Technical University of Denmark DTU

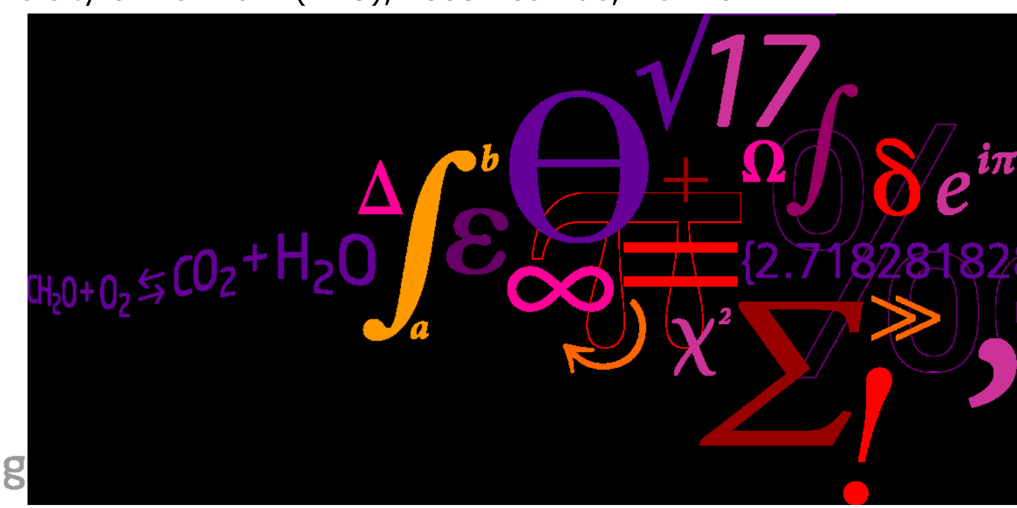
Radiometric calibration of a multispectral UAS camera for low irradiance and cloudy conditions

Sheng Wang[1], Pablo J. Zarco Tejada[2], Carsten Dam-Hansen[3], Anders Thorseth[3], Monica Garcia[1]

1. Department of Environmental Engineering, Technical University of Denmark (DTU), 2800 Kgs. Lyngby, Denmark
2. European Commission, Joint Research Centre, Directorate D - Sustainable Resources, Via E. Fermi 2749, 21027 Ispra (VA), Italy
3. Department of Photonics Engineering, Technical University of Denmark (DTU), 4000 Roskilde, Denmark

swan@env.dtu.dk

23/02/2017



Outline

- Motivations & background
- Objectives
- Methods
- Results
- Conclusion
- Ongoing work

Motivation 1

- Unmanned Aerial Systems (UAS) have significant potential in ecological and environmental monitoring (Watts et al., 2012; Anderson and Gaston, 2013; Vivoni et al., 2014).

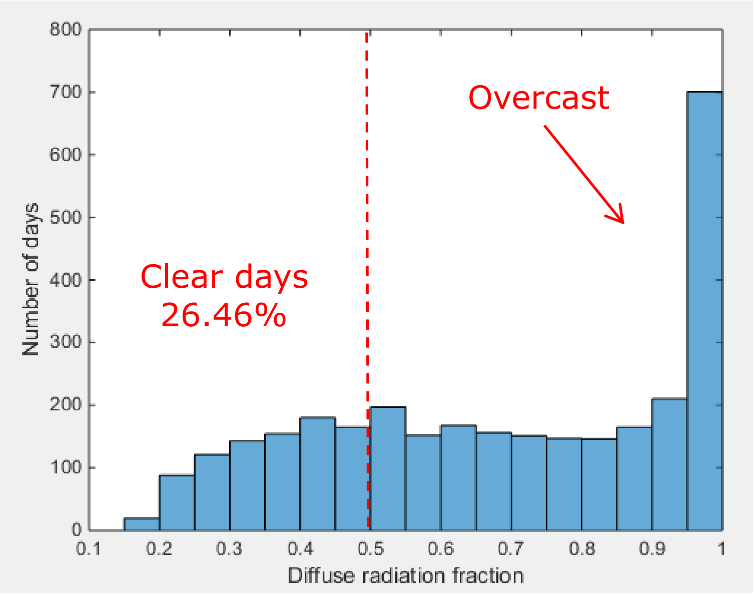
UAS:

- High spatial resolution (<1m)
- Flexible time and location
- Low cost
- Cloudy and overcast is OK

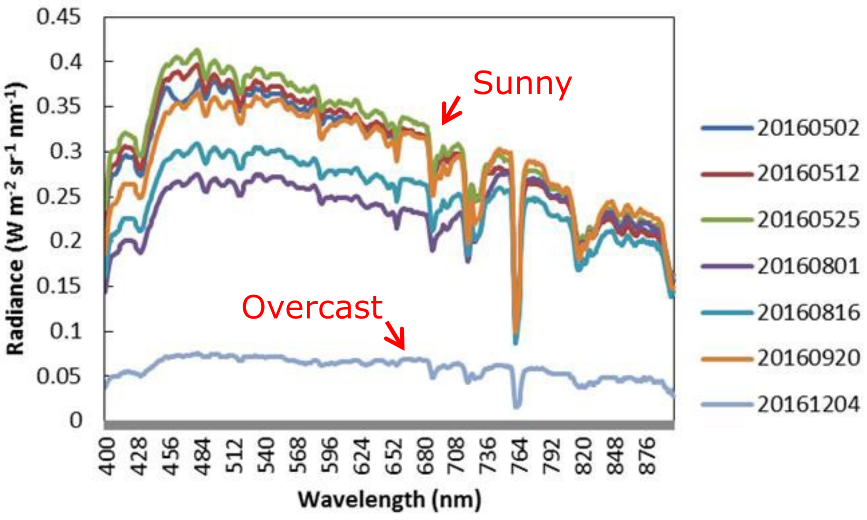
- However, miniaturized UAS sensors have low radiometric resolutions and SNRs. This may limit the applications in low illumination conditions.

Motivation 1

- Danish (high latitude) weather conditions: high fraction of overcast and low irradiance



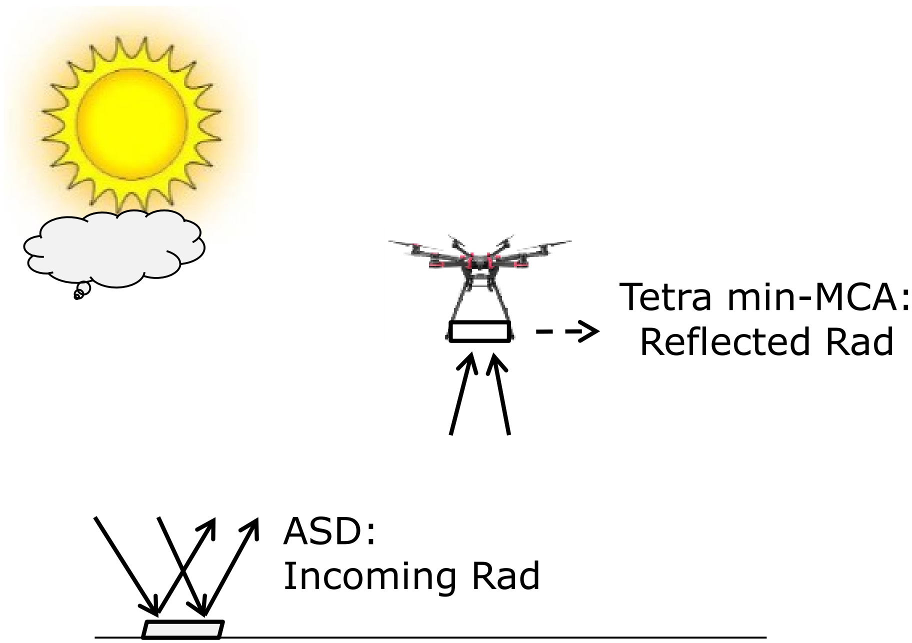
Observed daily diffuse radiation fraction in the Soroe eddy covariance flux site of Denmark from 2004 to 2012

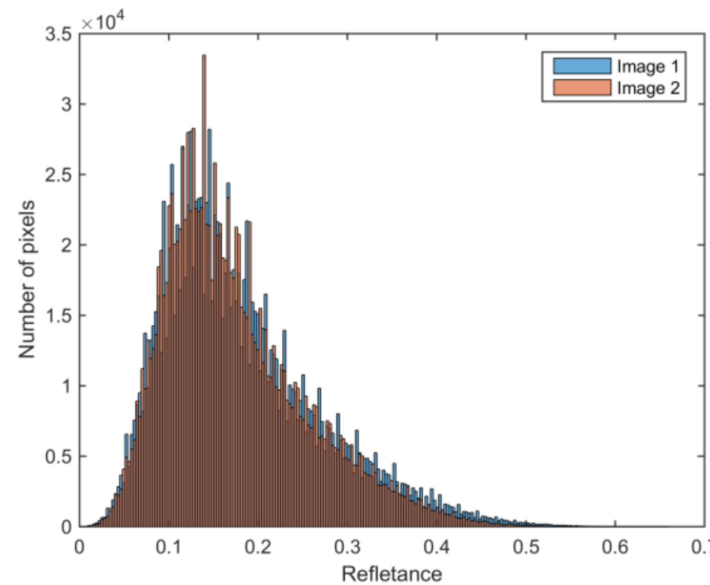


Spectral radiance of incoming solar radiation reflected by the Spectralon panel

Motivation 1

- Danish (high latitude) weather conditions: the movement of clouds affects the incoming radiation



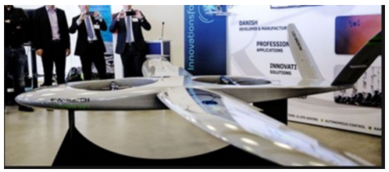


Reflectance histograms of two consecutive high overlapping multispectral images (800 nm)

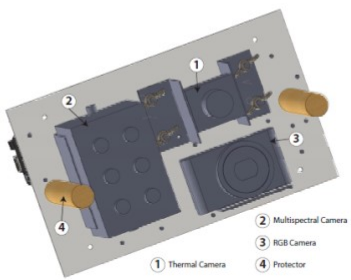
Motivation 2

- Smart UAS-based operational framework for ET and GPP estimation

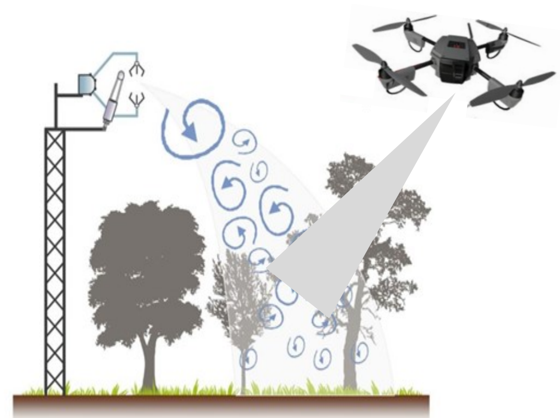
Drone



Payload



Model



Integrate UAS, EC observations and LSMs

Objectives:

(1) To better understand the links between photosynthesis, plant stress, growth and physiology?

(2) To predict land surface GPP and ET for various weather conditions (sunny, cloudy and overcast) by incorporating different spectral indices and LST.

Background

- Short Term Scientific Mission (STSM): to learn the protocols for radiometric calibration for a multispectral camera in order to produce high quality UAS optical imagery.

- Applicant: Sheng Wang, A PhD student from Department of Environmental Engineering, Technical University of Denmark (DTU), Copenhagen, Denmark
- Host: Dr. Prof. Pablo J. Zarco Tejada, Quantalab, Institute for Sustainable Agriculture (IAS), Spanish National Research Council (CSIC), Cordoba, Spain
- Time: 2016-01-17 to 2016-01-23 (1 week)

European Cooperation in Science and Technology

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

INSTITUTO DE AGRICULTURA SOSTENIBLE

Objective

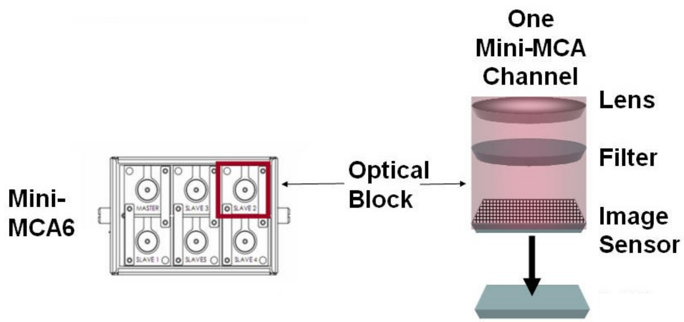
- Use the radiometric calibration protocols from STSM to conduct radiometric calibration of a multispectral camera to produce high quality UAS radiance and reflectance for high latitude low irradiance and cloudy conditions with light payload (< 2kg).

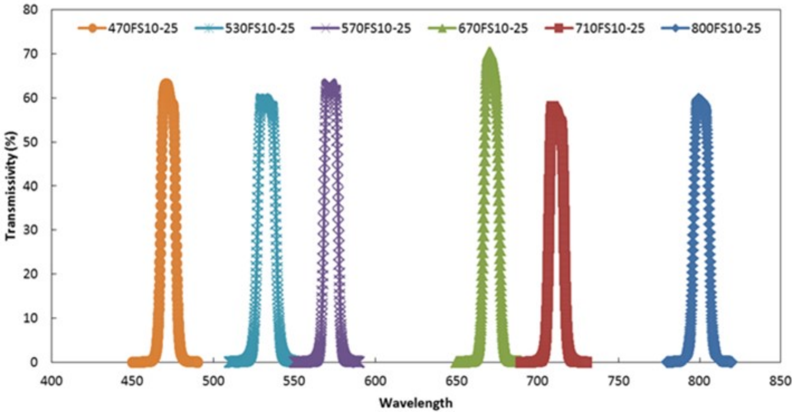
Methods

1) Radiometric calibration protocols at Quantalab (STSM)
    - Vignetting correction
    - Convert the image digital number to radiance
2) Laboratory radiometric calibration at DTU photonics
    - Extend the calibration to low illumination conditions
3) Outdoor image acquisition (ongoing)
    - Homogeneous targets (Teflon panels, grass, soil and snow): Validate radiance and check sensor stability
    - Test multiband cosine receptor for incoming radiance on UAS
    - Forest flux sites: Acquire images, validate surface reflectance

Instrument

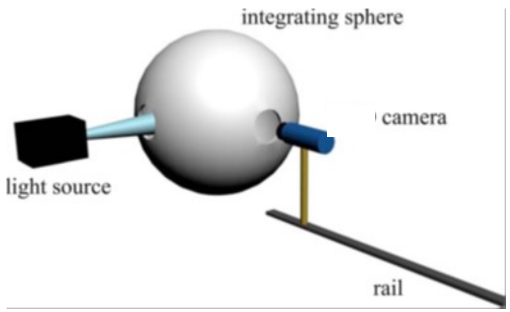
- Six-band multispectral camera: Tetra mini-MCA



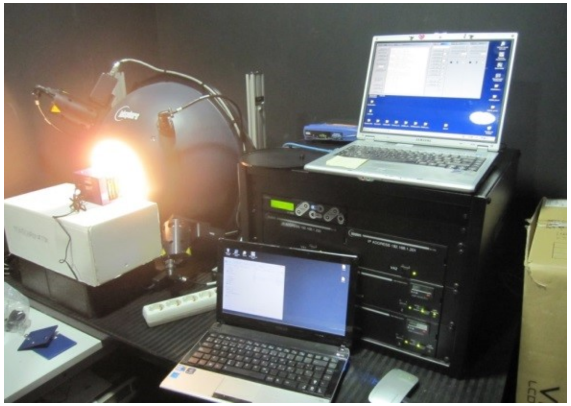


- Tetra mini-MCA is one of the most popular used multispectral cameras for UAS surveys (Zarco-Tejada et al., 2009, 2013, 2014; Berni et al., 2009; Laliberte et al., 2011; Bendig et al., 2012; Turner et al., 2014; Von Bueren et al., 2015).

1. Radiometric calibration protocols at Quantalab



- Vignetting correction: homogeneous illumination from the integrating sphere



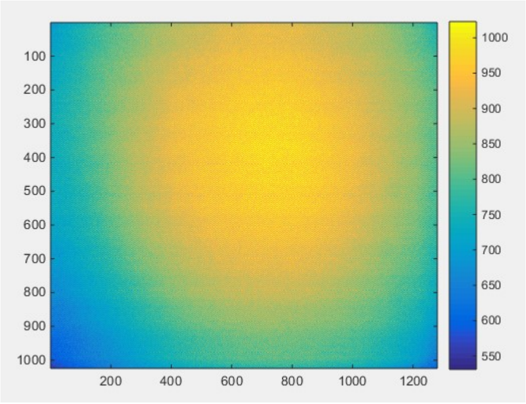
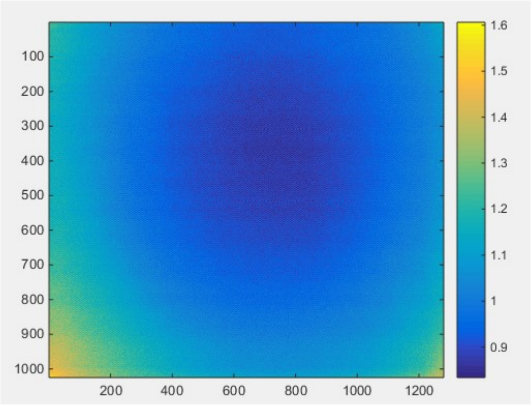


Image with the integrating sphere



Correction factors (correct to the mean value)

1. Radiometric calibration protocols at Quantalab

- Converting DN to radiance:
  - Link DN with radiance for each specific integration time setting: the gain factor

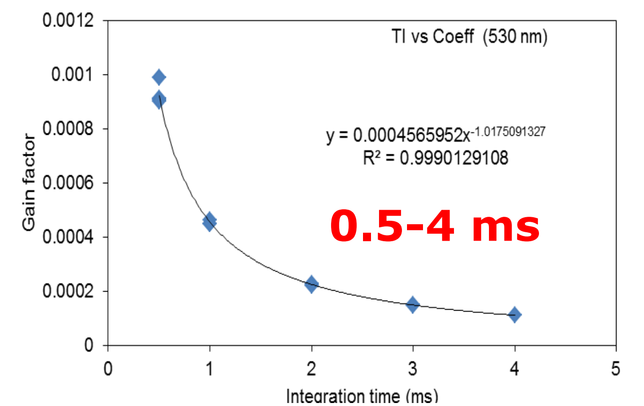
$$L = c1 \times DN + c0$$

Where L is the radiance from illumination levels, c1 is the gain, DN is the digital number, c0 is a coefficient related to the dark current.

  - Link gain with integration times: a calibration function (gains ~ integration times) for each channel

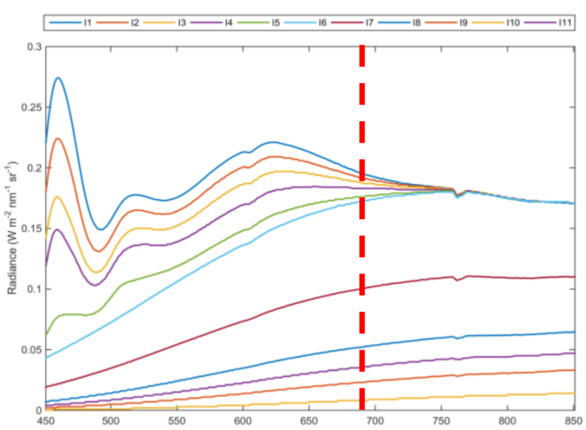
$$c1 = a \times t^{b}$$

Where c1 is the gain, t is the integration time, a and b are coefficients

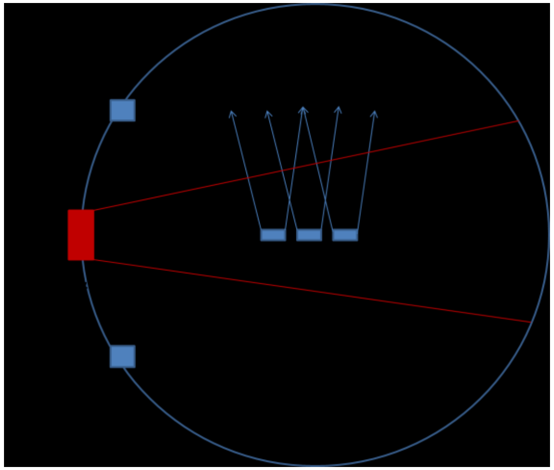


2. Laboratory radiometric calibration at DTU Photonics (low illumination conditions)

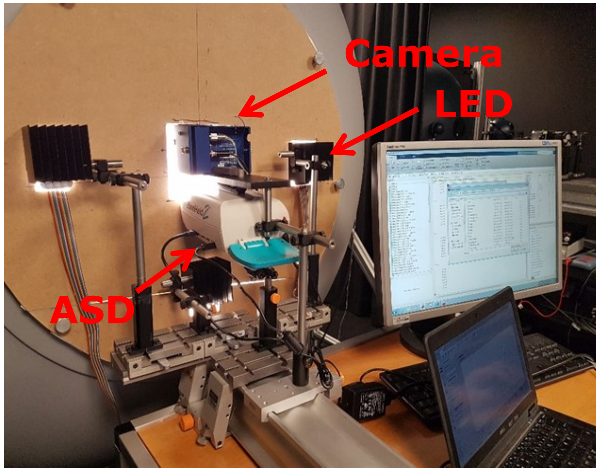
- Camera: Tetra mini-MCA
- Sphere: a 2m diameter integrating sphere (ISP2000, Instrument Systems)
- Light source: combined multicolor LEDs and 3 tungsten halogen lamps
- Radiance detector: ASD spectroradiometer (Analytical Spectral Devices, Inc.)



Spectral radiance from the integrating sphere



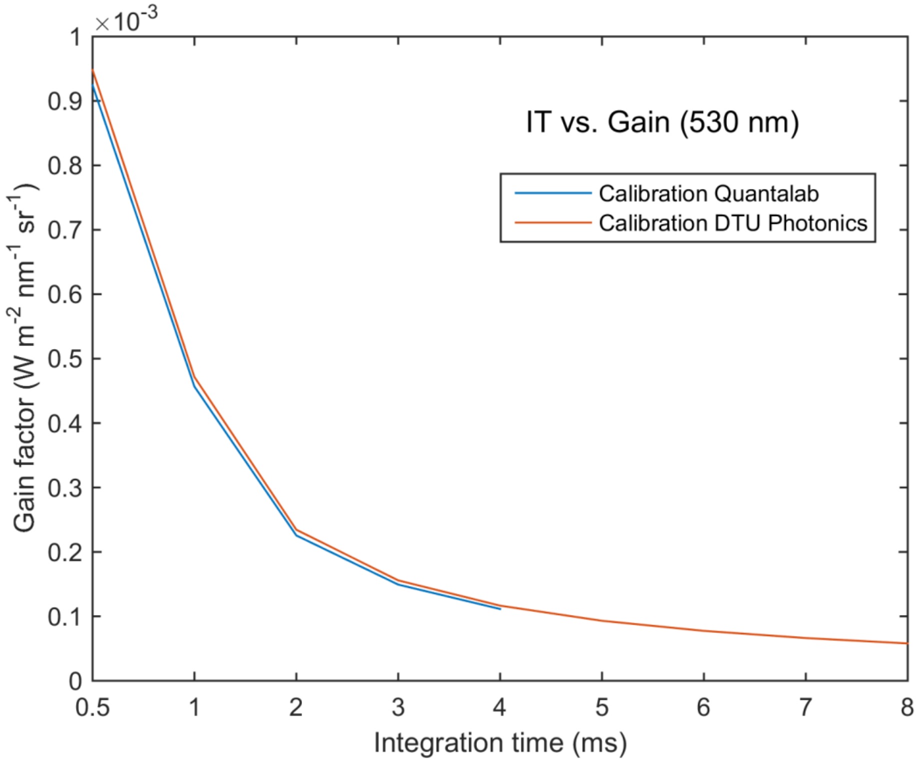
Top cross section view of this setup



Front view of this setup

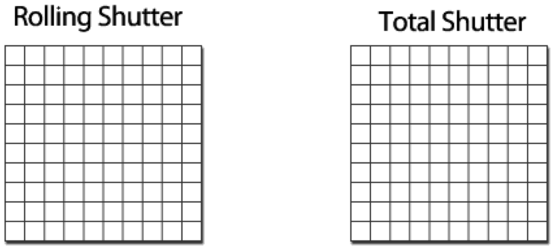
2. Laboratory radiometric calibration at DTU Photonics (low illumination conditions)

- DN~Rad: the extended calibration function for high integration times



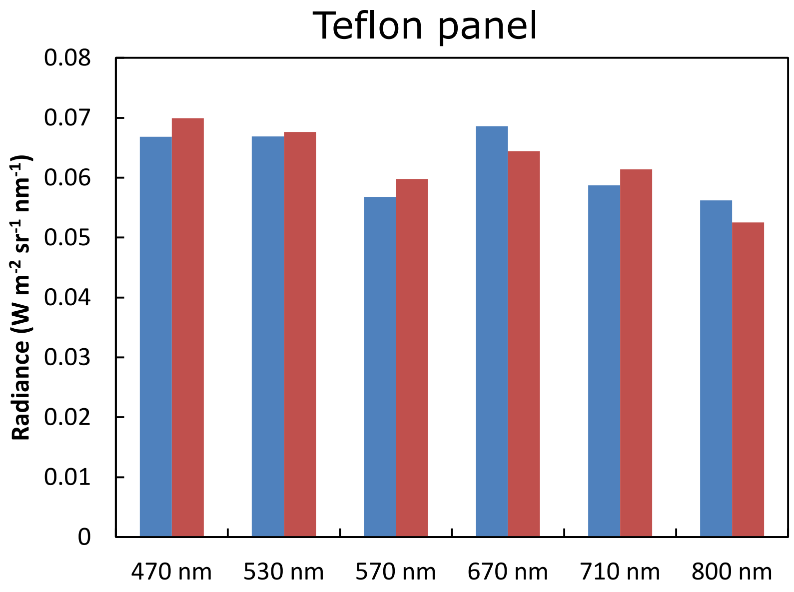
4 ms -> 8 ms

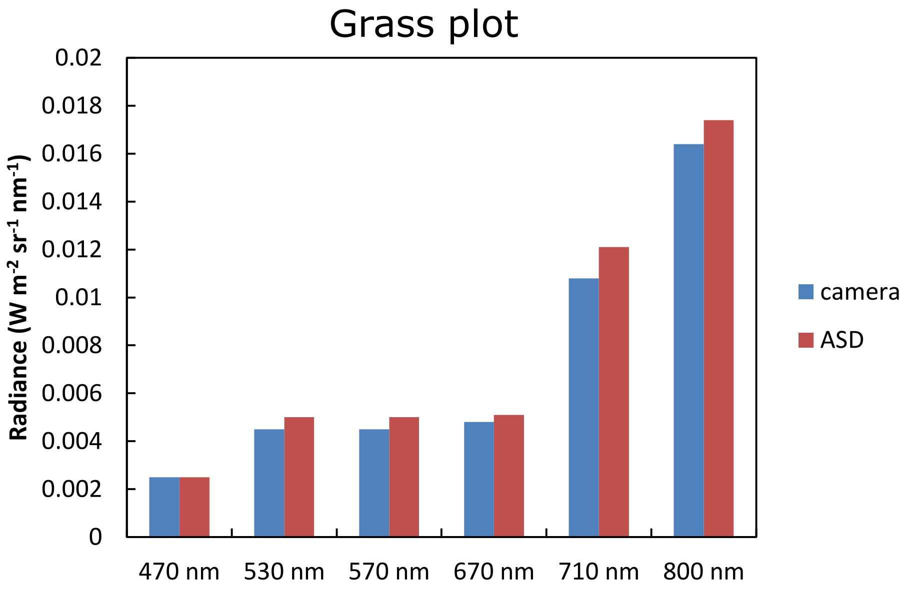
Rolling shutter



3. Outdoor experiment

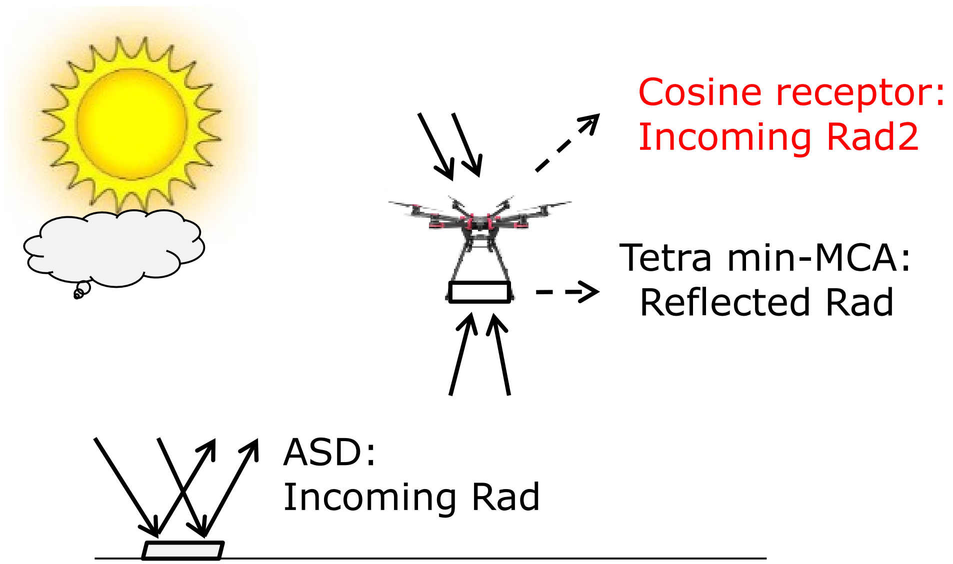
- Outdoor validation: Teflon panel and grass plot
- ASD & Tetra camera comparison: overall averaged difference = 5.87%





3. Outdoor experiment

- Test ultralight-multiband cosine receptor for incoming radiance to be used on UAS (DTU Photonics)
- Directly calculate the reflectance at UAS sensors, continuously record incoming radiation changing induced by the movement of clouds



Conclusion

- In high latitude regions, the quality of UAS multispectral imagery is restricted by low illumination and cloudy weather conditions.

- Images acquired with an integrating sphere, tungsten halogen lamps and combined LEDs allowed to perform vignetting correction and radiometric calibration.

- Onboard ultralight-multiband cosine receptor could provide incoming radiance at the UAS accounting for changes of illumination across images.

Ongoing work

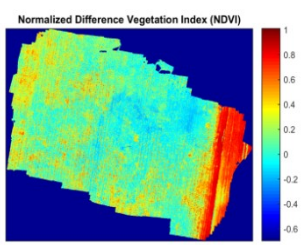
A joint model approach

Net radiation / PAR
(**Swin**, **Swout**, Lwin, **LWout**)

Tair

Humidity

NDVI



Soil moisture/ thermal inertia

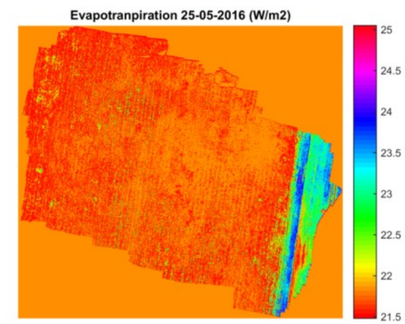
PT-JPL model

LUE model

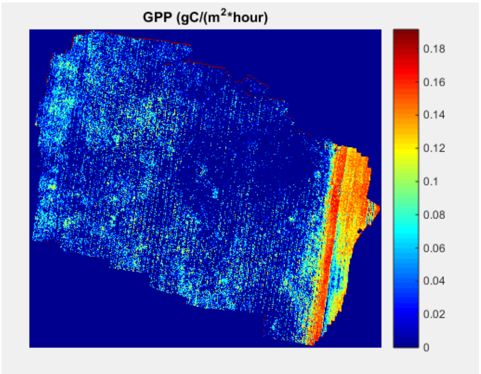
Interception $ETi = fwet * Etpc$

Transpiration $ETc = (1 - fwet) * fg * fT * fM * Etpc$

Soil evaporation $ETs = fSM_{ATI} * Etps$



Gross Primary Productivity $GPP = \varepsilon_{max} \times PAR \times fPAR \times fT \times fVPD$



How to make most use of six-band multispectral and LST for GPP and ET estimation?

Thanks for your attention!