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Gravity changes before and after the 2010 *Ms*7.1 Yushu earthquake

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Abstract: Absolute and relative gravity observations from 1998 - 2010 from the China Crustal Movement Observation Network, a major national scientific project, have been used to model the gravity field and its variations associated with the April 14, 2010 *Ms*7.1 Yushu earthquake. The evolution of the regional gravity field and its relationship with seismicity before and after the Yushu earthquake are studied. The observed gravity changes are closely related to the active Ganzi-Yushu Fault, and gravity measurements can be used to observe the migration of material accompanying active faults and crustal tectonics. The dynamic variation of the gravity field reflects its evolution prior to and during the Yushu earthquake. The gravity measurements near its epicenter are as large as 80×10^{-8} m/s^2, and they show wave-like increases with time prior to the Yushu earthquake.

Key words: absolute gravity; relative gravity; Yushu earthquake; tectonic deformation

1 Introduction

On April 14, 2010, the *Ms*7.1 Yushu earthquake, Qinghai Province, occurred at the eastern margin of the Tibetan Plateau, at the southern boundary of the Ganzi-Yushu Fault in the Bayan Har active block in China. This catastrophic earthquake occurred after the 2008 *Ms*8.0 Wenchuan earthquake. Before and after the Yushu earthquake, the Crustal Movement Observation Network of China (CMONOC) carried out repeated mobile gravity measurements in the Tibetan Plateau, and anomalous gravity variations were observed near the epicenter of the earthquake. Therefore, analyzing the spatiotemporal variations in the gravity field before and after Yushu earthquake is a practical way of studying the patterns of large earthquakes, by capturing earthquake precursors and hopefully predicting future strong earthquakes.

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2 Gravity data and processing

In 1998, 2000, 2002, 2005, 2008, and 2010, the basic network of the CMONOC has carried out six mobile gravity observation campaigns in mainland China. The absolute gravity surveys were carried out by the Chinese Academy of Sciences, the Institute of Survey and Geophysics, and the Institute of Seismology, using FG-5 absolute meters with precisions better than 5×10^{-8} m/s^2 [1,2].

This study focuses on the Tibetan Plateau and its adjacent regions (91° - 109°E, 24.5° - 40.5°N). The layout of the mobile gravity network is shown in figure 1.

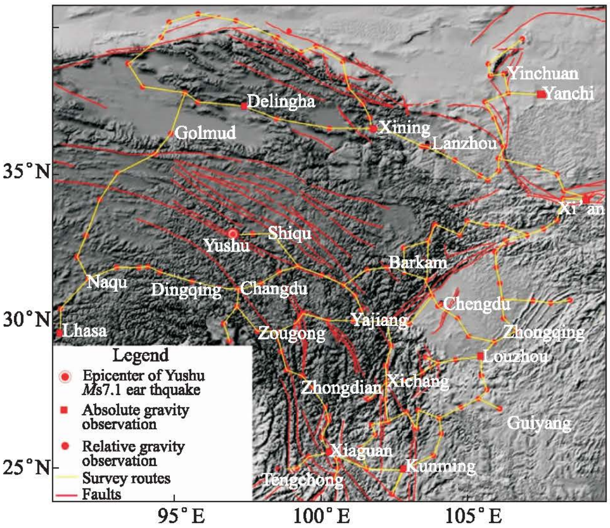

Figure 1 Map of the gravity network in the Yushu region

Relative gravity surveys were carried out jointly by two groups within the China Earthquake Administration and the State Bureau of Surveying and Mapping. Each group worked with three LCR-G gravimeters. To ensure consistent precision in gravity measurements and reduce the influence of instrumental error, the instrumental scales were ground-truthed on the national long baseline before measurement and the observational data formed a closed circuit over the course of three days.

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 seismic zone. 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.

3 Evolution of the gravity field

3.1 Gravity variations in successive periods (Fig. 2)

(1) From 1998 to 2000, the gravity field generally decreased, and it varied gently in the epicentral region of the *M*s7.1 Yushu earthquake. The negative variation in the western part of the survey area was near the epicenter of the 2001 *M*s8.1 earthquake west of the Kunlun Mountain Pass and may have been associated with this earthquake.

(2) From 2000 to 2002, the gravity field generally increased, in contrast to the prior period. This was mainly due to the recovery after the 2001 *M*s8.1 earthquake west of the Kunlun Mountain Pass. The regional gravity field increased in the west and decreased to the east, with a strong increase in the western Sichuan Plateau, a decrease in the Sichuan Basin, and a sharp gradient in between, separating areas that varied by up to 130×10^{-8} m/s^2.

(3) From 2002 to 2005, the gravity field generally decreased. The epicentral region of the *M*s7.1 Yushu earthquake was in an areas in which gravity decreased by up to 70×10^{-8} m/s^2. In the southeastern Sichuan-Yunnan region of the survey area, the gravity variations were strong. Gravity increased within the Sichuan-Yunnan rhombic block, decreased around it, and decreased by as much as 70×10^{-8} m/s^2 in the western Sichuan Plateau. In the area of Yajiang, Barkam, and Wenchuan, the gravity changed rapidly prior to the 2008 *M*s8.0 Wenchuan earthquake.

(4) From 2005 to 2008 (including after the 2008 *M*s8.1 Wenchuan earthquake), the gravity varied greatly over the survey area, with roughly half of the gravity field increasing and half decreasing. The eastern Sichuan-Yunnan block experienced an intense decrease in gravity, with a maximum decrease of up to 120×10^{-8} m/s^2 in the Yajiang area. Gravity varied gradually in the Sichuan Basin to the east of Chengdu, where it experienced a strong recovery after the *M*s8.0 Wenchuan earthquake. Gravity increased in the western area of the Qinghai-Tibet block, with a maximum increase of 100×10^{-8} m/s^2 in the Yushu area. Golmud and Delingha, the northern areas of the Qinghai-

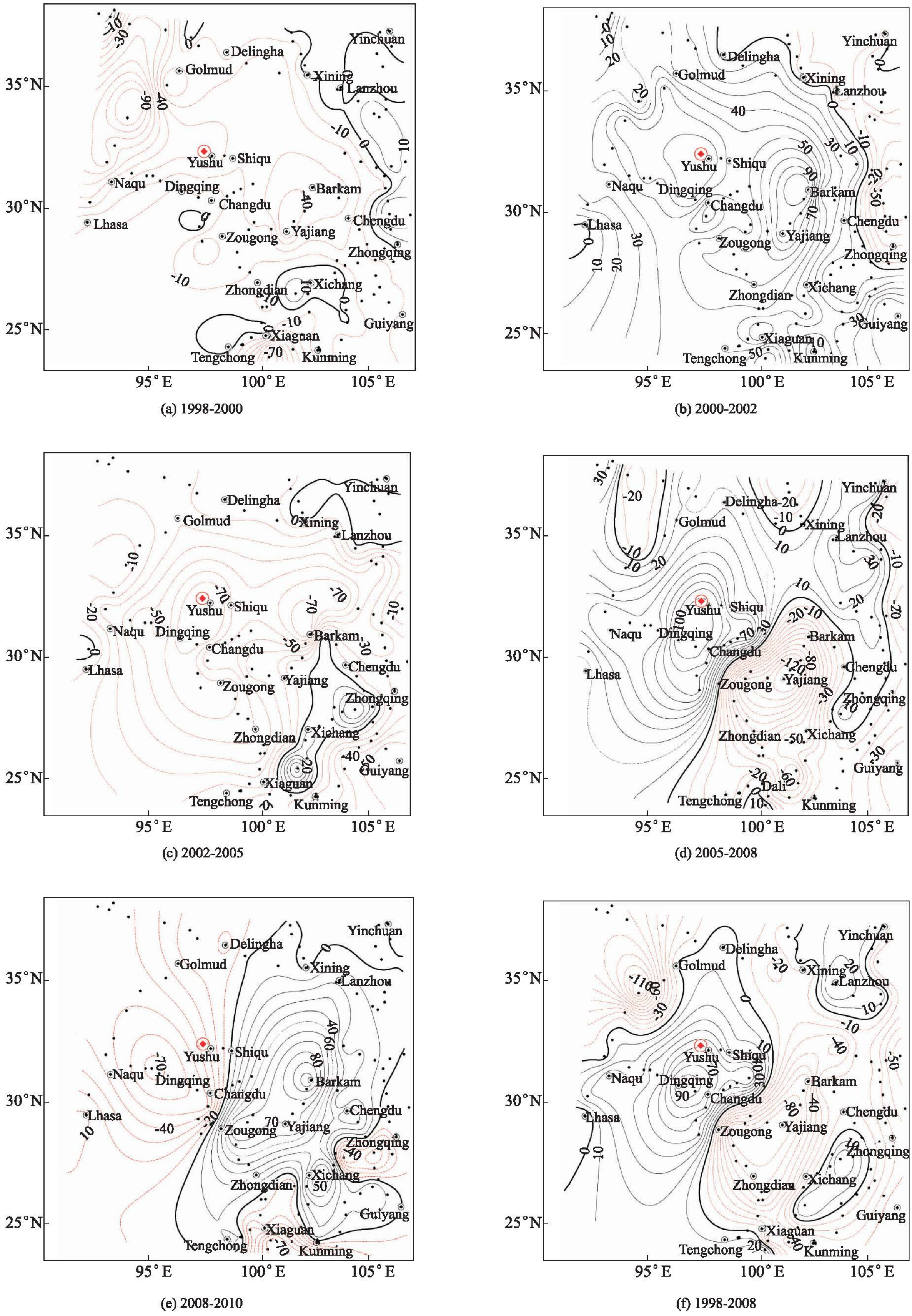

Figure 2 Isolines of gravity changes for different time periods, in 10^{-8} m/s^2

Tibet block, experienced a gradual increase in gravity. The location of the $Ms7.1$ Yushu earthquake was in the area with the steepest gravity gradient.

(5) From 2008 to 2010 (including after the 2010 $Ms7.1$ Yushu earthquake), the gravity continued to vary greatly over the entire survey area, with the opposite trend from 2005 to 2008. This was mainly a response to the $Ms7.1$ Yushu earthquake. The regional gravity field decreased to the west and increased to the east. There was a steep gradient between eastern Tibet and the western boundary of the Sichuan-Yunnan block. The gravity varied by up to 120×10^{-8} m/s^2. The $Ms7.1$ Yushu earthquake occurred in the gravity gradient zone near the transition from positive to negative gravity changes.

3.2 Gravity variations over longer periods

In order to analyze the longer-term trend in gravity and understand the background characteristics of the variation in the regional gravity field before the Yushu earthquake, we used the preliminary observations from 1998 as a benchmark and calculated the changes in gravity from 1998 through 2000 (Fig. 2(f)).

From 1998 to 2008, the regional gravity field changed significantly, with several areas of increase and decrease. Gravity decreased in the eastern part of the western Sichuan Plateau, with a maximum decrease of 80×10^{-8} m/s^2 in the Yajiang area. Gravity increased slightly in the Sichuan Basin to the east of Chengdu, which was mainly due to changes following the 2008 $Ms8.0$ Wenchuan earthquake. Gravity increased in the western part of the Southern Tibetan Plateau, with the largest increases in the Changdu and Dingqing area, of up to 90×10^{-8} m/s^2. The $Ms7.1$ Yushu earthquake occurred in an area with a steep gravity gradient. In Golmud, in the northern area of the Tibetan Plateau, gravity decreased by as much as 110×10^{-8} m/s^2 (in the Wudaoliang region), mainly after the $Ms8.1$ earthquake west of the Kunlun Mountain Pass.

3.3 The temporal variation of gravity at individual points

The temporal variation in gravity at a single point can highlight dynamic variations in gravity. The gravity variations at three points prior to the $Ms7.1$ Yushu earthquake are shown in figure 3.

The gravity at three points near the epicenter increased quasi-synchronously since 1998. The gravity measurements varied gradually from 1998 to 2000 and rose slowly from 2000 to 2005. They increased rapidly from 2005 to 2008, particularly at the point closest to the Yushu earthquake (-53×10^{-8} m/s^2 in 2005 to 66×10^{-8} m/s^2 in 2008). The differential gravity variation (the difference between two sequential periods) was as large as 110×10^{-8} m/s^2, and gravity decreased from 2008 to 2010, after the Yushu earthquake. The point nearest to the Yushu earthquake was less than 40 km away from its epicenter; this point may best indicate the sharp gravity fluctuation prior to the Yushu earthquake and the decrease in gravity following it.

4 Gravity variations and the $Ms7.1$ Yushu earthquake

Analyzing the time and space evolution of the regional gravity field shows that from 1998 to 2000 (Fig. 2 (a)), the regional gravity field near the Yushu epicenter varied gradually. From 2000 to 2002 (Fig. 2 (b)), the regional gravity field gradually varied from positive in the Tibetan Plateau in the west to negative in the Sichuan Basin to the east. This trend may have been caused by the eastward motion of the eastern part of the Bayan Har block after the 2001 $Ms8.1$ earthquake west of the Kunlun Mountain Pass. From 2002 to 2005 (Fig. 2(c)), the gravity varied fairly consistently

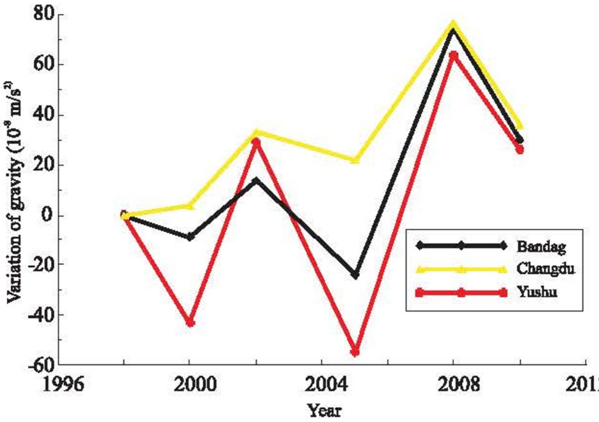

Figure 3 The temporal variations in gravity at stations near the epicenter of the Yushu earthquake

around the Sichuan-Yunnan rhombic block, with a steep gravity gradient in the Yajiang-Barkam-Wenchuan area, which may be associated with behavior prior to the *M*s8. 0 Wenchuan earthquake. From 2005 to 2008 (Fig. 2(d)), the gravity decreased in the Sichuan-Yunnan rhombic block and increased in the Qinghai-Tibet block by up to 100×10^{-8} m/s^2 in the area of the Yushu earthquake. There was a steep gravity gradient with a similar trend to the Ganzi-Yushu fracture near the Yushu epicenter, which was located at the intersection of a steep gravity gradient associated with the southern boundary of the Ganzi-Yushu Fault in the active Bayan Har block. Following the preparation for the Yushu earthquake from 2008 to 2010 (Fig. 2 (e)), the gravity field appeared to recover.

From 1998 to 2008 (Fig. 2(f)), the gravity field near the Yushu epicenter increased. Two negative gravity anomalies were present in the West Sichuan Plateau to the the east of the epicenter and in the Wudaoliang region to the northwest of the epicenter. The 2008 *M*s8. 0 Wenchuan earthquake and the 2001 *M*s8. 1 earthquake west of the Kunlun Mountain Pass occurred near those two anomalies. The 10-year duration of these variations better reflect the crustal tectonics in the Tibetan Plateau associated with these three large earthquakes.

Strong earthquakes are known to alter the stress distribution, leading to a rapid accumulation of nonlinear strain, thus causing the fault to be unstable and perhaps trigger a larger earthquake. The *M*s7. 1 Yushu earthquake occurred in the Ganzi-Yushu Fault Zone, which has a WNW-NW strike and is composed of the southern intersection of the Bayan Har block and the Xianshuihe Fault. The northern boundary of this block is the eastern Kunlun Fault Zone (which experienced the 2001 *M*s8. 1 earthquake west of the Kunlun Mountain Pass), and the eastern boundary is the Longmenshan Fault Zone (which experienced the 2008 *M*s8. 0 Wenchuan earthquake). Therefore, we consider the earthquake west of the Kunlun Mountain Pass, the Wenchuan earthquake, and the recovery following them to have an important effect on the dynamic variation of regional gravity field in the Tibetan Plateau. These earthquakes may have triggered the 2010 *M*s7. 1 Yushu earthquake at the southern boundary of the Bayan Har block, where gravity varied greatly.

5 Discussion and conclusions

Large earthquakes occur at the boundaries of active plates or on active faults. The *M*s7. 1 Yushu earthquake occurred at the southern boundary of the Ganzi-Yushu Fault in the Bayan Har block on April 14, 2010. Due to the tectonic activity along this fault zone and the intense discontinuous deformation, the accumulation of stresses contributed to the occurrence of this large earthquake.

(1) The Yushu earthquake originated in the deep crust, and its occurrence inevitably brought about variations in the geophysical fields, particularly gravity, within a certain range surrounding it. The gravity network used in this study recorded precursory activity to the *M*s7. 1 Yushu earthquake. This earthquake (Fig. 2 (d)) occurred in an anomalous area of gravity variation (associated with the accumulation of energy) and the associated steep gravity gradient, which promoted the fracturing of the earthquake.

(2) The *M*s7. 1 Yushu earthquake occurred at the southern boundary of the Ganzi-Yushu Fault in the Bayan Har block; the 2001 *M*s8. 1 earthquake west of the Kunlun Mountain Pass occurred in the East Kunlun Fault Zone at the northern boundary of this block; and the 2008 *M*s8. 0 Wenchuan earthquake occurred at the eastern boundary of Longmenshan Fault Zone. The large 2001 and 2008 earthquakes had an important effect on the development of the Yushu earthquake (Fig. 2(f)).

(3) The applicability of gravity surveys for earthquake prediction is largely dependent on the richness of the observational data. Observations of the evolution of regional gravity fields and their relation to seismicity are necessary for practical monitoring. Due to the resolution of the gravity network (100 – 200 km) and the interval between observations (2 – 3 years), the information obtained in this study cannot fully reflect the process of earthquake preparation and occurrence, and it cannot capture the complete seismogenic process. As large earthquakes frequently occur in mainland China, we should strengthen the observation of gravity variations, which may be very important for the prediction

of large earthquakes.

(4) Recent (Fig. 2(e)) and 10-year (Fig. 2(f)) observations of gravity indicate that gravity varied strongly and with a steep gradient between eastern Tibet and the western boundary of the Sichuan-Yunnan block. As this area has had a history of large earthquakes, we should focus on improving observations of the region.

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