Post-seismic deformation mechanism of the M_w 9.0 Tohoku-Oki earthquake detected by GPS and GRACE observations

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Abstract

Post-seismic deformation characteristics of the M_w 9.0 Tohoku-Oki earthquake are studied by using GPS and GRACE observations. GPS continuous observations show that the change rate of regional post-seismic displacements accords with the attenuation characteristic of the Omori formula. Significant post-seismic gravity changes are detected by GRACE also, which shows that gravity rises on both sides of the seismic rupture. Here we combine the theories of afterslip and viscoelastic dislocation to simulate the post-seismic deformations and explore the comprehensive application of GPS and GRACE observations. The results demonstrate the combination of afterslip and viscoelastic relaxation theories can make a reasonable explanation for the post-seismic deformations of the earthquake. The contribution of afterslip plays a major role in the initial stage, and it gradually weakens one or two years later, while the contribution of viscoelastic relaxation increases with time. The method of combining GPS and GRACE observations is formed to infer regional viscous structure.

Data and Methodology

GPS Continuous observations download from website of Nevada Geodetic Laboratory.

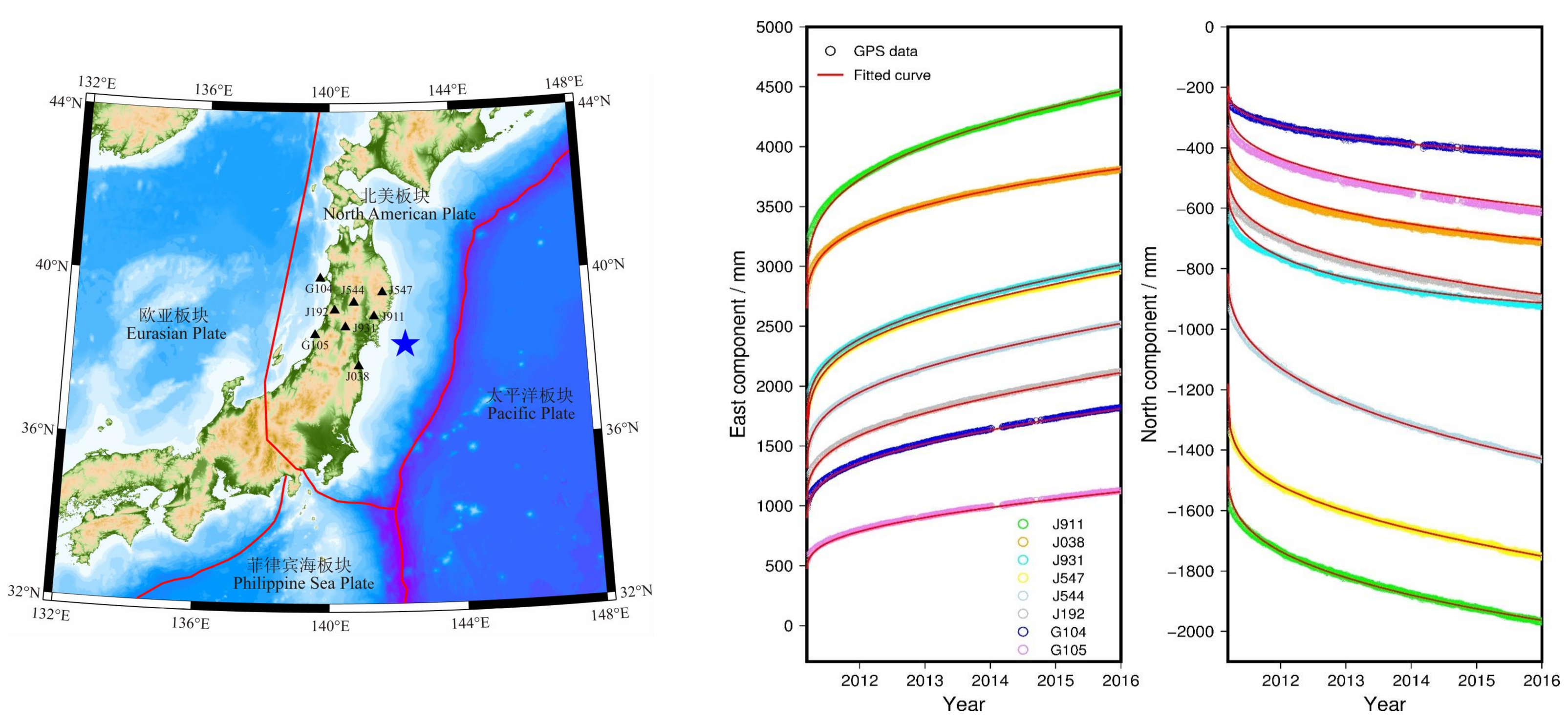

Fig.1 Post-seismic displacements of the M_w 9.0 Tohoku-Oki earthquake detected by GPS. The circles with different colors represent GPS observations, and the red curve represents the fitted results of the post-seismic displacements using the modified Omori's law.

GRACE The Release-05 solutions to degree and order 90 released by CSR.

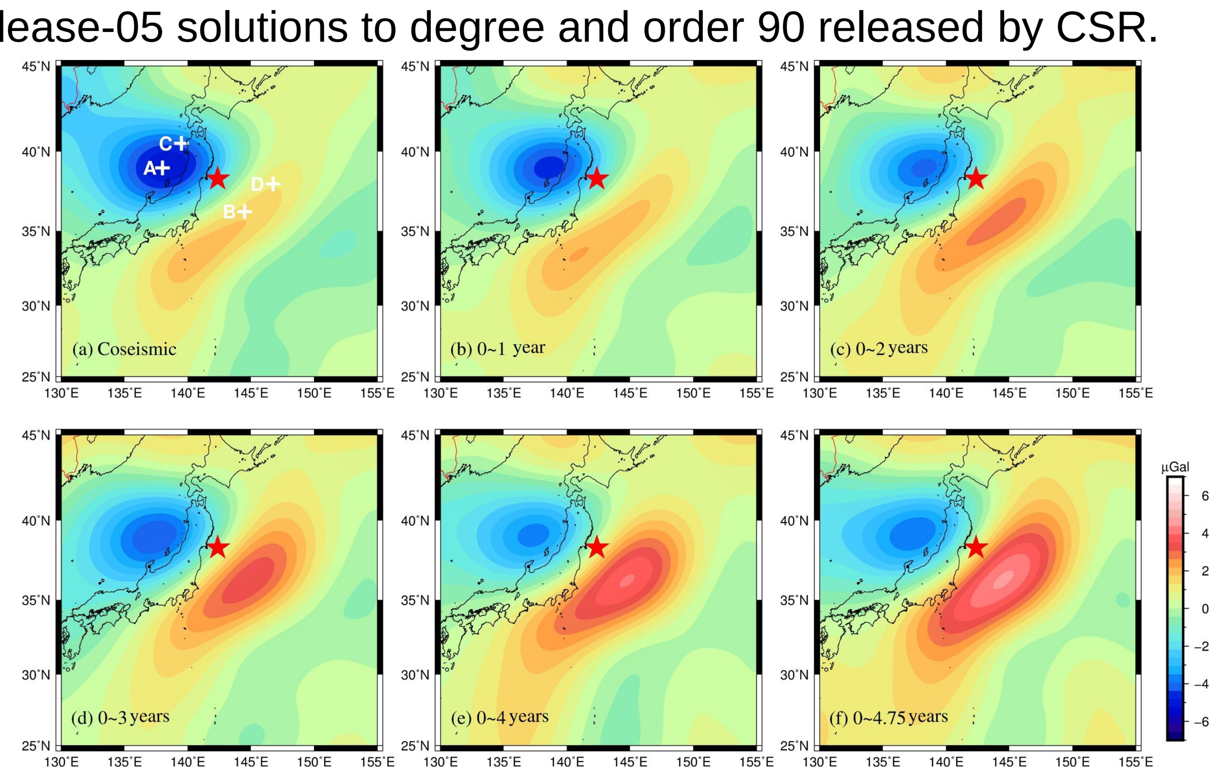

Fig.2 Co- and Post-seismic gravity changes of the M_w 9.0 Tohoku-Oki earthquake detected by GRACE

Simulation

- Combining the viscoelastic dislocation and afterslip theories
- Self-gravitating, half space, viscoelastic dislocation model (Wang et al., 2006)
- Fault slip model (Wei et al., 2012), afterslip model (Diao et al., 2014)
- Earth layering model in the region (PREM, Crust2.0, Diao et al., 2014)

Tab.1 Earth layering model

Layer	Layer thickness (km)	V_P ($km \cdot s^{-1}$)	V_s ($km \cdot s^{-1}$)	ρ ($kg \cdot m^{-3}$)	Medium
1	0~15	6.801	3.4210	2700.0	
2	15~25	7.400	4.2460	2900.0	Elastic body
3	25~40	8.100	4.4980	3370.0	
4	40~120	8.080	4.4700	3374.7	
5	120~220	8.050	4.5000	3371.0	Maxwell body
6	220~∞	8.732	4.7069	3500.0	

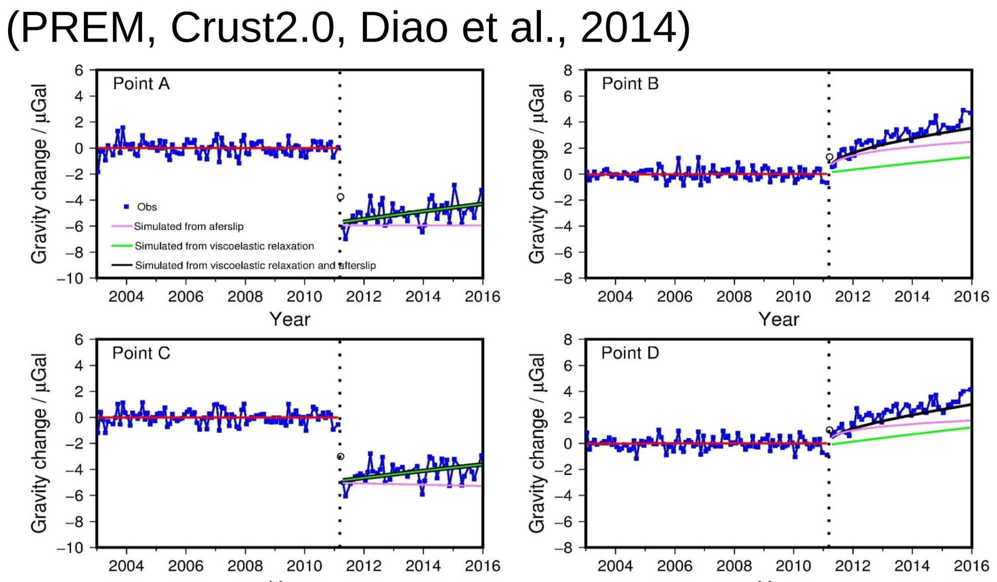

Fig.3 Comparisons between GRACE observations and post-seismic gravity changes caused by different deformation mechanisms

Results

Deformation mechanism

The combination of afterslip and viscoelastic relaxation theories can make a reasonable explanation for the post-seismic deformations of the earthquake.

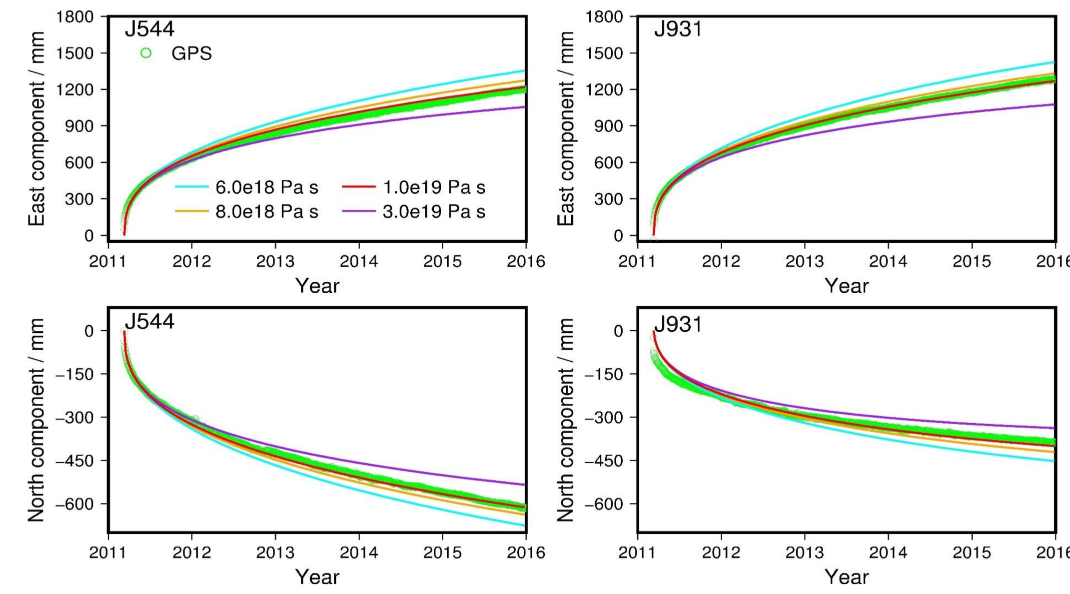

Fig.4 Comparisons between calculated and GPS observed post-seismic displacements

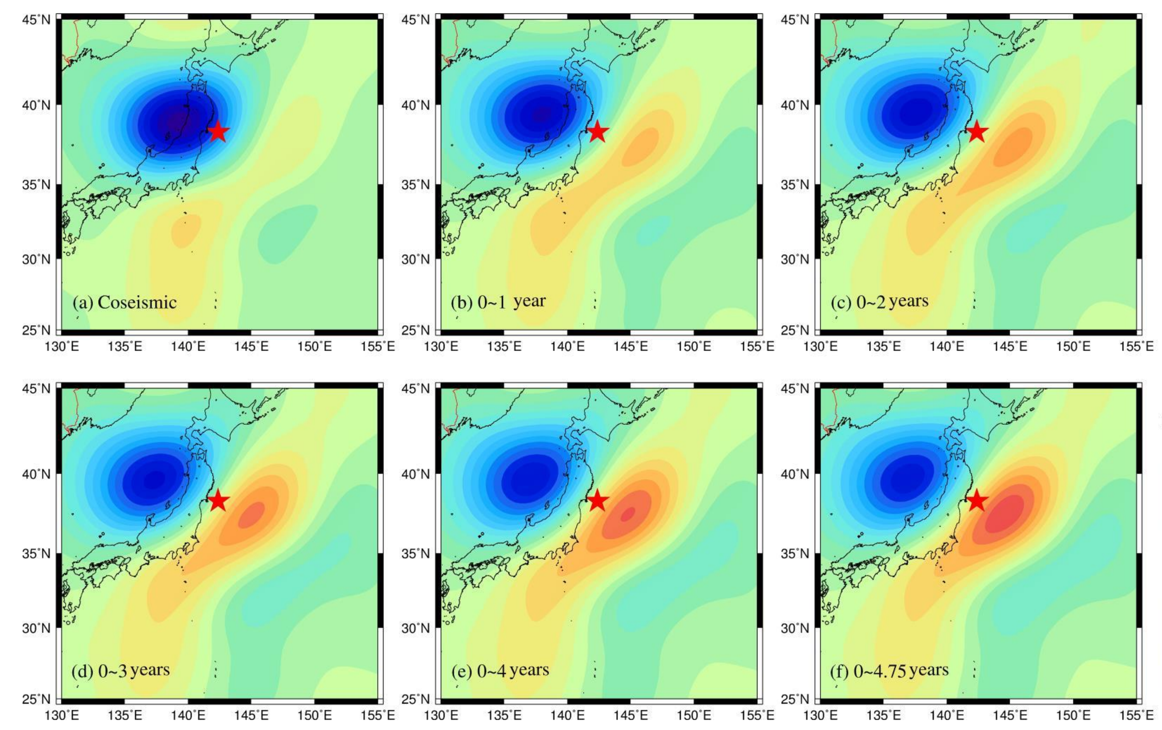

Fig.5 Co- and Post-seismic gravity changes caused by the viscoelastic relaxation and afterslip

Viscous structure estimation

Firstly, inverse a preliminary regional viscous structure by post-seismic GPS observation, then modify the viscosity of the deepest layer by GRACE observation, and fine tune the viscosity of the shallower layer by synthetically using GPS and GRACE observations. Finally, determine the regional viscous structure.

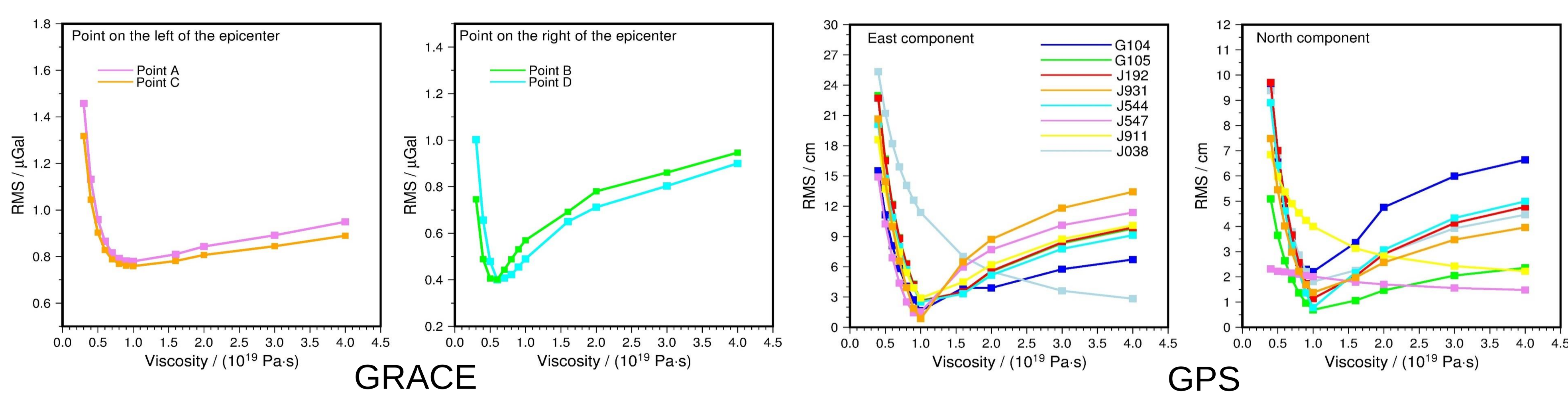

Fig.6 The relationship between the RMS errors and the viscosities of top mantle

Based on this method, the mantle viscous structure in the region of Tohoku-Oki earthquake is inverted. The viscosity of the mantle under 220 km is 1.0×10^{21} Pa·s, and the asthenosphere of 120~220 km is 5.0×10^{19} Pa·s. The rheological parameters are different on the two sides of the fault. The viscosity of the top mantle on the continental side is of the order of 1.0×10^{19} Pa·s, while that on the ocean side is of the order of 6.0×10^{18} Pa·s.

Summary

The regional post-seismic displacements are characterized by exponential function, and the post-seismic gravity changes on both sides of the seismic rupture show upward trend. The post-seismic GPS displacement and GRACE gravity change both can be explained by afterslip and viscoelastic dislocation. The results indicate that it is feasible to estimate the regional viscosity in the mantle using the intensive co- and post-seismic deformations caused by great thrusting earthquakes. More applications are hoped for in the future.

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