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CO_2-forced change in glacial response to precession likely causes the Middle-Pleistocene Transition and ~100-kyr glacial cycles

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Around ~800-1200 ka, the transition of glacial-interglacial cycles from earlier ~40-kyr into later ~100-kyr cyclicities without obvious changes in orbital parameters, known as the Middle-Pleistocene Transition (MPT), suggests that Earth's internal factors, in addition to external astronomical forcing, are also essential for the glacial cycles. However, it is still unclear how internal and external factors interact to lead to the MPT and the ~100-kyr cycle. Here, we statistically analyzed the power spectral relationship between the ~21-kyr, ~41-kyr, and ~100-kyr components within 57 paleoclimate archives and reconstructed the astronomical phase relative to the maximal changing rate of benthic foraminifer oxygen isotopes ($\delta^{18}O$) over the past 2700 ka to explore the role of astronomical forcings in driving glacial cycles and their relationship with internal factors. The statistical results show that the ~21-kyr power ratio complements the ~100-kyr power ratio. The precession phase covaries with pCO_2-modulated glacial dynamics and exhibits a contrasting correlation with the precession power ratio of benthic $\delta^{18}O$ before and after ~1500 ka. These findings suggest that pCO_2-modulated latitudinal extension of the icesheets determined the glacial response to precession. Around 1500 ka, the response apparently shifted into a nonlinear mode, enabling the gradual extension of glacial cycles into ~100-kyr periodicities at the expense of precession power, which signified the onset of the ~100-kyr glacial cycles. Our study confirms the nonlinear precession origin of ~100-kyr glacial cycles, featuring the possible low- and high-latitude interplay at the precession band.