THE EFFECT OF SEISMIC SWARMS ON SHORT-TERM SEISMIC HAZARD AND GUTENBERG-RICHTER B-VALUE TEMPORAL VARIATION. EXAMPLES FROM CENTRAL ITALY SEISMIC ACTIVITY DURING OCTOBER-NOVEMBER 2023

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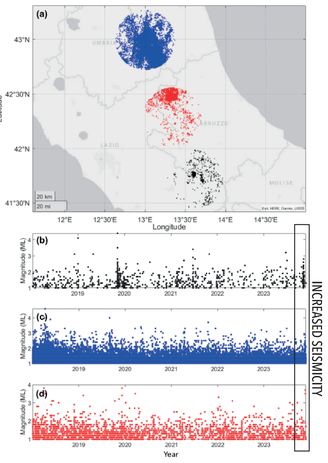
MOTIVATION

A ***"seismic swarm"*** (**SW**) is a type of earthquake sequence characterized by several small-to-moderate series of events occurring in a local area within a relatively short period of time. Differently from the classical ***"mainshock-aftershock"*** (**MA**) sequence type, where a strong event gives birth to the progeny of offsprings, the evolution of a **SW** usually dies off without the occurrence of a "significatively large" event. As the intuition suggests, it is very difficult to understand into which of the two types an ongoing seismic sequence will evolve, the labeling of **MA** or **SW** being possible only *a posteriori*.

An insight in this regard could be given by investigating how, and how differently, MA and SW do affect the short-term probabilistic rate. The delivery of near-real time probabilistic earthquake forecasts in the short-term is indeed essential to quantify how likely will be the occurrence rate of events with a given magnitude, in a small space-time domain, thus helping communities prepared for potentially destructive earthquakes.

In this work, we analyze the evolution of the short-term seismic hazard in the case of three seismic swarms occurred in Central Italy in October–November 2023, and quantify the possible variations of the probabilistic rate to be interpreted in terms of a sequence of swarm type.



THE SEISMIC CATALOG

In this study we consider the **events inside circles with 30 km radius**, centered at the geographical coordinates of:
- **Sora** (Frosinone, Lazio region, black dots)
- **Monte Cavallo** (Macerata, Marche region, blue dots)
- **Lucoli** (L'Aquila, Abruzzo region, red dots)

Entire temporal interval: 1 January 2018 - 27 November 2023.

Settings: *maximum depth 40 km; completeness magnitude ML 1.5* (Lilliefors test).

All the three areas experienced strong earthquakes in recent centuries, according to the CPTI15 historical seismic catalog.

During October-November 2023, they all have experienced swarm-like seismic activity, characterized by a high number of events, all with relatively small magnitudes.

Since 1 October 2023, the recorded events with ML 1+ are:
- 79 in the Sora catalog (2 evs with ML 2.5+, max mag ML 2.8);
- 363 in the Monte Cavallo catalog (5 evs with ML 2.5+, max mag 2 evs with ML 2.9);
- 59 in the Lucoli catalog (3 evs ML 2.5+, max mag ML 3.7).

ANALYSIS METHODS

THE ITALIAN OPERATIONAL EARTHQUAKE FORECASTING (OEF) SYSTEM

The **OEF-Italy system** produces **real-time short-term earthquake forecasts** in each 0.1° × 0.1° cell of a spatial grid covering the entire Italian territory, according to the standards of the Collaboratory for the Study of Earthquake Predictability. At every midnight, and after the occurrence of any ML 3.5+ event, the OEF-Italy system delivers the **weekly expected rate** of events with ML 4+ and 5.5+, and MMI VI+, VII+ and VIII+ (at user's will).

The forecast is **probabilistic** and based on the ensemble combination of ETAS, ETES and STEP models (typically used in statistical seismology), suitably weighted according to their past performance. **Only ML 2.5+ events are used** to compute the OEF rates, which is continuously updated according to the catalog recorded by the seismic surveillance system of the INGV.

THE GUTENBERG-RICHTER B-VALUE ESTIMATION

The **b-value parameter** of the **Gutenberg–Richter law** controls the proportion of larger shocks with respect to the smaller ones. Its temporal variation are analyzed here by means of the **weighted likelihood method**, which allows us to estimate this parameter based on the full history of available data: the larger is the distance between the time of the event and the actual time, the smaller is the influence of this event in the estimation.

The weighted-likelihood estimate is properly **corrected to account for magnitudes' binning**. The uncertainty is determined by considering the normal approximation.
No subjective choice in building the b-value time series (no selected-fixed number of events like in the rolling-window approach).

RESULTS: OEF PROBABILITIES

Consistency: all rates increase ~1.5 times.

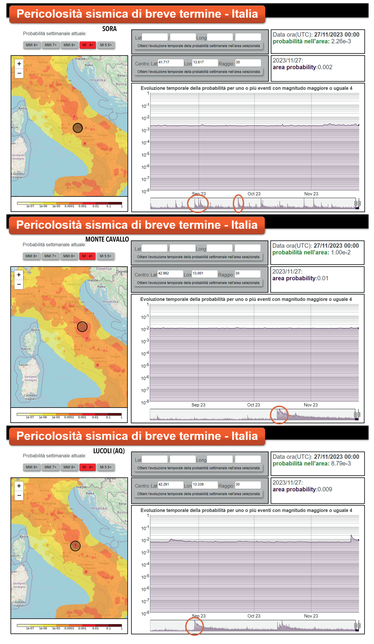
Small increase from the background rates to the highest peaks observed during the swarm activity since October 2023.

A single ML 3.7+ event (Lucoli) weighs more than a higher number of smaller events, provided they all have an ML of 2.5+, including two ML 2.9 (Monte Cavallo).

(MIN) 0 increase

(MAX) ~4 times increase

		Background (Last 5 yrs)	Maximum Probability Since October 2023	Area Probability on 27 November 2023
Sora	MMI VI+	0.003	0.004 (on 16 October)	3.04×10^{-3}
	MMI VII+	4×10^{-4}	6×10^{-4} (on 16 October)	4.55×10^{-4}
	MMI VIII+	8×10^{-5}	1×10^{-4} (on 16 October and 11 November)	9.8×10^{-5}
	ML 4+	0.002	0.003 (on 16 October, 11 and 25 November)	2.26×10^{-3}
	ML 5.5+	6×10^{-5}	9×10^{-5} (on 11 and 25 November)	6.92×10^{-5}
Monte Cavallo	MMI VI+	0.01	0.01 (stable in the period)	1.1×10^{-2}
	MMI VII+	0.001	0.002 (stable in the period)	1.61×10^{-3}
	MMI VIII+	3×10^{-4}	4×10^{-4} (stable in the period)	3.68×10^{-4}
	ML 4+	0.009	0.01 (stable in the period)	1×10^{-2}
	ML 5.5+	3×10^{-4}	3×10^{-4} (stable in the period)	3×10^{-4}
Lucoli, AQ	MMI VI+	0.006	0.02 (on 22 November)	9.45×10^{-3}
	MMI VII+	9×10^{-4}	0.004 (on 22 November)	1.37×10^{-3}
	MMI VIII+	2×10^{-4}	8×10^{-4} (on 22 November)	3.13×10^{-4}
	ML 4+	0.006	0.02 (on 22 November)	8.79×10^{-3}
	ML 5.5+	2×10^{-4}	7×10^{-4} (on 22 November)	2.76×10^{-4}



The OEF rates considerably increased after the occurrence of the strongest events in the three areas considered, during the entire period of operativity (from 2009).

- Sora: the maximum peaks were obtained during the 2009 L'Aquila sequence (proximity to the Abruzzo region), and during the 2013 sequence; rates increased by factors from 20 to 35 (ML 4+ evs ~ 0.05).

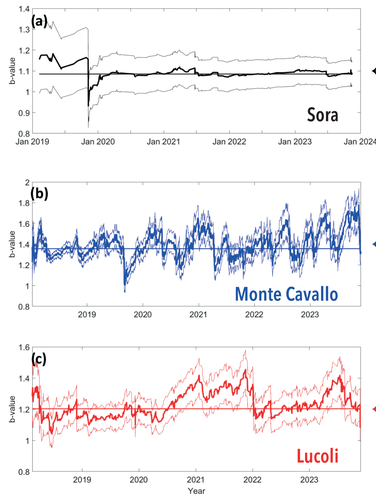
- Monte Cavallo: OEF rates increased by factors from 100 to 250 during the Central Italy sequence (2016). A 90% probability released for MMI VI+ and ML 4+ events after the Norcia Mw 6.5 earthquake.

- Lucoli: rates increased from two to three orders of magnitude during the 2009 L'Aquila sequence. On 6 April 2009 at 8:00 a.m., 80% probability of ML 4+ events during the following week.

OEF maxima probabilities after the strongest events experienced since 2005 VS those obtained during the current swarm activity (increase factor IF from the background).

		To Maximum probability since October 2023	To Maximum probability after the strongest event experienced since 2005	
Sora	MMI VI+	1.3	23.3	~ x 20
	MMI VII+	1.5	25	
	MMI VIII+	1.25	25	
	ML 4+	1.5	25	
	ML 5.5+	1.5	33.3	
Monte Cavallo	MMI VI+	1	90	~ x 250
	MMI VII+	2	300	
	MMI VIII+	1.3	266.6	
	ML 4+	1.1	100	
	ML 5.5+	1	266.6	
Lucoli, AQ	MMI VI+	3.3	133.3	~ x 60
	MMI VII+	4.4	222.2	
	MMI VIII+	4	250	
	ML 4+	3.3	133.3	
	ML 5.5+	3.5	200	

RESULTS: B-VALUE TEMPORAL VARIATIONS



No significant variation for the whole time period, indeed, this catalog shows the smallest OEF increase factor IF.

Fluctuation in the **b-value: in the last month it decreases** to the background value BKG (computed using all the events in the complete part of the catalog). This agrees with the fact that IF~1 for ML4+ and ML5.5+ OEF rates during the current swarm activity, and with the fact that Monte Cavallo catalog experienced some of the highest IFs after the strongest shock; it also contains the largest number of events.

Moderate fluctuations of the b-value, not significantly different from the background value: small decrease in the last part of the catalog, constrained within the uncertainty range. Recalling that Lucoli shows a slightly higher influence of the swarm activity on the OEF rates, a more evident fluctuation of the b-value could be expected. However, Lucoli experienced the lowest number of events during the current swarm activity, and the highest magnitude (a sufficient statistic for the b-value estimate is the mean magnitude).

The results obtained for the b-value are consistent with those obtained for the OEF rates, in terms of their relative variations.

For all three catalogs, the b-value not significantly deviates from the BKG during the seismic swarms in October-November 2023.

TAKE HOME MESSAGES

The effect of swarms in OEF is very limited --> no matter how many events occur: if they remain "small" (i.e., smaller than 4.0), the increase in the weekly probability of strong events in the area is less than one order of magnitude (i.e., 10 times).

For 2 out of the 3 time series considered, the b-value temporal variations show several fluctuations over recent years (both increase and decrease); this makes difficult to interpret a deviation from the background value during the seismic swarms --> it is impossible to infer something from the b-value.

Seismic swarms containing about 50–200 events, with a maximum observed magnitude smaller than 4.0, do not significantly influence neither the probability of strong impending events for OEF, nor b-value estimation methodologies.

Need to find other ways of studying seismic swarms to extract information related to future large events, e.g. new space-time-magnitude statistical relations, machine or deep learning techniques.

REFERENCE

What Is the Effect of Seismic Swarms on Short-Term Seismic Hazard and Gutenberg-Richter b-Value Temporal Variation? Examples from Central Italy, October–November 2023
Ilaria Spassiani and Matteo Taroni
Geosciences 2024, 14(2), 49; https://doi.org/10.3390/geosciences14020049