

REPLY TO ADAMS ET AL.:

Empirical versus process-based approaches to modeling temperature responses of leaf respiration

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Using an empirical approach, we report that the slope of the short-term log-transformed leaf respiration (R)–temperature (T) curves declines with increasing leaf T in a manner that is uniform across biomes (1); the results have utility for modeling carbon fluxes in terrestrial biosphere models (TBMs). The use of an empirical approach reflects the fact that, despite advances in understanding of factors regulating R (2–4) and its T -response (5), basic information on key determinants of R remains lacking, hindering development of a process-based model with utility for TBMs. Some, including Adams et al. (6), view Arrhenius theory as providing a way forward and argue that it is both predictive and mechanistic. As noted (6), this approach provides equivalent predictive power as the log-polynomial function (1), a finding that we do not dispute, and that was recently noted in a separate paper comparing several approaches to fitting short-term T -function of R (7). We also agree that global convergence in the shape of R – T curves is an indication that respiratory regulation is likely to be common across plants (6). Where we differ, however, is whether the applied Arrhenius approach (6) is mechanistic. Arrhenius theory is applicable to reactions catalyzed by single enzymes that are substrate-saturated. For respiratory metabolism in plants, neither assumption holds, because the respiratory system is made up of numerous, highly-regulated reactions that are rarely substrate-saturated (8). Thus, although activation energy (E_a) values of R , including temperature-dependent ones (9, 10), provide estimates of the temperature coefficient of

the overall respiratory system, they can be viewed as outputs of a statistical fit, because they do not necessarily provide insights into the individual mechanisms underpinning variation in R – T curves.

In the temperature-modified Arrhenius approach (9), changes in the slope of log-transformed R – T curves are achieved via adding a factor (δ) to account for T -dependent changes in the activation energy (i.e., T -sensitivity) estimated at 0 °C (E_0). Similarly, we (1) provide estimates of the T -sensitivity at 0 °C, and how the T -sensitivity of R declines with increasing leaf T (i.e., b - and c -parameters in the polynomial). Thus, in general terms, b and E_0 describe the T -sensitivity at 0 °C, with c and δ accounting for deceleration in R as leaves warm. Congruence in the two approaches therefore reflects their underlying operational similarities, raising the possibility that TBMs can indeed use either approach (1, 9).

Looking forward, development of a process-based model to account for the complexity of taxa- and environment-driven variations in R (11) remains a high priority. Notable advances are clarifying individual and collective mechanistic controls of R through models and experiments (2–5). Ideally in the future, a truly mechanistic approach based on these advances will emerge that meets the TBM integration requirements of being parameter-sparse, scalable, and spatially robust; however, current knowledge remains insufficient. Because of this fact, we suggest that empirical-based second order polynomials (1, 6, 9) fitted to globally relevant R – T curve datasets (1) are an appropriate way for current TBMs to model dynamic variations in short-term R – T curves.

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