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Earthquake prediction from China's mobile gravity data☆

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ABSTRACT

The relation between plate tectonics and earthquake evolution is analyzed systematically on the basis of 1998–2010 absolute and relative gravity data from the Crustal Movement Observation Network of China. Most earthquakes originated in the plate boundary or within the fault zone. Tectonic deformation was most intense and exhibited discontinuity within the tectonically active fault zone because of the differential movement; the stress accumulation produced an abrupt gravity change, which was further enhanced by the earthquake. The gravity data from mainland China since 2000 obviously reflected five major earthquakes (Ms > 7), all of which were better reflected than before 2000. Regional gravity anomalies and a gravity gradient change were observed in the area around the epicenter about 2 or 3 years before the earthquake occurred, suggesting that gravity change may be a seismic precursor. Furthermore, in this study, the medium-term predictions of the Ms7.3 Yutian, Ms8.0 Wenchuan, and Ms7.0 Lushan earthquakes are analytically presented and evaluated, especially to estimate location of earthquake.

1. Introduction

The Crustal Movement Observation Network of China (CMONC) is an important scientific engineering infrastructure project that is implemented within the Ninth National Five-Year Plan [1,2]. It includes a collection of gravity measurements that are important for seismic surveillance [3–8]. The Earth's surface gravity value depends on the location's latitude, altitude, and topography; tectonic deformation motion; and resulting crust's density changes [9–12]. The present

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study uses the Crustal Movement Observation Network's data to investigate the hypothesis that gravity observations can reveal earthquakes' focal mechanisms and enable medium-to short-term forecasting.

The examined data exhibit clear mobile gravity anomalies near the epicenter prior to major earthquakes. Zhu et al. [6–8] made medium-term predictions of the Ms7.3 Yutian, Ms8.0 Wenchuan, and Ms7.0 Lushan earthquakes by analyzing these anomalies; the predictions are especially accurate in locating the epicenter. In the present study, through a detailed analysis of these case studies, the gravity spatiotemporal variations and the relations between continental crust activity and earthquake occurrence are investigated.

2. Study area

The study area is situated on the intersection of the Circum-Pacific and Eurasian seismic belt of Chinese mainland. It is extruded by Pacific Plate and India Plate and Philippine Sea Plate and seismic faults develop there. China is one of the countries with serious earthquake disaster in the world and there have been six earthquakes with magnitude $\geq$7.0 since 21 century. To survey non-tide variation of gravity value in the mainland China and study the relation between the variation and local tectonic activity and seismic activity, regular repetition measurement gravity network has been built by China Earthquake Administration, which is made up of absolute gravity and relative gravity points and covers major tectonics on Chinese mainland.

3. Methods

In data processing, we combine the absolute gravity observations with the mobile gravity observations for the same period, during which absolute gravity points provide a large-scale, relatively stable, high-precision control network, and the mobile gravity observations act as a connective survey with this network, forming a dynamic monitoring network. This data-processing technique results in an initial benchmark for the gravitational field of the entire Chinese mainland. It can be effective at maintaining unity and stability, and it also provides rigorous and reliable solutions of the changes in gravity at the regional stations to obtain dynamic changes of the regional gravity field. During the processing of absolute gravity data, we made corrections for the earth's tides, light speed, local barometric pressure, polar motions, and vertical gradients. In the processing of relative gravity data, we corrected for the solid tide, barometric pressure, the first-order term, instrumental height, and periodic error.

For data from 1998, we acquire dynamic change images of gravity field in multiple spatiotemporal scales. One kind of dynamic change images is from two measurements which were continuous in time in order to acquire differential information of dynamic evolvement of gravity field in different periods, such as gravity variations for 1998–2000, 2000–2002, 2002–2005, 2005–2008, and 2008–2010. Another kind is from two measurements that interval of two works is longer to acquire accumulative information or background characteristic of gravity field between longer periods, such as gravity variation for 1998–2005 and 1998–2008.

4. Gravity variation and high seismicity

Gravity variations between different time periods reflect crust deformation due to geodynamic processes, precursor to an earthquake occurrence (Figs. 1–7). The distribution of gravity variations between 1998 and 2000 is presented in Fig. 1. A general decreasing trend is observed from west to east. Gravity variation values reduce gradually from a maximum in the southeast coast ($+80 \times 10^{-8}$ ms^{-2}) to a minimum toward the Qinghai–Tibet Plateau (-90×10^{-8} ms^{-2}). The gravity data for this time period reflect variation preceding the Ms8.1 West Kunlun Mountain Pass earthquake in 2001, Ms7.2 Jilin-Wangqing earthquake in 2002, and Ms6.8 Jiashi earthquake in 2003.

The seismogenic region of the 2001 West Kunlun Mountain Pass earthquake is placed in the northern part of the -90×10^{-8} ms^{-2} gravity variation contour. Northward, in the Tarim Basin, gravity values turn positive, diverging by up to 130×10^{-8} ms^{-2} The earthquake's epicenter is located in the intermediate area between the positive and negative values near the high-gradient zone [13]. The 2002 Ms7.2 Jilin-Wangqing earthquake's epicenter is located within the increasing gravity-variation gradient zone, whereas the 2003 Ms6.8 Jiashi earthquake's epicenter is located at the high-value gradient turning point [14].

In the subsequent years, i.e., 2000–2002, the gravity variation trend is reversed (Fig. 2); the change of gravity is gradually increasing from east to west, with the gravity variation value increasing from the southeast coast (-10×10^{-8} ms^{-2}) to the Qinghai–Tibet Plateau (60×10^{-8} ms^{-2}). These gravity data reflect the situation after the Ms8.1 West Kunlun Mountain Pass earthquake. The earthquake zone in the east–southeast appears within the widespread positive change area. The Ms8.1 West Kunlun Mountain Pass earthquake occurred during the reversal period, when gravity change was strong in the Tibetan Plateau. Therefore, the relative reversal before and after the earthquake is possibly a co-seismic response.

In 2002–2005, the overall gravity variation is positive, and it negatively changes from west to east, with highlighted regional variations. In the eastern part of China, two negative gravity-change regions are observed. The western part of China is divided into two gravity-change areas; smooth gravity changes are recorded north of the 36° parallel. In the south, gravity exhibits three significant change areas. These gravity variations reflect well the situation before the Ms7.3 Xinjiang Yutian earthquake in 2008, Ms6.9 Xizang Zegai earthquake in 2008, Ms6.8 Zhongba earthquake in 2008, and Ms8.0 Wenchuan earthquake in 2008. The Ms7.3 Xinjiang Yutian earthquake occurred within the high-gradient zone at the intersection between the West Kunlun fault and Altyn fault, corresponding to a gravity change from 50×10^{-8} ms^{-2} to -40×10^{-8} ms^{-2}. The Ms6.9 Xizang Zegai earthquake and Ms6.8 Zhongba earthquake occurred from a positive to a negative anomaly within the gradient zone, west of Lasa. Finally, in relation to the Ms8.0 Wenchuan earthquake, a sharp