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Towards a global reference frame for Plio-Pleistocene climate variability

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Stacked benthic oxygen isotope ($\delta^{18}O_b$) records from open-ocean sites have become the backbone for Plio-Pleistocene climate reconstructions. These records are often astronomically-tuned, including fixed values for (i) the response time (T_m) between forcing function (e.g. summer insolation) and the modelled ice-sheet variability, and (ii) an asymmetry coefficient (b) that corrects for the slow build-up and fast retreat of the ice sheets. In the widely applied LR04, Tm was set to 15-kyr and b to 0.6 for the past 1.5 Myr. Both values were considered to be significantly smaller during the lower Pliocene (i.e. T_m = 5-kyr, b = 0.3) due to the much smaller ice-sheets at that time. This consideration results in a time lag between the dominant 41-kyr component in the $\delta^{18}O_b$ record and the underlying obliquity cycle of 6.8±0.4, 5.5±0.5 and 2.8±0.8 kyr for the 0-1.5, 1.2-3.0 and 3.0-5.3 Ma time intervals, respectively. In the meantime, an independent astronomically calibrated time scale was also established for the Plio-Pleistocene of the Mediterranean sedimentary sequence. This time scale has been based on the correlation between dominantly precession-controlled sapropel depositions and carbonate cycles to the 65°N summer insolation time series. This tuned sequence has become the reference scale for the standard Geologic Time Scale 2004 and 2012, and provides highly accurate ages for magneto, bio, and chronostratigraphic events. Largest uncertainties are related to the adopted values for the dynamical ellipticity of the Earth and tidal dissipation by the Sun and the Moon, the accuracy of the astronomical solution and the inferred time lag between insolation forcing and sedimentary response. This time scale lacks, however, a $\delta^{18}O_b$ chronology, which hampers a thorough comparison with the LR04 and other open-ocean stacks. Here, we present the first high-resolution $\delta^{18}O_b$ record of the Mediterranean Pliocene to early Pleistocene, which primarily reflects global climate changes. Cross spectral analysis reveals the dominancy of the obliquity-related (41-ky) component in the $\delta^{18}O_b$ record, which lags obliquity by 7.1±0.5 and 6.4±0.7 kyr in respectively the 1.2-3.0 and 3.0-5.3 Ma time intervals. The obliquity-related time lags are 1.6 and 3.6 kyr larger than those adopted in LR04 for these time intervals. A constant 3-kyr time lag was however incorporated in the Mediterranean time scale associated with the lagged response between insolation forcing and the midpoints of the correlative sapropels and grey layers. The hypothesis of a more instantaneous response of Mediterranean climate to astronomical forcing during the Pliocene (i.e. a 0-kyr time lag) would hence be in much better agreement with the assumed response model of LR04. The application of the inverse modelling technique with the ANICE ice-sheet models, and using the Mediterranean and LR04 $\delta^{18}O_b$ data series as input, further indicates that the lagged response of surface temperature changes to obliquity forcing were considerable smaller during the Pliocene than during the late Pleistocene, whereas the opposite is found for the total sea level response. In particular, total sea level lagged surface temperatures by 8-9 kyr during the early Pliocene and 5-6 kyr during the late Pleistocene in the obliquity frequency band. This implies that the smaller T_m value as adopted in LR04 for the Pliocene merely reflects a surface temperature and not the ice-sheet response. This seems consistent with the fact that the response time of ice sheet build-up is governed more by the precipitation than the size of the ice sheet as put forward in the astronomically-tuned approach.