NGEE-Tropics

U.S. DEPARTMENT OF ENERGY | Office of Science

FATES:

~~Functionally Assembled Terrestrial Ecosystem Simulator~~

FAst Two-stream Ecosystem Simulator

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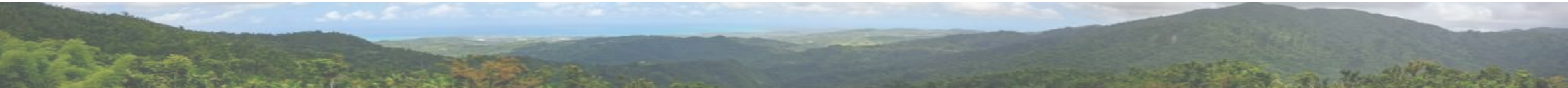
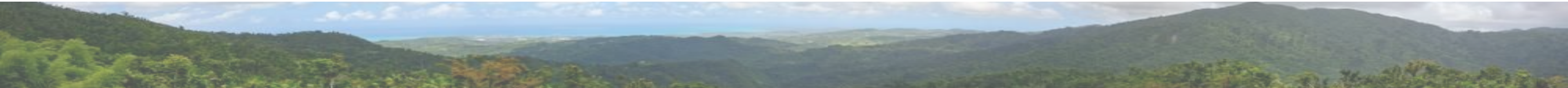


History Optimizations

- New! Output dimension control in the namelist!

fates_history_dimlevel = x,x

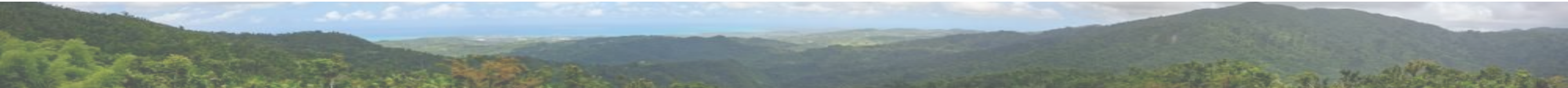
- First index is for model timestep variables, second is for daily variables
- 0 = no output
- 1 = grid-scale output only
- 2 = include output with the fourth dimension



History Optimizations

- Benefits:
    - Remove unnecessary arrays and calculations
    - Tests show levels 0,1 are 10% faster vs 2

*Test: derecho, 4x5°, 20 year simulation



The Photosynthesis Call Sequence

Photosynthesis Call Sequence
- Motivation

128 tasks - NE4 Grid, 20 year simulation years 10-20, full complexity, C-only

Name	Wall Total (s)
Model Time-step Loop	**2.1e+05**
FATES Photosynthesis	**1.5e+05**
Ecosystem Dynamics	**1.7e+03**

Evaluating the Photosynthesis Call Sequence

Nested Loops:

- Model Time-step Loop
  - Patch loop
    - Energy Balance Iteration Loop
      - Canopy x pft x leaf-layer loop
        - Photosynthesis solve, “Ci” loop

Solution 1: Photosynthesis Ci Solver - Closure Criteria

Convergence Criteria	ctsm_run (time)	photosynthesis (time)
(Base) Δ < 1e–6 [PPM], i_{max} = 5	60.9165	16.4021
Δ < 1e-2 [Pa Co2], i_{max} = 50	58.7354 (3.6%)	14.5168 (11.5%)

Solution 2: Solving Energy Balance Efficiently

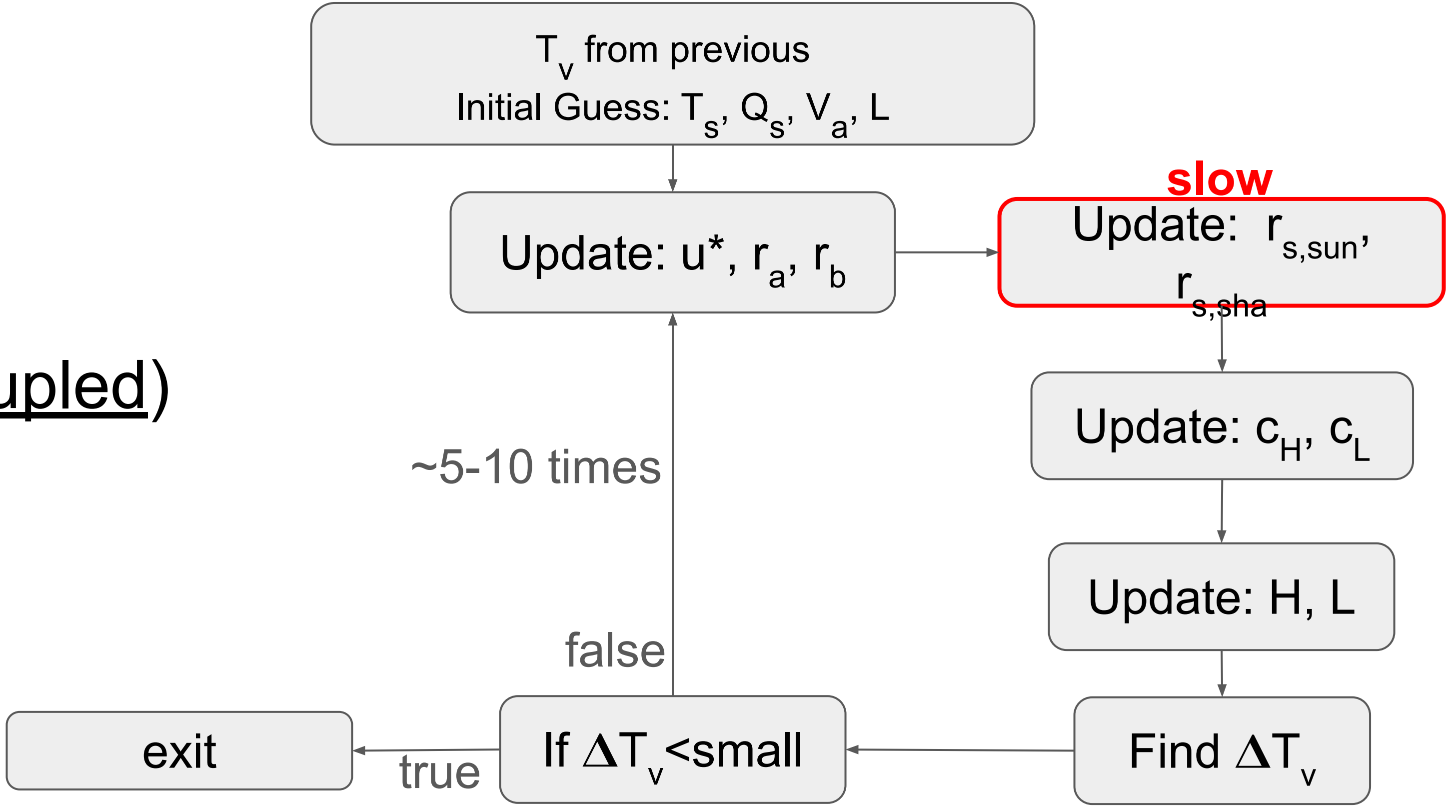
Canopy energy conservation gives

$$-\overrightarrow{S}_v + \overrightarrow{L}_v (T_v) + H_v (T_v) + \lambda E_v (T_v) = 0 \qquad (2.5.128)$$

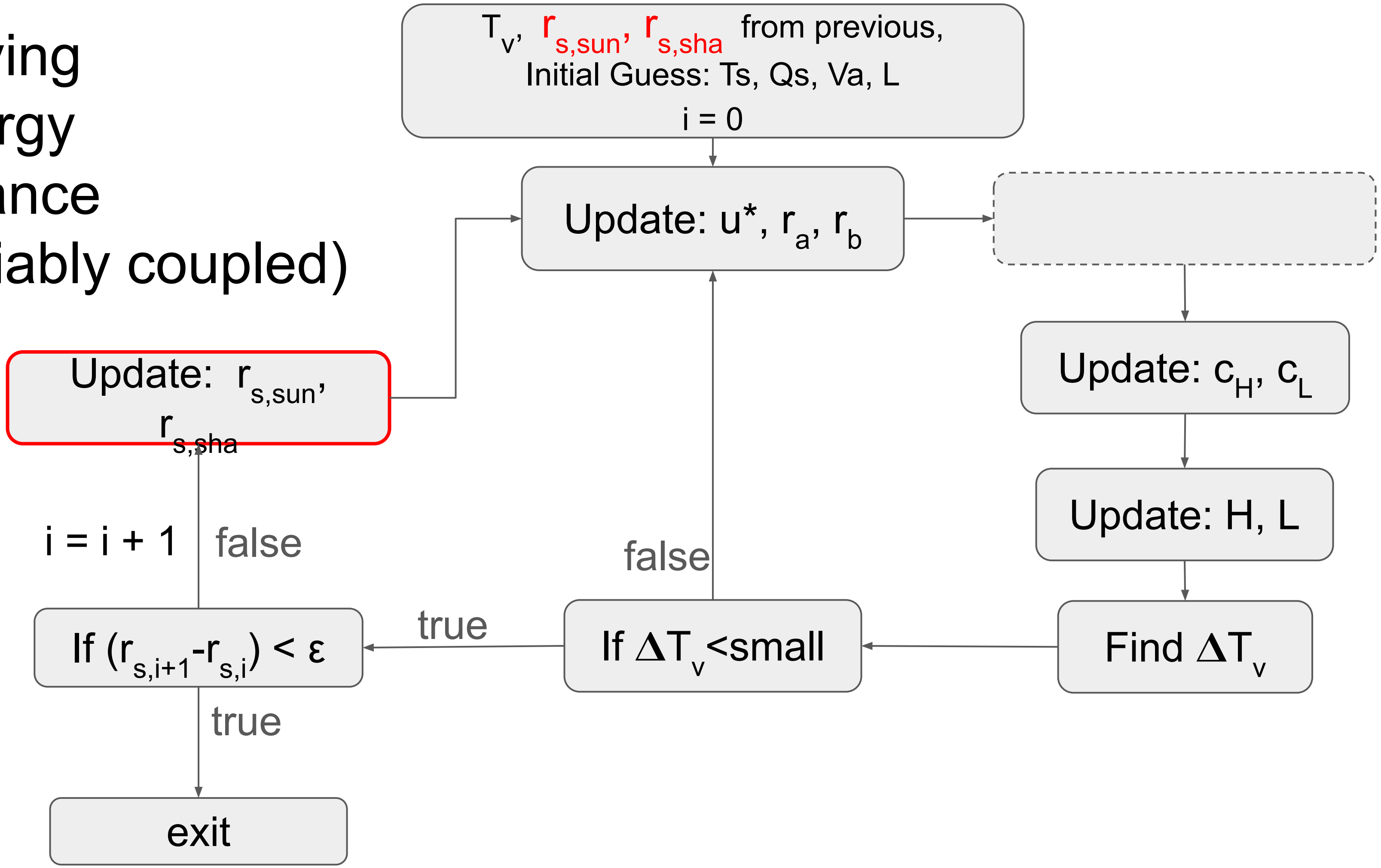
where $\overrightarrow{S}_v$ is the solar radiation absorbed by the vegetation (section 2.4.1), $\overrightarrow{L}_v$ is the net longwave radiation absorbed by vegetation (section 2.4.2), and H_v and λE_v are the sensible and latent heat fluxes from vegetation, respectively. The term λ is taken to be the latent heat of vaporization λ_{vap} (Table 2.2.7).

CLM5.0 Technical Documentation

Solving Energy Balance (existing, tightly coupled)

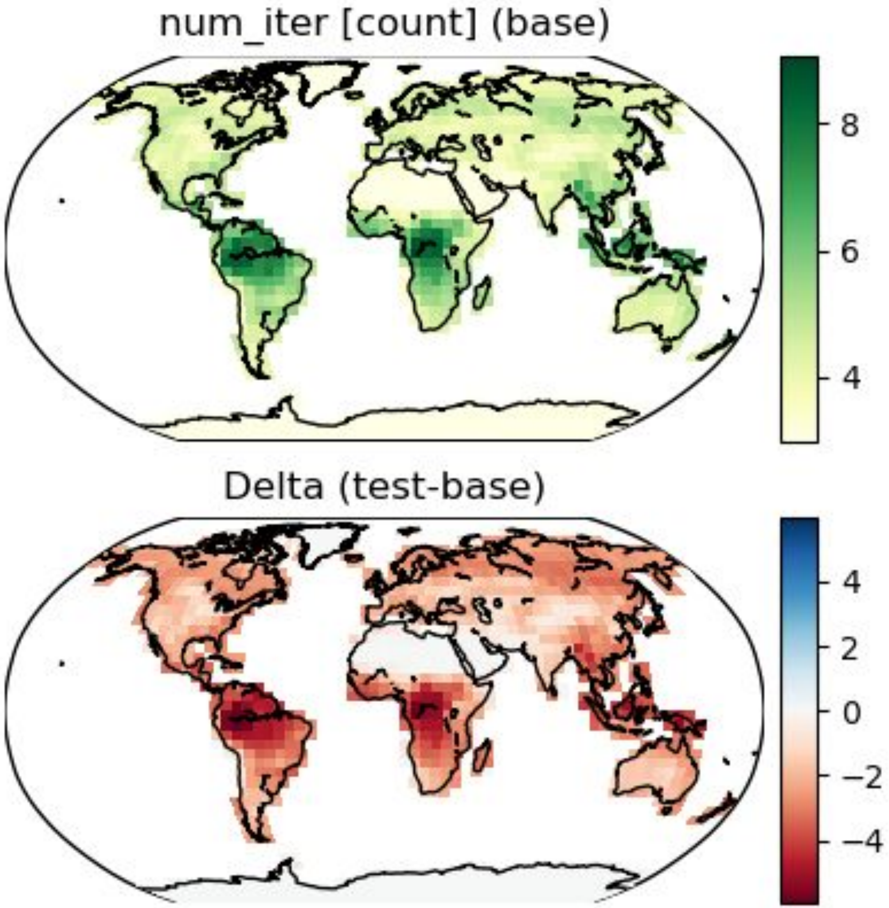


Solving Energy Balance (variably coupled)



Comparing Variably Coupled with Base

ε =0.001
Satellite Phenology



num_iter = mean number of times we call photosynthesis per solve

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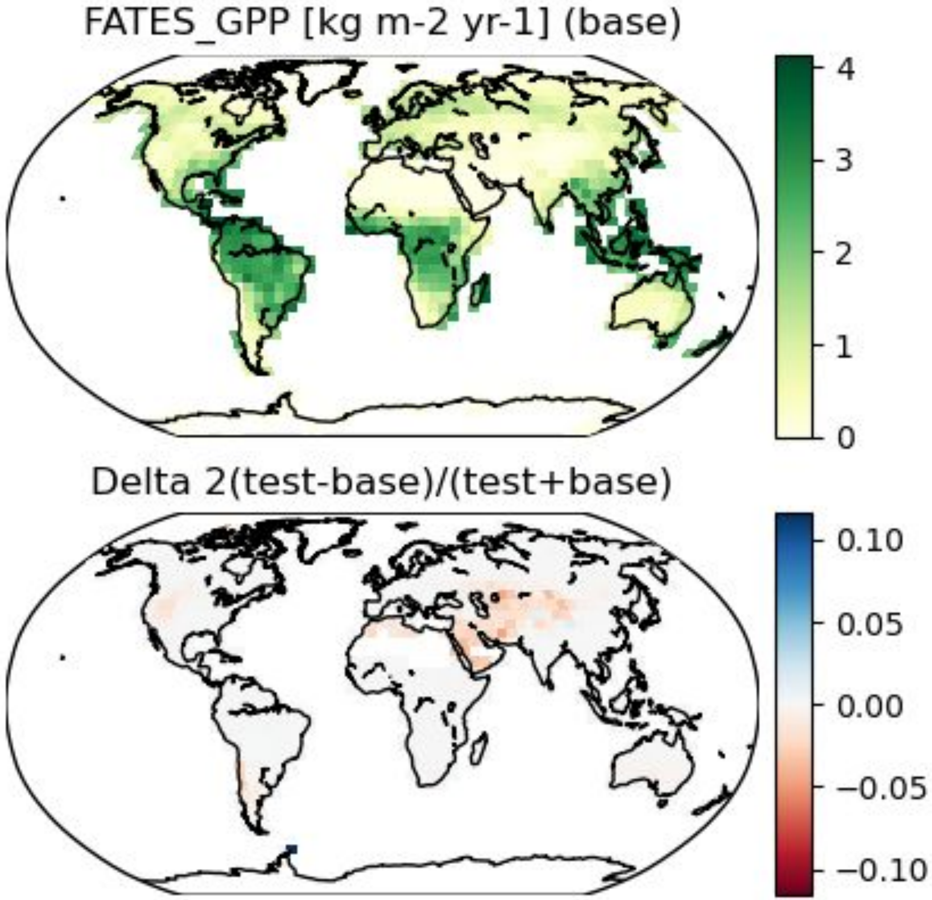

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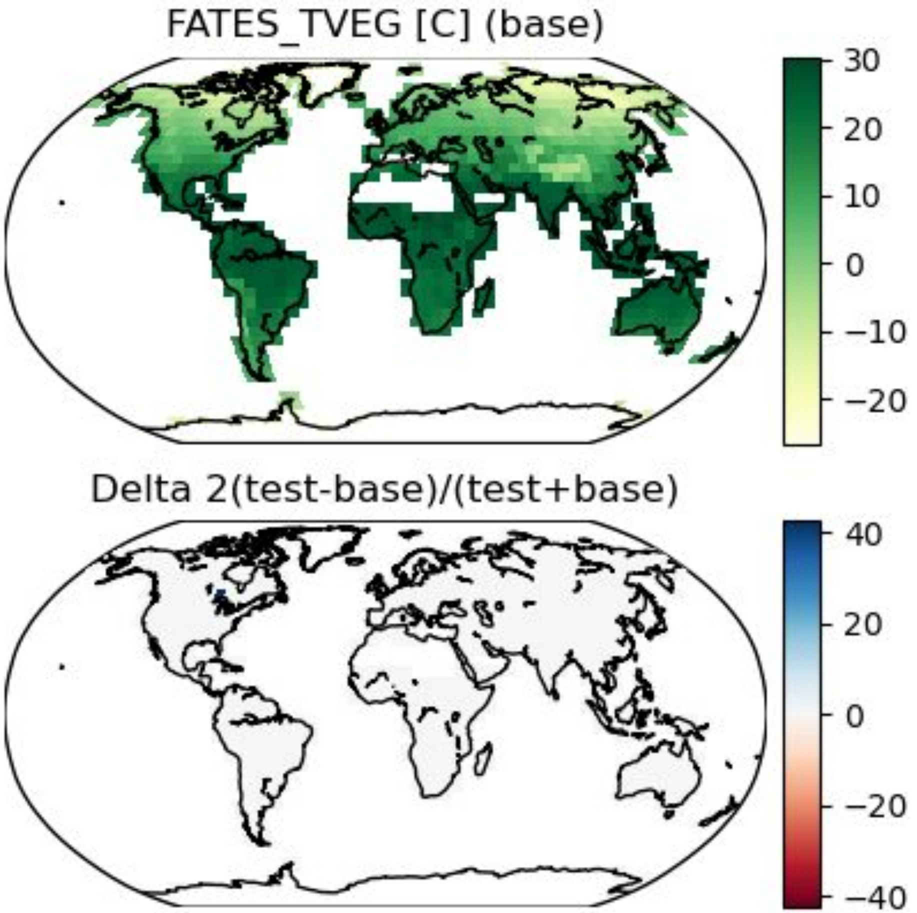


TVEG = Vegetation Temperature

Comparing Variably Coupled with Base - Timing

Fixed Biogeography
1-5th year of simulation
ε = 0.001

Run	Code	Mean(s)
base	ctsm_run	2966.6
	canflux	2183.6
	photosynthesis	2084.2
test	ctsm_run	2213.3
	canflux	1412.9
	photosynthesis	1285.0

"Full FATES"
5-10th year of simulation
ε = 0.01

Run	Code	Mean(s)
base	ctsm_run	6999.3
	canflux	5535.5
	photosynthesis	5333.4
test	ctsm_run	3601.7
	canflux	2076.8
	photosynthesis	1866.2

Two-Stream Radiation

Why Use Two Stream?

- Uses the same parameters as FATES with Norman radiation
- ELM, CLM and ED2 use Two-Stream
    - ED2 methods are very similar, and our team has experience with the math already
    - Use Gordon Bonan’s (CLM/ELM) methods for transforming user parameter constants into model constants
- Infinite “order”, i.e. its a continuum solution

Why Not Use Two Stream?

- Does not have a conceptual basis for lateral scattering across different media
- There are other methods and more sophisticated methods
    - SPARTACUS-Vegetation: Hogan, Quaife and Braghiere
    - 4SAIL
    - Stochastic RT: Spatial variability in tropical forest leaf area density from multi-return lidar and modeling, Detto et al.

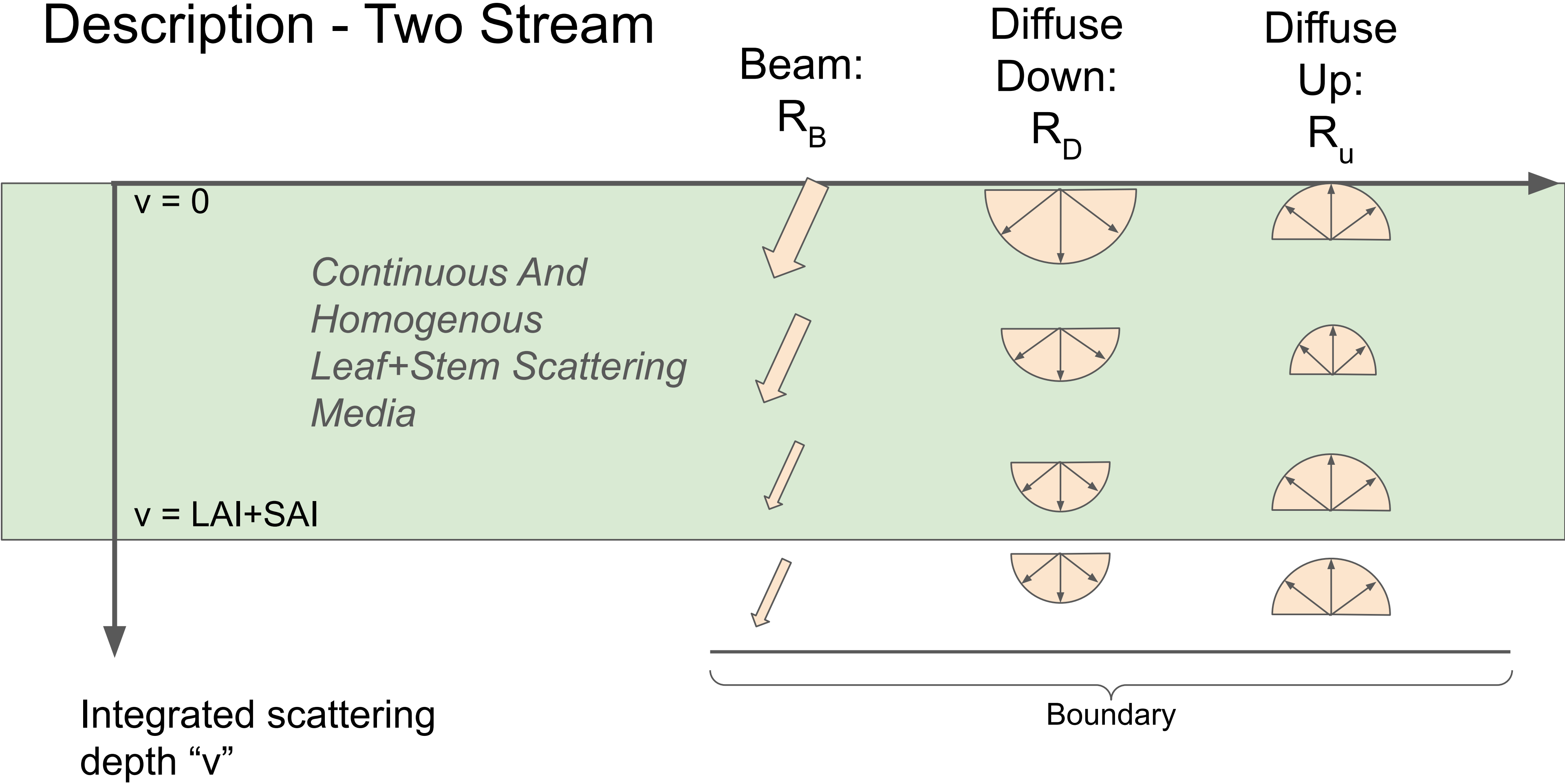
Two Stream Radiation Simulations are a better match iLAMB Observations Overall

e Shift [months]

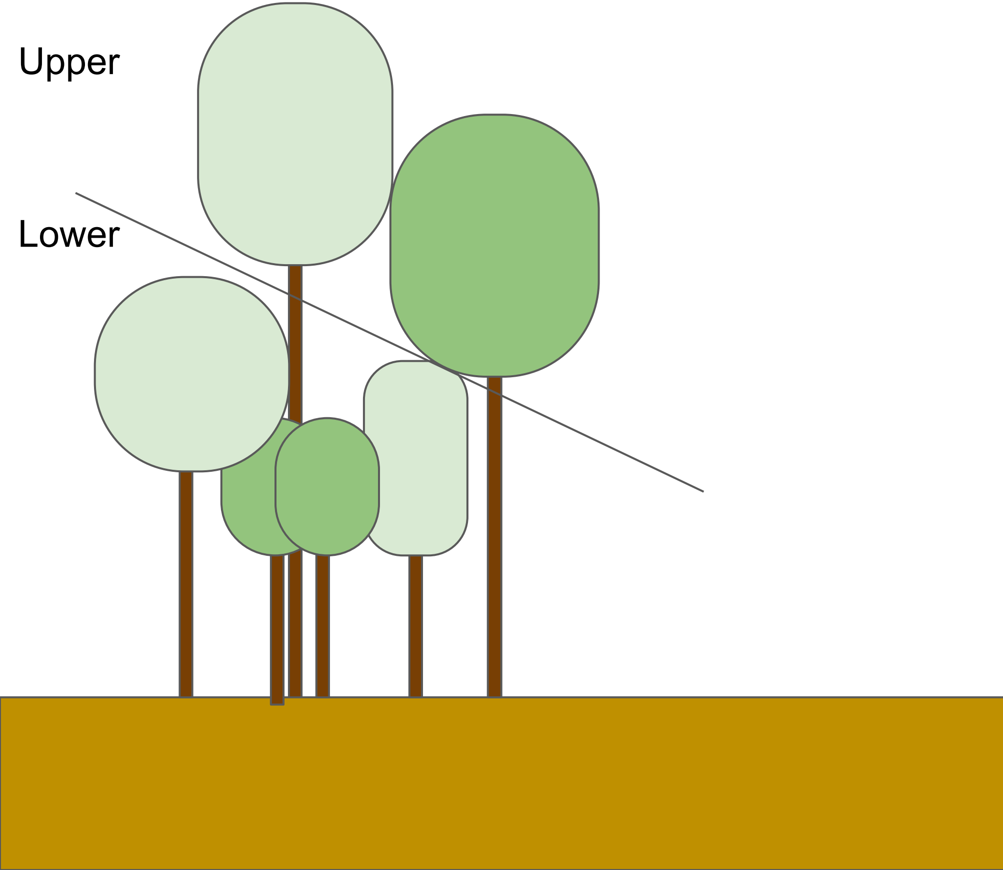
Benchmark	Bias Score [1]	RMSE Score [1]	Seasonal Cycle Score [1]	Spatial Distribution Sco	Overall Score [
CTSM5.1_CLM_big_leaf	0.394	0.527	0.602	0.976	0.605
CTSM5.1_FATES_norman	0.307	0.493	0.589	0.982	0.573
CTSM5.1_FATES_twostream	0.402	0.523	0.594	0.976	0.604

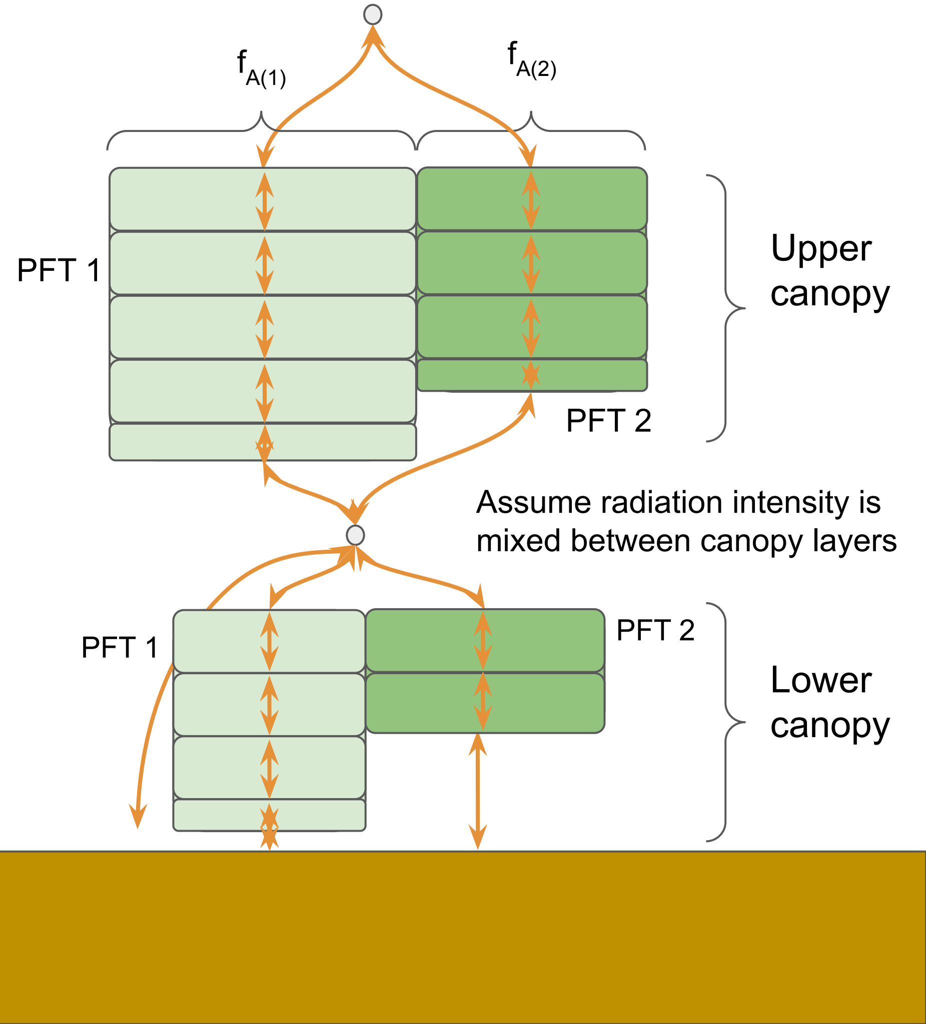
Courtesy of Adrianna Foster

Description - Two Stream



Speed: Norman Does Require Discretization

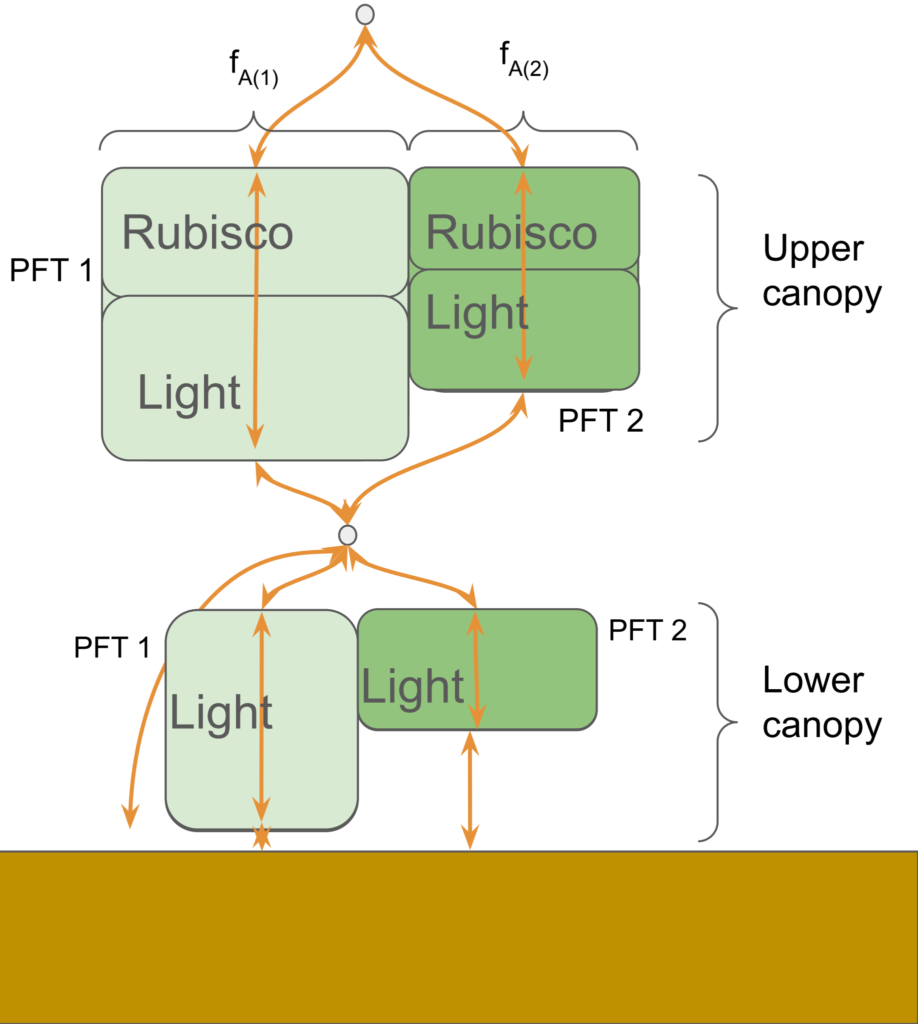




Speed: Two-Stream Does Not Require Discretization

Integrate analytical solution over depth, combine with photosynthesis equations

$$R_{up(v)} = A_{up} e^{-\kappa_b v} + B_1 e^{av} \lambda_1 + B_2 e^{-av} \lambda_2$$
$$R_{dn(v)} = A_{dn} e^{-\kappa_b v} + B_2 e^{av} \lambda_1 + B_1 e^{-av} \lambda_2$$



Acknowledgment

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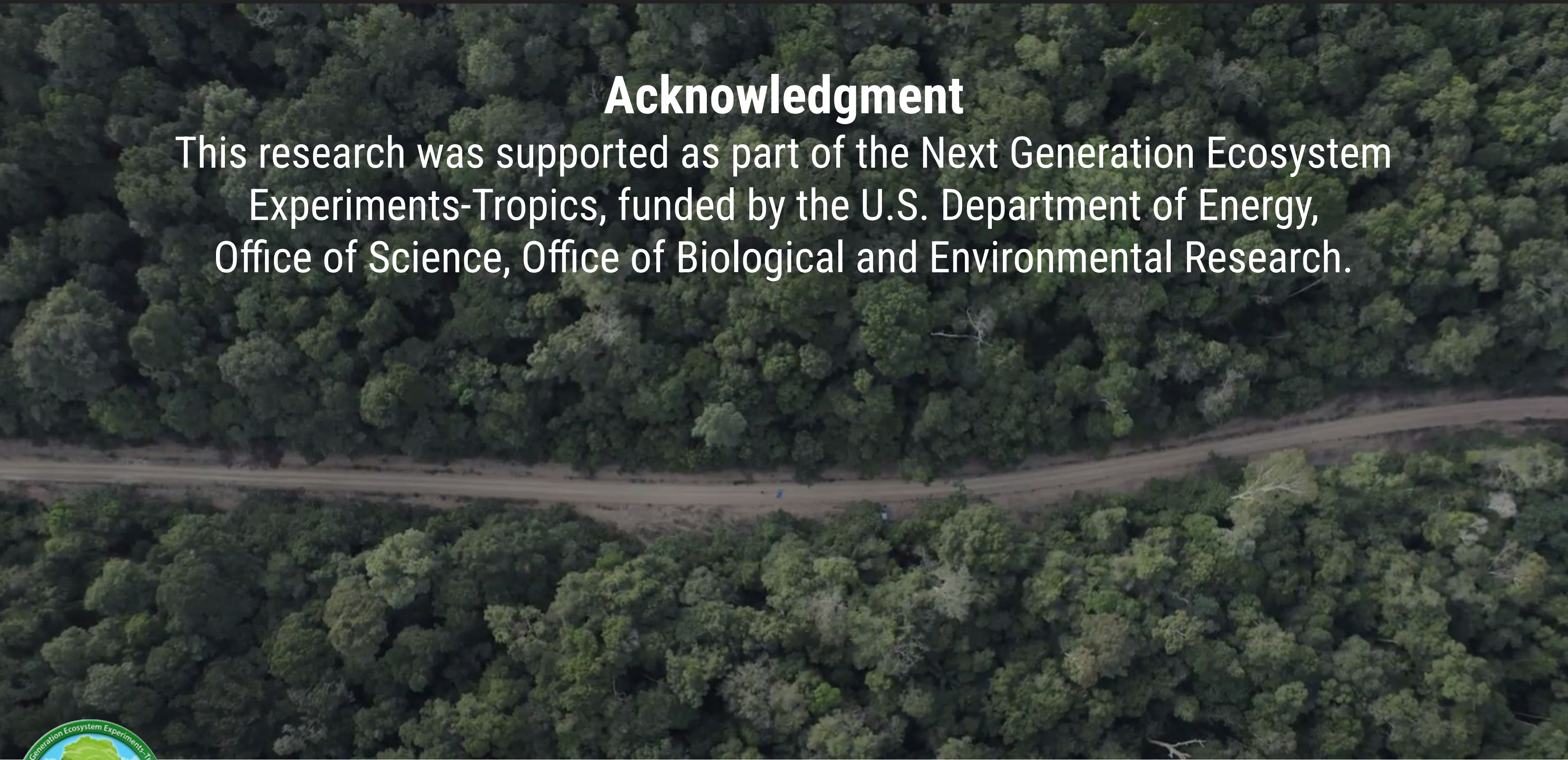

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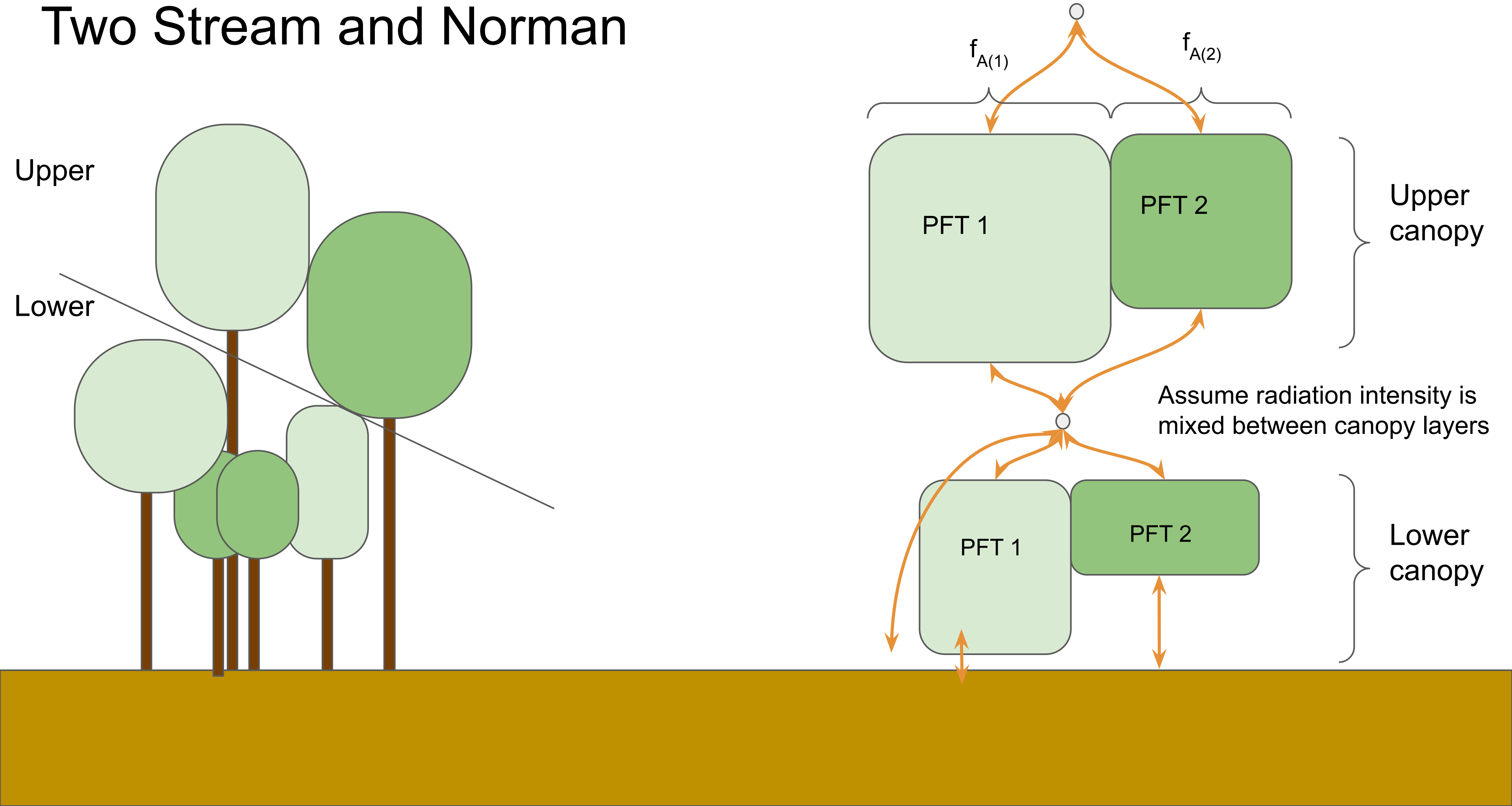
Two Stream and Norman



Photosynthesis Solver Ideas

- **Simple Idea:**
  - Review and update sensitivity analysis of Ci closure criteria

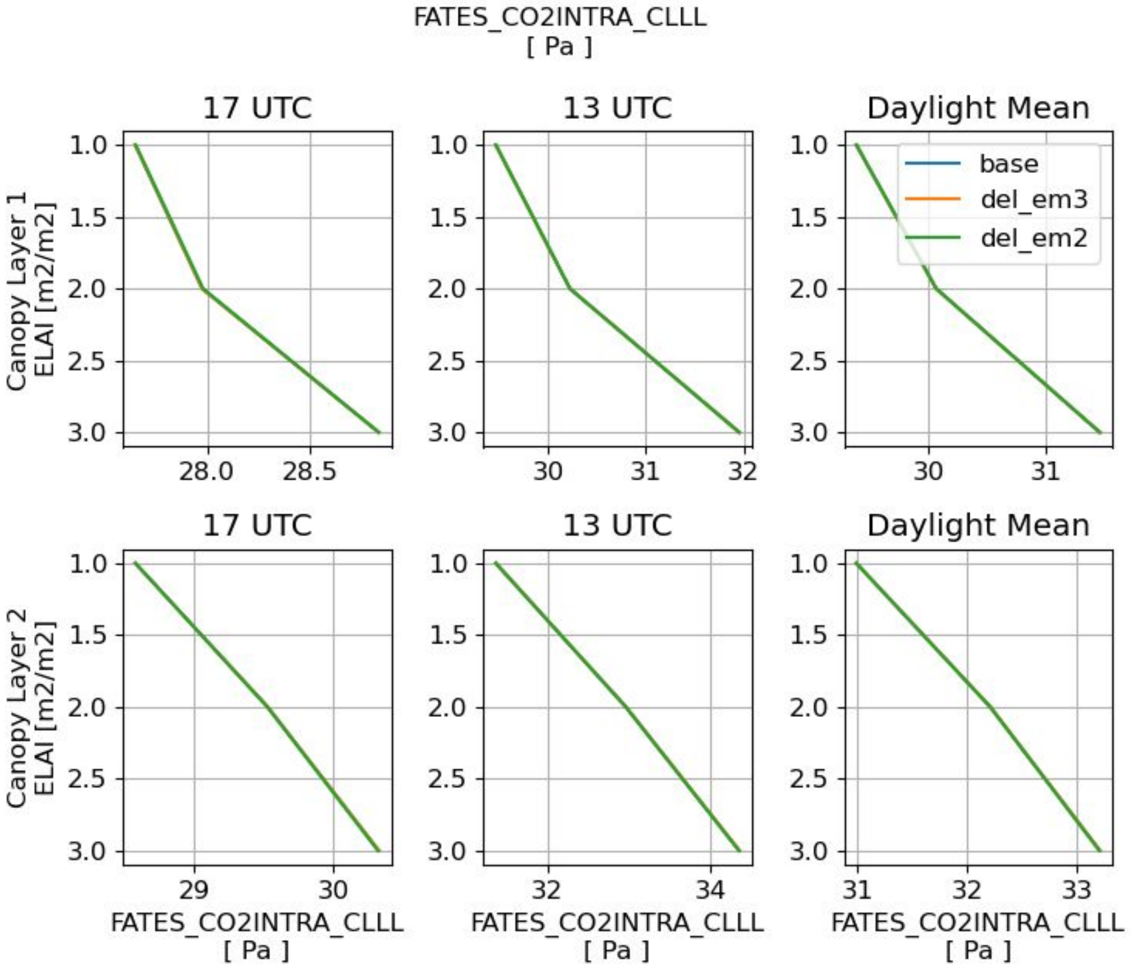
Test at BCI Panama, on single evergreen PFT, several years of simulation using inventory stand initialization and no dynamics

Photosynthesis Ci Solver - Closure Criteria

"base":
$(co2_{int}-co2_{int,old})/press_{can} < 2e^{-12}$

"del_em3":
$(co2_{int}-co2_{int,old})/co2_{can} < 1e^{-3}$

"del_em2":
$(co2_{int}-co2_{int,old})/co2_{can} < 1e^{-2}$



Motivational Timing Info (Energy Balance & Photosynthesis)

128 tasks - NE4 Grid, 20 year simulation years 10-20, full complexity, C-only

	Name	**Wall Total (s)**	Slowest Node (s)	Fastest Node (s)
Model Time-step Loop	elm_run	**2.1e+05**	3658.693	237.816
Energy Balance Loop	canflux	**1.569e+05**	2958.763	22.684
FATES Photosynthesis	edpsn	**1.537e+05**	2920.672	17.985
Ecosystem Dynamics	ecosystemdyn	**1.69e+03**	16.986	8.944
Radiation	surfrad	**2.6e+03**	34.895	1.727

Timing Info - Take Homes

- Fraction of time that FATES photosynthesis takes of land-timestep:

  1.537e+05/2.1e+05 = 73%

- Fraction of time that FATES photosynthesis takes of energy-balance iteration step:

  1.537e+05/1.543e+05 = 99.6%

- There is a wide gap between fastest and slowest procs
- Average number of energy balance iterations = **~6**

Comparing Variably Coupled with Base

ε =0.001
Satellite Phenology

QVEGT = Transpiration