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OPERATIONAL EARTHQUAKE LOSS FORECASTING IN ITALY: PRELIMINARY RESULTS

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ABSTRACT

The geophysical research community is currently focusing on operational earthquake forecasting (OEF) for the estimation and the update of seismicity based on continuous ground motion recording by seismic networks. OEF may provide results also in the short term, for example, in terms of weekly rate of events exceeding a certain magnitude threshold in each point of an area of interest. Therefore, it is worthwhile to investigate whether the OEF output may be employed for short-term risk management in regions affected by seismic swarms.

The present paper reports about feasibility, in Italy, of passing from OEF to operational earthquake loss forecasting (OELF), that is to probabilistically convert results of OEF in consequence-based seismic risk metrics. To this aim probabilistic hypotheses and procedures to get near-real-time estimates of seismic risk are developed and discussed. The procedure set up relies on Italian vulnerability data in the form of damage probability matrices for structural categories, and Italian exposure data in terms of buildings per vulnerability category and per municipality, and occupants per building typology.

As an application, estimation of seismic risk is provided for the recent Pollino (southern Italy) seismic sequence. For this case, loss (risk) is defined in terms of weekly expected number: of fatalities, injuries, and shelter-seeking people, in the area of the seismic swarm.

This preliminary study, without discussing OEF and vulnerability/exposure models, shows how to combine them to get probabilistically-consistent short-term seismic risk assessment in Italy.

INTRODUCTION

Short-term risk assessment (i.e., during seismic sequences) is emerging as a topic of increasing importance and of general interest because of its broad impact. A great deal of research in the geophysical community is currently devoted to operational earthquake forecasting (OEF; e.g., Jordan et al., 2011), that is the bulk of models and methods to constantly update estimates of seismicity rates on the basis of continuous earthquake monitoring. On the other hand, seismic risk management requires consequence-based measures of the earthquake potential. Indeed, loss forecasting allows

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cost/benefit analysis to compare different options for risk mitigation and to optimally allocate resources.

On these premises, the present study discusses, focusing on the Italian case, the feasibility of probabilistic seismic loss assessment, when the input is represented by the seismicity rates. The framework of loss forecasting starts from the OEF developed for Italy by Marzocchi et al. (2013), which provides the basis for a short-term adaption of probabilistic seismic hazard analysis (PSHA; e.g., McGuire, 2004), if the probability to observe a given macroseismic (*MS*) intensity level in one earthquake is available.[8] In fact, the risk assessment also needs models for the vulnerability of the built environment conditional to any earthquake intensity level. Finally, measures of consequences conditional to damage, that is exposure models, are also required. Starting from these risk components, a procedure is set up to compute several loss measures at the community level, consistent with the performance-based earthquake engineering approach (Cornell and Krawinkler, 2000).

In the following, the probabilistic framework for short-term loss forecasting is presented first. Then the models considered on the hazard side are briefly reviewed; i.e., OEF output, intensity prediction equations, and distribution of event magnitude. Then, exposure and vulnerability models, based on damage probability matrices (DPM) for Italy, are recalled. Finally, a preliminary application of the developed procedure is carried out starting for the 2012 Pollino (southern Italy) sequence, which featured a magnitude 5 mainshock. The risk metrics considered are expected values of: fatalities, injuries, and shelter-seeking people, in one-week time-horizon after the release time of the OEF data. These risk indices are evaluated at the municipality level, within 50 km from the geographical center of the swarm.

METHODOLOGY

Given a region monitored by a seismic sensor network, operational earthquake forecasting (OEF) models may provide, for each elementary area in which the territory is divided and identified by a pair of coordinates $\{x,y\}$, the estimated expected number of earthquakes above a magnitude of interest per unit time (for example one week). Such a rate, $\lambda(t,x,y\,|\,H(t))$, depends on the recent (recorded) seismicity history, $H(t)$, and consequently varies with time. In this context, the point of coordinates $\{x,y\}$ may be treated as a point-like seismic source; i.e., the centroid of a cell representing an elementary seismic source zone.

Considering a site of coordinates $\{w,z\}$, in which there is exposure to seismic risk, for example one or more residential buildings, it is possible to transform the rate above into the expected number of events that, at the $\{w,z\}$ location, will cause the occurrence of certain *MS* level.

The sought rate is obtained filtering $\lambda(t,x,y\,|\,H(t))$, that is multiplying it by the probability that an earthquake generated in $\{x,y\}$, with known distance from $\{w,z\}$, $R(x,y,w,z)$, causes the considered effect in terms of *MS* intensity (to follow).[9] Attenuation models providing such probabilities are dependent not only on $R(x,y,w,z)$, but at least on a random variable accounting for the earthquake intensity at the source; e.g., earthquake magnitude, *M*, or the *expected intensity at the epicenter* or I_E (Pasolini et al., 2008).

In the following section, the short-term seismic risk assessment is carried out using as earthquake intensity the macroseismic scale, similar to what is usually done in hazard assessment using ground motion intensity measures.

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[8] A perfectly analogous procedure can be set up in terms of ground motion intensity measures.
[9] This is not different from traditional seismic hazard analysis, except that the rate of events is not constant and does not necessarily refer to a homogeneous Poisson process to model earthquake occurrence.

LOSS FORECASTING BASED ON MACROSEISMIC INTENSITY

The rate of events, from the $\{x,y\}$ source, causing a specific macroseismic intensity, *ms*, at the $\{w,z\}$ site, $\lambda_{MS=ms}\left(t,w,z|H(t)\right)$, based on OEF output, is given in Equation (1), where $P\left[MS=ms|m,R(x,y,w,z)\right]$ is the probability of observing *ms* at $\{w,z\}$ given an earthquake of magnitude *m* at $\{x,y\}$; i.e., it is from an *attenuation law*. $f_M(m)$ is the magnitude distribution of earthquakes at the $\{x,y\}$ point-like seismic source.

$$\begin{aligned}\lambda_{MS=ms}\left(t,w,z|H(t)\right)&=\lambda\left(t,x,y|H(t)\right)\cdot P\left[MS=ms|R(x,y,w,z)\right]=\\&=\lambda\left(t,x,y|H(t)\right)\cdot\int_m P\left[MS=ms|m,R(x,y,w,z)\right]\cdot f_M(m)\cdot dm\end{aligned} \tag{1}$$

If the $\{w,z\}$ site is subjected to several point sources, in the same hypotheses of classical hazard analysis, the total rate is given in Equation (2), as the summation of terms in Equation (1) over the source area.

$$\lambda_{MS=ms}\left(t,w,z|H(t)\right)=\int_x\int_y\lambda\left(t,x,y|H(t)\right)\cdot\int_m P\left[MS=ms|m,R(x,y,w,z)\right]\cdot f_M(m)\cdot dm\cdot dy\cdot dx \tag{2}$$

Equation (2), which is factually a seismic hazard integral, may be extended to compute the rate of events causing some damage state (ds) to a building of a given structural typology (k). This is given in Equation (3), where $P\left[DS^{(k)}=ds|ms\right]$ is the damage probability for the structural typology of interest given macroseismic intensity, that is from a DPM.

$$\begin{aligned}\lambda_{DS^{(k)}=ds}\left(t,w,z|H(t)\right)&=\iint_{x,y}\lambda\left(t,x,y|H(t)\right)\times\\&\times\sum_{ms}P\left[DS^{(k)}=ds|ms\right]\cdot\int_m P\left[MS=ms|m,R(x,y,w,z)\right]\cdot f_M(m)\cdot dm\cdot dy\cdot dx\end{aligned} \tag{3}$$

In the short-term, it may be assumed that the rate in Equation (3) is constant (for example unless an update of seismicity from OEF is available). Thus, in the (small) time interval $(t,t+\Delta t)$, the probability of occurrence of an event producing a damage state equal to ds to a building of the structural typology *k*, can be computed through Equation (4).

$$P\left[DS^{(k)}_{(t,t+\Delta t)}=ds|H(t)\right]\approx\lambda_{DS^{(k)}=ds}\left(t,w,z|H(t)\right)\cdot\Delta t \tag{4}$$

If number of buildings of the *k*-th structural typology, $N_B^{(k)}$, is known for the $\{w,z\}$ site, then the expected number of buildings in damage state ds in $(t,t+\Delta t)$ can be computed via Equation (5). Such a result represents the *expected number of damaged buildings* in the $(t,t+\Delta t)$ interval. It is worth noting that a *maximum damage model* is implicitly assumed here; i.e., cumulated damages due to subsequent events are neglected.

$$E\left[N^{(k)}_{ds,(t,t+\Delta t)}|H(t)\right]=N_B^{(k)}\cdot P\left[DS^{(k)}_{(t,t+\Delta t)}=ds|H(t)\right] \tag{5}$$

In fact, Equation (3) may be extended in the direction of earthquake consequences if for each structural typology, and conditional to damage, the probability of the event to cause casualties, $P\left[Cas^{(k)}|ds\right]$, is available for the k-th structural typology. Then, it is possible to compute the rate of events producing the considered loss, $\lambda_{Cas^{(k)}}$, as in Equation (6).

$$\lambda_{Cas^{(k)}}\left(t,w,z|H(t)\right)=\iint_{x,y}\lambda\left(t,x,y|H(t)\right)\cdot\sum_{ds}P\left[Cas^{(k)}|ds\right]\times \\ \times\sum_{ms}P\left[DS^{(k)}=ds|ms\right]\cdot\int_{m}P\left[MS=ms|m,R(x,y,w,z)\right]\cdot f_M(m)\cdot dm\cdot dx\cdot dy \tag{6}$$

The latter equation is the one of interest as it is expressed in terms of ultimate earthquake consequences. In fact, rates of events causing fatalities, injuries, or shelter-seeking (displaced) people, may be computed.

In the same hypotheses of Equation (4), the probability of observing an event causing casualties, $P\left[Cas^{(k)}_{(t,t+\Delta t)}|H(t)\right]$, may be obtained via Equation (7). The *expected number of casualties* in the time interval of interest, $E\left[N^{(k)}_{Cas,(t,t+\Delta t)}|H(t)\right]$, can be computed through Equation (8), if the number of residents, $N_P^{(k)}$, in buildings of the k-th typology at $\{w,z\}$ is available.

The described procedure, the flowchart of which is given in Figure 1, allows to compute some site-specific indexes of seismic risk, starting from time-variant seismicity estimations from OEF.

$$P\left[Cas^{(k)}_{(t,t+\Delta t)}|H(t)\right]\approx\lambda_{Cas^{(k)}}\left(t,w,z|H(t)\right)\cdot\Delta t \tag{7}$$

$$E\left[N^{(k)}_{Cas,(t,t+\Delta t)}|H(t)\right]=N_P^{(k)}\cdot P\left[Cas^{(k)}_{(t,t+\Delta t)}|H(t)\right] \tag{8}$$

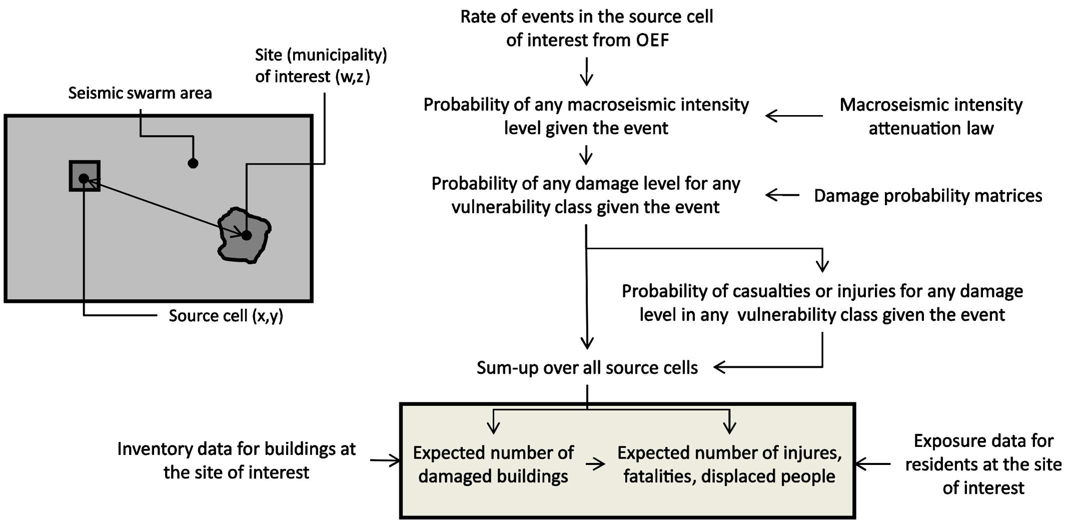

Figure 1. Sketch of the short-term risk assessment procedure based on operational earthquake forecasting models.

MODELS AND DATA FOR OELF IN ITALY

OEF AND SEISMICITY RATES

Seismicity rates from OEF, $\lambda\left(t,x,y\left|H(t)\right.\right)$, are provided by the CASSANDRA system of the (Italian) *National Institute of Geophysics and Volcanology* (INGV) for a grid spaced of about 0.1° and covering the whole national area and some sea. They are obtained based on the seismicity recorded by the country-wide seismic network of INGV and are updated at least daily. The time units of rates is one week and they refer to events with local magnitude equal or larger than 4. The magnitude of these events is supposed to be distributed according to a Gutenberg-Richter-type relationship, with unbounded maximum magnitude and *b*-value equal to one. The magnitude distribution does not change with the point source a specific rate value refers to.

Because it is not the focus of this work to scientifically discuss these OEF results, and these rates are only taken as input data for the present study, the reader is referred Lombardi and Marzocchi (2010) for further details.

EARTHQUAKE INTENSITY

The chosen attenuation model of macroseismic intensity is that of Pasolini et al. (2008), which is also adopted by INGV for the assessment of macroseismic national hazard (Gómez Capera et al., 2007). Intensity is defined by the Mercalli-Cancani-Sieberg (MCS) scale (Sieberg, 1931) and the explanatory variables of the model are epicentral distance, R_{epi}, and I_E. The model applies to the [0km,220km] interval of the former, while between 5 and 12 of the latter.

Pasolini et al. (2008) also provide a semi-empirical model relating I_E and the moment magnitude, M_w,[10] from which the distribution of epicentral intensity conditional to moment magnitude, $f_{I_E|M_w}\left(i_E\left|m\right.\right)$, may be obtained. In fact, it is related to the distribution of the residual in the regression of Pasolini et al. (2008). Thus for each point source, the I_E distribution, $f_{I_E}\left(i_E\right)$, may be obtained through the marginalization in Equation (9).

$$f_{I_E}\left(i_E\right)=\int_m f_{I_E|M_w}\left(i_E\left|m\right.\right)\cdot f_{M_w}\left(m\right)\cdot dm \tag{9}$$

The input magnitude distribution and the resulting distribution of epicentral intensity are reported in Figure 2. These distributions are conditional to the earthquake occurrence at the specific point-like source. According to the adopted model for *MS* attenuation, in the equations above the I_E random variable and the corresponding distribution have to replace *M* and $f_M\left(m\right)$, respectively.

In the following applications, sources with epicentral distance larger than 150km are neglected. Moreover, in order to convert the continuous model of *MS* provided by Pasolini et al. (2008) into a discrete model, mass probabilities associated to integer values of *ms* between 0 and 12 are computed.[11] Then, conditional to the occurrence of the earthquake, the resulting *ms* distribution for each site is scaled such that $P\left[0\le ms\le 12\right]=1$.

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[10] The model applies for M_w up to about 7; therefore, the magnitude distribution of the sources has been truncated to $M_w 7$; consequences of such an assumption were verified for negligibility.

[11] Natural numbers are used for *MS* grades in accordance with Pasolini et al. (2008).

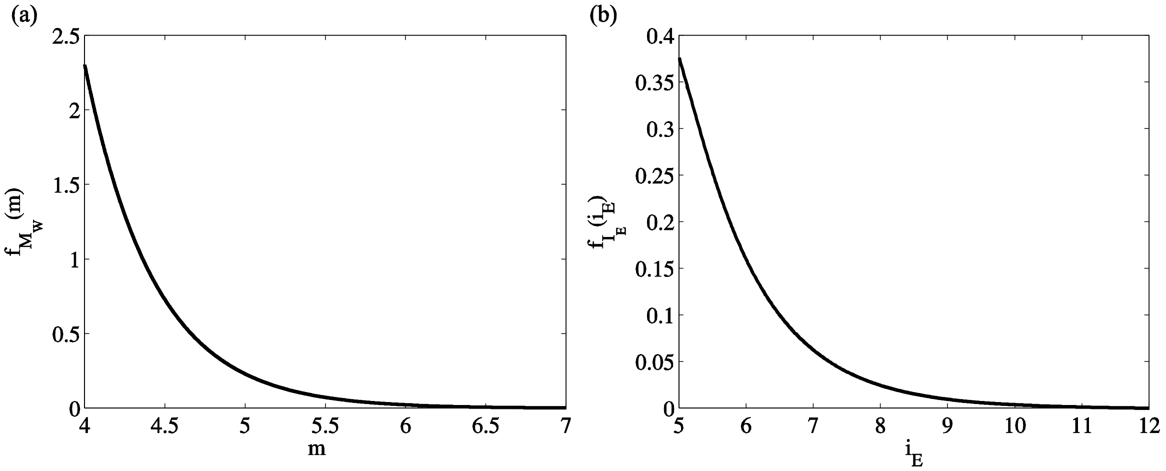

Figure 2. Moment magnitude distribution associated to each point source (a) and corresponding distribution of I_E (b).

VULNERABILITY AND EXPOSURE

For each structural typology and conditional to macroseismic intensity, models of structural vulnerability provide the $P\left[DS^{(k)} = ds|ms\right]$ terms, which are usually computed based on empirical data. These probabilities are traditionally arranged in the form of a matrix with the number of rows equal to number of structural typologies (or vulnerability categories) considered times the possible *MS* intensities, whereas the number of columns is the number of considered damage states. The resulting matrix is referred to as a damage probability matrix.

The DPM considered in this study is based on Italian observational data (Zuccaro and Cacace, 2009). The DPM, reported in Table 1, accounts for four different *vulnerability classes* from A to D, and six damage levels (*D*0 – no damage, *D*1 – slight damage, *D*2 – moderate damage, *D*3 – heavy damage, *D*4 – very heavy damage, *D*5 collapse). Vulnerability classes, damage levels and macroseismic scale, to which the DPM refers, are defined in accordance with the European macroseismic scale or EMS 98. In fact, in this paper, DPM are applied to the hazard assessment in term of MCS. Moreover it is worth to note that, due to the lack of Italian observational data, DPM values for $MS \geq 11$ are based on extrapolation.

Table 1. Considered damage probability matrix.

Class	*MS*	$P[D0\|ms]$	$P[D1\|ms]$	$P[D2\|ms]$	$P[D3\|ms]$	$P[D4\|ms]$	$P[D5\|ms]$
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	6	0.2887	0.4072	0.2297	0.0648	0.0091	0.0005
B	6	0.4437	0.3915	0.1382	0.0244	0.0022	0.0001
C	6	0.5905	0.3281	0.0729	0.0081	0.0005	0.0000
D	6	0.7738	0.2036	0.0214	0.0011	0.0000	0.0000
A	7	0.1935	0.3762	0.2926	0.1138	0.0221	0.0017
B	7	0.3487	0.4089	0.1919	0.0450	0.0053	0.0002
C	7	0.5277	0.3598	0.0981	0.0134	0.0009	0.0000
D	7	0.6591	0.2866	0.0498	0.0043	0.0002	0.0000
A	8	0.0656	0.2376	0.3442	0.2492	0.0902	0.0131
B	8	0.2219	0.3898	0.2739	0.0962	0.0169	0.0012
C	8	0.4182	0.3983	0.1517	0.0289	0.0028	0.0001
D	8	0.5584	0.3451	0.0853	0.0105	0.0007	0.0000
A	9	0.0102	0.0768	0.2304	0.3456	0.2592	0.0778
B	9	0.1074	0.3020	0.3397	0.1911	0.0537	0.0060
C	9	0.3077	0.4090	0.2174	0.0578	0.0077	0.0004
D	9	0.4437	0.3915	0.1382	0.0244	0.0022	0.0001

A	10	0.0017	0.0221	0.1138	0.2926	0.3762	0.1935
B	10	0.0313	0.1563	0.3125	0.3125	0.1563	0.0313
C	10	0.2219	0.3898	0.2739	0.0962	0.0169	0.0012
D	10	0.2887	0.4072	0.2297	0.0648	0.0091	0.0005
A	11	0.0002	0.0043	0.0392	0.1786	0.4069	0.3707
B	11	0.0024	0.0284	0.1323	0.3087	0.3602	0.1681
C	11	0.0380	0.1755	0.3240	0.2990	0.1380	0.0255
D	11	0.0459	0.1956	0.3332	0.2838	0.1209	0.0206
A	12	0.0000	0.0000	0.0000	0.0010	0.0480	0.9510
B	12	0.0000	0.0000	0.0006	0.0142	0.1699	0.8154
C	12	0.0000	0.0001	0.0019	0.0299	0.2342	0.7339
D	12	0.0000	0.0002	0.0043	0.0498	0.2866	0.6591

Casualty probabilities conditional to a given structural damage, $P\left[Cas^{(k)}|ds\right]$, are those of Zuccaro and Cacace (2011), in which the cases of dead or injured people are considered (injured is defined as someone requiring hospital care); Table 2. Zero probability is associated to damage levels equal to or lower than *D*3, whereas *D*4 and *D*5 casualty probabilities are provided for each vulnerability class. The probability of displaced residents for a building in damage level *D*4 or *D*5 is one, while is 0.5 for buildings in *D*3, and zero for lower damage levels.

Table 2. Casualty probabilities conditional structural damage and structural typology from Zuccaro and Cacace (2011).

Loss	Structural Typology	Vulnerability Class	*D*0	*D*1	*D*2	*D*3	*D*4	*D*5
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

[*]Only D in the following application.

As it regards exposure, municipalities are the elementary units in which the Italian territory is divided. Data regarding the number of buildings and the number of residents (both grouped by vulnerability class) are derived from the National census of 2001 (Zuccaro et al., 2012).

According to Zuccaro et al. (2012), casualty and injury assessment may be carried out considering that 65% of the total population is exposed at the time of occurrence of the earthquake, that is the term $N_P^{(k)}$ is multiplied by 0.65 (see Zuccaro and Cacace, 2011, for occupancy distributions).

APPLICATION TO THE 2012 POLLINO SEQUENCE

In this section OELF is applied to the Pollino (southern Italy) seismic sequence, which lasted several months and featured a M_w 5 mainshock event in October 2012.

Four different time instants are here considered for the risk assessment, they are based on OEF rates released at 00:00 (GMT) of the following days: (1) 01/01/2010; (2) 25/10/2012; (3) 26/10/2012; (4) 21/07/2013. Instant (1) is considered representative of conditions before the start of the seismic sequence, whereas (2) and (3) are right before and after the mainshock, respectively. Finally, (4) is several months after the mainshock. For each of these instants, INGV provided $\lambda\left(t,x,y\,|\,H(t)\right)$ for the whole national area. These rates, represented in Figure 3 for the four considered instants, were used without any manipulation in what follows.

From Figure 3 it can be noted that only on 26/10/2012 the Pollino area is the most hazardous in Italy. [12] More specifically, maximum values of seismicity is at the grid point of coordinates lat. 39.85° and long. 16.05°, which is hereafter identified as the center of the Pollino sequence.

The expected number of $M_w \geq 4$ events in the week following instant (3) is equal to 0.0615 (note some of maxima rates in Figure 3 are out of the colour scale). Rates estimated by INGV at the same point for instants (1), (2), and (4), are 0.0001, 0.0023, and 0.0007, respectively.

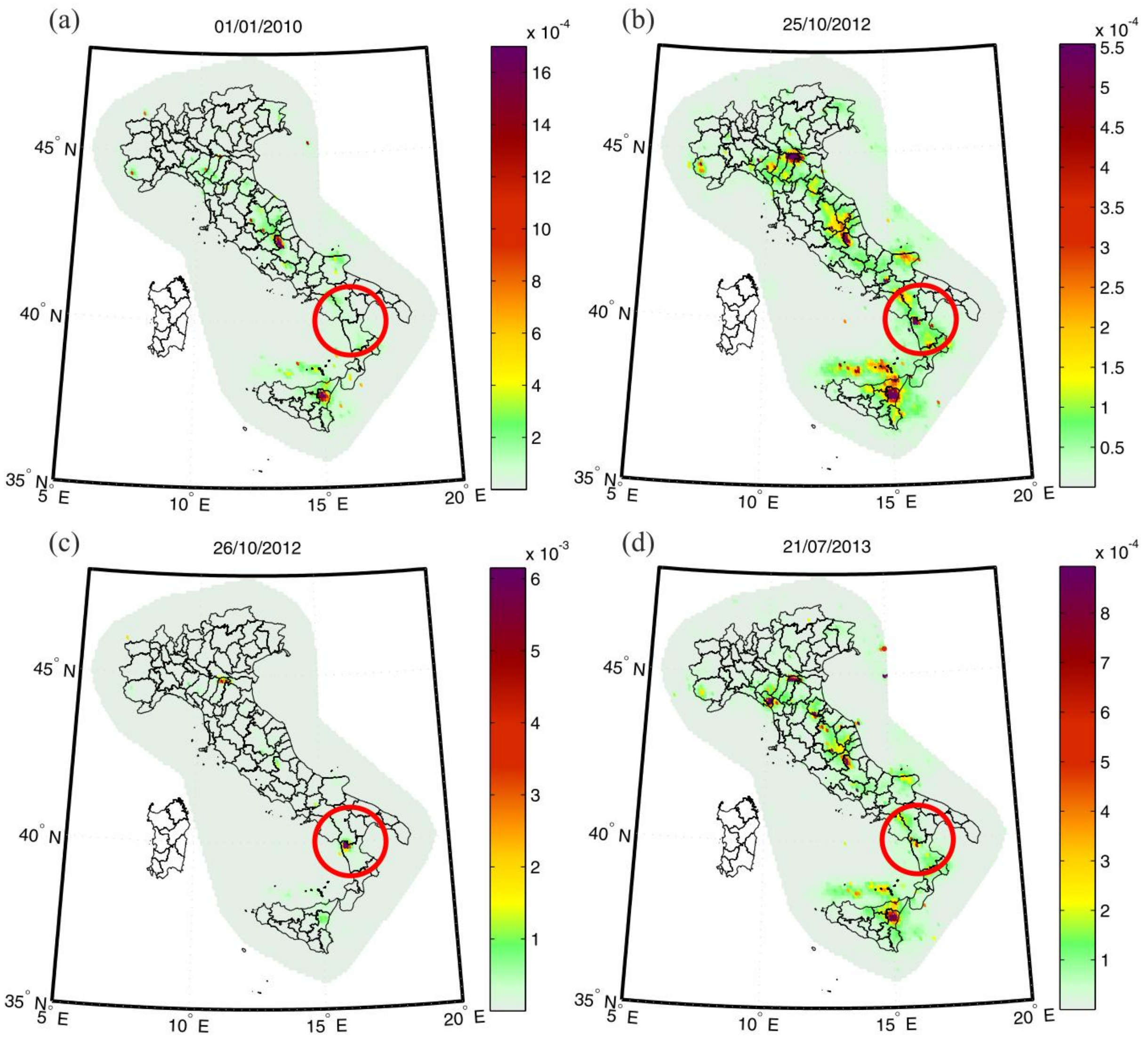

Figure 3. Seismic rates estimated through OEF at the four considered instants.

For the risk assessment, all municipalities within a radius of 50 km from the center of the sequence are considered, Figure 4.

The centroid of each municipality area is considered for computing the distance from each point-like seismic source, $R(x, y, w, z)$, which is required by the attenuation model. Clearly, there are two implicit assumptions behind this choice: the first is that it is possible to concentrate in a single point the whole vulnerability and exposure of each municipality; the second is that such a point is the geometrical centre of each municipality.

[12] That is right after the mainshock. This is a specific feature of the OEF models producing the input for the risk assessment developed herein.

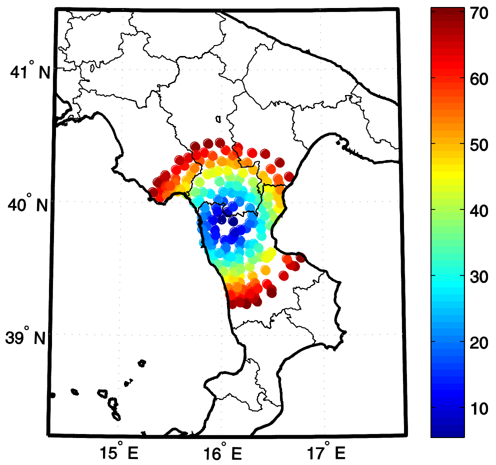

Figure 4. Distance (in km) of considered municipalities from the center of the sequence.

Appling Equation (5) and Equation (8), the expected number of: (i) collapsed buildings,[13] (ii) displaced, (iii) injured, and (iv) dead residents, in the week following each of the four considered instants was computed for each municipality. In tables from 3 to 6, results are summed up per bin of distance from the center of the Pollino area. In the same tables, risk indices are normalized with respect to the total number of buildings or residents in each distance bin.

These results allow to point out that risk measures are sensitive to the short-term seismicity variations inferred by OEF. In fact, the increments of seismic seismicity rates during the sequence, as observed in Figure 3, produce significant increments of the risk in terms of expected consequences. On the other hand, if absolute values of indices are considered, the largest computed risk (at time 3) is about one expected fatality over more than 400,000 residents.[14]

Table 3. Indices of seismic risk before the swarm.

01/01/2010										
Distance from the center	Total number of buildings	Total number of inhabitants	Collapsed buildings	Displaced people	Injured people	Dead people	Collapsed buildings [%]	Displaced people [%]	Injured people [%]	Dead people [%]
≤ 10km	4281	12567	0.03	0.29	0.01	0.00	6.65E-04	2.32E-03	9.25E-05	2.39E-05
≤ 30km	66243	188538	0.23	2.74	0.10	0.03	3.53E-04	1.45E-03	5.45E-05	1.43E-05
≤ 50km	149733	438990	0.52	6.14	0.23	0.06	3.48E-04	1.40E-03	5.21E-05	1.36E-05

Table 4. Indices of seismic risk right before the mainshock.

25/10/2012										
Distance from the center	Total number of buildings	Total number of inhabitants	Collapsed buildings	Displaced people	Injured people	Dead people	Collapsed buildings [%]	Displaced people [%]	Injured people [%]	Dead people [%]
≤ 10km	4281	12567	0.12	1.05	0.06	0.01	2.85E-03	8.35E-03	4.49E-04	1.14E-04
≤ 30km	66243	188538	0.62	6.43	0.28	0.07	9.32E-04	3.41E-03	1.49E-04	3.86E-05
≤ 50km	149733	438990	1.07	11.66	0.48	0.12	7.15E-04	2.66E-03	1.09E-04	2.82E-05

[13] Note that building in both damage levels *D*4 and *D*5 are considered as *collapsed*.
[14] According to the information available to the authors, no casualties were recorded in the Pollino sequence.

Table 5. Indices of seismic risk right after the mainshock.

26/10/2012										
Distance from the center	Total number of buildings	Total number of inhabitants	Collapsed buildings	Displaced people	Injured people	Dead people	Collapsed buildings [%]	Displaced people [%]	Injured people [%]	Dead people [%]
< 10km	4281	12567	1.87	15.17	0.89	0.22	4.37E-02	1.21E-01	7.06E-03	1.78E-03
< 30km	66243	188538	7.46	71.79	3.47	0.89	1.13E-02	3.81E-02	1.84E-03	4.72E-04
< 50km	149733	438990	10.68	107.79	4.83	1.24	7.13E-03	2.46E-02	1.10E-03	2.84E-04

Table 6. Indices of seismic risk several months after the mainshock.

21/07/2013										
Distance from the center	Total number of buildings	Total number of inhabitants	Collapsed buildings	Displaced people	Injured people	Dead people	Collapsed buildings [%]	Displaced people [%]	Injured people [%]	Dead people [%]
< 10km	4281	12567	0.06	0.53	0.03	0.01	1.35E-03	4.24E-03	2.02E-04	5.17E-05
< 30km	66243	188538	0.37	4.06	0.17	0.04	5.55E-04	2.15E-03	8.85E-05	2.30E-05
< 50km	149733	438990	0.73	8.25	0.32	0.08	4.86E-04	1.88E-03	7.39E-05	1.93E-05

CONCLUSIONS

The study discussed, focusing on the Italian case, the feasibility of probabilistic short-term seismic loss (risk) assessment, when the input is represented by the seismicity rates given by the operational earthquake forecasting procedures.

Given data available in terms of vulnerability and exposure for Italy, and the OEF data provided daily by the CASSANDRA system of the Italian *National Institute of Geophysics and Volcanology*, OELF appears feasible. According to the output of OEF, the forecasted consequence statistics are for one-week time-horizon after the time of the analysis. Risk metrics are the expected number of fatalities, injuries, and displaced residents. In fact, an illustrative application, which does not discuss the scientific merit of input seismicity data and vulnerability/exposure models employed, was developed. It refers to the 2012 Pollino (southern Italy) sequence, in which a M_w 5 mainshock was recorded. Risk indices were computed within an area of 50 km from the mainshock location even if, in principle, OELF results can be easily extended to the whole country and to operate continuously.

The main conclusions from this preliminary analysis were that: (i) 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, and (ii) risk measures seem to be sensitive to the short-term seismicity variations inferred by OEF, which provides the largest seismicity right after the mainshock.

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REFERENCES

Cornell CA, Krawinkler H (2000) "Progress and challenges in seismic performance assessment", *PEER Center News*, 3(2):1-3

Gómez Capera AA, Meletti C, Rebez A, Stucchi M (2007) "Mappa di pericolosità sismica in termini di intensità macrosismica ottenuta utilizzando lo stesso impianto metodologico di MPS04", Convenzione INGV-DPC 2004-2006/Progetto S1, Deliverable D7 (*in Italian*)

Jordan TH, Chen Y-T, Gasparini P, Madariaga R, Main I, Marzocchi W, Papadopoulos G, Sobolev G, Yamaoka K, Zschau J (2011) "Operational Earthquake Forecasting: State of Knowledge and Guidelines for Utilizations", *Annals of Geophysics*, 54(4):319-391

Lombardi AM, Marzocchi W (2010) "The ETAS model for daily forecasting of Italian seismicity in the CSEP experiment", *Annals of Geophysics*, 53(3):155-164

Marzocchi W, Lombardi AM, Casarotti E (2013) "The establishment of an operational earthquake forecasting system in Italy", Submitted to *Seismological Research Letters*

McGuire RK (2004) Seismic Hazard and Risk Analysis, Earthquake Engineering Research Institute Publication, Oakland, CA, USA

Pasolini C, Albarello D, Gasperini P, D'Amico V, Lolli B (2008) "The attenuation of seismic intensity in Italy, Part II: Modelling and Validation", *Bulletin of Seismological Society of America*, 98(2):692-708

Sieberg A (1931). "Erdebeben, in Handbuch der Geophysik", B. Gutenberg (Editor), 4:552–554 (*in German*)

Zuccaro G, Cacace F (2009) "Revisione dell'inventario a scala nazionale delle classi tipologiche di vulnerabilità ed aggiornamento delle mappe nazionali di rischio sismico", Proceedings of XIII Convegno l'Ingegneria Sismica in Italia, ANIDIS, Bologna, Italy, N. S4.39 (*in Italian*).

Zuccaro G, Cacace F (2011) "Seismic casualty evaluation: the Italian model, an application to the L'Aquila 2009 event" In: Spencer R, So E, Scawthorn C (Eds.), Human Casualties in Earthquakes: progress in modelling and mitigation, p. 171-184, Springer, London, UK.

Zuccaro G, Cacace F, De Gregorio D (2012) "Buildings inventory for seismic vulnerability assessment on the basis of Census data at national and regional scale", Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal, N. 2829.