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Coseismic gravity changes of the 2010 earthquake in central Chile from satellite gravimetry

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[1] The first map of coseismic changes in gravity and geoid height has been drawn using the data from the Gravity Recovery and Climate Experiment (GRACE) satellites for the 2004 Sumatra-Andaman earthquake. Here we present the second case of coseismic gravity change observation by satellite gravimetry, i.e., the change caused by an interplate thrust earthquake that occurred on 27 February, 2010 in Central Chile ($M_w = 8.8$). Gravity showed a negative jump with the largest drop of ~5 μgal on the back-arc side. The observed changes agree with those calculated assuming the realistic earth and fault parameters inferred from coseismic displacements of Global Positioning System (GPS) stations. Gravity in this area shows large seasonal and inter-annual variability, and postseismic gravity changes could be isolated only by carefully removing hydrological signals.

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1. Introduction

[2] Changes in the Earth's gravity field associated with earthquakes have been formulated nearly two decades ago [e.g., *Okubo*, 1991; *Sun and Okubo*, 1993]. The first reliable detection was made by an array of superconducting gravimeters after the 2003 Tokachi-Oki earthquake ($M_w = 8.0$), Japan [*Imanishi et al.*, 2004]. The two-dimensional distribution of coseismic gravity changes has been recovered for the first time by the GRACE satellites, launched in 2002 to investigate the time-variable gravity field, after the great Sumatra-Andaman (SA) earthquake ($M_w = 9.1$), 2004 December 26 [*Han et al.*, 2006].

[3] Fault dislocations modify the gravity fields by two mechanisms, i.e., deformation of layer boundaries with density contrasts (e.g., surface uplift and subsidence), and density changes of rocks due to volumetric strain (coseismic dilatation and compression). For an interplate thrust earthquake, uplift dominates vertical crustal movement, causing gravity increase localized around the epicentral area. Dilatation at the upper side of the down-dip end of the fault, on the other hand, causes gravity decrease of a longer wavelength [*Han et al.*, 2006]. The balance of these two principal factors is controlled, e.g., by thrust angles and fault depths; the latter (decrease) tends to be emphasized as the angle gets higher and the fault gets deeper.

[4] No earthquakes since the 2004 SA event have left gravity signatures detectable with GRACE. It is likely that the 2005 Nias earthquake ($M_w = 8.7$), Indonesia, showed detectable coseismic gravity changes, but it was difficult to isolate those signals due to its spatial and temporal proximity to the 2004 SA event that occurred only 3 months earlier [*Einarsson et al.*, 2010]. The 2010 February 27 Chile earthquake (the Maule earthquake) ($M_w = 8.8$) ruptured the boundary between the Nazca and the South American Plates known as the Constitución-Concepción seismic gap [*Madariaga et al.*, 2010] (Figure 1). This is the largest earthquake after the 2004 SA earthquake, and has a good chance of showing coseismic gravity changes detectable with GRACE.

2. Observed Gravity Changes

[5] The Earth's gravity field is modeled as a superposition of spherical harmonics. A monthly GRACE data set consists of the coefficients of spherical harmonics (Stokes' coefficients) with degree and order complete to 60. Figure 2 shows the time series of monthly gravity values at (36S, 70W), ~250 km east of the epicenter, from 95 data sets (Level-2, RL04, Center for Space Research, Univ. Texas) spanning the period from 2002 April to 2010 May. We replaced the Earth's oblateness values (C_{20}) with those from Satellite Laser Ranging [*Cheng and Tapley*, 2004], and applied a fan filter with averaging radius of 300 km to reduce short wavelength noise [*Zhang et al.*, 2009]. We also reduced longitudinal stripes following *Swenson and Wahr* [2006], by using polynomials of degree 3 for coefficients with orders 15 or higher.

[6] In order to correct for changes in soil moisture, snow and canopy water, we used the Global Land Data Assimilation System (GLDAS) hydrological model [*Rodell et al.*, 2004]. After expanding equivalent water depth data in GLDAS/Noah to spherical harmonics, we applied the same fan filter (but not the de-striping filter) and converted them to gravity using equation (8) of *Wahr et al.* [1998]. They show seasonal changes with maxima in austral winter, and peak-to-peak amplitudes of ~5 μgal. After subtracting the GLDAS hydrological signal from GRACE data, we still find non-negligible amount of seasonal changes, caused by factors not adequately modeled in GLDAS, e.g., ground water. Here we modeled the corrected data after 2006.5 (relatively large inter-annual changes exist in data before 2006.5) with seasonal (annual and semiannual) and linear changes, together with coseismic jumps (Figure 2). We estimated such jumps with a grid point spacing of 0.2°, and drew their distribution in Figure 3a. The change is

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