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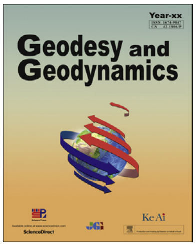

Coseismic gravity and displacement changes of Japan Tohoku earthquake (Mw 9.0)

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ABSTRACT

The greatest earthquake in the modern history of Japan and probably the fourth greatest in the last 100 years in the world occurred on March 11, 2011 off the Pacific coast of Tohoku. Large tsunami and ground motions caused severe damage in wide areas, particularly many towns along the Pacific coast. So far, gravity change caused by such a great earthquake has been reported for the 1964 Alaska and the 2010 Maule events. However, the spatial-temporal resolution of the gravity data for these cases is insufficient to depict a co-seismic gravity field variation in a spatial scale of a plate subduction zone. Here, we report an unequivocal co-seismic gravity change over the Japanese Island, obtained from a hybrid gravity observation (combined absolute and relative gravity measurements). The time interval of the observation before and after the earthquake is within 1 year at almost all the observed sites, including 13 absolute and 16 relative measurement sites, which deduced tectonic and environmental contributions to the gravity change. The observed gravity agrees well with the result calculated by a dislocation theory based on a self-gravitating and layered spherical earth model. In this computation, a co-seismic slip distribution is determined by an inversion of Global Positioning System (GPS) data. Of particular interest is that the observed gravity change in some area is negative where a remarkable subsidence is observed by GPS, which can not be explained by simple vertical movement of the crust. This indicated that the mass redistribution in the underground affects the gravity change. This result supports the result that Gravity Recovery and Climate Experiment (GRACE) satellites detected a crustal dilatation due to the 2004 Sumatra earthquake by the terrestrial observation with a higher spatial and temporal resolution.

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1. Introduction

The Tohoku earthquake (Mw = 9.0) of March 11, 2011 is one of the largest earthquakes that occurred in the Pacific coast of Tohoku. For this earthquake, both deformations of the Earth's surface at the time of faulting and transient crustal movements after the event have been disclosed by the Global Positioning System (GPS) measurements. However, gravity changes caused by earthquakes have been reported in many earthquake investigation cases. First gravity change caused by such a great earthquake has been detected for the 1964 Alaska earthquake in March 1964 with a LaCoste and Romberg geodetic meter (LCR) [1]. The gravity change caused by earthquake was reported with a FG5 absolute gravimeter [2]. First gravity change detection by an array of superconducting gravimeters was made after the 2003 Tokachi-Oki earthquake (Mw = 8.0), Japan [3]. The first map of co-seismic change in gravity was drawn using the data from the Gravity Recovery and Climate Experiment (GRACE) satellites for the 2004 Sumatra-Andaman earthquake [4]. The co-seismic gravity change was detected by satellite gravimetry for 2010 Chile earthquake (Mw = 8.8) [5,11]. In this study, a hybrid gravity measurement campaign (combined absolute and relative gravity measurement) was conducted after the event for investigating coseismic gravity changes.

On the other hand, the theory of changes in the Earth's gravity field associated with earthquakes has been nearly completed recently [6–9]. In this study, the theoretical co-seismic gravity changes caused by Tohoku earthquake were calculated by a dislocation theory based on a self-gravitating and layered spherical earth model [10]. In this computation, a co-seismic slip distribution is determined by an inversion of GPS data and constrained by coseismic observation gravity changes.

Finally, comparing the observed co-seismic gravity changes with theoretical results, we found that they agreed well with each other. However, for some particular area, we cannot interpret gravity changes simply with the vertical movement of the crust and also need to consider the effect caused by mass redistribution of the interior of the Earth. This result supports that GRACE satellites detected a crustal dilation due to the 2004 Sumatra earthquake by the terrestrial observation with a higher spatial and temporal resolution [4].

2. Observations

2.1. Co-seismic gravity change

The hybrid gravity measurement campaign covering the whole east coastline of Japan was conducted after the Tohoku earthquake. We measured the absolute gravity with same FG5 (#241) at the sites in red points and relative gravity with same LCRs (#581, #705) at the sites in blue points in Fig. 1. The time interval before and after the earthquake is within 1 year at almost all the observation sites which are including 13 absolute and 16 relative measurement sites. The absolute gravity sites are Miyazaki, Muroto, Toyohashi, Omaezaki, Ito, Tokyo, Tsukuba, Tsukubane, Sendai, Hachinohe, Usu, Erimo, Akkeshi from the south to the north. And the relative gravity sites are Yamato, Ogihama, Ayukawa, Onagawa, Oshu, Aikawa, Shizugawa, Natari, Miyato, Kahoku, Rifu, Yamagata, Shinjo, Soma, Mizusawa, Ofunato in the Tohoku region.

In the Fig. 2, black points show the coseismic observation gravity changes of main shock area sites in the near and far field with the observation error about 2–5 microgal. From point 1 to point 10 and from point 27 to point 29 represent the absolute observation sites and the others are the relative observation sites. Coseismic observation gravity changes of Tokyo, Tsukuba, Tsukubane, Sendai and Hachinohe are greater than the other sites in the far field (Miyazaki, Muroto, Toyohashi, Omaezaki, Ito, Usu, Erimo and Akkeshi). The gravity changes of Tokyo, Tsukuba and Tsukubane are increased about 10.0 microgal. However, the gravity changes of Sendai and Hachinohe are about −10.0 microgal. The greatest and least gravity changes of other sites are about 5.0 microgal and 0.0 microgal. And the observation error is about 2–5 microgal. Furthermore, the gravity changes of south sites (Miyazaki, Muroto, Omaezaki and Ito) are

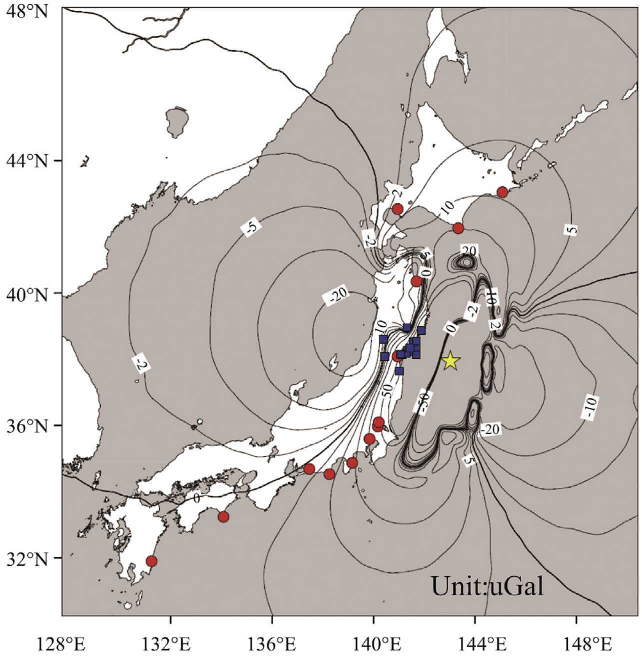

Fig. 1 – Calculated coseismic gravity changes by a dislocation theory based on a self-gravitating and layered spherical earth model. The red and blue points denote the absolute and relative gravity measurement sites. The gravity change computed with a dislocation theory [10]. The unit of the contour line is microgal (1 microgal = 10^{-8} m/s^2). Spherical geometry is considered and the elastic structure and the density profile is Preliminary Reference Earth Model (PREM). A co-seismic slip distribution is inferred by a geodetic inversion for GPS data of GEONET. The node of the gravity change passes near the coast of the Pacific Ocean on the Tohoku region, where the sign of the gravity change varies from positive to negative with the increasing epicentral distance.