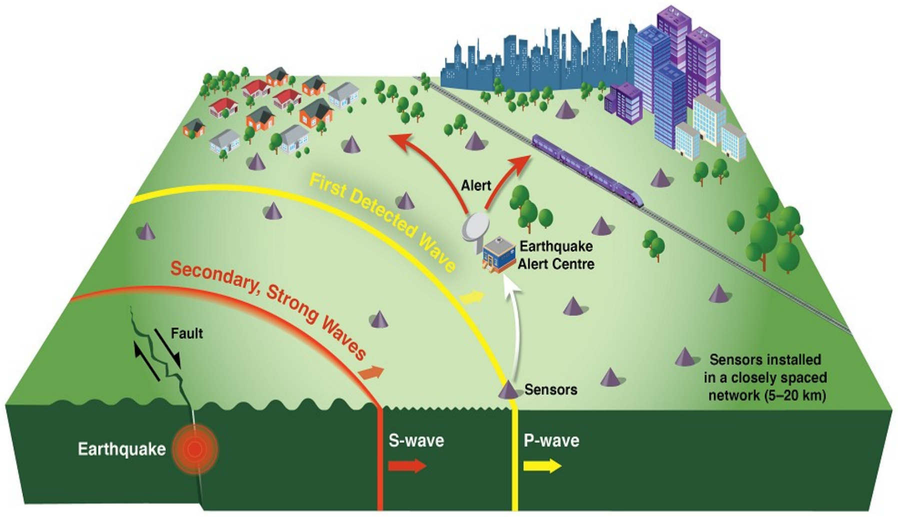
CONSIGLIO NAZIONALE DEGLI INGEGNERI

Webinar venerdì 12 aprile 2024

Tecniche tradizionali ed innovative di protezione sismica delle costruzioni



Earthquake Early Warning

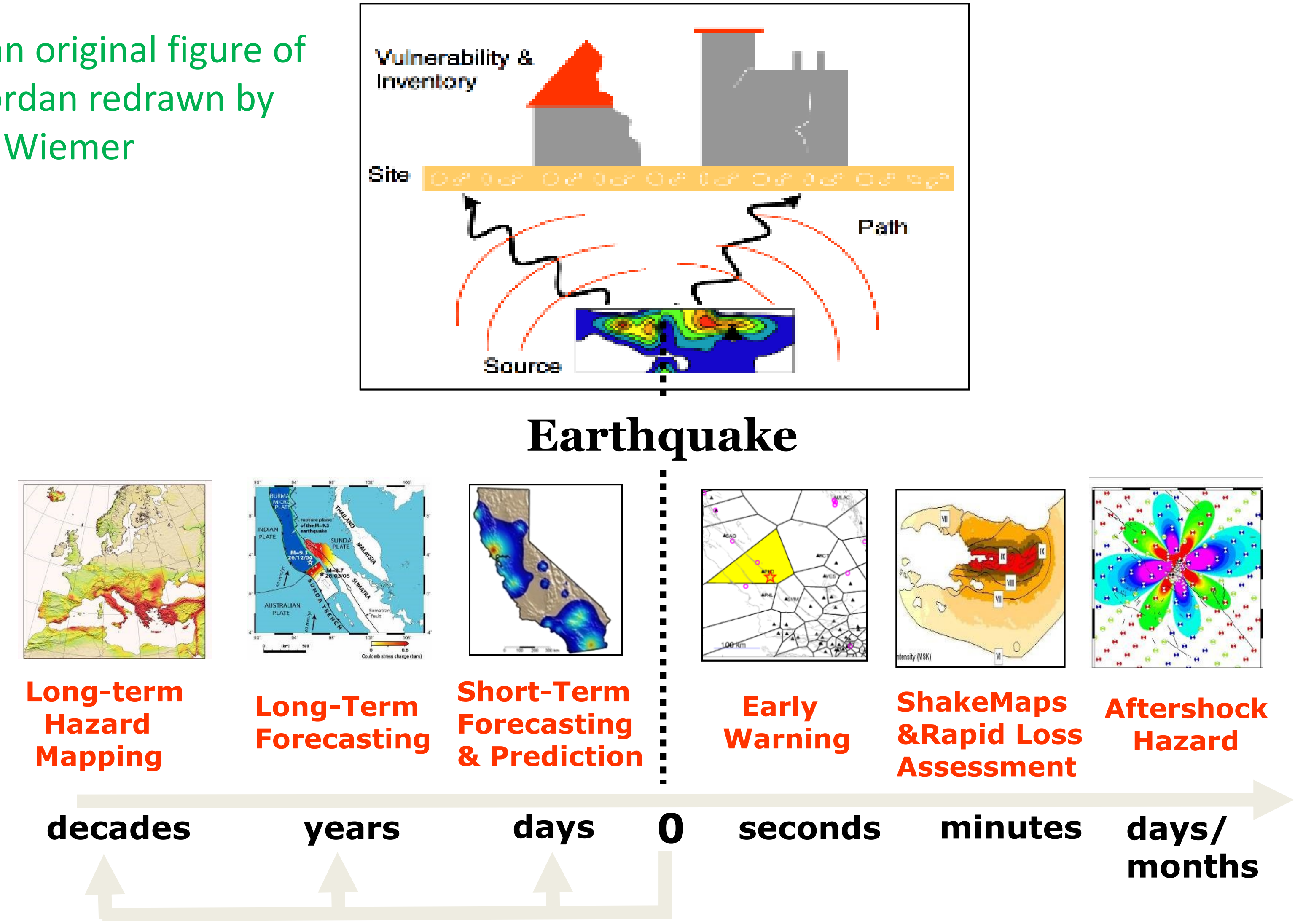
Aldo Zollo

Dipartimento di Fisica E. Pancini

Università di Napoli Federico II

The different time scales of the earthquake process

From an original figure of Tom Jordan redrawn by Stefan Wiemer



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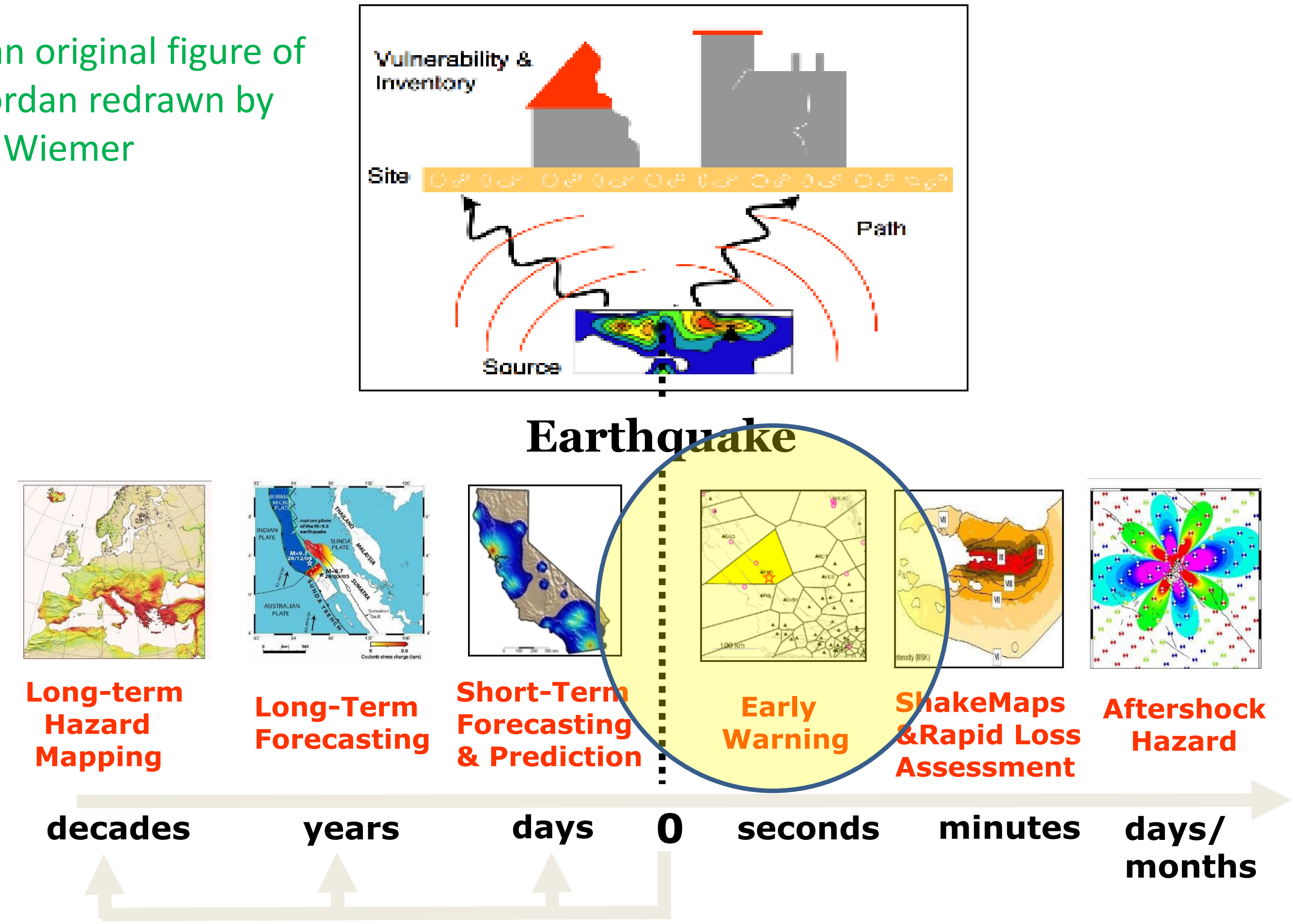
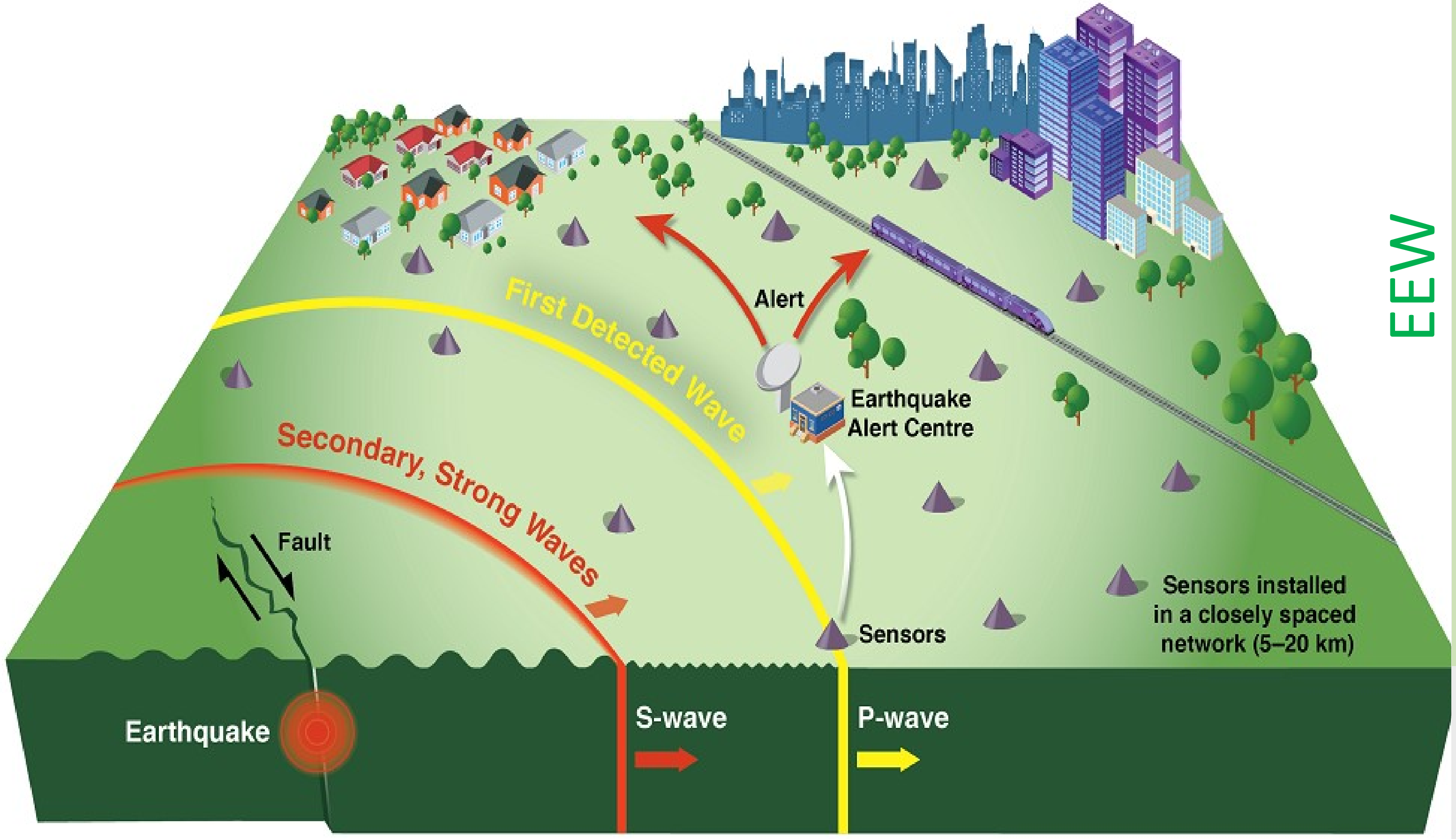
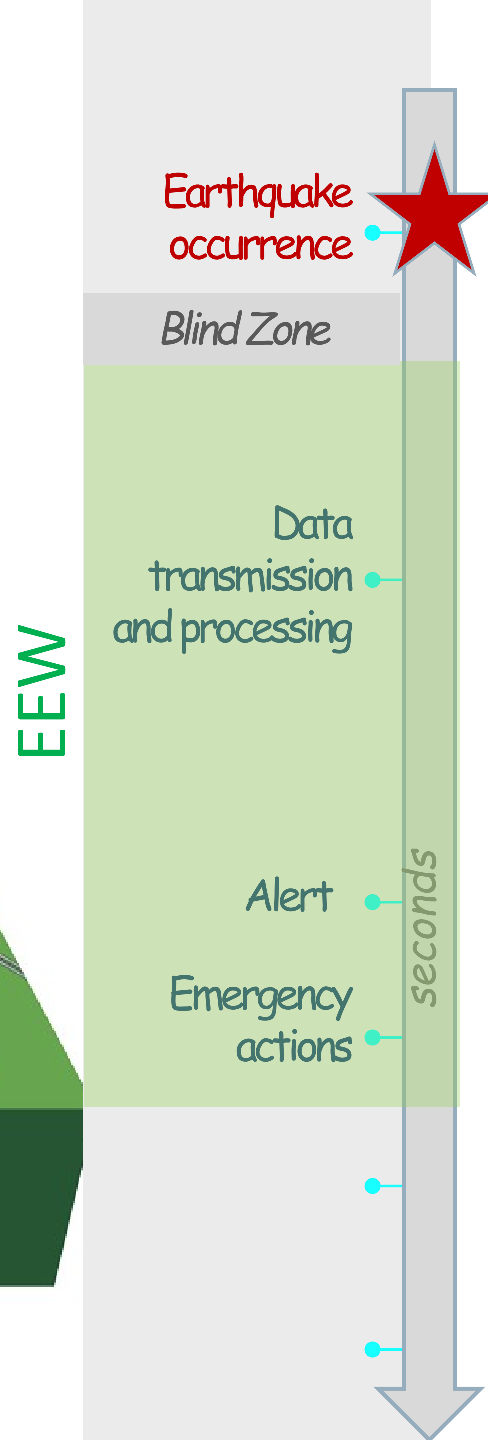


Earthquake Early Warning & Rapid Response Systems 1

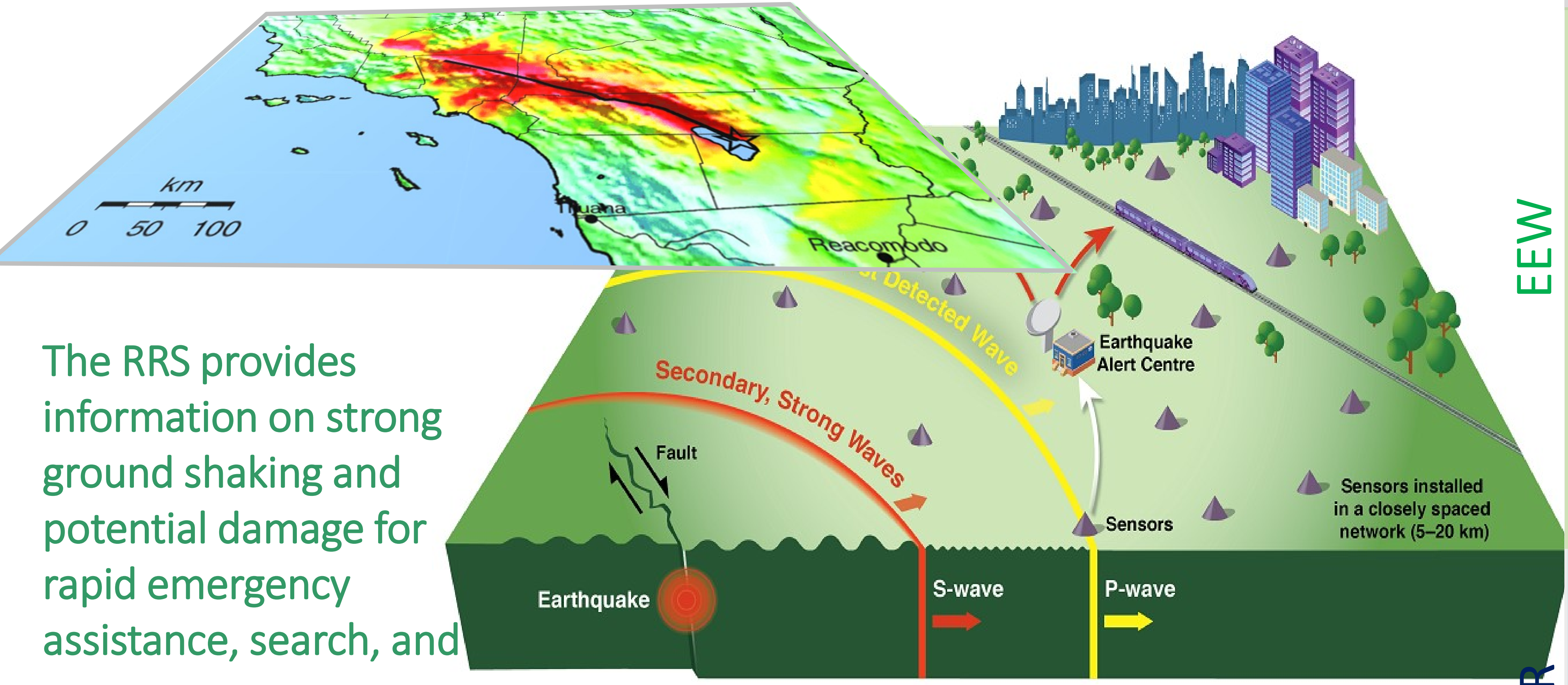
The EEWS identifies an ongoing earthquake and provides a warning before the ground shaking reaches the target site.



https://earthquakescanada.nrcan.gc.ca/eew-asp/system-en.php

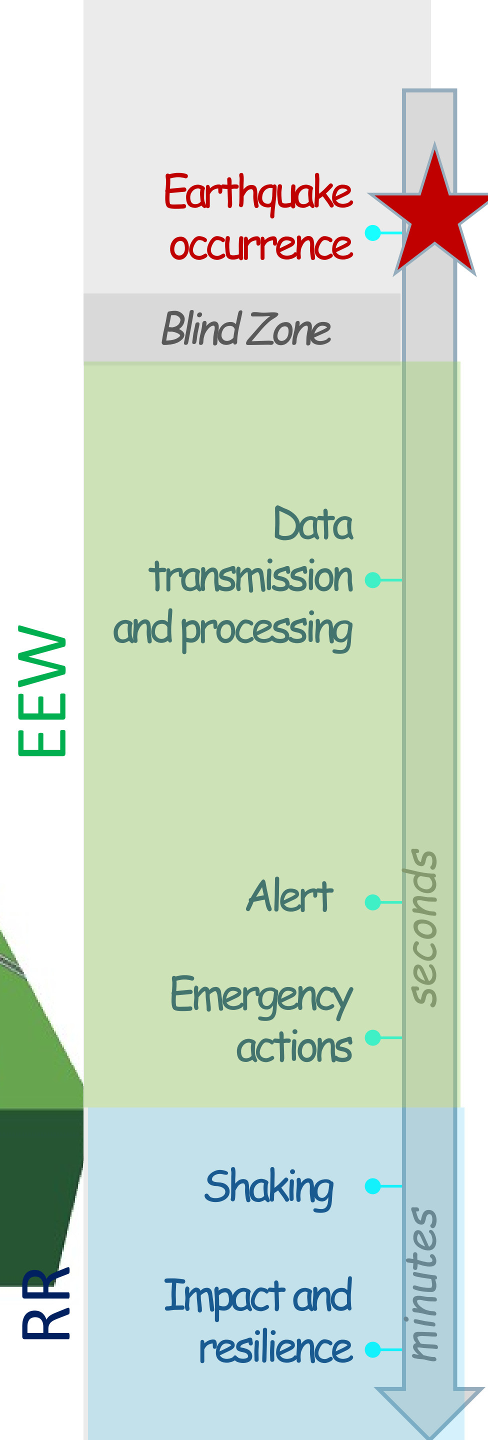


Earthquake Early Warning & Rapid Response Systems 2



The RRS provides information on strong ground shaking and potential damage for rapid emergency assistance, search, and rescue responses.

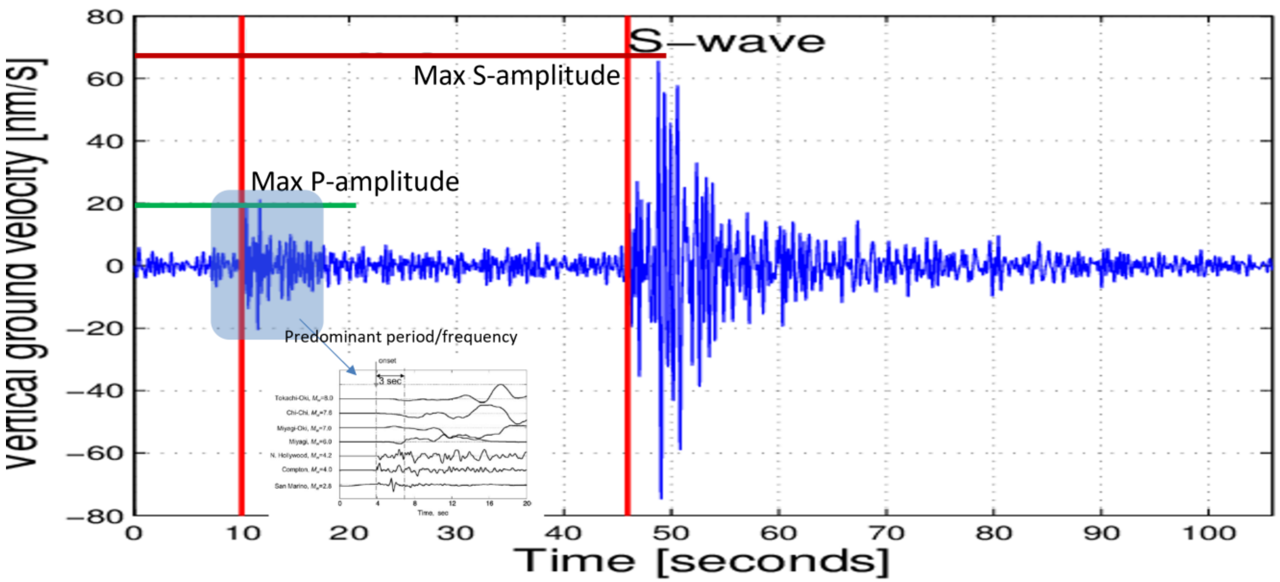
https://earthquakescanada.nrcan.gc.ca/eew-asp/system-en.php



Basic Concepts & configurations of EEWS

EEWS: automatic system able to identify an ongoing earthquake and provide a warning before the ground shaking reaches the target site

- **Measure the P-wave amplitude (Pd,Pv,Pa) and/or characteristic period (Tc,Tp)** on short, eventually expanded, time windows along the seismogram
- **Network-based or regional**: Use P-wave amplitude (Pd,Pv,Pa) and characteristic period (Tc,Tp) to predict magnitude , given the real-time earthquake location
- **Onsite or threshold-based**: Use P-wave amplitude (Pd,Pv,Pa) to predict Peak Ground Motion (PGV,PGA)
- **Integrated regional-onsite**: Use P-wave amplitude (Pd,Pv,Pa) and characteristic period (Tc,Tp) to produce P-wave-based «early shake map» for EW



Log (Max P-amplitude) $\propto$ Log (Max S-amplitude)
Log (P-wave characteristic period) $\propto$ Richter Magnitude

Basic Concepts & configurations of EEWS

EEWS: automatic system able to identify an ongoing earthquake and provide a warning before the ground shaking reaches the target site

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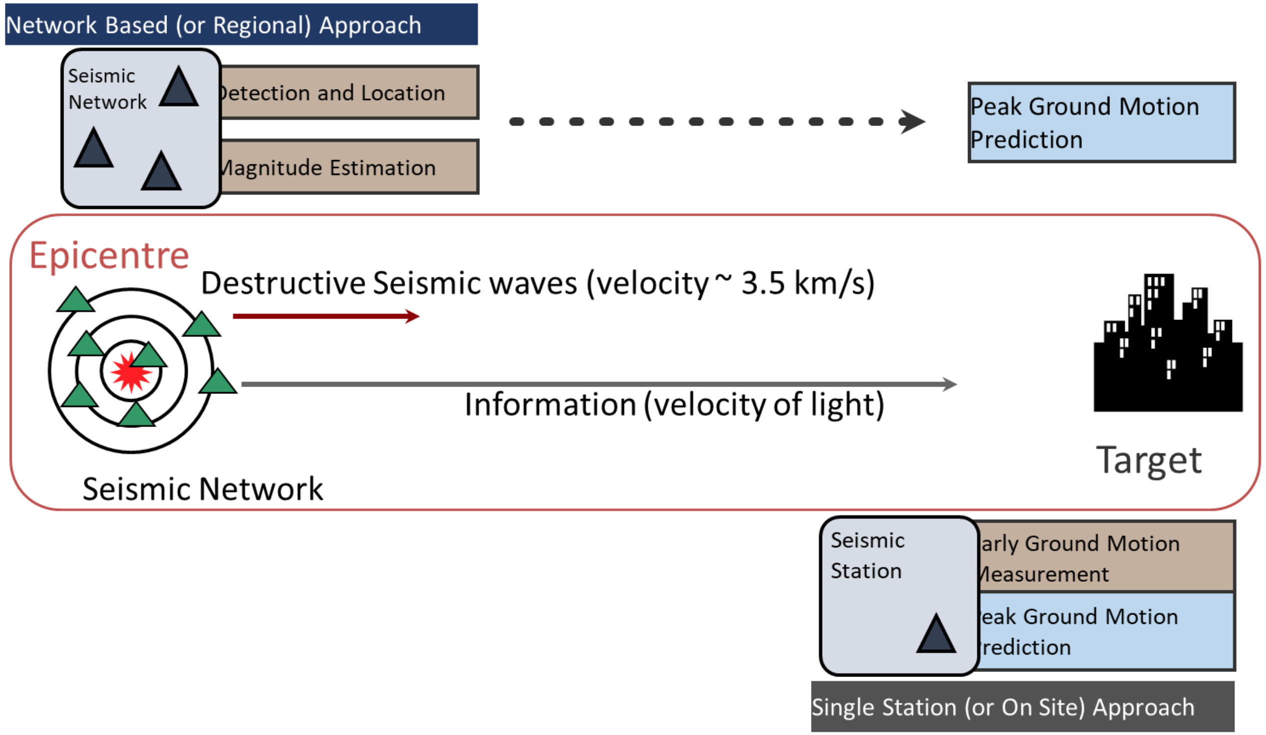


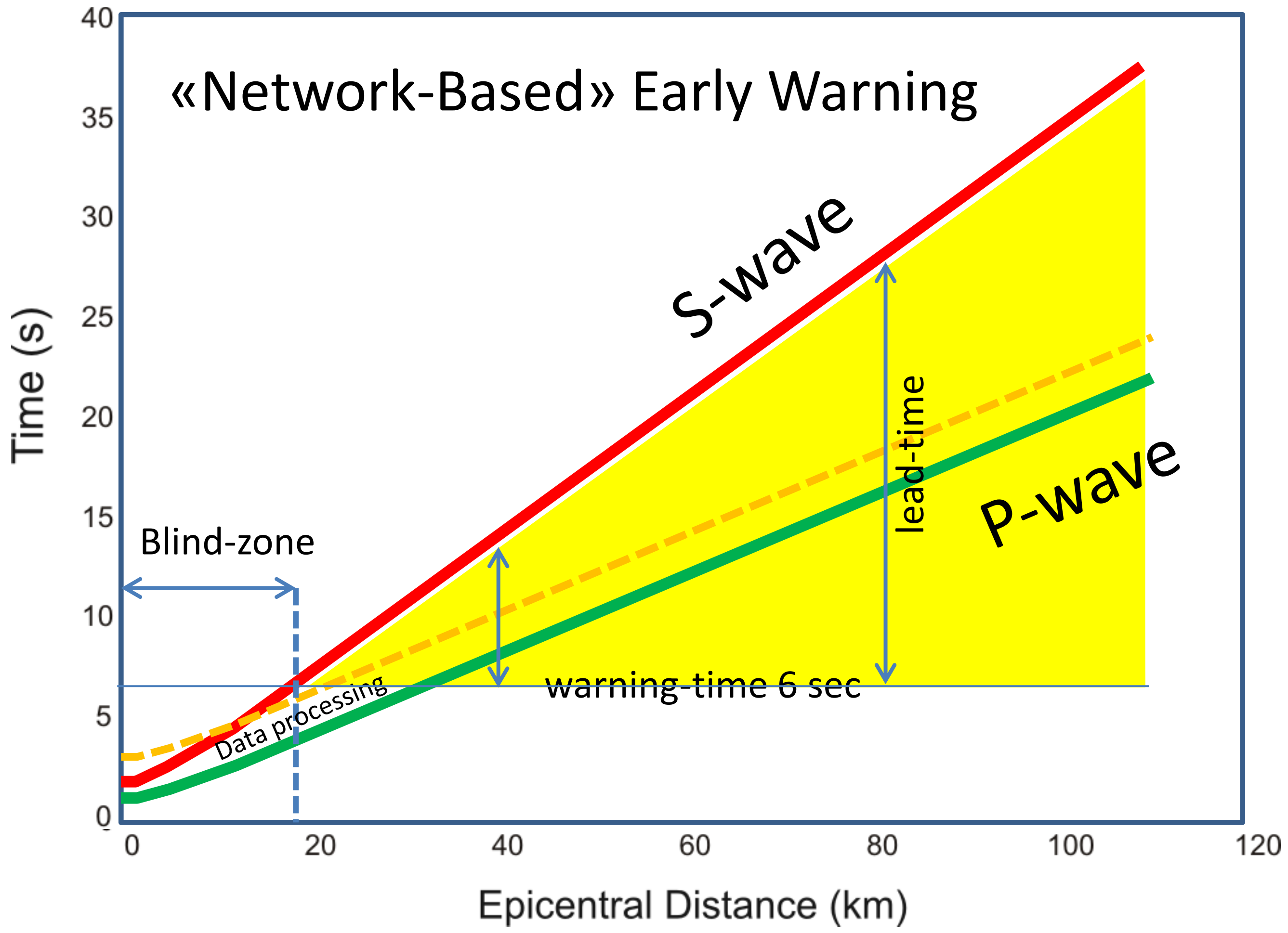
Warning-time and Lead-time: EW network-based systems

The **warning-time** is the time needed to issue the first eqk info and alert

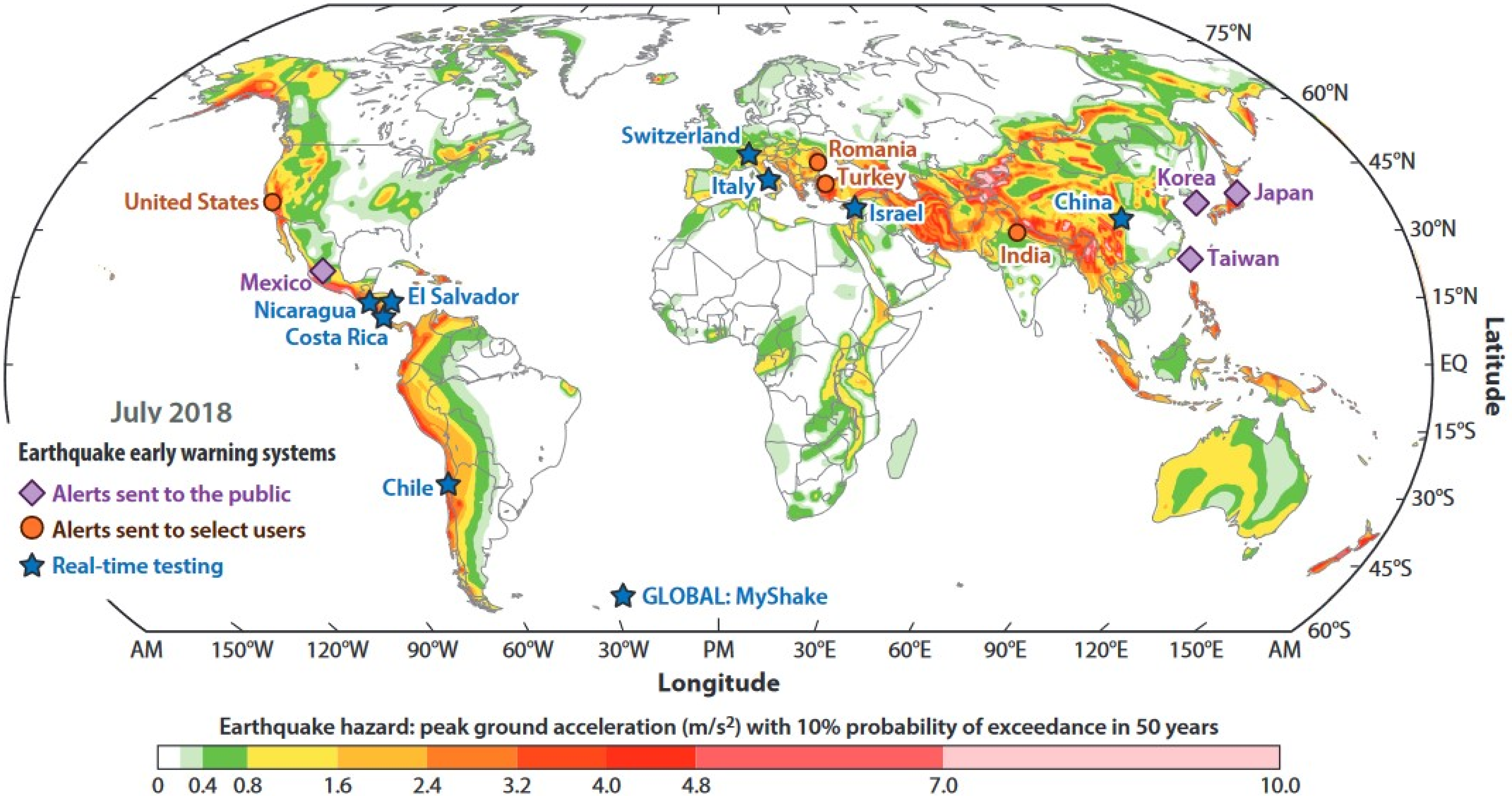
The **blind-zone radius** is the distance within which the first S waves arrive before the alert.

The **lead-time** is the time available for RT mitigation actions, e.g S-wave arrival time – warning time.

- The **network-based EWS** issues an alert based on eqk location-magnitude-predicted shaking
- The **warning time** depends on Pwave travel-time, telemetry and computations → travel-time at 4+ stations, telemetry, P-windows, data processing (ex. 6 sec)
- The **blind-zone radius** depends on the warning time
- The **lead-time** increases with the distance from the source
- Network-based EW systems provide fast and accurate source parameter determination, less reliable potential shaking estimates (through GMPEs)



Status of the earthquake early warning systems worldwide



Allen, R.M., Melgar, D., 2019. Earthquake Early Warning: Advances, Scientific Challenges, and Societal Needs. Annu. Rev. Earth Planet. Sci. 47, 361–388. https://doi.org/10.1146/annurev-earth-053018-060457

Current Applications & Potential Uses

Possible Actions Within 10-50 Seconds

Utilities

Power (fire prevention), gas

Industry

Hazardous chemicals, chip manufacturers, eye surgeons

Construction

Site safety, (active control buildings)

Transportation

Airports, rail and subway, bridges

Response community

Fire departments, rescue teams, government

Personal protection

Schools, housing complexes (evacuation), hosing unit (preparation)

James D. Goltz, 2002. Introducing Earthquake Early Warning in California: A Summary of Social Science and Public Policy Issues.

Research Directions in Earthquake Early Warning

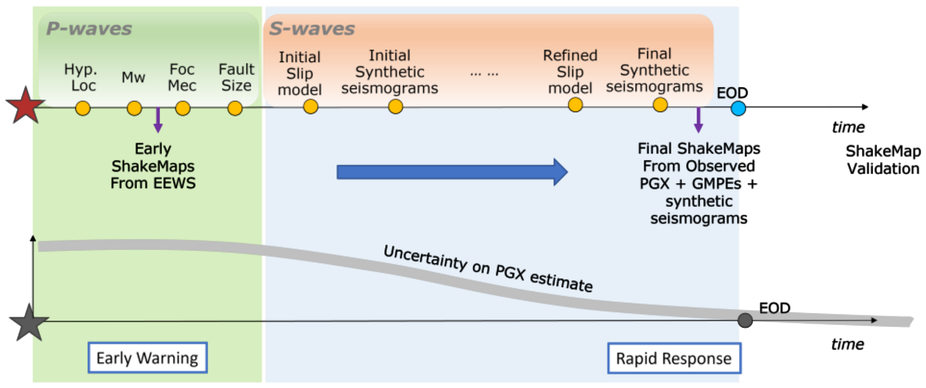
next-future developments

SERA JRA6 – Real Time Earthquake Shaking

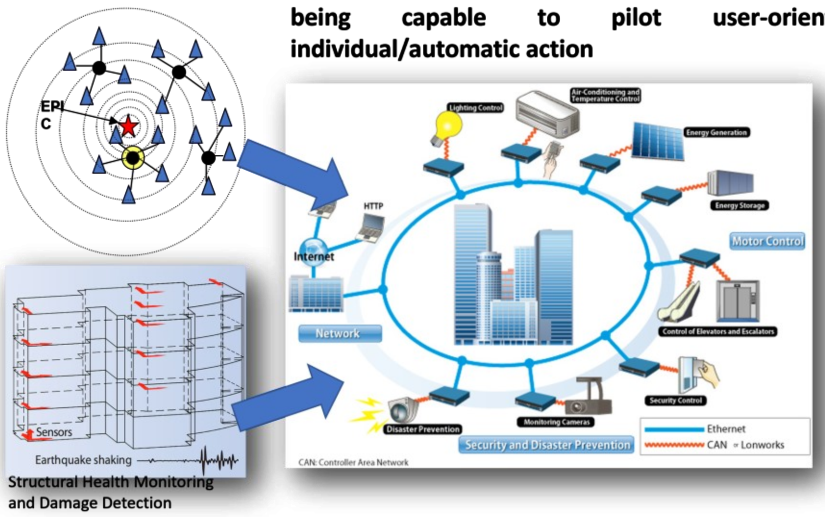
- **Linking Early Warning and Rapid Response time scales**
  - From «early» (P-wave) to «final» (S-wave) shake map
- **Designing end-to-end EEWS tailored to specific applications**
  - Link to control systems piloting automatic safety emergency actions

Time-Evolving ShakeMap Computation

Objective: peak ground motion prediction PGX (X=A,V or D)

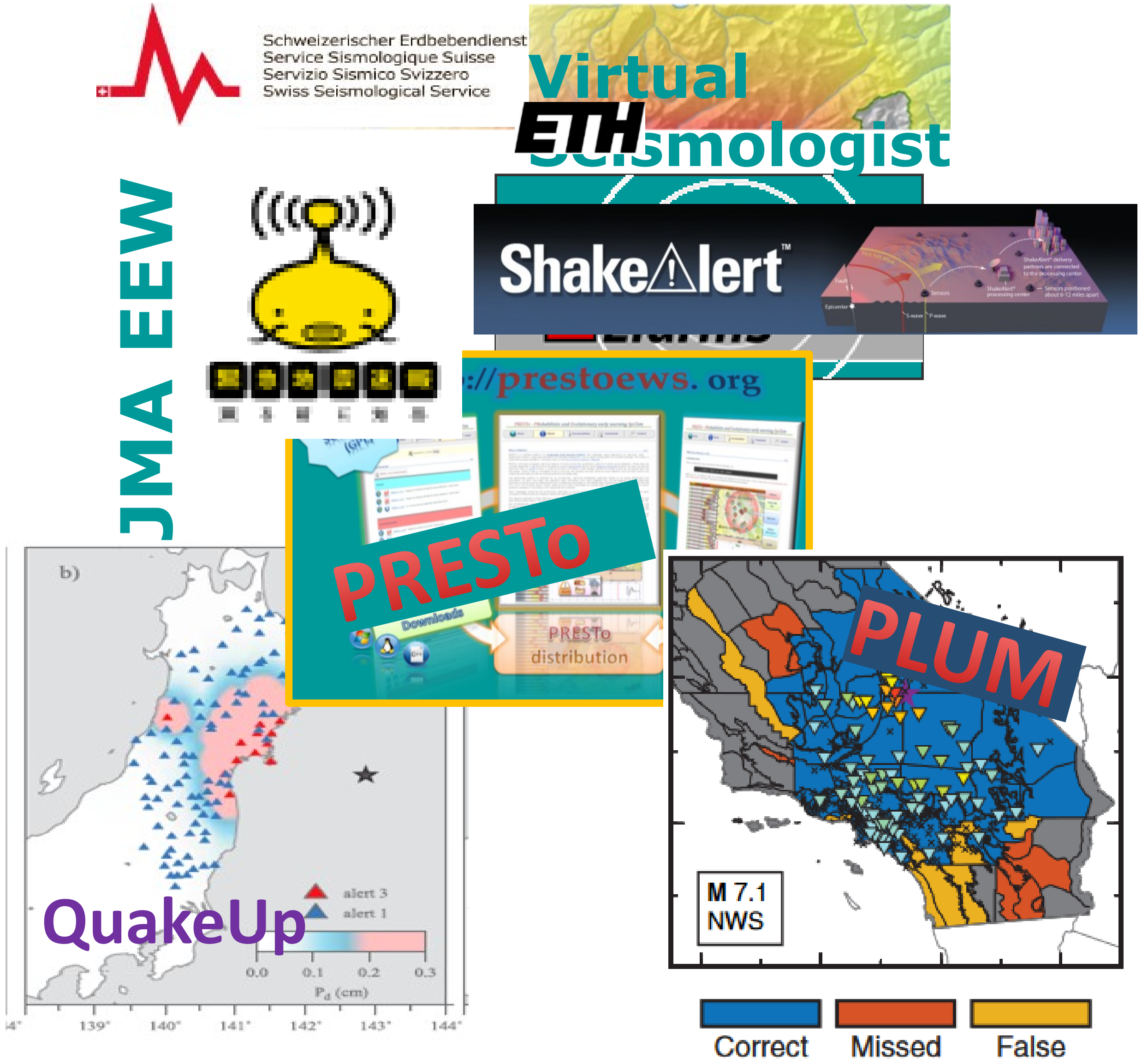


Manages both the regional and local information, being capable to pilot user-oriented individual/automatic action



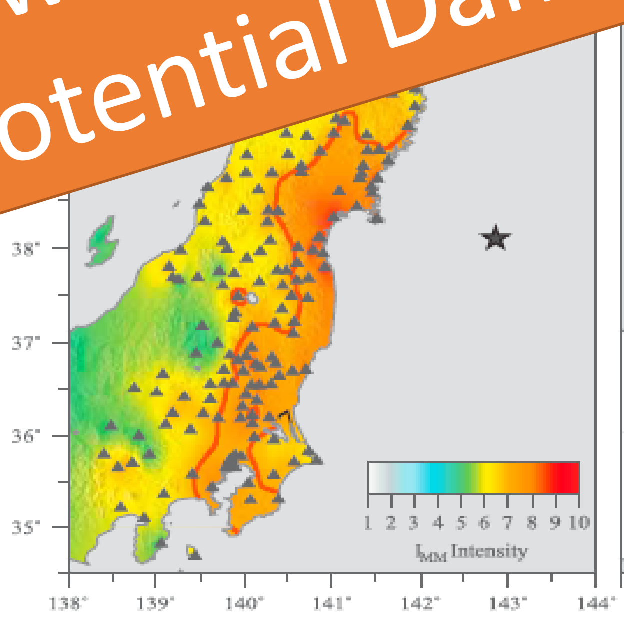
Network-based EEW: Basically two approaches

- Source-based
  - Fast determinations of location and magnitude are used to predict the peak ground shaking using a ground motion prediction equation (GMPE)
  - **JMA-EW, Shake-Alert(USGS), PRESTo (IT), Virtual Seismologist (ETH)**
- Shaking-Forecast-based
  - Future peak ground shaking is predicted from the recorded P (or S-near-source) ground shaking, with or without using the source location/magnitude information
  - **Finder, Wavefield-extrapolation, PLUM, PDZ-contouring (QUAKE_UP)**

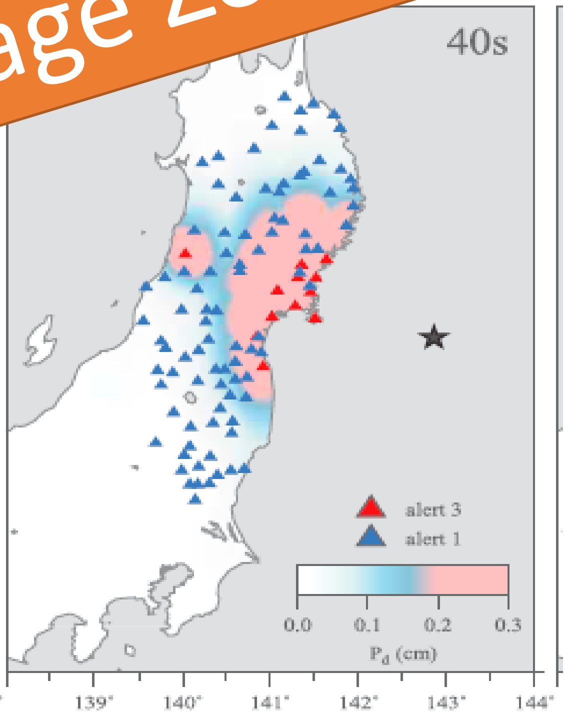


Track the expected strong shaking zone while the earthquake rupture is still ongoing

P-wave contouring of the Potential Damage Zone



Post-event Intensity



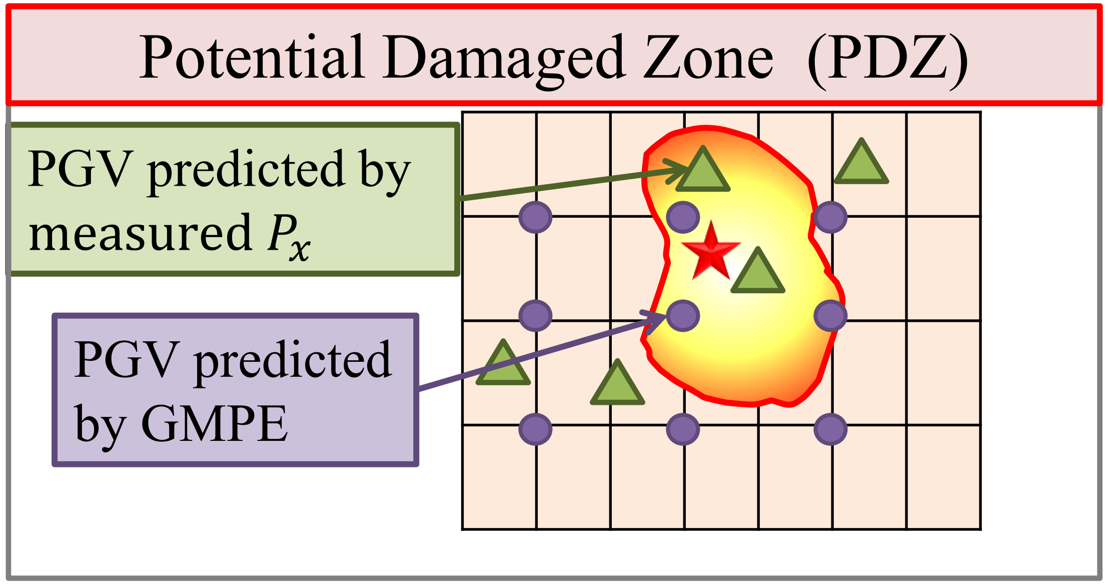
Real-Time PDZ

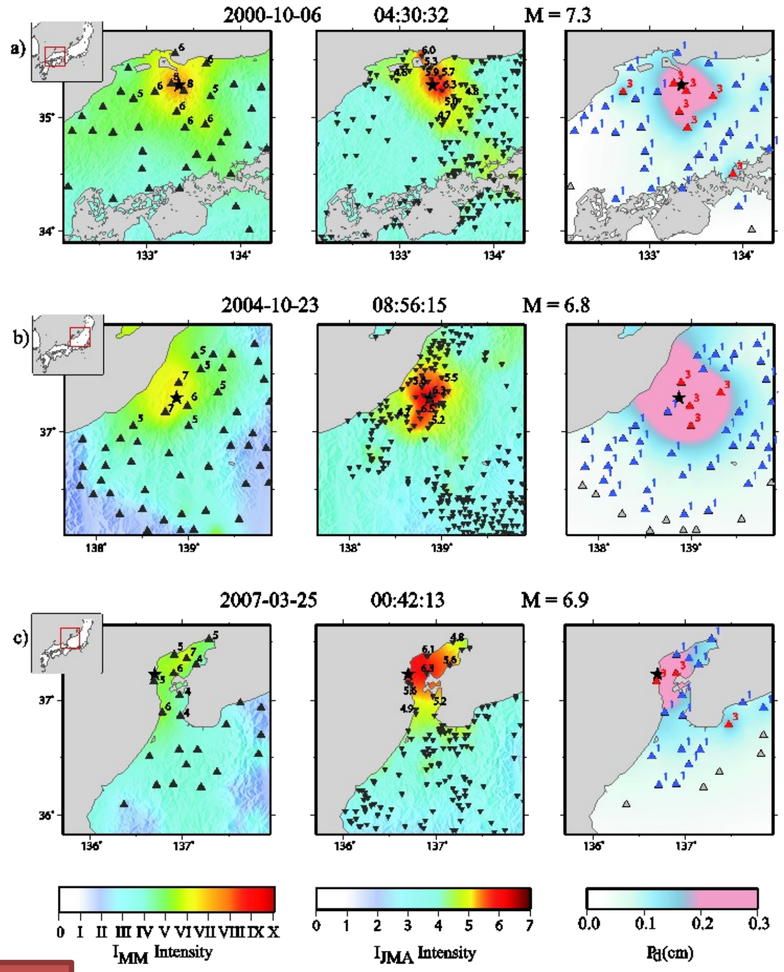
Shaking-Forecast-Based Early Warning System

Research developments at the University of Naples Federico II

Rapid Damage Evaluation: the concept of Potential Damage Zone

Rapid estimate of the **Potential Damage Zone** by interpolating predicted values of PGV/IMM at recording sites and at virtual grid nodes.

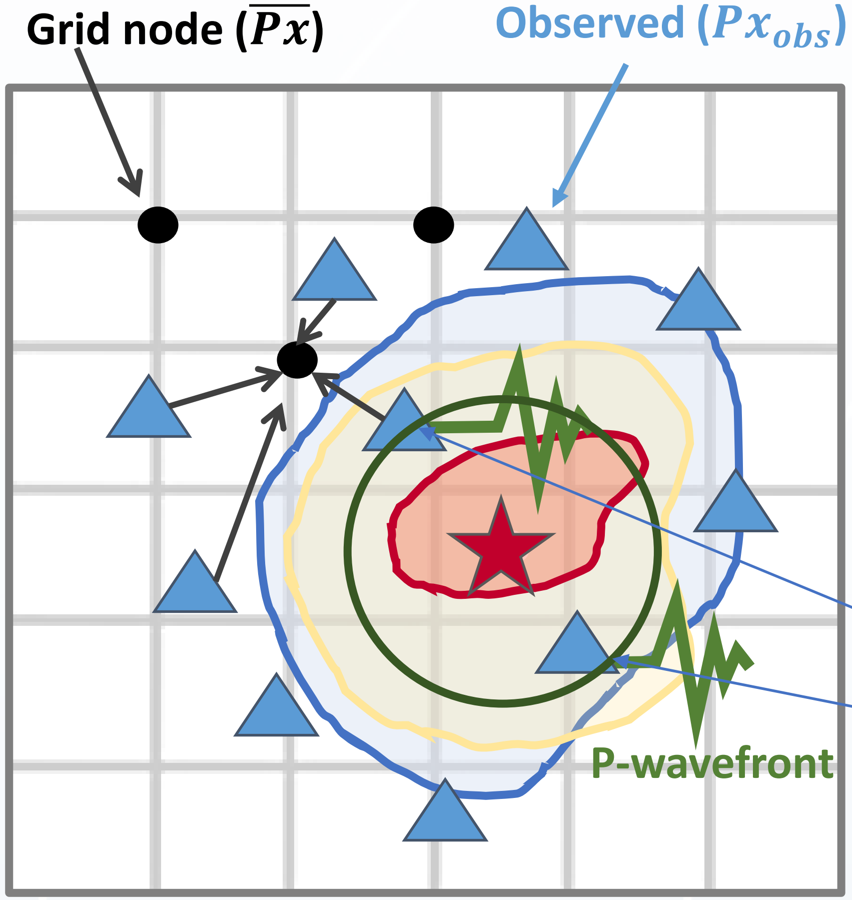




Colombelli et al., 2012 BSSA

The PDZ is the area delimited by an user-defined IMM/PGV potential damage countour level (e.g. IMCS>VII , PGV>6.37 cm/s. INGV Shakemap)

Early Shake-Map: P-wave contouring of PDZ

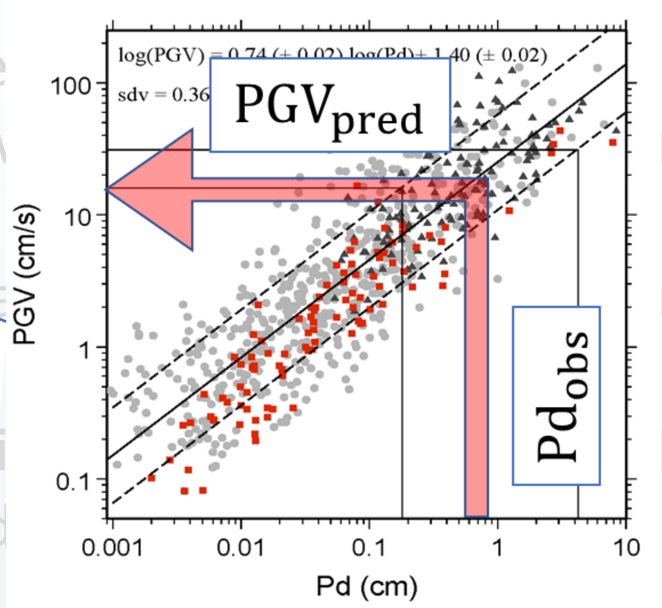


- Network of stations + spatial grid of virtual nodes

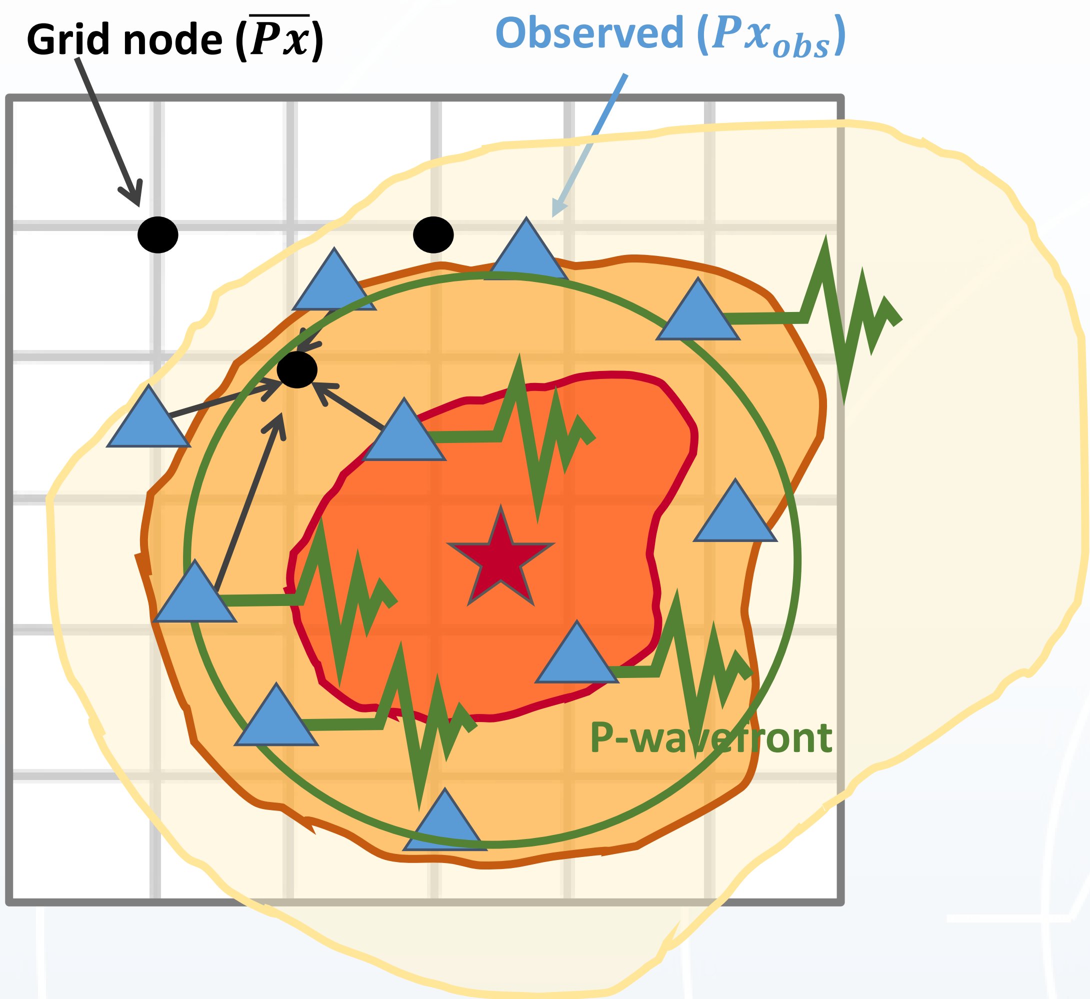
- First P-wave is detected at the closest station:
  - earthquake location & magnitude;
  - observed values of $P_d(P_v, P_a)$ → PGV at stations
  - predicted values of PGV from GMPE at the nodes
  - interpolation algorithm for the PDZ mapping;

- Succe… done on increased time … recordings

- The … sity) values larger than …) is mapped as a functi… PDZ can be alerted based … shaking.



Early Shake-Map: P-wave contouring of PDZ



- Network of stations + spatial grid of virtual nodes

- First P-wave is detected at the closest station:
  - earthquake location & magnitude;
  - observed values of $P_d(P_v, P_a)$ and τ_c ;
  - predicted values of $P_d(P_v, P_a)$ at the nodes ;
  - interpolation algorithm for the PDZ mapping;

- Successive measurements are done on increased time windows and new station recordings

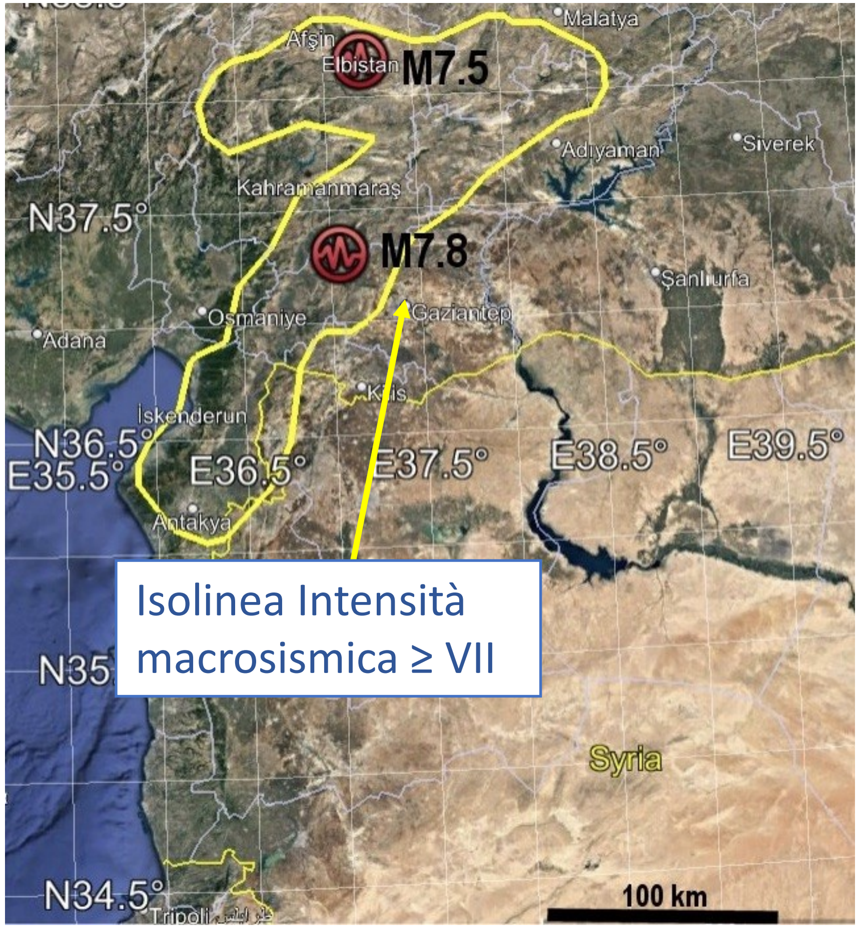
- The area with PGV (or Intensity) values larger than a given threshold (PDZ) is mapped as a function of time. Sites within PDZ can be alerted based on the expected level of shaking.

Two case studies

- Retrospective Performance Analysis of a Shaking-Forecast Based Early-Warning Method for the 2023 Türkiye-Syria Mw 7.8 Earthquake

- EEWS for High-Speed Railways in Italy : Design, development and prototype implementation

Turkey-Syria's earthquake doublet of Feb. 6, 2023 (Mw 7.8 and 7.6)

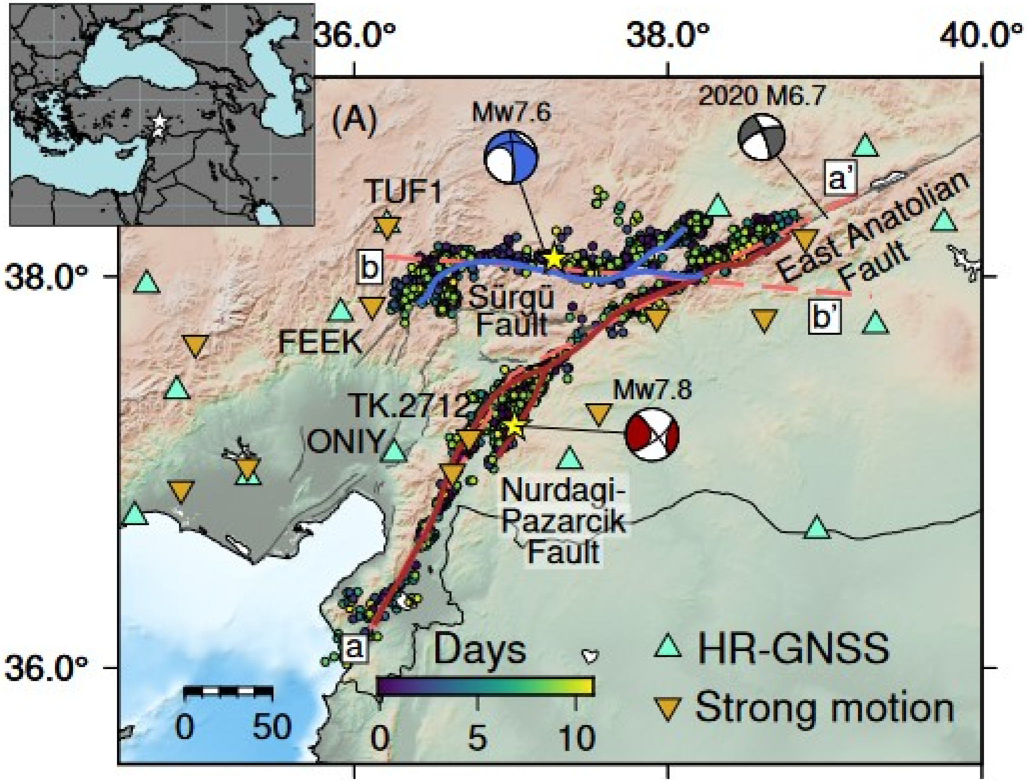


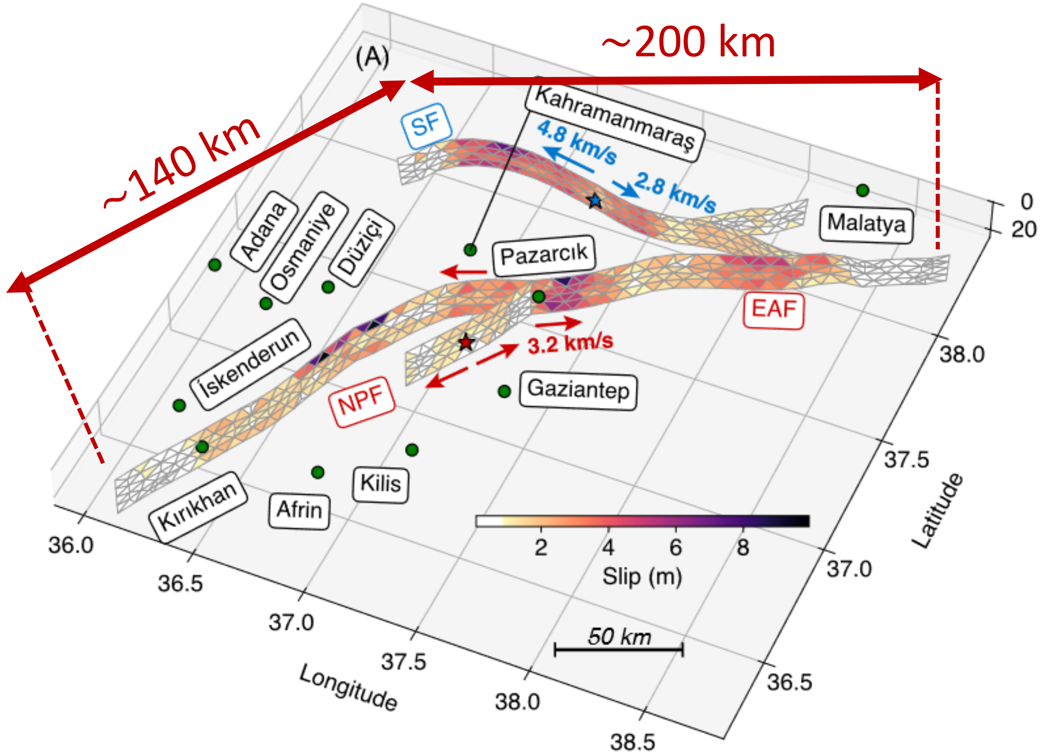
Erdik, et al., 2023, Temblor

Intensity	Shaking
I	Not felt
II	Weak
III	Weak
IV	Light
V	Moderate
VI	Strong
VII	Very strong
VIII	Severe
IX	Violent
X	Extreme

- On Feb. 6, 2023 at 4:17 a.m. the first earthquake of magnitude 7.8 struck the city of Pazarcık in south-central Turkey
- About 9 hours later (at 1:24 p.m.) a second earthquake of magnitude 7.5 had an epicenter near the city of Elbistan
- Both events are associated with the Eastern Anatolian Fault System (EAF)
- A large area was affected by a quake whose intensity (Mercalli scale) was VII+ (from "very strong" to "violent-extreme")

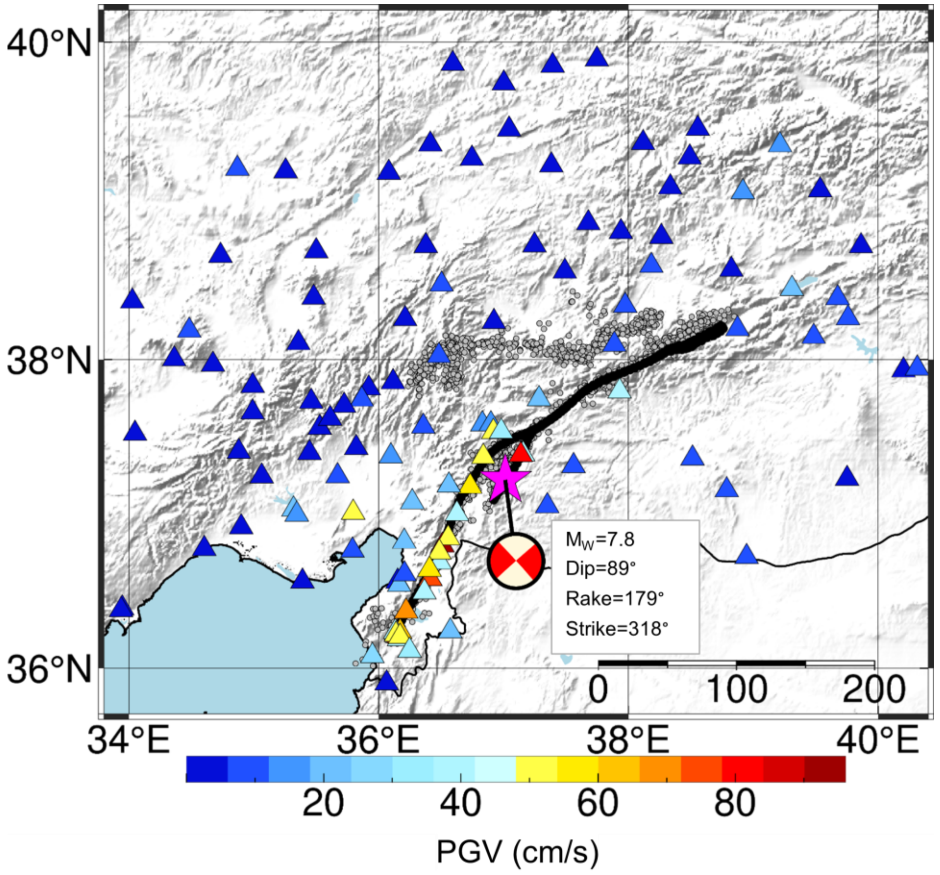
A complex rupture process



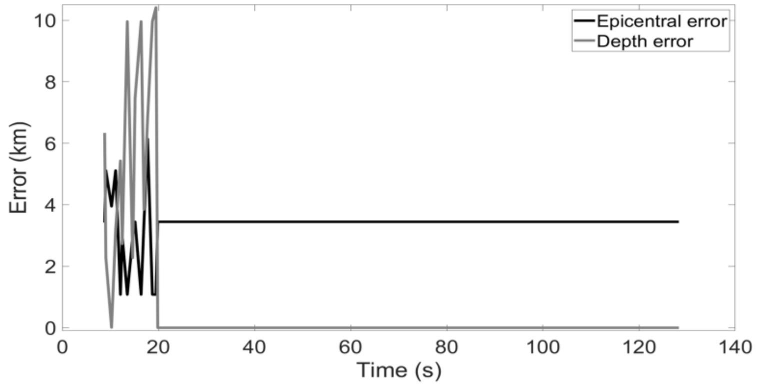


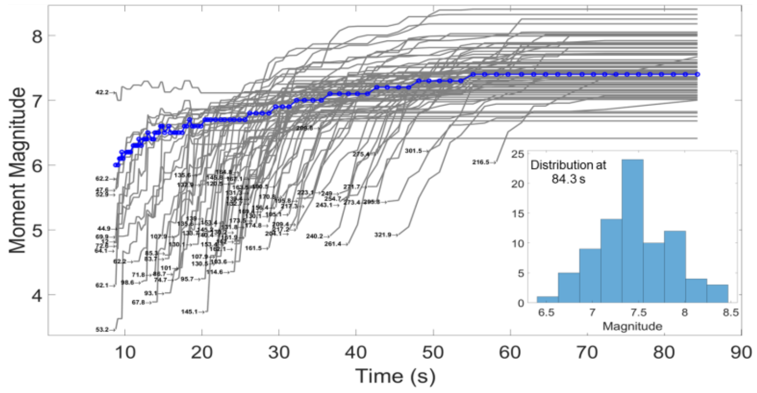
Melgar, D., Taymaz, T., Ganas, A., Crowell, B., Öcalan, T., Kahraman, M., Tsironi, V., Yolsal-Çevikbil, S., Valkaniotis, S., Irmak, T.S., Eken, T., Erman, C., Özkan, B., Dogan, A.H., Altuntaş, C., 2023. Sub- and super-shear ruptures during the 2023 Mw 7.8 and Mw 7.6 earthquake doublet in SE Türkiye. Seismica 2. https://doi.org/10.26443/seismica.v2i3.387

Earthquake Early Warning: Real-Time Location and Magnitude Estimation



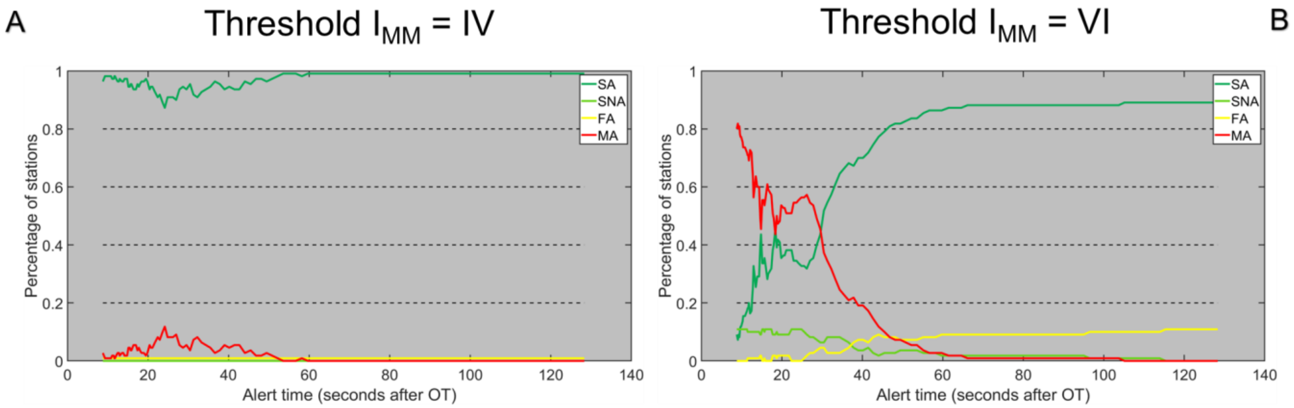
AFAD, Turkish accelerometric network

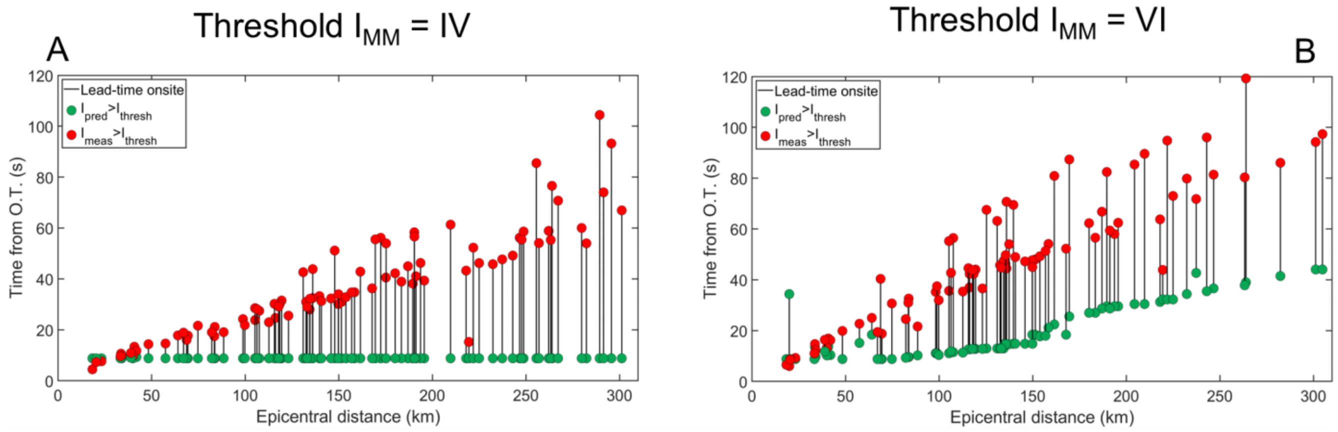




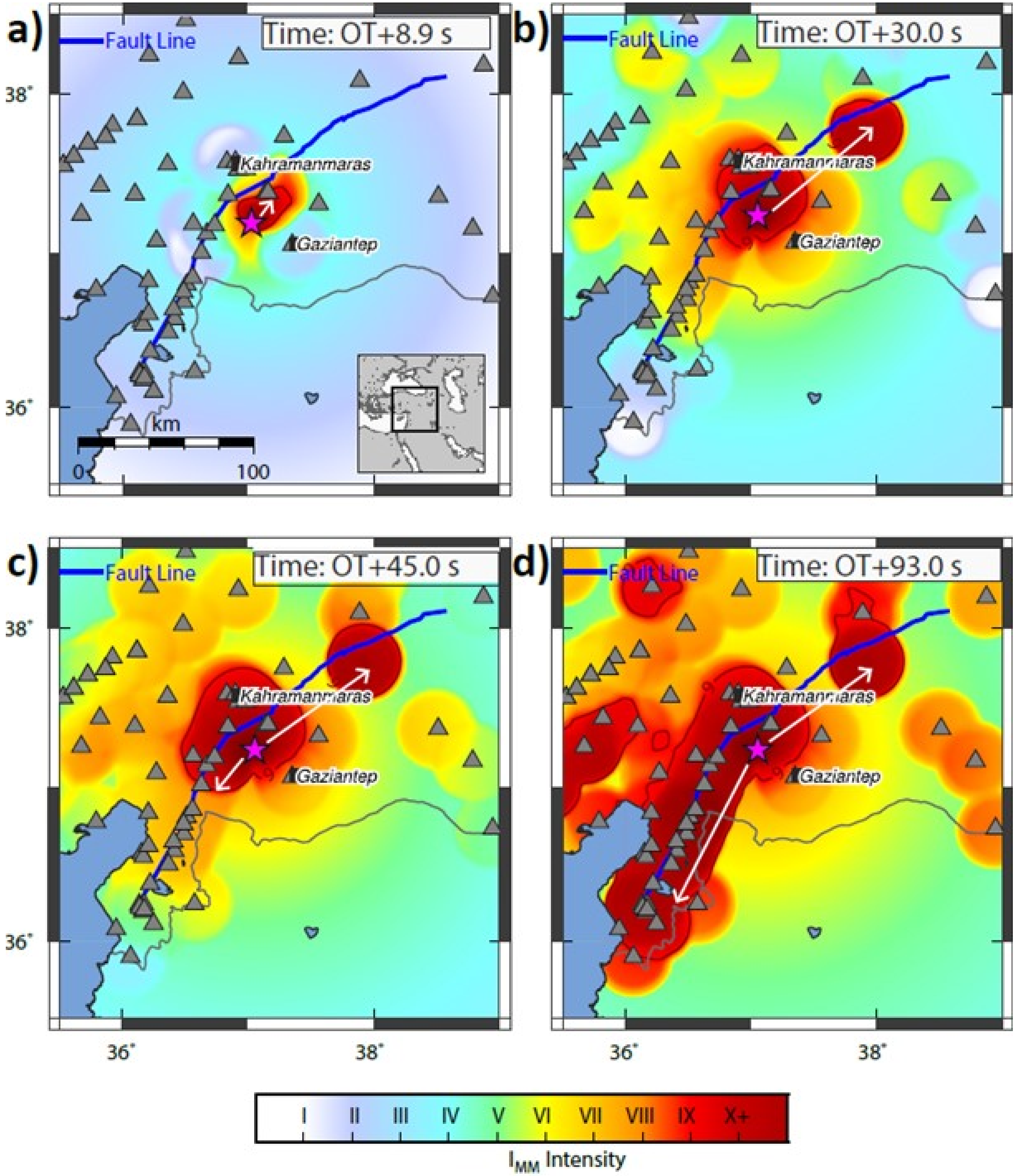
- Stable mainshock location 20 sec after the origin time
- Magnitude M6.5 at 20 sec, the value increase to 7.5 at about 50 sec
- The slow convergence of magnitude to the final value is due to the low energy release during the initial phase of the rupture process

Retrospective Performance Analysis





- Two thresholds of instrumental intensity IMM=IV and IMM=VI
- The empirical relation of Faenza & Michelini (2010): predicted Peak Ground Velocity → Intensities
- The percentage of successfull (SA,SNA), false (FA) and missed (MA) alerts are evaluated comparing the predicted and obseved values
- Results:
  - The lower IMM thresh provides a high percentage of SA since the event beginning
  - Setting the higher IMM thresh, only 40-60 sec after the OT we have high percentage of SA vs MA and FA
  - Lead times are larger for the lower IMM threshold, from few sec to 50-60 sec depending on the epicentral distance



P-wave based shake-map

The predicted potential damage zone as inferred from early recorded P-waves well delineates the geometry of the rupturing fault and tracks with a high precision the space-time rupture evolution.

EEW@High-Speed Railway in Italy

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

RFI RETE FERROVIARIA ITALIANA
GRUPPO FERROVIE DELLO STATO ITALIANE

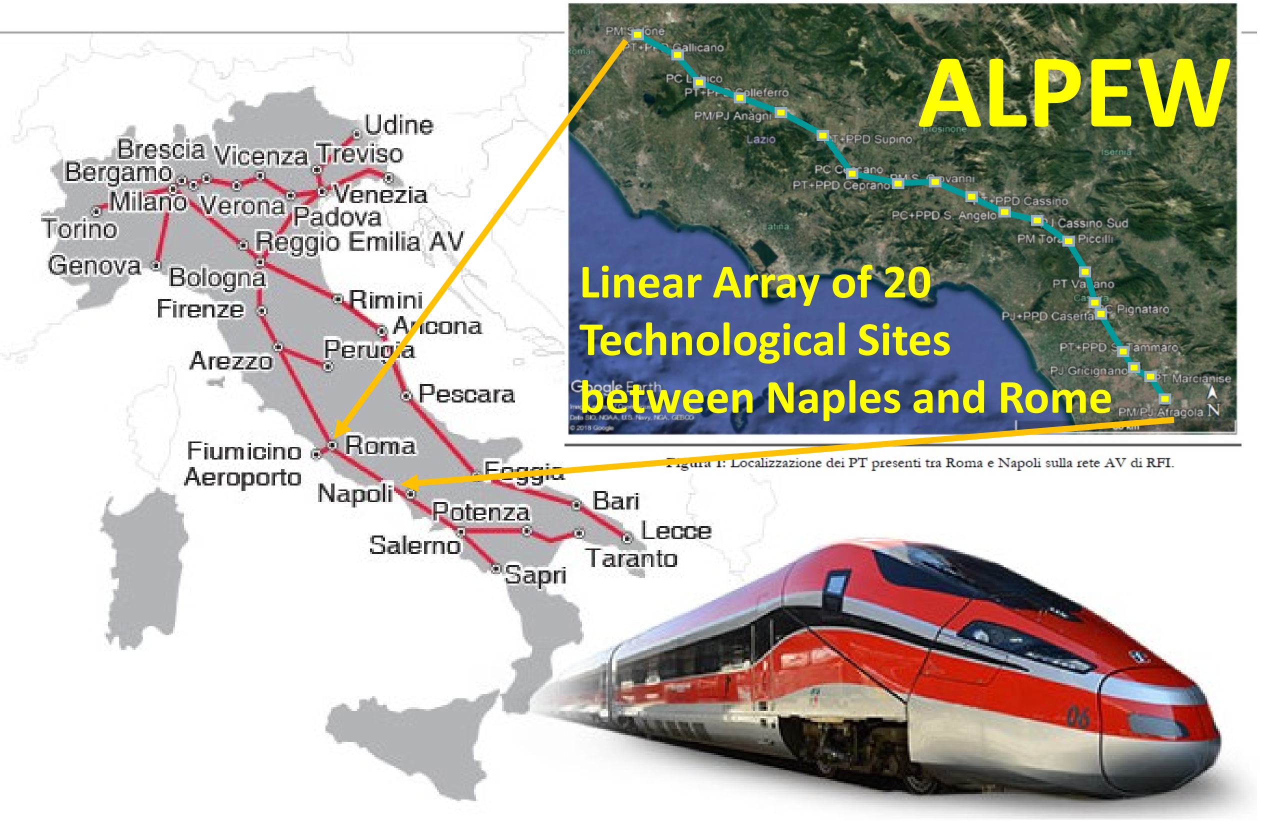
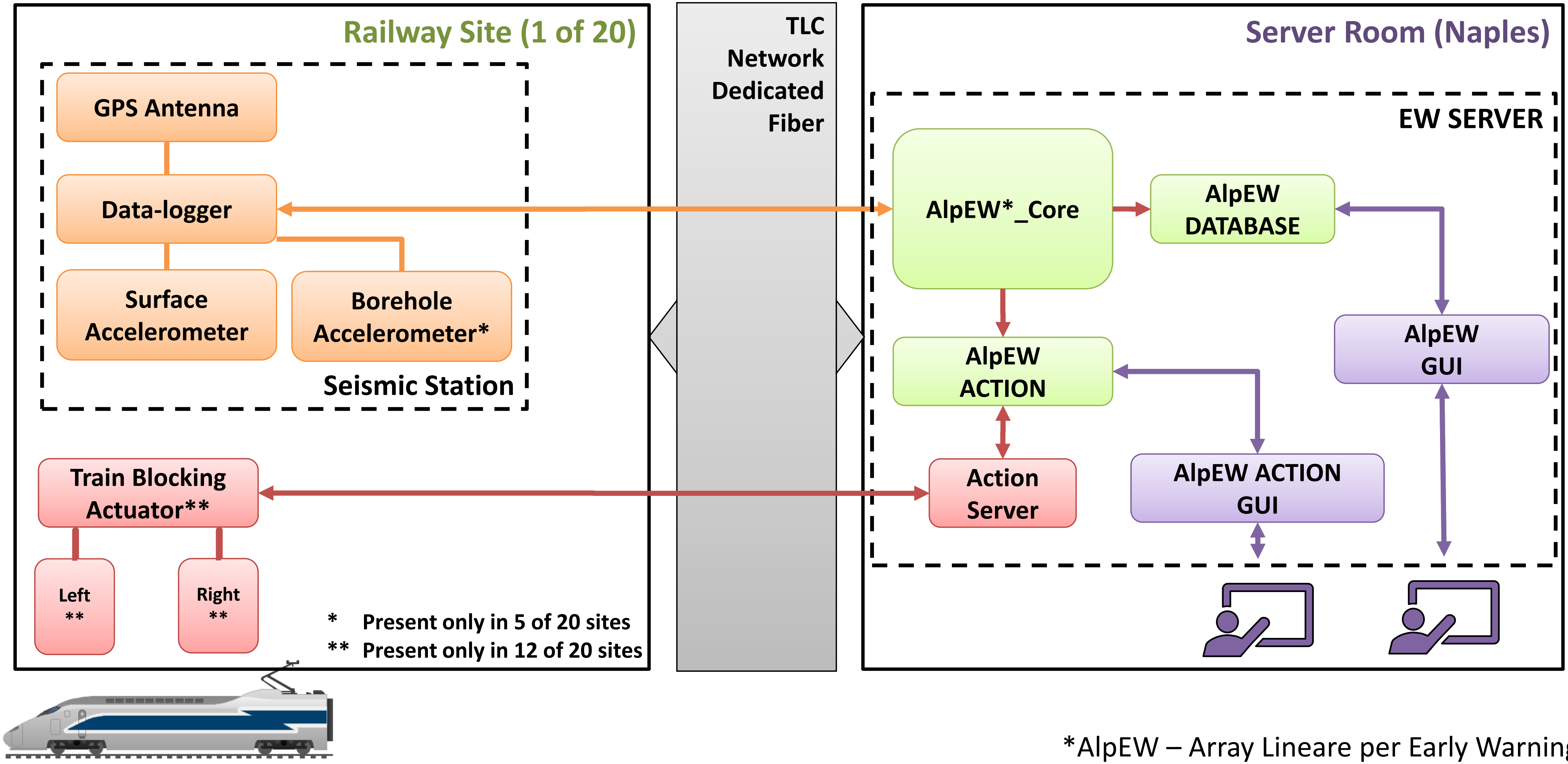


Figura 1: Localizzazione dei PT presenti tra Roma e Napoli sulla rete AV di RFI.

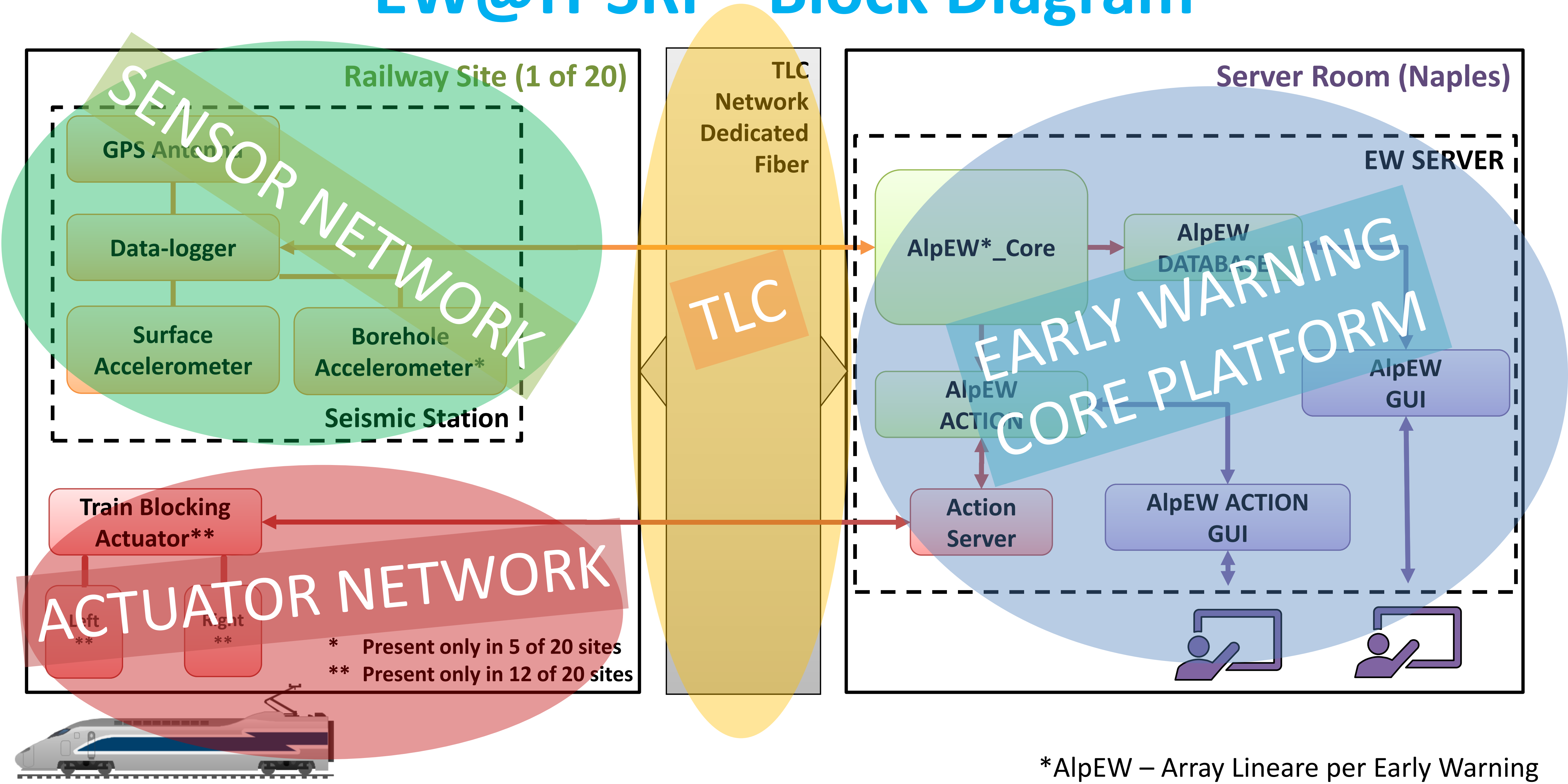
- ***Automatic actions***:
  - declare & **dispatch the alert** to the control room
  - **activate the devices** (Train Braking Actuators - CU) to stop the trains.
  - Define the «**end of the alert**» to re-start the train traffic (not automatic).
- ***Seismic impact evaluation***:
  - estimate the peak ground motion parameters (PGA, PGV) at the array nodes an all along the railway line

EW@H-SRI – Block Diagram



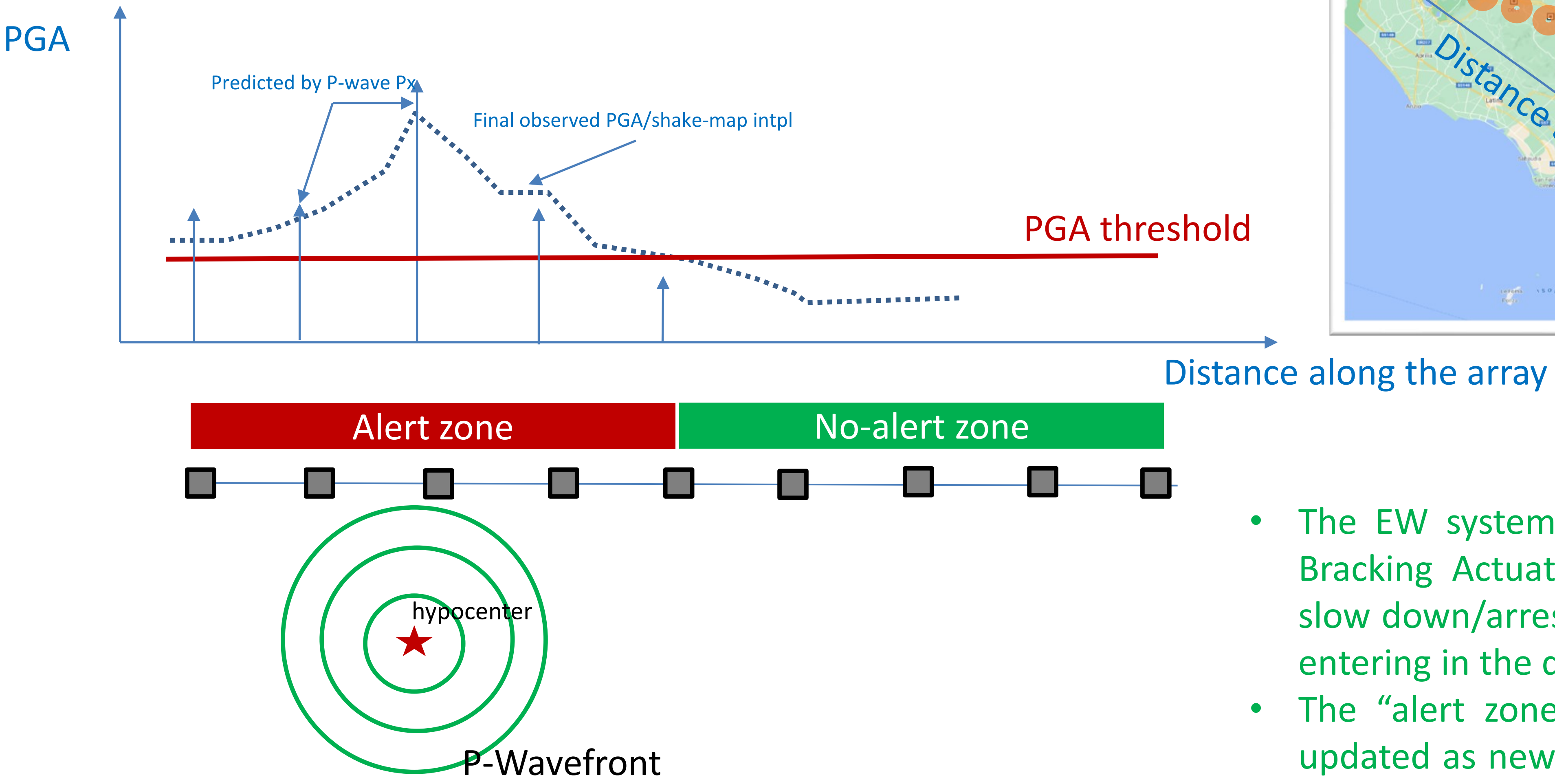
*AlpEW – Array Lineare per Early Warning

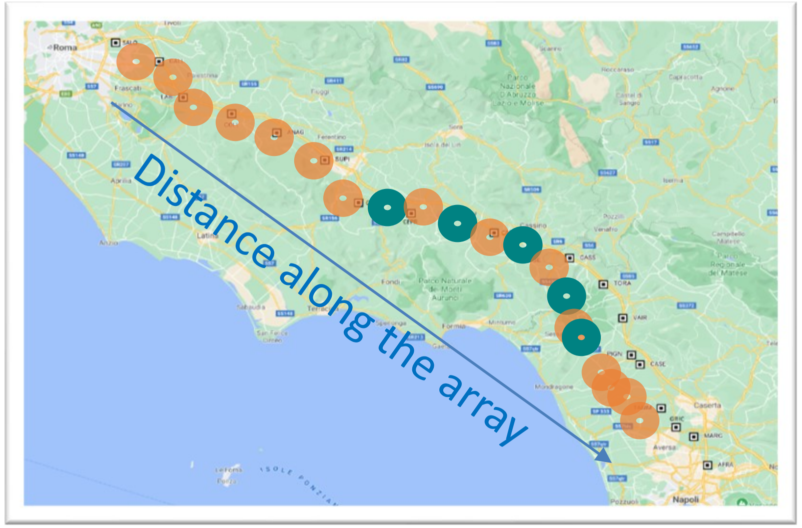
EW@H-SRI – Block Diagram



*AlpEW – Array Lineare per Early Warning

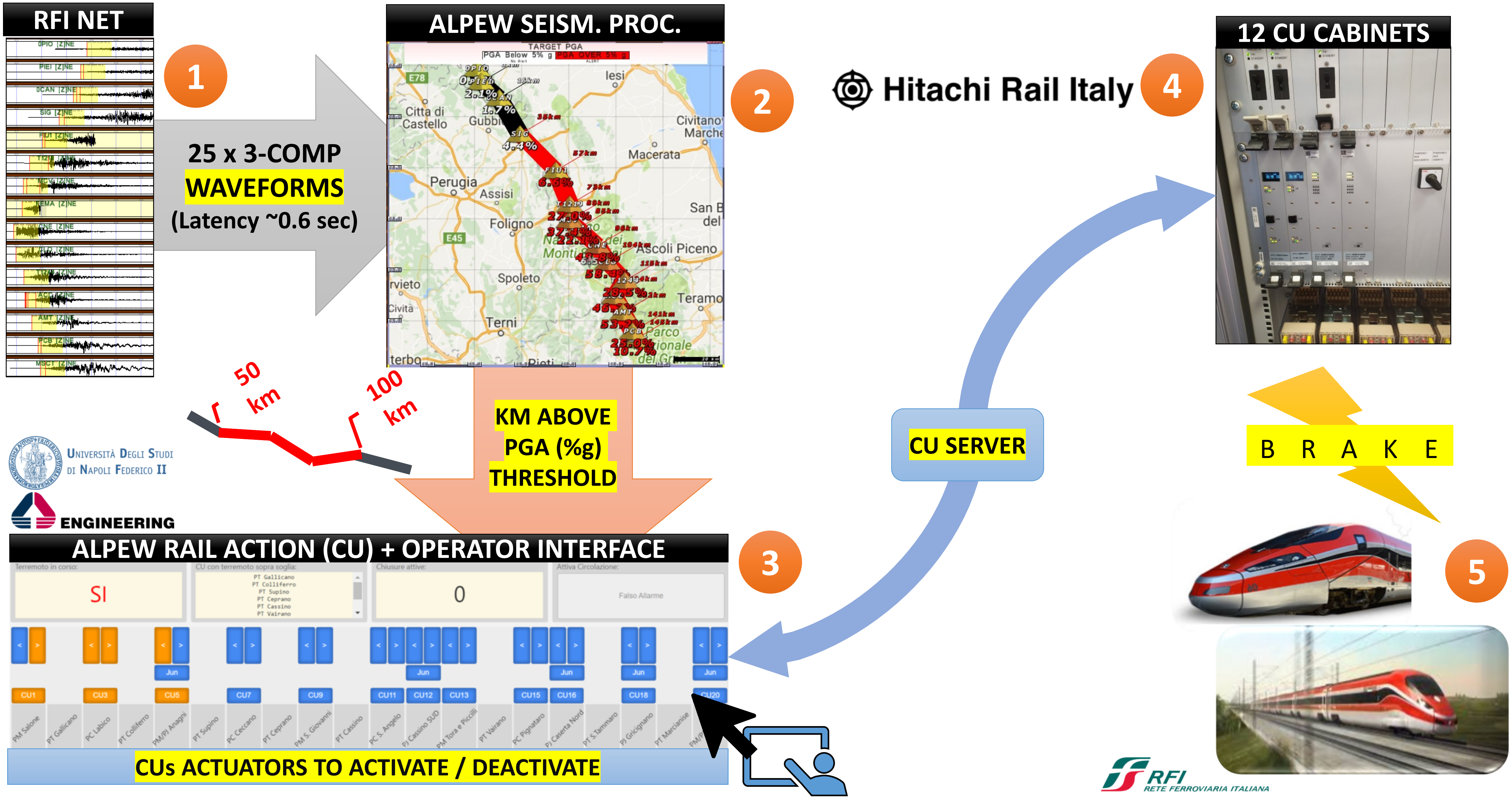
ALPEW: Alert and Early-Shake-Map





- The EW system interacts with the Train Bracking Actuators along the railway to slow down/arrest high-speed train before entering in the declared alert zone.
- The “alert zone” extent is progressively updated as new P-data are processed by the EW system

From Seismic Waveforms To Safety Actions on the Railway



Example of performance analysis: waveform playback

Earthquake: NORCIA [30-10-2016 06:40:17 (UTC)], Mw 6.5

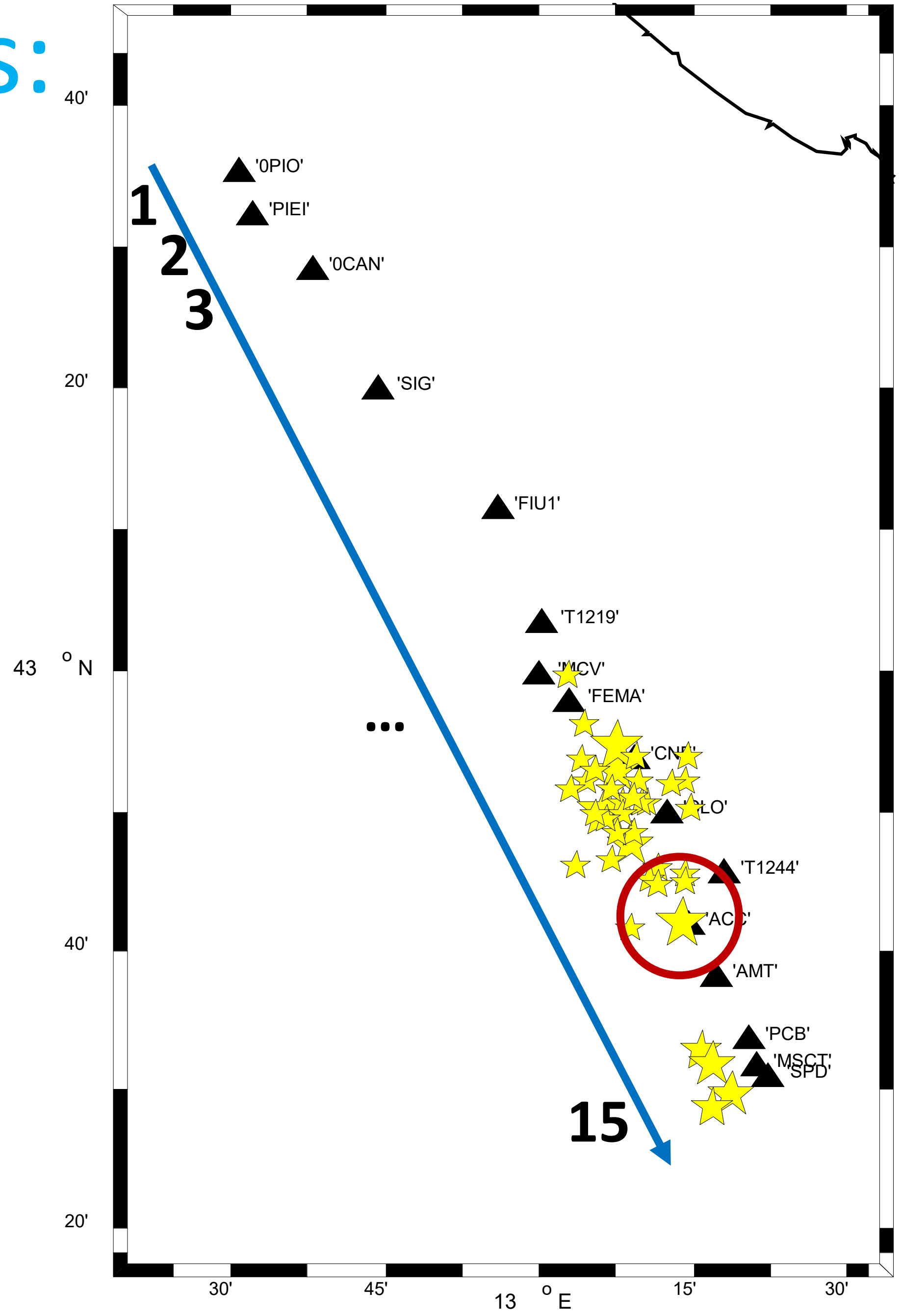
Virtual near-linear railway: 144 km long

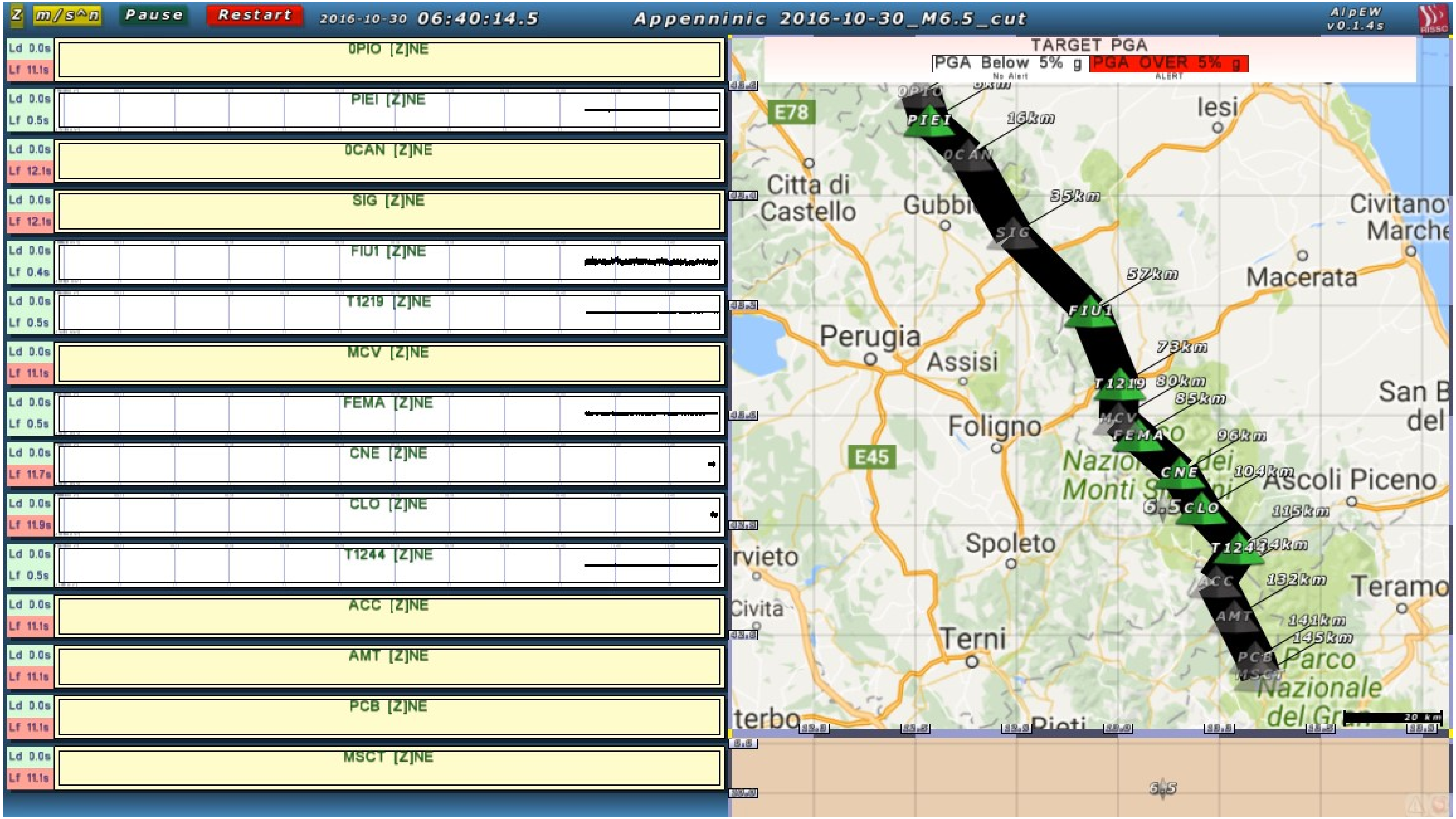
Array: NW-SE oriented array (15 stations, average spacing 10 km)

Alert decision module: Single-Station-Basic

PGA threshold level: 5%

EPL level: 50%

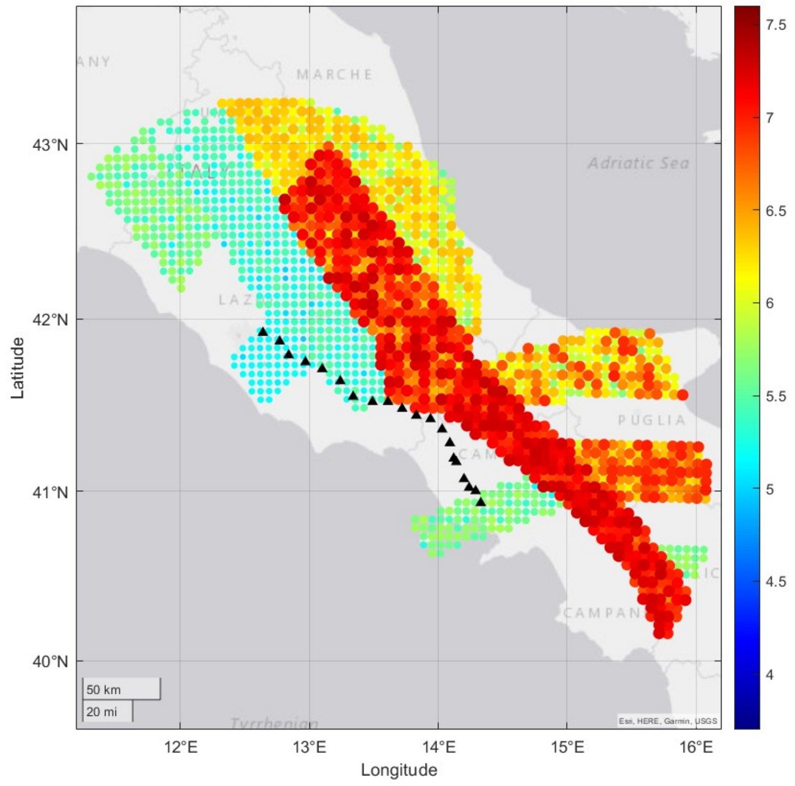


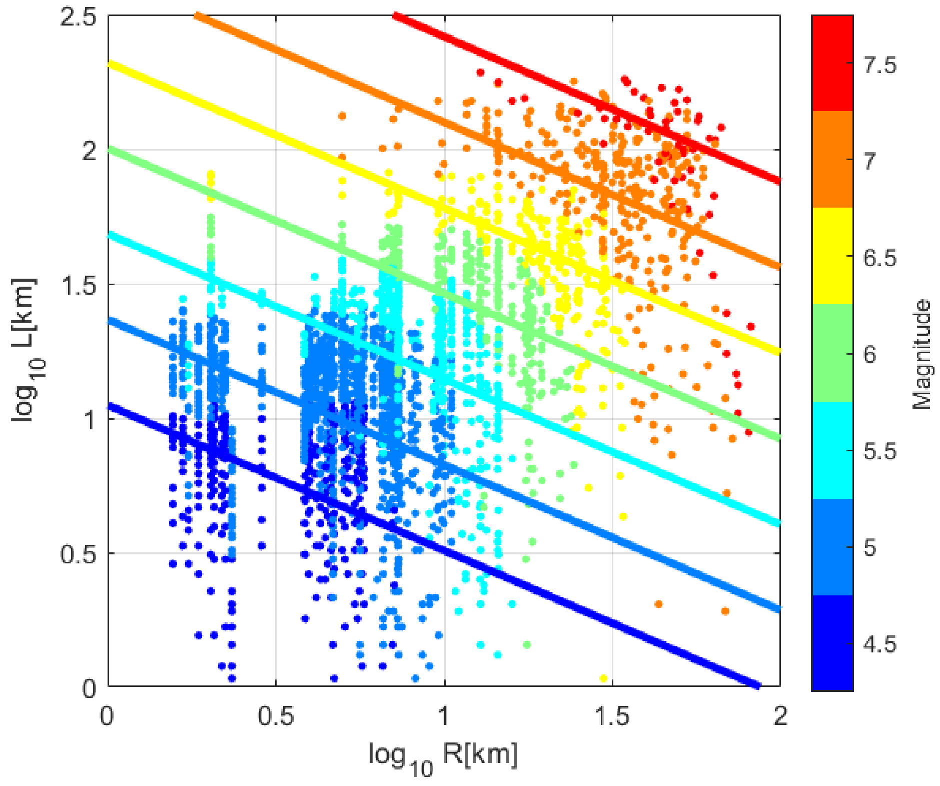


Z m/s^n Pause Restart 2016-10-30 06:40:14.5
Appennininc 2016-10-30_M6.5_cut
AlpEW v0.1.4s
0PIO [Z]NE
PIEI [Z]NE
0CAN [Z]NE
SIG [Z]NE
FIU1 [Z]NE
T1219 [Z]NE
MCV [Z]NE
FEMA [Z]NE
CNE [Z]NE
CLO [Z]NE
T1244 [Z]NE
ACC [Z]NE
AMT [Z]NE
PCB [Z]NE
MSCT [Z]NE
TARGET PGA
PGA Below 5% g
No Alert
PGA OVER 5% g
ALERT
16km
35km
57km
73km
80km
85km
96km
104km
115km
132km
141km
145km
6.5
20 km

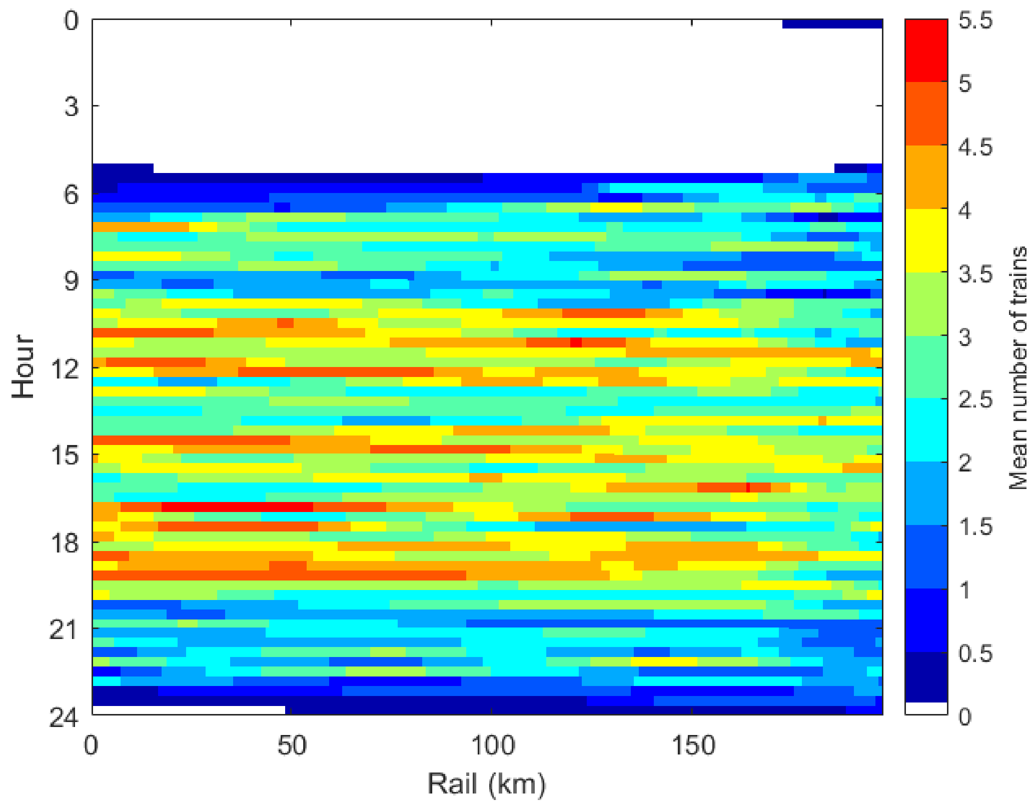
Length of the railway route at risk as a function of earthquake magnitude and distance

Given the PGA threshold set by the railway manager, we calculated the length of the segment along the Napoli-Roma railway that is potentially at risk of damage in the occurrence of an event with a given magnitude and distance from the railway. The earthquake sources are located with the seismogenic zones of the seismic hazard map of Italy





Effectiveness of the EW System for High-Speed Railways in Italy



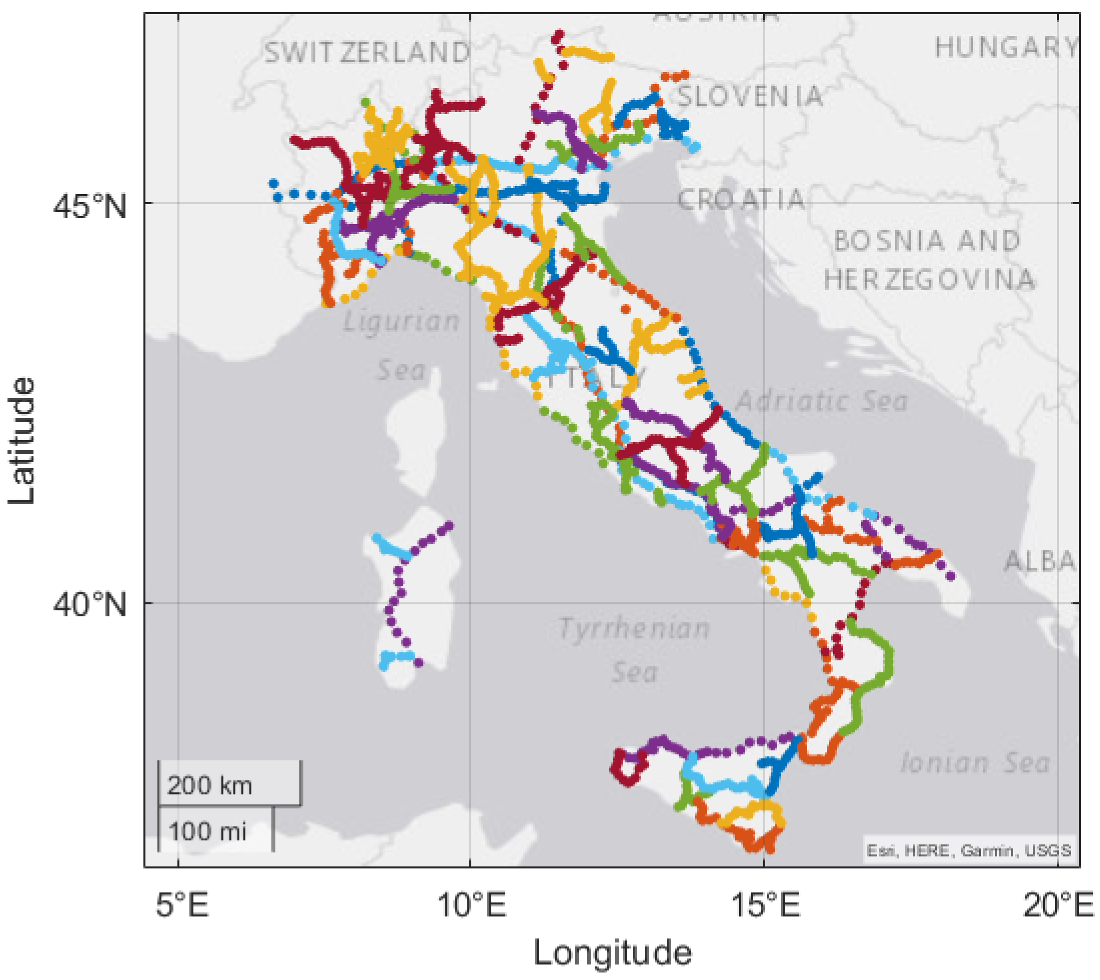
Average number of HS-train transits in 24 hours along the railway (20-minute window) calculated over a period of 2 months

Average number of trains travelling within or outside the Alerted Segment of the Railway (ASR)

	Low-Density Occupancy: 6h-10h & 20h-23h		High-Density Occupancy: 10h – 20h		
ASR (km)	# of trains within ASR	# of trains outside ASR	# of trains within ASR	# of trains outside ASR	Estimated Return Period (ys)
L = 10	0-1	5-6	0-1	9-10	10-15
L = 30	0-1	5-6	1-2	8-9	65-70
L = 50	1-2	4-5	2-3	7-8	~200
L = 100	3-4	3-4	5-6	5-6	~2000

For almost all the estimated ASR lengths and in both time slots, the relative percentage of trains that will be outside the ASR is always favourable, as compared to the trains that would be within the ASR. Except for the rare case of ASR = 100 km that corresponds to a large earthquake occurring very close to the line (M > 6.5 & R < 20 km).

Early Warning System for High-Speed Railways in Italy: Perspectives



- The development of an Early Warning System for High Speed railways in Italy is a signficant S&T challenge
  - short epicentral distances, expected reduced lead times
  - high impact of potential false/missed alarms.
- The system solution is tailored to the user needs
  - innovative technological and method solutions
  - Fully integration with the rail traffic control system
- The experience and know-how gained in this project will be used by RFI to develop in the next future a nation-wide , integrated EW and RR railway monitoring system in Italy

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