[First Workshop on Earthquake Early Warning: Strategies for Italy]

The event will also be available remotely at:
https://meet.google.com/fxb-humk-nye

Day 1: Tuesday, February 17, 2026

Focus: Current Status, Technological Requirements, International Experiences

08:00 – 08:45 | Registration & Welcome Coffee

08:45 – 09:00 | Opening Remarks

- Welcome from INGV leadership and workshop objectives

08:45 Luca Malagnini (Organizer)

08:50 Fabio Florindo (President of INGV)

08:55 Salvatore Stramondo (Director, Earthquake Department)

Oral Sessions

09:00 – 11:30 | Session I: The Italian Context

Topics:

- **The Italian National Seismic Network (RNSN):** Architecture, coverage, and current real-time performance.
- **The "Blind Zone" Challenge:** warning-time estimates based on real topologies (Italy, but also California, Turkey...).

09:00 ALDO ZOLLO – Università di Napoli Federico II: Towards the effective implementation and use of impact-based early warning systems in Italy

09:15 AYBIGE AKINCI – Istituto Nazionale di Geofisica e Vulcanologia - INGV Roma1: Physics-Based Ground Motion Simulations as a Resource for Earthquake Early Warning Studies: Experience from the Central Apennines, Italy

09:30 LUCIA MARGHERITI – Istituto Nazionale di Geofisica e Vulcanologia - INGV ONT: The Italian National Seismic Network

09:45 MATTEO PICOZZI – Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS: From Seismic Monitoring to Earthquake Early Warning: Evidence and Opportunities in Northeastern Italy

10:10 SIMONA COLOMBELLI – Università di Napoli Federico II: Fundamental grounds of Earthquake Early Warning: a deep look into the rupture process

10:15-10:45 | Coffee Break

10:45 FLAVIO CANNAVÒ – Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Etneo: Automatic Volcano Early Warning Systems developed and operated at the Etnean Observatory-INGV

11:00 ANTONIO AVALLONE – Istituto Nazionale di Geofisica e Vulcanologia - INGV Irpinia: Real-time GNSS from RING network for Early Warning applications

11:15 CLAUDIO MARTINO - Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Vesuviano: Development of the EEW project at INGV: algorithms, system integration and operational applications for alerting and rapid response

11:30 MARCO OLIVIERI - Istituto Nazionale di Geofisica e Vulcanologia - INGV Bologna: My prolonged thoughts on EEWS for Italy

11:45 CECILIA VALBONESI – Unitelma Sapienza/INGV: Balancing Necessity and Legal Accountability: The Advancement of EEWS in Italy

12:00 – 12:20 | Lightning Talks (posters of all Sessions, 1.5 minutes each)

12:20 – 14:00 | Networking Lunch

14:00 – 15:30 | Session II: International Perspectives

Topics:

- **Operational Systems:** Case studies from mature EEW systems (e.g., USA, Turkey, Irpinia).
- **Alert Protocols:** Strategies for massive alert dissemination and public interface.
- **Lessons Learned:** Handling false alarms and managing public expectations.

14:00 RICHARD ALLEN – UC Berkeley: After 6 years of EEW in the US, what have we learned?

14:15 RAN NOVITSKY NOF – The Geological Survey of Israel: From Network Upgrades to Public Trust: Lessons from the Operational Deployment of Israel's "Truaa" EEW System

14:30 STEFANO PAROLAI – Università di Trieste: Development and application of Decentralized Earthquake Early Warning Systems

14:45 SALVATORE BARBA – Istituto Nazionale di Geofisica e Vulcanologia - INGV Roma1: From Algorithms to Accountability: Governance Constraints of EEW Implementation in Italy

15:00 MAREN BÖSE – Swiss Seismological Service – SED, ETH Zurich: Building Earthquake Early Warning: From Algorithms to Public Alerts

15:15 RICHARD ALLEN – UC Berkeley: Android Earthquake Alerts: Global roll-out, performance and user feedback

15:30 – 16:00 | Coffee Break

16:00 – 16:45 | Session III: Enhancing the Infrastructure

Topics:

- **Technological Upgrades:** i) network densification; ii) suitable sensors to deploy; iii) use of DAS and other fiber-optic applications; iv) low-cost sensors
- **Algorithms:** which ones to apply?

16:00 SULEYMAN TUNC – Sentez Earth and Structure: Earthquake Early Warning System in Marmara Region

16:15 DOMENICO PATANÈ - Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Etneo: Performance Evaluation of Next-Generation QMEMS Accelerometers for Seismic Monitoring, Structural Health Monitoring, and Earthquake Early Warning

16:30 GAETANO FESTA – Università di Napoli Federico II, INGV-affiliated ONT: DAS-based EEW systems in Irpinia and Chile: perspectives and challenges for offshore and inland monitoring

16:45 End of oral sessions; end of activities of the first day

19:00 | Social Dinner for our Speakers and Guests, Ristorante Palmieri

Poster Sessions

Session I – The Italian Context

SAHAR NAZERI – Università di Napoli Federico II: Performance Assessment of QuakeUp Across Multiple Seismic Networks in Southern Italy Using Physics-Based Synthetic Seismograms

MARIA DI GIOIA – Università di Napoli Federico II: AI-based earthquake detection and magnitude estimation from early P-wave signals at Campi Flegrei volcano

MAURO PALO – Università di Napoli Federico II: A Modular AI-Based Architecture for Real-Time Classification of Earthquake and Noise Transient Signals

LUCA ELIA - Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Vesuviano: EEW Software Developed at RISSC-Lab and Application on the Irpinia Near-Fault Observatory

LORENZO CUGLIARI - Istituto Nazionale di Geofisica e Vulcanologia - INGV ONT: Between acceptance and preparedness. An ex-ante assessment for developing a people-centered Earthquake Early Warning system

ILARIA OLIVETI - Istituto Nazionale di Geofisica e Vulcanologia - INGV ONT: Masked graph neural network for rapid ground motion prediction in Italy.

Session II – International Perspectives

RAFFAELE REA – Università di Salerno: Comparative evaluation of impact-based and hybrid approaches for real time earthquake shaking prediction

Session III – Enhancing the Infrastructure

ANTONIO SCALA - Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Vesuviano: Feasibility study of an integrated earthquake and tsunami early warning system

FRANCESCO CAROTENUTO - Università di Napoli Federico II: A Proposal for a new generation of Earthquake Early Warning System actuators operating in critical environments

VALERIA LONGOBARDI - Università di Napoli Federico II: One-Second-Lead Earthquake Warning and Impact Assessment at Campi Flegrei

SALVATORE BARBA - Istituto Nazionale di Geofisica e Vulcanologia - INGV Roma1: SeismoCloud: From Low-Cost Distributed MEMS Sensors to Reliable, Low-Latency Earthquake Early Warning

CLAUDIO STRUMIA – Università di Napoli Federico II: Rapid Magnitude Estimation with DAS offshore Chile based on secondary converted phases: implication for EEW

Day 2, Wednesday, February 18 2026

08:15 – 09:00 | Welcome Coffee

09:00 – 10:30 Roundtable Discussion (Part A)

Moderator: Luca Malagnini; Panel: Aldo Zollo, Aybige Akinci, Richard Allen

- Pilot sites and national experimentation
- On-site vs. Network-based EEW
- Low-cost & cell phones
- EEW & Rapid Response

10:30-11:00 | Coffee Break

11:00 – 12:30 Roundtable Discussion (Part B)

Moderator: Alessandro Amato; Panel: Maren Böse, Ran Novitsky Nof, Cecilia Valbonesi

- What to do with an EEW?
- Schools and other end-users
- Legal framework of operations

12:30 Farewell lunch (hosted at INGV)

Abstracts

Session I – The Italian Context, Oral

ALDO ZOLLO – Università di Napoli Federico II

Towards the effective implementation and use of impact-based early warning systems in Italy

ABSTRACT

Earthquake early warning (EEW) systems aim to reduce seismic risk by issuing alerts in the seconds to tens of seconds between the detection of an earthquake and the arrival of damaging ground shaking. After a brief introduction of the basic principles of EEW and main performance metrics—warning time, lead time, and blind zone—the talk outlines the primary research directions currently shaping the field. These include improved physical understanding of rupture initiation, the growing role of artificial intelligence and machine learning, the integration of early warning with rapid response products, and the development of end-to-end systems tailored to specific users and infrastructures.

A key focus is the classification of network-based EEW approaches into source-based and impact-based systems. Source-based systems estimate earthquake location and magnitude to predict expected shaking through ground motion models, while impact-based systems directly forecast future ground shaking and potential damage from real-time observations of P-wave ground motion. Impact-based methods enable the rapid identification of Potential Damage Zones and the generation of evolving early shake maps while the rupture is still ongoing.

The capabilities of impact-based EEW are illustrated through retrospective applications to the 2016 Mw 6.5 Central Italy and 2023 Mw 7.8 Türkiye earthquakes, where P-wave–based shaking forecasts successfully captured the spatial extent and time evolution of strong ground motion associated with a complex, large rupture. As an end-to-end effective application, the earthquake early warning system developed in Italy for high-speed railways is described. This system integrates dense seismic monitoring, real-time processing, and automatic control actions to safely manage train operations. Its successful operational deployment in 2025 represents a significant step toward the effective, real-world use of impact-based earthquake early warning.

AYBIGE AKINCI – Istituto Nazionale di Geofisica e Vulcanologia - INGV Roma1

Physics-Based Ground Motion Simulations as a Resource for Earthquake Early Warning Studies: Experience from the Central Apennines, Italy

ABSTRACT

Earthquake Early Warning (EEW) systems rely on the rapid estimation of impending ground shaking before the arrival of damaging seismic waves. Observational earthquake records alone do not adequately sample the full range of magnitudes, rupture complexities, and source–receiver geometries required for EEW design and testing. For this reason, physics-based ground motion simulations and synthetic seismograms provide an essential complementary resource, enabling the construction of high-resolution libraries of pre-calculated hazard scenarios that can support short-term hazard assessment and impact forecasting.

In this contribution, we present experiences gained over the last year from broadband ground motion simulation activities carried out within the SECURE – Pianeta Dinamico project, using central Italy as a natural laboratory. Although these simulations were not specifically developed for EEW applications, they represent a valuable resource that can potentially inform EEW feasibility studies, algorithm testing, and performance evaluation.

We performed hybrid deterministic–stochastic kinematic rupture simulations for significant recent events (Mw ≥ 6), including the 2009 L'Aquila Mw 6.3 and 2016 Amatrice Mw 6.2 earthquakes (Pitarka et al., 2022; Akinci et al., 2024; Artale Harris et al., 2025). The availability of a large number of high-quality recordings from these events enabled robust validation and interpretation of the simulation results. Both 3D and 1D numerical simulations, incorporating detailed velocity structures and surface topography, were used to investigate the influence of rupture kinematics, directivity, and wave propagation on near-source ground-motion variability. End-to-end simulations were validated against extensive observational datasets and regional ground-motion models, successfully reproducing the amplitude and duration of recorded motions.

The results highlight how rupture-dependent variability, near-fault amplification, and spatial heterogeneity—features often simplified in empirical approaches—can influence expected shaking levels and spatial patterns of ground motion. The experience gained from this work and the recently developed physics-based earthquake simulation platform may provide a strong foundation for future EEW-oriented studies.

LUCIA MARGHERITI – Istituto Nazionale di Geofisica e Vulcanologia - INGV ONT

The Italian National Seismic Network

ABSTRACT

The Istituto Nazionale di Geofisica e Vulcanologia (INGV) operates permanent and mobile seismic networks, deployed over the entire Italian territory. Such networks produce observational data for fundamental scientific research and seismic surveillance. These networks are major research infrastructures and require both financial and human resources.

To date, the INGV RSN counts more than 400 stations providing real time data to INGV data centers. About 250 of the RSN stations are also equipped with accelerometric sensors which have a fundamental role in case of strong earthquakes. Archiving and distribution of the continuous data are censure by the Italian node of the European Integrated Data Archive EIDA https://eida.rm.ingv.it/en/.

To guarantee cutting edge seismological research and detailed monitoring activity, all the RSN stations have to generate high-quality data. We need to program a maintenance policy based on the importance of the specific station, but also to propose new projects for a real upgrade of the INGV Italian RSN.

MATTEO PICOZZI – Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS

From Seismic Monitoring to Earthquake Early Warning: Evidence and Opportunities in Northeastern Italy

ABSTRACT

Earthquake Early Warning (EEW) in Italy has progressed from feasibility studies to increasingly sophisticated, data-driven methodologies, supported by advances in seismic monitoring, real-time processing, and predictive modeling. Over the past decade, a series of studies has explored the potential of both regional and on-site EEW approaches, addressing key aspects such as rapid source characterization, prediction of ground-motion and damage-related parameters, site-specific effects, and operational performance during real earthquake sequences.

This contribution reviews the main results of these studies, with particular emphasis on approaches based on early P-wave information, radiated energy, machine-learning regressors, and partially non-ergodic frameworks that explicitly account for local site effects. Applications range from nationwide feasibility analyses to targeted implementations for critical infrastructures, public buildings, and transportation systems, as well as retrospective performance assessments during recent Italian seismic sequences. Together, these works provide quantitative evidence of the conditions under which EEW can deliver actionable information, and clarify the fundamental trade-offs between timeliness, accuracy, and spatial resolution in near-field settings.

Building on this scientific background, we discuss how current and emerging seismic monitoring infrastructures in Northeastern Italy can support the next generation of EEW capabilities. Dense permanent networks, high-quality strong-motion sensors, and novel technologies such as distributed acoustic sensing (DAS) offer new opportunities to improve detection speed, robustness, and spatial coverage in a region characterized by short source-to-site distances and complex tectonics.

The synthesis presented here aims to connect past EEW research with present-day monitoring capabilities, outlining realistic pathways toward operational and infrastructure-oriented EEW solutions for Northeastern Italy.

SIMONA COLOMBELLI – Università di Napoli Federico II

Fundamental grounds of Earthquake Early Warning: a deep look into the rupture process

ABSTRACT

When an earthquake happens, seismic waves develop at depth and propagate across Earth. In seconds, waves reach the surface, producing devastating effects on population, buildings and

infrastructures. Earthquake Early Warning Systems use source information inferred from the real-time recorded signals to alert distant sites before the arrival of the strongest ground shaking. Rapid characterization of the earthquake source process is crucial for the prompt activation of emergency procedures. However, the mechanism of nucleation, radiation and arrest of seismic fractures is still poorly understood, and, with that, the fundamental issue of seismology remains unsolved: how do earthquakes begin and what controls their final size?

These are among the key research questions of the FORESEEING (FrOm RupturE processS to Earthquake Early warnING) project, aimed at understanding the physical processes governing earthquake nucleation and translating this fundamental knowledge into Earthquake Early Warning (EEW) applications.

In this presentation, we discuss the open issues on the physical grounds of Earthquake Early Warning, passing through the fascinating world of seismic ruptures. We illustrate theories, models, parameters and recent observations that can shed light on the mechanisms of generation and propagation of seismic ruptures and discuss their implications for Earthquake Early Warning.

FLAVIO CANNAVÒ – Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Etneo

Automatic Volcano Early Warning Systems developed and operated at the Etnean Observatory-INGV

ABSTRACT

This contribution presents the results of long-term experience and continued scientific and technological efforts at the Etnean Observatory in the design, development, and operational implementation of automatic volcano early warning systems for Mt. Etna and Stromboli. Over many years of continuous research, monitoring, and system refinement, the Etnean Observatory has developed robust and reliable methodologies tailored to highly active volcanic environments. At Mt. Etna, the early detection of eruptive paroxysms is achieved through a machine learning-based algorithm that integrates multiparametric monitoring data, including seismic, infrasonic, and other geophysical signals. The system, named ETNAS, is designed to identify subtle precursory patterns and issue timely alerts, enhancing situational awareness during rapidly evolving eruptive scenarios. ETNAS has been operating in real time since 2022 and is formally integrated into the procedures of the Italian Civil Protection Department, supporting operational decision-making during volcanic crises.

At Stromboli, the early warning strategy is based on pattern recognition techniques applied to ground deformation data, enabling the detection of characteristic deformation trends preceding explosive activity. Collectively, these systems demonstrate the maturity and effectiveness of

automated, data-driven approaches developed through long-term commitment, supporting hazard assessment, risk mitigation, and civil protection actions in persistently active volcanic settings.

ANTONIO AVALLONE – Istituto Nazionale di Geofisica e Vulcanologia - INGV Irpinia

Real-time GNSS from RING network for Early Warning applications

ABSTRACT

Current Earthquake and Tsunami Early Warning Systems (ETEWSs) worldwide utilize ground motion observations from strong-motion accelerometers and broadband seismometers. These observations allow for the rapid estimation of magnitude, hypocenter, and other source parameters to distinguish the location and intensity of strong shaking. While ETEWSs perform well for magnitude estimation of small-to-moderate-size events, traditional inertial sensors generally struggle to record the full dynamic range of ground displacements, especially at low frequencies. To overcome this limitation, geodetic data, specifically GNSS displacements, have recently been incorporated into early warning algorithms and ground-motion models as a crucial complement to traditional seismic approaches.

We have considered a database of moderate magnitude seismic events in the Mediterranean region for which high-rate GNSS solutions were obtained. For each event with a known magnitude (Mw), an empirical scaling factor was derived to fit the observed displacement spectrum to the theoretical Brune source model low-frequency plateau. The primary objective of this research is to analyze the stability and potential variations of this derived scaling factor across the compiled event catalogue. Verifying the existence of a robust or "general" scaling factor is crucial, as its reliable determination could be directly applied for the rapid estimation of magnitude in the immediate aftermath of future moderate and large seismic events, significantly enhancing EWS performance.

The work will present the obtained results, will discuss major observed features (or lack thereof) in the scaling factor distribution.

CLAUDIO MARTINO - Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Vesuviano

Development of the EEW project at INGV: algorithms, system integration and operational applications for alerting and rapid response

ABSTRACT

The INGV EEW project is funded through the INGV projects “Rete Multiparametrica” and “DL50 – Centro Italia”, which are dedicated to the development of monitoring systems and provide the reference framework for the evolution of EEW solutions. In Italy, to date, an operational EEWS

at national scale is not yet in place; in fact seismic networks have been designed to monitor seismicity across the territory and to support Civil Protection surveillance within a rapid-response perspective.

Since Italy's main seismogenic sources are often close to urban settings; a quantitative understanding of warning-system performance is therefore crucial to identify areas where an EEWS can be effective and socially beneficial.

EEW is increasingly recognized within INGV as a strategic priority, combining scientific innovation with an operational mission for surveillance and rapid emergency management. The EEW project aims to consolidate a shared INGV vision of EEW as a high–public-value service, integrating existing monitoring networks, new technologies, and effective risk-communication practices.

A central theme of the project is the societal dimension of warning systems: acceptance, reaction time, expected behaviors, and training needs, with the goal of improving message usability and reducing inappropriate responses. The project also highlights how ideas and interdisciplinary collaborations within INGV have led to the creation of dedicated working groups. In particular, the Working Group "Urban and Structural Seismic Monitoring" aims to extend EEW beyond a purely scientific scope by including urban, infrastructural, and social contexts, enabling risk-mitigation applications and decision support.

From a technical standpoint, the project develops and validates AI-assisted algorithms for rapid event detection and classification, including the discrimination of signals generated inside versus outside the network, real-time quality control, and false-alarm reduction in complex environments—also through edge/AIoT solutions and annotated datasets for training/validation under low signal-to-noise conditions. In parallel, in close collaboration with academic partners, dedicated instrumentation is being developed for EEW and rapid response, including low-latency accelerometric nodes, on-board processing, and communication architectures optimized for operational deployment.

Finally, the project addresses Earthquake Early Warning Rapid Response (EEWRR) workflows based on early PGA analysis and on the use of Ground Motion Models calibrated for the Campi Flegrei area, with the aim of producing timely and actionable impact estimates for Civil Protection, infrastructure operators, and the population. EEWRR is particularly relevant when the blind zone severely limits the useful warning lead time of "classical" EEW. This is the case of Campi Flegrei caldera, which is characterized by shallow seismicity, strong local amplification, and rapid attenuation of seismic waves thus requiring complementary strategies focused on ultra-fast impact quantification and immediate operational response.

MARCO OLIVIERI - Istituto Nazionale di Geofisica e Vulcanologia - INGV Bologna

My prolonged thoughts on EEWS for Italy

ABSTRACT

Almost two decades ago, I joined the group of Italian seismologists that started thinking about Earthquake Early Warning in Italy and for Italy.

This presentation will contribute early results from work carried out at UC Berkeley in collaboration with Prof. Richard Allen, together with ideas and visions that could help the effective and rapid implementation of an Earthquake Early Warning System for the Italian territory.

CECILIA VALBONESI – Unitelma Sapienza - INGV

Balancing Necessity and Legal Accountability: The Advancement of EEWS in Italy

ABSTRACT

Earthquake Early Warning Systems (EEWS) pose a significant technical and scientific challenge aimed at enhancing the survival chances of populations exposed to seismic activity. The effectiveness of an EEWS in reducing risk, particularly regarding vulnerability and exposure, carries potential legal responsibilities for those involved, including scientists and experts. A critical issue is the connection between EEWS and the predictability and preventability of earthquake impacts, such as ground shaking affecting residents and infrastructure, as well as individuals' capacity for self-protective actions and the safeguarding of industrial facilities.

The experience of natural disasters in Italy, like the 2009 L'Aquila earthquake, highlights the complex interplay between science and law. Prior to the operational implementation of EEWS in Italy, it is important to: 1) review the legislative and technical measures taken by international legal frameworks in countries providing this service; 2) analyze the EU regulatory context that supports the introduction of EEWS as essential tools for safeguarding the right to life, and assess whether these frameworks obligate the Italian legal system to establish EEWS; 3) clarify the responsibilities of scientists and technicians managing EEWS in Italy; and 4) draw lessons from other nations to inform the rollout of EEWS.

Ultimately, it is vital to establish clear, shared protocols and disclaimers that define the service's limitations. Education plays a crucial role; individuals must not only expect reliable alarms but also understand the uncertainties in quick assessments, be prepared for potential risks, and know how to respond appropriately.

Session II – International Perspectives, Oral

RICHARD ALLEN – UC Berkeley

After 6 years of EEW in the US, what have we learned?

ABSTRACT

ShakeAlert has been issuing alerts in California, Oregon and Washington since October 2019. Construction of the seismic network was largely completed in 2025. We have issued alerts for more than 160 earthquakes and have learned a lot about the accuracy of the alerts, what the alerts are useful for, and how individuals respond to the EEW system. The alerts have been very accurate with 3 false events, and 14 missed alerts (all small magnitude) alongside the 160 true alerts corresponding to 98% precision and 91% recall. We have developed the technology to deliver the alerts to smartphones through the MyShake app and to all Android phones with just a few seconds of latency. Finally, user response to the alerts is very positive with the majority using the alerts to assess their surroundings ahead of shaking. Users still rate the alerts as useful even when they do not arrive before the shaking, which we interpret as being due to the education and information they provide.

RAN NOVITSKY NOF – The Geological Survey of Israel

From Network Upgrades to Public Trust: Lessons from the Operational Deployment of Israel's "Truaa" EEW System

ABSTRACT

Since January 2022, the State of Israel has operated "Truaa," a national Earthquake Early Warning (EEW) system designed to mitigate seismic risks along the Dead Sea Transform. This lecture shares the Israeli experience of transitioning from a research-based network to a fully operational public safety system, offering insights particularly relevant for regions with similar geographical constraints, such as Italy.

We review the system's architecture, which relies on a dense network of 120 strong-motion stations with low-latency telemetry (<1s) and the adaptation of the ShakeAlert "EPIC" algorithm to local conditions. A key challenge in Israel, shared by other narrow countries, is the "blind zone" caused by the proximity of population centers to fault lines. To address this, Israel adopted an "evolutionary" alerting policy that prioritizes urgency: alerting for lower magnitudes (Mw > 4.5) based on felt intensity thresholds (>5 cm/s^2) rather than structural damage alone.

The lecture will analyze Truaa's performance during its first three years, culminating in the system's first public activation on October 26, 2024. This unique event—triggered by a massive military explosion (370 tons) in Lebanon—was misclassified as a magnitude 5.2 earthquake,

sending alerts to over one million citizens. While technically a false alert regarding the source type, the event provided a rare real-world stress test for public behavior, and for operators and system performance.

STEFANO PAROLAI – Università di Trieste

Development and application of Decentralised Earthquake Early Warning Systems (Preliminary)

ABSTRACT

Decentralized on-site earthquake early warning systems are particularly useful for mitigating seismic risk in areas very close to potential seismogenic faults or for industrial plants and infrastructure that can benefit from automatic shutdowns to interrupt work activities.

This presentation will illustrate some examples of the application of decentralized on-site earthquake early warning systems and ad hoc instrumentation for their application, based both on simplified approaches using macroseismic intensity and on recently developed approaches that base decision-making on the probabilistic estimation of the exceeding of seismic intensity measure thresholds of the target structure.

SALVATORE BARBA – Istituto Nazionale di Geofisica e Vulcanologia - INGV Roma1

From Algorithms to Accountability: Governance Constraints of EEW Implementation in Italy

ABSTRACT

Earthquake Early Warning systems are often framed as a scientific or technological challenge. In reality, their success depends on governance, accountability, and operational integration as much as on algorithms and sensors.

International experiences show that technically mature EEW systems can remain partially or fully inactive when decision responsibilities, alert thresholds, and operational ownership are not clearly defined. In the Italian context, these constraints are amplified by complex institutional interfaces between scientific infrastructures, real-time networks, and civil protection procedures.

This contribution discusses EEW as a socio-technical system, highlighting key governance bottlenecks that must be addressed to move from experimental capability to operational deployment. The aim is not to propose a specific technical solution, but to identify minimal governance conditions required for EEW to function reliably, credibly, and sustainably at national scale.

MAREN BÖSE – Swiss Seismological Service – SED, ETH Zurich

Building Earthquake Early Warning: From Algorithms to Public Alerts

ABSTRACT

Since 2021, the ETHZ–SED SeisComP Earthquake Early Warning (ESE) framework has integrated two complementary algorithms: the Virtual Seismologist (VS) and the Finite-Fault Rupture Detector (FinDer). Built on a flexible and extensible architecture, the system uses a common real-time envelope processing library to derive acceleration, velocity, and displacement measures that support rapid magnitude estimation (VS) and finite-fault rupture modeling (FinDer). Together, these modules provide earthquake locations, magnitudes, origin times, rupture models, and associated uncertainties for real-time alerting and rapid response. The framework supports configurable alert dissemination and powers mobile EEW applications developed by our group, which have already delivered alerts to over one million users in Central America and are now being adapted for Switzerland and other European countries. Public surveys play an important role in assessing expectations for system design and in educating the public about the benefits and limitations of earthquake early warning (EEW) systems. We will report on our experience across multiple projects, including U.S. ShakeAlert, Central America, Switzerland, Taiwan, and New Zealand.

RICHARD ALLEN – UC Berkeley

Android Earthquake Alerts: Global roll-out, performance and user feedback

ABSTRACT

The Android Earthquake Alerts system uses Android phones to detect earthquakes globally, issue alerts to Android phones, and collect user feedback. Over 3 years of operation, the system detected an average of 312 earthquakes per month with magnitudes from M 1.9 to M 7.8 in Türkiye. Alerts were delivered in 98 countries for earthquakes with M $\geq$4.5, corresponding to ~60 events and 18 million alerts per month. User feedback shows that 85% of people receiving an alert felt shaking, and 36, 28, and 23% received the alert before, during, and after shaking, respectively.

Session III – Enhancing the Infrastructure, Oral

SULEYMAN TUNC – Sentez Earth and Structure

Earthquake Early Warning System in Marmara Region

ABSTRACT

Branches of the North Anatolian Fault Line, which have been dormant for a long time are prone to a major seismic event. Any major earthquake that will occur on these branches will affect not only Istanbul but also all provinces along the Marmara Sea.

The losses in human lives, economy and industry can be mitigated by Earthquake Early Warning Systems (EEWS). Regional EEWS detect earthquakes rapidly and determine whether they have the potential to cause damage. Predicting where and at what scale damage is expected, they alert the respective areas before the damaging shear waves arrive.

In the Marmara region, the challenge for EEW systems lie in the fact that most seismic activity is expected to occur off-shore: Large azimuthal gaps impede the estimation of the earthquake location and subsequently all other source parameters.

For this reason, the real-time seismic network was complemented by small-aperture seismic arrays (local clusters of sensors), which extract more information from the seismic waves than single-sensor stations and thereby improve the location estimates. The additional information provided by array-based measurements, such as slowness and back azimuth, provide for better ground motion predictions and an increase in lead time as they reduce the number of stations needed for a reliable location. We use seismic arrays alongside traditional single-sensor stations to provide an optimal solution.

DOMENICO PATANÈ - Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Etneo

Performance Evaluation of Next-Generation QMEMS Accelerometers for Seismic Monitoring, Structural Health Monitoring, and Earthquake Early Warning

ABSTRACT

Earthquake Early Warning (EEW) is increasingly moving toward dense, low-latency sensing architectures deployed in urban areas and on critical infrastructure, where rapid and reliable measurements of strong ground motion can directly support automated safety actions and impact-orientated decision-making. In this context, next-generation Micro-Electro-Mechanical Systems (MEMS) accelerometers—particularly Quartz MEMS (QMEMS)—provide a compelling pathway to scalable EEW, combining compactness, low power consumption, and cost-effectiveness with very low self-noise, high thermal stability, and wide dynamic range.

We evaluate the performance of a new QMEMS accelerometer (Epson M-A370) for seismic monitoring, Structural Health Monitoring (SHM), and Earthquake Early Warning (EEW) applications, comparing it with its predecessor (M-A352), other MEMS devices, and selected seismological FBA reference instruments. Laboratory characterization focused on self-noise, frequency response, and dynamic range, which are key determinants of trigger robustness and parameter stability in real-time processing pipelines. Field deployments within Urban Seismic Networks and Structural Health Monitoring (SHM) test sites (e.g., in the Campi Flegrei area and Durham) provided operational evidence of sensor performance under both very low noise ambient conditions and earthquake shaking (EEW INGV project). These deployments demonstrate the capability of QMEMS sensors to resolve microseisms as well as structural modal responses.

The obtained results indicate that these cost-effective, advanced MEMS sensors capture both low- and high-frequency earthquake motions with data quality comparable to conventional instruments while enabling the dense deployments required for near-field EEW. Our findings support the use of these next-generation QMEMS accelerometers as a core sensing technology for urban EEW, with SHM and digital-twin frameworks providing complementary, impact-focused interpretation for critical infrastructure and cultural heritage.

GAETANO FESTA – Università di Napoli Federico II, associato INGV ONT

DAS-based EEW systems in Irpinia and Chile: perspectives and challenges for offshore and inland monitoring

ABSTRACT

In the presentation, I discuss the use of Distributed Acoustic Sensing (DAS) data for Earthquake Early Warning, applying established methods to predict ground motion at target sites based on rapid event characterization. The analysis is based on DAS recordings from two installations: an offshore deployment along the Chilean subduction zone (in collaboration with the ERC-ABYSS project) and recent deployments at the Irpinia Near Fault Observatory (INGV–UNINA). Despite the complexity of DAS wavefields, including secondary phases, the results demonstrate that DAS can effectively support early warning, particularly in offshore settings, where lead times may increase by more than ten seconds. However, signal saturation and fiber geometry remain key challenges, introducing limitations and increasing uncertainties.

Session I – The Italian Context, Poster

SAHAR NAZERI – Università di Napoli Federico II

Performance Assessment of QuakeUp Across Multiple Seismic Networks in Southern Italy Using Physics-Based Synthetic Seismograms

ABSTRACT

In this study, we evaluate the QuakeUp earthquake early warning system (EEWS) using physics-based synthetic ground motions generated with the SPEED numerical simulation platform for southern Italy. Synthetic waveforms are produced for a range of earthquake scenarios and recorded at virtual stations corresponding to multiple real seismic networks (ISNet, INGV, and Civil Protection). This approach enables a systematic investigation of the effects of network configuration, source characteristics, and data integration on early-warning performance. Preliminary results demonstrate the potential of simulation-based testing to quantify QuakeUp detection capability and warning timeliness under realistic near-source conditions.

MARIA DI GIOIA – Università di Napoli Federico II

AI-based earthquake detection and magnitude estimation from early P-wave signals at Campi Flegrei volcano

ABSTRACT

Earthquake Early Warning (EEW) systems are early alert systems that analyze the first few seconds of seismic signals to rapidly characterize earthquakes and provide advance warning of the arrival of the most intense and damaging seismic waves at sites to be protected. Machine Learning methods (Random Forest and XGBoost) were used to predict the magnitude of seismic events recorded in the Campi Flegrei area in 2024. The dataset includes approximately 600 events, with magnitudes ranging from 1.0 to 3.8, recorded by three stations (CAAM, COLB, and CSTH) measuring the three components of ground motion.

Spectral-domain features were extracted from the first 0.5 seconds of the P-wave using the Fast Fourier Transform. Two approaches were compared: a single model that simultaneously receives data from the three stations and combines the predictions through averaging, and separate models trained for each station, whose predictions are subsequently averaged. The two approaches yield numerically comparable results, as does the use of Random Forest and XGBoost. However, the best performance was obtained using the first approach, based on XGBoost and the average of the three predictions.

Considering that the moment magnitude in the dataset ranges from 1.0 to 3.8, the model achieves a mean absolute error of approximately 0.19 and a root mean squared error of 0.24. The coefficient of determination $R^2 = 0.73$ indicates that the model explains about 73% of the variability in magnitude. Compared to standard analysis techniques without the use of Machine Learning, this approach provides an improved estimate of moment magnitude, with an error below 0.2 magnitude units obtained approximately 0.5 seconds after the arrival of the first P-wave. This represents a key aspect for EEW systems, and the model trained in this work could be integrated into on-site EEW systems in the Campi Flegrei area.

MAURO PALO – Università di Napoli Federico II

A Modular AI-Based Architecture for Real-Time Classification of Earthquake and Noise Transient Signals

ABSTRACT

A possible source of false alert of the EEW systems that monitor railways is the passage of trains that can be wrongly interpreted as the shake produced by an earthquake and can lead to unnecessary stop of the train traffic. We have developed a numerical workflow for the classification of seismic signals as recorded by a network of 20 accelerometers currently monitoring the Roma-Napoli high-speed train railway and operated by RFI. The classifiers utilize as input the spectrum of 0.5 s of signal recorded at each sensor and adopt a ML-based approach to distinguish the passage of a train from an earthquake or noise. Different classifiers have been tested: a Random Forest - a supervised classifier - with grid search for hyperparameter optimization and performance comparison, and a Gaussian Mixture Models, an unsupervised approach that assumes that the points of the feature space are the superposition of multiple Gaussians and provides a confidence level to the assigned label. After the classification, a spatio-temporal decision module aggregates results from all monitoring stations, estimates the propagation velocity of detected events, and checks the physical consistency of the signals across stations to validate the classification. The pipeline applied to two months of recordings of the 20 accelerometers provides very robust results with an extremely high classification accuracy.

LUCA ELIA - Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Vesuviano

EEW Software Developed at RISSC-Lab and Application on the Irpinia Near-Fault Observatory

ABSTRACT

RISSC-Lab (University Federico II of Naples) has developed and experimented, over more than 15 years, several earthquake early warning software. Here, we provide a brief overview of these

systems (PRESTo, SAVE, QuakeUp) and of the related products targeted at end-users and stakeholders (SismUp, CREW).

These pieces of software exploit short windows of P-wave signal to measure multiple parameters (e.g. pick-time, peak acceleration, velocity, displacement, predominant period) to predict, before the strong shaking, the local or regional impact of the earthquake, in the latter case also providing an estimate of location and magnitude. As more, or longer, P-wave signals and eventually S-wave signals become available, they are used to better refine the expected impact and to provide more accurate alarm messages to target sites.

Different approaches to EEW were implemented, i.e. network-based source parameters estimation and GMPE impact prediction, single-station local impact prediction, or real-time early P-wave shake map, using a physics-based interpolation of multiple on-site ground motion parameters and GMPE predictions.

We describe the real-time experimentation of some of these algorithms to the Irpinia Near Fault Observatory (ISNet seismic network), an advanced infrastructure built around the fast and controlled transmission of data streams. Finally, we mention some of the real-time testing in other networks, as well as an operational industrial EEW application for RFI, the Italian railway company (AlpEW, related GUI and high-speed train braking and emergency management system).

LORENZO CUGLIARI - Istituto Nazionale di Geofisica e Vulcanologia - INGV ONT

Between acceptance and preparedness. An ex-ante assessment for developing a people-centered Earthquake Early Warning system

ABSTRACT

Earthquakes pose a threat to people's safety and the socio-economic context, especially in areas of high seismicity such as Italy. Even moderate intensity events, occurring in a vulnerable territorial context, can generate significant damage and cause casualties. Earthquake Early Warning Systems (EEWS), already implemented in some regions of the world, offer a warning time, varying from a few seconds to tens of seconds, during which the population can be warned, or protection systems can be automatically activated. This time, although short, is essential to reduce the risk of damage and victims before the arrival of the strongest seismic waves.

In Italy, an EEWS is not yet operational. In the Marche region, however, with the support of the INGV projects ‘Multiparameter Network’ and ‘DL.50-Reconstruction Central Italy’, the simulation of the operation of an earthquake warning system took place [Marzorati et al., 2021]. The simulation was performed using the broadband network of seismometers which, from 2016 to the present, populated a large database with excellent seismic data subsequently analyzed with the algorithms developed by the PRESTo programme [Iannaccone et al., 2010; Satriano et al., 2011]. This integration has shown that an EEW system is capable of alerting communities located 30 km

or more from the epicenter of an earthquake at 5-10 seconds' notice, providing sufficient time to activate automatic risk mitigation protection measures. However, the effectiveness of an EEWS depends on both the technical component (upstream) and the response of the population (downstream). Therefore, it is essential that the transmitted information is accepted and understood by the end users. For this reason, we hope that the messages that will be sent to citizens will be composed in collaboration with local communities. This means taking into consideration aspects related to the area, past experiences (whether lived or not) and the historical memory of the contexts.

To analyze the acceptance, information needs and behavioral reactions of the alert receivers, a questionnaire developed by Becker et al. (2020) was translated in Italian and tailored on our context. The questionnaire, self-administered through Google Forms and accessible via QR code, was administered to a sample of high school students in the province of Ancona. Composed of 25 questions and divided in four sections, the tool allowed the collection of useful data to understand the perceived effectiveness of EEWS and the factors influencing the adoption of protective behaviors.

Preliminary results suggest that an Early Earthquake Warning System (EEWS) is generally accepted by the population when they have adequate awareness of the seismic risk and have received sufficient information on the behavior to adopt. Respondents claim that receiving a message, even a few seconds before feeling the quake, can be psychologically helpful. The actions that respondents would take are directly proportional to the increase in time between receiving the warning and the quake. An important and controversial aspect that emerges from the data collected is that the perception of seismic risk, measured among the sample of students who claim to have experienced an earthquake, even a recent strong one, is low on average. The combination of advanced technological solutions and continuous enhancement of public awareness is the key to mitigating the impacts of earthquakes, making such systems a key complement to protecting vulnerable communities.

ILARIA OLIVETI - Istituto Nazionale di Geofisica e Vulcanologia - INGV ONT

Masked graph neural network for rapid ground motion prediction in Italy.

ABSTRACT

We propose application of TISER-GCN (Bloemheuvel et al. 2022) to the Italian seismic network. TISER-GCN is a graph neural network (GCN) architecture designed to predict the maximum intensity measurements of ground shaking (PGA, PGV, SA(T)) from the pattern of the recorded seismic waveforms in the very first seconds after an earthquake's first P-wave arrival times. The input data used in this study consists of the three-component earthquake waveforms recorded primarily by the Italian National Seismic Network and collected in INSTANCE - a seismological benchmark dataset. We have selected about 3,000 earthquakes between 2005 and 2020 with

magnitude ≥ 3.0 and depth ≤ 50 km. To gather a high-quality dataset for training TISER-GCN, we have adopted various criteria to avoid possible signal saturation and privilege the use of true acceleration recordings whenever possible. TISER-GCN owns an innovative approach to incorporating both the temporal and spatial dimensions of data through graph structures leading to significant advancements and positioning it as one of the state-of-the-art models for this type of task. Noteworthy, it does not require previous knowledge of the earthquake source (location and magnitude) and can provide accurate predictions of the ground motions at farther seismic stations from the initial recordings of the earthquake at the nearest stations. The challenge is applying the model to the entire national network, comprising nearly 600 stations, thereby needing to overcome technical issues. This expansion requires adaptation to a sparse graph with null values for many stations, a significant step forward from previous works restricted to a smaller area featuring only 39 stations. Results show that masking stations where the P-wave arrives within the first 10 seconds, combined with the integration of additional information, reduces the mean squared error (MSE) by up to 6% for peak ground acceleration (PGA) and 5.5% for peak ground velocity (PGV), compared to the unmasked baseline. Moreover, the proposed approach yields near-zero median residuals across all IMs, mitigating the systematic underestimation observed when using a ground motion model specifically developed for Italy. These findings indicate that the model provides accurate predictions of ground motions, comparable to those obtained with the original TISER-GCN, which, however, requires a fixed seismic network geometry.

Session II – International Perspectives, Poster

RAFFAELE REA – Università di Salerno

Comparative evaluation of impact-based and hybrid approaches for real time earthquake shaking prediction

ABSTRACT

Earthquake Early Warning (EEW) systems use different strategies to provide a few seconds of advance notice before the arrival of damaging seismic waves. This study compares two EEW algorithms, PLUM (a purely impact-based approach) and QuakeUp (a hybrid method), using a simulation of the 2016 Mjma 6.6 Central Tottori earthquake. PLUM shows consistently high alert accuracy (≥90%) after threshold exceedance but offers limited lead times for sites close to the epicenter. QuakeUp can issue alerts earlier, as soon as 3 seconds after the origin time, providing lead times of up to 12 seconds at 40 km, although with lower initial accuracy. Overall, both systems deliver reliable warnings, highlighting the influence of algorithm design and station coverage on EEW performance.

Session III – Enhancing the Infrastructure, Poster

ANTONIO SCALA - Istituto Nazionale di Geofisica e Vulcanologia - INGV Osservatorio Vesuviano

Feasibility study of an integrated earthquake and tsunami early warning system

ABSTRACT

Current Tsunami Early Warning Systems (TEWS) rely on rapid estimates of earthquake source parameters to issue alerts within minutes after a seismic event. For near-coastal tsunamigenic earthquakes, further reducing alert time is crucial to increase evacuation lead time. We present a feasibility study evaluating the integration of earthquake magnitude and location estimates from QuakeUp, an impact-based earthquake early warning system (EEWS), into a TEWS workflow, and assess the trade-off between timeliness and accuracy in Probabilistic Tsunami Forecasting (PTF).

A hindcast of the 30 October 2020 Mw 7.0 Aegean Sea earthquake shows that QuakeUp can deliver stable source estimates within ~40 s from origin time, comparable to operational solutions available within minutes, and enabling PTF runup predictions consistent with observations. Simulations of Mw 6–7 earthquakes in the Messina Strait further confirm the robustness of the integrated workflow results, with first alerts issued within one minute. This study provides the first demonstration of a combined EEWS–TEWS approach for near-coastal tsunamigenic events, highlighting its potential for dual risk mitigation. Future work will focus on testing its performance in an operational setting, including the impact of network latencies and configuration-dependent efficiency.

FRANCESCO CAROTENUTO - Università di Napoli Federico II

A Proposal for a new generation of Earthquake Early Warning System actuators operating in critical environments

ABSTRACT

Earthquake Early Warning Systems (EEWS) are essential for seismic risk reduction by enabling rapid protective actions in critical infrastructures (e.g., nuclear plants, gas pipelines, etc). Advances in wearables, large language models are fostering next-generation actuators EEWS. These actuators extend beyond alerting by providing real-time, context-aware operational support throughout seismic phases.

VALERIA LONGOBARDI - Università di Napoli Federico II

One-Second-Lead Earthquake Warning and Impact Assessment at Campi Flegrei

ABSTRACT

Rapid dissemination of earthquake information is essential to reduce seismic risk in densely populated volcanic areas such as the Campi Flegrei caldera. The region experiences recurrent bradyseism and shallow seismicity, with recent moderate events strongly felt by the population. Standard Earthquake Early Warning systems are ineffective at this scale due to short source–station distances and small magnitudes. This study introduces a hybrid, on-site, impact-based EW system that estimates earthquake magnitude and expected peak ground motion within one second of a single-station P-wave detection. This approach is easily transferable provided that a calibration of magnitude and ground motion empirical relations is made on historical data-sets and represents a step toward low-latency alert systems that enhance community resilience.

SALVATORE BARBA - Istituto Nazionale di Geofisica e Vulcanologia - INGV Roma1

SeismoCloud: From Low-Cost Distributed MEMS Sensors to Reliable, Low-Latency Earthquake Early Warning

ABSTRACT

Earthquake Early Warning systems are often assumed to require dense networks of high-quality sensors to achieve low latency and high reliability. SeismoCloud explores an alternative approach: transforming a distributed, low-cost, and individually unreliable MEMS sensor network into a reliable EEW system through architectural design and distributed consensus.

The system is operational and largely open source, integrating low-cost MEMS stations and smartphone sensors within a cloud-based real-time processing pipeline. During the 30 October 2016 Mw 6.5 Central Italy earthquake, SeismoCloud generated an early warning within 4.5 seconds from origin time using MEMS data and estimated co-seismic displacements from public GNSS stations using the VADASE algorithm within ~11 seconds after P-wave arrival.

This poster focuses on system architecture, decision logic, and lessons learned on latency, false alarms, and missed alerts, highlighting implications for scalable EEW implementations.

CLAUDIO STRUMIA – Università di Napoli Federico II

Rapid Magnitude Estimation with DAS offshore Chile based on secondary converted phases: implication for EEW

ABSTRACT

Distributed Acoustic Sensing (DAS) converts fiber-optic cables into ultra-dense strainmeter arrays, offering space and time continuous earthquake recordings. While the potential in offline seismic characterization is becoming clear, a fundamental field of application for the exploitation of this new sensing paradigm is real time monitoring for Earthquake Early Warning. The potential use of existing fiber infrastructures allows to sense cables that get close to seismogenic sources, like subduction zones in offshore environments. In this setting, DAS-based EEW systems could greatly extend the lead time for issuing alerts to target sites.

Here, we analyze earthquakes recorded by the ABYSS network—450 km of offshore telecommunication cables along the Chilean subduction trench, sensed by three DAS interrogators—as a high-seismicity testbed. We defined a strategy for real time magnitude estimation, overcoming the limitations of offshore environments where direct P waves are often poorly recorded by DAS and followed by more energetic secondary phases. These results highlight DAS as a critical asset for rapid seismic alerting in high-risk subduction zones.