Uncertainty in Dating Ice Cores

Stories from Ice Cores

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- Introduction to Ice Core Dating
  - Ice Cores as Archives
  - Existing Dating methods

- Some Theory
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Introduction to Ice Core Dating

- Introduction to Ice Core Dating
- Ice Cores – The Archive
- Existing Dating Methods
- Uncertainty — a Nuisance?
- Uncertainty — a Nuisance?

Theory in a Nutshell

The Dating Uncertainty

Discussion

Introduction to Ice Core Dating
Ice Cores – The Archive

- Preserve valuable information about the climate and environment of the past
- Record chemical composition of snow, dust and atmospheric gases with high resolution for up to 700,000 years and longer [Parrenin et al., 2007]

Source: BAS image database
Ice Cores – The Archive

- Preserve valuable information about the climate and environment of the past
- Record chemical composition of snow, dust and atmospheric gases with high resolution for up to 700,000 years and longer (Parrenin et al., 2007)
- Dating is essential to interpret this information
- Dating: relate time to depth

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Ice Cores – The Archive

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- Dating: relate time to depth

Source: BAS image database
Existing Dating Methods

- layer counting using seasonality in signals

- glaciological modelling
  - model of accumulation: estimated from isotopic content of ice
  - model of mechanical processes after accumulation: i.e. firn densification, ice flow

- comparison with other dated records
  - e.g. ice cores, volcanic eruptions, insulation changes

- any combination of dating methods
Existing Dating Methods

- layer counting using seasonality in signals
- sufficient annual accumulation error accumulates
- glaciological modelling
  - model of accumulation: estimated from isotopic content of ice
  - model of mechanical processes after accumulation: i.e. firn densification, ice flow
  - poorly known parameters
- comparison with other dated records
  - e.g. ice cores, volcanic eruptions, insulation changes uncertainty in other record
  - uncertainty in link between records
- any combination of dating methods
Existing Dating Methods

- layer counting using seasonality in signals
  sufficient annual accumulation
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⇒ quantify uncertainty in the accumulation model and derive the dating uncertainty
Existing Dating Methods

- layer counting using seasonality in signals
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⇒ quantify uncertainty in the accumulation model and derive
the dating uncertainty
Comparison with other dated records

- Did certain climatic events occur at different locations?
- Were they synchronous?

13,000 yr BP

12,000 yr BP
Comparison with other dated records

- Did certain climatic events occur at different locations?
- Were they synchronous?

![Graph showing probability distributions for cooling events in two records at 13,000 yr BP and 12,000 yr BP.](image)
Comparison with other dated records

- Did certain climatic events occur at different locations?
- Were they synchronous?

⇒ Quantify uncertainty properly!
Theory in a Nutshell
Glaciological Model and its Uncertainty

Accumulation Model

chemical measurement: isotopic content of ice → annual accumulation rate → times covered by each slice of the core
Glaciological Model and its Uncertainty

Accumulation Model

chemical measurement: isotopic content of ice → annual log-accumulation rate → times covered by each slice of the core

\[ Y \xrightarrow{f(Y)} T = \frac{g(D)}{e^f(Y)} \]
Glaciological Model and its Uncertainty

Accumulation Model

chemical measurement: isotopic content of ice → annual log-accumulation rate → times covered by each slice of the core

\[ Y \rightarrow f(Y) \rightarrow T = \frac{g(D)}{e^{f(Y)}} \]

Its Uncertainty

\[ Y \rightarrow f(Y) = A + \varepsilon \rightarrow T = \frac{g(D)}{e^{A}} \]

'observed' log-accumul. rate
\( f \) involves uncertain parameters
model error

'true' log-accumul. rates
Glaciological Model and its Uncertainty

**Accumulation Model**

- Chemical measurement: isotopic content of ice
- Annual log-accumulation rate
- Times covered by each slice of the core

\[ Y \xrightarrow{f(Y)} T = \frac{g(D)}{e^f(Y)} \]

**Its Uncertainty**

- 'True' log-accumulation rates
- 'Observed' log-accumulation rate
- Model error

\[ Y \xrightarrow{f(Y) = A + \epsilon} T = \frac{g(D)}{e^A} \]
Bayesian Statistics

\[ f(Y) = A + \varepsilon \]

The model error
(likelihood)

\[ f(Y_i | A_i) \sim N(A_i, \sigma^2) \]
Bayesian Statistics

Knowledge from elsewhere
(prior distribution)

\[ f(Y) = A + \varepsilon \]

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The dating uncertainty
(posterior distribution)

Probability

- Mean annual accum
- True log-accum rate
- Observed log-accum rate
- Other dating
- Depth
- \( \delta^{18}O \)

\( Y_1 Y_2 \ldots Y_i \ldots \)

\( \Delta \Delta \)
Sources of Prior Knowledge

- recent weather records: do not capture climate in polar regions → accumulation model not applicable
- other ice cores: use layer counted (nearby) cores
- same ice core:
  - use $\frac{1}{2}$ of layer counted data to derive prior
  - use $\frac{1}{2}$ of layer counted data to compare our results (to explore the effect of prior assumptions on the dating uncertainty)
The Dating Uncertainty
Effect of Uncertainty in Accumulation

**Toy example**

A shallow core from Dyer Plateau, Antarctica (70°39’S, 65°01’W)

Accumulation prior

<table>
<thead>
<tr>
<th>Evidence from layer counting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitted distribution</td>
</tr>
</tbody>
</table>

Dating uncertainty

Annual accumulation rate $e^A$ in m

$P(e^A)$

$0.0 \ 0.5 \ 1.0 \ 1.5 \ 2.0$
Effect of Uncertainty in Accumulation

**Toy example**

A shallow core from Dyer Plateau, Antarctica (70°39’S, 65°01’W)

**Accumulation prior**

- Evidence from layer counting
- Fitted distribution

**Dating uncertainty**

- Number of years from layer counting

Fixed parameters:
- Annual accumulation rate $e^A$ in m

Date covered: $47.96 \pm 2.20$ years
Effect of all Sources of Uncertainty

Introduction to Ice Core Dating

Theory in a Nutshell

The Dating Uncertainty
- Effect of Uncertainty in Accumulation
- Effect of all Sources of Uncertainty

Discussion

Effect of all Sources of Uncertainty

Accumulation prior

Model parameter priors

Dating uncertainty:
$47.9 \pm 2.5$ years

Evidence from layer counting
Fitted distribution

Annual accumulation rate $e^A_i$ in n

Intercept $A_0$
Slope $b$

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Discussion
Current and Future Research

- only excerpt of our work
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- current research
  - gain better prior knowledge
  - include mechanical model and volcanic eruptions
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- future research
  - more complex accumulation models $f$
  - multicore, multiproxy analysis
  - statistical approach for layer counting (pilot: J. Wheatley)
    → combine
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- future research
  - more complex accumulation models $f$
  - multicore, multiproxy analysis
  - statistical approach for layer counting (pilot: J. Wheatley) → combine
- problems
  - hiatus: summer melting, ice flow disturbances
  - hard to quantify uncertainty further back in time
Introduction to Ice Core Dating

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Thank you!

Questions and comments ...