When Climate Meets Seismology
Exploring Multi-Hazards Risks in Changing Planet

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Introduction

Climate change is driving an increase in the frequency and severity of extreme weather events, posing significant threats to natural ecosystems and human-built environments. In seismically active regions, the interaction between climate-driven phenomena and geophysical processes can amplify seismic risks, jeopardizing critical infrastructure and ecological stability.
The REACTIVE project ("The research center for climate change due to natural disasters and extreme weather events"), coordinated by the Romanian National Institute for Earth Physics (NIEP) tackles these emerging challenges by exploring the complex, multi-hazard interactions between the atmosphere, hydrosphere, and lithosphere across local and national scales.

REACTIVE is part the project "Competence Center for Climate Change Digital Twin Earth for forecasts and societal redressement" (DTEClimate), funded within the framework of the National Recovery and Resilience Plan of Romania, together with other four specific projects with complementary aims: AI4DTE - "Artificial Intelligence in Earth Observation for Understanding and Predicting Climate Change" (a digital twin approach is proposed) Act4D - "Active Measures for Restoring Sweet-Water Lakes and Coastal Areas affected by Eutrophication" (to studying the impact of climate change on the biodiversity in sweet water lakes and related ecosystems), EO4NATURE - "Exploitation of Satellite Earth Observation data for Natural Capital Accounting and Biodiversity Management" (to studying the environmental challenges due to climate change by referring to the monitoring of ecosystems, management of biodiversity, biosafety, protection and ecological restoration of bioproductive capacity), and VeBDisease - "Assessing climate change impact on the vector-borne diseases in the One-Health context" (to study the climate impact on the transmission dynamics, geographic spread and re-emergence of vector-borne diseases through multiple pathways).

REACTIVE project

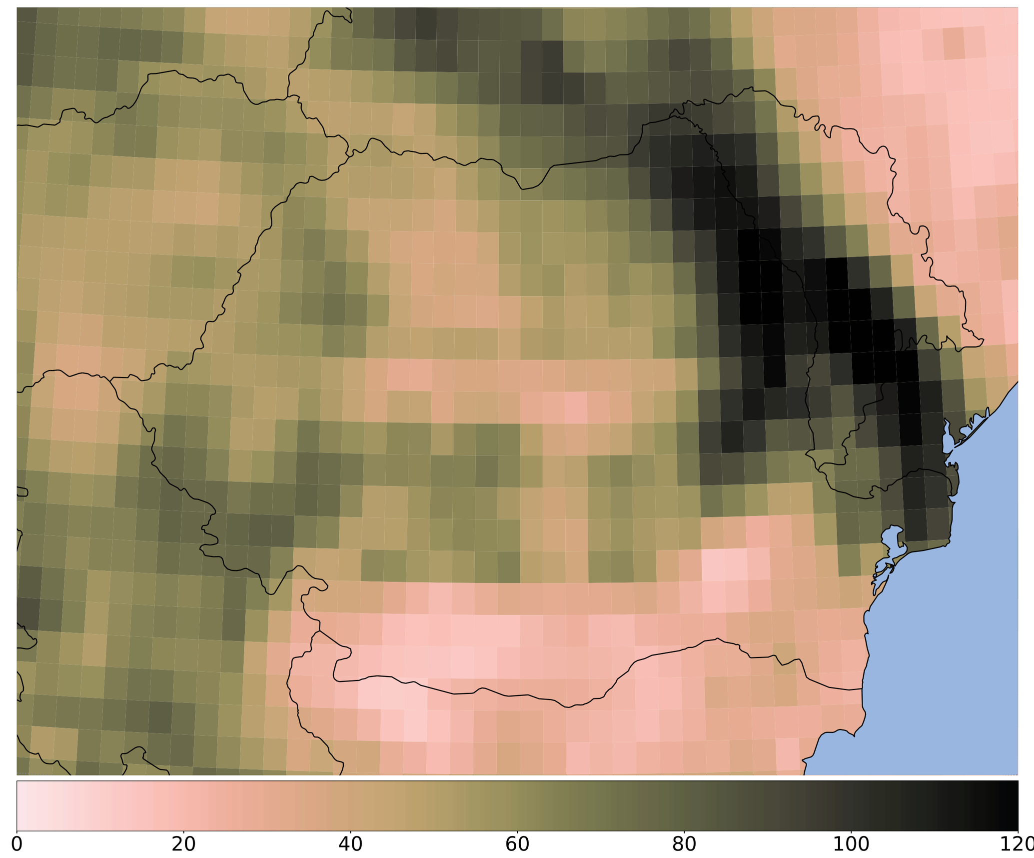
The objective of the REACTIVE project is to evaluate the impact of extreme weather events, including intense precipitation and abrupt temperature changes, on seismic risk in susceptible regions. REACTIVE also aims to improves the efficacy of monitoring stations in the Black Sea region by incorporating advanced data processing techniques into current early warning systems. The project enhances links to European and national monitoring infrastructures, promoting a collaborative framework for hazard assessment. The results encompass enhanced predictive models for seismic events affected by climate extremes and practical insights for risk assessors, infrastructure managers, and regulators. REACTIVE will enhance resilience and knowledge in responding to the intricate dynamics of multi-hazard threats associated with climate change by using historical and real-time data from seismic (Figure 2), GNSS, infrasound (Figure 5), and marine monitoring networks.

More specifically, the REACTIVE project, will develop an atmosphere-hydrosphere-lithosphere data monitoring service that will provide for the first time an integrated view of how climate-driven phenomena can affect soil structure and movement.The aim is to detect the following extreme events using existing monitoring networks:

- Powerful explosions in the atmosphere/lithosphere/hydrosphere
- Microbaroms (very low frequency sound waves generated by marine storms), hurricanes and tornadoes
- Volcanic eruptions, Meteorites, Landslides and avalanches
- Seasonal and annual variations of atmospheric properties.
- TEC atmospheric ionization
- Tsunamis - Measurement of water level, pressure and direction variations
- Atmospheric, Earth, Marine noise - anthropogenic signals
- Tornadoes, Severe storms. Lightning detection - Weather anomalies

Case study: Storm Boris 14–16 September 2024

Storm Boris was an unusual early-autumn low-pressure system that produced extreme rainfall across Central and Eastern Europe in mid-September 2024. High-pressure ridges to its northeast and northwest essentially anchored Boris in place for several days, allowing it to continuously funnel moisture into the same regions. This synoptic pattern is relatively rare (comparable to the setups of the historic 1997 and 2002 Central European flood events) resulting in a prolonged, stationary rainstorm. The most extreme rains were concentrated in Central Europe (especially Austria, Czechia, southern Poland, Slovakia), yet Boris also triggered severe downpours in Eastern Romania at an earlier stage of its life cycle.



Eastern Romania experienced torrential rainfall under Cyclone Boris's influence, with local totals exceeding 150 mm in less than 24 hours (Figure 1). At least 7 people lost their lives in the floods in Romania.

The most damages occurred in Galați County, where flash floods struck with little warning. In Galați alone, more than 20,000 residents were severely affected by the flooding.

Figure 1. Total precipitation (mm) between 10 Sep 00 UTC and 23 Sep 23 UCT base on ERA5 reanalysis data.

Seismic response to intense rainfall during Storm Boris

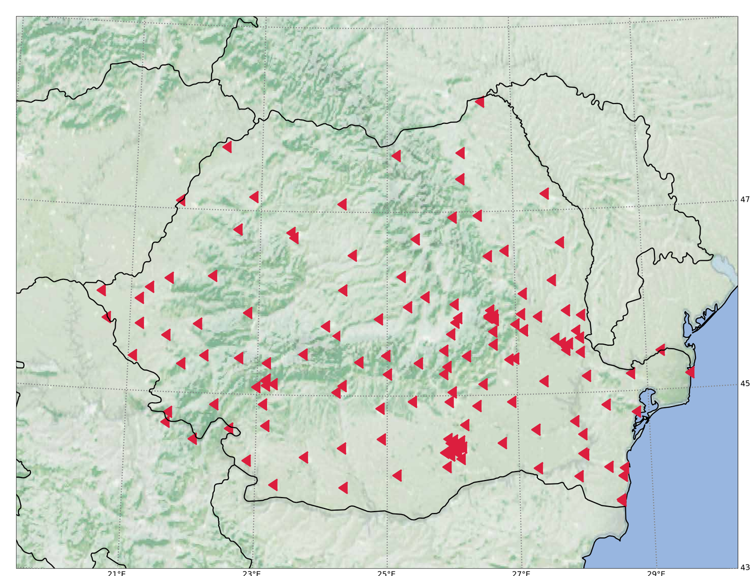


Figure 2. The National Seismic Network (NN) for Earth Physics.

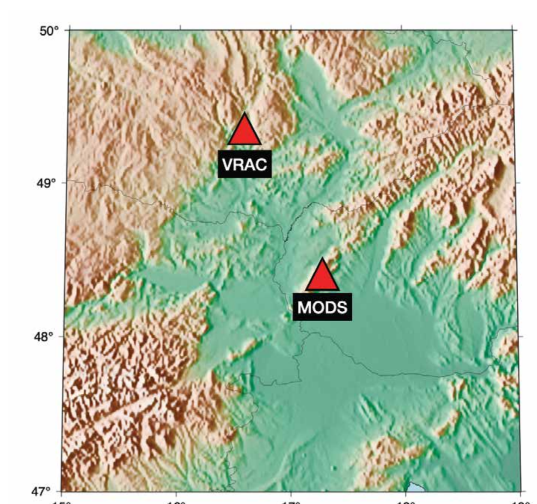
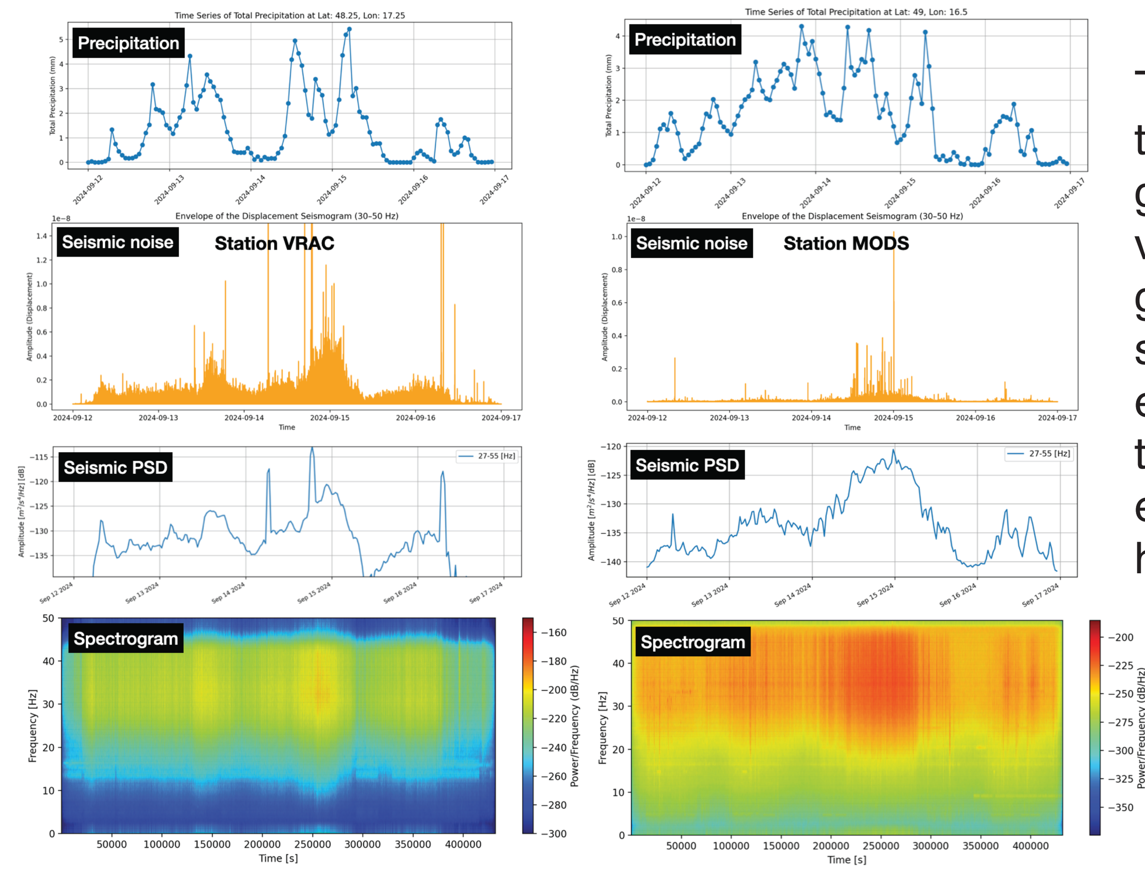


Figure 3. Map showing the locations of the two seismic stations within the region of maximum hourly precipitation recorded during the storm.

Figure 4 shows an overview of the seismic response to intense rainfall during Storm Boris. Time series recorded at each station (Figure 3) during the storm are represented on right and left columns. From top to bottom are represented the hourly total precipitation extracted from ERA5 reanalysis for the closest grid point to each seismic station, seismic noise envelope (velocity, after instrument correction) filtered above 30 Hz, capturing high-frequency ground motion, temporal evolution of power spectral density (PSD) at high frequency (> 30 Hz), derived from probabilistic spectral analysis; Spectrogram of the high frequency seismic noise, illustrating frequency content over time.

Temporal PPSD evolution closely mirrors precipitation trends, with PSD peaks aligning with rainfall maxima.The high-frequency energy (> 30 Hz) observed in the seismic signal coincides with intense rainfall episodes.The timing and structure of the seismic and spectrogram further support the direct coupling between surface rainfall and seismic noise (Figure 4).



These findings support the hypothesis that impacts from individual raindrops generate detectable high-frequency vibrations, transmitted through the ground and recorded by nearby seismometers.This effect is particularly evident during heavy rainfall, where the increased number and kinetic energy of raindrops produce sustained high-frequency ground motion.

Figure 4. Overview of the seismic response to intense rainfall during Storm Boris.

Infrasound signals detected during Storm Boris

In addition to traditional meteorological measurements, the evolution of the event was captured by NIEP's infrasound network and lightning detection from MTG Lightning. In particular, the infrasound arrays provided insights into the intensity and evolution of the cyclone.

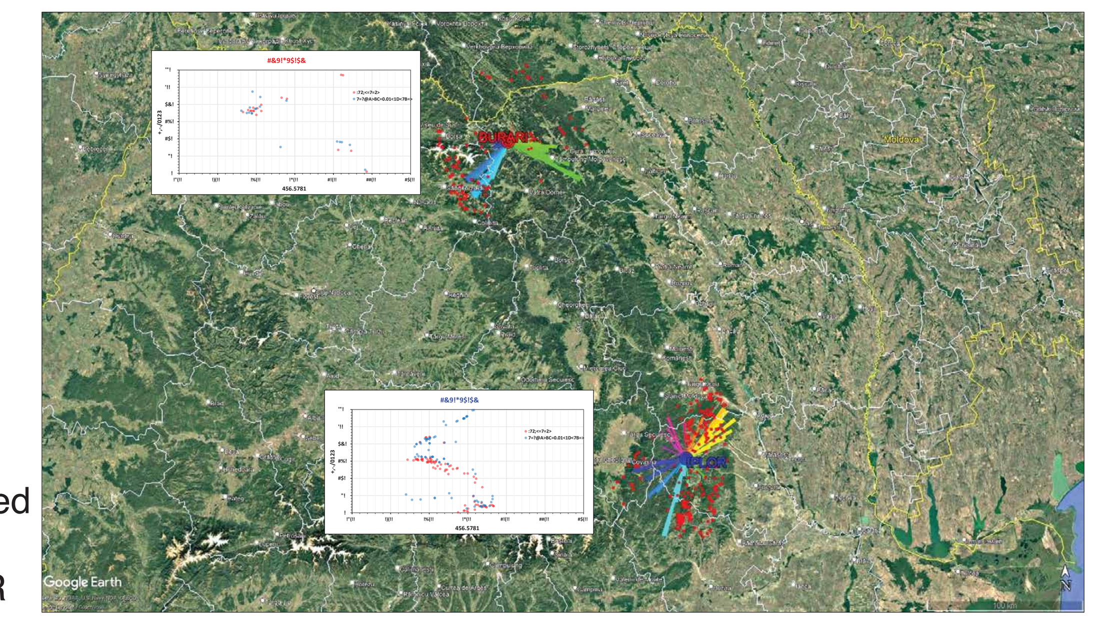


Figure 5: Lightning activity on 14 Sep as detected by MTG Lightning Imager and NIEP infrasound network (left). Detections at BURARI and IPLOR stations (right).

We investigated infrasound signals detected with BURARI and IPLOR arrays and lightnings on 14 Sep 2024 (Figure 5). Events are detected using DTK-PMCC detector and analyzed using DTK-GPMCC and DTK-DIVA software embedded in NDC-in-a-Box package.
Infrasound detections into 0.5 to 7 Hz frequency band could be correlated with lightning detected by the MTG Lightning Imager up to 50 km from the arrays where direct wave propagation path could be assumed. In order to automatically associate infrasound observations with MTG detections, a relationship between infrasound time-of-arrival and time of discharge signals (Alssink et al, 2008) was applied. A maximum deviation of 10° between observed infrasound back-azimuth and back-azimuth of MTG detections is allowed. Polar histogram of BURARI and IPLOR infrasonic detections along with MTG lightning detections for 14 Sep is shown (Figure 5) together with two scatter plots showing infrasound detections and associated lightning.

Conclusions

This multidisciplinary observational approach underscores the increasing role of integrated sensor networks in enhancing the predictive understanding of extreme weather events in the context of a changing climate.

References: Assink, J. D., L. G. Evers, I. Holleman, and H. Paulssen (2008), Characterization of infrasound from lightning, Geophys. Res. Lett., 35, L15802, doi:10.1029/2008GL034193