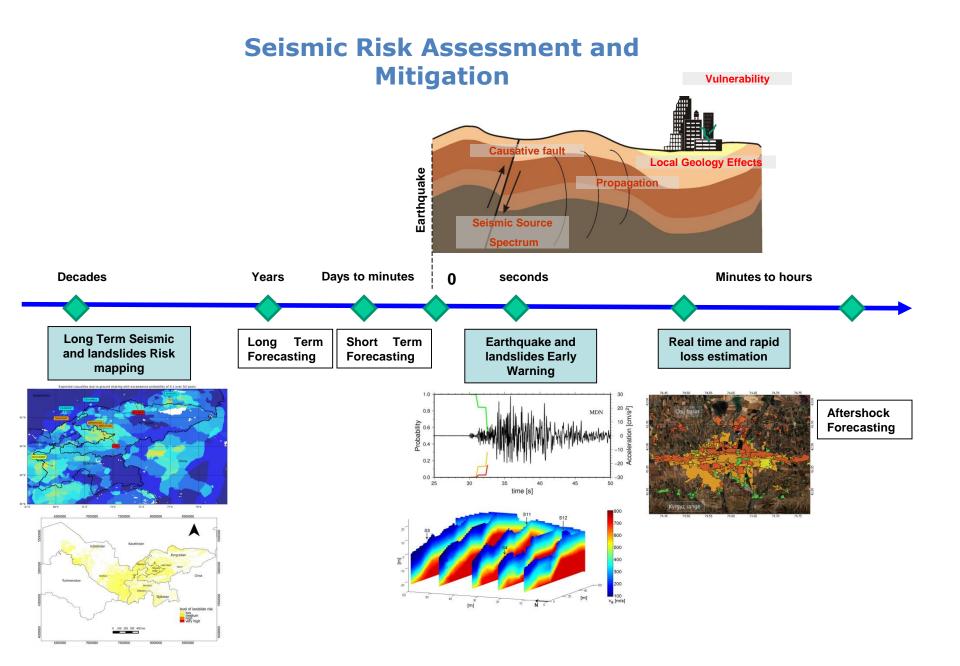
Earthquake Early Warning

S. Parolai



Objective

The goal of an EEW system is the estimation in a fast and reliable way an earthquake's damage potential before the strong shaking hits the target

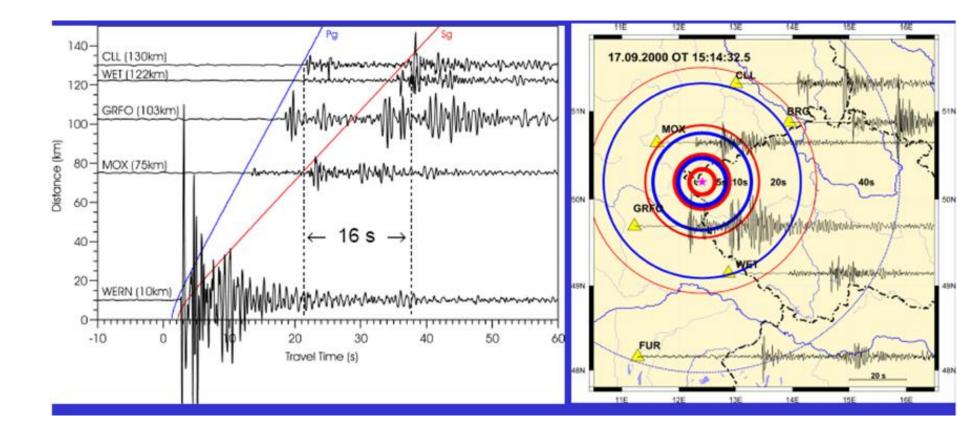
Principles

The idea of developing systems for launching early alert messages about incoming ground shaking dates back to 1868 (*Cooper JD, Letter to the Editor, San Francisco Daily Evening Bulletin, November 3, 1868*). It is based on the fact that information spread through electromagnetic signals travels faster (about 300,000 km/s) than seismic waves (a few km/s). Moreover, most of the radiated seismic energy is carried by S- and surface-waves, which travel slower than P-waves.

Early examples

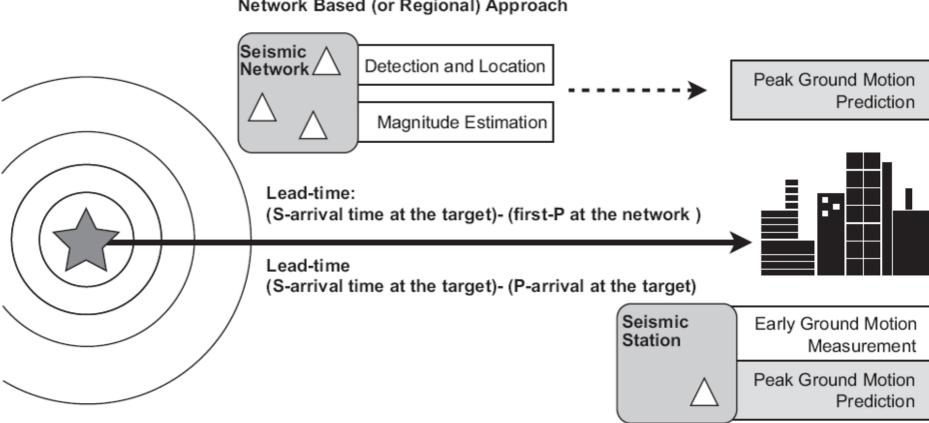
The first early warning systems were developed and installed during the cold war to detect incoming intercontinental ballistic missiles. These early warning systems were designed to alert target areas as soon as a missile was detected by a radar or a launch discovered by satellite systems.

from Satriano et al., SDEE, 2011



Approaches

There are two main approaches: **Regional** (or network-based) EEW systems and **Onsite** (or single-station) EEW systems.



Network Based (or Regional) Approach

from Satriano et al., SDEE, 2011

Single Station (or On Site) Approach

Methodology Regional network EEW system

Event detection and location

Magnitude estimation

Peak ground motion prediction at target site

Alert notification

Onsite approaches predict the ground shaking associated with S-wave starting from the ground shaking recorded for P-waves.

Some Onsite (or single station) EEW systems also estimate the location and magnitude of the event (e.g., Nakamura approach; Odaka approach; etc).

Starting from the Regional and Onsite schemes, more complex and hybrid systems can be established. For example, Onsite systems can be composed of several nodes communicating witheach others and fed with information coming from a Regional networks. The Regional scheme may in turn simplified into a concept involving a front-detection scheme when the source region is known.

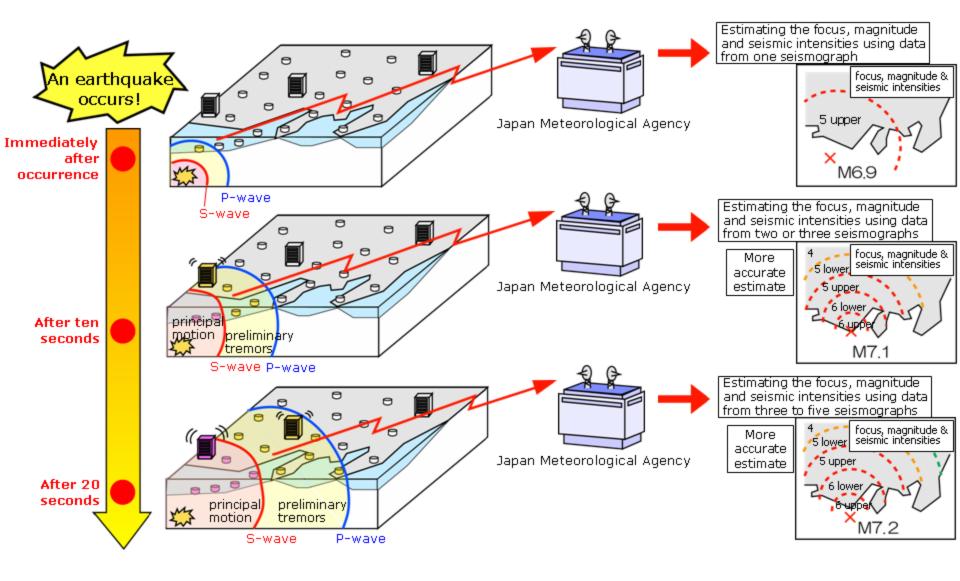
Time is a critical parameter in any EEW system. The system and procedures have to be designed in such a way as to maximize the **lead time** for the target area.

	Regional	Onsite
Network deployment	Source region	Target area
Data analysis	Network based	Single station
Output parameters	Location, magnitude	Location, magnitude or expected intensity
Accuracy on source parameter estimation	Good to high	Moderate
Lead-time	Ts at the target–Tp at the source	Ts at the target–Tp at the target

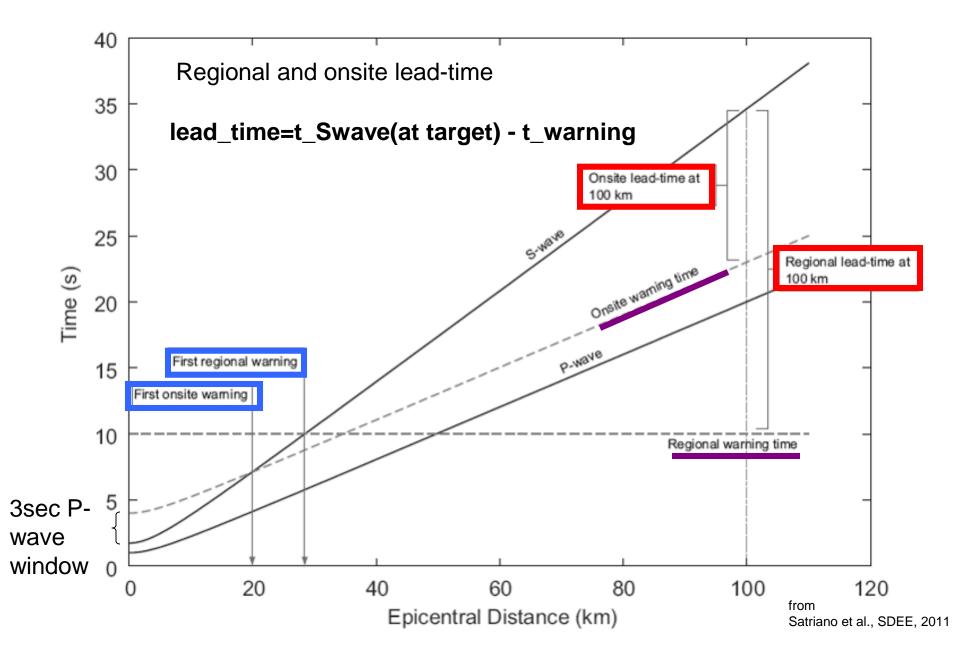
from Satriano et al., SDEE, 2011

Lead time maximization and improvements in the estimation of parameters (such as magnitude, location) however involve a trade-off. The minimization of the false alarms is also crucial.

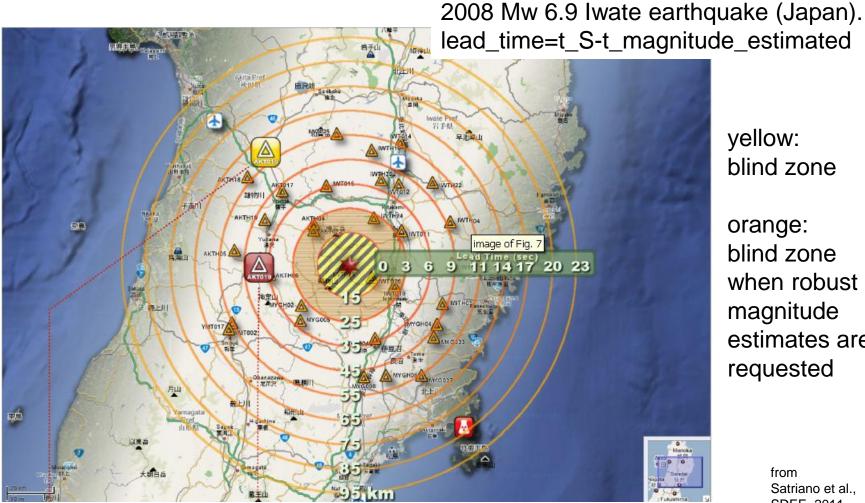
Therefore, any EEW system has to be tailored to the specific situation at hand.



from JMA webpage



Examples of estimated lead time

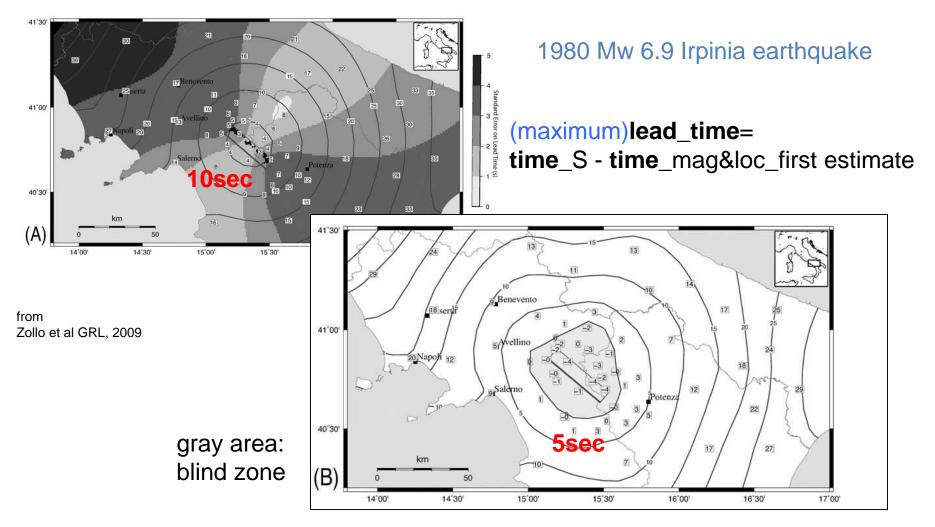


yellow: blind zone

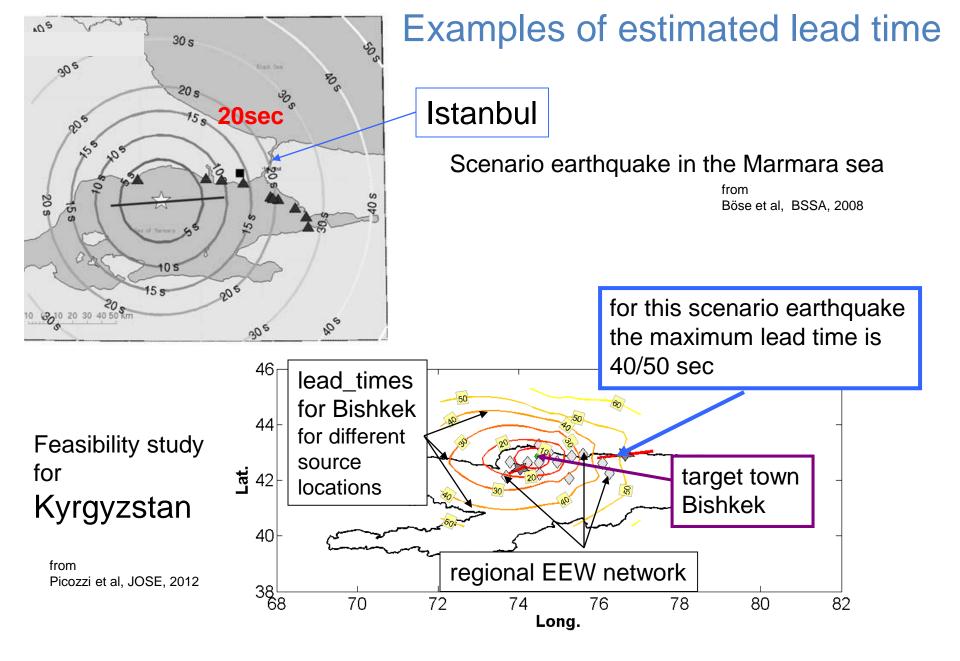
orange: blind zone when robust magnitude estimates are requested

> from Satriano et al., SDEE, 2011

Examples of estimated lead time



(effective)lead_time=time_S - time_EW_parameters_stable estimate



Procedures for estimating early warning parameters are generally based on evolutionary (time-dependent) schemes: the "quick & dirty" estimates obtained by analyzing information gathered by a single station are constantly updated as soon as new data are acquired by the system.

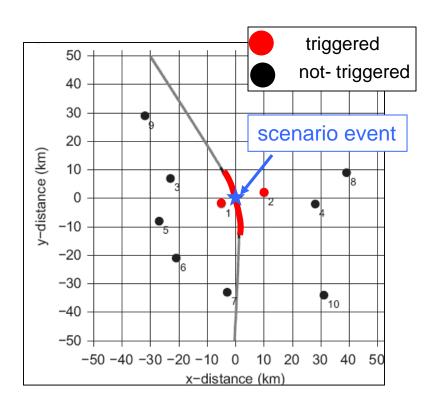
Example:

ElarmS (California, Wurman et al 2007):

- A) Detection based on STA(0.5sec)/LTA(5sec) ratio at each individual station.
- B) Initial hypocenter placed with respect to the triggered station (depth fixed according to the regional tectonic regime).
- C) When a second station is triggered, the epicenter is moved between the two stations.
- D) With three or more triggers, event location and origin time are estimated using a grid search algorithm.

Recently, new earthquake location procedures have been introduced. These make use of the concept of **not-yet-triggered** stations.

Ryedelek & Pujol (2004) constrained the epicentral location using only two triggered stations and a set of not-yet-triggered ones.



Stations 1 and 2 triggered:

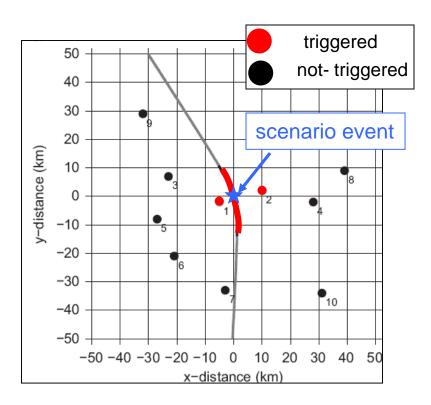
$$t_2 - t_1 = \frac{1}{V} (d_2(\mathbf{x}) - d_1(\mathbf{x})) = t t_2(\mathbf{x}) - t t_1(\mathbf{x})$$
(1)

Equation (1) defines a hyperbola (open curve). Station 3 has not yet triggered, therefore

$$\frac{1}{V}(d_3(\mathbf{x}) - d_i(\mathbf{x})) = tt_3(\mathbf{x}) - tt_i(\mathbf{x}) \ge 0, \quad i = 1, 2 \quad (2)$$

and similar inequalities can be set up for the other not-triggered stations. This set of inequalities identifies a segment (shown in red in Figure) over the hyperbola.

Recently, new earthquake location procedures have been introduced. They make use of the concept of **not-yet-triggered** stations.



$$\frac{1}{V}(d_3(\mathbf{x}) - d_i(\mathbf{x})) = tt_3(\mathbf{x}) - tt_i(\mathbf{x}) \ge 0, \quad i = 1, 2 \quad (2)$$

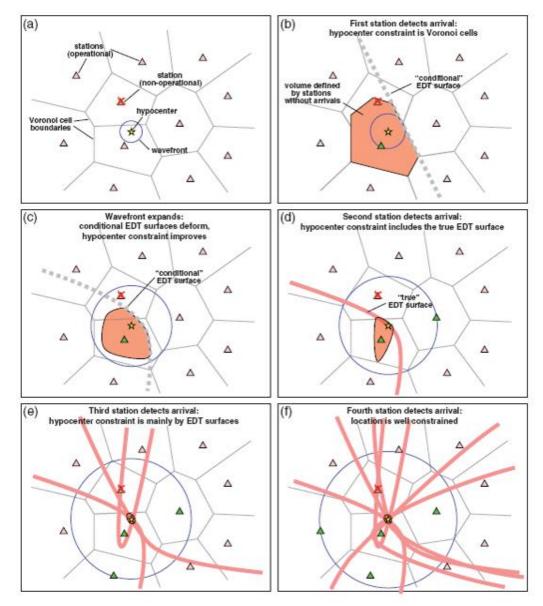
Horiuchi et al. (2005) extended this approach considering that, as time passes since the first two triggers: a) the constraint on the earthquake location given by (2) increases and b) other stations will trigger. Equation (2) can be generalized to

$$tt_{i}(\mathbf{x}) - tt_{i}(\mathbf{x}) \ge t_{now} - t_{i} \tag{3}$$

where i is a triggered-station and j not-trig-station. This inequalities identifies a volume containing the hypocenter which shrinks when t_now is running

Cua & Heaton (2007) extended the previous approach by introducing Voronoi cells, in order to start the location determination with only one triggered station.

The approach has been further developed by Satriano et al. (2008) and Rosenberg (2009).

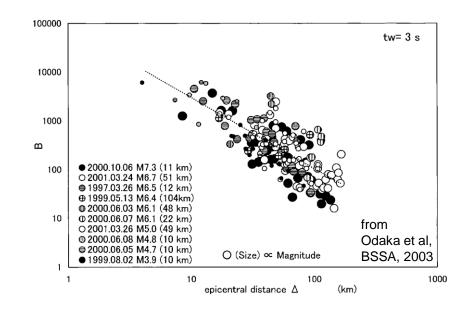


Regarding the **Onsite** approaches, there are some examples of location (and magnitude) **estimation using a single station**.

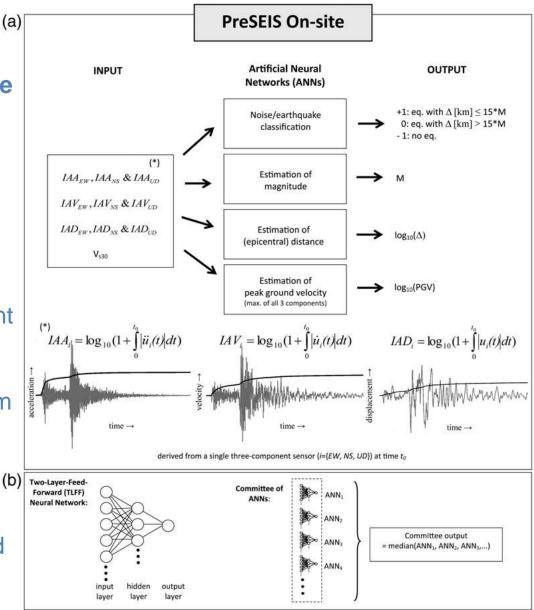
Nakamura (1984). The UrEDAS system first estimates the magnitude on the basis of the predominant period of the P-waves. Then, the hypocentral distance is inferred from the peak P-wave amplitude

using an empirical magnitude-amplitude relation that includes the hypocentral distance as a parameter. The azimuth of the epicenter is determined by polarization analysis over the three components.

Odaka et al (2003). The function B t *exp*(-A t) is fitted to the envelope of the vertical component of acceleration (considering the first 3 sec). It has been observed that log(B) is proportional to – log(distance). The distance is first found using the measured B value, then the magnitude is determined using empirical equations for P-wave amplitude as in the Nakamura method.



Böse et al (2012). The PreSeis On-site approach provides a rapid earthquake/noise discrimination, a near/far source classification, and estimates the moment magnitude, the epicentral distance, and the peak ground velocity at the site of observation. PreSeis uses the seismic acceleration, velocity, and displacement waveforms recorded at a single threecomponent Strong Motion (SM) or Broad-Band (BB) sensor. The algorithm is based on Artificial Neural Networks (ANNs). Moreover, it uses global data (b) sets of BB and SM records for the training phase. This makes the approach more general and less linked to a specific region.



Rapid magnitude estimation for EEW is based on the observation that quantities like peak displacement, characteristic period, etc., estimated in the first few seconds of the recorded P- or S-signal, can be correlated to the final earthquake size. The EEW magnitude estimation is therefore based on empirical relationships between early-measured parameters and the earthquake's size.

from Satriano et al., SDEE, 2011

Examples:

The use of the initial portion of recorded P-wave for magnitude determination was introduced by Nakamura (1988). The **predominant period** is computed from the initial 2-4 sec of P-wave. It is called τ_p after Allen and Kanamori(2003). It is computed in real time from the vertical component of velocity (V) and acceleration (A):

$$\tau_{p,i} = 2\pi \sqrt{\frac{V_i}{A_i}}$$
 where $V_i = \alpha V_{i-1} + v_i^2$ and a is a smoothing parameter from 0 and 1.
 $A_i = \alpha A_{i-1} + a_i^2$

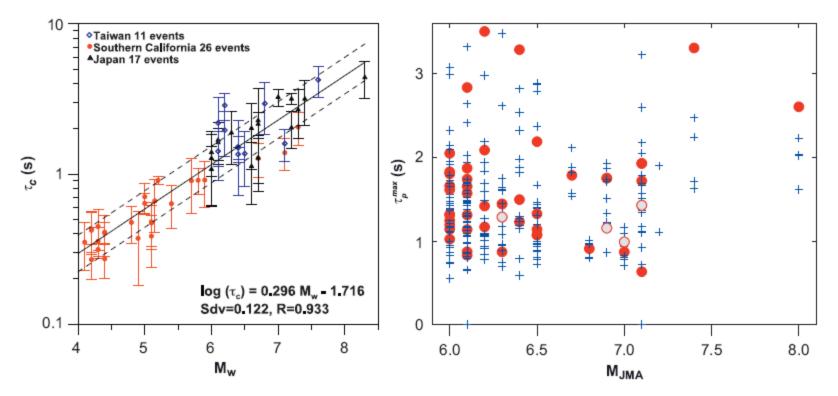
Nakamura (1988) and Allen and Kanamori (2003) observed that the predominant period linearly scales with the earthquake size.

Kanamori (2005) introduced the parameter τ_c which is similar to τ_p but defined as

$$r = \frac{\int_0^{\tau_0} \dot{u}^2(t) dt}{\int_0^{\tau_0} u^2(t) dt} \qquad \qquad \tau_c = \frac{1}{\sqrt{\langle f^2 \rangle}} = \frac{2\pi}{\sqrt{r}}$$

With τ_0 generally equal to 3 sec, and with displacement obtained by numerical integration and high-pass filtered at 0.075 Hz.

The effectiveness of this approach is still under debate.



Wu and Kanamori (2008): Correlation between τ_c and Mw of earthquakes in Japan, Southern California, and Taiwan. Rydelek and Horiuchi (2006): No-Correlation is seen between τ_p and M_{JMA} of earthquakes in Japan (Hi-Net)

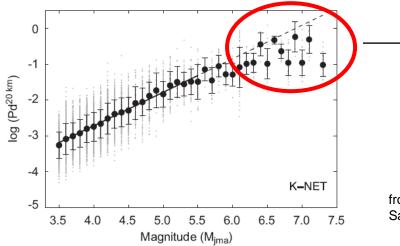
Satriano et al., SDEE, 2011

Different parameters from the predominant period have been introduced. Wu & Zhao(2006) and Zollo et al. (2006) investigated the peak displacement amplitude measured on the early P (and S) phases.

Wu and Zhao called this parameters Pd, measured on the vertical component, using the first 3 sec after the P arrival. They studied the attenuation of Pd with magnitude and distance in southern California:

 $\log P_d = A + BM + C \log R$

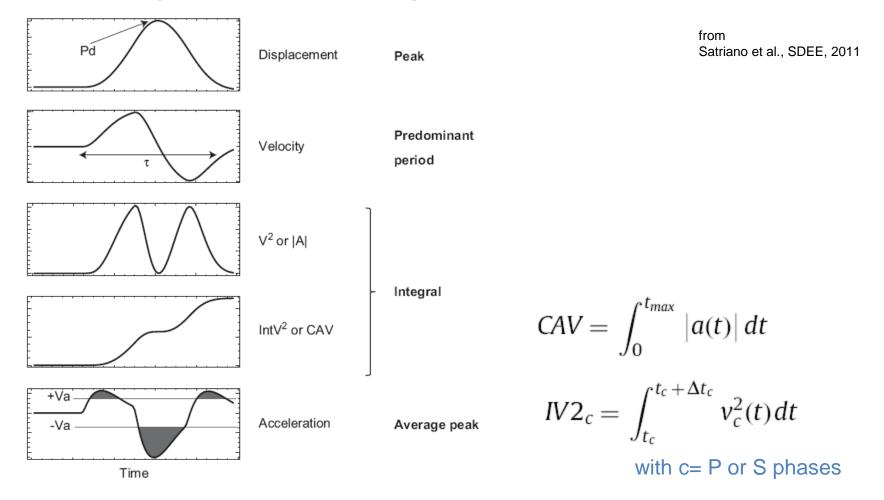
where the constants A, B, and C are determined trough regression analysis for the studied area. Once the distance is determined by the EEW algorithm, this empirical model is used to estimate M from the measured Pd.



The saturation effect is removed by considering larger windows (4sec of Pwave) or using the peaks read from the Swaves (Zollo et al, 2996; Lancieri and Zollo, 2008).

from Satriano et al., SDEE, 2011

Another class of EEW parameters used for estimating the earthquake size involves **integral measurements** (e.g. Festa et al., 2008)



ShakeAlert Every second counts

How does it work?

1st Example: Napa, M6 24 Aug 2014

2ND EXAMPLE: So. Cal. M7.8 Scenario

11

Ш

Napa

Time since earthquake

min:sec

IX

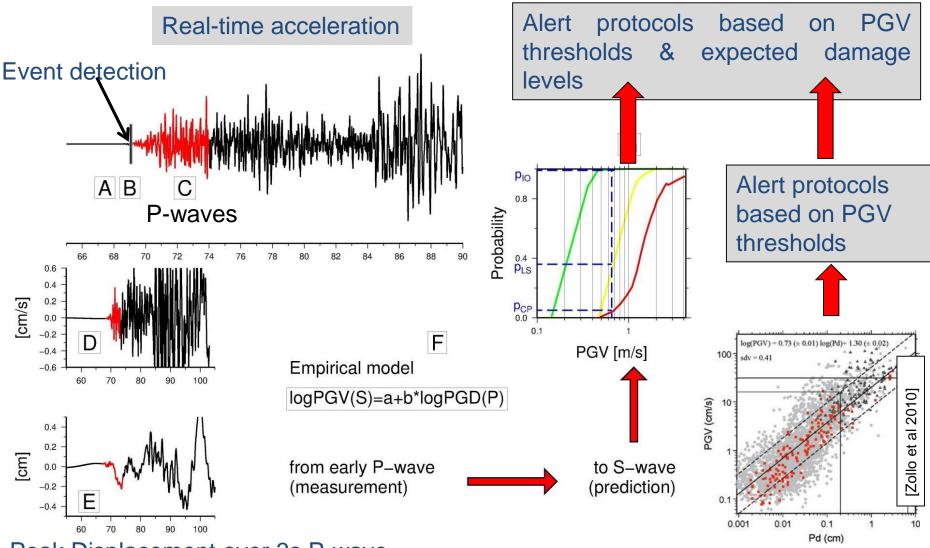
Berkeley

San Francisco

Shaking intensity: Weak Light Moderate Strong V. Strong Severe Violent Extreme

IV V VI VII VIII

Decentralised Onsite Early warning

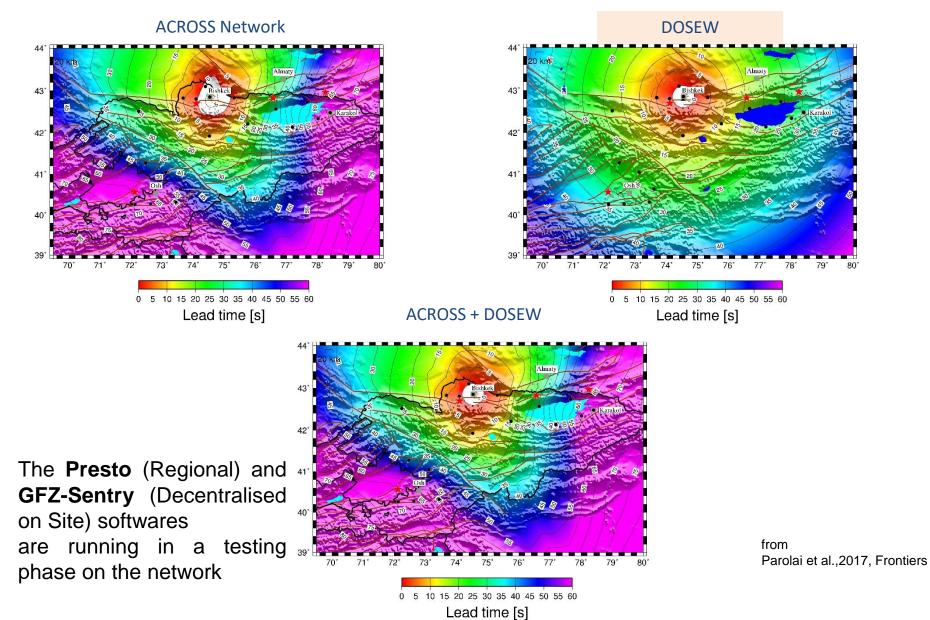


Peak Displacement over 3s P-wave

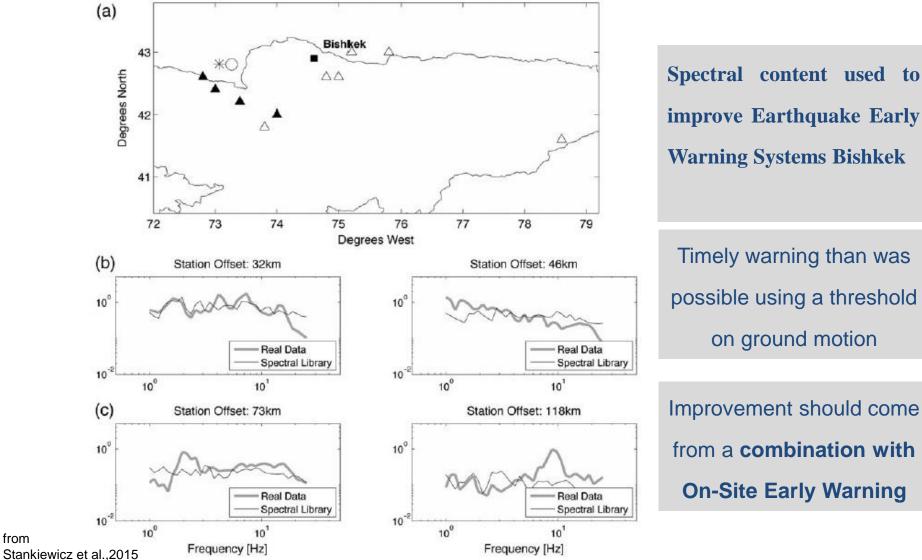
Recursive filters

http://www.dspguide.com/CH19. PDF

Online application to Kyrgyzstan: Lead time for Bishkek



Are magnitude and location necessary?



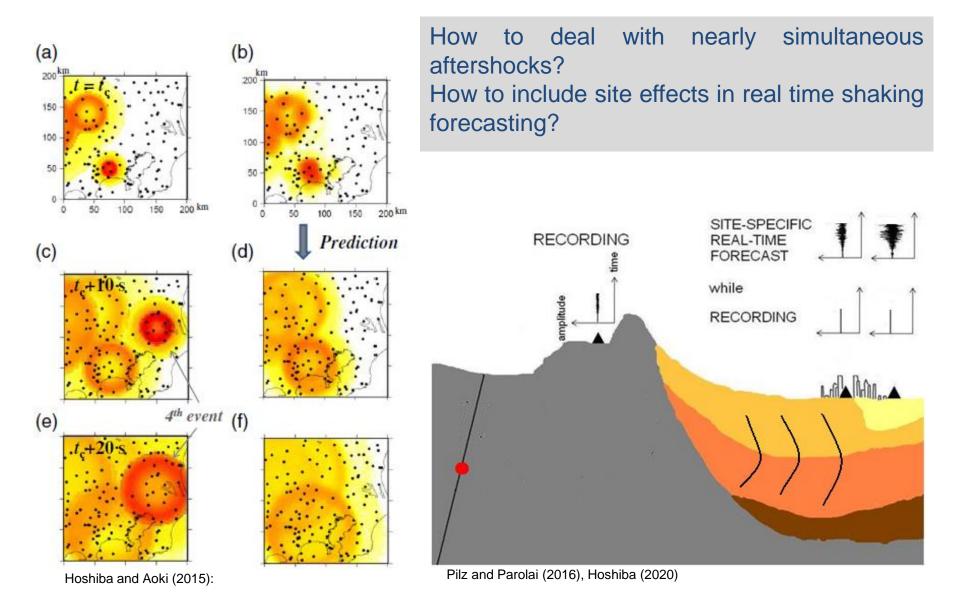
from

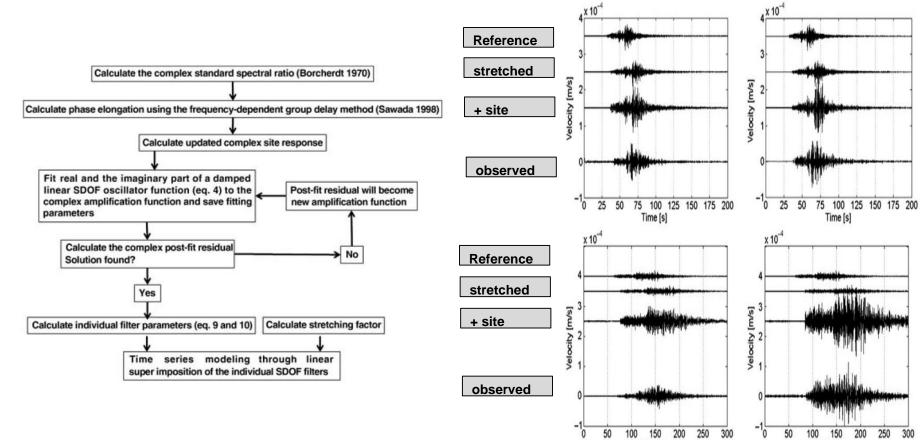
Timely warning than was possible using a threshold

on ground motion

Improvement should come from a combination with **On-Site Early Warning**

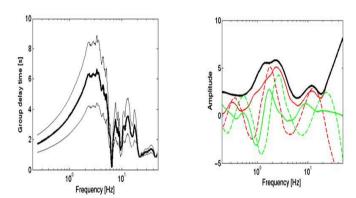
Some Emerging questions

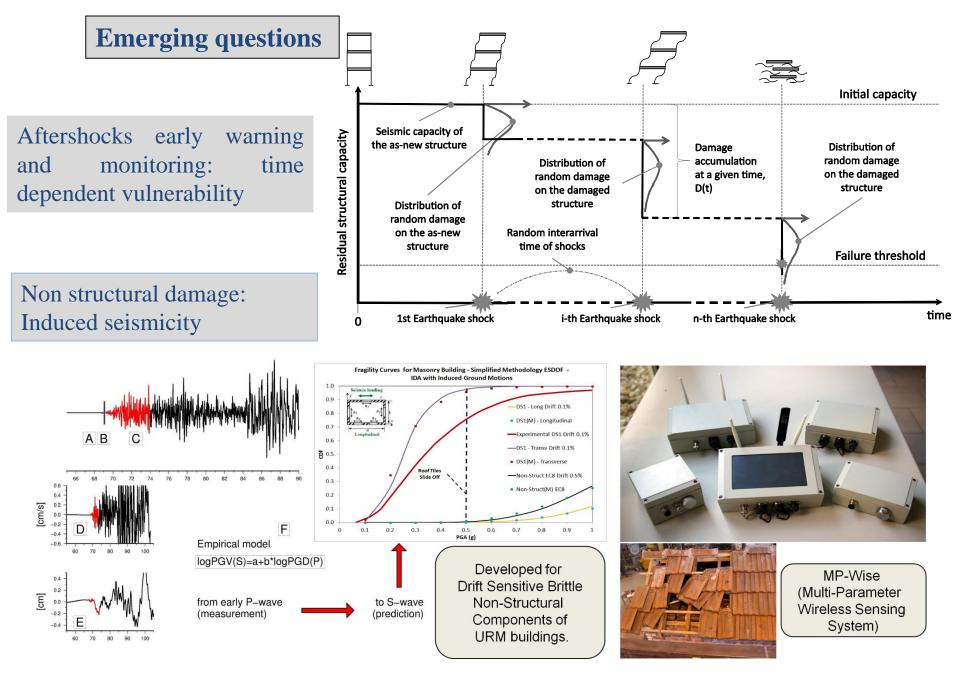




Time [s]

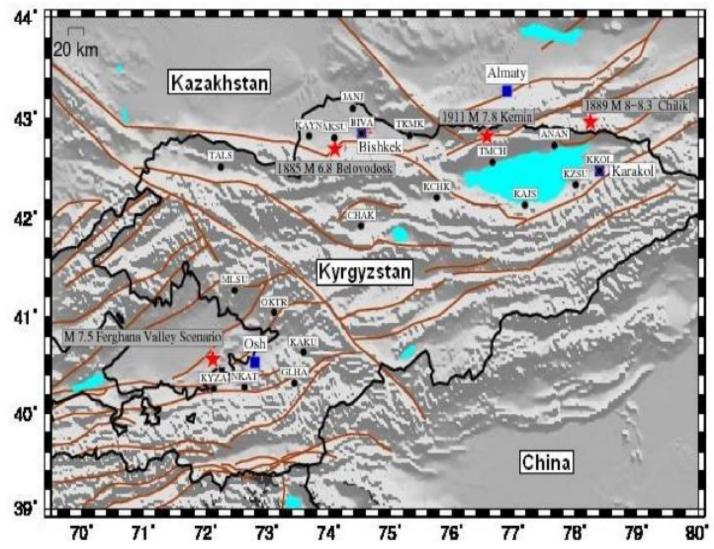
Time [s]

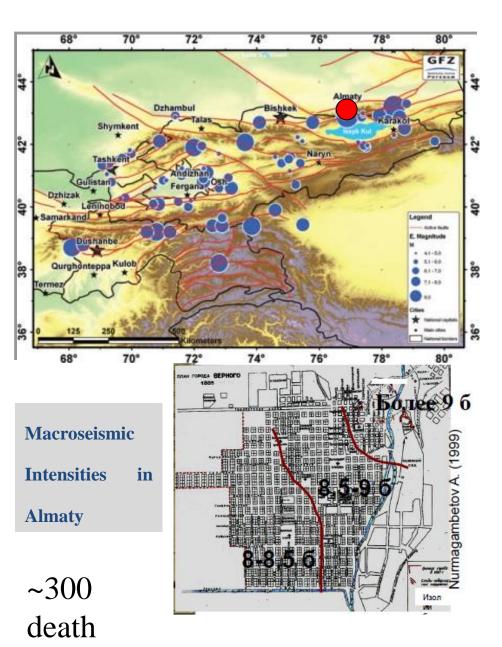




Applications

ACROSS Network





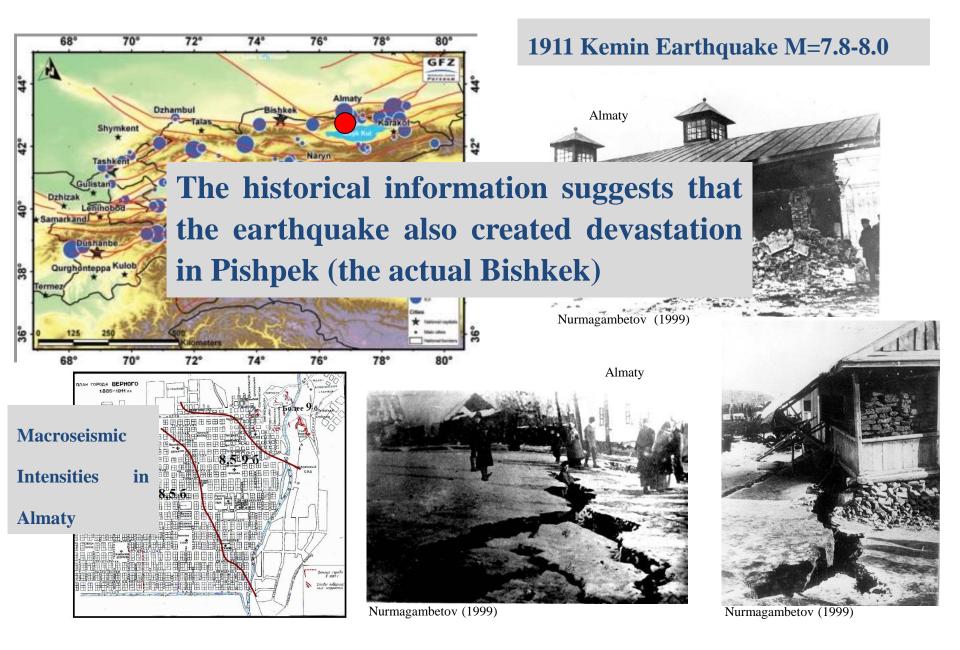
1887 Verny Earthquake M=7.3



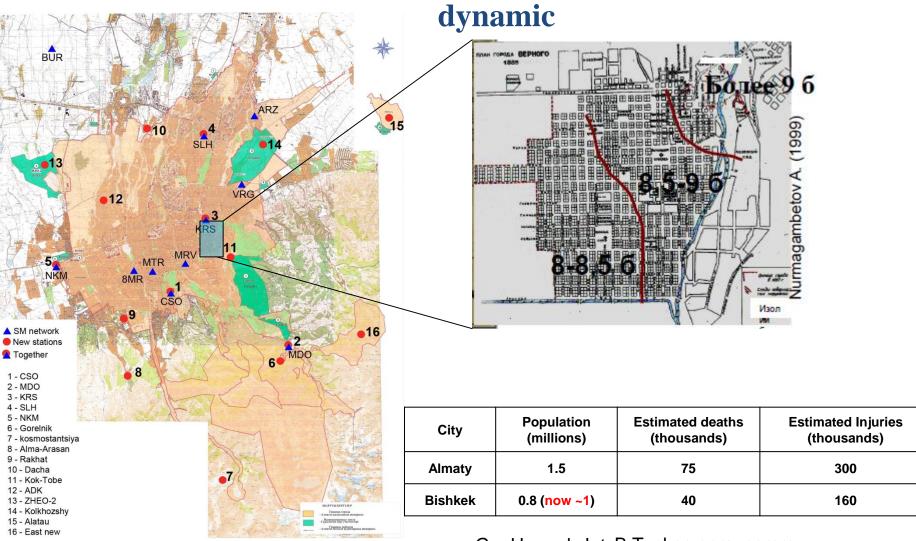
Nurmagambetov (1999)

Almaty

Nurmagambetov (1999)



High risk considering the urban

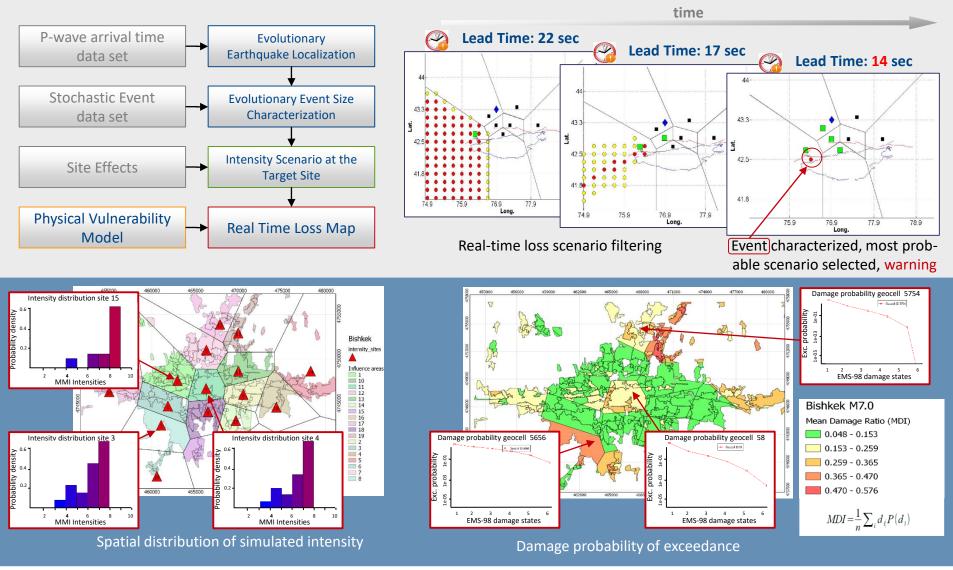


Parolai et al (2018) in preparation

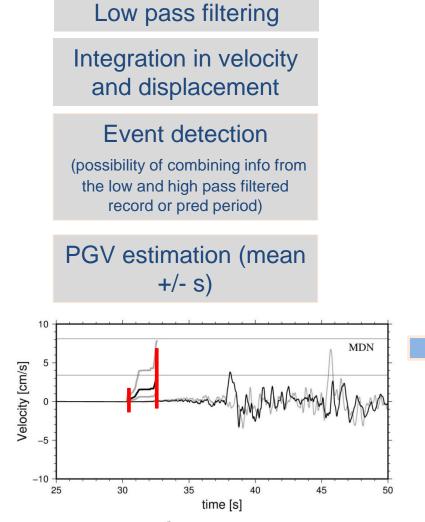
GeoHazards Int. B.Tucker, pers. comm.

Earthquake risk early warning

Picozzi et al (2013)



Decentralised On Site Early Warning



M 5.9 20th May 2012 Emilia earthquake

mean + σ > 8.1 cm/sec Intensity ≥VI

	mean – σ > 8.1 cm/sec	8.1 cm/sec>mean – σ > 3.4 cm/sec	mean – σ < 3.4 cm/sec
Mean >8.1 cm/sec			
8.1 cm/sec>mean>3.4 cm/sec			
Mean <3.4 cm/sec			

8.1 cm/sec > mean + σ > 3.4 cm/sec Intensity =V

	mean – σ > <mark>8.1</mark> cm/sec	8.1 cm/sec>mean – σ > 3.4 cm/sec	mean – σ < 3.4 cm/sec
Mean >8.1 cm/sec			
8.1 cm/sec>mean>3.4 cm/sec			
Mean < 3.4 cm/sec			Х

mean + σ < 3.4 cm/sec Intensity ≤IV

	mean – σ > 8.1 cm/sec	8.1 cm/sec>mean – σ > 3.4 cm/sec	mean – σ < 3.4 cm/sec
Mean >8.1 cm/sec			
8.1 cm/sec>mean>3.4 cm/sec			
Mean < 3.4 cm/sec			Х

from Parolai et al.,2015

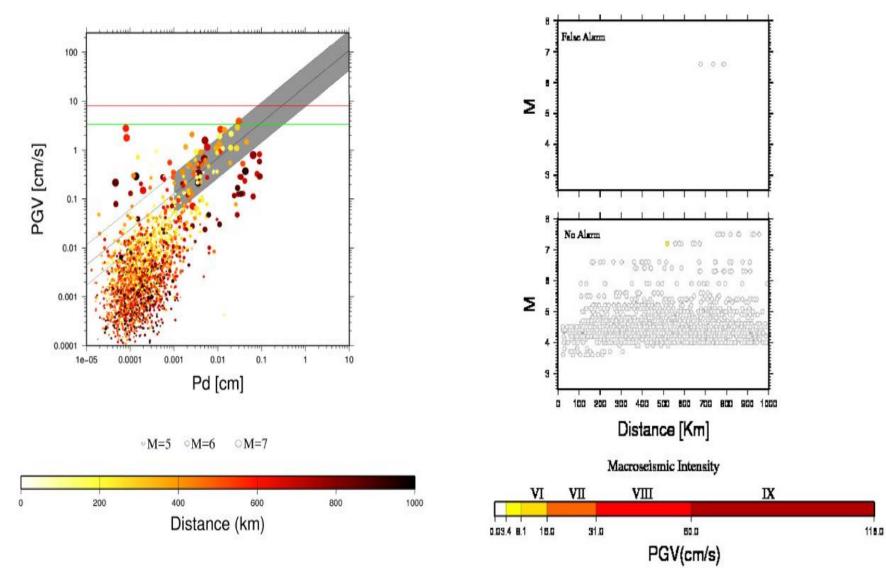


Decentralised Onsite-Early Warning

GFZ-Sentry Software, based on Parolai et al. (2015) and developed in cooperation with GEMPA GmbH.

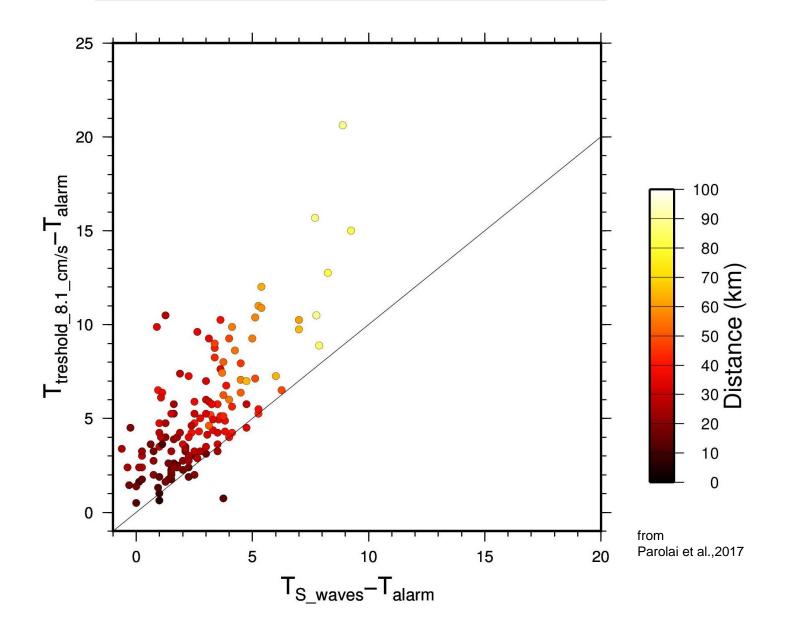
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Decentralised OSEW in testing

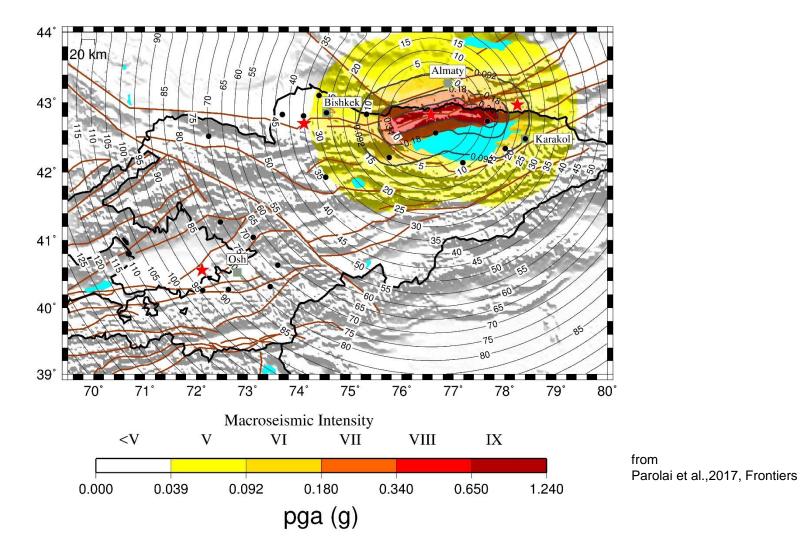


from Parolai et al.,2017, Frontiers

Application to KiK-Net and K-NET recordings



Offline application to Kyrgyzstan: Lead time for Repetition of the M 7.8 1911 Kemin Earthquake



1976 Seismic Sequence



Origin time: 20:00:13 UTC epicenter 46° 17' N - 13° 17' E Depth: 5 - 12 km

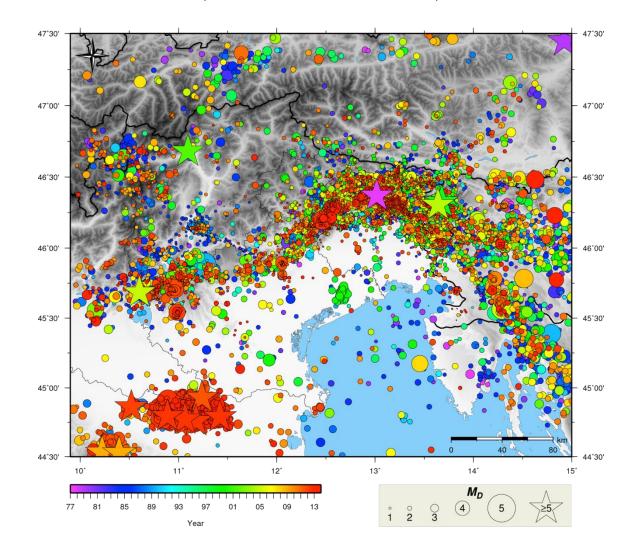
Magnitude: 6.0 mb 6.5 Ms 6.4 ML Epicentral intensity: X MKS

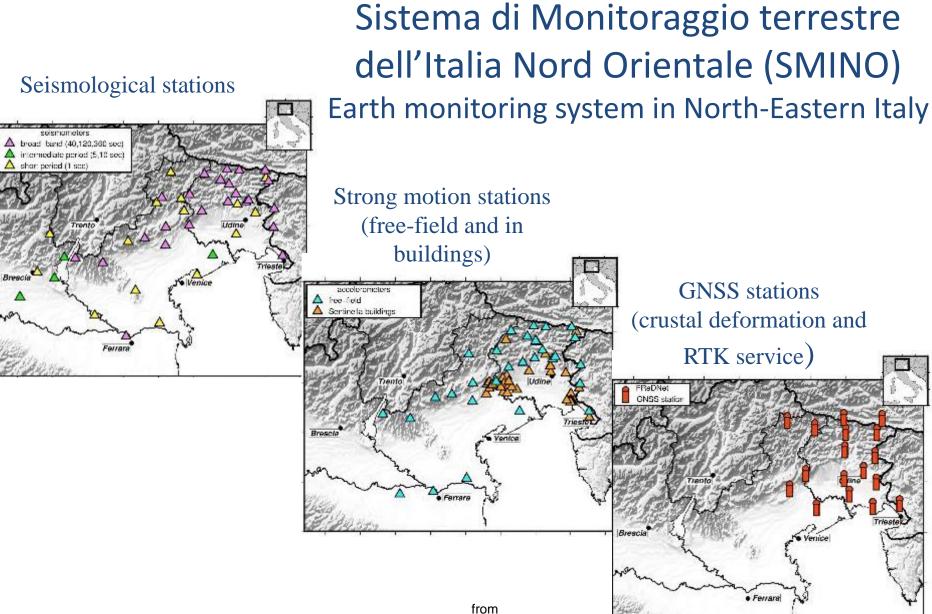
Max PGA recorded: 0,36 g

Felt at distance of : 579 km Impact Area : 5.700 km² Death toll: 989

People needing shelters: 110.000 Damage: 4.500.000 milions (lire in 1976)

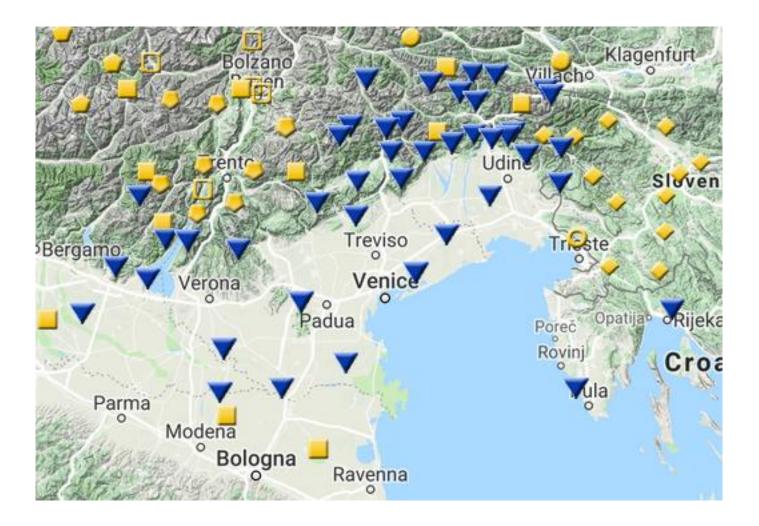
Earthquakes recorded since 1977 (>33.000 events)



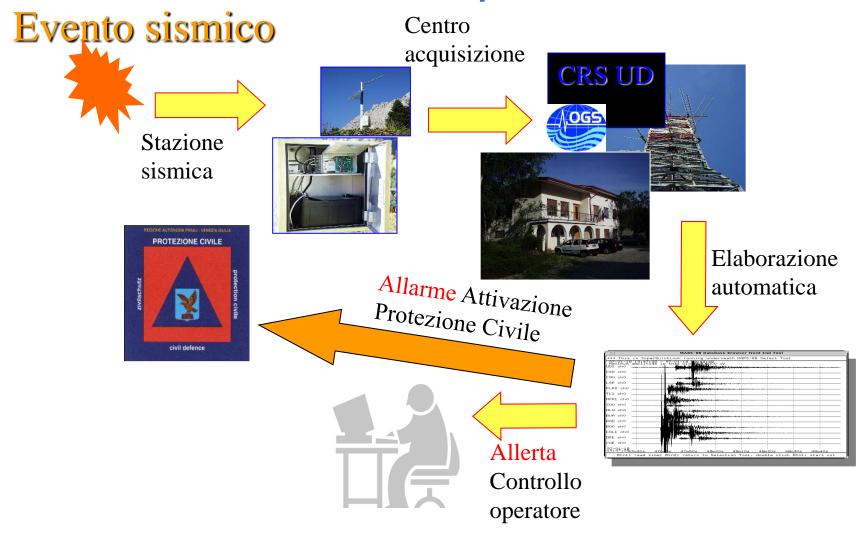


Bragato et al.,2020

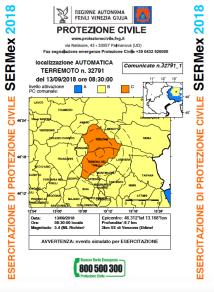
Integrated Trans-boundary network



Information in the immediate postevent phase



Communication towards Institutions





PROTEZIONE CIVILE DEL FRIULI VENEZIA GIULIA

TERREMOTO DI CAVAZZO CARNICO - TRASAGHIS (UD) DEL 11 AGOSTO 2018

grg 11:20 del 11/08/2018

Alls ore 05:30 di sabate <u>11 appola 2018</u>, la Relo Sismometrica dei Fruit Venezie Divila ha filevate un terremoto di magnitudo 3.3 con spisinete tra i comuni di Genazzo Canzona a Trassagli constitutaria guinza tra di 62.02230, la 10.1047172, postedata 2.8 di a tata applita a terre distanza da una stati di registra di mone aneggi (pi comento 22 event). la più filevante di la qui all'anti di constitutaria di constanza di eventaria vivupi potranno essene seguiti sui tato ingritto con magnitudo 2.8. di eventaria vivupi potranno essene seguiti sui tato ingritto con magnitudo 2.8. di eventaria di Centro e lo calizzzione scatanta de el erremoto dell'alla indezionataria e anti di constituto e lo calizzzione scatanta de el erremoto dell'alla indezionataria e constanza di Centro di Rotche Sismoligiche dell'OGI in colleboratore con la posto della di Centro di Rotche Sismoligiche dell'OGI in colleboratore con superso della della fina di la constanza con terremoto dell'alla indezionatare constanza di Centro di Rotche Sismoligiche dell'OGI in colleboratore con superso della della contenza e antima segne listenza colicataria constanza di contenza di constanza con terremoto dell'alla mache constanza constanza e la terremoto della constanza e la terremoto della constanza e constanza constanza e la terremoto della constanza e constanza constanza e la terremoto della constanza e constanza constanza e constanza constanza e constanza constanza e constanza e

Si elegano qui di seguito due figure: la prima mappa illustra l'epicentri dell'evento precursore, della scossa principale a della due repiche immediatamente successive, nombhé di que epicodi di microatamicità occorsi nella giornata di leri;





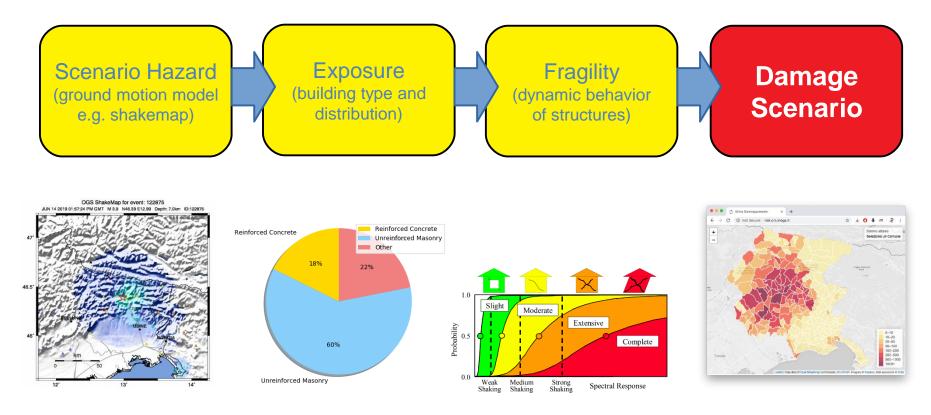
The Solomitagical Research Centre of DCS monitors the selamicity occurring in Narth-East Italy and its summarings pind polygon on the map) or manded by the network not by OCS. The automatic licenticies (in black) and related analysis can be inaccurate and ore updated (in black) as soon as new data are available. The magnitude is provided with the associated messarement error.



Communication to the public



A Real-time Damage Scenario Calculator



from Poggi et al.,2020

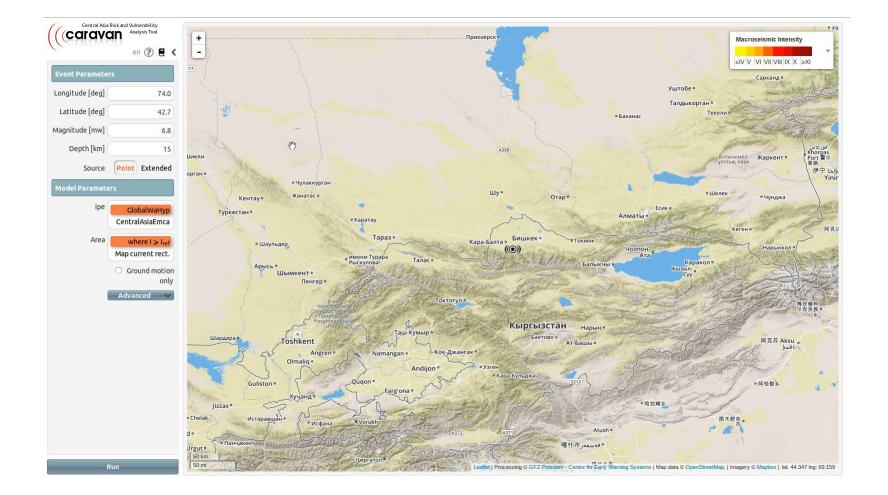
CARAVAN - earthquake impact forecasting

Description:

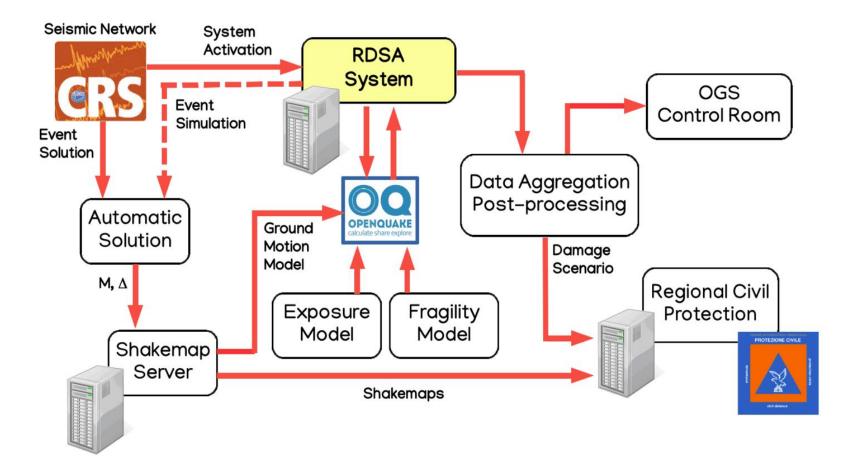
 Provides near-real time ground motion and loss (fatalities, displaced) estimation Stand-alone (client/server), web-based multilingual; include mapping •Currently on-demand: manual event characterization and FDSN event query Current focus: Central Asia Which events: manual M5+ **Type:** routine (auto mode in preparation) Dissemination: Centre for Early Warning; (optional: RSS feed; Email list; SMS) **Time lag:** <1 minute for first solution; possibly updated in real-time (automatic solution) based on stochastic simulations Yearly output: 3 (2014), possibly up to 50 **Trigger:** manual, GEOFON event, ACROSS

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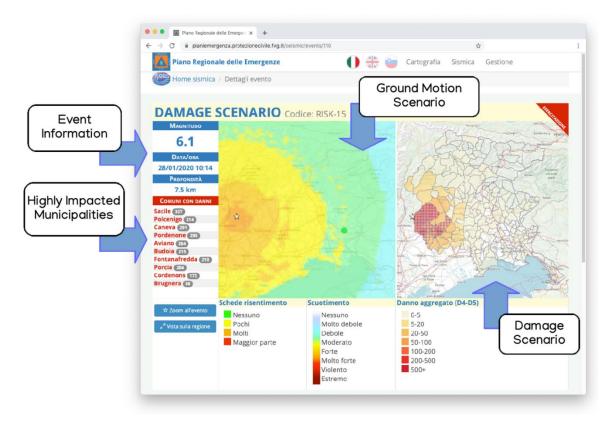
CARAVAN - Earthquake impact forecasting



Processing Infrastructure



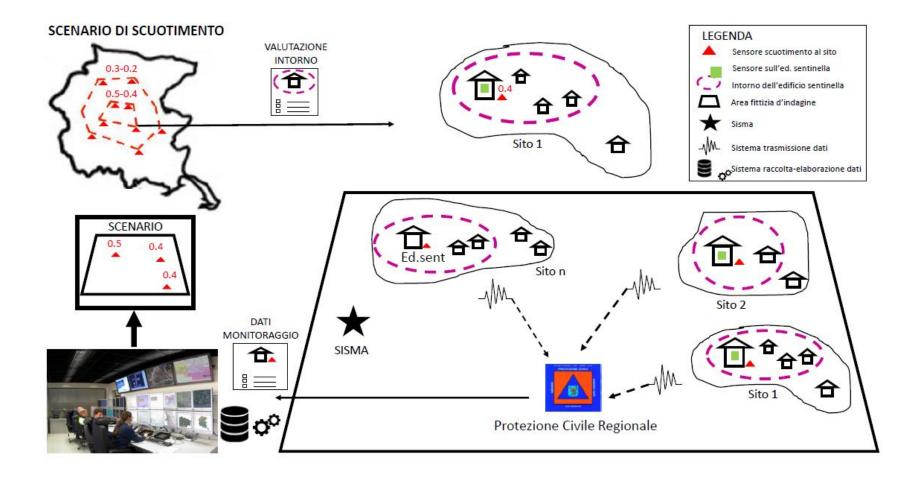
Estimated damage



Example of test scenario:

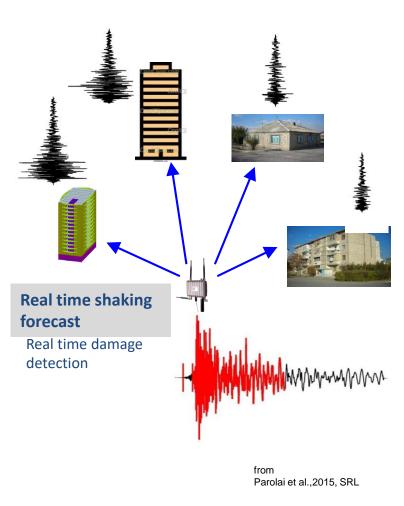
- Number of damaged buildings by aggregating severe damage (level D4) and total collapse (level D5) of the EMS98 scale.
- Option to produce a map of number of people impacted (based on simplified relationships)

Rapid Damage forecasting in buffer areas



from Grimaz et al.,2017

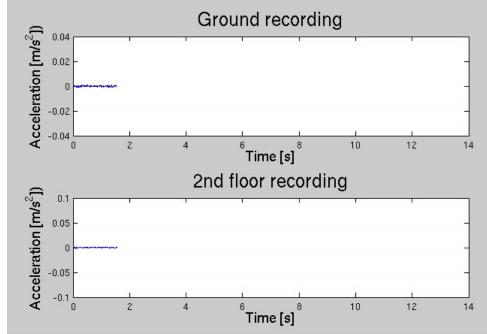
Method 1



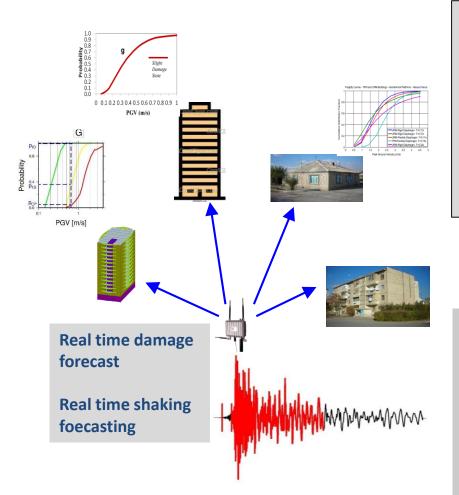
Real time estimation of shaking for different buildings.

Input: base of one of the sentinel building 1) recording at the base of one of the sentinel building (OGS-Uni Trieste)

2) Frequency of oescillation for building type (Uni Udine)

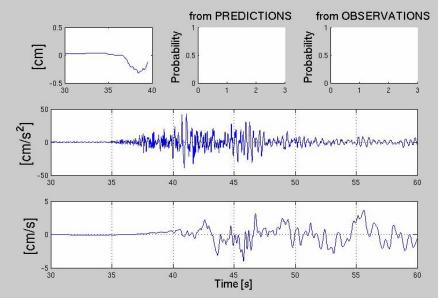


Method 2



from Parolai et al.,2015, SRL Megalooikonomou et al. 2018. Estimation of the probability of exceedance of acertain limit state for different buildings within an area

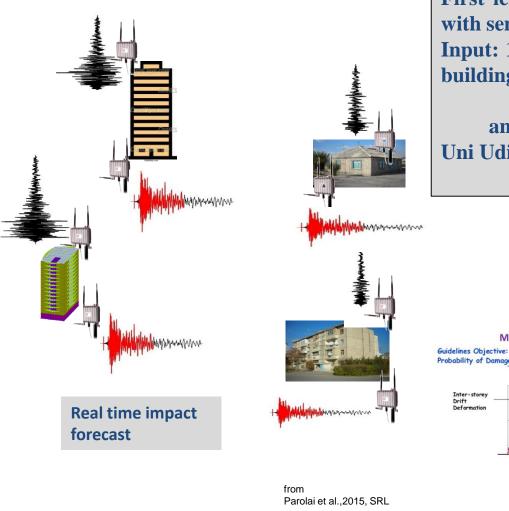
Input: 1) recording at the base of one of the sentinel building (OGS-Uni Trieste) 2)Fragility curves for building type (Uni Udine)



Method 3

Inter-storey Drift

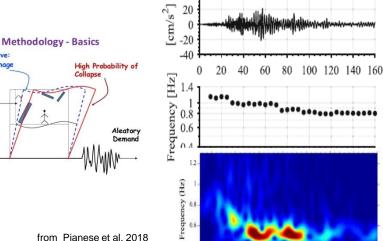
Deformation



First level estimate of possible damage in buildings with sensors at the base and at the top.

Input: 1) recording at the base of one of the sentinel building (OGS-Uni Trieste)

2) Real time measurement of interstorey-drift and/or resonance frequency variation (OGS-**Uni Udine**)



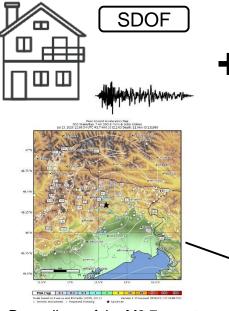
40

20

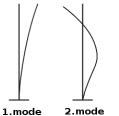
0.4 20 120 Time (s)

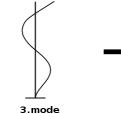
Estimating The Building's Dynamic Behavior

Generally, different buildings react differently to the same input ground motion. This depends on their different <u>structural dynamic behavior</u>, that influences expected damage.



Recordings of the M3.7 event 13.07.2020 (Tramonti di Sopra)



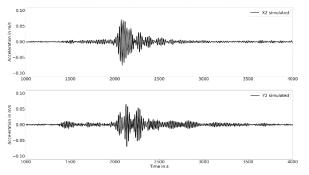






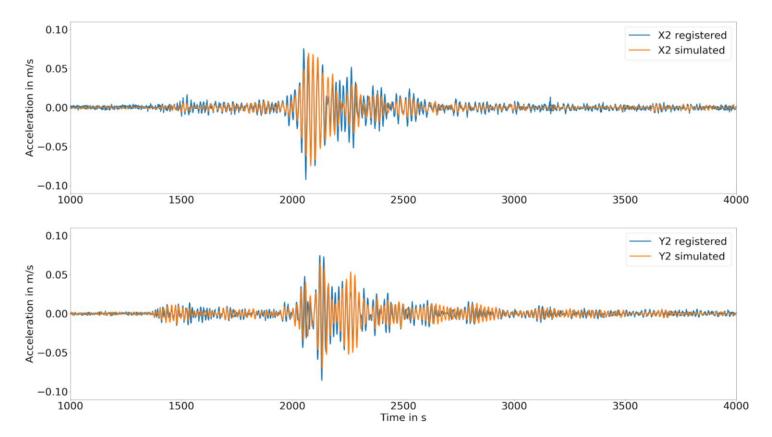


Monitored building in Aviano (UD) characterized by noise measurements (Sentinella/Armonia projects)

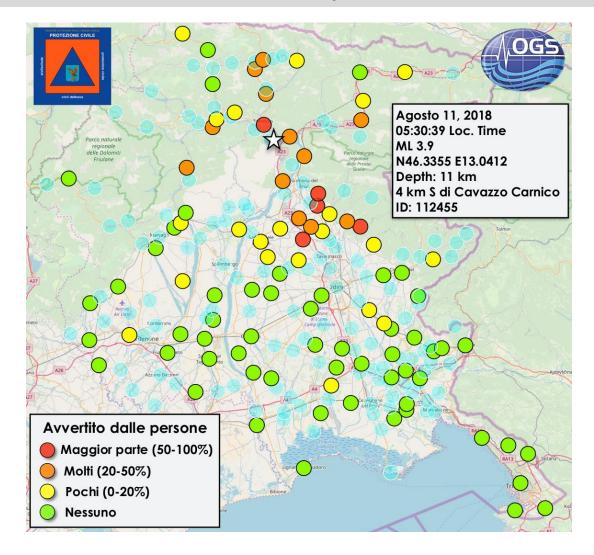


Simulated Acceleration at the top of the building

Recorded and simulated acceleration

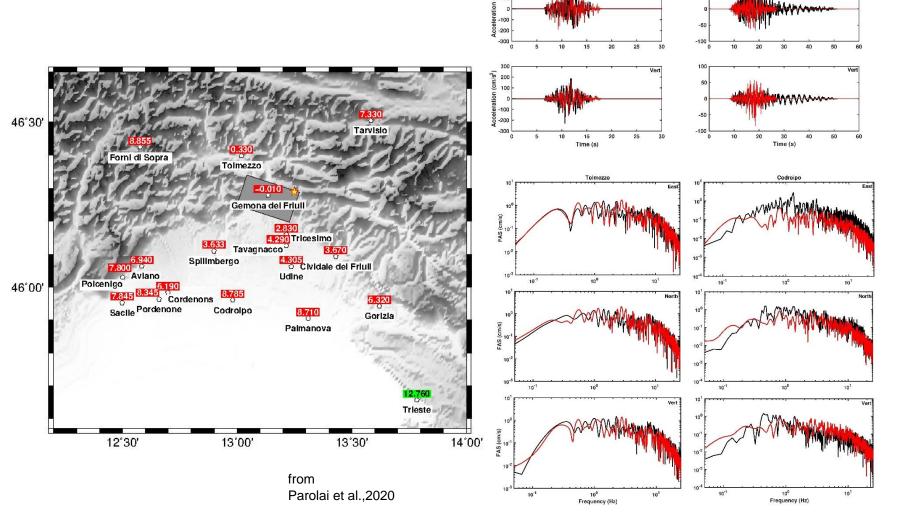


Integration of the information from seismic stations with those provided by the Civil protection volunteers: Sentinel buildings used as verification points



9

Feasibility for DOSEEW in case of repetition of the 1976 Event



Tolmezzo

eleration (cm/s²) 0 01 001-

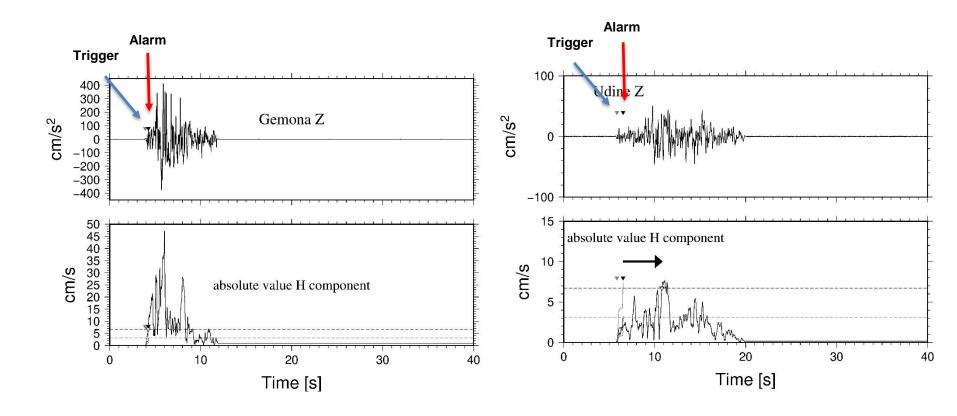
Ğ -200 -300

East

25

Codroipo

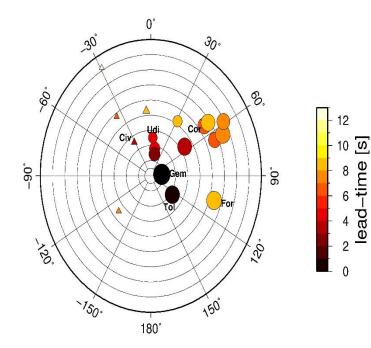
DOSEEW applied to the synthetic data



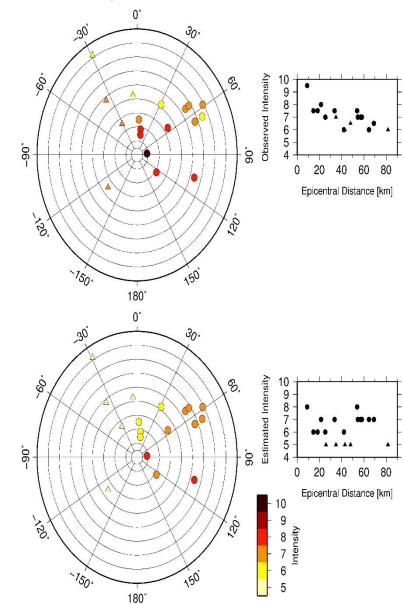
from Parolai et al.,2020

DOSEEW applied to the synthetic data

Strong dependency of lead-time on slip distribution



from Parolai et al.,2020



Possible reduction of 10% of injured persons

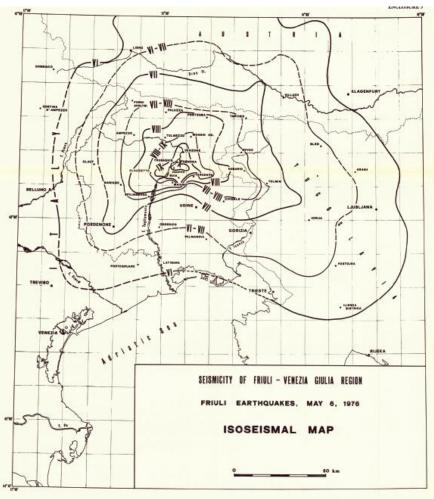


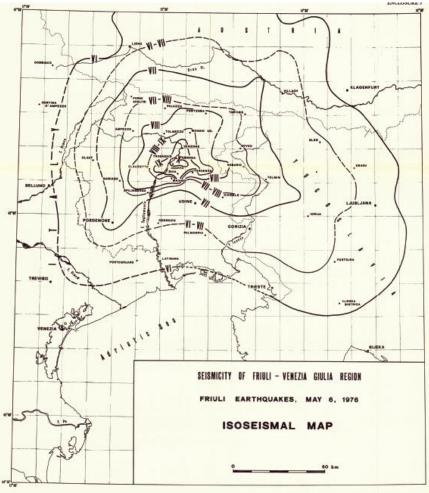
Table 1 - Summary of the localities and lead times vs injured person during the 1976 Friuli earthquake.

Locality	Lead time (s)	1976 Intensity	1976 Injured
Cividale	3.67	VII	18
Cordenons	6.19	VII	5
Tarvisio	7.33	VII	5
Pordenone	8.34	VII	27
Udine	4.30	VII	53
Forni di Sopra	8.85	VII-VIII	4
Sacile	7.84	VI-VII	6
Tavagnacco	4.29	VII-VIII	24
Spilimbergo	3.63	VII-VIII	10
Tricesimo	2.83	VII-VIII	10



Possible several seconds to stop the plant of TAL

No action was possible for this scenario for the Magnetic Marelli being in the blind zone



from Parolai et al.,2020

Magneti Marelli Automotive Lighting, Tolmezzo (UD)



- production of electronic
- components for LED lights
- 5.000 m²
- > 1100 employees

TAL – Transalpine Pipeline

- Italy, Austria and Germany
- 40% of the energy needs of Germany and the Czech Republic, and 90% of Austria
- 753 km
- 7500 m³/h
- 750 employees involved
- 1.2 x 10⁹ €

Damage Assessment for Rapid Response (DARR)

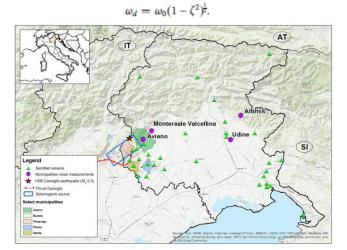
 $x_j = b_1 x_{j-1} + b_2 x_{j-2} - S_0(\Delta t)^2 a_{j-1},$

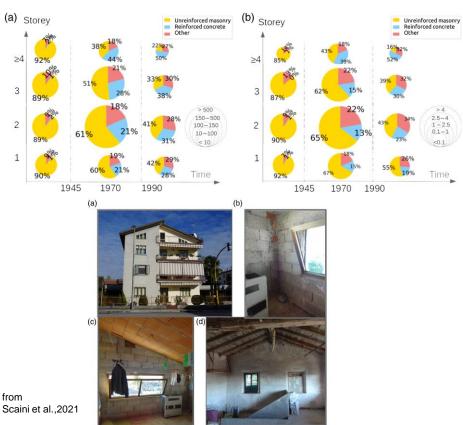
with the coefficients b_1 , b_2 , and S_0 defined as

$$b_1 = 2e^{-\zeta \omega_0 \Delta t} \cos(\omega_d \Delta t),$$

 $b_2 = -e^{-2\zeta \omega_0 \Delta t}$

$$S_0 = e^{-\zeta \omega_0 \Delta t} \sin \frac{(\omega_d \Delta t)}{(\omega_d \Delta t)},$$







Damage Assessment for Rapid Response (DARR)

Buildings classified by eave height

Buildings classified by shape ratio

(b

(c)

930040000057

930040000004

930040000071

93004000003

Percentual of typology

0-30

30-50

50-84

930040000006

Aviand

930940000009

004000061

930040000007

30040000011

93004000008

Target area for aviano

Circular buffer

Instrumented building

$$x_j = b_1 x_{j-1} + b_2 x_{j-2} - S_0(\Delta t)^2 a_{j-1}, \tag{1}$$

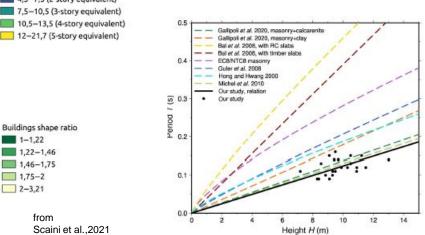
with the coefficients b_1 , b_2 , and S_0 defined as

$$b_{1} = 2e^{-\zeta\omega_{0}\Delta t}\cos(\omega_{d}\Delta t),$$

$$b_{2} = -e^{-2\zeta\omega_{0}\Delta t},$$

$$S_{0} = e^{-\zeta\omega_{0}\Delta t}\sin\frac{(\omega_{d}\Delta t)}{(\omega_{d}\Delta t)},$$

$$\omega_{d} = \omega_{0}(1-\zeta^{2})^{\frac{1}{2}}.$$
(2)



(a)



Buildings eave height (m) 0-4,5 (1-story equivalent) 4,5-7,5 (2-story equivalent) 7,5–10,5 (3-story equivalent) 10,5–13,5 (4-story equivalent) 12-21,7 (5-story equivalent)

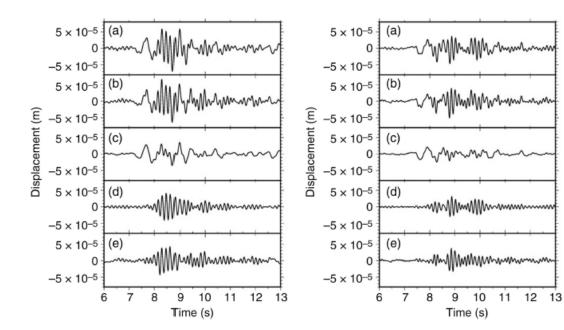
> 1-1,22 1,22-1,46 1,46-1,75 1,75-2 2-3,21

> > from Scaini et al.,2021

Damage Assessment for Rapid Response (DARR)

Y





 $x_j = b_1 x_{j-1} + b_2 x_{j-2} - S_0(\Delta t)^2 a_{j-1},$

 b_1

with the coefficients b1, b2, and S0 defined as

$$= 2e^{-\zeta\omega_0\Delta t}\cos(\omega_d\Delta t),$$

$$b_2 = -e^{-2\zeta\omega_0\Delta t},$$

$$S_0 = e^{-\zeta\omega_0\Delta t}\sin\frac{(\omega_d\Delta t)}{(\omega_d\Delta t)},$$

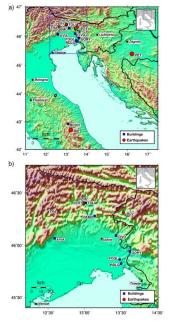
$$\omega_d = \omega_0(1-\zeta^2)^{\frac{1}{2}}.$$

from Scaini et al.,2021





Damage Assessment for Rapid Response (DARR)



Application to different areas



TABLE 1

Relative Displacement (in Centimeters) and Interstory Drift Limits (in Percentage) for Extensive and Complete Structural Damage for Selected Building Typologies (Simple Stone or Regular Unreinforced Masonry [URM], and Reinforced Concrete [RC] Frames and Shear Walls)

Building Typology	Relative Displa	cement (cm)	Interstory Drift Ratio (%)		
Damage Level	Extensive	Complete	Extensive	Complete	
Simple stone URM, low-rise (1–2 stories)	0.85	1.40	((
Simple stone URM, mid-rise (3–5 stories)	1.35	2.10		0.61	
Simple stone URM, high-rise (>5 stories)	1.61	2.41	0.34	l	
Regular URM, RC floors, low-rise (1-2 stories)	1.38	2.36		(
Regular URM, RC floors, mid-rise (3–5 stories)	2.19	3.50		0.45-0.72*	
Regular URM, RC floors, high-rise (>5 stories)	2.47	3.87	1		
RC frame, low-rise (1–3 stories)	3.01	4.51	0.13	0.30	
RC frame, mid-rise (4–7 stories)	4.49	6.74	0.12	0.27	
RC frame, high-rise (>7 stories)	6.10	9.15	0.16	0.38	
RC shear walls, low-rise (1–3 stories)	3.90	5.94	0.03	0.06	
RC shear walls, mid-rise (4–7 stories)	6.12	9.59	0.12	0.28	
RC shear walls, high-rise (>7 stories)	8.21	12.86	0.23	0.56	

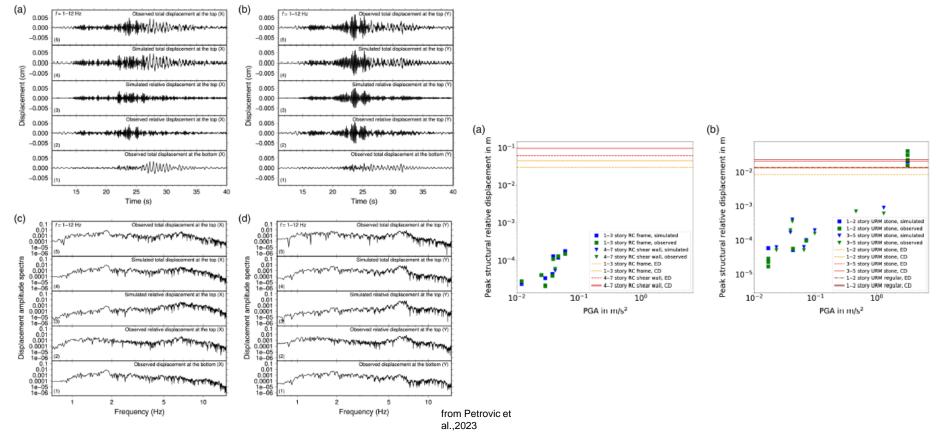
Relative displacement (displacement between top and bottom) limits are provided by Lagomarsino and Govinza? (2006) Interstory drift limits are provided by Boor et al. (2008) for URM and by the deliverables of the Risk-UE project (Mouroux and Brun, 2006) for RC. Limits were calculated based on finite-sterver drift limits are provided by Boor 2006) and represent the threshold for occurrence of extensive and complete damage, corresponding to D3 and both D4 and D5 damage level of European Macrosenirs Cale 1998 (EMS-98) (Grunthal, 1998). The same interstory Drift Ratio limit is provided for all masonry buildings for extensive damage, whereas for complete damage one value is provided for stone and one for regular URM. *Depending on precertage of voids.

from Petrovic et al.,2023





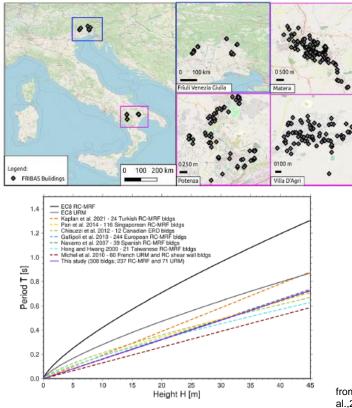
Damage Assessment for Rapid Response (DARR)



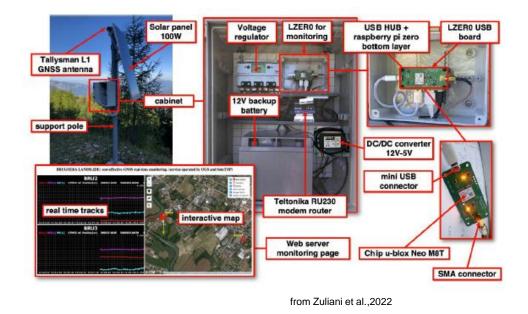


Some recent developments

Fribas data base



Integration of Strong motion and GNSS data Cost effective GNSS



from Gallipoli et al.,2023



