Development and validation of an approach to quantify maximum photosynthetic capacity of terrestrial plants from FLEX mission products

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Maximum photosynthetic capacity

The theme of this talk is that the **maximum photosynthetic capacity** of terrestrial plants could be considered to be central to the FLEX mission, for two different reasons:

1) On physiological timescales, it mediates the relationship between:

- *the environmental drivers of photosynthesis,*
- *the rate of gross carbon dioxide fixation,*
- *and the emission of chlorophyll fluorescence.*

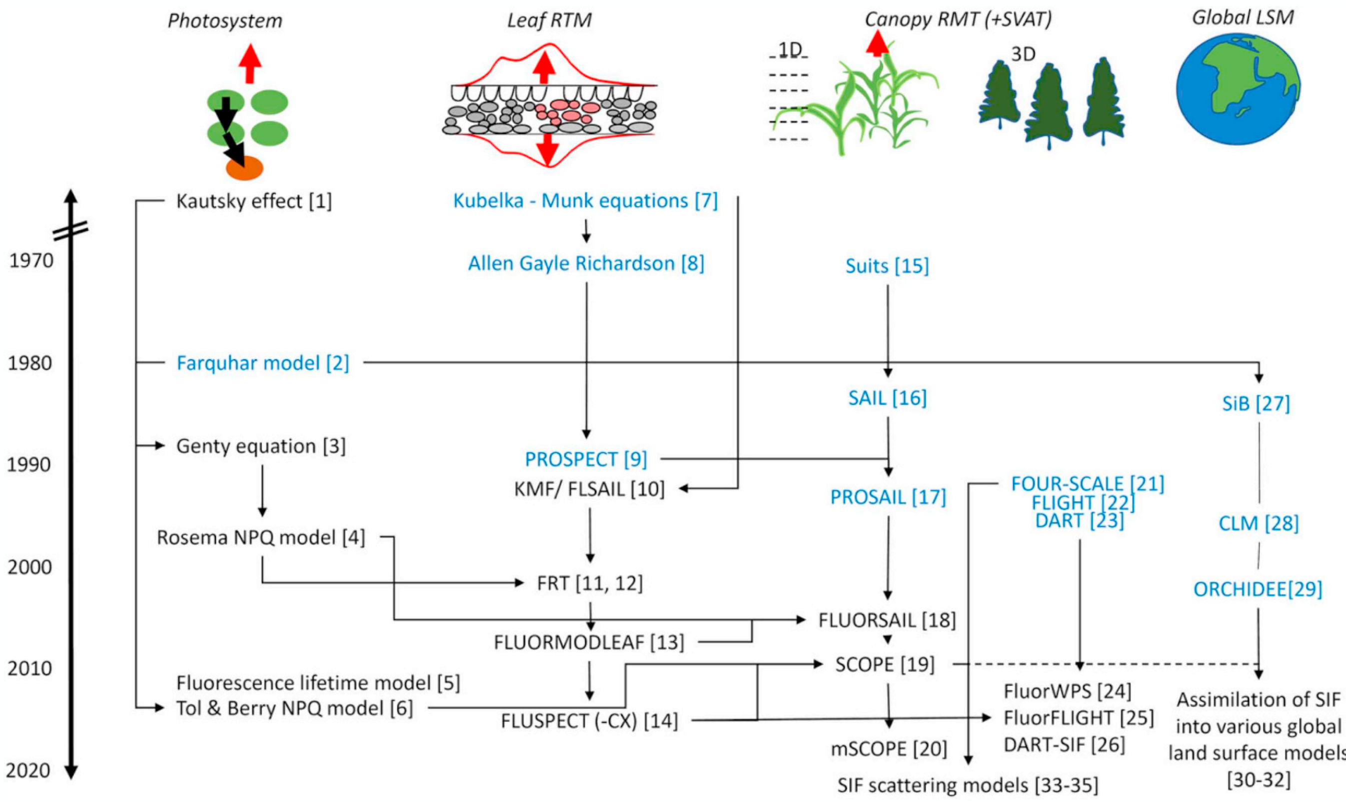
2) On ecological and evolutionary timescales, it is also modulated by:

- *plant functional type (or lineage functional type),*
- *environmental resources (i.e., light, temperature, water, carbon dioxide, nutrients),*
- *and environmental stressors (i.e., resource extremes, pollutants, herbivores, etc.).*

Traditional definition

How has photosynthetic capacity been defined?

- In recent decades, the plant sciences and Earth sciences communities have understood the maximum photosynthetic capacity of terrestrial plants via the Farquhar, von Caemmerer, and Berry (1980) framework.
- When the FvCB framework was originally extended to represent active and passive fluorescence by van der Tol et al. (2014), the underlying conceptual model of maximum photosynthetic capacity was preserved.



Mohammed, G. et al. 2019. Remote Sensing of Environment 231: 111177

Maximum activity of Rubisco

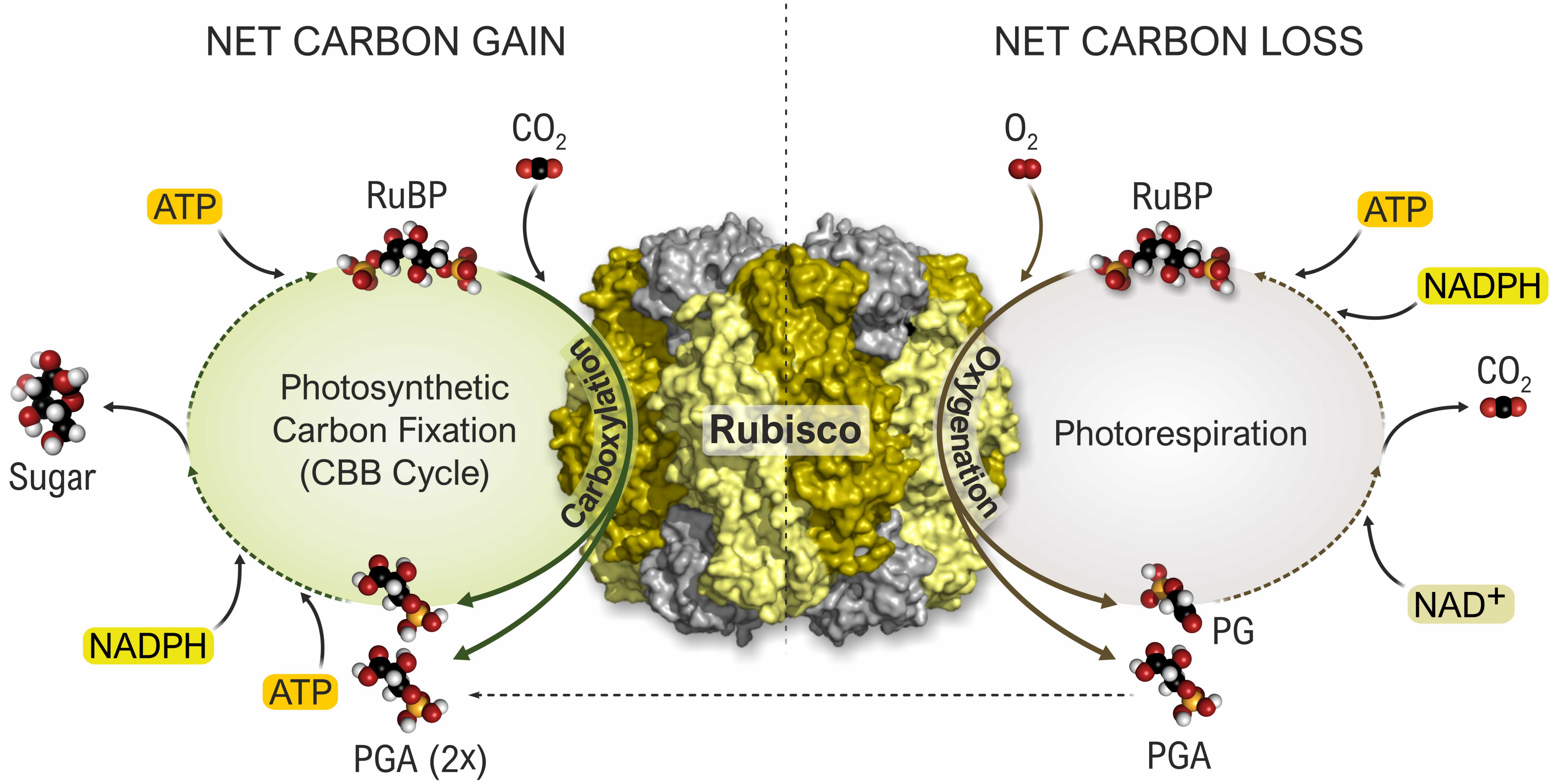
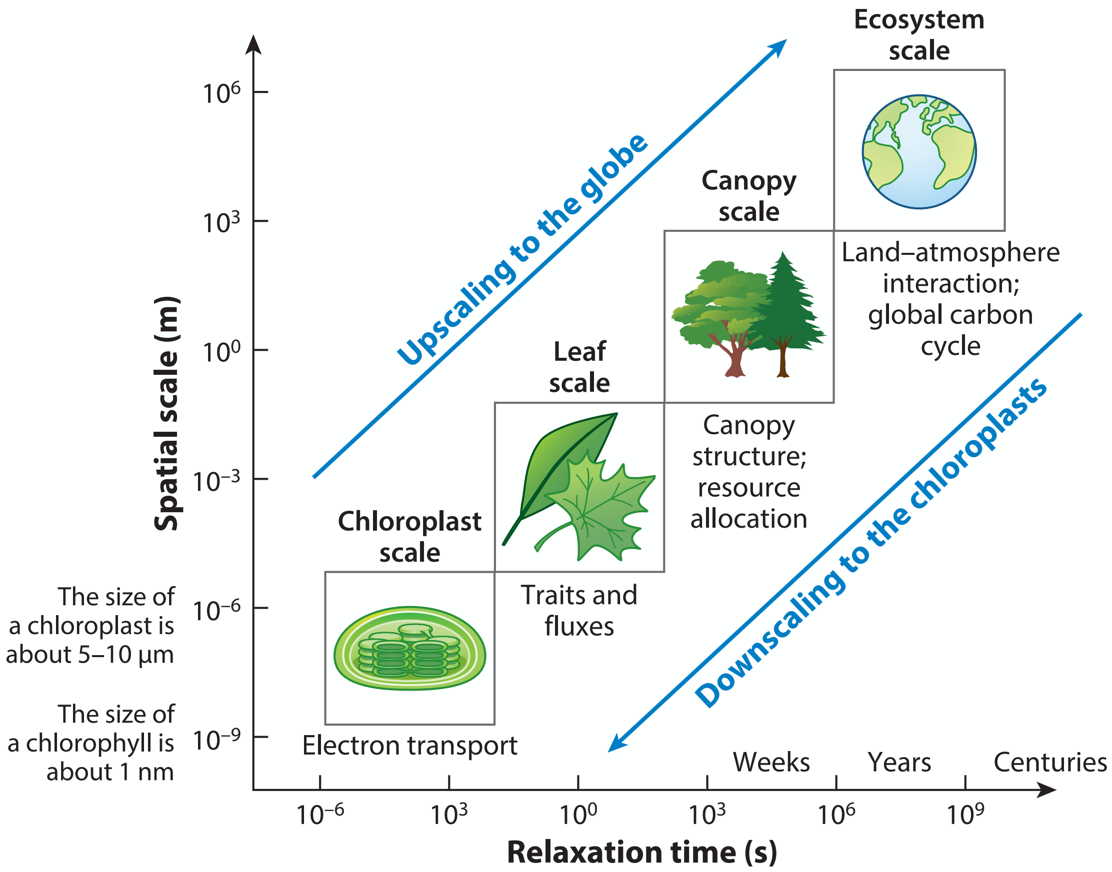


Diagram courtesy of Agrisera

Emerging definition



Yang, X. et al. 2026. Annu. Rev. Plant Biol., In press

How should we define photosynthetic capacity?

- The fact that the FvCB framework only resolves the key bottleneck in carbon metabolism has limited the generality, efficiency, and accuracy with which it has been possible to quantitatively relate photosynthesis and fluorescence.
- The Johnson-Berry (2021) framework opens a new path forward by resolving both of the proteins that determine maximum photosynthetic capacity: Cytochrome b6f, which controls electron transport, and Rubisco, which controls carbon metabolism.

Maximum activity of Cytochrome b6f

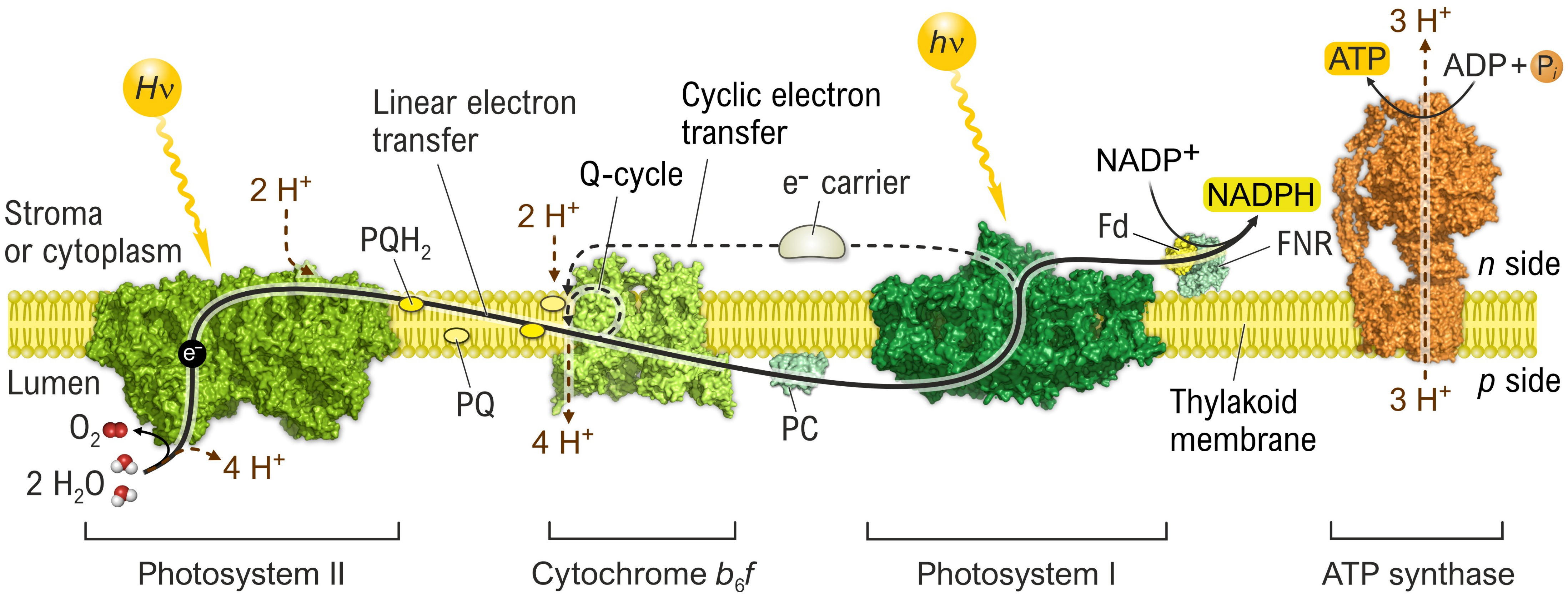
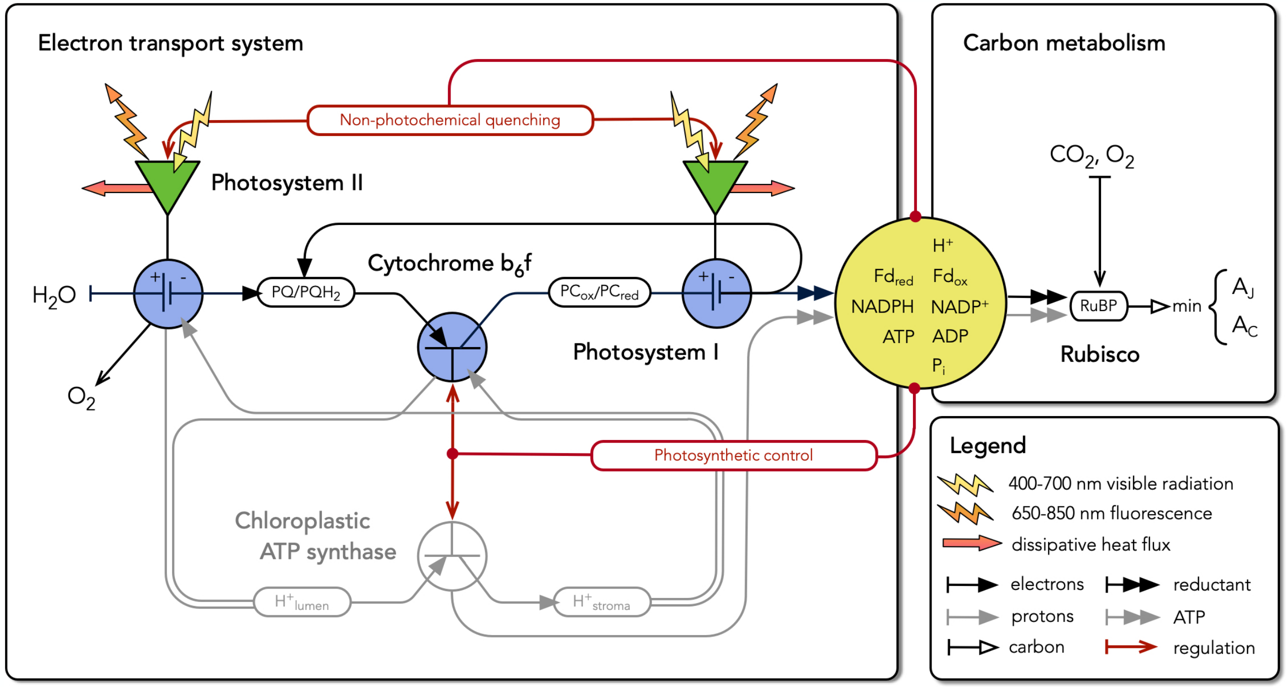


Diagram courtesy of Agrisera

Moving models beyond “Jmax”

The triple value proposition of resolving Cyt b6f

- It permits model calibration and validation with fully independent measurements.
- It permits modeling of all major regulatory interactions as dynamic internal variables.
- It permits calibration of fluorescence intensities with fluorescence lifetime measurements.



Johnson, J. and Berry, J. 2021. Photosynth. Res. 148: 101-136

Early adopters of Johnson-Berry

Classic land surface models

- BEPS *(Y. Zhang)**
- ELM-FATES *(A. Rogers)**
- ORCHIDEE *(F. Maignan)*
- SiB *(I. Baker)*

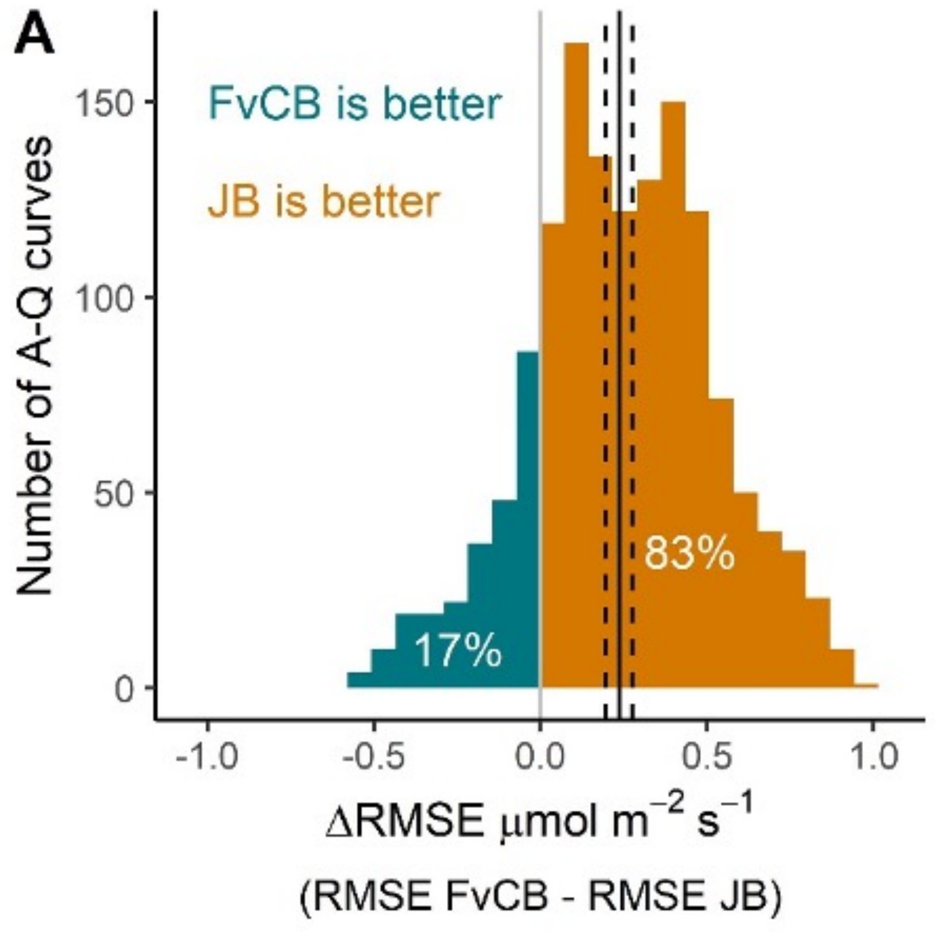
Hybrids or satellite simulators

- BESS *(Y. Ryu)**
- CLiMA *(C. Frankenberg)*
- SCOPE *(N. Parazoo)*
- TECs *(M. Chen)**

Radiative transfer models

- DART *(Z. Malenovsky)*

Application highlight: Lamour et al. 2026



Does resolving Cyt b6f improve model fit to leaf-level data?

- Lamour et al. have formally compared the Johnson-Berry model and the FvCB model in a standardized way against more than a thousand measurements of the photosynthetic light response, representing more than a hundred different C_3 species.

- The Johnson-Berry formulation fits the measured response of leaf-level gas-exchange better than a conventional implementation of FvCB with fixed curvature and variable Jmax, primarily due to improved fit at intermediate light levels.

Lamour, J. et al. 2026. In review

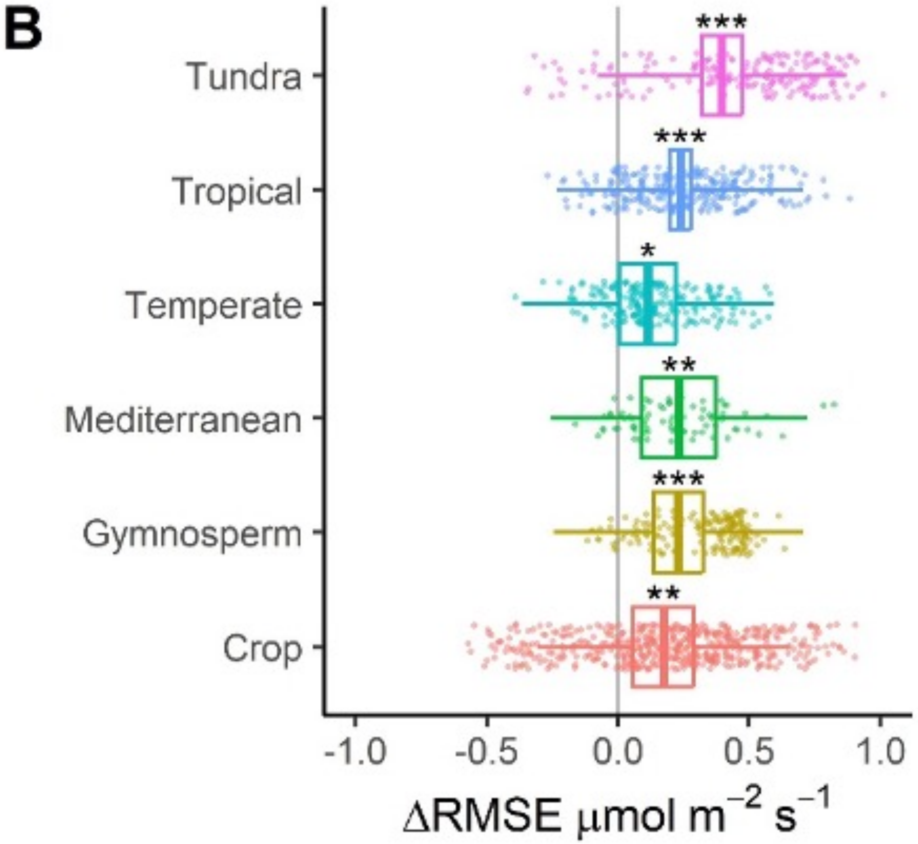
Application highlight: Lamour et al. 2026

Is the Cyt b6f approach generalizable across taxa?

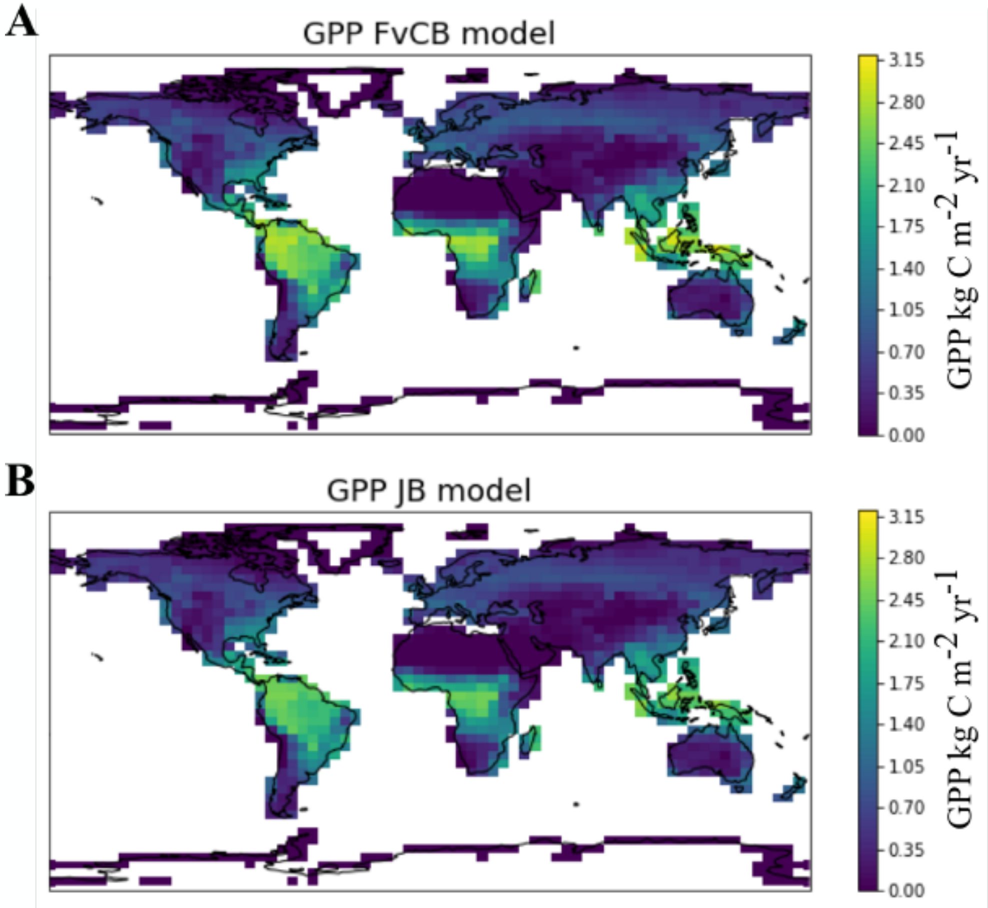
- The gas-exchange dataset used by Lamour et al. for the model intercomparison included light response curves from higher plant species representing every major terrestrial biome, from the arctics to the tropics.

- For all plant functional types, the fit of the Johnson-Berry model to the gas-exchange observations was significantly better than that of the conventionally-parameterized FvCB model, as judged by the change in RMSE.

Lamour, J. et al. 2026. In review

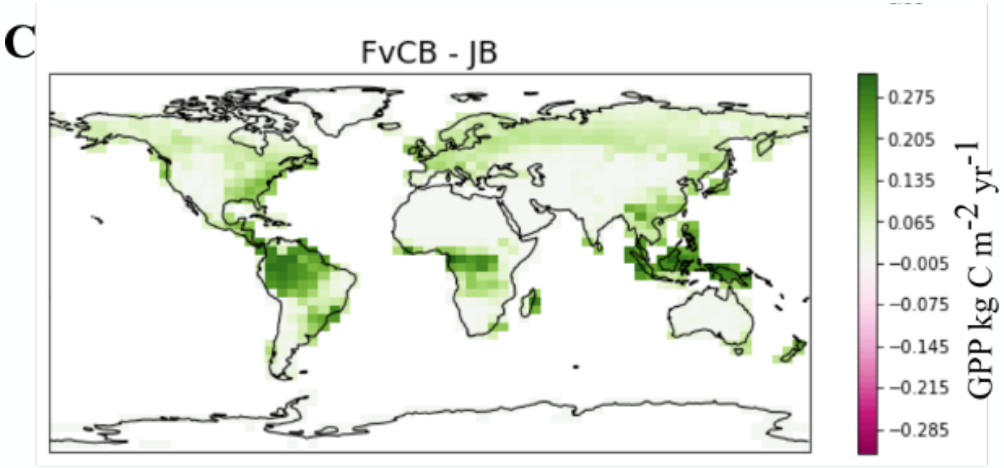


Application highlight: Lamour et al. 2026



How does this leaf-level effect scale up to the globe?

- Lamour et al. have run the E3SM land surface model, ELM-FATES, to quantify the impacts of these changes (left).
- Using a reduced complexity mode, switching from FvCB to Johnson-Berry decreased GPP by a total of 8% (below).



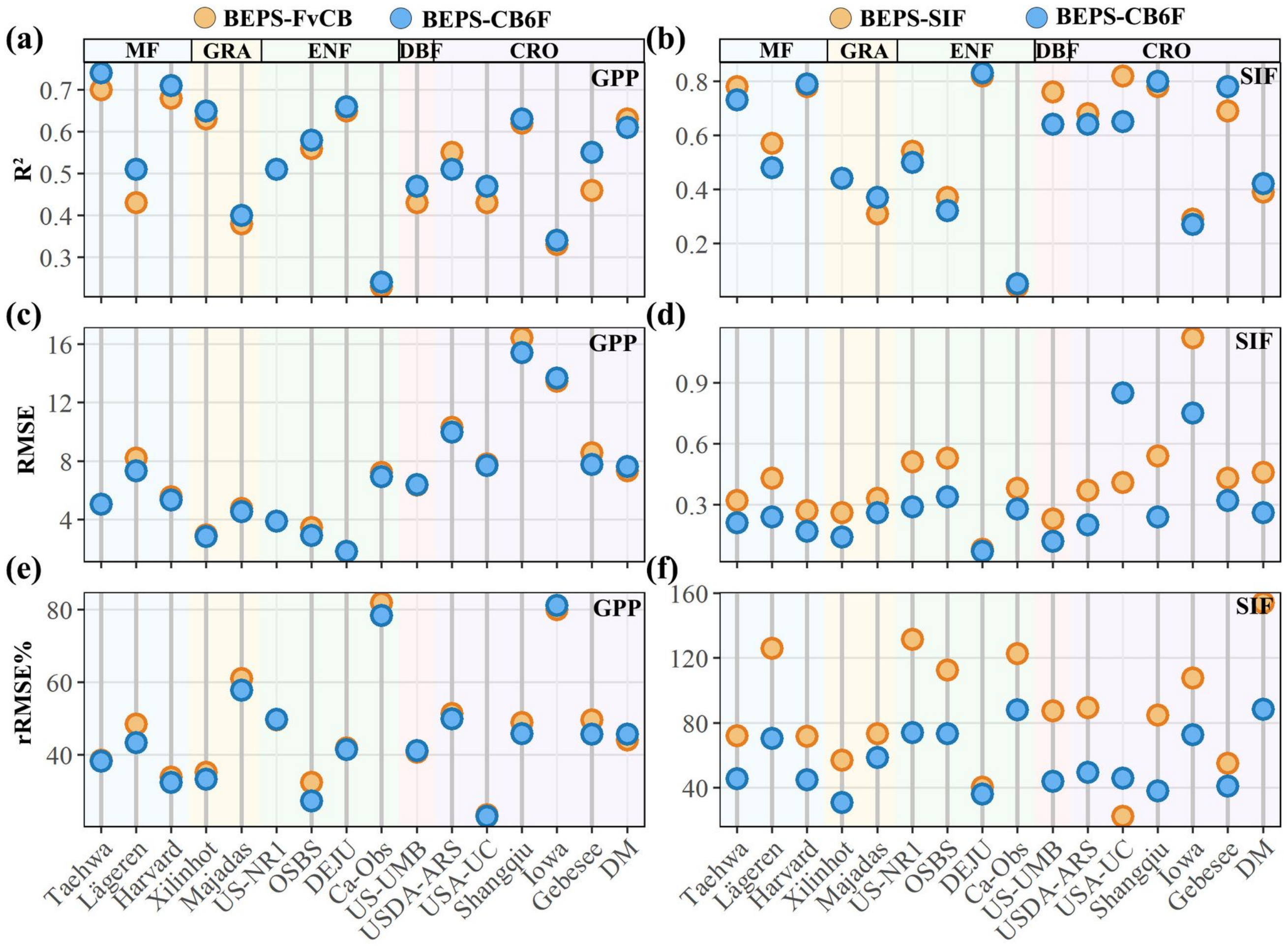
Lamour, J. et al. 2026. In review

Application highlight: Liu et al. 2026

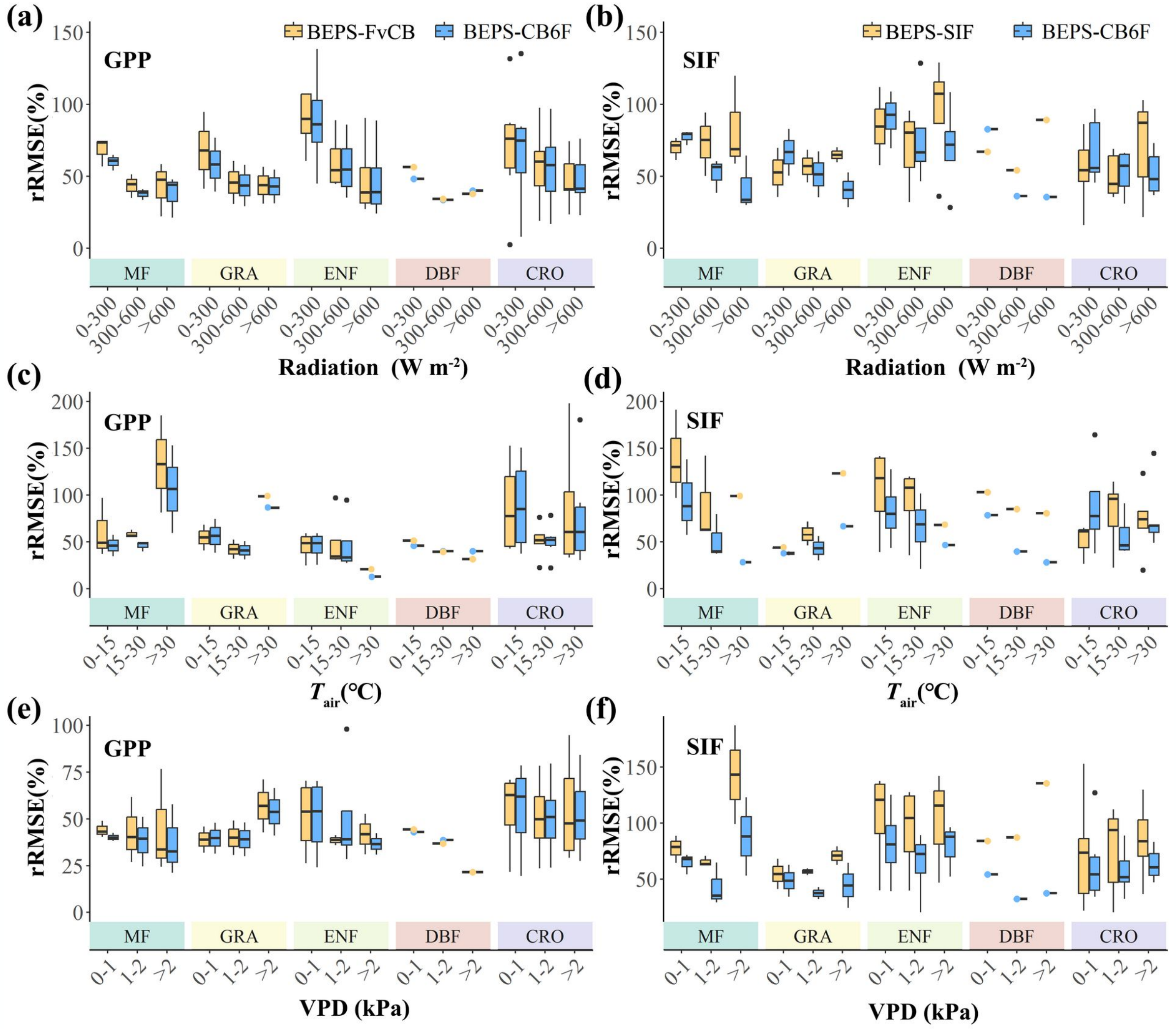
To what extent does resolving Cyt b6f help improve model fit to data at the canopy-level?

- Liu et al. implemented the Johnson-Berry model into the Biosphere-atmosphere Exchange Process Simulator (BEPS), and compared to eddy covariance and tower spectroscopy data at sixteen sites.
- The coupled model, termed BEPS-CB6F, yielded modest but consistent improvements in GPP at over 80% of sites (left column), and substantial improvements in SIF at more than 90% of sites (right column).

Liu, Y. et al. 2026. Global Change Biology, In press



Application highlight: Liu et al. 2026



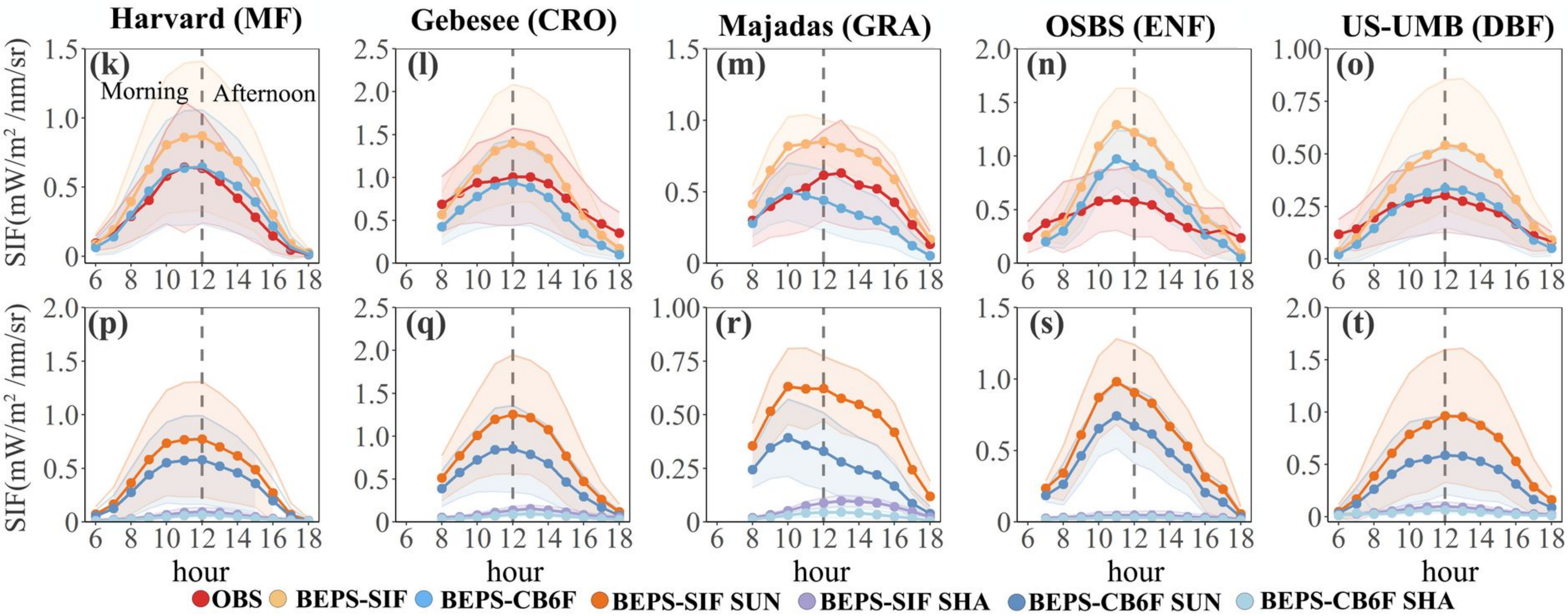
What are the environmental conditions where resolving Cyt b6f helps the most?

- Liu et al. also analyzed the improvements in BEPS-CB6F performance in relation to variation in three key environmental drivers of photosynthesis: light intensity, air temperature, and vapor pressure deficit.
- BEPS-CB6F alleviates GPP overestimation under low light, markedly improves SIF overestimation under high light, and also improves performance under high temperatures as well as high vapor pressure deficits.

Liu, Y. et al. 2026. Global Change Biology, In press

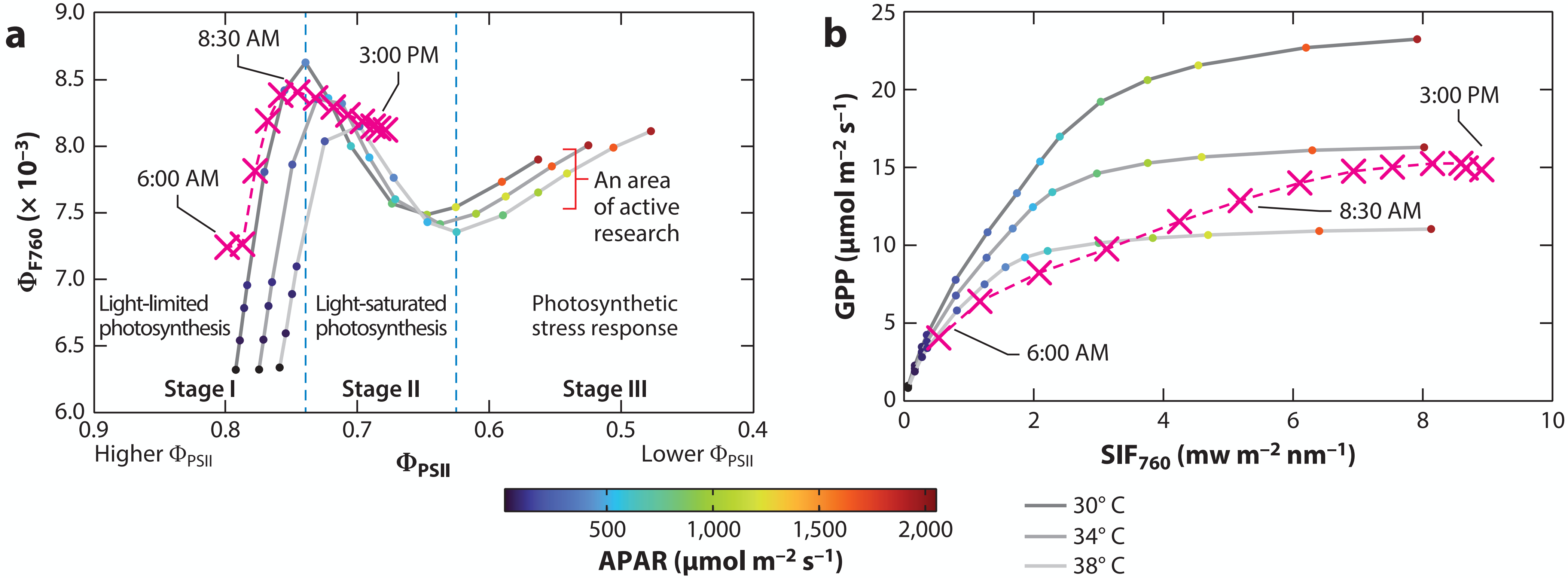
Application highlight: Liu et al. 2026

What drives this? While GPP improvements are in shade leaves, SIF improvements are in sun leaves.



Liu, Y. et al. 2026. Global Change Biology, In press

JB-SCOPE: should improve Stages I and II (i.e., normal Cyt b6f- and Rubisco-limited responses), and provide new perspective for studies of Stage III (i.e., stress responses)

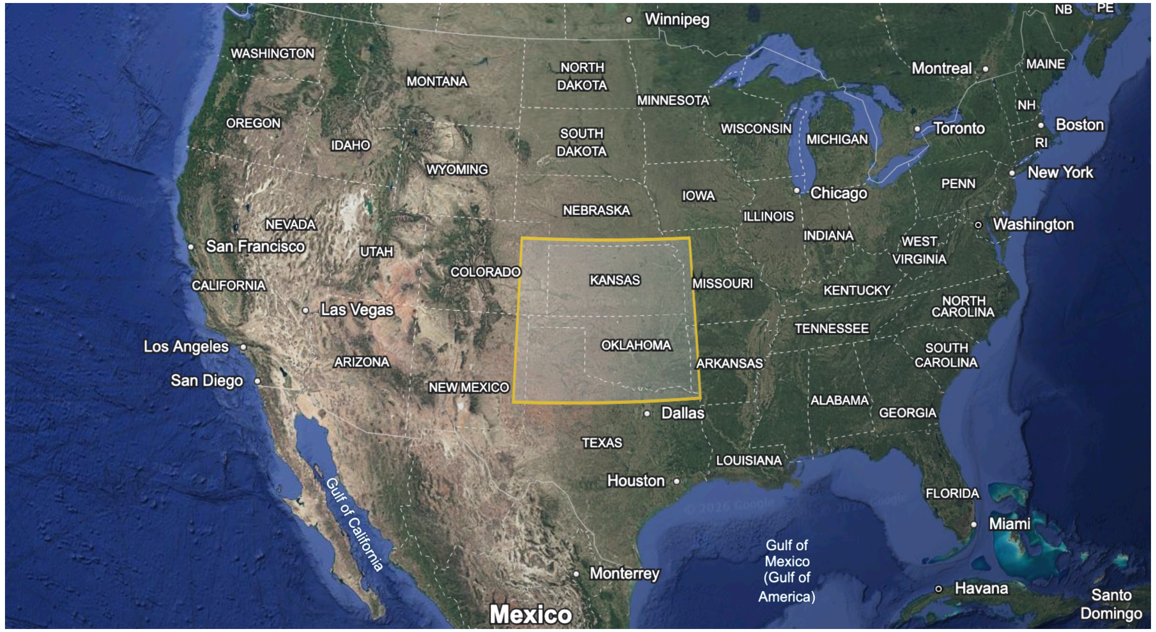


Yang, X. et al. 2026. Annu. Rev. Plant Biol., In press

KU contribution to ESA FLEX Cal/Val AO

Project objective

The overall objective of this project is to develop and validate an approach to quantify maximum photosynthetic capacity of terrestrial plants from FLEX mission products.



The approach

- We will implement the Johnson-Berry leaf-level photosynthesis model within the SCOPE model,
- perform inversions driven by FLEX data to retrieve estimates of the Cyt b6f and Rubisco, and
- compare these estimates to in situ measurements of the photosynthetic proteins across key plant functional types.

Long-term vision

We envision that this project will lay the foundation for a future FLEX L2C experimental science data product that quantifies leaf Cytochrome b6f and Rubisco contents, complementing the already planned products for leaf chlorophyll and carotenoid contents.