GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L00G12, doi:10.1029/2011GL049018, 2011

Coseismic gravity changes of the 2011 Tohoku-Oki earthquake from satellite gravimetry

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Received 22 July 2011; revised 26 August 2011; accepted 26 August 2011; published 22 September 2011.

[1] The massive Tohoku-Oki earthquake of a moment magnitude (M_w) of 9.0 occurred on 11 March, 2011 off the Pacific coast of the Northeastern Japan. The mass redistribution in and around the focal region associated with this earthquake was studied using the gravity changes detected by Gravity Recovery and Climate Experiment (GRACE) satellite. After the 2004 Sumatra-Andaman and the 2010 Central Chile (Maule) earthquakes, the present study presents the third case of clear detection of coseismic gravity changes by GRACE. The observed gravity changes were dominated by decrease over the back-arc region of ~7 μGal or less. This reflects, to a large extent, coseismic crustal dilatation of the landward plate. They agree well with the changes calculated with the Green's function for the realistic earth using fault parameters inferred from coseismic crustal movements. The spatial patterns of the gravity changes of these earthquakes are very similar because they are all shallow angle reverse faulting at convergent plate boundaries. We found linear relationship between gravity decreases and seismic moments. **Citation:** Matsuo, K., and K. Heki (2011), Coseismic gravity changes of the 2011 Tohoku-Oki earthquake from satellite gravimetry, *Geophys. Res. Lett.*, *38*, L00G12, doi:10.1029/2011GL049018.

1. Introduction

[2] Earthquakes changes the earth's gravity field by the two processes, i.e., deformation of layer boundaries with density contrasts (e.g., sea floor and Moho) and density changes of rocks around fault due to volumetric strains. Such coseismic gravity changes have been first detected by superconducting gravimetry after the 2003 Tokachi-Oki earthquake (Mw8.0) [*Imanishi et al.*, 2004]. Gravity Recovery and Climate Experiment (GRACE) satellites, launched in 2002 to study time-variable gravity field, revealed two-dimensional distributions of coseismic gravity changes of the 2004 Sumatra-Andaman earthquake (Mw9.0–9.3) [*Han et al.*, 2006], and the 2010 Central Chile (Maule) earthquake (Mw8.8) [*Han et al.*, 2010; *Heki and Matsuo*, 2010]. The Tohoku-Oki earthquake, M_w 9.0, which occurred at 05:46 UT, 11 March, 2011, at the Japan Trench east of NE Japan, ruptured the fault as large as 500 km × 200 km [*Ammon et al.*, 2011; *Ozawa et al.*, 2011]. Its magnitude is just between these two earthquakes, and will provide another good example of the detection of coseismic gravity changes by GRACE gravimetry.

2. GRACE Observation of Gravity Changes

[3] GRACE can measure the earth's gravity field accurate to several μGal with spatial and temporal resolutions of a few hundred km and a month, respectively. A GRACE data set consists of coefficients of spherical harmonics (Stokes's coefficient) with degree and order complete to 60. Here we used 105 data sets of monthly solutions (Level-2 data, Release 4) by Center for Space Research, Univ. Texas, from 2002 April to 2011 May. We replaced the Earth's oblateness values (C_{20}) with those from Satellite Laser Ranging [*Cheng and Tapley*, 2004] because of their poor accuracy. We applied the anisotropic fan filter with averaging radius of 300 km to reduce short wavelength noises [*Zhang et al.*, 2009], together with the de-correlation filter using polynomials of degree 3 for coefficients with orders 15 or higher to alleviate longitudinal stripes [*Swenson and Wahr*, 2006]. The movement of geocenter, expressed with the degree-one components (C_{10}, C_{11}, and S_{11}), was not taken into account because they contribute little to local gravity changes studied here.

[4] Gravity may change by various geophysical processes other than earthquakes. The largest of those would be seasonal and inter-annual hydrological changes on land [e.g., *Tapley et al.*, 2004; *Morishita and Heki*, 2008]. Although the width of the Japanese Islands is smaller than the spatial resolution of GRACE, fairly large seasonal mass changes due mainly to winter snow [*Heki*, 2004] may influence the GRACE data. Actually, GRACE showed such changes of amplitude of ~2 μGal, with the peak in winter [*Heki*, 2010]. To remove such hydrological signals, it has been effective to use the Global Land Data Assimilation System (GLDAS) hydrological model [*Rodell et al.*, 2004], which considers soil moisture, snow, and canopy water. Following *Heki and Matsuo* [2010], we removed the land hydrological contributions by subtracting the GLDAS Noah models.

[5] Figure 1 shows the time-series of monthly gravity changes at (38.0N, 138.0E), ~350 km west of epicenter. We can see a significant gravity decrease of ~5.0 μGal in 2011 March and the decrease reached ~7.0 μGal in April suggesting that coseismic gravity changes did occur there. Note that the gravity jump between February and March, 2011, underestimates the true coseismic change because the March data include ~10 days before the earthquake. Therefore, we estimated the true coseismic gravity changes using least-squares method assuming that 2/3 of coseismic jump occurred between February and March and 1/3 of the jump occurred between March and April.

[6] We show the two-dimensional distribution of the coseismic gravity changes in Figure 2a. The observed gravity changes are dominated by the negative changes in the back-arc region, with the largest decrease of ~7.0 μGal 300–400 km landward from the focal region. One-sigma

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0094-8276/11/2011GL049018