Predictions of Gross Primary Production from a suite of Terrestrial Biome Models display divergent relationships with key environmental variables

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Accurate simulations of gross primary production (GPP) are vital for Earth System Models that must inform public policy decisions. The instantaneous controls of leaf-level photosynthesis, which can be measured in manipulative experiments, are well established. At the canopy scale, however, there is no consensus on how GPP depends on (a) light or (b) other aspects of the physical environment such as temperature and CO₂. Models of GPP make a variety of different assumptions when ‘scaling-up’ the standard model of photosynthesis. As a troublesome consequence, they make a variety of different predictions about how GPP responds to projected environmental change.

This problem can be tackled by theoretical modelling and by empirical analysis of GPP as reconstructed from eddy-covariance flux measurements. Theoretical modelling has provided an explanation for why ‘light-use efficiency’ (LUE) models work well at time scales of a week or longer. The same logic provides a justification for the use of LUE as a key metric in an empirical analysis. By focusing on LUE, we can isolate the drivers of GPP independent of its over-riding control by absorbed light. We have used open-access eddy covariance data from over 100 sites, collated over 20 years (the number of sites has grown with time). These sites, located in a wide range of biomes and climate zones, form part of the FLUXNET network. We have combined the flux data with a satellite product (EVI from MODIS) that allows spatial estimates of the fraction of incident light absorbed by green vegetation. Matching soil moisture data were estimated using the SPLASH model, with appropriate meteorological inputs, and soil water-holding capacity derived using SoilGrids. LUE was then calculated as the amount of carbon fixed per unit of absorbed light. We then explored additive models (incorporating multiple explanatory factors) that support non-linear responses. Recognising that our longitudinal data lack independence, we controlled for the hierarchical nature of the dataset through a variance structure that nests measurement year within site location.

In arriving at a preferred parsimonious model, we show that daytime air temperature and vapour
pressure deficit, and soil moisture content are all salient predictors of LUE. The same explanatory terms are retained in iterations of this analysis run at timescales from weeks to months. As a model-comparison exercise, we used that portion of our dataset which overlaps the North American Carbon Program to apply our empirical model structure to site-based estimates of GPP generated by 19 discrete Terrestrial Biosphere Models (TBMs). The comparative analysis reveals wide variation between the TBMs in the shape, strength and even sign of the environmental effects on modelled GPP.

This empirical analysis suggests it is feasible to predict GPP using a single model structure, common across vegetation categories. And the appeal of such universal approaches is highlighted by inconsistent relationships with key environmental drivers within extant terrestrial models.