Oxygen flux simulation as a new tracer for the carbon and nitrogen cycles in a temperate forest ecosystem

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The O₂:CO₂ exchange ratio (ER) between terrestrial ecosystems and the atmosphere is a key parameter for partitioning global ocean and land carbon fluxes. The long-term terrestrial ER is considered to be close to 1.10 mol of O₂ consumed per mole of CO₂ produced. Due to the technical challenges in measuring directly the ER of entire terrestrial ecosystems (EReco), little is known about variations in ER at hourly and seasonal scales, as well as how different ecosystem and flux components (e.g., vegetation and soil, assimilation and respiration) contribute to EReco. In this modeling study, we explored the variability in and drivers of EReco and evaluated the hypothetical uncertainty in determining ecosystem O₂ fluxes based on current instrument precision used in micrometeorological methods such as the flux-gradient approach. We updated the one-dimensional, multilayer atmosphere–biosphere gas exchange model “CANVEG” by 1) implementing ER for various ecosystem components in the model; 2) implementing the control of triose phosphate utilization (TPU) and Medlyn's stomatal conductance equation to CO₂ assimilation; and 3) linking photosynthetic O₂ emission to nitrogen (N) assimilation sources. The model study was conducted at the Leinefelde FLUXNET site, a temperate beech forest in Germany, where eddy covariance, profile, and gas exchange chamber measurements were available.

We found that when assuming fixed ER for CO₂ assimilation and respiration, the hourly EReco showed strong variations over diel and seasonal cycles and within the vertical canopy profile, indicating the potential to partition eddy-covariance derived CO₂ fluxes with corresponding O₂ flux measurements. The O₂ and CO₂ mole fraction ratio of canopy air (ERcon) showed different values and mechanisms from EReco. The model showed more robust performances in future CO₂, temperature and air humidity conditions when taking into account TPU limitation and Medlyn's stomatal conductance algorithm in CO₂ assimilation processes. The predicted net carbon sink under elevated atmospheric CO₂ mole fraction increased less with TPU limitation than without. The most significant impacts on photosynthetic O₂ emission and hence the ER of CO₂ assimilation resulted from variation in nitrogen assimilation sources. The ER of net assimilation measured with branch-level gas exchange chambers showed little variation from 1.0 mol mol⁻¹, indicating
ammonia as the main N assimilation source. The model indicated that the O$_2$ emission would increase by up to 23% if nitrate was used as N assimilation source.

Our study successfully coupled oxygen with carbon fluxes within a multilayer atmosphere–biosphere gas exchange model. The modeling study yielded that the application of the flux-gradient measurement approach is feasible to derive ecosystem O$_2$ fluxes. To achieve better model behavior, it is necessary to incorporate TPU limitation in the assimilation model and to properly consider N assimilation during photosynthesis.