Postseismic self-healing of geoid undulations by water after the 2004 Sumatra-Andaman earthquake observed with GRACE

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GRACE (Gravity Recovery and Climate Experiment) is a satellite system composed of two identical satellites, and precise range measurements between them provide information on time varying gravity field of the earth. Its level-2 data sets are composed of the Stokes' coefficients with degree/order complete to 100 or so, and have been used mainly to infer seasonal and secular variations of hydrological masses. Global Positioning System (GPS) receivers have been routinely used to study changes related to earthquakes in terms of movements of crustal surface, and the advent of GRACE is opening a new possibility of detecting such changes in gravity and geoid height. Coseismic formation of geoid depression has been already reported for the 2004 Sumatra-Andaman earthquake by Han et al. (2006). We developed a software system to calculate geoid undulation formed by crustal and Moho uplift/subsidence and dilatation/compression of crustal and mantle rocks (such quantities can be calculated using Okada (1992) if fault parameters are known), and confirmed that the observed and calculated coseismic geoid height changes coincide with each other.

Detailed investigation of time series revealed that postseismic recovery of the coseismic geoid depression occurred with a time constant of about 0.6 year (Ogawa and Heki, submitted). Postseismic crustal movements measured with GPS are attributed to (1) afterslip, (2) viscous relaxation, and (3) pore fluid diffusion. If the mantle viscosity is of the order of 10e19 Pa s, the Maxwell time will be a few tens of years and the mechanism (2) cannot explain 0.6 year time constant. Postseismic GPS observations in Indonesia and Thailand revealed slow movements in the same direction as the coseismic displacements (Hashimoto et al., 2006). Hence the afterslip is considered to have occurred. However, the afterslip will bring geoid height change in the same sense as the coseismic one, and the mechanism (1) cannot explain polarity reversal between the co- and postseismic geoid height changes. The pore fluid diffusion is known to occur with a relatively short time scale and to give rise to postseismic changes opposite to the coseismic ones (Jonsson et al., 2003).

The formation of coseismic geoid depression is due mainly to the pair of peaks of dilatation and compression at the down-dip end of the fault. Hence, upward diffusion of water from the lower peak (compression) to the upper peak (dilatation), driven by pore pressure gradients, would cancel the coseismic geoid height changes. At the down-dip end of seismogenic zone, water included in subducting oceanic crust is released and diffuses in the wedge mantle serpentinizing mantle rocks. There, water content exceeds 1/1000 in weight. This is larger than coseismic dilatation and compression of rocks by a few orders of magnitudes, that is, diffusive movement of a part of total water content could cancel coseismic geoid depression. Freymueller et al. (2006) reported rapid postseismic uplift of GPS points in the Andaman Islands, which is consistent with upward movement of water in depth. In this study, we further show that the observed time constant is realistic considering super-criticality of mantle water whose viscosity is as low as gas.

References

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