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Model Order Reduction for the fast solution of 3D Stokes problems and its application in geophysical inversion

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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. All this data is essential to build Earth's evolution models and to reproduce many geophysical observables (e.g. elevation, gravity anomalies, travel time data, heat flow, etc) together with understanding the relationship between them. Determining the lithospheric state involves the solution of high-resolution inverse problems and, consequently, the solution of many direct models is required.

The main objective of this work is to contribute to the existing inversion techniques in terms of improving the estimation of the elevation (topography) by including a dynamic component arising from sub-lithospheric mantle flow. In order to do so, we implement an efficient Reduced Order Method (ROM) built upon classic Finite Elements. ROM allows to reduce significantly the computational cost of solving a family of problems, for example all the direct models that are required in the solution of the inverse problem. The strategy of the method consists in creating a (reduced) basis of solutions, so 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 order to check the Reduced Basis approach, we implemented the method in a 3D domain reproducing a portion of Earth that covers up to 400 km depth. Within the domain the Stokes equation is solved with realistic viscosities and densities. The different realizations (the family of problems) is created by varying viscosities and densities in a similar way as it would happen in an inversion problem. The Reduced Basis method is shown to be an extremely efficiently solver for the Stokes equation in this context.