Plant physiological traits from high resolution hyperspectral and thermal imagery: models and indices for early stress detection

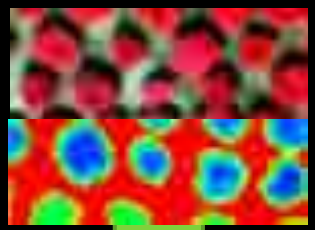
Pablo J. Zarco-Tejada

European Commission
Joint Research Centre (JRC)
Directorate D – Sustainable Resources

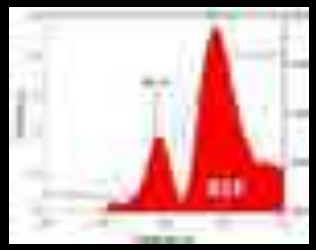

Headwind

Plant-trait retrievals for stress detection

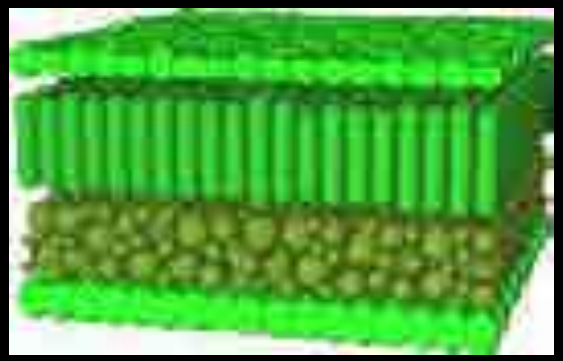
Image

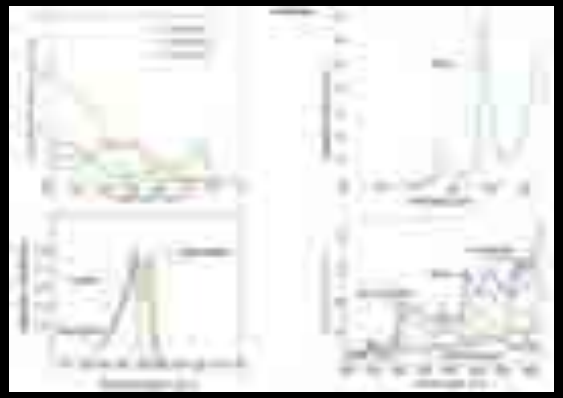


Spectra

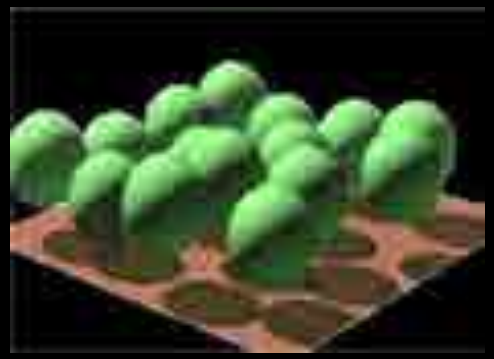


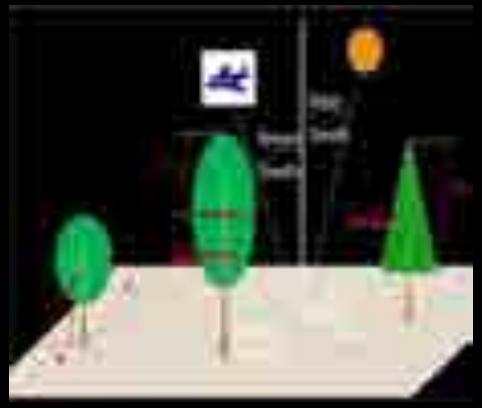
Leaf Model





Canopy Model





Model-retrieved Plant Traits

C_{a+b}
C_{x+c}
A_{nth}
C_w
C_m
LAI
LIDF

SIF

T

Challenges ?

“these guys are playing with toys…”

What do you do ?

"I work in remote sensing using unmanned vehicles"

Challenges ?

1. Conceptual
2. Technical
3. Self-imposed requirements

CSIC

Quantalab

Challenges ?

1. Conceptual
2. **Technical**
3. Self-imposed requirements

CASI Hyperspectral Imager


Year 2011


CSIC


CSIC

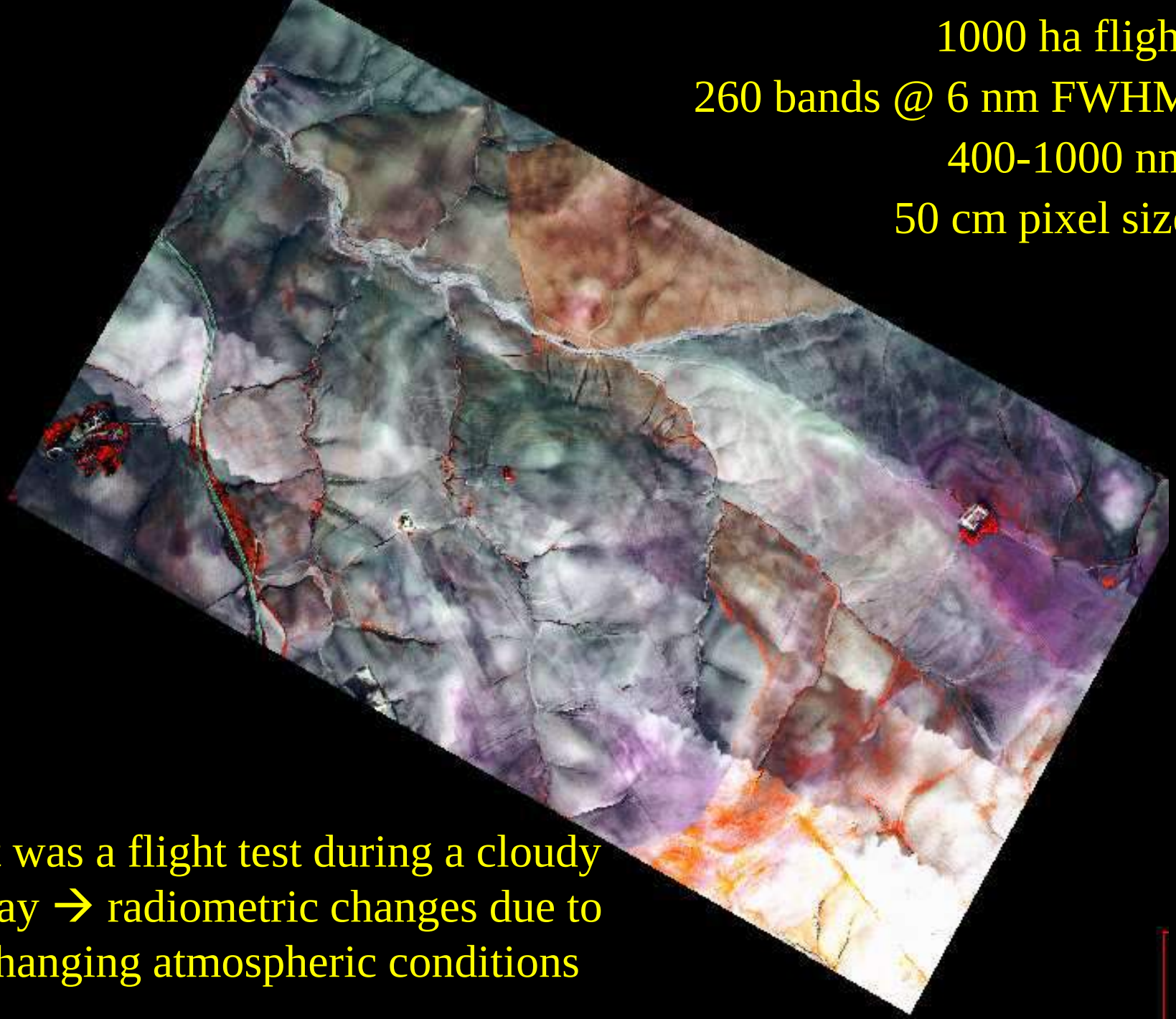
Micro-hyperspectral imager on board a 6 kg platform

Year 2015


CSIC


Henchwell


CSIC

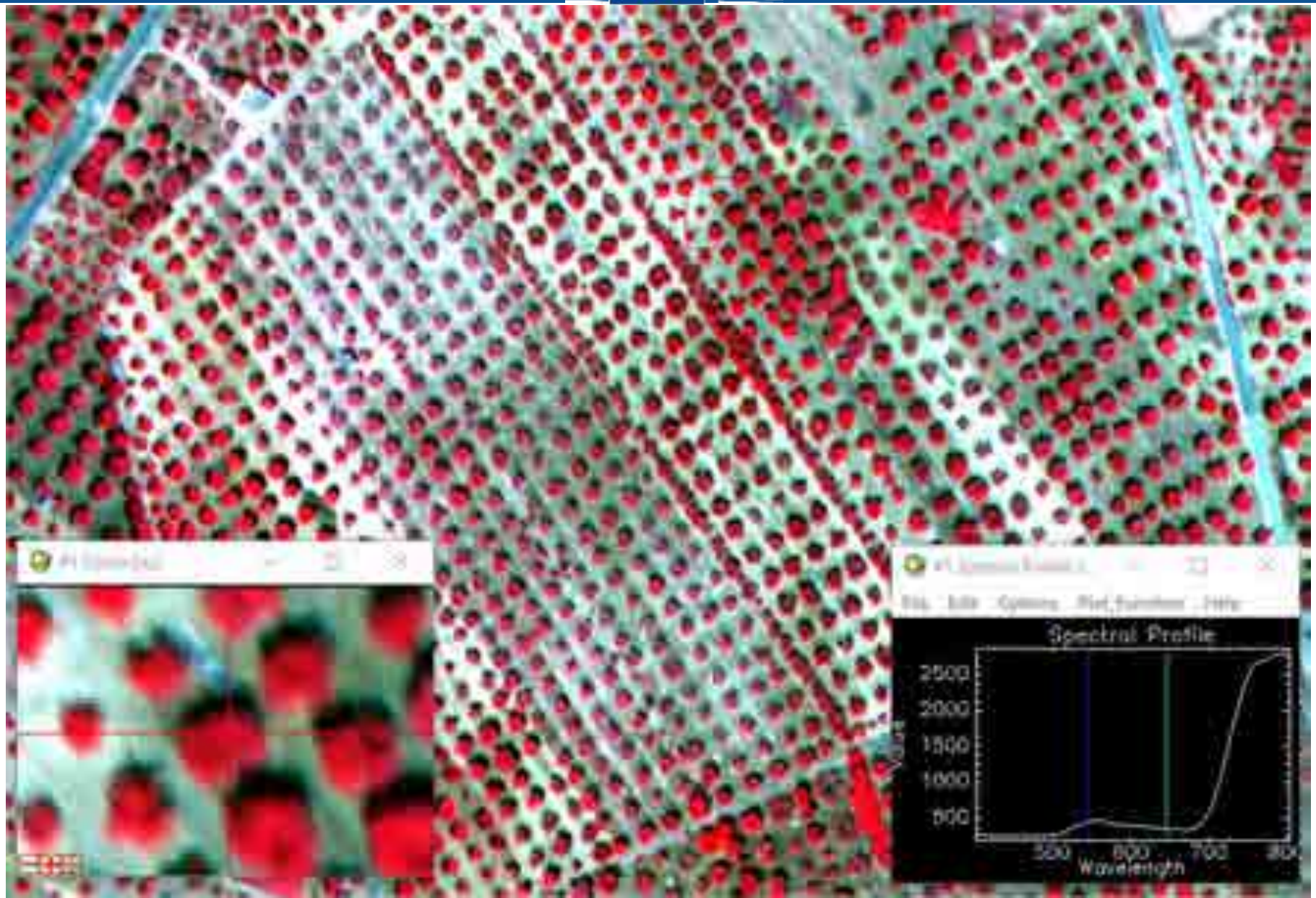


1000 ha flight
260 bands @ 6 nm FWHM
400-1000 nm
50 cm pixel size

It was a flight test during a cloudy day → radiometric changes due to changing atmospheric conditions

Radiometric calibration

Hyperspectral 45 cm



Challenges ?

1. Conceptual
2. Technical
3. **Self-imposed requirements**

Some dreams … as of 2005

- **VHR** in thermal + multi(hyper)spectral (sub-meter) to identify pure crowns / avoid mixed pixels
- Canopy temperature maps with **errors below 1 K** (absolute, not only relative)
- Processing capabilities for **1-day turn-around** times → decision making
- Imagery & products through **simpler tools** for GIS-unexperienced end-users / technicians
- Acceptable **cost**

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Remote Sensing of Environment

Cameras for stress detection

- → RGB / CIR cameras
  - → pNDVI & DSM generation
- → Thermal Cameras
  - → Water stress detection / irrigation
- →Multispectral cameras
  - → Nutrient stress detection (C_{ab}, C_{x+c})
  - → Physiological indices (PRI, F)
  - → Canopy structure (NDVI, EVI)
- → Hyperspectral imagers
  - → New indices / methods
  - → Combined spectral indices









Remote Sensing Indicators of Vegetation Stress

Visual

- **Pigments-traits C_{ab} / C_{ar}**
  - **Nutrient deficiencies / effects of diseases → less absorption at specific bands → captured by RT model inversion methods & sensitive indices**

- **Structural traits → canopy structure / LADF / vegetative growth**
  - **Nutrient / water stress & effects of diseases → affects canopy growth → effects in the near infrared → captured by indices sensitive to canopy structure**

Pre-visual

- **Xanthophyll cycle pigments (V+A+Z) & A_{nth} → rapid changes phot. Efficiency & photoprotective roles → PRI: Indicator of the epoxidation state (EPS) of the xanthophyll pigments → under stress V+A+Z ↑ → R530 ↓ → PRI ↑**

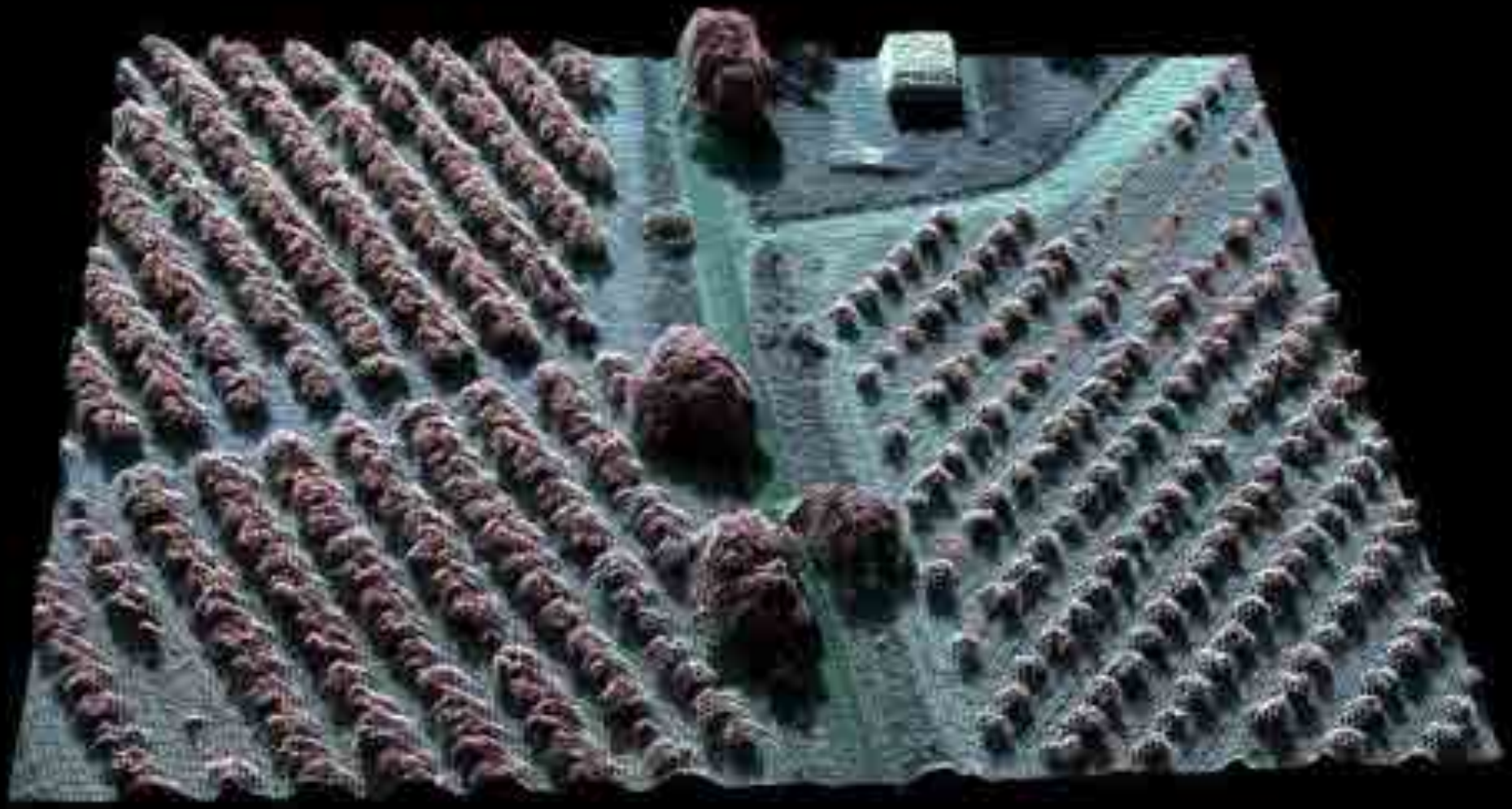
- **Chlorophyll Fluorescence (CF) → F emission → Photosynthesis**
  - **Excess energy → function of the photosynthetic state**
  - **3% - 4 % of the radiance levels**
  - **Main interest to monitor remotely photosynthesis & stress condition**

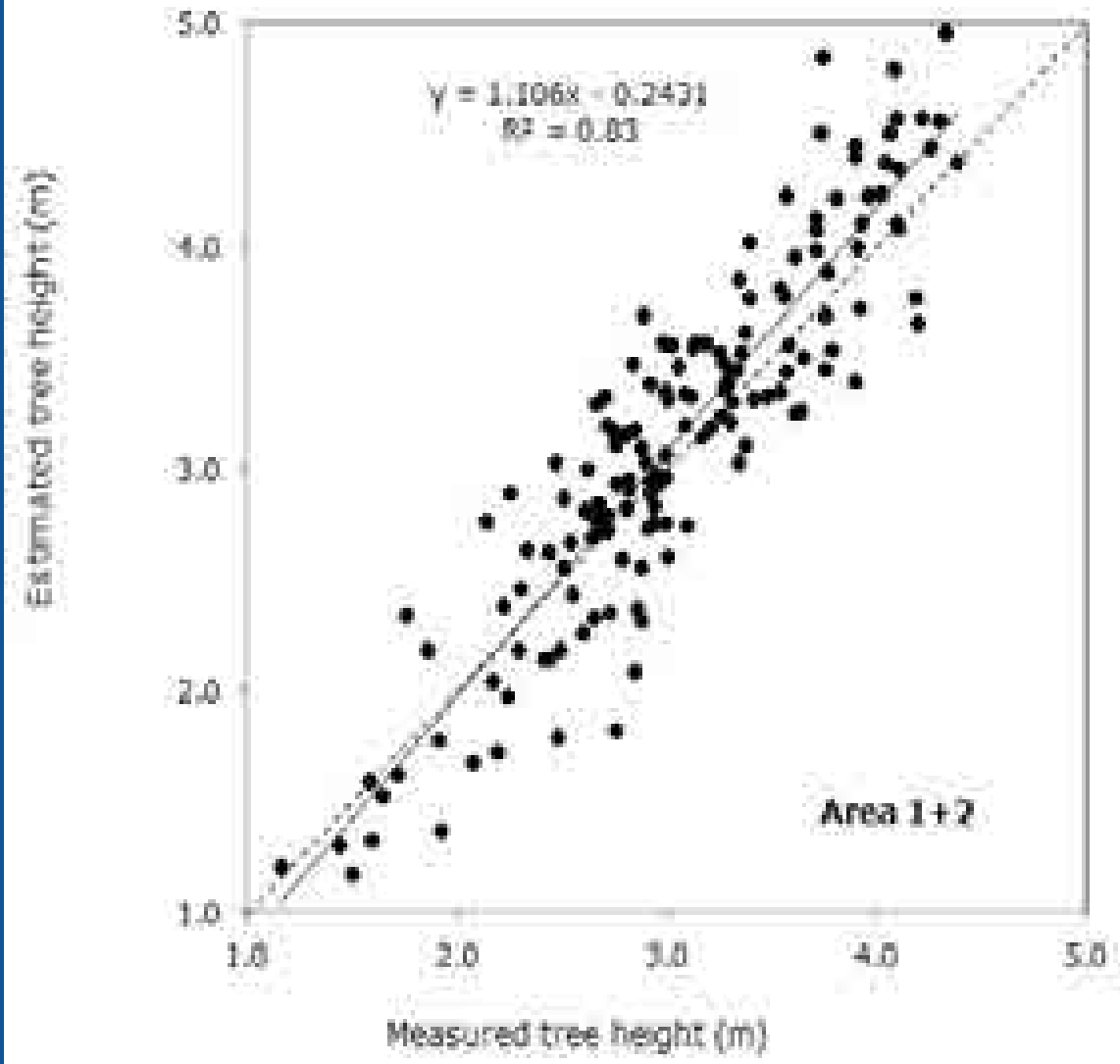
- **Temperature: T_c → T_c-T_a → CWSI**
  - **Stomata closure → Reduction in transpiration and CO_2 uptake → Decreased photosynthesis → *Temperature increase***

OPERATIONAL ?

USEFUL FOR RS ?

Structure





→ 10% R-RMSE (38 cm) when fully automated method is used (with no GCPs)

Tree height estimation via SfM

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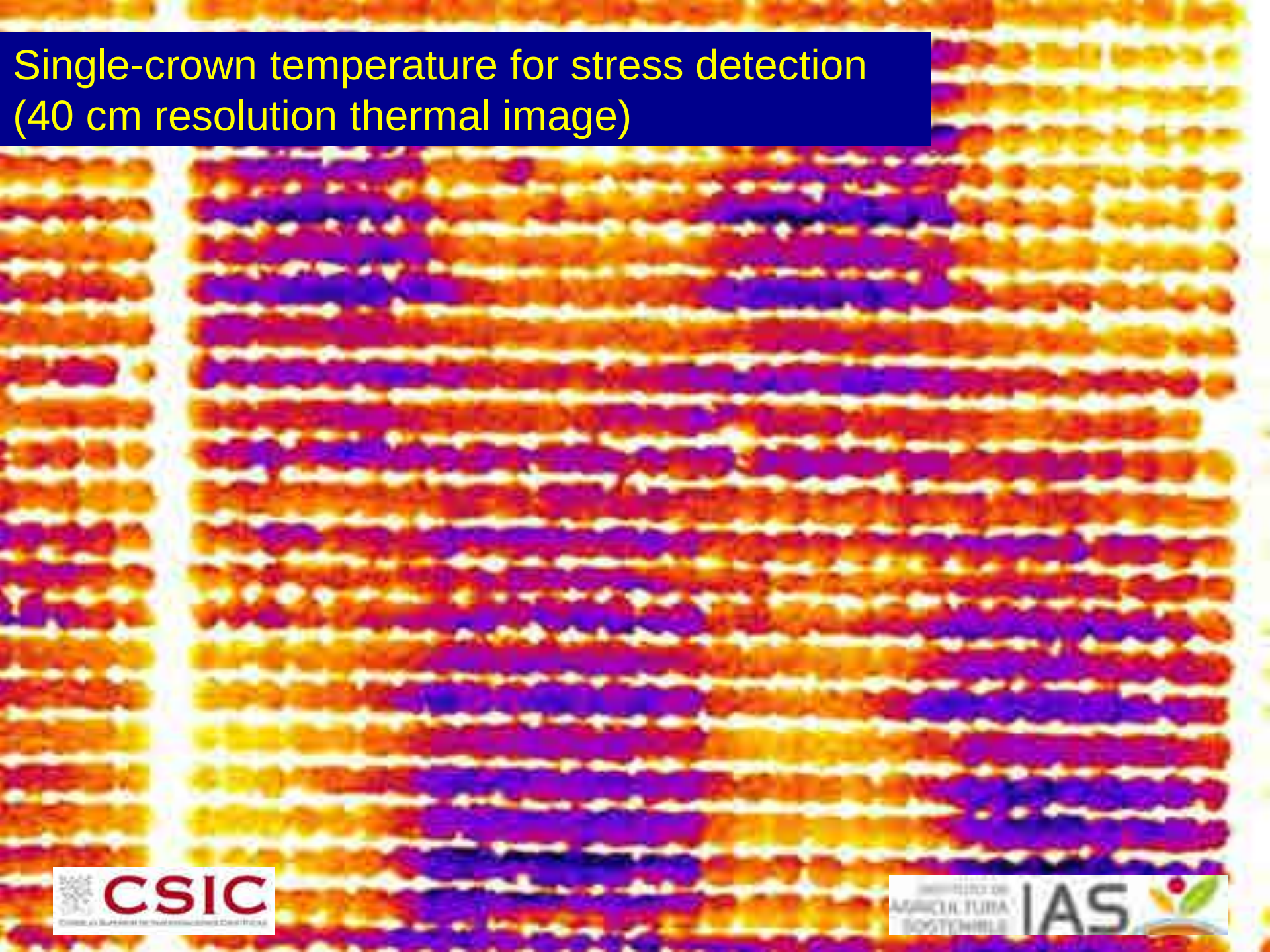
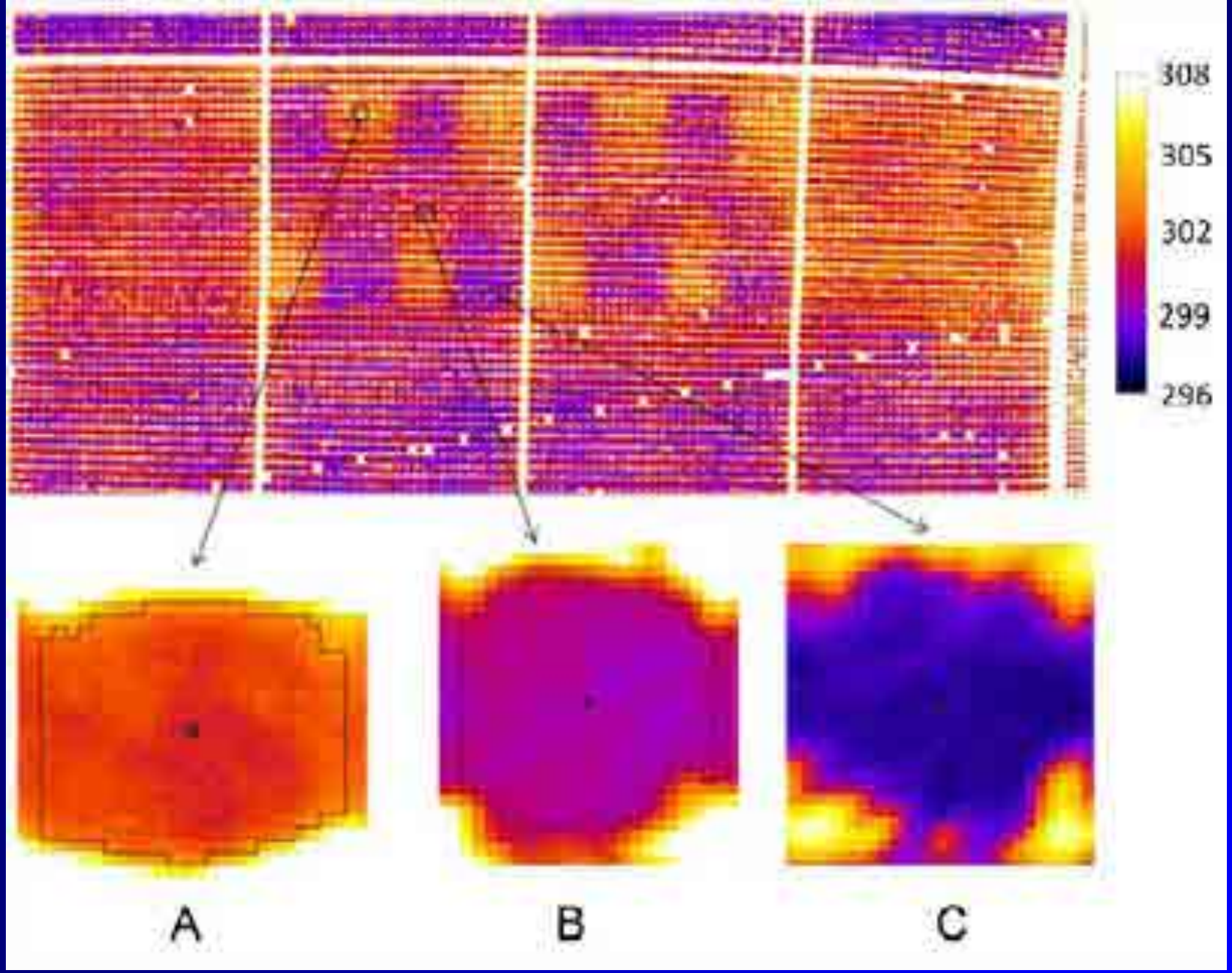
Thermal

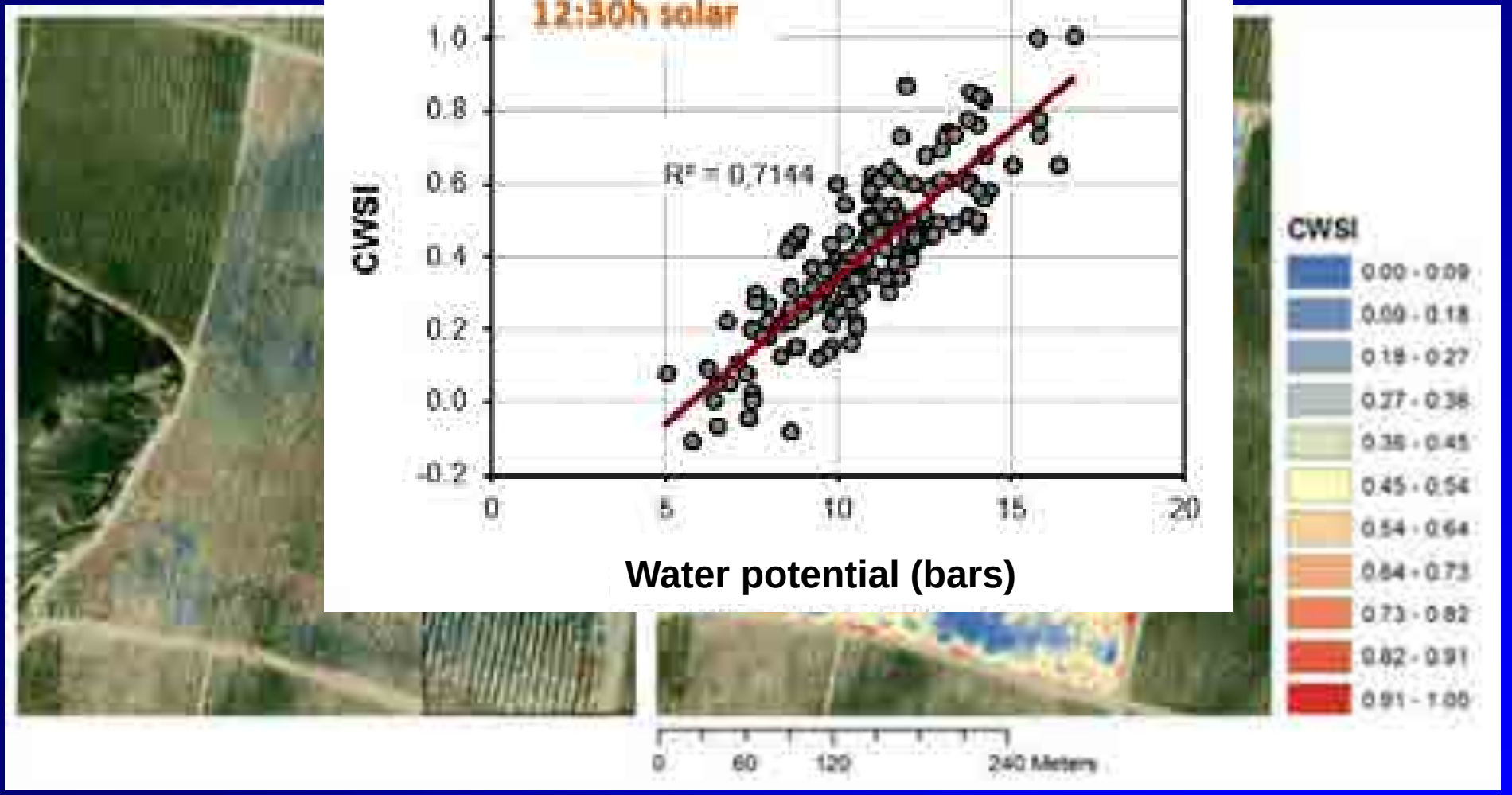
Single-crown temperature for stress detection (40 cm resolution thermal image)





Gonzalez-Dugo et al. (AgForMet, 2012)

CWSI map from UAV



Bellvert et al. (2013)

Map of CWSI – thermal-based indicator of stress from UAV

CWSI

0.0

1.0

Gonzalez-Dugo et al. (2013)

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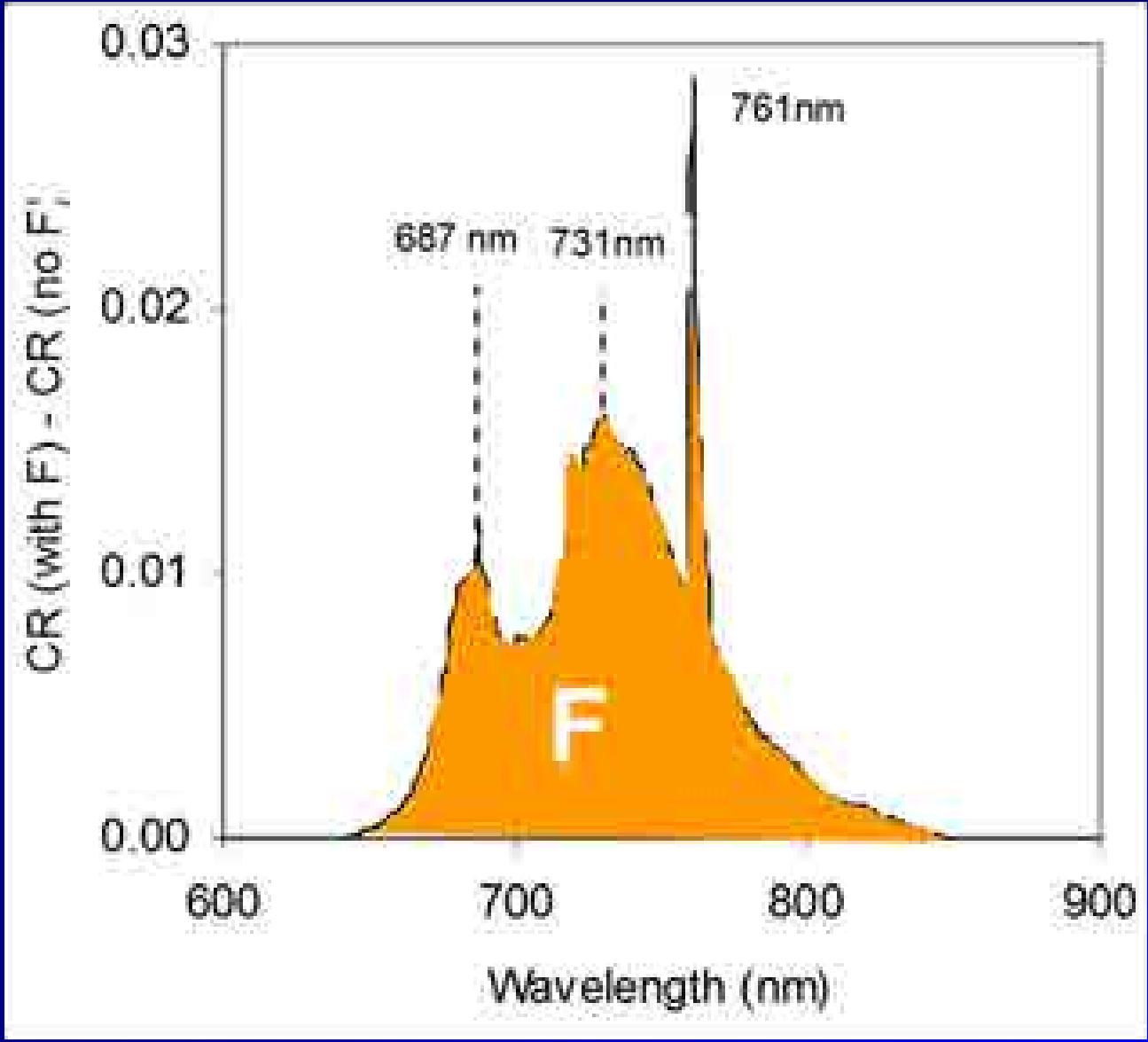
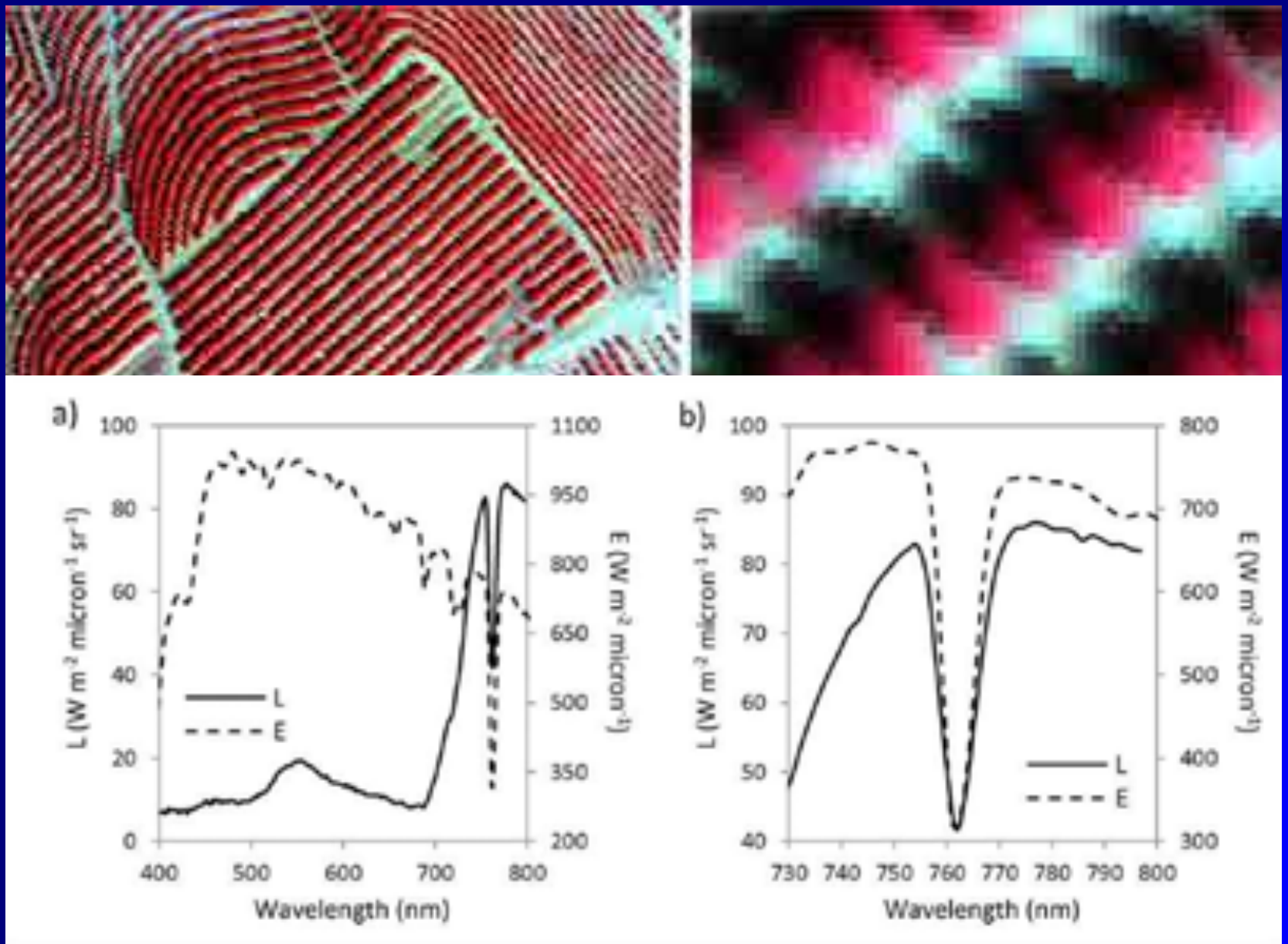
SIF & Pigments


0.03
0.02
0.01
0.00
CR (with F) - CR (no F)
761nm
687 nm
731nm
F
600
700
800
900
Wavelength (nm)

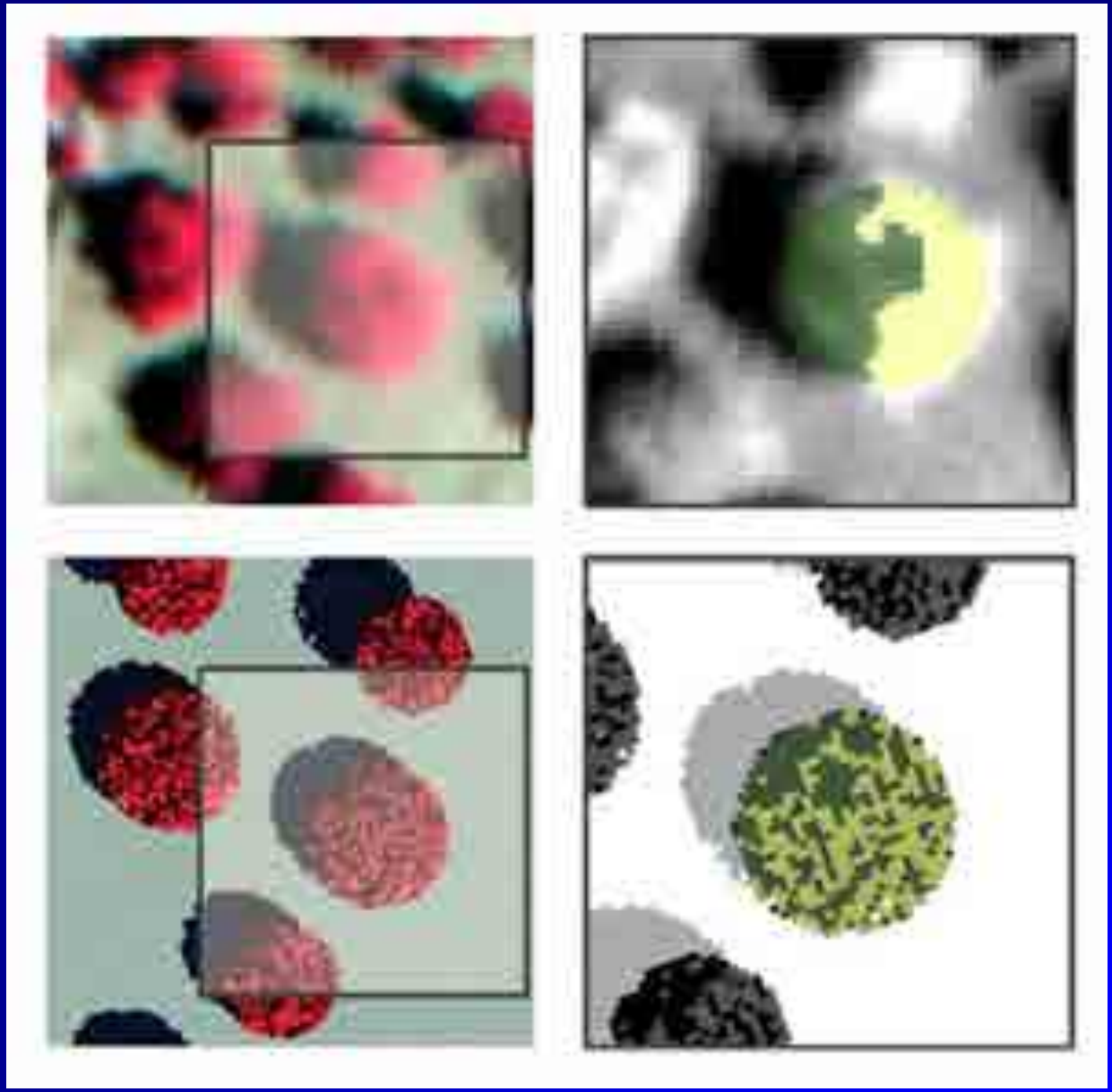
Understanding the retrieval of SIF from broad-band (2-6 nm) hyperspectral imagers on board UAVs



Assessment of SIF retreival using a 3D model (FluorFLIGHT)

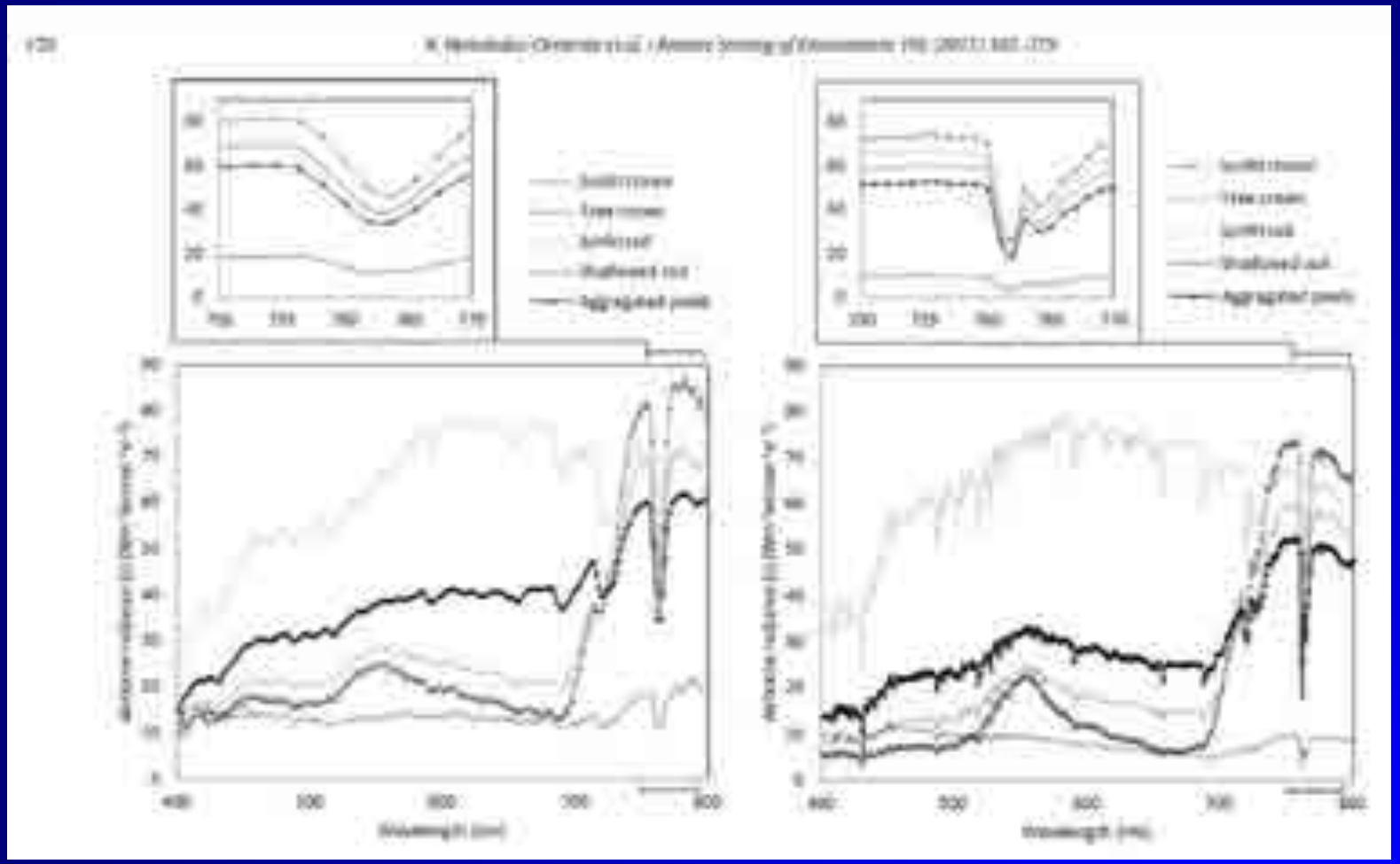
Hyperspectral data

FluorFLIGHT simulations



Hernández-Clemente *et al.* (2017)

Assessment of SIF retreival using a 3D model (FluorFLIGHT)



6.5 nm FWHM **1 nm FWHM**

Hernández-Clemente *et al.* (2017)

Assessment of SIF retrieval using a 3D model (FluorFLIGHT)

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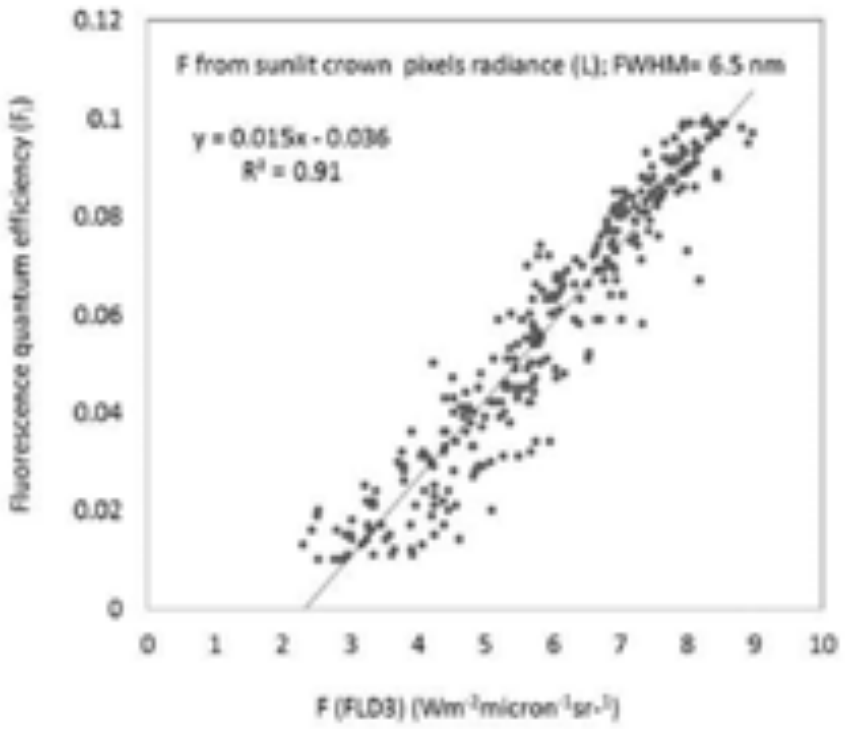
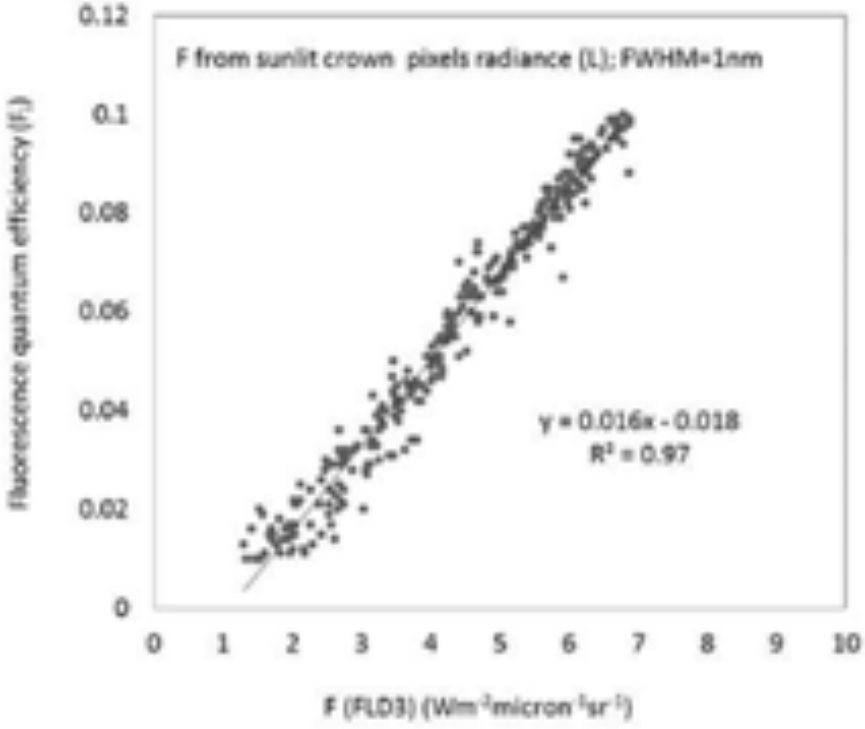


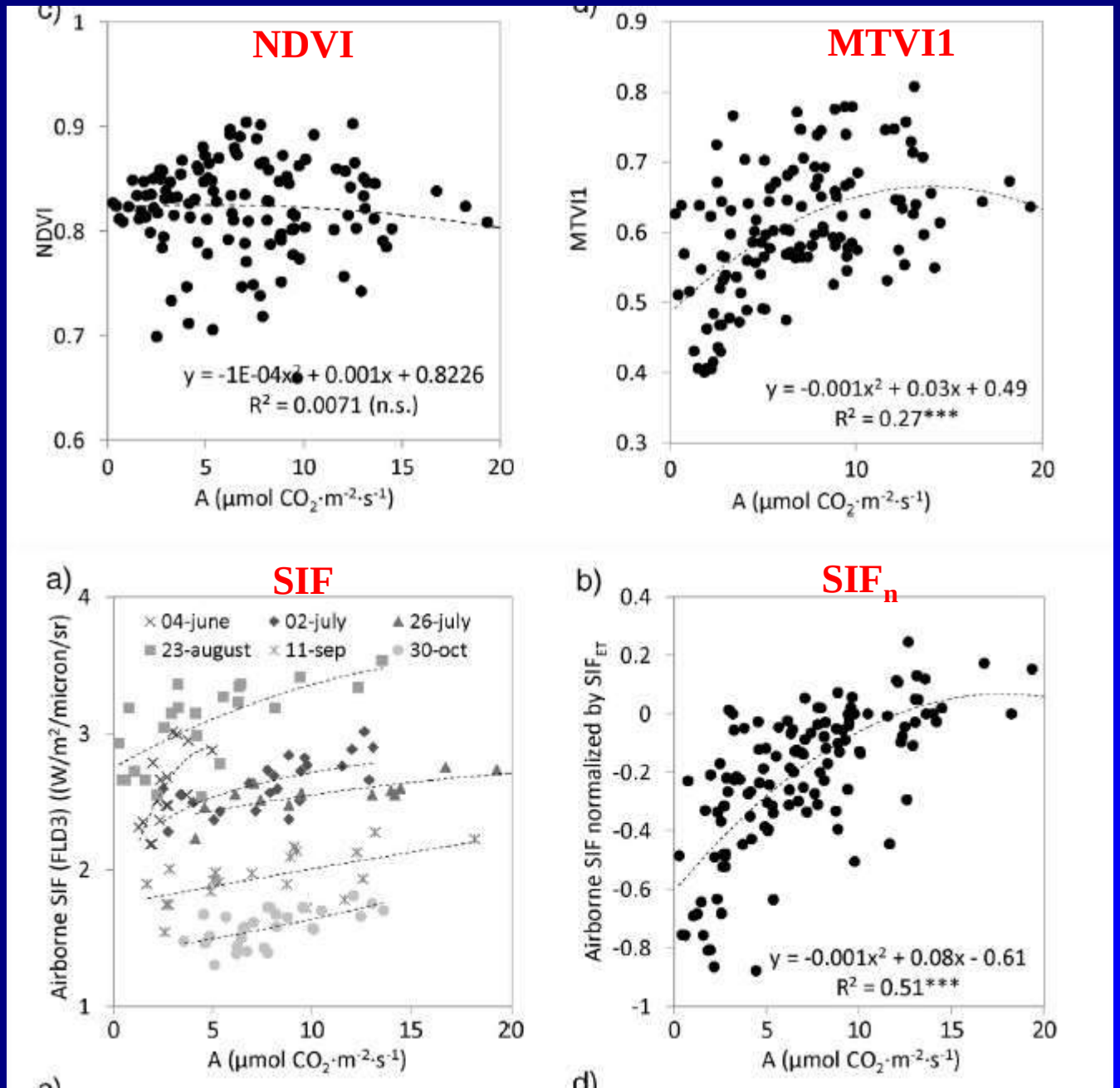
1 nm FWHM



6.5 nm FWHM & oversampling at 1.85 nm / band

Hernández-Clemente *et al.* (2017)

Using SIF for water stress detection in precision agriculture



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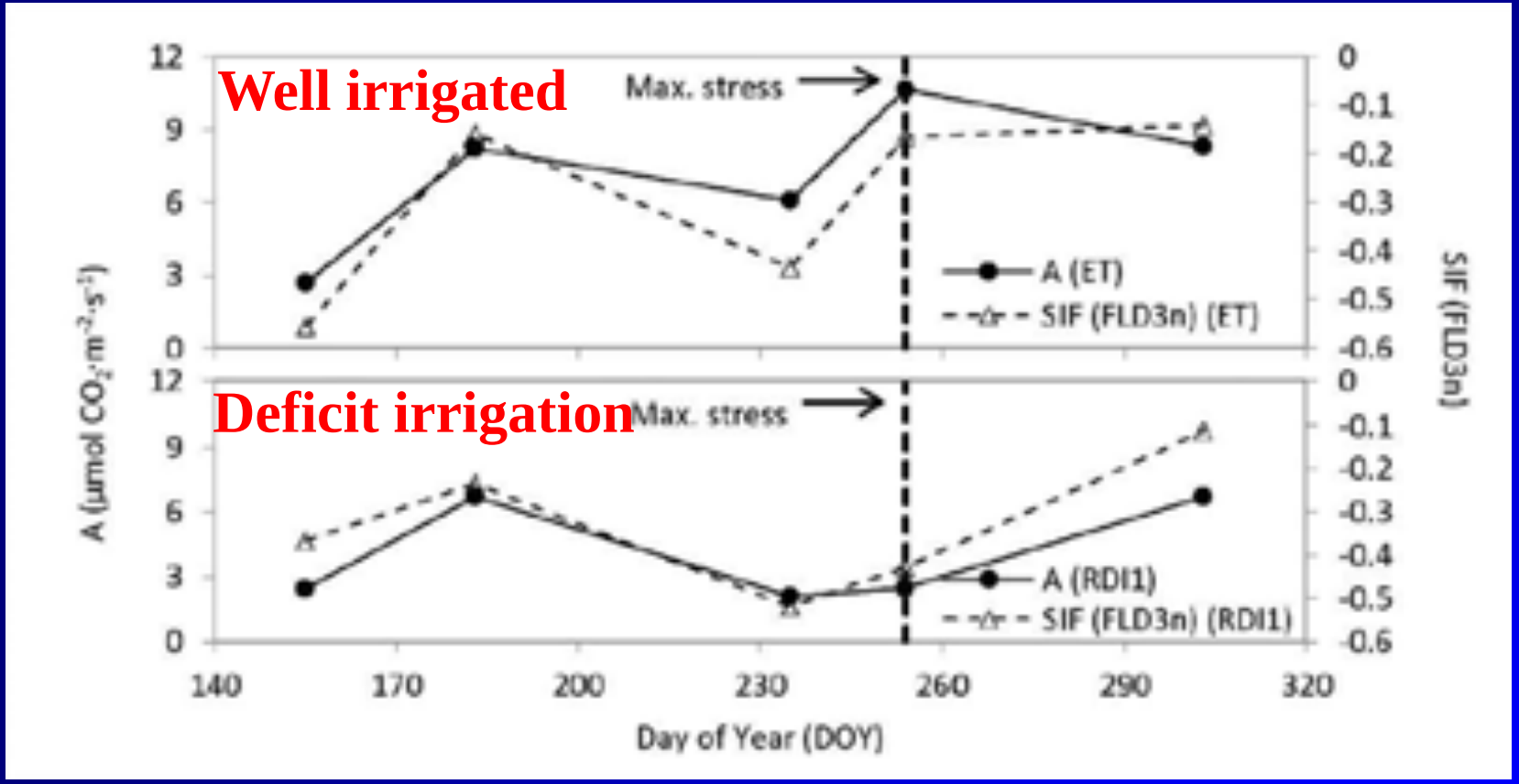
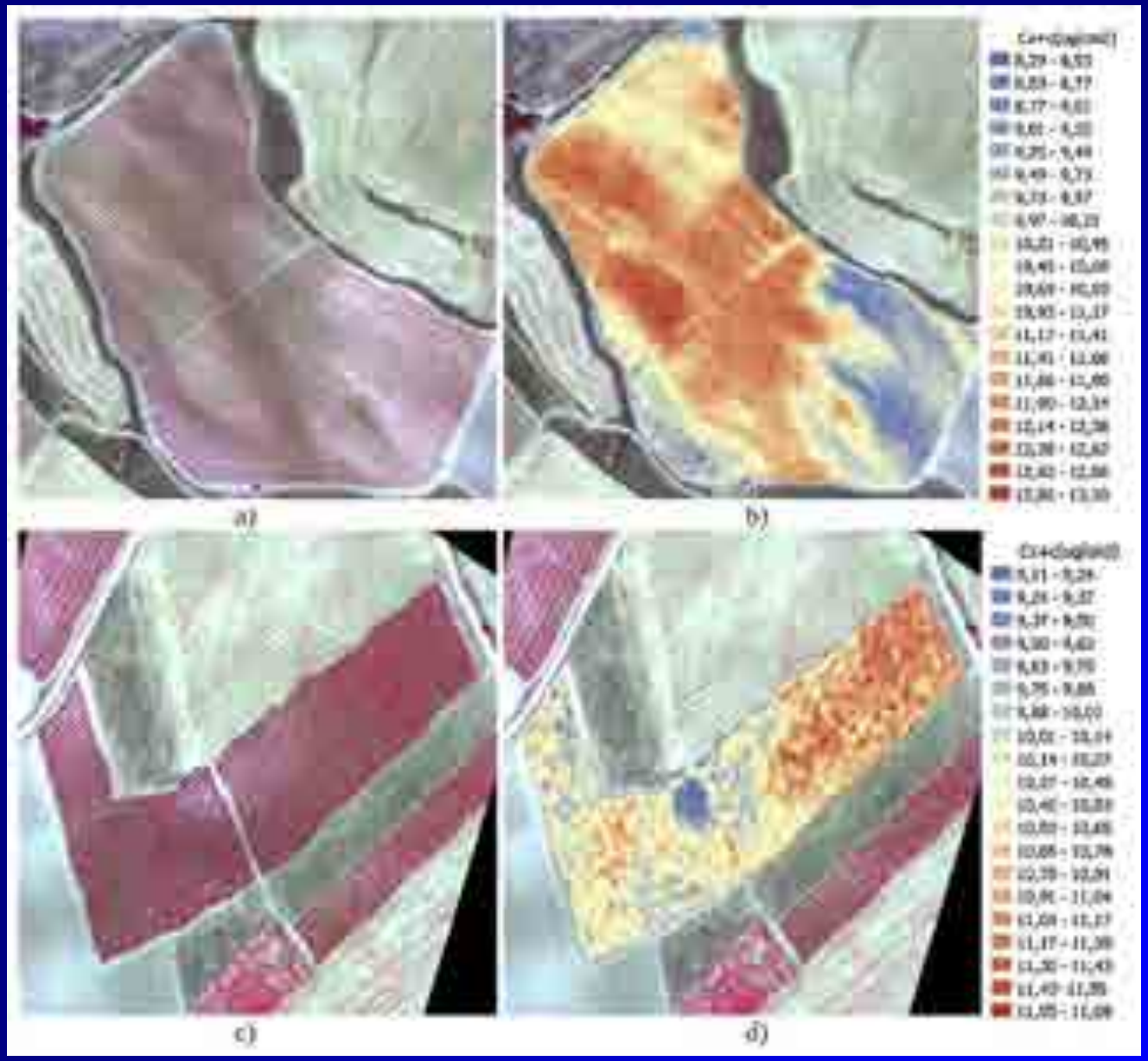


Zarco-Tejada *et al.* (2017)

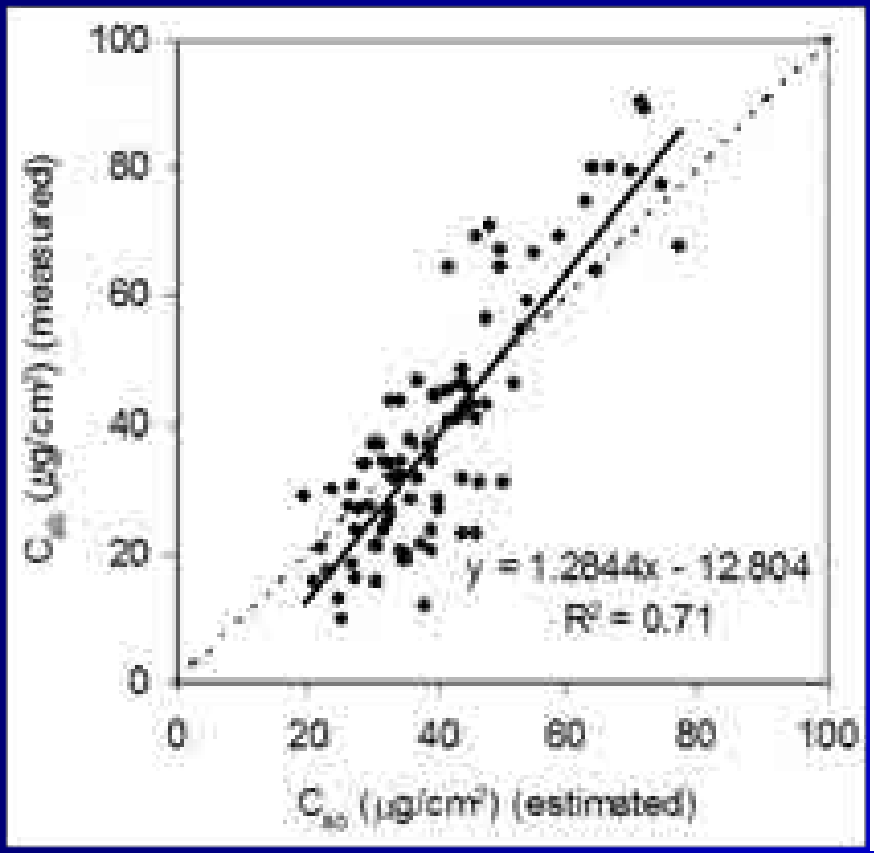
Chlorosis detection

Chlorophyll & Car content maps → ***nutrient stress***

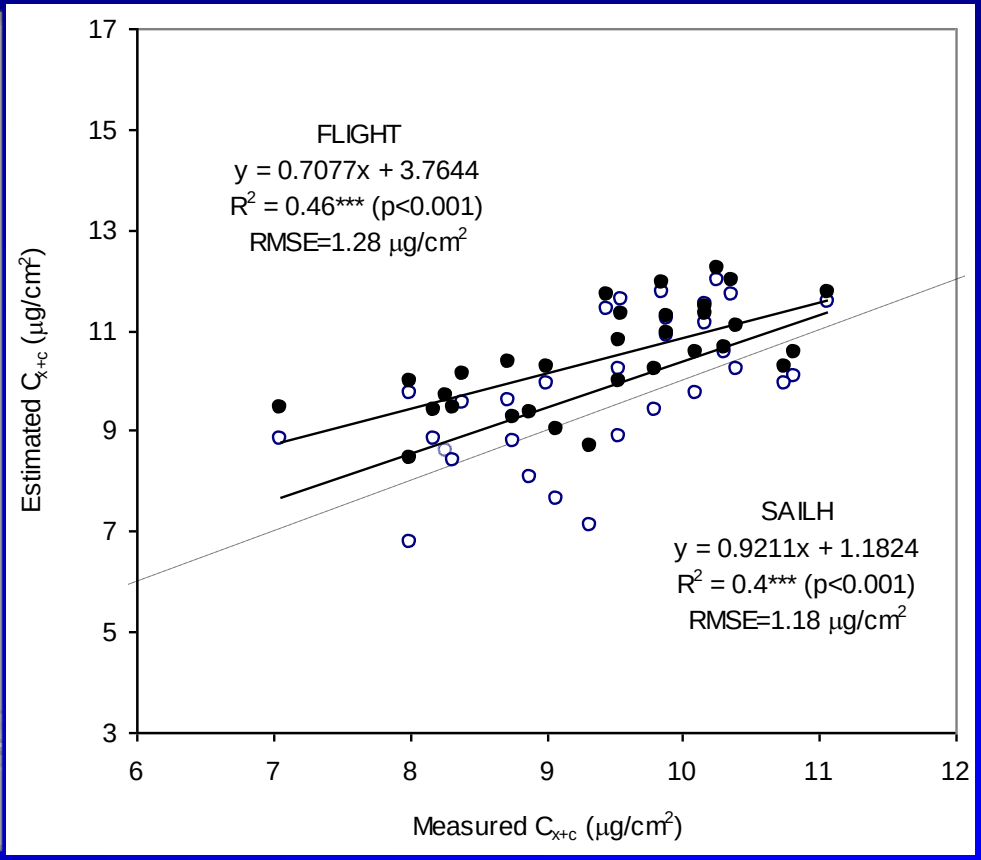


Zarco-Tejada *et al.* (2013)

Chlorophyll & Carotenoid content estimation



C_{a+b}

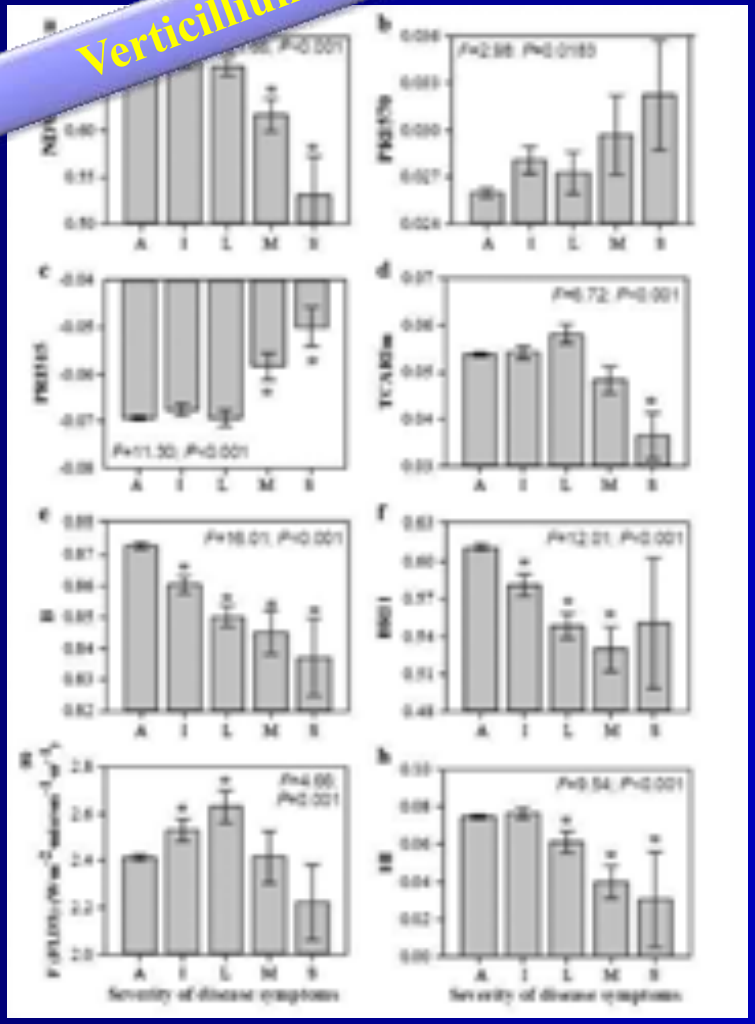


C_{x+c}

Disease detection

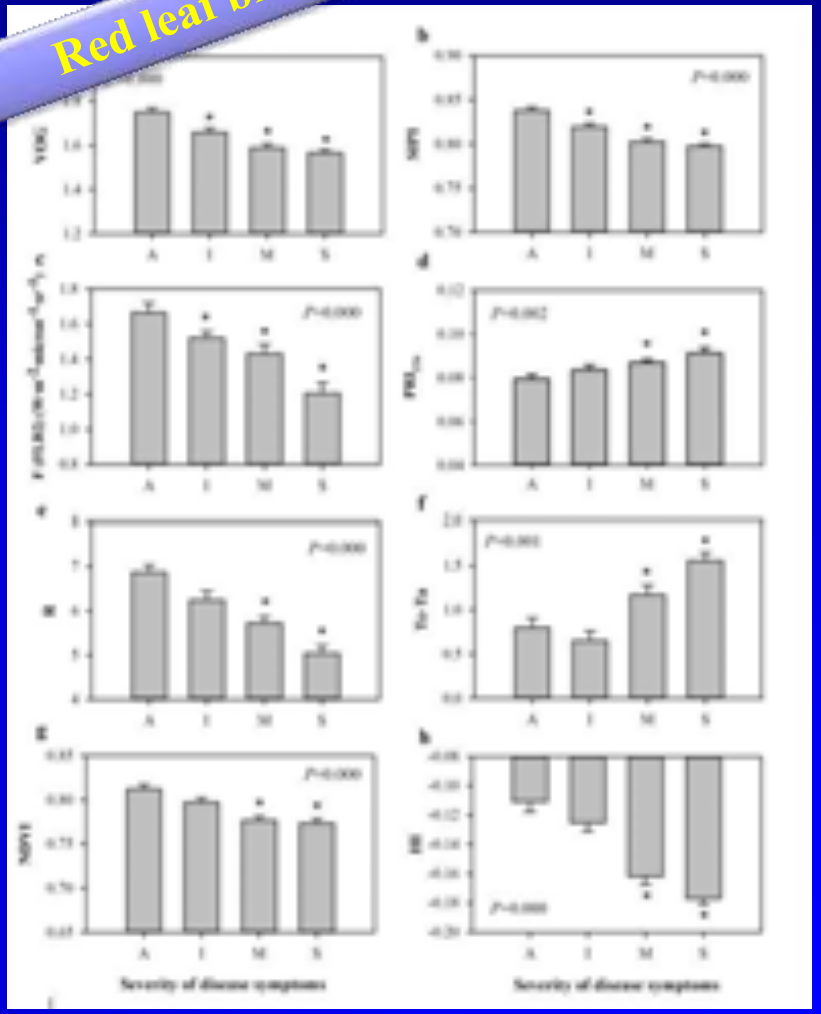
VHR hyperspectral & thermal indices for disease detection

Verticillium wilt



Calderon *et al.* (2013; 2015)

Red leaf blotch



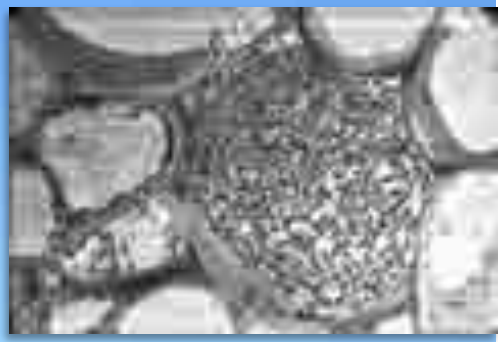
Lopez-Lopez *et al.* (2016)

VI isease

Verticillium

Ez-Lopez *et al.* (2016)

Gallipoli, Ottobre 2013



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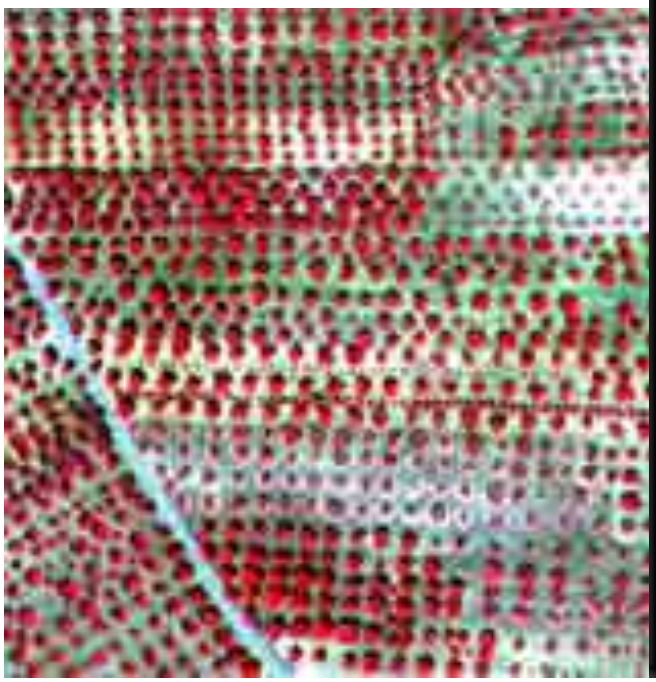
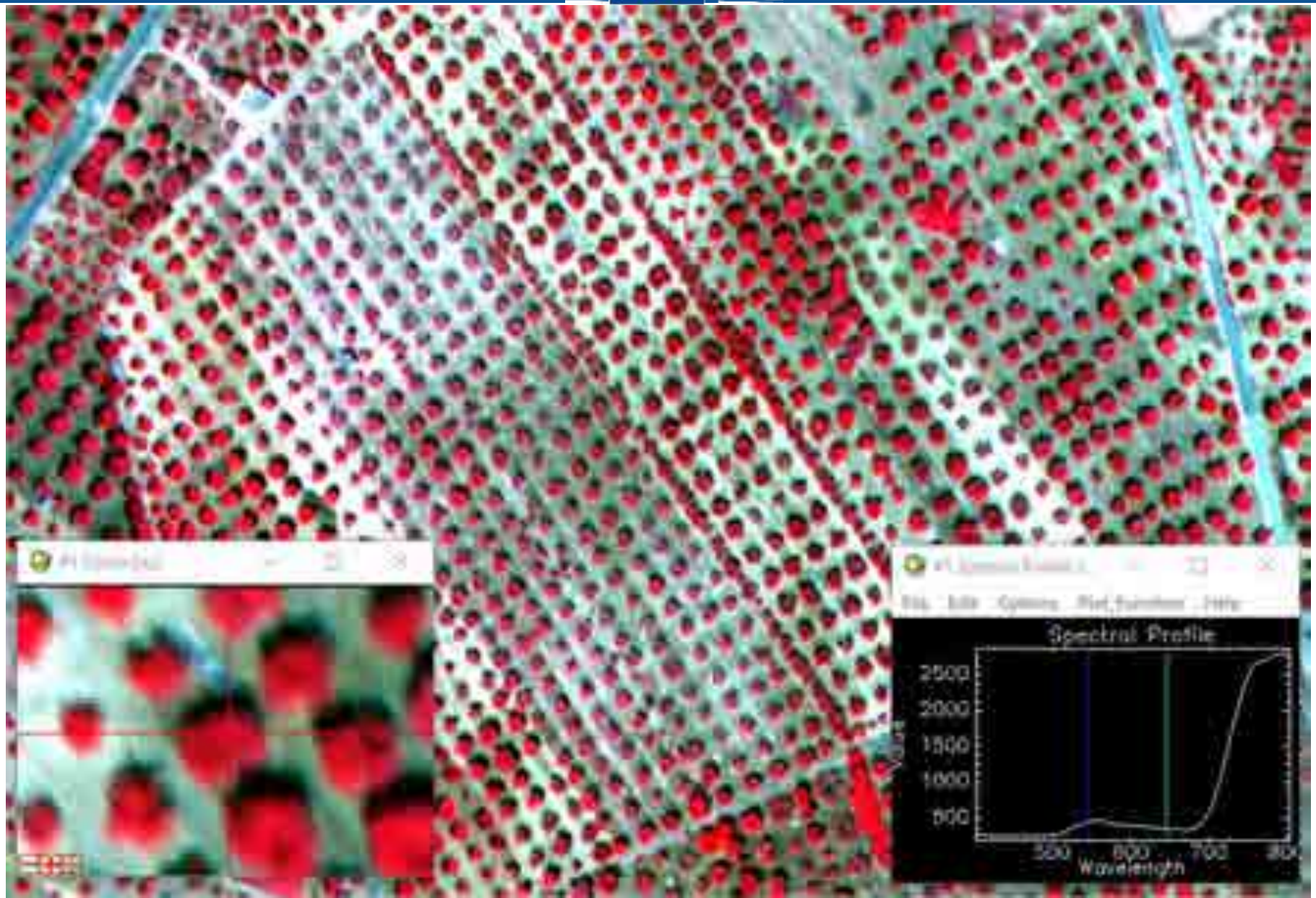
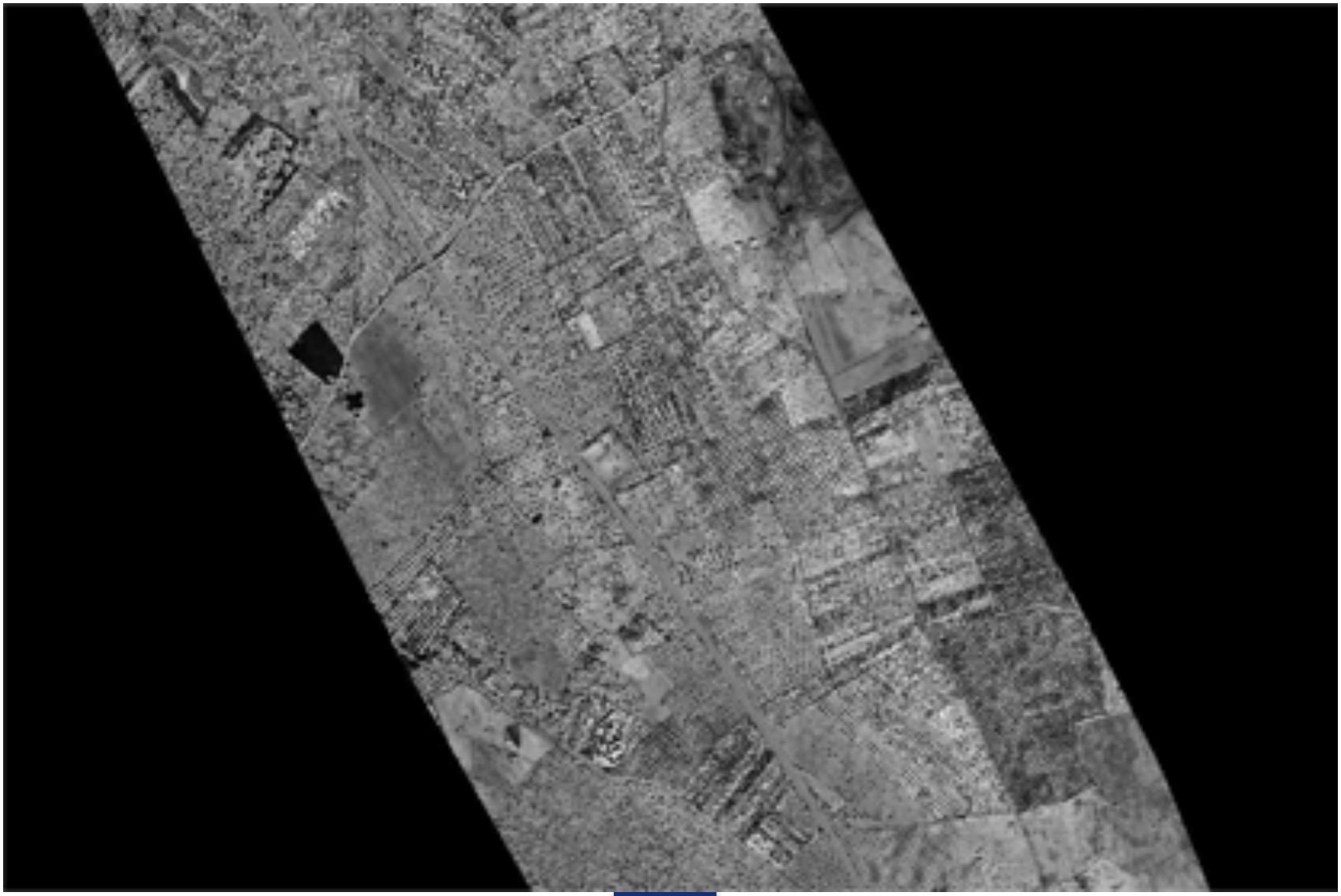
Hyperspectral 45 cm

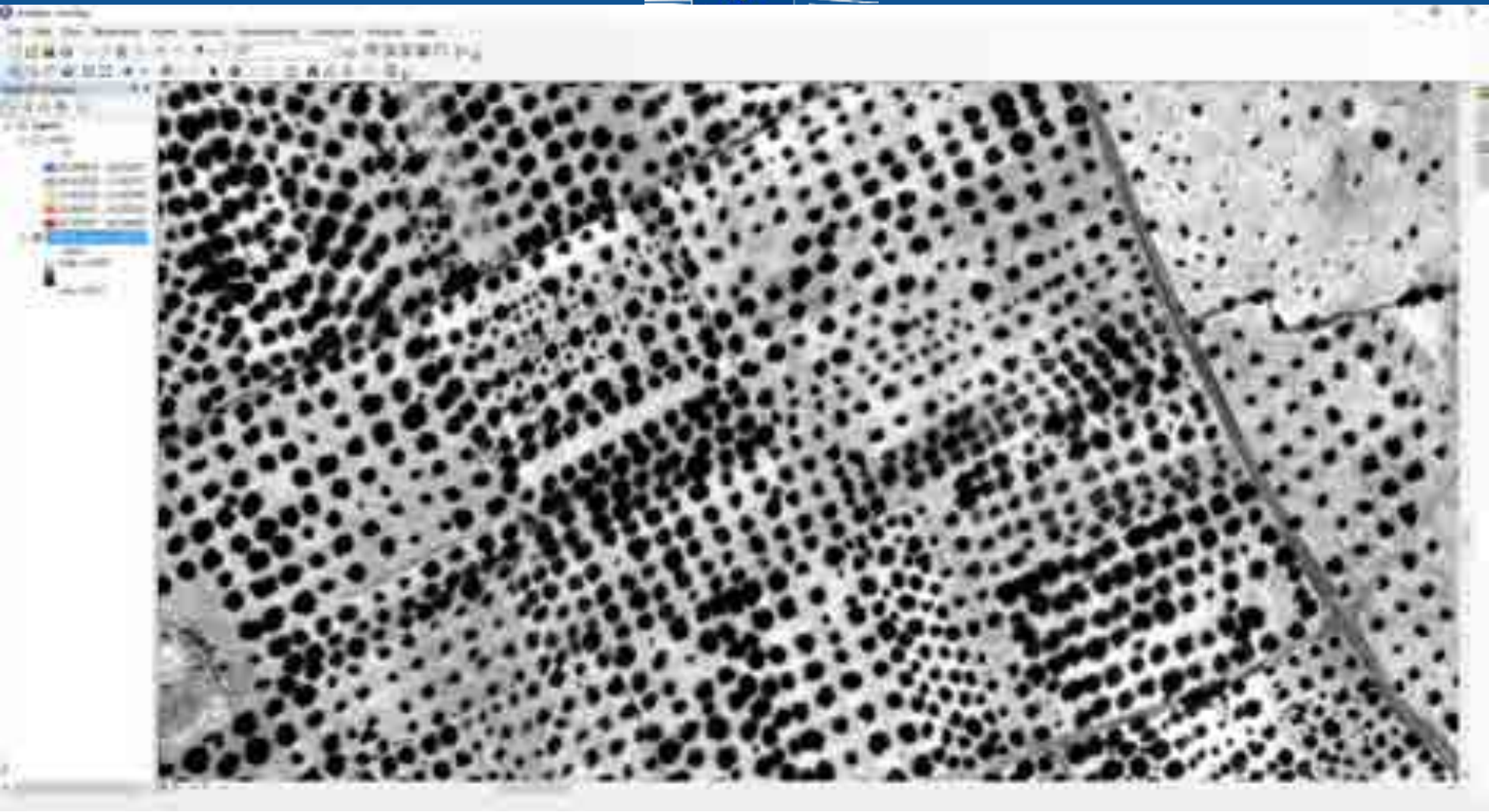


Hyperspectral 45 cm



European Commission

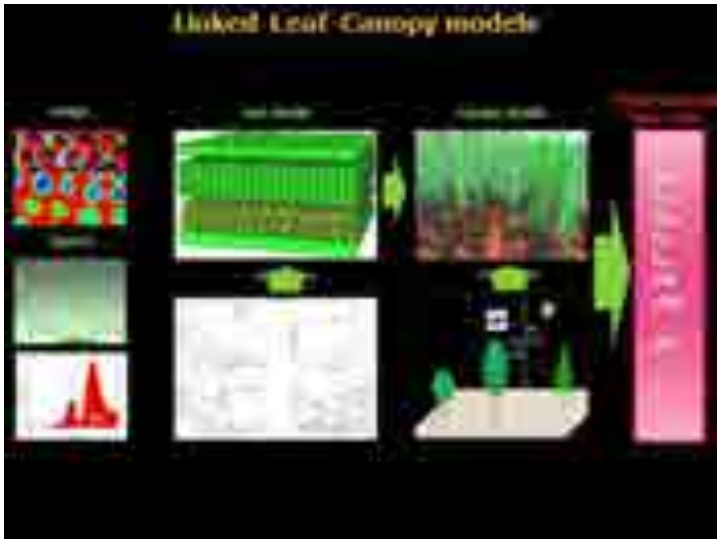




Thermal 60 cm

Thermal 60 cm

Model-retrieved Plant Traits



+

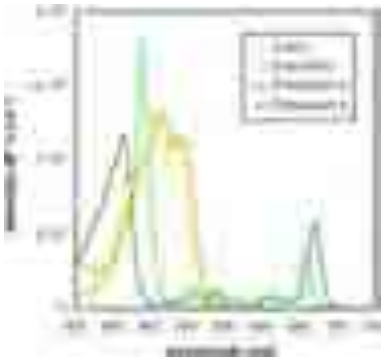
Index-based Plant Traits

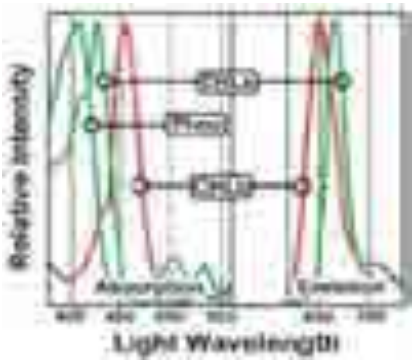
Spectral bandset Traits available

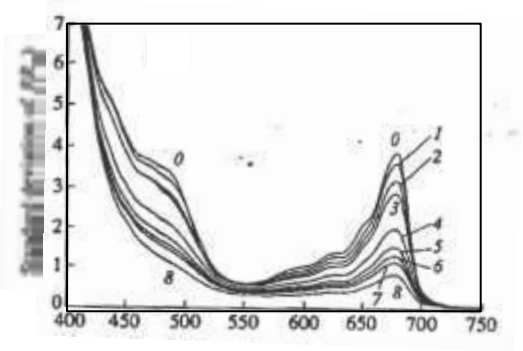
Linear & non-linear Deep / machine learning (LDA / SVM / NN)

Tree by tree physiological assessment

Chlorophyll degradation (Pheophytinization)

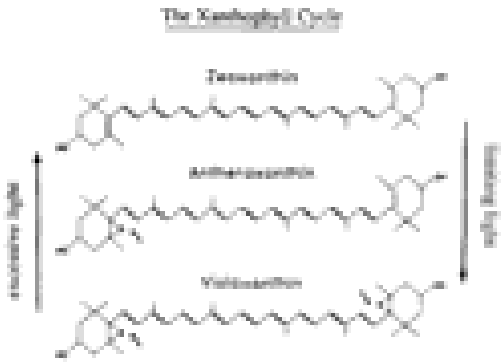


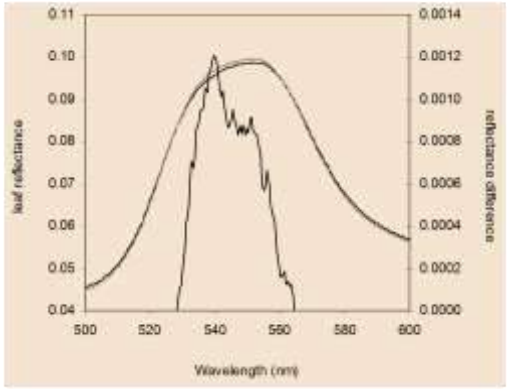




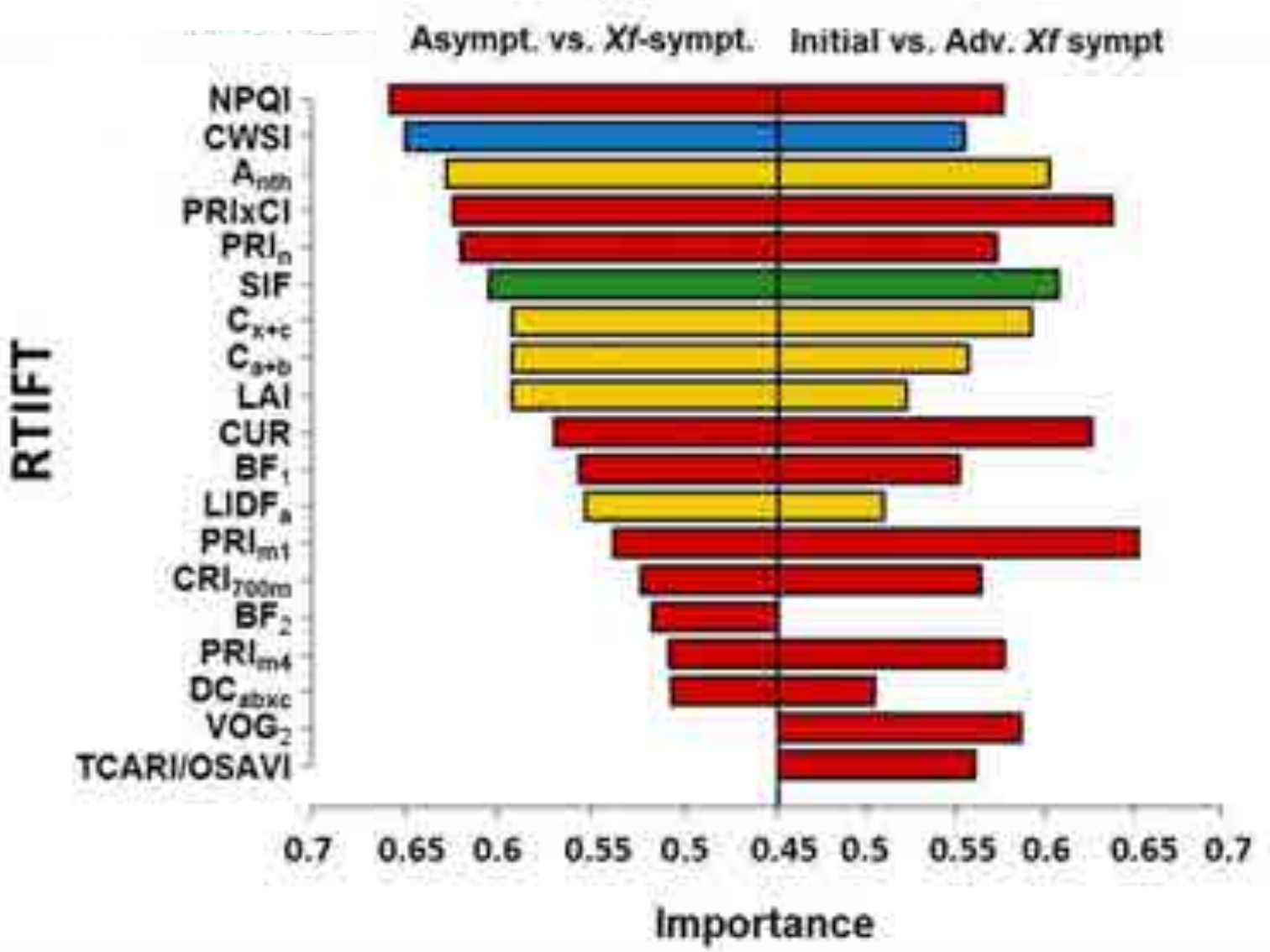
Merzlyak *et al.* (1997)

Xanthophyll cycle (Epoxidation state)

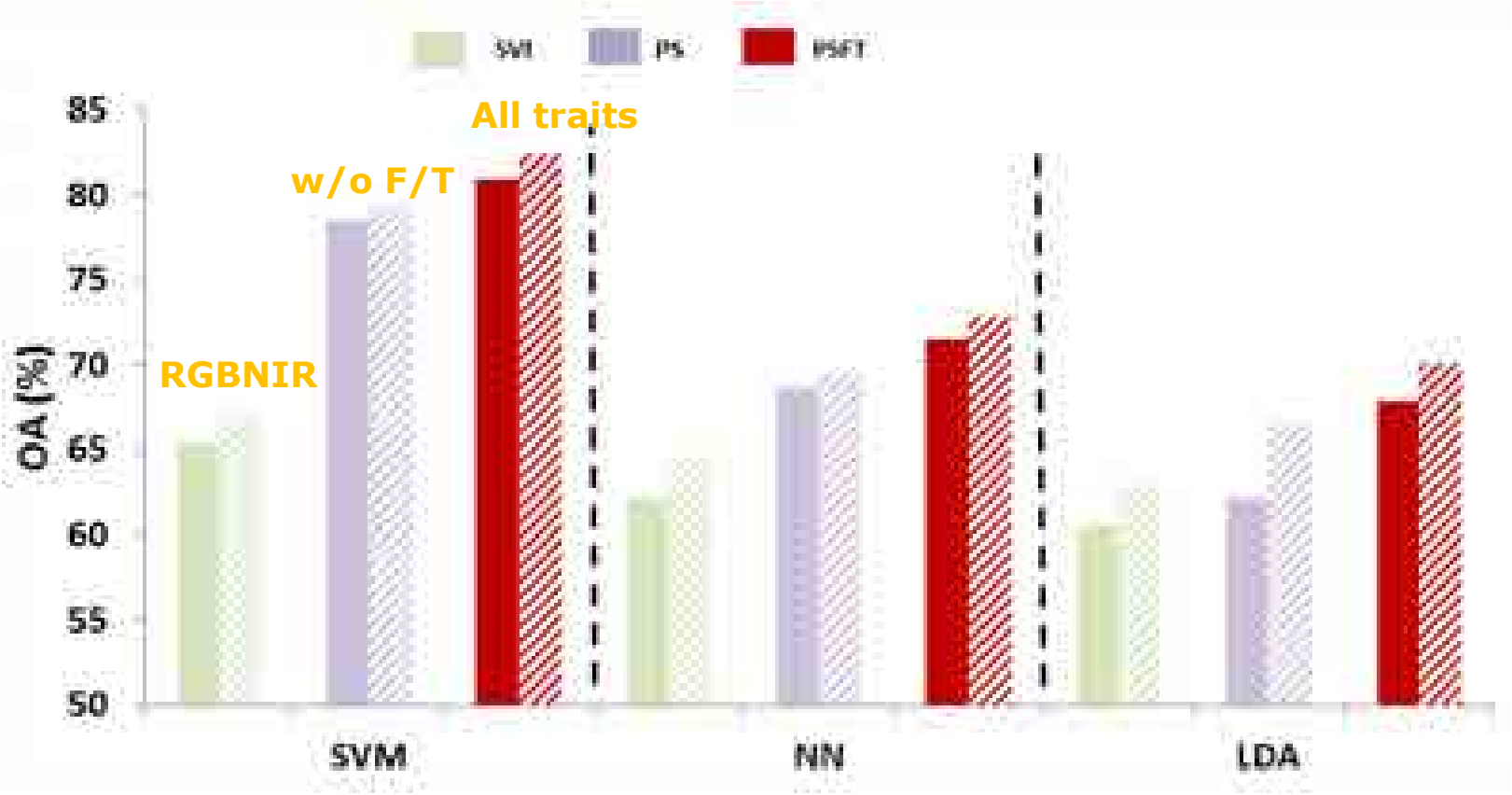




Sensitivity of Plant Traits to *Xf* symptoms



Overall accuracy – 2 year dataset



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Final remarks

- → Tremendous progress in the past 15 years: from "toys" to science: scientific papers are critical
- → Proved that we are not collecting *just* pretty pictures: quantitative RS is possible
- → Calibration / atm. correction is still a weakness for some RS users / vendors of drones
- → Progress is needed on hyperspectral use from drones: good quality spectra still hard to get
- → More studies demonstrating larger scale RS from drones are needed to convince at other levels

Do you remember the definition of remote sensing in the 1980s ?

"A solution looking for a problem"

European Commission

I have a drone. What can I use it for ?

Plant physiological traits from high resolution hyperspectral and thermal imagery: models and indices for early stress detection

Pablo J. Zarco-Tejada

European Commission
Joint Research Centre (JRC)
Directorate D – Sustainable Resources

CSIC

Benzin

(17’ endurance)

Benzin

(17’ endurance)

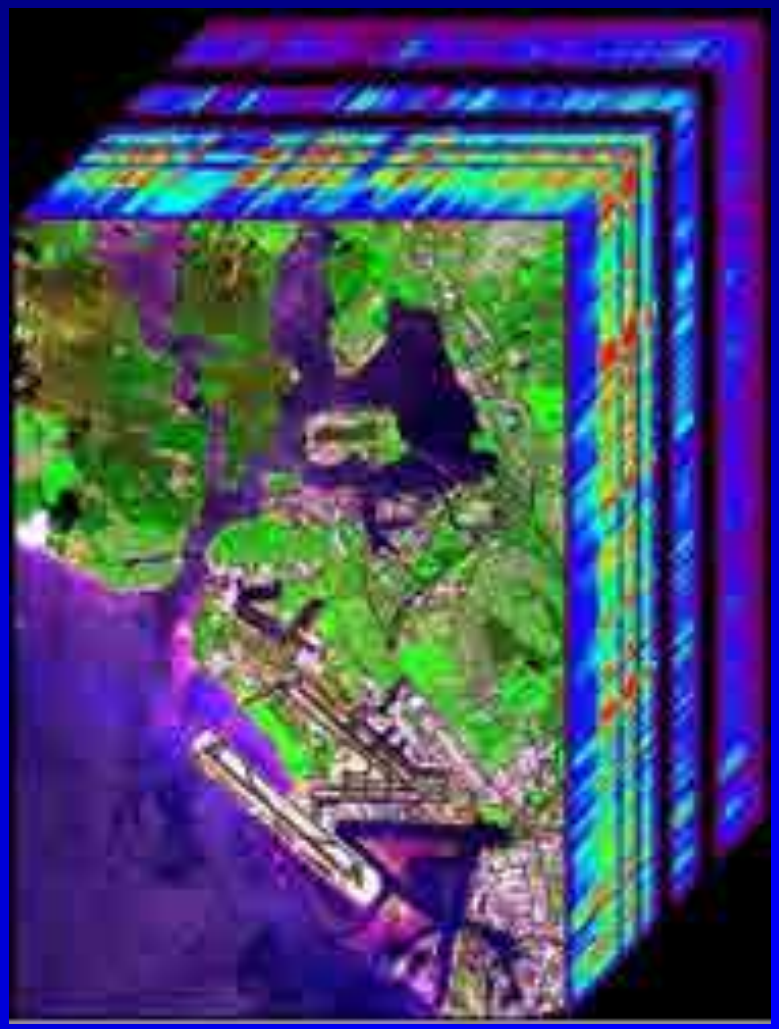

CSIC

CropSight

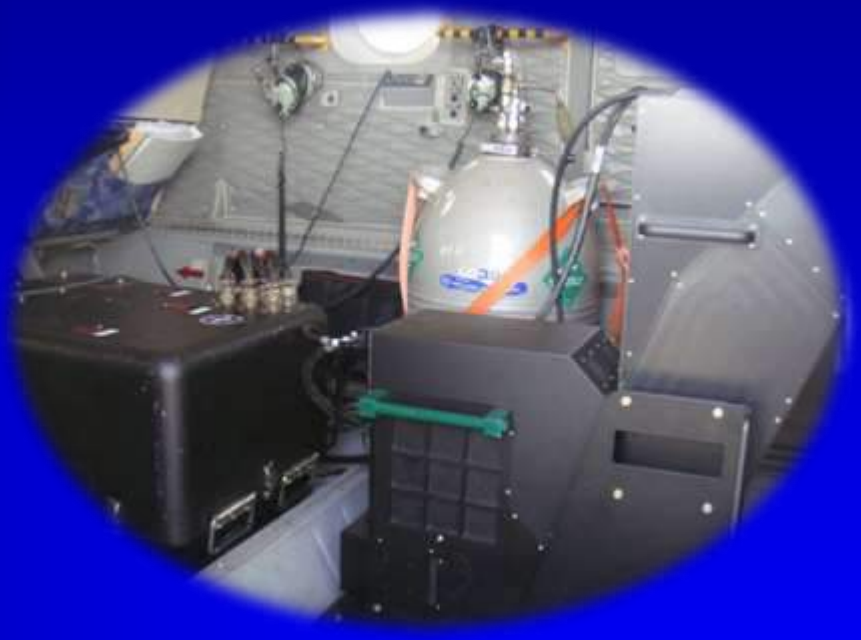
(1 h endurance)

Viewer

CASI hyperspectral imager – 228 spectral bands @ 2 m spatial resolution



AVIRIS NASA-JPL hyperspectral sensor -
224 contiguous spectral channels



MIVIS / AHS / Daedalus – INTA

- INTA (Spain)
- DLR (Germany)
- NERC (UK)

Remote Sensing Indicators of Vegetation Stress

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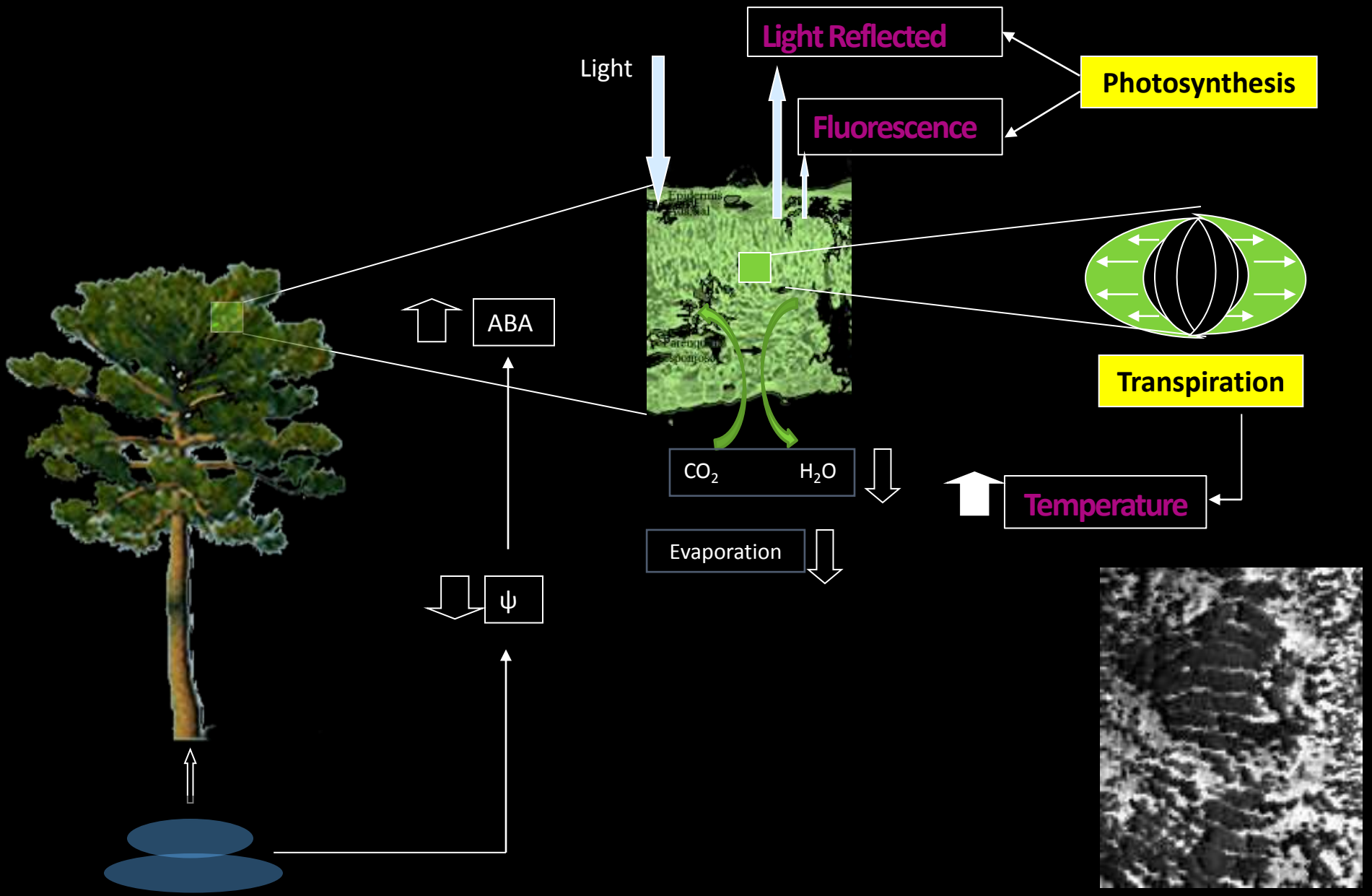
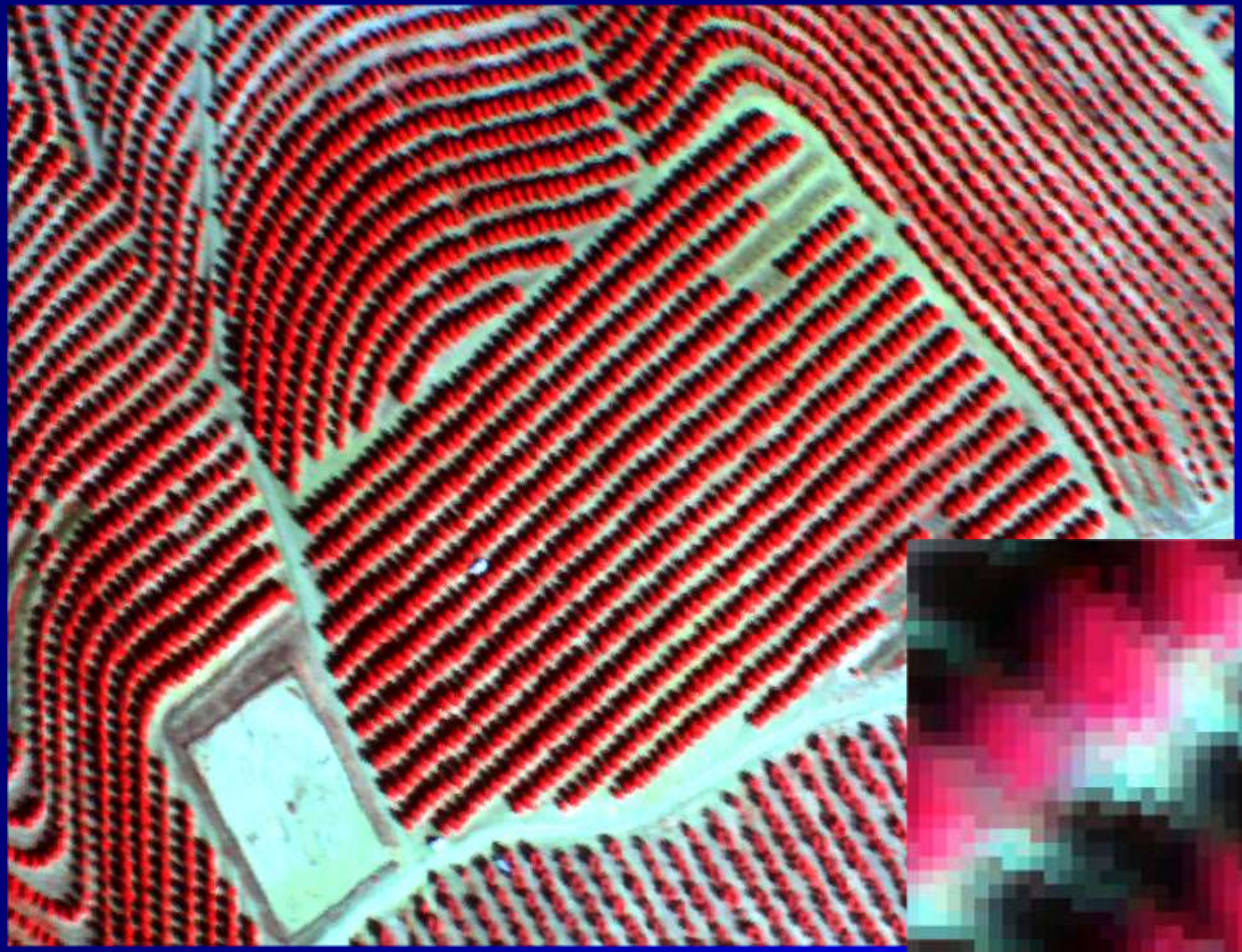
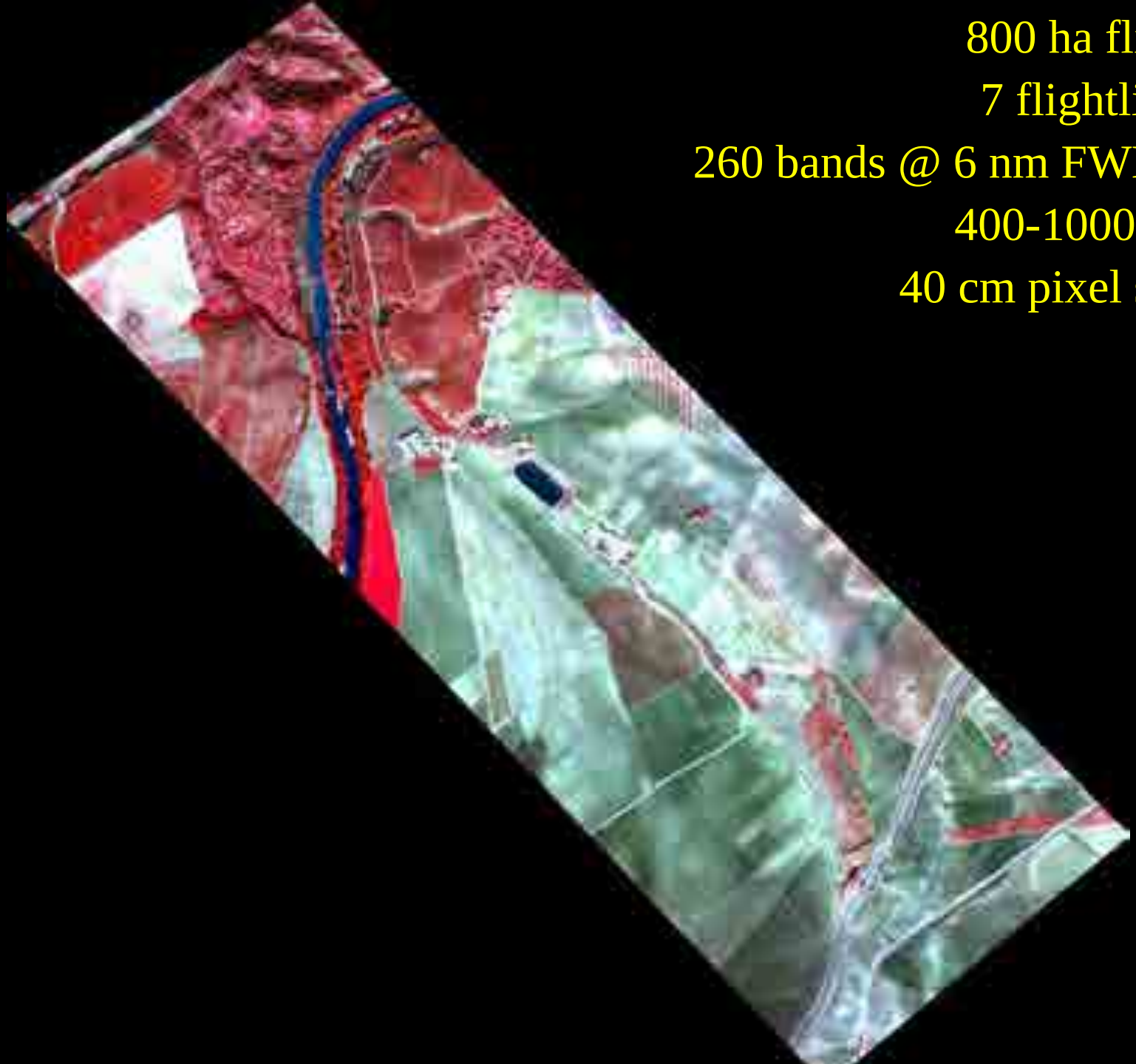

Light Reflected
Light
Photosynthesis
Fluorescence
ABA
Transpiration
CO_2
H_2O
Temperature
Evaporation
ψ

Low-cost UAV platforms



CSIC



800 ha flight
7 flightlines
260 bands @ 6 nm FWHM
400-1000 nm
40 cm pixel size