A 23 m.y. record of low atmospheric CO_2

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In their recent paper, Cui et al. (2020) used a new iteration of their C_3 plant proxy to reconstruct pCO_2 over the last 23 Ma. The initial version of this proxy used carbon isotope discrimination ($D^{13}C$, calculated as the offset between the $d^{13}C$ of plant tissue [$d^{13}C_p$] and atmospheric CO_2 [$d^{13}C_{atm}$]) to estimate paleo-CO_2 (Schubert and Jahren, 2015), but recent work by different research groups has questioned the utility of this proxy (e.g., Kohn, 2016; Stein et al., in press). Previously, we used $D^{13}C$ data from *Arabidopsis thaliana* plants grown experimentally under different moisture and pCO_2 conditions to show that this proxy is strongly impacted by variations in moisture availability and underpredicts pCO_2 (Lomax et al., 2019). Here, we argue that the new version of the C_3 proxy presented by Cui et al. (2020), which is centered on $d^{13}C_p$ rather than $D^{13}C$, suffers from the same shortcomings. Therefore, it is unsuitable for addressing the core question posed in their paper, that is, how pCO_2 levels in the geological past compare with those both in the present and predicted for the near future.

Using the new $d^{13}C_p$ proxy to reconstruct pCO_2 from our existing *A. thaliana* data set (Jardine and Lomax, 2020; Lomax et al., 2019) shows that, like its predecessor, this proxy underestimates pCO_2 (Fig. 1A), although the effect is even more pronounced than previously (Fig. 1B). The proxy struggles to successfully predict pCO_2 for plants grown in >400 ppm conditions, which is particularly problematic because this is the core threshold for assessing whether past pCO_2 values exceed those of today. pCO_2 estimates are likely lower in this iteration of the proxy because rather than deriving a new relationship between $d^{13}C_p$ and pCO_2, Cui et al. (2020) used the model parameters (the A, B and C terms) from their $D^{13}C$: pCO_2 curve (Schubert and Jahren, 2015). However, the $d^{13}C_{anomaly}$ term of Cui et al. (2020; see their Equations 1 and 2) does not equal the $D(D^{13}C)$ term of Schubert and Jahren (2015; see their Equations 1 and 4) (Fig. 1C). The result is that pCO_2 predicted from $d^{13}C_p$ is even lower than pCO_2 predicted from $D^{13}C$, with the downward bias becoming particularly apparent at pCO_2 > 400 ppm (Fig. 1B).

As with the $D^{13}C$ version of the C_3 proxy, the new $d^{13}C$-based proxy is impacted by moisture availability, especially at higher pCO_2 levels (Fig. 1A). This is a critical issue in the timeseries presented by Cui et al. (2020), because hydrological changes are likely to have accompanied pCO_2-driven temperature changes, for instance across the mid-Miocene Climatic Optimum, ~17–14 Ma (Loughney et al., 2020). The extent to which the increase in pCO_2 reconstructed for this time by Cui et al. (2020) (Fig. 1D) is due to increases in moisture availability cannot be evaluated with this proxy, nor can the impact of long-term continental drying through the late Neogene on the overall downward pCO_2 trend.

Cui et al. (2020) used Monte Carlo resampling to quantify uncertainty in their pCO_2 reconstruction, and presented these uncertainties via a LOWESS smoother with a 68% confidence interval. A 68% confidence interval represents an abnormally low level of statistical confidence, and is too narrow to robustly determine whether pCO_2 values in the past exclude today's levels or those of the future. Plotting 95% confidence intervals (and therefore utilizing the usual a = 0.05 level for statistical inference) shows that pCO_2 values of >500 ppm are entirely consistent with Cui et al.'s reconstruction for much of the last 23 Ma, including in the Pliocene and Pleistocene. The C_3 proxy therefore fails to reject elevated pCO_2 conditions for the late Neogene and Quaternary, despite the downward biasing in the pCO_2 estimates themselves (Fig. 1D).

Understanding the relationship between pCO_2 and global climate is vital for forecasting the response of the climate system to anthropogenic CO_2 emissions. As such, pCO_2 proxies are essential, but they need to be robust and thoroughly validated. Terrestrial fossil organic carbon may be ubiquitous in sediments, but because of impact of moisture availability on $d^{13}C_p$, and the inadequately derived relationship between $d^{13}C_p$ and pCO_2 used by Cui et al. (2020), we maintain (Lomax et al., 2019) that the C_3 proxy is not suitable for reconstructing pCO_2 in the geological past.

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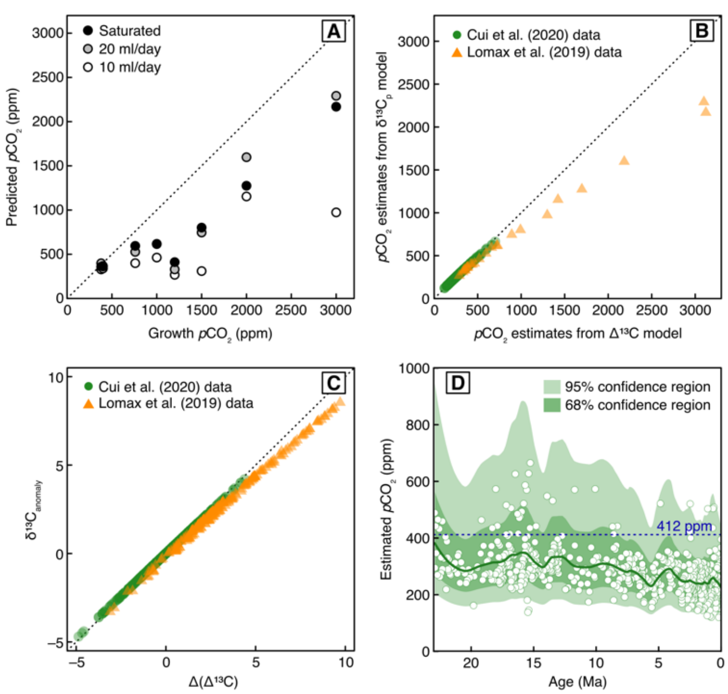

...d using the $d^{13}C_p$-based C_3 proxy ... data set of Lomax et al. (2019). Points are colored by water treatment. (B) Comparison of estimated pCO_2 using the $D^{13}C$-based C_3 proxy of Schubert and Jahren (2015) and the $d^{13}C_p$-based C_3 proxy of Cui et al. (2020). (C) Comparison of the $D(D^{13}C)$ term of Schubert and Jahren (2015) and the $d^{13}C_{anomaly}$ term of Cui et al. (2020). (D) The time series presented by Cui et al. (2020), based on their $d^{13}C_p$-based C_3 proxy, with a LOESS smoother and both 68% and 95% confidence intervals.