Vertical Scaling of Leaf Maintenance Respiration in FATES

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U.S. DEPARTMENT OF ENERGY | Office of Science

E3SM Energy Exascale Earth System Model

NGEE-Tropics

Motivation

- Switch in rdark equations from Ryan et al. 1991 to Atkin et al. 2017 increased respiration globally and resulted in a **low LAI bias.**
- Observational data from a tropical forest in Panama found **'the ratio between the dark respiration rate and the maximum carboxylation rate was lower near the ground than at the top-of-canopy'** Lamour et al. 2023

Why does respiration matter?

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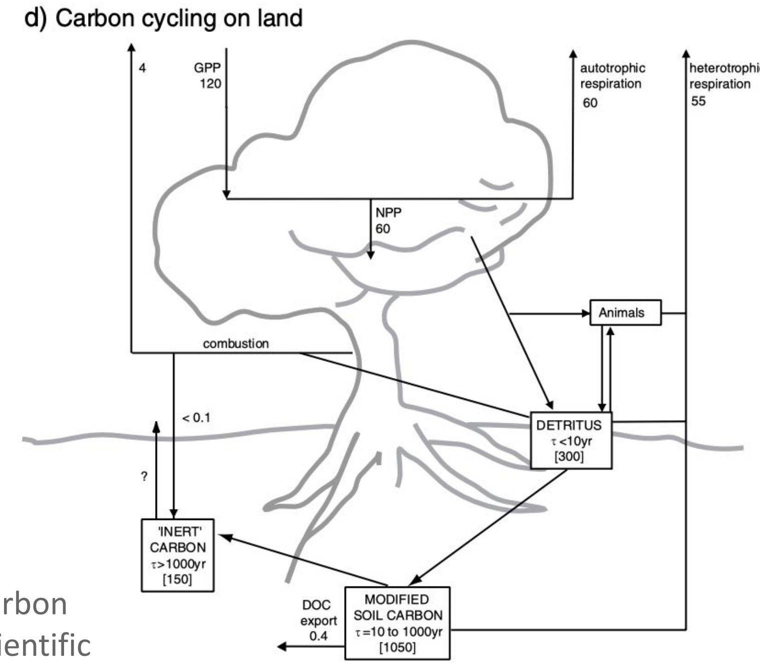
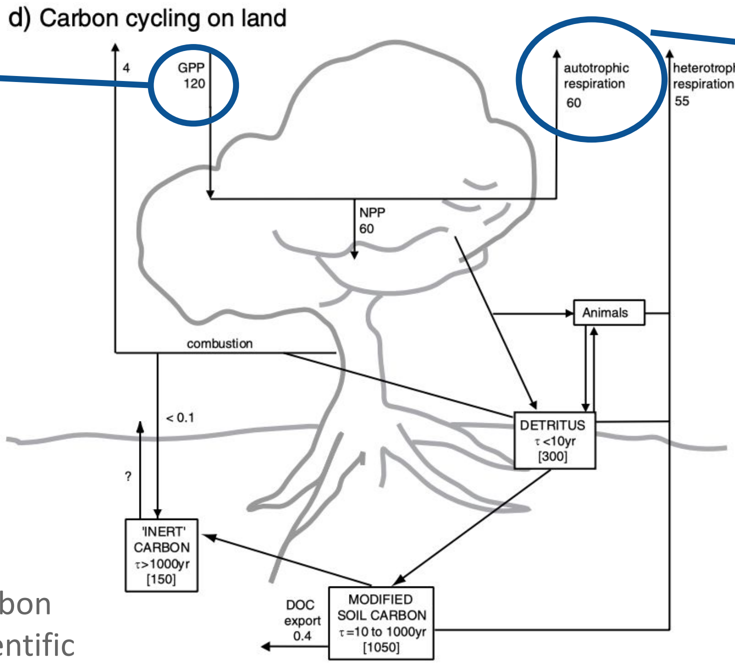


The carbon cycle and atmospheric carbon dioxide. Climate change 2001: the scientific basis, IPPC, 2001

Why does respiration matter?

GPP
120 PgC/yr



Autotrophic respiration
60 PgC/yr

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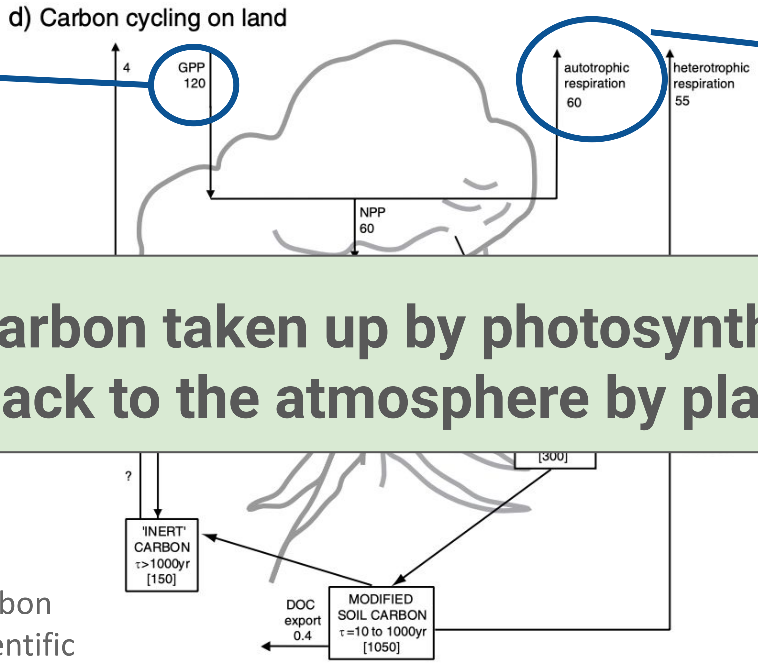

Autotrophic respiration
60 PgC/yr

~Half of the carbon taken up by photosynthesis is respired back to the atmosphere by plants

The carbon cycle and atmospheric carbon dioxide. Climate change 2001: the scientific basis, IPPC, 2001

Respiration in FATES

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Respiration = Growth respiration (GR) + Maintenance respiration (MR)

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$$\text{Leaf } MR_{top} = r_0 + (r_1 * lnc_{top}) + (r_2 * \text{temperature of last 10 days})$$

Top of canopy leaf MR

Base leaf MR

Effect of nitrogen on leaf MR

Effect of temperature acclimation on leaf MR

Atkin et al. 2017

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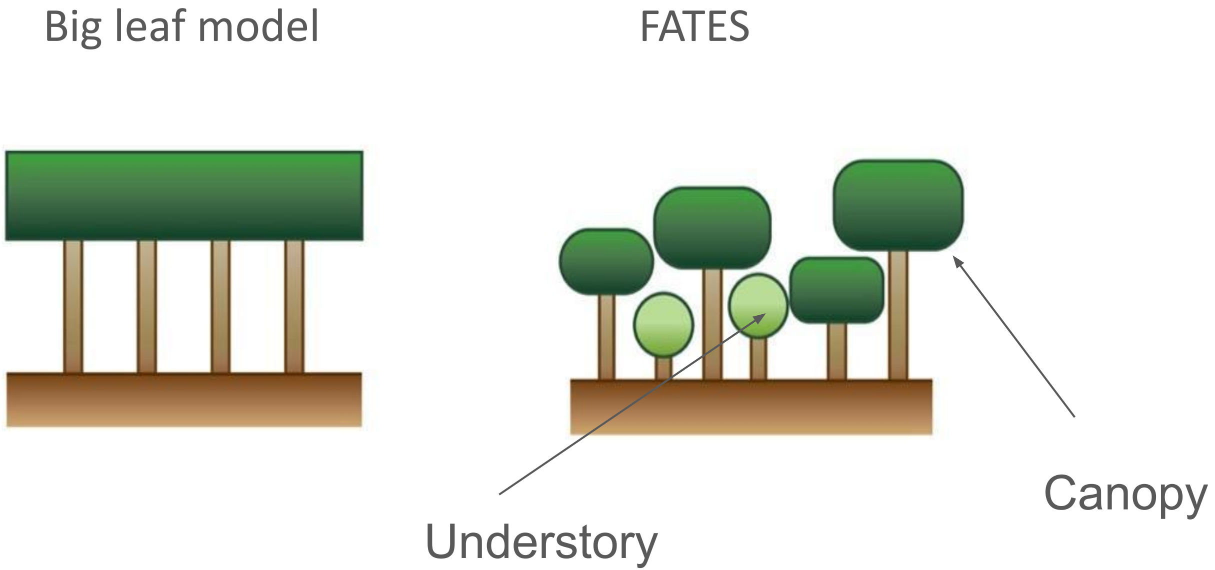
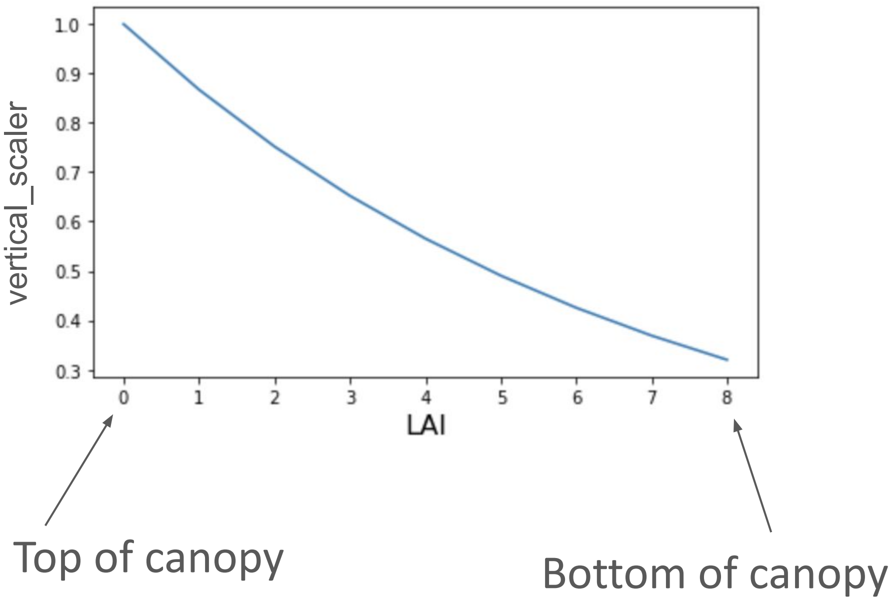
FATES has multiple canopy layers and leaf layers



In FATES photosynthesis is scaled vertically
because light is attenuated through the canopy



Lloyd et al. 2010

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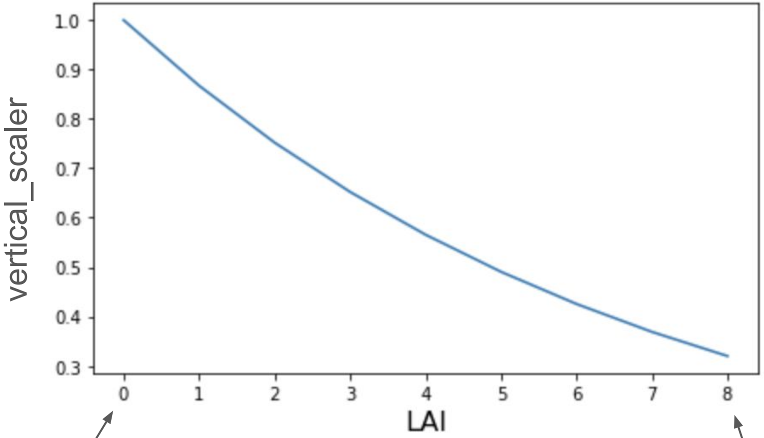


Top of canopy

Bottom of canopy

maximum rate of carboxylation

kn = exp(0.00963 * vcmax25top - 2.43)

vscaler = exp(-kn * cumulative_lai)

Number of leaf layers above

Lloyd et al. 2010

How does rdark change through the canopy?

Alternative hypotheses for rdark vertical scaling

$$\text{Leaf } MR_{top} = r_0 + (r_1 * lnc_{top}) + (r_2 * leaf\_temperature)$$

Alternative hypotheses for rdark vertical scaling

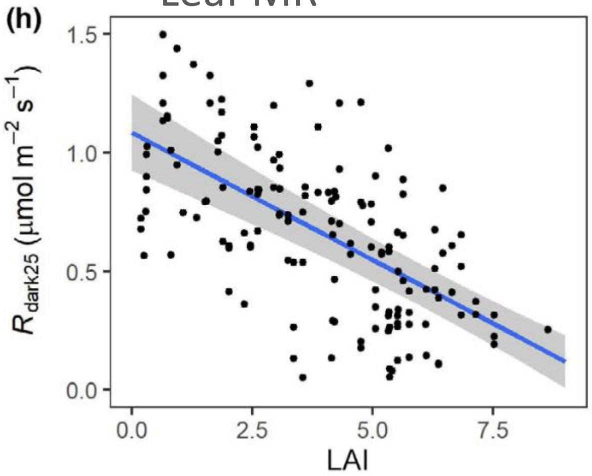
Leaf $MR_{top} = r_0 + (r_1 * lnc_{top}) + (r_2 * leaf\_temperature)$

V1: Leaf $MR = scaler * (r_0 + (r_1 * lnc_{top}) + (r_2 * leaf\_temperature))$

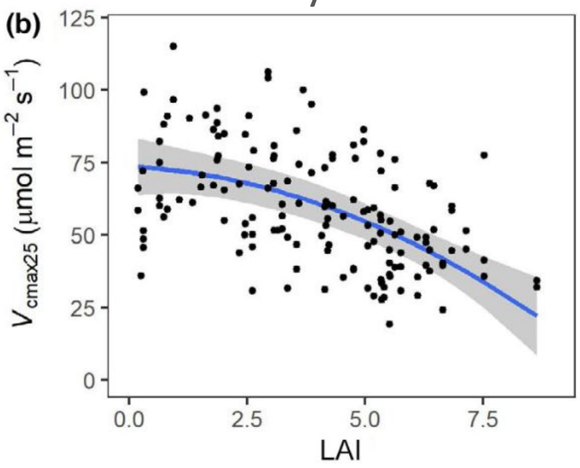
Same scaling as photosynthesis

Observations suggest a linear decrease in rdark *greater* than the decrease in photosynthesis

Leaf MR



Photosynthesis



Lamour et al. 2002

Alternative hypotheses for rdark vertical scaling

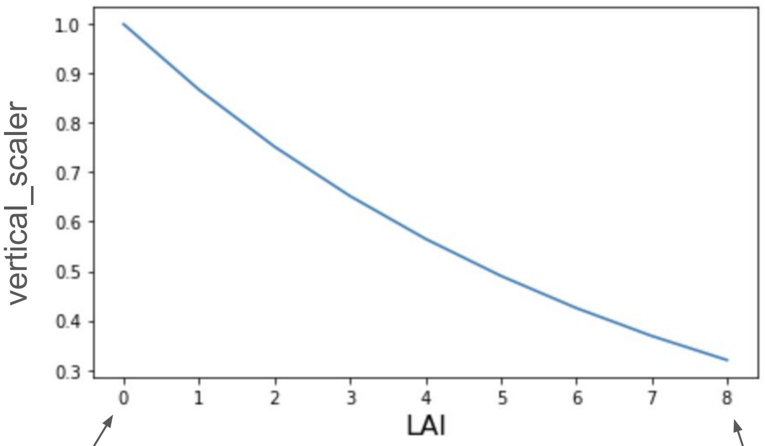
$\text{Leaf MR}_{top} = r_0 + (r_1 * \text{lnc}_{top}) + (r_2 * \text{leaf\_temperature})$

V1: $\text{Leaf MR} = \text{scaler} * (r_0 + (r_1 * \text{lnc}_{top}) + (r_2 * \text{leaf\_temperature}))$

V2: $\text{Leaf MR} = \text{rdark\_scaler} * (r_0 + (r_1 * \text{lnc}_{top}) + (r_2 * \text{leaf\_temperature}))$

rdark decreases more than photosynthesis

Adjust the decrease in rdark through the canopy



Top of canopy

Bottom of canopy

maximum rate of carboxylation

Decrease/increase this parameter

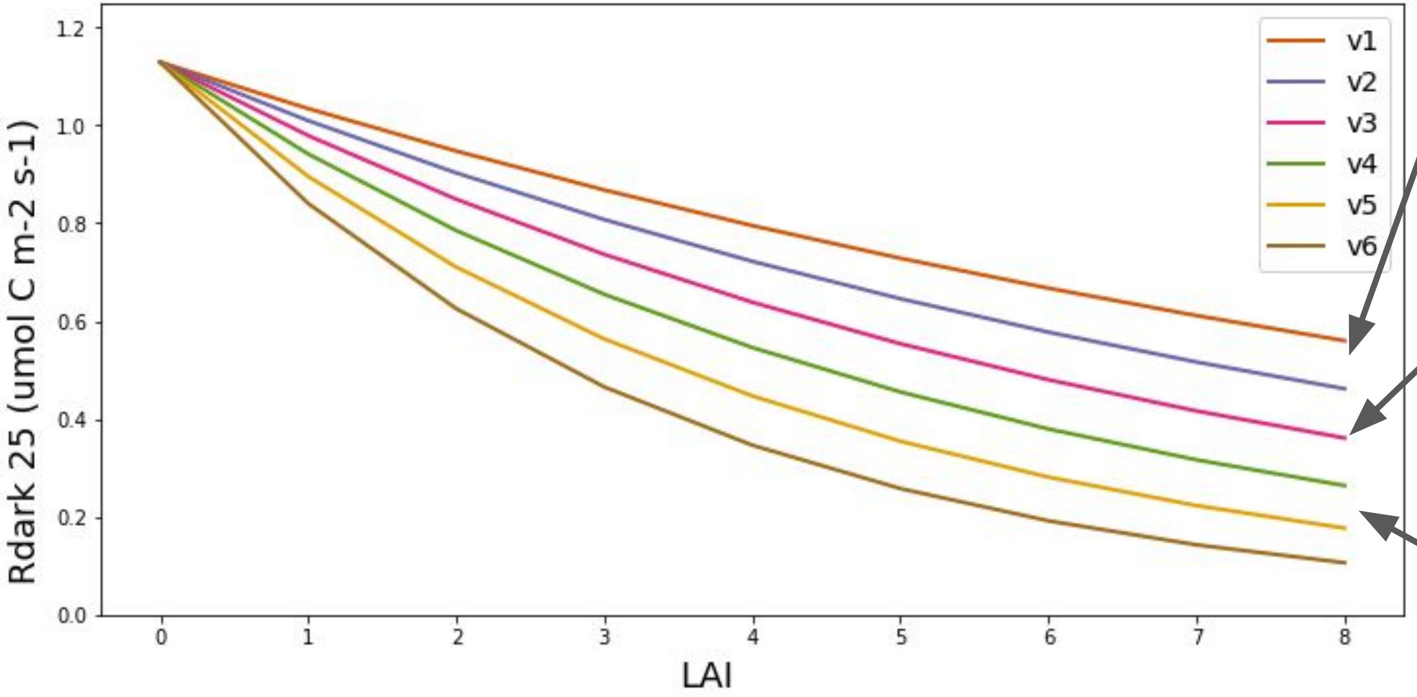
kn = exp(0.00963 * vcmax25top - 2.43)

rdark_scaler = exp(-kn * cumulative_lai)

Number of leaf layers above

Lloyd et al. 2010

Alternative hypotheses for rdark vertical scaling

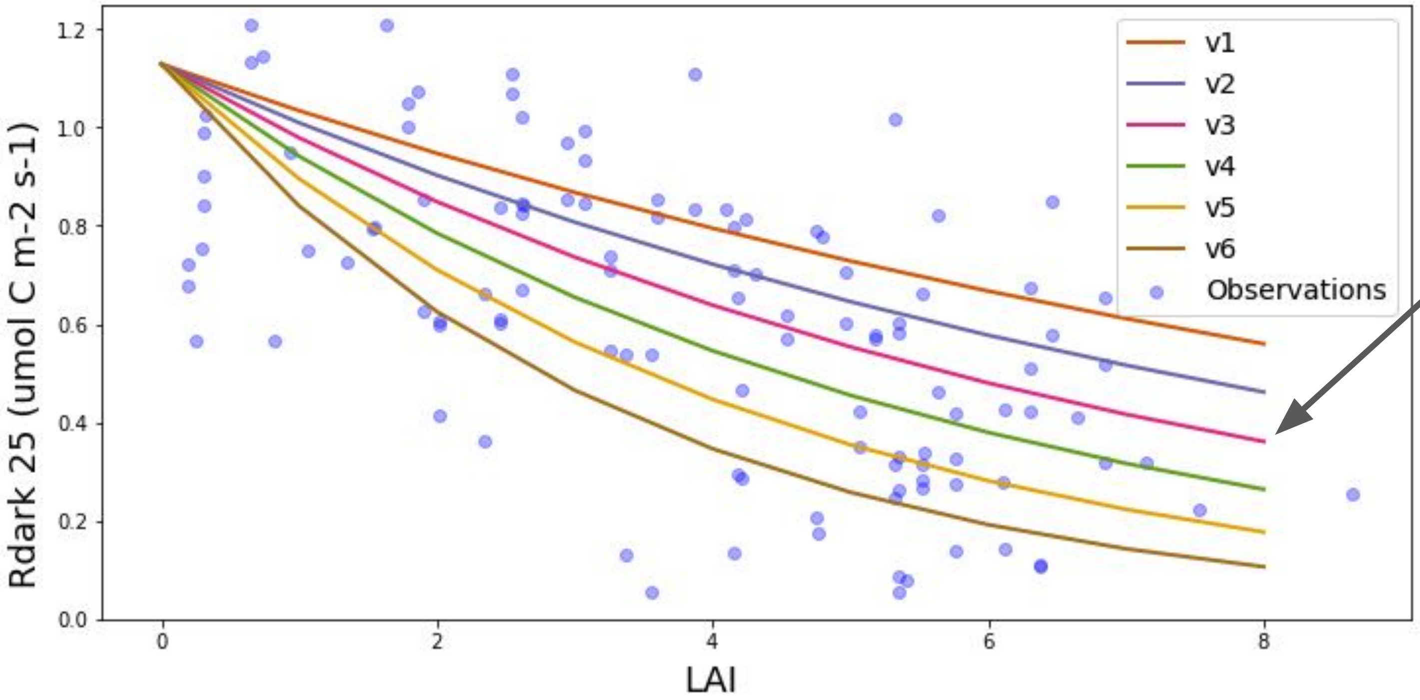


rdark decreases less than photosynthesis

Default FATES: rdark decreases the same rate as photosynthesis

rdark decreases more than photosynthesis

Alternative hypotheses for leaf MR vertical scaling



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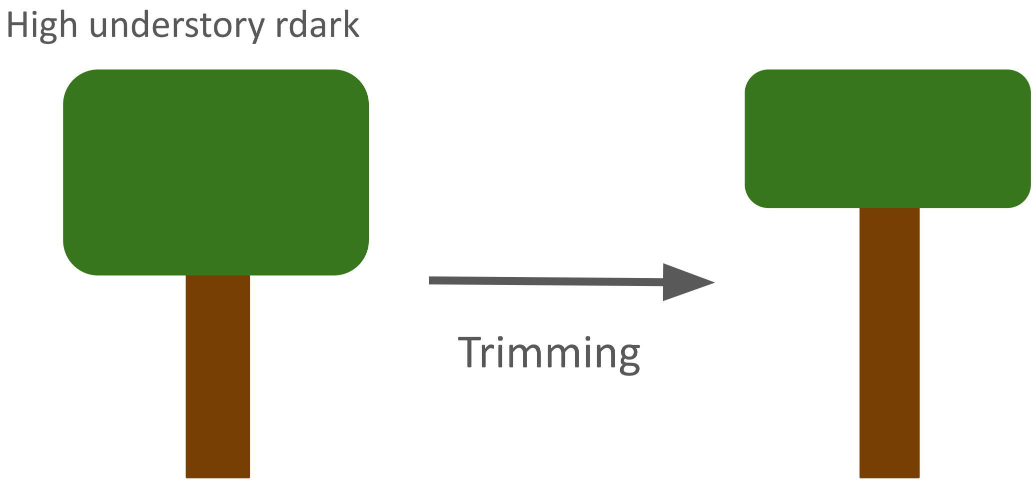
Default FATES: rdark decreases the same rate as photosynthesis

rdark decreases more than photosynthesis

H1: Lower understory rdark is expected to increase LAI

In FATES leaf layers in net negative carbon balance are shed and not replaced

(Downstream consequences for NPP, carbon storage, water cycle…)



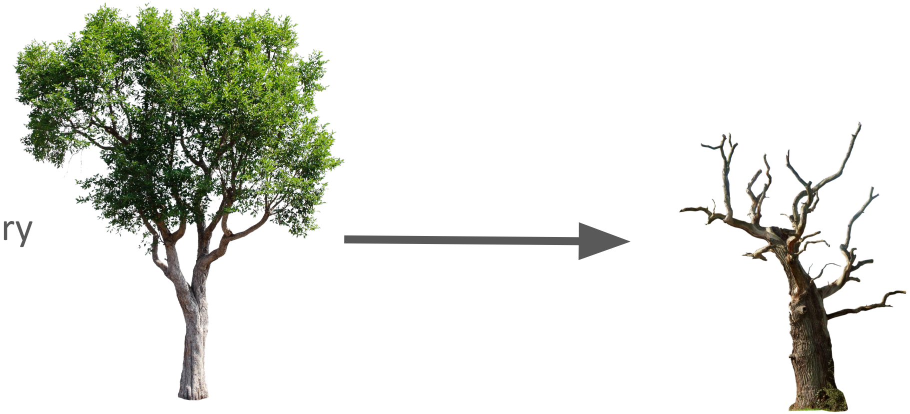
H1: Lower understory rdark is expected to increase LAI

In FATES leaf layers in net negative carbon balance are shed and not replaced

H2: Lower understory rdark is expected to decrease understory mortality

If respiration outweighs photosynthesis, plants deplete their stored carbon and die of carbon starvation mortality

High understory rdark



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In FATES leaf layers in net negative carbon balance are shed and not replaced

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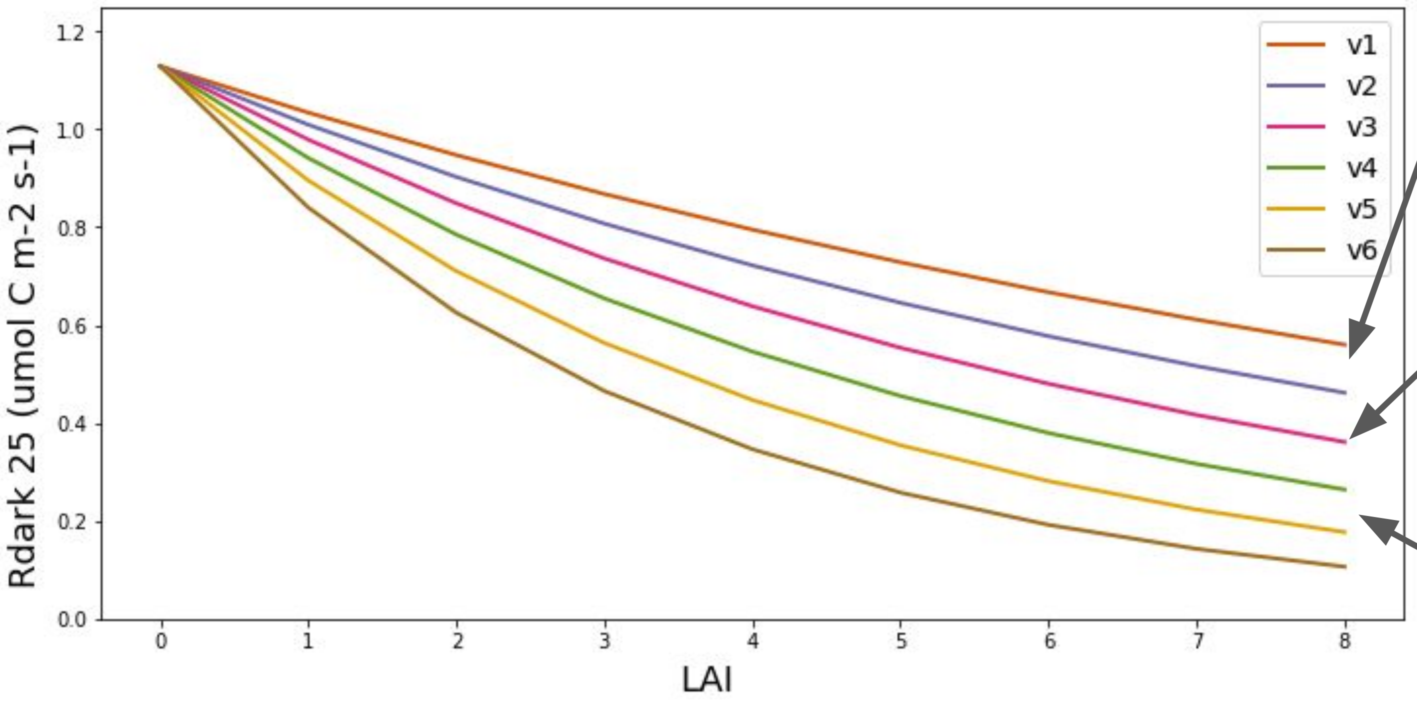
If respiration outweighs photosynthesis, plants deplete their stored carbon and die of carbon starvation mortality

H3: Lower understory rdark is expected to favour shade tolerant PFTs

Results

Alternative hypotheses for rdark vertical scaling



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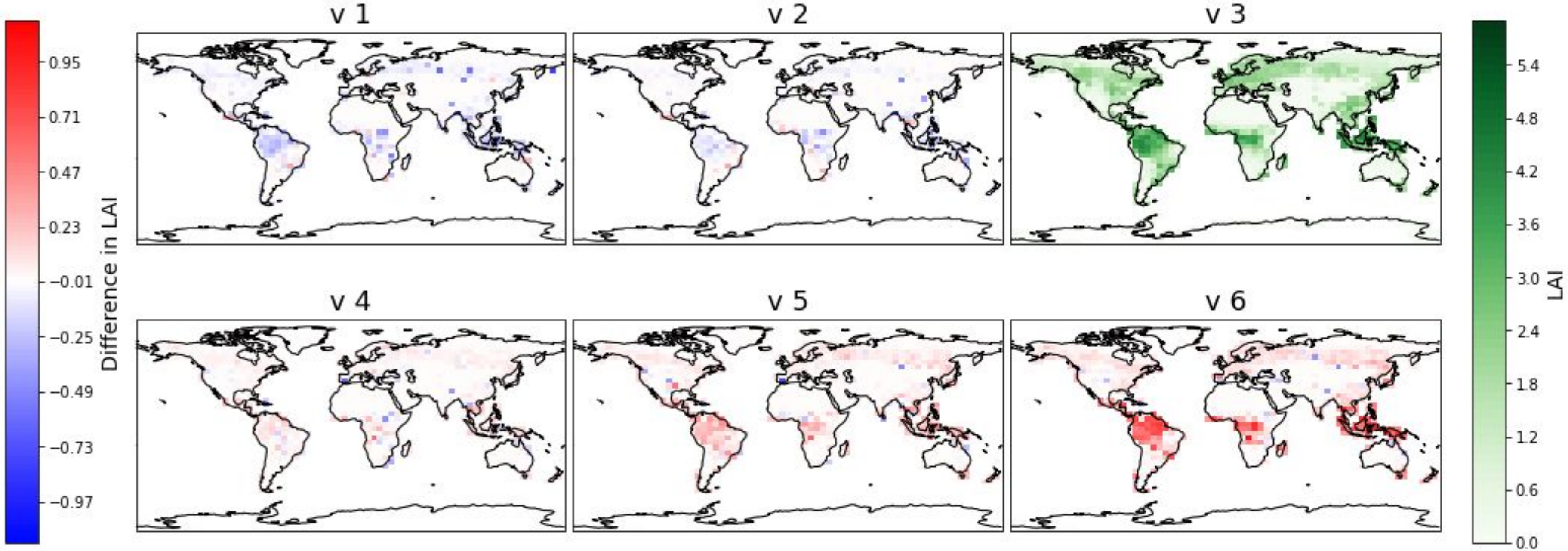
Default FATES: rdark decreases the same rate as photosynthesis

rdark decreases more than photosynthesis

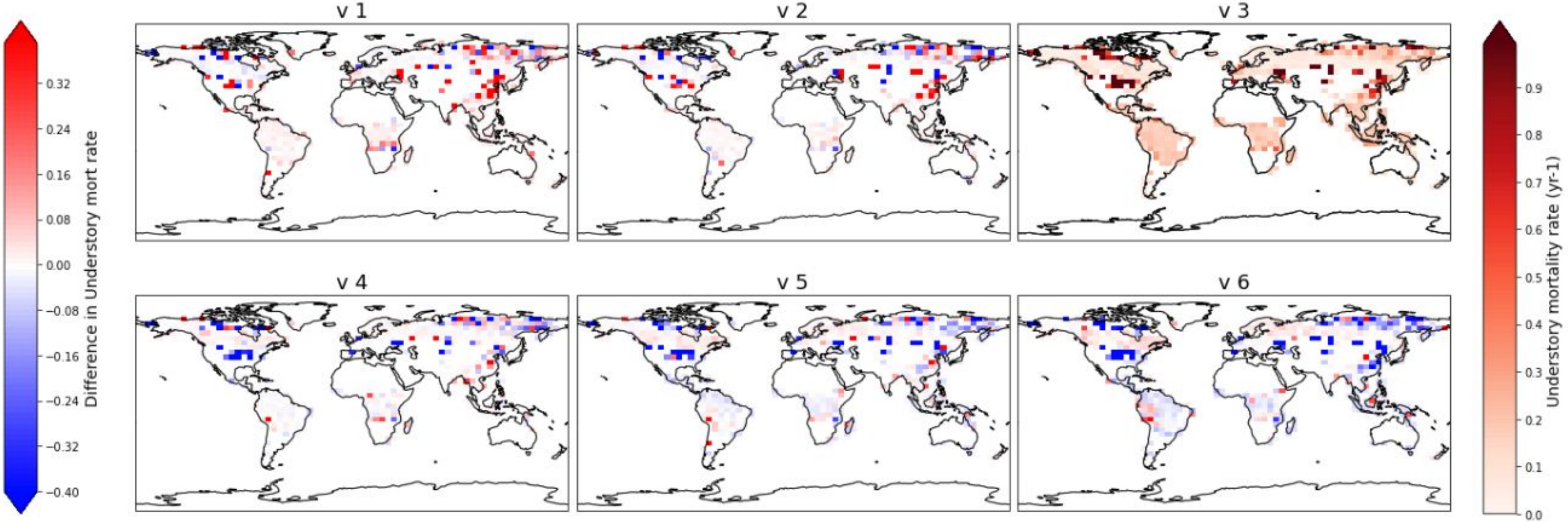
H1: Lower rdark in the understory increases LAI



Blue = lower LAI than default

Red = higher LAI than default

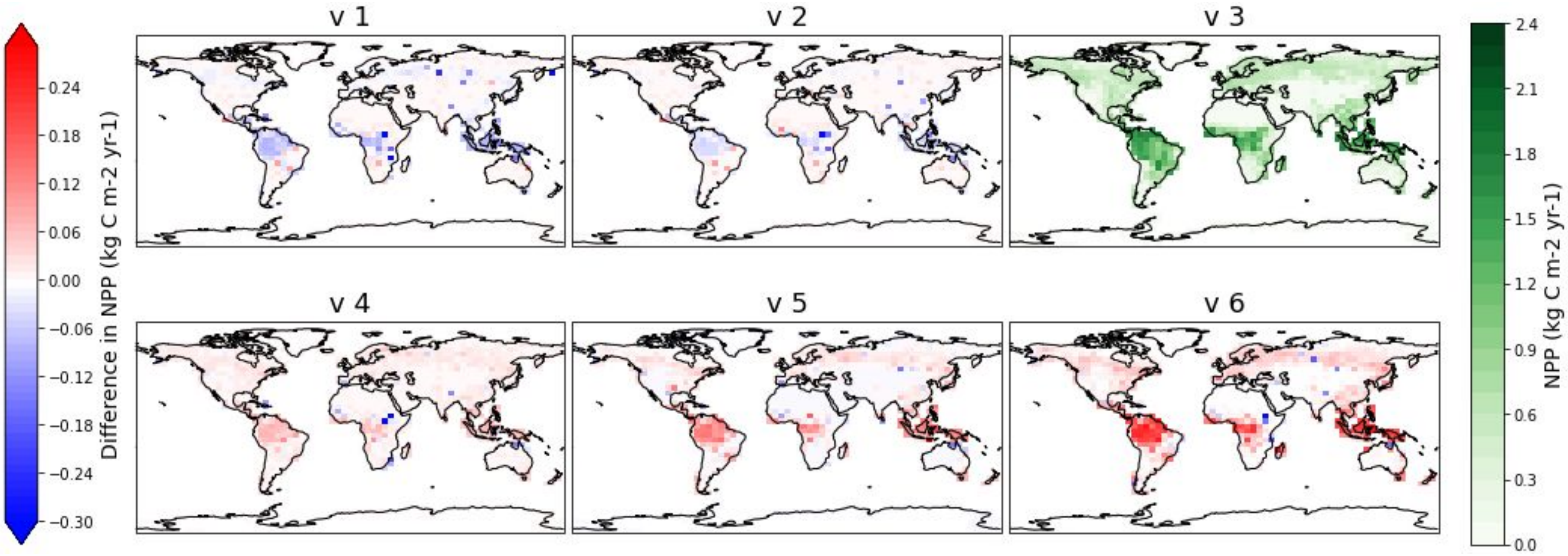
H2: Lower rdark in the understory decreases understory mortality (sort of)



Red = higher understory mortality than default

Blue = lower understory mortality than default

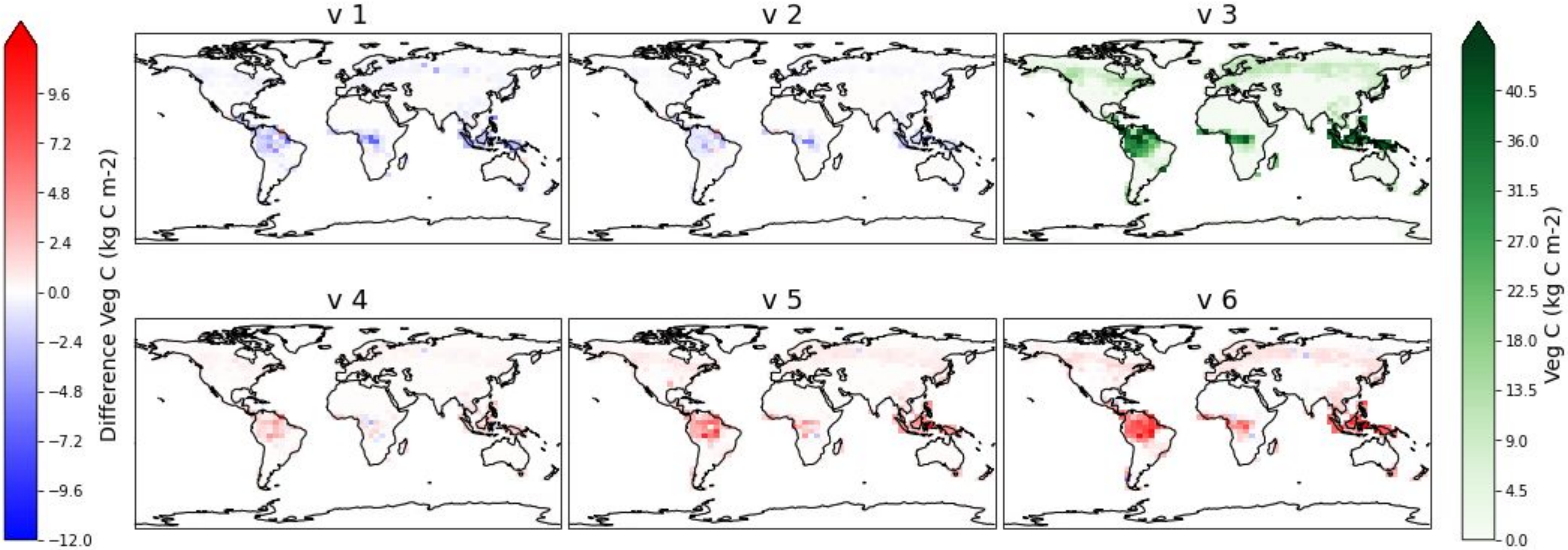
NPP increases with a decrease in understory rdark



Blue = lower NPP than default

Red = higher NPP than default

Vegetation carbon increases with a decrease in understory rdark

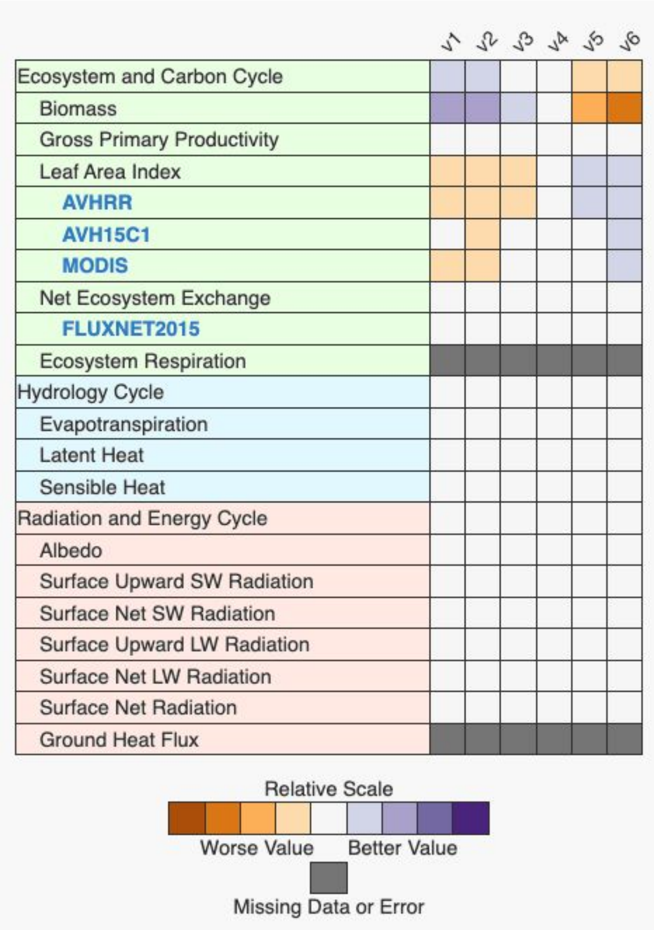


Blue = lower veg C than default

Red = higher veg C than default

Lower understory rdark improves the fit of FATES LAI to data

- ILAMB - model data comparison platform
- LAI improves with lower understory leaf MR



H3: Higher rdark in the understory is expected to favour light demanding PFTs

- Work by SULI intern Sharmila Dey

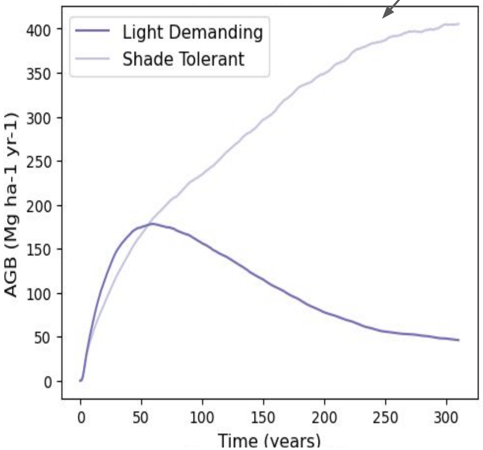
H3: Higher rdark in the understory is expected to favour light demanding PFTs

- Work by SULI intern Sharmila Dey
- Single site simulations at Barro Colorado Island, Panama
- Two PFTs - early and late successional
- Large ensemble to find a parameter set with some degree of coexistence
- Test alternative scaling schemes:
  - v1 = default
  - v2 = highest understory rdark
  - v3 = linear decrease in rdark (data from Lamour et al. 2023)

The vertical scaling of respiration reverses PFT dominance

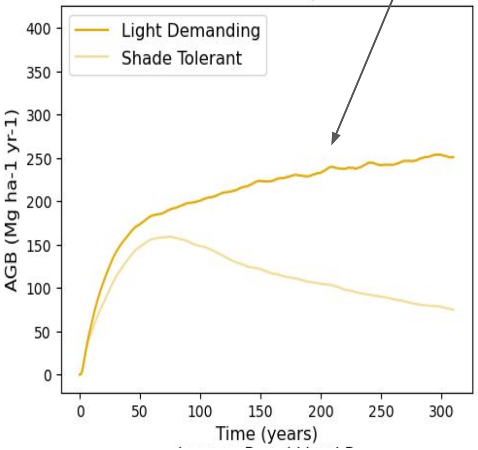
Shade tolerant dominates

v1



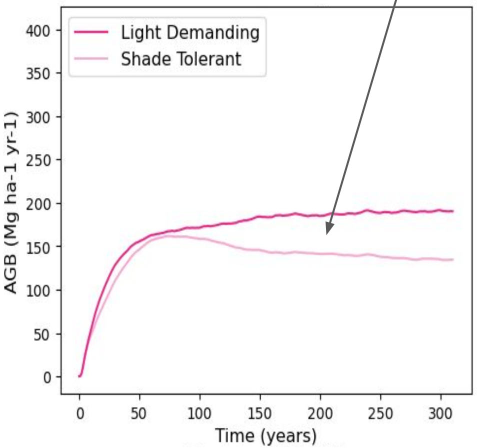
Light demanding dominates

v2



Coexistence

v3



Default FATES - lowest understory rdark

Highest understory rdark

Linear model - intermediate rdark

The vertical scaling of respiration reverses PFT dominance

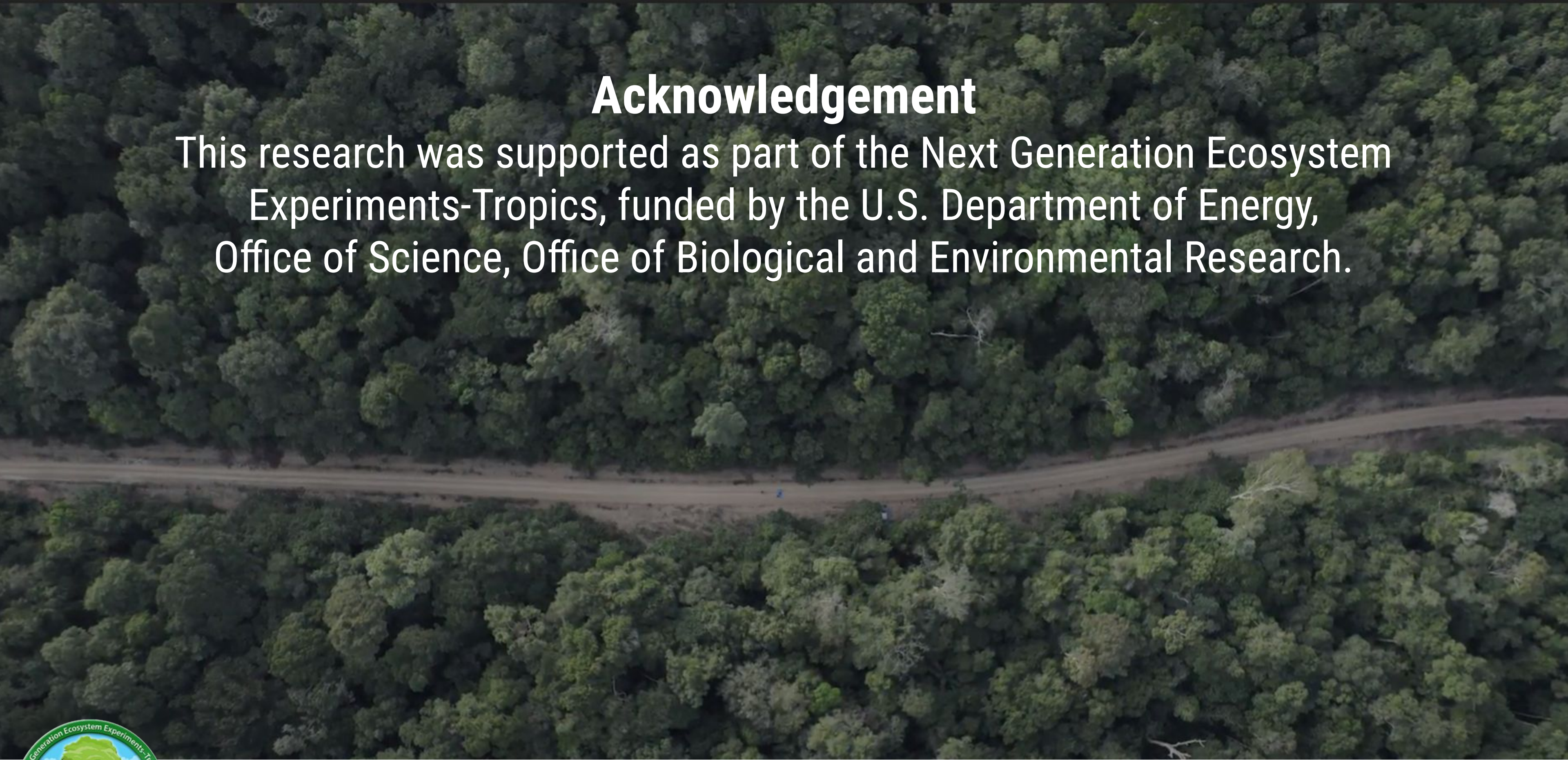
- H3 was supported - higher understory rdark lead to increased dominance of the light demanding PFT

The vertical scaling of respiration reverses PFT dominance

- H3 was supported - higher understory rdark lead to increased dominance of the light demanding PFT
- Caveats - these results are highly sensitive to parameterisation of PFTs
- Repeat with alternative parameterisations to show uncertainty

Summary

- Vertical scaling of rdark has a big impact on vegetation dynamics through its control on individual tree carbon budgets
- Low rdark in the understory leads to lower understory mortality and higher LAI
- Low rdark in the understory favours shade tolerant PFTs but changes to coexistence in response to vertical scaling are sensitive to parameterisation



Acknowledgement

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