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Integrating suborbital climate variability with classical Milanković theory

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Although much progress has been made since Milanković's publication of *Canon of Earth Insolation and its Application to the Ice Age Problem* in 1941, we still lack a complete understanding of how changes in the seasonal distribution of insolation and associated feedbacks result in the large glacial-interglacial changes in Earth's climate. An important missing piece of information is how suborbital- and orbital-scale climate variability interact to produce the observed patterns of Pleistocene glacial-interglacial cycles. IODP Site U1385 (the "Shackleton site") on the Iberian Margin is used to study how suborbital climate variability in the North Atlantic evolved as orbital and glacial boundary conditions changed during the past 1.5 million years, including the Middle Pleistocene Transition. The record demonstrates that millennial-scale variability was a persistent feature of glacial climate and exhibited strong threshold behaviour. From 1.5 to 1.25 Ma during the "41-kyr world", millennial variability was as strong and frequent as it was during Marine Isotope Stage 3, and persisted throughout the glacial period when obliquity dropped below the present value of 23.5°. Beginning at 1.25 Ma, the duration of the glacial cycle began to lengthen, and strong millennial variability occurred on glacial inceptions associated with low obliquity and during times of intermediate ice volume. During the "100-kyr world", the transitions into and out of glacial states (i.e., terminations and inceptions) are always marked by very strong millennial variability, suggesting that longer-term orbital changes in Earth's climate are realized through a series of rapid, millennial-to-centennial-scale events. Moreover, a strong correlation exists between millennial-scale increases in planktonic δ^{18}O (cooling) and decreases in benthic δ^{13}C, indicating suborbital variations in surface climate were translated to changes in deep-water circulation and remineralization of carbon in the abyssal ocean. Suborbital climate variability may be an important mechanism for synchronizing internal climate dynamics with external astronomical (Milanković) forcing, either indirectly by affecting noise intensity and resonance and/or more directly by affecting carbon storage in the deep-sea and atmospheric CO_2.