Modelling the impacts of diffuse light fraction on photosynthesis in ORCHIDEE

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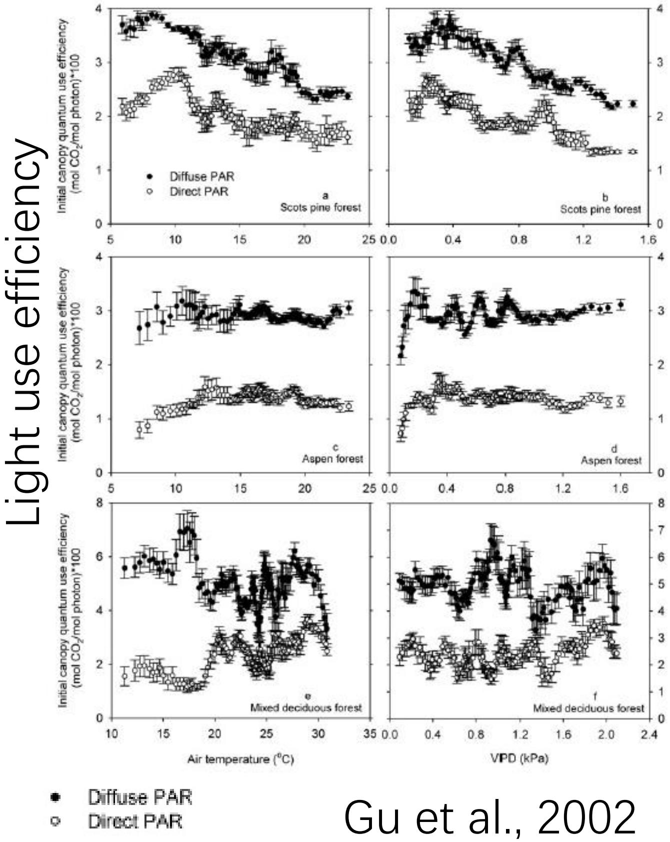
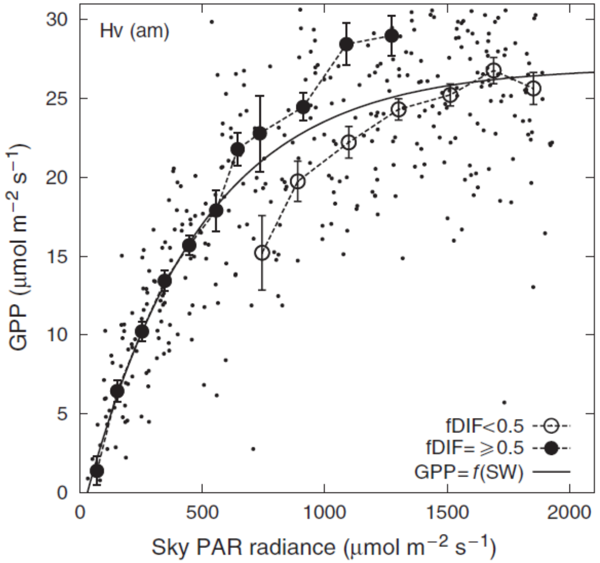
Background

1. Diffuse radiation is found to enhance photosynthesis by re-distributing radiation more evenly in vegetation canopy.

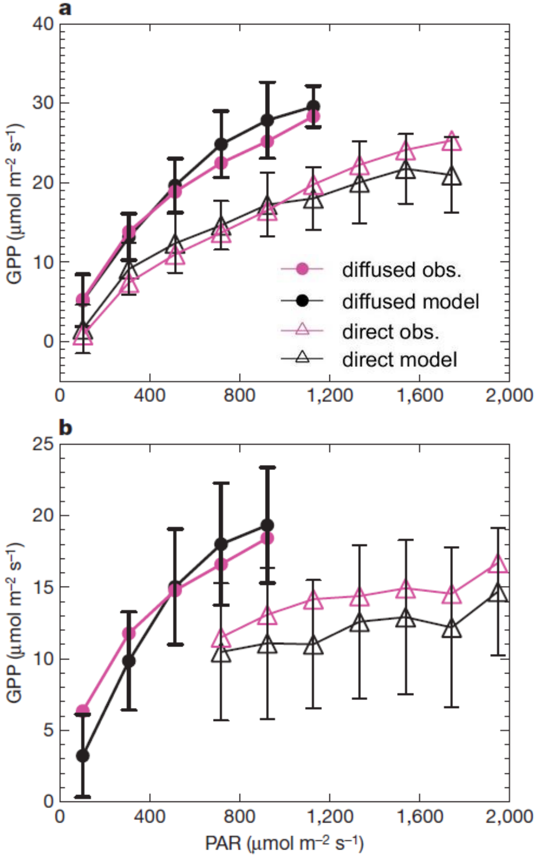


Gu et al., 2002



Alton et al., 2007

2. Some photosynthesis models have distinguished diffuse and direct radiation, but there remain few well-evaluated land surface models considering the effect of diffuse light



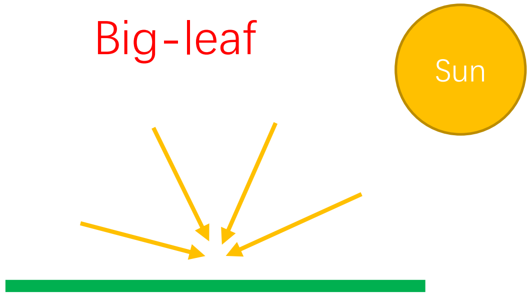
Mercado et al., 2009

3. It remains poorly known how diffuse radiation interact with other environmental factors like T, VPD

Targets: model the different transmission of diffuse and direct radiation in canopy in a land surface model ORCHIDEE,
evaluate the model with large fluxnet datasets (159)
investigate the interactions between diffuse radiation and environmental factors

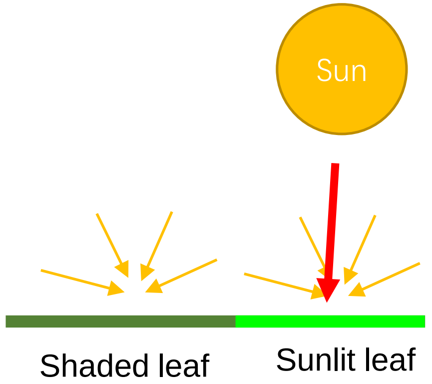
Different parameterizations of canopy light transmission

Big-leaf

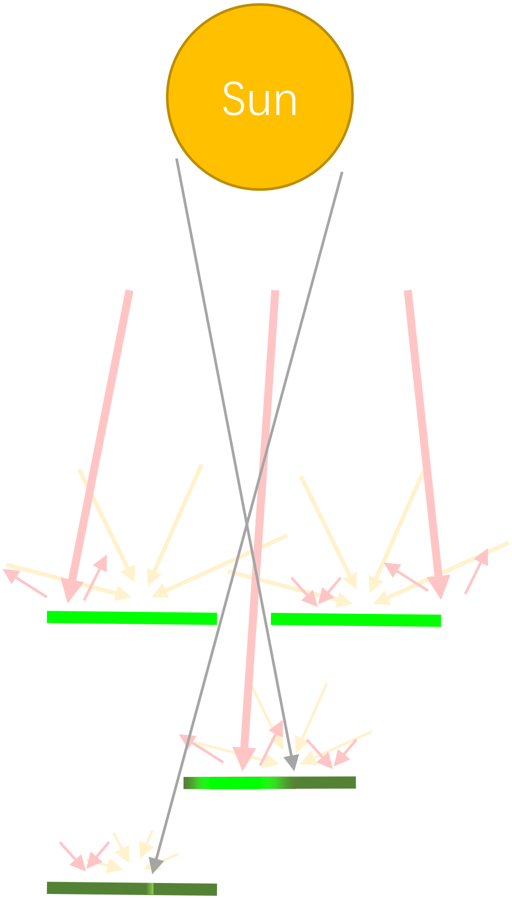


Two Big-leaf
(Dai et al. 2004)

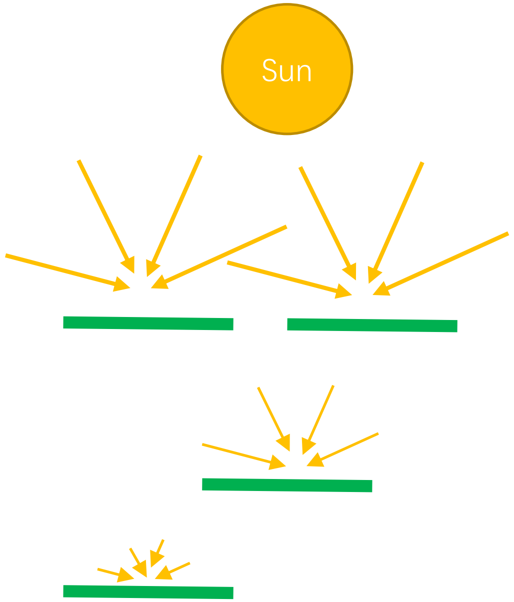
e.g. CLM4



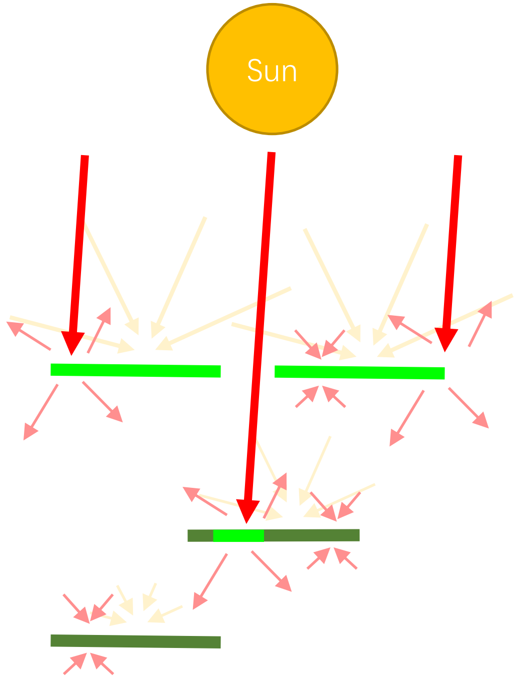
Complex model with penumbra
Future model?



Multilayer, no direct light
e.g. current ORCHIDEE trunk



Multilayer, diffuse and direct light
ORCHIDEE_DF (this work)



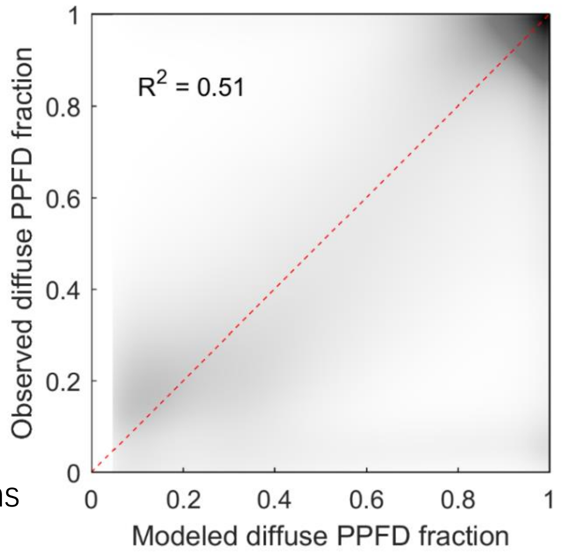
Light partitioning

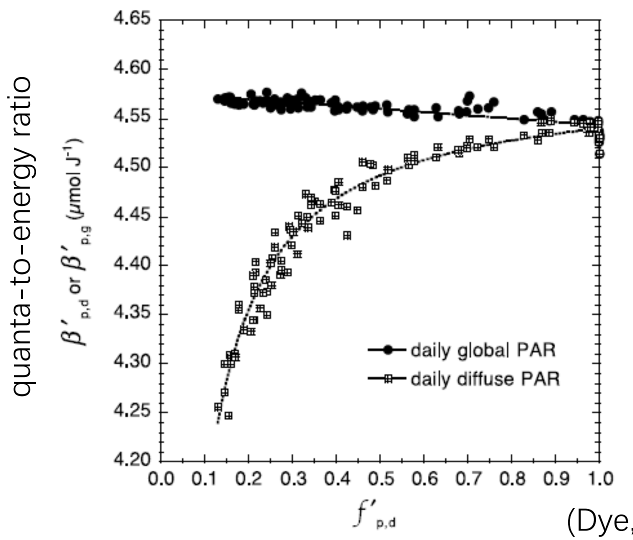
Several empirical methods were tried to decompose incoming solar radiation to diffuse and direct components (Erbs et al., 1982; Spitters et al., 1986; Weiss and Norman, 1985).

The **Weiss and Norman** method performs the best at flux site level.

$$f_V = \frac{R_{DV}}{R_V}\left[1 - \left(\frac{A - \text{RATIO}}{B}\right)^{2/3}\right]$$

fv: direct light fraction for PAR
R_{DV}: potential direct PAR at surface under clear sky conditions
R_V: potential total PAR at surface under clear sky conditions
RATIO: measured vs surface potential downward SW
A & B: parameters, =0.9 and 0.7 here



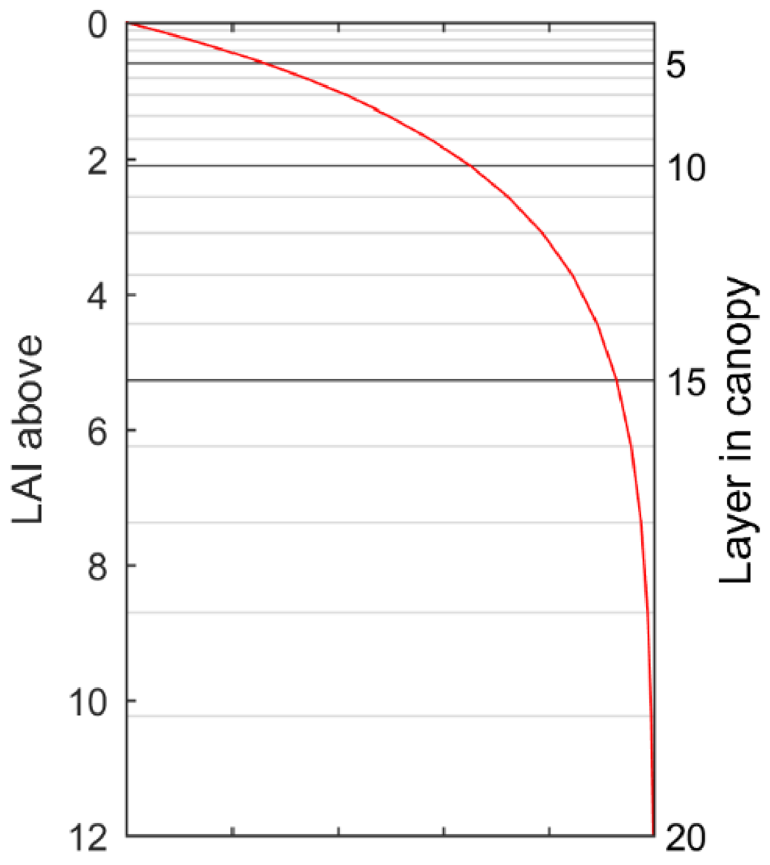


(Dye, 2004)

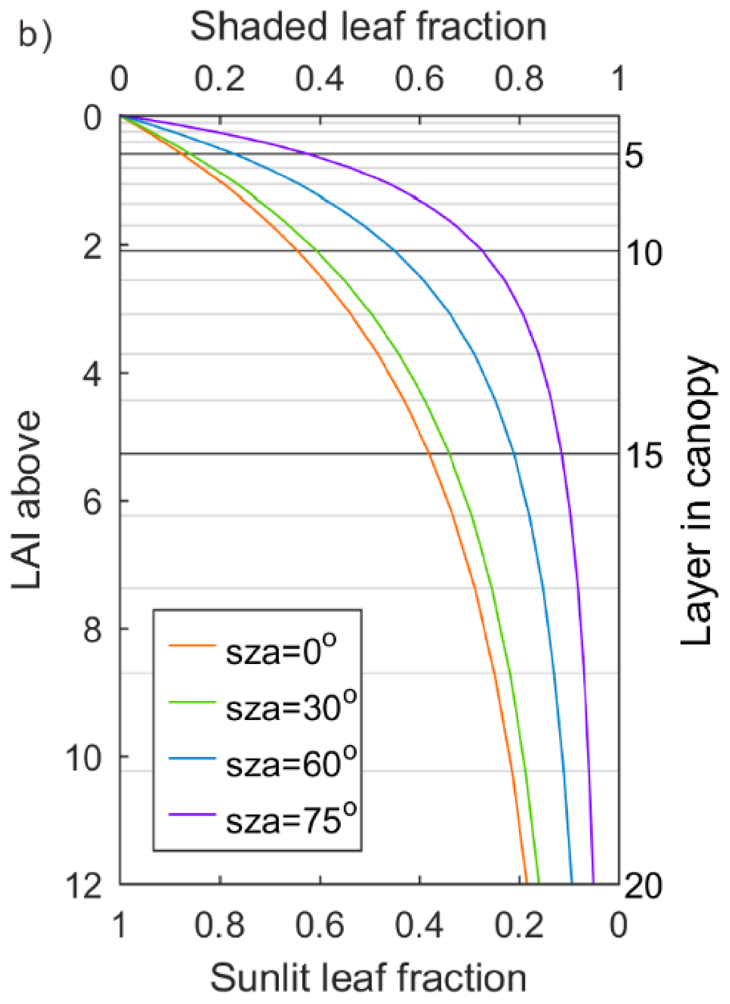
Diffuse light fraction

Observed quanta-to-energy ratio vary with diffuse light fraction, which is ignored by old ORCHIDEE but considered in ORCHIDEE_DF to calculate direct and diffuse PPFD

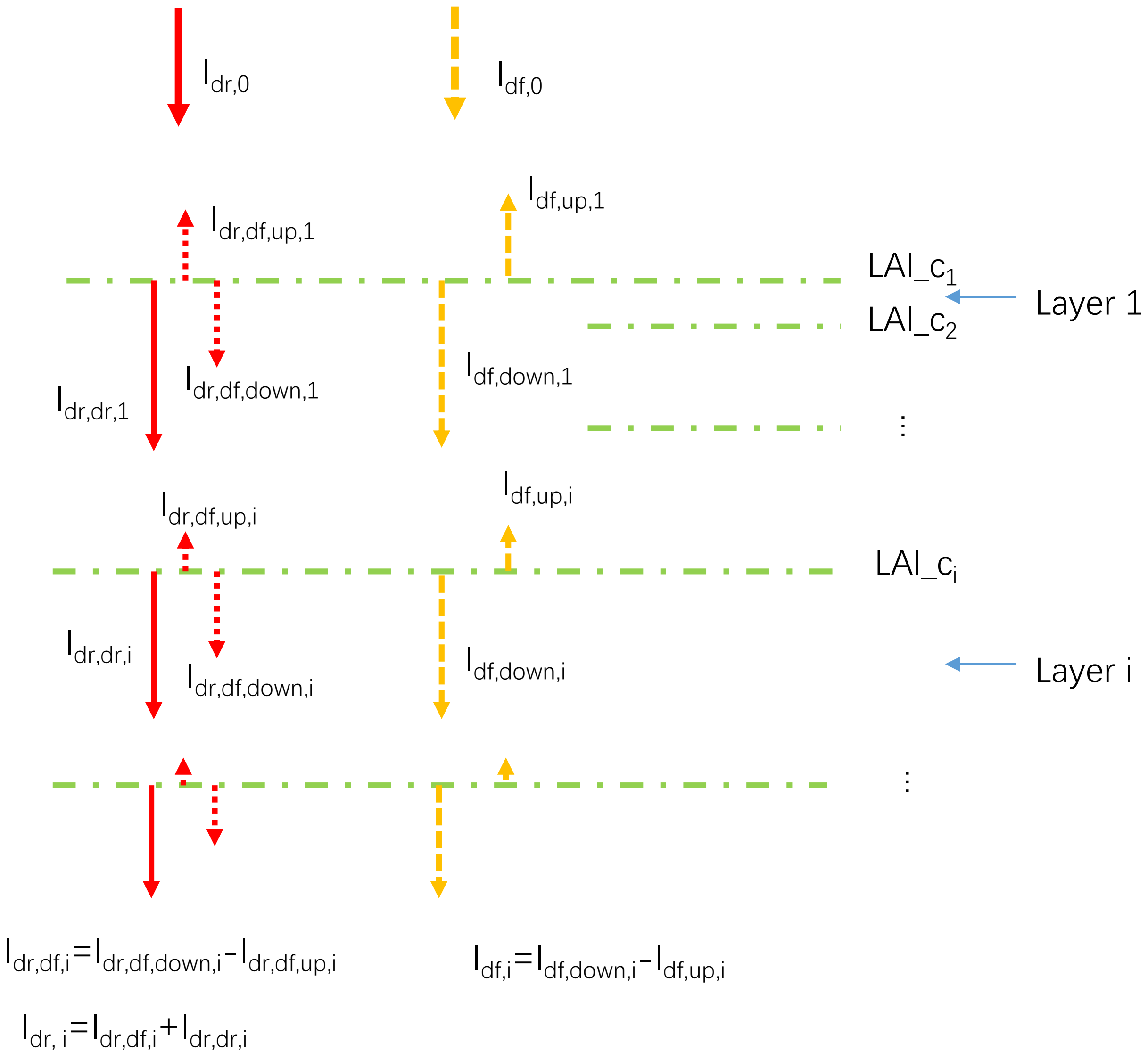
Canopy stratification



20 layers in maximum
Upper canopy has thinner layers,
lower canopy has thicker layers



Light transmission in ORCHIDEE_DF



For diffuse light $I_{df,i}$, a simple Beer-Lambert equation is used

$$I_{df,i} = (1-\rho)I_{df,0}e^{-k_d LAI\_c_i}$$

Canopy scattering

For direct-source radiation $I_{dr,i}$, the total attenuation of PPFD is presented as:

$$I_{dr,i} = (1-\rho)I_{dr,0}e^{-\sqrt{1-\sigma}k_b LAI\_c_i}$$

leaf scattering

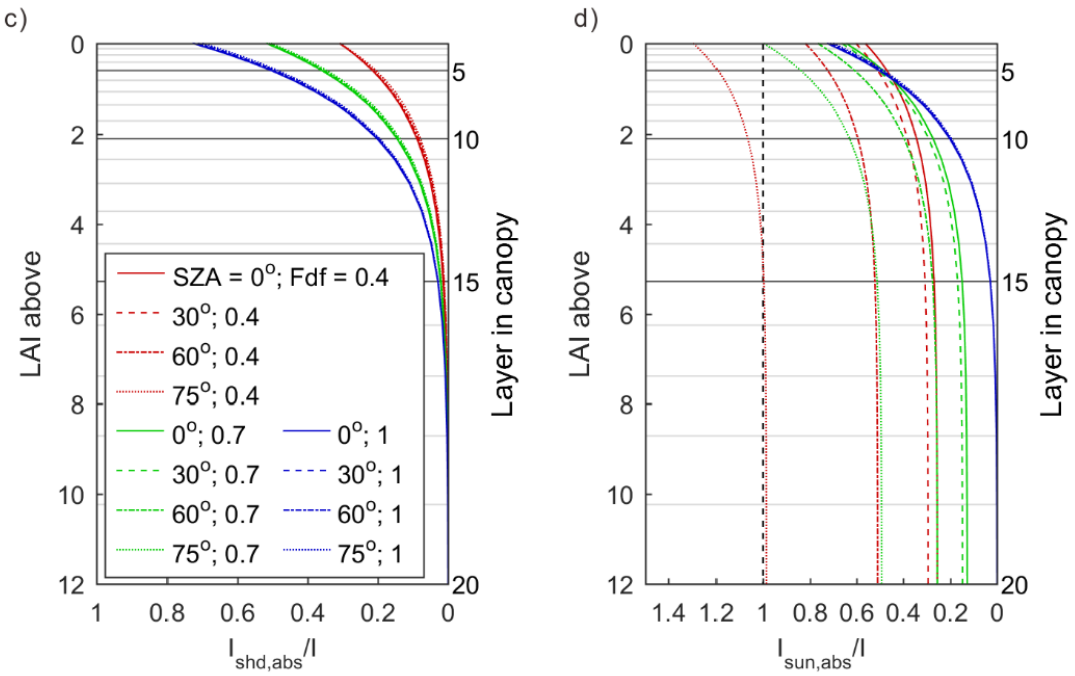
The transmission of direct light $I_{dr,dr,i}$, (direct components of direct-source radiation) is presented as:

$$I_{dr,dr,i} = I_{dr,0}e^{-k_b LAI\_c_i}$$

The leaf-scattered light $I_{dr,df,i}$ is presented as:

$$I_{dr,df,i} = I_{dr,i} - I_{dr,dr,i}$$

Light absorption



For shaded leaves, only diffuse radiation is absorbed:

$$I_{shd,abs} = I_{df,abs} + I_{dr,df,abs}$$

For sunlit leaves, both direct and diffuse radiation are absorbed

$$I_{sun,abs,i} = I_{shd,abs} + I_{dr,dr,abs}$$

Data to evaluate the model

Dataset:

- La Thuile fluxnet observations. 159 sites over 11 PFTs
- meteorology data gaps filled using the method of Vuichard and Papale (2015)

Simulation setup:

- 30yr spinup to equilibrate LAI + simulation over the full site years at each site

Data quality control for evaluation:

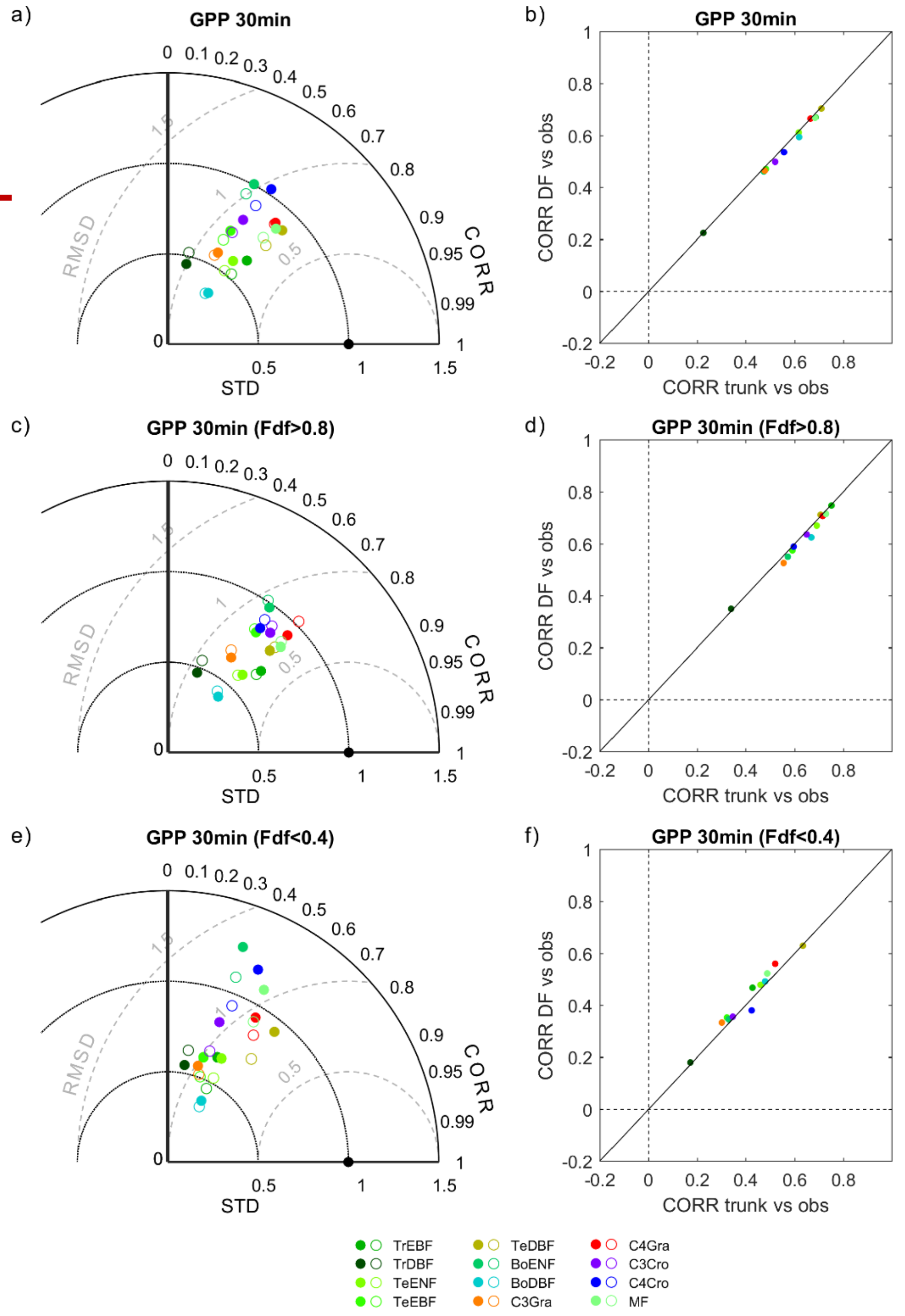
- GPP with low quality or at night time removed.
- Use only growing season GPP to remove the effect of phenology (growing season simply defined as the months with monthly GPP > yearly mean)
- Sites disturbed in the past 10 years removed and forests with LAI<2 removed

Definition of sunny conditions: fraction of diffuse light (Fdf<0.4),
cloudy conditions: Fdf>0.8

Results

ORCHIDEE_DF improved the GPP simulation under sunny conditions

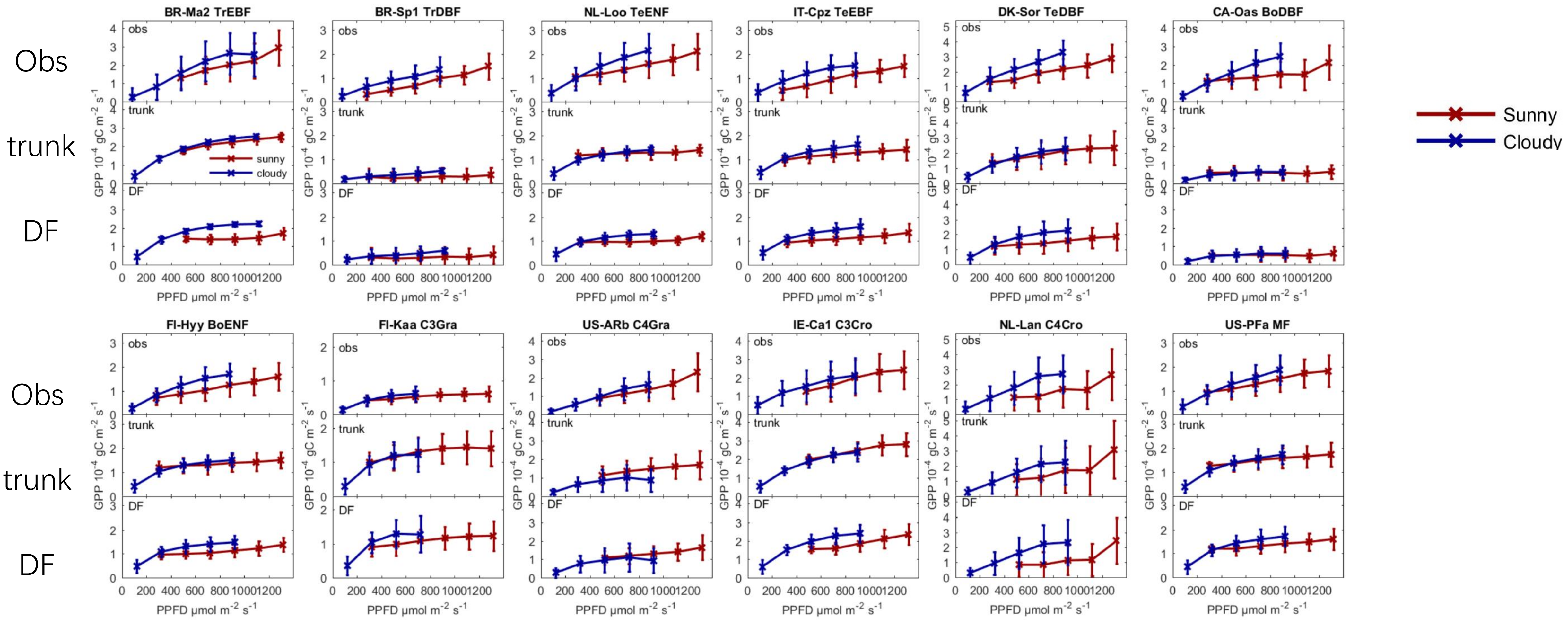
The GPP STD is underestimated in ORCHIDEE_DF (open circles) under the two cloudiness conditions. (Before recalibration)



Filled circles: ORCHIDEE trunk

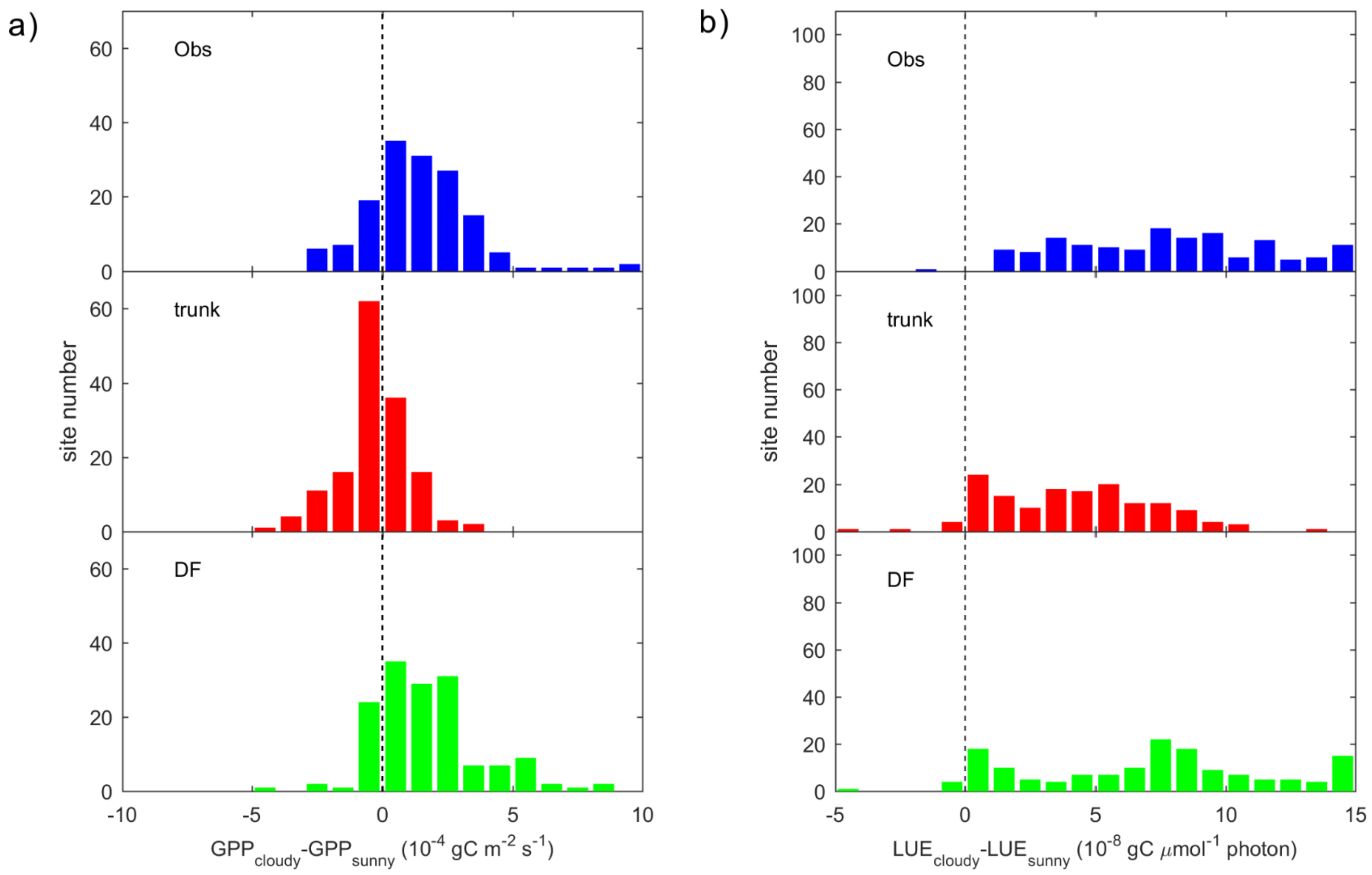
Open circles: ORCHIDEE_DF

Modeled diffuse light effect

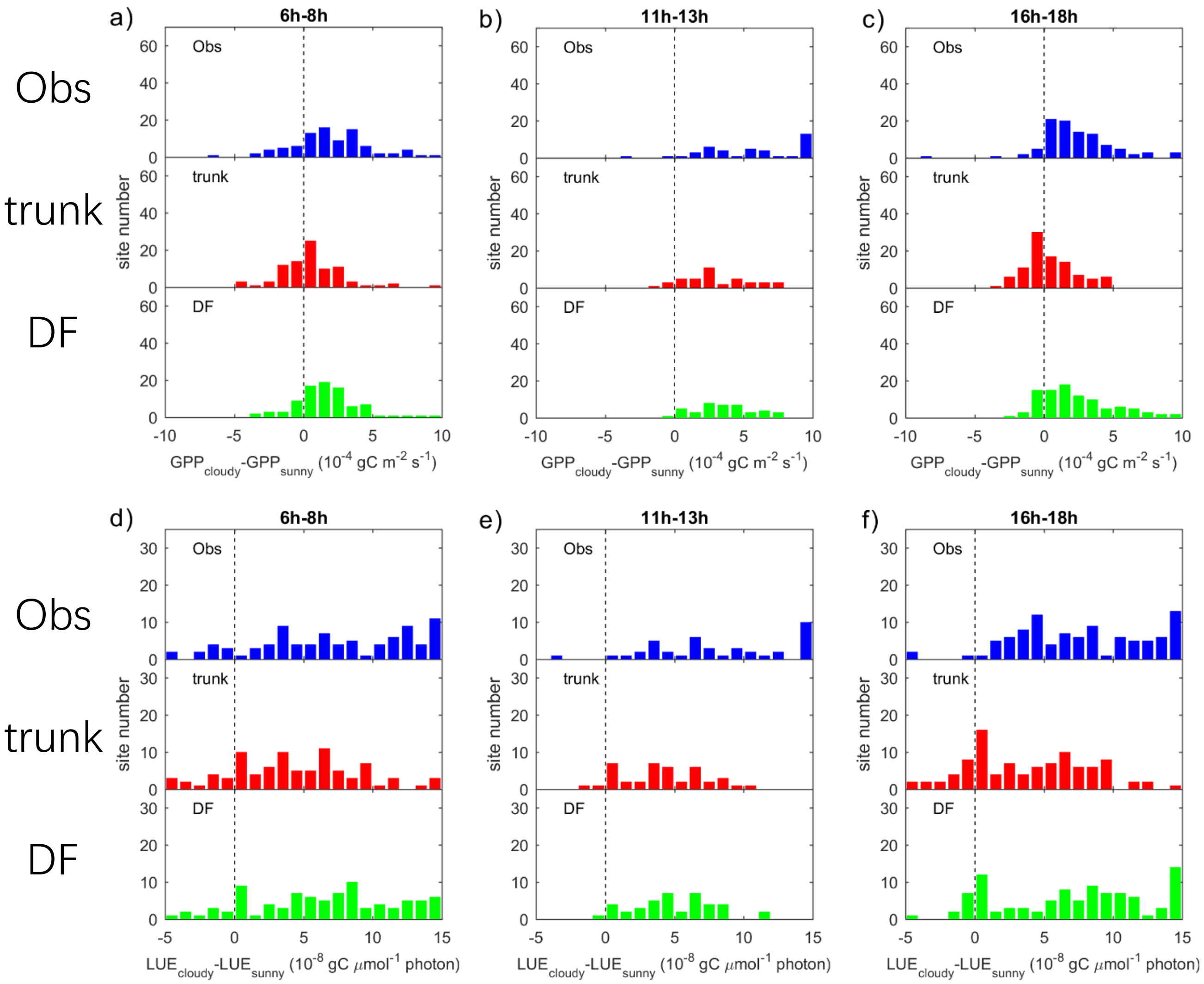


ORCHIDEE_DF captured the effect of diffuse light on GPP in most PFTs

The statistics of modeled diffuse light effect among sites



Diffuse light effect at different time of a day



The GPP increase in morning and afternoon is mainly due to the effect of diffuse light.

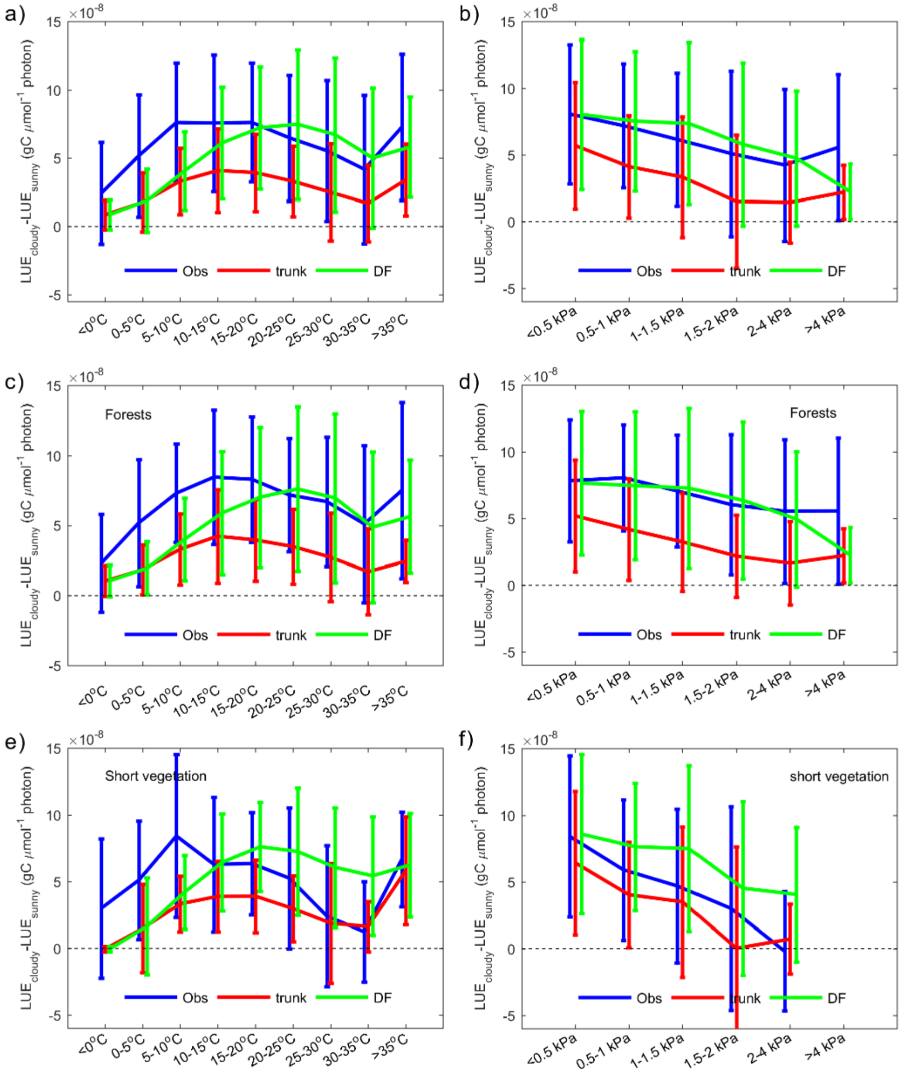
While at midday, environmental factors (T, VPD) may be the main reason causing GPP increase under cloudy conditions

Interaction between diffuse light and other environmental factors

All sites

Forests

Grass & Crop



Temperature

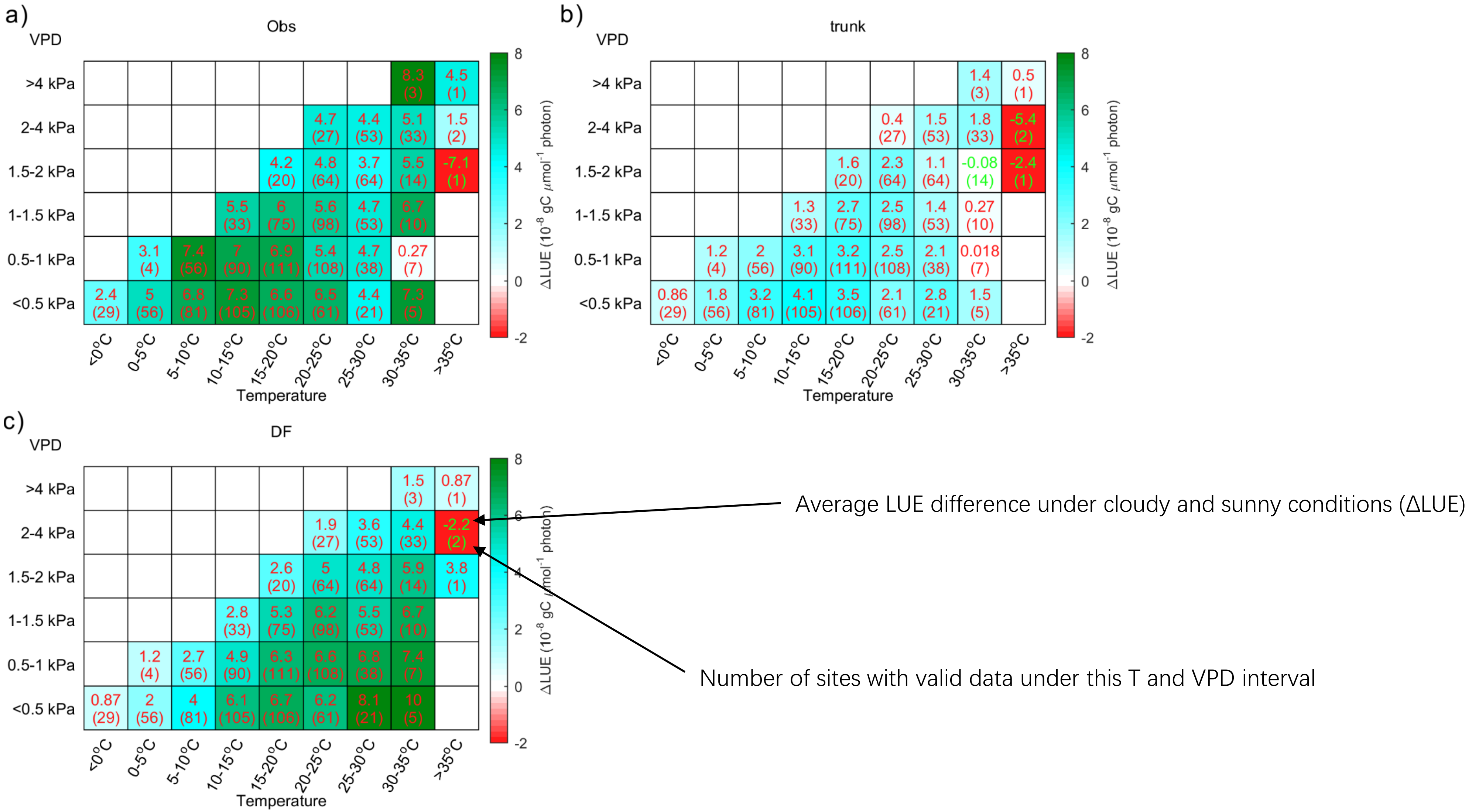
VPD

The diffuse light effect is strongest at mid temperature and low VPD

ORCHIDEE_DF underestimated the effect of diffuse light at low temperature but overestimates this effect at high temperature

ORCHIDEE_DF overestimated the effect of diffuse light at high VPD conditions in grasslands and croplands

Interaction between diffuse light and other environmental factors



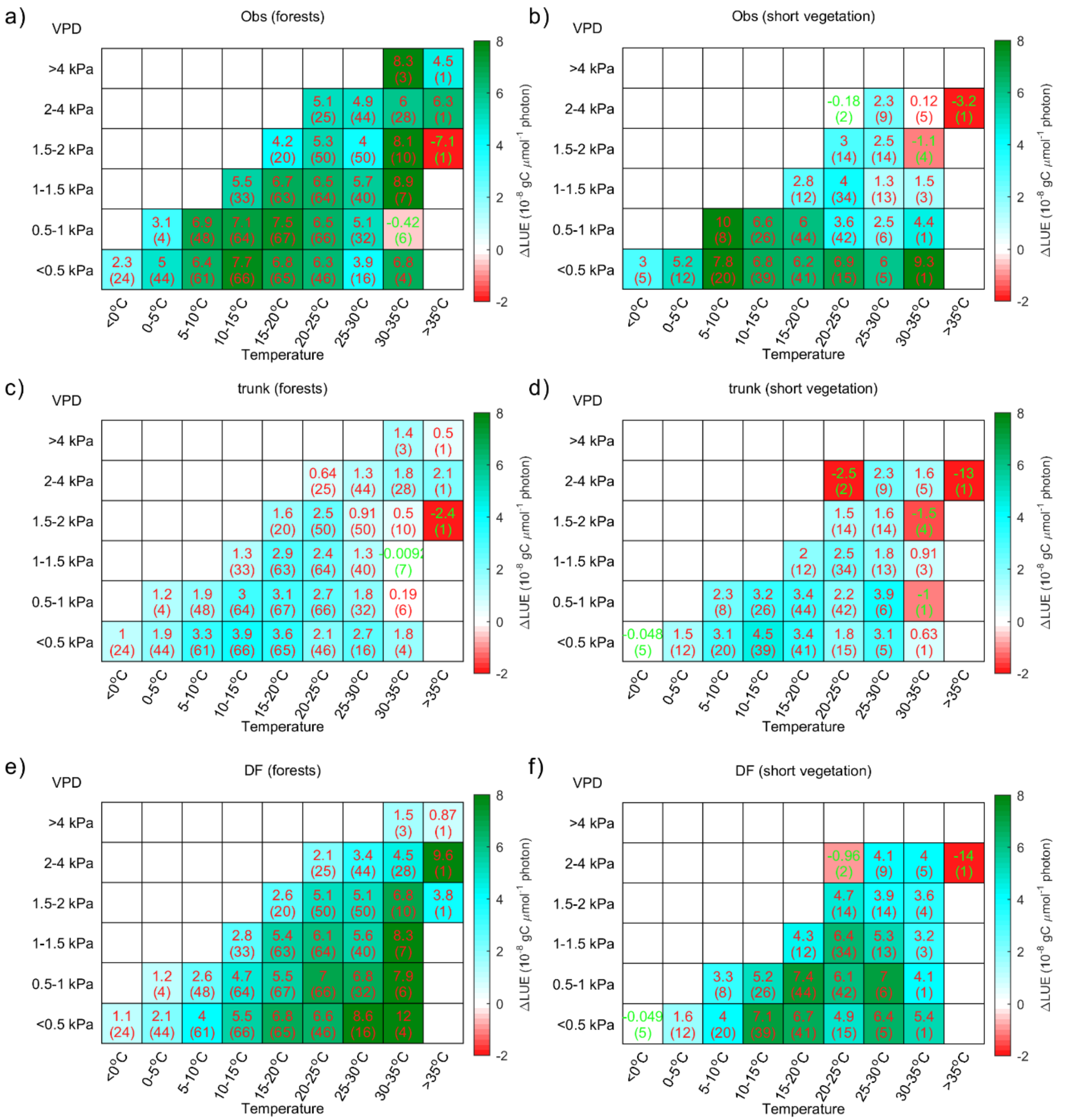
forests

grasslands and croplands

Obs

trunk

DF

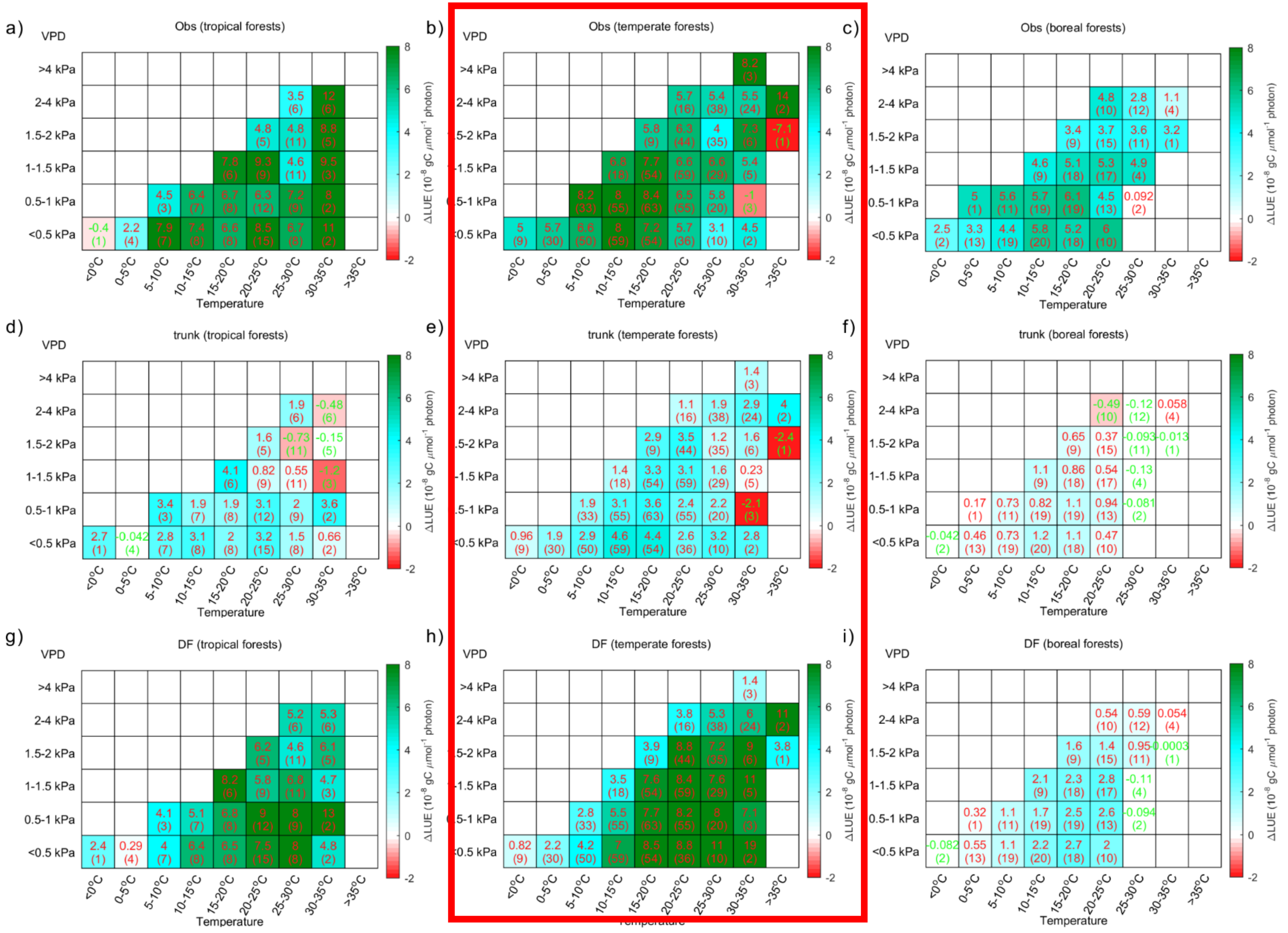


Interaction between diffuse light and other environmental factors

Obs

trunk

DF



Tropical forests

Temperate forests

Boreal forests

Summary

A new canopy light transmission module is added to ORCHIDEE trunk, the new model ORCHIDEE_DF is evaluated using flux data from 159 sites

Compared with ORCHIDEE trunk, ORCHIDEE_DF improves the GPP simulation under sunny conditions, and captured the enhancement of photosynthesis under cloudier conditions.

In morning and afternoon, photosynthesis difference between cloudy and sunny conditions is mainly due to the redistribution of light. At midday, the photosynthesis difference is mainly caused by environmental factors.

The impacts of diffuse radiation fraction maximized at low VPD and medium temperature. Current ORCHIDEE failed to perfectly capture the temperature dependence, mainly in temperate forests.

Thanks

An error in current ORCHIDEE

3 definitions of photosynthesis (Wohlfahrt and Gu, 2015):

True photosynthesis (Pt): total CO_2 fixation without allowing CO_2 loss through photorespiration (Rp) and leaf dark respiration (Rd)

Apparent photosynthesis (Pa): Pt-Rp

Net photosynthesis (Pn): Pa-Rd

In ORCHIDEE (Farquhar model), a general equation to calculate assimilation (A) is:

$$A = Vc - 0.5Vo - Rd$$

Pt Rp

The GPP output by ORCHIDEE is actually apparent photosynthesis – daytime leaf respiration

In the calculation of NPP, NEE, daytime leaf respiration is subtracted

Light absorption

At **canopy level**, the absorption at layer i is:

$$I_{i,abs} = \mathrm{d}I_{net}/dLAI\_c \mid LAI\_c_i$$

The absorption of I_{dr}:

$$I_{dr,i,abs} = I_{dr,0}(1-\rho_c)\sqrt{1-\sigma}k_b e^{-\sqrt{1-\sigma}k_b LAI\_c_i}$$

The absorption of $I_{dr,dr}$:

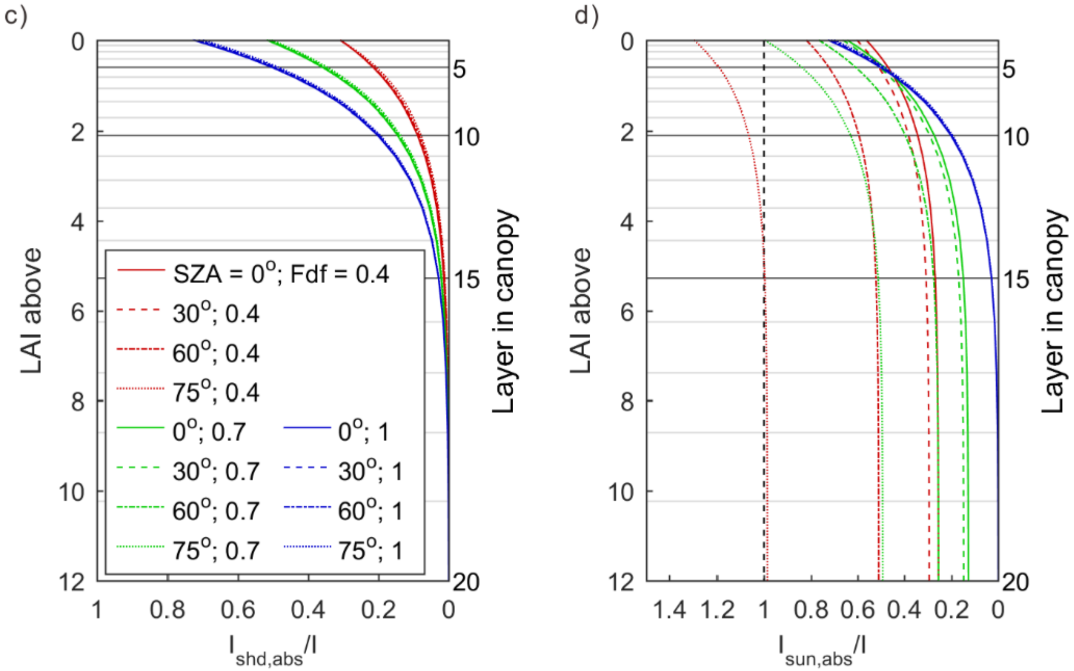
$$I_{dr,\mathrm{dr},i,abs} = k_b I_{dr,0} e^{-k_b LAI\_c_i}$$

The difference between $I_{dr,}$ $I_{dr,dr}$ is the absorbed $I_{dr,df}$:

$$I_{dr,\mathrm{df},i,abs} = I_{dr,i,abs} - I_{dr,\mathrm{dr},i,abs}$$

The absorption of I_{df}:

$$I_{df,i,abs} = k_d(1-\rho)I_{df,0}e^{-k_d LAI\_c_i}$$



At **leaf level**, the absorptions of I_{df}, $I_{dr,df}$, $I_{dr,dr}$ are respectively:

$$I_{df,i,abs,la} = I_{df,i,abs}$$

$$I_{dr,df,i,abs,la} = I_{dr,df,i,abs}$$

$$I_{dr,dr,i,abs,la} = (1-\sigma)k_b I_{dr,0}$$

For shaded leaves, the absorption is:

$$I_{shd,abs,i} = I_{df,i,abs,la} + I_{dr,\mathrm{df},i,abs,la}$$

For sunlit leaves, the absorption is:

$$I_{sun,abs,i} = I_{shd,abs,i} + I_{dr,dr,i,abs,la}$$