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Species-Specific Controls on Carbon–Water Coupling in European Temperate Forests: A Process-Based Sensitivity Analysis Using the CARAIB Dynamic Vegetation Model

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Temperate forests play a central role in Europe's carbon and water cycles, yet process-based vegetation models remain weakly constrained at the species and daily timescale, particularly with respect to physiological and radiative controls on carbon–water coupling. In Wallonia (Belgium), forests cover 33% of the territory and represent about 80 % of the country's forest area, with European beech (*Fagus sylvatica*), oaks (*Quercus robur* and *Quercus petraea*), Norway spruce (*Picea abies*) and Douglas fir (*Pseudotsuga menziesii*) among the dominant species.

Here, we present a species-specific, daily-scale sensitivity analysis of the CARAIB dynamic vegetation model at the FLUXNET/ICOS Vielsalm site (BE-Vie), a mixed forest site with European beech and Douglas fir as dominant species. Model performance is evaluated using eddy-covariance–derived gross primary production (GPP), total ecosystem respiration (TER), net ecosystem exchange (NEE) and actual evapotranspiration (AET) products for 1997–2021 processed with multiple friction-velocity (u*) filtering methods.

We systematically examine how forest management (year of plantation, thinning), nitrogen availability, plant functional traits, and radiative processes shape simulated GPP, TER, NEE and water-use efficiency (WUE, i.e., the ratio of GPP to transpiration). Physiological parameters constraining the model include slope of stomatal relationship (g□), specific leaf area (SLA), carbon-to-nitrogen ratio (C:N) and fraction of sapwood (fsw), as well as the level of isohydricity of the tree species. Radiative sensitivity is assessed using diffuse radiation fraction at the top of canopy and leaf optical properties. Soil respiration sensitivity is also assessed through parameters controlling its dependence on temperature and soil water content.

We put a particular emphasis on understanding the way the studied parameters impact the response of GPP, TER and NEE to droughts, by comparing drought years (e.g., 2018, 2019 and

2020) to normal years. The findings demonstrate that species-specific, process-based calibration is essential for improving dynamic vegetation model reliability in European temperate forests under management, climate and environmental changes.