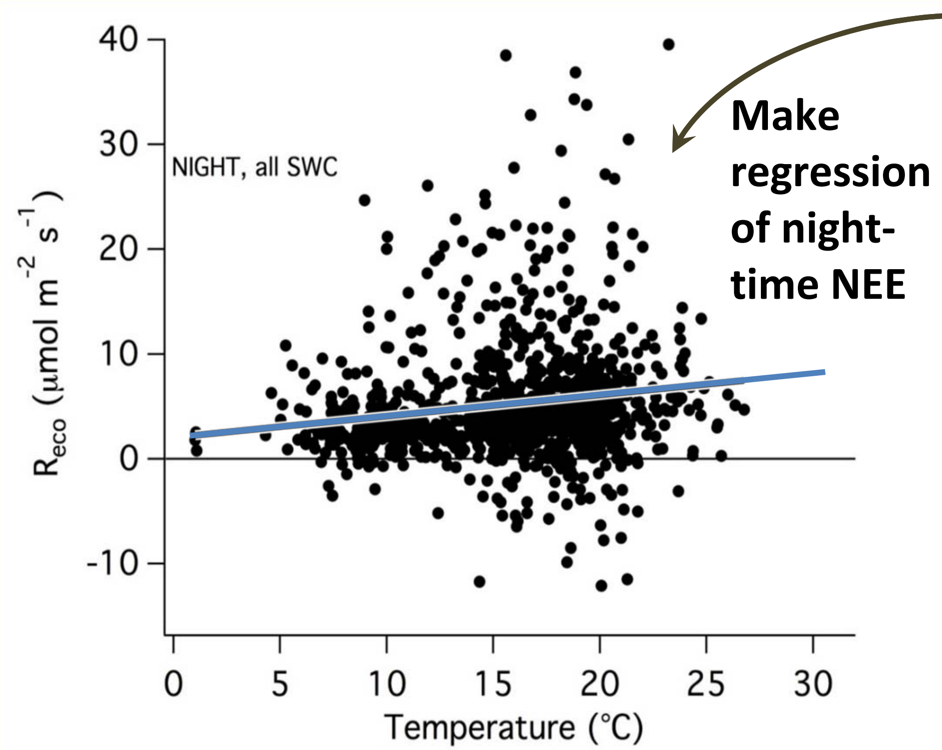
ECOSYSTEM-scale PROBLEM: *What is GPP?*

Standard Solution (Reichstein et al., 2005):
(1) DER = nighttime NEE regressed vs. Temperature

EDDY COVARIANCE FROM FLUX TOWERS OBSERVES NET ECOSYSTEM-ATMOSPHERE CO_2 EXCHANGE (**NEE**)

We want ***photosynthesis*** (Gross primary production, or **GPP**) and ***Daytime Ecosystem Respiration*** (**DER**)



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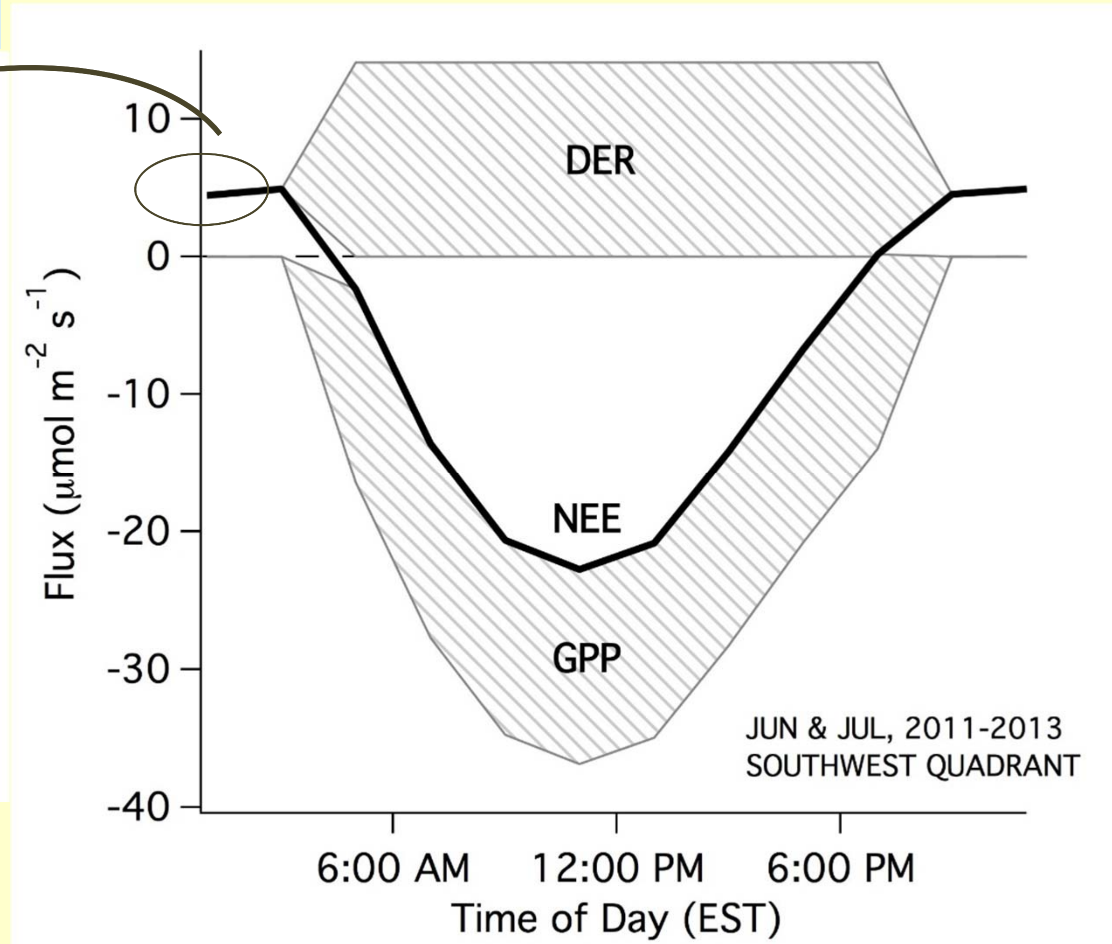

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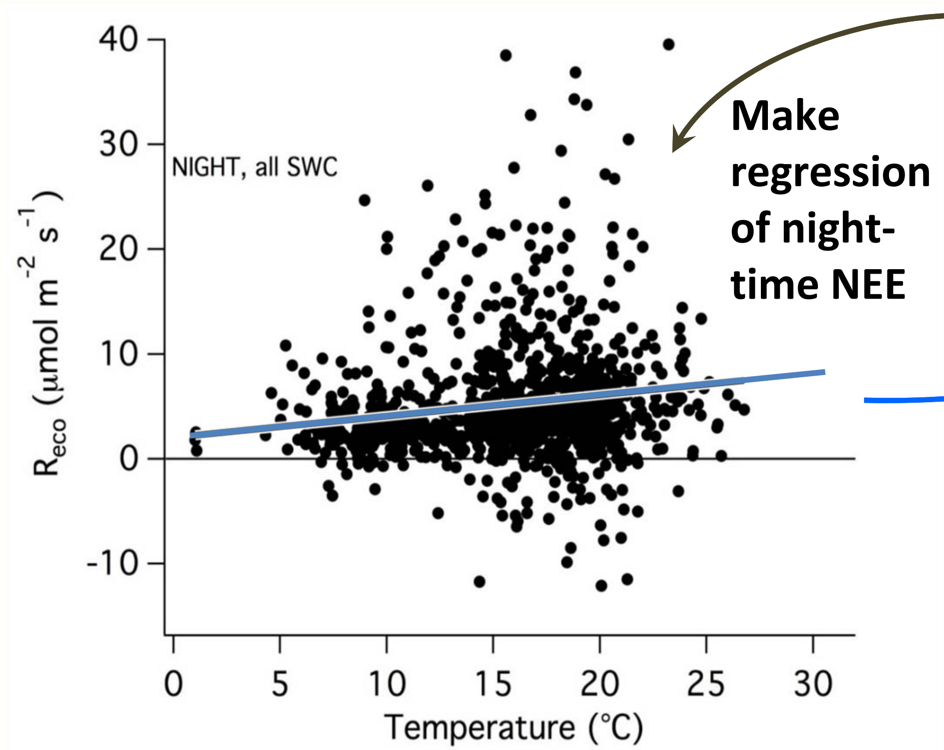

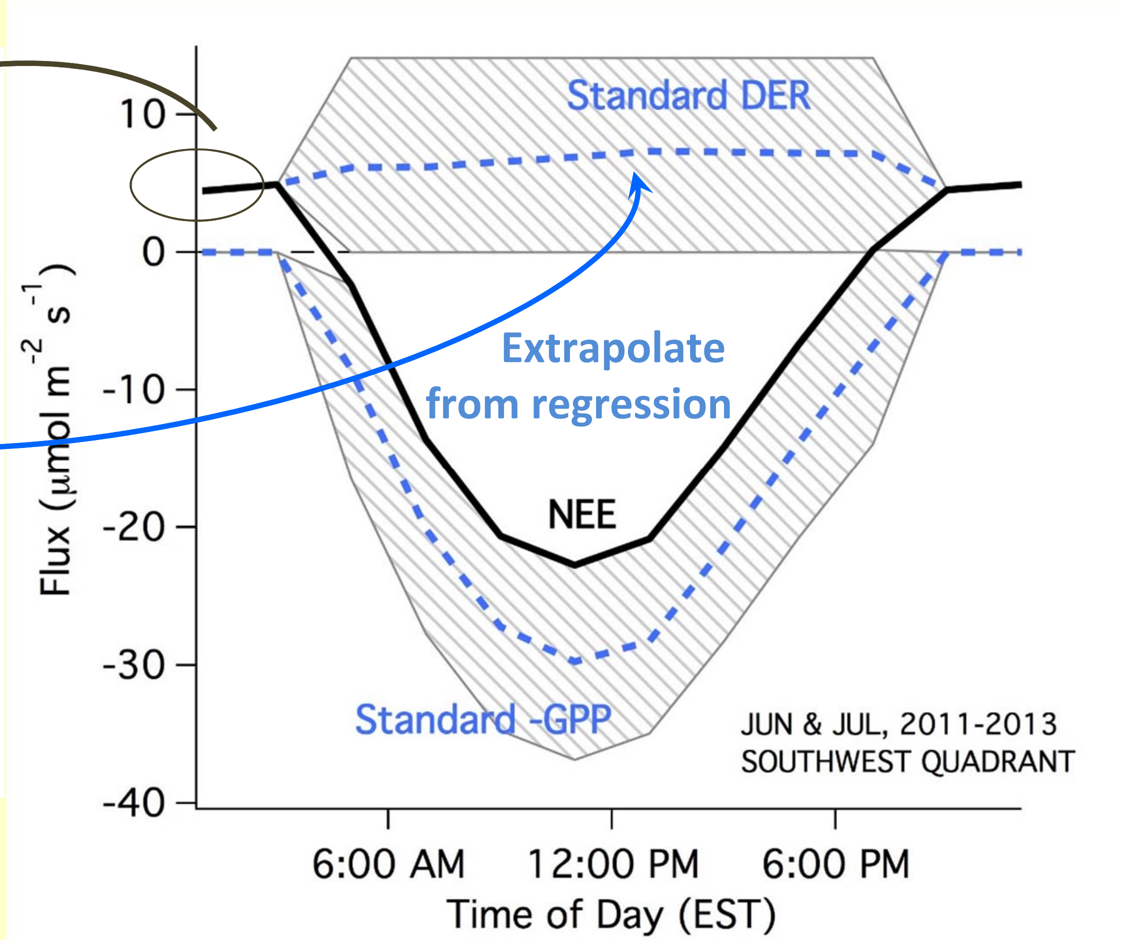

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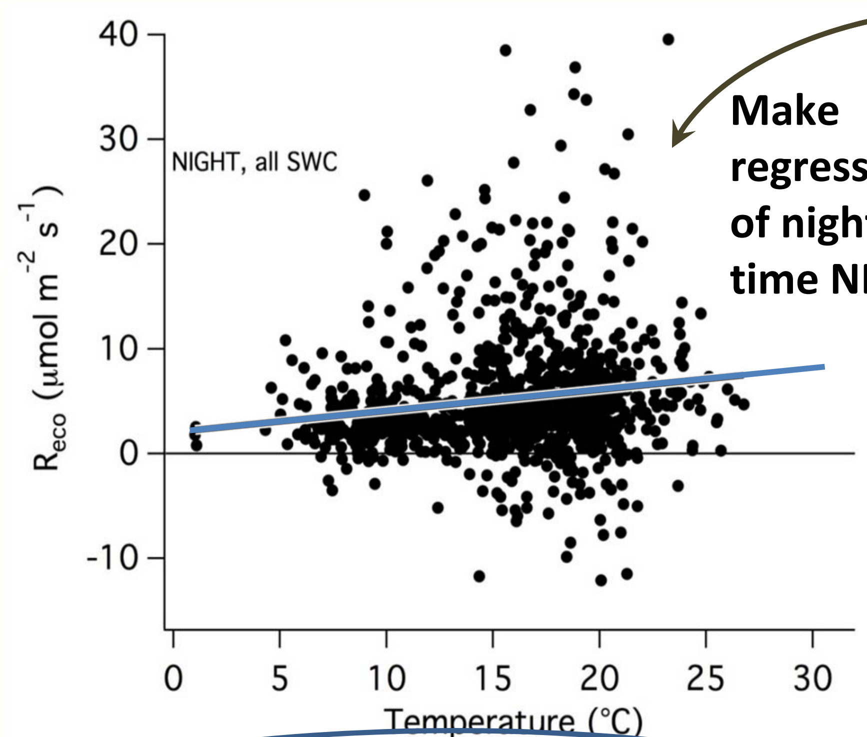

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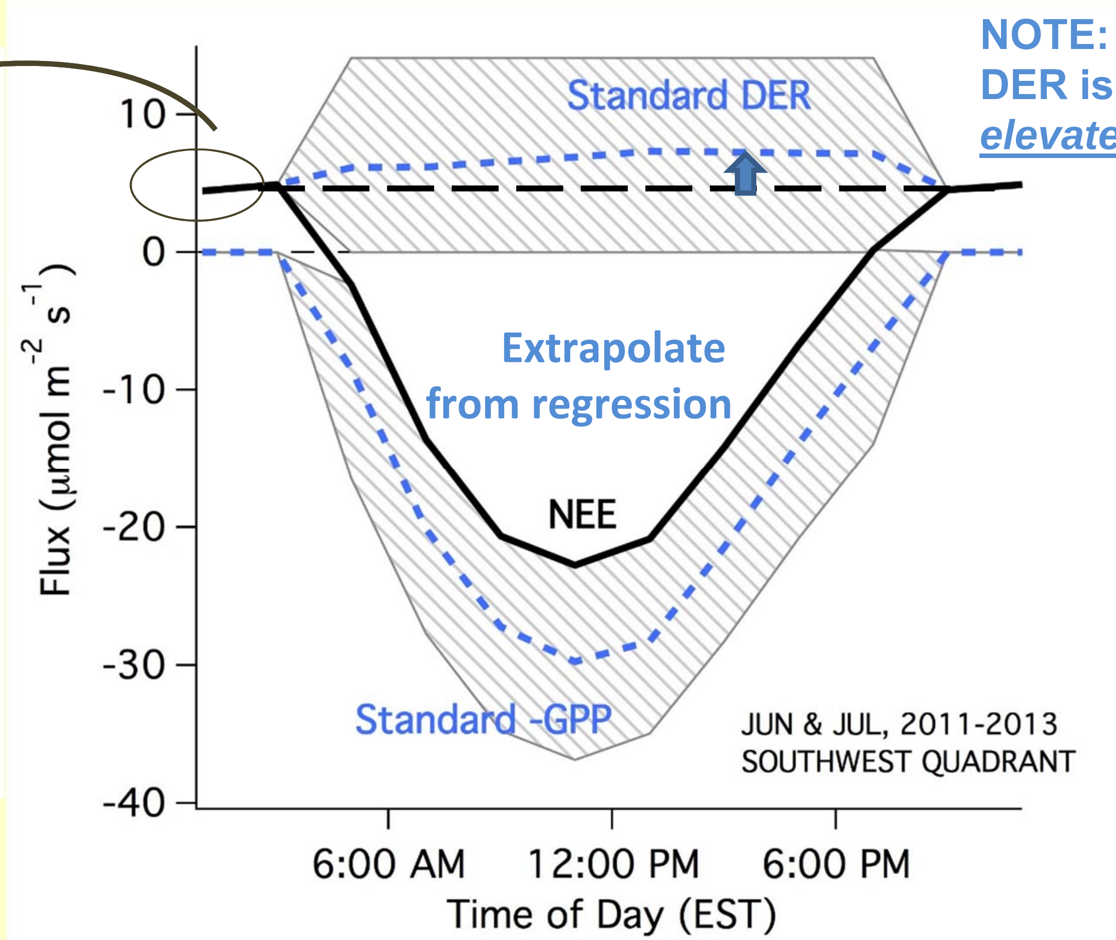

Key Assumption: Daytime physiology is like the nighttime

Alternative: Isotopic Scaling/Partitioning

One equations in two unknowns (GPP & R_{eco})

$$NEE = \underline{GPP} + \underline{R_{eco}}$$

Key: we need a second equation

Alternative: Isotopic Scaling/Partitioning

Two equations in two unknowns (GPP & R_{eco})

$$\mathrm{NEE} = \mathrm{GPP} + \mathrm{R}_{\mathrm{eco}}$$

Key: Adding this second equation:

$$\delta^{13}_{\mathrm{NEE}}\mathrm{NEE} = \delta^{13}_{\mathrm{GPP}}\mathrm{GPP} + \delta^{13}_{R}\mathrm{R}_{\mathrm{eco}}$$

Flux-weighted *Isotopic composition* of:

Net flux

photosynthetic flux

Respiration flux

$$\delta^{13}_{X} = \frac{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)_X}{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)_{\mathrm{ref}}} - 1$$

δ^{13} is ^{13}C content of sample relative to a standard

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works by solving for **GPP** and **DER (R_{eco} during the day),** given distinct stable isotopic signatures, δ^{13}

Yakir & Wang 1996, Bowling et al. 2001, …

$$\delta^{13}_X = \frac{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)_X}{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)_{\mathrm{ref}}} - 1$$

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Alternative: Isotopic Scaling/Partitioning

Two equations in two unknowns (GPP & R_{eco})

Requires:

(1) δ^{13}_{NEE} to be measureable

$$\mathrm{NEE} = \mathrm{GPP} + \mathrm{R_{eco}}$$

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Via eddy flux

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Alternative: Isotopic Scaling/Partitioning

Two equations in two unknowns (GPP & R_{eco})

Requires:

(1) δ^{13}_{NEE} to be measureable

(2) δ^{13}_{GPP} to be different from δ^{13}_{R}

$$\mathrm{NEE} = \mathrm{GPP} + \mathrm{R_{eco}}$$

$$\delta^{13}_{\mathrm{NEE}}\mathrm{NEE} = \delta^{13}_{\mathrm{GPP}}\mathrm{GPP} + \delta^{13}_{R}\mathrm{R_{eco}}$$

Via eddy flux

Via nighttime

We measure the isotopic composition of respiration at night (using Keeling plots)

$$\delta^{13}_{X} = \frac{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)_X}{\left({}^{13}\mathrm{C}/{}^{12}\mathrm{C}\right)_{\mathrm{ref}}} - 1$$

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Via eddy flux

Via nighttime

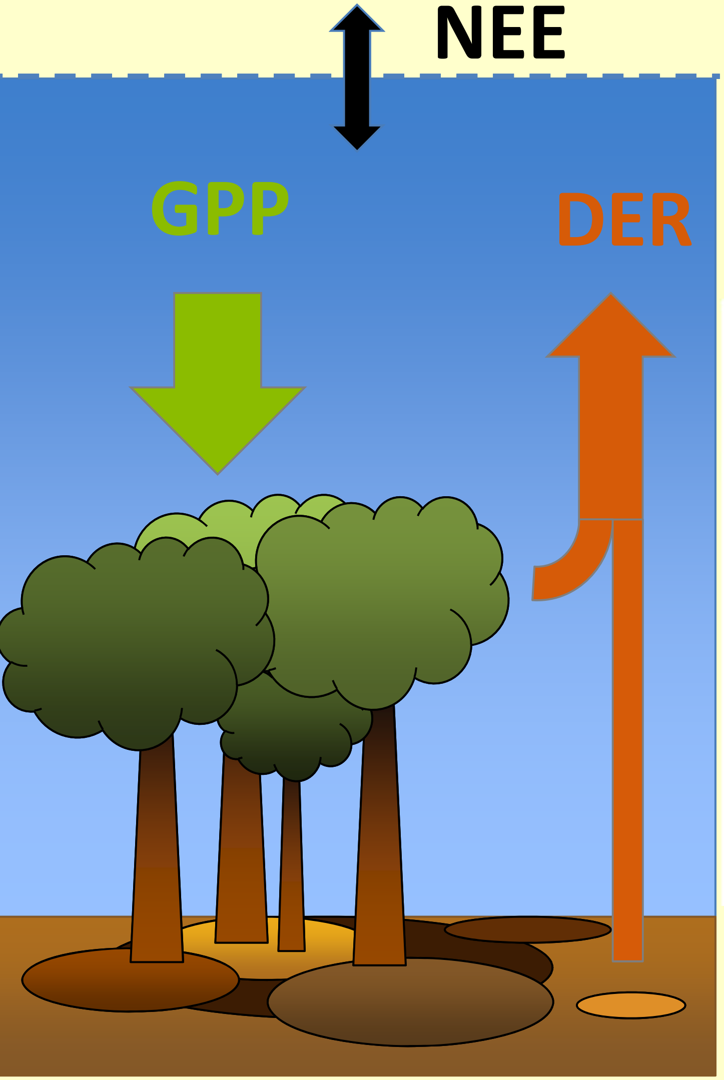
Approach – scaling leaf physiology to the canopy:

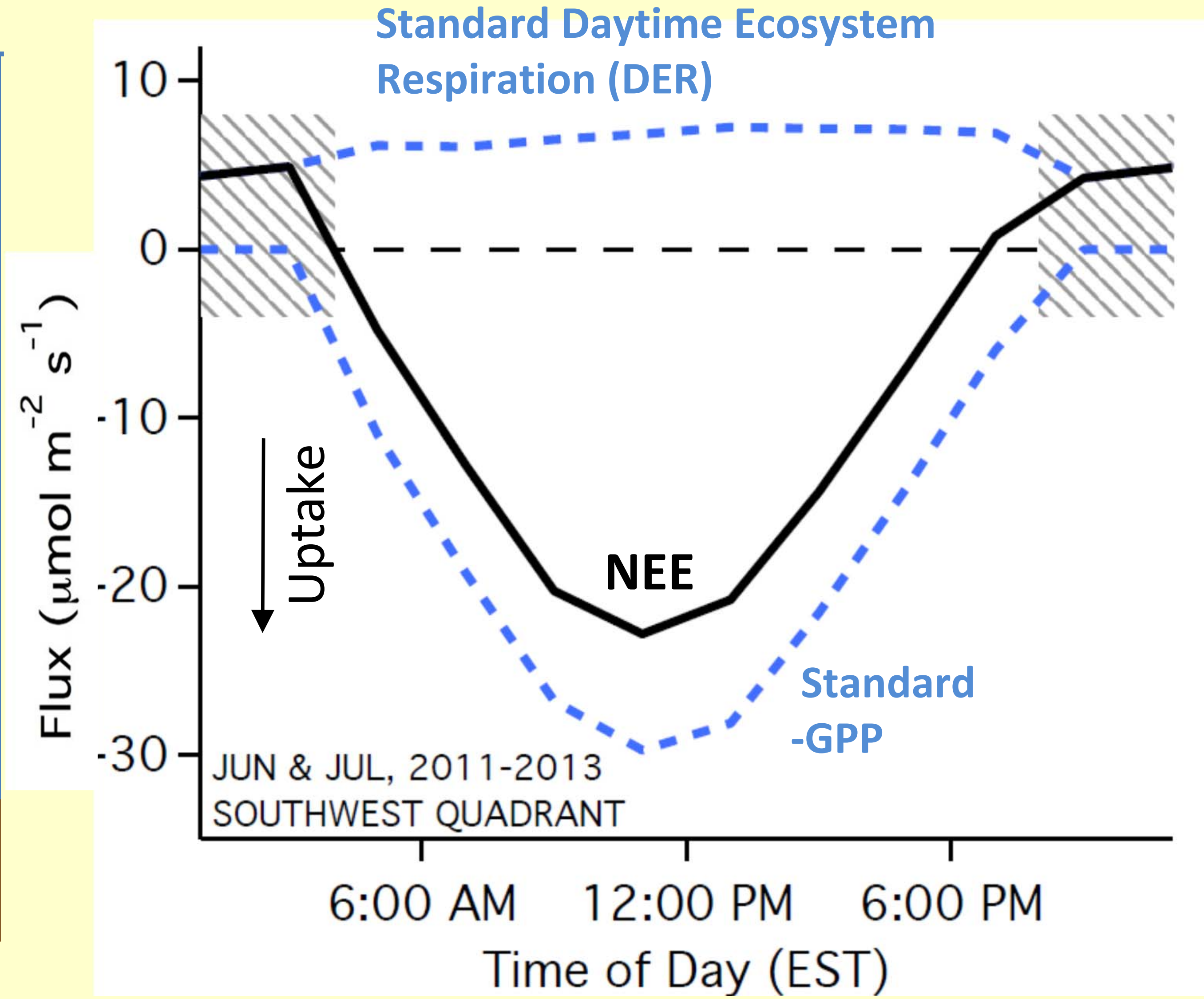
(1) *leaf-scale* knowledge of physiology to constrain *ecosystem-scale* iso-flux of GPP (depends on canopy-scale stomatal conductance)

→ (Farquhar et al. 1982 theory for leaf-scale photosynthetic discrimination)

(2) Diffusion laws and ecosystem heat and water fluxes to constrain *canopy scale stomatal conductance* -- – now validated with **flux measurements of carbonyl sulfide (OCS)** (Wehr, Commane et al. 2017)

KEY RESULT: suppression of *DER* in light (& lower *GPP*)





Wehr et al.

30 JUNE 2016 | VOL 534 | NATURE

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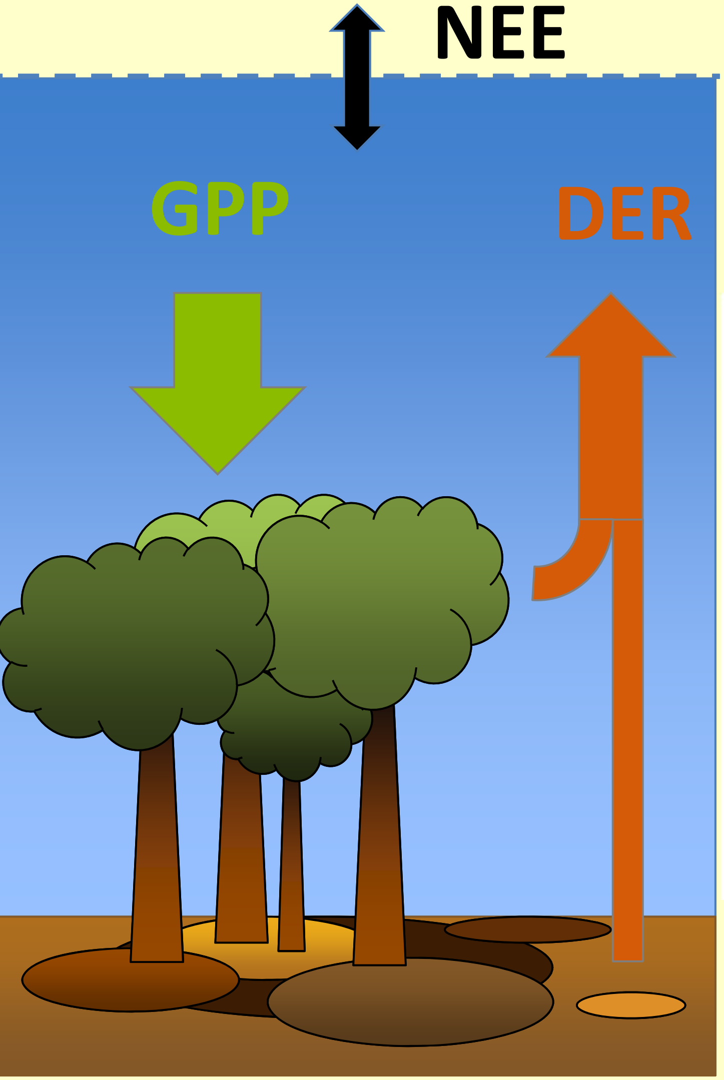

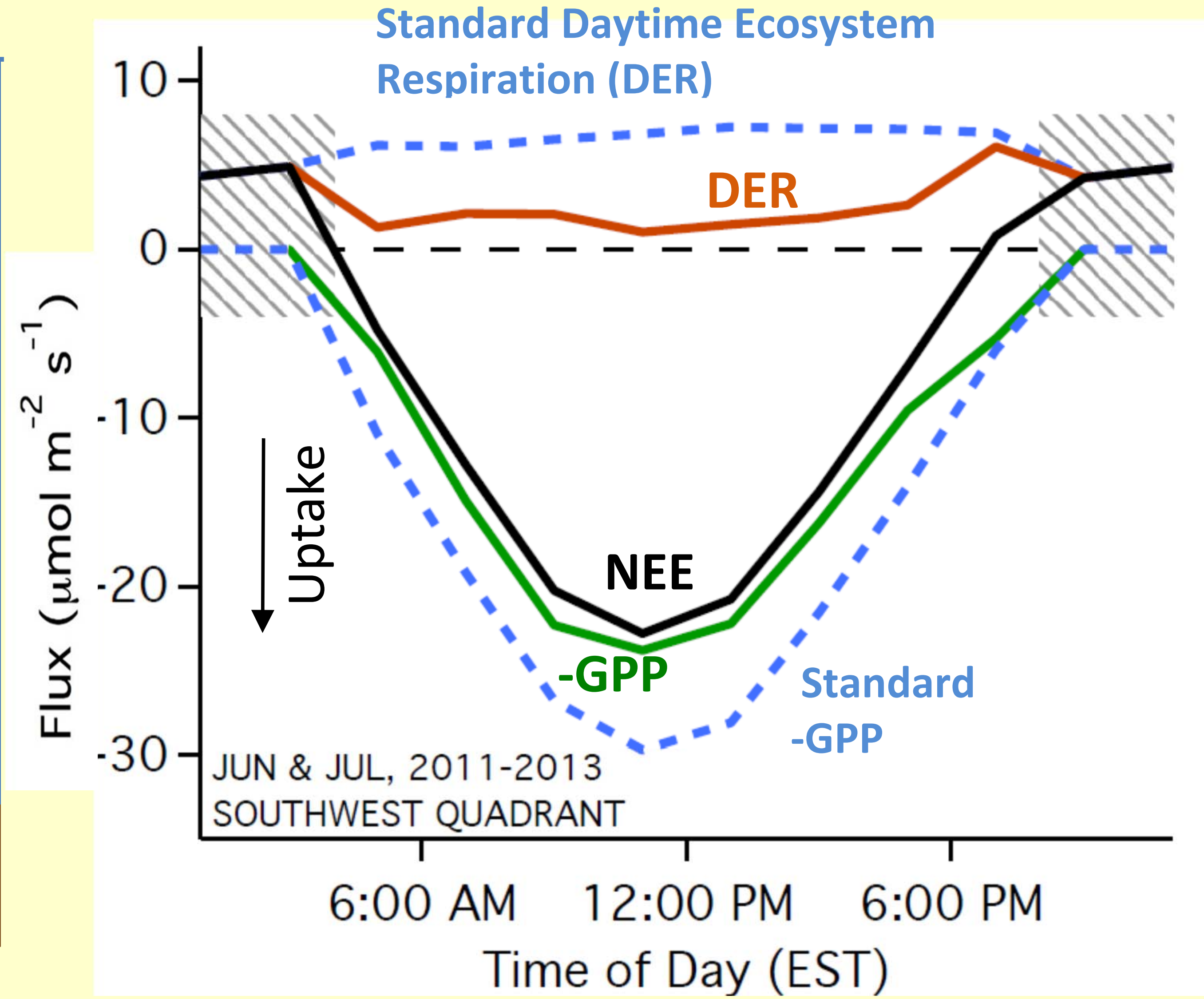

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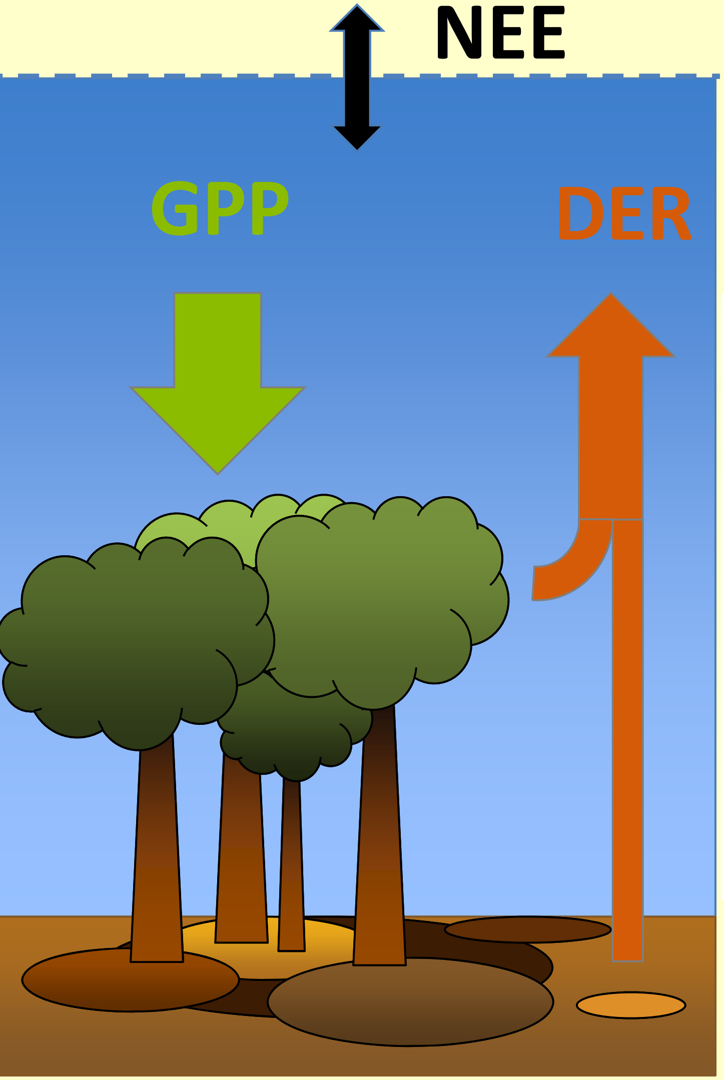

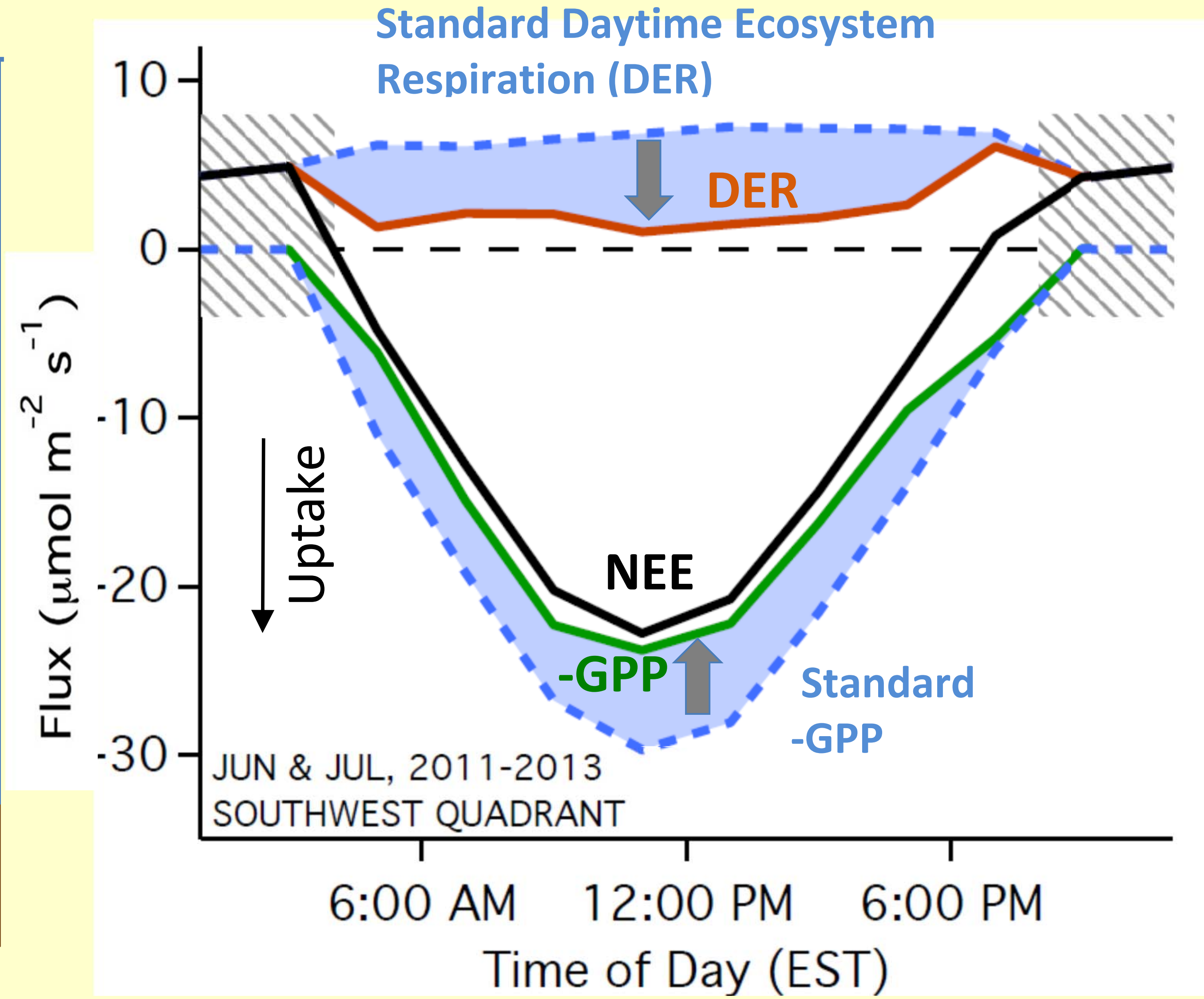

Wehr et al.

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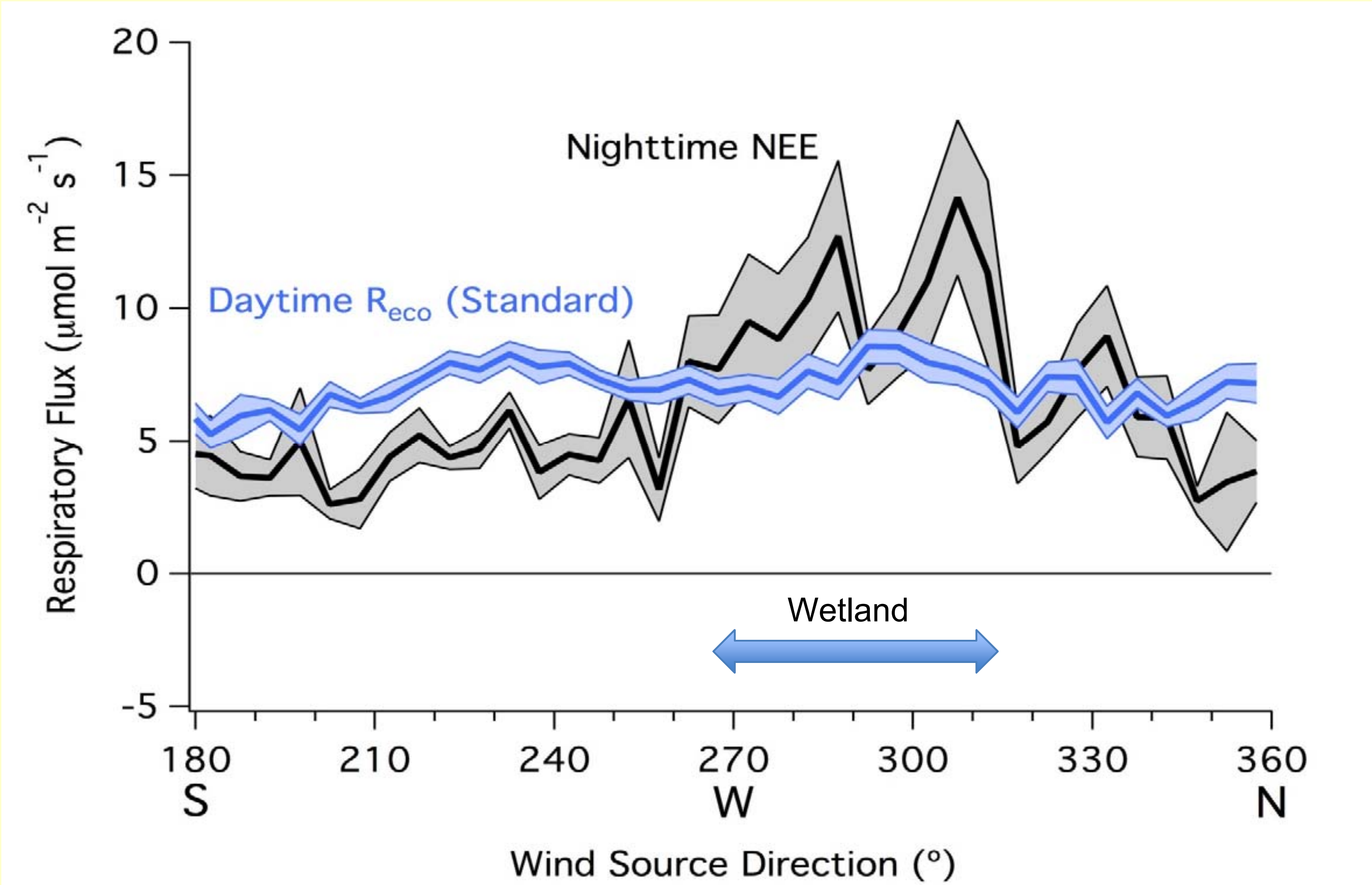
WARNING! Forest Heterogeneity

Seen in nighttime NEE



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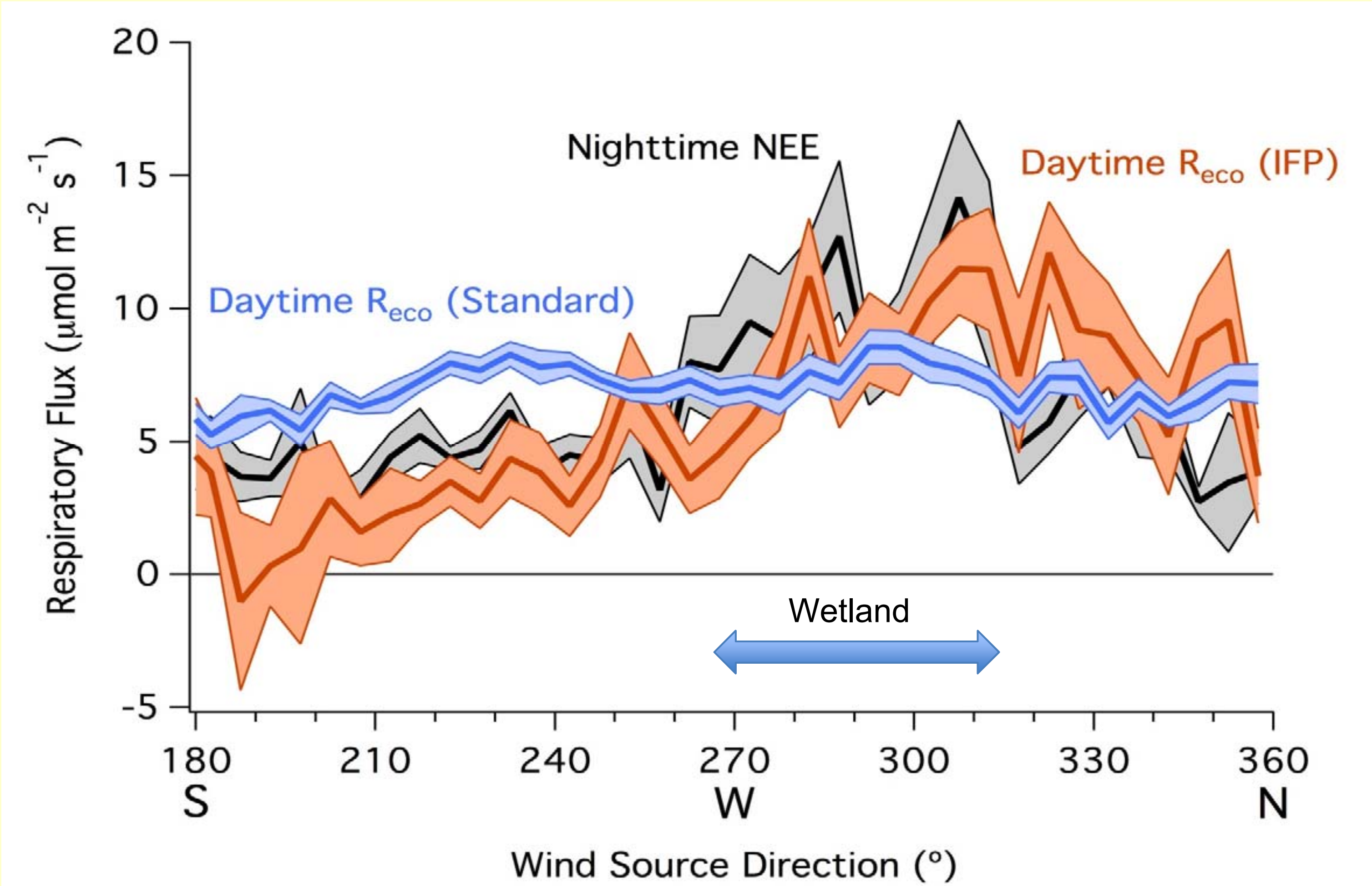

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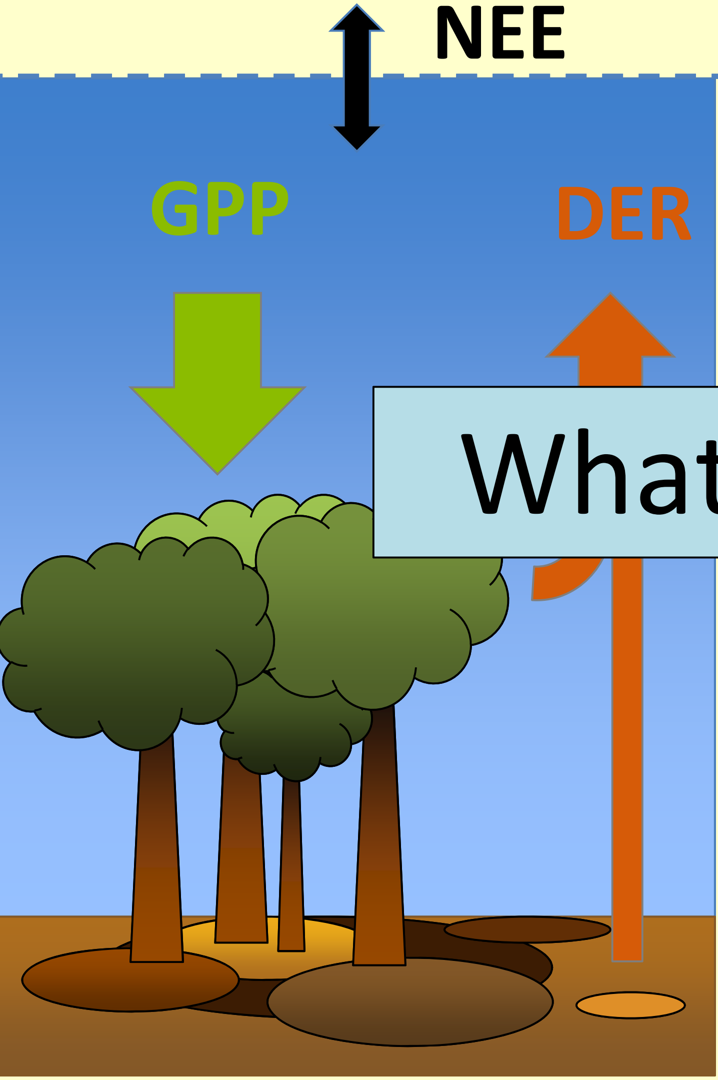

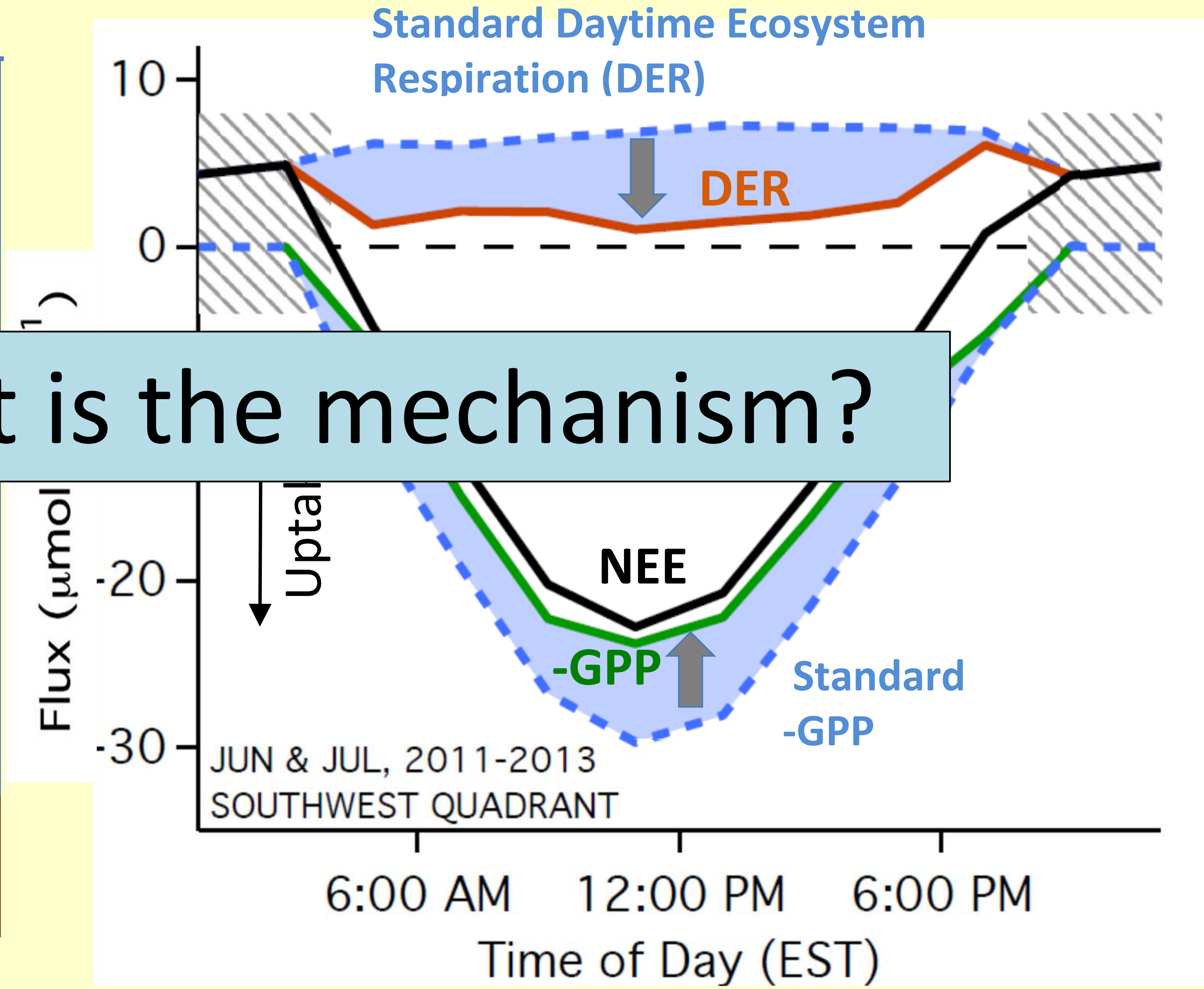

What is the mechanism?

Wehr et al.

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First detected ecosystem manifestation of the leaf-level 'Kok effect' – inhibition of respiration by light?

VOL. 3 (1949) BIOCHIMICA ET BIOPHYSICA ACTA 625

ON THE INTERRELATION OF RESPIRATION AND PHOTOSYNTHESIS IN GREEN PLANTS

by

B. KOK

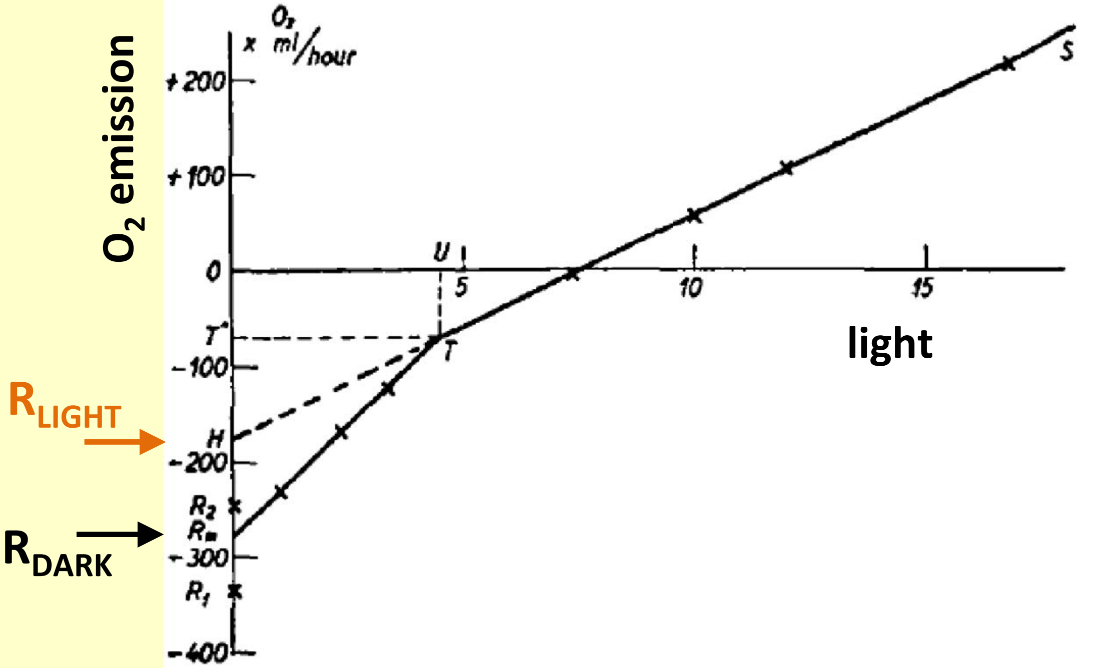

Fig. 3. *Chlorella*, grown in Knop solution + 100 mg glucose per L, during 3 days. Exp. 26-2-48.

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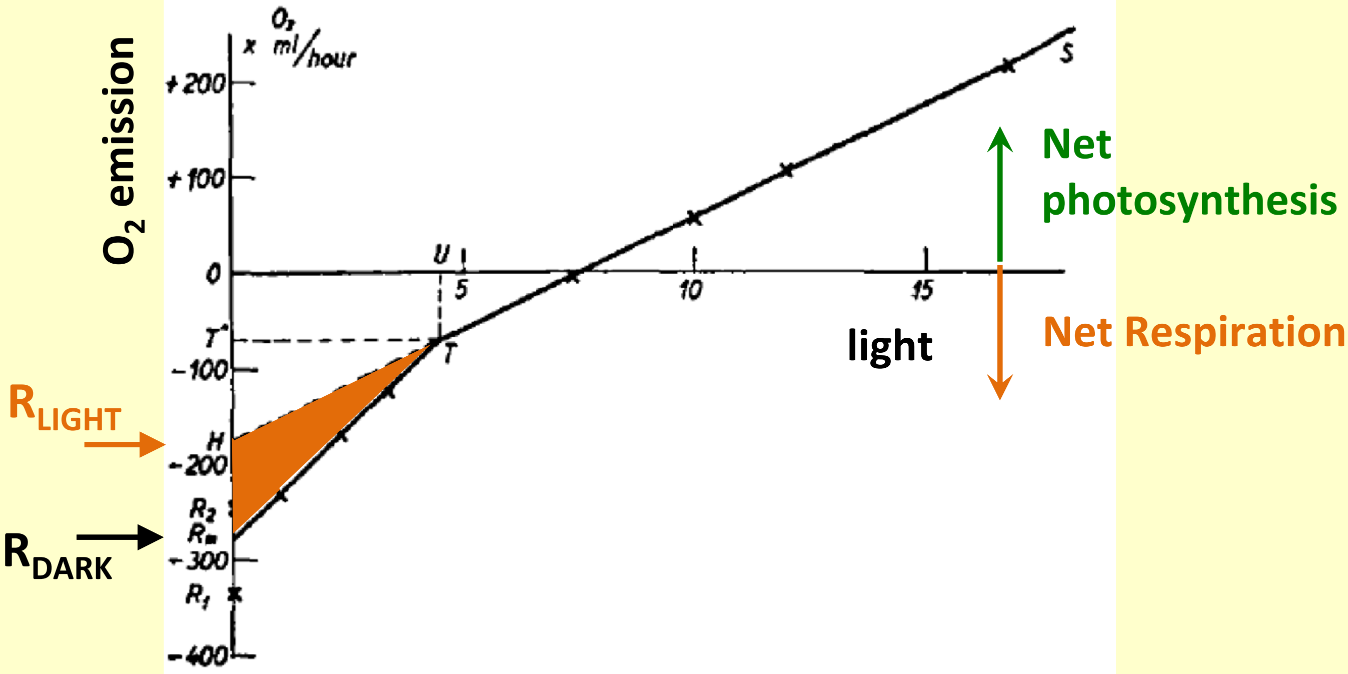

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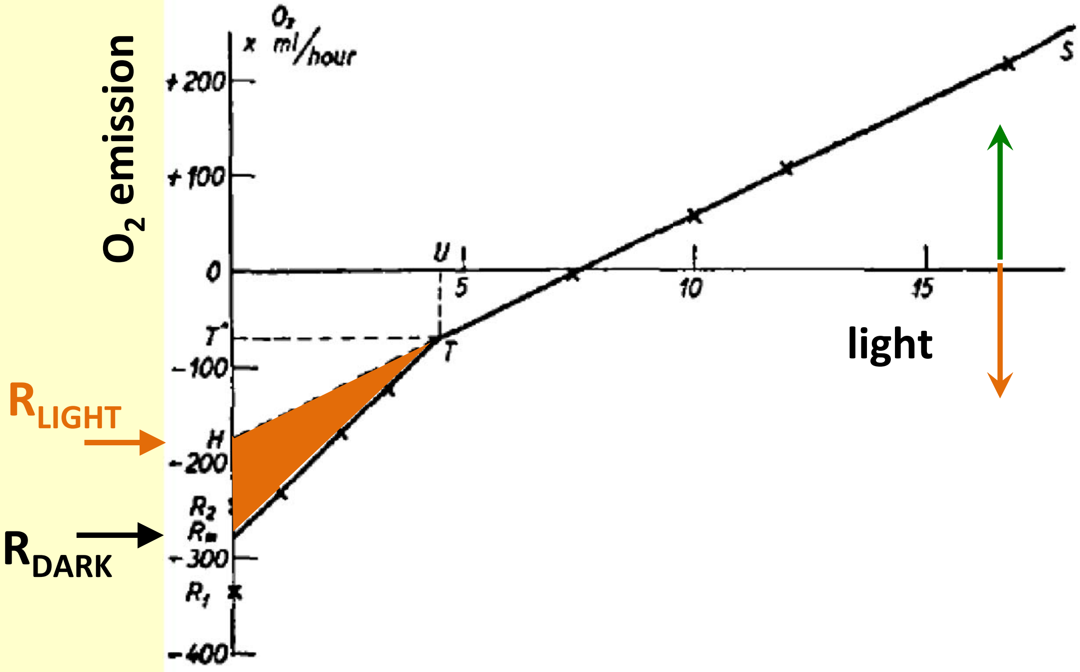

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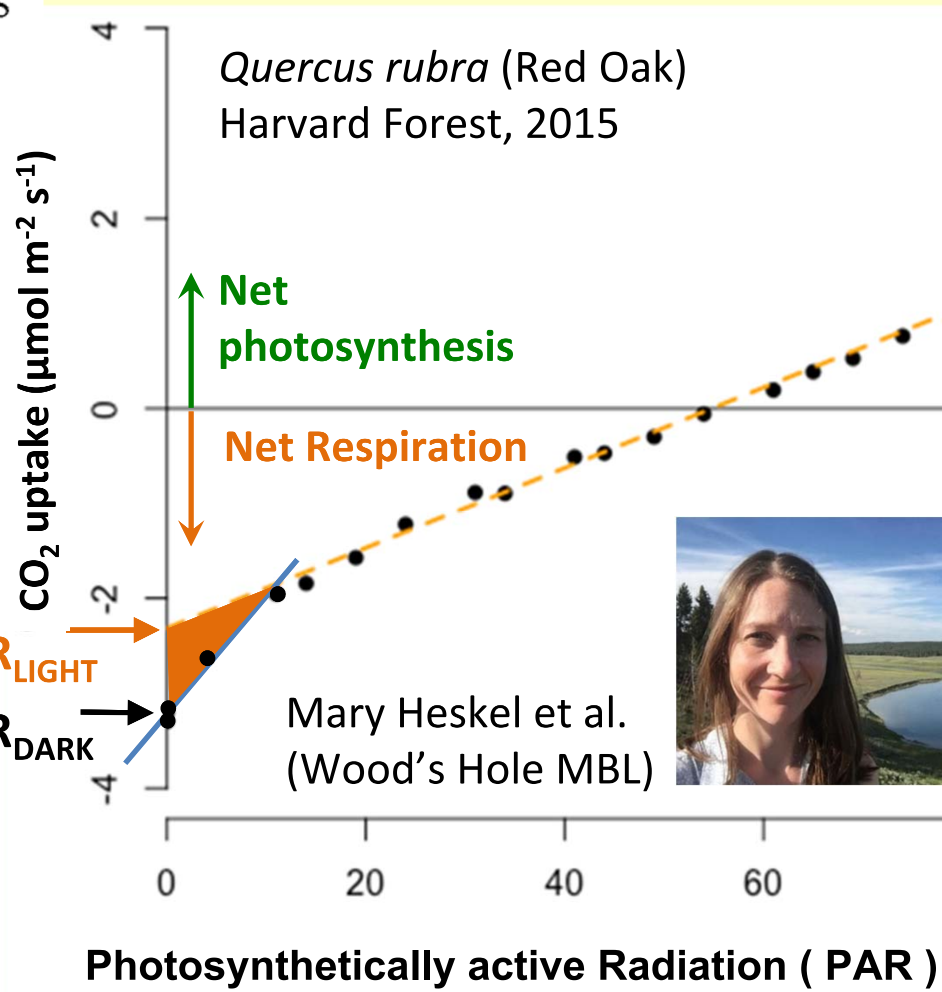
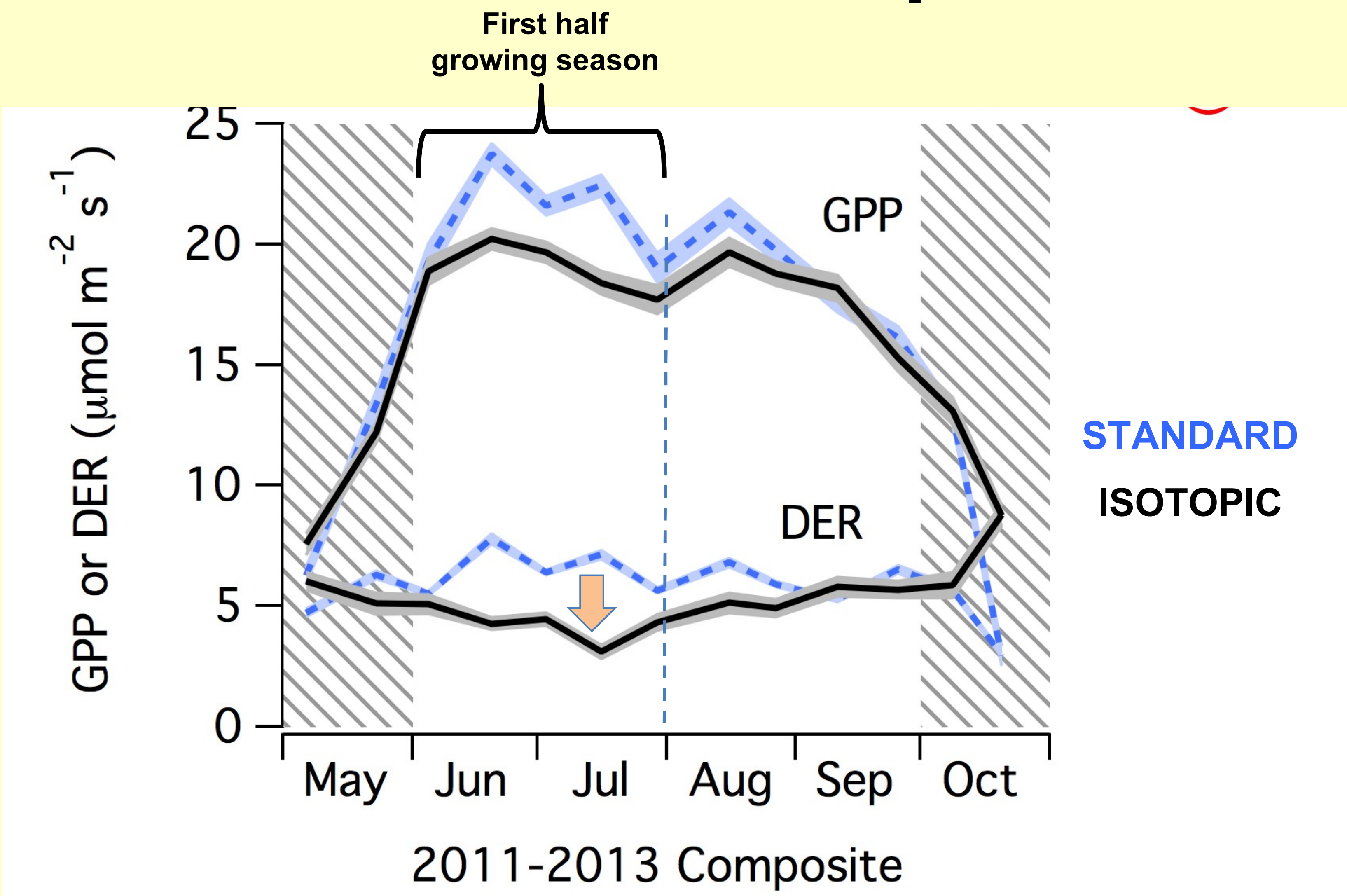


Slide 18

3 graph is getting out of the slide
Flavia Costa,

RESULT 2: Seasonal pattern



Wehr et al, 2016, *Nature*

Implications for Light-Use Efficiency (LUE) and Water Use Efficiency (WUE)

LUE important for estimating GPP from remote sensing:

GPP = PAR · *f*APAR · LUE

→ LUE = GPP / (APAR) (derived at eddy sites)

WUE important indicator of future C-water coupling:

$WUE_{intrinsic}$ = (GPP / Transp) · Δw = GPP / G_s

(adjusted for water vapor deficit)

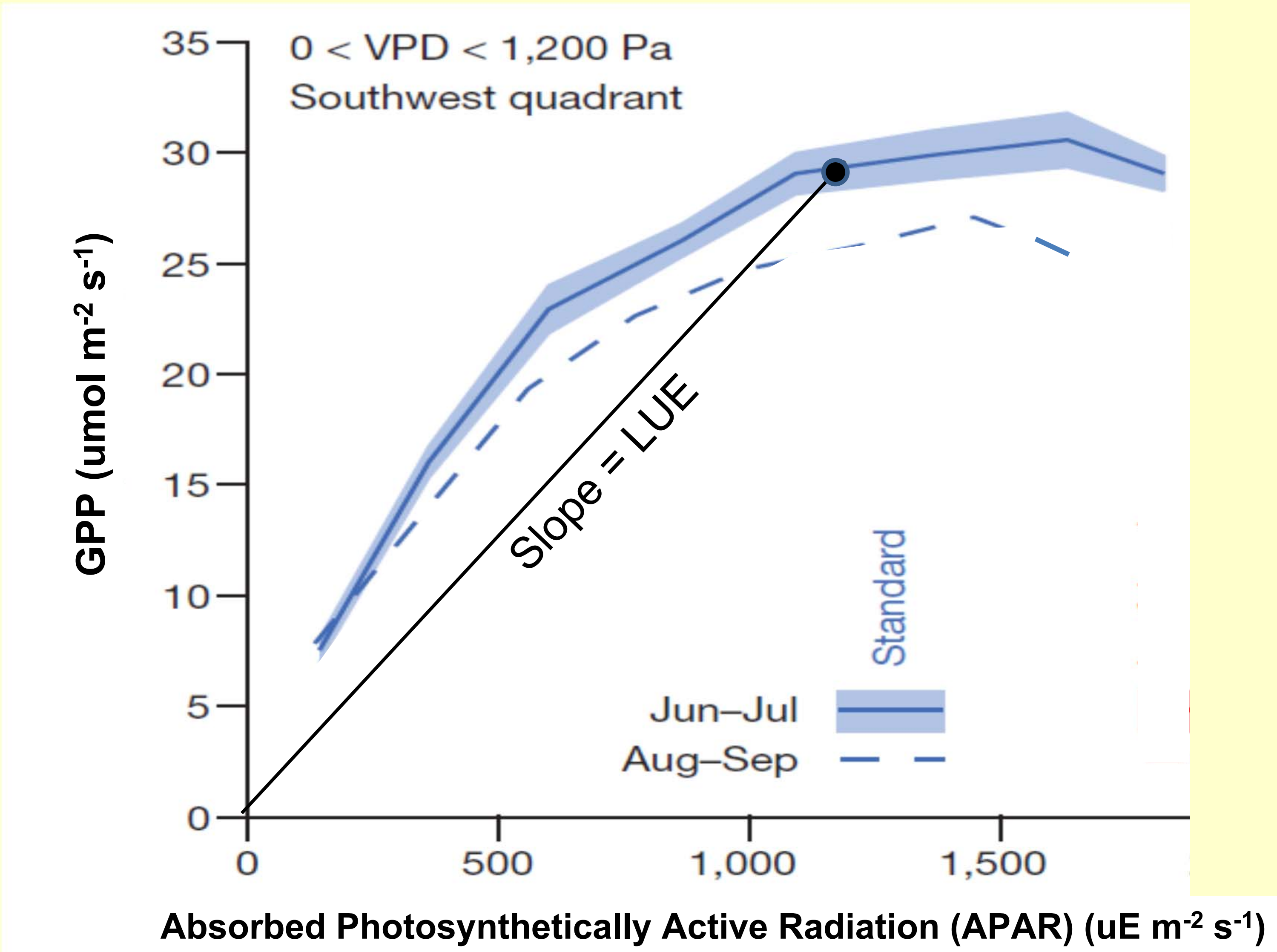
Important controversy about WUE trends (expected to increase with rising CO2):

+2.7%/yr (eddy flux network) vs +0.5%/yr (tree ring isotopes)

(Keenan et al. 2013) (Frank et al. 2015)

→ and atmospheric 13C? (Keeling... Sing, et al. 2017)

HF RESULTS: Seasonal Patterns



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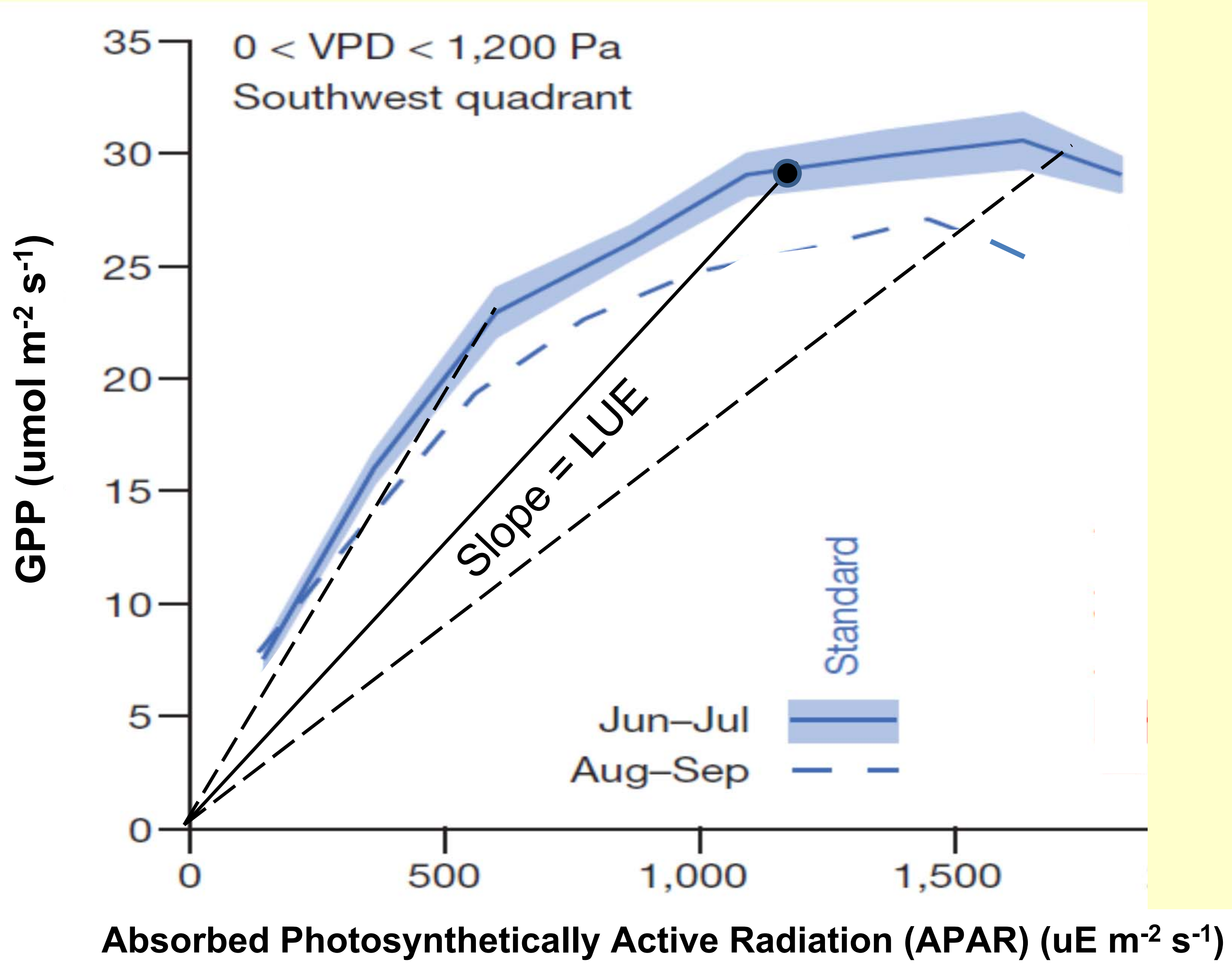

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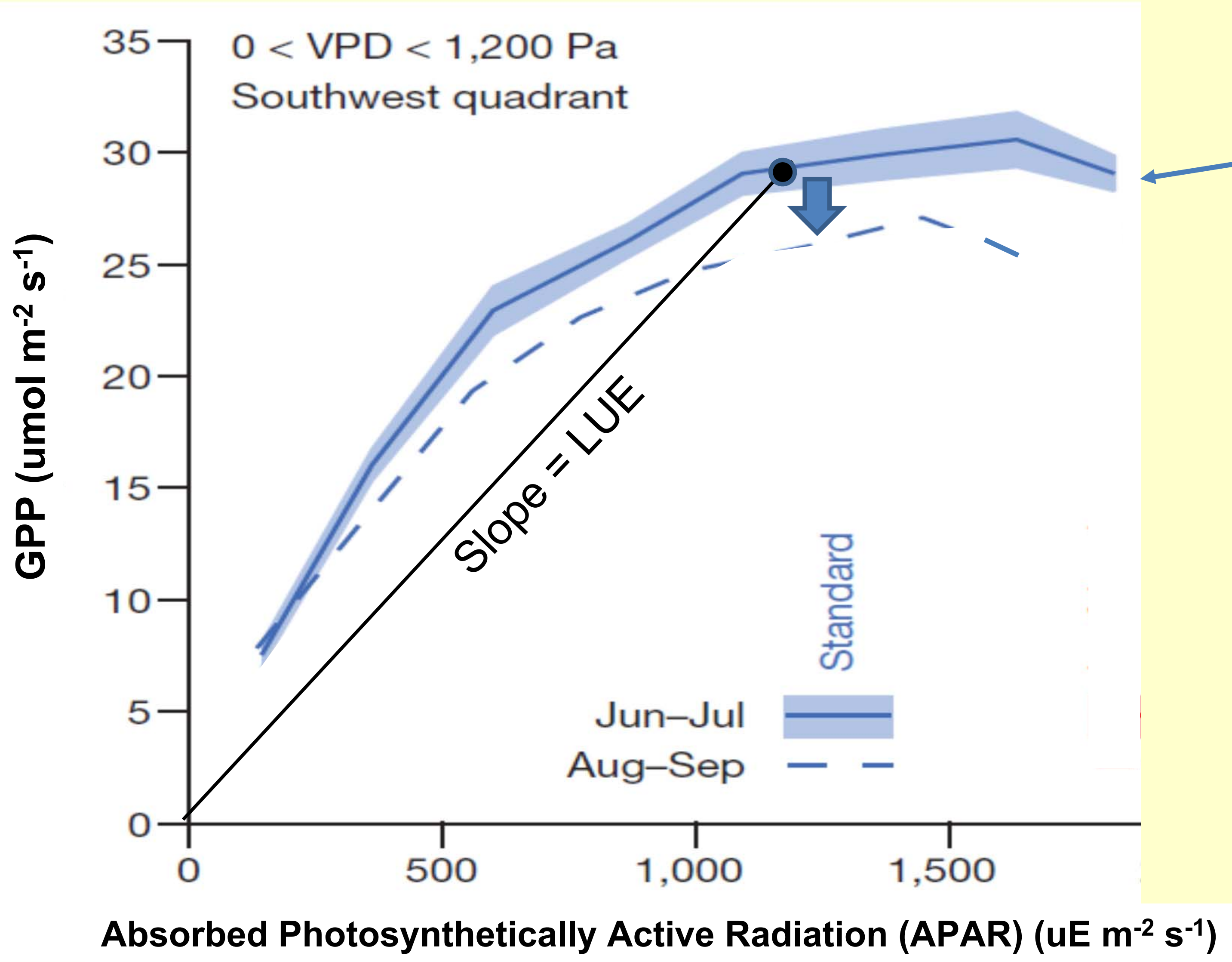
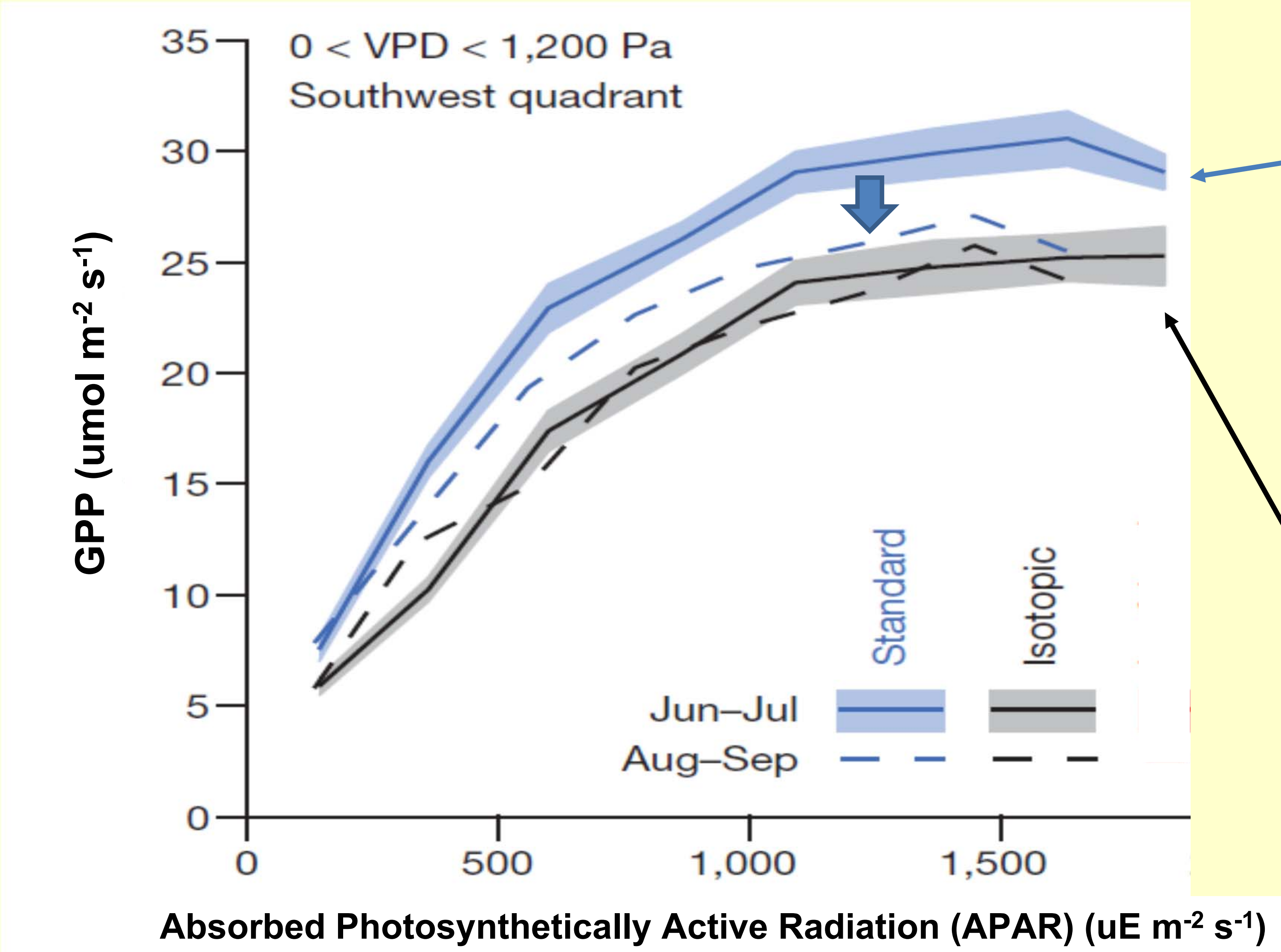


Standard partitioning shows declining photosynthetic capacity over the season

HF RESULTS: Seasonal Patterns



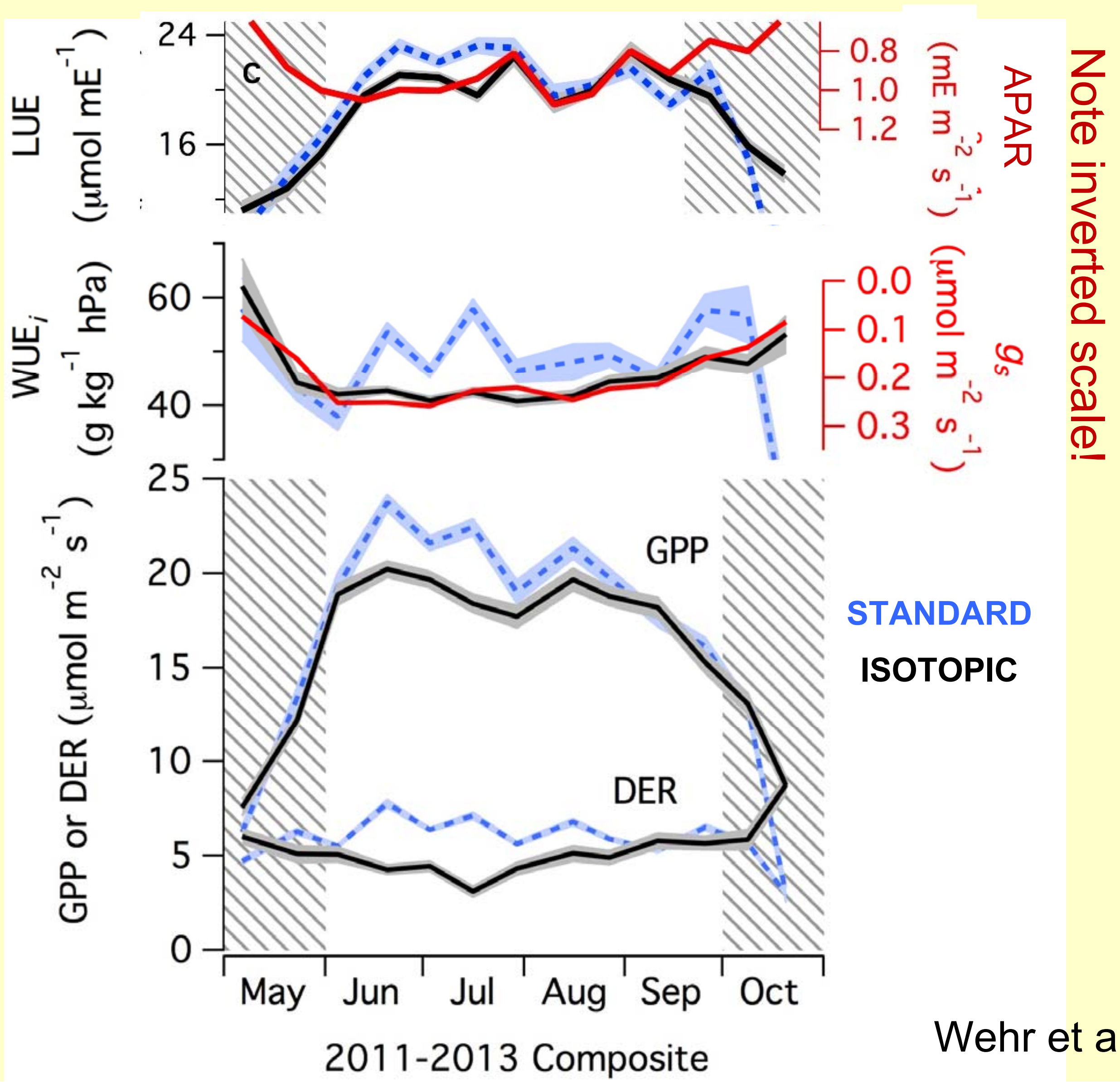
Standard partitioning shows declining photosynthetic capacity over the season

Isotopic partitioning suggests that canopy photosynthetic capacity is more stable

HF RESULT 2: Seasonal pattern

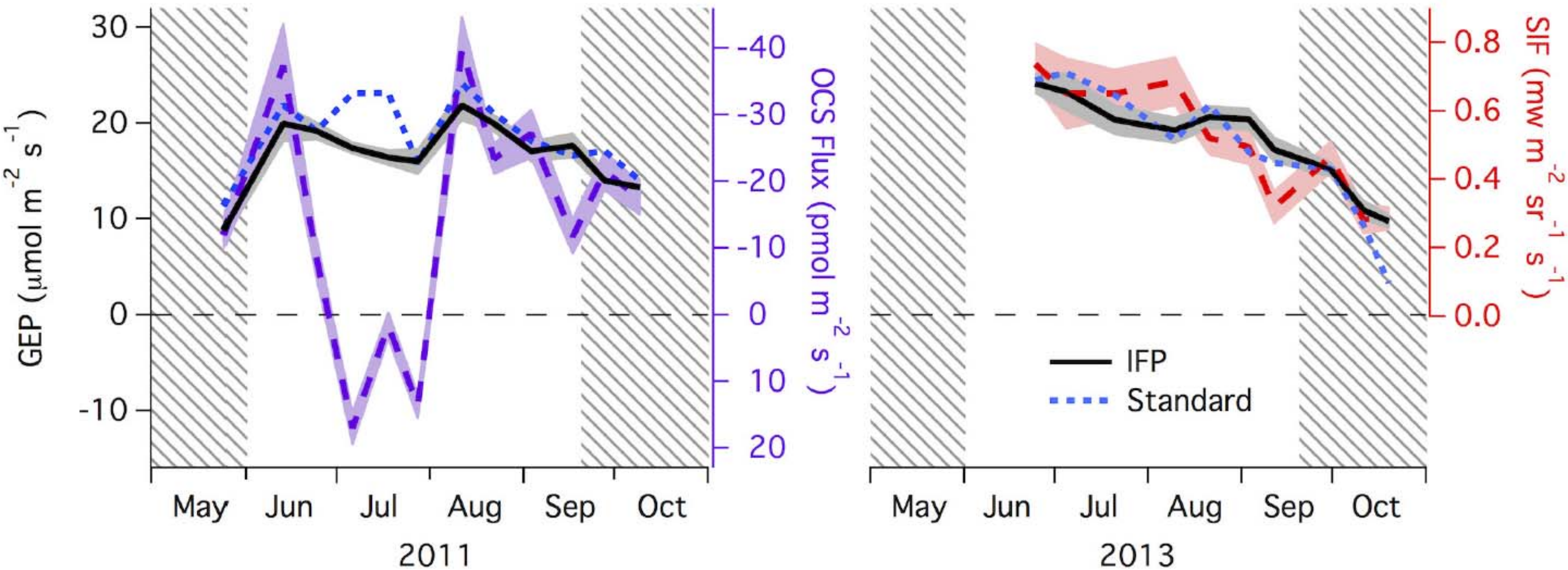
Isotopic LUE better anti-correlated with APAR

Isotopic WUE better anti-correlated with g_s



Wehr et al, 2016, *Nature*

Can we support or falsify GPP derivations (isotopic or conventional) with OCS or SIF?



At Harvard Forest, Not yet! – broadly follows both GPPs, can't distinguish between them

Wehr et al, 2016, *Nature*

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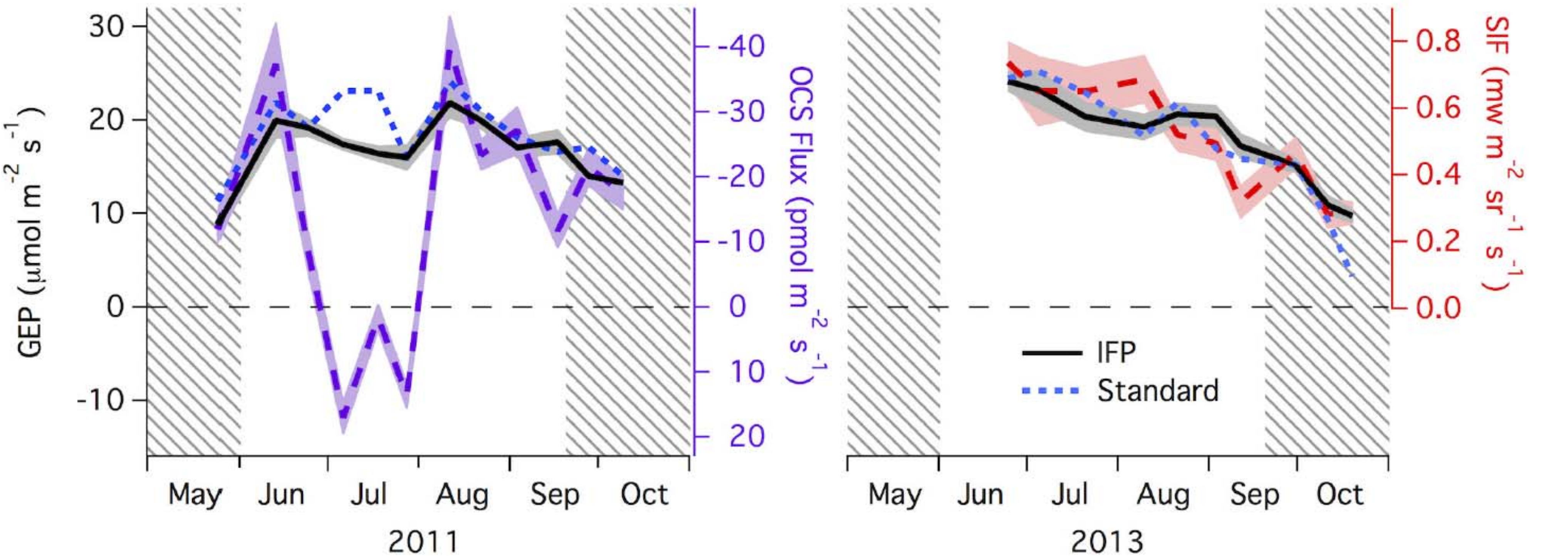


NEEDED: Gs (OCS) → …. → Photochemistry (SIF) → GPP

(A GPP model integrating front end (OCS) and back-end (SIF) constraints)

Canopy scale conductance via OCS flux measurements

Simple model

stomatal conductance

$$F = gC_n; \quad g = \left(g_{\mathrm{b}}^{-1} + g_{\mathrm{s}}^{-1} + g_{\mathrm{m}}^{-1} + g_{\mathrm{CA}}^{-1}\right)^{-1}$$

OCS flux

[OCS]

Boundary layer

Mesophyll (empirical Temp function)

"biochemical conductance" (constant or T-dependent)

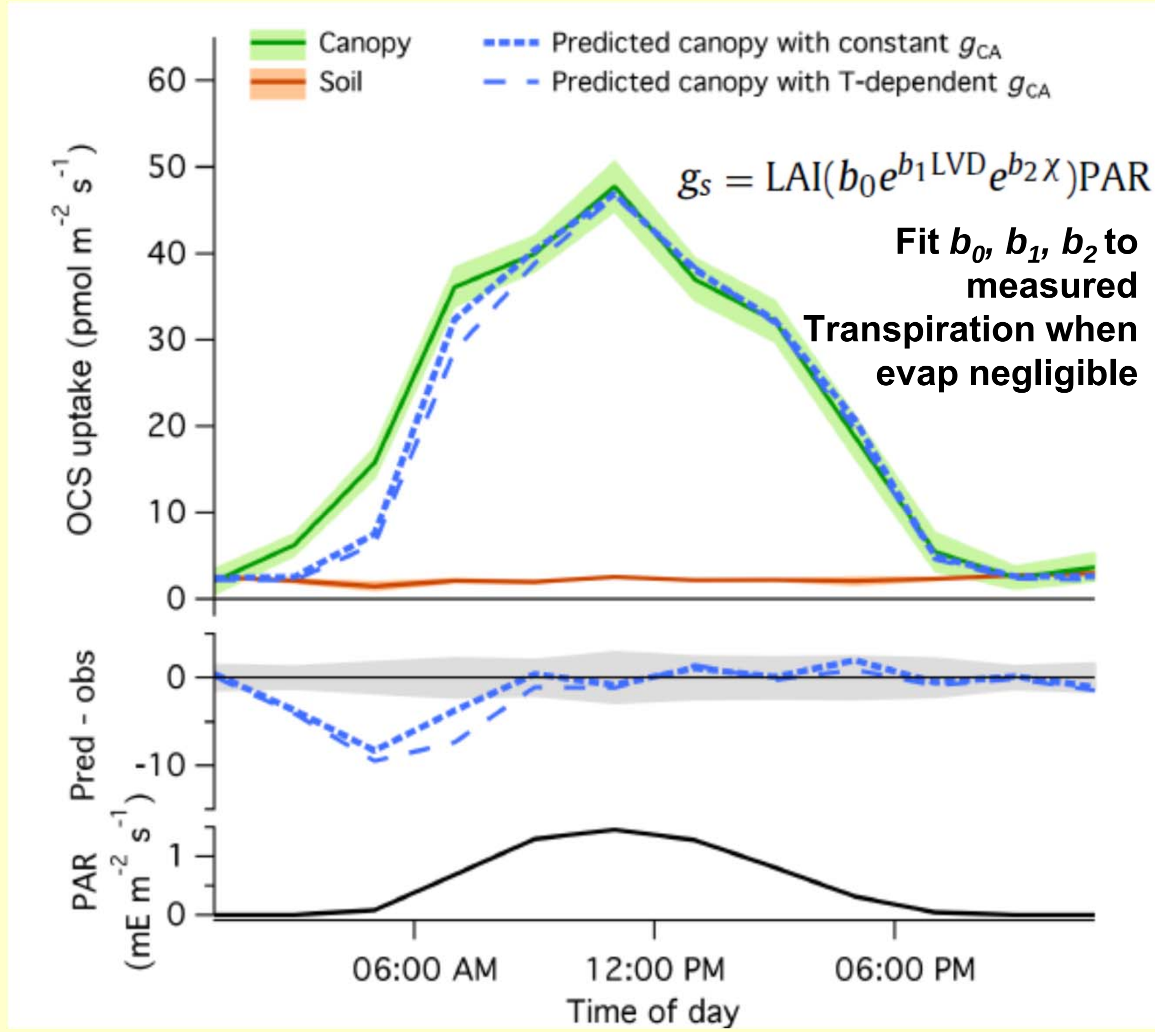
(Wehr, Commane et al. 2017)

Canopy scale conductance via OCS flux measurements

Simple model

$$F = gC_n; \quad g = \left(g_b^{-1} + g_s^{-1} + g_m^{-1} + g_{CA}^{-1}\right)^{-1}$$

- F: OCS flux
- C_n: [OCS]
- g_b: Boundary layer
- g_s: stomatal conductance
- g_m: Mesophyll (empirical Temp function)
- g_{CA}: "biochemical conductance" (constant or T-dependent)



(Wehr, Commane et al. 2017)

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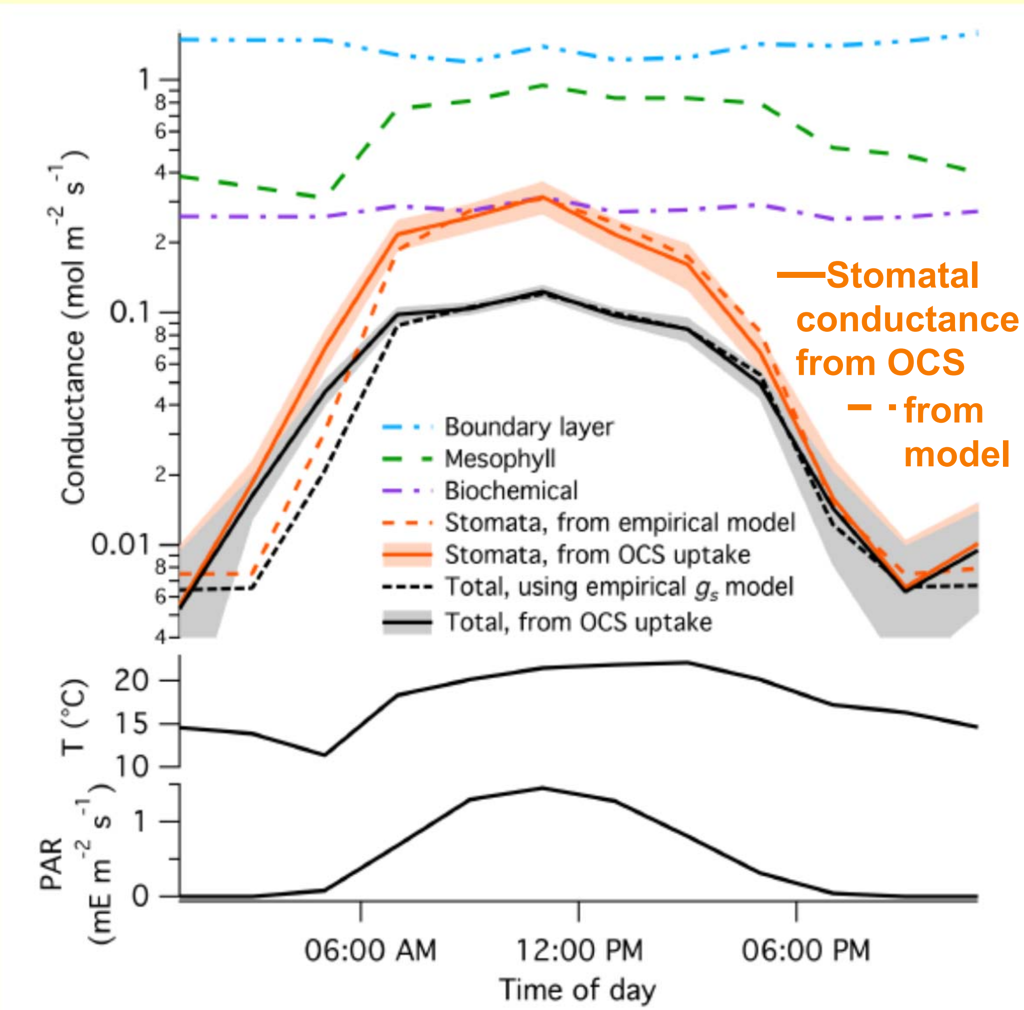

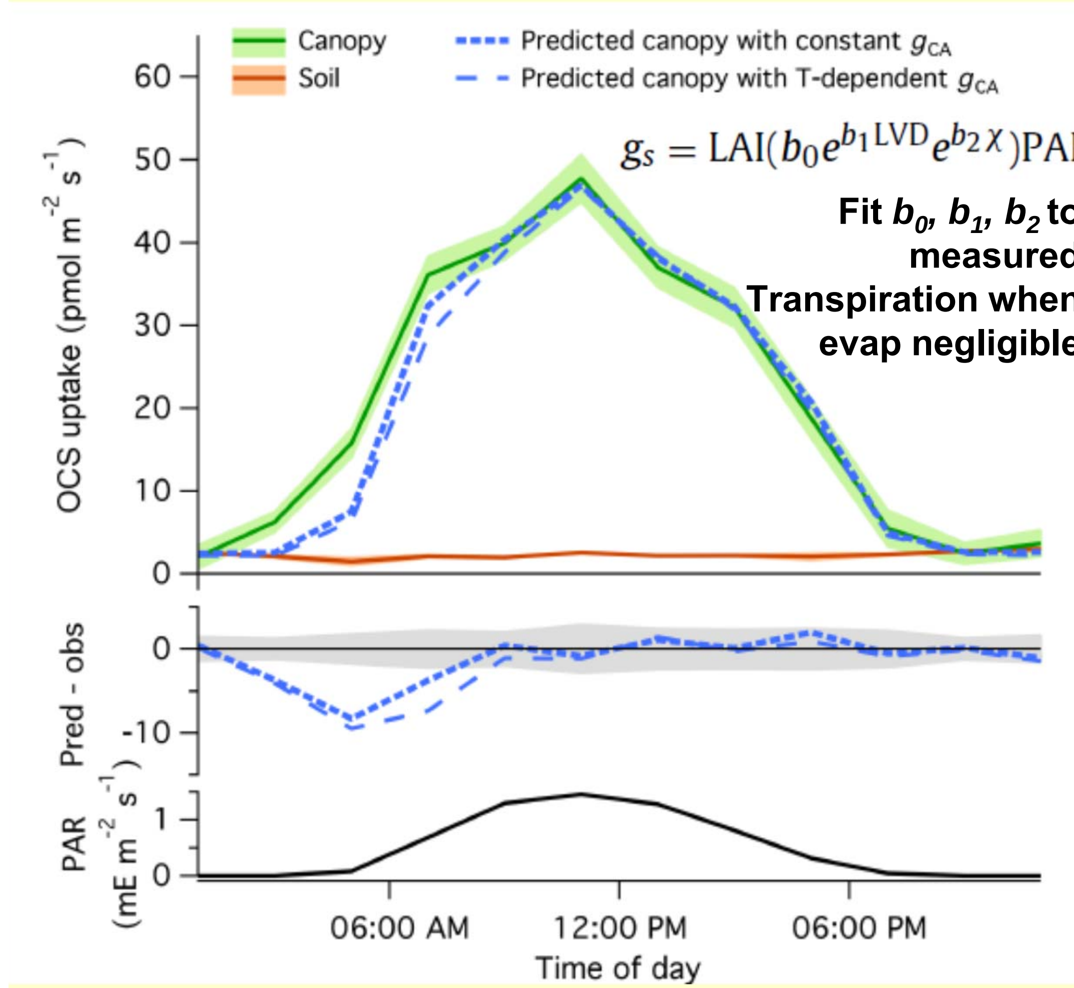

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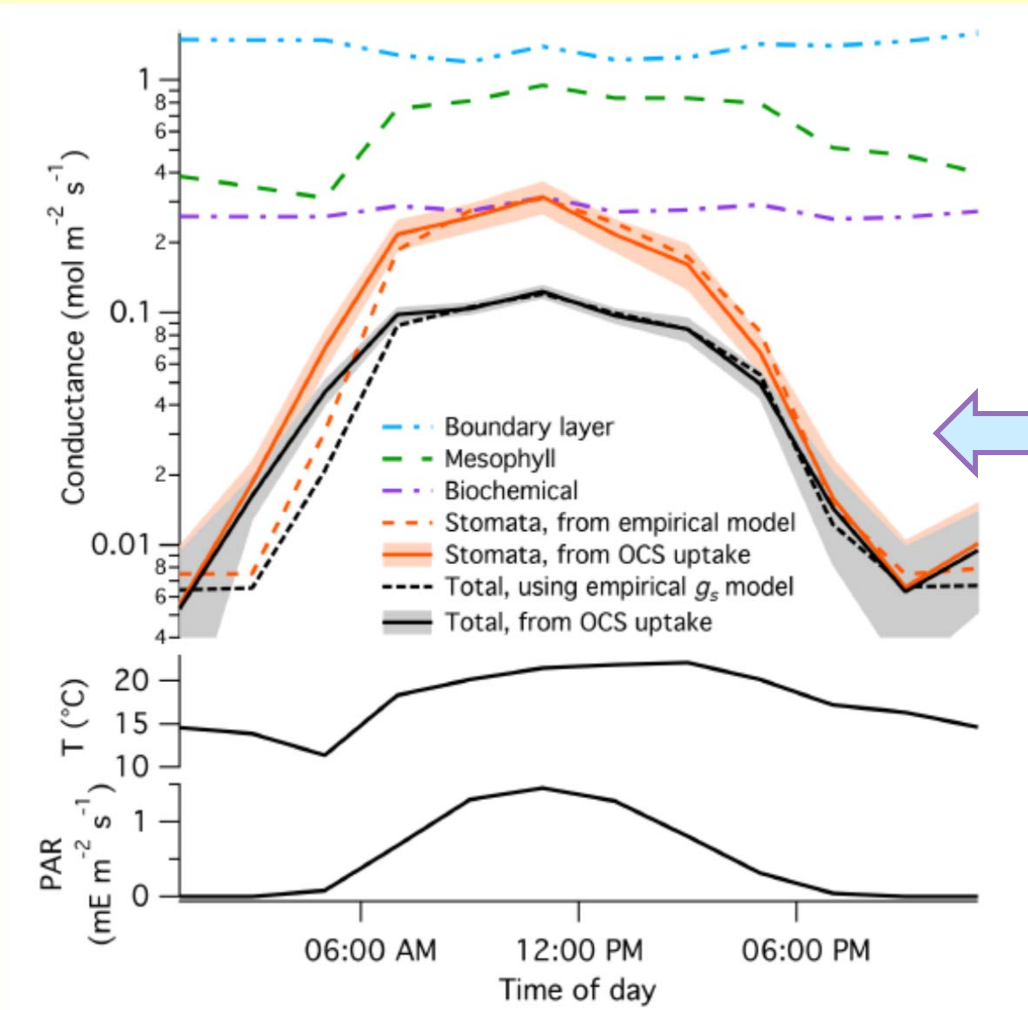
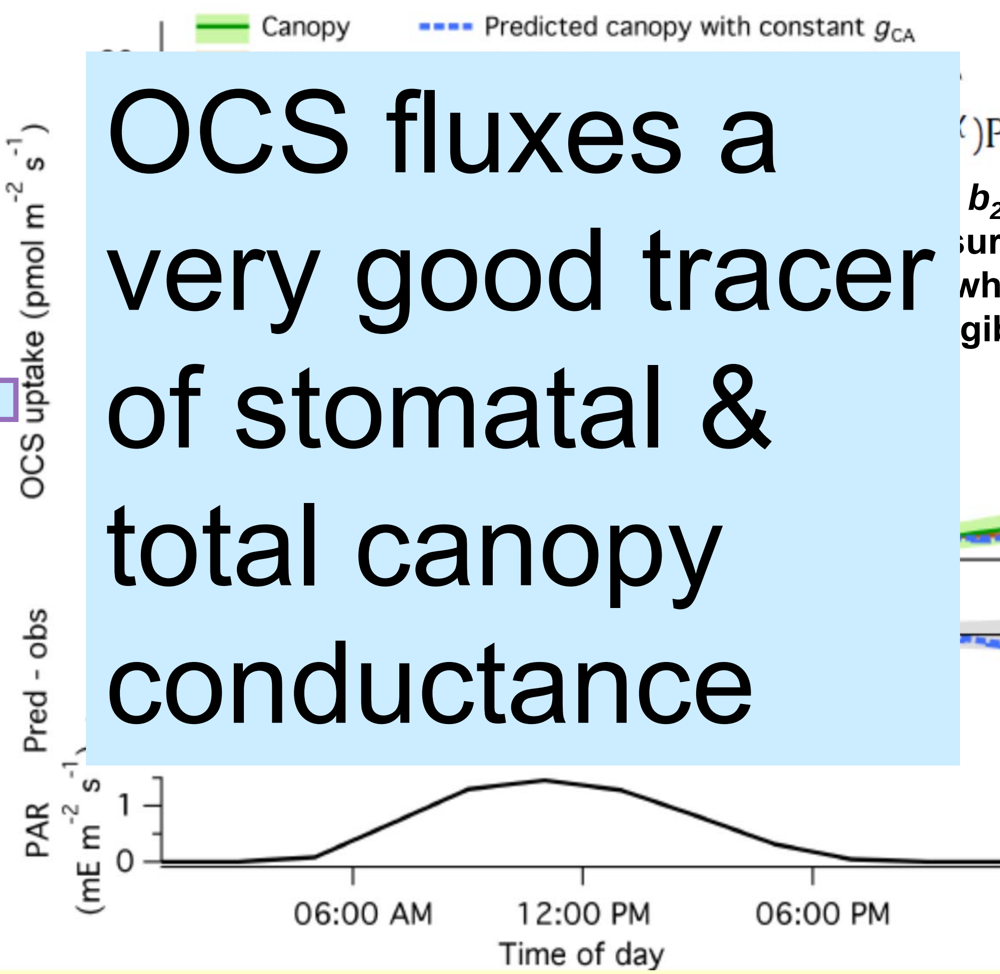
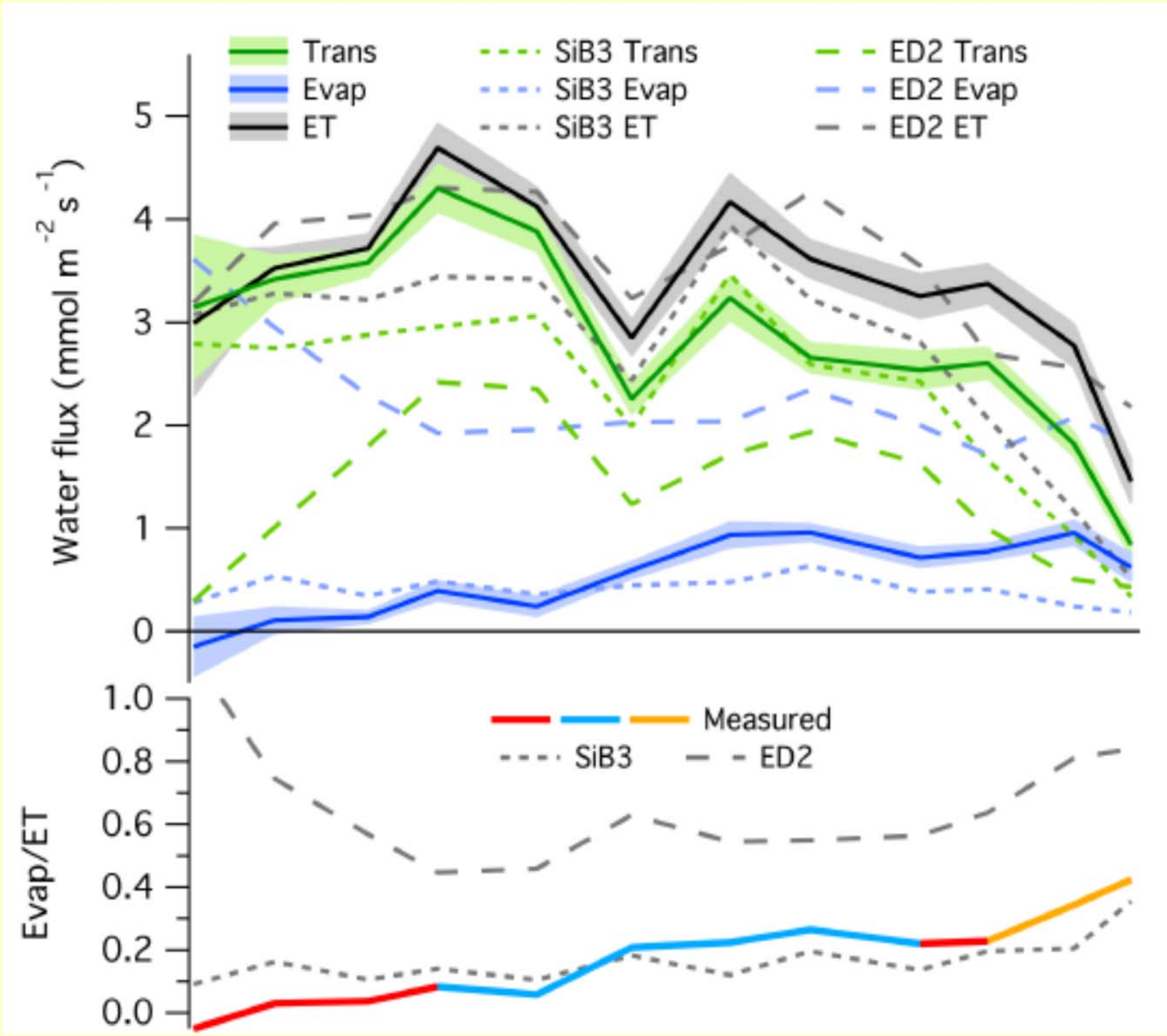




OCS fluxes a very good tracer of stomatal & total canopy conductance

(Wehr, Commane et al. 2017)

Application: allows transpiration-Evaporation partitioning via OCS flux measurements



Summary of ***What is GPP?***

1. Light inhibition of **daytime Respiration (R_{eco})** in leaves has ecosystem consequences.

   (Apparently this is the first direct ecosystem-level detection of the leaf-level Kok effect)

2. **This could make a big difference:** Standard methods overestimate **GPP by 25%**, and overestimate daytime respiration (**R_{eco}**) **by 100%** at Harvard Forest. **Does this also apply at hundreds of eddy flux sites around the world?**

3. **OCS a very good tracer of Gs, but Gs is not GPP.**

→ Let's use Gs(OCS) in a 'better' model incorporating tracers of different parts of the photosynthetic process.