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Enhanced photosynthetic efficiency in trees world-wide by rising atmospheric CO_2 levels

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The atmospheric CO_2 concentration is increasing rapidly due to anthropogenic emissions but the effect on the Earth's biosphere is poorly understood. The ability of the biosphere to fix CO_2 through photosynthesis will determine future atmospheric CO_2 concentrations as well as future productivity of crops and forests. Manipulative CO_2 enrichment experiments (e.g. FACE) are limited to (i) short time spans, (ii) few locations and (iii) large step increases in [CO_2]. Here, we apply new stable isotope methodology to tree-ring archives, to study the effect of increasing CO_2 concentrations retrospectively during the past centuries. We cover the whole [CO_2] increase since industrialization, and sample trees with global distribution.

Instead of isotope ratios of whole molecules, we use intramolecular isotope distributions, a new tool for tree-ring analysis with decisive advantages. In experiments on annual plants, we have found that the intramolecular distribution of deuterium (equivalent to ratios of isotopomer abundances) in photosynthetic glucose depends on growth [CO_2] and reflects the metabolic flux ratio of photosynthesis to photorespiration. By applying this isotopomer methodology to trees from Oak Ridge FACE experiment, we show that this CO_2 response is present in trees on the leaf level. This CO_2 dependence constitutes a physiological signal, which is transferred to the wood of the tree rings.

In trees from 13 locations on all continents the isotopomer ratio of tree-ring cellulose is correlated to atmospheric [CO_2] during the past 200 years. The shift of the isotopomer ratio is universal for all 12 species analyzed, including both broad-leafed trees and conifers. Because the trees originate from sites with widely differing D/H ratios of precipitation, the generality of the response demonstrates that the signal is independent of the source isotope ratio, because it is encoded in an isotopomer abundance ratio. This decoupling of climate signals and physiological signals is a fundamental advantage of isotopomer ratios (Augusti et al., Chem. Geol 2008).

These results demonstrate that increasing [CO_2] has reduced the ratio of photorespiration to photosynthesis on a global scale. Photorespiration is a side reaction that decreases the C gain of plants; the suppression of photorespiration in all analyzed trees indicates that increasing atmospheric [CO_2] is enhancing the photosynthetic efficiency of trees world-wide.

The consensus response of the trees agrees with the response of annual plants in greenhouse experiments, with three important conclusions. First, the generality of the isotopomer shift confirms that the CO_2 response reflects the ratio of photosynthesis to photorespiration, and that it creates a robust signal in tree rings. Second, the agreement between greenhouse-grown plants and trees indicates that there has not been an acclimation response of the trees during the past centuries. Third, the results show that the regulation of tree gas exchange has during past centuries been governed by the same rules as observed in manipulative experiments, in contradiction to recent reports (Keenan et al., Nature 2013).