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Phase relationships between orbital forcing and the composition of air trapped in Antarctic ice cores

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Orbital tuning is central for ice core chronologies beyond annual layer counting, available back to 60 ka (i.e. thousands of years before 1950) for Greenland ice cores. While several complementary orbital tuning tools have recently been developed using $\delta^{18}O_{atm}$, $\delta O_2/N_2$ and air content with different orbital targets, quantifying their uncertainties remains a challenge. Indeed, the exact processes linking variations of these parameters, measured in the air trapped in ice, to their orbital targets are not yet fully understood. Here, we provide new series of $\delta O_2/N_2$ and $\delta^{18}O_{atm}$ data encompassing Marine Isotopic Stage (MIS) 5 (between 100-160 ka) and the oldest part (380-800 ka) of the East Antarctic EPICA Dome C (EDC) ice core. For the first time, the measurements over MIS 5 allow an inter-comparison of $\delta O_2/N_2$ and $\delta^{18}O_{atm}$ records from three East Antarctic ice core sites (EDC, Vostok and Dome F). This comparison highlights a site-specific relationship between $\delta O_2/N_2$ and its local summer solstice insolation that increases the uncertainty associated with the use of $\delta O_2/N_2$ as a tool for orbital tuning. Combining records of $\delta^{18}O_{atm}$ and $\delta O_2/N_2$ from Vostok and EDC, we evidence a loss of orbital signature for these two parameters during periods of minimum eccentricity ($\sim$400 ka, $\sim$720-800 ka). Our dataset reveals a time-varying lag between $\delta O_2/N_2$ and $\delta^{18}O_{atm}$ over the last 800 ka that we interpret as variations of the lag between $\delta^{18}O_{atm}$ and precession. Large lags of $\sim$5 ka are identified during Terminations I and II, associated with strong Heinrich events. On the opposite, minimal lags ($\sim$1-2 ka) are identified during four periods characterized by high eccentricity, intermediate ice volume and no Heinrich events (MIS 6-7, the end of MIS 9, MIS 15 and MIS 17). We therefore suggest that the occurrence of Heinrich events influences the response of $\delta^{18}O_{atm}$ to precession.