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Scoring annual earthquake predictions in China

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ABSTRACT

The Annual Consultation Meeting on Earthquake Tendency in China is held by the China Earthquake Administration (CEA) in order to provide one-year earthquake predictions over most China. In these predictions, regions of concern are denoted together with the corresponding magnitude range of the largest earthquake expected during the next year. Evaluating the performance of these earthquake predictions is rather difficult, especially for regions that are of no concern, because they are made on arbitrary regions with flexible magnitude ranges. In the present study, the gambling score is used to evaluate the performance of these earthquake predictions. Based on a reference model, this scoring method rewards successful predictions and penalizes failures according to the risk (probability of being failure) that the predictors have taken. Using the Poisson model, which is spatially inhomogeneous and temporally stationary, with the Gutenberg–Richter law for earthquake magnitudes as the reference model, we evaluate the CEA predictions based on 1) a partial score for evaluating whether issuing the alarmed regions is based on information that differs from the reference model (knowledge of average seismicity level) and 2) a complete score that evaluates whether the overall performance of the prediction is better than the reference model. The predictions made by the Annual Consultation Meetings on Earthquake Tendency from 1990 to 2003 are found to include significant precursory information, but the overall performance is close to that of the reference model.

1. Introduction

During last 50 years, in numerous regions around the world (including China), earthquakes have caused enormous damage to both property and human life. For example, approximately 240,000 people lost their lives as a result of the *M*7.8 Tangshang earthquake, which occurred on July 28, 1976, and approximately 160,000 people were seriously injured. More recently, the *M*8.0 Wenchuan earthquake, which occurred on May 20, 2008 in a populated area in Sichuan Province, China, resulted in the loss of more than 70,000 lives. In China, preventing earthquake disasters and reducing their impact is an important task for both scientists and the government. The China Earthquake Administration (CEA), which was previously referred to as the State Seismological Bureau as well as the China Seismological Bureau, is a governmental agency that is dedicated to monitoring precursors of earthquakes and predicting the occurrence of earthquakes. The purpose of the Annual Consulting Meeting on Earthquake Tendency in China held each year by the CEA is to evaluate earthquake risk for most of the country for the coming year. By consensus of experts from the CEA institutes and provincial or municipal seismological bureaus, one-year predictions are made based on data from various observations, including seismicity parameters, deformation, apparent electric resistivity, underground water, stress, gravity field, and magnetic field. The findings of this meeting are published in a report called "The Annual Report of Earthquake Tendency" (Center for Analysis and Prediction, China Earthquake Administration, 1998, 1999, 2000, 2001, 2002; Center for Analysis and Prediction, State Seismology Bureau, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997). In particular, a map of several alarmed regions is marked as having high probabilities of large earthquakes (usually $M \geq 5.5$ in the western part and $M \geq 5.0$ in the eastern part of China). These predictions are reported to the central and provincial governments for incorporation into disaster reduction policies, and are only made available to the public after a period of one year, because the government is the only legal authority able to perform mitigation actions. Details on earthquake prediction in China have been reported by Mei et al. (1993), Wu (1997), Wu et al. (2007) and Bormann (2011).

However, in the following year, earthquakes of expected magnitudes occur in some of these alarmed regions, as well as in unmarked regions, whereas no expected earthquakes occur in the other alarmed regions. An important issue arises regarding how to evaluate the prediction performance of the Annual Consultation Meeting. Shi et al. (2001), denoted hereinafter as SLZ, evaluated the prediction performance of the 1990–1998 reports using the R score and found that the CEA annual predictions were marginally better than background-based random predictions. They concluded that the CEA predictions were still empirical and were in a preliminary stage of development.

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The present study attempts to verify the results of SLZ using the gambling score, as proposed by Zhuang (2010). Zechar and Zhuang (2010) used this method to evaluate the significance of the predictions by Shebalin et al., using the reverse tracing of precursor (RTP) algorithm (see, Shebalin et al., 2000, 2004, for details regarding the RTP algorithm). Molchan and Romashkova (2011) applied the gambling score to evaluate the prediction performance of the M8 algorithm. In the present study, for different testing purposes, we apply the gambling score 1) for discrete bets, which are only on the alarmed regions, and 2) for bets in the continuous space–time, using the extension of the gambling score to the point process cases. The first application evaluates whether the predictions contain useful information that is not included in the reference model. That is to say, if the predictor knows something better than the reference model, he can always win if he uses a suitable betting strategy to decide whether to bet. In the second scoring method, the predictor is always required to bet under every situation. In other words, the first scoring method is for gamblers, namely, the partial score, and the second scoring method is for decision makers, namely, the complete score.

2. Evaluation methods

2.1. The R score

The CEA annual predictions are statements on the occurrence of a future earthquake within a specific space–time–magnitude window (see Fig. 1). The performance of such predictions can be evaluated using the R score (also referred to as the Hanssen–Kuiper skill score, see, e.g., Harte and Vere-Jones, 2005; Shi et al., 2001). In the context of the contingency table, the R score is defined as the difference between the fraction of successful positive predictions and the fraction of unsuccessful negative predictions in a 2×2 contingency table:

$$R = \frac{a}{a+c} - \frac{b}{b+d} \quad (1)$$

where a is the number of correct positive predictions, b is the number of false alarms (wrong positive predictions), c is the number of misses (wrong negative predictions), and d is the number of correct negatives.

However, applying the R score to the CEA annual predictions is difficult for the following reasons:

- These predictions are announced for irregular regions of different sizes. Shi et al. divided the entirety of China into $0.5° \times 0.5°$ cells, and used each cell as an individual observation in the contingency table.
- These predictions are announced for different magnitude ranges. In the western part of China, the predicted magnitudes are usually 6± (5.5~6.5) or 6.0~7.0, and in the eastern part of China, the predicted magnitudes are 5.0~6.0. In SLZ, a cut-off magnitude of 5.0 was used for all the alarmed cells to fit the requirements of the R score testing.
- Most importantly, seismicity activity rates differ from region to region. The probabilities of earthquake occurrences are not the same in different cells, which makes the R score inapplicable. In other words, the R score tests the predictions against a Poisson model, the rate of which is spatially homogeneous, where the nonhomogeneous Poisson model is more suitable for use as a null model. In order to address this problem, in addition to the R score for the CEA predictions, SLZ also calculated the R score for the nonhomogeneous Poisson model. The predictions based on the nonhomogeneous Poisson

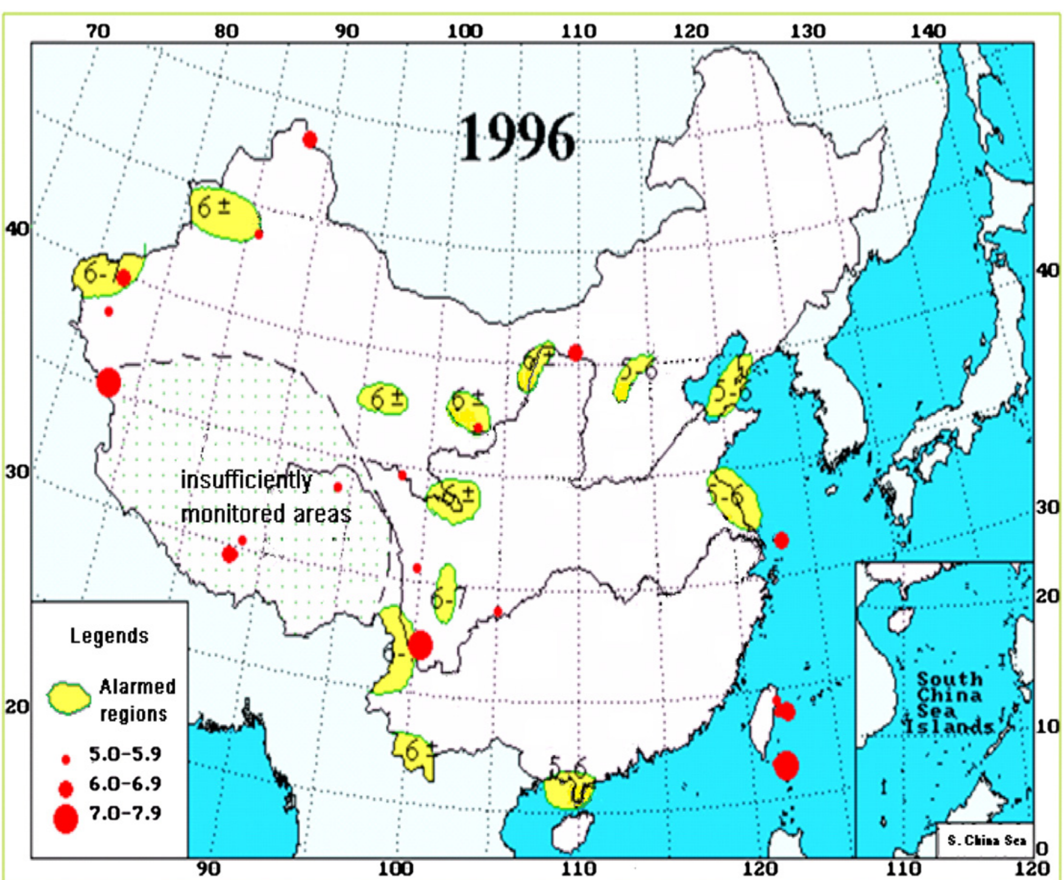

Fig. 1. The CEA annual predictions for large earthquakes occurring in 1996. The alarmed regions are marked in yellow and the numbers on the alarmed regions are the magnitude ranges of the expected future earthquakes. The earthquakes with magnitude of Ms 5.0 and above that occurred in 1996 are represented by the red dots.