Physica A xx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Bayesian prediction of earthquake network based on space–time influence domain

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HIGHLIGHTS

- Bayesian theory is first introduced to the study of earthquake network.
- The earthquake network is simplified to be a Bayesian network.
- The cases designed consider the time influence scope of each event.
- The results show that the success rate of the prediction is about 65%.
- In particular, the predictions for some nodes have high rate of accuracy.

ARTICLE INFO

Article history:
Received 29 March 2015
Received in revised form 2 November 2015
Available online xxxx

Keywords:
Earthquake networks
Complex networks
Bayesian networks
Prediction
Parameters learning
Inference

ABSTRACT

Bayesian networks (BNs) are used to analyze the conditional dependencies among different events, which are expressed by conditional probability. Scientists have already investigated the seismic activities by using BNs. Recently, earthquake network is used as a novel methodology to analyze the relationships among the earthquake events. In this paper, we propose a way to predict earthquake from a new perspective. The BN is constructed after processing, which is derived from the earthquake network based on space–time influence domain. And then, the BN parameters are learnt by using the cases which are designed from the seismic data in the period between 00:00:00 on January 1, 1992 and 00:00:00 on January 1, 2012. At last, predictions are done for the data in the period between 00:00:00 on January 1, 2012 and 00:00:00 on January 1, 2015 combining the BN with the parameters. The results show that the success rate of the prediction including delayed prediction is about 65%. It is also discovered that the predictions for some nodes have high rate of accuracy under investigation.

1. Introduction

Bayesian networks (BNs), also called belief networks, are one of graphical models based on probabilistic inference [1]. These graphical models are used to express knowledge about an uncertain domain [2–7]. BNs are usually represented by directed acyclic graph, containing nodes and edges. Each node represents a random variable, while edge represents the dependency between any two nodes. These conditional dependencies are usually estimated by employing prominent statistical and computational approaches, which are expressed by conditional probability. Therefore, BNs combine principles from graph theory, probability theory, and statistics. BNs are not only rigorous in mathematics, but also understandable in intuition, which contributes to the popularity in the statistics [5], the machine learning [6], and the artificial intelligence

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http://dx.doi.org/10.1016/j.physa.2015.11.006
0378-4371/

Please cite this article in press as: Y. Zhang, et al., Bayesian prediction of earthquake network based on space–time influence domain, Physica A (2015), http://dx.doi.org/10.1016/j.physa.2015.11.006

societies [7]. BNs are used to express and analyze the uncertainty and probabilistic events and are applicable to decisions that conditionally rely on a variety of control factors. BNs can make inference from incomplete, inaccurate or uncertain knowledge or information.

The pregnancy and occurrence of earthquake is a very complicated progress, which is hard to describe by using physical mechanics models [8]. The application of Bayesian theory is a practical way, using the method of probability statistic, which is often used to predict the occurrence of the earthquake through making use of the past experiences with mathematical rigor in judgment. Furthermore, it is proved that the application of Bayesian theory can make the static error reduce to the minimum [8].

Many scientists have already investigated the earthquake from the perspective of BNs. West and Harrison first presented the theory for Bayesian forecasting and dynamic models in 1997 [8]. Afterwards, Wikle et al. used the theory to develop a hierarchical Bayesian space–time model and implemented the model using an MCMC simulation framework in 1998 [9]. Wei Lin proposed a hierarchical level Bayesian model and presented the designs and implemental methods of Bayesian networks application for comprehensive earthquake prediction, especially Network Negotiatory Comprehensive Earthquake Prediction GDSS in 2004 [10]. Bent et al. studied the development of earthquakes in space and time by using a variety of Bayesian hierarchical model and make short time prediction in 2007 [11].

Since the earthquake system is complex, therefore, scientists try their best to find the universal laws which may contribute to find the essence characteristics of the seismic system. While the theory of complex networks is the key to know the complexity of system, people can investigate the structure and function of complex system from a global view to find the inter relationship.

Recently, the concept of complex networks was introduced to seismology to reveal complexity of seismicity in space and time [12]. The evolving network is called earthquake network, which is initiated by Abe and Suzuki. In 2004, they proposed the earthquake network construction method based on time series [13,14,12]; in 2011, Zhou-min Xie proposed a complex weighted network construction method [15]; in 2014, Douglas proposed a new methodology by using a time window to construct a global earthquake network [16]. In our previous work in 2014, we proposed an earthquake network construction method based on space–time influence domain [17].

In this paper, the earthquake network based on space–time influence domain considers the spatial and temporal correlations between earthquakes, which motivates us to construct a BN by making using of it. The nodes of BN are indicators of precursor anomalies or geologic attributes in previous research, while they are small regions in our research, containing many earthquake events. We have taken all the data into the network, analyzing the relationships among different nodes. Through large number of statistics, we give the conditional dependencies in the Bayesian network. According to the correlation among nodes, we make use of the earthquakes already happened to predict in which area earthquakes will occur within a certain time scope with higher probability. The success rate of the prediction is about 65%.

The paper is arranged as follows. In Section 2, the earthquake network construction method and the data used in our research are introduced. In addition, we have analyzed the relationship between core and energy. In Section 3, we construct the BN and continue BN parameters learning. At the last part of Section 3, we give an inference to verify the effectiveness of our model. Finally, in Section 4 and Section 5, the discussion and conclusion of this paper are presented, respectively.

2. Network construction method and data

2.1. Theoretical model

In this study, the network construction method proposed by us is as follows. We first follow Abe and Suzuki's approach to divide a geographical region into cubic cells and regard a cell as a vertex of the network if earthquakes with any values of magnitude occur therein [18]. And then, we assume that the seismic wave propagates in uniform medium so that the seismic attenuation is unified. The energy released by seismicity depends on the magnitude, influencing other regions in definite time and space. The larger the magnitude is, the huge amount of energy the seismicity releases, the broader the impact scope is. In the literature [19] the author gives the relationship between magnitude and influence domain which complies with the following forms:

$$\log_{10} L = a_1 M + b_1, \quad (1)$$

$$\log_{10} T = a_2 M + b_2, \quad (2)$$

where L and T are the influence radius and the influence time for a given magnitude M. Moreover, a_1, b_1, a_2 and b_2 are constants. The values of these constants are different with the geographical area.

If the event j occurs after event i, the time and space interval will be computed as the following formulas:

$$\Delta t = t_j - t_i, \quad (3)$$

$$\Delta d = 2R \sin^{-1}\left(\sqrt{\sin^2\left(\frac{\pi\,(x_i - x_j)}{360}\right) + \cos\left(\frac{\pi x_i}{180}\right)\cos\left(\frac{\pi x_j}{180}\right)\sin^2\left(\frac{\pi\,(y_i - y_j)}{360}\right)}\right), \quad (4)$$

Please cite this article in press as: Y. Zhang, et al., Bayesian prediction of earthquake network based on space–time influence domain, Physica A (2015), http://dx.doi.org/10.1016/j.physa.2015.11.006