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Simulated radiocarbon cycle revisited by considering the bipolar seesaw and benthic ^{14}C data

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Carbon cycle models used to interpret the IntCal20 compilation of atmospheric Δ^{14}C have so far neglected a key aspect of the millennial-scale variability connected with the thermal bipolar seesaw: changes in the strength of the Atlantic meridional overturning circulation (AMOC) related to Dansgaard/Oeschger and Heinrich events. Here we implement such AMOC changes in the carbon cycle box model BICYCLE-SE to investigate how model performance over the last 55 kyr is affected, in particular with respect to available ^{14}C and CO_2 data. Constraints from deep ocean ^{14}C suggest that the AMOC in the model during Heinrich stadial 1 needs to be highly reduced or even completely shutdown. Ocean circulation and sea ice coverage combined are the processes that almost completely explain modelled changes in deep ocean ^{14}C age, and these are also responsible for a glacial drawdown of ~60 ppm of atmospheric CO_2. A further CO_2 drawdown of ~25 ppm is caused by the colder ocean surface at the last glacial maximum. We find that the implementation of AMOC changes in the model setup that was previously used for the calculation of the non-polar mean surface marine reservoir age, Marine20, leads to differences of less than ±100 ^{14}C years. The representation of AMOC changes therefore appears to be of minor importance for deriving mean ocean radiocarbon calibration products such as Marine20, where atmospheric carbon cycle variables are forced by reconstructions. However, simulated atmospheric CO_2 exhibits minima during AMOC reductions in Heinrich stadials, in disagreement with ice core data. This mismatch supports previous suggestions that millennial-scale changes in CO_2 were probably mainly driven by biological and physical processes in the Southern Ocean. By modifying the ^{14}C production rate (Q), between one that varies so as to fit simulated atmospheric Δ14C to IntCal20 and an alternative constant Q, we can furthermore show that in our model setup the variability in deep ocean 14C age, especially during the Bølling/Allerød—Younger Dryas—Early Holocene climate transition, has its root cause in the carbon cycle, while a Q that achieves agreement with the IntCal20 atmospheric Δ14C record only enhances deep ocean age anomalies and thus optimizes agreement with the benthic 14C data.