Constraining the evolution of a dynamic 3D thermo-mechanical ice sheet model using relative sea-level records

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Introduction

Computer simulations of past ice sheets can be treated with increased confidence if they can be favourably compared with different strands of independent data.

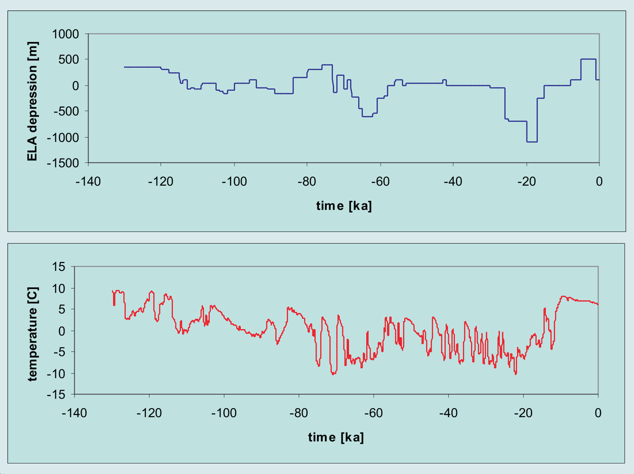
The aim of this research is, therefore, to derive a methodology, that compares relative sea level records with simulations of past sea level that result from modelling past ice sheets with a dynamic, high-resolution thermo-mechanical ice sheet model coupled to an isostatic adjustment model.

Relative sea level during the Quaternary is mainly affected by a) changes of water volume (sea water is stored in/released from ice sheets) and b) isostatic adjustment of the lithosphere due to changing surface loads. The ice sheet model is driven by a climatic forcing function determined so that the simulated ice sheet resembles the past ice sheet as reconstructed from geomorphological evidence. The Earth is approx-imated by a thin elastic plate (the lithosphere) above a relaxed half space (the mantle). Changes in water volume are derived from a global sea level curve and enter the model as a forcing function. This coupled ice sheet/isostatic rebound model is used to simulate the evolution of the Fennoscandian ice sheet during the last glacial cycle. Relative sea levels calculated by the simulation are compared to relative sea level records. This comparison provides an important constraint on the thickness of past ice sheets which is otherwise rarely available.

Mismatches of the simulation with the relative sea level data indicate shortcomings of the model forcing. However, this approach illustrates the benefit of using a model coupling realistic ice physics to a realistic Earth model to help constrain unknowns of Earth rheology and ice thickness. Ultimately, relative sea level data together with other strands of data, such as geomorphological evidence, and a coupled ice sheet/isostatic rebound model can be used to infer past climates.

Climatic Forcing

the model is forced by surface temperatures and the position of the equillibrium line altitude. Both fields are assumed to vary with latitude and time only.

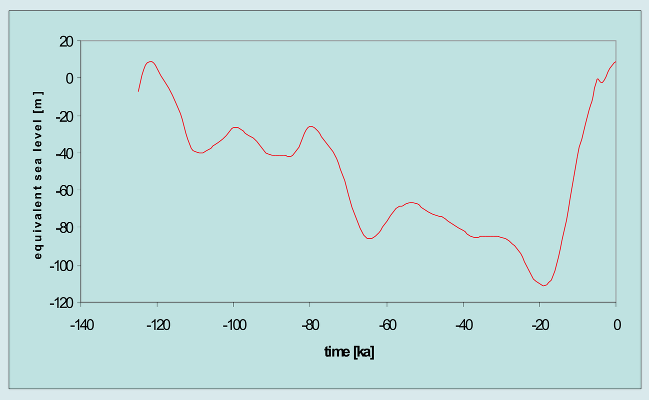


ELA forcing, determined by fitting the extent of the model along a transect in the SW quadrand

Temperatures at 60degN based on GRIP core

Equivalent Sea Level Change

Sea–level change due to changing surface loads is calculated by the isostatic rebound model. However, the global equivalent sea–level component cannot be calculated by the model, since only the past European and British ice sheets are simulated. A record of equivalent sea–level change is, therefore, needed as an external forcing function.



This data set is based on SPECMAP and sea-level obser-vations from the Huon Peninsula and Barbados

Ice Sheet Model

- ❍ three-dimensional, fully coupled thermo-mechanical model based on the shallow ice approximation:

$$\frac{H}{t} \quad (\mathbf{v}H) \quad M \quad S \qquad \frac{T}{t} \quad \frac{k}{{}_i c_p} \, {}^2 T \quad \mathbf{v} \quad T \quad \frac{}{{}_i c_p}$$

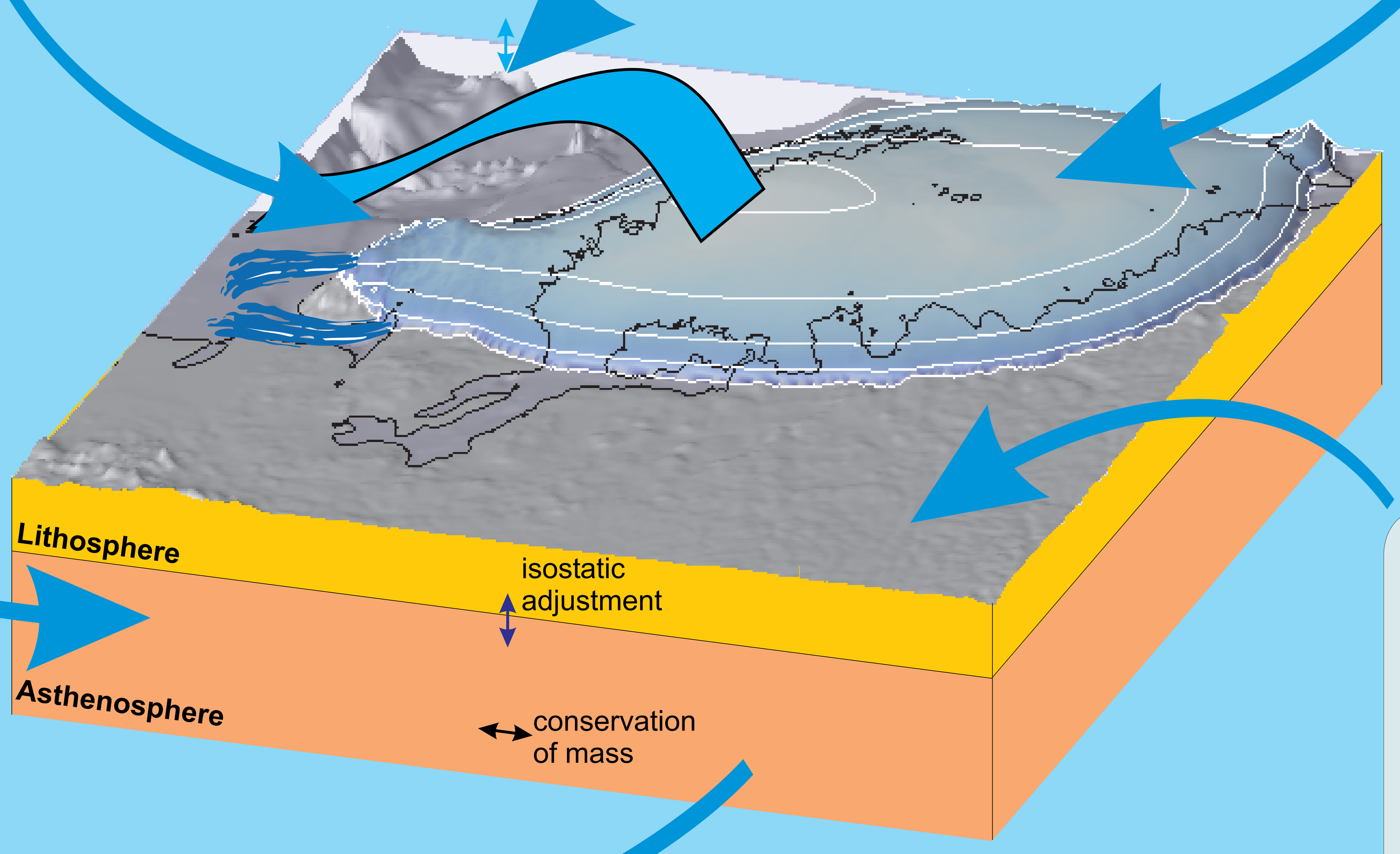
- ❍ run on a 281 by 236 grid with a spacing of 10km
- ❍ sliding law depends on basal temperatures (sliding is switched on when temperatures are at the pressure melting point of ice) and the gravitational driving stress:

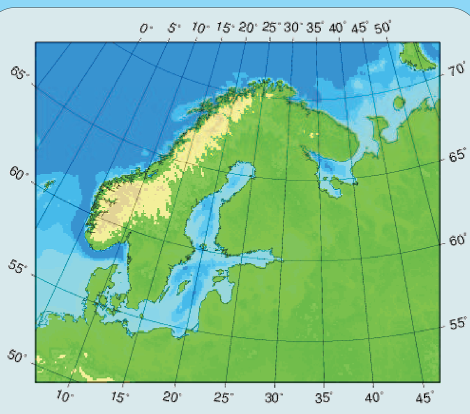
$$\mathbf{v}_b \quad (H \;\; (H \quad h))^3$$

- ❍ finite difference model written in F95 and parallelised using MPI

Earth Model

- ❍ The Earth is approximated by a thin elastic layer floating on top of
- ❍ relaxed half space (the asthenosphere)
- ❍ The model takes into account changing ice and water loads.
- ❍ Parameters for the simple approximation were found by fitting its behaviour to a full spherical self-gravitating Earth model.



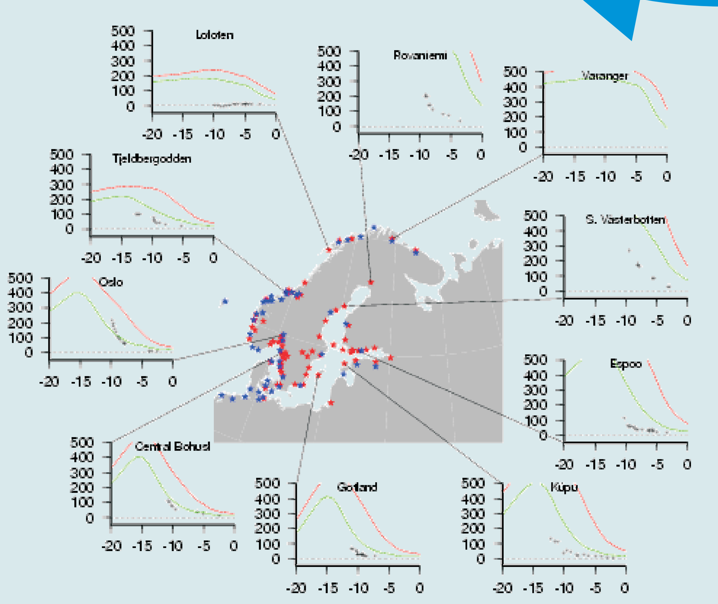


Bedrock topography used based on GTOPO30 and ETOPO5 projected on a grid with a resolution of 10km

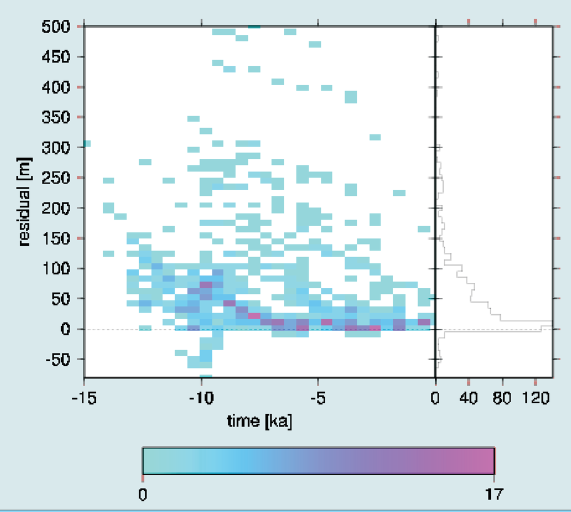
Results

Sea level curves for a number of selected sites.

- ❍ model fit in the SW qudrant is relatively good. Modelled ice sheet is fitted to geological reconstruction of the extent in this region
- ❍ large discrepancies in NE suggest shortcoming of mass balance forcing



The histogram shows differences between modelled SLC and observations. In addition the the large misfit in the NE, a timing problem of the modelled LGM becomes apparent.



Conclusion

- ❍ tools for comparing relative sea level observations and modelled relative sea level change were developed
- ❍ although the fit could certainly be improved,
- ❍ the misfit can be used to improve simulations. It clearly suggests shortcomings of the model forcing and timing
- ❍ RSL data are a good benchmark for ice sheet models since it is easy to define the quality of the fit

Future Work

- ❍ come up with a scheme to automatically adjust ice sheet forcing in order to improve the model fit
- ❍ add different strands of evidence of past ice sheet activity