Comment on “Abrupt warming events drove Late Pleistocene Holarctic megafaunal turnover”

Sune O. Rasmussen* and Anders M. Svensson

Cooper et al. (Research Article, 7 August 2015, p. 602) combined the annual-layer-counted Greenland Ice Core Chronology 2005 with chronological information from the Hulu Cave and Cariaco Basin records to produce a “revised” time scale. We argue that their time scale is incompatible with the nature of annual-layer-counted time scales and may lead to seriously flawed conclusions if used elsewhere at face value.

Cooper et al. investigated the relative timing of abrupt climate change and megafaunal extinction during the last glacial period (1). In the process, they created a time scale, denoted GICC05-Cariaco, based on a combination of data from marine sediments, speleothems, and ice cores, the latter presented on Greenland Ice Core Chronology 2005. Cooper et al. are obviously welcome to present data on their own time scale, but because they present their results as a revision of the GICC05 time scale developed by our group (2–5), we find it appropriate to discuss why we think GICC05-Cariaco represents a step in the wrong direction when it comes to time scale integration. We do not contest the megafaunal analysis: Cooper et al. state that the conclusions are robust to change of chronology.

When ice cores are dated by annual layer counting, the uncertainty accumulates with increasing age (6). Consequently, the determination of absolute ages is accurate for recent periods, whereas the accumulated uncertainty becomes large (i.e., low accuracy) in the last glacial period, compared with uncertainties of other dating methods, such as radiometric dating. However, even when the absolute accuracy is relatively low, layer counting still provides the possibility to determine event durations precisely. For example, at the onset of Greenland stadial 6 (GS-6), which according to GICC05 occurred 33,311 thousand years before 1950 C.E. (b1950), the GICC05 accumulated maximum counting error is 1191 years. In contrast, the outstanding precision allows for the determination of the duration of Greenland interstadial 6 (GI-6) and the subsequent stadial GS-6 to 1240 years, with a maximum counting uncertainty of 80 years (4). Thus, the duration estimate is an order of magnitude more precise than the absolute dating accuracy.

For radiometrically dated records, the situation is generally the opposite: relatively high accuracy and low precision. Cooper et al. use Cariaco-derived ages of the GI/GS-6 pair that yield a duration of 2627 years with a 1σ root mean square uncertainty of 271 years—i.e., more than twice the precise ice-core–based duration and not compatible with GICC05 within >3σ. Even though the individual ages of the interstadial onsets are compatible between the Cariaco and GICC05 time scales within their respective error margins, the associated event durations are not. On this background, we argue that the presented set of ages from Cariaco cannot meaningfully be combined with the GICC05 event durations.

The differences in how the interstadials are expressed in the Cariaco and Greenland records are illustrated on figure S3 in (1). The large discrepancy between GICC05 and GICC05-Cariaco is generally the opposite: relatively high accuracy and low precision. Cooper et al. use Cariaco-derived ages of the GI/GS-6 pair that yield a duration of 2627 years with a 1σ root mean square uncertainty of 271 years—i.e., more than twice the precise ice-core–based duration and not compatible with GICC05 within >3σ. Even though the individual ages of the interstadial onsets are compatible between the Cariaco and GICC05 time scales within their respective error margins, the associated event durations are not. On this background, we argue that the presented set of ages from Cariaco cannot meaningfully be combined with the GICC05 event durations.

The differences in how the interstadials are expressed in the Cariaco and Greenland records are illustrated on figure S3 in (1). The large discrepancy between GICC05 and GICC05-Cariaco.

Table 1. Data from (1) (first five columns). The GICC05-Cariaco ages (column 6) are obtained by error-weighted averaging hereof, demonstrating that interstadial durations are not needed for the construction of GICC05-Cariaco as claimed in (1). Column 7 shows the duration of each GI-GS pair in GICC05-Cariaco relative to GICC05. The column “Termination of interstadial” in table S3 of Cooper et al. is derived by adding estimated interstadial durations from (8) to the onset ages—i.e., assuming no stretching of interstadials. However, in the data of Fig. 1 and table S4 of Cooper et al., interstadials as well as stadials are stretched by the factor stated in the table. We conclude that the interstadial durations of table S3 in Cooper et al. are incorrect and refer to (9) for precise event durations. *, within GICC05 counting uncertainty. **, not consistent with GICC05 counting uncertainty.

<table>
<thead>
<tr>
<th>Event</th>
<th>Onset GICC05 (years b1950)</th>
<th>GICC05 uncertainty (years b1950)</th>
<th>Onset Cariaco (years b1950)</th>
<th>Cariaco uncertainty (years b1950)</th>
<th>Error-weighted mean (years b1950)</th>
<th>Stretching factor of GI and following GS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI-1</td>
<td>14,642</td>
<td>93</td>
<td>14,600</td>
<td>125</td>
<td>14,627</td>
<td>0.99**</td>
</tr>
<tr>
<td>GI-2</td>
<td>23,290</td>
<td>298</td>
<td>23,790</td>
<td>268</td>
<td>23,566</td>
<td>1.03*</td>
</tr>
<tr>
<td>GI-3</td>
<td>27,730</td>
<td>416</td>
<td>27,855</td>
<td>119</td>
<td>27,846</td>
<td>0.96*</td>
</tr>
<tr>
<td>GI-4</td>
<td>28,850</td>
<td>449</td>
<td>28,639</td>
<td>126</td>
<td>28,654</td>
<td>0.72**</td>
</tr>
<tr>
<td>GI-5</td>
<td>32,450</td>
<td>566</td>
<td>31,599</td>
<td>152</td>
<td>31,654</td>
<td>0.83**</td>
</tr>
<tr>
<td>GI-6</td>
<td>33,690</td>
<td>606</td>
<td>34,226</td>
<td>224</td>
<td>34,162</td>
<td>2.02**</td>
</tr>
<tr>
<td>GI-7</td>
<td>35,430</td>
<td>661</td>
<td>35,357</td>
<td>288</td>
<td>35,369</td>
<td>0.69**</td>
</tr>
<tr>
<td>GI-8</td>
<td>38,170</td>
<td>725</td>
<td>38,355</td>
<td>194</td>
<td>38,343</td>
<td>1.09**</td>
</tr>
<tr>
<td>GI-9</td>
<td>40,110</td>
<td>790</td>
<td>41,368</td>
<td>340</td>
<td>41,171</td>
<td>1.46**</td>
</tr>
<tr>
<td>GI-10</td>
<td>41,410</td>
<td>817</td>
<td>42,192</td>
<td>197</td>
<td>42,149</td>
<td>0.75**</td>
</tr>
<tr>
<td>GI-11</td>
<td>43,290</td>
<td>868</td>
<td>43,808</td>
<td>189</td>
<td>43,785</td>
<td>0.87**</td>
</tr>
<tr>
<td>GI-12</td>
<td>46,810</td>
<td>956</td>
<td>47,540</td>
<td>211</td>
<td>47,506</td>
<td>1.06**</td>
</tr>
<tr>
<td>GI-13</td>
<td>49,230</td>
<td>1,015</td>
<td>50,801</td>
<td>691</td>
<td>50,303</td>
<td>1.16**</td>
</tr>
<tr>
<td>GI-14</td>
<td>54,170</td>
<td>1,150</td>
<td>53,972</td>
<td>719</td>
<td>54,028</td>
<td>0.75**</td>
</tr>
<tr>
<td>GI-15</td>
<td>55,750</td>
<td>1,196</td>
<td>55,961</td>
<td>672</td>
<td>55,910</td>
<td>1.19**</td>
</tr>
</tbody>
</table>
suggests that uncertainties in the event identification and alignment and in the Hulu-Cariaco time scale transfer (not included by Cooper et al.) dominate over the analytical dating uncertainties.

If radiometric dates and annual-layer-counting results are to be meaningfully combined, we argue that the methodology must respect that radiometric dates are mutually independent with small uncertainties, whereas annual-layer-counted chronologies have large but highly correlated uncertainties. Furthermore, we argue that a combination of the two must take into account the uncertainties in aligning the records.

Cooper et al. claims that the interstadial durations from GICC05 have been maintained for the revised GICC05-Cariaco time scale. We see this as a step toward acknowledging that annual-layer-counted interstadial durations are indeed precisely determined, but it is unclear why Cooper et al. do not treat stadial durations in the same way. Furthermore, it turns out that the GICC05 interstadial durations do not actually enter the time-scale merging calculations: As demonstrated in Table 1, the ages of interstadial onsets in the GICC05-Cariaco time scale can be obtained by error-weighted averaging of the interstadial onsets in GICC05 and Cariaco. The approach assumes independent uncertainties for both records and disregards uncertainty of the alignment of events between records.

Table 1 also shows the stretching factor of each GI/GS pair in GICC05-Cariaco compared with GICC05. The maximum counting error estimates of GICC05 are below 5% at all depths, corresponding to stretching factors between 0.95 and 1.05. Back to GI/GS-3, the stretching factors are within those limits, but for older sections, interstadial-stadial durations are stretched or compressed more than what is consistent with the annual layer counting results. The extremes are GI/GS-6, whose duration is more than doubled, and GI/GS-7, which is compressed to 68% of its GICC05 duration.

As an example of how annual-layer-counted chronologies can be meaningfully combined with radiometric dates, Buizert et al. (7) combined GICC05 and Hulu ages in the construction of the West Antarctic Ice Sheet Divide time scale. Their age differences between aligned events are shown in Fig. 1 (black symbols with estimated matching uncertainties), together with the GICC05-Cariaco age differences from Cooper et al. (red symbols).

Based on a linear fit, GICC05 was stretched by a factor of 1.0063 to, on average, align Hulu and Greenland ages (blue dashed curve in Fig. 1) (7). All event durations are thus increased by 0.63%, suggesting a small bias in the layer counting during the construction of GICC05. A similar analysis using data from Cooper et al., which are less precise due to the matching via Cariaco, leads to a bias estimate of 0.96% (Fig. 1, red dashed line), well within the maximum counting error of GICC05.

We conclude that the GICC05-Cariaco time scale cannot be seen as a revision of GICC05 because it is not consistent with the constraints given by the annual layer counting on which GICC05 is based. We thus recommend that the GICC05-Cariaco time scale not be used for paleoclimatic reconstructions and, in particular, not for presentation of ice-core data.

### REFERENCES

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