The Last Interglacial climate in the high latitudes

*Part I*: A spatio-temporal surface temperature data synthesis
*Part II*: Toward improved Model-Data comparisons

Émilie Capron & Emma J. Stone
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Part I: A spatio-temporal surface temperature data synthesis
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A. Govin, D. J. Lunt, V. Masson-Delmotte, S. Mutilza,
Singarayer, P. J. Valdes, C. Waelbroeck, E. W. Wolff.
The Last Interglacial (LIG, ~129-116 ka)

Last Interglacial Maximum Annual surface temperature (Turney & Jones, 2010)
Limitations of existing LIG data synthesis

- Original chronologies are used

- Need for **HARMONIZED age scales** across the LIG
  (Govin, Capron et al. QSR 2015)
Limitations of existing LIG data synthesis

→ One UNIQUE time slice to represent the entire LIG

**Underlying hypothesis:**
Maximum LIG Warmth occurred synchronously across the world

What is the sequence of climatic events over the LIG?
→ Need for a **temporal** in addition to a spatial climatic evolution over the LIG

*e.g. Bauch et al. 2011; Govin et al. 2012*
LIG Model-Data Comparison

Simulations for different time intervals are tested against a unique LIG time slice:
→ Could partly explain model-data mismatches (Bakker & Renssen 2014)

Need for **multiple time slices** for more robust Model-Data comparison
Objectives of the study

• **New data synthesis**: to document the *magnitude* and *spatio-temporal evolution* of temperature changes across the LIG
  
  ✓ To define a *consistent time frame for multiple ice and marine records*
  ✓ To define *4 time slices* of temperature anomalies
  ✓ To estimate and propagate *temperature & age uncertainties*

• **Model-data comparison**: to illustrate the *potential of the new LIG data synthesis as improved benchmark for climate models*
LIG Data Selection

- 5 ice cores
- 39 marine sediment cores (42 SST records)
- High latitudes: $>40^\circ \text{N}$ & $>40^\circ \text{S}$
- Surface air temperature & SST records
- Temporal resolution of at least 2000 years
- Annual or summer signals

Air surface temperature (ice cores)
- MAT (forams)
- % NPS
- Mg/Ca

Alkenones
Radiolarians
Diatoms
SST
Strategy for building a consistent time frame

**AICC2012** as the reference time scale (Bazin et al. 2013, Veres et al. 2013)

- Common to 5 ice cores
- LIG absolute dating error $< 1.8$ ka (1σ)

**Absolute uncertainty over the LIG $<1.8$ ka**
Hypothesis (Govin et al. 2012): SST changes in the sub-antarctic zone of the Southern Ocean (resp. North Atlantic) occurred *simultaneously* with air temperature over Antarctica (resp. Greenland)
Strategy for building a consistent time frame

Southern Ocean SST tied to EPICA Dome C $\delta D$ record
Strategy for building a consistent time frame

North Atlantic SST tied to:
- NGRIP ice $\delta^{18}O$ (100-120 ka)
- EDC CH$_4$ (128-140 ka)
LIG high latitude climate temporal reconstructions

Need for uncertainty estimates on the surface temperature records.
Monte Carlo Analysis with 1000 age model simulations taking into account:

1. **Errors on SST reconstruction method**: from 0.6 to 2.1°C (average of 1.4°C)

2. **Age Uncertainties on tie point definition**: from 0.5 to 4 ka

<table>
<thead>
<tr>
<th>Depth_cm</th>
<th>Age_ka</th>
<th>Error_ka</th>
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<td>0.7</td>
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<td>2658.5</td>
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<td>2</td>
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</table>

### MD02-2488 (Southern Ocean)

<table>
<thead>
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<th>Age_ka</th>
<th>Error_ka</th>
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<tbody>
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<td>1498.7</td>
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<td>1738.5</td>
<td>128.7</td>
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<tr>
<td>1869.4</td>
<td>146.4</td>
<td>3</td>
</tr>
</tbody>
</table>

### ODP 980 (North Atlantic)

**± 2.6°C (2σ) in average**
LIG high latitude climate temporal reconstructions

Useful benchmarks for transient climate simulations
e.g. Loutre et al. 2013; Pfeiffer et al. in revision
<table>
<thead>
<tr>
<th>Time Slice</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>115 ka</td>
<td>(114-116 ka)</td>
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<tr>
<td>120 ka</td>
<td>(119-121 ka)</td>
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<tr>
<td>125 ka</td>
<td>(124-126 ka)</td>
</tr>
<tr>
<td>130 ka</td>
<td>(129-131 ka)</td>
</tr>
</tbody>
</table>
4 time slices of temperature anomalies & errors

- Temperature anomalies relative to present day
  - **Ice cores**: instrumental mean annual surface air temperature
  - **Marine cores**: World Ocean Atlas (WOA) 1998 SST (10-m deep) (*Kucera et al. 2005*)
4 time slices of temperature anomalies & errors

- **Temperature anomalies relative to present day**
  - **Ice cores**: instrumental mean annual surface air temperature
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- Estimation of **temperature errors**
4 time slices of temperature anomalies & errors
4 time slices of temperature anomalies & errors

115 ka

120 ka

125 ka

130 ka

Temperature anomalies versus modern values

- 5°C
- 2.5°C
- 0°C
- colder
- warmer than present
- 2σ uncertainty

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
LIG spatio-temporal evolution of temperatures

- Early Southern Hemisphere warming (130 ka) compared to the North Atlantic region

Temperature anomalies

- 5°C
- 2.5°C
- 0°C
colder
warmer than present

Diagram showing temperature anomalies at 130 ka.
LIG spatio-temporal evolution of temperatures

- Early Southern Hemisphere warming (130 ka) compared to the North Atlantic region
- Warmer-than-present conditions in both hemispheres (125 ka, 120 ka)
LIG spatio-temporal evolution of temperatures

- Early Southern Hemisphere warming (130 ka) compared to the North Atlantic region
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- Longer period of warmer-than-present conditions in the SH (vs. the North Atlantic)
Early Southern Hemisphere warming (130 ka) compared to the North Atlantic region

Warmer-than-present conditions in both hemispheres (125 ka, 120 ka)

Longer period of warmer-than-present conditions in the SH (vs. the North Atlantic)

Larger amplitude of North Atlantic temperature changes into and out of the LIG
Toward improved LIG climate model-data comparisons (Capron et al. QSR 2014; Stone et al. in revision)

New LIG data synthesis of high-latitude surface temperatures
(Capron et al. QSR 2014)

- Consistent time frame for marine and ice core records;
- Spatio-temporal evolution of LIG surface temperatures;
- 115, 120, 125 & 130 ka time slices of surface temperature anomalies with 2σ errors (including temperature & age uncertainties).

Inputs for ice sheet models to investigate the contribution of Greenland and Antarctic to sea level changes during the LIG.
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Modelling the LIG climate

- Changed orbital parameters (insolation)
- Changed GHGs
- Changed ice sheet
- Vegetation feedbacks
- Freshwater forcing

HadCM3 = SNAPSHOTS
- 4 simulations of 550 model years: 130, 125, 120 and 115 ka (BP)

Graphs showing changes in Carbon Dioxide, Methane, and Nitrous Oxide concentrations over time.
Model fails to reproduce **colder-than-present** North Atlantic Conditions

Model fails to reproduce **warmer-than-present** Southern Ocean Conditions

Model fails to reproduce **warmer-than-present** East Antarctic Conditions
What about other models?

CCSM3 – 130 ka
Reconciling the mismatch between data and model

Models **NOT** run with full 130 ka climate conditions:
- Interactive ice sheets
- Interactive vegetation
- Freshwater fluxes
What about the melting of the NH ice sheets from the previous glaciation?
How much freshwater?

Sea level rate was ~22 m/kyr at 130 ka during the glacial-interglacial transition (Grant et al. 2012)

- Changed orbital parameters (insolation) ✔
- Changed GHGs ✔
- Changed ice sheet ❌
- Vegetation feedbacks ❌
- Freshwater forcing ✔

Stone et al. (in revision)
130 ka

ORB+GHG

ORB+GHG+FWF

Stone et al. (in revision)
130 ka

ORB+GHG  ORB+GHG+FWF

Stone et al. (in revision)
130 ka

ORB+GHG

ORB+GHG+FWF

Stone et al. (in revision)
The effect of freshwater flux on Southern Europe climate at 130 ka
Model sensitivity to different amounts of freshwater
Model sensitivity to different amounts of freshwater

![Model sensitivity graph showing the relationship between average temperature anomaly and freshwater flux.](image-url)
The effect of removing WAIS

ORB+GHG+FW+NOWAIS (130 ka)

Summer

Annual

Stone et al. (in revision)
Comparison with model simulations (ORB+GHG only) shows that:

- The models cannot predict the warmer-than-present-day conditions shown in North Atlantic records
- The reconstructed early Southern Ocean and Antarctic warming is not captured
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**MISSING** processes/feedbacks in the models – **freshwater forcing from the penultimate glaciation?**

• The bipolar seesaw mechanism between the hemispheres at 130 ka can partially explain the asynchrony in hemisphere temperature response with a freshwater hosing of 0.2 Sv or more
• Lowering the WAIS with freshwater forcing only produces a **small improvement in model-data comparison** over Antarctica
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Some further points to consider:

- **Not transient** simulations
- Data needed in the vicinity of the WAIS
- What other feedback processes could fully reconcile the mismatch?
- Contributions of freshwater from the different ice sheets at the onset of the LIG
Strategy for building a consistent time frame

**Difficulties to define robust age model in the Norwegian Sea!**

Core MD95-2009 linked to core ENAM33 thanks to ash layer 5e-Low/bas-IV (orange dot) & climatic alignment.

Core HM71-19 aligned onto core MD95-2009 based on ash layers 5e-Midt/RHY & 5e-Low/bas-IV (orange dots) & climatic alignment.
Choice of the “Modern Reference” for marine records?
SST measurements from WOA 1998 (10m-deep) vs Sediment core Top SST values