Strong Earthquakes in the Yunnan-Sichuan Region: Evaluation of a Forward Long-to-intermediate-term PI Forecast

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Since the initial international cooperation in the framework of Collaboratory for the Study of Earthquake Predictability (CSEP) in 2007, a lot of forecast models have been developed and served for the earthquake forecasting experiment in different CSEP testing centers (Schorlemmer et al., 2018). This cooperation aims to reduce the impact from the little sample of the analyzed earthquakes to conduct the earthquake forecasting experiment for future large earthquakes. Through nearly 10 years of efforts on comparing the forecasting results with the observed earthquakes, many statistical test methods performing the consistency evaluation were provided, and have been the highlight point in CSEP platform. Within the CSEP test centers, the Central China North-South Seismic Belt, one of the focuses of special attention in China (Zhang et al., 2003), has numerous seismic recordings of disastrous earthquakes. As fundamental research for the predictability of earthquake in the first 10 years of CSEP work, a series of retrospective forecasting experiments have been made, such as the analysis for the completeness magnitude (Mignan et al., 2013), forecasting using ‘simple smoothed seismicity model’ and the ‘TripleS model’ (Zechar and Jordan, 2010). Among these models, pattern informatics (PI) algorithm has been widely applied to many global regions (Chen et al., 2005; Holliday et al., 2006; Nanjo, 2006; Jiang and Wu, 2010). As a model that aims to capture earthquake dynamics by pattern recognition, it could use the anomalous activation or quiescence of seismicity as an indication of increase of probabilities of target earthquakes and will output a spatial distribution of ‘hotspots’. For the performance that it can give the long-to-intermediate-term potential of ‘target earthquakes’ in a region with high seismicity level, having the ability to cooperate with the earthquake annual consultation in China, this algorithm has been used in the analysis for Central North-South Seismic Belt in China.

In previous works, within CSEP works in China, we have carried out a forecasting experiment using PI algorithm to perform a long-to-intermediate-term forecast for the target earthquakes larger than M0,6.0 in the Yunnan-Sichuan region (21.0°–41.5°N, 97.5°–107.5°E) in China (Zhang et al., 2016). The data we used was the earthquake catalogue provided by the China Earthquake Networks Center (CENC), which is a ‘mixed magnitude’ system that the magnitude type of earthquakes below 4.0 and above 5.5 are Chinese local magnitude Mr and surface wave magnitude Ms, respectively. For the events in between, the transition from the Chinese Mr to the Chinese Ms is not clearly defined. Since the number of earthquakes above cut-off magnitude is used to calculate the ‘hotspots’ in this algorithm, the ambiguity in the magnitude does not affect our result. For the ‘target earthquakes’, we choose the quick report catalog for large events provided by China National Seismograph Network to perform the retrospective evaluation. The surface wave magnitude Ms is used for the ‘target earthquakes’ to avoid the bias between different types of local magnitude defined in different seismic networks. After obtaining the ergodic behavior of the seismicity in this region based on the assumptions of meta-stable equilibrium (Tianpo et al., 2004, 2007), we discussed the applicability of such kinds of predictive algorithms. Then PI algorithm was put to forward forecasting for the next 5 years. The parameter sets in the forecasting are as follow: the cutoff magnitude 3.0; the 10-year ‘background window’ 1999/01/01 to 2009/01/01; 5-year ‘anomaly identification window’ 2009/01/01 to 2014/01/01; 5-year ‘forecast window’ 2014/01/01 to 2019/01/01; the grids divided the whole region into cells with 0.2° in latitude and longitude direction. The ‘hotspots’ which indicate the spatial distribution of strong earthquakes that occur in the forecast window are shown in Fig. 1a. In general, the ‘hotspots’ indicated the earthquake potential for next 5 years will be displayed for the top 30% of PI results. The two catalogues used in our study are given in supplementary data.

Forward forecasting is more valuable than retrospective evaluation in an earthquake forecasting experiment. During the 5 years of ‘forecast window’, there are six target events above Mr,6.0 (four events occurred before the time of our paper submitted in 2015 (Zhang et al., 2016): 2014/05/30 Yingjiang Mr,6.1, 2014/08/03 Ludian Mr,6.5, 2014/10/07 Jinggu Mr,6.6, 2014/11/22 Kangding Mr,6.3;
two events occurred afterward: 2016/01/21 Menyuan $M_{s}6.4$, 2017/08/08 Jiuzhaigou $M_{s}7.0$). In these earthquakes, Ludian $M_{s}6.5$ earthquake occurred in a densely populated area and caused the most casualties, mainly a result of falling walls and buildings. Now the ‘forecast window’ of 2014/01/01 to 2019/01/01 in our previous work has passed. Thus it is possible and essential to give an evaluation for the model performance. In this abstract, we apply relative operating characteristic (ROC) (Swets, 1973) analysis into the evaluation for PI forecasting experiments, which is shown in Fig. 1b. ROC method can give the evaluated distribution of false alarm rate and hit rate.
rate and hit rate based on each probability level determining the fluctuation analyzed by PI algorithm. In comparison with the performance of relative intensity (RI) algorithm (Nanjo, 2011), the ROC diagram of RI algorithm is also provided.

From the ROC curve in Figure 1b we can conclude that RI and PI algorithms outperform random guess in the ‘forecast window’. PI and RI algorithms have a little difference in the first stage of the ROC curve due to the ROC evaluation mechanism that probability threshold ROC used above which the target events should be regarded as a ‘hit’ event. When the threshold changes to a certain level, the earthquake intensity feature starts to be a significant indicator for the future target events, like the back part of the ROC curve of RI algorithm. To investigate the PI threshold value indicating the difference between the forecasting performance of PI and RI algorithm, we obtain the false alarm rate 0.1525 and hit rate 0.6667 as the transform point, shown by the red dashed line in the ROC diagram in Fig. 2b. The ‘hotspots’ plot in Fig. 2a shows the forecasting result of PI algorithm using the threshold value of ‘hotspots’ as −1.5135, with the alarm regions colored with orange other than the different values indicated by a color bar. It suggests that PI algorithm has approximately the same performance as RI algorithm when the threshold is set above −1.5135 and performs worse than RI algorithm when it is set below this value. Therefore, this threshold value should be the lowest limit if PI algorithm is expected to have a good performance in this ‘forecast window’, using the above model parameters set. From another perspective, the forecasting experiment is employed under the optimal choice of model parameters and will directly influence the ultimate result. Previous works (Mulargia, 1997) have also suggested that the threshold value for the significance of the association between the forecast result and the observed ‘target earthquakes’ must be greatly lowered once the retrospective studies can be investigated using standard techniques.

Key words: pattern informatics (PI) algorithm, long-to-intermediate-term forecast, relative intensity (RI) algorithm, relative operating characteristic (ROC) analysis, Yunnan-Sichuan region

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References

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