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Contemporary kinematic models and moment deficit of Chinese mainland

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ABSTRACT

There are lots of achievements about kinematics of Chinese mainland and its vicinity determined from historic earthquake data, Quaternary fault rates and geodesy observations, which provide basic data for analysis of seismic hazard in study areas. Based on impreciseness in using energy of 47 earthquakes with magnitude greater than 7.0 in previous study, we firstly collected source parameters, surface ruptures and displacements of major earthquakes carefully, and divided them into small segmentations with these data gathered. Secondly, we determined contemporary deformation field from latest earthquake mechanisms, Quaternary fault slip rates and geodesy observations. Finally, we evaluated moment deficit of study areas from historic earthquake data and predicted deformation field, and removed 10 percent of aseismic deformation. Combining with previous results, we analyzed the seismic hazard of study areas. The results show that there are some areas with large moment deficit in Chinese mainland. There are also large moment deficit areas, including regions around the Ordos Block, southeastern coast of China and the Bakal rift zone. Previous studies show that there may be some potential earthquakes in the near future in parts of areas mentioned above.

1. Introduction

Chinese mainland is located in a sophisticated deforming area with strong seismicity which arises from collision of the India plate and the Eurasia plate. Statistics show that 33 percent of continental earthquake in the worldwide occurred in Chinese mainland [1]. With economy developing and society urbanizing, more and more cities with large popularity come into true. Therefore, analyzing of seismic risks of Chinese mainland is crucial to our developing, nowadays.

There are a majority of achievements about the characteristics of deforming in China, with rapid development of space geodesy techniques [2,3]. However, these results mainly aim to analyze kinematic features based on strain rates and velocity field. In their opinions, potential risk areas may be in regions with large strain rate accumulation. However, there are a few kinds of deformation signals contained in geodesy deformation model, which are instantaneous information, aseismic deformation, permanent strain rates and interseismic locking parts. Therefore, permanent and aseismic deformation parts must be excluded if these deformation models are used to analyze seismic risks of study areas.

Holt et al. [4] determined velocity field of central and eastern Asia using historic earthquake catalogs. Ren [5,6] and Holt [7] studied deforming characteristics of Chinese mainland and its vicinity areas with Quaternary fault rates and GPS observations. These results have prepared basic data for seismic risks analysis of these areas.

In this study, we firstly collected earthquake mechanisms, surface displacements and ruptures of main earthquakes (with magnitude greater than 7) occurred in Chinese mainland and its adjacent areas from 1900 to 2015. Secondly, we divided these events into small parts according to surface ruptures, displacements and model used in our study. Thirdly, we determined contemporary deformation models from focal mechanisms, fault

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slip rates, and geodesy observations. Finally, we evaluated moment deficit of study areas with predicted models and historic events. With these results, we can analyze seismic risks of Chinese mainland and its adjacent area.

2. Data and methods

2.1. Data

First of all, we collected 1349 historic earthquakes with magnitude greater than 4.5 from 1900 to 2015 in Chinese mainland and its adjacent areas (Fig. 1(a)). These data mainly came from GCMT [8], some earlier results [9–13] and CENC (China Earthquake Networks Center) [14]. There are few earthquakes in the north-eastern China, Mongolia and the south China Block because of their rigidity. We also achieved Quaternary active faults [15] and geodesy observations [16–19] from some achievements before.

2.2. Inverse method

For the purpose of investigating large-scale continental deformation, Holt [20,21] gave a method to parameterize deformation field on the surface of the earth as a continuous velocity with a vector rotation function and bicubic spline interpolation. Based on their method, Ren [6] and Holt [7] divided Chinese mainland and its adjacent areas into irregular grids, and determined kinematic deformation models from combining these grids with focal mechanisms, active faults slip rates and geodesy observations. To decline the influence of major earthquakes, we attempt to achieve a finer model (Fig. 1(b)) and segment major earthquakes into small parts according to grid model and surface ruptures. Kostrov [22] and Molnar [11] proved the possibility of evaluating strain rate observations with earthquake moment tensors and fault slip rates. So, besides geodesy observations, earthquake and fault slip rate data also can be used to determine a long-term kinematic deformation model.

Strain rate observations $\dot{\varepsilon}^{obs}$ are evaluated from the summation of Kostrov's method [11,22] as follows

$$\dot{\varepsilon}_{ij}^{obs} = \frac{1}{2\mu VT}\sum_{k=1}^{N} M_0^k m_{ij}^k \tag{1}$$

where, N is the number of earthquakes in each grid. T is interval of earthquake catalogue, which is equal to 115 years in our article. μ is shear modulus, which is 3.0×10^{11} dyne.cm^{-2}. $M_0^k = \mu A \Delta u$ is scalar seismic moment of the kth event, where A is the fault area and Δu is the average slip during the earthquake. m_{ij}^k is unit moment tensor of the kth event.

$$m_{ij} = (u_i n_j + u_j n_i) \tag{2}$$

where u_i is the unit vector of the fault strike, and n_j is normal vector of fault surface. If strike, dip and rake angle are given, we can calculate these vectors according to trigonometric functions. In our article, we achieved focal mechanisms and seismic moment according to Section 2.1, and then evaluated $\dot{\varepsilon}_{ij}^{obs}$ of each grid from Eq. (1).

2.3. Relationship of strain rate tensors and moment rate tensors

In order to evaluate moment deficit, we transfer strain rates to moment rates using formulas as follows

$$\dot{M}_0 = 2\mu V\left(\frac{1}{2}\left|\dot{\varepsilon}_{\varphi\varphi} + \dot{\varepsilon}_{\theta\theta}\right| + \sqrt{\frac{1}{4}\left(\dot{\varepsilon}_{\varphi\varphi} - \dot{\varepsilon}_{\theta\theta}\right)^2 + \dot{\varepsilon}_{\varphi\theta}^2}\right) \tag{3}$$

where $\dot{\varepsilon}_{\varphi\varphi}$, $\dot{\varepsilon}_{\theta\theta}$, $\dot{\varepsilon}_{\varphi\theta}$ are the components of $\dot{\varepsilon}^{mod}$, φ denotes east, θ is the angle to the north,V is grid areas multiplied by seismogenic thickness (15 km) [4].$\dot{\varepsilon}^{mod}$ is deformation field determined in Section 3.1, and then we can achieve model moment rates ($\dot{M}_0^{mod}$)

Meanwhile, we can also calculate observed moment rates ($\dot{M}_0^{obs}$), and surplus rates subtracted from model results ($\Delta\dot{M}_0 = \dot{M}_0^{mod} - \dot{M}_0^{obs}$). Focal mechanisms can be archived from following formulas,

$$\theta = \arctan\left(\frac{-\dot{\gamma}_2 \pm \sqrt{\dot{\Gamma}^2 - \dot{\sigma}^2}}{\dot{\sigma} - \dot{\gamma}_1}\right) \tag{4}$$

$$\delta = \arctan\left(\sqrt{\frac{\dot{\Gamma}}{|\dot{\sigma}|}}\right) \tag{5}$$

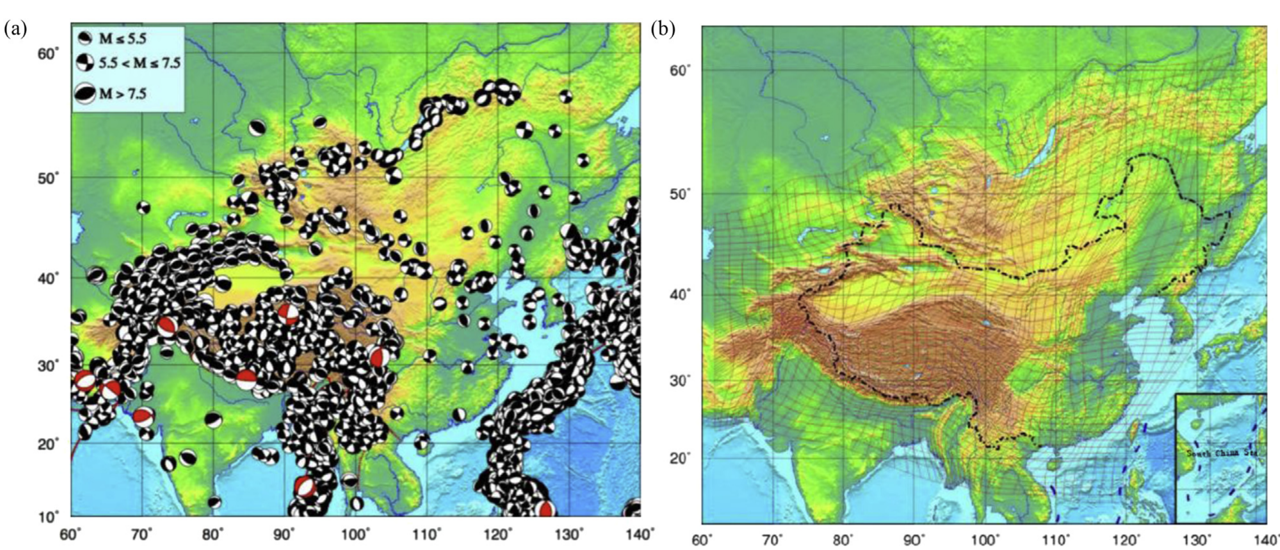

Fig. 1. (a) Mechanisms with magnitude greater than 4.5; (b) Finer grids used in the inversion.