Improved Stress Release Model and its Application to Earthquake Prediction in Taiwan

Shoubiao ZHU[1,2], *Yaolin SHI*[2]

[1]*The Institute of Crustal Dynamics, Chinese Earthquake Administration, Beijing,China, 100085*

[2] *Laboratory of Computational Geodynamics, Graduate University of Chinese Academy of Science, Beijing,China, 100049*

Corresponding Author: Yaolin Shi, shiyl@gucas.ac.cn

Abstract: *Stress release model (SRM) and coupled stress release model (CSRM) have been applied to seismicity study. However, it is found that the peaks of earthquake conditional probability intensity often occur before the seismicity high in time domain. In this paper, we modified the SRM and CSRM in aspect of the relation between stress and earthquake probability. We assume that highest seismicity does not occur at the time of peak of highest stress, instead, there exist a time delay from the time of highest stress to the time of highest seismicity. The modified model is applied to the study of earthquakes in Taiwan. The result shows that the modified models, including the SRM and CSRM, can be applied to smaller scale of time (100 years) and space (~300km). Accuracy of earthquake occurrence time predicted by the modified coupled stress release model is higher than that by the old model in a test of retrospect earthquake prediction.*

1. Introduction

Stress release model (SRM) was proposed by Vere-Jones in 1978 for statistical study of seismicity. Physically it is a stochastic version of the elastic rebound theory of earthquake genesis. The classical elastic rebound model suggests that the stress has been slowly accumulating until the burst of an earthquake occurrence for stress release. This can be simulated by the jump Markov process in stochastic field, and SRM was developed on the basis of Knopoff′s Markov model. Vere-Jones (1988) applied SRM to historical earthquakes for North China and obtained some interesting results. Zheng and Vere-Jones (1991, 1994) further studied SRM in detail, provided a computational algorithm, and achieved good results in practical use. Although Zheng and Vere-Jones (1991) divided North China into 4 seismic zones and calculated the parameters of SRM with the zones combined, they did not take into account the interaction between seismic zones and still adopted the simple SRM. On the basis of their study, Shi *et al.* (1998) and investigated the application of SRM to synthetic earthquakes, and found that the SRM is a good model when being applied to the entire system, but it behaves degraded when applied to a region as only a part of the entire system because of neglecting the influences of stress changes produced by the earthquakes occurred outside the region. They therefore proposed the coupled stress release model (CSRM) as an improvement with the inclusion of terms accounting for the influences of stresses interaction among earthquakes occurred in different regions. Liu *et al.* (1998) applied CSRM to historical M>6.0 earthquakes from 1480 to 2000 in North China, and compared the results obtained from both CSRM and SRM models by AIC criterion. They found that CSRM is superior to SRM, and can significantly raise the earthquake occurrence probability before some main earthquakes. Zhu and Shi (2002) found both the SRM and CSRM are still applicable in the smaller time and space scale, and that the accuracy of prediction earthquake by SRM is higher than that of Poisson Model. Even so, both the SRM and CSRM still have a flaw, in the models, the earthquake conditional probability intensity and seismicity do not always vary consistently, *e.g.*, the earthquake conditional probability intensity is sometimes already reduced to low values, but seismicity is still very active in the period of time. In this study, we will modify the stress release model and test the new model to seismicity analysis in Taiwan.

2. Modification of SRM and CSRM

In the stress release model, it is assumed that earthquake conditional probability intensity is proportional to the exponential of stress, and peak seismicity would occur at time of peak stress. However, this assumption contradicts observations sometimes. Earthquake *M-t* plot and variation of conditinal probability intensity with time in North China from 1480 to 2000 are shown in Figure 1 (Liu *et al.*, 1998). Although the conditinal probability intensity reached the peak around the year 1660, and reduced to low values from 1670 to 1800, the seismicity was very active both in frequency and magnitude from 1670 to 1740 (arrow donotes the inconsistent period of time) in North China. It is suggested that there exists a time delay between the stress high and the seismicity high.

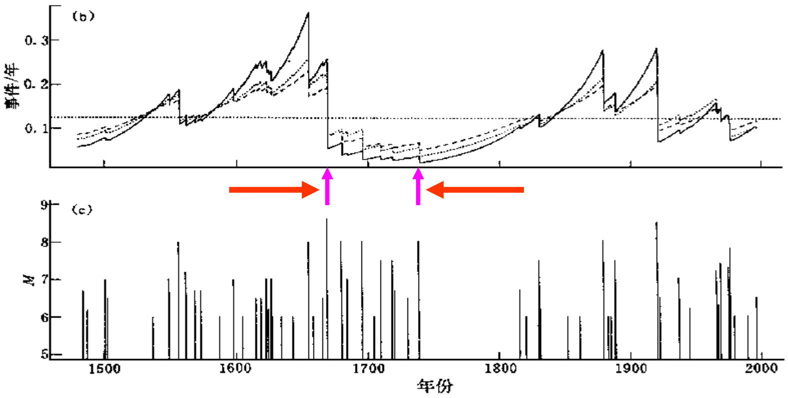

Figure.1 *Earthquake M-t plot and variation of conditinal probability intensity with time in North China from 1480 to 2000 (Liu et al., 1998) (arrow denotes the inconsistent period of time)*

Considering this time delay between the conditinal probability intensity and the seismicity, strong or moderate-strong events may still occur after a strong earthquake even though which may have significantly reduced the stress. Therefore, the equation for conditional intensity of earthquakes is modified as:

$$\lambda(t) = \exp\{a + b[t' - cS(t')]\} \qquad (1)$$

The conditinal probability intensity λ at time t , is related to the stress at time t', *i.e.*, the summation of linear increased stress with time, $a+bt'$, subtracts $S(t')$, the total released stress at time $t' = t - \Delta t$. In this case, not only *a*, *b*, *c* are model parameters to be decided by maximum likelihood method. $t' = t - \Delta t$, Δt is also a parameter to be searched for optimization.

Figure.2 shows the compassion of intensity curves of SRM and modified SRM in North China from year 1450 to 2000. It is apparent that the modified SRM is better than SRM from two aspects: 1. seismicity almost keeps abreast of conditinal probability intensity; 2. AIC in modified SRM (AIC=395.9) is less than that of in SRM (AIC=402.3).

In the same way, the conditinal probability intensity $\lambda(t)$ in CSRM is modified as:

$$\lambda(t) = \exp\{a + b[t' - c_1 S_1(t') - c_2 S_2(t')]\} \qquad (2)$$

Where $S_1(t')$, $S_2(t')$ are the sum of released stresses at time *t'* of both the inner and outer regions, respectively, *t'* is the same as in eqn. (1), and a, b, c_1,and c_2 are model parameters fitted from catalog data.

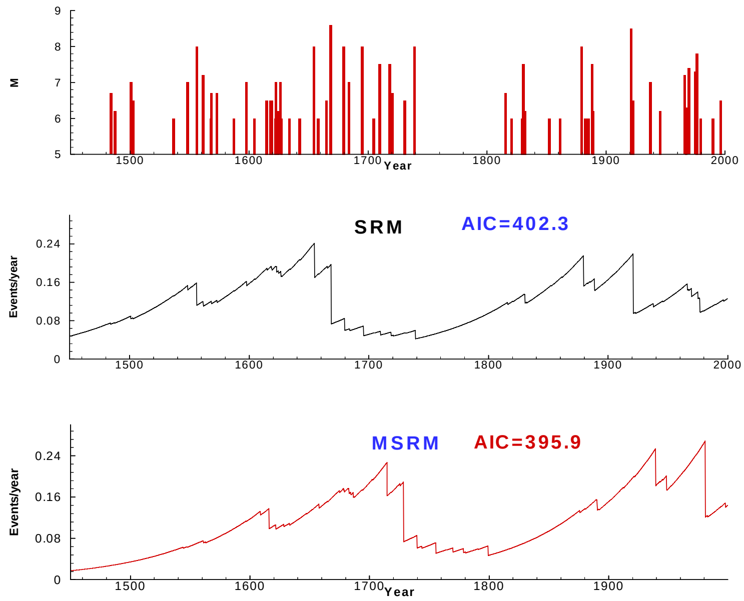

Figure.2 *comparison of SRM and modified SRM in north China from the year 1450 to 2000 (top is M-t plot, the middle conditinal probability intensity varies with time in SRM, the bottom corresponding curve in modified SRM)*

3. Comparison of the SRM with the MSRM in Taiwan area

In order to examine the modified stress release (MSRM) and the modified coupled stress release model (MCSRM), we re-calculate the AIC value and R-score with the MSRM and the MCSRM in Taiwan region. R-score is a parameter defined as success rate subtract false alarm rate, popularly used in China to evaluate earthquake predictions (Shi *et al.*, 2000). A Table of AIC value and R-score of 10 sub-regions is calculated for SRM, MSRM, CSRM, and MCSRM in Taiwan area. From the table, it is suggested that MSRM behaves better than SRM in AIC value, but not in the R-score. However, MCSRM is better than CSRM and SRM both in AIC value and in R-score.

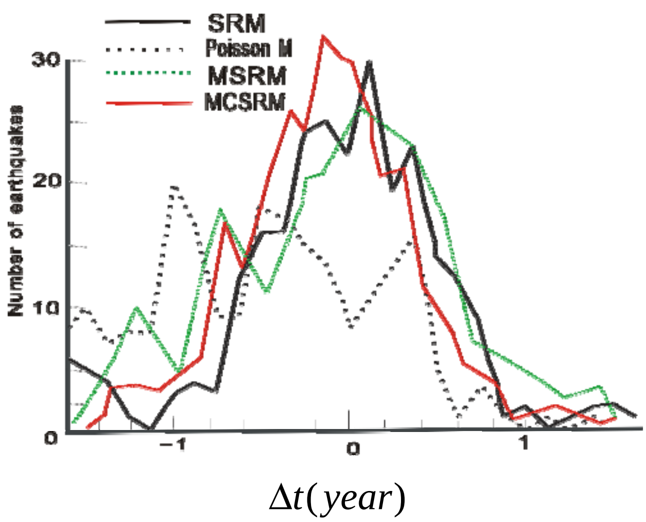

Figure 3 *Difference between earthquake occurrence time predicted by ISRM and by Poisson model and the number of earthquakes predicted*

Figure 3 shows the difference between the actual earthquake occurrence time and predicted occurrence time by SRM, MSRM, MCSRM, and Poisson model respectively. The square root of the difference between earthquake occurrence time predicted by Poisson model and actual occurrence time is 1.40 years, whereas it is 0.74 years by SRM, 0.86 years by MSRM and 0.61 years by MCSRM. Obviously, MCSRM has higher accuracy in earthquake prediction.

Parameter Δt, in principle, can be obtained in similar algorithm for a, b and c. As a matter of fact, Δt is searched by try and error method in this work so far. In Taiwan, Δt is usually assigned 2-4 years for trial. We found that larger Δt can usually improve the AIC value, but may reduce the R-score.

4 Conclusion

From this study we conclude that the modified stress release model (MSRM, MCSRM), which allow the peak seismicity appears after a time delay of peak stress, behaves better than SRM and CSRM in study of regional seismicity. Moreover, MCSRM can give a better estimates when trying to apply stress release models to earthquake prediction.

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