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Simulating atmospheric $d^{13}CO_2$ during the last 740 000 years: Model-based estimates in the context of ice core measurements

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The ratio of the stable carbon isotopes of atmospheric CO_2 ($\delta^{13}CO_2$) contains valuable information on the processes which are operating on the global carbon cycle. However current $\delta^{13}CO_2$ ice core records are still limited in both resolution, temporal coverage as well as precision. To make optimal use of the existing and future $\delta^{13}CO_2$ ice core records an estimate of the expected temporal variability would help to constrain for the acceptable measurement uncertainty and resolution to successfully retrieve the characteristic variability in $\delta^{13}CO_2$. In this study we performed simulations with the carbon cycle box model BICYCLE with special emphasis on atmospheric $\delta^{13}CO_2$, proposing how changes in $\delta^{13}CO_2$ might have evolved over the last 740,000 years. The overall model dynamic is validated with reconstructions of $\delta^{13}C$ in benthic foraminifera in thedeep Pacific and with atmospheric CO_2 ice core data. On glacial/interglacial timescales lower surface ocean temperature is most important for lower glacial $\delta^{13}CO_2$, followed by the release of isotopically lighter terrestrial carbon. In addition, changes in the terrestrial biosphere also dominate deep ocean $\delta^{13}CO_2$ but have only a limited effect on atmospheric pCO_2. All other oceanic processes lead to higher than present glacial $\delta^{13}CO_2$. Taken all processes together the effects nearly cancel each other and there are nearly no glacial/interglacial amplitudes in $\delta^{13}CO_2$ in line with ice core data. However faster variations of up to 0.3 ‰ occur throughout the whole simulation period. Due to our model configuration, terrestrial carbon storage is very sensitive to temperature changes over northern hemispheric lands, which accompany the reorganization of the Atlantic meridional ocean circulation during fast climate fluctuations (Dansgaard/Oeschger events). These fast events intensify the frequency and amplitude in $\delta^{13}CO_2$. However, due to ocean uptake of additional carbon as well as the signal attenuation in ice cores, the amplitudes of such events are strongly time scale dependent.