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Continent-wide increase of water-use efficiency in vegetation during severe droughts of the recent decade

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Recent severe droughts in Europe, Russia, China, and North America have caused widespread decline of agricultural yield and reduction of forest carbon uptake during the past decade. During droughts plants limit their water-loss at the expense of carbon uptake by partially closing their stomata, which increases the intrinsic water-use efficiency defined as the ratio of gross primary production to stomatal conductance. Here we present new evidence on this drought response of terrestrial vegetation derived from year-to-year changes in the ^{13}C:^{12}C stable isotope ratio in atmospheric CO_2 ($\delta^{13}C$). Observations from more than 50,000 flask samples from a global monitoring network show a strong increase in water-use efficiency over continent-wide scales during severe droughts in Europe (2003, 2006), Russia (2010), and the United States (2002). This large-scale area-integrated vegetation drought response can not be measured from laboratory experiments or local-scale field studies and the atmospheric $\delta^{13}C$ record thus offers a unique perspective on large-scale vegetation drought dynamics. Independent evidence from multiple eddy-covariance sites supports our inverse model interpretation of the observed global atmospheric $\delta^{13}C$ record. With the parameterized stomatal conductance and soil moisture response used in our study, as well as many current climate models, our vegetation model underestimates this increase in water-use efficiency during severe droughts. We therefore suggest minor modifications to better reproduce the observations. We conclude that the global $\delta^{13}C$ record provides a new opportunity to test and improve interannual drought dynamics in coupled biosphere-atmosphere models for CO_2.