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Assessing the persistence of millennial-scale oscillations during the penultimate glacial phase in southern Europe

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There is growing evidence that millennial-scale climate oscillations are a pervasive feature of glacial intervals. During the last glaciation (Marine Isotope Stage (MIS) 2–4), incursions of cold water into the North Atlantic appeared to coincide with abrupt reductions in southern European tree populations (Tzedakis et al., 2004: Geology 32, 109-112), suggesting down-stream impacts on continental temperature and hydroclimate. Ice-rafting into the North Atlantic during the penultimate glacial (MIS 6) is thought to be less extensive than at times during MIS 2–4, perhaps resulting in more subdued climate oscillations. Published pollen data from Lake Ioannina core I-284 (Epirus, NW Greece) suggest pronounced oscillations in tree population extent during early MIS 6 (185–155 ka), followed by much-reduced tree populations and subdued oscillations throughout late MIS 6 (155–135 ka) (Roucoux et al., 2011: Journal of Quaternary Science 26, 616-626). Previous studies of the diatom and isotope records from the MIS 7/6, 6/5e and 2/1 transitions, and from MIS 5e and 1 in Lake Ioannina core I-284 demonstrate the sensitivity of these proxies to changes in regional climate. Here we apply a combined diatom and stable isotope (carbon and oxygen) approach to evaluate the influence of millennial-scale oscillations on southern Europe hydroclimate during MIS 6. The new isotope data from Lake Ioannina core I-284 demonstrates higher precipitation / evaporation (P/E) ratios between c. 178 and 164 ka, associated with peak insolation during MIS 6e, and episodes of planktonic diatom expansion likely reflecting the interstadials of the 6e complex. Close correspondence between diatom planktonic frequencies, arboreal pollen and regional sea-surface temperatures together provide strong evidence for millennial-scale oscillations in regional precipitation at times during the early–mid MIS 6. The isotope data suggest overall cooler and drier conditions during the mid–late MIS 6, consistent with approaching glacial maxima. In contrast to the subdued changes in tree population extent at Ioannina, variability in P/E and oscillations in planktonic and facultative planktonic (Fragilariaceae) frequencies show that marked changes in lake conditions persisted into late MIS 6. The co-variation between high P/E ratios and Fragilariaceae expansion during this interval suggests oscillations in the extent and duration of seasonal lake ice cover under a cold climate, a correspondence that also characterised the first several millennia of MIS 6 under similar cold climate conditions linked to reduced insolation. We conclude that millennial-scale climate oscillations are a pervasive feature of the penultimate glacial (MIS 6) in southern Europe, and that even small amplitude climate oscillations can elicit large amplitude changes in limnological conditions.