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Fennoscandian paleo-environment and ice sheet dynamics during Marine Isotope Stage (MIS) 3

Report of a workshop held September 20–21, 2007 in Stockholm, Sweden

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Preface

This document compiles information on the paleoenvironment for a specific part of the last glacial cycle. The information is relevant for the analysis of climate and climate related processes in the safety assessment SR-Site. In particular, the information was used in setting up climate model simulations performed for SR-Site.

The aim of the report is to summarize the state of knowledge on a selected period during the Weichselian glaciation, as presented and discussed during a workshop arranged by SKB in September 2007. The participants of the workshop comprised most of the researches working on this period in Fennoscandia. In the report, the workshop participants have written their own abstracts and also directly contributed to the discussion and conclusions. Considering this aim and content of the report, it was not useful for this document to undergo the SR-Site review process.

Stockholm, September 2008

Jens-Ove Näslund
Person in charge of the SKB climate research programme

Contents

1 Introduction

1.1 Background

This report is a documentation of the two day workshop on *Fennoscandian paleo-environment and ice sheet dynamics during Marine Isotope Stage 3 (MIS 3)* arranged by the Swedish Nuclear Fuel and Waste Management Company (SKB), together with the Rossby Centre at the Swedish Meteorological and Hydrological Institute and Stockholm University.

The organizing committee of the workshop consisted of Jens-Ove Näslund (SKB), Barbara Wohlfarth (Stockholm University), Erik Kjellström (Rossby Centre), Jenny Brandefelt (Royal Institute of Technology, Stockholm) and Gustav Strandberg (Rossby Centre). The workshop was held at Villa Söderås on Lidingö, Stockholm.

SKB is responsible for the management of spent nuclear fuel and radioactive waste generated within the Swedish nuclear power program. Detailed site investigations for a deep geological repository for spent nuclear fuel have been carried out in the Forsmark and Oskarshamn regions along the Swedish Baltic Sea coast (Figure 1-1). Within the coming years, SKB will submit an application to build a deep geological repository at one of these sites. An important document in this application is a detailed assessment of long-term repository safety.

The deep geological repository will keep radiotoxic material separated from humans and the surface environment for 100,000 years and more. It is not possible to predict climate development in a 100,000 year time perspective. However, the extremes within which climate in Sweden may vary can be estimated with reasonable confidence. Within the limits defined by glacial and interglacial states, a number of characteristic climate conditions can be identified.

***Figure 1-1.** Location of the two candidate sites for a Swedish geological repository for spent nuclear fuel, Forsmark and Laxemar, and the Finnish repository site Olkiluoto.*

These climate conditions can be represented as *climate domains* /SKB 2006a/, and are defined as *climatically determined environments in which a set of characteristic processes of importance for repository safety appear together.* Three such climate domains have been identified and defined; i) a temperate climate domain, ii) a permafrost climate domain, and iii) a glacial climate domain (Figure 1-2). The purpose of identifying these domains is to create a framework for the assessment of issues which are of importance for repository safety associated with particular, climatically determined environments that may occur in Sweden. It is likely that all three climate domains will appear during the next 100,000 years, i.e. all reasonable climate evolutions included in the safety assessment will have to cover these domains. For a more detailed description of the climate domains and how they are used to construct site specific climate developments for the safety assessment, see /SKB 2006ab/.

In SKB:s last safety assessment, SR-Can, a reference climate evolution based on a reconstruction of conditions during the last glacial cycle was constructed using the above climate domains /SKB 2006b/ (see also section 2.1). This reference scenario represents a conceivable evolution and covers climate-related conditions and sequences of importance for repository safety that may be expected in a 100,000 year time perspective. Here it is important to note that there may be other climate developments which may have a stronger influence on repository performance than those reconstructed for the last glacial cycle. Therefore a number of additional climate evolutions are also analyzed in the safety assessment in order to cover the whole range of climate variations expected in the coming 100,000 years. These additional climate developments include e.g. a climate evolution with a warmer climate caused by an increased greenhouse effect, and an evolution dominated by cold and dry climates favouring permafrost growth /SKB 2006b/.

Figure 1-2. *Simplified picture exemplifying an areal distribution of the glacial, permafrost and temperate climate domains mentioned in the text.*

1.2 The 100,000 year climate conditions project

In 2006 a project was initiated with the aim of identifying and describing climatic extremes within which climate may vary in Sweden over a 100,000 year time span (see section 2.2, 2.4, 2.5, /Kjellström et al. 2008, Strandberg et al. 2008/). Based on forcing conditions which yielded extreme climate conditions during the last glacial-interglacial cycle, climate models are applied to produce climate variables for those climate situations. Three selected steady-state periods are simulated; i) a period within Marine Isotope Stage 3 (MIS 3), representing a cold and relatively dry period with a restricted ice sheet coverage over Fennoscandia (corresponding to e.g. Greenland Interstadial (GIS) 12 or 8 (47,000–45,000/38,000–37,000 years before present), ii) the Last Glacial Maximum (LGM) around 21,000 years before present, with an extensive ice sheet covering large parts of northern Europe and northern Eurasia and iii) a warmer climate with doubled atmospheric CO_2 concentration and a complete melting of the Greenland ice sheet. Boundary conditions for the LGM and GIS 12 or 8 scenarios are derived from paleoclimate proxy data and model data sets.

The climate modelling involves a global model, CCSM3 /Collins et al. 2006/ for producing boundary conditions that are then used by a regional climate model, RCA3 /e.g. Kjellström et al. 2005/. The horizontal resolution in CCSM3 is approximately 250 km (T42) in the atmosphere and 1° in the ocean, while in RCA3 the horizontal resolution is 50 km. Climate forcing conditions are taken to be as similar as possible in CCSM3 and RCA3 albeit with more regional detail in RCA3 when applicable (Appendix B). In addition to the standard set-up for each climate type, several sensitivity experiments are carried out. These consider e.g. a more realistic vegetation for the LGM and for the warm case and one experiment with increased dust load at LGM.

The regional climate model produces detailed information on climate variables such as near-surface air temperature and precipitation for Europe. Climate model output will be compared to other existing terrestrial and marine paleoclimate proxy data. For the studied cases, data on relevant climate parameters are extracted from the regional model for the Forsmark and Oskarshamn regions. Results from the project, in the form of regional climate model data for different climatic extremes, will be available for further studies in other projects within the SKB safety assessment programme.

To obtain good model set ups, it is important to have a good approximation of the extent and thickness of Northern Hemisphere ice sheets and sea-level during LGM and MIS 3 (GIS 12/8). The configuration of the ice sheets has a strong influence on the large-scale atmospheric circulation in the global model, which in turn determines the main features of the climate in the regional model. In addition to the impact on large-scale circulation, also the surface characteristics are strongly influencing the regional climate. In particular, differences in surface properties in areas covered by ice/snow or vegetation lead to fundamental differences in the representation of climate variables in the models. The regional and local features of the ice sheets and land surface properties are particularly important for the regional climate model. However, estimations of the timing, dynamics, extent and thickness of the ice sheets (Laurentide and Fennoscandian) during MIS 3 (GIS 12/8) are fragmentary and in some cases contradictory.

1.3 Purpose of the workshop

To be able to model a MIS 3 (GIS 12/8) scenario in the global and regional climate models as realistically as possible, the most recent and up-to-date knowledge on ice sheet extent, timing and thickness need to be used. The aim of the workshop was therefore to gather scientists who are working with MIS 3 related issues in Fennoscandia and to discuss and evaluate available information derived from field studies and ice sheet modelling.

The workshop focussed on the following overall questions:

- Is it possible to obtain a consistent picture of ice extent, sea level, topography, permafrost and vegetation during MIS 3 (and GIS 12/8 specifically), based on paleo data and ice sheet modelling that can be used as realistic input for climate model simulations?
- Do simulated climates in global circulation models correspond to the paleoenvironmental and paleogeographic picture? How can discrepancies between model results and palaeodata be explained?

Specific MIS 3 topics that were addressed were:

- Ice configurations in Fennoscandia, the Alps, North America, Russia (dynamic ice sheet behaviour and ice streaming in Fennoscandia).
- Topography and coastlines (incl. sea-level changes, isostasy, Baltic Sea during MIS 3).
- Vegetation zones in ice free areas (including tundra and permafrost distribution).

The workshop is related to the *Workshop on Weichselian glaciation history in Scandinavia – focus on glacial fluctuations prior to Last Glacial Maximum,* arranged by SKB at Stockholm University on March 15, 2005. A report on ice marginal fluctuations during the Weichselian, with conclusions from the 2005 workshop, can be downloaded at http://www.skb.se/upload/publications/pdf/TR-06-36webb.pdf.

The present report summarizes the presentations and discussions held during the 2007 workshop on *Fennoscandian paleo-environment and ice sheet dynamics during Marine Isotope Stage 3.* The main part of the report consists of abstracts for each presentation written by the individual contributors. Each abstract is followed by a summary of the presentation and a summary of the following discussion. The summaries were drafted by Barbara Wohlfarth and Jens-Ove Näslund. Finally, the report presents the discussions and conclusions on the present knowledge for MIS 3 in Fennoscandia with a focus on the topics listed above.

1.4 Workshop participant list

Participant	**Affiliation**
Helena Alexanderson	Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden*
Jenny Brandefelt	Royal Institute of Technology, Stockholm
Karin Helmens	Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden
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Jan Lundqvist	Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden
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* Temporary address: Department of Plant and Environmental Sciences, Norwegian University of Life Sciences.

2 MIS 3 – modelling: abstracts and presentations

2.1 Näslund J O: Introduction with background on SKB's assessments of nuclear repository long-term safety

The Swedish Nuclear Fuel and Waste Management Company plans to build a geological final repository for spent nuclear fuel in Sweden. In about 100,000 years, the radioactivity of the spent fuel will decline to a level comparable with the level from the uranium ore that was used to manufacture the nuclear fuel. The final repository must therefore function for at least 100,000 years, i.e. corresponding to the time period of one glacial cycle. In this context, SKB needs to study climate related processes during a 100,000 year cycle. These processes include e.g.:

- Maximum hydrostatic pressure at repository depth.
- Oxygen content and salinity of ground water.
- Glacially induced earthquakes.
- Maximum permafrost depth.

Forsmark and Oskarshamn have been selected as candidate sites for a final repository. Within a few years a decision will be made regarding which of the two sites that will be selected for an application to build the repository. In addition, safety assessments are also performed on a 100,000 year time scale for SKB's existing repository for low- and intermediate level nuclear waste in Forsmark /SKB 2008/.

In SKB's assessments of long term repository safety, a quantitative risk analysis is made. The safety assessments are based on relevant future climate scenarios. In the last safety assessment for the final repository of spent nuclear fuel, SR-Can /SKB 2006b/, the effect of several climate developments was analysed. To this end, numerical modelling studies of ice sheets, shore-level displacement and permafrost were conducted /SKB 2006a/. The results were used to construct a number of relevant climate developments, including 1) a reference evolution for the coming 100,000 years, which comprises a repetition of reconstructed conditions during the last glacial cycle, and 2) a scenario with an increased greenhouse effect. Based on the reference evolution, several other climate developments were also analysed, including one with climate conditions very favourable for permafrost growth.

In order to test how realistic the climate developments are which are used in SKB's safety assessment work, climate model simulations have been initiated (see section 1.2, 2.2, 2.4 and 2.5). For instance, realistic climate conditions assumed in the scenario and which are exceptionally favourable for permafrost growth /SKB 2006ab/ can be studied by climate model simulation of a cold and dry climate period in the past, when supposedly severe permafrost conditions occurred. Such a time interval is for example MIS 3, i.e., the period that preceded the Last Glacial Maximum ~ 18–20 thousand years (ka) ago. In order to obtain climate model simulations for one selected part of MIS 3, we need constraints on the climate, sea level, ice sheet configuration, paleogeography, etc during MIS 3 (section 1.2). The aim of the present workshop was to discuss these specific issues for MIS 3 in order to provide input to the climate modelling that will be conducted.

In addition, model simulations of extreme climates during the last glacial cycle are important for SKB's safety assessments in order to improve the knowledge on how climates may vary over a 100,000 year time scale.

2.2 Kjellström E: Climate conditions in Sweden in a 100,000 year time perspective – project overview

ABSTRACT. The project intends to study the climatic extremes within which the climate may vary over a 100,000 year time span. Based on forcing conditions which have yielded extreme conditions during the last glacial-interglacial cycle we apply climate models to reproduce climate variables in those climatic extremes. Information about forcing conditions is taken from models and palaeo data (e.g., ice cores). Forcing factors that are considered involve: insolation, atmospheric greenhouse gas content, extent of ice sheets, distribution of land and sea, topography, bathymetry, and vegetation. Three periods are studied: i) a period within MIS 3 representing a cold period with a relatively small ice sheet covering the Scandinavian region and presumably intensive permafrost in ice free areas of Sweden, ii) the Last Glacial Maximum with an extensive ice sheet covering large parts of northern Europe and iii) a future period in a warmer climate characterised by high greenhouse gas concentrations in the atmosphere and a complete loss of the Greenland ice sheet. The climate modelling effort involves a global model (CCSM3 from NCAR, USA) for producing boundary conditions that are used by a regional climate model (RCA3 from the Rossby Centre, SMHI). The regional model in turn provides detailed climate information at a horizontal resolution of 50 × 50 km in a domain covering Europe. Climate variables like near-surface air temperature and precipitation is standard output from the regional model. This output will be compared to existing paleodata in an effort to make a rudimentary evaluation of the model for the different types of climate. Emphasis is on Scandinavia but paleodata from other parts of Northern Europe will also be considered. For the studied periods, data on relevant climate parameters will be extracted from the regional model for the Forsmark and Oskarshamn regions, to be used in SKB's safety assessment work.

Used forcing conditions and model results, both from the global and regional climate models, will be documented and reported within the project. Results from the project in the form of regional climate model data for different climatic extremes will be available for further impact studies in other projects.

Summary of presentation on "Overview of 100,000 year climate modelling project"

The main project objective is to identify the extremes within which climate can vary on a 100,000 year time interval in the future. Three types of climate scenarios were chosen:

1. Restricted ice sheet configuration and extensive permafrost.
2. Dominating glacial conditions with extensive ice sheets over Northern Europe.
3. Warmer than present temperate climate conditions with a complete loss of the Greenland ice sheet.

Global and regional climate models are used in the project. The regional model uses input from the global model. The regional model is much more detailed, with mountain chains and the Baltic Sea relatively well represented (Figure 2-1). The planned steady-state model simulations are a good tool for analyzing climate extremes.

The following initial and forcing conditions are needed for both models (information should be similar for both models) (Appendix B):

- Astronomical forcing following the Milankovitch theory. It is assumed that the intensity of the sun is identical to today's conditions.
- Greenhouse gas concentrations are accounted for based on measurements from air trapped in ice cores.
- Aerosols.
- Ice sheet extent.
- Land/sea distribution.
- Topography, bathymetry.
- Vegetation.
- Sea level.

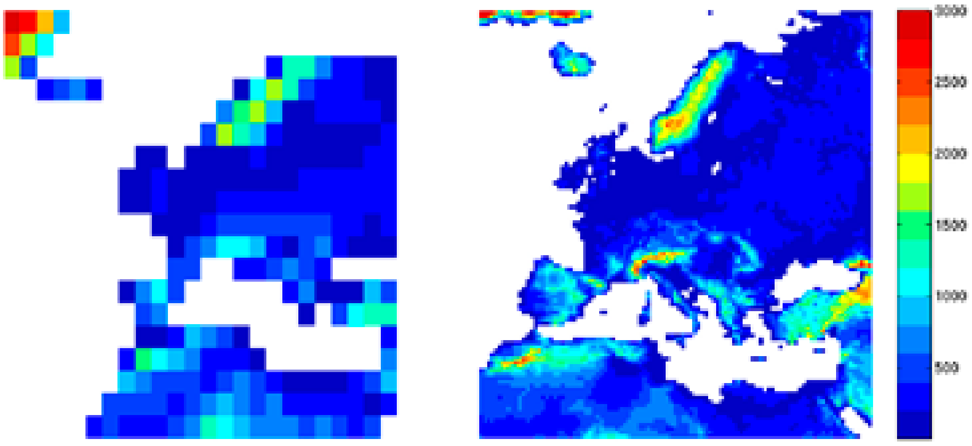

Figure 2-1. *Topography in the atmospheric part of the global (left) and regional (right) climate models CCSM3 and RCA3 for the permafrost (MIS 3) case. Note that the left figure only shows an excerpt of the global GCM model domain, while the right figure shows the full RCM domain. The colour scale represents the altitude in metres above sea level for each of the model grid boxes. The horizontal resolution of the global ocean model is higher and the Mediterranean Sea is not a lake in any of the two models.*

For the present workshop, the simulation of the cold *Permafrost case* is relevant. For this case study, we will identify extremes and validate results against paleodata. Other paleodata are used to determine and set the model forcings.

Results show that the LGM global model simulations give a climate that is up to ~ 7K colder than present /Brandefelt and Otto-Bliesner in press/.

2.3 Näslund J O: Examples of ice sheet configurations for MIS 3 from numerical ice sheet modelling

ABSTRACT. Examples of ice sheet configurations (global and regional over Fennoscandia) were presented. The compilation of results does not comprise all ice sheet modelling results for MIS 3, but a few examples. The two candidate periods for the MIS 3 climate simulations are Greenland Interstadial (GIS) 8 and 12, occurring at around 36 and 44 thousand years (ka) ago (ss09 timescale) /Johnsen et al. 1995/. Results for these time periods from four simulations of regional Fennoscandian ice sheet configurations were compared: i) /Hagdorn 2003/, ii) /Hagdorn et al. 2005/, iii) /Forsström 2005/, and iv) /Näslund 2006/.

The ice sheet models used in these simulations were for i) and ii) the GLIMMER model (GENIE Land Ice Model with Multiply Enabled Regions, originally developed by T. Payne); for iii) the SICOPOLIS model (SImulation COde for POLythermal Ice Sheets by R. Greve); and for iv) the UMISM model (University of Maine Ice Sheet Model, by J. Fastook). All models are ice sheet models with similar physics and thermodynamic descriptions. One major difference between the various simulations is the climate forcing method. /Hagdorn 2003/ and /Hagdorn et al. 2005/ use temperatures obtained from the Greenland Ice Core Project (GRIP) combined with European temperatures derived from other proxy data. /Forsström 2005/ uses Paleoclimate Modelling Intercomparison Project (PMIP) data (observed present-day climate and modelled LGM climate data scaled by GRIP data) as well as a modified PMIP-forcing /Kageyama et al. 2001/, while /Näslund 2006/ use exclusively GRIP temperatures.

A comparison of the different ice sheet configurations for MIS 3 made specifically for Fennoscandia reveal rather large variations in ice configurations (Figure 2-2). However, there are some common features: in all simulations the ice sheet coverage is restricted during this period, with southern Sweden free of ice and central Sweden basically ice free.

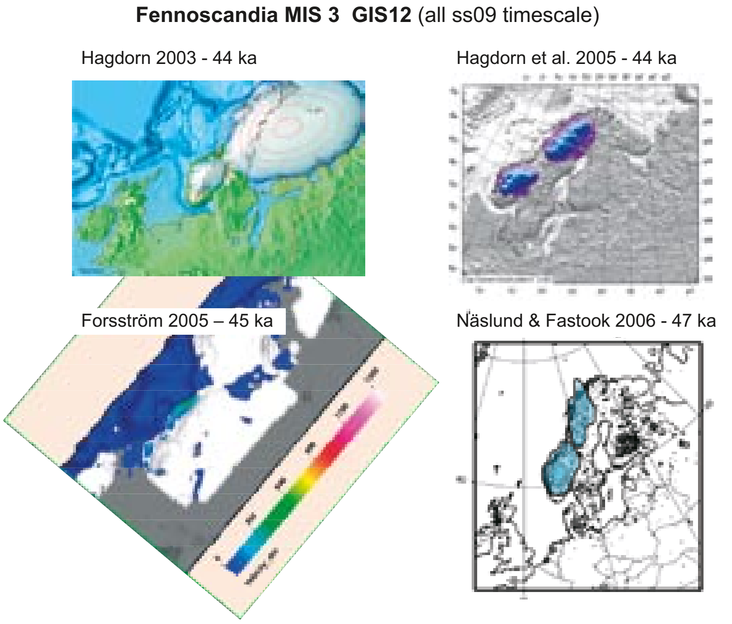

Figure 2-2. *Modelled MIS 3 Fennoscandian ice sheet configurations for 44–47 ka, all on the ss09 timescale /Johnsen et al. 2001/.*

The four models produce restricted ice configurations for MIS 3 (GIS 12) despite the different climate forcing methods (Figure 2-2). One thing to keep in mind, however, is that all climate forcing methods to some extent involve the same GRIP derived palaeo-temperatures.

The simulated *global* ice sheet configurations that were compared are comprised of: i) the coupled climate-ice sheet model simulation CLIMBER-2, made at the Potsdam Institute for Climate Impact Research /Calov et al. 2005/, and ii) the ICE-5G model by /Peltier 2004/. The ice sheet configurations (at –35 to –36 ka) clearly differ in these two simulations. The Laurentide ice sheet is thicker and higher in ICE-5G and has it highest point further west. ICE-5G also has a larger ice sheet over Fennoscandia and the Barents Sea than the CLIMBER-2 simulation.

As a next step, it is interesting to compare the result from the *global* MIS 3 ice sheet configuration for the Fennoscandian region with results from the *regional* Fennoscandian simulations. At –36 ka (GIS8) the coupled global ice sheet-climate model (CLIMBER-2) and ICE-5G have considerably larger ice sheets over Fennoscandia than in the regional simulations (Figure 2-3). In this comparison, it is also interesting to note that the regional simulation of /Forsström 2005/ and the global coupled ice sheet-climate model simulation of CLIMBER-2 use the same ice sheet model, but at around –35 to –37 ka the ice configurations differ considerably in the two modelling approaches (Figure 2-3). Which, if any, of the ice sheet configurations shown in Figure 2-3 are in line with geological observations?

Questions and comments

Kleman: The spatial mass balance forcing could play a role in the global models, e.g. where the "mass balance pole" is placed. Fastook places it over Greenland for Fennoscandian simulations. What is a realistic forcing of the spatial mass balance?

Kleman: The MIS 3 ice configuration in the Näslund/Fastook simulation seems ok with respect to present knowledge on Fennoscandian glacial history (the ice configuration in the presented simulations with the GLIMMER model seems not). There is no *geomorphological* evidence for ice configurations during MIS 3.

Näslund: Some of the presented Fennoscandian model simulations were calibrated against known ice margins (e.g. the simulation by /Näslund 2006/).

Mangerud: All glacial models get too much ice in northern latitudes.

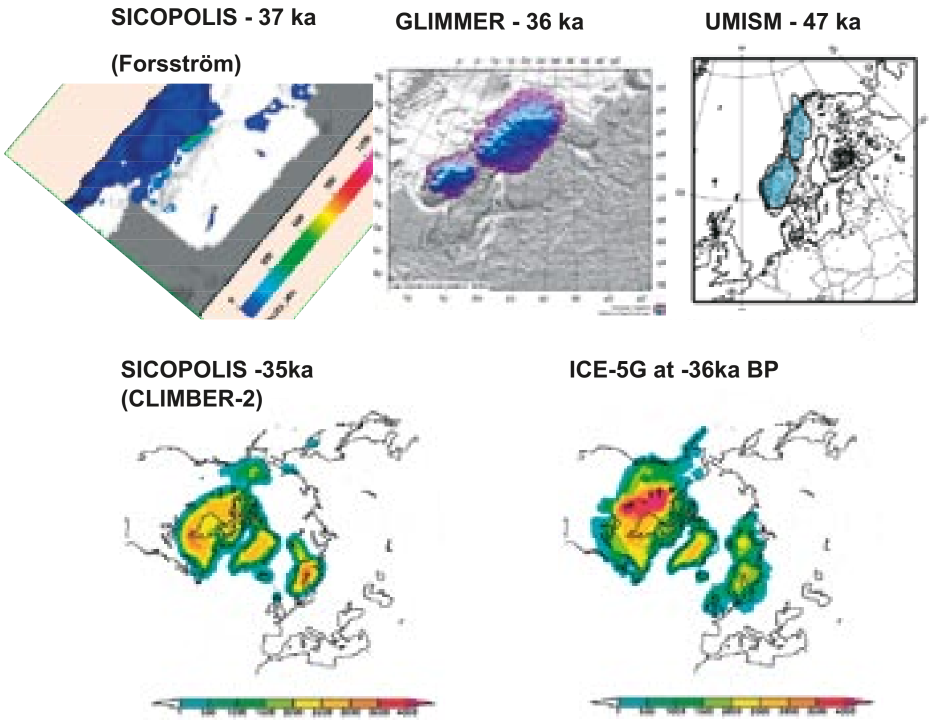

Figure 2-3. Comparison of simulated MIS 3 ice sheet configurations from regional and global modelling, all on the ss09 timescale /Johnsen et al. 2001/.

2.4 Brandefelt J: Simulations of global climate within the 100,000 year project

ABSTRACT. Simulations of three cases of extreme climate conditions for Sweden are performed:

i) Cold climate with an extensive ice sheet over Scandinavia.

ii) Cold climate with permafrost in Southern Sweden.

iii) Warm climate in which the Greenland ice sheet is assumed to have melted.

The simulated cold climates will be compared to paleo data from equivalent periods during the last 100,000 years; i) the last glacial maximum (LGM) around 21 thousand years (kyr) before present (BP) and ii) a period within Marine Oxygen Isotope Stage 3 (MIS 3).

The global simulations are performed with a coupled climate model with four dynamical components; atmosphere, ocean, land surface and sea ice. The forcings comprise: the solar constant, orbital year, greenhouse gas concentrations, aerosols and ozone are set constant. Greenhouse gas concentrations are taken from ice core data for the LGM and MIS 3 cases. Furthermore, the topography, bathymetry, sea level, vegetation and height and distribution of ice sheets are taken as boundary conditions for the simulations.

The cold climate simulation is chosen to represent the LGM. This choice is motivated by the Paleoclimate Modelling Intercomparison Project Phase II (PMIP2), within which several climate models have simulated the LGM climate. The boundary conditions are taken from the ICE-5G global ice sheet reconstruction /Peltier 2004/. This simulation has now (as of September 2007) been run for 1,050 years and appears to have reached an equilibrium with a Northern Hemisphere extra-tropical (30–90°N) annual mean surface temperature 13°C below present day conditions.

The permafrost climate is planned to be set to represent GIS8 around 35ka BP (on the ss09sea timescale developed by /Johnsen et al. 2001/ for the GRIP ice core). A combination of modelled ice sheets for this period is presented, which correspond to a sea level of –70 meters as compared to today. Input on the choice of period and forcings is welcome.

2.5 Strandberg G: Simulation of the European regional climate within the 100,000-year project

ABSTRACT. Only preliminary results from the regional model are available so far. The basics of regional modelling and the reasons to do it were presented. In a regional model (since the model domain is smaller than in a global model) one can afford a higher model resolution without using too much computer resources. A high model resolution is important to obtain a more detailed picture of the topography which affects the circulation in the atmosphere, but also the atmosphere itself. Frontal systems, cyclones and many other processes in the atmosphere, on the land surface and in the oceans are better represented in higher resolution. Still there are processes that are too small to be resolved even at a resolution of 50 km.

Output from the global model is used as input in the regional model. In that way the regional model takes into account what happens in the atmosphere outside the model domain. It also means that the features of the climate produced in the global model to some extent will also be present in the climate produced by the regional model.

When modelling the different cases in this project, not only the climate is different, but also the topography differs. The features of the land surface have to be considered in every grid point. Some particular questions are raised. Should ice sheets be modelled as mountains made of ice or mountains covered with ice? How should new land areas be represented in terms of albedo, soil type, vegetation etc? No answers were given, but some ideas of approaches were mentioned.

3 MIS 3 – information from geological observations: abstracts and presentations

3.1 Kleman J: The elusive MIS 3 ice sheet extents – geomorphological constraints, glaciological reasoning and research strategies

Summary of presentation "The elusive MIS 3 ice sheet extents – geomorphological constraints, glaciological reasoning and research strategies" (summarized by J-O Näslund)

Kleman discussed different aspects, such as ice volume, climate, topography, data types, geomorphology, preservation potential, available time, numerical modeling versus real data.

A possible analogue for a very restricted MIS 3 ice sheet in Fennoscandia could be the Barnes Ice Cap on Baffin Island. The Barnes Ice Cap would not re-form today if it were to be removed, i.e. we might look at the wrong places/processes.

Glacial geomorphology can not say anything about ice free periods. Information from ice free periods can only be retrieved from dating and stratigraphic work. The Fennoscandian and Laurentide ice sheets likely had active ice streams and these could potentially be traced in marine sediments and dated there. Thus there is a large potential for the future! Landform systems need to be dated to place them in time perspective/chronology, which can not be given by geomorphology. MIS 3 or other ice configurations need to be inbetween datable time slices in order to be dated. There is a larger preservation potential for early Weichselian endmoraines than for e.g. later MIS 3 endmoraines. MIS 3 endmoraines have a higher likelihood of being destroyed by subsequent wet based ice coverage.

Kleman reviewed different views on glacial history (Jan Lundqvist, Jan Mangerud), plus his own work and remarked that the research focus had been either on ice free periods or on ice covered periods, and that the drawback of these studies is their low resolution or non-existent chronology.

It is not possible, by ice sheet modeling, to simulate a 60 m sea level drop/ice volume for the early Weichselian (prior to 75 ka). Models cannot reproduce so much ice as implied by the general ice/sea level curve, which shows that there is a substantial temperature effect in the general curve.

Marginal moraines form when the ice margin stands still for hundreds of years. Any MIS 3 marginal moraines will be gone if the following ice was wet-based. The Fennoscandian topography and climate situation is fairly simple with mountains and the west wind belt, and basically the same conditions prevailed during the entire Weichselian glacial cycle.

North America is more complicated because of the Cordillera, which would first become ice covered. However a massive ice sheet was situated in the eastern part of North America. This eastern ice sheet has an own history with a certain element of freedom. The ice sheet could have changed its configuration and ice streams as seen by behaviour changes also between cycles e.g. appearance/disappearance in conjunction with Heinrich events. For the Laurentide ice sheet, the re-growth of ice, during subsequent cold phases, from remaining ice may give a completely new ice configurations and growth patterns.

For Fennoscandia we may need to think of new, different MIS 3 ice sheet configurations, based on new data. Questions to be asked are e.g., where could MIS 3 margins have been located? Corresponding to a 70–80 m of sea level drop, the MIS 3 margin would be where the LGM margin had been. If the Fennoscandian ice sheet was small, then the Laurentide ice sheet should have been very large. However it is unclear if there are any interstadials younger than MIS 4 in the Laurentide region.

Fennoscandian ice sheet

It takes ca 5 kyr for a complete deglaciation from an ice marginal position at the Polish coast. This occurred in a climate probably warmer than a MIS 3 interstadial. Ice build-up is precipitation limited and much slower than deglaciation. It takes ca 10 kyr to build up an ice sheet, i.e. during MIS 3 there was not enough time to melt and build up an ice sheet completely.

Comment by Näslund: Perhaps we may not need to consider a *complete* remove and build-up. This would support a not complete deglaciation during MIS 3.

Johan Kleman: Is there space for a remnant ice sheet somewhere (residual ice caps) for instance east of the mountain range (i.e. not complete deglaciation during MIS 3).

Laurentide ice sheet

Early Wisconsin ice sheets must have been built on successively larger interstadial ice volumes.

The "MIS 3 enigma": we need more dating of sites that can be linked to regional marginal positions. Geomorphology can contribute with overridden moraines, pointing to potential key sites and regions for stratigraphy.

Questions and comments

Mangerud: Rapid ice sheet fluctuations for the Fennoscandian ice sheet are possible, while the Laurentide was more sluggish. There was not much ice in Siberia, as seen by the presence of humans.

Kleman: Geomorphology can contribute with: 1) a focus on overridden marginal moraines instead of flow patterns, and 2) ideas of potential key sites/regions for stratigraphical studies.

3.2 Houmark-Nielsen M: MIS 3 ice streams and interstadial episodes in the south-western Baltic Basin

ABSTRACT. Marine isotope stage 3 (MIS 3, ca 60–25 kyr BP) displays rapid, high amplitude millennial scale climatic changes characterised by repeated episodes of sudden warmings triggering interstadial conditions, Greenland Inter Stadials (GIS 4-17), followed by gradual cooling until restoration of stadial conditions /NorthGRIP Members 2004, Huber et al. 2006/. Numerical models on the evolution of the Fennoscandian ice sheet during MIS 3 suggest a glacier configuration smaller than the Younger Dryas Fennoscandian ice sheet /Arnold et al. 2002, Boulton et al. 2001/.

However, there is evidence that ice-streams flowing through the Baltic Basin reached the north European lowlands during MIS 3 /Houmark-Nielsen 2007/. In southern Denmark, two Weichselian glacial advances took place prior to the Last Glacial Maximum (LGM, ca 27–17 ka BP): the Ristinge Stadial and the Klintholm Stadial. Clast provenance in till indicate glacier flow via the Baltic depression to Denmark by significant quantities of igneous and sedimentary rock fragments from easternmost Sweden and the Baltic Basin sea floor. Glacier expansion took place under relatively high glacio-eustatic sea level and ameliorated climate, which resemble the environmental conditions that ruled at the time of the Baltic ice streams at the end of MIS 6 and 2. The mechanism by which rapid flowing glaciers originating in the central Swedish uplands and the southern part of the Golf of Bothnia could reach the southern Baltic is controlled by several factors. The development of an "up stream" expanding zone of basal melting along a steep gradient ice sheet of restricted distribution could be triggered by abrupt climatic warming.

Such events are seen to end long time cooling cycles registered in North Atlantic Ocean cores /Bond et al. 1993/. Ice sheet instability is further enhanced by increased melt water production causing ice-bed decoupling over large areas. This may eventually cause marginal collapse and surging of those parts of the ice sheet that rest on soft, water saturated sediments deposited in ice-marginal melt water lakes in the Baltic Basin /Kjær et al. 2003/.

A crucial question though, is the age constraints and whether the two Baltic ice streaming events in Denmark follow the climate cycles recorded in the Greenland Ice Cores and the North Atlantic deep sea record. Thermo Luminescence (TL) and Optically Stimulated Luminescence (OSL) ages supplemented by AMS radiocarbon dating on inter-till clastic sediments and organic material suggest that these glacial episodes were relatively short lived (ca 5–8 kyr) and occurred at ca 55–50 kyr ago (Ristinge advance) and 35–30 kyr ago (Klintholm advance) /Houmark-Nielsen in press/. These ages point out two Bond Cycles of considerable duration: those initiated by GIS 14 and 8. Unfortunately, there is a considerable backlash in the age estimates (Figure 3-1). TL-dates are known to be underestimated by as much at 33% in age and OSL-ages, though considered close to a calendar time scale, are sparse in number. AMS-radiocarbon dates from sites where OSL-dating is available suggest a good matching of the two dating sets after adjusting ^{14}C ages to calendar scale /Houmark-Nielsen and Kjær 2003/. However, comparisons between several ^{14}C calibration curves for beyond 25 thousand years (kyr) before present (BP) indicate a gap of up to ± 5 kyr between oldest and youngest date /Not-Cal Group 2004/. This facilitates the matching of the two dating methods but reveals an unsatisfactorily dispersal of ages. The age for the Klintholm Stadial has recently been challenged by the dating of mammoth finds in central and northern Sweden (/Ukkonen et al. 2007/, section 3.7). Ages from areas that acted as deployment areas for Baltic ice streams overlap considerably. Though the above uncertainties in radiocarbon calibration leave some room for mammoth populations and Baltic ice streams to be separated in time there still seems to be an insufficient number of millennia available. Further OSL dating and a firmly cemented key to calibration of radiocarbon dates are required to solve this enigma.

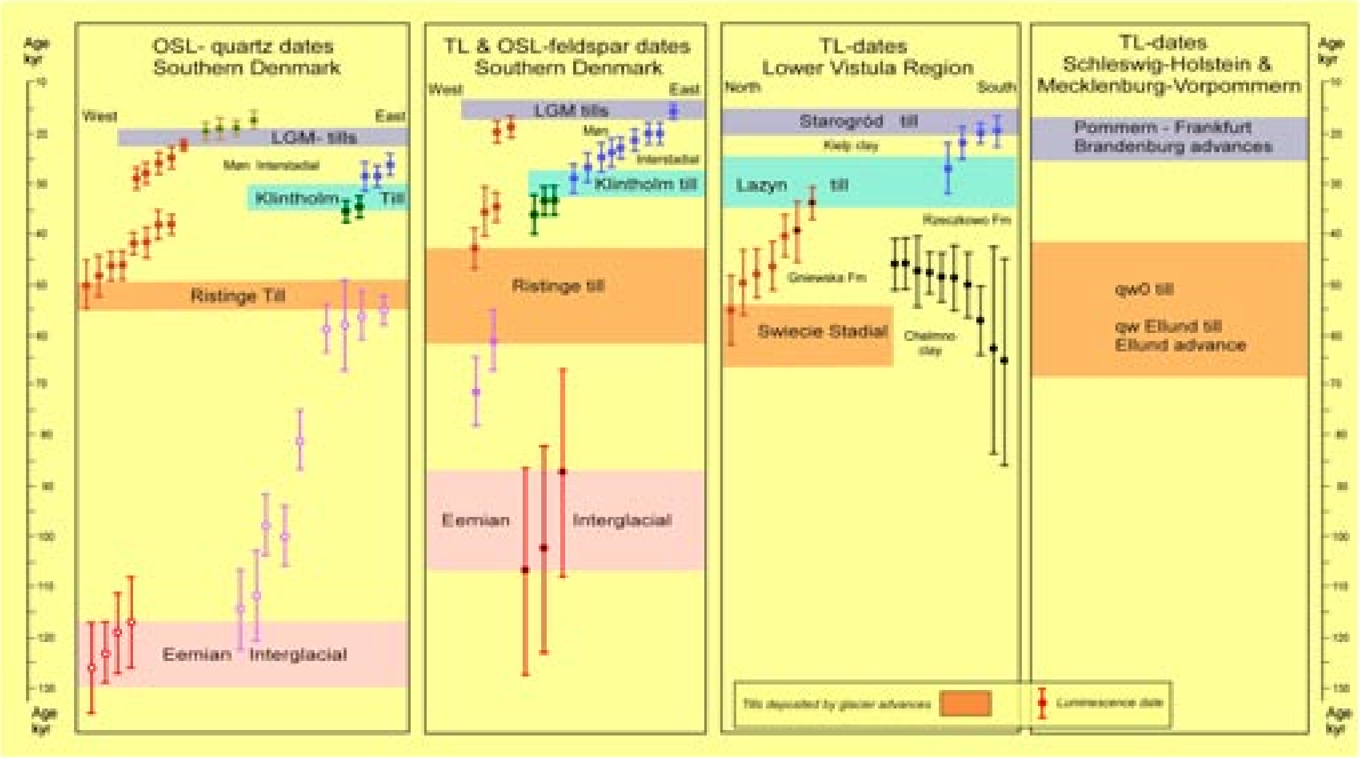

***Figure 3-1.** Luminescence dates from inter-till deposits in the southern circum Baltic region. Compiled from /Houmark-Nielsen 2007, Ukkonen et al. 2007/.*

Summary of presentation "MIS 3 ice streams and interstadial episodes in the south-western Baltic Basin"

It is necessary to re-discuss the shape and extent of the Fennoscandian ice sheet during MIS 3. There were fast changes in climate and ice volumes during MIS 3. According to the model by Boulton, the MIS 3 Fennoscandian ice sheet was smaller than during Younger Dryas.

Houmark-Nielsen has evidence however that the ice sheet extended at least twice during MIS 3 into Denmark and northern Poland, i.e. during the Ristinge and Klintholm glaciation/advances, which are dated to 55–50 and 35–30 kyr BP and occurred during a period of relatively mild climate and rising global sea level. Fast streaming Baltic glaciers could be an analogue for this situation, similar to MIS 6 and the last MIS 2 deglaciation, when it was warm and sea level was lower.

The /Boulton et al. 2003/ model gives maps with different basal temperatures; likely the ice-bed may have been decoupled, which could have led to ice sheet instability and marginal collapse.

A fairly good fit is seen between ^{14}C and OSL dates for sediments below and above the Ristinge and Klintholm till. Houmark-Nielsen explained the stratigraphy at Klintholm and Ristinge Klint, which are key sections for MIS 3 ice advances.

Ristinge Klint: Erratic boulders in the till come from the Baltic depression and the glacier movement can be traced through the Baltic. As shown by /Punkari 1996/, the Baltic depression is a gateway for ice streams. However the lowlands east of the Scandinavian mountains would not enhance fast flow more and instead outlet surges into ice dammed lakes could have occurred.

Between 60 and 55 kyr BP ice advanced from Norway and covered the northern part of Denmark during MIS 4; a fairly large ice sheet existed over southern Sweden during this advance. The Ristinge advance (Ristinge Klint till) occurred between 55 and 50 kyr BP. No endmoraines are available because of periglacial re-moulding and erosion by the next ice advances, however dead ice features are present. A long period of interstadial conditions with dead ice in Denmark and southern Sweden followed (ice margin through Småland up to Oslo) between 50 and 35 kyr. During the following Klintholm glaciation around 35 kyr BP, the eastern part of Denmark was glaciated. In front of the receding ice margin a Baltic ice lake formed between 33 and 31 kyr BP and the ice margin was likely situated in southern Sweden. Some parts of southern Sweden were thus ice free. Similar MIS 3 ice advances can be seen in the Lower Vistula region /Wysota et al. 2002/. The Lazyn till would correspond to the Klintholm till and the Swiece Stadial to the Ristinge till. /Müller 2004/ and /Stephan 2005/ related the Ellund till in northern Germany to the Ristinge till. The marine based parts of the ice sheet advanced at 31–29 kyr BP from Norway into northern Denmark and along the Swedish west coast. After deglaciation in the Skagerrak and Kattegat the maximum ice extension of the LGM took place around 23–21 kyr BP.

During the Ristinge glaciation 55–50 kyr BP, fast flowing glaciers occupied most of Denmark and down to northern Germany and Poland. During the Klintholm glaciation, at 37–32 kyr BP, the ice extended into eastern Denmark.

^{14}C ages of Mammoth finds (/Ukkonen et al. 2007/, section 3.7) do not fit to Houmark-Nielsen's model. Could the ice configuration possibly be pictured as an ice stream through the Baltic without support of interstream ice along the flanks? This is probably not realistic. Dating/chronology seem to be a serious problem too, unless the "calibrated" ^{14}C dates turn out to be underestimated and the OSL dates are slightly over-estimated. Thus a reliable ^{14}C calibration curve tops the list of forthcoming achievements in radiocarbon dating. Likewise, revisions of Fennoscandian ice sheet dynamics are indeed and the role of ice dammed lakes over time in the Baltic depression needs to be investigated. Overall conclusions: current research suggests that glacier ice was streaming through the Baltic basin during MIS 3 at 55–50 and 35–30 kyr ago while global sea level was rising and a mild climate prevailed in northern Europe.

3.3 Knudsen K L and Krog Larsen N: Fennoscandian ice sheet fluctuations during MIS 3 in Northern Denmark, Kattegat and Skagerrak: marine and non-marine environments

ABSTRACT. A multidisciplinary study of the extremely thick Quaternary sequence in northern Denmark was carried out in connection with exploration for deeply buried groundwater reservoirs in the area. The sequence is located within the Fennoscandian Border zone, and the SE-NW trending, tectonically active Sorgenfrei-Tornquist Zone crossing northern Denmark. The faulted and eroded pre-Quaternary surface, mainly consisting of Upper Cretaceous chalk, has a northerly dip in the area, reaching down to more than 200 m below present-day sea level. Quaternary sediments are up to 280 m thick near Frederikshavn and decrease in thickness towards the south, where they wedge out and sometimes disappear, exposing the pre-Quaternary surface. Nearly twenty 150–250 m deep exploration wells were drilled in order to find groundwater reservoirs and to develop a geological model of northern Denmark. The recovered samples were analysed using a wide range of sedimentological and biostratigraphical methods, and the chronology is based on OSL and AMS ^{14}C age determinations.

A thick marine sequence in northern Denmark, the Skærumhede Series, overlies the Skærumhede Till Formation (Saalian). The marine series is subdivided into the Lower, the Middle and the Upper Skærumhede Clay Formation, covering the time interval from the Late Saalian, through the Eemian, as well as the Lower and Middle Weichselian (ca 130–30 kyr BP). The marine sedimentation in the area was, however, interrupted by two glacial advances, represented by the Brønderslev Formation (ca 65–60 kyr BP) and the Åsted Formation (ca 55–50 kyr BP). The Brønderslev Formation is dominated by erratics from a northern source and is correlated to the Sundsøre Advance, whereas the Åsted Formation is correlated to the Ristinge Advance based on a significant content of Palaeozoic limestone, chert and smectite.

The marine Upper Skærumhede Clay Formation is overlain by a Mid-Late Weichselian succession, primarily consisting of glaciolacustrine clays and sands. Numerous, 2–13 km long, 0.5–2 km wide and up to 170 m deep, buried valleys have been mapped using SkyTEM and conventional TEM. Most of the valleys turned out to be incised into Eemian to Late Weichselian marine or lacustrine clays, and they have been refilled with silty and sandy sediments containing a mixed, redeposited Eemian and Weichselian foraminiferal fauna. Based on lithostratigraphic correlation and absolute datings, as well as the biostratigraphy of wells drilled through the flanks, the age of the valleys and the infilling sediment can be constrained to ~ 18 kyr BP at the time of deglaciation of northern Denmark.

Focussing on MIS 3, the borehole information from northern Denmark suggests a large Fennoscandian ice sheet in the beginning (Sundsøre and Ristinge Advances) and at the end of the period (Kattegat Advance). During the intervening period from ca 50–30 kyr BP, northern Denmark was a marine embayment connected to the North Atlantic, and there is no evidence of any large ice sheet in the area.

Summary of presentation "Fennoscandian ice sheet fluctuations during MIS 3 in Northern Denmark, Kattegat and Skagerrak: marine and non-marine environments"

Knudsen and Larsen presented results from an ongoing project dedicated at mapping and coring in buried tunnel valleys to search for groundwater in Northern Denmark. 200 m of Quaternary sediments were deposited in N Jutland and corings were made down to 200 m depth. Sampling was carried out at 1-m intervals. This allows reconstructing the stratigraphy from the Late Saalian to present at several localities. The general stratigraphy (in the surroundings of Skærumhede) is: Saalian till, Saalian deglacial marine deposits, Eemian marine deposits, Early Weichselian marine deposition, glaciation, Middle Weichselian marine deposition, glacial deposits. Other sequences show the Ristinge advance inbetween two Middle Weichselian marine layers. The Ristinge advance can however only be found in some cores, including cores in northernmost Denmark, further north than shown by Houmark-Nielsen. The Klintholm advance, reported by Houmark-Nielsen at 35 kyr BP, is not recognized in Northern Denmark. Clast source and clay content allow differentiating between different till units. OSL dating was not always successful. Many ages are too old because of incomplete bleaching and some OSL are also too young.

The generalized development for MIS 3 in Vendsyssel, northern Denmark is summarized as follows:

~ 65–60 kyr: Sundsøre advance from north
~ 60–55 kyr: marine conditions
~ 55 kyr: Ristinge advance from southeast
~ 50–30 kyr: marine conditions
~ 30–29 kyr: glaciolacustrine environment
~ 29–27 kyr: Kattegat advance from north
After MIS 3 the main advance followed and then a re-advance.

3.4 Mangerud J J, Løvlie R, Gulliksen S, Hufthammer A-K, Larsen E and Valen V: Correlations between Fennoscandian Ice-Sheet fluctuations and Greenland Dansgaard-Oeschger Events, 45,000–25,000 years BP

ABSTRACT. We have correlated fluctuations of the Fennoscandian ice sheet with Dansgaard-Oeschger events recorded in Greenland by using paleomagnetic directional excursions in deposits from western Norway and fluctuations in cosmogenic isotopes found in Greenland ice cores /Mangerud et al. 2003/. This could be done because during a magnetic excursion the geomagnetic field is weakened, causing higher production of the cosmogenic isotopes ^{10}Be and ^{36}Cl in the atmosphere and in snow deposited on the Greenland Ice Sheet. Thus we circumvent the problem of converting ^{14}C ages to ice core years. However, some 50 ^{14}C dates from our sites can be used to correlate with marine cores from the North Atlantic where the excursions were also recorded.

Two paleomagnetic excursions, the Skjong/Laschamp (about 41,000 years BP) and the Valderhaug/Mono Lake (about 34,000 years BP) have been identified in laminated clay deposited in ice-dammed lakes in three large caves in Western Norway and as peaks of ^{36}Cl and ^{10}Be in the GRIP ice core, Greenland. During both excursions the margin of the Fennoscandian ice sheet advanced and reached the continental shelf beyond the outermost coastline. The mild, 4,000 years long Ålesund interstadial, when the coast and probably much of the hinterland were ice free, separated the two glacial advances.

Summary of presentation "Correlations between Fennoscandian Ice-Sheet fluctuations and Greenland Dansgaard-Oeschger Events, 45,000–25,000 years BP"

Mangerud presented studies of cave sediments in the caves of Hamnsundhelleren, Skjonghelleren and Olahola, on the Norwegian west coast.

Skjonghelleren and Hamnsundhelleren have two laminated lacustrine sediment sequences and intercalated non-laminated sediments with bones (birds, fox, and polar bear). The interpretation is that glacier ice dammed the cave and a lake formed inside the cave where laminated sediments were deposited. When the ice sheet disappeared, the caves were used by polar foxes that brought in birds and other animal remnants for winter storage. This ice-free period is named the Ålesund interstadial and the fauna indicates conditions as on Svalbard today, but some of the fish and birds found in the cave deposits are today limited to the coast of Norway. 50 ^{14}C dates on bones place the Ålesund interstadial between 29 and 34 kyr ^{14}C BP.

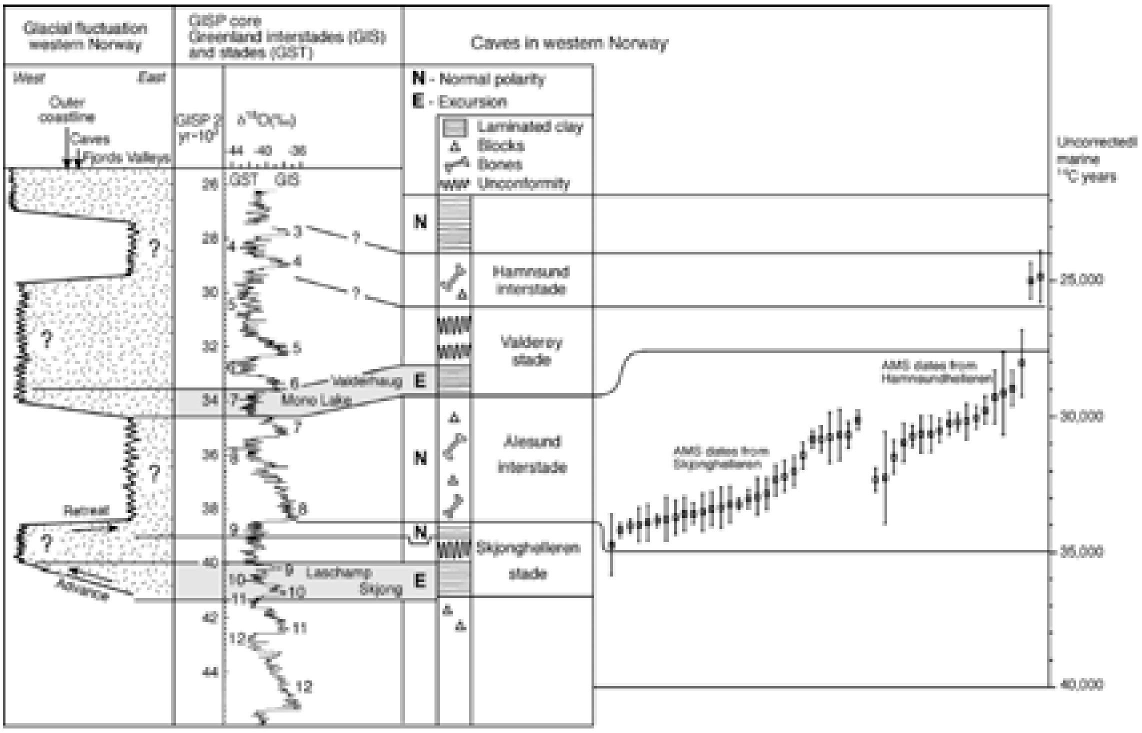

Figure 3-2. AMS ^{14}C dates of bones from the caves are shown in the right panel. The next columns to the left show the stratigraphy in the caves; laminated clay beds indicate that a glacier blocked the cave opening and block/bone beds reflect interstadials. The Greenland interstadials (GIS) and stadials (GST) are shown as numbers marked on the GISP2 ^{18}O curve and time scale. The cave stratigraphy is correlated with ice cores using the Mono Lake and Laschamp excursions. A main conclusion is shown in the left-hand column as a time-distance diagram of fluctuations of the margin of the Fennoscandian ice sheet.

Paleomagnetic investigations on the sediments inside the caves show the presence of the Laschamp event and the Lake Mungo event below and above the Ålesund interstadial respectively. The two paleomagnetic events can be correlated to peaks in ^{36}Cl and ^{10}Be fluxes in the GRIP ice core. This shows that the Ålesund Interstadial can be correlated to GIS 8.

The Norwegian coast was ice-free at 42 kyr BP, during the Ålesund interstadial between 38 and 34 kyr BP (reindeer shows that a wide zone was ice-free), while the ice margin was situated outside the coast at 41–38 kyr and at 34–30 kyr BP, all given in GISP2 years that probably are close to calendar years.

The classic maps on Fennoscandian ice configurations by Jan Lundqvist have been modified by including a figure showing the Ålesund interstadial at 35 kyr BP.

3.5 Mangerud J: Were Svalbard, the Barents Sea and Novaya Zemlya ice-free during MIS 3?

ABSTRACT. It has been shown that Svalbard was ice-free during most of MIS 3 and the glacio-isostatic recovery in the inner fjords at that time also indicate that the entire Barents Ice Sheet had melted or calved away /Mangerud et al. 1998/. These results are supported by recent results from Novaya Zemlya indicating that much of the islands were ice-free as late as 30 kyr BP /Mangerud et al. 2008a/. The main conclusions are: 1) that there was a long period during MIS 3 when the Barents Ice Sheet did not exist, 2) the MIS 2 ice sheet grew fast, and 3) that it existed for only a short period during the Last Glacial Maximum. The latter is based on amino acid modelling which indicates that Novaya Zemlya was covered by glacial ice at 0°C for maximum 3,000 years during MIS 2. If basal temperature was –5°C then ice cover could have lasted for 10,000 years.

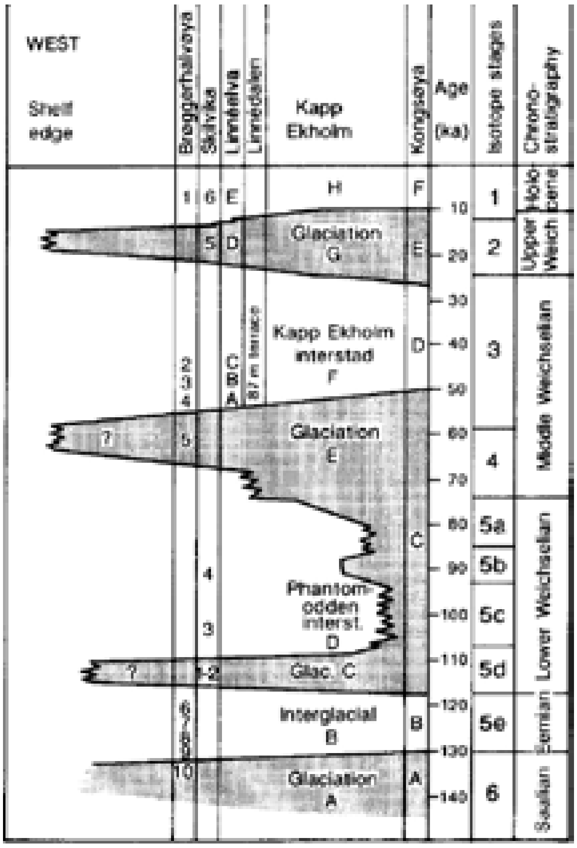

Figure 3-3. A glaciation curve for the northern Barents Sea-Svalbard during the last glacial cycle. Note that during the Kapp Ekholm interstadial the Barents Ice Sheet melted away completely. From /Mangerud et al. 1998/.

Summary of presentation "Were Svalbard, the Barents Sea and Novaya Zemlya ice-free during MIS 3"

Urals: Moraines showing a large ice extent dating to MIS 4, while no ice larger than today existed during MIS 3. During MIS 2 a studied local glacier was only 1 km larger than today /Mangerud et al. 2008b/.

Svalbard: LGM glaciation was maximum 10 kyr long and the MIS 3 glaciation was similar to present. A complete isostatic rebound of Svalbard, from a large MIS 4 glaciation, was reached early during MIS 3.

Novaya Zemlya and Barents-Kara seas: Novaya Zemlya was ice-free between 30 and 40 kyr BP and the entire Barents-Kara Seas were ice-free during MIS 3.

Conclusion: The Urals, Svalbard, Barents Sea and Novaya Zemlya were ice fee during MIS 3. The entire Barents-Kara sea area was ice free during MIS 3. Western Norway seems more sensitive to the 20 kyr Milankovitch cycles, while Svalbard seems more sensitive to the 41 kyr cycles.

Mangerud also presented two figures provided by Lars Olsen (Norwegian Geological Survey, NGU) with results showing that most of Norway was ice free around 44–59 kyr BP (early MIS 3) and 29–44 kyr BP. Mangerud suggests that many of the ^{14}C dates on which these conclusions are based could have problems, because they are mainly bulk dates on sediments with very low organic content.

3.6 Helmens K F: Environment conditions in the Sokli region (NE Finland) during an early MIS 3 interstadial based on multi-proxy evidence

ABSTRACT. High-resolution multi-proxy analyses and quantitative climate reconstructions carried out on a laminated clay-silt bed intercalated in the long Sokli sedimentary sequence in north-eastern Finland indicated ice-free and warm climate conditions during the early part of MIS 3.

Different lines of evidence (i.e. chironomid- and diatom-inferred mean July air temperatures; minimum mean July air temperatures based on aquatic plant fossils; and present-day preferred mean summer water temperatures applied to fossil bryozoa) indicate warming to present-day summer temperatures during at least part of the ice-free interval /Helmens et al. 2007b, Engels et al. 2008, Helmens et al. in press/.

The Sokli sedimentary sequence, which spans over the Last Interglacial-Glacial cycle and the Holocene (representing the last ca 130 kyr), is dated by independent AMS ^{14}C and optically stimulated luminescence (OSL) dating, which is in agreement with stratigraphic dating based on correlation with the deep-sea record /Helmens et al. 2000, 2007a/. Large error limits on the absolute dates for the MIS 3 lacustrine deposit preclude direct correlation of this warm interval with the interstadial sequence (IS) in the Greenland record. However, it is arguable that thinning and gradual retreat of the north-eastern margin of the Fennoscandian ice sheet from its MIS 4 limit in Russia /Svendsen et al. 2004/ started during IS 16 in the earliest part of MIS 3, but that only the prominent IS 14 around 53 kyr lasted long enough, and was warm enough, for the Sokli area to become deglaciated and the dramatic Dansgaard/Oeschger (D/O) warming event to be registered in the fossil record /Helmens et al. 2007b/.

The paleo-botanical data indicate that the terrestrial vegetation was a low-arctic shrub tundra /Bos et al. in press/. The distribution ranges of pine and tree birch were probably not far away, i.e. only a few hundreds kilometres south or south-east of Sokli. These results are in contrast with the inferred mammoth-steppe conditions in central and southern Sweden (/Ukkonen et al. 2007/, section 3.7).

Sudden changes in lake level/size indicated by the siliceous microfossil record together with very low LOI values indicates that major part of the early MIS 3 lacustrine deposit at Sokli probably accumulated in an ice-dammed lake /Helmens et al. in press/. Digital elevation data, together with geomorphologic evidence including N-S oriented eskers dated to an early MIS 3, are able to reconstruct the proxy-based glacial lake evolution. The northern retreat pattern combined with lacustrine accumulations in central Finland /Salonen et al. 2008/ suggest that important parts of eastern Fennoscandia were deglaciated during parts of early MIS 3 /Helmens et al. in press/.

In agreement with the proxy-based reconstructions, a climate model simulation for average MIS 3 interstadial conditions suggests high mean July temperatures for the sector northeast of the Fennoscandian ice sheet /Helmens et al. 2007b/. In the model, warm summer conditions are the combined result of enhanced July insolation compared to present and north-westerly winds advecting cool, but very dry air from the ice sheet. The combination of high insolation and dry air leads to a strong sensible heat flux and relatively warm conditions near the surface. It has become apparent, however, that the MIS 3 ice sheet configuration used in the climate model simulation is most probably too large /Helmens et al. in press/.

Summary of presentation "Paleo-environment conditions in the Sokli region (NE Finland) during an early MIS 3 interstadial based on high-resolution, multi-proxy evidence"

The Sokli site in Northern Finland contains a lacustrine sequence between two till beds. OSL and ^{14}C dates give a MIS 3 age and indicate that the site was ice free at ca 50 kyr (i.e. during parts of MIS 3). Reconstructed temperatures during the ice free interval correspond to present-day temperatures in the area. The vegetation consisted of shrub-tundra vegetation.

High-resolution, multi-proxy studies of the MIS 3 sediments were performed (macrofossils, pollen, diatoms, chironomids), and transfer functions were applied to chironomids and diatoms to obtain reconstructed temperatures. Also estimates of minimum mean July temperatures were obtained from aquatic plants. The proxy based climate reconstruction was compared to output from the LOVECLIM model.

Reconstructed mean July air temperatures (based on chironomids and diatoms) show temperatures as warm as present, minimum 13 degrees C, in the early part of the sequence, which compares well to results from aquatic plants. Pollen-inferred temperatures give lower values. During this interval, the flora was very diverse, but tree vegetation was not present, although temperatures would have been warm enough for trees. Possibly, the vegetation was lagging behind or the warm phase was too short to allow trees to migrate into the area.

LOVECLIM simulations (with a LGM ice sheet, not a restricted MIS 3 ice sheet) yields very warm and dry climate conditions, high heat flux and warm temperatures close to the surface due to high insolation and dry katabatic winds from the ice sheet.

It is difficult to say exactly where within MIS 3 the Sokli sequence belongs. GIS 16 was too short probably to trigger deglaciation. GIS 14 would be more likely; because it was warmer and is also very distinct in the sea level record and in speleothems and lasted ca 3,000 years.

Diatom analyses show distinct lake level changes. Probably, the lake during early MIS 3 was for a major part of the time-interval ice-dammed. It is possible that the ice margin disappeared quite far to the north or northwest during the warm interval.

Questions and comments

Mangerud: I agree that an attribution/correlation to GIS 14 sounds reasonable.

3.7 Ukkonen P: Mammoth dates from Fennoscandia and the Baltic States related to MIS 3

ABSTRACT. Mammoth tusks, molars and bones have been recovered from glaciogenic sediments throughout Fennoscandia and the Baltic countries from 66° N and southwards (Figure 3-4). All remains have been transported either by the advancing ice sheet or by melt water from a retreating glacier. In most cases, however, the final deposition of the remains has occurred relatively near, less than 50 km from the original deposition site, which clearly demonstrates the presence of local mammoth populations in this area, which during the LGM, was totally covered by the Fennoscandian ice sheet.

A large part of all dated mammoth remains from Sweden, Denmark, Estonia and Finland show ages ranging from c. 38 000 ^{14}C year BP to c. 24 000 ^{14}C year BP (44–26 thousand calibrated years), indicating ice-free conditions around the Baltic depression (Figure 3-4). This supports the model of restricted ice sheet distribution during the second half of the Middle Weichselian. However, the existence of large ice-free areas during that time interval contrasts with the Danish OSL-based glaciation chronology for the period 40–30 kyr ago (Houmark-Nielsen, section 3.2). Furthermore, this scenario leaves very little time for a glacier to grow and to melt.

Figure 3-4. *Spatial distribution of dated and undated mammoth remains from Sweden, Finland, Estonia and Denmark. Figure from /Ukkonen et al. 2007/. LGM = Last Glacial Maximum, kyr = thousand years.*

Based on oxygen isotope analyses of tooth enamel from Swedish mammoth finds, the palaeoclimate during the second half of the Middle Weichselian was considerably more homogenous than that experienced in Sweden today. ~ 1°C lower mean annual temperatures are implied for central Sweden, whereas the equivalent temperature decrease for southern Sweden is ~ 6°C. Further, the $\delta^{13}C_{diet}$ value of the Swedish enamel samples corresponds to that obtained from mammoth enamel in Switzerland, where the remains could be associated with an open landscape with few trees. This is in accordance with direct evidence of the diet of woolly mammoths, comprising primarily grasses and sedges with a smaller component of woody species, that is, plants typical for the mammoth steppe.

Summary of presentation on "Mammoth dates from Fennoscandia and the Baltic States related to MIS 3"

The main results are from /Ukkonen et al. 2007/. Most mammoth finds are from Denmark and comprise molars, tusks and bones. Teeth and bones are relatively fragile and cannot have survived multiple glaciations. Some Swedish finds have no traces of transport at all.

The north-south distribution shows that the obtained ages are between 25–45 kyr BP. Their transport was short, in most cases less than 10 km, although some finds (no 5) were transported longer, i.e. up to 50 km. Most of the finds correspond to the Klintholm advance, which is at conflict with the ice advance reconstructed by Houmark-Nielsen (section 3.2).

AMS ^{14}C dates on different parts of the same tusks give equal ages and the same age as the old conventional ^{14}C date. This supports the validity of the ^{14}C dates.

$\delta^{18}O$ on enamel shows that there was *no* temperature gradient between northern and southern Sweden during MIS 3, and not between Sweden and Russia either, but that a large temperature gradient existed between southern England and western Russia (oceanic influence?).

Questions and comments

Näslund: These results may later on be compared with the coming regional climate model output.

Mangerud: Please also include Norwegian data (some samples should be useful).

Lundqvist: I have part of a tusk-sample, which could be re-dated.

3.8 Alexanderson H: New interstadial OSL- and ^{14}C-dates in Sweden

ABSTRACT. In Småland, southern Sweden, several sites with sub-till sediments are known but none has been absolutely dated until now. New optically stimulated luminescence (OSL) ages from glacifluvial sediments below till give a wide range of ages, ~ 19–85 kyr /Alexanderson and Murray 2007/. Incomplete bleaching may explain part of the problem, but not for the youngest ages, 19–25 kyr. These young ages are stratigraphically consistent and correspond between sites. However, glacifluvial sedimentation in this area at this time requires either a very early deglaciation, or alternatively ice-free conditions just prior to the Last Glacial Maximum (LGM). None of these options is easily reconciled with the current view of the Weichselian glacial history of Fennoscandia /e.g. Houmark-Nielsen and Kjær 2003/. Nevertheless, the results from Småland seem to suggest ice-free conditions during at least part of MIS 3, and hint at a possible ice advance in late MIS 4.

In Jämtland, central Sweden, sub-till sediments have been described from many sites and based on i.e. palynological studies, the deposits have been placed in Weichselian interstadials e.g. /Lundqvist 1967/. Some absolute dates exist, but many of these are infinite conventional radiocarbon ages and thus rather inconclusive. The first results of five OSL-dates from Pilgrimstad cf. /Lundqvist 1967, Robertsson 1988/ give ages between 44 ± 4 and 48 ± 5 kyr. Two new AMS-^{14}C dates of macrofossils from the same levels yield 39.2 ± 2 kyr BP (uncalibrated) and > 40 kyr BP. This can be compared to 34–29 cal. kyr for a re-dated tooth from the Pilgrimstad mammoth /Ukkonen et al. 2007/. According to these ages, the organic-rich and sandy beds at Pilgrimstad are Mid-Weichselian in age and indicate an at least partly ice-free MIS 3 in this area.

Future work within this project, which aims at using and evaluating OSL-dating for late glacial and interstadial sediments in Sweden, will include further analyses and quality checks of the OSL-samples from Pilgrimstad, in order to reduce the apparent age range of the sediments. New complimentary OSL-samples from Pilgrimstad and from other nearby interstadial sites will also be analysed. In addition, the interstadial sediments at Dösebacka /Hillefors 1974/ on the Swedish west coast will be investigated during fall 2007.

Summary of presentation on "New OSL and ^{14}C dates for MIS 3"

Alexanderson reported on a new project dealing with an evaluation of OSL dating of late glacial and interstadial sediments in Småland, Värmland and Jämtland.

Småland: OSL ages are between 20 and 70 kyr; these are possibly not true depositional ages, but may reflect the time when the sediments were last reworked at the surface. In Hultsfred glaciofluvial sediments overlain by till gave ages of 85 and 60 kyr. Sub-till/interstadial sediments thus exist, but are mainly glacifluvial in origin. A possible interpretation is that the ice advanced during MIS 4 and that the area was ice free during stage 3. But this is not unequivocal.

Jämtland/Pilgrimstad: new excavation of the known Pilgrimstad section was undertaken in summer 2007. OSL samples from a sample series from 2006 give ages of between 44 and 48 kyr and two ^{14}C dates give ages of 39 ± 2 kyr and > 40 kyr BP. Although the water content estimate can highly influence the age of the OSL dates, OSL and ^{14}C dates indicate partly ice free conditions during stage 3.

Other Jämtland sites (Vålbacken, Grytan, Andersön, Bulägden): sampled for OSL dating in July 2007.

Dösebacka/Bohuslän: Earlier TL-ages gave 67–80 kyr and earlier ^{14}C-ages were 24 kyr, 32 kyr, and 36 kyr for the site. During a new fieldwork more samples will be taken for OSL dating.

3.9 Wohlfarth B: The paleodata contribution to the 100,000 year project

ABSTRACT. The paleo-data contribution to the 100,000 year project (section 2.2) focuses on: i) a compilation of available paleo data for northern Europe, i.e. within the range of the regional climate model; ii) the establishment of a data base for MIS 3 (similar to the one established in Bergen for the last deglaciation). Furthermore, help/advice is given to define model boundary conditions for the global and regional model (CO_2, CH_4, sea level etc) (sections 1.2, 2.4, 2.5). In addition, and also as a contribution to a parallel MIS 3 project (RESOLuTION), multi-proxy studies of the earlier investigated site Pilgrimstad in Jämtland will be conducted.

MIS 3 (60–30 kyr BP) is a time period with rapidly fluctuating temperatures (7–15 degrees C over Greenland), the so-called Dansgaard-Oeschger stadials and interstadials. These were also punctuated by Heinrich events, which occurred during the coldest phase of a stadial, after a series of interstadials. Sea level curves and marine and terrestrial (lake sediments, speleothems) records from various parts of the Northern Hemisphere also show these large amplitude temperature fluctuations. However, the picture is reversed for the Southern Hemisphere, were cooling occurred during warm Northern Hemisphere interstadials.

While MIS 3 ice sheet fluctuations and ice free conditions have been recorded from Norway and Denmark and based on ^{14}C dates on mammoths, the picture is rather uniform for Sweden, where a large ice sheet should have covered most of the country during MIS 3. Sweden has a number of Weichselian interstadial sites with lacustrine/organic sediments. ^{14}C dating of bulk sediments, macrofossils and different sediment fractions, would place these sites within MIS 3 (possible corresponding to GIS 14 or 12), while pollen stratigraphic records imply tree vegetation and thus a correlation to early Weichselian interstadials. The question thus is whether the general view of a MIS 3 ice sheet in Scandinavia is too simplistic. Ongoing multi-proxy analyses of the site Pilgrimstad in Jämtland will allow shedding light on these controversies.

4 Discussion

4.1 Problem of time available for building up and melting of ice sheets during MIS 3 stadial/interstadials

Kleman: An effort to theoretically link time, space and climate during long (5 kyr or more) MIS 3 interstadials, i.e. pronounced and long DO cycles, is seen in Figure 4-1. During stadials climate becomes progressively colder. Stadials are followed by an abrupt (few 100 years) jump to warm conditions. This could lead to ice surface melting and meltwater at the ice sheet bed, which in turn would increase basal sliding of the ice. Consequently the ice surface would decrease leading to a low gradient ice sheet, which would melt back to the mountains. The following, progressive cooling would then lead to new ice built up. This conceptual model gives a very dynamic ice sheet which may fit with the data.

Mangerud: This idea could be tested using the Younger Dryas.

Lundqvist: Remember that cold phases and ice sheet advance are not expected to occur simultaneously. There should be a time lag.

Figure 4-1. *A conceptual model to link time, space and climate during long (5 kyr or more) MIS 3 interstadials, as suggested by Kleman. 1 = Coldest phase of a stadial; the ice sheet would correspond to a Younger Dryas-sized ice sheet. In time this results in: 2 = maximum ice sheet extent during the warm phase of an interstadial. The warm phase leads to more surface water on the ice sheet and to more basal sliding and rapid melting; 3 = small ice sheet and residual ice configuration during the gradual DO cooling trend. The residual ice allows for a relatively fast subsequent ice build-up.*

Houmark-Nielsen: LGM ice build up can also be used as a model. Data show a gradual change in the position of the LGM marginal position from west to east: the maximum extent was attained at 27 kyr in western Norway, at 17 kyr in western Russia. The situation could have been similar during MIS 3, i.e. ice build up over western Norway, while the eastern part was ice free. Build up of ice could also have been possible during warm phases. The Ristinge advance left for example dead ice in Denmark which survived until the LGM.

Kleman: Ice sheet models may not simulate retreat phases correctly, because they can not handle glacial meltwater and calving in a good way. Ice sheet models are good for build up phases.

4.2 Dating methods

Wohlfarth: All Swedish ^{14}C and U/Th dates can not be wrong, which suggests that there were ice free phases during the Weichselian.

Mangerud: Contamination could still be a problem for these old dates.

Ukkonen: Is there a possibility of systematic errors in all ^{14}C datings?

Lundqvist: How reliable are the old ^{14}C dates? Are they subject to contamination problems only? Is there a possibility of having bacteria/micro organisms that lived longer than the tree etc affecting the ages? This would give too young ages. Very little material would be needed to change the age of very old samples (because of little ^{14}C remaining to be measured (half life is only ca 5,000 years)).

All: There are possibly large uncertainties in ^{14}C and OSL dates.

Kleman: How reliable are the Gudbrandsdalen dates from the ice sheet core area?

Mangerud: We do not know.

Näslund: Is there a contradiction between the interpretation of the Klintholm advance (Houmark-Nielsen) and the Ålesund interstadial (Mangerud)?

Mangerud and Houmark-Nielsen: No, the Klintholm advance is similar (even within c. 1,000 years) to the advance in Norway after the Ålesund interstadial.

The youngest mammoth dates allow only about 2,000 years to build up the classic LGM ice configuration, which is too little time according to present glaciological knowledge.

4.3 Model setup for MIS 3: Selection of period

Helmens: Perhaps one could use a stadial during MIS 3 instead of an interstadial, when it was much colder?

Näslund: The warm phases were chosen because we want a restricted ice sheet.

Helmens: Probably there was a restricted ice configuration also for cold phases (in line with that there is not enough time to build up large ice sheet).

Näslund: Good idea. Picking a stadial period is also not contradictory to the Danish evidence of Baltic ice streams (e.g. more ice) since they occur during the warm interstadial phases of MIS 3.

Brandefelt/Strandberg: The changes (interstadial to stadial) that can be done in the setup of the global model would probably not make a big change in the resulting temperatures.

Rummukainen: Initial and forcing conditions for the two alternatives (stadial/interstadial periods) are important for the result. Are there differences? If so test both.

Knudsen: Data are probably available for SSTs and sea ice for a modified MIS 3 (cold) setup.

Rummukainen: Perhaps start the MIS 3 global simulation with different SSTs and sea ice.

Wohlfarth: No compilation exists at present for MIS 3 for North Atlantic SSTs

Mangerud: The strong variations between cold and warm are only observed in the North Atlantic. There is therefore no need to obtain global information/data series. If a cold MIS 3 setup is attempted, try to locate cold MIS 3 temperatures for the setup. Then use the same ice sheet configuration and change only the atmospheric composition.

Houmark-Nielsen: What are the relative temperature changes between stadial and interstadial conditions? In the Baltic the changes are much less than those seen in the Greenland ice cores. Large temperature jumps in the Greenland record may be winter season colds (overestimates the amplitude).

Helmens: Perhaps one could simulate Stage 5d instead?

Wohlfarth: This would not be so good because of too little climate proxy data.

Conclusion: All participants agreed that it is probably best to make simulations based on the suggested MIS 3 setup. This will also allow a comparison of the results with paleodata. However, it is probably best to select a cold MIS 3 stadial (without an Heinrich event).

Note: As a result of the workshop discussions, it was after the workshop decided that the cold stadial preceding Greenland Interstadial (GIS) 12 was selected for the MIS 3 climate modelling. The astronomical forcing was set to the conditions at 44 kyrs BP (ss09 sea time scale /Johnsen et al. 2001/), see Appendix B.

4.4 Model setup for MIS 3: Ice sheet configurations

Brandefelt: The suggested model setup uses the Fennoscandian ice sheet configuration from /SKB 2006a/, the Laurentide ice sheet configuration from CLIMBER-2 and the Southern Hemisphere ice sheet configuration from ICE-5G.

Kleman: This suggestion is ok. For the Laurentide ice sheet, ice in Keewatin and Quebec is ok. In the model by Peltier (ICE-5G) no Cordilleran ice sheet exists, and the model shows more of an LGM situation for North America and for Fennoscandia than a MIS 3 situation. Climber-2 seems more realistic for the time period we have chosen. However ice thickness in Yukon/Alaska is too thick.

Brandefelt: What about the Alps?

Mangerud: The Alps had no topographic effect, only an albedo effect. Therefore it would be enough to just change the albedo.

Barbara will check ice cover in the Alps in the compilation by Ehlers & Gibbard.

Knudsen: There was a special issue on glaciation of the Alps in Boreas approximately 2 years ago.

Conclusion: The suggested model setup is good. The selected ice configuration is seen in Figures 4-2 and 4-3.

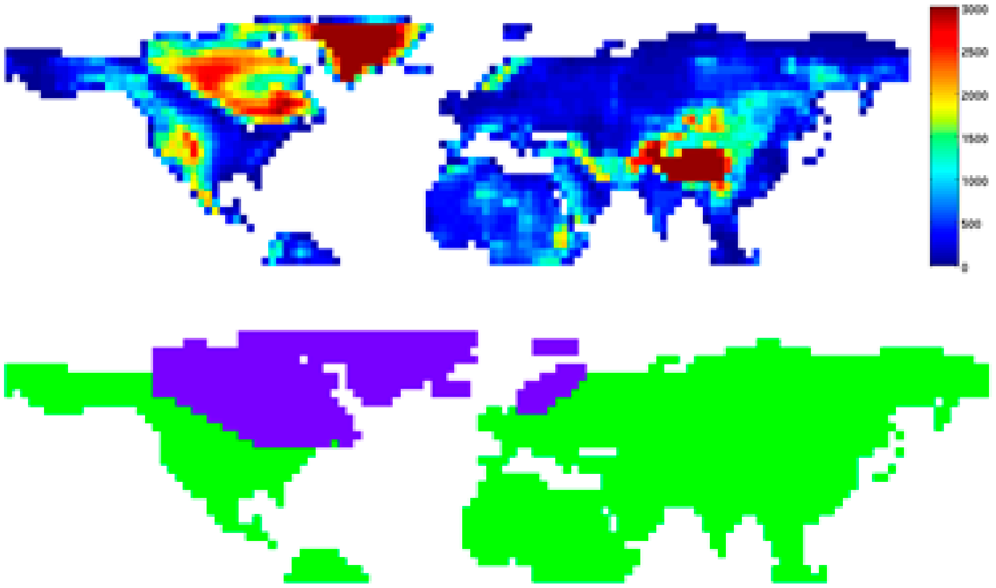

Figure 4-2. *Selected topography (upper) and ice distribution (lower) for the MIS 3 climate simulation with the global climate model CCSM3.*

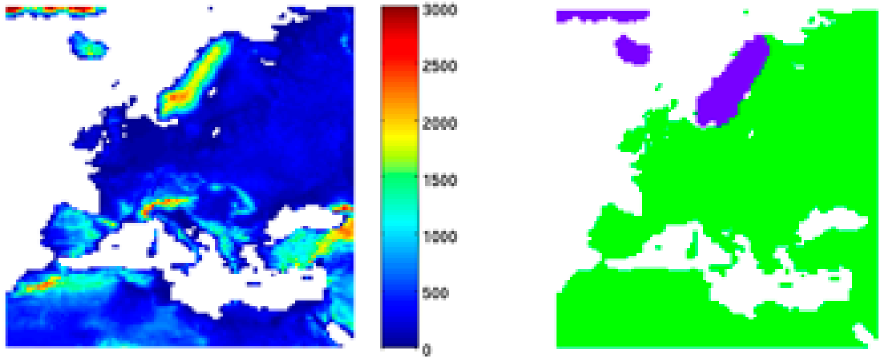

Figure 4-3. *Selected topography (left) and ice distribution (right) for the MIS 3 climate simulation with the regional climate model RCA3.*

4.5 Model setup for MIS 3: Coast lines/isostacy

Mangerud: The LGM setup is ok. The configuration for MIS 3 is also ok, in respect to the things we are aiming for. The largest change occurs in the Barents Sea.

Houmark-Nielsen: In the regional model it is important to have correct coastlines.

Conclusion: Use the results by Whitehouse from the Global Isostatic Adjustment model /SKB 2006a/ and compare that with Knudsen's results.

4.6 Model setup for MIS 3: Vegetation

Brandefelt: Should we put in various types of tundra? Sandy Harrison did not know of a global MIS 3 compilation.

Ukkonen: If we use a period with mammoths, there should be grass vegetation. Steppe tundra is needed for mammoths. Tundra and steppe have similar albedo, although the evaporation is different. Today's tundra is not productive enough for mammoths to feed on.

Hättestrand: There was tundra vegetation during these cold phases. Pollen data also suggest dry conditions.

Conclusion: As there exists no compilation of global vegetation data for MIS 3, present day conditions will be used in the global climate model. The regional climate model will also use present day vegetation in a first simulation. The resulting climate will then be used in a simulation with a vegetation model. Finally the resulting new vegetation from the vegetation model will be used in an additional simulation with the regional climate model to test the sensitivity of the change in vegetation on the regional climate.

4.7 Climate seasonality/LGM climate from GCM simulation

Kleman: What about climate seasonality, which is possibly very important for ice sheet behaviour?

Brandefelt: This will be analyzed in the climate model output.

Kleman: A major lowering of winter temperatures, with constant summer temperatures, may result in a colder and thicker ice sheet during build up phases. The build-up may still be relatively fast due to warm springs with still significant precipitation, i.e. not necessarily large precipitation starvation during cold periods. How could this be implemented in ice sheet models? What would the result be in terms of ice sheet properties? Probably colder ice sheets, in line with mapped cold based condition by Kleman and his research group at Stockholm University.

Brandefelt: We have results with colder LGM compared to previous climate simulations (Brandefelt and Otto-Bliesner in press), more in agreement with paleodata (still degrees off for instance for southern Europe).

4.8 Regional climate modeling

Strandberg: For the RCM modelling we can use the Kattegat sea paleo shore line for MIS 3 from Denmark from Knudsen et al.

4.9 Poster presentation

The meeting finished with Martina Hättestrand's poster presentation: "Weichselian interstadial records in northern Sweden".

5 Summary and conclusions

General conclusions on Marine Isotope Stage 3

Based on the data presented during the workshop it is not possible to obtain a coherent picture and sequence of events regarding ice sheet extent, sea level, topography, permafrost and vegetation for Fennoscandia during MIS 3. Proxy data are still too scattered both in time and space to make a detailed reconstruction of Fennoscandian ice sheet configurations throughout MIS 3.

Nevertheless, recent studies based on well-dated geological sections, the distribution of large-scale glacial landforms and mammal fossil bone records show a more dynamic glacial environment with less extensive and more variable ice cover than traditionally inferred for MIS 3. There is ample evidence for a restricted or possibly completely absent Fennoscandian ice sheet during at least parts of MIS 3 from both marine and terrestrial records.

There is evidence for ice free conditions in NE Finland during the early part of MIS 3 (corresponding possibly to GIS 14, ~ 55–50 kyr BP), in southern Sweden and Denmark between 50 and 35 kyr BP, along the western coast of Norway between 39–34 kyr BP (Ålesund Interstadial, corresponding to GIS 8 and 7) and between ca 29–27 kyr BP (Hamnsund Interstadial, corresponding to GIS 4 and 3) and in the Barents Sea between ca 50–29 kyr BP (Kapp Ekholm Interstadial). Moreover OSL ages of 48–39 kyr BP hint also at ice free conditions in central Sweden. Mammoth dates on the other hand suggest that the Baltic Sea region was ice free during a much longer time interval, i.e. between 44–26 kyr BP.

Based on these conflicting age estimates, it is, as mentioned above, not possible to draw an unequivocal picture of ice sheet extent and variation during MIS 3. However, conservative estimates could suggest an ice extent corresponding to the Younger Dryas ice margin. If the position of the ice margin was similar to that during the Younger Dryas, a prolonged period of ice-free conditions would have provided good conditions for permafrost to develop in southern Fennoscandia. If the ice sheet extent was much more restricted, and confined to the Scandinavian mountain range, it is less probable that permafrost existed in ice free areas in southern Sweden at that time, while ice free areas in central and northern Sweden may have experienced permafrost conditions at that time.

If the Fennoscandian ice sheet had a restricted size during MIS 3, ice sheet growth and decay rates were probably higher than the conventional picture prevailing today. A better understanding of the ice dynamics of the Fennoscandian ice sheet during the Weichselian is clearly needed.

Ice streams seem to have occurred in the Baltic depression at episodes of rising sea level and mild climate in Northern Europe during MIS 3.

The distribution of vegetation during MIS 3 depends on the ice sheet configuration. Shrub-tundra vegetation can be inferred for NE Finland at ca 55–50 kyr BP. Mammoth finds suggest that the vegetation in ice free areas of Fennoscandian during MIS 3 consisted of steppe tundra with grass.

In order to use and compare available data on ice sheet distribution, paleoenvironment etc it is important that to have a good absolute chronology. Such a chronology does not exist at present for the entire Weichselian, at least not for most types of data from Fennoscandia. It is therefore important to develop, test and use dating techniques that can help us to reach this goal. Examples are ^{14}C (better calibration curves beyond 26 kyr BP are needed), OSL-, ESR- and cosmogenic exposure dating. Reliable age constraints based on dense networks of OSL ages and calibrated ^{14}C dates are needed if a revision of Fennoscandian ice sheet dynamics in time and space is to be successful. More research in southern Sweden is therefore needed to establish a reliable stratigraphy and chronology for the last glaciation.

Project specific conclusions and outcome of the workshop

The paleodata and chronological constraints presented at the workshop are in line with a restricted ice sheet configuration as the one suggested for use in the climate model simulations.

The proxy data on vegetation are too sparse to reconstruct the vegetation cover in a larger area. As an alternative, additional off-line simulations with a vegetation model will be used to provide a vegetation cover that is consistent with the simulated climate.

Despite the non-coherent picture of paleodata for MIS 3 as a whole, the workshop resulted in that a suitable selection of time period, ice sheet configuration, coastline and treatment of vegetation could be made for the planned MIS 3 climate model simulations (see section 4.4 to 4.6).

6 Publication and documentation of the workshop

In addition to the present report, it was discussed that a special volume of Boreas could be dedicated to the MIS 3 topic of the workshop, including both paleodata and modeling aspects. According to the Boreas editor, we would need about 10 manuscripts to get a dedicated volume. All participants were positive to the idea to do a special issue, with both paleodata and model data in the same volume. The aim would be to have manuscripts ready by next summer. This would also allow us to include project climate model results. Also relevant persons not participating in the workshop should be able to contribute to the volume.

Mangerud: We should try and do a critical synthesis of paleodata in such a volume.

Näslund: We could also include papers comparing model results and paleodata.

Knudsen (co-editor Boreas): It is also possibly to fill part of a volume if we can not get 10 papers together.

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Appendix A

Circular 2 – workshop on

Fennoscandian paleo-environment and ice sheet dynamics during MIS 3

Sept 20–21 2007

Organised by Swedish Nuclear Waste Management Company (SKB)

Location: The workshop will be held at the conference centre Villa Söderås, situated on the island of Lidingö, in the inner archipelago of Stockholm. Phone number ind information on the conference centre is found on www.villasoderas.se/engelska/index2.html

Getting there: If you arrive by flight to Arlanda airport, you could either take the "Arlanda Express" train to Stockholm Central station. It takes 20 min, and costs 220 Swedish kr. Then from the Central station take a taxi to Villa Söderås on Lidingö. Choose the taxi company "Taxi Stockholm". They have a fixed price from the Central station to this conference centre of 280 Swedish kr (for a small (4 person) car). The taxi trip takes about 20–30 min.

Or alternatively, you could take a taxi directly from Arlanda to Villa Söderås, Lidingö. There is a fixed price with "Taxi Stockholm" also for this trip, 600 kr. This trip takes about 45–60 minutes. People not coming from Arlanda could use the option of going by taxi from for example the Central station. Other means of getting to Villa Söderås are described at the homepage above (in Swedish only).

Time: The meeting will start with lunch at 12 a clock Sept 20, so plan for arriving at the conference centre before noon. The meeting will end at 15 a clock Sept 21.

Below you will find the programme for the meeting, including questions to be addressed, and a participant list. Some of the titles of the presentations are still preliminary. For more details on the topic of the workshop, see circular 1.

If you have questions, on for instance specific request on food, please contact any of the organizers.

Welcome!

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Programme

The overall idea is to give introductory presentations day one, followed by discussions day two. Shorter discussions can also take place after each presentation. Following the general introduction of the meeting, each person has 20 minutes for presentation, followed by 10 min discussion.

September 20 – Day 1

11:00–12:00	*Arrival*
12:00–13:00	Lunch
13:00–13:15	Jens-Ove Näslund: *Introduction*
13:15–13:30	Erik Kjellström: *Overview 100,000 year project*
13:30–14:00	Jens-Ove Näslund: *Examples of modelled ice sheet configurations for MIS 3 (Fennoscandian and Laurentide)*
14:00–14:30	Johan Kleman: *Geomorphological evidence for ice sheet configuration during MIS 4 and 3 (Fennoscandian and Laurentide)* (prel. title)
14:30–15:00	Mikael Houmark: MIS-3 ice streams and interstadial episodes in the south-western Baltic Basin
15:00–15:30	Coffee break
15:30–16:00	Karin Louise Knudsen & Nicolaj Krogh Larsen: *Fennoscandian ice sheet fluctuations during MIS 3 in Northern Denmark, Kattegat and Skagerrak: marine and non-marine environments*
16:00–16:40	Jan Mangerud: *Correlation between ice-sheet fluctuations in Sunnmøre, western Norway, and Greenland D-O events during the period 45–25 ka BP* and *Were Svalbard, the Barents Sea and Novaya Zemlya ice-free during the middle part of MIS 3?*
16:40–17:10	Karin Helmens: Paleo-environment conditions in the Sokli region (NE Finland) during an early MIS 3 interstadial based on high-resolution, multi-proxy evidence
17:10–17:40	Pirkko Ukkonen: *Mammoth dates from Fennoscandia and the Baltic States related to MIS 3*
17:40–18:10	Helena Alexanderson: *New OSL and ^{14}C dates for MIS 3 in Sweden* (prel. title)
19:00–20:00	Dinner
20:00–	Informal discussions

September 21 – Day 2

08:30–09:00	Barbara Wohlfarth: Summary of day 1 incl. relevance for the questions to be addressed
09:00–09:15	Jenny Brandefelt: Simulations of global climate within the 100,000 year project
09:15–09:30	Gustav Strandberg: Simulation of the European regional climate within the 100,000-year project (preliminary title)
09:30–09:45	Barbara Wohlfarth: The paleo-data contribution to the 100,000 year project
09:45–10:15	Coffee break
10:15–12:00	General discussion
12:00–13:00	Lunch
13:00–15:00	Discussion, conclusions/recommendations, publication

Departure

Overall topics to be addressed

- Is it possible to obtain a consistent picture of ice extent, sea level, topography, permafrost and vegetation during MIS 3 (and GIS 12/8 specifically), based on paleo data, to use as input for climate model simulations?
- Do simulated climates in global circulation models correspond to the paleoenvironmental and paleogeographic picture? Discussion focussed mainly on LGM, due to scarce model results from MIS 3 at present. How can discrepancies between model results and palaeodata be explained?

Specific topics to be addressed, related to MIS 3

- Ice configurations in Fennoscandia, The Alps, North America, Russia (dynamic ice sheet behaviour and ice streaming in Fennoscandia).
- Topography and coastlines (incl. sea-level changes, isostasy, Baltic Sea during MIS 3).
- Vegetation zones in ice free areas (including tundra and permafrost distribution).

Appendix B

Model forcing conditions to be used for the permafrost case (a cold stadial in MIS 3) in the project "Climate conditions in Sweden in a 100,000-year time perspective"

This text contains a summary of the forcing conditions for the permafrost case studies that are undertaken in the 100,000-year project. It is our intention to use consistent forcing conditions in the GCM and the RCM although there will be some differences. These differences are related both to the finer resolution of the RCM (and thus the possibility to include more detailed regional information) and to different model formulation (an example is the treatment of the greenhouse gases. In the RCM we can only use CO_2 while in the GCM also other greenhouse gases are explicitly treated. To make the greenhouse gas concentrations consistent between the models we will express the concentrations of these other greenhouse gases in terms of CO_2-concentrations, i.e. so called CO_2-equivalents).

Motivation for choice of forcing conditions

We have tried to set up conditions favourable for a cold climate with only restricted ice sheet coverage over Scandinavia. The idea is that large areas of for instance southern Sweden would be ice free but subjected to permafrost. Such periods may have occurred during parts of the MIS 3. For geological information on MIS 3, see e.g. a compilation by /Lokrantz and Sohlenius 2006/ and a forthcoming review specifically on MIS 3 data by B. Wohlfarth produced within the present project.

Astronomical forcing

The variations in solar insolation due to changes in the Earth's orbit are relatively minor through much of MIS 3 /Berger and Loutre 2002/. We choose the orbital year 44,000 year before present. The solar constant is set to 1,365 W/m^2 (equal in all three cases).

Greenhouse gases and aerosols

CO_2 concentrations of 200 ppm$_v$. CH_4 420 ppb$_v$ and N_2O 225 ppb$_v$ are chosen according to ice core measurements. Ozone, mineral dust, sea salt and other aerosols are set to their pre-industrial concentrations. We know that keeping mineral dust at pre-industrial concentrations is probably a gross underestimation as ice core records indicate much higher concentrations for the glaciated time periods.

Table B-1. Forcing and boundary conditions in the three cases in the 100,000 year project. The permafrost case that is described in this appendix is highlighted in bold face. PD = Present day, PI = pre-industrial, LGM = Last Glacial Maximum, GIS = Greenland Ice Sheet. Data within [] are used only in the RCM simulations.

	Permafrost	LGM	Warm
Insolation	1,365 Wm^{-2}	1,365 Wm^{-2}	1,365 Wm^{-2}
Orbital year	44 ka BP	21 ka BP	1,990
CO_2	200 ppm(v)	185 ppm(v)	750 ppm(v)
CH_4	420 ppb(v)	350 ppb(v)	PD (1,714 ppb(v))
N_2O	225 ppb(v)	200 ppb(v)	PD (311 ppb(v))
Ozone	PI	PI	PI
Sulphate	PI	PI	PI
Dust, sea salt	PI	PI	PI
Ice sheets	Näslund, CLIMBER2, ICE-5G	ICE-5G (for LGM)	PD (Excluding GIS)
Land-sea distribution	ICE-5G (for LGM) [Whitehouse]	ICE-5G (for LGM)	PD
Sea level	–120 m [–70 m]	–120 m	PD [+7 meters]
Topography, bathymetry	ICE-5G [Whitehouse], PD	ICE-5G, PD	PD (Excluding GIS)
Vegetation	PD / GUESS	PD /Mahowald et al. 2006ab/	PD /Scholze et al. 2006/

Land-sea mask, orography, bathymetry

We want to simulate an atmospheric circulation that is such that little precipitation falls over the ice-free areas in eastern Sweden; we want a climate that is in agreement with a small ice sheet over Fennoscandia. To simulate this type of circulation the topography, primarily the Laurentide ice sheet, is important. We have tried to find a configuration of this ice sheet that fits the paleodata for ice sheet extent and gives a dry, cold climate in Sweden also in accordance with paleodata. Ice sheets are taken as a combination of Fennoscandian ice sheet from an earlier SKB project, Laurentide ice sheet from a simulation with CLIMBER-2 and the ICE-5G /Peltier 2004/ data for the Antarctic ice sheet for 14ka BP.

Other aspects of the land-sea mask and orography are taken from ICE5G /Peltier 2004/. In the RCM simulation, land-sea mask and orography will be taken from a simulation with a global isostatic model for an earlier SKB-project /SKB 2006/.

Vegetation

In the reference case we use today's vegetation. But as this is not a realistic vegetation cover for MIS 3 we intend to perform sensitivity studies. The obtained climate from the global AOGCM will be used as input to the well-validated regional-scale vegetation model GUESS /Smith et al. 2001, Hickler et al. 2004, Morales et al. 2005, 2007, Koca et al. 2006/ that, in turn, will simulate a new vegetation more in line with the climate. Finally, this new vegetation will be used in the AOGCM that will be rerun. A similar approach will be used for the regional model, i.e. the climate as simulated by the RCM will be used as input to GUESS which will give a new vegetation for use in the RCM.

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