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Improving estimates of Gross Primary Productivity by assimilating solar-induced fluorescence satellite retrievals in a terrestrial biosphere model using a process-based SIF model

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By offsetting about one fourth of carbon dioxide (CO_2) emissions released by anthropogenic activities into the atmosphere, terrestrial ecosystems play a pivotal role for climate. They assimilate CO_2 in leaf chloroplasts by photosynthesis, but most of the assimilated carbon is released back into the atmosphere through ecosystem respiration. Although the net carbon budget of terrestrial ecosystems is the main quantity of interest for climate studies, quantifying the gross fluxes is crucial in order to better understand the drivers of the net fluxes. As highlighted by the large spread in global land surface model (LSM) simulations relative to the spatio-temporal patterns of the terrestrial gross primary productivity (GPP), large uncertainties remain in our understanding of the carbon sequestration in land surfaces. Part of these uncertainties result from unknown or poorly calibrated parameters in LSMs. Over the past decade, the use of space-borne retrievals of solar-induced fluorescence (SIF) as a proxy of GPP at large temporal and spatial scales has grown in importance. Their use for constraining LSMs implies that these models are able to simulate SIF observables and represent the functional links between GPP and SIF.

In this study, we present the development of a SIF observation operator in the ORCHIDEE LSM. It relies on i) the representation of the fluorescence yield of photosystem II (PSII) at the leaf scale to simulate the dynamic regulation of SIF depending on meteorological conditions (e.g. incoming PAR, temperature, relative humidity, concentration of CO_2 at the leaf level), and on ii) the calculation of the total canopy fluorescence (PSI and PSII) based on a parametric modelling of the 1D radiative transfer model in SCOPE enabling fast computation of the radiative transfer. The calculation of the yield of PSII fluorescence depends on new parametric model to estimate the total Non Photochemical Quenching.

We then apply a Bayesian assimilation framework to assimilate monthly OCO-2-SIF product at 0.5° over 2015-2016 and hence calibrate ORCHIDEE over an ensemble of pixels for all vegetation plant functional types (PFTs). Through the optimization of photosynthesis and phenological ORCHIDEE parameters, the feedback on the simulated GPP is considerable with a decrease of the global budget by 33 GtC.yr-1 over the 1990-2009 period (from 162 GtC.yr-1 with the standard model parameters to 129 GtC.yr-1 after assimilation). Although the optimized global GPP budget gets in close agreement with that of independent FLUXCOM GPP products (Tramontana et al., 2016) (121 GtC.yr-1 in average over the same period), the spatio-temporal distribution of the improvement of ORCHIDEE relative to both OCO-2-SIF observations and FLUXCOM-GPP estimates show contrasted results between ecosystems. Indeed, our assimilation framework results in opposite variations in the modeled SIF and GPP for some PFTs. This suggest a biome dependency of the SIF-GPP relationship, likely through differences in PSII fluorescence yield at the leaf scale or in the radiative transfer regime, that needs to be resolve to enhance the observational constraint brought by space-borne SIF products on vegetation productivity. We discuss the benefits of using SIF data to constrain LSMs with regards to other available observations.