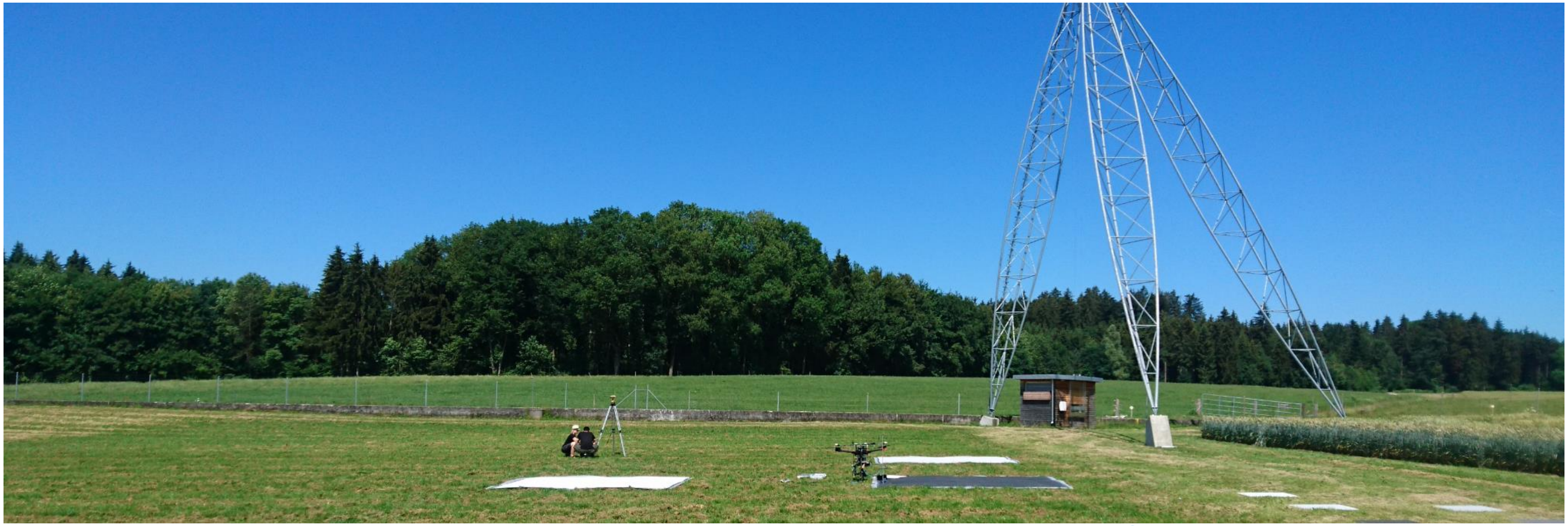
ETH zürich

Phenofly.net



Low-altitude / high-resolution (drone based) remote sensing for Field-Phenotyping

Helge Aasen[1*], Lukas Roth[1], Quirina Merz[1], Francesco Argento[1], Frank Liebisch[1], Norbert Kirchgessner[1], Andreas Hund[1], Achim Walter[1]

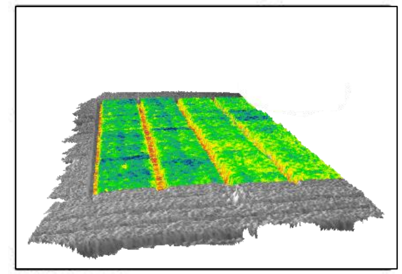
[1]Crop Science Group, Institute of Agricultural Sciences, ETH Zurich, Switzerland

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

- Phenotyping many genotypes across multiple (natural) environments is a lot of work
- Plant growth is a dynamic process
- Objective measures of traits are needed

➢ Automated, reproducible procedures would help ‘pixel’ in digital representation

field



data product

UAV remote sensing for field-phenotyping workflow

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

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

@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

- intro PhenoFly team
- intro field setup
- example canopy temperature
- example leaf area

@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

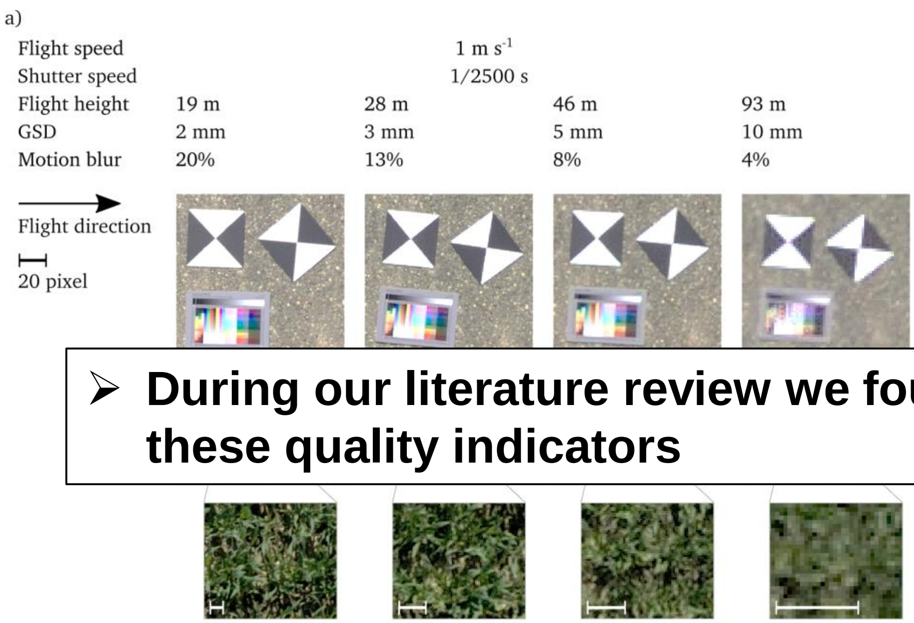
Mission planning

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

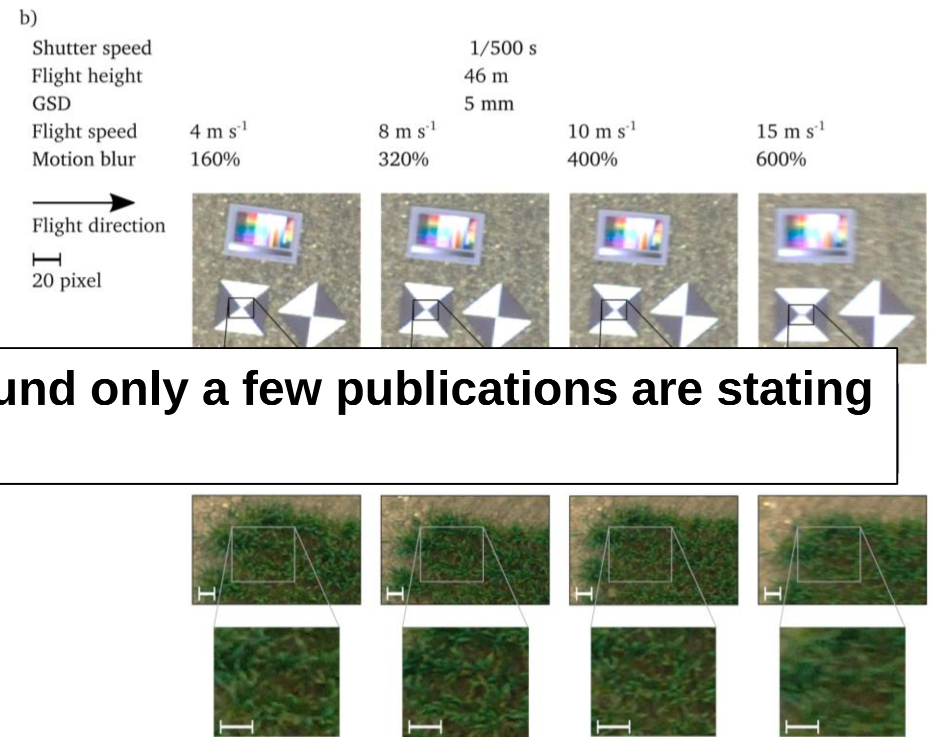
➢ Can be quite complex
  - Data product (point cloud, digital surface model, orthophoto)
  - Sensor (point, line or 2d imager)
  - Data type (RGB, spectral, thermal …)
  - Coverage (flight time, flight speed, altitude)
  - Ground sampling distance (altitude, resolution, motion blur ~ flying speed + integration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

Flight planning

- ground sampling distance



- motion blur



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

- GCP placement
- image overlap
- …

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

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

CROP SCIENCE 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) 1,25

Max. flight duration (min) 15

Distance between pixel centers / circle of confusion: 0.0059 mm

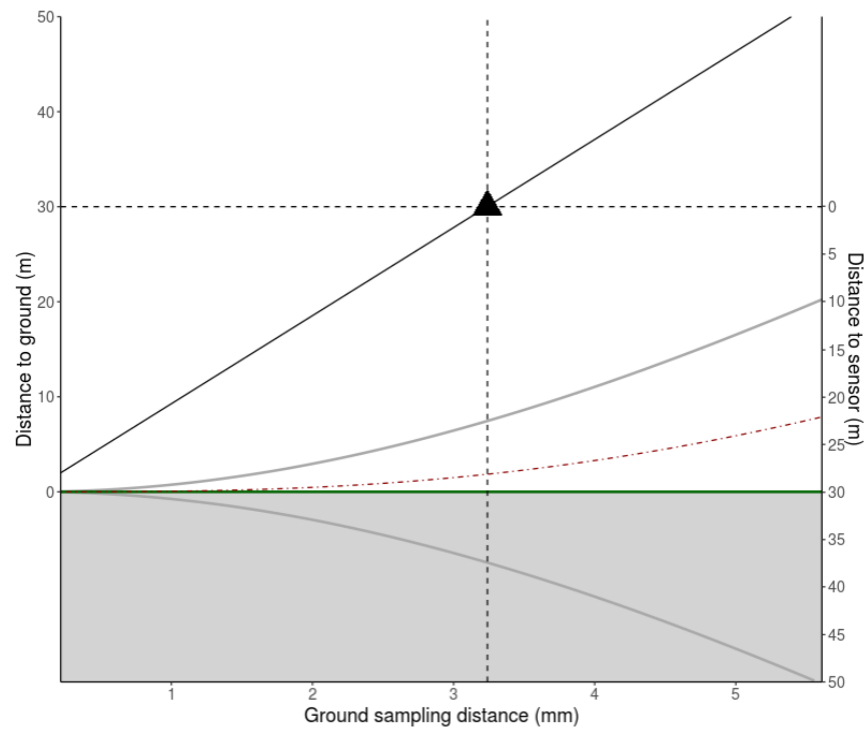
Lens

Focal length (mm) 55

Aperture (f-number) f/4.5

Photography | Mapping properties | Viewing geometry | Mission briefing

Flight height dependency



Lens intrinsic parameters

Angle of view:
horizontally: 35.9°
vertically: 24.4°
Hyperfocal distance:
113.4 m
Diffraction limited:
R (700 nm): 1.3 * circle of conf.
G (530 nm): no
B (470 nm): no

Dependant parameters

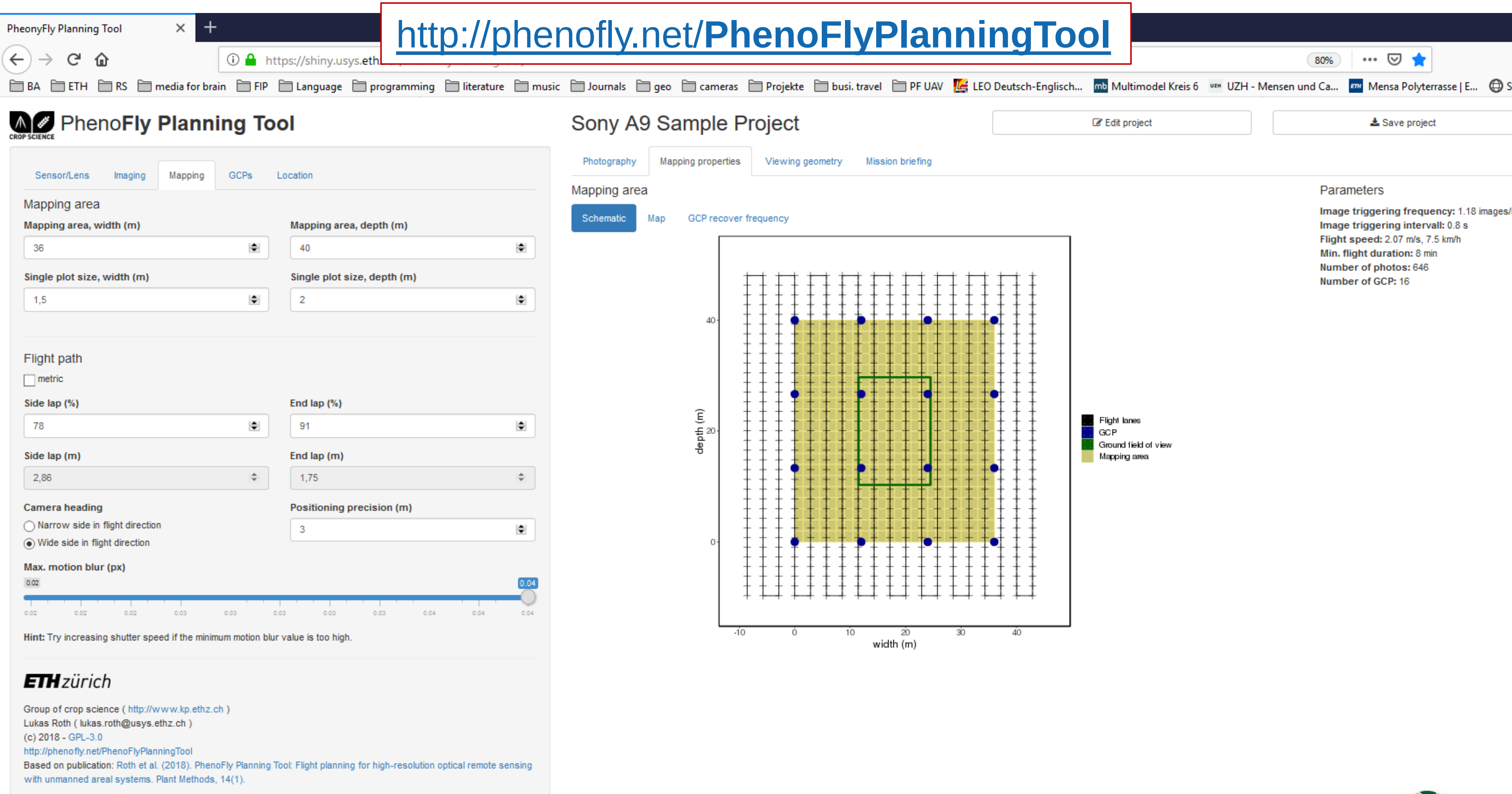
Ground field of view:
horizontally: 19.4 m
vertically: 13 m
Focus distance:
28.1 m
Depth of field in relation to ground:
near: 7.4 m
far: -7.4 m

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*."

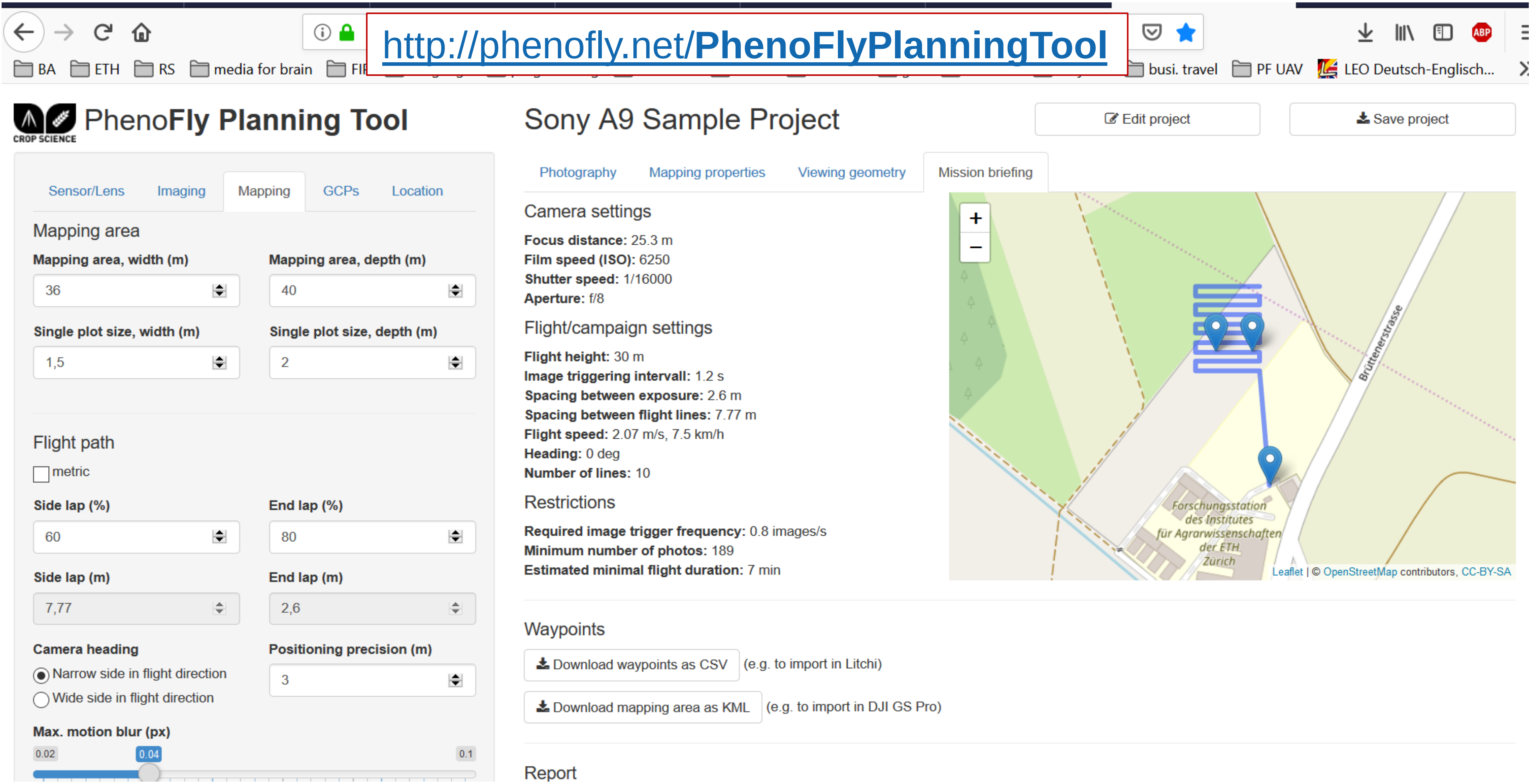
Flight planning

http://phenofly.net/PhenoFlyPlanningTool



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*.

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

CROP SCIENCE Phenofly.net

Spectral sensors for UAS RS

Headwall Nano-Hyperspec® VNIR

Simple consumer oriented systems

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)

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

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

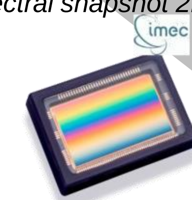
2009 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

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

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

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

Imec filter-on-chip
Hyperspectral snapshot 2D



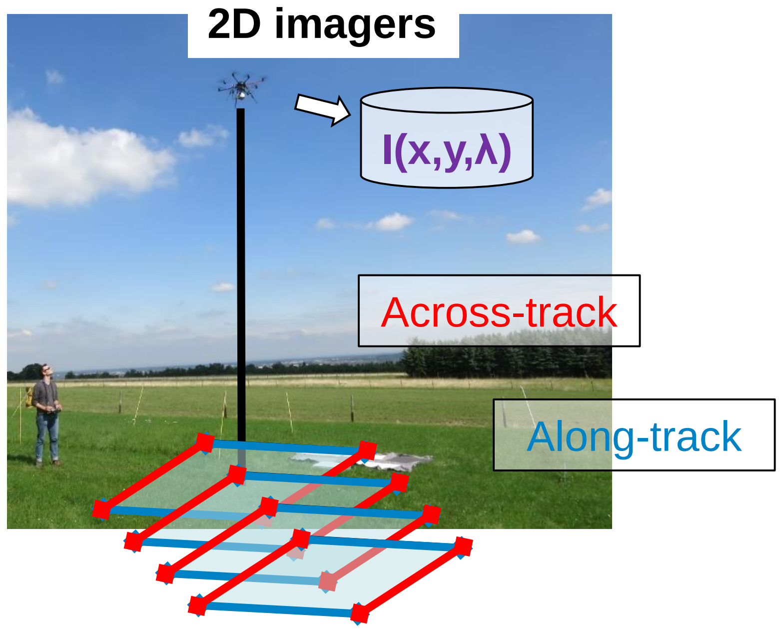
High-quality systems

HySpex
Mjolnir

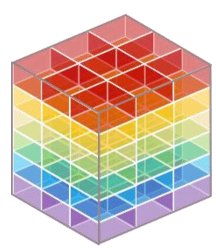
SPECIM FX10

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) 2D imagers



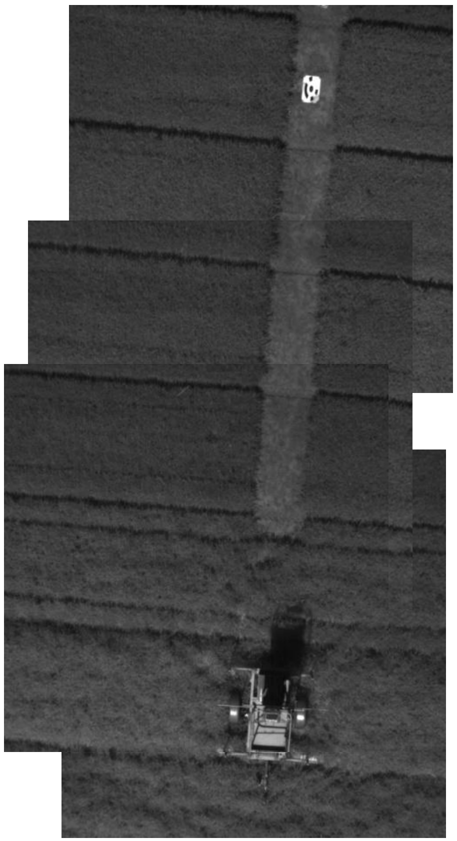
SfM + GCPs
(and/or imu + gnss)



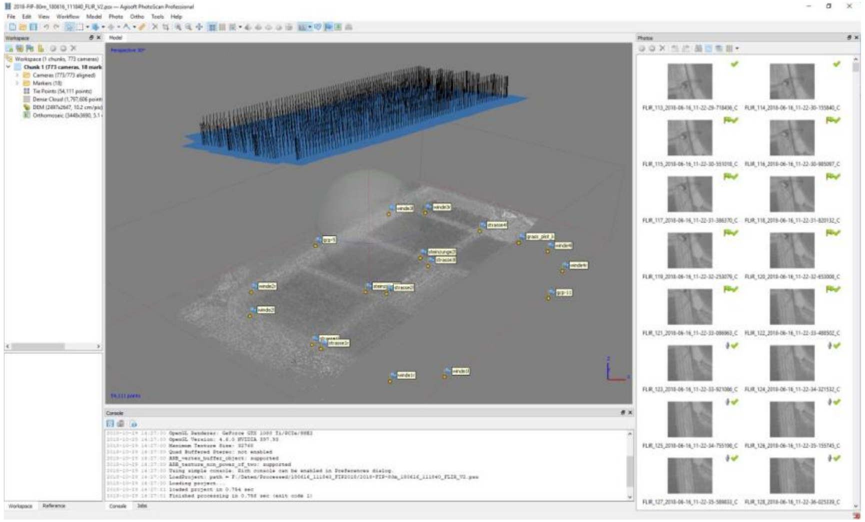
Orthorectification via

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

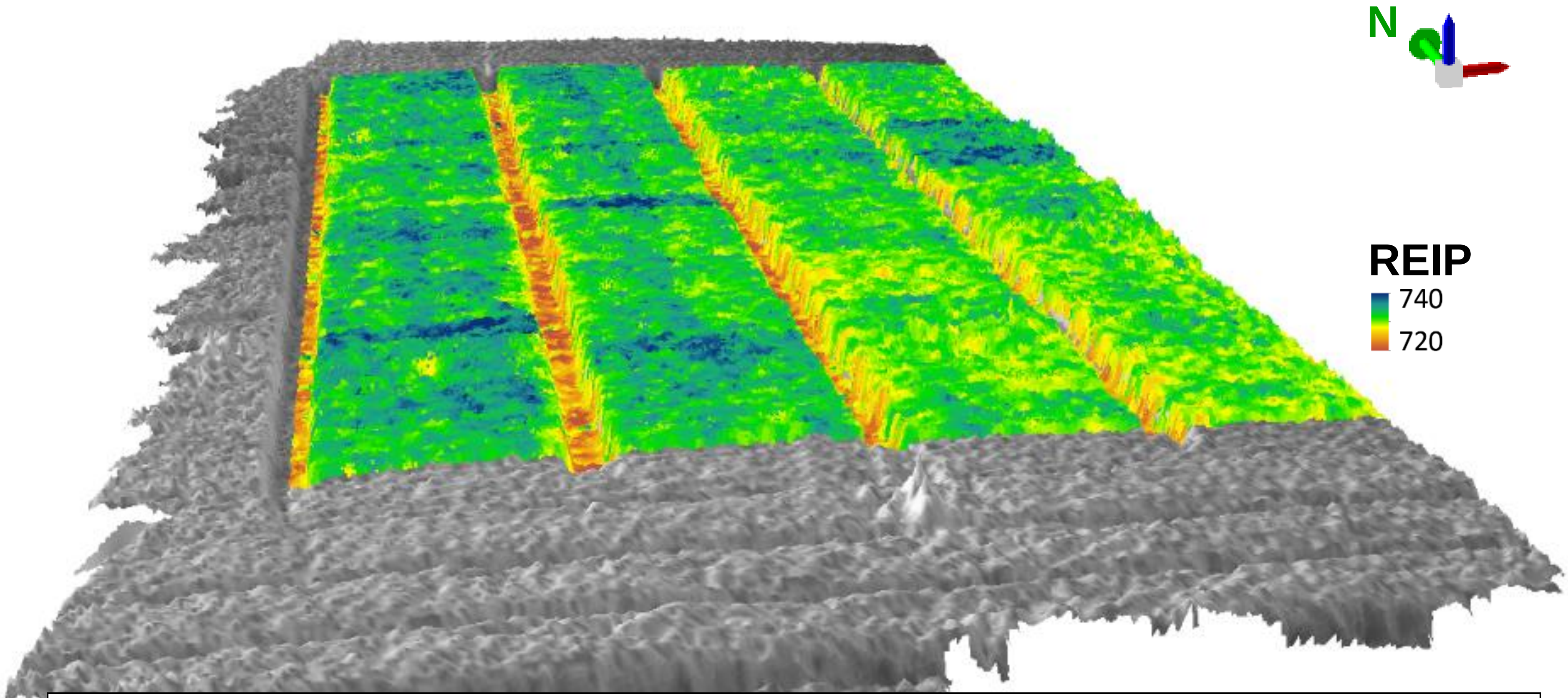


3D geometry

Orthorectified (spectral) scene

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 (/thermal) digital surface model

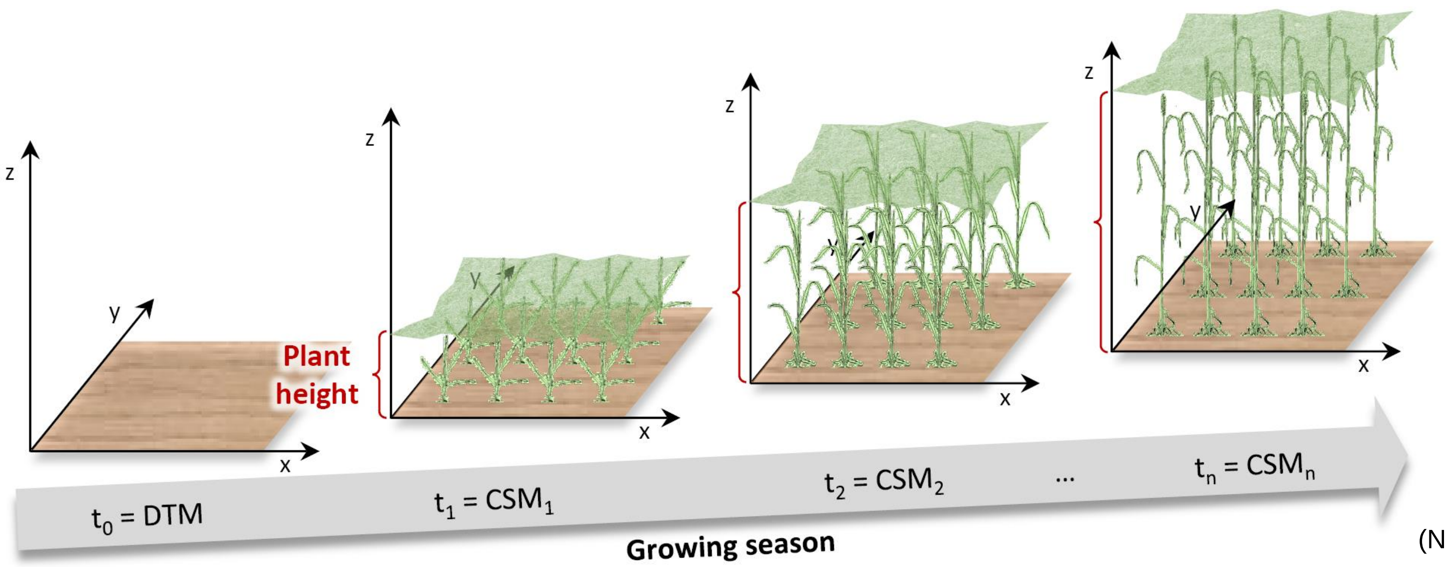


A spectral digital surface model is a representation of the surface in 3D space linked with spectral information emitted and reflected by the objects covered by the surface

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

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

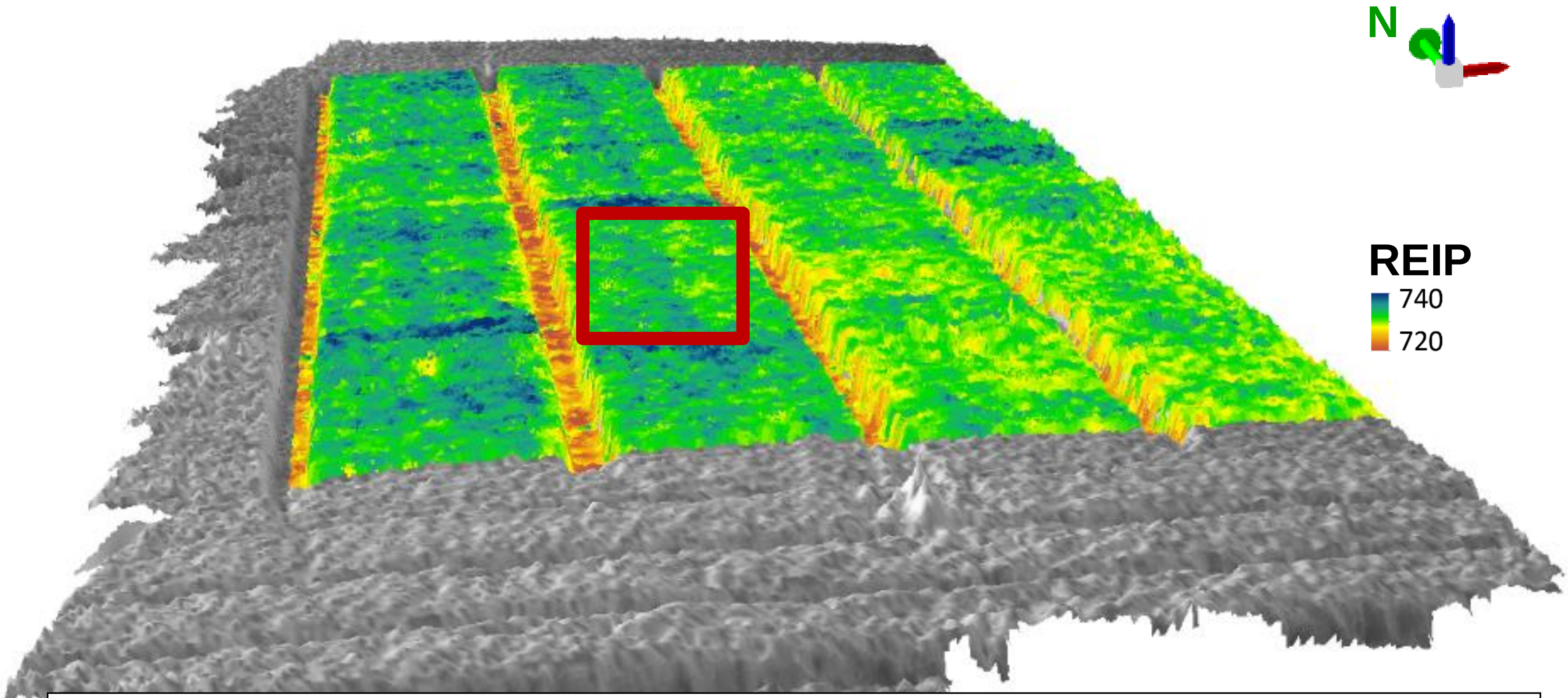
Track plant growth with 3D information



(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.

Spectral (/thermal) 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

Data processing

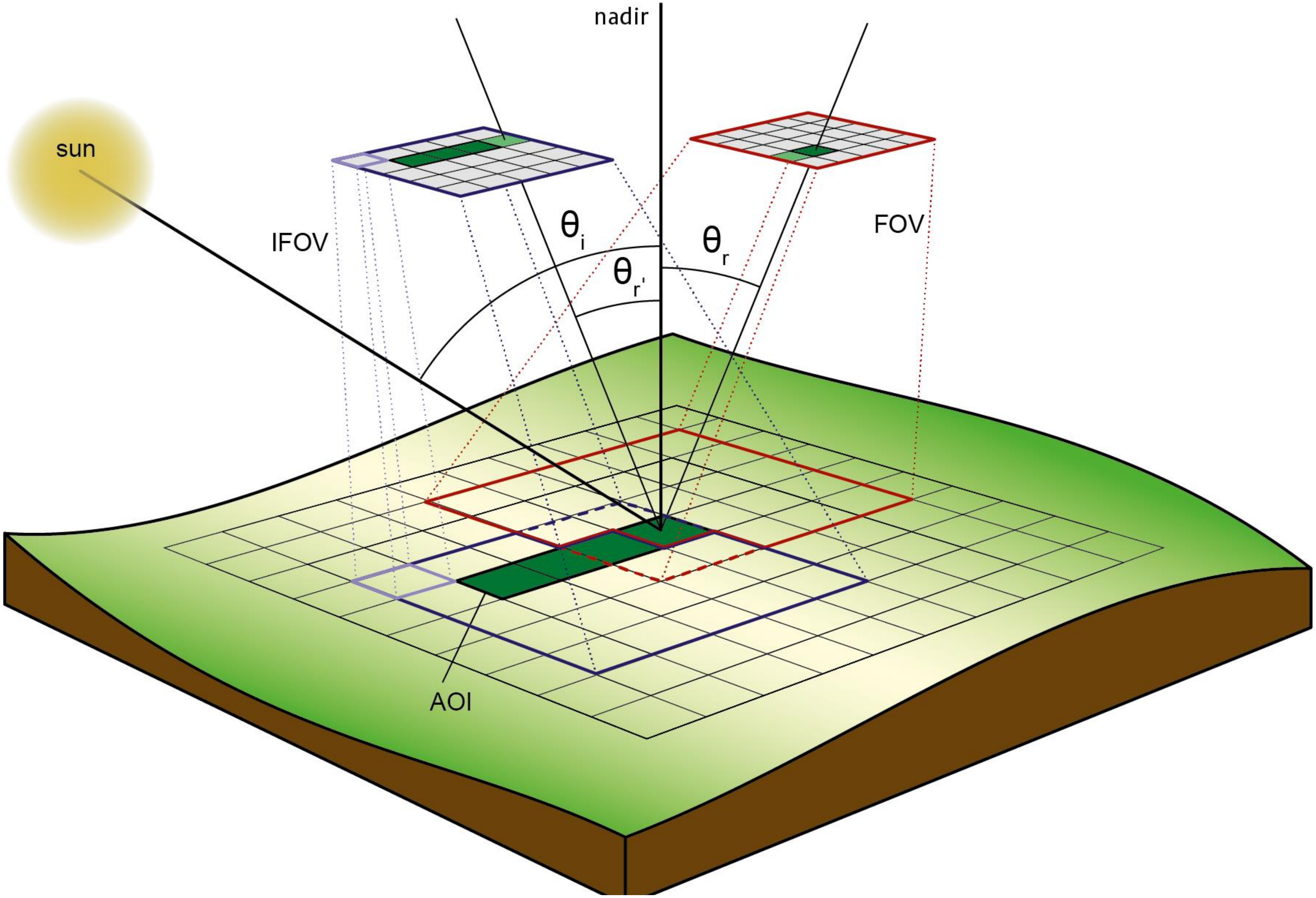
Flight planning, setup and flight	→	Data processing	→	Plant trait extraction	→	Database	→	P = G x E

- example: spectral data

Important if you want to use the radiometric information e.g. spectral, thermal or RGB info

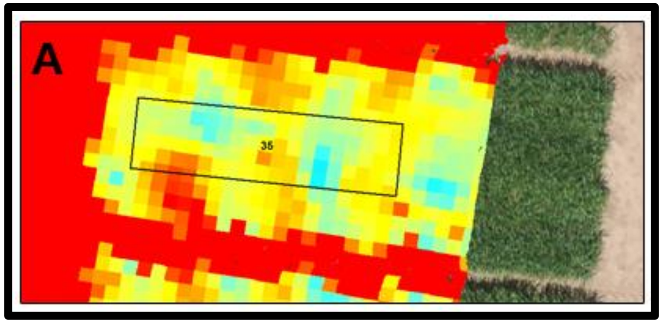
@PhenoFly | Helge.Aasen@usys.ethz.ch

Imaging spectroscopy with 2D imagers

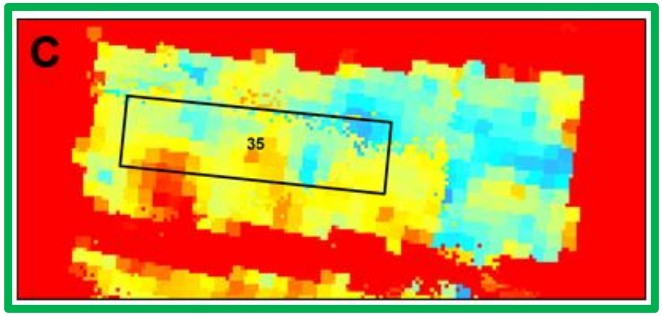


Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.

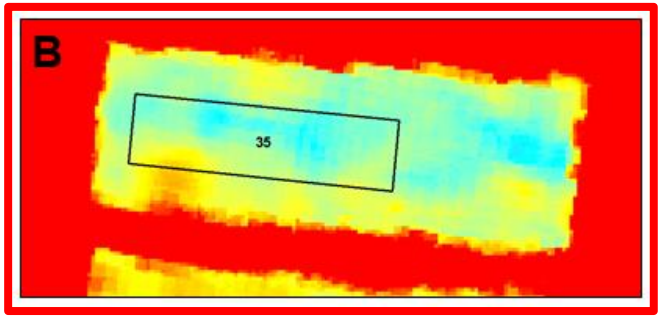
Imaging spectroscopy with 2D imagers



Single (most nadir) image

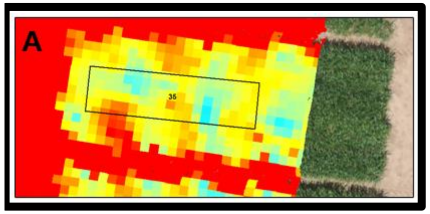


Mosaic, blending: disabled

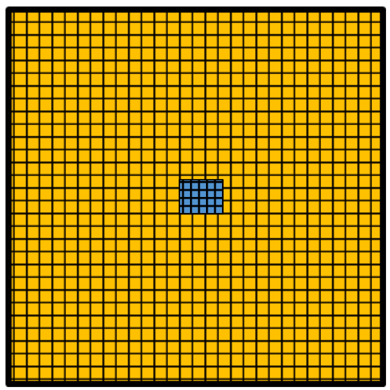


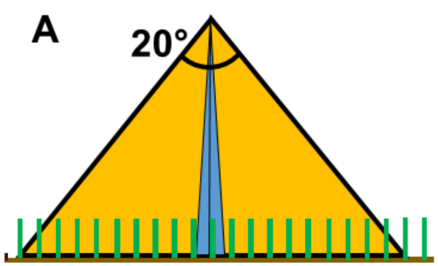
Mosaic, blending: average

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

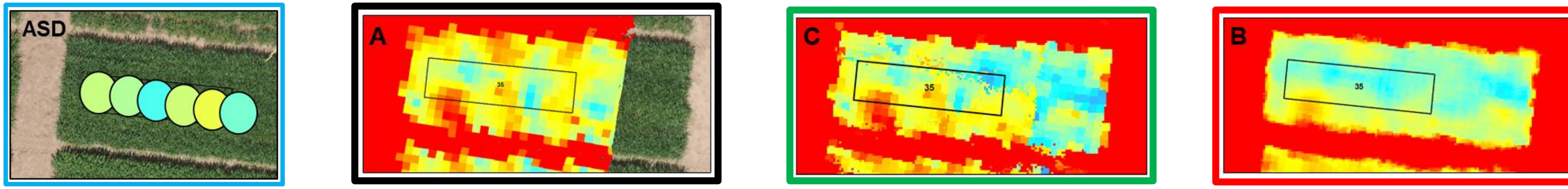


A: single image

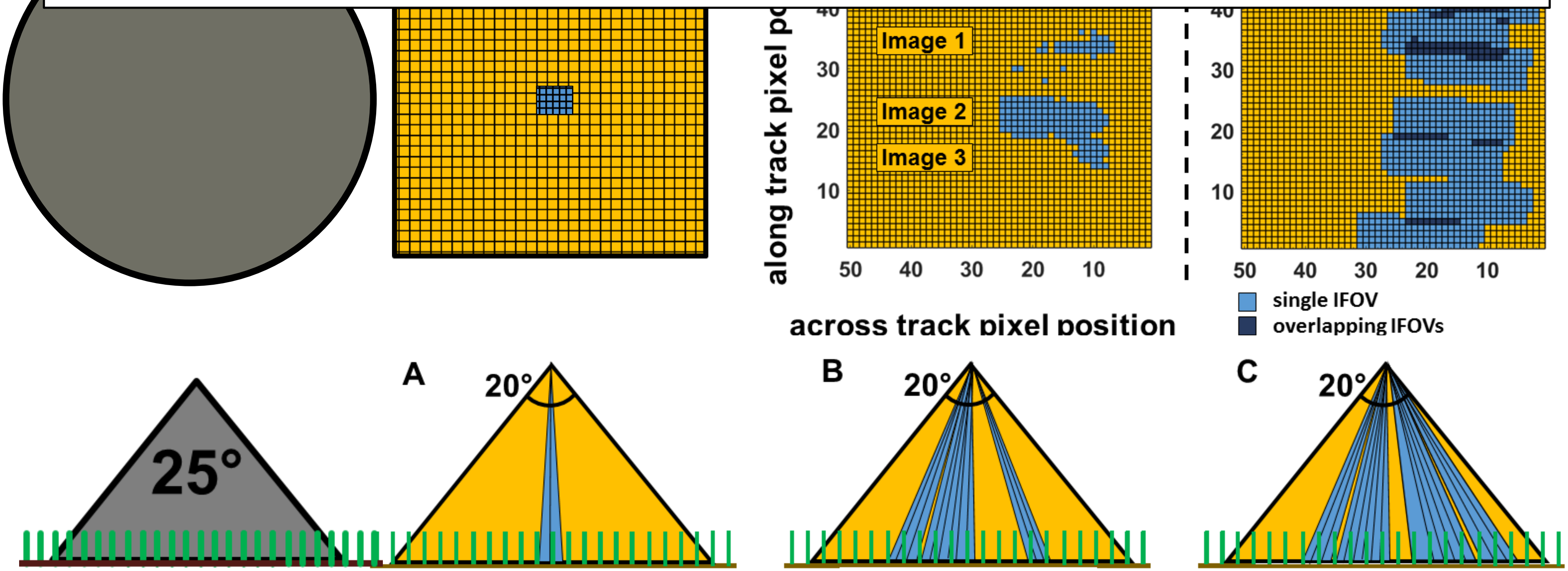




Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.

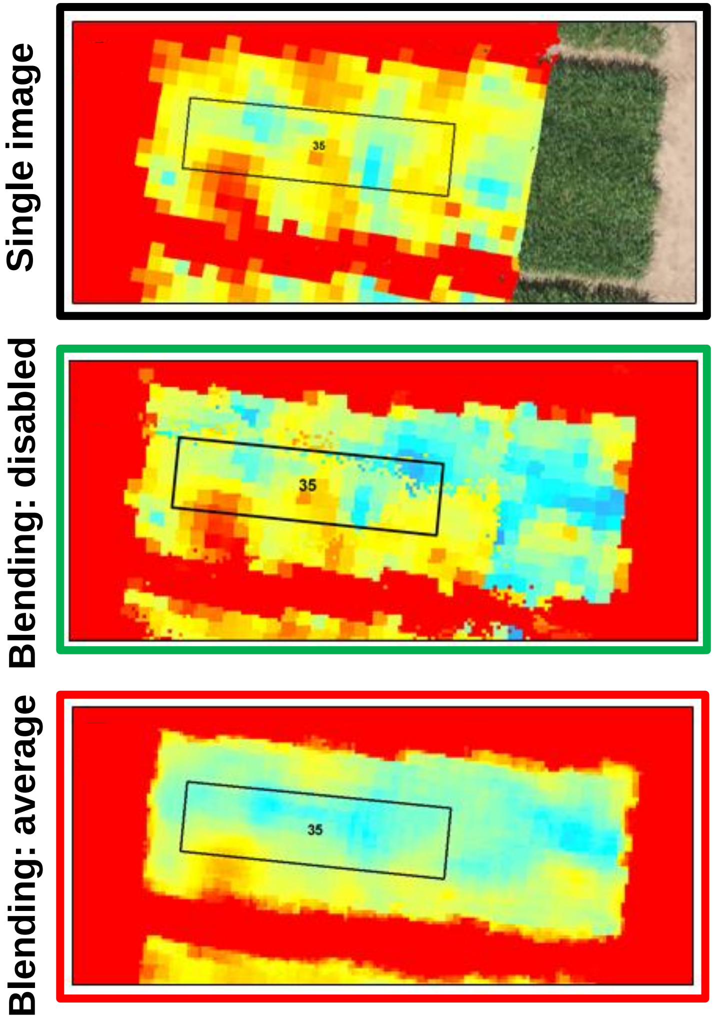


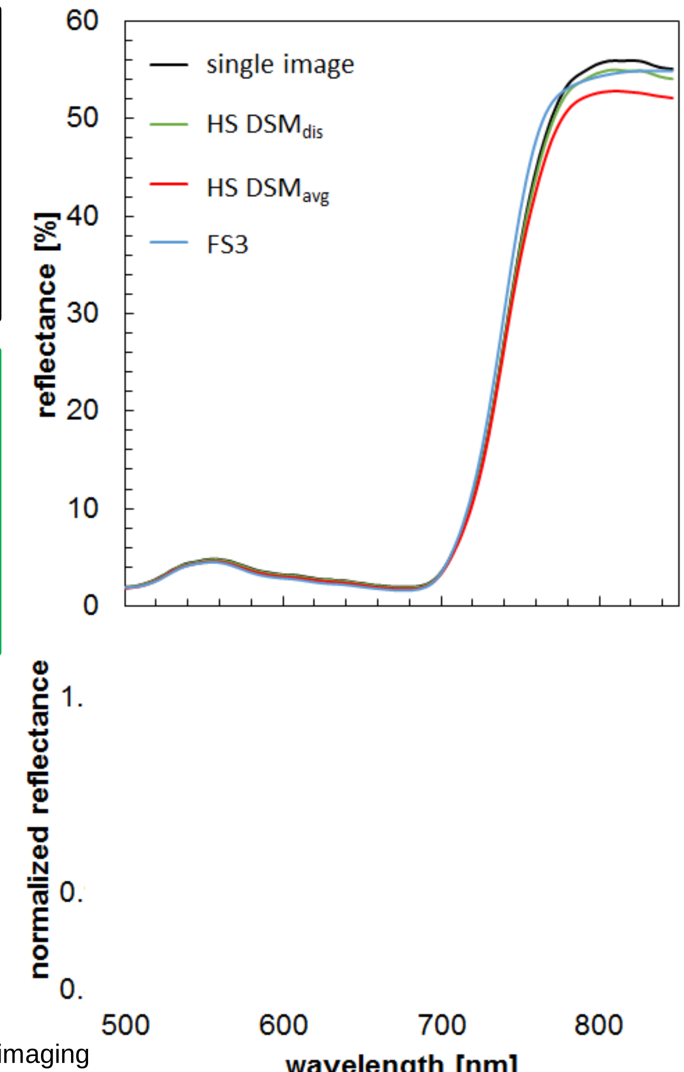
The specific field of view is the composition of pixels and their angular properties within a scene used to characterize a specific AOI on the ground

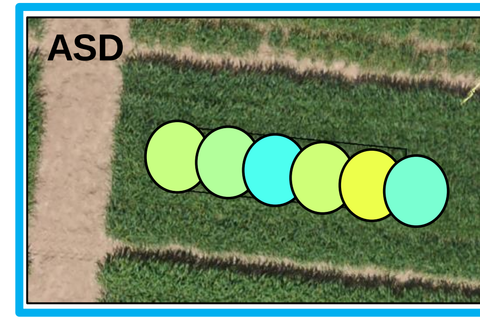


Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. Remote Sensing of Environment.

Imaging spectroscopy with 2D imagers

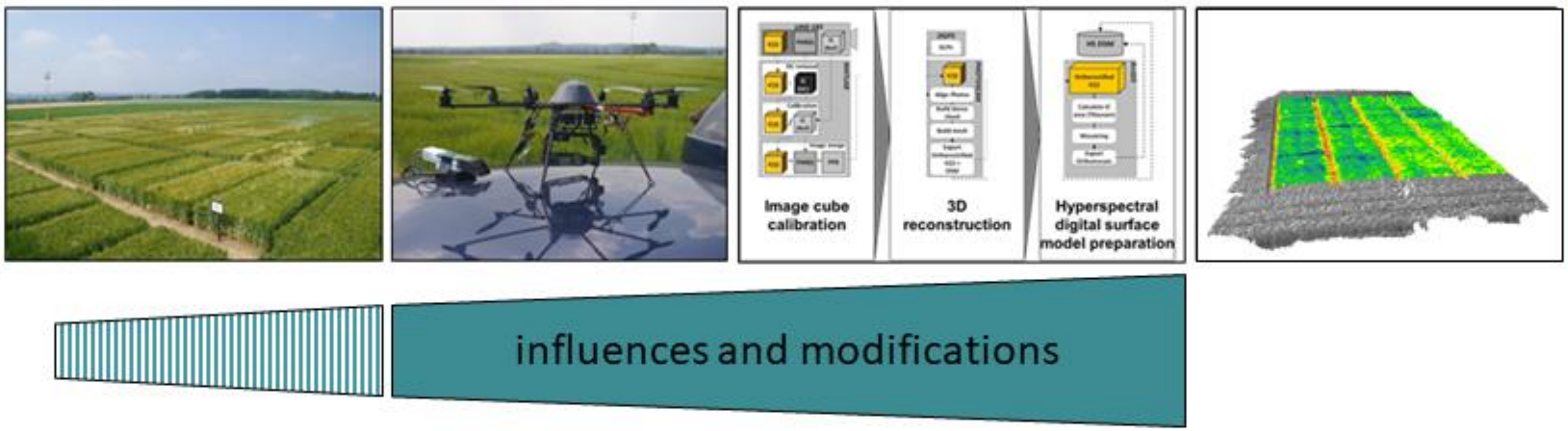






Aasen, H., Bolten, A., 2018. Multi-temporal high-resolution imaging spectroscopy with hyperspectral 2D imagers – from theory to application. RSE 'pixel' in digital representation

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

Outline

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

Understanding the data

- intro PhenoFly team
- intro field setup
- example canopy temperature
- example leaf area

@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 field
- 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

Low-altitude / high-resolution remote sensing at the Crop Science Group

Low-altitude remote sensing

Close range

Proximal

FIP[1]

LS, hyper-spec, thermal, RGB

Multi-rotor UAVs

Hyper-spec, thermal, RGB

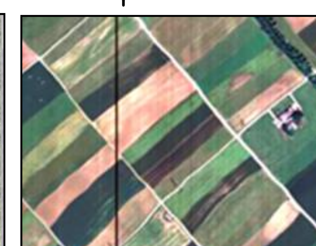
Fixed-wing UAVs

Multi-spec, RGB

Leaf, plant, plot

Plot to field (<2 ha)

Field to region (< 100 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

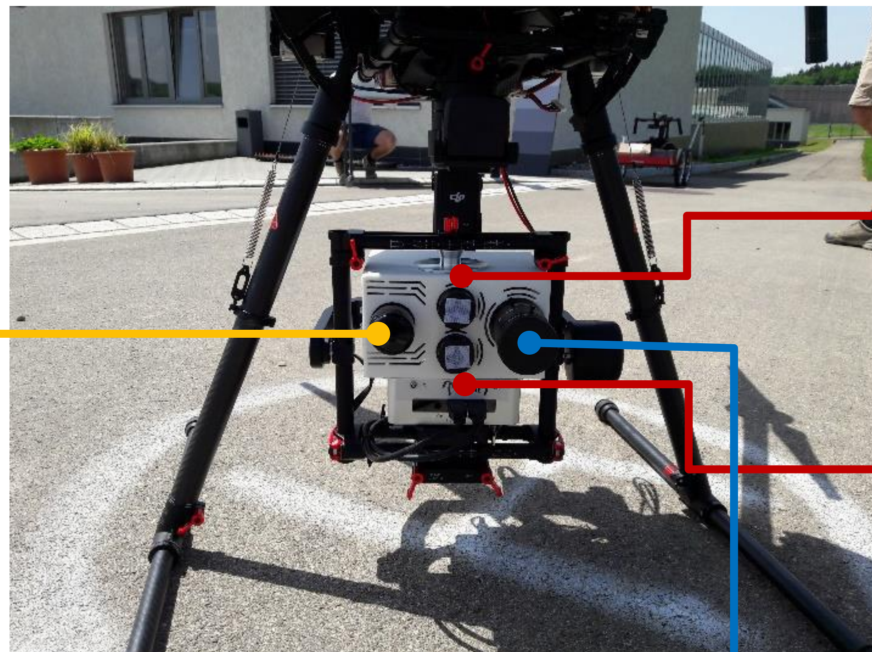
Plant research station Eschikon, ETH Zurich

[FIP field 360°]

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

Example: canopy temperature

PhenoFly multi-sensor payload



VIS spectral camera
IMEC SNm4x4
460-630 nm

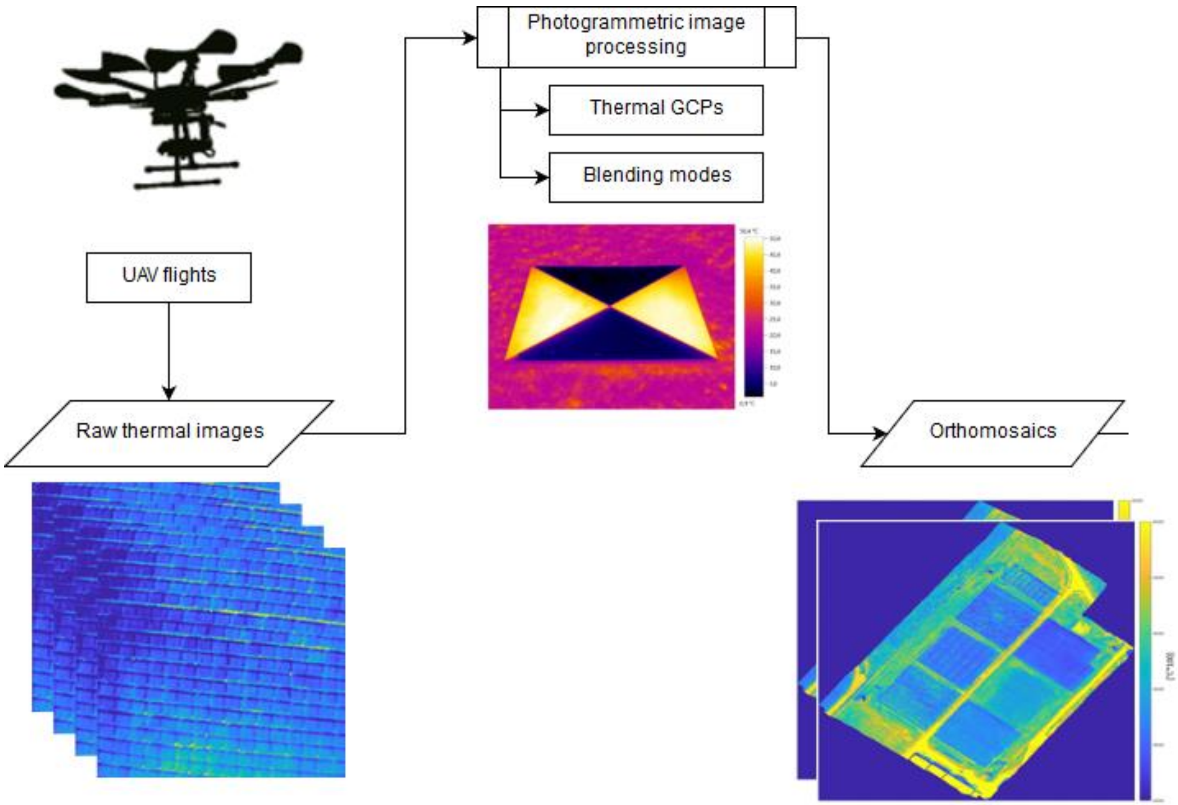
Thermal camera
FLIR A65

NIR spectral camera
IMEC SNm5x5
600-1000 nm

RGB camera
Point gray 12 mpix

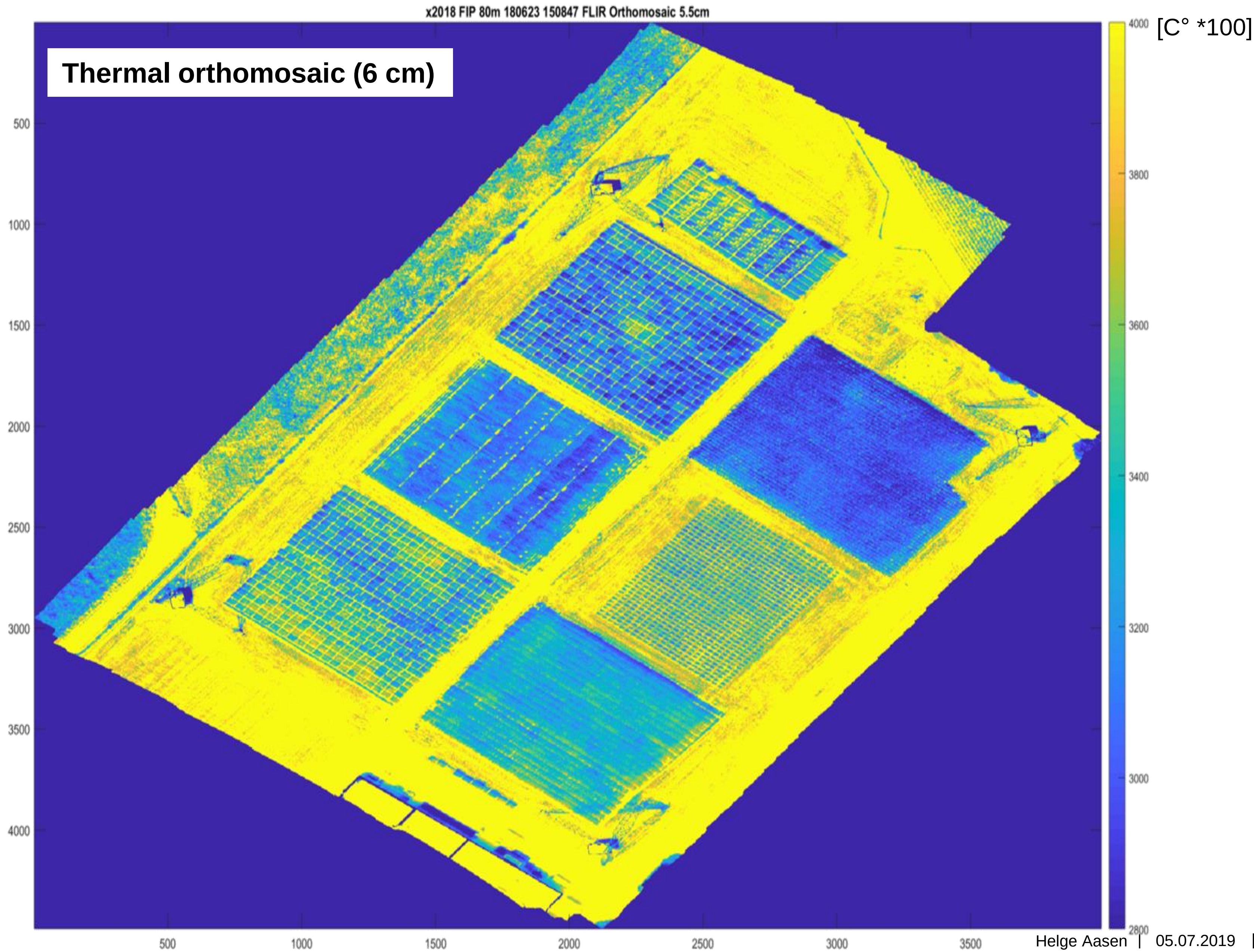
@PhenoFly | Helge.Aasen@usys.ethz.ch

Canopy temperature workflow

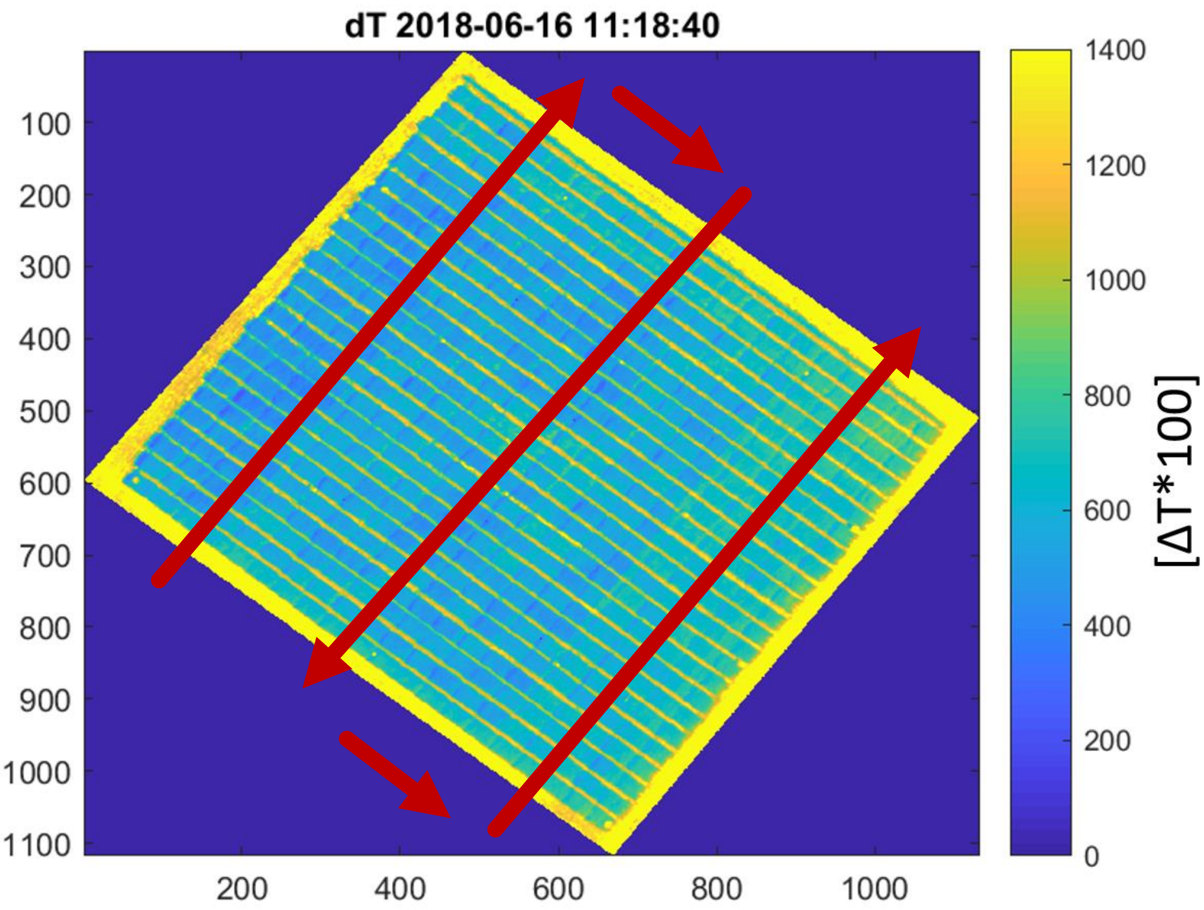


G. Perich, A. Hund, L. Roth, and H. Aasen, "UAV thermography to assess physiological plant parameters in high-throughput field phenotyping," *Frontiers in Plant Science*, "in preparation."

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



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



Influences on canopy temperature

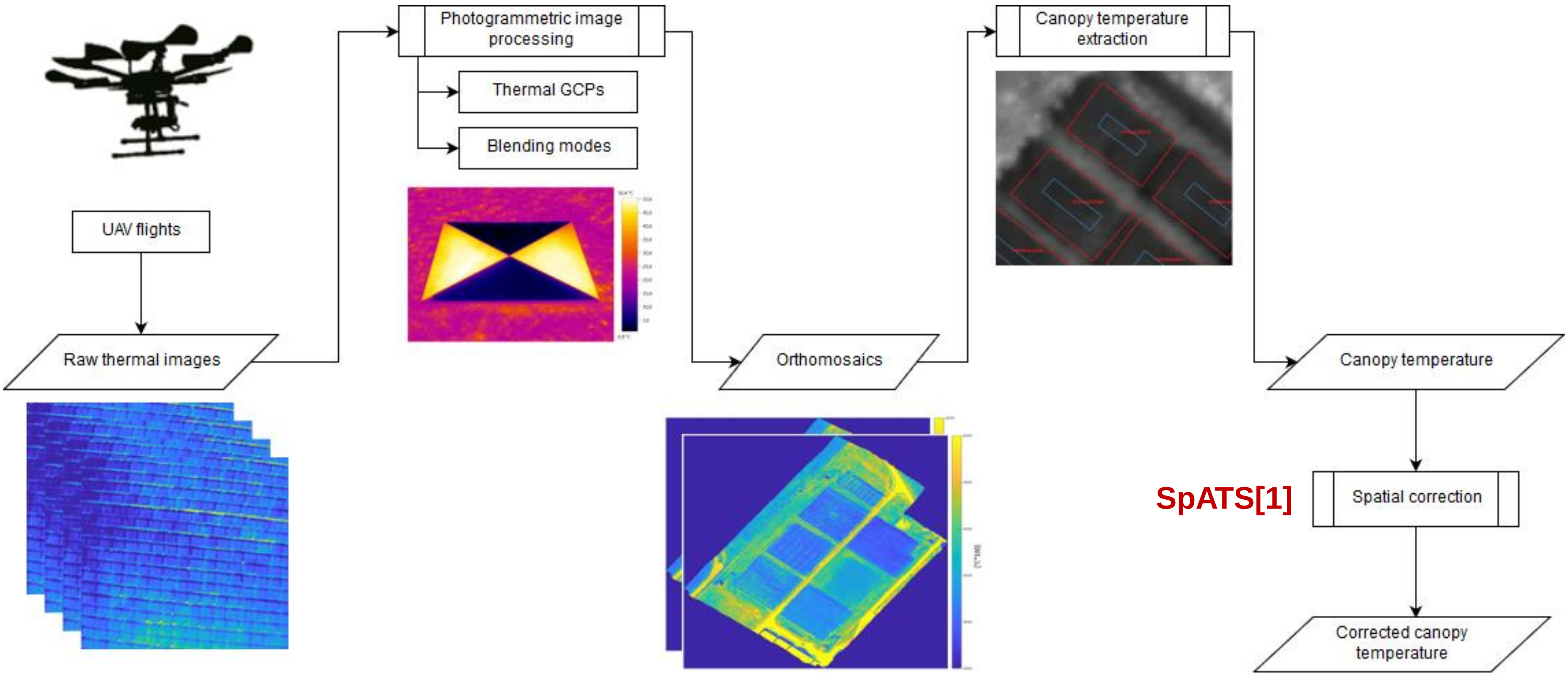
- Genotype
- Soil
- Management
- …

- Measurement conditions (illumination fluctuations)
- Measurement device

Flight pattern

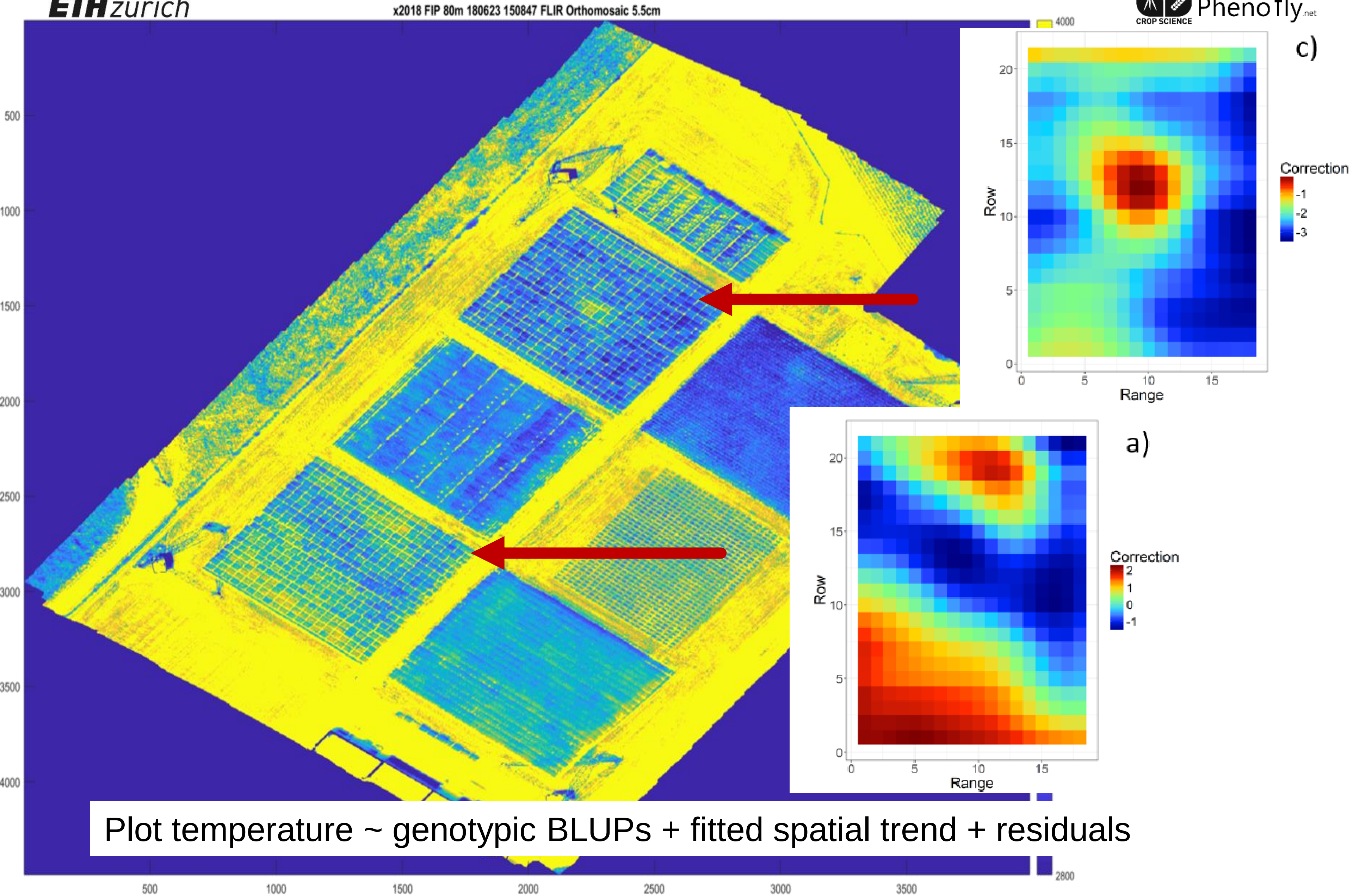
@PhenoFly | Helge.Aasen@usys.ethz.ch

Canopy temperature workflow



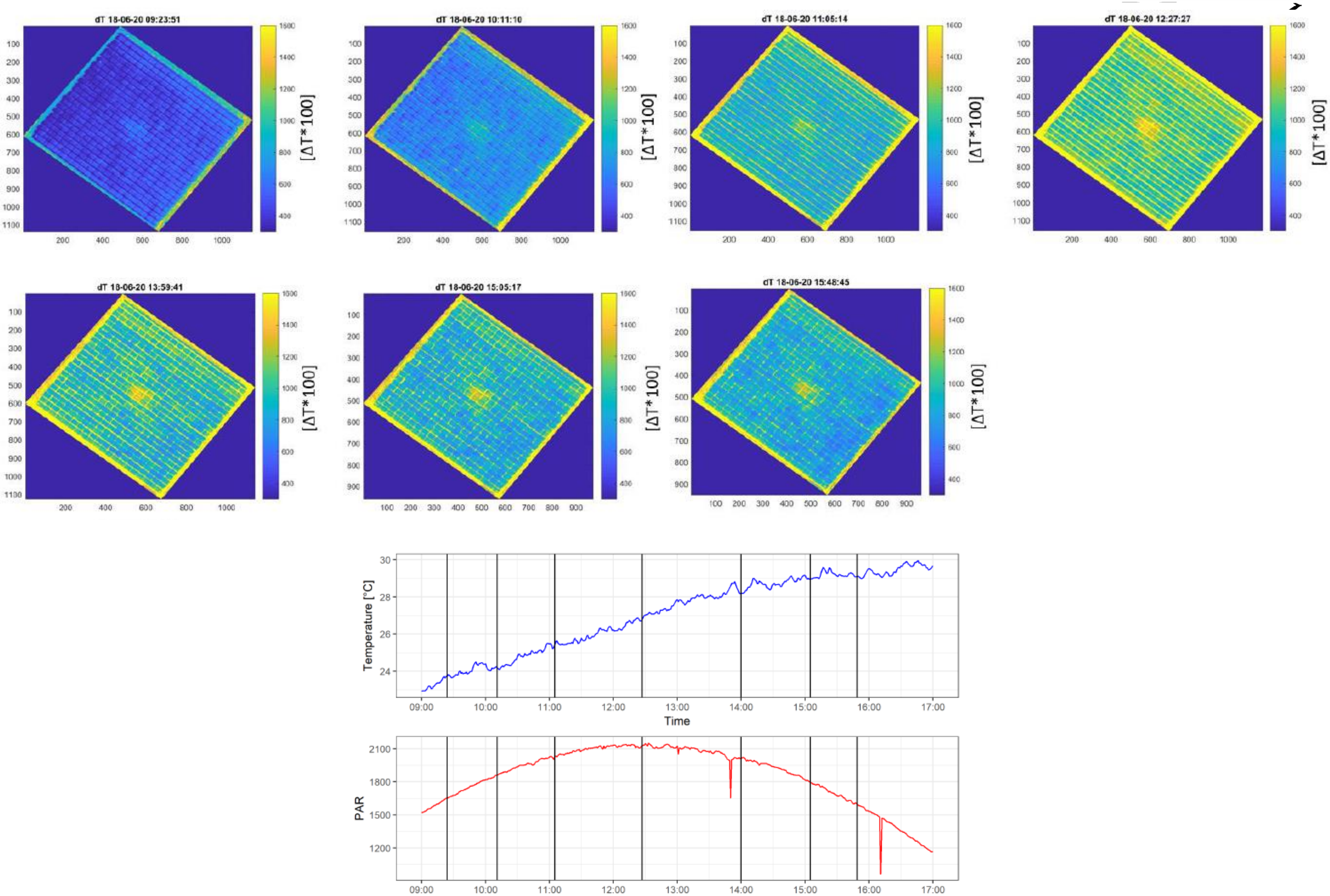
[1] M. X. Rodríguez-Álvarez, M. P. Boer, F. A. van Eeuwijk, and P. H. C. Eilers, "Correcting for spatial heterogeneity in plant breeding experiments with P-splines," *Spatial Statistics*, vol. 23, pp. 52–71, Mar. 2018.

G. Perich, A. Hund, L. Roth, and H. Aasen, "UAV thermography to assess physiological plant parameters in high-throughput field phenotyping," *Frontiers in Plant Science*, "in preparation."

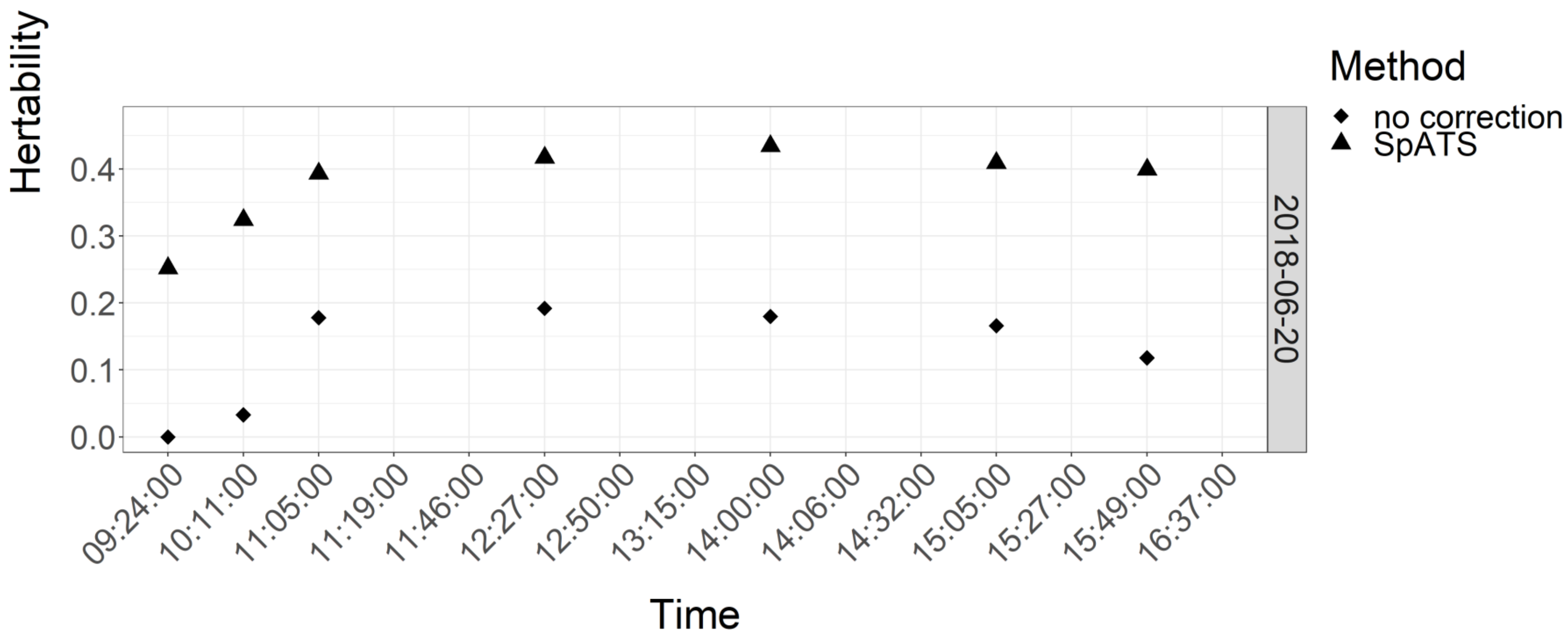


Plot temperature ~ genotypic BLUPs + fitted spatial trend + residuals

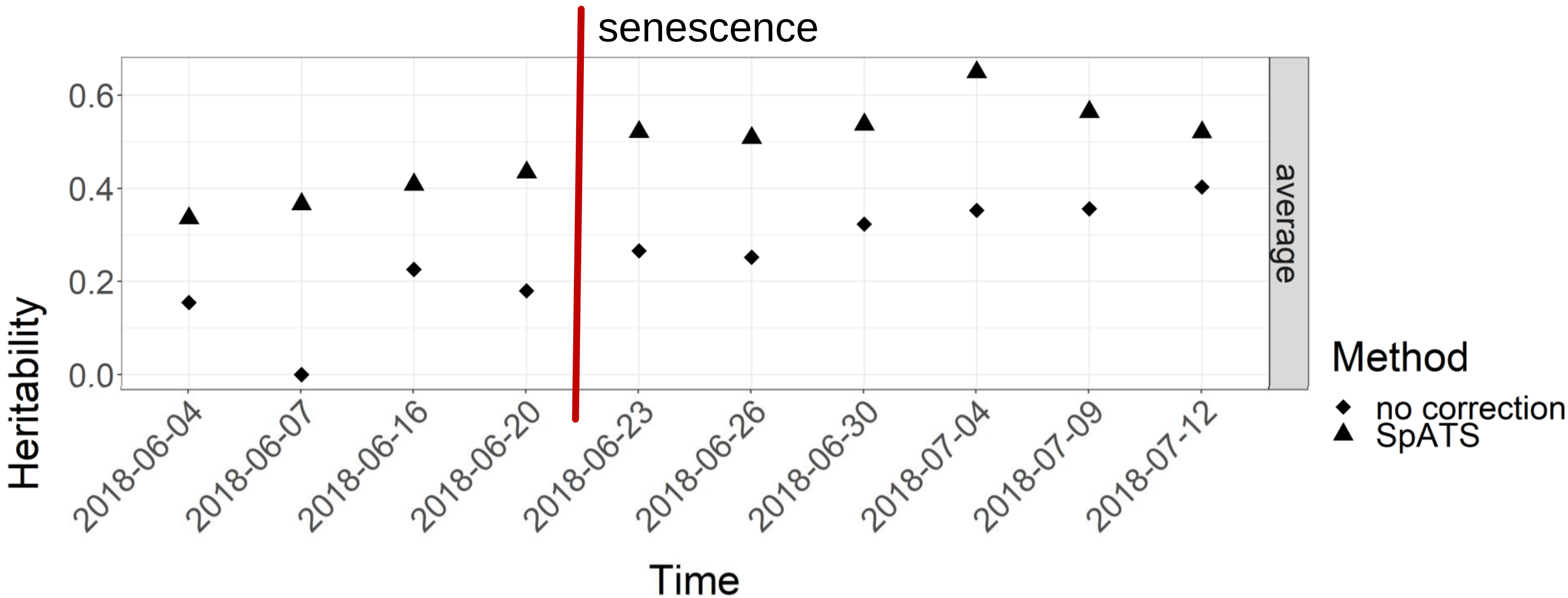
G. Perich, A. Hund, L. Roth, and H. Aasen, “UAV thermography to assess physiological plant parameters in high-throughput field phenotyping,” *Frontiers in Plant Science*, “in preparation.”



G. Perich, A. Hund, L. Roth, and H. Aasen, “UAV thermography to assess physiological plant parameters in high-throughput field phenotyping,” *Frontiers in Plant Science*, “in preparation.”

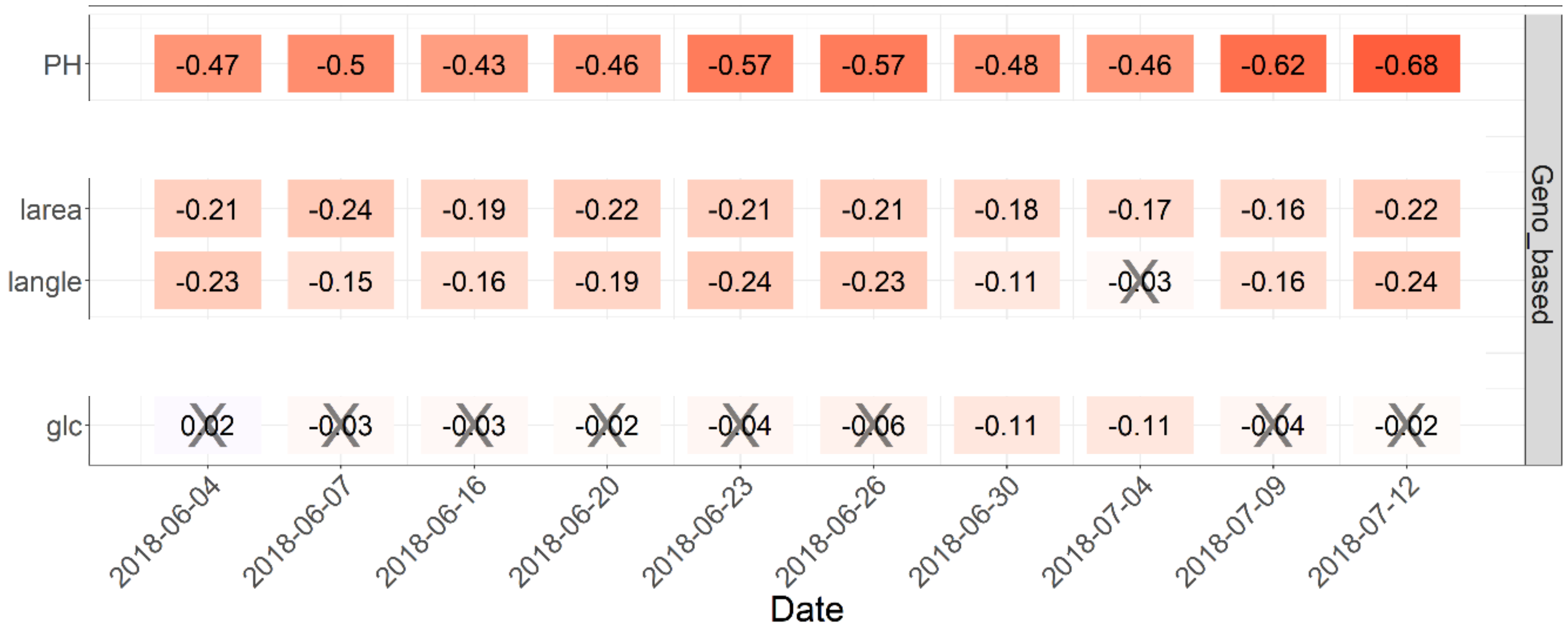


G. Perich, A. Hund, L. Roth, and H. Aasen, “UAV thermography to assess physiological plant parameters in high-throughput field phenotyping,” *Frontiers in Plant Science*, “in preparation.”



G. Perich, A. Hund, L. Roth, and H. Aasen, "UAV thermography to assess physiological plant parameters in high-throughput field phenotyping," *Frontiers in Plant Science*, "in preparation."

Correlations between the SpATS corrected plant traits and the canopy cover temperature for the solar noon measurements



G. Perich, A. Hund, L. Roth, and H. Aasen, "UAV thermography to assess physiological plant parameters in high-throughput field phenotyping," *Frontiers in Plant Science*, "in preparation."

Example: Extracting leaf area index using viewing geometry effects

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


Sony alpha 7 III
(24 mpix)

ETHzürich

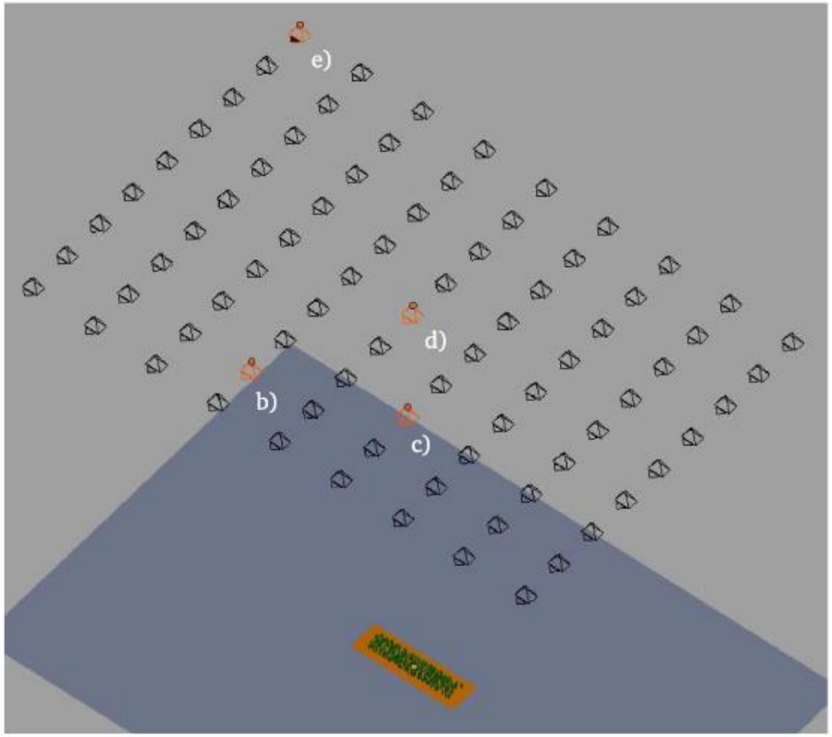
Phenofly.net

FIP field –plant research station Eschikon

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

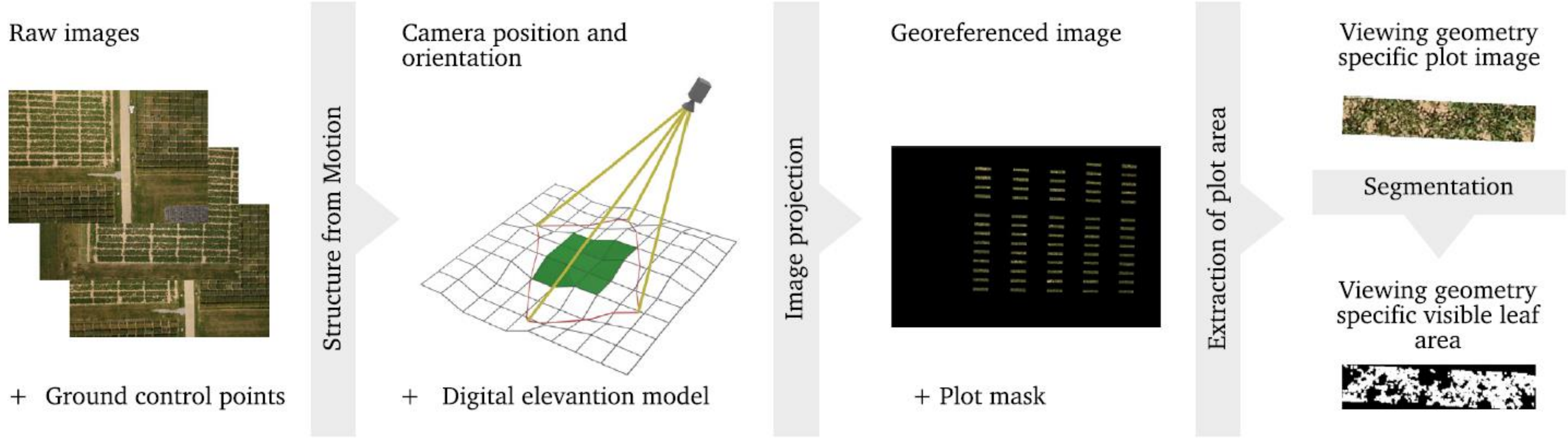
Extracting leaf area index using viewing geometry effects

a)



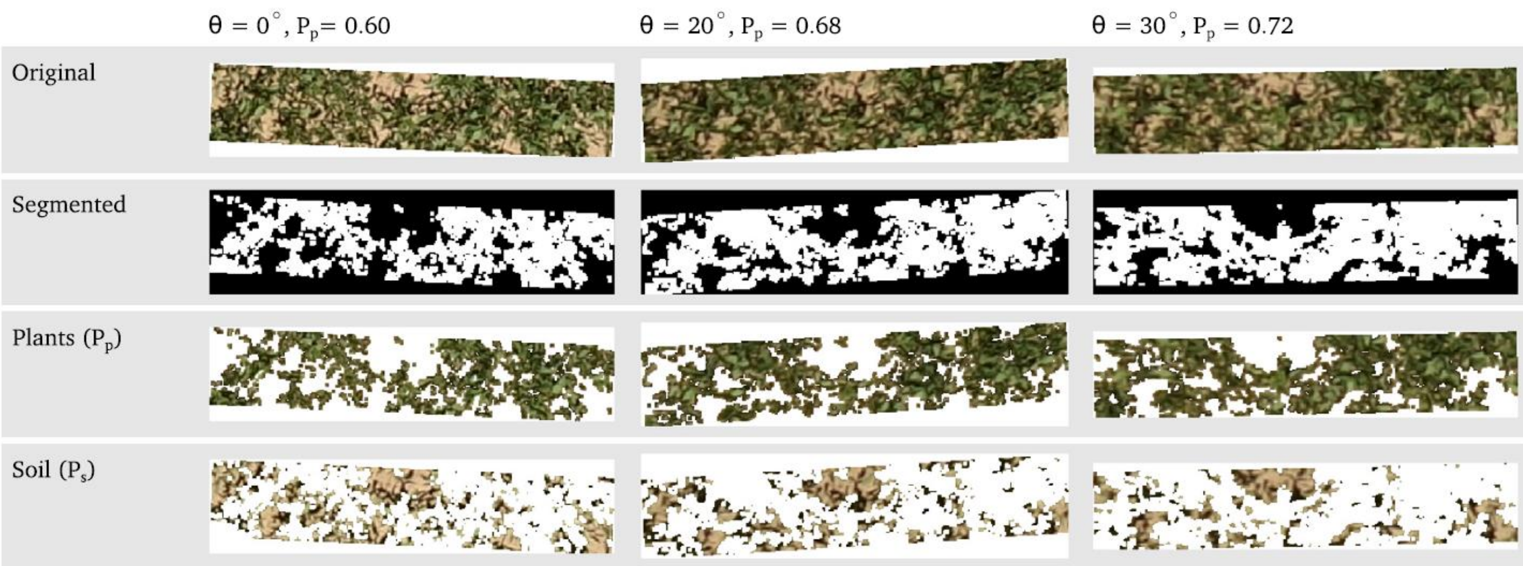
L. Roth, H. Aasen, A. Walter, and F. Liebisch, "Extracting leaf area index using viewing geometry effects—A new perspective on high-resolution unmanned aerial system photography," *ISPRS Journal of Photogrammetry and Remote Sensing*, 2018.

Extracting leaf area index using viewing geometry effects

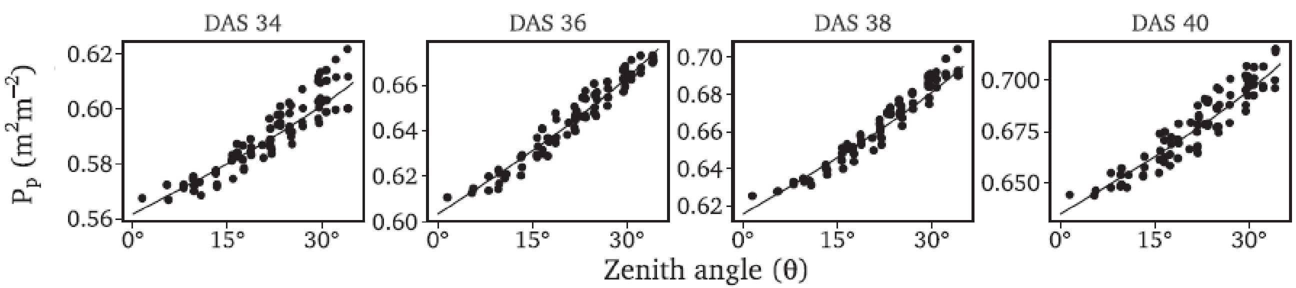


L. Roth, H. Aasen, A. Walter, and F. Liebisch, "Extracting leaf area index using viewing geometry effects—A new perspective on high-resolution unmanned aerial system photography," *ISPRS Journal of Photogrammetry and Remote Sensing*, 2018.

Extracting leaf area index using viewing geometry effects



GSD 0.007 m



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.

Conclusion

- High-resolution (drone based) remote sensing approaches offer great potential for field-phenotyping

- Mission planning is absolutely crucial
  - Know what you want to measure and plan accordingly
  - Think of efficiency and reliability: set up your site accordingly

- Know what you do and let others know

@PhenoFly Helge.Aasen@usys.ethz.ch

Conclusion

- High-resolution (drone based) remote sensing approaches offer great potential for field-phenotyping

- Mission planning is absolutely crucial
  - Know what you want to measure and plan accordingly
  - Think of efficiency and reliability: set up your site accordingly

- Know what you do and let others know
  - Keep track of metadata
  - Report important information in publications

- For the future:
  - I believe that high-resolution remote sensing will revolutionize field-phenotyping
  - Common protocols are needed (comparability / effectiveness)

@PhenoFly Helge.Aasen@usys.ethz.ch

ETH zürich

Phenofly.net

Thank you for your attention

EUROPEAN UNION

RI AT CZ

Interreg Austria-Czech Republic
European Regional Development Fund

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Landwirtschaft BLW

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

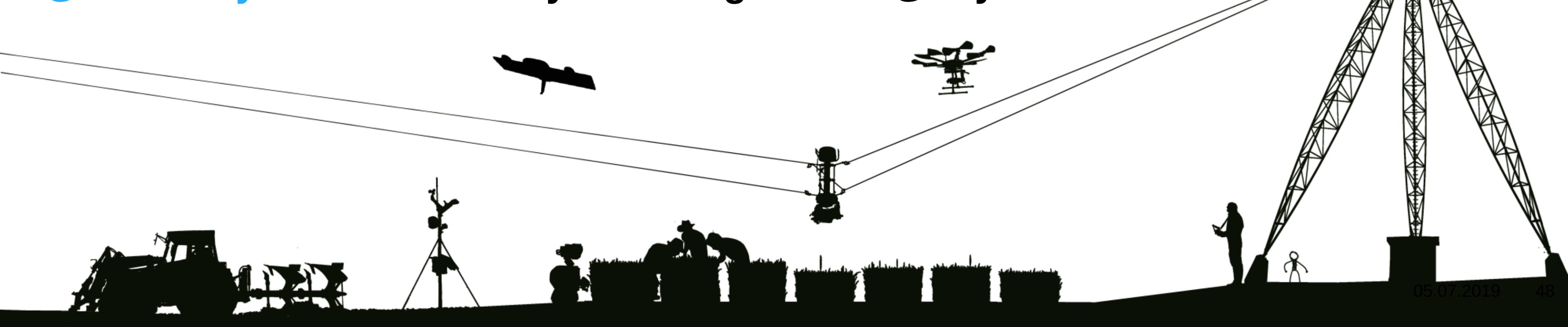
Innosuisse - Schweizerische Agentur für Innovationsförderung

ETH zürich

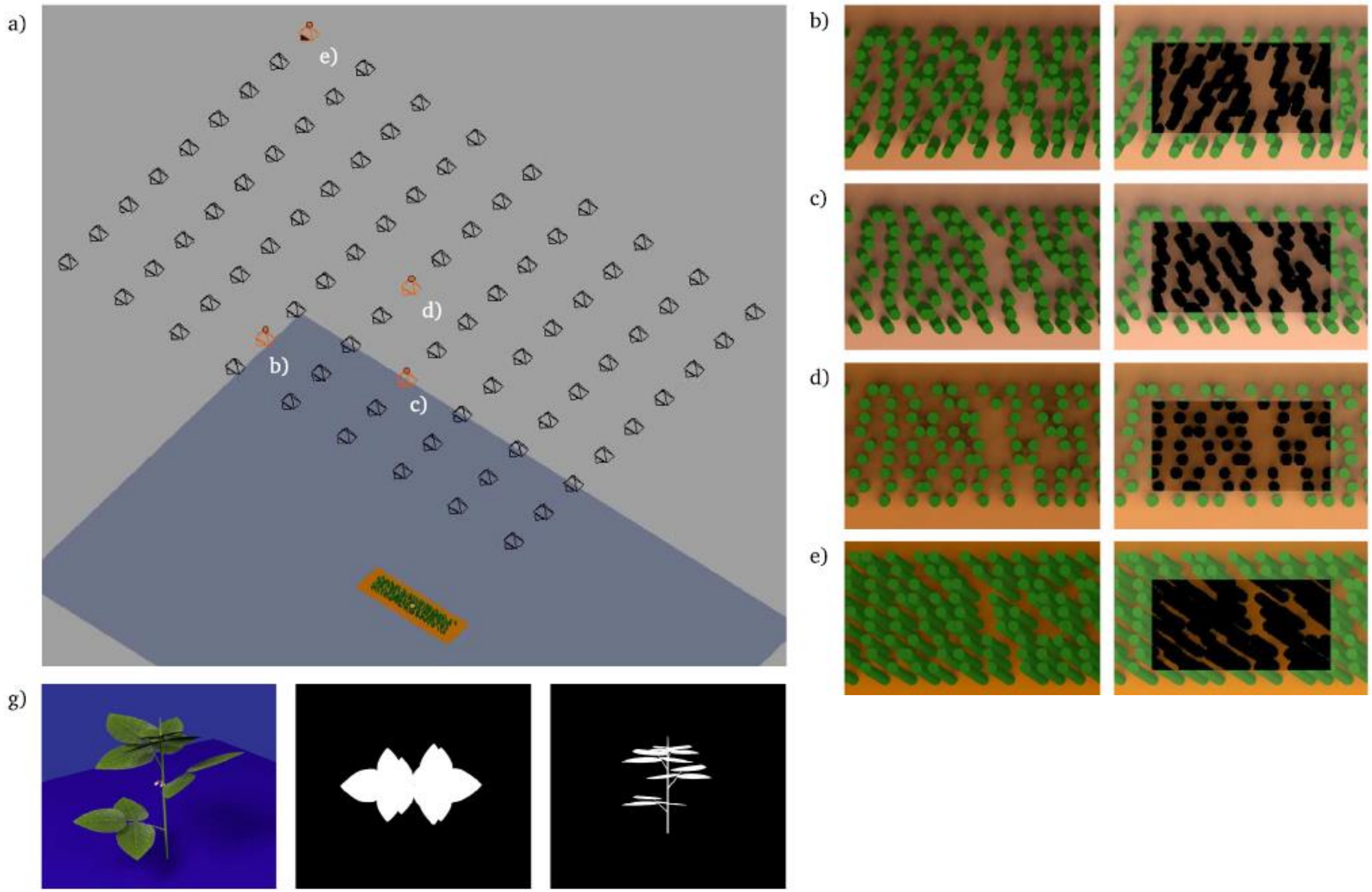
FNSNF
Swiss National Science Foundation

CROP SCIENCE I **www.kp.ethz.ch**

@PhenoFly I **www.PhenoFly.net** I **helge.aasen@usys.ethz.ch**



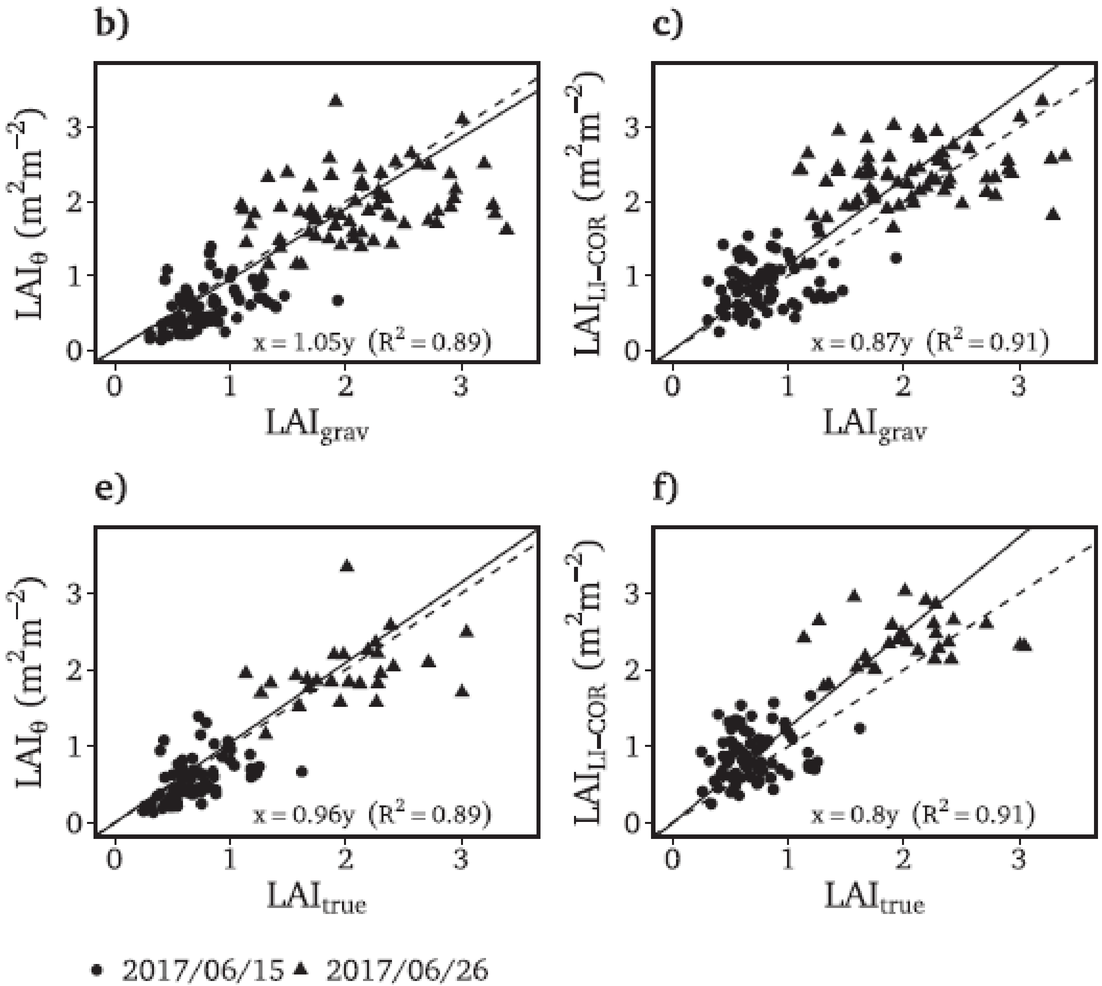
Extracting leaf area index using viewing geometry effects



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.

@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.