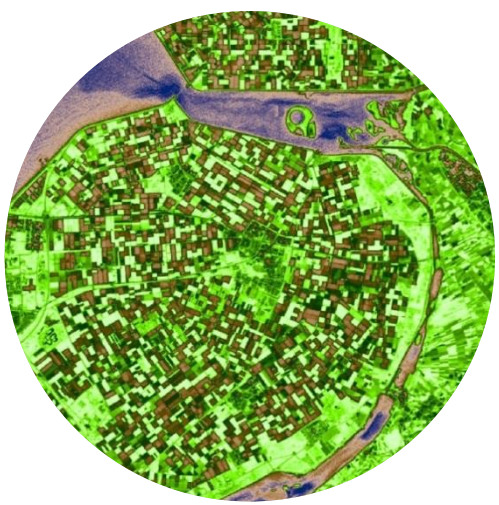
Improved characterisation of plant functioning using high-resolution imagery from UAVs

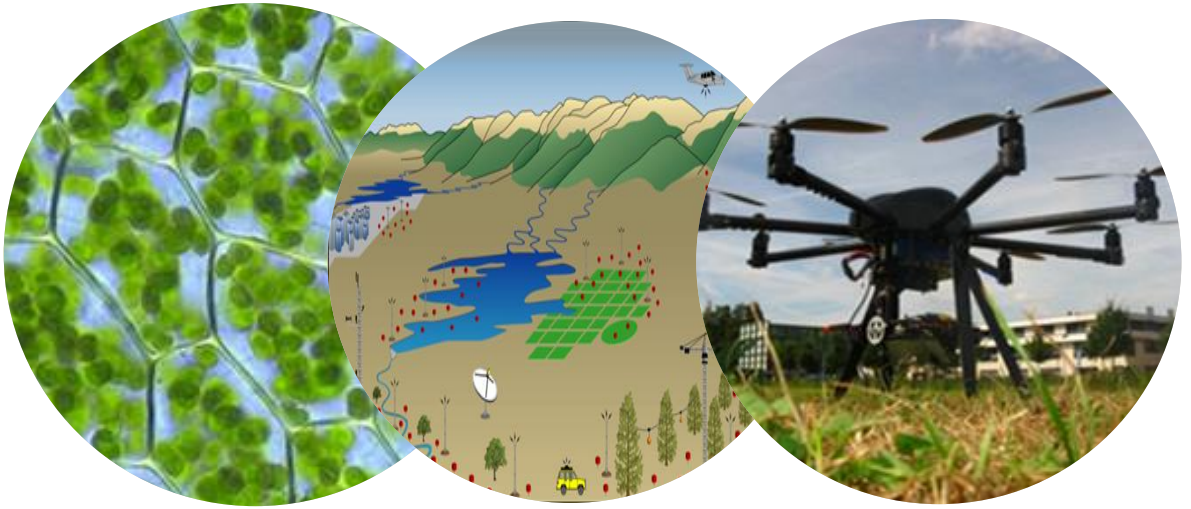
Lammert Kooistra[1], Harm Bartholomeus[1], Juha Suomalainen[1],
Saskia Keesstra[2], Sander Mucher[3] and many more

1: Laboratory of Geo-Information Science and Remote Sensing, and

2: Soil Physics and Land Management Group, Wageningen University

3: Alterra





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Plants around Wageningen

Comic
Bob & Bobette
Object communication headset
Published 1961

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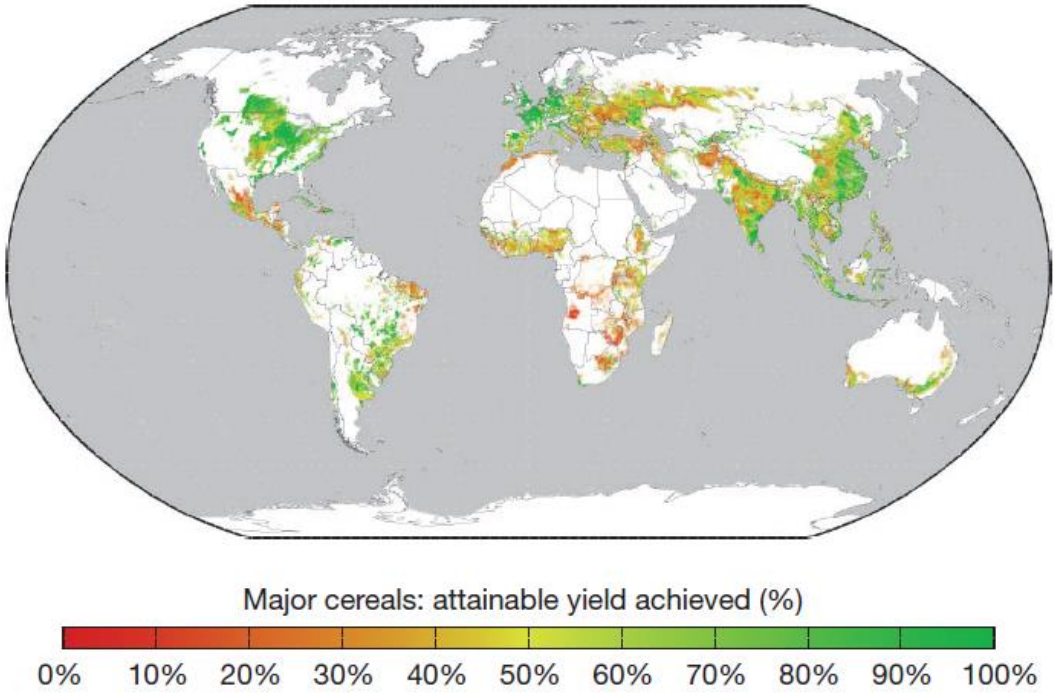
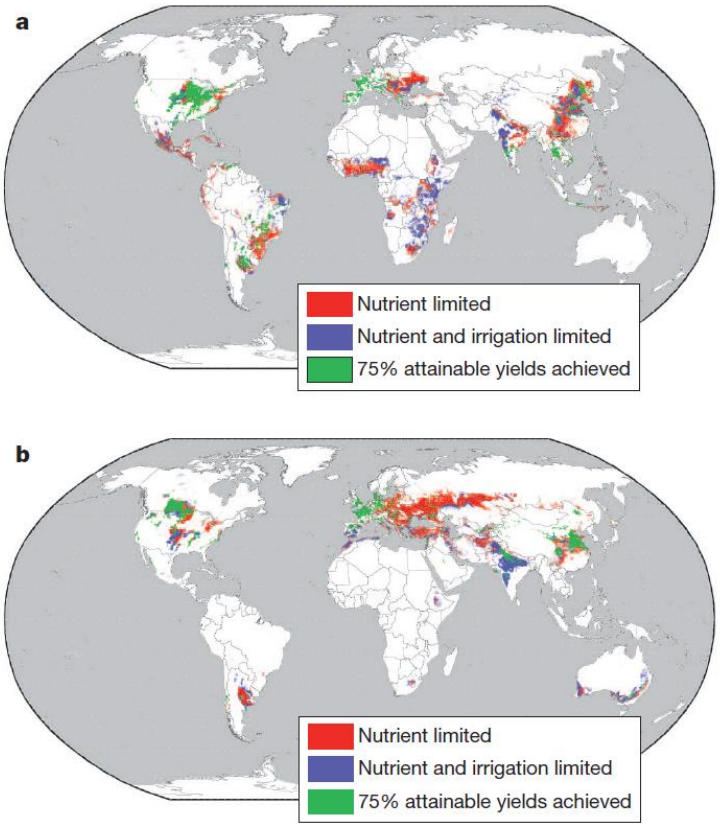
Food security and yield gaps



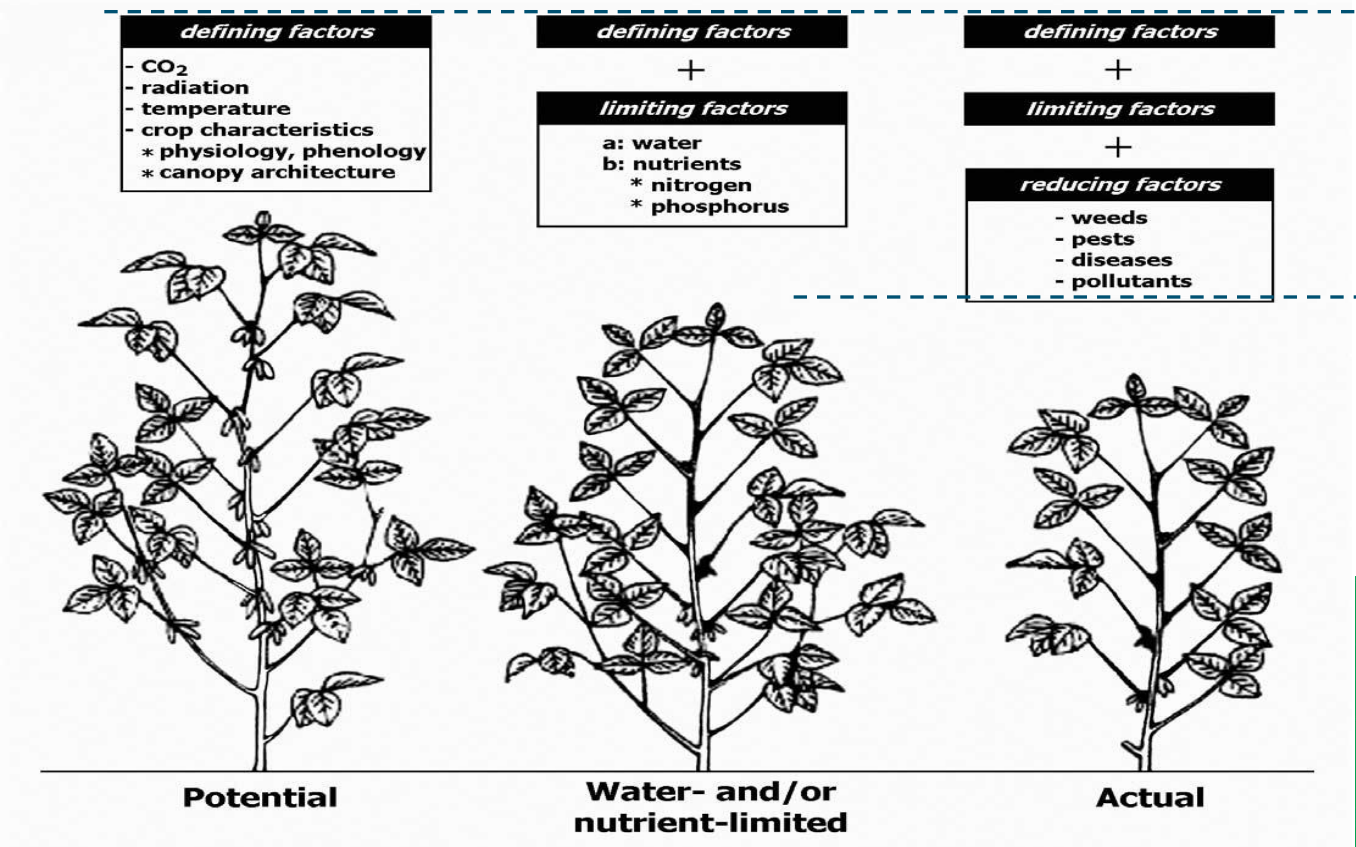
Yield Gap = Potential Yield – Actual Yield



a) Maize and b) Wheat

Mueller et al, Nature 2012

Crop growth modelling



Plant breeding
Phenotyping

Ecological functions and plant traits

Function	Easily measurable trait
Fecundity Dispersal Recruitment	Seed mass others?
Light interception Competitive ability	Vegetative height others?
Nutrient resorption Litter decomposability	Traits of living leaves NIRS spectrum; others?
Absorption (nutrients, water) Carbon flux (exsudation …)	Density, diameter Specific length

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Flevoland, 15-08-2011

Overview

- Why UAVs in Plant Science?
- Towards a UAV Research Facility
- UAVs in Plant Science: case studies
    - Forest ecology
    - Phenotyping
    - Precision agriculture
- Future developments

Why UAVs in plant science?

Satellites

Airplanes

''Bridging the gap''

Upscaling & downscaling

In-situ

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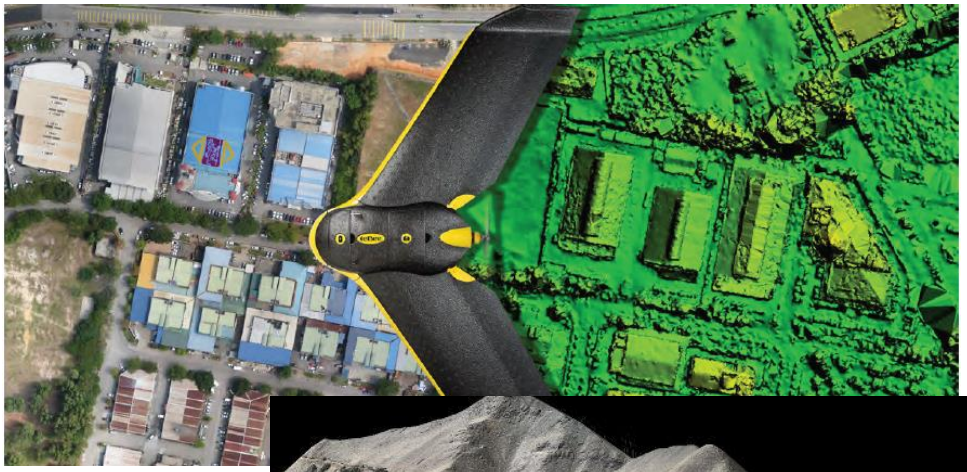
UAVs as flexible platforms

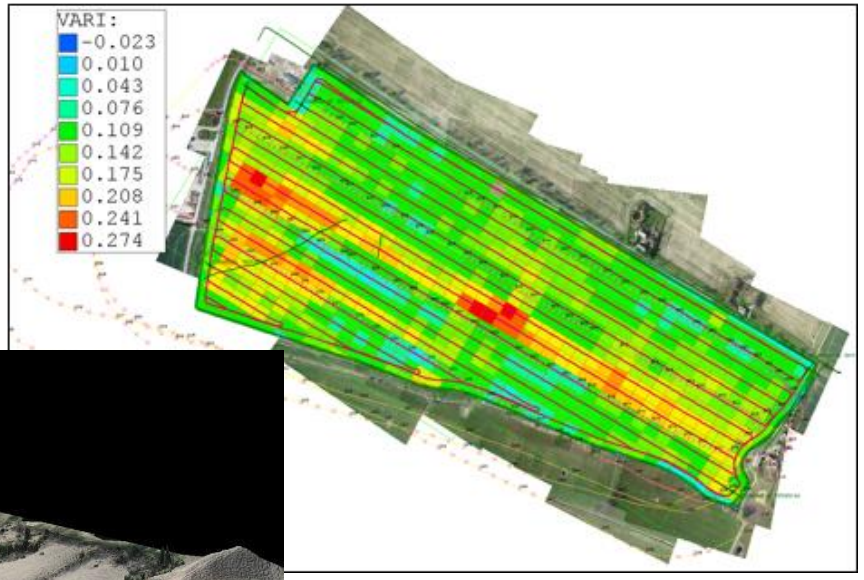
Your own flexible platform

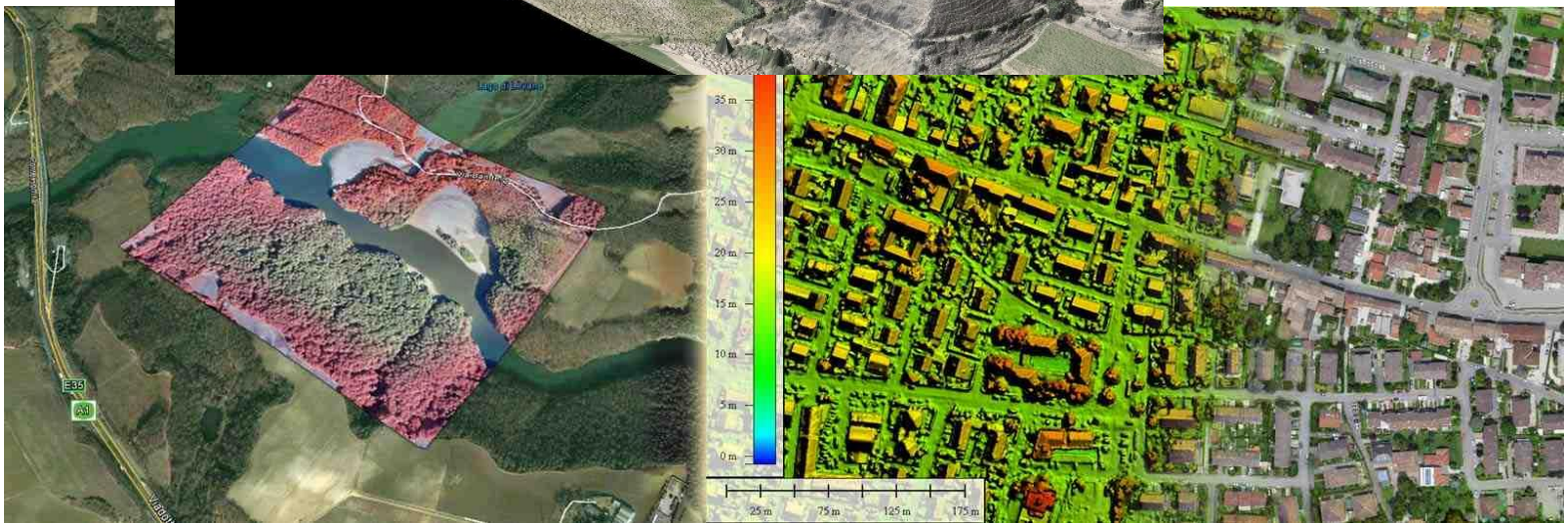
- Autonomy
- Timing: fill data gaps ~ flying below the clouds
- Sensors: application specific + increasing nr. camera's
- Coverage: increased spatial detail

Example Plant Science fields:

- Plant phenotyping: high-throughput
- Precision agriculture: field -> zone -> plant
- Ecology and forestry: scaling from plot to landscape level







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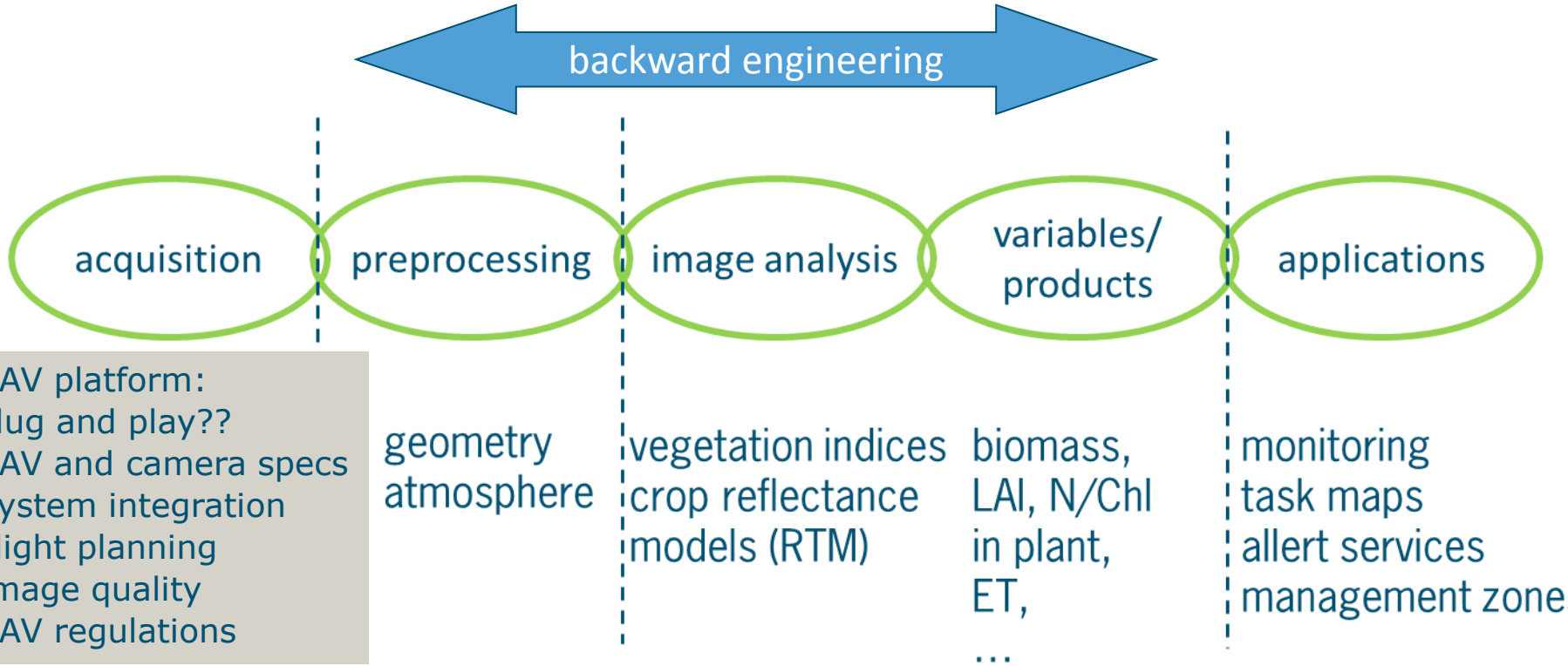
Remote Sensing Science: UAV in a chain



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Towards an operational UAV Research Facility

Objectives Research Facility:

- Platform for dedicated and high-quality experiments
- Calibration facilities and disseminating processing procedures to the UAS user community
- Test use in range of applications like habitat monitoring, precision agriculture and land degradation assessment

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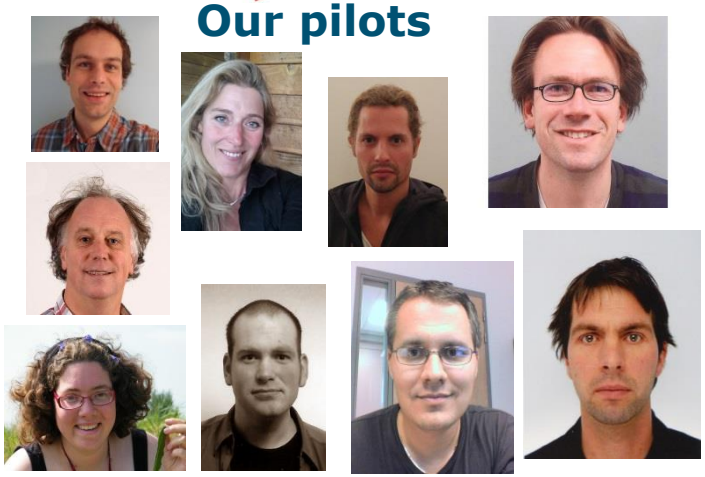
Our pilots



Our platforms

+ Operation Manual and Safety Management System

= Company exemption from the Dutch Aviation Authorities

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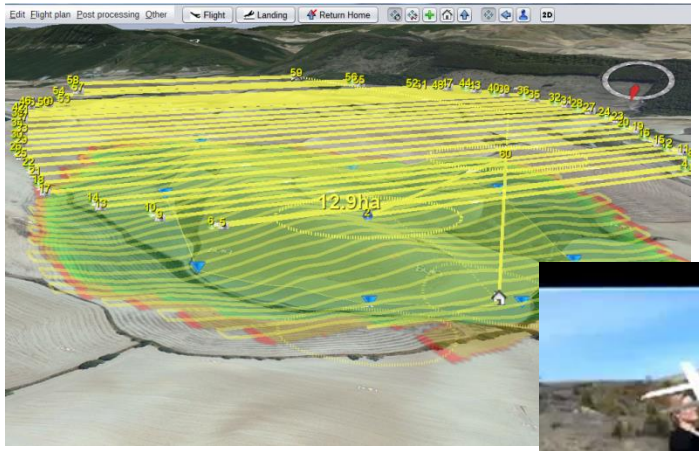
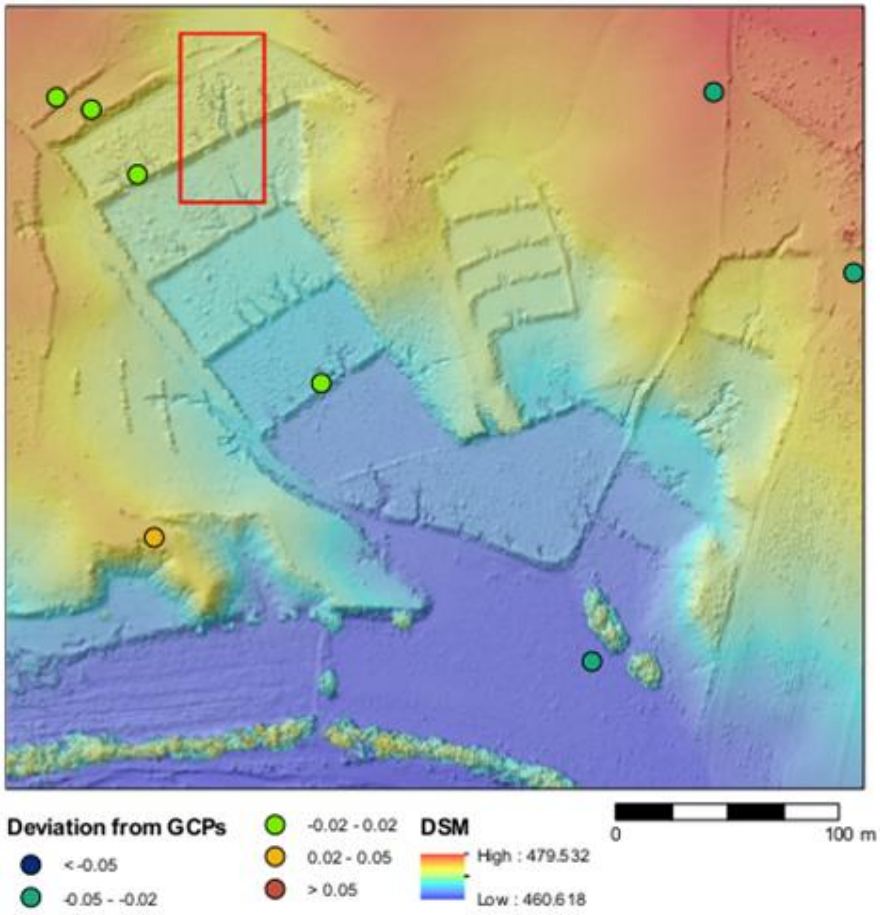
Flight planning: example erosion mapping

Niels Anders and Saskia Keesstra, WU-SLM





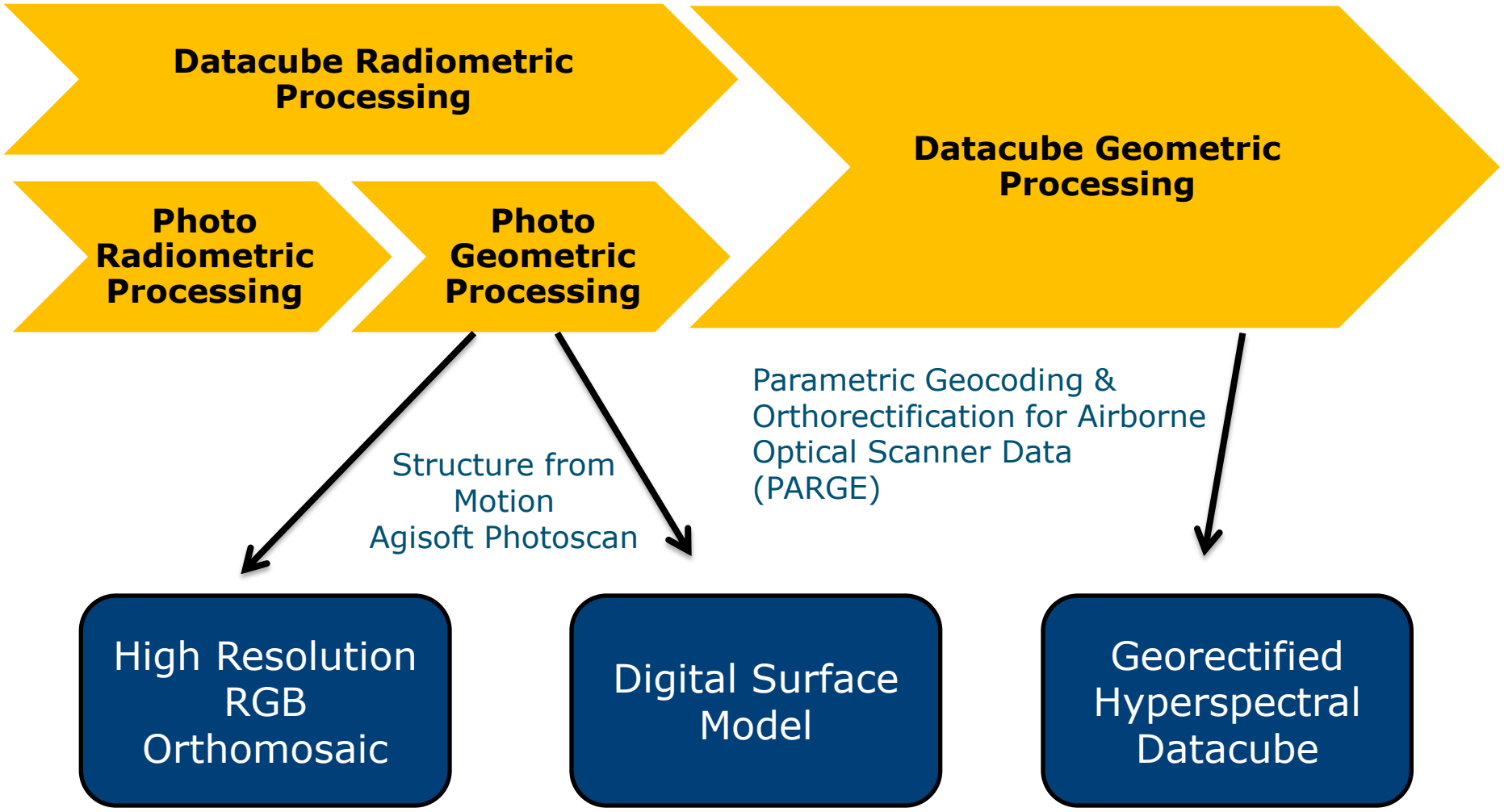
- Flight planning software
- On the basis of GPS
- Pilot monitors the flight, and does take-off and landing

Hyperspectral Mapping Concept

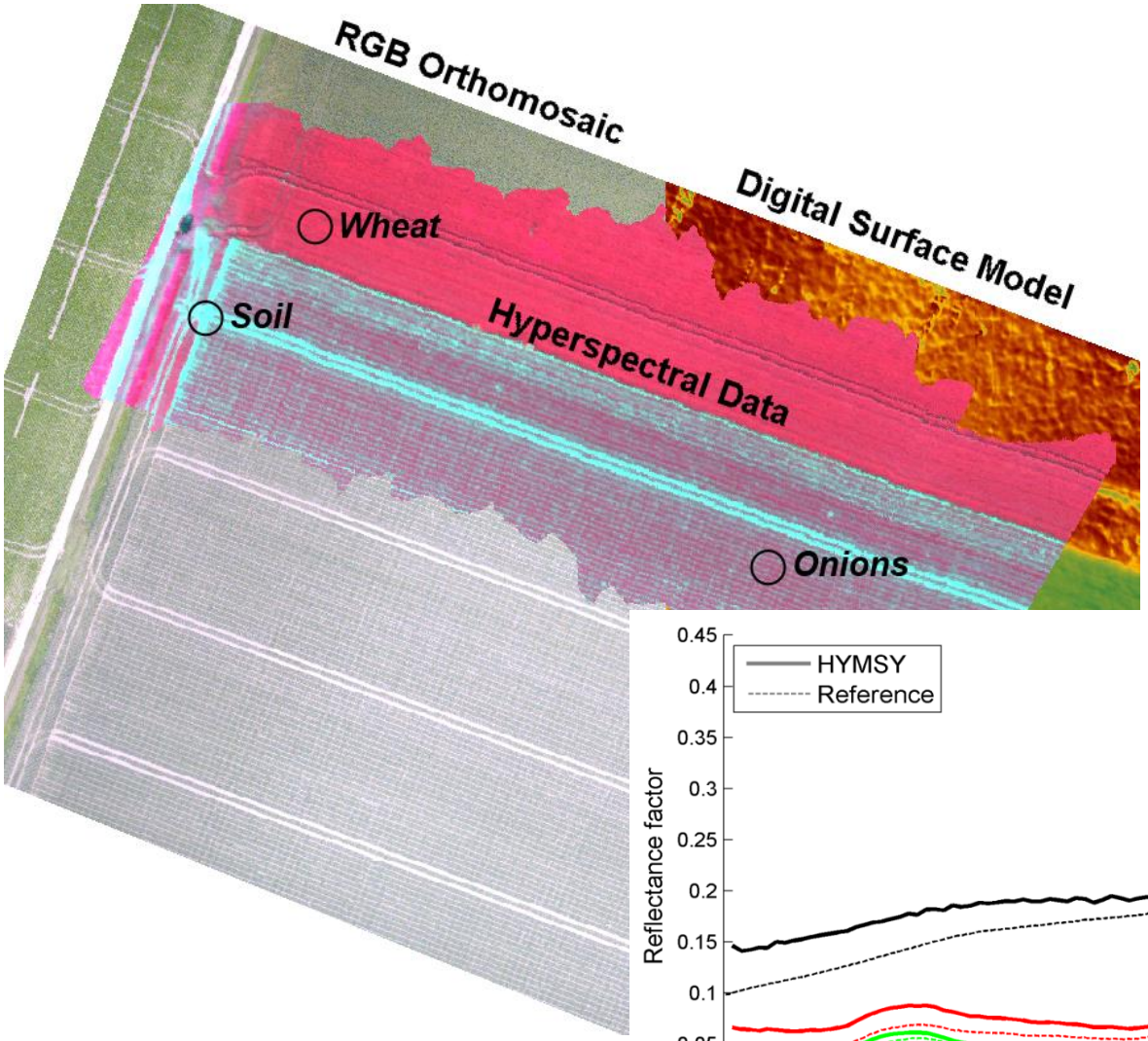
- Aerialtronics Altura AT8
  - Programmable autonomous flight
  - 2kg payload
  - 5-10 min flight time
- Pushbroom spectrometer
  - 450-950nm
  - FWHM 9nm
  - 20 lines/s
- Consumer RGB camera
- GPS/Inertia navigation System
  - Accuracy: 4m / 0.25°

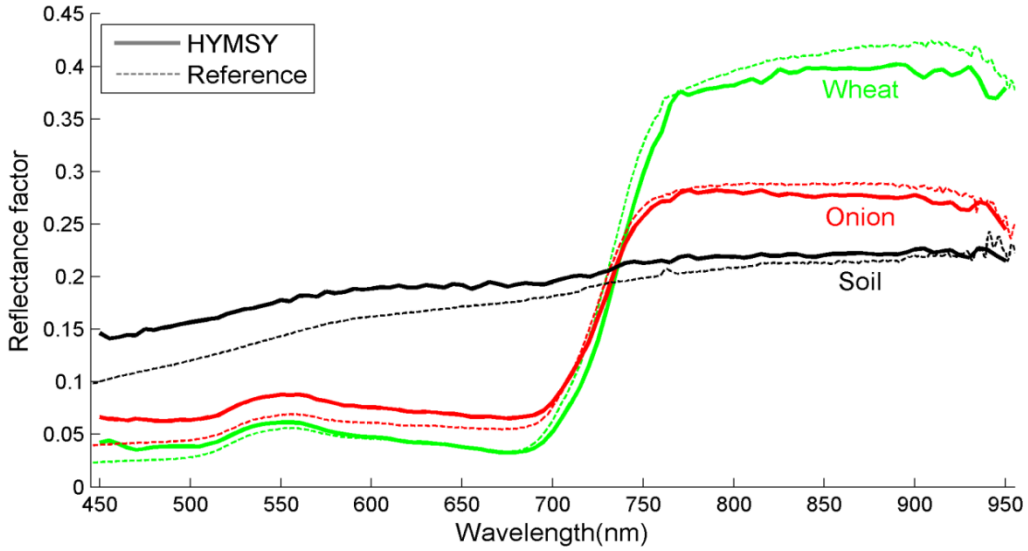
Source: Suomalainen et al., Remote Sensing, 2014

Overview of processing chain



Result Experimental Field Dronten

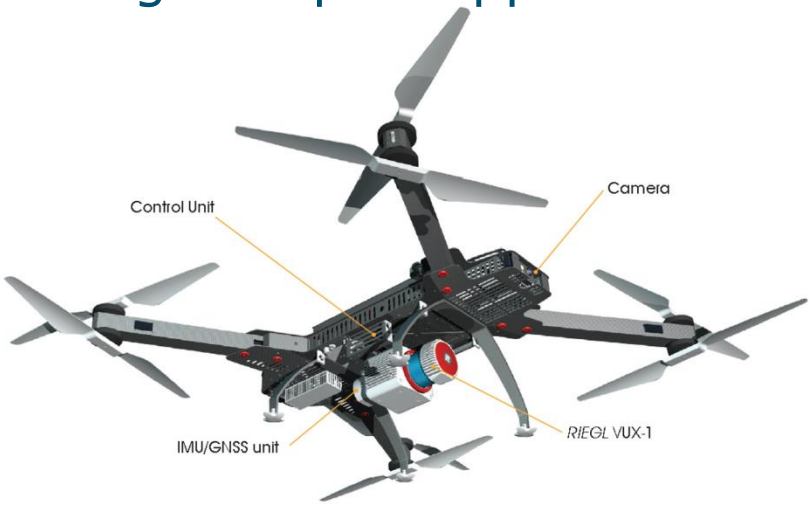




Sensors and camera's available

Camera's:

- HYMSY: hyperspectral line-scanner (100 bands)
- MUMSY: multi-spectral RGB-NIR: adapted Canon
- Rikola: frame camera: 16-80 bands 500-900 nm
- Sensilize Robin Eye: currently tested
- LiDAR: proposal for Riegl Ricopter approved



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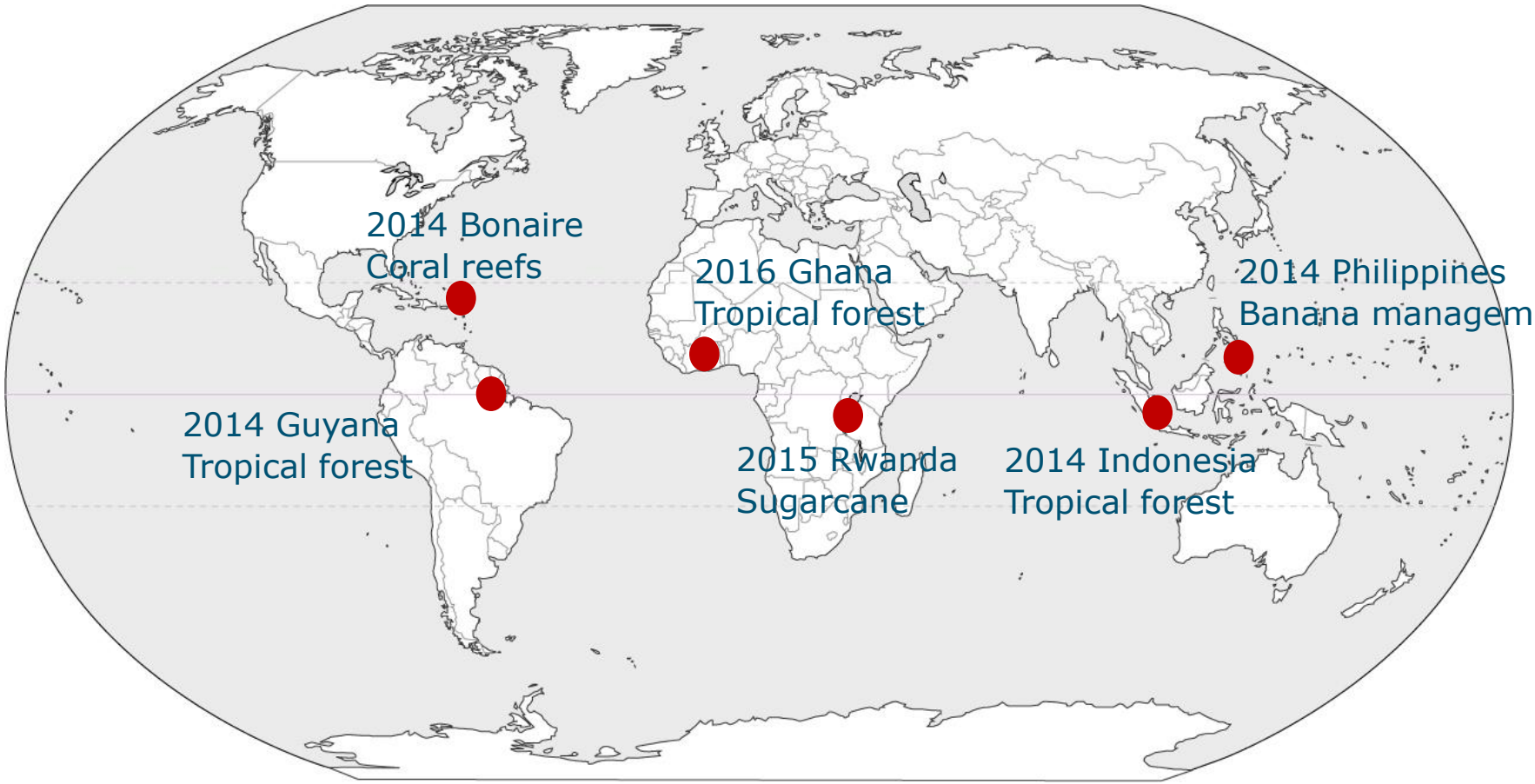
Current operations: globally



Mapping Tropical forests - Goal

- Mapping leaf biochemistry at high spatial detail (within tree level)
- Identify tree species
- Mapping of forest structure
- Determine damage e.g. due to logging

Orangutan nest

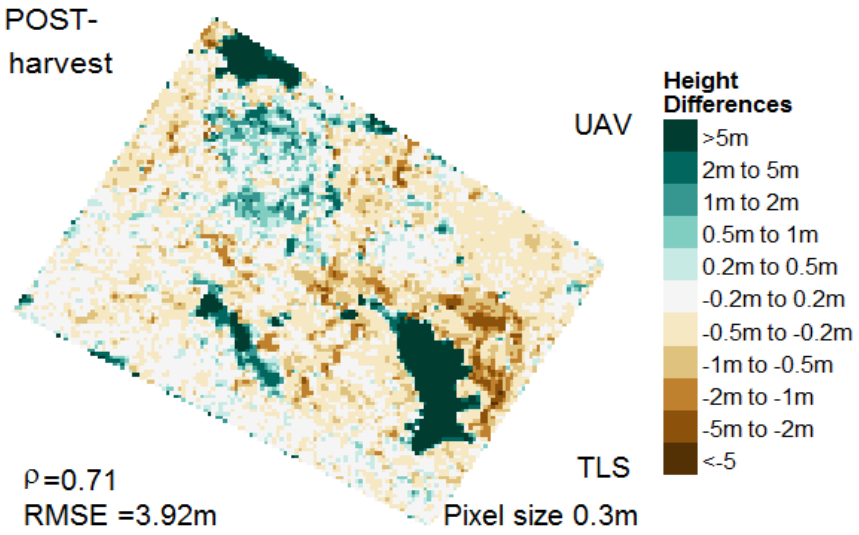
Tropical forest 3D model

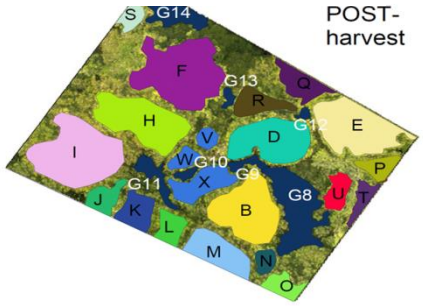
Forest canopy gap detection

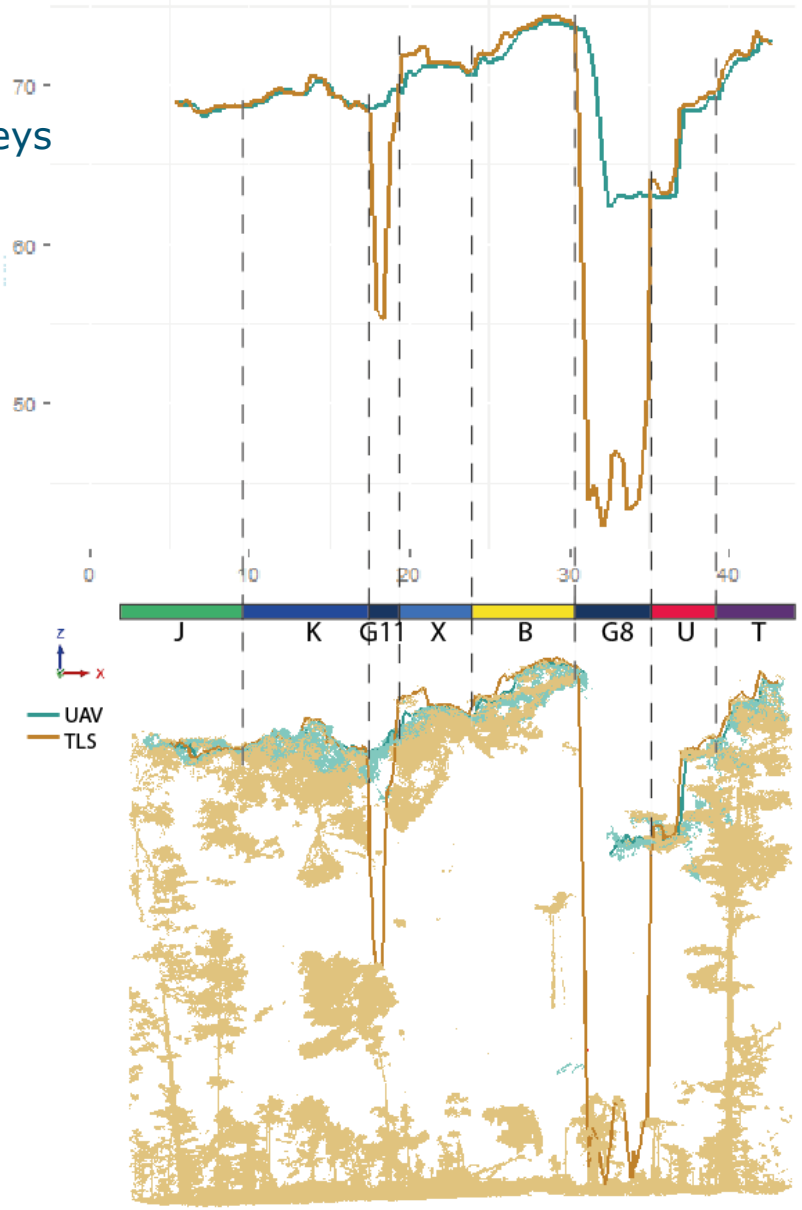
Sabine Rosca, Juha Suolamainen and Harm Bartholomeus, WU-GRS

Comparison with Terrestrial Lidar data:

- UAV data are more consistent over multiple surveys
- Gaps are poorly detected with photogrammetry







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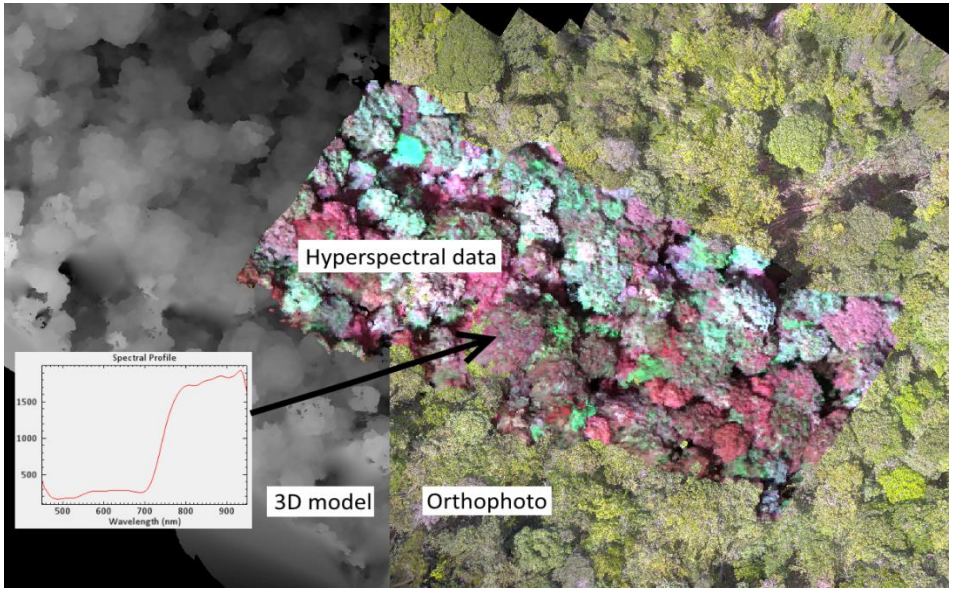
Mapping canopy traits of tropical forests

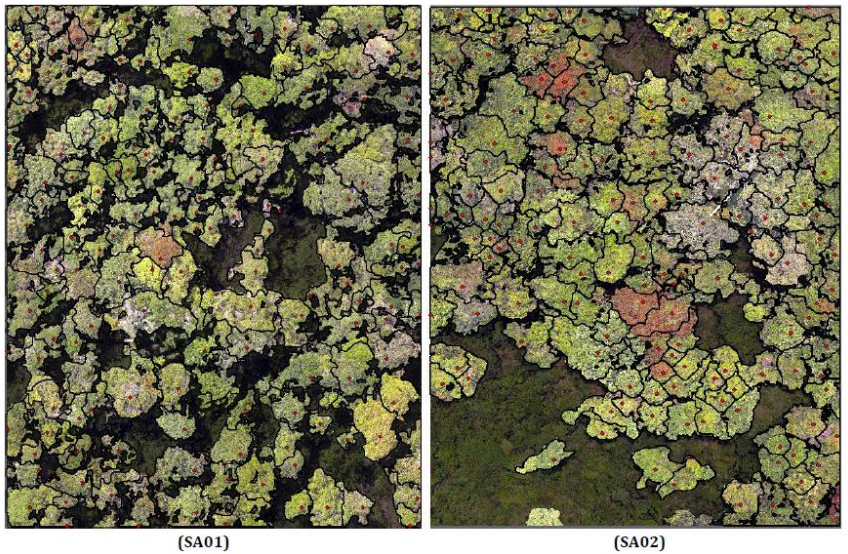


Relevant traits

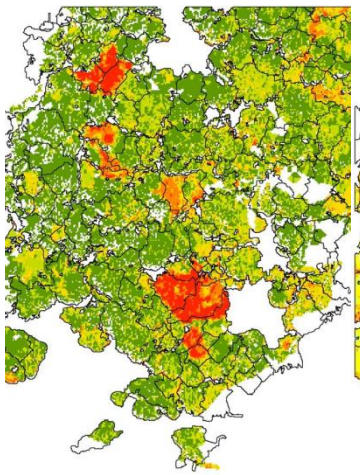
- Structure: tree crown location, dimension, height variation
- Biochemistry and pigments
- Spectral variation
- Species

2014 Guyana
Tropical forest

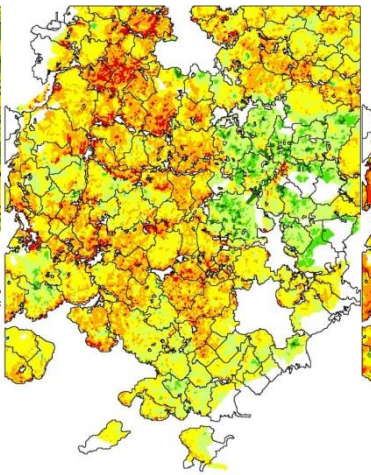
Tree crown delineation



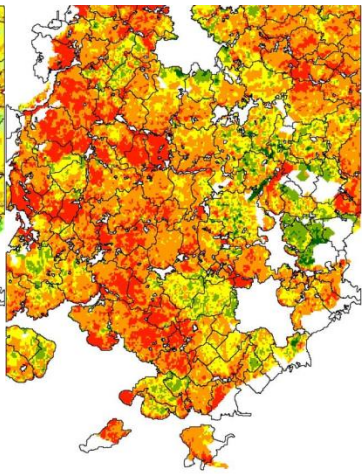
Anthocyanin



Carotenoid



Chlorophyll



Using the right tools…

Octocopter + Hyperspectral camera

DJI Phantom + RGB

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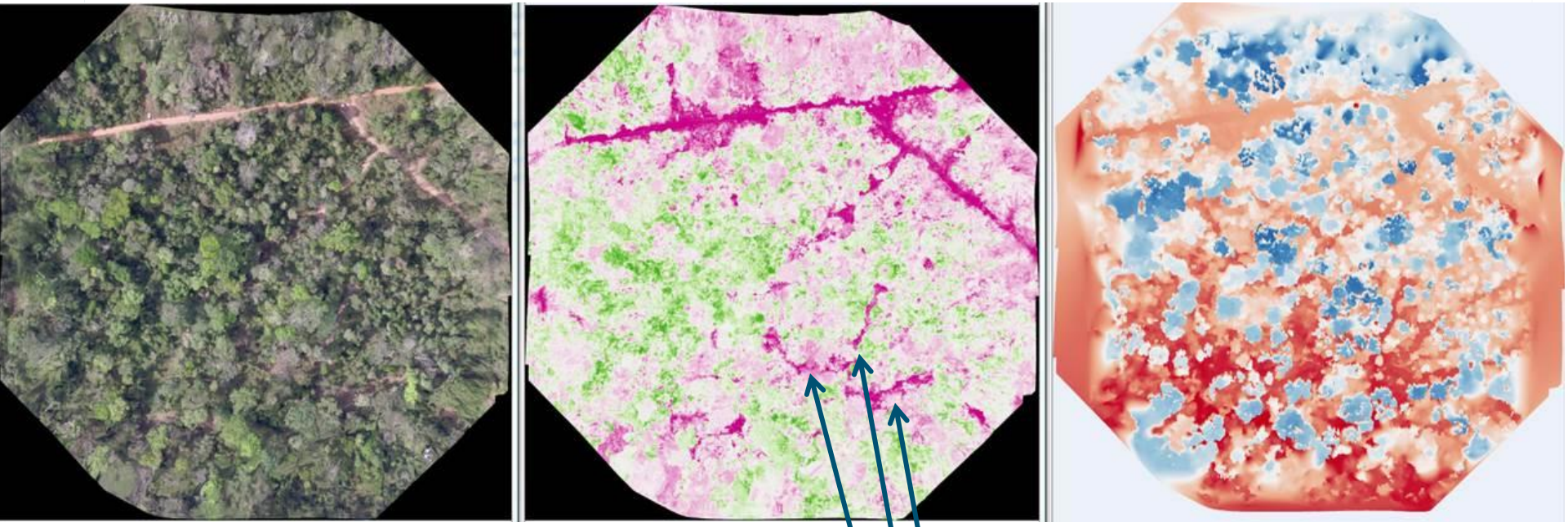
Which tools to use?

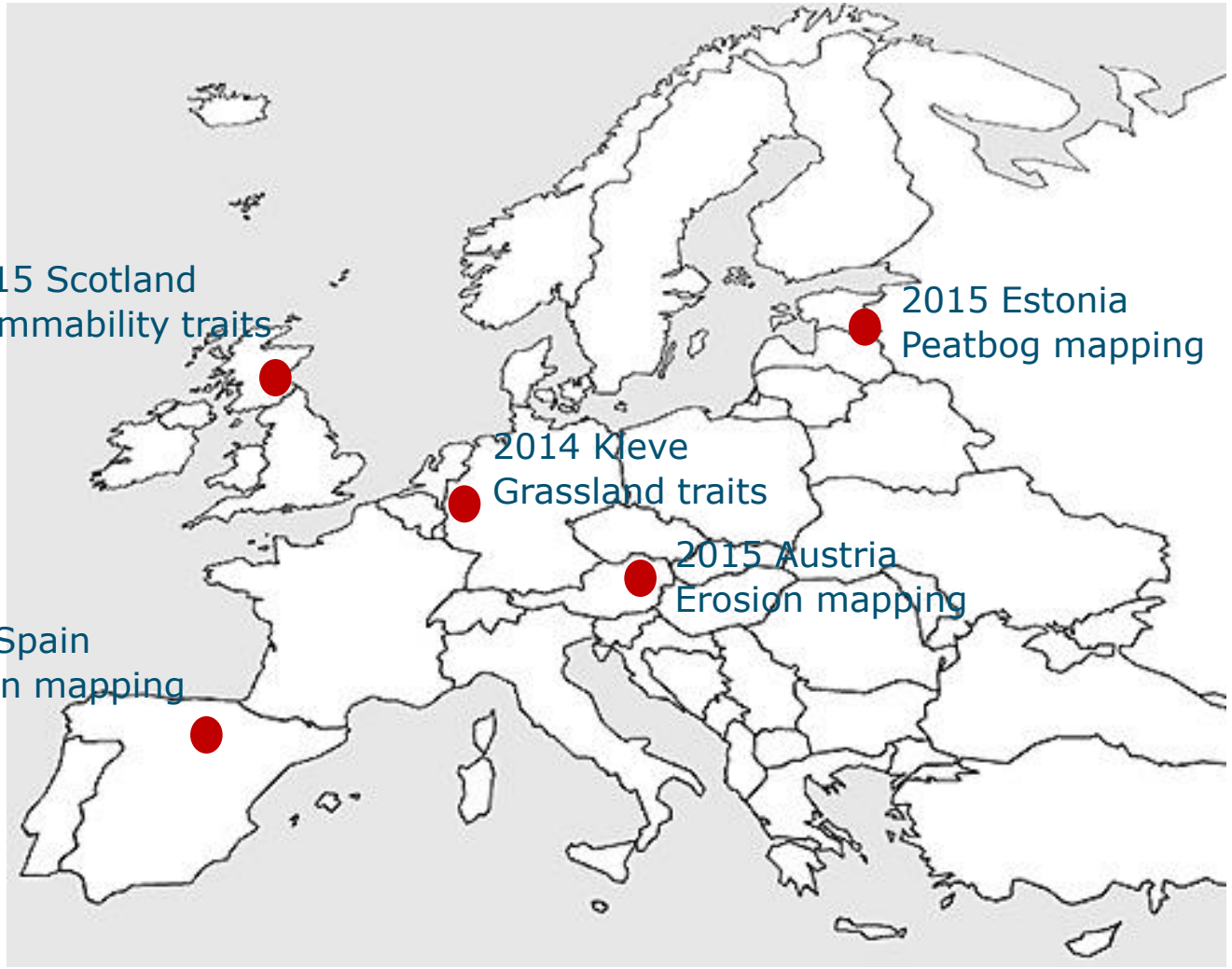


RGB Orthophoto NDRG Digital Surface Model

Logging Activities

- Detection of illegal logging
- Determine collatoral damage in regular logging

Current operations: Europe



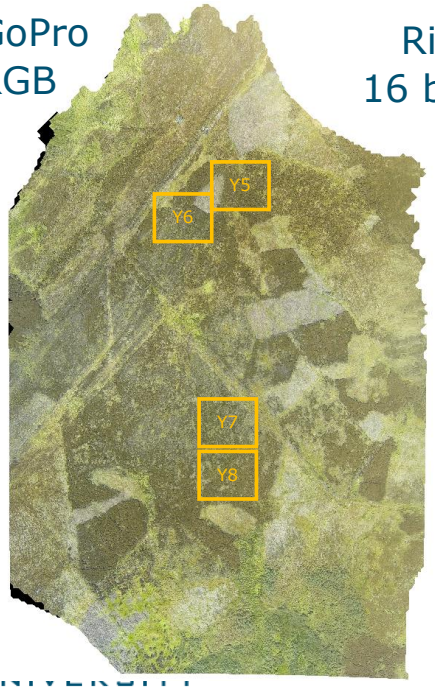
Mapping flammability traits Scotland

Systems Ecology VU A'dam: Blauw, Aerts, Cornelissen

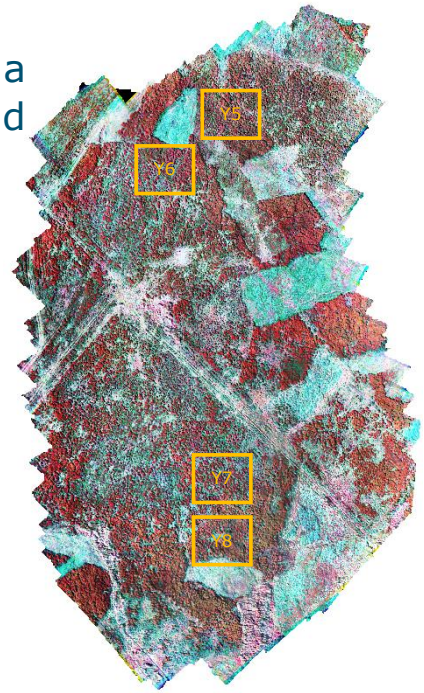
Relevant traits

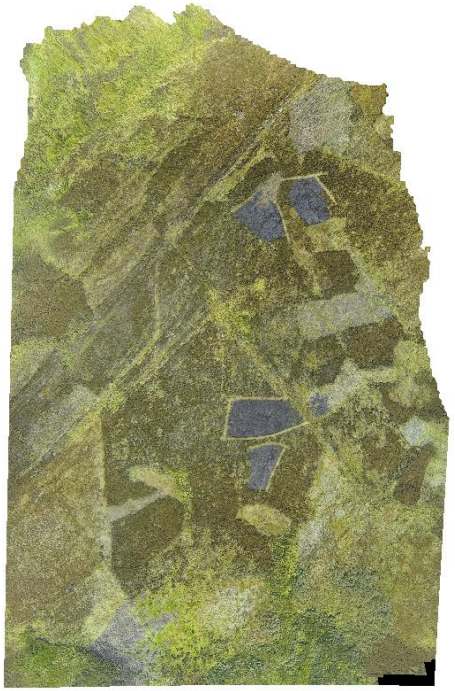
- PV, NPV
- LAI, biomass
- Coverage, moss %
- Moisture content

GoPro RGB

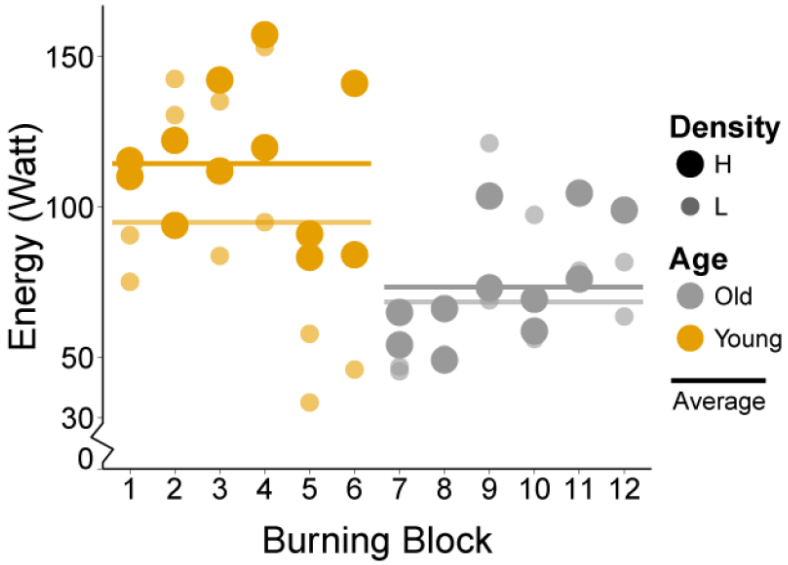


Rikola 16 band



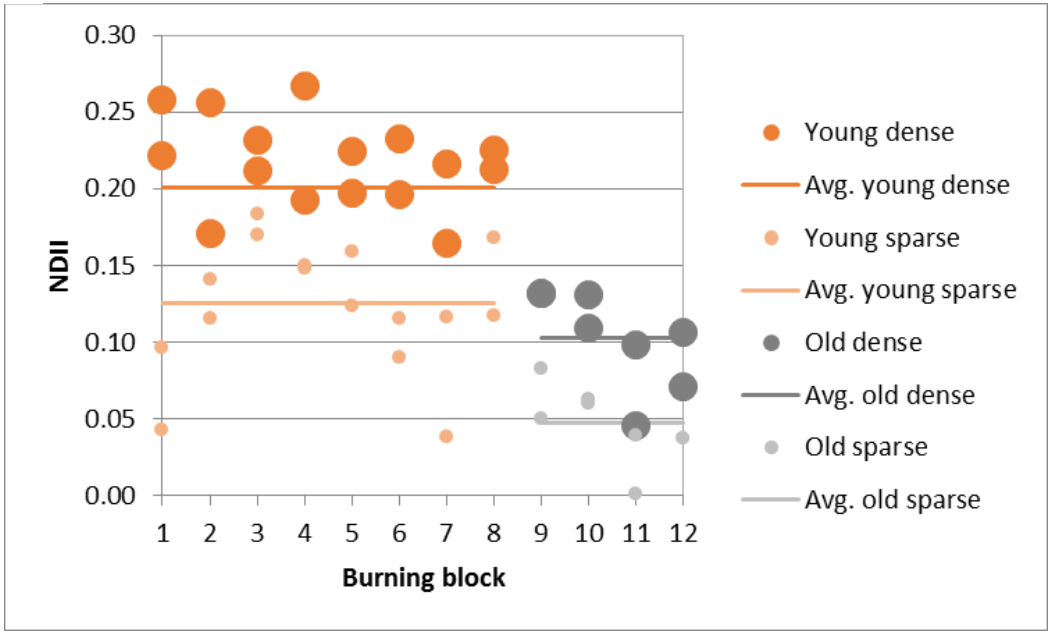


Heathland plant traits



Heat release per experimental block

Vegetation water content
as derived from spectral index
Normalized Difference Infrared Index



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Current operations NL

Applications:

- Coastal monitoring
- Habitat mapping
- Musselbank mapping
- Forest biomass and phenology
- Hail damage assessment
- Precision agriculture
- Agro experimental plots

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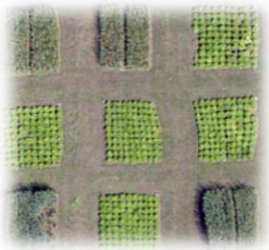
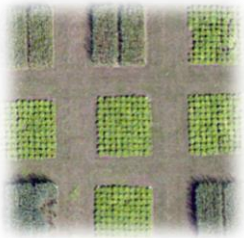
UAVs and plant trait mapping

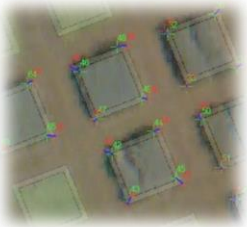
Bob van der Meij, Gerlinde de Deyn, Lammert Kooistra and others

Soil biology: 2015 endive and oat plots

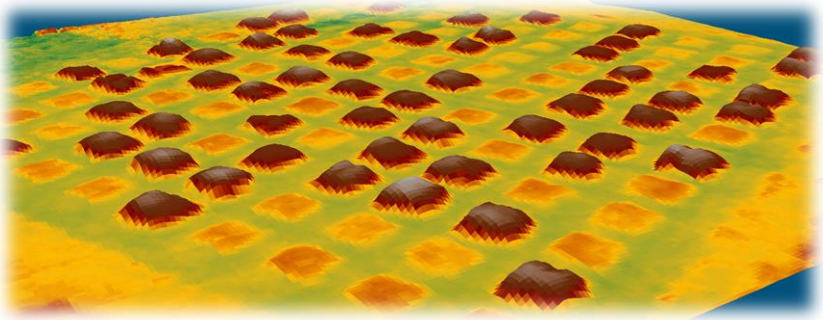
Digital Crop Model = DSM - DTM





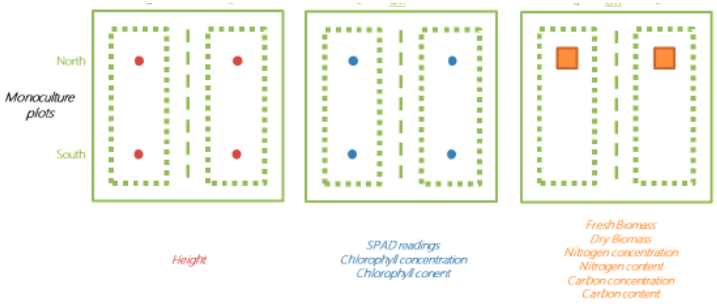


GCPs critical for geometrical correction



Field vs. UAV based field traits

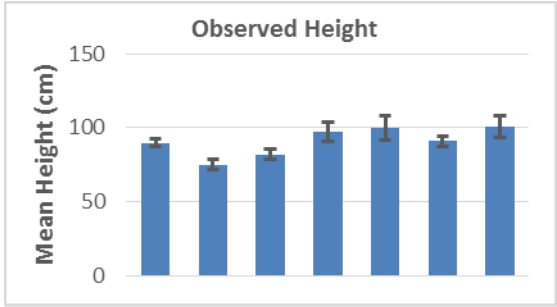
- June 2015
- 60 Oat plots
- Statistical VI models and PLS regression
- Field measurements

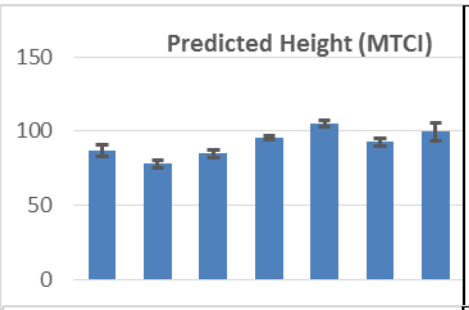


Van der Meij, De Deyn et al., Biogeosciences (in prep)

Field measured traits

UAV-HYMSY derived traits

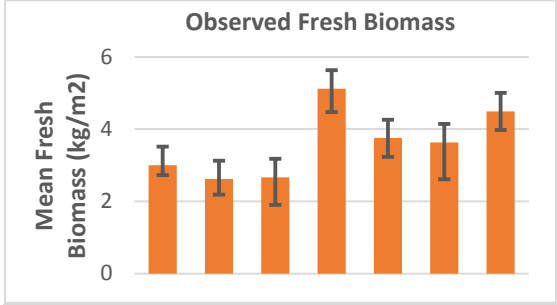


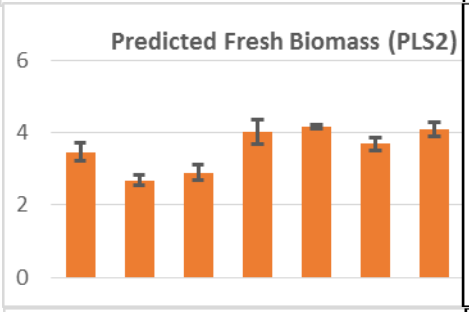


CVRMSE 3.03%

R^2 0.92

Sign. lvl. p<0.001

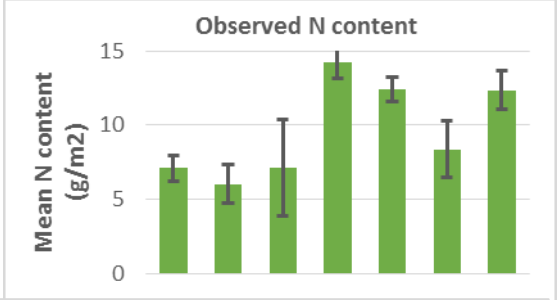


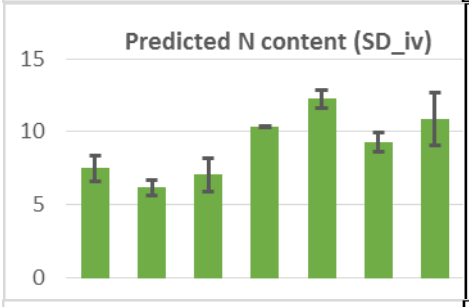


CVRMSE 14.01%

R^2 0.79

Sign. lvl. p<0.02

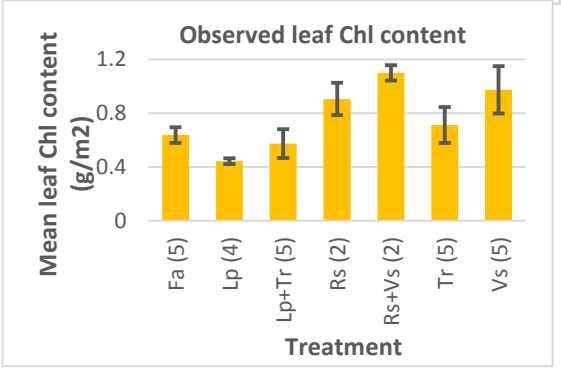


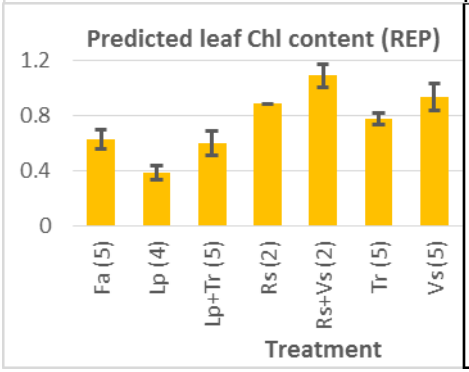


CVRMSE 16.61%

R^2 0.79

Sign. lvl. p<0.01





CVRMSE 4.93%

R^2 0.97

Sign. lvl. p<0.0001

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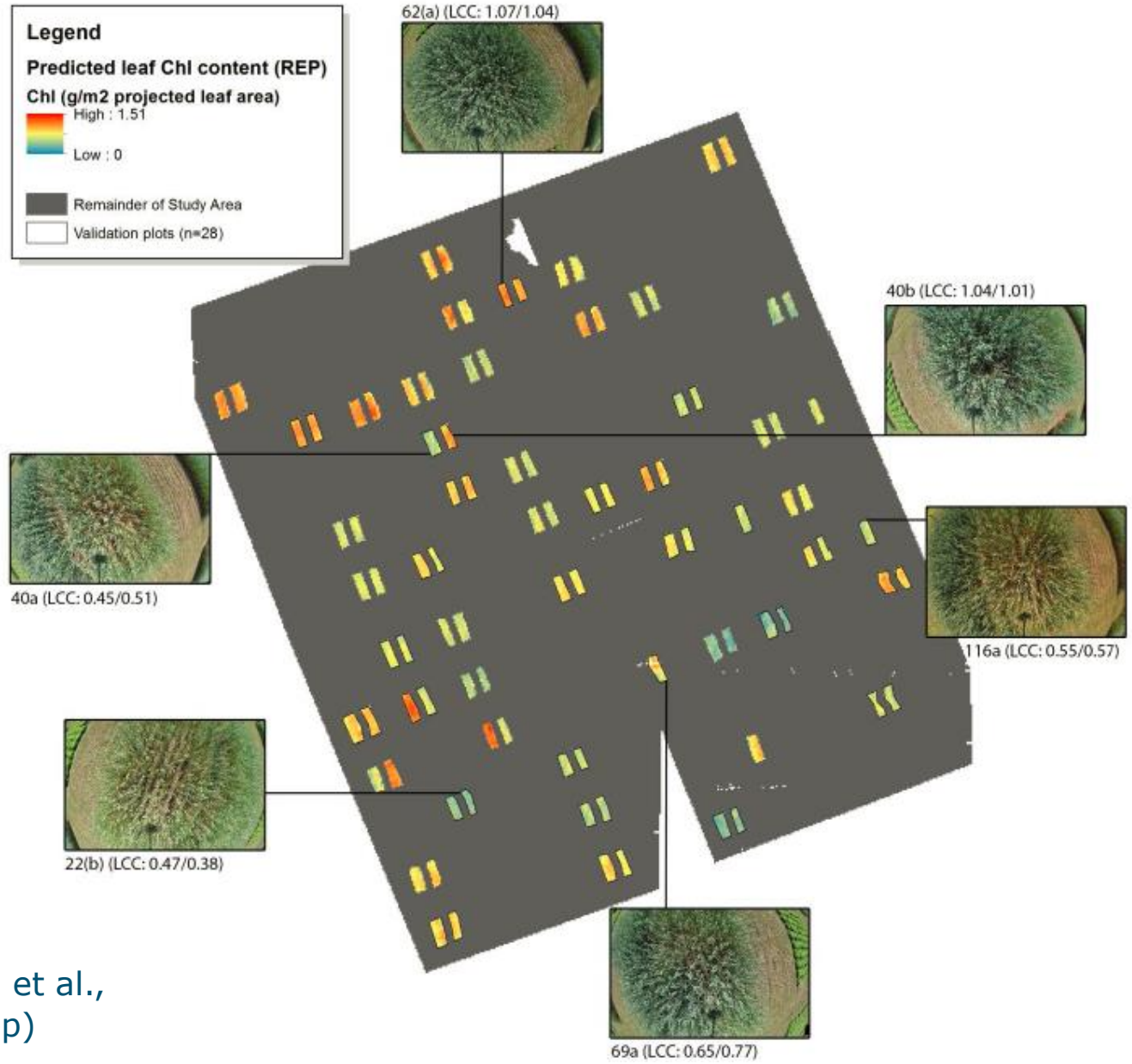
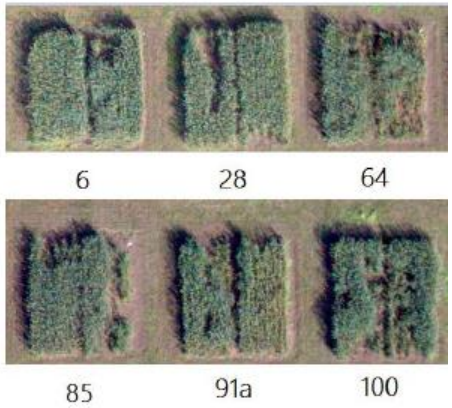
Prediction maps



Disturbed plots: non-representative sampling



Van der Meij, De Deyn et al., Biogeosciences (in prep)

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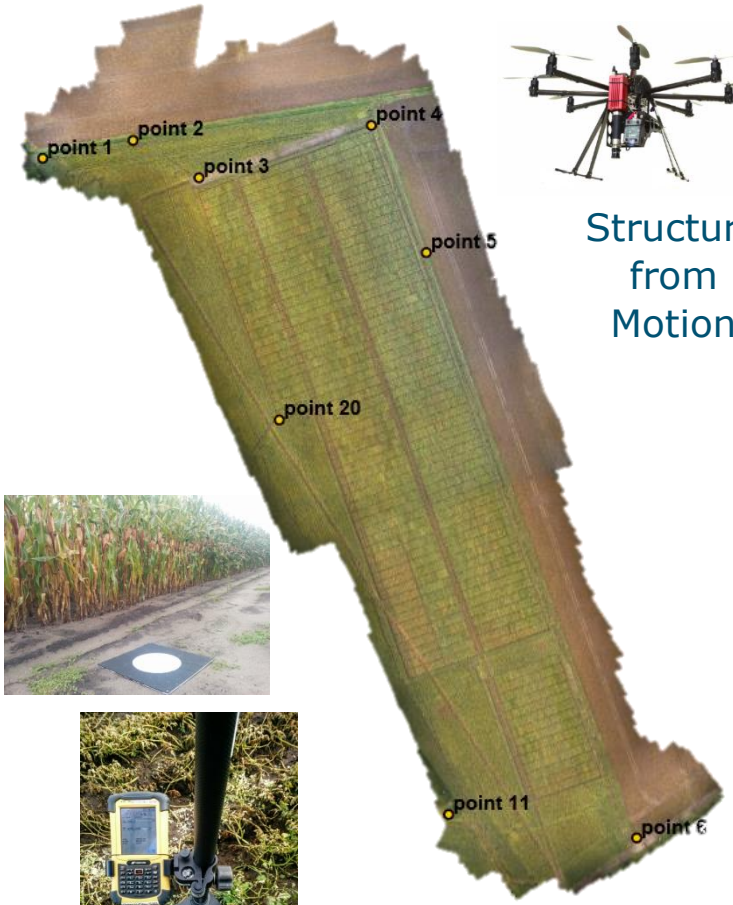
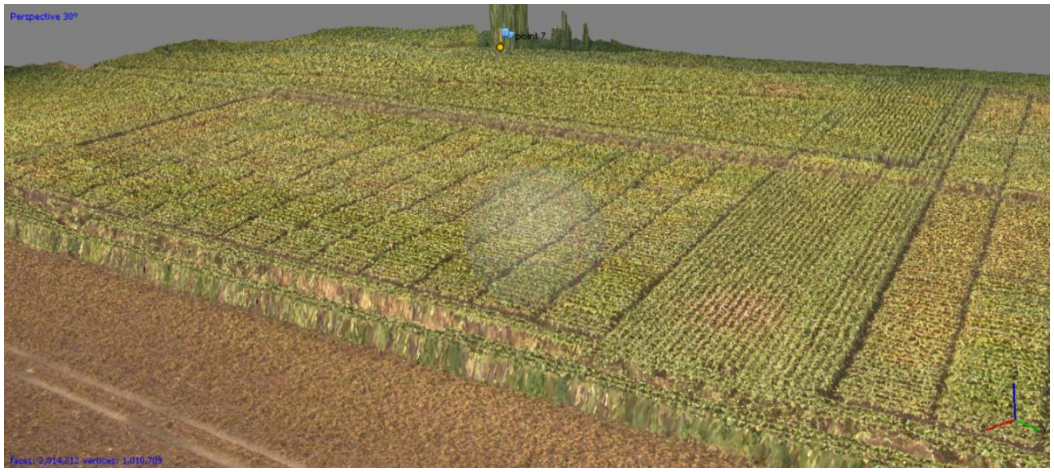
UAVs and Plant Phenotyping: Maize

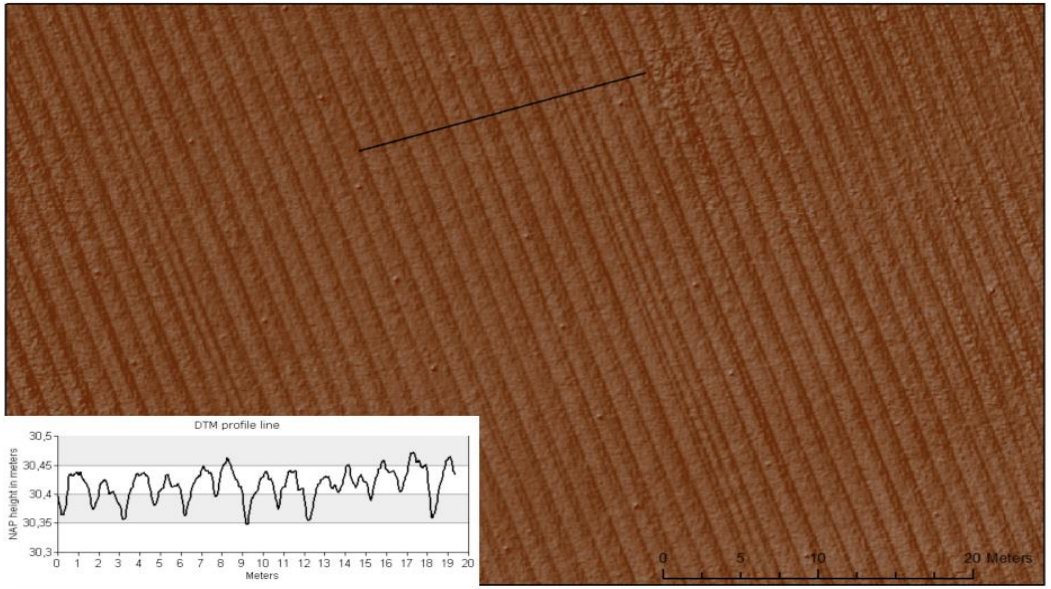
Darell van der Voort, Sander Mücher and Henk Kramer, Alterra



Structure from Motion



Digital Surface Model



Digital Terrain Model

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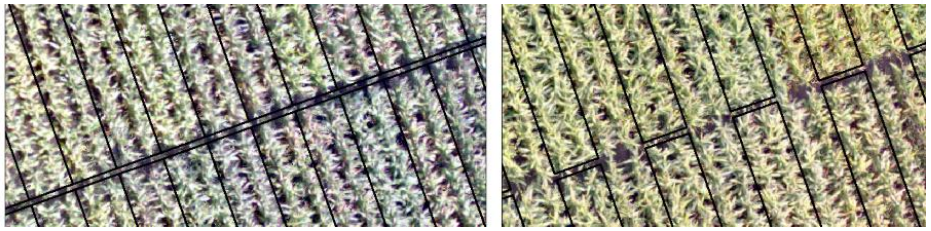
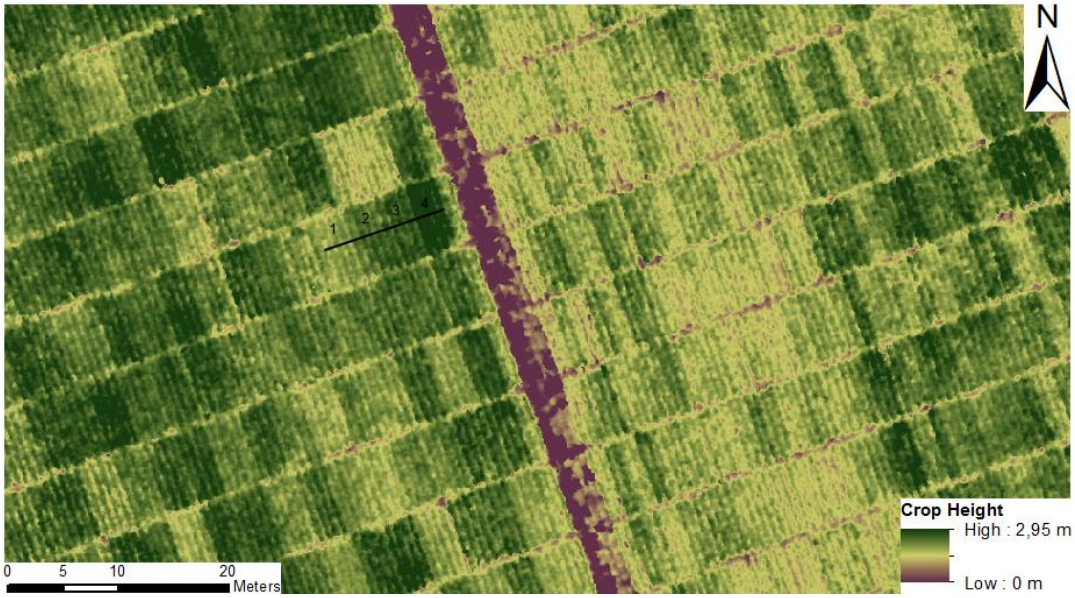
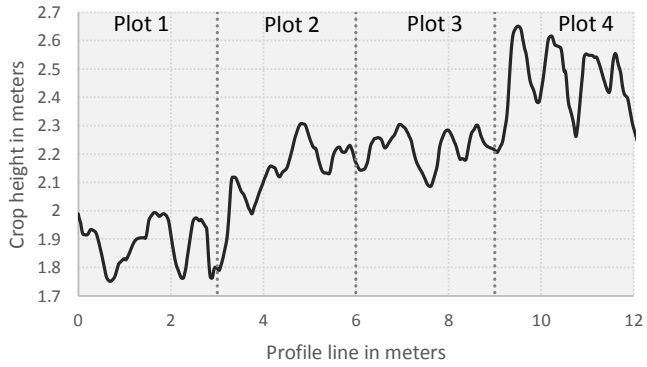
Crop Surface Model

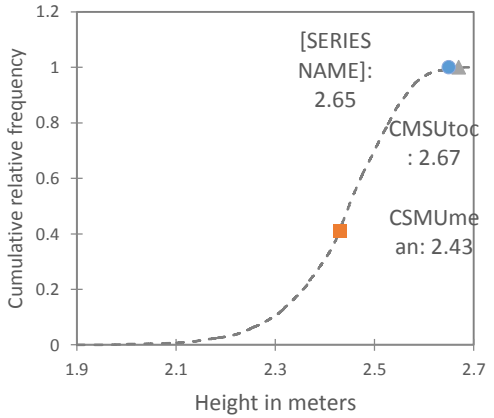
- Total of 3838 plots
- Average 16300 points p.p.
- 10.2 m2, +- 50 plants, 2 rows, 2 different plot set-ups
- Geometric calibration very important at such high detail





Digital Crop Height Model





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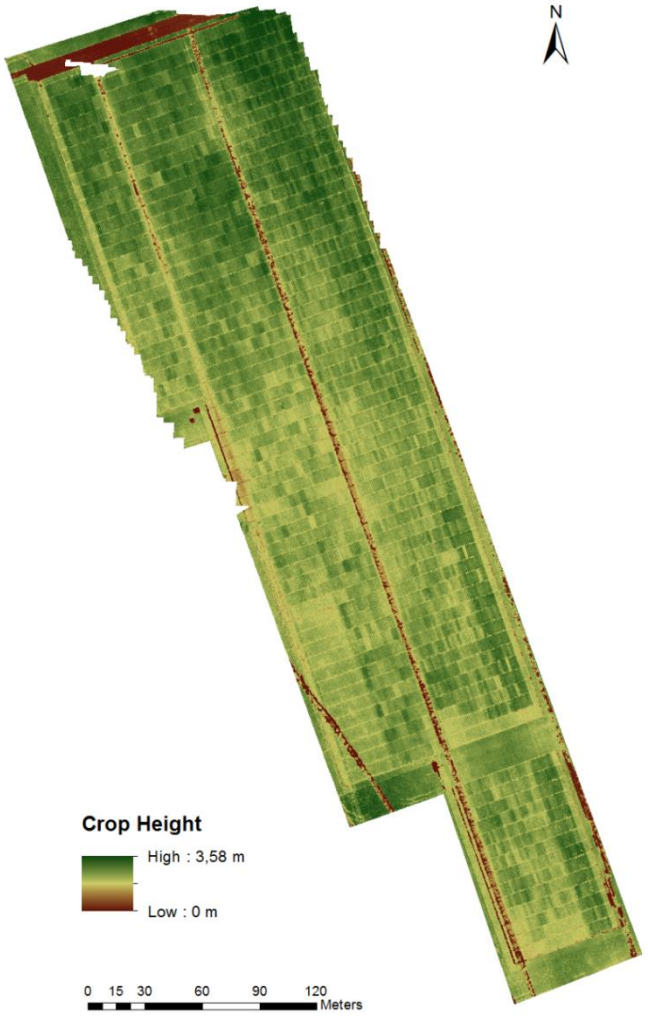
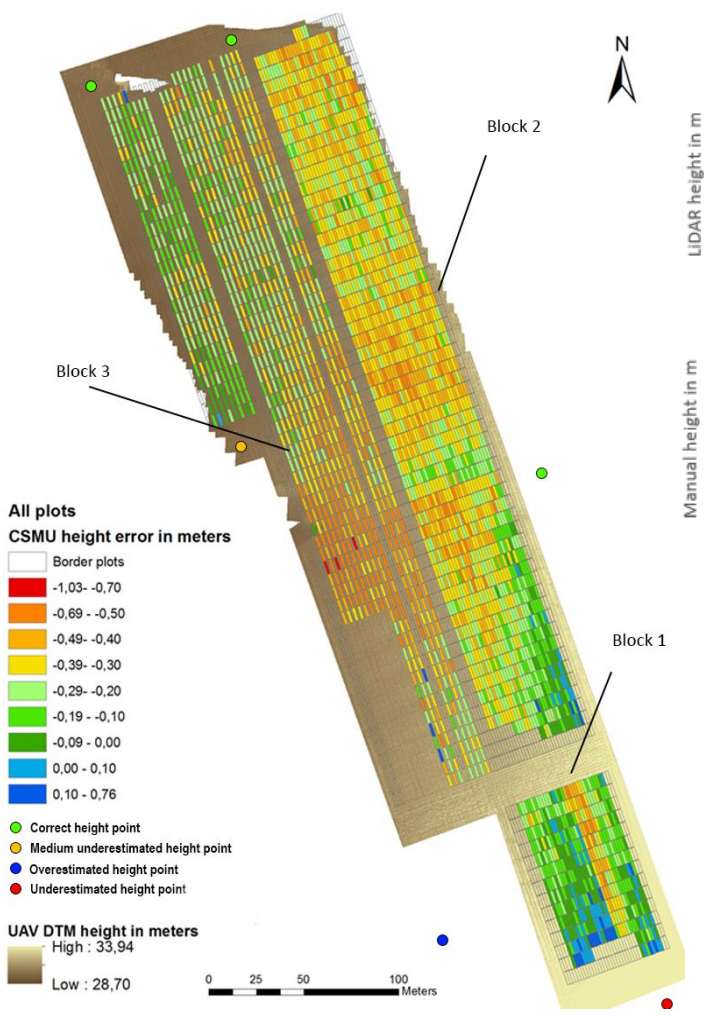
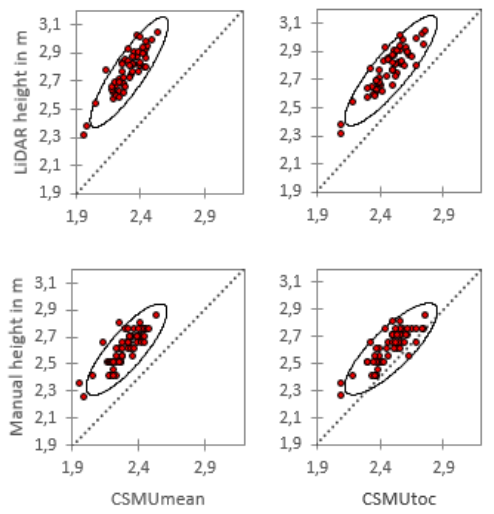
CSM vs Lidar and Manual







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Remote sensing and Precision Agriculture

- Precision Agriculture (PA) to reduce yield gap and efficient use of resources:
  - Good agricultural practice (agronomy)
  - Spatial explicit (within field) management
  - Optimal timing of fertilization, irrigation, disease field management actions (Beza et al., 2015)
- After GNSS, (remote) sensing new revolution for PA?
  - Fullfill combined spec, spat, temp requirements


31 May


11 June


23 June

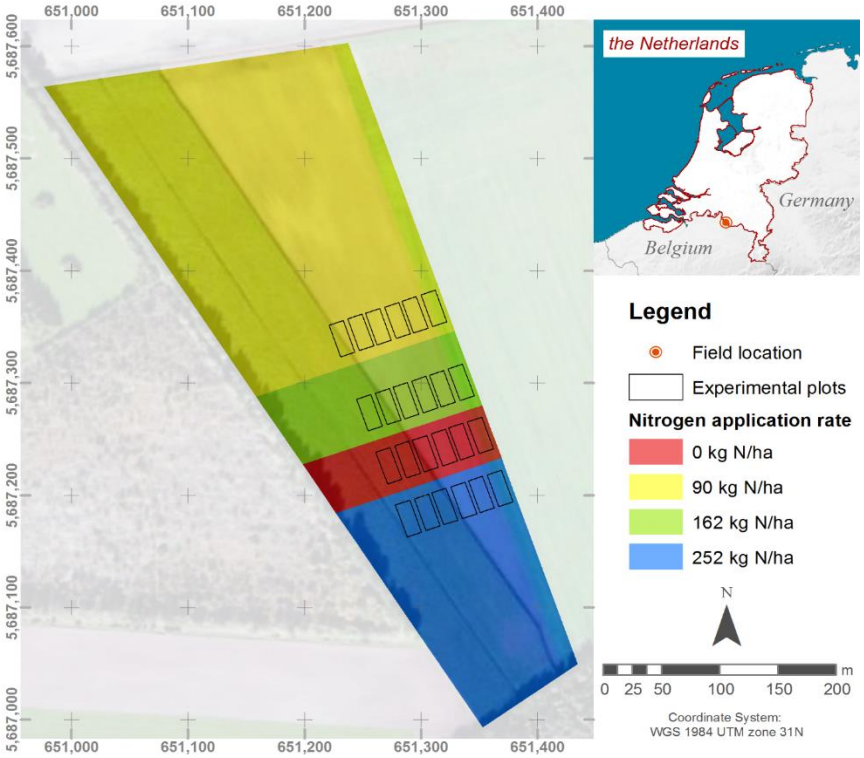

5 July


14 July


19 Aug


6 Sept

Potato fertilization experiment 2013



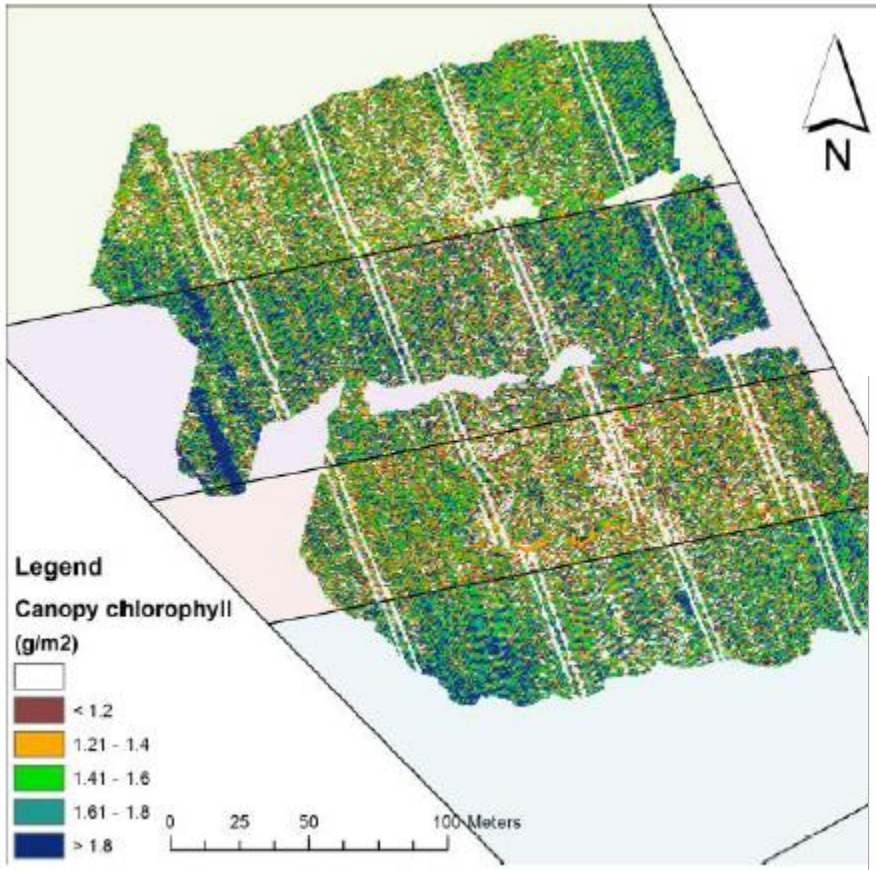
Field measurements (11 obs):

- Chlorophyl: SPAD
- LAI: Licor LAI2000
- Reflectance: Cropscan MSR16
- Test approach at plot level

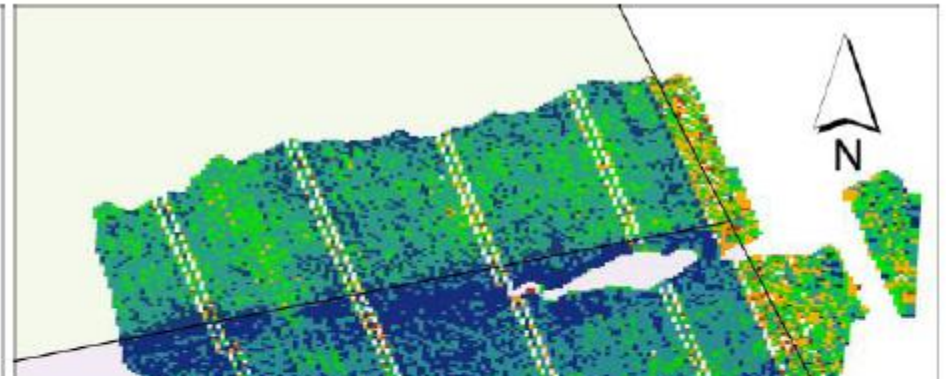
Source: Kooistra et al., 2013

Precision agriculture potatoes

Jacob van den Borne, Lammert Kooistra and others

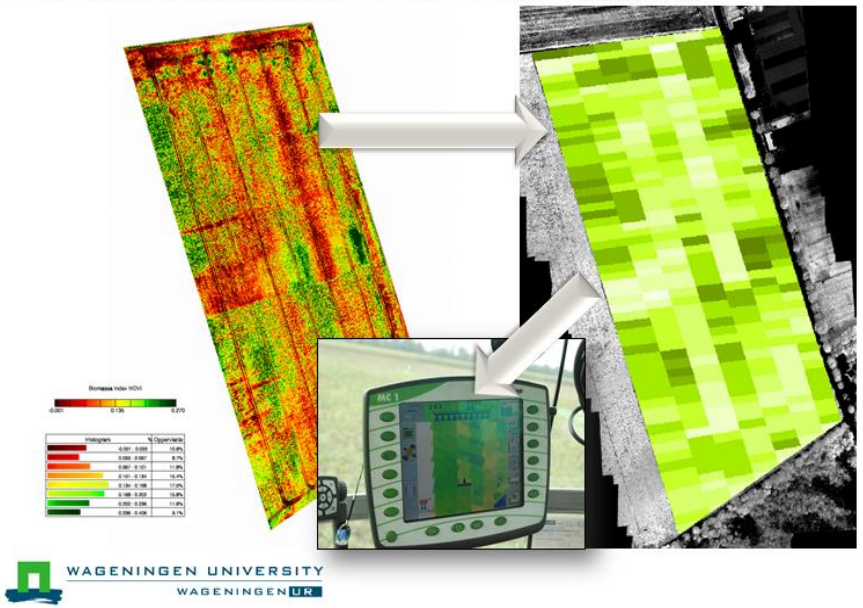


June 14



UAV image as input for sprayer taskmap

Image courtesy: Terrasphere, PRI, van den Borne Aardappels



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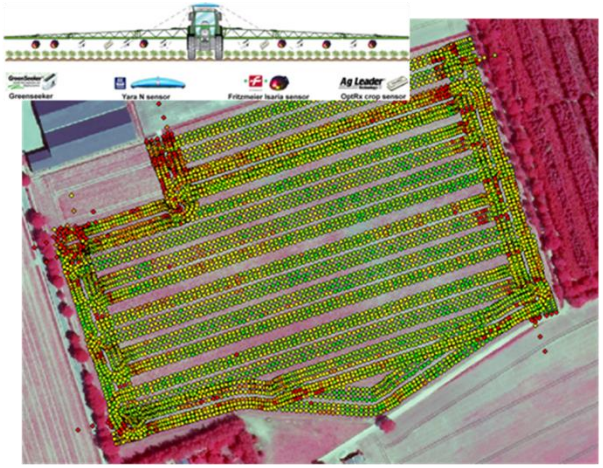
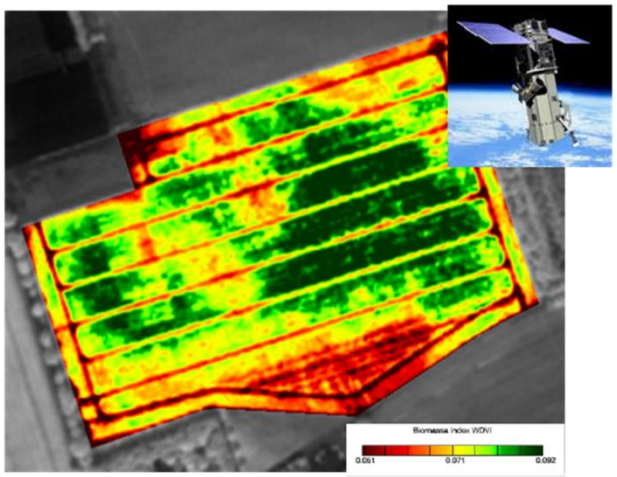
Towards integrated sensing



spatial-temporal-spectral scaling model



close sensing
+ flexible acquisition
+ active system
– no processing standards
– point observations

remote sensing
whole parcel +
preprocessing +
clouds –
not all days –

Date	AL17						AL7						AR7						AR17					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
06-06-2011																								
13-06-2011																								
20-06-2011																								
27-06-2011																								
11-07-2011																								
18-07-2011																								
25-07-2011																								
01-08-2011																								
22-08-2011																								

green: in control; yellow: warning; red: action required

sensor-based alerting service

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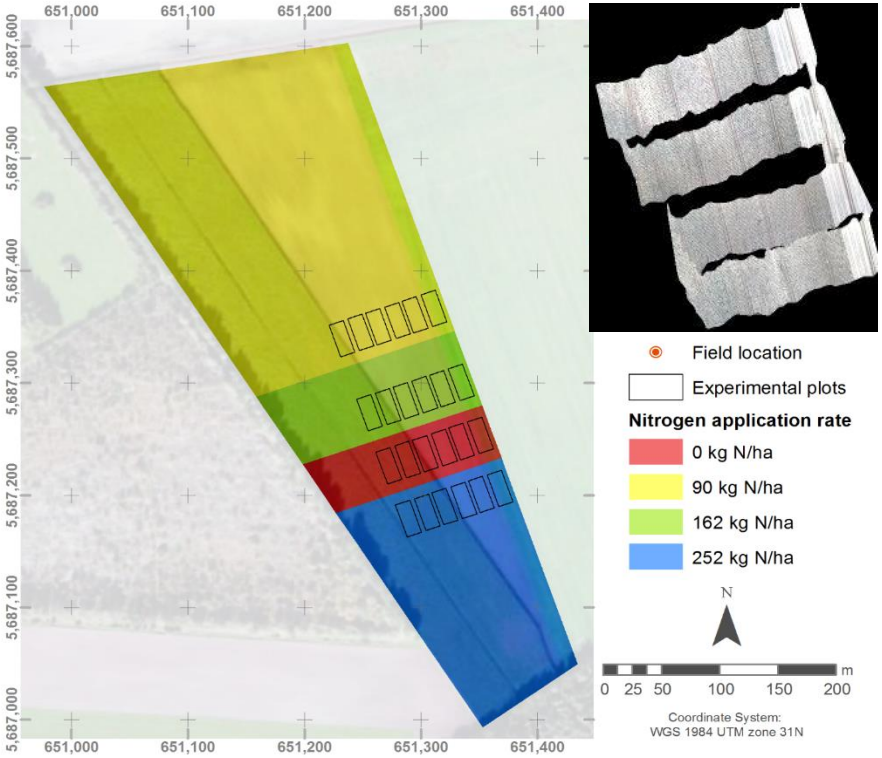
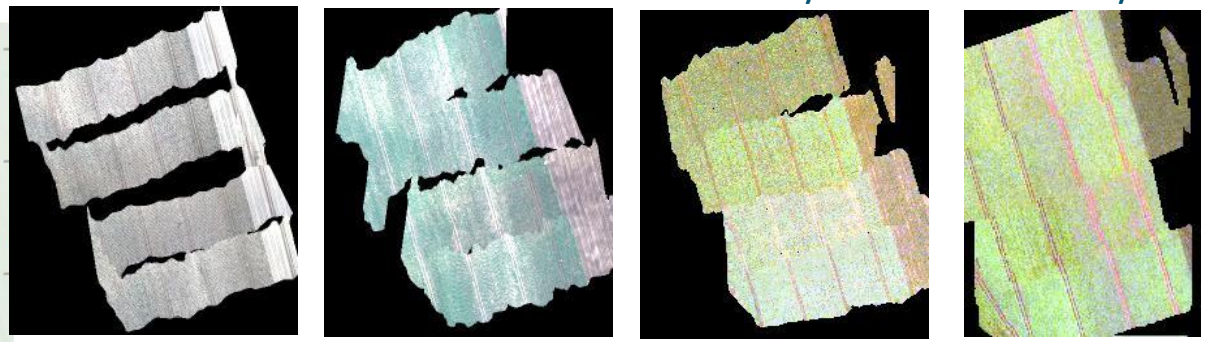
Potato fertilization experiment 2013



6 June HYMSY 14 June 5 July 17 July



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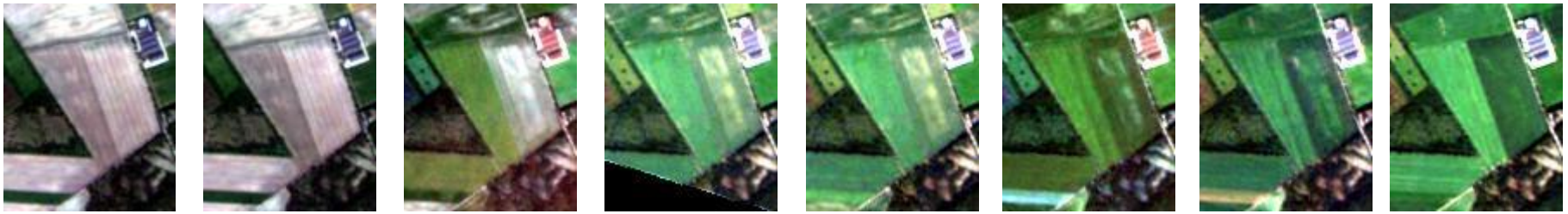

6 June 8 June 2 July 8 July 12 July 18 July 22 July 2 Aug

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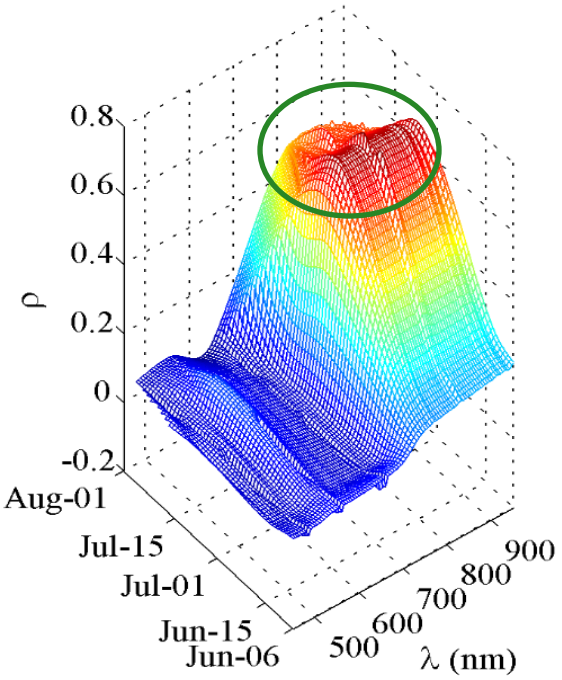
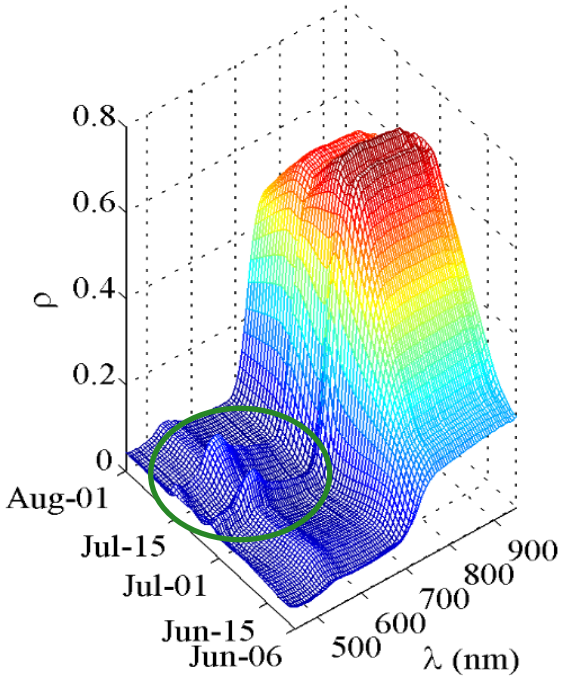
Formosat: 7m; RGB-NIR, reflectance; source: Dutch Satellite portal

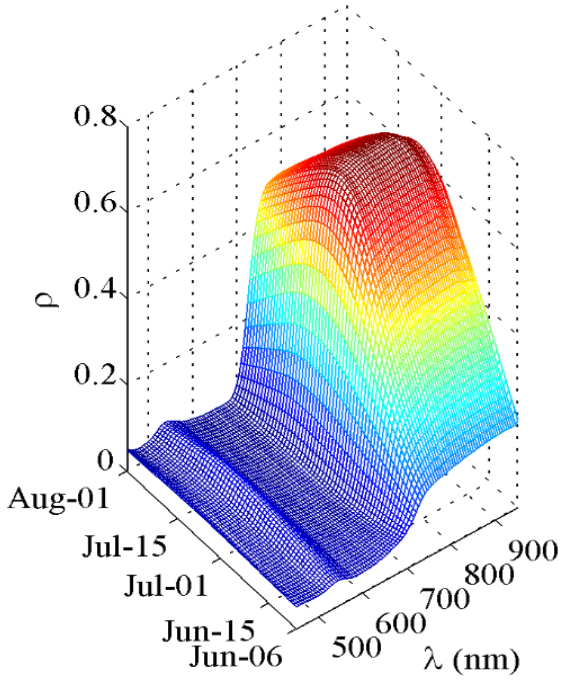
Spectral-temporal response surface



Direct Spline



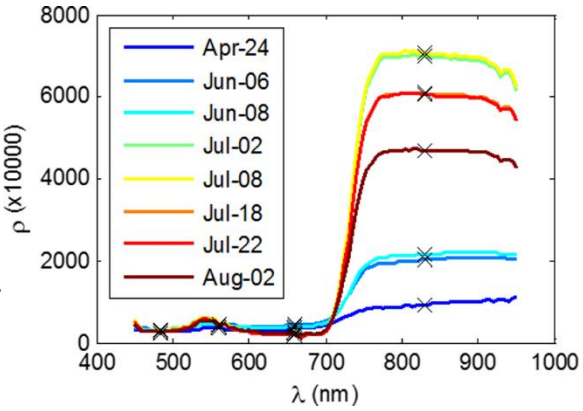
Impute + Spline



Bayesian

Source: Gevaert et al., JSTARS, 2015

The Formosat-2 spectral bands (x) imputed to 101 bands on various dates



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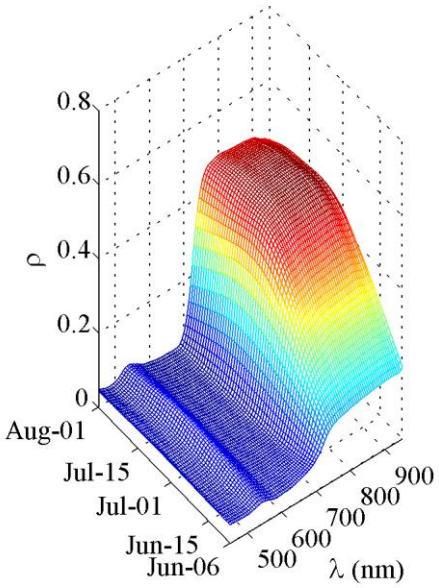
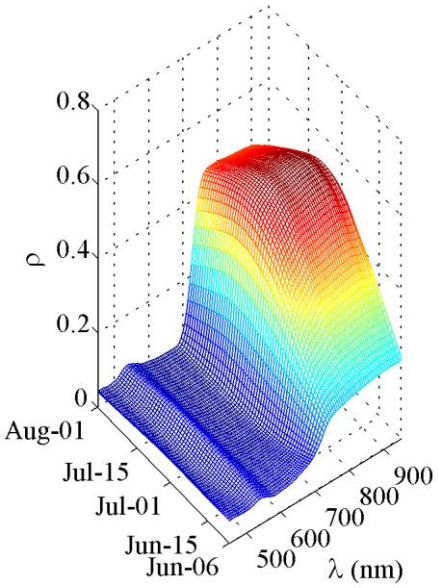
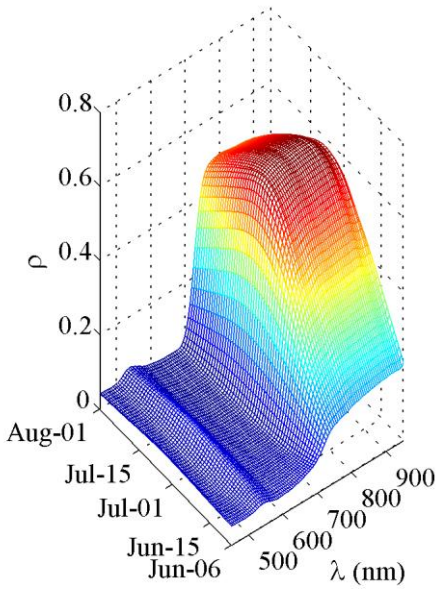
STRS comparison between N-levels



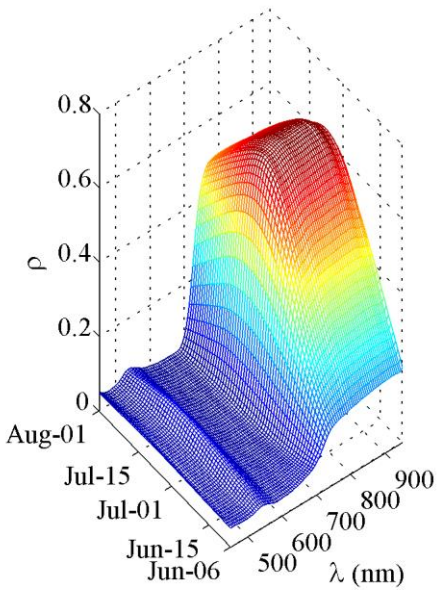
0 kg N/ha



90 kg N/ha



162 kg N/ha



252 kg N/ha

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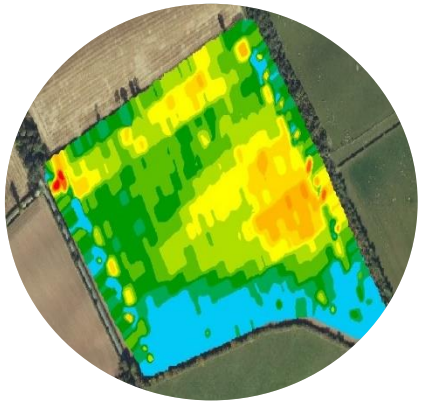
Source: Gevaert et al., JSTARS, 2015

From data to informed decisions



detection → diagnosis → decision rules → management activity

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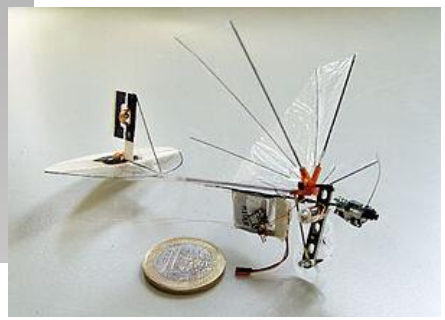
Future developments: flying robots?

Biomimicry and design of UAVs

Robird (TUT)

Delfly (TUD)



From Humming Man Project

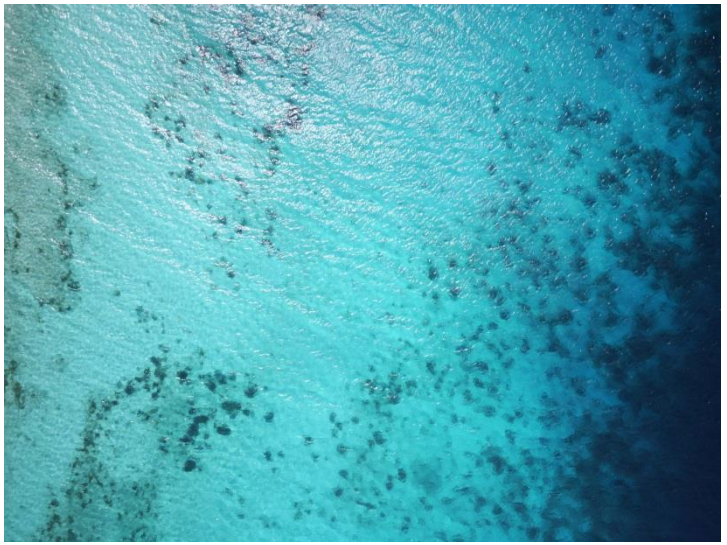
to Drone4Agro

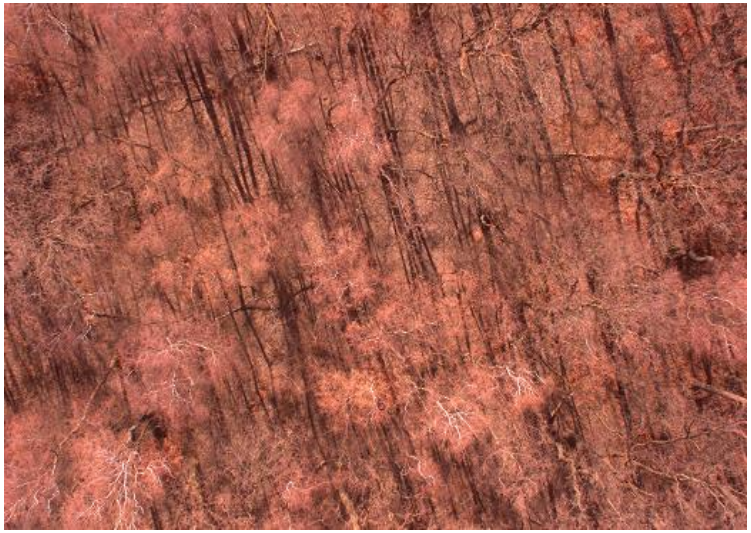
(onemandrone.com)

UAVs will be next generation flying sensors

- Must have: UAV as technical show case
- Presentation, PR and movies
- Easy accessible and affordable
- Real scientific instrument:
  - Autonomous imaging systems
  - Advanced experimental designs
  - Scaling from plot to landscape processes (incl time)
  - High-throughput and quantification
- Challenges:
  - Develop consistent remote sensing processing chains
  - Use strength of multi-disciplinary cooperation

Sensing a changing world





Thank you for your attention

Unmanned Aerial Remote Sensing Facility

www.wageningen-ur.nl/uarsf

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UARSF-team; MSc students (Bob, Darell, Sabina, Caroline, Jonas and others); PhD students (Marston, Benjamin, Corjan, Marinka, Eefje, Luke); WUR colleagues: Gerlinde de Deyn, Sander Mücher, Jappe Franke, Henk Kramer, Tamme van der Wal; Interreg project Smart Inspectors (Rolf Becker), FZ Jülich (Uwe Rascher); companies: van den Borne Potatoes, TTW Consultants for cultivation

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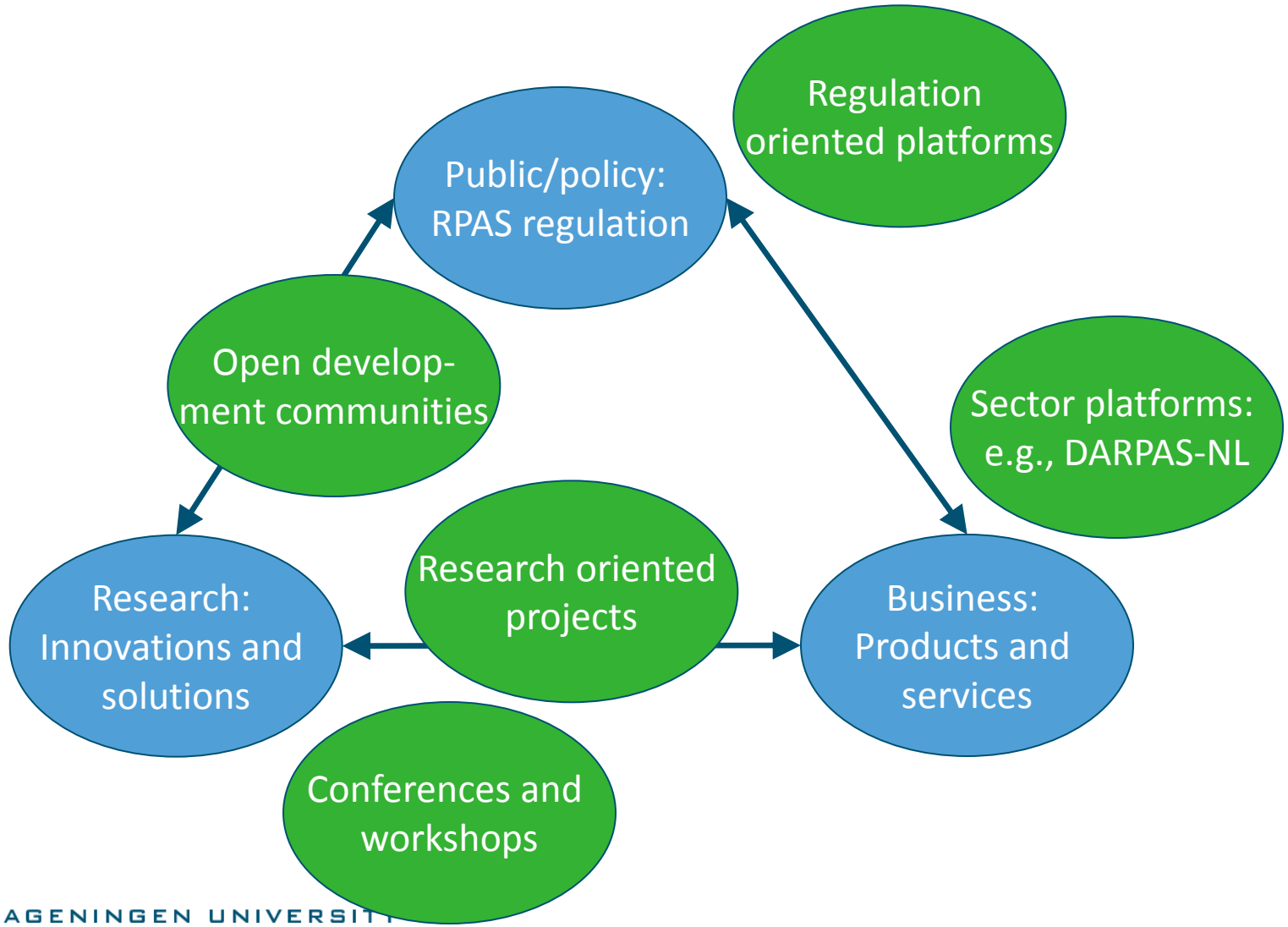
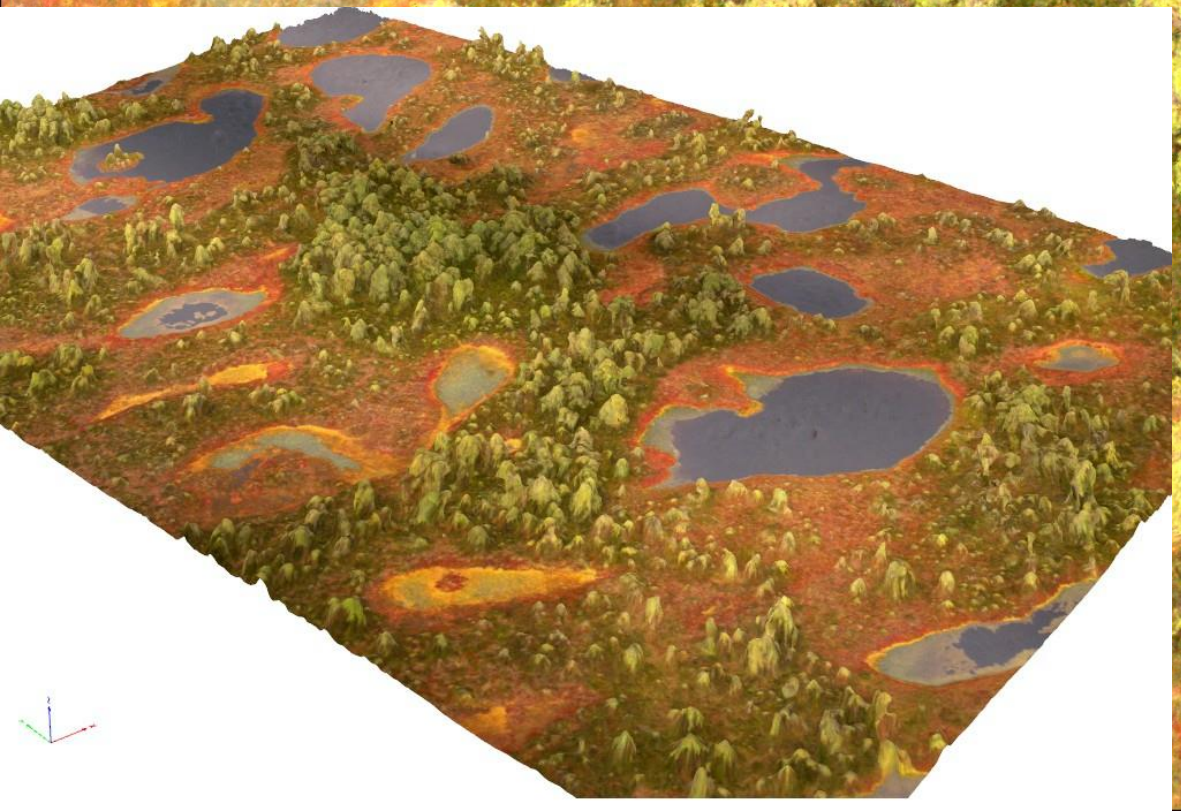
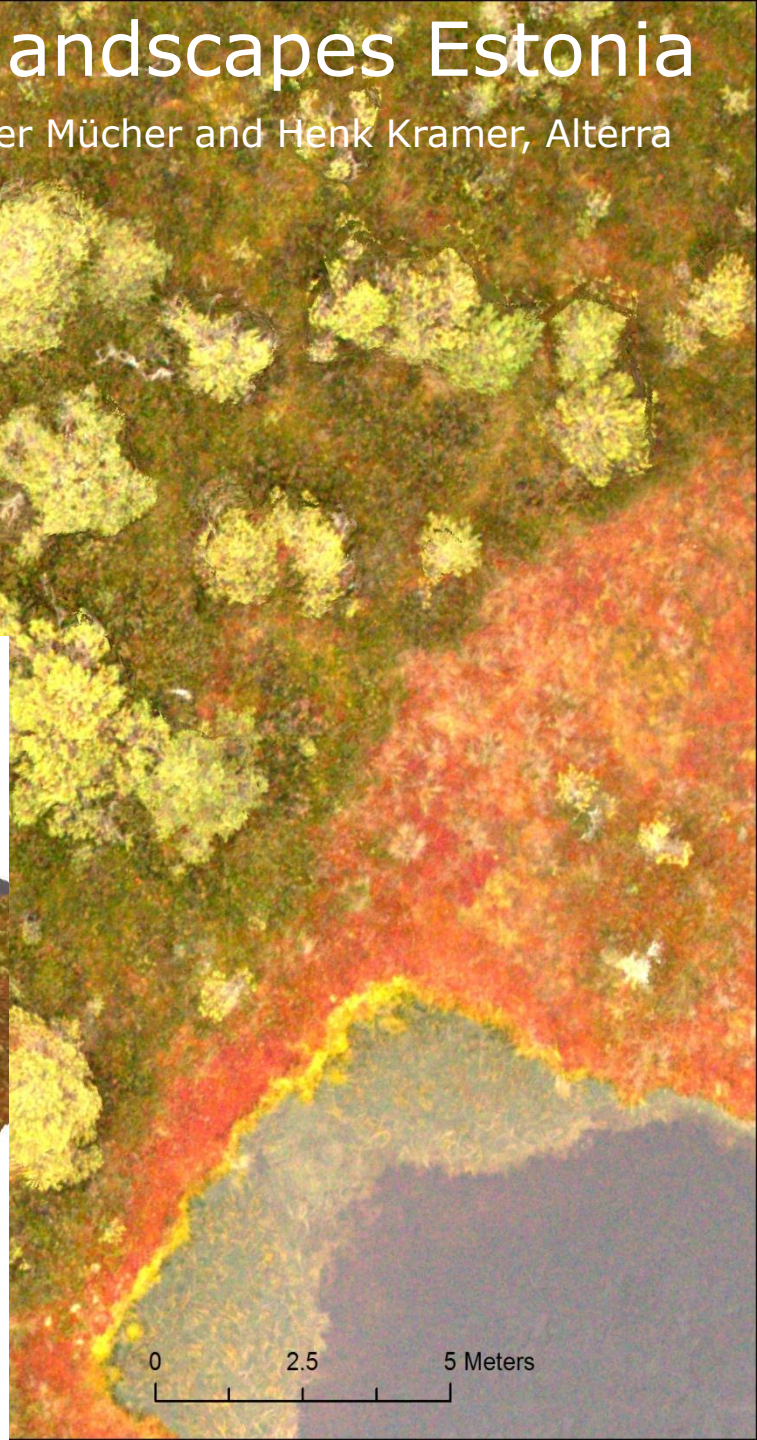
Towards UAV research networks



Mapping peat landscapes Estonia

Sander Mücher and Henk Kramer, Alterra





Future developments UAVs for Science

Complex field experiments

- Phenotyping: plant traits, shoot, Face experiment, Flex, different sensors (www.phenomics.nl)
- Ecology/forestry
- New sensor: lidar

Interactive monitoring

- Precision agriculture: fusion of different sensing streams
- Environmental microscope

UAVs and robotics

- Develop innovative machine vision methods
- Autonomous UAVs?: adapt flight paths

Challenges for UAV based remote sensing

- Develop consistent mapping products/services
  - Geometrical and radiometrical quality
  - Change from pixel based to machine vision methods
  - Combine strengths of different platforms
- Use strength of multi-disciplinary cooperation:
  - Technical: optics, electronics, software engineering
  - A broad range of applications
  - Organize cooperation!