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Predictability limit of convection models of the Earth's mantle

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The reconstruction of the convective flow in the Earth's mantle is a crucial issue for a diversity of disciplines, from seismology to sedimentology. In the past 15 years, several types of reconstructions have been proposed using convection models forward and backward in time. However, so far there are no studies of the limit of predictability these models are facing. Indeed, given the chaotic nature of convection in the Earth's mantle, uncertainties on initial conditions grow exponentially with time and limit forecasting and hindcasting abilities.

We use here an approach similar to those used in dynamic meteorology, and more recently for the geodynamo, to evaluate the predictability limit of mantle dynamics forecasts. Following the pioneering works in weather forecast [1], we study the time evolution of twin experiments, started from two very close initial temperature fields and monitor the error growth. We extract a characteristic time of the system, called Lyapunov time, which is used to estimate the predictability limit. The range of predictability depends on the initial error and the error tolerance in our model. We compute 3D spherical convection solutions using StagYY [2] and first evaluate the influence of the Rayleigh number on the limit of predictability. Then, we investigate the effects of various rheologies, from the simplest (isoviscous mantle) to more complex ones (plate-like behavior and floating continents).

We show that the Lyapunov time increases with the wavelength of the flow and reaches 130 My in the fully chaotic regime of mantle convection with plate-like behavior and floating contients. Such a Lyapunov time, together with the uncertainties in mantle temperature distribution, suggests prediction of the Earth's mantle structure from an initial given state is limited to <90 Myrs, although progress on the models will improve this estimation in the future.

References

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