Recognising the patterns in mantle convection and what they can tell us about Earth

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Key words Mantle dynamics, neural networks, probabilistic inversion, pattern recognitions

Inverting mantle flow for past configurations is one of the great outstanding problems in geodynamics. We demonstrate a new method for inverting present day Earth observations for mantle properties and history. Convection is a non-linear and chaotic, thwarting most standard inversion methods. Because of its chaotic and unpredictable nature, small errors in initial conditions, parameter selection, and computational precision can all significantly change the results produced by mantle convection simulations.

However, some patterns and statistics of convection contain the signature of the parameters used in the simulations over long time-scales. Geodynamical studies often vary these parameters to investigate their effects on the patterns produced. We show that with a large enough set of simulations, we can investigate the relationship between input parameters and convection patterns in a more rigorous way.

Probabilistic inversion is the only way to approach highly non-linear problems. We use neural networks to represent the probability density function linking convection simulation input parameters and the patterns they produce. This allows us to find input parameters, whilst taking into account all of the uncertainties that are inherent in the inversion of any Earth system: how well do we understand the physics of the process; what do we already know about that input parameter; and how certain are our observations?

We show that the mantle structures produced by 4.5 Gyr of convection simulations, considered at a single time frame, contain enough information on yield stress, viscosity coefficients, mantle heating rate, and the initial state of primordial material that we can infer them directly without requiring any other information, such as plate velocity.