BACC II Book

Chapter 2. Past climate variability

2.1.The Holocene (10,000 yr)

- Fist and foremost I thank reviewers for their trouble to read and make very useful comments;
- During the last month we have been trying to change and improve text and figures;
- We have been made new figures instead previous;
- Some of contributors had more time to check text carefully;
- The main problem and weakness: we need to supplement the team authors from another countries.

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2.1. The Holocene (past 10,000 yr)

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2.3.2. Gas composition forcing

2.3.3. Other factors

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Conclusion

References about 200, more than 40% (2004-2010)

Annex XX Climatic and Environmental Changes during the Lateglacial in the Baltic Sea Basin (15,000 – 11,500 cal yr BP)

Glossary of the terms??

Introduction

History of the basins that had existed on the territory of the modern Baltic Sea since the last deglaciation has been already studied for more than a hundred years. Nevertheless, the issues are still questionable of both the chronologies of transgression-regression phases of the pre-historic Baltic basins and their spatial characteristics.

The Lateglacial and Holocene history of the Baltic Sea Basin has been divided into four main stages: the Baltic Ice Lake (BIL) from deglaciation to ca. **11,550** cal yr BP, the Yoldia sea stage ca. **11,550-10,700** cal yr BP (brackish –water basin in the fist part of this stage and fresh water basin during the second phase), the Ancylus Lake (fresh water basin between ca. **10,700-9,500** cal yr BP) and the Littorina Sea (brackish – water basin, ca. **9,500** cal yr BP to present) (Andrén et al, 1998; Björck, 1999; Heinsalu, Veski, 2007; Zilén et al., 2008).

2.1. Sources and methods of the palaeoclimatic reconstructions for the BSB area

Pollen data from lakes and bogs deposits, isotopic evidence from continental, ice and lakes sites have provided the main sources of the information about climate during the last 10,000 years in the BSB area.

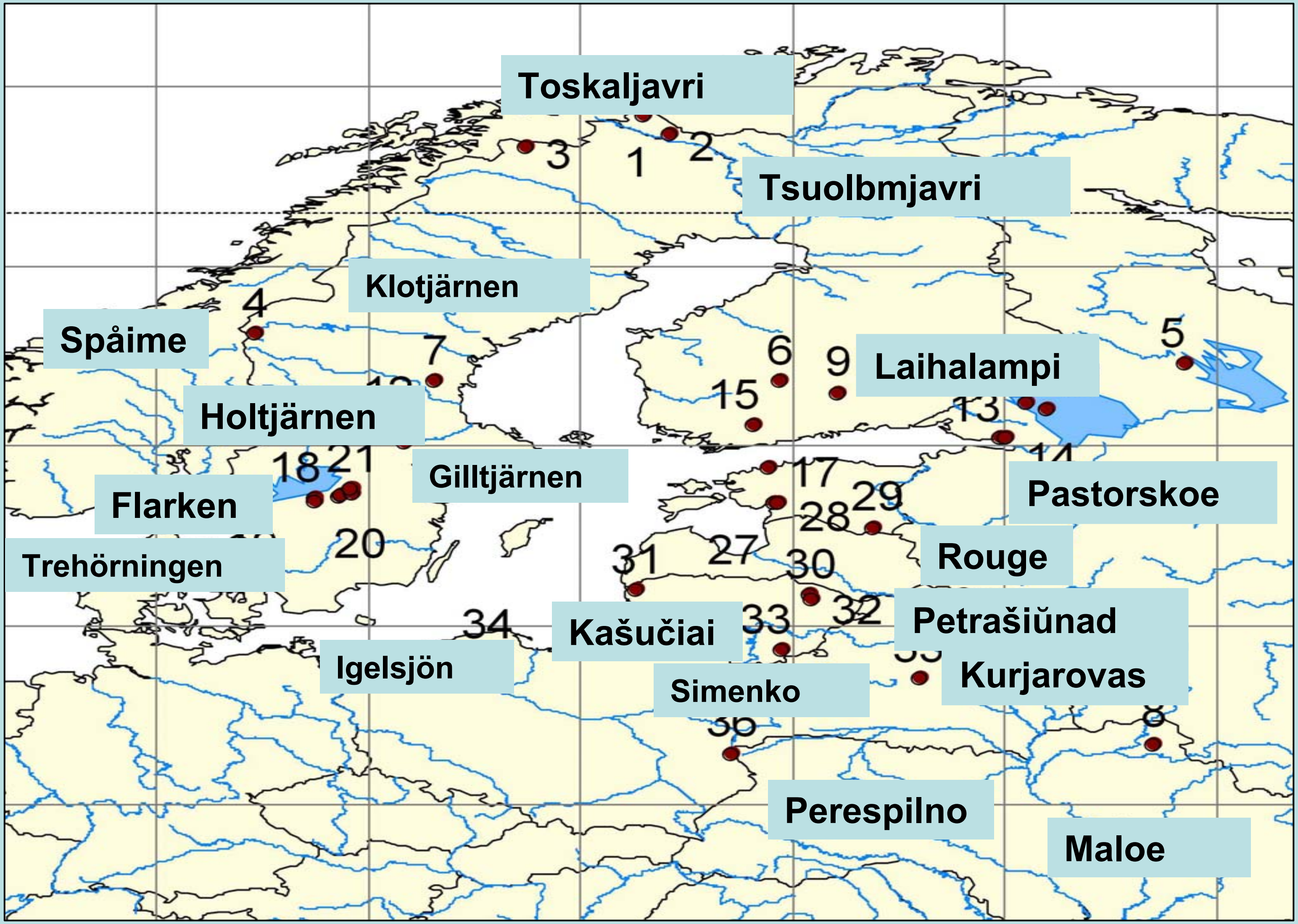
In last years a new quantitative information are appeared. This information based on the different type of transfer functions between modern pollen, diatoms and beetles fauna data and present climate parameters (annual and seasonal air temperature and annual sum of precipitation)

But these data are very scarce to reconstruct climate for the whole Holocene in the different part of the BSB area.

Major Indirect Data Sources

Data sources	Methods of investigation	Climate-related inferences
Bog or lake sediments	1. Pollen analysis. 2.Diatom analysis 3.Chironomid analysis 4. Isotope analysis	Air and surface water temperature, annual sum precipitation
Tree rings	1.Dendroclimatical analysis 2. Isotope analysis	Annual and seasonal air temperature, annual sum of precipitation
Ice cores from continental ice sheets	1. Isotope composition. 2. Geochemical analysis. 3. Trace chemistry and electrolithic conductivity	Temperature, gas composition, transparence of the atmosphere, volcanic eruptions
Continental sites	1. Pollen analysis. 2. Chironomid analysis	Annual and seasonal air temperature, annual sum of precipitation

Map of the key sites, which data was used in the chapter 2.2.



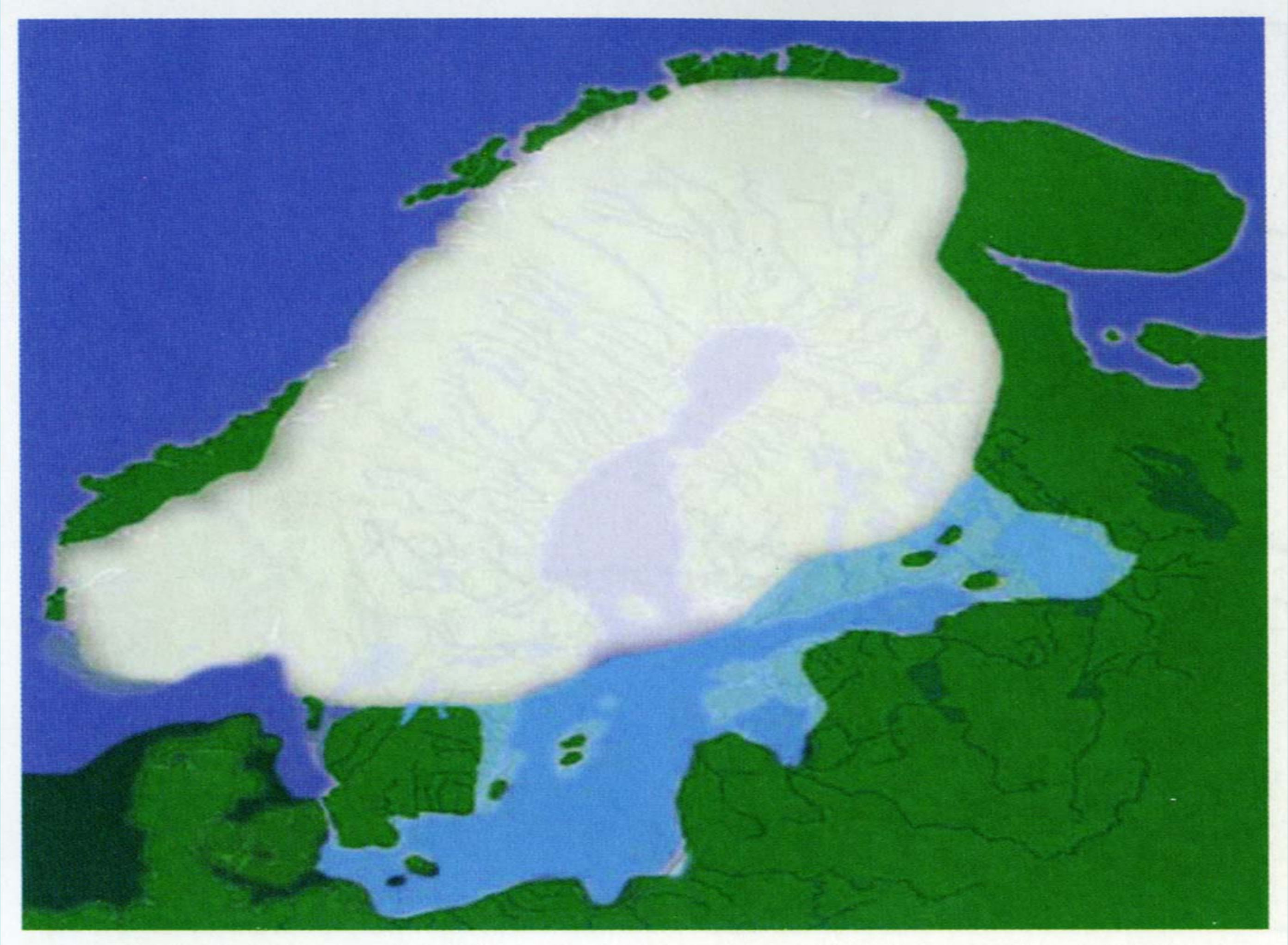
2.2.1. Climate of the boundary DR3/Holocene

The modern Greenland core chronology (GRIP, NGRIP, and Dye-3) places the Late Dryas/Holocene boundary at about 11,653 ice years ago. By ^{10}Be and ^{14}C isotope content in tree rings this boundary is dated at about 11,573 cal years ago, and by tree-ring chronology at ~11,590 cal years ago (Kobashi et al., 2008) .

This boundary DR3/Holocene almost coincides with the final drainage of the Baltic Ice Lake at Billingen area (Central Sweden).

Independent estimates on the isotope ratio $^{29}N/^{28}N$ and $^{40}Ar/^{36}Ar$ in Greenland cores show the temperature increase at the DR3/Holocene boundary was 10± 4°C within less than 50 years (Grachev, Severinghaus, 2005).

The Baltic Sea Ice just prior to the final drainage, ca. 11,700 – 11,600 cal yr BP (Andrén, 2003)



At the boundary of the Holocene a cold and dry climate was drastically changed to a warmer and humid one. The summer temperature in northwestern Russia increased from 4° to 10-12°C (Wohlfarth et al., 2007) and in Southern Finland from 7-10°C to 16-22°C (Bondestam et al., 1994).

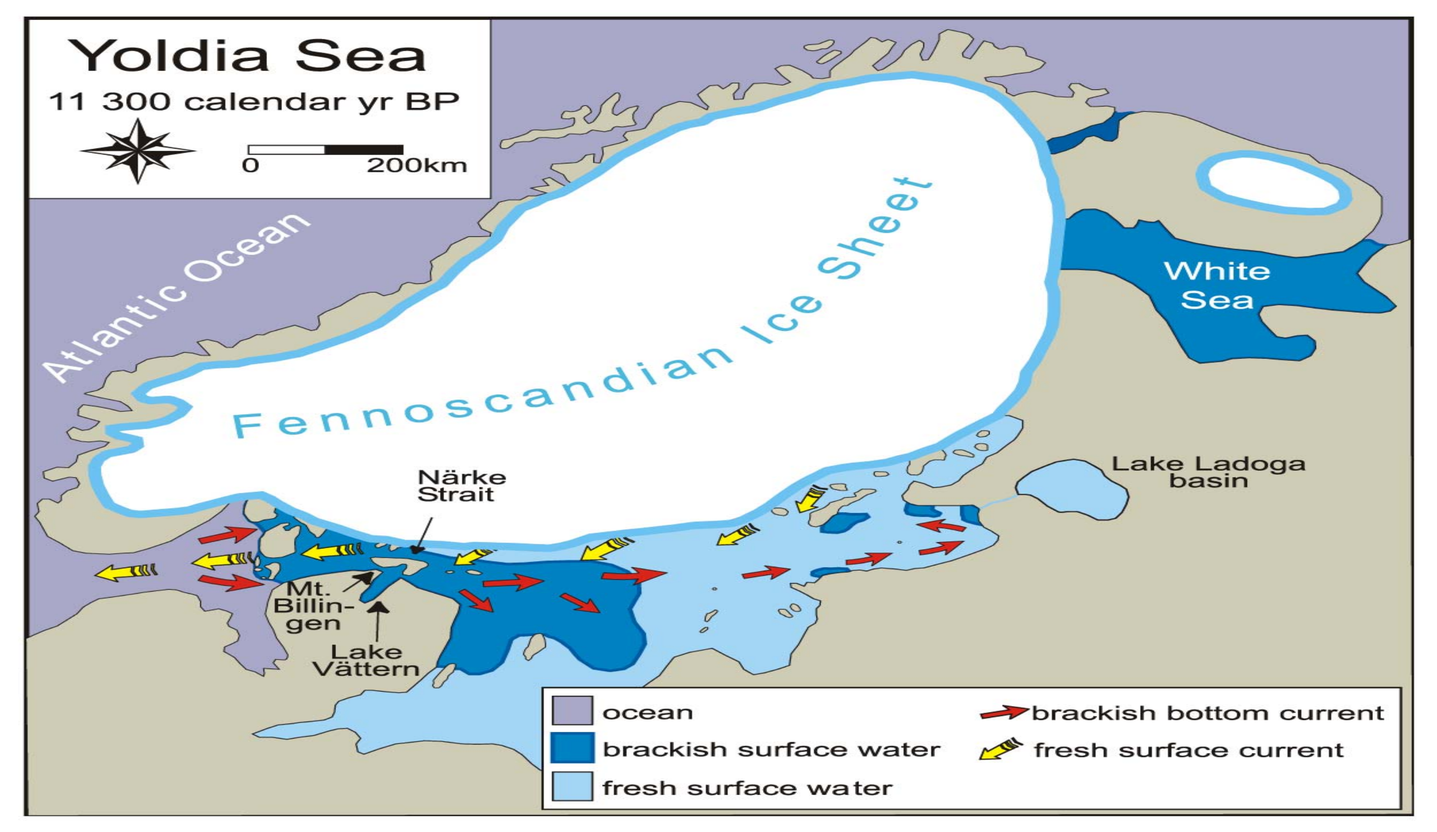
Tundra-steppe vegetation with predomination of shrubs and grass typical of the Late Dryas changed to vegetation of open forest

In the very first warm phase of the Preboreal around 11,530 – 11,500 cal yr BP as a result of an abrupt warming (within 50 years or less) the arboreal vegetation started spreading fast in ice-free regions, however climate was unstable (Bos et al., 2007).

After the final drainage of the BIL, sea water inflowed into the Baltic basin through the Närke/ Billingen strait due to rapid sea-level rise in response to melt of the Scandinavian ice sheet (Yu, 2003). As a result of this processes the brackish (Yoldia basin) is appeared between 11,300 and 11,100 cal yr BP.

This stage of the Baltic Sea almost coincides with the Preboreal cool oscillation. The end of the brackish phase of the Yoldia Sea is dated to 11,200 cal yr BP (Heinsalu, Veski, 2007), which corresponds to age of 11,190 GRIP ice core yr BP (Björck, 1999).

Palaeogeography and palaeohydrology of the brackish Yoldia Sea phase ca. 11,300 years BP (Heinsalu, Veski, 2007)



The penetration of salt water during the Yoldia Sea took probably place mainly along the south coast of the Gulf of Finland and the saline water pulse would flow as a near-bottom current.

2.2.2. The Early Holocene oscillations

The warming at the Holocene boundary, at about 11,530 and 11,500 cal yr BP, was interrupted by a short cold the Preboreal oscillation dated from ice cores at 11,430-11,270 ice core yrs BP (Kobashi et al., 2008). A relatively short cooling (duration about 160-200 yr) occurred approximately 250 years after the Holocene boundary warming (Rasmussen et al., 2006).

The coldest part of the Preboreal oscillation is dated at ~11,430-11,350 cal yr BP. The birch expansion that started during the warming in the beginning of the Early Holocene was interrupted by a dry continental phase with open grassland vegetation (Rammelbeek Phase) (Bos et al., 2007).

The Preboreal cool oscillation almost coincides with the short brackish phase of the Yoldia Sea. The end of the Yoldia Sea to dated to 11,200 cal yr BP, which corresponds to age 11,190 GRIP ice core yr BP.

At the beginning of the Late Preboreal time, between 11,270 and 11,210 cal yr BP, a sudden shift to warmer and more humid climate occurred and forest vegetation expanded again. Expansion of pine forests occurred in the later part of the Late Preboreal time.

As indicated by the GISP2 core isotope data, at the Preboreal/Boreal boundary air temperatures increased by 4 ±1,5°C (Grachev, Severinghaus, 2005).

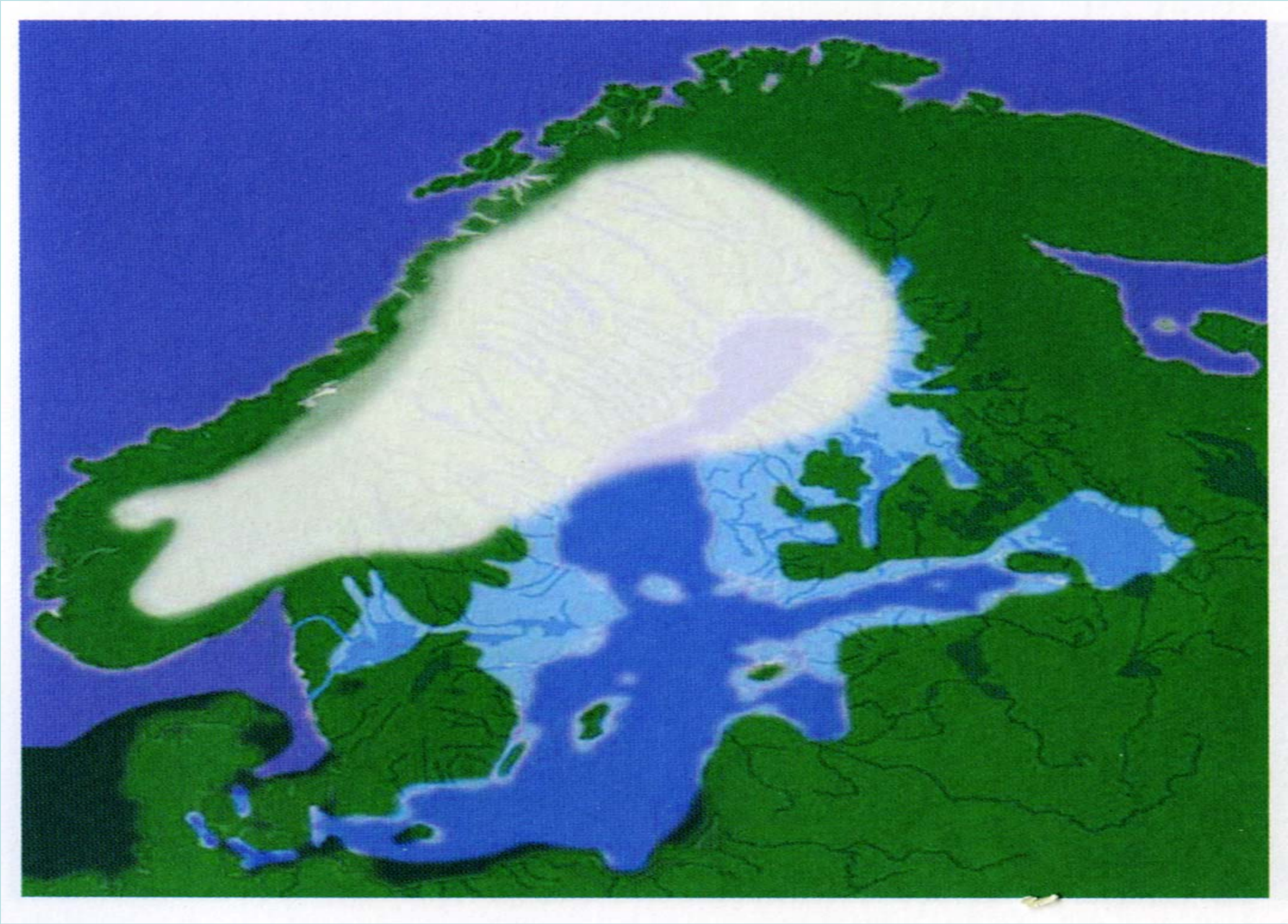
At the onset of the Boreal time (between 10,770 and 10,700 cal BP), dense woodland with pine started to develop in the southern part of the Baltic Sea Basin (Bos et al., 2007), on the Karelian Isthmus and in northwestern Russia boreal forest with *Pinus*, *Picea*, *Betula*, *Alnus incana* was present at the lower altitudes (Subetto et al., 2002).

According to estimates in (Hiekkilä, Seppä, 2003), in the southern Finland between 10,700 and 10,500 cal yr BP the mean annual temperatures were as much as –3.0 – 0.0°C. These temperatures correspond to the modern temperature at 70°N.

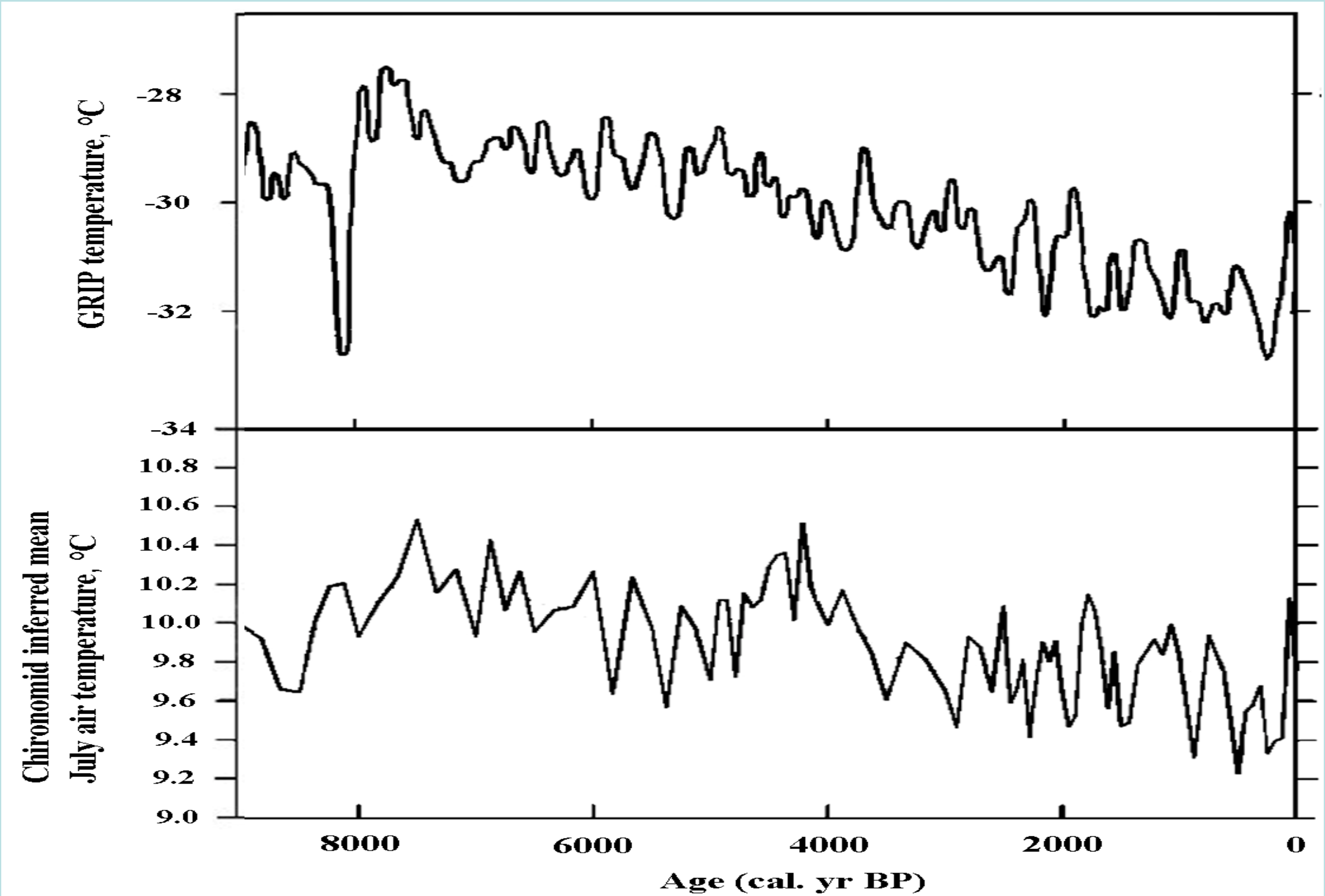
Over the greater part of southern Sweden, in Estonia, Latvia and Lithuania open boreal woodlands with birch vegetation were established. As compared to the Younger Dryas cooling summer air temperatures rose by 7-10°C.

Temperature started rising after 10,000 cal yr BP and lasted until the beginning of cooling at 8.2 cal yr BP.

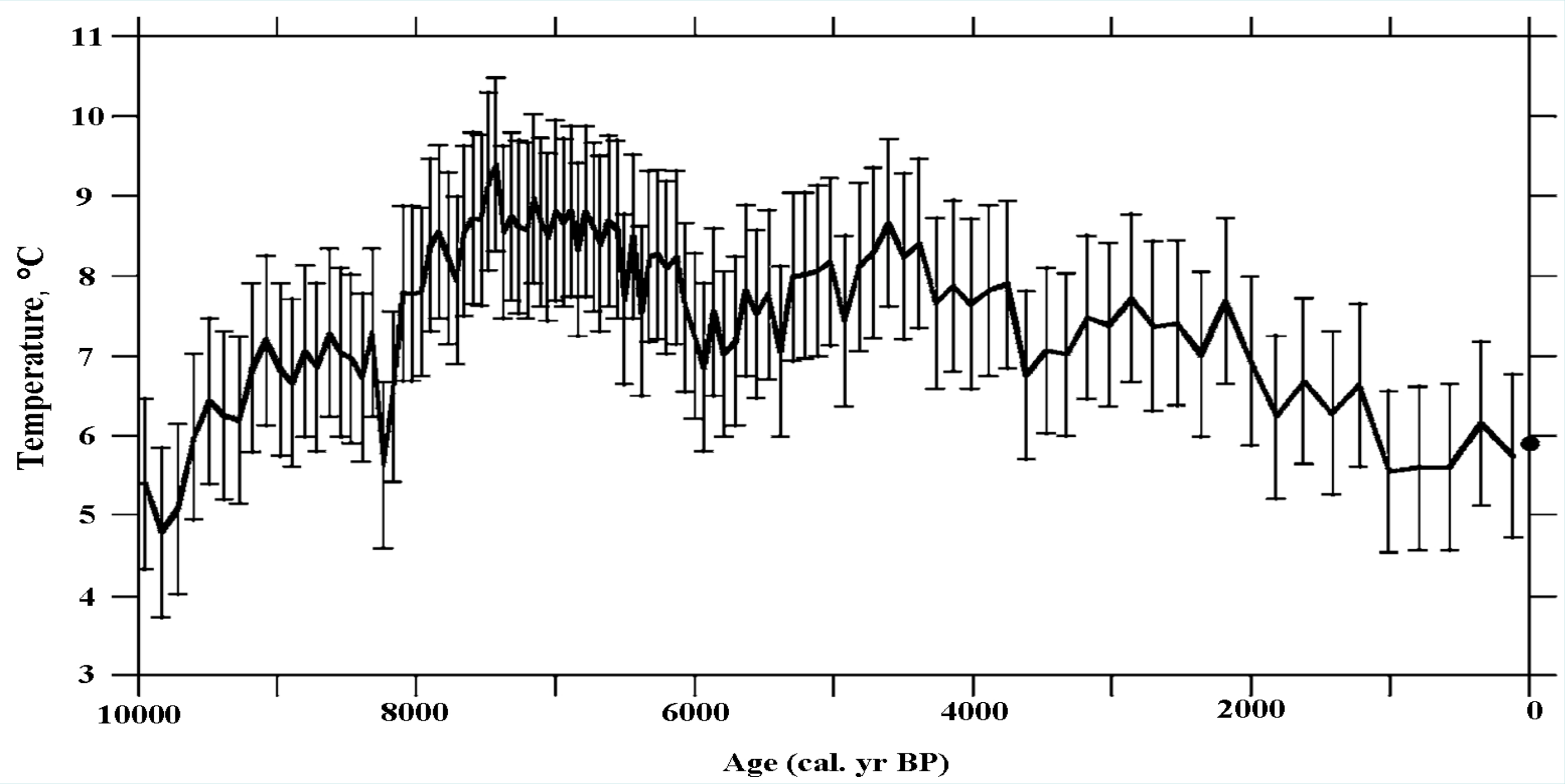
Ancylus Lake stage ca. 10,300 cal yr BP at the culmination of the Ancylus transgression (Andrén, 2003)



The general trends of the Holocene summer temperatures obtained from ice core data (GRIP) and based on the proxy data (chironomide) from site L. Toskaljavri (Northern Finland)



Mean annual temperature reconstructed from pollen data Lake Flarken (south-central Sweden) during the last 10,000 years (black line) (Seppä, Hammerlund, Antonssen, 2005). L.Flaken, 58°33'N



Present day annual temperature – (5.9°C) is marked by point

2.2.3. The 8.2 ka cool event

The 8.2 ka cooling had been known comparatively long time by changes in oxygen-isotope composition in ice cores from the Greenland. The cooling has been estimated by changes in air temperature by 6 ± 2°C in central Greenland (Dansgaard, 1993; Alley et al., 1997; Alley, Áqústsdóttir, 2005; Muscheler et al., 2004; Rohling et al., 2005). Later an independent method was developed to estimate both air temperature change amplitude and the duration of this cooling.

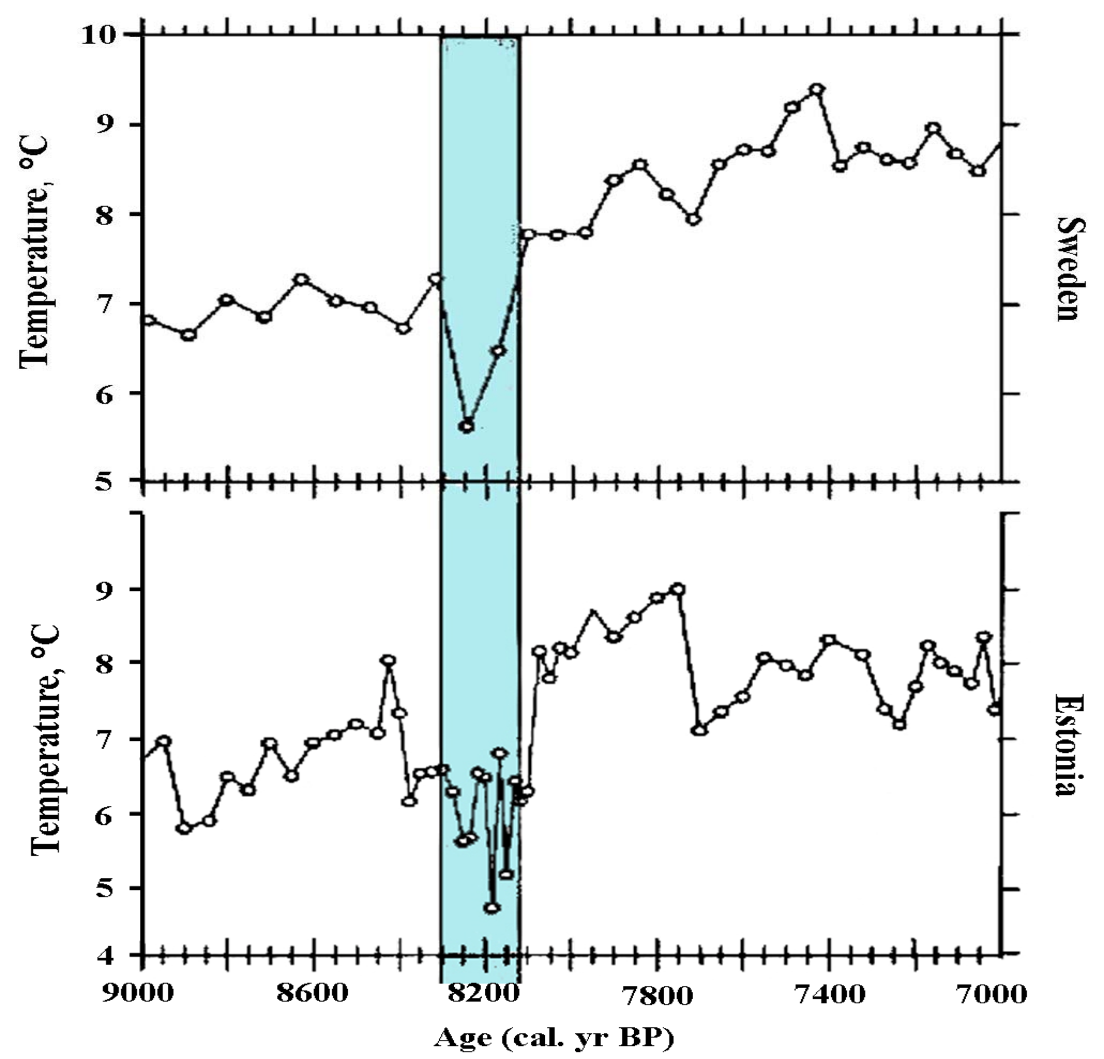
This data showed a complicated time structure of this event. The coldest phase of about 70 years in duration occurred in the middle of this interval. In the beginning and end of this event the climate was milder. In central Greenland air temperature decrease of 3 ± 1.1°C occurred within less than 20 years and the entire cooling episode lasted approximately 150 years.

Independent empirical data such as marine cores with high resolution, lake sediments, spore-pollen diagrams, speleothems and lake isotopic data, and others indicate that the cooling took place in the entire the Baltic Sea Basin, except for the most northern regions above 70°N.

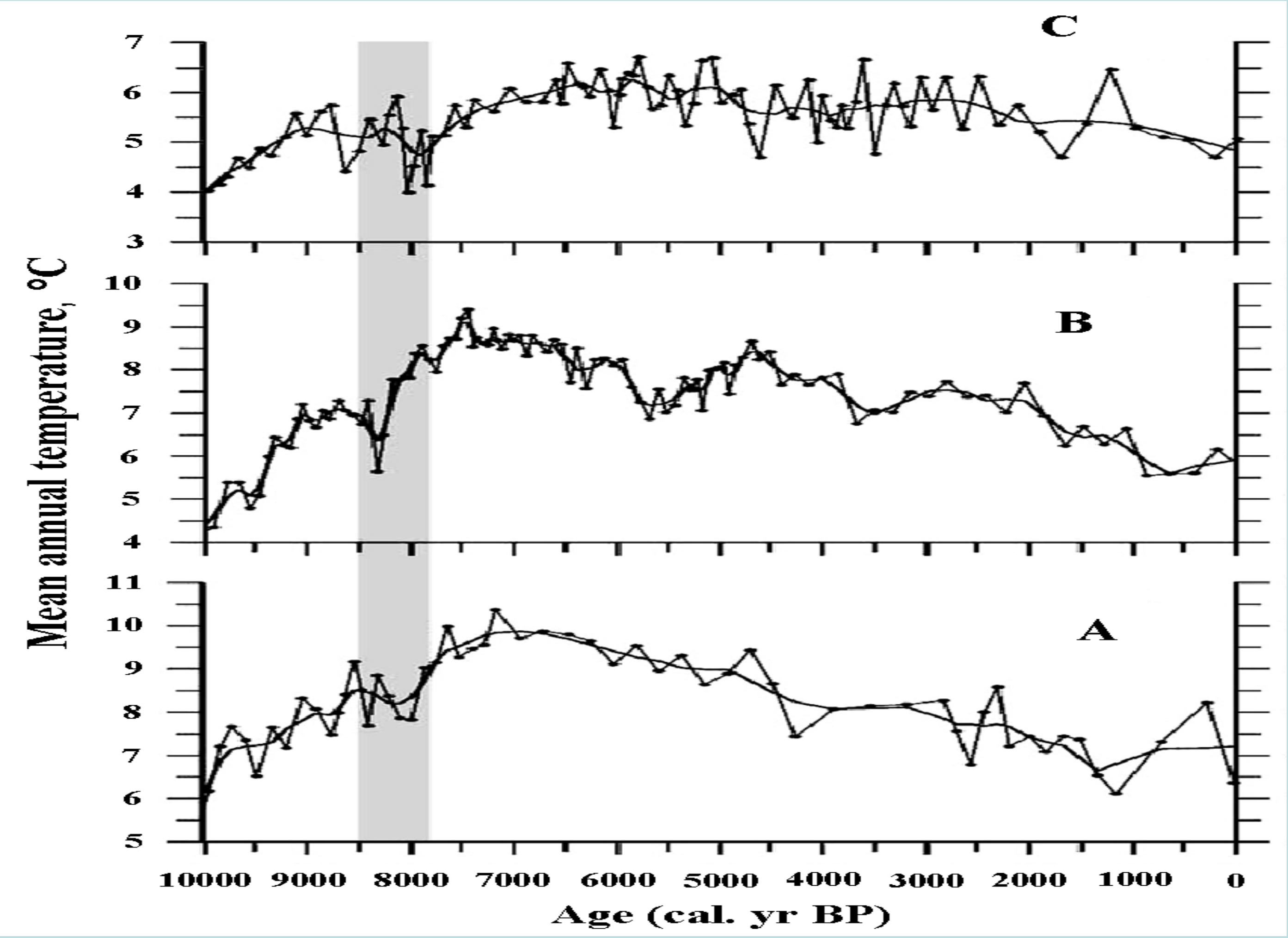
Decreasing of air temperature varied from 1°C to 2°C in the different part of the BSB, and duration of this event changed from 150 to 200 years (Snowball et al., 2002, 2010; Zillén, Snowball, 2009).

In Estonia this event lasted longer (Seppä, Poska, 2004; Veski et ai., 2004).This indicates a longer period of vegetation re-establishment after a decrease in annual air temperature by at least 1,5- 2,0°C.

Pollen based reconstructions air temperature (°C) from sites L.Rouge, Estonia (Veski et al. 2004) and L. Flarken, South-central Sweden (Seppä et al., 2005)



A quantitative reconstructions mean annual air temterature (°C) from fossil pollen data for the 3 lakes sites (C-Gilltjärnen, B-Flaken, A-Trehörningen) from Sweden. (Antonssen, Seppä, 2007)



The causes of the cool events during the Lateglacial and early Holocene

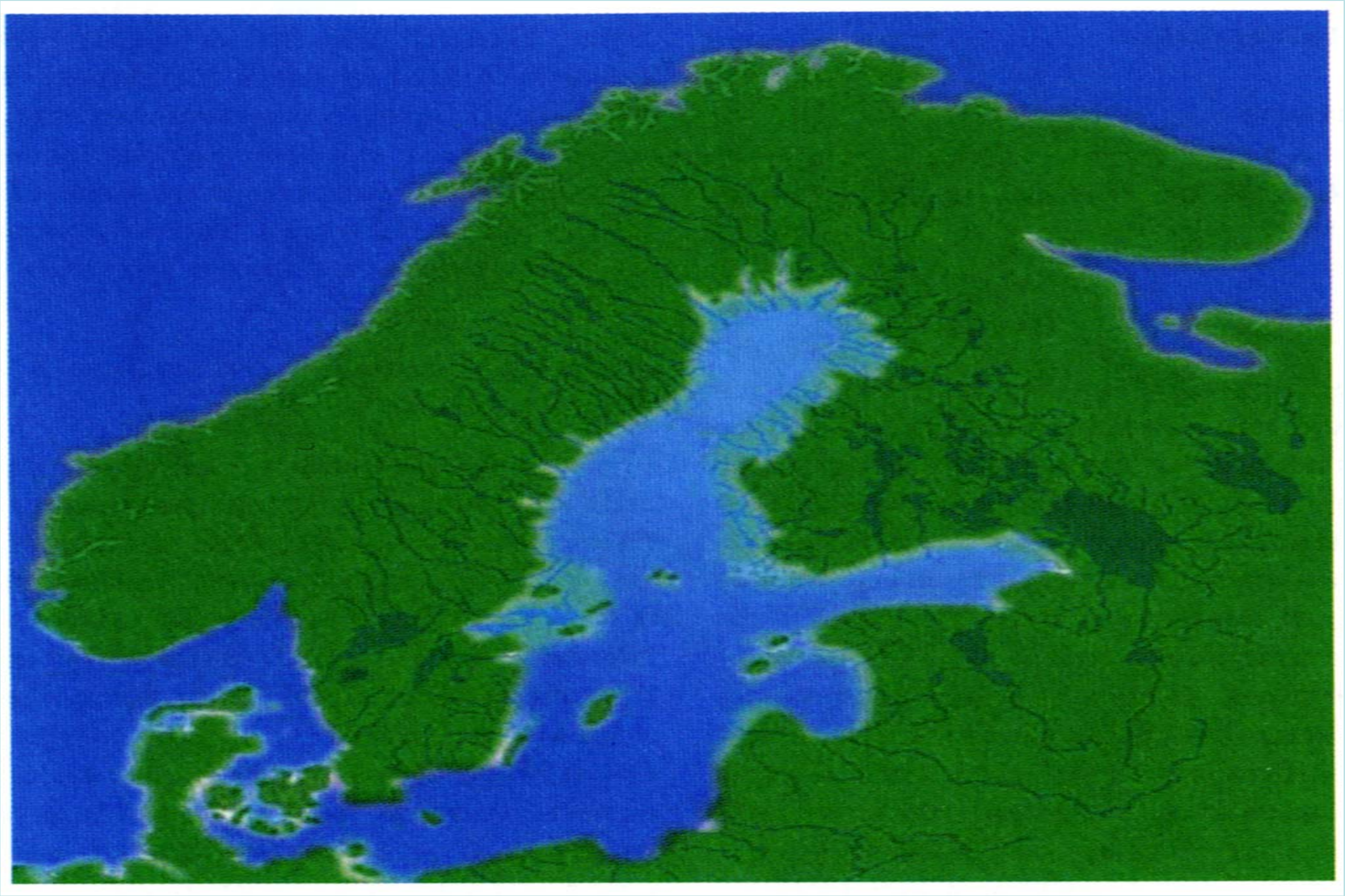
Causes of these events have been widely debated. Most of researchers relate this cool event and other cooling of the past 13,000 years to changes in the circulation of surface and deep water in the North Atlantic as the continental ice sheets melted.

There are reason to believe that the North Atlantic freshening led to transient shutdown of the North Atlantic overturning circulation.

The “8,2” event is the best-documented case of the North Atlantic freshening. With high confidence this event was caused by outburstflood freshening of the North Atlantic

Abrupt climatic changes (cooling and warming) is a great scientific and practical interest with potential repetition a such events in the future due to development the global climatic change under anthropogenic factors.

The Littorina Sea stages at about 7,000 cal yr BP to present time (Andrén, 2004)



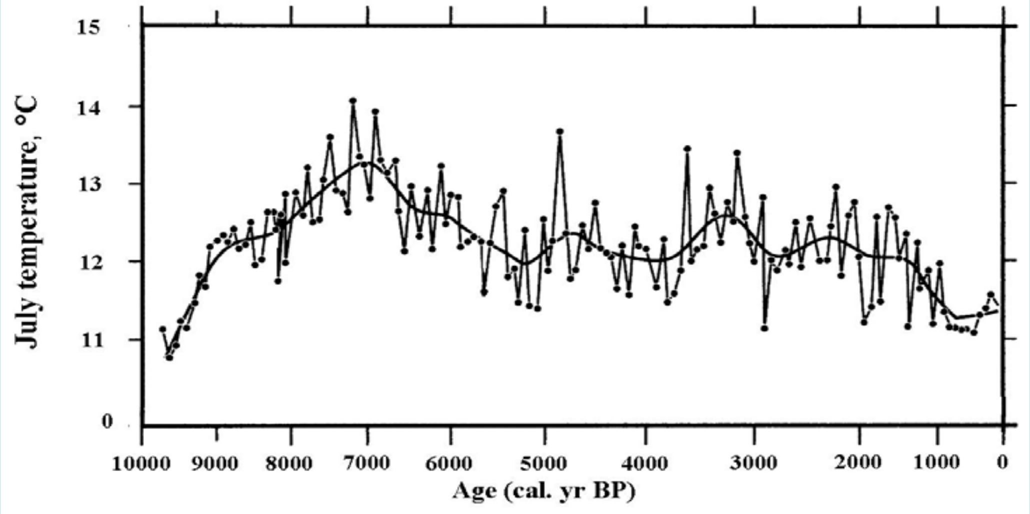
2.2.4. The Atlantic warming

The period between 7,500 and 5,500 cal yr BP ago was the warmest one for the entire Baltic Basin area, though the times of maximum temperatures were not synchronous in different parts of the region.

In Sweden, pollen and chironomids records show that the times of maximum temperatures changed in parts of Sweden between 7,900 and 5,700 cal yr BP with the amplitude varying from 0.8 to 1.5°C and higher.

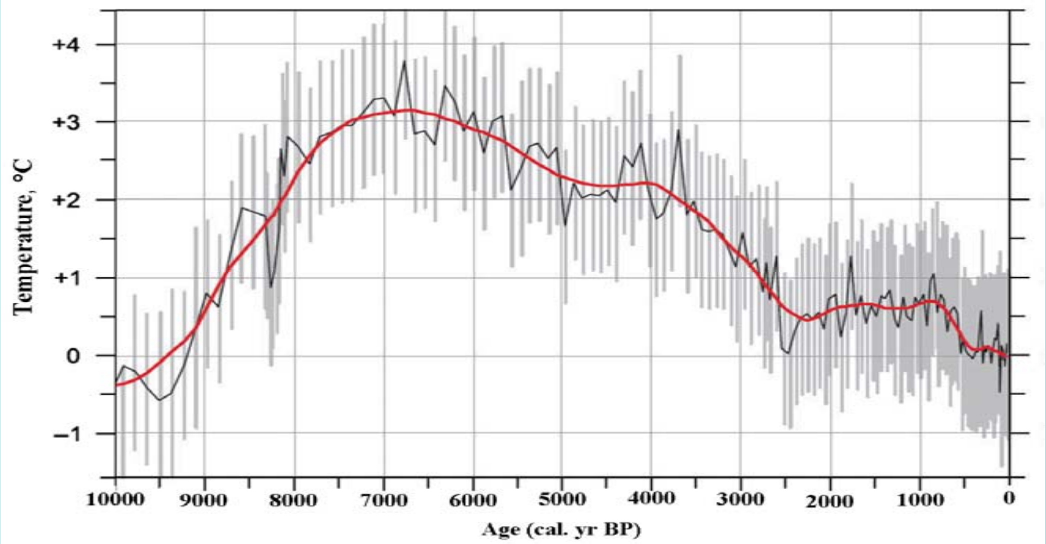
In the Northern Finland, maximum temperatures took place between 9,000 and 7,000 cal BP, and in north-western Russia, about 5800 to 5000 cal yr BP.

Summer air temperature (°C) during the Holocene in the different part of the Baltic Sea Basin

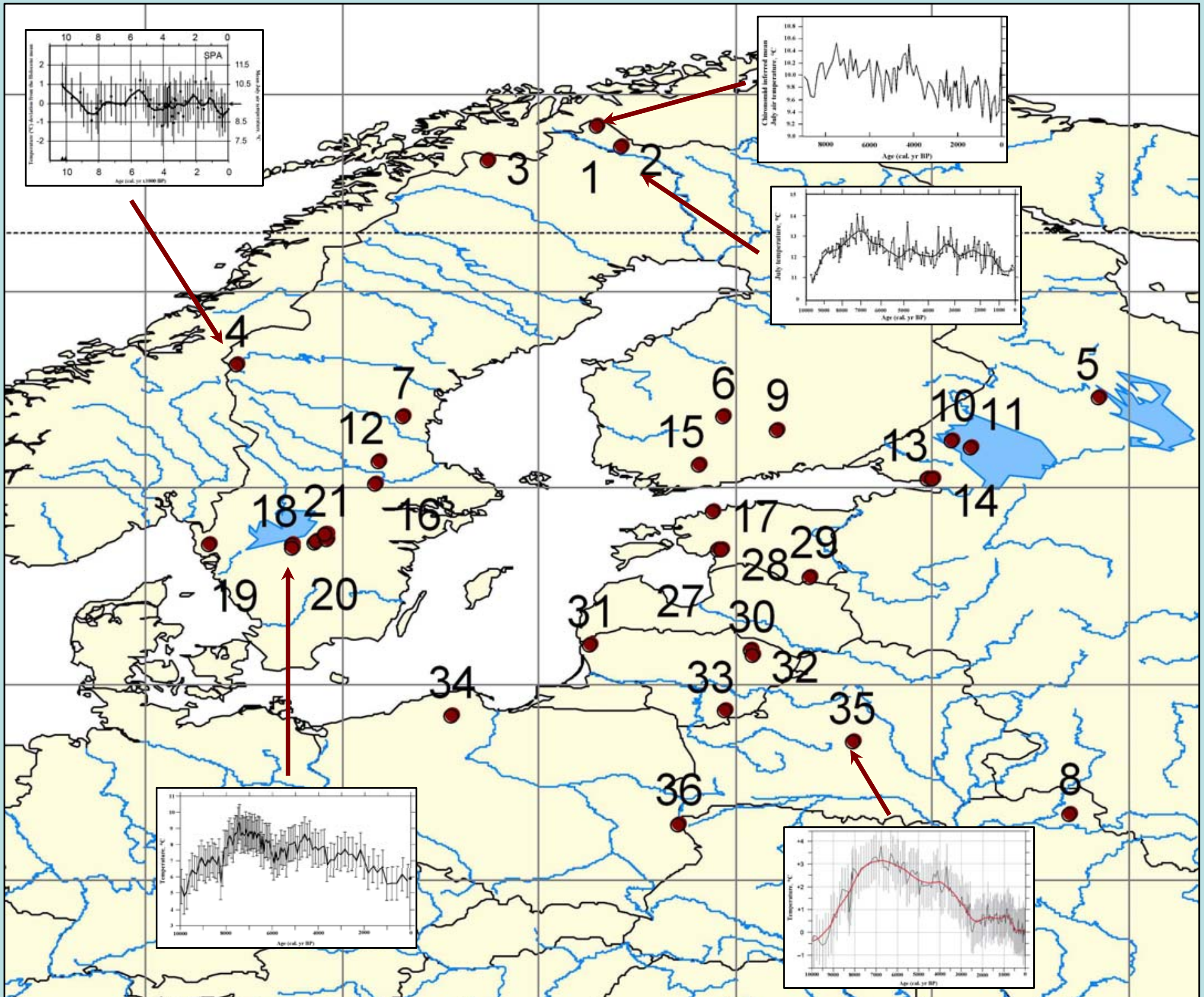


L.Tsuolbmjavri, Northern Finland

68°41'N



L.Kurjanovas, South Estern Latvia, 56°31'N



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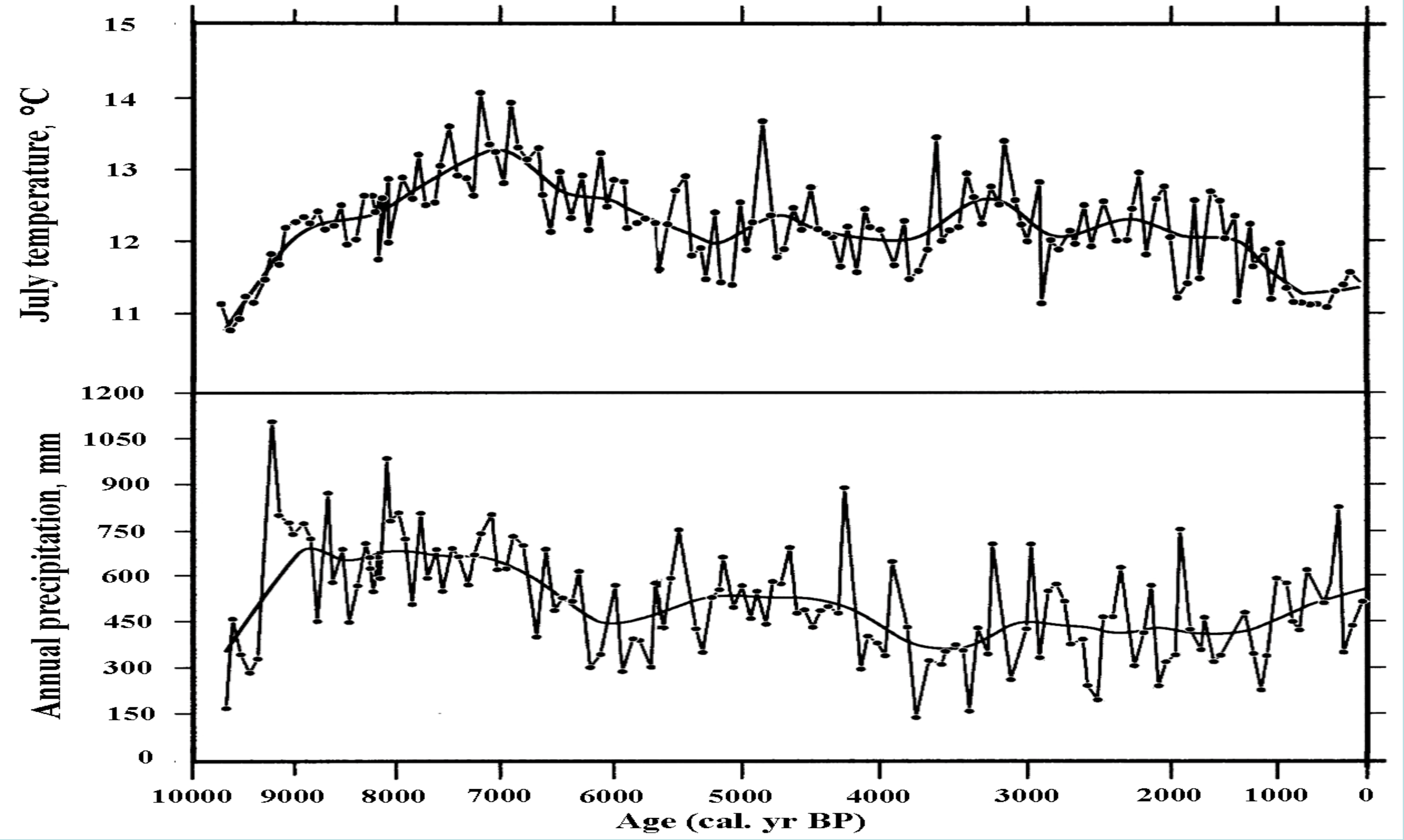
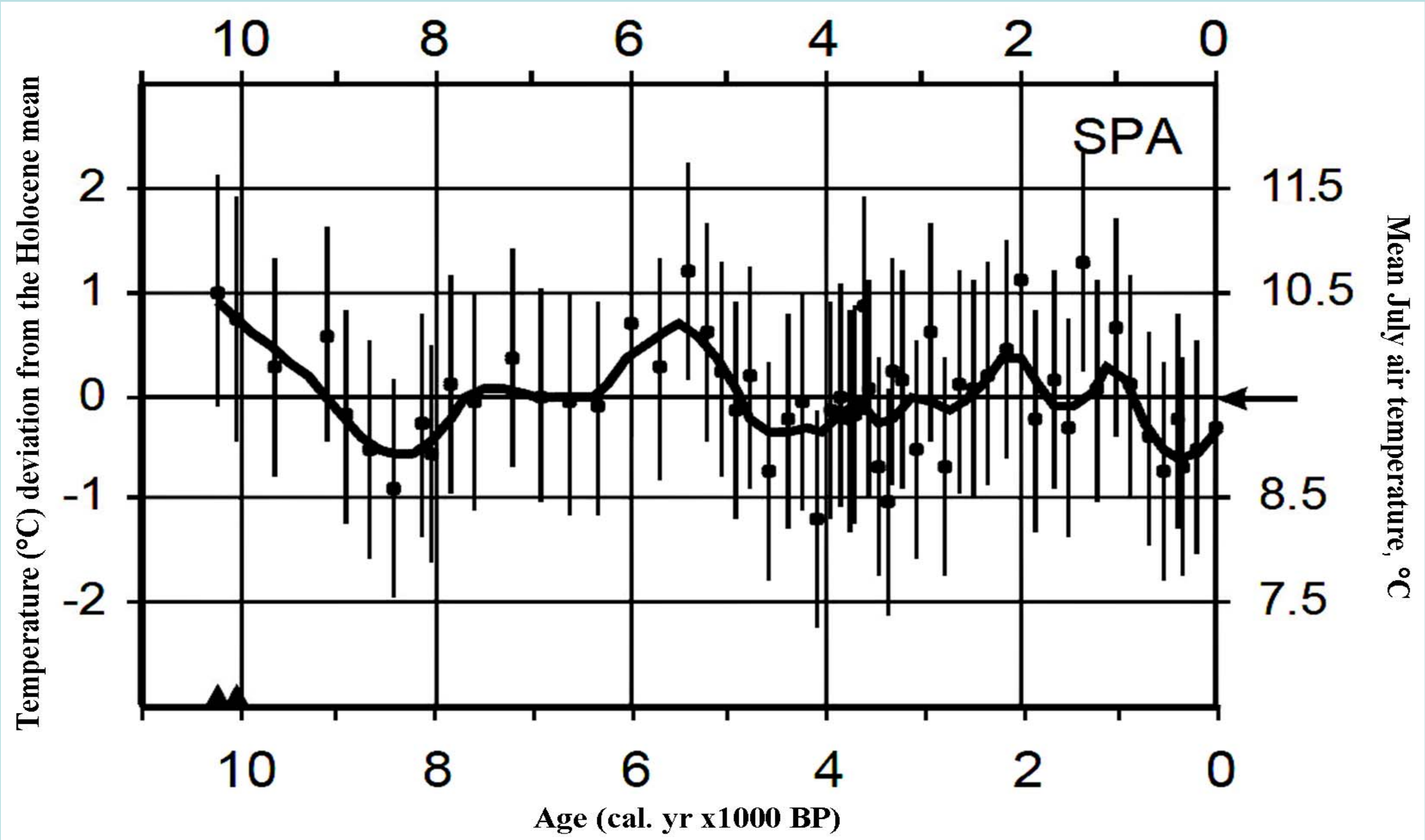
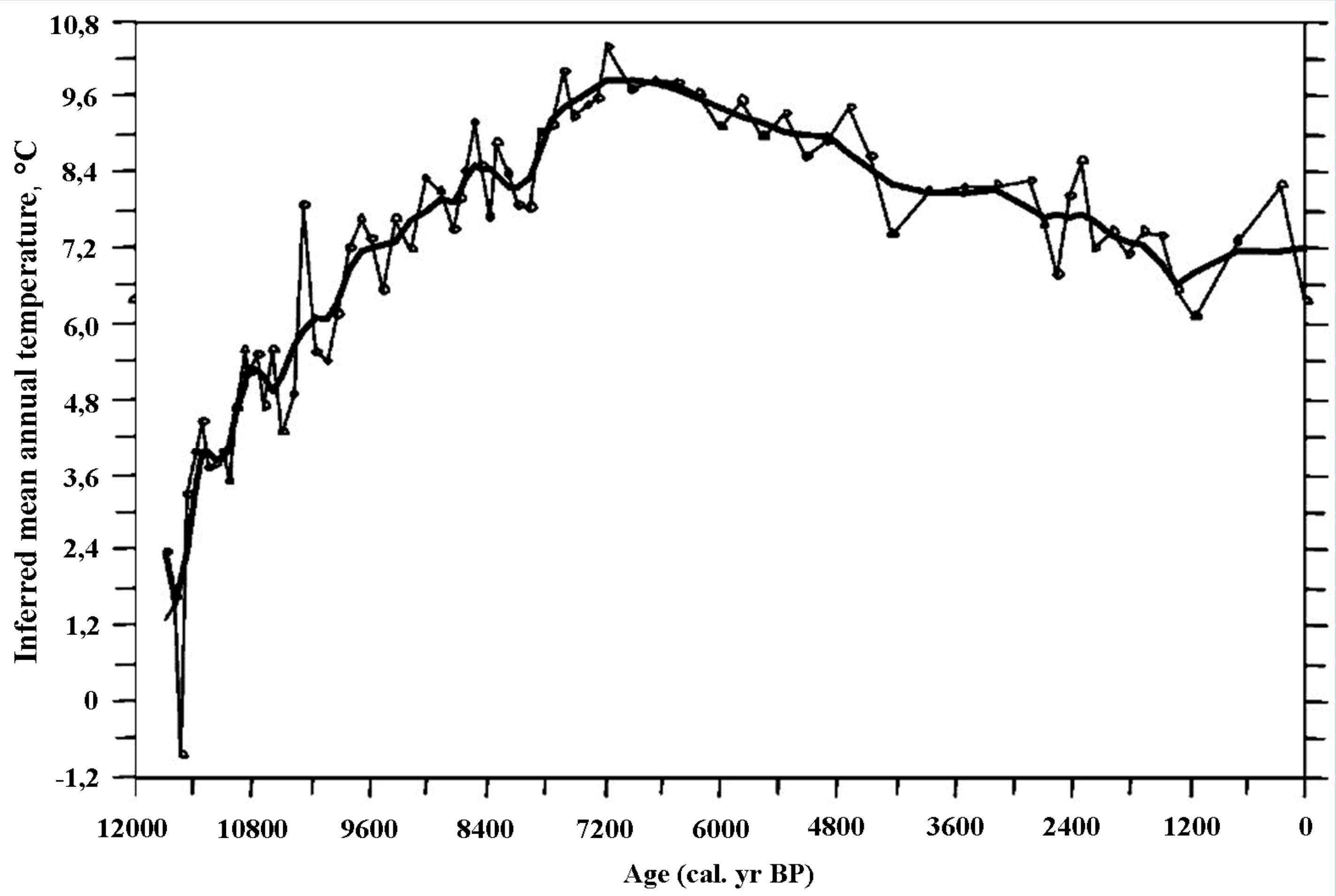
Inferred July mean temperature and annual precipitation based on pollen data of the Lake Tsuolbmajavri (Northern Finland) (Seppä, Birks, 2001)



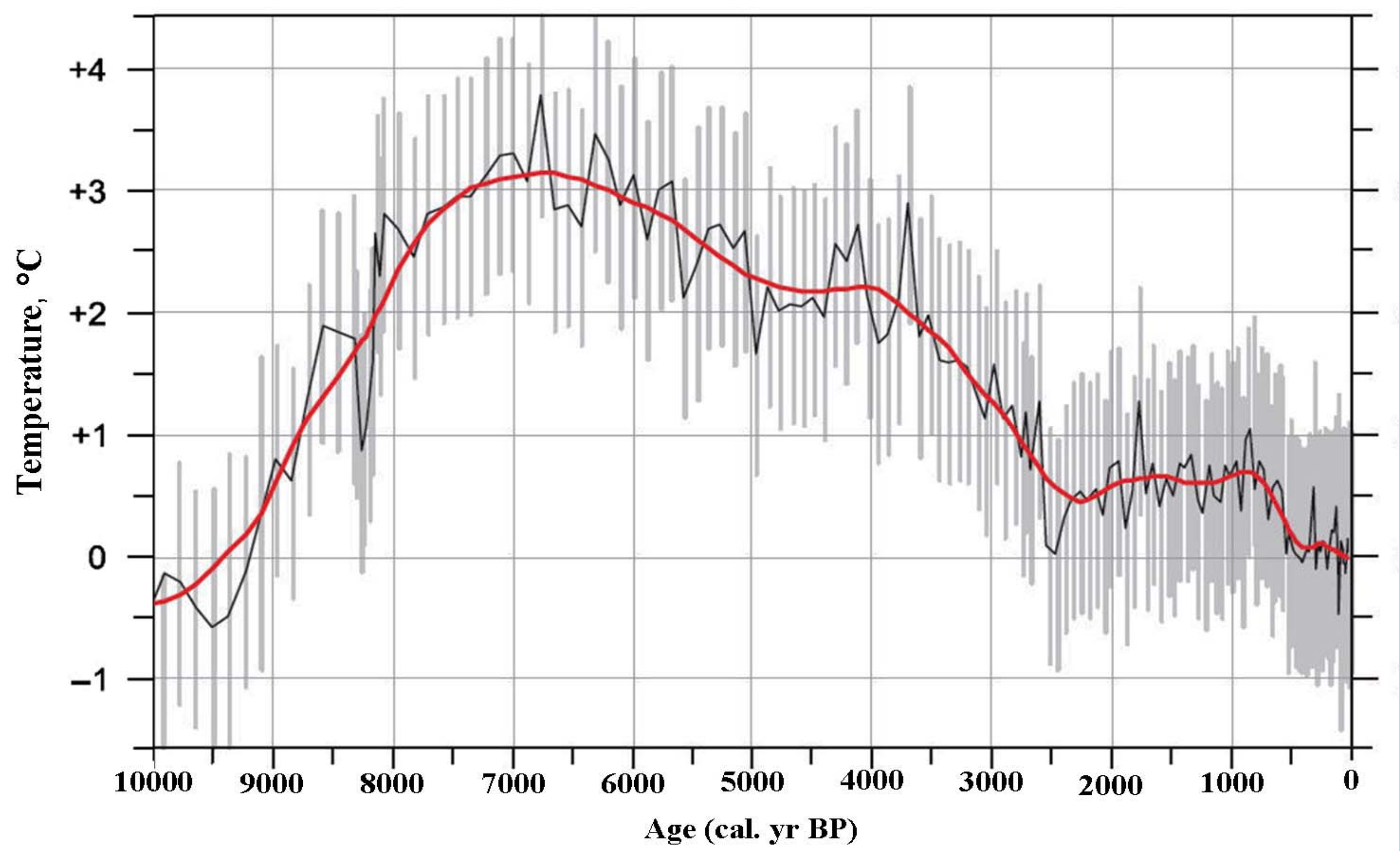
Chironomide-inferred mean July air temperature (°C) from the L. Spåime (northern Sweden) (Velle et al., 2005)



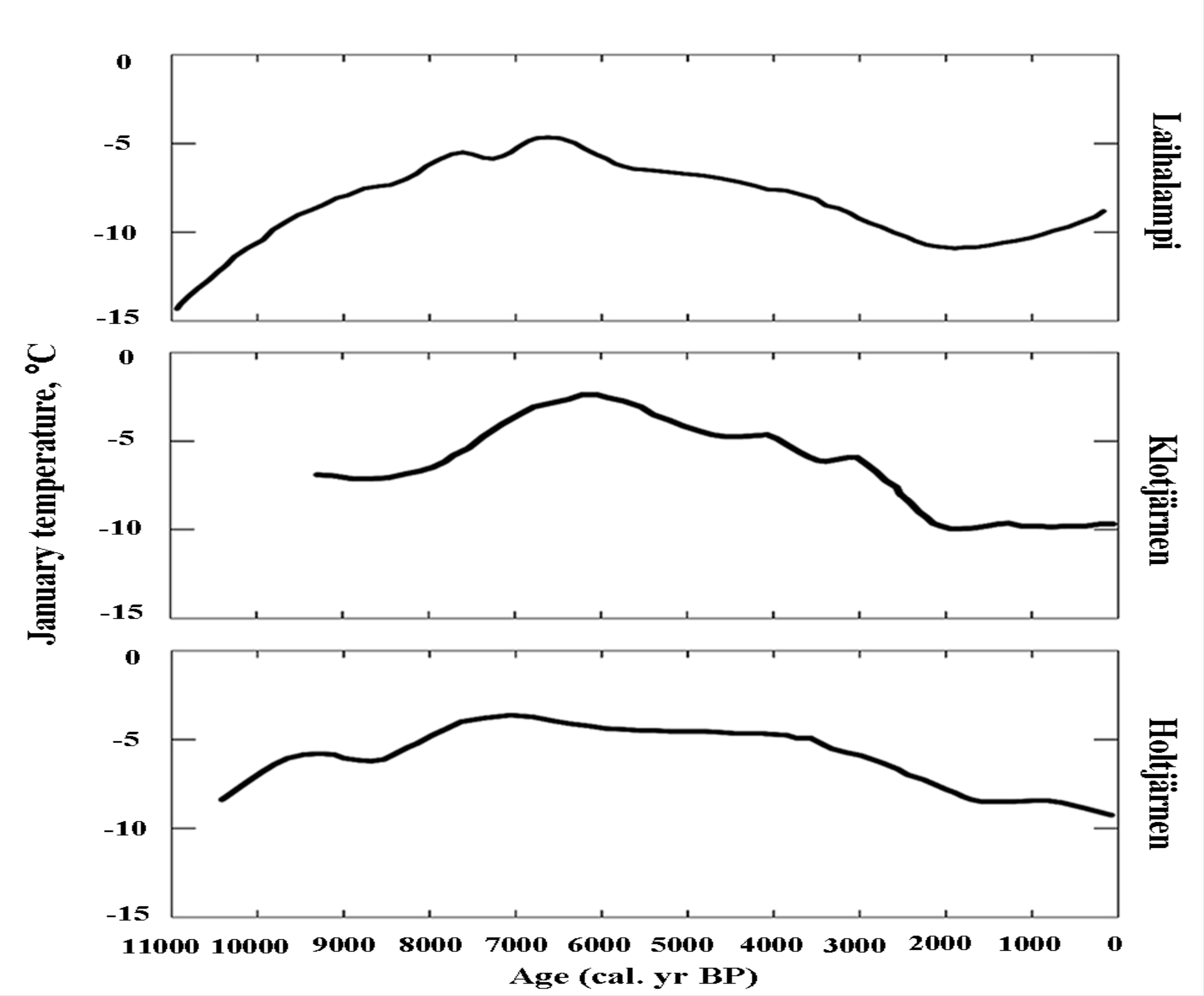
Mean annual temperature reconstruction of Lake Trehörningen for the past 11 700 years, southwest Sweden (Antonsson, Seppä, 2007).



Reconstructed summer temperature (ΔT) anomalies shown as deviations from the modern value, Lake Kurjanovas, Latvia (Heikkilä, Seppä, 2010).



The winter (January) air temperature (°C) in the different part of the BSB during the last 11,000 years (Giesecke et al., 2008)



L.Laihalampi,
Southern Finland

L. Klotjärnen,
Central Sweden

L. Holtjärnen,
Southern-central
Sweden

2.2.5 The late Holocene cooling

The global warming lasting almost 5 000 years, changed to a stable cooling trend, which most clearly expressed in middle and high latitudes including the Baltic Sea Basin.

The last interval of the Holocene climatic history, named the Neoglacial, is characterized by the negative trend of air temperature and increasing of the climate instability.

Different proxy data allow us to reconstruct a two-stage air temperature decrease in the Late Holocene. The first stage occurred between 5,000 and 4,500 cal yr BP and the second one between 4,300 and 3,300 (2,800) cal yr BP.

During each period the temperature drop was at least 1°C. A warming c. 3,200 and cooling c. 2,800 cal yr BP are revealed by detailed palaeoclimatic reconstructions.

Although the general trend of the Late Holocene cooling is undoubtedly related to decreased summer solar radiation due to astronomical factors, the causes of these oscillations need further studies.

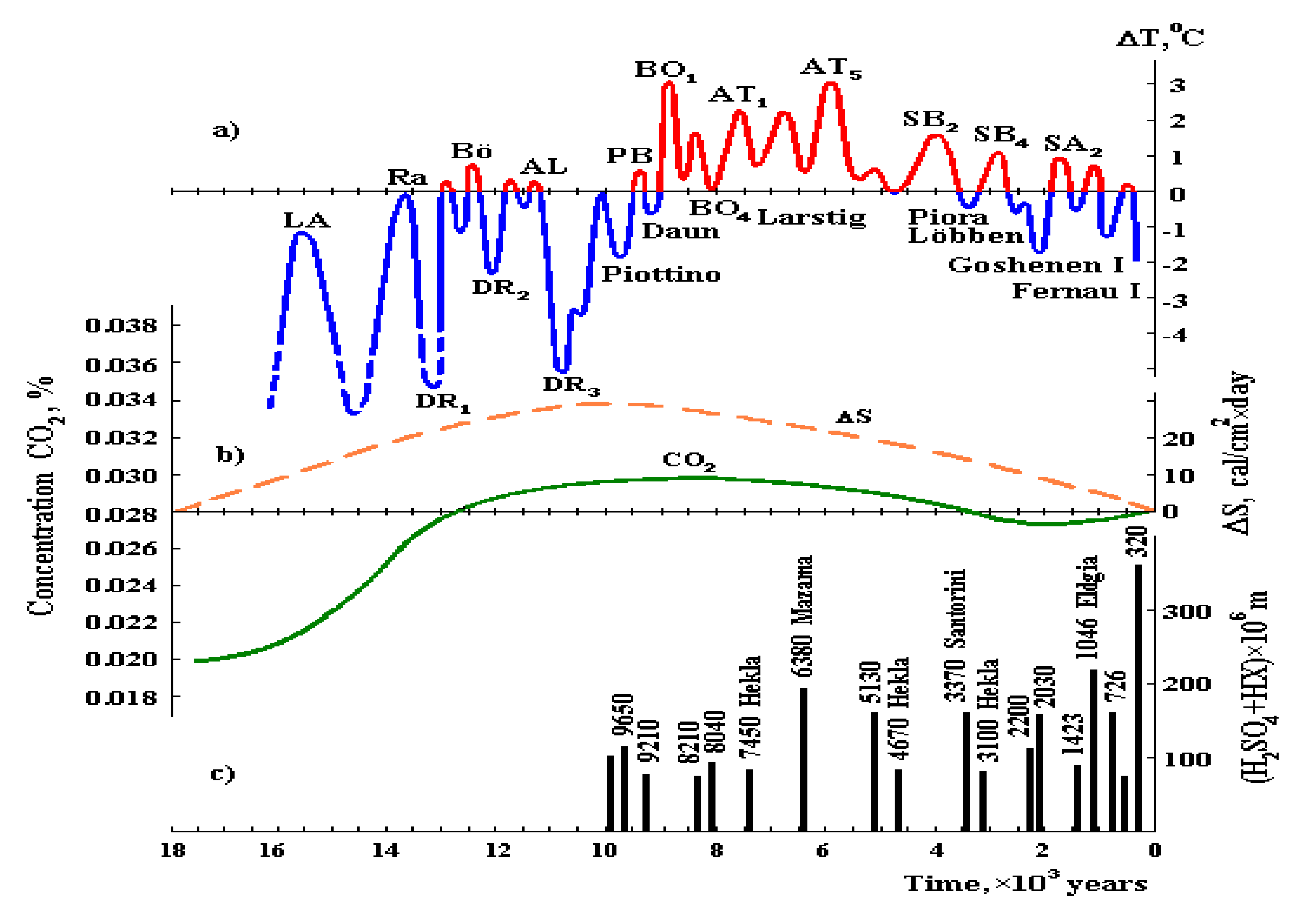
2.3. Causes of the climatic changes

- During the Holocene climate change in the Baltic Basin depended both on external and interior factors. The external factors include:
- Changes in incoming solar radiation due to astronomical factors and variations in the aerosol concentration in the upper atmosphere due to the volcanic activity;
- Changes in the concentration of greenhouse gases in the atmosphere (CO2, CH4, N2O) due to natural factors;
- Changes in surface albedo of the sea-lake itself and changes in vegetation on the surrounding land
- Changes in the intensity and type of circulation

In addition to the above factors that can be considered as an external forcing there are those (internal forcing) that lead to climate variability on multi-centennial timescales caused by extremely complicated and non-linear atmosphere-ocean interactions.

Proxy data from the areas adjoining North Atlantic shows rapid climatic cooling related to upper layer sea water freshening due to influx of large volumes of melt water from disintegrating continental ice sheets (Scandinavian and Laurentide). These can cause a weakening or even shutdown of the thermohaline circulation (THC).

The main forcing factors in the Lateglacial-Holocene

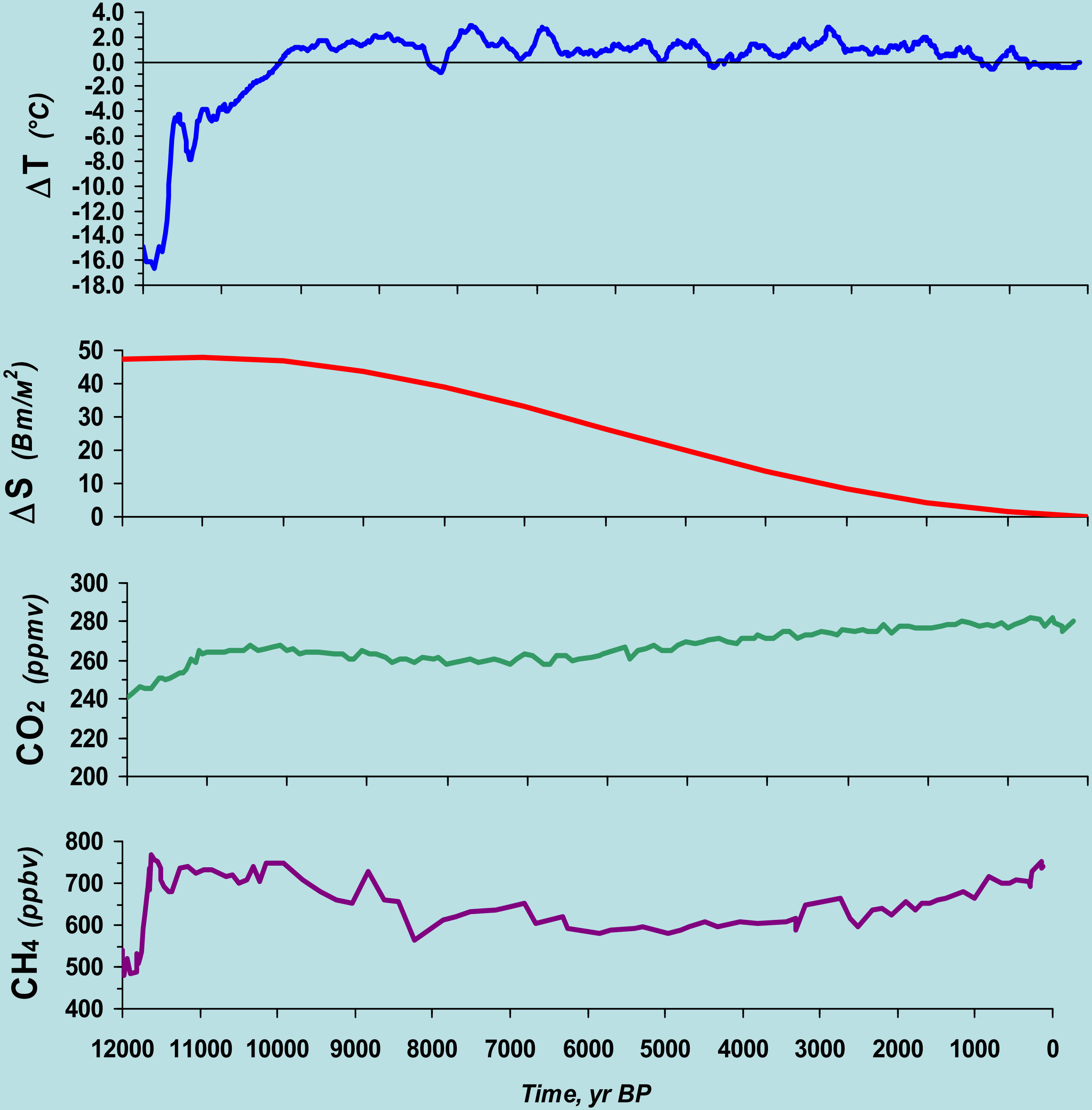


Conclusion

- Analysis of different proxy data for the past 12,000 cal years has revealed the following three stages of natural climate oscillations in the Baltic Sea region:
- 1. The 200-year long short-term cooling episodes related to deglaciation occurred between 11,000 and 8,000 years ago at the background of a stable positive temperature trend stipulated by a higher total summer solar radiation due to astronomical factors;
- 2. The period of warm and relatively stable climate took place between 8,000 and 4,500 cal years ago with air temperatures of 1.5-2.5°C above modern;
- 3. The Late Holocene (past 5,000-4,500 years) is characterized by the negative temperature trend and increased climate instability.

- References about 20 pages

- Glossary ??



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-2.0
-4.0
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-10.0
-12.0
-14.0
-16.0
-18.0
ΔT (°C)
50
40
30
20
10
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ΔS (Вт/м²)
300
280
260
240
220
200
CO₂ (ppmv)
800
700
600
500
400
CH₄ (ppbv)
12000
11000
10000
9000
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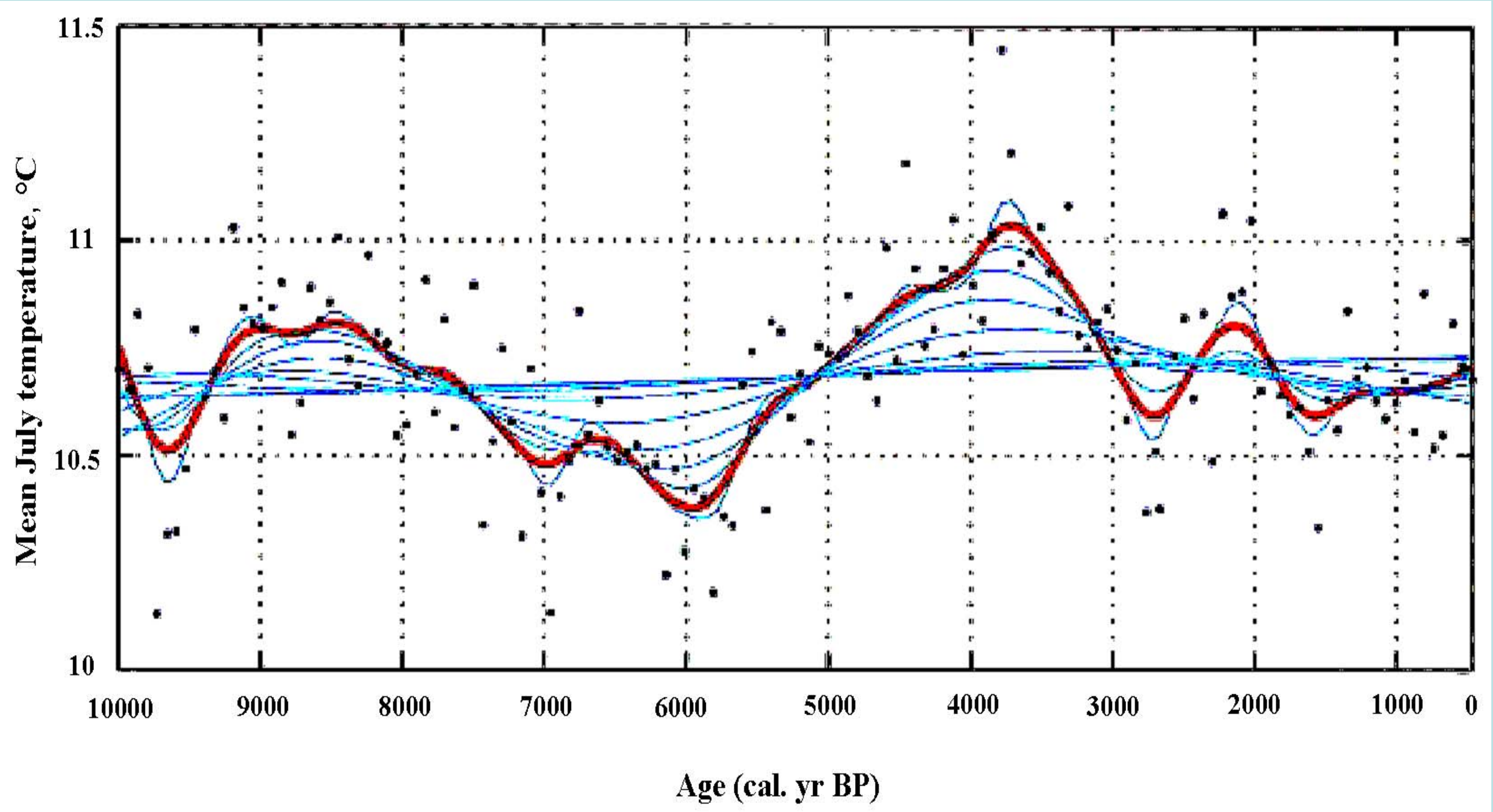
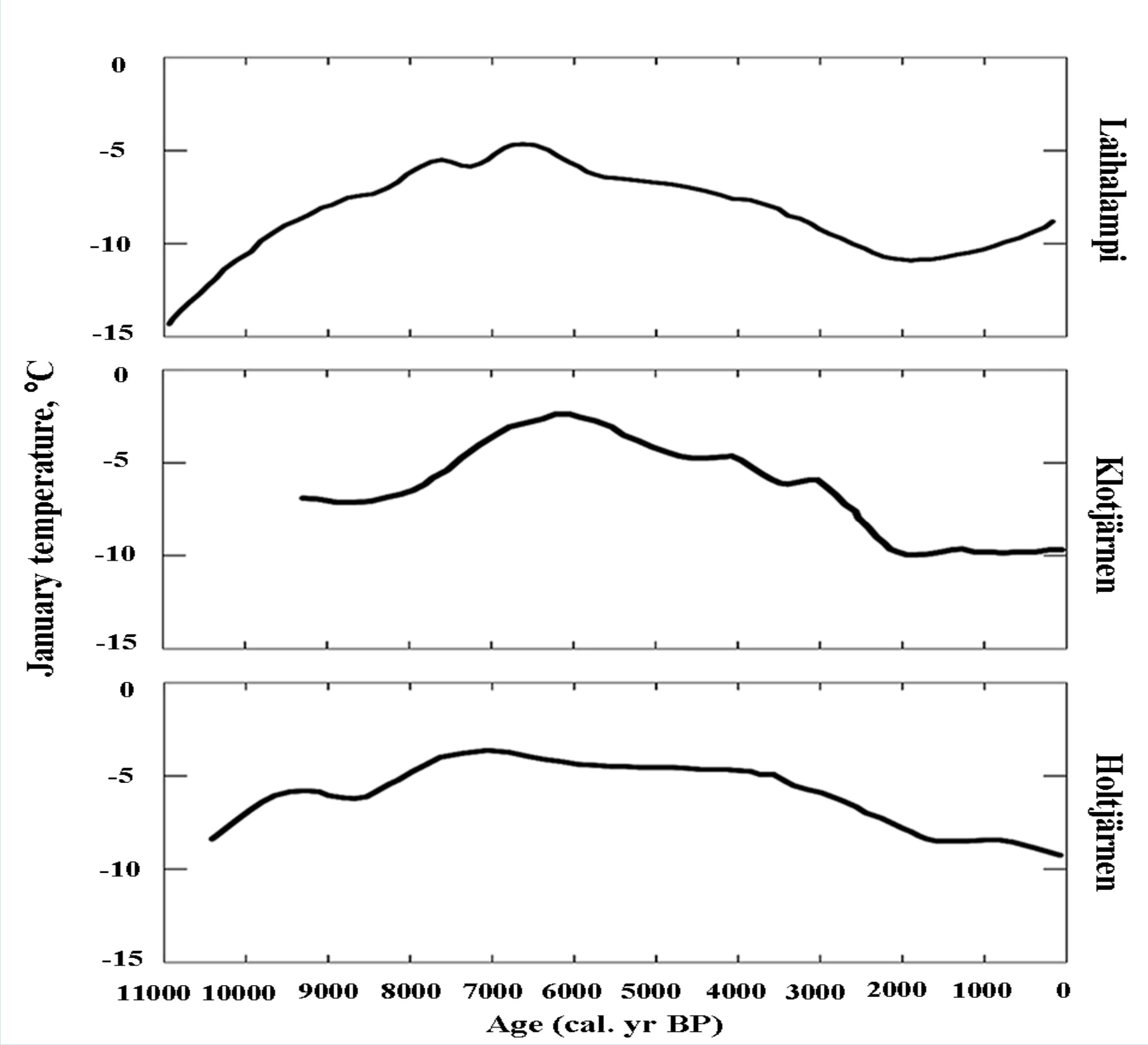
Time, yr BP

Reconstructed mean July temperatures at Lake Tsuolbmajavri for the last 10,000 years based on diatom data





January temperature, °C
Laihalampi
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Holtjärnen
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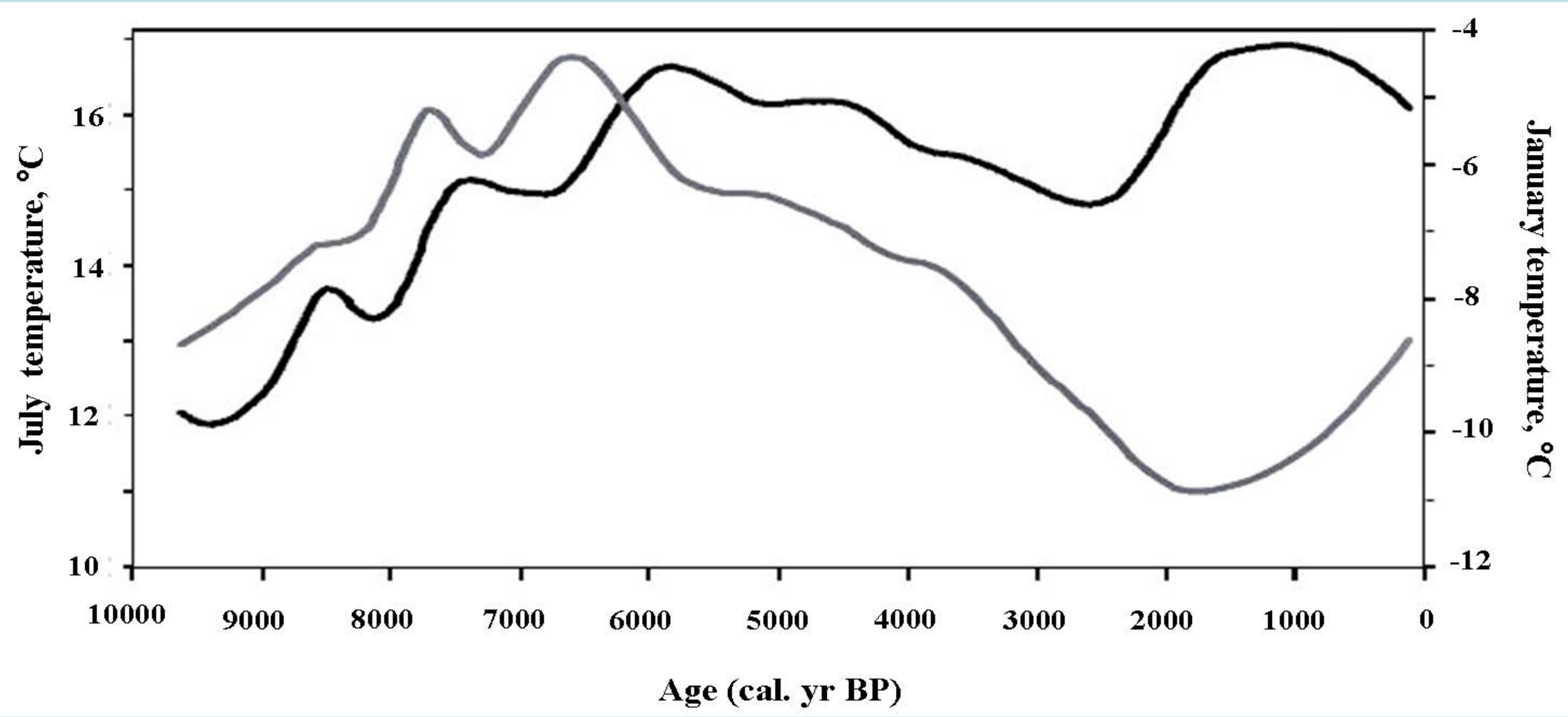
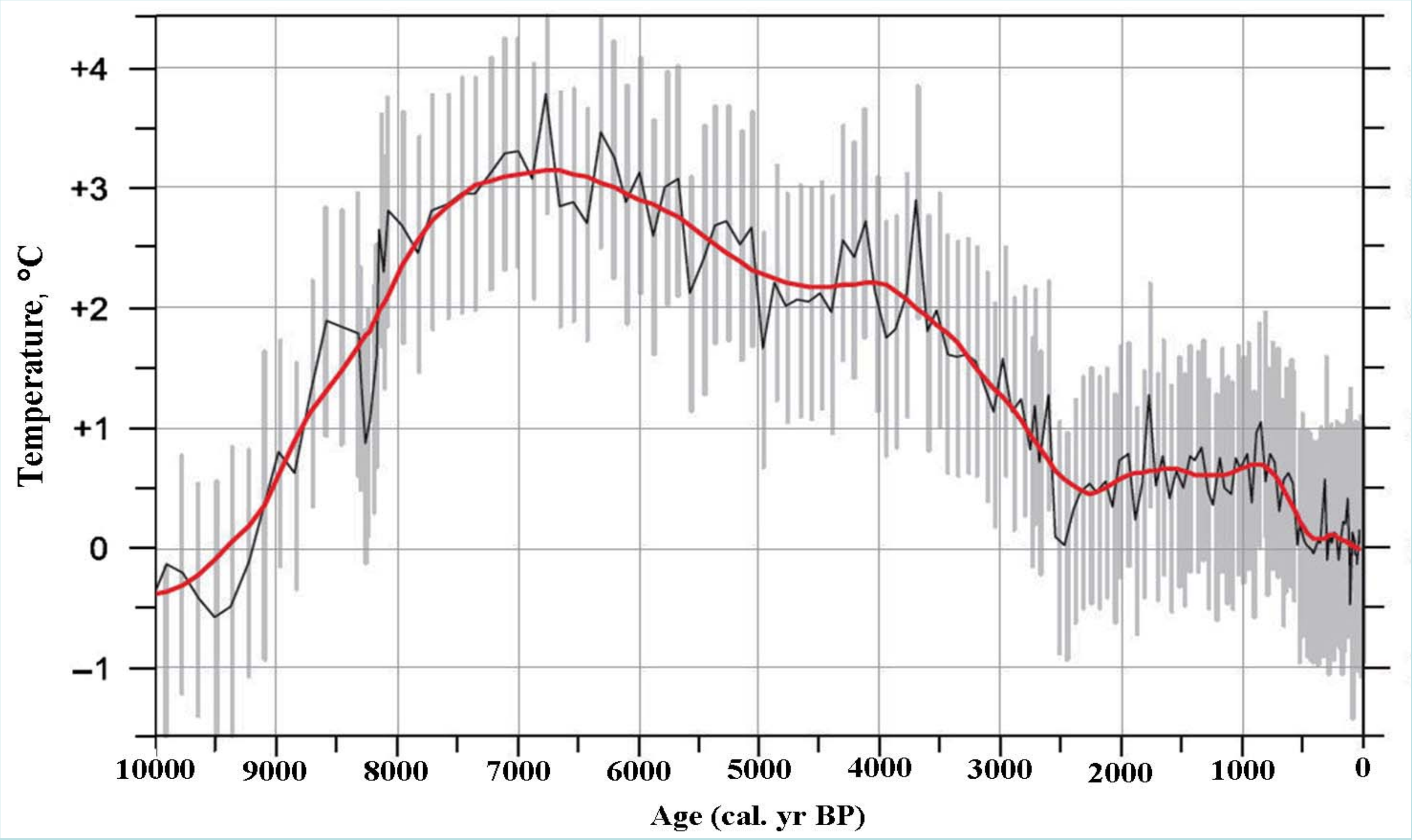
-10
-15
11000 10000 9000 8000 7000 6000 5000 4000 3000 2000 1000 0
Age (cal. yr BP)

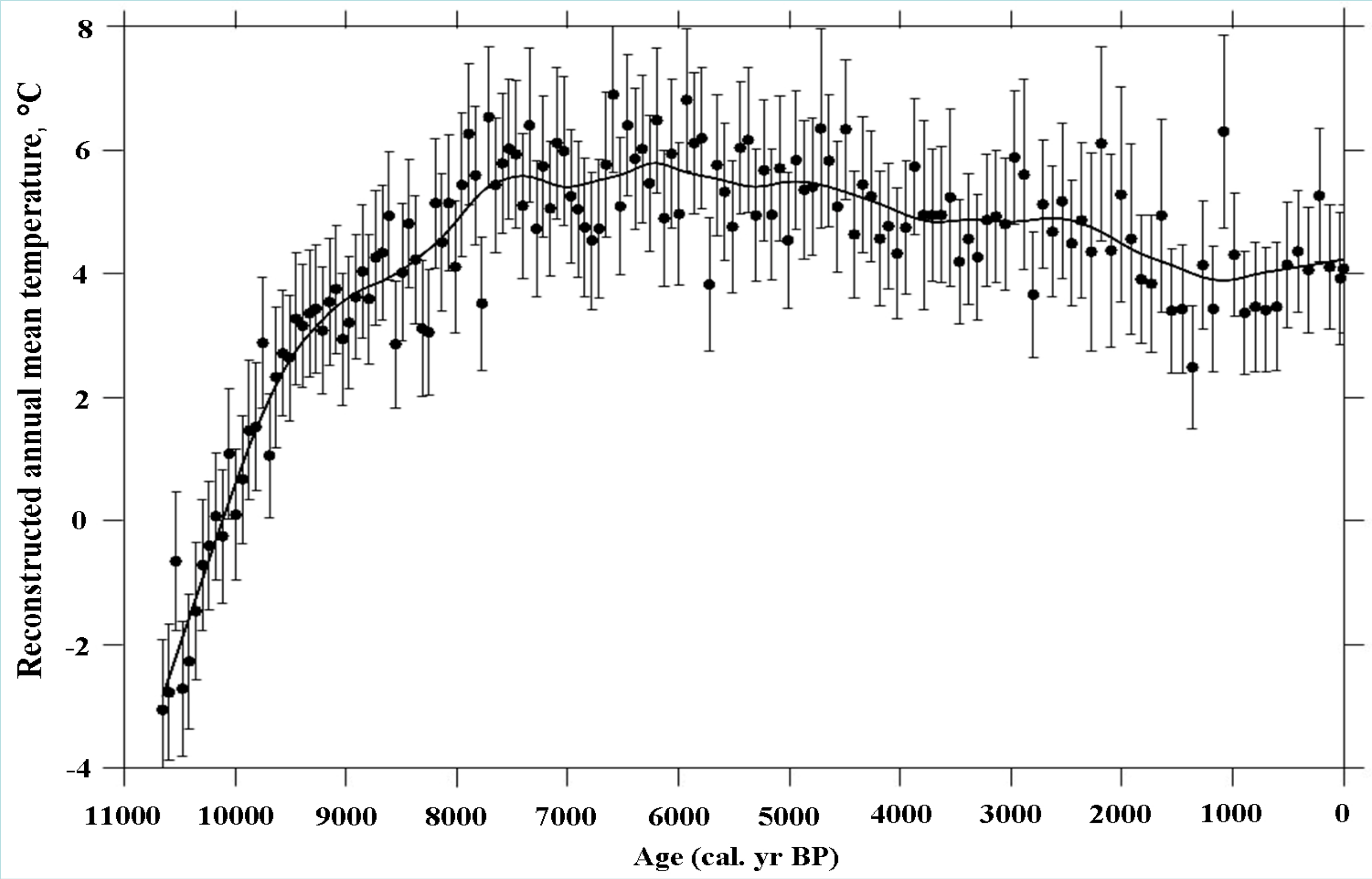


July temperature, °C
16
14
12
10
January temperature, °C
-4
-6
-8
-10
-12
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Age (cal. yr BP)

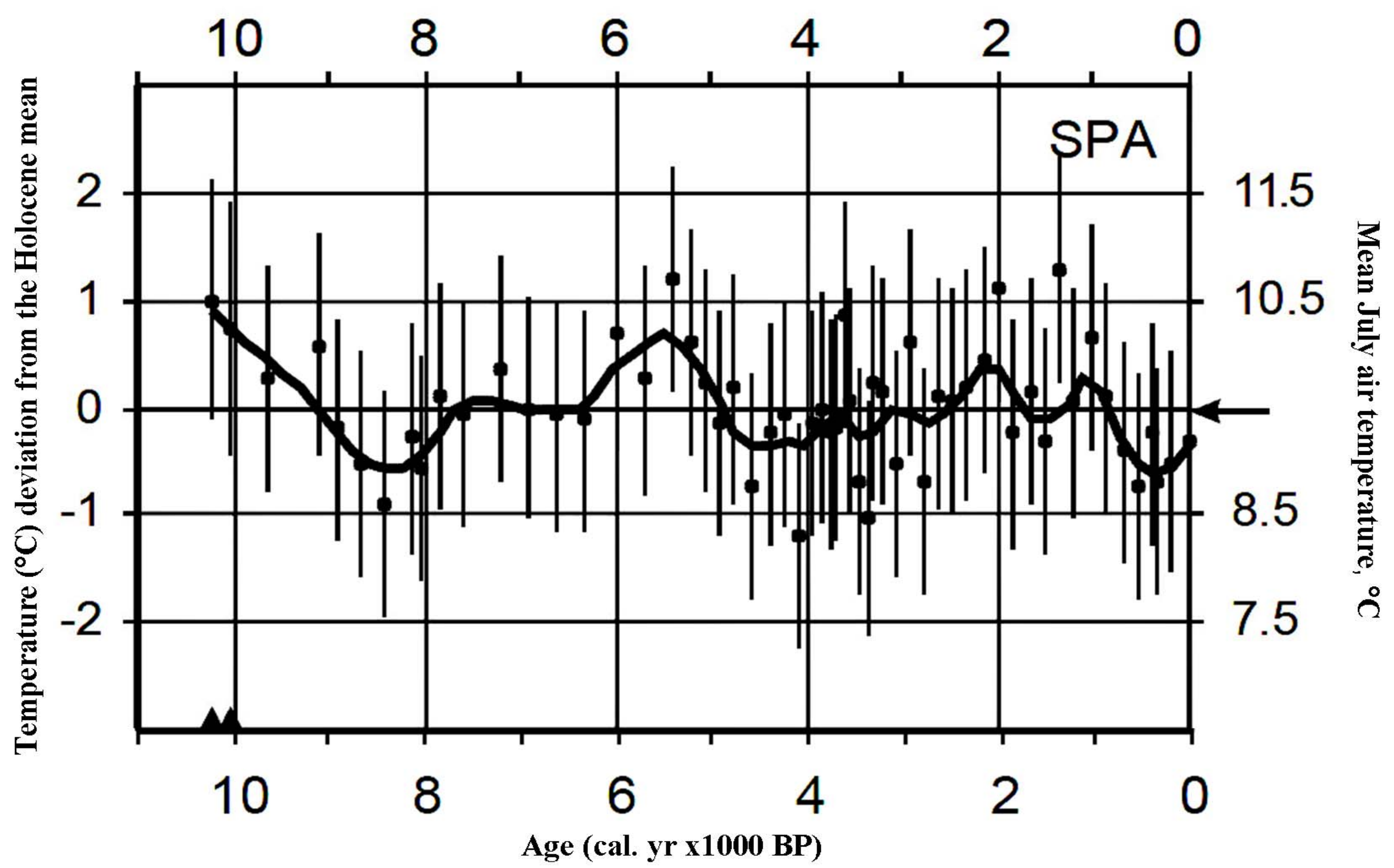
Anomalies of the summer air temperature (°C) obtained from pollen data L.Kurjanovas, SE Latvia (Heikeilä, Seppä, 2010)



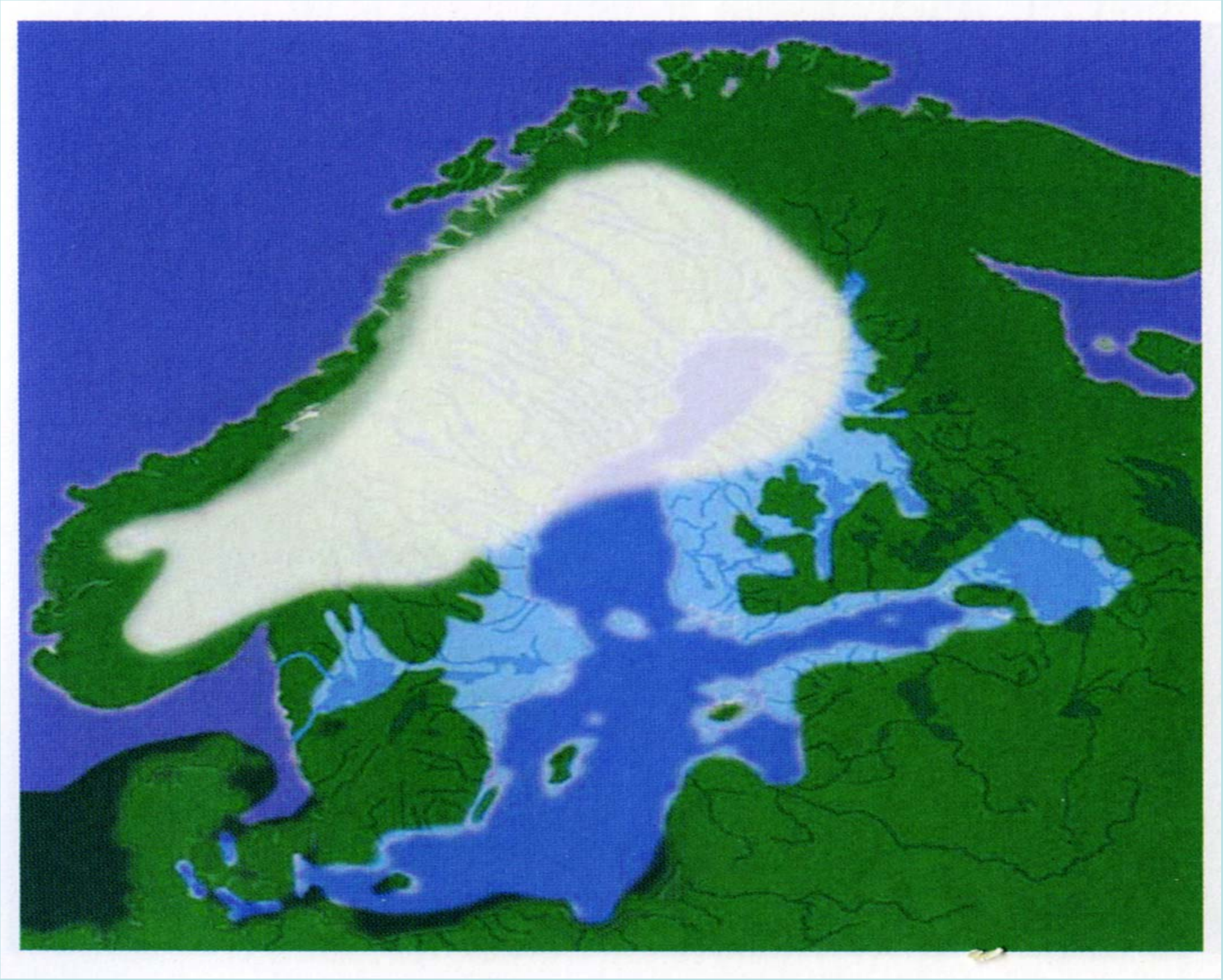
Annual air temperature reconstruction by pollen data from sedimentation of the L.Laihalampi (Finland),61°29‘N, 26°04‘E. Present annual temperature is 3.9°C



Chironomid-inferred mean July air temperature (°C) obtained from sedimentation L.Späime (Sweden) (Velle et al., 2005)



The configuration of the Ancylus Lake stage at c. 10 300 cal yr BP at the culmination of the Ancylus transgression. From Andren (2003)



Palaeogeography and palaeohydrology of the brackish Yoldia Sea phase around 11 300 years BP. From A.Heinsalu, S.Veski (2007)