Character and causes of the 8.2 ka climate event – comparing coupled climate model results and palaeoclimate reconstructions

English summary

Chapter 1: Introduction.

The “8.2 ka event”, centered around 8200 calendar years BP, is the most pronounced Holocene climate event in the Greenland ice core records. In these records the event is characterized by a pronounced ~160 year cooling of up to ~3.3 +/- 1.1ºC, coinciding with a decrease in ice accumulation rate, increasing wind speeds and a drop in atmospheric methane concentrations. The event is also recorded in many other terrestrial and marine proxy archives in the North Atlantic region and areas influenced by monsoons, suggesting at least a semi-global impact of the event.

The event is hypothesized to be related to a weakening in the North Atlantic thermohaline circulation, triggered by the final catastrophic drainage of the Laurentide Lakes (Lake Agassiz and Ojibway) at around 8470 cal. years BP which had formed in front of the melting Laurentide ice sheet. The fresh water from the lakes sufficiently freshened the North Atlantic surface waters, thereby inhibiting deep ocean convection and reducing associated northward oceanic heat flux.

The 8.2 ka event is often seen as an analogue for a future freshening of the North Atlantic Ocean and could serve as a test-case for sensitivity of ocean circulation to freshwater perturbations in climate models. As such, it has several advantages above other climate events. For example, there is a likely hypothesis for the cause of the event: the catastrophic drainage of the Laurentide Lakes, and the cause is quantifiable in terms of the estimated volume of freshwater in the lakes and release duration. In addition, the ocean response to the perturbation is significant and took place in a climatological setting that is close to modern climate in terms of global boundary conditions which is essential for realistically simulating the event with fully comprehensive coupled climate models. Because the event took place relatively recently, many high-resolution climate reconstructions are available from this period, which makes it possible to map the geographical distribution of the event.

The main objective of this study is to gain a better understanding of the character and causes of the 8.2 ka event. To address this main research objective, the following research questions were formulated, which are addressed in the subsequent chapter of this thesis.

1. a) What is the geographical distribution of the 8.2 ka event as recorded in proxy-archives and what is the climate expression at different geographical locations?  
   b) How does the distribution observed in proxy-archives compare to earlier modelling results in which a freshwater pulse is released into the Labrador Sea to simulate the 8.2 ka event?  

2. a) What is the importance of the volume and the duration of the freshwater discharge from the Laurentide Lakes on the ocean circulation response in simulations of 8.2 ka event?  
   b) What is the influence of meltwater from the background melting of the Laurentide ice sheet on the response of overturning circulation in addition to the freshwater discharge?
3. How is the simulated 8.2 ka event characterized in terms of spatial variations in magnitude, timing and duration of the temperature response?
4. a. What was the potential role of icebergs from the decaying Laurentide ice sheet in the 8.2 ka event?
   b. Can a two-stage lake drainage of the Laurentide Lakes explain oceanic and atmospheric events observed in climate reconstructions in the North Atlantic area?

**Chapter 2: Geographical distribution and model-data comparison**

We reconstructed the geographical distribution of the 8.2 ka event by combining the published proxy-data that record the event. Many proxy-records show anomalous changes around 8200 years ago, but the temporal resolution and chronological uncertainties are highly variable. As a result, these anomalous changes do not necessarily reflect a climate response that is associated with the 8.2 ka event as defined in central Greenland ice cores. To address this issue, we allocated a subjective rating to the records, indicating our opinion on the quality of the records and the confidence we have that the climate signal in these records is a representation of the 8.2 ka event.

The combined proxy evidence suggests that the 8.2 ka event is expressed as a cooling in eastern North America, Greenland, Scandinavia, Europe and the Mediterranean Sea. Dryer conditions occurred in Europe, Greenland, North Africa and the Mediterranean Sea, East Asia and the Caribbean. No convincing evidence is present from the Southern Hemisphere, except possibly for a warming. Strikingly, all evidence from the Alpine region reflects a wet response. Although there remains uncertainty in the interpretation of proxy data and their chronologies, the large number of records reflecting anomalous climate changes around the 8.2 ka event suggests that this reconstructed geographical distribution is robust.

We compared the reconstructed distribution of the event to climate model simulations of the 8.2 ka event with version 2 of the ECBilt-CLIO coupled climate model. In one particular experiment discussed in Chapter 2, a freshwater pulse of $4.3 \times 10^{14}$ m$^3$ was released over 20 years into the Labrador Sea in an early Holocene climate state. The simulated temperature anomalies related to the freshwater perturbation show cooling in high northern latitudes, which is most pronounced around the North Atlantic Ocean. A slight warming is simulated in the Southern Hemisphere. Simulated annual precipitation anomalies reflect a dry response over Europe, polar regions and tropics. Furthermore, a conspicuous increase in precipitation is simulated around 20$^\circ$S in boreal winter, associated with an enhancement of intertropical convergence zone (ITCZ) convection.

In general, the reconstructed geographical distribution of the temperature and precipitation response for the 8.2 ka event is captured reasonably well by simulation results, thereby supporting the hypothesized forcing of the event by the drainage of the Laurentide Lakes.

**Chapter 3: Importance of the volume and the duration of the freshwater discharge and influence of meltwater**

To evaluate the relative importance of the volume and duration of the freshwater discharge we utilized version 3 of the ECBilt-CLIO-VECODE coupled climate model.
Starting from an early Holocene climate state we released freshwater pulses varying in volume and duration based on published estimates. Our results showed that increasing volumes produced a prolonged weakening of the Meridional Overturning Circulation. On the other hand, releasing these volumes over varying durations did not lead to a notably different response. These results imply that the amount of freshwater released is the decisive factor in the response of the ocean, while the release duration only plays a minor role, at least when considering the short release durations (1, 2 and 5 years) of the applied freshwater pulses.

Using the same model we evaluated the influence of a baseline flow (0.172 Sv) in the Labrador Sea to account for the background-melting of the Laurentide ice sheet. The baseline flow results in a more realistic early Holocene climate state with no deep ocean convection in the Labrador Sea. Applying the freshwater discharges described above into a control climate with a baseline flow produced a prolonged weakening of the overturning circulation compared to the same experiments in an early Holocene climate without baseline flow. This implies that in experiments with a baseline flow, less freshwater is needed to produce an event of similar duration.

Convection strength in the Labrador Sea may play an important role in the duration of the overturning circulation recovery. Intensified convection in the Labrador Sea immediately after the perturbation in the experiments without a baseline flow may facilitate the removal of the freshwater anomaly through convection, while convection remains dampened in the experiments with a baseline flow by the lower density of the surface water. These experiments illustrate that model studies covering the 8.2 ka event should consider including a representation of a baseline flow in their early Holocene climate state.

Chapter 4: Characterization of the 8.2 ka event in a coupled climate model

To characterize the 8.2 ka event as simulated in a coupled climate model we developed an analysis method that isolates the forced temperature response and provides information on spatial variations in magnitude, timing and duration that characterize the climate event. As input we analyzed 10 ensemble members (identical experiments with slightly different initial conditions) of a freshwater perturbation modelling experiment that produced an event in Greenland that was in close agreement with Greenland ice cores.

The analysis produces a characteristic geographical fingerprint for the December, January, February (DJF) and June, July and August (JJA) season. An anomalous cooling is simulated in the Labrador Sea, Greenland, most of the North Atlantic Ocean and the east bounding land masses, the Arctic Ocean and south bounding land masses, the Mediterranean and northern Africa. In DJF an anomalous cold response is present in central Asia, while in JJA the northern Indian Ocean cools. In the Southern Hemisphere, an anomalous warming is present over the subtropical South Atlantic and in specific areas of the Southern Ocean, reflecting a bipolar seesaw.

Furthermore, the analysis shows that delays in the temperature response to the freshwater forcing are present, mostly in the order of decades (30 years over central Greenland). The North Atlantic Ocean initially cools in response to the freshwater perturbation, followed in certain areas by a warm response. This delay, occurring more
than 200 years after the freshwater pulse, hints at an overshoot in various areas in the ocean circulation recovery to the freshwater perturbation. The duration of the simulated event varies for different areas, and the highest probability of recording the event in proxy archives is in the North Atlantic Ocean area north of 40ºN.

The method applied is ideal for tracing the climate fingerprint to any forcing. For instance, the climate response to a weak forcing mechanism, such as changes in solar intensity, can be investigated. In addition, delayed responses such as the late warming in the North Atlantic can be detected. A condition is that the climate response to a forcing is similar in the different ensemble runs.

Chapter 5. Potential role of icebergs in the 8.2 ka event and evaluation of a two-stage lake drainage scenario

To examine the potential role of icebergs originating from the decaying Laurentide ice sheet in the 8.2 ka event, we used ECBilt-CLIO-VECODE coupled climate model equipped with a dynamical iceberg component. In this model, an early Holocene climate state is perturbed by a large iceberg discharge released near the Hudson Strait outlet. The effect of the iceberg discharge on ocean circulation is compared to the effect of a release of an identical volume of freshwater alone.

These experiments show that, compared to a freshwater perturbation with the same (freshwater) volume, a perturbation by an iceberg discharge leads to expanded sea-ice cover in the North Atlantic Ocean, a stronger weakening in NADW production, and stronger cooling over central Greenland. This stronger response to the iceberg discharge is the result of sea-ice facilitation caused by lower SSTs resulting from latent heat of melting. The resulting increased sea-ice cover is responsible for inhibiting convection by reducing oceanic heat loss to the atmosphere and by freshening surface waters when melting. Conversely, the inhibited convection maintains the increased sea-ice cover, and thus represents a powerful positive feedback.

A two-stage lake drainage scenario is evaluated with the same model to see if this could explain the apparent conflict in timing between the lake drainage and the cooling in Greenland. We released two freshwater pulses separated by a 200-year gap, and accompanied the second freshwater pulse with an iceberg discharge. The volumes of the freshwater pulses and the 200-year gap were based on published estimates. The volume of the iceberg discharge corresponded to the size of the ice-dam that disappeared around the 8.2 ka event. In two different scenarios concerning the second stage we released the icebergs over 5 years and 100 years.

These simulations show that a two-stage lake drainage scenario combined with an iceberg discharge representing the collapse of the ice-dam accounts for the events recorded in deep ocean sediment core MD99-2251 around the 8.2 ka event. In addition, it provides a solution for the 200-year gap between the dated lake outburst at 8470 year BP and the start of the event in Greenland, and for the climate anomalies preceding the 8.2 ka event as reported in earlier studies. However, we note that these experiments do not account for the lack of a marked cooling preceding the 8.2 ka event in Greenland oxygen isotope profiles.