Low-altitude / high-resolution remote sensing – from theory to application

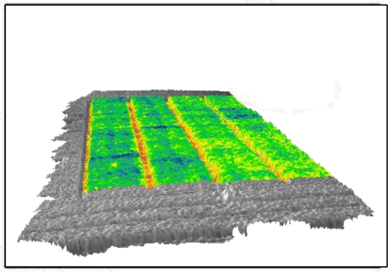
Helge Aasen[1*], Lukas Roth[1], Quirina Merz[1], Francesco Argento[1], Frank Liebisch[1], Andreas Hund[1], Norbert Kirchgessner[1] and Achim Walter[1], Andreas Bolten[2], Georg Bareth[2], Eija Honkavaara[3], Arko Lucieer[4], Pablo Zarco-Tejada[5]

[1]Crop Science Group, Institute of Agricultural Sciences, ETH Zurich, Switzerland
[2]GIS and RS Research Group, Institute of Geography, University of Cologne, Germany
[3]Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute, Finland
[4]Discipline of Geography and Spatial Sciences, School of Technology, Environments and Design, College of Sciences and Engineering, University of Tasmania, Australia
[5]European Commission (EC), Joint Research Centre (JRC), Italy

@PhenoFly | Helge.Aasen@usys.ethz.ch

particle / object
in environment

field



'pixel' in digital
representation

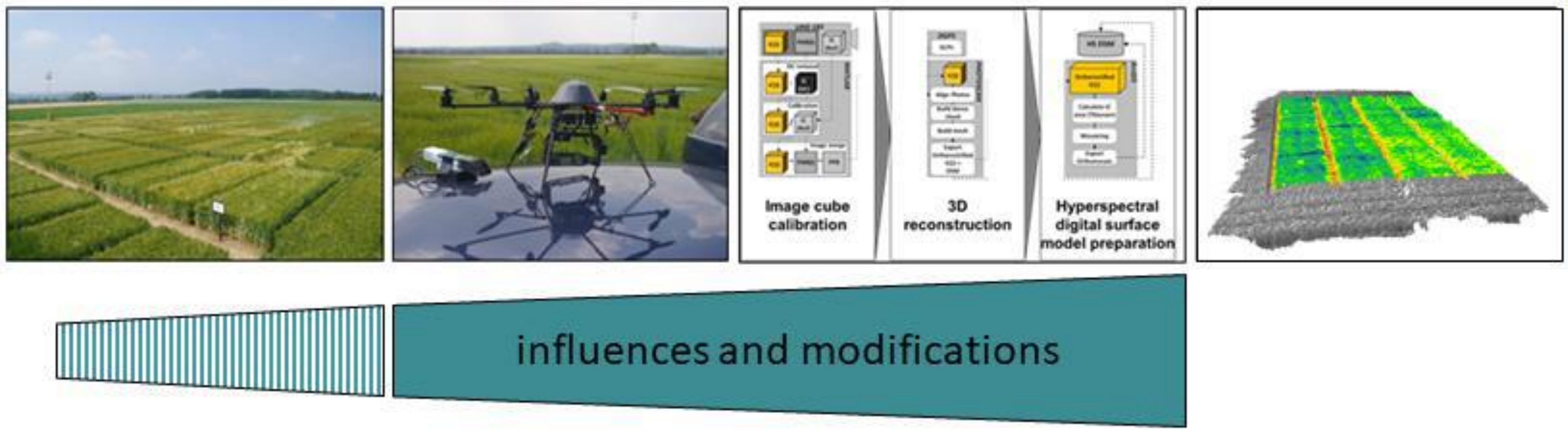
data
product

Aasen, H., Honkavaara, E., Lucieer, A., Zarco-Tejada, P., 2018. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. Remote Sensing

particle / object in environment

‘pixel’ in digital representation

field



Aasen, H., Honkavaara, E., Lucieer, A., Zarco-Tejada, P., 2018. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. Remote Sensing

@PhenoFly | Helge.Aasen@usys.ethz.ch

PhenoFly mission statement

- The **PhenoFly team** develops sensing systems and analysis procedures that deliver quantitative data to capture reliable information about vegetation
- Our **vision** is to bring (high-throughput) phenotyping approaches from large facilities to the landscape
- We **aim** to understand the interaction of plants with their environment to facilitate a more sustainable use of resources.

Flight planning, setup and flight → Data processing → Plant trait extraction → Database → P = G x E

Understanding the data

@PhenoFly | Helge.Aasen@usys.ethz.ch

Outline

Flight planning, setup and flight	→	Data processing	→	Plant trait extraction	→	Database	→	P = G x E

Understanding the data

@PhenoFly | Helge.Aasen@usys.ethz.ch

ETH zürich

Phenofly.net

Outline

Flight planning, setup and flight → Data processing → Plant trait extraction → Database → P = G x E

Understanding the data

@PhenoFly | Helge.Aasen@usys.ethz.ch

Mission planning

- Selection of equipment
- Flight planning
- (Legislation, weather, security & health measures)

➢ Can be quite complex
  - Data product (point cloud, digital surface model, orthophoto)
  - Sensor (point, line or 2d imager)
  - Data type (RGB, spectral, thermal …)
  - Coverage (flight time, flight speed, altitude)
  - Ground sampling distance (altitude, resolution, motion blur ~ flying speed + integration time)
  - Focus distance depth of field
  - GCP placement

@PhenoFly | Helge.Aasen@usys.ethz.ch

Mission planning

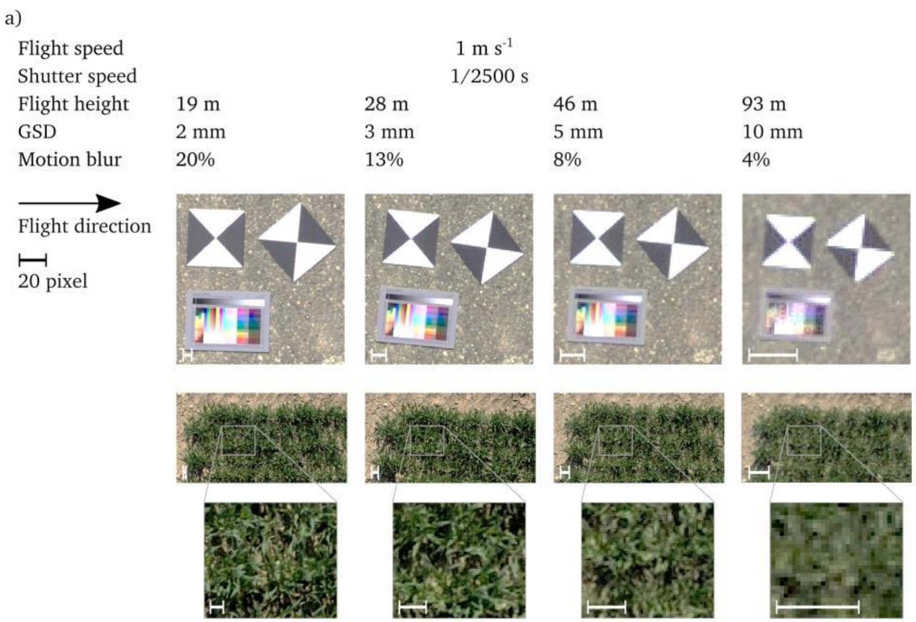
- Selection of equipment
- Flight planning
- (Legislation, weather, security & health measures)

➢ Can be quite complex
  - Data product (point cloud, digital surface model, orthophoto)
  - Sensor (point, line or 2d imager)
  - Data type (RGB, spectral, thermal …)
  - Coverage (flight time, flight speed, altitude)
  - Ground sampling distance (altitude, resolution, motion blur ~ flying speed + integration time)
  - Focus distance and depth of field
  - GCP placement

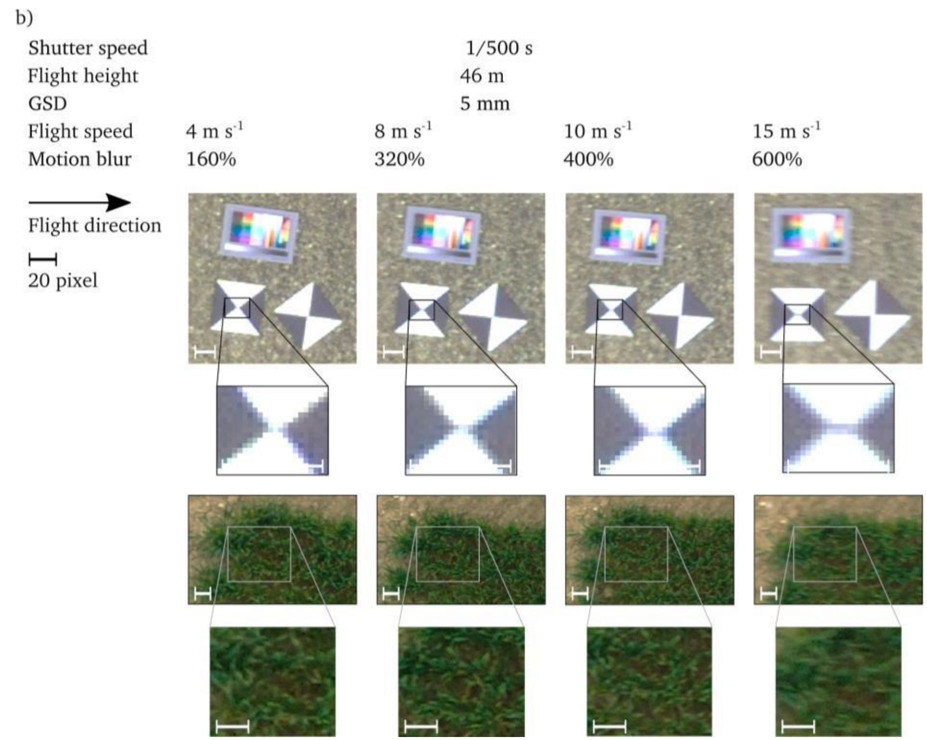
@PhenoFly | Helge.Aasen@usys.ethz.ch

Flight planning

ground sampling distance ~ altitude + sensor



motion blur ~ flying speed + shutter speed

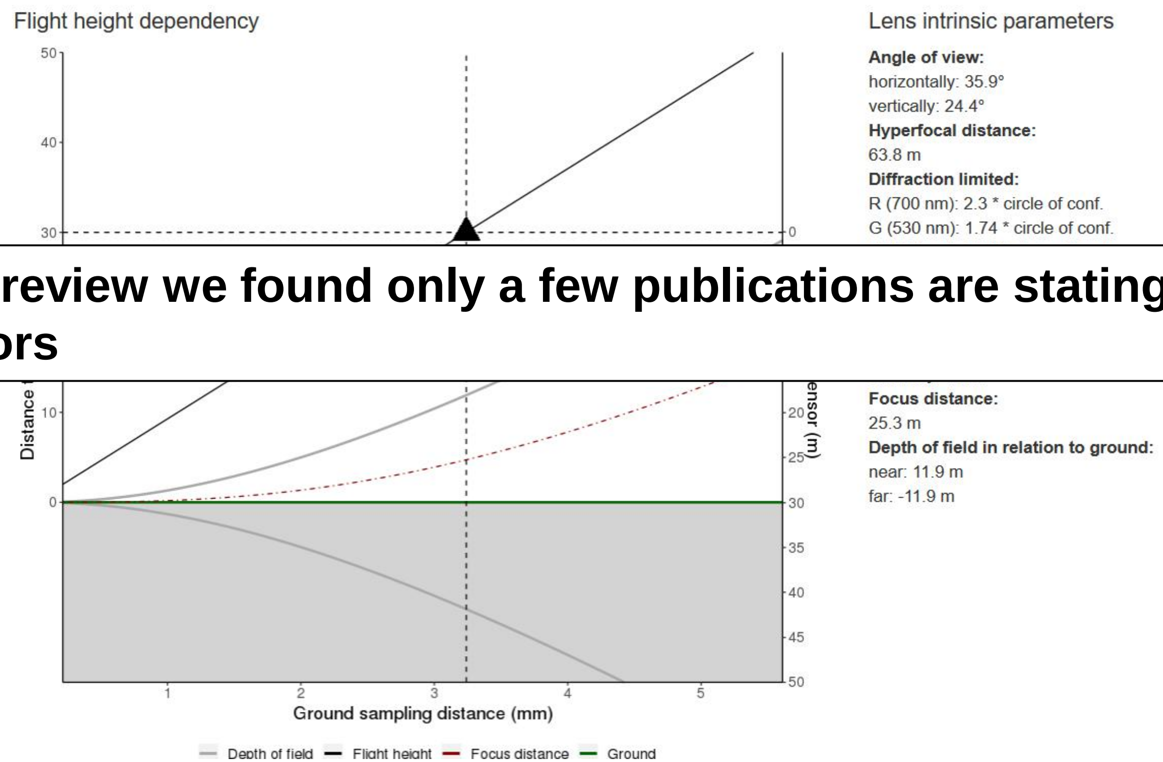


L. Roth, A. Hund, and H. Aasen, “PhenoFly Planning Tool - Flight planning for high-resolution optical remote sensing with unmanned areal systems,” *Plant Methods*, “accepted.”

@PhenoFly | Helge.Aasen@usys.ethz.ch

Flight planning

focus distance ~ lens configuration



- **During our literature review we found only a few publications are stating these quality indicators**

L. Roth, A. Hund, and H. Aasen, “PhenoFly Planning Tool - Flight planning for high-resolution optical remote sensing with unmanned areal systems,” *Plant Methods*, “accepted.”

Flight planning

http://phenofly.net/**PhenoFlyPlanningTool**

PhenoFly Planning Tool

Sony A9 Sample Project

Edit project | Save project

Sensor/Lens | Imaging | Mapping | GCPs | Location

Sensor

Sony A9 on DJI M600P

Sensor size, x (mm) 35,6

Sensor size, y (mm) 23,8

Number of recorded pixels, x (px) 6000

Number of recorded pixels, y (px) 4000

Max. shutter speed (1/s) 32000

Max. film speed (ISO) 6400

Max. image trigger freq. (1/s) 2

Max. flight duration (min) 15

Distance between pixel centers / circle of confusion: 0.0059 mm

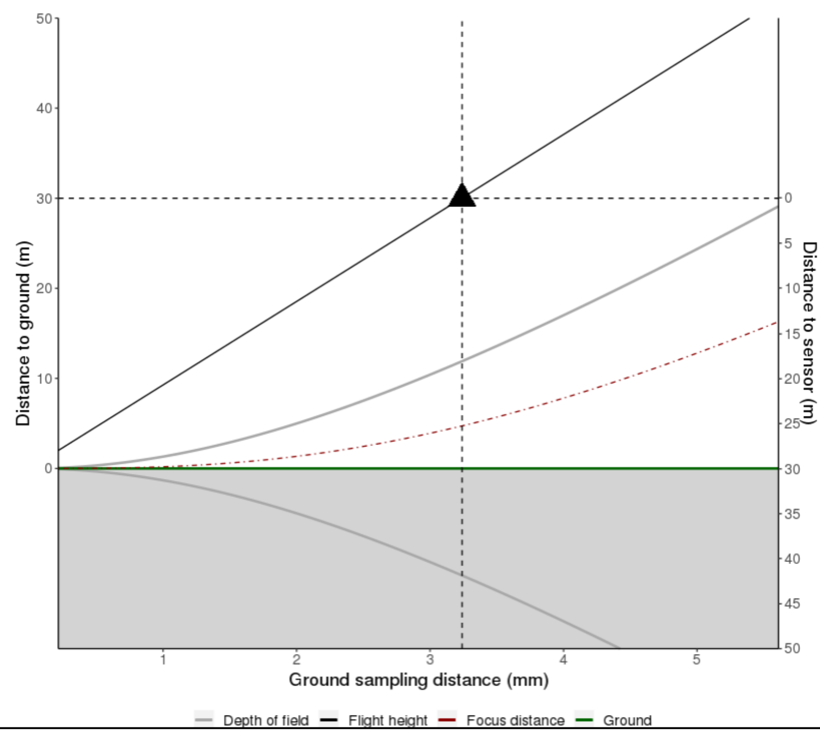
Lens

Focal length (mm) 55

Aperture (f-number) f/8

Photography | Mapping properties | Viewing geometry | Mission briefing

Flight height dependency



Lens intrinsic parameters

Angle of view:
horizontally: 35.9°
vertically: 24.4°
Hyperfocal distance:
63.8 m
Diffraction limited:
R (700 nm): 2.3 * circle of conf.
G (530 nm): 1.74 * circle of conf.
B (470 nm): 1.55 * circle of conf.

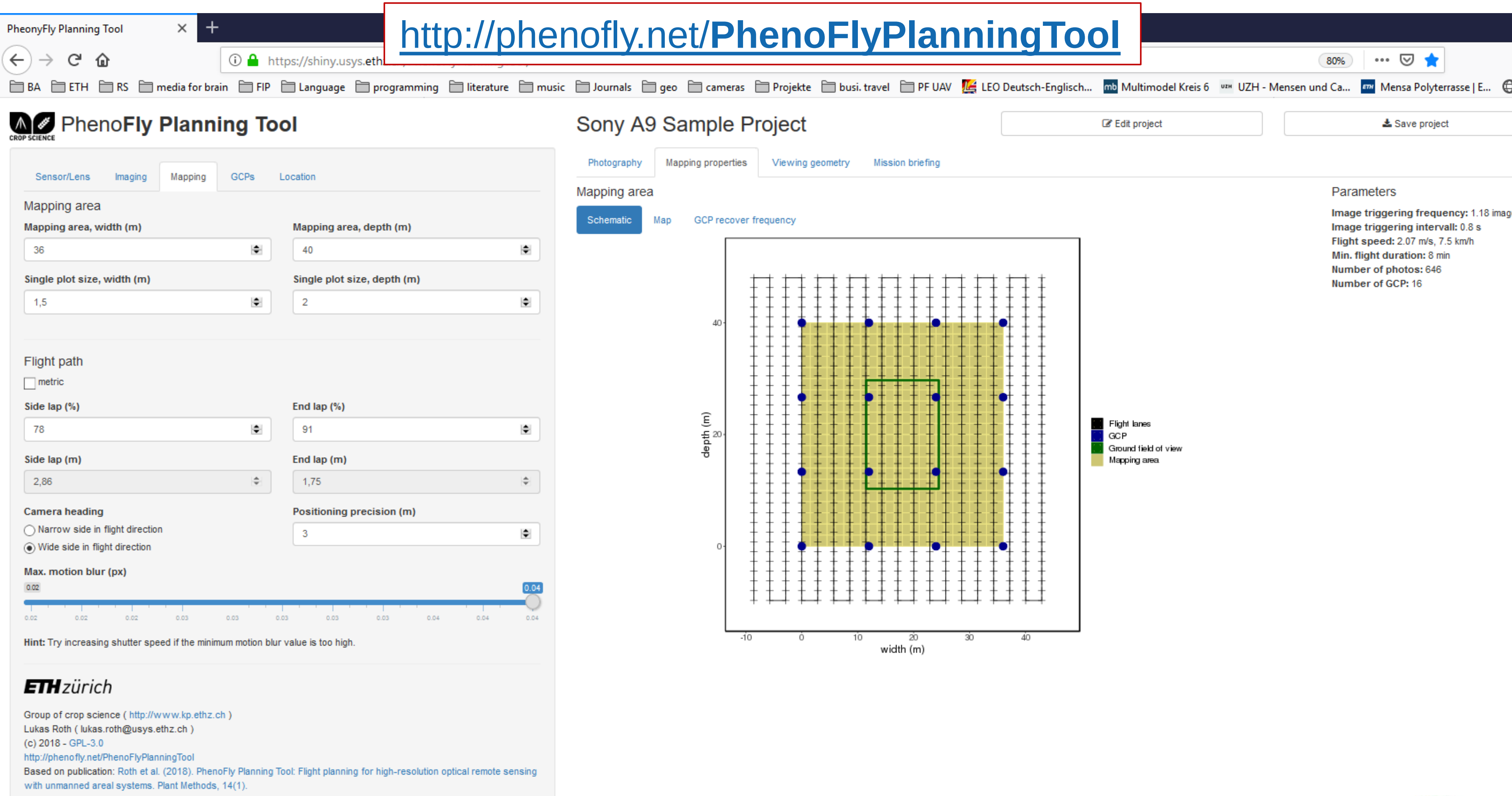
Dependant parameters

Ground field of view:
horizontally: 19.4 m
vertically: 13 m
Focus distance:
25.3 m
Depth of field in relation to ground:
near: 11.9 m
far: -11.9 m

L. Roth, A. Hund, and H. Aasen, 2018 “PhenoFly Planning Tool - Flight planning for high-resolution optical remote sensing with unmanned areal systems,” *Plant Methods*,

Flight parameter quality assurance

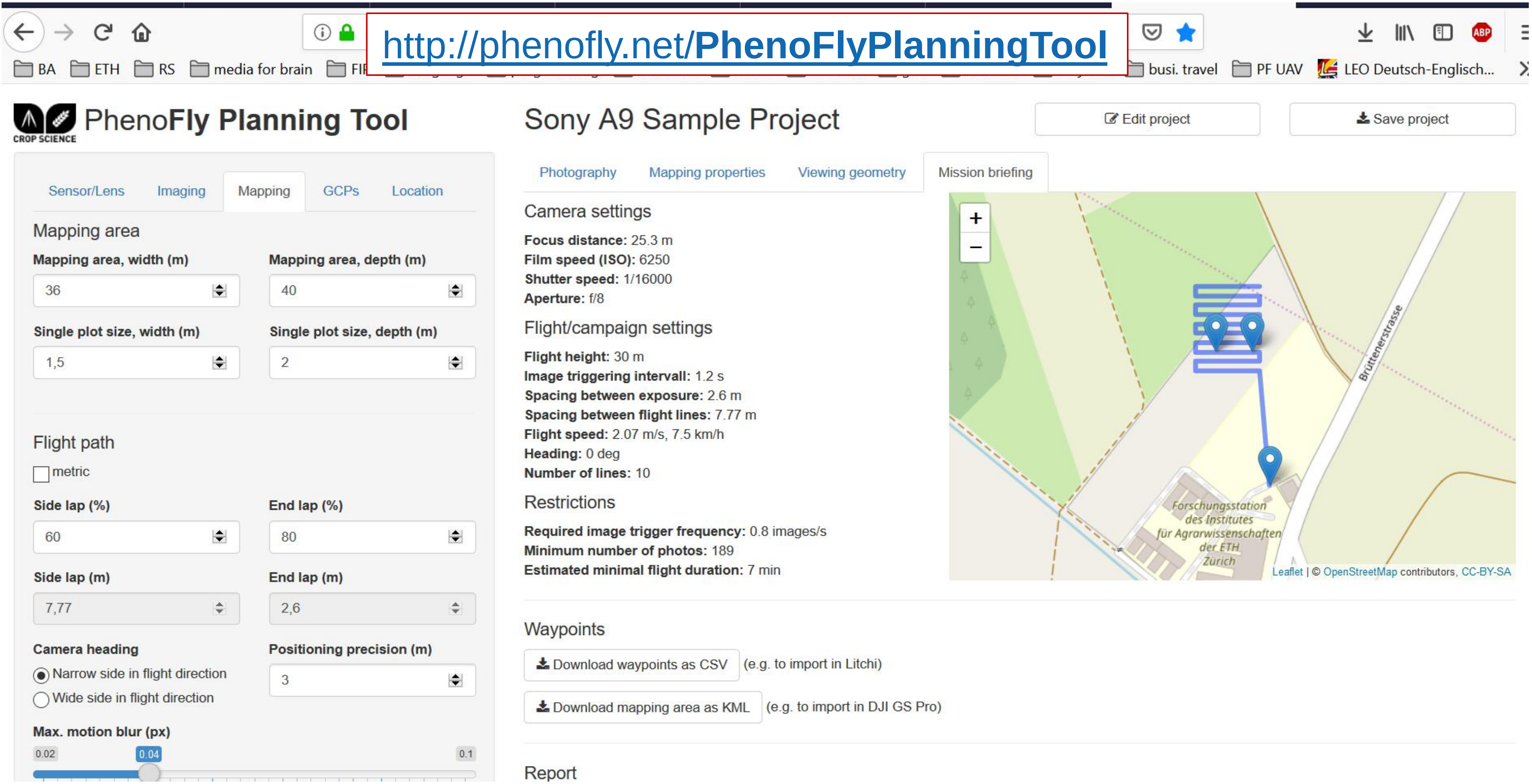
http://phenofly.net/PhenoFlyPlanningTool



TraitSpotting

L. Roth, A. Hund, and H. Aasen, 2018. “PhenoFly Planning Tool - Flight planning for high-resolution optical remote sensing with unmanned areal systems,” *Plant Methods*.

Flight planning



L. Roth, A. Hund, and H. Aasen, 2018 "PhenoFly Planning Tool - Flight planning for high-resolution optical remote sensing with unmanned areal systems," *Plant Methods*,

@PhenoFly | Helge.Aasen@usys.ethz.ch

Mission planning

- Selection of equipment
- Flight planning
- (Legislation, weather, security & health measures)

- Can be quite complex
  - Data product (point cloud, digital surface model, orthophoto)
  - Sensor (point, line or 2d imager)
  - Data type (RGB, spectral, thermal …)
  - Coverage (flight time, flight speed, altitude)
  - Ground sampling distance (altitude, resolution, motion blur ~ flying speed + integration time)
  - Focus distance (focus distance and depth of field)
  - GCP placement
- Think of it even before you by your equipment

@PhenoFly | Helge.Aasen@usys.ethz.ch

ETH zürich

Phenofly.net

Spectral sensors for UAS RS

Headwall Nano-Hyperspec® VNIR

Simple consumer oriented systems

Parrot Sequoia / Micasense Red-Edge
Mutli-spectral 2D imager

TetraCam mini-mca
Multispectral 2D imager
(Berni et al., 2009)
(Kelcey and Lucieer, 2012)

Cubert UHD 185
2D Hyperspectral snapshot imager
(Aasen et al., 2015)

Rikola FPI – NIR/SWIR (1100 – 1600 nm)
2D Hyperspectral sequential 2D imager
(Honkavaara et al., 2016)

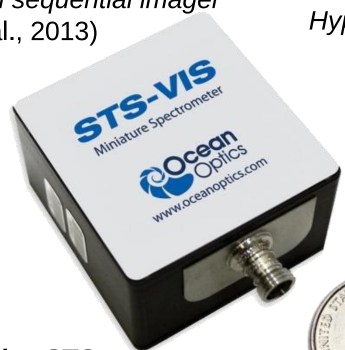
2009 2012 2013 2014 2015 2016 2017 2018 2019

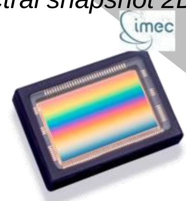
Rikola FPI – VNIR
2D Hyperspectral sequential imager
(Honkavaara et al., 2013)

Imec filter-on-chip
Hyperspectral snapshot 2D

High-quality systems

HySpex
Mjolnir





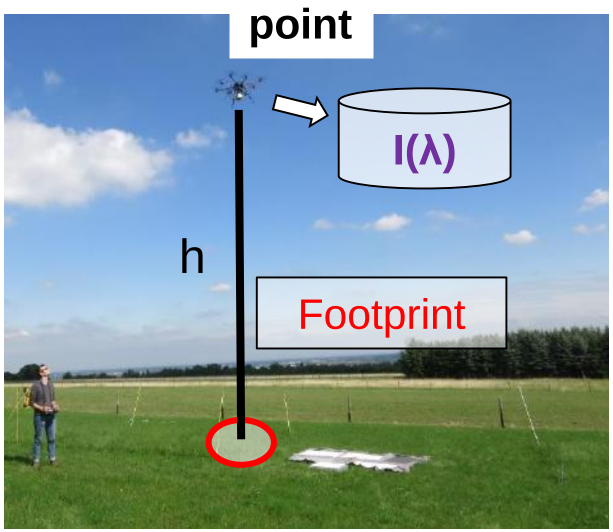
SPECIM FX10

Headwall micro-HyperSpec
Hyperspectral line-scanner
(Zarco-Tejada et al., 2012)
(Lucieer et al., 2014)

OceanOptics STS
Hyperspectral points-pectrometer
(Burkart et al., 2014, 2015)

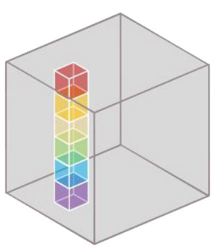
Aasen, H., Honkavaara, E., Lucieer, A., Zarco-Tejada, P., 2018. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. Remote Sensing

Spectral sensor types for UAS RS



Orthorectification via

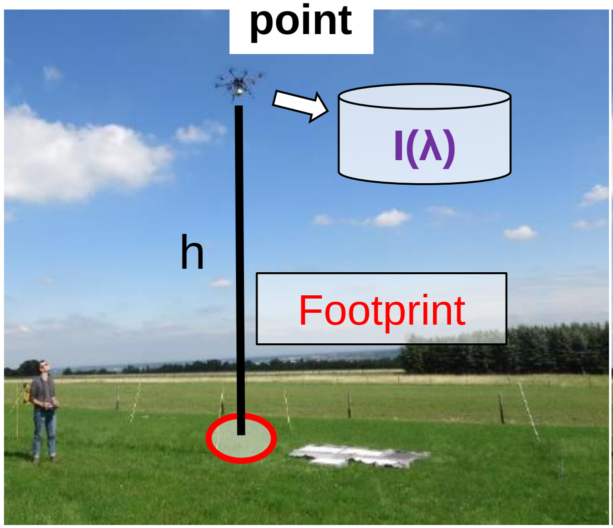
imu + gnss
(or machine vision
SfM + GCPs)

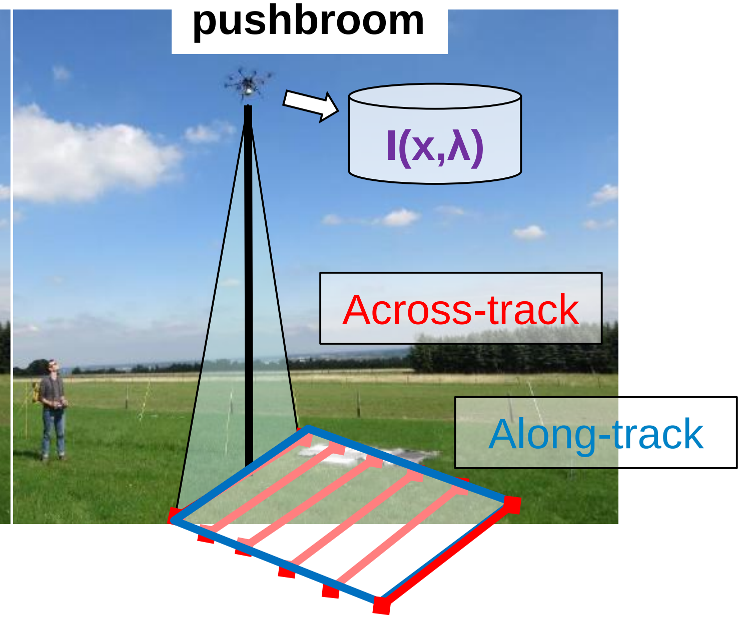


Drawings kindly provided by
Stefan Livens (VITO)

Aasen, H., Honkavaara, E., Lucieer, A., Zarco-Tejada, P., 2018. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. Remote Sensing

Spectral sensor types for UAS RS

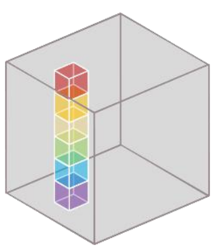




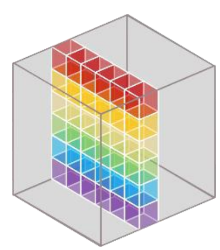
Orthorectification via

imu + gnss
(or machine vision
SfM + GCPs)

imu + gnss
(or machine vision
SfM + GCPs)

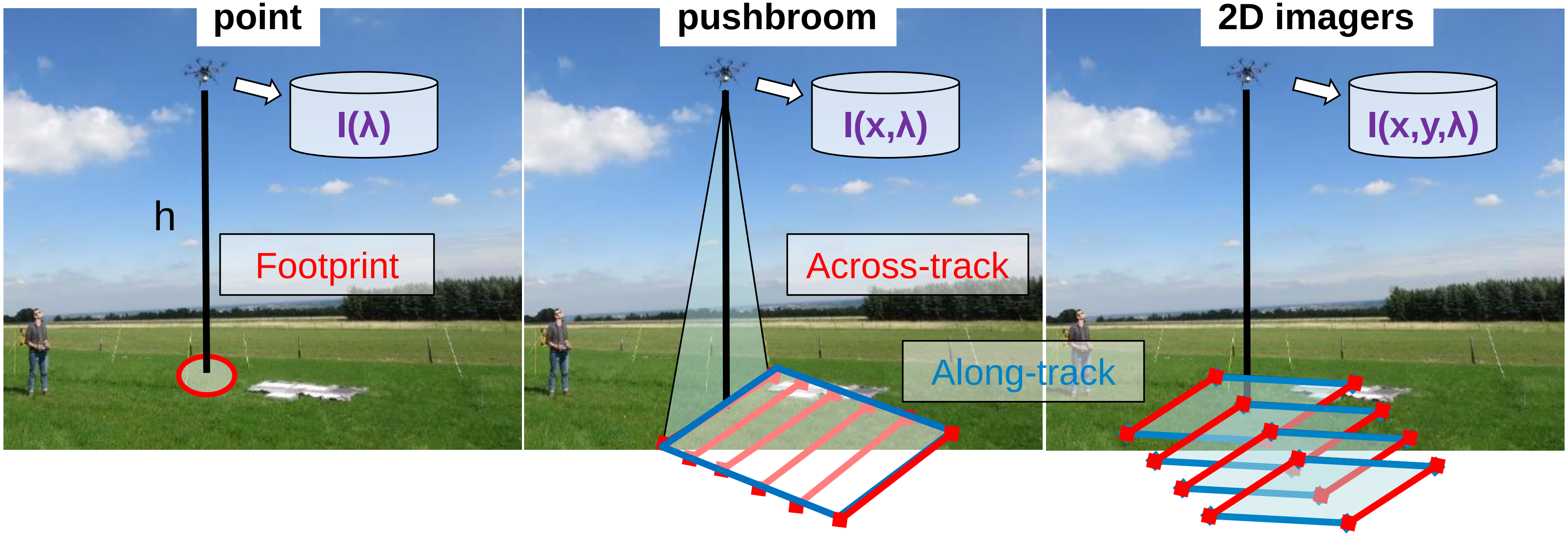


Drawings kindly provided by
Stefan Livens (VITO)



Aasen, H., Honkavaara, E., Lucieer, A., Zarco-Tejada, P., 2018. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. Remote Sensing

Spectral sensor types for UAS RS

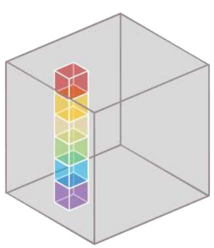


Orthorectification via

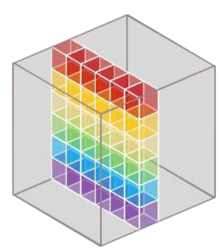
imu + gnss
(or machine vision SfM + GCPs)

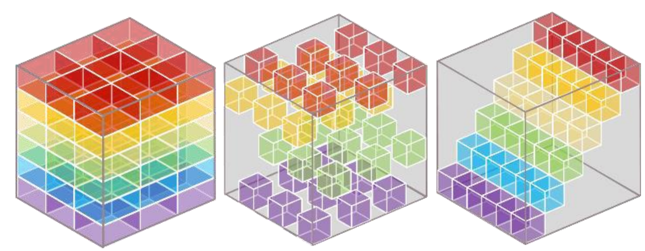
imu + gnss
(or machine vision SfM + GCPs)

SfM + GCPs
(and/or imu + gnss)

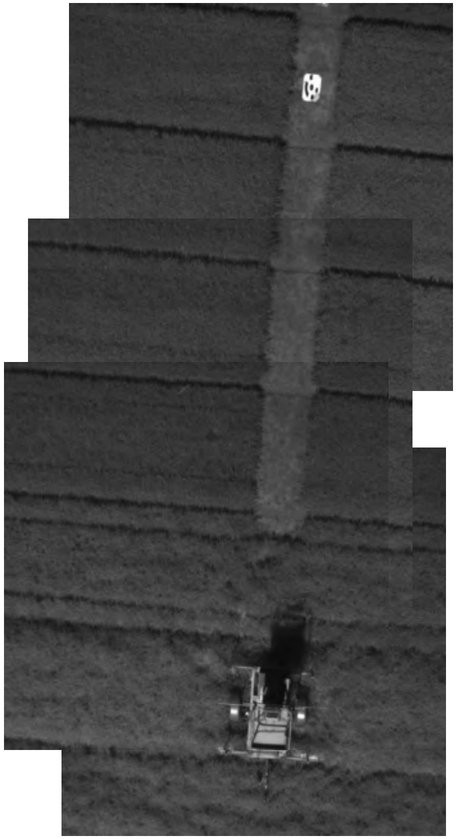


Drawings kindly provided by Stefan Livens (VITO)

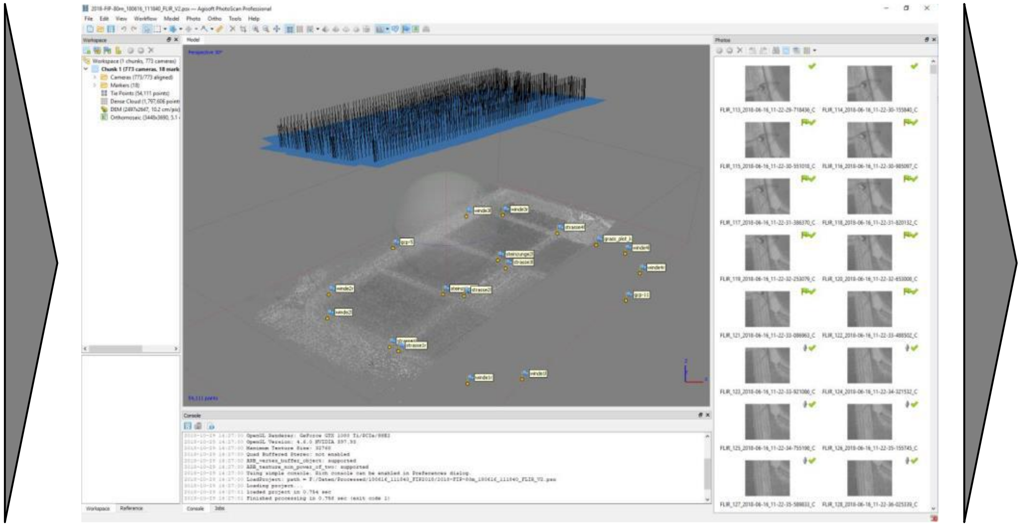


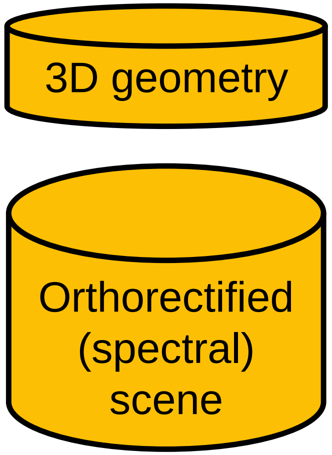


Aasen, H., Honkavaara, E., Lucieer, A., Zarco-Tejada, P., 2018. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. Remote Sensing



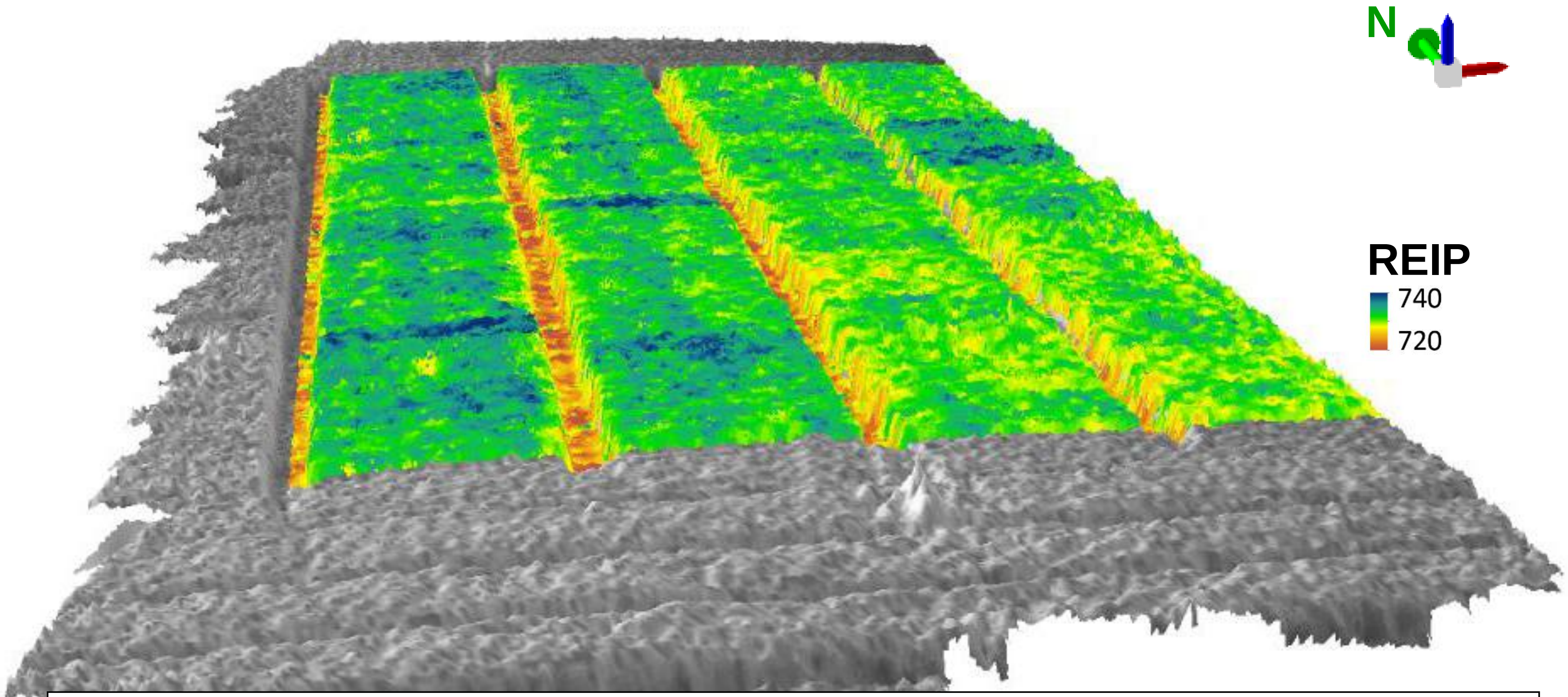
Structure from Motion





Aasen, H., Burkart, A., Bolten, A., Bareth, G., 2015. Generating 3D hyperspectral information with lightweight UAV snapshot cameras for vegetation monitoring: From camera calibration to quality assurance. ISPRS Journal of Photogrammetry and Remote Sensing

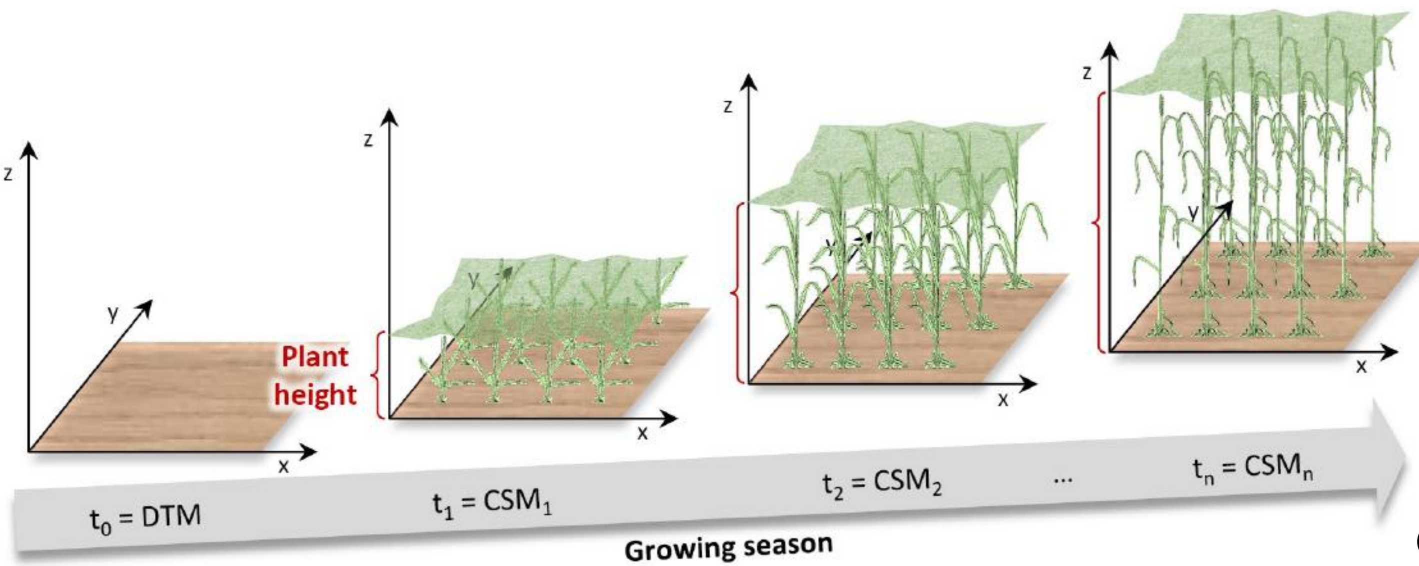
Spectral digital surface model



A spectral digital surface model is a representation of the surface in 3D space linked with spectral information emitted and reflected by the objects covered by the surface

Aasen, H., Burkart, A., Bolten, A., Bareth, G., 2015. Generating 3D hyperspectral information with lightweight UAV snapshot cameras for vegetation monitoring: From camera calibration to quality assurance. ISPRS Journal of Photogrammetry and Remote Sensing

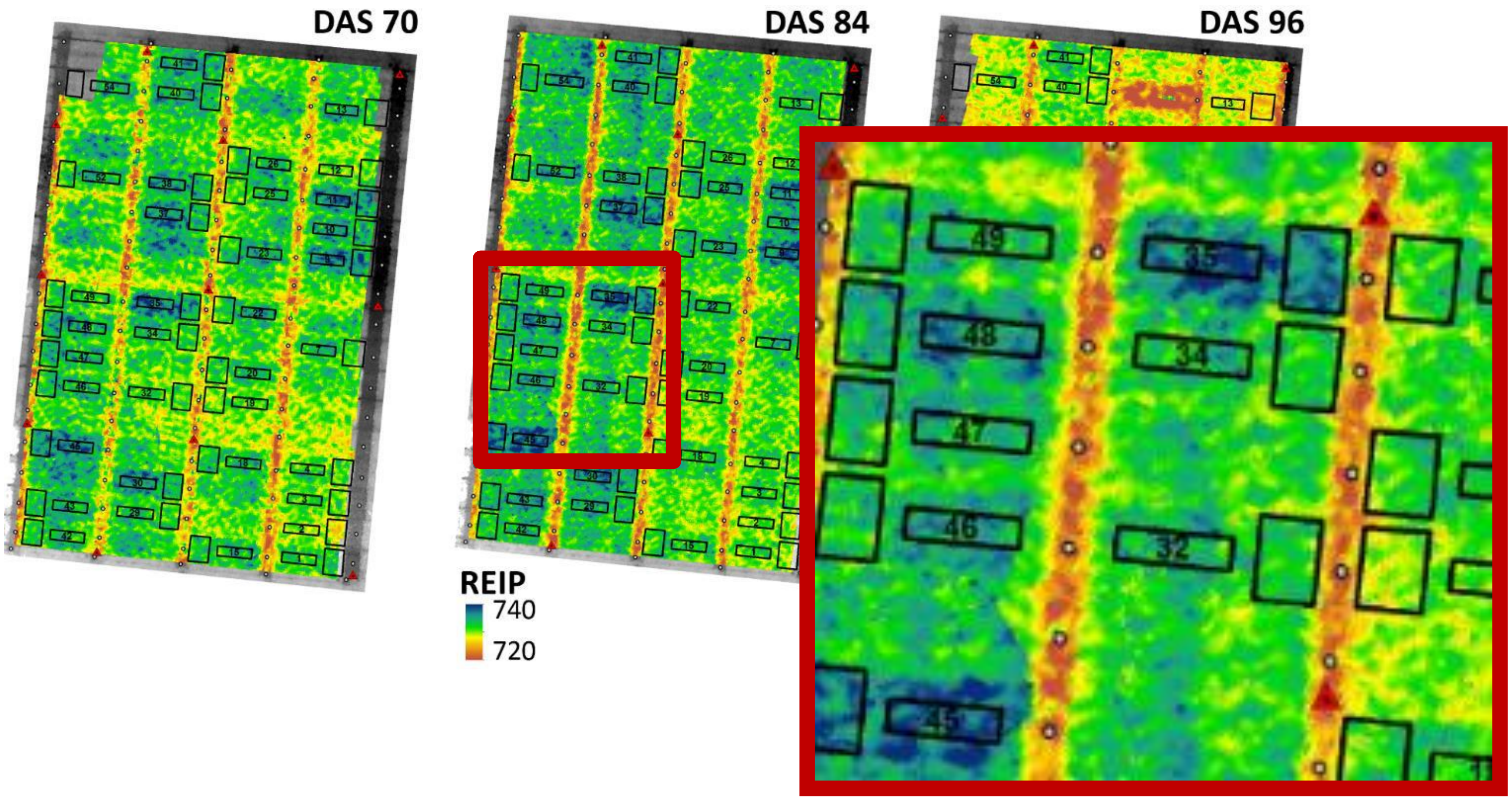
Track plant growth with 3D information



(N. Tilly, 2015)

- H. Aasen, A. Burkart, A. Bolten, and G. Bareth, “Generating 3D hyperspectral information with lightweight UAV snapshot cameras for vegetation monitoring: From camera calibration to quality assurance,” *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 108, pp. 245–259, Oct. 2015.
- J. Bendig *et al.*, “Combining UAV-based plant height from crop surface models, visible, and near infrared vegetation indices for biomass monitoring in barley,” *International Journal of Applied Earth Observation and Geoinformation*, vol. 39, pp. 79–87, Jul. 2015.
- N. Tilly, H. Aasen, and G. Bareth, “Fusion of Plant Height and Vegetation Indices for the Estimation of Barley Biomass,” *Remote Sensing*, vol. 7, no. 9, pp. 11449–11480, Sep. 2015.
- H. Aasen and A. Bolten, “Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – From theory to application,” *Remote Sensing of Environment*, vol. 205, pp. 374–389, Feb. 2018.
- H. Aasen and G. Bareth, “Ground and UAV sensing approaches for spectral and 3D crop trait estimation,” in *Hyperspectral Remote Sensing of Vegetation - Volume II: Advanced Approaches and Applications in Crops and Plants*, Second Edition., P. Thenkabail, J. G. Lyon, and A. Huete, Eds. Taylor and Francis Inc., “accepted.”
- L. Kronenberg, K. Yu, A. Walter, and A. Hund, “Monitoring the dynamics of wheat stem elongation: genotypes differ at critical stages,” *Euphytica*, vol. 213, no. 7, Jul. 2017.

Tracking biochemical traits with spectral data



- Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.
- H. Aasen, M. L. Gnyp, Y. Miao, and G. Bareth, “Automated Hyperspectral Vegetation Index Retrieval from Multiple Correlation Matrices with HyperCor,” *Photogrammetric Engineering & Remote Sensing*, vol. 80, no. 8, pp. 785–795, Aug. 2014.
- H. Aasen and G. Bareth, “Ground and UAV sensing approaches for spectral and 3D crop trait estimation,” in *Hyperspectral Remote Sensing of Vegetation - Volume II: Advanced Approaches and Applications in Crops and Plants*, Second Edition., P. Thenkabail, J. G. Lyon, and A. Huete, Eds. Taylor and Francis Inc., “accepted.”

ETH zürich Phenofly

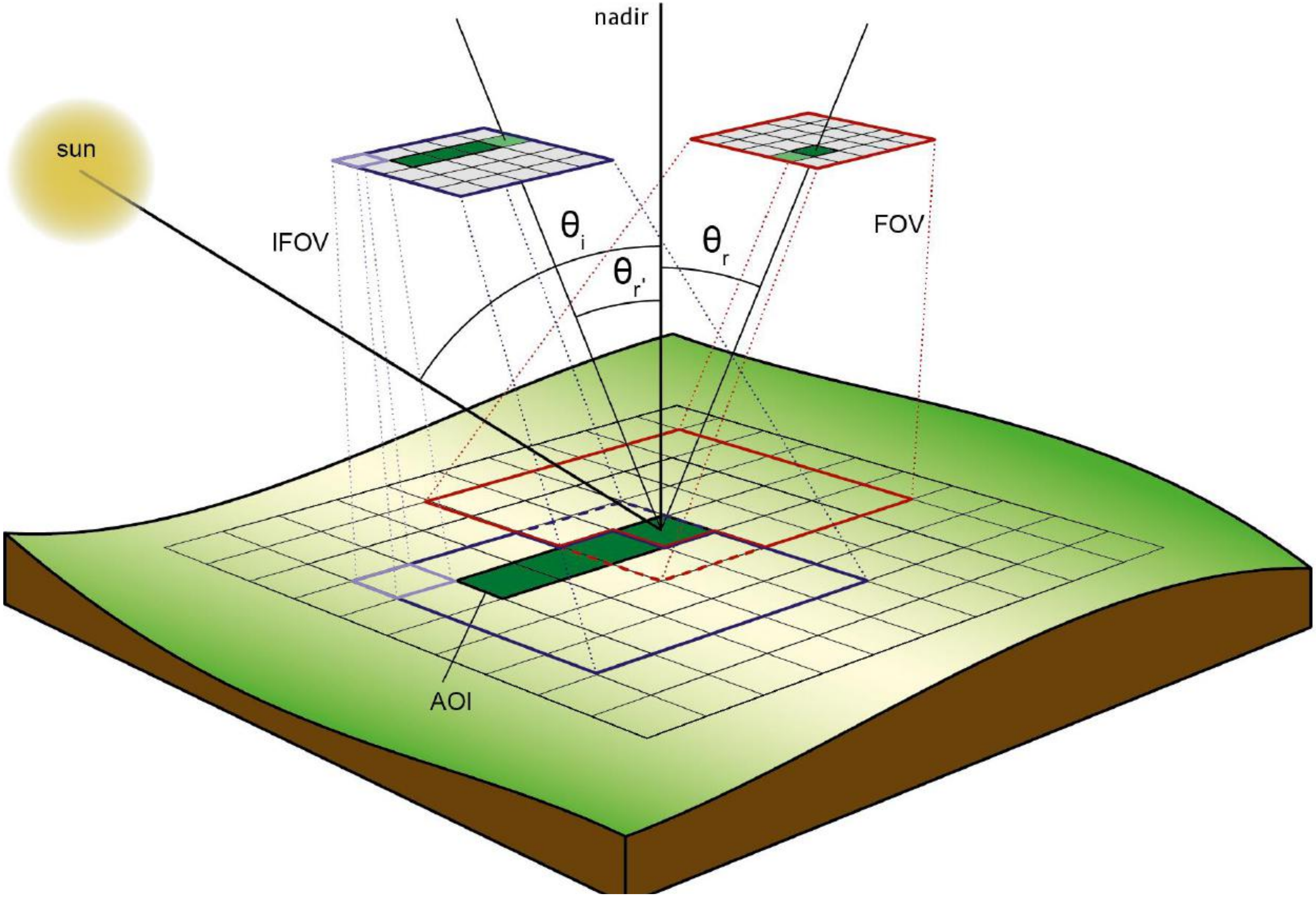
Outline

Flight planning, setup and flight → Data processing → Plant trait extraction → Database → P = G x E

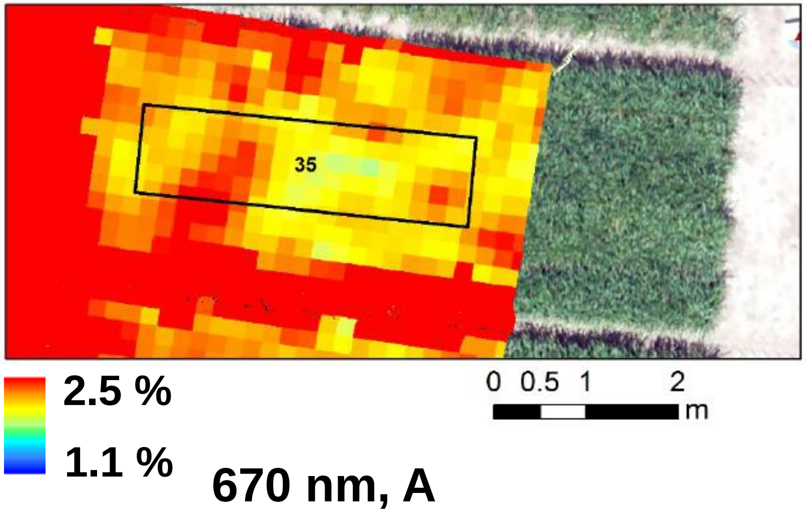
Understanding the data

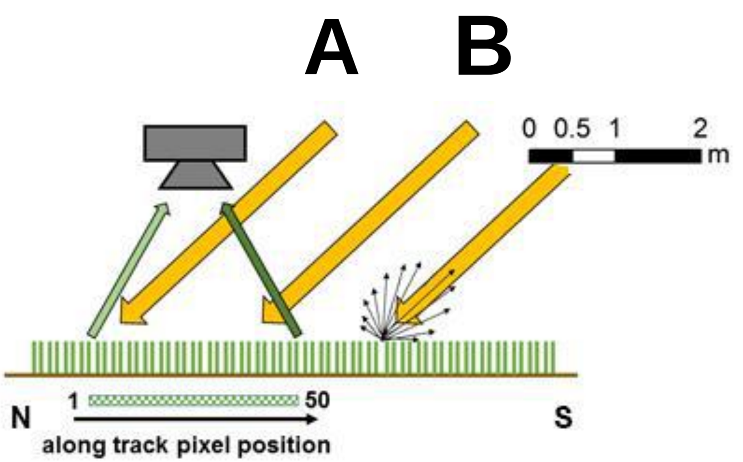
@PhenoFly | Helge.Aasen@usys.ethz.ch

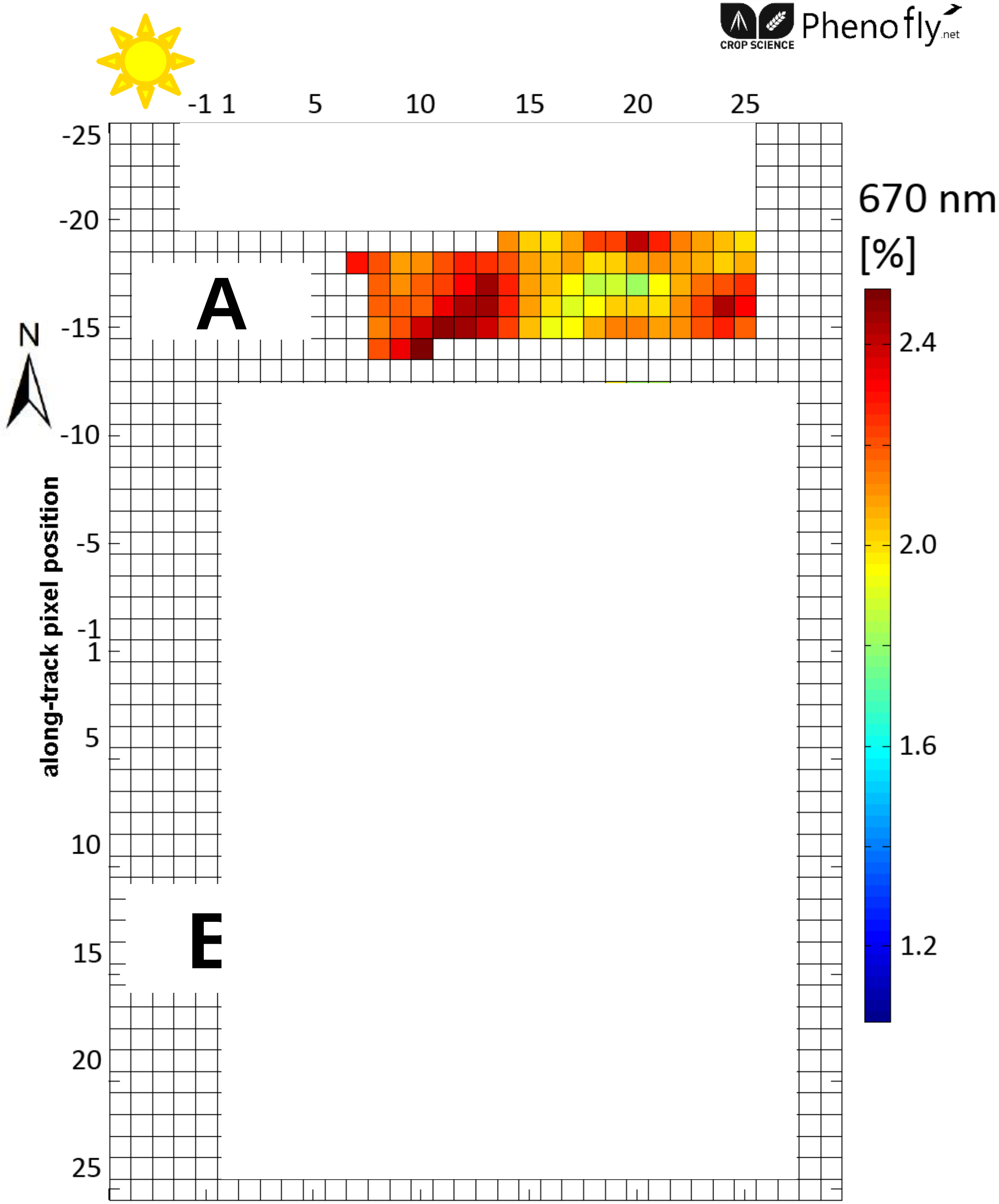
Imaging spectroscopy with 2D imagers



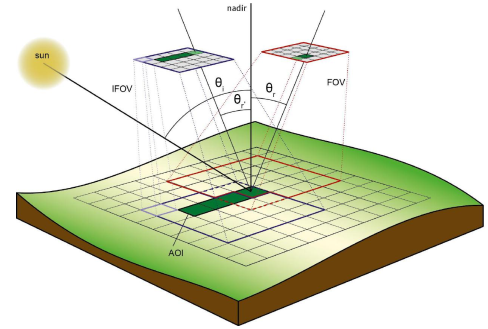
Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.

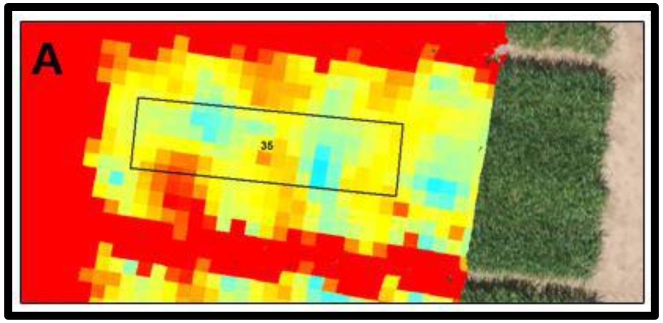




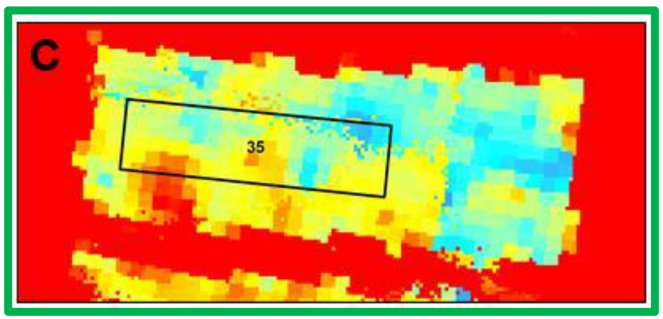


Aasen, H., 2016. Influence of the viewing geometry on hyperspectral data retrieved from UAV snapshot cameras, in: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences.

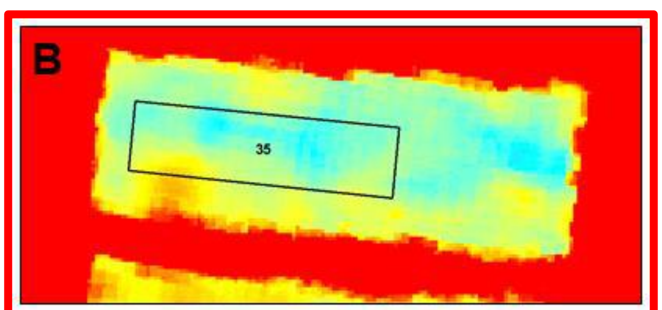




Single image



Mosaic, blending: disabled

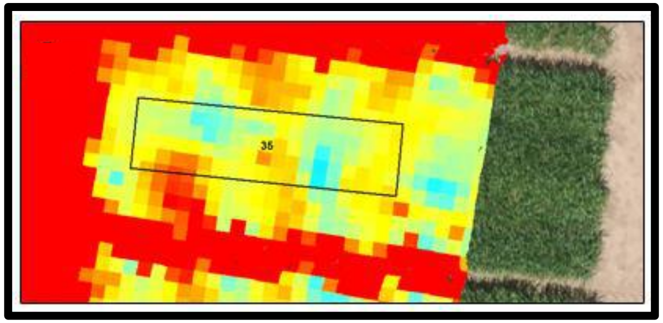


Mosaic, blending: average

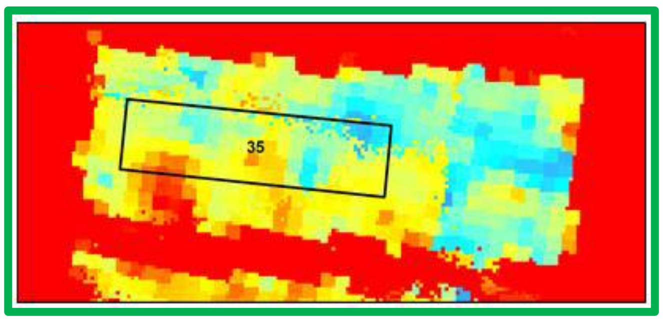
Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.

Influence of the SFOV

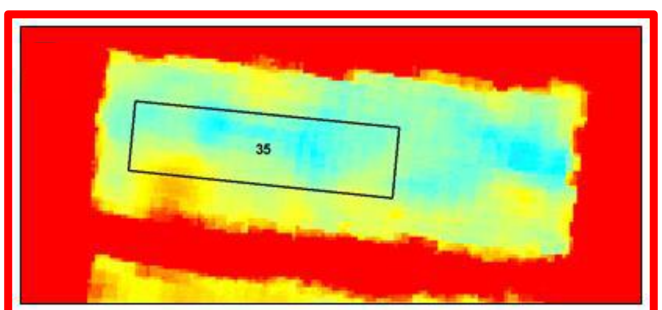
Single image

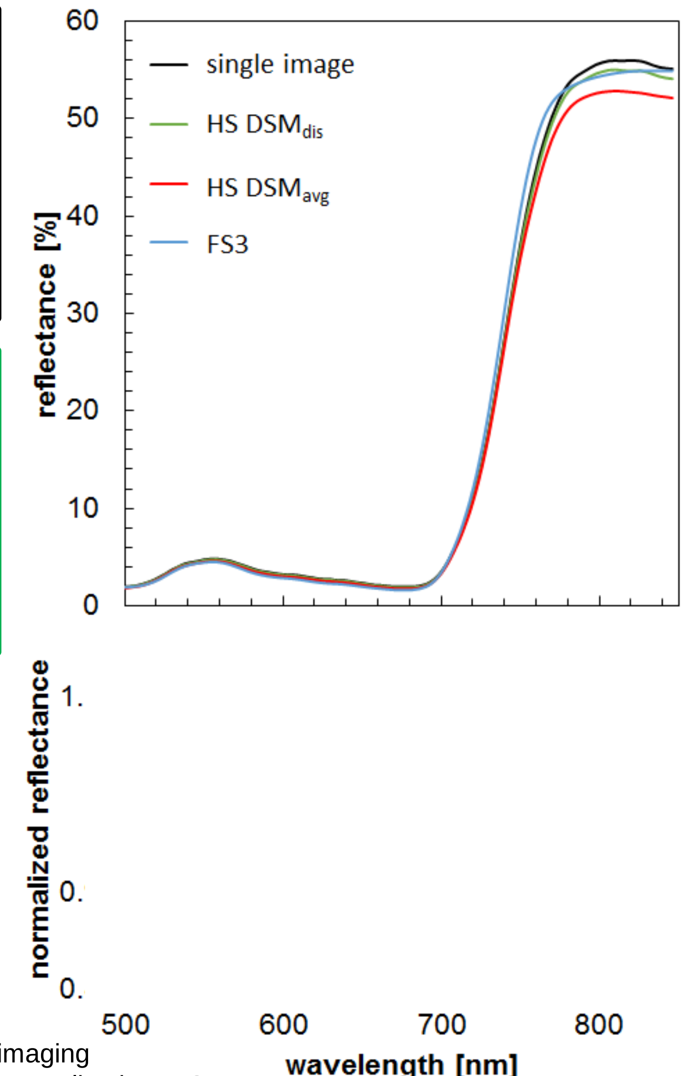


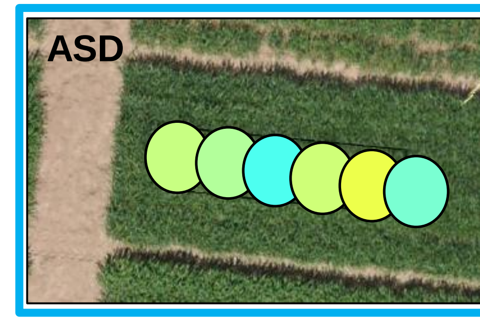
Blending: disabled



Blending: average

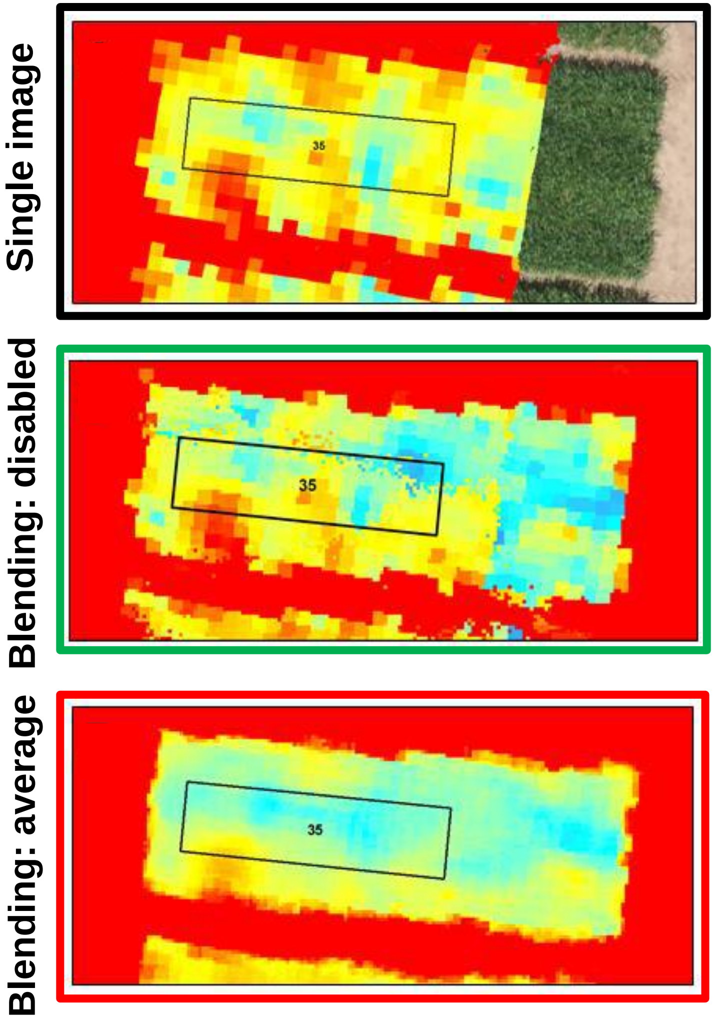


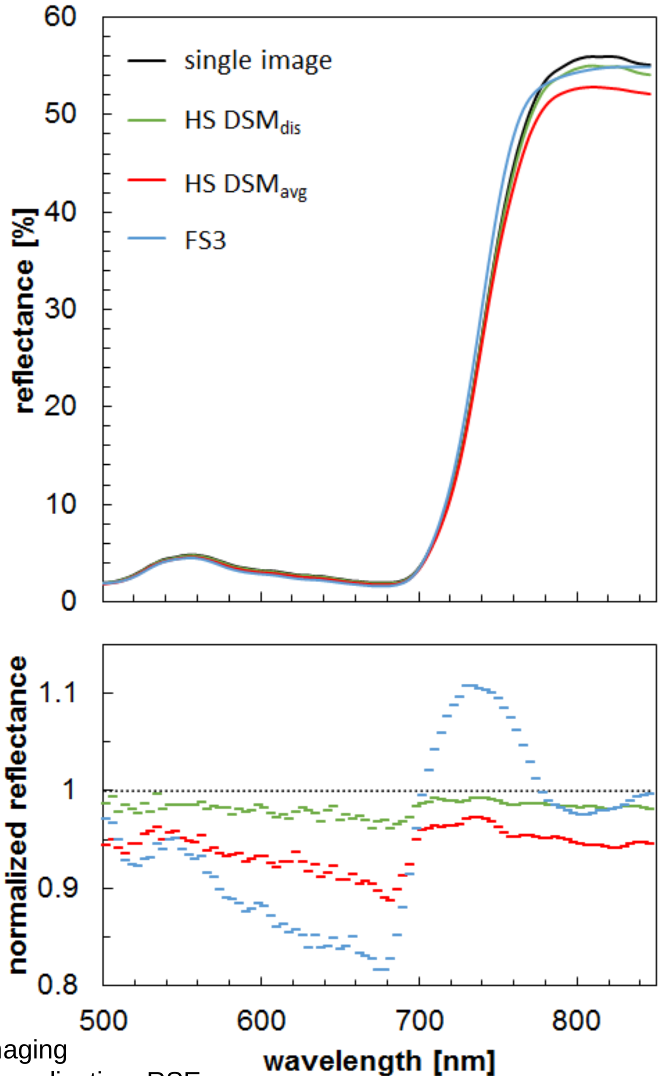


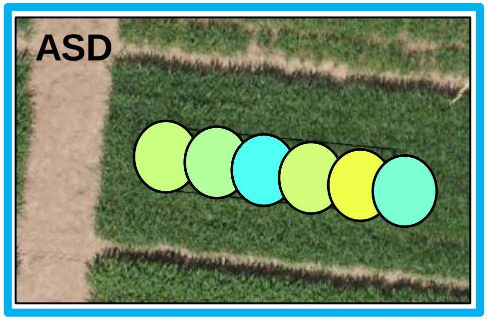


Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. RSE

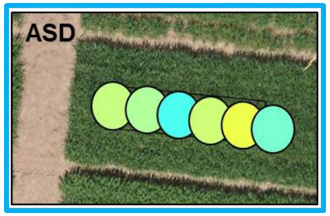
Influence of the SFOV

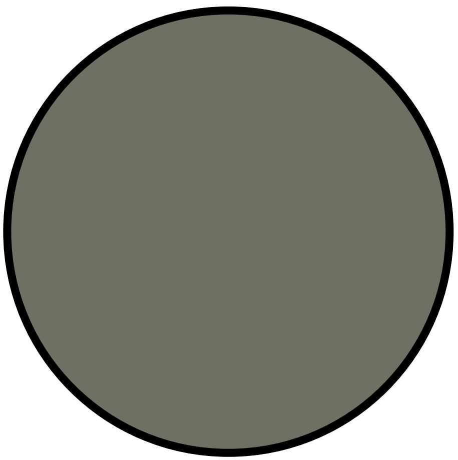


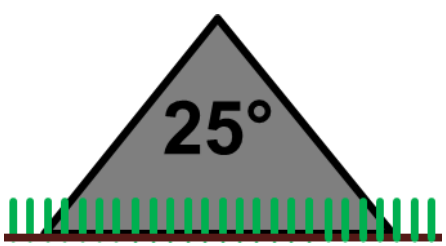




Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. RSE

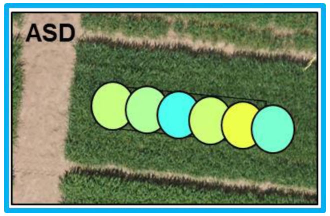


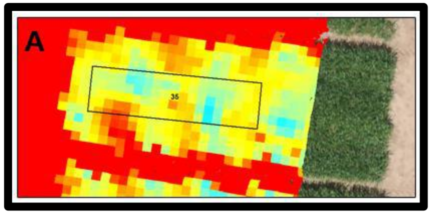




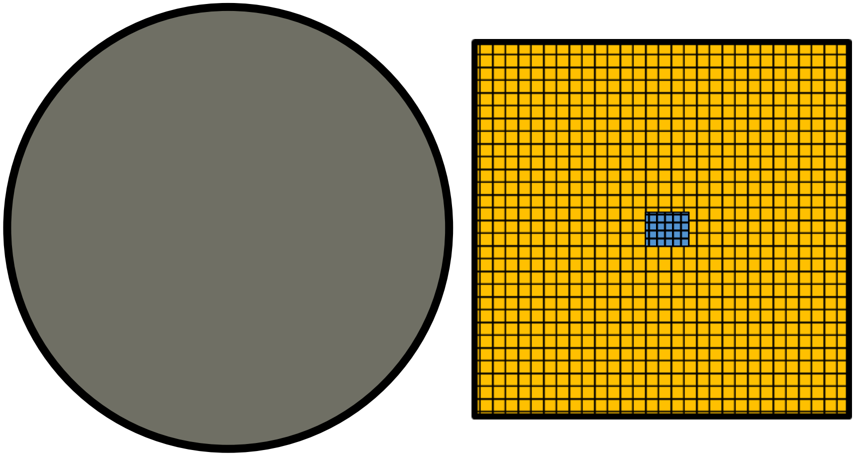
Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.

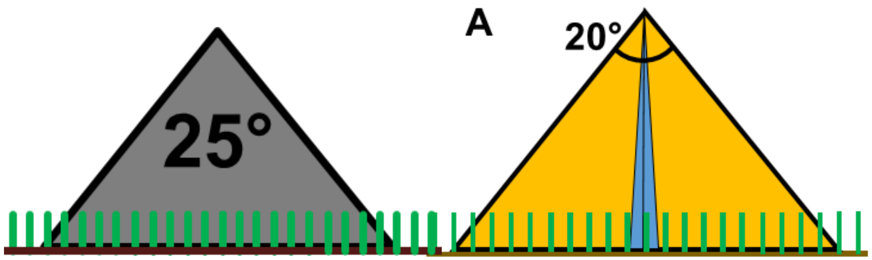
@PhenoFly | Helge.Aasen@usys.ethz.ch



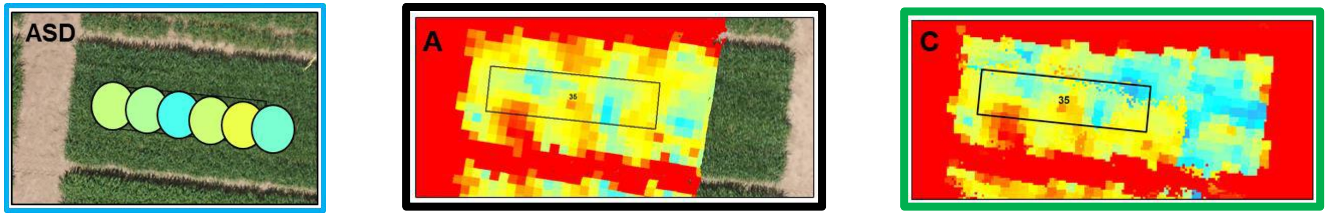


A: single image



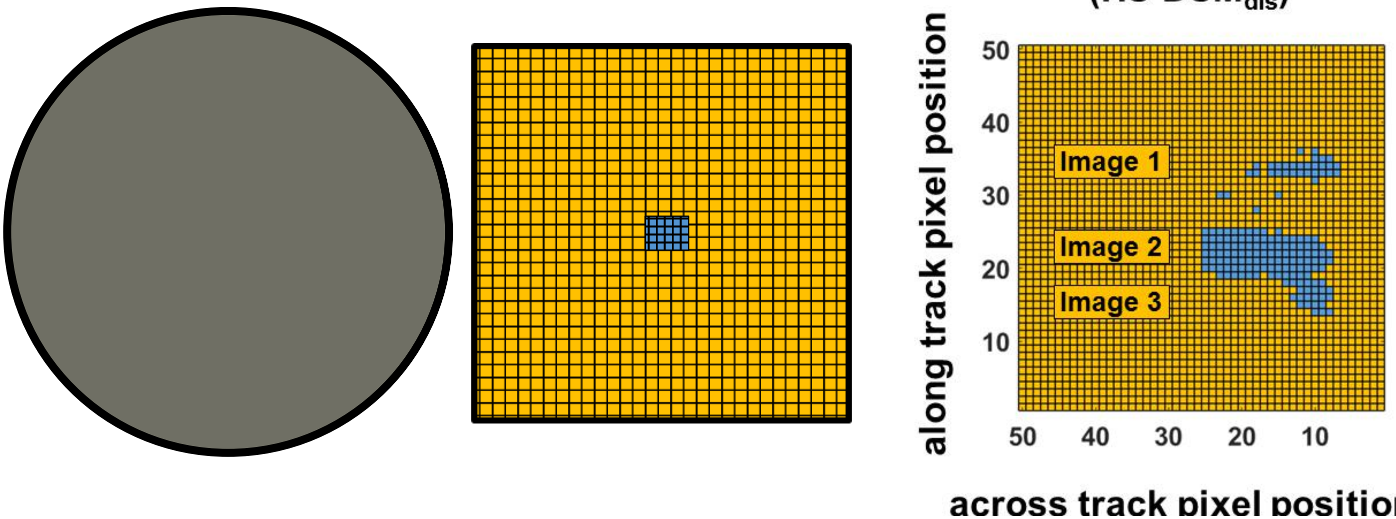


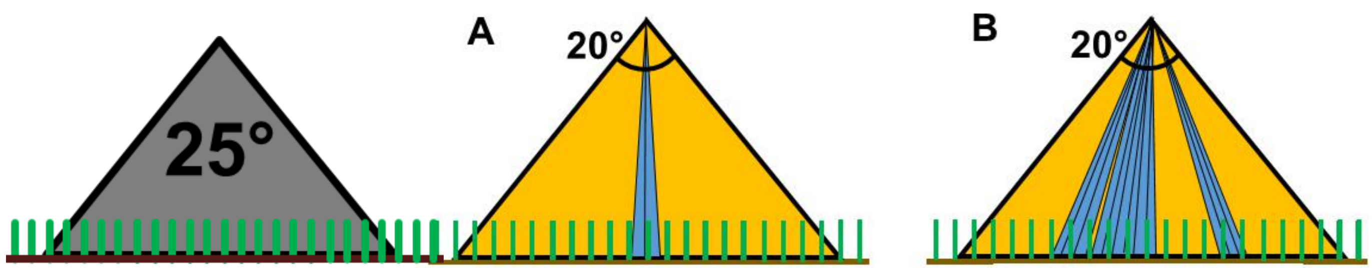
Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.



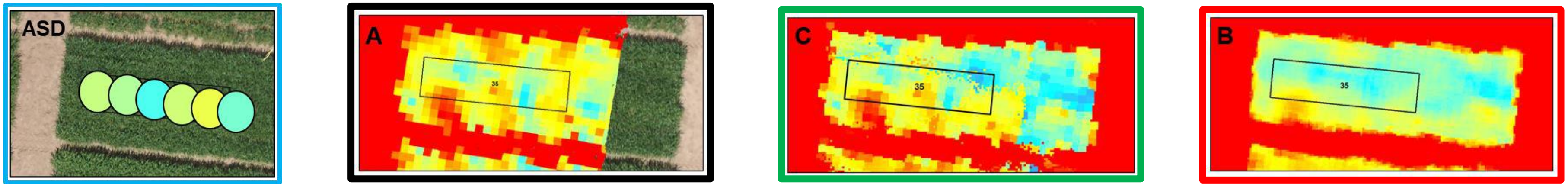
A: single image

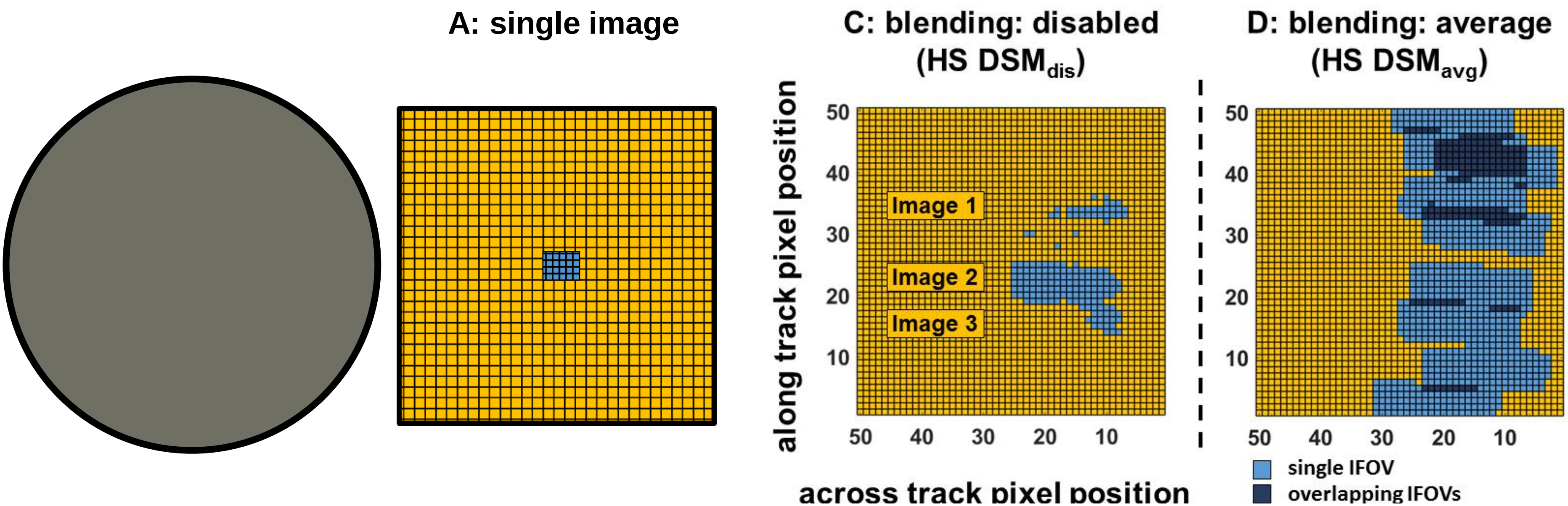
C: blending: disabled
(HS DSM_{dis})

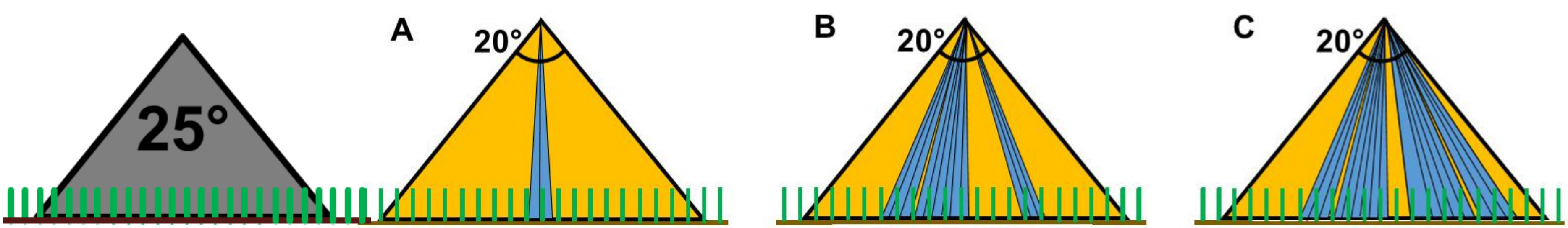




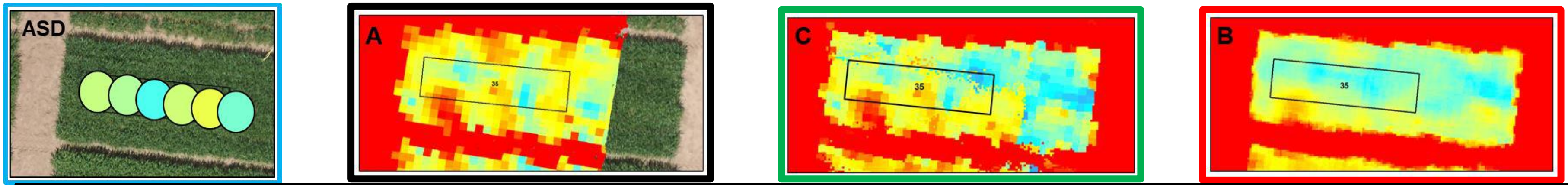
Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.



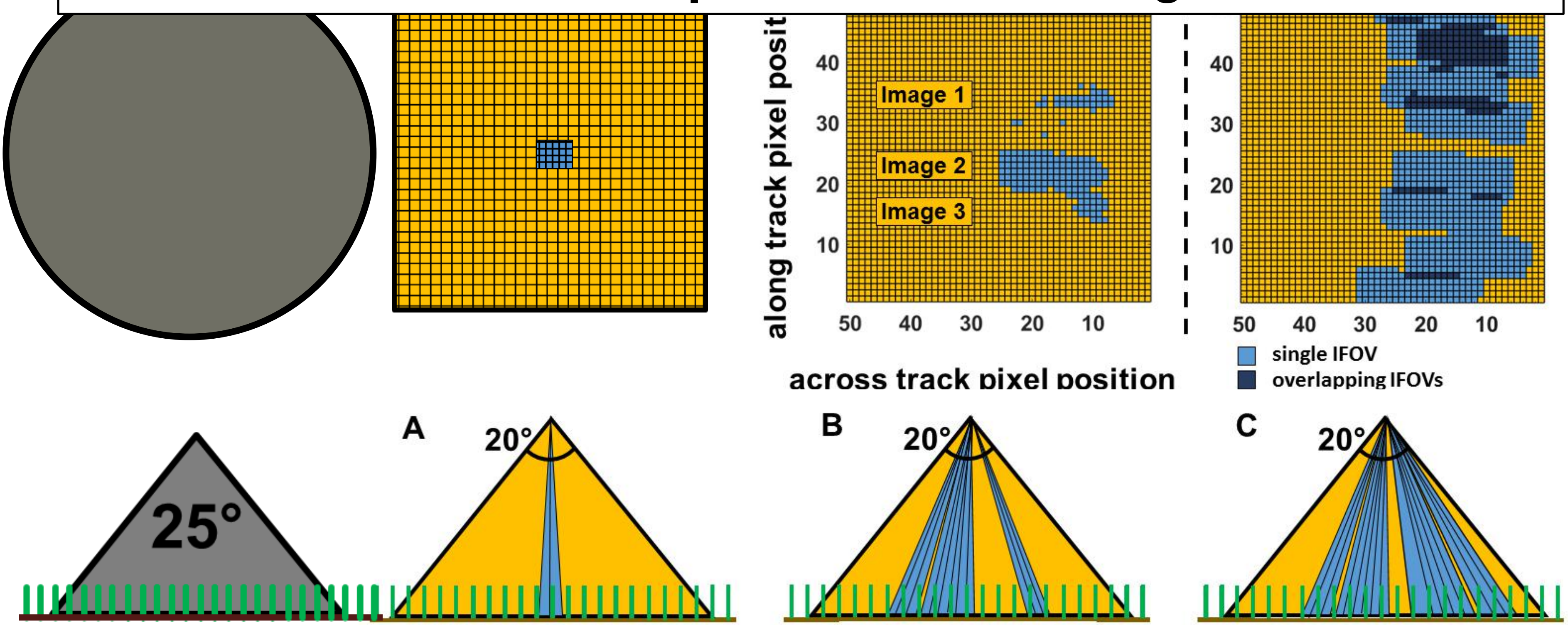




Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.



The specific field of view is the composition of pixels and their angular properties within a scene used to characterize a specific AOI on the ground



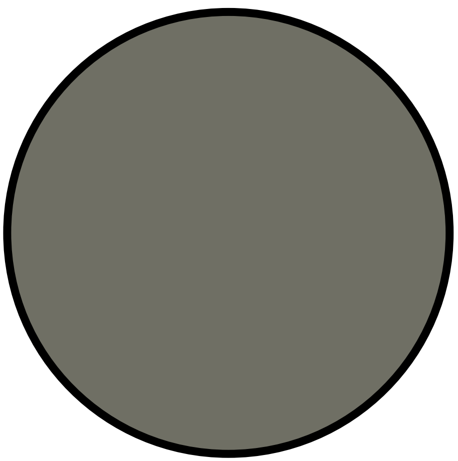
Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.

Hemispherical conical reflectance factor (HCRF)

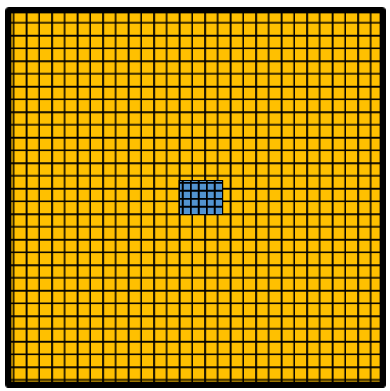
Hemispherical directional reflectance factor (HDRF)

Hemispherical conical reflectance factor (HCRF)

Field spectrometer

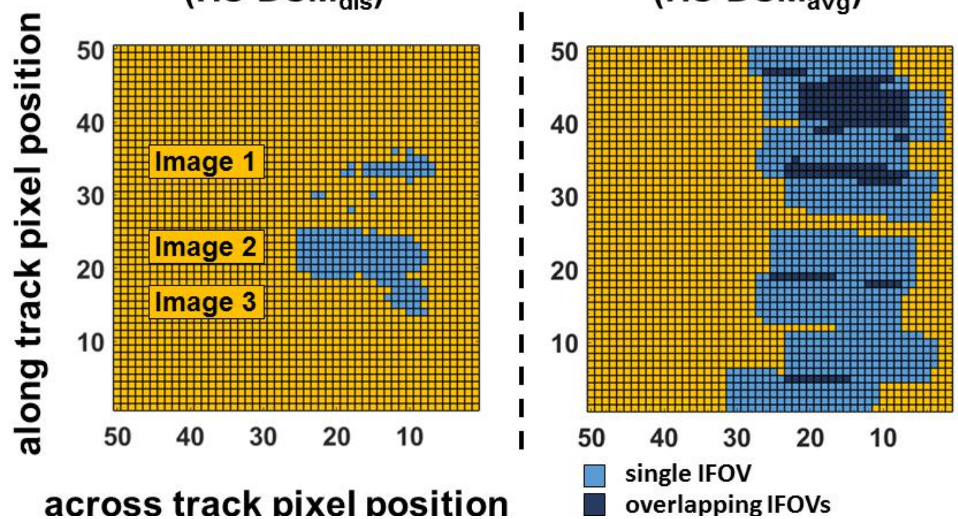


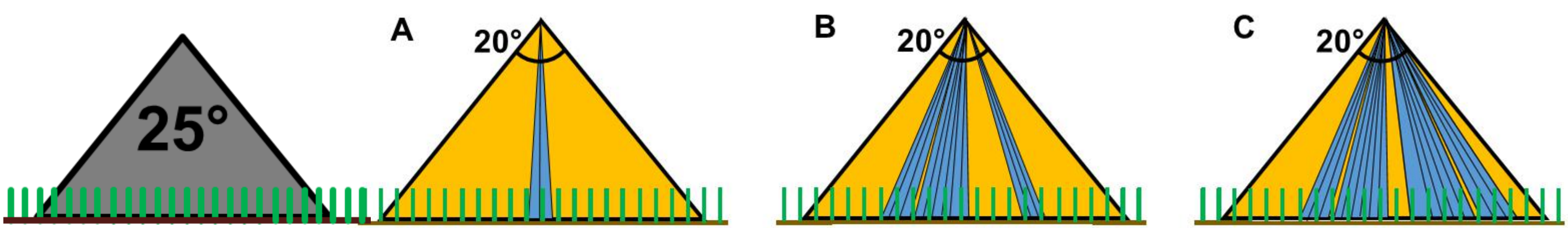
A: single image



C: blending: disabled ($HS\ DSM_{dis}$)

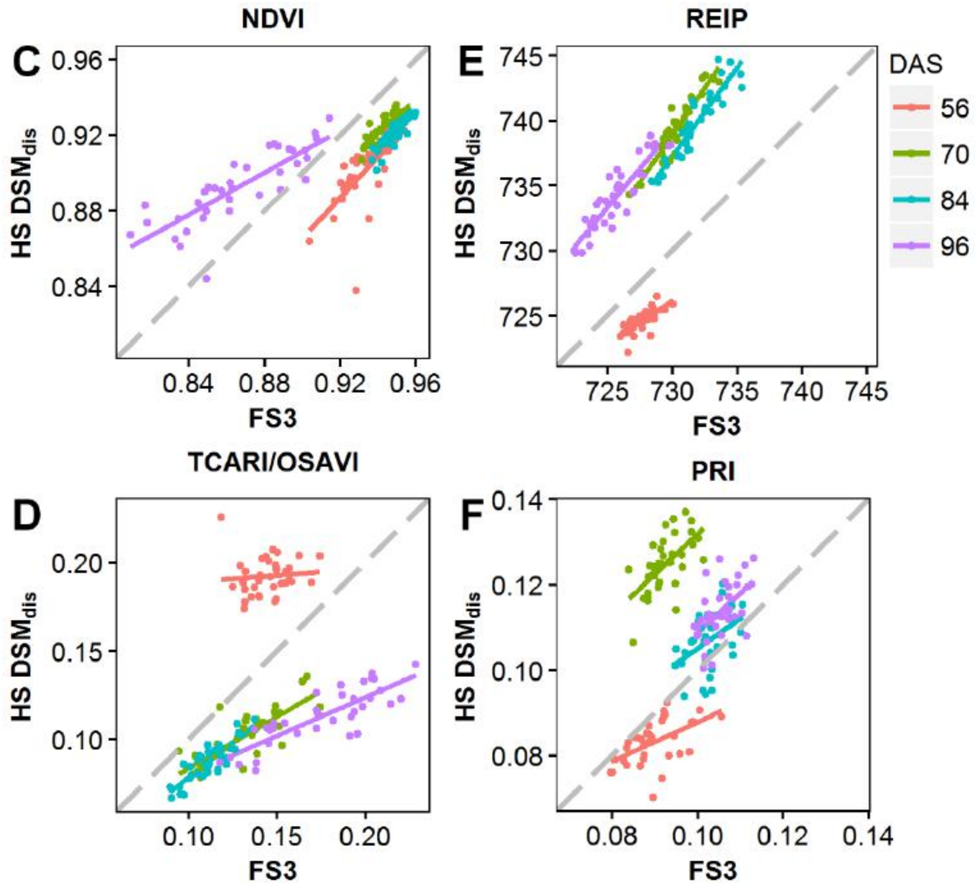
D: blending: average ($HS\ DSM_{avg}$)





Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.

Influence of the SFOV on retrievals (VIs)

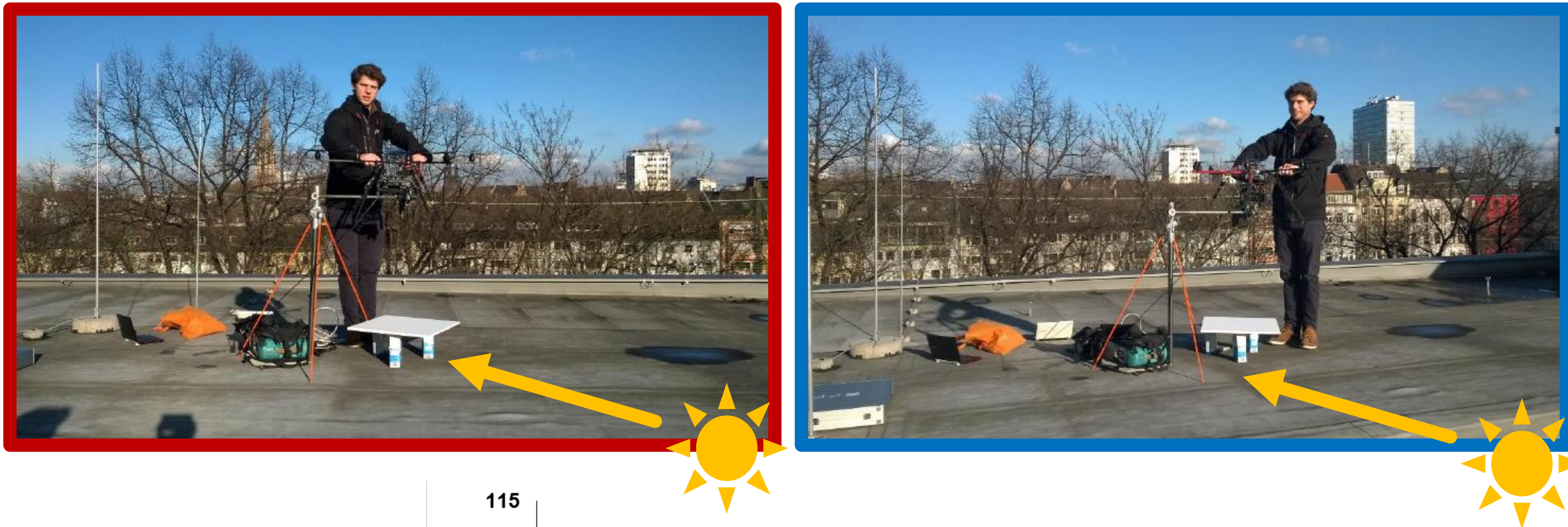


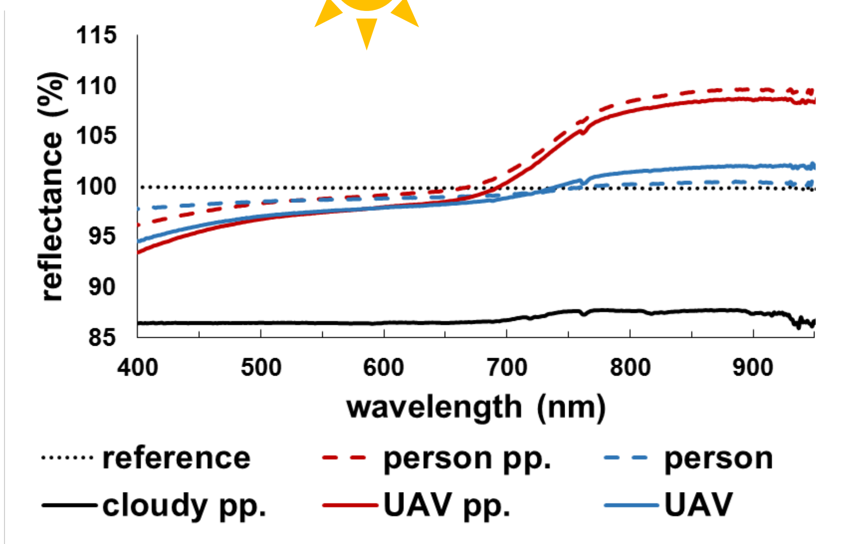
Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.

… a comment on UAV radiometric calibration procedures

@PhenoFly | Helge.Aasen@usys.ethz.ch

Radiometric calibration protocol





➢ **Not suited for radiometric calibration**

Aasen, H., Bolten, A., in review. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application..

Helge Aasen |
@PhenoFly | Helge.Aasen@usys.ethz.ch

Metadata and standardization

Table 5. Numeric (n) or qualitatively (q) mandatory (m), and advised (a)auxiliary and metadata for spectral data processing. Although the direct and diffuse illumination ratio is important, it is set to advised, since it is not easy to measure.

Pixel		Image		Scene	
signal-to-noise ratio	(n, m)	capturing position	(n, m)	sensor description (including version)	(q, m)
radiometric resolution	(n, m)	illumination conditions	(q, m)	band configuration (FWHM, band center)	(n, m)
viewing geometry	(n, m)	direct and diffuse illumination ratio	(n, a)	geometric processing procedures and accuracies (including software version and parameters)	(q, m)
		capturing time	(n, m)	top-of-canopy reflectance calculation method	(q, m)
				reflectance uncertainty	(n, a)
				environmental conditions during measurement	(q, m)

Aasen, H., Honkavaara, E., Lucieer, A., Zarco-Tejada, P., 2018. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. Remote Sensing

Outline

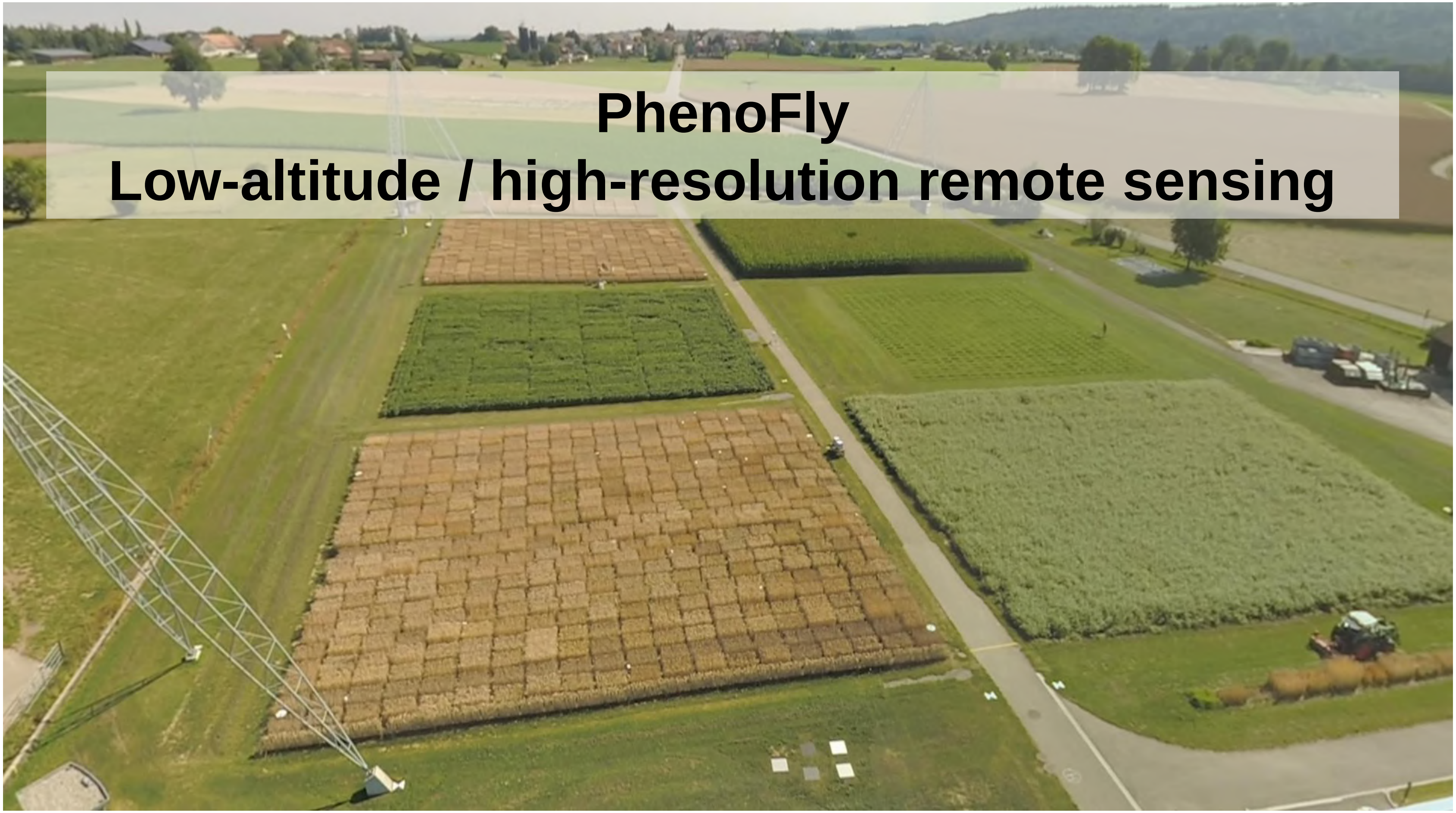
Flight planning, setup and flight → Data processing → **Plant trait extraction** → Database → P = G x E

Understanding the data

ETH zürich

Phenofly.net

PhenoFly
Low-altitude / high-resolution remote sensing



@PhenoFly | Helge.Aasen@usys.ethz.ch

Low-altitude / high-resolution remote sensing at PhenoFly

Low-altitude remote sensing

Close range

Proximal

FIP[1]

LS, hyper-spec, thermal, RGB

Multi-rotor UAVs

Hyper-spec, thermal, RGB

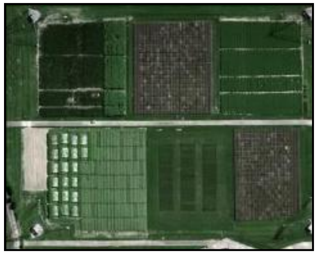
Fixed-wing UAVs

Multi-spec, RGB

Leaf, plant, plot

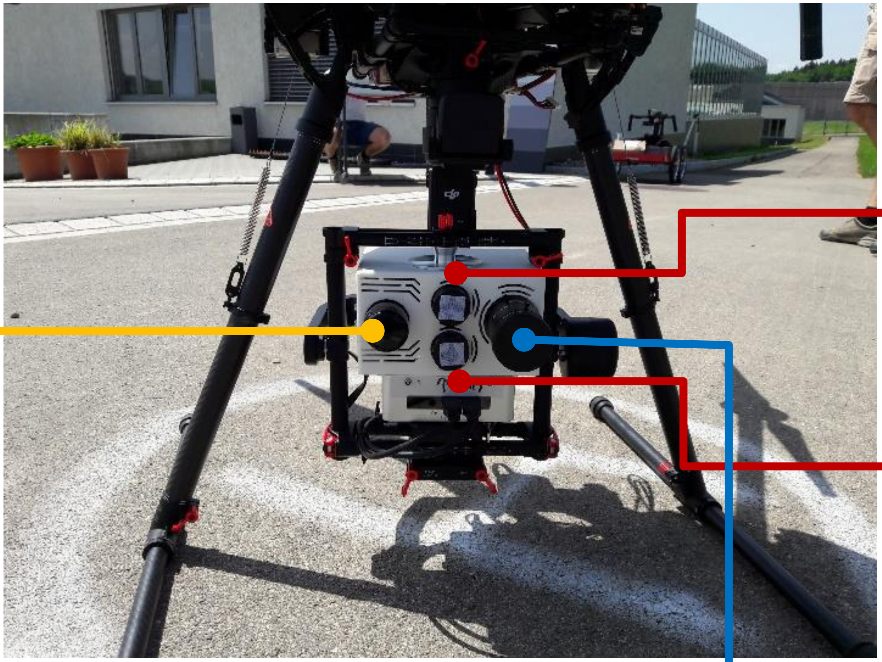
Plot to field (<2 ha)

Field to region (< 50 ha)



[1]Kirchgessner, N., Liebisch, F., Yu, K., Pfeifer, J., Friedli, M., Hund, A., Walter, A., 2017. The ETH field phenotyping platform FIP: a cable-suspended multi-sensor system. Functional Plant Biology

Multi-sensor pack



Thermal camera
FLIR A65

VIS spectral camera
IMEC SNm4x4
460-630 nm

NIR spectral camera
IMEC SNm5x5
600-1000 nm

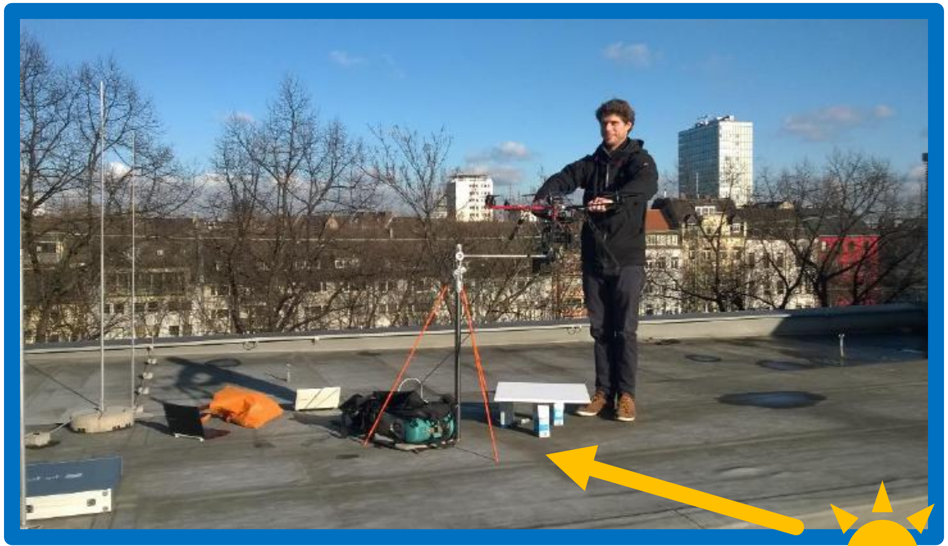
RGB camera
Point gray 12 mpix

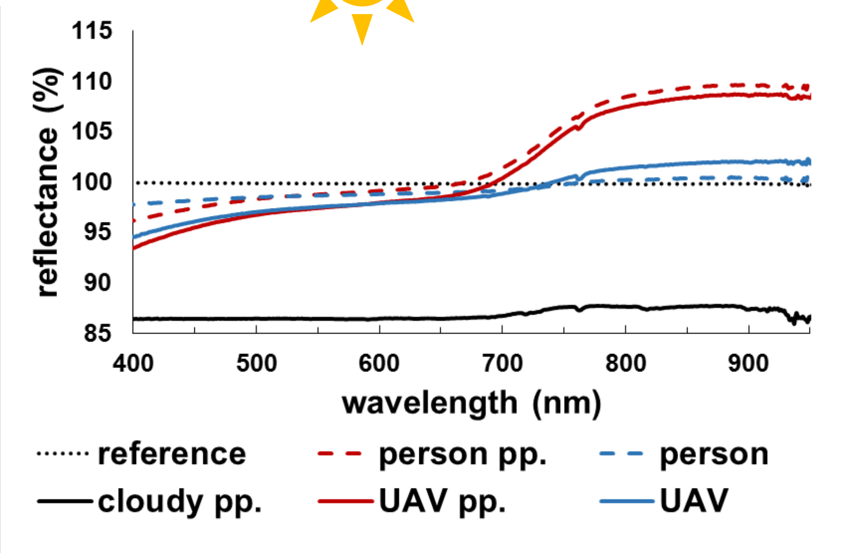
@PhenoFly | Helge.Aasen@usys.ethz.ch

Plant research station Eschikon, ETH Zurich

[FIP field 360°]

Example 2: Radiometric calibration protocol





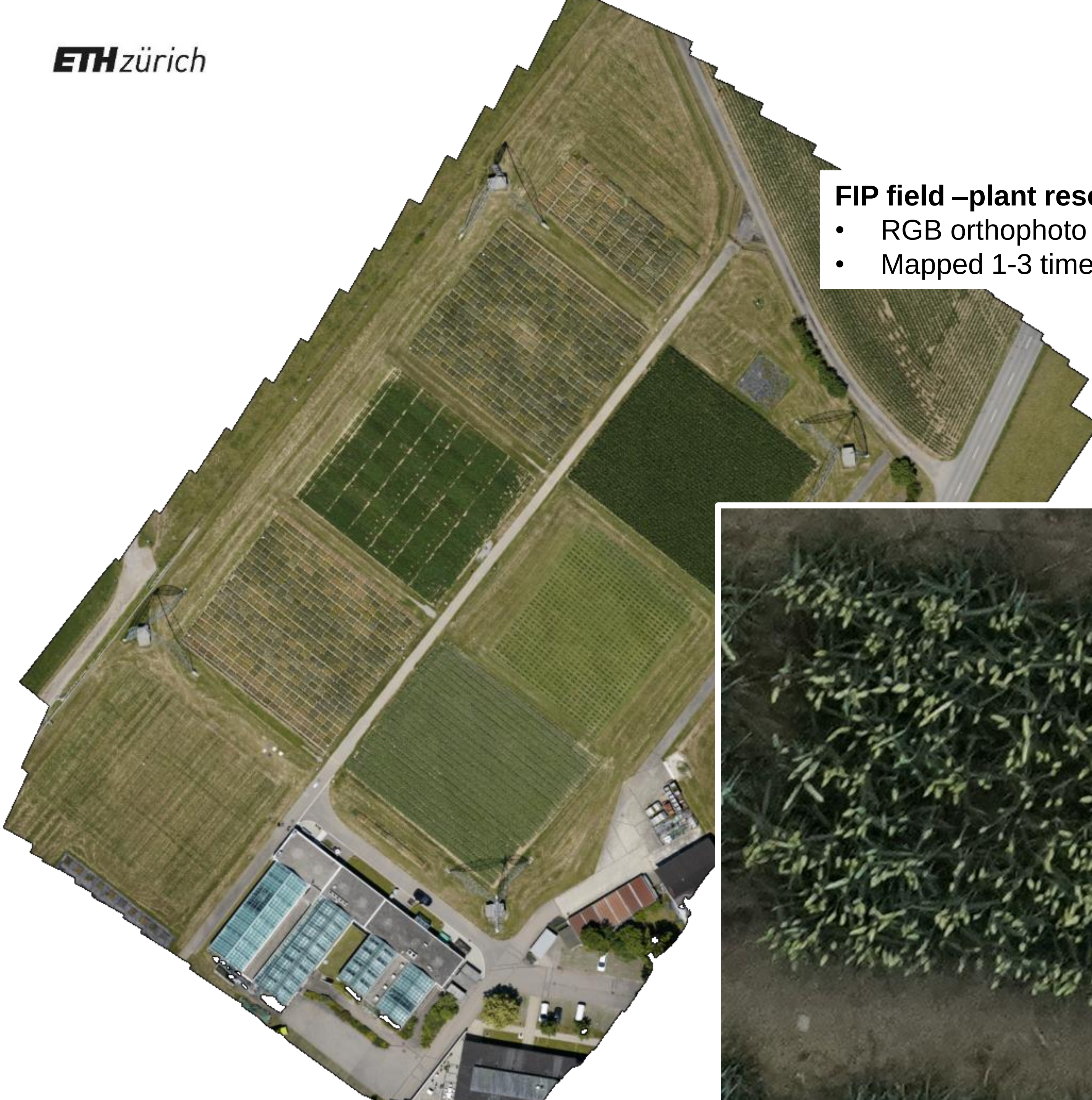
Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application.. RSE

ETH zürich

Phenofly.net

FIP field –plant research station Eschikon

- RGB orthophoto and DSM (> 0.003 m)
- Mapped 1-3 times a week



ETH zürich

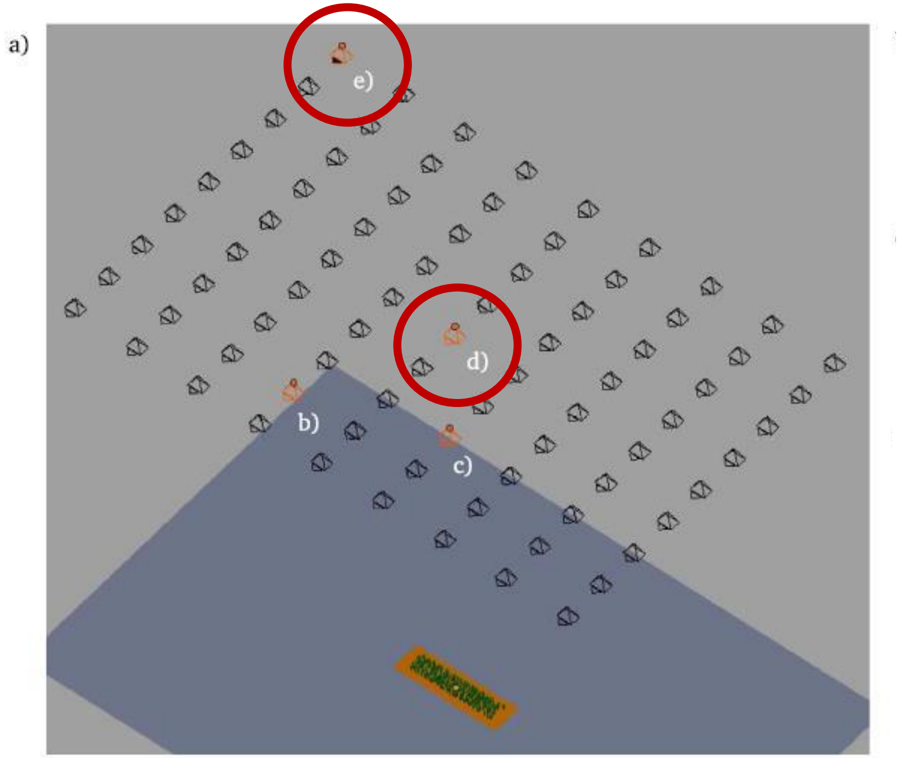
CROP SCIENCE Phenofly.net

Extracting leaf area index using viewing geometry effects

L. Roth, H. Aasen, A. Walter, and F. Liebisch, “Extracting leaf area index using viewing geometry effects—A new perspective on high-resolution unmanned aerial system photography,” *ISPRS Journal of Photogrammetry and Remote Sensing*, 2018.

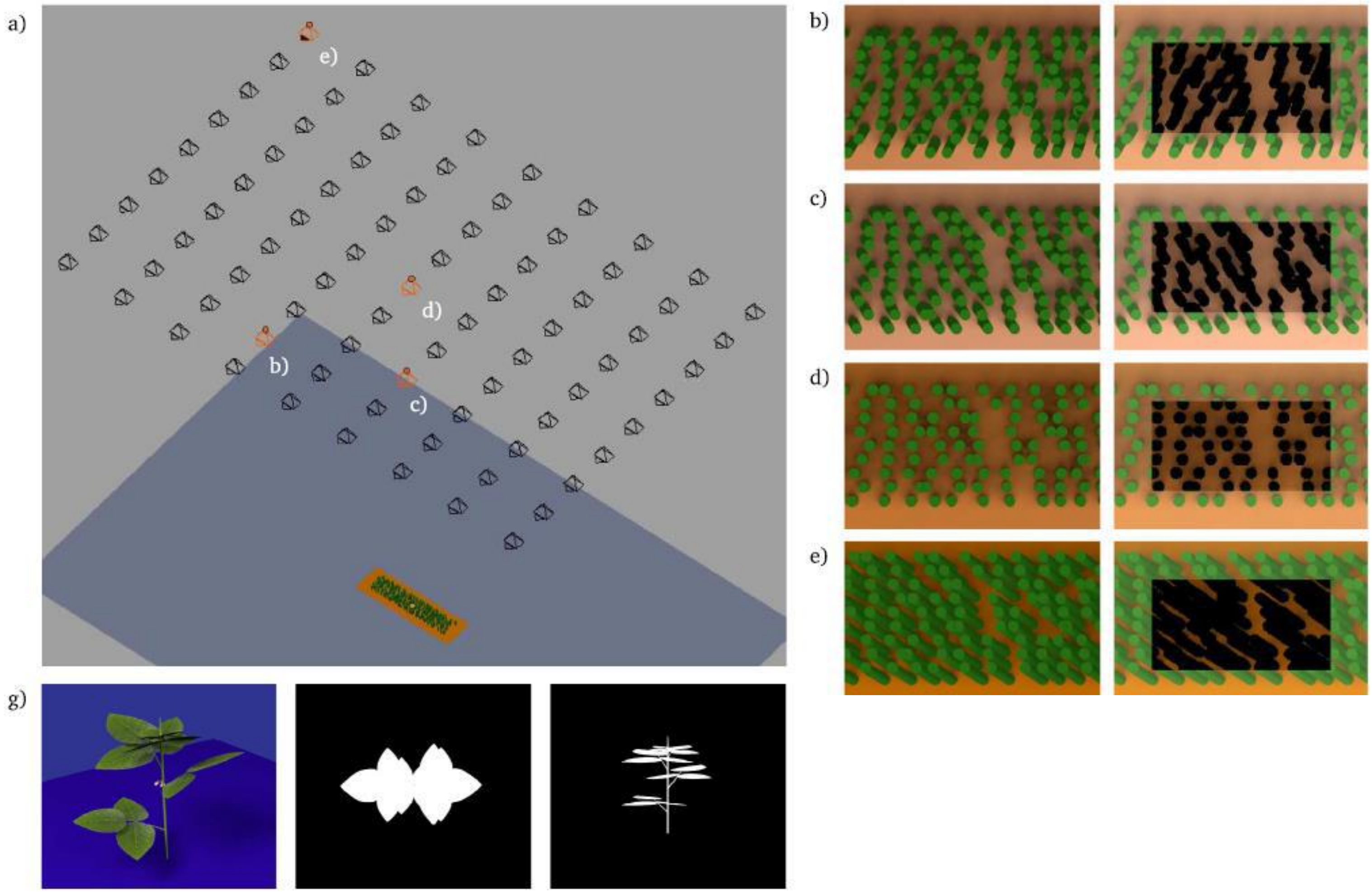
@PhenoFly | Helge.Aasen@usys.ethz.ch

Extracting leaf area index using viewing geometry effects



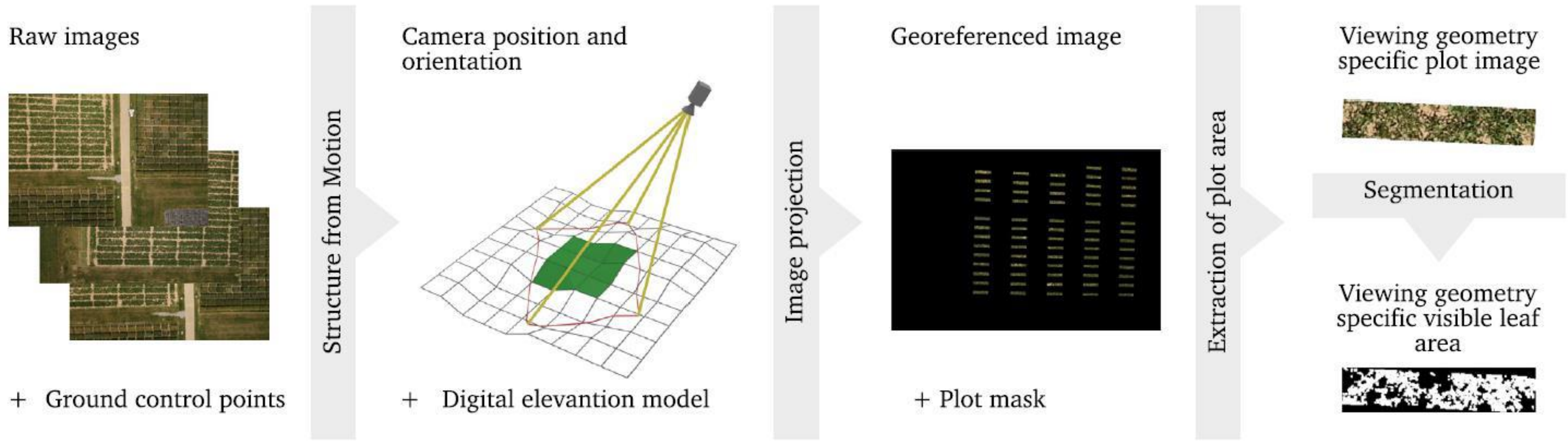
L. Roth, H. Aasen, A. Walter, and F. Liebisch, “Extracting leaf area index using viewing geometry effects—A new perspective on high-resolution unmanned aerial system photography,” *ISPRS Journal of Photogrammetry and Remote Sensing*, 2018.

Extracting leaf area index using viewing geometry effects



L. Roth, H. Aasen, A. Walter, and F. Liebisch, "Extracting leaf area index using viewing geometry effects—A new perspective on high-resolution unmanned aerial system photography," *ISPRS Journal of Photogrammetry and Remote Sensing*, 2018.

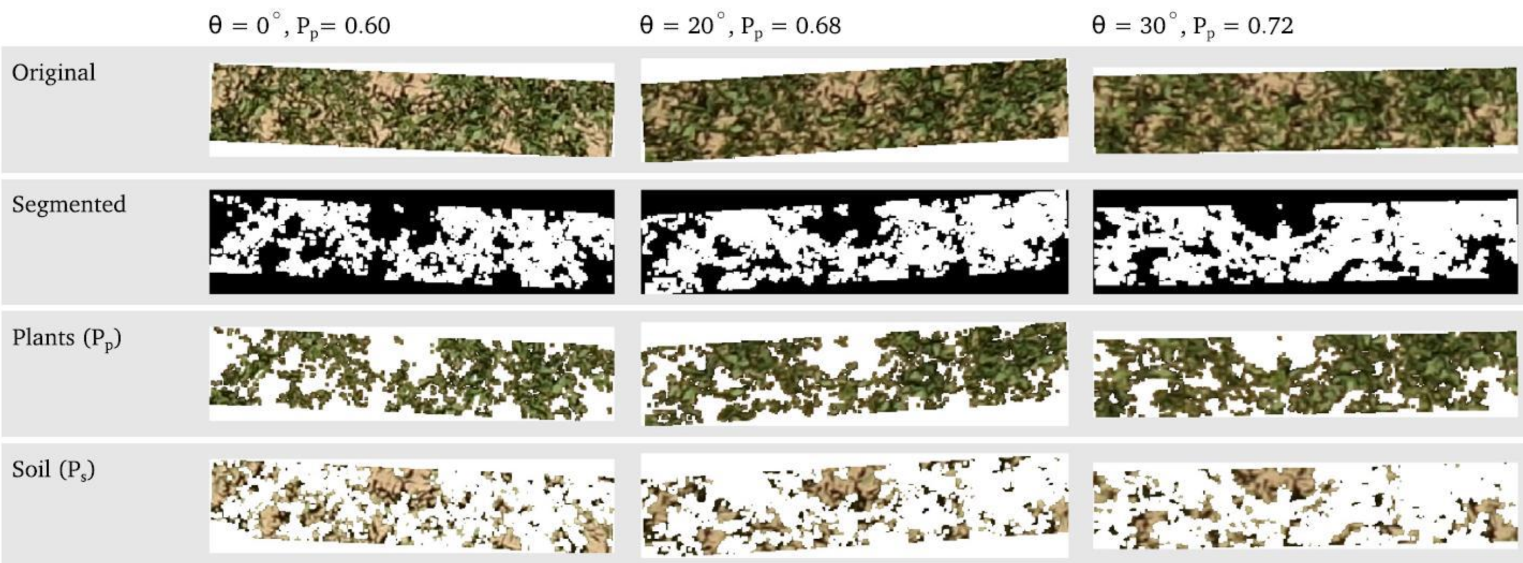
Extracting leaf area index using viewing geometry effects



L. Roth, H. Aasen, A. Walter, and F. Liebisch, “Extracting leaf area index using viewing geometry effects—A new perspective on high-resolution unmanned aerial system photography,” *ISPRS Journal of Photogrammetry and Remote Sensing*, 2018.

Extracting leaf area index using viewing geometry effects

images



simulation

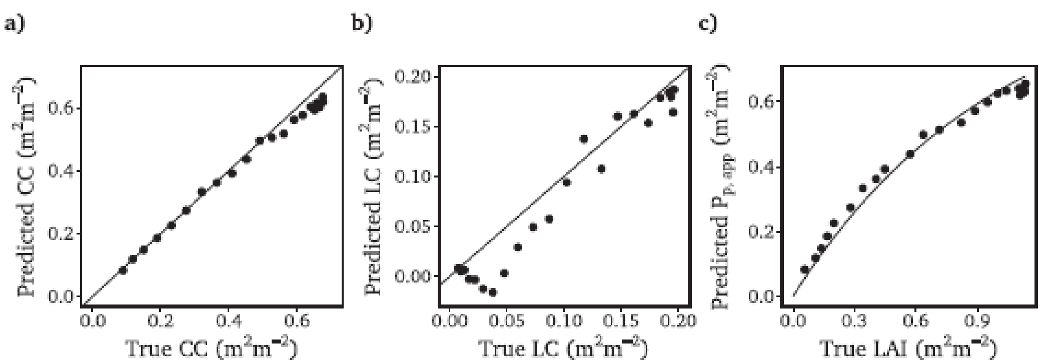
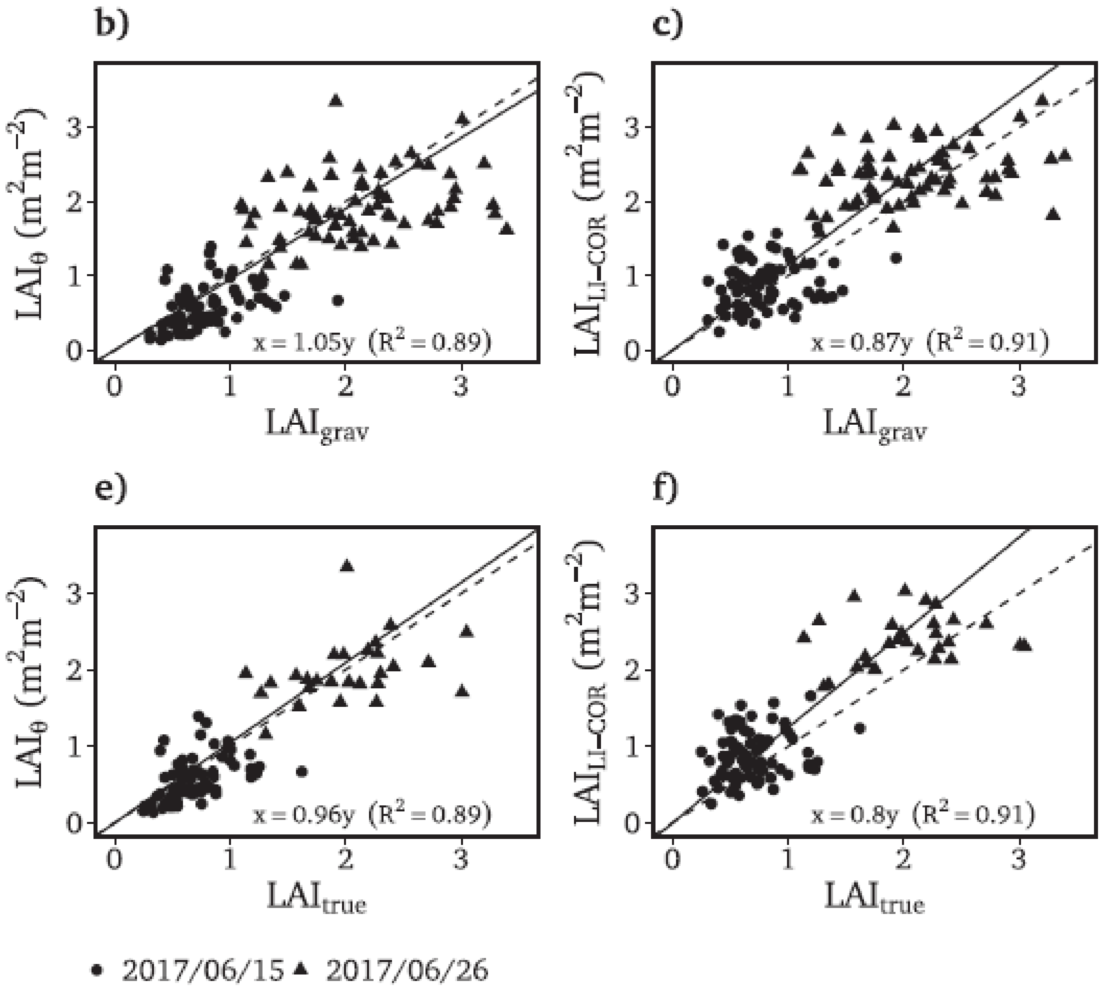


Fig. 7. Prediction performance of the CC/LC viewing geometry model for soybean growth simulation data for canopy cover (CC, **a**), lateral cover (LC, **b**) and apparent plant area fraction (P_{papp}) versus leaf area index (LAI) (**c**). Black lines show an implied 1:1 relationship (**a** and **b**) respectively a negative exponential relationship (**c**).

L. Roth, H. Aasen, A. Walter, and F. Liebisch, "Extracting leaf area index using viewing geometry effects—A new perspective on high-resolution unmanned aerial system photography," *ISPRS Journal of Photogrammetry and Remote Sensing*, 2018.

Extracting leaf area index using viewing geometry effects



L. Roth, H. Aasen, A. Walter, and F. Liebisch, "Extracting leaf area index using viewing geometry effects—A new perspective on high-resolution unmanned aerial system photography," *ISPRS Journal of Photogrammetry and Remote Sensing*, 2018.

@PhenoFly | Helge.Aasen@usys.ethz.ch

Conclusions

- You need to know what you are doing
  - It is your reasonability to generate reliable data
  - Know your sensing system and your flight parameters
  - Think of what you want to measure – and what you are measuring

- UAS remote sensing is ready
  - Provide reliable data
  - New approaches beyond classical approaches

- What is next…
  - Multi-modal remote sensing - combining 3D, spectral, thermal data

- Aasen, H., Honkavaara, E., Lucieer, A., Zarco-Tejada, P., 2018. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. Remote Sensing 10, 1091.
- Aasen, H., Bareth, G., accepted. Ground and UAV sensing approaches for spectral and 3D crop trait estimation, in: Thenkabail, P., Lyon, J.G., Huete, A. (Eds.), Hyperspectral Remote Sensing of Vegetation - Volume II: Advanced Approaches and Applications in Crops and Plants. Taylor and Francis Inc.

ETH zürich

Phenofly.net

Multi-modal remote sensing: Combining different data types

- **Segmentation approach**: either uses spectral (or color) information or 3D information for a pre-segmentation or classification
- **Complementation approach**: uses spectral and 3D data as complementary data to estimate different traits from both type of data
- **Combination approach**: combines 3D and spectral data to estimate one trait

- Aasen, H., Bareth, G., accepted. Ground and UAV sensing approaches for spectral and 3D crop trait estimation, in: Thenkabail, P., Lyon, J.G., Huete, A. (Eds.), Hyperspectral Remote Sensing of Vegetation - Volume II: Advanced Approaches and Applications in Crops and Plants. Taylor and Francis Inc.

Conclusions

- You need to know what you are doing
  - It is your reasonability to generate reliable data
  - Know your sensing system and your flight parameters
  - Think of what you want to measure – and what you are measuring
  - State quality parameters
- UAS remote sensing is ready
  - Provide reliable data
  - New approaches beyond classical approaches
- What is next…
  - Multi-modal remote sensing - combining 3D, spectral, thermal data
  - From pixel to object base image analysis - Exploring the high spatial resolution

- Aasen, H., Honkavaara, E., Lucieer, A., Zarco-Tejada, P., 2018. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. Remote Sensing 10, 1091.
- Aasen, H., Bareth, G., accepted. Ground and UAV sensing approaches for spectral and 3D crop trait estimation, in: Thenkabail, P., Lyon, J.G., Huete, A. (Eds.), Hyperspectral Remote Sensing of Vegetation - Volume II: Advanced Approaches and Applications in Crops and Plants. Taylor and Francis Inc.

Thank you for your attention and special thanks to:

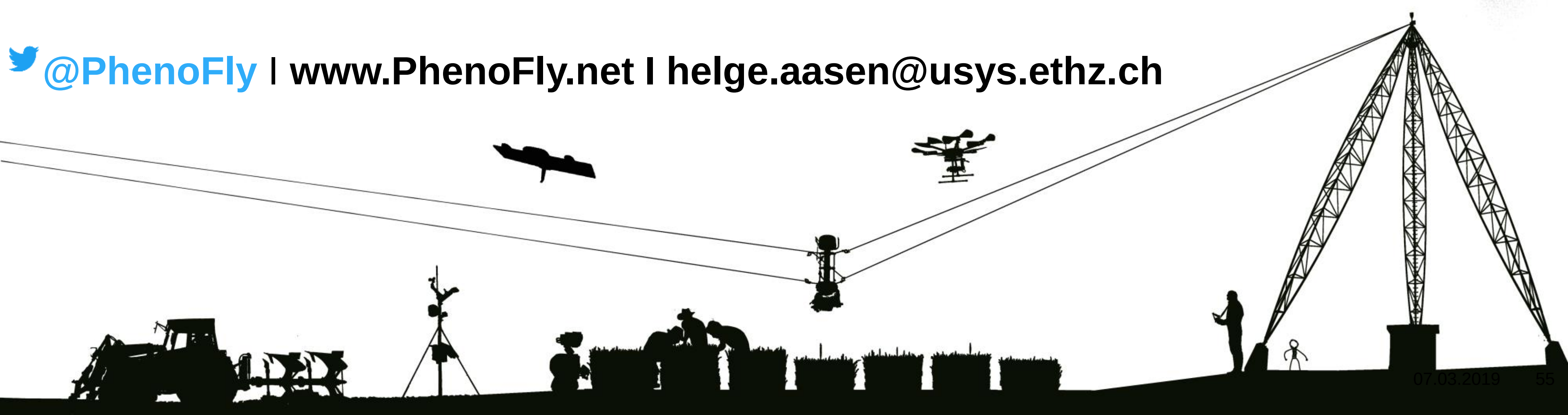
CROP SCIENCE

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Bundesamt für Landwirtschaft BLW

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Innosuisse - Schweizerische Agentur für Innovationsförderung

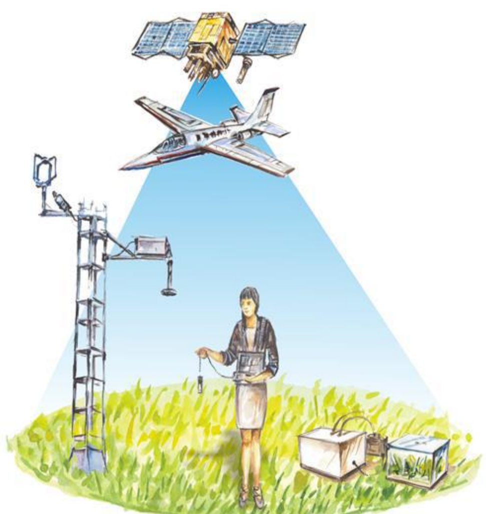
FNSNF
Swiss National Science Foundation

@PhenoFly | www.PhenoFly.net | helge.aasen@usys.ethz.ch



SENSECO: Optical synergies for spatiotemporal sensing of scalable ecophysiological traits (COST Action CA17134)

WG 1	WG 2	WG 3	WG 4
Closing the scaling gap: from leaf measurements to satellite images	Closing the temporal gap: from daily observations to seasonal trends	Realizing synergy between passive EO spectral domains	Establishing data quality through traceability and uncertainty



The main objectives:

- To tackle the scaling gap between leaf and satellite measurements in order to link driving mechanisms at the leaf scale to photosynthesis at the global scale.
- To improve the time-series processing of satellite sensor data for modelling vegetation processes related to seasonal productivity.
- To improve synergies between passive optical EO domains.
- To ensure measurements comparability across different scales, space and time.