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Field-scale monitoring of drought stress using chlorophyll fluorescence with the coupled SCOPE-AgroC model

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International Network on Remote Sensing of Terrestrial and Aquatic Fluorescence

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Plant physiological link between drought stress and SIF emission

- Drought stress is the combined effect of high VPD and low soil water potential

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- Stomata are closed, reducing sub stomatal CO_2 concentrations

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- Drought stress slows down Calvin cycle but drought stress as such does not reduce light absorption

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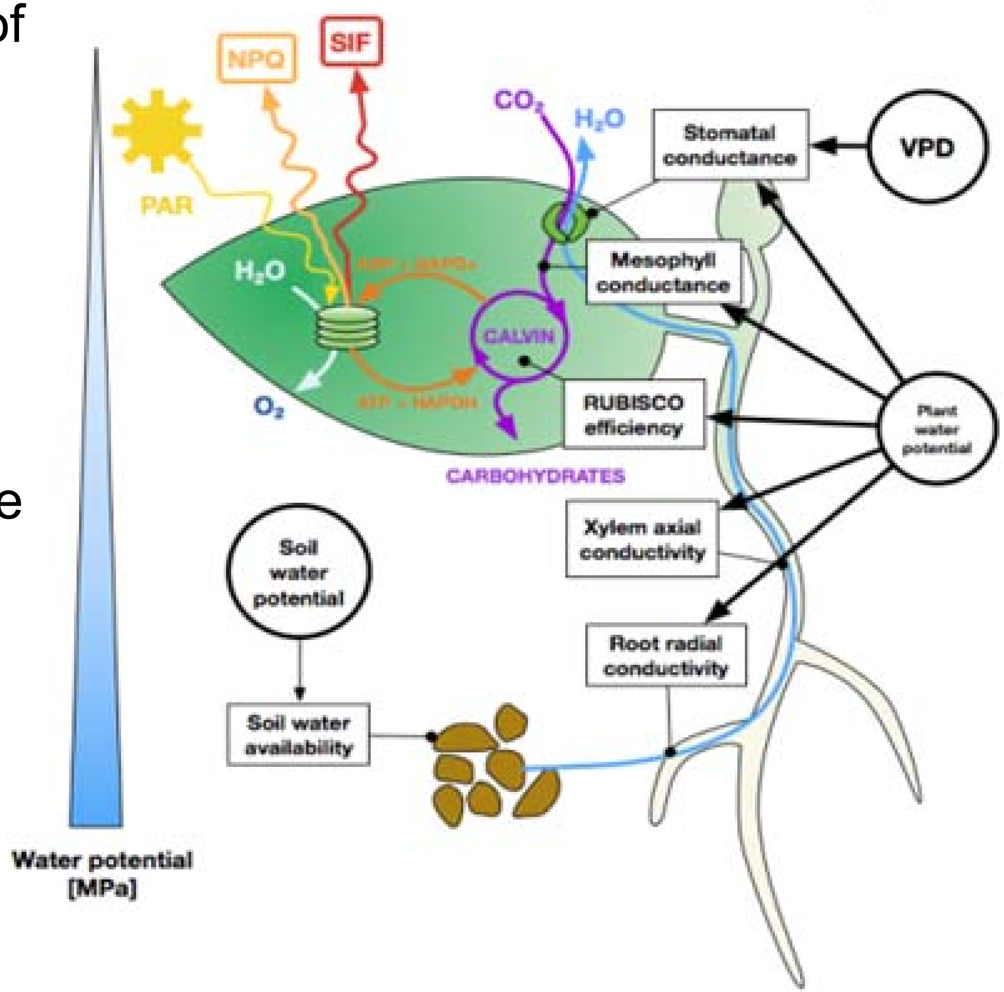
- Fluorescence and NPQ provide alternative electron sinks



Research questions

1. How does the SIF signal react to drought stress at different time horizons and stress levels?

2. How is the SIF emission related to plant processes?

3. Can we improve the estimations of transpiration and photosynthesis rates of crops under stress conditions by assimilating SIF observations into plant growth models?

Measurements of SIF over grassland during summer 2018

SIF was measured continuously with the FloX sensor (JB hyperspectral) in Jülich, (Germany)

Grass species: Achillea millefoleum, Poa sp. and Lolium perenne (common species)

Grass was not mown during growing season

The year 2018 had severe drought periods

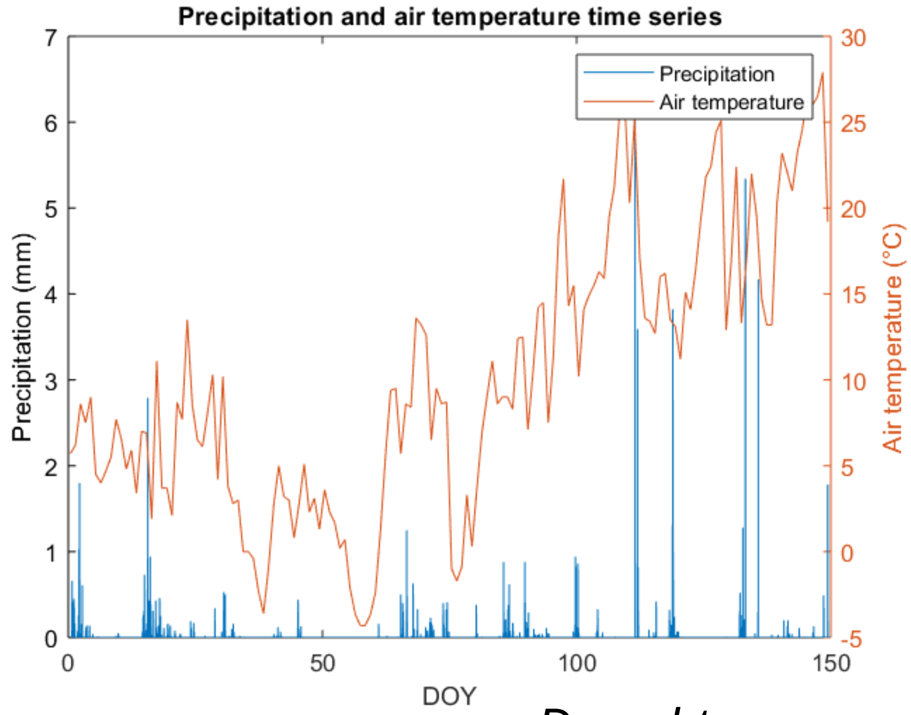
→ First insights on link between drought stress and fluorescence with FloX

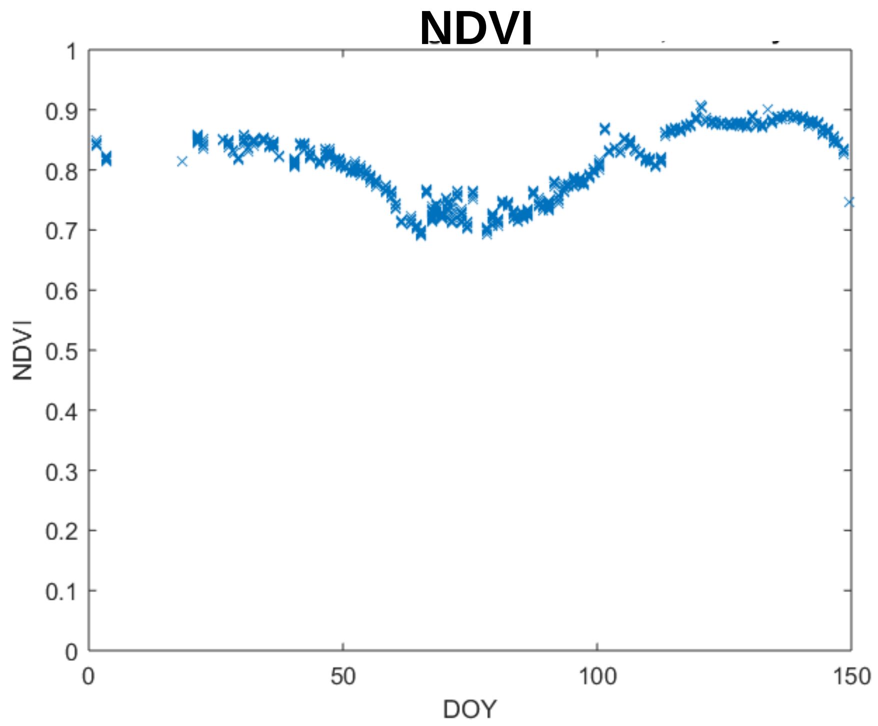
SIF reaction to drought stress: expected results

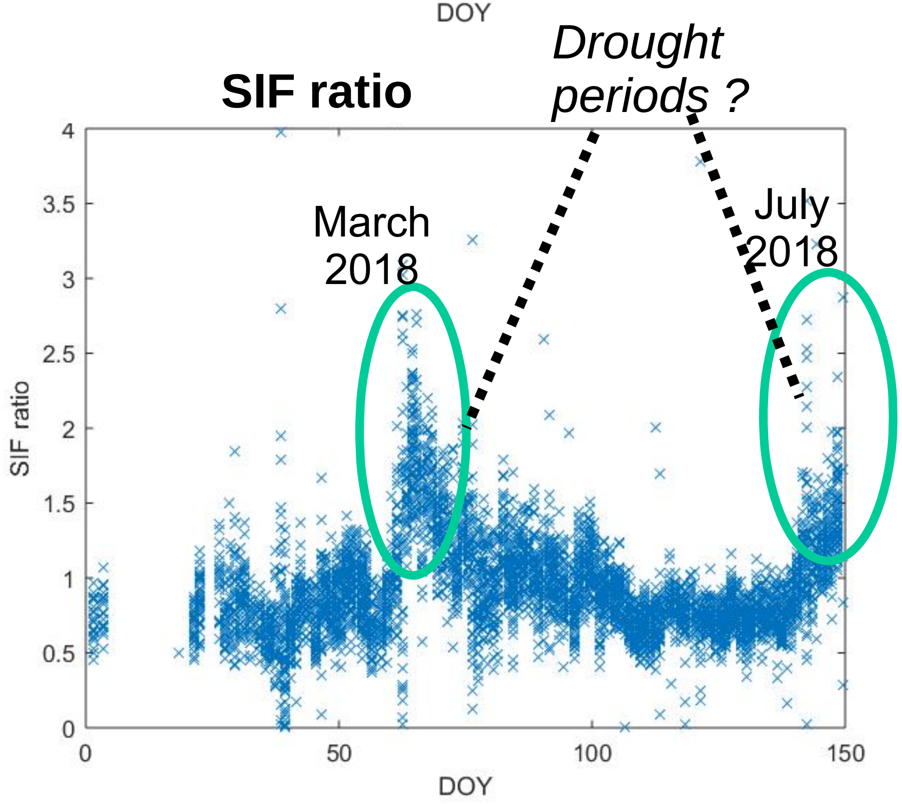
Drought stress increases SIF ratio?

→ Changes in reabsorption?
Different photosystem activities?

Pattern absent in NDVI signal



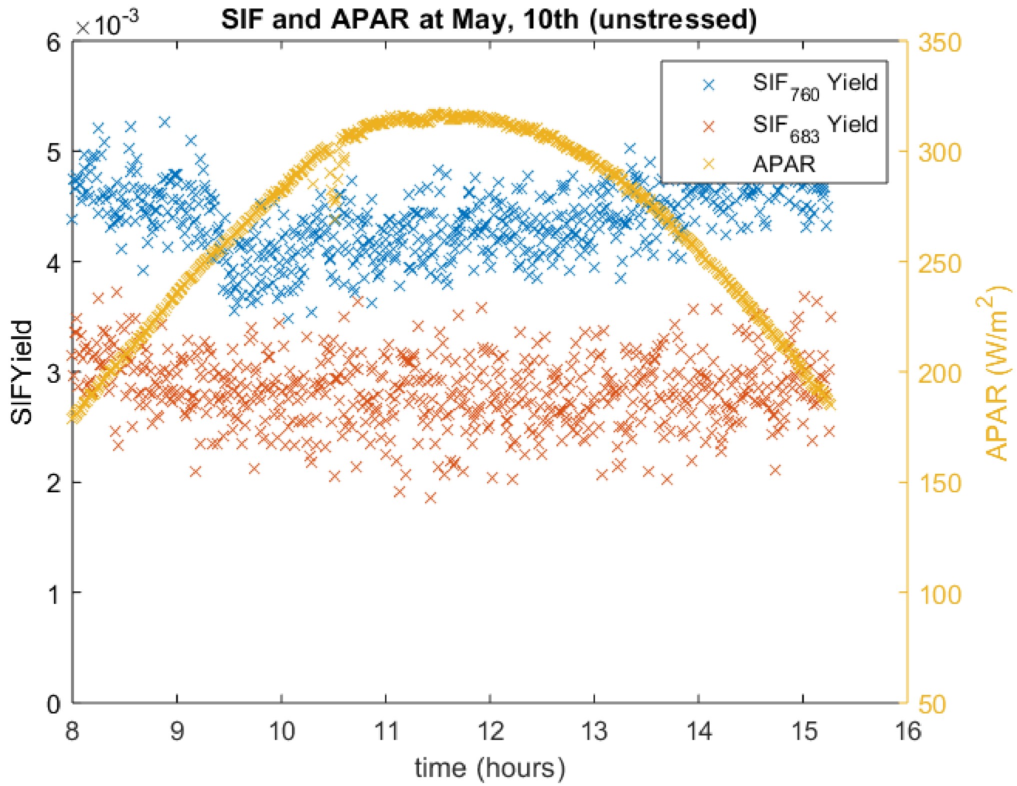


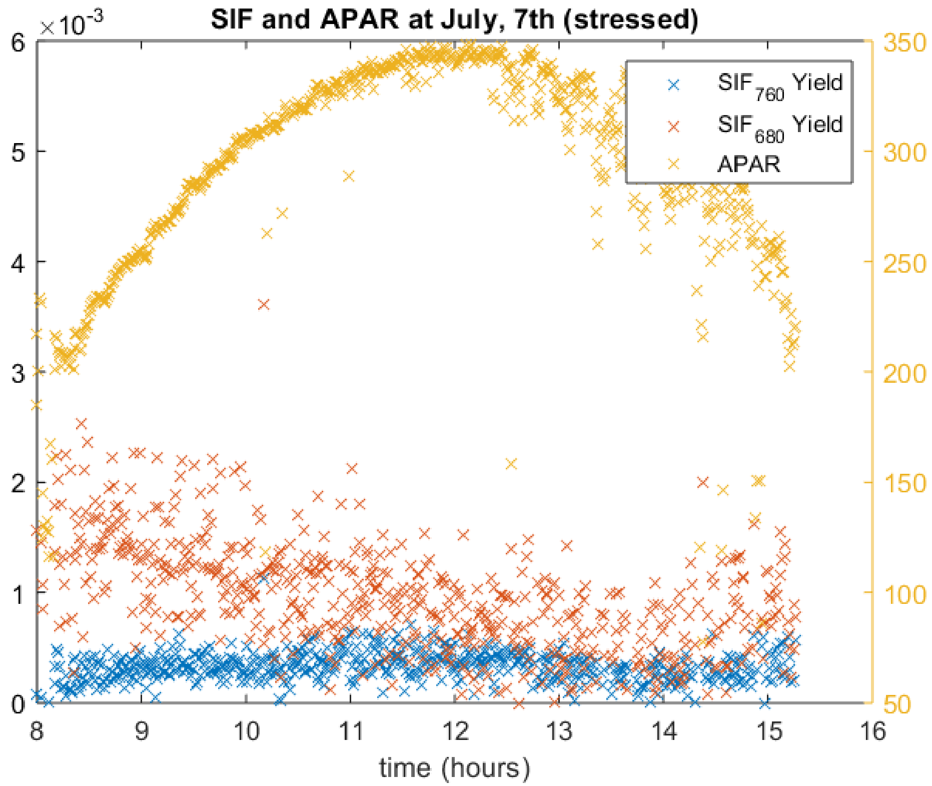


SIF reaction to drought stress: first insights

Comparing stressed day (July, 7th) to unstressed day (May, 10th)

- SIF yield (stress) < SIF yield (no stress) (increase in NPQ?)
- Stress: SIF_{680} > SIF_{760} (structural changes? photosystems?)

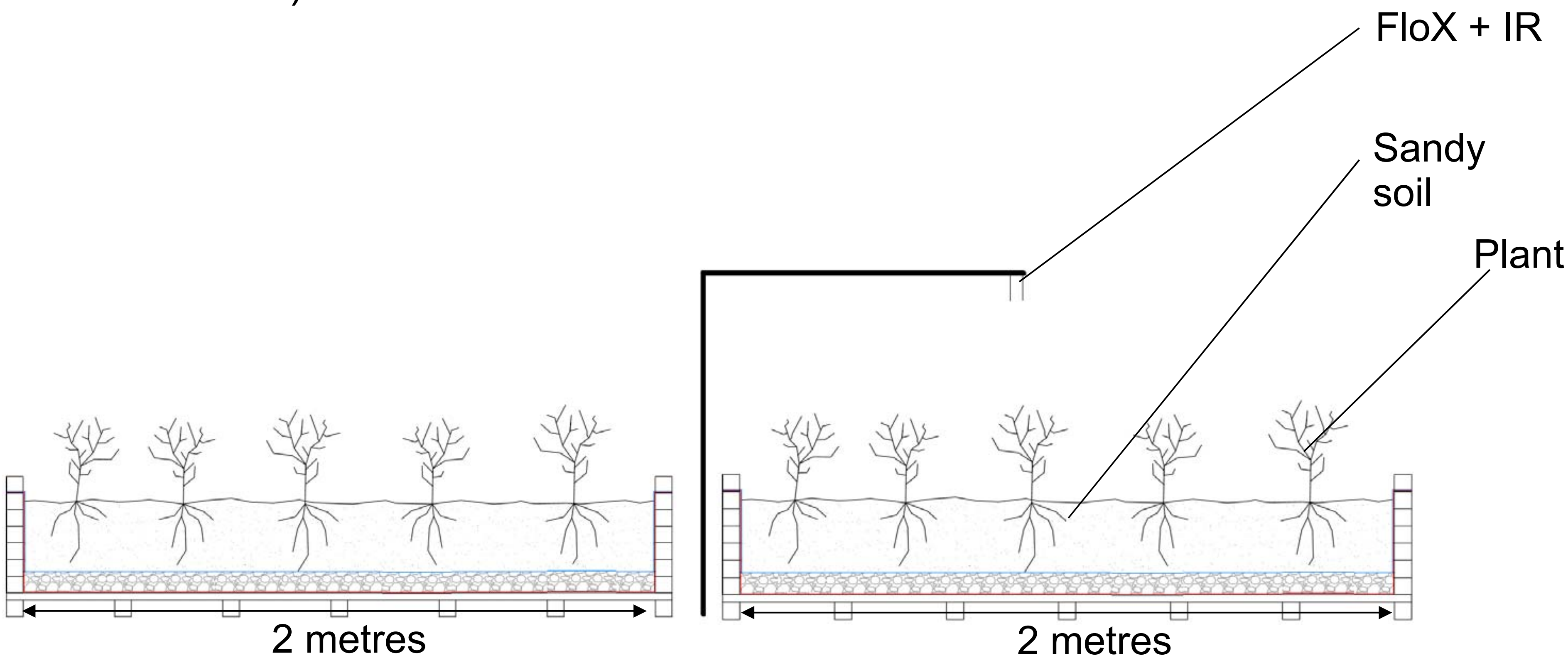




Controlled experiment

Investigate the response of SIF to drought stress

- Two plant boxes: stressed box and control (unstressed) box
- Plant type: spring barley
- Monitor SIF emission continuously
- Compare SIF to IR and in-situ measurements (PAM, gas exchange, soil moisture)



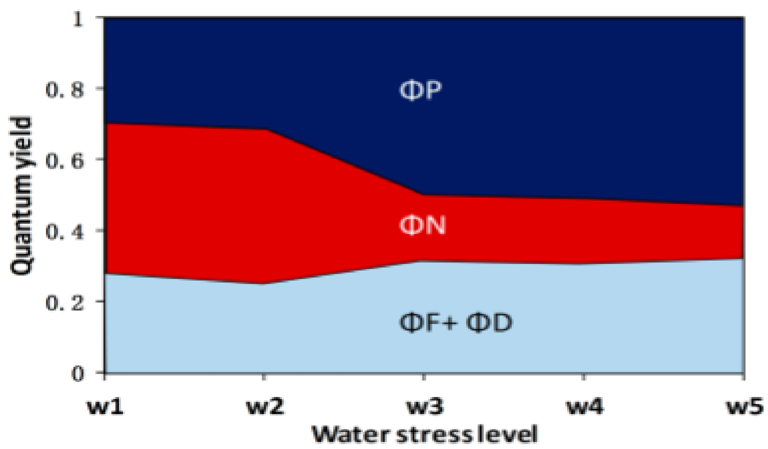
SIF reaction to drought stress: expected outcome

Expected: short-term increase of SIF emission, followed by a rapid decrease

Longer term: NPQ ↗ Fluorescence ↘

NPQ serves as main protection mechanism for the photosynthetic apparatus

Stress has different effect on SIF_{760} and SIF_{680}



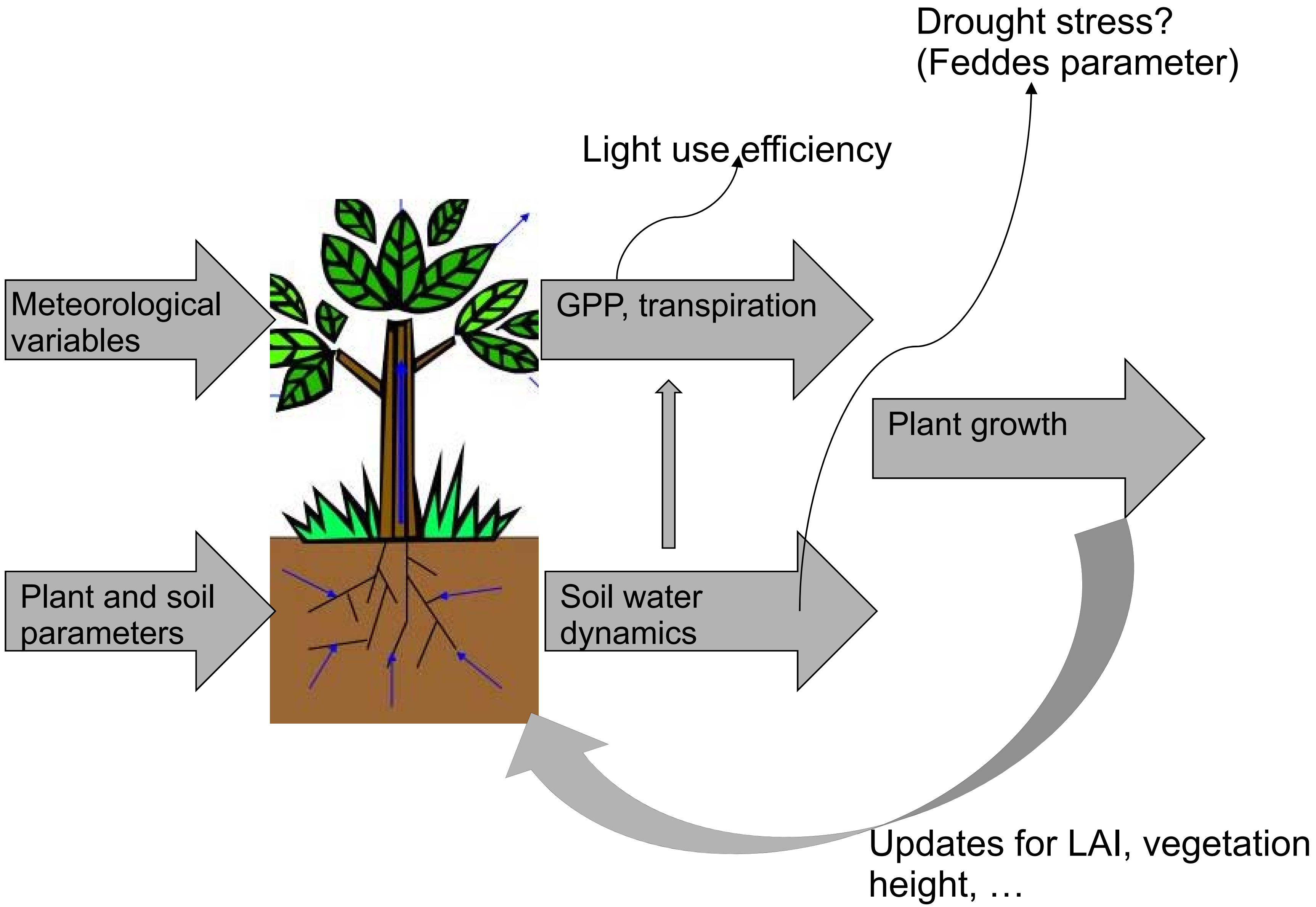
Source: Chou et al., 2017

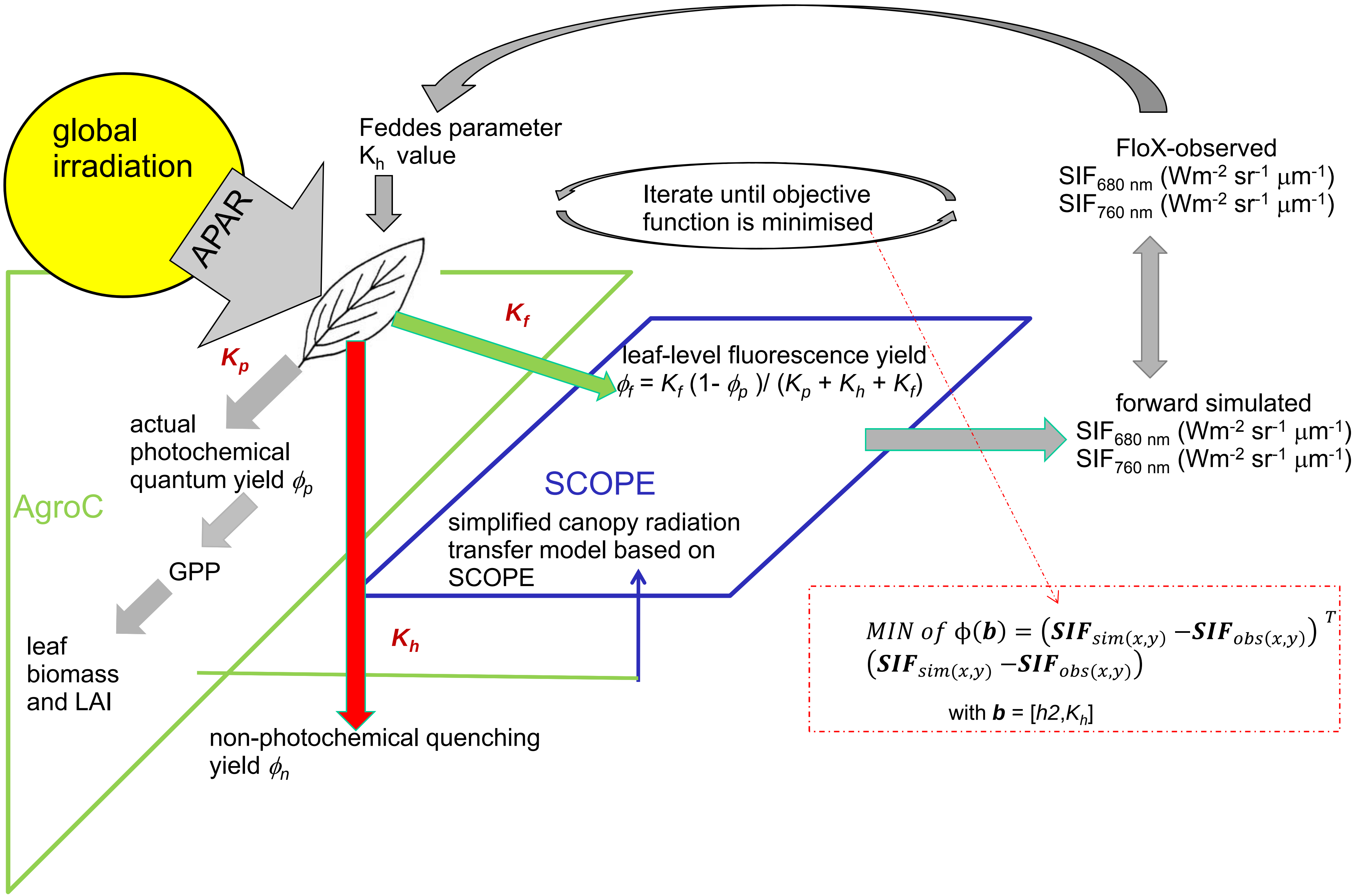
High stress ← Low stress

Visualisation of the photochemical, non-photochemical an fluorescent quantum yield at different stress levels

w1: maximum stress to w5: minimum stress

AgroC: a state of the art plant growth model (Klosterhalfen et al., 2017)





global irradiation
APAR
Feddes parameter K_h value
Iterate until objective function is minimised
FloX-observed
$SIF_{680\ nm}$ ($Wm^{-2}\ sr^{-1}\ \mu m^{-1}$)
$SIF_{760\ nm}$ ($Wm^{-2}\ sr^{-1}\ \mu m^{-1}$)
K_f
K_p
leaf-level fluorescence yield
$\phi_f = K_f\,(1 - \phi_p)/(K_p + K_h + K_f)$
forward simulated
$SIF_{680\ nm}$ ($Wm^{-2}\ sr^{-1}\ \mu m^{-1}$)
$SIF_{760\ nm}$ ($Wm^{-2}\ sr^{-1}\ \mu m^{-1}$)
actual photochemical quantum yield ϕ_p
AgroC
SCOPE
simplified canopy radiation transfer model based on SCOPE
GPP
$MIN\ of\ \phi(\boldsymbol{b}) = (\boldsymbol{SIF}_{sim(x,y)} - \boldsymbol{SIF}_{obs(x,y)})^T (\boldsymbol{SIF}_{sim(x,y)} - \boldsymbol{SIF}_{obs(x,y)})$
with $\boldsymbol{b} = [h2, K_h]$
K_h
leaf biomass and LAI
non-photochemical quenching yield ϕ_n

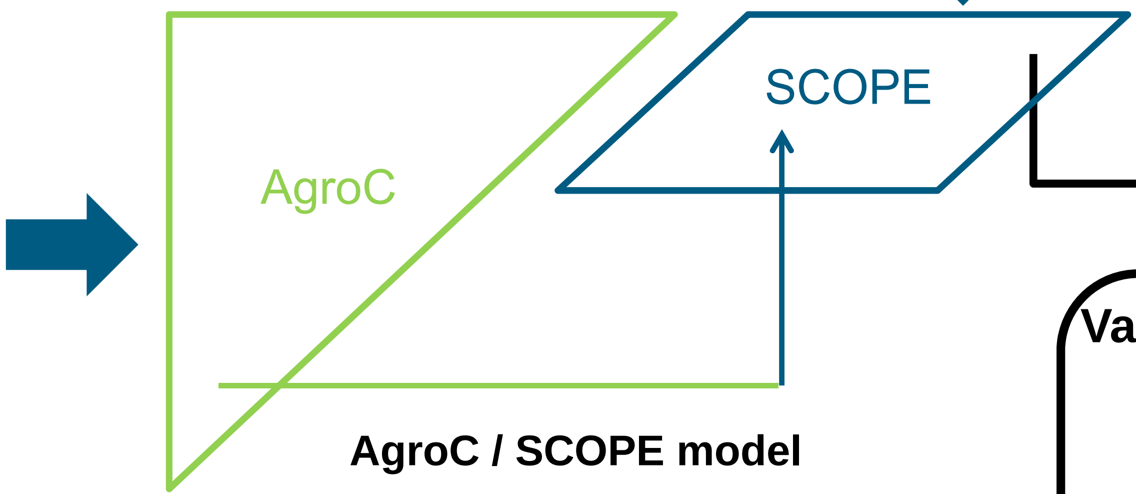
Validate coupled SCOPE-AgroC model with field scale experiment

SIF data

Stress parameter inversion

Meteorological variables

Soil & plant properties



AgroC / SCOPE model

Validation

EC data

UV-Vis data

Soil moisture

PAM measurements

Coupling AgroC and SCOPE: expected outcome

Incorporating SIF in AgroC is expected to lead to

- Better GPP/ET estimations
- Creation of stress parameter maps

UAV picture - 2018 MOSES Campaign, Selhausen (F. Jonard)

Conclusion and perspectives

Drought stress affects SIF by different ways

SIF_{760} and SIF_{680} react differently to drought stress

Box experiment will give insight of timing of these processes

Incorporation of SIF in crop growth model

- Photosynthesis serves as bridge between the models
- Better determination of water stress parameter is expected

THANK YOU

Coupling: details (Lee et al. 2015)

Lee et al. 2015: $\phi_f = \frac{K_F}{(K_F + K_D + K_N)}(1 - \phi_p)$

ϕ_p: AgroC

K_D: constant value

K_N: optimised value

$F = \phi_f . \mathrm{APAR}$

Link between measured SIF and calculated SIF

$$\mathrm{SIF}_{\mathrm{wavelength}} = \frac{F}{k}$$

k: calculated with look-up table