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Evaluating a generic parameterization approach for modelling photosynthesis across eddy-covariance sites

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Earth's climate is strongly influenced by global biogeochemical cycles. Atmospheric carbon dioxide (CO_2) is the main component of one of the most crucial biogeochemical cycles, i.e., the carbon cycle. Terrestrial ecosystems can regulate the atmospheric CO_2 concentration, and absorb a substantial fraction of anthropogenic emissions via photosynthesis. Quantifying and understanding the rate of carbon assimilation through photosynthesis, or gross primary production (GPP), at different spatial and temporal scales, is of utmost importance.

In this direction, the development of an eco-evolutionary optimality (EEO) perspective on ecophysiological plant parameters has been proposed as a robust theoretical framework to capture GPP dynamics. Its translation into modelling frameworks has been proposed by combining the least-cost and coordination principles and implemented in big leaf light use efficiency models. These models have been contrasted against *in situ* observations of carbon fluxes from FLUXNET at daily and sub-daily scales, distinguishing between instantaneous (fast) and acclimated (long-time) biochemical and stomatal response of leaf for the latter case. A fundamental assumption and difference to many other modelling approaches is the constant parameterization across all plant-functional-types (PFT) in this case. We further investigate the applicability of the approach in this study.

We simulate half-hourly GPP across 191 FLUXNET sites, representing a wide variety of vegetation and climatic zones to evaluate the extent of observational support to a global EEO approach as implemented in the P-model (Mengoli et al., 2022). Model assessment metrics such as Nash-Sutcliffe efficiency (NSE), root mean squared error (RMSE), and coefficient of determination (R^2) were calculated between observed and simulated GPP at various timescales for this purpose. The analysis is performed globally, but also within PFT and bioclimatic regimes. Furthermore, we relax the acclimation time-periods, gradually from 1 to 80 days, to identify potential changes in acclimation windows between sites and how it varies across PFTs.

Negative values of NSE, suggesting poor model performance, were found for almost 50% of sites at half-hourly, daily, weekly, and monthly timescales. Specifically, inter-annual variability of GPP cannot be reproduced for most of the sites when sub-daily GPP was aggregated to annual values. It was observed that the model performs better in croplands, followed by mixed and deciduous broadleaf forests, and then grasslands and savannas. The model can perform better at boreal and temperate sites than at tropical and arid sites. Moreover, we found different time-period of acclimation across different PFT, for example, croplands have an average timescale of 10-15 days for acclimation whereas it is 75-80 days for evergreen needle leaf forests.

One known limiting aspect in the current implementation is the lack of the effects of soil water limitation on photosynthesis. As a consequence, we found that model performance was positively correlated with the aridity index of sites. Specifically, model fails to capture annual GPP at arid sites. We further analyse and discuss how exploring soil moisture effects on photosynthesis parameters may lend support to this framework although model performance across some of the energy demand driven sites suggests a cautionary remark on the applicability of the approach.