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

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Rasmussen and Svensson correctly point out that there is currently no satisfactory method to fully align the Greenland and Cariaco Basin records of climate change. However, our approach using interstadial onsets as tie-points allows direct comparison between radiocarbon dates and Greenland climate records. Crucially, both the standard Greenland and the merged Greenland-Cariaco time scales show that interstadial warming was associated with megafaunal genetic transitions.

A major challenge for testing hypotheses of synchronous climate and environmental change is high-precision alignment of geochronological frameworks. Nowhere is this more problematic than in comparison of the radiocarbon (14C) time scale with the Greenland ice core records of abrupt and extreme climate change during the Late Pleistocene. We thank Rasmussen and Svensson for their Comment (1) on our paper (2). It was not our intention to provide a replacement chronology for the excellent Greenland Ice Core Chronology 2005 (GICC05) time scale generated by these authors. Instead, we wished to test our observation that there was indeed a relationship between megafaunal extinctions and abrupt and extreme climate warming events, as preserved in Greenland

REFERENCES

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on the GICC05 time scale [table 1 in (2)]. As a result, we developed a methodology that allows direct comparison between radiocarbon ages and Greenland climate. By combining the tropical Cariaco Basin (Hulu Cave) radiocarbon record of shifts in the Intertropical Convergence Zone with Greenland temperature, we were able to exploit the positive attributes of these independent records and thereby bring abrupt interstadial transitions and high-resolution radiocarbon into the same calendar time scale. This provided an alternative chronology that would allow us to test the conclusions reached by using GICC05 on its own, given the known accuracy problems of this record at greater annual ice layer counts. However, we do not advocate the use of the revised GICC05-Cariaco chronology as a replacement alternate age model for the complete GICC05 record.

As Rasmussen and Svensson remark, a full merging of chronologies has to take into account the different nature of annual-layer-counted and radiometric chronologies and their associated and very different uncertainties (i.e., independent versus dependent errors), something that is at present difficult to do in a robust, objective statistical model. Such a substantial exercise was beyond the scope of this paper, and we focused on the timing of abrupt interstadial transitions only, given our initial conclusions derived using just GICC05. We took a conservative approach by combining the strengths of GICC05 and Cariaco-Hulu to derive an alternative replicated framework for the timing of the onset of abrupt and extreme warming during Dansgaard-Oeschger events (within the uncertainties of both sequences). By taking advantage of the counting precision on the Greenland interstadial durations (3) (as stated explicitly in our supplementary materials), we could directly compare the calibrated megafaunal data set to climate. Given the magnitude of the uncertainties in calibrating radiocarbon ages across the full time scale, we considered the use of centennial-length durations appropriate; furthermore, as reported by Wolff et al. (3), the onset of some interstadials is difficult to precisely identify due to the complex structure of events; hence, Greenland interstadials 13 to 15 were not used in our calculations. We are sympathetic to the use of the duration of Greenland stadials and interstadials as a test of different age models, but as Rasmussen and Svensson and colleagues have previously reported, “alternative but reasonable sets of criteria could have been developed that would have given a different count and a different uncertainty” (3). Furthermore, it is clear that major challenges remain in capturing all missing Greenland layers, as evidenced by recent work questioning even the relatively recent Late Glacial and Holocene part of the record (4, 5). Developing more precise and accurate geochronological frameworks in the future will require new approaches to alignment, incorporating all sources of error.

The key point remains that regardless of the chronology used, we reach the same conclusion: Interstadial warming events are strongly associated with the regional replacement or extinction of major genetic clades or species of megafauna.
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