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Climate variability in the Baltic Sea Basin over the last 12,000 calendar years:Lessons from past for future

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Assessment of the climate changes in the Baltic Sea Basin BACC II

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- **The materials of this report served the base for the Chapter “Past climate variability” of new generation monographic “Climate Assessment in the Baltic Sea Basin”**

- **By studying past climate changes when the Earth was as colder or warmer then now we can gain knowledge about natural climatic and environmental variability on decadal to multi-millennial timescales and relate them to the recent changes originating from anthropogenic influence;**

- **Understanding the climate dynamics and variability during the warm time periods, and the likelihood of abrupt changes within the system, requires improved insight into interactions between forcing such as freshwater dischange, changes in solar irradiance, volcanic eruptions and greenhouse gas concentration, and sensitive components of climate system such as thermohaline circulation, sea ice extent, and ice sheets.**

The Lateglacial-Early Holocene history of climate in the Baltic Sea Basin is closely related to its paleogeography at the time of melting the Scandinavian Ice Sheet;

The Baltic Sea is a young sea, it formed after the glacier began to recede about 18,000 yr ago due to changes in orbital configuration of the Earth around the sun;

The Lateglacial and Holocene history of the Baltic Sea Basin has been divided into four main stages: the Baltic Ice Lake (BIL) from the beginning of the deglaciation time to ca. 11,550 cal yr BP, the second stage - the Yoldia sea 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 next stage - the Ancylus Lake (fresh water basin between ca. 10,700-9,500 cal yr BP) and the last stage -the Littorina Sea (brackish – water basin, ca. 9,500 cal yr BP to present)

Paleogeography of the Baltic Sea Basin between 12,000 and 7,000 cal yr BP (Andren,2003; Heinsalu, Veski, 2007)

The Baltic Ice Lake ca. 11,700-11,600 yr BP

The Yoldia Sea stage ca. 11,400-11,300 yr BP

e Ancylus Lake ca. 10,300 yr BP

The Littorina Sea, ca. 9,500 yr BP to present

- **The new advanced methods and technology have allowed estimating changes in the past air temperature and extending the temporal data arrays to the past for several hundreds or even thousands of years;**

- **Based on this data conclusion can be made that the climatic variability in the past is compatible with the modern one and in some cases it even exceeds it. The new term «abrupt climate changes» has been introduced implying that climate change occurs on the decadal time;**

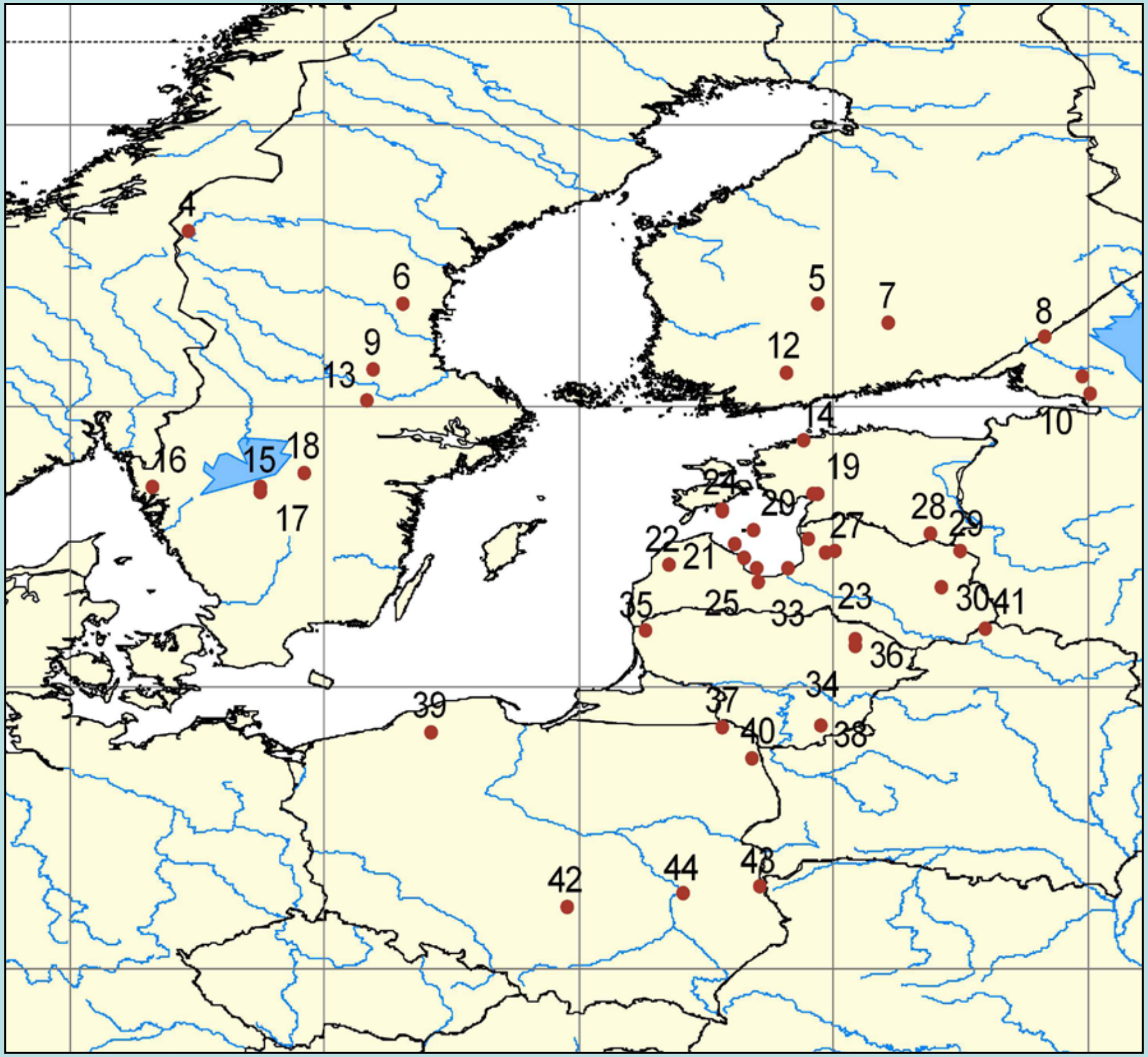
- **Studying the causes and mechanisms of such rapid climate changes in the past is very important for understanding the nature of modern climatic fluctuations and for assessing future climate changes.**

- **The instruments to reconstruct the climate of the Baltic Sea area during the Holocene are multifaceted :**
- **Bio geochemical records that, at least partly, reflect past environmental conditions and can be used to reconstruct past temperature in some seasons and/or annual sum of precipitation;**
- **Among these the more widely used are pollen and spores assemblages derived from dated lake sediments, tree-rings, and fossil insects that may indicate the spatial spread of different species and thus give information about past temperatures and humidity;**
- **The temporal resolution of these reconstructions depends therefore on many factors, and ranges between the annual and decadal scales of tree-rings to multi-centuries and multi-decadal scales attainable from some lake and bogs sediments.**

Major indirect data sources

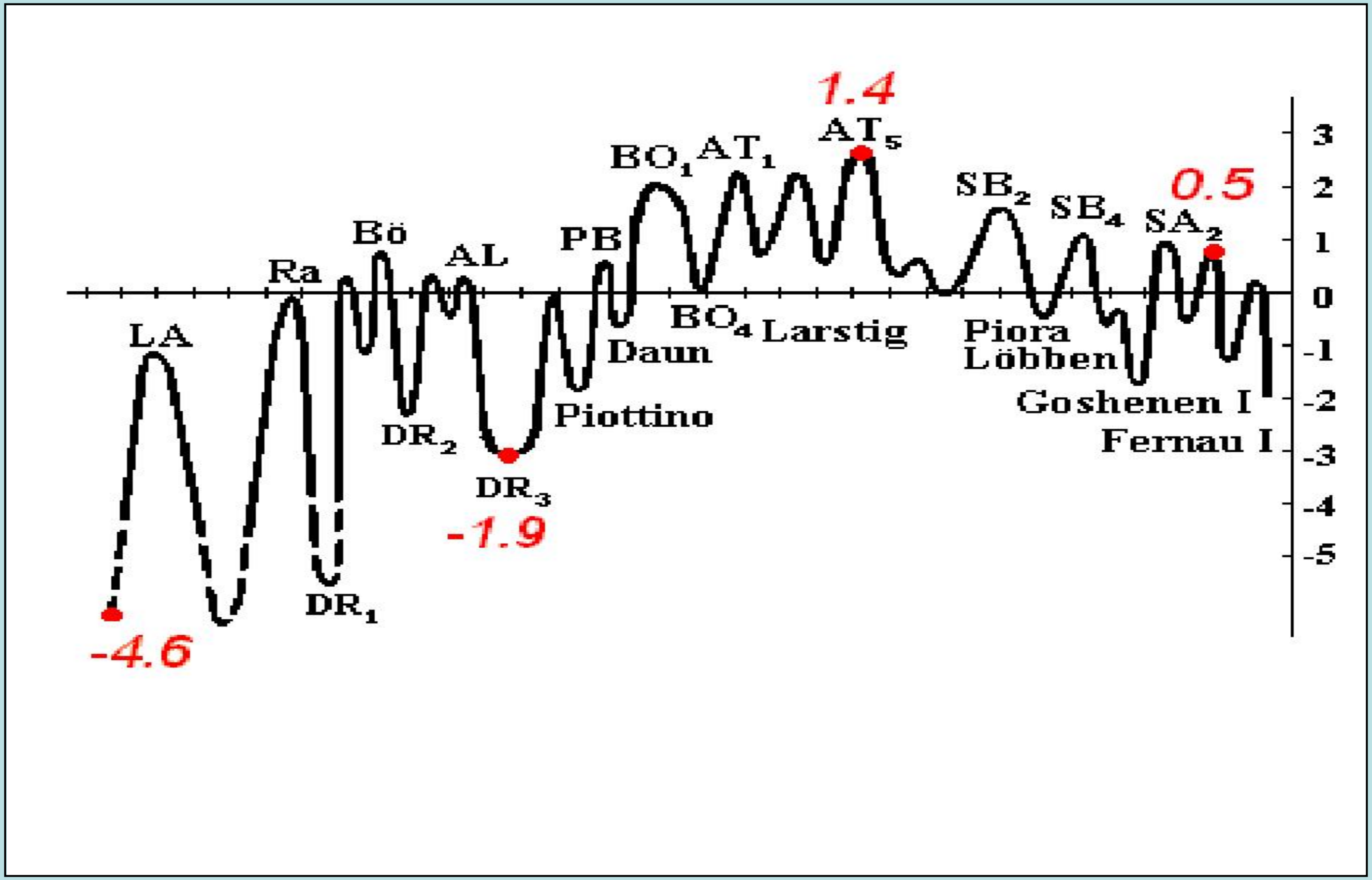
Data sources	Methods of investigations	Climate-related inferences
Bog or lake sediments	1. Pollen analysis. 2.Diatom analysis 3.Chironomid analysis 4. Isotope analysis	1. Pollen analysis. 2.Diatom analysis 3.Chironomid analysis 4. Isotope analysis
Tree rings	1.Dendroclimatical analysis 2. Isotope analysis	Annual and seasonal air temperature, annual sum of precipitation
Ice cores on 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	air temperature, annual sum of precipitation

The map of some key dated sites. All data present calibrated radiocarbon ages “cal yr BP” expressing the number of sidereal years before 1950 AD



The summer air temperature at the high latitudes of Northern Hemisphere (60-75°) over the last 16,000 years

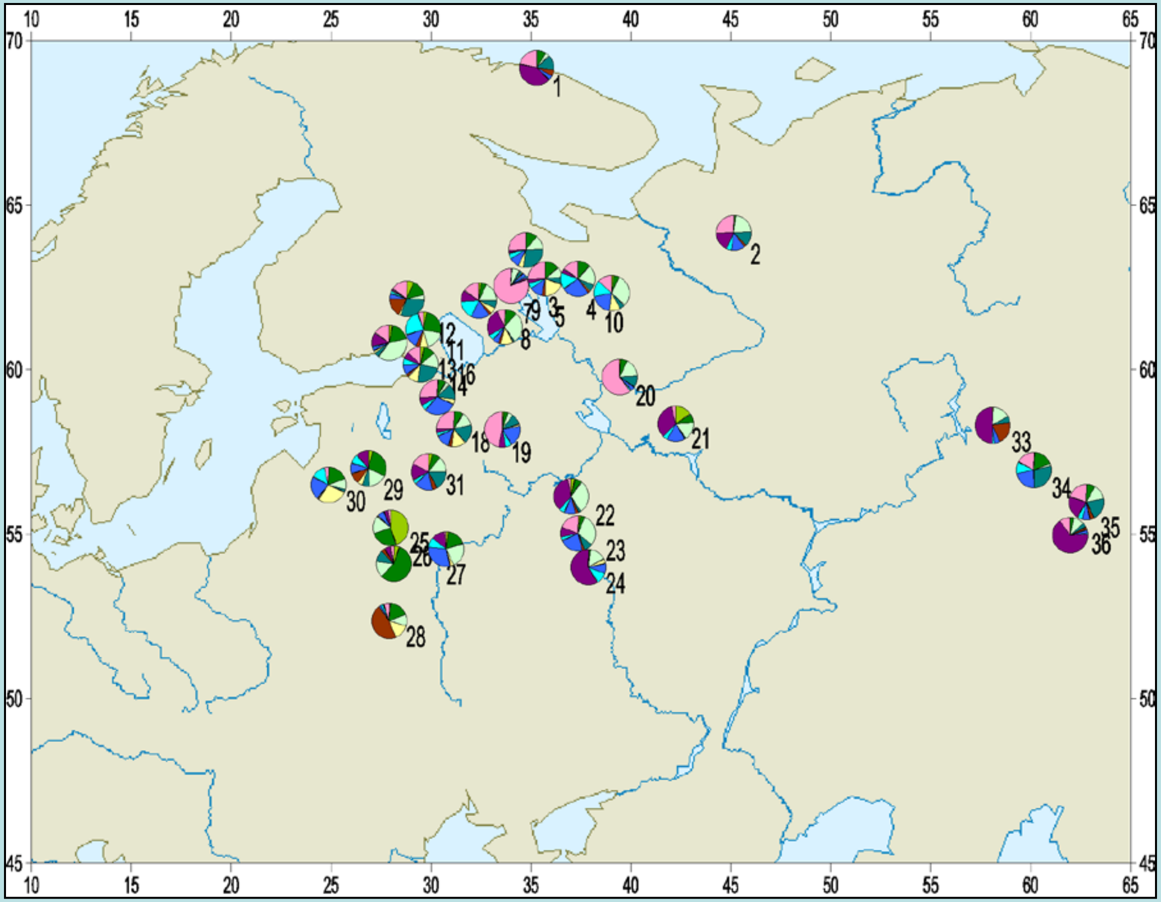
The red points show the value of the mean global air temperature obtained by averaged map-reconstructions for the Northern Hemisphere as a whole (Borzenkova et al.,1992, up data)

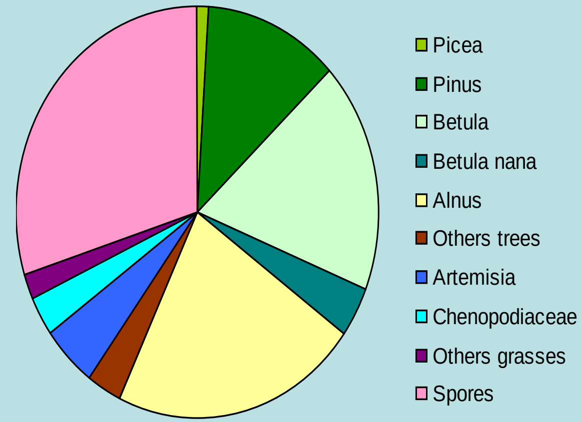


The Baltic Sea area underwent a series of climatic phases during the Holocene

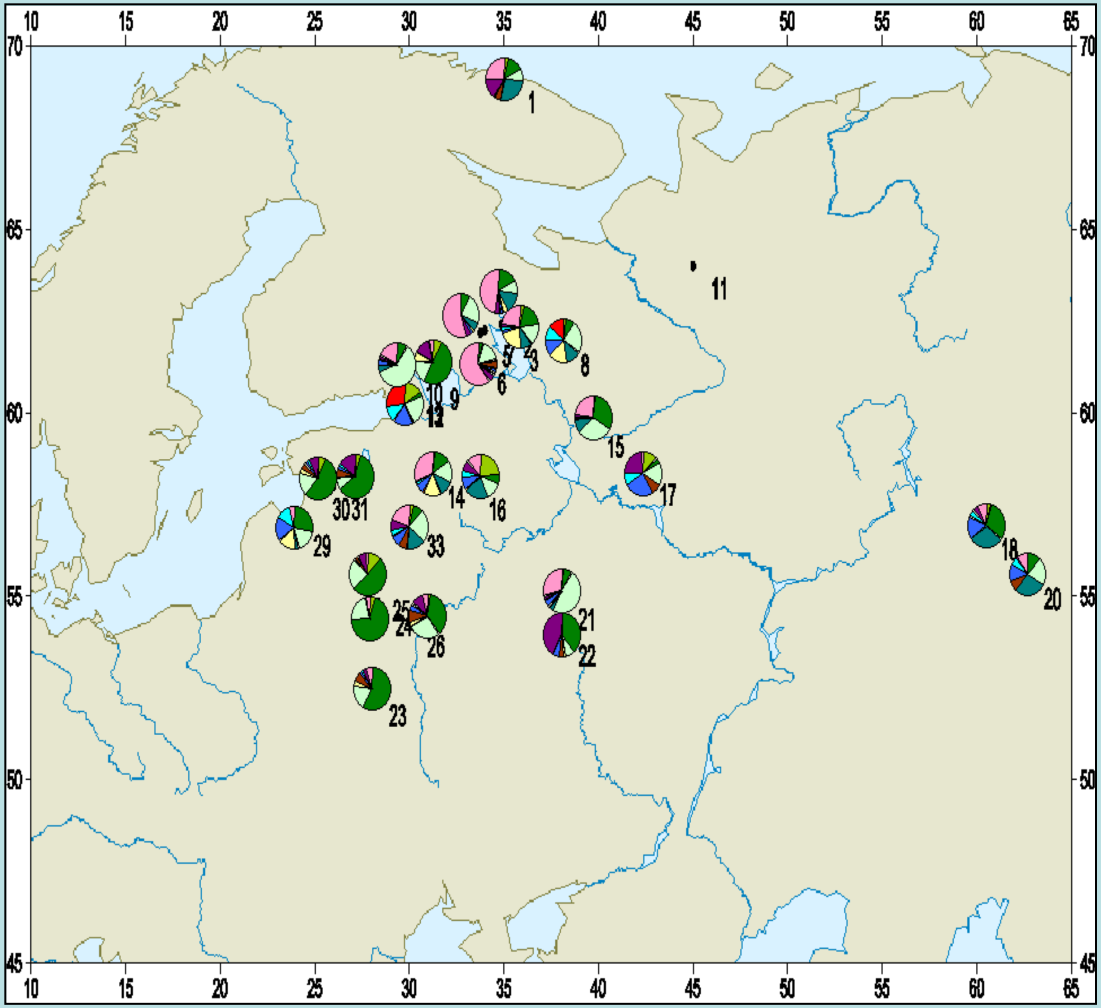
- The boundary of the Younger Dryas/Holocene the coincides with the final drainage of the Baltic Ice Lake at the Billingen area in the Central Sweden and dated at about 11,653 ice years ago and by tree-ring chronology at ~11,590 cal years BP;
- At this boundary a cold and dry climate was rapid changed to a warmer and humid one. The summer temperature in northwestern Russia increased from 4° to 10-12°C and in Southern Finland from 7-10°C to 15°C and higher;
- Tundra-steppe vegetation with predomination of shrubs and grass typical of the Late Dryas changed to vegetation of open forest associations.

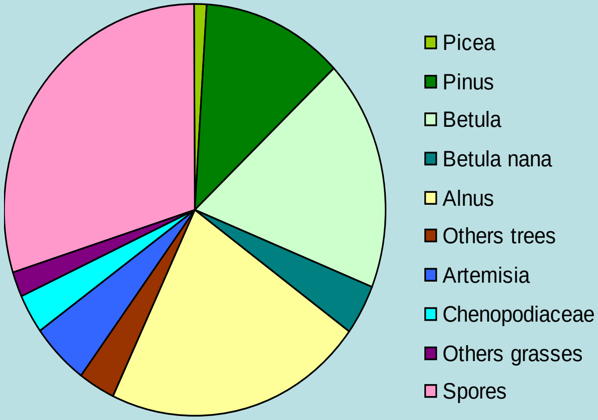
Vegetation composition during the Younger Dryas cool event c. 12,700 cal yr BP





Vegetation at the boundary the DR_3 /Early Holocene c. 11,500 cal yr BP





The Early Holocene oscillations

The warming at the Holocene boundary was interrupted by short cold oscillations:

The three cold episodes about 11,200 (The Preboreal oscillation), cold events about 9,300 and 8,200 cal yr BP are revealed more pronounced. The duration of every cold period is about 150 to 200 years, which is compatible with the "Little Ice Age" cooling during the historical time;

The first cool episode (the Preboreal cool oscillation) occurred approximately 250 years after the final drainage of the Baltic Ice Lake and was almost coincides with the short brackish phase of the Yoldia Sea. The coldest part of the Preboreal oscillation is dated at ~11,430-11,350 cal yr BP.

The 8.2 ka cool event

Of particular interest is the cooling event near 8,200 cal yr ago when outline of the Baltic Sea Basin was very close to present one;

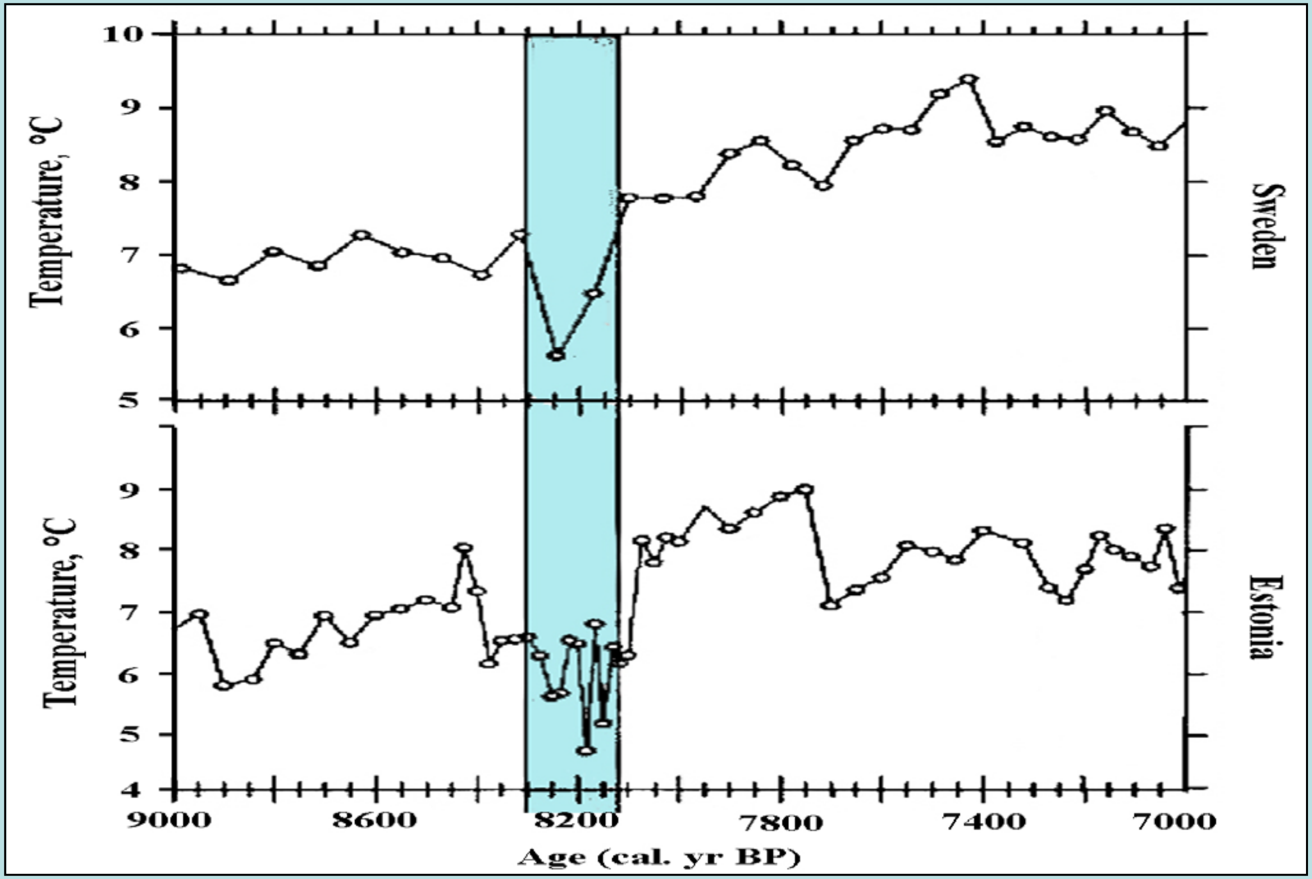
The last cold episode known as an "8.2 ka event" is best of all covered with independent proxy records, including the quantitative estimates of temperature. This cold episode is recorded over the entire Baltic Sea region, excluding the northernmost regions;

A 1,5-2,5°C reduction in the summer temperature is more explicit in western part of the region and weaker in its eastern part.

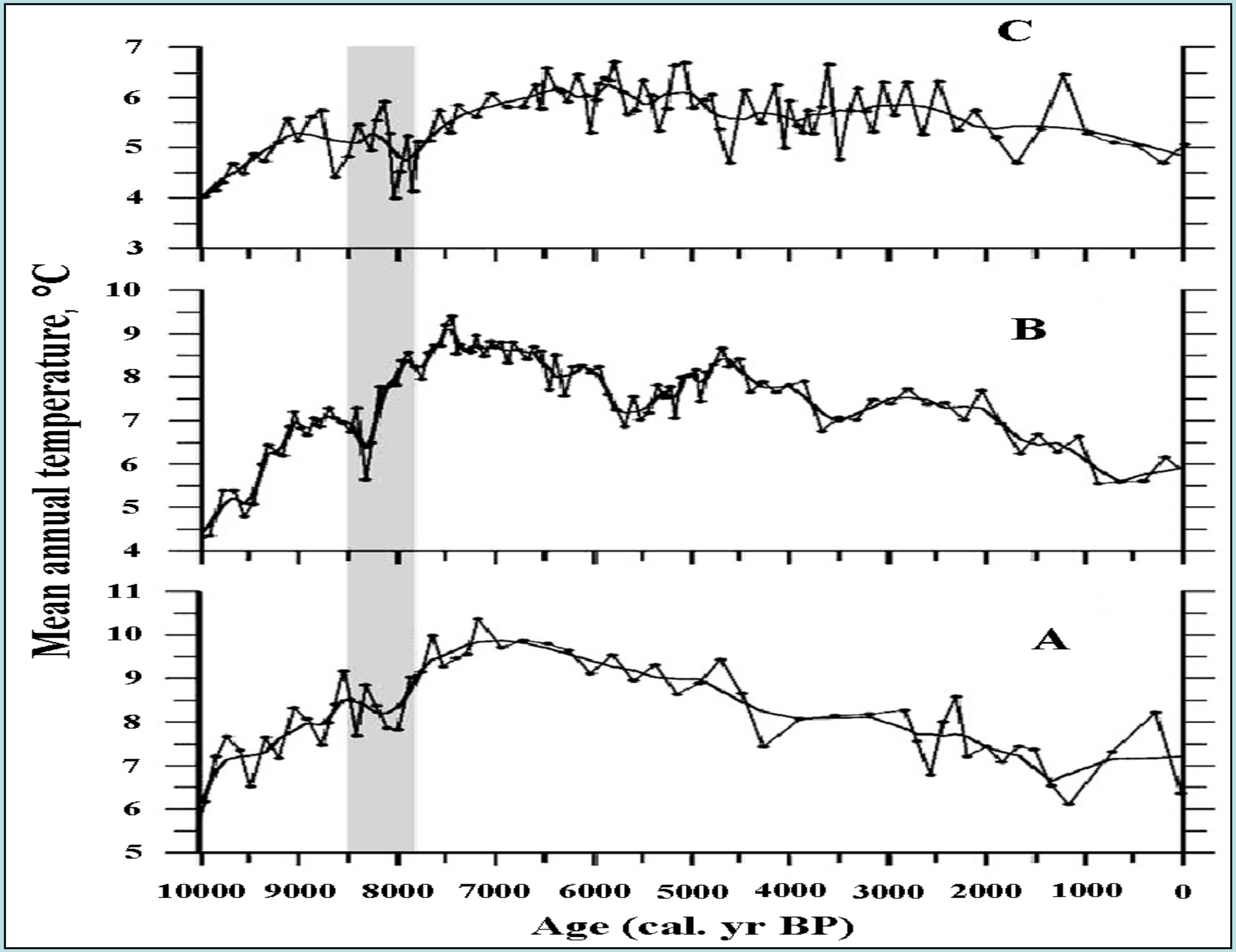
Ice-core data showed a complicated time structure of this event. The coldest phase of about 70 years in duration occurred in the middle of this interval. In central Greenland air temperature decrease of 3 ± 1.1°C occurred within less than 20 years and the entire cooling episode lasted approximately 150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

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).

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



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



The "8,2 ka" cool event in the global scale

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

Causes of cool events have been widely debated. Most of researchers relate the cool events during the beginning of the Holocene to changes in the circulation of surface and deep water formation 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;

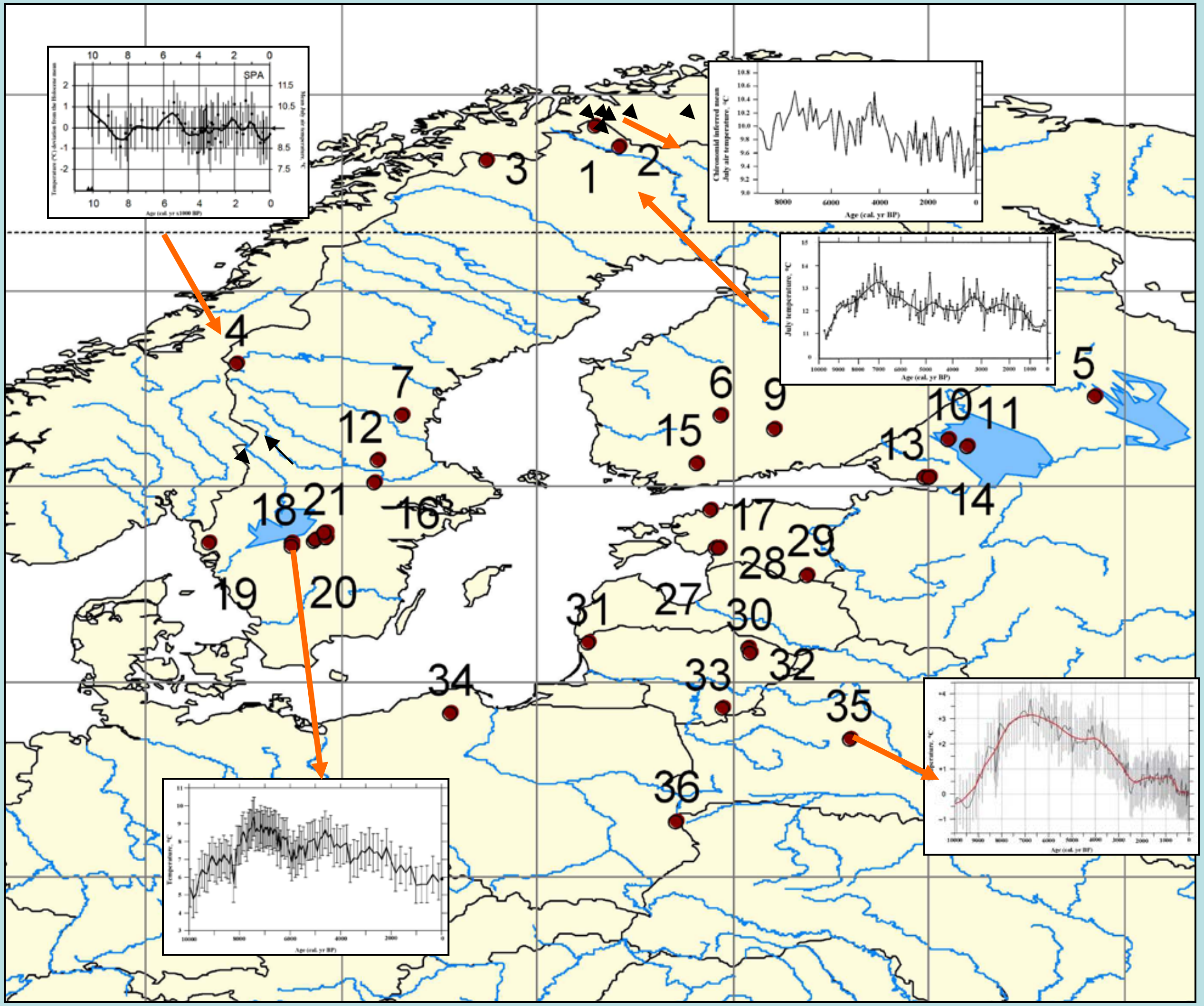
The “8,2” event is the best-documented case of the North Atlantic freshening. With high confidence this event was caused by outburst flood freshening of the North Atlantic;

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 mid Holocene warm interval (the Holocene Thermal Maximum, HTM)

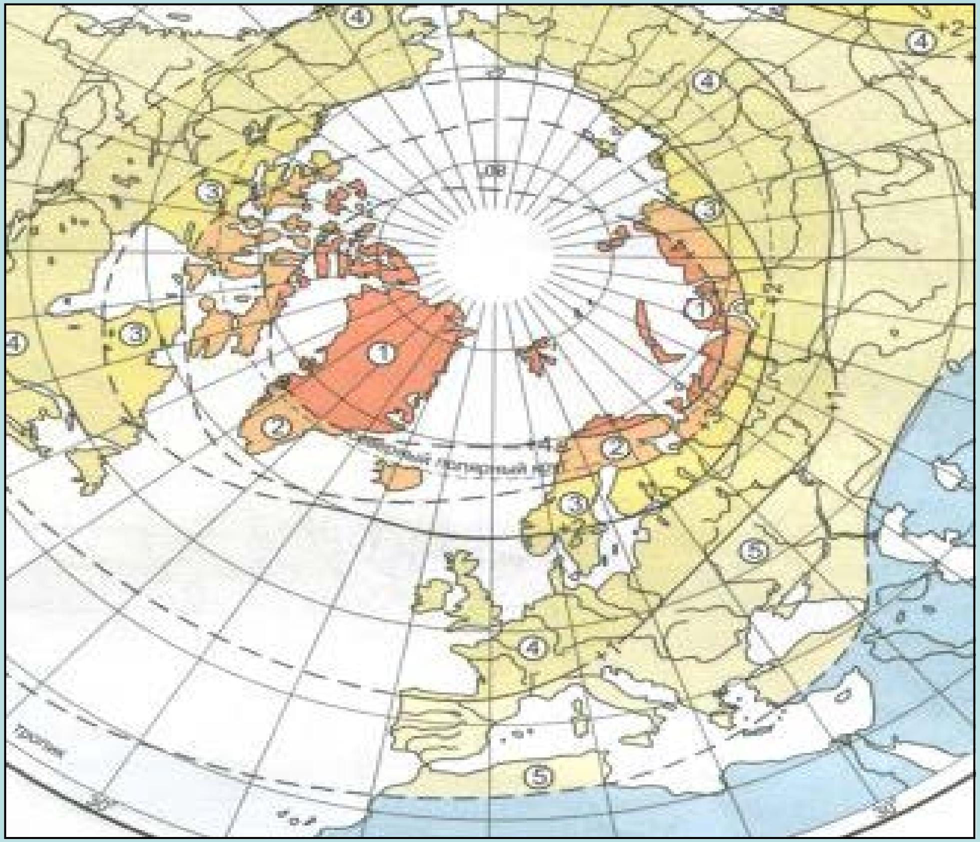
The period between 7,500 and 5,500 cal yr BP ago was the warmest one for the entire Baltic Basin area, though the times of maximum temperatures were not synchronous in different parts of the region;

In all pollen-based records, the mid- Holocene temperature anomalies are positive with respect to modern values, and the highest temperatures occur at the beginning of the warm interval.

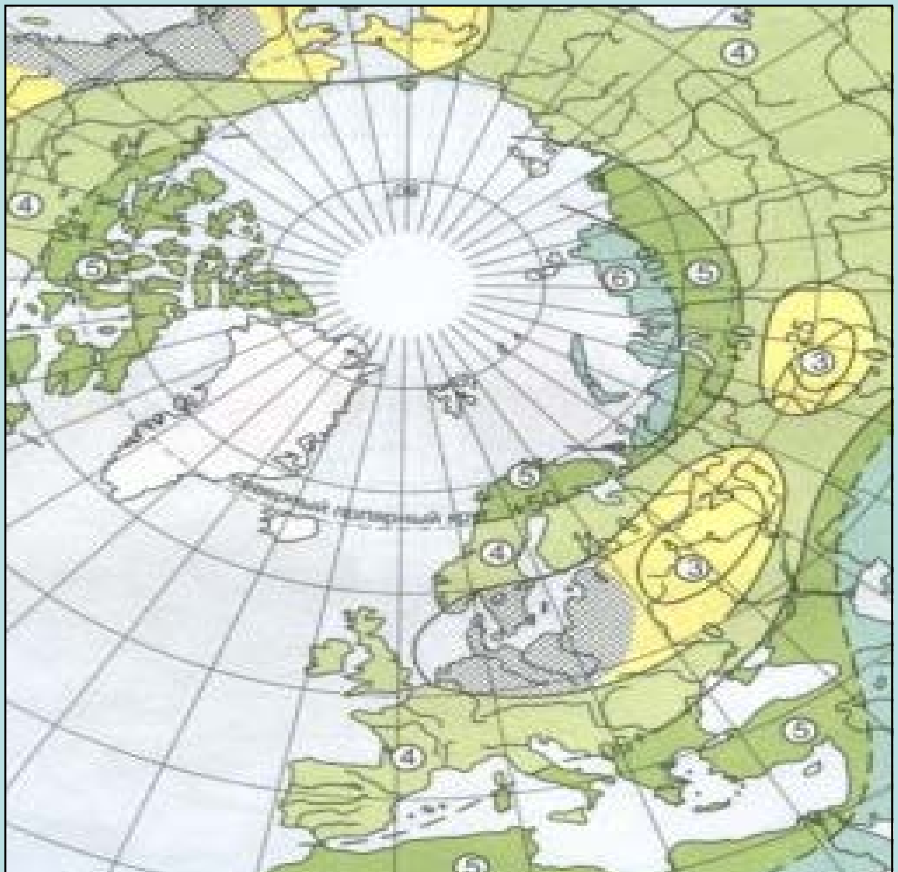


The Atlantic warming in different part of the Baltic Sea Basin

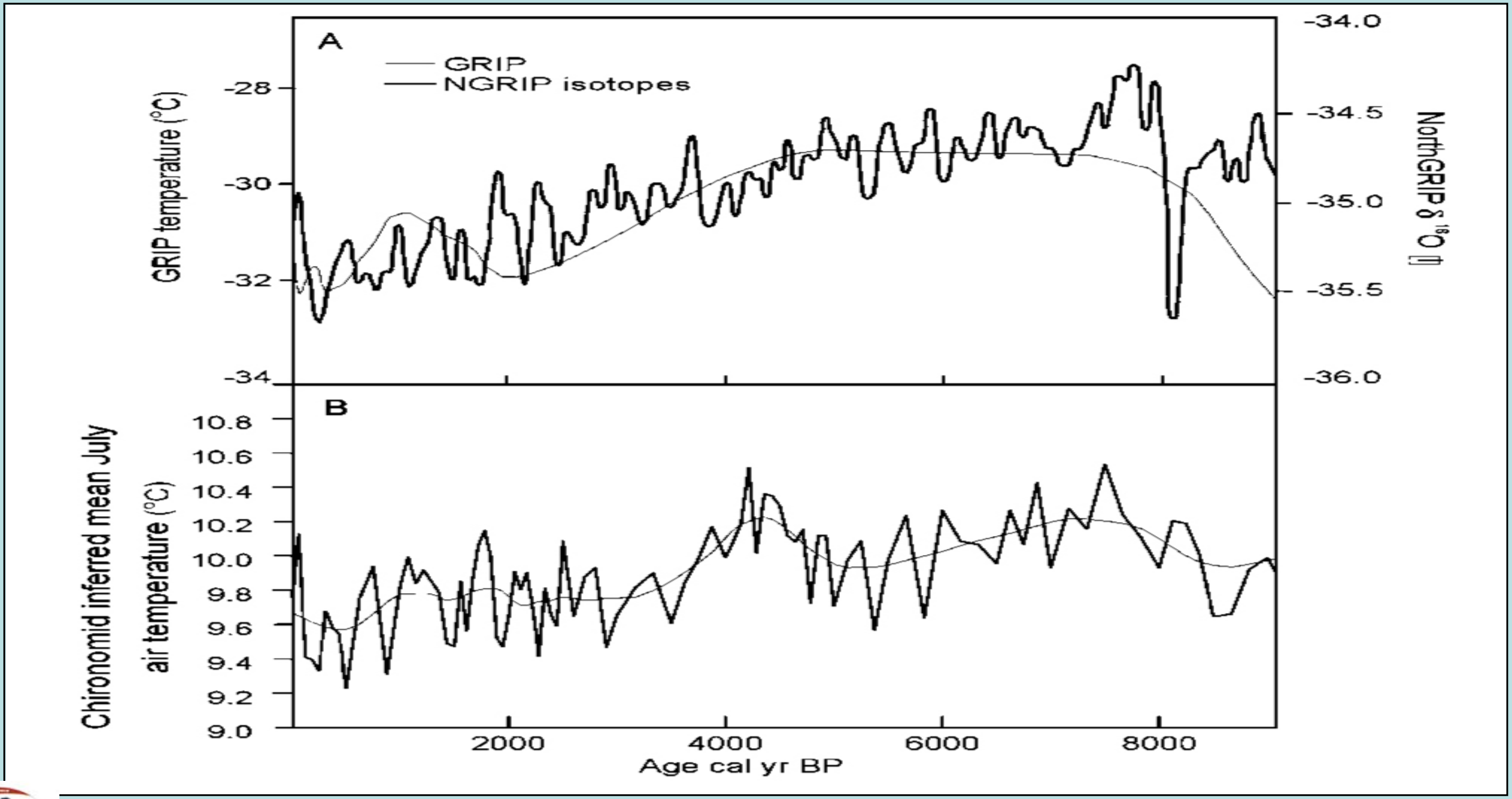
Summer (July) air temperature (C) in anomalies from present one over the warmest part of the Holocene (6,000-5,000 yr BP). By A.Velichko, I.Borzenkova, B.Klimanov (2009)



Annual sum of precipitation (anomalies from present one, mm/year) 6,000-5,000 cal. yr BP by A.Velichko, I.Borzenkova, B.Klimanov (2009)



The general trends of the Holocene summer temperatures in the Toskaljavri area (Finland, 68°N, 22°E) obtained from chironomid data and main features of the direct borehole temperature measurements of the GRIP ice-core



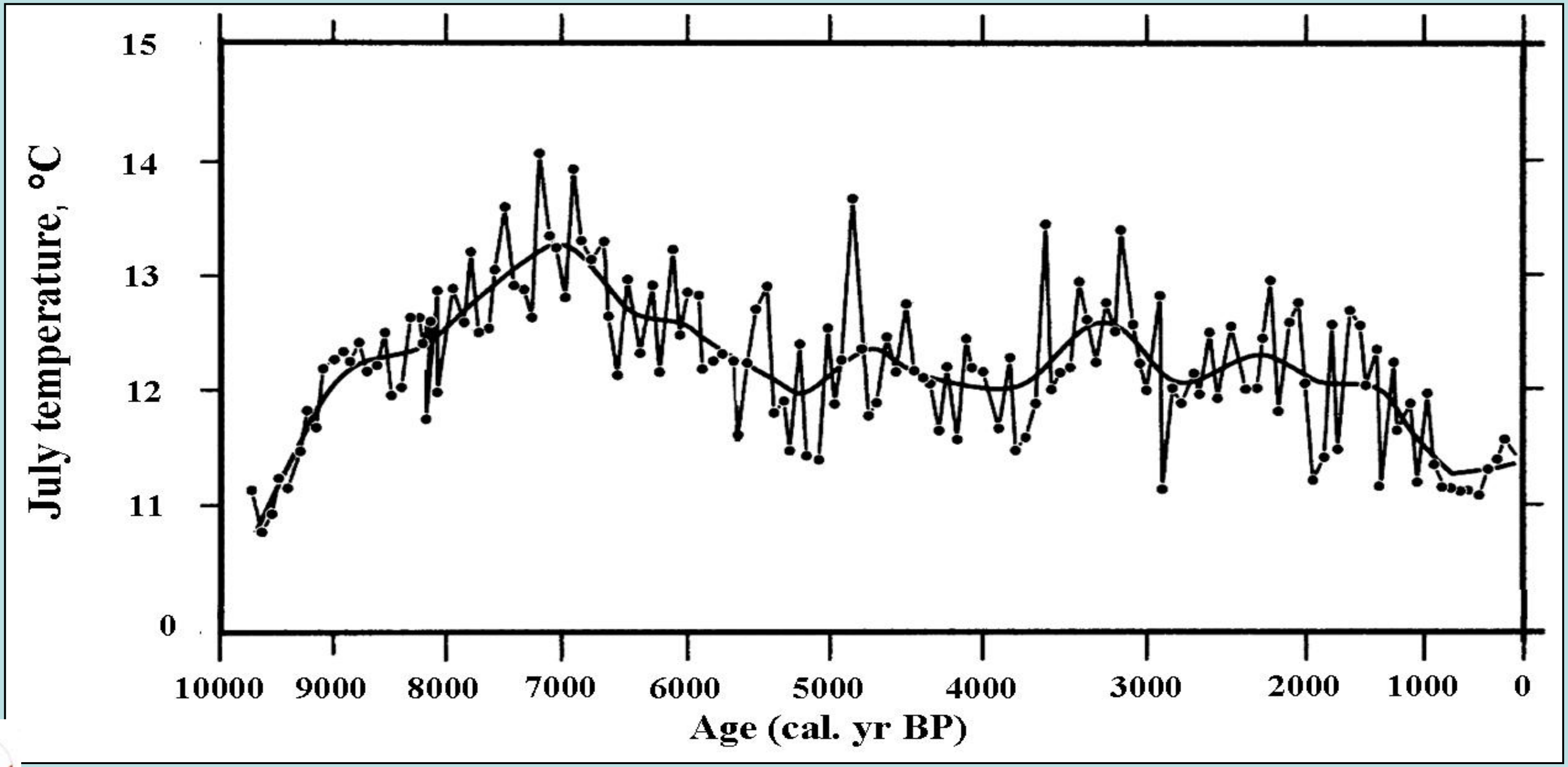
In Sweden, pollen and chironomids records show that the times of maximum temperatures changed in different parts of Sweden between 7,900 and 5,700 cal yr BP with the amplitude varying from 0.8 to 1.5°C and higher;

In the Northern Finland, maximum temperatures took place between 9,000 and 7,000 cal BP, and in the north-western Russia, about 5,800 to 5,000 cal yr BP;

The magnitude of the temperature anomalies decreases southwards. Mean July temperatures in northernmost Fennoscandia and the Kola peninsula were 1,5-2,0°C higher then present and in southwestern Norway they were 1–1.5°C higher than modern one.

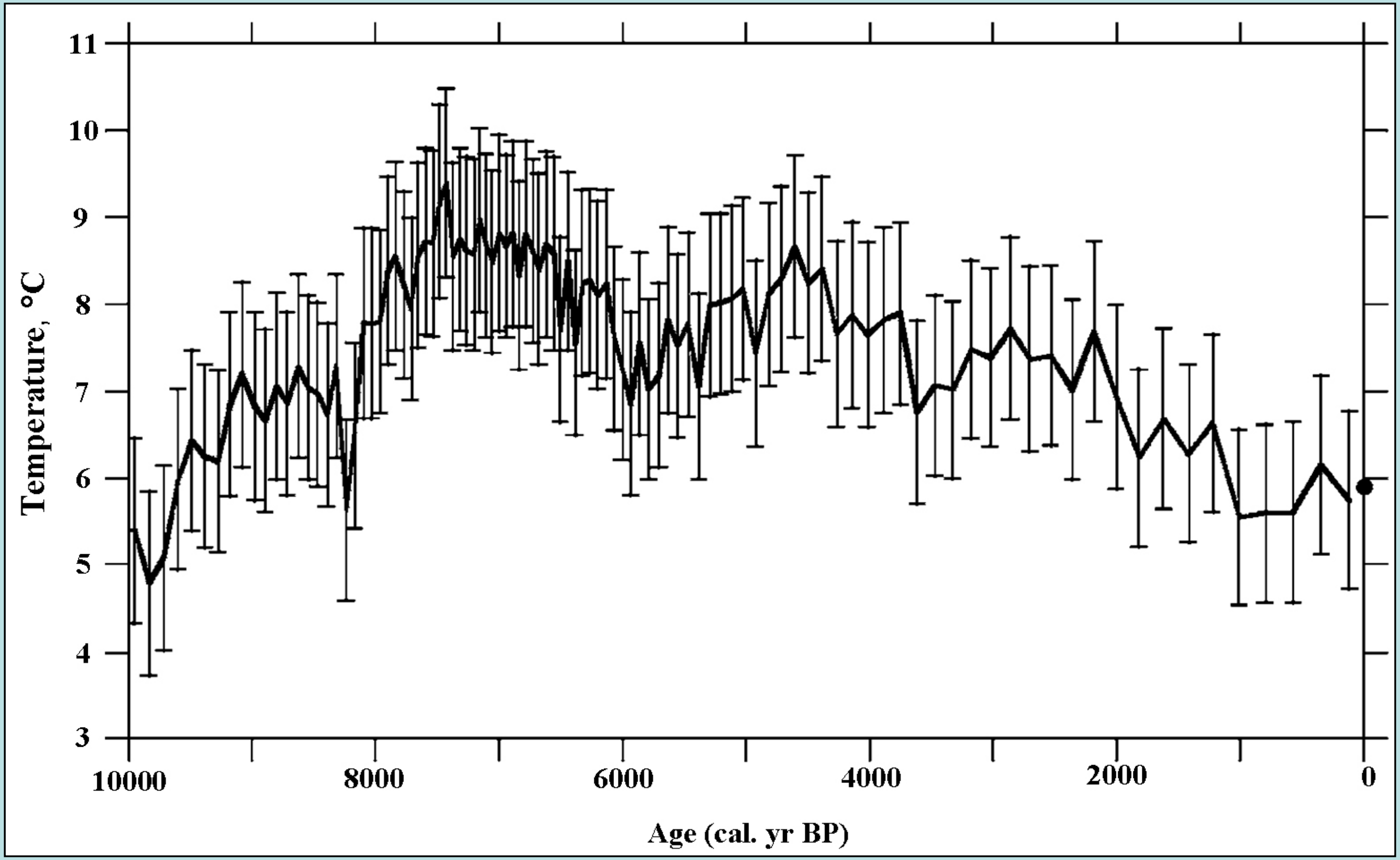
Summer air temperature (°C) during the Holocene in the different part of the Baltic Sea Basin

L.Tsuolbmjavri, Northern Finland, 68°41'N

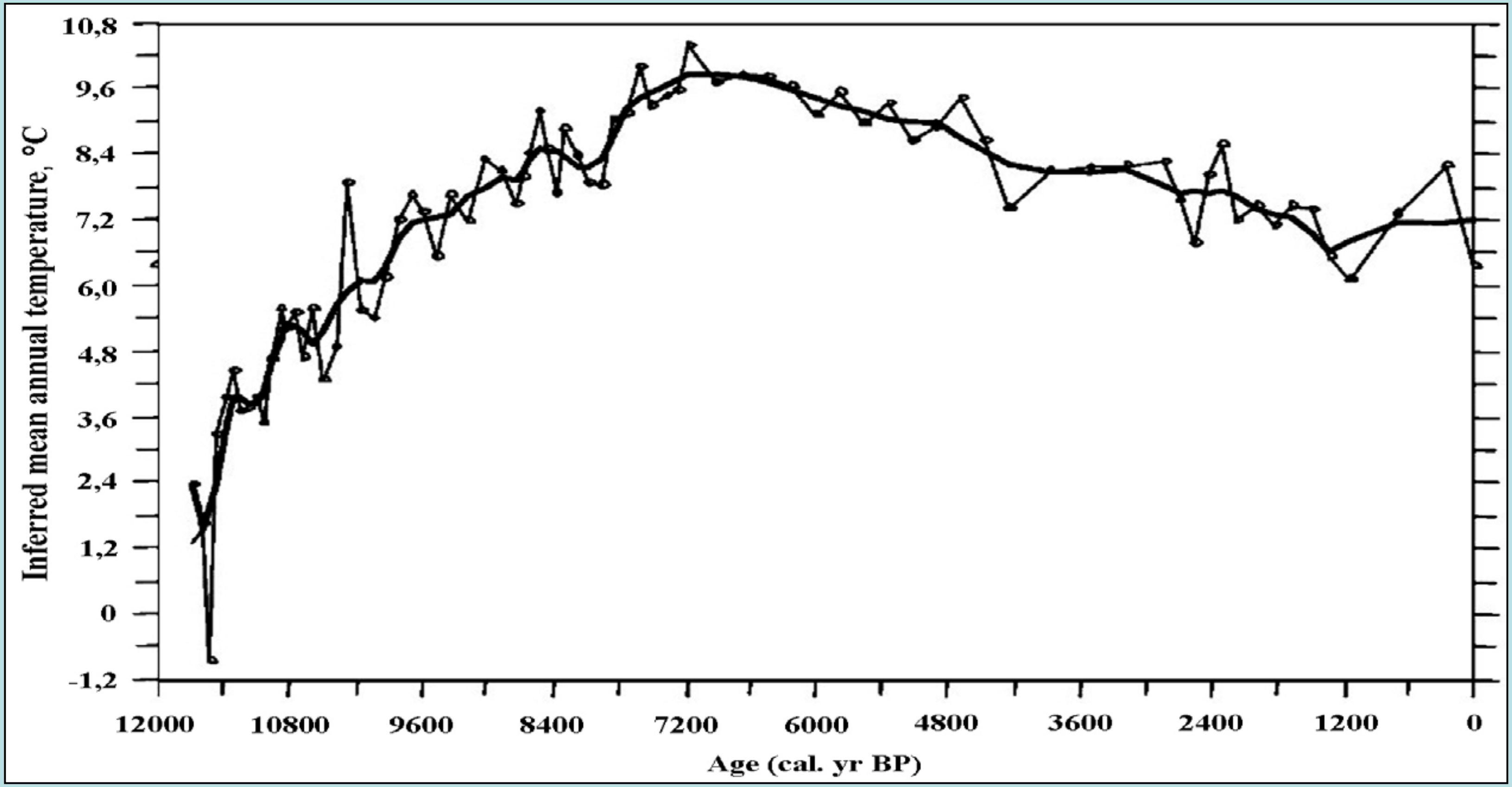


Mean annual temperature reconstructed from pollen data Lake Flarken (south-central Sweden) during the last 10,000 years (black line) (Seppä, Hammerlund, Antonssen, 2005).

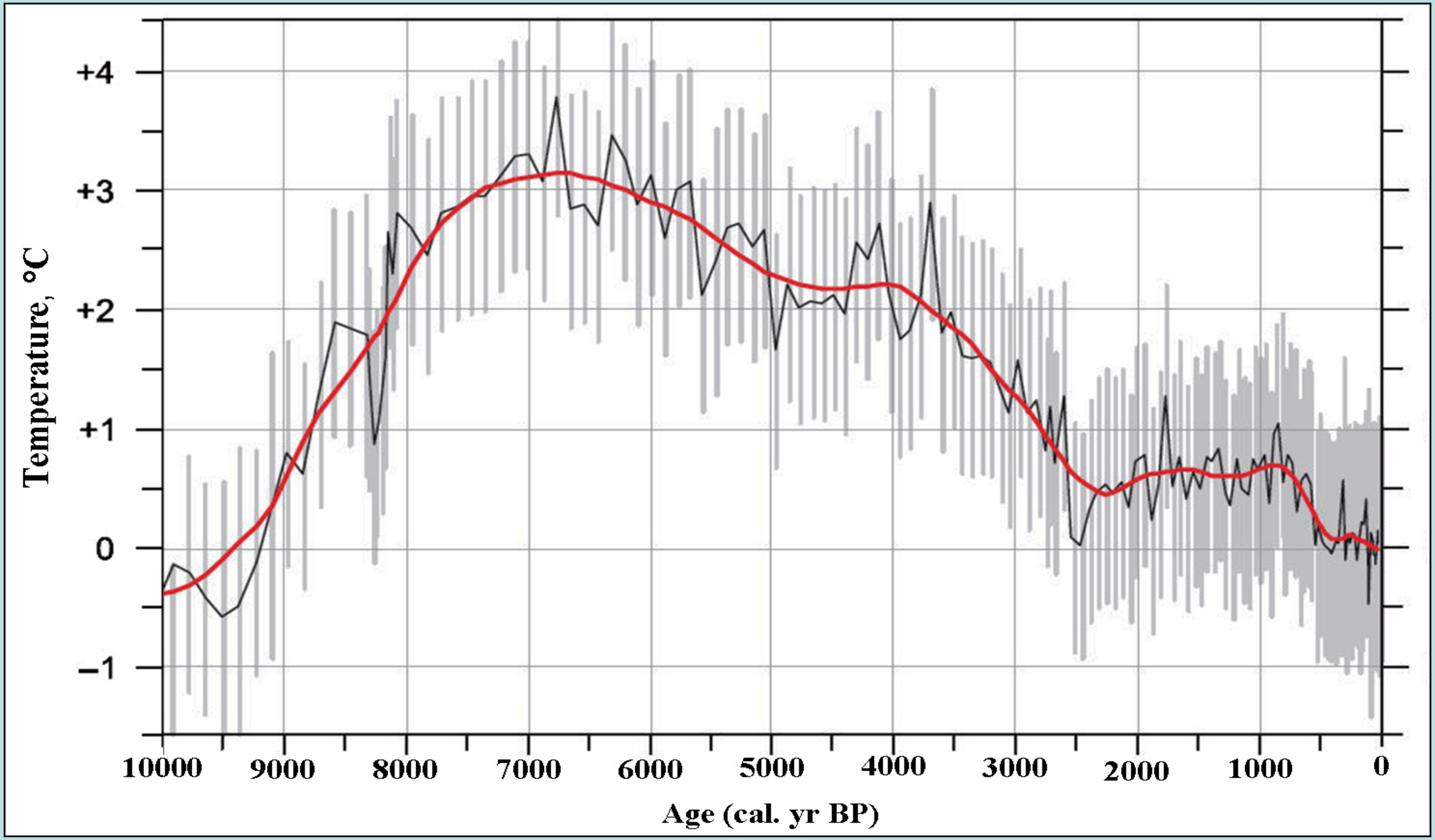
Lake Flarken, 58°33'N



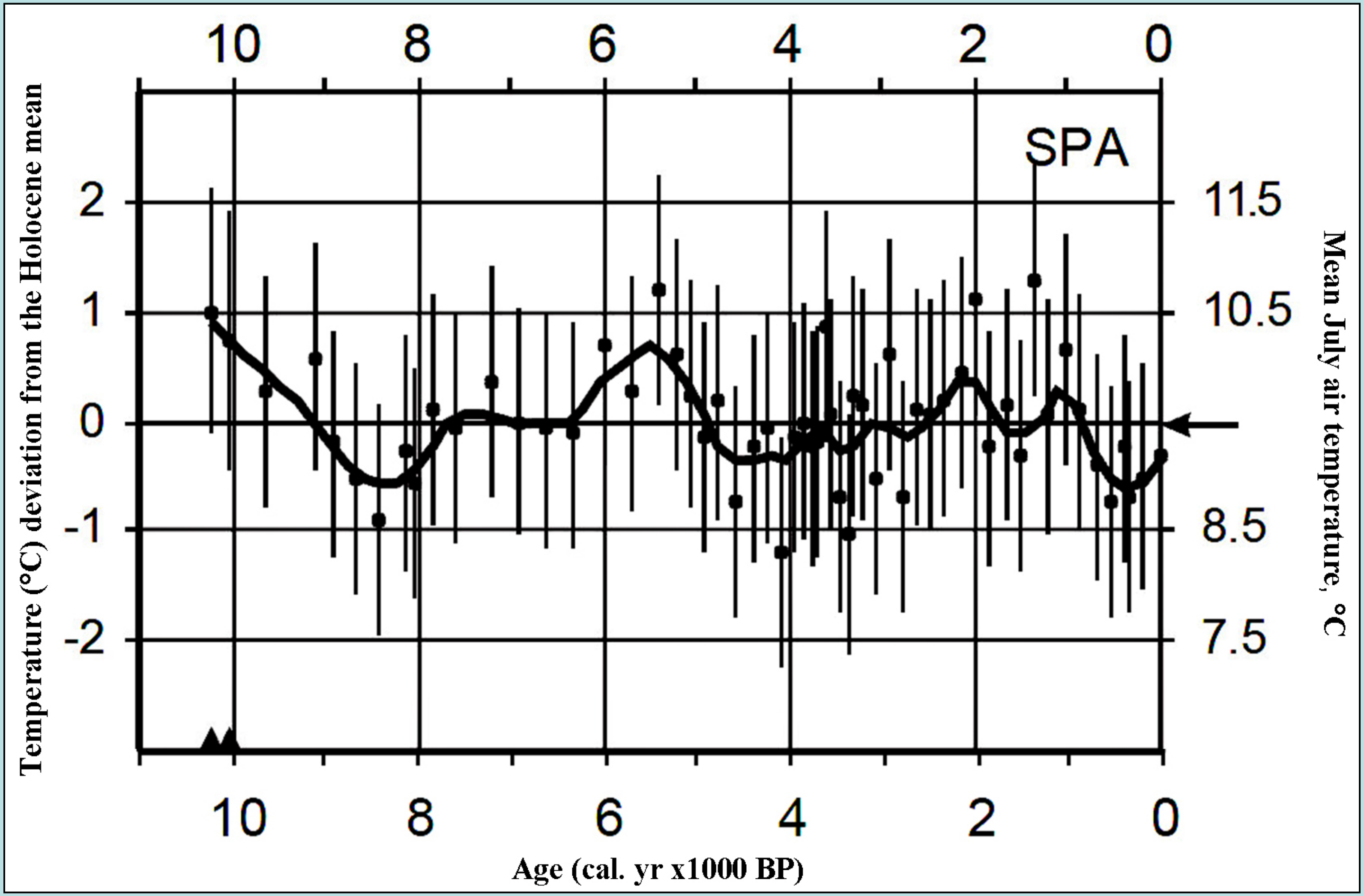
Mean annual temperature reconstruction of Lake Trehörningen for the past 11,700 years, southwest Sweden (Antonsson, Seppä, 2007)



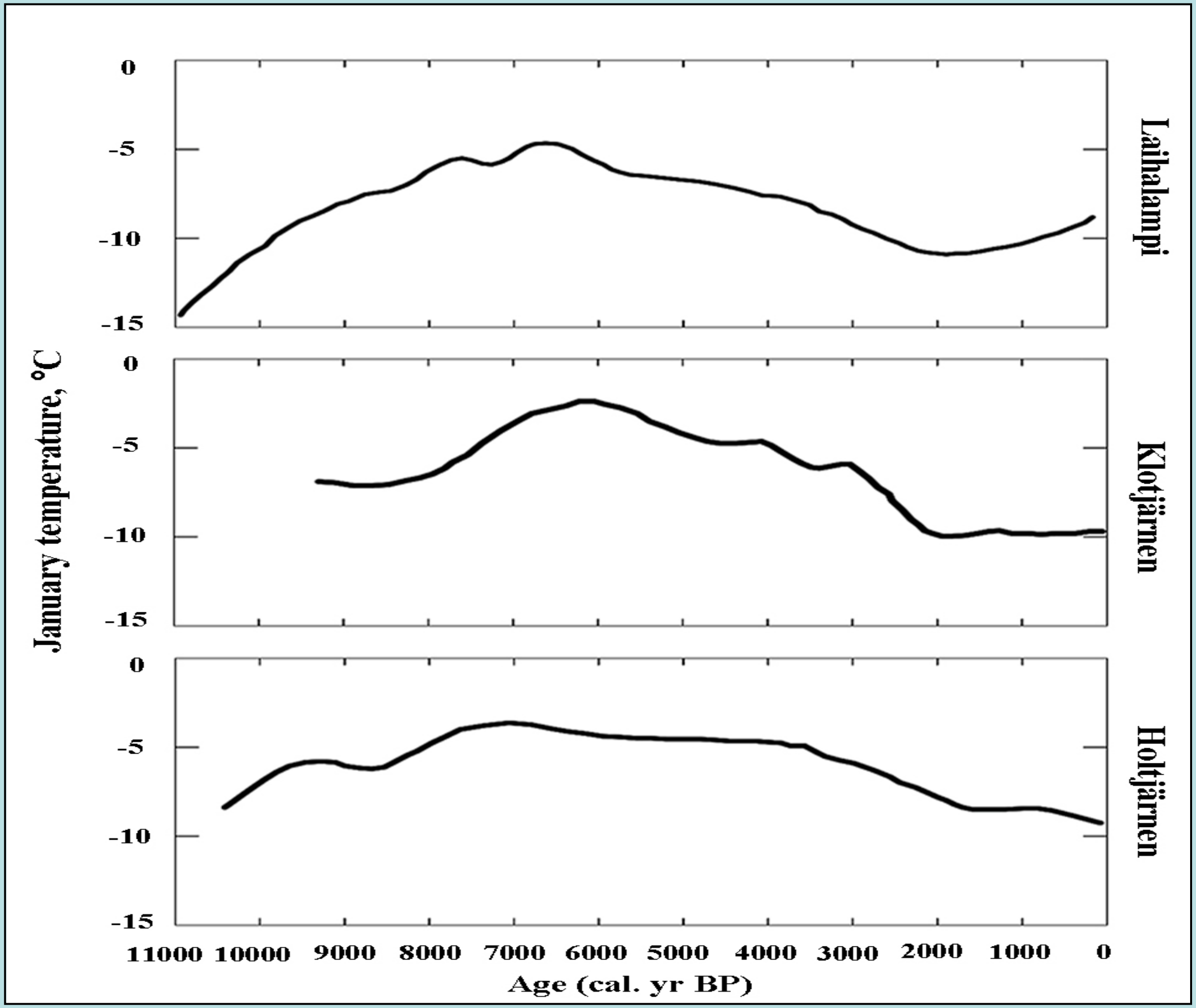
Anomalies of the summer air temperature (°C) from the present one
Lake Kurjanovas, Southestern Latvia, 56°31'N



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



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

The stable carbon-isotope and oxygen-isotope records of lake carbonates from Sweden lakes showed that time between 8,000 and 4,000 cal yr BP was characterized by stable and dry climate conditions;

A recent study from calcareous lake sediments in the central Estonia reports changes in ostracod assemblages, indicating a major low-water period c. 7600–3700 cal. yr BP;

It seems that the Atlantic time was dominated by dry and warm summer climates in the Baltic region, which is attributed to the dominating anticyclonic circulation during the summertime.

The Late Holocene climate changes

The global warming lasting almost 5,000 years, changed to a stable cooling trend about 4,500 cal yr BP, which most clearly expressed in middle and high latitudes including the Baltic Sea area;

The Baltic Sea region cooled by about 5,000 to 4,500 cal yr BP coincidental with decreased summer solar insolation due to astronomical factors;

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 paleoclimatic 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.

Causes of the climatic changes over the Lateglacial-Holocene

During the Holocene climate change in the Baltic Basin depended both on external and interior factors. These factors include:

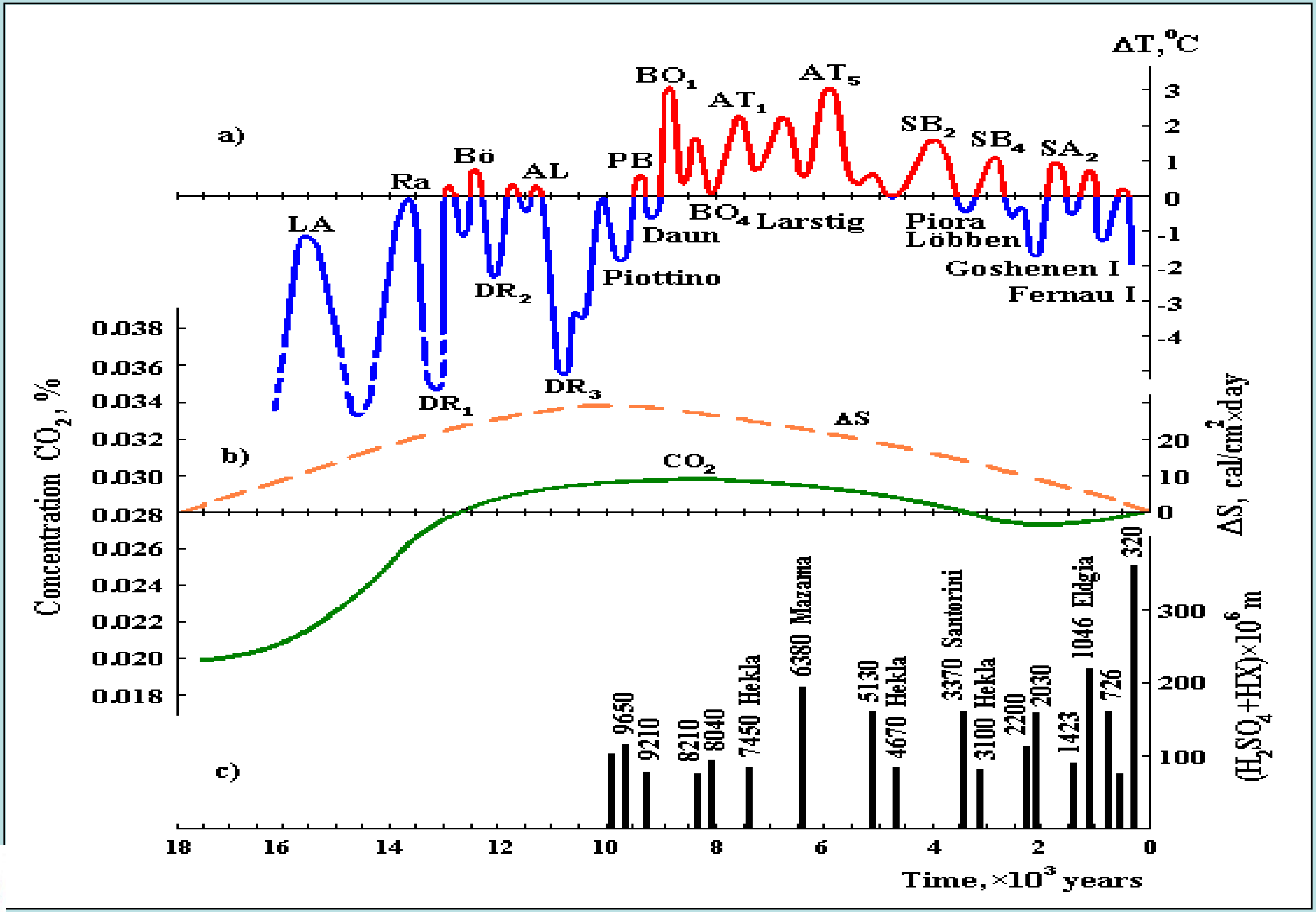
Changes in incoming solar radiation due to astronomical factors and variations in the aerosol concentration in the upper atmosphere due to the volcanic activity;

Changes in the concentration of greenhouse gases in the atmosphere (CO_2, CH_4, N_2O) due to natural factors;

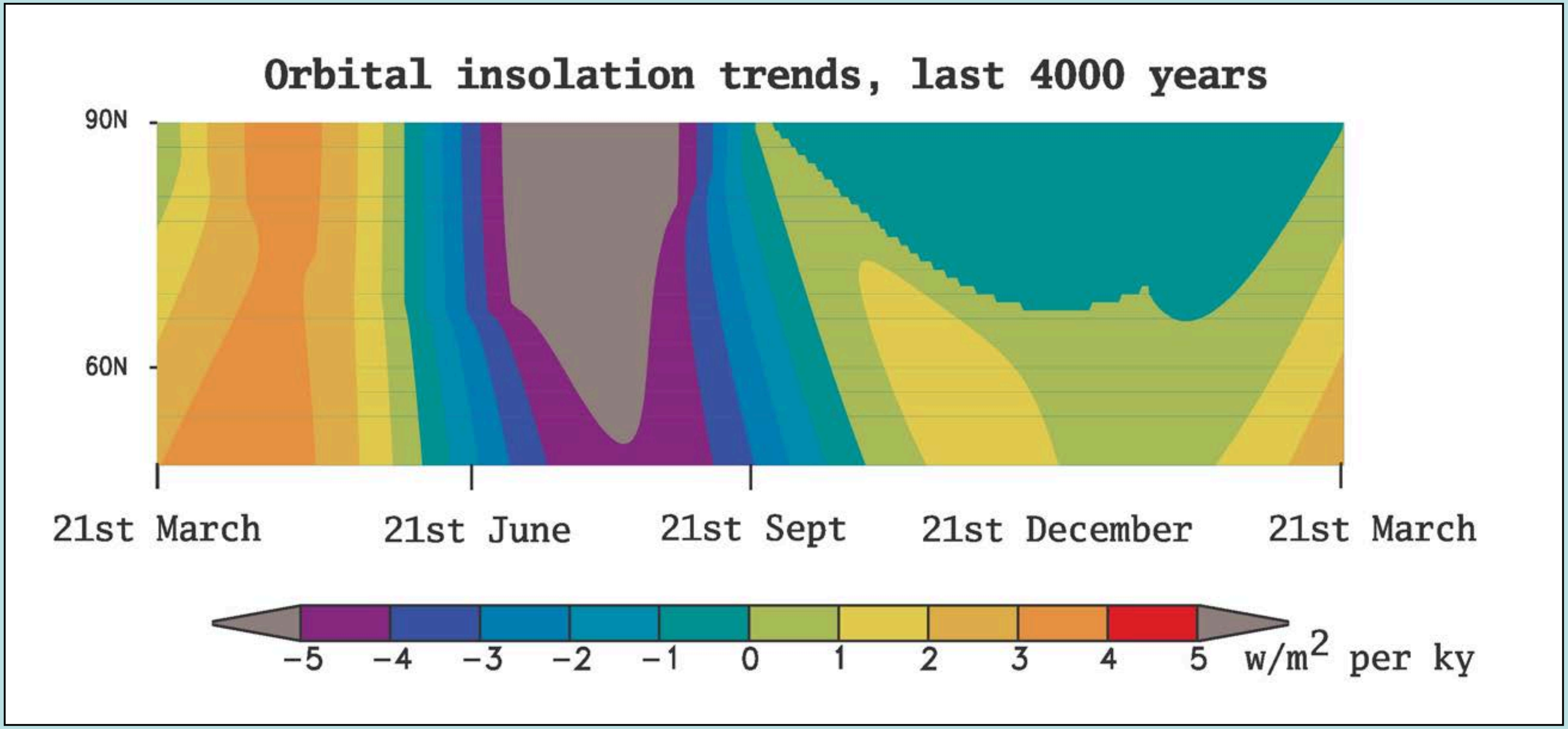
Changes in surface albedo of the sea-lake itself and changes in vegetation on the surrounding land;

Changes in the intensity and type of circulation.

The main forcing factors in the Lateglacial-Holocene



Linear trends of solar insolation at the high latitudes of the Northern Hemisphere as a function of season and latitude over the last 4000 years (Laskar et al., 2004).



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).

- **What does climate changes during the last 10,000 years tell us about present and future climate variability in the Baltic Sea Basin?**

- ***What can we learn from past climate and environment variability of the Baltic Sea Basin for future time?***

- **The diverse empirical data collected recently expands considerably and changes to some extent our ideas about climatic variations in the past. These new views can be summarized as follows:**

- **Climatic changes even in the warmest epochs of the past appeared to be more complicated than it had been previously supposed;**
- **Intervals of relatively stable climate were interrupted by rapid (from the geological point of view) changes that in individual cases were of drastic nature;**
- **Rapid climatic changes considerably affect the biosphere as a whole. These rapid climatic events will be able occurred in the modern and future time due to both the natural and man-made factors**

The mechanism of some of these abrupt cool events in the beginning of the Holocene is likely to depend on a massive influx of fresh glacial meltwater into the ocean and intensified hydrological cycle under global warming. In high latitudes, abrupt climate changes are most noticeable, especially in the regions adjoining to the North Atlantic area;

In case the modern global warming due to the growth of greenhouse gases concentration lasts longer, the future consequence of this process might be the freshening of the sea surface layer;

The Baltic Sea Basin is the key region for studies on the effect on regional climate of refreshing of the upper layer of the Atlantic Ocean due to increased precipitation, melting mountain and sheet glaciers in the Northern Hemisphere.

- **The conclusion that freshening the surface water layer in the North Atlantic might have been the cause of cooling and decreased concentrations of greenhouse gases in the atmosphere in the past, can be of great importance for the modern global warming implications;**

- **The intensification of the global hydrological cycle especially as a result of increased precipitation in high latitudes, as well as mountain and continental sheets melting, in particular, of the Greenland Sheet, may have led to irreversible climate change in the North Atlantic and adjoining areas;**

- **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**


Thank you for your attention