JÜLICH Forschungszentrum

Solar-induced chlorophyll fluorescence (SIF) image data acquisition from a rotary-wing UAV platform

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An opportunity in plant science closing the gap between ground and airborne/satellite-based measurements of photosynthetic activity

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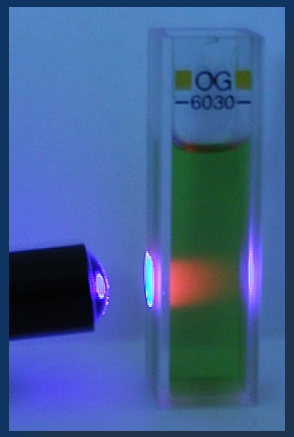
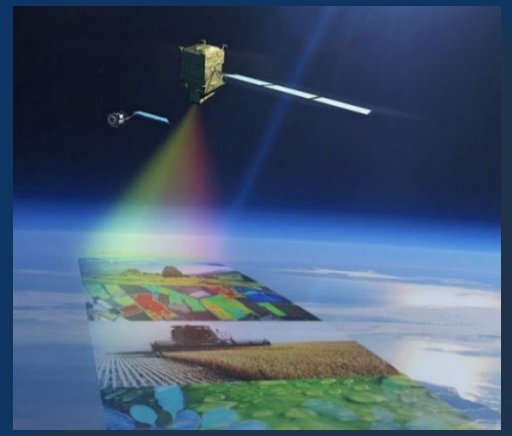
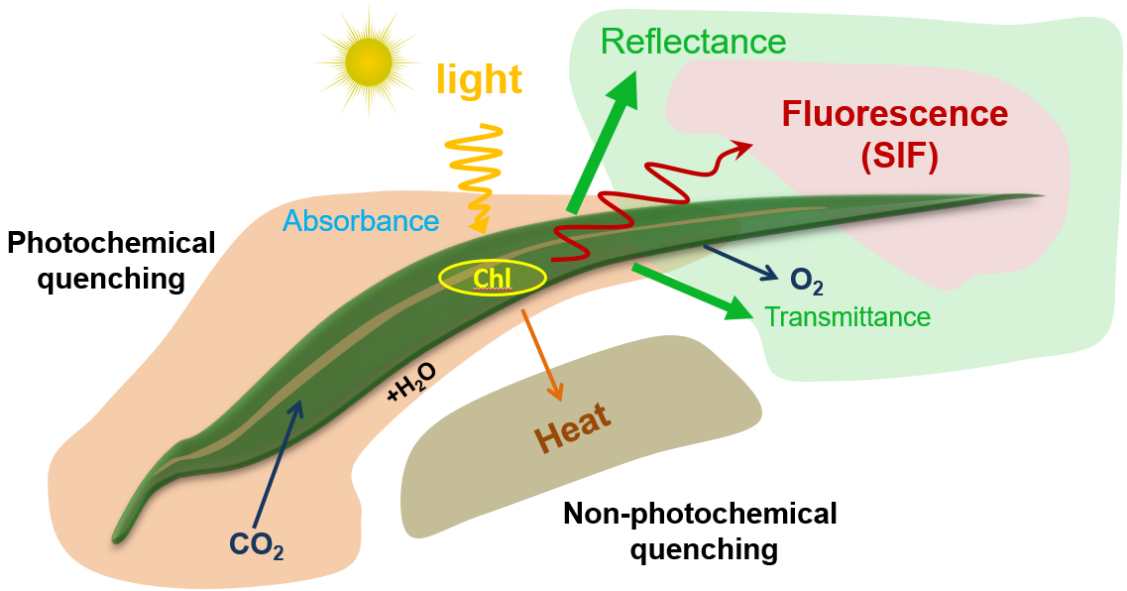


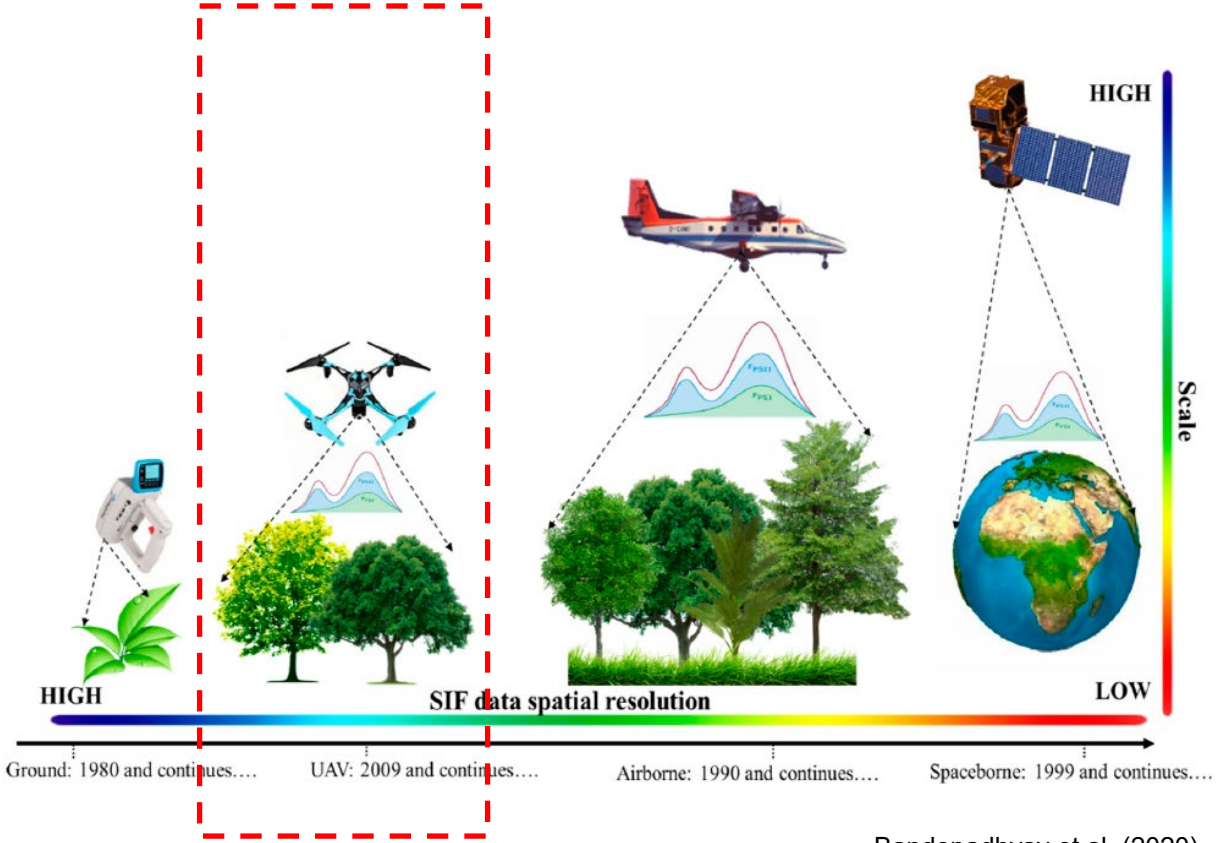






Solar-induced chlorophyll fluorescence (SIF) is the most direct measure of photosynthetic activity





- SIF can be measured from different scales at different spatial and temporal resolutions
- Underrepresentation of sensors measuring SIF from UAVs due to technical limitations in the past

Bandopadhyay et al. (2020)

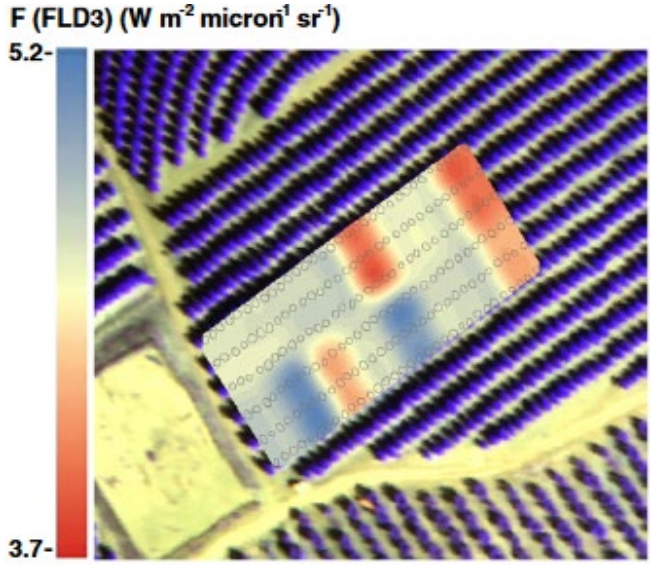
Requirements and developed UAV sensors to measure SIF

- Requirements for reliable SIF measurements (Grossmann et al., 2018; Pacheco-Labrador et al., 2019)
  - Full-width half-maximum (FWHM) < 0.4 nm
  - Signal-to-noise ratio (SNR_{max}) > 1000
  - Dynamic range (DR) > 16 bit

- Point-spectrometers:
  - Piccolo Doppio (Maseyk et al., 2018),
  - AirSIF (Bendig et al., 2018, 2020),
  - AirFloX(Quiros-Vargas et al., 2020)
  - UAS-SIF (Chang et al., 2020)
  - FluorSpec (Wang et al., 2021)

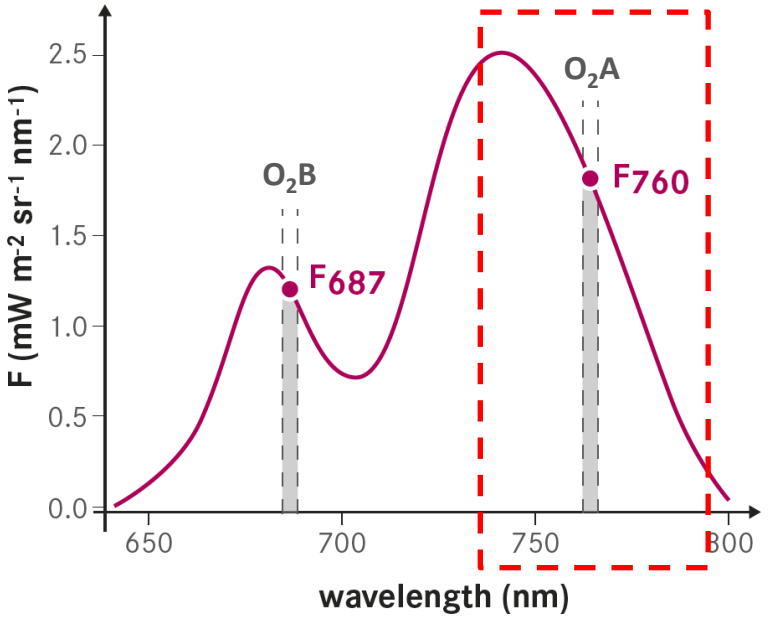
Bendig et al., submitted

- Scanning(imaging)-spectrometers:
  - Headwall Micro-Hyperspec VNIR (Zarco-Tejada et al., 2012, 2013)

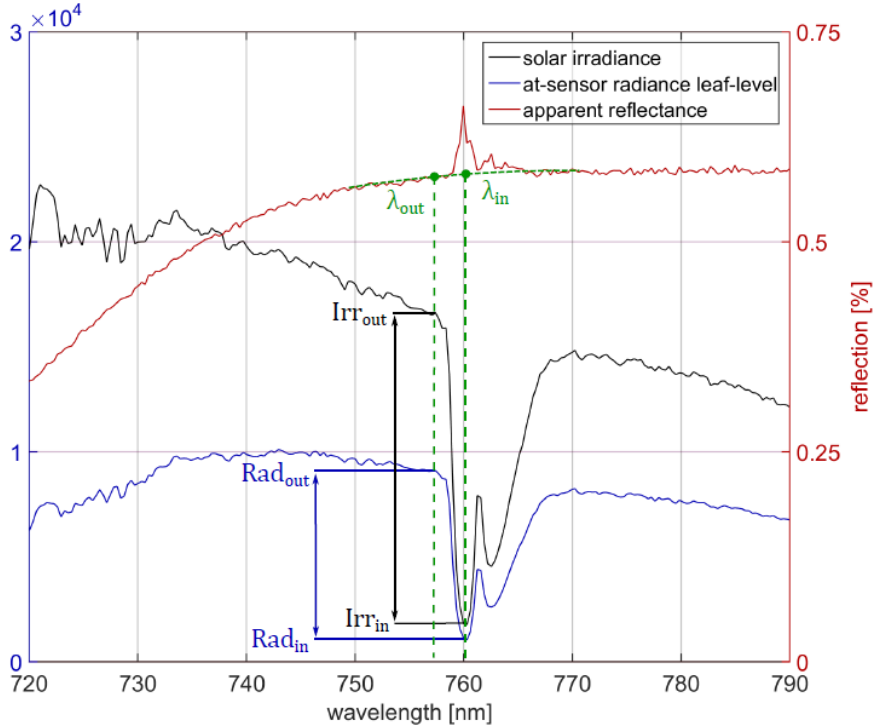


Zarco-Tejada et al., 2012

Dual-camera system – SIF retrieval



ESA, 2015



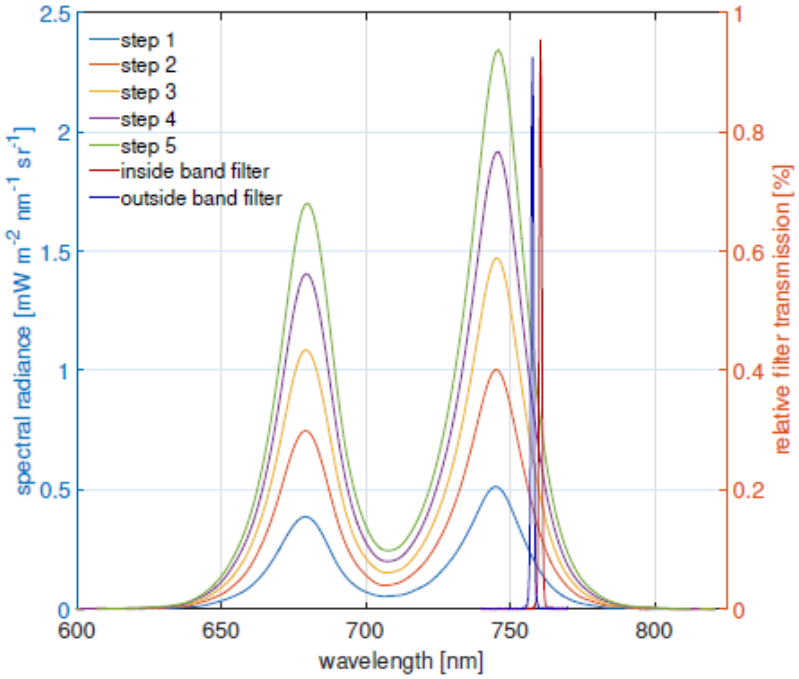
Kneer et al., submitted

$$SIF_{760} = \frac{Rad_{in} \cdot Irr_{out} - Rad_{out} \cdot Irr_{in}}{Irr_{out} - Irr_{in}}$$

- SIF retrieval in the oxygen A absorption band (O_2-A) at 760 nm using the Fraunhofer Line Discriminator (FLD) method (Plascyk, 1975)

Dual-camera system – hardware details filter properties

Kneer et al., submitted



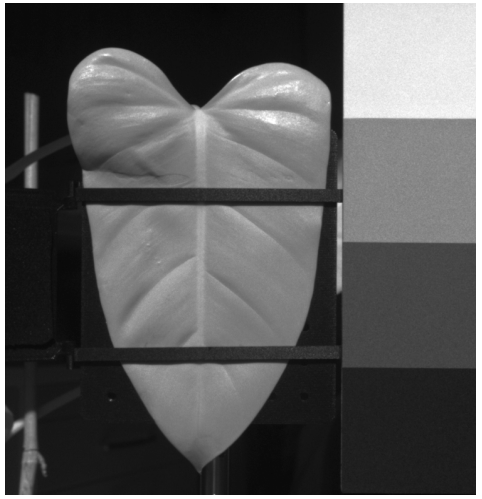
Kneer et al., submitted

Cameras	Resolution (full)	2048 x 2048
	Sensor size [mm]	13.3 x 13.3 / 18.8 (diag.)
	Dynamic range [db]	87
	Binning	2x2, 4x4
System	FOV (full) [deg]	29.8 (hor. & ver.) / 41.2 (diag.)
	Storage [GB]	SSD: 500 / microSD: 128
	Power consumption [W]	36 max.
	Weight [kg]	1.89

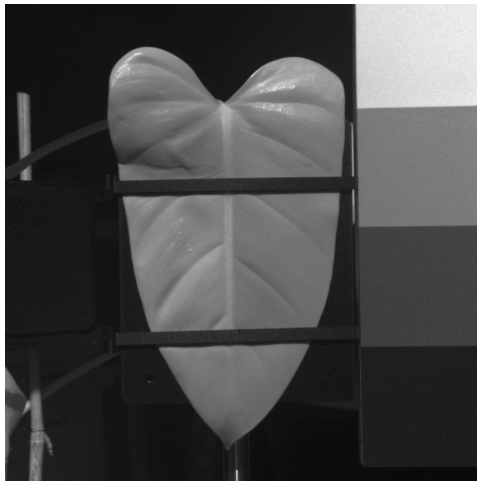
- Two ultra-narrowband interference filters
  - Central wavelengths (CW) at 757.9 and 760.7 nm (out- and inside band filter)
  - FWHM < 1.2 nm
  - Peak transmission of > 90 %

Laboratory measurements – first step

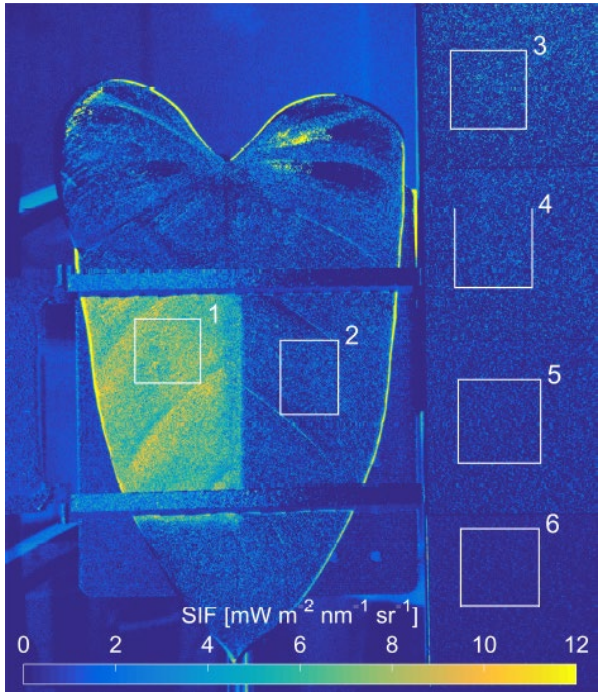
Outside band image - 757.9 nm



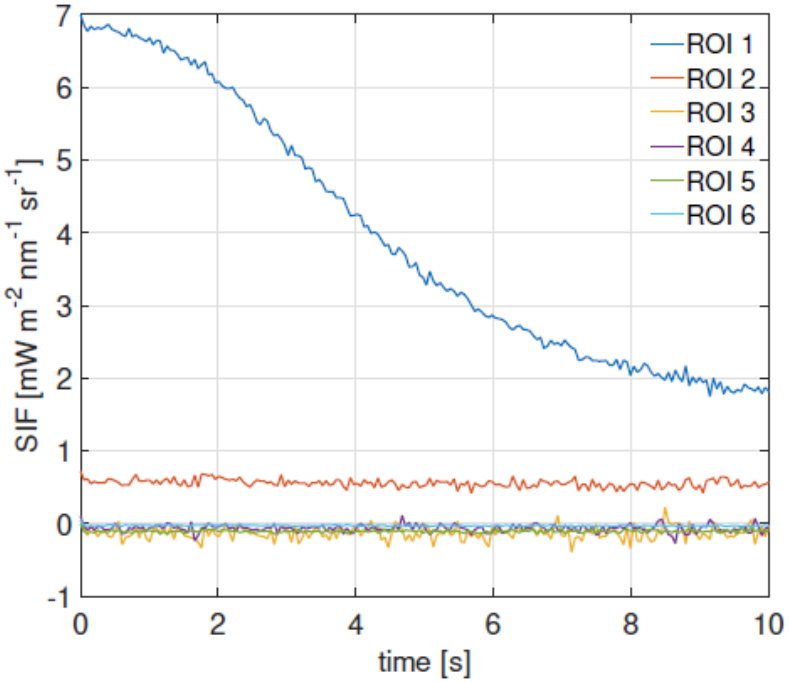
Inside band image - 760.7 nm



SIF_{760} image



Time series of SIF_{760}



Kneer et al., submitted

- ‘dark-light transition experiment’ of a philodendron leaf
  - Sensor-leaf distance: 50 cm
  - Acquisition of 200 image pairs/SIF images in 10 s (20 fps)
  - Part of the leaf was covered 30 min before data acquisition

UAV measurements – third step

Date: 13 June 21

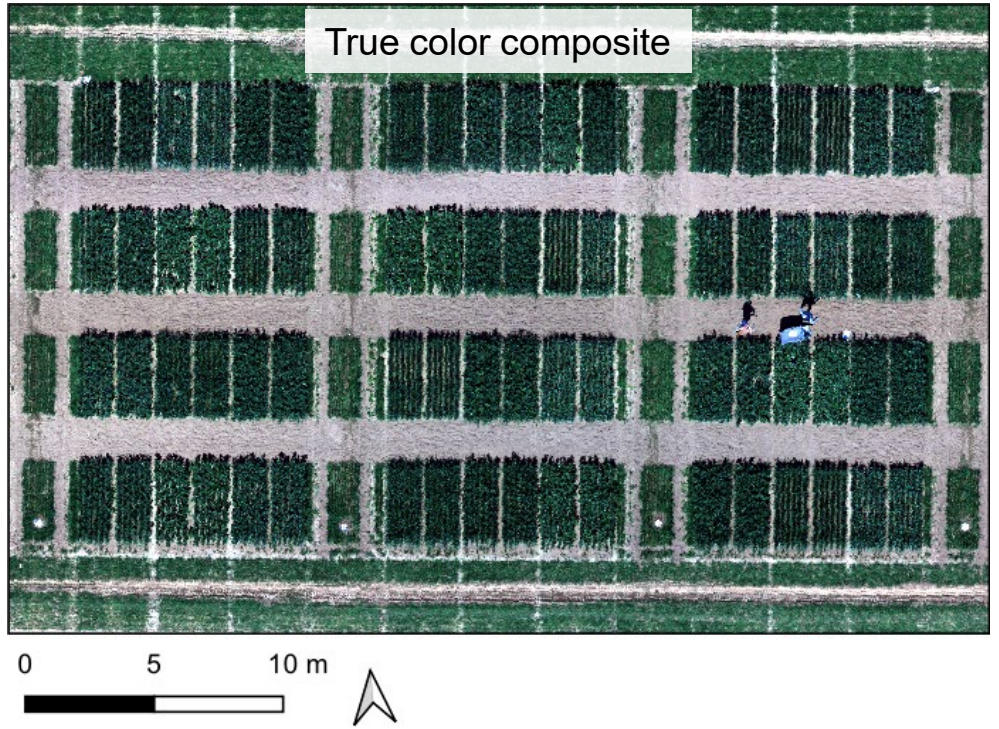
Acq. time: 13:30

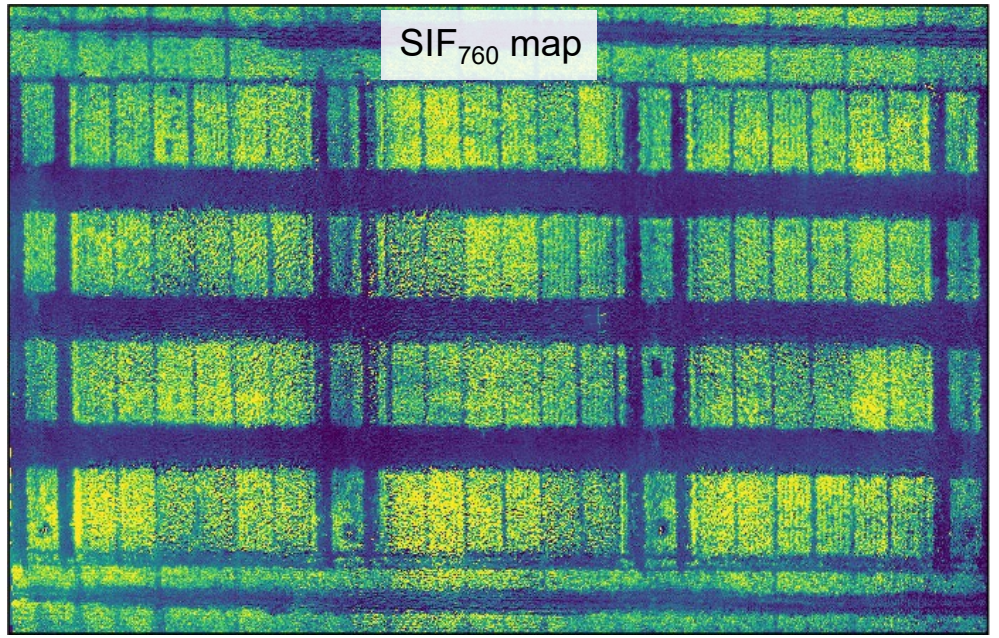
Int. time 757.9: 14 ms

Int. time 760.7: 70 ms

Altitude: 25 m

Frame rate.: 1 fps





UAV data processing, calibration and corrections

1) **dark current correction** based on five to ten dark images collected before data acquisition

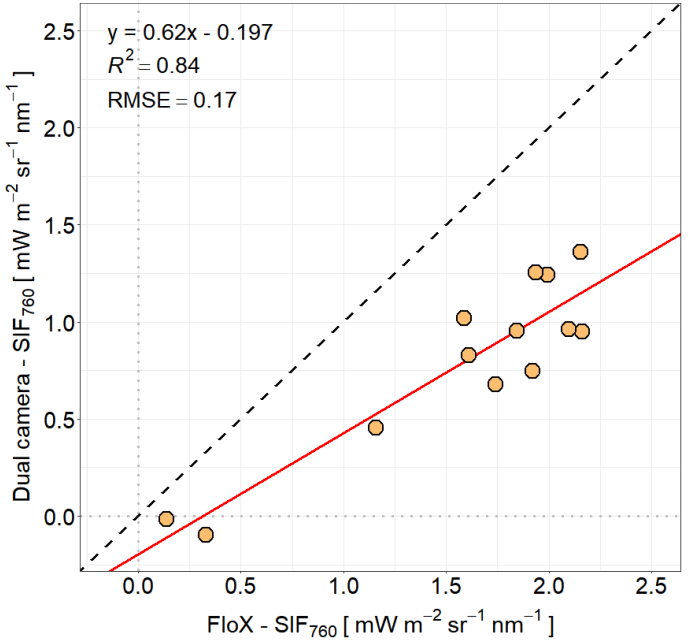
2) **flat field correction** to reduce illumination inhomogeneities introduced by the lens (e.g., vignetting, angle-dependent shifts of filter transmission)

3) **radiometric calibration** to convert DNs to radiance with coefficients determined in laboratory

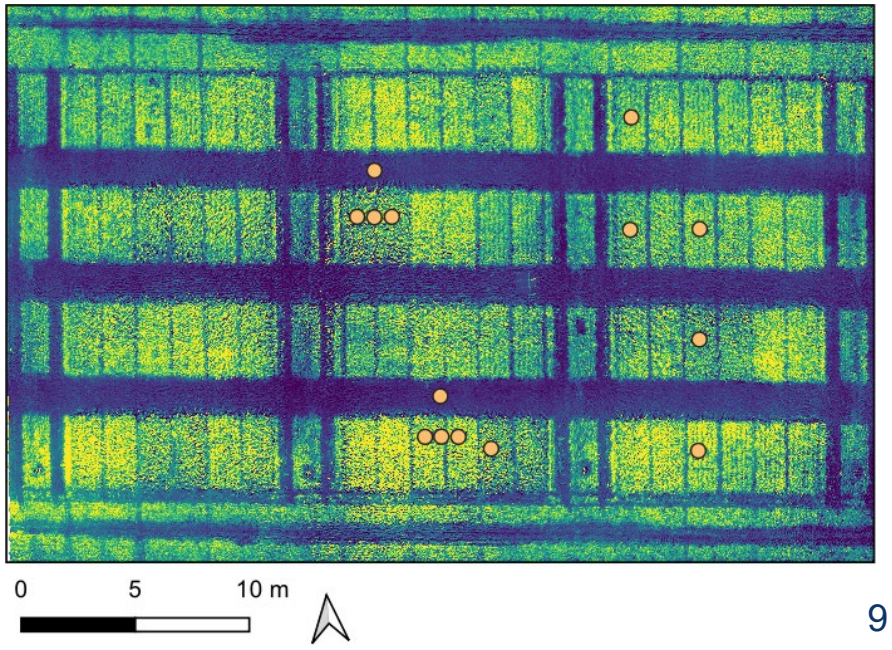
4) **Ortho mosaic composition** using structure from motion technique (standard workflow for multi-camera systems in Agisoft Metashape)

5) **SIF retrieval:** FLD method

Comparison to proximal SIF measurements



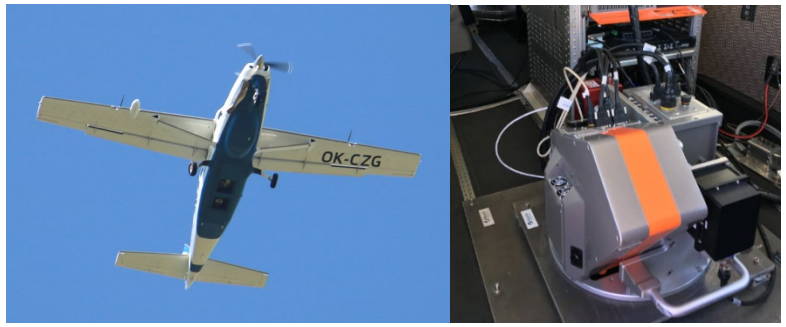
- Comparison of the UAV dual-camera system SIF of vegetation and bare soil to an established ground measurement device (FloX, JB-Hyperspectral GmbH)



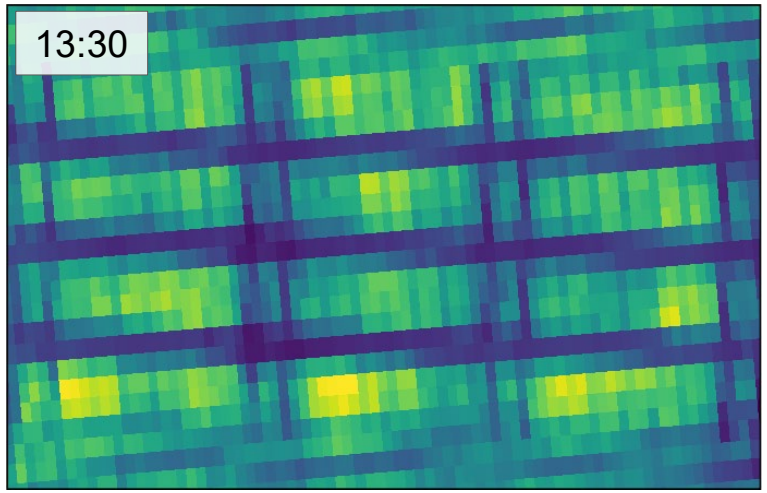
Comparison to airborne SIF measurements

UAV
Dual-camera system

Airborne
HyPlant

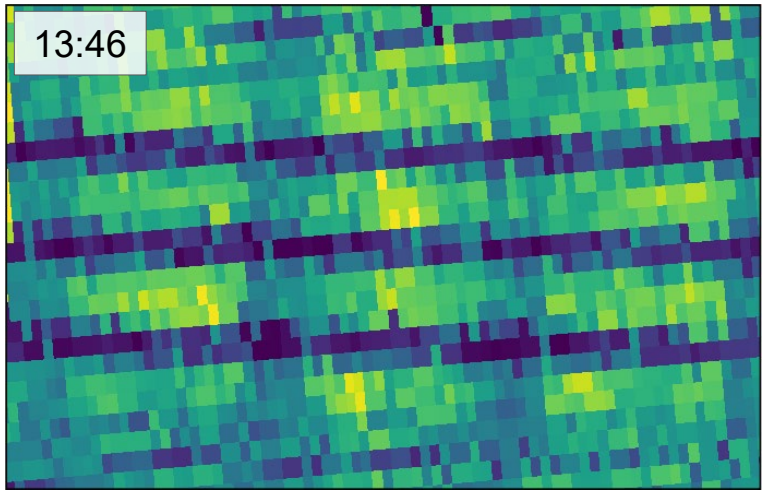


Altitude: 25 m
GSD: 0.5 x 1 m (resampled)

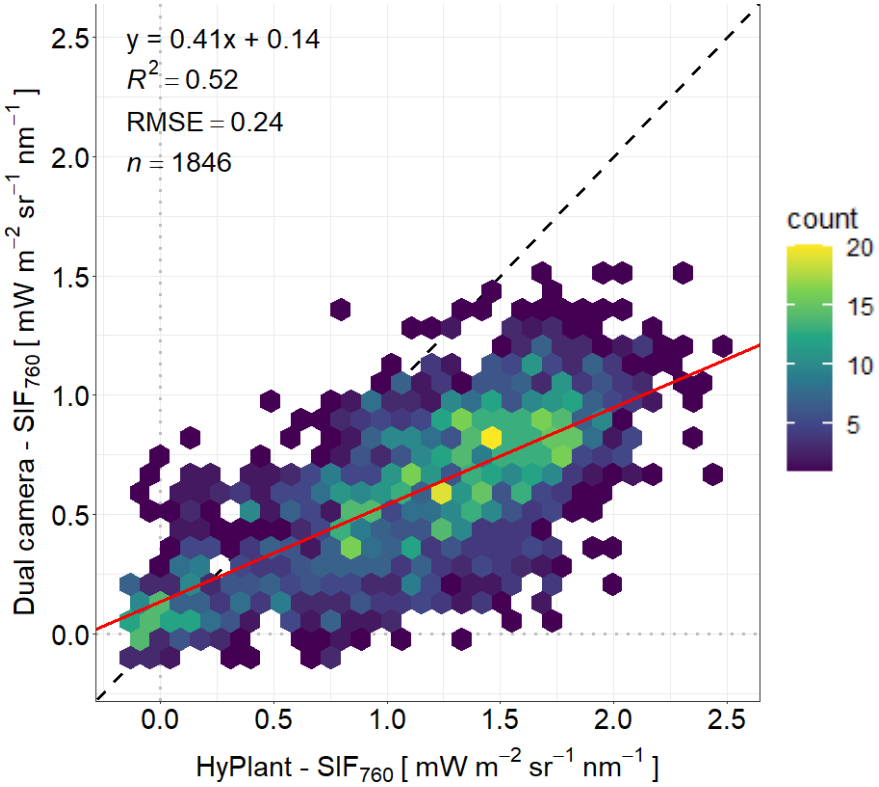


-0.3 1.5
SIF_{760} [mw m^{-2} nm^{-1} sr^{-1}]

Altitude: 350 m
GSD: 0.5 x 1 m



-0.3 2.4
SIF_{760} [mw m^{-2} nm^{-1} sr^{-1}]



- Comparison of the UAV dual-camera system SIF of vegetation and bare soil to a high-performance airborne imaging spectrometer (HyPlant)

Conclusion & outlook

- Development of a light-weight UAV camera system (1.8 kg) for the mapping of SIF
- Although the technical requirements for SIF sensors are not fully met → spatial assessment of ‘relative’ differences in SIF is possible
- UAV-based ‘relative’ SIF information can serve as a bridge to quantitatively connect the absolute measurements of SIF as provided by established ground and airborne sensors
- Dual-camera system is of high potential for the heterogeneity mapping of larger areas such as a 300 x 300 m pixel of the future Fluorescence Explorer (FLEX)
- Development of an atmospheric correction scheme for the dual-camera system as well as including a third camera to improve the absolute SIF retrieval

Thanks for your attention!

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