Geophysical Research Abstracts
Vol. 21, EGU2019-4241, 2019
EGU General Assembly 2019

Reconstructing past mantle flow with the adjoint method in the presence of a mismatched model

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Geodynamic retrodictions — that is, reconstructions of past states of the Earth's mantle obtained using presently available information and their comparison against the geologic record — are a promising new tool that allows the testing of hypotheses and assumptions regarding the dynamics of the solid Earth. The history of past mantle states is obtained by solving an inverse problem via the adjoint method: the difference between the observed present-day mantle structure and the prediction of a geodynamic model is minimised by refining iteratively the initial condition in the past.

The theory and uniqueness properties of the adjoint method for mantle convection are well understood. But its application to real Earth cases is still in its infancy and, before it can be brought to bear in full, a number of key technical aspects must be explored. In particular, most studies using the adjoint method for global mantle convection have employed synthetic tests where the exact same model was used to generate the reference evolution and to solve the inverse problem, thus committing a so-called inverse crime. When solving the geodynamic inverse problem for the real Earth we are bound to use an approximate and simplified models where many model parameters are poorly known. Indeed, as stated before, one goal of geodynamic retrodictions is to improve current constraints on geodynamic models. This motivates us to investigate the impact of model inconsistencies on geodynamic retrodictions. We ran synthetic tests where we inverted a reference "true" history of mantle convection with purposefully mismatched models.

We focus here on three key ingredients of geodynamic retrodictions that are affected by significant uncertainties: the rheology of the mantle, the present-day state of the mantle and the history of plate motions. Our results show that the adjoint method can satisfactorily minimize the misfit even in the presence of a realistic model mismatch. The reconstructed initial condition, however, can be characterized by severe artefacts, in particular in the thermal boundary layers, and the reconstructed history of mantle flow can be negatively affected.