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Toward unified ice core chronologies with the DatIce tool

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Objectives

▶ Present the DatIce software tool
  ▶ This tool implements an inverse method for multiple ice cores dating
  ▶ It provides an improved chronology, using a prior chronology and independent observations
  ▶ This tool is available to the scientific community

▶ This talk is NOT a presentation on paleoclimatology
Mathematical formalism

We want to use data from previous chronology and observation markers to get a new chronology.
Mathematical formalism

\( X \) : unknown vector representing a chronology

\[
J(X) = \underbrace{\| X - X^b \|_B^2}_{\text{misfit to the background}} + \underbrace{\| h(X) - Y^o \|_R^2}_{\text{misfit to observations}}
\]

We are looking for \( X^a \), "the best new chronology" that minimizes the \( J \) function.
**Objectives**

- Mathematical formalism
- Data flow chart

**Background inputs**

- Background error covariance matrix

**Observation inputs**

**Outputs**

- Improved chronologies
  - $A^a$: new accumulation rate
  - $T^a$: new thinning
  - $C^a$: new close-off depth

**On going work**

- DatIce code

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**Data flow chart**

**INPUTS**

- **background from models**
  - $A^b$: accumulation rate
  - $T^b$: thinning
  - $C^b$: close-off depth

- **observations**
  - absolute tie-points
  - relative tie-points

**COMPUTATION**

\[
J(\tilde{X}) = \left\| h(\tilde{X}) - Y^o \right\|^2_R + \left\| \tilde{X} - \tilde{X}^b \right\|^2_B
\]

**OUTPUTS**

- improved chronologies
  - $A^a$: new accumulation rate
  - $T^a$: new thinning
  - $C^a$: new close-off depth

\[
\tilde{X}^a = (\tilde{\alpha}^a, \tilde{\tau}^a, \tilde{\gamma}^a)^t
\]
Background inputs
Background error covariance matrix

The background error covariance matrix $B$ gives us information about the background chronology error and appears in the cost function:

$$\|X - X^b\|^2_B = (X - X^b)^t B^{-1} (X - X^b)$$

$B$ is very often poorly known and it is therefore modeled.

Available options in DatIce are diagonal matrix and block diagonal matrix. Users must provide standard deviation and correlation profiles.

$$B = \begin{pmatrix}
\ddots \\
\vdots \\
\ddots \\
\end{pmatrix} \text{ or } B = \begin{pmatrix}
B_\alpha & \text{ } & \text{ } \\
\text{ } & B_\tau & \text{ } \\
\text{ } & \text{ } & B_\gamma
\end{pmatrix}$$
DatIce tool handles two kinds of observations:

- **absolute** tie-points: ice and gas ages markers, thinning and delta-depth correction markers.
- **relative** tie-points: ice and gas stratigraphic links, ice age difference markers.

The observation covariance error matrix $R$ is the $B$ analogue for observations errors.

$$||h(X) - Y^o||_R^2 = (h(X) - Y^o)^t R^{-1} (h(X) - Y^o)$$
After the minimization step we get corrections coefficients $\hat{X} = (\hat{\alpha}, \hat{\tau}, \hat{\gamma})^t$ that will allow us to determine the new chronology. $A^a = \alpha^a A^b$: new accumulation, $T^a = \tau^a T^b$: new thinning, $C^a = \gamma^a C^b$: new CODIE.
Input and output files extracts

Background

depth   relative density   accumulation rate   thinning function   delta-depth   CODIE
...
147    0.989               2.2289                0.92505                -1           -1
148    0.989               2.22                  0.92455                -1           -1
149    0.989               2.2031                0.92404                -1           -1
150    0.989               2.1866                0.92354               65.856383    71.270056
151    0.99                2.1699                0.92303               65.820846    71.270163
...

Ice age markers

depth   age in years BP (b1950)   uncertainty in years (1 sigma)
...
3166.87   767679              5090               2001          2002
3180.6    787736              6000               2000
3189.83   797460              6010

Outputs

<table>
<thead>
<tr>
<th>real depth (m)</th>
<th>$\alpha^b$</th>
<th>$\tau^b$</th>
<th>$A^b$ m yr$^{-1}$</th>
<th>$T^b$</th>
<th>$A^a$ m yr$^{-1}$</th>
<th>$T^a$</th>
</tr>
</thead>
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<tr>
<td>0</td>
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<td>1.00999</td>
<td>0.03099</td>
<td>1.0006</td>
<td>0.0295346</td>
<td>0.999071</td>
</tr>
<tr>
<td>$\Psi^b$ yr</td>
<td>$\Psi^a$ yr</td>
<td>$\sigma^b \alpha^b$</td>
<td>$\sigma^b \tau^b$</td>
<td>$\sigma^a \Psi^a$ yr</td>
<td>$\sigma^a \alpha^a$</td>
<td>$\sigma^a \tau^a$</td>
</tr>
<tr>
<td>-55</td>
<td>-55</td>
<td>0.135227</td>
<td>0.0366051</td>
<td>1.66132</td>
<td>0.048101</td>
<td>0.128876</td>
</tr>
</tbody>
</table>
Choosing the good coefficients for $B$ (and $R$) still remains a great challenge.

We are currently working on an automatic statistic procedure to calibrate $B$ and $R$. For instance, we expect:

$$E[J(\tilde{X}^a)] = p$$  \quad (p: \text{number of observations})

Talagrand, ECMFW workshop, 1999 and Desroziers et al, 2009
DatIce code

- v1.0
- Fortran 90
- ascii input format
- ascii and netcdf output format
- [http://datice.gforge.inria.fr](http://datice.gforge.inria.fr)
- next talk from Lucie Bazin will present new DatIce applications.