

Single-Station Earthquake Early Warning System Using Machine Learning (R&D)

Pablo Lara

AI for Earth Sciences Workshop

March 24, 2026

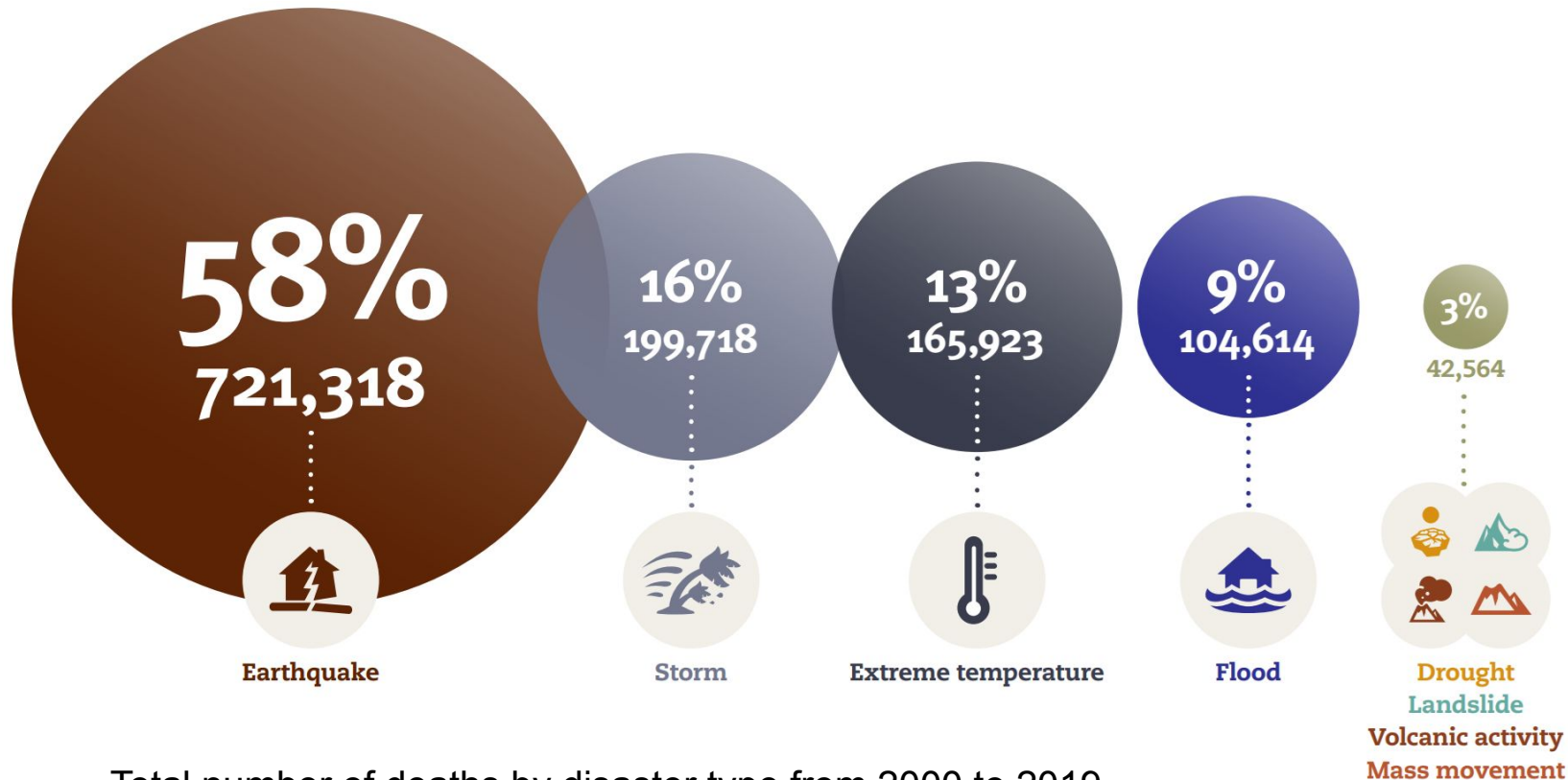
LA-UR-26-20590

Background and Education

- Education
 - B.S. Electrical Engineering (Pe)
 - M.S. Computer Science (Br)
 - Ph.D. in Earth Science (Fr)
 - Advisors: Quentin Bletery, Jean-Paul Ampuero
 - Co-advisor: Adolfo Inza
 - Thesis: Detection of seismological signals based on artificial intelligence
 - Postdoc (US)
 - Mentor: Chris Johnson
 - Deep-Embedded-Clustering of Microseismicity Identifies Multiple Failure Mechanisms at The Geysers Geothermal Field
 - Transparent Earth

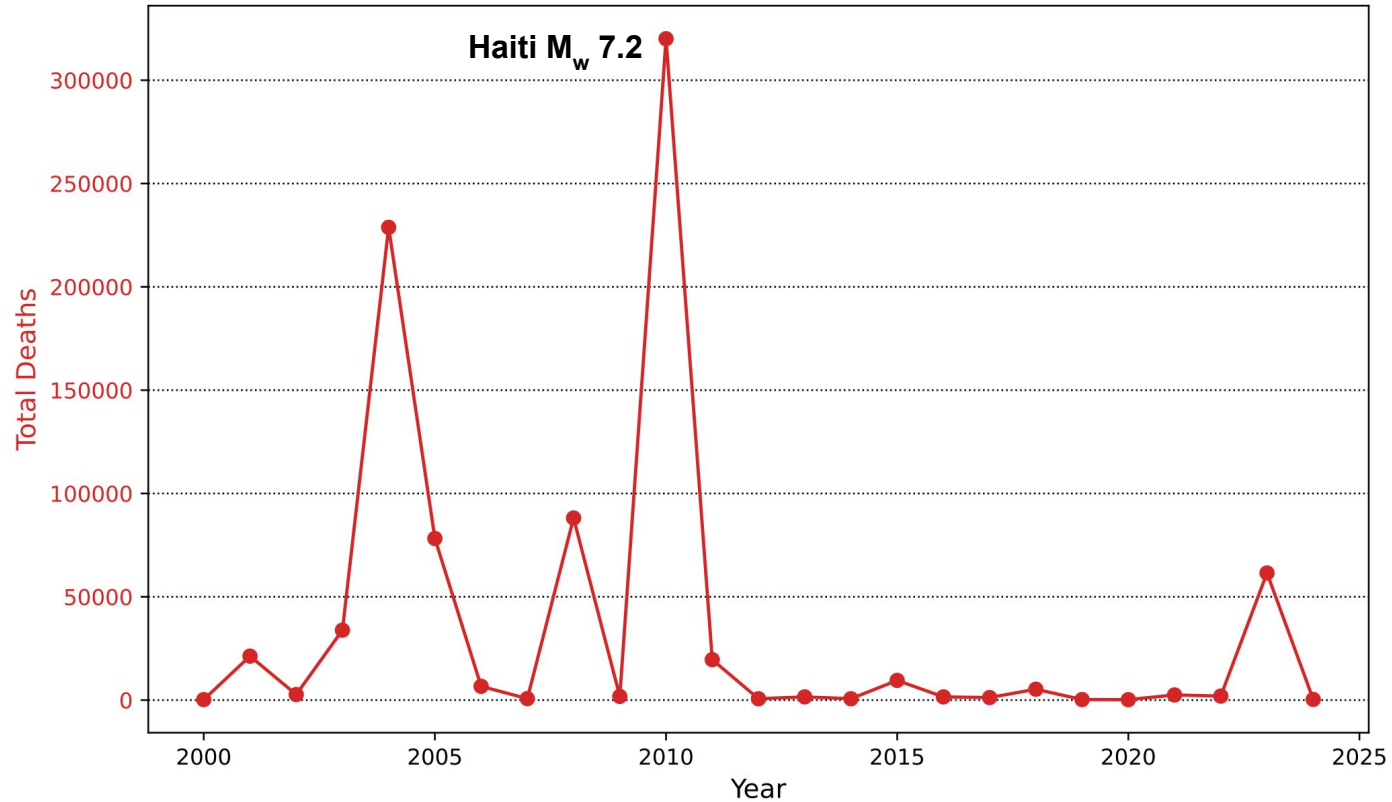


INTRODUCTION

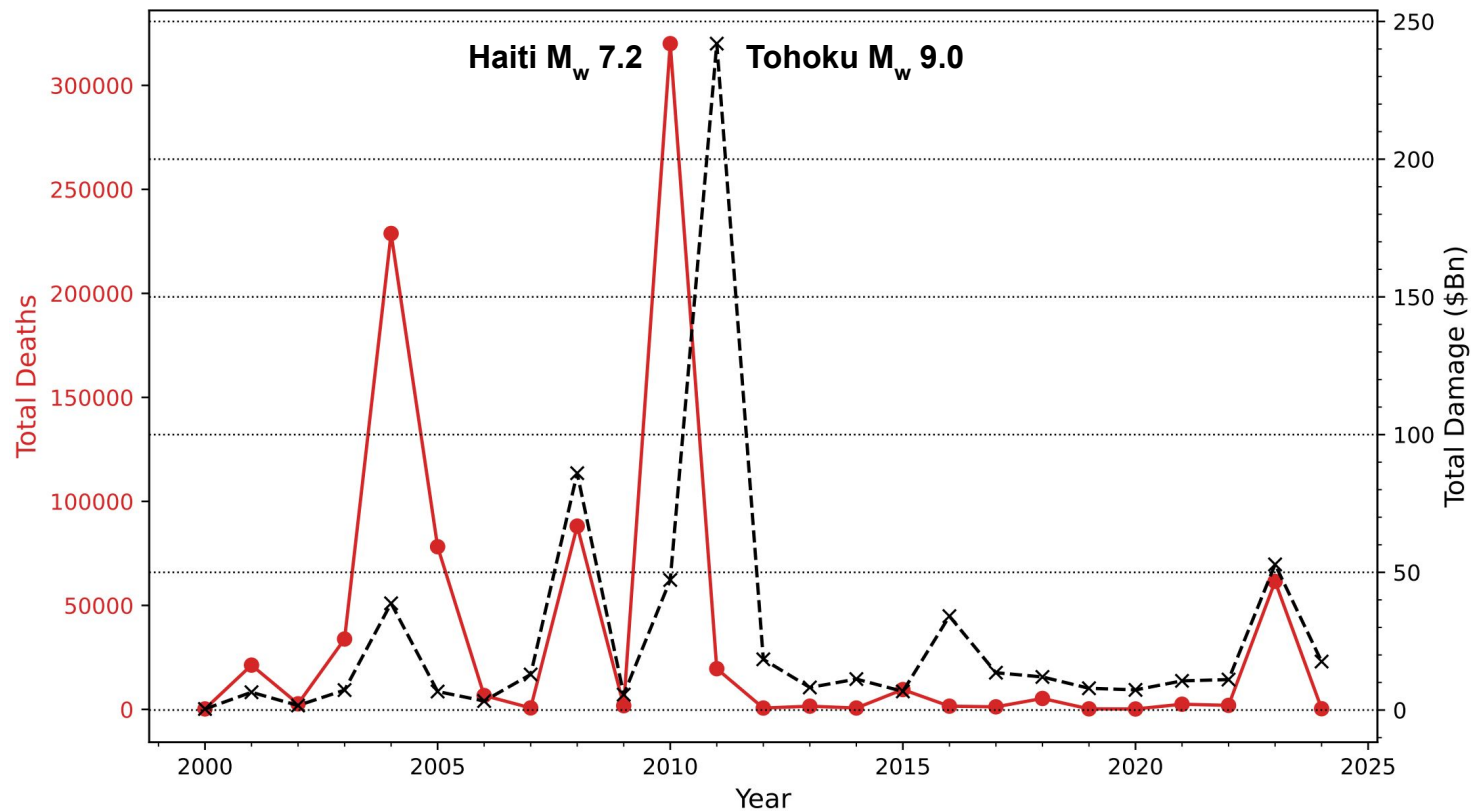


Total number of deaths by disaster type from 2000 to 2019

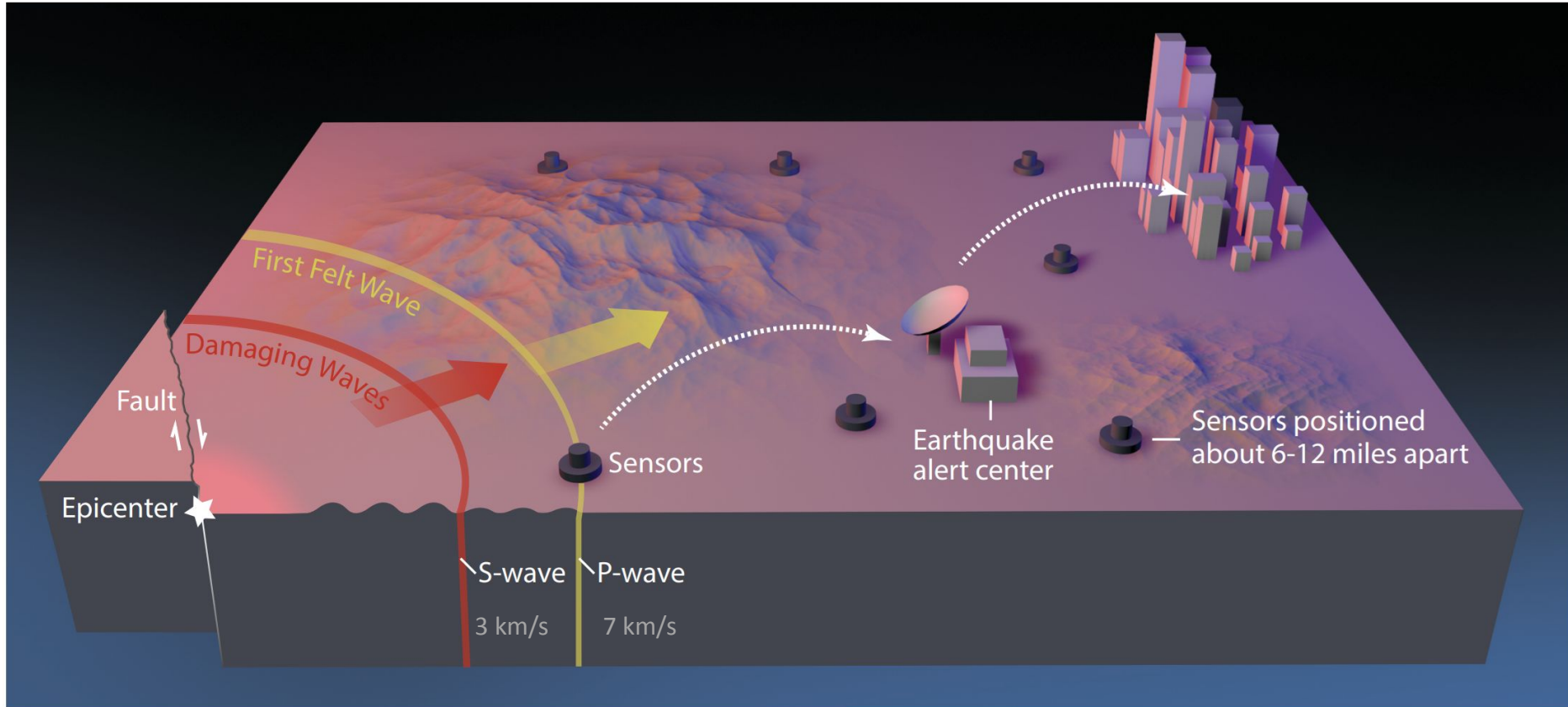
Deaths and economic losses per year from earthquakes since 2000.



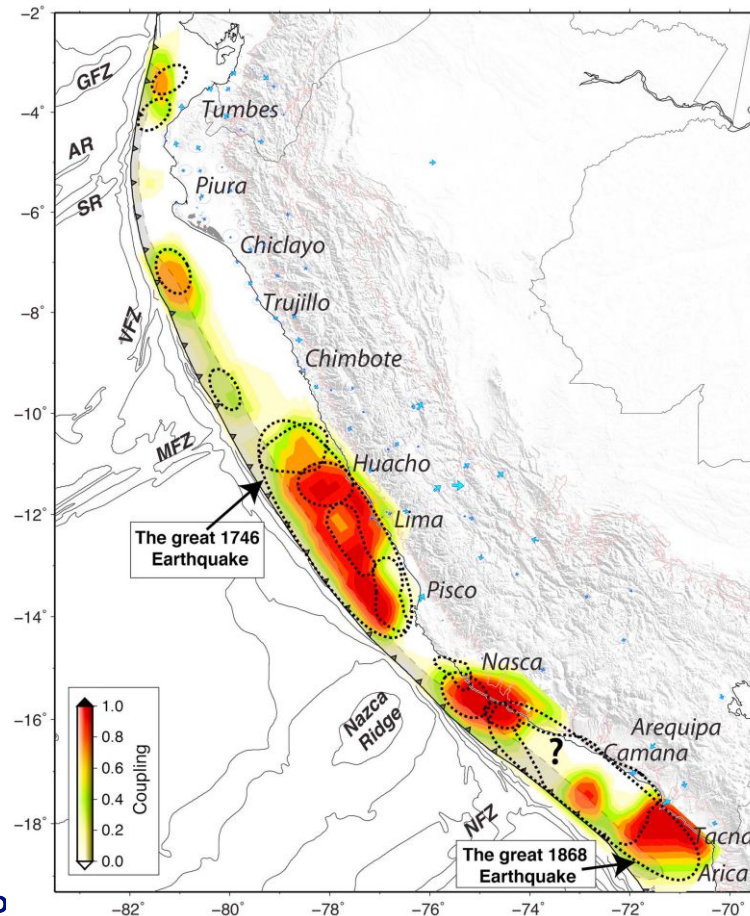
Deaths and economic losses per year from earthquakes since 2000.



How an Earthquake Early Warning System (EEWS) works



Seismic risk knowledge in Peru



People live near potential megathrust earthquakes



Government requirements

Issue alerts as quickly as possible
Alert message processed on-site



EEWS based on a single station
Easy installation on low-cost devices (Raspberry Pi 4)

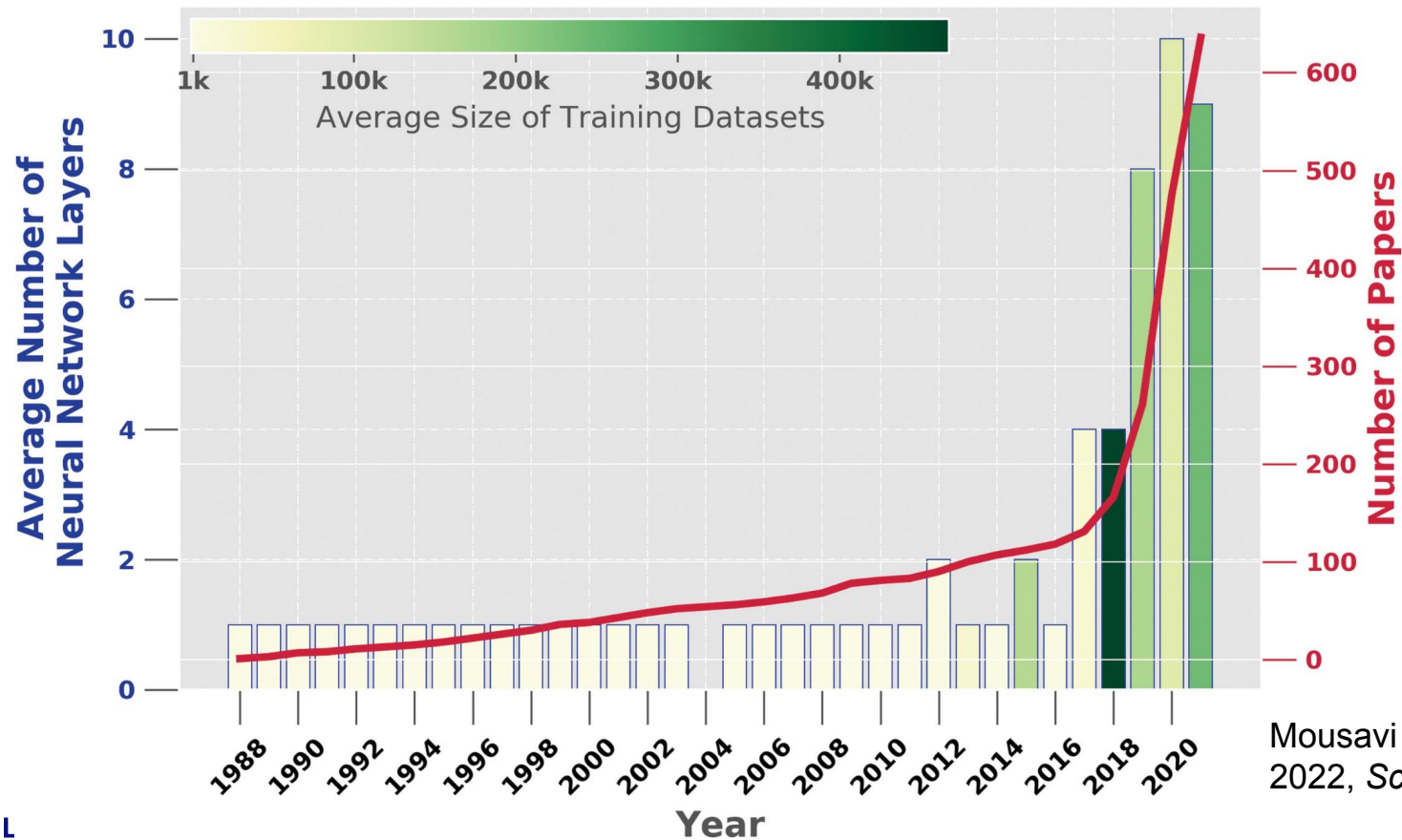
SASPe stations



SASPe stations



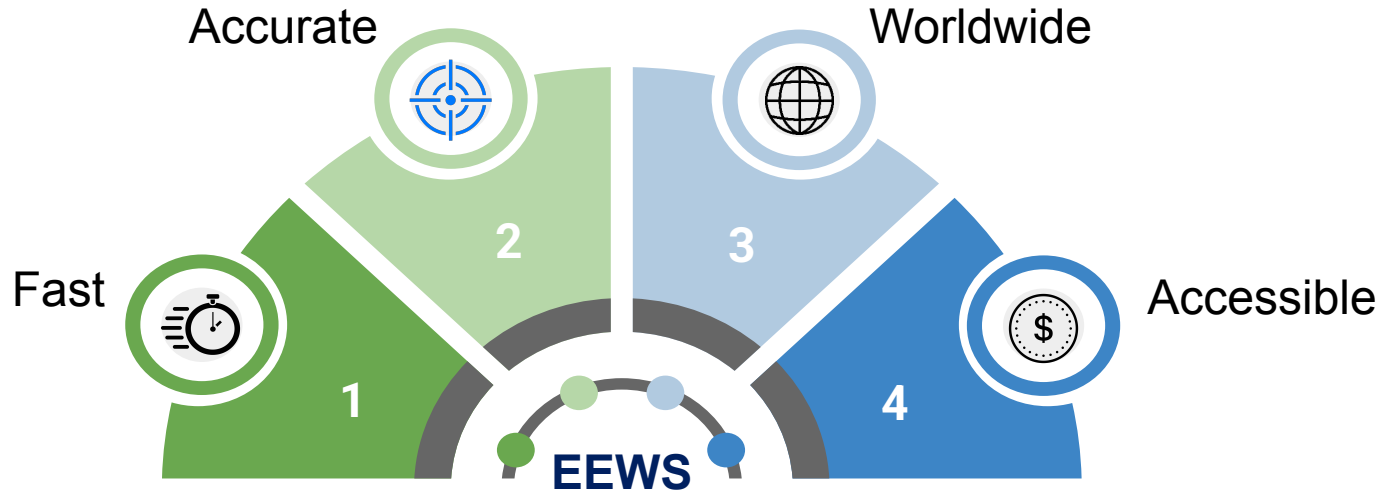
Cumulative number of seismology papers that employed neural networks



Mousavi & Beroza,
2022, *Science*

Scientific questions

1. Can an EEWS issue fast and accurate alerts?
2. Can an EEWS be applied in Peru or anywhere?
3. Can an EEWS be accessible to everyone?



PART 1

THE ENSEMBLE EARTHQUAKE EARLY WARNING SYSTEM (E3WS)

JGR Solid Earth

Research Article |  Open Access |  

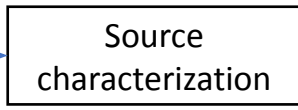
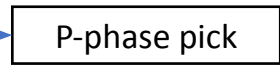
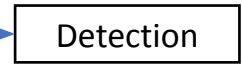
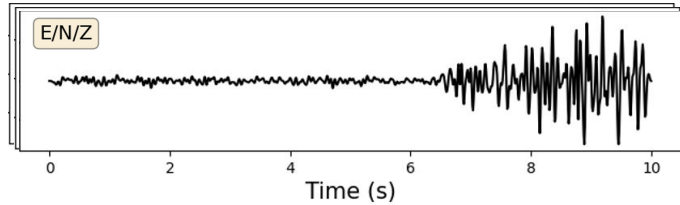
Earthquake Early Warning Starting From 3 s of Records on a Single Station With Machine Learning

Pablo Lara , Quentin Bletery, Jean-Paul Ampuero, Adolfo Inza, Hernando Tavera

First published: 02 November 2023 | <https://doi.org/10.1029/2023JB026575>

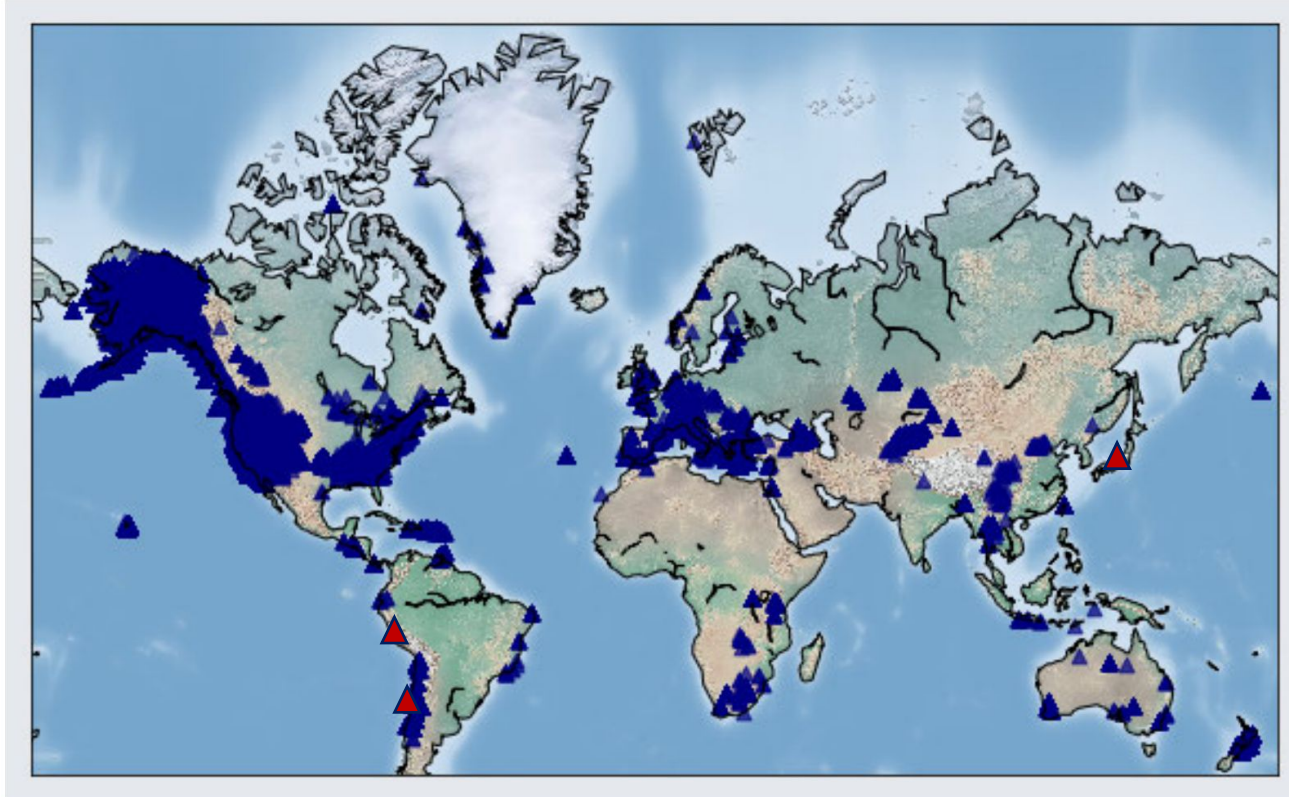
Inputs and outputs

First 3 s of the earthquake recorded by a single station



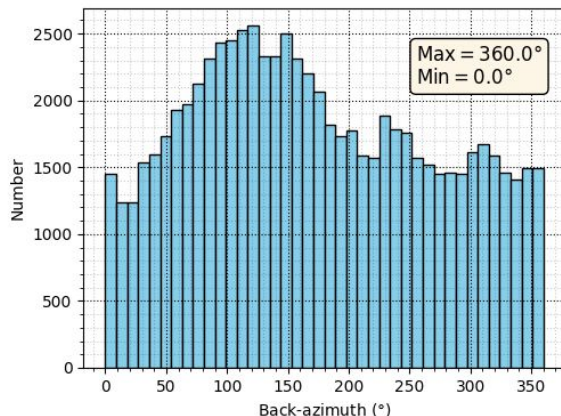
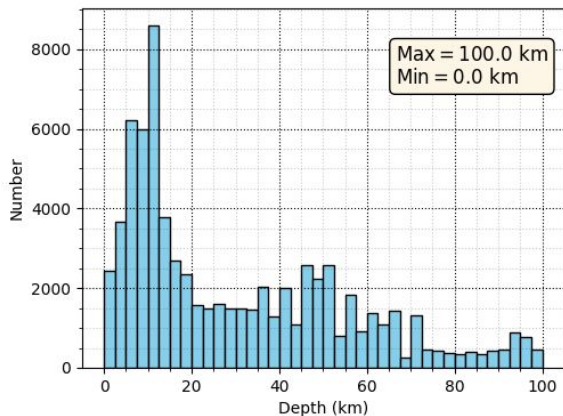
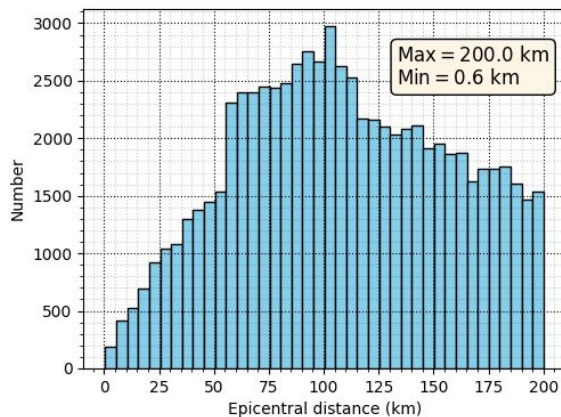
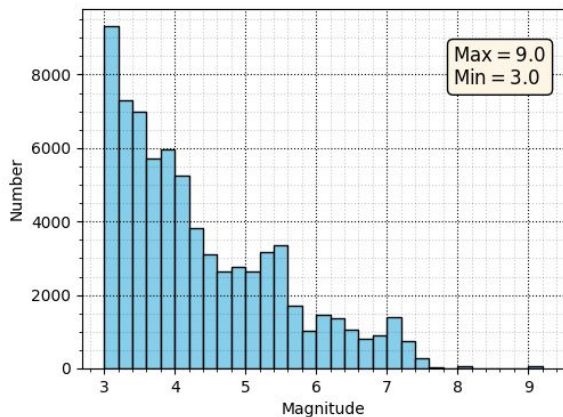
magnitude, location

Locations of seismic instruments recording earthquakes



STEAD: STanford Earthquake Dataset

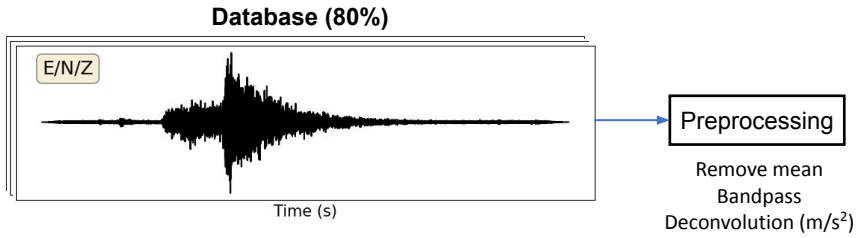
Database



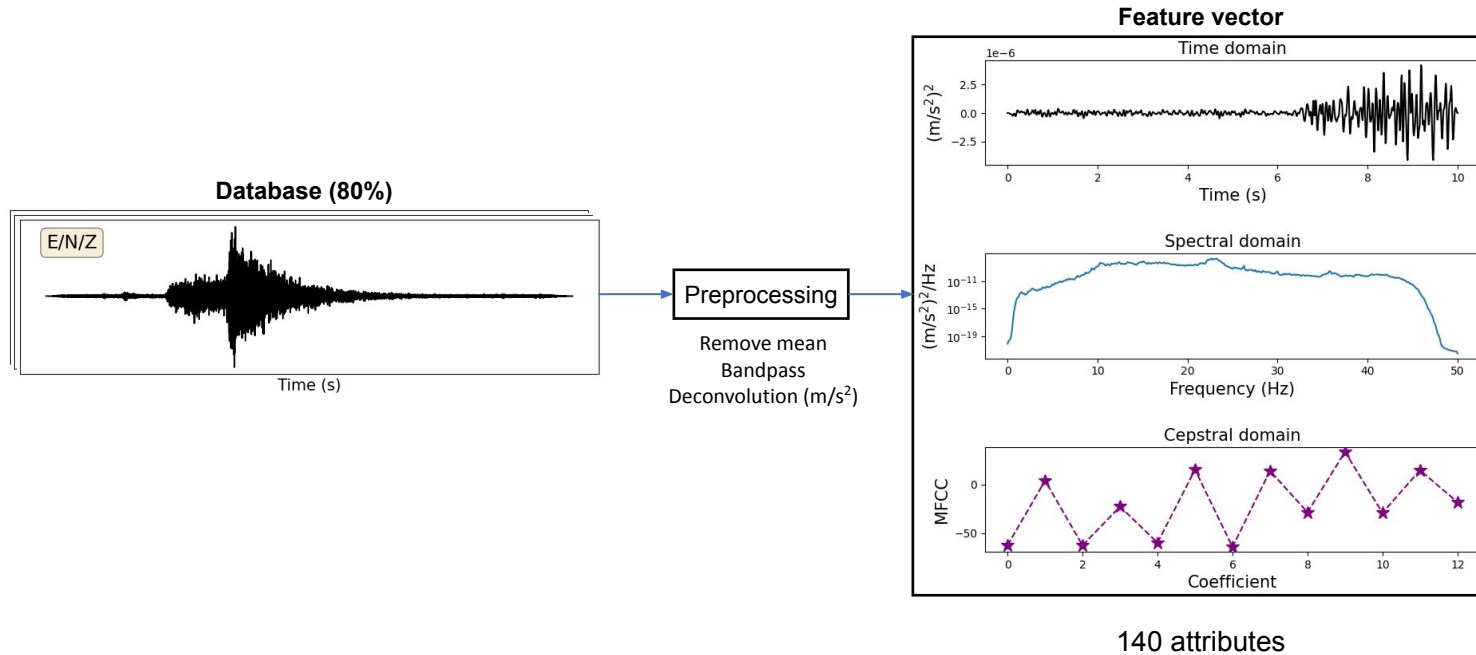
- Peru
- Chile
- Japan
- STEAD

22,000 earthquake events associated with ~100,000 earthquake observations

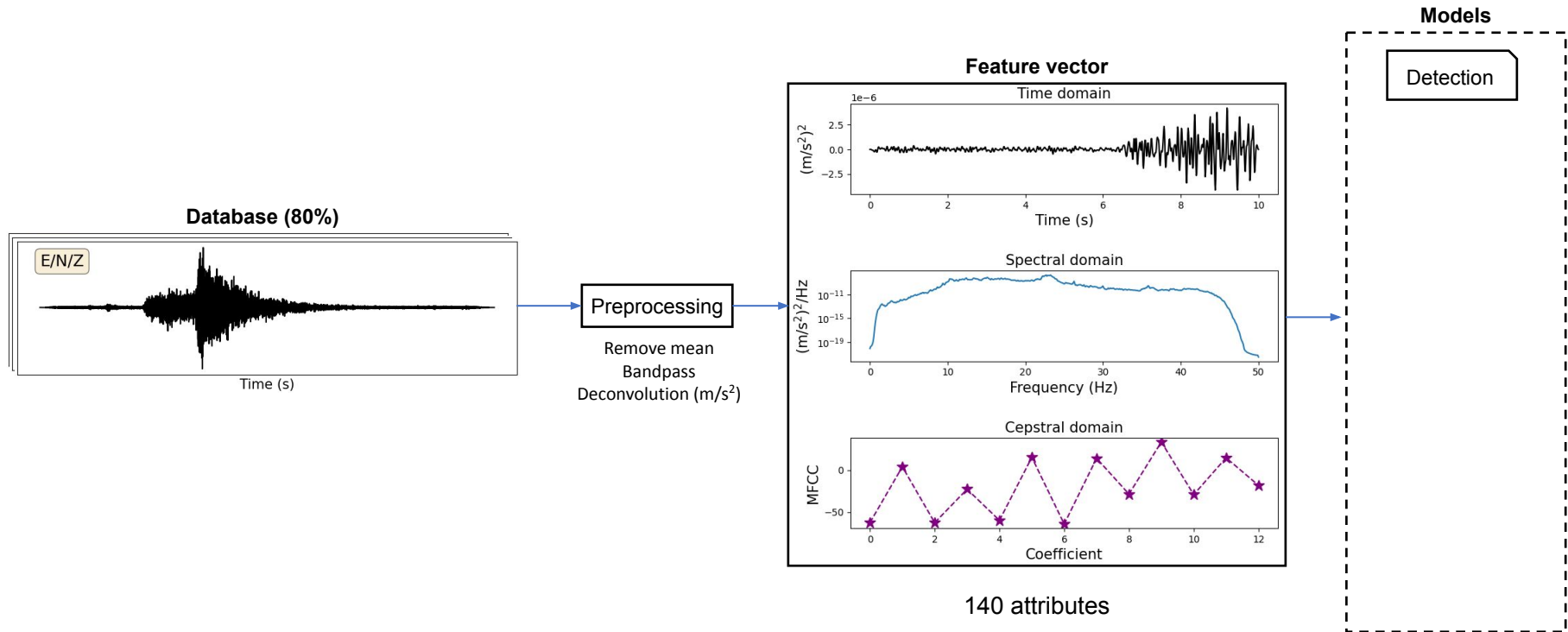
Training



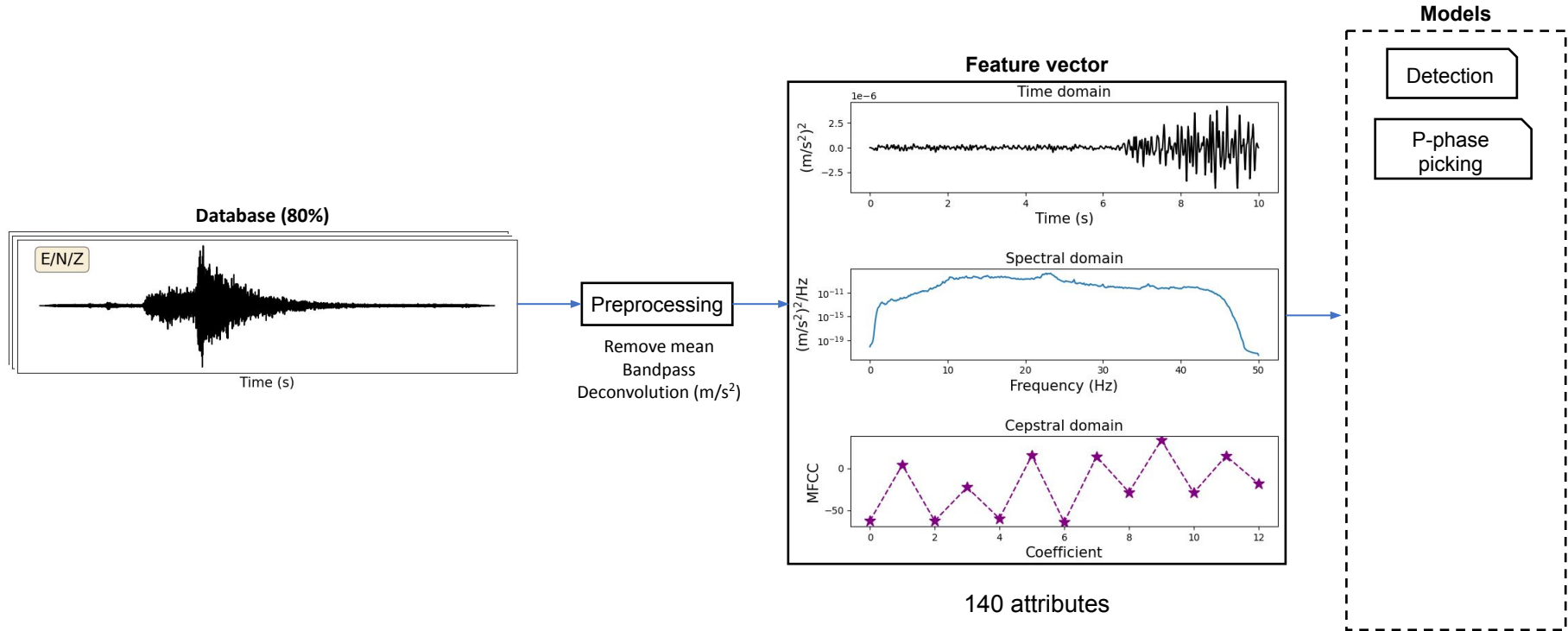
Training



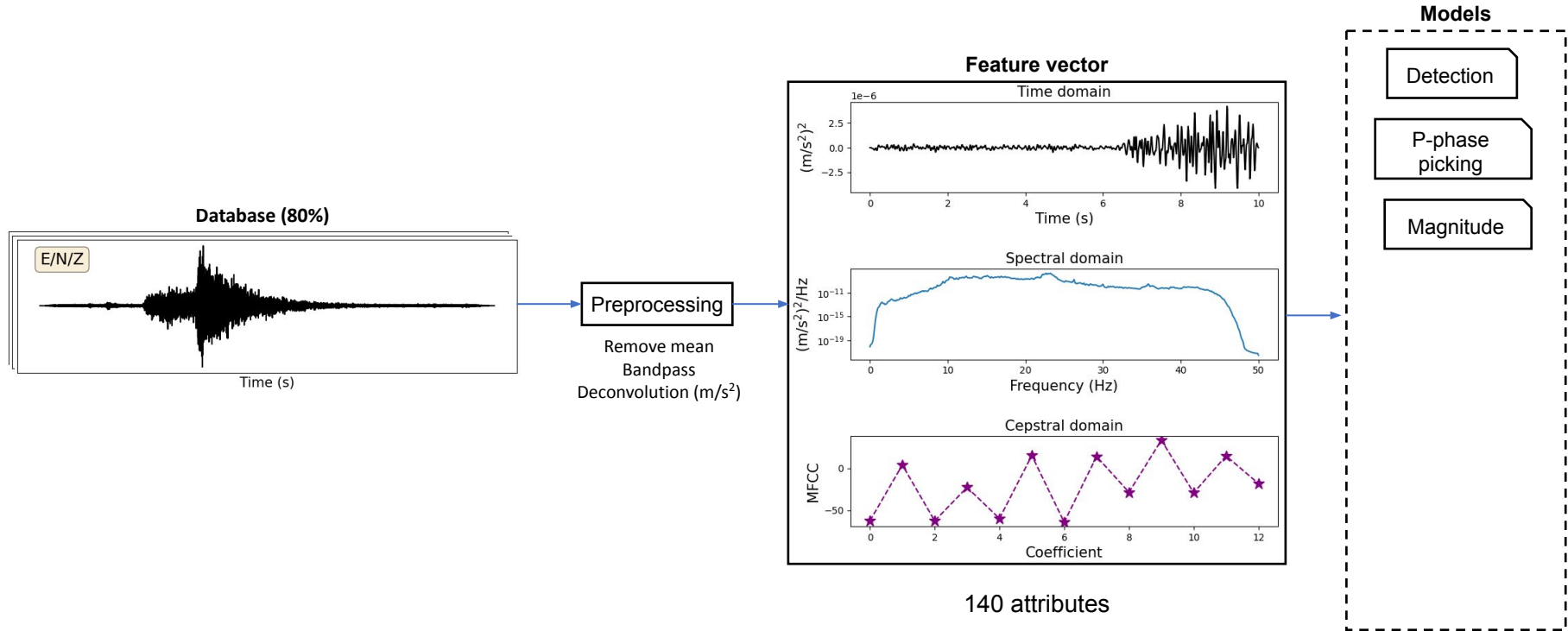
Training



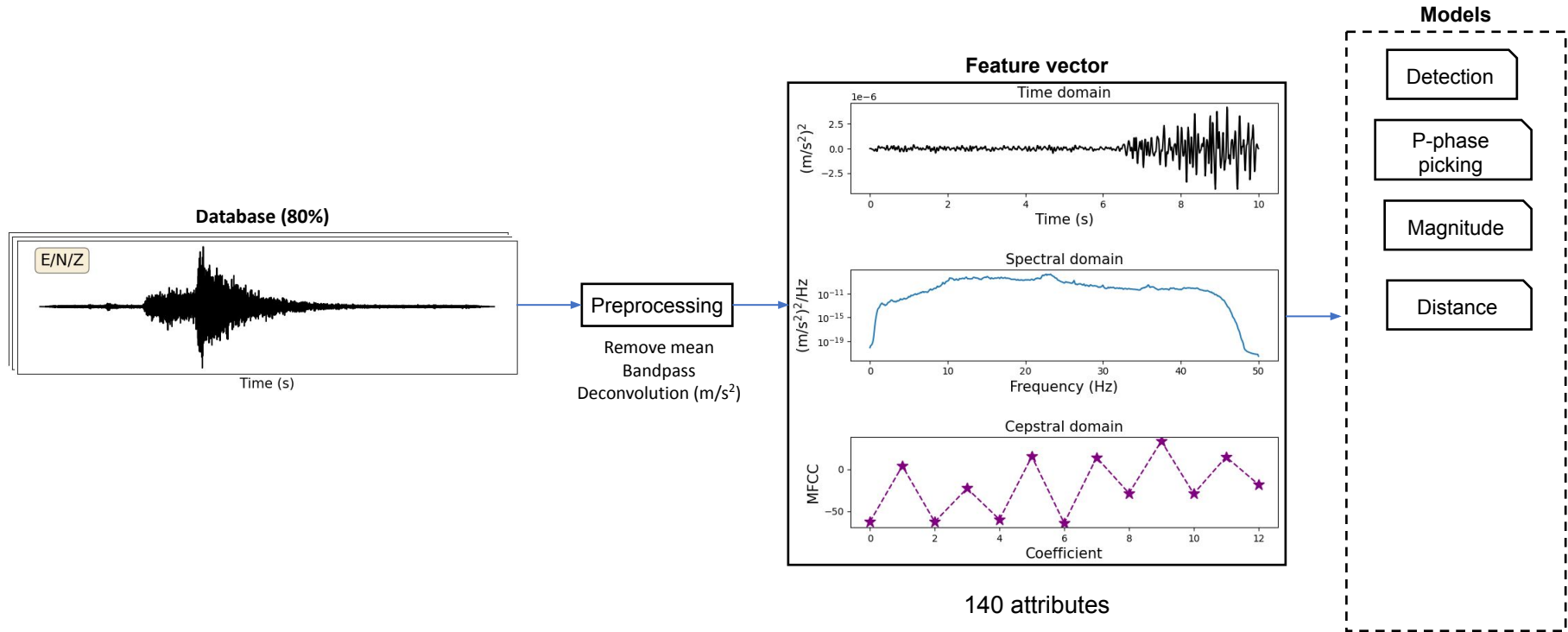
Training



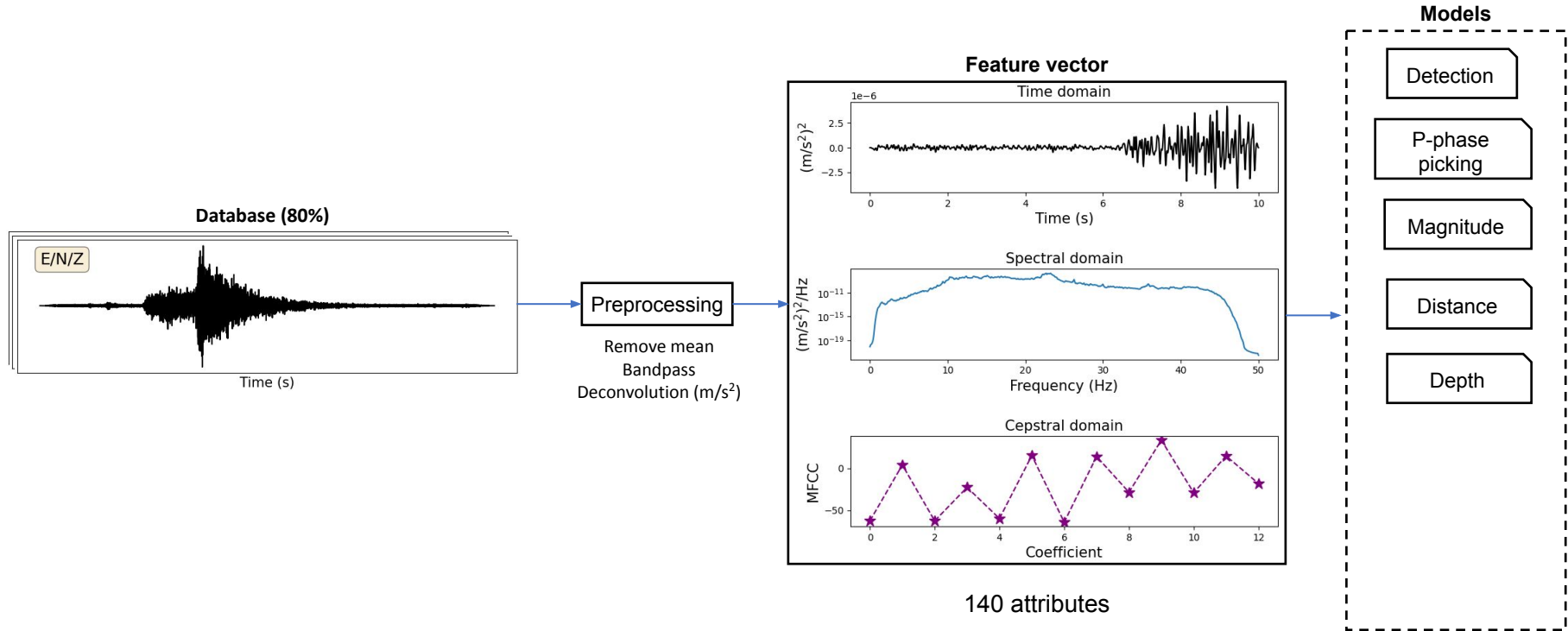
Training



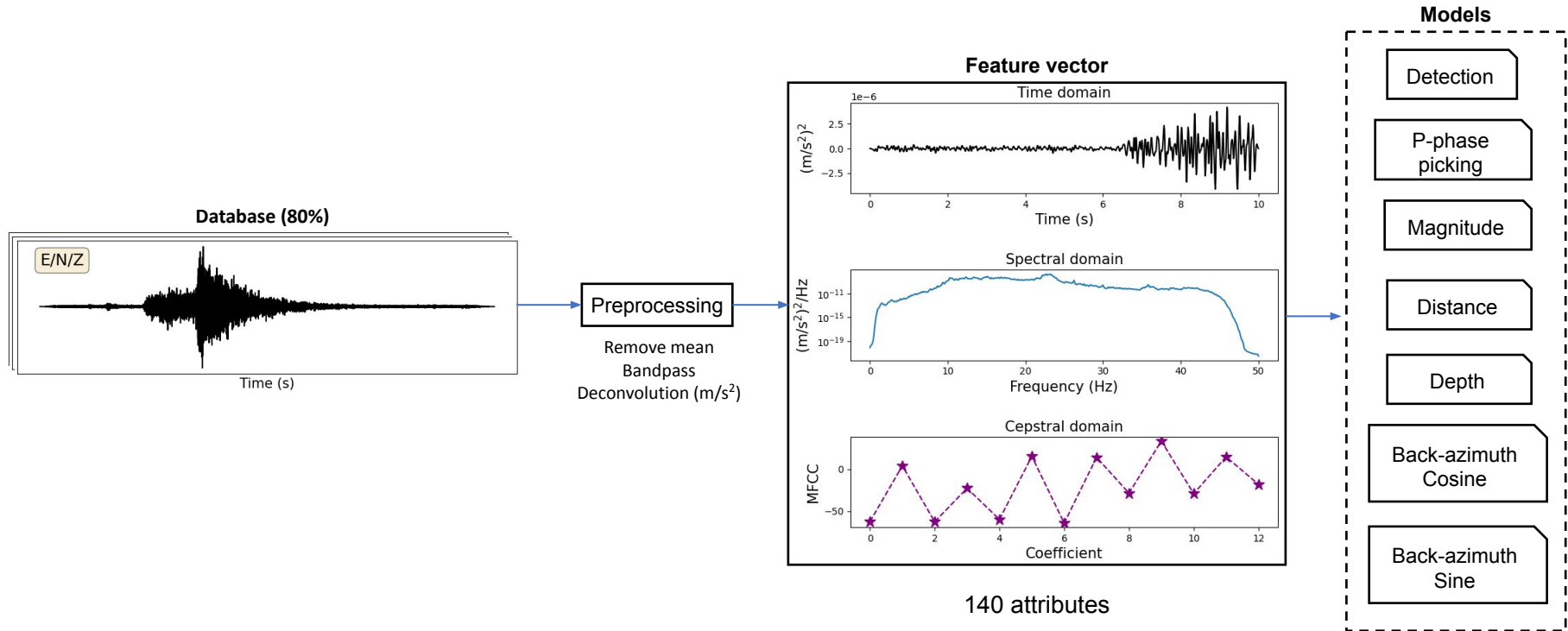
Training



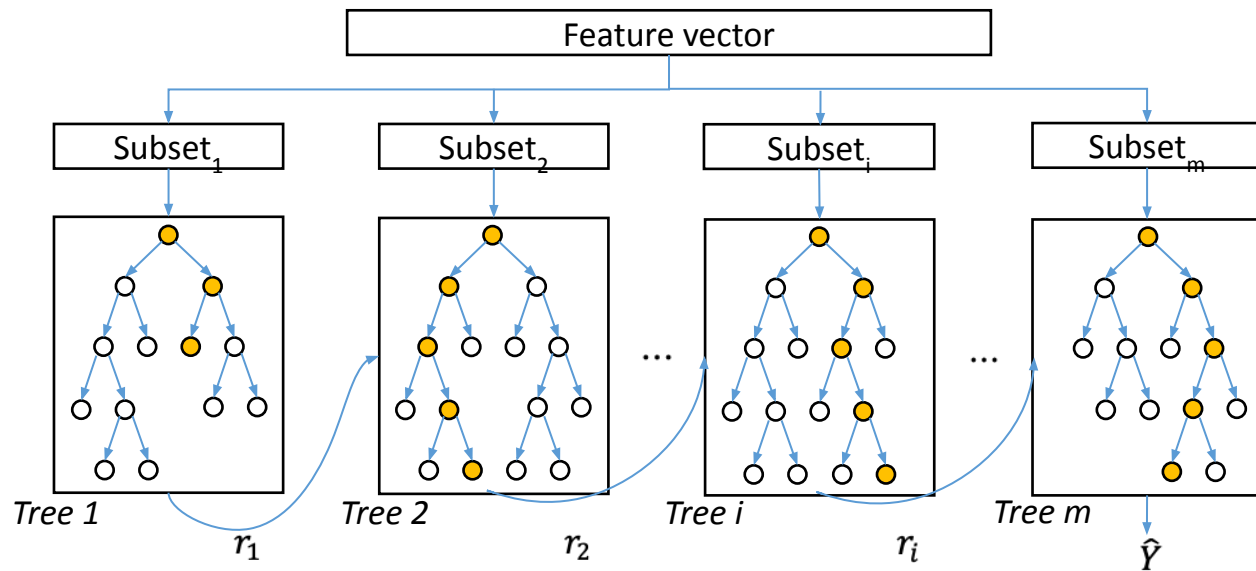
Training



Training

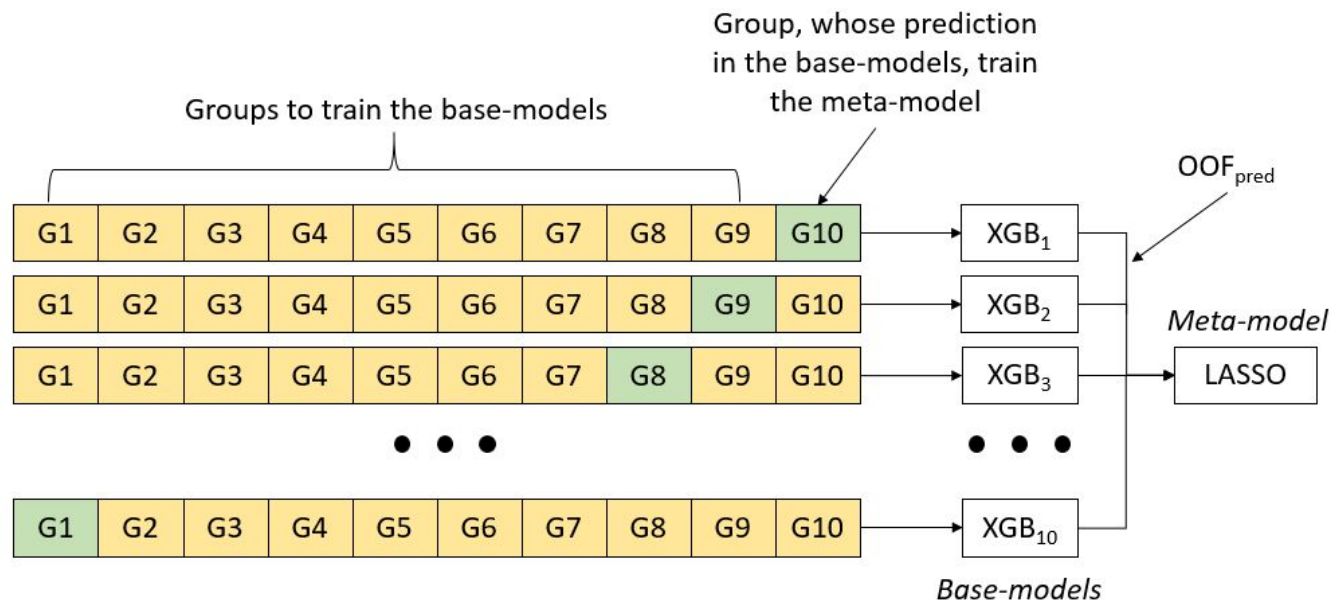


E3WS: Detection & P-phase picking model



eXtreme Gradient Boosting (XGB)

E3WS: Source characterization



LASSO: Least Absolute Shrinkage and Selection Operator

Detection results

Detector

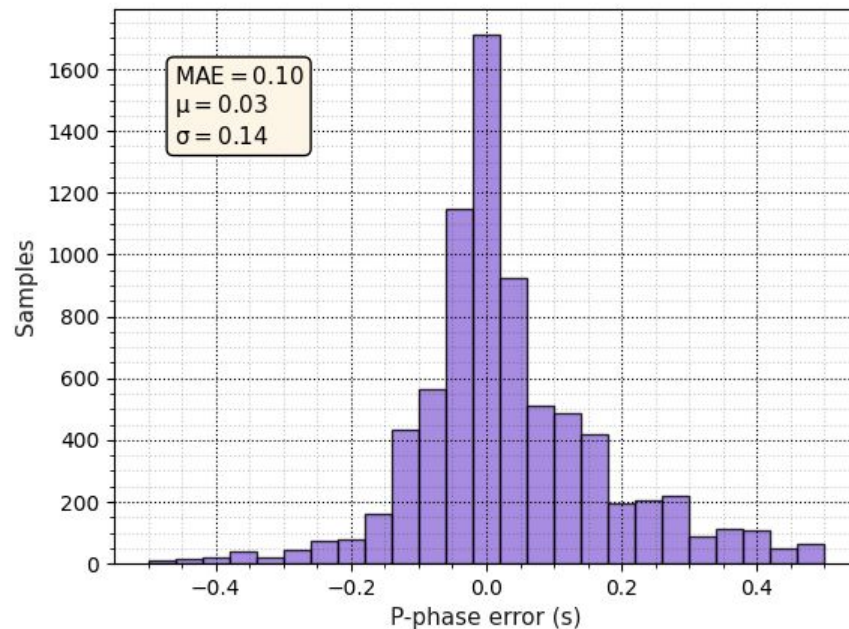
Overall (%):		True class	
		Noise	Earthquake
99.9			
Detected	Noise	11264	10
class	Earthquake	0	8778
Accuracy (%):		100.0	99.9

Detection and P-phase picking results

Detector

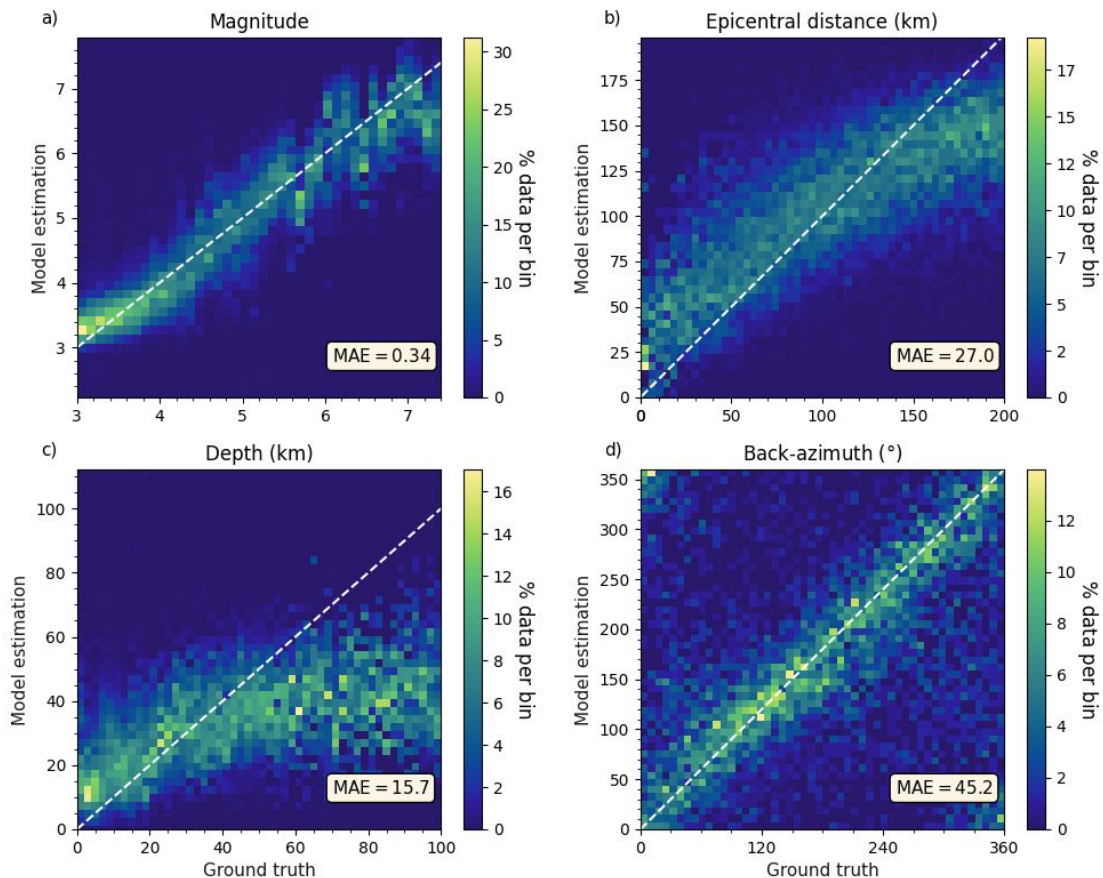
Overall (%):		True class	
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P-phase picker

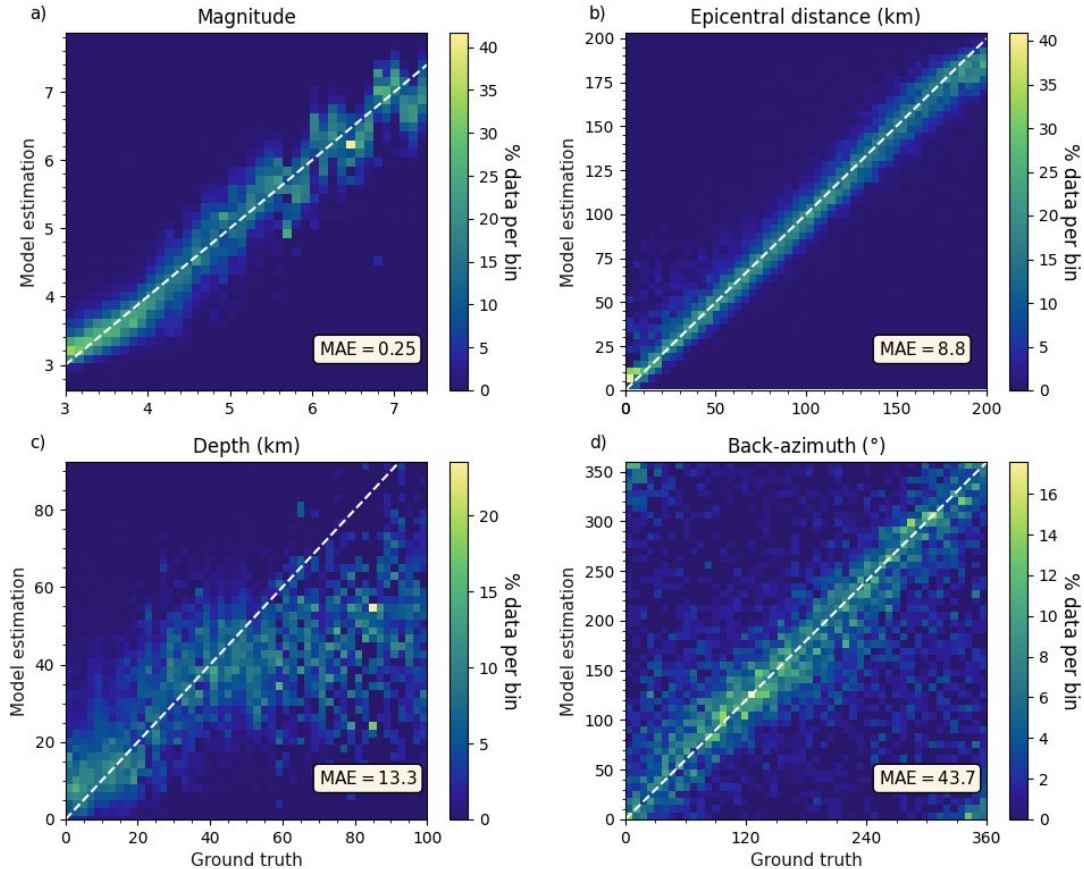


MAE: Mean Absolute Error

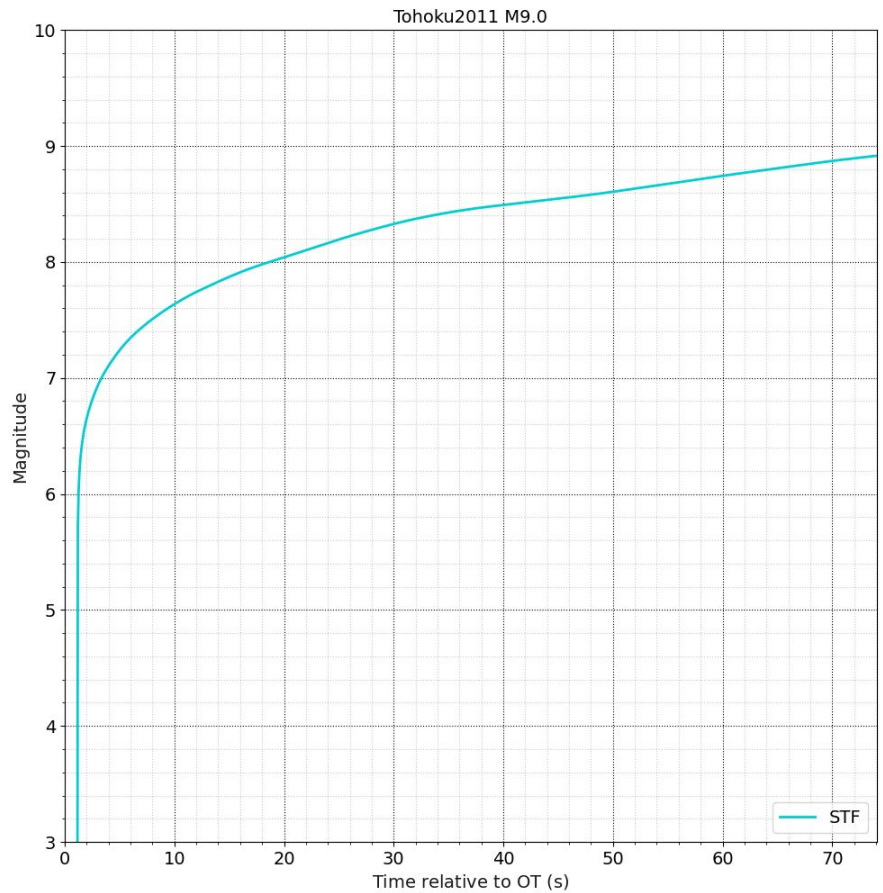
Source characterization results. Single station. P-wave: 3 s



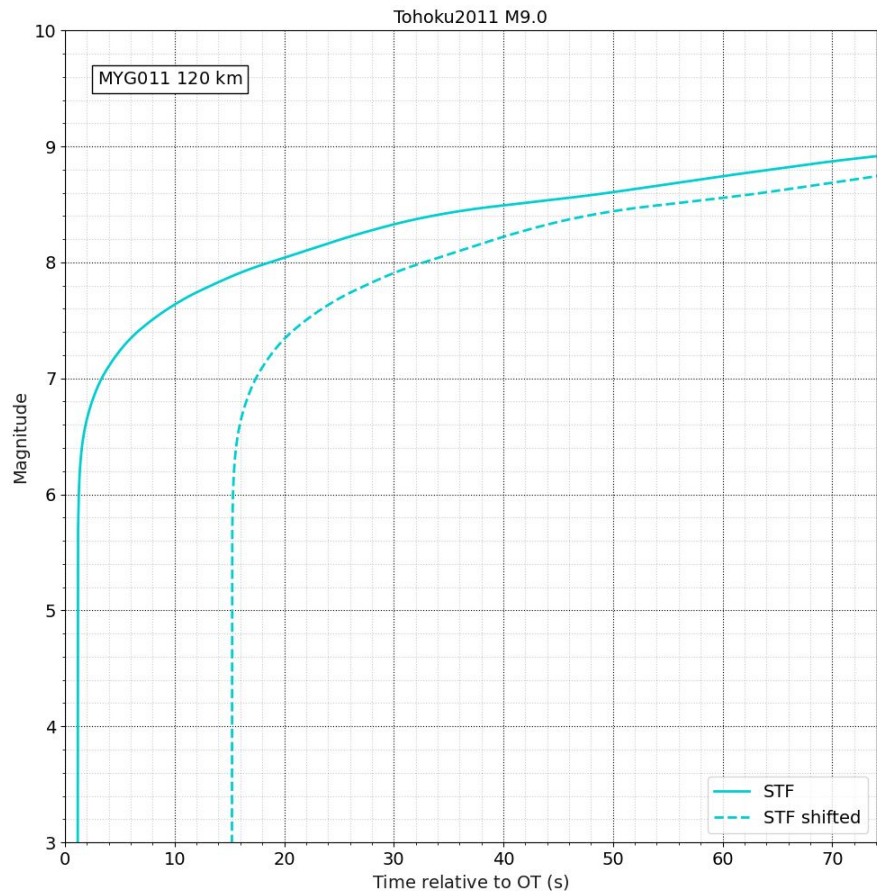
Source characterization results. Single station. P-wave: 46 s



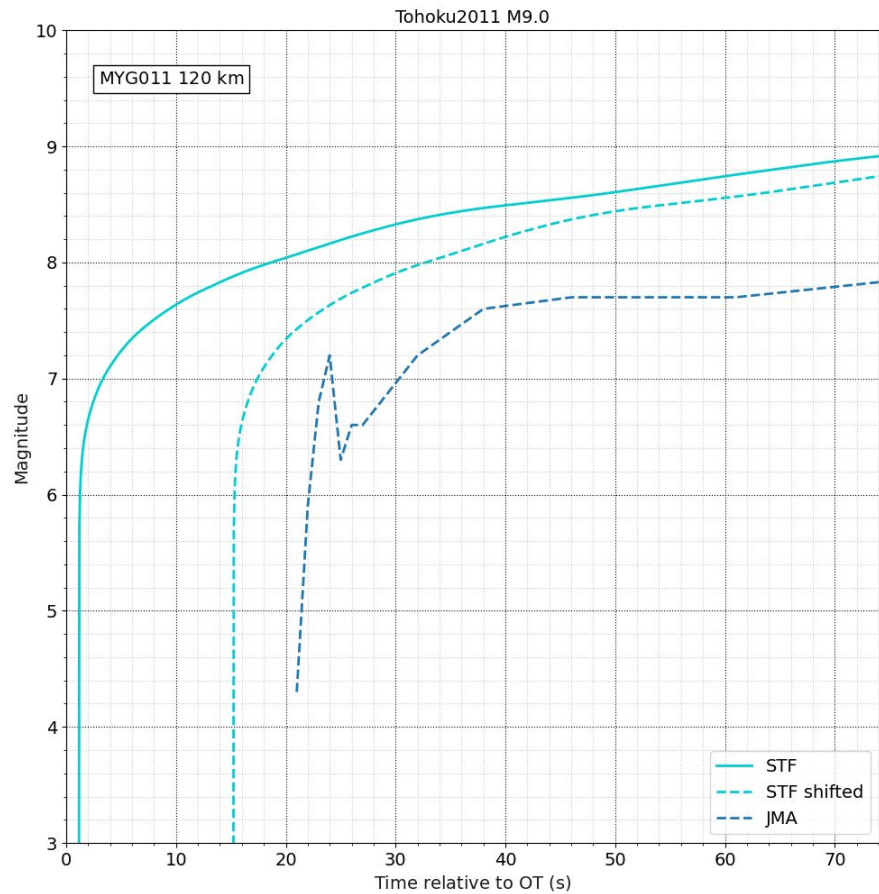
Simulated real-time scenario



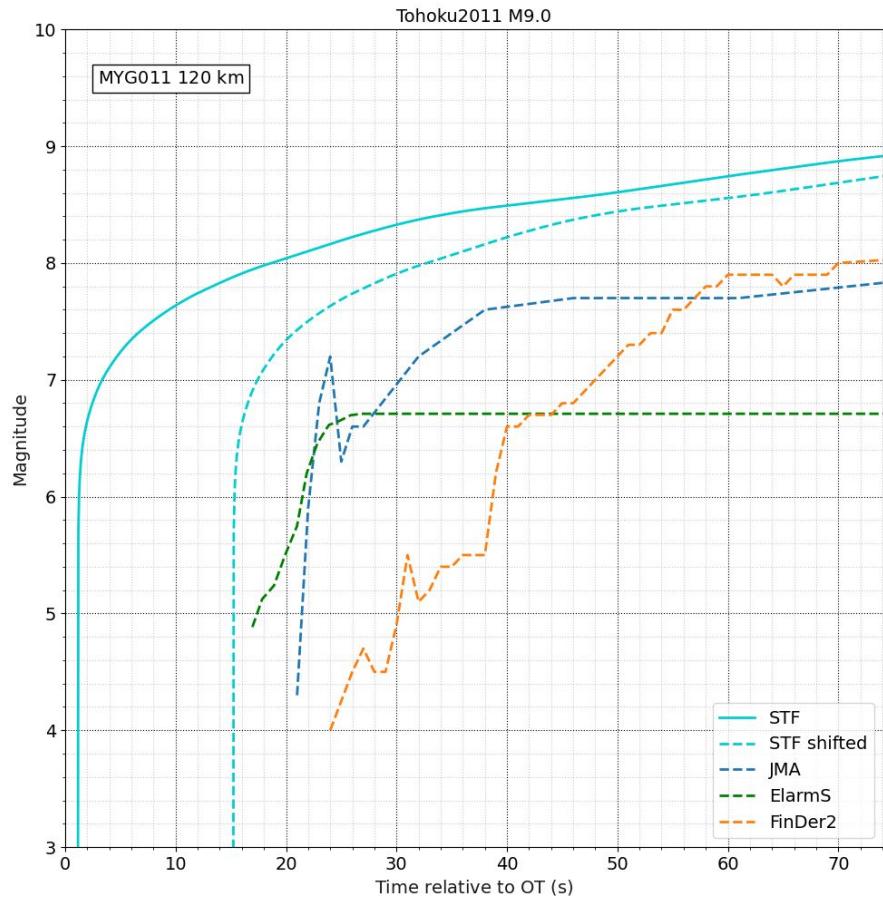
Simulated real-time scenario



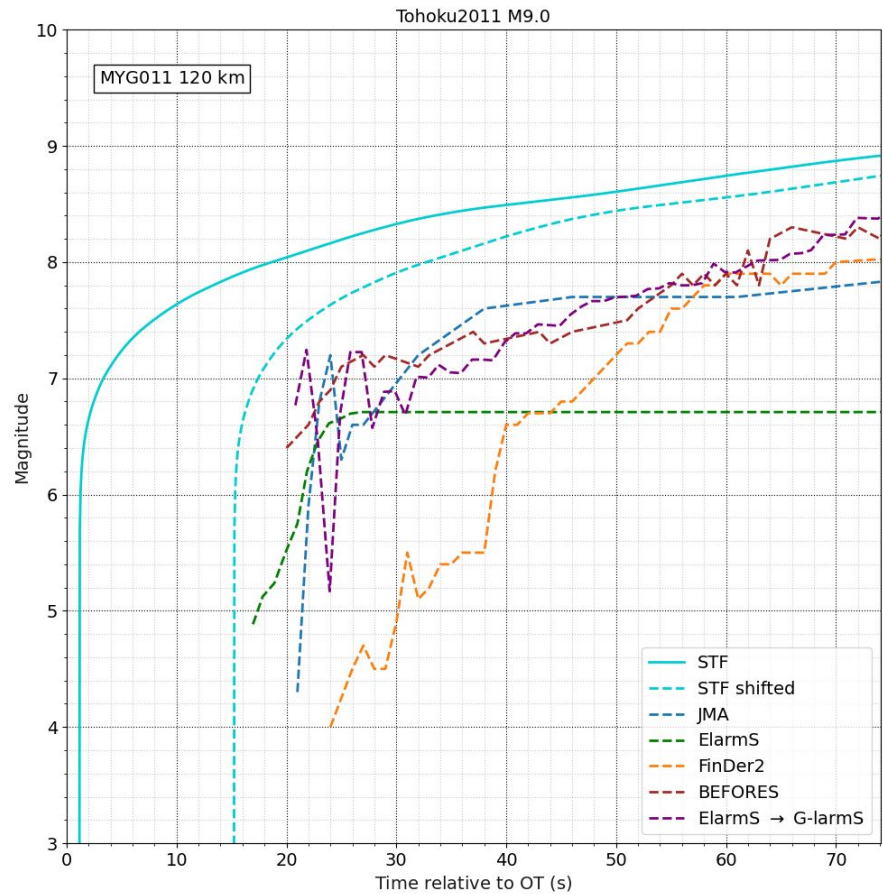
Simulated real-time scenario



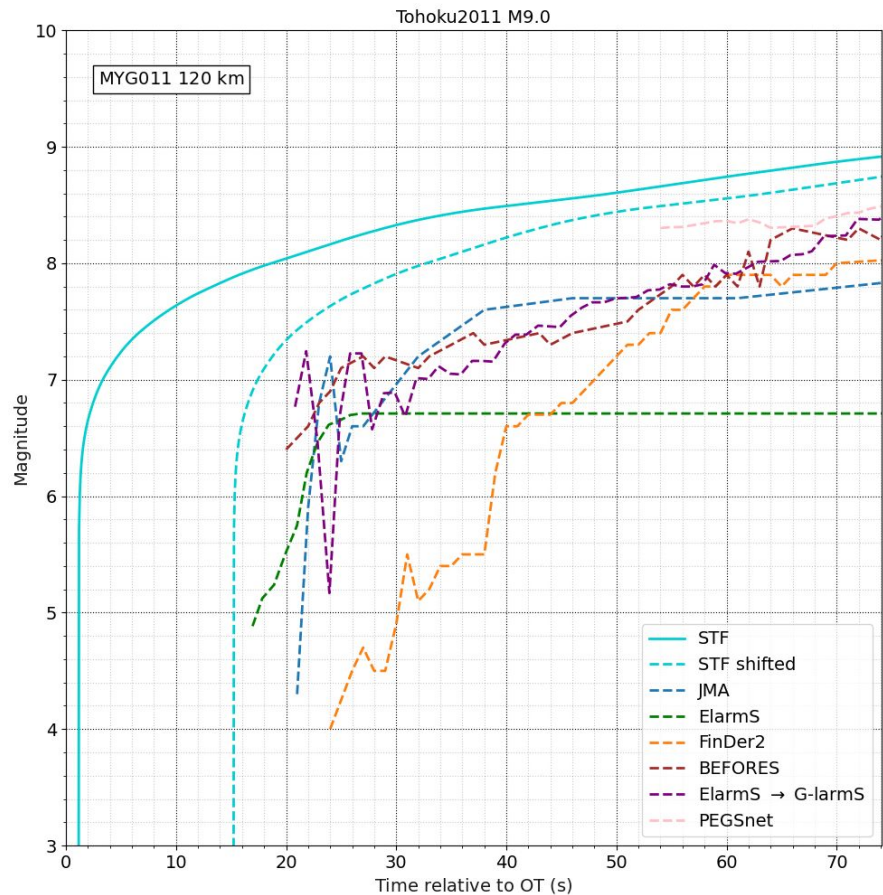
Simulated real-time scenario



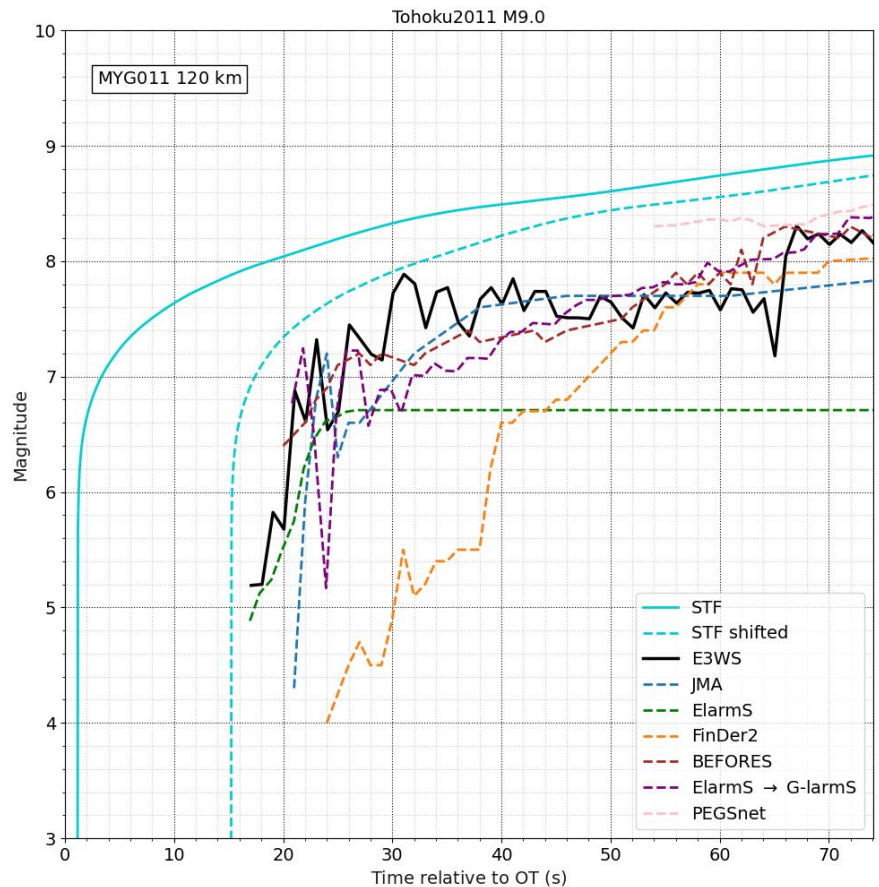
Simulated real-time scenario



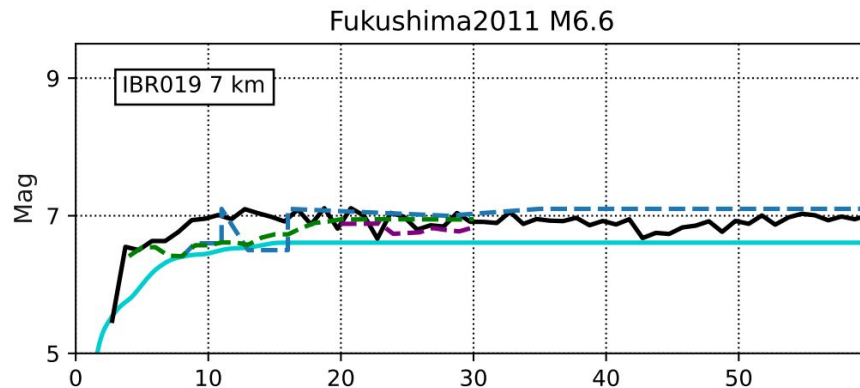
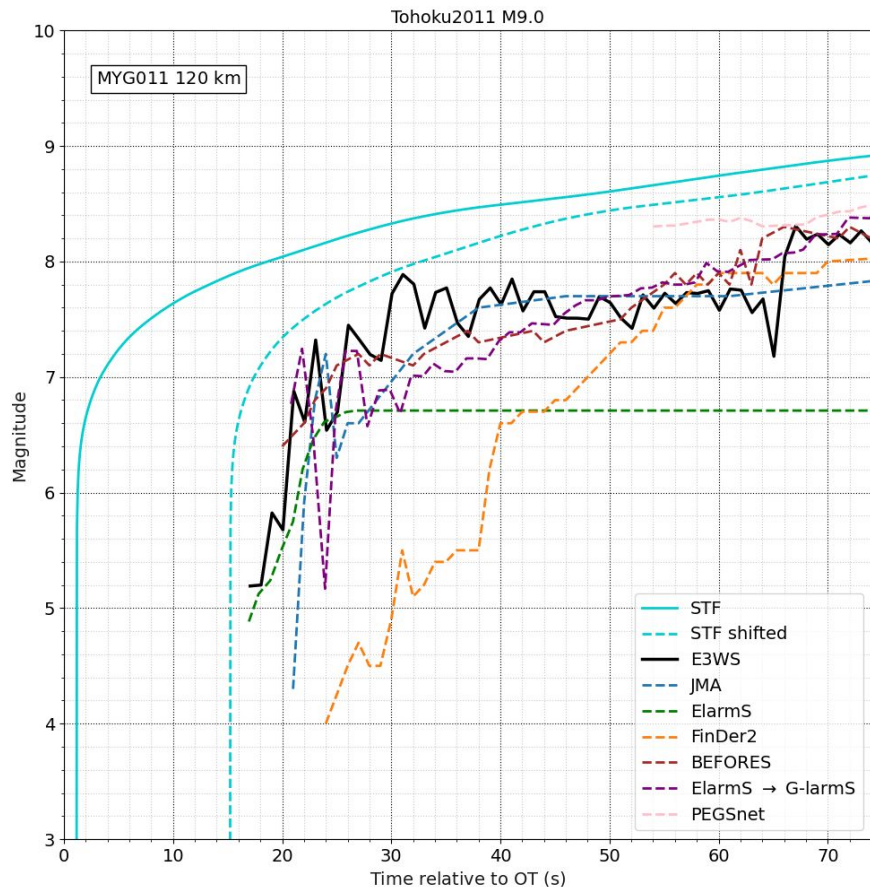
Simulated real-time scenario



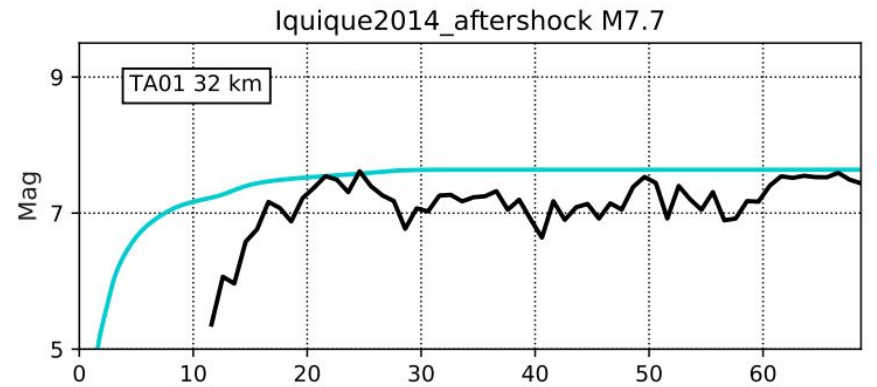
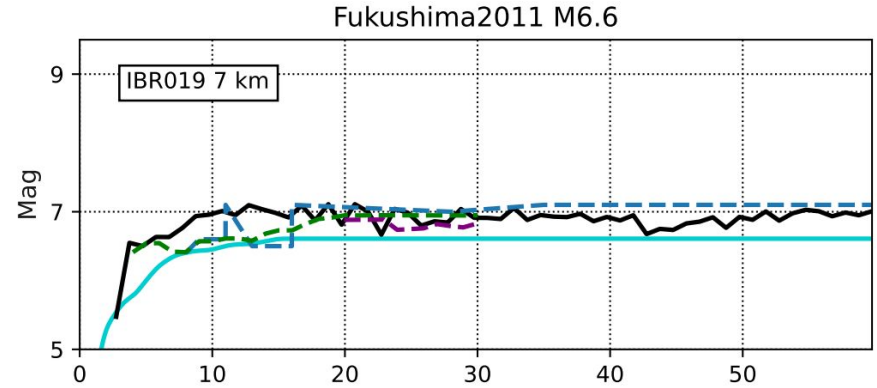
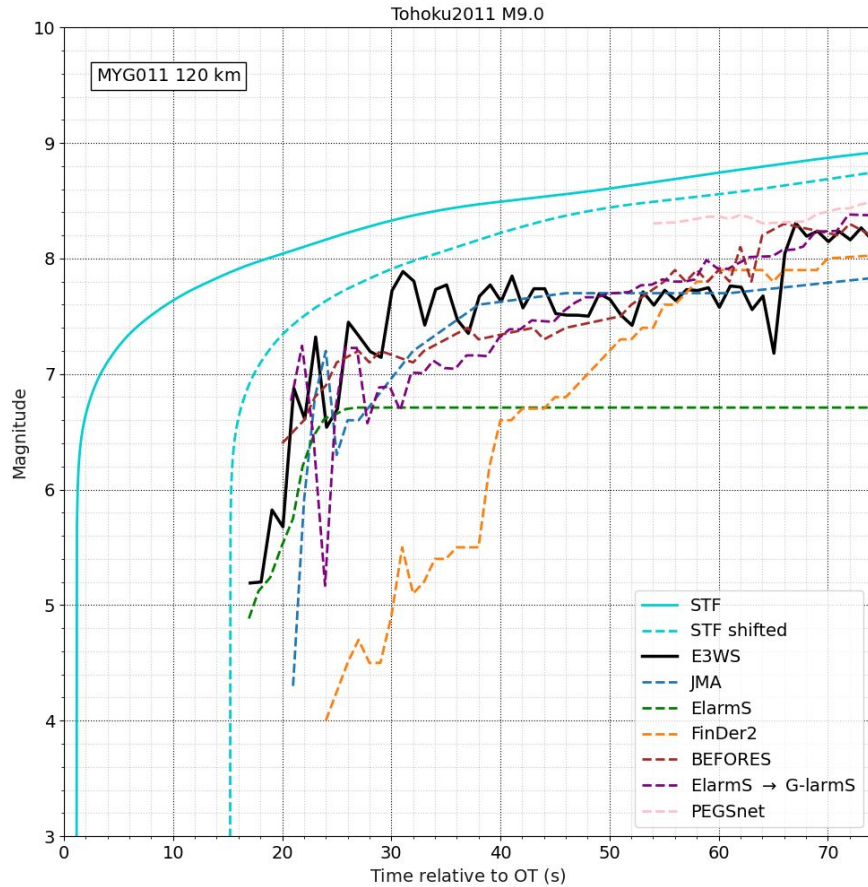
Simulated real-time scenario



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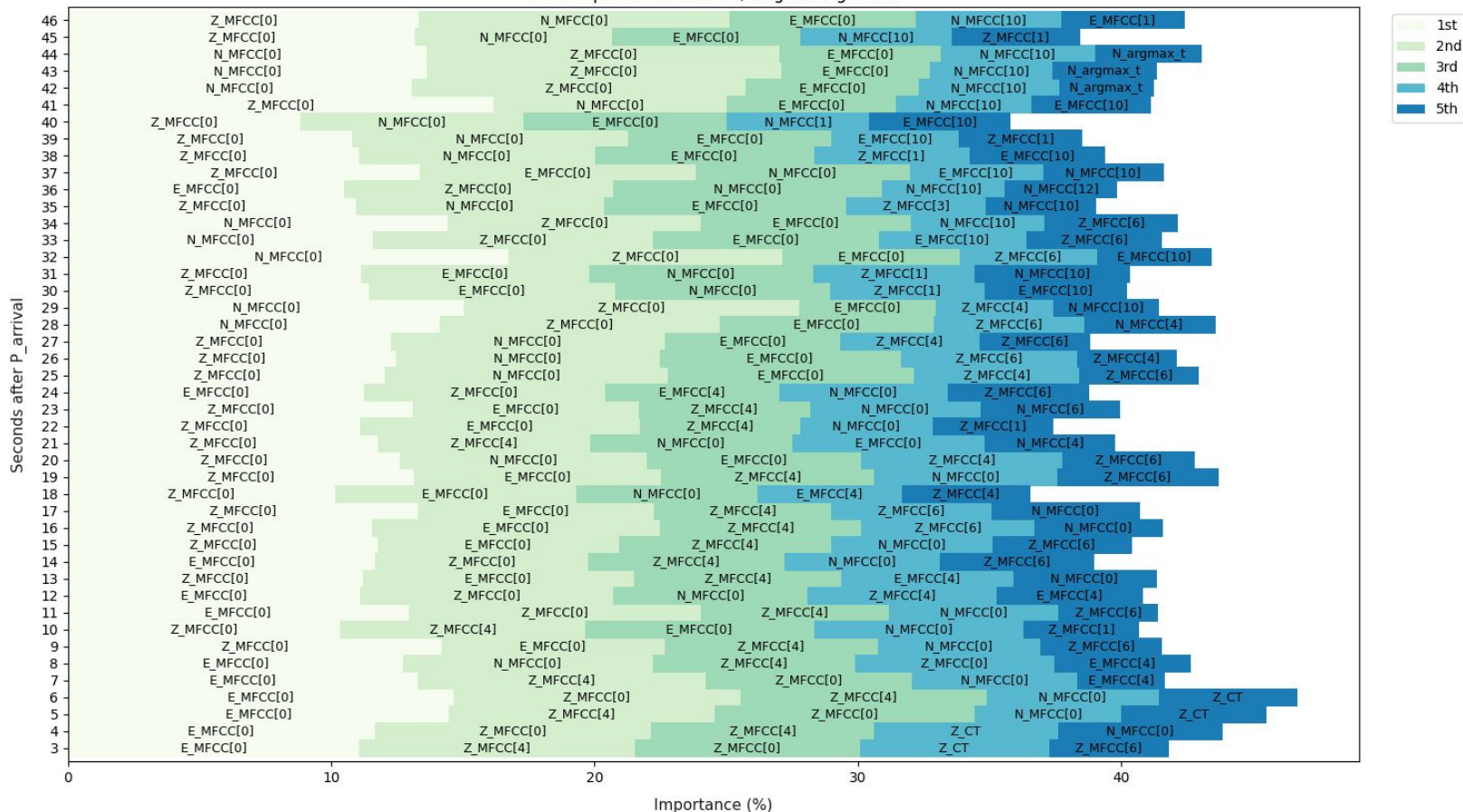


Simulated real-time scenario



Feature Importance

Most important attributes, target: Magnitude



PART 2

THE PERUVIAN EARTHQUAKE EARLY WARNING SYSTEM (SASPE)



Estación 1

Estación 2

E1

E2

SASPE

RESEARCH ARTICLE | DECEMBER 20, 2024

Implementation of the Peruvian Earthquake Early Warning System

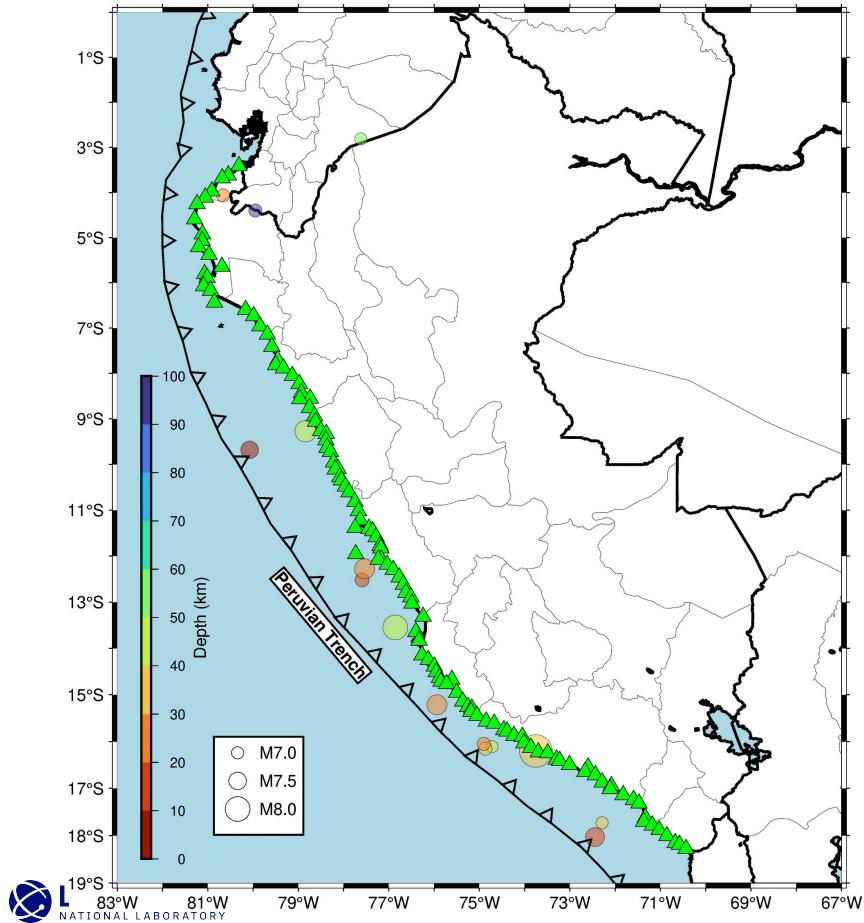
Pablo Lara ; Hernando Tavera; Quentin Bletery; Jean-Paul Ampuero; Adolfo Inza; David Portugal; Benazir Orihuela; Fernando Meza

+ Author and Article Information

Bulletin of the Seismological Society of America (2025) 115 (1): 191–209.

<https://doi.org/10.1785/0120240119> | [Article history](#) 

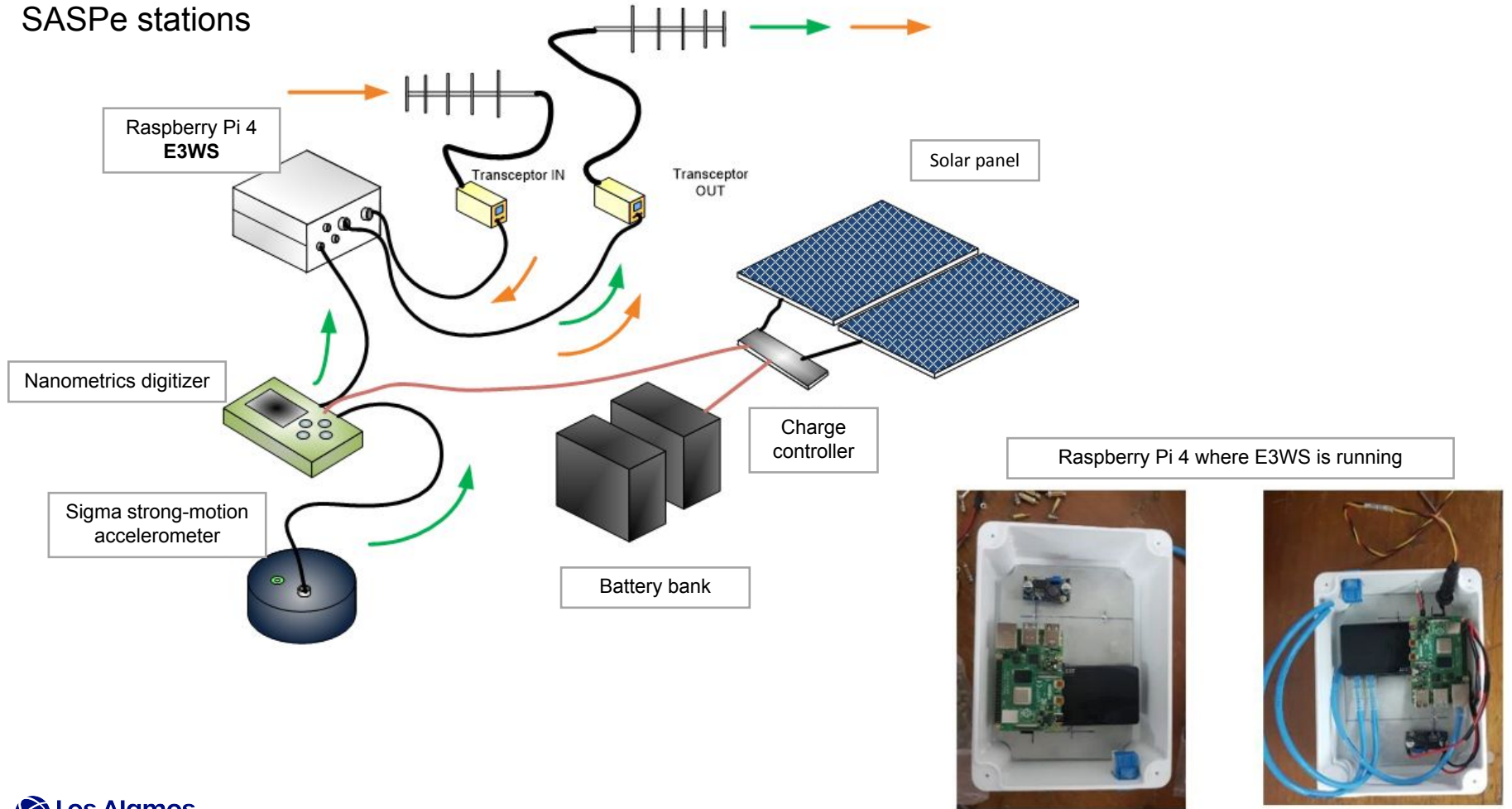
SASPe stations



San Lorenzo station

*SASPe: Sistema de Alerta Sismico Peruano
(Peruvian EEWS)*

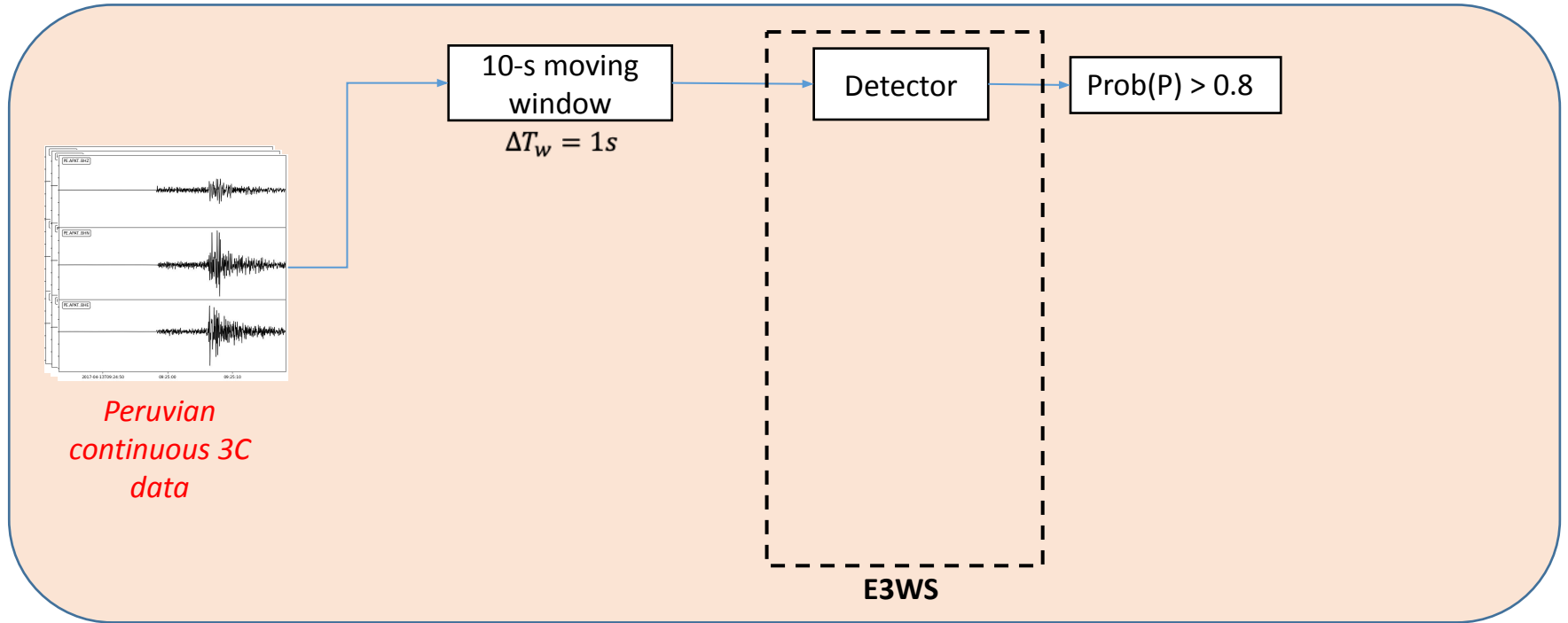
SASPe stations



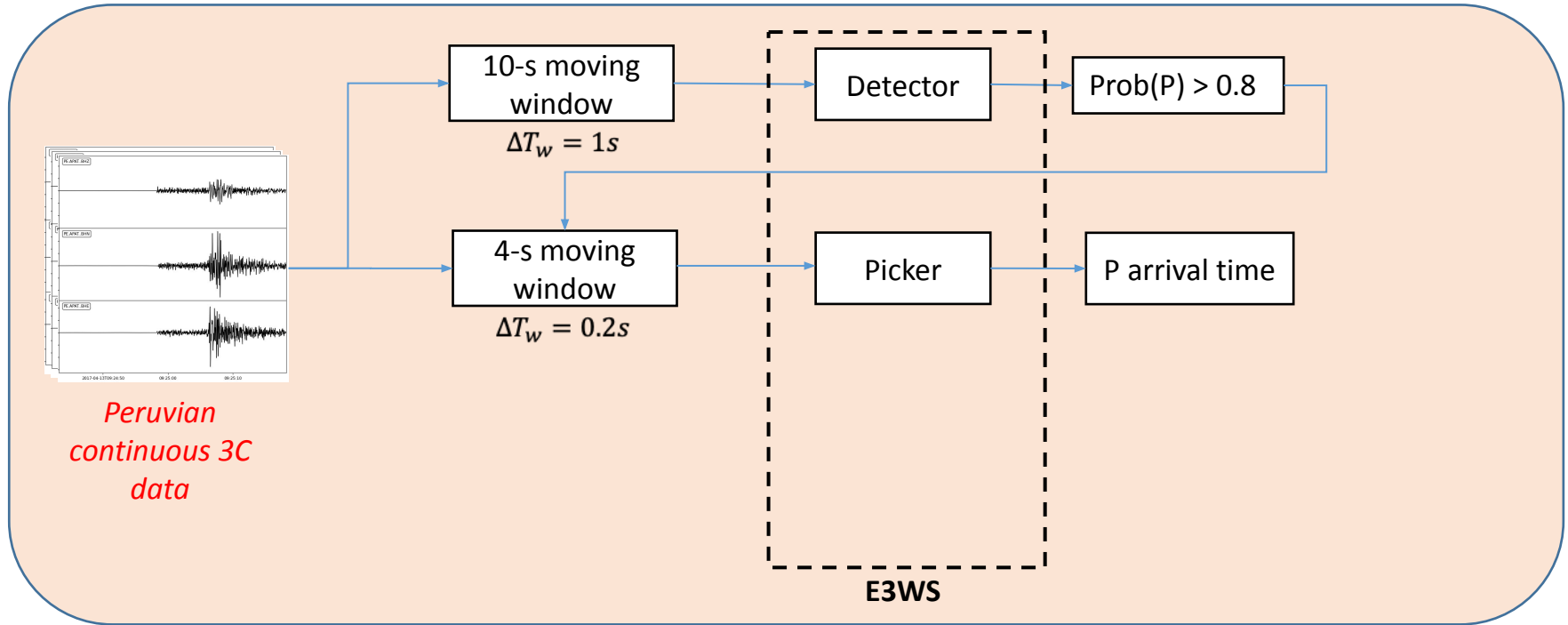
Raspberry Pi 4 where E3WS is running



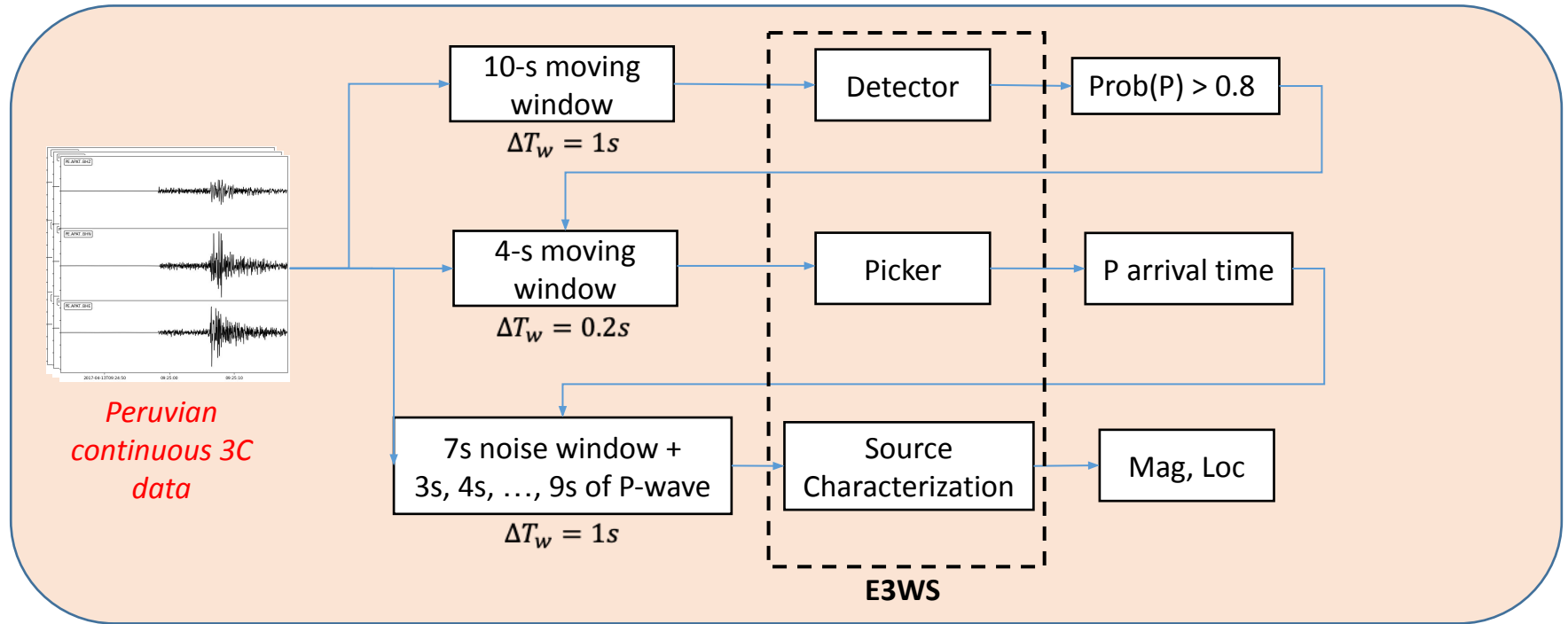
How SASPe work?



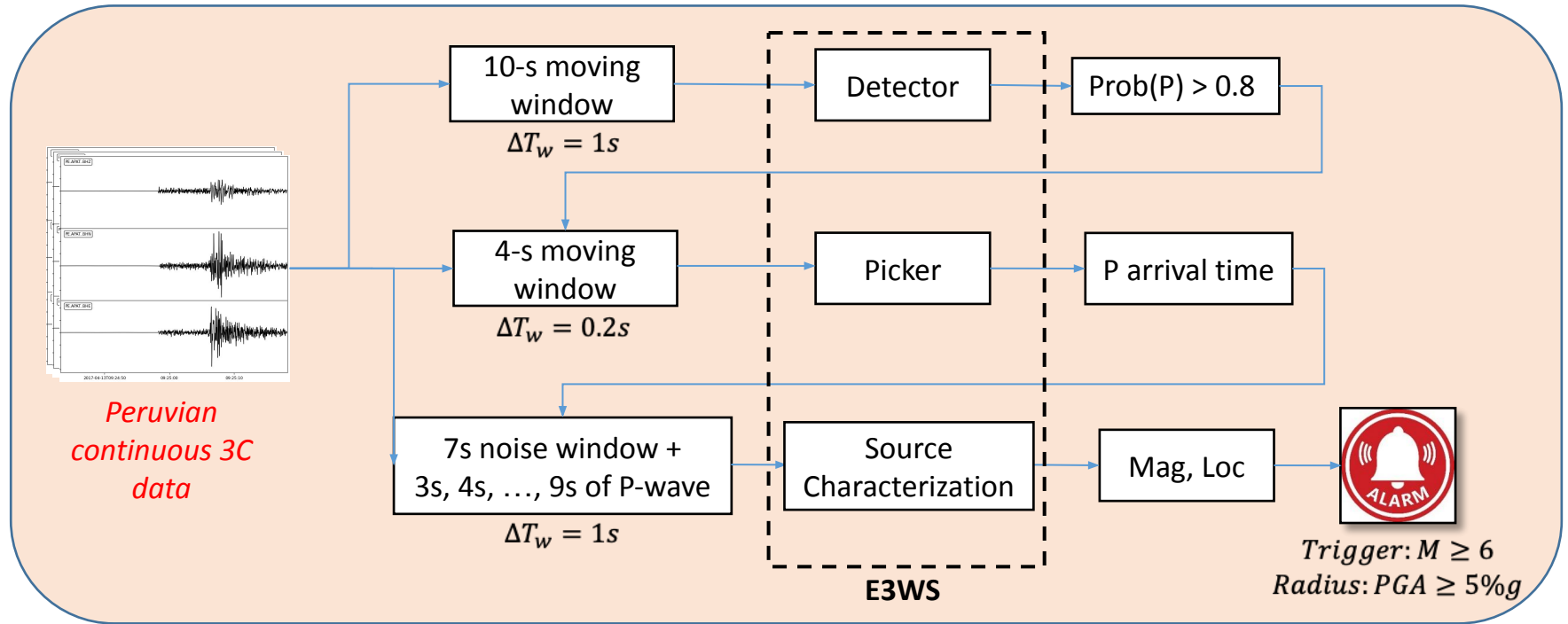
How SASPe work?



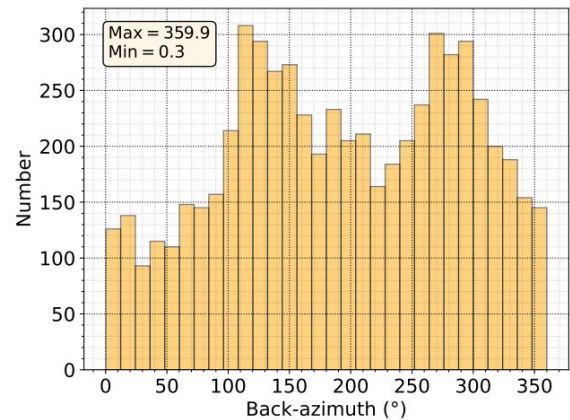
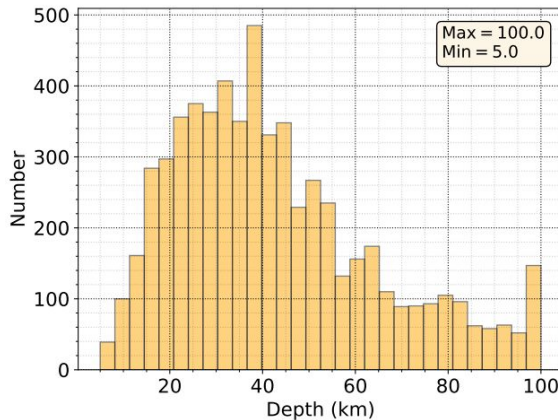
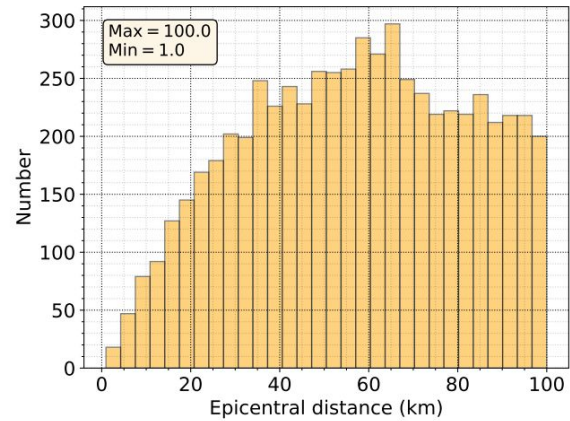
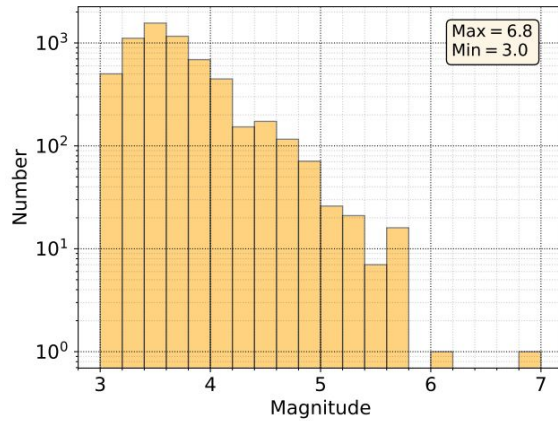
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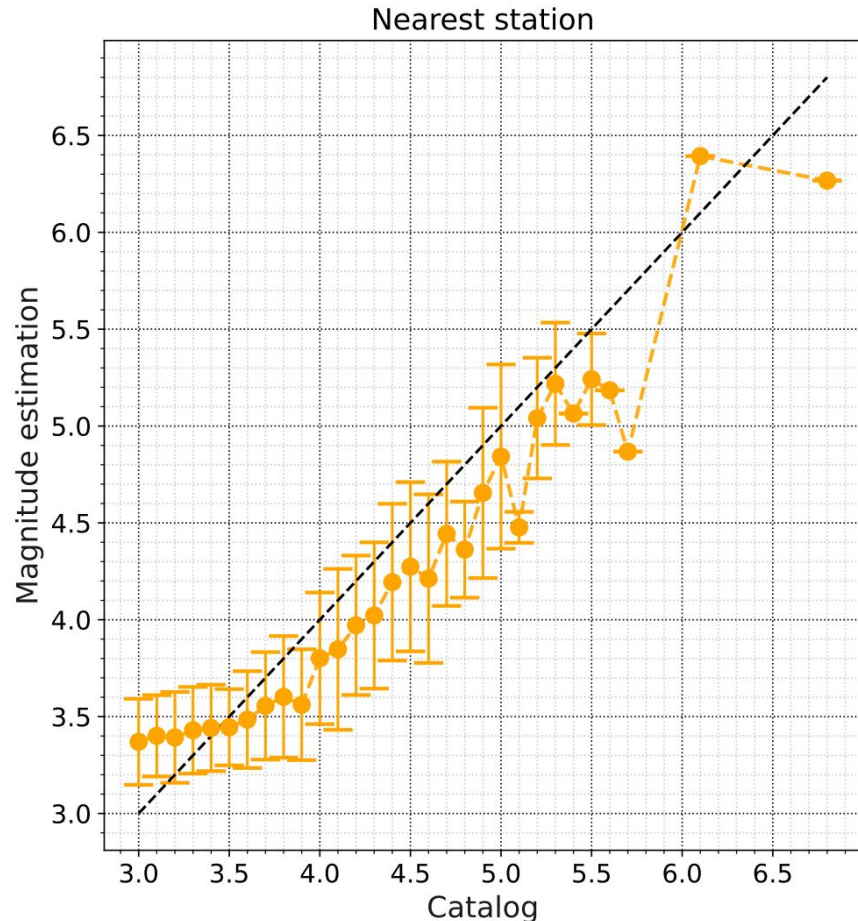
SASPe database, more than 2 years of continuous monitoring



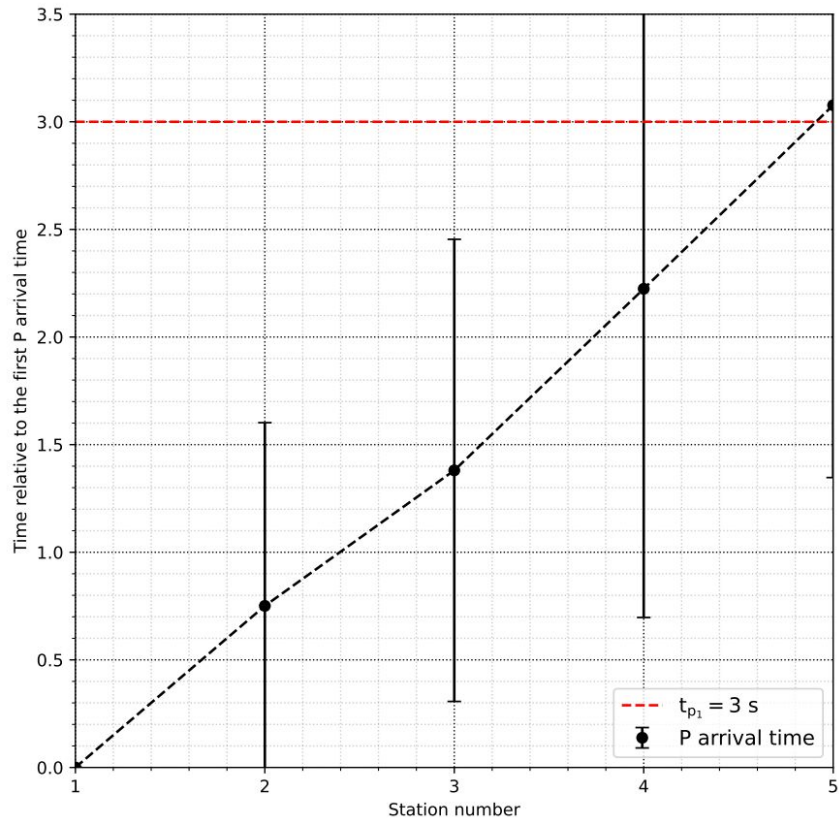
Detection and magnitude results

- There were no false positives or false negatives in the alarm issuance.
- All $M \geq 6$ earthquakes were estimated as $M \geq 6$.
- All $M < 6$ earthquakes were estimated as $M < 6$.

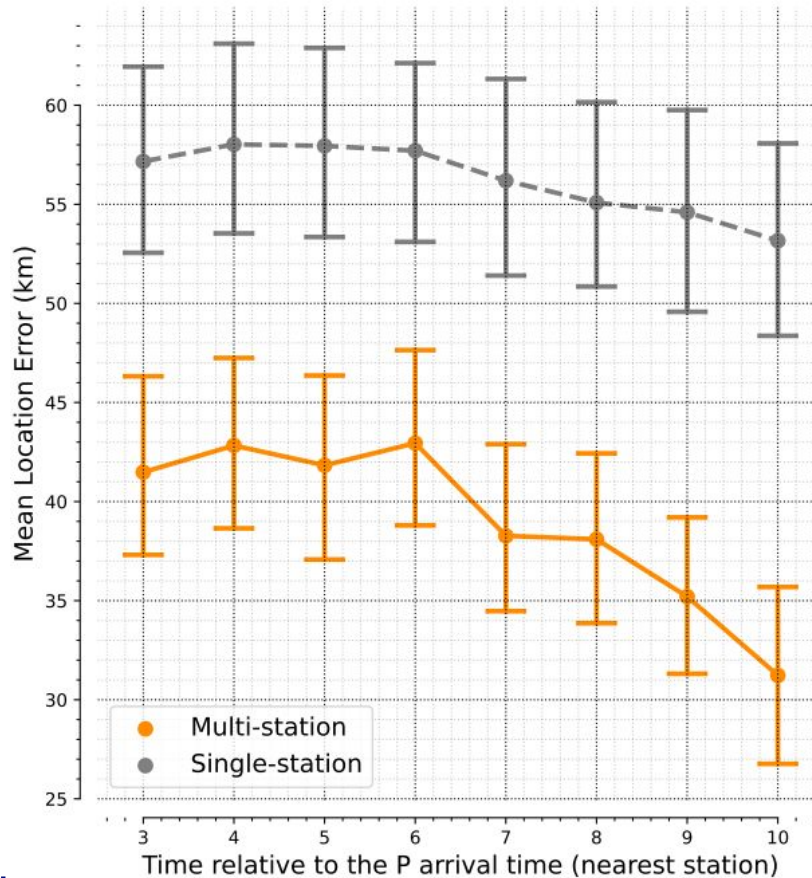
False positives: Noise classified as earthquakes with $M \geq 6$.
False negatives: Earthquakes with $M \geq 6$ classified as noise.



Stations that detect the P-wave when the first station has 3 seconds of the earthquake

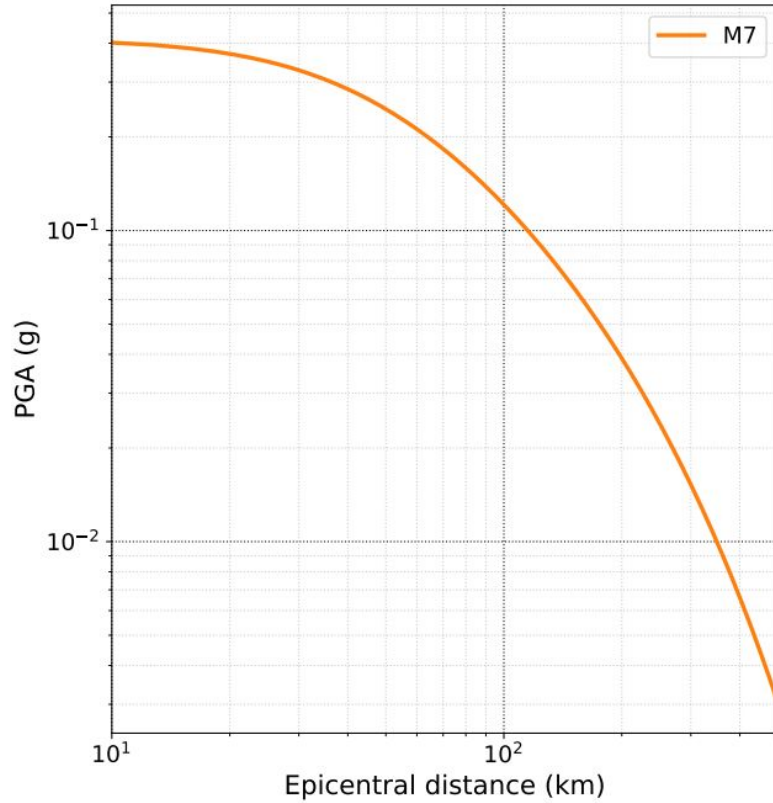


Location improvement

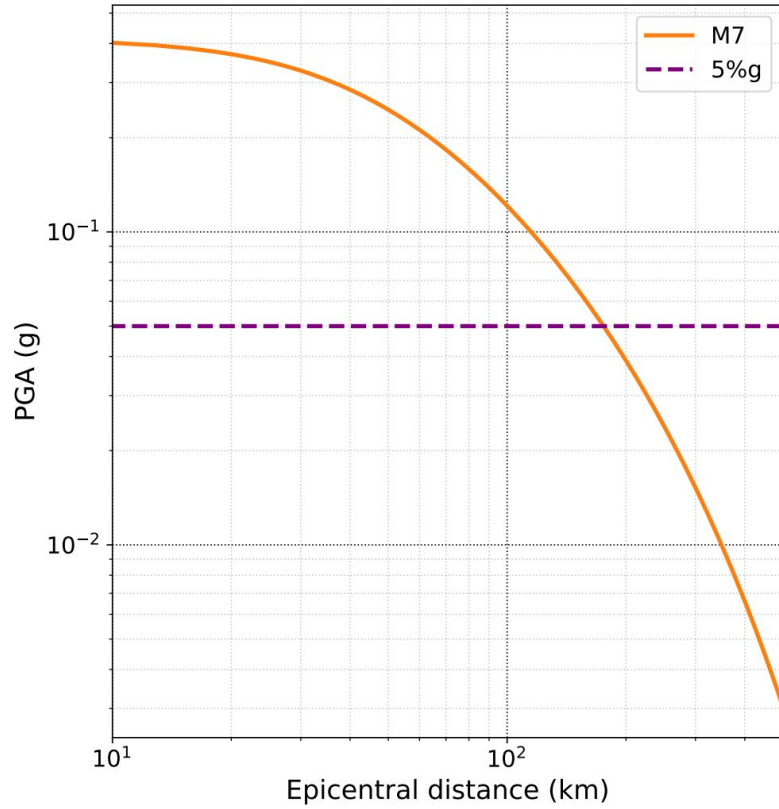


Location improvement
without losing time!

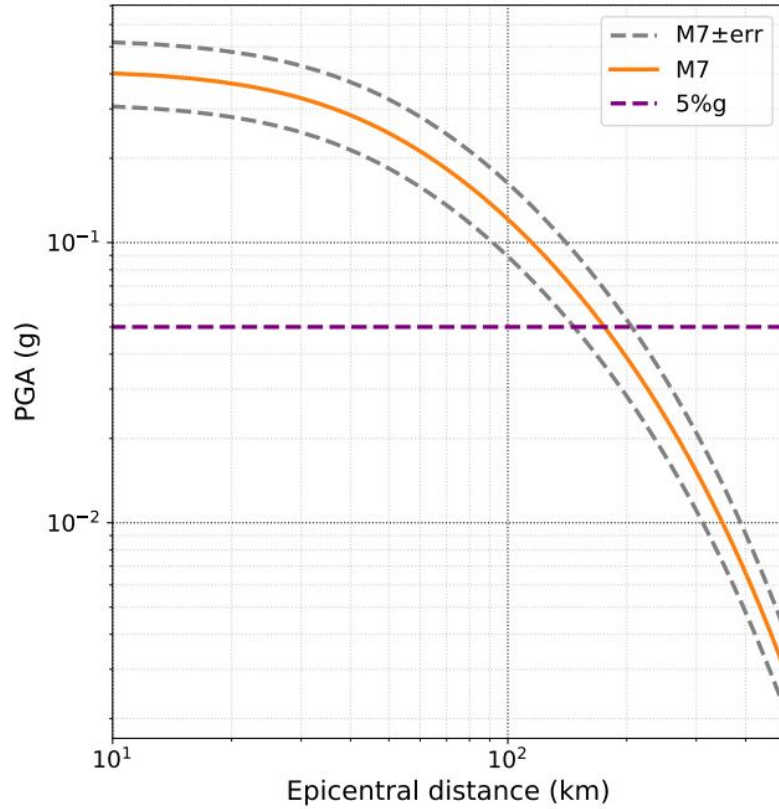
Alert radius



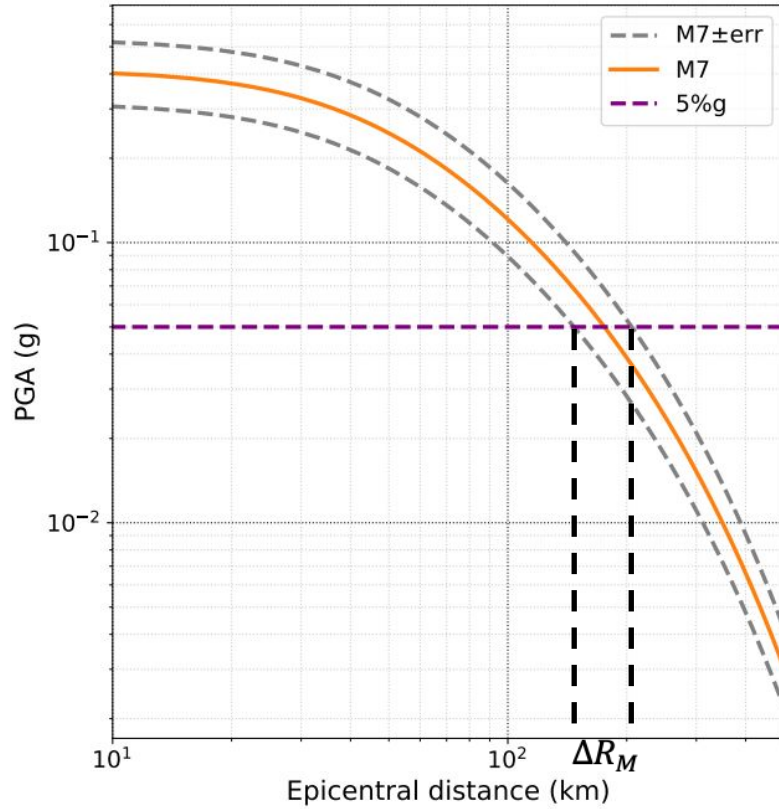
Alert radius



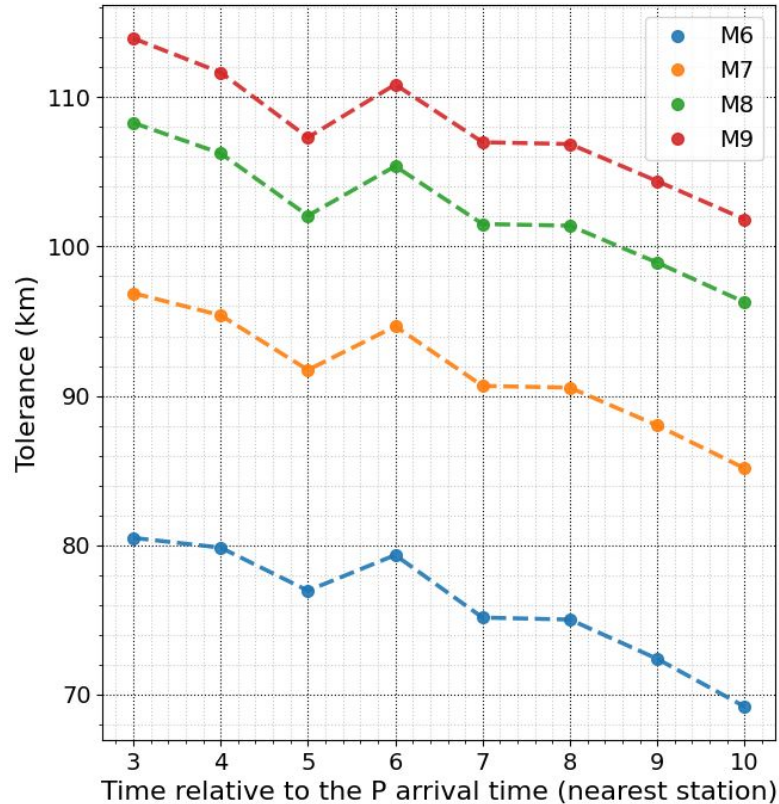
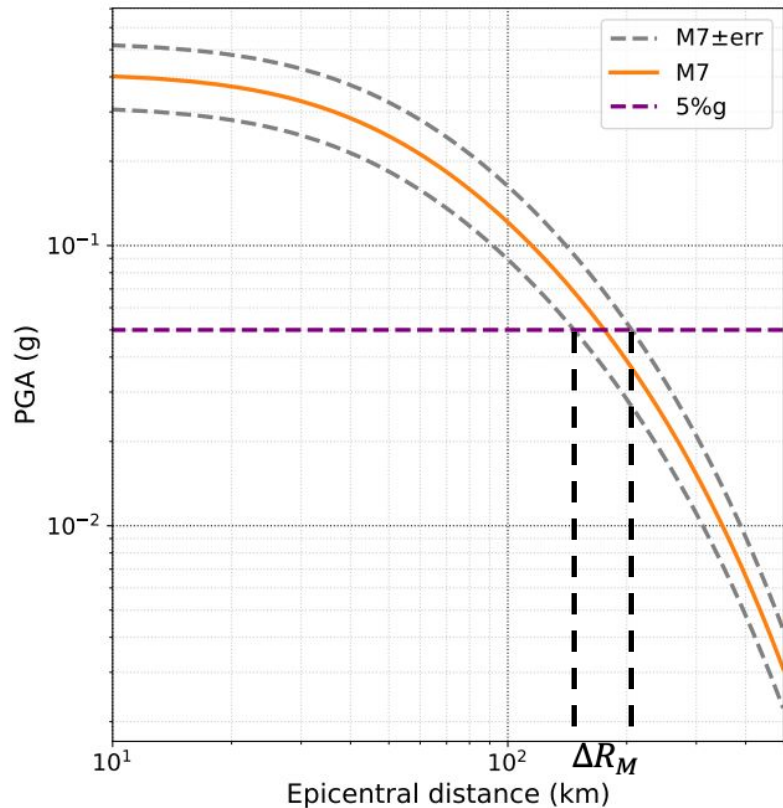
Alert radius



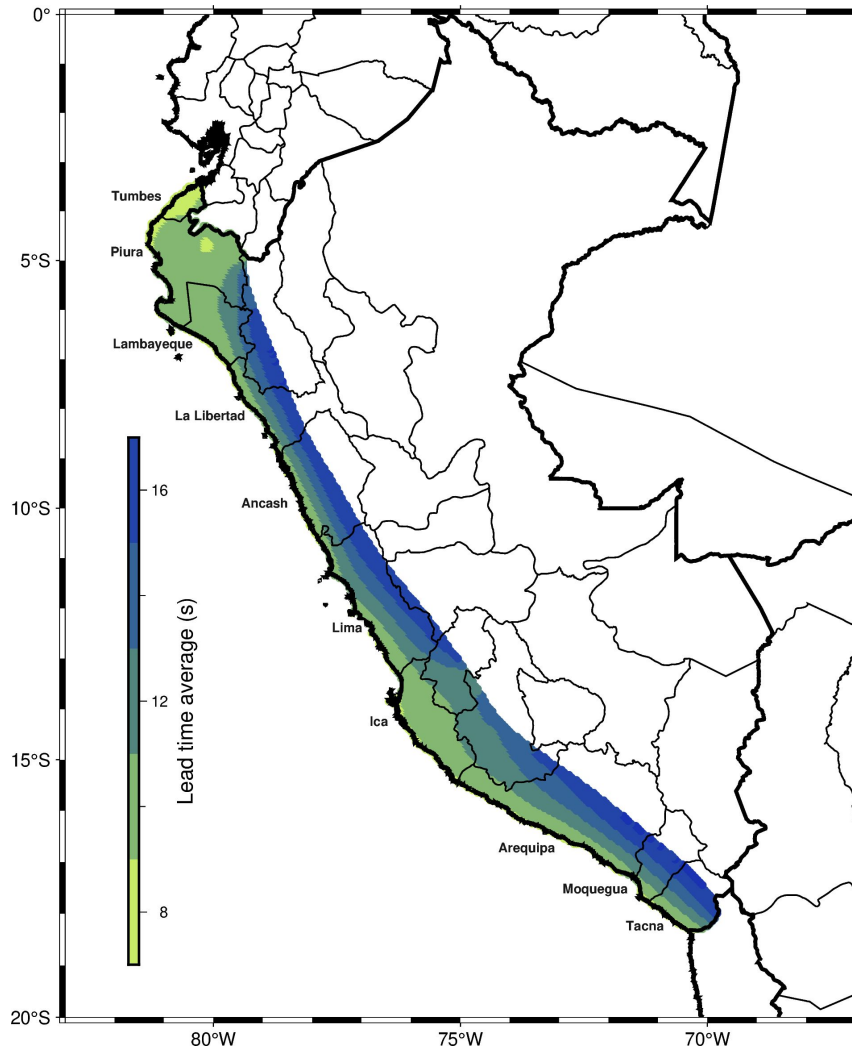
Alert radius



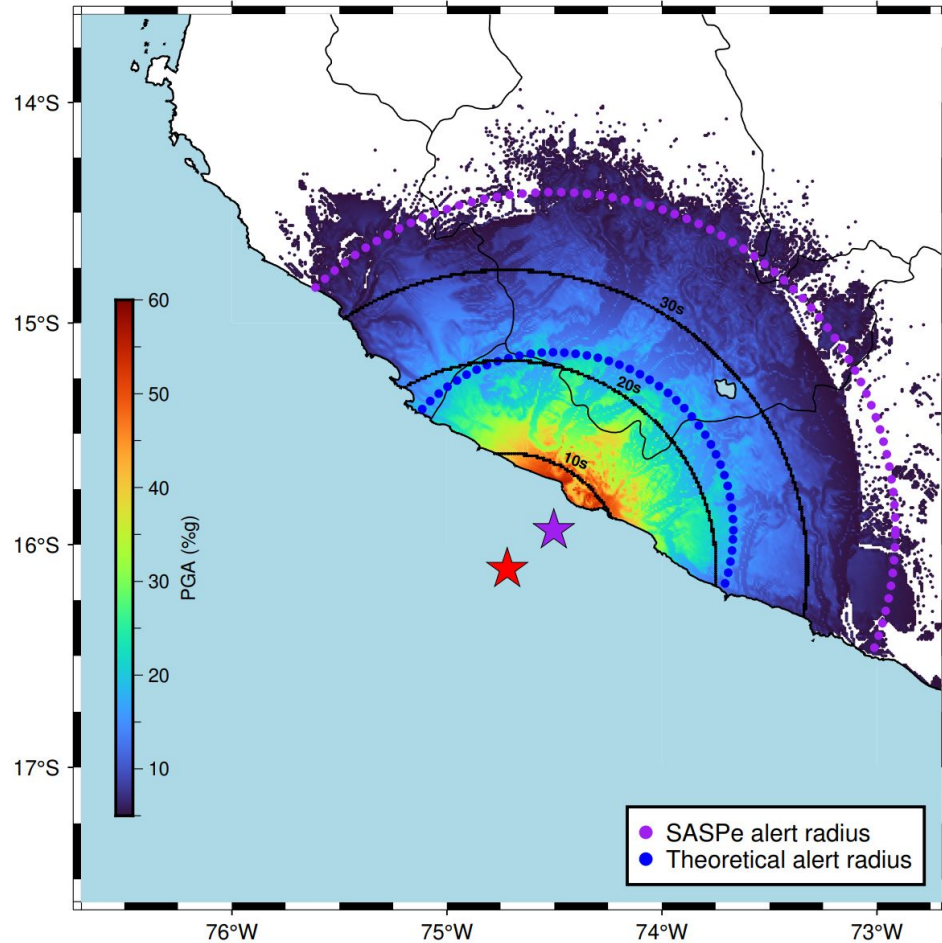
Alert radius and Tolerances



Lead time Nearby megathrust earthquakes



SASPe performance during the M7 Arequipa earthquake on June 28, 2024



SASPe drills and campaigns

SASPe
SERVIDOR DE ALERTA SISMICA PERUANO

CADA SEGUNDO CUENTA

El SASPe nos brindará segundos importantes para actuar en caso de un sismo de magnitud *igual o mayor a 6.0*

SIMULACRO SASPe
MIÉRCOLES 04 DE DICIEMBRE
PARQUE CÉSAR VALLEJO, AV. CASAS - SAN MIGUEL - 11:00 a.m.

MOMENTO 1 El simulacro inicia con el sonido de la alarma sísmica, la cual avisa que un sismo se acerca. **¡Aprovecha estos segundos!**

MOMENTO 2 Aplica tu Plan Familiar de Emergencia y ubícate en una zona segura en el lugar donde te encuentres.

MOMENTO 3 Cuando la alarma sísmica haya terminado, evaccía hacia las zonas seguras externas o puntos de reunión.

Para más información visita www.igp.gob.pe/saspe o escanea este código QR

#SASPe

UNA PRESENCIA VIGILANTE

IGP

#SASPe



PERÚ Ministerio del Ambiente

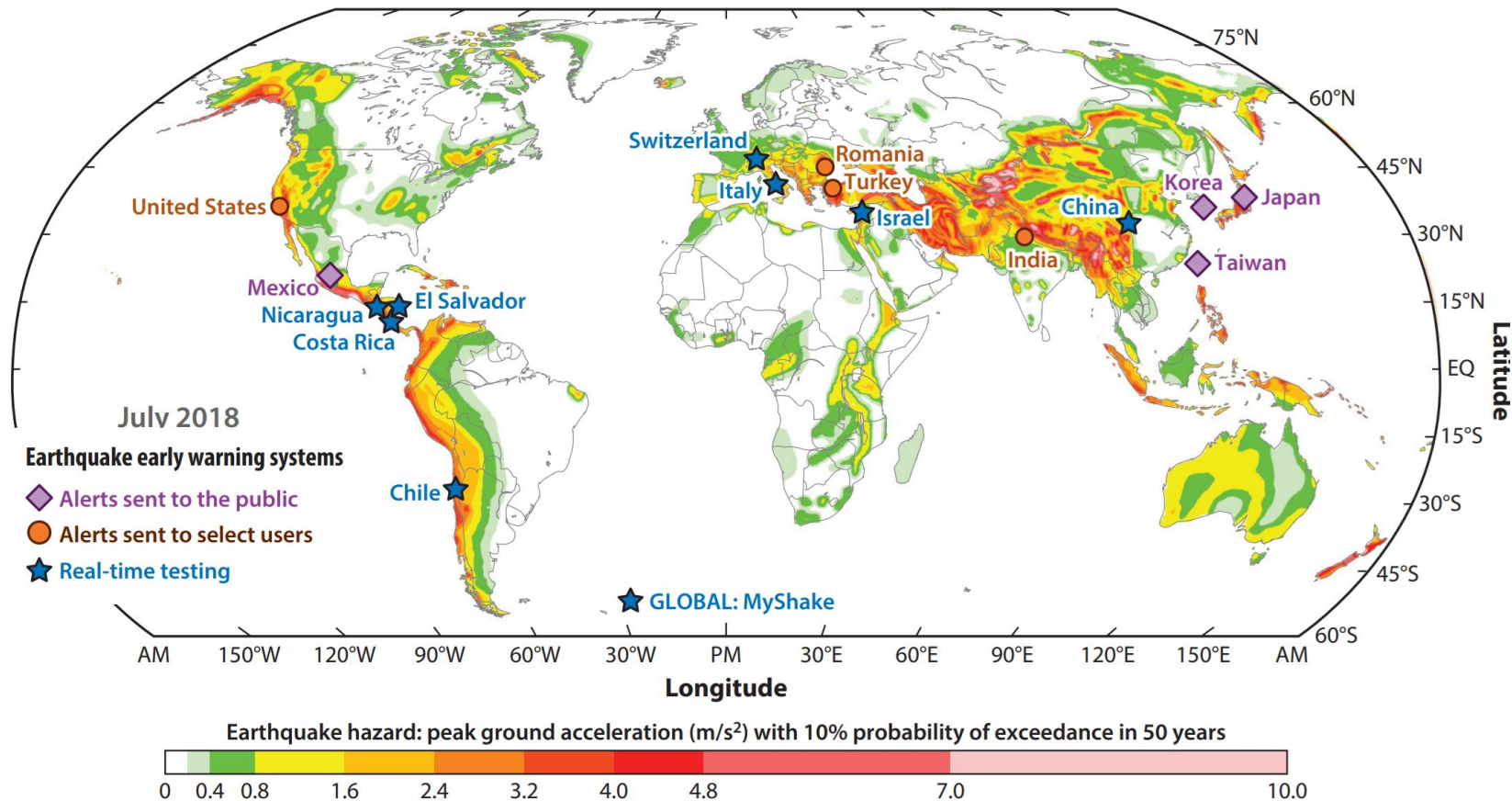


Television

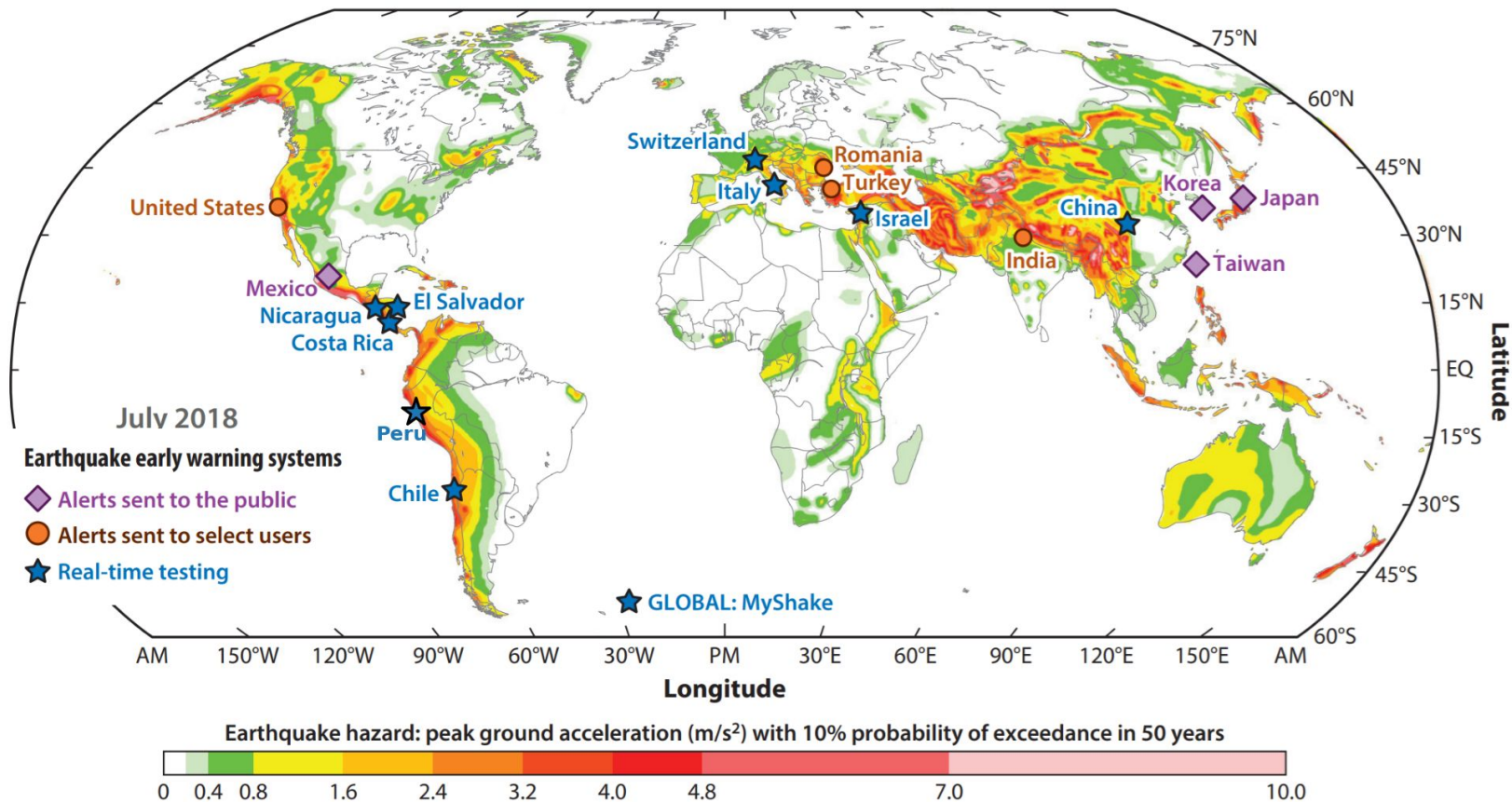


Radio

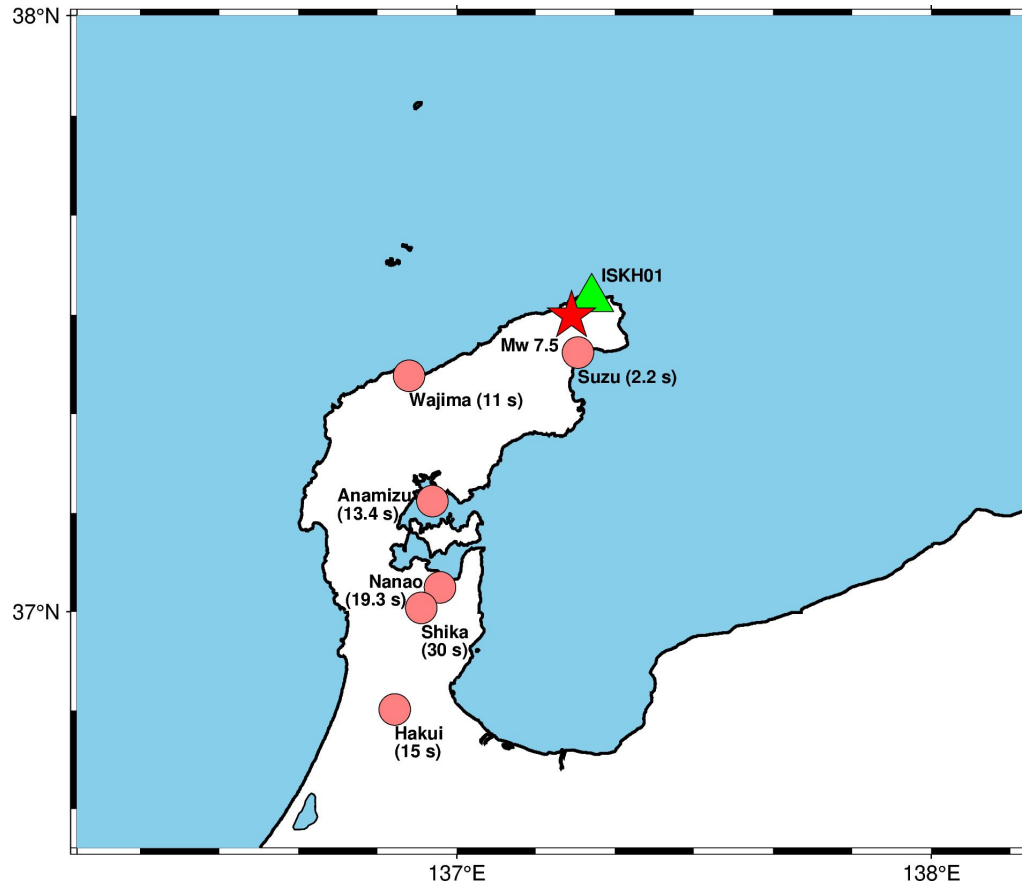
Countries with an EEWs



Countries with an EEWs



E3WS applied to the 2024 M_w 7.5 Noto earthquake, Japan



CONCLUSIONS

1. I designed E3WS, the first fully single-station, AI-based EEWS, detecting earthquakes and estimating magnitude/location in as little as 3 seconds of P-wave data. (**Innovation**)

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3. Proven effective across diverse seismic contexts. (**Global Applicability**)
4. E3WS can be used with both low-cost and high-cost sensors, enabling deployment in resource-constrained regions. (**Accessibility**)
5. Works with single or multiple stations, refining real-time (without losing time to issue alerts) and post-event seismic analyses. (**Versatility**)

PERSPECTIVES

1. **Synthetic Data Integration:** Enhance training by incorporating synthetic data to improve magnitude and location estimates.

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2. **Global Expansion with Low-Cost Sensors:** Utilize affordable sensors (e.g., Raspberry Shake) to enable seismic monitoring in regions with limited infrastructure.

PERSPECTIVES

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5. **Extraterrestrial Applications:** Explore E3WS adaptability in extraterrestrial environments, such as on the Moon or Mars.

FORUM



THANKS!



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<https://github.com/PabloELara/E3WS>