

EVALUATING C4 PHOTOSYNTHESIS REPRESENTATION AT NEON GRASSLAND SITES

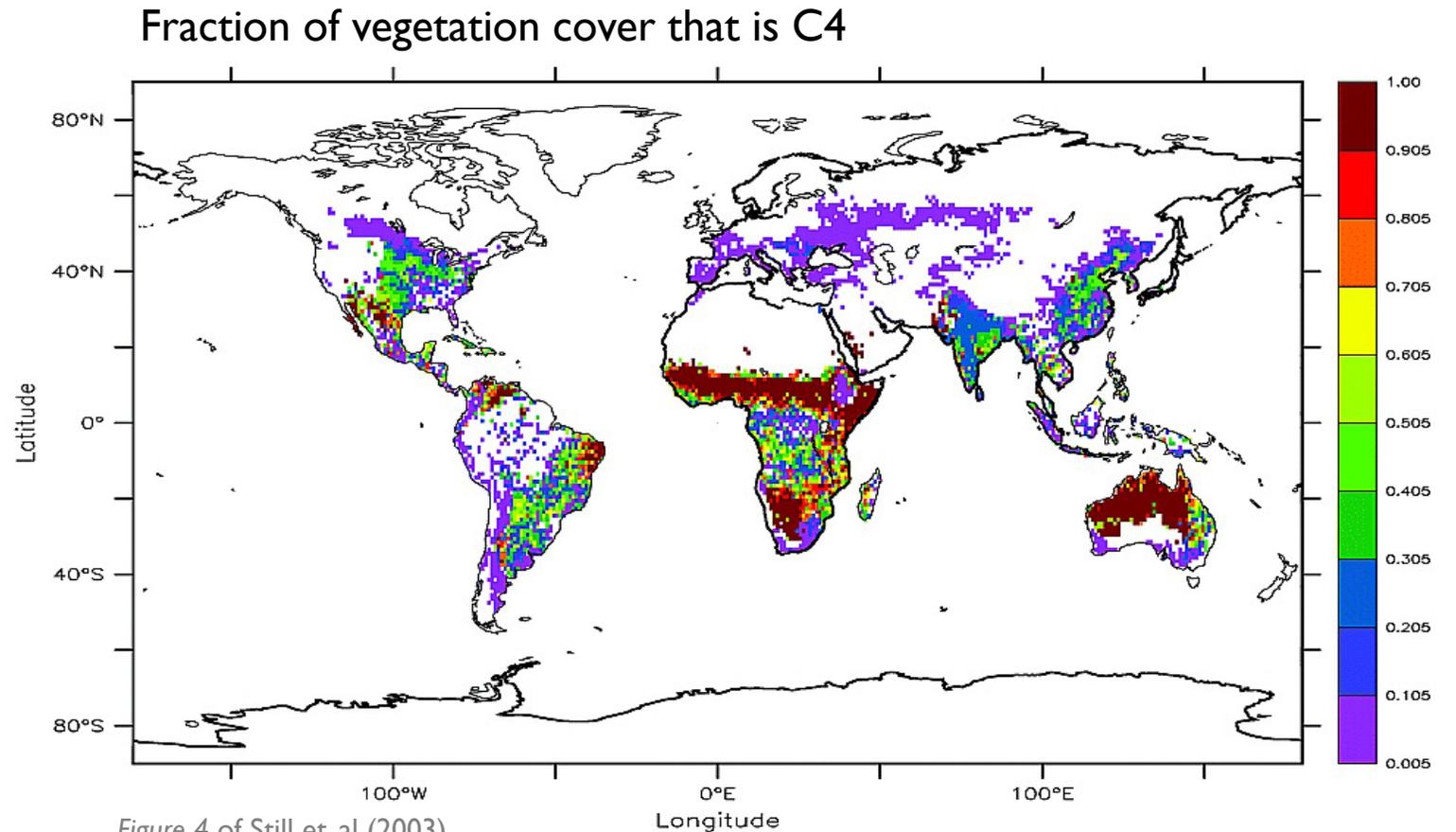
Rachel Hallmark¹ and Danica Lombardozzi^{1,2}

Land Model Working Group Meeting – 24 February 2026

¹Colorado State University, ²NSF National Center for Atmospheric Research

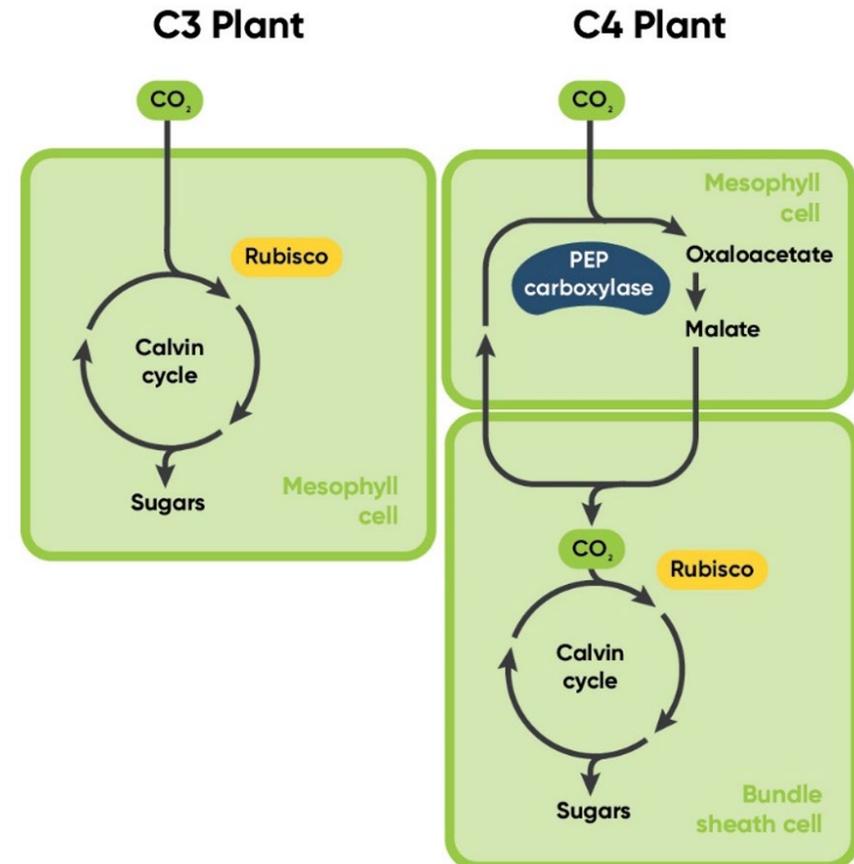
C4 PHOTOSYNTHESIS IN THE EARTH SYSTEM

- Accounts for ~20% of terrestrial gross primary productivity (GPP)
- Important for understanding ...
 - Climate-carbon feedbacks
 - Global energy fluxes
 - Agricultural productivity



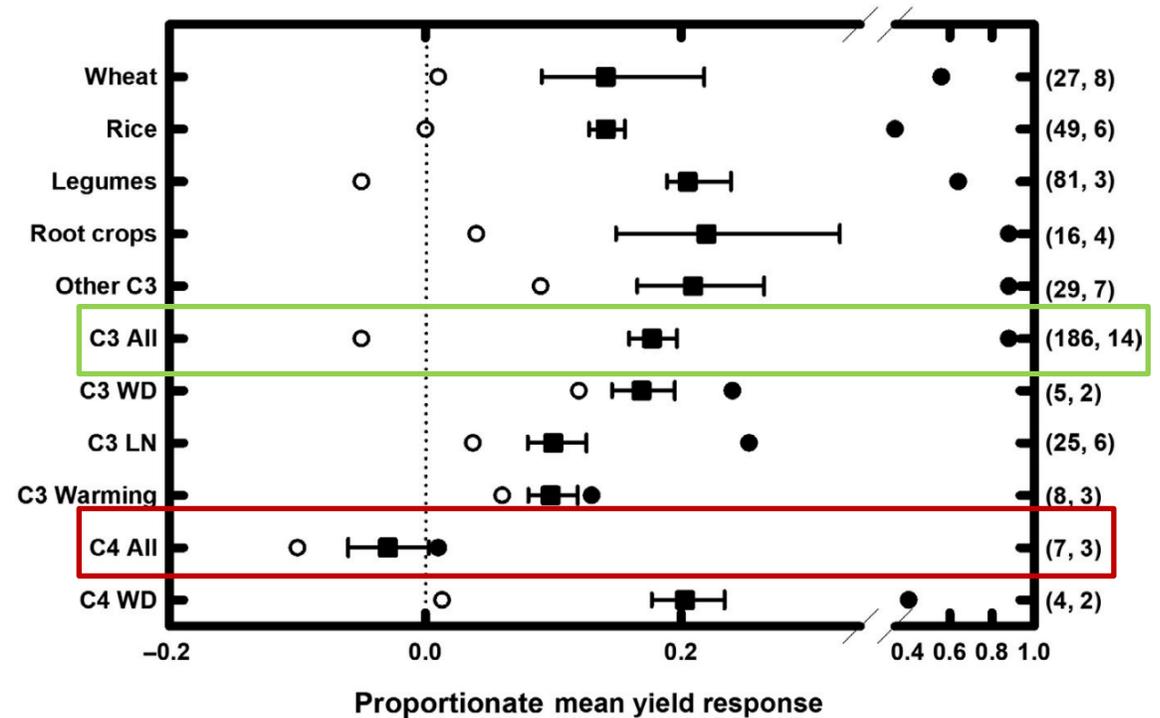
C4 PHOTOSYNTHESIS IN THE EARTH SYSTEM

- C3 vs. C4 physiology
 - C4s more efficient at CO₂ use and better adapted to hot, dry environments
 - C3s favored in cooler, wetter climates



C4 PHOTOSYNTHESIS IN THE EARTH SYSTEM

- C3 vs. C4 physiology
 - C4s more efficient at CO₂ use and better adapted to hot, dry environments
 - C3s favored in cooler, wetter climates



Adapted from Figure 2 of Ainsworth and Long (2020)

C4 PHOTOSYNTHESIS IN CLM

- C4 photosynthesis is poorly represented in ESMs
- CLM uses Collatz et al. model, originally parameterized for corn
- Never evaluated in natural systems

OBJECTIVES



Evaluate how well CLM
simulates GPP at C3
and C4 grass sites
relative to NEON
observations

OBJECTIVES



Evaluate how well CLM simulates GPP at C3 and C4 grass sites relative to NEON observations



Assess whether CLM captures expected physiological differences between C3 and C4 grasses under modified environmental conditions

METHODS – SATELLITE PHENOLOGY MODE

CLM Satellite Phenology

- Vegetation phenology prescribed
- Limited nutrient cycling
- “simplified” model
- Isolates photosynthetic responses from other feedbacks

OBJECTIVE I

Evaluate CLM GPP simulations at C3 and C4
grassland against NEON observations

METHODS – MODEL EXPERIMENTS

CLM Satellite Phenology

NEON grassland



Run default simulation

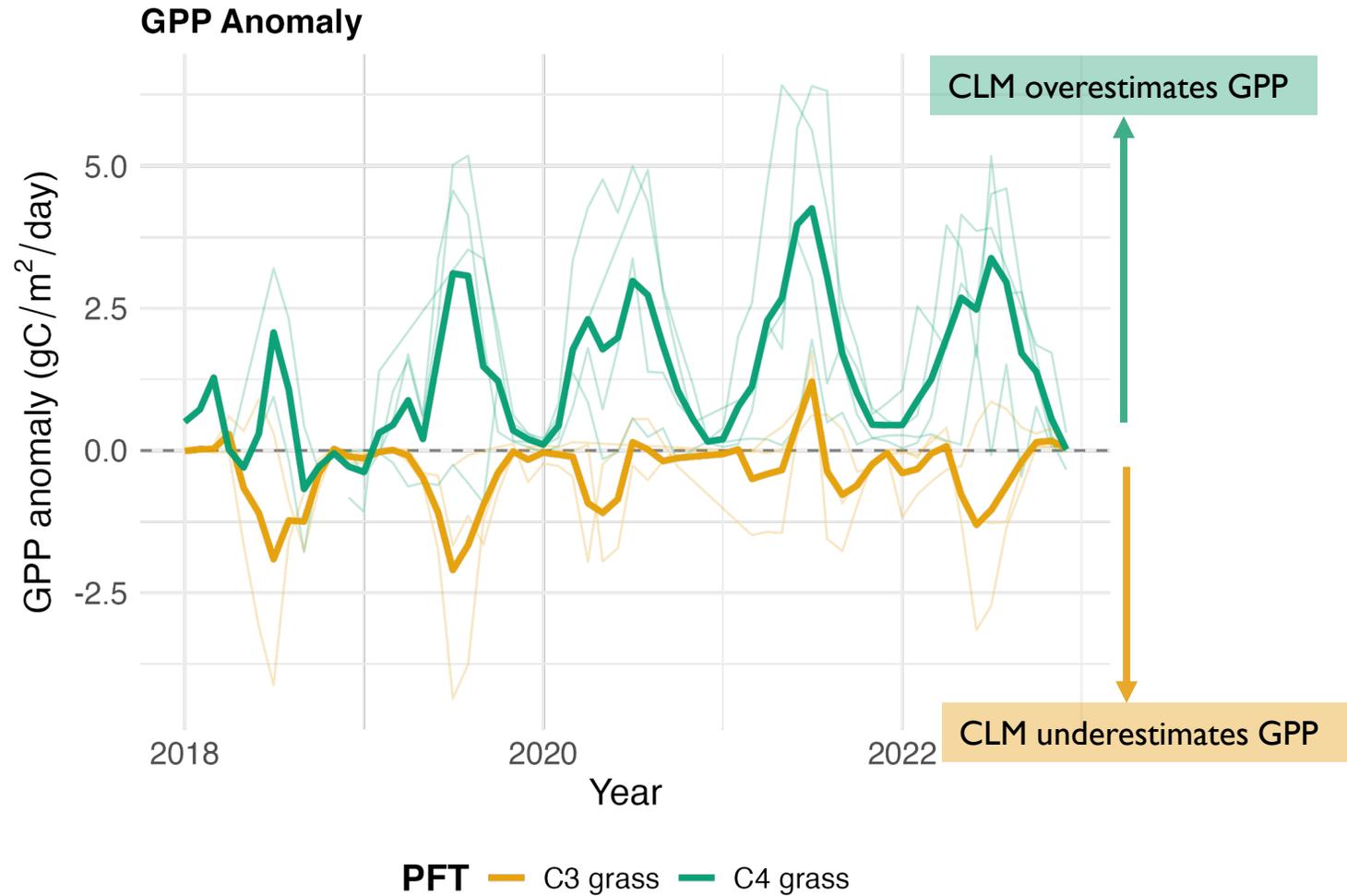


Output

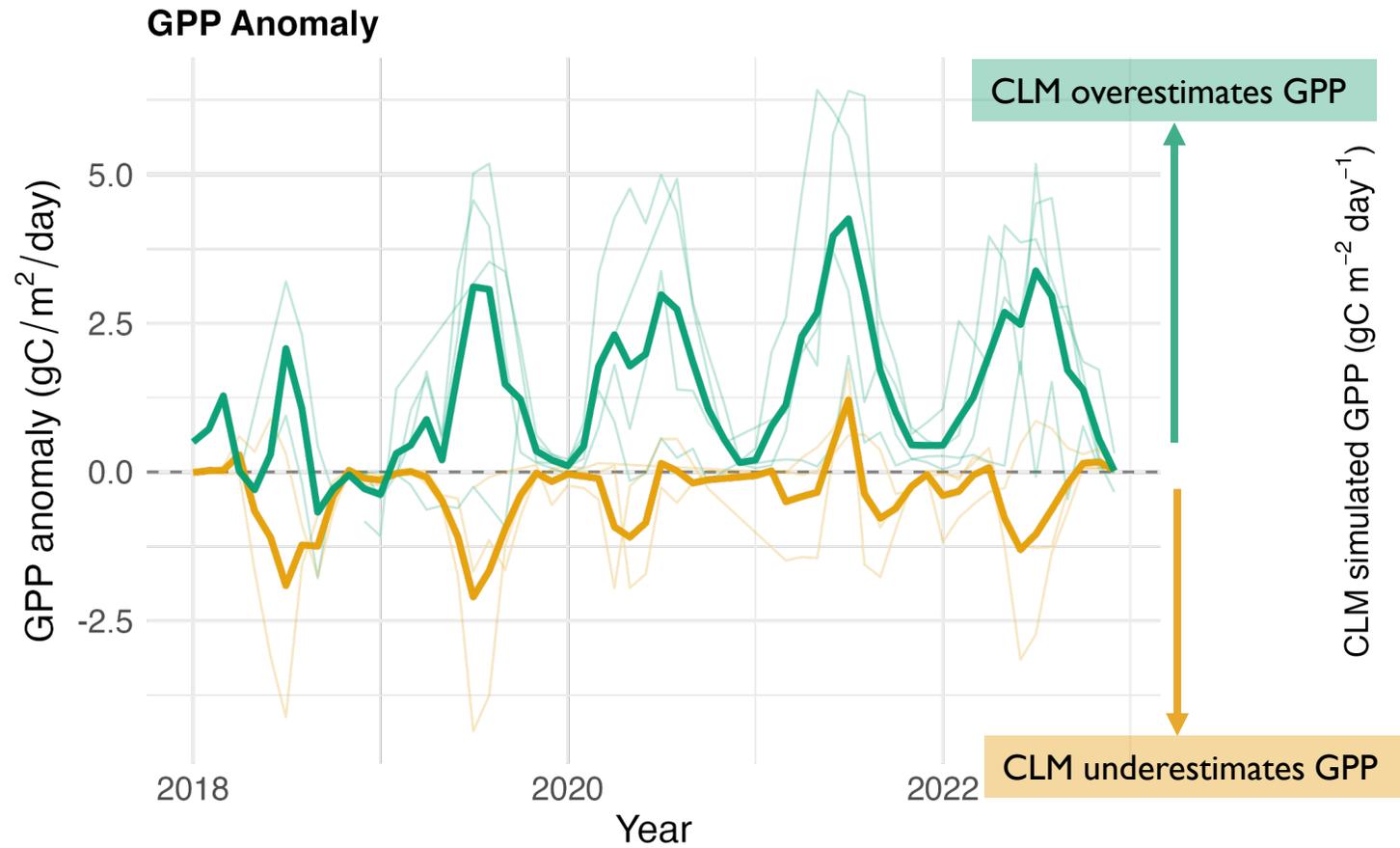


NEON observations

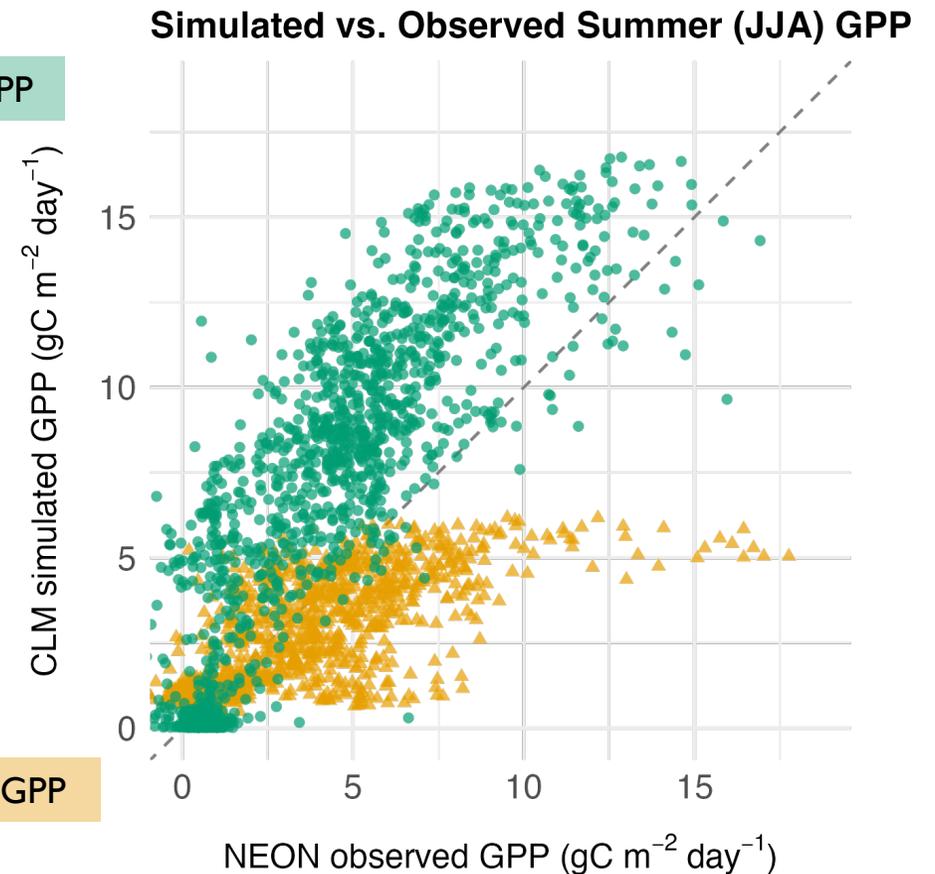
CLM OVERESTIMATES GPP AT C4 GRASS SITES



CLM OVERESTIMATES GPP AT C4 GRASS SITES



PFT — C3 grass — C4 grass



PFT ▲ C3 grass ● C4 grass

OBJECTIVE 2

Assess whether CLM captures expected physiological differences between C3 and C4 grasses under modified environmental conditions

METHODS – MODEL EXPERIMENTS

CLM Satellite Phenology

NEON grassland



Modify environmental conditions

Increase CO₂ to 550ppm

Lower CO₂ to 280ppm

Impose year-long drought
with halved precipitation

METHODS – MODEL EXPERIMENTS

CLM Satellite Phenology

NEON grassland



Modify environmental conditions

Increase CO₂ to 550ppm

Lower CO₂ to 280ppm

Impose drought year-long
drought with halved
precipitation

Run simulation

Run simulation

Run simulation



Output

Output

Output

METHODOLOGY – MODEL EXPERIMENTS

CLM Satellite Phenology

NEON grassland

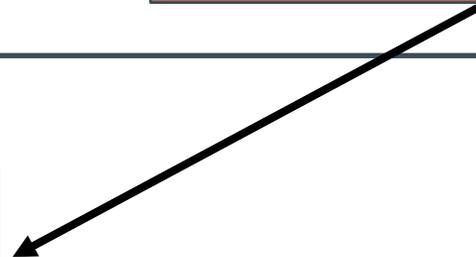
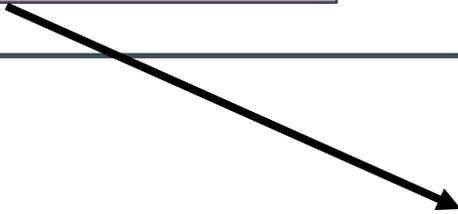
Modified simulations

High CO2 output

Low CO2 output

Drought output

Default simulation output



METHODS – MODEL EXPERIMENTS

CLM Satellite Phenology

NEON grassland

All simulations

High CO2 output

Low CO2 output

Drought output

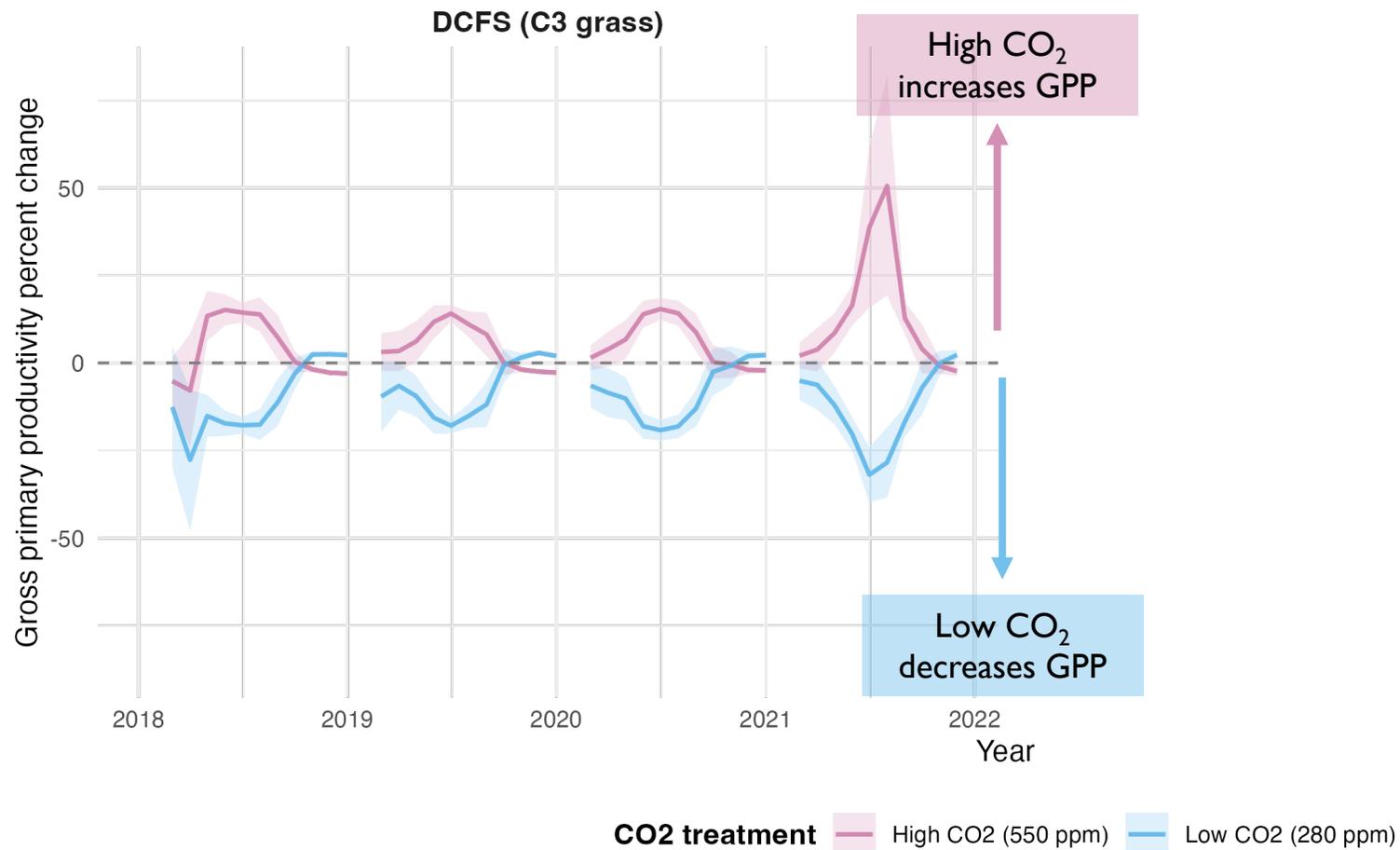
Default output

NEON observations



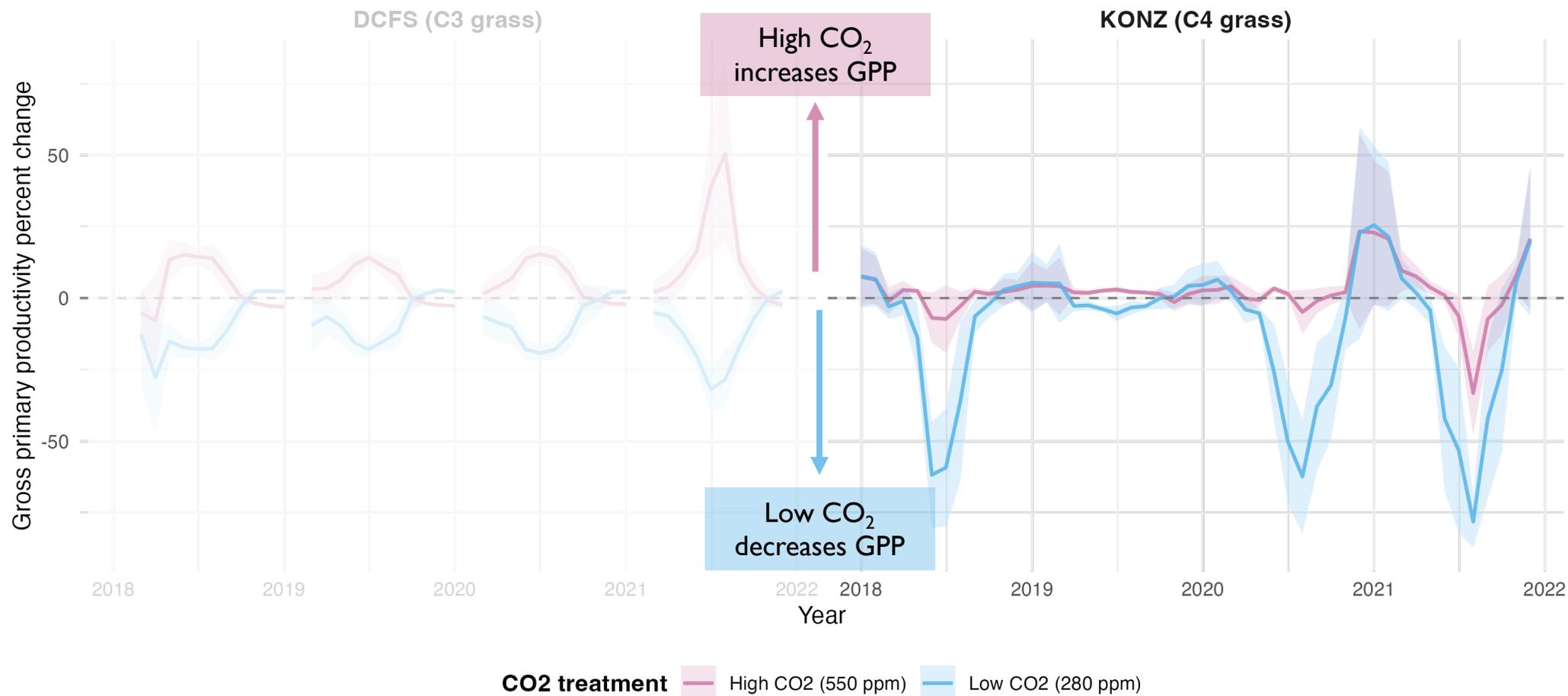
GPP RESPONDS TO MODIFIED CO₂

GPP Response to Modified CO₂ in CLM-SP Simulations



GPP RESPONDS TO MODIFIED CO₂

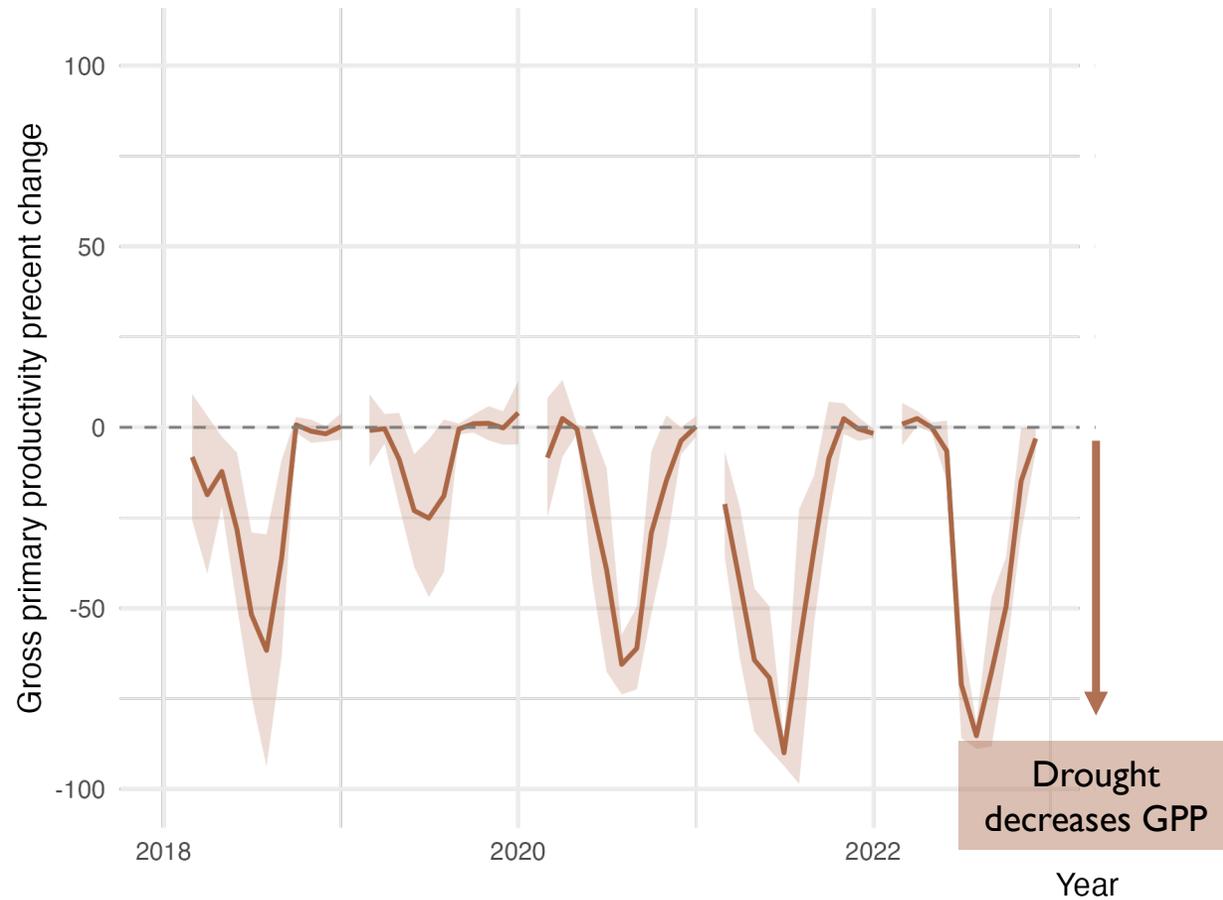
GPP Response to Modified CO₂ in CLM-SP Simulations



SIMULATED DROUGHT DECREASES GROWING SEASON GPP AT C3 AND C4 SITES

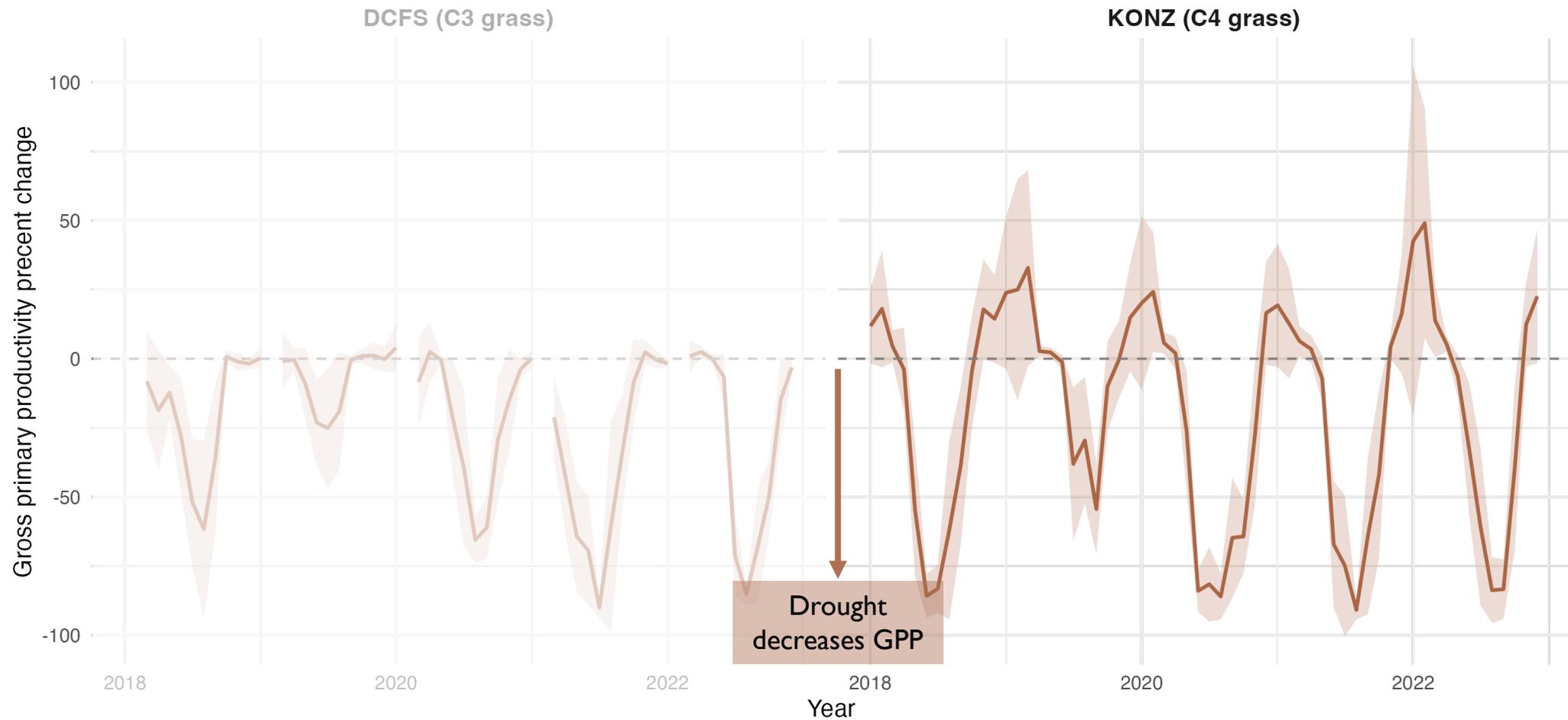
GPP Response to Year Long Drought in CLM-SP Simulations

DCFS (C3 grass)



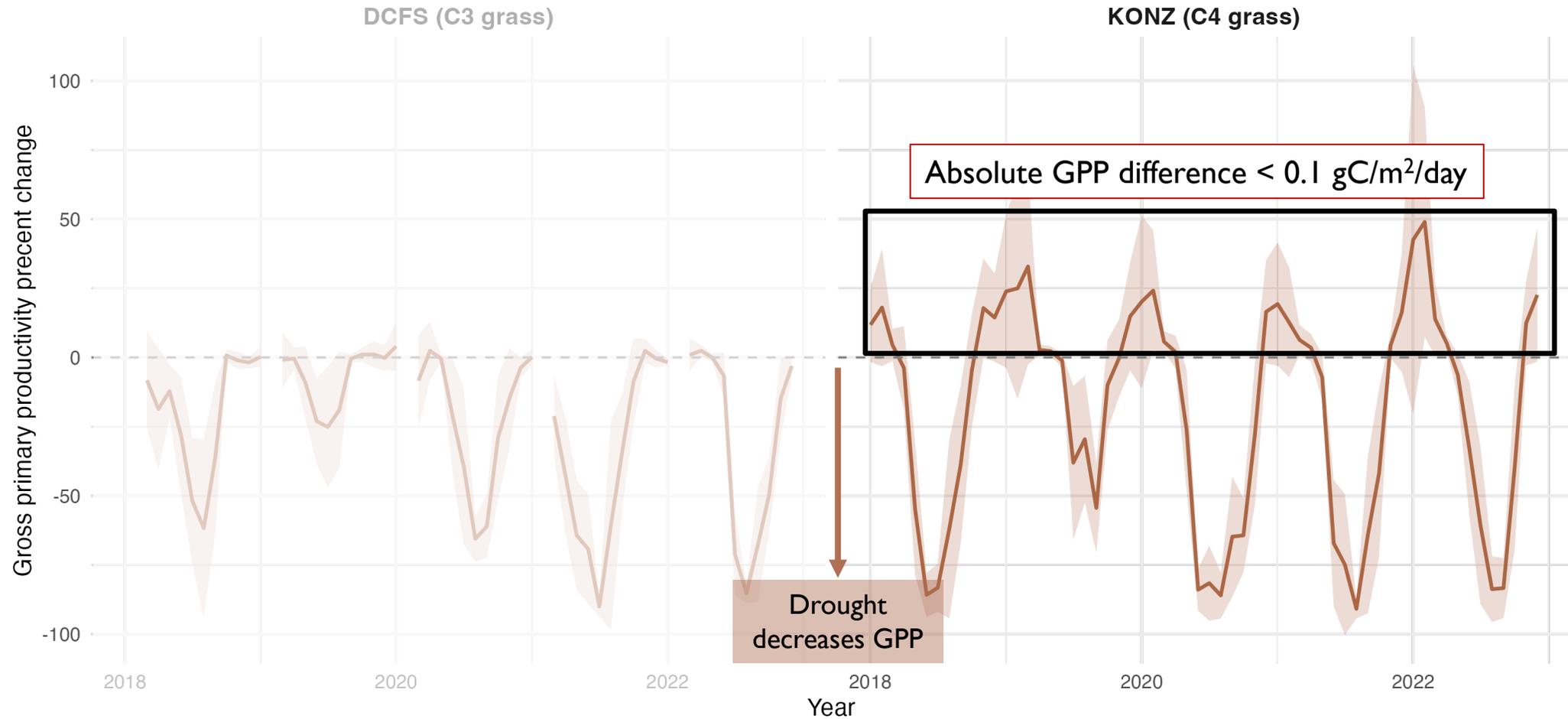
SIMULATED DROUGHT DECREASES GROWING SEASON GPP AT C3 AND C4 SITES

GPP Response to Year Long Drought in CLM-SP Simulations



SIMULATED DROUGHT DECREASES GROWING SEASON GPP AT C3 AND C4 SITES

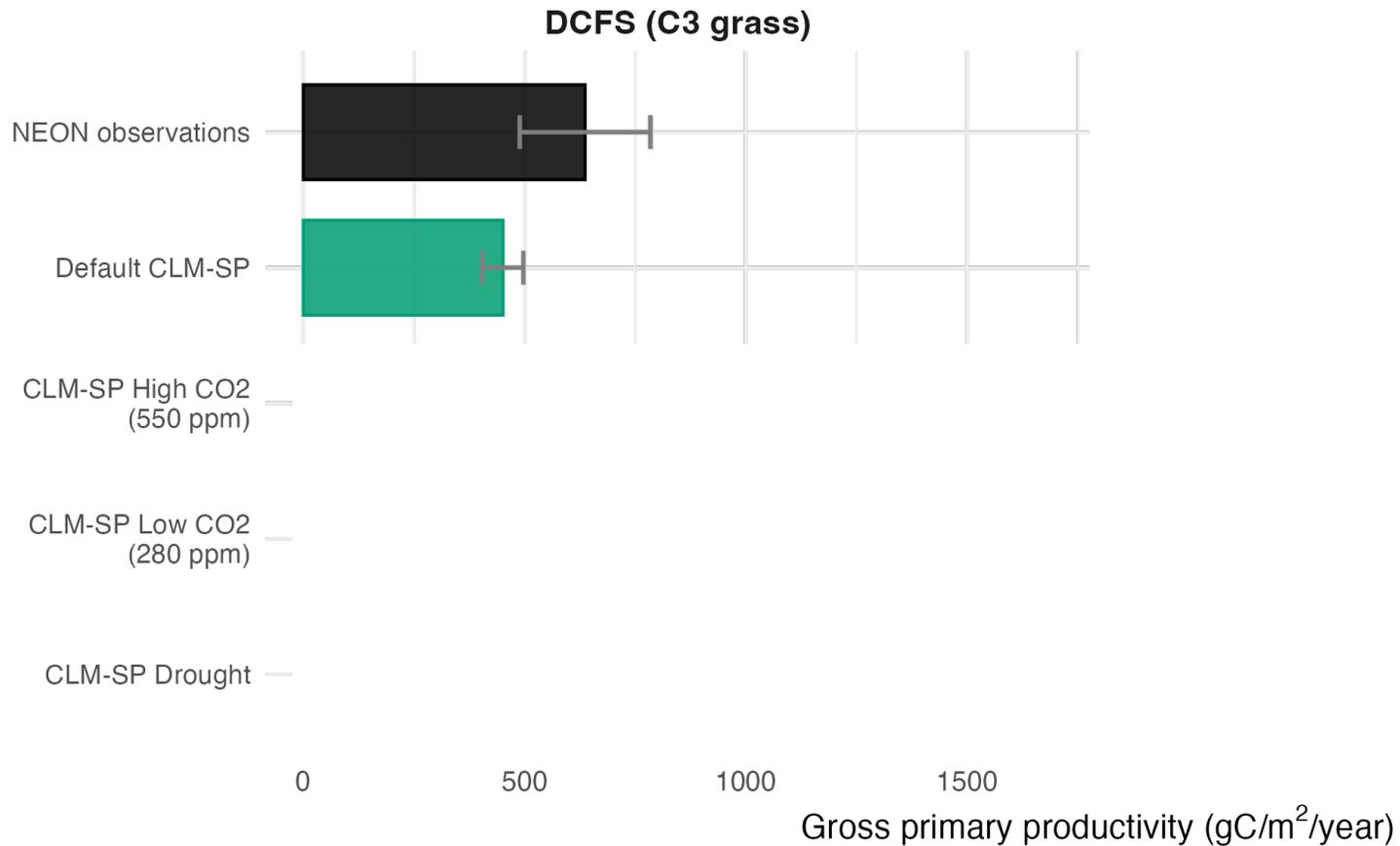
GPP Response to Year Long Drought in CLM-SP Simulations



SIMULATED GPP BIAS VARIES WITH PFT AND ENVIRONMENTAL CONDITIONS

Annual GPP by experiment

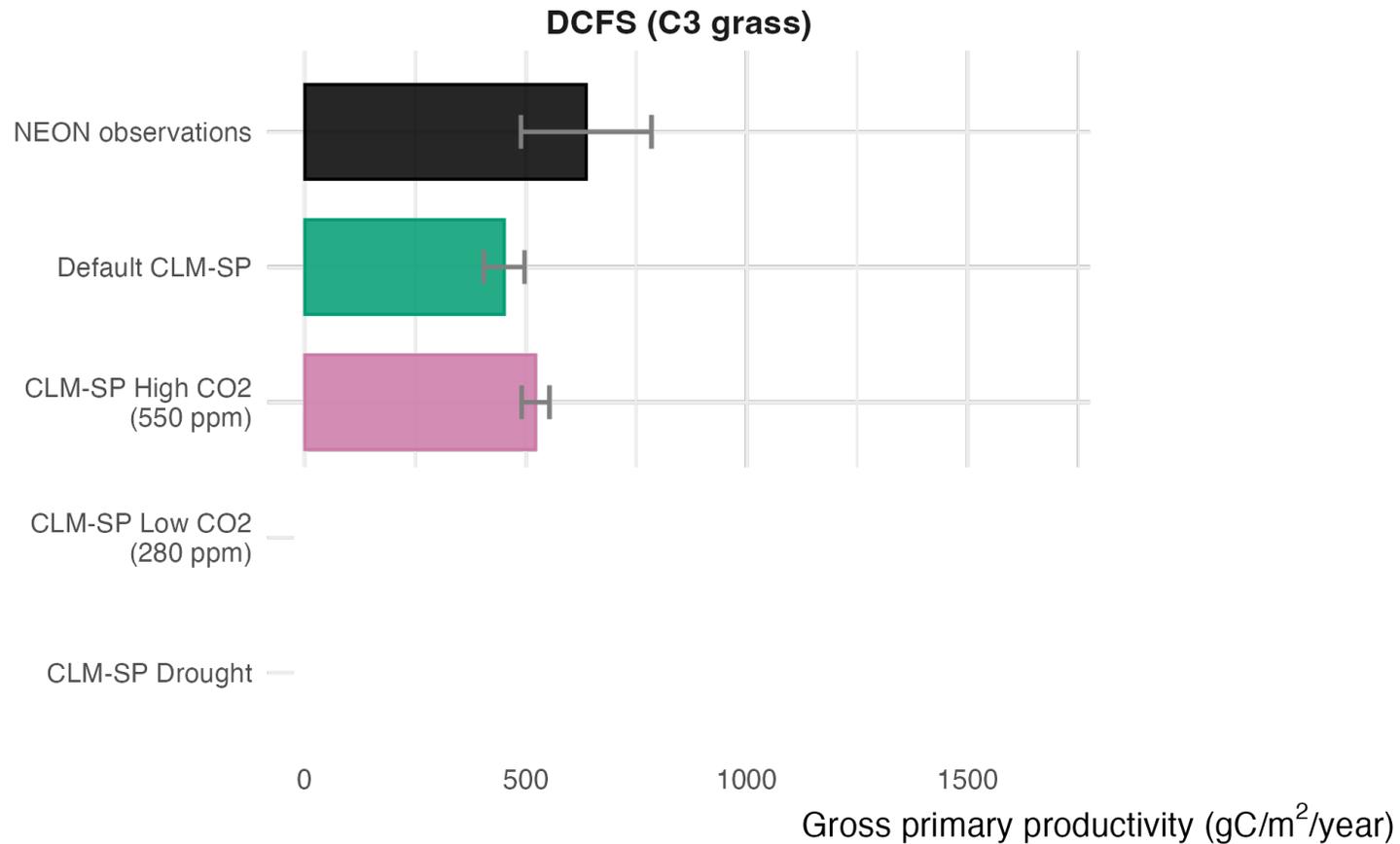
Error bars = ± 1 SD across years (2018–2022)



SIMULATED GPP BIAS VARIES WITH PFT AND ENVIRONMENTAL CONDITIONS

Annual GPP by experiment

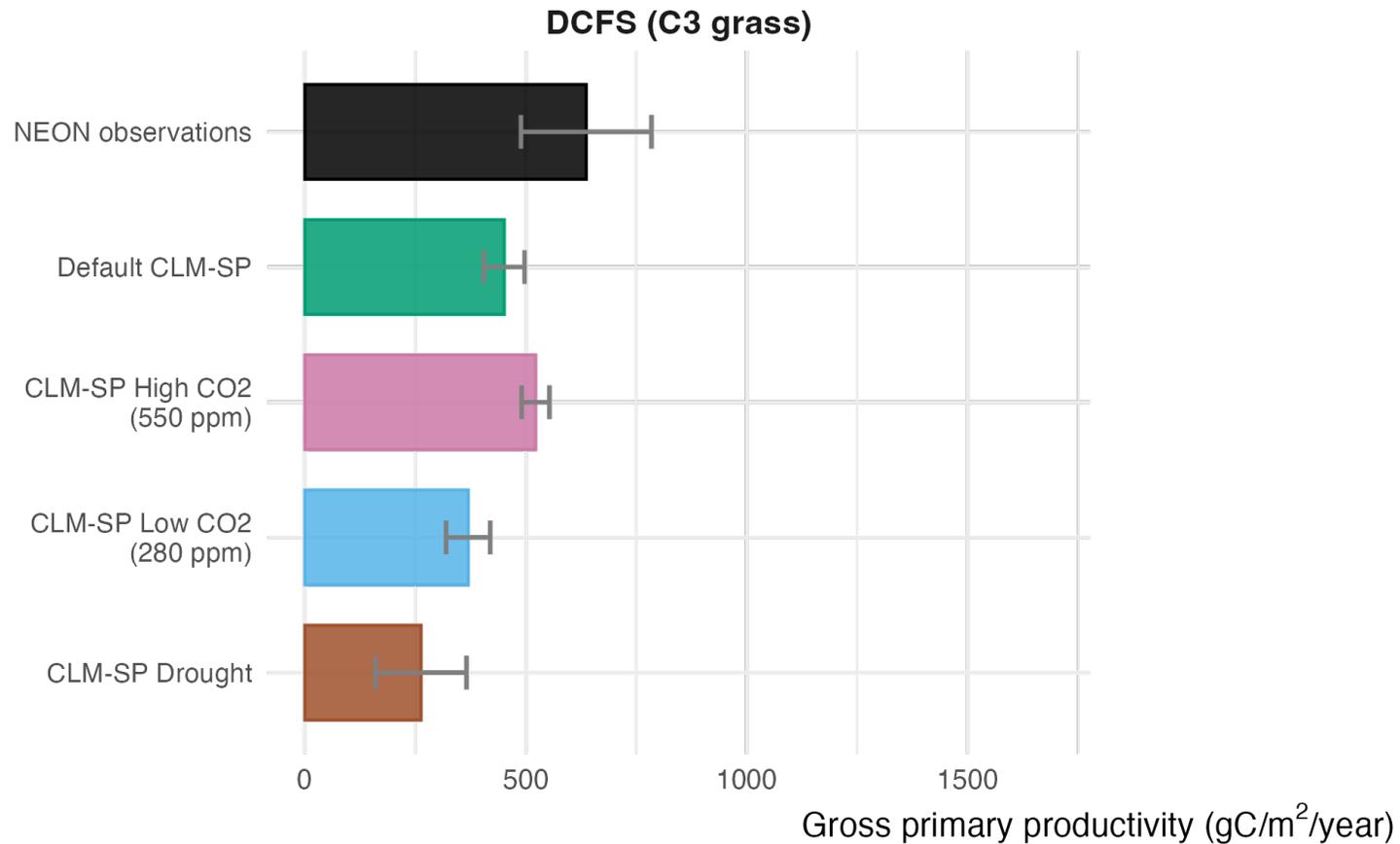
Error bars = ± 1 SD across years (2018–2022)



SIMULATED GPP BIAS VARIES WITH PFT AND ENVIRONMENTAL CONDITIONS

Annual GPP by experiment

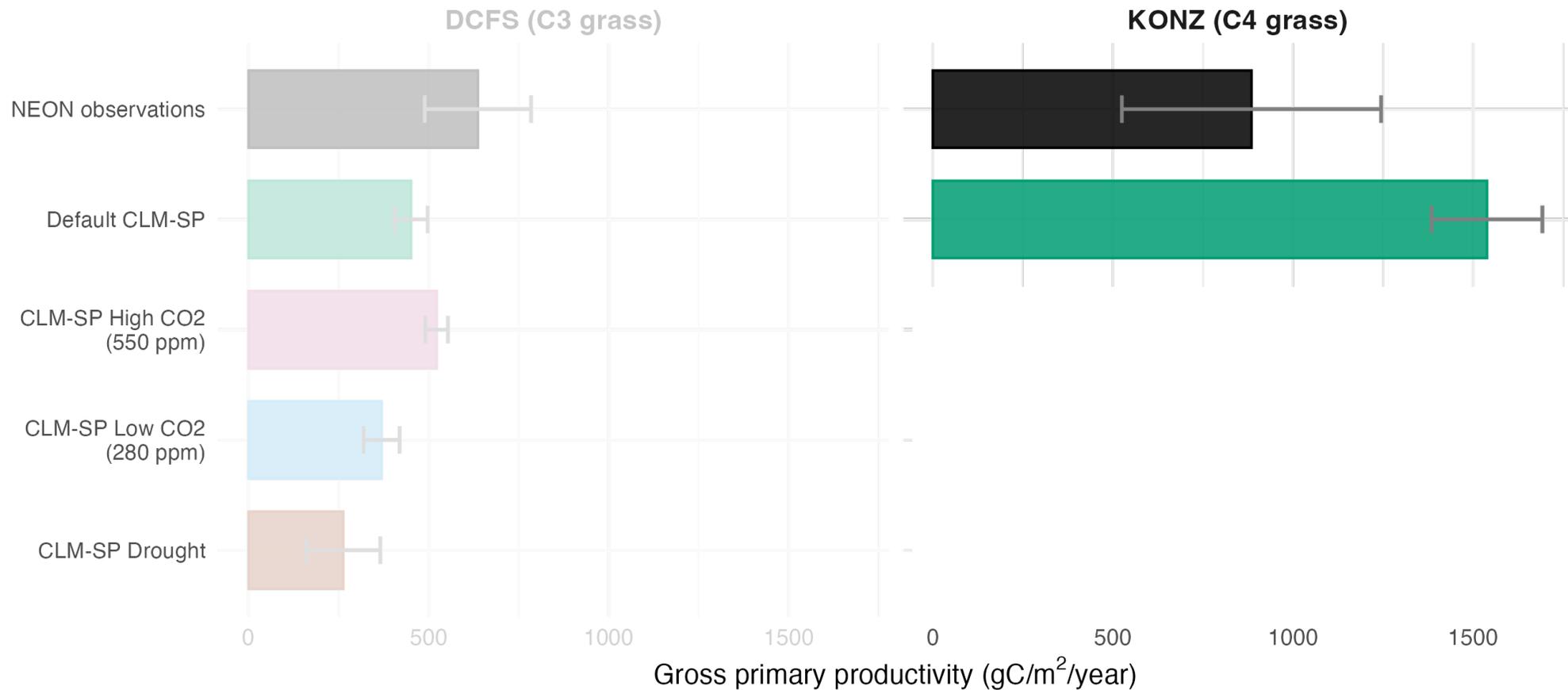
Error bars = ± 1 SD across years (2018–2022)



SIMULATED GPP BIAS VARIES WITH PFT AND ENVIRONMENTAL CONDITIONS

Annual GPP by experiment

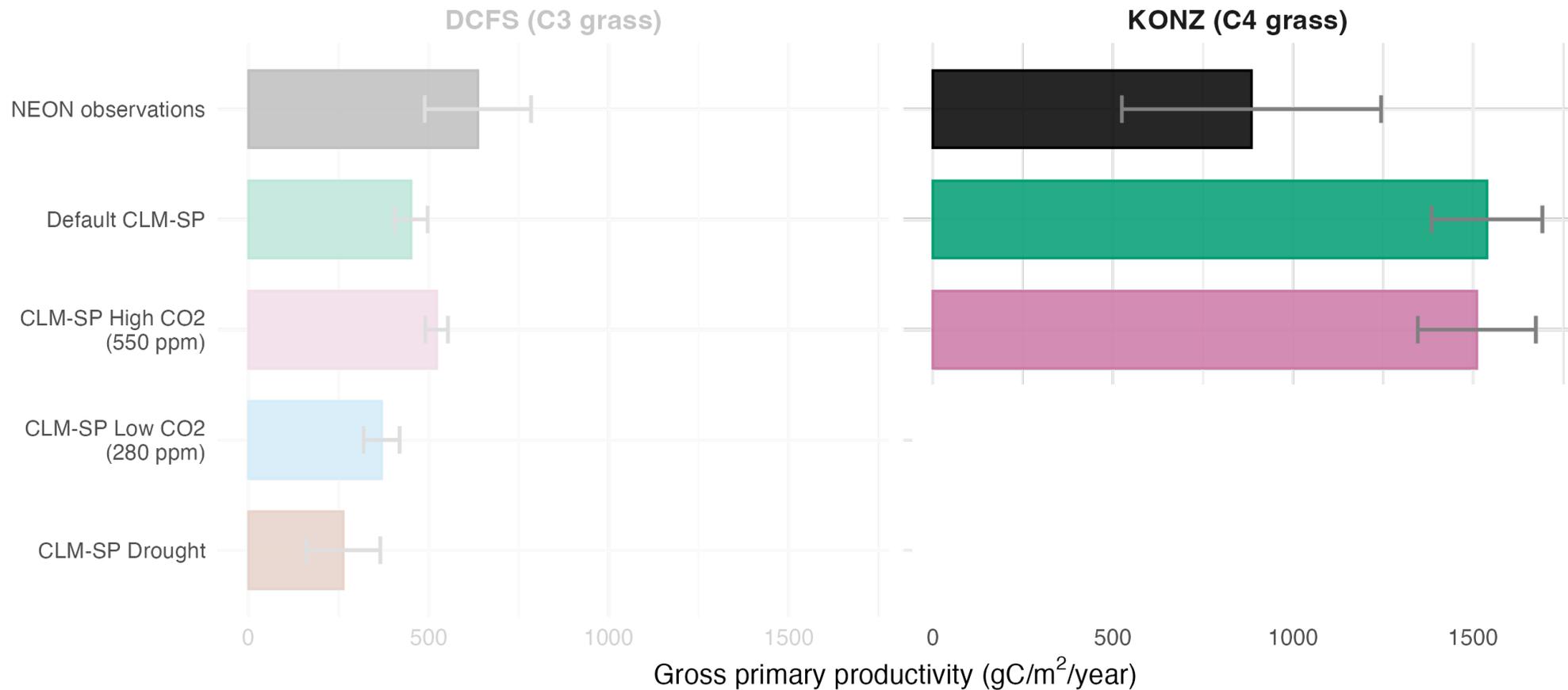
Error bars = ± 1 SD across years (2018–2022)



SIMULATED GPP BIAS VARIES WITH PFT AND ENVIRONMENTAL CONDITIONS

Annual GPP by experiment

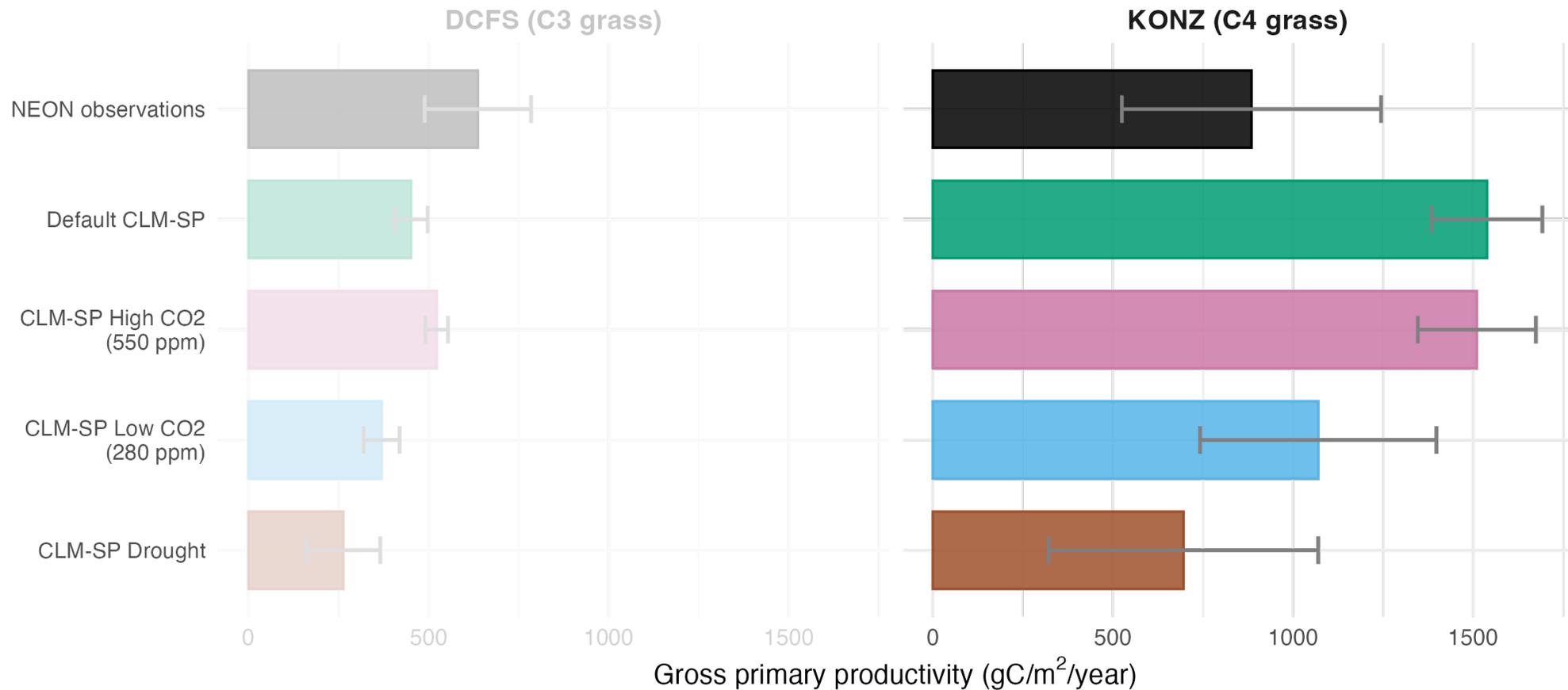
Error bars = ± 1 SD across years (2018–2022)



SIMULATED GPP BIAS VARIES WITH PFT AND ENVIRONMENTAL CONDITIONS

Annual GPP by experiment

Error bars = ± 1 SD across years (2018–2022)



CONCLUSIONS AND FUTURE WORK

Conclusions

- CLM overestimates GPP at C4 sites, slightly underestimates at C3 sites
- C4 site more sensitive to low CO₂ than C3, but less responsive to higher CO₂
- Simulated environmental stress lowers GPP compared to default simulations across both photosynthetic pathways ...
 - C3 site – GPP gets further from observations
 - C4 site – GPP gets closer to observations

CONCLUSIONS AND FUTURE WORK

Conclusions

- CLM overestimates GPP at C4 sites, slightly underestimates at C3 sites
- C4 site more sensitive to low CO₂ than C3, but less responsive to higher CO₂
- Simulated environmental stress lowers GPP compared to default simulations across both photosynthetic pathways ...
 - C3 site – GPP gets further from observations
 - C4 site – GPP gets closer to observations

Future Work

- Expand analysis of modified simulations to other sites
- Explore patterns between sites of the same PFT
- Investigate environmental differences between sites that may influence GPP

CONCLUSIONS AND FUTURE WORK

Conclusions

- CLM overestimates GPP at C4 sites, slightly underestimates at C3 sites
- C4 site more sensitive to low CO₂ than C3, but less responsive to higher CO₂
- Simulated environmental stress lowers GPP compared to default simulations across both photosynthetic pathways ...
 - C3 site – GPP gets further from observations
 - C4 site – GPP gets closer to observations

Future Work

- Expand analysis of modified simulations to other sites
- Explore patterns between sites of the same PFT
- Investigate environmental differences between sites that may influence GPP

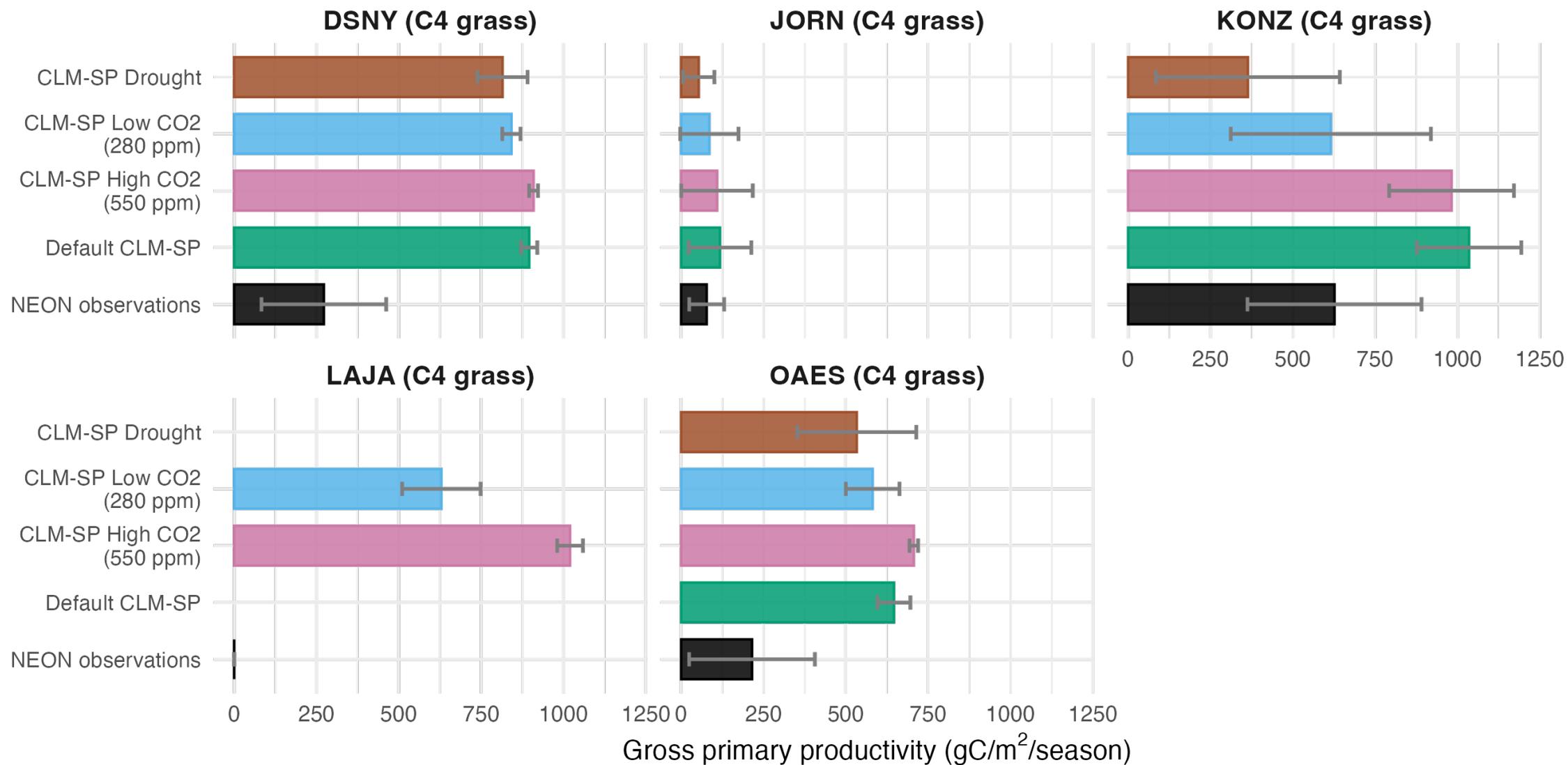
Thank You!

Communication: r.hallmark@colostate.edu

EXTRA SLIDES

Summer (JJA) GPP by experiment at C4 sites

Error bars = ± 1 SD across years (2018–2022)



Summer (JJA) GPP by experiment at C3 sites

Error bars = ± 1 SD across years (2018–2022)

