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Geodetic observations of the co– and postseismic deformation of the 2013 Okhotsk Sea deep-focus earthquake

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1. Introduction

The 2013 Okhotsk Sea earthquake (*M*w 8.3) is the second largest deep earthquake after the 1994 Bolivia earthquake (*M*w 8.3) was recorded by the seismic sensors. However, it is still unknown about the temporal-spatial characters of crustal deformation induced by the deep-focus earthquakes, including the co- and post-seismic deformations. A thorough comparison should be conducted through the theoretical computation and geodetic observations. With the development of modern geodetic technologies and the seismic dislocation theory, we can improve the understanding of deep earthquakes using continuous GPS (Global Positing System) time-series and/or GRACE (Gravity Recovery and Climate Experiment) gravity data and the modeled calculation.

We are motivated to model the co- and post-seismic displacements induced by this event based on the seismic elastic/viscoelastic dislocation theory, and compare the modeled results to the geodetic observations to investigate the temporal-spatial surface deformation character of this great deep-focus earthquake. First, we compute the coseismic displacements and compare to the GPS-derived result. We then try to retrieve the coseismic gravity changes from the monthly GRACE gravity data using the same procedure dealing with the shallow earthquake. Based on the continuous daily time-series of three IGS stations, we examine the postseismic deformation induced by this earthquake, and used to study the rheology structure of the asthenosphere in the Kamchatka region combining with the viscoelastic dislocation theory. Finally, we compute the coseismic deformation induced by other two great deep-focus earthquakes.

2. Adopted Fault modes

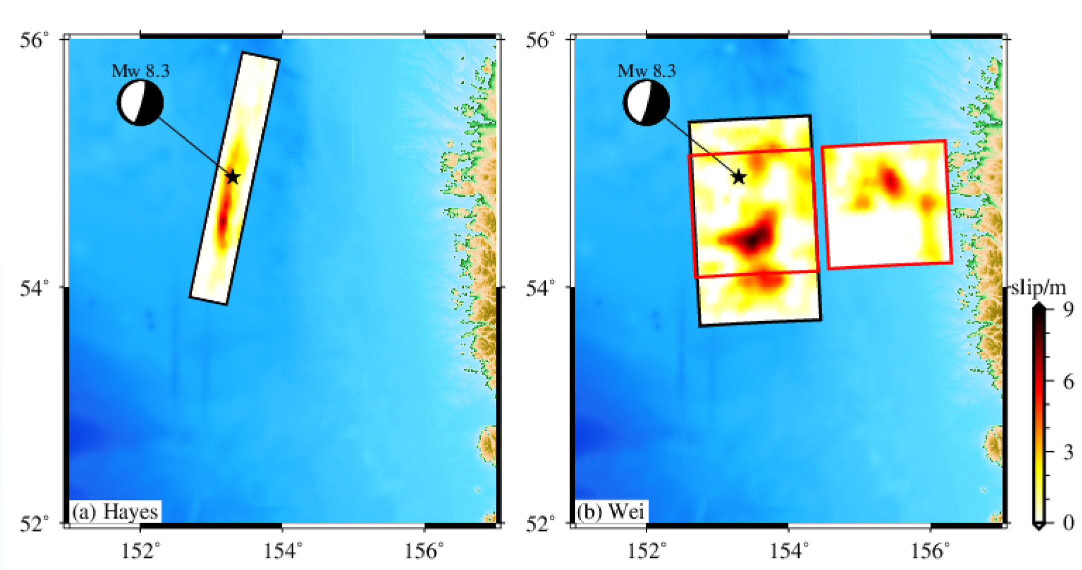

Figure 1: The adopted finite fault models derived from Hayes (2015) and Wei *et al.* (2013). The black star represents the epicenter, the hot-type color represent the slip. As Hayes's model shows, there is only one-time rupture and the maximum slip is up to 6 m; Wei's model shows two-stage ruptures and the maximum slip is about 9 m. The beach ball with the magnitude represents this event is a normal-type faulting.

3. Modeled and GPS-derived coseismic displacements

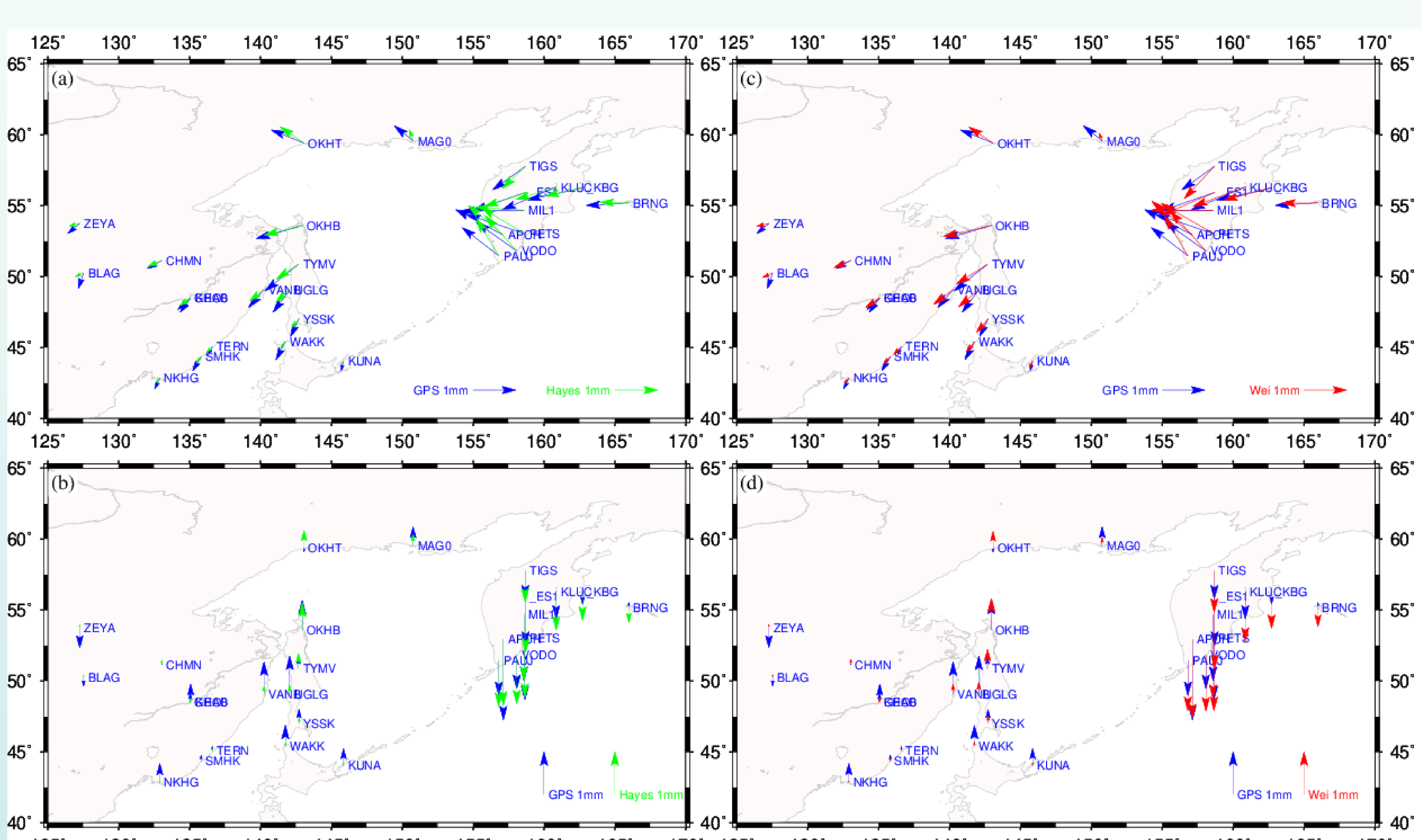

Figure 2. The modeled and GPS-derived coseismic horizontal and vertical offsets of the selected GPS stations at the Siberia region, the Kamchatka Peninsula and Sakhalin Island. (a) Comparison of the horizontal component between Hayes's model (green) and GPS (blue); (b) comparison of the vertical component between Hayes's model (green) and GPS (blue); (c) comparison of the horizontal component between Wei's model (red) and GPS (blue) and (d) Comparison of the vertical component between Wei's model (red) and GPS (blue).

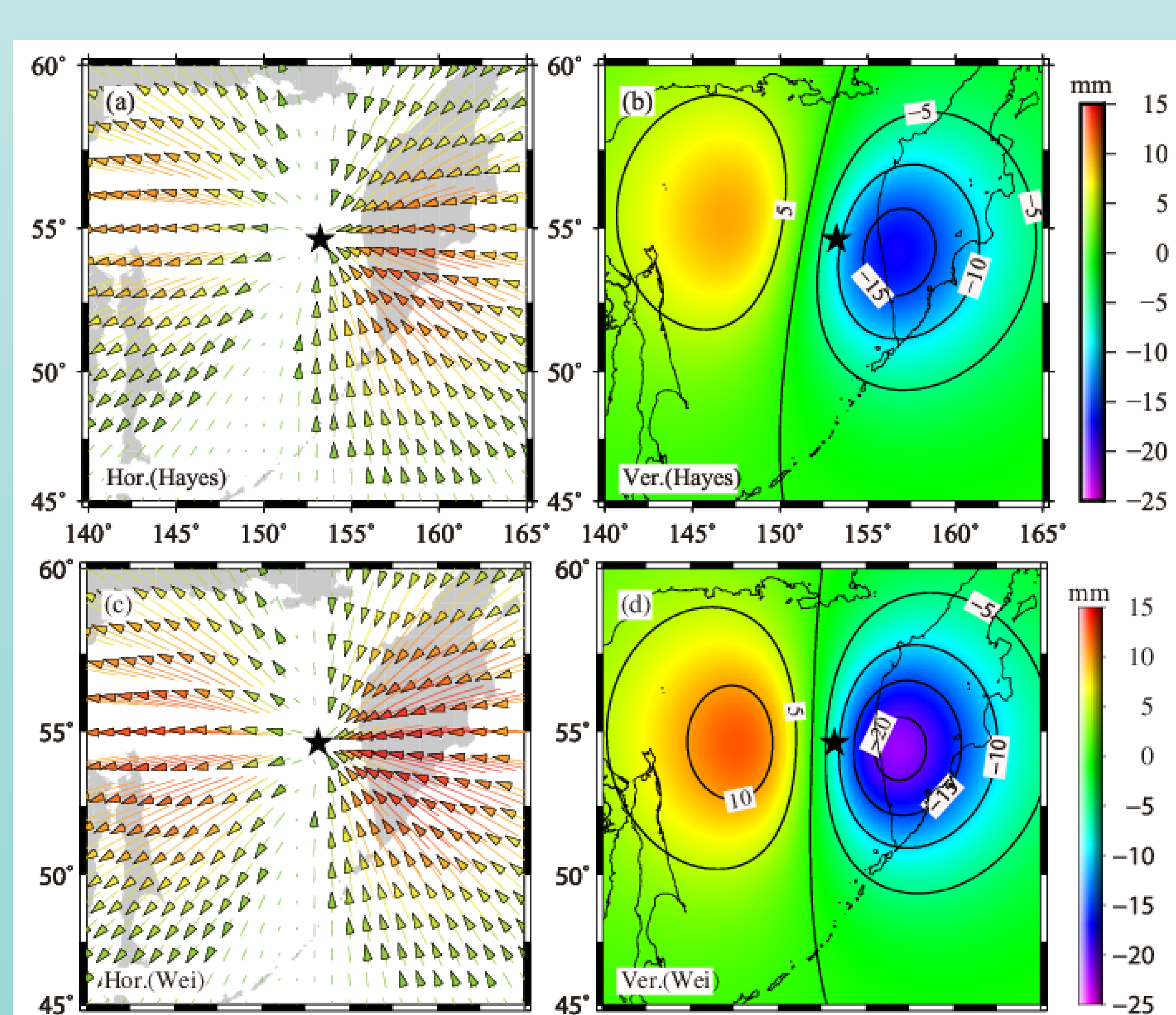

Figure 3. The modeled horizontal and vertical displacements at the deformed surface of the solid Earth for the PREM model using the elastic dislocation theory, the black asterisk represents the epicenter, unit: millimeters. The color maps with contour lines represent the surface displacements. [(a) The horizontal component from Hayes's model; (b) the vertical component from Hayes's model, (c) the horizontal component from Wei's model and (d) the vertical component from Wei's model.]

4. Modeled and observed coseismic gravity changes

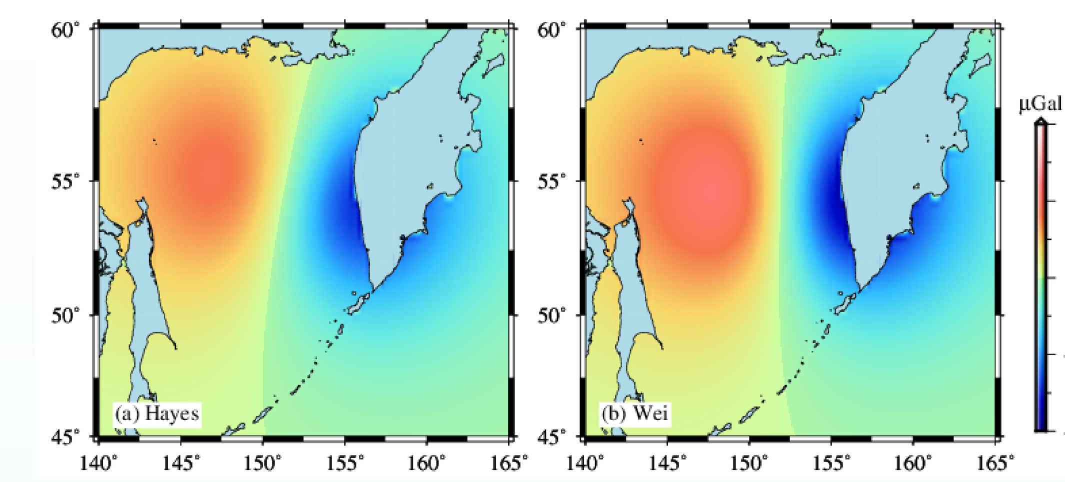

Figure 4. Gravity changes induced by the coseismic seafloor vertical displacements of (a) Hayes's model and (b) Wei's model, where the second-order loading

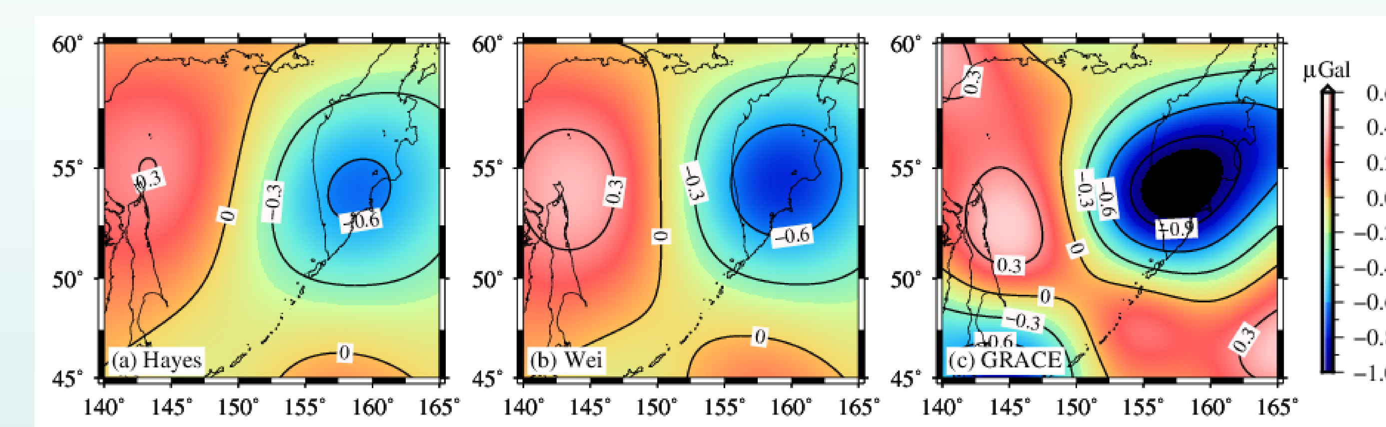

Figure 5. The corrected modeled and observed coseismic gravity changes. The modeled gravity changes with the sea water correction and 350 km Gaussian smoothing of (a) Hayes's model and (b) Wei's model and (c) the GRACE-derived gravity changes using the least-squares approach to fit the monthly data from 2002 to 2016.

5. Observed postseismic displacement

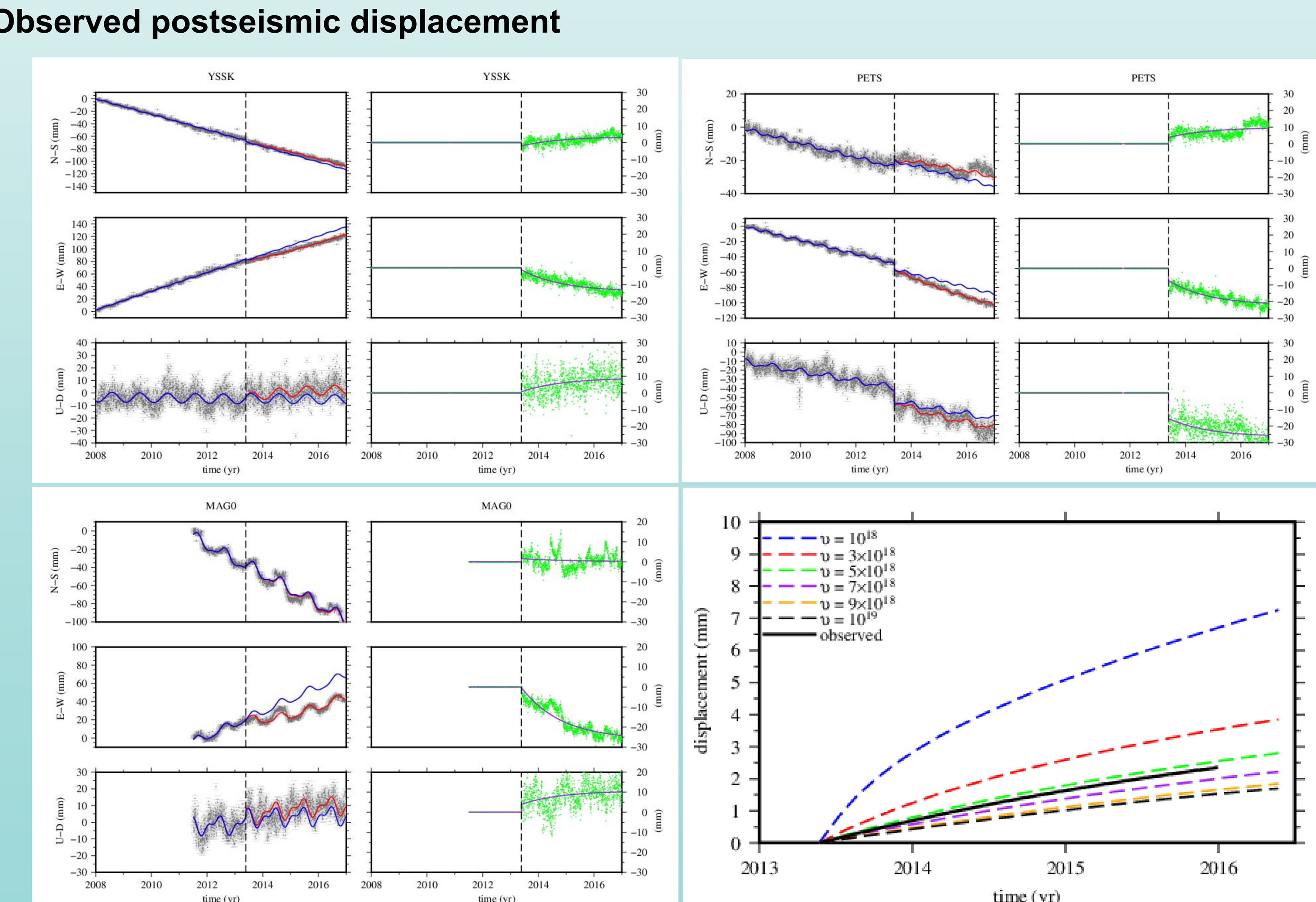

Figure 6. The observed post-seismic displacement of each component at the YSSK, PETS, and MAG0 station. The green line stands for the time of the earthquake, the red lines represent the fitting lines with the post-seismic displacements, the blue lines denote the interseismic displacements and the black dots denote the original time-series. The green solid dots denote the residual displacements of the original displacements minus the interseismic displacements and the purple lines denote the post-seismic displacements

6. Comparison to the 1994 Bolivia earthquake

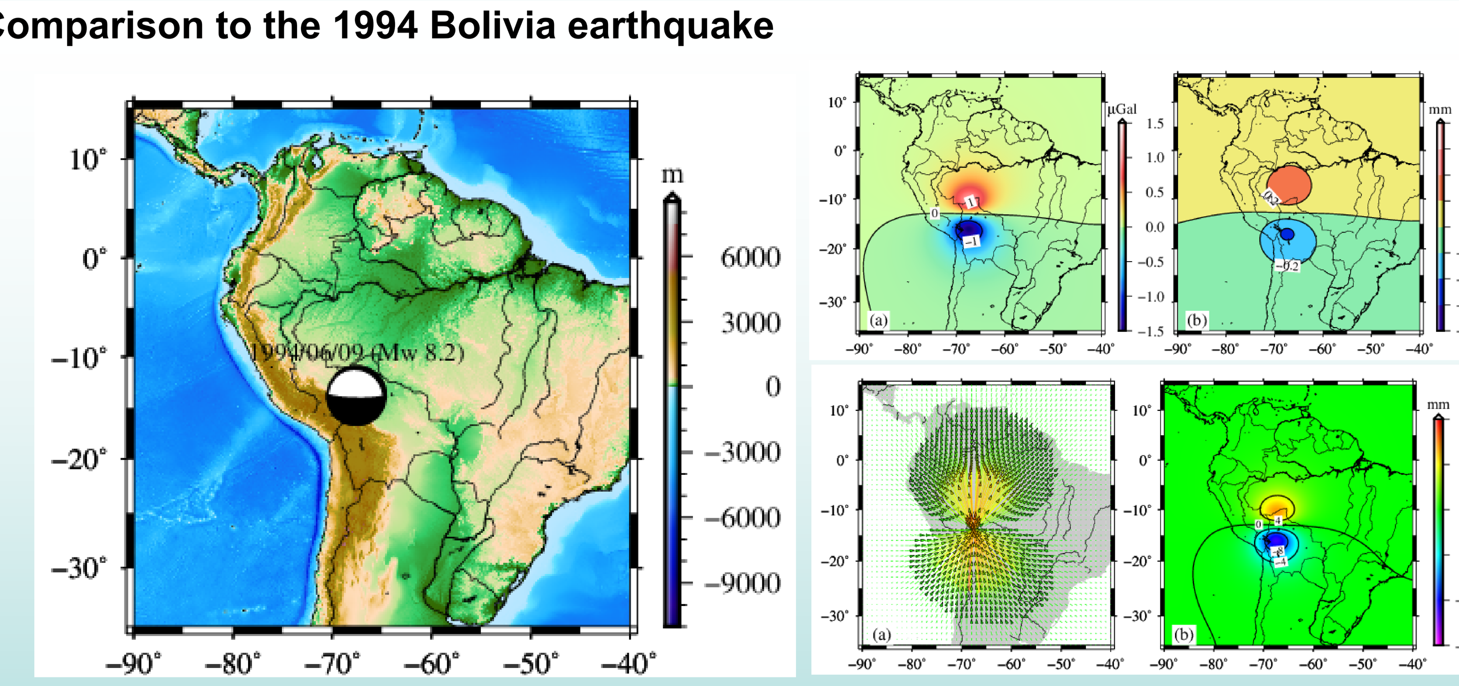

Figure 7. Location map of the 1994 Bolivia earthquake (*M*w 8.2). Each event is represented by using the beach ball with the data and the magnitude, the color image represents the topography. Coseismic horizontal and vertical displacements induced by the 1994 Bolivia earthquake (*M*w 8.2). The values of the horizontal and the vertical components are shown from the color map. The horizontal displacements are represented with the arrows and the vertical component is shown with the contour lines. The peak value reaches 1 cm and is detectable by the GPS or tidal gauges. Coseismic changes in gravity and geoid of the solid Earth induced by the 1994 Bolivia earthquake (*M*w 8.2). The color maps with the contours represent the coseismic changes in gravity and the geoid height. The peak value of the gravity changes is about 1 μGal, and this earthquake only slightly disturb the geoid height with magnitude of submillimeter.

Conclusion：

1. Coseismic 3D displacements following this great deep-focus event are investigated by the theoretical modeling and confirmed by the geodetic observations in the near and far field.

2. Coseismic gravity changes following this event are clearly detected by the GRACE and verified by the dislocation theory with different source models, but with better spatial pattern and explanation compared to the previous study.

3. Postseismic 3D displacements for three years induced by this great deep-focus earthquake are retrieved by the IGS stations and used to reveal the rheological structure in Kamchatka region combined with the viscoelastic dislocation theory for the first time.

Reference:

Xu C., X. Su, T. Liu and W. Sun (2017).Geodetic observations of the co- and post-seismic deformation of the 2013 Okhotsk Sea deep-focus earthquake. *Geophys. J. Int.*, 209, 1924-1933, doi:10.1093/gji/ggx123.