Geophysical Research Abstracts
Vol. 15, EGU2013-4245, 2013
EGU General Assembly 2013


# Inverse geodynamic modeling to constrain effective viscosities and densities of the lithosphere

Tobias Baumann, Boris Kaus, and Anton Popov
University of Mainz, Institute for Geosciences, Mainz, Germany (baumann@uni-mainz.de)

The rheology of the lithosphere on geological timescales has been a matter of intense debate over the last decades. Here we discuss a new method that can be used to constrain the rheology of the present-day lithosphere or crust from geophysical observations. We combine three-dimensional geodynamic flow models with Monte Carlo techniques to constrain the effective viscosities and densities of geodynamic models by inverting surface observations.

In general, performing geodynamic forward models is expensive in terms of computational costs. Moreover, approaching the inverse problem with a Monte Carlo method requires many forward models to be calculated. To tackle the complexity of the inverse problem, we have developed a massively parallel program layout. It mainly consists of two parts: i) parallel geodynamic forward modelling with the LaMEM code ("Lithospheric and Mantle Evolution Model"); and ii) parallel implementation of a direct search technique (Neighbourhood algorithm, Sambridge, 1999), which is known for its ability to efficiently sample a parameter space. LaMEM implements solving the Stokes problem with a staggered FD method and modeling of the gravity field.

Coupling geodynamic forward models with the original parallel version of the neighbourhood algorithm by Sambridge turned out to be challenging for several reasons. First, the run-times of geodynamic models are much larger compared to typical models for which the Neighbourhood algorithm was used previously. Moreover, the iterative solvers used in geodynamic forward modeling can result in large variations in run-time between different forward models, depending on the viscosity contrast. Thus, avoiding synchronisation or blocking communication in the parallel implementation is important to reach good scalability on high performance computers. We have reimplemented the parallelisation of the Neighbourhood algorithm to overcome the above-mentioned challenges and have successfully performed inverse models on over 8192 processors of a Bluegene/Q machine. Our updated parallel framework implements an explicitly handled version of the MPI message buffer, and fully non-blocking communication.

To study the feasibility of our approach we evaluated the method with synthetic salt-tectonics setups that employ a forward salt-dome simulation (which includes sedimentation, erosion and downbuilding). Gravity anomalies and surface (Stokes) velocities measured on top of our models are used as constraints to drive the inversion. The results show that it is possible to constrain the rheology of our model setups. An analytical solution for a simple case demonstrates that whereas the gravity problem is non-unique, adding Stokes changes it into a uniquely constrained problem, despite increasing the parameter space.

**Acknowledgements**
Funding was provided by the European Research Council under the European Community's Seventh Framework Program (FP7/2007-2013) / ERC Grant agreement 258830. Numerical computations have been performed on JUQUEEN of the Jülich high-performance computing center. We thank M. Sambridge for providing us with a parallel version of his Neighbourhood algorithm.

**References**
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