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# The atypical interglacial of MIS 11c and the long-term change in interglacial intensity over the past 800 kyr

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Eleven interglacials have been identified in the past 800 kyr (Past Interglacials Working Group of PAGES 2016). Around 430 kyr BP, a change in interglacial strength, known as the Mid-Brunhes Event (MBE), was observed in atmospheric $CO_2$ levels, and in proxy records of Antarctic and global surface temperatures, marking a transition to stronger interglacials, such as Marine Isotope Stages (MISs) 5e and 11c (Fig. 1). While the onset of interglacials seems linked to an increased Northern Hemisphere summer insolation, uncertainties persist due to complex interactions involving astronomical forcing, ice volume, $CO_2$ levels, and temperature.

Active research areas in Late Pleistocene interglacials focus on those not aligning with the astronomical theory of ice ages, and on long-term changes in interglacial intensity over the past 800 kyr. To address these topics, the PAGES working group on Quaternary Interglacials (QUIGS) convened in Grenoble, France. Here we highlight some of the topics covered, and a few of the presentations that led to particular areas of discussion.

The unusual MIS 11c interglacial is known for its prolonged high sea-level and atmospheric $CO_2$ concentrations, despite weak summer-insolation forcing (Tzedakis et al. 2022). The prolonged Termination V was suggested to be associated with the largest sea-level contribution from the Greenland Ice Sheet over the last 800 kyr. Alessio Rovere showed how large ice sheets may drive high sea-level stands, with MIS 12 believed to have featured one of the most extensive glaciations (Batchelor et al. 2019). Claire Jasper's study of iceberg rafted debris (IRD) in the Southern Ocean's Atlantic sector, during Termination V and MIS 11c, indicated a protracted period of Antarctic Ice Sheet iceberg discharge and melt. Steve Barker suggested that the asynchronous phasing of obliquity and precession during Termination V (Fig. 1) may explain the prolonged nature of this deglaciation.

The necessity to develop a coordinated modeling protocol over the Termination V-MIS 11c time period was discussed. In this framework, the group agreed on the importance of constraining the volume and extent of the MIS 12 ice sheet, and developing a coherent temporal framework for the rate of sea-level rise, and for various paleoclimate proxies representative of different parts of the Earth System across the deglaciation.

The second part of the discussions delved into the MBE, addressing challenges related to the metrics of interglacial intensity. Mean Ocean Temperature reconstructed by Markus Grimmer emerged as a potential metric for distinguishing between strong and weak interglacials. A debate arose regarding the classification of early interglacial peaks in $CO_2$, known as overshoots, and whether they are part of the interglacial or termination. Takahito Mitsui presented a model predicting interglacial intensity based on the previous glacial strength and summer insolation, received at both northern and southern high latitudes during deglaciation. According to Mitsui et al. (2022), the increase in interglacial intensities after the MBE is related to the amplitude increase in obliquity cycles. Finally, Quizhen Yin pointed out that in some records, such as Chinese loess, there is no discernable increase in interglacial strength across MBE. This observation gave rise to the alternative suggestion: can we use records where MBE is not detectable to understand what causes the observation of MBE in other records? In conclusion, an outline for a short position paper effort was defined on our current knowledge of interglacial intensity, incorporating both paleoclimate records and modeling.

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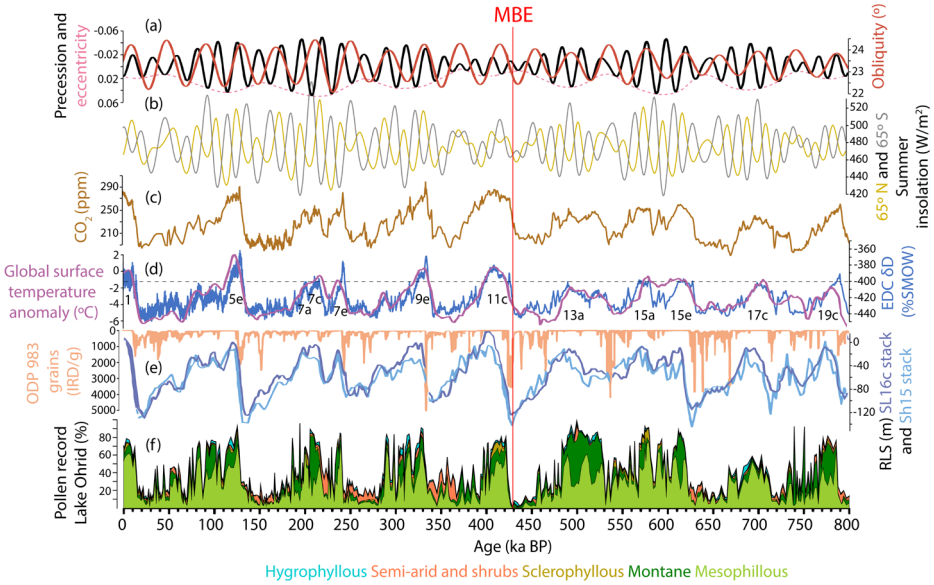


**Figure 1:** Paleoclimate reconstructions over the last 800 kyr (modified from Tzedakis et al. 2022). **(A)** Eccentricity (red dashed), precession (black), obliquity (red solid), and **(B)** summer solstice insolation at 65°N (orange) and 65°S (gray). Antarctic EDC ice-core records of **(C)** atmospheric $CO_2$ and **(D)** δD of ice (blue) on AICC2023 timescale (Bouchet et al. 2023). A 400‰-threshold (dashed line) separates pre- and post-MBE interglacials. Global average surface temperature (anomaly vs. present) (purple). **(E)** IRD in North Atlantic ODP Site 983 (salmon); two reconstructions of relative sea level (dark and light blue). **(F)** Pollen from Lake Ohrid (Donders et al. 2021).