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Three-dimensional subduction-induced flow patterns in the mantle: Insight from fluid dynamic modelling

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Accurate determination of the subduction-induced flow patterns and volume fluxes in the Earth's mantle is paramount in understanding trench-migration velocities and plate velocities at subduction zones, and the geochemical heterogeneity in the mantle. It is thus vital to get a detailed three-dimensional understanding of the subduction-induced flow patterns on Earth. The rate at which lithospheric plates are subducted into the mantle is dependent on the absolute trenchward subducting plate velocity and the absolute trench migration velocity, whilst the plate velocity and trench velocity themselves are dependent on a large number of physical parameters. This study focuses on the relative contribution of each of these subduction modes to the total rate of subduction and their influence on the flow field in the mantle. Three-dimensional fluid dynamic laboratory simulations show that the plate/mantle viscosity ratio and stratification of the mantle influence the kinematic style of subduction. However, in all models, plate-parallel motion induces poloidal flow structures in the mantle while rollback motion of the slab induces quasi-toroidal flow around the lateral slab edges. None of the simulations show any indication that rollback of the slab might induce poloidal flow around the slab tip. This is in agreement with some previous laboratory and numerical modelling studies of subduction but in disagreement with others. The disagreement might be explained by the absence or presence of kinematic boundary conditions and related sinking kinematics of one particular set of models or the incorrect scaling of another set of models. The finding that rollback-induced mantle flow occurs in a quasi-toroidal fashion around the lateral slab edges and not in a poloidal fashion around the slab tip implies that the width of a slab is an important parameter in determining trench velocity. This implication is indeed supported by numerical subduction models and global trench migration calculations.