A new approach to thermal-mechanical modeling of subducting slab with real-time update of thermal boundary condition in a framework of solid mechanics

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To simulate subduction dynamics numerically, there are two contrasting approaches depending on whether the subducting slab is assumed as a viscous fluid (i.e., fluid mechanics) and viscoelastic solid (i.e., solid mechanics). In the approach of solid mechanics, a viscous mantle resistance against subduction is reproduced by viscous dashpot elements attached on surface of subducting oceanic plates. The dashpot approximation for mantle was successful for modeling realistic features of subducting slabs, such as slab advancing, retreating and stagnation on 660 km phase boundary, in frameworks of viscoelastic solid mechanics. However, it is difficult to calculate a temperature change of subducting slab due to nonexistence of hot mantle which provides thermal energy to the slab by conduction. Thermal structure of the subducting plate is important in various geodynamical phenomena such as dehydration of hydrous minerals, metastable olivine, and subduction initiation. In present study, we performed thermal-mechanical finite element modelling for subducting slab sinking spontaneously into mantle by gravity, based on linear Maxwell viscoelasticity. A wide range of temperature profiles of mantle is applied as depth-dependent temperature boundary conditions of subducting slabs. In each time-step, temperature boundary condition of surface enveloping the slab is evolved in real-time following the location of the surface. Our model displayed a clear tongue thermal structure in which cold core and hot surface of subducting slab are formed. An extent of metastable olivine is systematically correlated with slab dip, sinking velocity, and age of subducting plate. In addition, we adopted temperature-dependent viscosity of dashpots to investigate the effect of basal viscosity of oceanic plate before subduction initiation. When we defined local high temperature structure (e.g., plume) around the dashpots, the lateral heterogeneity in viscosity along the basal boundary of oceanic plate emerges. Above thermally weakened dashpot, the oceanic plate is bent downward and subsequently collapsed to start subduction. We argue that our model with viscoelastic plate, dashpot approximation for mantle, and real-time update of temperature boundary condition can successfully reproduce geodynamics of subducting plates including the formation of metastable olivine and subduction initiation by plume impingement. This means that our new method has a potential to simultaneously solve physics of elastic short timescale (e.g., earthquakes and rupture dynamics) and viscous long timescale (e.g., slab deformation and dehydration), which are both greatly affected by temperature.

Keywords: Thermal tongue structure, Temperature boundary condition, spontaneous subduction, solid mechanics

