Evidence from lake sediments, marine sediments, and ice cores
Outline

• Archives
• Proxies
• Uncertainties
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Geographical distribution

- Lakes: all land areas
- Marine: all oceans
- Ice: ice caps and glaciers
Archive: Lake sediments
Lake sediments - sampling
Lake sediments - proxies

Multi-proxy approach

Limnic response

Terrestrial response

LOI, TOC, TN, C/N, δ^{18}Osi, δ^{13}C, δ^{15}N, Rock Eval
Mineral magnetic properties, grain size, XRF
Pollen, diatoms, δ^{13}C on long-chain alkenons

Geochronology

^{14}C
IRSL
Tephra
Paleointensity
Age modelling

Vegetation, catchment run-off
Hässeldala Port

Summary pollen diagram

Trees

Shrubs, dwarf shrubs

Herbs, graminids

Depth cm (below surface)

Lithology

Trees

Dwarf shrubs

Herbs and graminids

Pollen diagram

Analysed by Mamite Andersson

Wohlfarth et al. JQS 2006
Lake sediments: age

Wohlfarth et al. Geology 2008
Lake sediments - proxies

Helmens et al. Geology 2007
Lake sediments: uncertainties

- Sampling and sample spacing
- Age – $^{14}$C age/calibrated age
- Transfer functions for temperature and precipitation reconstructions
- Indicator plant species
- Ecology of plants and animals
- ....
- ....
- ....
- ....
Archives: Ice cores

- Counting annual layers
- Identify reference horizons
- Link with insolation
- Ice flow model

Accumulation zone
Ablation zone
Flow lines
Bedrock
Proxies in ice cores

- Water molecules
- Soluble and insoluble impurities
- Gases in air bubbles
Proxies for temperature

Stable water isotope ratios $\delta^{18}$O, $\delta$D

• Temperature at the time of condensation
• Temperature of the source
• Isotopic content of the source
Temperature reconstruction

Green curve: NorthGRIP
Red curve: Dome C

Jouzel et al., Science, 2007
Chemical ice core records
Example:

Sea ice reconstruction

- Methane sulphonic acid (MSA)
- Produced by algae
- Melting of seasonal sea ice as primer for growth
Law Dome MSA vs. sea ice extent

Curran et al., *Science*, 2003

Law Dome MSA vs $SIE_{\text{max}}$

1973 -1994

$n = 22$
Law Dome MSA vs. sea ice extent

- Positive MSA-sea ice relationship
- Strong decadal signal
- 20% decrease in sea ice since 1950

Curran et al., *Science*, 2003
Example: $\text{CO}_2$

![Graph showing CO2 levels over time with data points from Mauna Loa atmospheric, Law Dome, Siple, EPICA DML, and S. Pole.](image)

- **Mauna Loa atmospheric**
- **Law Dome (Etheridge et al., 1996)**
- **Siple (Friedli et al., 1986)**
- **EPICA DML (Siegenthaler et al., 2005)**
- **S. Pole (Siegenthaler et al., 2005)**
Greenhouse gas records


Lüthi et al. and Loulergue et al., *Nature*, 2008
Ice cores – Uncertainties I

Uncertainty in the archive:
- Upstream effects
- Ice flow disturbance near bedrock
- Biasing through deposition process
Precipitation bias

Stable water isotope ratios $\delta^{18}$O, $\delta$D

- Temperature only recorded when it snows.

IAEA GNIP database - http://isohis.iaea.org

Johnsen et al., JQS, 2001
Temperature proxy calibration

Huber et al., EPSL, 2006
Ice cores – Uncertainties II

Analytical uncertainty:

- Instrumental uncertainty
- Calibration uncertainty
Insufficient quantitative understanding of proxy

Long range transport, $C_{\text{air, free troposphere}}$

Reactions with other atmospheric constituents

Uplift $C_{\text{air, source}}$

Deposition en route

Low-/mid-latitude source

Deposition $C_{\text{air, polar}}$

Polar snow & ice $C_{\text{ice}}$
MSA around Antarctica

- **Dolleman Island**
  *Pasteur et al. 1995*
  Negative relationship

- **Lambert Glacier**
  *Sun et al. 2002*
  Negative relationship

- **Law Dome**
  *Curran et al. 2003*
  Positive relationship

- **Newall Glacier**
  *Welch et al. 1993*
  Positive relationship

Legend:
- Light blue: Winter sea ice extent
- Dark blue: Summer sea ice extent
Weddell sea MSA vs. sea ice

- Negative MSA-sea ice relationship for Weddell Sea
- Positive MSA-sea ice relationship with Amundsen Sea: artefact of the Antarctic Dipole

Abram et al., *JGR*, 2007