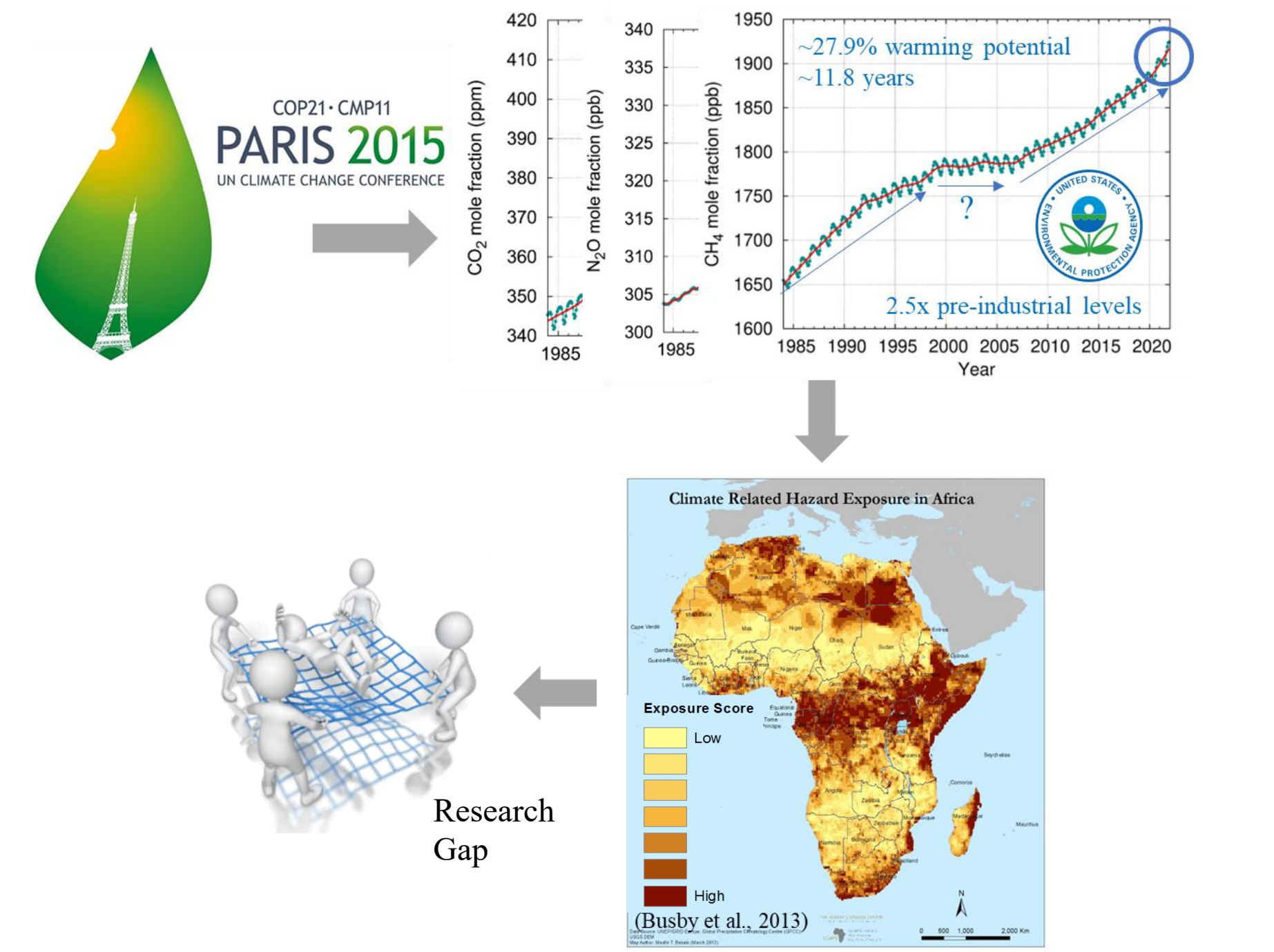


# Assessing Spatial and temporal heterogeneity of Soil Carbon dioxide emissions across anthropized land use Gradient in the Sudanian savanna

Oussou E.F.<sup>1,2,5</sup>, Sy S.<sup>2</sup>, Bliefernicht J.<sup>2</sup>, Spangenberg, I.<sup>2,4</sup>, Guug, S. S.<sup>7</sup>, Steinbrecher, R.<sup>4</sup>, Neidl, F.<sup>4</sup>, Schäffler-Schmidt, A.<sup>4</sup>, Kiese, R.<sup>4</sup>, Ayamba, M.<sup>7</sup>, Yalo, N.<sup>5</sup>, Asiwaju-Bello, A. Y.<sup>6</sup>, Sawadogo, W.<sup>2,4</sup>, Olusegun, C. F.<sup>8</sup>, Amekudzi, L. K.<sup>3</sup>, and Kunstmann, H.<sup>2,4</sup> (francis.oussou@uni-a.de)

<sup>1</sup>Federal University of Technology, Akure, WASCAL, Department of Meteorology and Climate Science, Akure, Ondo State, Nigeria (francis.oussou@uni-a.de) <sup>2</sup>University of Augsburg, Institute of Geography, Augsburg, Germany <sup>3</sup>Kwame Nkrumah University of Science and Technology, Kumasi, Ghana <sup>4</sup>Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Germany <sup>5</sup>Laboratoire d'Hydrologie Appliquée (INE), Université d'Abomey-Calavi, Benin <sup>6</sup>Department Applied Geology, Federal University of Technology Akure, Nigeria <sup>7</sup>West African Science Service Centre on Climate Change and Adapted Land Use, WASCAL Competence Centre, Burkina Faso <sup>8</sup>Department of Earth & Environmental Sciences, Michigan State University, USA

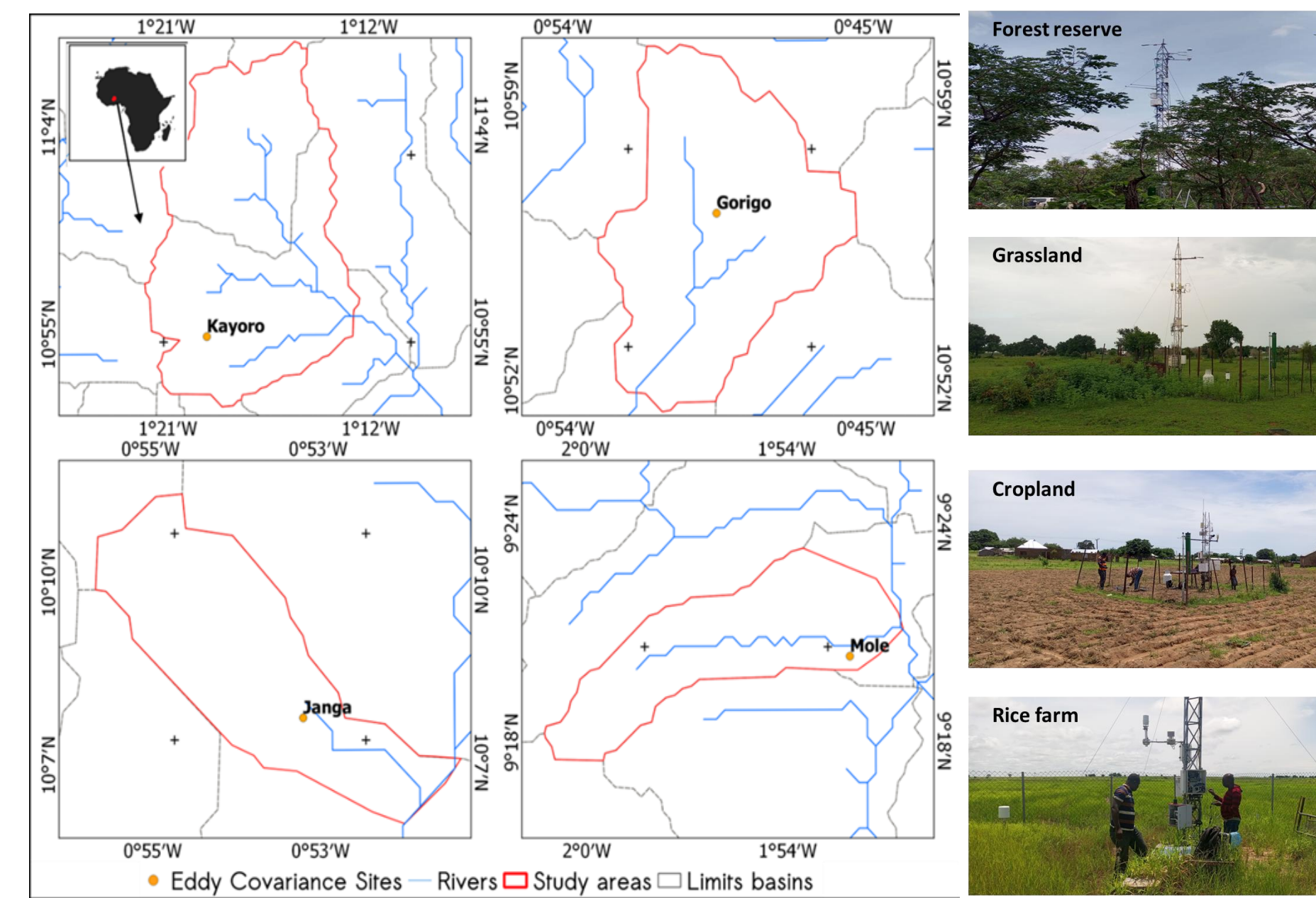
## MOTIVATION



- Impacts of key greenhouse gas (GHG) emissions in West Africa are still not well documented
- This study aims to examine CO<sub>2</sub> fluxes across different land-use types within the Sudanian savanna

## DATA & TOOLS

- Experimental design**
  - Designed chamber is made of 37 x 26.7 cm size collar and intransparent cover implanted at 10 m from the EC tower
  - Five sub-trial points (chambers) are deployed at each site to ascertain the spatial variability.
- Gas sampling & Lab analysis**
  - GHG was sampled with syringes
  - GHG measurement at KIT Lab (Germany)
  - Isotope Ratio Mass Spectrometry test ALL-1.1c (2015-02) used for carbon (δ13C) and nitrogen (δ15N)



## METHODS

- CO<sub>2</sub> flux measurements and calculation**

- Data preprocessing & validation
- Soil property estimation
- Statistical analysis framework
- Advanced modelling & validation



Fig. 2: Chamber-based greenhouse gas sampling plots; closed (middle) and opened (right).

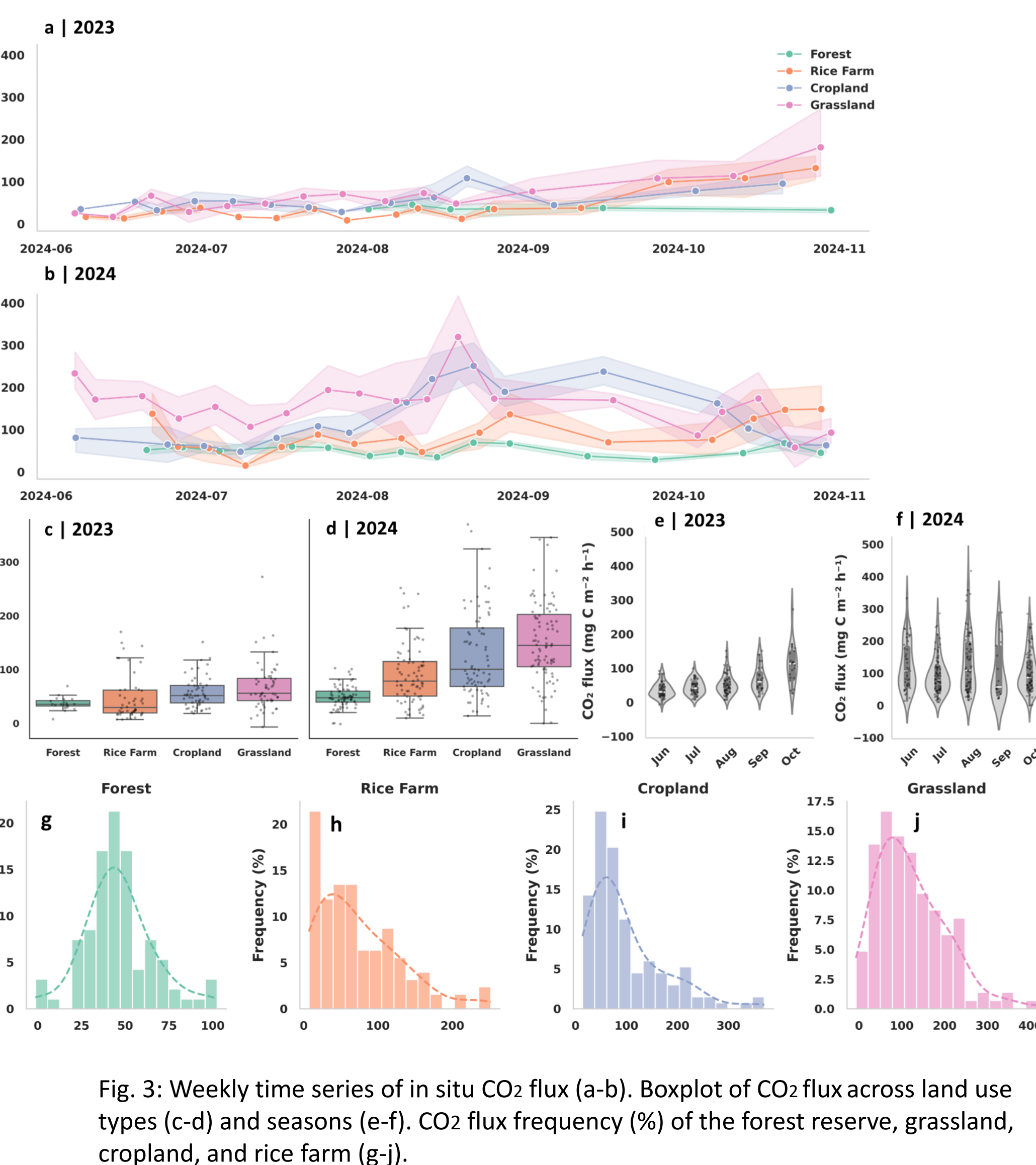
$$F_{CH} = \frac{dq}{dt} \times \frac{V \times P \times M_w}{R \times T} \times \frac{60}{A \times 1000} \text{ (Eq. 1); } WFPS [\%] = \frac{W_{vol}}{(1 - \frac{BD}{2.65})} \text{ (Eq. 2)}$$

$F_{CH}$ : GHG flux ( $\mu\text{g C m}^{-2} \text{ h}^{-1}$ )  
 $dq/dt$ : change in the mixing ratio over time ( $\text{ppb min}^{-1}$  or  $\text{ppm min}^{-1}$ ) resulting from the linear fit,  
 $V$ : chamber volume ( $\text{m}^3$ ),  $P$ : air pressure (Pa),  $M_w = 12$  for  $\text{CO}_2$  and  $\text{CH}_4$  and 28 for  $\text{N}_2\text{O}$  ( $\text{g mol}^{-1}$ ),  
 $T$ : average temperature during the closure time ( $^{\circ}\text{K}$ ),  
 $A$ : surface area of the chamber ( $\text{m}^2$ ) and  $R$ : universal gas constant ( $\text{J mol}^{-1} \text{ }^{\circ}\text{K}^{-1}$ )  
 $WFPS [\%]$ : Water filled pore space  
 $W_{vol}$ : Soil water content [%];  $BD$ : Bulk density

## RESULTS & DISCUSSION

### CO<sub>2</sub> flux diagnostics and dynamics across land-use types

- Forest ecosystems exhibited the lowest cumulative CO<sub>2</sub> efflux among all land uses, with  $\Sigma$ Median values of 0.59 t C ha<sup>-1</sup> season<sup>-1</sup> in 2023 and 1.46 t C ha<sup>-1</sup> season<sup>-1</sup> in 2024, bounded by  $\Sigma$ Min- $\Sigma$ Max ranges of 0.26–0.85 t C ha<sup>-1</sup> season<sup>-1</sup> in 2023 and 1.42–1.62 t C ha<sup>-1</sup> season<sup>-1</sup> in 2024.



### Effects of Land Use, Year, and Season on CO<sub>2</sub>

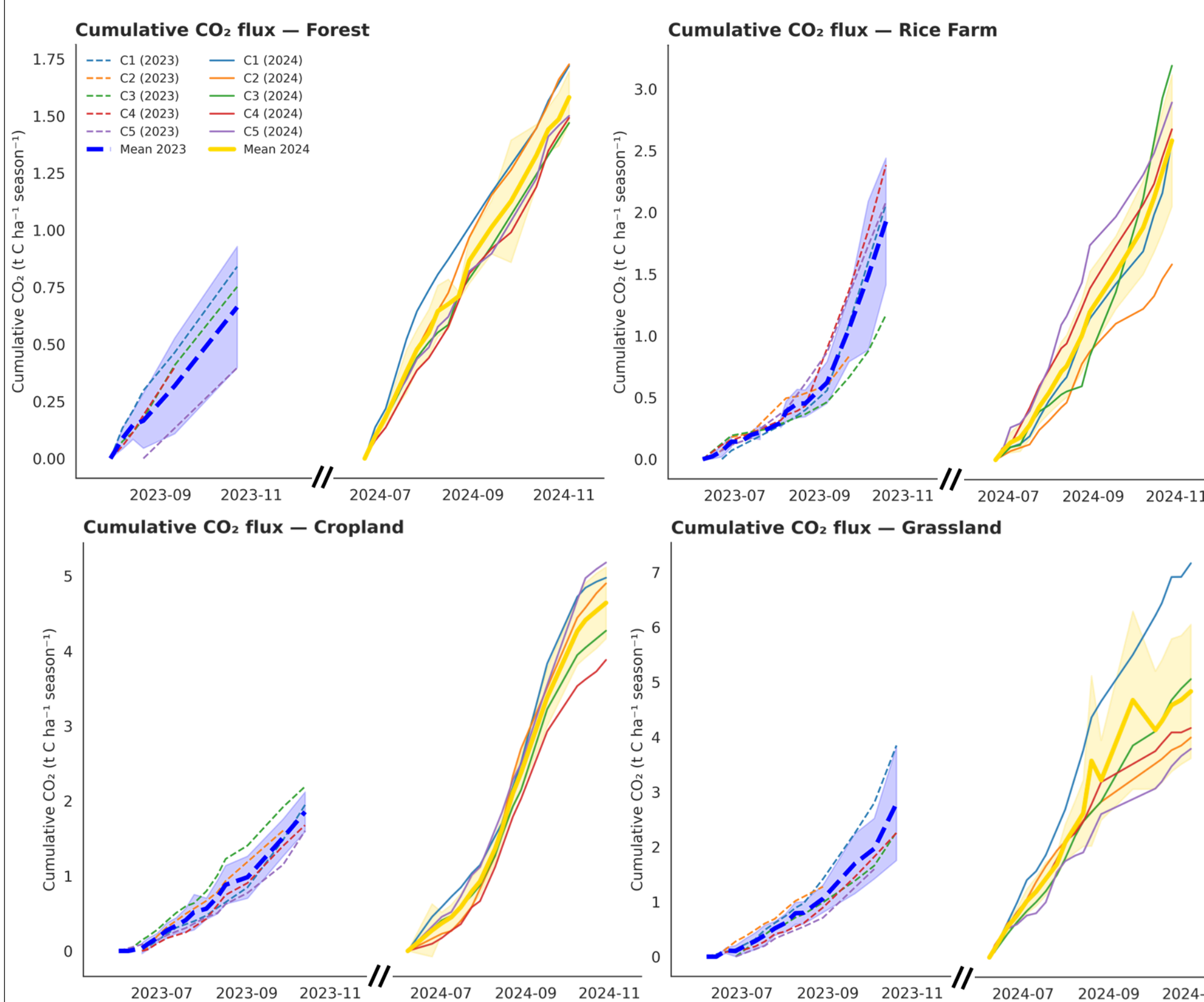


Fig. 4: Cumulative CO<sub>2</sub> flux (t C ha<sup>-1</sup> season<sup>-1</sup>) of the forest reserve, grassland, cropland, and rice farm.

- Grassland systems showed the strongest cumulative CO<sub>2</sub> losses, with  $\Sigma$ Median values increasing sharply from 1.91 t C ha<sup>-1</sup> season<sup>-1</sup> in 2023 to 5.07 t C ha<sup>-1</sup> season<sup>-1</sup> in 2024, and extreme  $\Sigma$ Max values reaching 3.40 t C ha<sup>-1</sup> season<sup>-1</sup> and 7.18 t C ha<sup>-1</sup> season<sup>-1</sup>, respectively.
- Two-way ANOVA results revealed that land use was the strongest driver of flux variation ( $\eta^2 = 0.232$ ), followed by year ( $\eta^2 = 0.102$ ), with a smaller but significant interaction effect ( $\eta^2 = 0.017$ ).

### Environmental Controls and Interaction Effects on CO<sub>2</sub>

- The baseline OLS (Ordinary Least Squares) showed relatively low explanatory power ( $R^2 = 0.24$ ), indicating that simple linear relationships between environmental variables and CO<sub>2</sub> flux are insufficient.
- Adding interaction terms improved model performance ( $R^2 = 0.32$ ; lower AIC), which suggests that environmental effects are context-dependent and vary according to prevailing conditions.

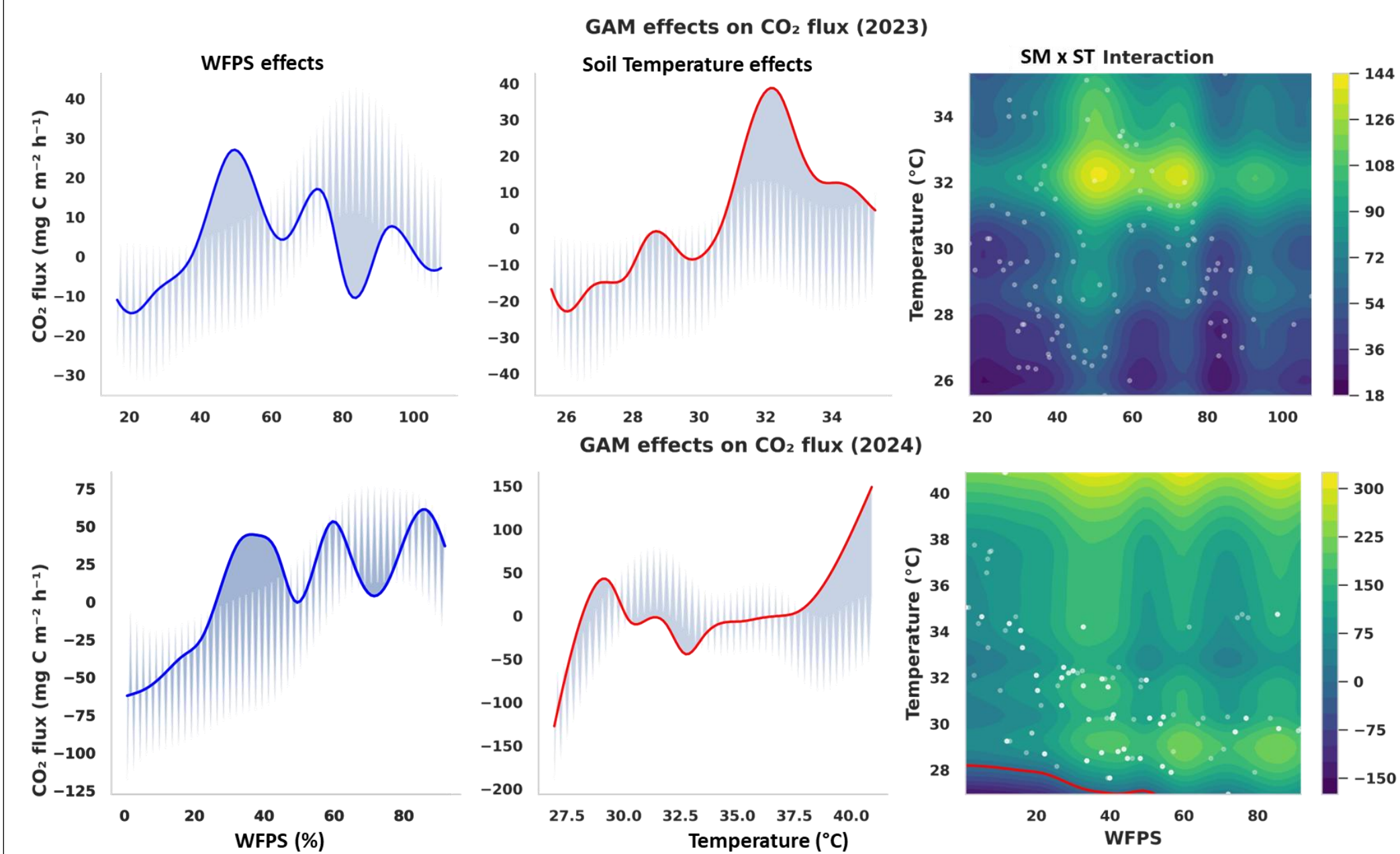


Fig. 5: CO<sub>2</sub> responses to soil moisture (% WFPS) and soil temperature ( $^{\circ}\text{C}$ ) change

- The generalized additive model (GAM) confirmed strong nonlinear relationships between CO<sub>2</sub> flux and environmental drivers.
- Smooth terms for SM and ST were highly significant ( $p < 0.001$ ), and the model explained a substantial proportion of variance (pseudo- $R^2 = 0.44$ ).
- Cross-validation showed moderate predictive ability (mean  $R^2 \approx 0.37$ ), indicating generalizable but variable ecosystem responses.

### Mixed-Effects Modeling and Variance Structure

- Linear mixed-effects models revealed that CO<sub>2</sub> flux variability was strongly structured by both temporal and spatial hierarchy.
- Inclusion of random effects substantially improved model performance, with the advanced mixed model achieving a conditional  $R^2$  of 0.83, compared to a marginal  $R^2$  of 0.61.
- Forest systems showed the lowest residual variance (more stable CO<sub>2</sub> flux)
- Agricultural systems exhibited substantially higher variability, confirming that managed ecosystems are more heterogeneous in their CO<sub>2</sub> flux responses.

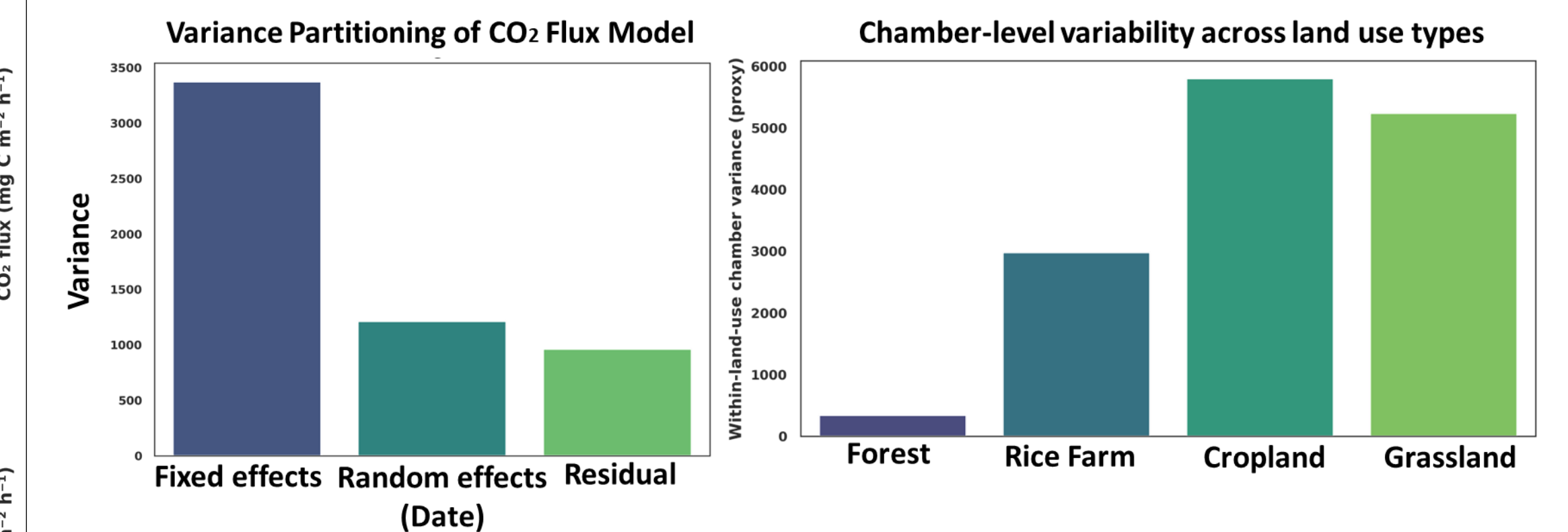


Fig. 5: Variance partitioning across hierarchical levels & Chamber-level variability across land-use types

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