A 23 m.y. record of low atmospheric CO₂

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In their recent paper, Cui et al. (2020) used a new iteration of their C₃ plant proxy to reconstruct pCO₂ over the past 23 m.y. The initial version of this proxy used carbon isotope discrimination (∆¹³C, calculated as the offset between the δ¹³C of plant tissue [δ¹³Cp] and atmospheric CO₂ [δ¹³C atm]) to estimate paleo-CO₂ (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., 2020). Previously, we used ∆¹³C data from Arabidopsis thaliana plants grown experimentally under different moisture and pCO₂ conditions to show that this proxy is strongly impacted by variations in moisture availability and underpredicts pCO₂ (Lomax et al., 2019). Here, we argue that the new version of the C₃ proxy presented by Cui et al., which is centered on δ¹³Cp rather than ∆¹³C, suffers from the same shortcomings. Therefore, it is unsuitable for addressing the core question posed in their paper, that is, how pCO₂ levels in the geological past compare with those both in the present and predicted for the near future.

Using the new δ¹³Cp proxy to reconstruct pCO₂ from our existing A. thaliana data set (Lomax et al., 2019; Jardine and Lomax, 2021) shows that, like its predecessor, this proxy underestimates pCO₂ (Fig. 1A), although the effect is even more pronounced than previously (Fig. 1B). The proxy struggles to successfully predict pCO₂ for plants grown in >400 ppm conditions, which is particularly problematic because this is the core threshold for assessing whether past pCO₂ values exceed those of today. pCO₂ estimates are likely lower in this iteration of the proxy because rather than deriving a new relationship between δ¹³Cp and pCO₂, Cui et al. used the model parameters (the A, B, and C terms) from their ∆¹³C/pCO₂ curve (Schubert and Jahren, 2015). However, the δ¹³C anomaly term of Cui et al. (see their equations 1 and 2) does not equal the ∆(δ¹³C) term of Schubert and Jahren (2015), see their equations 1 and 4 (Fig. 1C). The result is that pCO₂ predicted from δ¹³Cp is even lower than pCO₂ predicted from ∆¹³C, with the downward bias becoming particularly apparent at pCO₂ > 400 ppm (Fig. 1B).

As with the ∆¹³C version of the C₃ proxy, the new δ¹³C-based proxy is impacted by moisture availability, especially at higher pCO₂ levels (Fig. 1A). This is a critical issue in the time series presented by Cui et al., because hydrological changes are likely to have accompanied pCO₂-driven temperature changes, for instance, across the mid-Miocene Climatic Optimum, ca. 17–14 Ma (Loughney et al., 2020). The extent to which the increase in pCO₂ reconstructed for this time by Cui et al. (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 pCO₂ trend.

Cui et al. used Monte Carlo resampling to quantify uncertainty in their pCO₂ 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 pCO₂ values in the past exclude today’s levels or those of the future. Plotting 95% confidence intervals (and therefore utilizing the usual α = 0.05 level for statistical inference) shows that pCO₂ values of >500 ppm are entirely consistent with Cui et al.’s reconstruction for much of the past 23 m.y., including in the Pliocene and Pleistocene. The C₃ proxy therefore fails to reject elevated pCO₂ conditions for the late Neogene and Quaternary, despite the downward biasing in the pCO₂ estimates themselves (Fig. 1D).

REFERENCES CITED

Cui, Y., Schubert, B.A., and Jahren, A.H., 2020, A 23 m.y. record of low atmospheric CO₂: Geology, v. 48, p. 888–892, https://doi.org/10.1130/G47681.1.

Jardine, P.E., and Lomax, B.H., 2021, Data and code for “A 23 m.y. record of low atmospheric CO₂”, Comment in Geology: Figshare, https://doi.org/10.6084/m9.figshare.13194554.

Kohn, M.J., 2016, Carbon isotope discrimination in C₃ land plants is independent of natural variations in pCO₂: Geochemoical Perspectives Letters, v. 2, p. 35–43, https://doi.org/10.7185/geochemlet.1604.

Lomax, B.H., Lake, J.A., Leng, M.J., and Jardine, P.E., 2019, An experimental evaluation of the use of ∆¹³C as a proxy for palaeoatmospheric CO₂: Geochimica et Cosmochimica Acta, v. 247, p. 162–174, https://doi.org/10.1016/j.gca.2018.12.026.

Loughney, K.M., Hren, M.T., Smith, S.Y., and Pappas, J.L., 2020, Vegetation and habitat change in southern California through the Middle Miocene Climatic Optimum: Paleoenvironmental records from the Barstow Formation, Mojave Desert, USA: Geological Society of America Bulletin, v. 132, p. 113–129, https://doi.org/10.1130/B35061.1.

Schubert, B.A., and Jahren, A.H., 2015, Global increase in plant carbon isotope fractionation following the Last Glacial Maximum caused by increase in atmospheric pCO₂: Geology, v. 43, p. 435–438, https://doi.org/10.1130/G36467.1.

Stein, R.A., Sheldon, N.D., and Smith, S.Y., 2020, C₃ plant carbon isotope discrimination does not respond to CO₂ concentration on decadal to centennial timescales: The New Phytologist, https://doi.org/10.1111/nph.17030 (in press).