Bridging the gap between seismology and engineering: towards real-time damage assessment

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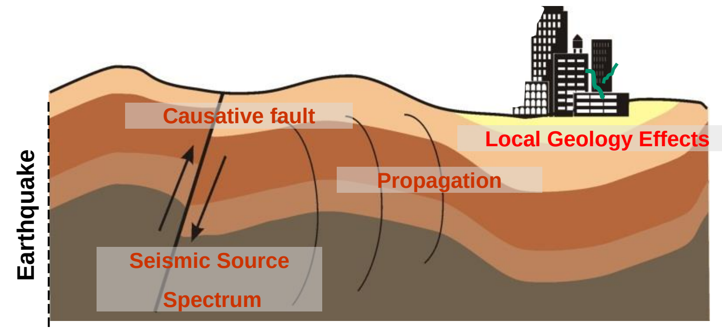
16TH EUROPEAN CONFERENCE ON
EARTHQUAKE ENGINEERING
THESSALONIKI
18 - 21 JUNE 2018

Istituto Nazionale
di Oceanografia e di Geofisica Sperimentale

Seismic Risk Assessment and Mitigation



Decades | Years | Days to minutes | 0 | seconds | Minutes to hours

Long Term Seismic and landslides Risk mapping

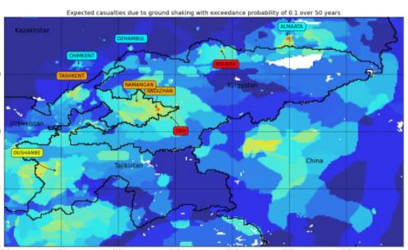
Long Term Forecasting

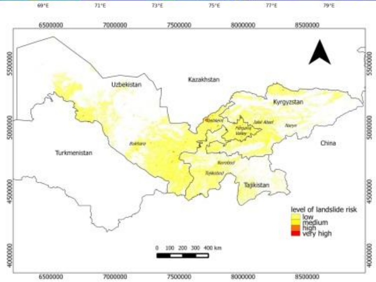
Short Term Forecasting

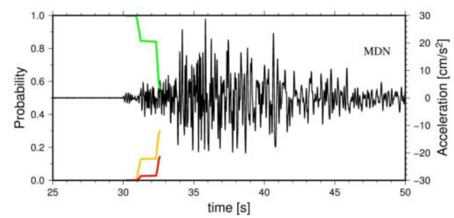
Earthquake and landslides Early Warning

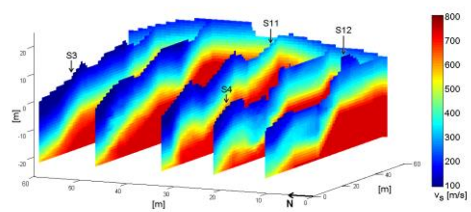
Real time and rapid loss estimation

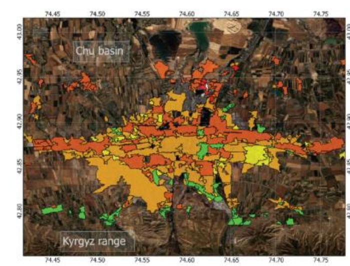
Aftershock Forecasting











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.

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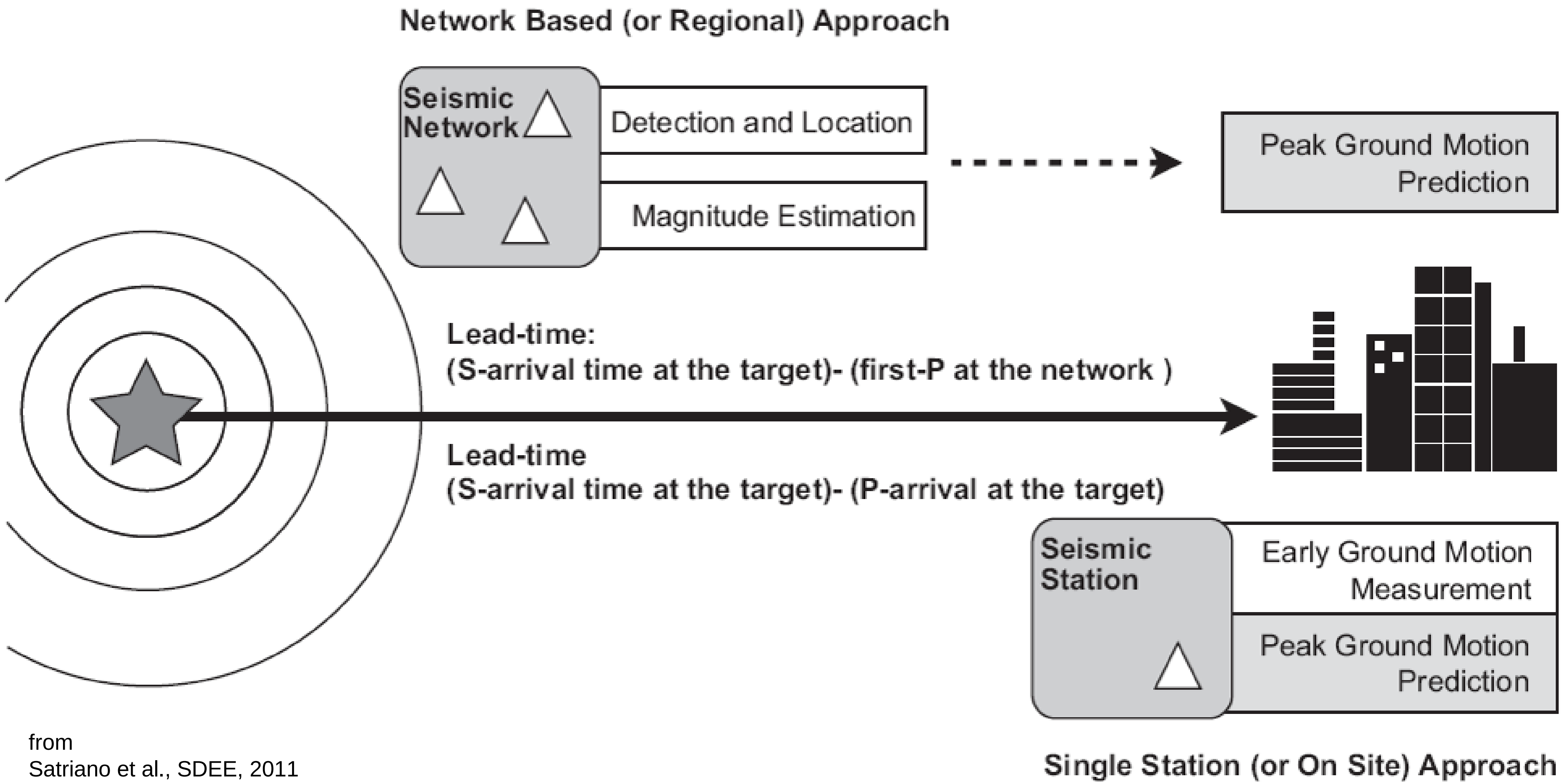
Approaches

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



from
Satriano et al., SDEE, 2011

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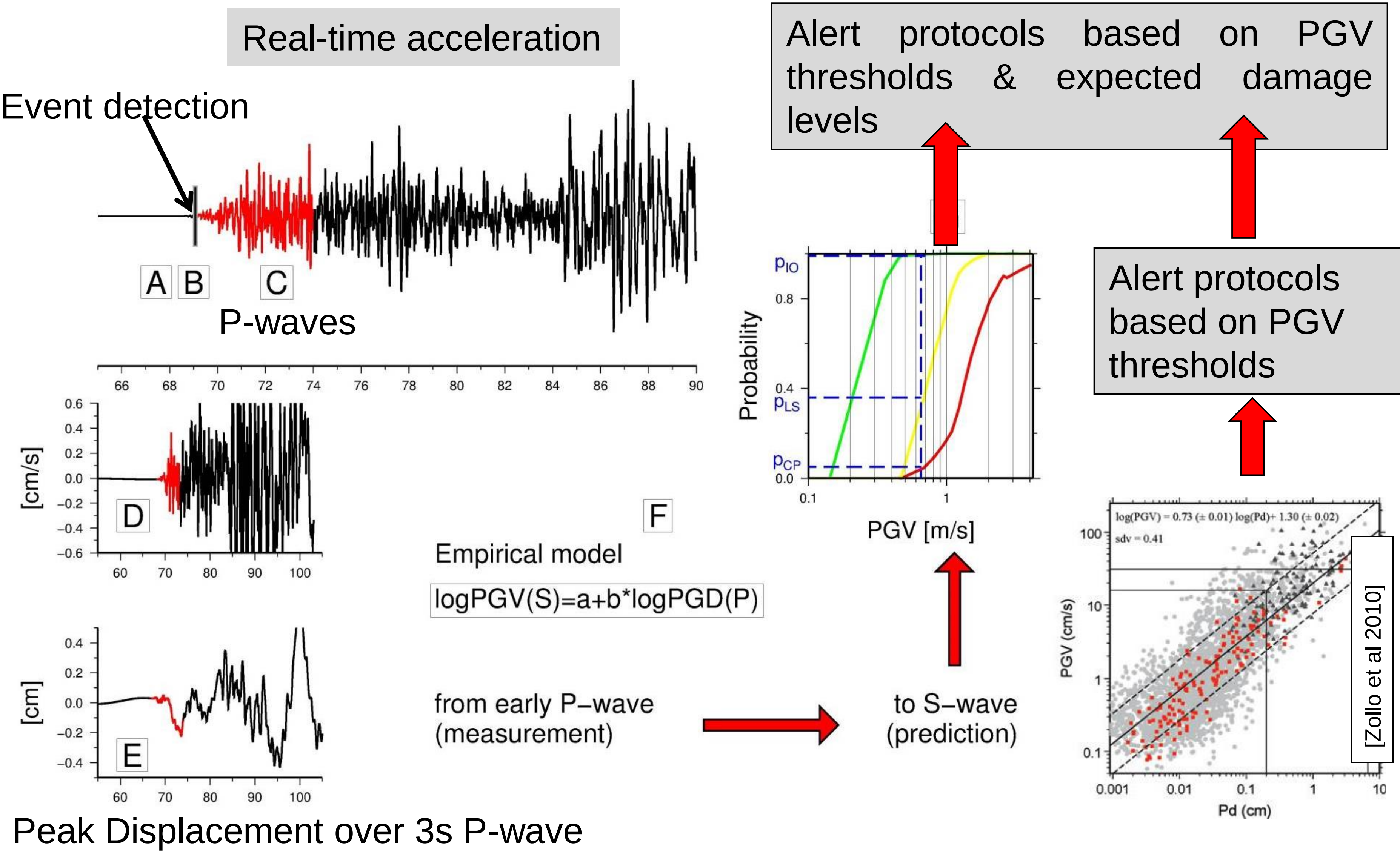
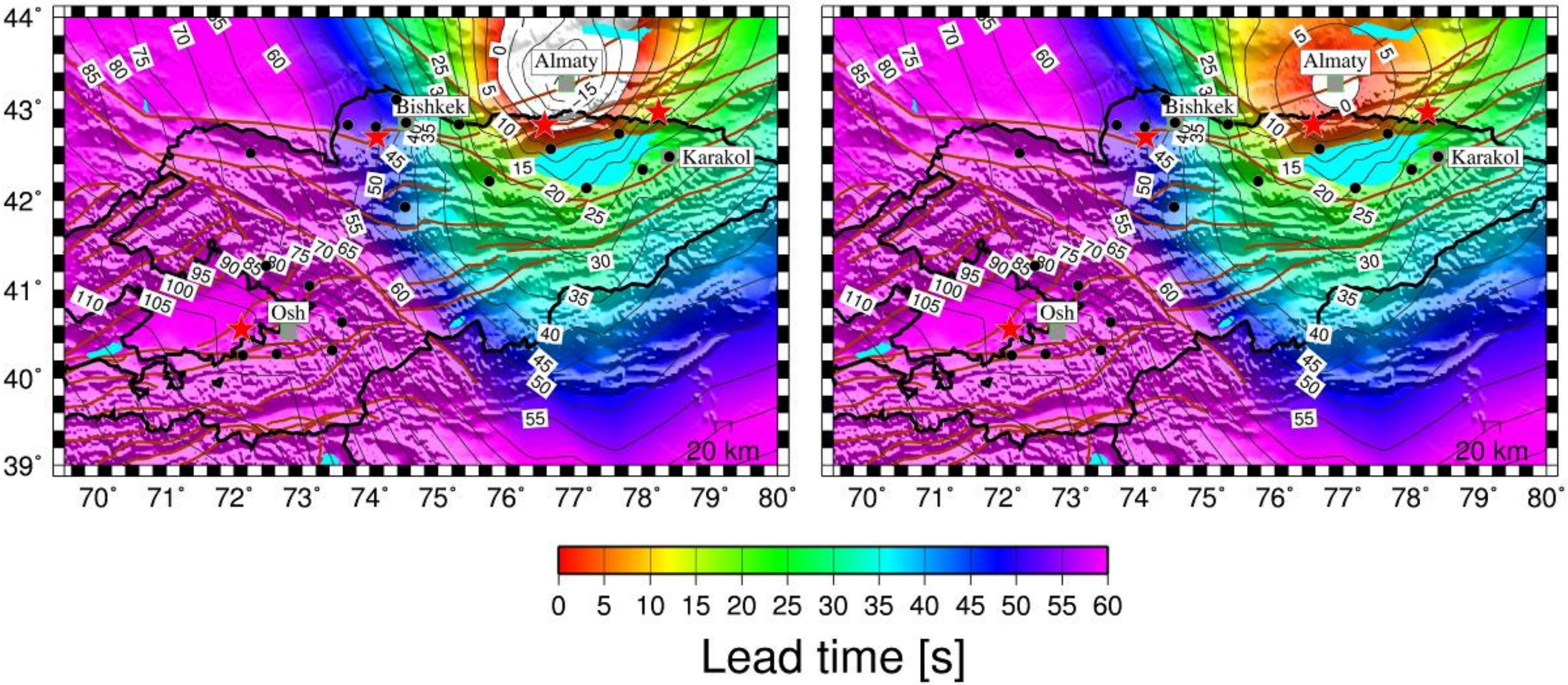
Decentralised Onsite Early warning

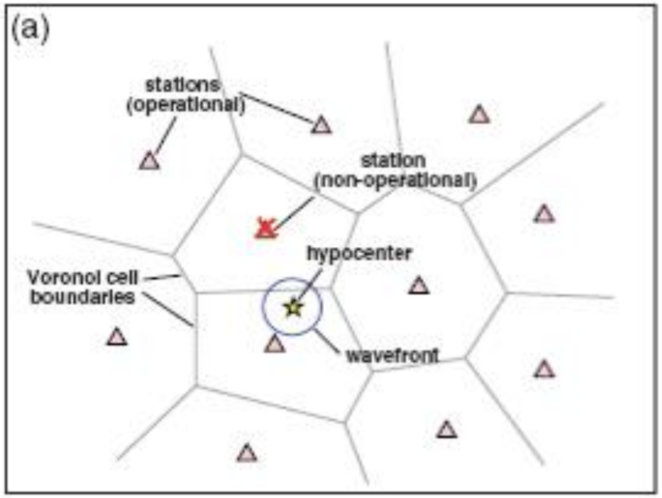


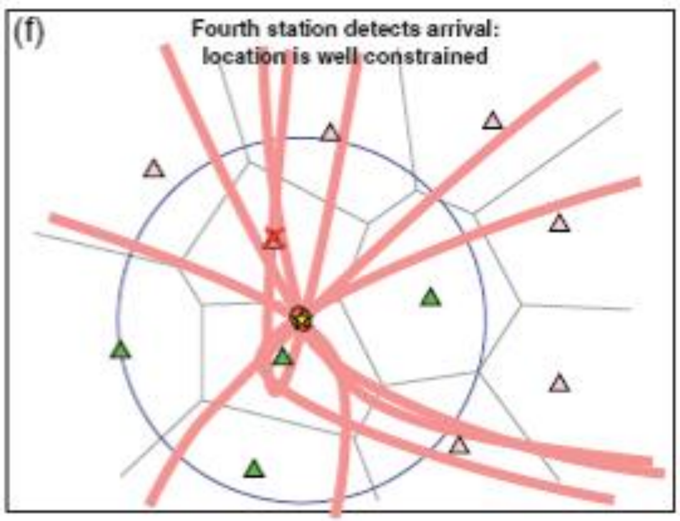
Example of regional and onsite system combination



Left: The lead-times for Almaty (Kazakhstan) when using a regional approach as a function of the location of possible seismic events (i.e., a 0.1 by 0.1° grid).
Right: The lead-times for Almaty using a combined regional and on-site approach, as a function of the location of possible seismic events (i.e., a 0.1 by 0.1◦grid).

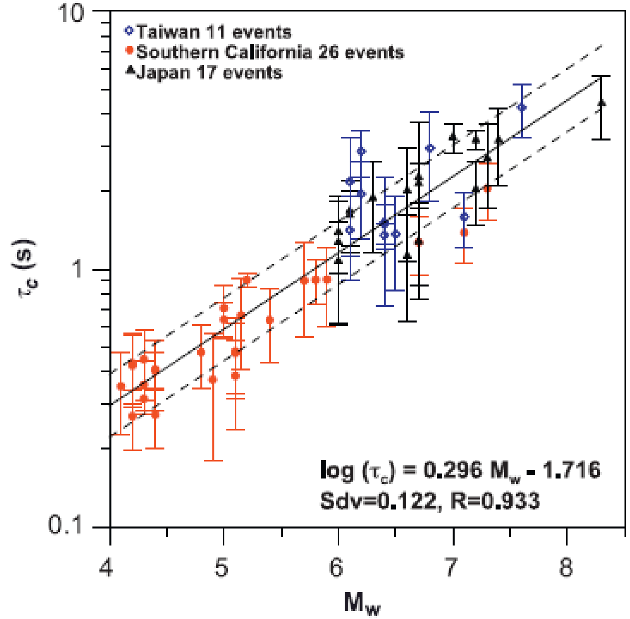
Rapid location estimation





Cua & Heaton (2007) Satriano et al. (2008) and Rosenberg (2009).

Rapid Magnitude estimation

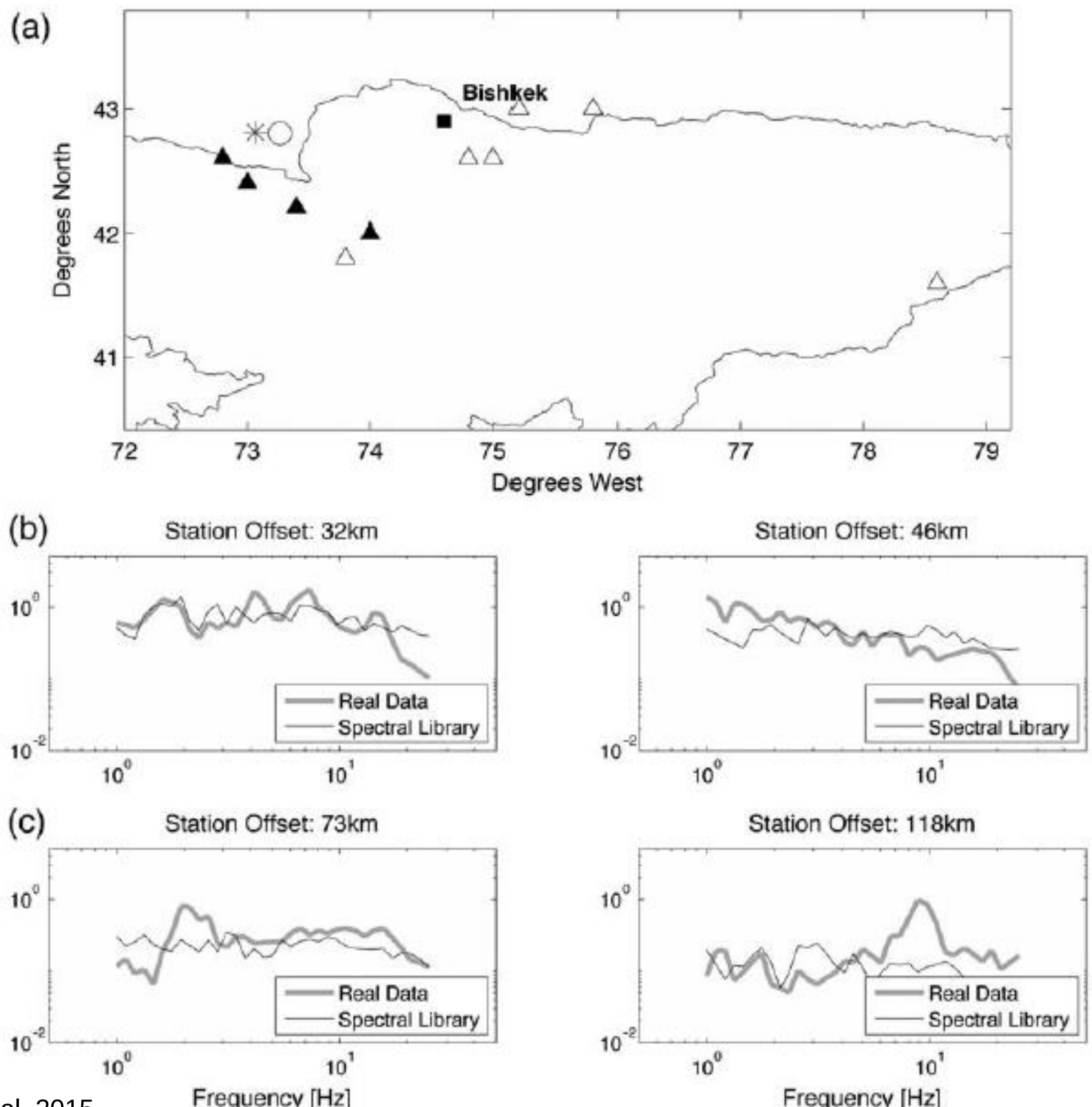


$$r = \frac{\int_0^{\tau_0} \dot{u}^2(t)\,dt}{\int_0^{\tau_0} u^2(t)\,dt}$$

$$\tau_c = \frac{1}{\sqrt{\langle f^2 \rangle}} = \frac{2\pi}{\sqrt{r}}$$

Nakamura (1988) and Allen and Kanamori(2003)
Kanamori (2005)

Are magnitude and location necessary?



from
Stankiewicz et al.,2015

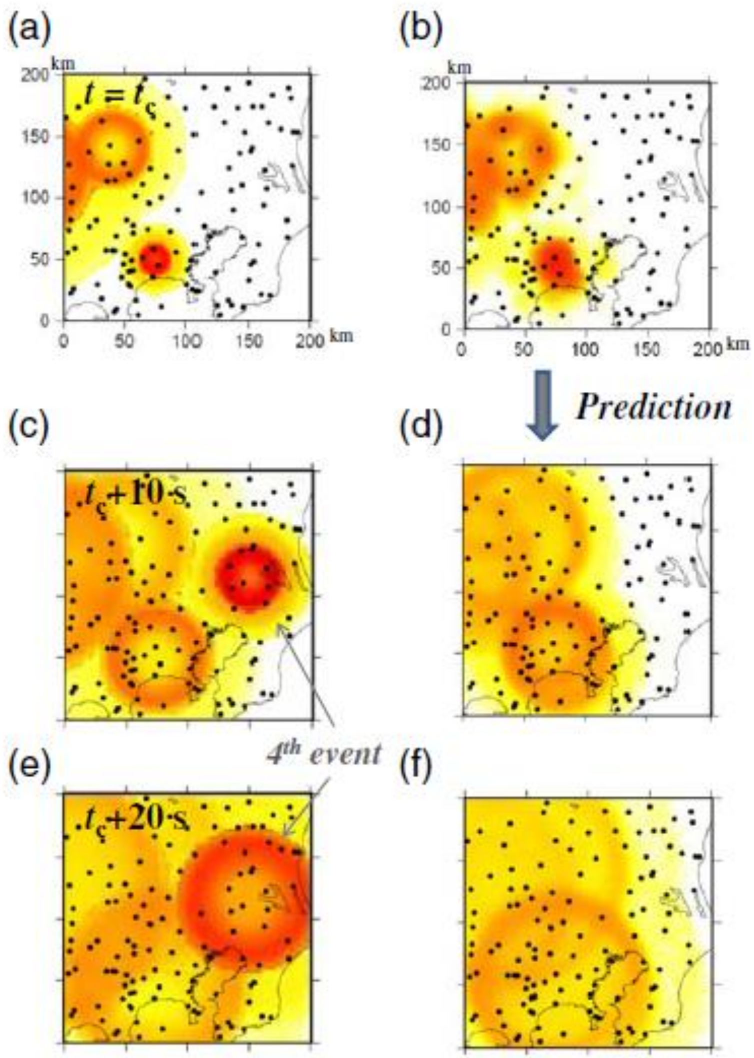
Spectral content used to improve Earthquake Early Warning Systems Bishkek

Timely warning than was possible using a threshold on ground motion

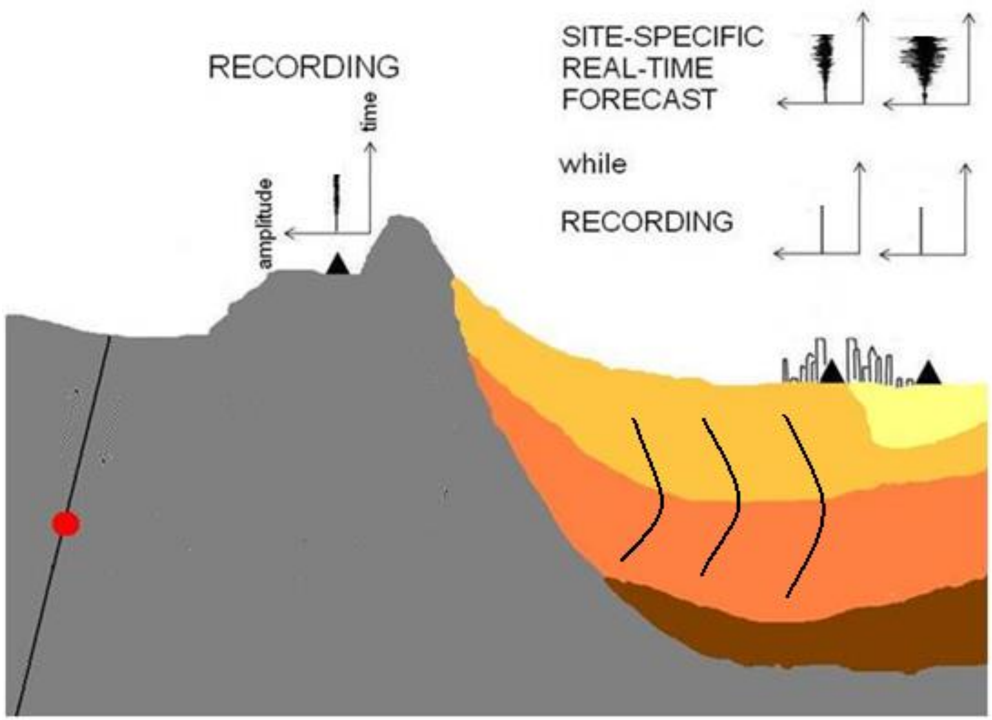
Improvement should come from a **combination with On-Site Early Warning**

Some Emerging questions

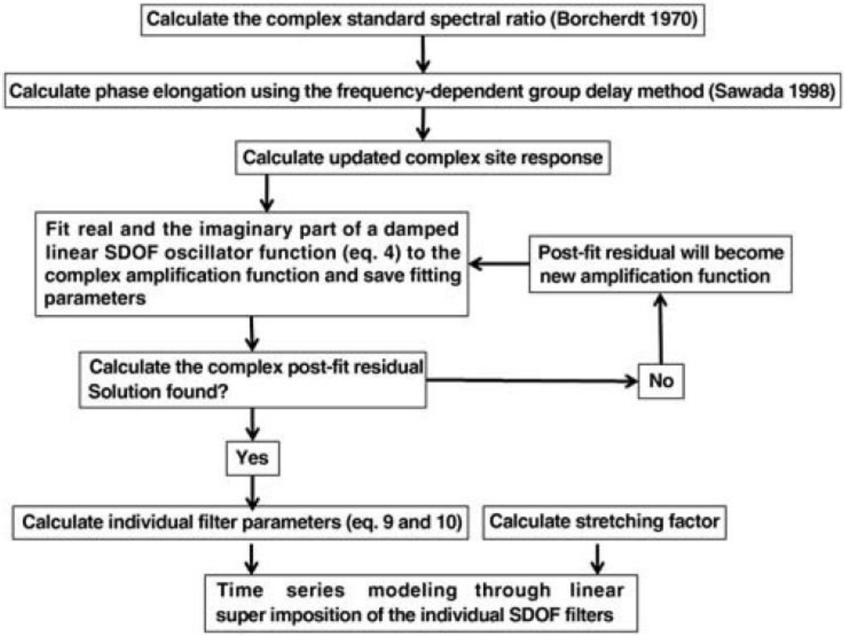
How to deal with nearly simultaneous aftershocks?
How to include site effects in real time shaking forecasting?

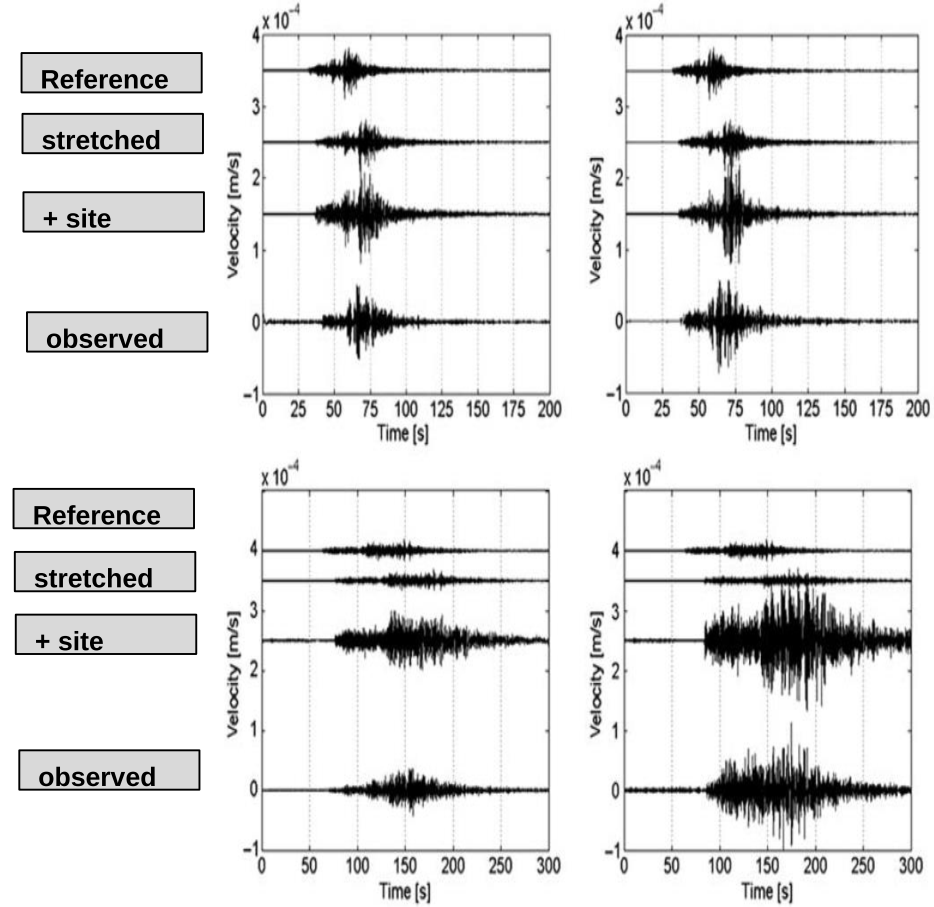


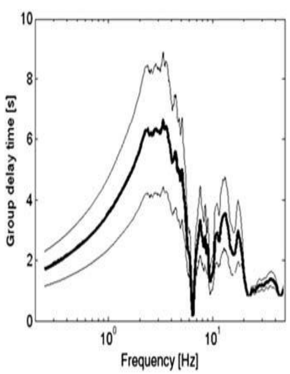
Hoshiba and Aoki (2015):

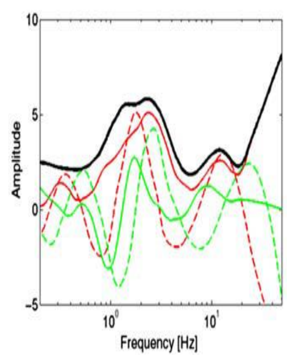


Pilz and Parolai (2016)



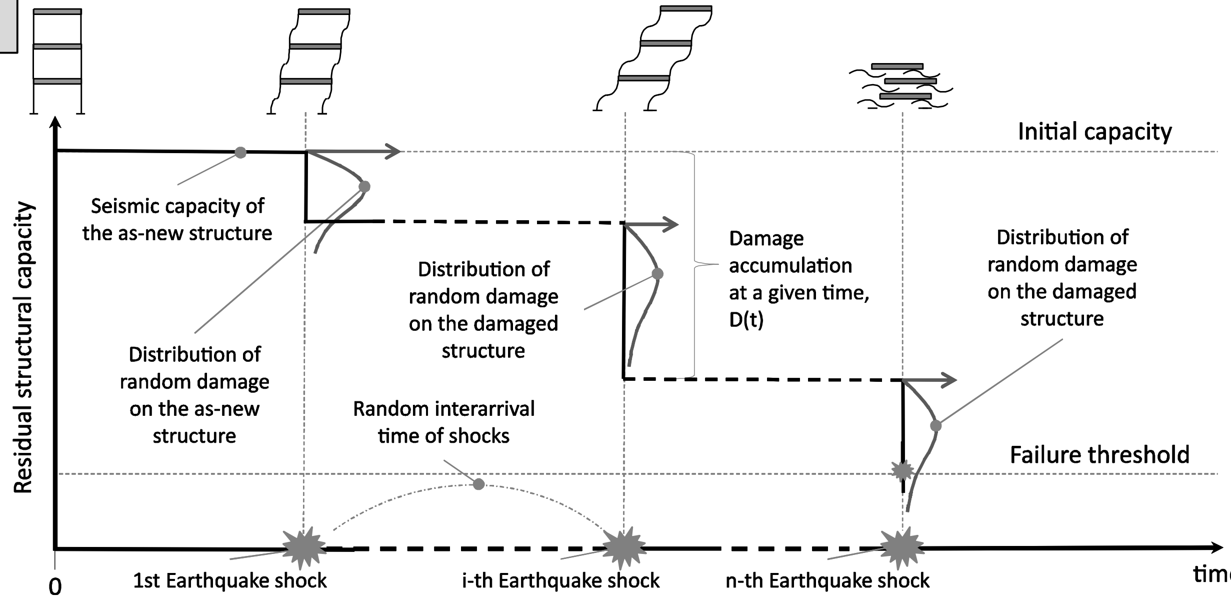






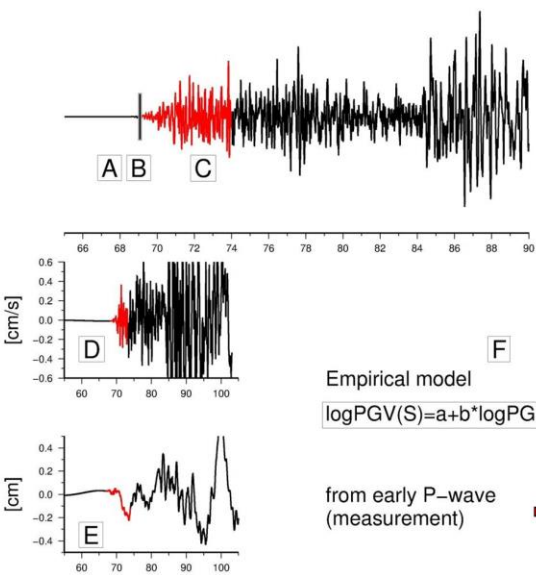
Recordings of (top row) a localM4.1 event (17 May 2012) and (bottom row) a regionalM5.0 earthquake (12 September 2012) at network sites (left column) DU03, (middle column) DU06, and (right column) DU30. Each plot shows the north–south component recording at the reference site (top waveform), the stretched waveform at the reference site (second waveform from top), the simulated waveforms for the soft-soil site (third waveform from top), and the recorded ground motion at the soft-soil site (bottom waveform).

Emerging questions



Aftershocks early warning and monitoring: time dependent vulnerability

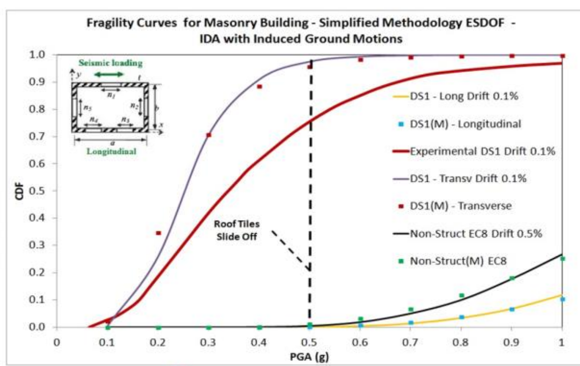
Non structural damage: Induced seismicity



Empirical model

logPGV(S)=a+b*logPGD(P)

from early P–wave (measurement) → to S–wave (prediction)

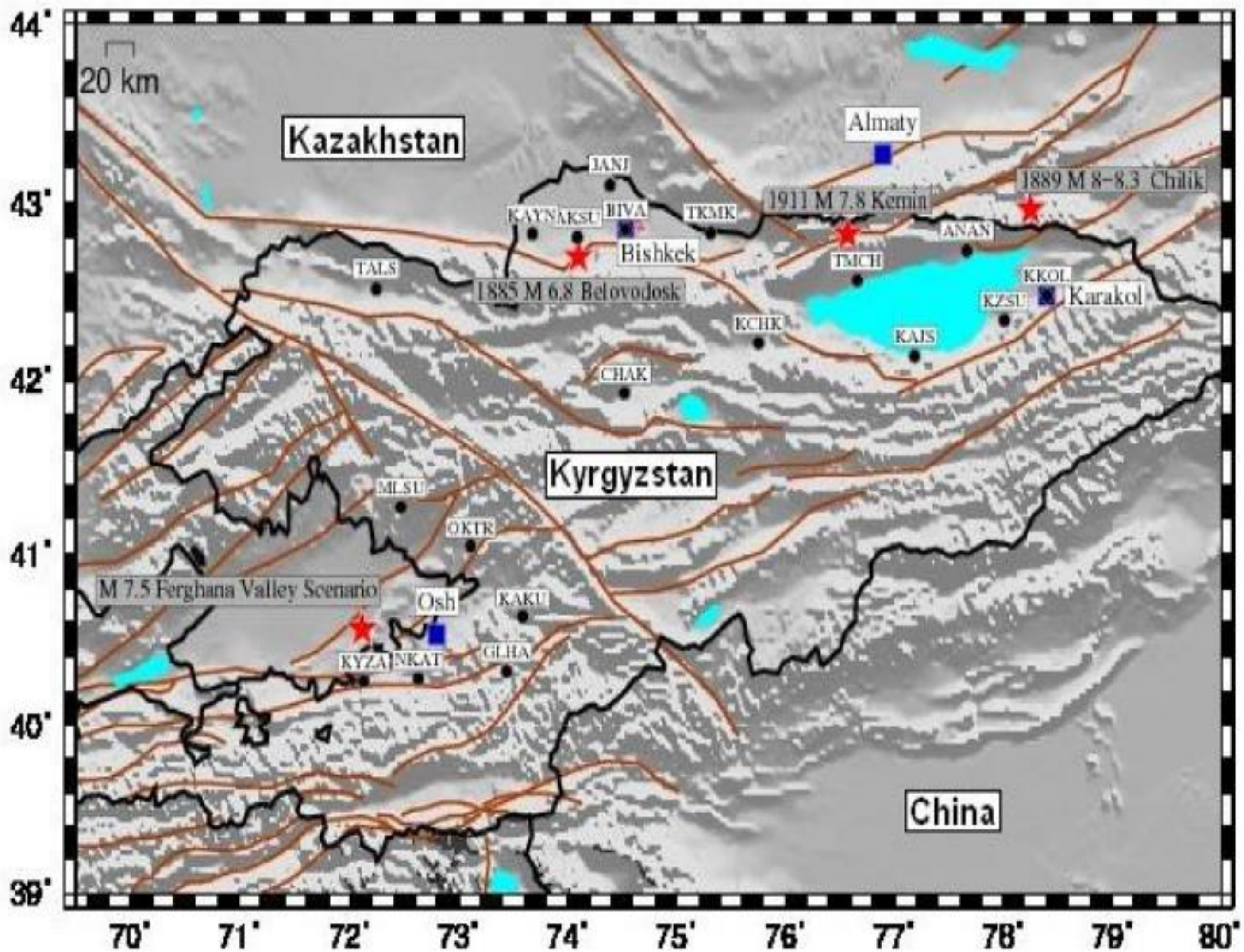


Developed for Drift Sensitive Brittle Non-Structural Components of URM buildings.

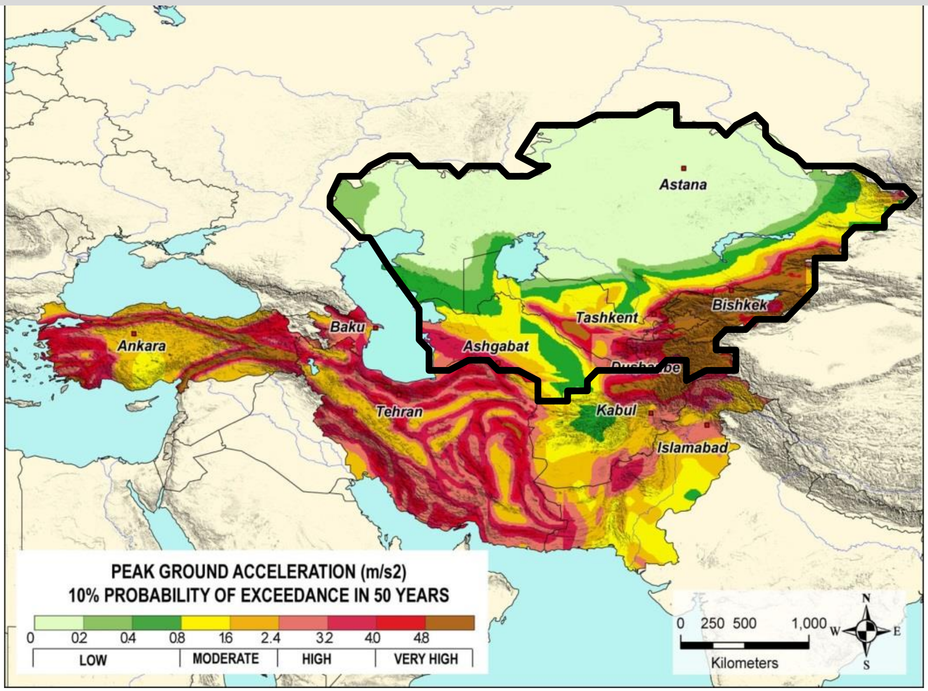
MP-Wise (Multi-Parameter Wireless Sensing System)

Applications

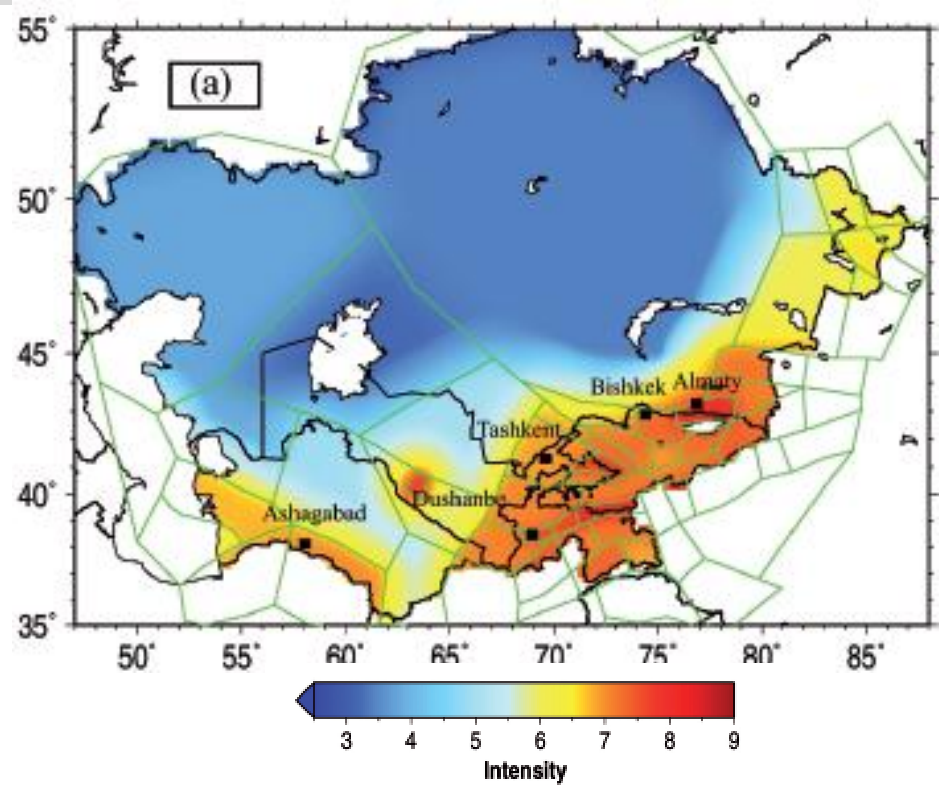
ACROSS Network



Central Asia is amongst the regions with the highest earthquake hazard worldwide

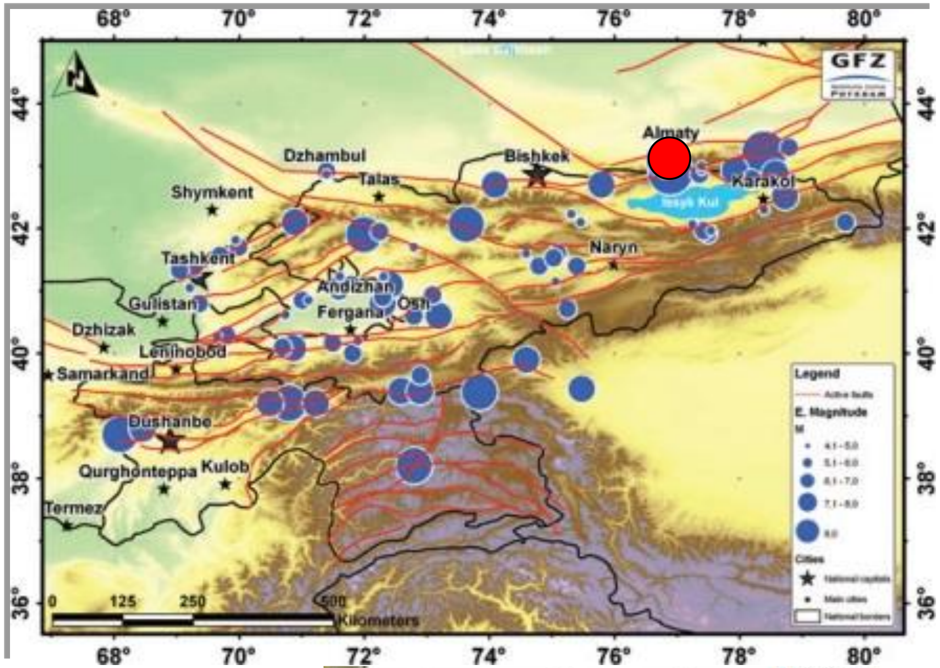


GSHAP (1999)



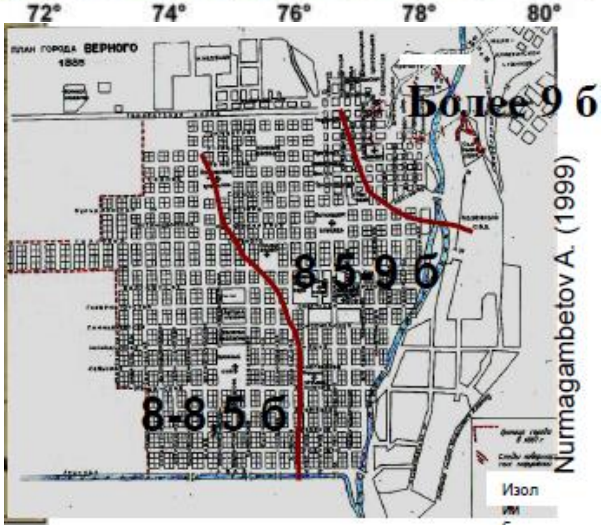
Ullah et al (2015))

1887 Verny Earthquake M=7.3



Macroseismic Intensities in Almaty

~300 death

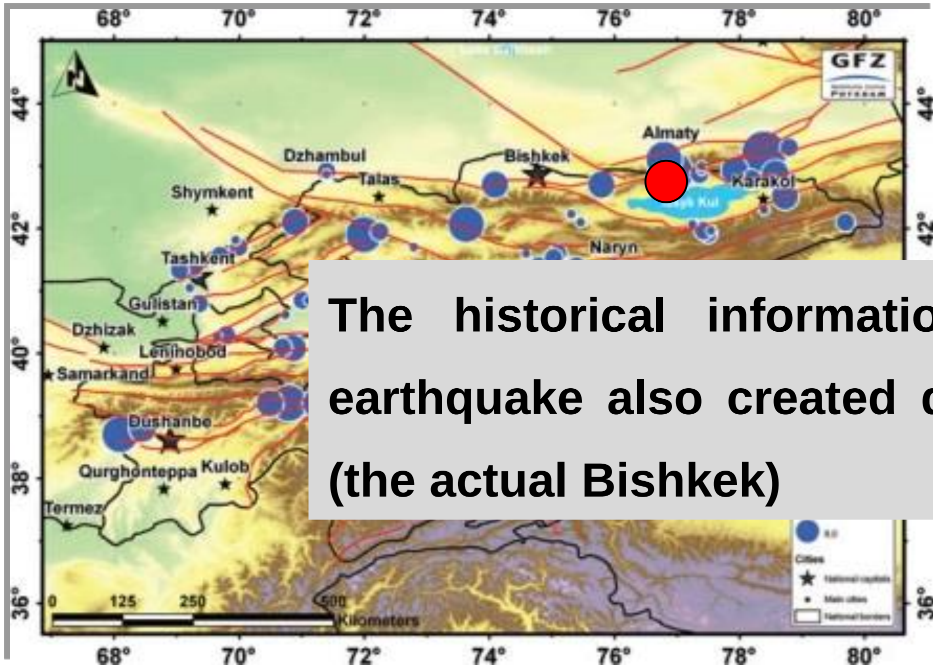


Nurmagambetov (1999)

Almaty

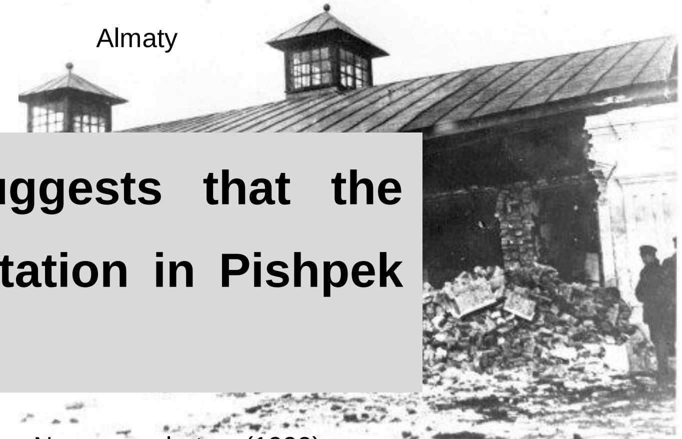
Nurmagambetov (1999)

1911 Kemin Earthquake M=7.8-8.0



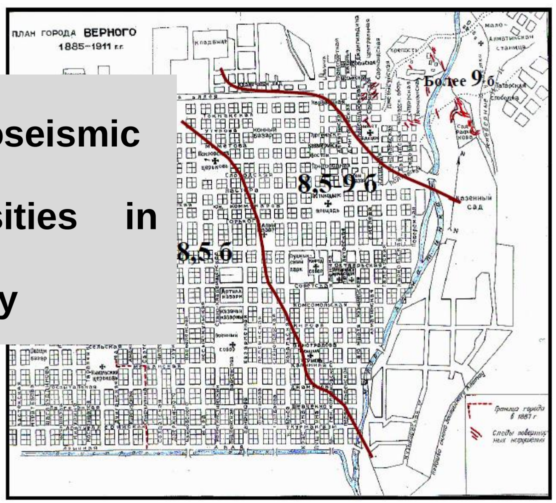
The historical information suggests that the earthquake also created devastation in Pishpek (the actual Bishkek)

Almaty



Nurmagambetov (1999)

Macroseismic Intensities in Almaty

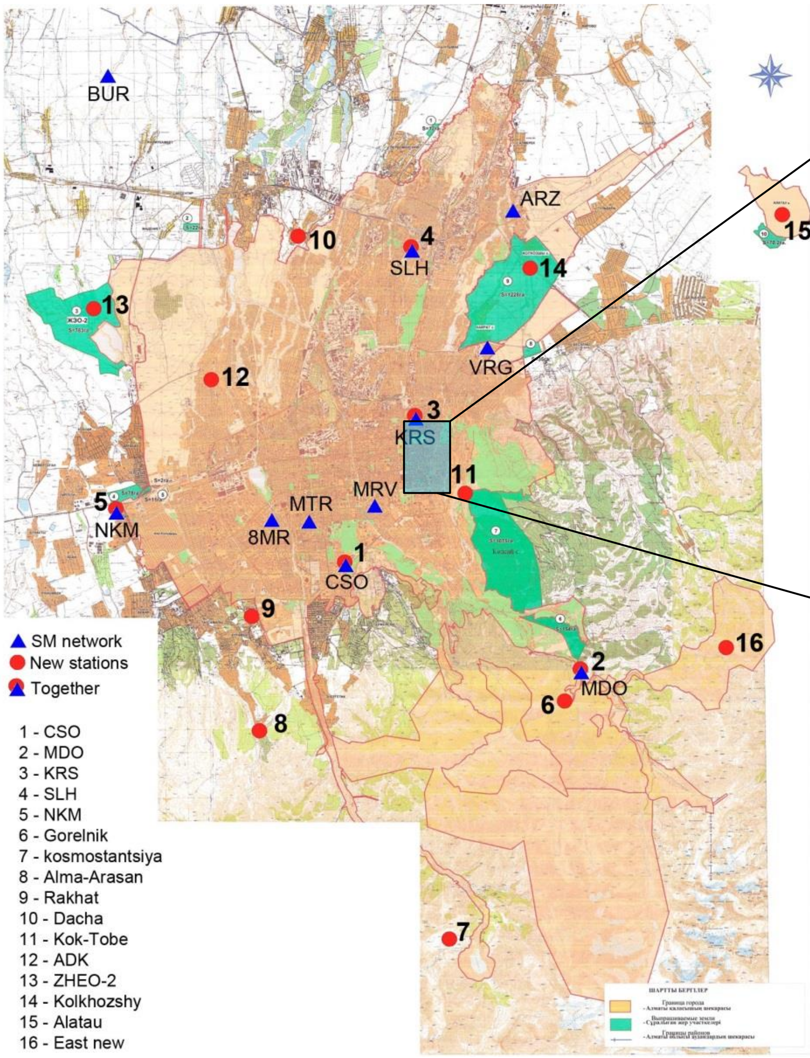


Almaty

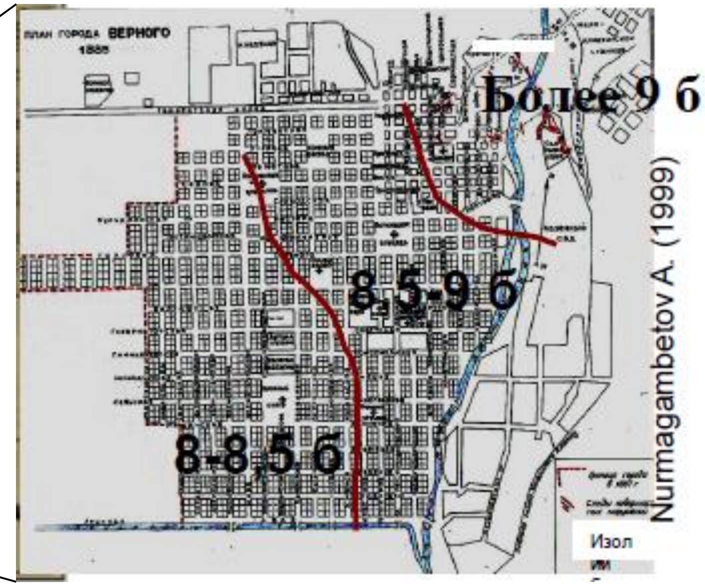
Nurmagambetov (1999)

Nurmagambetov (1999)

High risk considering the urban dynamic



Parolai et al (2018) in preparation



City	Population (millions)	Estimated deaths (thousands)	Estimated Injuries (thousands)
Almaty	1.5	75	300
Bishkek	0.8 (now ~1)	40	160

GeoHazards Int. B.Tucker, pers. comm.

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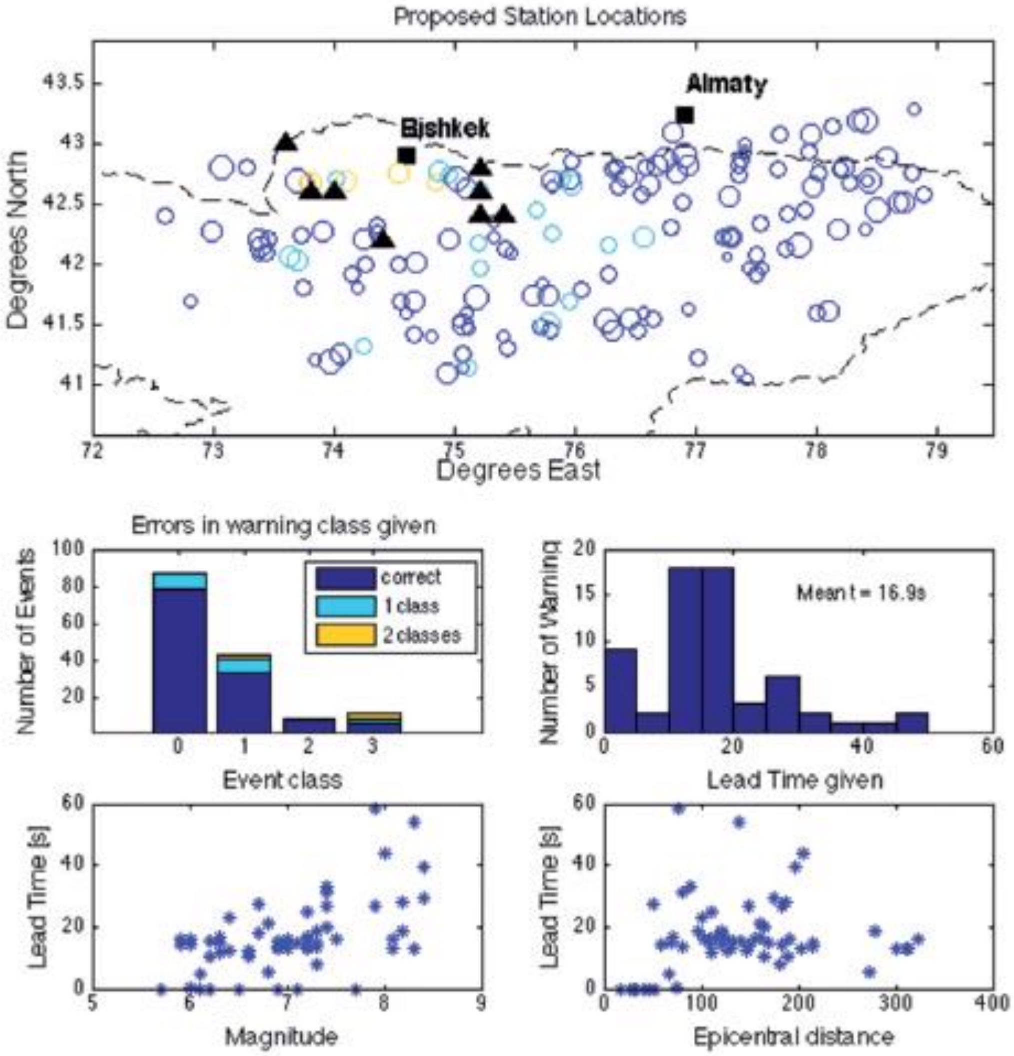
Regional Network Design: using a Genetic Algorithm



Extension to more than one target

Largest improvement in performance when the network is increased up to 5 station.

Separate warning systems for each target are more efficient than a multi-target one

Stankiewicz et al.,2015

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Earthquake risk early warning

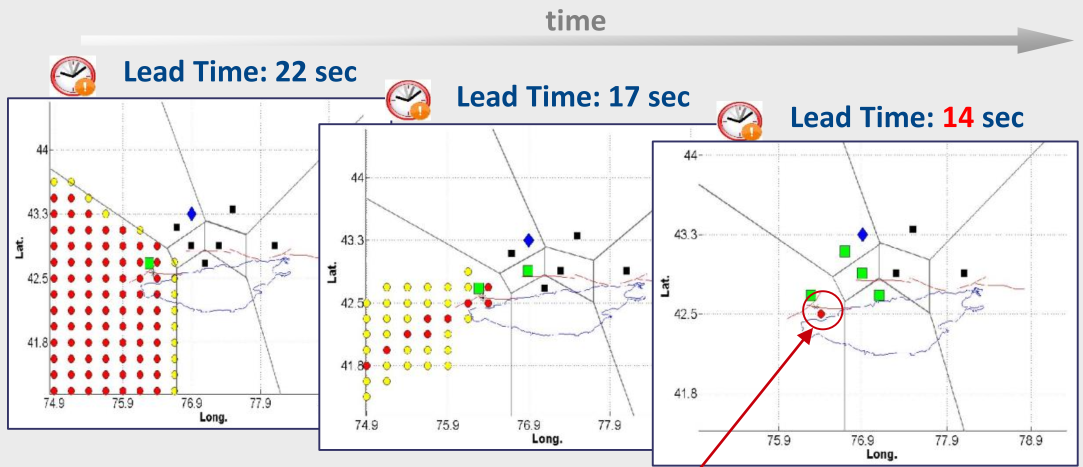
Picozzi et al (2013)

P-wave arrival time data set → Evolutionary Earthquake Localization

Stochastic Event data set → Evolutionary Event Size Characterization

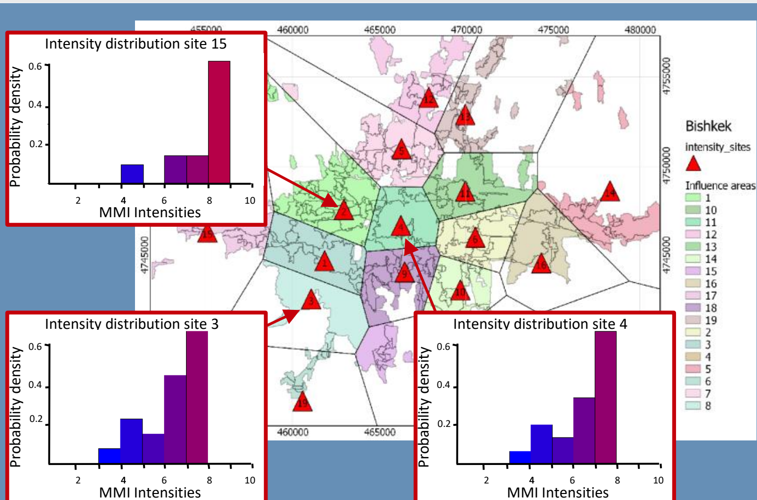
Site Effects → Intensity Scenario at the Target Site

Physical Vulnerability Model → Real Time Loss Map

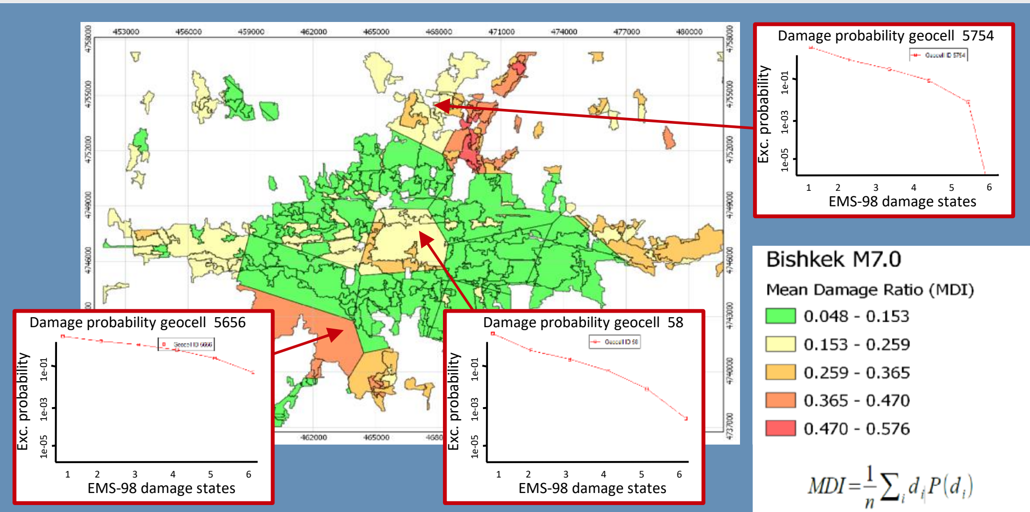


Real-time loss scenario filtering

Event characterized, most probable scenario selected, warning



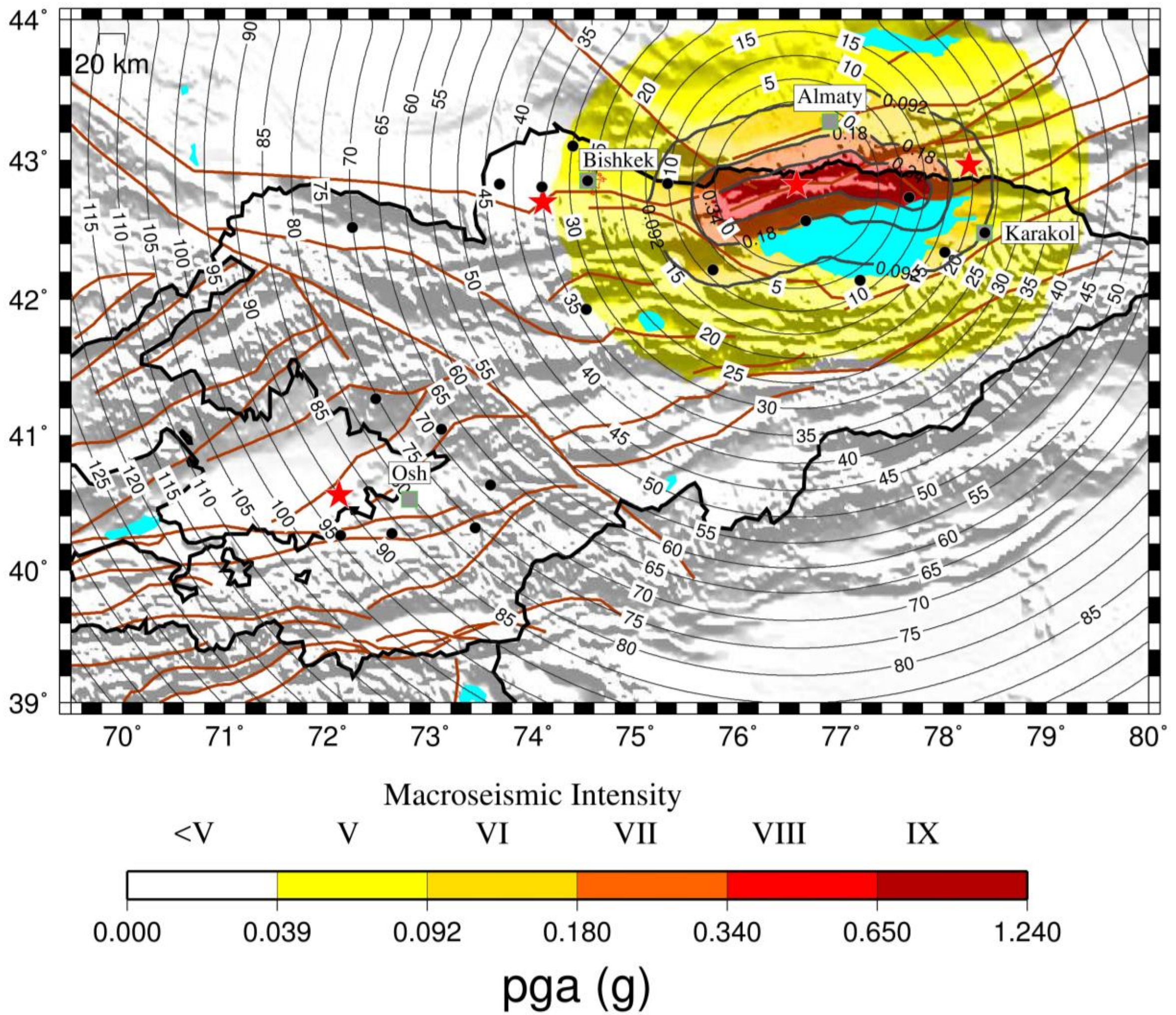
Spatial distribution of simulated intensity



$$MDI = \frac{1}{n}\sum_i d_i P(d_i)$$

Damage probability of exceedance

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



from
Parolai et al.,2017, Frontiers

Decentralised On Site Early Warning

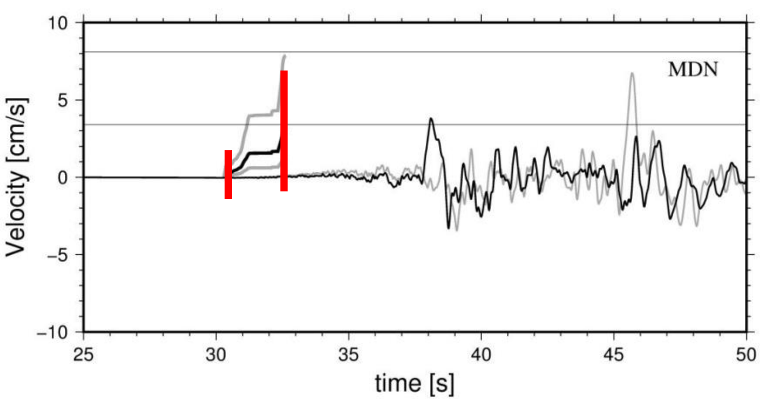
Low pass filtering

Integration in velocity and displacement

Event detection

(possibility of combining info from the low and high pass filtered record or pred period)

PGV estimation (mean +/- s)



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

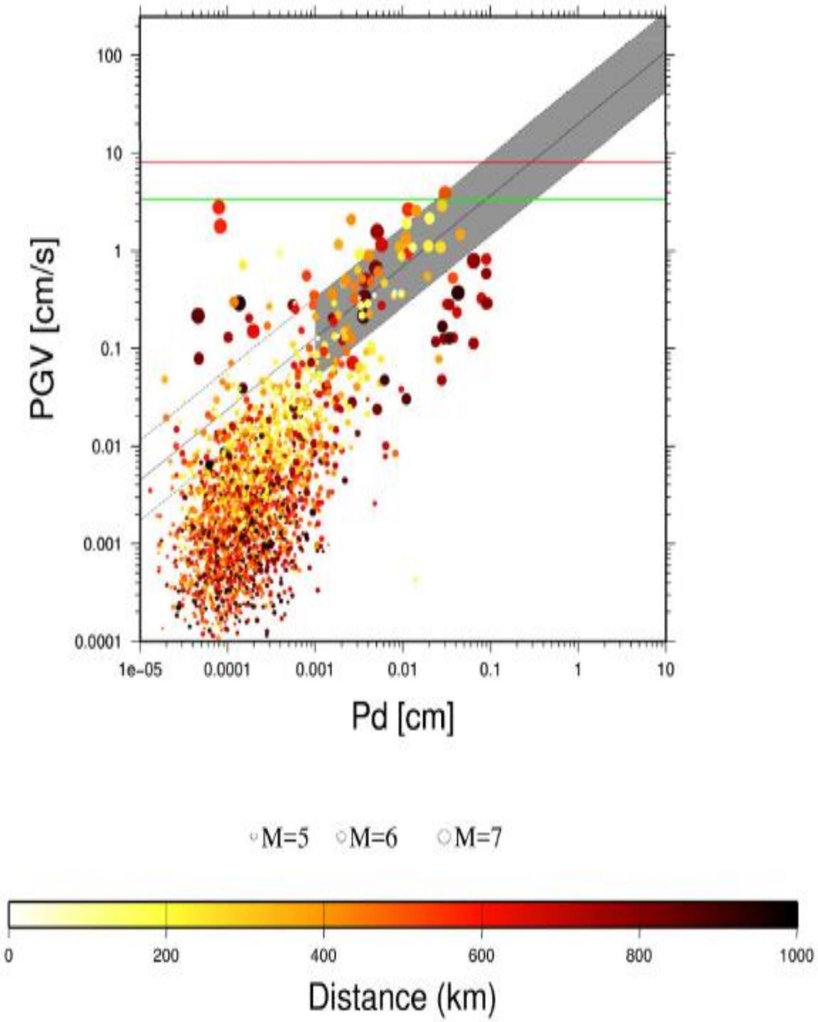
	mean − σ >**8.1** cm/sec	**8.1** cm/sec>mean − σ > **3.4** cm/sec	mean − σ <**3.4** cm/sec
Mean >**8.1** cm/sec			
8.1 cm/sec>mean>**3.4** cm/sec			
Mean <**3.4** cm/sec			X

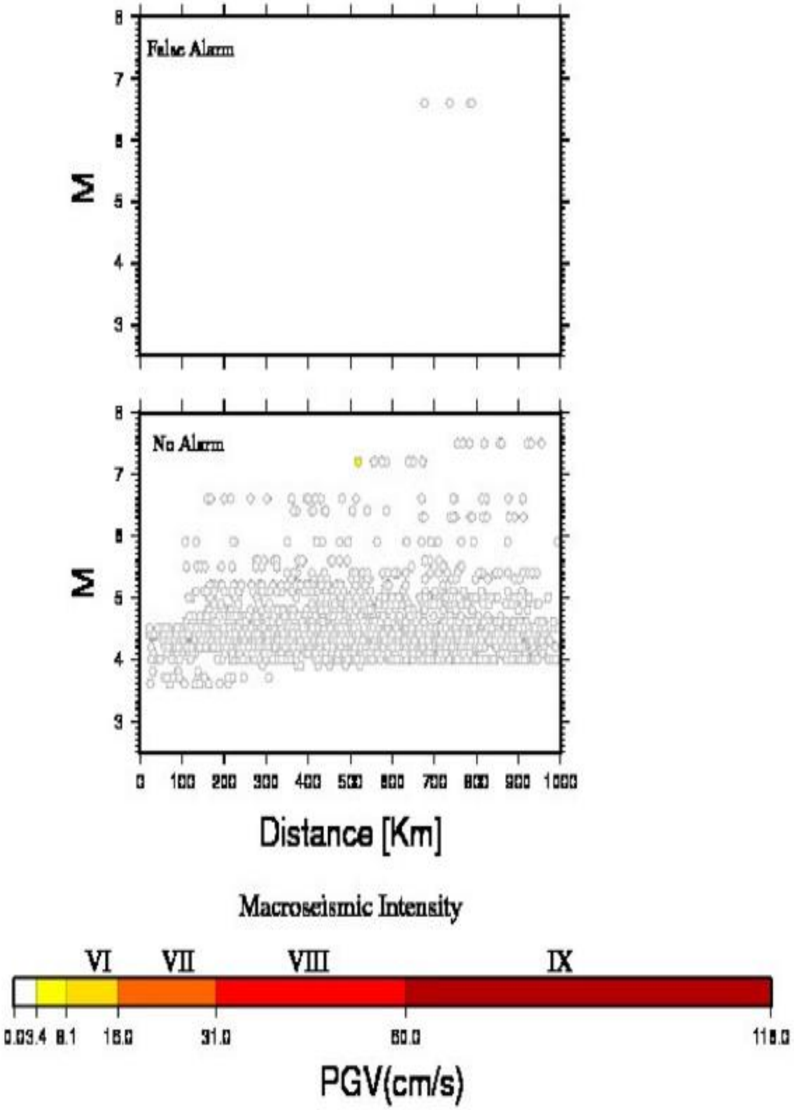
mean + σ < 3.4 cm/sec Intensity ≤IV

	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			X

from
Parolai et al.,2015

Decentralised OSEW in testing





from Parolai et al.,2017, Frontiers

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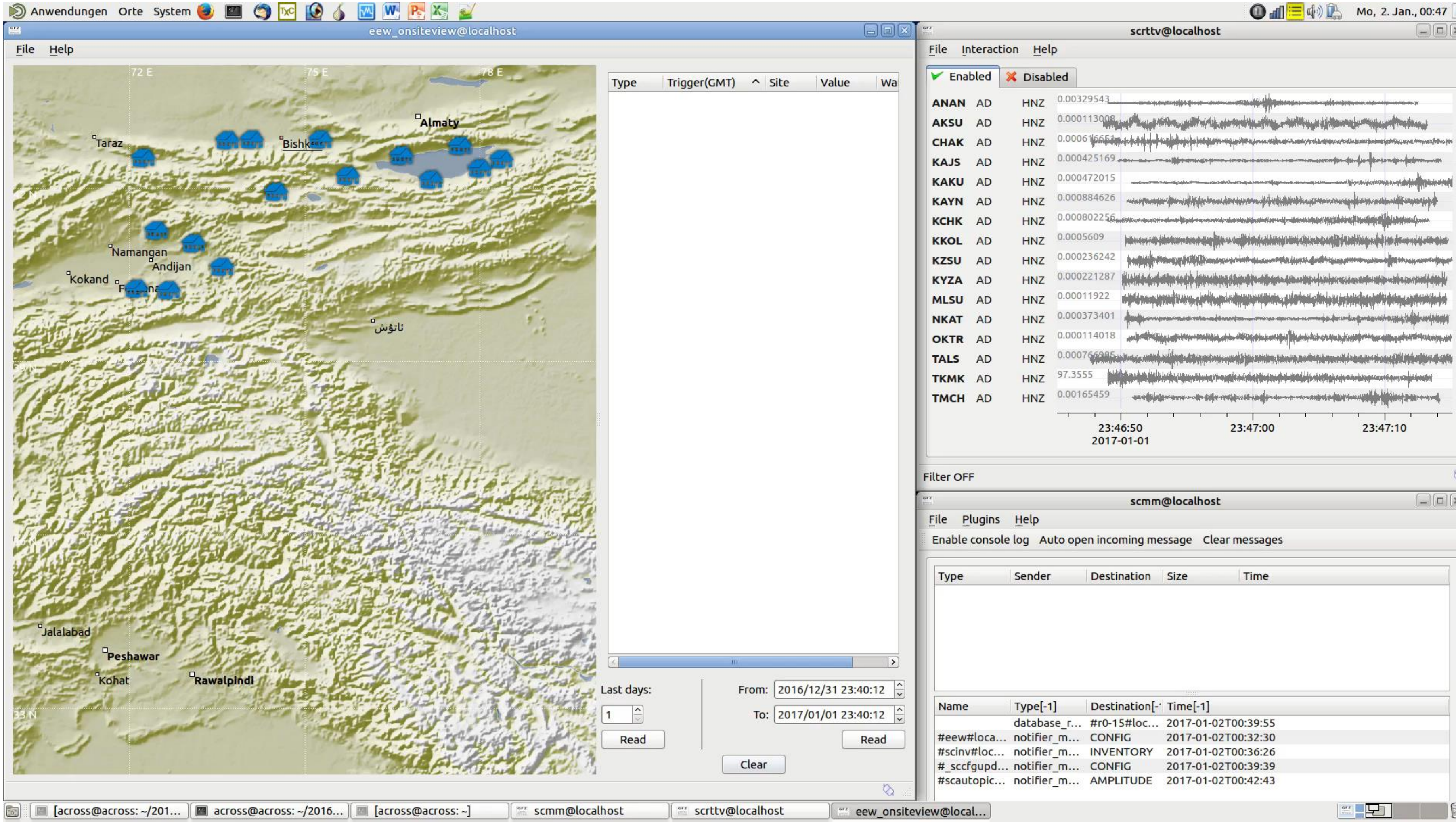
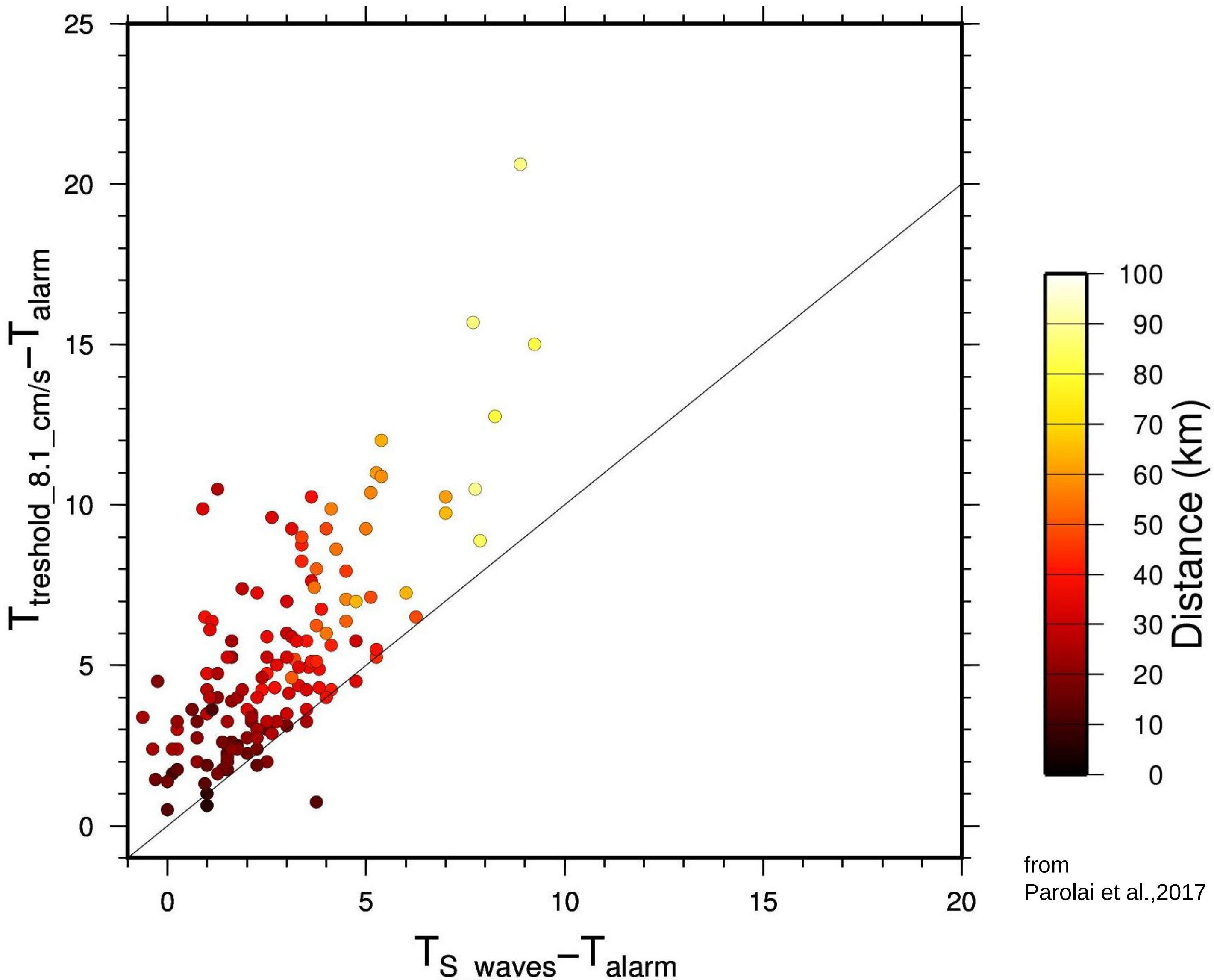
Decentralised Onsite-Early Warning

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



OGS

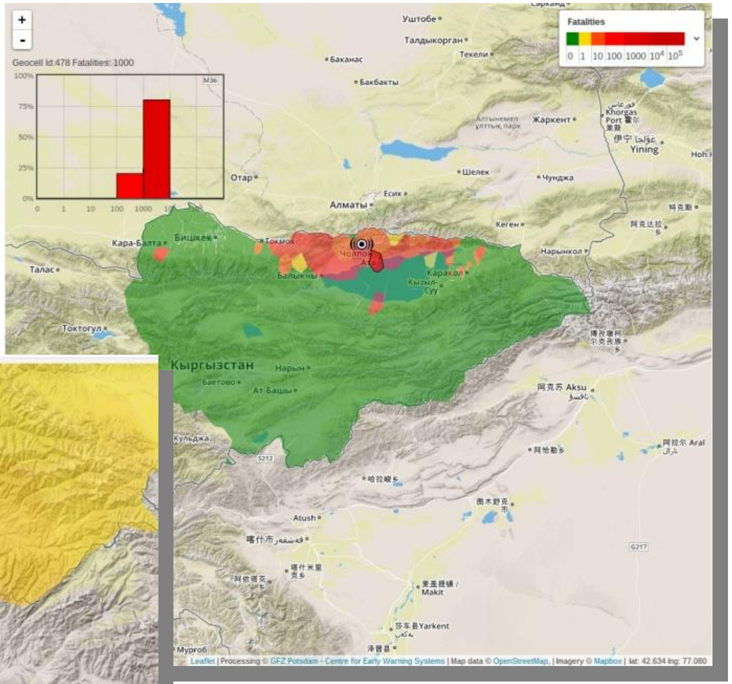
Application to KiK-Net and K-NET recordings

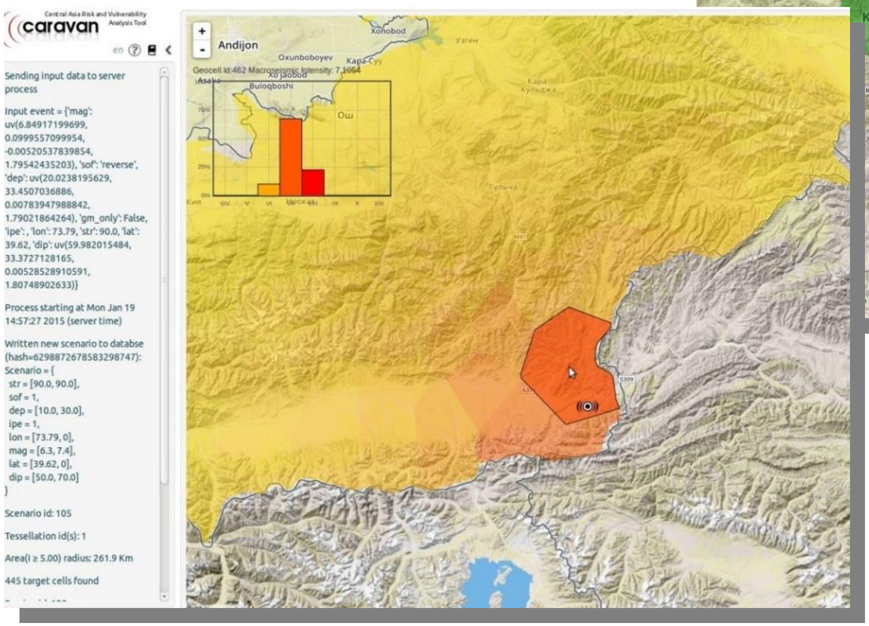


from
Parolai et al.,2017

Real time risk assessment and rapid response

- Better emergency management
- Integrated with early warning
- Goal: reliable information to decision-makers within minutes from the event

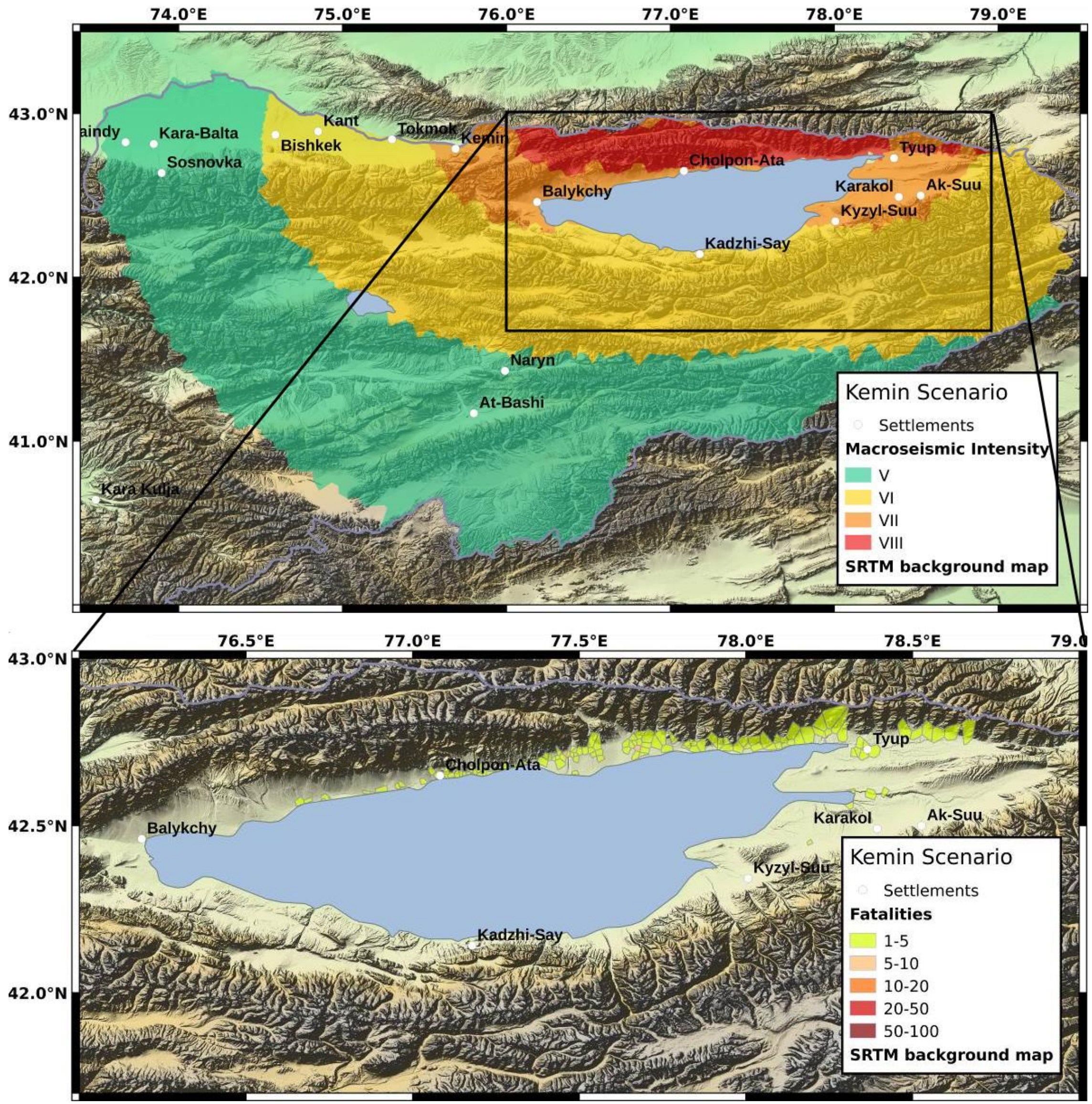


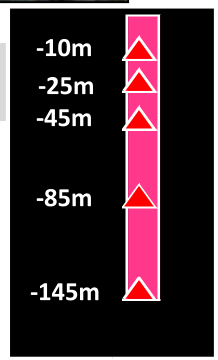


Central Asia Risk and Vulnerability Analysis Tool
caravan

Pittore et al 2017

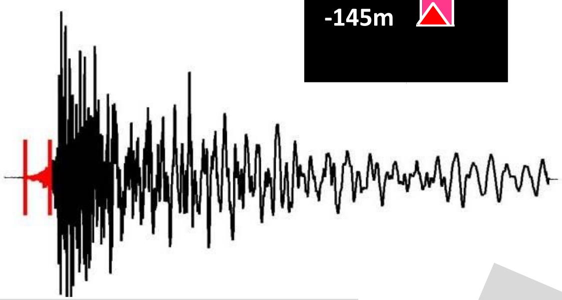
Real time risk assessment and rapid response

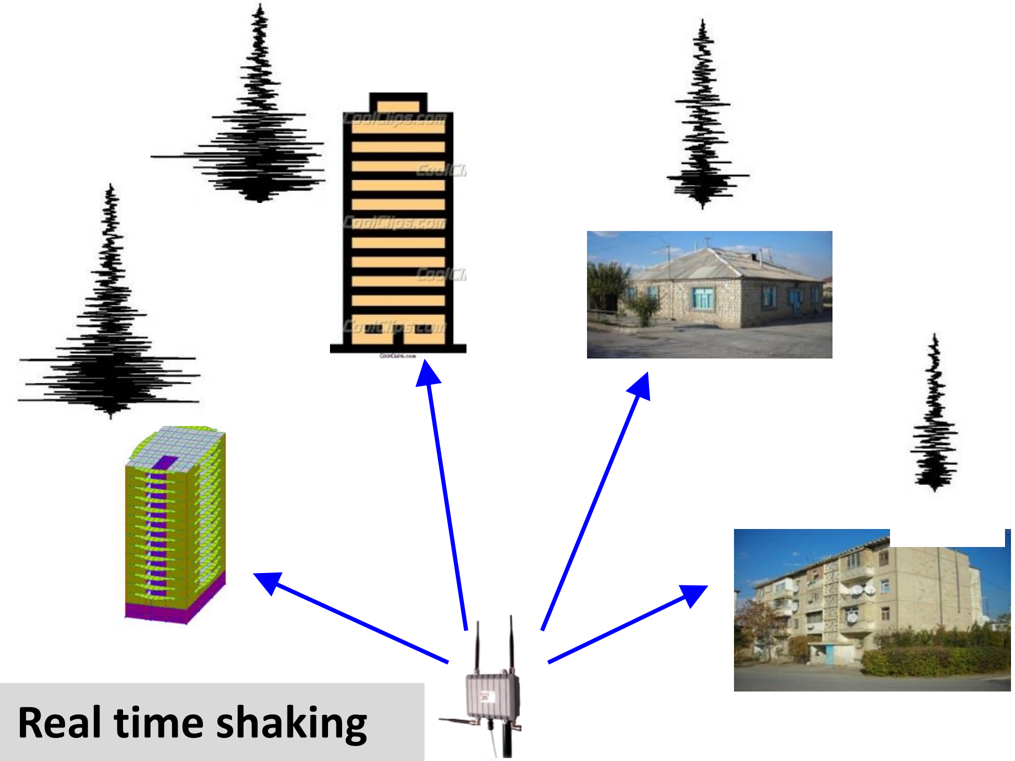




On Site Early Warning

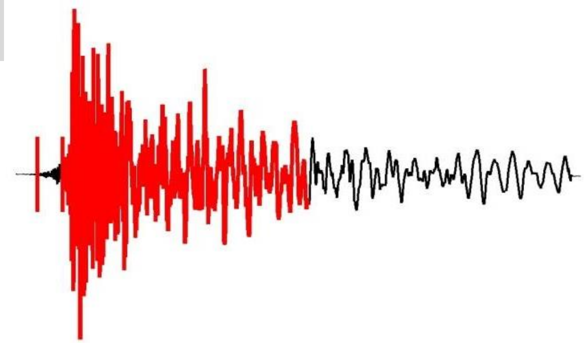
Shaking+damage Forecasted on the node!





Real time shaking forecast

Real time damage detection



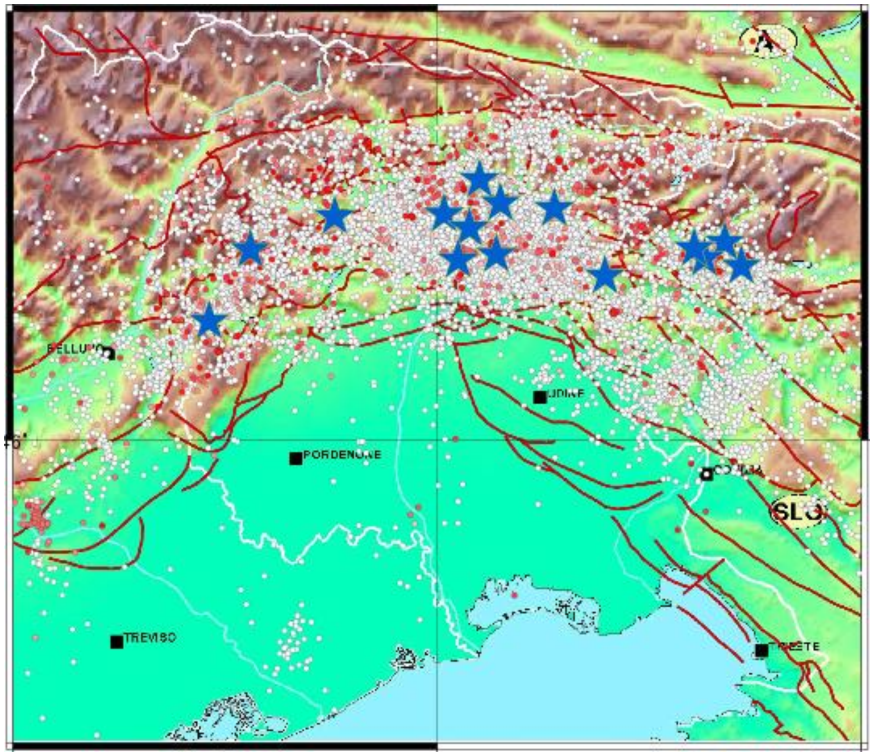
Aftershock hazard: take actions independent from models of aftershock rate

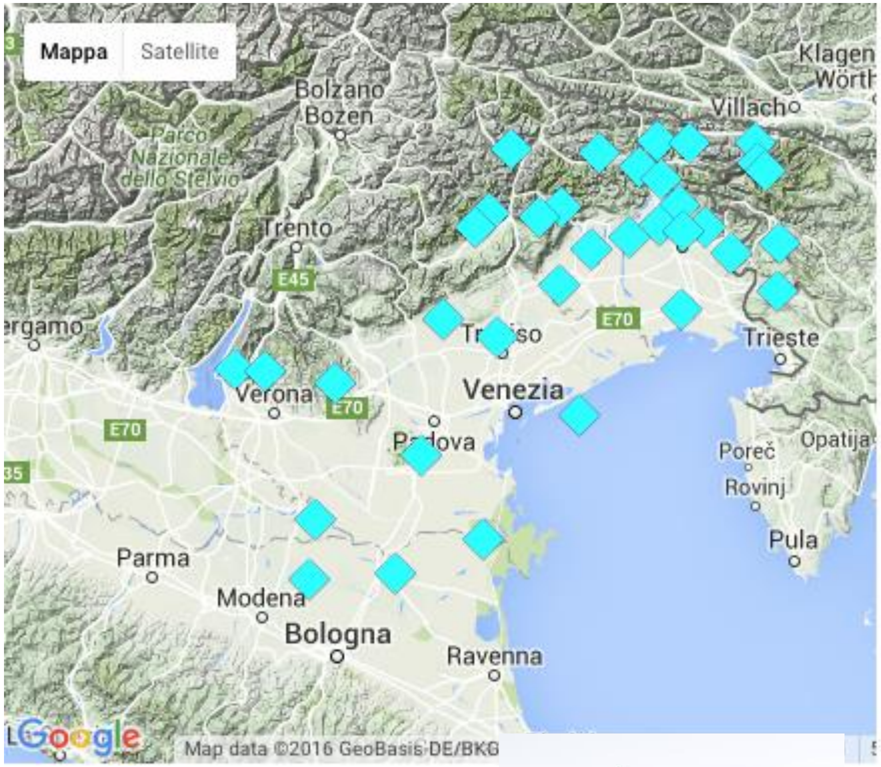
Cumulated damage effect: from building monitoring to incremental damage assessment, to updated vulnerability models

Aftershock sequence

from
Parolai et al.,2015, SRL

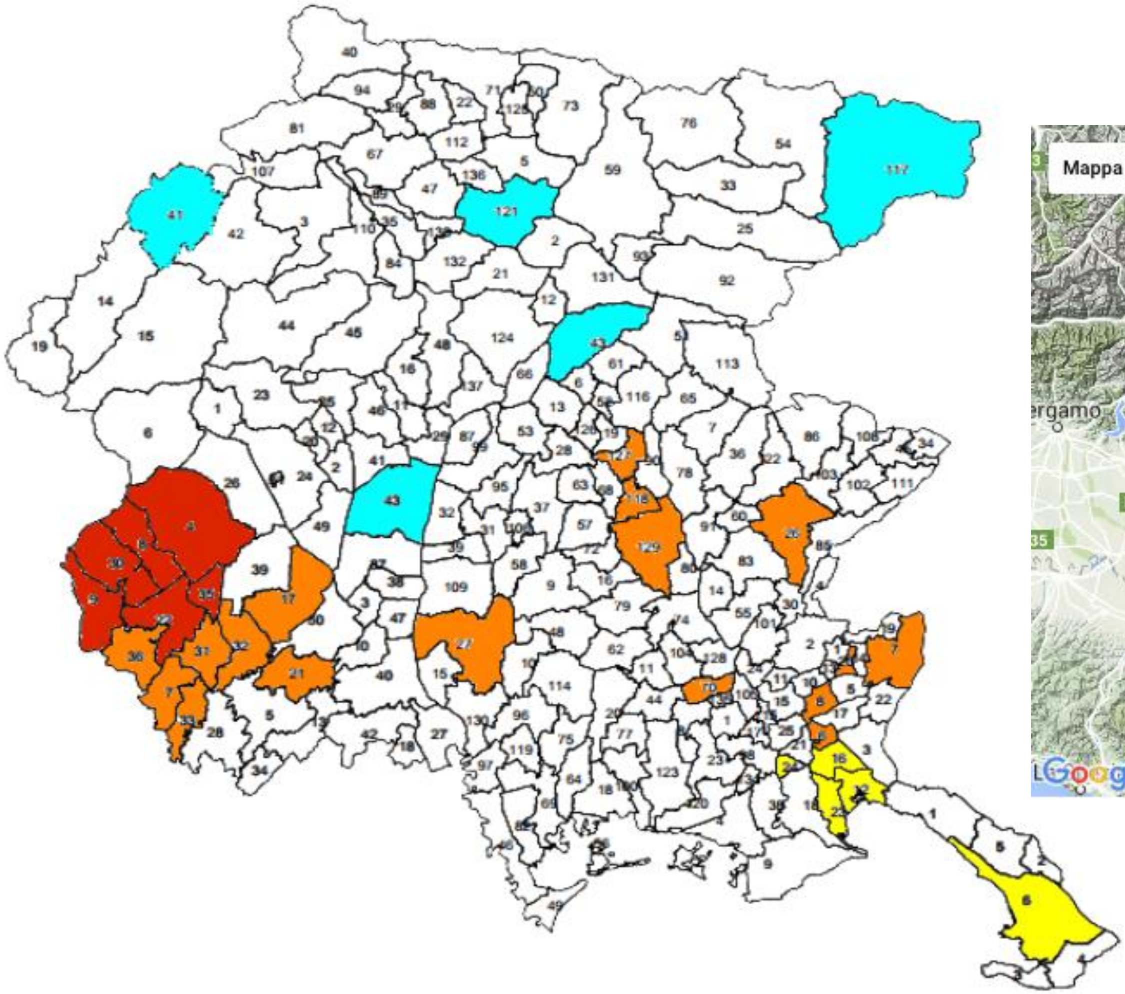
Pilot site: North Eastern Italy

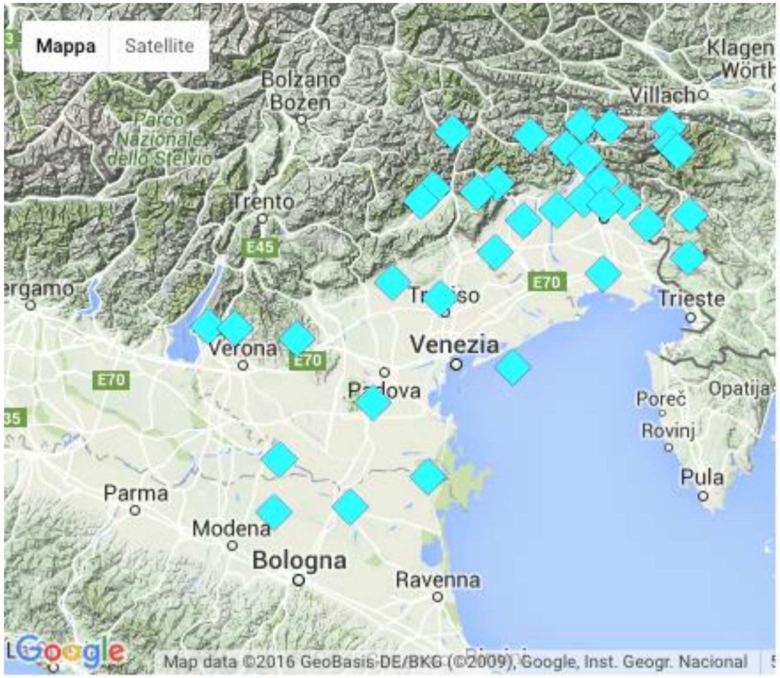




- 2018: installation of ~100 strong motion stations (**Edifici Sentinella, Armonia**) Coop. with Uni Udine, Uni Trieste
- Regional+ Onsite
- DOSEW for critical infrastructures
- Necessity of considering site response
- Close cooperation with Civil protection and Industry

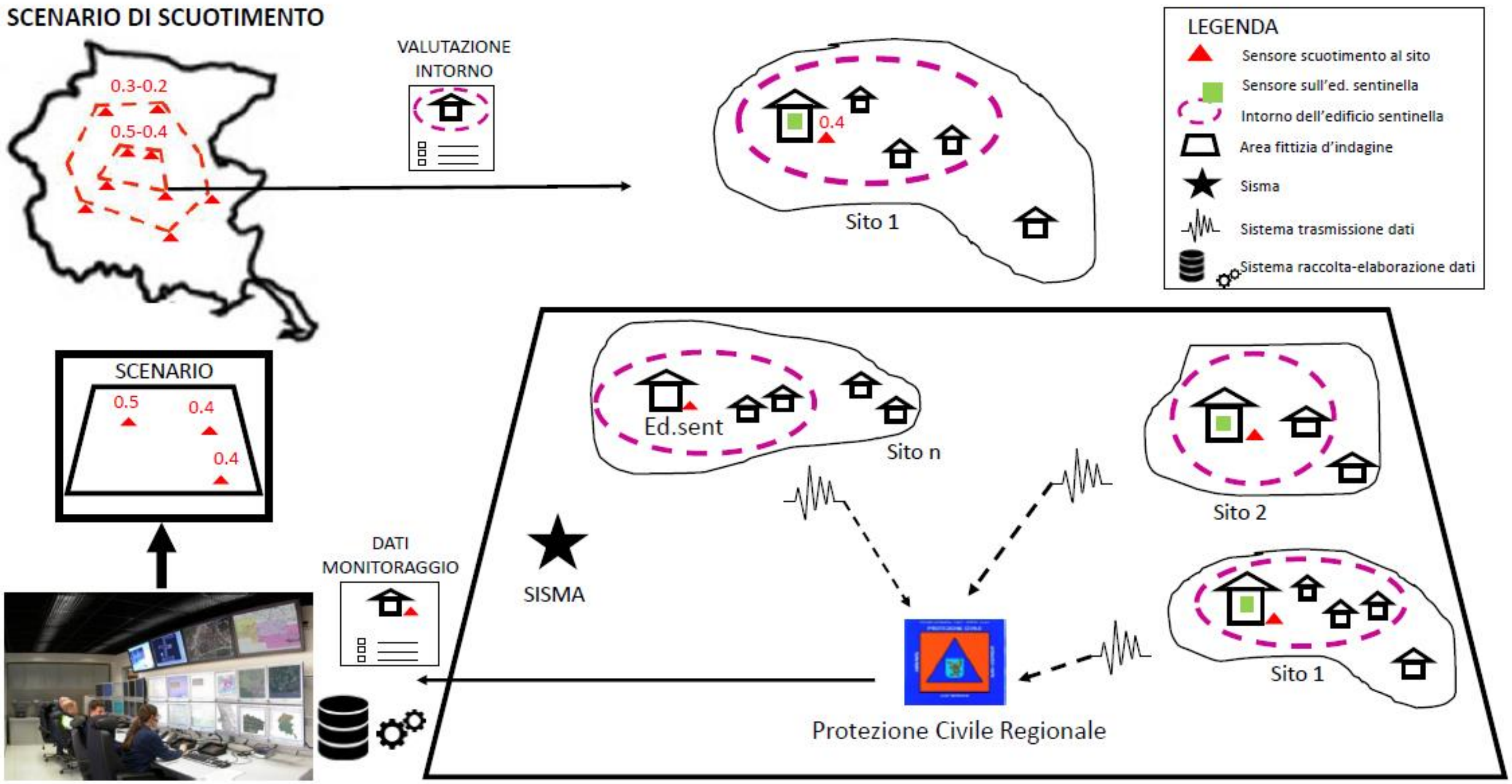
Municipality chosen for the first new installations





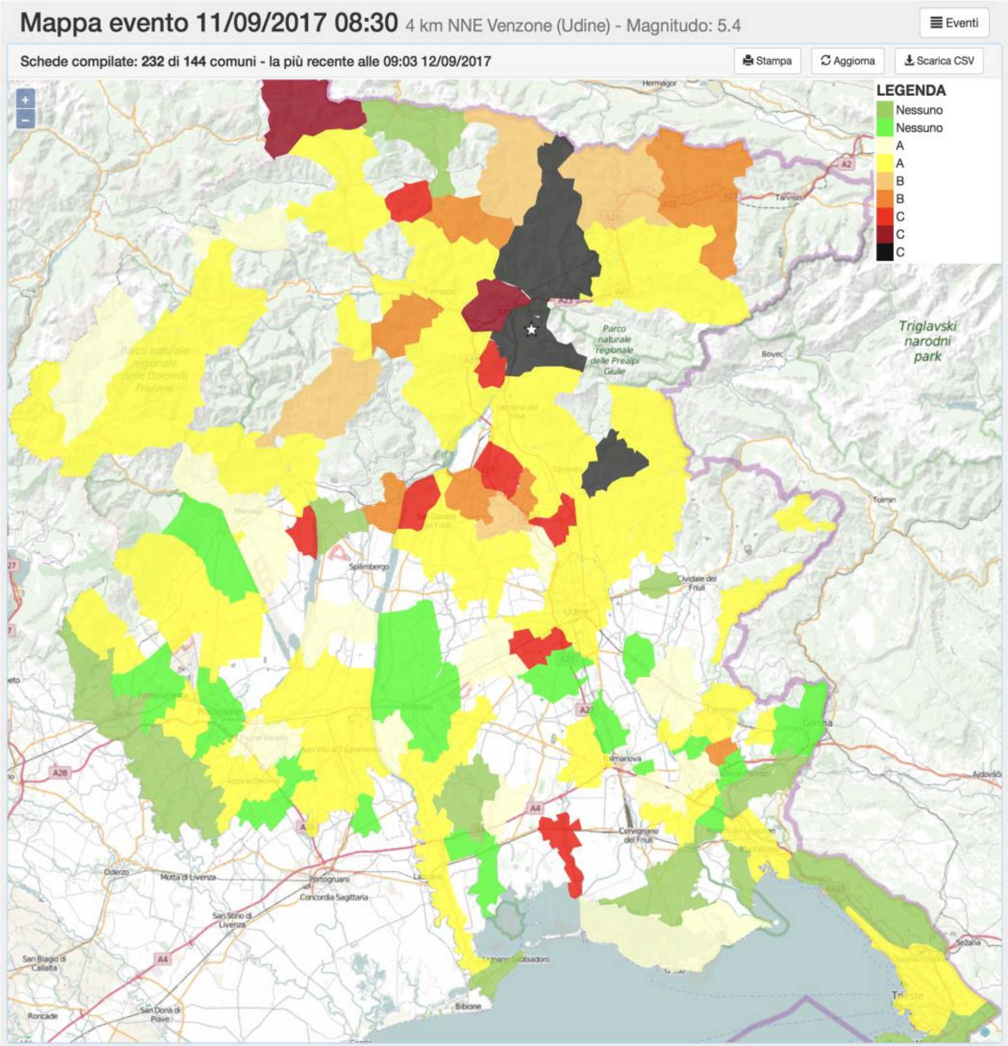
from Grimaz et al.,2017

Rapid Damage forecasting in buffer areas



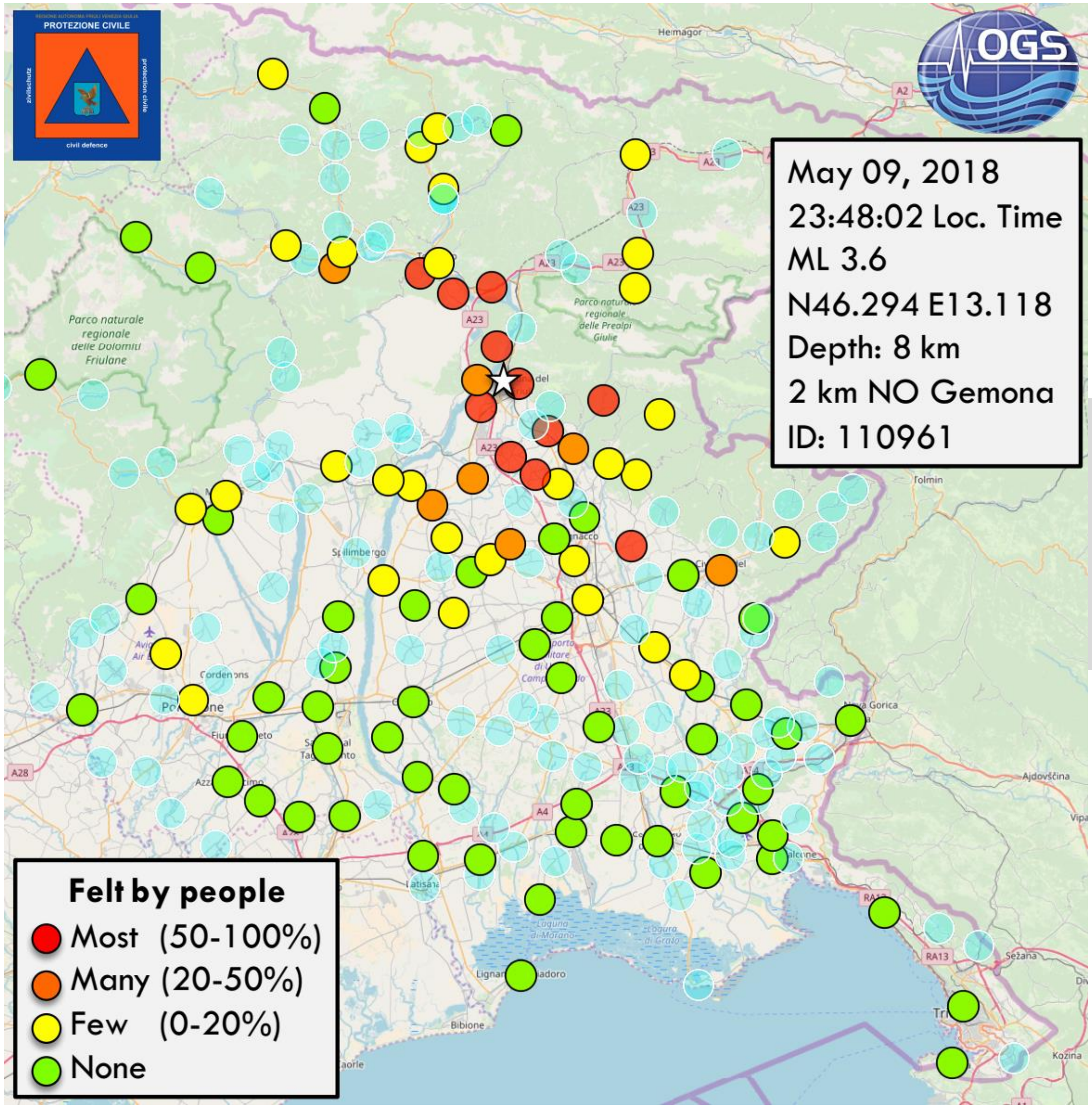
from Grimaz et al.,2017

Expert Crowd sourcing: Civil protection Volunteers



Results showing the impact distribution based on the form filled by the volunteers of the regional civil defense

Expert Crowd sourcing: Civil protection Volunteers



Results showing the impact distribution based on the form filled by the volunteers of the regional civil protection

Cooperation and network operations

Close cooperation with end users

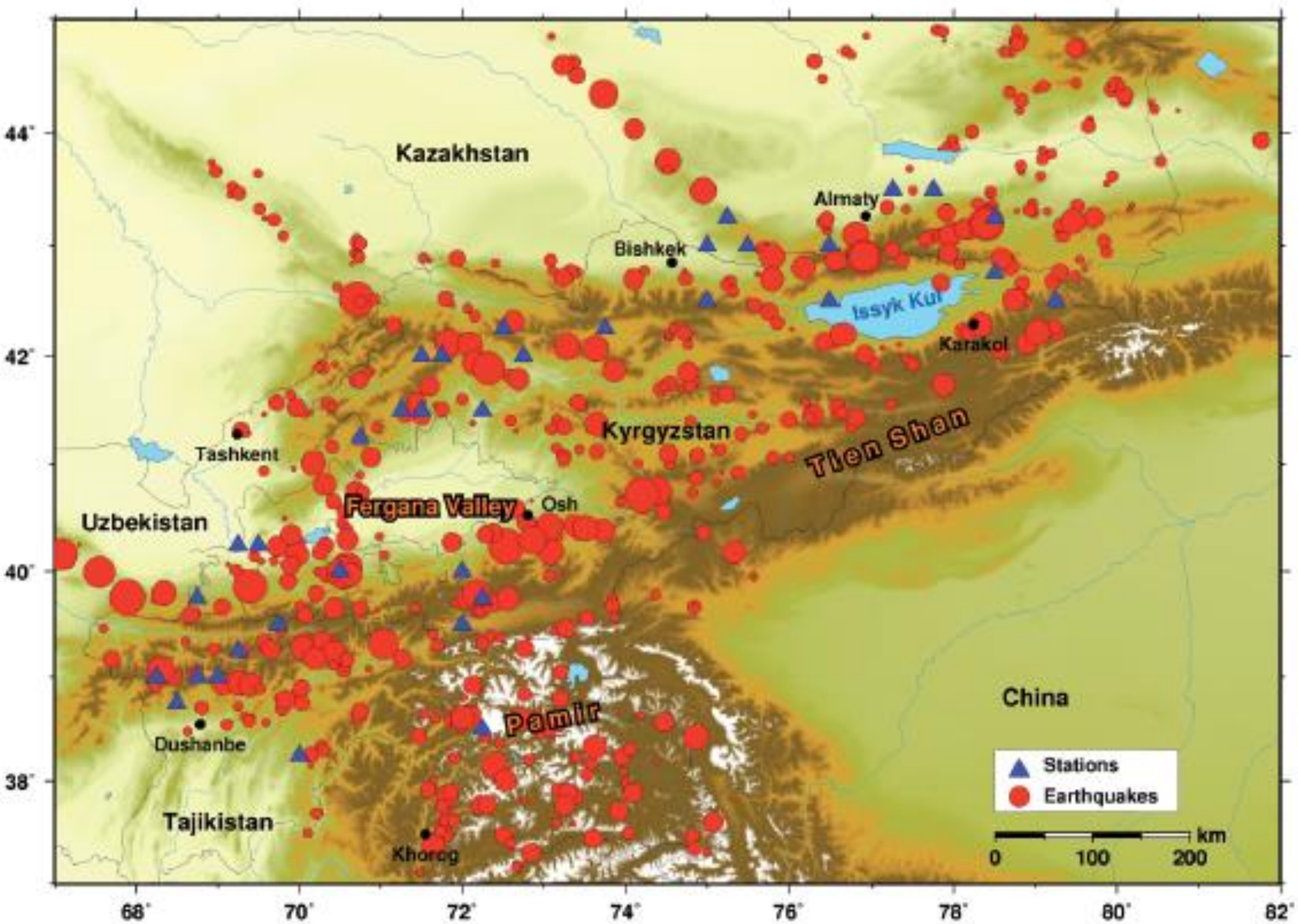
December, 2016, CAIAG was visited by the Kyrgyz Republic Minister of Emergency Situations, Mr. K. Boronov, the State Secretary Mr. T. Temiraliev, and the Deputy Head of the Center of Crisis Situations Managment, Mr. A. Mambetov.

Outreach and education

Thank You!

Acknowledgements: I am thankful to D. Bindi, A.Oth, K. Megalooikonomou, M. Pilz, M. Picozzi, K. Fleming, J. Stankiewicz M. Wieland, P.Comelli, S. Grimaz, A. Rebez, I. iervolino who contributed to this presentation

Regional Network Design: using a Genetic Algorithm



Extension to more than one target**: Osh, Almaty, Bishkek, Dushanbe, Tashkent**

35 station network made of five, **7** stations subnetworks

Stankiewicz et al.,2015

Decentralised On Site Early Warning

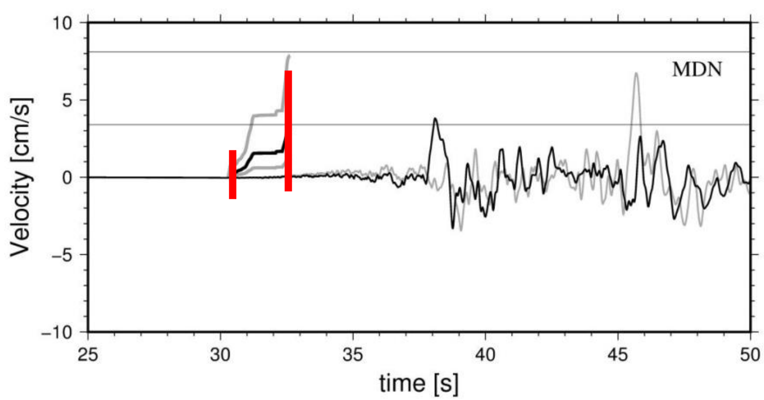
Low pass filtering

Integration in velocity and displacement

Event detection

(possibility of combining info from the low and high pass filtered record or pred period)

PGV estimation (mean +/- σ)



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 >**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			X

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			X

from
Parolai et al.,2015

Decentralised On Site Early Warning

Low pass filtering

Integration in velocity and displacement

Event detection

(possibility of combining info from the low and high pass filtered record or pred period)

PGV estimation (mean +/- σ)

$$P(green, t) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\log(3.4)} e^{-\frac{(x-\mu(t))^2}{2\sigma^2}} dx$$

$$P(orange, t) = \frac{1}{\sigma\sqrt{2\pi}} \int_{\log(3.4)}^{\log(8.1)} e^{-\frac{(x-\mu(t))^2}{2\sigma^2}} dx$$

$$P(red, t) = \frac{1}{\sigma\sqrt{2\pi}} \int_{\log(8.1)}^{\infty} e^{-\frac{(x-\mu(t))^2}{2\sigma^2}} dx$$

mean + σ > 8.1 cm/sec Intensity ≥VI

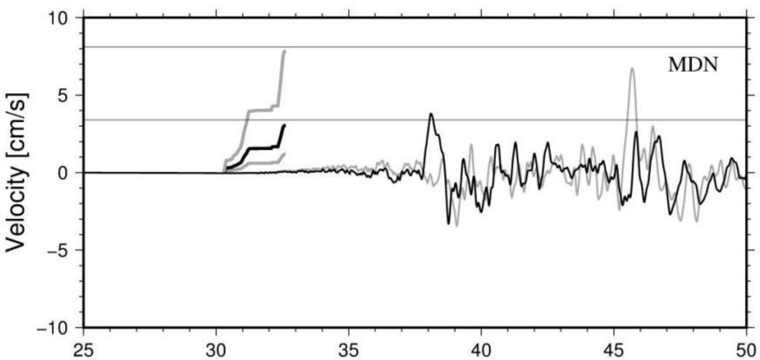
	mean − σ >**8.1** cm/sec	**8.1** cm/sec>mean − σ > **3.4** cm/sec	mean − σ <**3.4** cm/sec
Mean >**8.1** cm/sec			
8.1 cm/sec>mean>**3.4** cm/sec			
Mean <3.4 cm/sec			

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

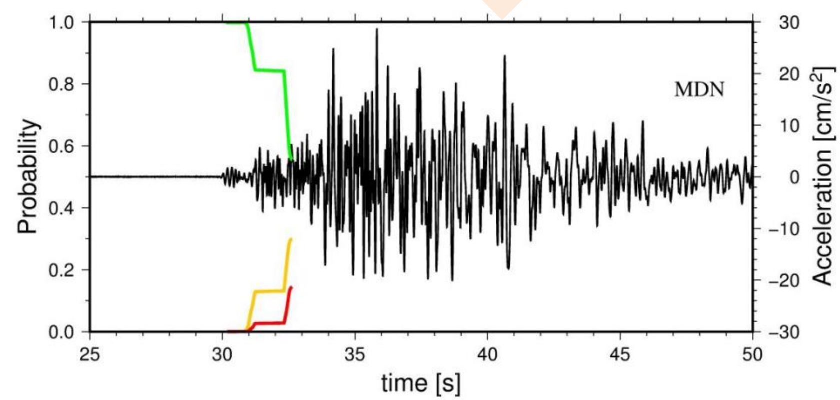
	mean − σ >**8.1** cm/sec	**8.1** cm/sec>mean − σ > **3.4** cm/sec	mean − σ <**3.4** cm/sec
Mean >**8.1** cm/sec			
8.1 cm/sec>mean>**3.4** cm/sec			
Mean <**3.4** cm/sec			

mean + σ < 3.4 cm/sec Intensity ≤IV

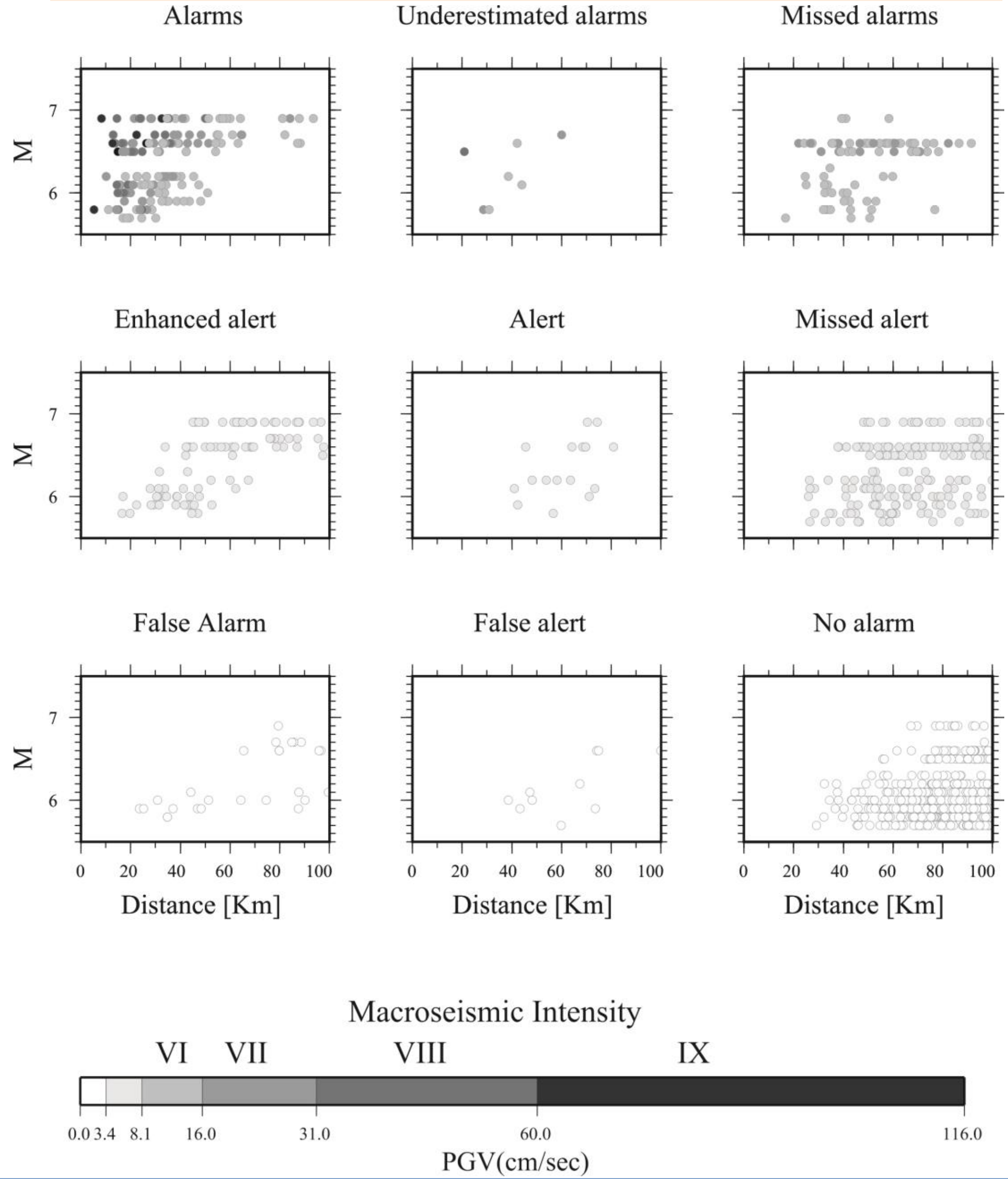
	mean − σ >**8.1** cm/sec	**8.1** cm/sec>mean − σ > **3.4** cm/sec	mean − σ <**3.4** cm/sec
Mean >**8.1** cm/sec			
8.1 cm/sec>mean>**3.4** cm/sec			
Mean <**3.4** cm/sec			



from
Parolai et al.,2015



Application to KiK-Net and K-NET recordings



from
Parolai et al.,2017

REGIONE AUTONOMA FRIULI VENEZIA GIULIA

Protezione Civile della Regione

Nucleo operativo piani d'emergenza

800 500 300

Piano comunale di emergenza

Palmanova

Sindaco

A

1. Per informazioni sull'attività sismica in atto contattare la Sala Operativa regionale al numero verde sopraindicato
2. Aggiornare all'occorrenza gli indirizzi email utilizzati dalla SOR per trasmettere alle autorità comunali di protezione civile le notifiche di evento sismico.
3. Organizzare mailing-list per la diffusione delle informazioni sull'evento ai referenti degli edifici rilevanti in caso di evento sismico (scuole, case di riposo e di cura, edifici pubblici soggetti ad affollamento, ecc).

B

4. Convocare l'Ufficio tecnico e/o il Responsabile comunale di p.c. per coordinare le verifiche sul territorio ad iniziare dagli edifici e dalle infrastrutture strategiche e rilevanti secondo l'ordine di priorità predefinito nel Piano comunale di emergenza, tenendo conto della presenza o meno di alunni nelle scuole e della presenza di zone o fabbricati pericolosi per la circolazione.
5. Se necessario richiedere il supporto tecnico specialistico attraverso la SOR al numero verde per verifiche ad edifici strategici e rilevanti.
6. Assumere provvedimenti a salvaguardia delle persone in difficoltà.
7. Assumere eventuali provvedimenti di sospensione precauzionale dell'attività scolastica e in altri edifici rilevanti.

C

8. Attivare il proprio Gruppo comunale di p.c. per l'assistenza alla popolazione presso le aree di attesa e le aree di ricovero coperte individuate nel piano comunale di emergenza.
9. Coordinarsi con la Prootezione Civile della Regione per eventuali provvedimenti da adottare a tutela della pubblica incolumità e per l'informazione alla popolazione.
10. Contattare le aziende del territorio comunale soggette a AIA (autorizzazione integrata ambientale) per accertarsi sull'esito delle verifiche in atto.

Gruppo comunale di Protezione Civile

A

1. Aprire le comunicazioni radio con la SOR per ricevere informazioni sulla scossa registrata.
2. Compilare e trasmettere alla SOR i dati sul risentimento sismico locale utilizzando l'apposito questionario presente sul sito http://sismica.protezionecivile.fvg.it.

B

3. Dare supporto al personale scolastico o di altri edifici rilevanti nel caso di evacuazione degli stessi fino alla ripresa o al termine delle normali attività.

C

4. Dare assistenza alla popolazione presso le aree di attesa/aree di ricovero.
5. Su richiesta della SOR e qualora attivati dal Sindaco, intervenire a supporto di altri comuni limitrofi per analoghi interventi di assistenza alla popolazione.

Addetti alla sicurezza degli edifici rilevanti (scuole, case di riposo, ...)

A

1. Informarsi attraverso Internet (http://www.protezionecivile.fvg.it/ProtCiv/default.aspx/reti_monitoraggio.htm) o la locale autorità di protezione civile sull'epicentro e la magnitudo dell'evento al fine di valutare la situazione.

B

2. Attivare il segnale di evacuazione secondo la pianificazione di emergenza specifica dell'edificio, coordinare le operazioni e verificare l'avvenuta evacuazione.
3. Assumere informazioni sull'evento chiamando i numeri indicati dal Piano di emergenza dell'edificio.
4. Eseguire una prima valutazione di danno alle parti strutturali e non strutturali dell'edificio richiedendo l'intervento dell'ente proprietario per gli eventuali approfondimenti tecnici del caso.
5. Dopo le opportune verifiche di fruibilità dei locali disporre, se del caso, il rientro delle persone nell'edificio per la ripresa delle attività.

C

Nessuna ulteriore attività

Cittadini

A

1. Informarsi attraverso Internet (http://www.protezionecivile.fvg.it/ProtCiv/default.aspx/reti_monitoraggio.htm) o la locale autorità di protezione civile sull'epicentro e la magnitudo dell'evento al fine di valutare le azioni più prudenti da adottare in relazione alle caratteristiche della propria abitazione.

B

2. Seguire le norme di autoprotezione valide per il luogo nel quale si è presenti al momento del terremoto. Fare riferimento alla documentazione prodotta dal Dipartimento di Protezione Civile http://www.protezionecivile.gov.it/jcms/it/cosa_fare_sismico.wp

C

3. Assicurarsi sullo stato di salute delle persone attorno a se.
4. Recarsi nella propria area di attesa individuata dal Piano comunale di emergenza per ricevere informazioni sull'evento e fare le proprie eventuali richieste di assistenza.

Procedure of emergency for different Alert level (A,B,C)

REGIONE AUTONOMA FRIULI VENEZIA GIULIA

Protezione Civile della Regione

Nucleo operativo piani d'emergenza

Numero Verde Emergenze 800 500 300 Protezione Civile

Università degli studi di Udine

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Scheda di segnalazione dei risentimenti sismici sul territorio

da compilare online su http://sismica.protezionecivile.fvg.it

Evento

Data

Ora

Compilatore

Compilatore

Luogo

Comune

Località/Quartiere

Effetti sulle persone

Il terremoto è stato avvertito ○ Sì ○ No

	Nessuno	Pochi (0-20%)	Molti (20-50%)	Maggior parte (50-100%)
Avvertito in casa solo ai piani superiori da				
Avvertito in casa anche al piano terra da				
Avvertito con spavento da				

Effetti su edifici

	Nessuno	Pochi (0-20%)	Molti (20-50%)	Maggior parte (50-100%)
Caduta di controsoffitti o altri oggetti appoggiati				
Caduta di camini, cornicioni o tegole				
Crepe evidenti nelle pareti				
Crolli parziali di elementi strutturali portanti				
Crolli generalizzati				

Note

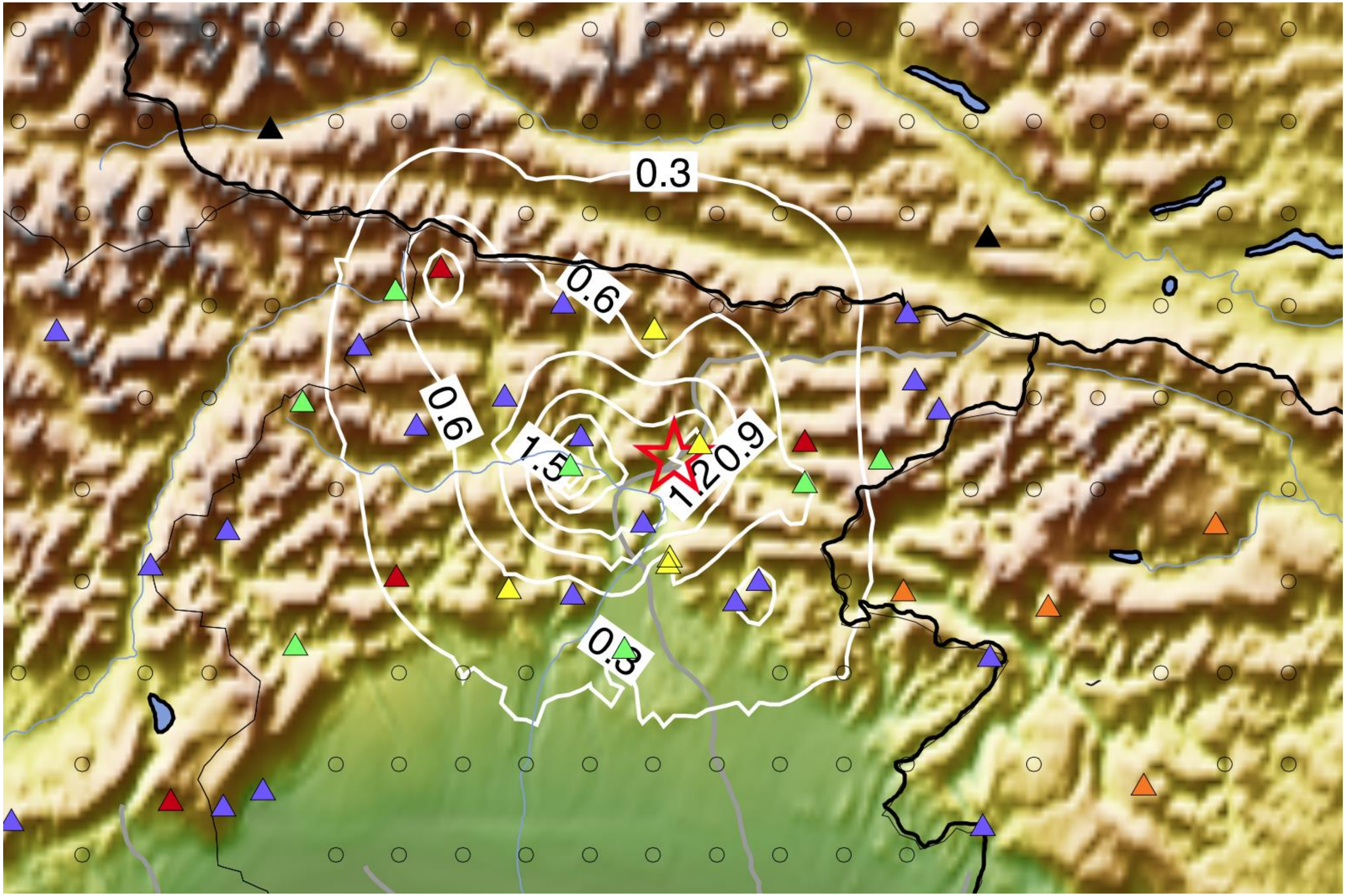
Note

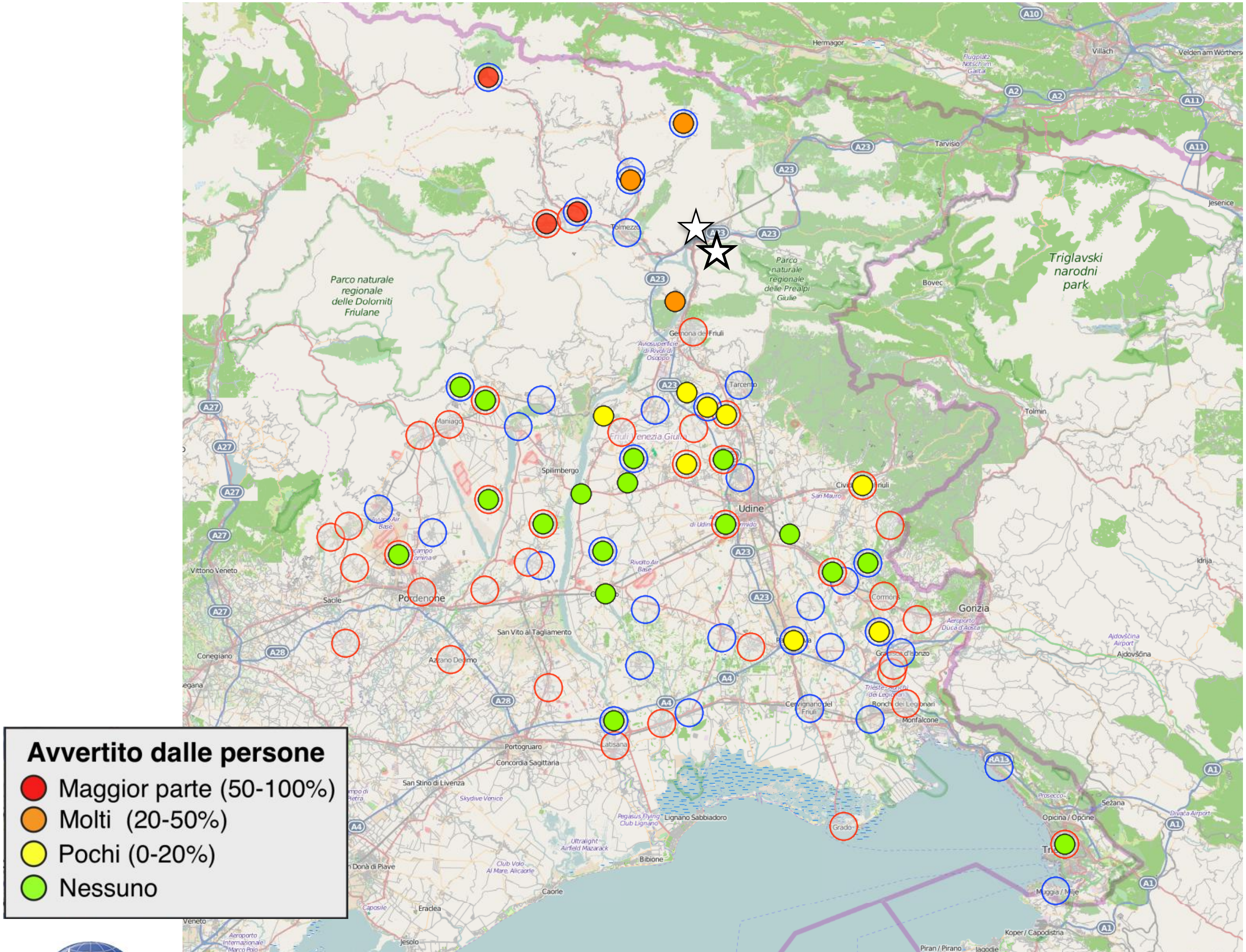
Scheda stampata il 02/05/2014 Pagina 1 di 2

Evaluation form of the earthquake effects at municipality level

GFZ
Helmholtz Centre
POTSDAM

OGS Peak Velocity Map (in cm/s) for event: 86085 - [L. Moratto]
Fri Jan 30, 2015 01:45:49 AM MST M 4.1 N46.39 E13.15 Depth: 14.6km




Avvertito dalle persone
Maggior parte (50-100%)
Molti (20-50%)
Pochi (0-20%)
Nessuno
Udine
Gorizia
Pordenone
Spilimbergo
San Vito al Tagliamento
Portogruaro
Concordia Sagittaria
San Stino di Livenza
Lignano Sabbiadoro
Bibione
Caorle
Eraclea
Jesolo
Monfalcone
Conegliano
Vittorio Veneto
Sacile
Tarvisio
Villach
Hermagor
Bovec
Tolmin
Idrija
Ajdovščina
Sežana
Koper / Capodistria
Piran / Pirano
Jesenice
Parco naturale regionale delle Dolomiti Friulane
Parco naturale regionale delle Prealpi Giulie
Triglavski narodni park

Decentralised Onsite-Early Warning

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