Investigating the CO_2 Response of Secondary-Succession Forests at Duke and Oak Ridge FACE Experiments Simulated with ELM-FATES-CNP

Bharat Sharma[1], Anthony Walker[1], Ryan Knox[2], Charlie Koven[2], Rosie Fisher[3], Elizabeth Agee[4], Ram Oren[5], Rich Norby[1], Daniel Ricciuto[1], Xinyuan Wei[1], Xiaojuan Yang[1]

[1]Oak Ridge National Laboratory; [2]Lawrence Berkeley National Laboratory; [3]Center for International Climate Research; [4]DOE Office of Scientific and Technological Information; [5]Duke University

Correspondence : sharmabd@ornl.gov

AGU Annual Meeting, San Francisco, CA, USA, Dec 11-15, 2023

Introduction

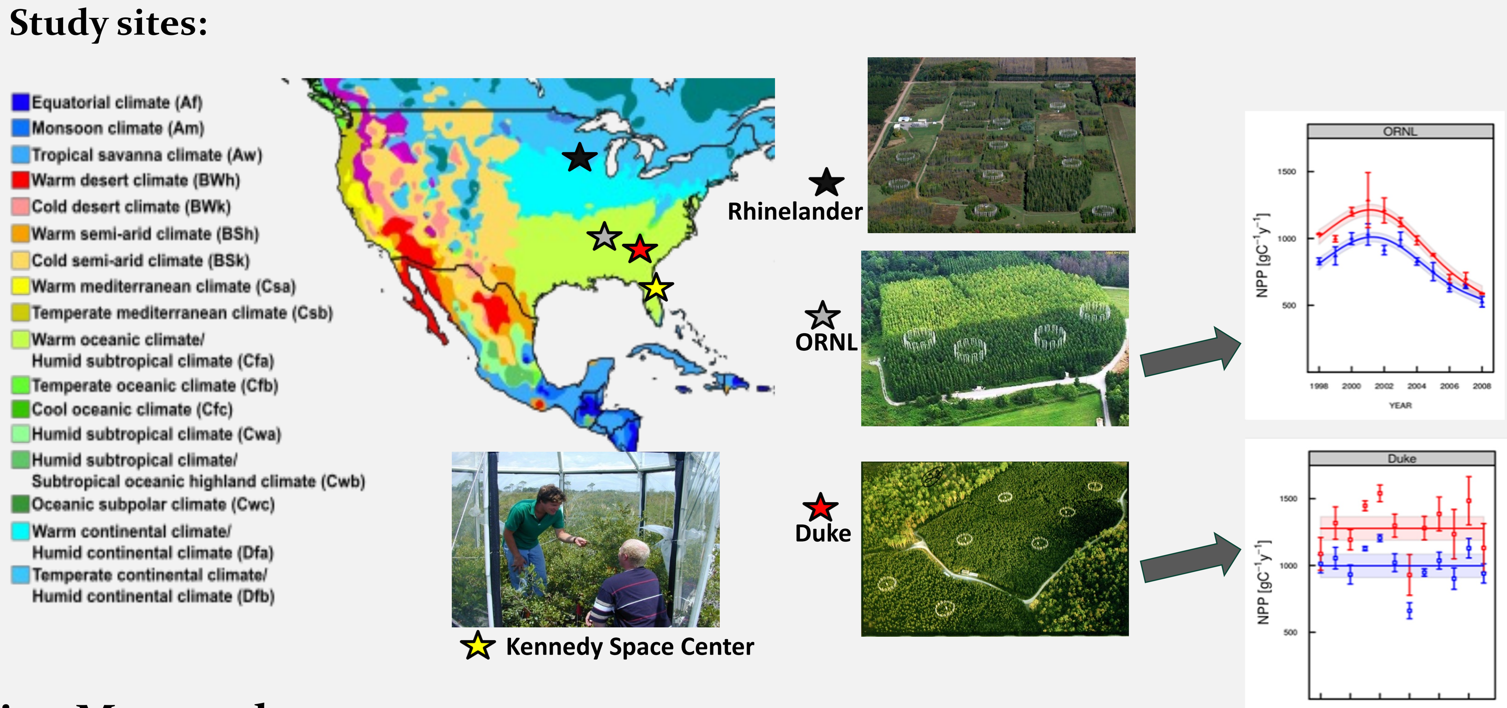
- Many terrestrial biosphere models have suggested that elevated atmospheric CO2 (eCO2) has caused a large fraction of land C sequestration during recent decades and predict that this sequestration will continue to increase in the future.
- First-generation Free Air Carbon Dioxide Enrichment experiments (FACE) provide information on eCO2, nitrogen (N), and decade-long demographic process interactions in secondary forests and plantations, e.g., Duke and Oak Ridge National Lab (ORNL).
- We observe contrasting patterns of net primary productivity (NPP) at Duke and ORNL.
- Given that the response of NPP to eCO2 is related to stand structure, nutrient limitation, and progressive nitrogen limitation (PNL), the objectives of this study are to:

Objective

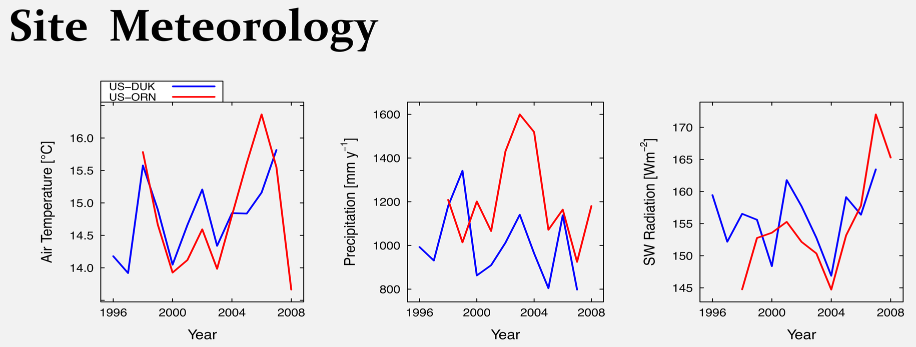
- Long-term: Evaluate the interactions of stand development with nutrient dynamics and their influence on ecosystem eCO2 responses using ELM-FATES-CNP, a nutrient-enabled and size-structured vegetation demography model with carbon and nutrient cycling.
- Here we present simulations of Duke and ORNL FACE experiments with ELM-FATES-CNP to investigate and improve NPP representation of secondary plantation forests in which the FACE experiments were sited.

Methods

- Nutrient-enabled ELM-FATES-CNP (Knox *et al.,* 2023) is recently developed and can run with both relative demand (RD) and equilibrium chemistry approximation (ECA) representations of nutrient acquisition. ELM-FATES is run within the Offline Land Model Testbed (OLMT).
- ELM-FATES-CNP includes a dynamic allocation scheme whereby the target leaf:fine-root biomass ratio (L2Fr) is a function of relative carbon and nitrogen and phosphorus storage.
- Code versions:
- ELM: 85e6083 (30th Jan 2023) ; FATES: e663a6e (2nd Dec 2022); OLMT: ca1be8d
- **Study sites:**

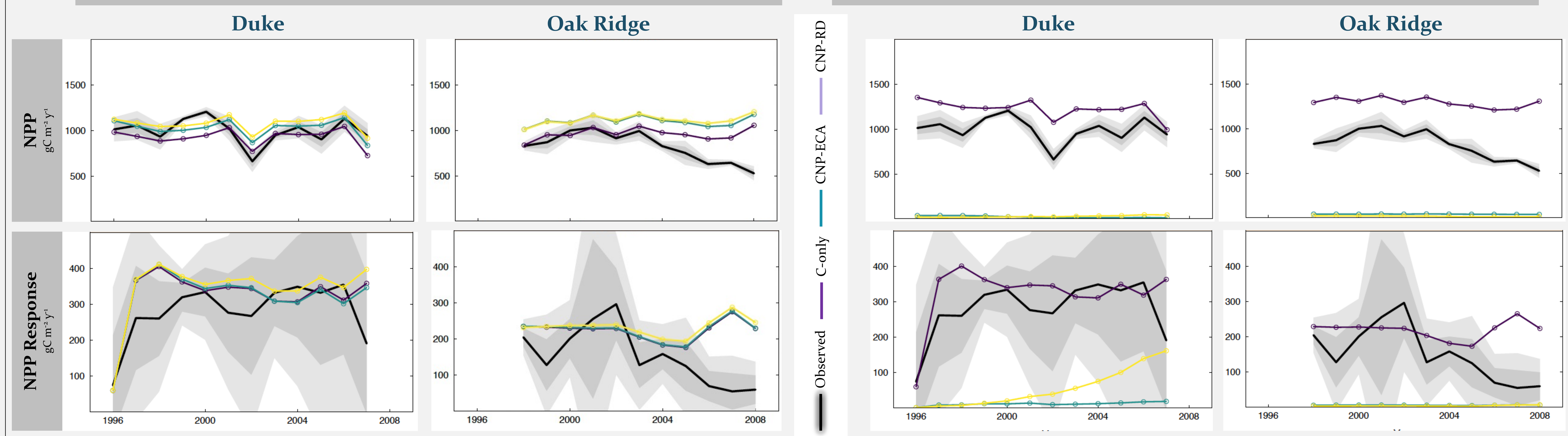


Site Meteorology



NPP dynamics and response to CO2 was related to stand structure / stage of secondary succession across ecosystem-scale U.S. based Free Air CO2 Enrichment (FACE) experiments. (Walker et al., 2019)

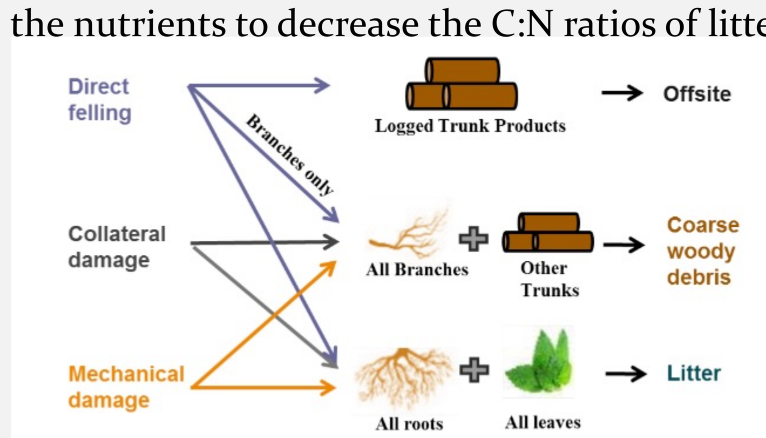
Simulated vs. Observed eCO2 Responses

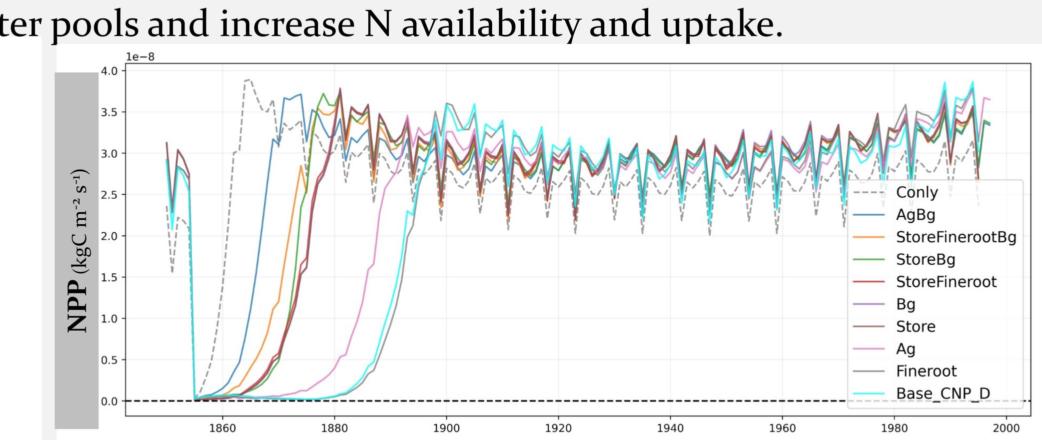


- NPP and NPP responses are well captured with ELM-FATES-CNP at Duke in the simulated equilibrium forest. However, the PNL related decline is not captured by the model at Oak Ridge.
- The FACE-site plantations were established about a decade before the start of FACE experiments at Duke and Oak Ridge. To align the simulated forest age with the FACE-site plantation age, we simulated a logging event a year prior to plantation establishment and allowed FATES to regenerate the forest naturally.
- **Growth rate of NPP in the simulated secondary plantation forests is much slower than observed.**

What is slowing the post-disturbance recovery rate in FATES?

1. The ELM soil decomposition goes into nitrogen immobilization overdrive, due to a large influx of litter carbon from the logging and the high C:N ratios of litter compared with soil pools. Fixed stoichiometry of the soil pools and "microbial" carbon use efficiencies exacerbate the problem. To simulate a more realistic growth rate of the plantation, we removed carbon from various litter but kept the nutrients to decrease the C:N ratios of litter pools and increase N availability and uptake.

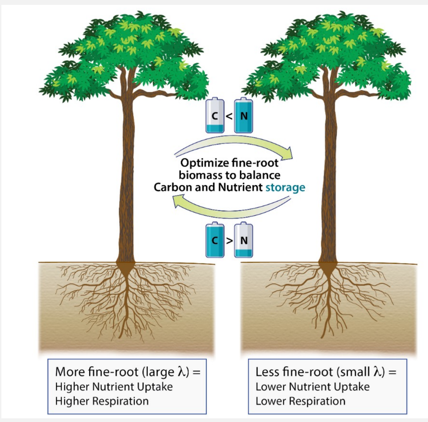




Conly: Carbon only simulation
AgBg: Above and Below ground wood mass removed
StoreFinerootBg: Storage mass, fine root biomass, and below ground wood mass removed
StoreBg: Storage mass and below ground wood mass removed
StoreFineroot: Storage mass and fine root biomass removed
Bg: below ground wood mass removed
Store: Storage mass removed
Ag: Above ground wood mass removed
Fineroot: fine root biomass removed
Base_CNP_D: Base/default CNP simulation

- More carbon we remove from various litter pools, higher is the NPP recovery, possibly due to higher N availability and uptake.
- Even with all of the carbon from logging removed C only recovery is still faster.
- Main litter pools: Storage, Bg

2. The dynamic fine-root allocation scheme in ELM-FATES-CNP regulates uptake of nutrients. This scheme seeks to adjust resource allocation above- and below-ground in for plant growth to be equally limited by carbon, nitrogen and phosphorus. There is high sensitivity of NPP and biomass to the choice of coefficient of Proportional Integral Derivative (PID) controller coefficients.



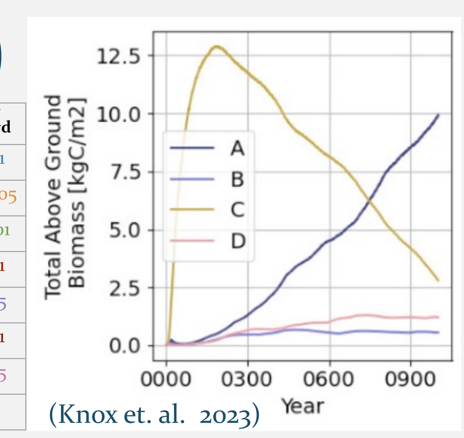
$$f_{cn} = ln\left({}^{N,P}_{s}max\left[\frac{C_{so}/\acute{C}_{so}}{M_{so,s}/\acute{M}_{so,s}}\right]\right)$$

$$\lambda = \lambda_{t-1} + K_{p(pft)} f_{cn} + K_{i(pft)} \int f_{cn}\, dt + K_{d(pft)} \frac{df_{cn}}{dt}$$

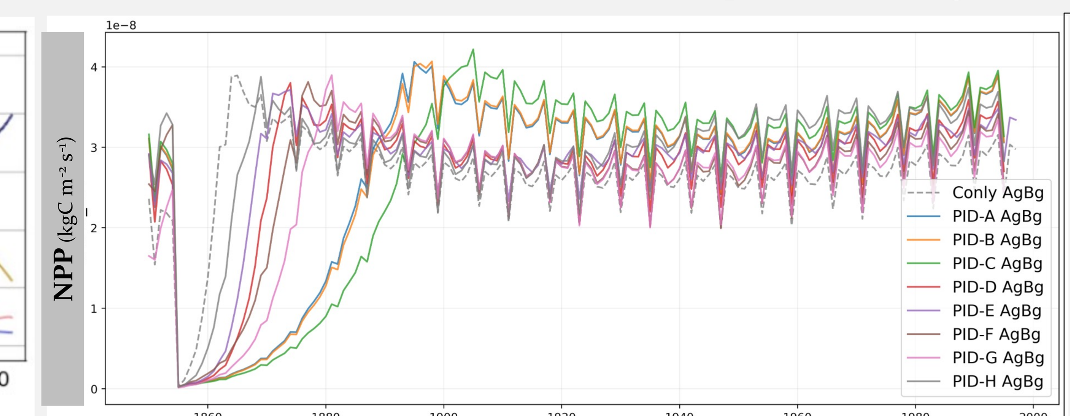
Where,
K_p : Proportional
K_i : Integral
K_d: Derivative

PID	K_p	K_d
A	0.0005	0.1
B	0.0005	0.005
C	0.0001	0.01
D	0.001	0.1
E	0.001	0.5
F	0.005	0.1
G	0.005	0.5
H	0.001	1

(Knox et. al. 2023)



(Knox et. al. 2023)



- PID coefficient have strong control on dynamic allocation of nutrients and biomass response.
- There is a tradeoff between recovery rate and maximum production.
- Although not a clear response, but increasing Derivative coefficients, increased rate of NPP growth.
- PID E and H have higher NPP growth due to higher L2FR post logging and more N availability and uptake.

Summary

- NPP CO2 responses simulated fairly well, missing PNL-related decline at ORNL in equilibrium ecosystem.
- Plant growth was very slow in the CNP simulations post logging or secondary ecosystem.
- NPP recovery is strongly influenced by a) Litter Carbon at site post logging and b) PID coefficients.

Next Steps

- Investigate coupling of nutrient dynamics with stand structure development and their influence on eCO2 responses.

Supplementary Plots →

More info on FACE-MDS → project

Selected References:

Walker, A.P., De Kauwe, M.G., Medlyn, B.E. et al. Decadal biomass increment in early secondary succession woody ecosystems is increased by CO2 enrichment. Nat Commun 10, 454. 2019. https://doi.org/10.1038/s41467-019-08348-1

Ryan G Knox, Charles D. Koven, William J. Riley, et al. Nutrient Dynamics in a Coupled Terrestrial Biosphere and Land Model (ELM-FATES) ESS Open Archive. 2023. https://doi.org/10.22541/essoar.167810418.80767445/v1

Sponsor: U.S. Department of Energy, Office of Biological and Environmental Research.

U.S. DEPARTMENT OF ENERGY | Office of Science

FACE-MDS

Oak Ridge National Laboratory