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Coseismic geoid height changes of the 2011 Tohoku-Oki earthquake in GRACE monthly gravity data

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Abstract. A Mw 9.0 earthquake occurred off the coast of Japan in the Pacific Ocean on March 11, 2011. At shorter time and spatial scales, mass redistribution caused by an earthquake produces local variations of the geoid reaching a few centimeters. In this paper, we apply the bilinear wavelets analysis based on the Abel-Poisson scale and its corresponding wavelet functions to GRACE monthly gravity data in order to detect coseismic changes of the geoid heights due to the Tohoku-Oki earthquake. As a result, we can clearly distinguish that multiscale geoid heights are decreased temporarily in the order about -4 meter on average throughout the region between February 2011 and March 2011 when compared with monthly geoid heights observed by GRACE satellite.

1 Introduction

A Mw 9.0 earthquake occurred off the coast of Japan in the Pacific Ocean on March 11, 2011 deforming the surface near the epicenter permanently up to 10-30 meters horizontally and a few meters vertically [1], [2], [3].

The gravity signals associated with earthquakes are superimposed on gravity variations of geofluid origin, and GRACE data give an integrated view of all the contributions contaminated by a noise exceeding the planned mission noise level.

In order to investigate earthquake-induced coseismic changes of geoid heights associated with the Tohoku-Oki earthquake, we apply the bilinear multiscale wavelets analysis based on the Abel-Poisson scale and its corresponding wavelet functions as described in [4] to GRACE Level 2 Release 04 monthly gravity data.

2 Wavelet transform and Results

In general, frequencies are spatially changing due to the contribution of a certain combination of frequencies referred to the gravity signal at each point on the Earth's surface and this phenomenon is not reflected in the spherical harmonics. Therefore, one has to take advantage of the different characteristics of signal and noise in space and frequency using a wavelet analysis in order to extract the earthquake-induced signals.

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The spherical wavelet transform is a mathematical tool for breaking up a complicated phenomenon on the sphere into many simple pieces at different scales and positions. The power of wavelets is based on a multiresolution analysis which is well localized both in the space and in the frequency domains. Basically, this is done by convolving the function against rotated and dilated versions of the mother wavelet [5]. Here, Abel-Poisson scaling function and its corresponding wavelets are used as the mother wavelet and 16 GRACE L2 Release 04 monthly gravity data from GeoForschungsZentrum (GFZ), spanning the period from January 2010 to May 2011, are processed. No solution for January 2011 is available.

Fig. 1 shows the decrease of geoid heights in the order meter, indicating that coseismic changes of geoid heights associated with the Tohoku-Oki earthquake did occur.

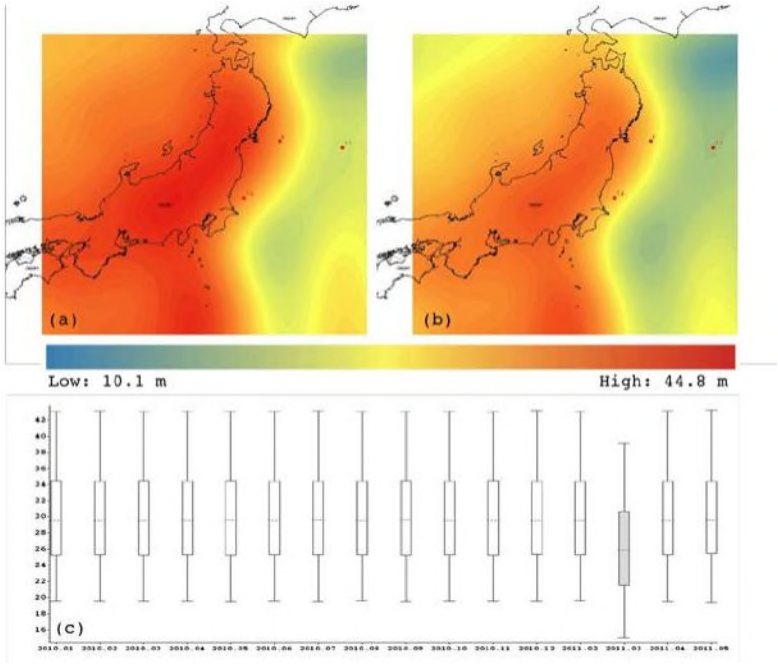

Fig. 1. Multiscale geoid heights using the Abel-Poisson scale function and wavelets on individual points of a 0.1°×0.2°, (a) with range 19.467~43.054 m for February 2011 and (b) with range 14.890~39.789 m for March 2011. (c) Time-series of box plots with respect to multiscale geoid heights for the period from January 2010 to May 2011 (unit: meter).

Multiscale geoid heights from February 2010 to May 2011 are differenced with the multiscale geoid height for January 2010 selected as the reference for comparison in more detail. As shown in Fig. 2, we can clearly distinguish that multiscale geoid heights are decreased temporarily in the order about -4 meter on average throughout the region between February 2011 and March 2011.

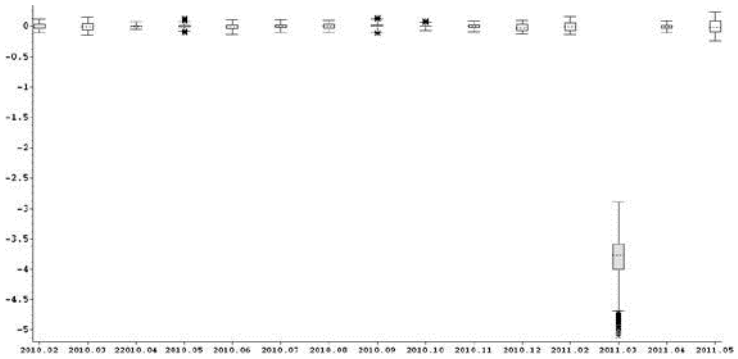

Fig. 2. Time-series of box plots with respect to the differences between multiscale geoid heights for the period from February 2010 to May 2011 and the multiscale geoid height for January 2010 selected as the reference. (unit: meter)

3 Conclusions

Wavelet transform based on spherical wavelet functions is a useful tool in order to reveal information like the earthquake-induced signals corresponding to the high degree of spherical harmonic coefficients. According to the results, coseismic decreases of multiscale geoid heights due to the Tohoku-Oki earthquake were happened temporarily in the order -4 m on average throughout the region between February 2011 and March 2011 and these phenomena quickly disappeared on April 2011.

GRACE space-borne gravimetry is useful to complement geodetic observations since the total gravity change resulted from great earthquake is a distinct and independent observation type. More applications are hoped for in the future.

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