Geophysical Research Abstracts
Vol. 16, EGU2014-14714, 2014
EGU General Assembly 2014

Digital deformation of the lithosphere: how simulation helps to unravel the dynamics of the solid Earth

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Better understanding the physics of the Earth is and will remain one of the major goals of solid Earth sciences. Whereas geophysical methods give a fair idea of the structure of the present-day Earth, geological data indicate that most processes occur over millions of years and, thus, provide information on how the Earth behaved on a much longer timescale. If both types of data should be reconciled, models are needed that describe how the lithosphere deforms and results in mountain belts such as the Himalayas. However, most geological tectonic models are just cartoon models drawn with software tools. They satisfy the geological (and often geophysical) data, but they do not necessarily tell much about the underlying physics of the lithosphere and the mechanics of deformation. As a result, there are many competing geological models explaining the same data sets.

A different approach is to use thermo-mechanical numerical models to simulate collision scenarios on the computer. Over the last two decades, such models have become quite sophisticated and nowadays one can take realistic rock rheologies into account that vary from brittle (or elastoplastic) under low temperatures to ductile (or viscous) at higher temperatures. Typically such geodynamic models are used in a forward manner, in which various theoretical scenarios are simulated as a function of changing parameters such as plate speed, thermal structure of the lithosphere and rock rheology. The best fitting models are the ones that appear to be most consistent with the data. This shows how lithospheric collision could have occurred. Yet, since the number of model parameters is large and the models remain computationally intensive even in 2D, we cannot check every parameter combination. The result is that it is often tricky to understand the underlying physics of such models, although progress can be made with the help of scaling analysis and (semi-)analytical solutions. Moreover, present-day geophysical information such as seismic tomography is often computed at the end of a model simulation but the data is rarely directly used as input variables in the models. Another approach is, therefore, to perform geodynamic inverse modelling, which combines present-day geophysical data with geodynamic forward models and changes the input parameters until a 'best-fit' is obtained.

Combining dynamic forward models with geophysical observational constraints and inverse models is, thus, a very promising future research direction that will allow a better understanding of the dynamics of the Earth.