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The intensity and timing of orbital variations in boreal summer monsoons in the late Quaternary climate

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Late Quaternary monsoon records show lags with respect to the orbital forcing that vary between 2-3 kyr, close to model results of zero lag, and considerably longer lags of 5-8 kyr. It has been hypothesized that such lags arise from factors that were, up til now, not included in the modelling experiments, namely variations in glacial-age boundary conditons. Here we address this issue using long, transient climate simulations that do include varying ice sheets and greenhouse gas concentrations. We find that glacial boundary conditions reduces monsoon spectral power at the precession band (and introduces power at the eccentricity band), with orbital forcing remaining the dominant control. Precession lags are not affected by the glacial-age boundary conditons. At the obliquity band ice-sheet variations dominantly force monsoon variations, with greenhouse gases playing a secondary role. As a result the obliquity phase of different monsoon systems lies between summer insolation maxima and ice minima/greenhouse gas maxima, with a lag that varies with distance to the Eurasian ice sheet.