Simulation of the Fennoscandian ice sheet during the last glaciation using a high-resolution ice sheet model

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1. Introduction

We attempt to integrate three strands of knowledge:

- the varying extent of the ice sheet in time derived from geological data,
- the isostatic rebound history of the region
- and fully coupled model reconstructions of the ice sheet and the lithosphere.

Simulations of the Fennoscandian ice sheet during the last ice age (120ka BP to present) are carried out using a high-resolution thermo-mechanical ice sheet model coupled to an isostatic adjustment model. The model predicts thermal conditions at the ice base, location and magnitude of ice streams and overall flow patterns. The ice sheet is initially driven with estimated values for ice rheology, effective lithospheric thickness and basal sliding and uses climate functions constructed from palaeoclimatological proxy data. The initial climate forcing is then adjusted using an inverse procedure such that the modelled glacial limits match those reconstructed from geological data.

2. The Model

Ice Sheet Model

- 281 times 236 nodes grid with 10km node spacing
- shallow ice approximation:

$$\frac{H}{t} \quad {}_{H} \quad \bar{\mathbf{v}}H \quad M \quad S \qquad\qquad \frac{T}{t} \quad \frac{k}{{}_{i}c_{p}} \quad {}^{2}T \quad \mathbf{v} \quad T \quad \frac{}{{}_{i}c_{p}}$$

- binary sliding law
- implemented in F95 and parallelised using MPI

Earth Model

the Earth's adjustment to changing surface loads is approximated using a two layer model:

- elastic plate (the lithosphere) above
- a relaxed half-space (the mantle)
- updated every 1000a

3. Model forcing

Global sea level curve is derived from the SPECMAP data set.

Temperature curves at a latitude of 60degN based on the GRIP core (S-10 and S-15) and paleoclimatic reconstructions along a transect through Europe (standard)

ELA depression as determined by fitting the modelled ice sheet extent to geologic reconstructions along a profile (see Figure 2)

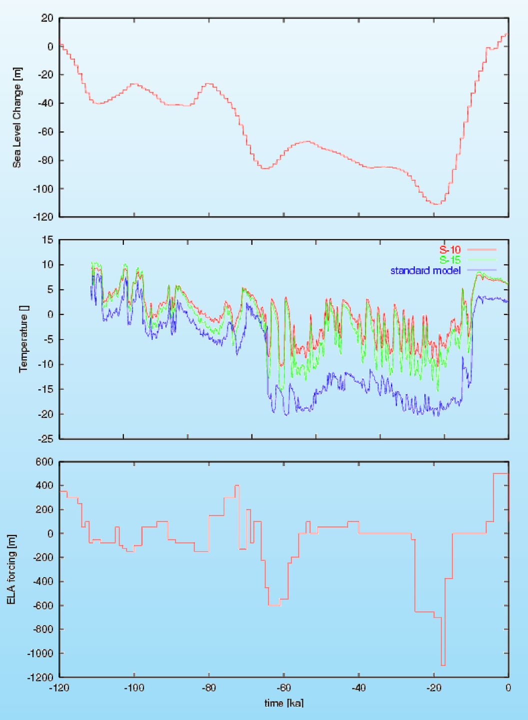

Figure 1: Climate forcing functions used for the model run.

4. Ice Sheet along Transect

- ELA was adjusted so that modelled ice extent is matched with geological reconstruction. This process was very time consuming it required running the model for 5ka, checking the output, modifying the ELA and hotstarting the model again
- standard ELA function is used for all model runs
- S-10 and S-15 are warmer than standard temperature, however produce the same max extent

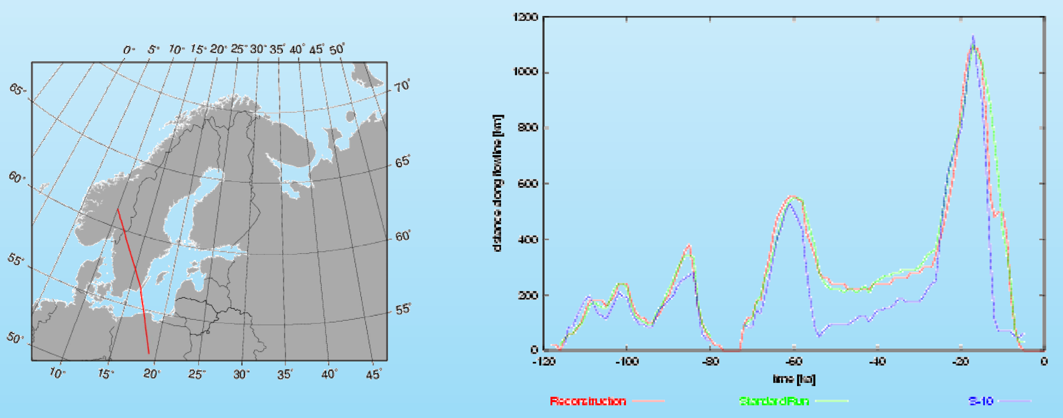

Figure 2: a) Map of Northern Europe showing the location of the profile. b) Ice sheet extent of the reconstructed ice sheet, the standard experiment and the S-10 experiment along profile.

5. Sea Level Change

Sea level change due to ice loading.

- SLC curves match observations in SW reasonably well
- bad match in the North. Ice sheet does not decay until very late (see Ice Sheet evolution)

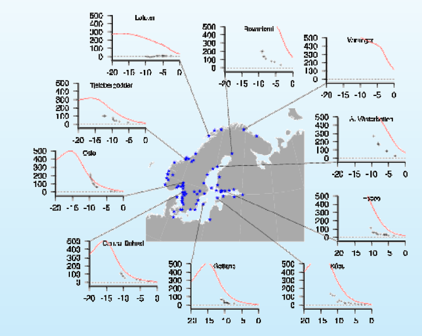

Figure 3a: SLC for selected sites

Plot showing observed versus calculated sea level changes; size of sphere indicates aga; colours indicate different sites. Overall, the model produces too thick an ice sheet.

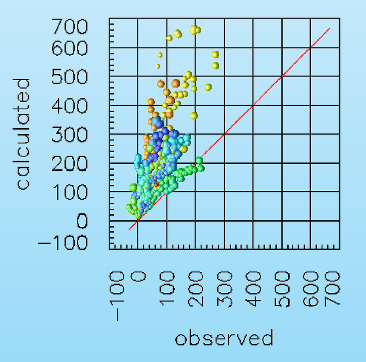

Figure 3b: observed SLC versus modelled SLC

6. Sliding and basal temperatures

- sliding is triggered when basal temperatures reach melting point of ice
- sliding is proportional to power of gravitational driving stress
- preferentially occurs where topography is depressed

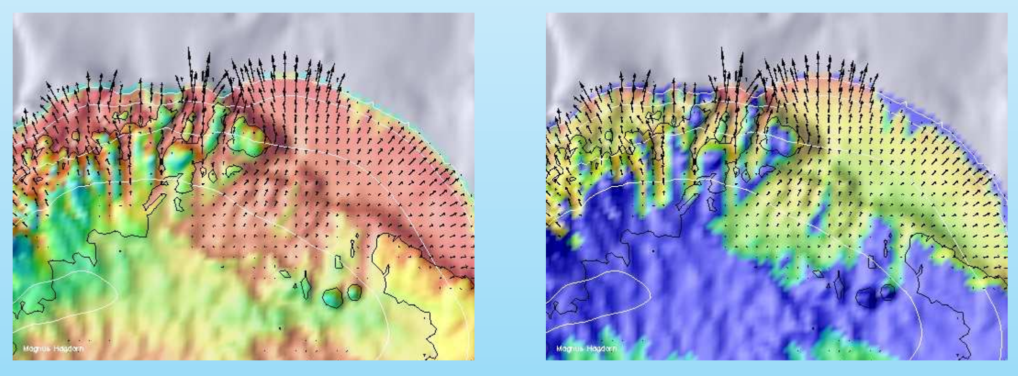

Figure 4: a) Temperatures at the ice base (red - warm, blue - cold). b) basal velocities on a log scale (blue - zero velocity, yellow - high velocities ~km/a)

7. Ice Sheet Evolution

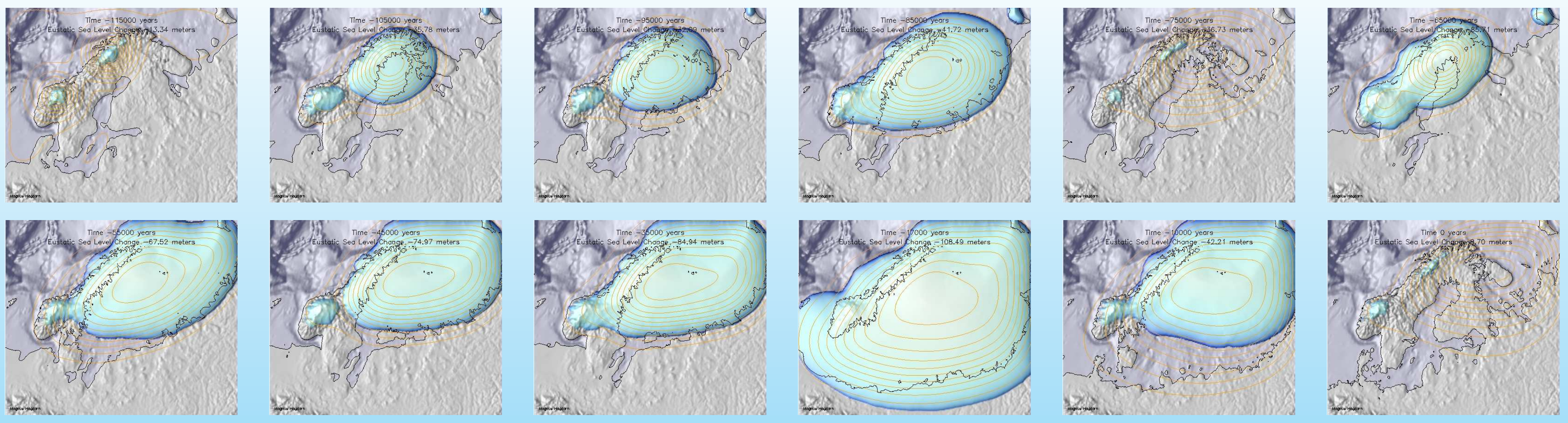

Figure 5: Time slices showing ice surfaces of the S-10 experiment. Orange contours show the geometry of the glacio-isostatic sea level change.

8. Conclusions

High-resolution ice sheet models can be used to combine geological observations, such as ice extent, locations of ice streams and relative sea level data, to form a coherent picture of the system.

- The modelled ice sheet matches both the geological data along the transect and the isostatic rebound data in the SW reasonably well.
- The match in the North is very poor since the ice sheet is unconstrained there, suggesting problems with the climate parameterisation. New model runs with different climate forcing reduced the ice sheet extent in the NW, thus producing a better fit with rebound data.
- An automated inversion procedure is very much needed, since adjusting the ELA forcing function is very time consuming.

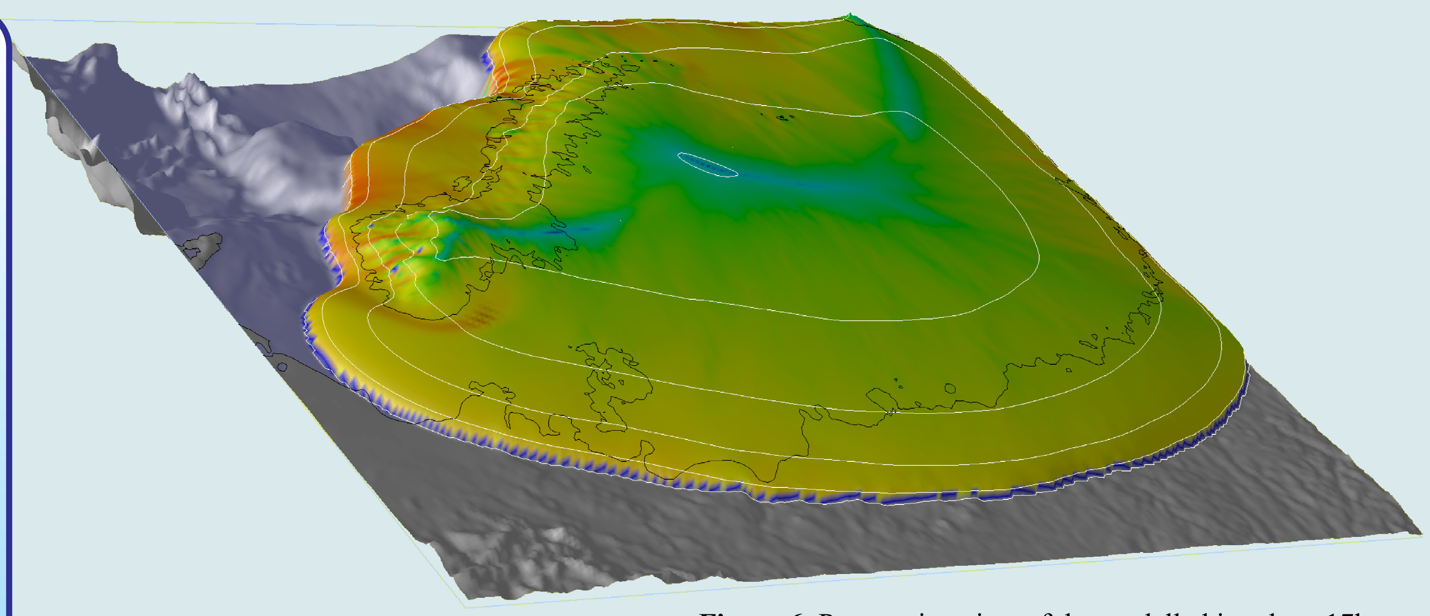

Figure 6: Perspective view of the modelled ice sheet 17ka BP. The colours show the magnitude of the surface velocities (red - fast, blue - slow). The Norwegian channal ice stream can be clearly seen.