Recovering lateral variations in lithospheric strength from bedrock motions with a coupled ice sheet-lithosphere model

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Introduction

Sea level is generally studied with glacial isostatic adjustment models consisting of a prescribed ice history (such as ICE-3G) and a visco-elastic earth model governing deformation to surface loading. These ice histories result from an optimization procedure given a collection of sea level data and a specific earth model. The earth model is in general laterally homogeneous. We present a coupled dynamical ice flow-lithosphere model to construct synthetic bedrock motion time series to assess their potential in resolving lithospheric structure while simultaneously producing the best fitting ice model. We feel this approach could complement existing methods since the dynamical ice flow model is based on ice rheology and paleoclimatic data, which makes it a completely independent approach compared to existing ice histories. Moreover, we use a lithospheric model which incorporates lateral variations in lithospheric structure.

The model

Fig. 1 shows a schematic representation of the model. It has two main components;

(i) the lithospheric model is based on the generalized flexural equation, which incorporates lateral variations in lithospheric structure.
(ii) the ice model is a shallow ice approximation type II ice flow model, and a mass balance component described as

$$B = b\,(h-E) \qquad (1)$$

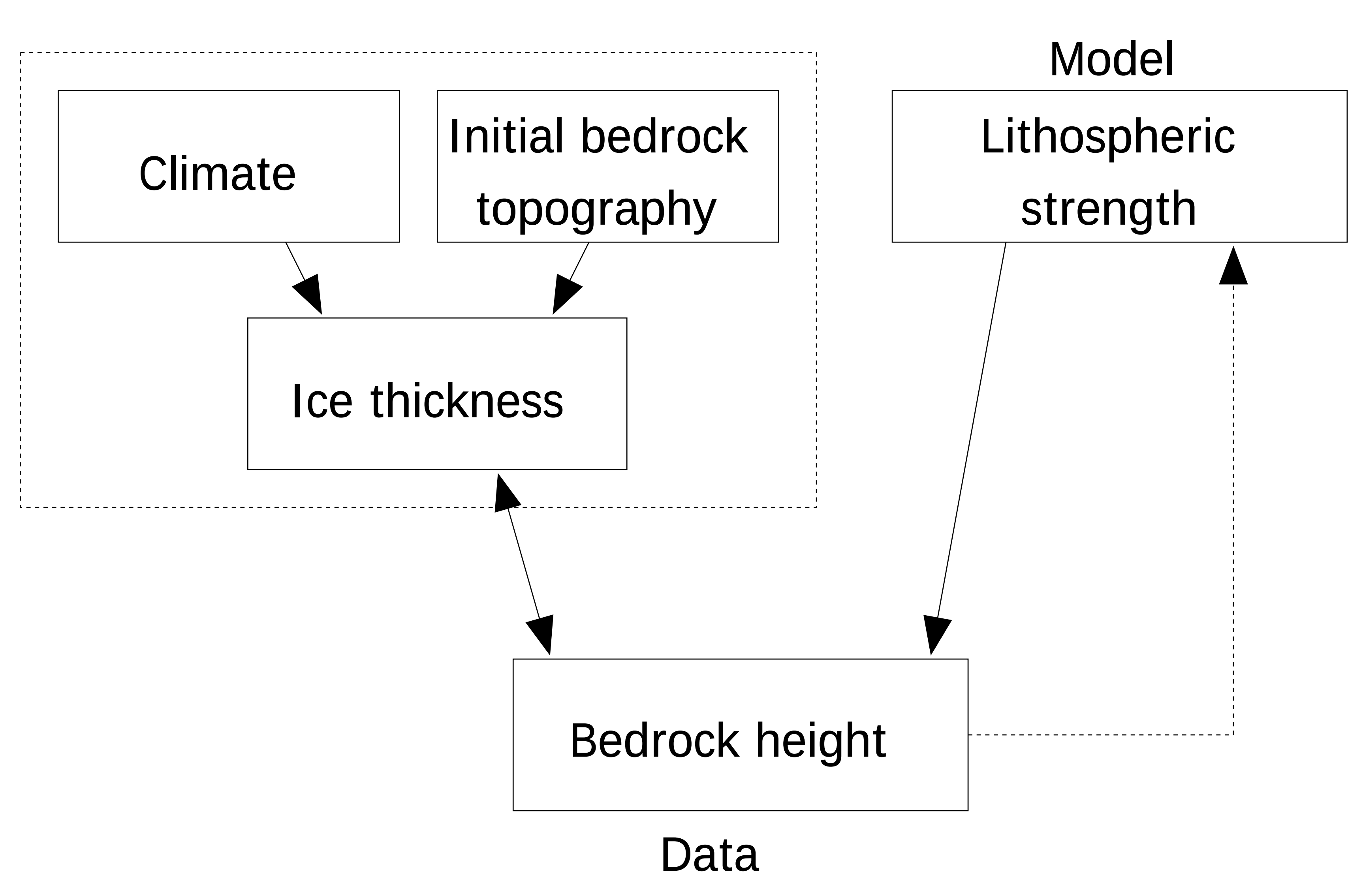
with b the mass balance gradient, h the surface elevation, and E the equilibrium line altitude. For more details, see Ref.

Results

Fig.2 shows the geometry for the inverse experiments. For the 1D experiments, the true geometry had the transition from D1 to D2 in the middle of the domain, in the 2D experiments this location was varied. Synthetic data were generated at each crossing of the dashed lines in Fig. 2. Figs. 3 and 4 show the results of the 1D and 2D experiments.

Conclusions

The model can distinguish between homogeneous and laterally varying lithosphere. It can produce the corresponding strengths provided that data are available from both sides of a transition and the location of the transition is known from independent sources such as seismology. The method is not very sensitive to noise, but is sensitive to systematic biases such as insufficient knowledge of climatic conditions or mantle viscosity. This new method is capable of giving best estimates of lithospheric structure and best fitting ice history simultaneously.



Model

Climate

Initial bedrock topography

Lithospheric strength

Ice thickness

Bedrock height

Data

Fig. 1: Schematic overview of modelling components.

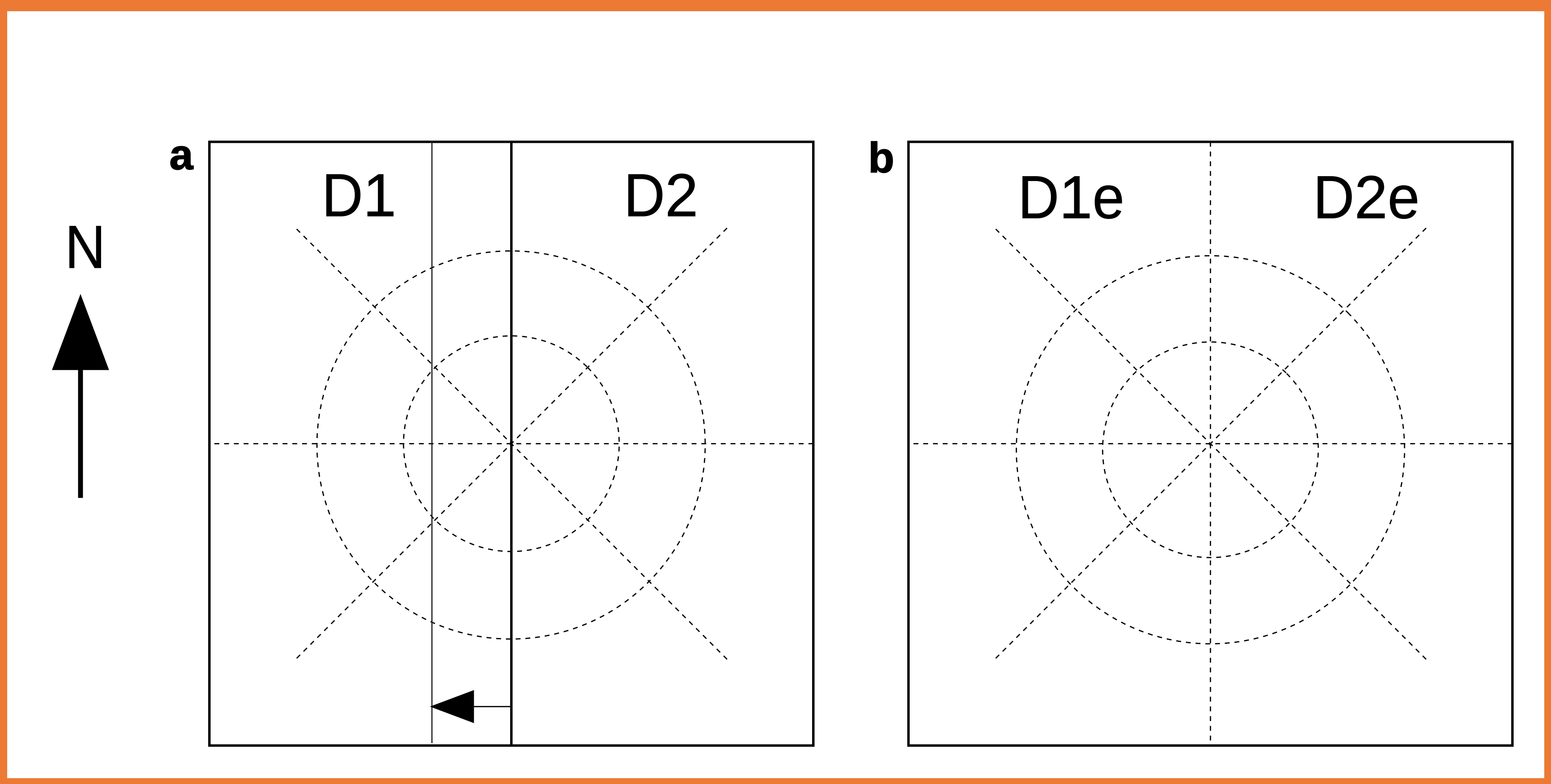


Fig. 2: a: True geometry for inverse problems with values for D1 and D2 of 10e22 Nm and 10e25 Nm respectively. b: Forward modelling geometries with several combinations of D1e and D2e. In this case the seperation between regions of different strength is always in the middle of the domain.

1D:

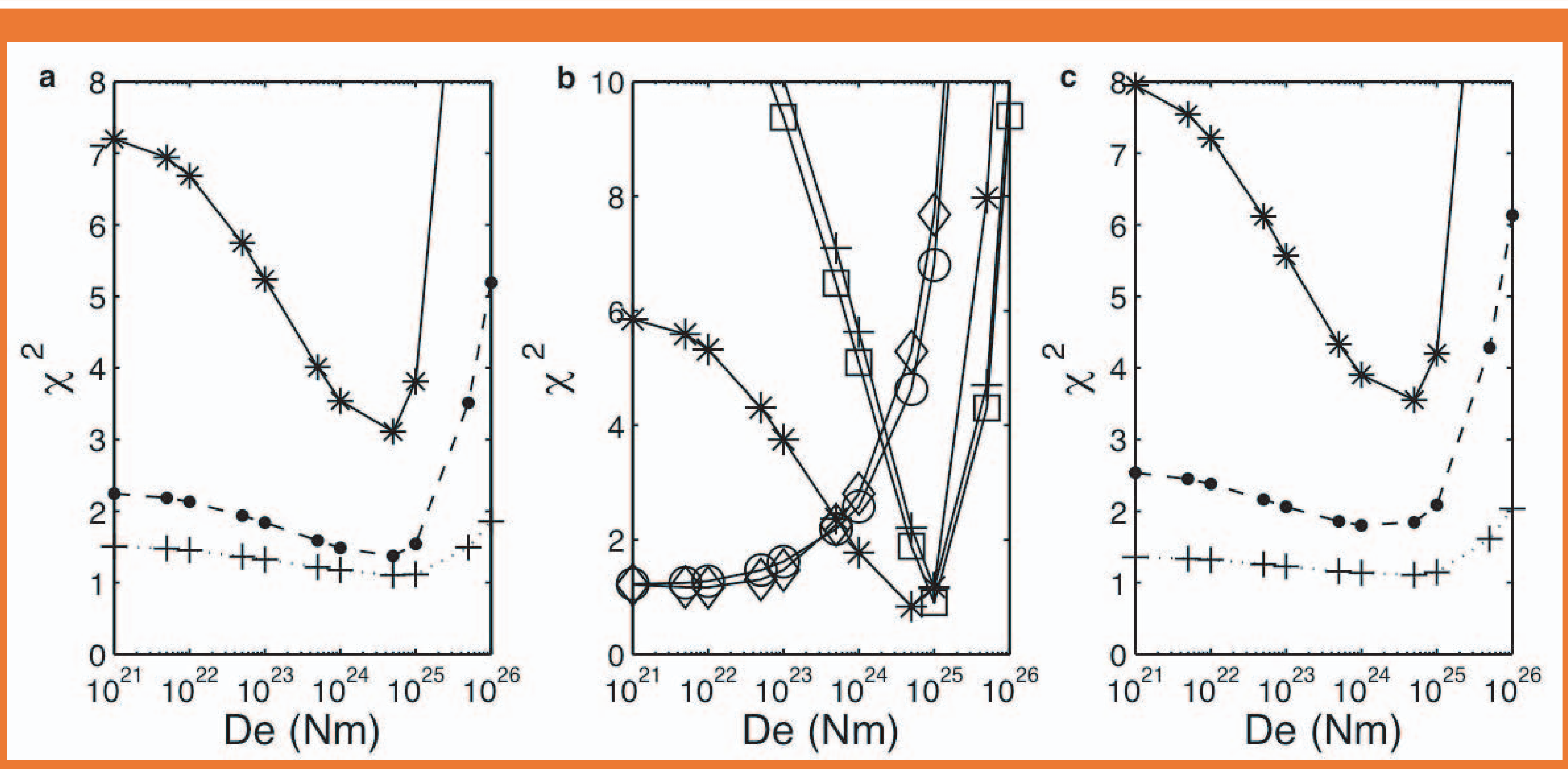


Fig. 3: Results of 1D inversion, hence D1e=D2e=De (Fig. 2). The misfit is calculated with a χ2-formula. a: misfit for 5%, 10% and 20% noise in the data. b: same for data with 5% noise from specific directions only resulting in minimum misfit when the local strength equals De. Now the χ2-value approaches one unlike in plot a for 5% noise indicating that a single strength for the domain cannot reproduce the data well. c: same as a, but now for an ice history prescribed every 500 years instead of using the full dynamical model. Results are clearly worse.

2D:

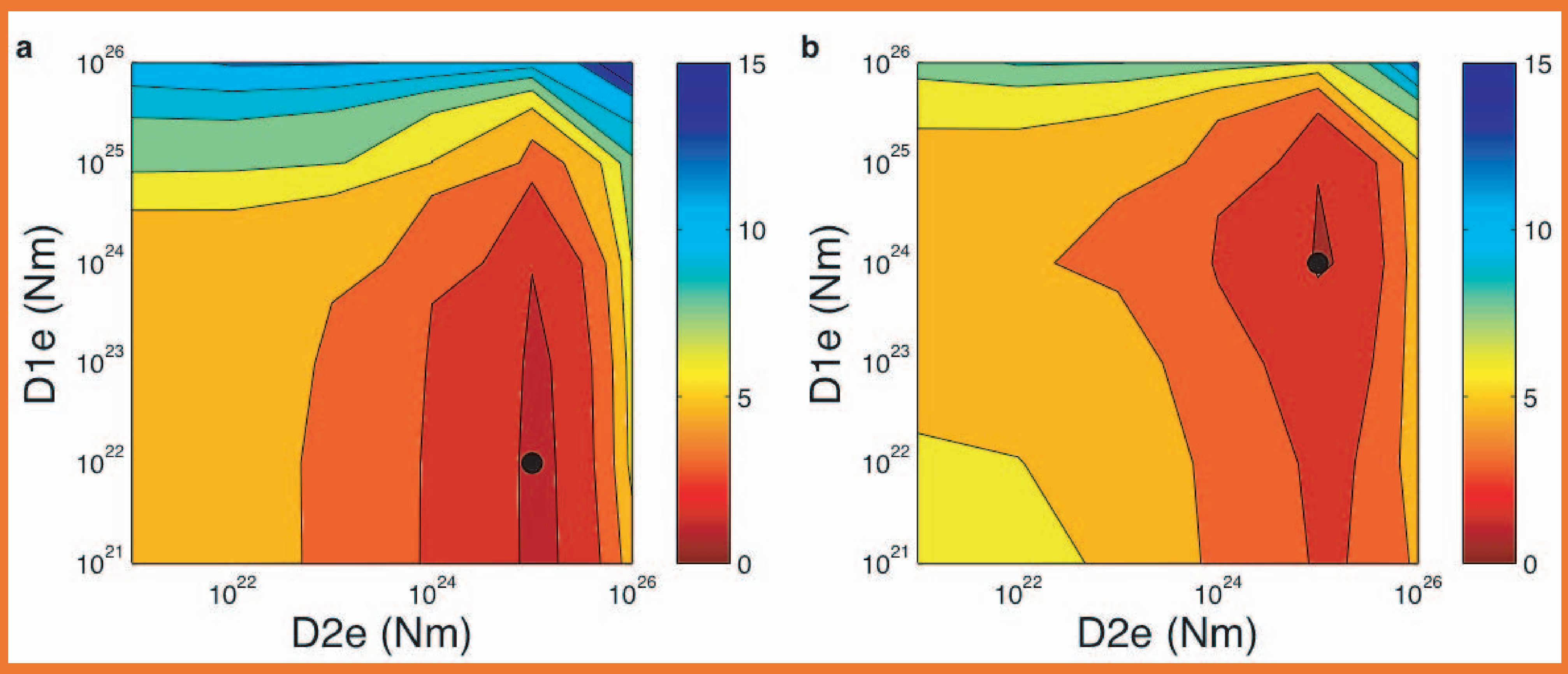


Fig. 4: Results of 2D inversion. a: χ2-values for a true transition in the middle of the domain. b: same for a true transition moved 150 kilometers to the left. The location of the minimum is now shifted, but the corresponding χ2-value is similar to the minimum in plot a. Clearly, a 2D inversion performs better than a 1D inversion. However, locations of transitions in strength cannot be resolved.

Ref: J. van den Berg, R.S.W. van de Wal and J. Oerlemans (2006). Recovering lateral variations in lithospheric strengths from bedrock motion data using a coupled ice sheet-lithosphere model. J. Geophys. Res., 111, B05409, doi:10.1029/2005JB003790.