T043-018 Room: C416 Time: May 29 14:45-15:00

Long-term Crustal Deformation in and around Japan Simulated by a 3-D Plate Subduction Model

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We constructed a 3-D model of long-term crustal deformation due to steady plate subduction in and around Japan by combining a realistic 3-D structure model and its viscoelastic slip-response functions. The lithosphere-asthenosphere system is modelled by an elastic surface layer overlying a Maxwellian viscoelastic half-space. As to the plate interfaces, we used a standard 3-D model developed by Fukui, Sato & Iwasaki [2001]. According to plate tectonics, oceanic plates bend and descend beneath continental plates at subduction zones with constant rates on a long-term average. Interaction between an oceanic plate and a continental plate is simply represented by the increase of tangential displacement discontinuity across the interface [Sato & Matsu'ura, 1988, 1993]. Thus we can calculate surface deformation by imposing the steady slip at constant rates Vpl on the plate interfaces. Here, we use the relative plate motion given by NUVEL-1A to define the steady slip rates Vpl.

The numerical result with the 3-D steady subduction model shows that far-field horizontal velocities are nearly uniform on each side of the plate boundary, indicating simple convergent block motion. The convergence rate between the North American plate and the Pacific plate is about 8 cm/yr in the northeast Japan, and the rate between the Eurasia plate and the Philippine Sea plate is about 4 cm/yr in the southwest Japan. It should be noted that the global relative plate motion is realized by imposing the steady slip at constant rates Vpl only on the plate interfaces. In the neighbourhood of the plate boundaries we can find significant perturbation of the global plate motion.

The vertical motion caused by the steady plate subduction is characterized by steep uplift on the continental side, sharp subsidence at the trench axis, and gentle uplift on the oceanic side. The maximum subsidence rate is about 4 mm/yr in the northeast Japan and 2.5 mm/yr in the southwest Japan. The maximum uplift rates are about 2.5 mm/yr in the northeast Japan and 1.5 mm/yr in the southwest Japan, respectively. The calculated deformation patterns show the remarkable effects of 3-D plate interface geometry. The large-scale bends of the plate boundaries in the northeast Japan (Tokachi-oki) and in the southwest Japan (Bungo Channel) bring about broad subsidence at the regions, which is caused by the horizontal extension of the continental plate due to steady subduction along the curved plate interface.

Gravity anomalies computed from the vertical displacement may be directly compared with observations, since the gravity anomalies are zero at the initial isostatic state. We computed the increase rates of free-air gravity anomalies from the uplift rates caused by steady plate subduction, and found that its pattern is consistent with the observed pattern of free-air gravity anomalies.