Rapid Multi-Risk Needs Evaluation and Planning Platform

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CBR Ground Shaking Map
ShakeMap Manual

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Executive summary

The CBR Ground Shaking Map web platform, developed within Work Package 4 (WP4) of the EMERGE project, provides a near real-time system for rapid assessment and visualization of earthquake ground shaking across the cross-border region of North Macedonia, Albania, and Greece. Built on established ShakeMap methodologies originally developed by the United States Geological Survey and further advanced by European implementations such as those of National Institute of Geophysics and Volcanology in Italy, the platform delivers fast, standardized, and scientifically robust shaking information immediately after seismic events.

The system automatically generates ShakeMaps for earthquakes above a configurable magnitude threshold (default $M_L \geq 4.0$), integrating real-time strong motion recordings, macroseismic intensity observations, ground motion prediction equations, and site condition models. It relies on seismic data streams processed through widely used monitoring infrastructure, including SeisComP, and employs modeling tools consistent with the Global Earthquake Model framework and the OpenQuake Engine.

The resulting products include spatially continuous maps of Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), spectral acceleration at key periods, and macroseismic intensity distributions. These outputs are complemented by uncertainty grids, station observations, GIS-ready datasets, and interactive web layers, enabling both rapid situational awareness and detailed post-event analysis.

Technically, the system combines observed data with interpolation methods and ground motion models to address gaps in station coverage, particularly in urban areas where seismic risk is highest, but instrumentation remains incomplete. Site amplification effects are incorporated through V_{S30}-based characterization models, ensuring more realistic representation of local ground response.

Operationally, the platform is fully automated: seismic event detection triggers ShakeMap generation via SeisComP, and results are immediately published on a dedicated web portal while simultaneously being shared through web services with the broader EMERGE platform for near-real-time impact assessment.

The system supports multiple user needs, including emergency response, civil protection decision-making, infrastructure management, scientific research, and public communication. By providing standardized, rapidly accessible shaking information across national borders, the platform significantly strengthens regional cooperation and improves earthquake preparedness and response capabilities.

Overall, the CBR Ground Shaking Map represents a key advancement in regional seismic monitoring infrastructure, combining robust scientific methodology with operational automation to enhance earthquake risk reduction and cross-border resilience.

1. Introduction

The CBR Ground Shaking Map web platform was implemented and adjusted within the framework of the Work Package 4 (WP4) of the EMERGE project and is classified as sensitive under Deliverable D4.2.

This report presents the technical specifications, operational framework, and user guidelines for the developed web platform. The platform is based on the principles of the ShakeMap system developed by the United States Geological Survey, USGS (Wald et al., 2003), as well as on European implementations and products developed by the National Institute of Geophysics and Volcanology in Italy, INGV (Faenza et al., 2008).

The platform is an internet-based system designed to rapidly generate and visualize earthquake ground-motion information beyond basic earthquake parameters, such as magnitude and epicentral location. Like the original ShakeMap framework, the system provides rapid mapping of ground-motion parameters immediately after seismic events with local magnitude greater than 4.0.

The generated ShakeMaps portray the spatial distribution and severity of ground shaking by producing:

- grids of acceleration and velocity amplitudes,
- spectral response parameters,
- and color-coded intensity maps illustrating the variation of shaking across the affected region.

The ShakeMap processing algorithms integrate recorded strong motion data together with available macroseismic intensity observations to provide reliable constraints on observed shaking levels. In addition, advanced interpolation methodologies and ground motion prediction models are applied to estimate shaking in regions with sparse or unavailable observations. Through the combination of recorded and modeled data, the platform provides a comprehensive representation of earthquake shaking.

Near-real-time ShakeMap products are widely used by national and local authorities, emergency management agencies, civil protection institutions, researchers, and engineers for: emergency response and rapid situational awareness, seismic loss estimation, public information dissemination, scientific investigations, and disaster preparedness and mitigation planning.

This document serves as a user manual for the CBR Ground Shaking Map web service and provides guidelines for accessing, interpreting, and utilizing the generated ShakeMap products. The manual also presents the technical background and implementation aspects of the system, including:

1. Technical Guide – overview of the ground-motion records, data acquisition, ground motion models, and site characterization maps used within the ShakeMap framework;
2. Activation procedure – description of the triggering thresholds, intensity measures, available products and formats, and practical use of the generated ShakeMap products;
3. Software and Implementation Guide – overview of the web platform structure, web pages, and technical information intended for system operators, developers, administrators, and end users.

The implemented module focuses specifically on ShakeMap generation for the cross-border region encompassing North Macedonia, Albania, and Greece, contributing to improved regional seismic monitoring, rapid earthquake response, and cross border seismic risk assessment.

2. Technical guide

The ShakeMap generation is based on recorded strong-motion data obtained from seismic instruments installed across the participating countries. The primary strategy of the monitoring network is to achieve denser instrumentation within urban areas, where population density and infrastructure exposure are greatest. Following this approach, the generated ground shaking maps are expected to provide the highest accuracy in urban regions, where the potential seismic risk is highest and where emergency response and recovery operations are likely to be most critical and complex.

However, the current distribution of seismic stations is not sufficiently dense to provide complete coverage of all urban and populated areas. As a result, interpolation and modeling procedures are necessary to estimate ground motion parameters in regions with limited or no direct observations.

Estimating ground motion in areas with sparse station coverage and subsequently interpolating both recorded and estimated values onto a fine spatial grid suitable for mapping and contouring, requires several processing steps. These include acquisition and quality control of recorded seismic data, application of ground motion prediction models, correction for local site effects, spatial interpolation of ground motion parameters and generation of continuous ground shaking maps.

Through the combination of recorded observations and modeled estimates, the ShakeMap system provides a spatially continuous representation of earthquake ground shaking across the investigated region.

2.1. Ground motion records and data acquisition

ShakeMap requires reliable estimates of earthquake source parameters, including magnitude, epicentral location, and when available, recorded shaking Intensity

Measures (IMs) from seismic stations. To support this functionality, ShakeMap can be integrated with several seismic processing systems widely used by seismological networks worldwide, including SeisComP (GFZ and gempa GmbH, 2008) and AQMS (Biondi et al., 2025).

The generated ShakeMaps are based primarily on recorded strong motion data obtained from seismic stations distributed across the monitored region using SeisComP server. These recordings provide the fundamental observational constraints required for estimating the spatial distribution of earthquake ground shaking.

Parametric data used by ShakeMap generally include the following ground motion parameters: Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Spectral Acceleration (SA) amplitudes at periods of 0.3 s, 1.0 s, and 3.0 s.

These parameters are automatically calculated from the recorded waveforms and are used as direct inputs for the ShakeMap interpolation and modeling procedures.

In addition to instrumental recordings, ShakeMap can optionally incorporate observed macroseismic intensity data. Macroseismic observations (e.g. MMI) are especially valuable in areas with sparse instrumental coverage, as they provide supplementary information regarding the perceived effects and damage caused by the earthquake.

2.2. Ground Motion Models

ShakeMap employs Ground Motion Models (GMMs) to generate initial estimates of earthquake ground shaking in regions where direct observations are unavailable or insufficient. GMMs describe the relationship between earthquake source characteristics, propagation effects, local site conditions, and expected ground motion amplitudes.

The Ground Motion Models (GMMs) implemented within the ShakeMap framework are selected from the suite of models available through the open-source hazard and risk assessment software OpenQuake (Pagani et al., 2014; Silva et al., 2014). The models are derived from empirical strong-motion observations and are calibrated for different tectonic settings, earthquake source characteristics, and ground-motion conditions.

The selection of an appropriate GMM depends on several factors, basically tectonic regime (e.g. active vs. stable continental) and type of seismicity (e.g. shallow crustal vs. subduction).

The adopted GMMs provide the initial ground-motion field, representing expected shaking under reference site conditions, which is subsequently refined through the incorporation of recorded seismic observations and site-specific amplification corrections.

2.3. Site Characterization Map

Local geological and soil conditions can significantly influence earthquake ground motion through site amplification effects. To account for these effects, ShakeMap utilizes a site characterization model based primarily on the spatial distribution of the average shear wave velocity in the upper 30 meters of the ground profile (VS30).

Each region implementing ShakeMap should ideally possess a detailed VS30 map covering the entire area of interest. These maps are typically developed based on the joint analysis of the outcomes from geotechnical investigations, geophysical surveys and geological classifications (e.g. Mori et al., 2026).

In regions where detailed VS30 data are unavailable, a globally applicable alternative approach proposed by Allen and Wald (2007) is commonly used. This method estimates VS30 values from topographic slope data derived from digital elevation models. Some effort was made in D4.1 to assess site conditions for Greek stations, but for the sake of consistency across all three countries the proxy-based Vs30 calculation method that uses topography has been selected here.

3. Activation procedure

3.1. Triggering Threshold

The ShakeMap system is always triggered by the SeisComP system in case an event is detected. The event detection is mainly based on reaching the STA/LTA (short-term average to long-term average ratio) threshold, which is one of the most widely used standard techniques for automatic event location. During the event detection process, calculations for potential epicenter and magnitude are made and this data, together with calculated PGA values from each station, are transferred to the ShakeMap system as input parameters. The decision whether to trigger the ShakeMap system is made based on the magnitude level which can be configured by the SeisComP operator. For the current implementation of the CBR Ground Shaking Map platform, the default triggering threshold is set to local magnitude ML = 4.0. Local magnitude is used considering that most seismic monitoring agencies in the region at hand perform detection and then local magnitude estimation based on the location and convolved Wood-Anderson displacement amplitudes. Earthquakes equal to or greater than this threshold automatically initiate the ShakeMap generation process and the publication of ground shaking products on the web platform.

The platform provides flexibility for authorized users and system operators to modify the triggering threshold according to their specific operational or research needs. Lower thresholds may be useful for scientific studies and local seismic monitoring, while higher thresholds may be preferred to limit processing to potentially damaging earthquakes only.

3.2. Ground motion parameters

The intensity measures derived from the strong motion recordings within the ShakeMap system are based primarily on peak ground motion parameters. For practical and operational reasons, the system calculates and displays only the peak values of the most important ground motion parameters, including PGA and PGV. However, peak parameters alone may not fully describe the frequency-dependent characteristics of earthquake ground motion, particularly for larger earthquakes and events recorded at greater epicentral distances. In such cases, the spectral content of seismic motion becomes increasingly important for engineering analysis and structural response evaluation. To address this, the platform additionally generates spectral acceleration (SA) maps for selected periods of 0.3, 1.0 and 3.0 seconds.

3.3. Products and formats

The ShakeMap platform generates several products that provide information about earthquake ground shaking and its spatial distribution. The available products include:

Output and Metadata Files

- HDF files contain input data, output grids, and metadata.
- JSON metadata files containing processing information, timestamps, and system parameters.
- GeoJSON station files with seismic station data, observed intensities, and predicted parameters.

Static Maps and Figures

- Macroseismic Intensity (MMI) maps.
- Peak Ground Acceleration (PGA) maps.
- Peak Ground Velocity (PGV) maps.
- Spectral Acceleration (SA) maps for selected periods.
- Regression and GMM comparison plots.
- MMI legends and overview thumbnails.

Interactive Maps

- Interactive GeoJSON map layers with different resolutions.
- PNG overlay files for geographic visualization.
- Finite fault geometry files when available.
- Ground-Shaking Grids
- XML grids of interpolated ground-motion values.
- XML grids of ground-motion uncertainty.

GIS Products

- GIS shapefiles for spatial analysis.

- ESRI raster grid files.
- Google Earth KMZ files containing shaking layers and station information.
- Smoothed contour files in GeoJSON format.

These products support rapid visualization, scientific analysis, emergency response, and integration with GIS and seismic hazard assessment tools.

4. Software and implementation

4.1. Operational workflow

The event detection platform based on SeisComP creates file (event.xml) containing data describing the event (magnitude, location, event time, etc.) and additional file (event.dat.xml) with calculated values for PGA, PGV and SA, from the real-time data from each station that has participated in the event detection process.

As soon as these files are created, SeisComP calls a script that triggers the ShakeMap module which uses the created files in combination with internal files describing the soil structure and characteristics in the region, as input in the ShakeMap generation process.

The output products of ShakeMap are directly published on the web portal (http://shakemap.iziis.ukim.edu.mk/) implemented and configured by IZIIS for the purposes of this project, for visual representation of the events and their effects in the area.

In parallel, the output products of ShakeMap paired with permanent ground displacement calculation for the CBR, are posted via WEB API protocol in GeoJSON format to the EMERGE web-based platform (developed by EUCENTRE in WP2), where these data are used for near-real-time needs assessment.

4.2. ShakeMap for web user interface

The ShakeMap webpage is a customizable open-source tool for visual presentation of ShakeMaps (https://github.com/INGV/shakemap4-web). Its implementation in this project is intended for providing near real-time earthquake shaking maps for the central Balkan region, mainly N. Macedonia, Albania and Northern Greece, showing ground motion intensity after seismic events. The maps are automatically generated without human control, and their purpose is mainly for informational and educational purposes and research.

Home page

The home page presents a list of the latest events (Figure 1). Each event is a clickable link which leads to a page where all the data describing the event are presented.

Event preview page

The event preview page gives an option for leaflet view, using interactive GIS maps or static view using image files (Figure 2). Each event presents maps illustrating PGA, PGV and PSA (0.3s, 1s, 3s) values around the region of the epicentral area.

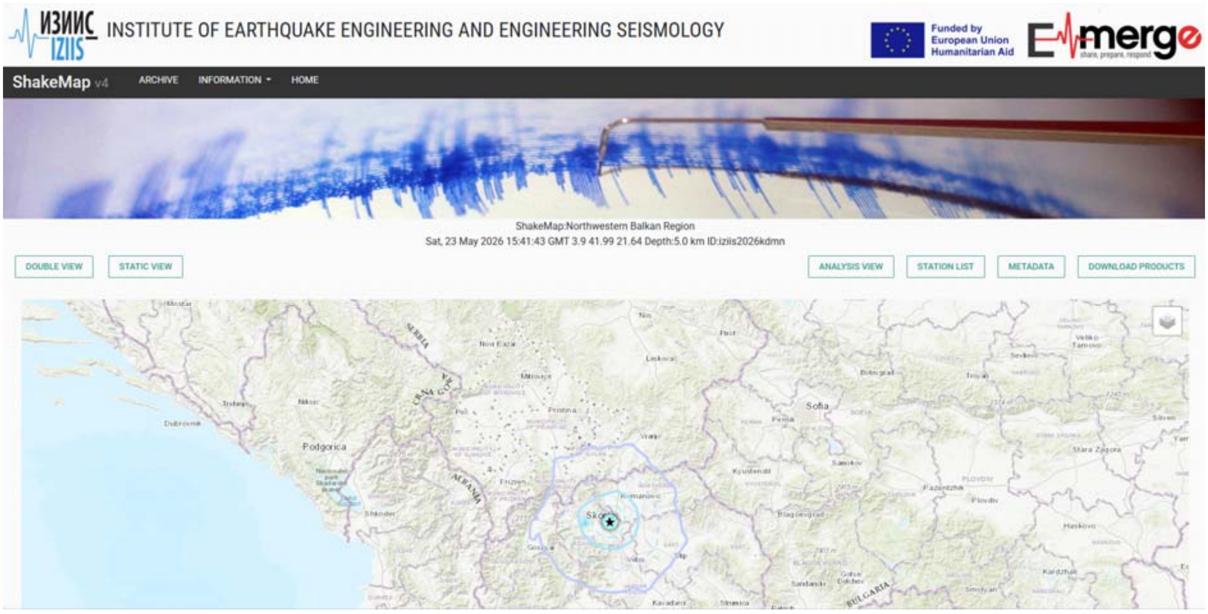

Figure 1 Event preview page (leaflet view)

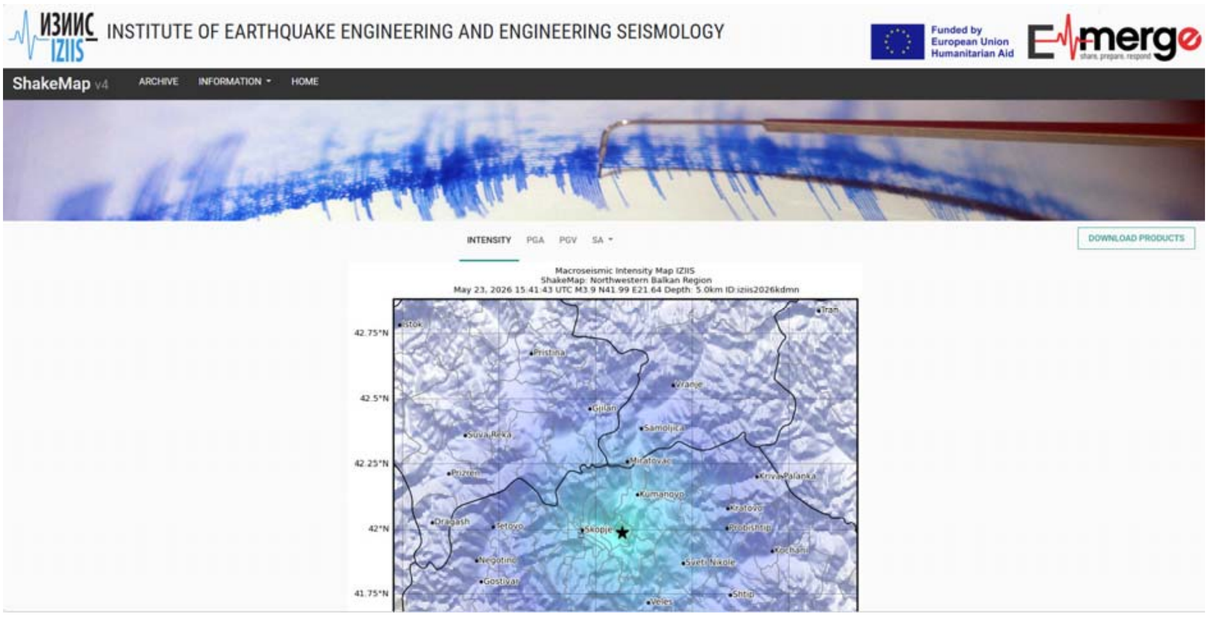

Figure 2 Event preview page (static view)

Besides the maps, each event is accompanied by separate pages for:

- Stations list (Figure 3) – provides information about the stations that participated in the event detection process
- Basic analysis – presenting charts relating intensity, PGA and PGV to the distance of the station, based on its site class
- Metadata – metadata if available, describing the creation process
- Downloads – offers possibility for downloading the event's ShakeMap products in jpg, pdf or GeoJSON format

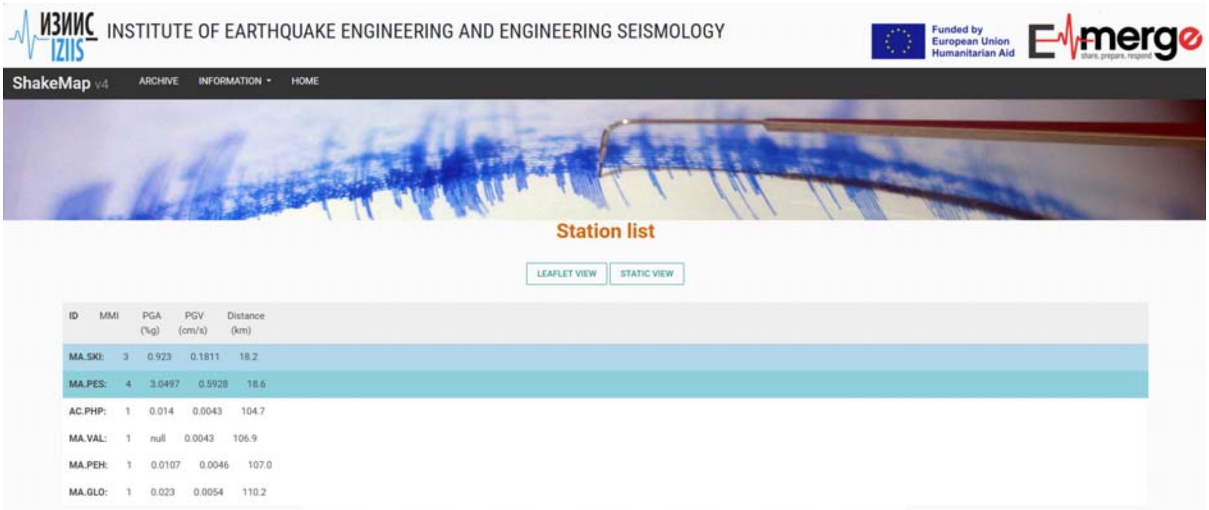

Figure 3 Stations list page

<u>Archive page</u>

This page offers users the possibility to filter events by time and magnitude level (Figure 4).

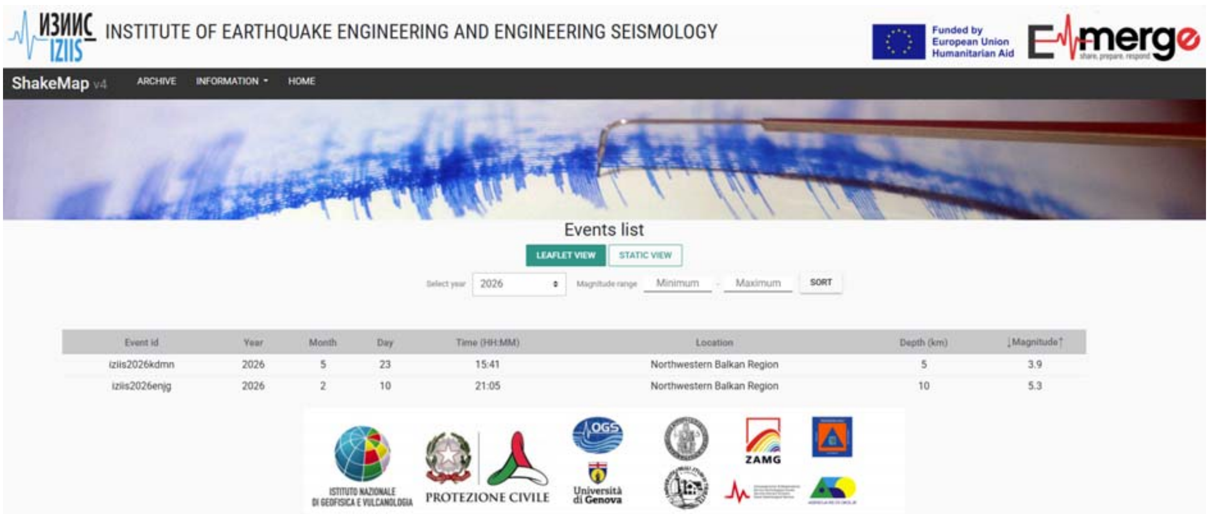

Figure 4 Archive page

5. Application of ShakeMap

Generated ShakeMap products support a variety of applications:

- Emergency response and civil protection - providing rapid information on the areas most affected by strong ground shaking;
- Damage and loss assessment - identification of regions potentially exposed to severe shaking;
- Seismic monitoring and scientific research - enabling analysis of earthquake source characteristics and ground motion distribution;
- Infrastructure and lifeline management - supporting prioritization of inspections and recovery activities;
- Public information and awareness - accessible visualization of earthquake effects;
- Cross-border cooperation - providing a common platform for earthquake monitoring and sharing information among the participating countries.

The availability of standardized ground shaking products contributes to improved situational awareness and supports informed decision making during and after seismic events.

6. Concluding remarks

The CBR Ground Shaking Map platform developed within the EMERGE project provides a reliable and efficient framework for the rapid assessment and visualization of earthquake ground shaking in the cross-border region of North Macedonia, Albania, and Greece. The system is based on the established ShakeMap methodology and integrates recorded strong-motion data, ground-motion prediction models, and site characterization information to generate near-real-time shaking maps and related products.

This manual has presented the fundamental components of the platform, including data acquisition procedures, ground-motion modeling, triggering criteria, available products and formats, and the operational workflow of the web-based system. The generated ShakeMap products provide valuable information for emergency response organizations, civil protection authorities, researchers, infrastructure operators, and local communities.

As the seismic monitoring network expands and additional ground motion observations become available, the accuracy and reliability of the generated maps are expected to improve further. The platform therefore represents an important contribution to regional seismic monitoring, earthquake risk reduction, and cross-border cooperation, supporting more effective preparedness, response, and recovery activities following future earthquakes.

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