



Probability Prediction of Short- and Medium-Term Seismic Intensity in North China Based on non-stationary Poisson model

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Abstract. Based on the seismic magnitude-frequency relationship observed for earthquakes with a local magnitude (M_L) of 2.0 or higher in North China between 1970 and 2022, a maximum cutoff magnitude of $M_L7.3$ is projected under long-term conditions. Based on a three-year-scale scanning, we forecast the maximum cutoff magnitude for the year 2023 as $M_L5.5$, with a seismic activity intensity of $M_L5.0$. This paper provides seismic frequencies and probabilities for earthquakes with $M_L4.0$ and $M_L5.0$ or higher in North China, Yanshan–Bohai Seismic Belt, Shanxi Seismic Belt, Hebei Plain Seismic Belt, and Yishu Seismic Belt in 2023. The analysis indicates that the Hebei Plain Belt is likely to have the highest probability of earthquakes with $M_L4.0$ or higher. In the long-term background, the maximum cutoff magnitude for Shandong and its neighboring areas is estimated to be $M_L6.0$. Through a three-year-scale scanning approach, it is forecasted that the maximum cutoff magnitude for the year 2023 in the areas will be $M_L4.9$, with seismic activity intensity at $M_L4.3$. Additionally, this paper divides Shandong and nearby regions into seven tectonic regions for seismic magnitude-frequency calculations and provides seismic probability forecasts for each region.

Keywords: non-stationary poisson model; North China; probability prediction.

1 Introduction

Estimating maximum magnitude and activity intensity is crucial for earthquake forecasting^[1]. From a temporal perspective, while long-term and large-scale seismic events can be approximated as stationary Poisson processes, attempting to fit earthquake events to a stationary Poisson process when the statistical time scale and spatial range is not sufficient often results in an overestimation or underestimation of seismic activity levels. Consequently, in seismic hazard models, segmented, non-stationary, or time-dependent Poisson processes are commonly employed to assess seismic intensity probabilities over extended periods within specific seismic belts^[2].

This study aims to investigate seismic activity intensity probabilities across various spatiotemporal scales by leveraging the non-stationary Poisson process characteristics

of earthquakes and the seismic activity intensity established by the Gutenberg–Richter (GR) or modified GR relationships. Using earthquake activity data in North China with $M_L \geq 2.0$ or higher since 1970 as the foundational dataset, we analyze the seismic activity characteristics in North China and its sub-regions, such as the Yanshan–Bohai Seismic Belt and the Shandong region. This analysis enables us to forecast the seismic activity intensity in the short- and medium-term, facilitating annual consultation and assessment objectives^[3-4].

2 Calculation Method

Assuming that seismic events follow a stationary Poisson process, due to the ergodicity, the probability of earthquakes with magnitude M occurring g times within a given period t can be expressed as:

$$P(N(M \geq M_K) = g) = \frac{(vt)^g}{g!} e^{-vt} \tag{1}$$

where P represents the seismic occurrence probability for earthquakes greater than the specified threshold magnitude. If seismic occurrences follow a non-stationary Poisson process, the occurrence probability can be understood as the function $v(t)$ of time t , satisfying:

$$v = \frac{1}{T} \int_0^T v(t) dt \tag{2}$$

Based on actual earthquake catalogs, a “periodic statistical sequence” sample can be constructed. Appropriate sequence prediction methods, such as the autoregressive moving average model (ARMA)^[5-6], can be used for the estimation of $v(t + \tau)$.

In this context, the determination of the ARMA algorithm’s order (p, q) is crucial. Theoretically, high-order cumulative quantity methods can fully suppress Gaussian noise, but they are sensitive to special matrices and have longer computation times. Therefore, possessing a larger (p, q) order does not necessarily lead to better results. The modified Yule–Walker equation can be expressed in matrix form as^[7-8]:

$$R_e a_e = 0 \tag{3}$$

where:

$$R_e = \begin{bmatrix} R_x(q_e + 1) & R_x(q_e) & \dots & R_x(q_e + 1 - p_e) \\ R_x(q_e + 2) & R_x(q_e + 1) & \dots & R_x(q_e + 2 - p_e) \\ \dots & \dots & \dots & \dots \\ R_x(q_e + M) & R_x(q_e + M + 1) & \dots & R_x(q_e + M - p_e) \end{bmatrix} \tag{4}$$

$$a_e = [1, a_1, \dots, a_p, a_{p+1}, \dots, a_{p_e}]^T \tag{5}$$

When $M \geq P_e \geq p$, $q_e \geq q$ and $q_e - P_e \geq q - p$, $rank(R_e) = p$.

3 Yearly Scale Maximum Magnitude Estimation

Data selected for the calculation of magnitude-frequency relationships comprise earthquakes with $M_L 2.0$ or higher in North China from 1970 to 2022^[9-10]. Long-term data are used to forecast yearly-scale seismic activity intensity, as shown in Table 1. Under the long-term background, the maximum cutoff magnitudes in North China and Shandong are $M_L 7.3$ and $M_L 6.0$, respectively. With a three-year window length and a one-year step size, a time window scan is conducted for earthquakes with $M_L 2.0$ or higher in North China and Shandong. The maximum estimated cutoff magnitudes for the year 2023 in the two regions are $M_L 5.5$ and $M_L 4.9$, with seismic activity intensities of $M_L 5.0$ and $M_L 4.3$, respectively. Through the magnitude-frequency relationship calculation, it is observed that the maximum cutoff magnitude and seismic activity intensity in the Shandong region are lower than those in the North China region^[11-12].

Table 1. Calculation Results of magnitude-frequency relationships in North China and Shandong

Study Region	Maximum Cutoff Magnitude under Long-term Background	Maximum Estimated Cutoff Magnitude for 2023	Estimated Seismic Activity Intensity for 2023
North China Region	7.3	5.5	5.0
Shandong Region	6.0	4.9	4.3

Based on earthquake data in North China with $M_L 2.0$ or higher from 1970 to 2022, the ARMA model is applied to determine the order, and it is found that $(p, q) = (2, 4)$ has a relatively small fitting error. According to the ARMA model, North China is divided into the Yanshan-Bohai Seismic Belt, Shanxi Seismic Belt, Hebei Plain Seismic Belt, and Yishu Seismic Belt. Subsequently, we predict the occurrence frequencies and probabilities of $M_L 4.0$ and $M_L 5.0$ earthquakes, with the results shown in Fig. 1 and Table 2. Notably, in North China, Yanshan-Bohai Seismic Belt, Shanxi Seismic Belt, Hebei Plain Seismic Belt, and Yishu Seismic Belt, the probabilities of earthquakes with $M_L 4.0$ or higher are 1.0, 0.85, 0.77, 0.93, and 0.66, respectively. Earthquakes with $M_L 4.0$ mainly concentrate near the Hebei Plain Seismic Belt. For earthquakes with $M_L 5.0$ or higher, the occurrence probabilities in these regions are 0.78, 0.63, 0.65, 0.59, and 0, respectively.

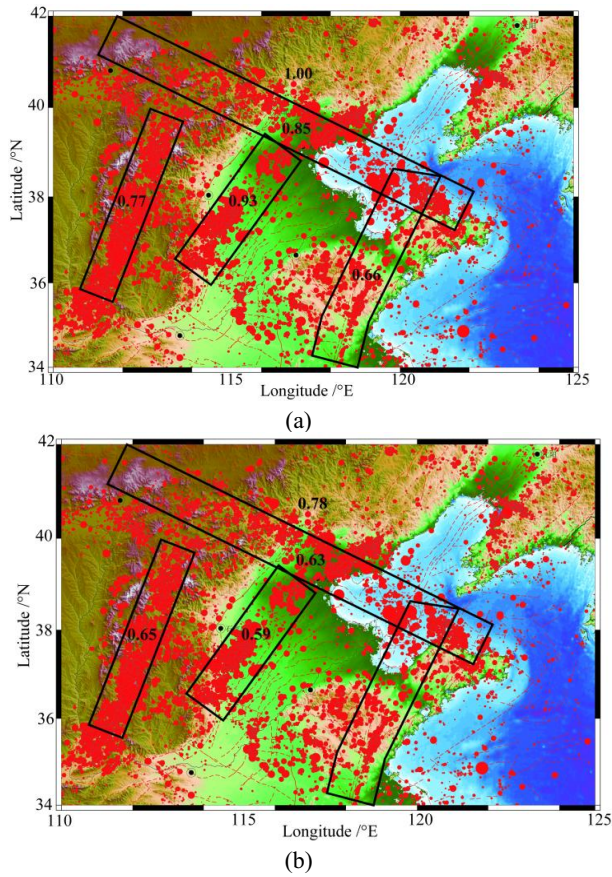


Fig. 1. Probability of Earthquakes with (a) $M_L \geq 4.0$ or Higher and (b) $M_L \geq 5.0$ or Higher in North China in 2023

Table 2. Probability prediction of seismic intensity in North China in 2023 using non-stationary poisson distribution process

	$M_L \geq 4.0$		$M_L \geq 5.0$		$M_L \geq 6.0$	
	Frequency	Probability	Frequency	Probability	Frequency	Probability
North China Region	12	1.00	1.5	0.78	0.6	0.47
Yanshan-Bohai Seismic Belt	1.9	0.85	1.0	0.63		
Hebei Plain Seismic Belt	2.6	0.93	0.9	0.59		
Shanxi Seismic Belt	1.5	0.77	1.1	0.65		
Yishu Seismic Belt	1.1	0.66				

Based on the non-stationary Poisson process, we utilize the ARMA model to divide the Shandong region into seven tectonic regions, encompassing North Shandong, the Liaocheng–Lankao Belt and the border region between Hebei, Shandong, and Henan, the Bohai Sea region, the northern Yishu Belt, the southern Yishu Belt, the Yellow Sea region of North Jiaodong, and northern regions of South Yellow Sea. Our inquiry extends to forecasting the seismic frequency and probabilities of $M_L3.0$ and $M_L4.0$ earthquakes in 2023, with results shown in Fig.2 and Table 3. Evidently, the seismic probability of events with $M_L3.0$ or higher exceeds 0.6 across all seven tectonic regions. Among these, the Yellow Sea region of North Jiaodong and the northern region of South Yellow Sea hold a remarkable probability of 0.99 each, while the southern Yishu Belt region follows closely at 0.91. As for earthquakes with $M_L4.0$ or higher, four regions exhibit probabilities exceeding 0.6, with the Yellow Sea region of North Jiaodong at 0.74, warranting special attention.

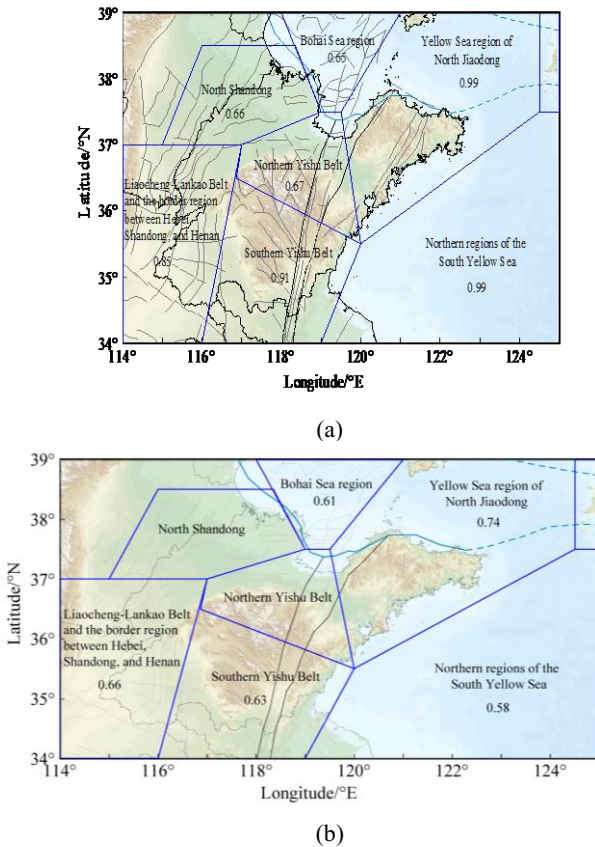


Fig. 2. Seismic probability of (a) $M_L3.0$ or higher earthquakes and (b) $M_L4.0$ or higher earthquakes in the Shandong region in 2023

Table 3. Probability prediction of seismic intensity in Shandong in 2023 using the non-stationary poisson distribution process

	$M_L \geq 3.0$		$M_L \geq 4.0$		$M_L \geq 5.0$	
	Frequency	Probability	Frequency	Probability	Frequency	Probability
Shandong region	17.8	1.0	2.7	0.94	0.9	0.59
North Shandong	1.1	0.66				
Liaocheng–Lankao Belt and the border region between Hebei, Shandong, and Henan	1.9	0.85	1.1	0.66		
Bohai Sea region	1.0	0.65	0.9	0.61		
Northern Yishu Belt	1.1	0.67				
Southern Yishu Belt	2.4	0.91	1.0	0.63		
Yellow Sea region of North Jiaodong	6.5	0.99	1.4	0.74		
Northern regions of the South Yellow Sea	6.4	0.99	0.9	0.58		

4 Conclusions

We conducted a seismic magnitude-frequency analysis using earthquake data of $M_L 2.0$ or higher from 1970 to 2022 in the North China region. Under the long-term background, this study determined the maximum cutoff magnitude to be $M_L 7.3$. Utilizing the three-year-scale scanning method, we predicted a maximum cutoff magnitude of $M_L 5.5$ for the year 2023, alongside a seismic activity intensity of $M_L 5.0$. Moreover, our projections for 2023 in the North China region include an expectation of 12 earthquakes with $M_L \geq 4.0$ and a seismic probability of 1.00, 1.5 earthquakes with $M_L \geq 5.0$ and a seismic probability of 0.78, along with 0.6 earthquakes with $M_L \geq 6.0$ and a seismic probability of 0.47.

In the Shandong region and its neighboring areas, the long-term maximum cutoff magnitude was estimated to be $M_L 6.0$. With the three-year-scale scanning approach,

our analysis foresaw a maximum cutoff magnitude of $M_L 4.9$ in 2023, with a seismic activity intensity of $M_L 4.3$. Throughout the year, the Shandong region was anticipated to encounter 17.8 earthquakes with $M_L \geq 3.0$ and a seismic probability of 1.00, 2.7 earthquakes with $M_L \geq 4.0$ and a seismic probability of 0.94, as well as 0.9 earthquakes with $M_L \geq 5.0$ and a seismic probability of 0.59.

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