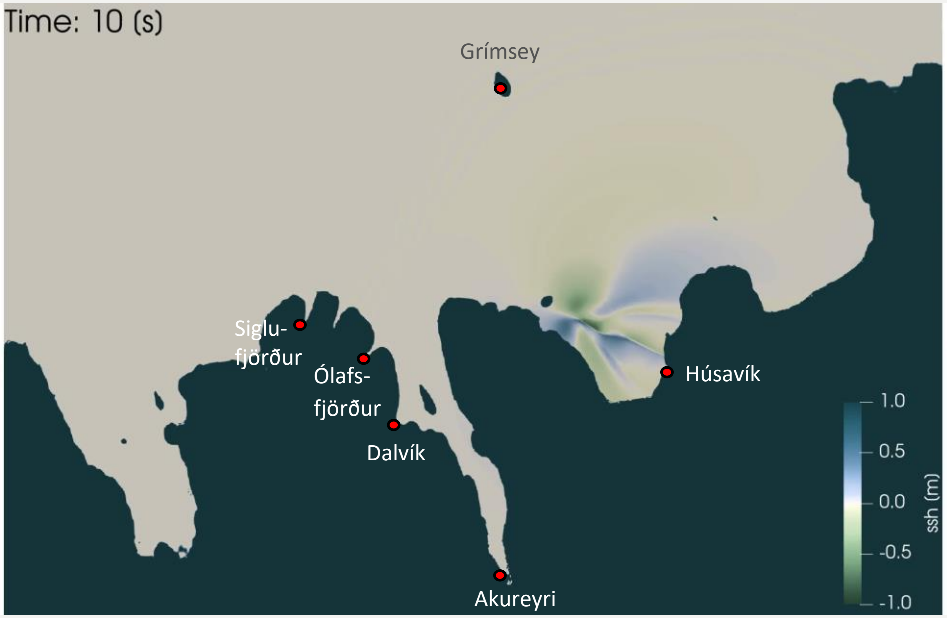
Complex fault geometry

- Less seafloor displacement: Middle $\sim 0.5\ m$

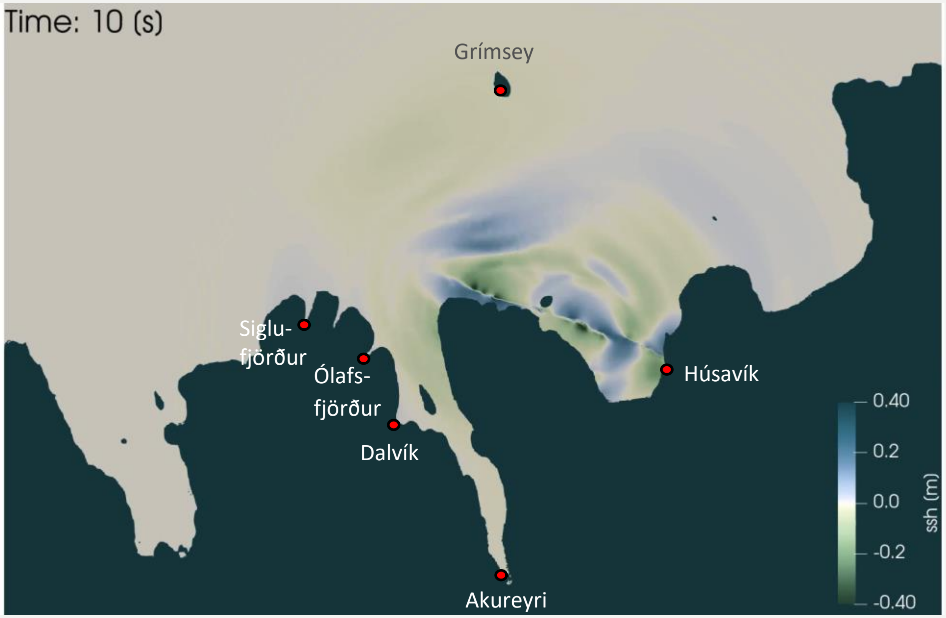
Vertical coseismic seafloor displacement in combination with near-surface rake rotation is capable to generate a localized tsunami

Note the different scales between simple and complex scenarios

Simple East

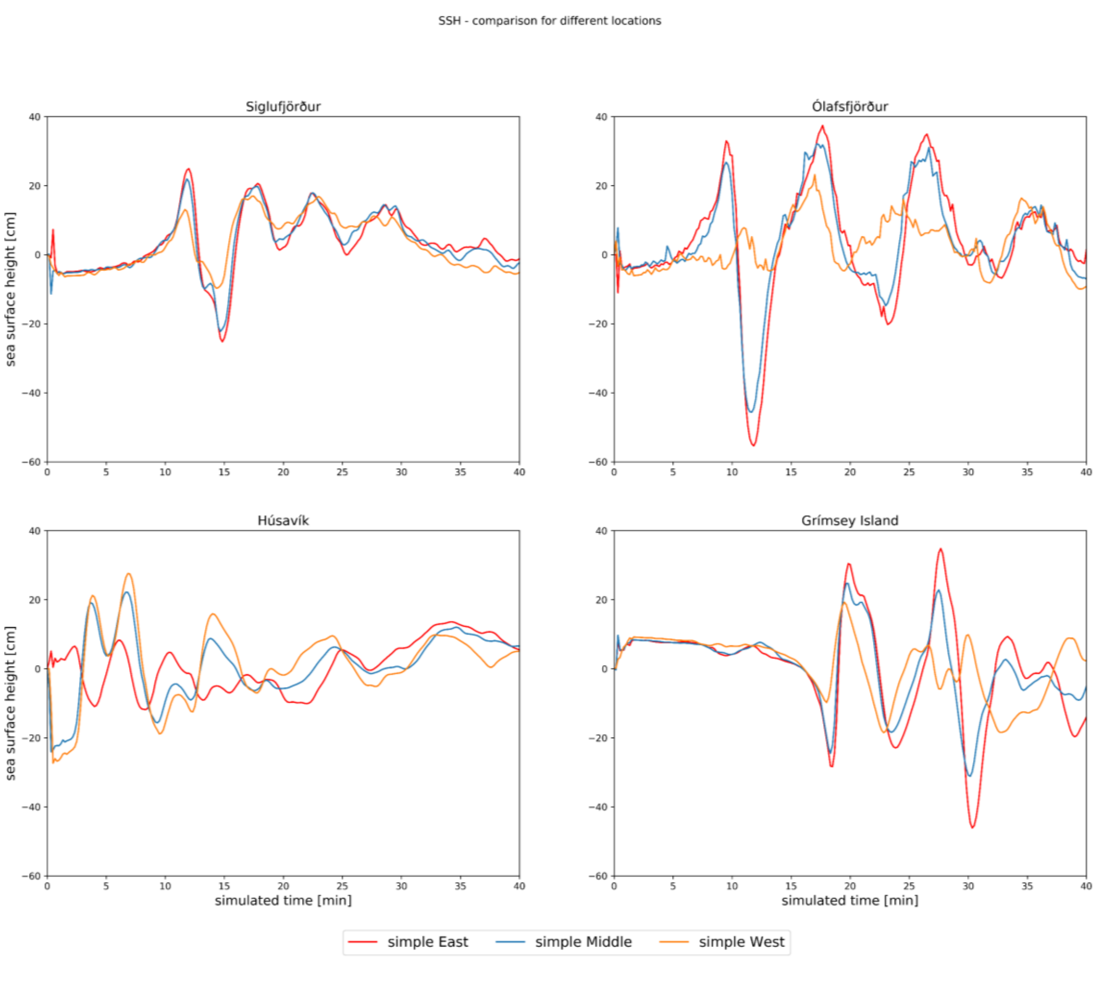


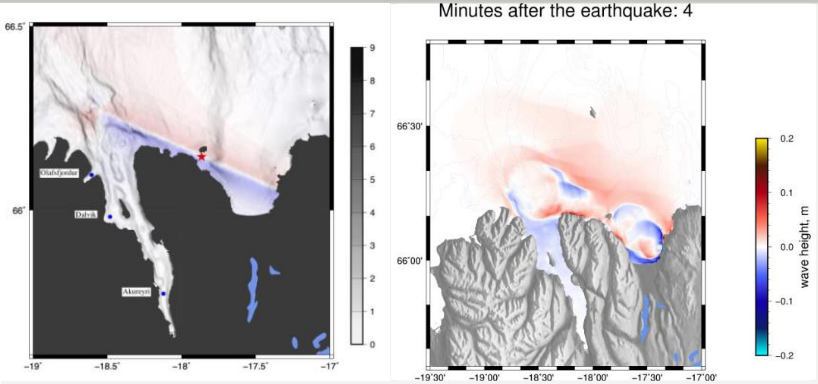
Complex Middle



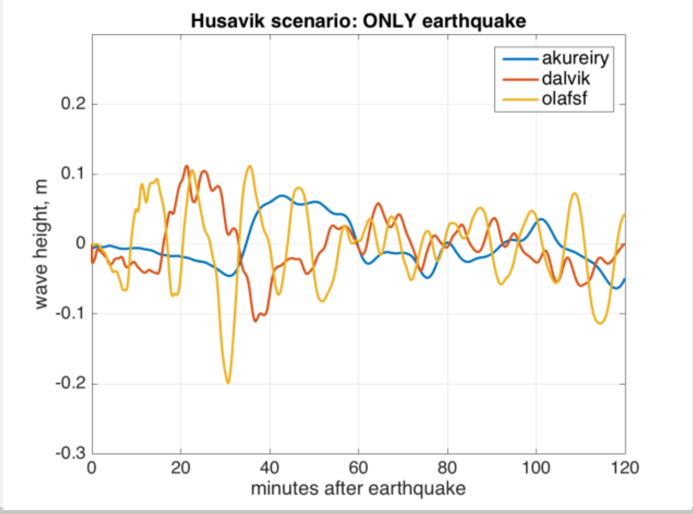
Input of time-dependent seafloor displacements to initialize bathymetry pertubations

Tsunami propagation

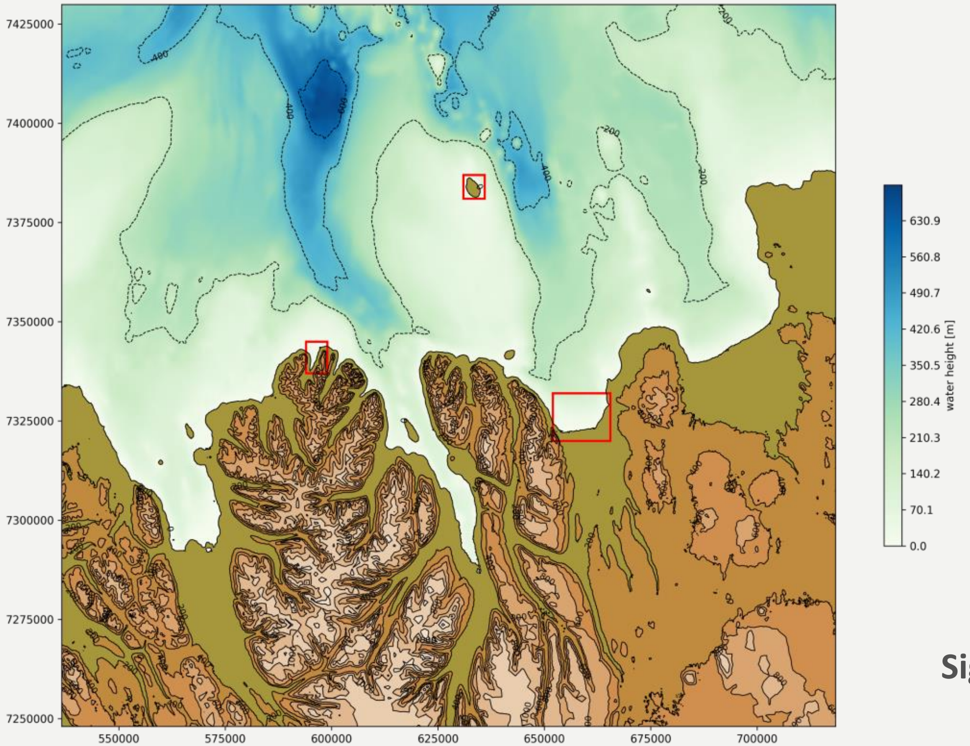


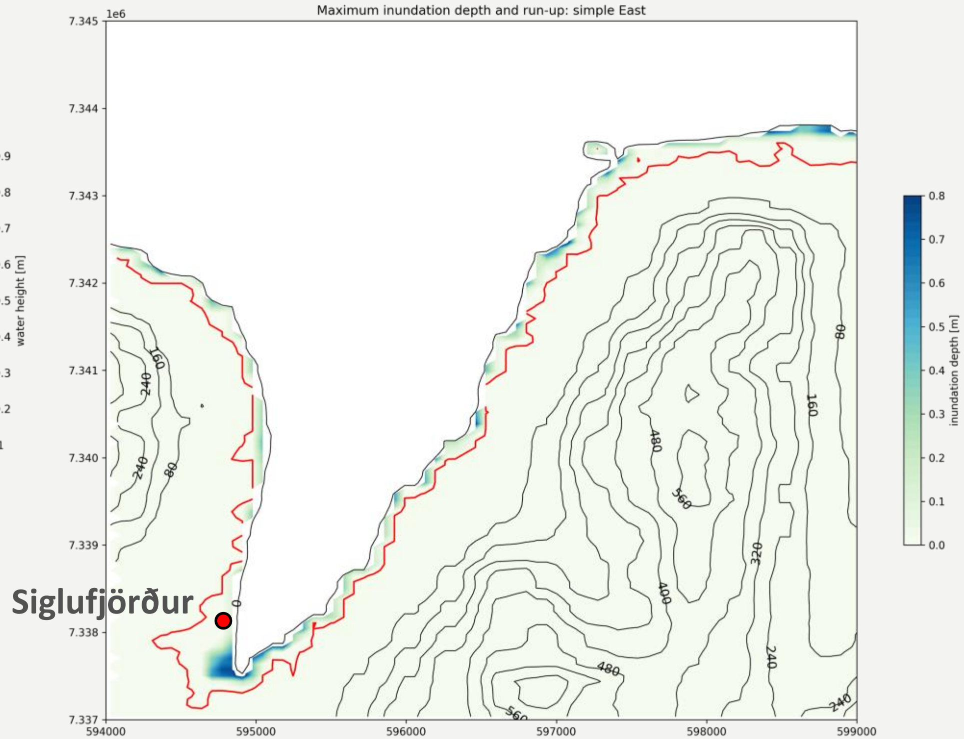


Ruiz-Angulo et al. (2019) followed the simple Okada method and used an uniform M7 fault-slip earthquake, triggered in the middle of the HFF

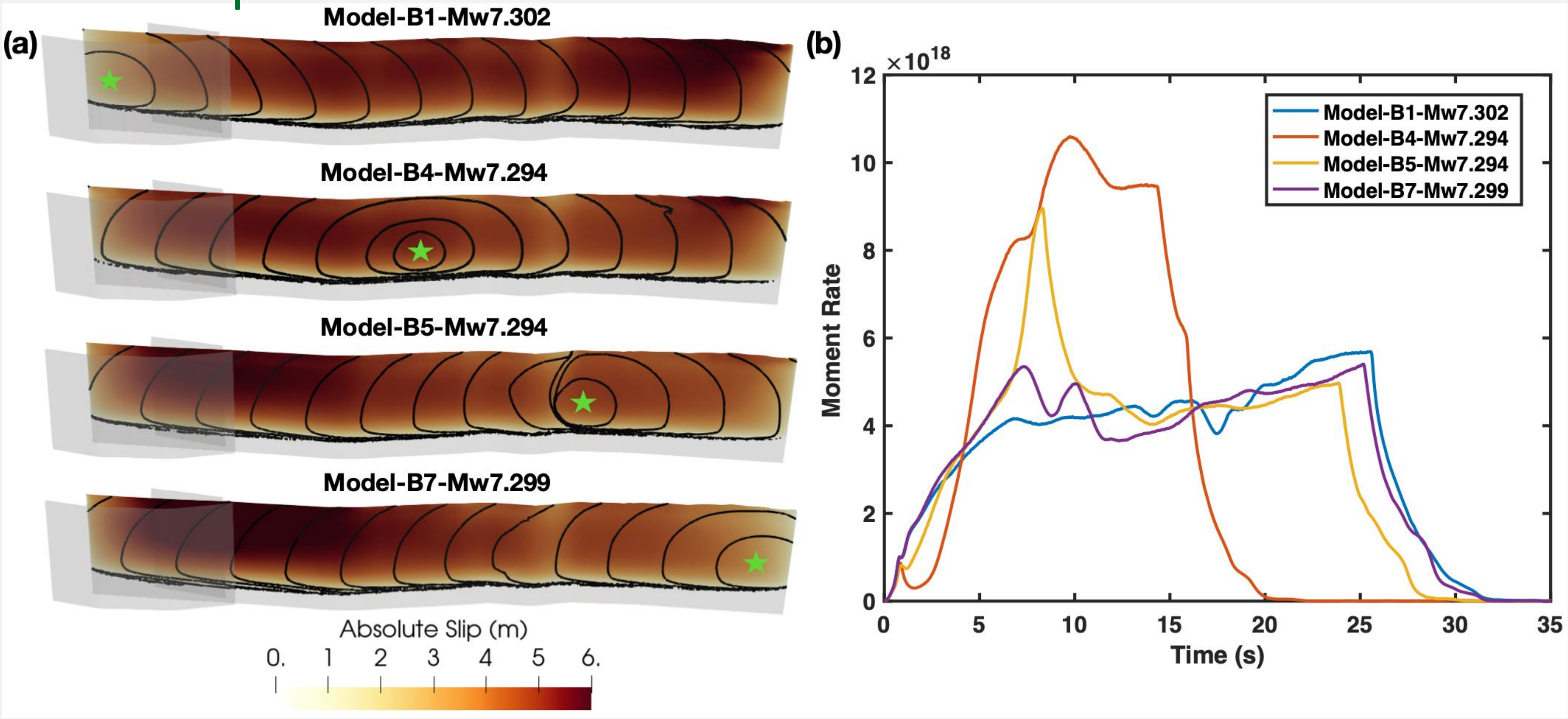


Simple East


water height [m]


Maximum inundation depth and run-up: simple East
inundation depth [m]
Siglufjörður

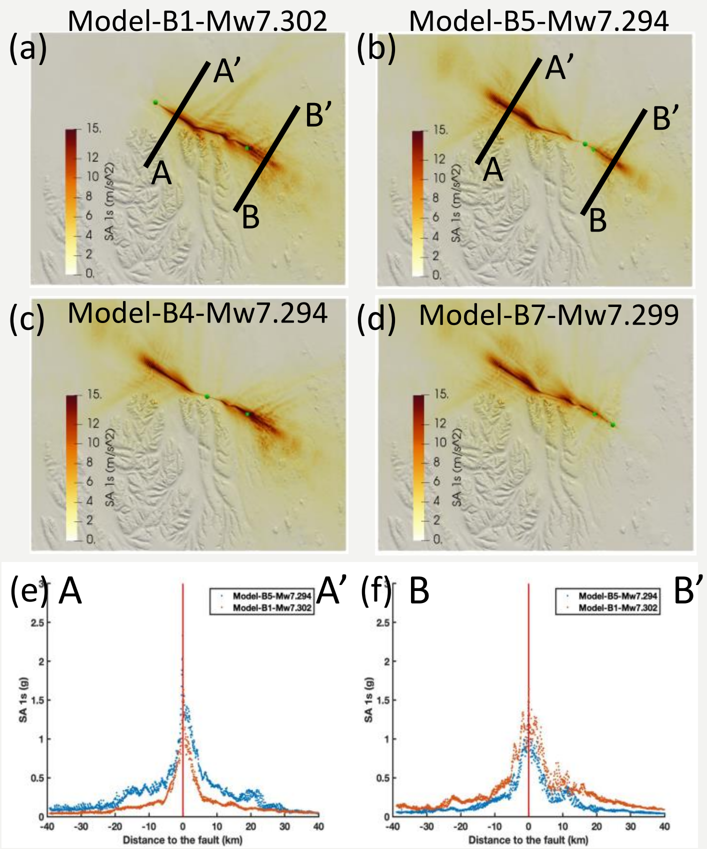
Model simple

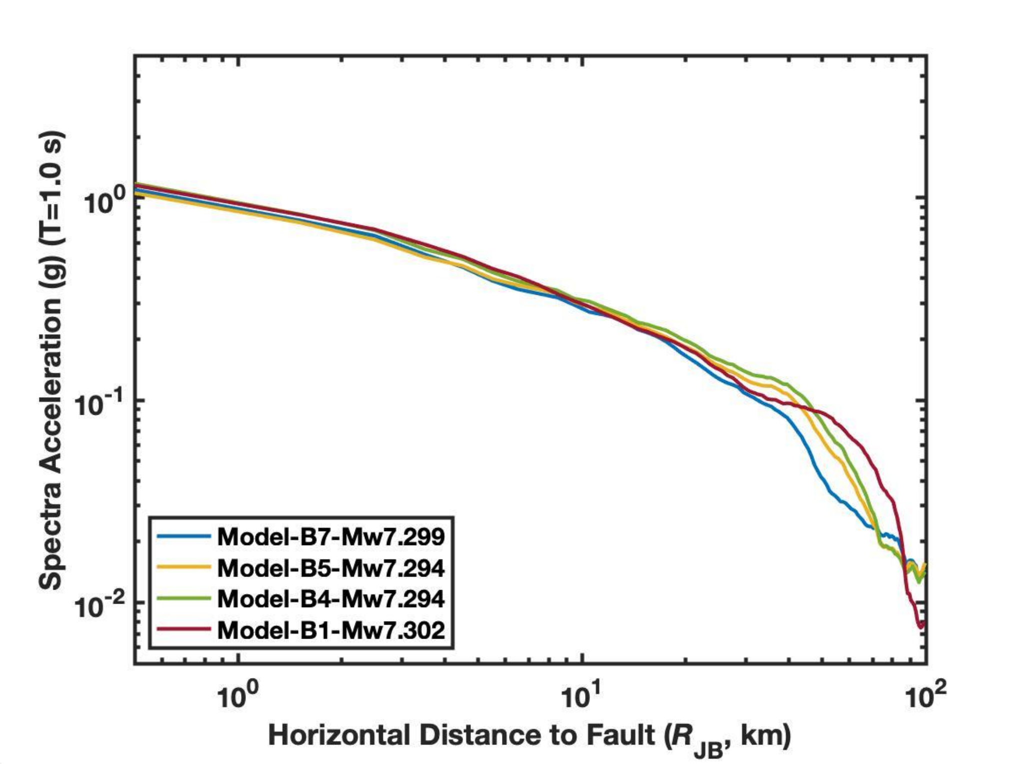


- All scenarios break the whole main fault and generate similar magnitudes
- Hypocentre location variations result in different dynamic ruptures and slip distribution on faults
- Depending on the hypocentre location relative to the geometry change, the rupture behaves different at the geometry complexity
- Nearly constant rupture velocity at same depth when the rupture nucleates at one side of the fault

Coupling effect of rupture directivity & geometry:

Symmetric vs asymmetric ground shakings across the fault (A-A’, B-B’).





- The average attenuation relationship of our physics-based ground motion match well with the GMMs from the tectonic and seismic symmetric SISZ *[Kowsari et al, 2020]*
- All scenarios generate nearly identical GM attenuation relationship in the near field, even though the ground motion maps vary significant

Summary

- Using the geologic and seismic data constrained models, we are able to reproduce large “historic magnitude” rupture scenarios
- Vertical coseismic seafloor displacement in combination with near-surface rake rotation is capable to generate a localized tsunami
- The Húsavík-Flatey transform fault system in North Iceland has the potential to generate tsunamigenic earthquakes
- Crest-to-valley difference for worst-case scenario (simple East) up to 1 m near Ólafsfjörður
- Max. inundation up to 70 cm near Siglufjörður
- Siglufjörður located within potential run-up area

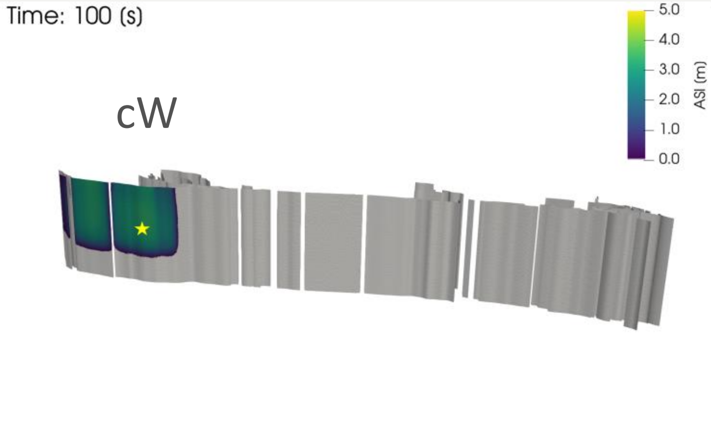
Thank you for your attention!

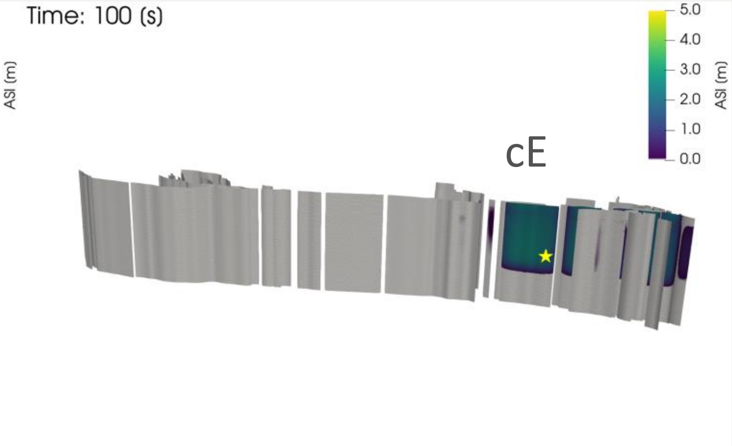
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 823844

Backup

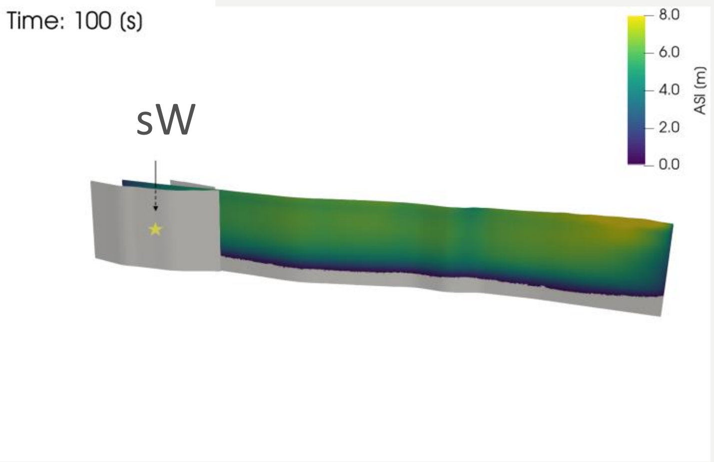
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 823844

Absolute Slip – complex





Absolute Slip – simple



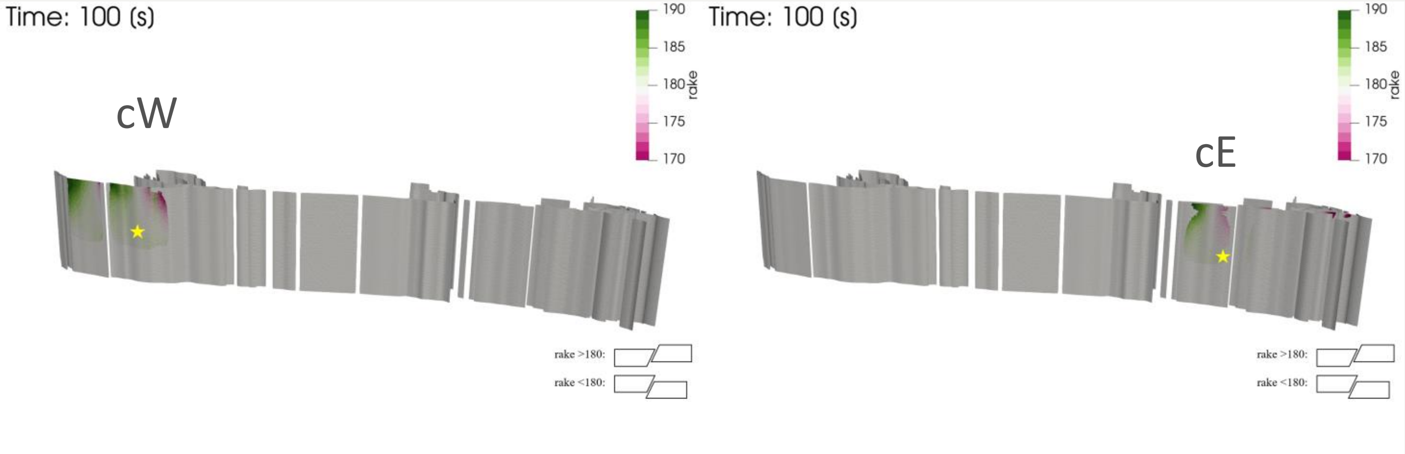
Simpler fault geometry

- Strong shallow fault slip
  (but not always occuring offshore)

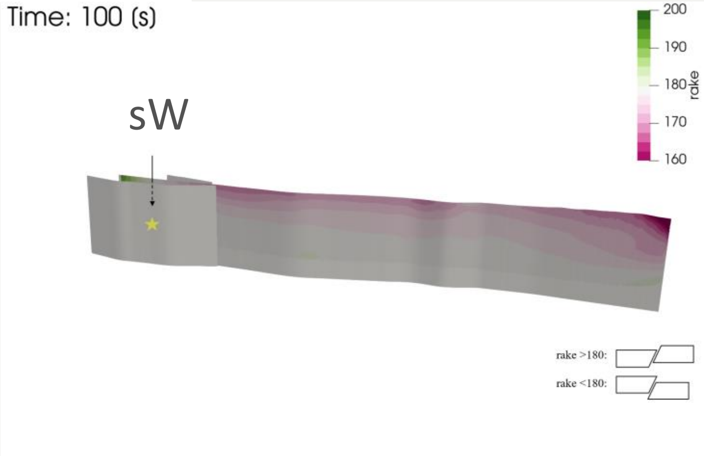
Complex fault geometry

- Less slip
- Not all fault segments are activated

Rake – complex



Rake – simple



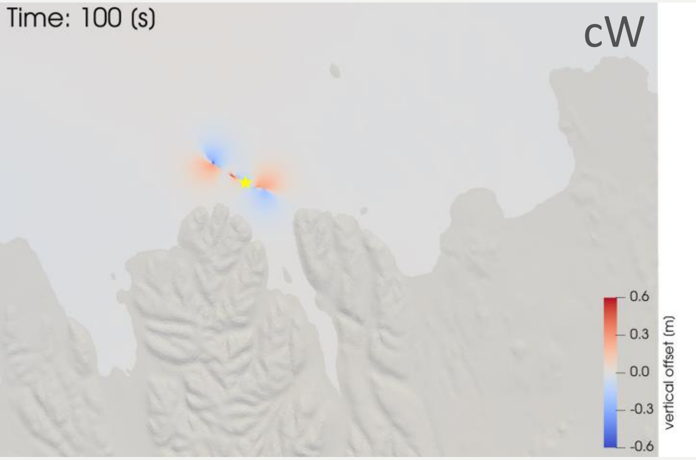
Simpler fault geometry

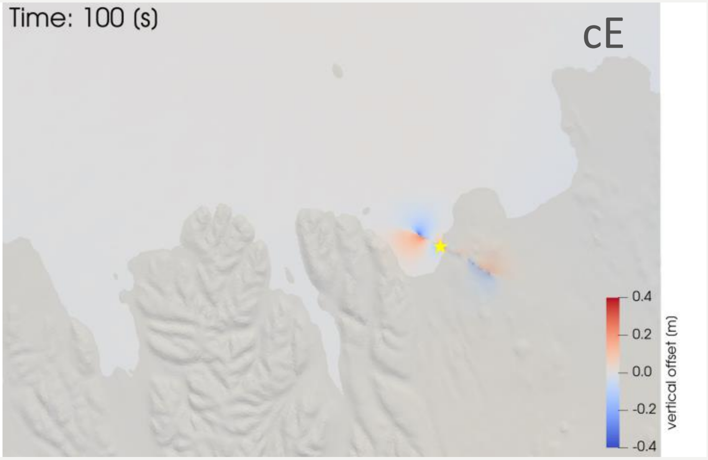
- Near-surface rake rotation of $\pm$ 20°

Complex fault geometry

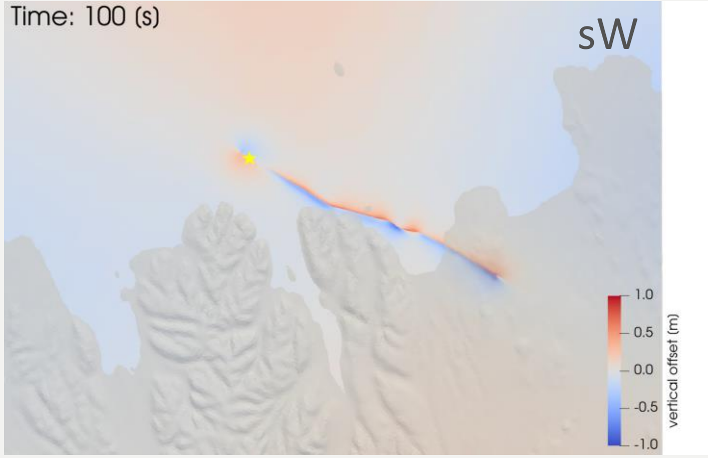
- Near-surface rake rotation of $\pm$ 10°

Vertical displacement – complex





simple



Simpler fault geometry

- Seafloor uplift of up to 75 cm for simple West

Complex fault geometry

- Less seafloor displacement (max. 56 cm for complex West)

Dynamic earthquake rupture outputs

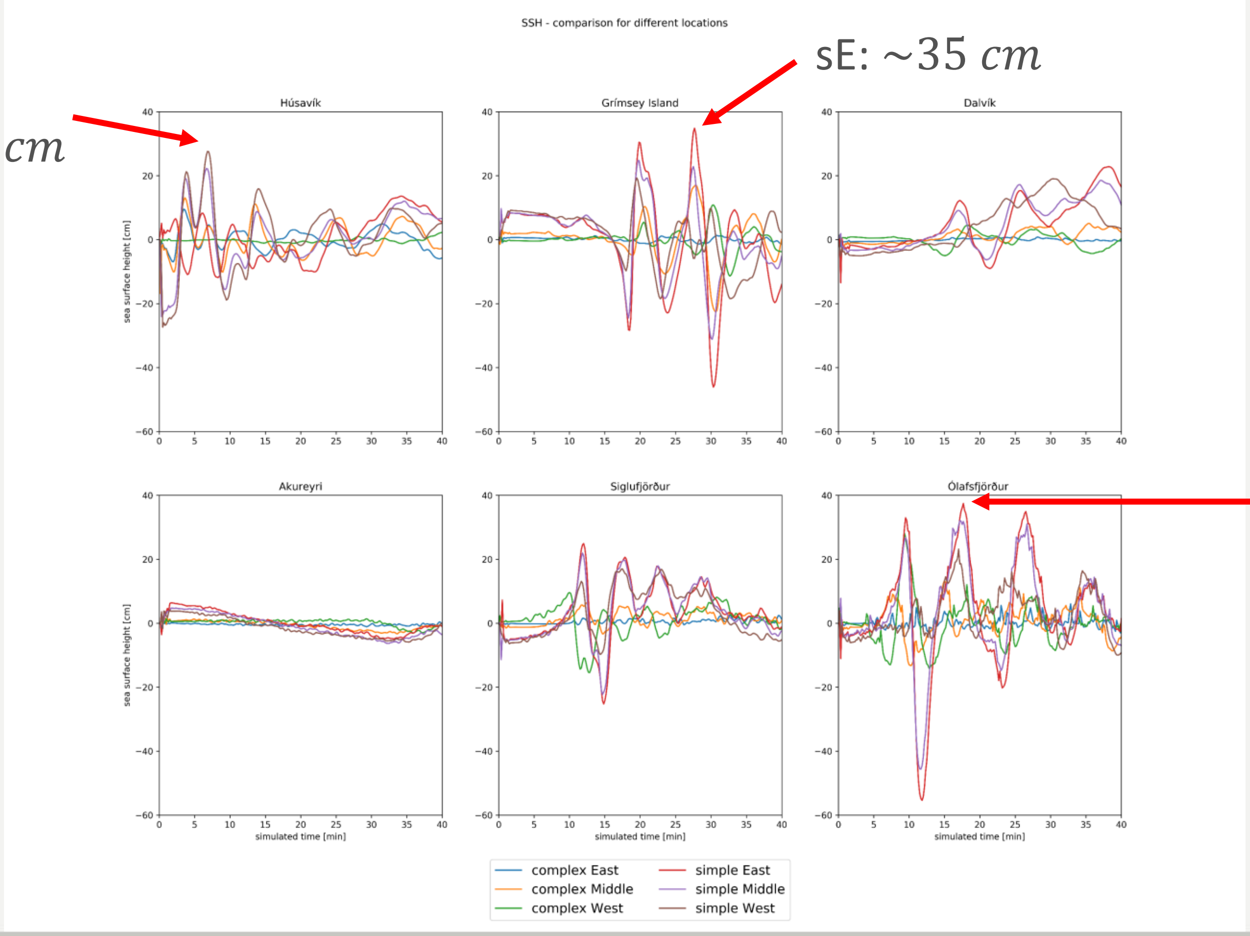
	simpler	fault	geometry	complex	fault	geometry
hypocentre	West	Middle	East	West	Middle	East
M_W	7.343	7.333	7.341	6.74	7.07	6.68
max ASI [m]	10.34	8.11	7.90	3.5	5.23	2.74
max offshore ASI [m]	6.93	6.58	7.90	3.5	5.23	2.74
max PSR [m/s]	15.05	14.93	15.14	10.44	11.59	8.66
max offshore PSR [m/s]	13.53	12.58	15.14	10.44	11.59	8.62
vertical seafloor displacement (after tanioka) [m] - min - max - Δ	min: -0.74 max: 0.75 Δ≈1.5	min: -0.79 max: 1.05 Δ≈1.8	min: -0.76 max: 0.95 Δ≈1.8	min: -0.66 max: 0.56 Δ≈1.2	min: -0.79 max: 0.44 Δ≈1.2	min: -0.42 max: 0.23 Δ≈0.65

Ssh over time for synthetic tide gauge stations in the vicinity of coastal towns in North Iceland

sW: $\sim 28\ cm$

sE: $\sim 35\ cm$

sE: $\sim 38\ cm$



Simple East – time series