

CLIMATE CHANGE IN THE HOLOCENE - AN OVERVIEW

H.J.B. Birks

University of Bergen,
University College London,
Jesus College, Oxford

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Introduction

How do we reconstruct past climate change in the Holocene?

- Peat stratigraphy, megafossils, and macrofossils
- Pollen analysis
- Palaeoclimate modelling
- Palaeolimnology
- Ice cores

How has climate changed during the Holocene in Europe?

Are there any relationships between Holocene climate change and societal change?

How can we distinguish between human activity and climate change in the Holocene?

Conclusions

INTRODUCTION

Enormous **progress** in reconstructing climate history of the Holocene (= post-glacial), the last 11600 years of Earth's history, since the earliest published investigations (1829) by Heinrich Dau in Denmark.

Holocene climate research has seen many paradigm 'shifts' in the last 178 years as a result, not only of new ideas and conceptual breakthroughs, but also of new and improved **techniques**, of studying **different proxies**, of increased **scientific rigour**, improved **project design**, and greater attention to **detail**, and of investigating **different geographical areas** (e.g. low latitudes, high latitudes).

Apologies

1. Geographical **parochialism** - inevitable bias towards areas where I have some direct experience (e.g. N.W. Europe, mid-West North America, arctic and alpine areas, central Asia)
2. Methodological **bias** - inevitable bias towards terrestrial proxies (e.g. pollen) and towards Holocene terrestrial palaeoecology where I have some direct experience
3. Review is inevitably very **incomplete** – apologise for the many major omissions (e.g. marine studies, glacial studies)

HOW DO WE RECONSTRUCT CLIMATE CHANGE IN THE HOLOCENE?

Pioneering Holocene climate research was, I suspect, motivated by **natural curiosity** about our past and about 'secrets of the past'. Since about 1985 and discussions about global warming, Holocene climate research has acquired a **key role** in providing unique information about natural climatic variability since the last glacial period.

Peat stratigraphy, Megafossils, and Macrofossils

North-west Europe – particularly Scandinavia

Heinrich Dau (1790-1831) – recognised different peat types and described (1829) the occurrence of pine trunks (**megafossils**) in Danish bogs and changes in peat colour (pale or dark peat).



Occurrence of buried trees (**megafossils**) in bogs attracted much public interest in Denmark in 1830s. Danish Academy of Science offered a prize for 'solving the problem' of how did pine trees once grow on Danish bogs and what caused the extinction of pine from Denmark.

Japetus Steenstrup (1813-1897) won the prize. He proposed (1841) four periods in forest history – aspen, pine, oak, and alder.



Emphasised the importance of plant and animal remains preserved in peat bogs as the best available means of investigating past environments and past climate. Suggested **changes in moisture** and **possibly in temperature** to explain changes in peat stratigraphy and the occurrence of wood remains.

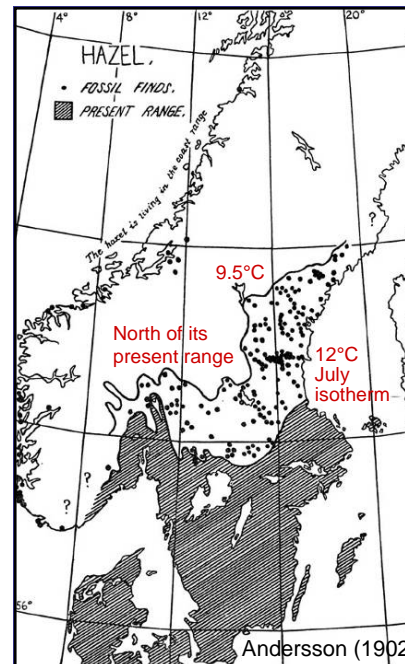


Christian Vaupell (1821-1862) looked at the **width of tree rings** of the buried pines. Concluded that the pines had not grown in cold conditions as Steenstrup had suggested but had grown under warm but dry conditions. Had there been shifts in temperature as well as moisture?

In Sweden where there are strong north-south gradients in **temperature** today, Gunnar Andersson (1865-1928) and Rutger Sernander (1866-1944) examined seeds, fruits, leaves, etc. (**macrofossils**) in peat layers (e.g. hazel nuts).



Rutger Sernander



Corylus avellana (hazel)

Fossil finds suggested **summers 2-2.5°C warmer** than today in mid-Holocene about 8000 years ago. Andersson emphasised changes in summer temperature and the idea of a 'thermal maximum'. Also fossils of *Trapa natans*, *Cladium mariscus*, and *Emys orbicularis* suggest warmer summers.



Axel Blytt (1843-1898) in Norway explained tree layers in bogs and changes from dark to pale peat as evidence for alternations between **dry** (continental = Boreal) and **wet** (oceanic = Atlantic) periods (1876) and proposed a theory for the immigration of the Norwegian flora during these oceanic and continental periods.

Sernander combined the Swedish ideas based on macrofossils with Blytt's moisture changes to propose the famous Blytt-Sernander four climatic periods in the Holocene (1894).

	<u>Climate</u>	<u>Approx age BP</u>
Sub-Atlantic	Cool, wet	0-2500
Sub-Boreal	Warm, dry	2500-5000
Atlantic	Warmest, wet	5000-8000
Boreal	Warm, dry	8000-10000
(Pre-Boreal	Sub-arctic)	

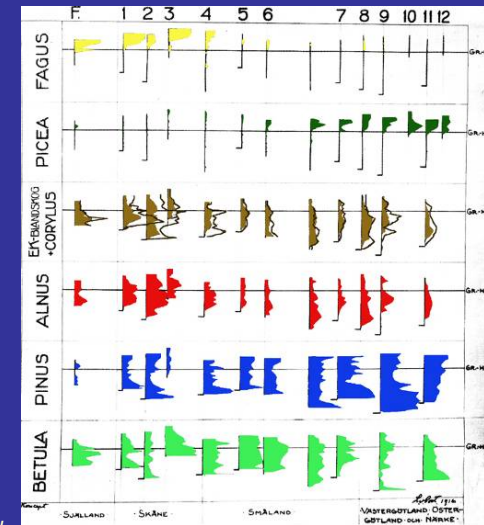
Change from Sub-Boreal to Sub-Atlantic thought to be an **abrupt climatic change**, even a catastrophe – the 'Fimbul-winter' of the sagas.

Rapid typical Scandinavian polarisation of ideas – Blytt-Sernander scheme with rapid change (1894, 1908) versus Andersson's (1902) more uniform, gradually rising temperature curve, a thermal maximum, and subsequent decrease. Ferocious disagreements in print between Sernander (Uppsala 'school') and Andersson (Stockholm 'school'). Never resolved until the development of pollen analysis.

Pollen Analysis

Sweden's Lennart von Post (1884-1950) presented in 1916 the technique of pollen analysis at the 16th Scandinavian meeting of natural scientists in Kristiana (now Oslo).

Proposed that in contrast to large tree remains in peat, pollen could give a **continuous** record of vegetational change. He showed strong within-regional similarities in pollen stratigraphy and strong between-regional differences and proposed that there is 'regional parallelism' and changes not only within regions but also between regions.



Only chronological horizon was C.A.

Weber's Grenzhorizont, the change from dark to pale fresh peat at the Sub-Boreal – Sub-Atlantic transition, the boundary between the Bronze Age and the Iron Age.

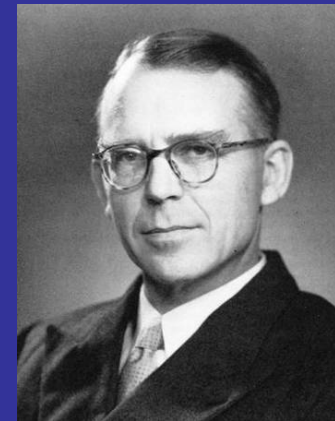
Lennart von Post was awarded the Vega Medal from the Swedish Anthropological and Geographical Society in 1944. His Vega lecture was "The Prospect for Pollen Analysis in the Study of the Earth's Climatic History" (New Phytologist 1946, 45: 193-217).

Proposed, based on pollen diagrams from Europe, New Zealand, Tierra del Fuego, North America, Hawaii, and China that there is a consistent **three-fold division** of the Holocene characterised by protocratic (I), mediocratic (II), and terminocratic (III) elements, resulting from an initial climatic improvement, a climatic optimum, and subsequent climatic deterioration. Recognised that changes in precipitation had also been important in China and New Zealand.

Major advances in pollen analysis made by **Johs. Iversen** (1904-1971) and **Knut Fægri** (1909-2001), especially detailed identifications and ecological interpretations.



Knut Fægri



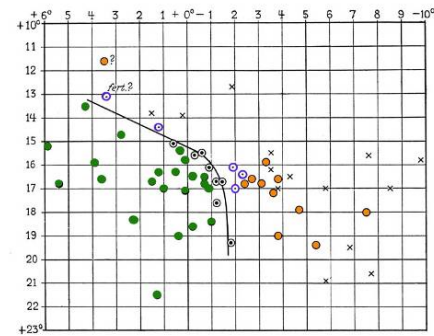
Johs. Iversen

Viscum album (mistletoe), *Hedera helix* (ivy), & *Ilex aquifolium* (holly) at or near their northern limits in Denmark (Iversen 1944)

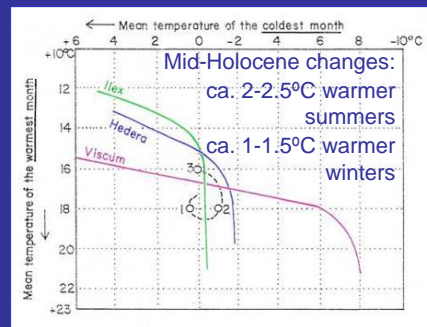
Considered occurrence, growth, and fruit production in relation to mean temperature of the coldest month and of the warmest month to delimit 'thermal limits'.



Hedera helix



● Develops normally within the station area
 ○ Mostly sterile, only exceptionally bearing fruit in the tree top
 ○ Bearing fruit only against favourable exposed cliffs
 ○ Never bears ripe fruit
 × Hedera missing within the station area



The thermal-limit curves for *Ilex aquifolium*, *Hedera helix*, and *Viscum album* in relation to the mean temperatures of the warmest and coldest months. 1, 2, and 3 represent samples with pollen of *Ilex*, *Hedera*, & *Viscum*, *Hedera* & *Viscum*, and *Ilex* & *Hedera*, respectively.

Walther *et al.* (2005) show shifts in the northern limit of *Ilex* (holly) in last 50 years in response to climatic changes, confirming its sensitivity to climatic shifts



Ilex aquifolium



Viscum album

John Imbrie (awarded the Vega Medal in 1999, 45 years after von Post) and the late Nilva Kipp (1971) revolutionised marine palaeoclimatology by developing '**transfer functions**' to reconstruct quantitatively past climate from fossil assemblages. Tom Webb and Reid Bryson (1972) applied the same general idea to pollen data in the mid-West USA.



John
Imbrie



Tom
Webb

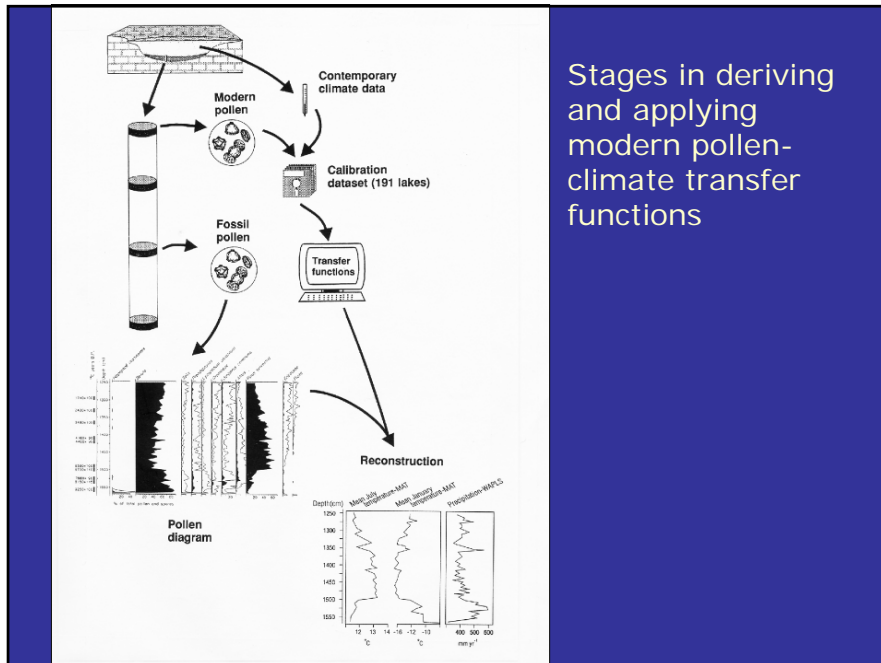
Requires **modern biological assemblages** (e.g. pollen) and **modern climate data** and appropriate numerical procedures to model the relationship between modern pollen and modern climate

$$Y_m = f(X_m)$$

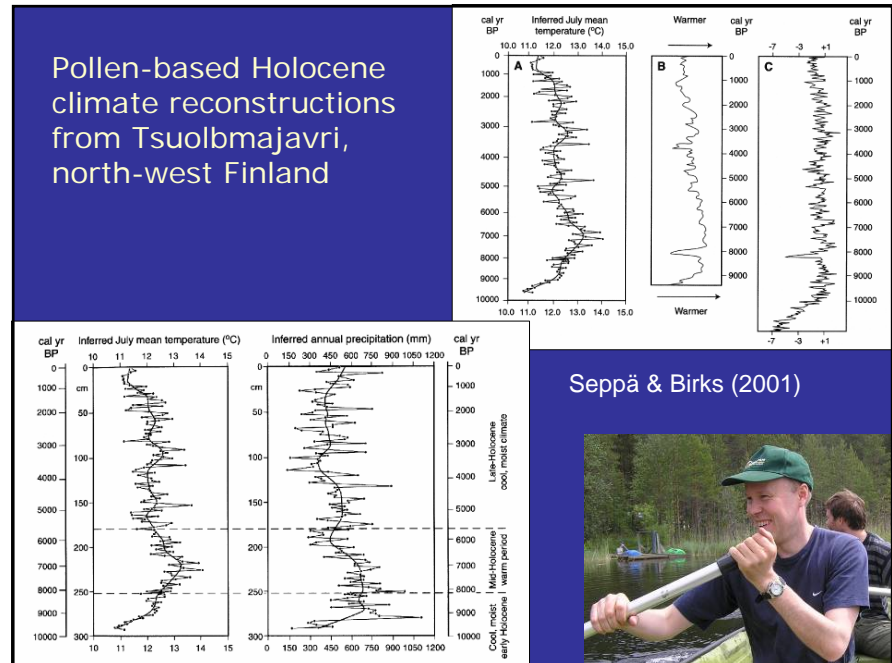
where Y_m is modern pollen data, X_m is modern climate data, and f is transfer function

Then apply the inverse of f to **fossil pollen data** (Y_f) to infer **past climate** (X_f):

$$\hat{X}_f = f^{-1}(Y_f)$$

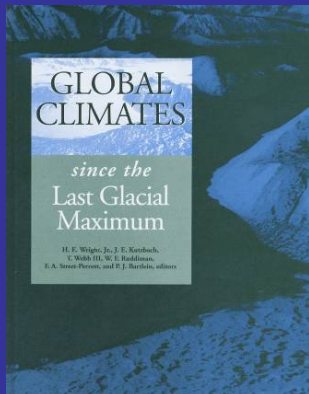


Stages in deriving and applying modern pollen-climate transfer functions



Palaeoclimate Modelling and COHMAP

International COHMAP (Co-operative Holocene Mapping Project) started in 1977, published first major paper in *Science* in 1988 and a monographic book in 1993.



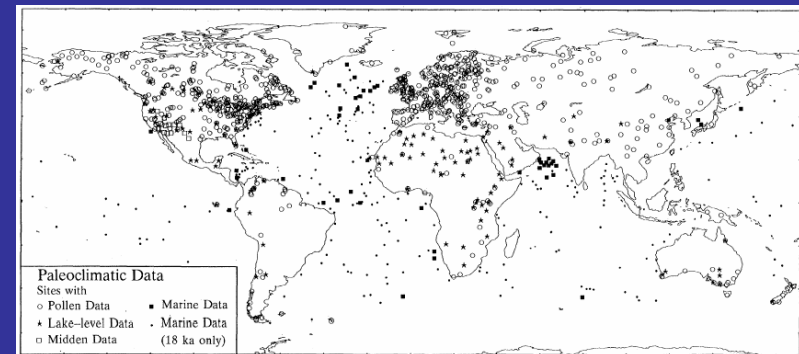
Herb Wright



John Kutzbach

Major paradigm shift – integration of "data people" with palaeoclimatic modellers using the Community Climate Model (CCM) at NCAR.

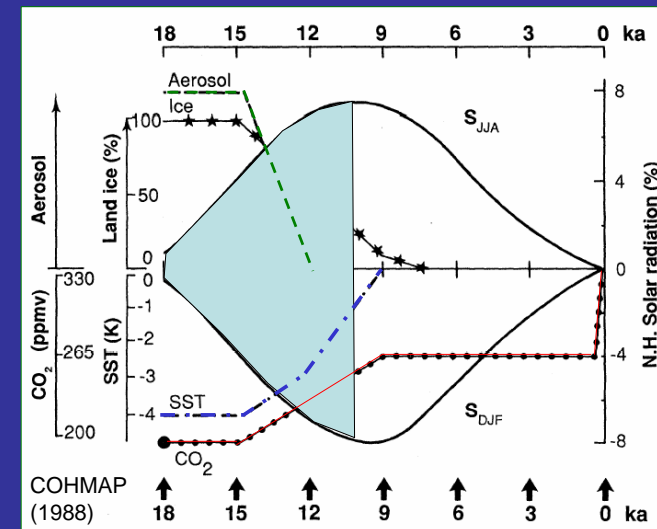
Basic idea was to **simulate past climates** at 18, 15, 12, 9, 6, 3, and 0 ka and to compare model simulations with palaeodata, mainly terrestrial pollen, lake-level, and midden data, and marine plankton data.



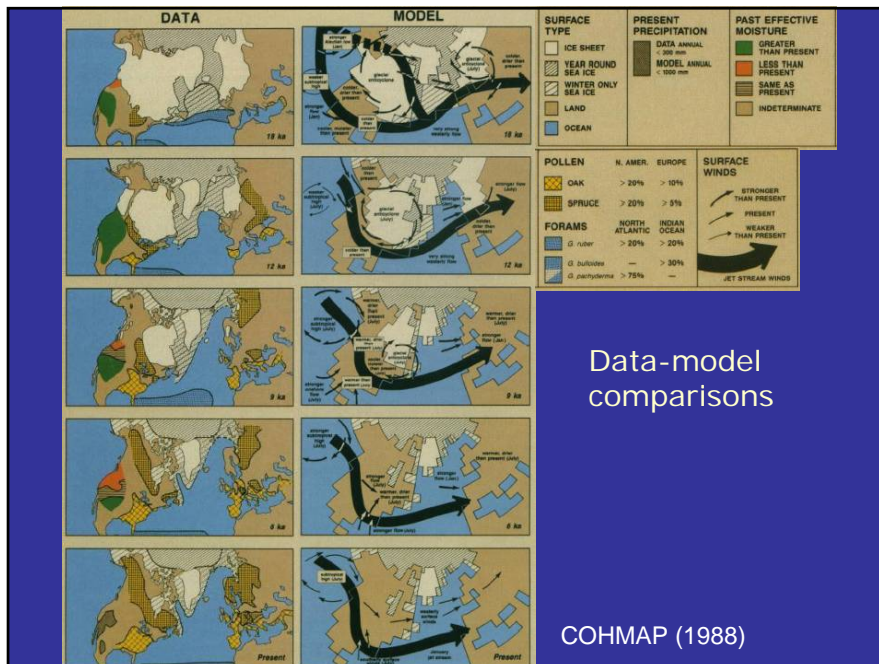
COHMAP (1988)

Input to the CCM as prescribed boundary conditions were orbitally determined insolation, mountain and ice-sheet orography, atmospheric trace-gas concentrations, sea-surface temperatures, sea-ice limits, snow cover, albedo, and effective soil moisture.

Changes in insolation result of 22 000 year precession cycle, 40 000 year tilt cycle, and 100 000 year eccentricity cycle in the earth-sun geometric relationship.



Major new paradigm for Holocene climate research at millennial scales.



Orbital changes could explain in broad terms the history of climate and landscape development since the last glacial maximum at 18 000 years ago.

Climate events of short duration were not considered in the data synthesis or in the modelling experiments.

"Application of a well-tested climate model is at present the only method for predicting these future climatic and environmental changes. COHMAP research is contributing to the testing of these models and to the understanding of past climates."

COHMAP (1988)

Turning point in Holocene climate research

1. Use of climate models
2. Proxy data-model comparisons

Palaeolimnology

In the late 1980s major advances were being made in palaeolimnology, the study of lake history by sediments accumulating in the lake – diatoms, chironomids, cladocera, ostracods, sediment inorganic and organic geochemistry, stable isotopes (H, C, N, O), geochronology, magnetics.

Some of these advances were in response to the need to develop a quantitative palaeolimnology in 'acid-rain' research.



John Smol

Ingemar Renberg
& Rick Battarbee



In terms of Holocene palaeoclimatic research, major contributions have come particularly from low-latitudes (e.g. Africa, S. America, S.E. Asia) and from the Great Plains of North America in providing unique evidence for changes in hydrology.

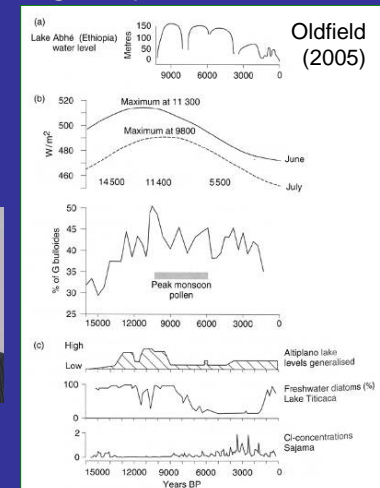
All indicate **wetter** conditions during the first half of the Holocene, followed by varying **degrees of desiccation**.



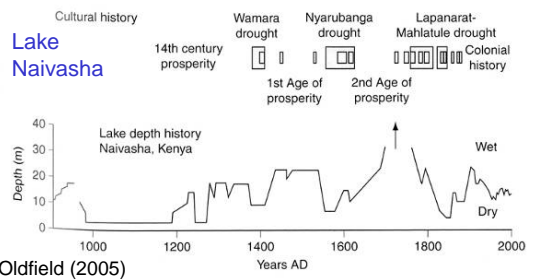
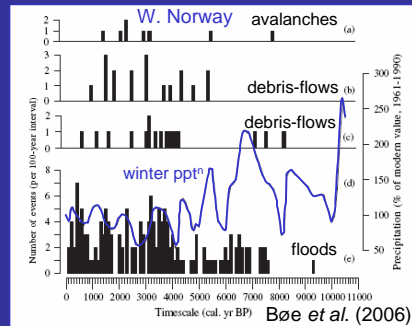
Sheri Fritz



Dirk Verschuren



Lake sediments can also provide records of **extreme events**, in terms of extreme low lake-levels and droughts or floods. Peat stratigraphical studies also very informative.



Paradigm – major changes in **hydrological events** and also in **extreme events**, as well as temperature changes during the Holocene

Ice-Cores

Ice-core science began in 1960s with the Camp Century core from north-west Greenland. Now many polar and alpine ice-cores.



Willi Dansgaard



Richard Alley



Sigfus Johnsen

RICHARD B. ALLEY

THE TWO-MILE TIME MACHINE

ICE CORES, ABRUPT CLIMATE CHANGE, AND OUR FUTURE

2000

Ice-cores

THIN ICE

Unlocking the Secrets of Climate in the World's Highest Mountains

MARK BOWEN

Kilimanjaro ice-field February 2000

Sajama summit (7500 m) Bolivia

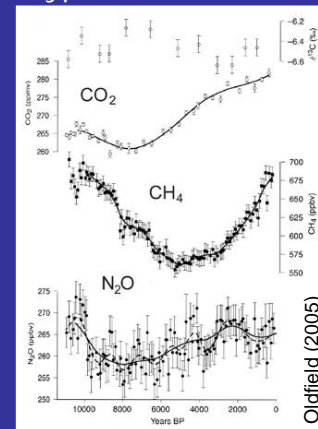
Lonnie Thompson

Bowen (2005)

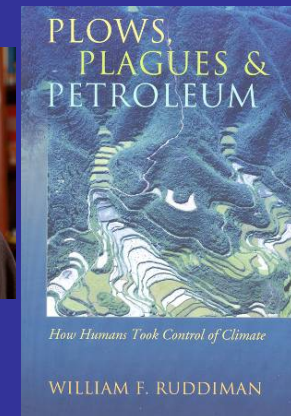
Many important discoveries from the polar and the alpine ice-cores -

1. evidence for unprecedented **rapid climate variations** in the Greenland ice-cores at centennial and even decadal scales
2. quantitative reconstruction of **greenhouse gas concentrations** (CO_2 , CH_4 , etc) from air bubbles enclosed in the ice
3. **low-latitude alpine ice-core records** of dust deposition, ice accumulation, and volcanic tephra

Air bubbles in Antarctic Dome ice cores provide a basis for investigating the concentrations of atmospheric trace-gases in the Holocene. Increase of CO_2 at 8000 BP & CH_4 at 5000 BP has led to the 'Anthropocene' hypothesis of Bill Ruddiman



Bill Ruddiman



Ruddiman's (2003) 'Anthropocene' hypothesis proposes that the 8000 BP CO₂ increase and the 5000 BP CH₄ increase are largely result of human activities.

Some **support** for the hypothesis, some evidence **against** it.

Major impact on future research and thinking, especially on the spatial extent of deforestation and land abandonment in the Holocene as deduced from pollen analytical data and on estimating carbon sequestration and release as a result of human activity.

"Ruddiman has opened up a range of possibilities that will take a long time to evaluate fully"

Oldfield (2005)

HOW HAS CLIMATE CHANGED DURING THE HOLOCENE IN EUROPE?

Davis *et al.* 2003 Quaternary Science Reviews 22: 1701-1716

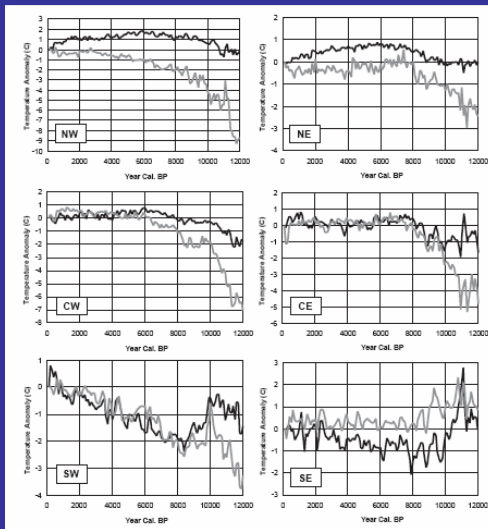
2363 modern pollen samples for Europe west of Urals and North Africa.

510 Holocene cores.

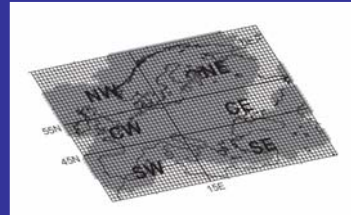
Pollen taxa assigned to 21 plant functional types (PFT) (e.g. temperate summergreen, boreal summergreen, grass, heath, warm grass shrub).

Expressed modern and fossil taxa as 21 PFT, % of total sum. Did modern analogue technique (MAT). Leave-one-out RMSEP

MTCO	2.58°C	Mean temperature of coldest month
MTWA	2.25°C	Mean temperature of warmest month
TANN	2.35°C	Mean annual temperature



Considered **six regions** in Europe and presented regional anomalies for summer and winter.

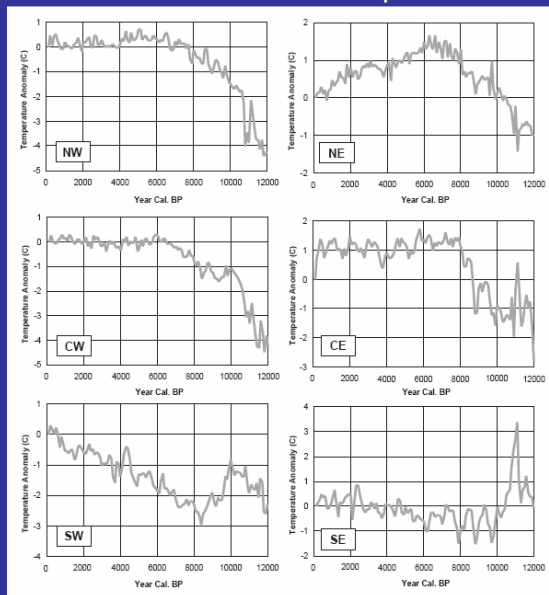


Davis *et al.* (2003)

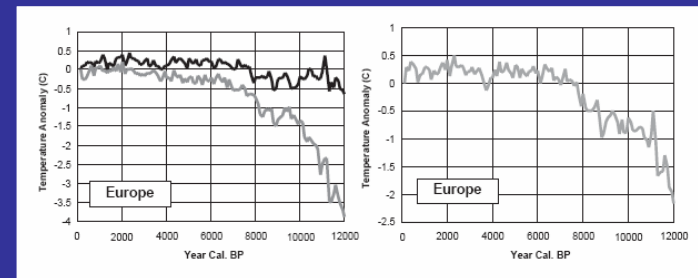
Features of interest

1. Major spatial and seasonal differences **between regions**.
2. Traditional mid-Holocene thermal maximum only seen in **Northern Europe** and mainly in summer.
3. Mid-Holocene **cooling** in Southern Europe.
4. Central Europe rather intermediate.
5. Larger changes in **winter temperature** than in summer temperature.

Mean Annual Temperature



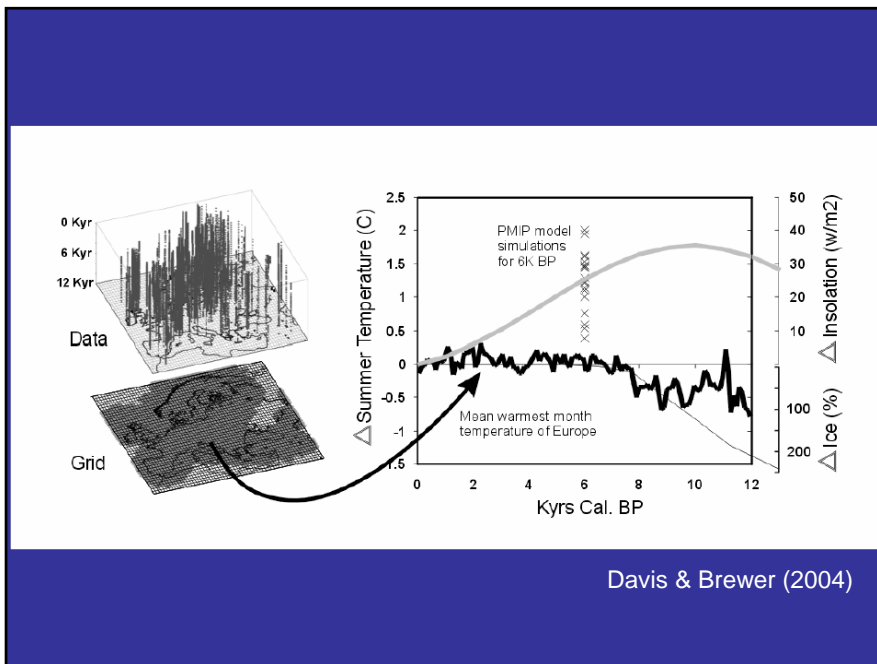
Davis *et al.*
(2003)



Davis *et al.* (2003)

Almost linear increase in thermal budget to 7800 BP, followed by relatively stable conditions for rest of Holocene.

Early Holocene warming and later equilibrium mainly modulated by **increasing winter temperatures** in west, which have continued to rise at a progressively reduced rate to the present day.



PMIP model simulations for 6K all suggest Δ summer temperature of 0.5-2°C

In Holocene, gradients were weakest in mid Holocene when high latitudes were warmer than today but low latitudes were cooler.

Forcing functions – N. Hemisphere ice cover and insolation. Overall temperatures appear to be primarily a function of ice-cover alone. Gradient is a function of both ice-cover and insolation gradient.

No palaeoclimate model predicts mid-Holocene cooling in southern Europe.

Weakened S – N temperature gradient would explain northward expansion of Monsoon climate in early-mid Holocene.

Davis *et al.* (2003) reconstructions clearly a challenge to modellers and palaeoclimatologists.

Need for validation using independent proxies in Europe.

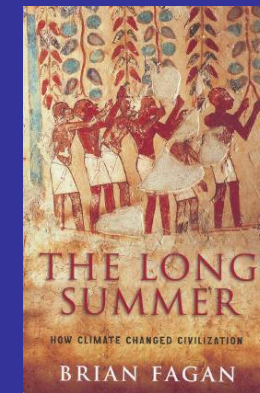
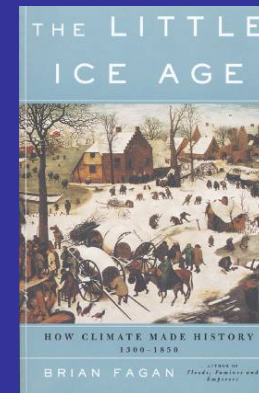
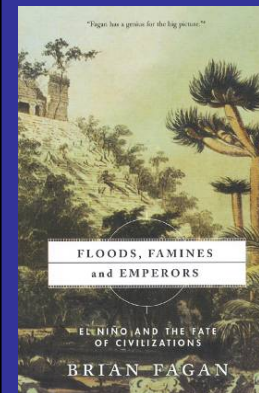
1. Plant macrofossils
2. Chironomids
3. Stable isotopes and speleothems
4. Other pollen taxa
5. Glacial history

Also need reconstructions for precipitation or (precipitation – evaporation)

Is the apparent mid-Holocene cooling in southern Europe a result of human activity on the vegetation?

ARE THERE ANY RELATIONSHIPS BETWEEN HOLOCENE CLIMATE CHANGE AND SOCIETAL CHANGE?

Role of environmental change in early agriculture
Holocene 'environmental crises'



Human activity in southern Scandinavia in relation to climate

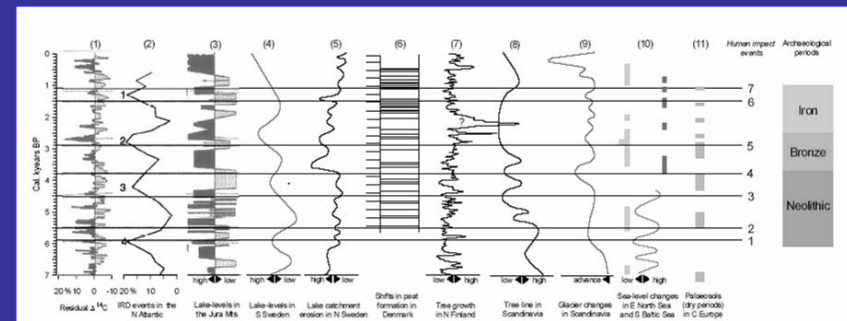
Seven major phases of human activity, forest clearance, and agriculture

1. 5900 cal BP
2. 5500 cal BP
3. 4500 cal BP
4. 3800 cal BP
5. 3000-2800 cal BP
6. 1500 cal BP
7. 1100 cal BP



Berglund (2003)

Relationship of seven major human phases and palaeoclimate proxies



Berglund (2003)

Agricultural society and landscape appear to have developed step-wise.

Depends on the interaction between **technology** and sociology and the **ecological carrying capacity** of a region.

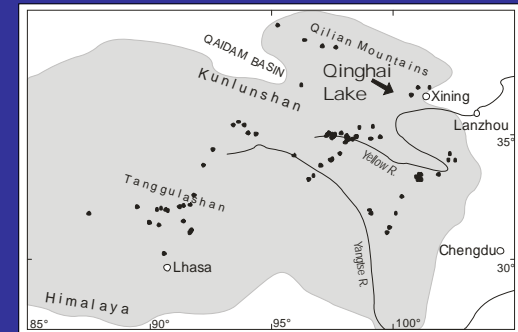
The ecological carrying capacity of a region depends primarily of **climate**, also on soils.

HOW CAN WE DISTINGUISH BETWEEN HUMAN ACTIVITY AND CLIMATE CHANGE IN THE HOLOCENE?

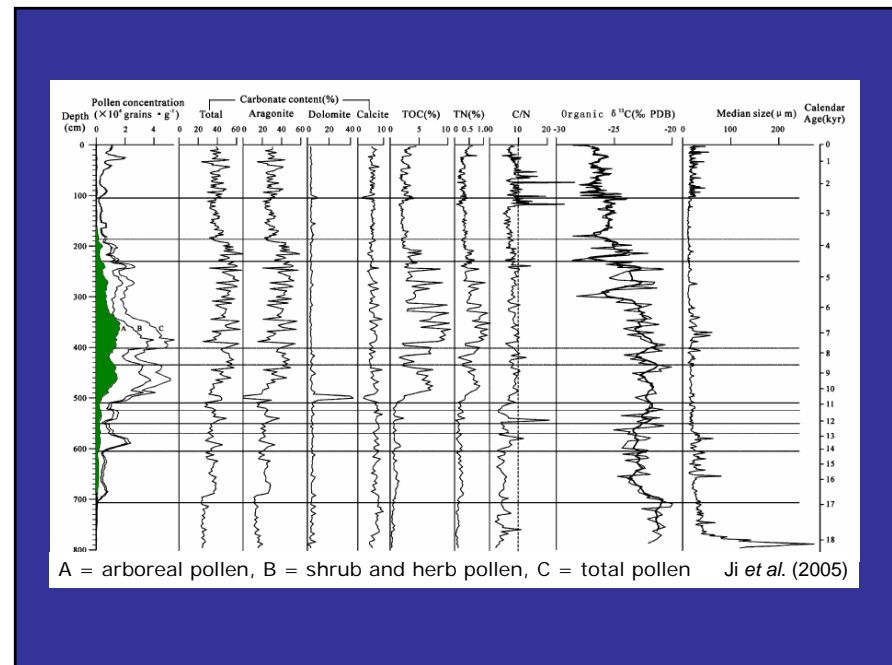
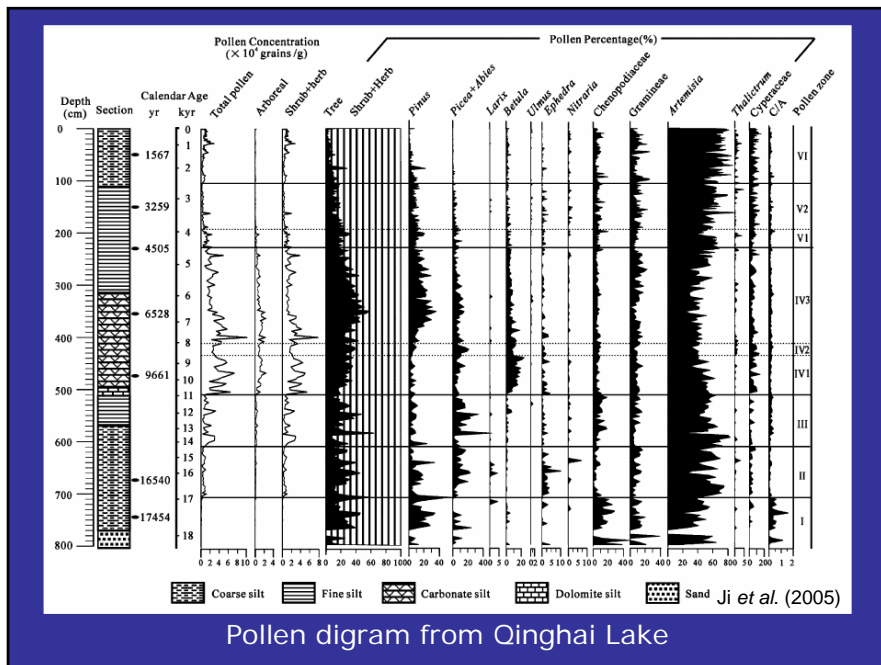
NE Tibetan Plateau studies by Ulrike Herzschuh, John Birks, Chengjun Zhang, Steffen Mischke, Gerrit Lohmann, Xiadong Liu, Xingji Liu



Ulrike Herzschuh



Herzschuh *et al.* submitted



Forest decline on the north-eastern Tibetan Plateau appears to be a result of climatic change in mid-Holocene (ca. 6000 years BP).

Decreasing moisture availability as a result of diminished monsoon activity.

No need to invoke human activity as major cause of forest decline.

Probably a combination of both with climate change triggering changes in land-use practices.

Very difficult to evaluate the relative roles of climate change and land-use human activities.

Very sparse archaeological record.

CONCLUSIONS

Palaeorecords indicate changes in temperature (winter and summer), seasonality, and precipitation.

High-latitude records mainly reflect changes in **temperature** and **seasonality**.

Low-latitude records largely reflect major changes in **precipitation minus evaporation** (P-E).

Major changes in the **hydrological** regime, especially at low latitudes.

Significant natural variability at **decadal**, **centennial**, and **millennial** scales, especially in **precipitation**, and with considerable **spatial variation**. Palaeoclimate reconstructions provide insights into the rates, magnitudes, and spatial distribution of **natural** climate variability.

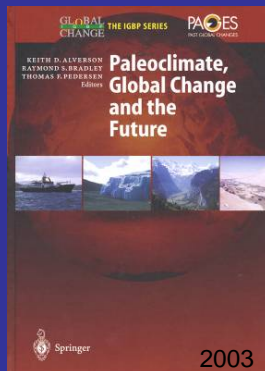
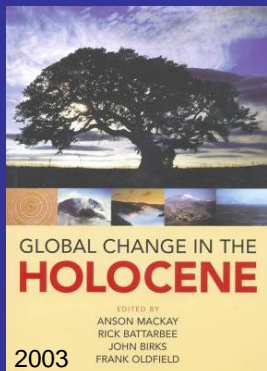
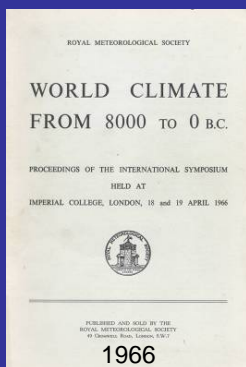
Global summaries are thus of **limited relevance**, whereas changes at different latitudes are more relevant and are of considerable significance environmentally, ecologically and socially.

THE PROSPECT FOR POLLEN ANALYSIS IN THE STUDY OF THE EARTH'S CLIMATIC HISTORY

By LENNART VON POST
Geological Department, University, Stockholm

BEING THE VEGA LECTURE DELIVERED ON 24 APRIL 1944

1946 *New Phytologist* 45:193-217



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