Report of Transnational Access Projects

(Note: the information here will be publicly disclosed in the Geo-INQUIRE website, do not include sensitive information)

Project ID: *C3-TA2-542-1-6*

Principal investigator: *Dr Atefe Darzi, University of Iceland -*

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Project team (if applicable): *Dr. Benedikt Halldórsson (Icelandic Meteorological Office and University of Iceland)*

Project title: Iceland-specific earthquake hazard and risk modeling

Project acronym: *ICEHRM*

Hosting installation: *EF-PSHA – Probabilistic Seismic Hazard Analysis (TA2-542-1)*, Swiss Seismological Service (SED), ETH Zurich

Hosting team: Dr Laurentiu Danciu, Swiss Seismological Service (SED), ETH Zurich

Period of access: 13-24 July 2026 (on-site), followed by two weeks of remote access

Report of activities:

The access focused on establishing a reproducible, branch-resolved OpenQuake benchmark for Iceland and on quantifying how the hazard represented by the 2020 European Seismic Hazard Model (ESHM20, Danciu et al. 2024) changes when its European-scale source characterization is replaced by Iceland-specific seismicity information. The ESHM20 input package for Iceland, supplied through the European Facilities for Earthquake Hazard and Risk (EFEHR) and the Swiss Seismological Service (SED), was reproduced and examined for the nation-wide site grid and the whole 4,725 logic-tree branches including 21 seismogenic-source recurrence branches and 225 Ground-Motion Model (GMM) branches corresponding to 15 Iceland-adjusted models and 15 default shallow-crust branches. The OpenQuake Engine (OQ)-LTS-v3.23, and QGIS software were used along with Python for processing and data analysis.

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A detailed magnitude–frequency distribution (MFD) analysis was performed of every ESHM20 shallow-crustal source-model realization relevant to Iceland. The analysis included 21 source-model realizations: 12 branches of the Area Source Model (ASM) and nine branches of the hybrid Smoothed Seismicity Model plus Fault Source Model (SSM+FSM). The ASM consisted of nine truncated Gutenberg–Richter (TGR) branches, formed by three alternative a- and b-value parameterizations combined with three maximum-magnitude alternatives, and three tapered-Pareto branches representing alternative corner magnitudes. For each area source (see Figure 1), the individual branch curves, branch weights, recurrence parameters, maximum magnitudes, weighted means, and weighted 5–95% epistemic ranges were calculated and compared with annualized catalog rates. The catalog calculations used the ESHM20 magnitude-dependent completeness periods using the Icelandic ICEL–NMAR earthquake catalog developed by Jónasson et al. (2021) as presented in Figure 2.

Particular emphasis was placed on the nine SSM+FSM realizations, which combine background smoothed seismicity and explicit in-buffer active-fault sources. These branches represent combinations of three fault slip-rate alternatives and three maximum-magnitude alternatives. In the ESHM20 implementation, the SSM point sources and the fault sources remain separate OpenQuake source objects, and their hazard contributions are summed during the calculation. Their earthquake rates were therefore first evaluated separately and subsequently combined at the MFD and hazard levels. Weighted-mean SSM+FSM recurrence curves and uncertainty ranges were derived for each Icelandic seismic zone and for the complete national model. This enabled direct comparison of the hybrid model against the area-source representation and provided a clearer assessment of whether the Icelandic hazard is primarily controlled by distributed background seismicity, explicit fault activity, or their interaction. The distinction is especially important because the ESHM20 hybrid model is designed to combine active faults with complementary background smoothed seismicity while avoiding double counting near mapped faults.

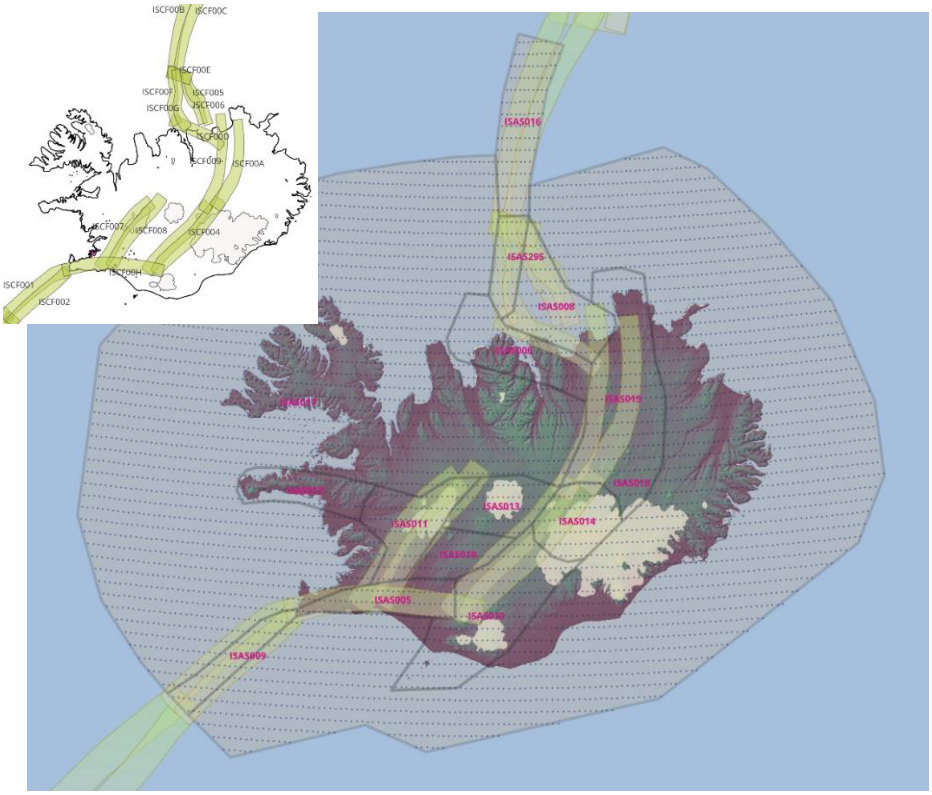

Figure 1. Area source model (gray polygons), fault source models (yellow zones) and spatial smoothed seismicity central points (blue dots) presented in ESHM20 for Iceland.

The local source models were compared with their corresponding ESHM20 area-source zones across Iceland, including the southwest transform system, the northern transform regions such as the Tjörnes Fracture Zone and the Dalvík sector, and the volcanic and extensional regions associated with the Western, Eastern, Northern, and central Icelandic volcanic zones. This nationwide comparison allowed the local recurrence parameters and magnitude–frequency distributions to be evaluated consistently against the corresponding ESHM20 ASZ representations (Figure 3). The spatial aggregation was first investigated in detail for the South Iceland Seismic Zone (SISZ) and the Reykjanes Peninsula Oblique Rift (RPOR), which together form the principal transform system of southwest Iceland. In the ESHM20 area-source representation, this regional comparison is associated with source zone ISAS005, which overlaps the six local ICESZ subzones representing the SISZ–RPOR system (Bayat et al. 2022; Halldorsson et al. 2022). The SISZ contains the large historical earthquake belt across the South Iceland Lowlands, while the RPOR represents its westward continuation across the Reykjanes Peninsula toward the offshore Mid-Atlantic Ridge.

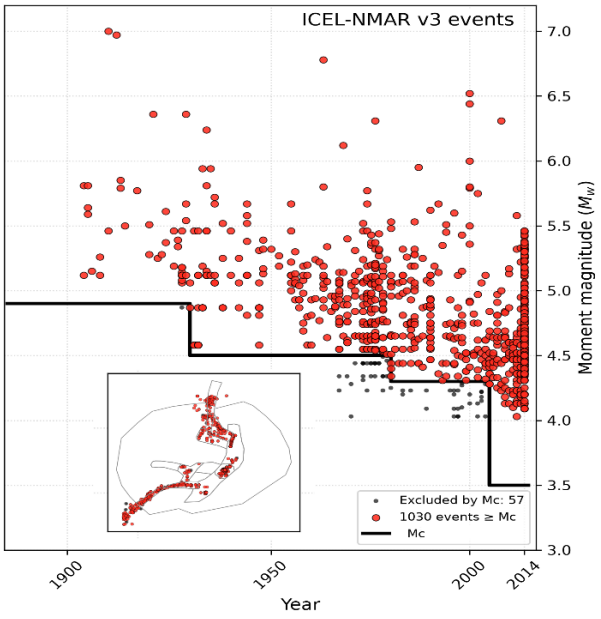

Figure 2: Time-dependent magnitude of completeness applied to the ICE-NMAR catalog of Iceland, red symbols show the 1,030 events retained above M_c, while grey symbols indicate excluded events.

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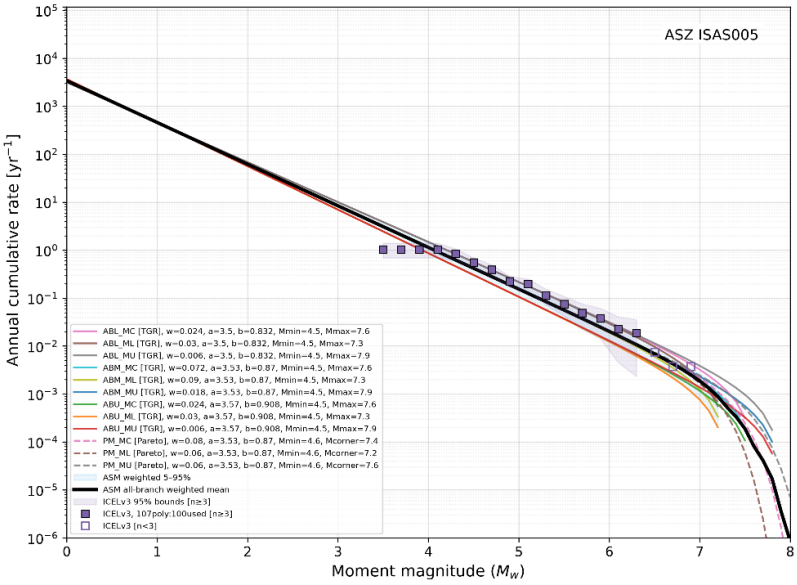

Figure 3: Comparison of the ESHM20 area-source MFD branches for source zone ISAS005 with the cumulative rates estimated from the ICEL-NMAR-v3 catalog, including the weighted mean and 5-95% uncertainty range.

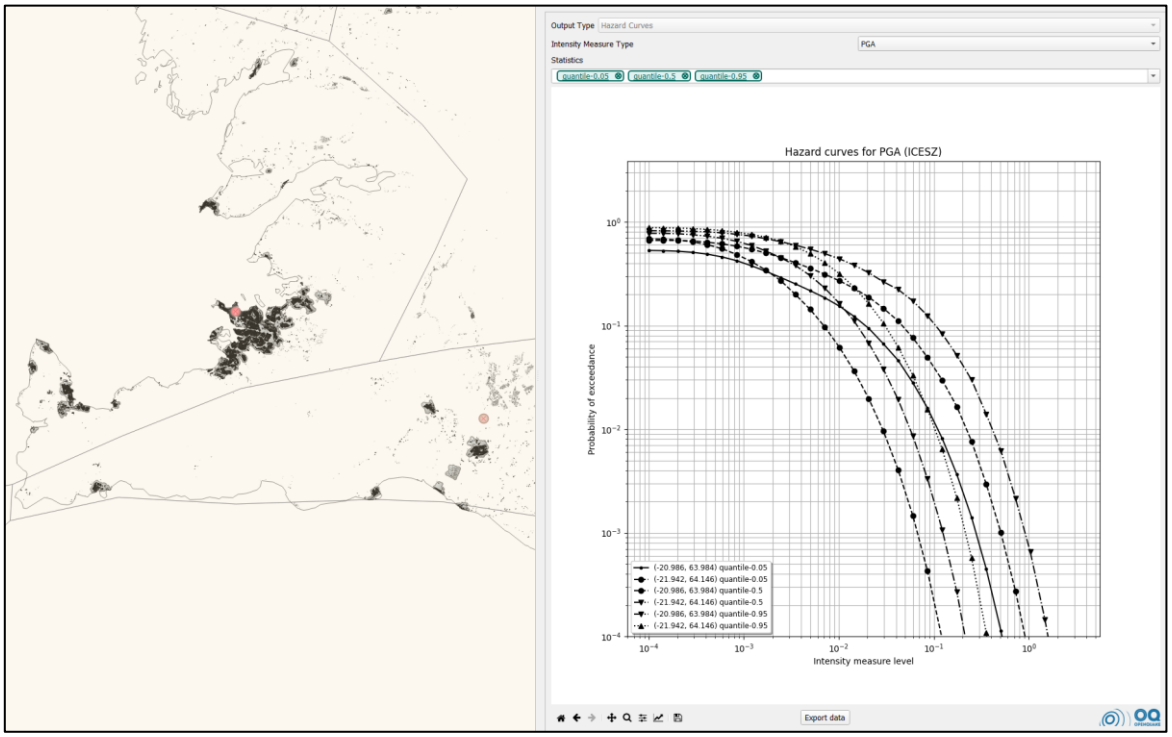

Figure 4: QGIS and OQ-IRMT visualization of PGA hazard curves for Reykjavík and Selfoss (orange circles) using the ICESZ source model, showing the median and 5th and 95th percentile hazard estimates. Black dots show buildings concentration.

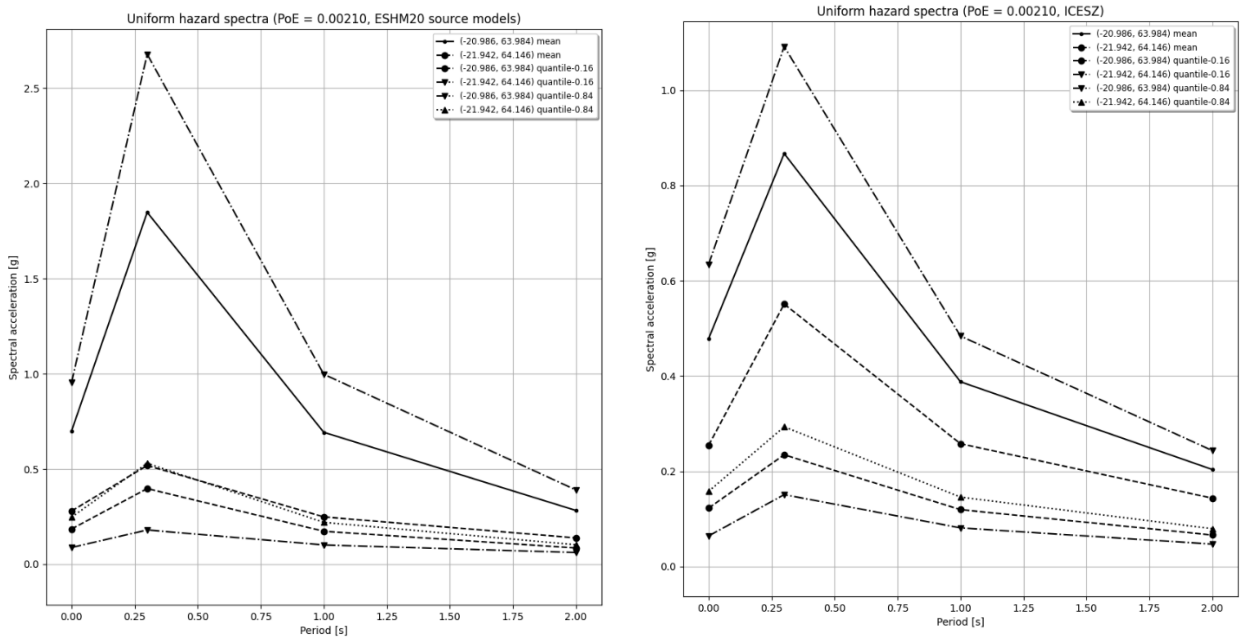

Figure 5: Uniform Hazard Spectra corresponding to 475 years return period, for Reykjavik and Selfoss sites using the ESHM20 source models (left) and ICESZ local source model (right) with the same GMM and site model settings.

For transferring the ESHM20 gridded and fault-source rates to the Icelandic seismic source zonation (ICESZ), SSM rates assigned using the exact intersection between each smoothed-seismicity grid cell and each ICESZ polygon. Fault-source rates are distributed according to the proportion of the fault-buffer located within each ICESZ zone. PSHA were then performed using the complete source and ground-motion logic trees to produce hazard curves and maps for Peak Ground Acceleration (PGA) and Spectral Acceleration (SA) at selected oscillator periods. The maps provide a spatially continuous benchmark for comparing the ESHM20 ASM and SSM+FSM representations and for identifying where local source zonation, recurrence rates and explicit fault contributions have the greatest effect on the estimated hazard.

An OpenQuake-compatible six-branch ICESZ source-model logic tree was also constructed. It combines alternative Icelandic recurrence parameterizations for the SISZ–RPOR region and the rest of Iceland while retaining the original ESHM20 GMM logic tree and site conditions. This controlled configuration isolates the effect of replacing only the seismogenic source model. Classical Probabilistic Seismic Hazard Analysis (PSHA) calculations were conducted for PGA and SA at 0.3, 1.0 and 2.0 s, including weighted means and epistemic quantiles. Hazard curves were calculated for Reykjavík - the capital and the country's largest concentration of population, and Selfoss - urban center in the SISZ close to epicenter of the 2000 and 2008 damaging South Iceland earthquakes (Figure 4). As shown in Figure 5, at the same annual probability of exceedance (PoE = 0.0021, 475 years return period), replacing the ESHM20 source models with the local ICESZ model reduces the estimated hazard, particularly at short-to-moderate periods with significantly stronger influence occurs in Selfoss located within the highly active SISZ, rather than in Reykjavik. The ICESZ model also produces a considerably narrower uncertainty range for Selfoss, especially in the upper quantile. These results provide the technical basis for the next project phase, which will incorporate Icelandic GMMs, frequency-dependent site amplification, and Iceland-specific exposure, vulnerability and fragility models.

Project outcomes:

The principal publication arising from the Transnational Access will present a reproducible OpenQuake benchmark for Iceland and a component-by-component comparison between ESHM20 and Iceland-specific seismic hazard and risk models. The study will subsequently assess the influence of other Iceland-specific components, including the local GMMs, the nationwide frequency-dependent site-amplification model and the local fragility and vulnerability models. Component-by-component sensitivity analyses will identify whether differences are primarily controlled by seismicity rates, source modelling, maximum magnitude, ground-motion modelling or site effects.

A second publication is planned on developing and validating an Iceland-specific smoothed-seismicity model using the updated ICEL-NMAR earthquake catalog, including comparison with the ESHM20 SSM through pseudo-prospective testing of earthquake occurrence rate models. The study will also investigate catalogue completeness, declustering, treatment of volcano-tectonic unrest and the consistent combination of background seismicity. The preferred model will be implemented in OpenQuake.

Note: Data, products, software and publications resulting from TA activities must be publicly accessible under a CC-BY 4.0, GPLv3 or equivalent open license. No embargos beyond June 2026 are allowed. They must cite Geo-INQUIRE as the source of funding. Minimal citation: "*Geo-INQUIRE is funded by the European Union (GA 101058518)*".

References:

1. Bayat, F., Kowsari, M. & Halldorsson, B., 2022. A new 3-D finite-fault model of the Southwest Iceland bookshelf transform zone. *Geophysical Journal International*, **231**, 1618–1633. doi:10.1093/gji/ggac272
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3. Halldorsson, B., Kowsari, M., Bayat, F., Abril, C., Darzi, A., Bessason, B. & Snæbjörnsson, J.Þ., 2022. A provisional seismic source zonation of Iceland for the ESHM20 based on new physics-based bookshelf fault system models and a revised earthquake catalogue. *Proceedings of the 3rd European Conference on Earthquake and Engineering Seismology (3ECEES)*, pp. 3739-3748 (No. 4494).
4. Jónasson, K., Bessason, B., Helgadóttir, Á., Einarsson, P., Gudmundsson, G.B., Brandsdóttir, B., Vogfjörd, K.S., *et al.*, 2021. A Harmonised Instrumental Earthquake Catalogue for Iceland and the Northern Mid-Atlantic Ridge, Geophysics. doi:10.1002/essoar.10505713.4