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External and internal forcing of African Humid Periods from MIS 6 to MIS 1

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During the last million years, northern Africa has alternated between arid and humid conditions, as recorded by different kinds of climate archives, including fossil pollen, lake sediments, marine sediments and archaeological remains. Variations occur at millennial scale, with dry phases being similar to the current desert state in the region, and with wet phases, known as African Humid Periods (AHPs), characterised by a strong summer monsoon which can carry enough moisture inland to support rivers, lakes and lush vegetation further north than seen today. Recent sediment records from the Mediterranean Sea revealed that the previous five AHPs had different intensities, in relation to rainfall and vegetation extent. Motivated by these findings, our work focuses on explaining what caused such differences in intensity. To this end, we use the CLIMBER-2 climate model to study the AHP response to changes in three drivers of atmospheric dynamics: Earth's orbit variations, atmospheric concentration of CO_2 and inland ice extent. Global transient simulations of the last 190,000 years are used in new factorisation analyses, which allow us to separate the individual contributions of the forcings to the AHP intensity, as well as those of their synergies. We confirm the predominant role of the orbital forcing in the strength of the last five AHPs, and our simulations agree with previous estimates of a threshold in orbital forcing above which an AHP develops. Moreover, we show that atmospheric CO_2 and the extent of ice sheets can also add up to be as important as the orbital parameters. High values of CO_2, past a 205 ppm threshold, and low values of ice sheets extent, below an 8 % of global land surface threshold, yield the AHPs with the most precipitation and vegetation. Additionally, our results show that AHPs differ not only in amplitude, but also in their speed of change, and we find that the non-linear vegetation response of AHPs does not correlate with a single forcing and that the vegetation growth response is faster than its subsequent decline. In regards to future change, an extension of the simulations until the next 50,000 years, shows CO_2 to be the main driver of AHPs, with orbital forcing only setting the pace and their intensities being scenario-dependent.