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Modeling the post-seismic deformations of the Aceh, Nias and Benkulu earthquakes

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The giant seism of Aceh (december 2004) broke a large portion of the boundary between the Indian ocean and the Sunda block. It was followed by the Nias and Bengkulu earthquakes. For the first time in history, the deformations associated with a very large earthquake can be followed by GPS, in particular by the SEAMERGE (far-field) and SUGAR (near-field) GPS networks.

A 3D finite element code (Zebulon) is used to model both the cosismic and the post-seismic deformations. The modeled zone is a large portion of spherical shell around Sumatra, between 40°N and 20°S and from the Earth's surface to the core-mantle boundary. The mesh is refined close to the subduction zone.

We show that taking into account the lateral variations of the elastic properties in the superficial layers (accretionary prism, continental crust...) is important for modeling the coseismic deformation: it affects by more than 30% the ratio near-field over far-field of the predicted surface displacements. The inverted cosismic displacements on the subduction plane provide a very good fit to the GPS data for the three seisms.

The curves of post-seismic displacement, non-dimensionalized by the cosismic displacement, present three very different patterns as function of time: For GPS stations in the far-field, the total post-seismic displacement after 4 years is as large as the cosismic displacement. The slope of the curves varies slowly. In the near-field, the post-sismic displacement reaches only some 15% of the cosismic displacement and it levels off after 2 years. In the middle-field (south-west coast of Sumatra), the post-sismic displacement also levels-off with time but more slowly and it reaches more than 30% of the cosismic displacement. We show that in order to fit these three distinct displacement patterns, we need to invoke both viscoelastic deformation in the asthenosphere and a low-viscosity wedge or sliding in the lower part of the subduction plane.

The viscoelastic properties of the asthenosphere are rather precisely constrained: they are consistent with a Maxwell rheology with a viscosity of the order of 5 10^{18}Pas or a Burger rheology with a long-term viscosity of 3 10^{19} Pa-s and a transient creep represented by a Kelvin-Voigt element with a viscosity of 3 10^{18}Pas and $\mu_{Kelvin} = \mu_{elastic}$/3. The viscosities of the low viscosity wedge or of the low-viscosity channel are of the order of 2. 10^{18}Pas.

These large post-seismic deformations affect the deviatoric stresses in the whole Sunda-block. They should also be considered in the interpretation of the intersismic signal.