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Intramolecular isotope distributions reveal lower than expected increases in photosynthesis over the past 200 years

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The ability of the biosphere to act as CO_2 sink through photosynthesis strongly influences future atmospheric CO_2 concentrations and crop productivity. However, plant responses to increasing atmospheric CO_2 are poorly understood, in particular on time scales of decades that are most relevant for the global carbon cycle. Most plants in the global terrestrial vegetation and most crops use the C_3 photosynthetic pathway. Photorespiration is a side reaction of C_3 photosynthesis that reduces CO_2 assimilation in all C_3 plants. By studying intramolecular isotope distributions (isotopomer abundances) in century-long archives of plant material, we reconstruct how the atmospheric CO_2 increase since industrialization has changed the ratio of photorespiration to photosynthesis.

For 12 tree species from five continents, we observe that the CO_2 increase has reduced the photorespiration / photosynthesis ratio. However, the observed reduction is on average 50 % smaller than expected from CO_2 manipulation experiments. This apparent discrepancy is explained by results from a factorial CO_2 / temperature manipulation experiment, which shows that isotopomers reflect the integrated effect of CO_2 and temperature on the photorespiration / photosynthesis ratio. Thus, the 50 % smaller suppression of photorespiration in trees is explained by increases in leaf temperature of 2 °C, due to global warming and a possible contribution of reduced transpirational cooling due to stomatal closure.

Previous studies of long-term effects of increasing CO_2 on trees have measured ^{13}C fractionation of leaf gas exchange ($\Delta^{13}C$) in tree-ring series. In several studies a discrepancy was observed: strong historic increases in photosynthesis are estimated, but increases in biomass are not observed. The temperature influence revealed by our isotopomer data resolves this discrepancy; the lower estimate of CO_2 fertilization has major implications for the future role of forests as CO_2 sink and for vegetation-climate interactions.

Isotopomer abundances reflect metabolic regulation, because enzyme isotope effects alter the isotope abundance in individual intramolecular positions. Thus, isotopomers of long-lived metabolites of historic plant material are the first tool to connect plant ecophysiology with paleo research. Another strength is that ratios of isotopomers are independent of source isotopic signatures ($\delta^{13}C$ of CO_2 and δD of water). Thus, isotopomer ratios and source isotopic signatures are orthogonal signals of plant processes and of environmental changes, respectively. Glucose has seven deuterium- and six ^{13}C isotopomers, each influenced by specific fractionation mechanisms, therefore several climatic and/or physiological signals may be retrieved from just one metabolite.