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Ultra-fast solution of Stokes problem via Model Order Reduction within 3D inversion of lithospheric structure

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The determination of the present-day physical state of the thermal and compositional structure of the Earth's lithosphere and sub-lithospheric mantle is one of the main goals in modern lithospheric research. It involves the solution of high-resolution inverse problems and, consequently, the solution of many direct models is required.

The accuracy of inversion procedures can be improved by taking into account a dynamic component, arising from sub-lithospheric mantle flow, to the topography. Although this is not usually included because of the increase in computational cost: it is required to solve a Stokes problem at every inversion step. In three-dimensional domains its computational cost becomes prohibitive for traditional numerical techniques.

One option to overcome the computational limitations is the use of Reduced Order Methods (ROM). ROM are extremely efficient techniques that suit very well in the context of inversion methods. The ROM approach consists in building a reduced basis of solutions, in such a way that when a new problem has to be solved, its solution is sought within the basis instead of attempting to solve the problem itself. In our tests the computational cost of the inversion process has been reduced to up to 5% of the cost compared to a traditional Finite Element solver (95% of reduction).

In this work we present an example of a synthetic inversion case in which:
a) The ROM implementation is used to efficiently solve the direct models simulating the sub-lithospheric mantle flow.
b) The inversion is performed using a Metropolis-Hastings algorithm (Monte Carlo Markov Chain method) which is able to invert simultaneously for different parameters
c) The parameters we want to invert for are the depths of the Lithosphere-Asthenosphere Boundary (LAB) at each point of our domain

The example is implemented in a 3D domain reproducing a region of Earth covering up to 400 km depth. Within the domain, the Stokes equation is solved via ROM with realistic viscosities and densities computed from the LAB values at each iteration of the inversion algorithm.