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A numerical model setup for subduction: From linear viscous to thermo-mechanical rheologies

Matthieu Quinquis (1), Susanne Buiter (1,2), Nicola Tosi (3,4), Cédric Thieulot (2,5), Petra Maierová (6), and Javier Quinteros (7)

(1) Geodynamics Team, Geological survey of Norway, Trondheim, Norway, (2) PGP, University of Oslo, Oslo, Norway, (3) Department of Planetary Geodesy, Technical University Berlin, Berlin, Germany, (4) Department of Planetary Physics, Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany, (5) Faculty of Geosciences, Utrecht University, Utrecht, the Netherlands, (6) Department of Geophysics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic, (7) Deutsches GeoForschungsZentrum GFZ, Potsdam, Germany, Section 2.5

Subduction modelling requires choosing values for domain size, crust and lithosphere thicknesses, material properties, rheological parameters, and boundary conditions. Some of these values can be constrained by observations of present-day subduction zones, such as lithosphere age and thickness, whereas others have a larger uncertainty and require critical evaluation of geophysical and experimental results. To test the model response to systematic variations in input parameters, numerical studies often start from a 'reference' subduction model. 'Reference model' setups of subduction studies vary and can be 2-D or 3-D, include an overriding plate or not, consider purely mechanical or thermo-mechanical behavior, and use linear viscous or visco-plastic rheologies. Typically, not only the setup differs between various studies, but also the values of mechanical and thermal input parameters. This variability in the initial setup of numerical studies of subduction zones makes it difficult to compare the results of different studies directly.

We have defined a numerical 'reference model' for subduction of a 70 Ma old oceanic plate under a 40 Ma old oceanic plate. We progressively increase complexity of our subduction model from (1) a linear viscous rheology, through (2) linear viscous with temperature advection, to (3) simplified, and (4) more elaborate thermo-mechanical models. We present a quantitative comparison of results for these four setups from five different numerical codes. The participating codes use finite element (ELEFANT, SULEC, ELMER, SLIM-3D) and finite volume (YACC) methods.

Our models show a three-stage evolution of subduction: 1) A subduction initiation phase, 2) a free subduction phase, and 3) a phase where the slab tip interacts with the bottom boundary. We quantitatively compare the evolution of slab tip depth, trench retreat, root-mean-square velocities, viscous dissipation of energy, root-mean-square temperature and depth of the 800ºC isotherm. The linear viscous models (with and without temperature advection) show less than 5% variation in the common output values between the five participating codes. Minimum variability is observed during the free subduction phase, whereas the largest difference occurs when the slab tip interacts with the bottom boundary. We hope that our results will be useful for future subduction studies, offering not only a set of numerical test problems, but also suggesting a subduction reference model setup.