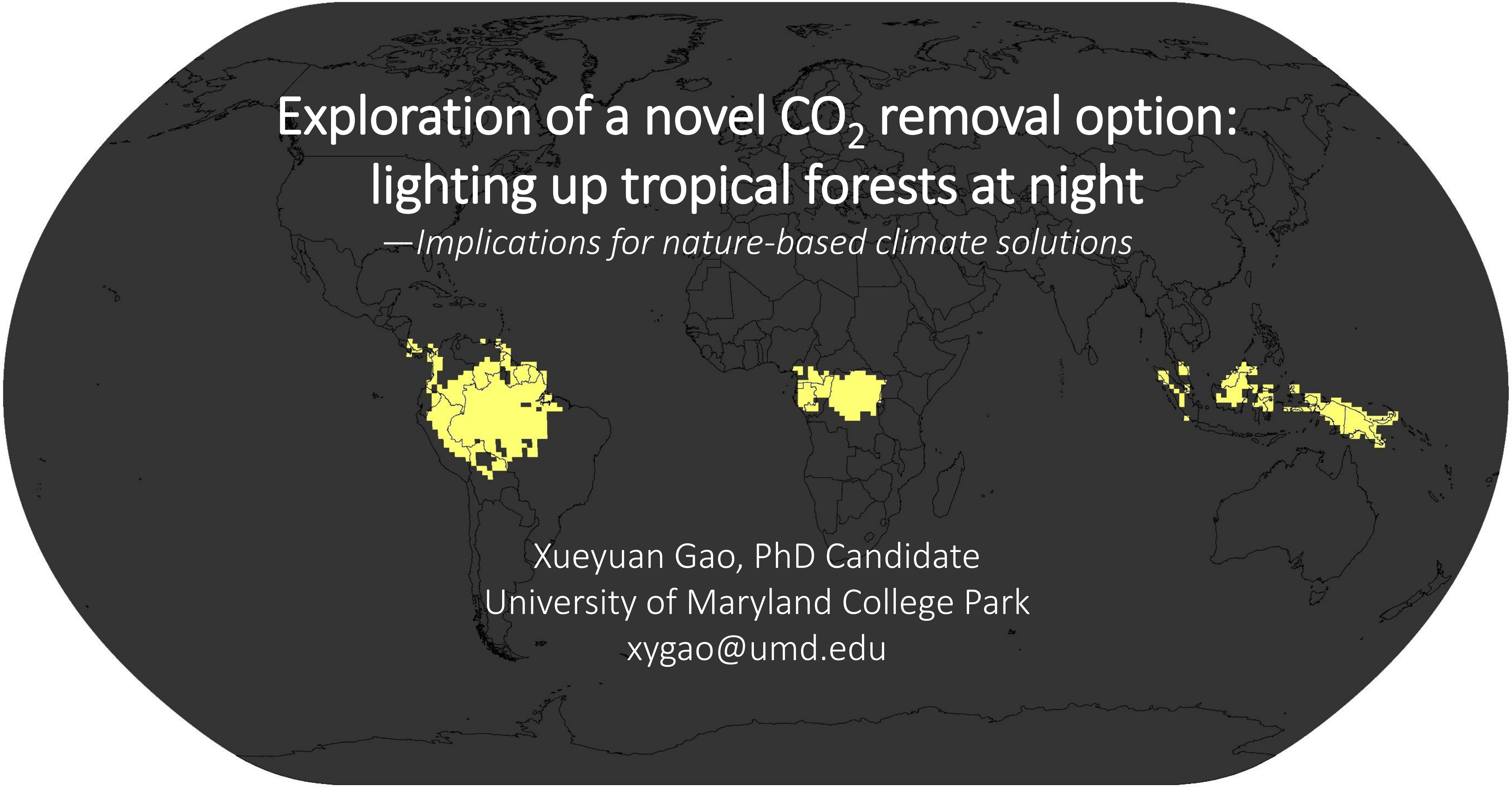
Exploration of a novel CO_2 removal option: lighting up tropical forests at night

—Implications for nature-based climate solutions



Xueyuan Gao, PhD Candidate
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Initial Idea: Lighting up the dark side of the Earth

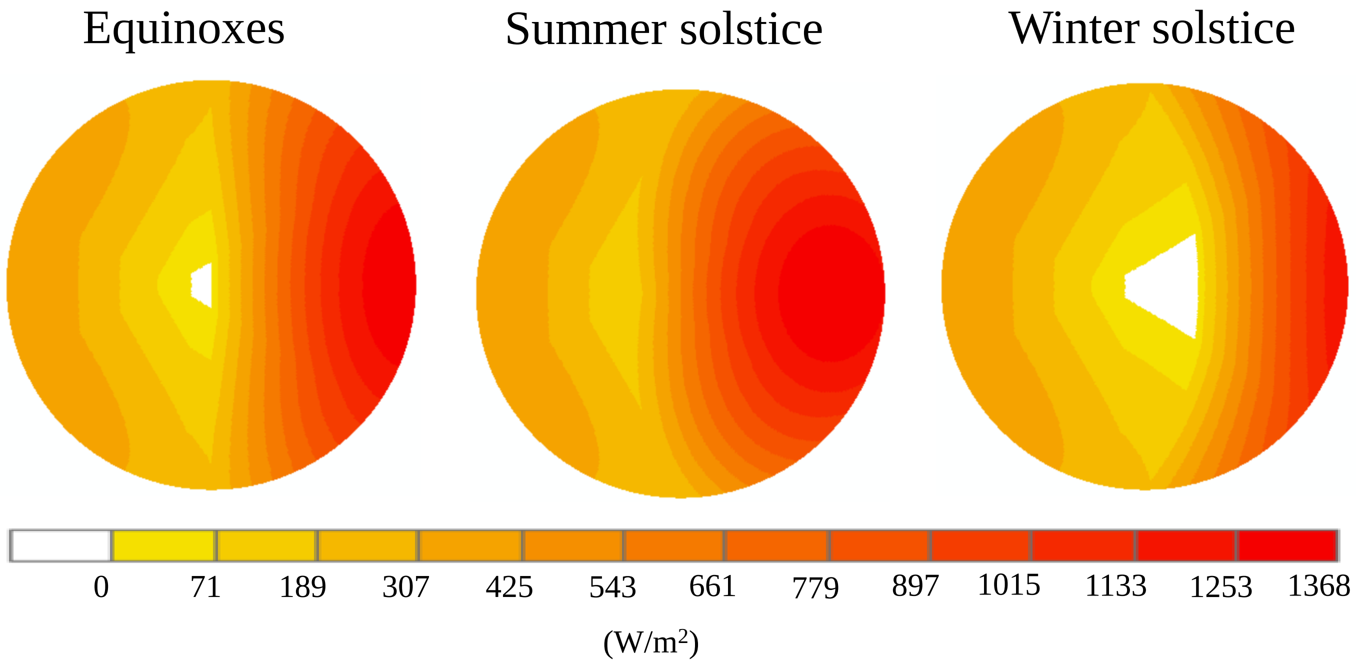
No lichen

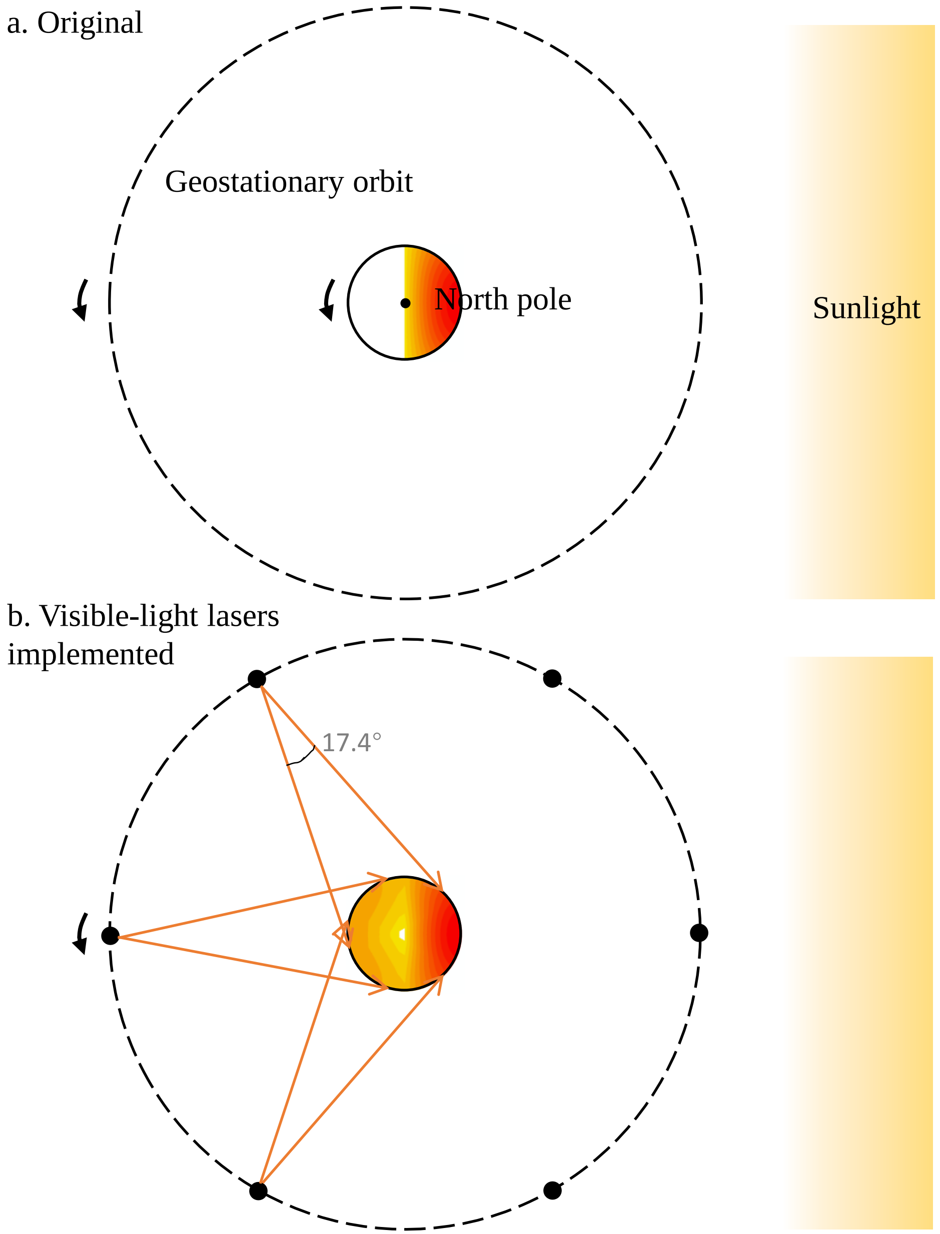
A lot of lichen

Plan #1 Launch visible-light lasers to the geostationary orbit

Radiation distribution on TOA

The central point is the North pole





Temperature increase due to increased radiation

Stefan–Boltzmann law

Original:

$$S \times \pi R^2 \times (1 - ref) = \sigma \times 4\pi R^2 \times T^4$$

$$T = 252K(-21°C)$$

Under Plan#1:

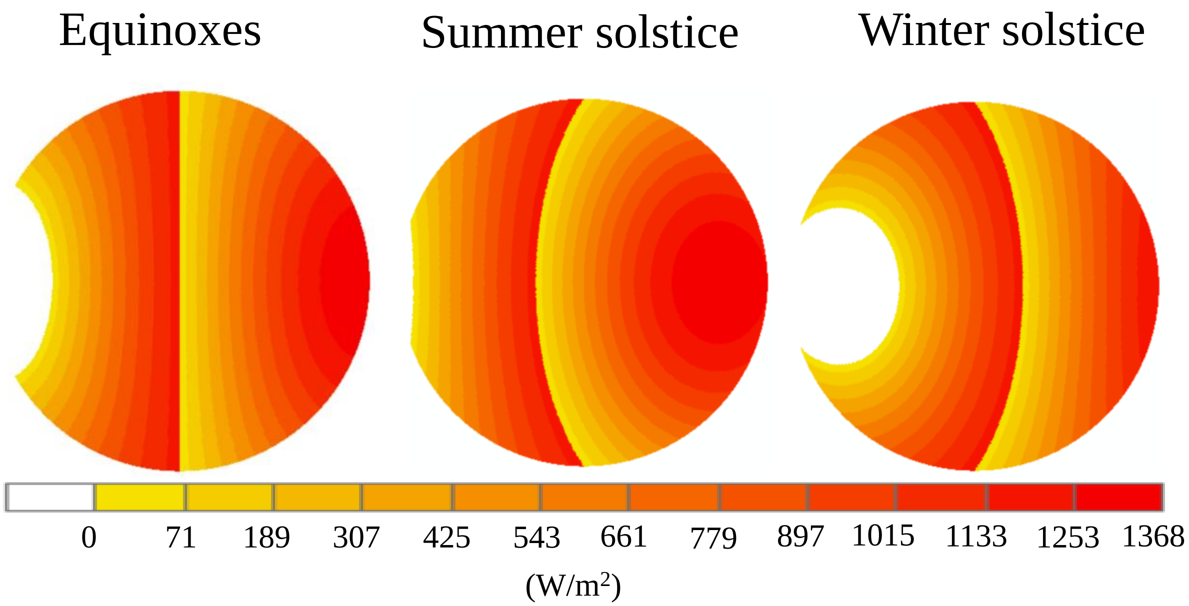
$$S \times \pi R^2 \times 1.4 \times (1 - ref) = \sigma \times 4\pi R^2 \times T^4$$

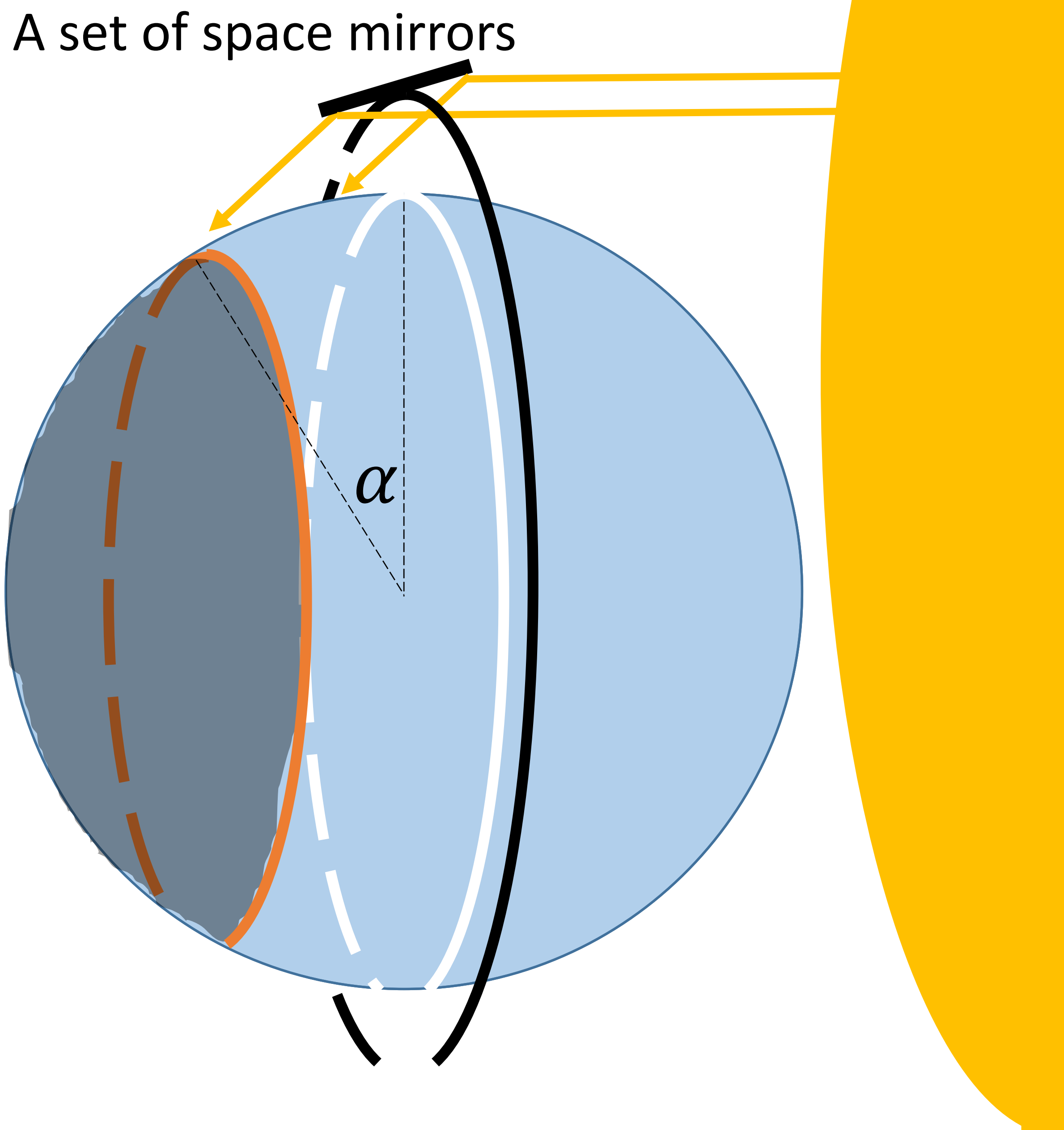
$$\Delta T = \left(\sqrt[4]{1.4} - 1\right)T = 0.09T = 22.68\ K/°C$$

Plan #2 Launch space mirrors to reflect the sunlight

Radiation distribution on TOA

The central point is the North pole





Temperature increase due to increased radiation

Under Plan#2:

$$S \times \pi R^2 \times b \times (1 - ref) = \sigma \times 4\pi R^2 \times T^4$$

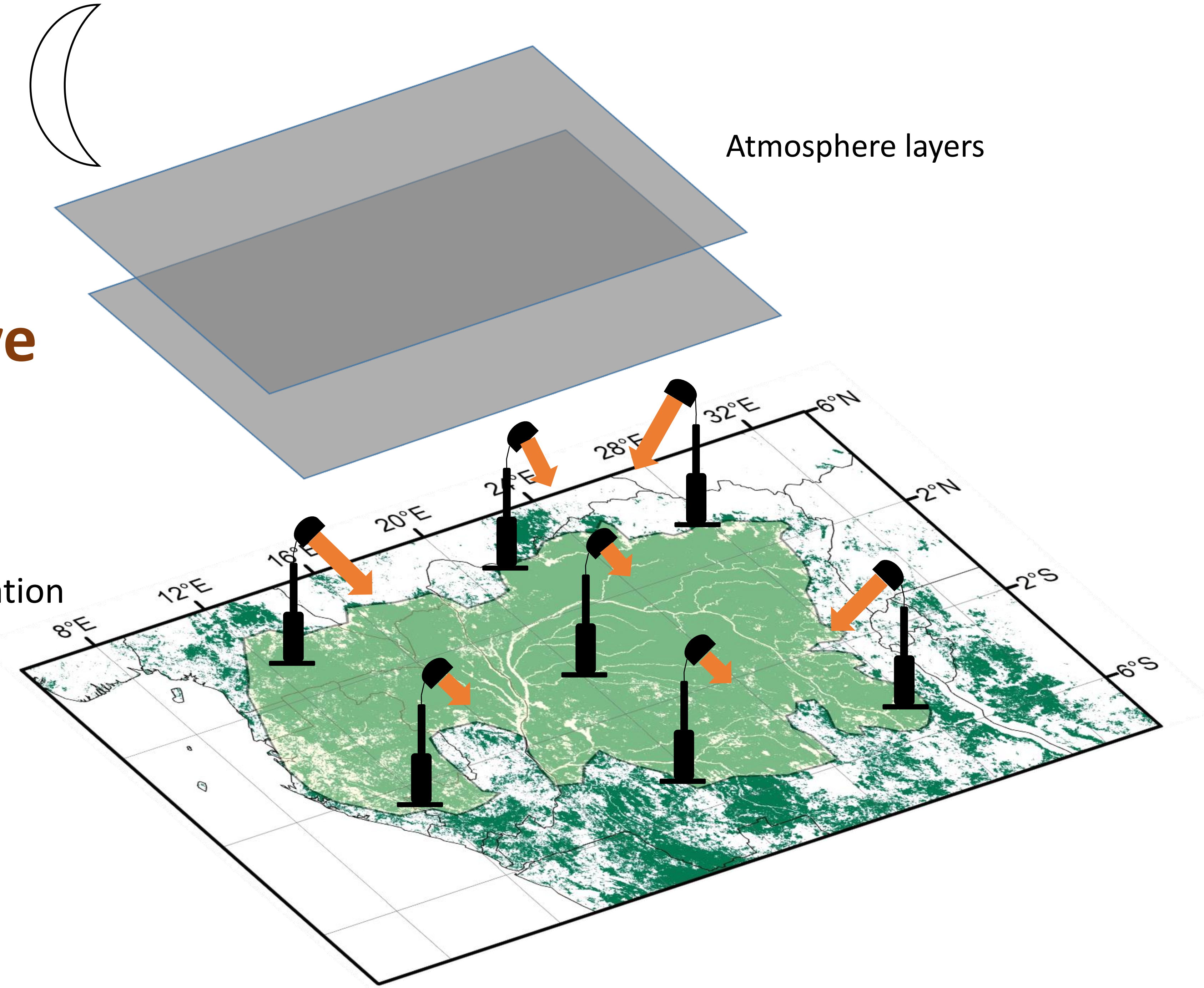
$$\Delta T = \left(\sqrt[4]{b} - 1\right)T$$

	$\alpha = 30°$	45°	60°
ΔT (k or °C)	16.38	36.04	64.86

---

* $$b = (1 - cos\alpha)^2 \times \left(1 - \frac{tan\alpha}{tan\frac{\alpha}{2}}\right) + \frac{2}{cos\alpha} - 1$$

Lighting up tropical forests at night via lamp networks above the forest canopy

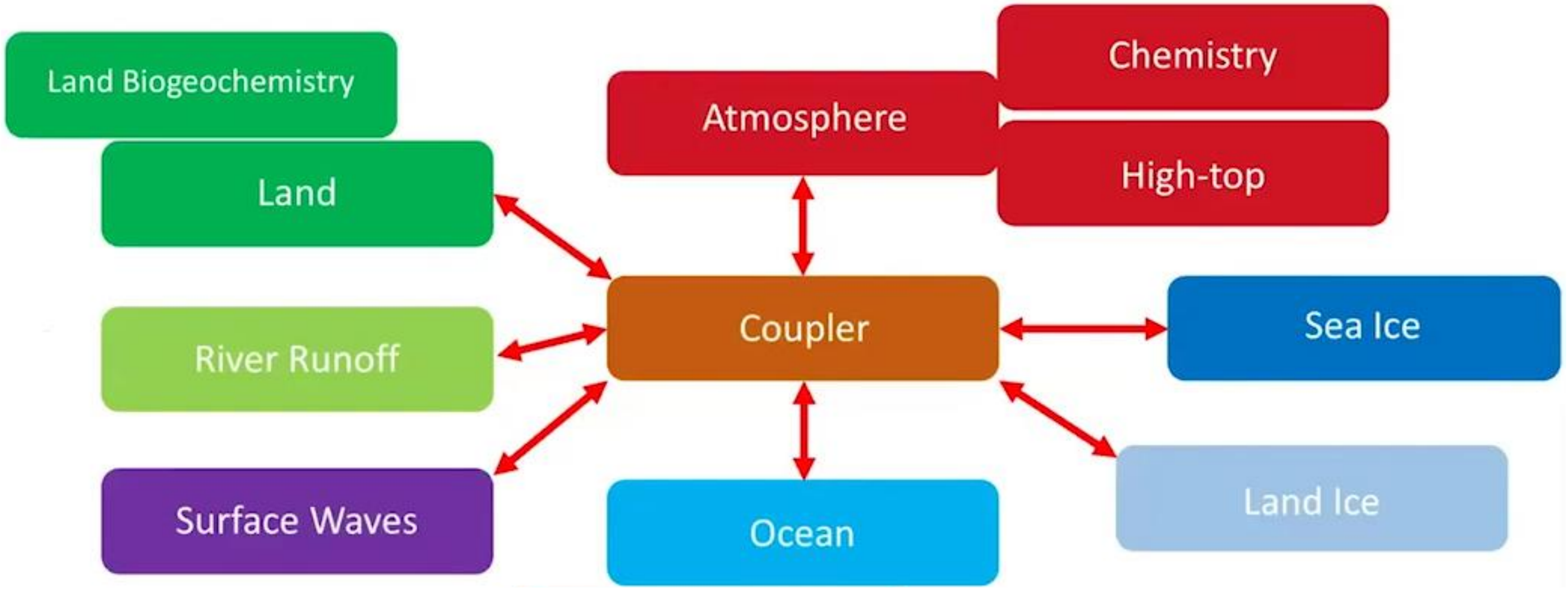


1. Quantification of carbon sequestration
2. Impacts on local climate and eco-environment
3. Technical and economic feasibility

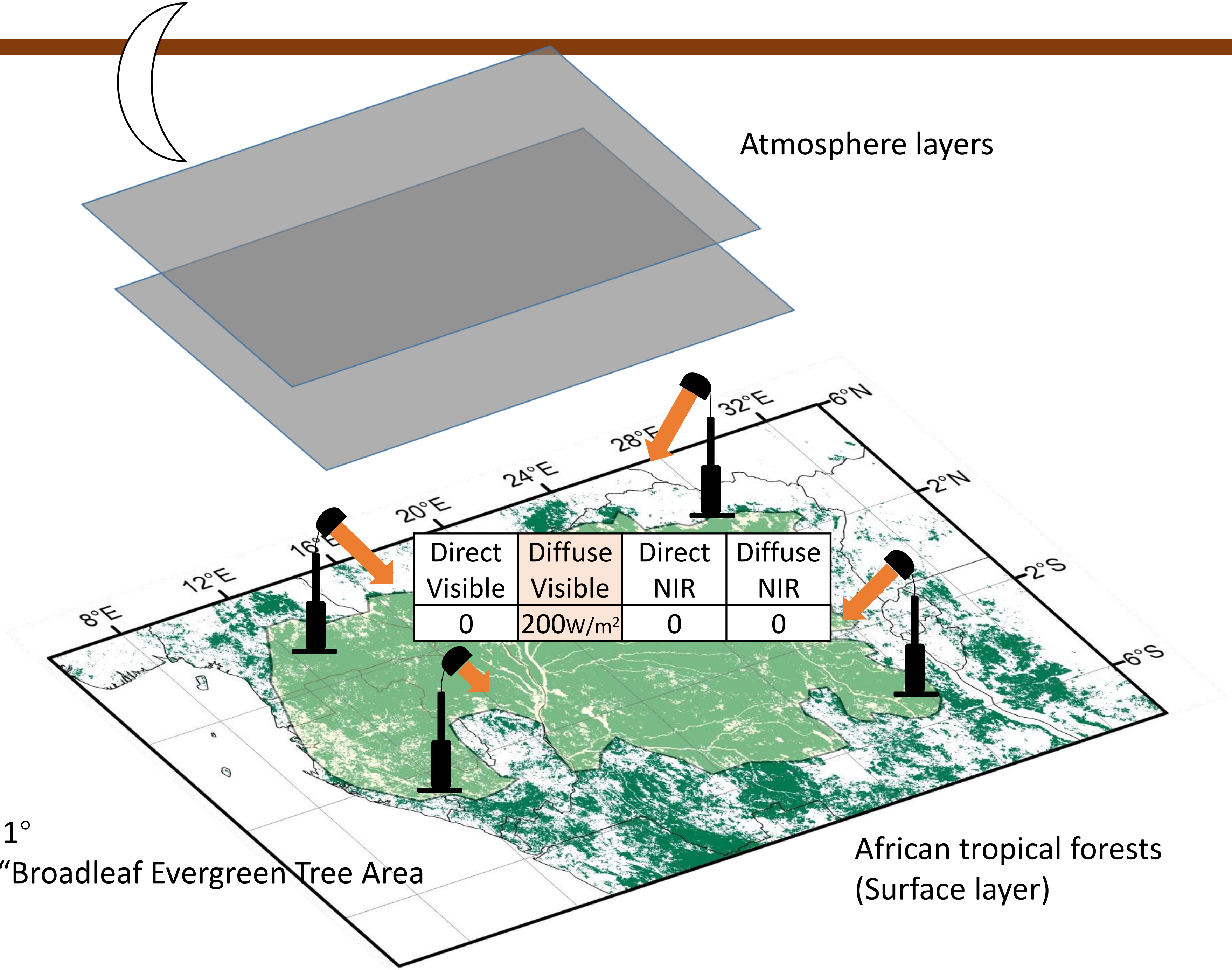
Methodology

Numerical experiments by fully coupled Community Earth System Model version 2 (CESM2) developed by the U.S. National Center for Atmospheric Research (NCAR).

Supported by NCAR **Cheyenne high-performance computing platform** and NCAR **Graduate Student Small-Allocation Computing Award**.



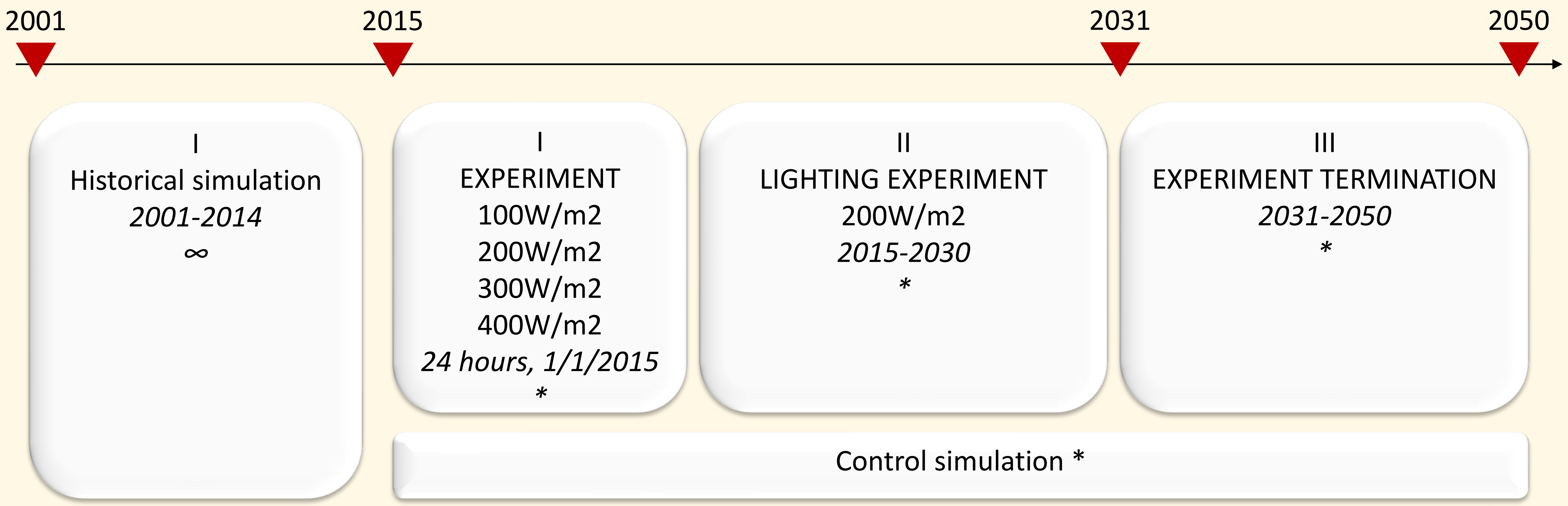
Methodology



Direct Visible	Diffuse Visible	Direct NIR	Diffuse NIR
0	200W/m²	0	0

Nominal horizontal resolution: 1°
Tropical forests are defined by “Broadleaf Evergreen Tree Area Percentage” > 60%

Methodology



∞: CESM2 esm-hist-BPRP, two members

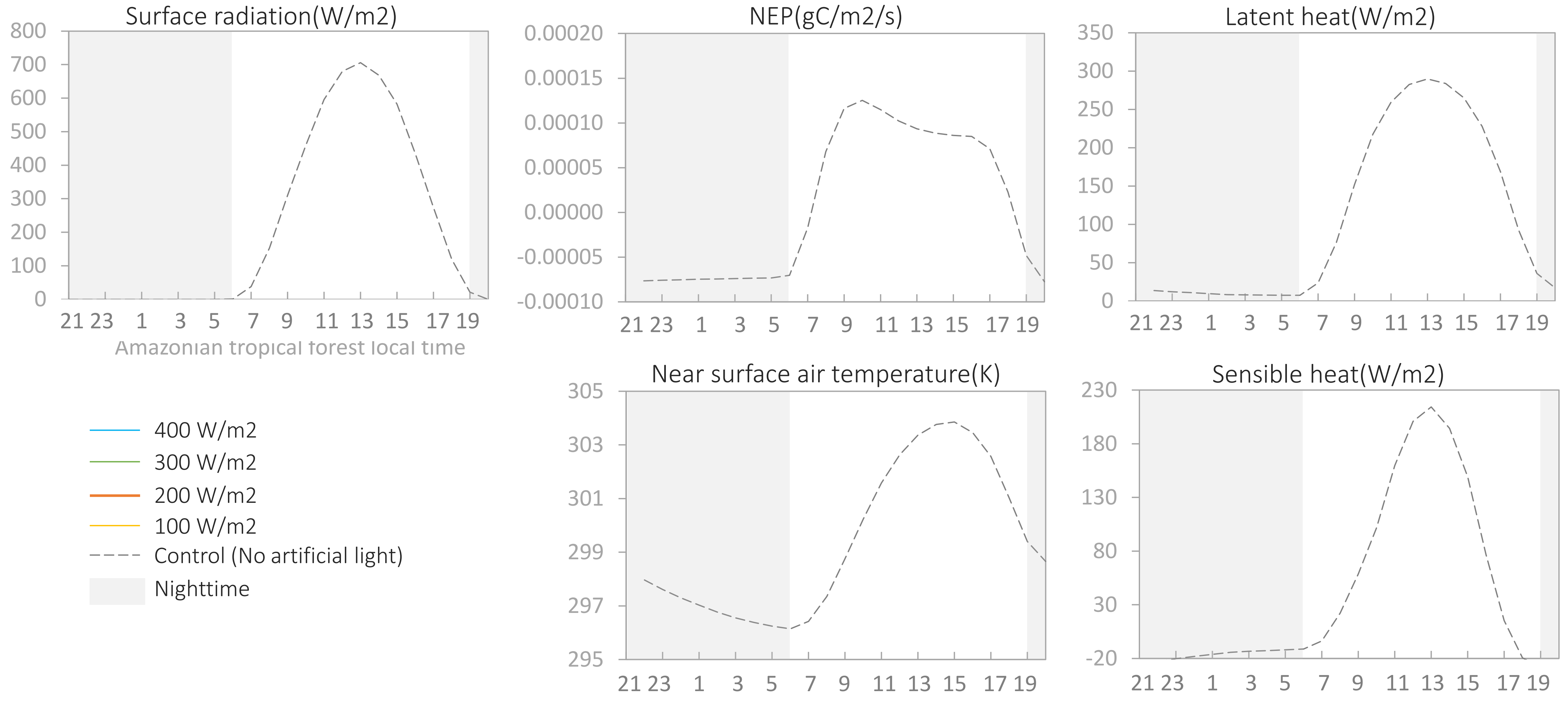
* : CESM2 esm-SSP126-BPRP, two members

I

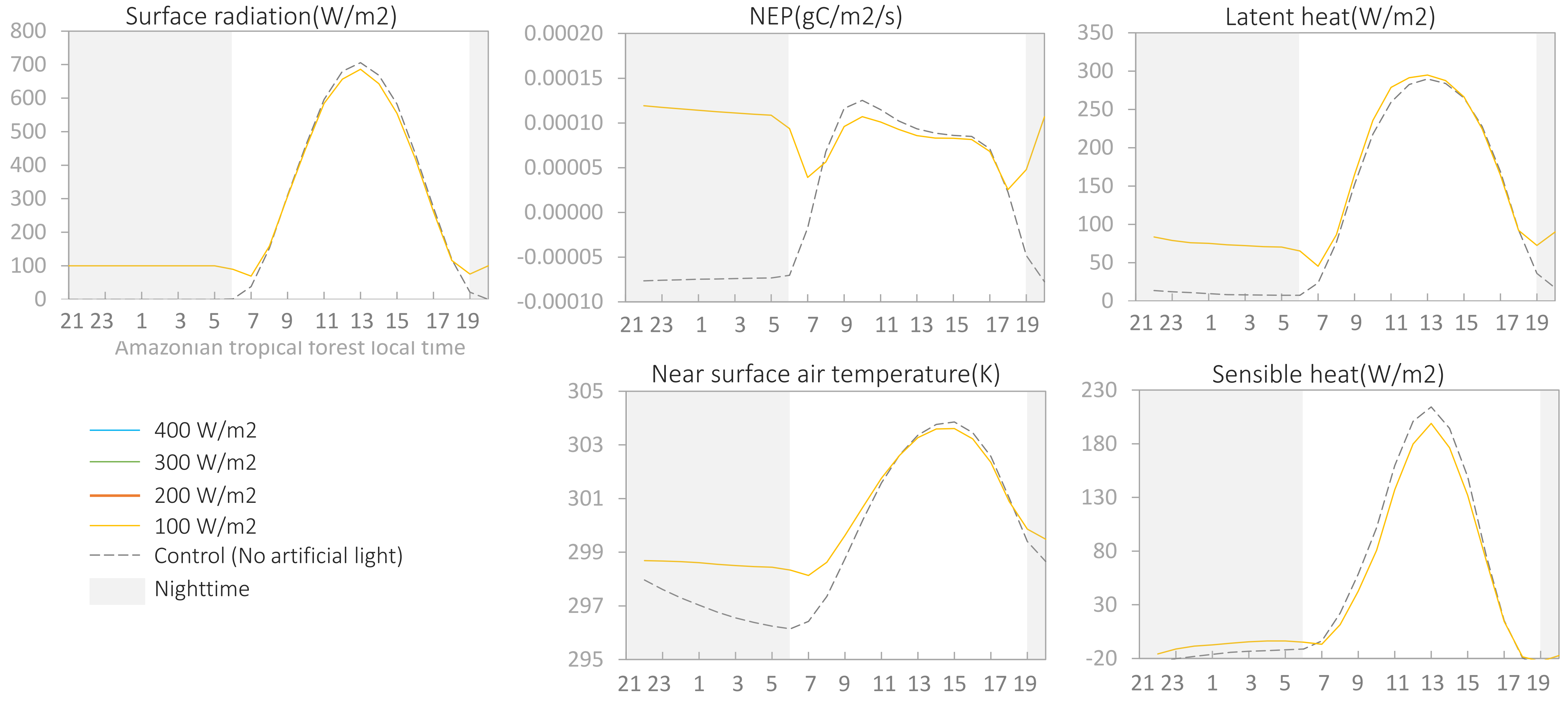
24-hour Experiment

“Tropical forest responses under various lighting powers”

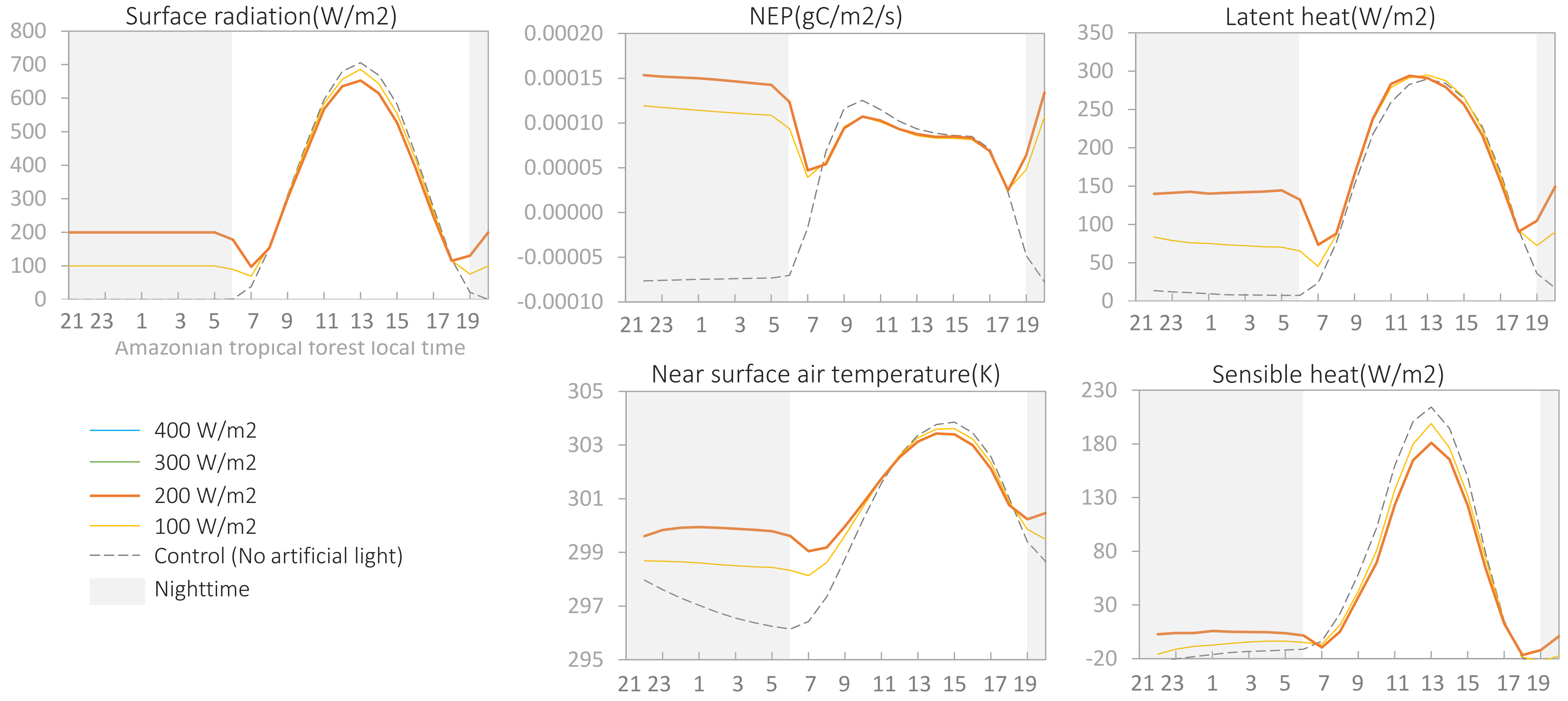
24-hour Amazon Tropical Forest Responses Control



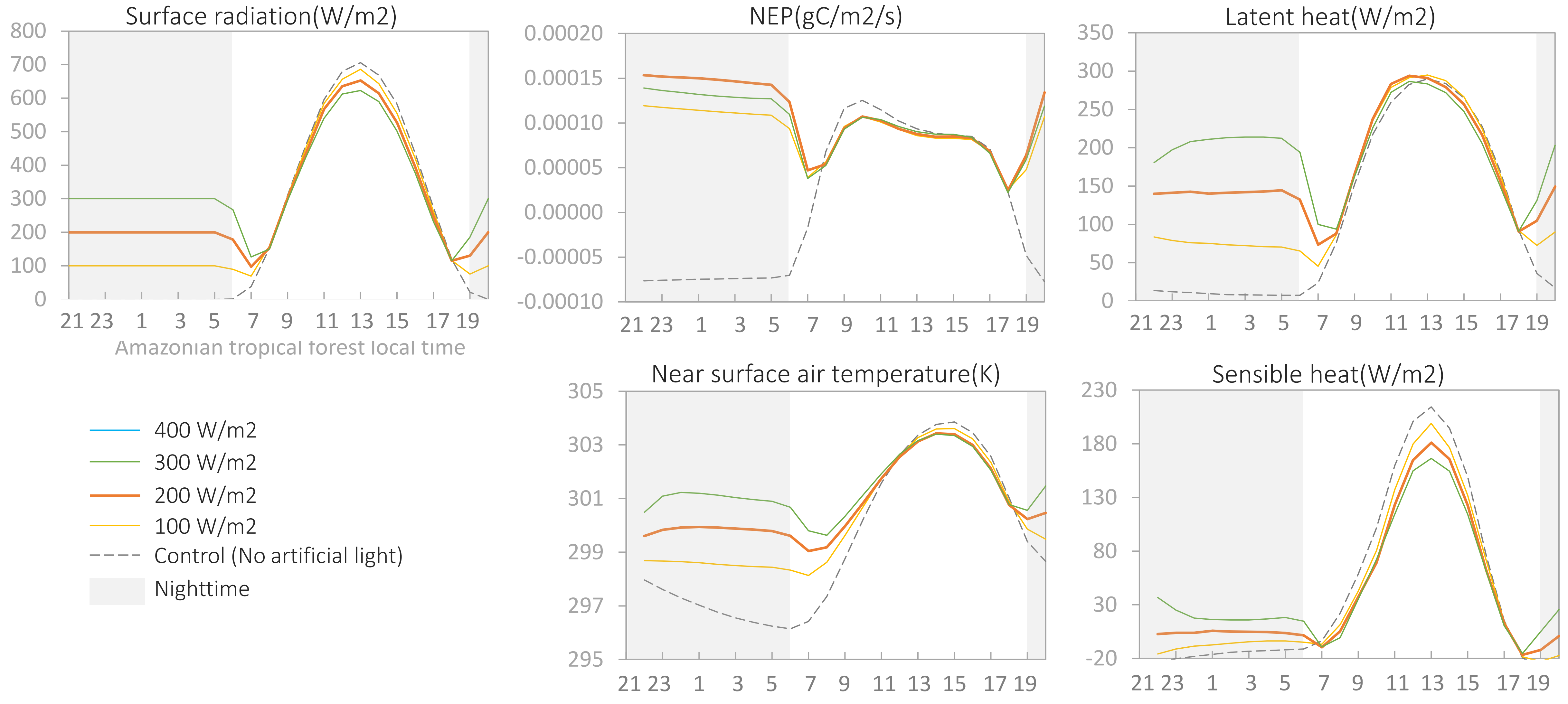
24-hour Amazon Tropical Forest Responses 100W/m2



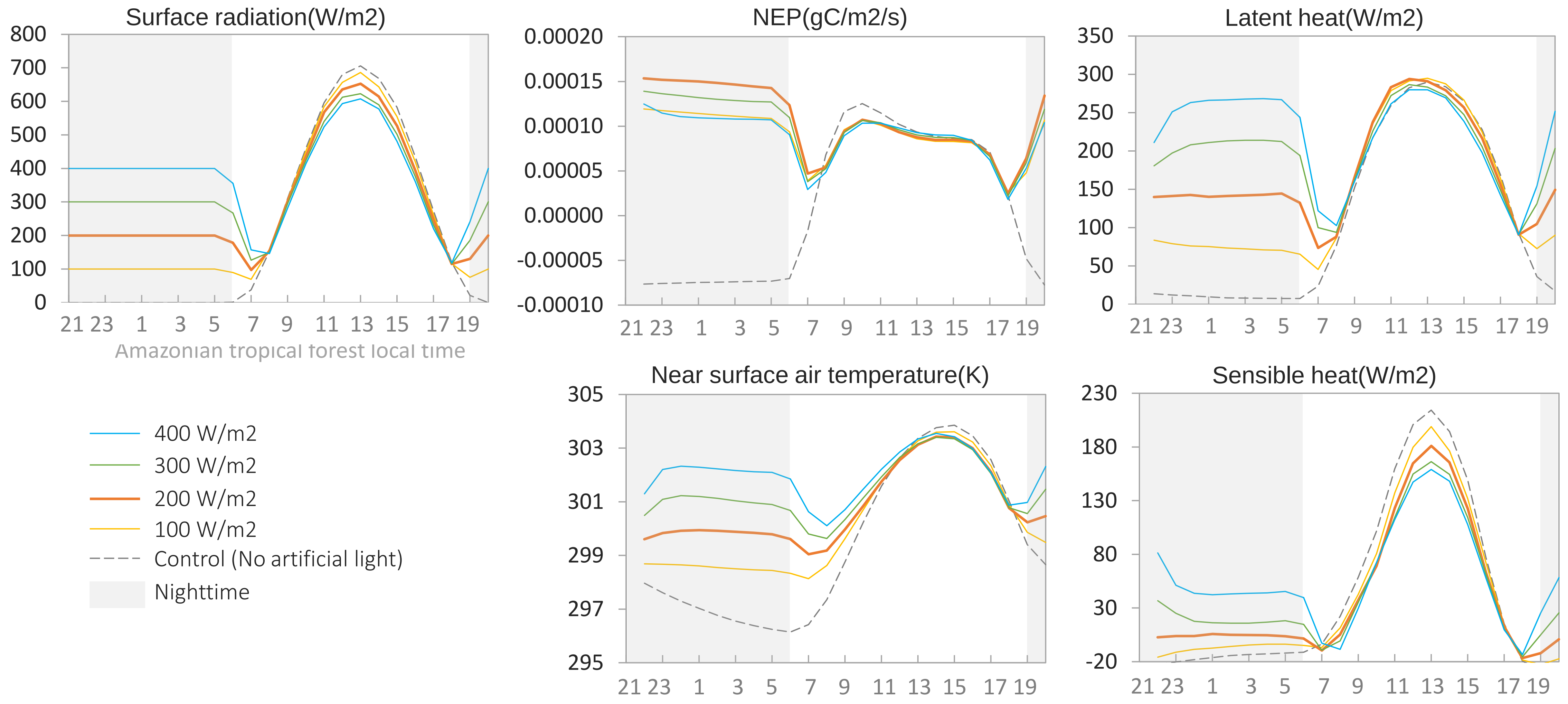
24-hour Amazon Tropical Forest Responses 200W/m2



24-hour Amazon Tropical Forest Responses 300W/m2



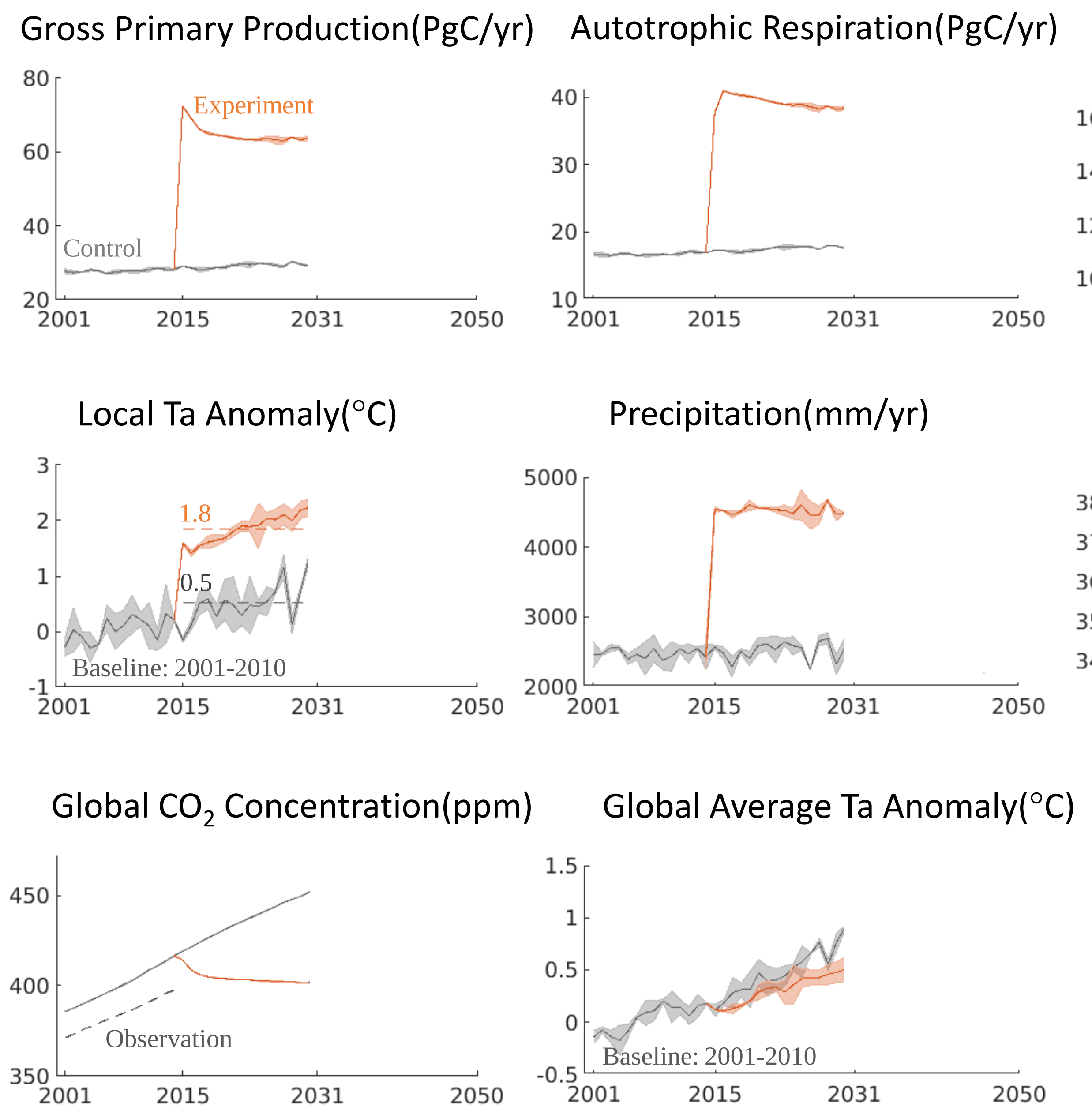
24-hour Amazon Tropical Forest Responses 400W/m2



Results

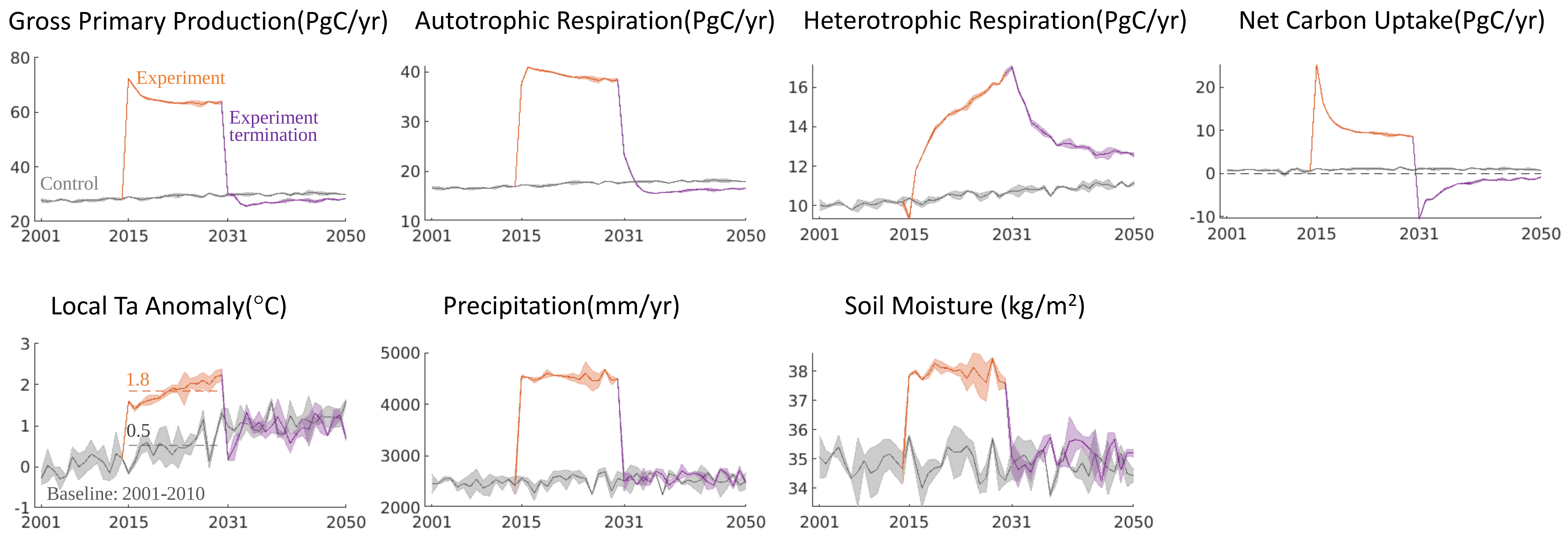
1. 200W/m^2 is the optimal lighting power in terms of increasing additional photosynthesis
2. Local temperature increase was overestimated by CESM2 (See Discussion)

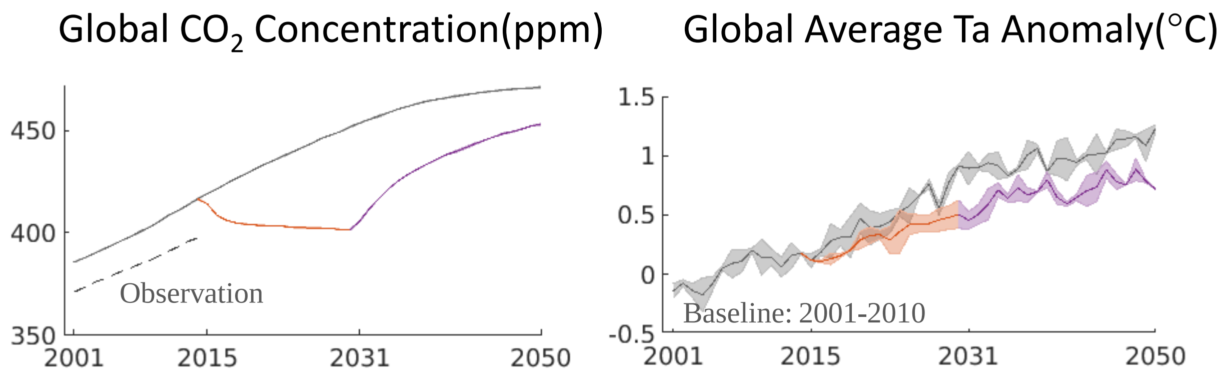
II
16-year Experiment
“Tropical forest responses under 200W/m2 from 2015-2030”



Global Tropical Forest Carbon Flux and Climate Responses

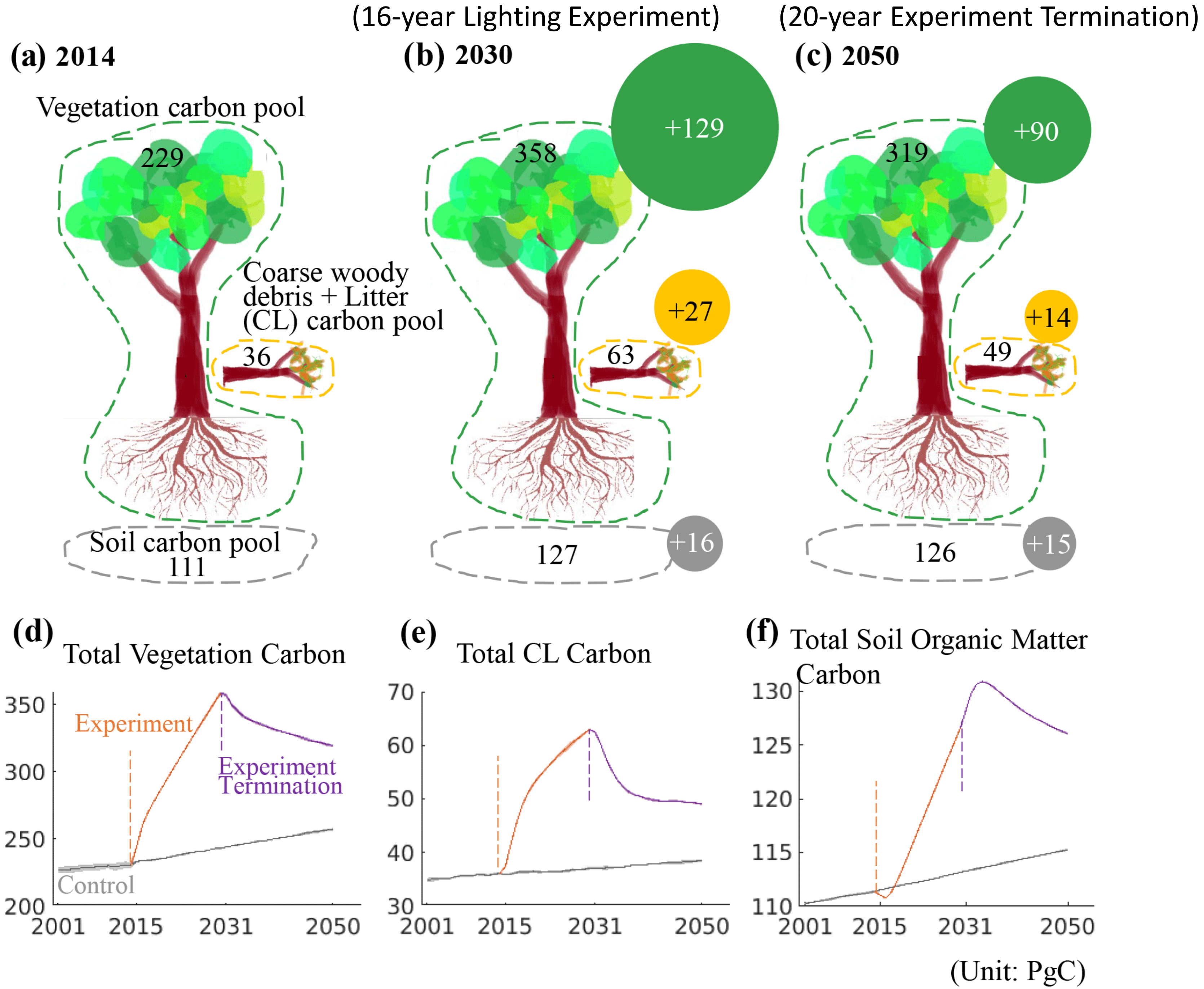
III
20-year Experiment Termination
“Tropical forest responses after the termination of lighting experiment from 2031-2050”





Global Tropical Forest Carbon Flux and Climate Responses

Where did the net-absorbed carbon go?



Discussion 1: Ecosystem-level field experiments are needed

Physiological responses of tropical trees to longer photoperiods at the ecosystem level remain among the biggest uncertainties in model simulations. Tree growth might be limited by nutrient and water supply.

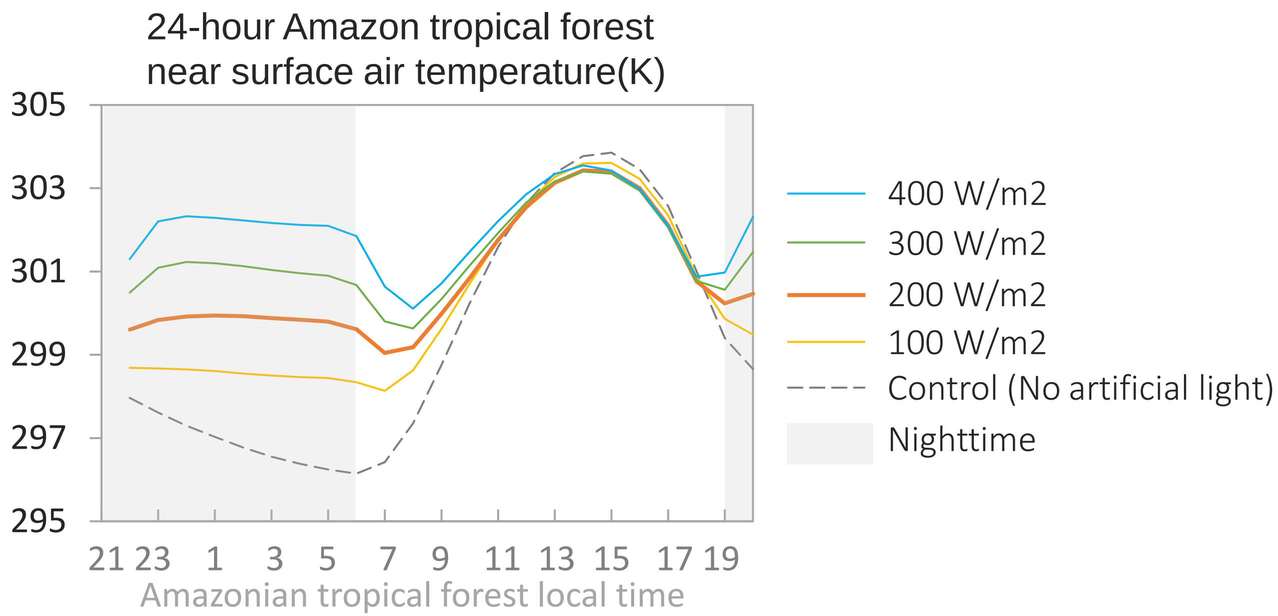
Ecosystem-level field experiments are needed to understand how tropical forest ecosystems respond to longer photoperiods.

Discussion 2: CESM2 overestimated local air temperature increases due to the omission of chemical energy stored during photosynthesis

The canopy energy conservation used to calculate temperature:

$$-\vec{S}_v + \vec{L}_v(T_v) + H_v(T_v) + \lambda E_v(T_v) = 0$$

[S_v is the solar radiation absorbed by the vegetation, L_v is the net longwave radiation absorbed by vegetation, and H_v and λE_v are the sensible and latent heat fluxes from vegetation, respectively. L_v, H_v, and λE_v depend on the vegetation temperature T_v.]

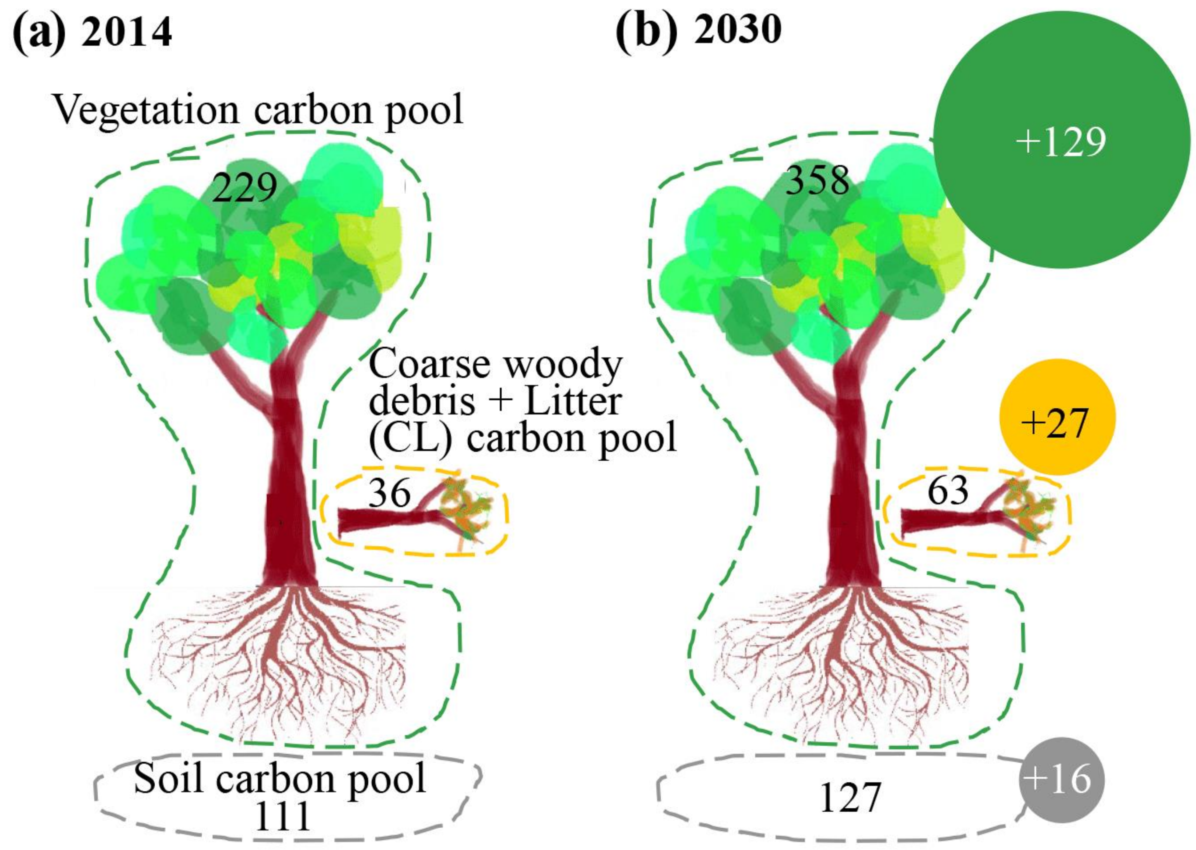


In CESM2 and other modern Earth system models (Sellers, 1992), the chemical energy that is stored during photosynthesis and released by respiration is ignored as the net chemical energy usually amounts to less than **1 %** of absorbed insolation (around 0.6 % in Trenberth et al., 2009).

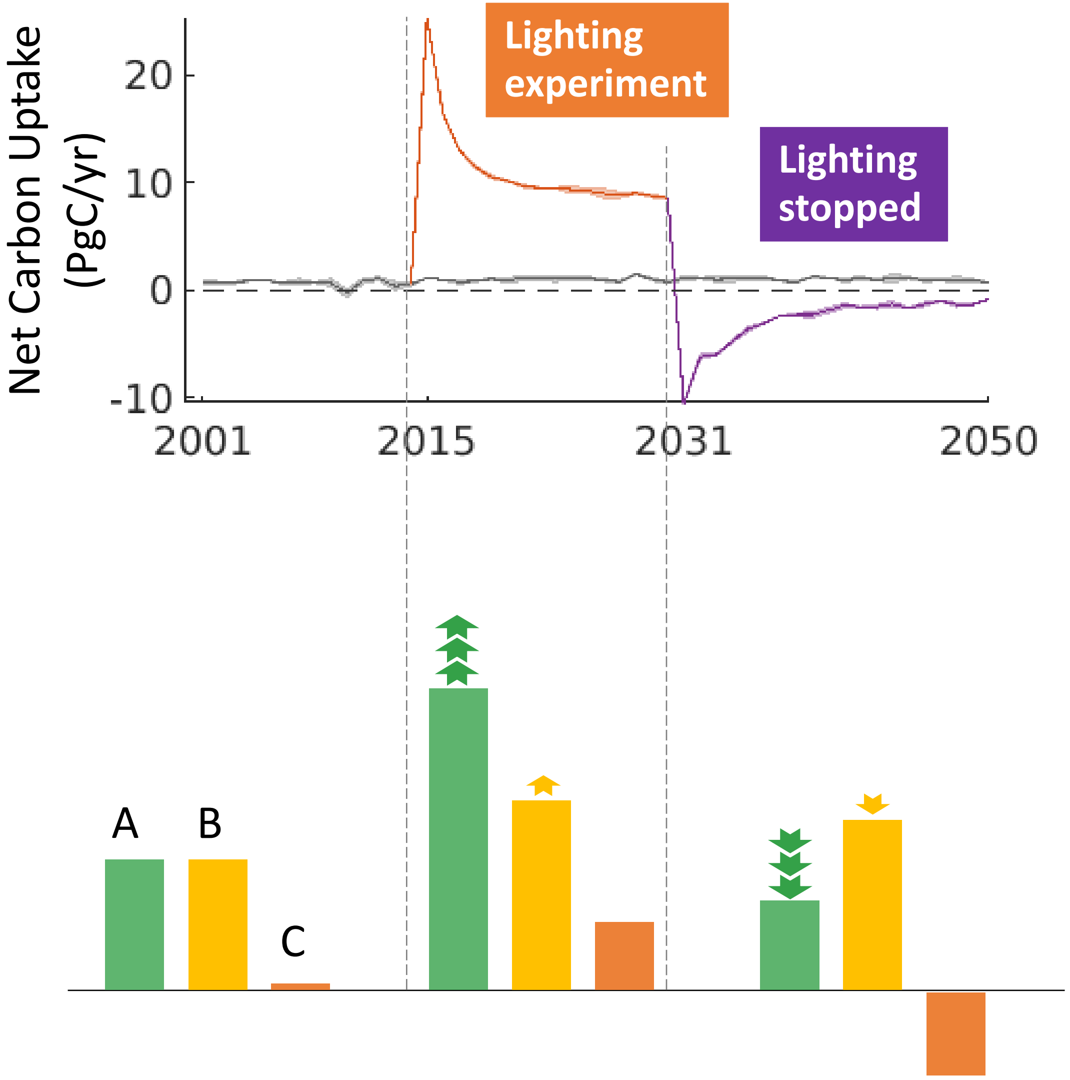
Temperature simulation results should be treated carefully when Earth system models are used to do experiments related to solar radiation modifications.

In our lighting experiment from 2015 to 2030, however, **17 %** of absorbed insolation was fixed in the ecosystem as chemical energy and did not contribute to local air temperature increase. The model failed to exclude this chemical energy storage from the energy equation. Therefore, the model overestimated the local temperature increase.

(16-year Lighting Experiment)



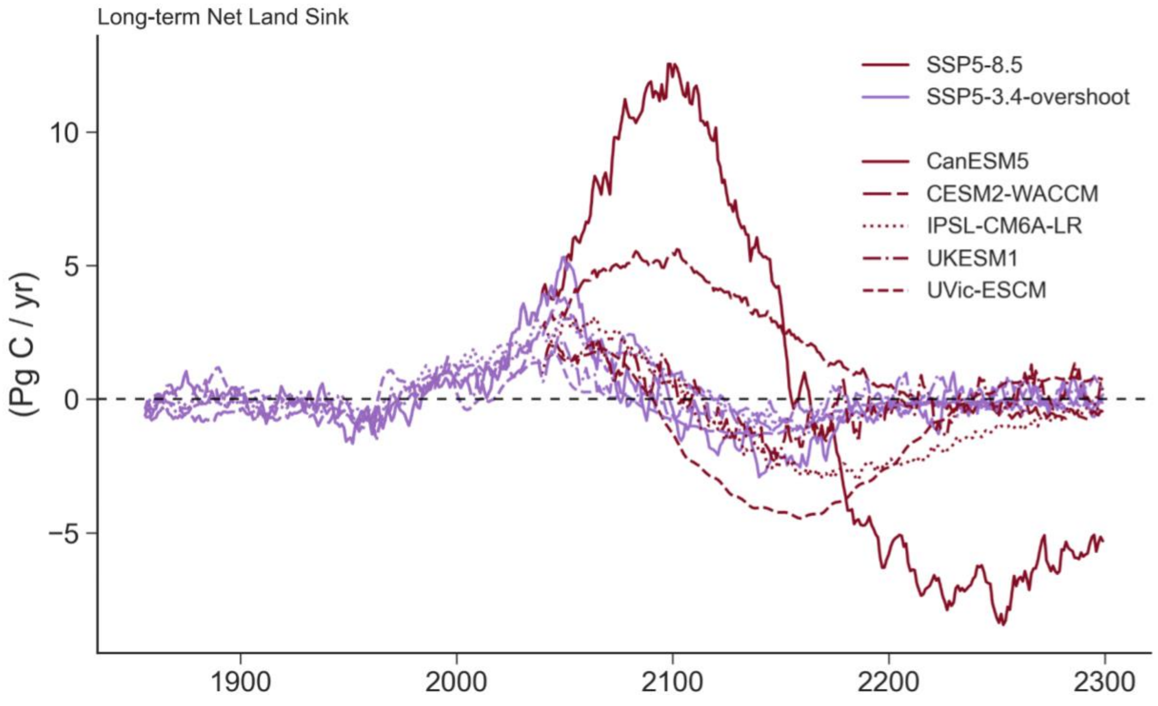
Discussion 3: Post-action CO_2 outgassing from tropical forests



"Stimulant Effect"

A: Vegetative primary productivity
B: Heterotrophic respiration
A-B=C: Net ecosystem productivity

Similar phenomena in overshoot scenario simulations and Free Air Carbon Dioxide Enrichment (FACE) experiments



C. Koven, et al. 2021

The fate of carbon in a mature forest under carbon dioxide enrichment

Mingkai Jiang, Belinda E. Medlyn, John E. Drake, Remko A. Duursma, Ian C. Anderson, Craig V. M. Barton, Matthias M. Boer, Yolima Carrillo, Laura Castañeda-Gómez, Luke Collins, Kristine Y. Crous, Martin G. De Kauwe, Bruna M. dos Santos, Kathryn M. Emmerson, Sarah L. Facey, Andrew N. Gherlenda, Teresa E. Gimeno, Shun Hasegawa, Scott N. Johnson, Astrid Kännaste, Catriona A. Macdonald, Kashif Mahmud, Ben D. Moore, Loïc Nazaries, ... David S. Ellsworth + Show authors

Nature **580**, 227–231 (2020) | Cite this article

17k Accesses | **132** Citations | **687** Altmetric | Metrics

"Although the eCO_2 treatment induced a 12 per cent increase in gross primary production, this additional carbon uptake did not lead to increased carbon sequestration at the ecosystem level. Instead, the majority of the extra carbon was emitted back into the atmosphere via soil respiration..."

It suggests that CO_2 removal methods focused on enhancing ecosystem carbon sequestration by altering environmental factors in the short term could induce this post-action CO_2 outgassing.

Discussion 4: Where does the energy come from?

Technically: more low-carbon energy-generation plants (building large-scale solar and wind farms in the Sahara)

"If one could generate enough clean power for the forests, why not just use that energy directly to offset fossil fuel activities."

Economically: both DACC and this strategy are energetically and financially costly and are unrealistic at present; even if the clean-energy-generation capacity increases, we cannot expect the global clean energy supply to only be invested in absorbing CO_2.

1. Society has urgency to intervene in Earth's climate by wartime-like crash deployment of carbon removal technologies.
2. An energy revolution is realized and we achieve a significant surplus of clean energy.

Discussion 5: The impact on local wildlife and biodiversity

Given the potentially inverse relationship between more light at night and ecosystem health, policy makers may consider extending the photoperiod to an appropriate level to increase carbon sequestration while protecting local biodiversity from disastrous impacts. The trade-off between nighttime carbon sequestration and biodiversity preservation should be rigorously evaluated and weighed in the decision-making process.

Alternative options:

1. Giving nighttime artificial lighting to plantations which are free from biodiversity issues.
2. Greening the urban areas which already have strong artificial light pollution at night.

Conclusions

1. **Implications for Earth system models users:**
   Temperature simulation results should be treated carefully when Earth system models are used to do experiments related to solar radiation modifications.

2. **Implications for nature-based climate solutions:**
   Enhancing terrestrial ecosystem carbon sequestration by altering environmental factors might be an inefficient approach for climate change mitigation and could induce post-action CO_2 outgassing.

3. **Implications for geoengineering measures (e.g. stratospheric aerosol injection)**
   Current geoengineering studies mainly focus on the evaluation of climate goals that a potential solution might or might not accomplish; however, the changes in Earth's climate after terminating a geoengineering measure tend to be overlooked. This study suggests the importance of post-geoengineering analysis in geoengineering studies.

Earth Syst. Dynam., 13, 219–230, 2022
https://doi.org/10.5194/esd-13-219-2022

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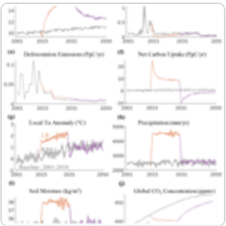
Research article

31 Jan 2022

Exploration of a novel geoengineering solution: lighting up tropical forests at night



Xueyuan Gao[1], Shunlin Liang[1], Dongdong Wang[1], Yan Li[2], Bin He[3], and Aolin Jia[1]
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Gao, X., et al. Exploration of a novel geoengineering solution: lighting up tropical forests at night, Earth Syst. Dynam., 13, 219–230, https://doi.org/10.5194/esd-13-219-2022, 2022.

- **2022 AAG Council Award for Outstanding Graduate Student Paper at Middle Atlantic Division of the AAG (MAD-AAG) Meeting.**

University of Maryland Department of Geographical Sciences Seminar

February 9th (Thursday) 3:45pm (EST)

Lefrak Hall 1158 & Zoom

Please reach out to me for a zoom link:
xygao@umd.edu

GEOG SEMINARS

DEPARTMENT OF GEOGRAPHICAL SCIENCES

Feburary 9, 2023
3:45pm-5:00pm
In-person seminar & zoom

Exploration of a novel carbon dioxide removal option: lighting up tropical forests at night

— *Implications for nature-based climate solutions*

Plants primarily conduct photosynthesis in the daytime, offering an opportunity to increase photosynthesis and carbon sink by providing light at night. We used the fully coupled Community Earth System Model to explore the feasibility of a novel carbon dioxide removal proposal: lighting up tropical forests at night via lamp networks above the forest canopy. Simulation results show that additional light increased tropical forest carbon sink by 10.4+-0.05 petagrams of carbon per year, resulting in a decrease in atmospheric CO_2 and suppression of global warming. In addition, local temperature and precipitation increased. When the lighting experiment was terminated, however, tropical forest photosynthesis decreased quickly while soil respiration remained high, making forests a net carbon source. This study suggests that enhancing terrestrial ecosystem carbon sequestration by altering environmental factors might be an inefficient approach for climate change mitigation and could induce post-action CO_2 outgassing.

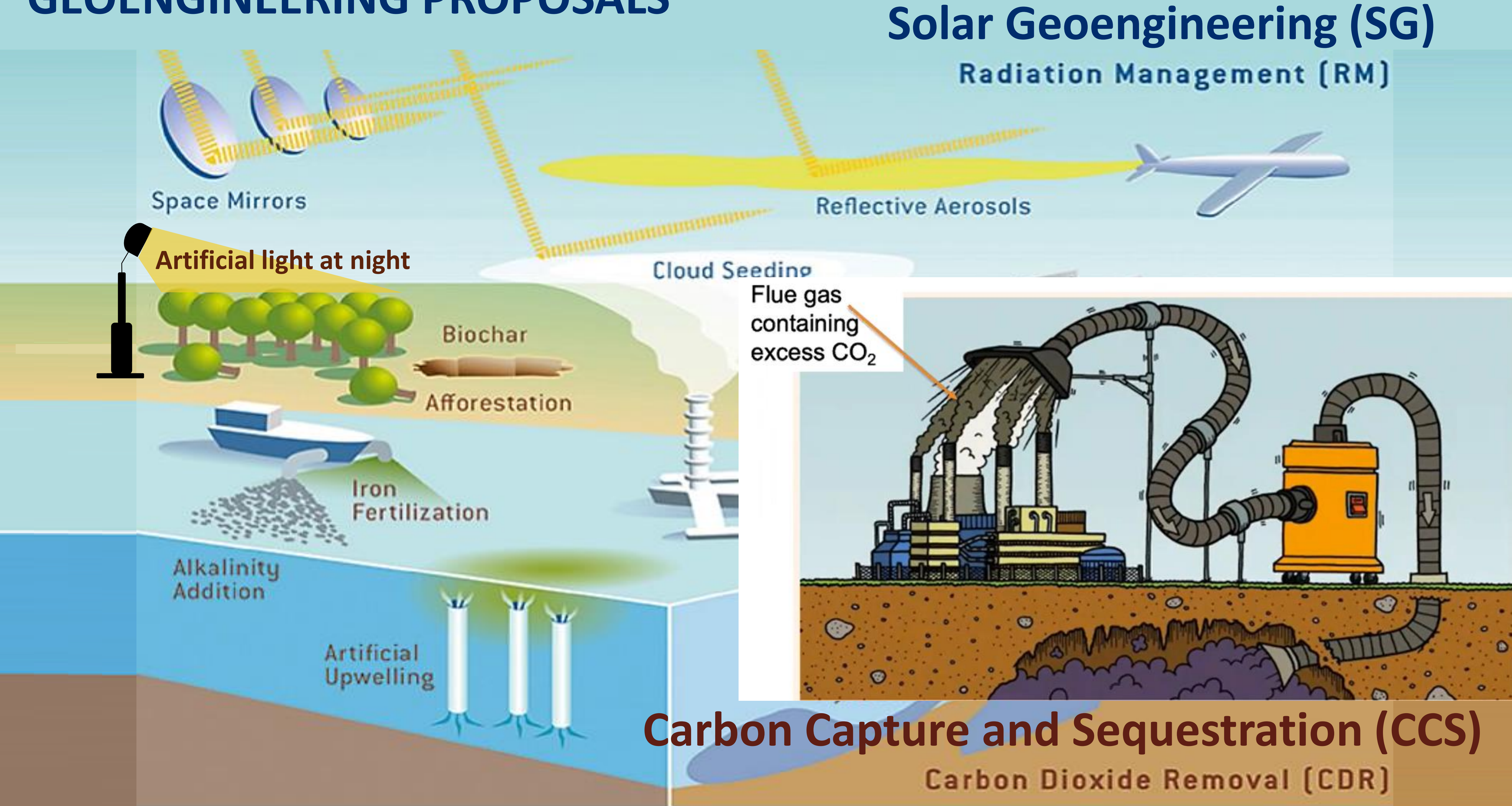
Key words: nature-based climate solutions

Xueyuan (Eric) Gao
PhD Candidate
Research interest: terrestrial ecosystem carbon cycle, carbon dioxide removal, climate change mitigation, remote sensing, Earth system models, integrated assessment models.
He was awarded the 2022 AAG Council Award for Outstanding Graduate Student Paper.

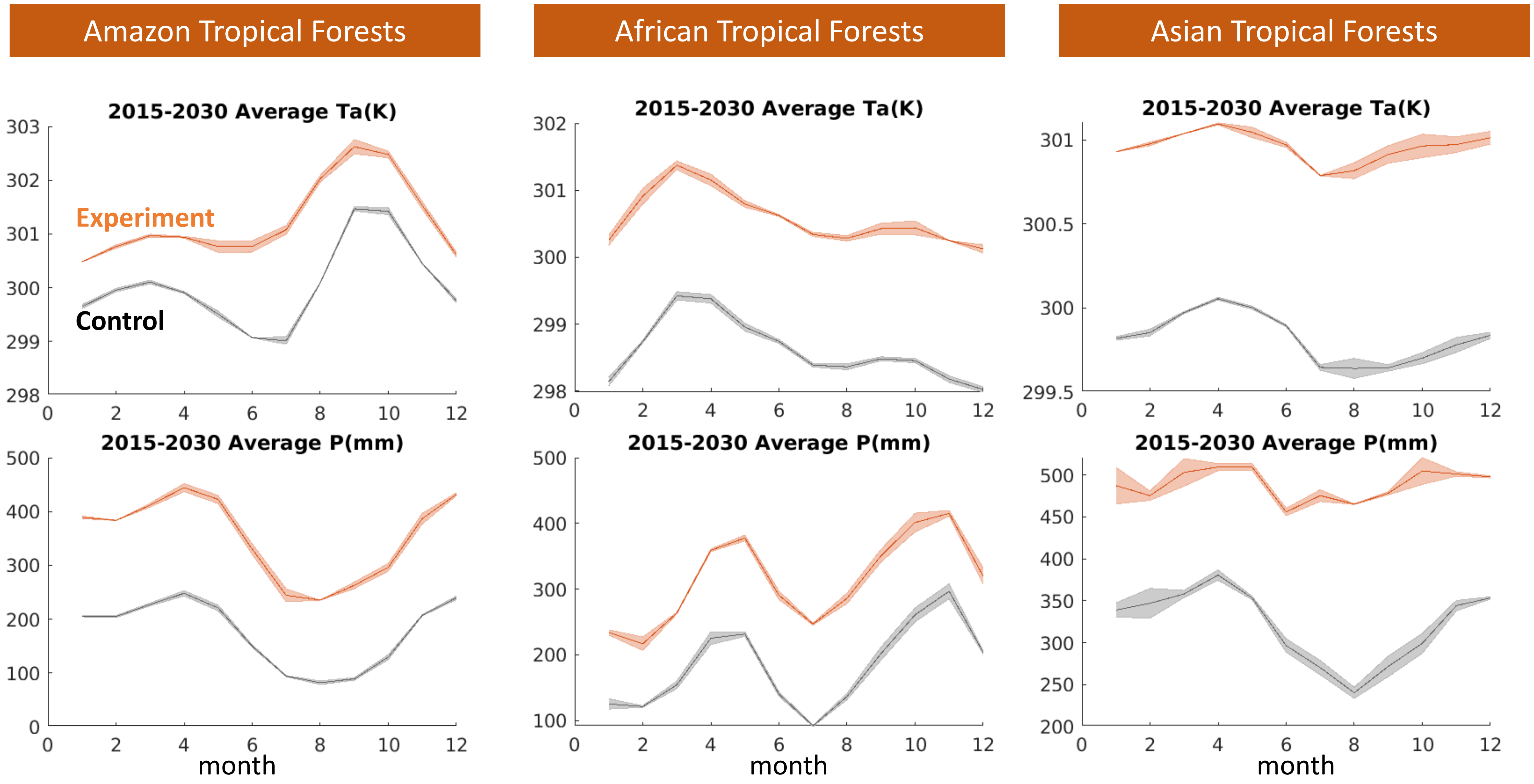
Location
Lefrak 1158
Or join Zoom Meeting
https://umd.zoom.us/j/4185059570?pwd=VlJTOXF0SlAxZW1WN3VVZm1QQWlLUT09
Meeting ID: 418 505 9570 Passcode: 718021

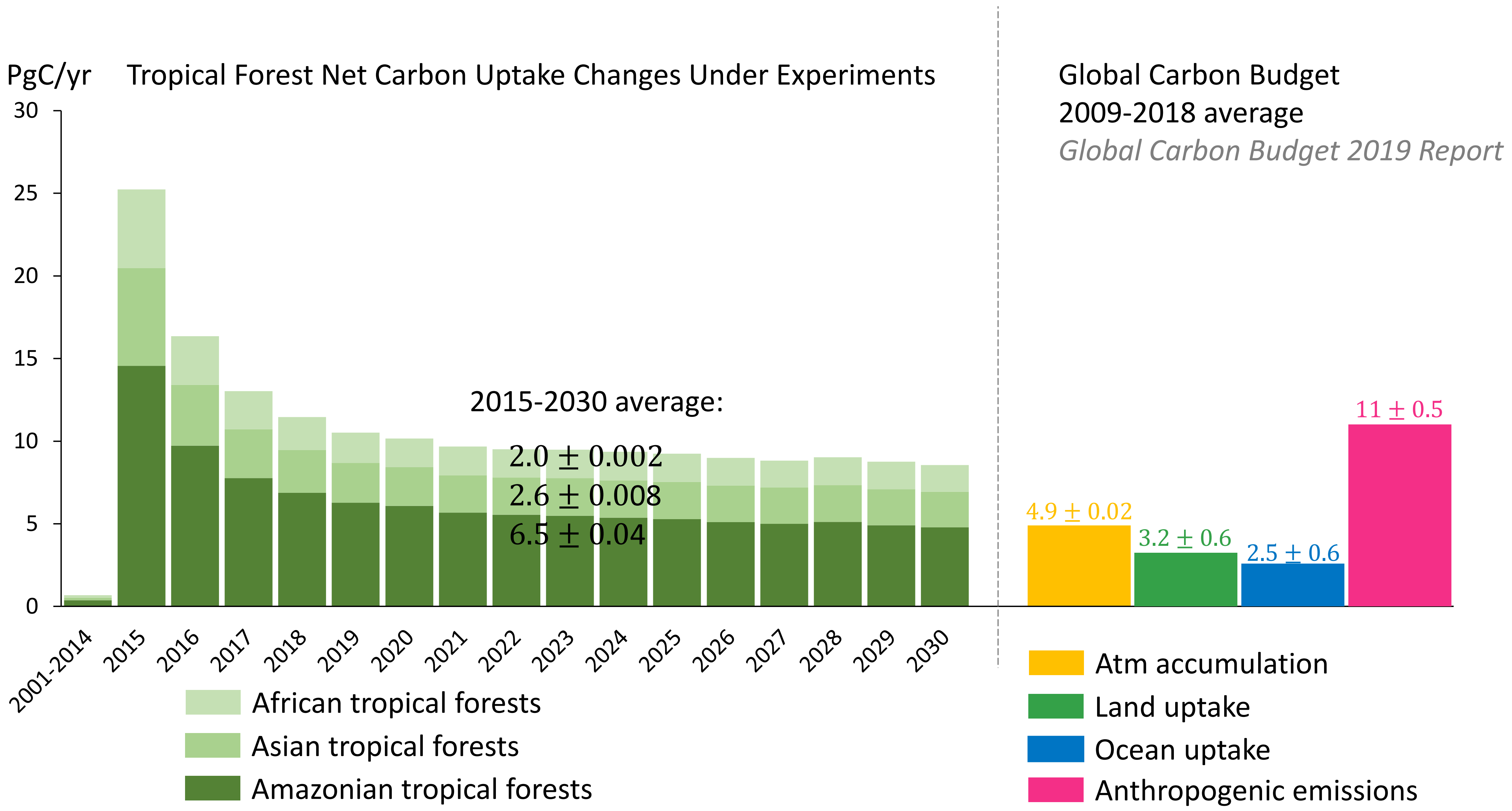
Supplements

GEOENGINEERING PROPOSALS

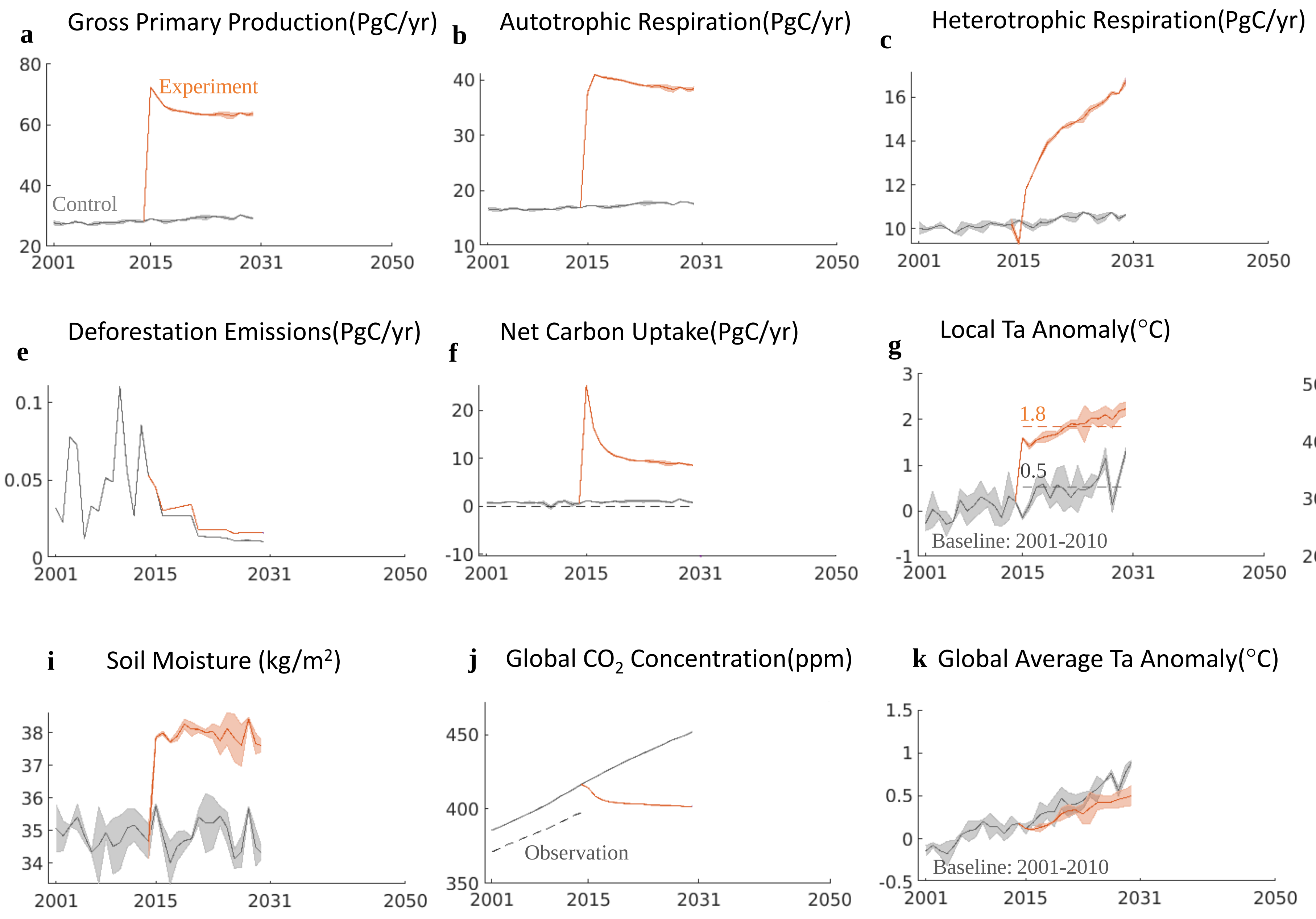


Seasonal trends in local temperature and precipitation increase

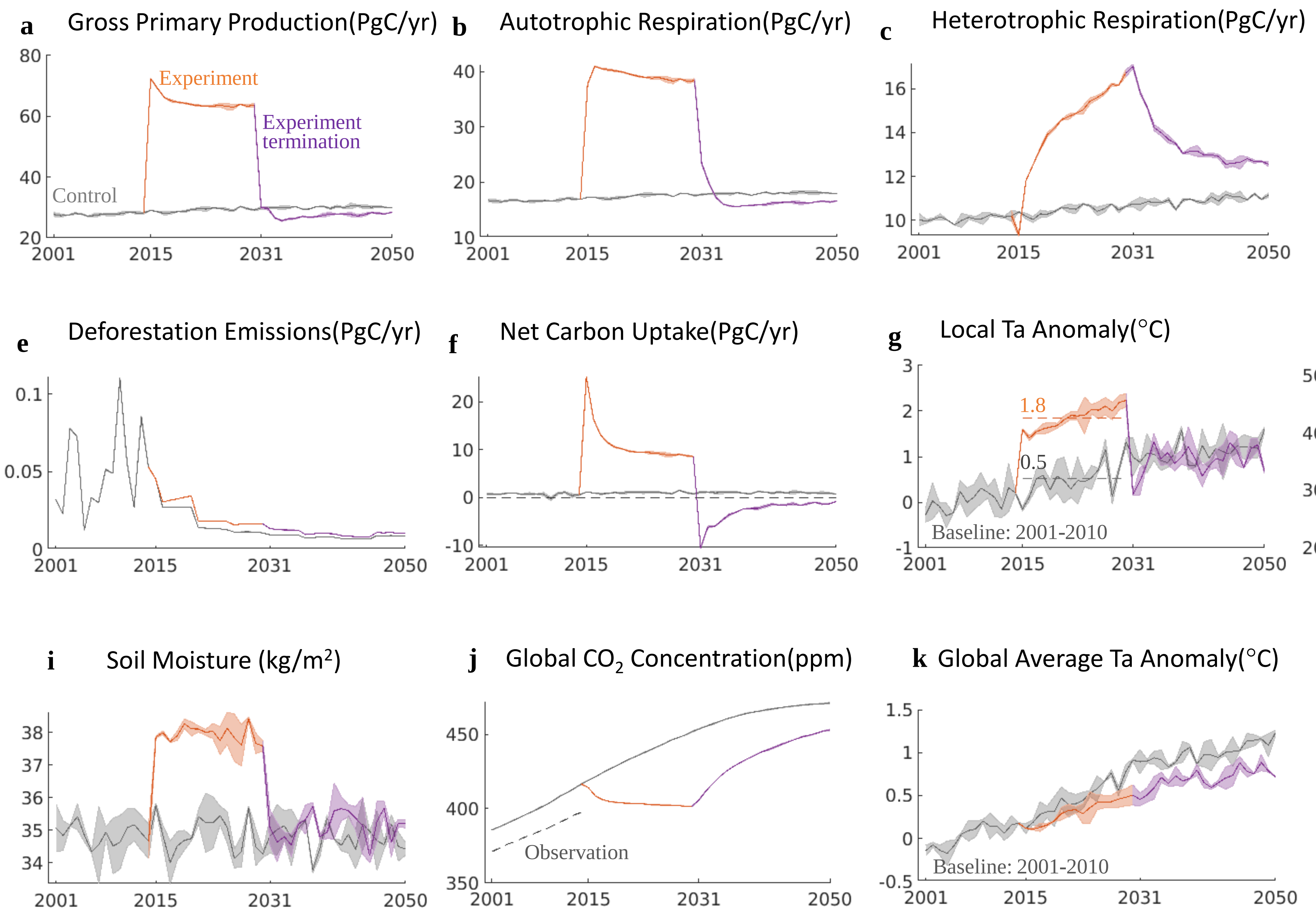




PgC/yr
Tropical Forest Net Carbon Uptake Changes Under Experiments
30
25
20
15
10
5
0
2015-2030 average:
2.0 ± 0.002
2.6 ± 0.008
6.5 ± 0.04
2001-2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
African tropical forests
Asian tropical forests
Amazonian tropical forests
Global Carbon Budget
2009-2018 average
Global Carbon Budget 2019 Report
4.9 ± 0.02
3.2 ± 0.6
2.5 ± 0.6
11 ± 0.5
Atm accumulation
Land uptake
Ocean uptake
Anthropogenic emissions

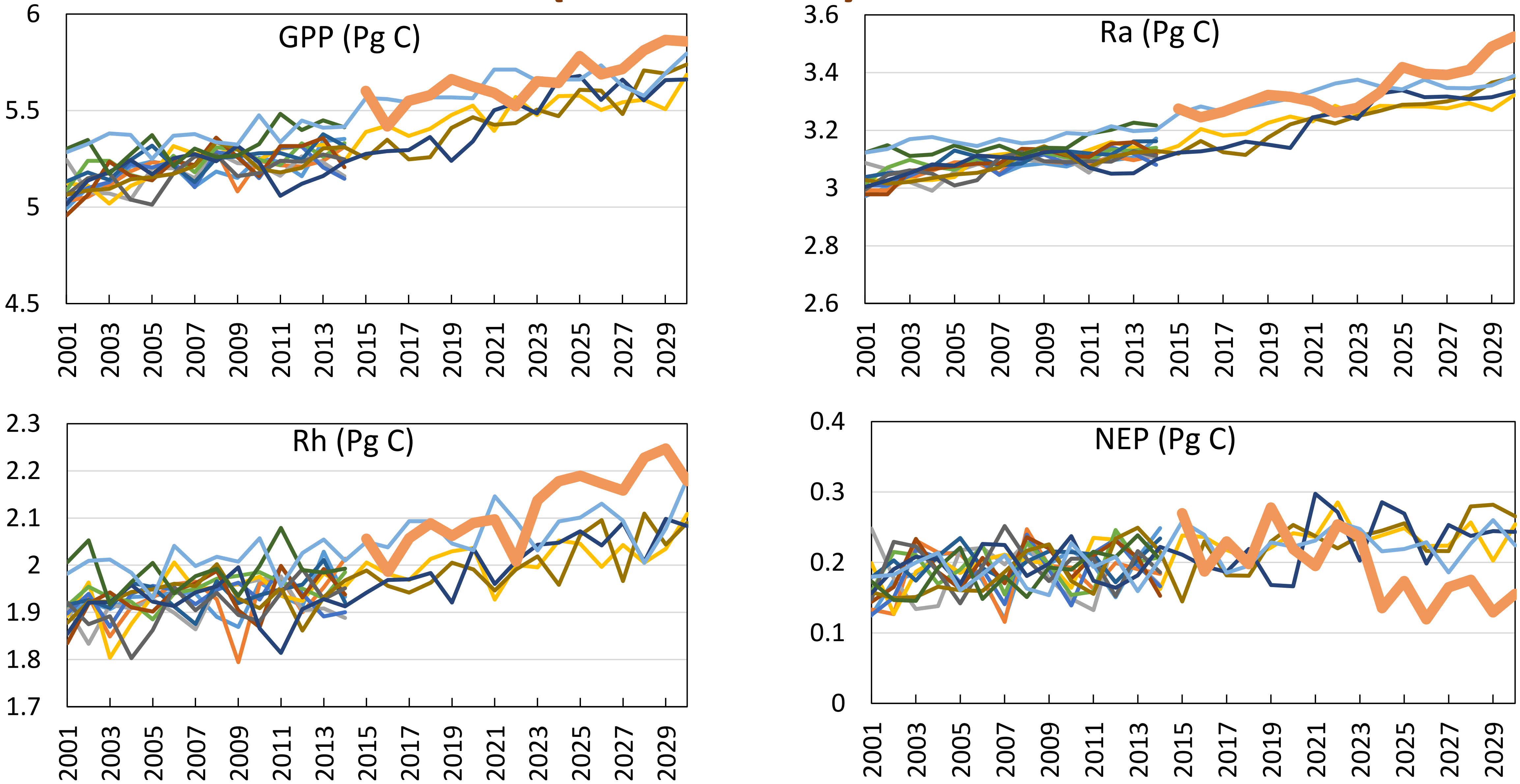


Global Tropical Forest Carbon Flux and Climate Responses



Global Tropical Forest Carbon Flux and Climate Responses

Control simulation (2001-2030) SSP585 VS SSP126



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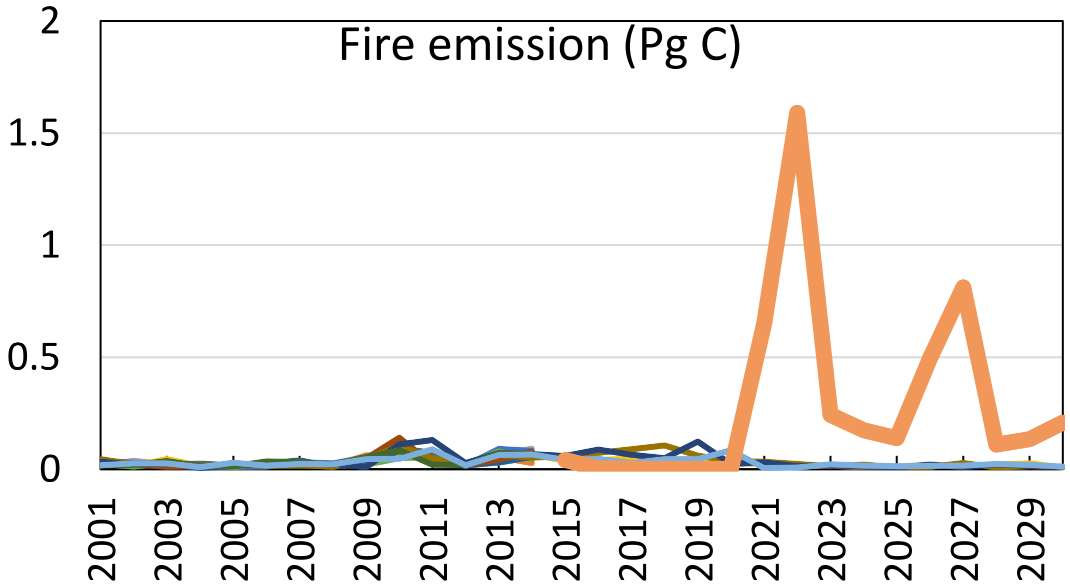
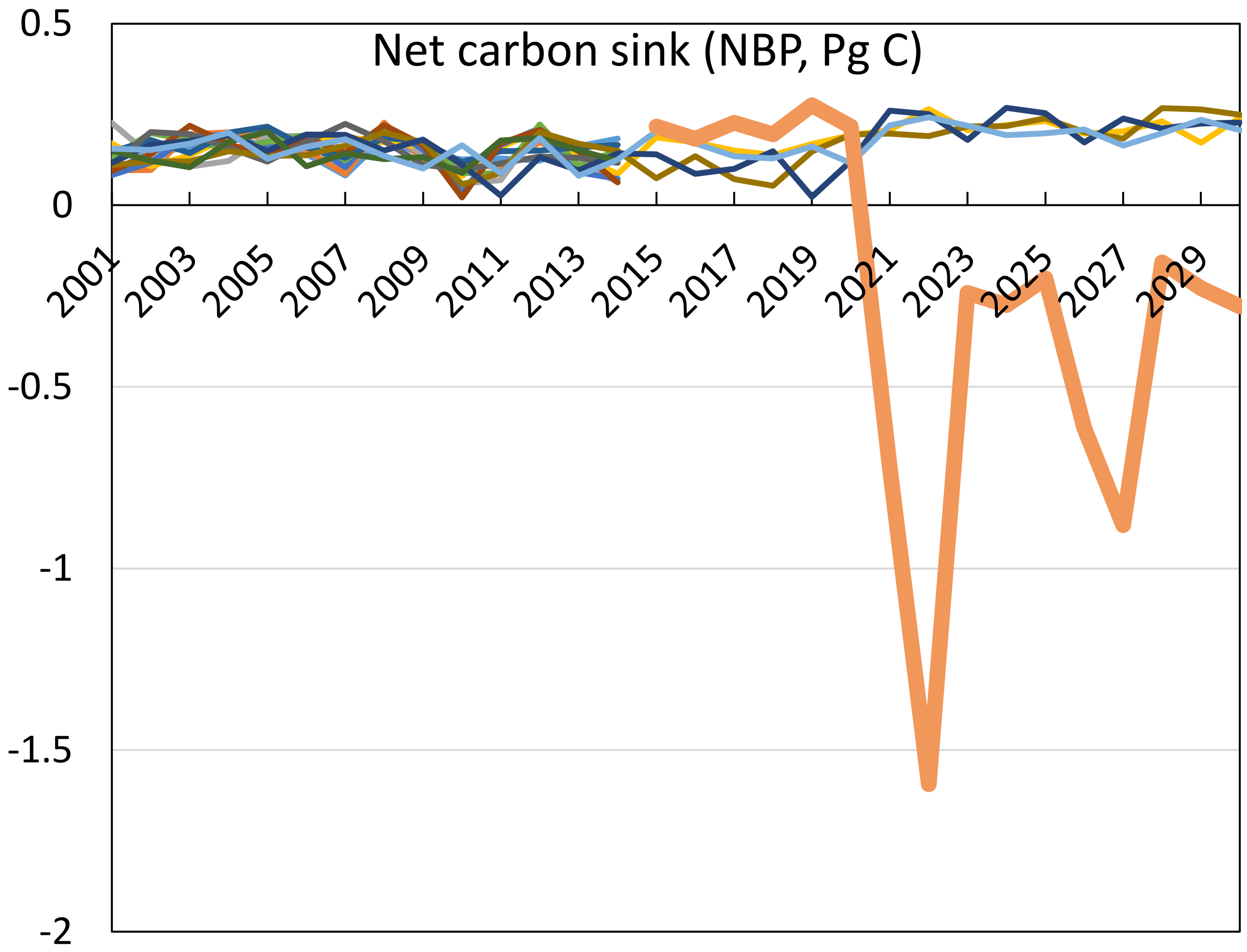
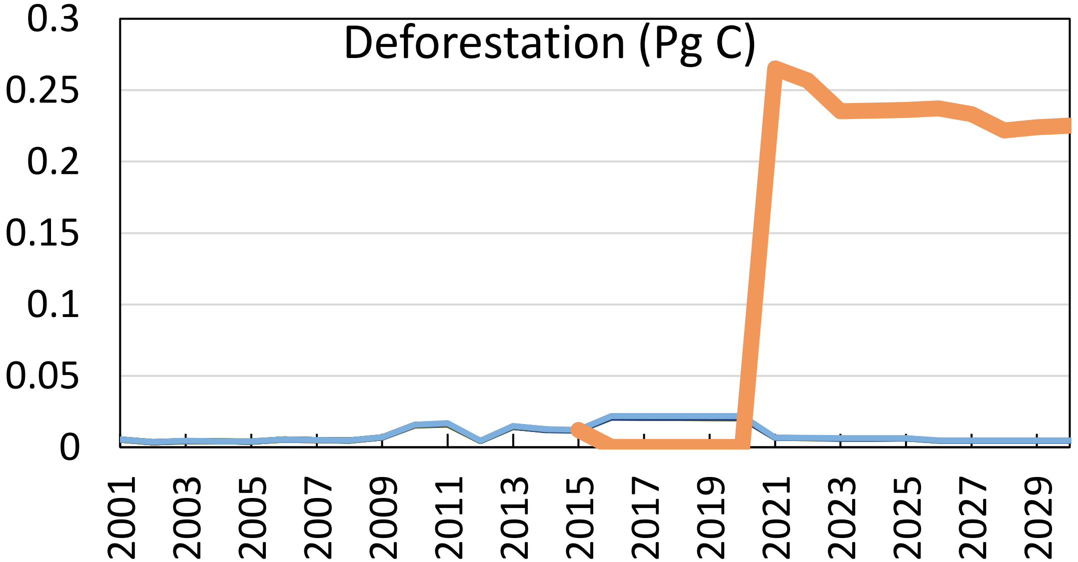
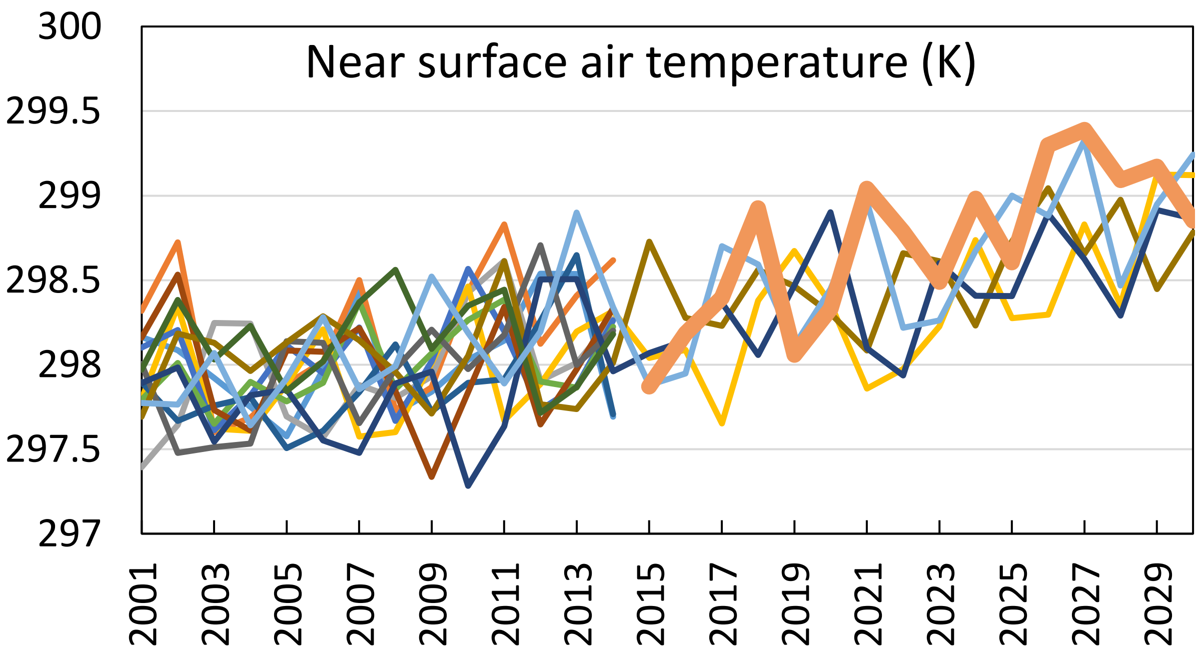
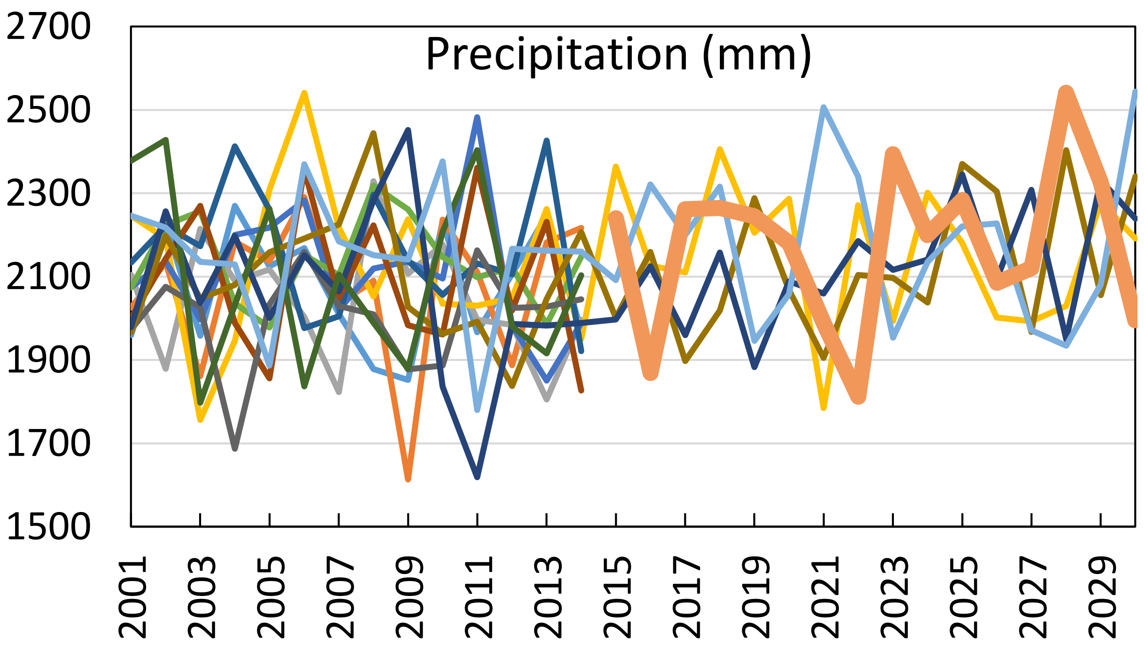




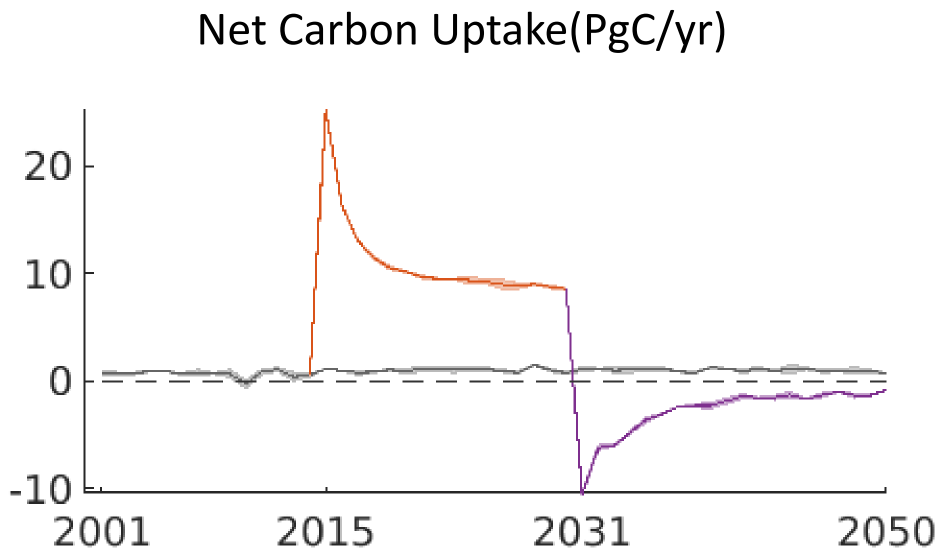


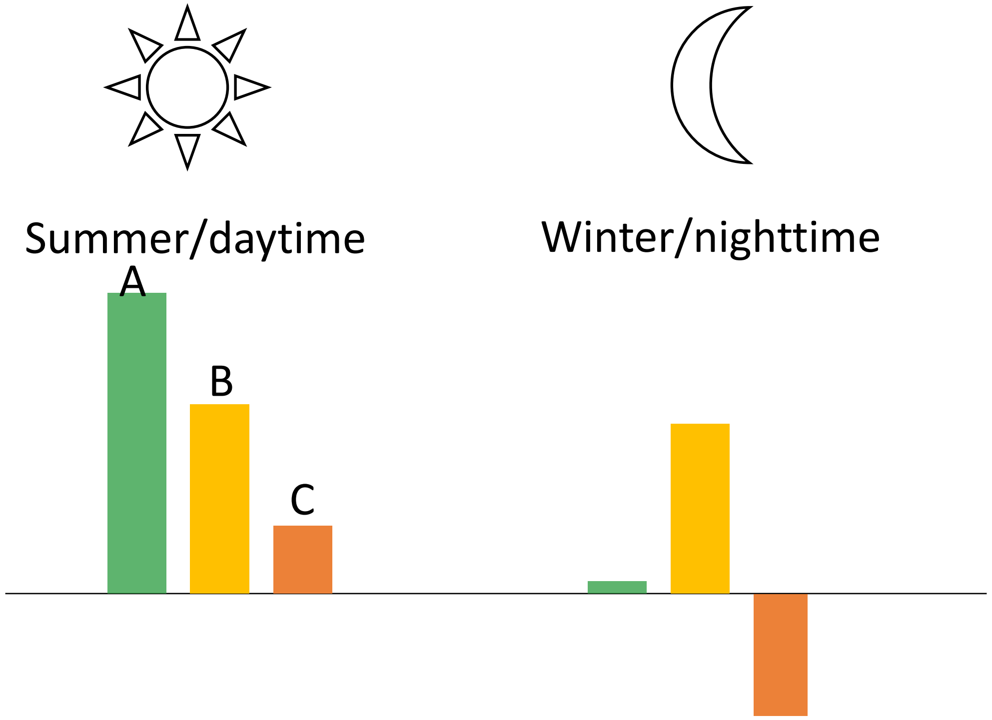
Control simulation (2001-2030) SSP585 VS SSP126





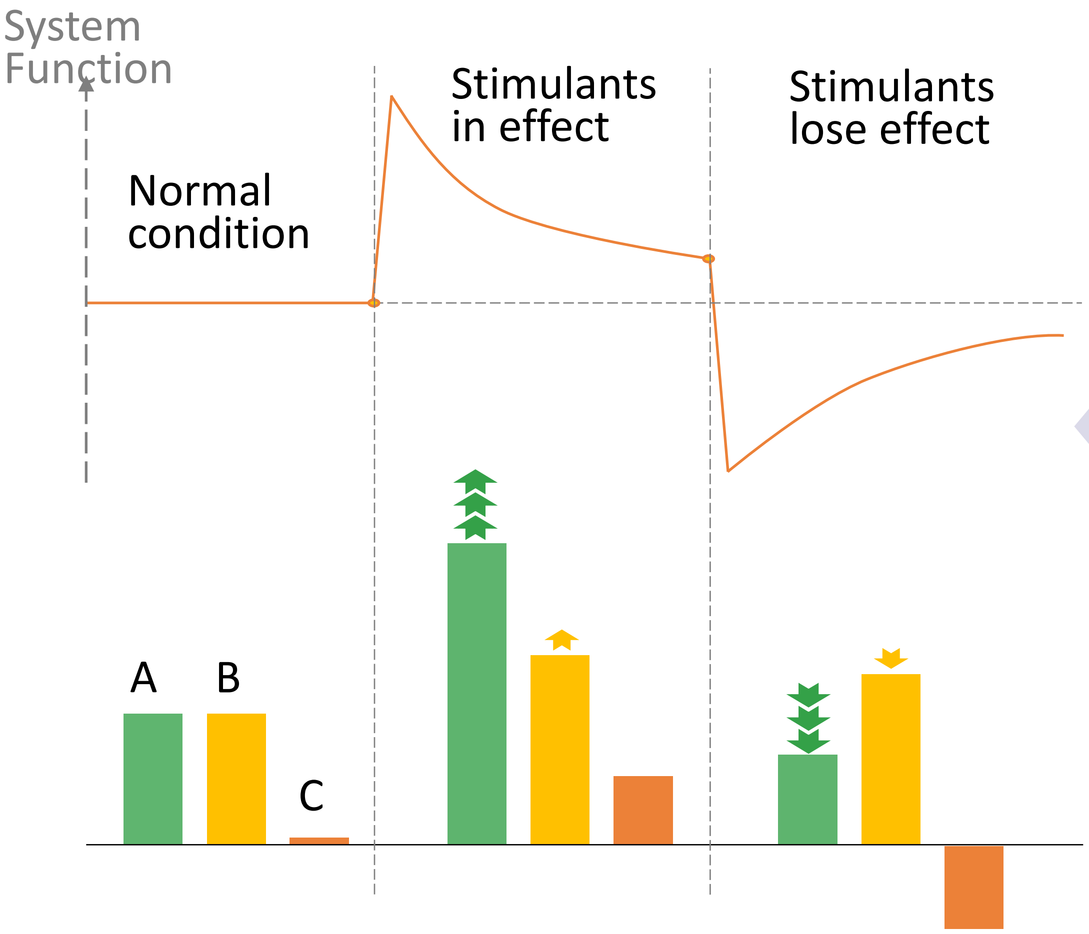
Discussion 3: Post-action CO_2 outgassing from tropical forests

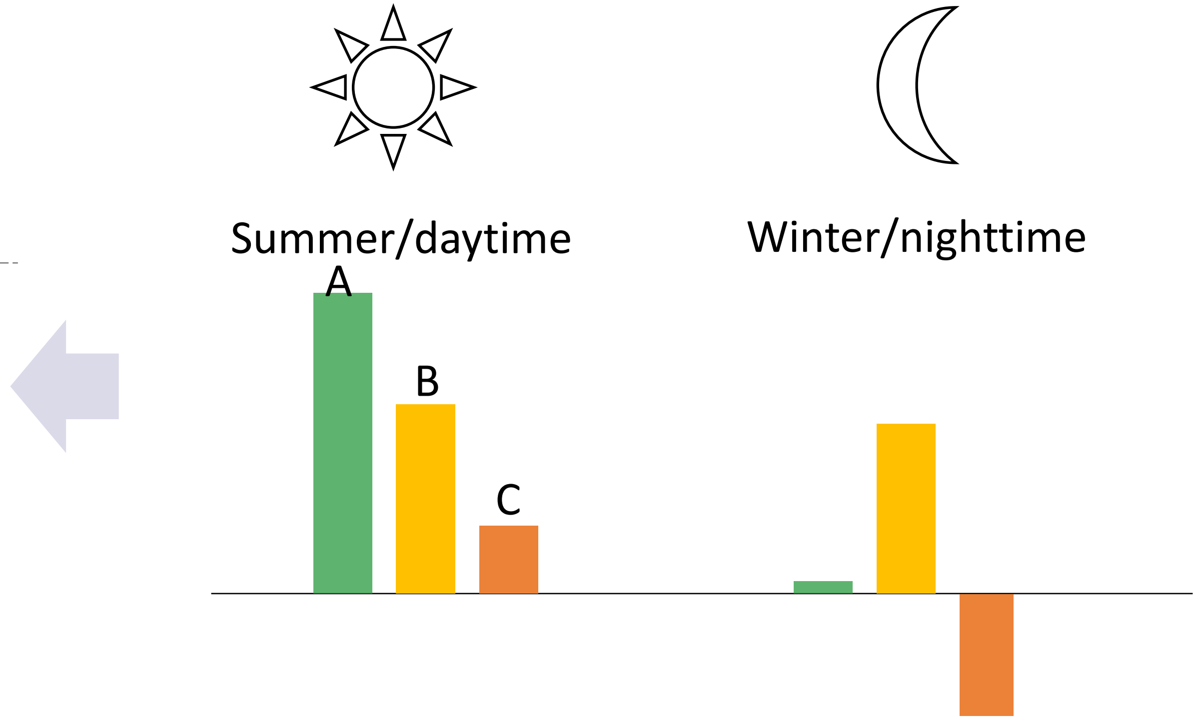




A: Vegetative primary productivity
B: Heterotrophic respiration
A-B=C: Net ecosystem productivity (system function)

Discussion 3: “Stimulant Effect”





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