SPRUCE-MIP Overview

Multi-model comparison to understand peatland carbon and methane responses to warming and elevated CO_2.

A collaborative effort to benchmark, diagnose, and improve terrestrial model predictions.

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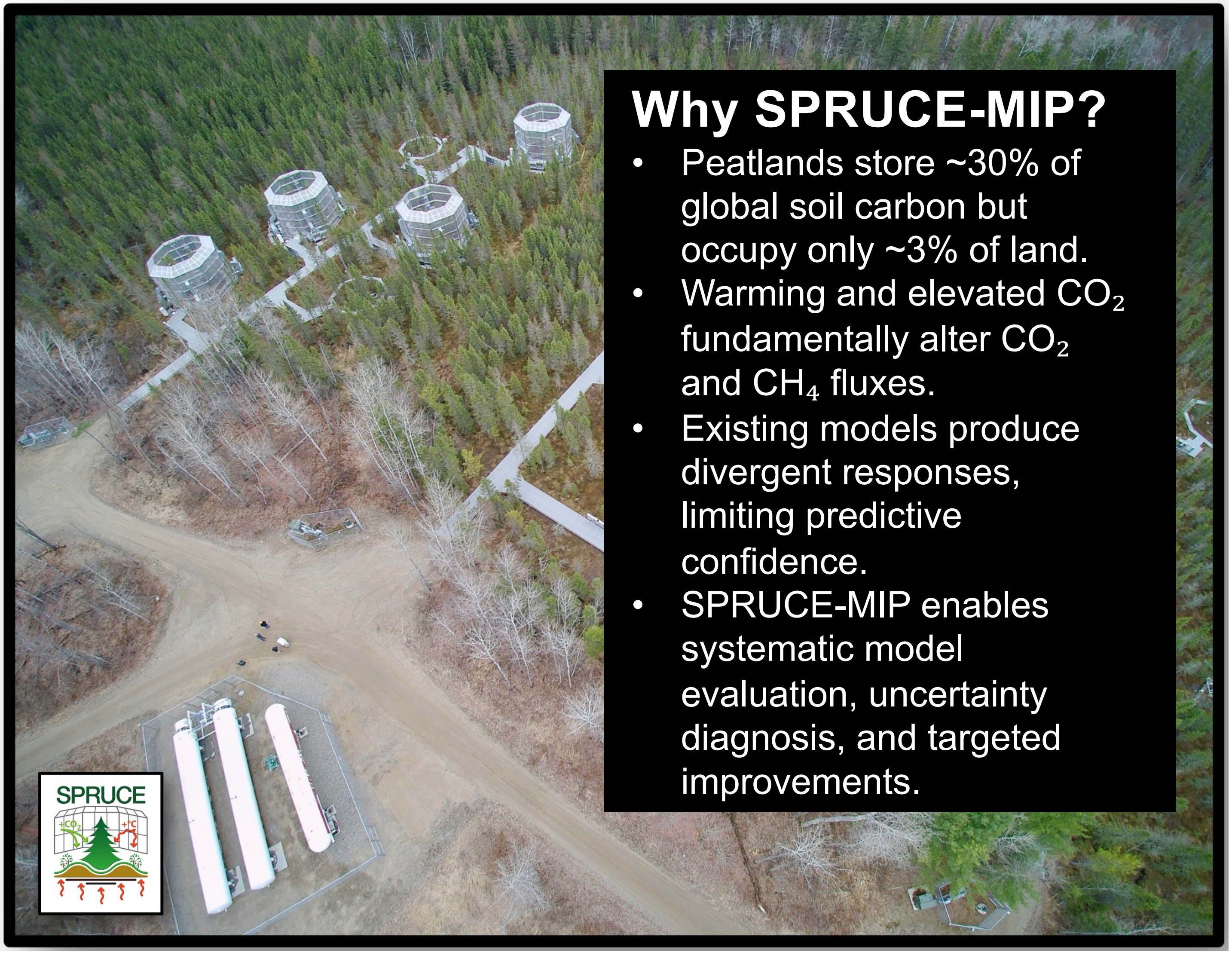
May 2025 | SPRUCE All Hands Meeting

Motivation



Why SPRUCE-MIP?

- Peatlands store ~30% of global soil carbon but occupy only ~3% of land.
- Warming and elevated CO_2 fundamentally alter CO_2 and CH_4 fluxes.
- Existing models produce divergent responses, limiting predictive confidence.
- SPRUCE-MIP enables systematic model evaluation, uncertainty diagnosis, and targeted improvements.

Key Scientific Questions

Model Fidelity:

How well do current models reproduce observed CO_2 and CH_4 flux responses to SPRUCE warming and elevated CO_2 treatments?

Process Representation:

What process-level differences drive intermodel variability in carbon and methane flux predictions?

Uncertainty Diagnosis:

What are the dominant sources of model uncertainty, and how can they be reduced through targeted experiments or parameter refinements?

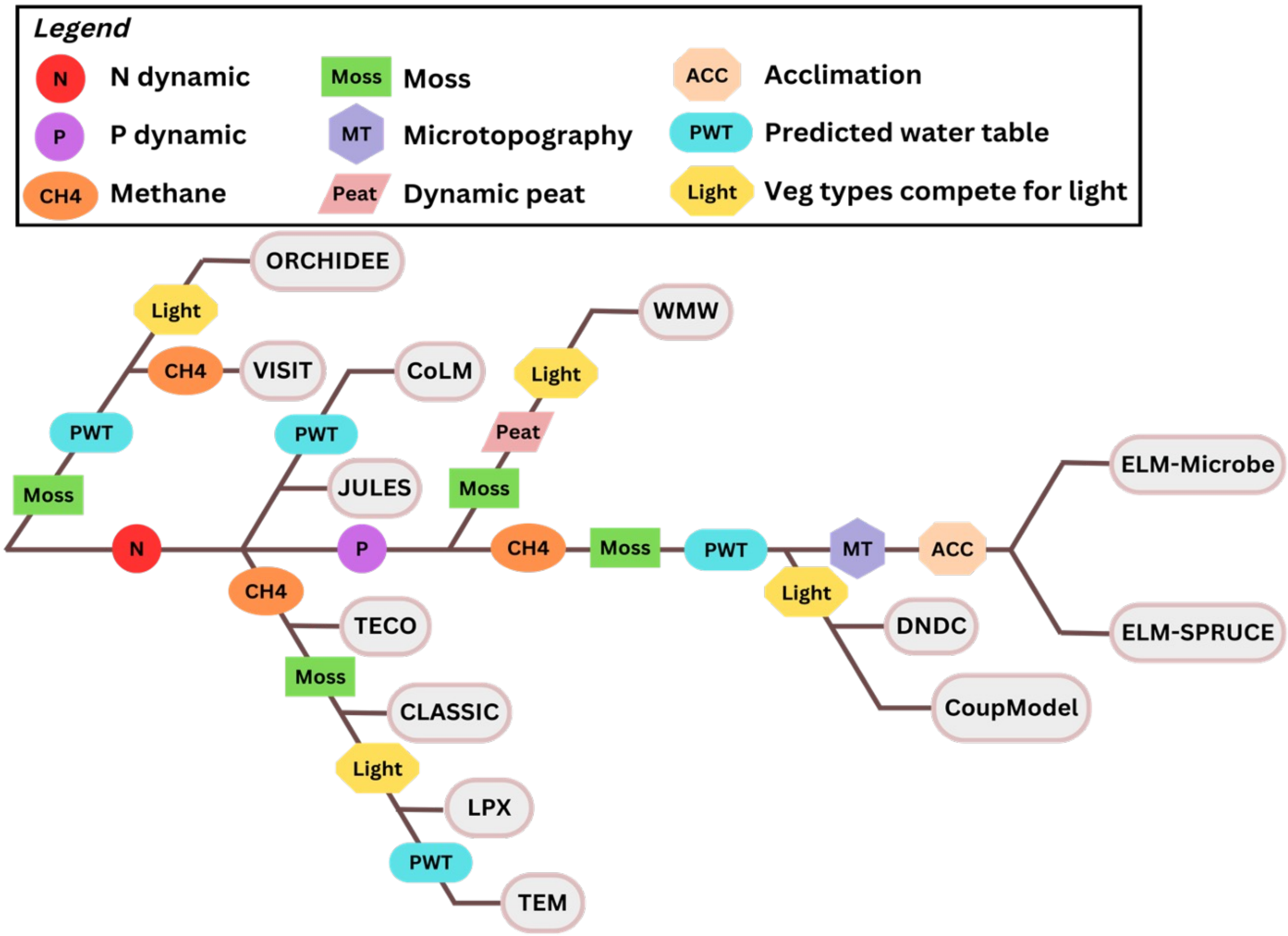
Implications for Projections:

What do model outcomes reveal about the future of peatland carbon cycling and their role in Earth system feedbacks?

Participating Models in SPRUCE-MIP

Model	Full Name	Affiliation (Team Contact)	Reference
CLASSIC	Canadian Land Surface Scheme Including Biogeochemical Cycles	Environment and Climate Change Canada (Joe Melton)	Melton et al. (2020)
CLM-Microbe	CLM with Microbial Processes	San Diego State University (Xiaofeng Xu)	TBD
CoLM	Common Land Model	Sun Yat-Sen University (Xingji Lu)	REF (unspecified)
CoupModel	Coupled Heat and Mass Transfer Model	McGill University (Hongxing He)	Jansson and Moon (2001)
DNDC	DeNitrification-DeComposition Model	Tennessee State University (Dafeng Hui)	Li et al. (1992)
ELM-Microbe	ELM with Microbial Processes	San Diego State University (Xiaofeng Xu)	Ricciuto et al. (2021)
ELM-SPRUCE	Energy Exascale Earth System Model (ELM)	Oak Ridge National Laboratory (Xiaoying Shi)	Shi et al. (2021)
JULES	Joint UK Land Environment Simulator	University of Exeter (Ayesha Hussai)	Burke et al. (2017)
LPX-Bern	Land surface Processes and eXchanges model	University of Bern (Qing Sun/Fortunat Joos)	Spahni et al. (2013)
MWM	McGill Wetland Model	McGill University (Siya Shao)	St-Hilaire et al. (2010)
ORCHIDEE-PEAT	ORganizing Carbon and Hydrology In Dynamic Ecosystems model	East China Normal University (Chunjing Qiu)	Qiu et al. (2018, 2019)
TECO-SPRUCE	Terrestrial ECOsystem Model	Cornell University (Yiqi Luo)	Weng and Luo (2008), Huang et al. (2017)
PTEM	Peatland Terrestrial Ecosystem Model	Purdue University (Qianlai Zhuang)	Zhuang et al. (2003), Zhao et al. (2022)
VISIT	Vegetation Integrative Simulator for Trace Gases	University of Tokyo (Akihiko Ito)	Ito and Inatomi (2012)

Key Process Representations Across Participating Models



Experimental Design

Model Forcing and Simulation Protocol

Spin-up: Models initialized using ambient plot atmospheric forcing (2015–2021) under pre-industrial conditions.

Transient run: Historical simulation from 1850 to 2014 using historical meteorological and CO_2 data.

Experiment Phase

From 2015 to 2021, all models run 11 simulations using plot-specific meteorological forcing and CO_2 concentrations:

- 1 ambient plot
- 10 treatment plots (warming and/ aCO_2 or elevated CO_2)

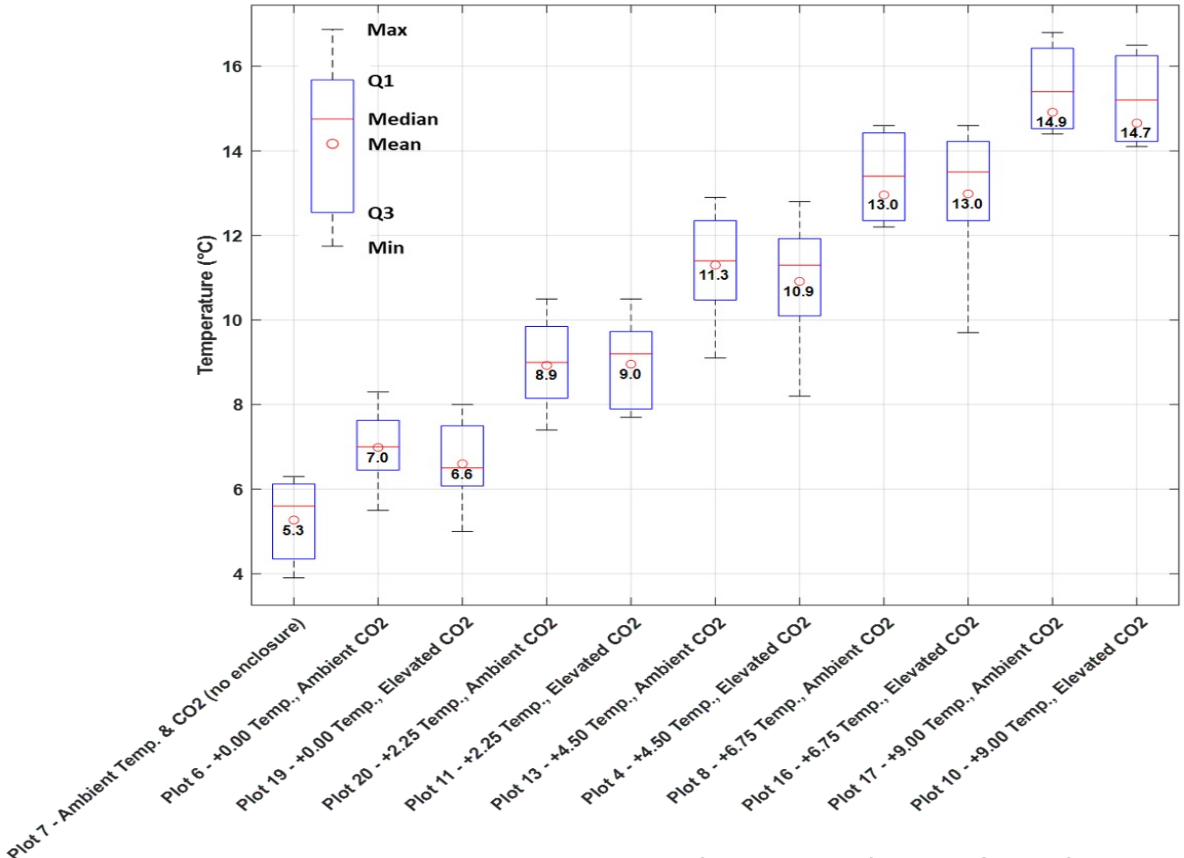
Evaluation

Model outputs (e.g., NEE and other components) will be compared with SPRUCE plot-level observations.

SPRUCE Simulation Matrix: Warming and CO_2 Treatments

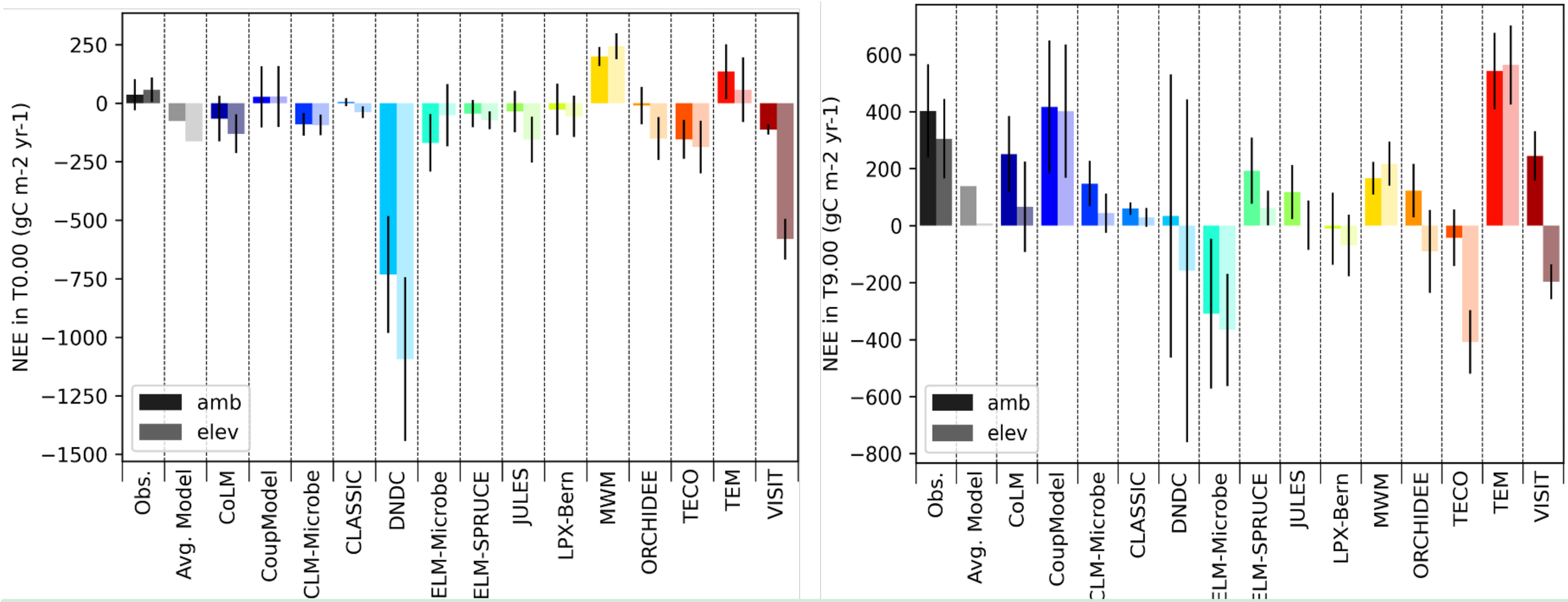
Simulation	Warming	CO_2 concentration
CTL	ambient	ambient
Warming+0	+0 °C	ambient
Warming+2.25	+2.25 °C	ambient
Warming+4.50	+4.50 °C	ambient
Warming+6.75	+6.75 °C	ambient
Warming+9.00	+9.00 °C	ambient
Warming+0+CO_2	+0 °C	900ppm
Warming+2.25+CO_2	+2.25 °C	900ppm
Warming+4.50+CO_2	+4.50 °C	900ppm
Warming+6.75+CO_2	+6.75 °C	900ppm
Warming+9.00+CO_2	+9.00 °C	900ppm

Observed Plot-Level Temperature Response to SPRUCE Treatments (2015–2021)



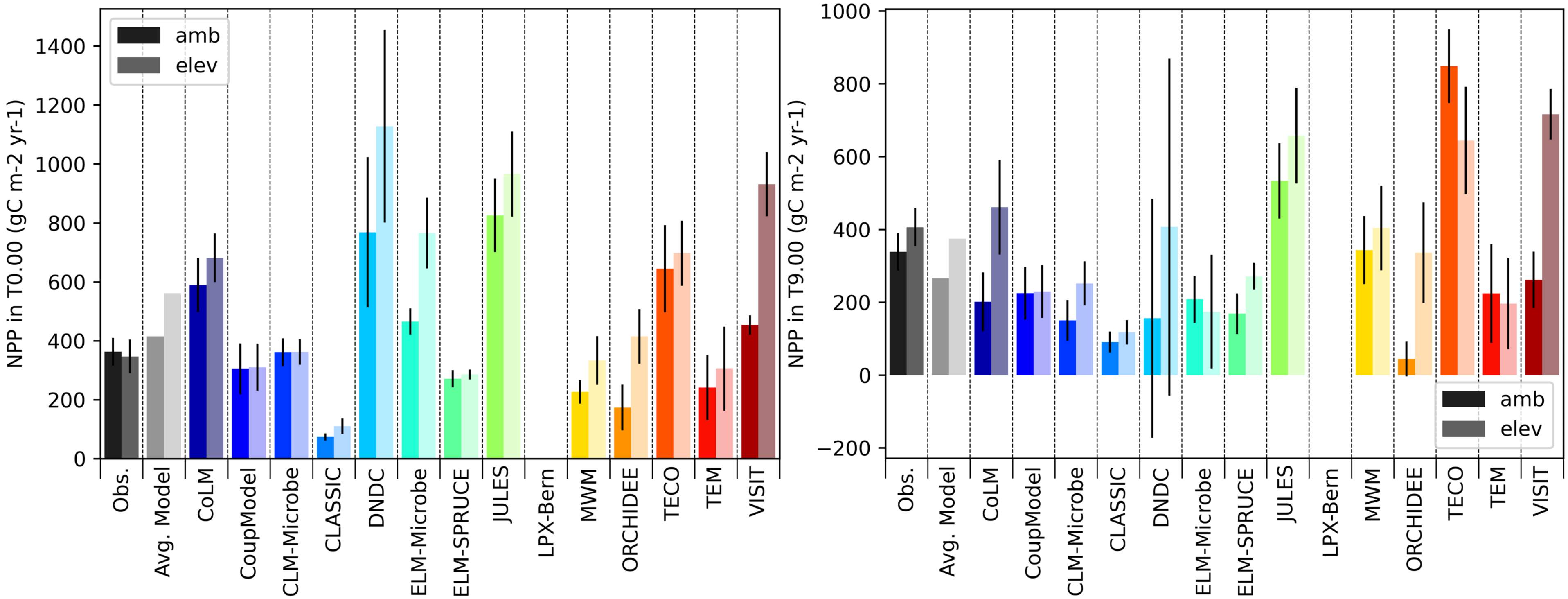
Boxplots show annual mean temperatures from each of the 11 SPRUCE plots, capturing 7-year means and variability under ambient vs. elevated CO_2 and across five warming levels. Numbers above each box indicate the 7-year average temperature.

Observed and Simulated NEE Across Models: +0 °C vs. +9°C Warming



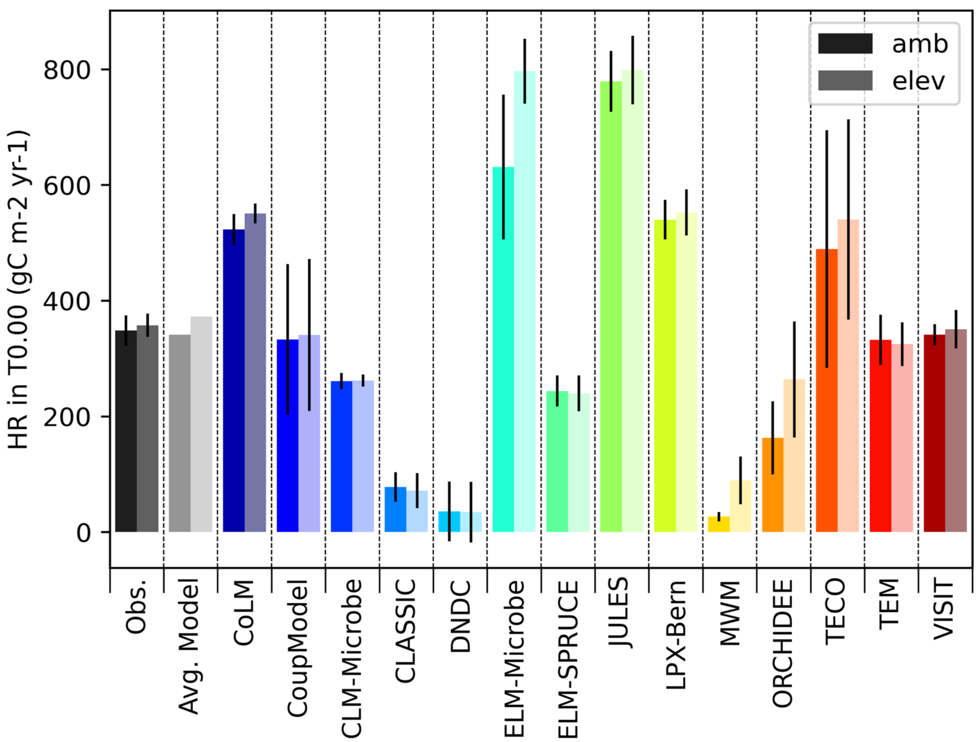
Consistent sources: CoupModel, MWM, PTEM simulate positive NEE (carbon loss) under both +0 and +9 °C conditions.
Sink-to-source transitions: CLASSIC, CLM-Microbe, CoLM, ELM-SPRUCE, JULES transition from net sink to source with warming across both CO_2 treatments.
CO_2-dependent transitions: DNDC, ORCHIDEE, VISIT switch to sources under aCO_2 but remain sinks under eCO_2.
Persistent sinks: ELM-Microbe, LPX-Bern, TECO retain sink behavior under all conditions.

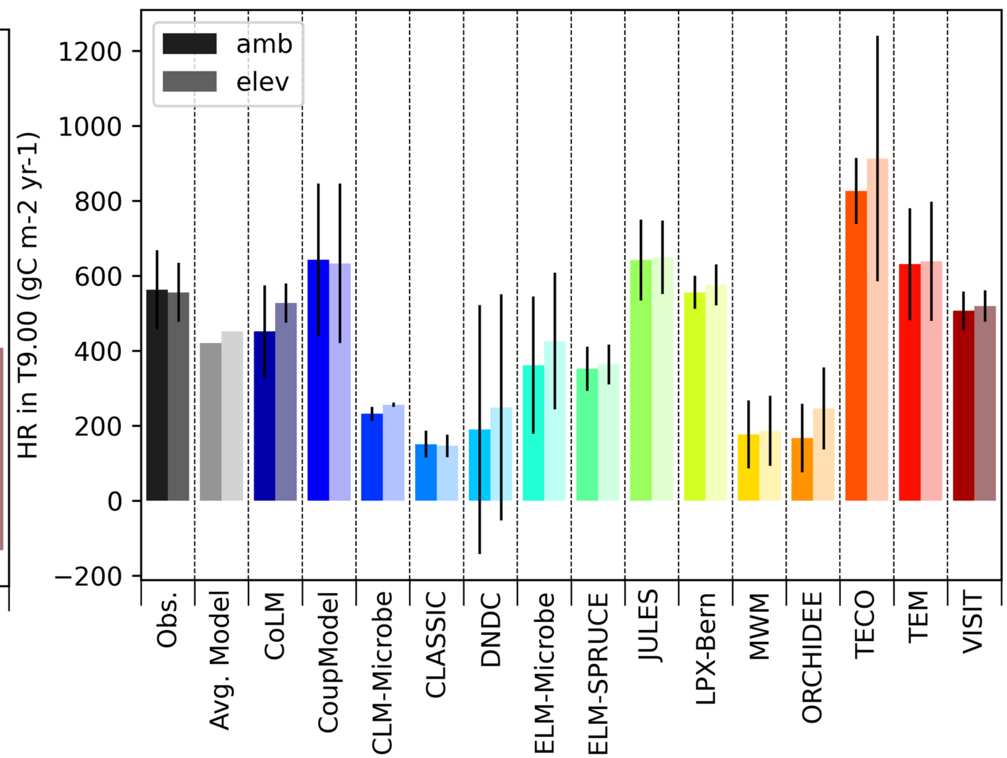
Observed and Simulated NPP Across Models: +0°C vs. +9°C Warming



Best match: CLM-Microbe and model mean
Underpredicting models: CLASSIC, CoupModel, ELM-SPRUCE, MWM, ORCHIDEE, PTEM
Overpredicting models: CoLM, DNDC, ELM-Microbe, JULES, TECO, VISIT
Strong eCO_2 response: ORCHIDEE, VISIT, ELM-Microbe, DNDC
+9 °C effect: Most models simulate **declining NPP** under warming

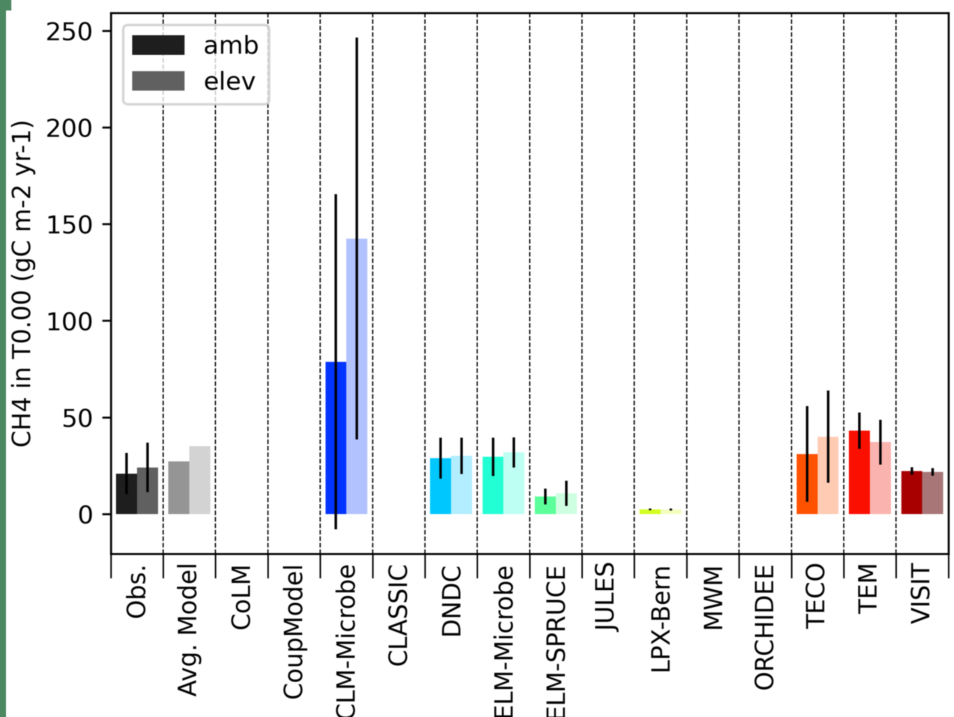
Observed and Simulated HR Across Models: 0°C vs. +9°C Warming

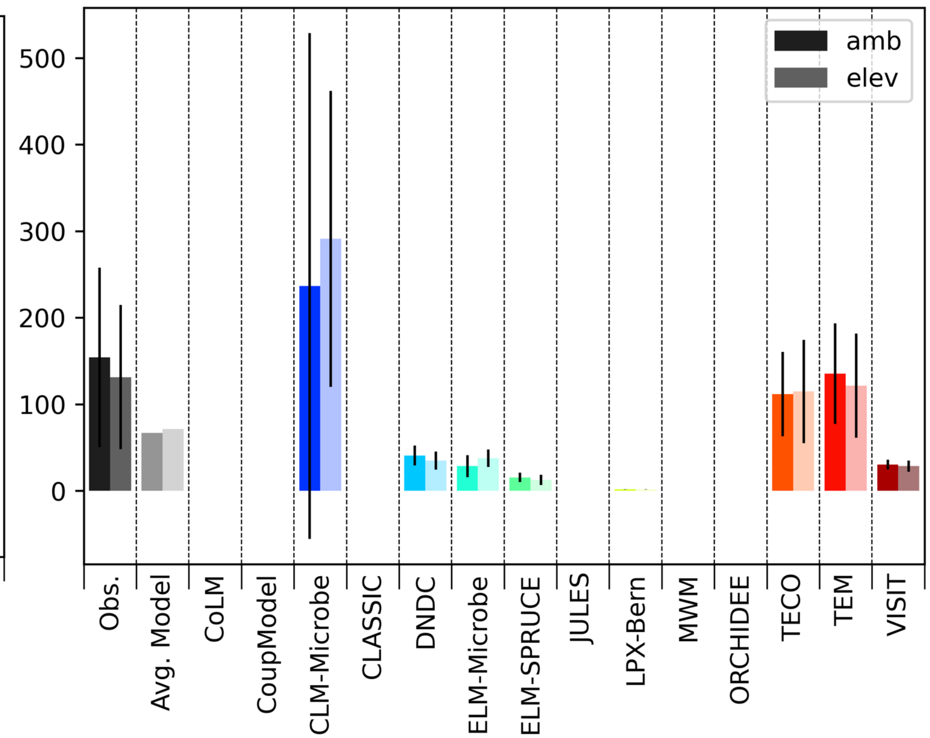




Good agreement: CoupModel, PTEM, VISIT, and model mean match observed HR
Underpredicting models: CLASSIC, DNDC, ELM-SPRUCE, MWM, ORCHIDEE
Overpredicting models: CoLM, ELM-Microbe, JULES, LPX-Bern, TECO
Strong eCO_2 sensitivity: MWM, ELM-Microbe, ORCHIDEE, TECO
Warming effect: Most models simulate **increased HR under +9 °C warming**

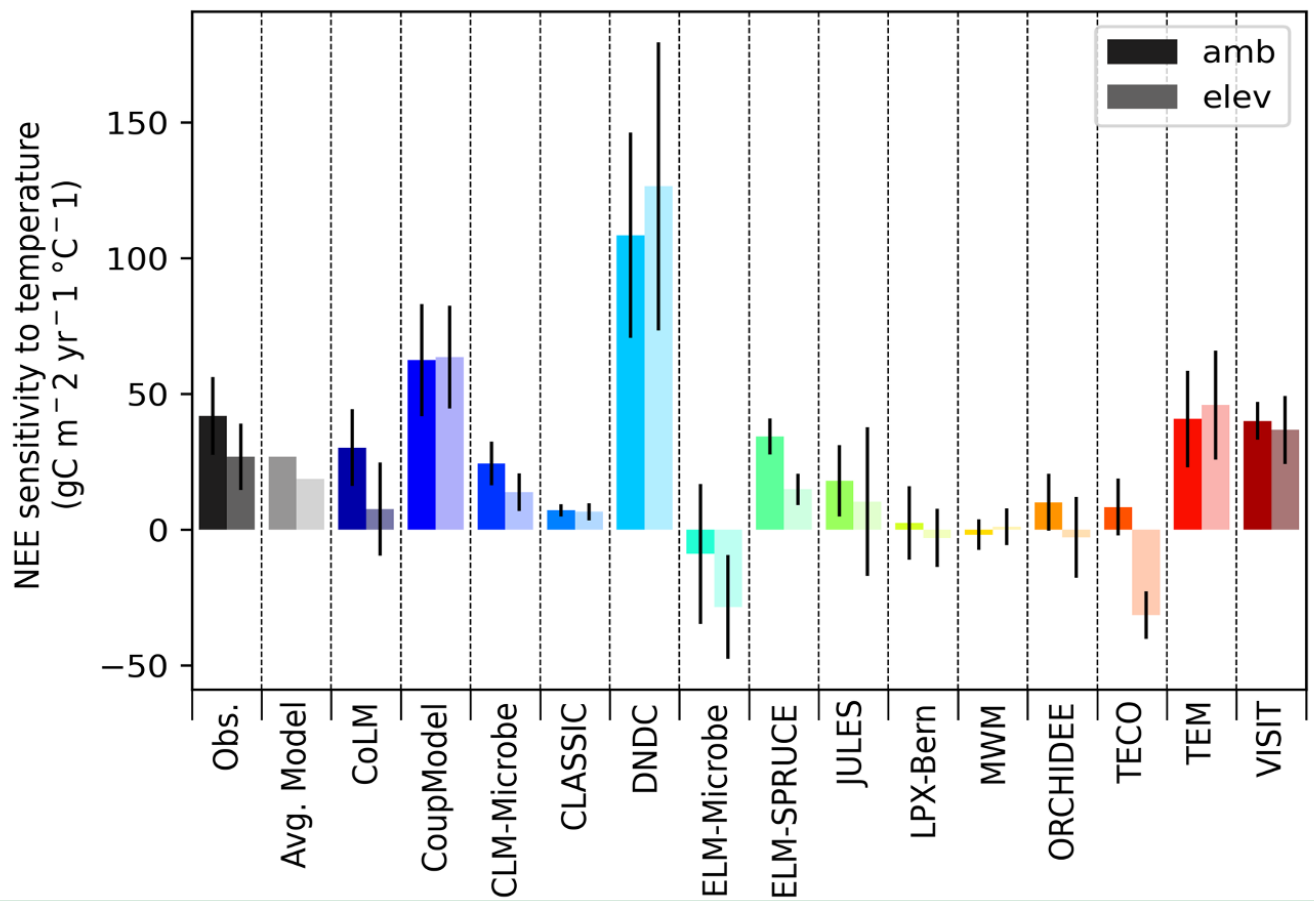
Observed and Simulated CH_4 Across Models: +0°C vs. +9°C Warming





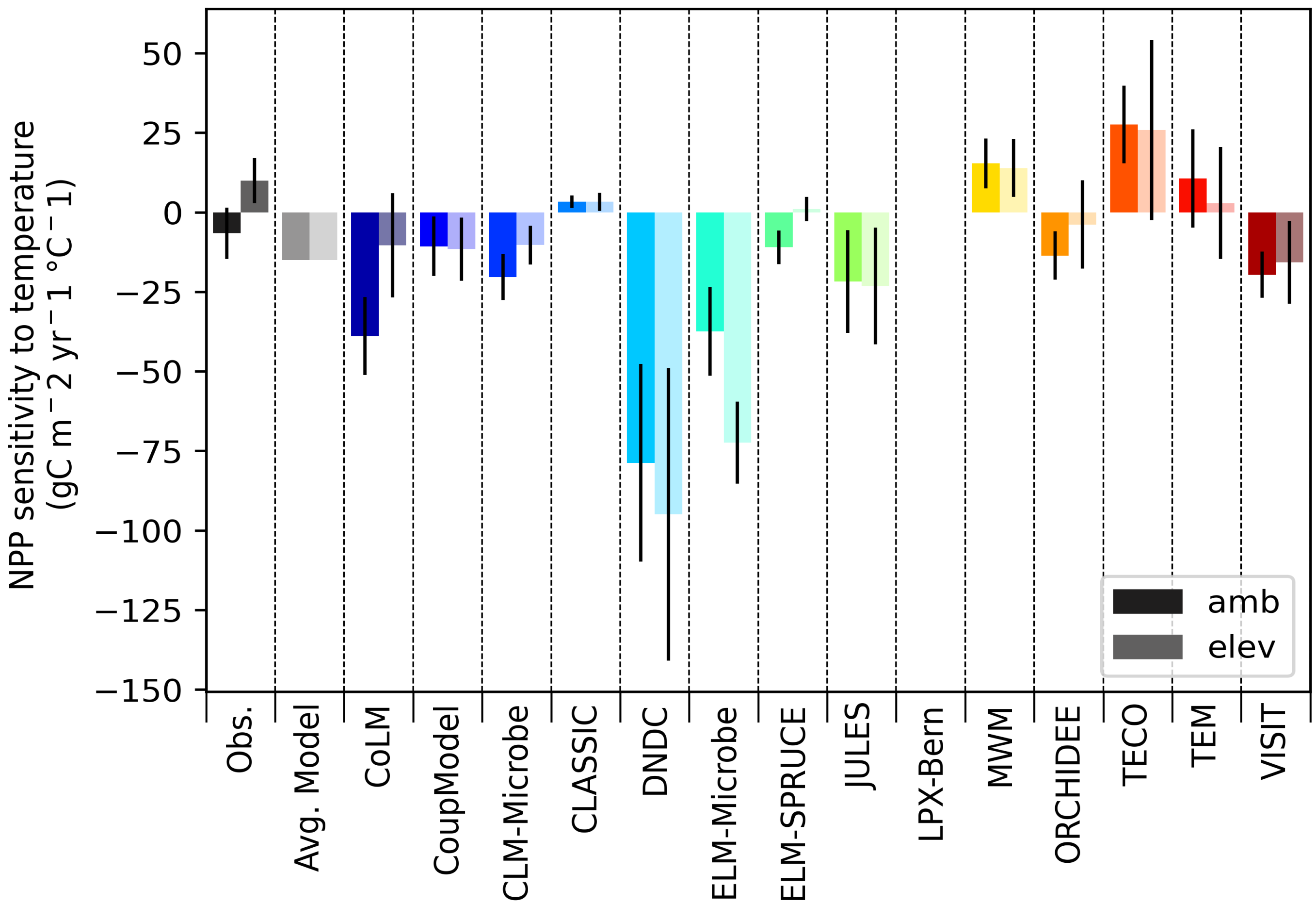
Best match: VISIT aligns closely with observations
Underpredicting models: LPX-Bern, ELM-SPRUCE
Overpredicting models: CLM-Microbe, DNDC, ELM-Microbe, PTEM, TECO
Strong eCO_2 sensitivity: CLM-Microbe (+81%), TECO (+29%), ELM-SPRUCE (+18%), PTEM (+14%)
Warming effect: Most models simulate **increased CH_4 emissions under +9 °C**, consistent with observations

Observed and Simulated NEE Sensitivity to Temperature



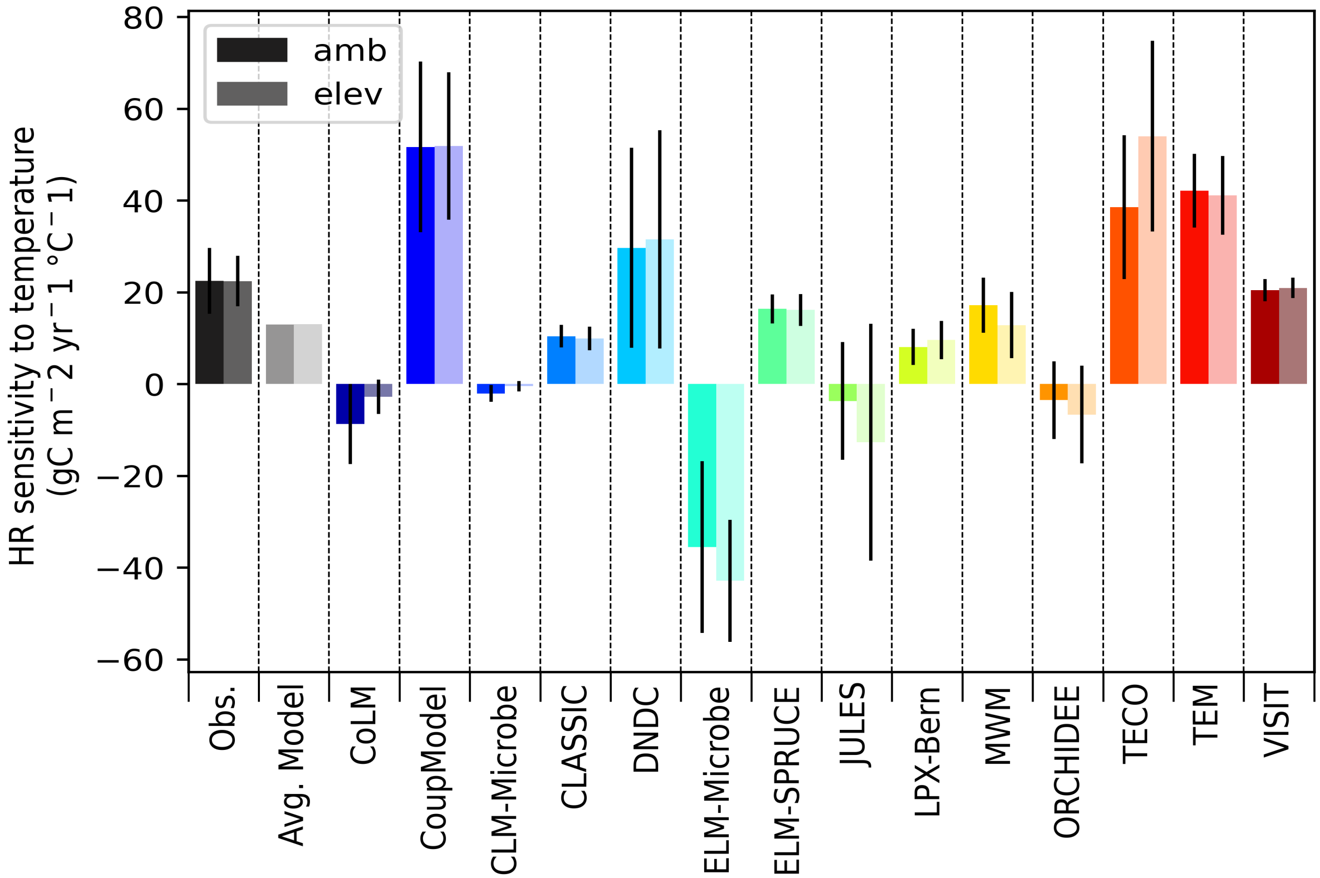
Most models show positive NEE sensitivity (warming increases net carbon loss). Largest responses from DNDC, CoupModel, MWM.

Observed and Simulated NPP Sensitivity to Temperature



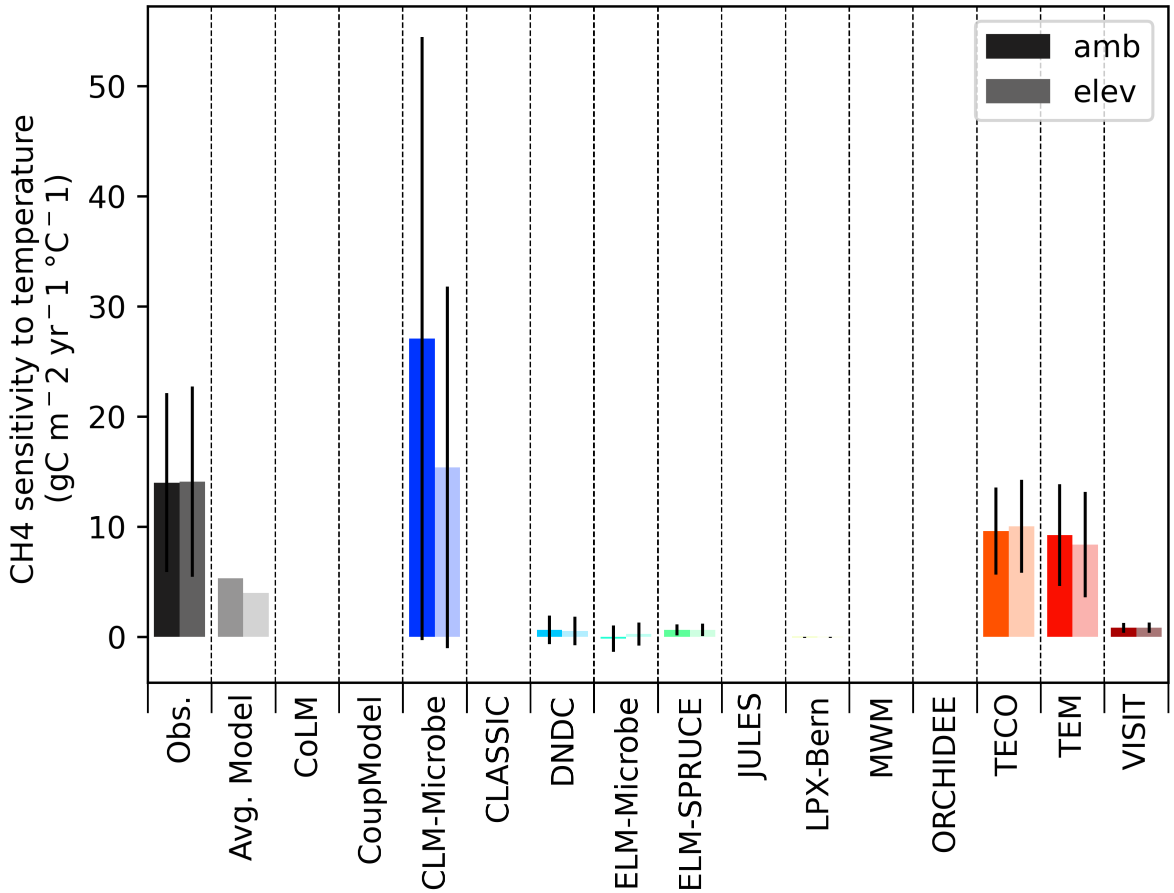
Observed NPP turns positive under eCO_2 with warming, but most models show negative sensitivity.

Observed and Simulated HR Sensitivity to Temperature



Observed HR increases with temperature. Majority of models reproduce this, but a few show declining HR.

Observed and Simulated CH4 Sensitivity to Temperature



Observed CH_4 emissions rise with temperature. Only some models reflect this trend; others are near-zero.

Summary of Key SPRUCE-MIP Findings

•**Consistent sources**: CoupModel, MWM, PTEM simulate carbon loss (NEE > 0) across all the warming and CO_2 conditions

•**Sink-to-source transitions**: CLASSIC, CLM-Microbe, CoLM, ELM-SPRUCE, JULES transition from sink to source under warming and both CO_2 conditions

•**CO_2-dependent transitions**: DNDC, ORCHIDEE, VISIT become sources under aCO_2, remain sinks under eCO_2

•**Persistent sinks**: ELM-Microbe, LPX-Bern, TECO remain carbon sinks under all scenarios

Process Diagnostics:

•**NPP**: Declines in most models with warming; observations suggest recovery

•**HR**: Increases with temperature in most models, consistent with data

•**CH_4**: Few models (e.g., PTEM, TECO, CLASSIC) replicate observed CH_4 response to warming

Takeaway: Model divergence in NEE pathways and process sensitivities underscores the need for improved representation of peatland carbon processes.

SPRUCE-MIP: Next Steps

- The SPRUCE-MIP synthesis paper is nearly complete and is targeted to submit for journal publication this summer.
- Other interesting topic papers are encouraged to be started such as nutrient cycling, Sphagnum dynamics, CH_4 dynamics.
- A SPRUCE-focused international peatland workshop is planned for Fall 2025, bringing together both empirical and modeling communities.
- The MIP will initiate new simulation phases, including:

  - Extending the model intercomparison to multiple peatland sites

  - Forcing models with downscaled ESM climate projections, and

  - Exploring additional experimental treatments, such as water table drawdown and nutrient additions.

Acknowledgments

• SPRUCE experimental team and data providers
• Modeling teams
• Coordinators: Xiaoying Shi, Daniel Ricciuto, and collaborators
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Thank you for your attention!

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