Physics-based constraints for probabilistic seismic hazard assessment in Húsavík–Flatey fault zone, Northern Iceland

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Motivation

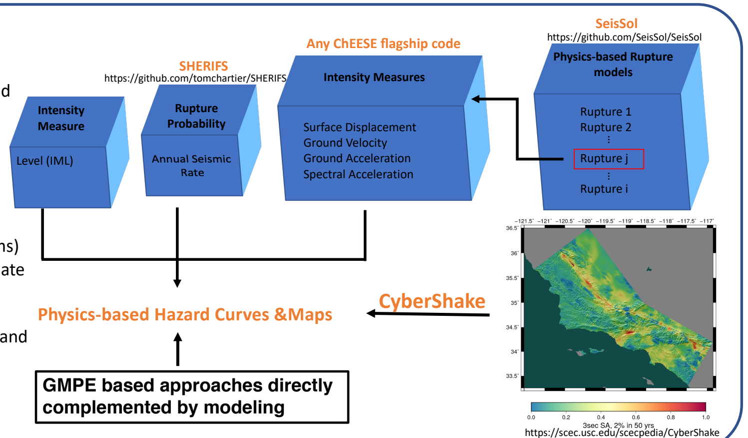
- Standard probabilistic seismic hazard assessment (PSHA) is generally based on empirical, time-independent assumptions that are simplified and not based on earthquake physics.
- Physics-based numerical models such as dynamic rupture simulations account for the physics of ruptures on faults, wave propagation through 3D structures, site effects, and their non-linear coupling effect, which can be significant in their respective contributions depending on the generally complex geological environment (e.g., Wollherr et al., 2019).
- The Húsavík–Flatey fault system in north Iceland features complex geometries, consisting of multiple right-lateral strike slip segments distributed across ~100 km, providing a good chance to study the complex fault interaction, dynamic and static stress transfers and rupture jumping across a complex fault network.
- The moment accumulated on the HFF since the last major earthquake in 1872 can result in an earthquake of magnitude 6.8 to 7 (Metzger and Jonsson, 2014), posing a high risk to the Húsavík community.

Workflow

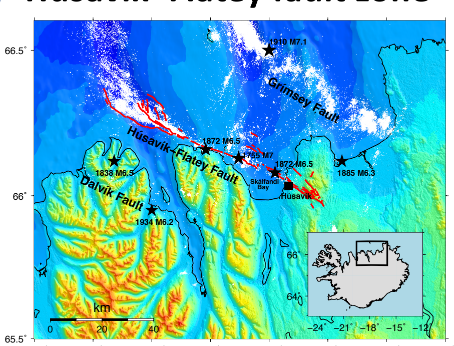
SeisSol : to build a physics-based dynamic earthquake catalog of mechanically plausible events. Ground shaking intensities Calculated for each rupture scenario.

SHERIFS (seismic hazard and earthquake rates in fault systems) (Chartier et al., 2019) : to estimate the annual seismic rate.

Physics-based PSHA can complement the GMPE results and independently verified with CyberShake.



Húsavík–Flatey fault zone



Gray dots show relocated earthquakes (Abril et al., 2019) and black stars mark the historic large earthquakes (Jónsson et al., 2019).

Model Setting

Linear slip weakening: μ_s=0.55, μ_d=0.1, Dc=0.4 m

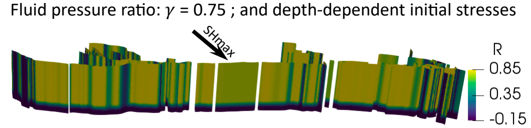
SHmax: azimuth of the maximum horizontal compressive stress: 155

Stress shape ratio: $(s_2 - s_3)/(s_1 - s_3) = 0.5$

where $s_1 > s_2 > s_3$ are the principal stress magnitudes

Fault stress ratio: R= $[\tau - \mu_d\sigma_n(1-\gamma)]/[(\mu_s - \mu_d)\sigma_n(1-\gamma)]$

Fluid pressure ratio: γ = 0.75 ; and depth-dependent initial stresses



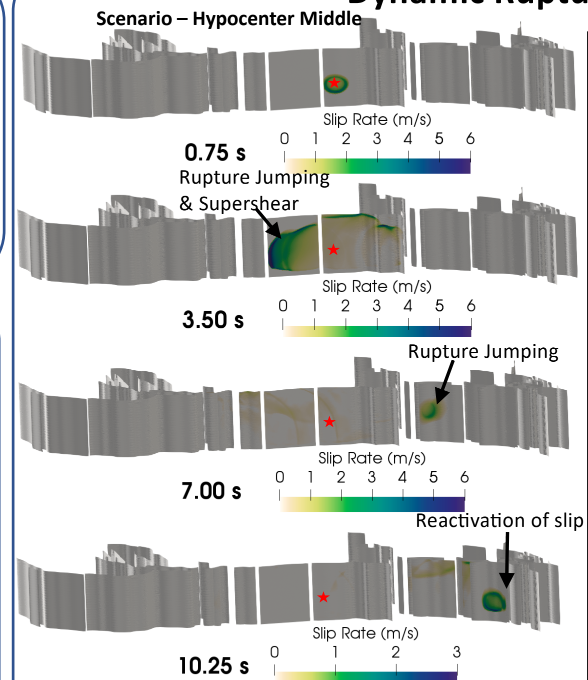
Distribution of the initial fault stress ratio. The higher the ratio is, the fault is closer and easier to break. Refer to the Ulrich et al (2019) for detailed parameters description.

55 fault segments used in the dynamic simulations

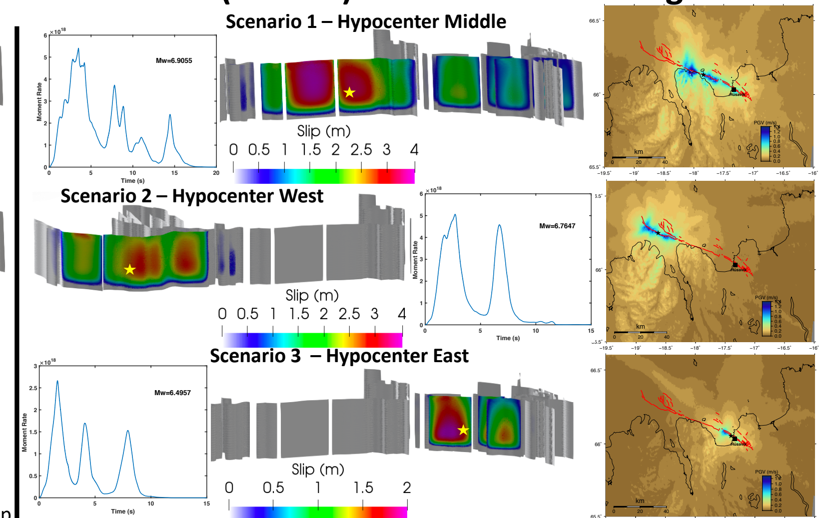
Seismogenic depth of the HFF is 6.5-12 km depth. 10 km is used in the showing cases.

Slip rate on the HFF is about 1/4 of total plate transform motion ~19.4 mm/year (Einarsson, 2014)

Dynamic Rupture Scenarios (SeisSol) and Ground Shaking



Overview of the dynamic rupture propagation of a Mw 6.9 rupture scenario. Rupture velocity increases substantially to supershear after a delay of rupture jump to a new segment..



Húsavík

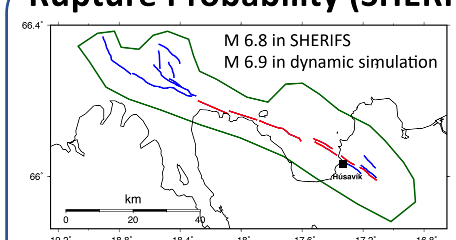
Velocity (m/s)
Acceleration (m/s^2

Scenario 1	Scenario 2	Scenario 3
PGV: 0.572	PGV: 0.054	PGV: 0.494
PGA: 3.829	PGA: 0.210	PGA: 2.390
SA 1.0s: 6.350	SA 1.0s: 0.513	SA 1.0s: 3.857
SA 2.0s: 3.001	SA 2.0s: 0.301	SA 2.0s: 2.573
SA 5.0s: 0.489	SA 5.0s: 0.075	SA 5.0s: 0.534

Three dynamic rupture scenarios and the corresponding moment rate, and distribution of the RotD50 peak ground velocity (PGV), with various ground intensity type measures in Húsavík town.

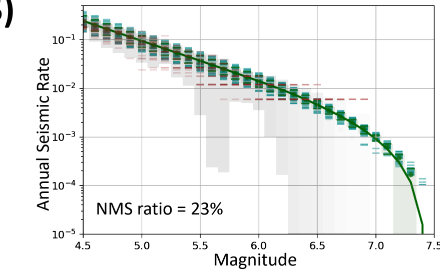
- Highly heterogenous ground shaking intensity distribution, and intense localization of shaking in the vicinity of geometric complexities, such as fault bends or rupture transition between segments.
- The dynamic rupture simulations generate similar magnitude events as the historic events, indicating reasonable initial settings of the dynamic model.
- Varying the hypocenter locations break different segments of the fault system and produce different magnitude events.
- The ruptures jump generally correspond to the moment rate troughs.
- The PGV distribution map shows amplification of the ground shaking in the rupture forward direction, and lights up some topography features, indicating the effect of the rupture directivity and topography on the ground shaking.

Rupture Probability (SHERIFS)



Faults with length >= 5 km, with red line marking the fault to fault rupture scenario in this example. Green lines show the background boundary. The magnitude estimated using scaling laws in SHERIFS is comparable with the dynamic rupture simulation.

The maximum magnitude of the earthquake is ~7.2 when the whole HFF rupture together.



NMS: non-mainshock slip. The slip budget not released by earthquakes (e.g., aseismic slip, shut off by rifting). The green line indicates the simulation result and shows great fit with the catalog seismic rate, showing by the red dashed line. (SHEEC catalog by Stucchi et al., 2013; Grünthal et al., 2013 and relocated catalog by Abril et al., 2019)

Future work and goals: 1). Add the off-fault plasticity and attenuation in the dynamic models and build the physics-based rupture database.

2). Update the fault to fault (FtF) rupture scenarios in SHERIFS, based on the dynamic rupture database, to improve the annual seismic rate estimation, and come up with improved earthquake forecast model.

3). Produce physics-based seismic hazard curves and maps.

4). Build physics-based GMPEs to complement current equations.

5). Figure out the largest potential earthquake in the study region and the coupled tsunamic hazard.

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References: C. Abril, A. Tryggvason, O. Gudmundsson, R. Steffen. Earthquake Relocation in the Tjörnes Fracture Zone. Proceedings of Northquake 2019 - The 3rd International Workshop on Earthquakes in North Iceland. Húsavík, 2019; Chartier, T., Scotti, O., & Lyon-Caen, H. (2019). SHERIFS: Open-Source Code for Computing Earthquake Rates in Fault Systems and Constructing Hazard Models. Seismological Research Letters, 90(4), 1678-1688; Einarsson, P. (2014). Mechanisms of Earthquakes in Iceland. In Encyclopedia of Earthquake Engineering, M. Beer, I. A. Kougioumtzoglou, E. Patelli, and I. S.-K. Au, eds. (Berlin, Heidelberg: Springer Berlin Heidelberg), pp. 1–15. Available at: http://link.springer.com/10.1007/978-3-642-36197-5_298-1 [Accessed December 4, 2019]; Grünthal, G., Wahlström, R., & Stromeyer, D. (2013). The SHARE European Earthquake Catalogue (SHEEC) for the time period 1900–2006 and its comparison to the European-Mediterranean Earthquake Catalogue (EMEC). Journal of seismology, 17(4), 1339-1344; Metzger, S. and S. Jónsson, Plate boundary deformation in North Iceland during 1992-2009 revealed by InSAR time-series analysis and GPS, Tectonophysics 634, 127-138, 2014; Sigurjón Jónsson, Rémi Matrau, Renier Viltres,and Benedikt Ófeigsson (2019), Update on GPS Measurements in North Iceland. Proceedings of Northquake 2019 - The 3rd International Workshop on Earthquakes in North Iceland. Húsavík, 2019; Stucchi, M., Rovida, A., Capera, A. G., Alexandre, P., Camelbeeck, T., Demircioglu, M. B., ... & Sesetyan, K. (2013). The SHARE European earthquake catalogue (SHEEC) 1000–1899. Journal of Seismology, 17(2), 523-544; Ulrich, Thomas, Alice-Agnes Gabriel, Jean-Paul Ampuero, and Wenbin Xu (2019), Dynamic viability of the 2016 Mw 7.8 Kaikōura earthquake cascade on weak crustal faults, Nature Communications, 10(1213), doi:10.1038/s41467-019-09125-w; Wollherr, S., Gabriel, A. A., & Mai, P. M. (2019). Landers 1992 "reloaded": Integrative dynamic earthquake rupture modeling. Journal of Geophysical Research: Solid Earth, 124(7), 6666-6702.