Physics-based earthquake-tsunami modelling of the Húsavík-Flatey transform fault zone in North Iceland

Fabian Kutschera[1], Sara Aniko Wirp[1], Bo Li[1], Thomas Ulrich[1], Alice-Agnes Gabriel[1], Benedikt Halldórsson[2,3], and Claudia Abril[2]
[1]Institute of Geophysics, Department of Earth and Environmental Sciences, Ludwig-Maximilians-University, Munich, Germany
[2]Division of Processing and Research, Icelandic Meteorological Office, Reykjavík, Iceland
[3]Faculty of Civil and Environmental Engineering, University of Iceland, Reykjavík, Iceland

1. Introduction

The occurrence of tsunamis due to earthquake-induced seafloor displacement within strike-slip tectonic regimes are rare and their hazards therefore often underestimated (*cf.* local tsunami in the Palu Bay following the 2018 Mw 7.5 Sulawesi earthquake in Indonesia, Ulrich et al., 2019). We assess the tsunami potential of the ~100 km long Húsavík-Flatey Fault Zone (HFFZ) in North Iceland using state of the art methods and show that the HFFZ is capable to generate tsunamigenic earthquakes.

2. Background

The HFFZ connects the Mid-Atlantic Ridge (MAR) with onshore fault systems traversing Iceland. A maximum seismogenic potential of up to $M_W 7$ was estimated on the locked HFFZ (Metzger and Jónsson, 2014), posing a significant threat to coastline communities.

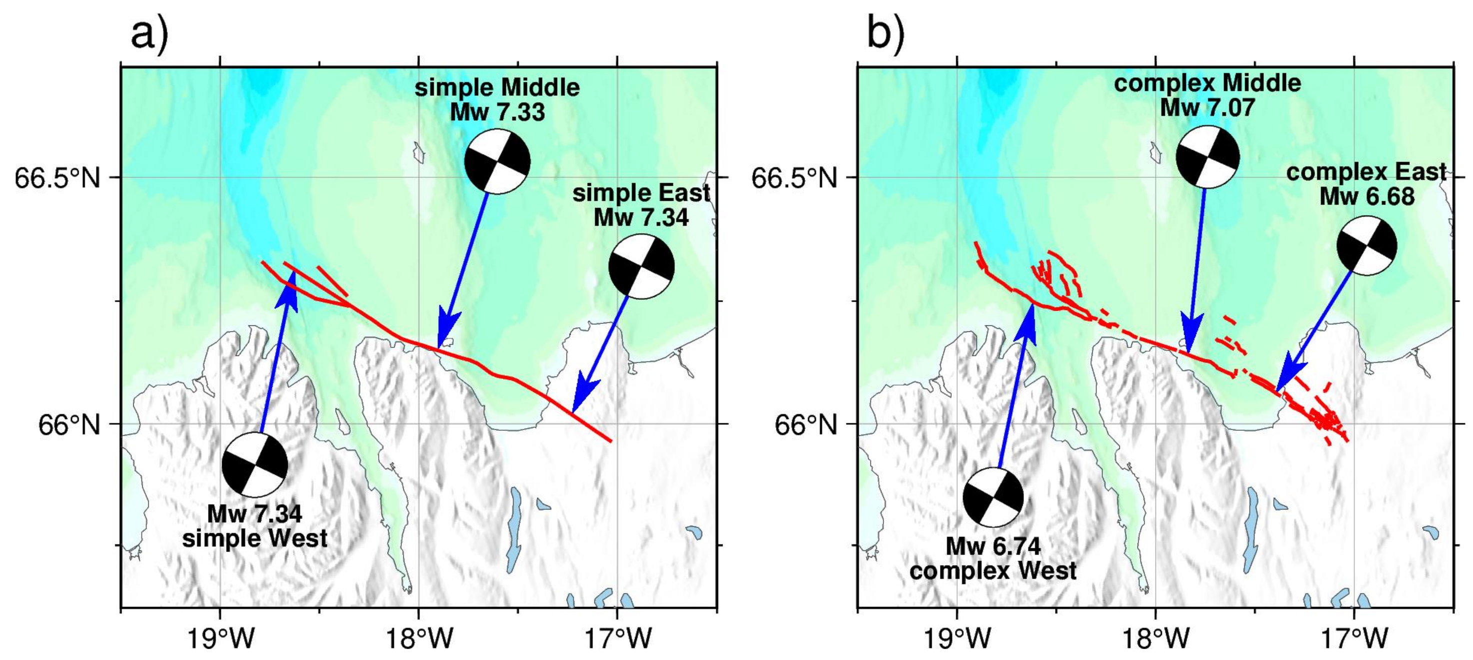


Fig 1.: Proposed fault geometries in red and equivalent moment tensors plotted at the epicenter locations. a) Simple fault geometry. b) Complex fault structure of the HFFZ with 55 fault segments.

3. Methods and ingredients

Ingredients:

- Complex bathymetry and topography (Ryan et al., 2009).
- 3-D subsurface structure (Abril et al., 2020).
- Newly inferred simple and complex fault geometries.
- Different hypocenter locations (Fig 1.) while keeping the hypocenter depth constant at 7 km within the assumed locking depth (Metzger and Jónsson, 2014), resulting in six one-way linked simulations and one "worst-case" fully coupled scenario.
- Primary stress orientations and stress shape ratio (Ziegler et al., 2016; Angelier et al., 2004) together with Anderson's theory.

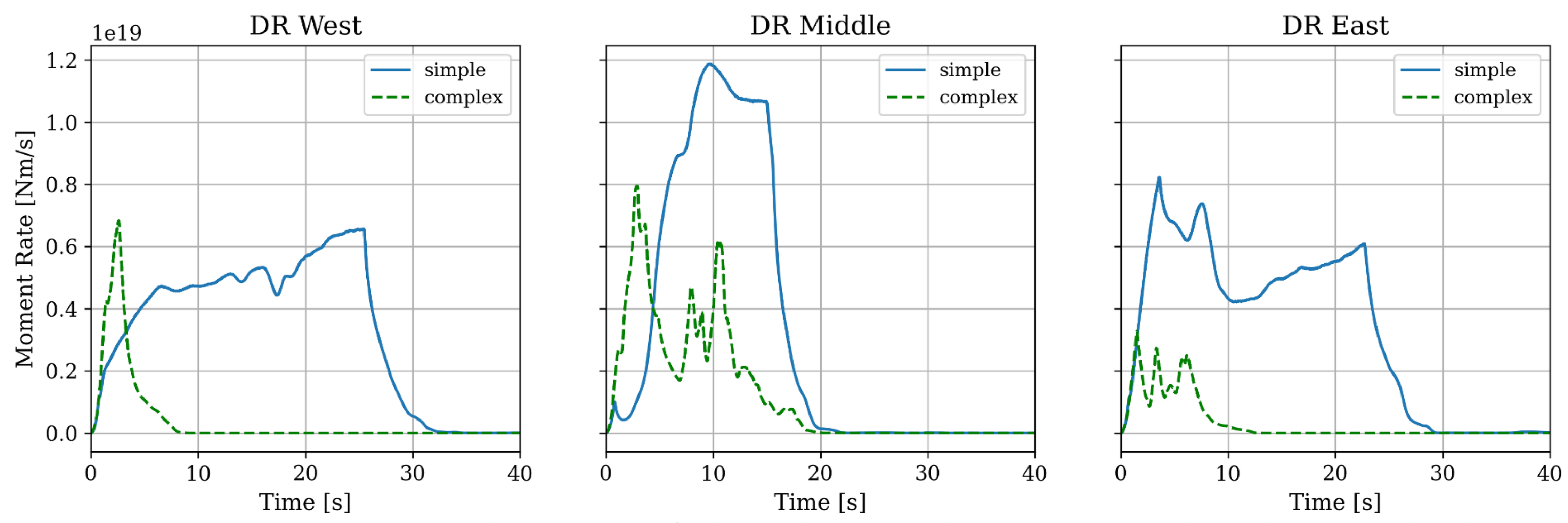
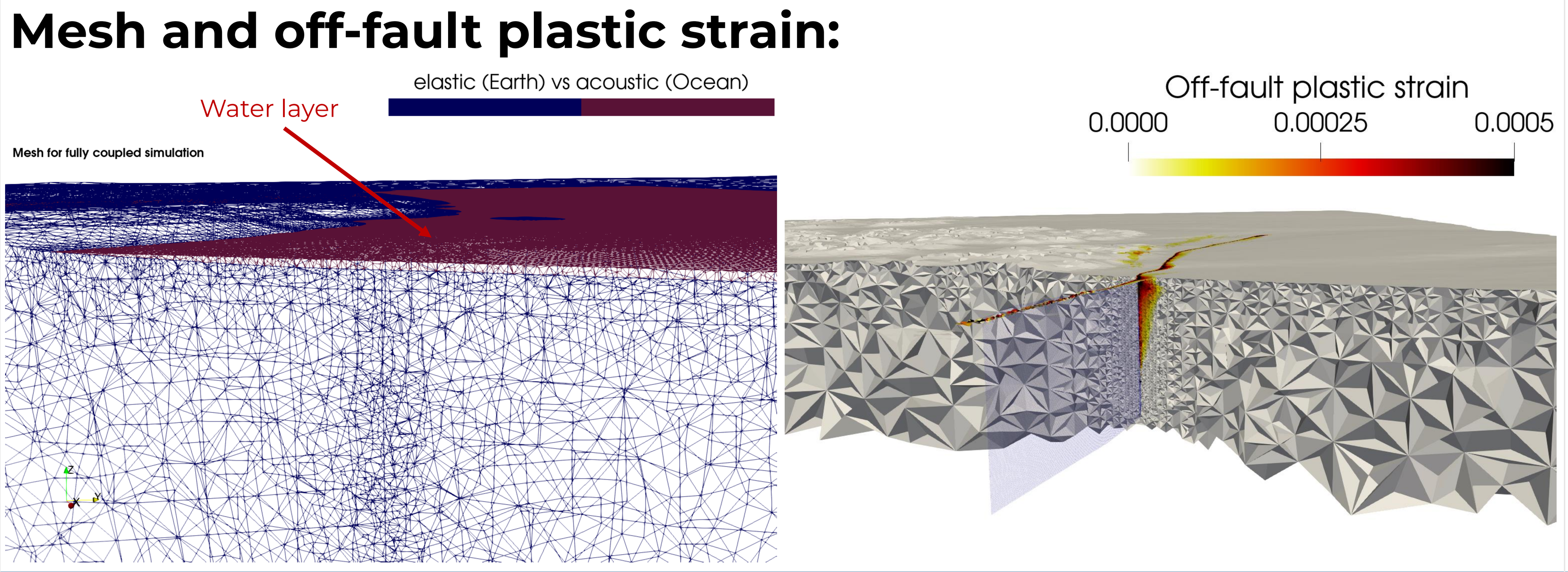


Fig 2.: Moment rate releases of the dynamic rupture (DR) simulations.

Physics-based methods:

- One-way linked dynamic earthquake rupture and shallow water equations (non-linear) tsunami workflow (Madden et al., 2021) using SeisSol and sam(oa)²-flash (Meister, 2016). Time-dependent seafloor displacement is used as forcing (*cf.* Abrahams et al. AGU 2020) together with the contribution of horizontal ground deformation to the vertical displacement (Tanioka and Satake, 1996).
- Fully coupled elastic-acoustic earthquake-tsunami simulation (Krenz et al., SC 2021) using SeisSol *(https://github.com/SeisSol, http://www.seissol.org)* to account for the 3D seismic and gravity wave generation and propagation (i.e., ocean response) simultaneously.

Mesh and off-fault plastic strain:



4. Results

Dynamic earthquake rupture output:

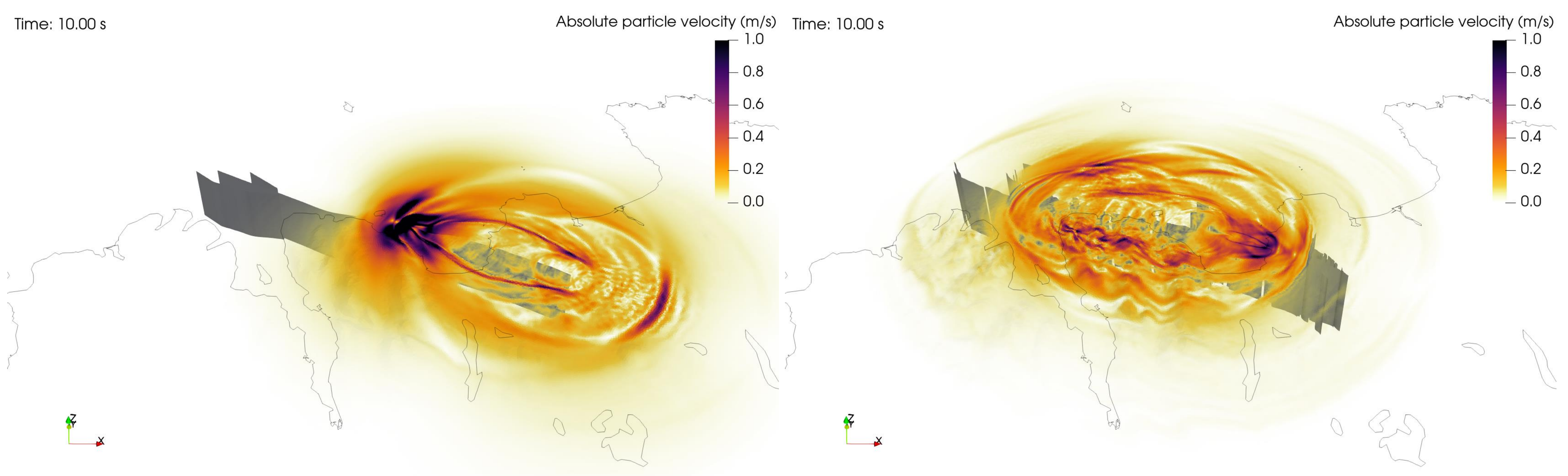


Fig. 3.: Left: Wavefield of the simulation "simple East", which we define as the worst-case scenario. Right: Wavefield of DR complex Middle.

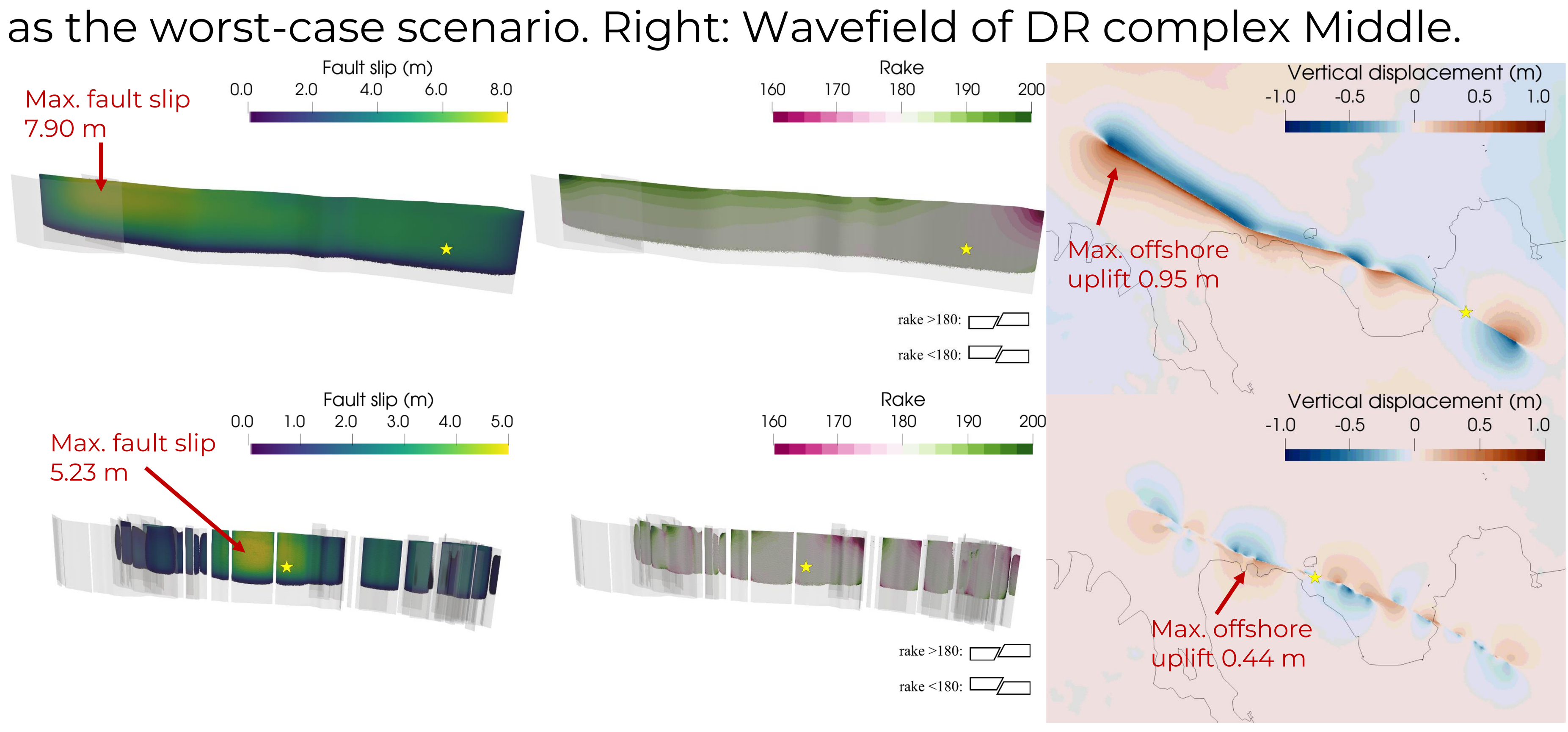


Fig. 4.: Absolute fault slip, near-surface rake rotation (*cf.* Kearse and Kaneko, 2020) and vertical displacement for the worst-case scenario ("simple East", 1st row) and for "complex Middle" (2nd row).

Time-dependent tsunami generation:

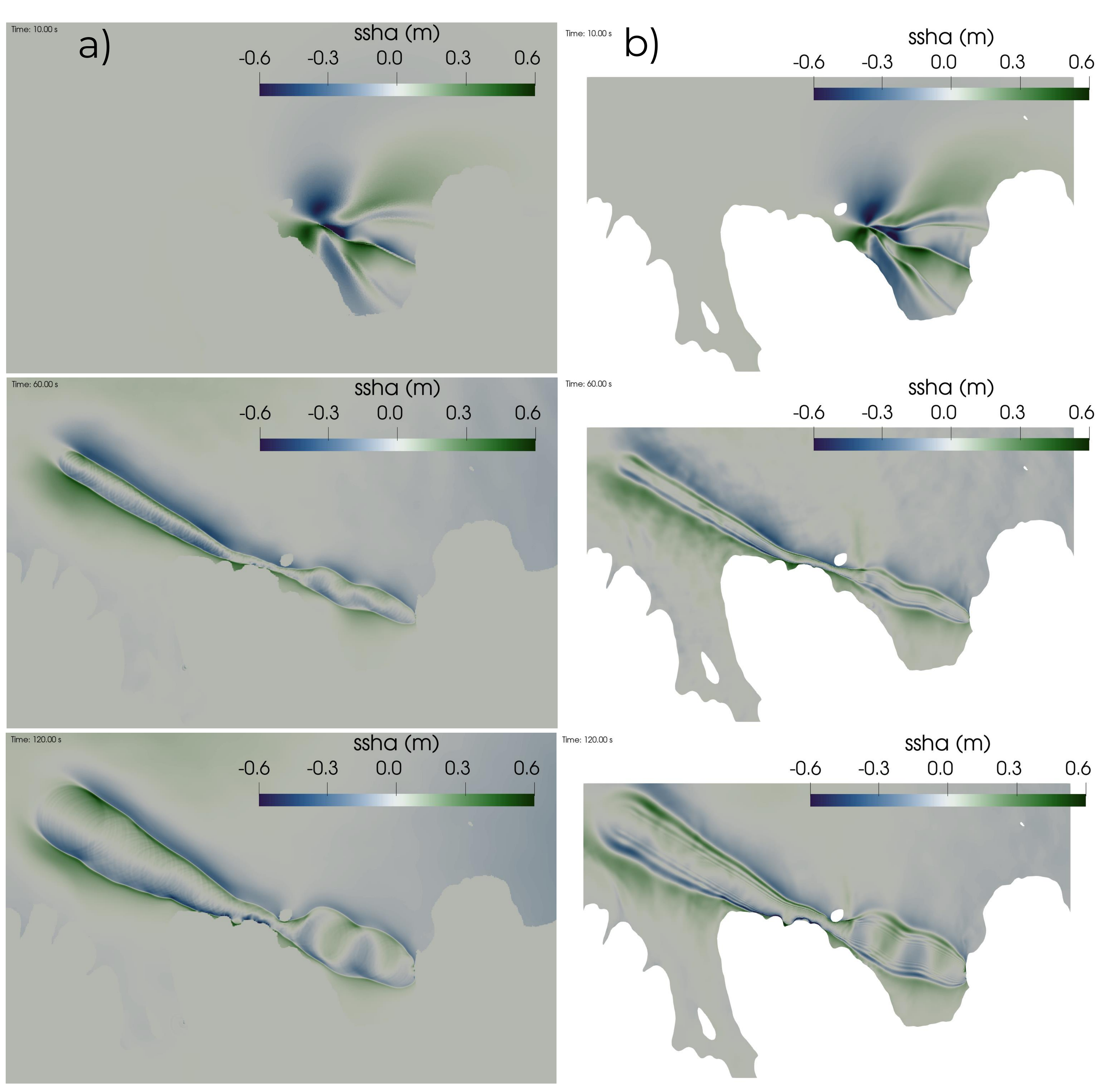


Fig. 5.: Tsunami genesis comparison for the worst-case scenario "simple East" showing the sea surface height anomaly (ssha) over time.

a) One-way linked simulation.
b) Correspond-ing 3D fully coupled simulation.

5. Conclusions

- We obtain realistic earthquake-tsunami simulations using the one-way linked and state of the art fully coupled modelling workflows informed by seismic and geodetic data.
- Our fully coupled model compares well with the one-way linked simulation but solves an entirely new class of earthquake-tsunami interaction including acoustic wave propagation.
- Our worst-case scenario can produce a localised tsunami ($\sim 50cm$) due to large shallow fault slip ($\sim 8m$), dynamic rake rotation ($\pm 20°$) and coseismic vertical displacement ($\pm 1m$).

The ChEESE project has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement № 823844. The TEAR project is funded by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 852992).