Deliverable 1.14

D1.14 Mid-Term Report of the Consortium including impact assessment and risk register

Deliverable information	
Work package	[WP1: Management]
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Summary

Deliverable 1.14 is the Mid-Term Report and it contains the explanation of the work carried out by the beneficiaries for each work package (WP) for the period September 2019 - August 2021.In this deliverable we also include an overview of the project results towards the objective of the action in line with the Grant Agreement, a summary of deliverables and milestones that have been submitted, a summary of the exploitable results and an explanation about how they can/will be exploited.

This deliverable will set the basis for the technical part of the upcoming periodic report for the first reporting period [M1-M24], which will be submitted by the end of October 2021. It will also provide the essential information to the Scientific Advisory and International Partner Board (SAIPB) as the project's status report, upon which they will be able to deliver D1.11, Mid-term report of the Scientific Advisory Board, which will comment on the progress made and suggest changes for the second half of RISE.

This deliverable is prepared by the contribution of all RISE Consortium.

Map of RISE beneficiaries that have contributed to the report.

1. Project Overview and Executive Summary

1.1 RISE Main Objectives as stated in the work plan

The concept and vision of RISE is to promote a paradigm shift in how earthquake risk is perceived and managed. We believe that by taking advantage of advances in scientific understanding, and dramatically changing technological capabilities, earthquake hazard and risk will soon be appreciated not as a constant in time, but as an evolving, integrated and dynamic risk. In our concept, dynamic risk depends on location, changing with soil conditions, topography, structural type, occupancy and use and even location within a structure. However, dynamic risk also includes changes with time, for example increasing when a seismic sequence is active nearby and due to an improved dynamic geophysical understanding of faulting and earthquake processes. The key objective of RISE is therefore to markedly advance real-time earthquake risk reduction capabilities for a resilient Europe, limiting the negative impact of future earthquakes. To archive that, RISE proposes a series of coordinated activities in the domains of Operational Earthquake Forecasting, Earthquake Early Warning, Rapid Loss Assessment and Recovery and Rebuilding Efforts. Examples of the challenges RISE addresses are:

- Advance real-time seismic risk reduction capacities of European societies by transitioning to a new concept of dynamic risk.
- Improve short-term forecasting and operational earthquake forecasting by developing and validating the next generation of forecasting models.
- Enhance the quality of earthquake prediction and earthquake forecasting by launching a European collaborative effort for validation and rigorous testing.
- Contribute to the establishment of sound and rational risk reduction procedures
- Improve the preparedness of societies, emergency managers, and long-term recovery management.

RISE is multi-disciplinary, involving earth-scientists, engineering- scientists, computer scientists, and social scientists. RISE is engaging 19 partners from eight different European countries and five international partners.

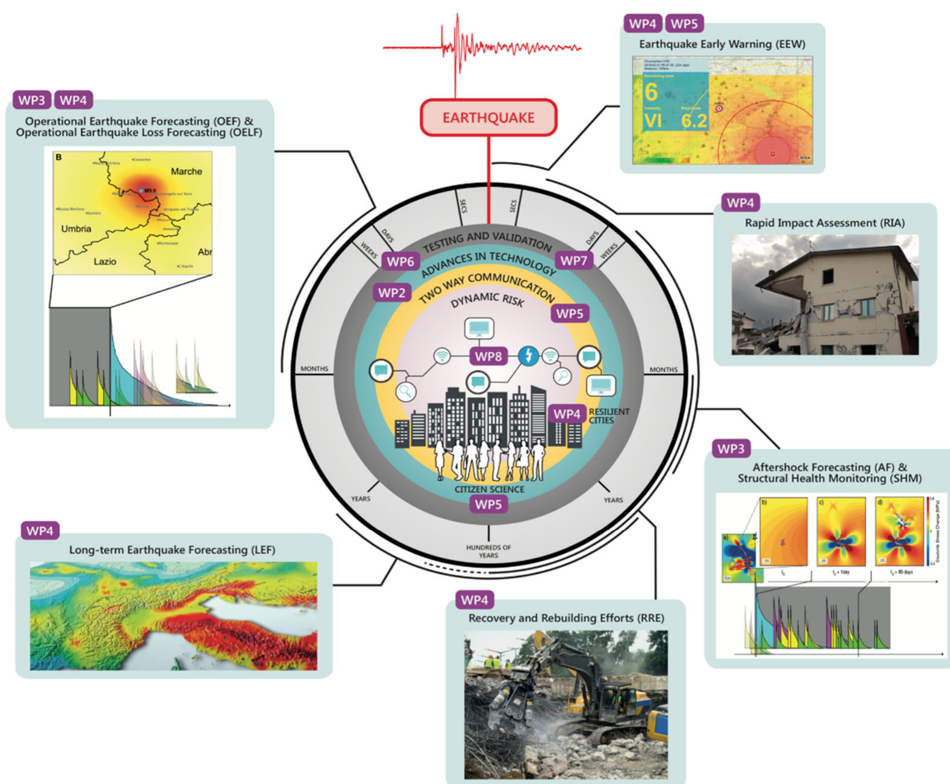


Figure 1 Conceptual view of the RISE work packages relative to the mainshock time.

1.2 Executive Summary

This mid-term report summarises the activities within the Horizon 2020 funded project RISE for the period Sept 2019 - August. 2021. RISE stands for Real-time earthquake rIsk reduction for a reSilient Europe; it brings together 19 partners from across Europe and five international participants into a multi-disciplinary effort involving earth-scientists, engineering-scientists, computer-scientists, and social-scientists.

In our self-assessment, the RISE project is fully on track to achieve its ambitious goals, with very few activities delayed. Despite the challenges posed by the Corona pandemic, the activities are on track, and coordination and motivation of the team remains high. The RISE project has been strongly engaged in internal and external communication and dissemination activities: We built an attractive and well-visited web site (http://www.rise-eu.org) and twitter presence (@research_rise), we distributed 5 internal and 3 external newsletters and have presented our research on numerous conferences and meetings. Until today, 25 peer reviewed publications have been submitted and are openly available via Zenodo (https://zenodo.org/communities/rise-h2020). Bi-weekly scientific session has been held via zoom; the only mid-term meeting that was attended by more than 70 people. All RISE activities are supported by an experienced management office centred at ETH, the management board (MB) consists of well engaged and experienced WP leaders, so far 11 management board meetings have been held. We established a management structure that is in charge of the production of templates, guidelines, internal communication and exchange tools, of the continuous evaluation of project risk and quality. We also established processes for reviewing the deliverables and milestones and for regular consultation with the EC Officer to avoid mistakes and delays. So far. RISE has delivered 24 Deliverables and 32 Milestones, only 5 were delayed.

In the RISE vision, reducing earthquake risk and enhancing resilience requires progress on numerous technological, societal, and methodological frontiers but all targeted towards a common and sustainable framework on dynamic risk that RISE is providing. Within this framework, WP2 has been exploring the use of new technologies, for example conducting proof of concept distributed acoustic sensing campaigns in challenging urban environments, developing scalable strategies to store and access these large data volumes effectively developing, testing and installing a new and higher preforming low-cost accelerometer (QuakeSaver), developing and testing a portable excitation source for testing structures. We demonstrated and operationalised enhanced observational capabilities of seismic networks, greatly increasing the quality and quantity of earthquake catalogues available for seismicity analysis and forecasting. The dynamic exposure model we are developing using OpenStreetMap/OpenBuildingMap data is proving to be a highly useful tool for dynamic risk assessment.

RISE scientists have been building a new generation of models for OEF (WP3) to substantially improve earthquake forecasting performance, building on the existing best performing forecasting models of CSEP. In the first half of RISE, all modellers have developed the mathematical background of their models and published these methodologies. The models are ready to provide their output in an agreed format to be applied to a new forecasting experiment in Italy under the CSEP umbrella. These models are developed with testing in mind at the earliest stage of model development an and the RISE testing centre (WP7) is co-leading the development of the CSEP2.0 software framework and of new classes of tests, such as tailored tests of specific hypothesis, ensemble testing, GMM testing. The teams are also developing the framework and tools for testing seismic risk models and scenario damage forecasts.

In WP4, RISE engineering teams have been developing the second generation real time seismic structural assessment and RLA tools for Europe. The aim is to operationalize earthquake loss forecasting for Europe, including time-variant hazard and time-variant vulnerability that accounts for damage accumulation. Both time invariant and time variant exposure and vulnerability models are being developed. WP4 released the database of building exposure models for 44 European countries together with the open source tools for disaggregating the national exposure models with high resolution. A first database of European capacity curves for over 480 building classes has been released. An efficient workflow has been developed to modify the vulnerability models to account for damage accumulation (dynamic vulnerability module) during seismic sequences using OpenQuake engine (open software for RLA). The European ShakeMap system is up and running. ShakeMap products from recent events have been downloaded and combined with high resolution exposure and vulnerability models to produce various damage and loss outputs using the 'Scenario from ShakeMap' calculator. Work on real time recovery forecasting complements

and extends the loss estimation through a newly developed framework that infers the cost and time required to repair damaged buildings after an earthquake and estimates recovery trajectories at regional scale. The dynamic framework will be extended to account for building sensor data. We have been working towards the development of European services for RLA, integrating all real time risk related components already available with numerous new developments to create a single dynamic risk platform. We will demonstrate (WP6) the potential of the approach and technologies in Switzerland that is being selected as a testbed. There are continuous exchanges with EPOS to ensure that the operational services developed in RISE are made available and sustainable in Europe.

While developing methodologies, technologies and tools for OEF, OELF, RLA, RIA; RISE social scientists have been working on dynamic risk communication (WP5); how to cope with the challenges due to high level of uncertainties in earthquake risk and how to best communicate the risk for better preparedness such as rehearsing evacuation procedures, ensuring supplies are in hand and all lines of communication are open. With the support of five scientific collaborations, RISE scientists worked on the demonstration of EQN, the smartphone app turning smartphones into motion detectors, the very first smartphone based EEW system. RISE researchers also work on securing the broad societal, economic, and scientific impact of the project; an impact which is both demonstrable and long-term. This process started on day one of the project, continues throughout, and exposes all activities in RISE to an ongoing dialogue targeting stakeholder and end-user needs.

During final 18 months of RISE we expect that there will be numerous advances in RISE tasks, but most of all we will bring together these individual and sometimes loosely connected efforts into workflows that demonstrate at local, national and European scale the usefulness of the dynamic risk assessment framework that RISE is promoting.

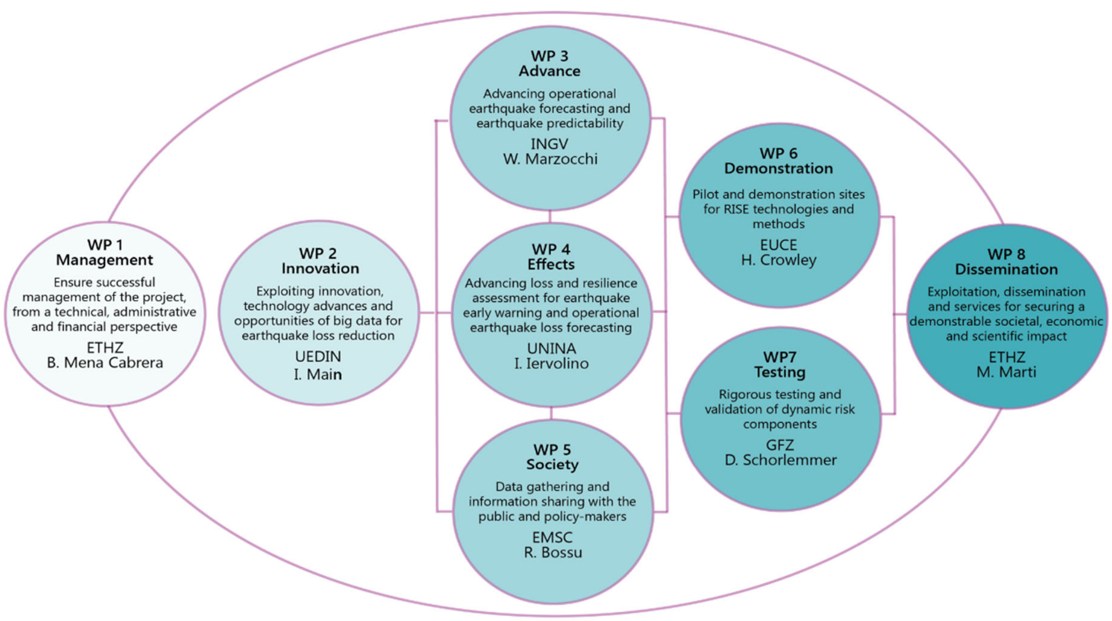


Figure 2 Structure of RISE and responsible WP leaders.

2. Work Package Progress

RISE comprises 81 deliverables and 63 milestones over 42 Months, 24 of the deliverables and 32 of the milestones were being scheduled within the first reporting period. Figures below show the status of the milestones and deliverables for the first reporting period, with a coloured representation of the current status. The green colour represents the deliverable/milestone submitted/achieved on time, the orange colour means achieved/submitted with delay and the red colour represents delayed and pending.

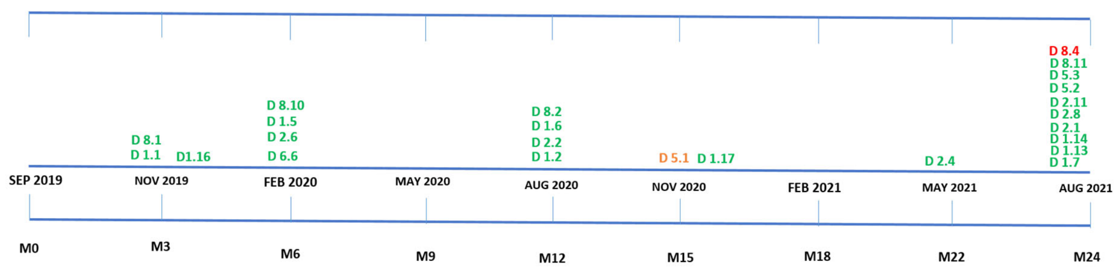


Figure 2.1 Status of RISE Deliverables as of 31 Aug 2021

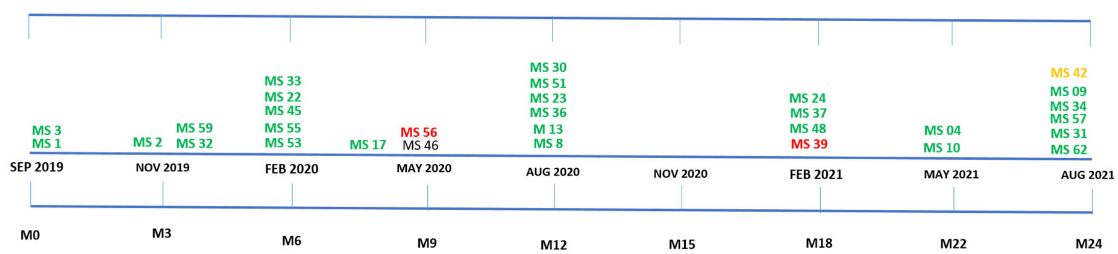


Figure 2.2 Status of RISE Milestones as of 31 Aug 2021

This section of the report summarizes the work carried out in each work package.

In this section, we include:

- Explanation of the work carried out during the reporting period in line with the Annex 1 to the Grant Agreement.
- An overview of the project results towards the objective of the action in line with the structure of the Annex 1 to the Grant Agreement including summary of deliverables and milestones, and a summary of exploitable results and an explanation about how they can/will be exploited.
- We will report separately for each WP; the overall WP structure is repeated in Figure 1.2.

2.1 Work Package 1

Overview

WP1 is responsible for the project management of RISE from a technical, administrative and financial perspective. The primary focus is to deliver the RISE project within the budget and timeline specified in the proposal. WP1 oversees the project development progress and the overall impact. The objectives and the achievements towards these objectives are summarized below:

1) **Ensure coordination, effective management, control, internal communication and reporting; maintain an adequate risk assessment and management process**

Achievements:
The project started with the Kick-Off Meeting in September 2019 (MS3), where the basis of communication was set, the management structure, the work plan and various tools to be used throughout the project were introduced. In the first quarter of the project together with WP8 we launched the RISE website (http://www.rise-eu.org/) (MS59). A platform called Alfresco was chosen for the internal communication as well as the project's main document sharing space (https://alfresco.ethz.ch/share/page/site/rise/dashboard) (MS2). Mailing lists were set up targeting different groups. While emails are the primary way of internal communication, the important news, event dates, project information, publications, deliverables, milestones, meeting minutes are all shared on Alfresco. The newsletters prepared by WP8 also support the internal communication of the project. In the first quarter, we worked on an Implementation Plan, where a detailed task based work plan and the task teams were established. This Implementation Plan forms part of the Project Management Plan and is updated every year (D1.1, D1.2). WP1 put together a data management plan (DMP) (Deliverable 1.16), which covers in detail the access procedures to data and products, including measures to provide open access (i.e. free on-line access) to scientific publications originating from the project. As part of the DMP, RISE Community space was opened on Zenodo Platform, to share all RISE Open access data and publications (https://zenodo.org/communities/rise-h2020?page=1&size=20). So far there are over 25 RISE publications shared at RISE Community space on Zenodo.

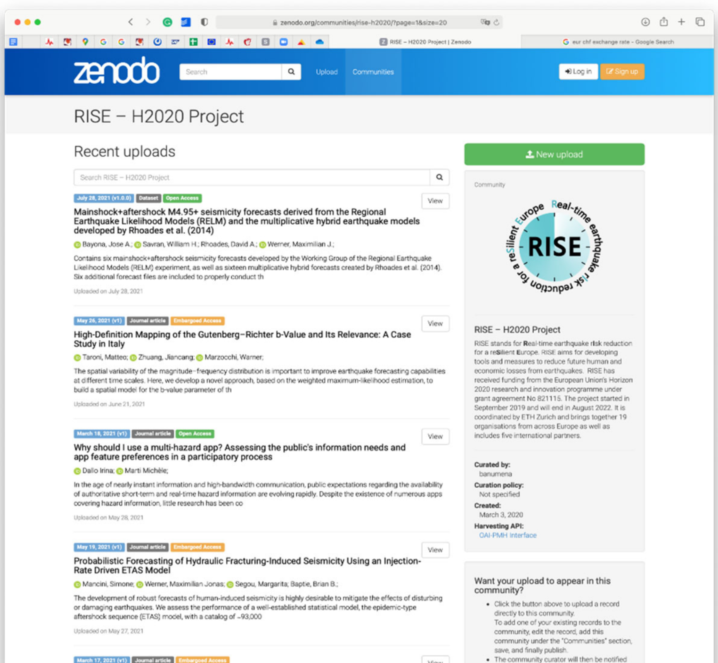


Figure 1.1 Snapshot from RISE site at ZENODO

To ensure good communication across different work packages, control the progress made and achieve adequate risk assessment, WP1 has been organizing Management Board (MB) meetings every two months. These meetings have been very successful with the dedicated WP leaders attending every MB meeting and reporting the progress in each task. All MB meeting minutes can be found on Alfresco and are submitted as deliverables (D1.5, 1.6).

WP1 is responsible for RISE reporting and ensures ontime submission of the deliverables and milestones. The main responsible for each of the deliverables and milestones are informed/reminded at least a month in advance of the submission. The list of deliverables and milestones that have been submitted recently and the ones to be submitted in the upcoming months are shared and discussed with the MB in every MB meeting. WP1 runs a revision process before submission of each deliverable. Every deliverable is reviewed by the WP leader or by an experienced researcher. So far all deliverables and most of the milestones are on track.

A couple of milestones are delayed, mostly due to Covid restrictions. These are mostly related to activities that require on-site meetings. Although we carried out most of the RISE meetings successfully online with good participation, we prefer to hold some events in person for networking and socialisation purposes (MS42: Swiss Stakeholder Panel, MS Early Career Scientists Winter School, MS 62: Training workshop of early career scientists). The Consortium is planning to achieve these milestones in Autumn 2021. If the related workshops can still not be held in person, we will then have to convert these to virtual events.

WP1 initiated a series of scientific focus-meetings in September 2020 called "ZOOMing into RISE". These meetings take place every two weeks, and last an hour where two-three RISE researchers present their work to RISE participants, typically 40 - 50 people will zoom in. Each meeting is dedicated to a work package. So far there has been 16 ZOOMing into RISE meetings. These focus meetings enhance the cross-institute and cross-work package collaboration and having Q&A sessions allows researchers to exchange ideas.

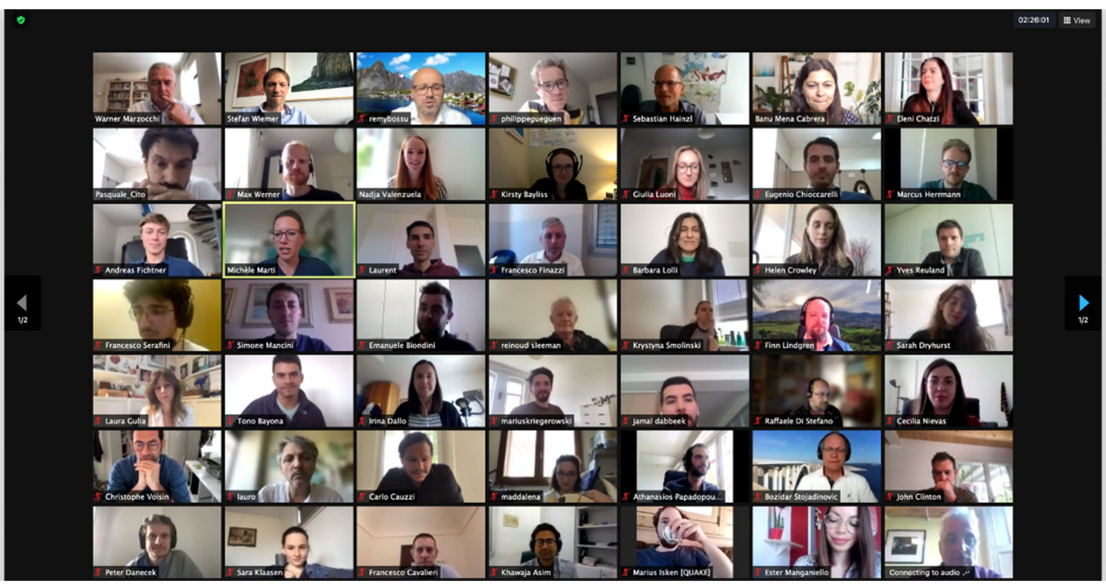


Figure 1.2 Snapshot of a Zooming into RISE session.

The RISE Mid-Term Conference was held online in May 2021 (MS4). The meeting was very successful, despite being held online, with many interactions and exchange of ideas thanks to various new tools that allow online communication (Gather Town, Mural and Zoom were used for the virtual Mid-Term conference). It was an opportunity to not only share our research results, but also brainstorm how to extract project's challenges and convert them to project's highlights.

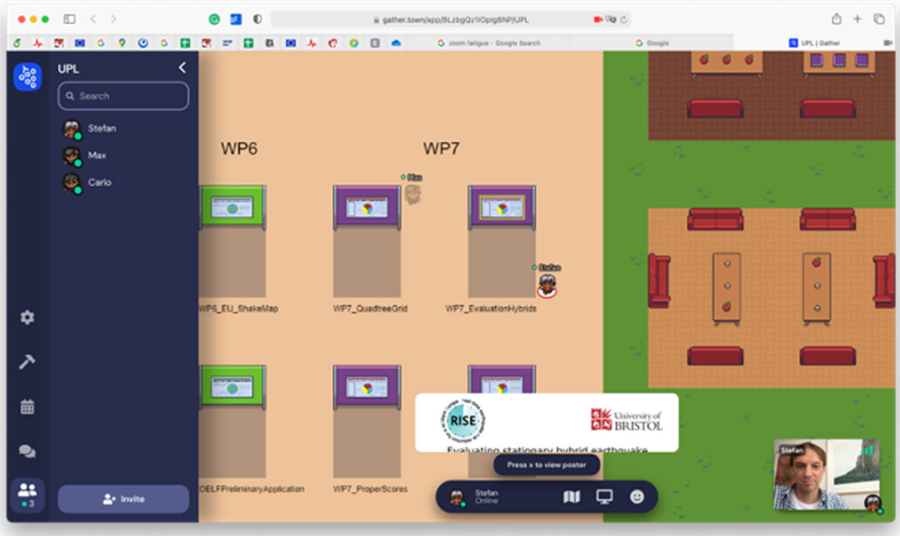


Figure 1.3 Snapshot of Gather Town from Mid-Term Conference

2) Implement an efficient governance structure: Coordinator, General Assembly (GA) and Management Board (MB)

Achievements:
The Project Coordinator (Stefan Wiemer), with the support of the Project Office (RISE Manager Banu Mena Cabrera, Communication Officer Michele Marti and admin/financial officer Romano Meier) maintains the global coordination and organization of the activities.

The GA and the MB were established at the Kick-Off Meeting. A representative from every beneficiary, the project Coordinator, the WP leaders and the Project Manager form the GA. In the first GA meeting, the members selected Helen Crowley (EUCENTRE) to lead the GA. GA meets in line with the RISE general meetings (unless there is a need for an additional meeting), therefore has met twice so far. GA meeting minutes are taken and shared with the RISE community on the project's intranet. Important decisions such as amendment requests are voted on, the progress of the project, the risks and actions to be taken are discussed in the GA meetings.

MB meetings are held every two months and have been meeting regularly since the start of the project. WP leaders and the Coordinator and the Project Manager form the MB. The WP progress, the upcoming deliverables and milestones, the plan for RISE meetings, seminars and workshops are typically discussed in MB meetings. WP leaders inform the WP and joint WP meeting plans, their planned or ongoing publication processes in the MB meetings. MB meeting minutes are well recorded and shared with the RISE community on Alfresco platform.

3) Ensure the evaluation activities of the Boards supporting RISE: The Scientific Advisory International Partner Board (SAIPB) and the Stakeholder Panel (SP).

Achievements:
The SAIPB was established at the start of the project. Invitations to take part in RISE SAIPB were sent and seven experienced researchers from the US, Mexico, New Zealand, Japan and Italy accepted being part of the SAIPB within this domain. The members of the SAIPB were invited to the Kick-Off meeting and the first SAIPB meeting was held. The second SAIPB meeting was held online in December 2020 and the third SAIPB meeting was held during the RISE Mid-Term Conference in May 2021. Through these meetings, SAIPB members are regularly informed of the activities of RISE, and have the opportunity to ask questions to RISE researchers and give advice on various topics. SAIPB members have access to the project's intranet, therefore can view any project documentation such as the submitted deliverables, milestones, meeting minutes,

publications, project related news, upcoming meetings etc. They also receive the internal and external newsletters.

RISE formed a relatively small SP and is currently working towards expanding the SP with the support of the Horizon Results Booster Service (HRBS). RISE project together with TURNKEY project formed a Project Group and applied to the HRBS for Module A (Creation of Results Portfolio and matched to the Relevant Stakeholders). The first SP meeting is planned in the coming months.

Summary of achievements in WP1 tasks

Task 1.1 Financial & Administrative Management:

This task is responsible for the financial and administrative duties coupled with monitoring and controlling associated risks of the project. In this scope, the project management plan (PMP) is submitted as a deliverable (D1.1) and updated yearly (D1.2). The PMP notifies the EU on the current state of deliverables and milestones and dissemination of the activities in all work packages. It includes an implementation plan, which describes the tasks in great detail, creates a roadmap for short and longer term, divides the tasks into subtasks, and helps keep track of the people involved and Person Months (PMs) spent at each task. Task leaders are responsible for their own task and report primarily the work to the WP leader. This approach is applied to each Work Package. The PMP includes a Risk Register section, where potential risks are listed and necessary actions are advised. This Risk Register is regularly updated and shared with the MB in MB meetings. Updated Risk Register is added to the updated PMP every year.

WP1 monitors the expenses of RISE beneficiaries. Every year WP1 collects a financial summary from all beneficiaries. WP1 released the Cumulative Expenditure Report (CER) in December 2020, which reports the cumulative expenditure of each beneficiary for the period 01/09/2019 to 30/11/2020 (D1.17). Next CER will be submitted in Dec 2021.

Task 1.2 Management of RISE activities

Due to the broad span of RISE activities in the scientific, technological and social settings, we must ensure the overall integration of all these facets in all activities and Work Packages. This integration is achieved by designated activity coordinators in all these domains and WP leaders working together and communicating their activities regularly. WP leaders form the Management Board(MB) that meets every two months to monitor RISE activities and coordinate cross WP tasks. MB meetings are well documented, meeting minutes are submitted as deliverables (D1.5, 1.6). The management of RISE activities are detailed in Project Management Plan (D1.1) that is updated every year (D1.2).

Task 1.3 Legal issues (ETH)

Managing and preparing the consortium agreement (CA), including annexes and any amendments to the Grant Agreement (GA) that may be needed during the project is under the responsibility of this task. CA manages the intellectual property rights of the foreground. Negotiations between participants regarding stipulations in the consortium agreement are well managed by the ETH team and the RISE CA is signed by all RISE beneficiaries in September 2019. The Consortium requested an amendment package from the EC, which included a number of changes to the original GA. The amendment package was approved by the EC in September 2020. The changes included a 6 months' non-paid extension to the project due to delays in some activities during Covid lock-downs and execution of a beneficiary.

Task 1.3 ensures the implementation and fulfilment of the GA and CA by all consortium participants and actively seeks advice from the Project Officer for requests/questions from beneficiaries, when needed. WP1 is now working towards another amendment to the GA which is related to the parenting request of a RISE beneficiary.

Task 1.4 Strategic integration with related projects and platforms

Task 1.4 supervises activities aimed at guaranteeing integration of RISE project achievements with current European platforms (e.g. EPOS, CSEP, EUROVOLC, COPERNIUCUS and ARISTOTLE). RISE teams work in close collaboration with CSEP, and RISE forecasting models are being implemented in the CSEP2 platform. RISE has been in close contact with EPOS and ARISTOTLE representatives and the exchange is ongoing. Task 1.4 guides and monitors the proper integration. As the project is progressing well and the scientific results are expected to be implemented into services, more progress is foreseen in the second half of the project regarding the integration of RISE products into various European platforms.

Task 1.5 Project internal communication

The objective of this task is to ensure effective internal communication and interactions within the RISE consortium (beyond project meetings). The following actions have been implemented:

- Dedicated email distribution lists are created for the whole consortium, each WP and specific sub-groups. The main communication is done through emails and enhanced by using Alfresco Platform as the project's intranet.
- Alfresco platform, launched in September 2019, is used as a shared work space (document repository, data & document exchange, project information, meeting calendar).
- Together with WP8, 5 internal newsletters have been released so far.

Task 1.6 Meetings and workshops

This task is responsible for RISE meetings. The following meetings have been set up:

Meetings at sites with treatments in operation:

These are general RISE Meetings. The first one was the Kick-Off Meeting. It took place in Zurich in September 2019, with a large participation from all RISE beneficiaries as well as the RISE International partners and the EC Project Officer. It was a 2½ days meeting with presentations, poster sessions, parallel running WP workshops, coffee breaks and a conference dinner. The Kick-Off meeting was very successful in introducing the RISE members, starting a collaboration, planning the work ahead, discussing science and setting up the various RISE boards and meetings.

Figure 1.4 Group Photo of the RISE Kick-off meeting in Zurich

Likewise, the Mid-Term Conference was planned to take place in Florence, Italy but due to the pandemic we had to hold that meeting virtually. Despite being online, we had a very successful Mid-Term Conference in May 2021. The meeting was split in 3 half days (to avoid being ZOOM fatigue) and we used various virtual platforms to facilitate interactions between people. We had a few general presentations followed by parallel running WP sessions, where we used Mural visual boards. We had sessions on project's highlights and challenges aimed at brainstorming for the major outcome of the project. We used Gather Town for poster sessions, where people could virtually enter a poster area, view the poster on their screen and at the same time chat with a small number of people in front of that poster, just like in a real poster session.

We plan a physical meeting of the full consortium in Florence, May 11 - 13 2022, if conditions allow.

- Regular MB meetings to control the progress of the work and updates of the project plan: We have MB meetings every two months. The meeting minutes are shared by the consortium through Alfresco, and also submitted to the EC as deliverables (D1.5, D1.6)

- Stakeholder Board (SB)meeting after Mid-Term Conference & Final Conference. (M1.1 and M1.2): This task has not been achieved yet, we are now planning the first Stakeholder Board Meeting, as we just had the Mid-Term Conference in May 2021. However, the members of the SB are informed about the project and accepted their participation in the SB.

- Scientific Seminar Series twice a month: RISE initiated a seminar series in September 2020 called "ZOOMing into RISE" that takes place virtually twice a month. It is an hour-long seminar given by 2-3 RISE scientists presenting their work. Every seminar is dedicated to a WP and includes a Q&A session. We organized 16 ZOOMing into RISE seminars so far.

- WP and Task Meetings: These meetings are organized by WP and Task leaders. We keep the record of all WP-level meetings on Alfresco platform. WP leaders provide meeting minutes of such meetings and share on Alfresco.

- WP1 helps connect researchers in different teams at different institutions for various data/method exchange and collaboration, by organizing small group meetings when/where needed.

Task 1.7 General assembly meetings

General Assembly meetings are organised with a frequency in coherence with the conferences. During the General Assembly meetings, the progress of the project will be discussed with the General Assembly member of each Party and necessary decisions will be taken.

The first GA meeting took place during the Kick-Off Meeting in Zurich. The second GA meeting was held online, during the Mid-Term Conference. We keep the meeting minutes for the RISE GA Meetings and share them with the Consortium through Alfresco.

List of submitted deliverables and achieved milestones

D1.1 Project management plan updated, submitted in Nov 2019.

D1.2 Project management plan updated, submitted in Aug 2020.

D1.5 Minutes of Meeting of the RISE management board conducted, submitted in Feb 2020.

D1.6 Minutes of Meeting of the RISE management board conducted, submitted in Aug 2020.

D1.16 Data Management Plan, submitted in Feb 2020.

D1.17 Cumulative Expenditure Report (D.17), submitted in Dec 2020.

MS01: RISE Boards nominated (SP, SAB, MB, GA), Sep 2019.

MS02: Project internal communication established, Nov 2019.

MS03: Kick-off meeting, Nov 2019.

MS04: Midterm-conference, May 2021.

MS59: RISE web page fully operational, Sept 2019.

MS55: Implementation of periodic monitoring of Key Performance Indicators, Feb 2020.

Summary of Exploitable Results

Deliverable reports (D1.1, 1.2, 1.5, 1.6, 1.16)

RISE website: http://www.rise-eu.org/

RISE Open Access Data Repository: Zenodo

https://zenodo.org/communities/rise-h2020?page=1&size=20

1.2.2 Work package 2

Overview

The overarching aim of this work package is to assess and exploit the opportunities for innovation, technology advances and big data to improve Operational Earthquake Forecasting (OEF), Earthquake Early Warning (EEW) and Rapid Loss Assessment (RLA). These are disruptive new technologies and capabilities that together provide significant improvements to the technological basis for real time monitoring and earthquake risk reduction.

We address this in seven separate tasks as described below. The focus is on assessing, developing and testing the capability of the technologies listed to address the overarching goals of RISE. WP2 delivers input to all subsequent WPs, and is specifically linked to WP3 (earthquake forecasting), WP7 (Forecast testing) by providing improved input forecast methods, primary waveform data, and earthquake catalogues, and to WP6 (Pilot and Demonstration), where we will thoroughly optimise and test the technical innovations, and to WP8 (exploitation and dissemination).

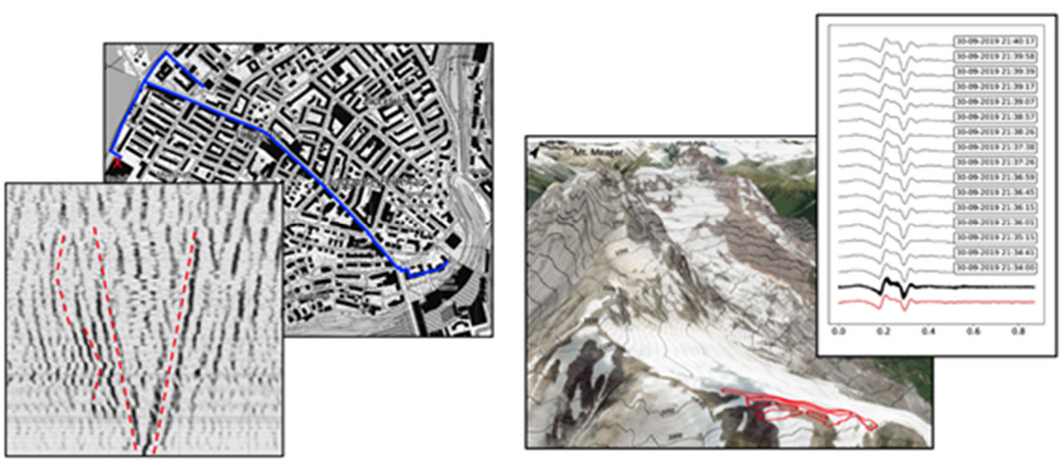
Summary of achievements in WP2 tasks:

Task 2.1 Utility and value of high-density DAS

Krystyna Smolinski, Sara Klaasen, Andreas Fichtner, ETH Zurich

Within this task, we investigate the use of emerging Distributed Acoustic Sensing (DAS) technologies from several perspectives: (1) the logistics of using DAS in urban environments and in terrain where dense networks of conventional seismic sensors cannot be installed easily, (2) the possibility to detect and characterize a broader spectrum of seismic events than with existing seismic networks, and (3) the feasibility of local tomography studies using DAS recordings of ambient noise or deterministic events.

In addition to several small experiments, we conducted three major ones, which are summarized in the figure below.



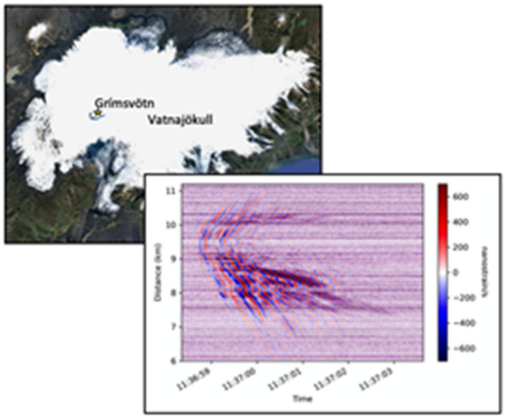


Figure 2.1.1: Top left: Telecom cable layout used for a DAS experiment in Bern (upper right). Anthropogenic noise correlations (lower left) can be used to constrain structure at 10 m scale. Top right: Deployment of a DAS cable on a ridge of Mount Meager, and active volcano in British Columbia (left). The DAS array recorded a previously unknown level of seismic activity, including numerous repeating events (right). Bottom left: In April 2021, we deployed a 12 km long cable around Grimsvötn, Iceland's most active volcano (upper left). The DAS array records numerous low-magnitude volcanic earthquakes that are not seen on the regional seismic network stations.

In the Swiss capital Bern, we performed an urban DAS experiment (D2.2), using around 6 km of dark telecommunication fibre. The installation of the DAS interrogator in a server room of the University of Bern was unexpectedly easy, and the data quality is remarkable. We were able to estimate local seismic wave speeds directly from surface waves excited by road traffic. Furthermore, simple jumping on the pavement allowed us to locate channels to within a few metres and even to estimate local subsurface structure to several tens of metres of depth. The analysis of anthropogenic noise correlations reveals prominent surface waves, complemented by occasional reflections that may originate from the basements of buildings. A local tomography using these noise correlations is work in progress.

On Mt. Meager in British Columbia, we performed the first DAS experiment on a glacier-clad active volcano, together with colleagues from the University of Calgary. The data reveal a previously unknown level of seismicity, including high-frequency events that form distinct clusters and long-period tremor. In addition to painting an entirely new picture of Mt. Meager's activity, this experiment also demonstrates that DAS experiments are logistically possible in harsh terrain where the installation of traditional seismometer arrays with similar coverage in space and frequency would be close to impossible.

Encouraged by the results from Mt. Meager, we performed the largest DAS experiment to date on an active volcano, Grimsvötn, in Iceland. Almost completely covered by the Vatnajökull ice cap, Grimsvötn is the most active volcano of Iceland, on a long time scale. Using a specially designed sled, we trenched more than 12 km of cable in the ice, half-way around and into the caldera. Similar to Mt. Meager, the data reveal the presence of an unexpectedly high seismicity, with numerous small events that have not been detected by the regional seismometer network. The seismicity also includes previously unknown tremor.

In summary, our experiments so far have shown that DAS is feasible in challenging environments (D2.1, MS08), including cities (D2.2, MS09), and that the data indeed contain valuable information on local structure and seismicity that would be difficult to obtain by other means.

Task 2.2 Next generation sensors and hyper-dense networks for use in EEW, OEF and RLA

Marius Paul Isken, Marius Kriegerowski, QuakeSaver GmbH

The aim of Task 2.2 is the research and development of cost-effective connected seismological instruments (MEMS and short-period coil) and open-source software towards real-time dynamic monitoring and risk assessment. This includes the research and development as well as evaluation of integrated meaningful signal processing routines on the instrument's firmware (IoT edge computing) and the real-time communication and analysis of the produced high-level seismological data products. These data products are gathered in a centralized server infrastructure, which enables the management of large fleets of sensors and intuitive visualization for interpretation through easy-to-use web interfaces. Further, exchange formats for accessing real-time data products with the RISE are defined and served through the QuakeSaver software.

Objectives

The objectives of task 2.2 can be summarized in:

- Development of cost-effective MEMS and short-period connected (Ethernet, WiFi, 4G/LTE) seismic sensors for indoor and outdoor use (Hardware)
- Development of open-source sensor firmware for modular integration of real-time signal processing routines (edge computing) towards real-time SHM, dynamic exposure, ground-motion characterization, rapid loss assessment and potentially improved EEW. (Firmware)
- Development of centralized and scalable server infrastructure for management of large fleets of seismic instruments and collection of high-level seismic data products from the sensors. Integration of data exchange formats for integration into e.g. rapid-loss assessment, dynamic exposure models of EEW systems. (Software)
- Development of intuitive user interfaces for the sensor firmware and centralized management and analysis console. (Software)
- Evaluation and testing of the developed seismic instruments at RISE demonstration sites in Europe and Japan (see Task 6.2).
- Publishing the developed software as open-source (OSS), following the high-quality standards of software development and European guidelines defined in Open source software strategy 2020-2023.

Achievements

QuakeSaver developed two kinds of connected cost-effective smart seismic sensors for monitoring within the RISE project (D2.4): (1) A highly sensitive seismometer for real-time monitoring of buildings and seismicity at local, regional and global scale. These sensors are designed to be deployed indoors and in harsh outdoor environments. (2) A compact sensor for indoor installation equipped with a low noise MEMS accelerometer for building and strong-motion monitoring.

The developed sensor software platform is connected to retrieve information in real-time and configure the sensors remotely. Furthermore, the developed sensor software serves as a foundation for RISE partners to access the computing capabilities of embedded devices to extract meaningful high-level seismological data products from the sensor time series, through an extensible software plugin mechanism. Together, the hardware and software deliver MS10.

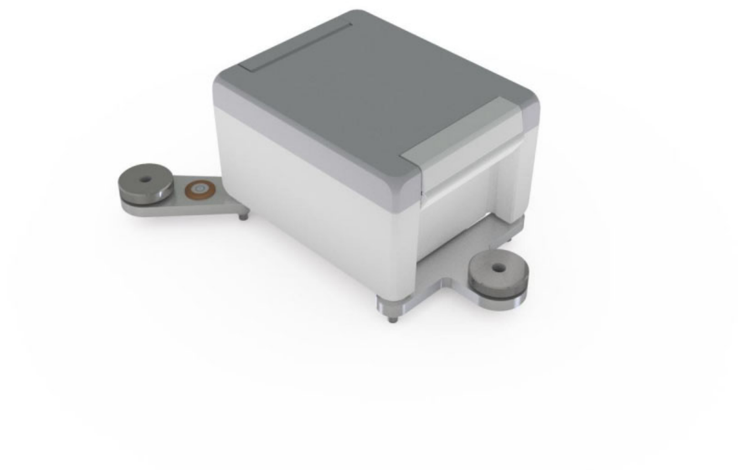


Fig 2.2.1: QuakeSaver highly-sensitive short-period and strong-motion accelerometer HiDRA smart seismic sensor for use in harsh outdoor environments, following IP65 standard.

Key features of the short-period QuakeSaver HiDRA sensor (Fig. 2.2.1) are:

- 3-component short-period seismometer with a cut-off frequency f_c of 0.5 Hz.
- Ultra-low noise 24-bit ADC (RMS ~2 counts; 139 dB) with variable sampling rate of 50 Hz, 100 Hz and 200 Hz and analog pre-amplification 1x, 2x and 4x.
- Low noise 3-component 20-bit MEMS accelerometer with variable sampling rate from 50 Hz, 100 Hz and 200 Hz and configurable range of 2 g and 4 g (optional).
- Flexible power supply from 9 to 18 V.
- Hygrometer, barometer (atmospheric pressure) and thermometer for continuous system and instrument health monitoring.
- Connected via Ethernet (4G in development).
- Time synchronisation via NTP and/or external GNSS antenna.

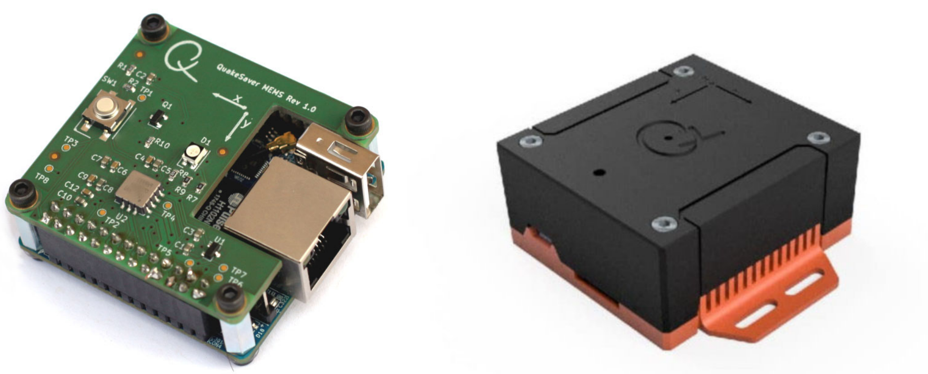


Figure 2.2.2: QuakeSaver MEMS accelerometer. (left) The bare-bones compute unit with Ethernet port for scale. (right) The sensor unit enclosure for indoor deployment in buildings.

Key Features of the QuakeSaver MEMS (Fig. 2.2.2) sensor developed in the RISE project:

- Low noise 3-component 20-bit MEMS accelerometer with variable sampling rate from 50 Hz, 100 Hz and 200 Hz and configurable range of 2 g and 4 g.
- 5 V Power supply over USB. Power consumption ~1 Watt.
- Connected via WiFi and Ethernet.

Advances in sensor, communication and embedded computation technology allowed the development of low-cost sensors. The evaluation and testing of QuakeSaver MEMS sensors was undertaken with RISE partners at ETH Zürich. Within the RISE project we developed a flexible software architecture which is empowering the sensor instrument to process the data "on-the-edge". This innovative approach opens new ways for data handling and real-time processing of the data for swift integration into exposure maps and RLA models. Simple data products for example are Peak-Ground-Acceleration and Velocity (PGA/PGV), instrument intensities (e.g. spectral intensity of JMA Shindo). We now rely on cooperative development and research with RISE partners to fill this ecosystem with meaningful data processing modules e.g. analysis of dominant frequency of a building, tailored to the demands of stakeholders. Next to the real-time processing capabilities the QuakeSaver sensors implement well-established data exchange protocols for streaming the seismic data in real-time to central data centers.

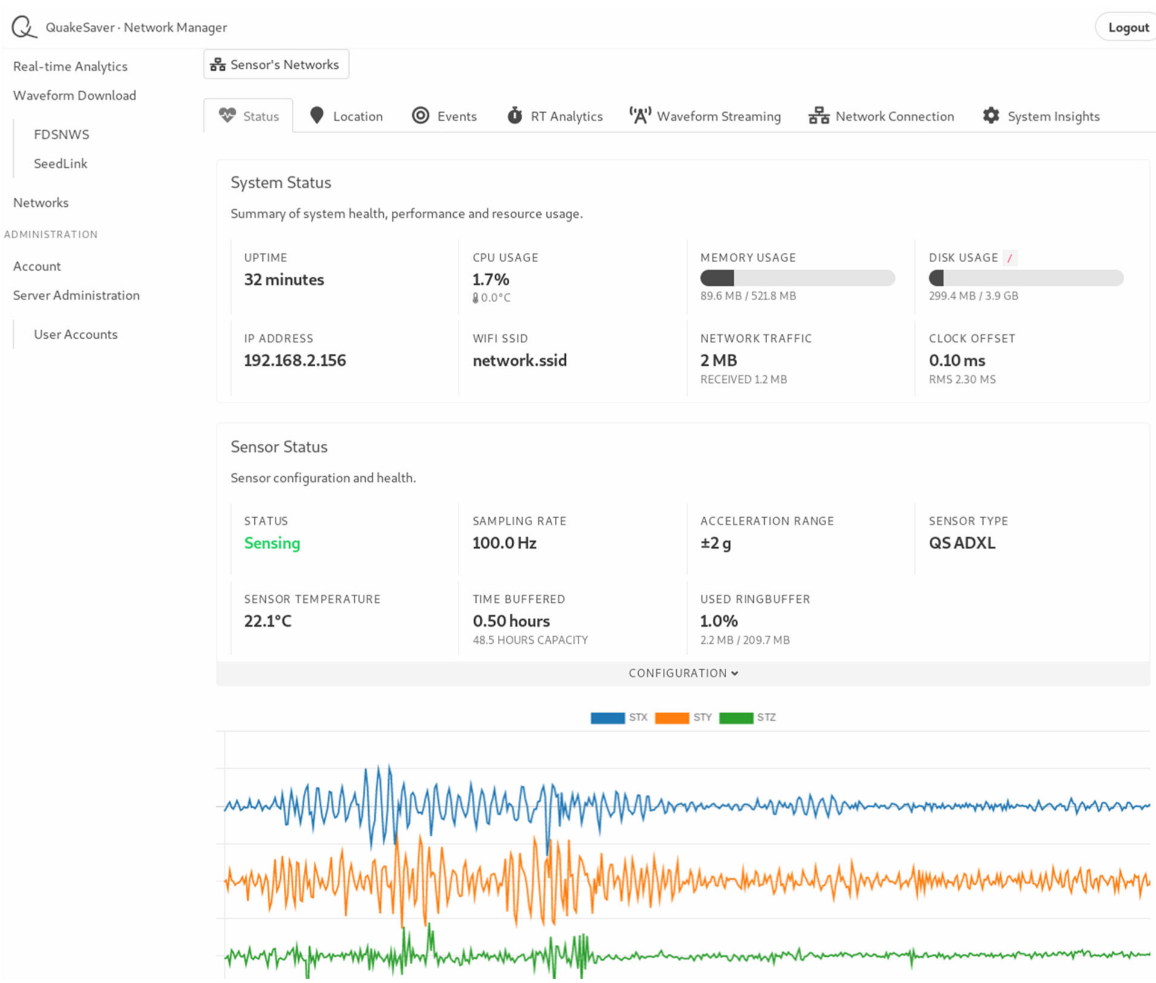


Figure 2.2.3: Sensor user interface to configure and monitor a sensor in the field.

The increased numbers of sensors and ever increasing amount of sensor data demand sophisticated software solutions to manage the growing fleet of seismic sensors. This developed backend allows it to manage a fleet of QuakeSaver sensors in a modern and reliable fashion. Intuitive and powerful user interfaces are accessible from any device and in any browser. Sensors can be grouped into virtual networks and configured remotely in bulk or individually.

The digital twin of each sensor provides a detailed reflection of all parameters and continuous data analysis such as network aggregated PGA. Data products are graphically presented as maps, lists and accessible as descriptive GeoJSON for seamless integration in any GIS software. This enables a continuous overview and health monitoring of your entire network within a glimpse.
A batch of 30+ sensors have been delivered for evaluation to RISE partners in Grenoble (ISTERRE), ETH Zürich (ETHZ), Istanbul (BOUN) and University of Montenegro.

QUAKE applied for a patent at the European Patent Office (EPO), protecting a compact seismic instrument which can be easily installed and enables edge-computing to enhance the usefulness of seismic instruments. The patent is currently under review by the EPO.

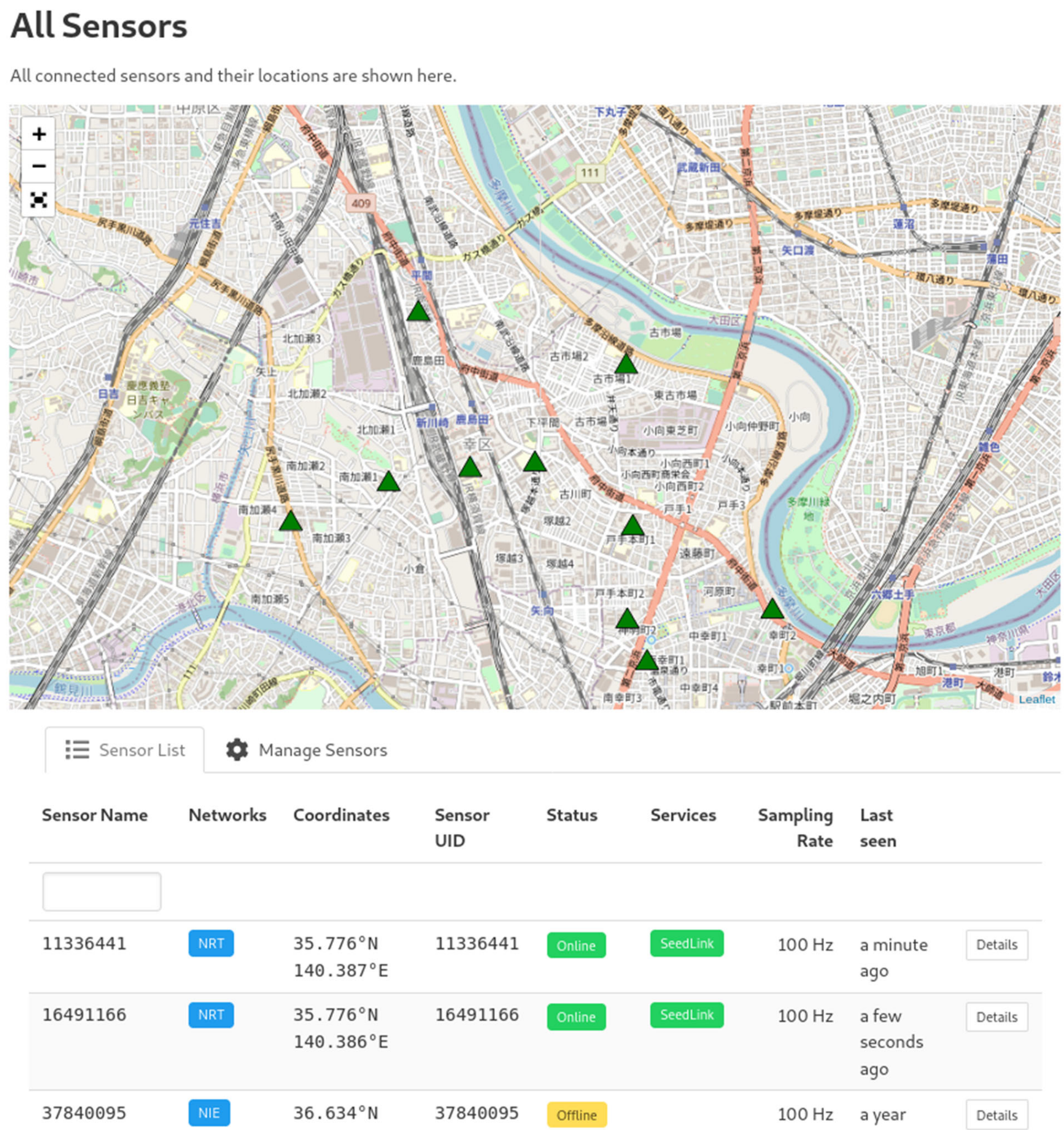


Figure 2.2.4: Network management of sensor fleets through an intuitive browser interface. Sensors' digital twins can be managed and monitored remotely.

Outlook and Challenges

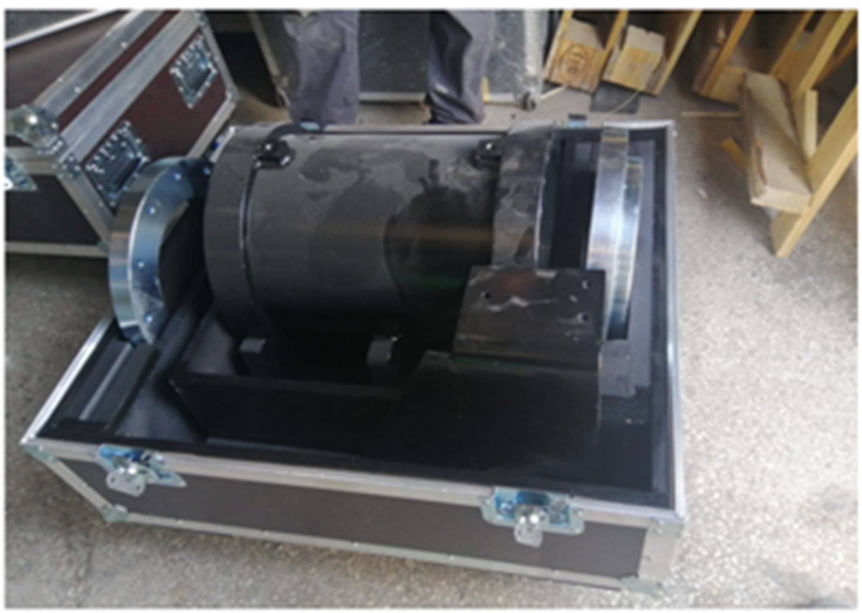
The two sensors are currently under evaluation by QUAKE as well as by project partners. A recently conducted study showed that the more sensitive integrated sensor has a low amplitude noise signal at 1 Hz which becomes apparent only in extremely quiet environments. This issue will require modifications in the PCB design to decouple the power supply from the analog sensor front-end carried out by QUAKE contracted electro-technical engineer. Further modifications of the PCB are required to integrate an industrial compute platform designed for large scale applications.

A major unforeseeable challenge has been the global chip crisis, which is a direct result of the COVID-19 pandemic. This crisis has led to significant shortages of electrical parts on the global market. Across many industries the demand and supply chain has collapsed. Due to shortage of critical electrical components (e.g. MEMS accelerometer, analog-digital-converter, industrial SD

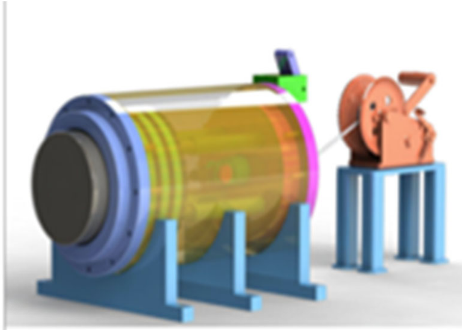
cards and more) the production of more seismic sensors will be delayed until the market has recovered. Some expert estimate that the crisis will be overcome in mid-2023[1]. We are eagerly working to find alternatives for unavailable components, redesigning PCBs and taking other measures to mitigate the effect of the ongoing crisis in the best interest of the RISE project.
Our further work will engage cooperation with RISE partners to research and develop on-device algorithms to deliver meaningful real-time data products into the exposure and hazard modeling communities. Further development of the software stack will be needed to guarantee a redundant, high availability and robust infrastructure that will scale for global application of the developed system. Funds allocated in the amendment are dedicated to employ a professional full-stack software developer.
We will open-source the developed sensor software with the scientific community under a open-source licenses (i.e. GPLv3) to empower and drive the sensor's capabilities to an open real-time system.

Task 2.3. Innovative portable excitation sources for field testing of existing and densely instrumented structures

The objective of this task is to design and have manufactured portable excitation sources for field testing of instrumented buildings. Towards this objective, we have designed and built an eccentric mass shaker to test multi-story buildings (D2.3, MS13). Images and the properties of the impact hammer and the shaker are given below.



1 https://www.techtimes.com/articles/260243/20210514/global-chip-shortage-persist-until-2023-demands-pc-slightly-soften.htm



Momentum Capacity [kgm/s]	100
Impact mass (kg)	80
Maximum contraction (mm)	54
Impact area (mm²)	31400
Maximum Velocity (mm/s)	1250 mm/s
Number of springs	4
Maximum force need for setting the springs (N)	~2000 N = 200 kg
Maximum height (mm)	430
Maximum width (mm)	466
Maximum length (mm)	~1000

Figure 2.3.1 Impact Hammer (upper photo) and properties (lower table).

TECHNICAL PROPERTIES	
Eccentricity Per Disc	0,181 kgm
Number of Discs	4 on each shaft, 8 in total
Mass Per Disc	4,2 kg
Maximum Force	1575 kgf
Axis of Force	Horizontal: X or Y (Depending on initial disc position)
Maximum Frequency	25 Hz
General Dimensions	Height: 440 mm Lenght: 250 mm Width: 470 mm
Total Weight	105 kg
Power Requirements	6 kW Single Phase 220 V AC

Figure 2.3.2. Eccentric mass shaker (left) and properties (right).

We have performed tests by using the impact hammer in an instrumented building, the Polat Tower in Istanbul. A picture of the building and the location of the instrumentation are given below.

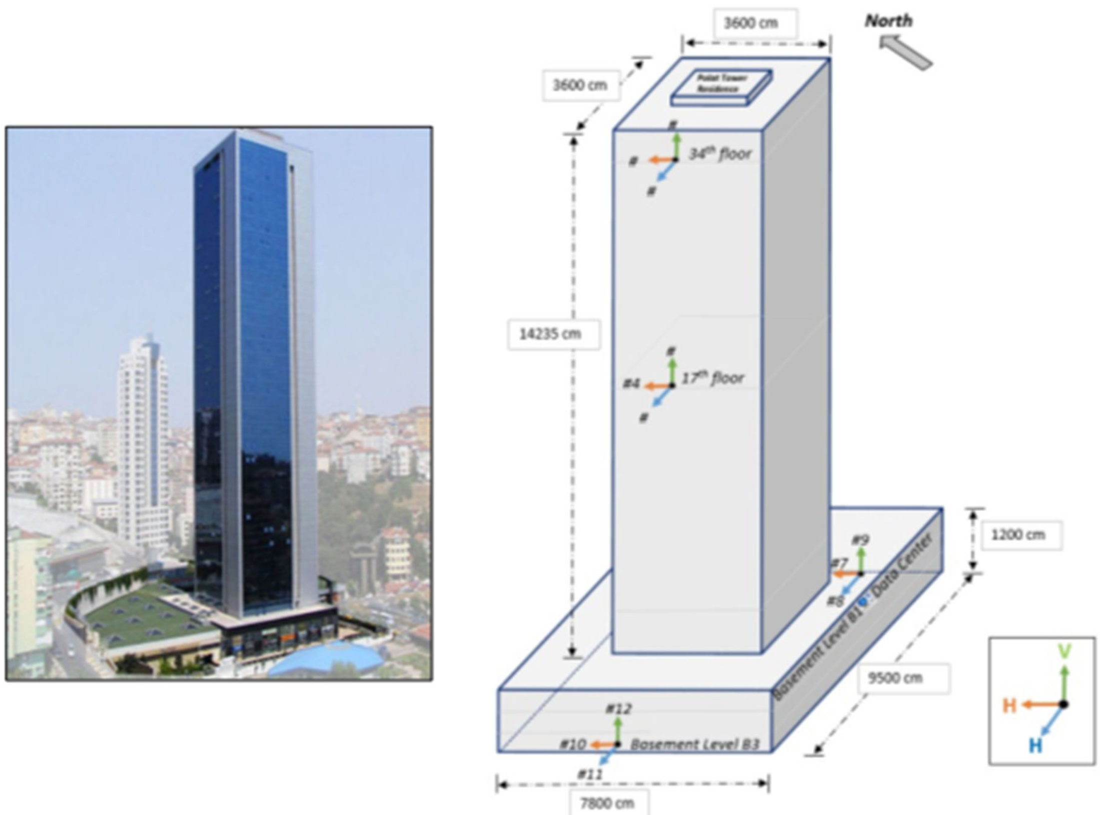


Figure 2.3.3. The Polat Tower in Istanbul. The diagram on the right shows the locations of the instrumentation used in the test experiment.

The objective in using the impact hammer was to identify how far down the impulse from the 34th floor can travel down. We have bolted the hammer on the floor of 34th level, as well as propped against one of the shear walls, as shown in figure 2.3.4 below.

Figure 2.3.4. The impact hammer in situ.

The impact signal (i.e., the accelerations) recorded at the 34th, 24th, 17th and 15th floors are shown in the seismograms of Figure 2.3.5 below. Note that, since we used temporary acceleration sensors with different properties and they were not time synchronized, the locations of the impact do not coincide. We were able to detect the impact all the way down to the 17th floor. The signal at the 15th floor was not clear enough to identify the signal on the raw record, though this might still be possible with advanced signal processing techniques. This set of seismograms confirms that the wave travel times between the floors can in principle be identified with the new impact hammer (Figure 2.3.1). With suitable clock synchronization in future, wave travel times, as well as wave reflections and transmission coefficients at floor levels, could provide a much better insight into the dynamic properties of multi-story buildings. Further tests are continuing using more precise sensors and different floor levels.

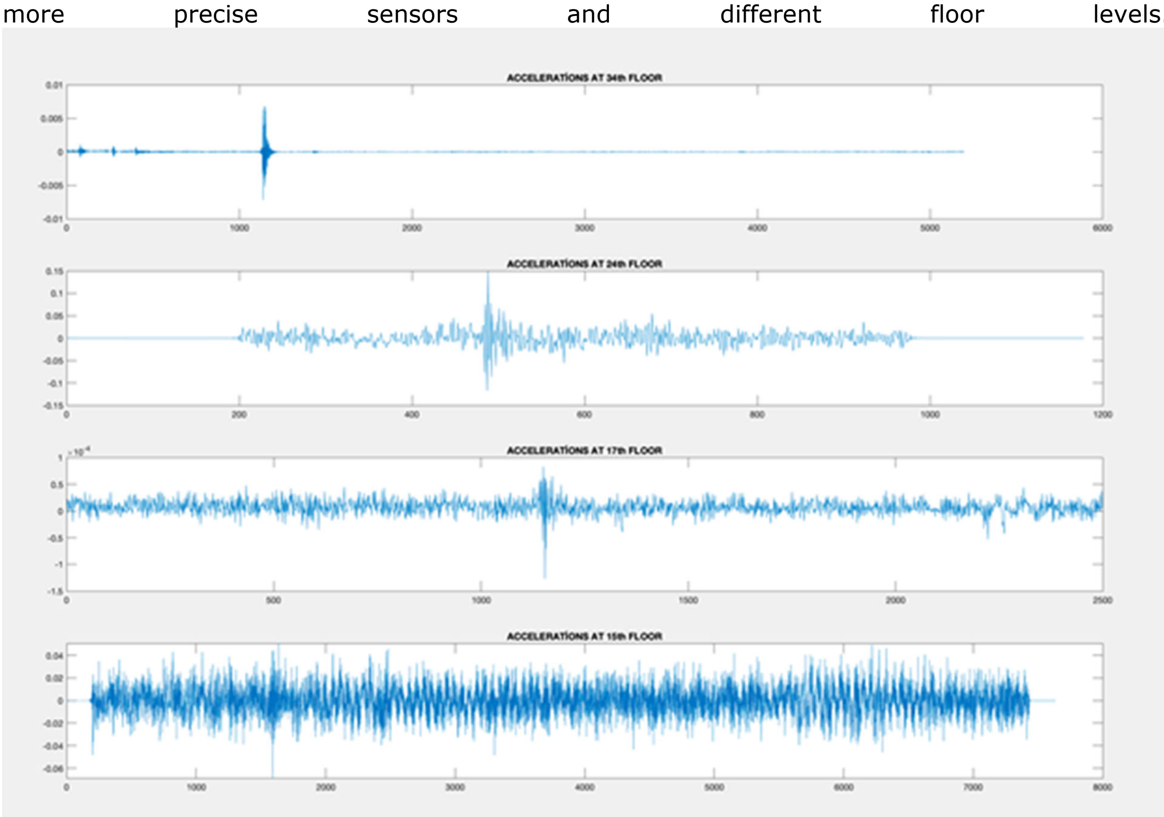


Figure 2.3.5. Signals recorded by accelerometers placed at the 34th, 24th, 17th and 15th floors of the Polat building.

We are also studying new approaches to identify wave travel times in buildings. The commonly used current approaches are all based on the phase-shifts of characteristic peaks in the signals. However, a part of that phase-shift is created by damping. We are working on new methods to separate the wave travel and damping components of phase-shifts.

The eccentric mass shaker has already been tested on ground surface to confirm its limitations for use in buildings (e.g., to avoid too much force being applied or to avoid resonant vibrations). Next it will be tested in buildings for soil-structure interaction investigations and modal identification.

Task 2.4 Advancing observational capabilities

L. Chiaraluce[1], M. Michele[1], R. Di Stefano[1], B. Castello[1] –D. Latorre[1], A. Vuan[2], S. Campanella[2], M. Sugan[2]

[1] Istituto Nazionale di Geofisica e Vulcanologia, [2] Osservatorio Geofisico Sperimentale

(1) Post-processing existing data to improve the baseline for OEF and predictability research

In order to produce a higher-resolution earthquake location catalog of the Italian peninsula with homogeneous local magnitudes (M_L), we are generating a work-flow to relocate the Italian seismicity contained in the CLASS 1.0 (Latorre et al., in prep) catalogue. CLASS consists of absolute locations obtained by applying a non-linear inversion location method (NonLinLoc; Lomax et al., 2000) in a 3D regionally fine tomographic velocity model [from Di Stefano and Ciaccio, 2014] for the 1981-2018 period (Figure 2.4.1).

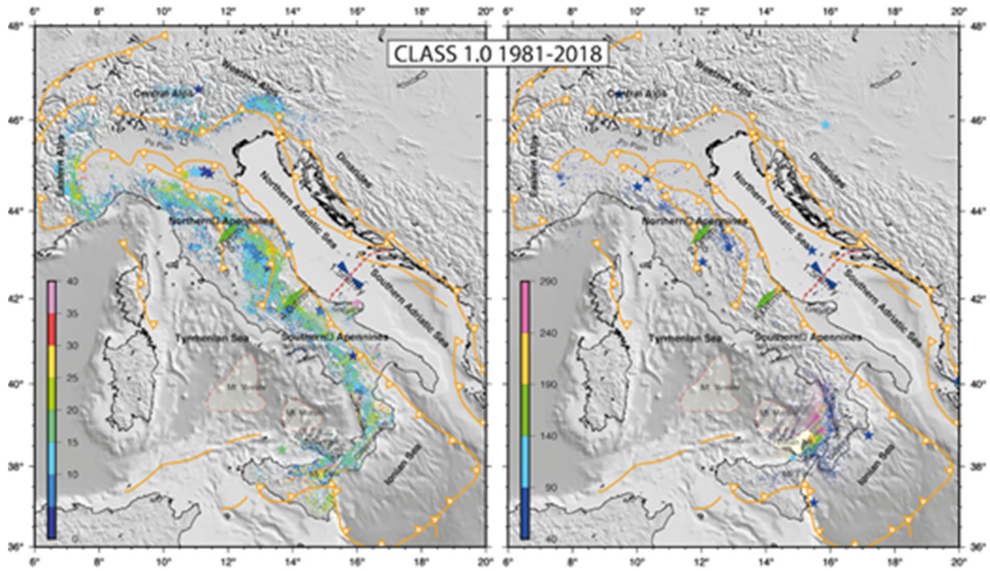


Figure 2.4.1 – Shallow (left; <40km) and deep (right; 40-200km) seismicity distribution of the Italian peninsula from CLASS 1.0, in the period 1981-2018, for a total of 422,557 events*. Colours are related to depth in kilometres' scale.*

Keeping CLASS 1.0 as a reference, within RISE we are working to generate a new catalogue composed by relative earthquakes locations (CARS 1.0) retrieved by using the Double Differences (DD; Waldhauser and Ellsworth, 2000) location algorithm. The dataset before 2005 will be generated by using only absolute arrival times (~5M P + ~3.5M S-readings) while cross-correlation derived relative arrival times measurements will be used for the subsequent period.

To enhance the resolution of the starting catalogue, we post-process CLASS 1.0 by re-locating the events with the same location code (NLL) but with smaller scale regionalized 1D velocity and station corrections. We use local 1D models, the same ones we will use in the HypoDD relocation procedure, because we are aware that the 3D model is somewhere locally too coarse, generating artefacts. Moreover, these are the same models that are going to be used in the INGV monitoring system, so we will have the option to use the work-flow we are constructing in future applications. Finally, the newly-computed station corrections will allow us to mitigate the oversimplification involved in locating events with 1D velocity models. The Italian region is divided into 18 sub-regions possessing homogeneous geological and seismotectonic characteristics (red polygons in Figure 2.4.2).

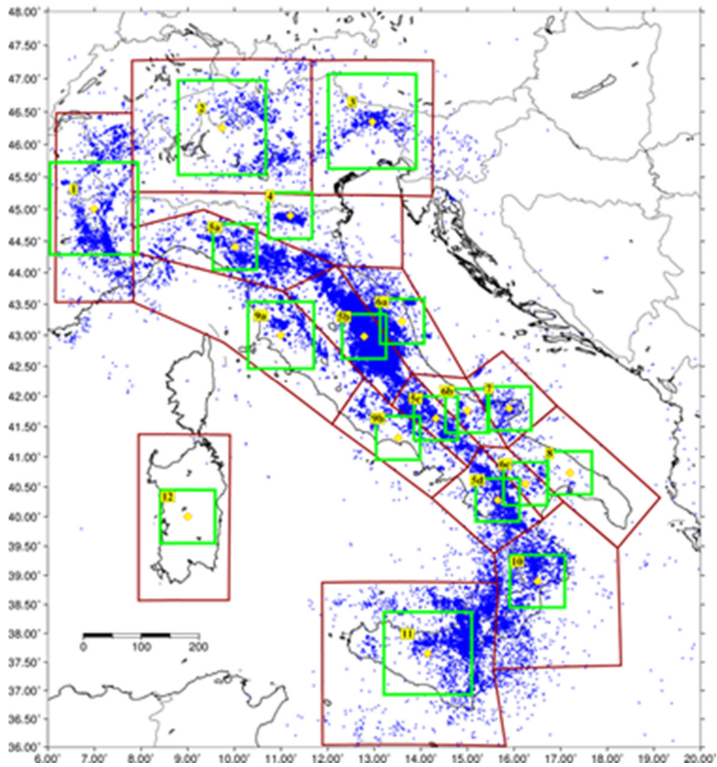


Figure 2.4.2 - Map of Italy with highlighted the 18 areas. The green boxes indicate the zones containing the grid nodes of the tomographic models, around the centre of each area (yellow symbol).

Based on CLASS 1.0 catalogue of events and related picks, we generated a dataset of waveform cuts designed to perform cross-correlation analysis that will allow us to include additional delay times in the double-difference relocation process. We selected only the events in the 2005–2018-time window because the oldest were recorded only at a small number of stations, and were not recorded in digital form.

We included hypocentre, station location information, origin time, and P- and S- onsets in the waveforms' header to favour different applications. We also include a 30s sample of pre-event noise allowing a variety of signal analysis approaches to enhance the signal to noise ratio in future processing.

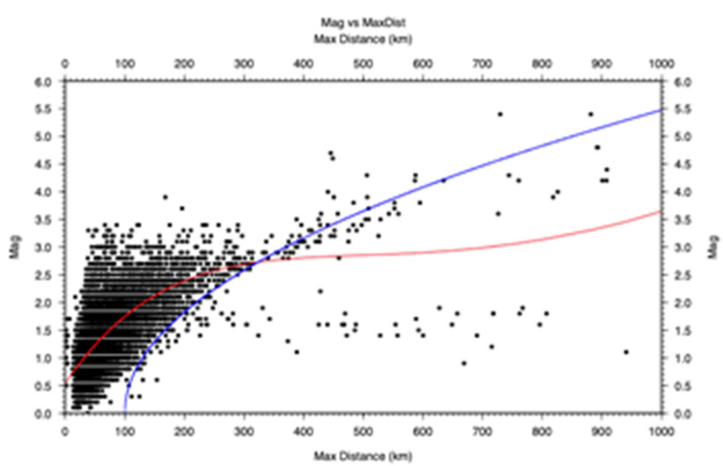


Figure 2.4.3 - Magnitude as function of distance. Red line is the not selected polynomial best fit, while the blue line is the empirical relation we used.

For each event, we cut signals from all the stations within a distance compatible with an empirical function linking magnitude of the event to the distance of the most faraway station, based on bulletin data over the last 40 years. To concentrate on more reliable data, we set the maximum distance for the smaller (M_L<1.0) events to 100 km (Figure 2.4.3).

Finally, to produce a homogeneous catalogue of local magnitude (M_L) for the 2005–2018-time window we are working to build a dataset of maximum amplitudes, performing the analysis on the waveform's cuts we produced for the cross-correlation analysis. Since homogeneity starts with producing homogeneous estimations of the maximum amplitudes, we adopted the same deconvolution-convolution, filtering, and signal peaks searches across the whole dataset. While this was not always possible in the runtime production of monitoring data over the evolving analysis systems, it is possible a-posteriori. To this end we developed a specific tool to:

- remove disturbing frequencies maximizing the signal to noise ratio by performing spectral analysis to define the corner frequencies of an adaptive band-pass filter;
- convert filtered signals into those that would have been recorded on the Wood-Anderson seismograph used to define the local magnitude M_L scale
- determine maximum and minimum amplitudes of the signal from the P onset to after the S onset or a synthetic S-travel time on the NS and EW components and, additionally for future regression studies to past data, on the vertical component;
- store max and min peaks and related metadata (e.g., corner frequencies, time distance between min and max) in a database table.

We eliminate the instrument saturation effect, principally for stations near the source for large events where the signal exceeds the dynamic range of the instrument, by a pre-processing procedure which automatically identifies and rejects the majority of the saturated waveforms, minimizing the mis-identification of good waveforms.

The resulting amplitude tables will allow us to calculate M_L, applying both different selection criteria on the amplitudes and different attenuation laws. In the first phase, we will apply Di Bona [2016] derived for the Italian region including station correction terms for the Italian seismic networks [Mele and Quintiliani, 2020].

In the next months, we will firstly finalize the computation of station corrections and the cross-correlation measurements. Once ready, we will start the relative location procedure and ML computation.

(2) Template matching

Template matching was run to search within the 8 years (2009-2016) time window in between the 2009 L'Aquila and 2016 Central Italy sequence, to provide new insight about the earthquake preparatory phase. We explored the continuous data by exploiting 48,000 well-located earthquakes, provided by Task 2.4.1. Available codes are rewritten to improve the performance and scalability. Scientific results will be provided within the next 3 month and will concern a background seismicity analysis and clustering coalescence prior to the 2016-2017 sequence in Central Italy.
The technical improvements, needed to address massive computations, involved: a) performance: ≈200% speedup in single-threaded mode, linear speedup using multiple threads. GPU support with further performance improvements: 50 templates per second per node with 4 GPU (NVIDIA V100), and higher speedups possible using longer signals. Faster post-processing thanks to AVRO data serialization, b) algorithm: new detections based on maximum cross-correlation, irrespective of time lag between channels and Median Absolute Deviation (MAD) of the stacked cross-correlation: the maximum cross-correlation is precomputed at all times and a robust threshold on cross-correlation is used. Filtering of detections is based on minimum distance between peaks of cross-correlation (spurious/duplicate events), c) usability: CLI, logging, input & output handling (scan all file system for valid inputs, skip missing/incomplete data, output single structured binary output with optional compression), arbitrary signal length, template duration (per channel basis), and sampling rate, d) robustness & correctness: better error handling, among fixed bugs: negative normalization in Obspy cross-correlation routine, drop multiple detections within template length, more stable magnitude estimation (missing data, template data and other bug fixes), detections at beginning or end of the signal, full usage of data (template/signal traces matching before processing), e) maintainability: less code (-80%) and dependencies, enhanced readability (refactoring into functions, meaningful variable nomenclature), modularity, easier deployment via registered PyPI package.

We show in Figure 2.3.4 the new detections in time for each template used before the 2016-2017 sequence (first 23500 templates). In the same long-time frame, we are also testing new detections by using M_L>1.5 aftershocks of the 2016-2017 seismic sequence.

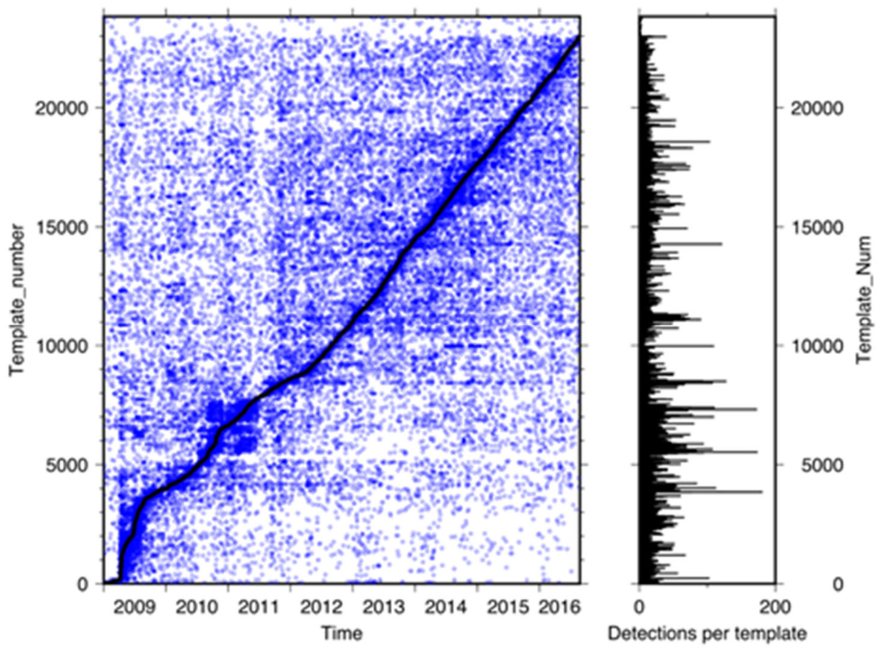


Figure 2.3.4 – 2009-2016 detections obtained by template matching using ~ 24000 templates before the 2016-2017 Central Italy seismic sequence (black dots on the left). The template number is sorted over time and new detections increase close to the templates.

More details about this aspect of task 2.4 (i.e. parts 1 and 2 above) including the cited references, can be found in D2.8.

(3) Improved modelling of seismicity

In addition, we have

- Developed a new method for data□driven optimization of seismicity models using diverse data sets, such as spatial maps of faults, slip rates and strain rates (Bayliss et al., 2020).
- Quantified the effect of quarry blasts as a source of potential systematic bias on estimates of earthquake recurrence models for the Italian catalogue (Gulia & Gasperini, 2021).

These provide improvements to modelling earthquake recurrence by integrating datasets with appropriate weights that otherwise need to be combined using expert judgement, and by providing more realistic estimates of random and systematic uncertainties that are important determinants of the quality and skill of operational earthquake forecasts. We also note that quarry blasts are more likely to be an issue as high-density, low cost sensor networks and waveform processing techniques described above, and hence the minimum detected magnitude decreases.

Task 2.5 Explore the use of ambient noise correlations to systematically monitor the temporal evolution of active faults

Laurent Stehly, Université Grenoble Alpes.

The aim of this task is to monitor the temporal evolution of the mechanical properties of the crust in seismically active regions in order to 1) better understand the seismic cycle and in particular on the way the Earth's crust is affected by seismicity and 2) look for possible precursory signals that could improve OEF.

To that end, we use seismic noise correlations to map the temporal evolution of seismic wave velocities and associated structural changes in the crust. We would like in particular to identify seismic velocity changes around active faults and their environment that are caused by earthquakes (change of strain, visco-elastic response of the crust to earthquakes, damaging of the crust) or that could precede earthquakes (fluid pressure change at depth for instance).

Primary target

We are currently focusing on two regions: The Gulf of Corinth (Greece) and Central Italy, where we use seismic noise correlations to monitor the temporal evolution of seismic velocities :

1) We choose to focus on central Italy in order to test the hypothesis that an increase of H2O-CO2 fluid pressure precedes the nucleation of large earthquakes in the Apennines. In particular, our aim is to detect and map the spatial extent of changes in the upper crust associated with the Mw 6.3 2016 Amatrice and Mw6.1 Visso/Norcia earthquakes.

2) The Gulf of Corinth Rift (Greece) is one of the most active tectonic structures of the Euro-Mediterranean area. It is characterised by an exceptionally high extension rate in a N-S direction of greater than 10 mm/yr and is made up of a complex network of mostly normal faults. On average some 15,000 events are detected per year. Most of them have low magnitudes ranging from 0.5 to 4, but there have been a few damaging earthquakes per century, including a sequence of five M>5 earthquakes which struck the eastern part in 1981, and two earthquakes of M>6 in 1888 and 1995 close to the city of Aigion. The high extensional deformation rate of the Corinth Gulf is mainly accommodated by seismic swarms, with alternating intense seismic crises and quiet periods, and occasionally by mainshocks. It is thought that change of fluid pressure at depth may play an important role in the dynamic of this seismicity.

Achievements

Database of pre-processed seismic noise records: In order to monitor the temporal evolution of the crust in southern Europe, we analysed the data of all seismic broadband stations distributed by the ORFEUS service European Integrated Data Archive (EIDA) for one decade (2010-2020), and for which data are distributed by the ORFEUS This database of noise records represents ~4.5 Tbytes of data after downsampling to 5 Hz. The initial dataset volume analysed is at least 20 times that volume, i.e ~80 Tb.

Database of noise correlations and associated normalised velocity changes dv/v: The database of pre-processed seismic noise records was used to build a post-processed database of seismic noise correlations for Greece and Italy. For each station pair, we cross-correlated the normalized vertical records day by day. We interpret these noise correlations as an approximation of the actual Green's functions between the stations within that time window. This allows us to use the coda wave component of the recovered Green's functions to measure the temporal evolution of seismic velocities (specifically dv/v defined above) in the 1-3s period band where surface waves are sensitive to the upper crust, and with a sliding window of 2 months.

Results for Italy and Greece: evolution of the crust associated with large magnitude earthquakes and seismic swarms: using this methodology, we have been able to produce maps of the dv/v measured for the year 2015-2017 in Italy. By averaging the dv/v measurements done around each station, we were able to map the velocity changes. Our results show that the 2016 Mw6.3 Amatrice and the Mw6.1 Visso-Nocia earthquakes had different consequence on the Earth's crust: the Amatrice earthquakes was followed by a small drop in normalised velocity of 0.02% which is confined in 50km^2 area around the epicenter. By contrast, the Visso-Norcia earthquake sequence was followed by a larger normalised velocity drop of 0.06% that extended to the north up to the Po plain. For the moment, no significant change in the medium has been identified prior to any of these earthquakes.

In the Gulf of Corinth, we showed that each Mw5 earthquake as well as the major seismic swarm of 2015 are all associated with post-seismic normalised velocity drops of the order of 0.05%. Moreover, the seismic crisis of October of 2015 was associated with a change of velocity in the west part of the Gulf of Corinth. This change of velocity has a complex spatial pattern, with an increase of velocity in some areas, and a decrease of velocity in some others. This suggests that the strain has increased in some regions and decreased in some others.

Future directions

Increasing the temporal evolution of our observations in order to look for precursory changes. In order to look for potential changes in the Earth's crust that could precede either large magnitude earthquakes in Italy or seismic swarms in Greece, we would like to increase the temporal resolution of our observation from two months to a few days.

One difficulty is that as we work with smaller time windows our dv/v measurements are more and more sensitive to instabilities in the distribution of noise sources. To circumvent this difficulty, we developed a simple method to screen seismic noise records to look for unconventional signals that are neither earthquakes or typical seismic noise (MS17). We did not detect any precursory signal preceding earthquakes, but this has allowed us to distinguish when the seismic noise is stationary, and thus suitable to be used for dv/v measurements, or non-stationary.

We are currently re-measuring the temporal evolution of seismic waves velocity in Italy using only the time window over which seismic noise is stationary. We hope to reach a temporal resolution of a few days, and thus to get the ability to detect potential precursory changes in the crust to large magnitude earthquakes. A joint workshop is planned to explore how the changes in velocity could be used in operational earthquake forecasting (WP3) and tested on future CSEP experiments (WP7).

Task 2.6 Strategies for scalability, high-volume data access and archival beyond existing waveform services, exploiting cloud-based services

KNMI, GFZ, INGV on behalf of the ORFEUS Foundation

The last decade has witnessed disruptive technological developments and new research practices that require adaptation and improvement of the way seismological data centers manage waveform data, metadata, and the associated services and products. Notable examples are: (i) the emerging use of Distributed Acoustic Sensing (DAS) systems for seismological studies (e.g. in Task 2.1); (ii) the increased availability of low-cost seismic sensors ranging from portable field instrumentation to MEMs accelerometers for structural monitoring (e.g. in Task 2.2); (iii) the initial experiences in using the seismic sensors embedded in smartphones and smart household appliances for earthquake early warning and rapid response applications. This means that massive datasets – possibly up to 10^6-10^9 times larger than those generated by traditional sensors – are soon being routinely produced, and that seismological data centers need to implement technical solutions for the management of such huge amounts of data, from acquisition to access and usage by stakeholders.

Users are expecting to be able to access and process the data efficiently, without having to download and store locally the datasets they are interested in. This prompts datacenters to provide new processing, possibly Cloud-based solutions, developed in close collaboration with High Performance Computing (HPC) facilities and scientific computing centers. Selected European data centers, all contributing to the European Integrated Data Archive (EIDA) within ORFEUS (http://www.orfeus-eu.org/data/eida/), started to gain experience to address the above challenges within the EC-funded project EOSC Hub (https://www.eosc-hub.eu/) and are consequently aligning their data management strategies to the recommendations compiled and the lessons learned therein. In particular, the ORFEUS Data Center in the Netherlands recently switched to a 'Cloud first' approach for data storage while retaining the use of standardised webservices as the preferred way to serve the users.

Standardized web services and traditional data management strategies are still suitable technical options to serve large-N (i.e., comprising a large number of sensors) datasets but new solutions are definitely needed for DAS experiments concerning metadata curation, data acquisition, archival, distribution and use (e.g., dastools; Quinteros, 2021), as extensively documented in a pilot study (Quinteros et al., 2021) conducted by ORFEUS/EIDA associated datacenters – GFZ & RESIF - and the IRIS Data Management Center.

Spurred by the need to test a seismological "computational" archive where storage resources and computational resources converge, INGV - also a core node of the ORFEUS/EIDA infrastructure – has prototyped and will soon deliver a framework (SeiSpark) for Big Data processing and interactive explorations centered on the analytics engine Apache Spark. It is expected that experiences like SeiSpark will be replicated at scientific computing centers in the future, yet a distributed infrastructure for combining service access and direct access to data for HPC purposes seems not yet ready.

All the aforementioned experiences satisfy MS18, and are documented more fully in RISE Deliverable D2.11: they represent the state-of-the-art and possibly the avant-garde on the topic at hand. Crucial for successful future standardised developments and implementations is the involvement of and coordination with several additional data centers worldwide, within the framework of the Federation of Digital Seismograph Networks (FDSN; https://www.fdsn.org/), **as well as the encouragement of international collaborations among scientists, datacenter operators and managers** (e.g. https://www.erasmus.gr/UsersFiles/microsite1193/Documents/SESSIONS_ABSTRACTS3.pdf).

Task 2.7 Develop an open, dynamic and high-resolution exposure model for EEW, OEF and RLA based on crowdsourced big data

The aim of Task 2.7 is to develop a high-resolution (building-level), dynamic, and open exposure model for Europe. The work on Task 2.7 is split into technical work and scientific/engineering work. The technical work includes the setup of the server infrastructure for this massive processing of data. Achievements so far include:

- The server infrastructure for processing OpenStreetMap building data has been set up.
- Full exposure models for the San Francisco and Cologne test cases have been generated.
- Prototype algorithms that combine the aggregated exposure model of the European SERA project with data on individual buildings from OpenStreetMap have been implemented.
- A first version of the exposure model for Attica (Greece) has been completed. Refinements and adjustments are under way.
- A completeness web application to manually assess the building completeness per level 18 tile has been developed and used to analyse completeness for the Attica region.
- A collaboration has been established with the Heigit centre of the University of Heidelberg to include a completeness analysis into the MapSwipe smartphone application, which was developed by Heigit for the Humanitarian OpenStreetMap Team. Building up on MapSwipe allows us not only to use a well-established platform actively used by the Humanitarian OpenStreetMap Team, with the subsequent capacity to reach a large number of already engaged users, but also to import data on the presence and absence of buildings already input via the app.
- Automated algorithms that estimate the completeness of OpenStreetMap buildings from remote-sensing-based estimates of built-up area have been implemented.

List of submitted deliverables and achieved milestones in WP2

D2.1 Large-scale DAS logistic feasibility study on new applications (A. Fichtner)
D2.2. Deployment of prototype (DAS) array (A. Fichtner)
D2.4 Field ready internal next generation sensors (M.P. Isken)
D2.6 Specifications on portable excitation sources and structure selection (E. Safak)
D2.8 Progress of new generation catalogues for public dissemination of new generation catalogues for public dissemination (L. Chiaraluce)
D2.11 Technical solutions on open, dynamic, high volume, cloud-based services (C. Cauzzi)

MS08: Deployment of experimental arrays, effects of coupling, instrument characteristics and detectability of regional earthquakes (ETH, WP2&6)
MS09: Urban DAS array fully operational in a city (ETH, WP2&6)
MS10: Hardware and software for indoor and outdoor sensor, first test deployment (pending, due May 2021, Quake, WP2 & WP6)
MS13 Acquisition of portable impact generator and eccentric mass shaker; improvements to the capacity of the vibroseis truck (BOUN)
MS17: Screening for ambient noise anomalies in test regions (UGC)
MS18: Finalisation of the whitepaper and selection of the preferred technical solutions (KNMI, WP2&WP8)

Summary of Exploitable Results in WP2

Deliverable reports (D2.1, 2.2, 2.4, 2.6, 2.8, 2.11)

In narrative terms we have delivered the following exploitable results:

- Proof of concept of DAS deployment in an urban setting and in challenging field environments
- New generation low-cost seismic sensors
- New seismic source generators for active testing of building response to strong motion, with proof of concept the signal can be detected through 15 storeys of a multi-story building, and that wave travel times can be measured
- New generation earthquake catalogues for Italy
- New method for data□driven optimization of seismicity models using diverse data sets
- Proof of concept seismic interferometry can detect very small changes in seismic velocity, at least for post-seismic stress relaxation
- Technical solutions for open, dynamic, high volume, scaleable, cloud-based European data archiving and provision services in anticipation of the explosion of data from existing and new technologies
- Models developed for the assessment of exposure to seismic risk at a street by street level, applied to San Francisco and Cologne.

PEER-REVIEWED PUBLICATIONS

- Bayliss, K., Naylor, M., Illian, J., and Main, I. (2020), "Data□Driven Optimization of Seismicity Models Using Diverse Data Sets: Generation, Evaluation, and Ranking Using Inlabru", JGR Solid Earth (125), doi: 10.1029/2020JB020226
- Gulia, L., Gasperini, P. (2021) "Contamination of Frequency–Magnitude Slope (b-Value) by Quarry Blasts: An Example for Italy. Seismological Research Letters; doi: https://doi.org/10.1785/0220210080
- Nievas, C.I., Pilz, M., Prehn, K., Schorlemmer, D., Weatherill, G. & Cotton, F. (2021). Calculating earthquake damage building by building: the case of the city of Cologne, Germany, Bulletin of Earthquake Engineering, under review.
- Quinteros, J., J. A. Carter, J. Schaeffer, C. Trabant, and H. A. Pedersen (2021). Exploring Approaches for Large Data in Seismology: User and Data Repository Perspectives, *Seismol. Res. Lett.*, doi: 10.1785/0220200390.

CONFERENCE PUBLICATIONS/POSTERS/PRESENTATIONS

- Delattre, F., Kriegerowski, M., Schorlemmer, D. (2021). Rabotnik – An asyncronous and flexible data and task management ecosystem. Second International Conference on Natural Hazards and Risks in a Changing World 2021. Abstract submitted for a poster.
- Evaz Zadeh, T., Nievas, C.I., Schorlemmer, D. (2021). Tile- and building-by-building-based damage calculations. Second International Conference on Natural Hazards and Risks in a Changing World 2021. Abstract submitted for a poster.
- Garcia Ospina, N., Schorlemmer, D. (2021). OBMGapAnalysis - Automatic building completeness assessment with open settlement datasets. Second International Conference on Natural Hazards and Risks in a Changing World 2021. Abstract submitted for a poster.
- Nievas, C.I., Pilz, M., Cotton, F., Prehn, K., Razafindrakoto, H., Schorlemmer, D., Weatherill, G., Spies, T. (2021). The use of high-resolution building exposure models: earthquake damage scenario for the city of Cologne, Germany. Second International Conference on Natural Hazards and Risks in a Changing World 2021. Abstract submitted for oral presentation.
- Nievas, C.I., Pilz, M., Cotton, F., Prehn, K., Razafindrakoto, H., Schorlemmer, D., Weatherill, G., Spies, T. (2021). Earthquake Damage Scenario for the City of Cologne, Germany. 17. D-A-CH Tagung: Erdbebeningenieurwesen und Baudynamik. Online Conference. 16-17 September 2021. Abstract accepted for oral presentation. Short paper submitted.
- Nievas, C.I., Schorlemmer, D. (2021). Inside the Global Dynamic Exposure model: bringing together aggregated models and crowd-sourced building-level data. Second

International Conference on Natural Hazards and Risks in a Changing World 2021. Abstract submitted for a poster.

- Prehn, K., Schorlemmer, D. (2021). Clickpleteness – How to assess the degree of completeness of building stock data in OpenStreetMap. Second International Conference on Natural Hazards and Risks in a Changing World 2021. Abstract submitted for a poster.
- Schorlemmer, D., Cotton, F., Delattre, F., Evaz Zadeh, T., Fleming, K., Garcia Ospina, N., Hirata, N., Kriegerowski, M., Nievas, C.I., Prehn, K., Shinde, S., Wyss, M. (2021). Global Dynamic Exposure and the OpenBuildingMap – A Crowd-Sourced Approach to Disaster Risk Assessment and Reduction Second International Conference on Natural Hazards and Risks in a Changing World 2021. Abstract submitted for oral presentation.
- Shinde, S., Fleming, K., Nievas, C.I., Schorlemmer, D. (2021). A census-derived aggregated exposure model (AEM) for Japan Second International Conference on Natural Hazards and Risks in a Changing World 2021. Abstract submitted for a poster.
- Quinteros, J. (2021). dastools - Tools to work with data generated by DAS systems, Potsdam: GFZ Data Services. doi:10.5880/GFZ.2.4.2021.001.

1.2.3 Work package 3

Overview

The purpose of this Work Package is to enhance earthquake predictability over the current state of the art in order to improve operational earthquake forecasting capabilities. The goal is achieved through two major steps: i) improving the understanding of the earthquake generation process; ii) implementing numerical codes which translate these advances in knowledge into improved OEF models.

Summary of achievements in WP3 tasks:

Task 3.1 Exploring seismic and non-seismic precursory signals

The aim of this task is to investigate if and how the inclusion of some seismic and non-seismic precursors provides further insights in the physical mechanism of large earthquake occurrences, and eventually transform the knowledge gained into actual forecast models.

Until now, we have sketched a mathematical framework in which we may embed, in a Bayesian framework, the observation of precursors with the more classical probabilistic earthquake forecasting. We are also exploring the potentiality of the seismic noise to increase earthquake predictability but we have not yet achieved a conclusive result.

Task 3.2. Enhancing earthquake predictability

The aim of this task is to explore earthquake predictability and its limits. Here we study and analyze hypotheses that are not yet ready to be implemented as a forecasting model during RISE, but have the potential to push the limits of earthquake predictability in the near future. Most of the work has been made in investigating the space-time independence of the Gutenberg-Richter (GR) law and of more generic magnitude-frequency distributions (MFDs). In particular:

- We have studied the potential of the spatio-temporal variations of the b-value in short-term forecasting models. In particular, we have more deeply investigated the foreshock traffic light system based on the variation of the b-value, to address some issues raised in the recent scientific literature.
- We have analyzed the presence of quarry blast contamination in seismic catalog and the consequent impact on the b-value and a-value estimations
- We have proposed a new energy-dependent MFD, in which the corner magnitude of a tapered distribution is not constant in space and time, but instead it depends on the elastic energy available.
- We have shown the problems of the MFD related to the high-resolution earthquake catalog. These catalogs undoubtedly brought a lot of new information about the spatial distribution of the seismicity and of the associated tectonic structures, but they are affected by several problems in the MFD which may limit their use in statistical seismology and hazard/forecasting studies.

- In a preliminary study we have seen that the MFD in Central Italy during the Amatrice Norcia sequence is different in different seismogenic sources that have been found using Machine learning technique. In particular, in some structures the MFD is constant through time. In other structures the MFD is significantly changing through time and it is influenced by what happens in other structures. Interestingly, in the structure where the largest earthquake occurred (Norcia earthquake), the b-value increased before the event.
- We have proposed a new technique to calculate the spatial distribution of the b-value thorough the concept of weighted log-likelihood function.

Task 3.3. A new generation of OEF models

The aim of this task is to develop a new generation of models for Operational Earthquake Forecasting to substantially improve earthquake forecasting performance. Building on the existing best-performing forecast models that CSEP has established, we move beyond the state-of-the-art by adopting novel approaches based on continuum mechanics, statistical physics, and statistical/stochastic modelling. All models will be independently tested in WP7.

All codes have to be ready in a later phase of the project. In this first part of the project, all modelers have worked in developing the mathematical background for their models. This is testified by the several publications that have been published or just submitted in international scientific journals. Some of them consists of

- Building OEF models based on the physics of the rate and state and Coulomb Failure Function
- Improvements of the ETAS modeling introducing space-time variability of some key parameters
- Development of a new Bayesian modeling (named INLABRU) to be applied in California and in Italy.
- Methods to account for the catalog incompleteness during real-time forecasts
- Building models based on foreshocks and on the implementation of the EEPAS model (Every earthquake is a precursor according to a scale). For now, this model has been applied only retrospectively to the Italian seismic catalog (HORUS, Lolli et al., 2020) and the forecast performance was evaluated and compared using the Molchan tests and the Area skill Score statistic. The foreshocks-based model has been improved and applied to Southern California, showing a significant increase in the retrospective forecast performance.
- Development of the EEPAS model for Italy

Moreover, all RISE modelers, together with the colleagues working at RISE-WP7 and at the Southern California Earthquake Center, have worked to define the format for the forecasting models to be applied to a new forecasting experiment in Italy. This experiment will be carried out under the umbrella of the Collaboratory for the Study of Earthquake Predictability (CSEP) in collaboration with WP7. A first version of the “rules of the game” will be circulating soon among all modelers.

We have also checked if the high-resolution earthquake catalogs that are currently under development may directly bring to an improvement of OEF models.
From a practical point of view, we have installed the first OEF system in Israel.

Task 3.4 Knowledge transfer from and to other scales

The purpose of this task is to learn from experiments at different spatial scales to improve OEF. In particular, we explore the scales of centimetres (rock deformation labs), the scale of decameters (underground labs such as the Bedretto lab in Switzerland) and GeoEnergy reservoir scale. Induced seismicity in this context offers important opportunities to understand earthquake physics under somewhat more controlled and repeatable conditions.
In task 3.4 there are two main branches of research as described in the implementation plan:

1. extending modelling approaches developed and calibrated by ETH for induced seismicity analysis to natural sequences
2. testing next generation OEF forecast models developed in T3.3/3.4 at the rock-laboratory scale, exploiting a new triaxial press at ETH (LabQuake-X) as well as the decameter Bedretto underground experiment.

For subtask 1, activities have focused on developing a hybrid “seed” model (GreenPoroSeed) for the study of aftershock sequences linked to poro-elastic stress changes. The modelling approach takes advantage of Green Function’s method to calculate the poro-elastic stress changes in a stratified medium due to dislocation. Once the stress changes are computed, these will be passed to a stochastic seismicity simulator to assess possible reactivation. The ‘seeds’ are hypothetical hypocenters distributed in space that can get reactivated if the conditions of stress are satisfied. Testing of the approach is finished, and in the future, we will focus on the application to real sequences.

For subtask 2, there are no classical OEF models available for application at the small scale. We are currently working with empirical and simplified numerical models to test their forecasting abilities against data collected at the Bedretto Underground Laboratory for Geoenergy and Geosciences. Models are different in class (i.e., injection volume or pressure-based formulation) and in terms of parameters estimate (frequentist, Bayesian, LS-joint inversion). Model performances are then evaluated by using a standard CSEP approach (using metrics such as the N-test or LL-estimate). In the next months, we will further test the models and the comparison approach, possibly implementing a more robust comparison based on the full probability distribution for each temporal bin. Furthermore, the LabQuake machine (the new ETH triaxial press) will soon produce some potential dataset to test new models at the scale of 10 cm.

Task 3.5. Incorporating expert judgment in earthquake forecasting for risk assessment purposes

This Task aims at defining procedures to incorporate a wider range of observations and a-priori knowledge to the current OEF models. It is believed that especially during times of a seismic crisis, expert assessment that incorporates expert knowledge can also be used to interpret and communicate the output of probabilistic earthquake forecast models to the media, the public and decision-makers.

Due to the ongoing pandemic, the work planned in this task has been deeply revised in its timeline. In essence we are planning to organize an international workshop towards the end of the project, gathering OEF scientists, decision-makers, interested stakeholders, and experts in communication to eventually define a “best practice” that will be the deliverable D3.5.

List of submitted deliverables and achieved milestones in WP3

The deliverables of WP3 are all expected in the second part of the project. So far we have successfully submitted all expected milestones that are

MS23 Scheme of OEF model to include anomalies
MS24 Defining testing experiments
MS46 Data object and format definition for exchange between modules

Summary of Exploitable Results in WP3

In essence, the results that have been obtained so far consist of one practical product, i.e., the preparation of the first OEF for the state of Israel (Falcone et al., 2021). The other results are mostly publications that testify the evolution of the theoretical work under preparation. Here we just report some of them

Bayliss, K., Naylor, M., Illian, J., and Main, I. (2020), "Data□Driven Optimization of Seismicity Models Using Diverse Data Sets: Generation, Evaluation, and Ranking Using Inlabru", JGR Solid Earth (125), doi: 10.1029/2020JB020226

Falcone G., I. Spassiani, Y. Ashkenazy, A. Shapira, R. Hofstetter, S. Havlin, and W. Marzocchi (2021). An Operational Earthquake Forecasting experiment for Israel: Preliminary Results. *Front. Earth Sci.*, In press.

Gasperini, P., E. Biondini, B. Lolli, A. Petruccelli, and G. Vannucci. 2021. *Retrospective Short-Term Forecasting Experiment in Italy Based on the Occurrence of Strong (Fore) Shocks*. Geophysical Journal International 225 (2): 1192-1206.

Gulia, L., and P. Gasperini (2021). *Contamination of Frequency–Magnitude Slope (b-Value) by Quarry Blasts: An Example for Italy*, Seismol. Res. Lett. XX, 1–14, doi: 10.1785/0220210080.

Gulia L., P. Gasperini and S. Wiemer (2021). Comment on “High-Definition Mapping of the Gutenberg–Richter b-Value and Its Relevance: A Case Study in Italy” by M. Taroni, J. Zhuang and W. Marzocchi”, *SRL, in press.*

Herrmann M., W. Marzocchi (2021). Inconsistencies and Lurking Pitfalls in the Magnitude–Frequency Distribution of High-Resolution Earthquake Catalogs. *Seismol. Res. Lett.,* **92**, 909-922, doi:10.1785/0220200337

Spassiani I., W. Marzocchi (2021). An Energy-dependent Seismic Moment-Frequency Distribution for Earthquakes. *Bull. Seismol. Soc. Am*., **111**, 762-774, doi: 10.1785/012020190

Taroni M., J. Zhuang, W. Marzocchi (2021). High-Definition Mapping of the Gutenberg-Richter b-value and its relevance: a Case Study in Italy. *Seismol. Res. Lett.* In press. doi:10.1785/0220210017

Taroni M., J. Zhuang, W. Marzocchi (2021). Reply to comment by L. Gulia, P. Gasperini, and S. Wiemer on "High-Definition Mapping of the Gutenberg–Richter b-Value and Its Relevance: A Case Study in Italy" by M. Taroni, J. Zhuang and W. Marzocchi (*Seismol. Res. Lett.*, doi:10.1785/0220210017). *Seismol. Res. Lett.*, in press.

Zhang Y., J. Fan, W. Marzocchi, A. Shapira, R. Hofstetter, S. Havlin, Y. Ashkenazy (2020). Scaling Laws in Earthquake Memory for Interevent Times and Distances. *Phys. Rev. Res*. **2**, 013264.

Zhang Y., D. Zhou, J. Fan, W. Marzocchi, Y. Ashkenazy, S. Havlin (2021). Improved aftershocks forecasting model based on longterm memory. *New J. Phys.,* **23**, 042001.

1.2.4 Work package 4

Overview:
WP4 deals with loss and resilience assessment for earthquake early warning (EEW) and operational earthquake loss forecasting (OELF). The main objectives of the work package are summarized in the following:

- develop second-generation, real-time seismic structural assessment and rapid loss assessment tools for Europe;
- operationalize earthquake loss forecasting for Europe, including time-variant hazard and fragility, accounting for accumulating damage;
- develop near real-time recovery forecasting, rebuilding management and resilience assessment for infrastructures;
- advance technologies for data-driven structural health monitoring and damage detection in structural systems in the context of EEW and OELF during seismic sequences;
- improve structure-specific early warning algorithms for real buildings;
- develop a user-ready risk-cost-benefit analysis framework for quantifying socio-economic costs.

Each of these issues is specifically addressed by a task that has been working from the beginning of the project (September 2019). In the following, the main achievements of each task (i.e., from task 4.1 to 4.6) are summarized.

Summary of achievements in WP4 tasks:

Task 4.1 Exposure, Vulnerability and ShakeMaps for OELF and RLA

This task provides data, models and scripts/software related to European exposure, vulnerability and ShakeMaps to other tasks and applications within RISE. The main progress and achievements for each of these components is summarised below.

Exposure Models

Both time invariant and time variant exposure models are being developed and tested in the RISE project.

Time invariant models:

- The database of building exposure models for 44 European countries initiated in the SERA project has continued to be developed and reviewed and has now been publicly released on both GitLab and Zenodo (10.5281/zenodo.4062044). These exposure models cover the number and economic value of residential, commercial and industrial buildings, as well as their occupants.
- Open source tools for disaggregating the aforementioned national exposure models to a higher level of resolution (necessary for scenario assessment) have been developed in collaboration with the Global Earthquake Model : https://github.com/GEMScienceTools/spatial-disaggregation
- A paper on the impact of exposure model resolution on European seismic risk modelling has been drafted and submitted for review in the Bulletin of Earthquake Engineering (see exploitable results section).
- Ongoing improvements are being made to the spatial and temporal distribution of population using open data from the ENACT project (https://ghsl.jrc.ec.europa.eu/enact.php). Particular attention is being made to the variation of population during different times of the day and seasons.
- Task 2.7 is developing a Dynamic Exposure Model that is frequently updated using OpenStreetMap/OpenBuildingMap data. Collaboration with this task is ongoing to ensure that this individual building data can be combined with the statistical building data from the time invariant exposure models for 44 European countries (described above).
- Scripts are under development to automatically adapt the population in the aforementioned exposure models following an event (based on the assessed damage states from rapid loss assessment, by correlating the damage state with the likelihood of evacuation).

Vulnerability Models

Both time invariant and time variant vulnerability models are being developed and tested in the RISE project. This task focuses on time invariant vulnerability models and provides data to Task 4.2 which deals with time variant vulnerability (i.e. state-dependent fragility and vulnerability).

- A first database of European capacity curves for over 480 building classes has been released on GitLab and Zenodo (10.5281/zenodo.4062410).
- Open source software to develop fragility and vulnerability models with these capacity curves has been tested and a publication has been submitted for review (see exploitable results section).
- A selected set of capacity curves for European reinforced concrete building classes has been shared with Task 4.2 and checks on the resulting fragility functions with different methodologies/tools have been made.
- An efficient workflow has been identified to modify vulnerability models (and account for damage accumulation) during sequences of events using the existing open source software for rapid loss assessment (OpenQuake-engine).

ShakeMaps

- The European ShakeMap system prototype is up and running at http://shakemapeu.ingv.it/ . Among the developments carried out within RISE are: (a) the transition to the latest version 4 of the ShakeMap software that is optimally coupled with OpenQuake; (b) the development of a dedicated GUI by INGV that candidates as ShakeMap v4 community portal. The prototype European ShakeMap system uses the USGS ShakeMap codes and input from the ORFEUS RRSM and ESM strong-motion systems to deliver maps of expected and recorded ground shaking within minutes of any event with M >= 4.0 in the Euro-Mediterranean region. The predicted maps are initially constrained by the earthquake locations and magnitudes provided by Euro-Mediterranean Seismological Centre (EMSC) together with the recordings of the RRSM and subsequently updated as soon as manually revised ESM ground-motion estimates are available. The system uses the authoritative configuration for Switzerland and Italy and will in the future include any other regional configuration as adopted by other European institutions running USGS ShakeMap.
- EMSC felt reports have been tested by the United States Geological Survey by comparing ‘Did You Feel It?’ and felt report data at overlapping sites, and integration in the ShakeMap system is being considered.

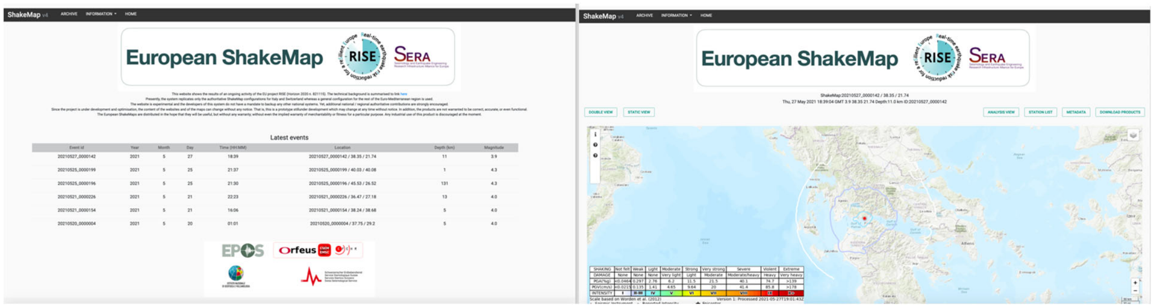


Figure 4.1.1 Screenshots of the European ShakeMap system (http://shakemapeu.ingv.it/)

Task 4.2 Improve and operationalize earthquake loss forecasting (OELF)

This task aims to provide measures of short-term seismic risk at regional and national scale. On the basis of results of the Italian system for operational earthquake forecasting (OEF-Italy) (Marzocchi et al., 2014) the operational earthquake loss forecasting (OELF) system, named MANTIS, was developed (Iervolino et al., 2015). In the first version of MANTIS the possible damage accumulation during seismic swarms was neglected, whereas in this task the upgraded version of the OELF system, MANTIS V.2, is under development to account for this issue. To this end, a preliminary workflow of the upgraded system was developed. More specifically, given that new OEF releases are expected every day or after the occurrence of a potentially damaging earthquake, the following steps are followed after each new OEF release:

1- The occurrence of an earthquake is checked. If an earthquake has occurred, the procedure goes to step 2, otherwise step 3 is implemented;
2- A damage estimation on each building class representative of the existent building portfolio of the site of analysis (e.g., municipality) is performed by analysing the recorded data of ground motion (e.g., recorded ground motions and/or shakemaps);
3- The rates released by OEF-Italy are used for a probabilistic assessment of the seismic hazard and, thus, the expected losses (e.g., expected number of collapsed or unusable buildings) are computed, accounting for the estimated damage, if any, of the building portfolio and for the possible damage accumulation in the forecasting unit time (i.e., one week).

In both step 2 and 3, the possible damage accumulation is modelled extending to the building classes the methodology already developed for single structure (Iervolino et al., 2020). One fundamental ingredient of the whole procedure is the state dependent fragility functions representative of the existing structural typologies. So far, Italian reinforced concrete (RC) structure classes were considered and a preliminary assessment of the state-dependent fragility functions was provided, profiting from the Incremental Dynamic Analysis (IDA) and Back-to-Back IDA and considering four damage states. To this end, two main issues that significantly affect the results were addressed i.e., the choice of a suitable intensity measure and the identification of the optimal number of ground motions for the execution of the nonlinear-dynamic analyses.

Task 4.3 Develop near real-time recovery forecasting for infrastructures

This task provides a framework to infer the cost and time required to repair damaged buildings after an earthquake and to estimate recovery trajectories and thus, resilience, at regional scale. Considering the time dimension of earthquake losses, this task complements and extends the loss estimates of task 4.1. The main achievements and findings are as follows:

Demand-and-Supply of Impeding Factors

In regional recovery, impeding factors, which present requirements that have to be met before actual repair works can start, govern community recovery (task 4.3.4):

- Main impeding factors for functional recovery, e.g., housing capacity, at regional aggregation scales are inspection, engineering assessment and permitting. For short-term community resilience, these factors have a significantly higher influence than repair and retrofit efforts, see Figure below.
- A simulation framework has been developed for bottom-up modelling of the demand and

supply related to the impeding factors. When regional preparedness and hazard levels are known, this framework also enables the generation of log-normal surrogates of the duration demand for all impeding factors.

- A bottom-up modelling approach, which considers the supply and demand in impeding factors for each asset, enables estimating the influence of properties, such as inspection resource availability, repair times and other parameters with large regional variability, on community post-earthquake recovery.

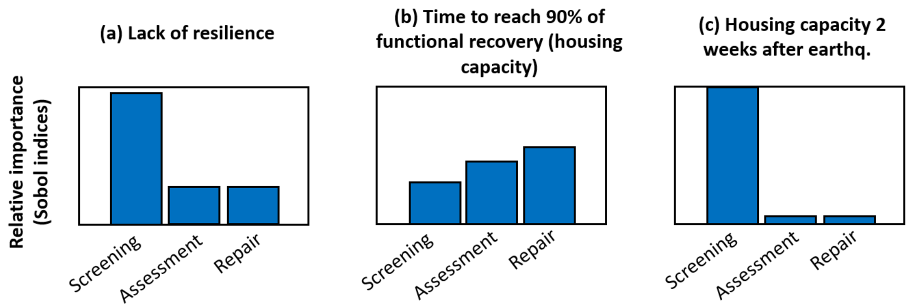


Figure 4.3.1 Relative importance of two major impeding factors, i.e., visual screening and engineering assessment, on community resilience metrics: lack of resilience as the overall lack of housing supply (a); time required to regain 90% of the pre-disaster housing capacity (b); and short-term recovery of housing capacity, after two weeks (c). Results reflect a hypothetical scenario earthquake in Zurich (Switzerland)

Dynamic updates of loss assessment

Uncertainties from rapid regional loss assessment are considerable and, if convoluted with uncertainties pertaining to recovery predictions, increase so as to reduce the potential use for informed decision making. Therefore, a dynamic updating framework for regional assessment of the loss of functionality, as a starting point for recovery trajectories, has been developed. Related findings have been included in two conference publications (see section Summary of Exploitable Results in WP4).

- Information inflow from a small subset of inspected buildings after an earthquake is used to reduce the uncertainty related to early estimates of shake maps (task 4.3.7).

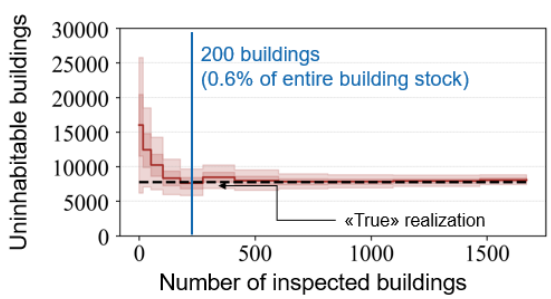


Figure 4.3.2 Reduction in the uncertainty related to the number of uninhabitable buildings obtained by leveraging machine-learning tools on the results of first building inspections (Bodenmann et al. 2021a)

- Improved understanding of local building typologies, a side product of visual inspection, reduces the uncertainty in typological attribution matrices that link publicly available building information with building fragility. Therefore, the uncertainty on aggregated quantities, such as unsafe buildings and required repair efforts, and their spatial distribution is reduced (Bodenmann et al. 2021b).

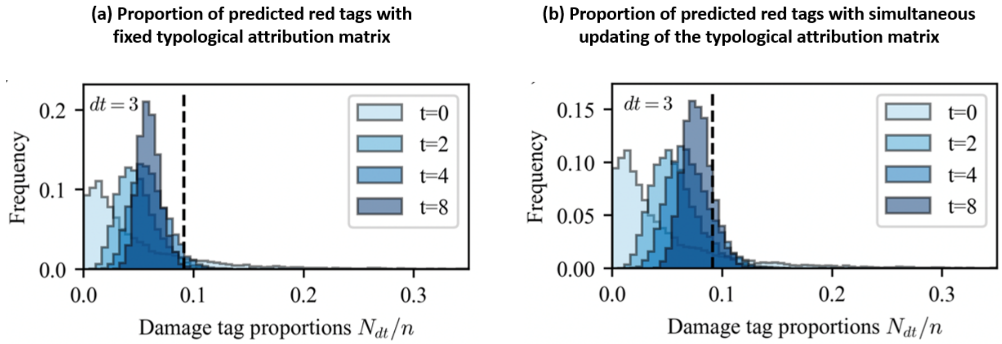


Figure 4.3.3 Reduction in the uncertainty of predicted number of unsafe buildings (red tag) with fixed typological attribution matrix (a) and updated typological attribution (b). Uncertainties are reduced after eight days of inspections and updating the typological attribution allows for a reduction in the bias.

- In collaboration with task 4.4 and 4.6, the dynamic framework will be extended to account for sensor data and to demonstrate the societal benefit of such a framework.

Repair efforts for damaged buildings

With historic data of repair efforts scarce in regions of low-to-moderate seismic hazard, such as Switzerland, component-level formulations are required to derive the repair efforts for a typical Swiss building (task 4.3.1).

- Repair efforts depend on regional preparedness and construction techniques. Assessment using engineering heuristics, component-based formulations (such as contained in the American FEMA P-58 guidelines) and global assessment (such as contained in the Italian NTC 2018) are compared to provide bounds of possible repair efforts for a typical Swiss building class.

Task 4.4 Advance technologies for data-driven SHM and damage detection

This task develops methods for the processing of data that is recorded from monitored buildings during earthquake events, in order to extract indicators of the damage that has been potentially sustained by the building. Such quantitative and near-real-time assessment of single buildings contributes towards rapid loss assessment (RLA) and automated building tagging. The main type of measurements assumed available in this respect are acceleration measurements, as the most mature technology for high frequency sampling during earthquake events. While strain information, delivered by fibre optics installations, and residual displacement information, e.g. from satellite systems, can be considered, these do not yet reflect the precision and resolution needed for such real-time diagnostic tasks (unless the damage is severe and thus, visible).
The main achievements are described below:

Definition of robust Damage-sensitive features

Damage-sensitive features (DSFs) form metrics that can be extracted from, usually acceleration-based, monitoring data extracted during shaking events.

- DSFs indicate the occurrence and location of damage sustained by the building. The calculation of the transmissibility between sensors at the ground and top floor level is sufficient to detect the occurrence of nonlinearity in the global building response. We are particularly interested in the extent of nonlinearity sustained by the building, in order to understand the extent of loading it has been exposed to and eventually link this to calculations of vulnerability. In terms of localization, we demonstrate that criteria that are formulated on the basis of an assumed distribution of sensors along and across floors (e.g. Transmissibility Assurance Criterion – TAC) are further successful in localizing damage (*Reuland et al., 2021c*).
- In addition, investigation of the exhibited correlation of such DSFs with pre-defined damage states allows for smart-tagging of earthquake-hit buildings (task 4.4.4) as either safe or unsafe for re-occupancy. Several DSFs have been evaluated and compared, indicating the potential of a probabilistic formulation of transmissibility-based indicators.

These results have been reported in a conference contribution at the International Structural-Health Monitoring and Intelligent Infrastructure Conference (*Reuland et al., 2021d*) and a journal publication is submitted (*Reuland et al., 2021c*).

- Probabilistic formulations of DSFs prove robust against sensor noise and have been validated with respect to their potential in indicating presence and location of damage, on building structures tested on shaking tables (beyond verification in simulated data).
- Forward model simulations have been carried out to link continuous DSFs with discrete damage graded (DGs), as indicated in the figure below. This information relates to the inputs required in task 4.2 for the calculation of state-dependent vulnerability and task 4.3 for assessment of repair and rebuilding efforts. DSFs allow for a probabilistic classification into predefined DGs. However, they can further deliver insights into the experienced response through their correlation with nonlinearity indicators that define hysteretic work, residual stiffness drop and maximum transient displacement. The benefits of SHM-driven automated building tagging, in function of the number of sensors deployed, will be studied in a next step alongside task 4.6.

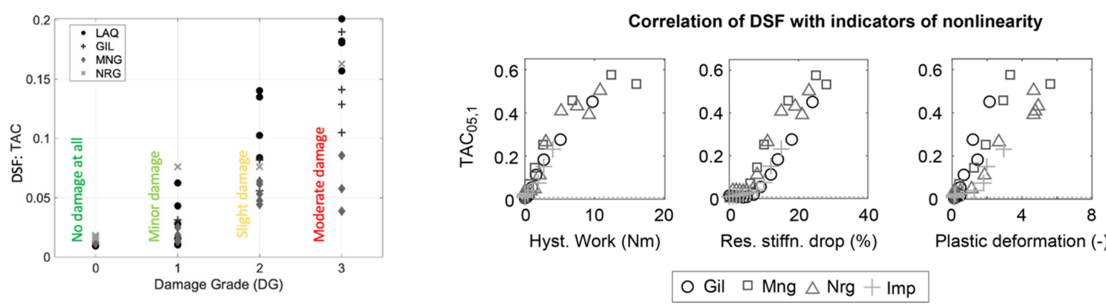


Figure 4.4.1 Correlation of DSFs with discrete DGs (left) and indicators of nonlinearity (right).

Building monitoring

Aiming to assess the amount of data required to detect the presence of damage (task 4.4.1) and to understand localization potential (task 4.4.2), multiple masonry buildings have been measured during planned demolition. Demolition here serves as a means of generating higher levels of excitation than the ambient conditions.

- The measurements, included in MS37, have shown that the dynamic properties of masonry buildings change with the amplitude of shaking, even in absence of visible damage, which is a necessary starting point to reduce false alarms in damage detection. Transient nonlinear behavior is observed in what is commonly assumed as the linear elastic regime in behavior models (*Martakis et al., 2021a*).
- The variability due to the amplitudes of shaking seem to primarily affect the masonry properties, rather than further elements of the soil-structure interaction system. This observation facilitates the formulation of relevant thresholds for damage detection and eventually aids in reducing the number of sensors required (as reported in *Martakis et al., 2021a*).
- A comparison among different representative units of masonry building typologies indicates that low-rise masonry buildings with flexible floor systems are more affected by amplitude-dependent dynamic properties than mid-rise masonry buildings, or masonry buildings with stiff floors. Similarities between buildings forming a typological class will be explored in the next steps of task 4.4, opening the path toward data-driven regional loss assessment (RLA).
- Implementation on experimental data from shake-table tests, carried out by other researchers, has demonstrated the effect of the amplitude of shaking on the dynamic properties and thus, on the damage-sensitive features (see figure below), underlining the value of acquisition of high-amplitude linear reference signals.

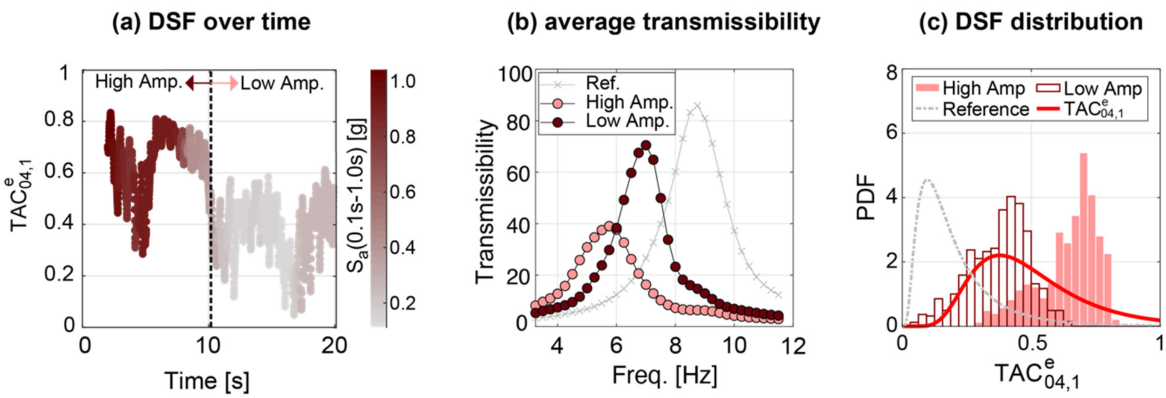


Figure 4.4.2 The evaluation of the DSF (i.e Transmissibility-assurance criterion, TAC) over time shows that amplitude-dependency of dynamic properties. Comparing the strong shaking in the first 10 seconds of the earthquake with the lower-amplitude shaking indicates that the system regains higher stiffness values after the strong-motion shaking.

Task 4.5 Development of location- and structure-specific Earthquake Early Warning algorithms for real buildings

The objective of Task 4.5 is to develop location- and structure-specific Earthquake Early Warning (EEW) algorithms for buildings. Towards this objective, eight EEW ground stations closest to the fault in Istanbul and two high-rise buildings instrumented by KOERI (Kandilli Observatory and Earthquake Research Institute) of Bogazici University are being considered to test the algorithms developed. The development includes the following sub-tasks:

- Subtask 1 (M01-03): Compilation of 20-year-long earthquake records from the EEW stations and the instrumented buildings.
- Subtask 2 (M04-09): Development of the attenuation of various ground motion parameters from the EEW stations to the building's base.
- Subtask 3 (M09-12): Identification of the correlation of critical response parameters of the building with the base motion.
- Subtask 4 (M13-18): Identification of threshold response values of the buildings for structural safety (from the design calculations and current seismic design codes), and the corresponding critical base motions that will create them.
- Subtask 5 (M19-24): Identification of ground motion values at EEW stations that will cause critical base motions for the building.
- Subtask 6 (M25-36): Development of software to perform the subtasks outlined above to issue real-time early warning on buildings.

SUBTASK 1 (Completed):
Last 20-years records from the earthquakes with at M_L>4.0 at eight EEW stations and the two buildings are compiled and processed. The locations of the EEW stations and the two buildings are shown in the figure below. Only those EEW stations on land are considered in the study.

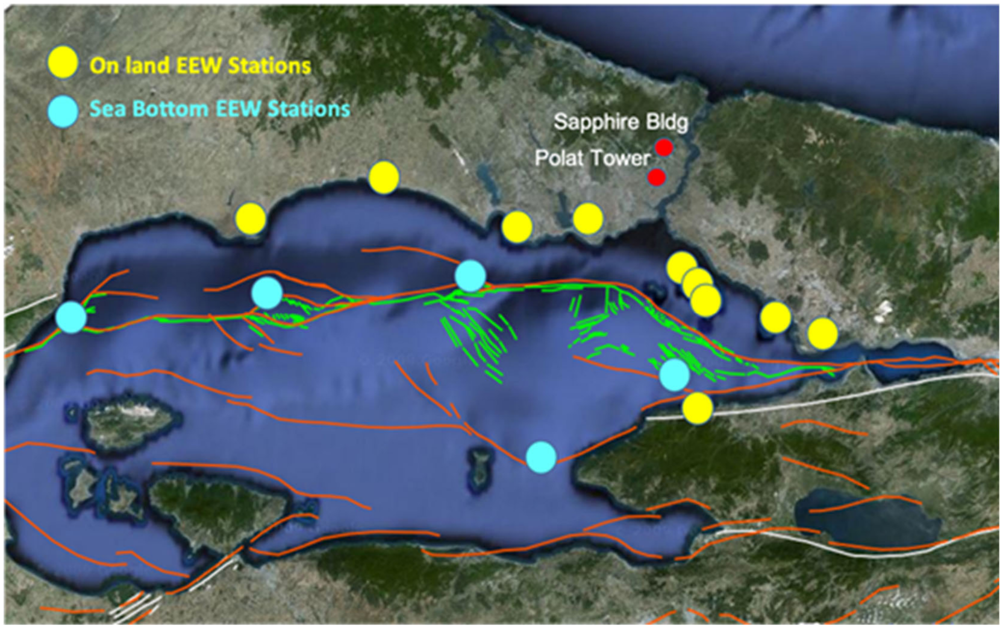


Figure 4.5.1 Locations of the EEW stations and the two buildings considered in the study

The list of M_L>4.0 earthquakes considered in the study are listed in the following table.

No	DATE	TIME-UTC	LATITUDE	LONGITUDE	DEPTH (k	ML	LOCATION
1	20130730	05:33:08	40,3037	25,7803	9,8	5,3	GÖKÇEADA(ÇANAKKALE)
2	20131124	19:49:37	40,7843	31,8760	8,0	4,8	ULUMESCİT(BOLU)
3	20131127	03:13:37	40,8510	27,9198	9,6	4,7	MARMARA E. AÇIKLARI
4	20131127	03:21:35	40,8470	27,9120	7,4	4,0	MARMARA E. AÇIKLARI
5	20140524	09:25:01	40,3242	25,4687	23,3	6,5	EGE DENİZİ
6	20140804	22:22:44	40,6025	29,1655	10,7	4,0	TERMAL (YALOVA)
7	20141122	19:14:15	45,7420	27,2147	27,9	5,6	ROMANYA
8	20150117	00:42:34	39,8848	30,3955	5,5	4,3	KARACOBANPINARI-TEPEBASI (ESKISEHIR)
9	20150123	10:19:42	40,0647	28,5870	5,0	4,5	MUSTAFAKEMALPASA (BURSA)
10	20150202	04:41:03	40,3412	26,0567	13,4	4,1	SAROS KORFEZI (EGE DENIZI)
11	20150416	18:07:43	35,0750	26,9095	22,1	6,1	GIRIT ADASI ACIKLARI (AKDENIZ)
12	20150429	04:40:53	42,0393	29,3078	14,1	4,0	KARADENIZ AÇIKLARI
13	20151028	16:20:02	40,8205	27,7648	12,7	4,5	MARMARA DENIZI
14	20151116	14:45:43	40,8258	28,7590	7,7	4,2	MARMARA DENIZI
15	20160607	04:09:45	40,2627	29,1460	11,5	4,6	GURSU -BURSA
16	20160625	05:40:11	40,7032	29,2147	6,8	4,4	YALOVA ACIKLARI
17	20160717	08:55:41	40,7118	29,1800	7,4	4,0	YALOVA ACIKLARI
18	20161015	08:18:32	42,2063	30,7133	11,4	5,0	KARADENIZ
19	20161228	23:20:57	45,3533	26,5457	49,7	5,9	ROMANYA
20	20170206	03:51:39	39,5575	26,0197	5,5	5,5	GULPINAR ACIKLARI-ÇANAKKALE
21	20170206	10:58:00	39,5098	26,0747	6,8	5,3	BABAKALE-AYVACIK-ÇANAKKALE
22	20170207	02:24:02	39,5212	26,0873	5	5,3	GULPINAR ACIKLARI-ÇANAKKALE
23	20170212	13:48:15	39,5177	26,116	11,1	5,3	GUPINAR AYVACIK-CANAKKALE
24	20170308	20:09:58	39,9760	27,6575	7	4,1	ÇATAK-GONEN-BALIKESIR
25	20170612	12:28:38	38,8512	26,2583	20,7	6,3	EGE DENIZI
26	20170617	19:50:04	38,8542	26,4365	14,1	5,6	EGE DENIZI
27	20170622	02:48:52	38,8205	26,4593	15,3	5,0	EGE DENIZI
28	20170721	22:31:00	36,9620	27,4053	5	6,2	GOKOVA KORFEZI
29	20171231	20:12:02	40,5655	27,8653	4,3	4,3	ERDEK ACIKLARI MARMARA DENIZI
30	20180408	21:16:31	40,8615	31,6625	5,8	4,9	YESILCELE-(BOLU)
31	20190924	08:00:21	40 .8780	28 .2060	11.2	4.7	SILIVRI ACIKLARI-ISTANBUL (MARMARA DENIZI)
32	20190926	20:20:18	40 .8743	28 .2367	12.7	4.3	SILIVRI ACIKLARI-ISTANBUL (MARMARA DENIZI)
33	20191010	16:52:03	40,7008	29,2572	10,3	4,1	YALOVA ACIKLARI
34	20200111	13:37:36	40,8548	28,242	16,2	4,8	SİLİVRİ ACIKLARI
35	20200122	19:22:15	39,0575	27,8445	8,5	5,6	AKHİSAR MANİSA

The pictures of the two high-rise buildings are shown below.

Figure 4.5.2 The two high-buildings considered in the study

SUBTASK 2 (Completed):
The ground motion parameters considered for the development of the attenuation relations from the EEW stations to the buildings' bases are listed below:

- PGA - Peak Ground Acceleration
- PGV- Peak Ground Velocity
- SA02 – Spectral Acceleration at 0.2 second period.
- SA1– Spectral Acceleration at 1.0 second period.
- CAV – Cumulative Absolute Velocity
- Ia – Arias's Intensity
- SI _ Spectral (i.e., Housner's) Intensity

As an example, the attenuation from Burgaz EEW station to Sapphire building is shown below.

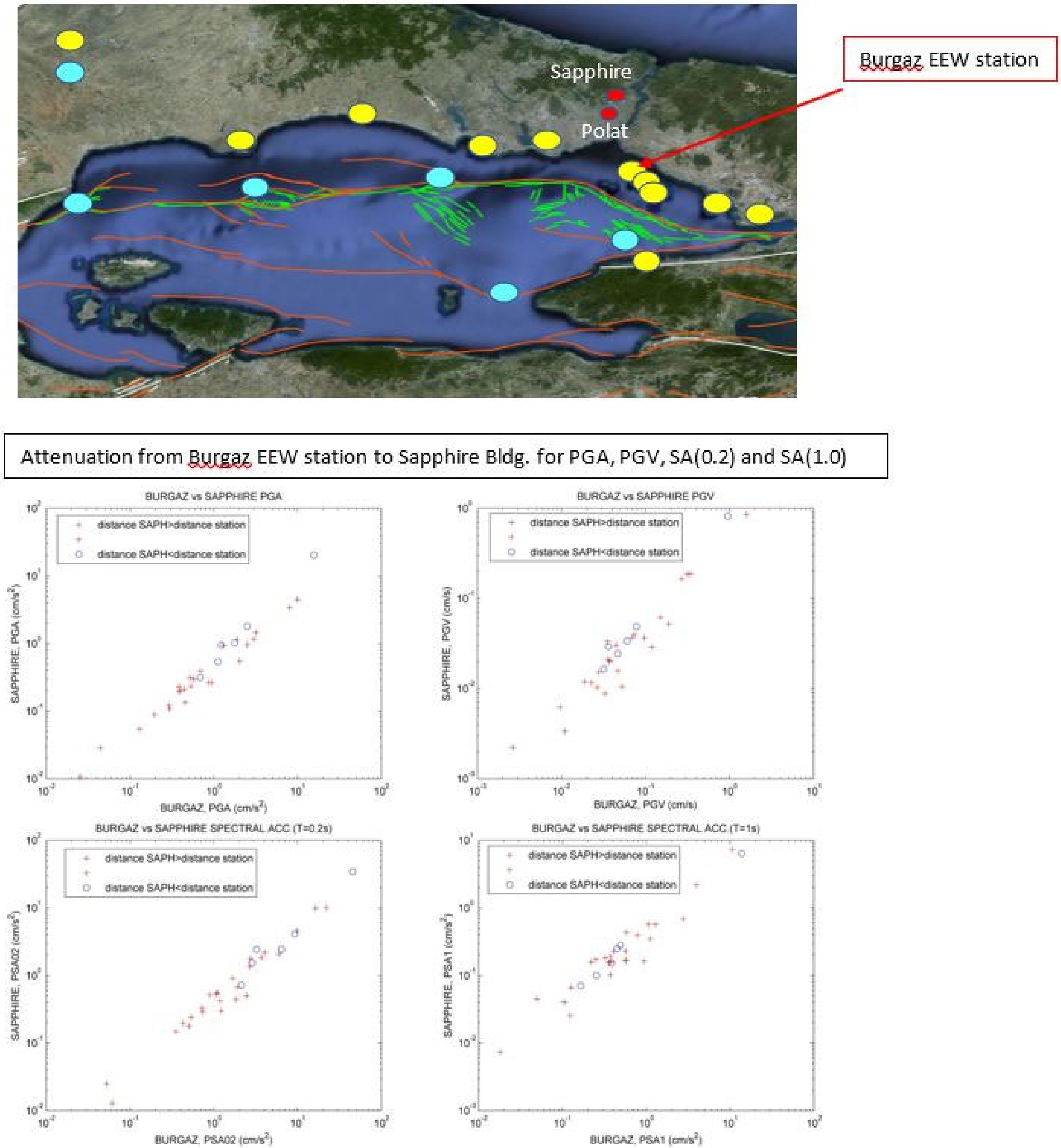


Figure 4.5.3 Attenuation from Burgaz EEW station to Sapphire building

SUBTASK 3 (Completed):
To identify the critical response parameters that correlate with the building's base motions, we studied the critical response parameters with the parameters of ground accelerations considered in Subtask 2. We have concluded that, in terms of structural safety, the top-story displacement, inter-story drift and base-shear are the critical parameters that correlate best with base accelerations.

SUBTASK 4 (Ongoing):
To identify the threshold values of the three critical response parameters determined in Subtask 3, we have developed an analytical model of the building that is calibrated with the records, and are currently studying the original design calculations and considering the provisions specified in current seismic design codes.

SUBTASK 5 (To be done):
This task will first determine the ground motion parameters that will cause the threshold response in the building by using the information created in Subtasks 3 and 4. Then, by using the attenuation relations developed in Subtask 2, we will determine the ground motion parameters

that should be recorded at the EEW stations.

SUBTASK 6 (To be done):
This task will develop software to issue real-time safety warnings in the building based on the records at the EEW stations and identify the safety warning time that is feasible.

Task 4.6 A user-ready risk-cost-benefit analysis framework for quantifying socio-economic impact

Background

RISE adopts an integrative, holistic view of risk reduction; a dynamic risk concept that uses all of the relevant information available to assess risk at different stages of the earthquake cycle, and an equally all-encompassing view on dissemination and communication of this information to everyone in society. We do so in order to maximise synergies, ensuring harmonisation and consistency; this information is so important that everyone needs to know, and understand it unambiguously, in order to make decisions on their own behalf and for others.
The tangible advances we propose for real-time earthquake risk reduction for more resilient societies will also need investment decisions by national governments, regional governments, industry, building owners, infrastructure operators, and sometimes even individuals. However, such investment decisions must be underpinned by a transparent, reproducible, community-accepted and quantitative process of rational decision making, quantifying the risks, costs and benefits of risk management strategies. Societies must decide how much they are willing to invest in disaster-risk reduction, and how to invest limited resources in the most effective way, considering multiple hazards. Key questions to answer are: how much risk is acceptable given available risk mitigation resources? What are the costs for a given mitigation or resilience measure? And what are the benefits of these measures? Such risk-cost-benefit analyses form the backbone of rational decision making. Justifying investments in earthquake safety is becoming ever more important in today’s and tomorrow’s information societies which have to choose between multiple options for risk mitigation, and balance the requests from different hazard communities. To request substantial future investments by governments or industry in advancing observational capabilities, into OEF, EEW or RLA, scientists and engineers must demonstrate a positive risk-cost-benefit balance.

Cost Benefit Analysis

Cost Benefit Analysis (CBA) is a systematic procedure for evaluating decisions that have an impact on the society. In the concept of earthquake risk, we will use CBA to quantify the socio-economic impact of alternative risk mitigation measures. We consider that when no mitigation measure is in place, we have the status quo. The status quo can be the starting point of how well the alternative mitigation measures perform. If the perceived benefits (i.e., reduction in losses) are less than the expected costs to mitigate the risk to the structure, then the status quo will be maintained. In a CBA problem, the following steps are followed:

- Define the target, such as a building, a building class, a region or a country
- Status quo: No mitigation action
- Define mitigation actions
- Determine direct cost of the mitigation actions
- Determine loss with and without mitigation actions
- Compare different mitigation actions with each other

Different mitigation actions will impact either selected individuals, groups and/or organizations. It is important to indicate who will benefit and who will pay the costs associated with different alternative options when undertaking a CBA.
RISE is working on a wide range of closely coordinated activities that all contribute to the unifying dynamic risk framework. Each of these modules works on improving the current state of art in its domain; earthquake early warning (EEW), operational earthquake forecasting (OEF), operational earthquake loss forecasting (OELF), structural health monitoring (SHM), rapid loss assessment (RLA), recovery and rebuilding efforts (RRE) and dynamic risk communication. While evaluating the output products of these modules in terms of their costs and benefits, we highlight the innovation in these tasks being developed within RISE and their potential impact on risk mitigation. Our aim is to eventually provide a robust framework for use in investment decision making by governments/stakeholders/funding agencies.

We started with developing the framework to evaluate immediate-to-long-term benefits of risk mitigation actions (Table 1). We first defined the key players (RISE modules) being EEW, RLA, RRE, SHM. Our view is not to favour one module or another, though some of the innovations we are currently developing within RISE may provide cost effective solutions and complement each other in different ways within the framework.

<table>
<tr><th></th><th>Time</th><th colspan="2">RISE Modules</th><th>Products/Benefits</th><th>Possible Mitigation Actions</th><th>Costs</th></tr>
<tr><td rowspan="4">DYNAMIC RISK COMMUNICATION</td><td>Short</td><td colspan="2">EEW with optimized seismic network</td><td>- Max warning times for correct alerts
- Min number of missed alerts
- Reduced damage to equipment, people
- Reduced injuries, social losses, BI</td><td>- Shutdown critical systems
- Take cover
- Moving away from hazards
- Protection of manufacturing processes</td><td>- Cost of improving seismic network
- Cost of action
- Cost of false/missed alerts</td></tr>
<tr><td rowspan="2">Short - Medium</td><td rowspan="2">RLA</td><td>SHM</td><td>- Time gain in emergency response
- Improved understanding of building damage
- Reduced fatalities/injuries social losses, BI</td><td rowspan="2">-Emergency response
- Recovery Planning</td><td>- Cost of Sensors
- Electricity for measuring, streaming, processing data
- Cost of False & missed alarms</td></tr>
<tr><td>DYNAMIC VULNERABILITY

- Damage accumulation
- Time variability of exposure
- Integration of real-time SHM observations</td><td>- Improved OELF (significant during seismic swarms when short term seismic risk assessment is needed)</td><td>Cost of Person months for developing the methodology
Cost of seismic network & maintenance</td></tr>
<tr><td>Medium-Long</td><td colspan="2">RRE</td><td>Recovery functions</td><td>-Reduced Property damage, BI social losses</td><td></td></tr>
</table>

Table 1. Framework for Risk Cost Benefit Analysis

Below we will summarize CBA efforts in various RISE Modules:

EEW AND CBA:

Objectives:

The aim is to evaluate the effectiveness of an earthquake early warning system (EEWS) in reducing earthquake casualty risk and optimize an existing seismic network in order to maximize earthquake early warning capabilities at minimum cost. A demonstration of the devised framework is carried out for Switzerland. With respect to the network optimization, we use a genetic algorithm to determine the optimal sensor distribution in a seismic network that maximizes its EEW performance, as quantified via the maximum warning time for correct warnings in damaging earthquakes. The work is carried out in two parts:

Part 1: Risk-based EEW Performance Evaluation and Optimization

by M. Böse, A. N. Papadopoulos, L. Danciu

The goal of Earthquake Early Warning (EEW) is to issue an alert before the damaging seismic waves of an earthquake hit, using waves that have already left the source but have not reached the location yet. We use warning time as a key performance indicator and assess the risk-based EEW performance using the example of Switzerland. We simulate 1k realizations of a 100 year long stochastic earthquake catalog with ~24k scenario earthquakes (5.0 ≤ M ≤ 7.4), which samples the earthquake rate forecast of the Swiss Hazard Model in space and time (Figure 4.6.1). We link the predicted ground-motions to the built environment and determine warning time statistics for different loss classes (here fatalities and injuries; Figure 4.6.2). Finally, we apply a genetic algorithm to optimize the Swiss Seismic Network by proposing sites for new stations in order to optimize its EEW performance for damaging earthquakes (Figure 4.6.3).

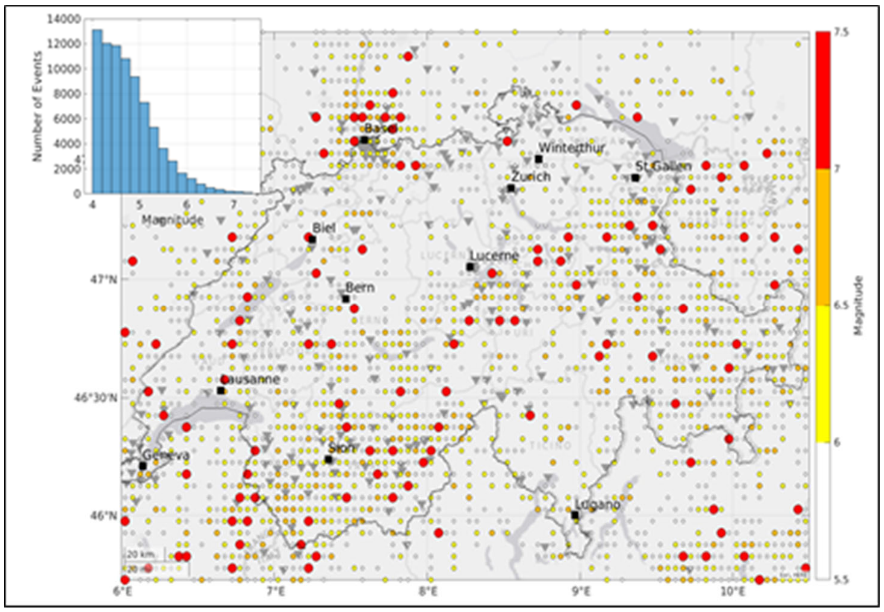


Figure 4.6.1. Stochastic earthquake catalog, including ~24k scenario earthquakes (5.0 ≤ M ≤ 7.4) in and around Switzerland.

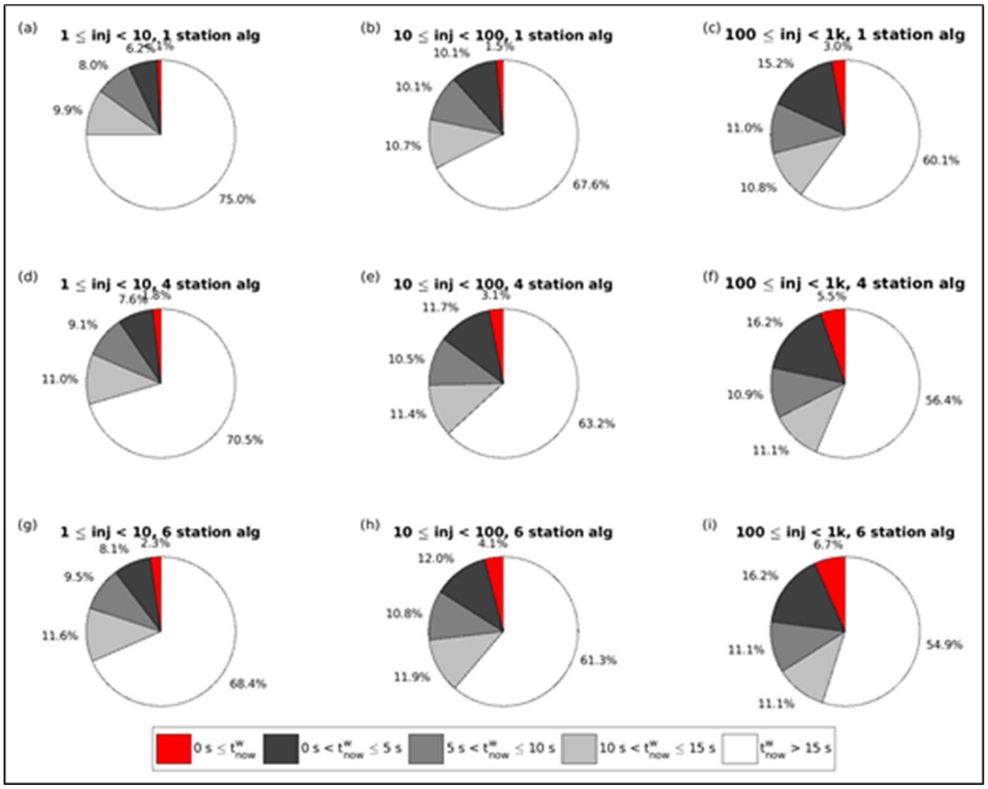


Figure 4.6.2. Warning time statistics (preliminary) for different loss classes (here injuries) and EEW algorithms. Warning times include 2 s data latency.

SEISMIC NETWORK OPTIMIZATION WITH GENETIC ALGORITHM

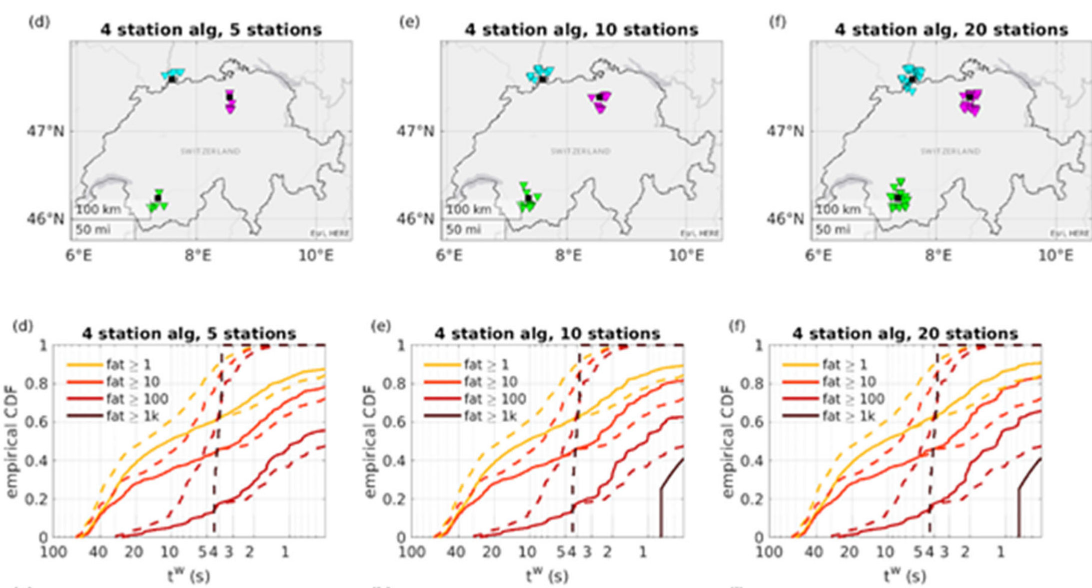


Figure 4.6.3. Proposed sensor locations (top) with the goal to optimize EEW performance for damaging earthquakes and their impact on warning time for different loss classes (here fatalities): lower dashed line: performance for current network; upper dashed line: maximum performance for an idealized network; solid line: performance for optimized network after deployment of 5, 10 or 20 new stations (from left to right). Warning time statistics include 2 s data latency.

Part 2: Effectiveness of EEW in mitigating seismic risk

by A. N. Papadopoulos, M. Böse, L. Danciu

Earthquake early warning systems (EEWS) aim to rapidly detect earthquakes and provide timely alerts, so that users can take protective actions prior to the onset of strong ground shaking. The promise and limitations of EEWS have both been widely debated. On the one hand, an operational EEWS could potentially mitigate earthquake risk by triggering potentially cost- and life-saving actions. On the other hand, the effectiveness of an EEWS hinges on the accuracy and timeliness of its alerts. EEWSs have substantially improved over the years, yet there are physical constraints as well as variability in the correlation between the early parts of the signal and earthquake source and ground-motion parameters that limit the alert speed and accuracy, even for an ideal system. Herein, we rely on regional event-based probabilistic seismic risk assessment, and devise a quantitative and fully customizable framework for evaluating the effectiveness of EEW in mitigating risk. We demonstrate this framework using Switzerland as a testbed.

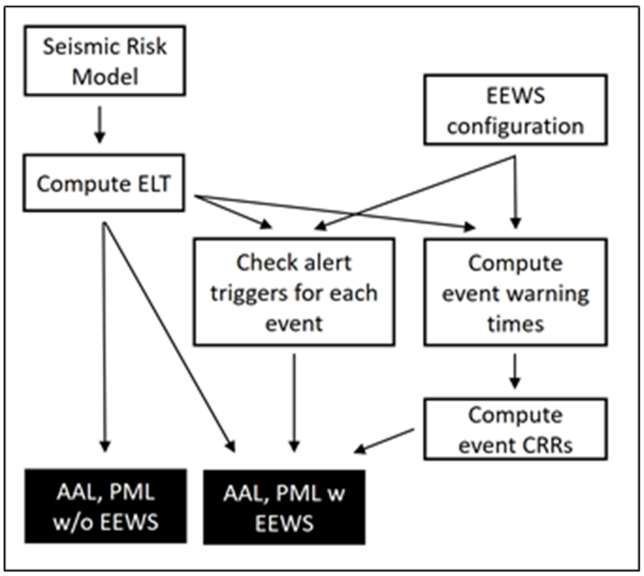


Figure 4.6.4. Workflow for assessing EEWS effectiveness

The proposed framework is illustrated in **Error! Reference source not found.** and can be briefly summarized in the following steps:

1) A regional seismic risk model is used to generate a so-called event loss table (ELT). The latter comprises a catalogue of simulated earthquakes, generated from an underlying earthquake source model, together with associated losses (herein casualties, i.e. fatalities and injuries) computed using models of ground shaking intensity, exposure and vulnerability for the region of interest.
2) Given a seismic network configuration, the potential warning time at a site of interest is estimated for each earthquake in the ELT. Also, assessed is whether an alert is issued, given a set of pre-determined alerting criteria.
3) For each earthquake for which an alert is issued, the warning time is used to determine the potential reduction of the event loss. To this end, a logical framework is devised using judgement informed by literature data from post-earthquake surveys. More precisely, the EEWS-adjusted loss for each event i can be computed as:

$$C_{EEWS}^{i}(t_i^w) = C_0^i * \left(1 - CRR(t_i^w) * F_{alert}^i * F_{day}^i\right)$$

where C_0^i is the event i loss without EEW, CRR denotes the casualty reduction ratio as a function of warning time t_i^w,F_{alert}^i is a binary flag that defines whether an alert is issued for event i or not, while F_{day}^i is again a binary flag that is equal to one when the earthquake occurs during the day (we assume that alerts issued during the night will not have an effect on casualties). CRR is computed as:

$$CRR(t_i^w) = P_s * P_r * \min(1.0, WV(t_i^w))$$

where P_s denotes the probability that an individual receives and notices the warning message, and P_r denotes the probability that the recipient responds to the warning. WV effectively represents the probability of casualty avoidance as a function of warning time, among individuals that receive and react to the warning. For the latter, we partition the sample space into recipients that will respond to the alert with the recommended duck cover and hold on (DCHO) protocol and those that will attempt to evacuate. The equation given below can then be used to estimate WV. The description of the various parameters contained therein, along with values that were deemed reasonable, is given in **Table 1**. An investigation of the effect of some these parameters on WV is also shown in **Error! Reference source not found.**.

- $\boldsymbol{WV(t_i^w) = P(CA|t_i^w) = P(CA|t_i^w, SDCHO) \cdot P(SDCHO|t_i^w, ADCHO) \cdot P(ADCHO)}$
- $\boldsymbol{+P(CA|t_i^w, SE) \cdot P(SE|t_i^w, AE) \cdot P(AE)}$

4) Using the EEWS-adjusted ELT, traditional risk metrics such as average annual losses (AAL) or probable maximum loss (PML) curves can be derived and contrasted with the original non-EEWS-adjusted estimates (**Error! Reference source not found.**). This analysis can also serve as a stepping stone for a downstream cost-benefit analysis.

Table 2. Parameters for estimation of WV

- **Table 1. Parameters for estimation of WV**

Probability terms - Equation (**Error! Reference source not found.**)	Description	Value for fatality avoidance	Value for injury avoidance
$P(CA\|t^w, SDCHO)$	Probability of casualty avoidance given successful DCHO	10%-40%	50%-80%
$P(CA\|t^w, SE)$	Probability of casualty avoidance given successful evacuation	99.9%	70%
$P(SDCHO\|t^w, ADCHO)$ = $F_{SDCHO}(t_i^w\|ADCHO)$	Probability of successful DCHO given attempted DCHO and warning time	LN ($\tilde{t}_{DCHO}^w$ = 8.8 s, $\sigma_{\ln t^w}$ = 0.4)	
$P(SE\|t^w, AE)$ = $F_{SE}(t_i^w\|AE)$	Probability of successful evacuation given attempted evacuation and warning time	LN ($\tilde{t}_{evac}^w$= 20-45 s, $\sigma_{\ln t^w}$ = 0.8)	
$P(ADCHO)$	Probability of DCHO attempt	30%	
$P(AE)$	Probability of evacuation attempt	70%	

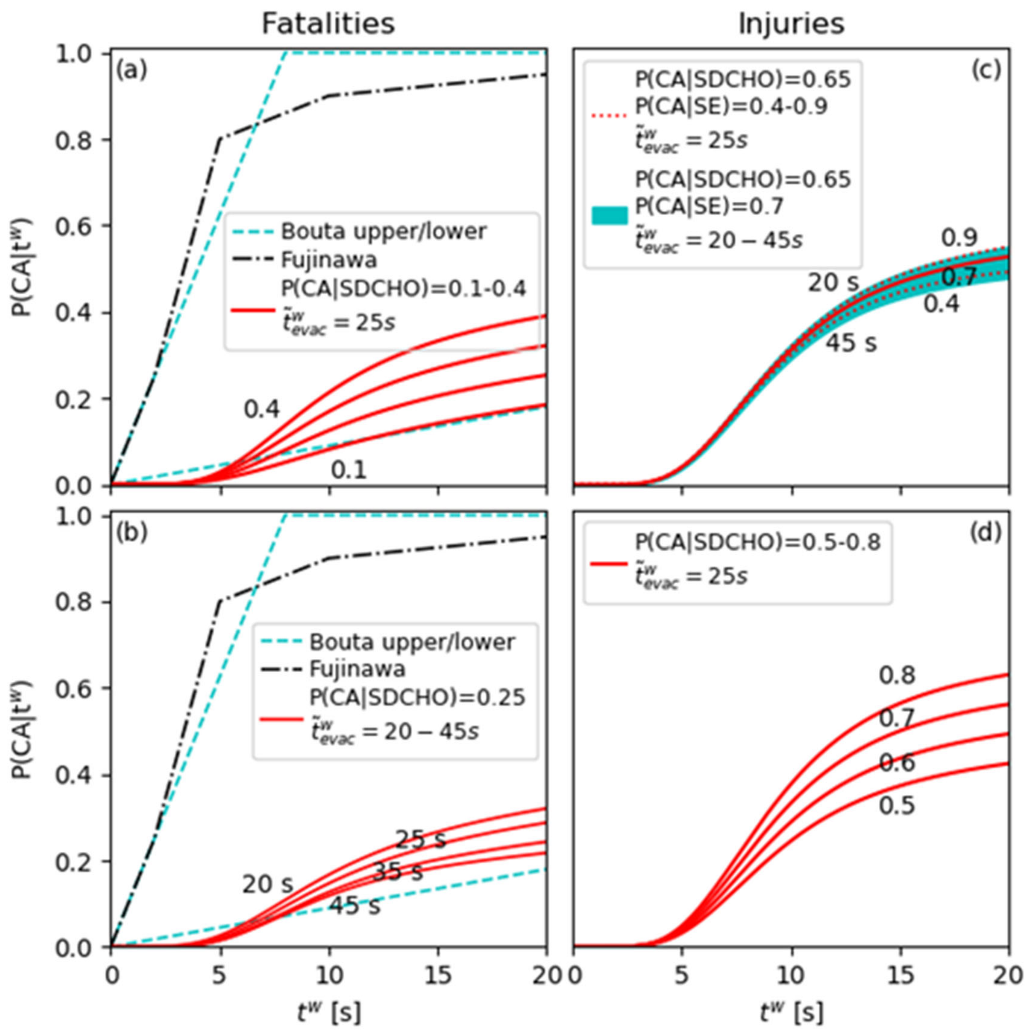


Figure 4.6.5. Effect of different parameters on P(CA|t^w) for fatalities (a,b) and injuries (c,d) and comparison with other studies. Parameters not specified in the legends are taken as listed in Table 1.

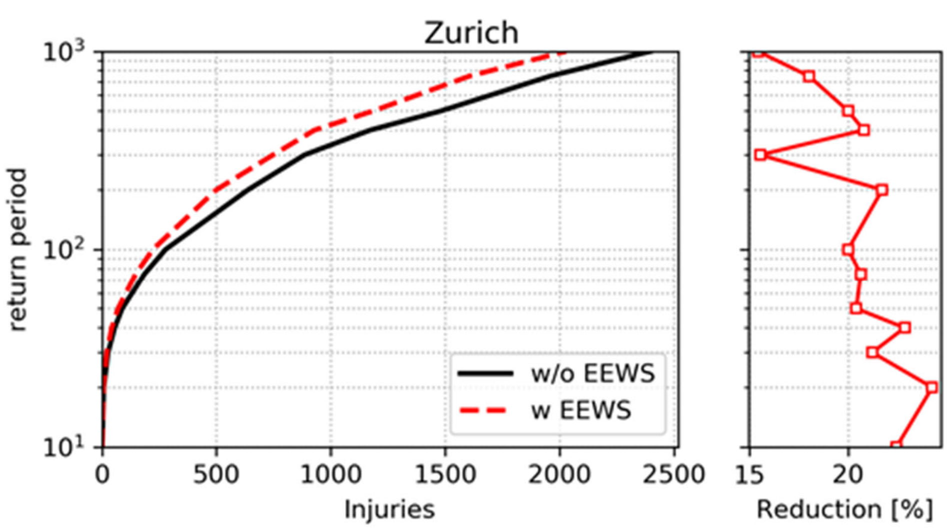


Figure 4.6.6. Injury PML curve for the city of Zurich with and without EEWS

2. Structural Health Monitoring and CBA

by Yves Reuland and Eleni Chatzi

When the dynamic structural response of a building to an earthquake signal is recorded, for instance with accelerometers, damage-sensitive features (DSFs) can be computed. The value and distribution of the DSFs, derived in near-real time, offer insights into the presence and severity of damage.
The comparison of the DSFs, extracted during shaking of a structure, with predefined probabilistic distributions, that are for instance derived via suited structural models, allows for transforming the building performance into discrete damage grades (labels), for which alerts and warnings can be issued. Thus, a main target of SHM is to attribute, after an earthquake, the appropriate building tag. This can be delivered in the form of red-Amber-Green (RAG) alerts, i.e., as either safe (green), unsafe (red) or uncertain (orange) (Figure 4.6.7). Following such an approach, the number of buildings requiring rapid visual inspection by human inspectors can be reduced, thus improving the resilience assessment and functional recovery of the residential building stock.

Costs:

- Costs of sensors
- Electricity to measure, stream and process data
- Cost of false or missed alarms

Benefits:

- Faster inspection/assessment
- Faster emergency response reaction
- Improved understanding of building damage and possible the required repair actions
- Faster/Targeted recovery planning
- Improved resilience assessment

Challenges:

- SHM does not improve the structure but provides time savings and acceleration of rapid response & recovery.
- Design a realistic earthquake scenario (nonlinear dynamic simulations, correlated seismic signals, inter-building variability) and the related computational cost of urban-scale applications.
- How to monetize the related costs and benefits, such as the price of false/missed alarms or the profit from accelerating reaction immediately after an earthquake and/or in city-scale assessment (longer term goal)?
- Uncertainties in quantifying standardized inspection processes, as for instance the number of involved inspectors, how fast they work.
- Uncertainties in terms of the extent of damage and size of the event.
- Damage to non-structural elements and risk related to adjacent buildings cannot be measured.

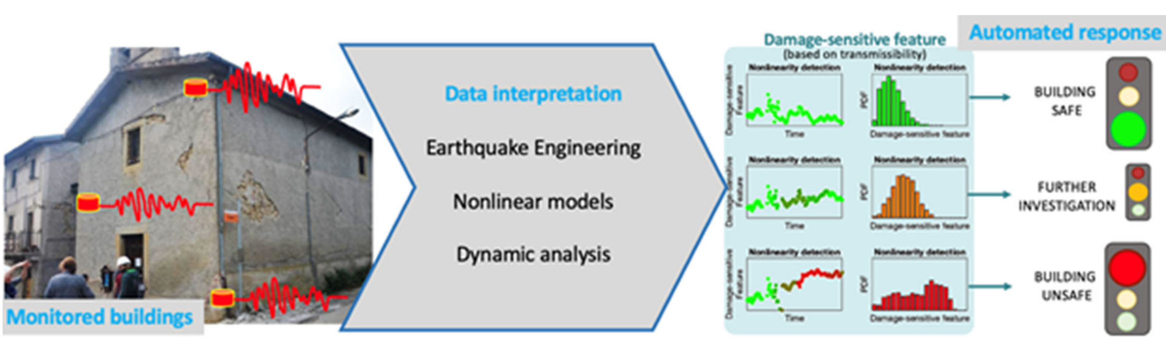


Figure 4.6.7 Representation of SHM used for building tag, after an earthquake delivered in the form of red-Amber-Green (RAG) alerts, i.e., as either safe (green), unsafe (red) or uncertain (orange).

3. Operational Earthquake Loss Forecasting and CBA

by Eugenio Chioccarelli
Combining results of operational earthquake forecasting with the vulnerability and exposure of the built environment, the operational earthquake loss forecasting (OELF) system provides measures of short-term seismic risk.
OELF can be improved in order to account for damage accumulation during seismic swarms. This requires:

1. Development of state-dependent fragility functions for each building class representative of the existent Italian building portfolio
2. Development of a methodology for damage accumulation on building classes on the basis of what already proposed for single-structure
3. Recorded ground motions of earthquakes.

Costs: PMs for developing the methodology

Benefits: Improved OELF

Illustrative cases of past seismic sequences will be analysed to discuss the effect of damage accumulation.

In the following figure, an illustrative scheme of OELF results is provided. For each building class, the domain of the possible performances of the structures is discretized in three damage states (DS). Before the first earthquake of the analysed sequence, the entire existent building portfolio is assumed undamaged, i.e., it is in DS_0; after the earthquake, MANTIS V.2 forecasts the percentages of buildings in each DS. During the following forecasting and earthquakes, the damaged building portfolio is considered, that is, the structures can be already damaged when the shocks occur.

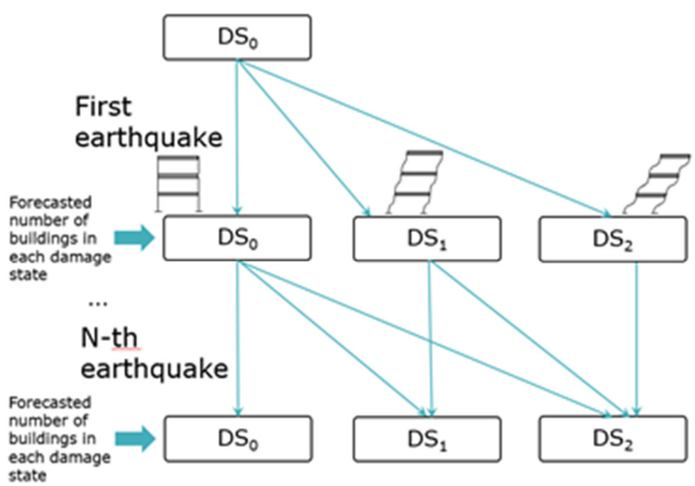


Figure 4.6.7 Schematic representation of damage accumulation

The case study developed in Task 6.2 shows that the differences in forecasting whether or not the damage accumulation is considered are important when it comes to aftershocks. Conversely, the forecasting on the mainshock produces similar results. However, the result of such a comparison depends on the characteristics of the considered seismic sequence and localization/extension of the studied area with respect to the sources of the earthquakes.

List of submitted deliverables and achieved milestones in WP4

WP4 has not submitted any deliverables yet. In fact, the first deadline is due by February 2022 according to the current Gantt chart. As pertaining to milestones, MS32 and MS33 were delivered between December 2019 and February 2020, in cooperation with WP5 and WP6. The MS linked to only WP4, that is, MS27, MS28 and MS29, are ongoing and will be provided by the fixed deadline (February 2022).

Summary of Exploitable Results in WP4

1) Peer reviewed publications

- Cetin, M. and Safak, E. (2021). An Algorithm to Calibrate Analytical Models of Multistory Buildings from Vibration Records, Earthquake Spectra (accepted for publication, in print).
- Chioccarelli E., Iervolino I. (2021) Comparing short-term seismic and COVID-19 fatality risks in Italy. Seismological Research Letters. DOI: 10.1785/0220200368
- Crowley H., Despotaki V., Silva V., Dabbeek J., Romão X., Pereira N., Castro J.M., Daniell J., Veliu E., Bilgin H., Adam C., Deyanova M., Ademović N., Atalic J., Riga E., Karatzetzou A., Bessason B., Shendova V., Tiganescu A., Toma-Danila D., Zugic Z., Akkar S., Hancilar U. (2021) "Model of Seismic Design Lateral Force Levels for the Existing Reinforced Concrete European Building Stock," Bulletin of Earthquake Engineering, DOI: https://doi.org/10.1007/s10518-021-01083-3
- Dabbeek J., Crowley H., Silva V, Weatherill G., Paul N., Nievas C. (2021) "Impact of exposure spatial resolution on seismic loss estimates in regional portfolios," Bulletin of Earthquake Engineering, DOI: 10.1007/s10518-021-01194-x
- Martakis P, Reuland Y, Chatzi E (2021a) "Amplitude-dependent model updating of masonry buildings undergoing demolition", Smart Structures and Systems, 27(2), pp.157-172. DOI: http://dx.doi.org/10.12989/sss.2021.27.2.157
- Martakis P, Reuland Y, Imesch M, Chatzi E. (2021b) "Destructing to PreserveRealistic seismic assessment of masonry buildings through probabilistic model updating based on monitored demolitions", submitted to Bulletin of Earthquake Engineering.
- Martins L, Silva V, Crowley H, Cavaleri F (2021) "Vulnerability Modellers Toolkit, an Open-Source Platform for Vulnerability Analysis," Bulletin of Earthquake Engineering, https://doi.org/10.1007/s10518-021-01187-w
- Reuland Y, Martakis P, Chatzi E (2021c) "Comparative study of damage-sensitive features for rapid data-driven seismic structural-health monitoring", submitted to Earthquake engineering & structural dynamics.

2) Conference publications

- Bodenmann L, Reuland Y, Stojadinovic B (2021a) "Using regional earthquake risk models as priors to dynamically assess the impact on residential buildings after an event", 1st Croatian Conference on Earthquake Engineering, March 22-24, Zagreb, Croatia.

- Bodenmann L, Reuland Y, Stojadinovic B (2021b) "Dynamic updating of building loss predictions using regional risk models and conventional post-earthquake data sources", Proceedings of the 31st European Safety and Reliability Conference, September 19-23, Angers, France.

- Caglar, N.M. and Safak, E. (2021). Predicting Seismic Response of a Tall Building to a Large Earthquake Using Recorded Waveforms from Small Earthquakes, accepted for presentation and will appear in the proceedings of the *European Safety and Reliability Conference,* 19-23 September 2021, Angers, France.

- Crowley H, Silva V, Kalakonas P, Martins L, Weatherill G, Pitilakis K, Riga E, Borzi B, Faravelli M (2020) "Verification of the European Seismic Risk Model (ESRM20)," Proceedings of the 17th World Conference on Earthquake Engineering, Japan.

- Martakis P, Reuland Y, Chatzi E (2021e) "Amplitude dependency effects in the structural identification of historic masonry buildings" EuroStruct August 29-September 1, 2021, Padova, Italy.

- Martakis P, Reuland Y, Ntertimanis V, Chatzi E (2020) "Vibration monitoring of an existing Masonry Building under Demolition", International Association for Bridge and Structural Engineering Symposium, 20-22 May 2020, Wroclaw, Poland.

- Orlacchio M., Chioccarelli E., Baltzopoulos G. and Iervolino I. (2021) "State-dependent seismic fragility functions for Italian reinforced concrete structures: preliminary results" Proceedings of 31st European Safety and Reliability Conference (ESREL), France.

- Reuland Y, Martakis P, Chatzi E (2021d) "Damage-sensitive features for rapid damage assessment in a seismic context", 10th International Conference on Structural Health Monitoring of Intelligent Infrastructure, 30 June – 2 Jul 2021, Porto, Portugal.

3) Other exploitable results/data

- Database of European building exposure models (10.5281/zenodo.4062044)
- Database of European capacity curves (10.5281/zenodo.4062410)
- Open source tools for disaggregating exposure models to higher resolution (in collaboration with the Global Earthquake Model): https://github.com/GEMScienceTools/spatial-disaggregation
- Open source software to develop fragility and vulnerability models using European capacity curves (in collaboration with the Global Earthquake Model): https://github.com/GEMScienceTools/VMTK-Vulnerability-Modellers-ToolKit
- European ShakeMap system: http://shakemapeu.ingv.it/
- Fragility functions for Italian residential r.c. building classes
- Prototype of OELF V.2

1.2.5 Work package 5

Overview

The aims of work package 5 are:

(1) to provide clear and accurate information to policy-makers and the public to enable strategic planning and appropriate preparation for seismic events and;

(2) to offer timely, appropriate information to a geographical area when the seismic risk rises and explore crowdsourced EEWS for global earthquakes; and

(3) to collect large numbers of eyewitness observations, both direct and indirect, about the degree of shaking being felt and possibly the damage incurred. This, in turn, will improve rapid situation awareness and augment data at a relatively low cost.

The specific objectives of work package 5 are:

- To discuss the needs and understand the existing decision-making environments and usual routes of communication for each of the different audiences for risk messages (long-term decision-makers, government and organizational leaders, emergency services, public) in different countries.
- Review best practices in risk communication, focusing on dynamic information communication in a range of fields, including medical, economic/financial, natural hazards, engineering, and environmental.
- Undertake an iterated user-centred design process to develop a method of communication, with user-testing across different countries involved to integrate the design process. This will culminate in a formal controlled evaluation of the communications.
- Improve procedures for using internet-based intensity questionnaires for two-way communication and deriving useful scientific information on earthquakes (e.g., fast characterization of seismogenic faults).
- Exploit the LastQuake* (280k users), Earthquake Network† (400k users) and MeteoSuisse Apps (2 Million Users) for their synergies for crowdsourced EEWS and RIA.

- Detect triggered landslides through social media monitoring.

Task 5.1 Dynamic Risk Communication

Operational Earthquake Forecasting (OEF)

Operational earthquake forecasting - short term forecasting of seismic activity in a geographical area - is a difficult thing to communicate well. During normal, quiet times the chances of a damaging earthquake in any area is very low. During periods of elevated activity, the chances can approach 100%. These extremes of probability make any linear scale challenging to develop. The concept of probability is also hard to explain, and more so for a 'one off event' such as the future time period expressed in a forecast. The usual way to explain probabilities is to turn them into frequencies - 'out of 100 people like you we'd expect x to….' The equivalent translation for future time is the much-less-easily-understood 'out of 100 possible ways that next week could turn out we'd expect an earthquake to happen in x of them'. Finally, even on top of the probabilistic (inherently, aleatorically, uncertain) nature of the forecast, there are large uncertainties about our knowledge and abilities to forecast (epistemic uncertainties).

Yet, just because our knowledge is incomplete, and earthquakes cannot be predicted, doesn't mean to say that knowing there is an increased chance of one happening in a particular area isn't valuable. Preparedness: rehearsing evacuation procedures, ensuring supplies are to hand and all lines of communication are open, can make the difference between life and death, and yet not have large overhead costs.

The key to all this is good communication - of what can be done, and of the level of (un)certainty. This is the challenge of Task 5.1.

The first stage of task 5.1 was a review of how other domains have approached these challenges, and what can be learned from their successes and failures. Weather forecasters - particularly those that specialise in storms and hurricanes - have decades of experience of attempting to communicate the rapidly-changing likelihoods and potential impacts of these hazards. Flood forecasters, those working in financial markets, and (especially recently) epidemiologists have all also faced similar challenges. Our review pulled together the major lessons to be learned from years of research and practice in these fields from both literature and interviews with professionals:

1) Ensure that your audiences are as familiar as possible with what you are going to communicate, how to interpret it, and how to act on it.

- Work with journalists and the media (e.g. the twice-yearly workshops run by the Storm Prediction Service in the US in which media professionals and forecasters meet) to ensure that you are providing the information they need and that they understand the communications and their limitations, so that they can accurately convey the information to the public. Ensure the media are ready to interpret the hazard into the risks for the public: what would the consequences of a seismic event actually be, locally? Regular meetings are important as they ensure that new journalists are trained up, and that everyone is familiar with the communications before any event becomes 'news'.

- Similarly, hold regular (e.g. annual) meetings with emergency responders, infrastructure managers, and others who would need to respond to a seismic event. As above, ensure that you are providing the information they need and that they understand the communications you are providing. You could consider running practice drills to ensure that in the event of heightened activity, they all know what actions they should take. It is important for forecasters to be aware of 'thresholds' that trigger different emergency responses so that the consequences of every action or sign that forecasters might take or detect are known by everyone (as learned by tornado forecasters in the US, where certain threshold probabilities can trigger school closures in some states etc).

- Produce regular (e.g. daily or weekly) forecast information, even in times where there is no change or no significant seismic activity. This ensures that the channels of communication are open, well-oiled, and that everyone in the chain of communication is familiar with 'normal' activity and is therefore more ready to respond to any significant changes (as learned by the UK's Environment Agency when communicating flood forecasts).

- Work with schools, businesses, communities and with the media/government to ensure that children and the public in medium or high hazard areas (or across a whole country) know what preparations to make in the case of a raised level of alert, and what to do in the event of an earthquake. When an earthquake occurs, everyone needs to know instantly what to do, without having to stop and think about it. This requires regular training from a young age. The evidence that those who had had school training in how to respond in a storm in the US all survived an event when it happened, whilst there were deaths amongst those who didn't, suggests how important this training can be.

2) Be aware of the psychology of 'risk': someone's perception of a risk is, quite rightly, influenced by far more than just the likelihood and severity of an event.

- Individuals' personal vulnerability (how the event would affect them personally if it happened, e.g. their financial situation, health status, the vulnerability of their house to damage), their previous experience with seismic events, and how much they feel they have responsibility and control over the outcome of an event are important parts of how they will react to information about a risk. Instead of trying to make people worry about an event happening, it is probably more helpful to aim for 'resilience' (as the UK flood resilience teams do). Ensure that people feel that there are concrete and achievable steps they can take, individually, to protect themselves, and to make reminders of the hazard and what actions to take a regular part of life (e.g. through making the seismic forecast a part of the weather forecast in medium to high hazard areas, alongside reminders of what to do in the event of an earthquake).

- Trust in the sources of information about the risk is very important. Try to avoid politicisation by working with a very broad range of organisations, including religious groups across the spectrum, all political groups, all media outlets, local community groups and social/charitable groups. People judge communicators on what their motivations seem to be, so ensure that there are no perceptions of conflicts of interest: it is entirely motivated by the desire to save lives and livelihoods, and that the actions that can be taken are individual as well as collective and societal.

3) Test all potential communications with their intended audiences to try to maximise their ease of comprehension (and minimise the chance of misunderstandings). There are a few particular areas that are worth considering:

- Work with others to help communicate the potential impacts of forecast events, not just the event itself. Learn from the experience of the winter storm forecasters in the US who warned that a storm was coming, but the public didn't anticipate what exact challenges, risks and impacts that weather would bring.

- Small numbers are very hard to understand. Ways to avoid tiny (and hence meaningless) absolute risks are to communicate relative risks, represent the numbers in a graphical way (e.g. through colours or points on a scale), use a larger time frame over which they are being considered, give the numbers context in the form of comparators (e.g. 'as likely as…' or 'similar to the event in 1956'). However, each of these will have a different effect on the audience so need to be empirically tested.

- Give people context to help them understand the risk, such as examples from the past with which to compare the predicted future (e.g. showing what the seismic activity has been over the past year, or during a period of seismic activity that would be familiar to them).

- Do not use verbal terms (e.g. 'likely', 'severe') without a cue as to the numerical likelihood or impact that they represent – different people will interpret words in different ways.

- Too much information at once makes it much more likely that the important message will be lost. Design your communications so that people get only the information they need to make their key decisions first, and then allow them to drill down to more detail if they want. For example, do they need information across a broad geographical area (in which case a map might be most helpful), or do they need information only about a small geographic area, but in more detail or over time (in which case a timeline might be most helpful). What level of event do they need to know about (any felt event, or only above a certain threshold of impact)?

- What time period do your different audiences want/need the forecast to cover? Over what time period does it become too uncertain/too little trusted to be of use?

- Graphics are very useful, and familiarity of a graphical format makes it much easier for people to understand 'at a glance'. Weather forecasts, using certain icons and terminology, have become embedded within culture (although some aspects, such as probabilistic information, are still widely misunderstood). Where possible use formats or icons that are culturally familiar, but always have a text explanation available. Where a new format promises better comprehension through empirical testing, don't be afraid to introduce it, but ensure that the audience are exposed to it (with explanation) regularly and during seismically quiet times, to allow them to become familiar with the format and how to interpret it.

- Remember however, that not all commonly used graphical techniques are necessarily examples of best practice. For example, according to cartographic principles, circles of different sizes are considered a good way of conveying different quantities on a map as it is thought that this gradation in size tunes into an intuitive perception that bigger symbols represent higher (larger, stronger etc) values. On this basis, such an approach is widely used in map design. However, evidence suggests that perceptual biases mean that people find it very hard to accurately assess areas and volumes (Lipkus and Hollands, 1999). This means that representing variation in quantities within areas bounded by circles is not likely to lead to accurate perceptions.

- Be very careful in the use of colours. Although 'red/green' may be a common way to indicate levels of danger, it can not only produce misperceptions (that 'green' is 'safe') but also is difficult for those with different forms of colour blindness. Colour gradient scales should also be chosen carefully to avoid artifacts of perception that seem to create banding rather than indicating a smooth gradient.

- Ensure that behavioural advice is given alongside the forecast, telling people what action they should take as a result of the forecast (reminding them that a high-impact event can occur at any time), as the UK Met Office has learned is helpful for their forecasts.

- One communication method rarely suits all. Expert audiences and lay audiences interpret things differently; emergency responders and the public have different information needs; people with different experiences of the hazard are likely to respond differently. Be prepared to have several different types of communication, and where possible to allow people to choose which they want (e.g. different presentations on a website or app).

- Give quantified uncertainties in the form of a range (or represent the range graphically – what format you use will need testing), but also be careful to warn people of the unquantifiable uncertainties and that seismic events are inherently unpredictable. Although weather forecasters have been wary of using probabilistic forecasts, and they can be misunderstood, there is evidence that a public audience can make better decisions when armed with probabilities than deterministic forecasts (although using low absolute probabilities may be tricky). Here training and working with the media to help them phrase the probabilities and give regular translations of what they mean in lay language in their communications may help.

- Be as transparent as possible about the information available to you. You might consider following the UK Environment Agency's lead in allowing public access to the readings on individual sensors via their website, so that they can see the raw data and the sensors most local to them.

- Consider communicating information about likely timings. Although it is not possible to forecast when a seismic event may occur, it may be useful for audiences to know how long seismic events usually last, and how long they should wait after an event before leaving a place of safety (as was found by the US tornado forecasters), or starting emergency support etc. (as was found by USGS in their trials of operational earthquake forecasting).

- Expect to have to provide a personal interpretation service for those who are concerned and want to check with a 'real person' how to interpret the forecast (particularly in times of heightened seismic activity). If this is outsourced to a media or communications centre they need to have the expertise to do the interpretation accurately.

- Consider 'pre-bunking' common misinformation/misunderstandings.

4) Don't confuse 'everyday' forecast communications with warnings. The two have different aims (forecasts are providing regular information, warnings are there to trigger behaviour) and hence use very different communications strategies.

This was delivered as D5.1.1.

Following these pieces of advice, we are now carrying out interviews and focus groups with the different audiences and stakeholders in Italy, Switzerland and Iceland (including public, civil protection, the media and seismologists) to review the current communication pathways for long term risks, variable short-term risks (operational earthquake forecasts (OEF)), earthquake early warnings (EEW) and rapid impact assessments, in each country. This aims to help us to identify and understand current practice and where - and to whom - these different communications might be best used (which will form the basis for D5.1.2).

We are also carrying out interviews and focus groups with these same audiences and stakeholders in order to co-develop communications of long term risks, OEF, EEW and rapid impact assessments that are meaningful, comprehensible and useful to each audience and stakeholder group (forming the basis of D5.1.3).

The work detailed above led us to co-developing with identified audiences and stakeholders a dashboard design that can communicate operational earthquake forecasts (OEF) in a meaningful way to each group.

So far we have carried out:
65 semi-structured interviews with the public in Iceland, Switzerland and Italy
2 focus groups with expert seismologists
4 focus groups with the Italian public

Over the coming months we are testing our newly-designed prototype communications with further focus groups in each country, as well as with key people who could be involved in implementation of OEF.

Earthquake Early Warning

Of all the natural hazards worldwide, earthquakes cause the most fatalities and financial losses. One strategy to increase society's ability to take protective actions is the implementation of earthquake early warning (EEW) systems. Three global initiatives effectively drive these developments, namely the Sendai Framework for Disaster Risk Reduction, the Paris Agreement and the Sustainable Development Goals. Currently, EEW systems are operating in nine countries and being tested for implementation in thirteen countries (Cremen & Galasso, 2020).

The primary aims of EEW systems are to notify the general public about imminent strong ground shaking so that they can protect themselves on the spot and to trigger automated shutdown or safety procedures such as slowing down trains and securing critical infrastructure (Allen & Melgar, 2019). In recent years, several research groups around the world have assessed how the public perceives EEWs and what actions are triggered or intended to be taken (Becker et al., 2020; McBride et al., 2020; Nakayachi et al., 2019; Sutton et al., 2020; Tan et al., 2021). We contribute to this investigation by exploring the public's expectations and needs in European countries and also countries where damaging earthquakes are expected only every 50 to 150 years, e.g. Switzerland.

So far, we have conducted several expert interviews with seismologists, social scientists and practitioners working on EEW systems. In addition, we conducted 65 semi-structured interviews with the public in Iceland, Switzerland and Italy to get a first impression of the public's attitudes towards EEWs. Based on these insights, we designed different EEWs designs and refined them in an iterative process with EEW experts. The resulting designs were then tested with the Swiss public (n=596), using a between-subject experiment survey. Thereby, we focused on three issues: i) Which preferences with regard to receiving EEWs does the public have?, ii) Which message elements trigger which actions?, and iii) How could a second message look like?.

The main results are:

- The Swiss public **would like** to receive EEWs.
- The public prefers to receive EEWs for **all earthquakes they may feel**.
- The public prefers a warning time of **20 or more seconds**, which is technically not feasible.
- The EEWs should be sent as **push notifications** on smartphones.
- Many people think they know how an EEW system works but in reality they do not.
- Pictograms, audio messages and messages for strong shaking **trigger** people to take actions.
- **Maps motivate** people to look for further information and warn others.
- On the message itself, people would like to have included behavioural recommendations for during the shaking, information about possible aftershocks and general information about the quake. Information that should/could be accessed via a link are behavioural recommendations for after the shaking, the extent of the damages and more detailed information about the expected aftershock sequence.

The next steps will be to publish the detailed results in a peer-reviewed publication and to compare them with the findings of the other countries to identify cross-cultural differences/commonalities. In addition, we aim at conducting a similar survey in Italy.

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Tan, M. L., Prasanna, R., Becker, J. S., Brown, A., Kenney, C., Lambie, E., & Johnston, D. M. (2021). Outlook for earthquake early warning for Aotearoa New Zealand: Insights from initiating a community-of-practice. 9.

Rapid Impact Assessment

Rapid Impact Assessment (RIA) after a severe earthquake can support civil protection agencies and emergency services to rapidly gain an overview of the expected building damages, number of fatalities, injured and displaced persons as well as economic losses. Such information allows coordinating and allocating the resources for the emergency response in an efficient manner. Of course, similar outputs can also be produced in advance, whereby these scenarios can be used to build up and support the awareness for damaging earthquakes among different stakeholders.

To gain first insights about the compilation, design and current use of RIA, we conducted interviews with experts working in the field. We had a look at the following products: PAGER (national and global), ShakeCast (national), QLARM (global), InaSAFE (national) and Globale Dynamic Exposure Model (global, still in development). The insights of these interviews fed into the design of the products currently developed to communicate the results of the European Seismic Risk Model 2020 (ESRM2020) and the Swiss Seismic Risk Model.

Regarding the ESRM2020, we have already conducted an interactive online survey testing the web-viewer of the risk model with potential end-users. Currently, further testing of different communication materials, e.g. maps and text elements is in the planning.

In the framework of the Swiss Risk Model, first designs of RIA and event scenarios have been tested with relevant federal and cantonal stakeholders in an online workshop. Additional tests with different users including relevant authorities, first responders, media and the public will be conducted in the upcoming months. The aim is to explore whether the outputs include all relevant information, is well understood and appealing. Based on the feedback, we will adapt the products accordingly.

Task 5.2 Crowdsourced EEWS and RIA

Achievements of task 5.2 concern EEW, rapid public information and rapid impact assessment, they are beyond initial project expectations and benefited from 5 unforeseen scientific collaborations.

Perhaps the most important result of this task is the demonstration that EQN, the smartphone app turning charging smartphones in motion detectors, is the first smartphone-based EEW system. During the studied period, early warnings were provided in 11 countries and for X earthquakes of magnitude 4.5 or greater. Moreover, an early warning of at least 8 seconds was delivered for intensity 6 (i.e. slightly damaging) during the destructive 2020 Albanian earthquake.

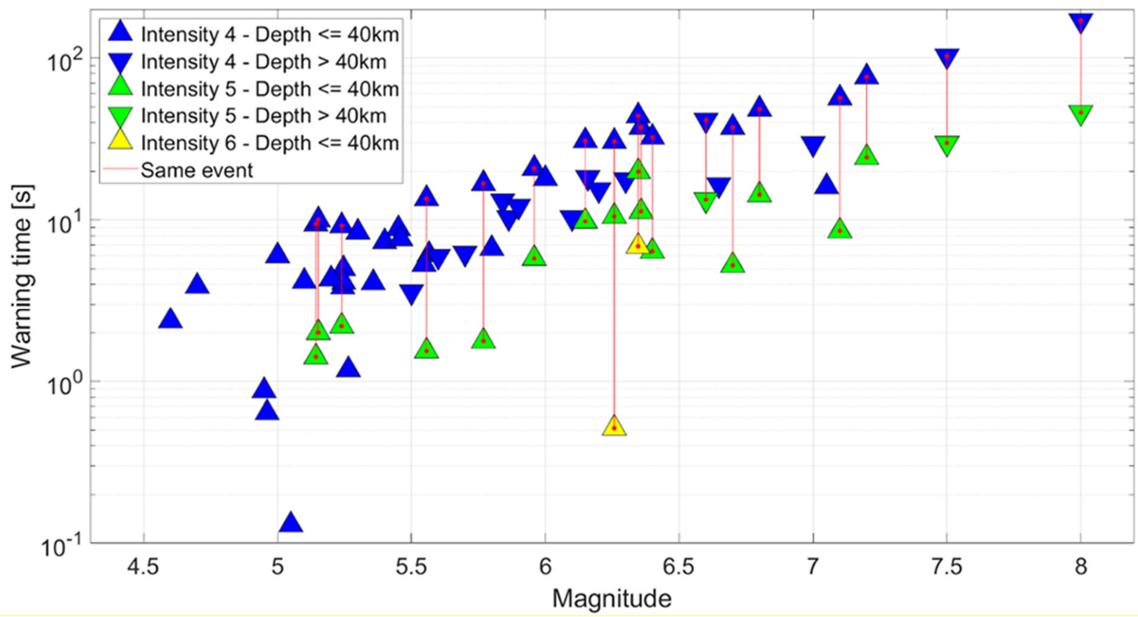


Figure 5.2.1 Estimated warning times for the 53 earthquakes detected worldwide with magnitude equal or greater than 4.5 with positive warning time. Blue, green and yellow triangles depict warning times for target intensities 4, 5, and 6, respectively. Crustal and deep earthquakes are shown by triangles and inverted triangles, respectively. Warning times related to the same event are connected by red lines. For sake of clarity, magnitude is altered by a random shift of +/-(0.03, 0.06) for earthquakes sharing the same magnitude.

In addition, a user's survey was performed after the M8 2019 Peru earthquake demonstrating a high level of satisfaction, but that only a fraction (25%) of users actually takes protective actions even when fully understanding the meaning of the warning. If the efficiency in terms of individual risk reduction may not be as high as one could expect, users still acknowledge that EQN service helps, by offering a warning to psychologically cope with tremor.

A new CsLoc (Crowdseeded Seismic locations) have been developed for rapid and reliable seismic locations of felt earthquakes at global scale. It is based on the combined analysis of crowdsourced and seismic data. EMSC routinely detects online reaction of witnesses when an earthquake strikes, such as increases in the traffic of its website, in the launches of its LastQuake app or the number of tweets containing the keyword "earthquake" in various languages. The location of this "crowdsourced detection" deine the area where seismic stations are likely to have recorded the tremor, and the time of this detection to select the observed arrival times. Arrival times not compatible with seismic wave propagation are disregarded and a classical seismic location process launched. The time and location external constraints allows fast (typically one minute) and reliable (within 10 to 15 km) seismic locations even with a limited number of seismic stations. The service is already available in the EMSC webpage "for seismologists only". Beyond what was planned in the project, CsLoc now integrates magnitude computation and an attempt is being carried out to complement data from seismic stations available online with the data from the more than 1 000 citizen seismic sensors RaspberryShake. This should allow us to lower the threshold magnitude for located earthquakes.

Several developments both internal and external to RISE are based on the felt reports collected through the LastQuake system. Felt reports are collected through a set of cartoons depicting different shaking and damage levels. These felt reports are exploited for rapid public information and rapid impact assessment. Thanks to the increased visibility of the LastQQuake system and improvements in EMSC IT infrastructure, the number of crowdsourced felt reports have reached 750k for the last 12 months (a 3-fold increase from the previous 12-months) and 16k for the damaging Petrinja Croatia earthquake of Dec. 29th 2020.

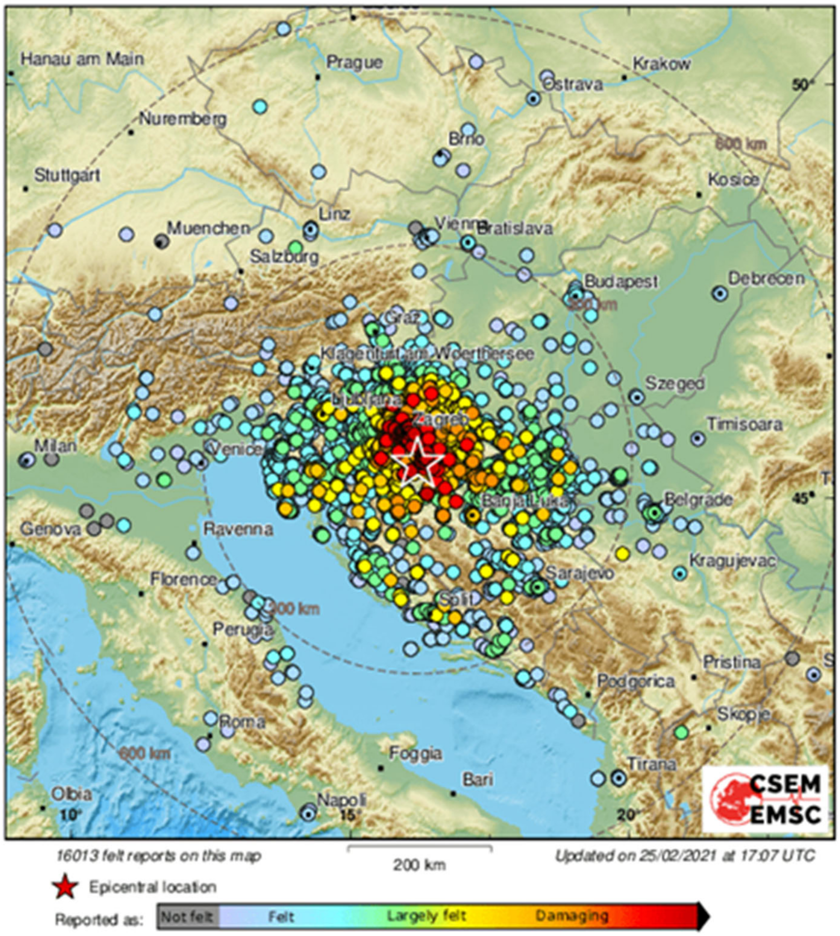


Figure 5.2.2 Map of the individual felt reports crowdsourced for the Petrinja, Croatia earthquake

They are exploited for earthquake source parameters determination using the BOXER method. This development is of interest for rapid earthquake information More and more often, felt reports are collected for events for which the seismic location is not available for tens of minutes and sometimes many hours. Tests showed that an epicentral location can be determined in a few minutes. The application of BOXER in the EMSC data processing will significantly speed-up the information made publically available in such cases.

Two unplanned research actions have been carried out using felt reports. A methodology is being developed with the US Geological Survey to integrate felt reports in ShakeMaps (a product mapping the spatial distribution of shaking). Once finalized it will allow any institute to ingest felt reports in their own ShakeMaps (a real time delivery mechanism for felt reports is being tested in the sister Turnkey project). With M. Böse at ETH Zurich, felt reports are used as input for the FinDer software, which normally analyzes real time accelerometric data for the determination of rupture geometry of large earthquakes. The method has been validated on past earthquakes with results available within a few tens of minutes. It is being tested in operational conditions. Rupture geometry (length and orientation) is key for more reliable impact scenarios for large (M6.5+) earthquakes.

In terms of rapid impact assessment, crowdsourced data proved valuable as illustrated in a study of the M6.4 destructive 2020 Albania earthquake. Within 8 min of the earthquake occurrence the possibility of damage was detected through the *doughnut effect* (i.e. the initial lower crowdsourcing rate from damaged areas than from undamaged ones). Presence of damage was confirmed 30 min later when epicentral intensity -initially underestimated at 6 due to the doughnut effect- reached intensity 8. Finally, an hour after the quake - which happened in the middle of the night - the first geo-located pictures of structural damages and collapses were received. A collaboration was also initiated with Newcastle University to organize collected geo-located pictures in a remote survey of earthquake damage for the Zagreb, Croatia 2020 earthquake. Results are promising and lead to several improvements in EMSC collection tools.

Landslides can be a secondary effect of earthquake shaking and because they can significantly hamper response by blocking roads, it is essential to detect and map them. A method to detect landslides through publication on Twitter has been developed in collaboration with Qatar Computing Research Institute (QCRI). Tweets containing keywords related to
landslides in various languages as well as pictures are collected and analyzed by artificial intelligence to select the relevant ones. The AI training has been particularly time-consuming but was indispensable as it rejects more than 99% of the collected tweets. This project was joined by the landslide team of the British Geological Survey (BGS) which is interested in the tool capacity for documenting landslides (beyond the triggered ones) which should save them significant time of their manual harvest of information from social media.

Task 5.3 Improving earthquake information in a multi-hazard context

Until the nineties, classical public warnings and hazard information had been communicated via traditional channels, such as radio, television, sirens and loud speakers. Modern technologies including computers, smartphones and other digital applications have only been available for a few decades. Several recent studies showed that the public, in countries where the needed infrastructure is broadly available, wants to receive hazard warnings as push notification via apps on their smartphones.

We see two approaches to communicate earthquake information via an app. Either one designs an international earthquake app (e.g. EMSC) or one develops national-wide multi-hazard apps. Especially in countries where damaging earthquakes only occur rarely, the majority of the public would never download an app only providing earthquake information. Thus, within Task 5.3, we explore how earthquake information can be best communicated on multi-hazard platforms. To this end, we chose Switzerland as a case country where we analyze how earthquake information can be best embedded in the already existing national multi-hazard apps (e.g., weather app) that are used by a large part of the public in order to support people in taking informed decisions.

More precisely, we apply a user-centered systemic and mixed methods approach, with a major emphasis on user requirements driving technological developments. Throughout the project, we continuously collaborate with scientists from different fields and stakeholders from the society, thus following a Transdisciplinarity approach. In total, we’ve already conducted three studies and one study is still on-going.

Study I - What defines the success of maps and additional information on a multi-hazard platform?

The aim of this study was to test different start page and hazard announcements design and assess the public’s preferences. To this end, we conducted an online survey that consisted of five question blocks: (i) use of communication channels; (ii) start page designs; (iii) hazard announcements; (iv) cognitive and normative factors; and (v) sociodemographic data. The survey contained an online conjoint choice experiment (N=768, fully randomised between-subject design), which allowed us to test different start page designs and hazard announcements representing the diversity of elements used in multi-hazard platforms.

The main results are that the public prefers…

- … a **single map** on which all current hazards are displayed.

- … **textual information** about the current hazards below the map.
- … hazard classifications with **four or five categories**.
- … a combination of **pictured** and **textual** behavioural instructions for unpredictable hazards such as earthquakes. For predictable hazards such as storms, they prefer written behavioural recommendations in comparison.
- … hazard announcements with a **sharing function**.

More details here: Dallo, I., Stauffacher, M., & Marti, M. (2020). What defines the success of maps and additional information on a multi-hazard platform? International Journal of Disaster Risk Reduction, 49, 101761

Study II - Why should I use a multi-hazard app? Assessing the public's information needs and app feature preferences in a participatory process.

In order to better understand which hazards, information and features people prefer to have on a multi-hazard app, we conducted seven workshops à four to five participants. The procedure of the virtual workshops was a result of two test runs that allowed us to identify which tools best fit the purpose of our workshops and how we could facilitate interactions between the participants. At the end, they consisted of four parts – an introduction phase, group work, a plenary discussion, and a closing phase. During the group work, the participants were split into two groups and they discussed which hazards they would combine, which information they want on a multi-hazard app and which features should be available.

The main results are that the public prefers...

- … the combination of **multiple hazards** on an app. To this end, not only combining natural hazards but also anthropogenic and socio-natural hazards.
- … only the **most relevant information** is provided on the app and a **forwarding function** forwards the users to the official website to access more detailed information. People define the following as relevant information: location, time, hazard severity, behavioral recommendations and the contact details of emergency services.
- … **short-term & real-time information** (containing behavioural recommendations & contact numbers)
- … features such as **push notifications**, a **button to ask for help**, **sharing feature, chat forum, 'I am Safe' button, report button.**
- … **interlinking/using existing apps**, such as sending push notifications via general-purpose apps (e.g., weather apps) and communicating specific information on disaster apps.

More details here: Dallo, I. & Marti, M. (2021). Why should I use a multi-hazard app? Assessing the public's information needs and app feature preferences in a participatory process. International Journal of Disaster Risk Reduction, 57, 102197. doi: 10.1016/j.ijdrr.2021.102197

Study III - An analysis of the earthquake map of the MeteoSwiss app with regard to comprehensibility and its potential for improvement

The aim of this study was to assess whether the current earthquake information on the Swiss weather app (MeteoSwiss) is understood correctly. As a pre-study before the survey, we conducted interviews with the public in order to identify which information on the earthquake map on the MeteoSwiss app is understood and which leads to confusion. Additionally, we interviewed four experts – from MeteoSwiss, the Swiss Seismological Service, and a company focusing on design –, which helped us to come up with improvement suggestions of the information currently presented. We used the insights from these interviews to set up a survey with the aim to test the interpretation of the current earthquake map and to check whether our maps adjusted based on the expert interviews are preferred by the public. In total, 356 people filled out the survey, representing the German-speaking part of Switzerland.

The main results are that…

- … communicating earthquake information together with other natural hazards on one platform especially **the time aspects is misleading**. For the weather-related hazards (e.g. storms, heatwaves, floods) warning before the events are mainly provided but for earthquake post-event information is presented. Many people currently do not understand this and think the earthquake information presented is a forecast.

- … one has to clearly differentiate between the **icon of the earthquake's epicenter and the users' location**. We recommend using the pin for the user location that is used by google maps, and not a red circle for example.
- … in times with no earthquake occurred, a **grey map is misinterpreted**. People think that the sensors are not working or that they do not have to worry about earthquakes. A white map with no borders or the regional borders are a much better solution.
- … the complementary textual information for the map should contain the location and time of the earthquake, which damages have to be expected, what one should do during and after the shaking, the possibility to report a hazard and the source of the information.

Study IV - TBD [on-going]

The focus of the next study is to explore how start pages and hazard notifications can be designed so that people understand whether it is a warning, information during an on-going hazard event or post-event information. In addition, we figure out how one can visually and textually indicate whether people should/ it is recommended to take actions in order to increase their ability and willingness to take actions.

Overall conclusion

We recommend to test the communication products with the different target audiences in order to ensure that their needs and expectations are meet and their abilities and environmental contexts are considered.

The results of the four studies and the practical recommendations will be summarized in Deliverable D5.10.

List of submitted deliverables and achieved milestones in WP5

D5.1.1: Review of best practice in communication of dynamic risk in all fields

MS30: First draft of communication measures

MS36: Concept for multi-hazard warning app completed

Summary of Exploitable Results in WP5

1) **Peer-reviewed publications**
    a) Dallo, I., Stauffacher, M., & Marti, M. (2020). What defines the success of maps and additional information on a multi-hazard platform? International Journal of Disaster Risk Reduction, 49, 101761
    b) Dallo, I. & Marti, M. (2021). Why should I use a multi-hazard app? Assessing the public's information needs and app feature preferences in a participatory process. International Journal of Disaster Risk Reduction, 57, 102197. doi: 10.1016/j.ijdrr.2021.102197
2) **Conference contributions**
    a) Dallo, I., Stauffacher, M., & Marti, M. (2020, May). Understanding public's preferences for information provided on multi-hazard warning platforms. In EGU General Assembly Conference Abstracts (p. 1420).

b) Dallo, I. and Marti, M.: How to best involve different stakeholders in the design process of products and services to communicate multi-hazard information?, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-815, https://doi.org/10.5194/egusphere-egu21-815, 2021.

c) Dryhurst, S., Luoni, G., Dallo, I, Freeman, A. & Marti. M (2021, June). How to communicate Operational Earthquake Forecasts. JpGU General Assembly 2021, online, 30 May - 6th June 2021.

3) Other exploitable results/data/reports

a) Dallo, I. & Marti, M. (2020). Multi-Gefahren-Plattformen – Präferenzen der Bevölkerung. [only available in German] URL:https://ethz.ch/content/dam/ethz/special-interest/usys/tdlab/docs/research/multigefahrenplattform.pdf [18.01.2021]

b) Dallo, I. & Marti, M. (2020). Multi-Gefahren App: Wieso sollte ich sie nutzen? [only available in German] URL:https://ethz.ch/content/dam/ethz/special-interest/usys/tdlab/docs/research/multigefahrenapp-informationsinhalte.pdf [31.05.2021]

c) CsLoc exists as a service and will be integrated in the LastQuake system

1.2.6 Work package 6

Overview

The diverse pilot and demonstration activities in WP6 cover a wide range of potential applications of OEF, EEW, RLA and SHM; they also cover very different scales, from building scale application to national and even Europe-wide scale.

The main objectives of WP6 are to:

- Demonstrate how the use of big data collected through innovative technologies at the building-level can be used for critical risk mitigation services including OELF, performance-based EEW and SHM at a city level (Task 6.1).
- Provide clear applications to demonstrate the chain from earthquake predictability to OELF and RLA at national levels (with focus on Italy and Iceland) (Tasks 6.2,6.3).
- Clearly integrate a large number of activities from WPs 2 to 8 by developing a user-centric dynamic risk framework for Switzerland (Task 6.4).
- Make clear steps towards the development of services for RLA, EEW and OEF at a European level (Task 6.5).

The following sections highlight the main achievements towards these objectives in each task of work package 6.

Summary of achievements in WP6 tasks

Task 6.1 Pilot projects for demonstrating the use of innovative technology in buildings within OELF, RLA, performance based EEW & SHM

This task aims at bringing together the outcomes and products of the following tasks/activities:

- Low-cost sensors developed/deployed by QuakeSaver as part of Task 2.2.
- SHM of the Grenoble City Hall (France).
- SHM of a modern 15-storey reinforced concrete building in Budva (Montenegro).
- High-resolution dynamic exposure model for Europe developed within Task 2.7.
- New generation of OEF models from Task 3.3.
- State-dependent fragility models developed as part of Task 4.2 for use in RLA and OELF.
- Detection of damage through SHM from Task 4.4.
- Operationalisation of performance-based EEW from Task 4.5.

Update on sensors in Buildings

A meeting was held on 30th September 2020 to discuss the status of the installation of sensors in different structures and to define the format with which progress and the characteristics of each SHM monitoring activity would be reported in MS37. A template was agreed upon and was later used to successfully deliver the milestone in February 2021, which included not only the buildings under Task 6.1 covered in the implementation plan but also three buildings monitored by IBK-ETH as part of Task 4.4, with whom a close collaboration was established. The milestone report was deemed relevant and useful by the partners involved, as it facilitates the exchange of data among different institutions. The deployment of some of the building sensors was delayed at that point in time due to the COVID pandemic. Since the delivery of MS37, QUAKE has delivered sensors to BOUN, GF-UCG and UGA. The status of these is as follows:

- BOUN: Five tri-axial MEMS accelerometers were received from QUAKE at the end of May 2021 and will be installed in the Polat building (see MS37 for details), where the impulse generator designed and built as part of Task 2.3 is already set up. BOUN is working on the integration of these new sensors with the existing monitoring system of the building. Due to COVID restrictions it has not been possible for QUAKE colleagues to travel to Istanbul to aid in this, but this is being overcome via emails and videos. One of the challenges of the integration arises from the fact that the existing monitoring system uses force balance accelerometers (FBAs) with very low noise levels, while the noise level of the QUAKE MEMS is much higher, 22 μg/√Hz. This means that records of ambient vibration (which are most of the data in real-time monitoring) might not be reliable, especially on the lower floors of the building. The sensors would nevertheless be fine to record moderate to large earthquake-induced vibrations (e.g. M>4). Comparison tests will be carried out by BOUN in the laboratory to identify the frequency bands and the most appropriate floor levels for real-time monitoring.

- GF-UCG: Six tri-axial MEMS accelerometers were received from QUAKE in June 2021, of which three have already been installed in the selected building in Budva, Montenegro (hotel built in 2015, 15 storeys above ground, 3 storeys below ground, details can be found in MS37). Two of the sensors have already been installed on the 13th floor and another has been installed at the basement, at the locations shown with crosses in the following building plans.

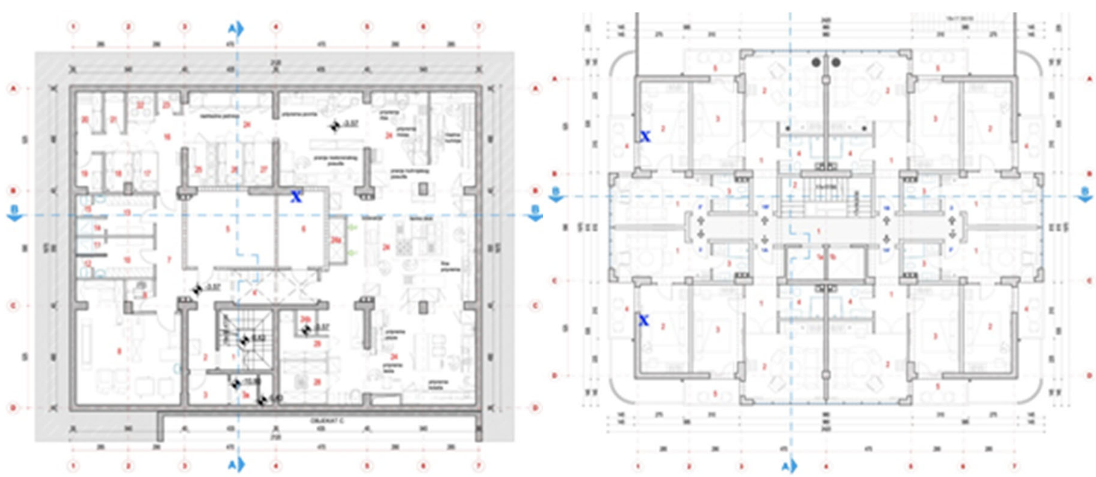


Figure 6.1.1 Location of the three QUAKE MEMS sensors installed in the building in Budva: basement (left) and 13th floor (right).

- Of the remaining three sensors, two will be installed on the 13th floor as well, and one on the 14th floor. Installation during the summer months is challenging due to the hotel working at the peak of the tourist season; installation is expected to be completed by the end of August 2021. It is planned that QUAKE will deliver one High Dynamic Range (HiDRA) sensor in the future to be deployed in the same building. A numerical model of the building has been developed and dynamic results have been obtained.

- UGA: Six tri-axial MEMS accelerometers were received from QUAKE and are currently being tested at the ISTerre/UGA laboratory before being deployed. It is planned that five sensors will be installed at the building of the Grenoble City Hall (see details in MS37) and one sensor will be installed in the neighbouring Perret tower (Tour Perret), a 1925 ~100-m observation tower that has been recently instrumented and is being monitored due to damage having been detected. The analysis on the Grenoble City Hall will consist of:
    - in-situ analysis of MEMS performance compared to that of force-balance accelerometer sensors
    - a posteriori analysis of seismic events that could have been detected by MEMS from the permanent instrumentation of the building
    - evaluation of the fluctuation of modal parameters according to external forcing (temperature, wind...) on both systems
    - analysis of the modal variations and integration to a SHM system

UGA has already conducted successful experiments on the Grenoble City Hall using the permanent instrumentation of the building, which includes sensors installed in 2004 as well as an additional sensor and a weather station installed in 2019. Rotational modes of the building have been assessed using both translational and rotational sensors, and comparisons between dynamic properties estimated from earthquake vibrations and ambient noise measurements have been carried out.

Plans for the deployment of sensors in Sion, VS, Switzerland, have been modified as per needs revealed by the testing of five first-generation QUAKE MEMs devices by SED-ETH in September 2020. Results obtained by SED-ETH showed that the dynamic range was not sufficient to record ambient motions from structures or to make reliable P-wave arrival picks from moderate sized earthquakes in the near-field for use in EEW in Switzerland. This type of sensor can be (and is being) effectively used in regions of high seismicity, but their application to areas of moderate seismicity (like Switzerland) may be hindered by the lack of dynamic range. The testing has also revealed issues with the software, which are understood to have been already addressed by QUAKE. For these reasons, the original plan of installing a large number of more economical sensors is being changed to the possibility of installing 10 to 20 next generation 6-component sensors from QUAKE that add a short period geophone to the same MEMs. These are expected to be sufficiently sensitive to record ambient motions from structures and/or moderate earthquakes, and should adequately recover the entire amplitude range from weak to strong motions (though will lack sensitivity at longer periods). Delivery from QUAKE is expected for early 2022, due to the on-going global chip crisis which leads to shortages of critical electronic components. Once the sensors arrive, they will be temporarily deployed in the Prime Tower building in Zurich (130-m high, the tallest structure in Zurich with fundamental periods at 1.5-3s), where SED-ETH currently operate a semi-permanent high dynamic range accelerometer on the roof. They will be checked for signal quality and used to document the dynamic characteristics of the building. The permanent deployment is still planned to be in Sion, in the vicinity of a number of long-term active seismic swarms. Half the sensors will be deployed in a mid-rise building (the new campus for HES-SO, a 3rd level institution in the centre of the city), the rest will be deployed around the city and the seismic swarms to improve EEW times. Locations for EEW network improvements will also be guided by the cost-benefit study for EEW carried out as part of Task 4.6. SED-ETH will visit Sion in August 2021 to organise permissions and scout locations for the sensors.

<u>Outcome of inter-task and work package discussions</u>

As this is an integrative task by nature, some of the key activities at this stage are still related to encouraging an inter-task and inter-package dialogue to gain understanding on all the components that will be assembled and put to work together in the planned pilot demonstrations.

A series of meetings were held jointly with Tasks 4.2, 4.4 and 4.6 regarding the connection between SHM and state-dependent fragility models. The central questions were, firstly, the definition of the most appropriate parameter/s that can be derived from SHM data to identify the existence or not of damage and its extent (i.e. quantification within a scale) and, secondly, the use of such parameters within a RLA or OELF workflow to update/constrain the boundary conditions when using state-dependent fragility models to estimate damage. The meetings have been essential for bringing together different research groups and creating the necessary links for a common understanding and shared language of the different components of the RLA and OELF chains to come together and incorporate SHM. Other relevant discussion points have been: (i) the applicability of observations from individual monitored buildings to large building portfolios, (ii) the need to account for the natural wandering of the dynamic properties of buildings due to weather conditions to be able to identify damage through SHM, and (iii) the limitations of residual stiffness/period elongation to characterise damage extent, particularly when working with single-degree-of-freedom numerical models. All these discussions address the components of Sub-Task 6.1.3 marked in red in the figure below.

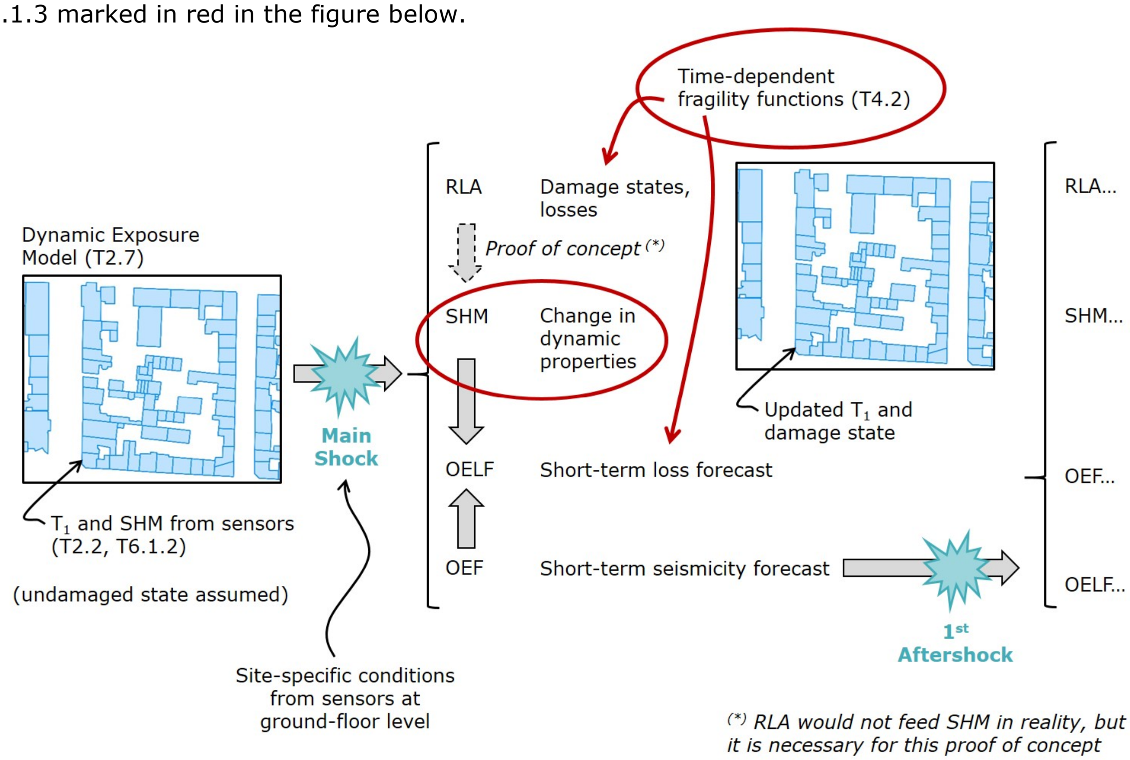


Figure 6.1.2 Schematic description of the pilot demonstration of Sub-Task 6.1.3. Marked in red are the components that have been in the centre of the discussion and analysis at this point in time.

Some of the most relevant conclusions of these discussions were:

- Even when working with SDOFs the definition of residual stiffness is not trivial, as its definition can depend on the hysteretic model used, the number of cycles, history before the cycle and the direction of new loading.
- Residual stiffness/period elongation may not be a viable/unique parameter to make the connection between state-dependent fragility models and structural health monitoring considering SDOF models.
- Generally, starting damage conditions - even for SDOFs - cannot be identified by a single parameter, this directly descends from the definition of hysteretic rules defining SDOFs. Other matters of relevance to understand the damage state: residual displacement, number of non-linear cycles, dissipated energy, evolution of plasticity.
- IBK-ETH is working on developing a simple example that will show the procurement of data-driven indicators to estimate the damage states, which should serve as an input for damage-state fragility/vulnerability models and OELF.
- Such parameters can be used to estimate discrete damage states/tags of a monitored building after an earthquake. This can be used to constrain the boundary conditions when running an operational earthquake loss forecasting (OELF) model.

Task 6.2 Demonstrating OEF and OELF at regional and national levels: Italy

This task aims to demonstrate the improved OELF system developed in Task 4.2 using real data. The 2009 L'Aquila seismic sequence was chosen for an illustrative application of the updated version of MANTIS. The M6.1 mainshock of the sequence occurred at 01:32 on 06/04/2009 and five aftershocks with a moment magnitude larger than 5 occurred up to 9/04/2009. The time interval considered in the application is from 05/04/2009 to 10/04/2009.

Since the recorded data in each site of analysis (i.e., each municipality within the region of interest) were not available, four recording stations, and the corresponding municipalities, were selected: L'Aquila, Antrodoco, Famignano and Celano. The following figure depicts, in the upper panel, the forecasted distribution of the IM evaluated for the municipality of L'Aquila at 00:00 of each day. Such distributions are computed via a short-term probabilistic hazard analysis adopting the rates of the OEF-Italy system as an input. In the lower panel of the same figure, the elastic response spectra of the recorded ground motions at L'Aquila station are reported. These spectra are used for damage estimation on the building portfolio.

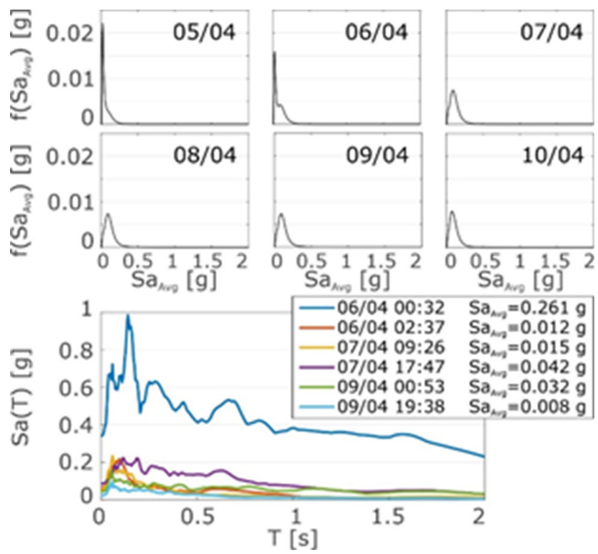


Figure 6.2.1 Upper two rows: the distribution of the IM evaluated for the site of L'Aquila. Lower diagram: the spectra of M>5 earthquakes between 06/04/09 and 09/04/09 recorded from L'Aquila station.

The results of the application of MANTIS v.2 are reported in the following figure. More specifically, it provides, for each municipality and for each day, the forecasted percentages of buildings in each damage state.

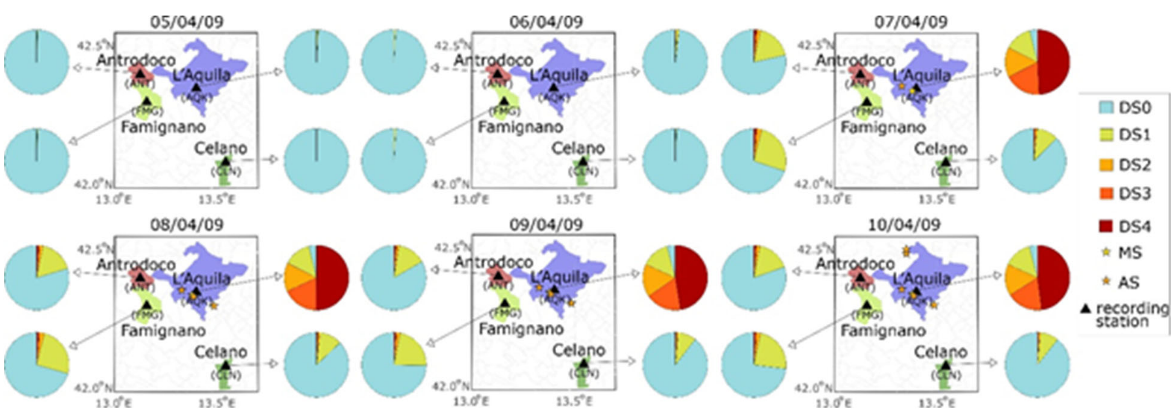


Figure 6.2.2 Preliminary results of OELF v.2: application to 2009 L'Aquila seismic sequence - forecasted percentages of building in each damage state. The four considered recording stations are between 1.8 km and 30.8 km away from the epicenter of the mainshock. The shocks are represented with stars, the yellow one is the mainshock while the orange ones represent the aftershocks.

Task 6.3 Application of the chain from earthquake predictability to EEW and RLA in Iceland

Progress on this task has been delayed due to limited participation of the task lead (IMO) in the project. The RISE General Assembly, together with the Management Board, have discussed and proposed mitigation actions that would allow other partners of the project to undertake demonstration activities in Iceland during the final 2 years of the project. Discussions with IMO are ongoing.

Task 6.4 Application of a User-Centric Dynamic Risk Framework for Switzerland

Background:

Why is Switzerland a testbed?
Switzerland is a country of moderate seismicity but high seismic risk, owing to the high population, infrastructure density and the historical building stock. Earthquakes are the natural hazard with the highest risk potential. Switzerland also operates one of the densest and most modern seismic networks in Europe: The Swiss Seismological Service currently processes real-time data from about 250 broadband and strong motion stations, with an average station spacing of less than 10km. Within RISE, we are integrating all real-time risk-related components already available with numerous new developments to create a single dynamic risk platform. This will demonstrate the potential of the approach and technologies and lead to a measurable improvement in the resilience of Switzerland. Below we summarize the goals of this task and the actions that have been taken so far within RISE.

Work Plan from the Grant Agreement and achievements towards the goals

• Initiate a continuous stakeholder dialog leading to updated, Swiss-specific user requirements

<u>Progress on dialog with Swiss Stakeholders</u>

We are building an International Stakeholder Panel, with strong representation from Swiss stakeholders. The Swiss stakeholders that we have been in communication with are Swiss Civil Defense, Federal Office of Civil Protection, Cantonal civil defense Basel and Cantonal Civil Defense Valais.

• Improve observational capabilities, integrating new sensors and new processing tools

<u>Progress on Low-Cost Posthole Sensor Package:</u>

The Low-Cost Posthole Sensor Package development aims to develop a fully integrated seismic station (hereinafter "sensor") that is affordable and easy to deploy in quantities required for dense local networks (10s–100s of stations), allows 24/4 online streaming, yet still has adequate performance for local to regional seismic monitoring.

Our reference and starting point is the mobile aftershock pool used at SED where each station is equipped with standard instruments from established manufacturers and allows off-the-grid online recording on solar powered equipment for most of the year. We follow an iterative development strategy to reduce cost, bulk, power usage and complexity while maintaining adequate performance.

Our general development procedure thus is as follows:

1. Identify limitations in existing components with respect to goals
2. Look for alternative components or identify subcomponents for custom development
3. Develop, integrate, deploy and test
4. Repeat

The system size and weight and, in extension, ease of installation, are mainly determined by the battery size. This can be improved by a) using less power and b) replacing the traditional lead-acid with lithium-ion technology that offers much higher energy densities, however, suffers from low temperature limitations. In our concept we plan to overcome the latter by placing the battery at an adequate depth where diurnal and seasonal temperature variations are sufficiently limited (depth of frost penetration, typ. 80cm - 100cm at central European latitudes). The greatest potential with regard to power consumption is found in the data communication components where up to 90% of the entire system power is consumed.

Our Protoype-1 sensor was built from purely off-the-shelf components. It was not intended for production even in small quantities but was used to carry out a number of basic tests with regard to ease of installation (posthole digging in various soils using motorized augers), power usage and temperature measurements. Furthermore, it served as a starting point to identify mechanical assembly options and component constraints due to the size and shape of the casing.

With Prototype-2 the external design and form factor was finalized and we developed a custom casing and internal frame to meet the following requirements:

- Suitable for prolonged field deployments (waterproof, robust, with a diameter that is matched to standard motorized auger sizes)
- Mass manufactural in small quantities
- Easy to assemble / disassemble
- Providing adequate coupling for the integrated seismic sensor

In addition, we developed a LiIon battery with custom thermal management that makes optimal use of the available space and follows best practices with respect to charge balancing and battery protection.

With regard to the electronic components, we are taking a two-pronged approach. The first one is again limited to ready-to-buy components as in Prototype-1 but with a selection from smaller and lesser known manufacturers that typically sell at lower prices and can provide support for customization. This approach provides the shortest path to a production ready prototype – we expected it to be completed later this year. However, there are also a number of limitations that come with it:

- Selection is limited to what is available on the market. This mainly affects power optimization paths because low power operation is often not a main priority for device manufacturers. In addition, some of the latest 4G communication technologies are targeted at device developers and ready-to-use modems exist only to a limited extent or are still in the process of being developed.
- Shape and size constraints further limit the selection of suitable components
- Cost optimization potential is limited due manufacturers needing to recoup development costs and make a profit

The second (parallel) approach we’re taking is thus to custom develop most of the electronic components in-house except for the seismic sensor itself. Due to resource and time constraints we limit from-scratch developments to a minimum, and instead focus on electronic modules from the maker sphere with custom software where needed. The status of the individual components is shown below:

<table>
<tr><th>Component</th><th>Status</th><th>Cost saving potential</th><th>Power saving potential</th><th>Difficulty / Risk</th></tr>
<tr><td>Low power main controller / CPU</td><td>Working</td><td>N/A</td><td>N/A</td><td>Low</td></tr>
<tr><td>Power management</td><td>Developed, tests pending</td><td>N/A</td><td>N/A</td><td>Moderate</td></tr>
<tr><td>LTE Cat-M1 low power modem and controlling software</td><td>Working</td><td>Moderate</td><td>High</td><td>Moderate</td></tr>
<tr><td>MSEED packaging and streaming software</td><td>Working</td><td rowspan="3">High</td><td rowspan="3">Low</td><td>Low</td></tr>
<tr><td>High precision time stamping</td><td>Open</td><td>High</td></tr>
<tr><td>A/D-Conversion</td><td>Open</td><td>High</td></tr>
</table>

Due to resource constraints we may decide to only include some (or none) of the above components in the final assembly in case the engineering effort exceeds the scope of the work package.

Figure 6.4.1 Prototype development stages. Left: classical mobile station from the SED aftershock pool (reference), Center: Protoype-1 built from off-the-shelf components, Right: Prototype-2 with custom casing (caps not shown), internal frame, battery, sensor and power electronics.

<u>Quake Sensors:</u>
Sensors developed by RISE Partner Quake are aimed to be used in:

1) Dense EEW Networks
2) Structural Monitoring

In September 2020, 5 QuakeSaver MEMs devices were delivered to ETH. Early tests indicated that the dynamic range of the MEMs were not sufficient to support applications in either ambient structural monitoring or EEW (Figure 6.4.2), the targets of the SED deployments.
Further, chronic software issues were identified, though by now most have been satisfactorily addressed.
In the meantime, the QuakeSaver team are developing a 6 component device that will include the same MEMS and additionally a 3 component geophone, supporting a much wider dynamic range that is of strong interest to us to test and reply. This is a substantially more expensive device and hence the number of devices to deliver is reduced from the order of 100 very low cost devices (~100-200CHF/piece) to a number on the order of 10-20 of mid-range priced devices (1-2kCHF/piece).
Currently, there is a global shortage of chips that means development and production is reasonably delayed.
Late summer / autumn 2021 QuakeSaver will provide SED devices that have been thoroughly tested - both in terms of hardware and software - by the QuakeSaver partners. When they arrive and pass testing, these sensors will be deployed in the Sion area (Figure 6.4.3) - half will densify the backbone network for EEW, the other half will be placed in a single structure for monitoring (yet to be identified).

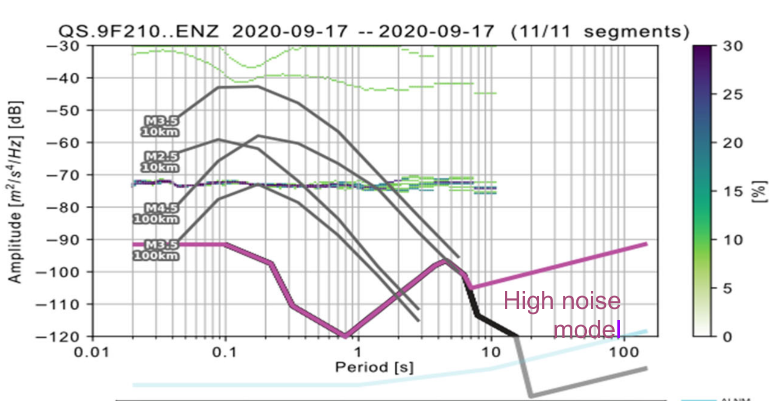


Figure 6.4.2 Current sensor noise level

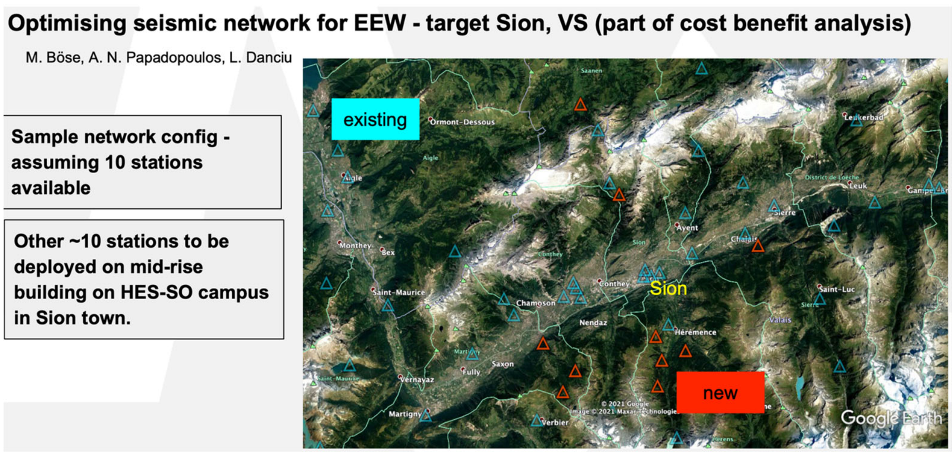


Figure 6.4.3 Earthquake early warning network in Sion

More than 25 Sensors are currently being installed by RISE Partners at ISTERRE, BOUN Istanbul and Univ. of Montenegro (see Task 6.1 above). Critical software issues have been resolved. We now are polishing the sensor and backend software for tighter integration into RISE Infrastructure, where seismic data products can be easily distributed and consumed by different RISE working groups through meaningful online REST APIs. We will call for a workshop with relevant partners in fall 2021. Regarding the high-quality, not so cheap, short-period HiDRA sensors we are finishing the final design of the PCB. Development HiDRA sensors are offered to interested RISE partners.

<u>Urban DAS Pilot Experiment:</u>
We performed a DAS experiment in the Swiss capital Bern to assess the potential for local-scale tomography in the context of seismic hazard analysis. It took 2.5 weeks in Bern, Switzerland to deploy around 6 km of fibre shown in Figure 6.4.4, including repeated sections. Location of fibre is known, but we needed to locate channels and test the ability to constrain very local Earth structure microzonation and RLA.

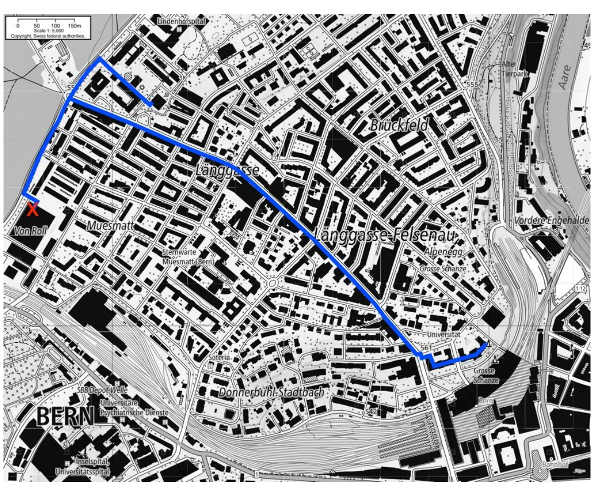


Figure 6.4.4 Blue line is the fibre, red cross shows the DAS interrogator location

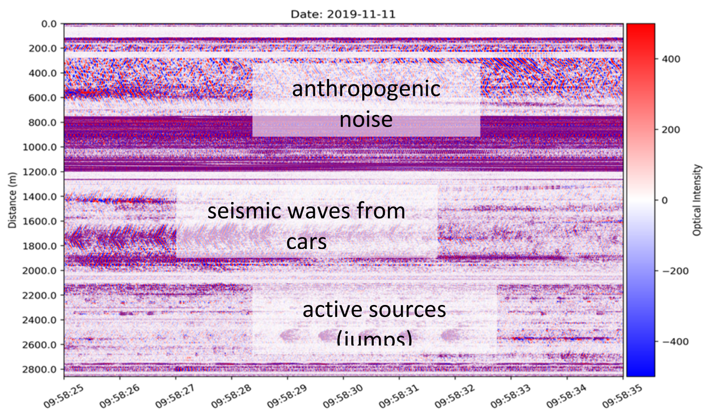


Figure 6.4.5 Anthropogenic noise correlation

• A national Dynamic Risk Information Service (DRIS) that will serve to a wide range of stakeholders in real-time harmonized and standardized information on dynamic risk:

- **OEF** and OELF information for different forecast periods, building on tested ensemble models, integrating also expert judgements.
- Information will be available via standardized web services to all applications connected to the IoT, we will demonstrate this capability with selected industry applications.
- **EEW** alerts, based on the enhanced, VS based national EEW system, enriched with dense low-cost sensors in the Valais Near Fault observatory and SHM sensors in buildings.
- **RLA** and **RRE** capability after significant events integrating low-cost sensors and felt reports collected via citizen-science feedback.
- Multi-hazard information on secondary events (landslide potential, lake tsunamis).
- Integration of **SHM** from selected buildings into EEW, OEF, OELF and RLA, deploying also measurements acquired using the portable excitation source in selected buildings.

The work carried out in the abovementioned domains (OEF, EEW, RLA, RRE, SHM, CBA) for Switzerland are summarized below:

<u>Time dependent earthquake probabilities in Switzerland:</u>

In contrast to time-independent, long-term earthquake probabilities, dynamic earthquake probabilities provide the basis for decision making in the case of temporally elevated seismic hazard. The Epidemic-Type Aftershock Sequence (ETAS) model is currently among the best-performing earthquake forecasting models. It describes spatio-temporal earthquake occurrence, and in particular the occurrence of aftershocks, based on several well-established empirical laws. The work carried out thus far has focused on general methodological improvements of the currently existing forecasting model. We developed a method to calibrate ETAS models allowing for time-varying magnitude of completeness, enabling us to use a larger and more representative fraction of the available data. Furthermore, experiments are being carried out to assess the potential of combining ETAS models with b-value variations in space and time.

On top of this, we will incorporate information about local strain rates, fault maps, and Coulomb stress changes, in the ETAS model (Figure 6.4.6). For all these potential model improvements, rigorous performance evaluation has been and will be carried out to ascertain that they lead to gains in forecasting. The resulting next-generation dynamic earthquake forecasting model can then be used to provide tailor-made earthquake probabilities for Switzerland, given the time-horizon, location, and magnitude range a user is interested in. Such near real-time forecasts are issued in the form of stochastic event catalogs.

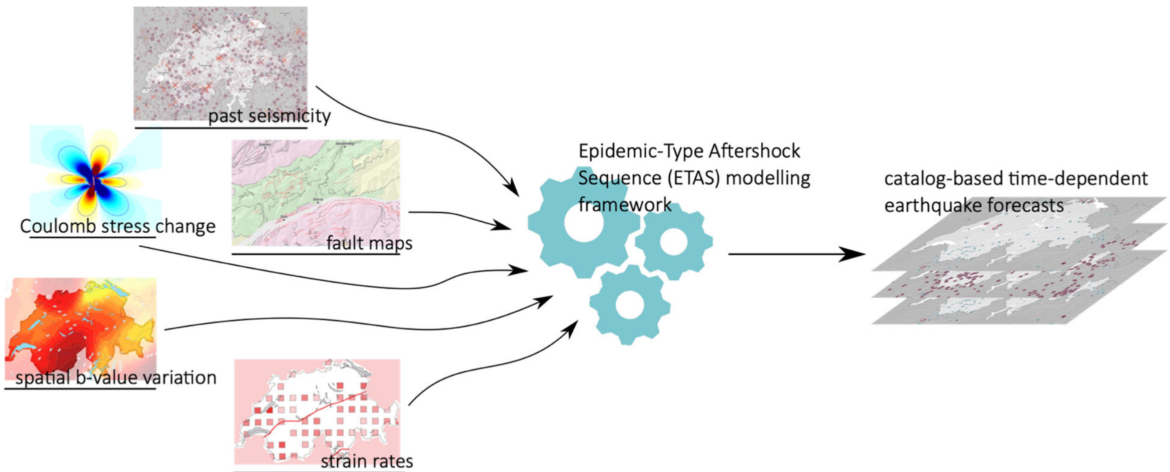


Figure 6.4.6 Multiple sources of information are combined within an ETAS (Epidemic-Type Aftershock Sequence) modelling framework, to produce catalog-based time-dependent earthquake forecasts for Switzerland.

<u>Earthquake Early Warning in Switzerland:</u>
Earthquake early warning systems (EEWS) aim to rapidly detect earthquakes and provide timely alerts, so that users can take protective actions prior to the onset of strong ground shaking. An operational EEWS could potentially mitigate earthquake risk by triggering potentially cost- and life-saving actions. Despite the physical constraints that limit the alert speed and accuracy, EEWSs have substantially improved over the years. We rely on regional event-based probabilistic seismic risk assessment and develop a quantitative and fully customizable framework for evaluating the effectiveness of EEW in mitigating risk. We demonstrate this framework using Switzerland as a testbed.

We have ~280 high-quality seismic stations (Figure 6.4.7) and we use 2 EEW algorithms (Virtual Seismologist & FinDer). We are carrying out a risk based EEW performance evaluation. The details of this work are explained under Task 4.6.

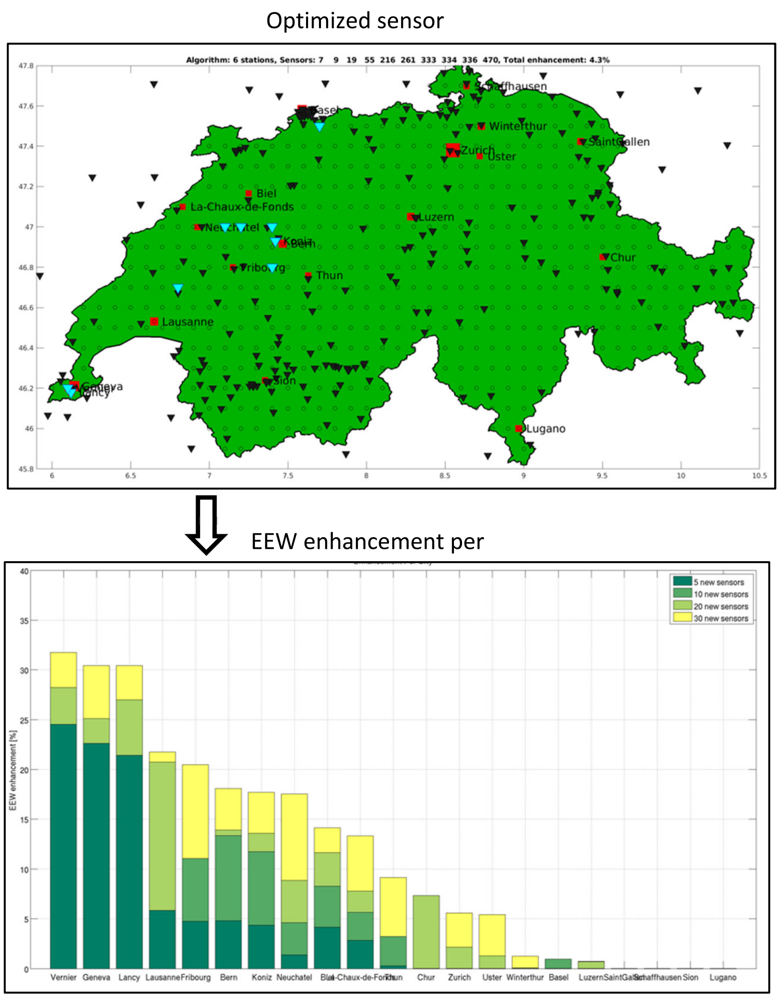
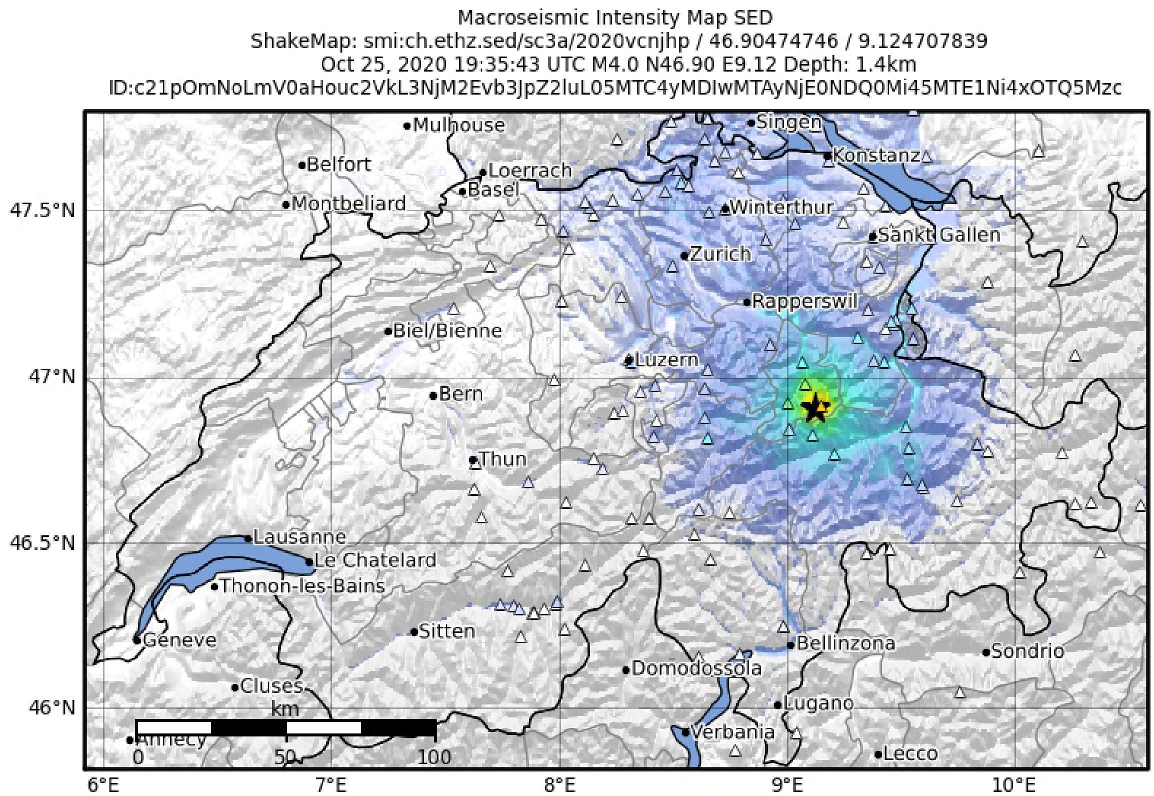


Figure 6.4.7 Risk based EEW performance evaluation for Switzerland. Upper Figure shows optimized sensor distribution; bottom figure shows EEW enhancement per city.

<u>Swiss Shakemaps:</u>

Swiss ShakeMaps seamlessly integrate the latest updates on hazard and engineering seismology science and products (e.g., amplification maps) at Swiss Seismological Service (SED) (Figure 6.4.8). International coordination is achieved through joint developments with other ShakeMap operators in Europe (mainly INGV) and worldwide (USGS), including collaborations within RISE (Task 6.5) and EPOS TCS Seismology. SED has recently adopted the latest software Shakemap v4, that is optimally coupled with OpenQuake GSIM, and a refined site amplification model for macroseismic intensity. SED, INGV, ODC continue to jointly develop and maintain the prototype EU ShakeMap v4 system, rolled out in Fall 2020. The latest results from SERA (GMMs, amplification), RISE & TURNkey (EMSC felt reports) are being integrated. It will provide rapid shaking information input to RISE risk products.



SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
PGA(%g)	<0.0556	0.212	0.808	1.97	4.82	11.8	28.7	70.1	>171
PGV(cm/s)	<0.0178	0.0775	0.337	0.898	2.39	6.37	17	45.2	>120
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based on Faenza and Michelini (2010, 2011) Version 4: Processed 2021-07-09T14:42:15Z

△ Seismic Instrument ○ Reported Intensity ★ Epicenter

Figure 6.4.8. Swiss ShakeMap for the Elm earthquake, 25.10.2020, Mw 4.0

<u>Rapid Loss Assessment for Switzerland:</u>

Rapid loss assessment (RLA) provides near-real time earthquake impact estimates to be communicated to the public and stakeholders. RLA requires fast integration of early event data such as recorded ground motion amplitudes, inferred hypocenter location etc. Figure 6.4.9 illustrated the RLA workflow developed for Switzerland. The adopted procedure relies on the Swiss ShakeMap system. Once an earthquake is detected and ground shaking information becomes available on the system, the estimated mean and dispersion of macroseismic intensity across the country is pulled and fed into the OpenQuake engine, along with local exposure and vulnerability models, to estimate the earthquake's impact to the built environment and population.

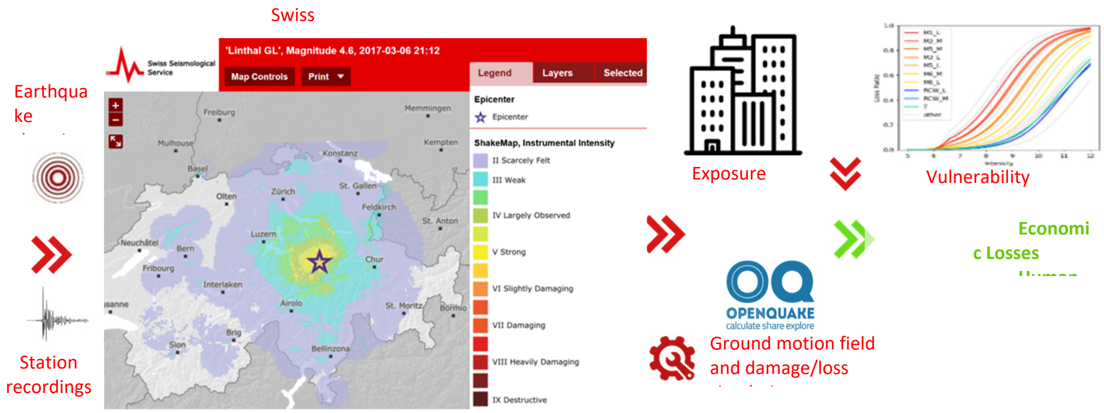


Figure 6.4.9. Swiss RLA Workflow

The obtained impact estimates need to be effectively communicated to the public. To this end, suitable rapid impact assessment forms are being developed to present said information in an efficient and intuitive manner. Figure 6.4.10 presents an example for a hypothetical repeat of the 1356 Basel earthquake. The rapid impact assessment forms contain a range of different metrics of interest, from structural damage to economic losses to fatalities, injuries and displaced population.

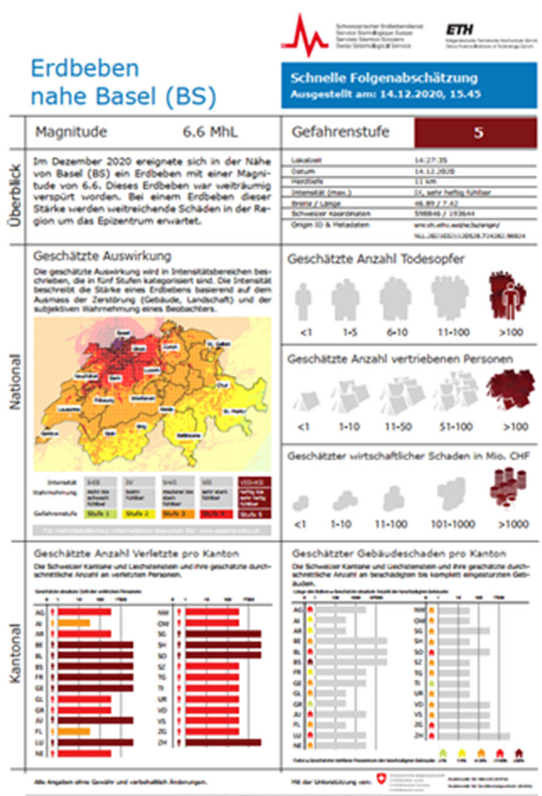


Figure 6.4.10. Rapid impact assessment sheet for an example earthquake

<u>Structural Health Monitoring on Buildings in Switzerland:</u>

A number of typical masonry buildings (9 so far), located in the greater Zurich area, have been measured by the SMM group during the process of demolition (Martakis et al.,. 2021a; 2021b). Contrary to ambient monitoring, these rather specialized measurements offer the opportunity to measure under stronger shaking. The analysis of the recorded data has shown that the amplitude of shaking influences the building response, shifting this from assumed linearity, even within the equivalent linear range, where buildings are still considered healthy (no damage). This process is reversible (see Figure 6.4.11a). However, in absence of vibrations which exceed the typical ambient levels, this implies challenges for delivering robust damage-related alarms aimed for real-time structural health monitoring and damage detection. The conducted experimental campaign, on actual masonry buildings, aims to thus characterize the properties of these buildings under low levels of shaking and to infer the conditions under which the behaviour may be characterized as healthy. For buildings falling into similar typologies, i.e., low-rise pre-code masonry buildings with flexible floor systems, similar amplitude-dependent behaviour is observed (see Figure 6.4.11b) (Martakis et al., 202ac). In addition, implementation of an inverse model updating procedure, relying on a Bayesian framework, indicates that clusters of buildings seem to share similar properties, such as the shear and elasticity moduli. Thus, adoption of a typology system that can reflect this clustering, bears potential for application of structural health monitoring at city-scale, as defined in task 4.4.

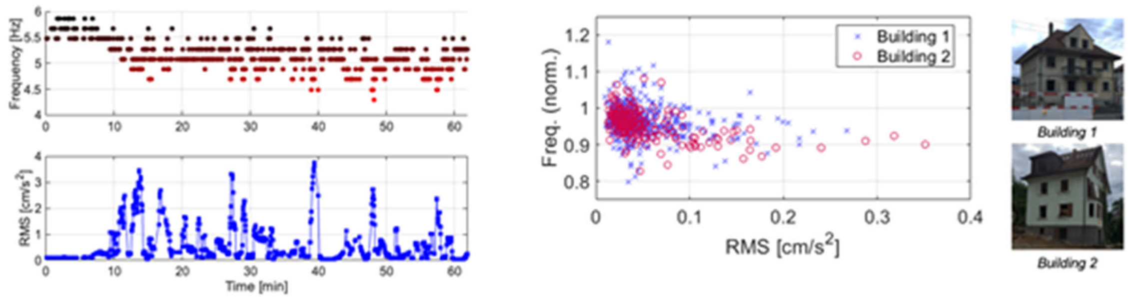
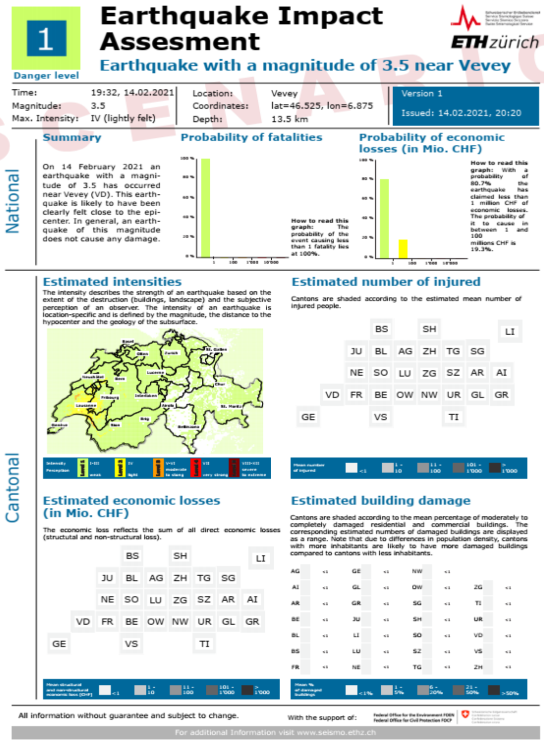


Figure 6.4.11. a) Reversible drop in frequency (top) due to higher amplitudes of excitation (bottom) for an existing masonry building, in absence of visual signs of damage, b) Similarities in stiffness reduction, induced by increased excitation amplitudes for two typologically similar buildings.

• A targeted two-way communication strategy for Switzerland and improved tools for multi-hazard warning and information using web and App-based techniques.

Near-real time computation of useful earthquake impact estimates is communicated to the public and/or stakeholders. Figure 6.4.12 illustrates the template for earthquake impact assessment. The provided information ranges from predicted human losses (injuries, fatalities) to damage estimates and economic losses. Ensuring clear communication of rapid loss estimates using correct color scales, wording, and product resolution is among the ongoing efforts of WP5.



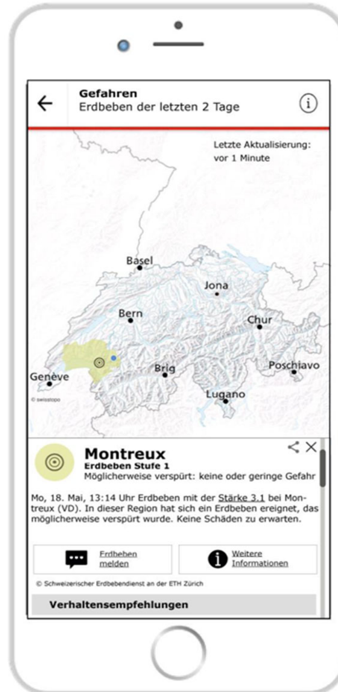


Figure 6.4.12. Template for earthquake impact assessment

Enhancing communication for real-time risk in CH:

- What we have already done:
  - Focus interviews with 20 people from the Swiss public to gain first insights into their perception of EEW and OEF.
  - Expert interviews with 22 European experts to learn more about current developments, experiences, and challenges in dynamic risk communication

- What we are currently working on:
  - Establishing a Swiss stakeholder panel to assess the needs of primary professional users and to test product prototypes
  - Planning a workshop with Swiss natural hazard experts to assess their needs towards dynamic risk information
  - Conducting an online survey and focus groups discussion with the Swiss public to assess key products of dynamic risk information

<u>Post-earthquake recovery:</u>

Predictions of repair and recovery efforts start where traditional seismic risk analysis and loss assessment stops. Figure 6.4.13 illustrates the post-earthquake recovery timeline includes many steps that are required based on the building state, such as rapid visual screening, in-depth engineering analysis, repair planning, permitting and finally, repair or replacement works. In this sequential functional recovery path, the impeding factors that precede the actual repair works have an important influence on the resilience. Therefore, these factors are modelled as services with a supply, e.g. availability of inspectors, and demand, e.g. number of buildings with an open inspection request. This bottom-up model enables studying the influence of impeding factors on the resilience, as shown in Figure 6.4.14a for housing functionality in the city of Zurich under a simulated earthquake scenario, and the steps involved in recovery and rebuilding efforts (RRE). Through modelling recovery trajectories, the aspect of time and thus resilience is added to rapid loss assessment. Challenges regarding precise and reliable recovery predictions in Switzerland are related to challenges due to absence of past data of repair and rebuilding efforts, both at building-level and at regional scale.

Aiming at a reduction of the uncertainty in rapid-loss assessment that results from early, yet imprecise, shake maps, a machine-learning tool has been implemented to use the continuous flow of inspection results of the first days after an earthquake to reduce the uncertainty on uninhabitable buildings, which provides the starting point of recovery trajectories.

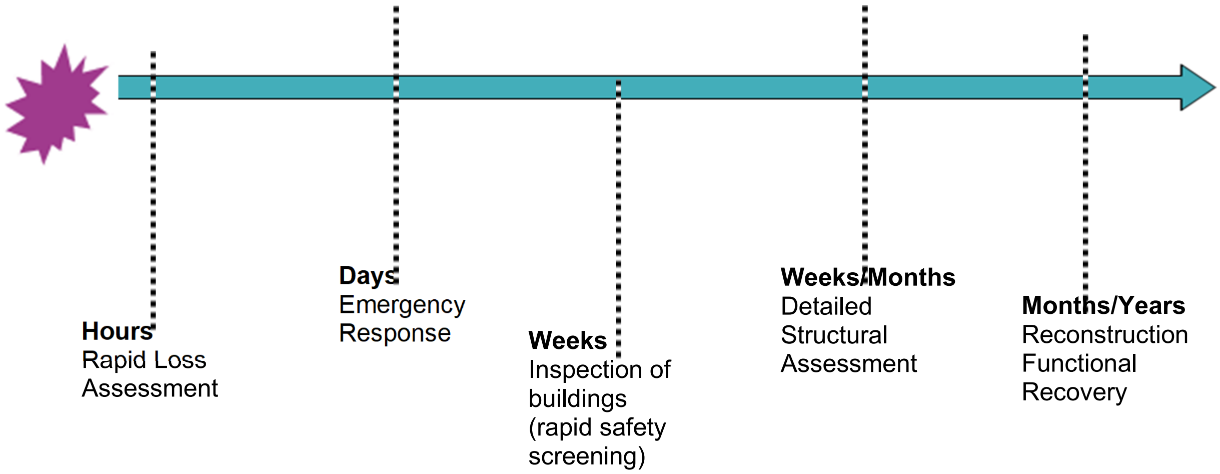


Figure 6.4.13. Post-earthquake recovery timeline

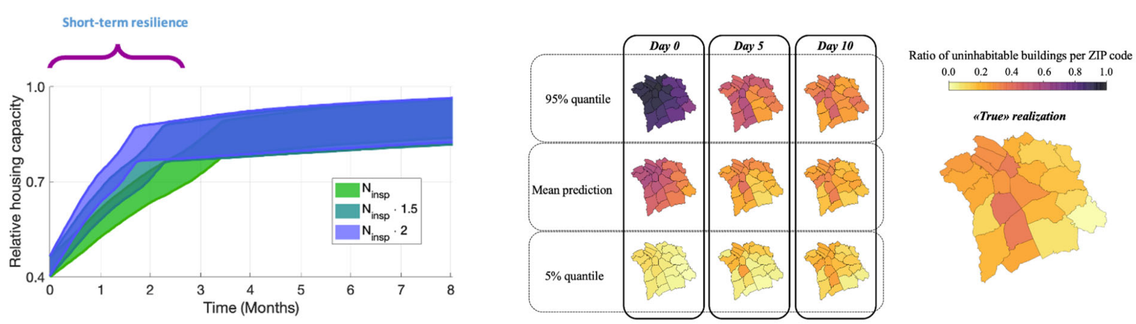


Figure 6.4.14. *Influence of the supply of inspectors on the speed of community recovery after a simulated earthquake in Zurich (left) and reduction in uncertainty that is possible with machine-learning tools after a fraction of the damaged buildings has been inspected (right).*

• A risk-cost-benefit analysis (T4.6) that evaluates available developing pathways from a socio-economical perspective, resulting in a white-paper on real-time earthquake risk reduction options for Switzerland. Combined, these actions will amount to a sound and rational risk reduction plan to manage low-probability/high-impact events in Switzerland. It will also serve as a demonstration and blueprint for other nations to consider for building their own national Dynamic Risk Information Service.

Within CBA, we developed a framework to evaluate immediate-to-long-term benefits of risk mitigation actions (Table 1), where the key players are EEW, RLA, SHM, RRE. Our view is not to favour one over another, however some of the innovations we are currently developing within RISE may provide cost effective solutions and complement each other in different ways within the framework. The ongoing work in CBA covers several RISE modules that are being developed in other tasks. The details of the CBA work carried out can be found in Task 4.6 section.

	Time	RISE Modules	Products/Benefits	Possible Mitigation Actions	Costs

<table>
<tr><td rowspan="4">DYNAMIC RISK COMMUNICATION</td><td>Short</td><td colspan="2">EEW with optimized seismic network</td><td>- Max warning times for correct alerts
- Min number of missed alerts
- Reduced damage to equipment, people
- Reduced injuries, social losses, BI</td><td>- Shutdown critical systems
- Take cover
- Moving away from hazards
- Protection of manufacturing processes</td><td>- Cost of improving seismic network
- Cost of action
- Cost of false/missed alerts</td></tr>
<tr><td rowspan="2">Short - Medium</td><td rowspan="2">RLA</td><td>SHM</td><td>- Time gain in emergency response
- Improved understanding of building damage
- Reduced fatalities/injuries social losses, BI</td><td rowspan="2">-Emergency response
- Recovery Planning</td><td>- Cost of Sensors
- Electricity for measuring, streaming, processing data
- Cost of False & missed alarms</td></tr>
<tr><td>DYNAMIC VULNERABILITY

- Damage accumulation
- Time variability of exposure
- Integration of real-time SHM observations</td><td>- Improved OELF (significant during seismic swarms when short term seismic risk assessment is needed)</td><td>Cost of Person months for developing the methodology
Cost of seismic network & maintenance</td></tr>
<tr><td>Medium-Long</td><td colspan="2">RRE</td><td>Recovery functions</td><td>-Reduced Property damage, BI social losses</td><td></td></tr>
</table>

Table 1. Framework for Risk Cost Benefit Analysis

Combined efforts explained above will amount to a sound and rational risk reduction plan to manage low-probability/high-impact events in Switzerland. It will also serve as a demonstration and blueprint for other nations to consider for building their own national Dynamic Risk Information Service. Figure 16 shows schematically the time dependent probabilistic risk workflow engine that the IT team of ETH is working on.

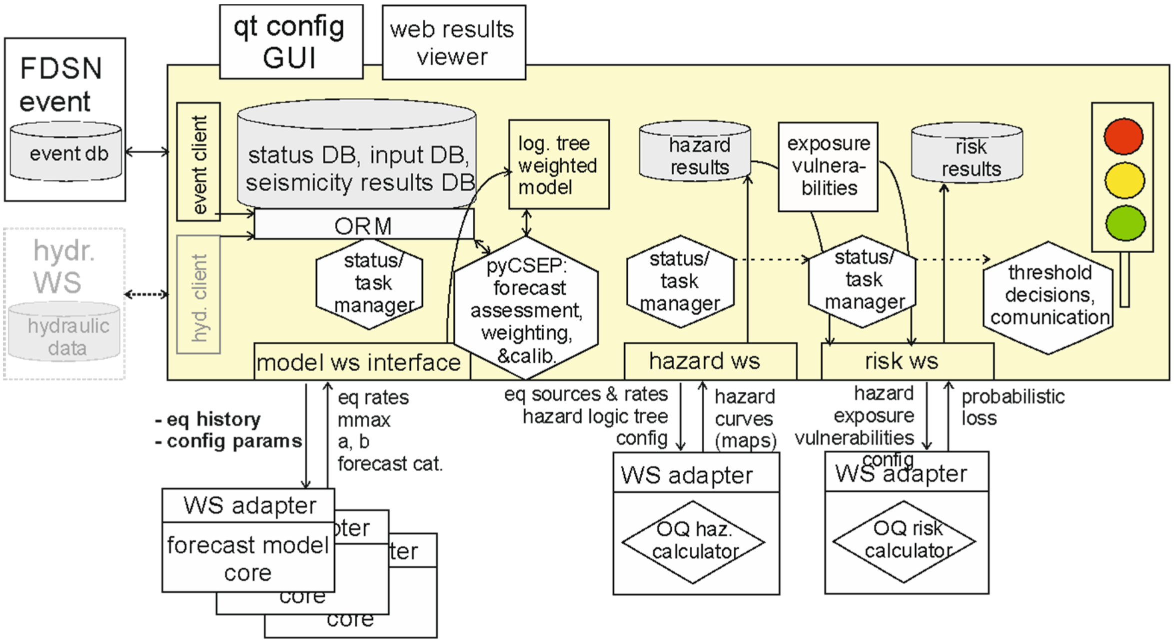


Figure 6.4.15 Time dependent probabilistic risk workflow engine

Task 6.5 Demonstrating RLA, EEW and OEF capabilities at a European level

Thanks to the developments reported previously in Task 4.1, the European ShakeMap system is now online (http://shakemapeu.ingv.it/) and exposure and vulnerability models for 44 European countries are available. So far in this task, the following steps towards the development of European services for Rapid Loss Assessment (RLA) have been made:

- Modifications to the 'Scenario from ShakeMap' calculator of the open source OpenQuake-engine (see flowchart below) have been made so that it can use ShakeMaps inputs (Grid XML and uncertainty XML) from other URLs (i.e. not just USGS), and from locally stored files.
- Web services have been produced such that the European ShakeMap products can be automatically downloaded using 'curl'.
- ShakeMap products (grid XML and uncertainty XML files) from recent events have been downloaded and combined with (high resolution) exposure and vulnerability models to produce various damage and loss outputs using the 'Scenario from ShakeMap' calculator (see example figure below).

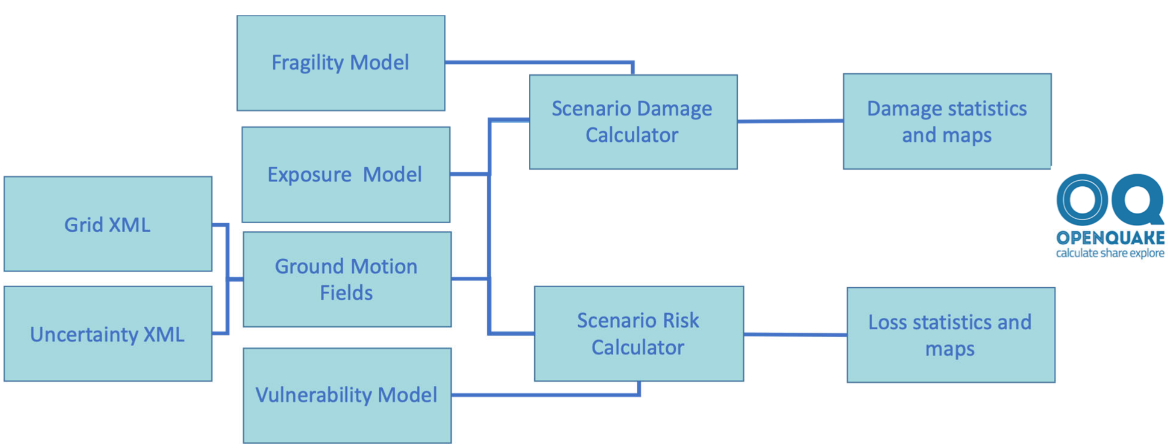


Figure 6.5.1 Scenario from ShakeMap Calculator (OpenQuake-engine https://github.com/gem/oq-engine/tree/master/openquake)

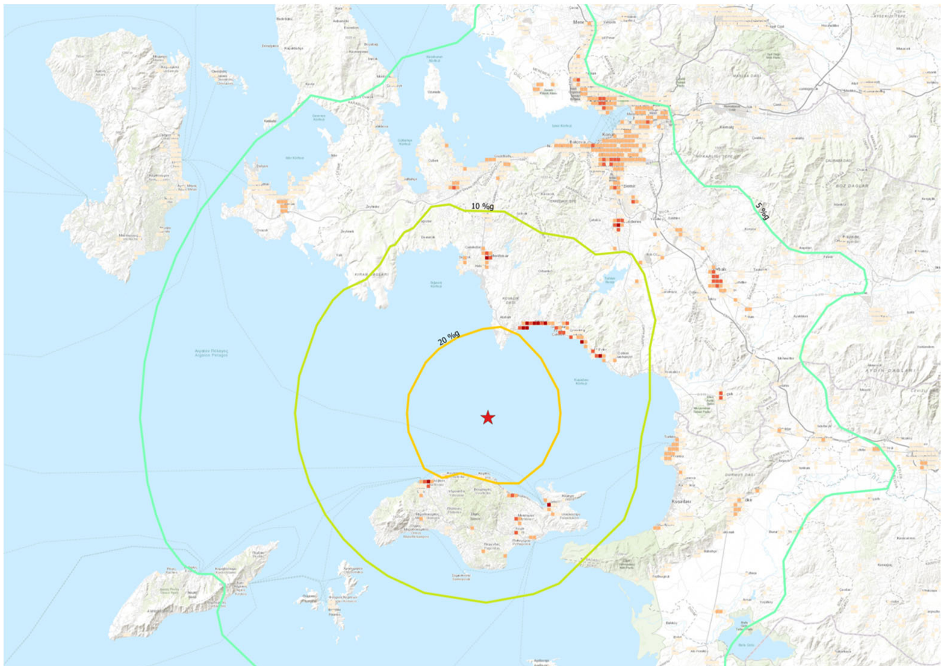


Figure 6.5.2 Rapid damage assessment after the 30th October 2020 Samos/Izmir earthquake: map of the density of completely damaged buildings

List of submitted deliverables and achieved milestones in WP6

- D6.6 Framework for the assessment of economic losses in a dynamic risk context, 28 February 2020

- MS37 Sensors set up and collecting data in buildings in Tokyo, Lourdes, Turkey and Valais, 28 February 2021

Summary of Exploitable Results in WP6

1) Peer reviewed publications

- Guéguen, P., Guattari, F., Aubert, C. and Laudat, T., (2021). Comparing direct observation of torsion with array-derived rotation in civil engineering structures. *Sensors*, *21*(1), p.142.
- Martakis, P., Reuland, Y. and Chatzi, E. (2021a) Amplitude-dependent model updating of masonry buildings undergoing demolition, Smart Structures and Systems, 27(2), 157-172, https://doi.org/10.12989/sss.2021.27.2.157
- Martakis P, Reuland Y, Imesch M, Chatzi (2021b) "Destructing to Preserve: Realistic seismic assessment of masonry buildings through probabilistic model updating based on monitored demolitions", submitted to Bulletin of Earthquake Engineering.

2) Conference publications

- Martakis P, Reuland Y, Chatzi E (2021c) "Amplitude dependency effects in the structural identification of historic masonry buildings" EuroStruct August 29-September 1, 2021, Padova, Italy

3) Other exploitable results/data/reports

- Web services for automatic download of European ShakeMap products.

- Enhancements to the OpenQuake-engine 'Scenario from ShakeMap' calculator (https://github.com/gem/oq-engine)

1.2.7 Work package 7

Overview

This work package is capturing all RISE testing activities with the aim to build in testing to the RISE components. It continues testing as developed by CSEP and expands testing capabilities to all components of the hazard and risk computational chain. This will be accomplished through the installation of the RISE testing center operating on the CSEP2.0 software framework that will be developed. CSEP2.0 will cover new types of tests and optimizations. A special focus is put within the RISE group to bring together modeling and testing to ensure that testing is built into models at the earliest stage.

The RISE testing center is expanded to new types of tests: (1) tailored tests of specific hypotheses, (2) ensemble testing, (3) GMM testing and testing of seismic risk models or scenario damage forecasts. Each of these major goals is represented by a task within the work package.

Summary of achievements in WP7 tasks:

Task 7.1 Developing and implementing the CSEP2.0 framework and test-centre

Goal: This task aims to re-design and re-implement the CSEP1.0 framework and software from a monolithic software to a flexible and modular code base that enables reproducibility and allows for future extensions.

Achievements / Progress

1. pyCSEP, a new CSEP2.0 software toolkit for earthquake forecast developers:

In collaboration with project partner SCEC, we designed pyCSEP, a Python package to help earthquake forecast developers embed model evaluation into the model development process (Savran and Werner, 2020, 2021; Savran et al., 2021a, *under review*; Savran et al., 2021b, *in preparation*). The package contains the following modules (Figure 7.1.1): (1) earthquake catalog access and processing, (2) data models for earthquake forecasts, (3) statistical tests for evaluating earthquake forecasts, and (4) visualization routines. pyCSEP can evaluate earthquake forecasts expressed as expected rates in space-magnitude bins, and simulation-based forecasts that produce thousands of synthetic seismicity catalogs. Most importantly, pyCSEP contains community-endorsed implementations of statistical tests to evaluate earthquake forecasts, and provides well defined file formats and standards to facilitate model comparisons. The toolkit will facilitate integrating new forecasting models into testing centers, which evaluate forecast models and prediction algorithms in an automated, prospective and independent manner, forming a critical step towards reliable operational earthquake forecasting.

pyCSEP follows a community-based open-source software development approach, as described by Savran and Werner (2021), and thus enables researchers to integrate functionality for their own objectives that builds on the prior work of others. Thus far, two publications used the toolkit (Bayona et al., 2020; Savran et al., 2020), two more are under review (Bayona et al., 2021, *under review*; Savran et al., 2021a, *under review*) and several are in an advanced stage.

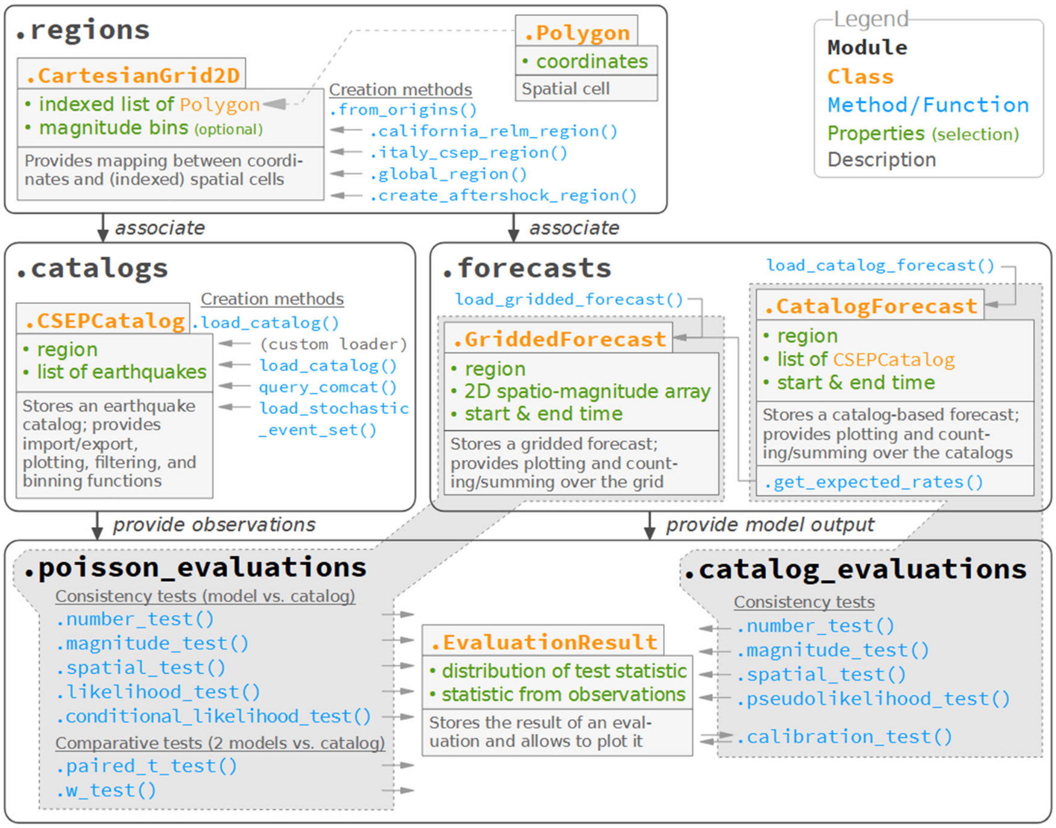


Fig. 7.1.1 Schematic of the pyCSEP classes and code structure. Taken from Savran et al. (2021b, *in preparation*).

2. Virtual workshops and tutorials to introduce the pyCSEP toolkit:

After the initial release of the pyCSEP toolkit, we held a series of virtual workshops between February and June 2021 to familiarize the RISE community of earthquake forecast modellers and testers with the hands-on use of pyCSEP. Over thirty participants attended, mainly RISE beneficiaries. The workshops included hands-on tutorials for using pyCSEP as well as contributing to pyCSEP via git-based code integration. Tutorials are available at the pyCSEP website (https://docs.cseptesting.org/index.html) and an associated manuscript is in preparation including Jupyter notebooks to reproduce all associated results (Savran et al., 2021b, in preparation).

3. Prospective evaluation of the 10-year CSEP earthquake forecast experiment in Italy (Iturrieta et al., 2021, *in preparation*):

A prospective evaluation of the CSEP forecasting experiment was conducted between 2010 and 2019 in the Italy testing region by Iturrieta et al. (2021, in preparation). Fully prospective testing of the models submitted in 2009 was carried out within the context of the RISE project with the following purposes: (i) to assess the predictive skills of different forecast models in Italy, (ii) to provide benchmark results for upcoming experiments to be developed within the project, (iii) to validate the performance of the pyCSEP package with standard testing metrics, and (iv) to understand the limitations of previous testing experiments, while providing guidelines in upcoming experiments.

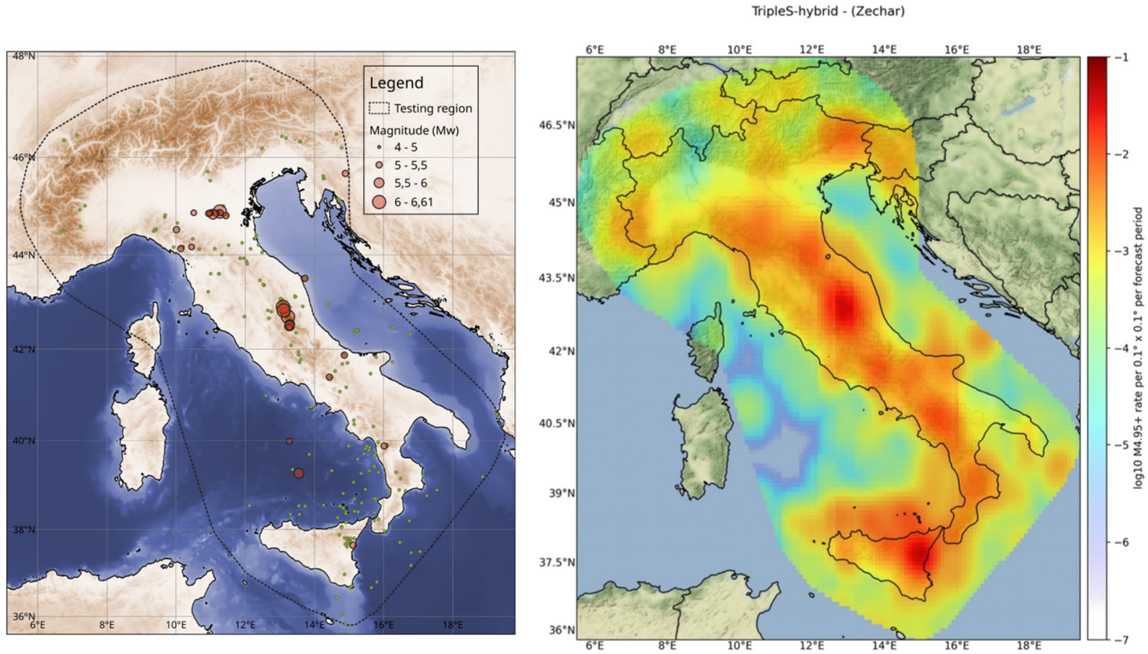


Figure 7.1.2. *(Left) Italy region delimitation with the observed earthquakes during the testing time period 2010-2019. (Right) Forecast example (TripleS_Hybrid, Zechar et al., 2010), where each cell corresponds to the forecasted number of earthquakes with Mw >= 4.95 in the 0.1x0.1 grid cells. Taken from Iturrieta et al. (2021, in preparation).*

Originally, 19 long-term forecasts were submitted to the experiment, assuming a Poisson likelihood function with expected rates provided by the modellers, defined within a 0.1°x0.1 grid and 0.1 magnitude binning over time periods of 5 and 10 years (Figure 7.1.2). Authoritative data sets were agreed between testers and modelers, such as training and testing catalogs, fault database, completeness magnitudes, etc. The models were composed of different underlying assumptions and components, such as using historical seismicity, instrumental seismicity, physics-based modeling, explicitly accounting for geological faults, time-dependence, spatially variable b-values, and others. This model diversity allowed our testing to provide insights into the best-performing model assumptions that could be considered in future forecasts. A multi-score testing approach was used consisting of CSEP1 consistency tests, conditional log-likelihood and information scores, the t-test, and the parimutuel gambling score. Results are shown in Figure 7.1.3.

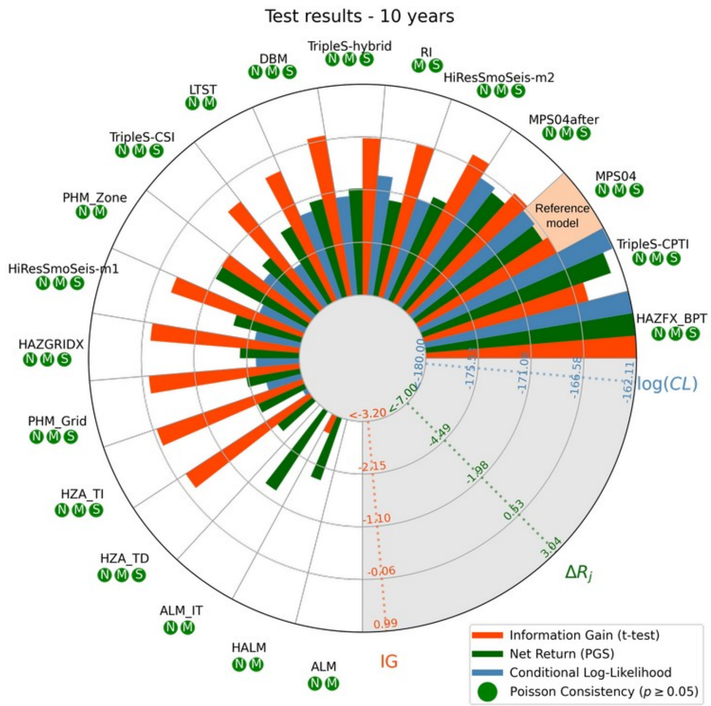


Figure 7.1.3. *Results of the prospective evaluation of the nineteen 10-year forecasts submitted to the CSEP Italy during 2010-2019. Shown are a number of test results, including consistency tests, likelihood and information scores, all qualitatively ranked in descending counter-clockwise order. Just two forecasts outperform the Italian national reference model in this ranking (MPS04). Taken from Iturrieta et al. (2021, in preparation).*

The main conclusions are that the best performing models include historical seismicity catalogues as an input, and that models that included an explicit contribution from geological faults performed above average. Models that included a spatial variation of the b-value performed the worst. Finally, models with high spatial complexity performed worse, mostly due to spatial overfitting.

In collaboration with WP3, we are in advanced stages of planning a new CSEP Italy experiment that builds on these insights, implements newly developed models from WP3 and is based on a new experimental design that relaxes the strict Poisson likelihood assumption in consistency tests.

4. Multi-resolution spatial grid for earthquake forecasting (Khawaja et al, 2021, *in preparation*):

The spatial gridding of 0.1° x 0.1° used in global CSEP experiments thus far is comparatively dense given that large regions in the world have little to moderate seismicity, while some experience concentrated seismicity. The uniform gridding approach leads to 6.48 million spatial cells on the globe. Meanwhile, the distribution of earthquakes around the globe is highly non-homogenous. Almost 99% of the spatial cells contain no earthquake with magnitude >= 5.15 between 1976 and 2013. This leads to an unjustifiably high-resolution grid in low-seismicity regions and also introduces an unnecessary computational burden. Therefore, we (Khawaja et al., 2021, in preparation) propose a quadtree-based gridding approach that is capable of providing a multi-resolution spatial grid. The quadtree is a hierarchical tiling strategy for storing and indexing geospatial data. The globe is divided into 4 tiles, and then each tile can be divided into four children tiles until a final desired grid is acquired. In a multi-resolution grid, the resolution can be determined by a density criterion (or multiple criteria), e.g., the maximum number of earthquakes allowed per cell (N_{max}). This means that only those cells (tiles) are divided further into sub-cells that contain more earthquakes than N_{max}. Thus, instead of dividing the whole globe into 0.1° x 0.1° cells, the quadtree approach can be employed to generate high-resolution (small) grid cells in seismically active regions and low-resolution (big) grid cells in seismically quiet regions. It offers earthquake forecast modellers and testers the liberty of choosing a suitable grid based on the dataset available for training of forecast models and their evaluation. The proposed multi-resolution gridding approach reduces the total number of cells in the grid from millions to a few thousand cells, thereby reducing the number of cells without earthquakes and limiting the computational cost associated with the model generation and evaluation.

The flexible design of the pyCSEP toolkit and the community-based open-source software development approach allowed us to plug this new gridding approach into pyCSEP seamlessly as a new region class. Therefore, the users of pyCSEP can create a new type of data-driven spatial grid to create forecasts and run all the available CSEP tests to evaluate their forecast models.

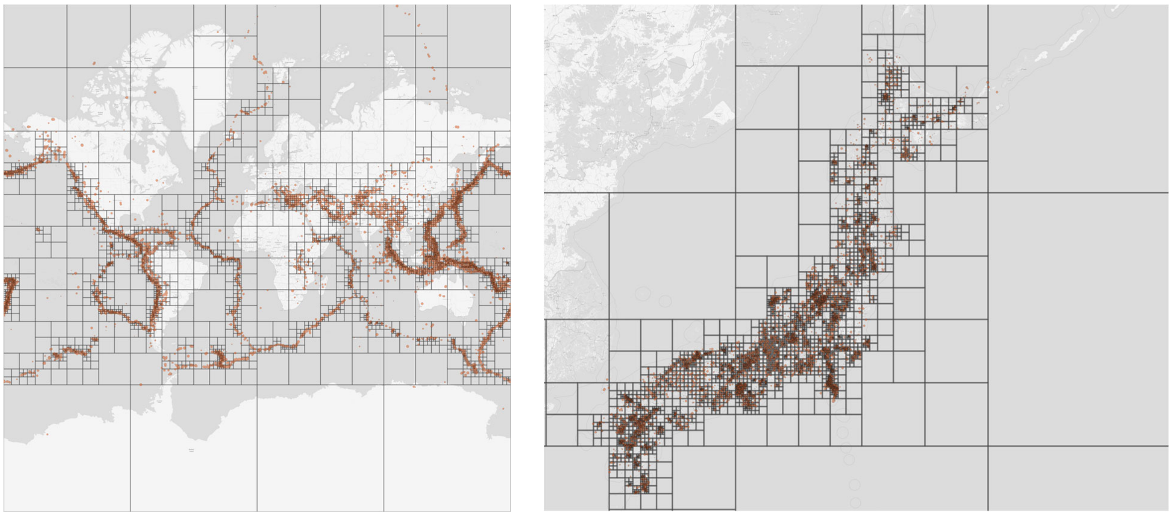


Figure 7.1.4: *Earthquake catalog based multi-resolution grids acquired using the quadtree approach for (left) the global region and (right) the Japanese testing region. Taken from Khawaja et al. (2021, in preparation).*

Task 7.2. Test new physics-based, stochastic and hybrid OEF models

Goal: This task aims to evaluate newly developed physics-based, stochastic and hybrid earthquake forecast models that might be suitable for operational earthquake forecasting (OEF) in order to drive model improvement and characterise confidence in the model forecasts.

Progress / Achievements

1. Retrospective Tests of Coulomb-stress and ETAS model forecasts during the 2019 Ridgecrest earthquake sequence (Mancini et al., 2020):

Operational earthquake forecasting protocols commonly use statistical models for their recognized ease of implementation and robustness in describing the short☐term spatiotemporal patterns of triggered seismicity. However, recent advances in physics☐based aftershock forecasting reveal comparable performance to the standard statistical counterparts with significantly improved predictive skills when fault and stress☐field heterogeneities are considered. Mancini et al. (2020) performed a pseudo-prospective forecasting experiment during the first month of the 2019 Ridgecrest (California) earthquake sequence. They developed seven Coulomb rate☐and☐state models that couple static stress☐change estimates with continuum mechanics expressed by the rate☐and☐state friction laws. Their model parameterization supports a gradually increasing complexity; they start from a preliminary model implementation with simplified slip distributions and spatially homogeneous receiver faults to reach an enhanced one featuring optimized fault constitutive parameters, finite☐fault slip models, secondary triggering effects, and spatially heterogeneous planes informed by pre☐existing ruptures. The data☐rich environment of southern California allowed them to test whether incorporating data collected in near☐real time during an unfolding earthquake sequence boosts our predictive power. They assessed the absolute and relative performance of the forecasts by means of statistical tests used within CSEP and compared their skills against a standard benchmark epidemic☐type aftershock sequence (ETAS) model for the short (24 hr after the two Ridgecrest mainshocks) and intermediate terms (one month) (Figure 7.2.1). Stress☐based forecasts expect heightened rates along the whole near☐fault region and increased expected seismicity rates in central Garlock fault. Their comparative model evaluation not only supports that faulting heterogeneities coupled with secondary triggering effects are the most critical success components behind physics☐based forecasts, but also underlines the importance of model updates incorporating near☐real☐time available aftershock data reaching better performance than standard ETAS. They explored the physical basis behind their results by investigating the localized shut down of pre☐existing normal faults in the Ridgecrest near☐source area.

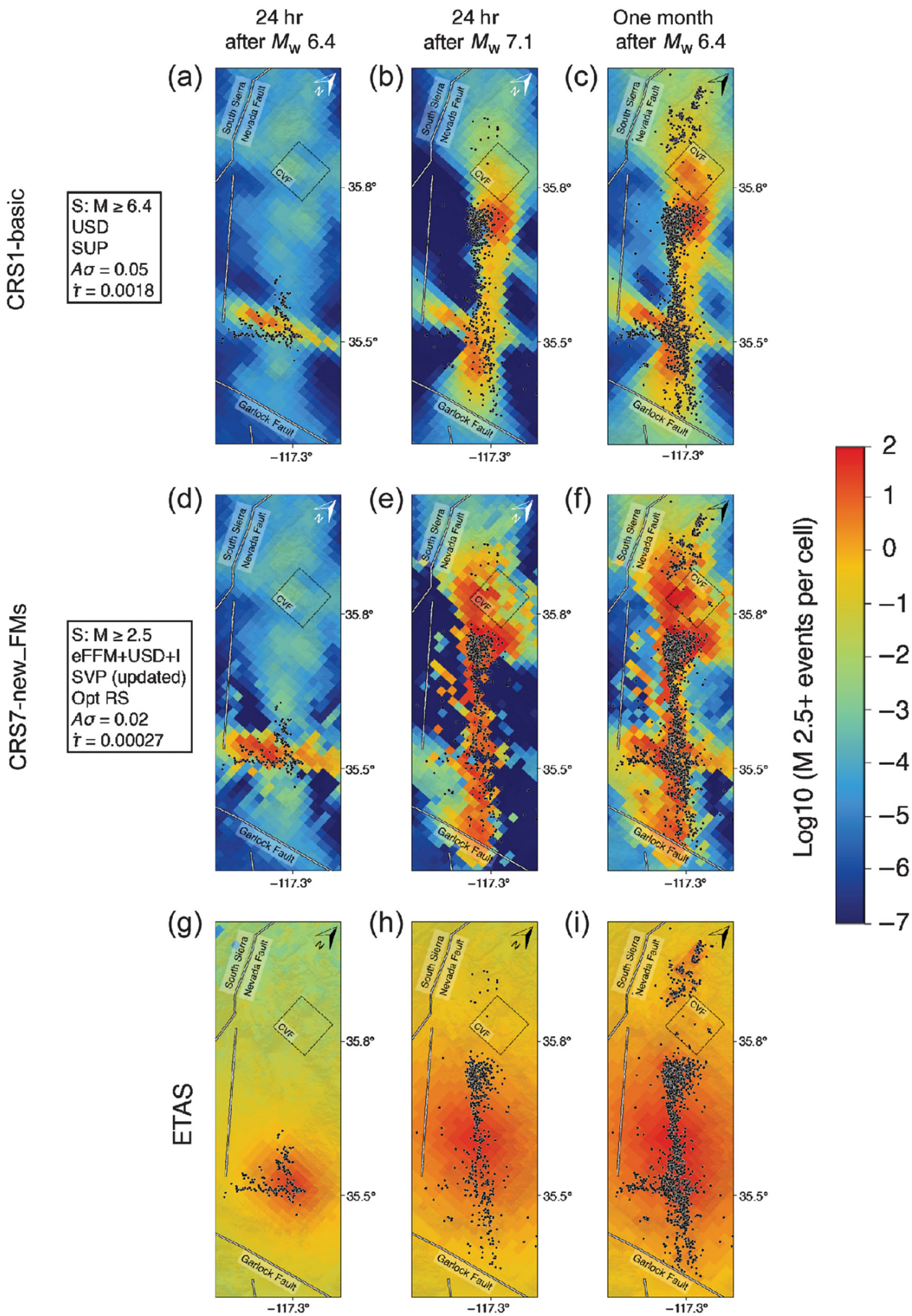


Figure 7.2.1: *Maps of expected seismicity rates for (a–c) CRS1, (d–f) CRS7, and (g–i) ETAS in the area of main aftershock productivity for the first 24 hr following the two mainshocks and for the first month of the Ridgecrest sequence. Observed events (Mw2.5+) in each time window are represented as circles. The dashed□line square indicates the area of the Coso volcanic field (CVF). eFFM, edited finite□fault slip model; I, isotropic stress field; Opt RS, optimized rate□and□*

state parameters; S, sources (minimum magnitude); SUP, spatially uniform receiver planes; SVP, spatially variable planes; USD, uniform slip distribution. Aσ☐values are in MPa and τ˙☐values are in MPa/yr. Taken from Mancini et al. (2020).

2. Pseudo-prospective tests of the UCERF3-ETAS model forecasts during the 2019 Ridgecrest earthquake sequence (Savran et al., 2020):

The 2019 Ridgecrest sequence provides the first opportunity to evaluate the Uniform California Earthquake Rupture Forecast v.3 with Epidemic☐Type Aftershock Sequences (UCERF3☐ETAS) in a pseudo-prospective sense. For comparison, Savran et al. (2020) included a version of the model without explicit faults more closely mimicking traditional ETAS models (UCERF3☐NoFaults) (Figure 7.2.2). They evaluated the forecasts with new metrics developed within CSEP. The metrics consider synthetic catalogs simulated by the models rather than synoptic probability maps, thereby relaxing the Poisson assumption of previous CSEP tests. Their approach compares statistics from the synthetic catalogs directly against observations, providing a flexible approach that can account for dependencies and uncertainties encoded in the models. They found that, to the first order, both UCERF3☐ETAS and UCERF3☐NoFaults approximately capture the spatiotemporal evolution of the Ridgecrest sequence, adding to the growing body of evidence that ETAS models can be informative forecasting tools. However, they also found that both models mildly over predict the seismicity rate, on average, aggregated over the evaluation period. More severe testing indicates the over predictions occur too often for observations to be statistically indistinguishable from the model. Magnitude tests indicate that the models do not include enough variability in forecasted magnitude☐number distributions to match the data. Spatial tests highlight discrepancies between the forecasts and observations, but the greatest differences between the two models appear when aftershocks occur on modeled UCERF3☐ETAS faults. Therefore, any predictability associated with embedding earthquake triggering on the (modeled) fault network may only crystalize during the presumably rare sequences with aftershocks on these faults. Accounting for uncertainty in the model parameters could improve test results during future experiments.

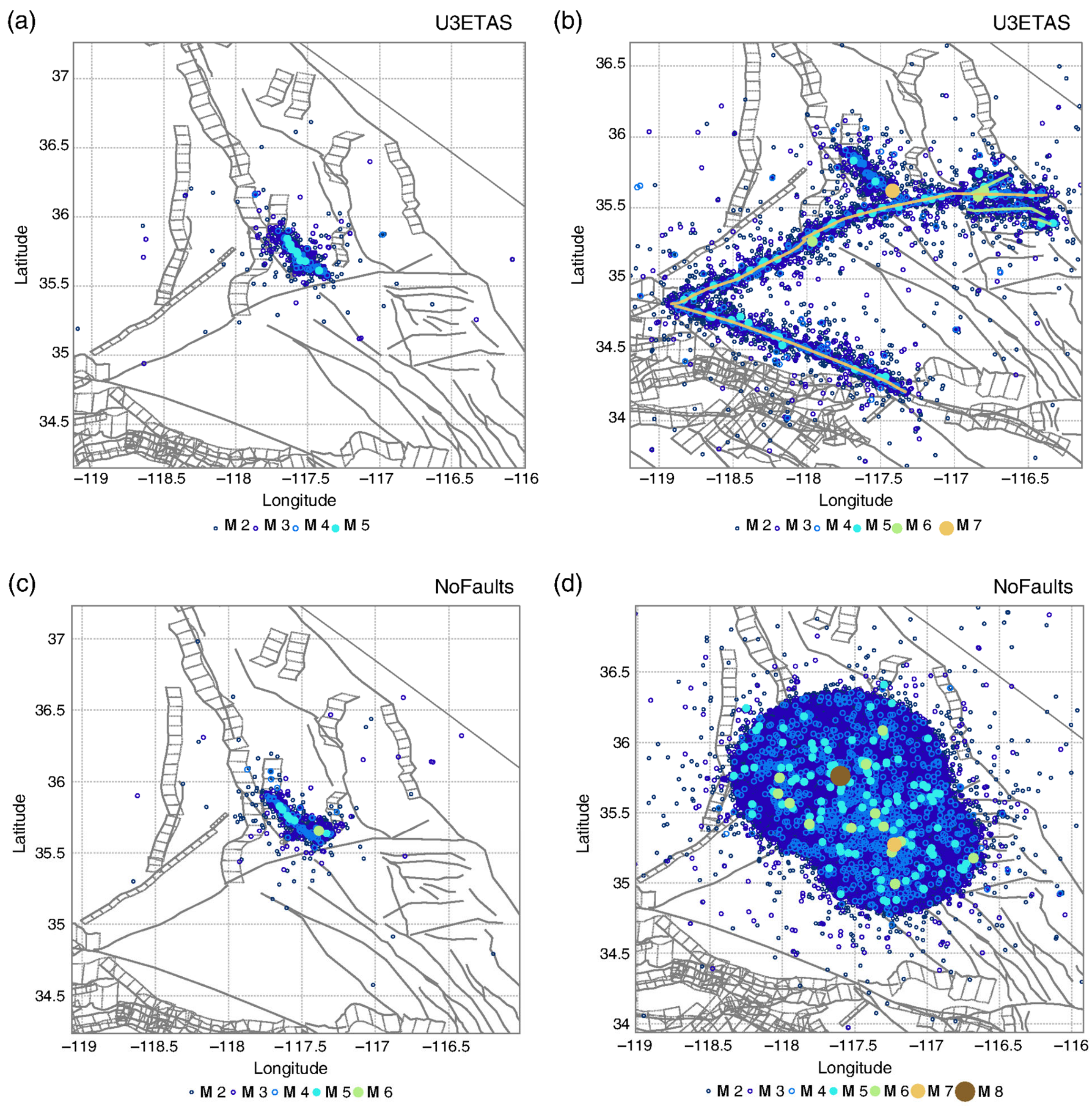


Figure 7.2.2: *Synthetic catalog realizations showing seven days of aftershocks following the Mw 7.1 mainshock. (a) "Typical" UCERF3□ETAS synthetic catalog, defined as the catalog the event count of which lies along the median among all simulated catalogs. (b) "Extreme" UCERF3-ETAS synthetic catalog, which is defined as the catalog the event count of which falls in the uppermost 0.1th percentile of the forecasted number distribution. Notice the triggered ruptures on the Garlock and San Andreas faults that in turn generate aftershocks along these faults. (c) "Typical" synthetic catalog generated by UCERF3□NoFaults (hereafter, NoFaults) and (d) an "extreme" catalog from NoFaults, which lacks triggering of ruptures on prescribed faults resulting in a nearly isotropic aftershock distribution. The "extreme" catalogs highlight the predominant differences between these two models and suggest that differences will be most noticeable when large aftershocks occur on mapped faults in UCERF3-ETAS. Taken from Savran et al. (2020).*

3. Retrospective tests of an injection rate driven ETAS model during the 2018/2019 hydraulic-fracturing induced seismicity at Preston New Road (UK) (Mancini et al., 2021):

The development of robust forecasts of human-induced seismicity is highly desirable to mitigate the effects of disturbing or damaging earthquakes. Mancini et al. (2021) assessed the performance of a well-established statistical model, the epidemic-type aftershock sequence (ETAS) model, with a catalog of ~93;000 microearthquakes observed at the Preston New Road (PNR, United Kingdom) unconventional shale gas site during, and after hydraulic fracturing of the PNR-1z and PNR-2 wells.

Because ETAS was developed for slower loading rate tectonic seismicity, to account for seismicity caused by pressurized fluid, they also generated three modified ETAS with background rates proportional to injection rates. They found that (1) the standard ETAS captures low seismicity between and after injections but is outperformed by the modified model during high-seismicity periods, and (2) the injection-rate driven ETAS substantially improves when the forecast is calibrated on sleeve-specific pumping data. They finally forecast out-of-sample the PNR-2 seismicity using the average response to injection observed at PNR-1z, achieving better predictive skills than the in-sample standard ETAS. The insights from this study contribute toward producing informative seismicity forecasts for real-time decision making and risk mitigation techniques during unconventional shale gas development.

4. Prospective evaluation of long-term hybrid forecast models in California (Bayona et al., 2021, *under review*):

The Regional Earthquake Likelihood Models (RELM) experiment, conducted within CSEP, showed that the smoothed seismicity (HKJ) model by Helmstetter et al. (2007) was the most informative time independent earthquake model in California during the 2006–2010 evaluation period. The diversity of competing forecast hypotheses and geophysical datasets used in RELM was suitable for combining multiple models that could provide more informative earthquake forecasts than HKJ. Thus, Rhoades et al. (2014) created multiplicative hybrid models that involve the HKJ model as a baseline and one or more conjugate models. In retrospective evaluations, some hybrid models showed significant information gains over the HKJ forecast. Bayona et al. (2021, *under review*) prospectively assessed the predictive skills of 16 hybrids and 6 original RELM forecasts using a suite of traditional and new CSEP tests that rely on a Poisson and a binary likelihood function, respectively. In addition, they compared the performance of each forecast to that of HKJ. The evaluation dataset contains 40 target events recorded within the CSEP California testing region from 1 January 2011 to 31 December 2020, including the 2016 Hawthorne earthquake swarm in southwestern Nevada and the 2019 Ridgecrest sequence. Consistency test results show that most forecasting models overestimate the number of earthquakes and struggle to explain the spatial distribution of epicenters, especially in the case of seismicity clusters. The binary likelihood function significantly reduces the sensitivity of spatial log-likelihood scores to clustering (Figure 7.2.3); however, most models still fail to adequately describe spatial earthquake patterns. Contrary to retrospective analyses, these prospective test results show that none of the models are significantly more informative than the HKJ benchmark forecast, which they interpreted to be due to temporal instabilities in the fit that forms hybrids. These results suggest that smoothing high-resolution, small earthquake data remains a robust method for forecasting moderate-to-large earthquakes over a period of five to fifteen years in California.

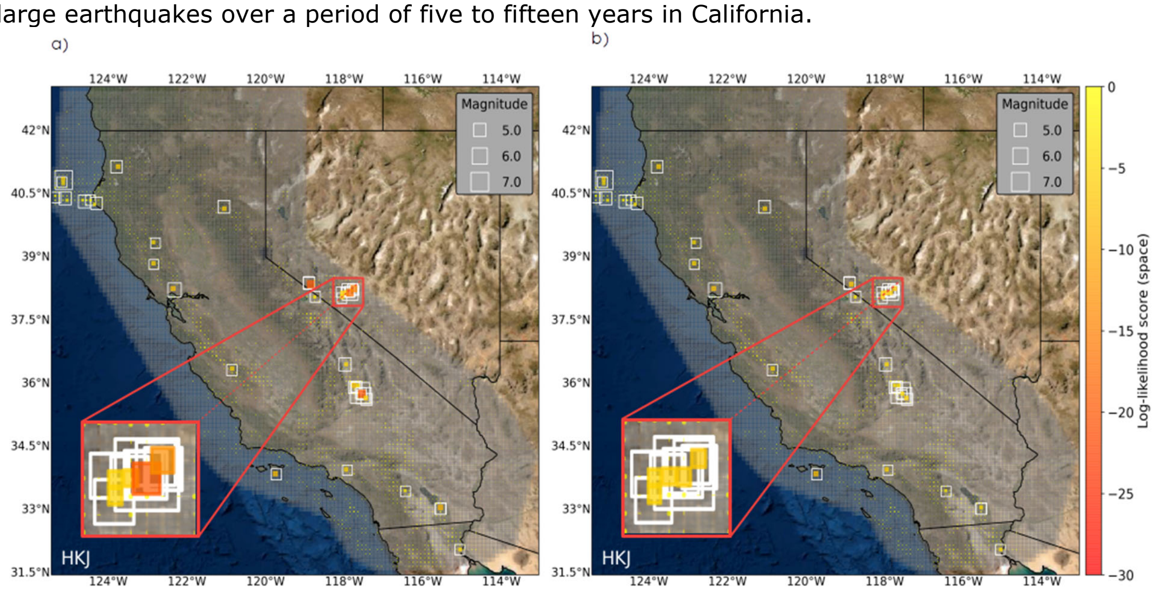


Figure 7.2.3: *Spatial distribution of log-likelihood scores obtained in each spatial cell by the HKJ forecast, using a) a Poisson and b) a binary likelihood function. The Poisson-based S-test penalises the model for the unlikely occurrence of the 2016 Hawthorne earthquake swarm (zoomed in) and the 2019 Ridgecrest sequence in a few spatial cells more severely than the S-test that relies on a*

binary probability function. White squares denote the epicentral locations of the M4.95 target earthquakes. Taken from Bayona et al. (2021, under review).

Task 7.3. Optimizing earthquake forecasting capabilities through ensemble modelling

Goal: This task aims to develop approaches for optimally combining earthquake forecasts and to characterise model uncertainty for the purpose of decision making and model evaluation.

Progress / Achievements
Ensemble modeling is a common tool in weather forecasting to improve forecasting capability merging the outcomes of different models. In the first part of the project, we have deeply investigated the strategies adopted in different fields and we have started the development of one original procedure.

The most innovative part of the work done is that we do not focus only on obtaining the best forecasting model, but we also take into account in a proper probabilistic scheme the epistemic uncertainty. In essence the work made so far consists of:

- Reviewing the existing literature on how to combine at best the outcomes of different forecasting models; we have started to explore the implementation of some of these procedures in earthquake forecasting which presents some important differences with weather forecasting, for example, the fact that the time series that we want to forecast are composed by a few 1's (i.e., target earthquakes) and many 0's (i.e., no earthquake has occurred).
- developing a theoretical scheme to merge outcomes of different models to obtain a forecasting distribution which takes into account the aleatory variability and epistemic uncertainty in a proper way; this is very important because it allows a meaningful consistency test of the forecasting model.
- developing a new procedure to weigh the outcomes of different models through a dedicated logistic regression, and through Monte Carlo simulation. The evaluation of these procedures is still ongoing.

Task 7.4. Formal testing of ground motion forecasts, micro-zonation, exposure and loss models

Goal: This task aims to develop formal testing of ground motion models and eventually integrate testing as a part of the ground motion modelling.

Progress / Achievements
Ground motion models (GMMs) predict the probability of exceeding a certain level of ground motion intensity. GMMs are empirical prediction equations and usually derived using regression over a large number of observations, but are rarely independently tested against new data. GMMs depend on the source, path and site of an event, usually in the form of magnitude, distance and Vs30, respectively. With larger datasets and more available metadata, a trend has been to include more and more variables in the prediction equations. However, several studies (e. g. Delavaud et al. 2009; Kaklamanos & Baise, 2011) have shown that more complex models do not necessarily mean better accuracy in the predictions. One example of increased complexity in models is including non-linear site amplification factors in GMMs. Because non-linear site amplifications mainly occur for soft soils sites and strong ground motions, recordings of such phenomena are rare. Non-linear site amplification models are therefore mainly based on numerical simulations. Loviknes et al. (2021) have tested four well-known non-linear amplification models used in GMMs against the new independent dataset of Bahrampouri et al. (2020). In the study, the empirical site amplification is derived from the observations and tested against site amplification models and a simple linear amplification model. The test shows that for most sites the simple linear amplification model has a better score than the non-linear models. The study considers ground motions up to 0.2 g, which is equivalent to moderate seismicity areas and the result of the test suggests that in this range of ground motions, including non-linear amplification factors in GMMs and building codes cannot be justified.

Although testing within seismic hazard assessment has become increasingly common (e.g. Mak et al., 2015, 2017), it is still a field under development. In this task, we aim to build upon the method of Loviknes et al. (2021) and others, to further develop not only testing procedures for

GMMs, but also develop a new kind of data driven ad-hoc GMMs with testing as an integrated part of the prediction models.

Summary of Exploitable Results in WP7

1) Peer-reviewed publications

- Bayona, J., Savran, W. H., Rhoades, D. A., Werner, M. J. (2021, *under review*), Prospective evaluation of multiplicative hybrid earthquake forecasting models in California, under review in *Geophysical Journal International*.
- Iturrieta, P., Savran, W. H., Khawaja, A., Marzocchi, W., Taroni, M., Falcone, G., Schorlemmer, D. (2021, *in preparation*), Testing the performance and spatial consistency of 10-yr earthquake forecasts in Italy.
- Khawaja, M. A., Schorlemmer, D., Hainzl, S., Iturrieta, P., Savran, W. H. (2021, *in preparation*), Multi-resolution grids in earthquake forecasting: the quad-tree approach.
- Loviknes, K., Kotha, S. R., Cotton, F., Schorlemmer, D. (2021), Testing Nonlinear Amplification Factors of Ground-Motion Models. - Bulletin of the Seismological Society of America. https://doi.org/10.1785/0120200386GFZPublic
- Mancini, S., Segou, M., Werner, M. J., Parsons, T. (2020). The predictive skills of elastic Coulomb rate☐and☐state aftershock forecasts during the 2019 Ridgecrest, California, earthquake sequence. *Bulletin of the Seismological Society of America*, *110*(4), 1736-1751. https://doi.org/10.1785/0120200028
- Mancini, S., Werner, M. J., Segou, M., Baptie, B. (2021). Probabilistic Forecasting of Hydraulic Fracturing☐Induced Seismicity Using an Injection☐Rate Driven ETAS Model. *Seismological Research Letters*. https://doi.org/10.1785/0220200454
- Savran, W. H., Werner, M. J., Marzocchi, W., Rhoades, D. A., Jackson, D. D., Milner, K., Field, E., Michael, A. (2020). Pseudoprospective Evaluation of UCERF3☐ETAS Forecasts during the 2019 Ridgecrest Sequence. *Bulletin of the Seismological Society of America*. 110 (4): 1799–1817. https://doi.org/10.1785/0120200026
- Savran, W. H., Werner, M. J., Schorlemmer, D., and P. J. Maechling (2021a, *under review*), pyCSEP: A Python Package For Earthquake Forecast Developers. *The Journal of Open Source Software*, https://github.com/openjournals/joss-reviews/issues/3507 (last accessed 16 August 2021)
- Savran, W. H., Bayona, J., Iturrieta, P., Khawaja, A., Bao, H., Bayliss, K., Herrmann, M., Maechling, P., and M. J. Werner (2021b, *in preparation*), pyCSEP: Software for Earthquake Forecast Developers, in preparation for *Seismol. Res. Lett*.
- Zhang, L., Werner, M. J., Goda, K. (2020). Variability of ETAS parameters in global subduction zones and applications to mainshock–aftershock hazard assessment. *Bulletin of the Seismological Society of America*, *110*(1), 191-212. doi: https://doi.org/10.1785/0120190121
- Zhang, L., Goda, K., Werner, M. J., Tesfamariam, S. (2021). Spatiotemporal seismic hazard and risk assessment of M9. 0 megathrust earthquake sequences of wood☐frame houses in Victoria, British Columbia, Canada. *Earthquake Engineering & Structural Dynamics*, *50*(1), 6-25. doi: https://doi.org/10.1002/eqe.3286

2) Conference publications

- José Bayona, William Savran, Maximilian Werner and David Rhoades (2021), Prospective Evaluation of Multiplicative Hybrid Earthquake Forecast Models for California, SSA Annual Meeting.
- José Bayona, William Savran, Anne Strader, Sebastian Hainzl, Fabrice Cotton and Danijel Schorlemmer (2021), Two Global Ensemble Seismicity Models Obtained From the Combination of Interseismic Strain Rates and Earthquake-Catalog Data, SSA Annual Meeting.
- José Bayona, William Savran, Maximilian Werner and David Rhoades (2021), Prospective evaluation of Multiplicative Earthquake Forecast Models for California, EGU General Assembly Conference.
- José Bayona, William Savran and Maximilian Werner (2021), Are regionally calibrated earthquake forecast models more informative than global models? First results from California and Italy, SCEC Annual Meeting.
- Khawaja M. Asim, Danijel Schorlemmer, Sebatian Hainzl, Pablo Iturrieta, William H. Savran (2021), Quadtree based multi-resolution grids for global earthquake forecast experiment, European Seismological Commission.
- Khawaja M. Asim, Pablo Iturrieta, Sebastian Hainzl, Danijel Schorlemmer (2021), Effects of Spatial Grid Resolution on the Performance Evaluation of Earthquake Forecast Models.

- Loviknes, K., Schorlemmer, D., Cotton, F., Kotha, S. R. (2021): Testing non-linear amplification factors used in ground motion models - Abstracts, EGU General Assembly 2021. https://doi.org/10.5194/egusphere-egu21-4829

3) Other exploitable results/data/reports

- Savran, W. H., Werner, M. J., Schorlemmer, D., and P. J. Maechling (2021). pyCSEP - Tools for Earthquake Forecast Developers (version 0.4.1). https://github.com/SCECcode/pycsep (last accessed 16 August 2021)
- Savran, W. H. and Werner, M. J. (2020), How predictable are earthquakes? A new software toolkit helps earthquake forecasters decide. SCEC newsletter. https://www.scec.org/article/639 (last accessed 16 August 2021)
- Savran, W. H. and Werner, M. J. (2021), Sustainable Research Software through Open-Source Communities. SCEC newsletter. https://www.scec.org/article/700 (last accessed 16 August 2021)

1.2.8 Work package 8

Overview

WP 8 focuses on securing the broad societal, economic, and scientific impact of RISE; an impact which is both demonstrable and long-term. This process started on day one of the project, continues throughout, and exposes all activities in RISE to an ongoing dialogue targeting stakeholder and end-user needs. Supported by the RISE stakeholder panel, WP8 adopts an interdisciplinary and multi-hazard user perspective and translates all RISE outputs and deliverables into tangible products and services, useful for and used by a wide range of stakeholders. WP8 contains a comprehensive set of communication, dissemination, exploitation, and decision-support activities, prioritised in relation to what is needed to maximise impact.

Task 8.1: Plan for the Exploitation and Dissemination of Results (PEDR)

PEDR is the master plan to maximise the demonstrable, long-term socio-economic impact and to achieve a measurable increase in the resilience of our societies against the threat of earthquakes. A set of measures, metrics, and formats were established to promote RISE activities and define their success. For quantitative measurements, the following metrics are considered: website users, Twitter followers, newsletter subscribers, publications, and number of participants of stakeholder exchange. For the qualitative impact, starting in M12, the impact of each WP with regards to science, society, technology, and economy, was collected and will be updated and completed for the last PEDR deliverable 8.3.

- Deliverable 8.1 (submitted in M3): The first Plan for the Exploitation and Dissemination of the project's Results (PEDR) defined the above-mentioned metrics, including quantitative goals, to measure the RISE project's impact.
- Deliverable 8.2 (submitted in M12): The second PEDR provides an overview over the quantitative key performance indicators achieved by M12 and first insights into the quantitative metrics, provided the work packages could already show first achievements.
- Deliverable 8.3 (Deadline: February 2022): It is planned that the last PEDR will summarize all quantitative and qualitative metrics. Therefore, the document will show the project's impact achieved after more than two years.

Summary quantitative KPIs

All quantitative metrics could have been increased so far and therefore met most of the defined sub-goals. The sub-goals of M6 and M12 regarding the number of unique website users could not be reached. However, the number of website visitors has risen steadily since the project started and in the last couple of months, the average number of unique website visitors were always above the defined goal. This continuous increase is a positive development that is expected to grow further. Through regular communication activities on Twitter, the goal of 100 followers was reached within a year without problems. Only a few more followers are still missing until the goal of 250 followers is also achieved by M24. The same mostly applies to newsletter subscribers, but probably more effort is needed to reach the next defined sub-goal. All detailed information on the defined and the so far reached KPIs can be found in the table of the chapter "Summary of Exploitable Results in WP 8.

Summary qualitative metrics

WP3, 4 and 6 already reported a number of impacts in terms of science, society, technology and economy after the first project year. As these qualitative metrics had to be assessed in the deliverable due in M12, the work on some WPs were still ongoing, and the impact will be more evident at a later stage of the project. Therefore, we will provide a more detailed update in the next PEDR, D8.3 "Update PEDR". In the following, a summary of the impacts achieved by WP 3, 4 and 6:

- **WP3** has made notable progress in the field of earthquake forecasting. With a focus on developing new and extending existing approaches to model seismicity, some models have already demonstrated to improve forecasting performance. Since April 2020, the physics-based forecast community gathered regularly in virtual meetings, which quickly attracted international researchers outside of the RISE community. The achieved progress in WP3 advances operational earthquake forecasting and contributes to an improved assessment of the dynamic risk.
- **WP4** achieved different results in the field of risk and resilience assessment for earthquake early warning, as well as short- and long-term risk management during and after seismic sequences. In the context of rapid loss assessment and operational earthquake loss forecasting (OELF) services for Europe, researchers of WP4 developed static and time-invariant exposure models for 45 countries and time-invariant vulnerability models representing over 500 building classes. These models allow the implementation of OELF for Europe (in collaboration with WP3), which also serves for rational decision making (WP8). Other important activities of WP4 concern the data-driven structural health monitoring. The main objective pertains to the assessment of the feasibility of an automated 'smart'-tagging of earthquake-hit buildings as safe or unsafe for users. In fact, the replacement of lengthy and potentially subjective visual-inspection campaigns with data-driven tagging offers the potential for approximate, yet rapid, assessment of the building state in the immediate aftermath of an earthquake. Furthermore, the development of a framework for cost-benefit analysis has been started. Results of such an analysis are supposed to have a strong impact on economy and society, as they should support a dialogue with end-users such as decision makers and the public.
- **WP6** has developed low cost medium quality MEMS sensors (in WP2), which were then deployed in a number of buildings by QuakeSaver, for example, in the Tokyo Metropolitan Government Building (16 QuakeSaver strong-motion sensors were installed in March 2020) and the Narita International Airport (16 QuakeSaver strong-motion sensors installed in May 2020). Testing frameworks for Operational Earthquake Loss Forecasting (OELF) at the national scale (Italy) and Rapid Loss Assessment (RLA) at the regional scale (Europe) have been developed with preliminary versions of all of the necessary components (i.e. operational earthquake forecasts (OEF), ShakeMaps, time invariant exposure models, time invariant vulnerability models). These components will be updated (and time variance will be incorporated) as developments in the other work packages progress.

Task 8.2 Standardization of data and data access services

Within the RISE consortium, as well as for the proof-of-concept implementations of time-dependent hazard and risk services in Switzerland and Italy, the following concepts have been adopted:

Service coverage:

1. Expected ground motion per site, expected casualties, building damage grade, economic loss, and complex impact indices per grid cell (for authorities per political unit) for event specific loss estimation
2. Hazard maps & curves, risk map and curves, and temporal evolution curves for probabilistic time specific loss
3. Complex earthquake risk index for integration with other natural risks
4.

Service design:

Use REST (pull) web services rather than push services

Reasons:

- *No subscription required*
- *Thresholding responsibility with service provider*
- *Easy experimenting by the client*
- *No update/modification thresholding (responsibility with the client)*

Push services may be adequate after a public trial phase with service-level based infrastructure and for operative subscribers; currently we are lacking a good link to an operative user community to design these.

Request patterns:
- WMS getcapabilities, getmap, getfeatureinfo for mapping products (https://www.ogc.org/standards/wms)
- Still to be defined for curve, timeline, and multihazard products

Response formats:
- GDAL-supported formats for maps (https://gdal.org/)
- NRML (Natural Risk Markup Language) as implemented by the https://github.com/gem/oq-engine for hazard & risk information
- CAP (common alerting protocol, http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2.html) for multi-hazard integration

Pending deliverable:
Current service definition concepts are developed based on experience and needs of hazard scientists within the RISE community – we have not been able yet to build a strong working link with industry partners to verify their needs and get input for a formalized request definition. (delayed deliverable 8.2.1)

Task 8.3 RISE operational services and applications

The frameworks developed in RISE for operating rime dependent seismic risk infrastructures separate between the probabilistic case (starting from OEF), and the event case (starting from a scenario, or observed earthquake):

For the **probabilistic case**, steps were undertaken to technically link the testing of OEF models with their application for operative forecasting. With RT-RAMSIS (https://gitlab.seismo.ethz.ch/indu/rt-ramsis) , a software framework has been adopted to manage the workflow of:

a) retrieving past (current) seismicity,
b) remotely invoking calibration, and application of OEF models for time intervals in future,
c) weight forecast results based on past performance of the individual models (this step is developed within the CSEP initiative; its adaptation into the RT-RAMSIS framework is pending)
d) use weights for logic tree branch weighting for openquake-based PSHA computations for these time intervals
d) translate probabilistic hazard results into probabilistic risk assessments, and present results (the implementation of this step is pending)

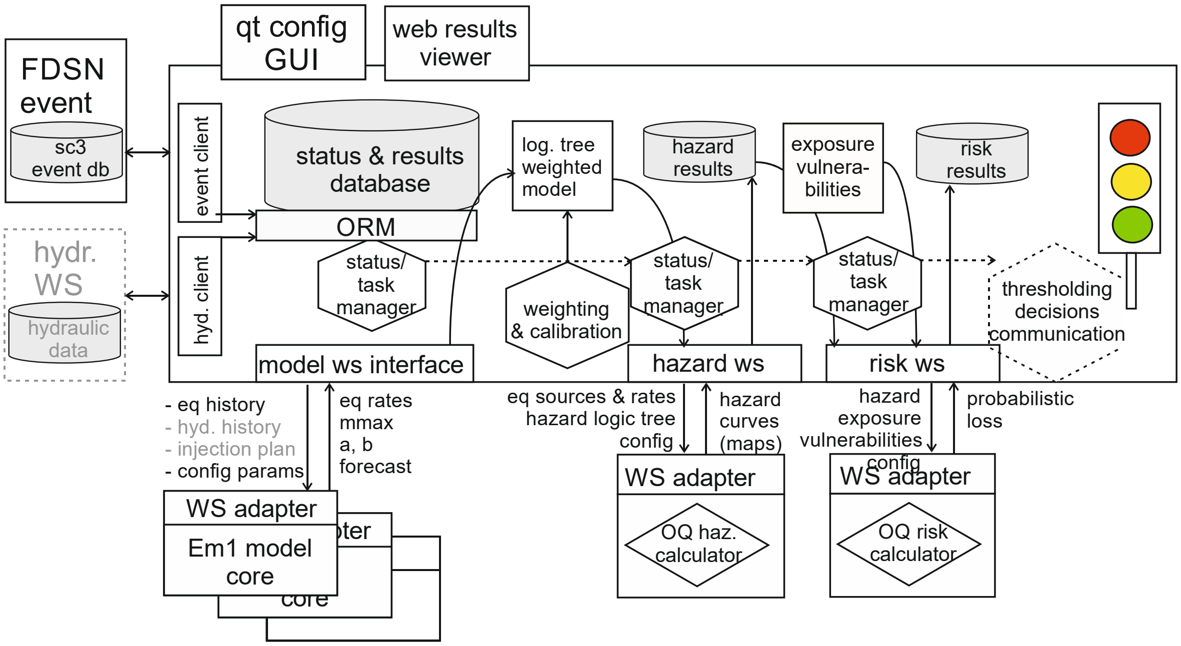


Figure 8.3.1 RT-RAMSIS framework for managing time dependent earthquake forecasting and hazard assessment

CSEP and RT-RAMSIS developer communities have jointly reviewed and modified the requirements for generically interfacing OEF models, adapted RT-RAMSIS to deal with models returning forecasted earthquake catalogs rather than their statistical descriptors (event numbers, a, b), and developed a proof-of-concept wrapper to use one of the CSEP-tested models (https://github.com/swiss-seismological-service/SFM_WernerHiResSmoSeis-m1-italy-5y) with RT-RAMSIS.

The general plan is to use RT-RAMSIS for both the CSEP testing center as well as the proof-of-concept forecast operations – this allows that the integration/operationalization of OEF models needs to be done only once, and will be applied consistently in model testing and model application. Currently, the CSEP community is finalizing the algorithms for assessing model performance (step c), while the RAMSIS community is working on virtualization and hazard assessment. By the end of the project, at least one of the RISE models (the improved ETAS model by Mizrahi/Nandan, ETHZ) will be operated in forecast model for Switzerland, providing information such as time dependent hazard maps, and curves.

Further, ongoing tasks are:

- The organizational preparation of a Europe-wide forecasting service within the framework of EFEHR
- Evaluation & definition of adequate data representations / visualizations and risk statements for a platform open to the general public. The first draft of this step will be adapted from the representation of the (static) Earthquake Risk Model Switzerland.

For the event case, the workflow includes the following steps:

a) arthquake parameter assessment (integrated and forwarded for RISE by EMSC: https://www.seismicportal.eu/webservices.html)
b) rapid ground motion observation (on an European level by ORFEUS: http://orfeus-eu.org/rrsm/)

c) integration with macroseismic observations, and spatial extrapolation including soil conditions, to optain a best possible shakemap(for RISE as an ORFEUS contribution by INGV: http://shakemapeu.ingv.it/)
d) Calculation of expected losses based on shakemap and the European building stock inventory provided by EFEHR (http://www.efehr.org/en/efehr/Services-and-Partners/)

While on a European level, these components are built, the first end-to-end technical integration is underway for Switzerland, including a public platform providing rapid earthquake loss estimations for authorities and the public after an earthquake. Representation of loss estimation results have been developed based on example data of the Swiss Risk Model, and reviewed in workshops with Swiss national and cantonal authorities; the operative service to create and distribute those after potentially damaging earthquake events in Switzerland is currently under development and expected to be completed in late 2022. The format can be used for observed earthquakes as well as for scenarios.

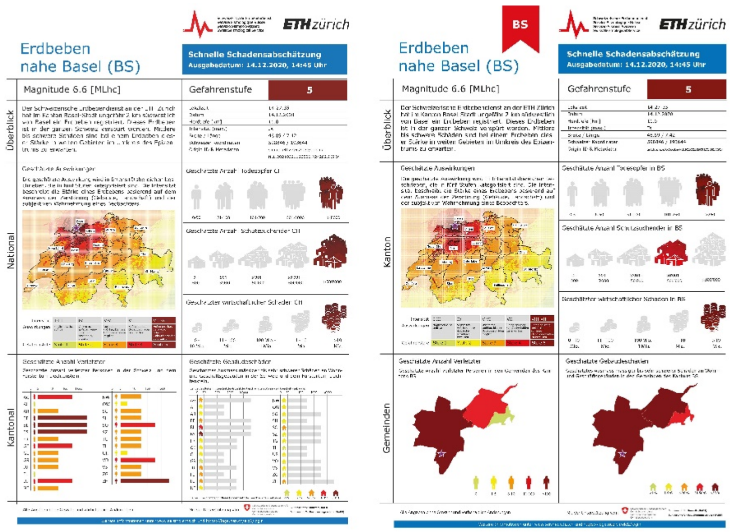


Figure 8.3.2 Event specific loss estimations: Fact sheets currently implemented for the general public (left) and cantonal authorities.

Task 8.4 RISE external communication, good practice series, and training

A number of communication tools are used targeting different external audiences, such as project website, external newsletter, social media (e.g. Twitter), best practice reports, special issue publications, training workshops. Some of these communication tools are already established for the RISE project (project website, newsletters, twitter account) and others have been continuously compiled as the project evolves and results achieved (good practice reports, conference presentations etc.).

Website

RISE website was launched in September 2019 by WP8. External website is used for sharing relevant project information, dissemination materials and linking to the internal website. The RISE website promotes visibility and transparency towards stakeholders. It contains a number of sections including news and events, project results, reports, publications, deliverables. The full content of the website is accessible on www.rise-eu.org. The website is regularly updated by WP8. The number of website visitors has risen steadily since the project started as shown in the table below (chapter "Summary of Exploitable Results in WP 8").

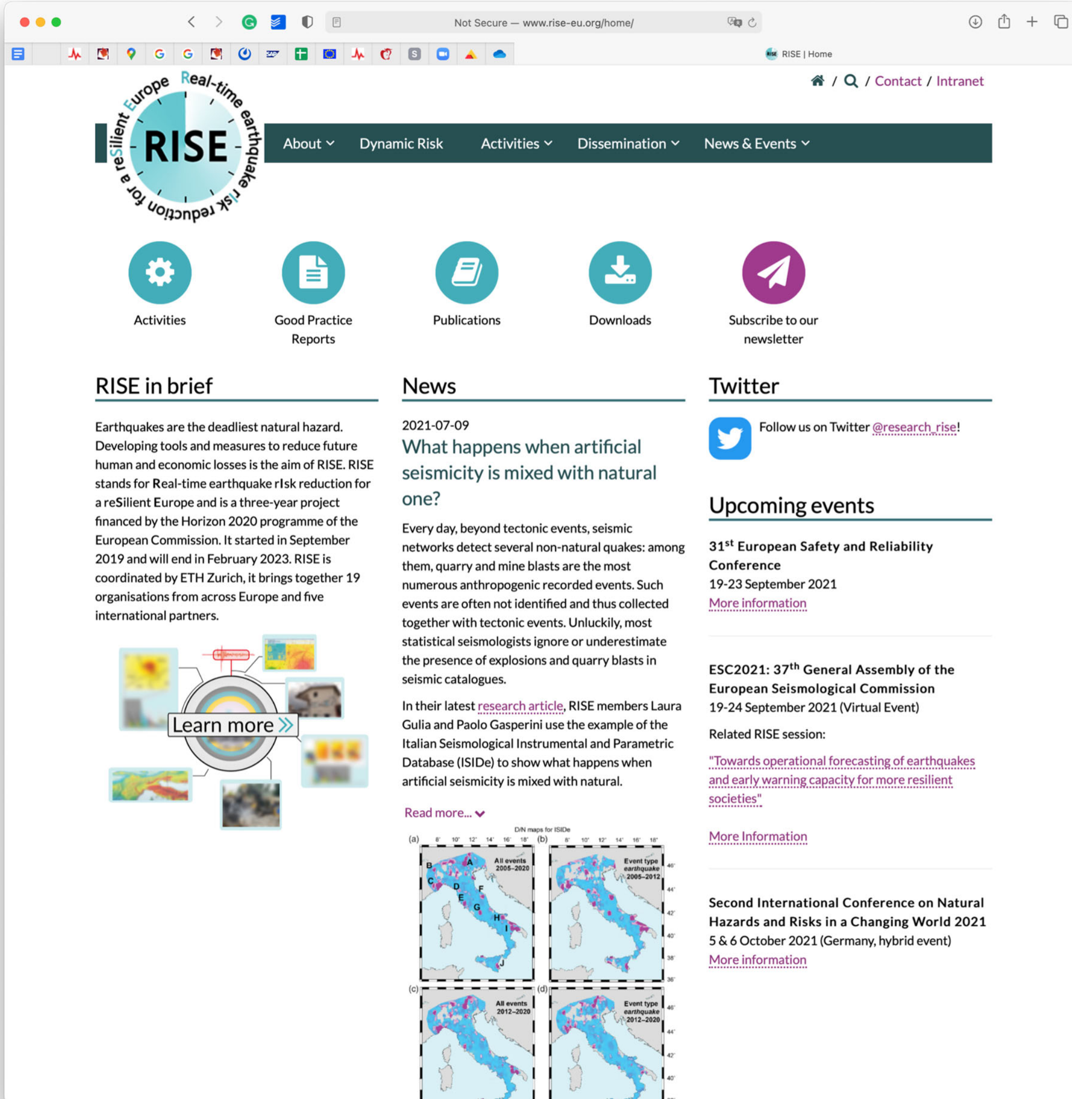


Figure 8.4.1 Snapshot from the RISE website

Twitter

On the RISE Twitter account (@research_RISE) can we share project updates, interesting news, available open positions, etc. RISE Communications team maintains both the website and the twitter account, gathers the relevant information and publishes them.

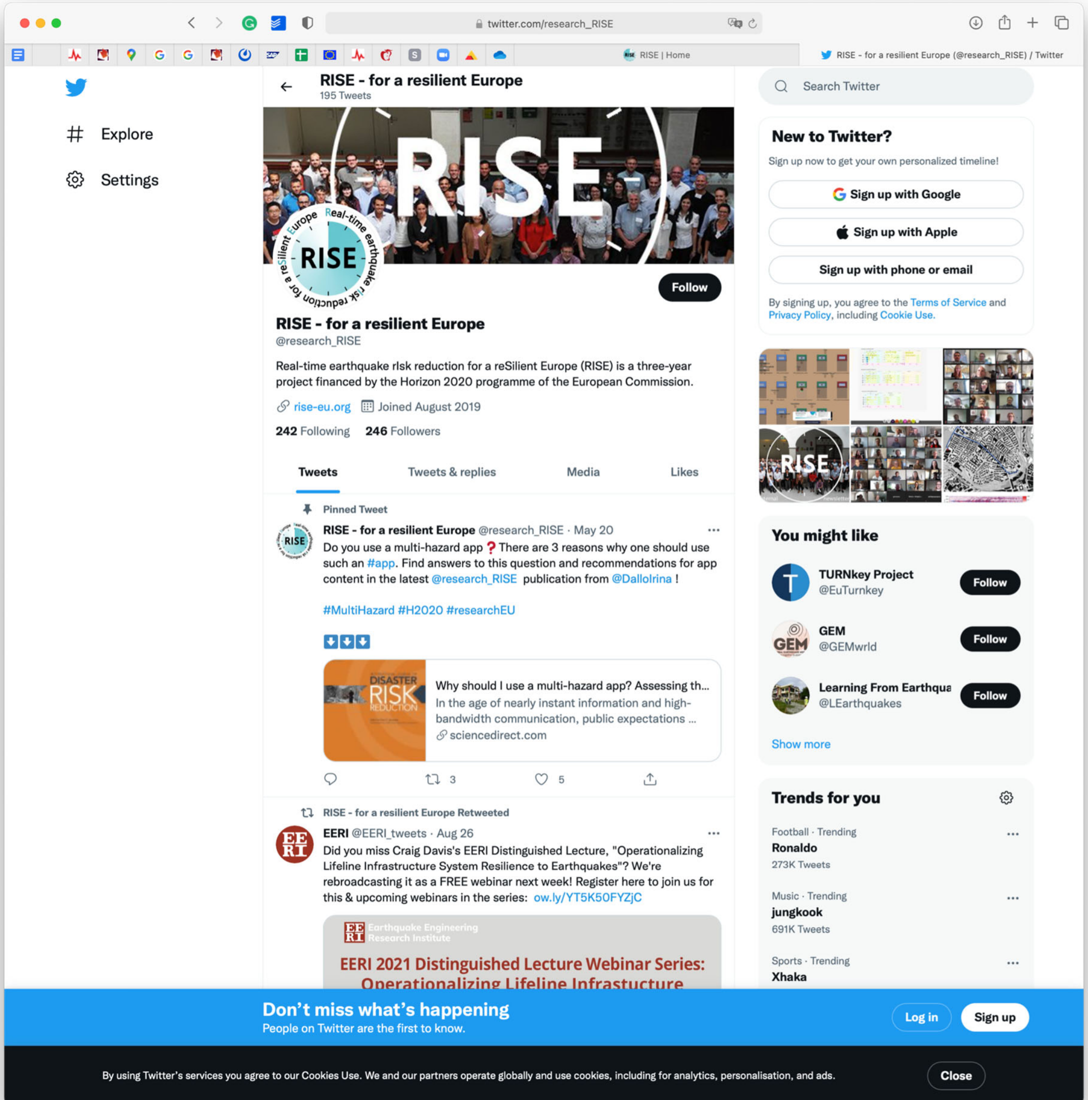


Figure 8.4.2 Snapshot from the RISE twitter account

External Newsletter

RISE external newsletters target all interested stakeholders and aim at communicating project updates and progress. It covers information on WPs, meetings, calendar and any miscellaneous topic that the RISE community wants to share with the public. Each issue includes a closer look at a specific topic of RISE research and releases information suitable for non-expert readers. The external newsletter is published once a year during the RISE project. So far, two external newsletters have been published, the third is planned for September 2021.

Good Practice Reports

RISE will compile a series of at least five good practice reports based on RISE deliverables. They will be compiled into a homogenized online library of open access reports and will be made available for browsing on the RISE website. Each good practice report will undergo an internal peer review. The reports will be written with an end-user perspective in mind. As they form an important legacy of RISE, the following two reports are already planned:

- European rapid loss assessment
- Communicating Seismic Forecast Data

Stakeholder Panels (SP)

The knowledge generated as well as the products and services developed within RISE are only useful and successful when they meet future end-users needs. We aim at translating RISE outputs and deliverables into tangible products and services, useful for and used by a wide range of stakeholders. While the external communication activities mainly focus on informing the RISE community, our stakeholders and end-users; the stakeholder panel aims at establishing a dialogue with exponents of these communities. Although we have some delays due to Covid-19, we are working on expanding the SP by contacting more institutions. A subgroup of the Stakeholder Panel will form the National Swiss Stakeholder Board.

List of submitted deliverables and achieved milestones in WP8

Deliverable (D) Milestone (M)	Title	Lead	Type	Month	Deadline
D. 8.1	Update PEDR	ETHZ	Report	3	11. 2019
MS 59	RISE web page fully operational	ETHZ	Web online	4	12. 2019
D. 8.10	External Newsletter released	ETHZ	Websites, patents fillings etc.	6	02. 2020
MS 22	OEF output format for testing	INGV	Format define	6	02. 2020
MS 55	Implementation of periodic monitoring of Key Performance Indicators	ETHZ	Monitoring operational	6	02. 2020
MS 60	15th publication related to RISE submitted	ETHZ	Papers on web	20	10.2021

Summary of Exploitable Results in WP8

Key performance indicator(s)	**M6**	**M12**	**M18**	**M22**

Number of unique website visitors Quantitative Goal: Monthly average: 500 M12:6’000 total unique visitors M24: 12’000 total unique visitors M36: 18’000 total unique visitors	23 (Aug. 19) 130 (Sep. 19) 116 (Oct. 19) 213 (Nov. 19) 185 (Dec. 19) 225 (Jan.20) Total: 892	23 (Aug. 19) 130 (Sep. 19) 116 (Oct. 19) 213 (Nov. 19) 185 (Dec. 19) 225 (Jan.20) 401 (Feb. 20) 378 (March 20) 443 (Apr. 20) 495 (May 20) 397 (June 20) 477 (July 20) 439 (28 August 2020) Total: 3’922 (28.08.2020)	23 (Aug. 19) 130 (Sep. 19) 116 (Oct. 19) 213 (Nov. 19) 185 (Dec. 19) 225 (Jan. 20) 401 (Feb. 20) 378 (March 20) 443 (Apr. 20) 495 (May 20) 397 (June 20) 477 (July 20) 381 (Aug. 2020 474 (Sept. 2020) 471 (Oct. 2020) 448 (Nov. 2020) 503 (Dec. 2020) 878 (Jan. 2021) 603 (25.02. 2021) Total: 7’241 (25.02.2021)	23 (Aug. 19) 130 (Sep. 19) 116 (Oct. 19) 213 (Nov. 19) 185 (Dec. 19) 225 (Jan. 20) 401 (Feb. 20) 378 (March 20) 443 (Apr. 20) 495 (May 20) 397 (June 20) 477 (July 20) 381 (Aug. 2020 474 (Sept. 2020) 471 (Oct. 2020) 448 (Nov. 2020) 503 (Dec. 2020) 878 (Jan. 2021) 679 (Feb. 2021) 701 (March 2021) 770 (Apr. 2021) 659 (May 2021) 415 (23.06.2021) Total: 9’862 (23.06.2021)
Number of Twitter followers Quantitative Goal: M12: 100 followers M24: 250 followers M36: 300 followers	74 followers (12.02.2020)	161 followers (28.08.2020)	210 followers (18.02.2021)	238 followers (24.06.2021)
Number of external newsletter subscribers Quantitative Goal: M12: 100 subscribers M24: 200 subscribers M36: 250 subscribers	92 (12.02.2020)	149 (28.08.2020)	212 (25.02.2021)	225 (23.06.2021)

Number of publications in scientific journals Quantitative Goal: M12: 20 publications M24: 30 publications M36: 100 publications	0	13	18	26
Participants of stakeholder exchange Quantitative Goal: Until M36: Workshops: 3 Presentations: 50 Other exchange opportunities: 5	0	0	Presentations: 3	Presentations: 12

1.3 List of submitted deliverables and milestones

List of submitted deliverables until 31 July 2021:
D1.1 Project management plan updated
D8.1 Update PEDR
D1.16 Data Management Plan
D8.10 External Newsletter released
D6.6 Framework for the assessment of economic losses in a dynamic risk context
D1.5 Minutes of Meeting of the RISE management board conducted
D2.6 Specifications on portable excitation sources and structure selection
D2.2 Deployment of prototype array
D1.2 Project management plan updated
D1.6 Minutes of Meeting of the RISE management board conducted
D8.2 Update PEDR
D5.1 Review of best practice in communication of dynamic risk in all fields
D1.17 Cumulative Expenditure Report 1
D2.4 Field ready internal next generation sensors

List of achieved milestones until 31 July 2021:
MS01: RISE Boards nominated (SP, SAB, MB, GA)
MS03: Kick-off meeting
MS02: Project internal communication established
MS32: Real time data exchange between EMSC and Bergamo
MS59: RISE web page fully operational
MS53: Development of instrumental intensity computation for IoT sensors
MS55: Implementation of periodic monitoring of Key Performance Indicators
MS45: Concept for modularization
MS22: OEF output format for testing
MS33: Implementation of the AIDR platform for landslides and fire detection
MS17: Screening for ambient noise anomalies in test regions

MS46: Data object and format definition for exchange between modules
MS08: Deployment of experimental arrays, effects of coupling, instrument characteristics and detectability of regional earthquakes
MS13: Acquisition of portable impact generator and eccentric mass shaker; improvements to the capacity of the vibroseis truck
MS36: Concept for multi-hazard warning app completed
MS23: Scheme of OEF model to include anomalies
MS51: Review of ensemble modelling procedures in other fields
MS30: First draft of communication measures
MS48: Software development for tailored experiments completed
MS37: Sensors set up and collecting data in buildings in Tokyo, Lourdes, Turkey and Valais
MS24: Defining testing experiments
MS10: Hardware and software for indoor and outdoor sensor, first test deployment

1.4 Tasks that have delays
List of delayed milestones:
MS42: National Swiss stakeholder board established
MS56: Community agreement on requirements and technical baseline for dynamic risk service standardisation
MS39: Upgraded EEW capability in Iceland operational

3. Impact Assessment

The RISE project is designed to have a substantial, diverse and lasting impact on earthquake resilience across Europe and globally. Below is a list of goals stated in the GA, and the actions that are being taken towards achieving these tasks.

1) The unified dynamic risk framework advocated and implemented in RISE offers a sustainable platform for future developments related to real-time seismology. It will be designed and built to ensure that future advances in OEF, EEW, RLA and RRE can be readily plugged in and harmonised.

ONGOING DEVELOPMENTS:

- We developed a software framework to handle all OEF, time dependent risk and CSEP model testing on the same platform.
- We will integrate pySCEP with RT-RAMSIS for the evaluation of the forecast results
- We will deploy OEF models developed within RISE on the RT-RAMSIS framework for both OEF and CSEP model testing.
- On an independent platform, based on USGS shakemap and openquake, we set up a proof of concept operational (near real time) loss estimation for Switzerland.

2) The RISE project will establish at least three new services to be operated within EPOS Seismology.

ONGOING DEVELOPMENTS:

Some of the services that are planned to be integrated to EPOS:
- RISE Dynamic exposure model integrating European exposure model of SERA with data on individual buildings continuously updated from Openstreetmap in near real time
- A new community based pyCSEP software toolkit for earthquake forecast developers
- Harmonized European Shakemaps using state of the art methods and models

★ RISE will publish its results in peer-reviewed international journals and proceedings; we anticipate about 100 RISE-related publications. We will also host at least three dedicated sessions at international conferences and three stakeholder workshops.

ONGOING DEVELOPMENTS:

- RISE has already published over 25 articles. RISE publications can be viewed at:
  https://zenodo.org/communities/rise-h2020
  http://www.rise-eu.org/home

3) RISE will establish new concepts and 'good practice' guidelines for communicating earthquake risk. These advances will be a highly valuable resource for all nations exposed to earthquake risk in Europe and greatly improve the capability to manage and communicate low-probability/high-impact events.

ONGOING DEVELOPMENTS:

- We plan five 'good practice' reports until the end of the project.
- The first two good practice reports are due M24:
  1) Communicating seismic forecast data
  2) European Rapid Loss Assessment

4) RISE will define new community standards, protocols and Uniform Resource Identifiers for data exchange of dynamic risk, allowing a wide range of Internet based services and applications to access risk information in standardised ways, valuable also for the construction and insurance industries.

ONGOING DEVELOPMENTS:

- CAP: very basic time dependent probabilistic warning
- NRML (Natural Risk Markup Language): probabilistic hazard but no time dependency

- EEWD messages (Extended QuakeML): event and observed shaking, no expected shaking
- EWBS emergency broadcasting hardware & protocol, not content specific; e.g. for EEW

5) RISE will create a simulation platform for network design, scenario calculations, sensitivity analysis and cost-benefit analysis. Investments in earthquake resilience are costly (some more, some less). It is increasingly important to maximise the impact such investments have, and justify the expenses by performing, before the investment, a careful business plan that includes a transparent and quantitative cost-benefit analysis (CBA).

ONGOING DEVELOPMENTS:

- RISE is evaluating alternative risk mitigation measures that are being developed/improved within RISE in terms of their costs vs. benefits.
- RISE is proposing a systematic procedure for evaluating decisions based on CBA, assessing whether perceived benefits exceed the costs.
- The suggested CBA framework will support decision making.

6) RISE will optimise tools for improving observational capabilities and integrate them as part of standard seismological software packages used by national and regional seismic networks. This will be a lasting contribution to improving the quality of many of the earthquake catalogues that form the backbone of analysis and forecasting.

ONGOING DEVELOPMENTS:

- DAS produces excellent data quality and increases the number of detected local events greatly.
- Strategies for inclusion of massive datasets in European seismic data archives and infrastructures are being developed.
- New generation high resolution catalogues in Italy are already being used in developing forecast models. Proof of concept published for daily updates of OEF.

7) RISE will initiate formal testing of earthquake forecast models as part of the global CSEP initiative in Italy, with pilot tests in Turkey, Iceland and Europe wide. These additional testing regions and the CSEP EU testing centre will accelerate progress in earthquake predictability related research.

ONGOING DEVELOPMENTS:

- pyCSEP Python software toolkit for testing earthquake forecasts is prepared.
- Prospective CSEP Italy-Phase 2 completed.
- pyCSEP tutorial with Jupyter notebooks is prepared.
- Tests of Coulomb and ETAS models on Amartice and Ridgecrest are performed.
- Assessment of multiplicative ensemble models in California are done.
- Tests of non-linear amplification factors are performed.

8) The next generation earthquake forecast models that will be developed, calibrated and validated promise to achieve a substantial information gain over existing models and advance the usefulness of OEF at a national scale. The models will be widely adopted by seismological services around the world.

ONGOING DEVELOPMENTS:

- Developing a scheme of OEF model to include anomalies (Bayesian framework)
- Investigating spatial variability of b-value and time varying completeness
- Improved Coulomb aftershock forecasts by real-time updating receiver mechanisms
- Pseudo-prospective testing of Foreshock Traffic Light system
- Defining testing experiments for Italy, global and Europe.
- Modeling long term memory of seismicity with ETAS
- Innovative procedures to forecast earthquakes: Inlabru, refined physics-based models

9) By exploring the use of innovative technologies, we will pave the way for their widespread application in real-time seismology. Low-cost sensors, dense arrays and the use of distributed acoustic sensing using fibre optic cables may offer breakthrough capabilities for EEW and RLA, but

a careful technology assessment is needed now to select the right option. The same holds true for innovation in data analysis.

<u>ONGOING DEVELOPMENTS:</u>

- DAS is deployed in urban and challenging environments.
- We are running additional DAS experiments in regions of significant seismic hazard (e.g. Athens). We are building DAS based earthquake catalogs. We are developing novel event detection algorithms based on image processing techniques.
- Two new types of sensors are being developed within RISE. A patent is pending for smart seismic sensors. Open source sensor software is published Smart on-device algorithms for earthquake safety are developed.

10) RISE will contribute to developing equality and diversity in earth sciences and engineering in the team we have brought together. For example, we expect female PIs in RISE to act as role models for future generations of leading scientists.

<u>ONGOING DEVELOPMENTS:</u>

- RISE has been contributing to equality and diversity in both earth science and engineering. Female PIs are working in project management, as WP leaders, leading communication and dissemination activities, charing General Assembly and Management Board Meetings and working towards scientific achievements of RISE in various tasks. Female scientists are contributing to RISE at all levels; from management to WP leadership, task leadership, as young researchers (PhD students and postdocs).

11) TARGET (from the GA): The RISE web presence, newsletter and dedicated stakeholder events will serve as independent and fact based information from highly respected scientists about the capabilities and limitations of real-time risk reduction capabilities.

<u>ONGOING DEVELOPMENTS:</u>

- RISE will further develop software and Apps for two-way communication and earthquake alerts. By making these Apps capable of adoption by other national services, RISE will contribute to the accelerated spread of good practise and real-time seismology throughout Europe.
- RISE will demonstrate, in multiple real-world applications at different scales, the feasibility and use of EEW, OEF and RLA. This will be a substantial step forward in these areas and also provide much needed role models for other regions to follow.

4. Risk Register

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures "Update on measures taken during the first 24-Month of the project (see in bold)"
1	Technical risk -- Project duration of 3 years too short Potential Impact -- Failure to deliver in time and quality	WP1, WP2, WP3, WP4, WP5, WP6, WP7, WP8	Mature communities and partners; the time available before grant initiation sufficient to secure all required resources; MB monitors timely delivery implementation status. Use CE principles. Regular tracking is done by the MB and all WP leaders.
2	Technical risk -- Dependencies too strong between WPs Potential Impact -- Delayed delivery in one WP hindering progress in other WPs	WP2, WP3, WP4, WP5, WP6, WP7, WP8	Frequent communication and exchange between WP; alternative models/sensors available, MB monitors timely delivery implementation status. All tasks are performed in parallel in RISE, so far no interruptions due to dependencies are observed. The Implementation Plan supports the link between tasks and WPs. WP and joint WP meetings ensure the communication and coordination of inter-linked tasks.
3	Financial risk -- Underestimation of required resources for scientific developments (medium) Potential Impact -- Scientific contributions fail to be integrated, tested or distributed	WP2, WP3, WP4, WP5	RISE design based on the experience of past successful projects of comparable class; monitor spending closely, increase in-kind contributions if needed. RISE project benefits from in-kind contributions where needed.
4	Financial Risk -- Available resources spread too thinly, with too many WPs and beneficiaries (medium) Potential Impact -- Failure in maintaining the planned workflow and timeline	WP2, WP3, WP4, WP5, WP6, WP7	RISE Office collects annual financial updates from all partners, to ensure the workflow, the timeline and the budget are maintained as planned.
5	Strategic risk -- Failure to integrate RISE services in EPOS (small) Potential Impact -- Long-term sustainability may not be achieved	WP8	RISE design done in close coordination with EPOS-IP, many individuals also have responsible roles in EPOS.

6	**Strategic risk -- Disconnect between earthquake engineers & seismologist (small) Potential Impact -- Limited integration and reduced impact on risk reduction.**	**WP2, WP3, WP4, WP5**	**Each WP is designed to be interdisciplinary. Use meetings for exchange and community building, rely on our stakeholder panel to provide an end-user perspective.** **Online workshops in various tasks brought together engineers are seismologists. Engineers and seismologists have been working together in good communication and coordination so far.**
7	**Strategic risk -- Disconnect between natural scientists, social scientists and economists (small) Potential Impact -- Limited integration and reduced socio-economic impact**	**WP5, WP8**	**WPs designed to be interdisciplinary. Use meetings for exchange and community building, rely on our stakeholder panel to provide an end-user perspective.** **Tasks involving social scientists have been attending common project meetings with natural scientists. There is ongoing data and knowledge exchange between them. There has been a very good connection between them so far.**
8	**Strategic risk -- Failure to timely identify and mitigate risks (small) Potential Impact -- Potential risks are** **discovered too late to enable efficient recovery**	**WP1, WP2, WP3, WP4, WP5, WP6, WP7, WP8**	**Benefit from experienced WP leaders; MB regularly update the Risk Register; monitor mitigation measures.** **MB meets every 2-months and discusses the status of the WPs, the pending deliverables and milestones for the next months ahead, discusses any issues that may cause potential delays and ensures the timely implementation of the project.**
9	**Strategic risk -- Underestimate ethical or privacy related risks (small) Potential Impact -- Improper use of data and products, lack of acceptance.**		**Rigorous application of the Ethical standards and guidelines of Horizon2020; monitored by MB and SAB.** **We prepared a Data Management Plan (DMP), submitted to the Commission as D 1.16, which sets the rules for data used and produced in RISE. DMP is shared by all RISE partners.**
10	**Strategic risk -- Over-dependence on key individuals (medium) Potential Impact -- Lack of community building, poor involvement of partners**	**WP1, WP8**	**Adopt a management plan tailored to the complexity of the project and use MB, ExeCom to monitor overdependence.** **MB closely follows the proper involvement of all partners. Necessary actions are taken, when facing poor involvement of a RISE partner.**
11	**Strategic risk -- Reduced visibility and impact (medium) Potential Impact** **-- Failure in maximizing the impact**	**WP8**	**Use and regularly monitor key performance indicators, alert MB if goals are not met.** **PEDR (D 8.1) listing the KPIs and the updated PEDR (D8.2) which lists the improvement of KPIs by time are submitted to the EC.**

12	**Covid 19 – Delay in certain tasks, milestones and deliverables due to lock-down period**	**WP1, WP2, WP3, WP4, WP5, WP6, WP7, WP8**	**6 months project extension is granted by the EC through an amendment.**