Mantle Flow Trajectories in the Presence of Poorly Constrained Initial Conditions: Analysis of an Ensemble of Models

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A crucial goal in geodynamics is the development of time-dependent earth models so that poorly known mantle convection parameters can be tested against observables gleaned from the geologic record. To this end one must construct model trajectories to link estimates of the current heterogeneity state to future or past flow structures via forward or inverse mantle convection models. Unfortunately, the current heterogeneity state which is derived from seismic imaging methods is subject to substantial uncertainty due to the finite resolution of seismic tomography. These uncertainties are likely to considerably affect the computed flow trajectory, in what is known as the butterfly effect. Here we study mantle convection models to assess the effects of varying initial conditions on the evolution of mantle flow. We compute convection calculations with identical flow parameters but different initial temperature fields. A base temperature field is generated by allowing a mantle convection calculation to evolve until a statistical steady state is reached. This temperature field is then used to initialize our reference case. We proceed to modify this reference temperature field in three different forms to reflect tomographic choices of damping and smoothing: in the first case, we apply a radial averaging to the reference temperature field. In the second case, we truncate a spherical harmonic expansion of the reference field at degree 20. In the final case, we apply an S20RTS filter to the reference field. In all cases we track the divergence of the perturbed models from the reference model. Furthermore, we test the efficiency of surface velocity assimilation, following from the work of Colli et al (2015), in locking two convecting systems and driving their divergence to a minimum. We find in all experiments that the divergence grows exponentially before hitting a maximum value, within 4 transit times, at which point it ceases to grow. In addition, surface velocity assimilation leads either to a reduction of the divergence or prevention of its further growth and within 3 transit times, the maximum possible convergence between reference and perturbed models is reached for all cases, further confirming the results seen in Colli et al (2015).