Enhanced Wetland Representation and Parameter Optimization for Carbon-Flux Simulations in CLM5-FATES

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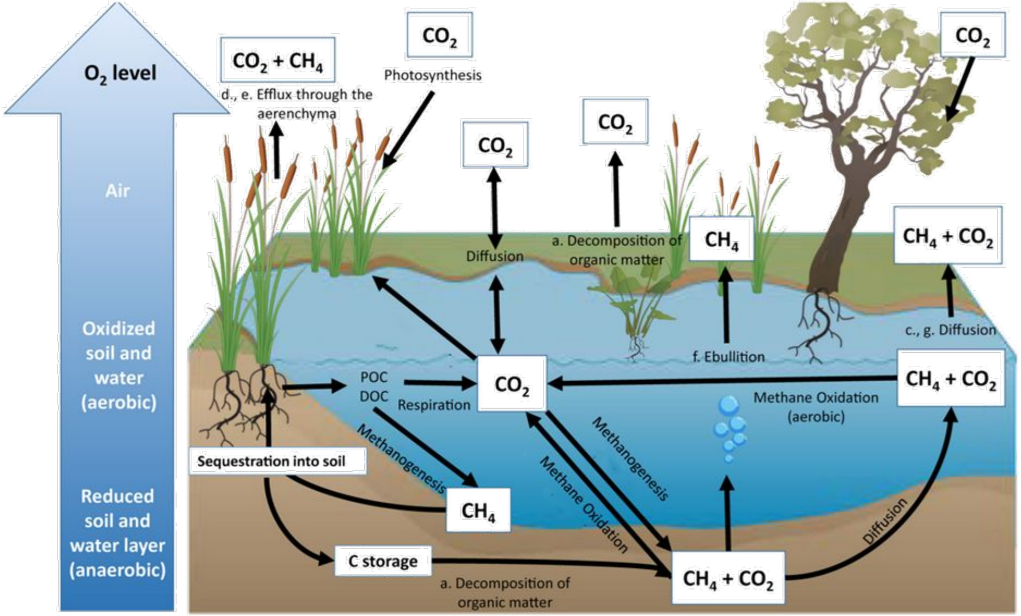
Introduction



(Limpert et al., 2020)

- Wetlands: significant carbon reservoirs and the largest natural source of methane
- Require further development in process-based model in terms of conceptual understanding of in situ wetland processes, technical approaches for incorporating real-world phenomena into models, and parameter uncertainty (Forbrich et al., 2024)

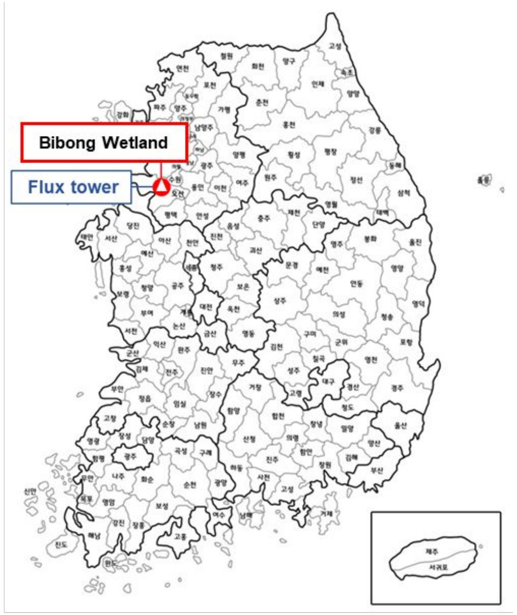
Objectives

1. Establish a wetland-specific modeling environments in CLM5-FATES that could incorporate site-specific vegetation and soil characteristics

2. Identify key parameters governing carbon fluxes and optimize them using observational data

3. Apply the model to the freshwater wetland in Korea and assess its performance in simulating carbon fluxes

Study Site



- **Location:** 37.27° N, 126.86° E

- **Mean annual temperature:** 13.1 °C (annual maximum: 29.9 °C; annual minimum: −14.6 °C)

- **Mean annual precipitation:** 1,432.3 mm

- **Dominant vegetation:** Common reed (*Phragmites australis*) and bulrush (*Schoenoplectus* spp.) (C_3 grasses)

- **Observational data:**
  - Eddy-covariance flux tower: May, 2023 - Present
  - Monthly 17 CO_2 & CH_4 static chamber measurement from 2024

Key Parameters for Carbon Fluxes

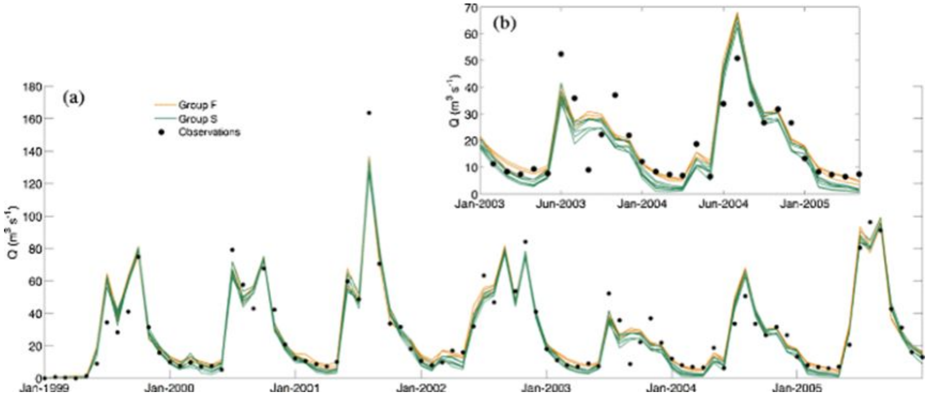
- Parameter sensitivity analysis on permanently flooded freshwater wetland sites with similar vegetation FLUXNET-CH_4
- Variance-based global sensitivity method using PCE (Polynomial Chaos Expansion)-based Sobol sensitivity indices
- Generalized Likelihood Uncertainty Estimation (GLUE) approach to derive optimal confidence intervals using RMSE as a informal likelihood function

[1st-order Sobol Index]

$$S_i = \frac{\mathrm{Var}\left(\mathcal{M}_i(X_i)\right)}{\mathrm{Var}(Y)}, \qquad i = 1, \ldots, n$$

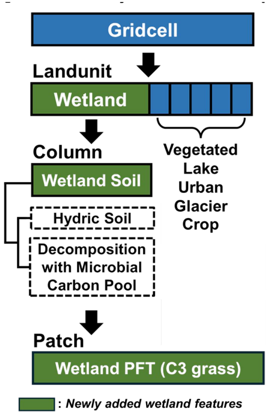
[2nd-order Sobol Index (Interactions)]

$$S_{ij} = \frac{\mathrm{Var}\left(\mathcal{M}_{ij}(X_{ij})\right)}{\mathrm{Var}(Y)}, \qquad 1 \leq i < j \leq n$$

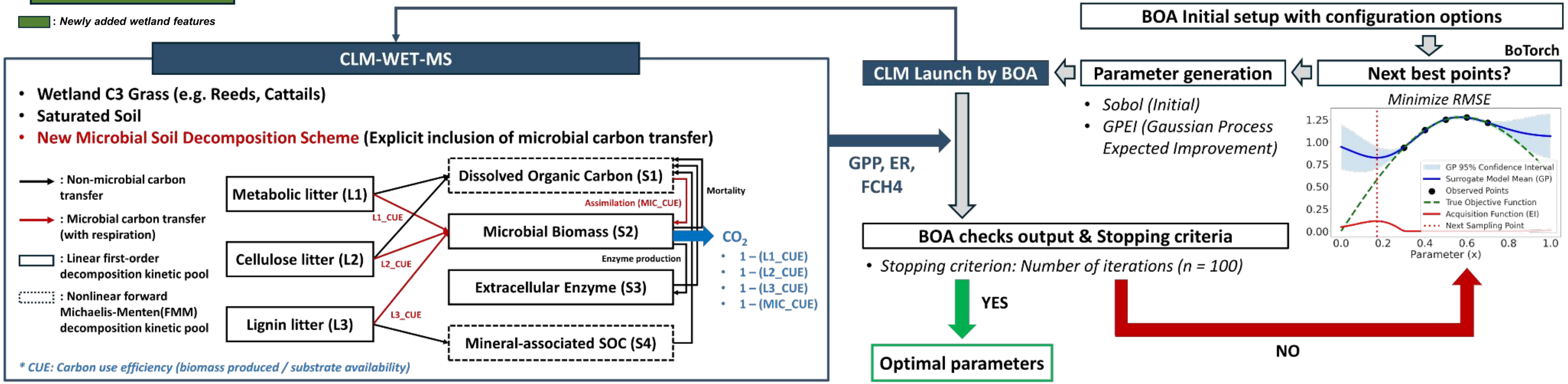


(Rivera et al., 2015)

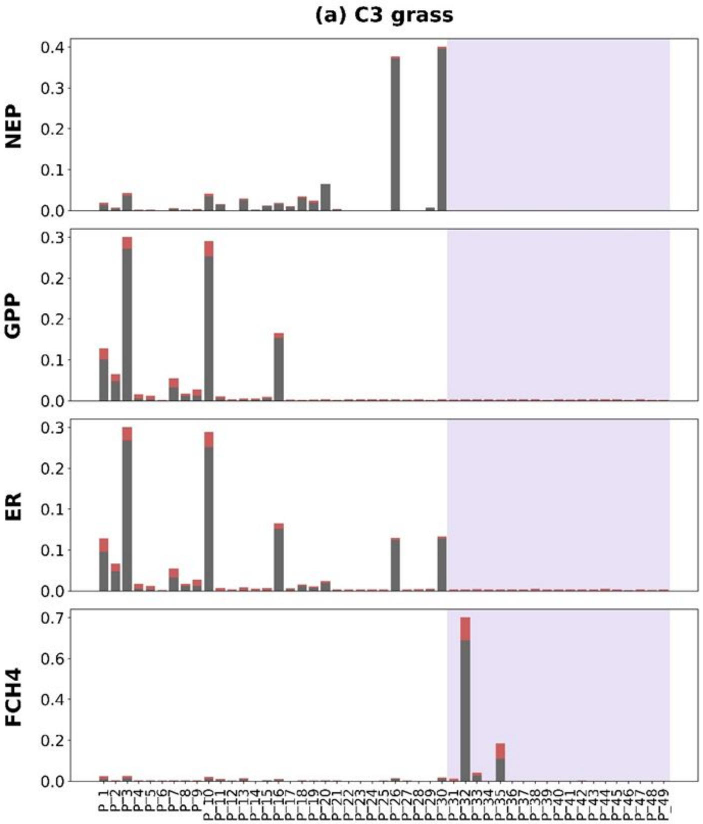
Wetland Modeling Environment

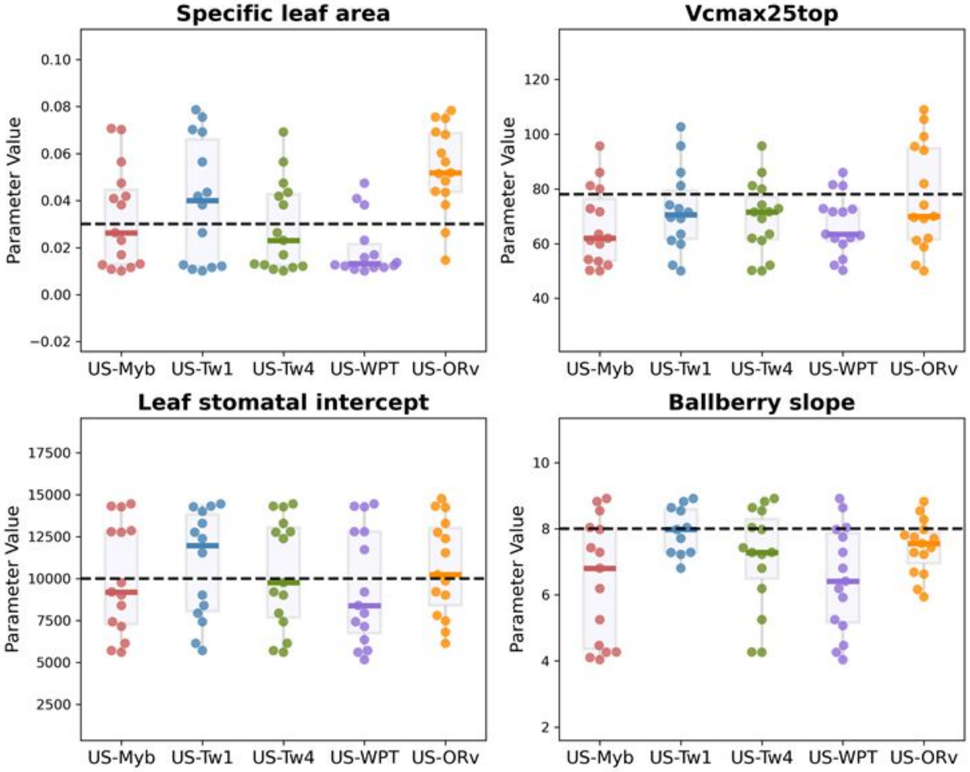


- Wetland landunit activation with hydric soil
- Decomposition pool and carbon transfer pathway with microbial carbon use efficiency (Tao et al., 2023)
- Parameter optimization with BOA (Bayesian Optimization for Anything; Scyphers et al., 2024)
- Hierarchical optimization from GPP, ER, to FCH4 (Yazbeck et al., 2025)

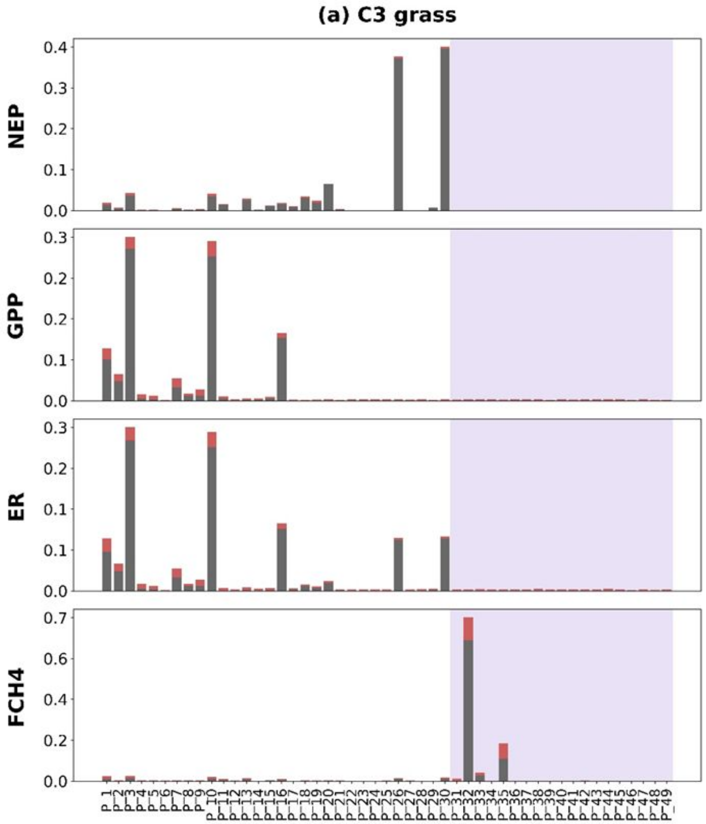


Results

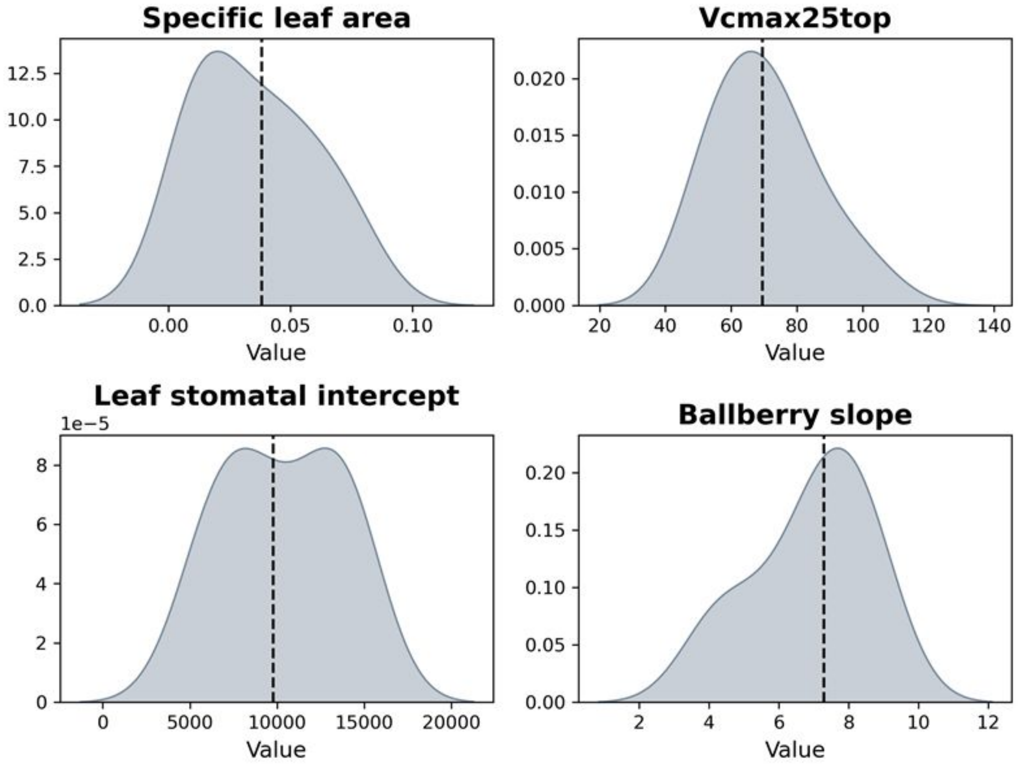

(a) C3 grass
NEP
GPP
ER
FCH4


Specific leaf area
Vcmax25top
Leaf stomatal intercept
Ballberry slope
Parameter Value
US-Myb
US-Tw1
US-Tw4
US-WPT
US-ORv

Results

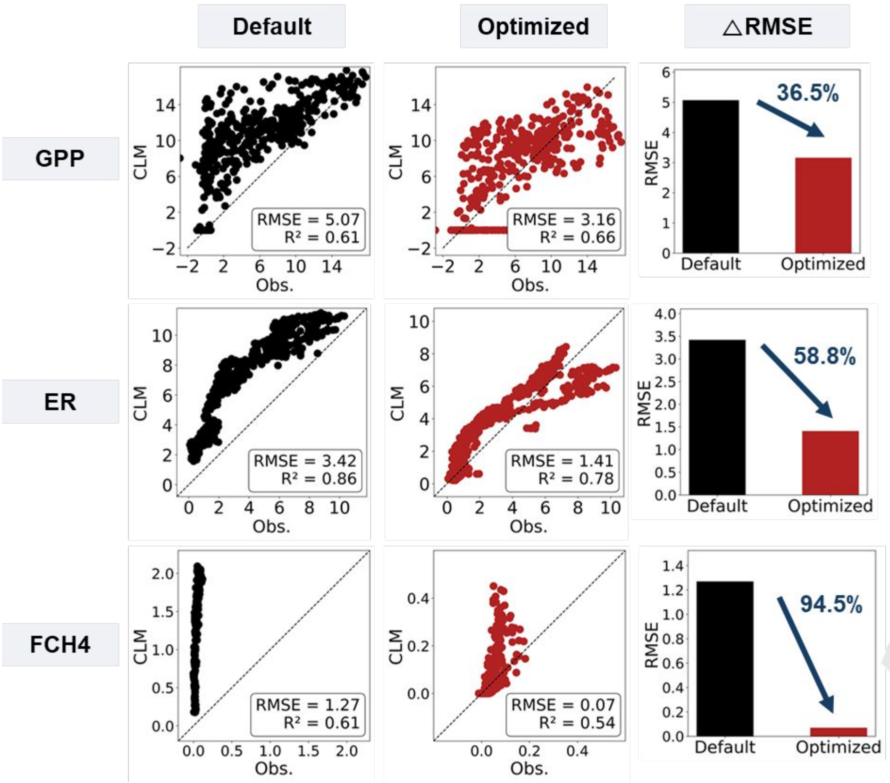


(a) C3 grass
NEP
GPP
ER
FCH4



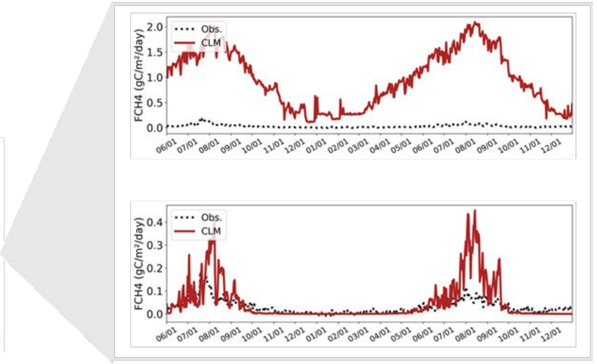
Specific leaf area
Vcmax25top
Leaf stomatal intercept
Ballberry slope
1e−5
Value
Value
Value
Value

Results

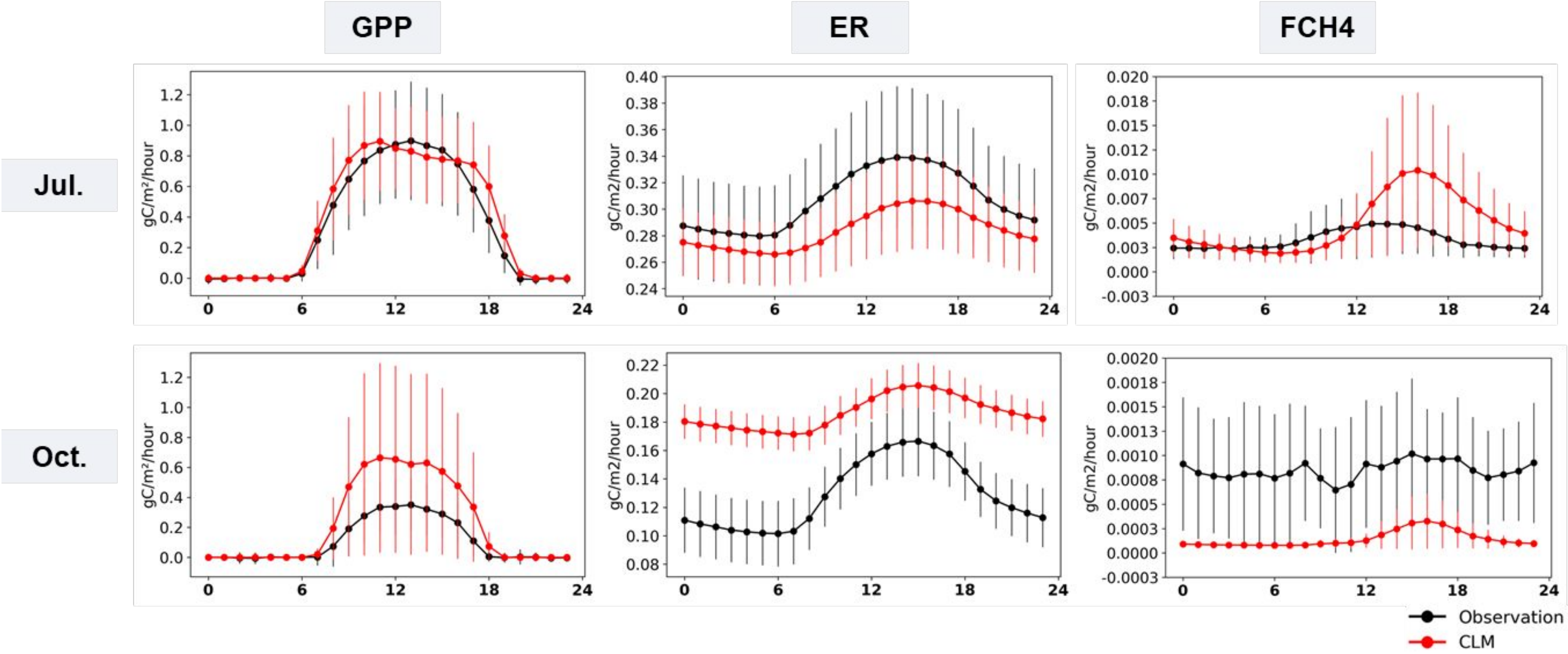


Performance evaluation (daily flux):

- **Optimization period:** 1 June 2023–31 December 2024
- **Results:** Error reductions achieved across all fluxes compared to the baseline simulation; Methane flux RMSE reduced by 94.5%



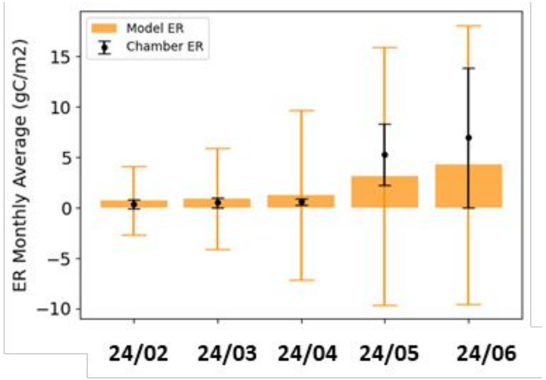
Results



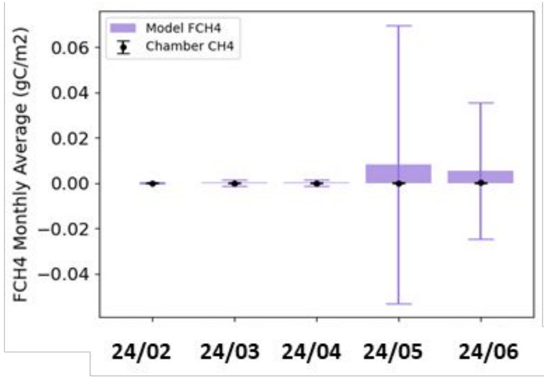
- Optimized model's hourly diel pattern evaluation
- Compared peak growth (July) and senescence (October)
- Increased uncertainty in October compared to July's diel cycle

Results

ER



FCH4



- Monthly model result comparison with chamber measurement
- Need to address temporal scale difference

Working on..

CH4 Production	Aerenchyma Transport	Ebullition	Diffusion	Oxidation

Gas Diffusion Transport Model

$$A = \frac{C(z) - C_a}{\frac{r_L z}{D p T \rho_r} + r_a}$$

$$T = \frac{f_N N_a L}{0.22} \pi R^2$$

- Hard to get direct measurements & Parameters known to be highly uncertain
- Parameters
  - r_L: root length to depth ratio
  - D: diffusion coefficient
  - p: porosity
  - ρ_r: root fraction in soil layer
  - R: aerenchyma radius

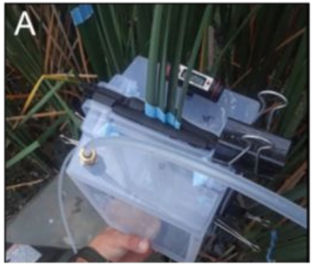
Observation-based Aerenchyma Flux

$$A = \frac{C(z_j) - C_a}{\left(\frac{z_j r_{pft}}{\rho_r L} \sum_{j=1}^{n} \frac{\rho_{rj}}{z_j}\right) + r_a}$$

Field measurement-based resistance per leaf area to methane flux

From leaf-chamber & Porewater methane concentration

- Replace equations with observation-based aerenchyma conductivity & LAI



(Villa et al., 2020)

- Methane module improvement with observed aerenchyma conductivity of wetland vegetation, in collaboration with Ohio State University (Prof. Gil Bohrer).

THANK YOU

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