Simulating 3D radiation transfer in kiwifruit orchards:
a virtual laboratory for the horticulture industry

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eurofins

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Plant & Food™ Research
Rangahau Ahumāra Kai

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

Outline

1. Motivation

2. Why 3D radiative transfer?

3. A Virtual kiwifruit orchard

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Climate change has slowed down agricultural productivity growth by 21%
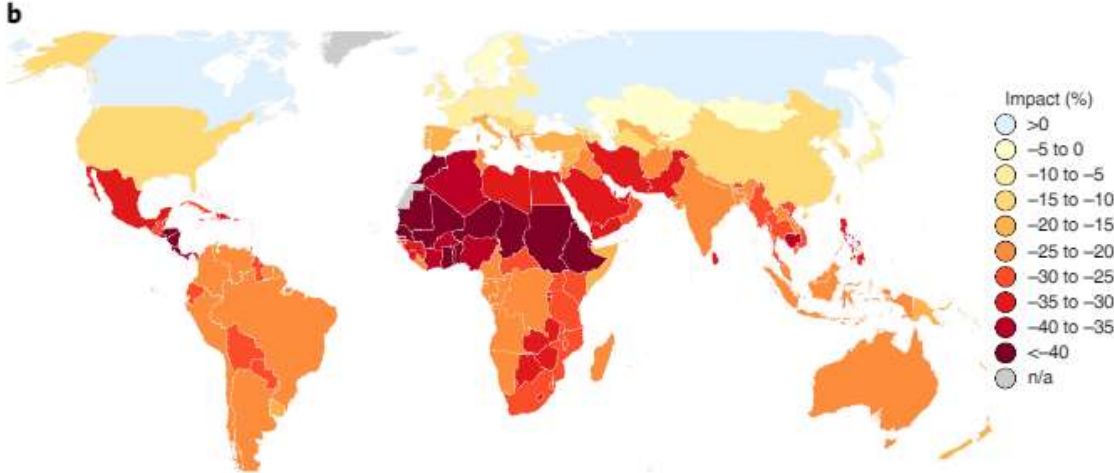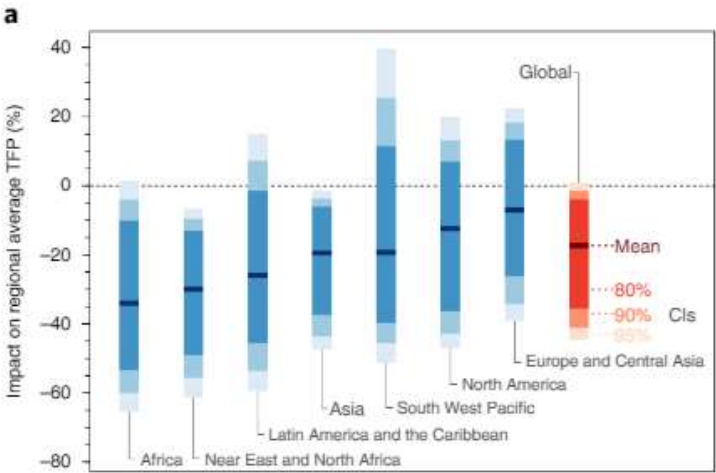
Ortiz-Bobea et al. (2021)

Traditional farm management practices are becoming obsolete

Impact on local horticulture industry

Increase of regulations on freshwater management.

Reduce production of GHG and use of agro-chemicals.
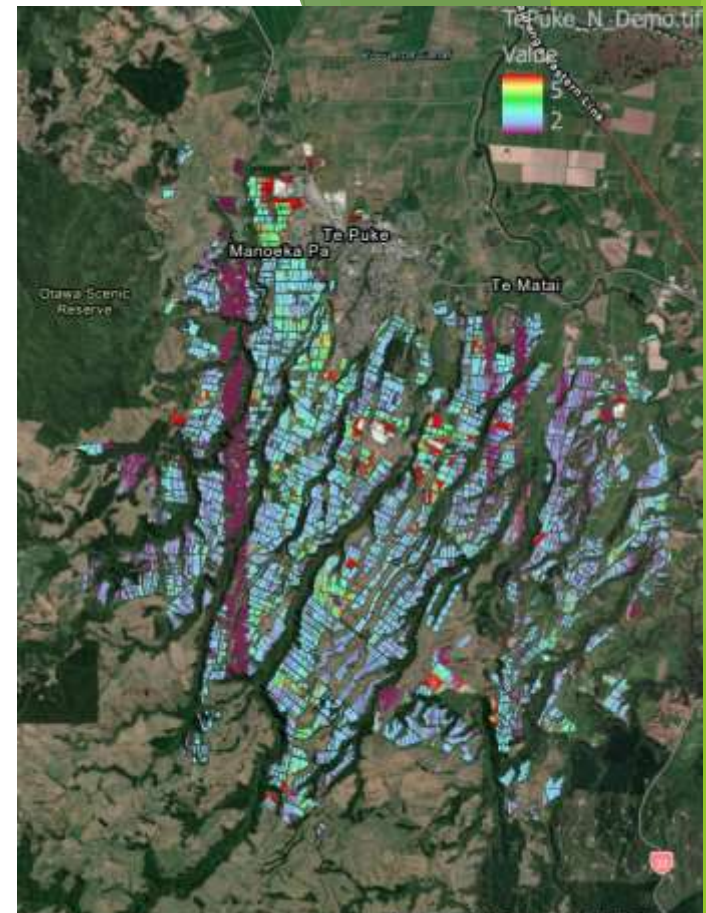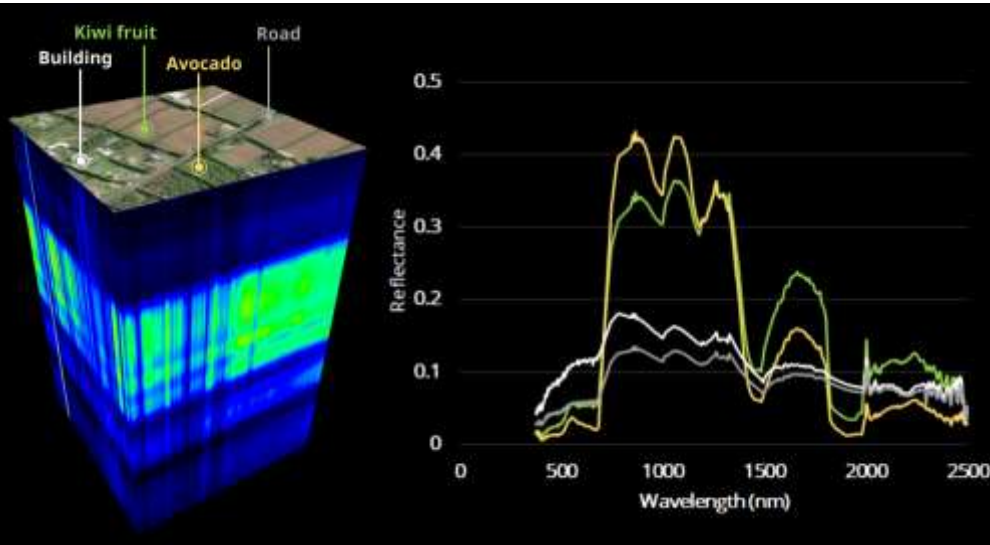
E.g. fertilisers, pesticides

Increased focus on product quality

Customers demand quality and environment-friendly products.

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Precision agriculture

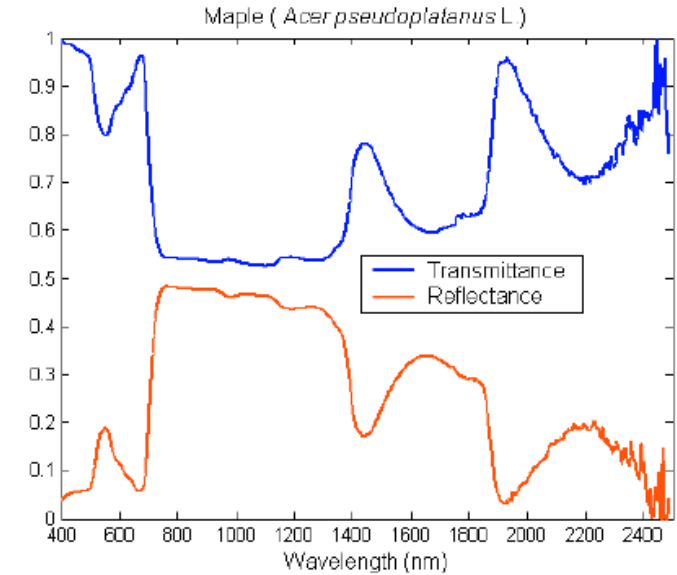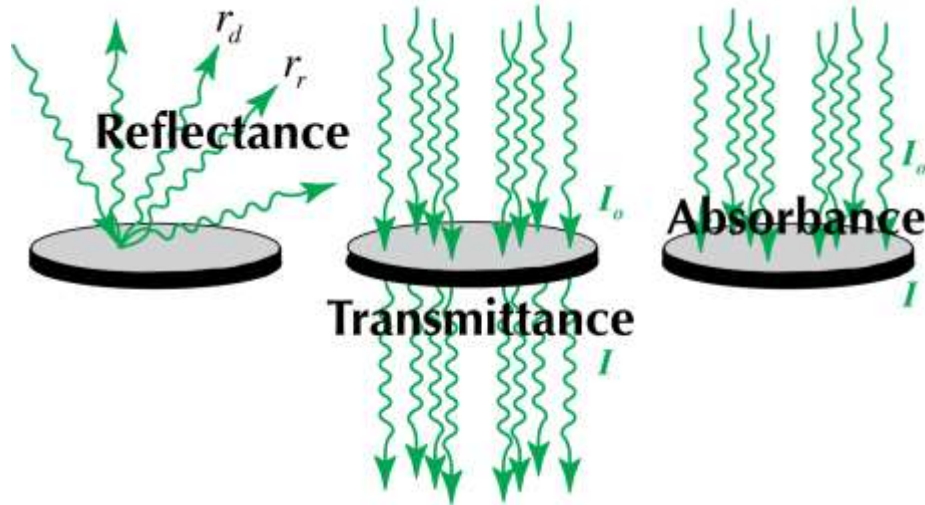Hyperspectral imaging data cubes measuring canopy reflectance spectra

Leaf Nitrogen concentration over large areas

Outline

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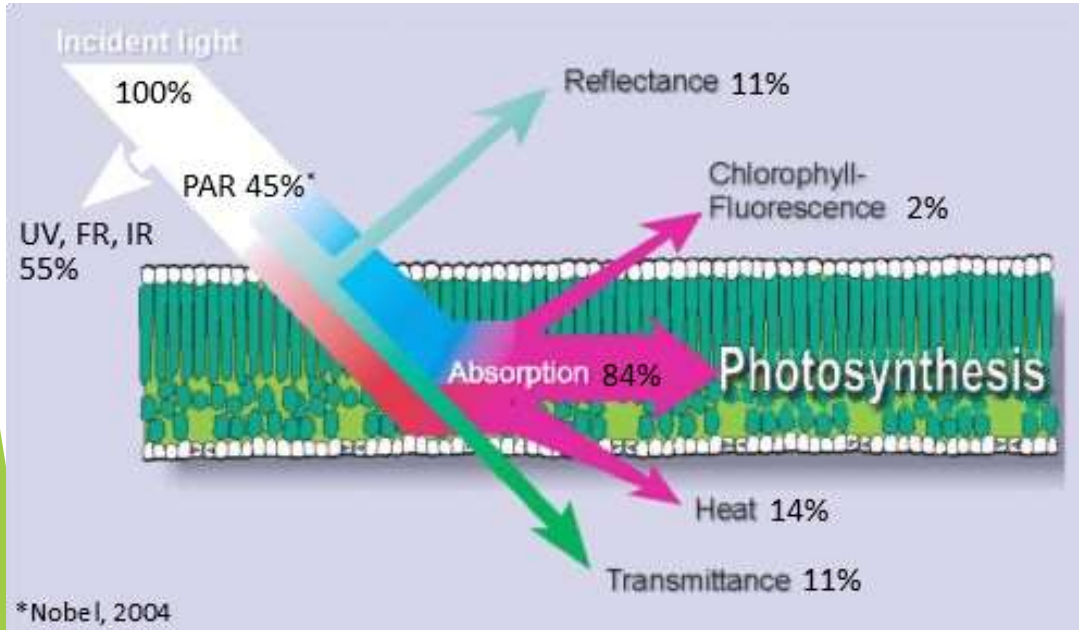
3. A Virtual kiwifruit orchard

How vegetation responds to sunlight

Maple (*Acer pseudoplatanus* L)

- Leaf optical properties vary with wavelength
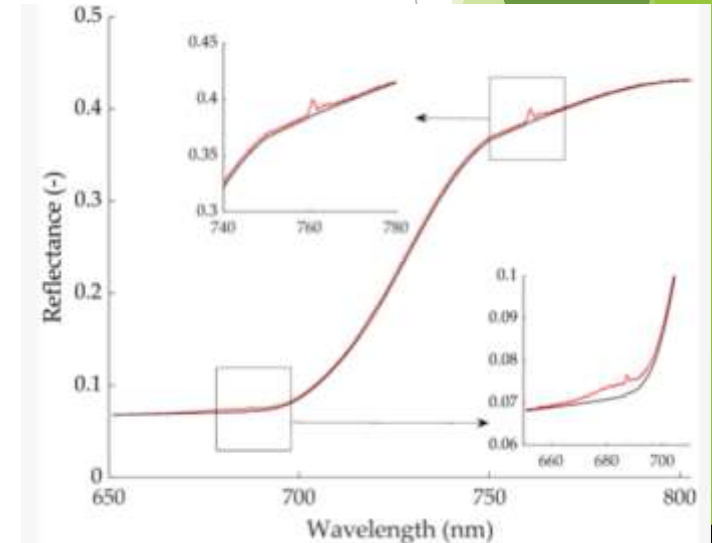- Depend on biophysical and biochemical parameters

The challenge of sun-induced fluorescence

- SIF reveals the performance of photosynthetic activity
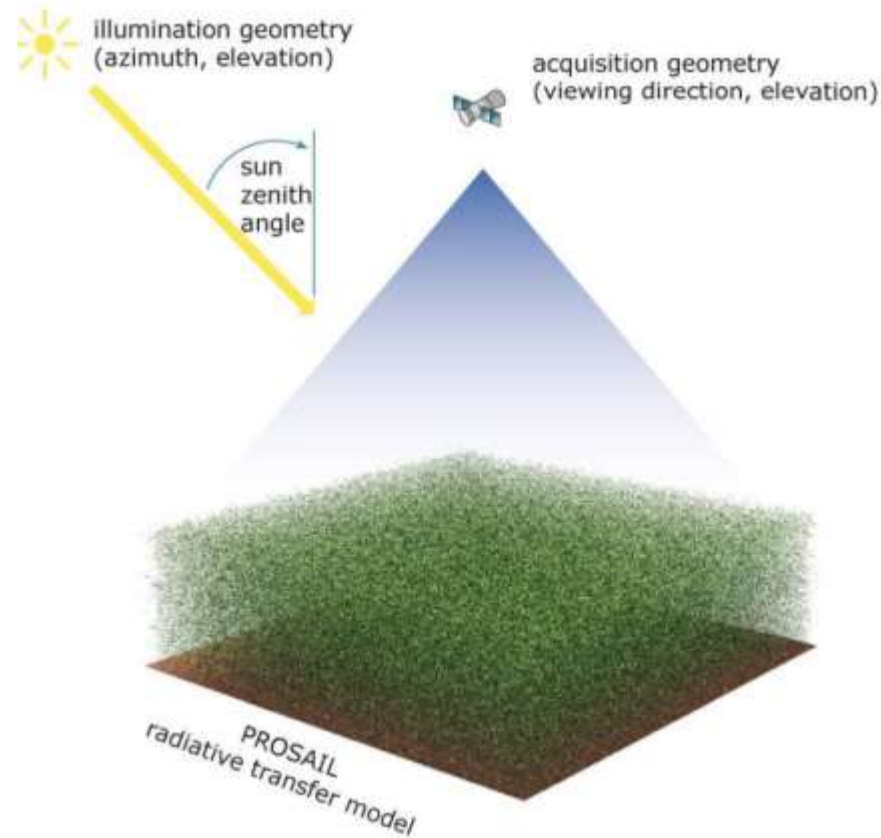- Early indicator of plant stress

... but
- it is incredibly difficult to measure with remote sensing.
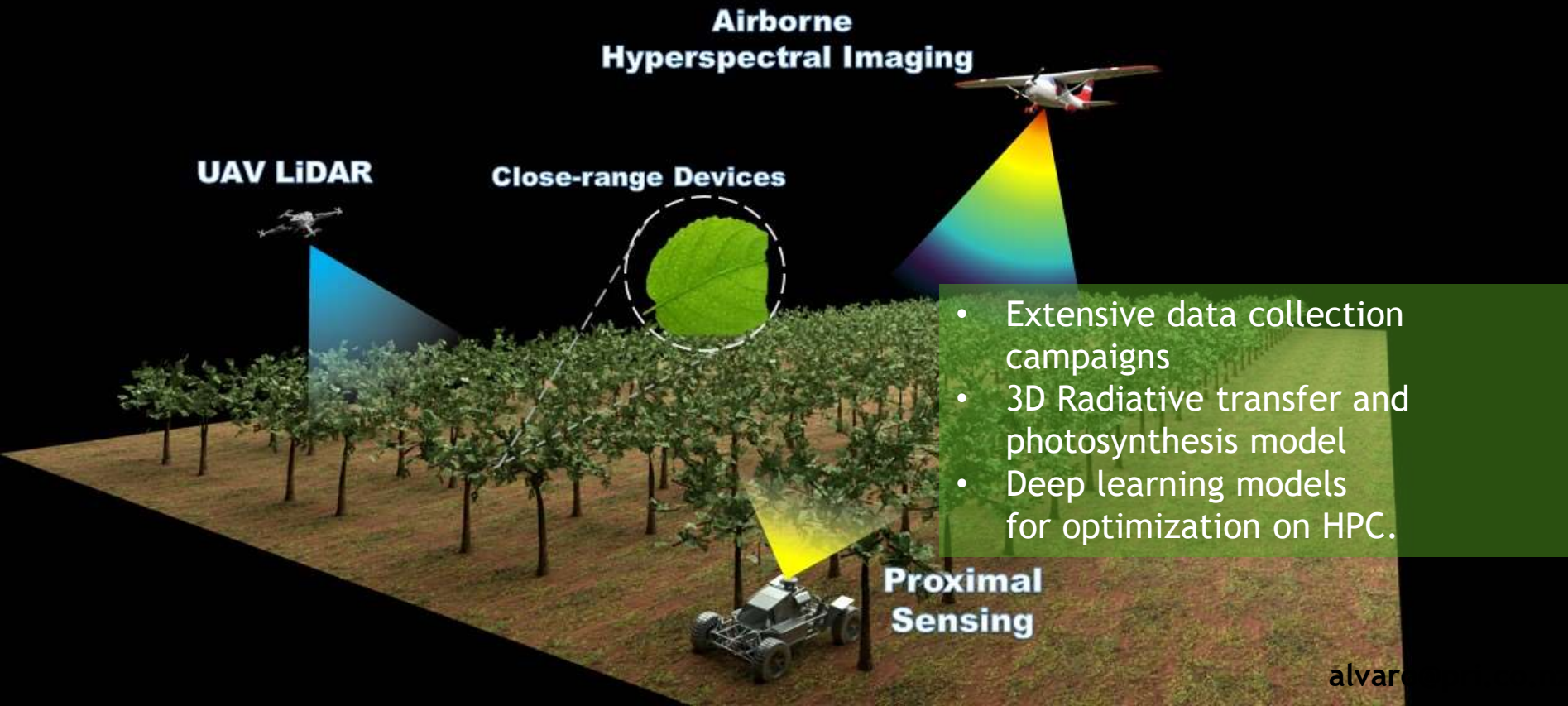- Requires understanding of radiation transfer and photosynthesis

From leaf to canopy radiative transfer

- Turbid medium approximation
- 1D calculation
  - Vertical heterogeneity can be included
  - Horizontal heterogeneity missing

S. Jacquemoud et al. (2009), PROSPECT + SAIL models: a review of use for vegetation characterization. Remote Sensing of Environment, 113, pp. 56-66.
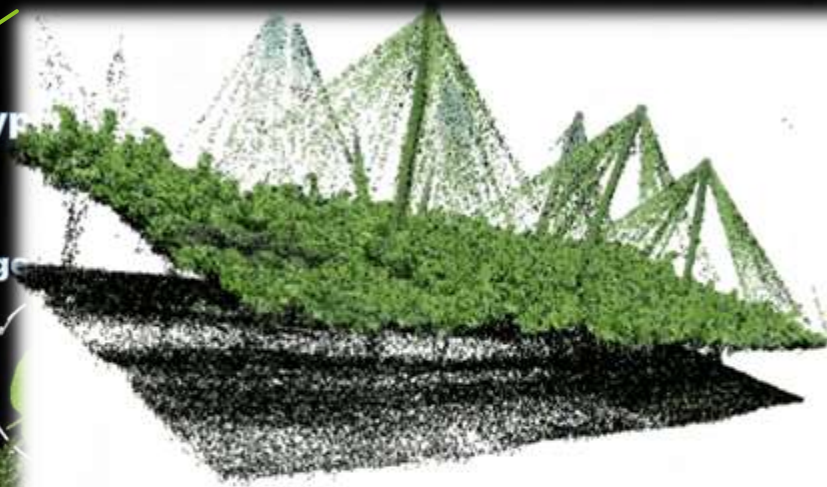
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Our strategy

- Extensive data collection campaigns
- 3D Radiative transfer and photosynthesis model
- Deep learning models for optimization on HPC.

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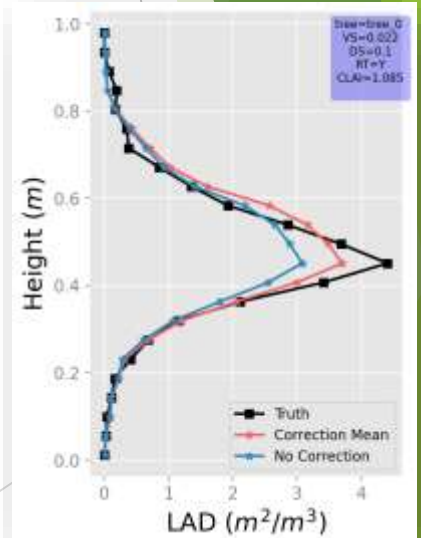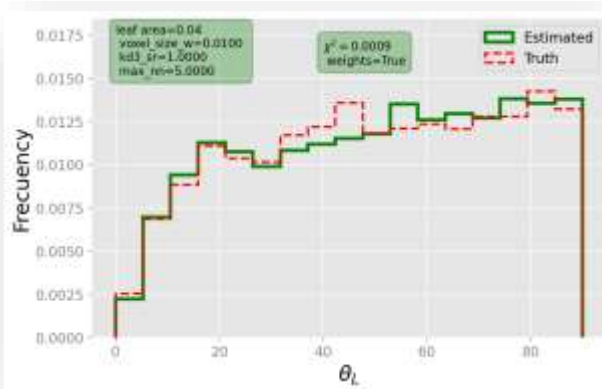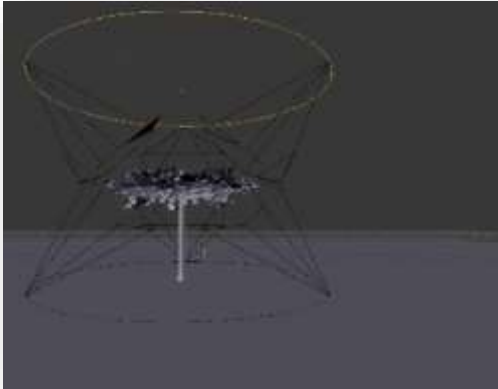
UAV LiDAR

Hyp

Close-range

Proximal
Sensing

alvar

Reconstructing canopy structure from LiDAR

▶ Procedural tree generation model (Weber & Penn, 1995)

▶ LiDAR simulation on `Blender`

▶ Extract leaf angle distribution and leaf area density.
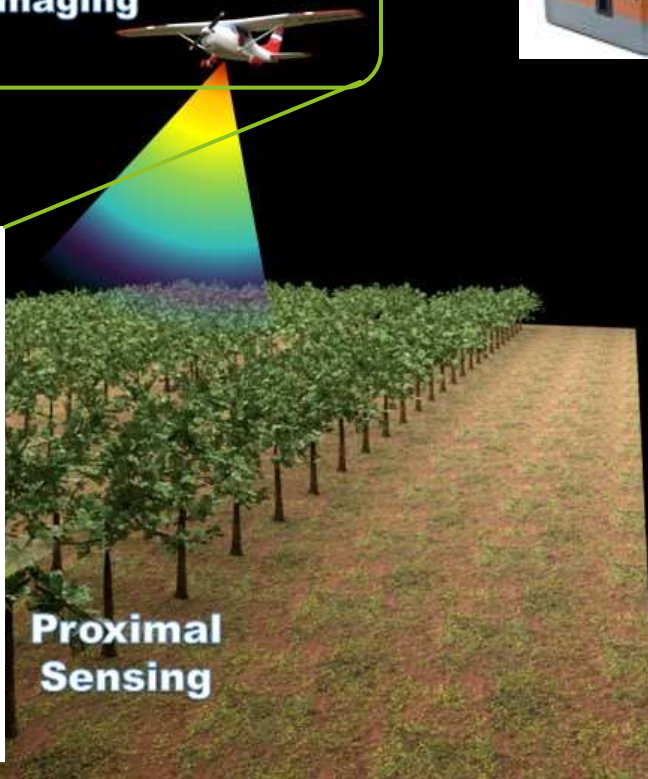
SPECIM
SPECTRAL IMAGING
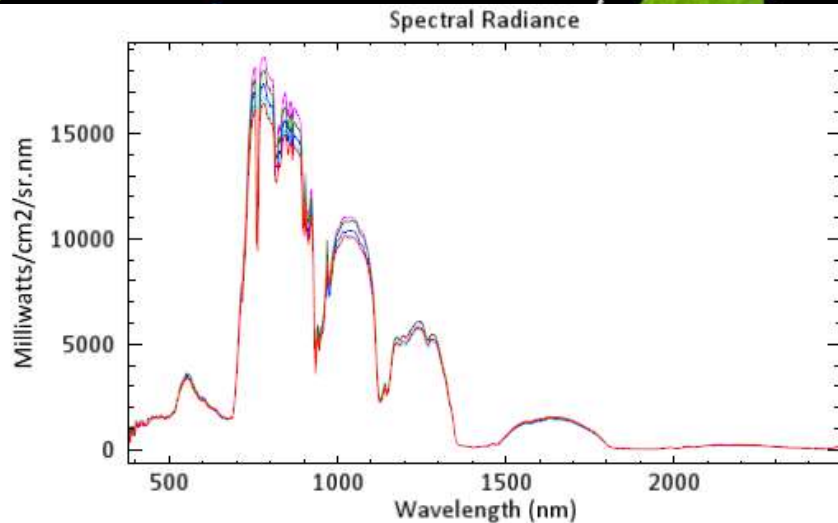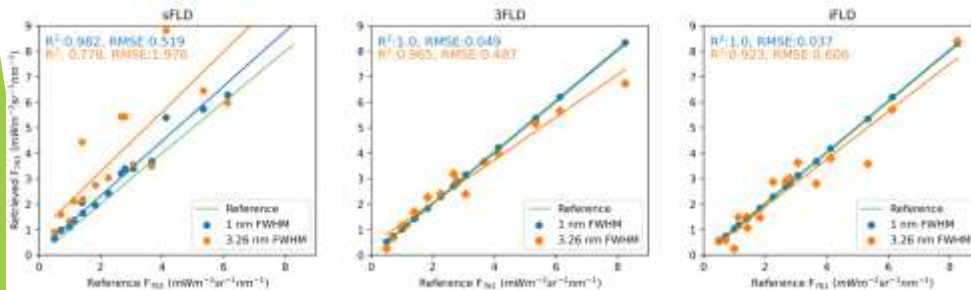
AISAFENIX

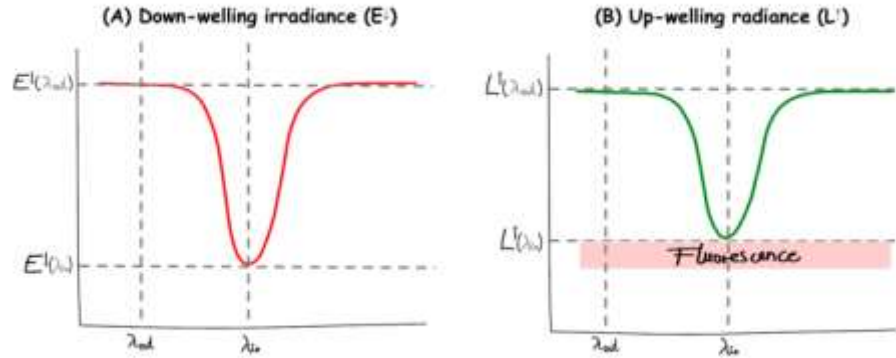Airborne Hyperspectral Imaging

UAV LiDAR

Close-range Devices

Spectral Radiance

Proximal Sensing

Milliwatts/cm2/sr.nm

15000

10000

5000

0

500   1000   1500   2000

Wavelength (nm)

Extracting SIF from Hyperspectral imaging

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Airborne Hyperspectral Imaging
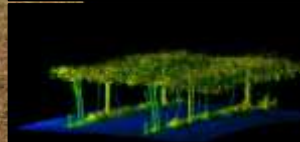
UAV LiDAR
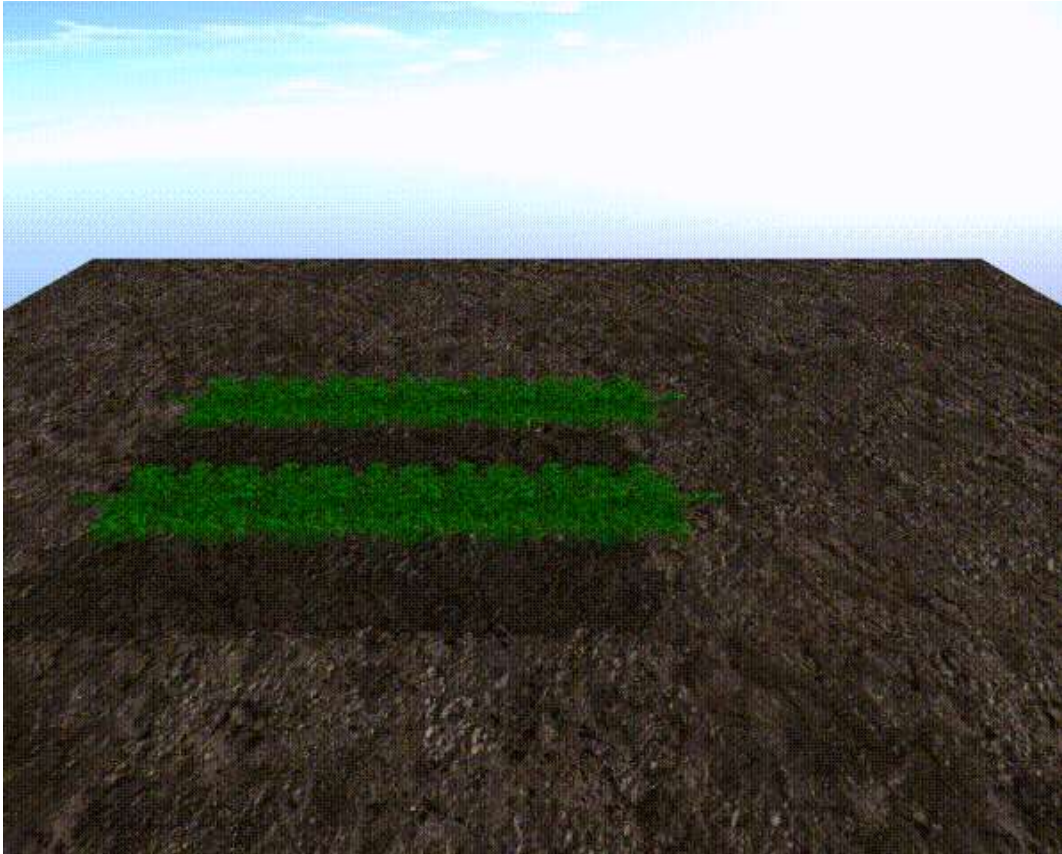
Close-range Devices

Ground truth devices
- *Fluorescence system*
- *Leaf spectra and solar irradiance*
- *Leaf sampling for wet chemistry*
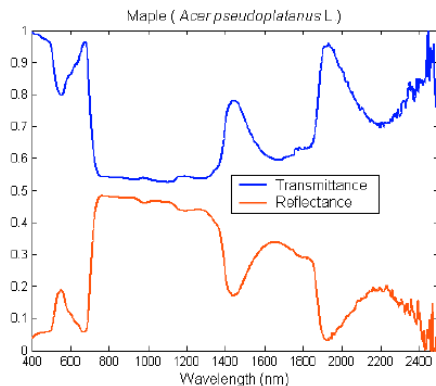- *GPS RTK*

Proximal Sensing

Integrated 3D Radiative transfer model

1. Import virtual canopy with structural parameters from LiDAR into ray tracing radiative transfer modelling framework (Helios)
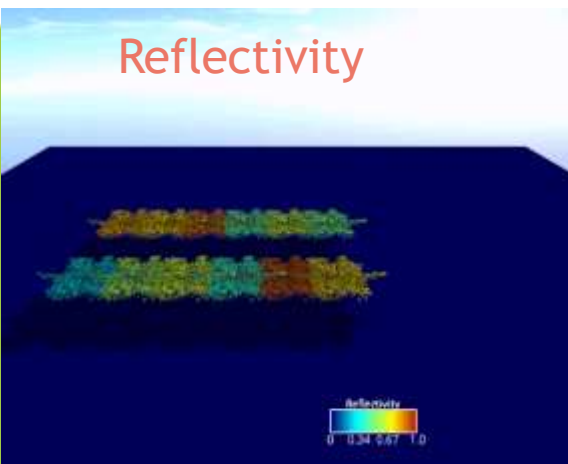
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Integrated 3D Radiative transfer model

Chlorophyll
Carotenoids
Brown pigments
Water
Dry matter
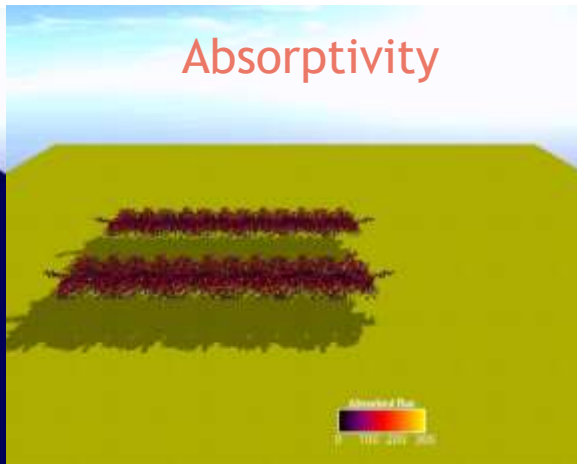Anthocyanins

PROSPECT

Maple (*Acer pseudoplatanus* L.)

Reflectivity

Absorptivity

1. Import virtual canopy with structural parameters from LiDAR
2. Reverse Ray-tracing with leaf optical properties from PROSPECT

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Integrated 3D Radiative transfer model

Chlorophyll
Carotenoids
Brown pigments
Water
Dry matter
Anthocyanins

xanthophyll cycle
Fluorescence quantum
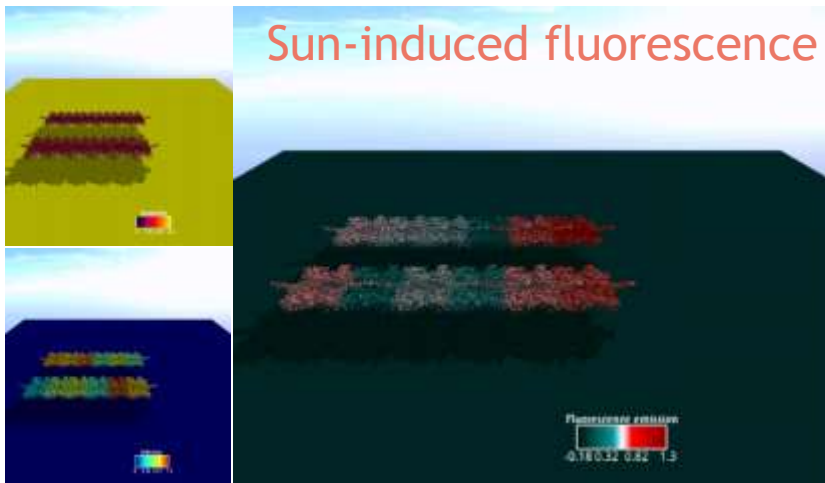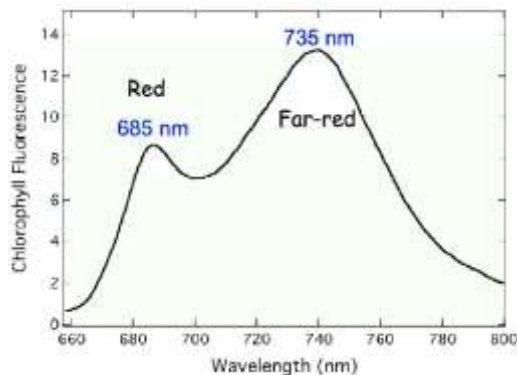yield efficiency

FLUSPECT

Sun-induced fluorescence

1. Import virtual canopy with structural parameters from LiDAR
2. Reverse Ray-tracing with leaf optical properties from PROSPECT
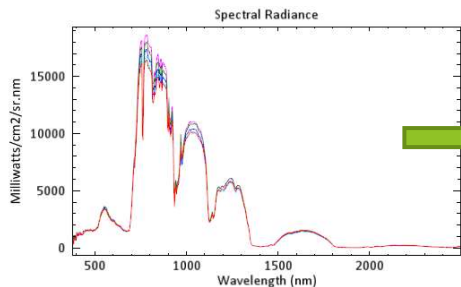3. Incorporate emission from Fluorescence with FLUSPECT

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Integrated 3D Radiative transfer model

Sun-induced fluorescence

Chlorophyll
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Brown pigments
Water
Dry matter
Anthocyanins

xanthophyll cycle
Fluorescence quantum
yield efficiency
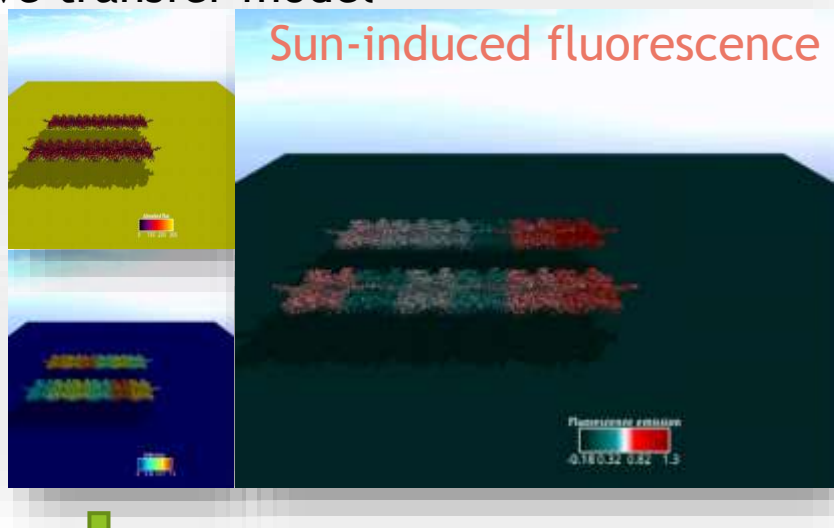
Modelling requires
optimal parameter
space search in
HPC.

Best parameter estimates

Stress maps + Insights on drivers of stress

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A Virtual Orchard

A developing digital laboratory to test the impact of
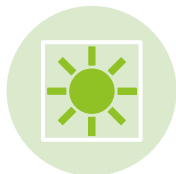
- Management practices
- Environment
    - Weather events
    - Pest and disease
- Optimise specific targets
    - Yield
    - Quality
    - Use of fertilisers

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Conclusions

Optimal assessment of plant health key for horticulture industry

Sun-induced fluorescence can trace early signs of plant stress

Developing capability to deliver a robust modelling framework for kiwifruit and other industries

Detailed modelling possible thanks to existing **eScience infrastructure**

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