What does Grace satellite mission tell us about seismic cycle?

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Launched in March 2002, the GRACE mission measures the temporal variation of the gravity field at a spatial resolution of about 400 km, and at a temporal resolution from ten days to one month.

These information complements ground based geodetic and geophysical ones. The temporal variations of the Earth gravity field are dominated by the effect of the water circulation between the atmosphere, the oceans, the land hydrological systems and the polar ice caps. Such mass redistributions cause geoid variations of a few millimetres at various temporal and spatial scales. Locally, large seismic events also generate geoid variations of similar amplitude, which may also be detectable by GRACE [Gross, Chao, 2001; Mikhailov et al., 2004; Sun, Okubo, 2004; de Viron et al., 2008].

One of the largest earthquakes in recent decades, the M_w 9.2 Sumatra-Andaman, earthquake, occurred on December 26th 2004 at a particularly complex subduction boundary, along which the Indian and Australian plates subduct below a set of microplates comprising the forearc sliver plate, the Burma and the Sunda ones. The Sumatra-Andaman earthquake ruptured at least 1300 km of this subduction boundary. It was followed by numerous aftershocks and by a second very large earthquake, the M_w 8.7 Nias earthquake, on March 28th, 2005. During the following years, slip at depth has continued, as showed by the sequence of recorded aftershocks and regional GPS data.

The December 2004 Sumatra-Andaman event is associated with a large gravity co-seismic anomaly in the Andaman Sea and very fast post seismic relaxation that is well monitored by Grace [Panet et al., 2007; 2010]. This gravity variation is due to vertical displacement of density interfaces (mostly the upper crust boundary and the Moho), and to rock density changes resulting from variations of the stress field (dilatation/compression). At large scales, the density variation effect dominates that of the vertical displacement. Part of the gravity low has been attributed to non-uniform coseismic subsidence of the Andaman Sea overriding plate [Panet et al., 2007].

Comparison of Grace data with the sparse GPS available information allowed us to construct a relaxation model and to discuss the amount of afterslip. In our post-seismic model the observed GPS displacements and gravity variations are well explained by of visco-elastic relaxation plus small amount of afterslip at the downdip extension of the co-seismically ruptured fault planes. Our model comprises 60 km thick elastic layer above a visco-elastic asthenosphere with Burgers body rheology. The mantle below depth 220 km has Maxwell rheology. Assuming a low transient viscosity in the 60—220 km depth range, the GRACE data are best explained by constant steady-state viscosity throughout the ductile portion of the upper mantle (e.g. 60—660 km). This suggests that the localization of relatively low viscosity in the asthenosphere is chiefly in the transient viscosity rather than the steady-state viscosity. The data indicate that mantle viscosity is as low as $8{,}10^{18}$ Pa s in the 220—660 km depth range, maybe indicating a transient behaviour of the upper mantle in response to the exceptionally high amount of stress released by the earthquakes. The remaining misfit to the GRACE data, larger at the smaller spatial scales, was explained by a cumulative afterslip of about 75 cm at depth continuation of the co-seismic rupture, over 30— months period spanned by the GRACE models. It produces small crustal displacements at the level of GPS errors.

Our results confirm that satellite gravity is an essential complement to the ground geodetic and geophysical networks, for understanding the seismic cycle and the Earth inner structure.

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