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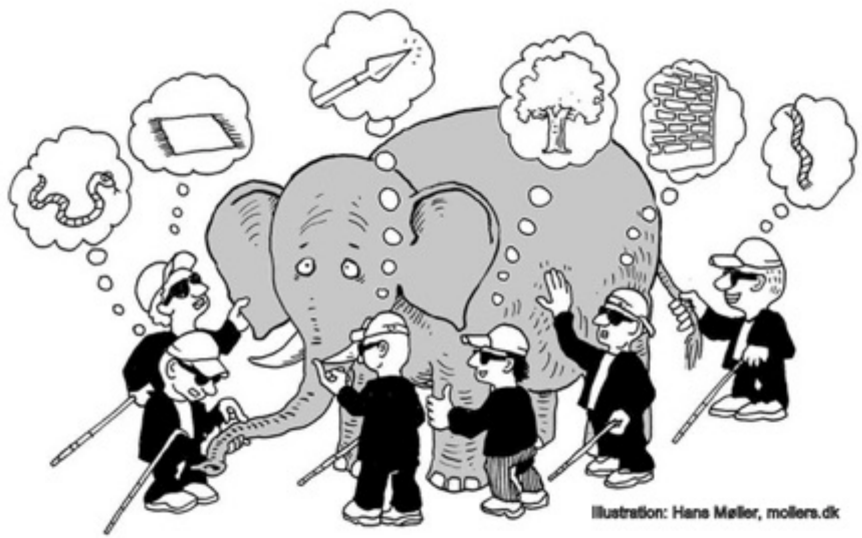
Gross Primary Productivity
or
The blind men and the Elephant



Georg Wohlfahrt

Institut für Ökologie, Universität Innsbruck, Austria

Outline

- ⌘ Definition of gross primary productivity (GPP)
- ⌘ Why bother with the unmeasurable?
- ⌘ Review: multiple constraints on GPP (the blind men theme)
- ⌘ Eddy covariance CO_2 flux partitioning revisited
- ⌘ Carbonyl sulfide (COS) – the silver bullet?
- ⌘ Conclusions

Definitions

$$P_n = \underbrace{\underbrace{\underbrace{V_c}_{(a)} - 0.5 \cdot V_o}_{(b)} - R_{day}}_{(c)}$$

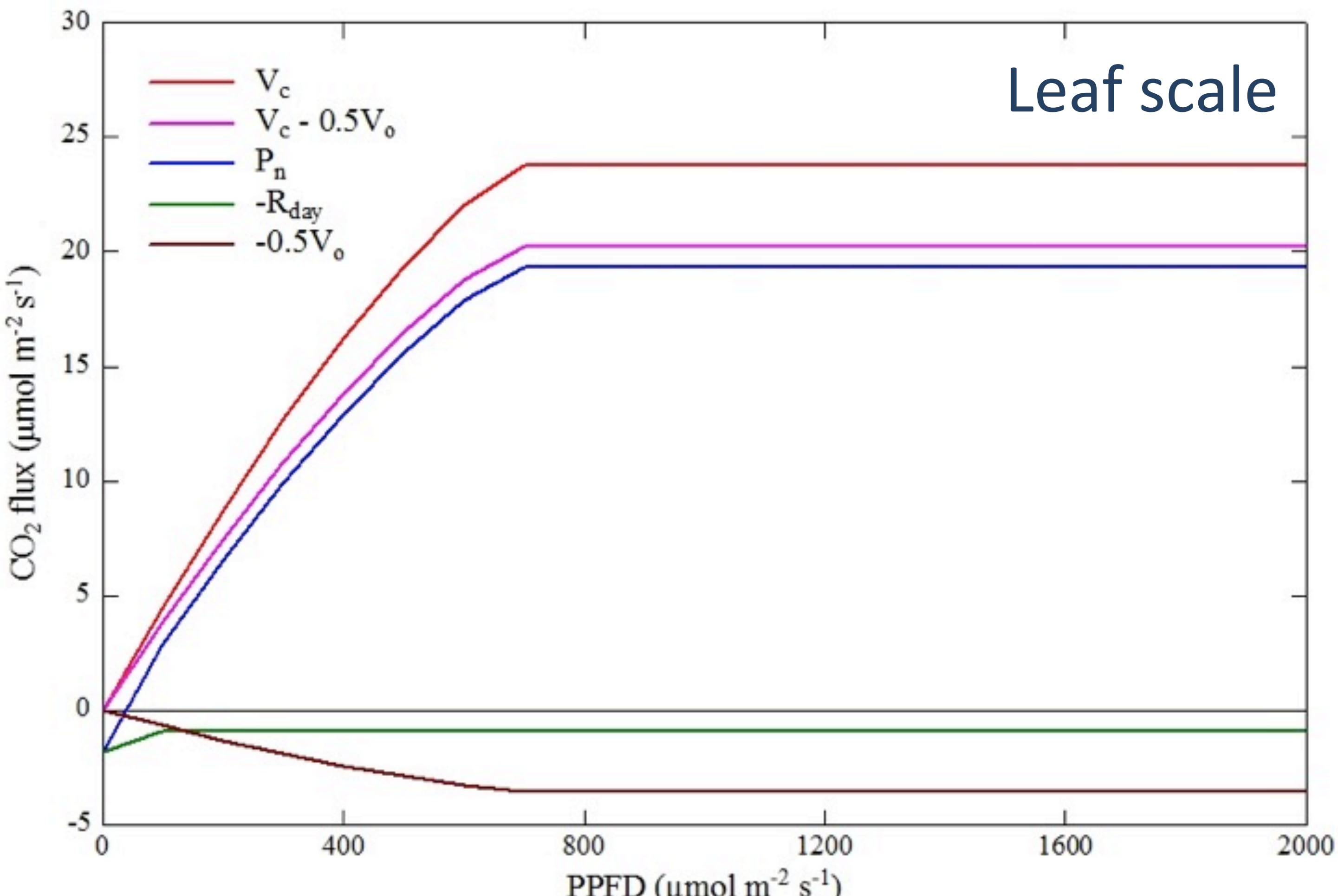
(a) V_c: carboxylation rate, gross photosynthesis, 'true' photosynthesis

(b) V_c-$0.5V_o$: 'apparent' photosynthesis, GPP

(c) V_c-$0.5V_o$-R_{day}: net photosynthesis

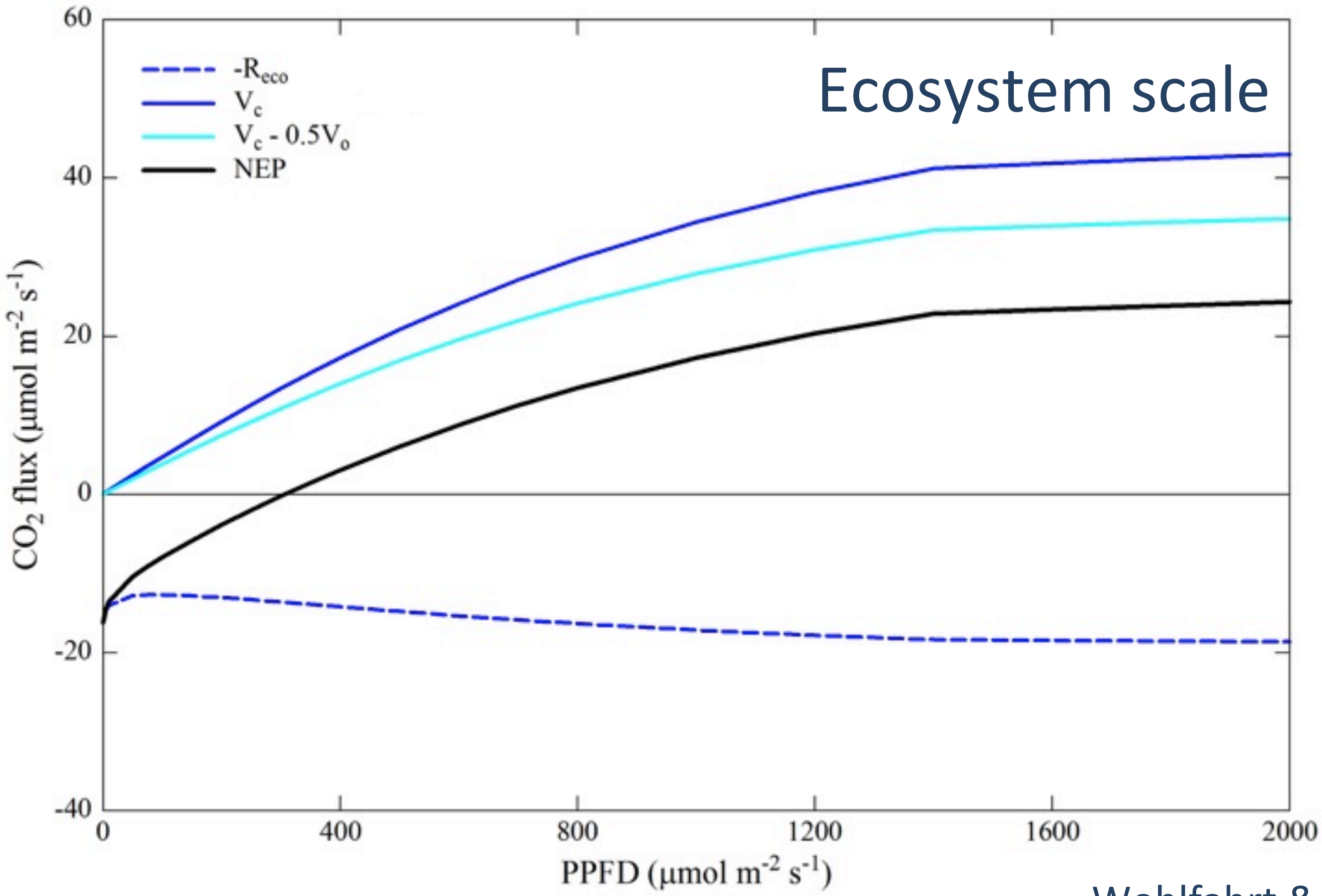
Wohlfahrt & Gu (2015)

Definitions



Wohlfahrt & Gu (2015)

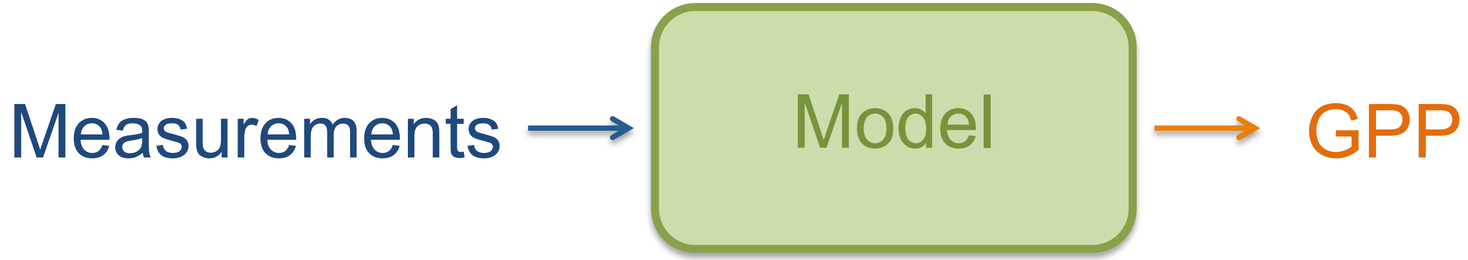
Definitions



Wohlfahrt & Gu (2015)

Why bother with GPP?

⌘ GPP can only be estimated by indirect methods.



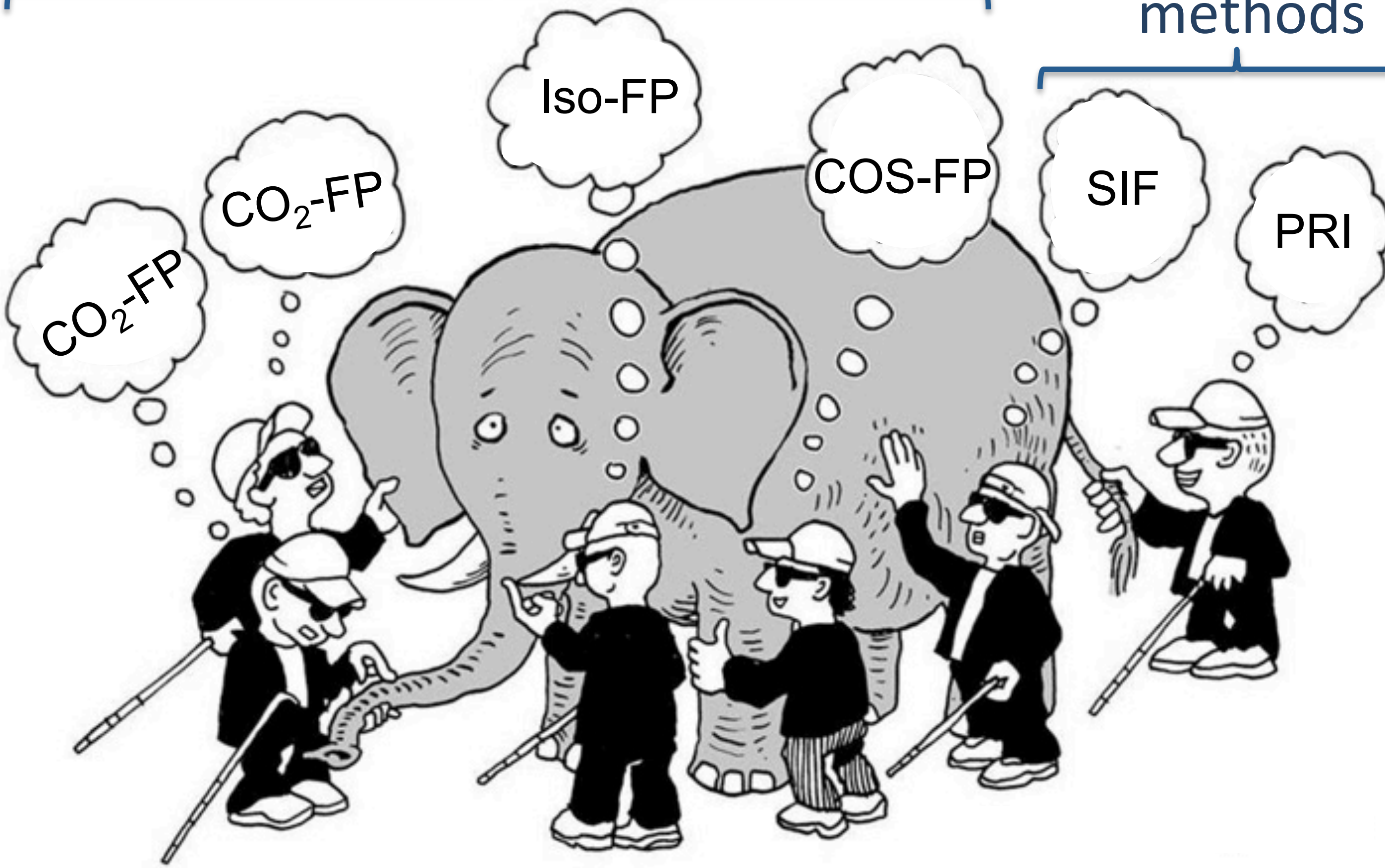
Why bother with GPP?

- GPP can only be estimated by indirect methods.
- The main motivation for estimating GPP experimentally is that carbon cycle models simulate uptake (photosynthesis) and release (ecosystem respiration) of CO_2 separately and thus require separate calibration data.
- The net CO_2 exchange being the difference between two large fluxes (GPP and ER) is very sensitive to partial errors.
- Calibration against NEP is problematic due compensating errors which, because of contrasting drivers of photosynthesis and respiration, may cause unrealistic predictions under changing climatic conditions.

Multiple constraints on GPP

Flux partitioning (FP) methods

Light use efficiency (LUE) methods



Multiple constraints on GPP

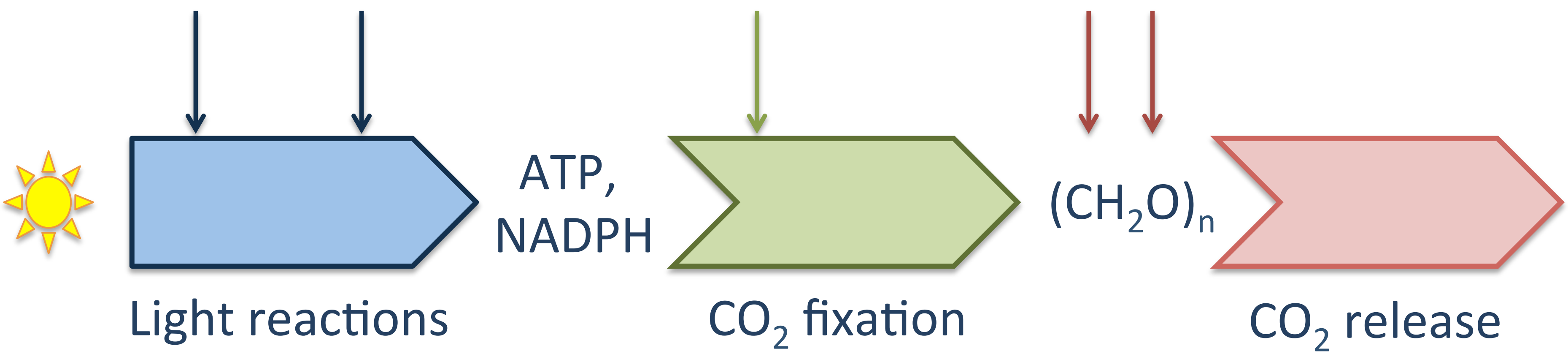
(i) Photochemical reflectance index (PRI)

(ii) Sun-induced fluorescence (SIF)

(iii) Carbonyl sulfide (COS-FP)

(iv) Isotopic flux partitioning (Iso-FP)

(v) CO_2 flux partitioning (I and II)



CO_2 flux partitioning I

Measurements → Model → GPP

NEP

$NEP_n = -ER_n$

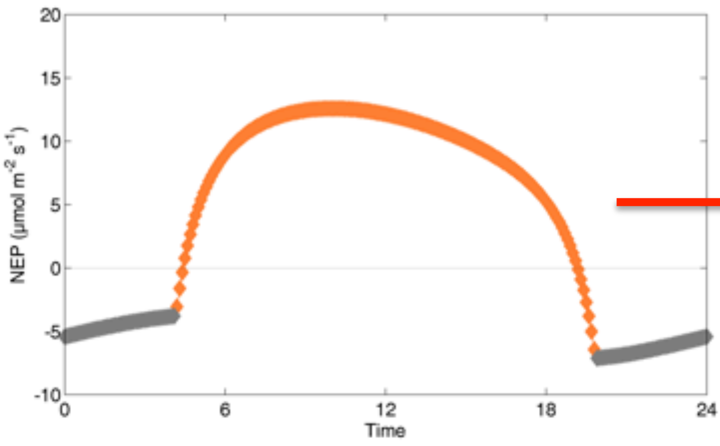
$ER_n = ER_d = f(T)$

$NEP_d = GPP - ER_d$

$GPP = NEP_d + ER_d$

Reichstein et al. (2005)

CO_2 flux partitioning I



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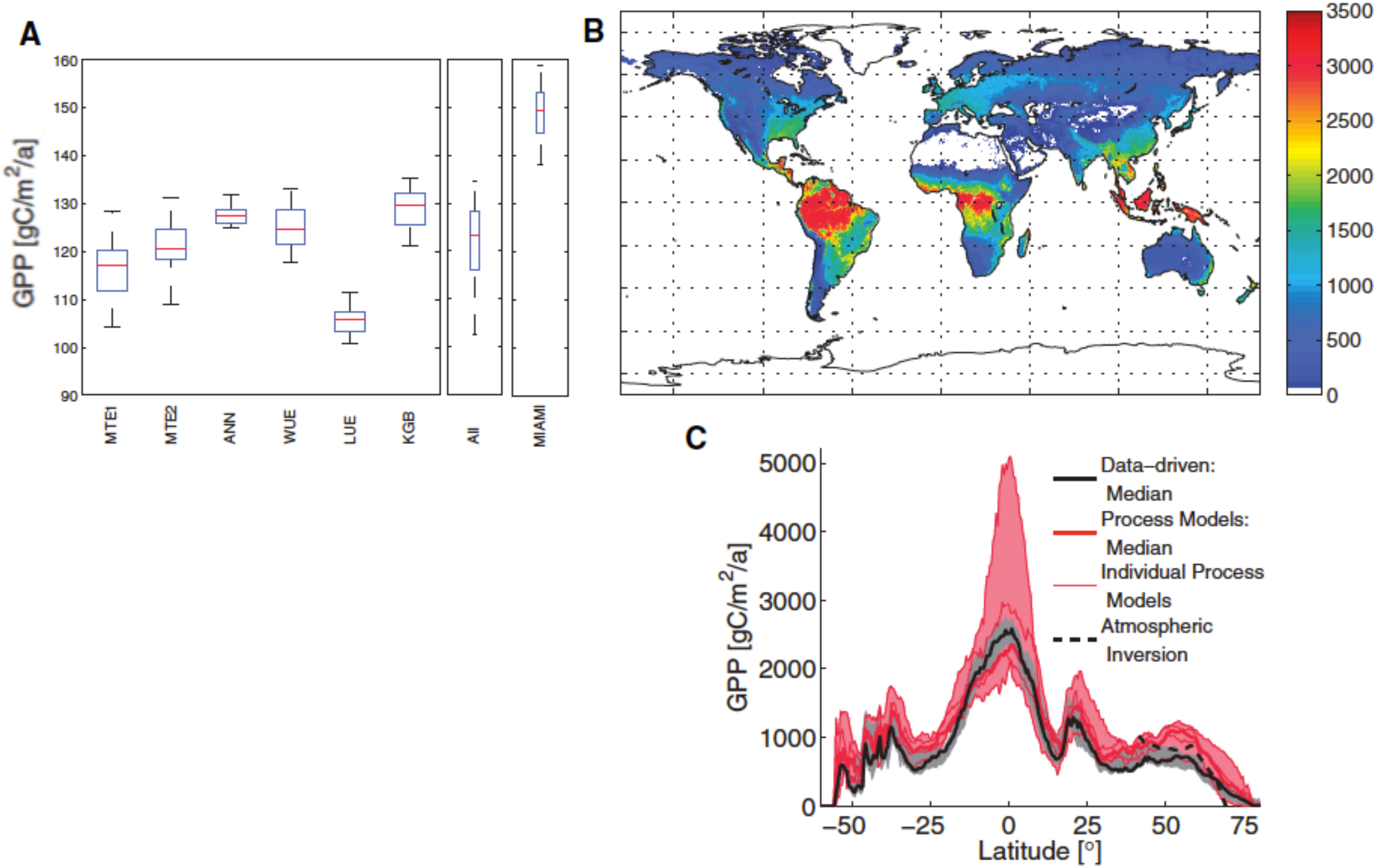
CO_2 flux partitioning I



Beer et al. (2010)

CO_2 flux partitioning II

Measurements → Model → GPP

NEP

$NEP_n = -ER_n@T_{ref} \cdot e^{\beta \cdot T}$

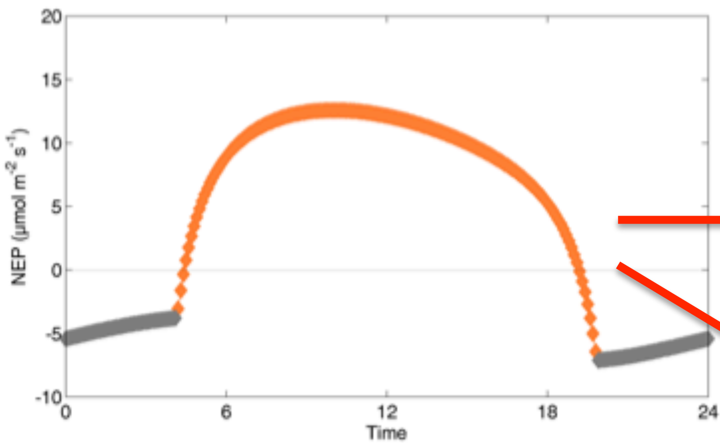
$GPP = NEP_d + ER_d@T_{ref} \cdot e^{\beta \cdot T}$

$GPP = f(PAR, VPD)$

$NEP_d = GPP - ER_d@T_{ref} \cdot e^{\beta \cdot T}$

Lasslop et al. (2010)

CO_2 flux partitioning II



Isotopic flux partitioning

Measurements → Model → GPP

F_N, $\delta_N F_N$, δ_R, δ_a, C_a, λE, H, R_{net}, r_a, VPD, T_a

$$F_N = F_A + F_{NR}$$

$$\delta_N F_N = \delta_A F_A + \delta_{NR} F_{NR}$$

… and several other auxiliary eqs.

solve eqs. for F_A, F_{NR}

Isotopic flux partitioning

$F_N = F_A + F_{NR}$ Net CO_2 flux

$\delta_N F_N = \delta_A F_A + \delta_{NR} F_{NR}$ Isoflux

$\delta_A = \delta_a - \Delta$

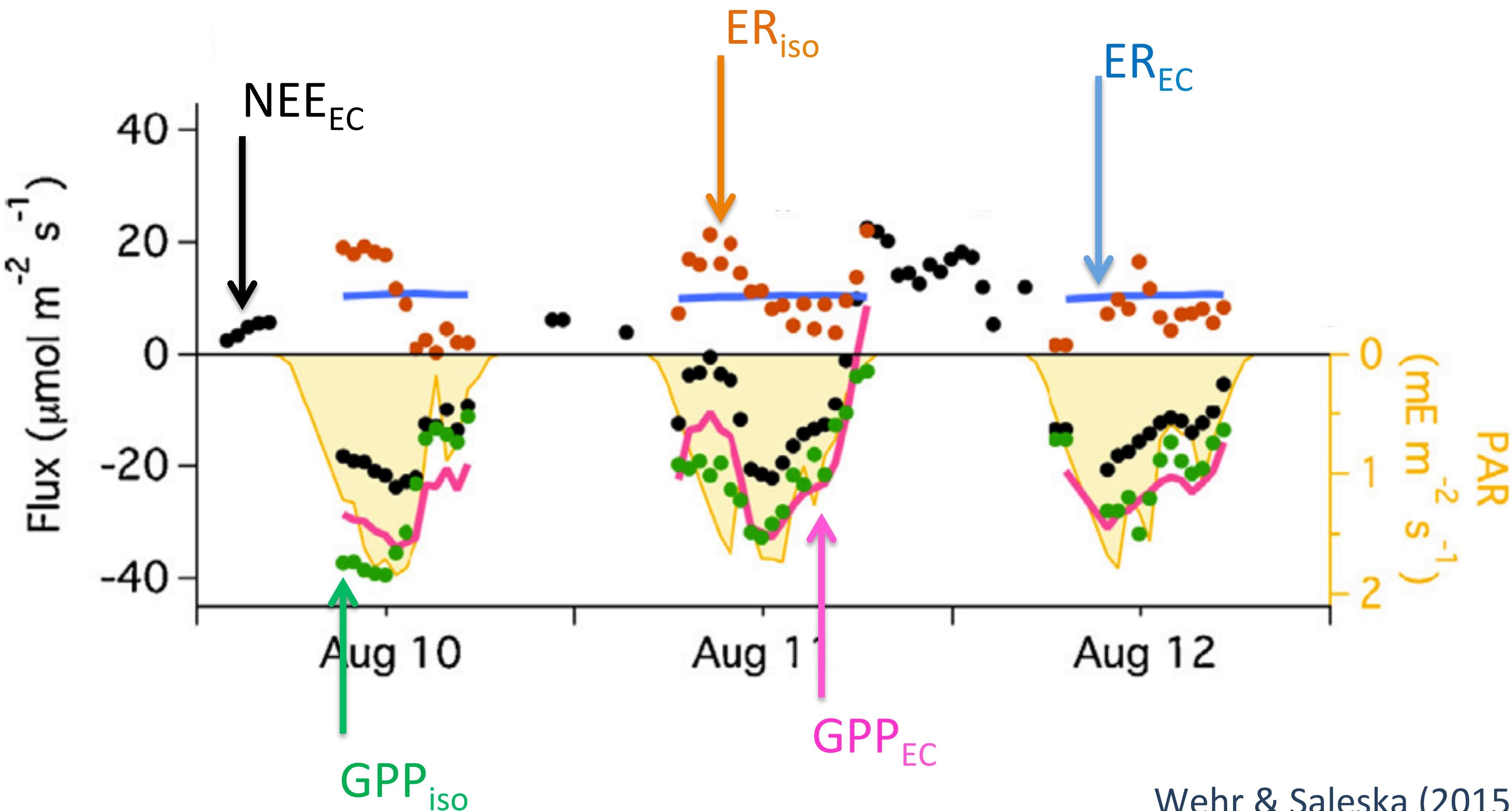
$\Delta = a + (b - a)\, C_i/C_a$ Farquhar et al. (1982)

$-F_A = g_c\,(C_a - C_i)$ Fick‘s law; big-leaf approximation

$g_c = f(\lambda E, H, R_{net}, r_a, VPD, T_a)$ Penman-Monteith

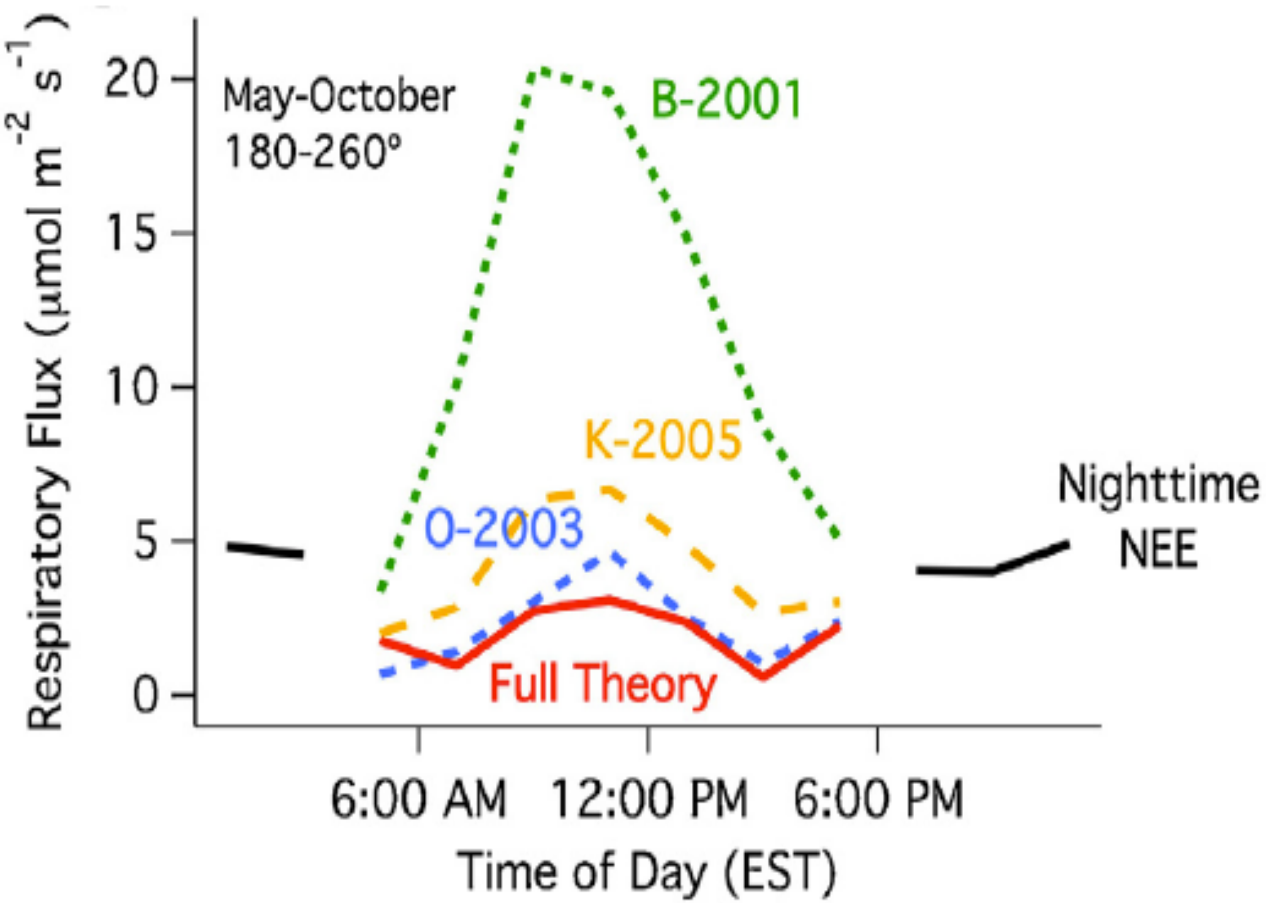
Yakir & Wang (1996), Bowling et al. (2001), Ogee et al. (2003), Wehr & Saleska (2015)

Isotopic flux partitioning



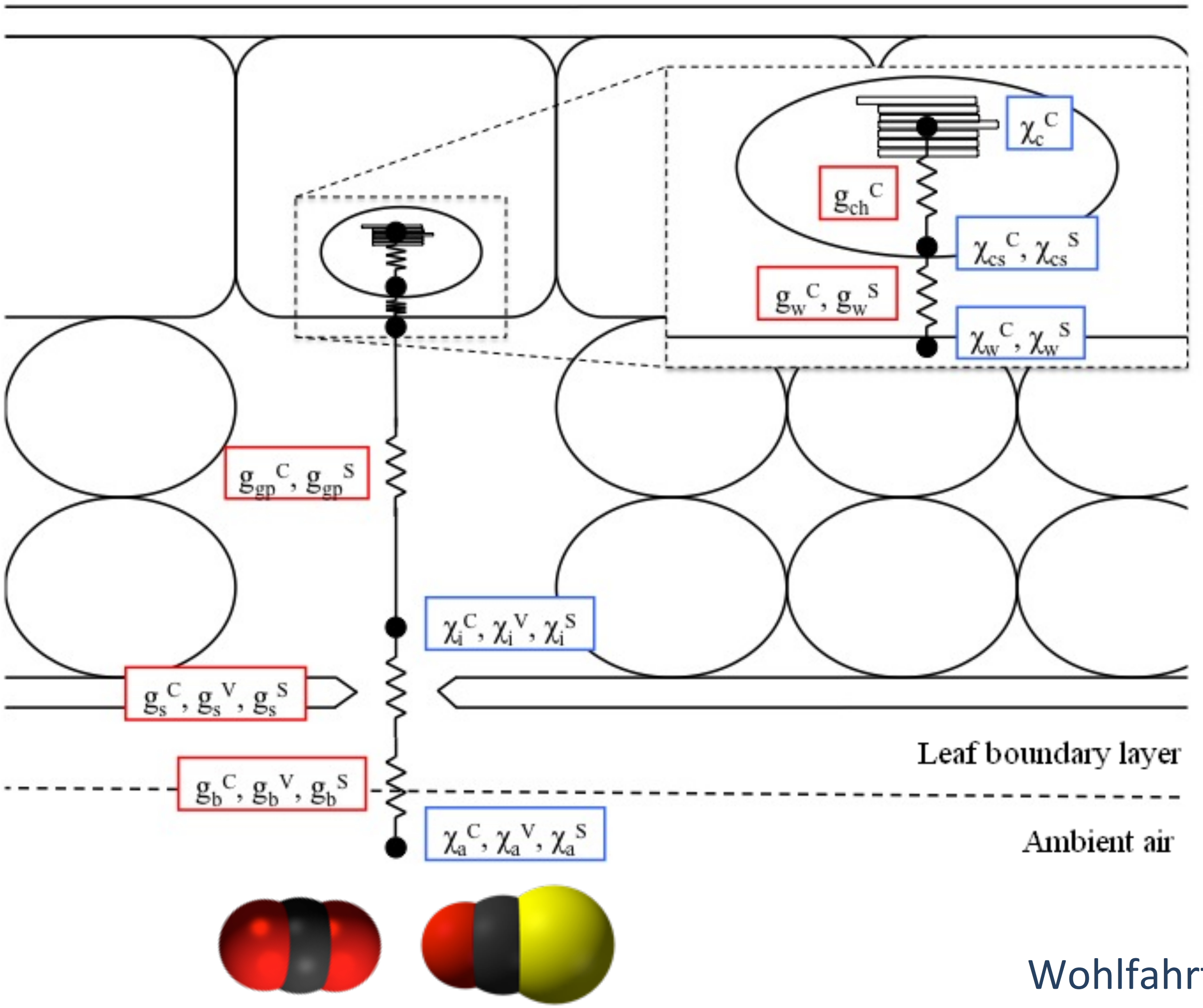
Wehr & Saleska (2015)

Isotopic flux partitioning



Wehr & Saleska (2015)

COS flux partitioning



Wohlfahrt et al. (2012)

COS flux partitioning

Measurements → Model → GPP

F_{COS}, χ_{COS}, χ_{CO2}

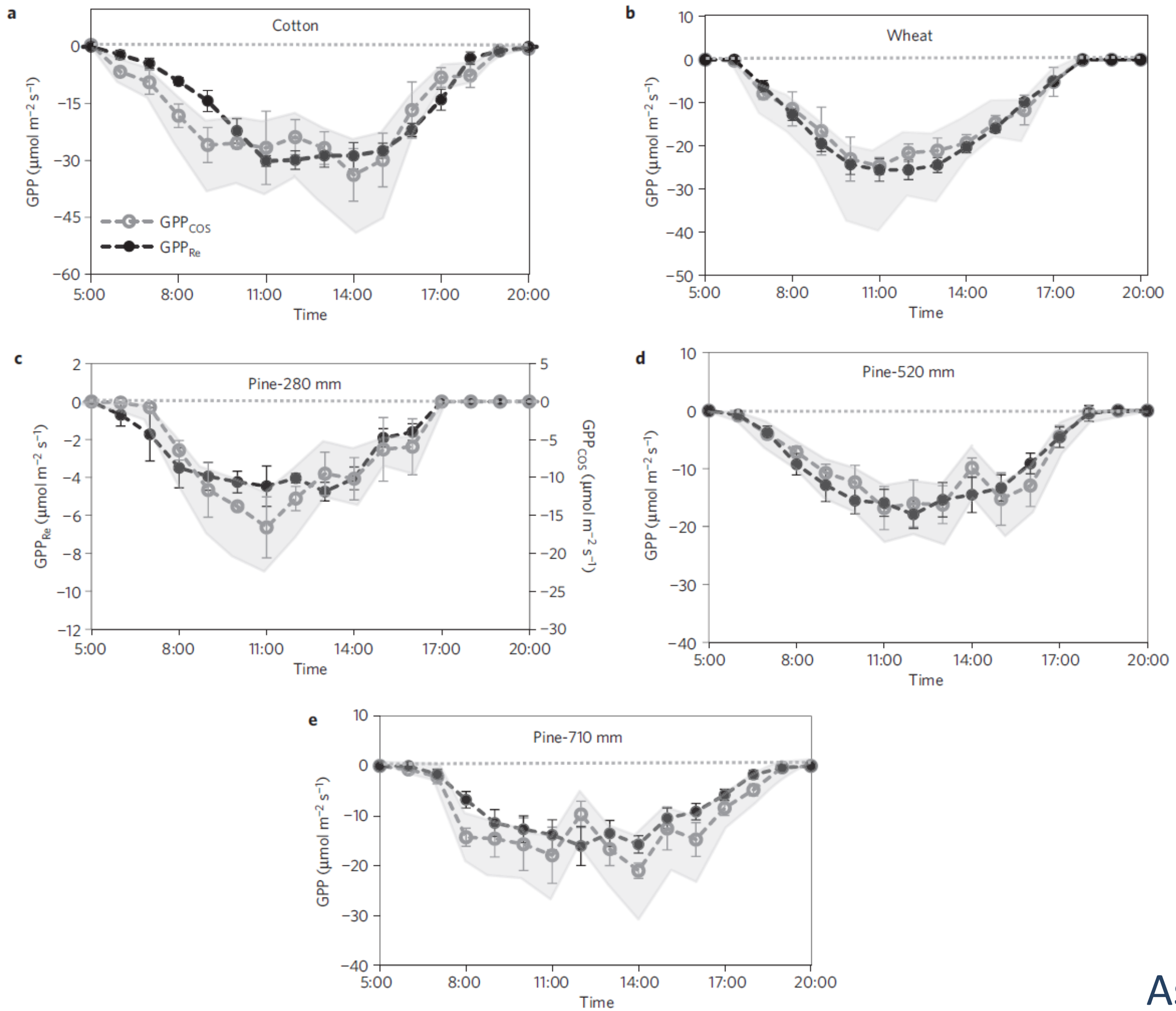
$\lambda = (F_{COS}/\chi_{COS}) / (GPP/\chi_{CO2}) \approx \text{const.}$

no other COS sources or sinks

$GPP = (\chi_{CO2}/\chi_{COS}) \cdot (F_{COS}/\lambda)$

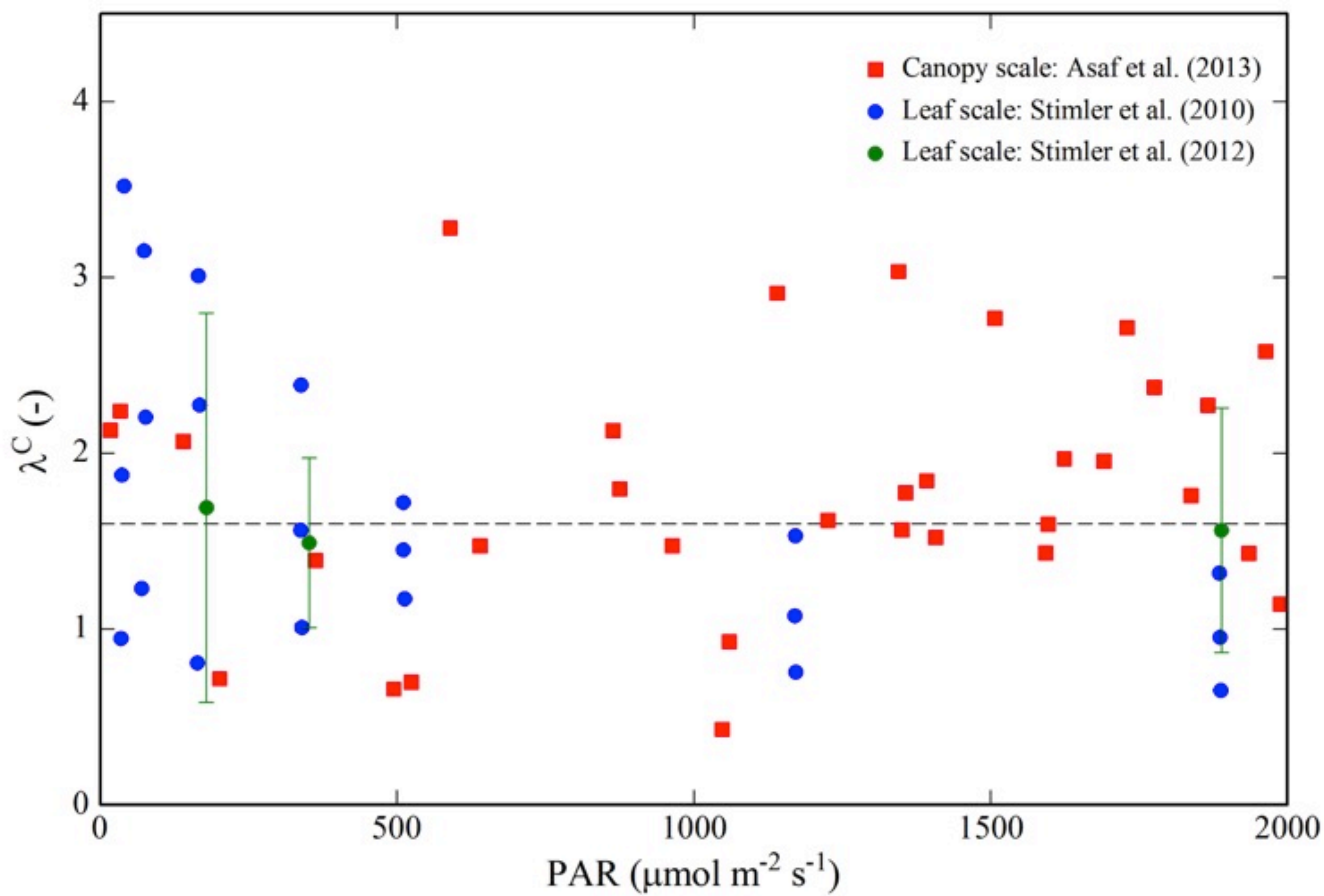
Wohlfahrt et al. (2012)

COS flux partitioning

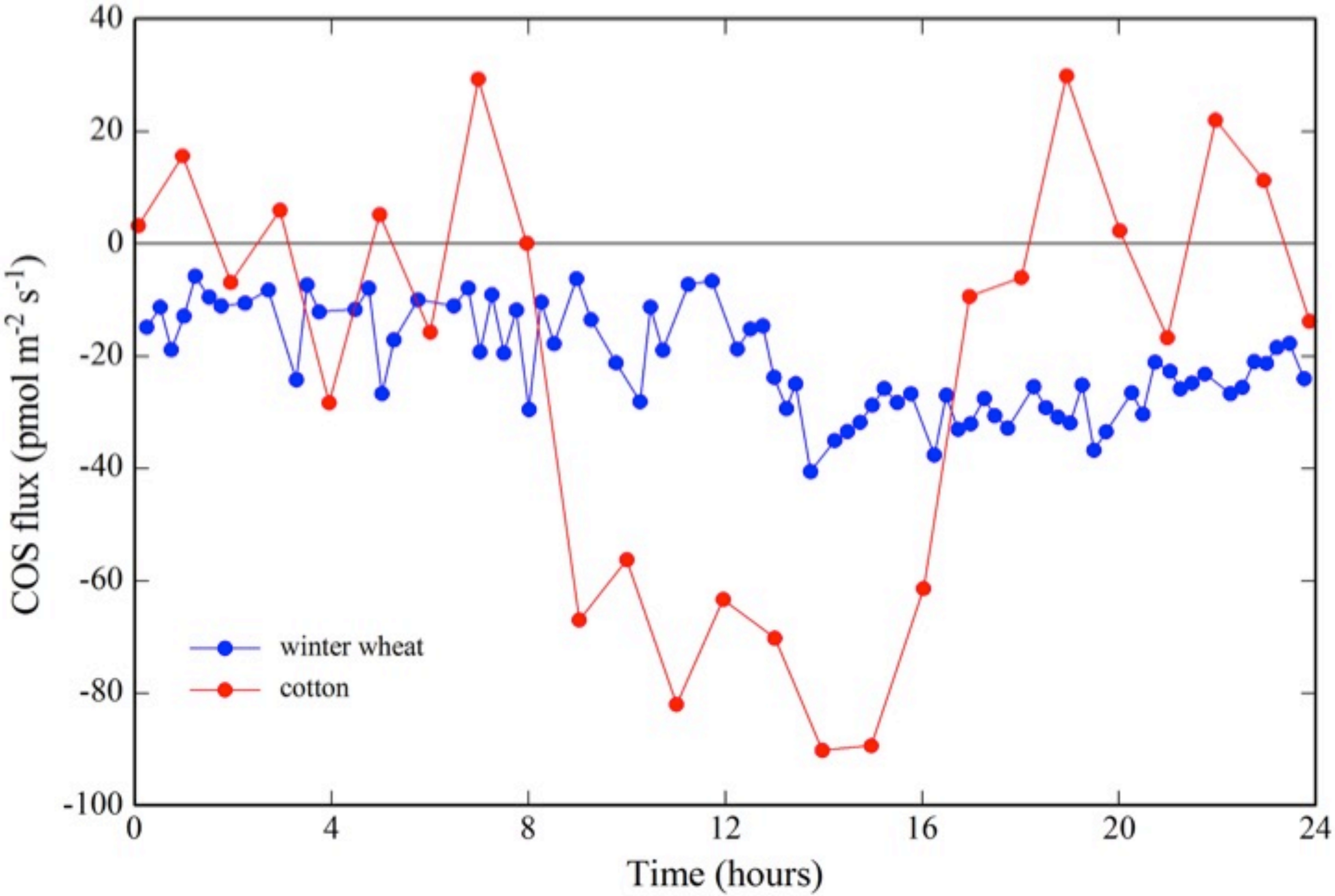


Asaf et al. (2013)

COS flux partitioning

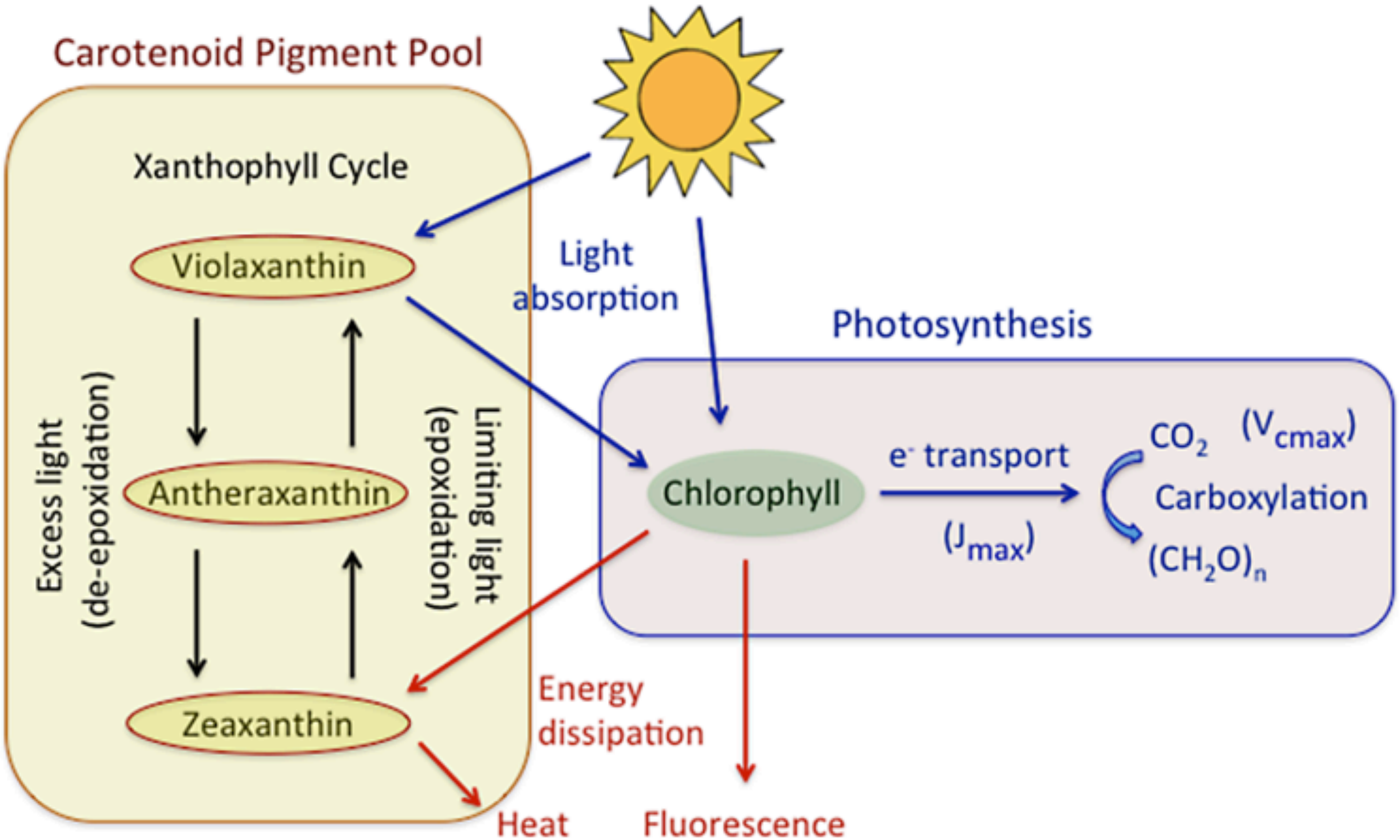


COS flux partitioning



data from Asaf et al. (2013; cotton) and Billesbach et al. (2014; winter wheat)

Photochemical reflectance index (PRI)



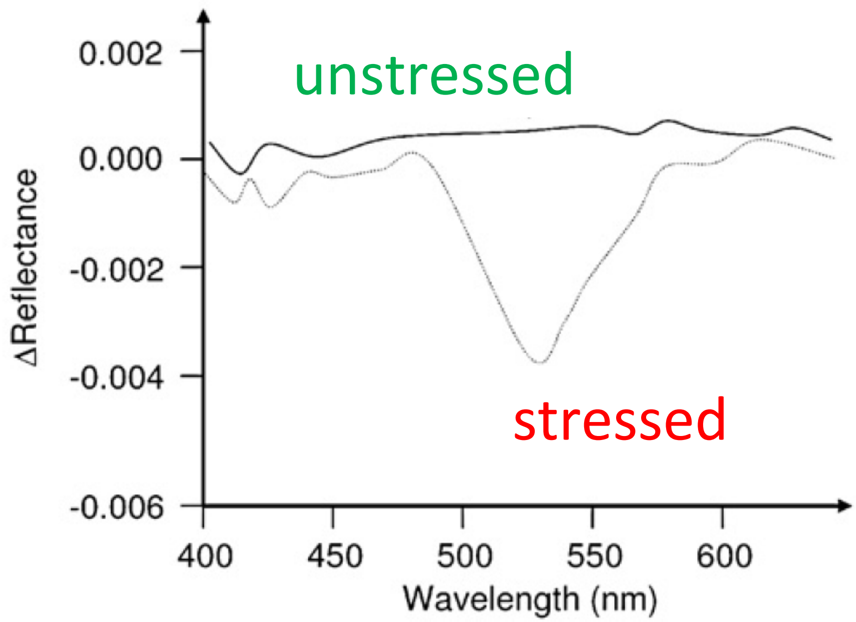
Gamon (2015)

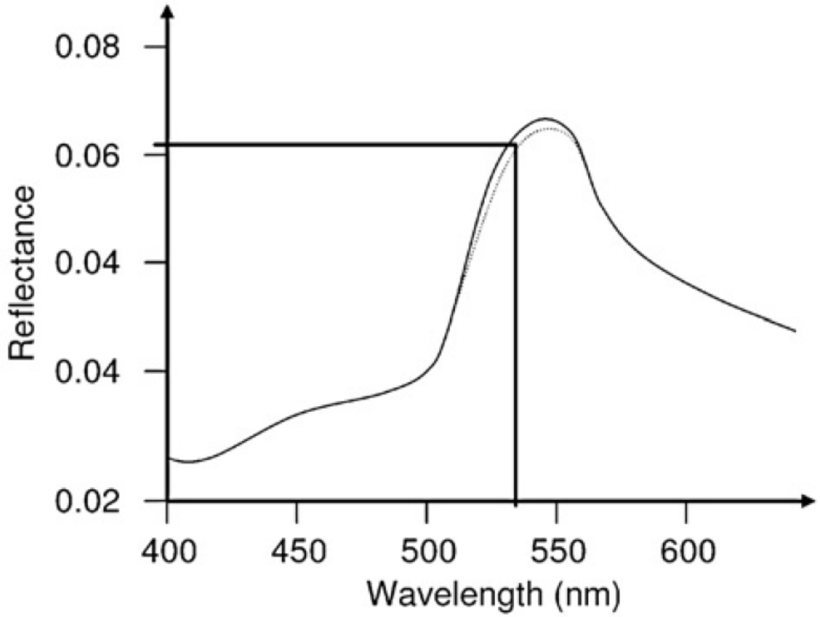
PRI

$$PRI = (\rho_d - \rho_r)/(\rho_d + \rho_r)$$

ρ_d = 531nm, ρ_r = 570nm

Gamon et al. (1992)





Hall et al. (2008)

PRI

Measurements → Model → GPP

PAR, NDVI, PRI, f_{dif}, f_{sun}

$fAPAR = f(NDVI)$

$\varepsilon = f(PRI, f_{dif}, f_{sun})$

$GPP = PAR \cdot fAPAR \cdot \varepsilon$

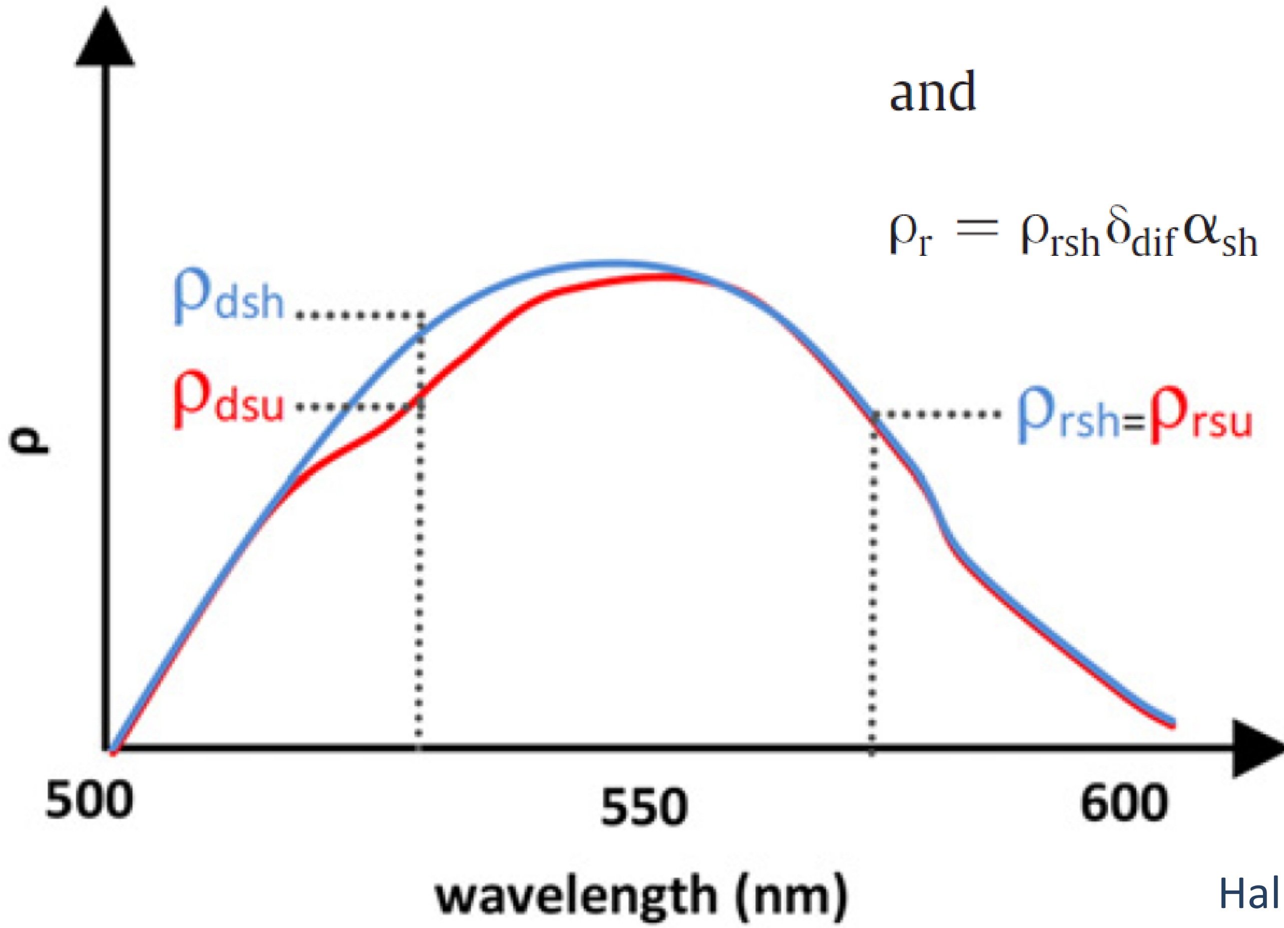
Hall et al. (2008)

PRI

$$\rho_d = \rho_{dsh}\delta_{dif}\alpha_{sh} + \rho_{dsu}\alpha_{su},$$

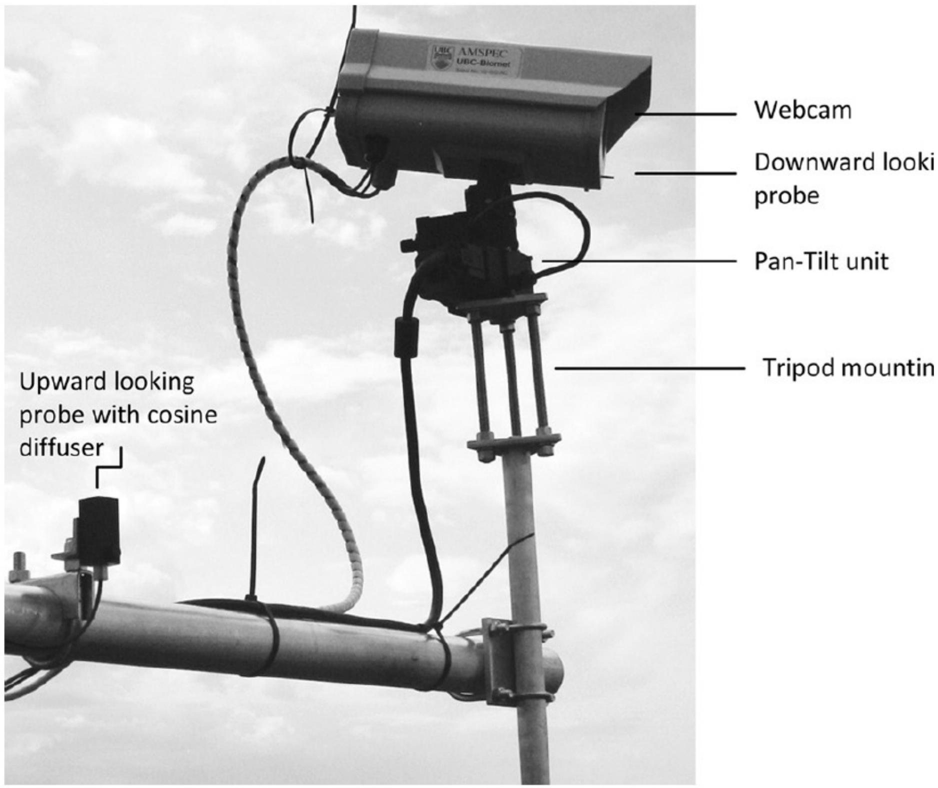
and

$$\rho_r = \rho_{rsh}\delta_{dif}\alpha_{sh} + \rho_{rsu}\alpha_{su},$$

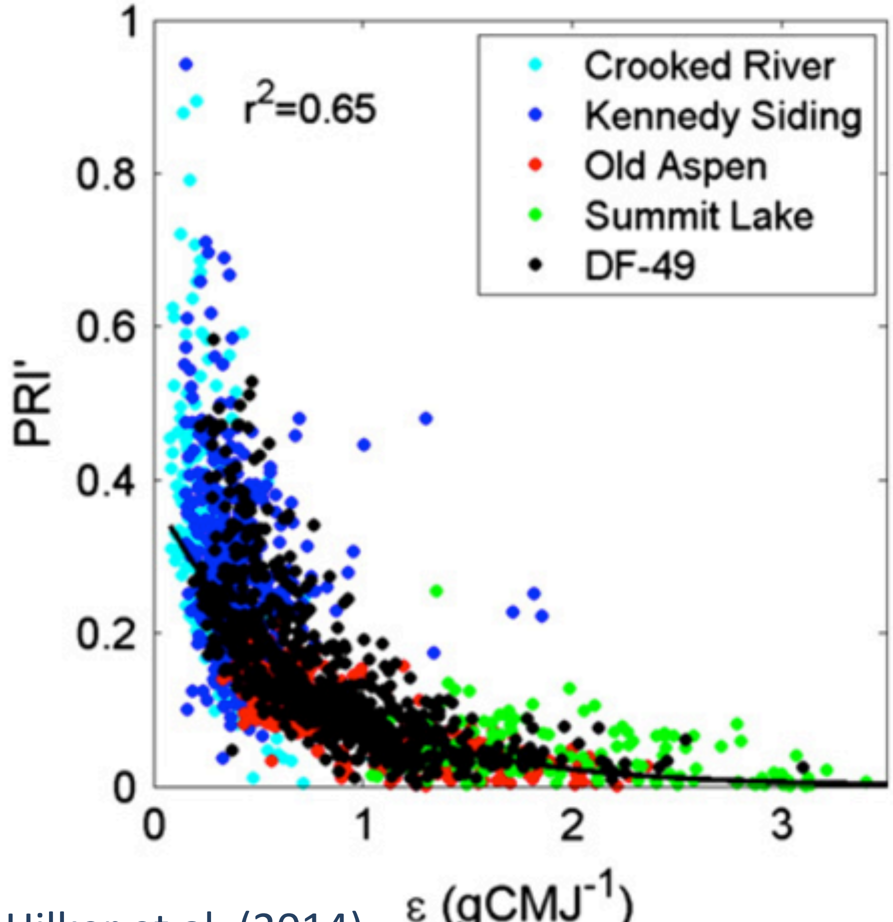


Hall et al. (2011)

PRI

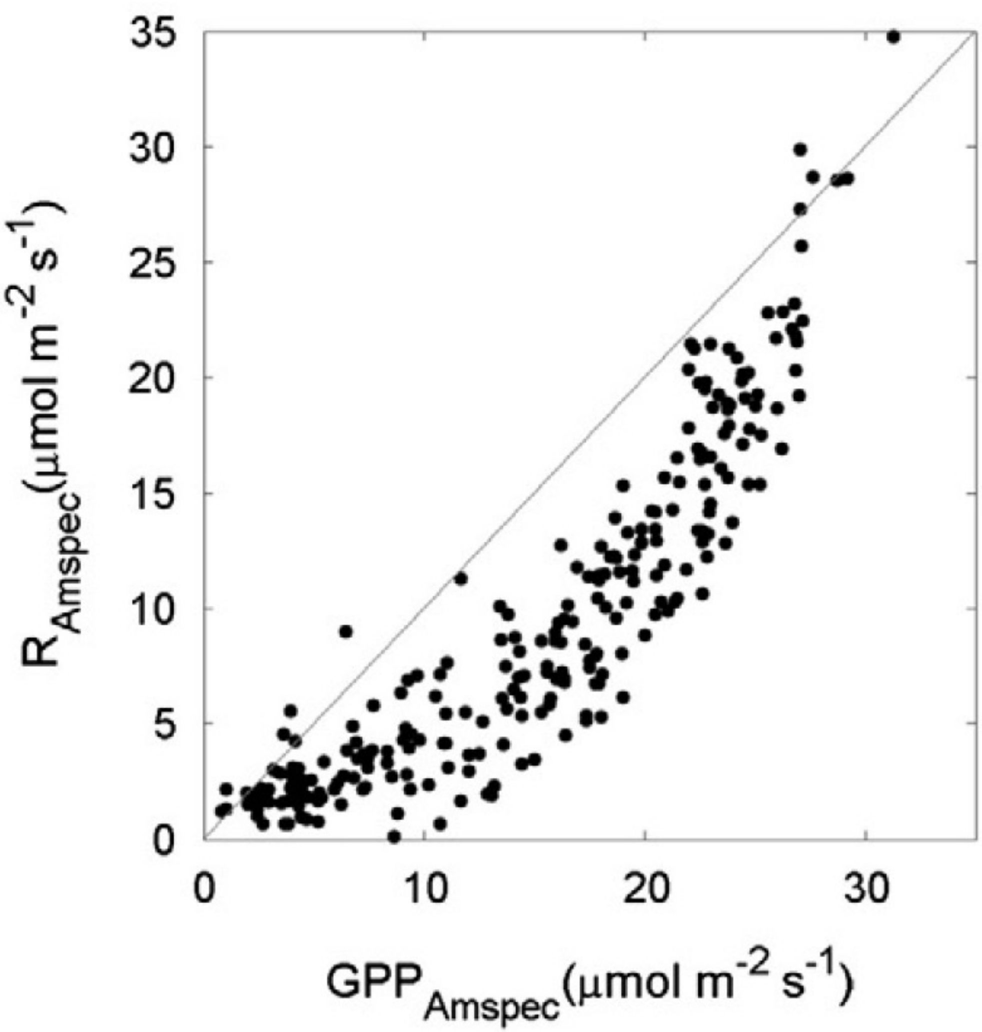


Hilker et al. (2010)



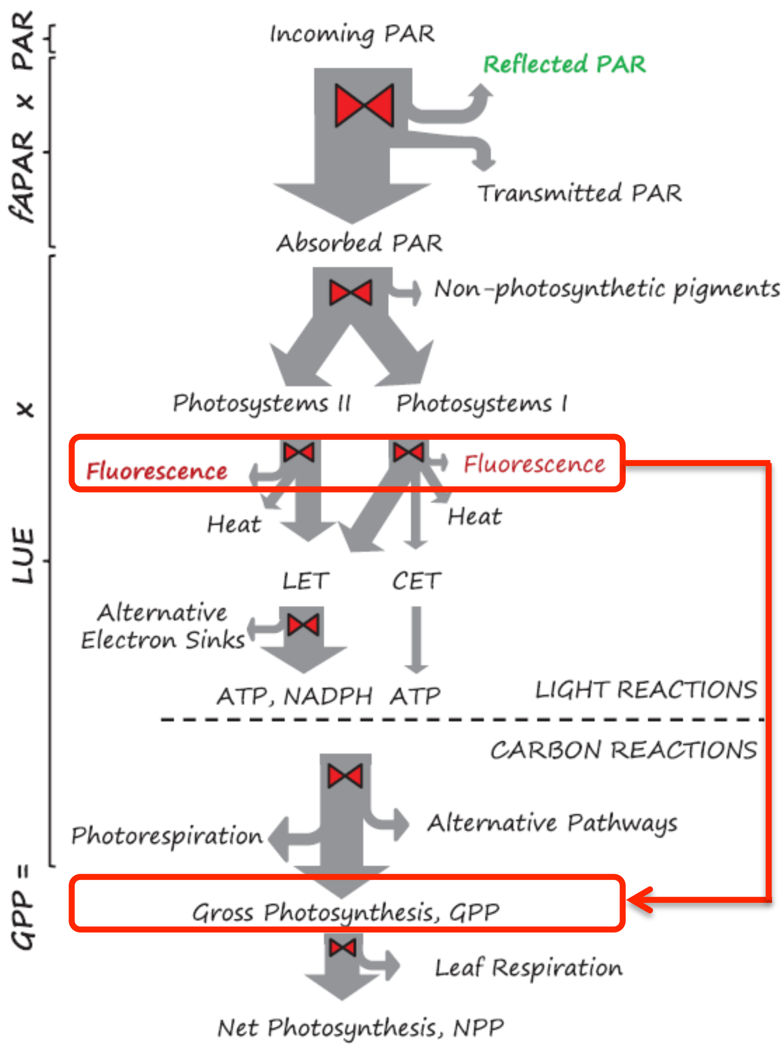
Hilker et al. (2014)

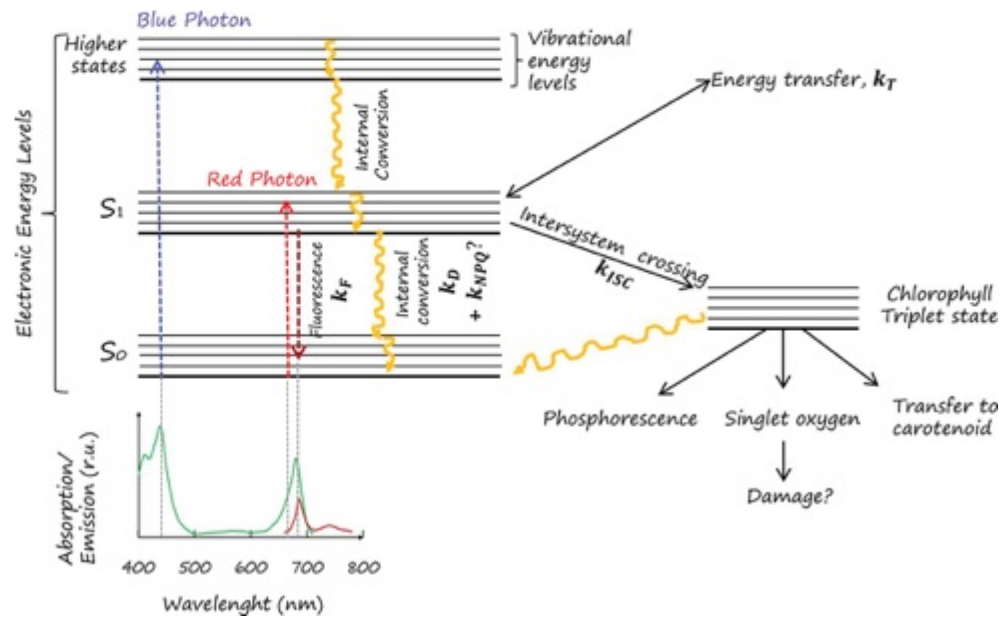
PRI



Hilker et al. (2014)

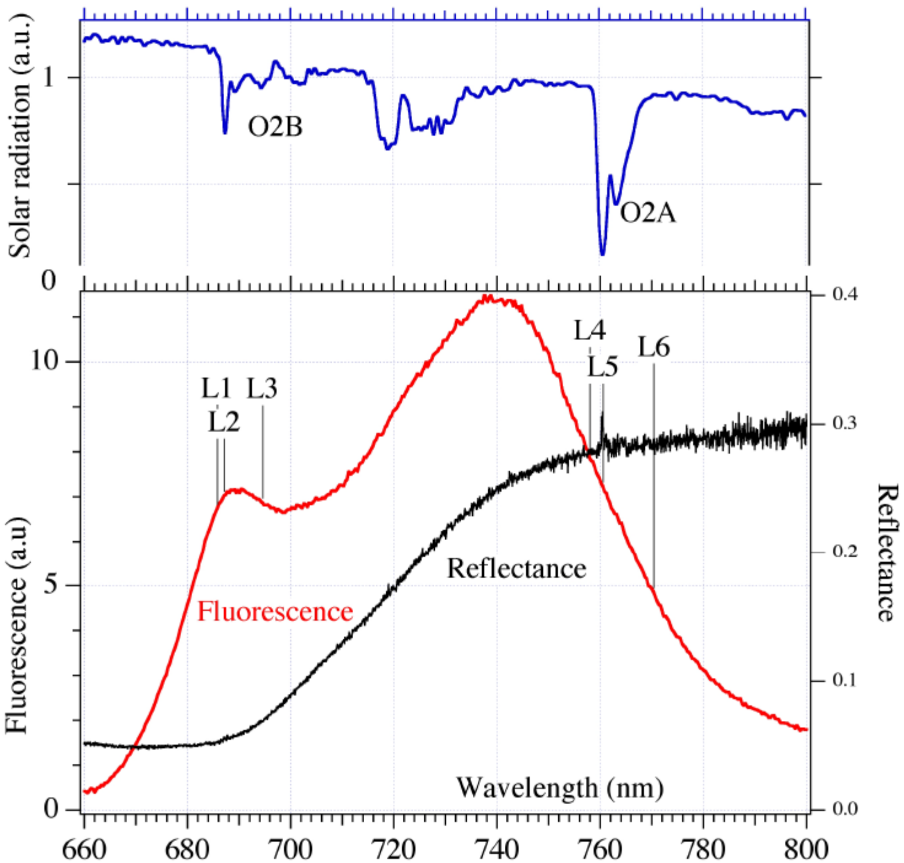
Sun-induced fluorescence



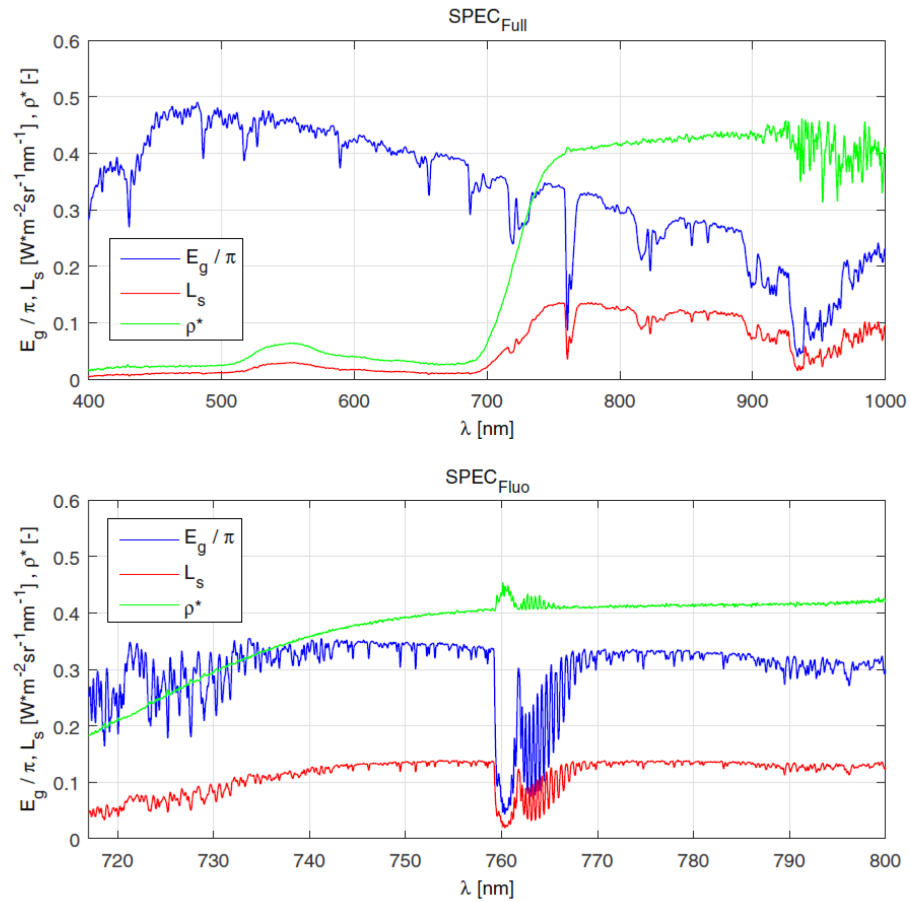


Porcar-Castell et al. (2014)

Sun-induced fluorescence



Rascher et al. (2008)



Cogliati et al. (2015)

Sun-induced fluorescence

Measurements → Model → GPP

SIF

$GPP = PAR \cdot fAPAR \cdot \varepsilon_p$

$SIF = PAR \cdot fAPAR \cdot \varepsilon_f$

$\varepsilon_p/\varepsilon_f \approx \Phi_p/\Phi_f \approx const.$

$GPP = SIF \cdot \varepsilon_p/\varepsilon_f$

Lee et al. (2013)

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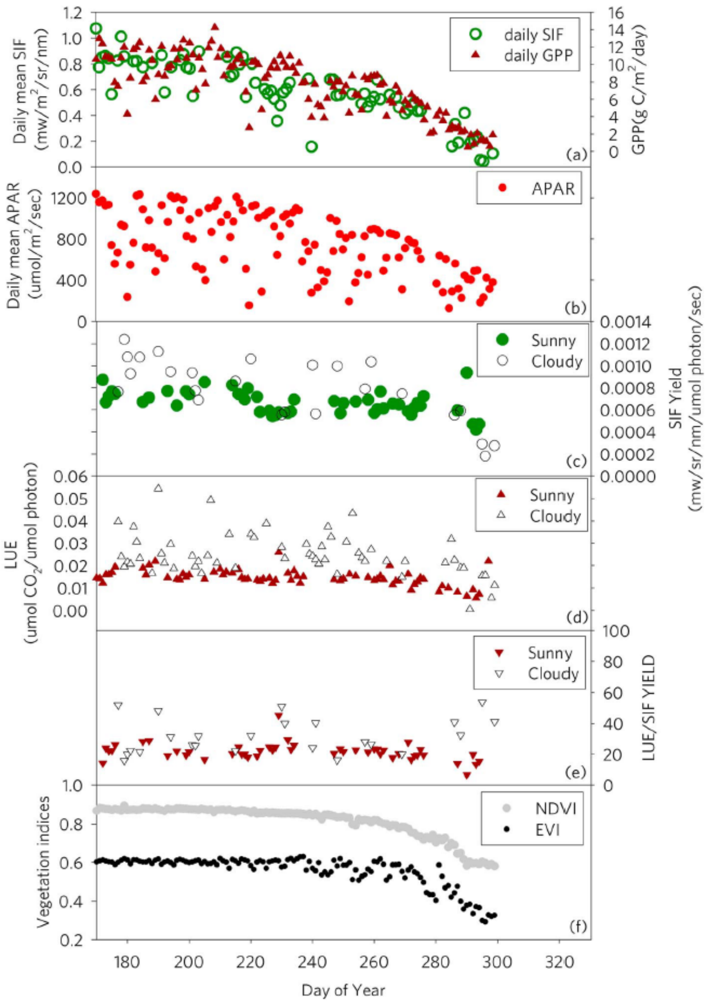
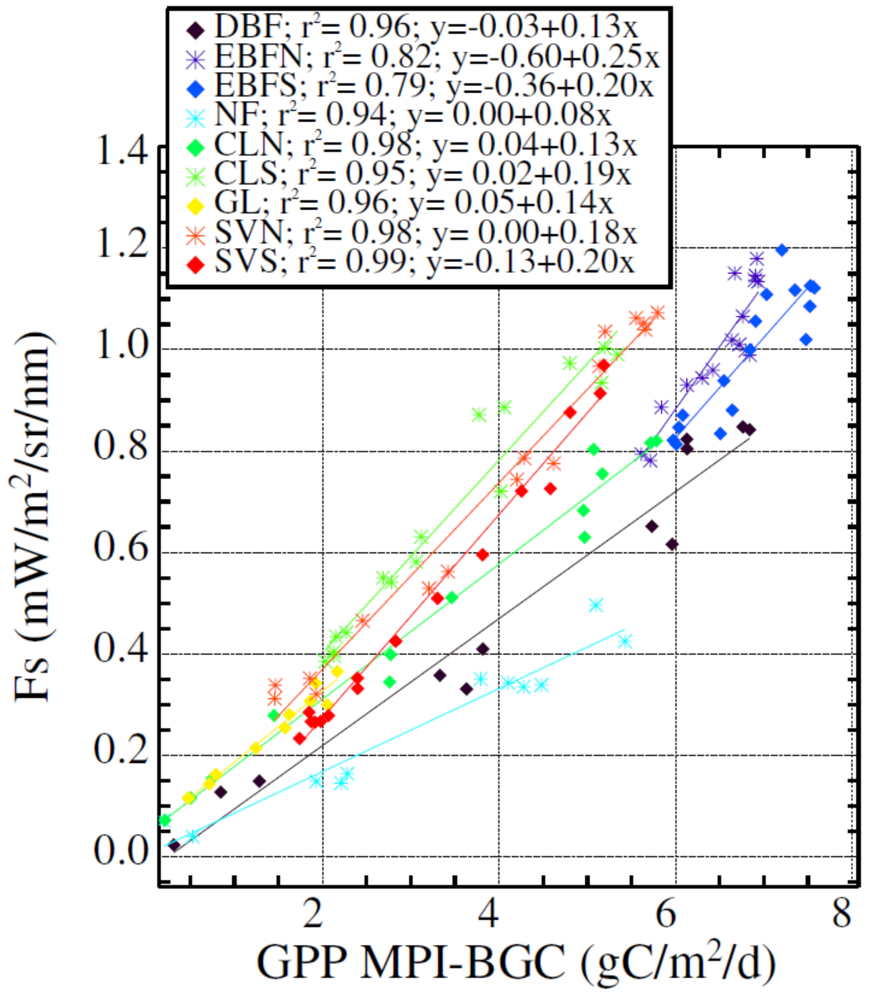
Sun-induced fluorescence

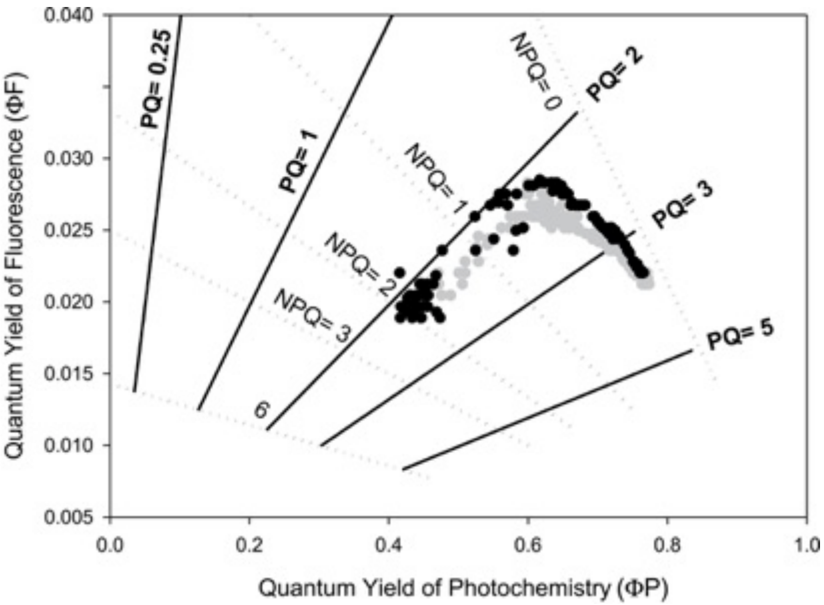


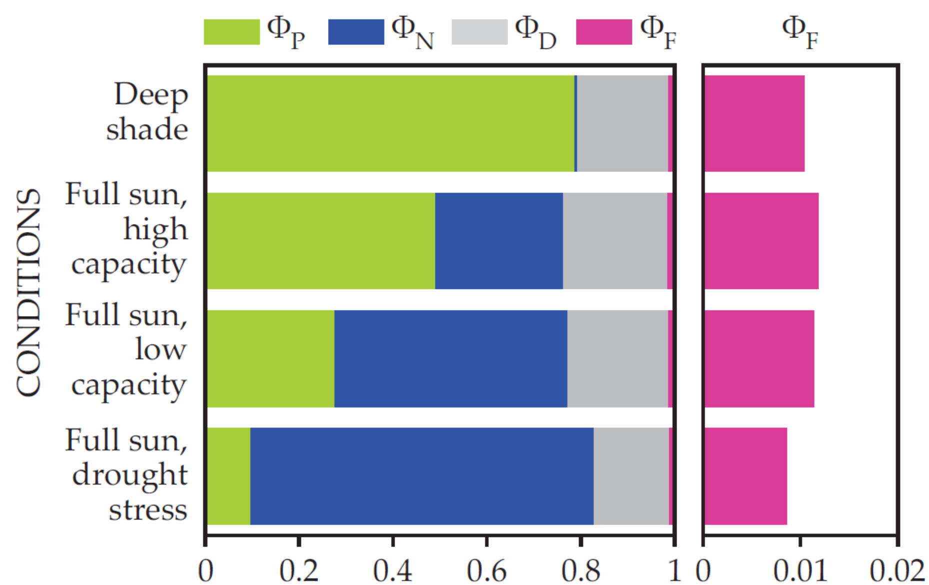
Yang et al. (2015)



Guanter et al. (2012)

Sun-induced fluorescence





Porcar-Castell et al. (2014)

Schlau-Cohen & Berry (2015)

CO_2-FP revisited

$NEP_n = -(R_{dark} + R_{non\text{-}leaf})$

$NEP_d = V_c - 0.5V_o - (R_{day} + R_{non\text{-}leaf})$

f(T)

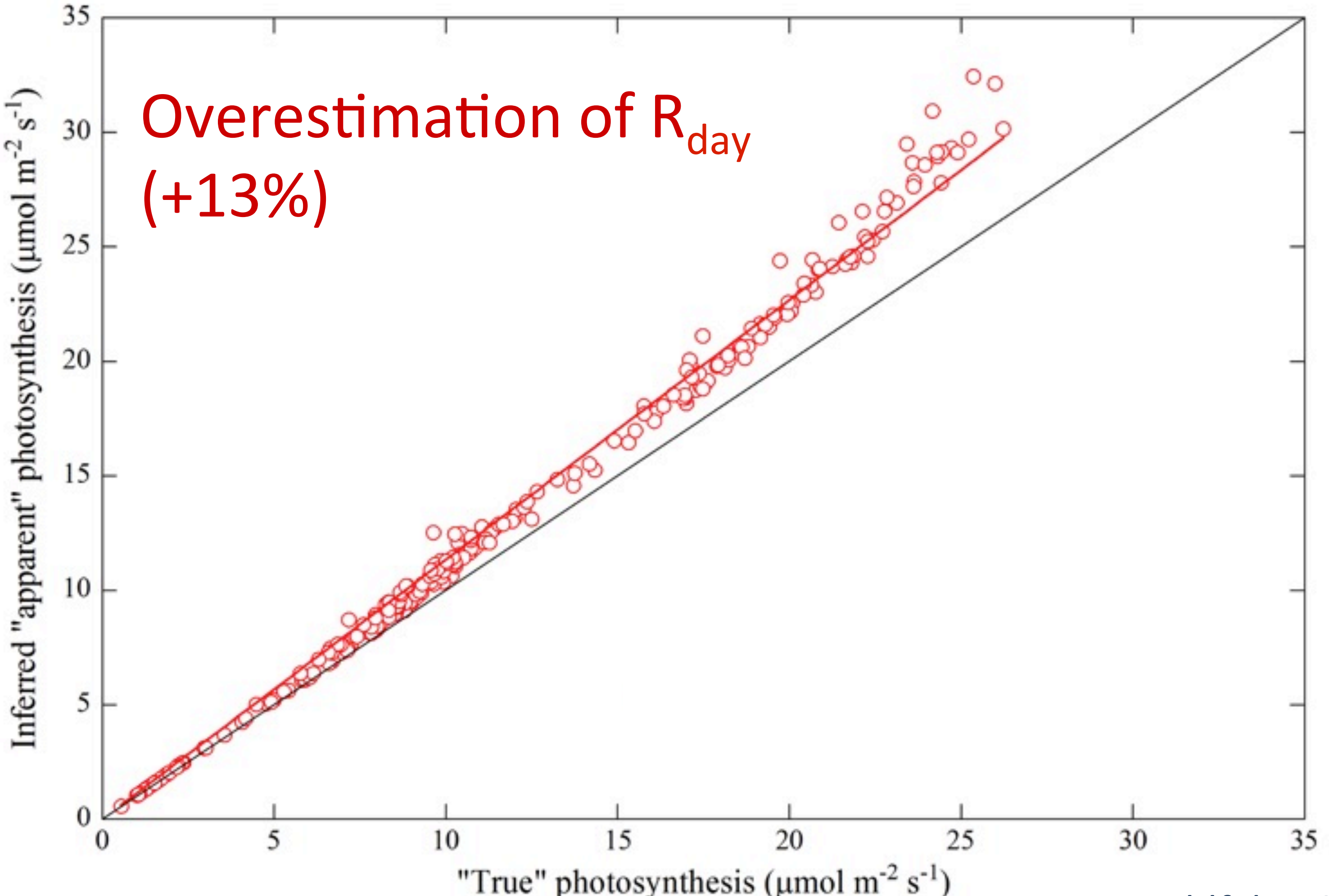
$R_{day} = R_{dark} \cdot k$

$0.2 < k < 1.3$

(Niinemets, 2014)

#1: because $R_{day} < R_{dark}$, NEP_n overestimates daytime ecosystem respiration

CO_2-FP revisited



Wohlfahrt & Gu (2015)

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CO_2-FP revisited

$R_{day} = R_{dark} \cdot k$

$0.2 < k < 1.3$

(Niinemets, 2014)

$NEP_n = -(R_{dark} + R_{non\text{-}leaf})$

f(T)

$NEP_d = V_c - 0.5V_o - (R_{day} + R_{non\text{-}leaf})$

#1: because $R_{day} < R_{dark}$, NEP_n overestimates daytime ecosystem respiration

#2: NEP_n carries no information about photorespiration

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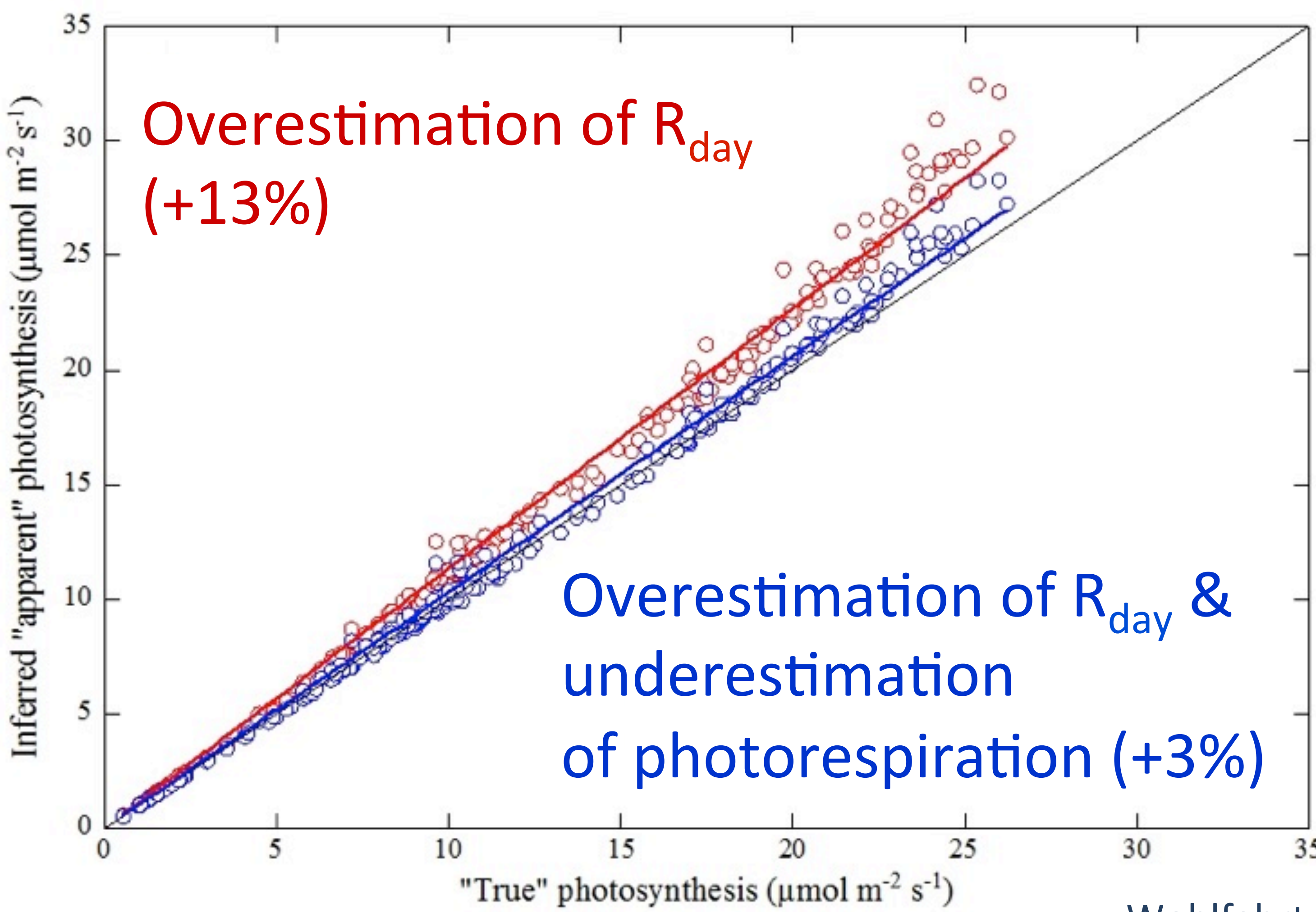
CO_2-FP revisited



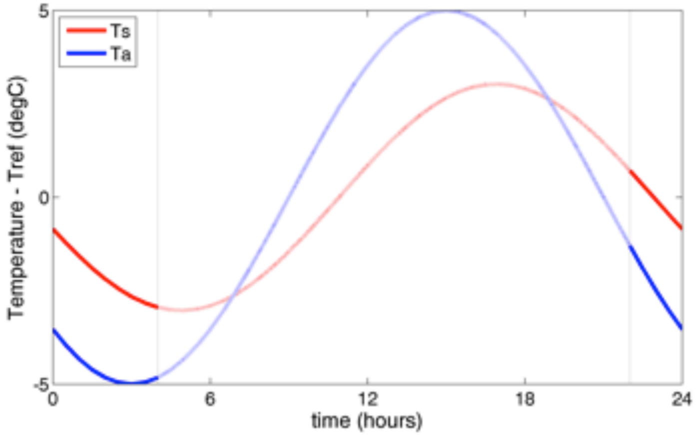
Wohlfahrt & Gu (2015)

CO_2-FP revisited

$R_{eco} = R_s + R_{ag}$

$R_s = f(T_s)$

$R_{ag} = f(T_a)$



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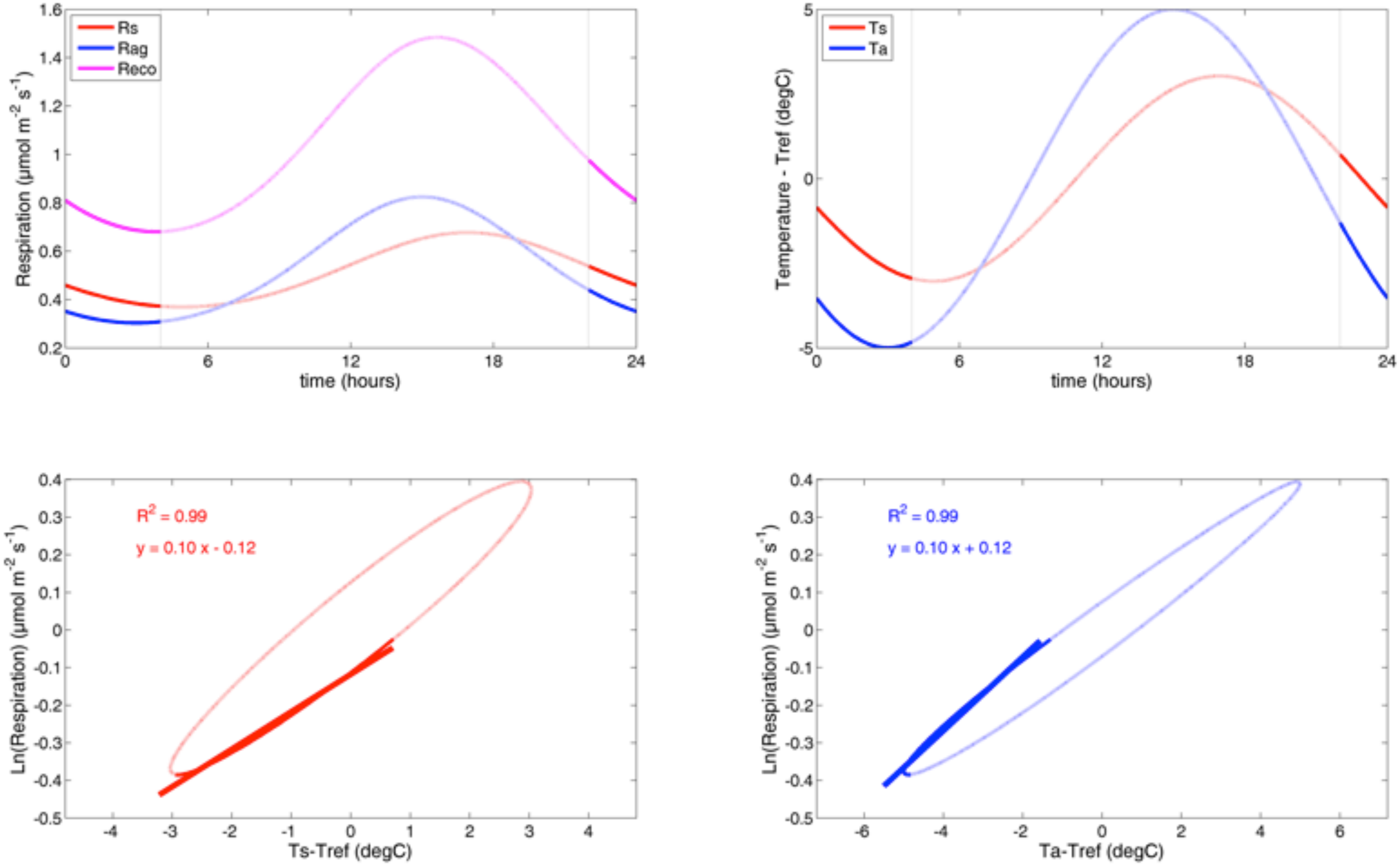
CO_2-FP revisited



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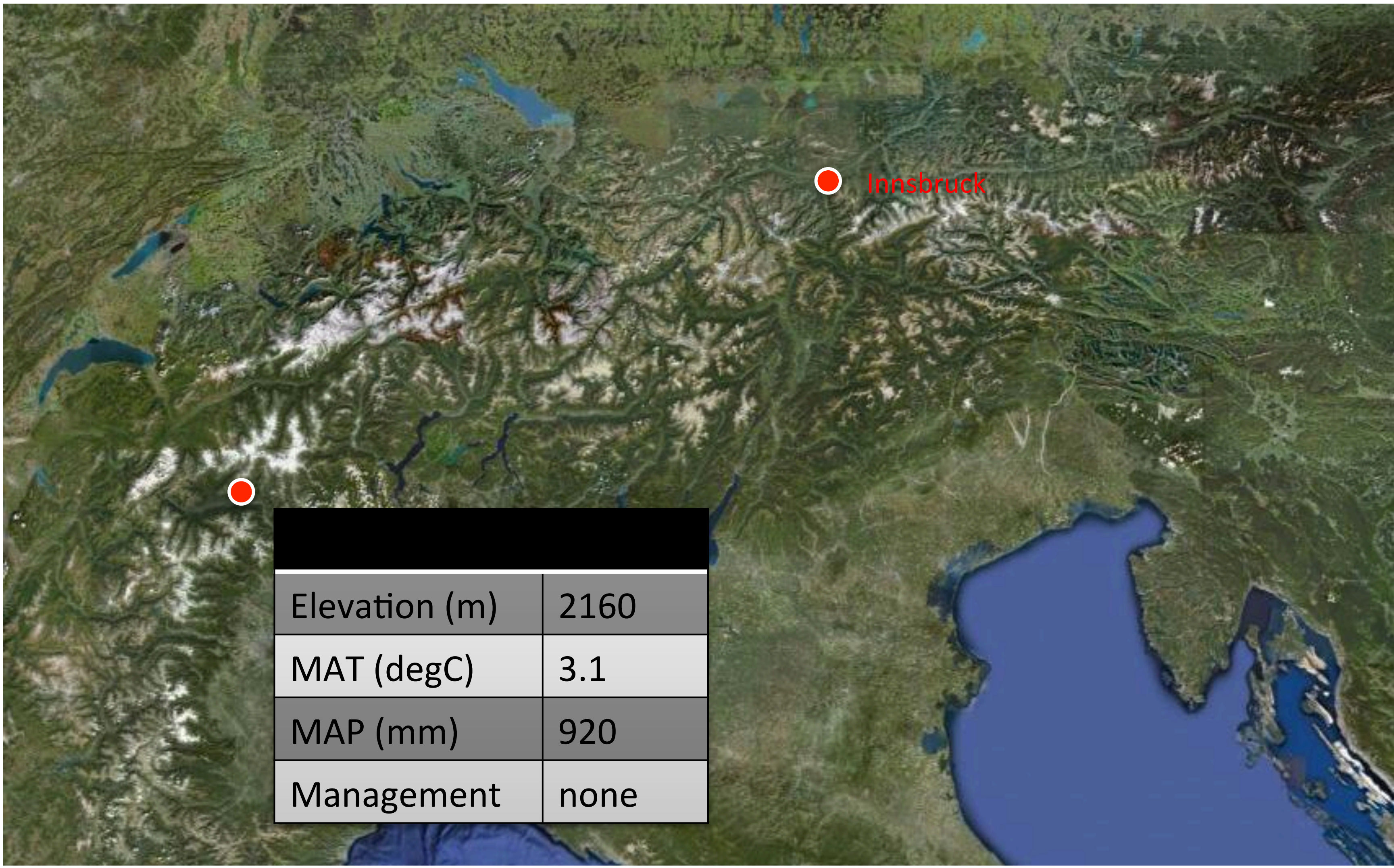
CO_2-FP revisited

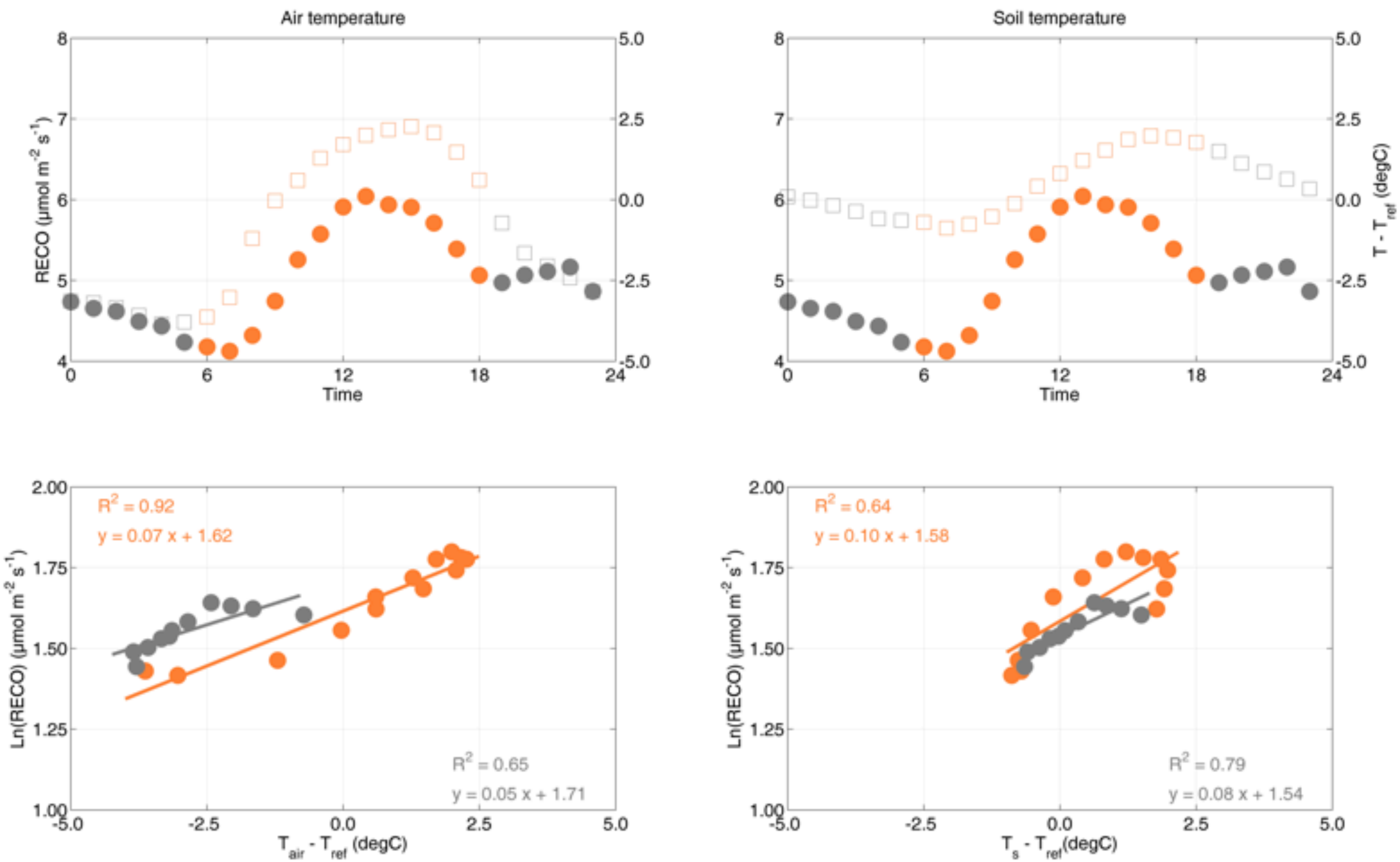


[redacted]	
Elevation (m)	2160
MAT (degC)	3.1
MAP (mm)	920
Management	none

CO_2-FP revisited

"dark" R_{eco}

CO_2-FP revisited



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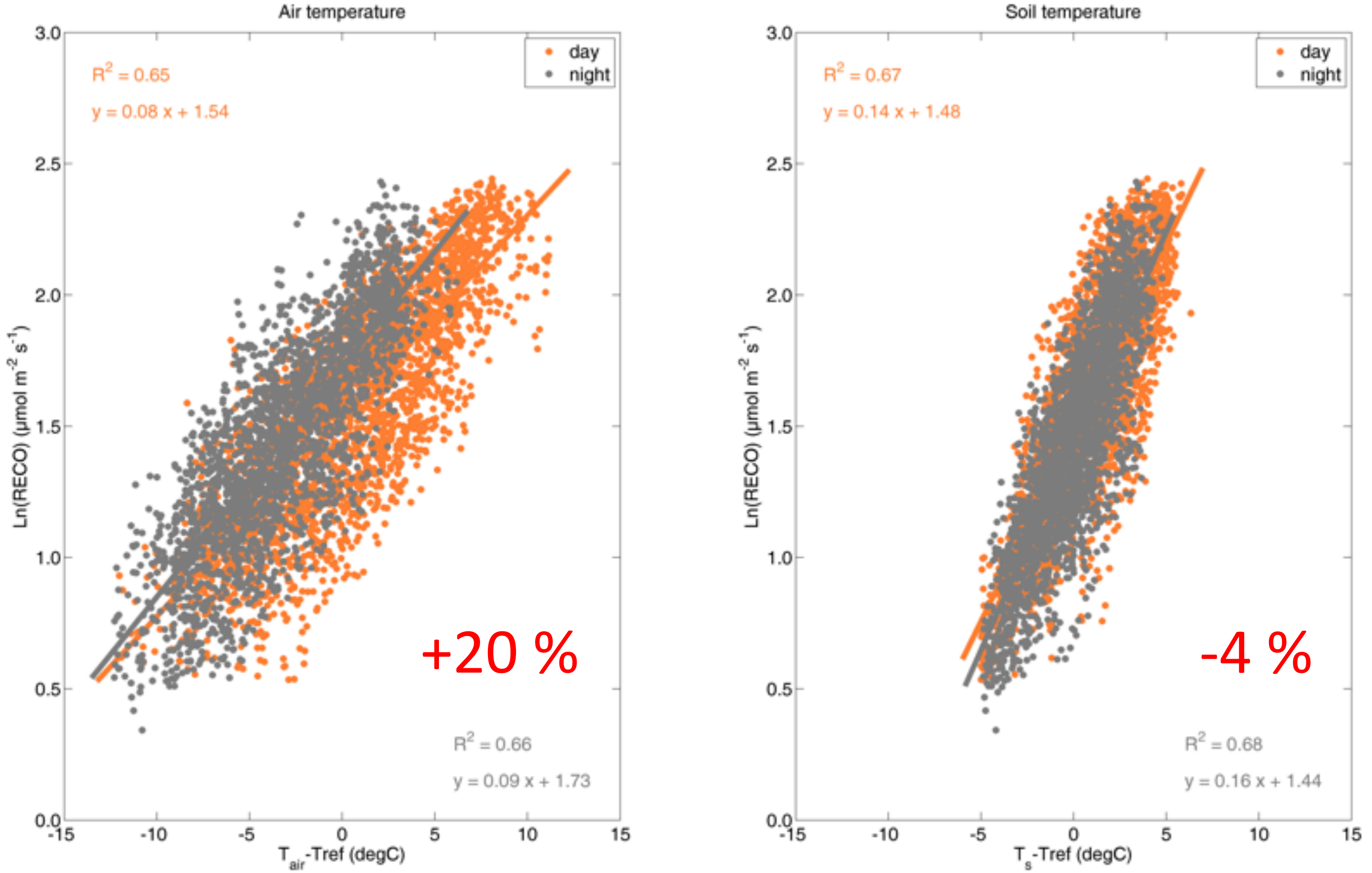
CO_2-FP revisited



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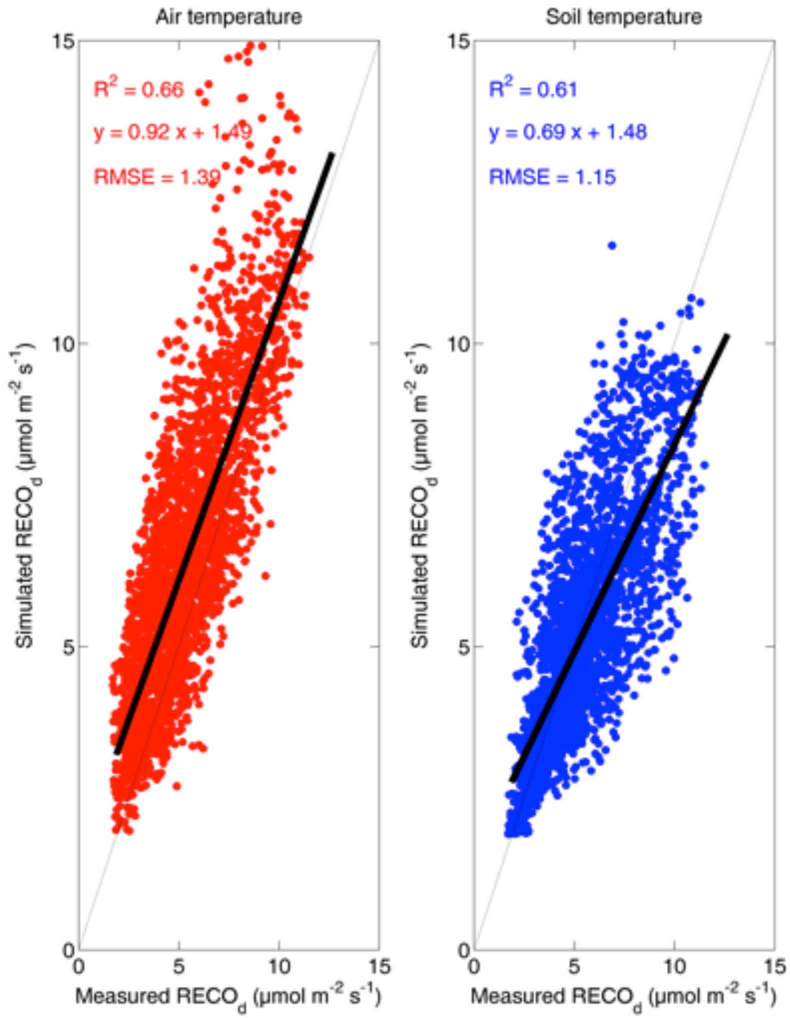
CO_2-FP revisited



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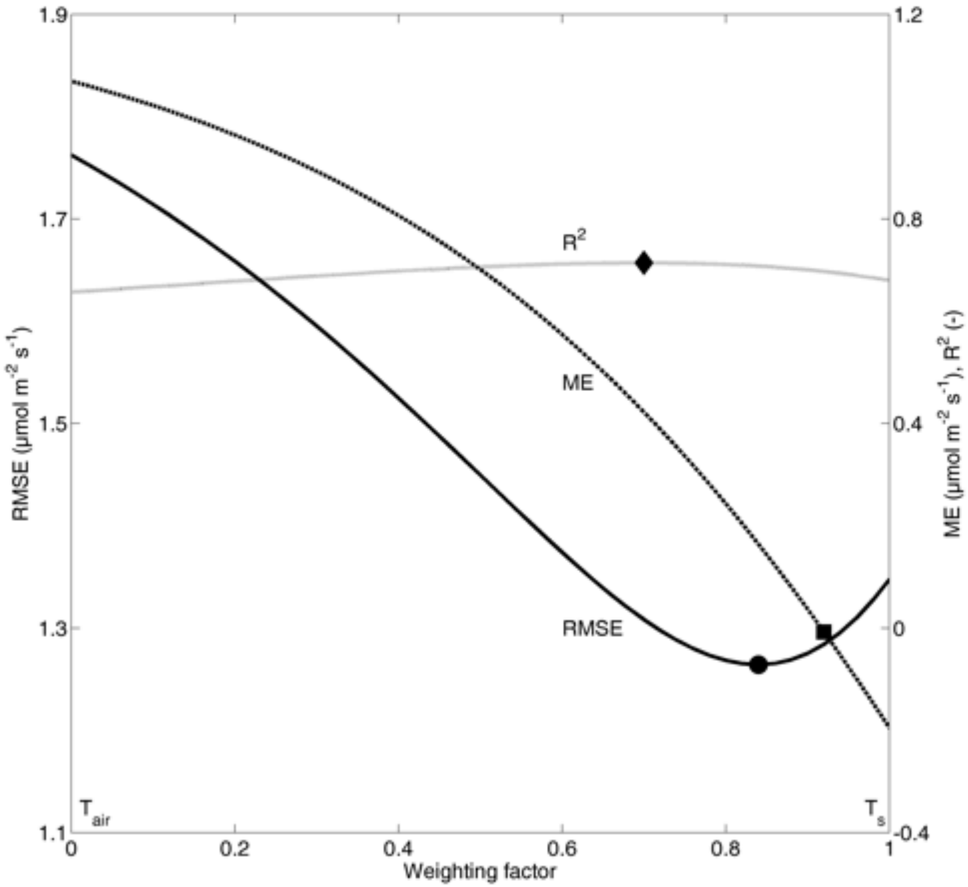
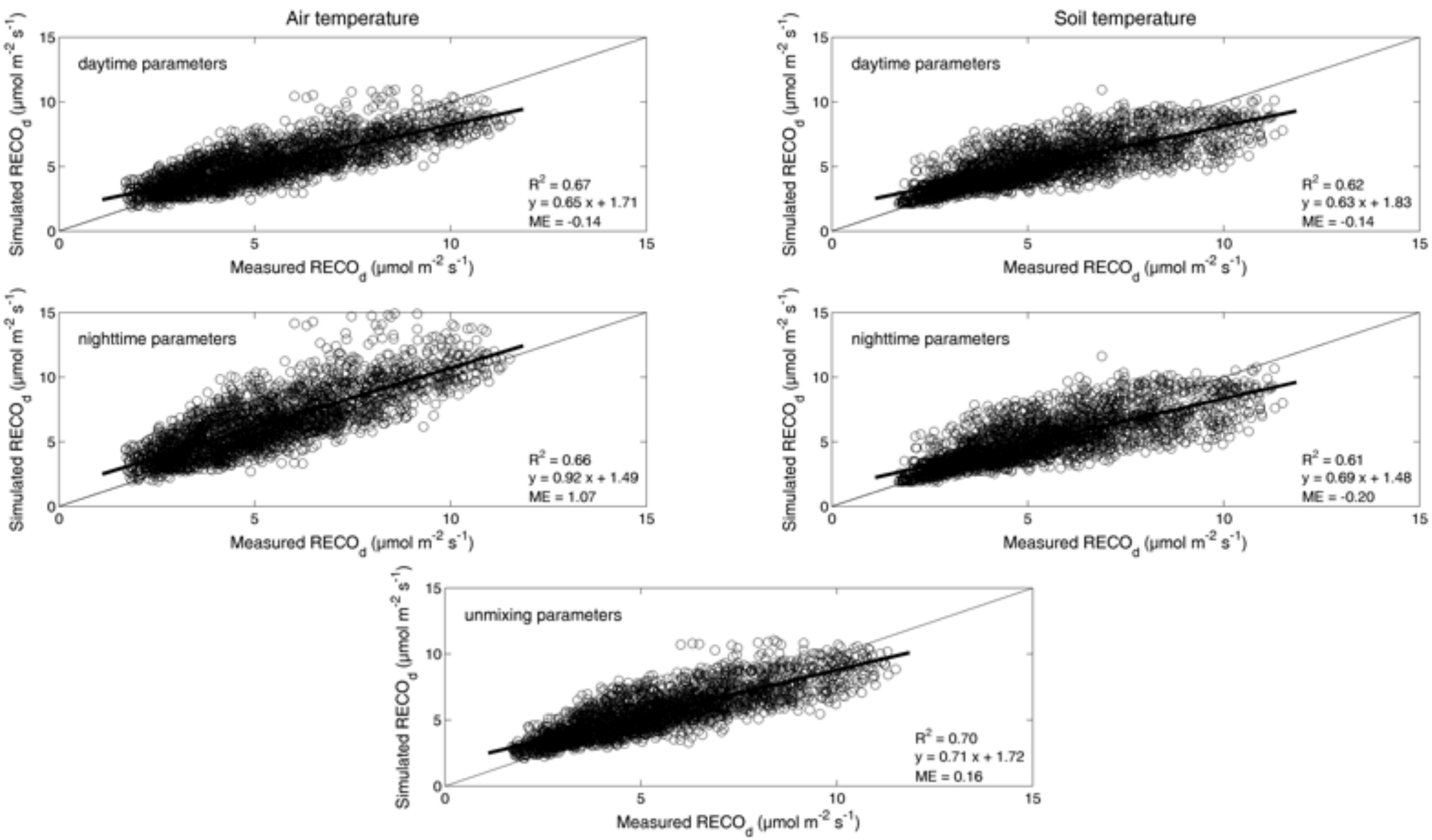
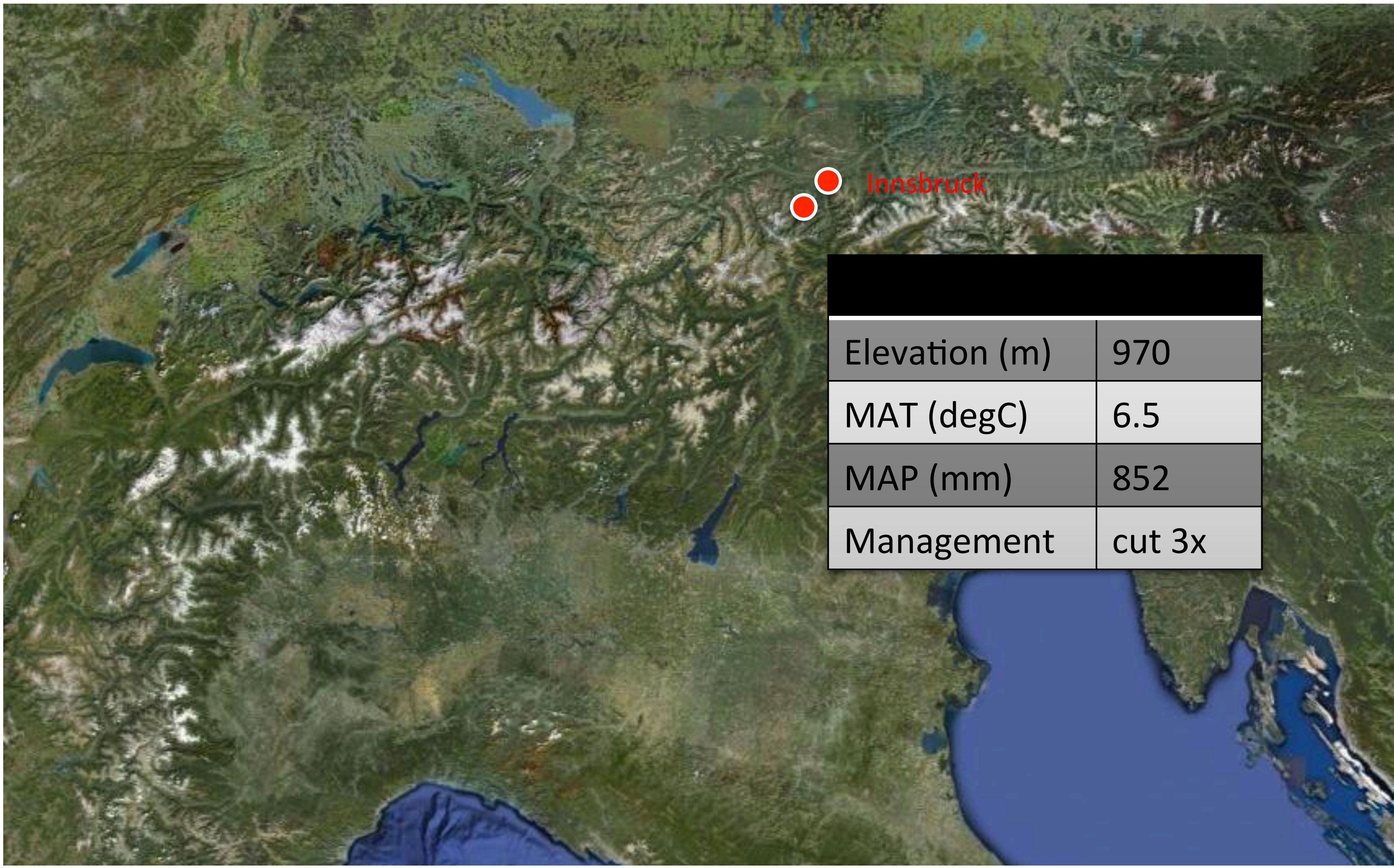
CO_2-FP revisited



CO_2-FP revisited



COS flux partitioning



[redacted]	
Elevation (m)	970
MAT (degC)	6.5
MAP (mm)	852
Management	cut 3x

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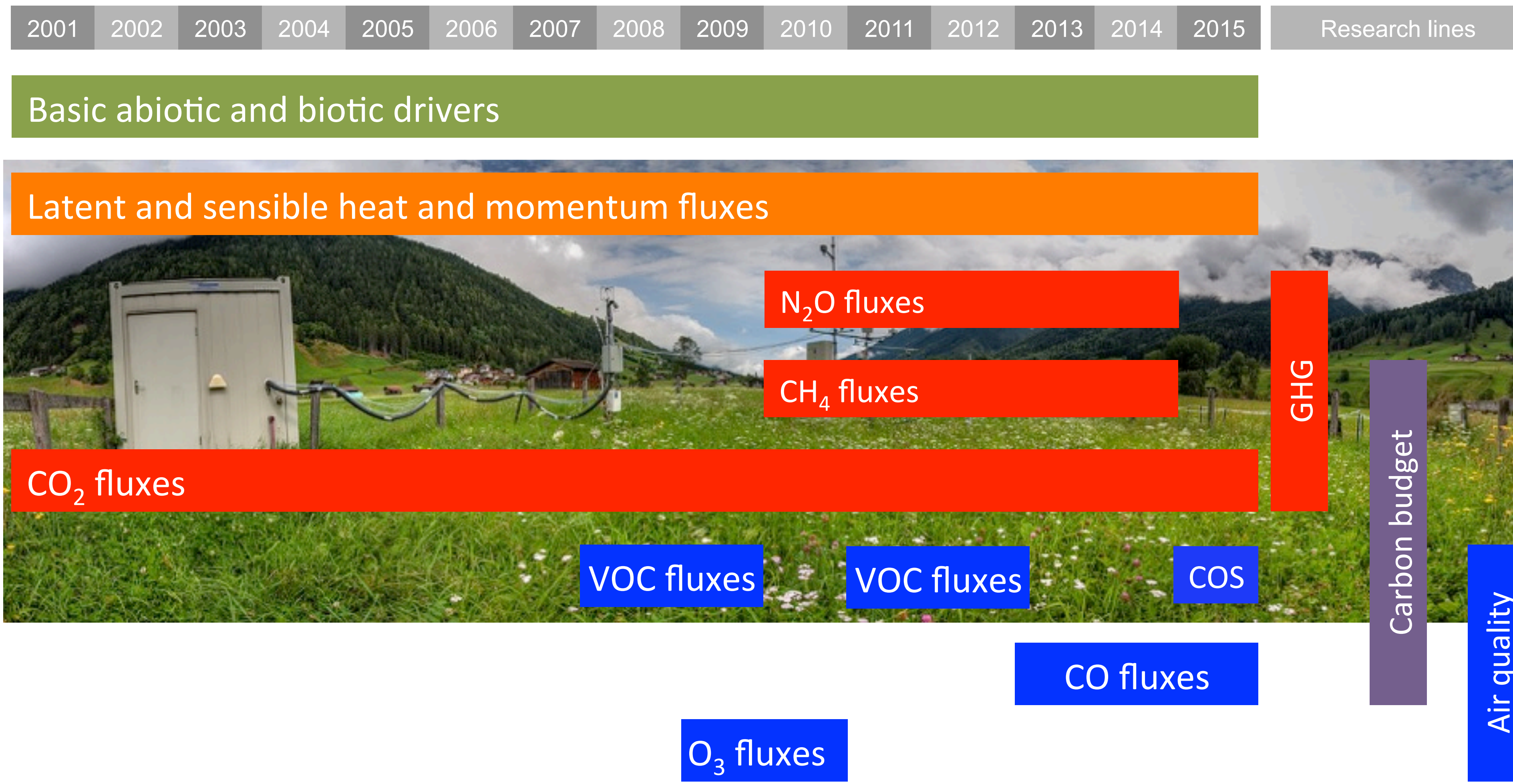
COS flux partitioning



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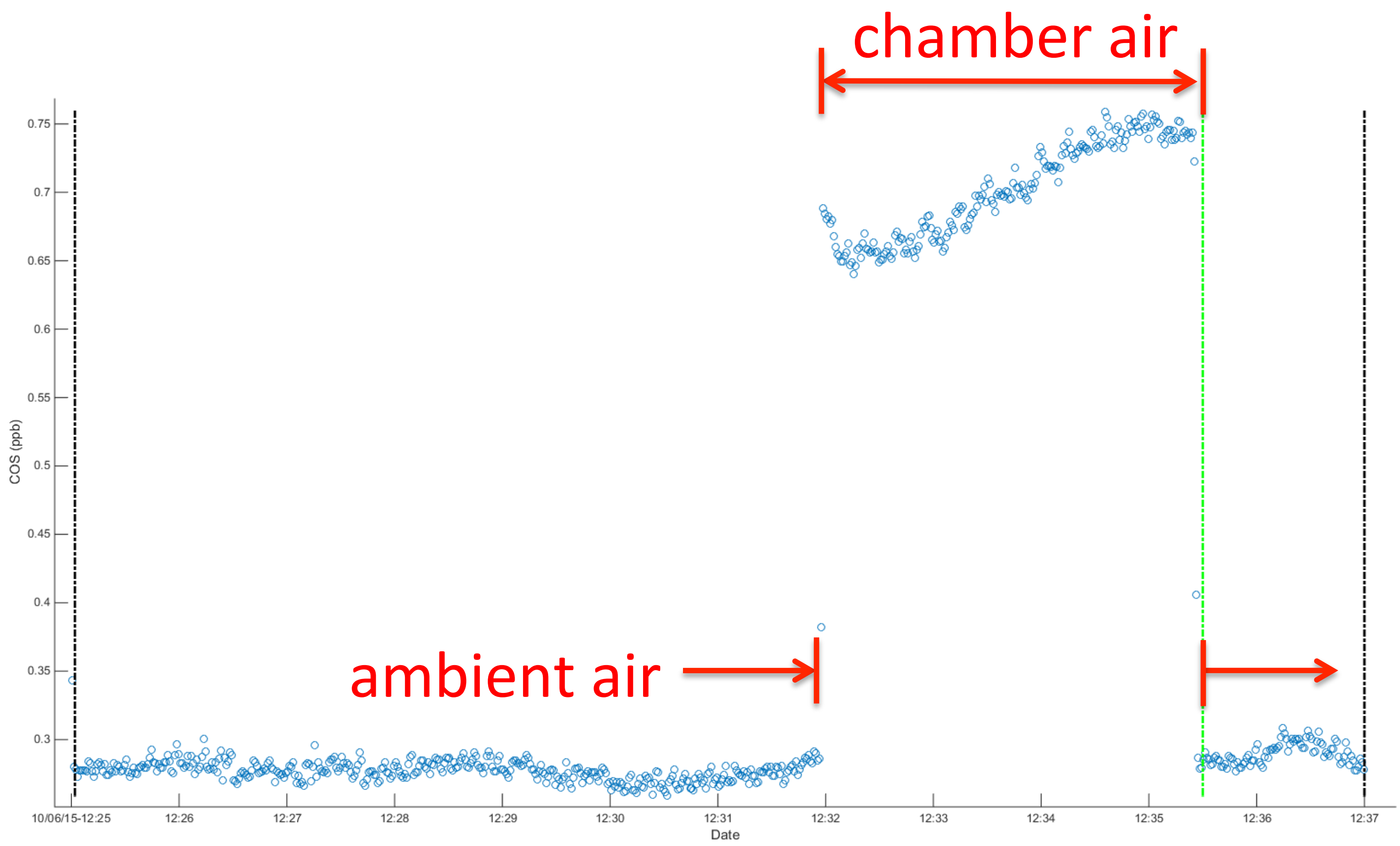
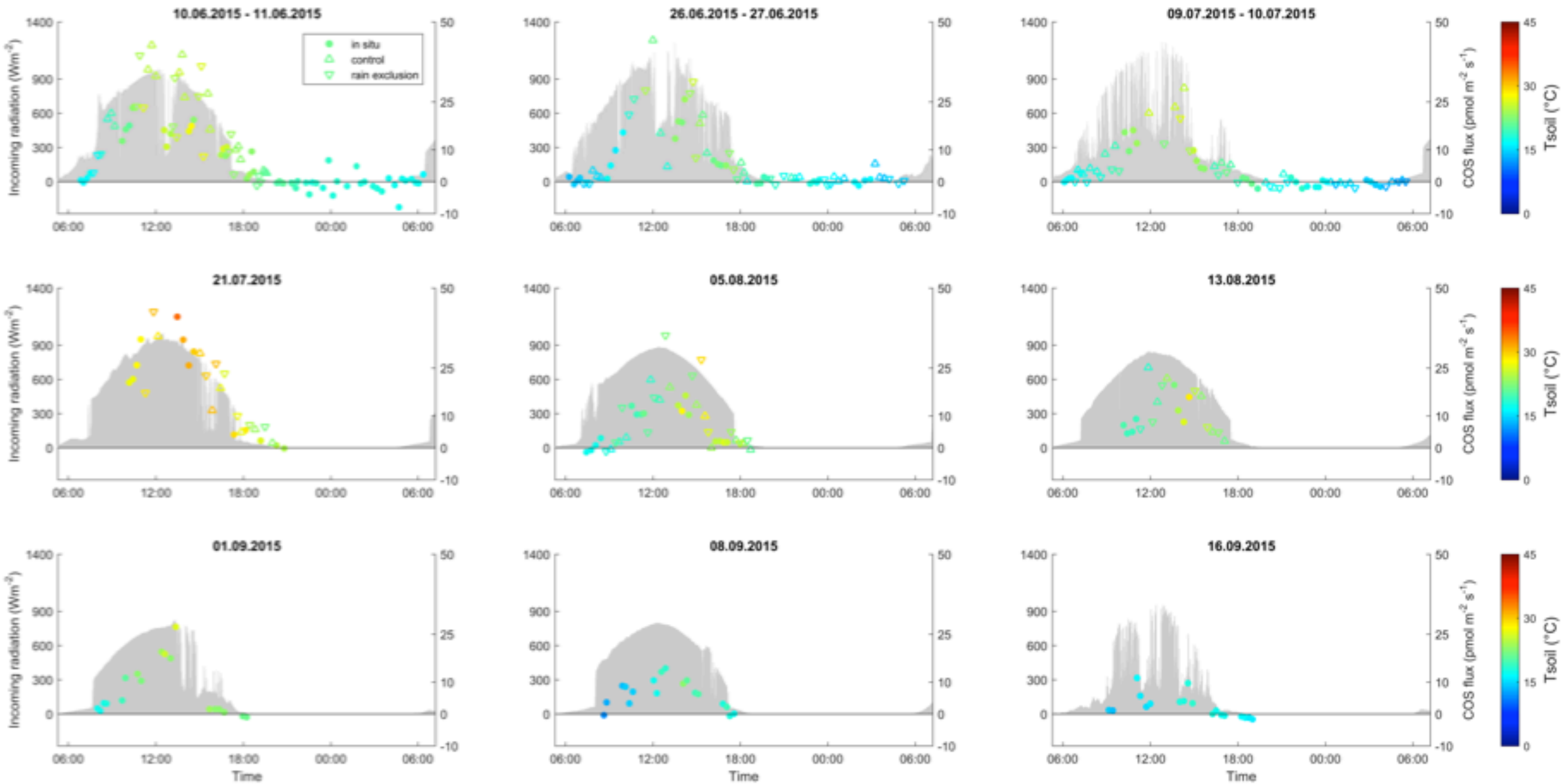
COS flux partitioning



COS flux partitioning



Kitz et al. (submitted)

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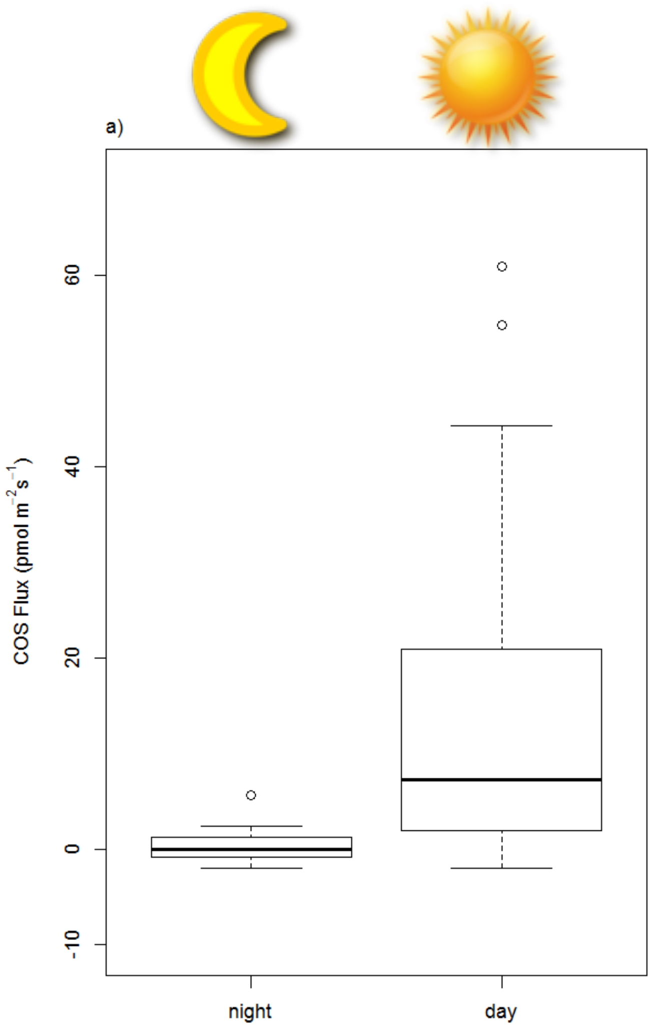
COS flux partitioning



Kitz et al. (submitted)

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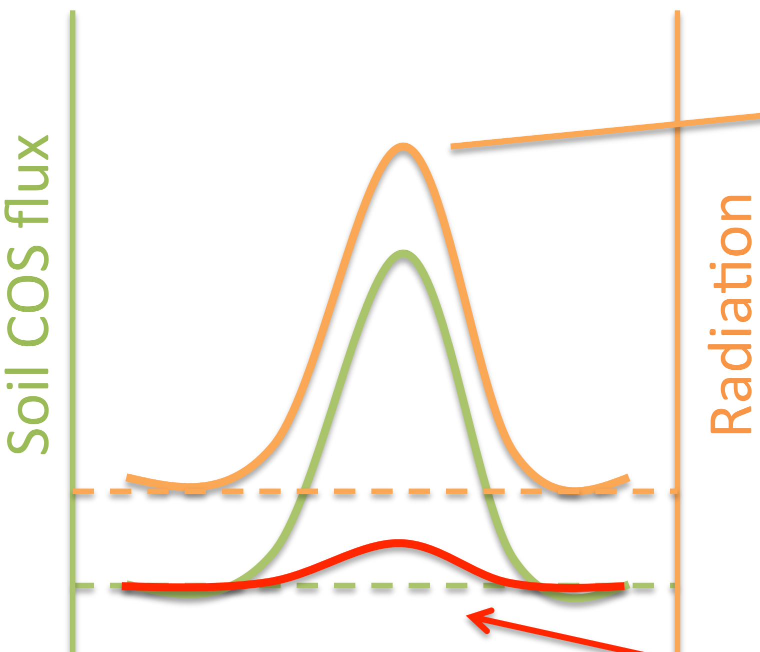
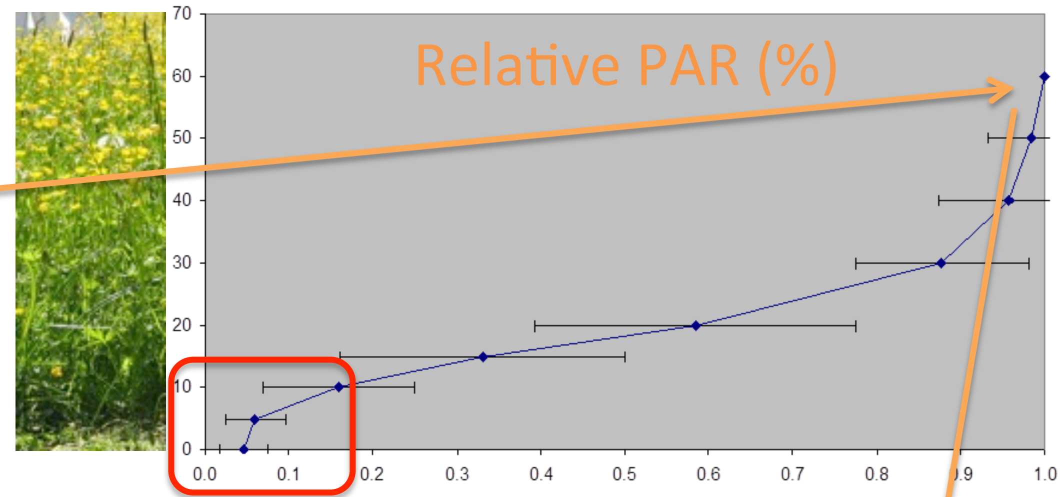
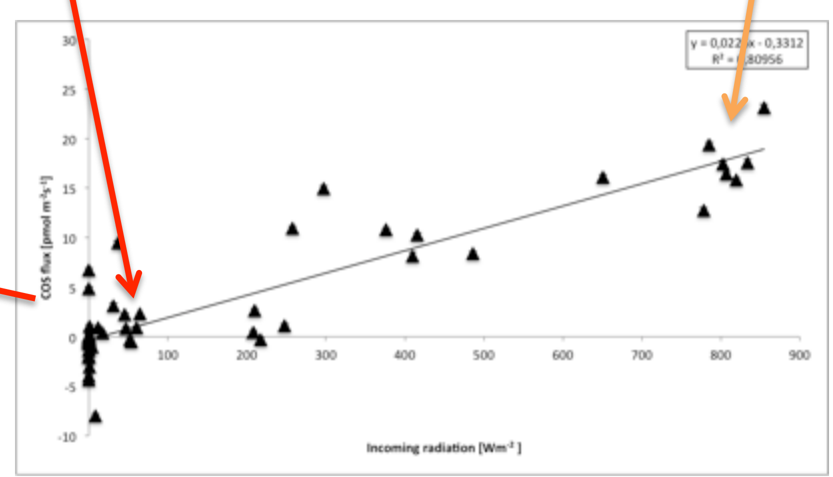
COS flux partitioning







„True“ soil COS exchange

Kitz et al. (in preparation)

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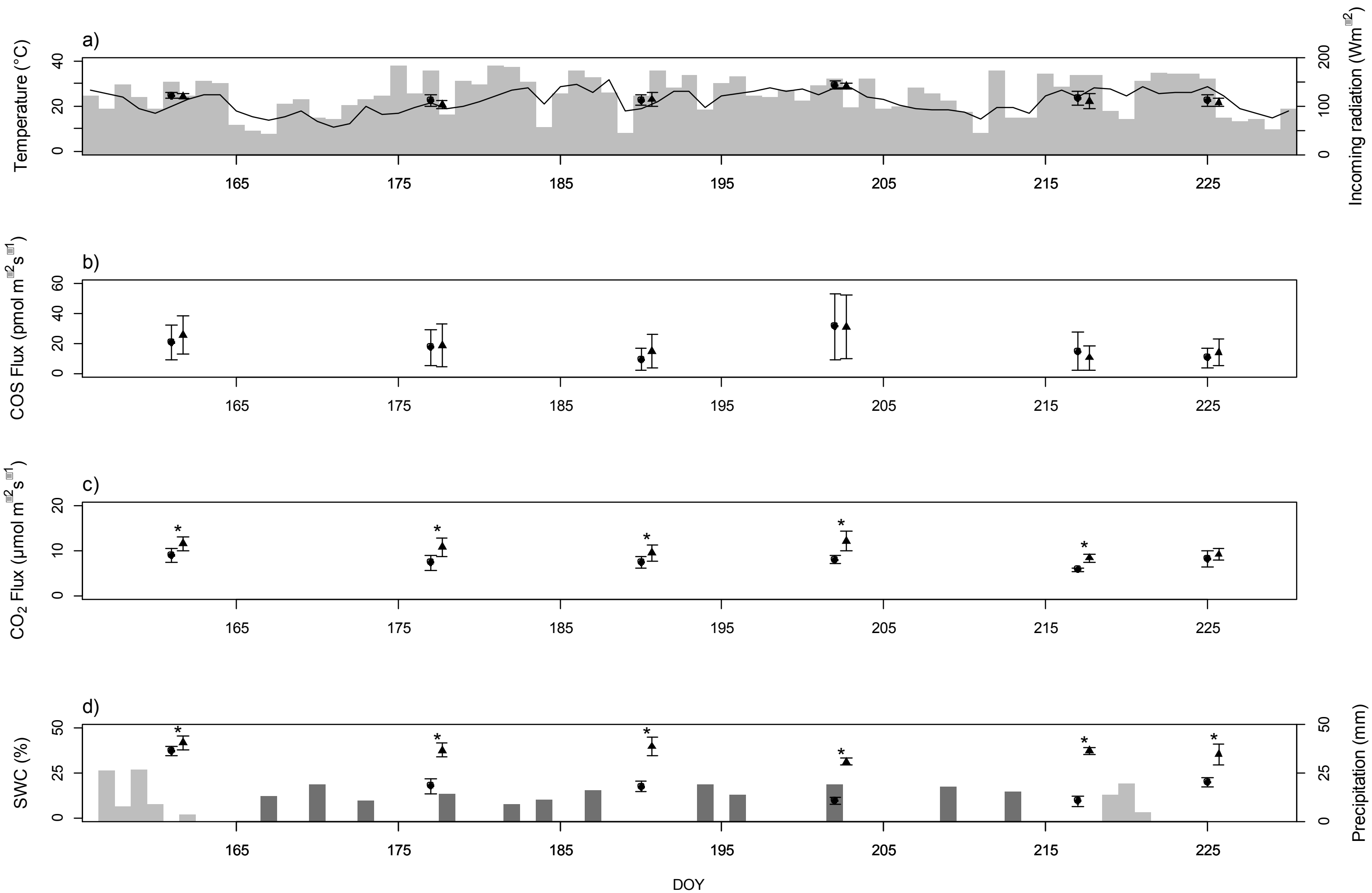
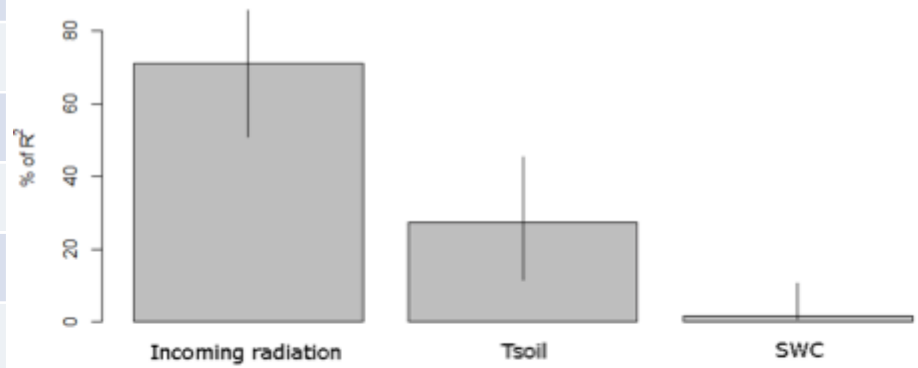
COS flux partitioning



Kitz et al. (submitted)

COS flux partitioning

	Dependent variable:
	log10(COS_flux)
Incoming radiation	0.001*** (0.0001)
Tsoil	0.048*** (0.009)
SWC	0.005 (0.003)
Constant	-0.855*** (0.250)
Observations	55
R^2	0.704
Residual Std. Error	0.241 (df = 51)
F Statistic	40.417*** (df = 3; 51)
Note:	*p<0.05 **p<0.01 ***p<0.001



R^2 = 70.39%, metrics are normalized to sum 100%.

Kitz et al. (submitted)

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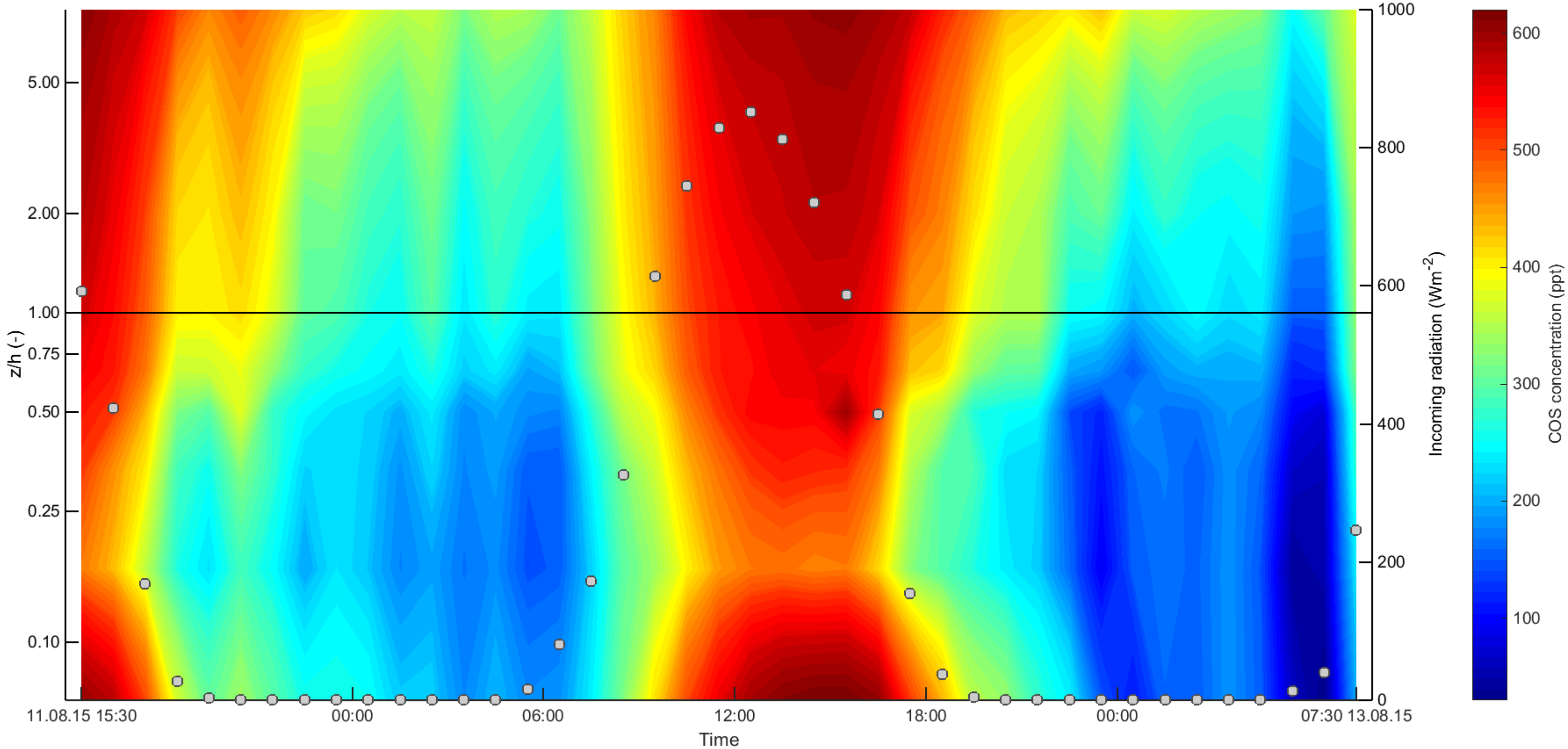
COS flux partitioning



Spielmann et al. (in preparation)

University of Innsbruck
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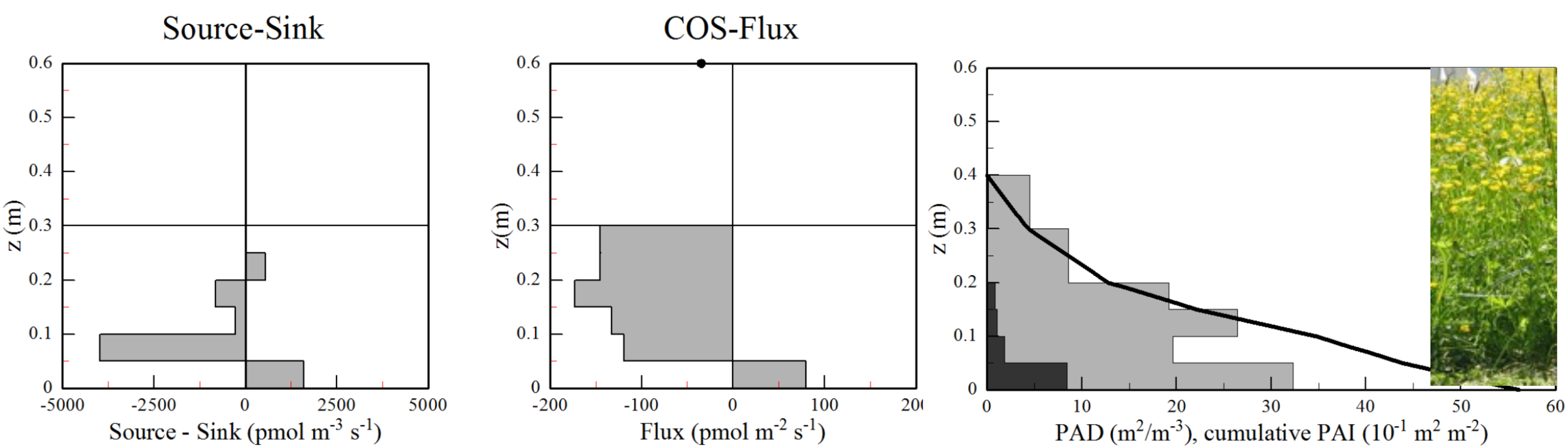
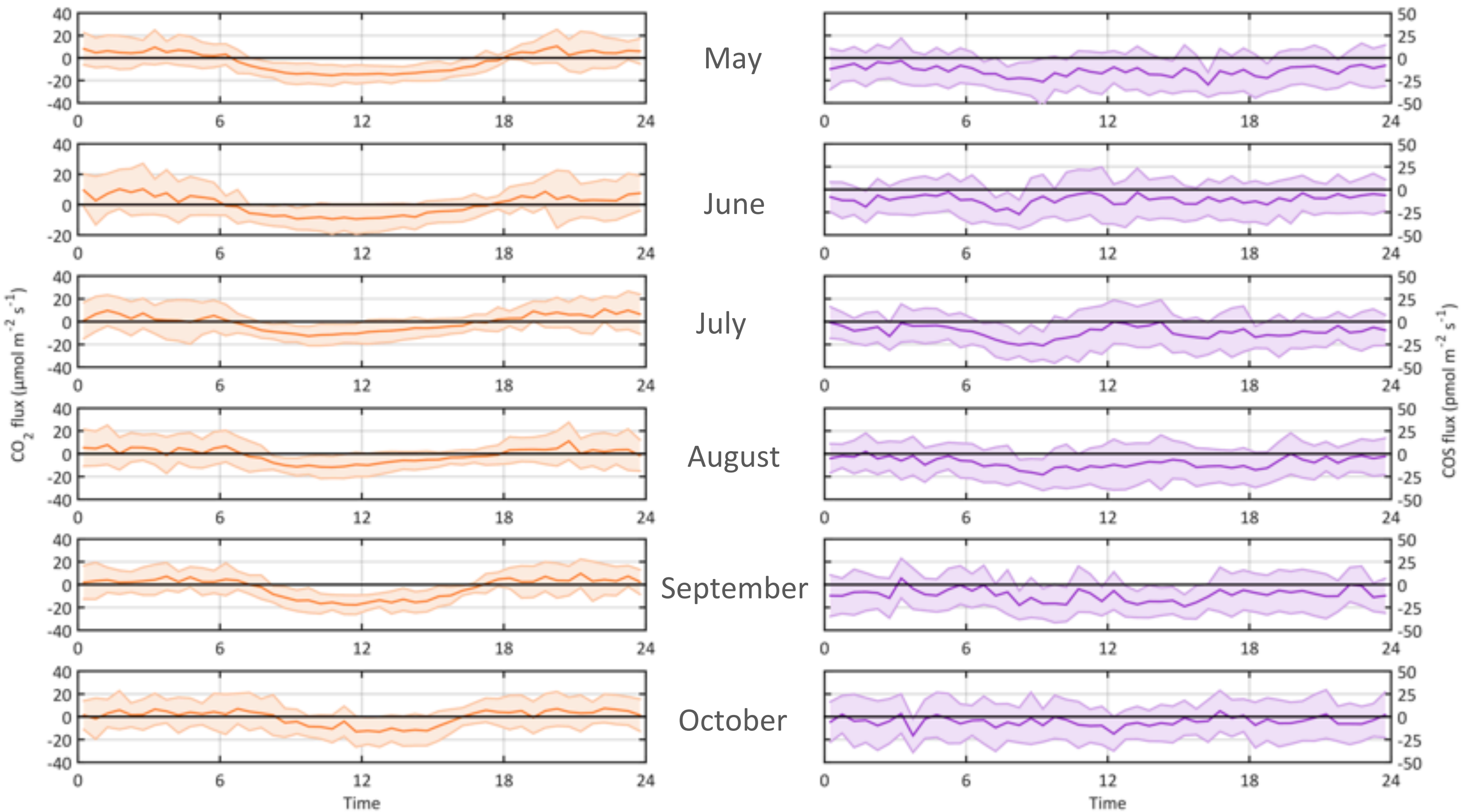
COS flux partitioning

Example for inversion of Lagrangian turbulent transport model (around midday)



Spielmann et al. (in preparation)

COS flux partitioning



Spielmann et al. (in preparation)

Conclusions

	Level of complexity	Level of understanding	Wider applicability
CO_2 flux partitioning	L	M	H
Isotopic flux partitioning	H	M	L
COS flux partitioning	M	L	L
Sun-induced fluorescence	H	L	VH
Photochemical reflectance index	M	L	VH

L … low, M … medium, H … high, VH … very high

Conclusions

⌘ And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right,
And all were in the wrong!

The blind man and the Elephant (John Godfrey Saxe, 1816-1887)