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# Towards Understanding the Inter-Annual Variation of Model Parameters Used to Simulate Gross Primary Productivity

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A persistent challenge for models simulating carbon fluxes, such as gross primary productivity (GPP), is that the inter-annual variability (IAV) is currently not well-represented, often underestimating the peak GPP values, while also struggling with representing the onset and end of vegetation activity. We hypothesize that the difficulty with representing IAV can be attributed to temporally fixed model parameters, and yearly varying parameters can partially alleviate it. We test this hypothesis using two models: a simple light-use efficiency (LUE) model with response functions of solar radiation, air temperature, vapor pressure deficit, cloudiness, and soil water content, and an optimality-based model that includes parameter acclimation and drought stress. These functions have multiple parameters requiring calibration.

First, we calibrated all the model parameters per site-year and found that both models can

simulate annual GPP better with annually calibrated parameters (median normalized Nash-Sutcliffe efficiency, viz. NNSE: 0.74 for the LUE model) compared to parameter calibration per site (median NNSE: 0.5) or per plant functional types (median NNSE: 0.23). Thereafter, we focused on calibrating parameters of one environmental response function as year-specific (one function at a time), while simultaneously calibrating year-invariant parameters for all other functions. These exercises were conducted for 198 eddy-covariance sites. The ability to represent IAV of GPP in arid sites was substantially improved when hydrological parameters were allowed to vary between years, both for herbaceous and forest ecosystems. However, for tropical, temperate and boreal climates, improvements in IAV emerged from parametric variability controlling the GPP responses to temperature, light or atmospheric dryness. Given the paucity of arid and semi-arid sites in the dataset, allowing year-specific parameters for vapor pressure deficit and atmospheric $CO_2$ effects yielded a median annual NNSE of 0.73 across the whole dataset for the LUE model. These results challenge our perception on temporally static parameterizations, reflecting the need to learn the empirical relationships between observations and temporally-varying parameters, or improve the representation of missing state variables. It further suggests that these may be strongly linked to below-ground plant dynamics, largely unobserved in current Earth observation networks.

However, by analyzing mean absolute deviation of parameter values from per site and per site-year model calibrations, we found that temporal variation of parameters was lower than their spatial variation. For example, spatial variability of parameters, such as optimal temperature for photosynthesis, was 82.6% higher than temporal variability. Though we show that the temporal variability of model parameters is important to better capture the IAV of GPP flux, our analyses are currently limited to eddy-covariance sites, and only for the measurement periods at these sites.

As a next step, further research is needed to explain or statistically learn the temporal variability of model parameters using environmental variables, which can be used to predict the spatiotemporal variability of model parameters at sites with no observational data or predict the future temporal trend of model parameters. This, in turn, will likely improve the performance of simulated IAV of GPP and, consequently, enhance our ability to represent unknown linkages between IAV and longer time scales.