CONVEGNO
"Strategie per la riduzione
della vulnerabilità sismica
degli elementi non strutturali"

Bologna – 19 ottobre 2018

Operational Earthquake Loss Forecasting

La frontiera nella gestione del rischio sismico a breve termine

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SAIE

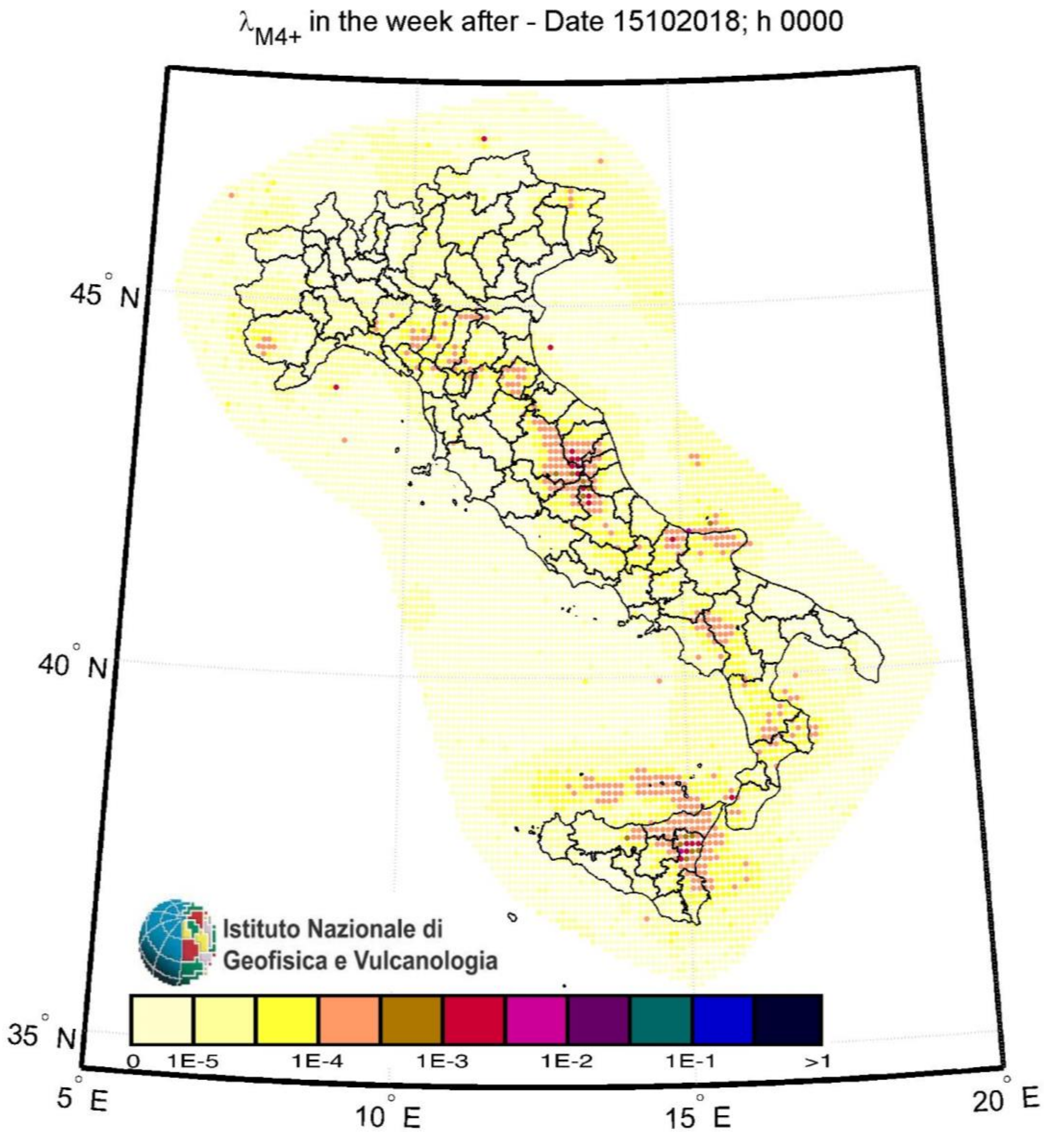
ISI Ingegneria Sismica Italiana

- **The CASSANDRA system of INGV provides weekly rates of events with magnitude (M) 4+ for a 0.1°grid including the whole country. (Updated daily.)**

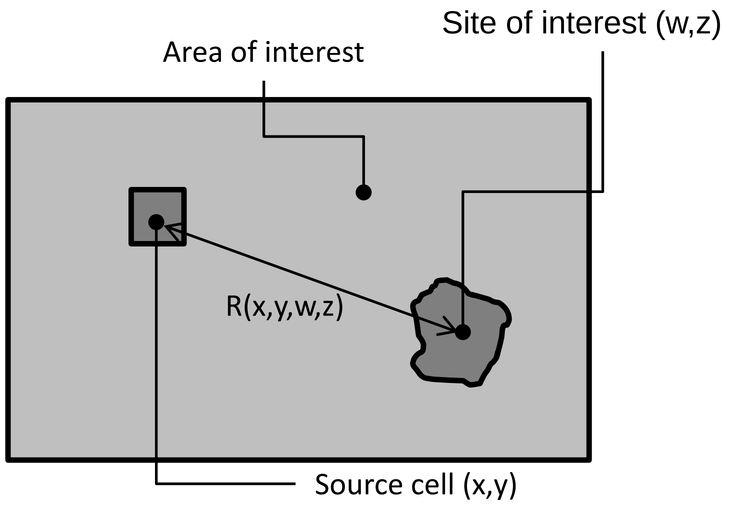
- **The Italian Civil Protection asked to investigate whether it is possible (and useful) to use the INGV data to produce consequence estimates.**

$$D\left(A^*\right) \text{ is optimal } \overset{def}{\Longleftrightarrow} E\left[L \mid A^*\right] \leq E\left[L \mid A_i\right] \quad \forall i = 0,1,\ldots,n.$$

- **The framework is that of performance-based earthquake engineering, that is including probabilistic measures of hazard, vulnerability and exposure at a national scale.**



1. Probabilistic seismic hazard analysis based on OEF



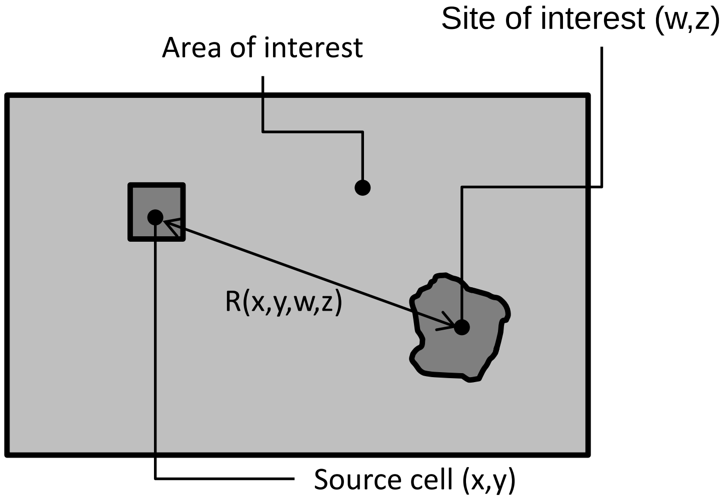
The goal here is to pass from OEF rates at a cell to **rates of events causing some seismic intensity (MS) at a site of interest** (for example one where exposure to seismic risk exists)

$$\underbrace{\lambda_{MS=ms}\left(t,w,z\middle|H(t)\right)}_{\text{Rates of events at (w,z) with MS=ms because of earthquakes occurring at (x,y)}}=\underbrace{\lambda\left(t,x,y\middle|H(t)\right)}_{\text{OEF rates at (x,y)}}\cdot\int_m \underbrace{P\left[MS=ms\middle|m,R(x,y,w,z)\right]}_{\text{MS prediction equation (attenuation law)}}\cdot \underbrace{f_M(m)}_{\text{Distribution of M for earthquakes at (x,y)}}\cdot dm$$

Indicating that varies with time (OEF updates)

Indicating dependence on recorded history

2. Weekly rates of events causing building damage



The goal here is to pass from OEF rates at a cell to rates of events causing some damage state (DS) to a building of a certain structural typology (k) at site of interest

Rates of events at (w,z) causing DS=ds because of earthquakes occurring in the whole area

OEF rates at (x,y)

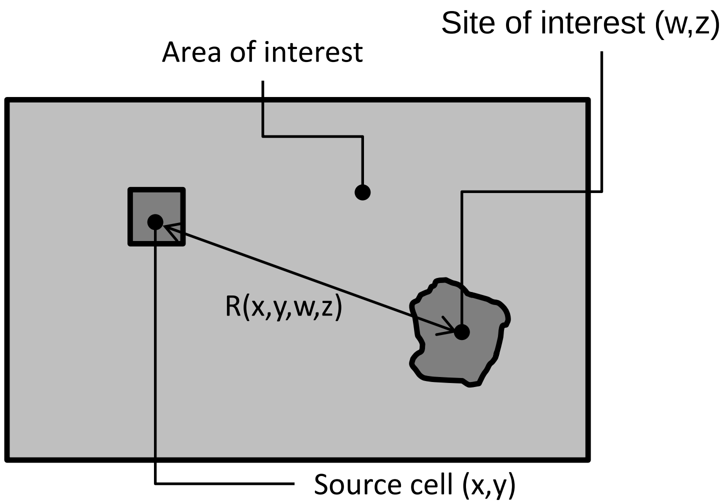
Probability of some damage state to a structure of typology K given ms intensity

Same as per the previous slide

$$\lambda_{DS^{(k)}=ds}\left(t,w,z\,|\,H(t)\right)=\iint_{x,y}\lambda\left(t,x,y\,|\,H(t)\right)\cdot\sum_{ms}P\left[DS^{(k)}=ds\,|\,ms\right]\cdot\int_{m}P\left[MS=ms\,|\,m,R(x,y,w,z)\right]\cdot f_M(m)\cdot dm\cdot dy\cdot dx$$

Summing up over all source cells gives the total damage rate at (w,z) site

3. Weekly rates of events causing individual loss



The goal here is to pass from OEF rates at a cell to rates of events causing some individual consequence to an occupant of a building of a given structural typology (k) at site of interest

Rates of events at (w,z) causing casualty in buildings of typology k

OEF rates at (x,y)

Summation is to account that casualty can be caused by any DS

Probability of casualty in a building of typology K given damage state DS=ds

$$\lambda_{Cas^{(k)}}\left(t,w,z\middle|H(t)\right)=\iint_{x,y}\lambda\left(t,x,y\middle|H(t)\right)\cdot\sum_{ds}P\left[Cas^{(k)}\middle|ds\right]\times$$

$$\times\sum_{ms}P\left[DS^{(k)}=ds\middle|ms\right]\cdot\int_{m}P\left[MS=ms\middle|m,R(x,y,w,z)\right]\cdot f_M(m)\cdot dm\cdot dx\cdot dy$$

Same as per the previous slide

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Expected losses in the week after the OEF rates release

In the short-term, it may be assumed that the rates just shown are constant, that is the occurrence of events follows a point-wise Poisson stochastic process, the parameter of which is updated at each OEF release.

$$E\left[N^{(k)}_{ds,(t,t+\Delta t)}\left|H(t)\right.\right] \approx N_B{}^{(k)} \cdot \lambda_{DS^{(k)}=ds}\left(t,w,z\left|H(t)\right.\right)\cdot \Delta t$$

- $E\left[N^{(k)}_{ds,(t,t+\Delta t)}\left|H(t)\right.\right]$: Expected number of buildings of typology k at (w,z) in damage state DS=ds in the week after OEF rates release
- $N_B{}^{(k)}$: Buildings of typology k at (w,z)
- $\lambda_{DS^{(k)}=ds}$: Rate of events causing damage to typology k at (w,z)
- Δt: One week

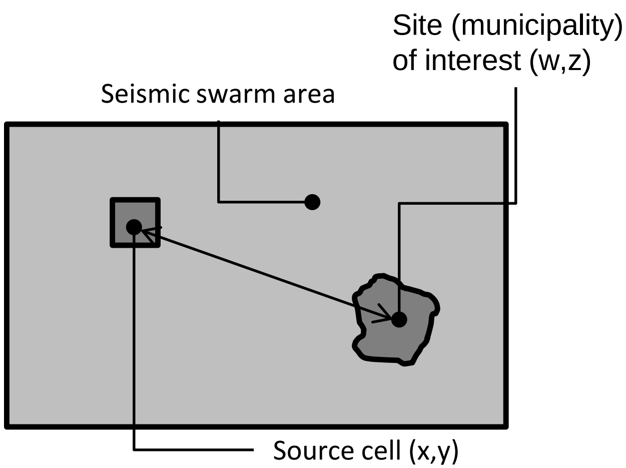
→ **Expected number of displaced and shelter-seeking people**

$$E\left[N^{(k)}_{Cas,(t,t+\Delta t)}\left|H(t)\right.\right] \approx N_P{}^{(k)} \cdot \lambda_{Cas^{(k)}}\left(t,w,z\left|H(t)\right.\right)\cdot \Delta t$$

- $E\left[N^{(k)}_{Cas,(t,t+\Delta t)}\left|H(t)\right.\right]$: Expected number of casualties due to damage to buildings of typology k at (w,z) in the week after OEF rates release
- $N_P{}^{(k)}$: Occupants in buildings of typology k at (w,z)
- $\lambda_{Cas^{(k)}}$: Rate of events casualties in buildings of typology k at (w,z)
- Δt: One week

→ **Expected number of fatalities and injuries**

Operational earthquake loss forecasting (OELF) procedure summary



Rate of events in the source cell of interest from OEF

↓

Probability of any macroseismic intensity level given the event ← **Intensity attenuation law**

↓

Probability of any damage level for any vulnerability class given the event ← **Vulnerability model**

↓

Probability of casualties or injuries for any damage level for any vulnerability class

Sum-up over all source cells

↓

Inventory data for buildings at the site of interest → Expected number of damaged buildings → Expected number of injures, fatalities, displaced people ← **Exposure data for residents at the site of interest**

Iervolino I., Chioccarelli E., Giorgio M., Marzocchi M., Zuccaro G., Dolce M., Manfredi G. (2015) Operational (short-term) earthquake loss forecasting in Italy. *Bulletin of the Seismological Society of America*. 105(4): 2286–2298.

Vulnerability based on damage probability matrices

Class	MS	DS0	DS1	DS2	DS3	DS4	DS5
A	5	0.3487	0.4089	0.1919	0.0450	0.0053	0.0002
B	5	0.5277	0.3598	0.0981	0.0134	0.0009	0.0000
C	5	0.6591	0.2866	0.0498	0.0043	0.0002	0.0000
D	5	0.8587	0.1328	0.0082	0.0003	0.0000	0.0000
A	…	0.2887	0.4072	0.2297	0.0648	0.0091	0.0005
B	…	0.4437	0.3915	0.1382	0.0244	0.0022	0.0001
C	…	0.5905	0.3281	0.0729	0.0081	0.0005	0.0000
D	…	0.7738	0.2036	0.0214	0.0011	0.0000	0.0000

Probabilities of casualty given structural damage

Loss	Structural Typology	Vulnerability Class	DS0	DS1	DS2	DS3	DS4	DS5
Fatalities	Masonry	A or B or C	0	0	0	0	0.04	0.15
Fatalities	R.C.	C or D*	0	0	0	0	0.08	0.3
Injuries	Masonry	A or B or C	0	0	0	0	0.14	0.7
Injuries	R.C.	C or D*	0	0	0	0	0.12	0.5

Exposure by municipality

Code	Name	Prov.	A	B	C	D	ab_A	ab_B	ab_C	ab_D
1001	Agliè	001	222	163	286	186	697	535	350	990
1002	Airasca	001	75	60	152	138	497	351	357	2350
1003	Ala di Stura	001	186	209	220	47	218	100	64	95
1004	Albiano d'Ivrea	001	192	147	80	84	646	419	199	432
1005	Alice Superiore	001	136	121	85	76	177	116	51	270
1006	Almese	001	261	318	511	792	1006	741	547	3364
1007	Alpette	001	144	125	122	42	116	51	32	101
1008	Alpignano	001	222	288	620	832	1214	1400	1573	12461
1009	Andezeno	001	153	110	83	116	512	315	164	714
1010	Andrate	001	141	131	123	44	250	104	61	62
…	…	…	…	…	…	…	…	…	…	…

Buildings per vulnerability class (A–D) — Residents per vulnerability class (ab_A–ab_D)

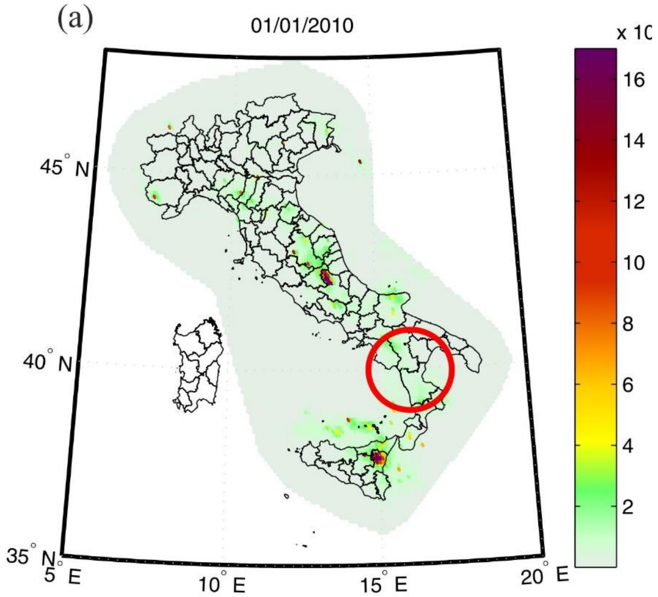
Illustrative example

- In 2012 the Pollino (southern Italy) area was affected by a seismic sequence, which lasted several months and featured a M 5 mainshock event in October 2012.

- Four different time instants are here considered:
  (a) 01/01/2010 – several months before the mainshock;
  (b) 10/25/2012 – right before the M 5 mainshock;
  (c) 10/26/2012 – right after the M 5 mainshock;
  (d) 07/21/2013 – is several months after the mainshock.

- For the week after each of these days the following is computed for the municipalities in the Pollino area:
  (1) Expected number of colapsed buildings;
  (2) Expected number of shelter-seeking people;
  (3) Expected number of injuries;
  (4) Expected number of fatalities.

CASSANDRA's OEF rates



Maximum OEF rate at the mainshock location:

(a) $1x10^{-4}$;

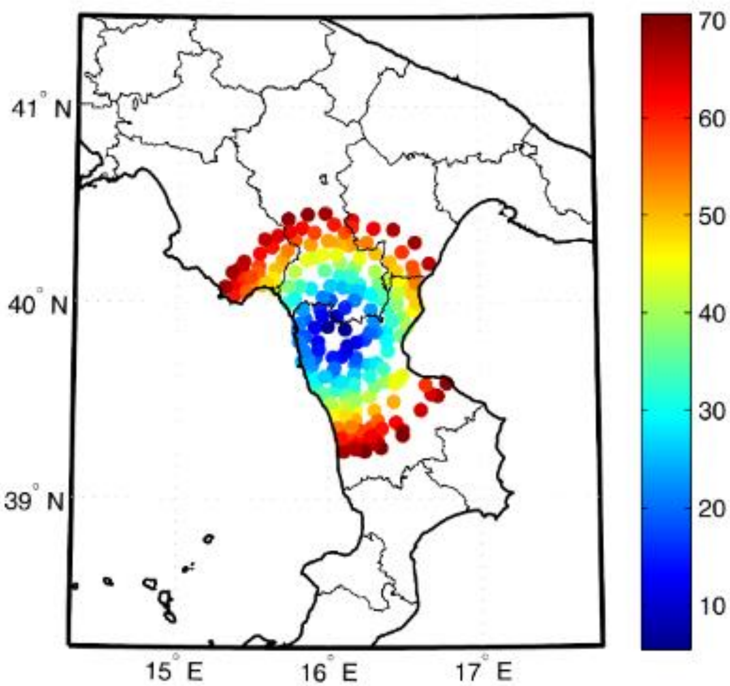
(b) $2.3x10^{-3}$;

(c) $6.2x10^{-2}$;

(d) $7x10^{-4}$.

Short-term risk assessment results

Distance from the center	Total number of buildings	Total number of inhabitants
< 10km	4281	12567
< 30km	66243	188538
< 50km	149733	438990



(a) 01/01/2010

Distance from the center	Collapsed buildings	Displaced	Injuries	Fatalities	Collapsed buildings [%]	Displaced [%]	Injuries [%]	Fatalities [%]
< 10km	0.03	0.29	0.01	0.00	6.65E-04	2.32E-03	9.25E-05	2.39E-05
< 30km	0.23	2.74	0.10	0.03	3.53E-04	1.45E-03	5.45E-05	1.43E-05
< 50km	0.52	6.14	0.23	0.06	3.48E-04	1.40E-03	5.21E-05	1.36E-05

(b) 25/10/2012

Distance from the center	Collapsed buildings	Displaced	Injuries	Fatalities	Collapsed buildings [%]	Displaced [%]	Injuries [%]	Fatalities [%]
< 10km	0.12	1.05	0.06	0.01	2.85E-03	8.35E-03	4.49E-04	1.14E-04
< 30km	0.62	6.43	0.28	0.07	9.32E-04	3.41E-03	1.49E-04	3.86E-05
< 50km	1.07	11.66	0.48	0.12	7.15E-04	2.66E-03	1.09E-04	2.82E-05

(c) 26/10/2012

Distance from the center	Collapsed buildings	Displaced	Injuries	Fatalities	Collapsed buildings [%]	Displaced [%]	Injuries [%]	Fatalities [%]
< 10km	1.87	15.17	0.89	0.22	4.37E-02	1.21E-01	7.06E-03	1.78E-03
< 30km	7.46	71.79	3.47	0.89	1.13E-02	3.81E-02	1.84E-03	4.72E-04
< 50km	10.68	107.79	4.83	1.24	7.13E-03	2.46E-02	1.10E-03	2.84E-04

(d) 21/07/2013

Distance from the center	Collapsed buildings	Displaced	Injuries	Fatalities	Collapsed buildings [%]	Displaced [%]	Injuries [%]	Fatalities [%]
< 10km	0.06	0.53	0.03	0.01	1.35E-03	4.24E-03	2.02E-04	5.17E-05
< 30km	0.37	4.06	0.17	0.04	5.55E-04	2.15E-03	8.85E-05	2.30E-05
< 50km	0.73	8.25	0.32	0.08	4.86E-04	1.88E-03	7.39E-05	1.93E-05

MS attenuation is from Pasolini et al. (2008)

L'Aquila 2009*

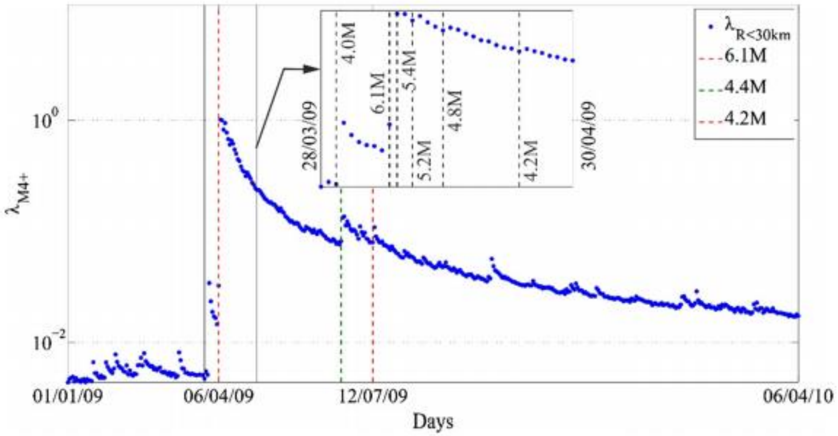


Fig. 5 Sum of the following week's (with respect to the date in the abscissa) rates of M 4+ events within 30 km from the centre of the sequence, and dates of M 4.2+ events occurred in the area of Fig. 1 (see also Table 1 for date of each event). In the picture, M refers to moment magnitude M_W

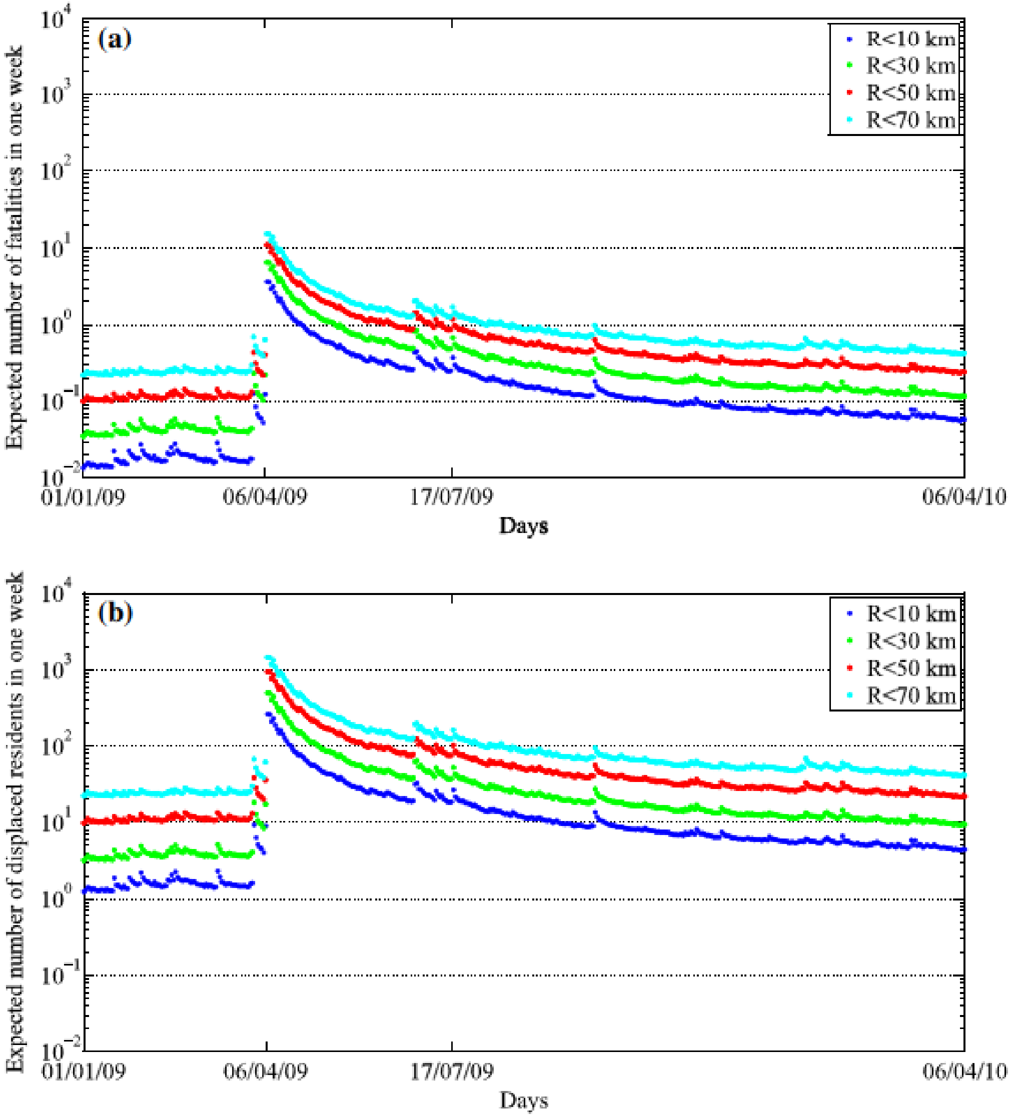


Fig. 6 Expected number of **a** fatalities and **b** displaced residents in the week following the date in the abscissa, summed over all municipalities within 10, 30, 50 and 70 km from the centre of the sequence

*Chioccarelli E., Iervolino I. (2016) Operational earthquake loss forecasting: a retrospective analysis of some recent Italian Seismic Sequences. *Bulletin of Earthquake Engineering*, 14:2607–2626.

Emilia 2012*

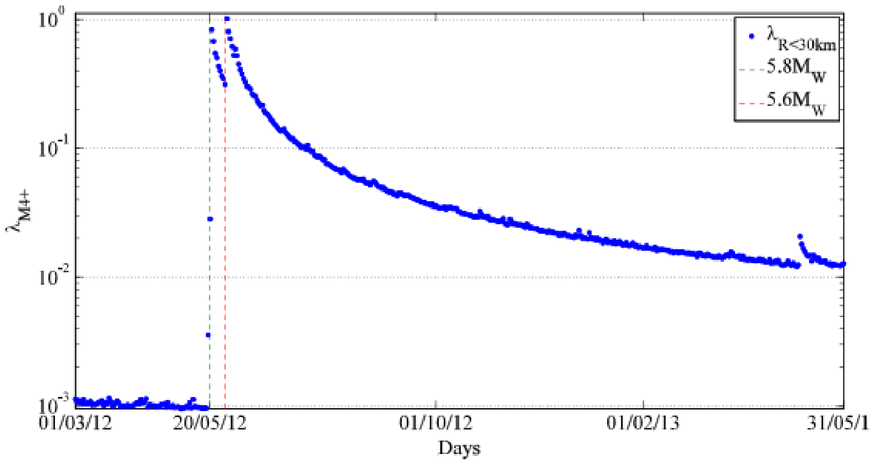


Fig. 8 Sum of the following week's (with respect to the date in the abscissa) rates of M 4+ events with 30 km from the centre of the sequence, and dates of main events occurred in the area

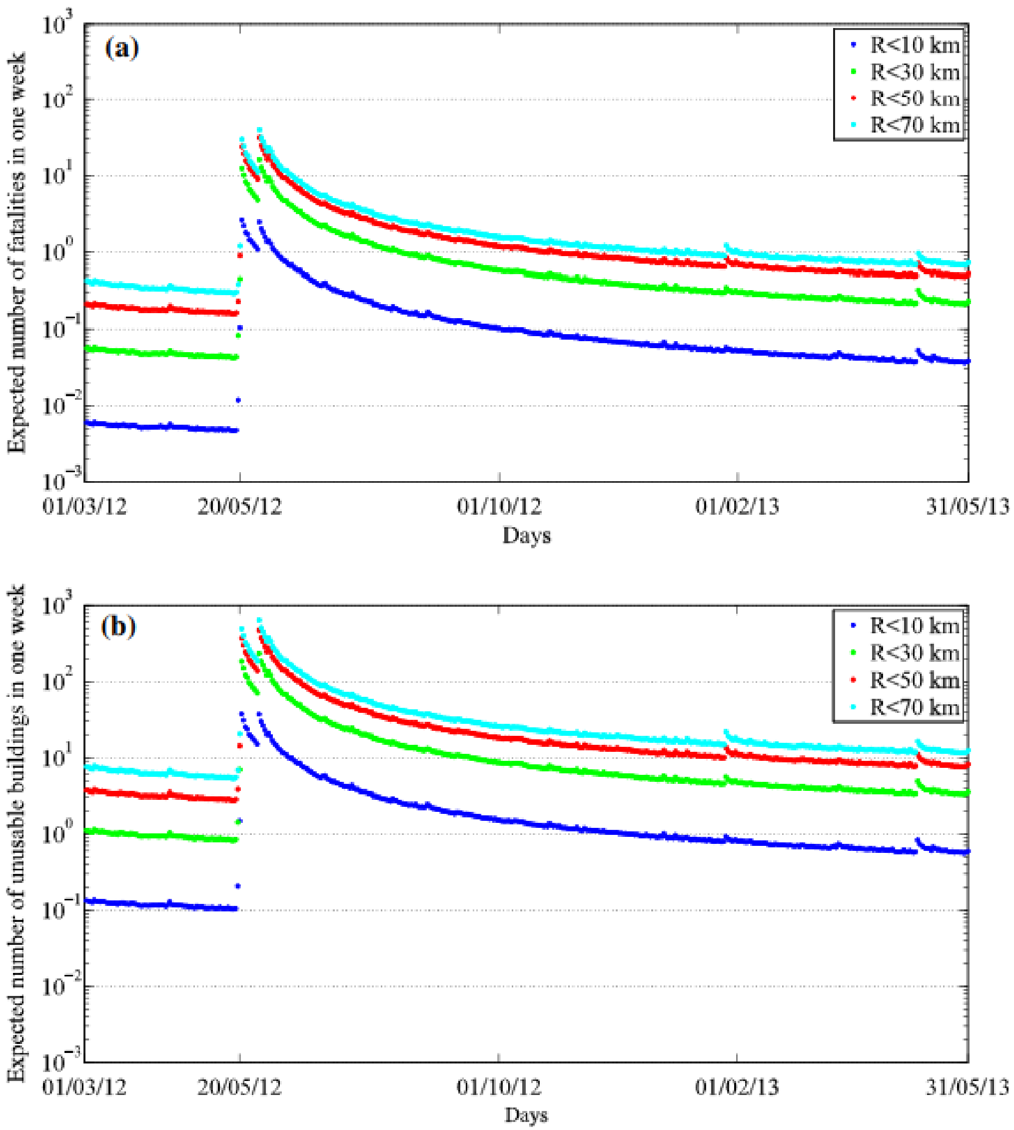


Fig. 9 Expected number of **a** fatalities and **b** unusable buildings in the week following the date in the abscissa, summed over all municipalities within 10, 30, 50 and 70 km from the centre of the sequence

*Chioccarelli E., Iervolino I. (2016) Operational earthquake loss forecasting: a retrospective analysis of some recent Italian Seismic Sequences. *Bulletin of Earthquake Engineering*, 14:2607–2626.

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Garfagnana 2013*

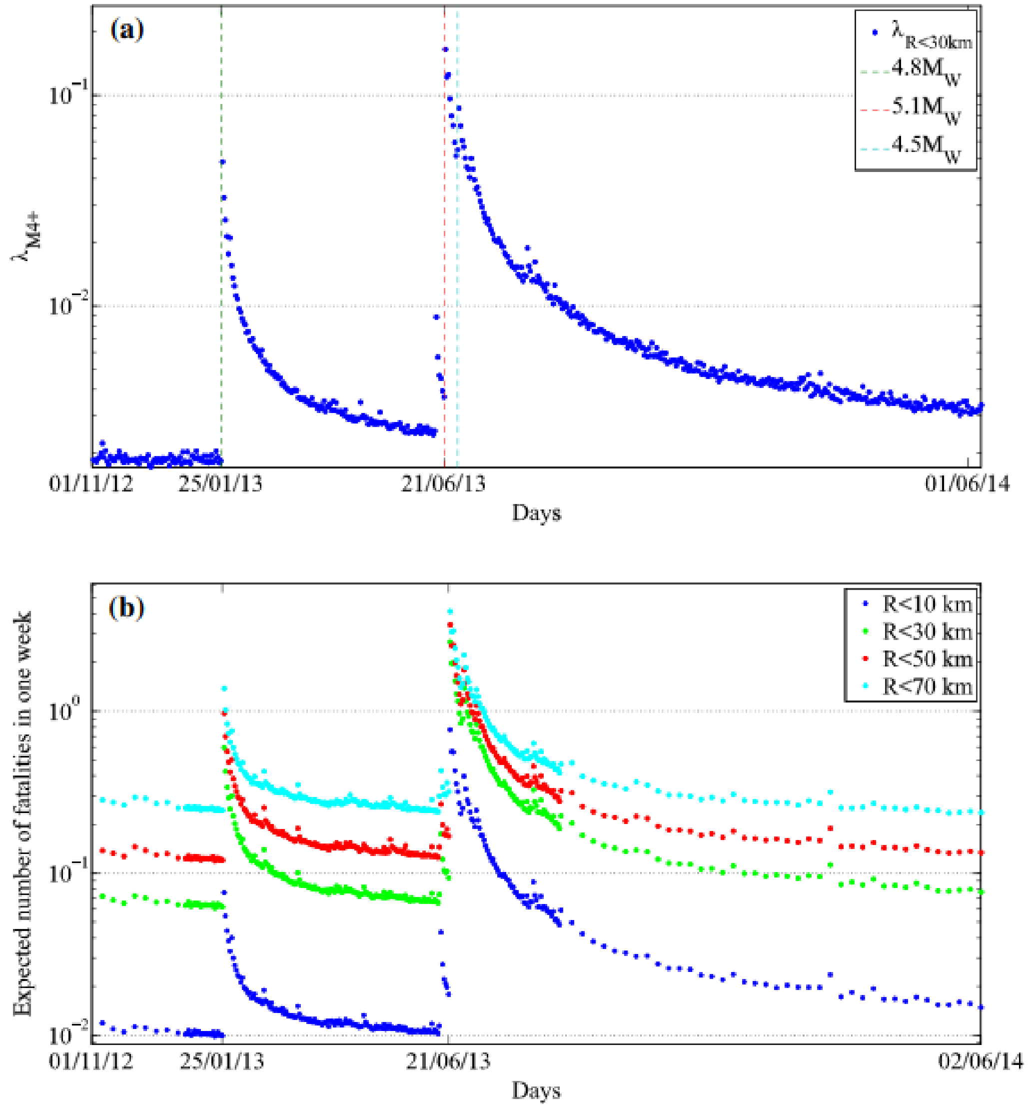
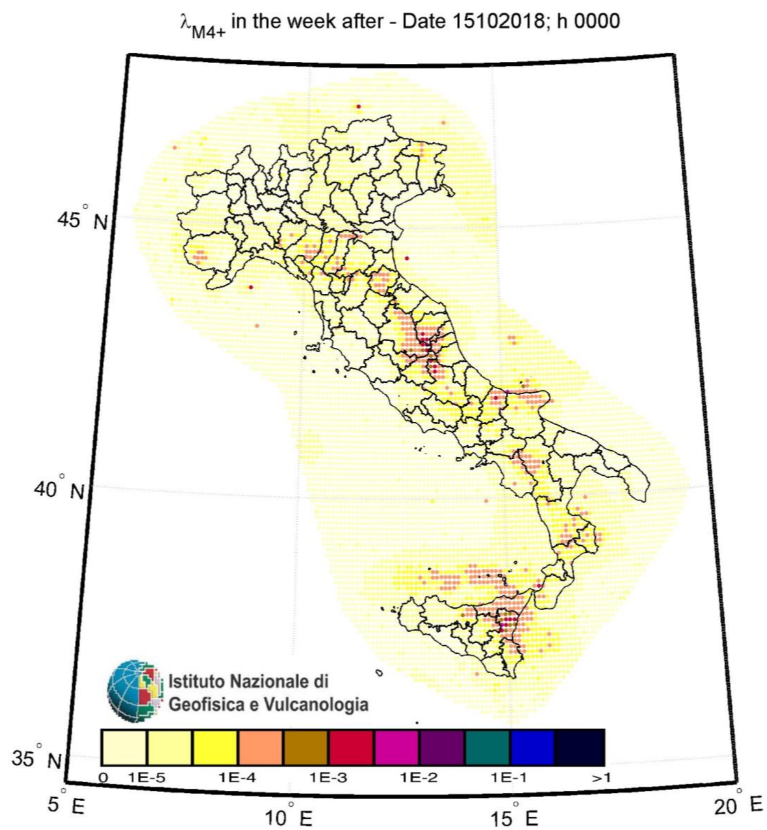


Fig. 11 **a** Sum of the following week's (with respect to the date in the abscissa) rates of M 4+ events within 30 km from the centre of the sequence, and dates of main events occurred in the area; **b** weekly expected number of fatalities summed over all municipalities within 10, 30, 50 and 70 km from the centre of the sequence

*Chioccarelli E., Iervolino I. (2016) Operational earthquake loss forecasting: a retrospective analysis of some recent Italian Seismic Sequences. *Bulletin of Earthquake Engineering*, 14:2607–2626.

The experimental system provides the weekly rates of damages and casualties per vulnerability class and by municipality (1/2)



Weekly unusable and collapse probability (Oct 15-22)

Name	P[unus.|A]	P[unus.|B]	P[unus.|C]	P[unus.|D]	P[coll.|A]	P[coll.|B]	P[coll.|C]	P[coll.|D]
Agliè	1.08E-05	3.35E-06	9.78E-07	1.89E-07	3.21E-06	6.62E-07	1.21E-07	2.61E-08
Airasca	1.62E-05	5.05E-06	1.47E-06	2.99E-07	5.02E-06	1.04E-06	1.87E-07	4.34E-08
Ala di Stura	1.20E-05	3.72E-06	1.08E-06	2.12E-07	3.62E-06	7.45E-07	1.34E-07	2.84E-08
...	...	...	...	...	...	...	...	...

Weekly injury and fatality probability (Oct 15-22)

Name	P[inj.|A]	P[inj.|B]	P[inj.|C]	P[inj.|D]	P[fat.|A]	P[fat.|B]	P[fat.|C]	P[fat.|D]
Agliè	6.53E-07	1.20E-07	2.10E-08	4.70E-09	1.68E-07	3.18E-08	5.64E-09	2.99E-09
Airasca	1.05E-06	1.91E-07	3.29E-08	7.77E-09	2.68E-07	5.05E-08	8.80E-09	4.95E-09
Ala di Stura	7.42E-07	1.34E-07	2.28E-08	4.83E-09	1.91E-07	3.57E-08	6.16E-09	3.10E-09
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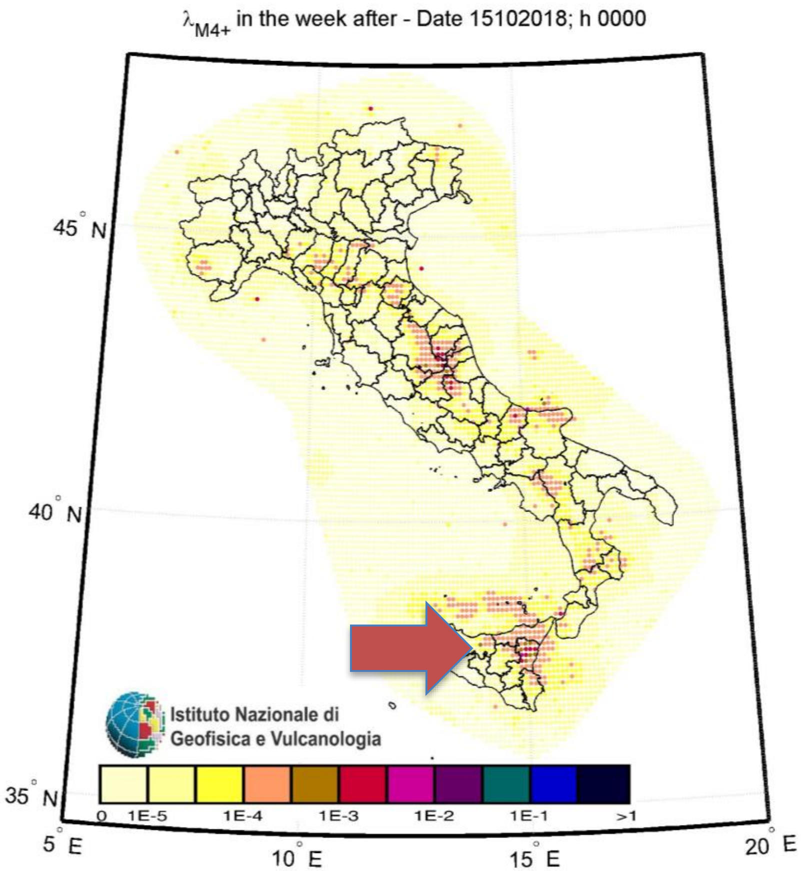
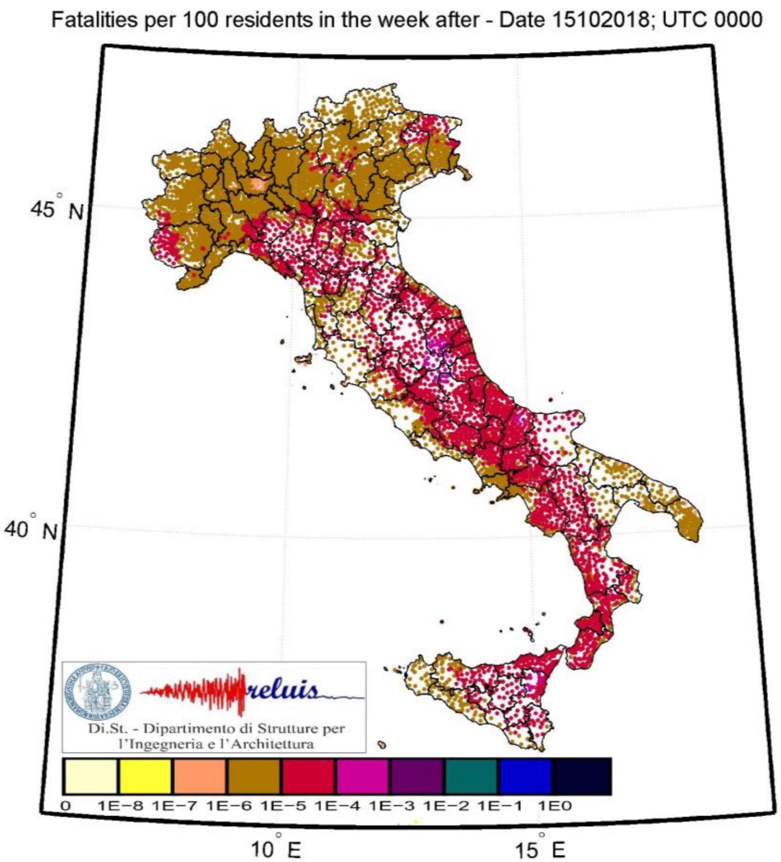
The experimental system provides the weekly rates of damages and casualties per vulnerability class and by municipality (2/2)



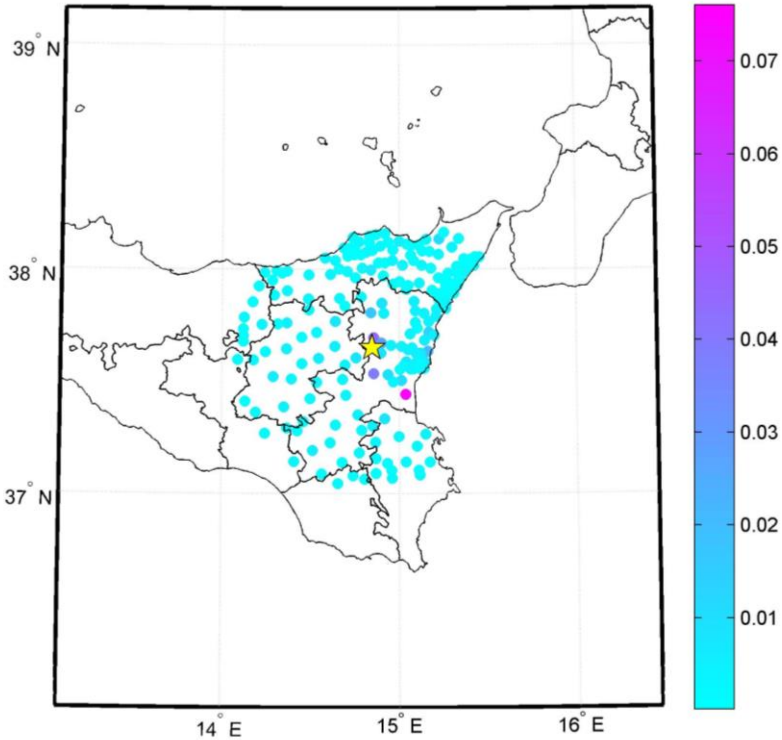


(CASSANDRA data provided by Marzocchi)

Iervolino I., Chioccarelli E., Giorgio M., Marzocchi M., Zuccaro G., Dolce M., Manfredi G. (2015) Operational (short-term) earthquake loss forecasting in Italy. *Bulletin of the Seismological Society of America*. 105(4): 2286–2298.

For an area around the largest OEF rate, MANTIS_K. computes the expected loss in week following week the OEF data release.

Area of interest



Expected weekly losses (June 6-12)

Distance from the maximum rate	Total number of buildings	Total number of residents	Collapsed buildings	Displaced	Injuries	Fatalities
≤ 10km	26484	71872	0.62	6.89	0.350	0.094
≤ 30km	181869	910778	2.63	36.93	1.545	0.422
≤ 50km	293036	1225505	3.99	49.70	2.032	0.550
≤ 70km	493148	1770947	5.37	63.86	2.533	0.683

Iervolino I., Chioccarelli E., Giorgio M., Marzocchi M., Zuccaro G., Dolce M., Manfredi G. (2015) Operational (short-term) earthquake loss forecasting in Italy. *Bulletin of the Seismological Society of America*. 105(4): 2286–2298.

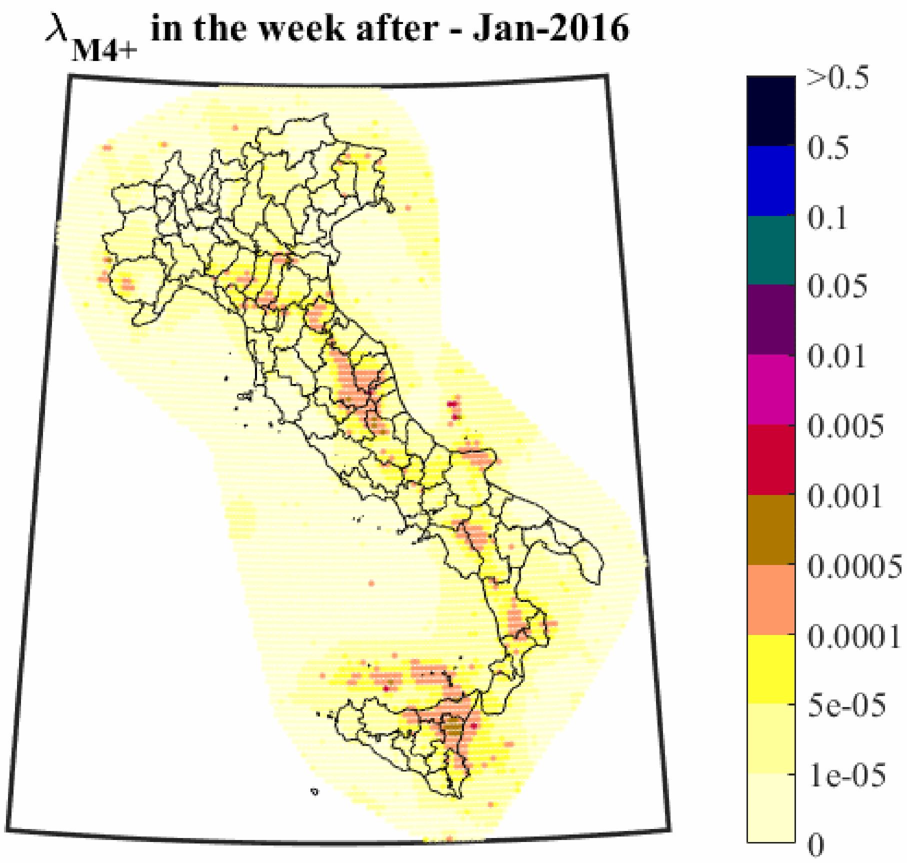
Summary

- The study discussed **the feasibility of probabilistic short-term seismic loss (risk) assessment in Italy**, based on OEF. Risk metrics investigated are the **expected number of fatalities, injuries, and displaced residents in one week**.

- Probabilistically-consistent short-term seismic risk assessment in Italy appears to be feasible, yet it is conditional to the OEF and vulnerability/exposure models available. **The procedure does not depend from any specific OEF model.**

- Risk measures seem to be sensitive to the short-term seismicity variations inferred by OEF, which provide the largest seismicity right after the mainshock.

- **A prototypal system for continuous OELF analysis, MANTIS K., is currently under experimentation.** It automatically receives OEF data from the CASSANDRA system of INGV and performs risk assessment for the whole country as well as for the region around the location where the largest seismicity is observed.


λ_{M4+} in the week after - Jan-2016
>0.5
0.5
0.1
0.05
0.01
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0.001
0.0005
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5e-05
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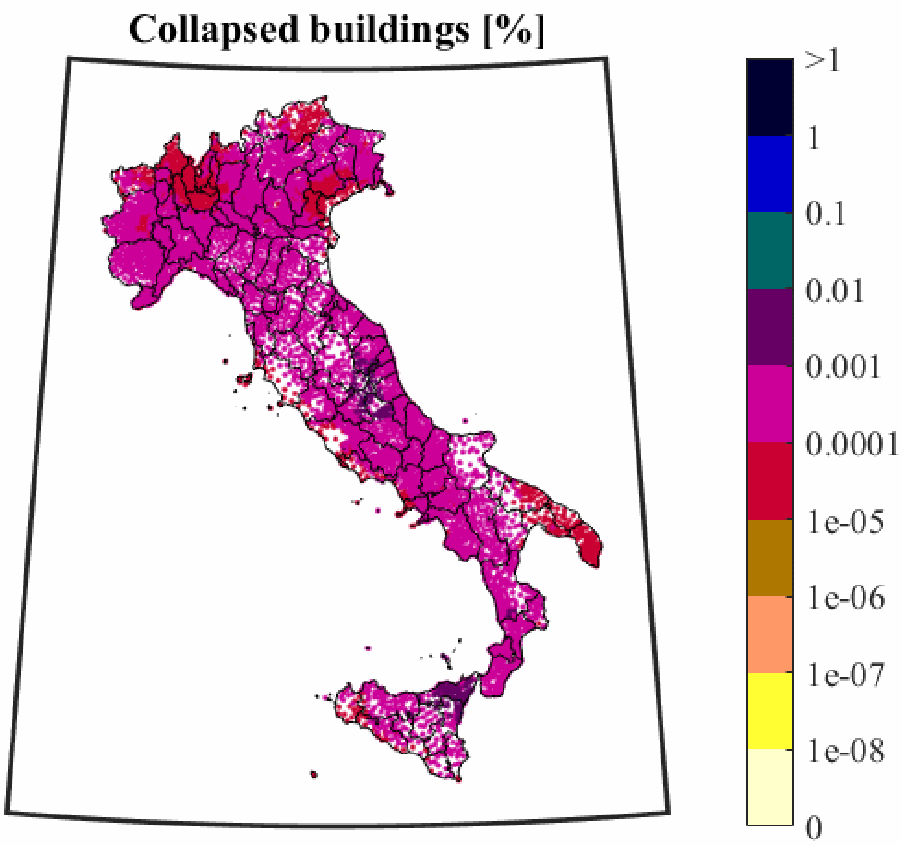
0


Collapsed buildings [%]
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1
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0.0001
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1e-06
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