Report of Transnational Access Projects

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Project ID: *C3_TA3-84-1_2*

Principal investigator: *BOULANOUAR ABDERRAHIM, National School of Applied Sciences, Abdelmalek Essaadi University, Al-Hoceima, Morocco*

Project team (if applicable):

Project title: Feasibility of a Network-Based Earthquake Early Warning System in Morocco: Lessons from the 2023 Mw 6.8 Al Haouz Earthquake

Project acronym: *SGITA*

Hosting installation: *TA3-84-1, Università di Napoli Federico II, Physics Department*

Hosting team: *Aldo Zollo[1], Antonio Scala[1], , Luca Elia[1], Sonia Sorrentino[1]*

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Period of access: *From 26/02/2026 to 16/03/2026*

Report of activities:

In this TA activity, we used the QuakeUp method (Zollo et al., 2023; https://doi.org/10.1029/2022EA002657), developed by the research group at the host institution (Università Federico II, Napoli, Italy), to carry out a preliminary study of the feasibility of a network-based earthquake early warning system in Morocco. The analysis used data from a six-month period in 2023 and focused in particular on the Mw 6.8 Al Haouz earthquake of 8 September 2023, which occurred in the Marrakech-Safi region. The earthquake caused severe human and structural losses, with nearly 3,000 fatalities, more than 5,600 injuries, and widespread damage to buildings and infrastructure in the near-source region. Approximately 60,000 buildings were reported as heavily damaged, about one third of which collapsed.

*The QuakeUp package (*https://doi.org/10.5281/zenodo.11103858) *offers key capabilities relevant to this feasibility assessment:*

- *Real-time estimation of earthquake source parameters, including hypocentral location, depth, and magnitude.*
- *Uses observed P-wave amplitudes together with empirically calibrated magnitude and ground-motion attenuation relationships. For this study, the calibration was based on the six months of available data from the study region.*
- *As the P-wavefront propagates across the CNRST network, the system progressively updates the predicted Potential Damage Zone (PDZ), defined as the region where predicted shaking exceeds the intensity threshold MCS VIII. The predicted PDZ can then be compared with ShakeMap estimates and damage distributions derived from post-event surveys.*

To complement the mainshock analysis, we also performed retrospective playback tests for two aftershocks within the six-month dataset: an M5.6 event on the same date as the mainshock and an M5.0 event on 14 September 2023.

For source-parameter estimation, we used the 1-D P-wave velocity model of Moudnib et al. (2023) (https://doi.org/10.1007/s40808-022-01630-0).

At the end of the playback, the magnitude estimate stabilized at M 6.6. This is slightly lower than published Mw estimates in the cited studies, but represents reasonably close agreement for this preliminary feasibility test (Caldeira et al., 2023, https://doi.org/10.1007/s10950-025-10357-1; Billel Touati et al., 2024, http://dx.doi.org/10.26464/epp2024019)

The retrospective playback of the Mw 6.8 mainshock of 8 September 2023 (Fig. 1) produced a maximum ShakeMap intensity of VII. Figure 1 shows a snapshot of the evolving solution, including the spatial intensity pattern, origin time, hypocentral parameters, magnitude estimate, and the propagation of the P- and S-wavefronts.

We selected Rabat, Casablanca, Agadir, Marrakech, and Oujda as target cities. The target times, used here as an indication of the potentially available warning time, exceeded 20 s for all cities except Marrakech, which is close to the source. The resulting values were 23 s for Agadir, 33 s for Casablanca, 49 s for Rabat, and 133 s for Oujda.

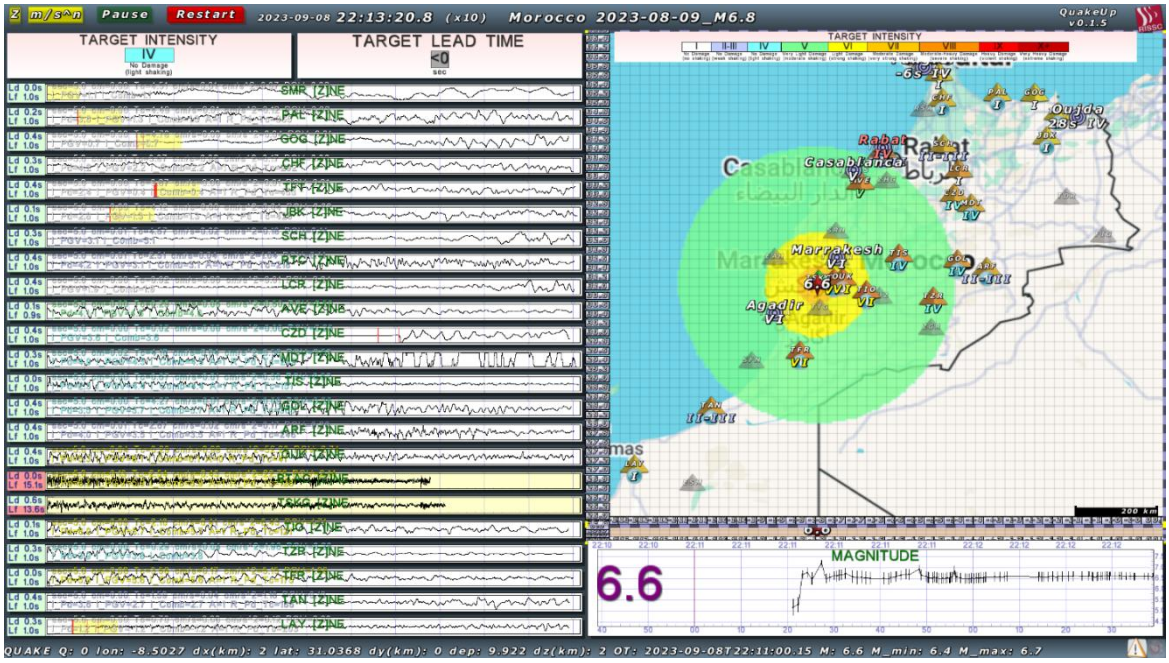

Figure 1: Snapshot after playing back the waveforms of the Mw 6.8, September 8, 2023 Morocco earthquake recorded by the CNRST network using QuakeUp v1.5. The ShakeMap obtained contains: the epicenter location, the stations deployed in the study area, the intensity variation from one station to another, the final depth, the variation of magnitude over time, and the variation of P and S waves shown as circles. On the left are the seismograms of the stations used, along with the automatic picking of the P wave.

Table 1: Estimated magnitude of the Al Haouz earthquake by various institutes (DOI: 10.26464/epp2024019)

Source	Magnitude (M_w)
This study	6.6
Global CMT	6.90
USGS (W-phase)	6.85
gCAP	6.87
InSAR	6.82

The available network for this study consisted of 22 seismic broadband stations and 2 accelerometers distributed over a very large region. Despite this limited coverage, the playback results are promising. A denser network would be desirable to improve coverage and performance, especially in the most vulnerable areas such as the Al Haouz region.

Table 2: Estimated focal depth of the Al Haouz earthquake by various institutes (https://doi.org/10.1007/s10950-025-10357-1)

Agency	Depth (km)
This study	9.92
IGN (Spain)	25
IPMA (Portugal)	20
USGS (USA)	19
INGV (Italy)	10
EMSC (France)	26

The focal-depth estimates in Table 2 range from 9 to 26 km. The value obtained in this study (9.92 km) is very close to the INGV estimate (10 km), while differing from several other agency solutions. The use of local Moroccan recordings is an important advantage for this analysis; however, this comparison should be regarded as part of a preliminary feasibility study rather than as a definitive assessment of the most accurate depth estimate.

We determined empirical relationships between $log(PGV)$ *and* $log(Px)$ *for 3 s, 6 s, and 9 s time windows. The* $log(PGV)$ *versus* $log(Pa)$ *relationship is approximately linear, and its slope decreases as the window length increases.*

The regression coefficients were compared across the three-time windows to assess how the model parameters and errors vary with the duration of the analysis window.

The coefficient of determination is greater than 0.9 for the tested relationships, indicating a very good fit of the $log(PGV)$ *versus* $log(Px)$ *model. The standard error (SE) ranges between 0.1 and 0.28, with higher values for Pa in the 6 s and 9 s windows.*

We also derived preliminary magnitude and attenuation relationships, $M = A + B\ log\ (Px) + C\ log\ R$ *and* $log(PGV) = A + BM + C\ log\ R$. *Together with the playback tests, they provide encouraging evidence of EEW feasibility in Morocco despite current network-coverage limitations, while further validation remains necessary.*

Although preliminary, these results indicate that QuakeUp represents a promising candidate for the future implementation of an operational hybrid network/impact-based Earthquake Early Warning system in Morocco. At the same time, this feasibility study highlights the need to further strengthen the existing seismic

infrastructure to fully exploit the potential of such a system, for example by increasing station density in the areas most exposed to seismic risk and, where possible, by complementing the network with additional accelerometric sensors.

Project outcomes:

An abstract on Earthquake Early Warning Systems in Morocco was submitted to the Mediterranean Geosciences Union Annual Meeting, to be held from 8 to 11 November 2026 in Cairo, Egypt.

Abstract code: MedGU-26-P57

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