S15p-155

GIS-Based Project for SHA using the Unified Scaling Law for Earthquakes, Lake Baikal Region case study

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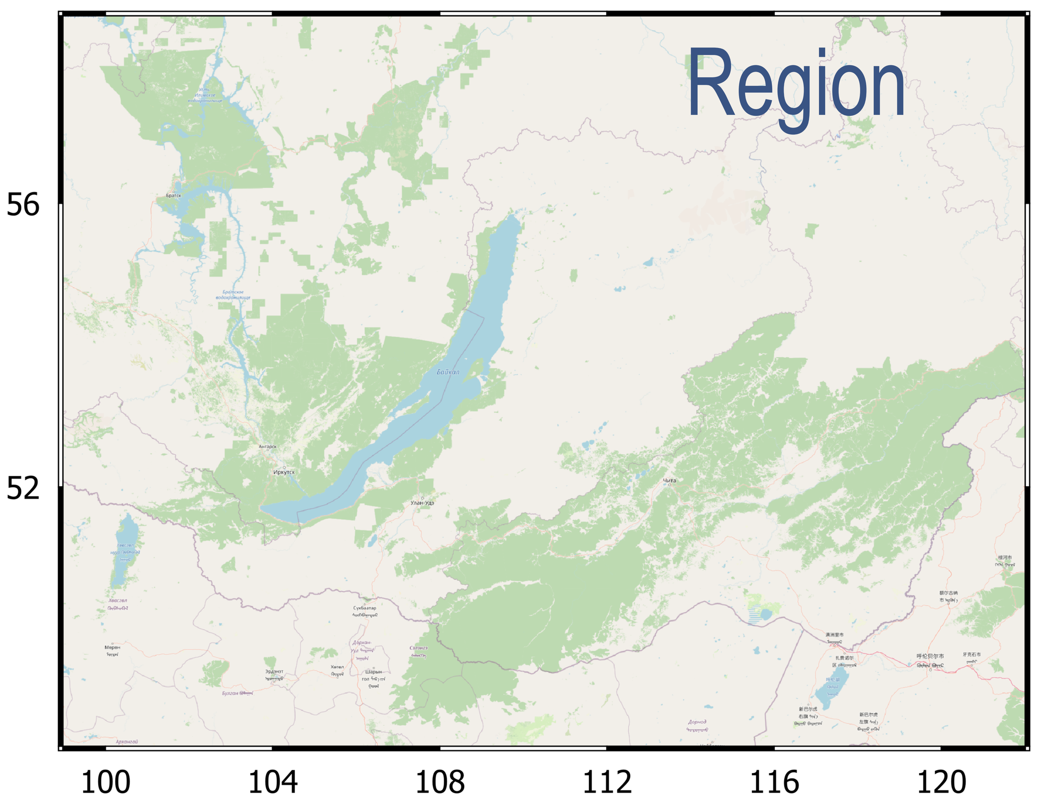
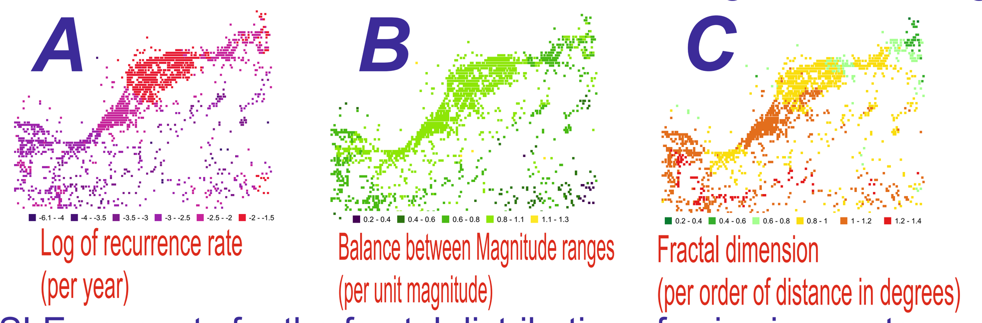


USLE coefficients evaluated for the regional catalog



USLE accounts for the fractal distribution of seismic events, is an essential component the NDSHA [Panza et al.,2021]. It generalises the classical Gutenberg–Richter relationship as follows [Kossobokov & Mazhkenov, 1988; Keilis-Borok et al., 1989; Nekrasova & Kossobokov, 2020; Kossobokov, 2021]:

$$\log_{10} N(M,L) = A + B\times(5-M) + C\times\log_{10} L, \quad M- \le M \le M+$$

where N(M, L) is the expected annual number of earthquakes of magnitude M in a seismic-prone area of linear dimension L, and A, B, and C are constants.

The coefficients A and B correspond to the classical Gutenberg–Richter a- and b-, whereas coefficient C quantifies the local fractal dimension of earthquake epicentres using the SCE algorithm [Nekrasova et al., 2015].

USLE confirmed multiplicative scaling of earthquakes changes the traditional view on the recurrence of catastrophic events and helps estimating seismic hazard in an adequate way.

Project technical description

System Type:
Web-based Geographic Information System (Web-GIS)
Web-GIS solutions rely entirely on Open Source technologies, leveraging both desktop and server-based components of QGIS. Data storage is handled by SpatiaLite geodatabases, known for their ease of administration without additional dependencies or installations.

Objective:
To provide an interactive tool for assessing, visualising, and analysing SH in the Lake Baikal region using the USLE approach. The system includes seismic hazard maps (SHMs), modelling of macroseismic impacts, and validation tools.

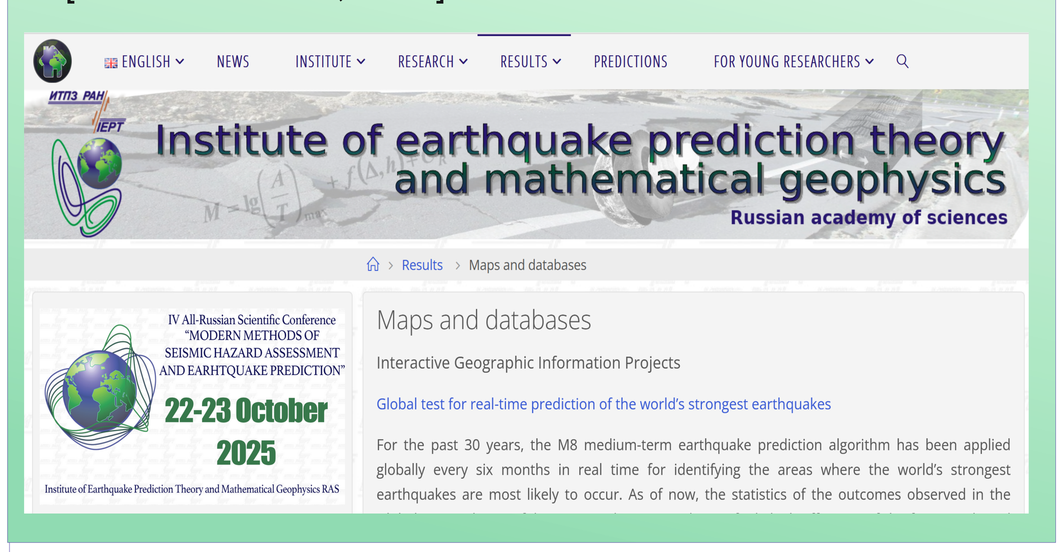
Target Users:
Scientific researchers, emergency management and disaster response authorities, infrastructure engineers, urban planners, other relevant professionals.

Solution client-server Architecture
Client-side: HTML5, CSS3, JavaScript, OpenLayers/Leaflet
Server-side: PostgreSQL/PostGIS, GeoServer
Data formats: GeoJSON, Shapefile, GeoTIFF
Coordinate Reference System: Web Mercator (EPSG:3857)

Hosting Information

The Institute of Earthquake Prediction Theory and Mathematical Geophysics,Russian Academy of Sciences actively develops its capacity for presenting scientific results via Web-GIS technology.
Since launching its Web-GIS platform in 2019, the Institute has created and maintained specialised interactive maps displaying data on the strongest global earthquakes, as well as lineaments and seismogenic nodes of selected seismically active regions.

All Web-GIS resources are centrally accessible through the main entry page "Maps and Databases" https://www.itpz-ran.ru/ru/resultaty/maps-and-databases/, providing bilingual project descriptions in Russian and English to maximise user engagement.
The platform's capabilities and developments have been detailed in various conference reports and articles [Podolskaia et al., 2022].



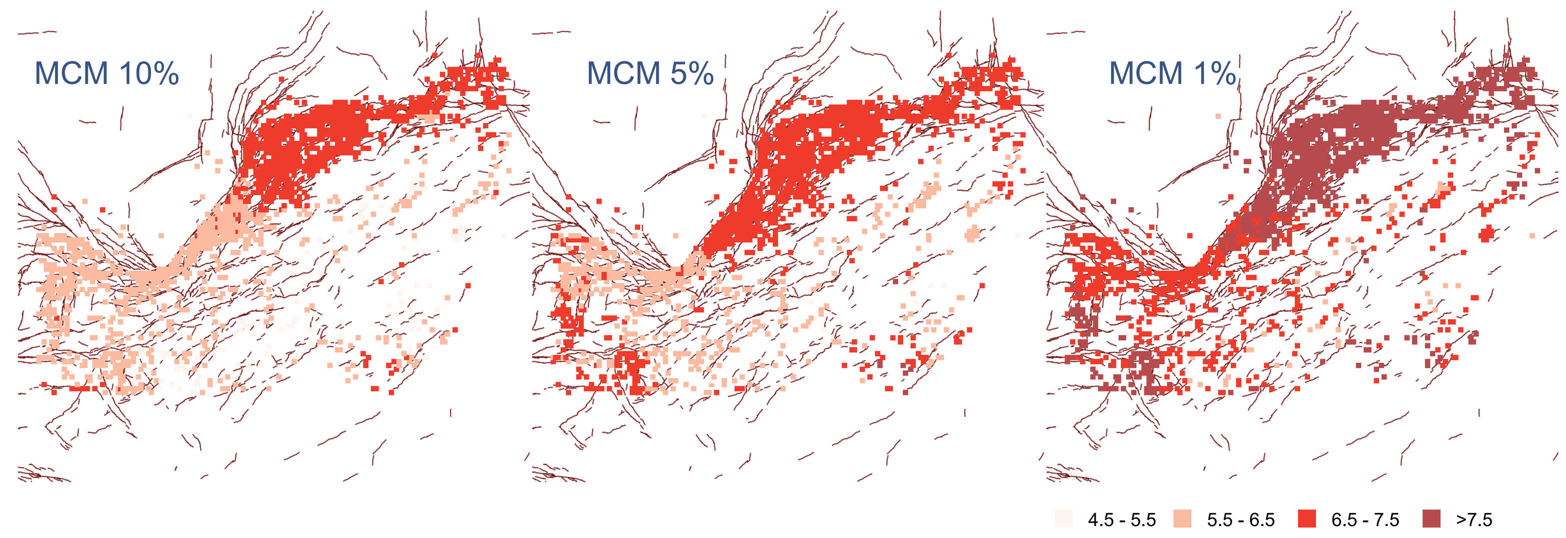
Data

USLE coeffisients evaluated fort he local catalogue compiled at Baikal Division of the Geophysical Survey, Federal Research Centre of the Russian Academy of Sciences, from 1994 to 2019. The catalogue is sufficiently complete at least for energy class K above 8.5 (K = 4 + 1.8×M).

Method

The long-term estimates of the USLE coefficients to characterize seismic hazard in terms of Maximum Credible Magnitude (*MCM*, M_{MCM}). Specifically, consider the values of *A*, *B*, and *C* obtained for seismic locus.
For magnitude M1 ≤ M ≤ M2 calculate at grid points c_i the expected number of events in T years, $N_T(M_{MCM}) = T\times N(M_{MCM})$ and find the maximum magnitude M+ with the expected number $N_T(M_{MCM}) = p\%$ or greater.

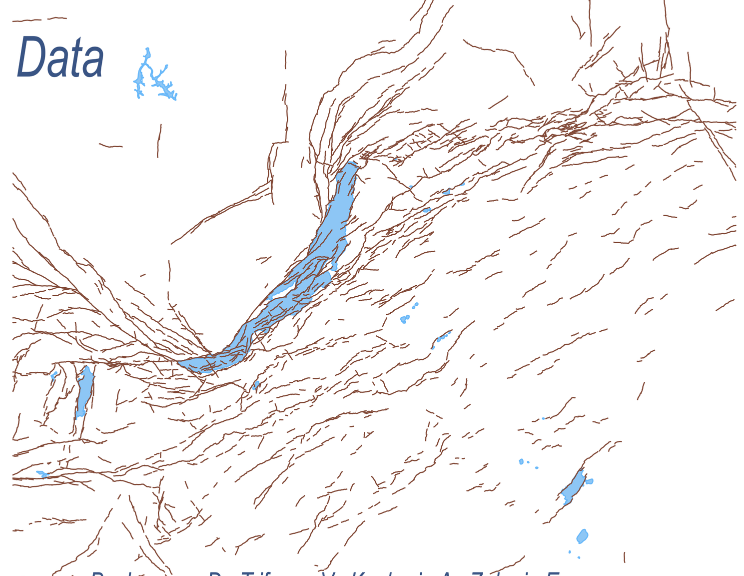
Identification of potential seismic sources, Seismic hazard maps (SHMs) in terms of MCM



Maximum Credible Magnitude maps

Seismic Impact Modelling, SHMs in terms of macroseismic intensity

Data



Bachmanov D., Trifonov V., Kozhurin A., Zelenin E.. Active Faults of Eurasia Database AFEAD v2022. 2022, https://doi.org/10.13140/RG.2.2.25509.58084.

Method

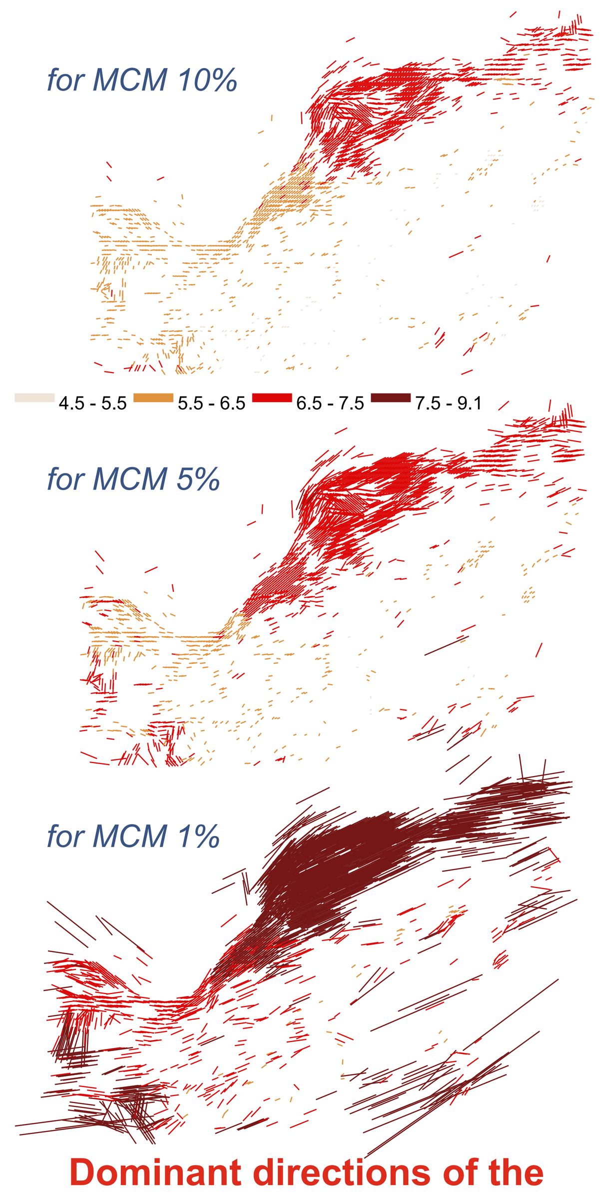
Seismic effect describe from each of the earthquake-prone cells c_i.

Soft (plugins)

Dominant Directions of the local Active Fault System estimation (DDLAFS) plugin. Geoinformatika. 2022; (4):54–62.

Earthquake Anisotropic source zone Model Plugin estimates elliptical earthquake source zones based on user input. For each location–magnitude pair (c_i, $M_{MCM,i}$), it calculates an ellipse with semi-axes: A(M) = ½ × 10^(α + βM), B(M) = ½ × 10^(γ + δM). The constants α, β, γ, and δ define the typical length and width of the source zone. These values should be region-specific if available, or taken from studies in similar tectonic settings (e.g., Wells and Coppersmith, 1994). The orientation of each ellipse follows the dominant fault strike (ψ_i) near the epicentre. If no strike is defined, the plugin defaults to a circular source zone using the Shebalin (1968) model.

Macroseismic Intensity Anisotropic Propagation Model Plugin generates seismic hazard zones both inside and outside an earthquake source zone. It uses a user-provided line layer that defines the elliptical boundaries of the source zone. The plugin calculates the extent of macroseismic intensity propagation outside the source zone using a specialized formula based on seismic parameters, including the Shebalin (1968) empirical model. Parameters such as magnitude (M), focal depth (H), intensity (I), and constants (b, c, v) are used to estimate the anisotropic spread of seismic effects.

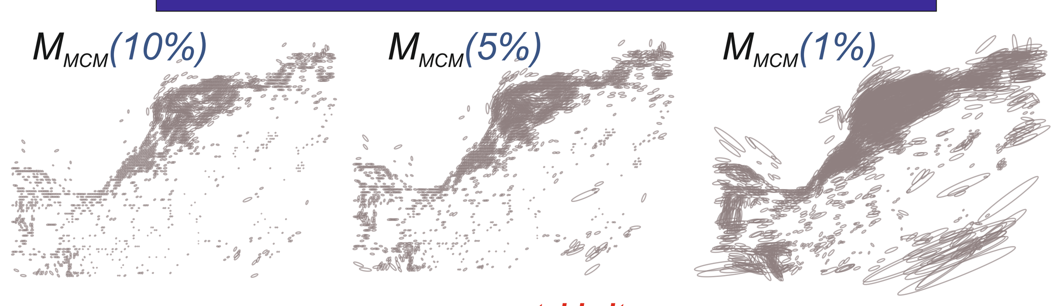


Dominant directions of the active faults {ψ_i}, color-coded in respect to MCM

Anisotropic seismic impact

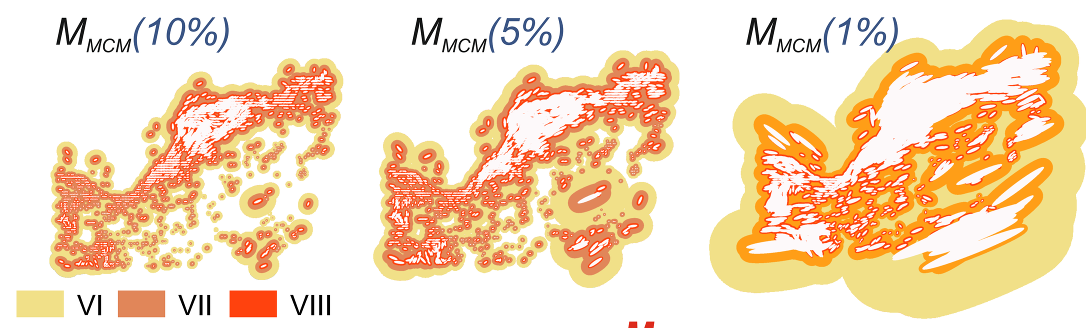
earthquake source zone {c_i, M_i, ψ_i}

$$I_e(M, \Delta, h, \varphi, \alpha, \beta, \gamma, \delta) = RAND(I(M, A(M), h), I(M, 0, h))$$



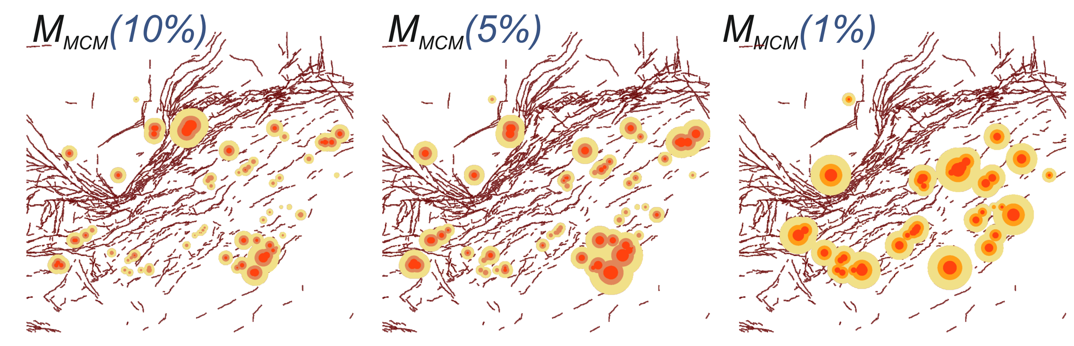
... outside it

$$I_e(M, \Delta, h, \varphi, \alpha, \beta, \gamma, \delta) = I(M, A(M) + \Delta r(M, \varphi), h)$$



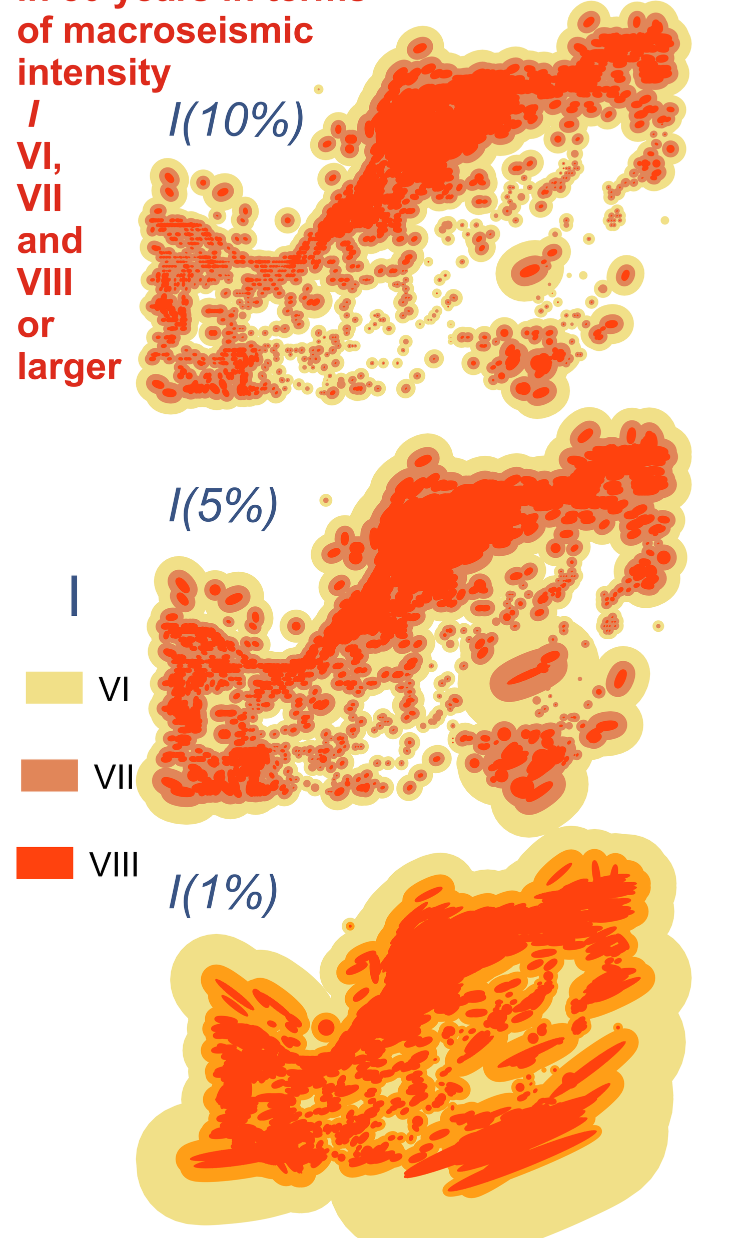
earthquake source zone {c_i, M_i, ψ_i}, ψ_i = "None"

$$I = b\times M - \nu\times\log_{10}\sqrt{\Delta^2 + h^2} + c$$

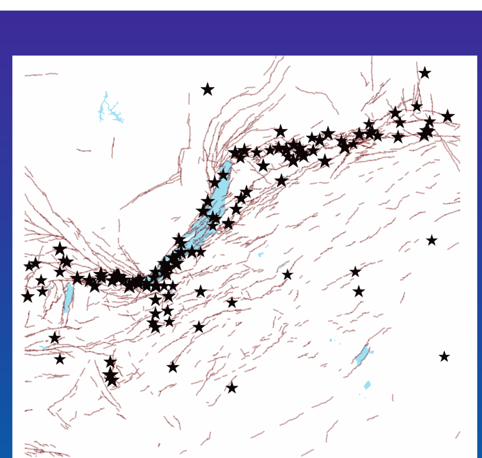


USLE-based SHMs for 10%, 5% and 1% probability of exceedance in 50 years in terms of macroseismic intensity

I VI, VII and VIII or larger

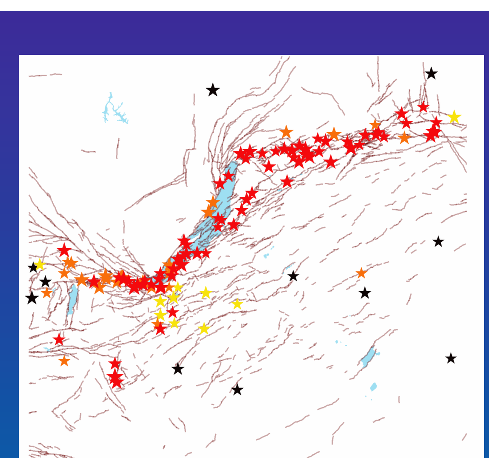


Verification



139 earthquakes of magnitude MLH ≥ 5.5 that occurred from 3000 BC to 2013 AD in the Lake Baikal Region

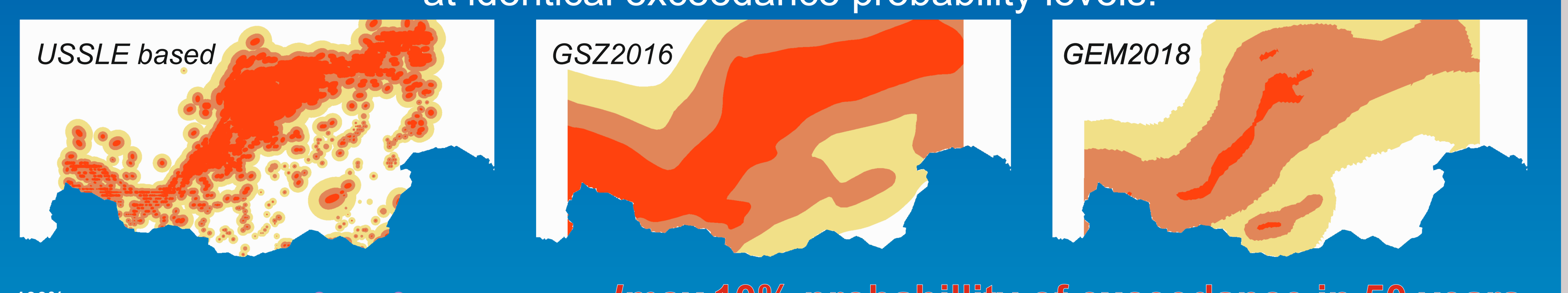
Ulomov VI, Medvedeva NS (2014) Specialized Catalog of Earthquakes for General Seismic Zoning of the Territory of the Russian Federation. Schmidt institute of physics of the earth RAS, p 512 (in Russian).



For USLE based 10% of exceedance SHM:
81 earthquakes
(58% of the total 139 earthquakes)
are located in the area of expected intensity VIII,
36 (26%) — in area of intensity VII,
and only 10 (7%) within the area of intensity VI,
10 earthquakes (9 %) —
out of 10% of exceedance SHM.

Comparison

USLE based SHMs are compared with the General Seismic Zonation 2016 (*GSZ2016*) and Global Earthquake Model 2018 (*GEM2018*) hazard maps at identical exceedance probability levels.



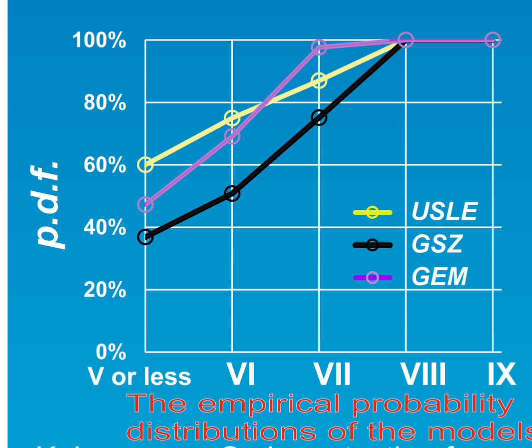
Imax 10% probabillity of exceedance in 50 years

GEM Global SEISMIC HAZARD MAP version 2019.1

Pagani M, Garcia-Pelaez J, Gee R, et al. The 2018 version of the Global Earthquake Model: Hazard component. Earthquake Spectra. 2020; 36(1_suppl):226-251. doi:10.1177/8755293020931866

I(PGA)=2.5×log10(PGA)+6.89

GOST R 57546-2017 National Standard of the Russian Federation. Earthquakes. Scale of seismic intensity. Date of introduction 2017-09-01 (in Russian)



The empirical probability distributions of the models

The Kolmogorov-Smirnov two-sample statistic λ_{KS} applied to pairs of the model maps 55778 cells (10x10 km)

Pair	D	λKS	Probability a
USLE vs GEM	0.13	21.3	≈ 0.0
USLE vs GSZ	0.24	40.5	≈ 0.0
GEM vs GSZ	0.23	37.6	≈ 0.0

Kolmogorov–Smirnov testing for each pairwise set of SH maps from the three selected models shows that the null hypothesis of identical distributions is rejected with over 99.9% confidence for all pairs.

**The NDSHA maps are superior to the PSHA maps in terms of the effectiveness of ground shaking prediction.
A significant discrepancy in the area of expected macroseismic intensity VIII and above leads to a sharp difference in the seismic risk values for objects in the study area.
As emphasized in comparisons (e.g., Panza et al., 2022), PSHA, unlike NDSHA, has never been subjected to unbiased testing. Unlike PSHA, NDSHA focuses on large-scale patterns rather than subtle details. The formalized and standardized nature of PSHA often leads to limited and consequently inaccurate results in the research process.**

The project is currently underway. We understand the complexity of using seismic catalog data, the quality of which varies from location to location and may affect the results and interpretation. However, the robust nature of the calculations, confirmed by the low error values in the bulk of seismic regions, allows us to conclude a general agreement with the assumption of spatial self-similarityand to continue the research using regional data on earthquakes and active faults.