Some effects of lateral viscosity variations caused by subducting slabs and plate margins on long-wavelength geoid

Masaki Yoshida[1]; Tomoeki Nakakuki[2]; Motoyuki Kido[3]

[1] IFREE, JAMSTEC; [2] Dept Earth Planet Syst Sci, Hiroshima Univ; [3] RCPEV, Graduate School of Sci., Tohoku Univ.

The observed geoid anomaly shows very broad highs over the subduction zones, especially over the circum-Pacific trench, when the longest-wavelength components (the spherical harmonic degree are 2 to 3) are subtracted (Hager, 1984). Our previous work (Yoshida, 2004) has shown that the long-wavelength geoid anomaly is significantly affected by the lateral viscosity variations (LVVs) in the mantle, i.e., stiff (high viscous) subducting slabs and weak (low viscous) plate margins related to the plate-tectonic mechanism, by the use of the two-dimensional mantle convection model. In this study, we have examined possible effects of such LVVs on the long-wavelength geoid by using three-dimensional spherical shell models. In contrast with a traditional propagator matrix method by Hager, our new numerical approach can treat the mantle flow including LVVs. The finite volume method is used for the discretization of basic equations governing the instantaneous mantle flow with spatially variable viscosity. To construct more actual global density models compared with our previous models (Yoshida et al., 2001; Yoshida, 2004), we have used a coupled model with (1) the global subducting slab model based on the seismicity in the upper mantle, and (2) the S-wave global tomography model (Becker and Boschi, 2002) in the lower mantle. The radial viscosity variation is layered; the lithosphere, upper mantle, transition zones, lower mantle, and the bottom boundary layer. The low viscous asthenosphere is also considered. The reference viscosity is fixed at 10^{21} Pa s in the upper mantle. The viscosity contrast between the lithosphere and the mantle is taken to be $10^{4.5}$, which is the actual effective viscosity of the lithosphere (Gordon, 2000). The viscosity of the plate margins is determined by using the global strain-rate model (Kreemer et al., 2003).

We have first calculated the geoid anomaly by using a no-LVV model, in which the stiff subducting slabs and the weak plate margins are not considered. The result shows that geoid highs over the subduction zones arise only when the vertical viscosity contrast between the upper mantle and the lower mantle (R_{LM}) is 10^3. This value seems to be one order larger than the viscosity contrast suggested by the post-glacial rebound analysis (e.g., Peltier, 1998). We have next imposed the stiff subducting slabs only in the upper mantle, the viscosity of which is the same as that of the lithosphere, on the no-LVV model. The geoid anomaly shows regionally strong negative pattern over the subduction zones, especially, the Jawa and the South America trenches, even when R_{LM} is significantly high, 10^4. This is because the surface deformations in such regions strongly depress due to the mechanically strong coupling between the lithosphere and stiff subducting slabs. Even when we have imposed weak plate margins on this model, the geoid pattern remains largely unchanged. Here we have systematically examined the effects of the viscosity contrast of subducting slabs in the range between 10^0 (i.e., no viscosity contrast) and $10^{4.5}$ on the geoid anomaly. We have confirmed that when the viscosity contrast of the subducting slabs is around 10^1 to 10^2, the geoid anomaly over the subduction zones becomes positive pattern over such regions, if R_{LM} is around 10^3. Imposing weak plate margins on this model reproduces the broadly positive anomaly which explains the observation. However when R_{LM} is lower than 10^2, the geoid anomaly over the subduction zones still remains broadly negative. These results indicate that the viscosity of subducting slabs is significantly weaker than that of lithosphere. The weaker lithosphere may lead to the stronger slabs to account for the observations. Our study suggests that subducting slabs in the upper mantle is not strongly coupled with deep slabs under the transition zone when the stiff slabs in the lower mantle are considered.