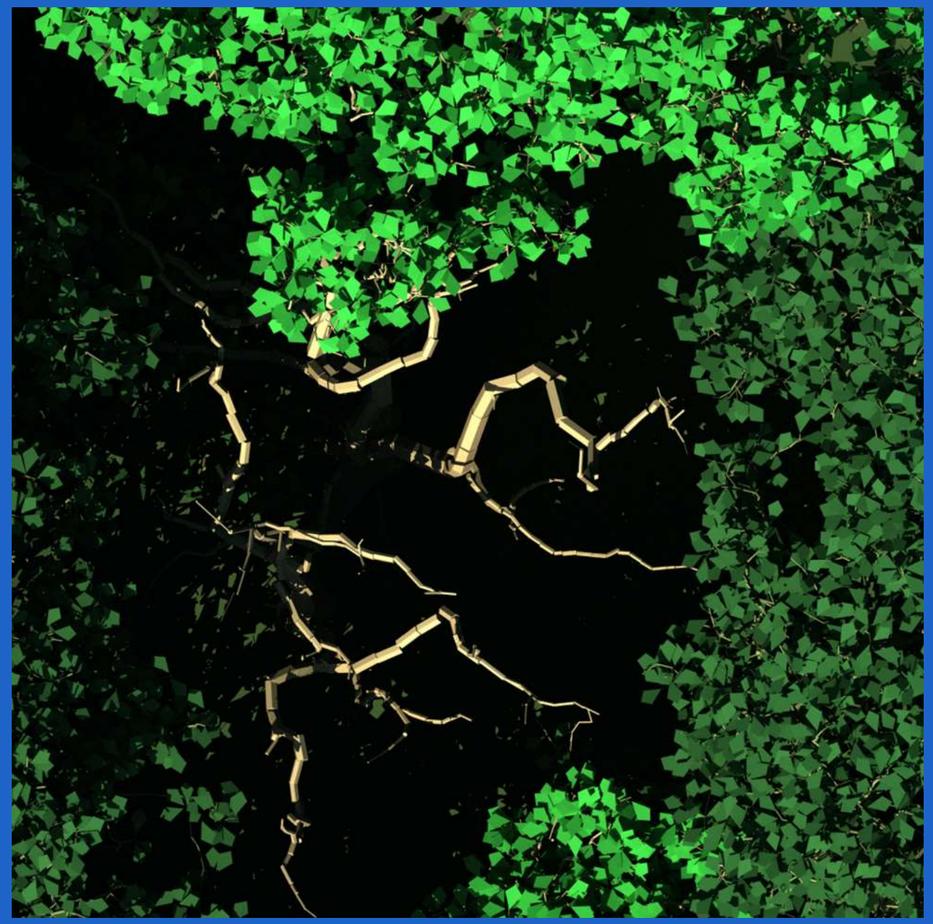
FACULTY OF BIOSCIENCE ENGINEERING

# 4D-EXPLICIT RADIATIVE TRANSFER MODELING FOR REAL FOREST: ADVANCES AND APPLICATIONS

Chang Liu, Kim Calders, Niall Origo, Mathias Disney, Félicien Meunier, William Woodgate, Jean-Philippe Gastellu-Etchegorry, Yingjie Wang, Joanne Nightingale, Eija Honkavaara, Teemu Hakala, Lauri Markelin, Hans Verbeeck



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CAVElab
Computational & Applied Vegetation Ecology

GEZBIO

UCL

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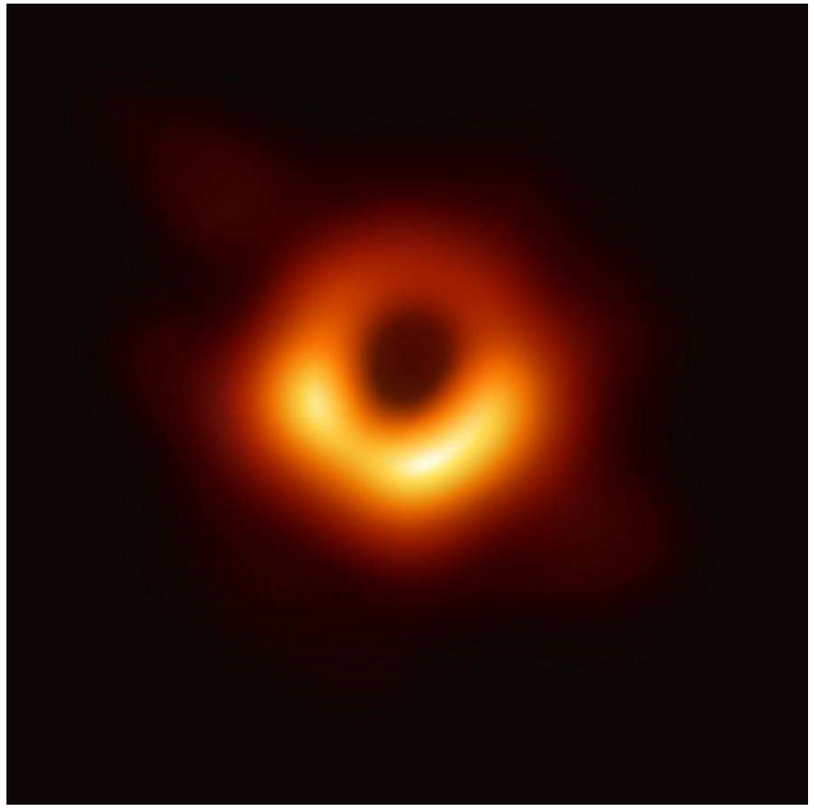
NATURAL ENVIRONMENT RESEARCH COUNCIL

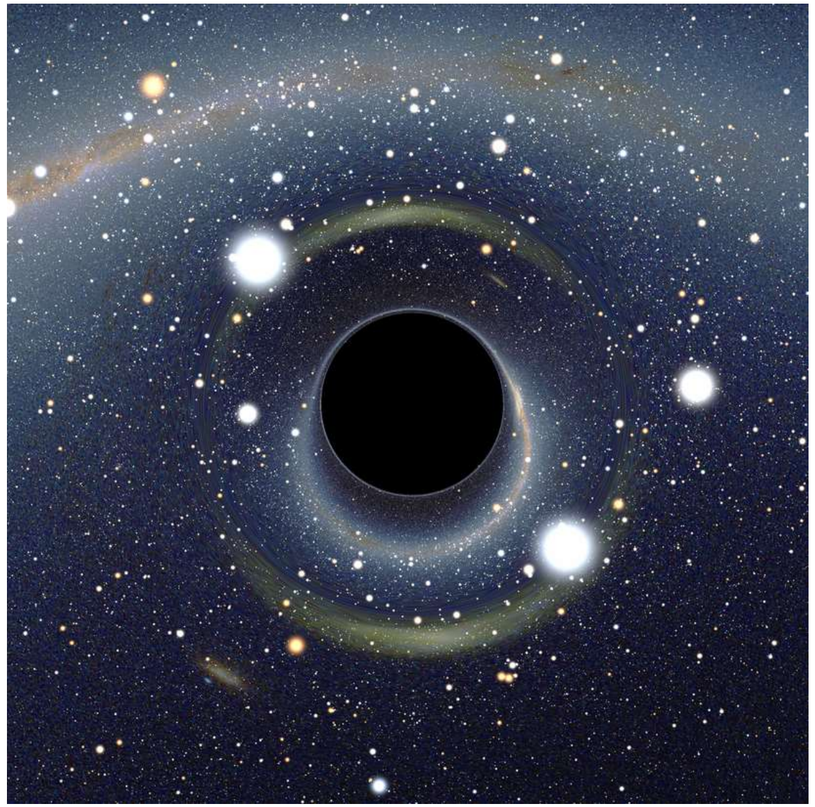
THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

NLS FINNISH GEOSPATIAL RESEARCH INSTITUTE FGI

# HYPOTHESIS IN MODELING



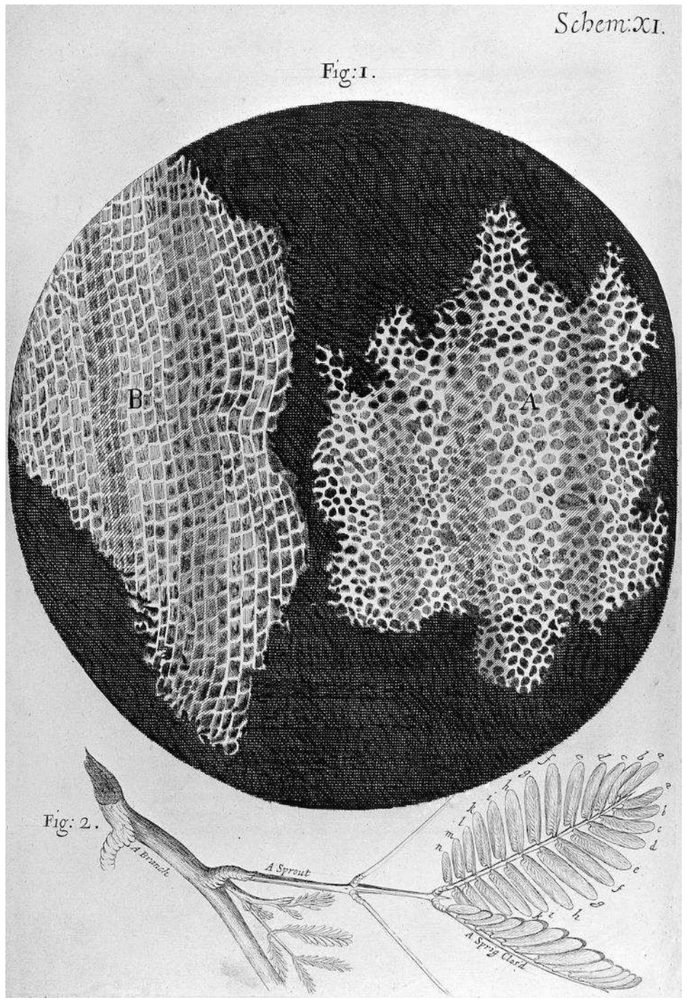
Direct observation of black hole*



Simulated view of black hole with hypothesis**

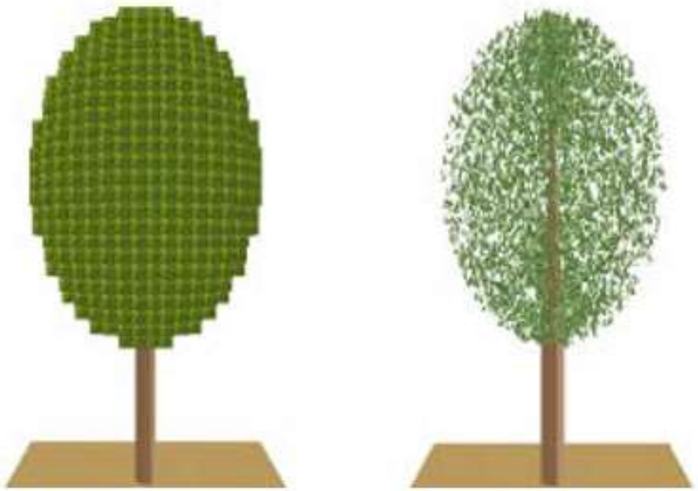
* Direct image of a supermassive black hole at the core of Messier 8. Oldham, et. al. (2016).
** Simulated view of a black hole in front of the Large Magellanic Cloud. Riazuelo, Alain (2019).

# ADVANCES IN TECHNOLOGY AND EQUIPMENT IMPROVEMENT LEAD TO THE ADVANCE IN SCIENTIFIC RESEARCH.

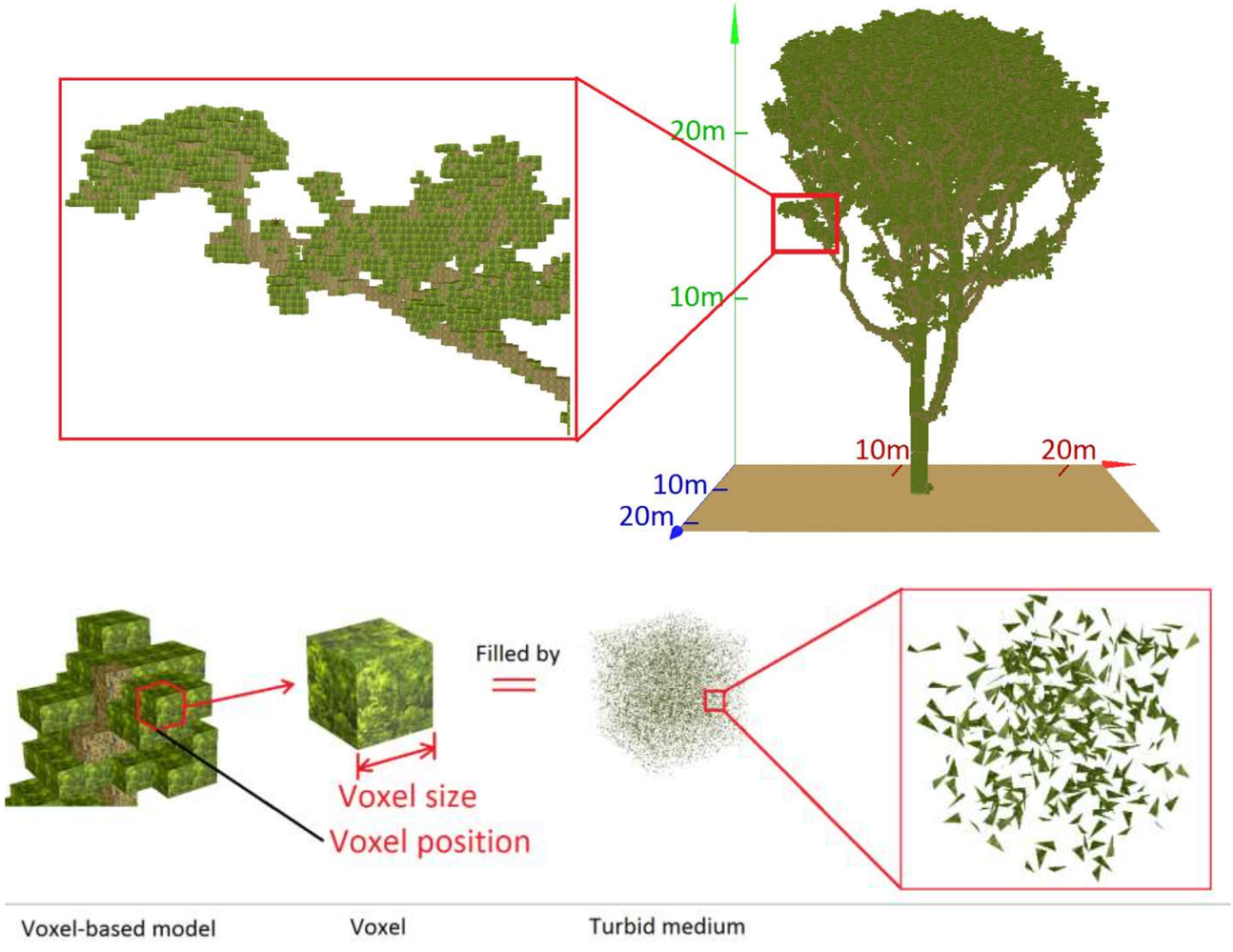



# HYPOTHESIS ON FOREST RADIATIVE TRANSFER MODELING

1D vegetation model: PROSAIL

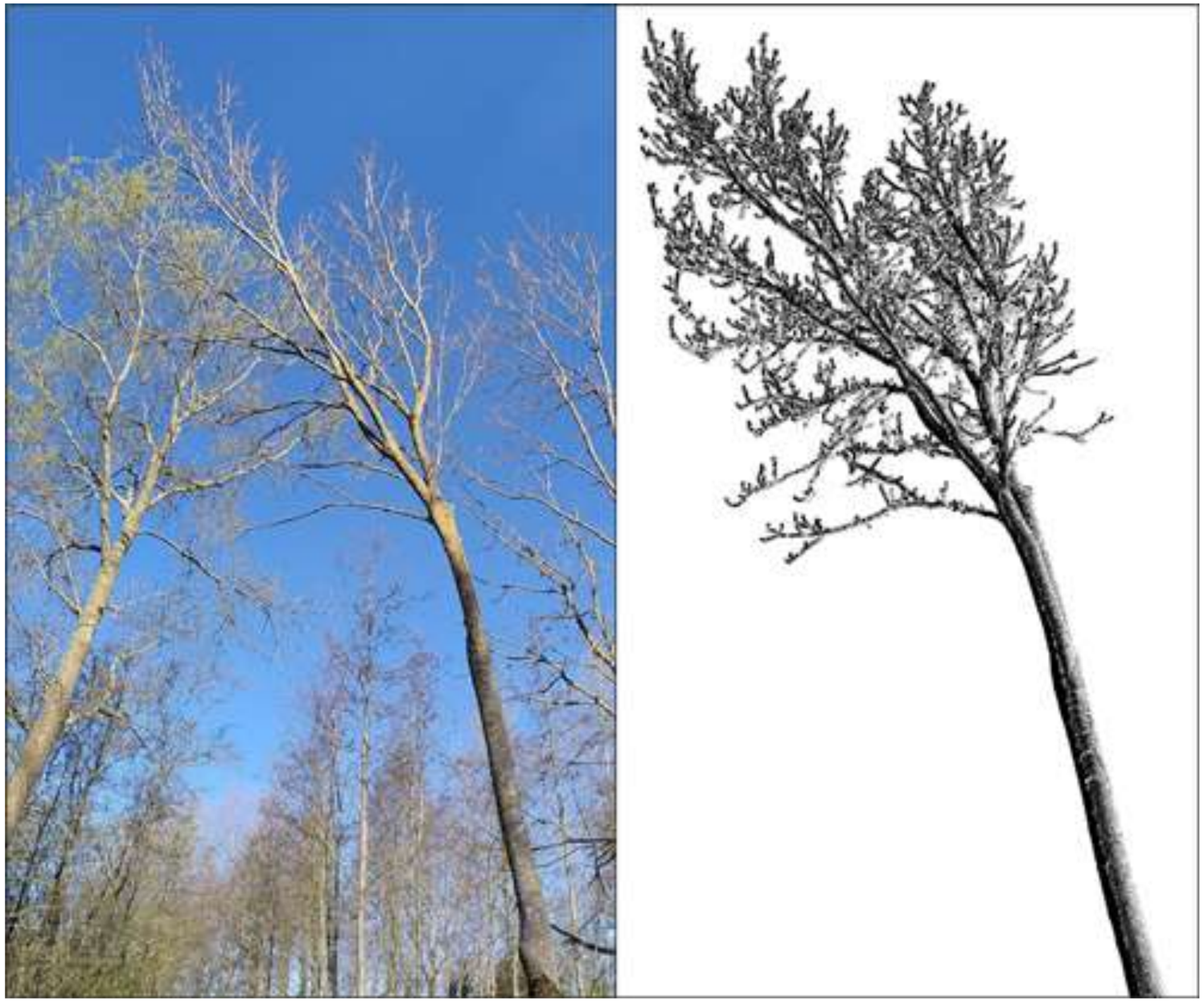


Simple 3D geometries as tree macrostructure




3D voxel model

# Photograph and terrestrial LiDAR measurement of a common ash tree*



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* Demol et. al. (2022)

# MULTI-TEMPORAL 3D-EXPLICIT RT MODELING OF 1-HA REAL FOREST.

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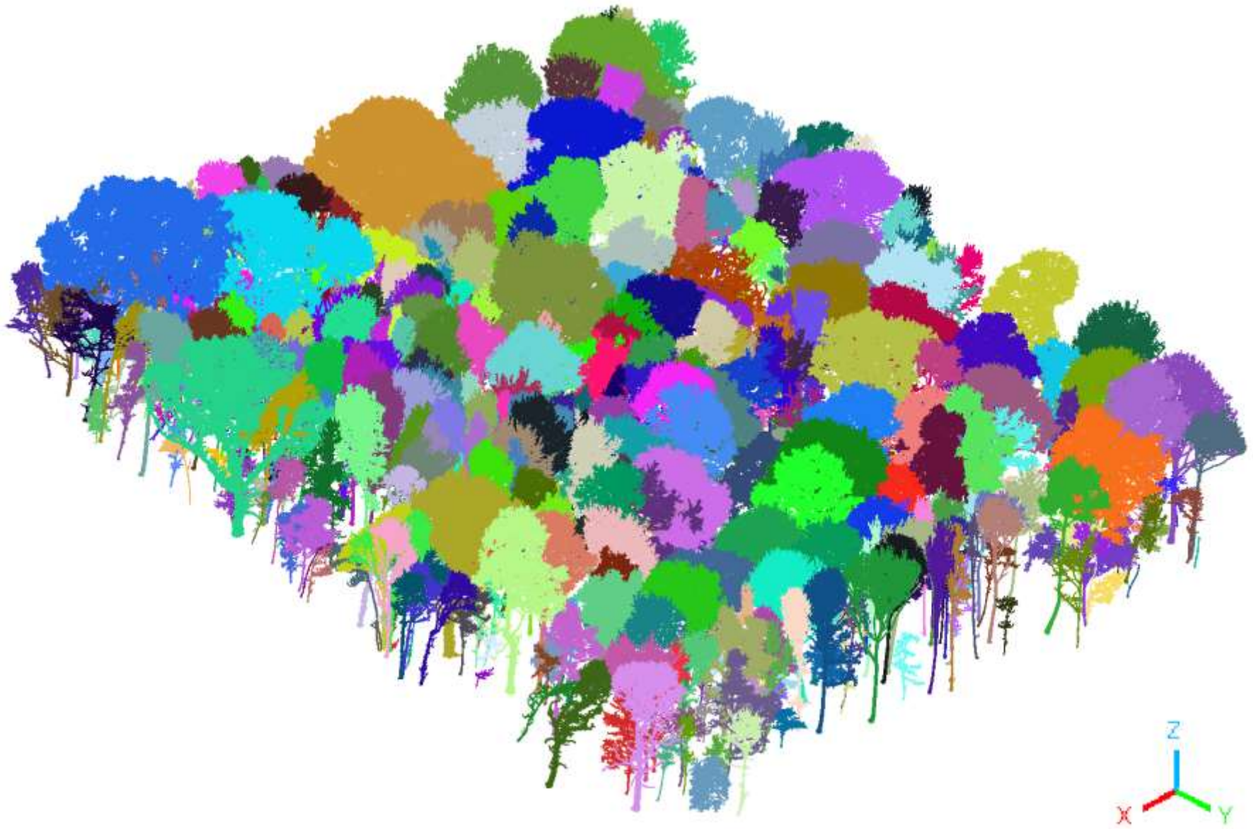
Field LiDAR scanning of six-hectare Wytham Woods forest

# MULTI-TEMPORAL 3D-EXPLICIT RT MODELING OF 1-HA REAL FOREST.





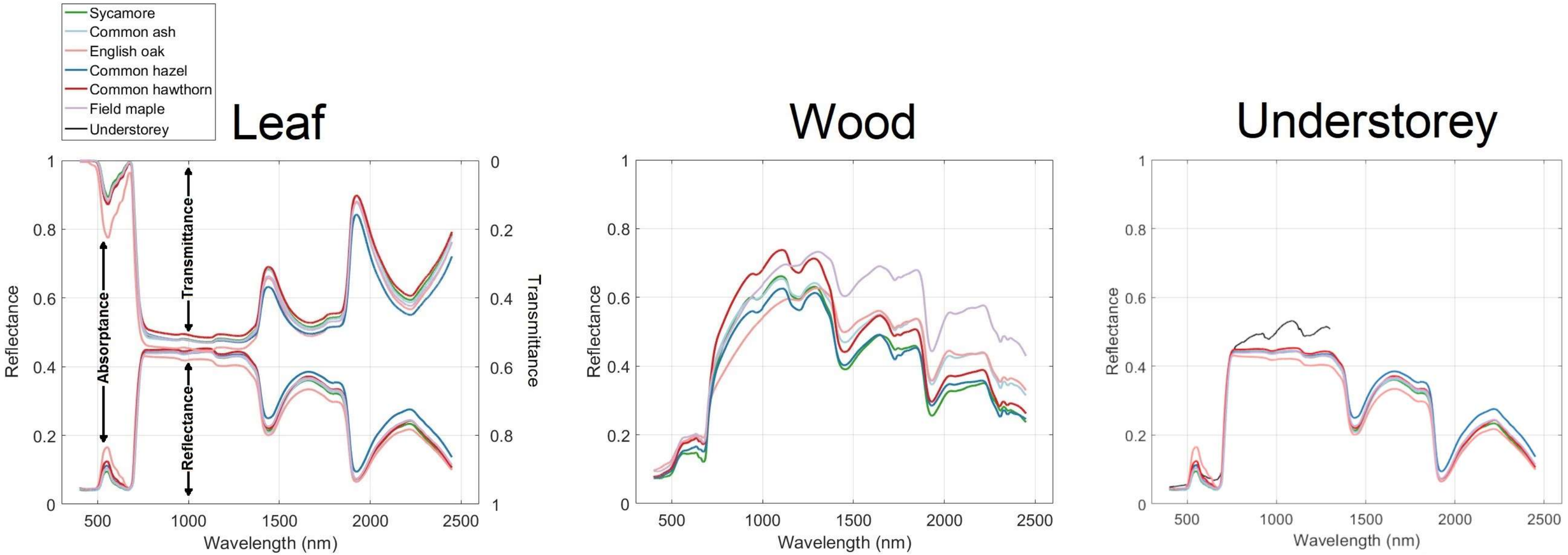
2015

2022*

Multi-temporal LiDAR measurement of one-hectare Wytham Woods forest. Each color is an individual tree, 550 trees in total.

* Liu, Calders, Verbeeck, et.al., paper in progress.

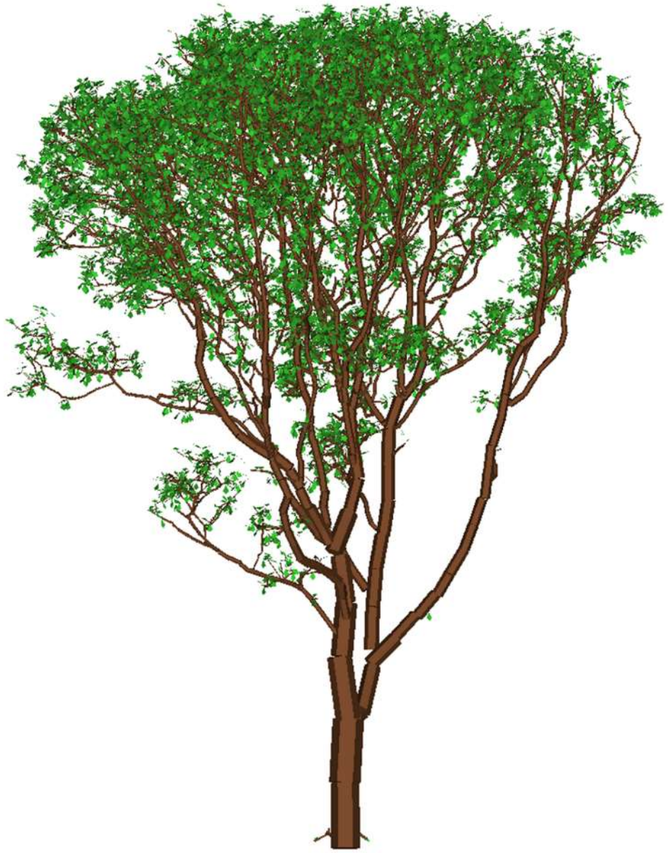
# MULTI-TEMPORAL 3D-EXPLICIT RT MODELING OF 1-HA REAL FOREST.



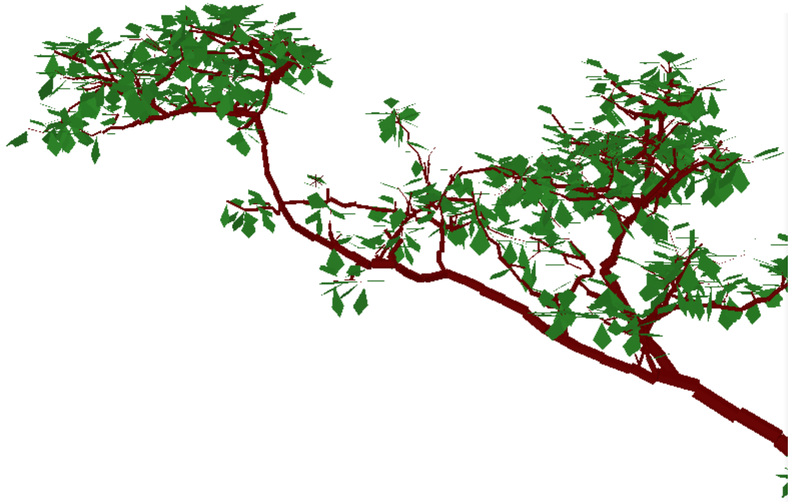

Field measured spectral properties

# MULTI-TEMPORAL 3D-EXPLICIT RT MODELING OF 1-HA REAL FOREST.

Terrestrial LiDAR point cloud

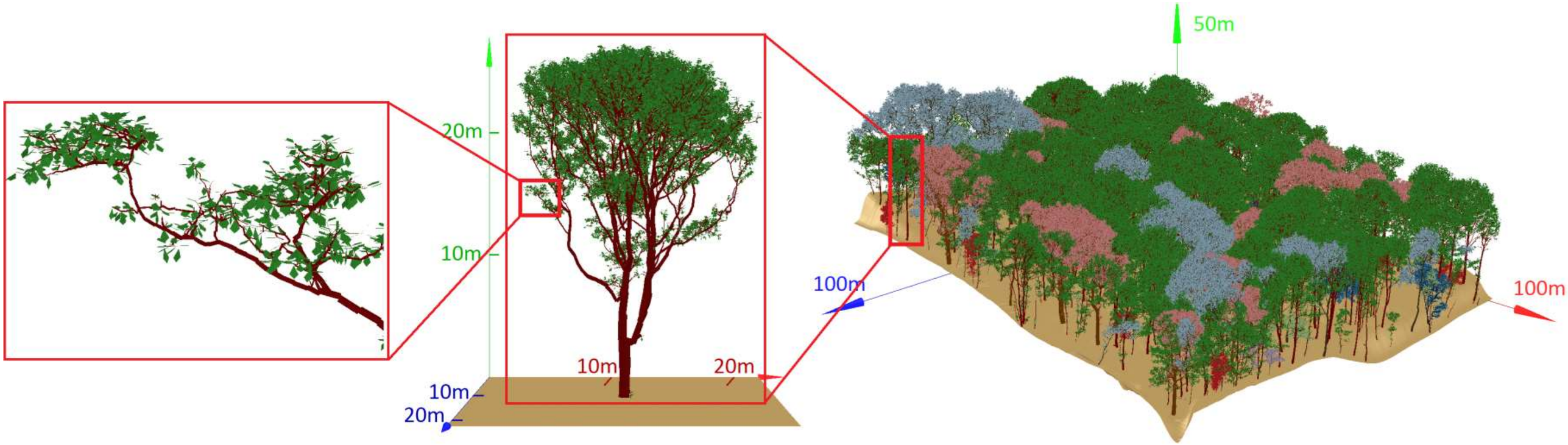


Reconstructed 3D-explicit model



Model detail: branches and leaves

# MULTI-TEMPORAL 3D-EXPLICIT RT MODELING OF 1-HA REAL FOREST.

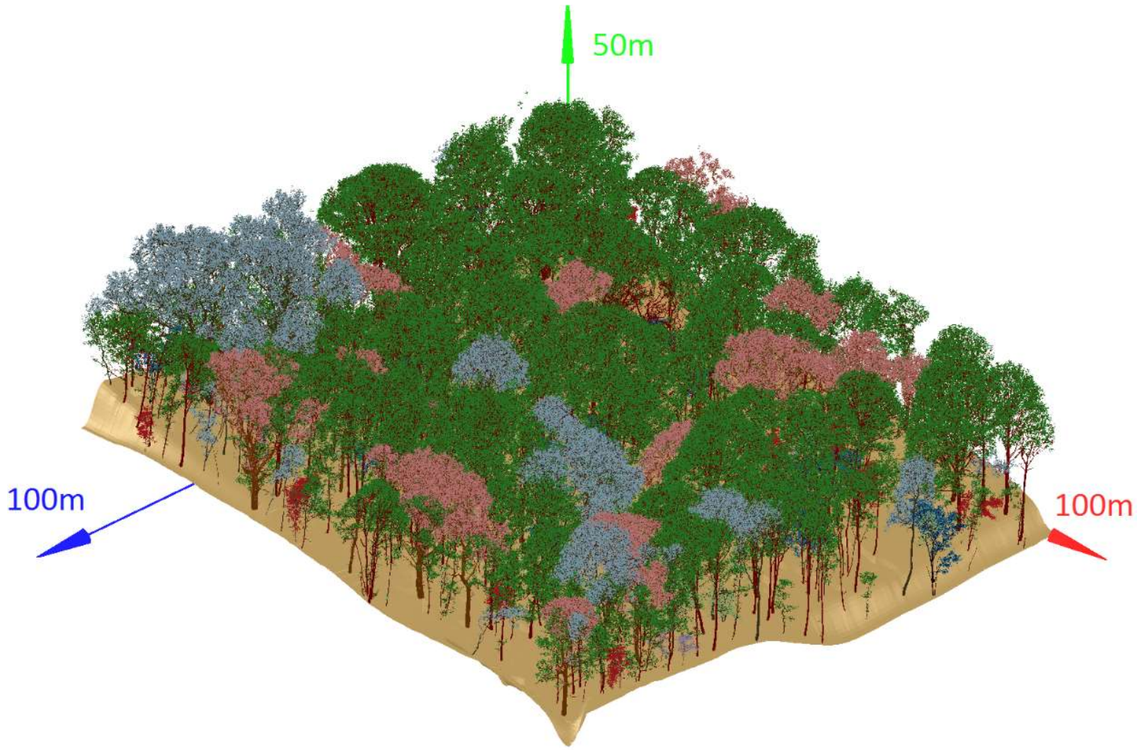



3D-explicit model of one-hectare Wytham Woods forest in 2015.

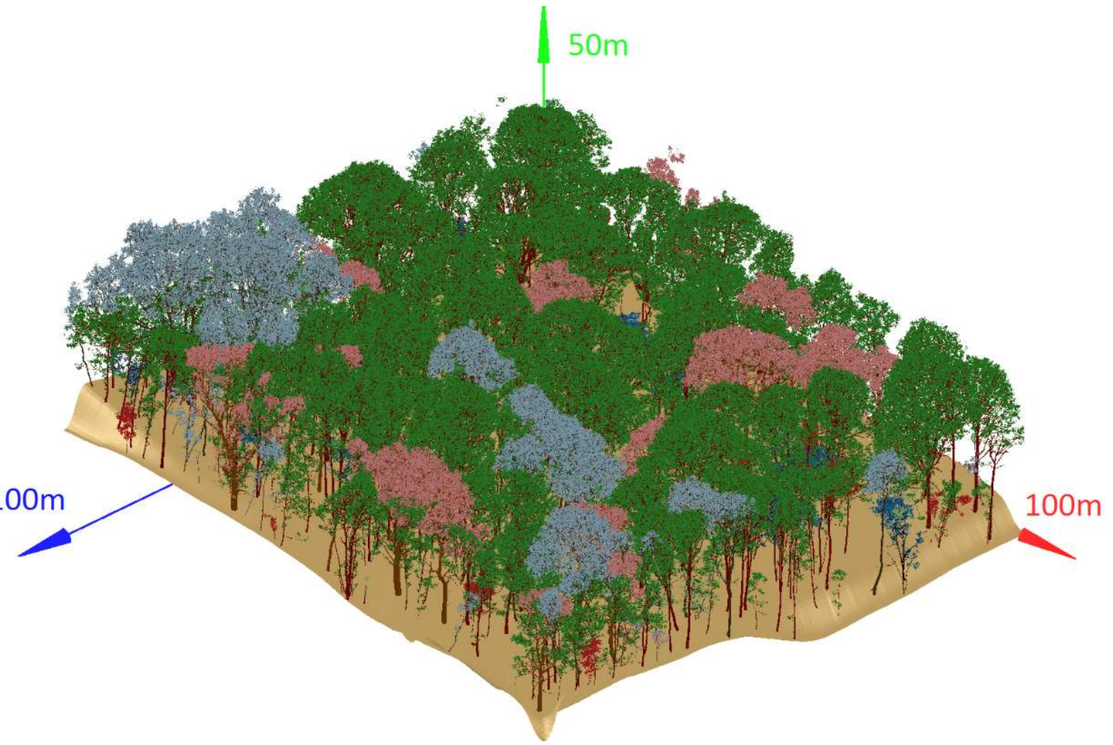
550 trees reconstructed in total.

Calders et. al. (2018).

# MULTI-TEMPORAL 3D-EXPLICIT RT MODELING OF 1-HA REAL FOREST.




2015




2022*

Sycamore
(*Acer pseudoplatanus*)

Common ash
(*Fraxinus excelsior*)

English oak
(*Quercus robur*)

Common hazel
(*Corylus avellana*)

Common hawthorn
(*Crataegus monogyna*)

Field maple
(*Acer campestre*)

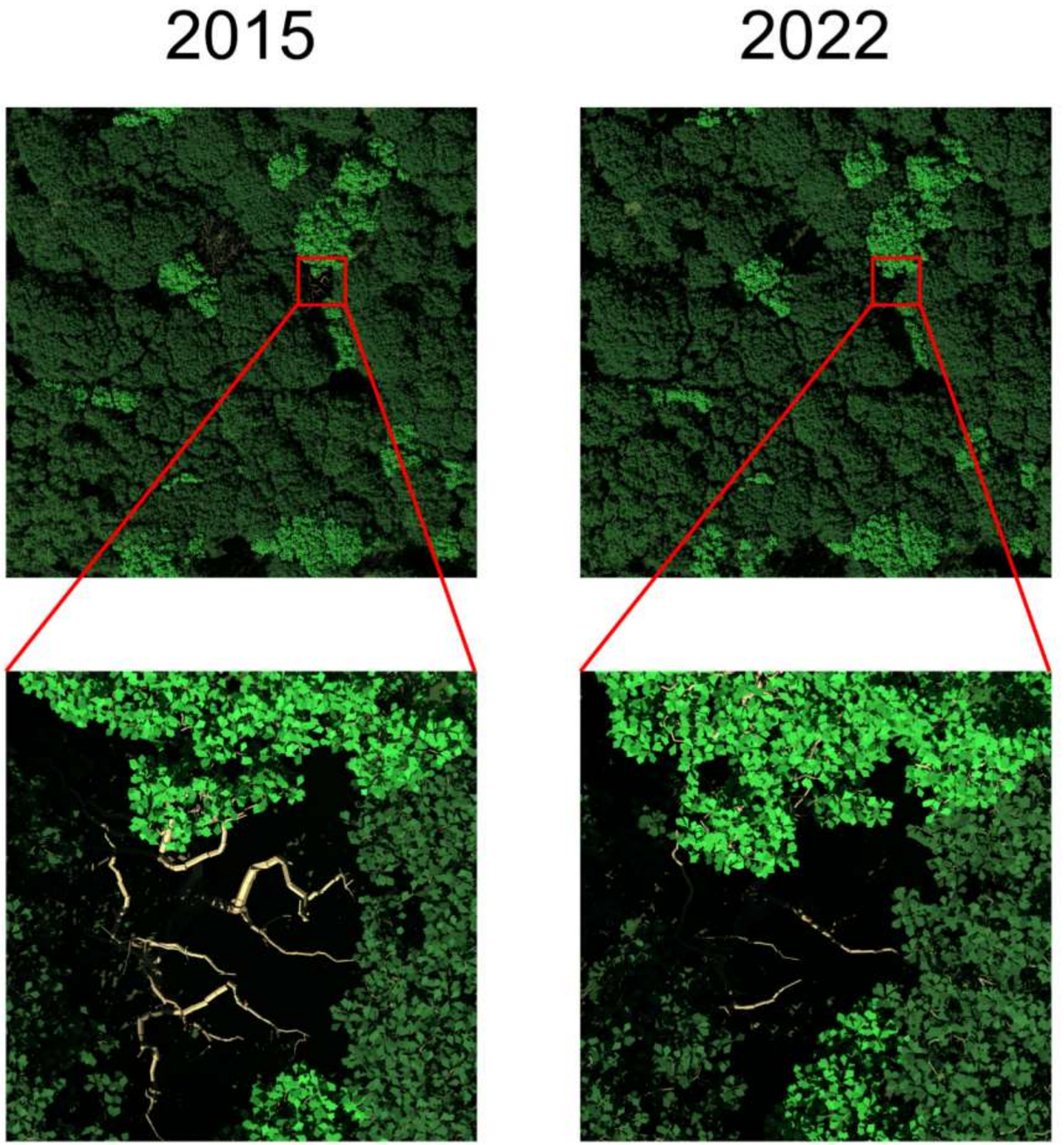
Unknown

Multi-temporal 3D-explcit models of one-hectare Wytham Woods forest.

* Liu, Calders, Verbeeck, et.al., paper in progress.

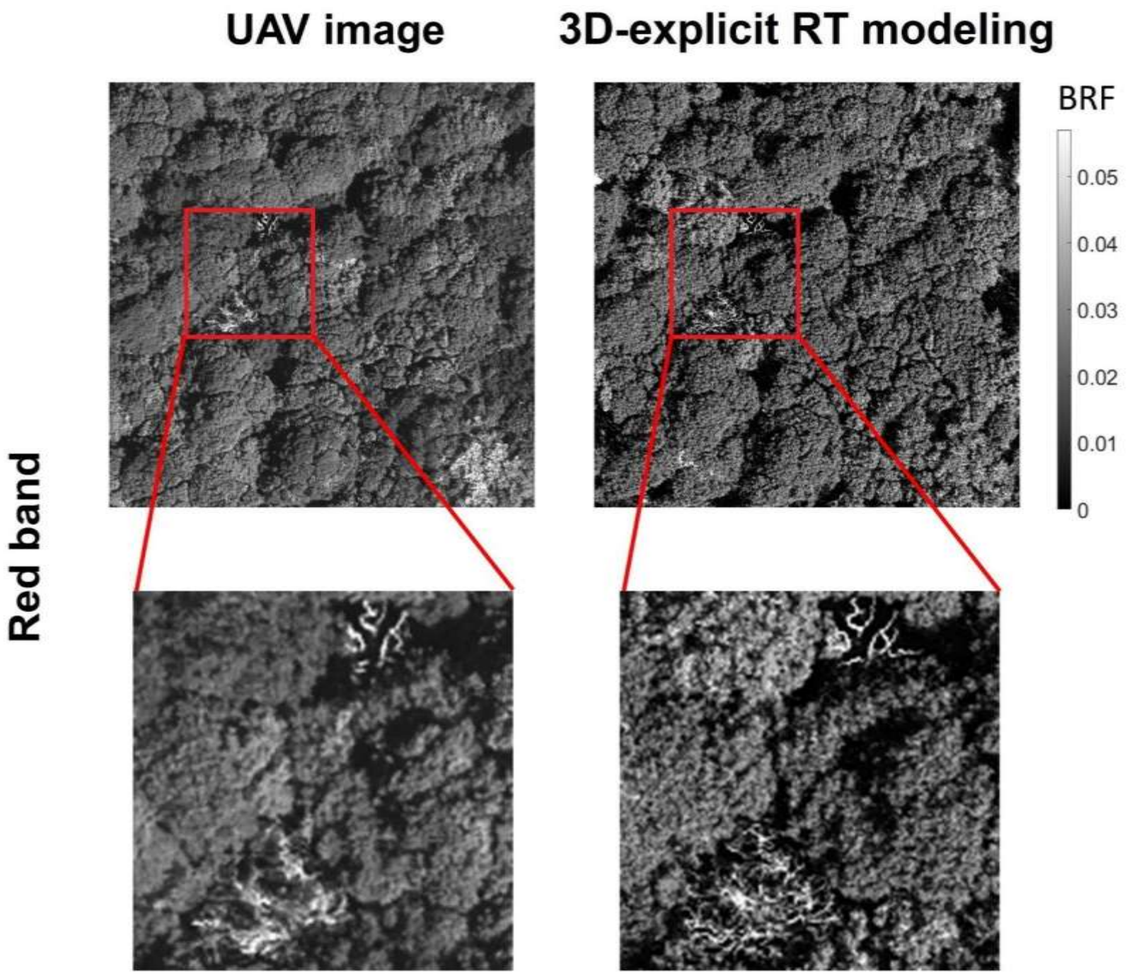
# MULTI-TEMPORAL 3D-EXPLICIT RT MODELING OF 1-HA REAL FOREST.

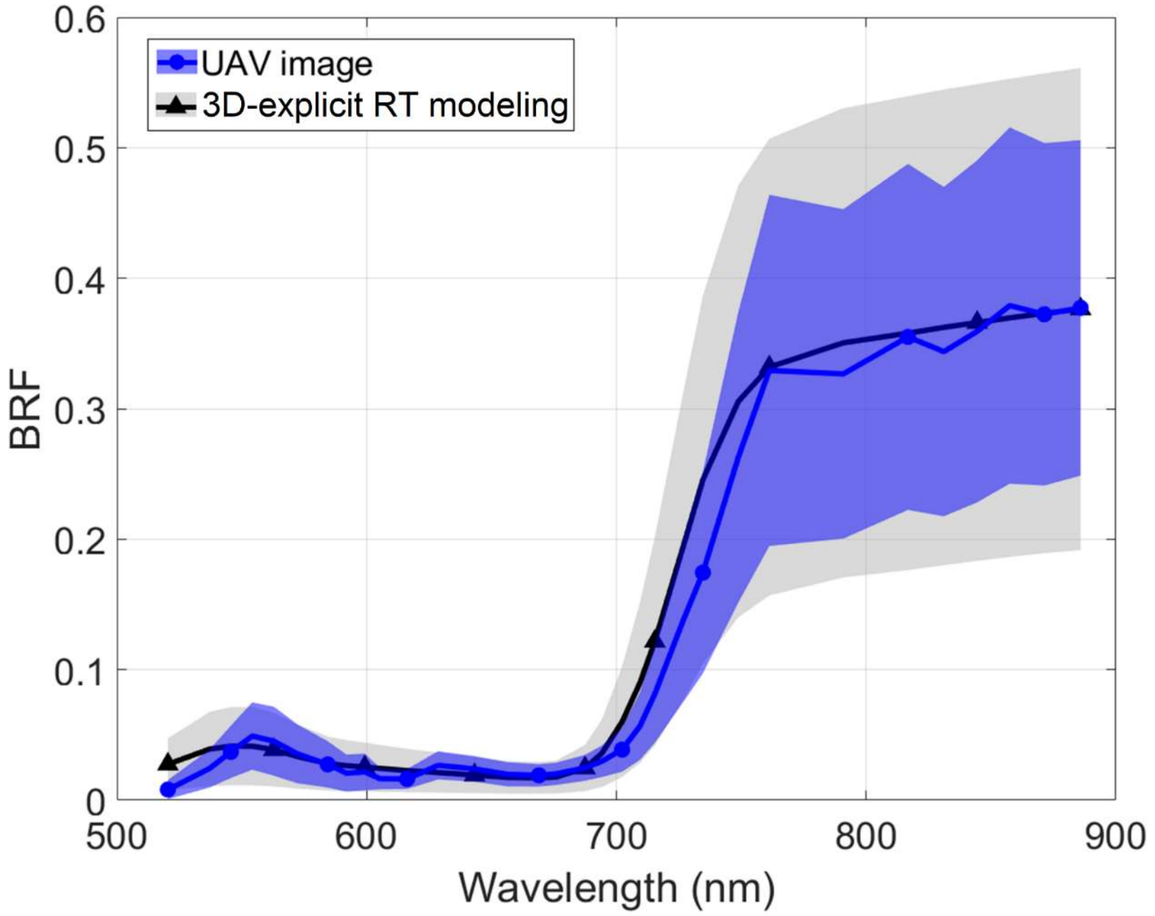
Simulated nadir images.
1cm resolution.




Liu, Calders, Verbeeck, et.al.,
paper in progress.

# VALIDATION AGAINST UAV HYPERSPECTRAL DATA.
# 32 BANDS FROM 520 - 886 NM.




Reflectance comparison against UAV images

Liu, Calders, Verbeeck et. al., submitted.

# MODELING EFFICIENCY

- One-hectare scene:
  1.8 million objects in total
  (leaves + stems/branches + DEM)

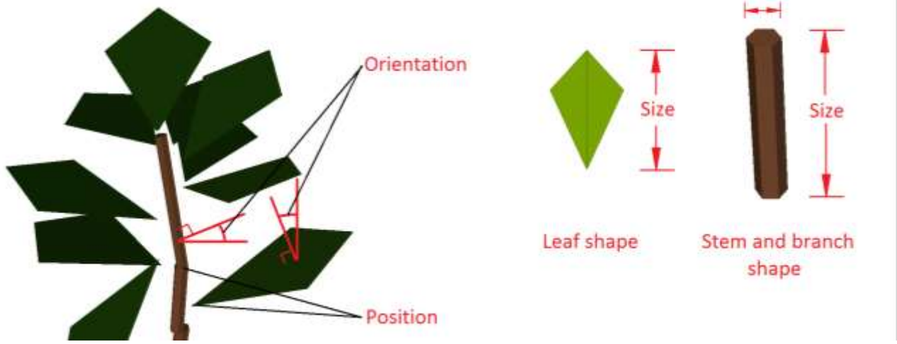
- 360 x 90 scattering direction

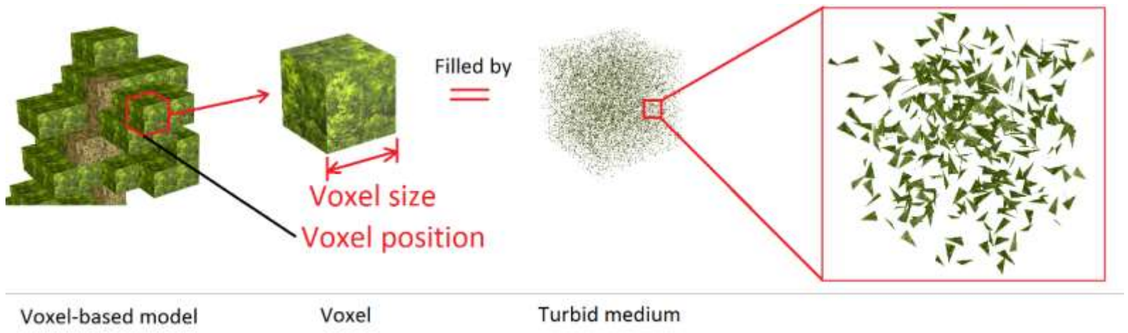
Platform:
- Intel Xeon Gold 6240
  (Cascade Lake @ 2.6 GHz)
- One node × 18 processors
- DART-Lux mode*

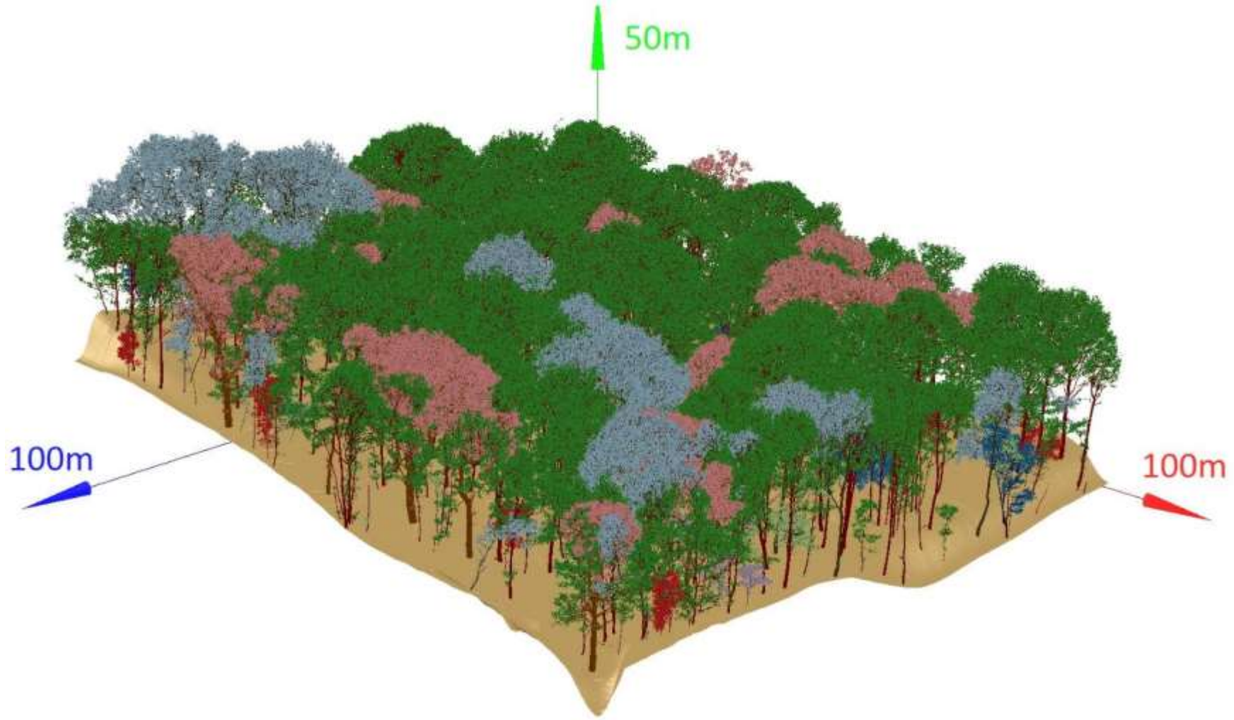
| RT modeling type | Time consumption | RAM consumption |
|---|---|---|
| Sentinel-2 observation (10 m resolution) | 3.4 mins | 4.8 GB |
| UAV observation (25 cm resolution) | 8.5 mins | 5.8 GB |
| Ultra-high resolution observation (1 cm resolution) | 2524.8 mins | 393 GB |

* Wang et. al. (2022).

# VALIDATING COMMONLY USED STRUCTURAL HYPOTHESIS IN FOREST RT MODELING: VOXEL-BASED 3D REPRESENTATION




3D-explicit model


Voxel-based model

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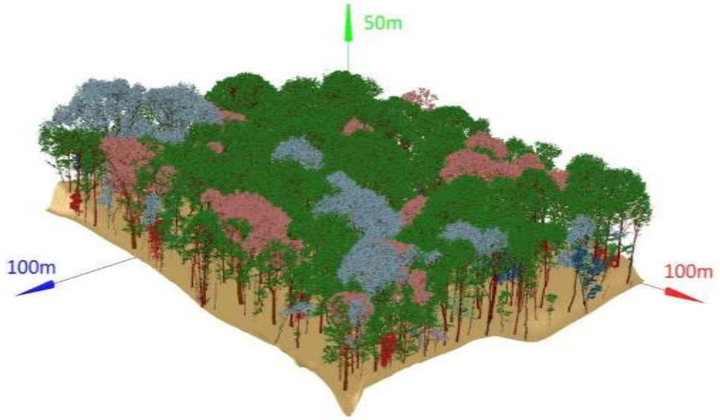
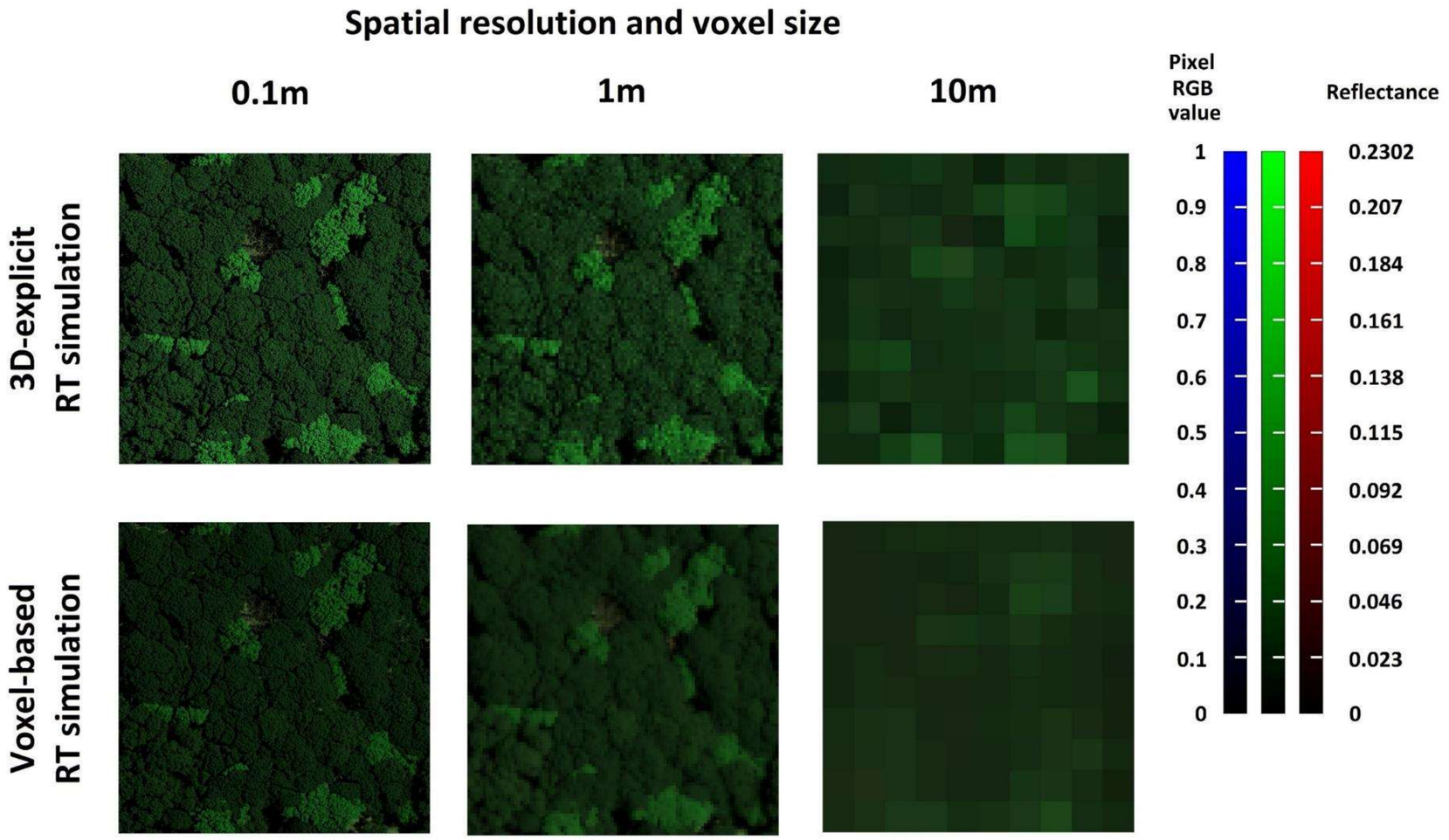


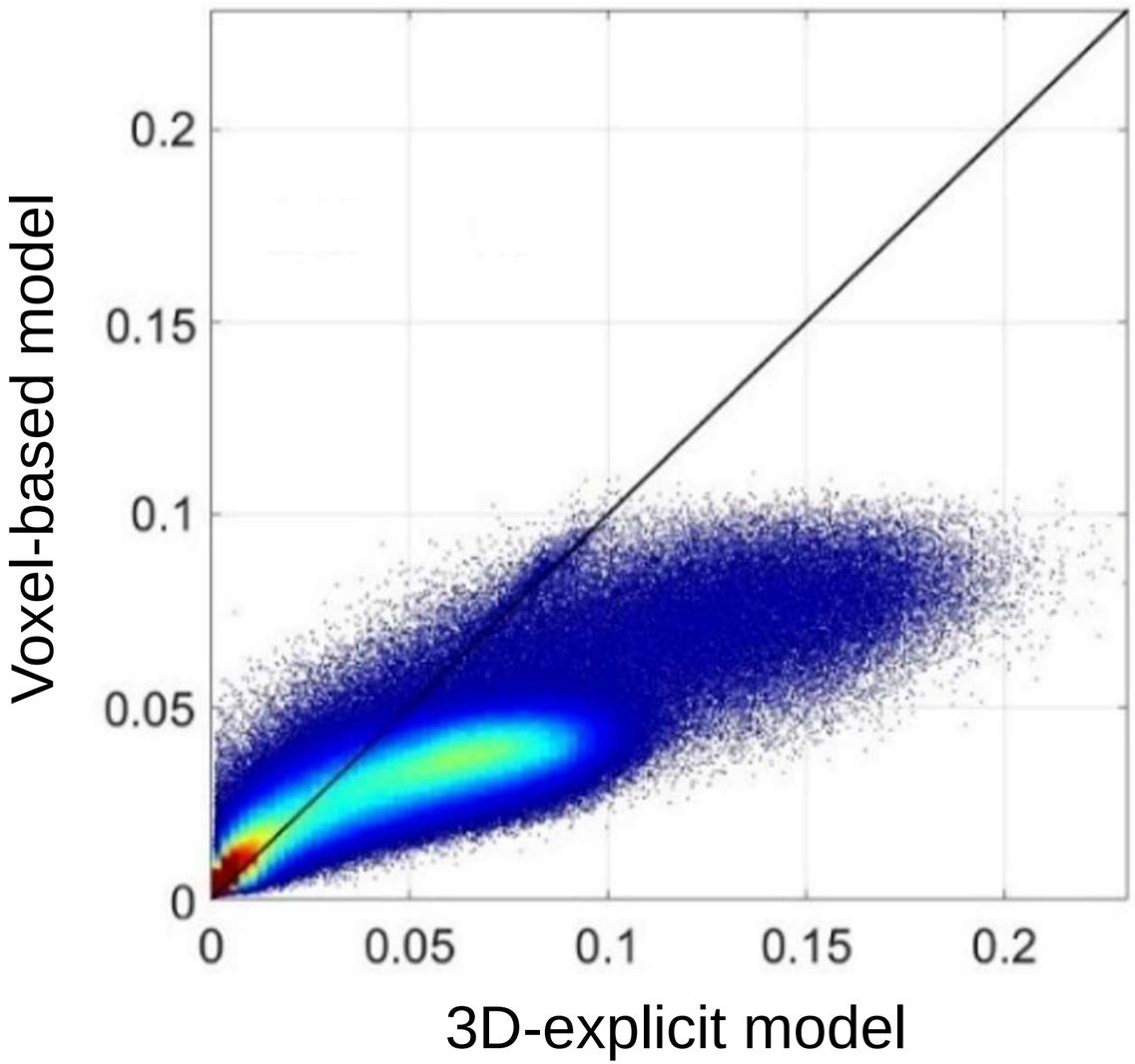

3D-explicit model

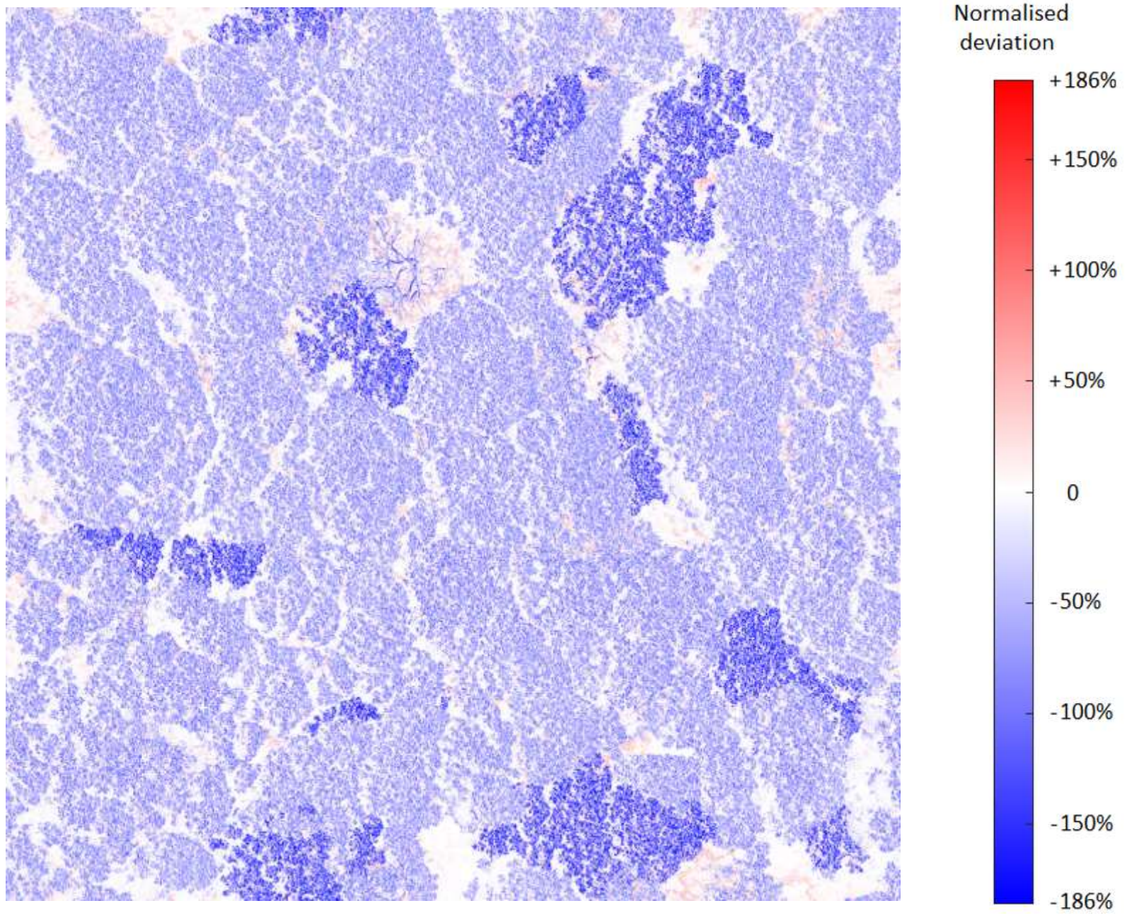

Voxel-based model




Simulated nadir images

# VALIDATING COMMONLY USED STRUCTURAL HYPOTHESIS IN FOREST RT MODELING: VOXEL-BASED 3D REPRESENTATION



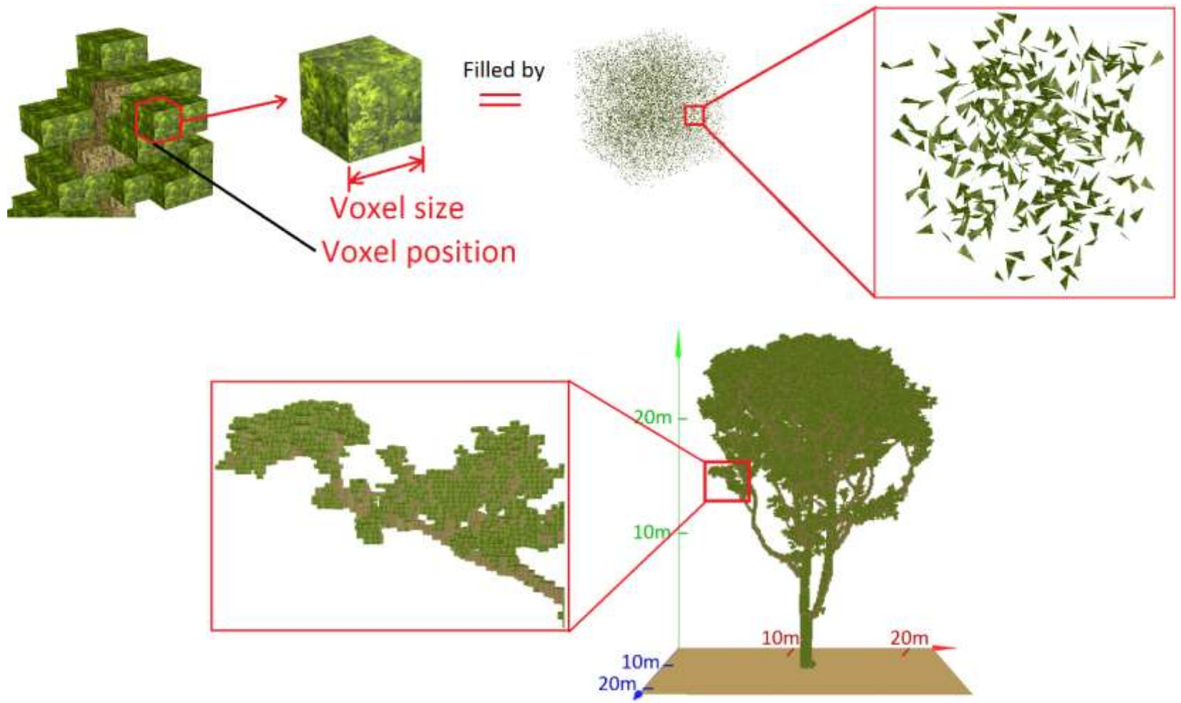

Albedo,
FAPAR,
Vegetation Index,
…

→

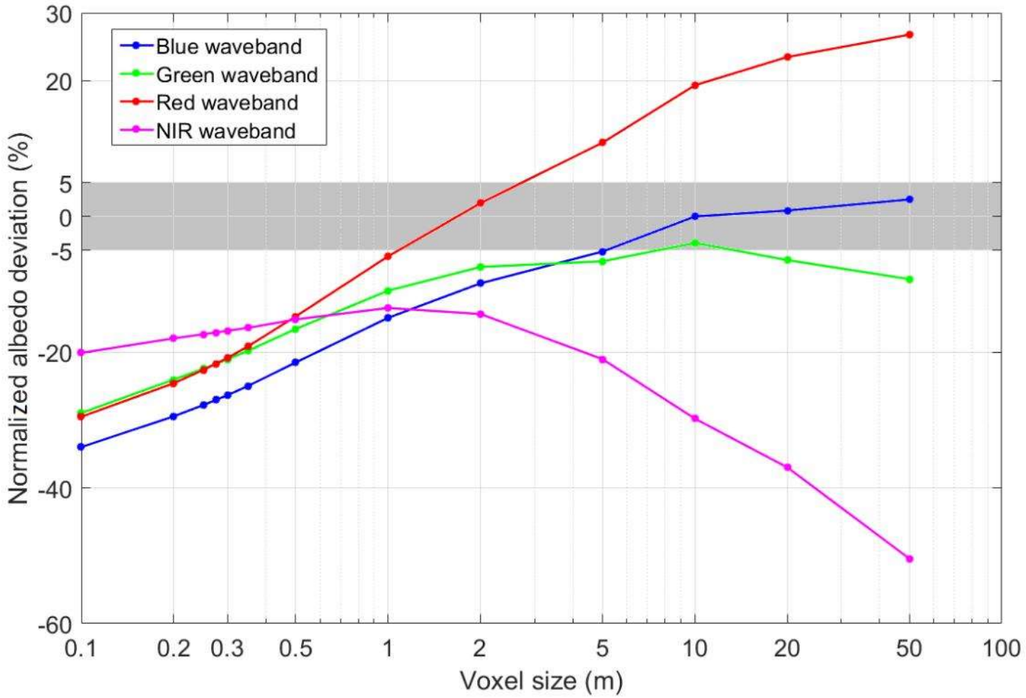
SCAN ME

# VALIDATING COMMONLY USED STRUCTURAL HYPOTHESIS IN FOREST RT MODELING: VOXEL-BASED 3D REPRESENTATION

## Hypothesis of turbid medium causes RT deviations in voxel-based model




Voxel-based model

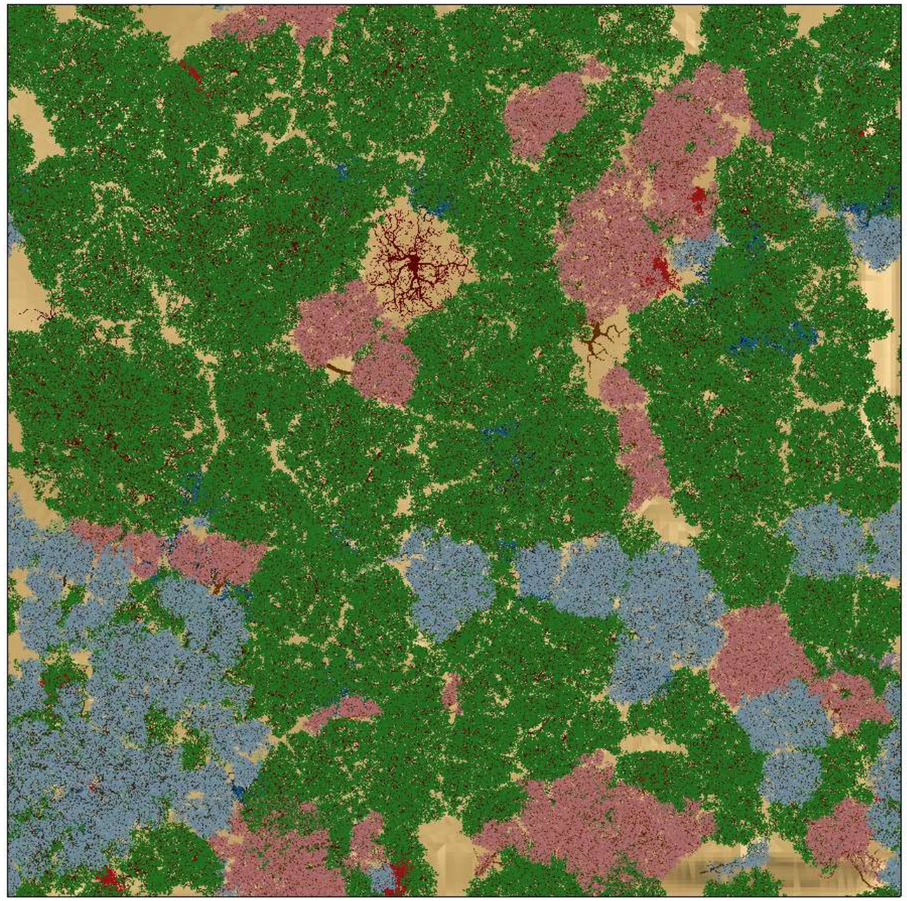



RT deviation

Liu et. al. (2022),
*JGR: Atmospheres*

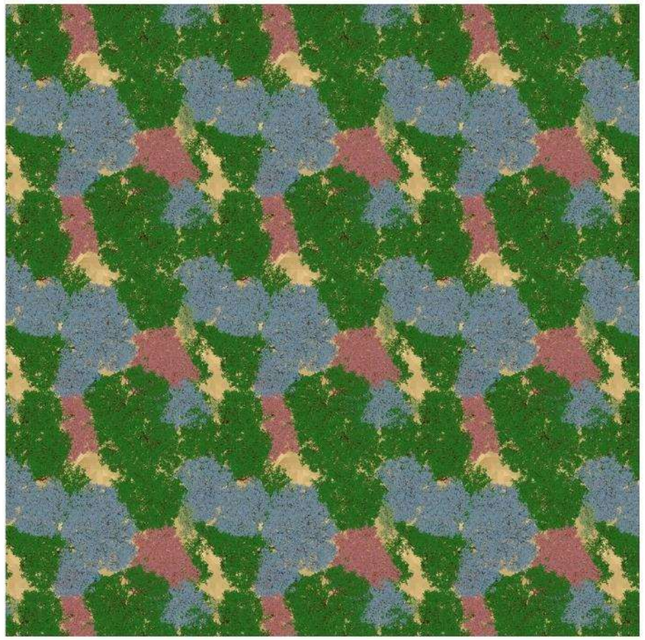
- Light interaction deviation inside voxel
- Structural deviation of voxelized canopy

# VALIDATING COMMONLY USED STRUCTURAL HYPOTHESIS IN FOREST RT MODELING: SUBSAMPLING IN 3D RECONSTRUCTION

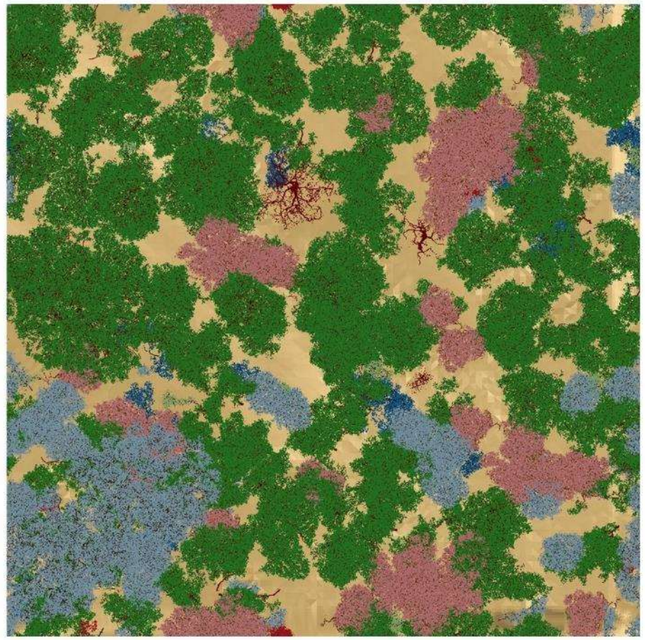


Original complete forest plot

**Subplot subsampling**



**Tree library subsampling**

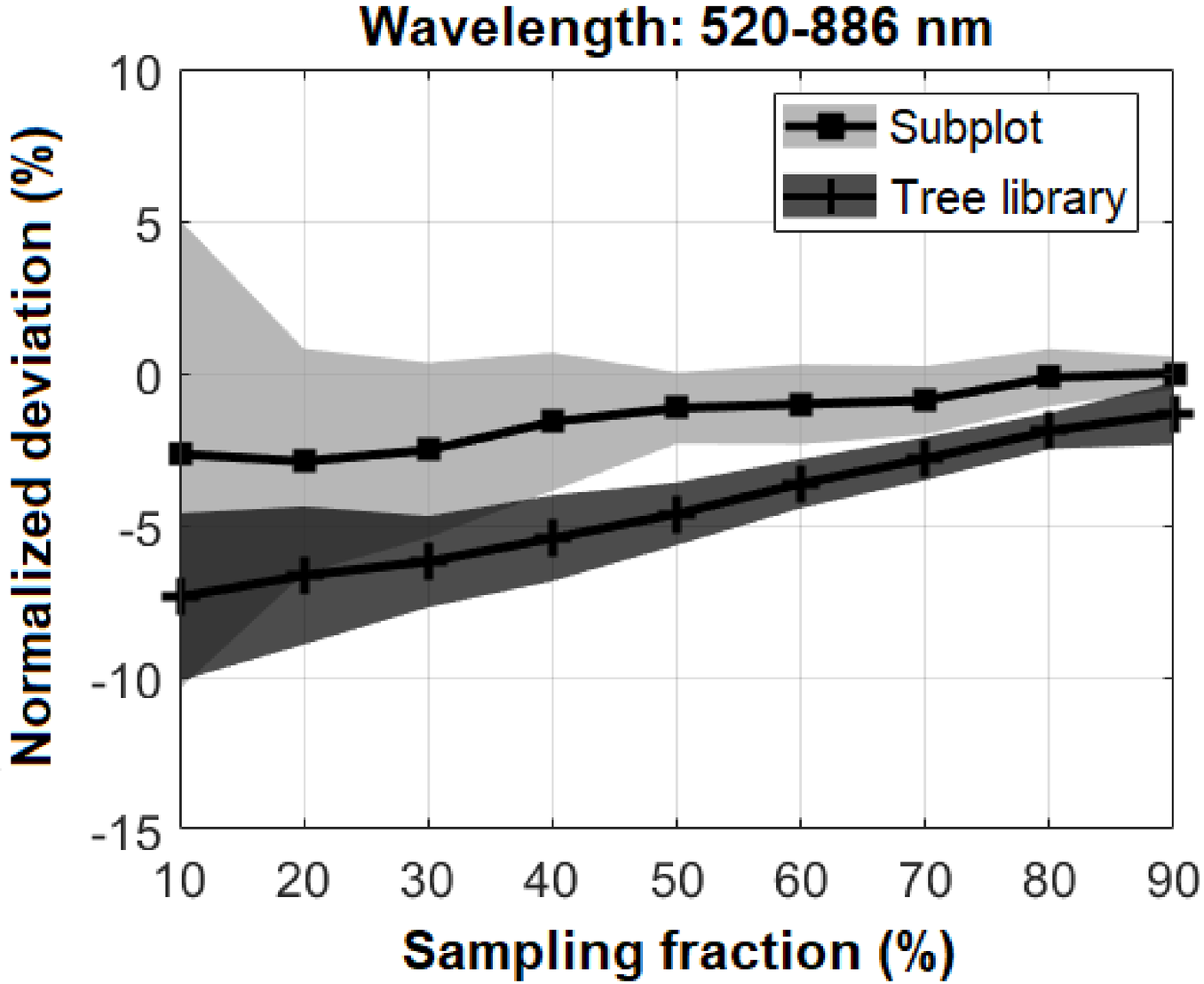


Reconstruction with 10% sampling fraction

Liu, Calders, Verbeeck et. al., submitted.

# VALIDATING COMMONLY USED STRUCTURAL HYPOTHESIS IN FOREST RT MODELING: SUBSAMPLING IN 3D RECONSTRUCTION

Quantified relations between subsampling fraction and RT deviations.




Liu, Calders, Verbeeck et. al., submitted.

# OUTLOOK OF 3D-EXPLICIT RTM IN GEOPHYSICS AND QUANTITATIVE REMOTE SENSING

Inspiration from subsampling experiments:

Why canopy cover is the main driver of reflectance variation in the experiment?

Can we describe this driving process, or even RS observation in a physical, realistic, and quantified way?

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# OUTLOOK OF 3D-EXPLICIT RTM IN GEOPHYSICS AND QUANTITATIVE REMOTE SENSING

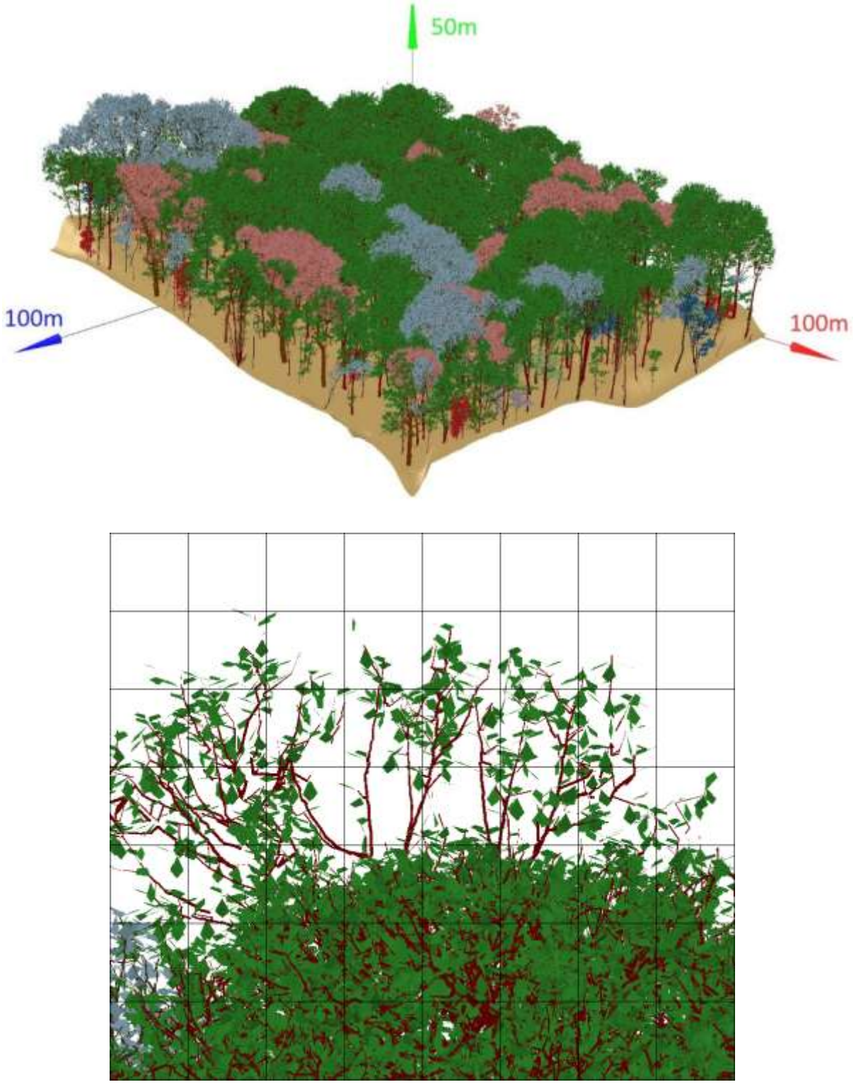
Light (in the broad sense) is the carrier of information (parameters) of the Earth's surface layers.

How does light interact with hydrosphere, pedosphere, anthroposphere, biosphere, atmosphere and carry their parametric information?
How can we extract the parametric information of earth surface layer from light, for scientific research and application?

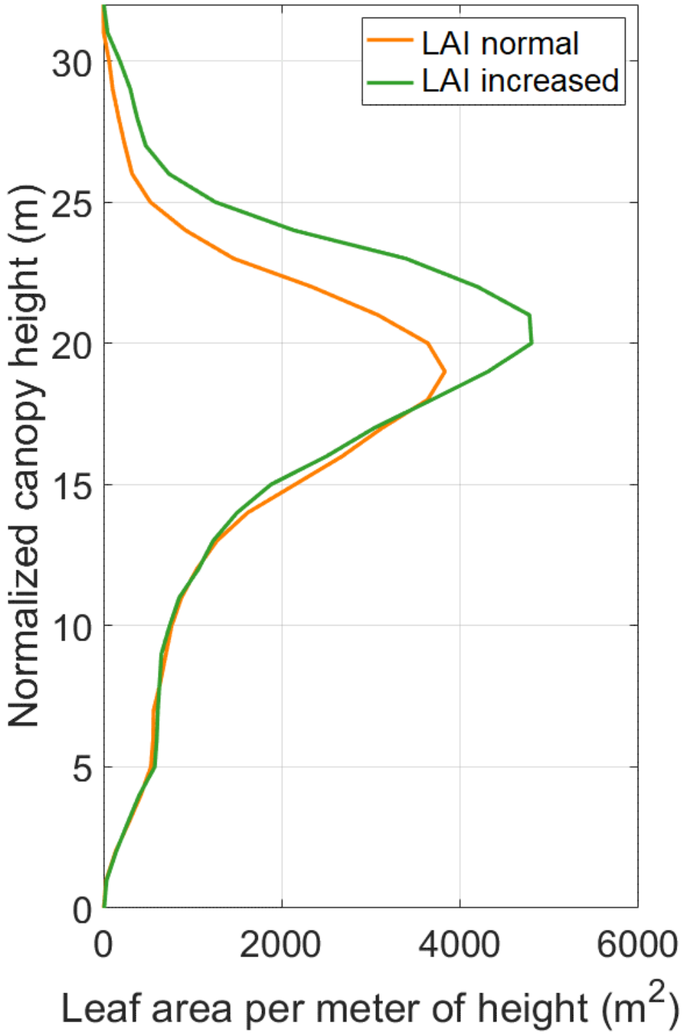
I think this is the role of remote sensing science in the science of Earth's surface resources and environment.

-- Academician Xiaowen Li, founder of  Li–Strahler geometric-optical model

# HOW DOES LIGHT INTERACT WITH FORESTS AND CARRY THEIR PARAMETRIC INFORMATION?
# QUANTIFICATION IN A MORE PHYSICAL, TRACEABLE, AND REALISTIC WAY.




Leaf area calculation in 3D




Leaf area vertical profile

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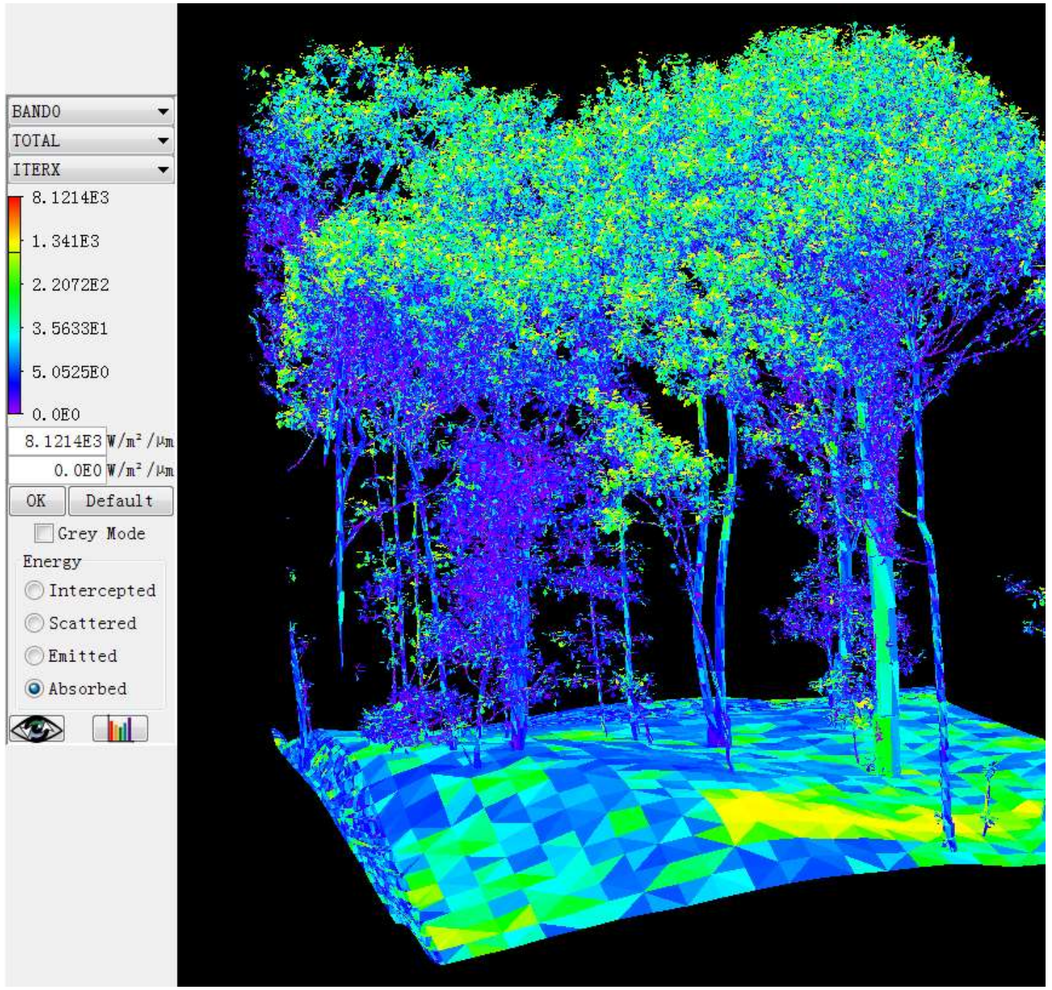
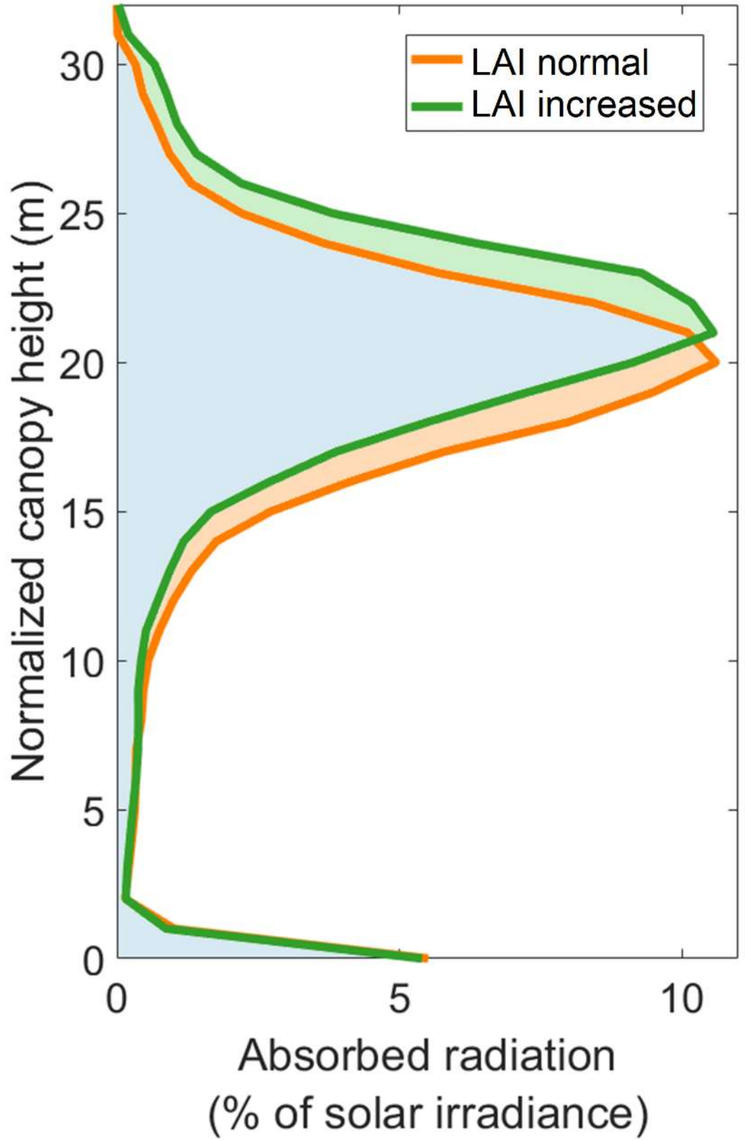



Radiation Absorption
of each object



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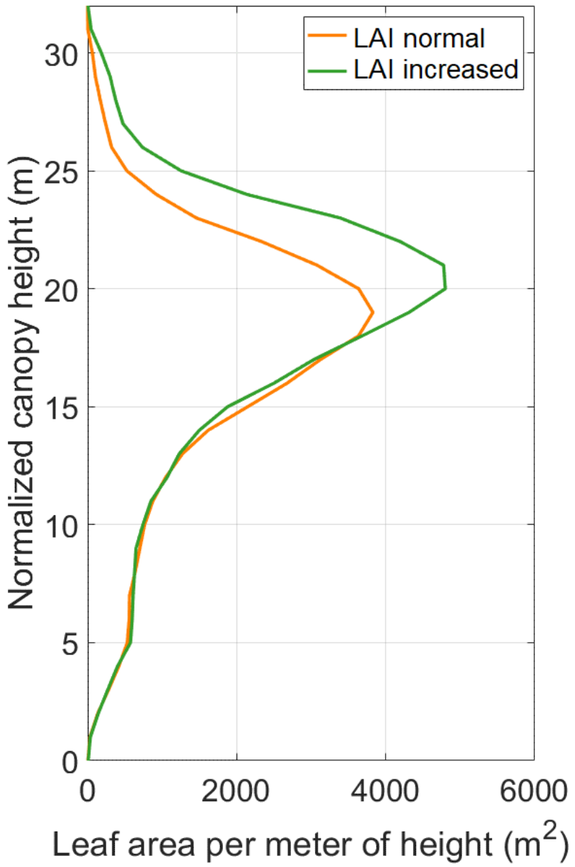


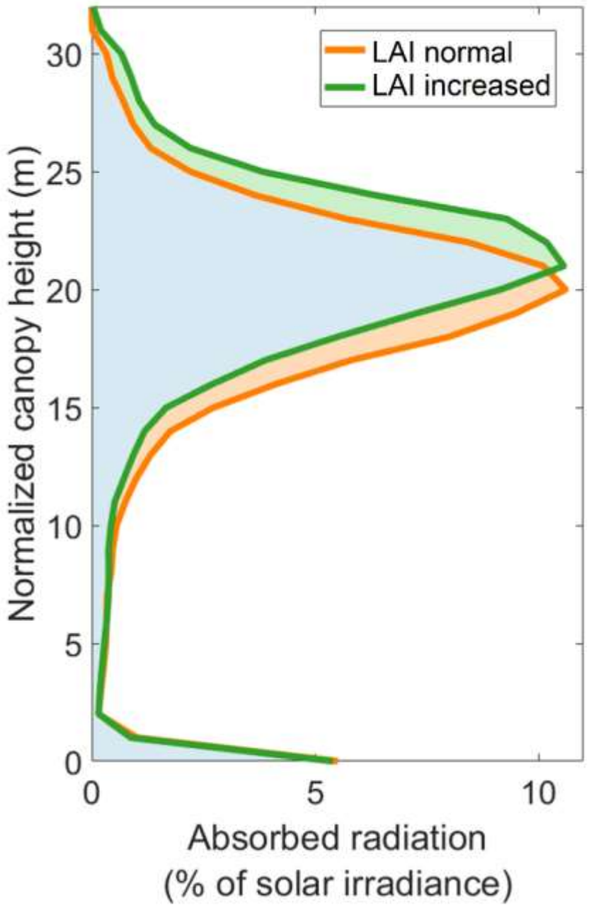


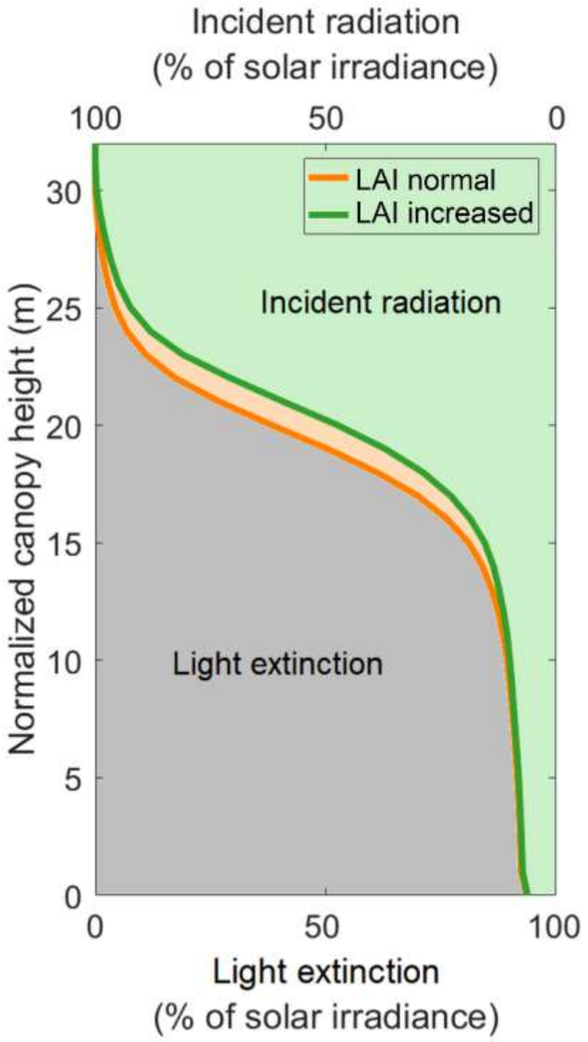


Leaf area vertical profile

FAPAR vertical profile

Light extinction

Light extinction in 2D

Liu, Calders, Verbeeck, et.al., paper in progress.

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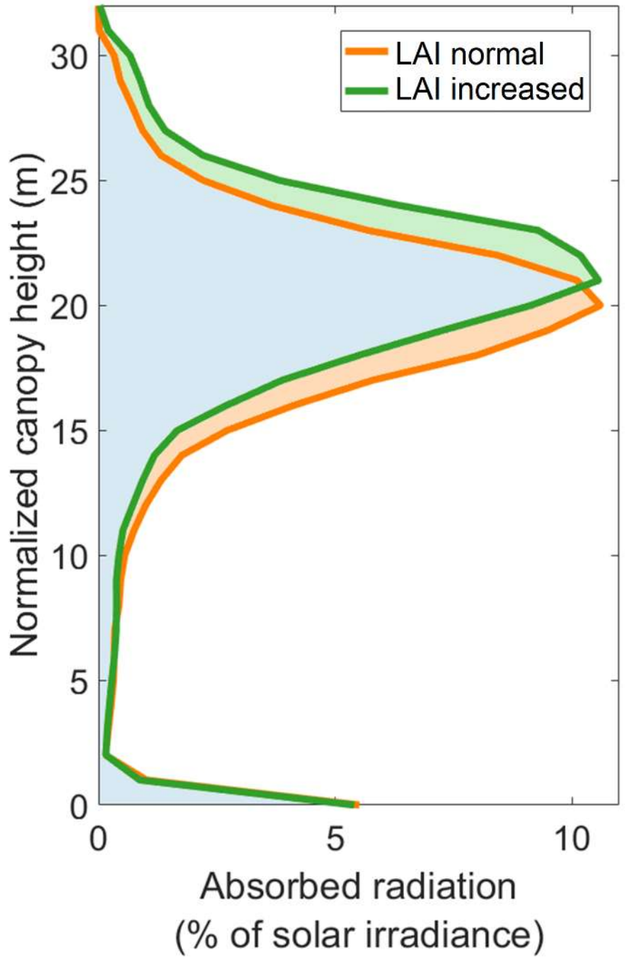



FAPAR vertical profile

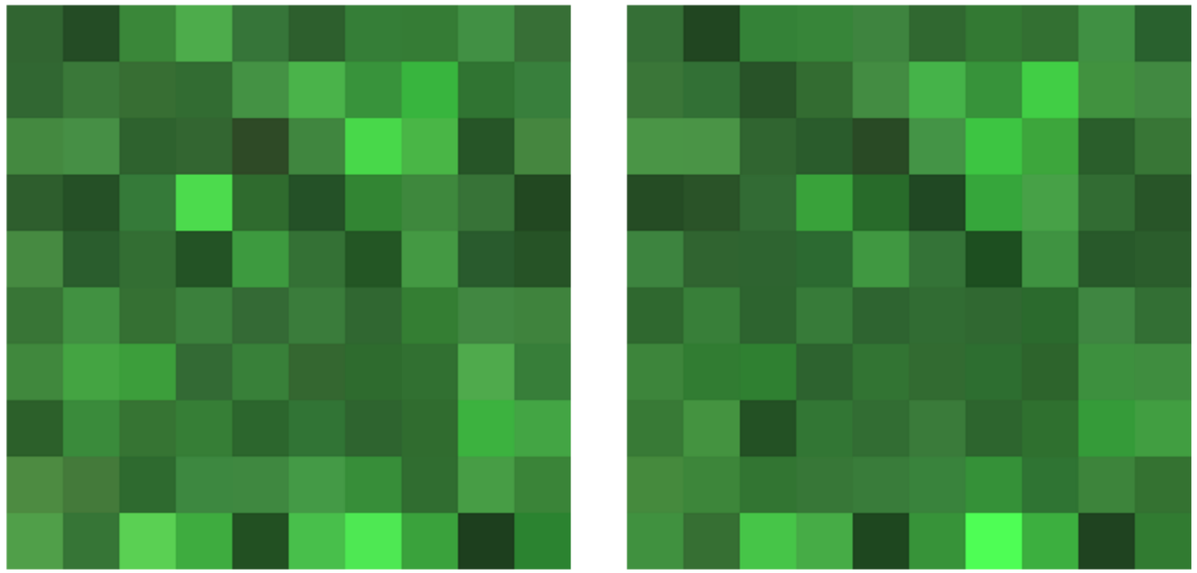
| FAPAR (%) | LAI 3.77 | LAI 4.77 |
|---|---|---|
| Leaf | 69.3 | 73.3 |
| Wood | 13.5 | 10 |
| Ground | 6.4 | 6.2 |
| Total | 89.2 | 89.5 |

Liu, Calders, Verbeeck, et.al., paper in progress.

# HOW DOES LIGHT INTERACT WITH FORESTS AND CARRY THEIR PARAMETRIC INFORMATION?
# QUANTIFICATION IN A MORE PHYSICAL, TRACEABLE, AND REALISTIC WAY.

LAI normal

LAI increased



Simulated Sentinel-2 images

| | **LAI normal** | **LAI increased** | **Relative variation** |
|---|---|---|---|
| $FAPAR_{leaf}$ | 69.3% | 73.3% | +5.8% |
| Albedo | 0.0218 | 0.0205 | -6% |
| Nadir reflectance | 0.0221 | 0.0213 | -3.6% |

Liu, Calders, Verbeeck, et.al., paper in progress.

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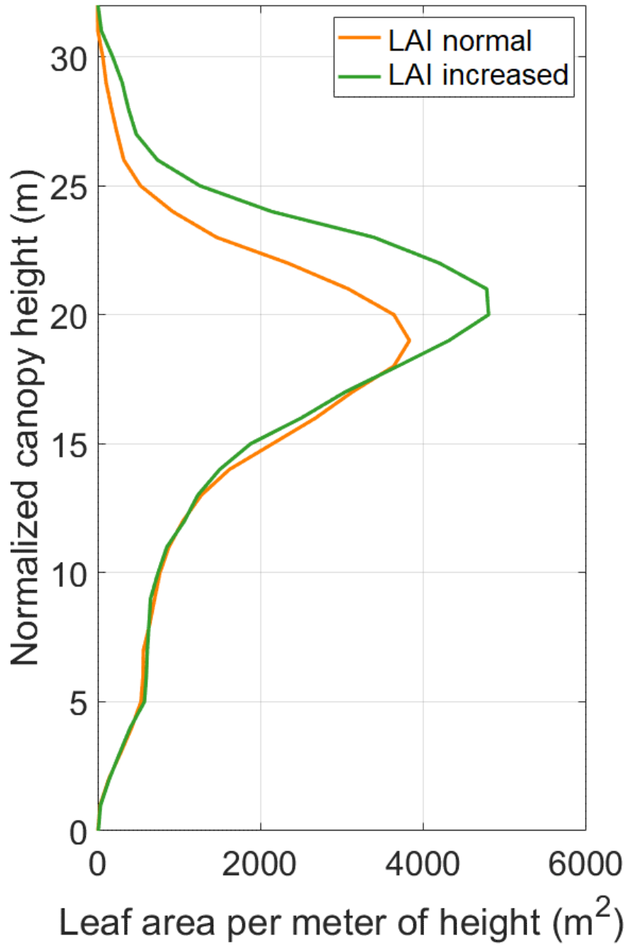
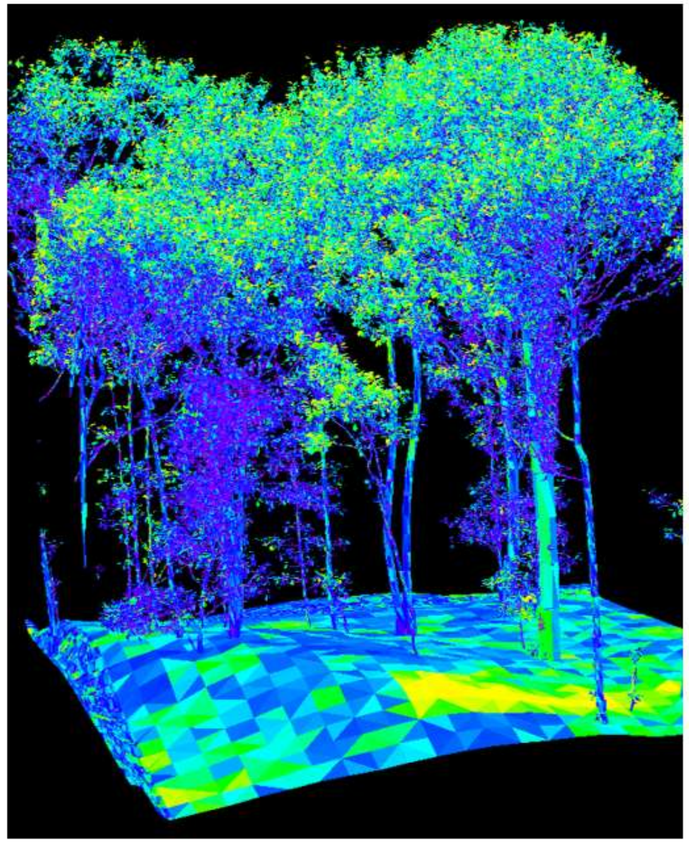
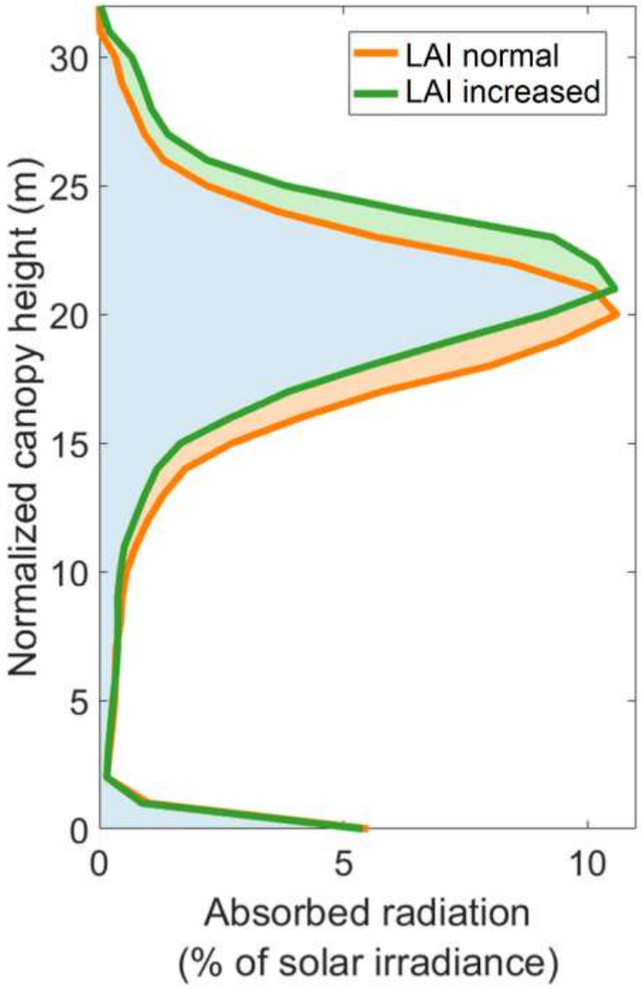



Leaf area vertical profile



Radiation Absorption of each object




FAPAR vertical profile

Liu, Calders, Verbeeck, et.al., paper in progress.

# CONCLUSIONS

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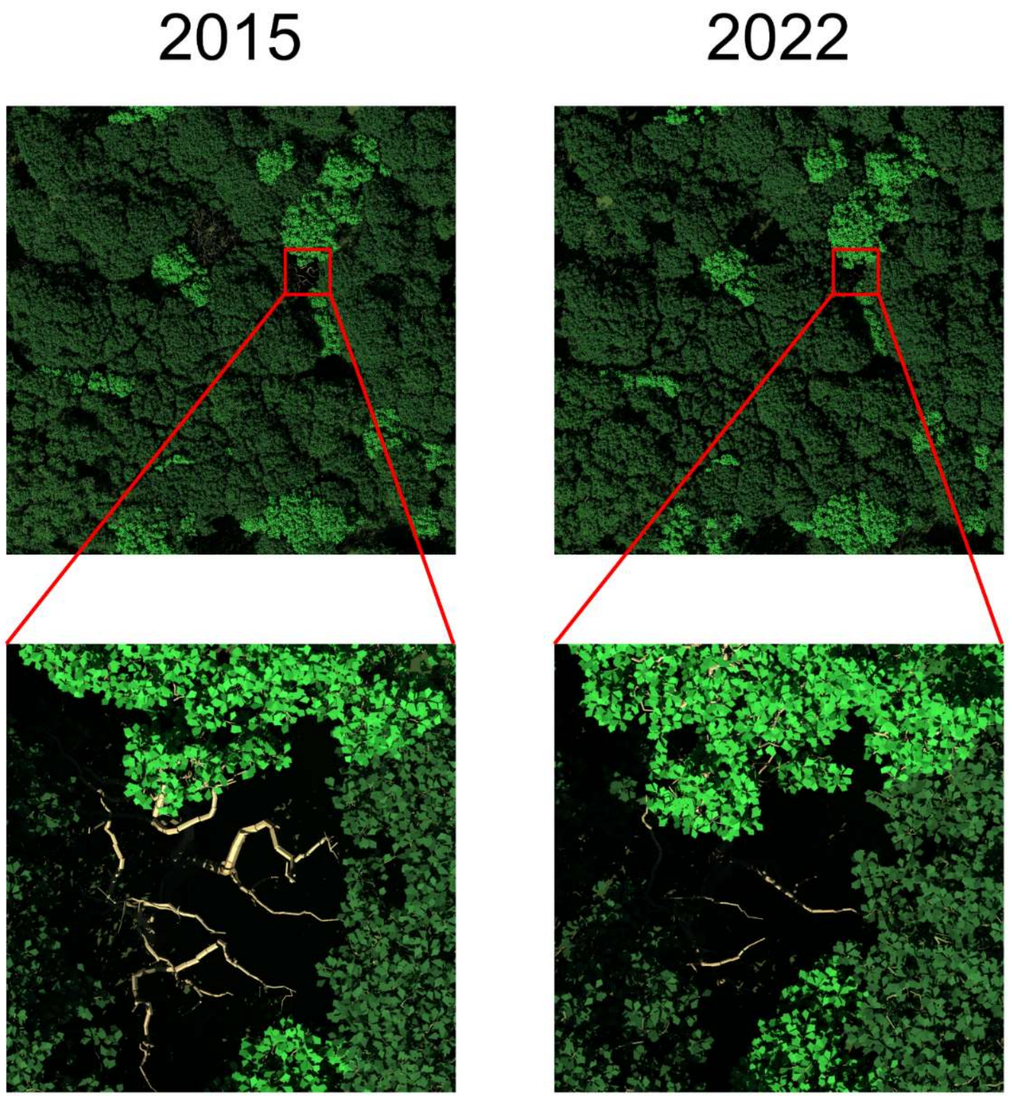
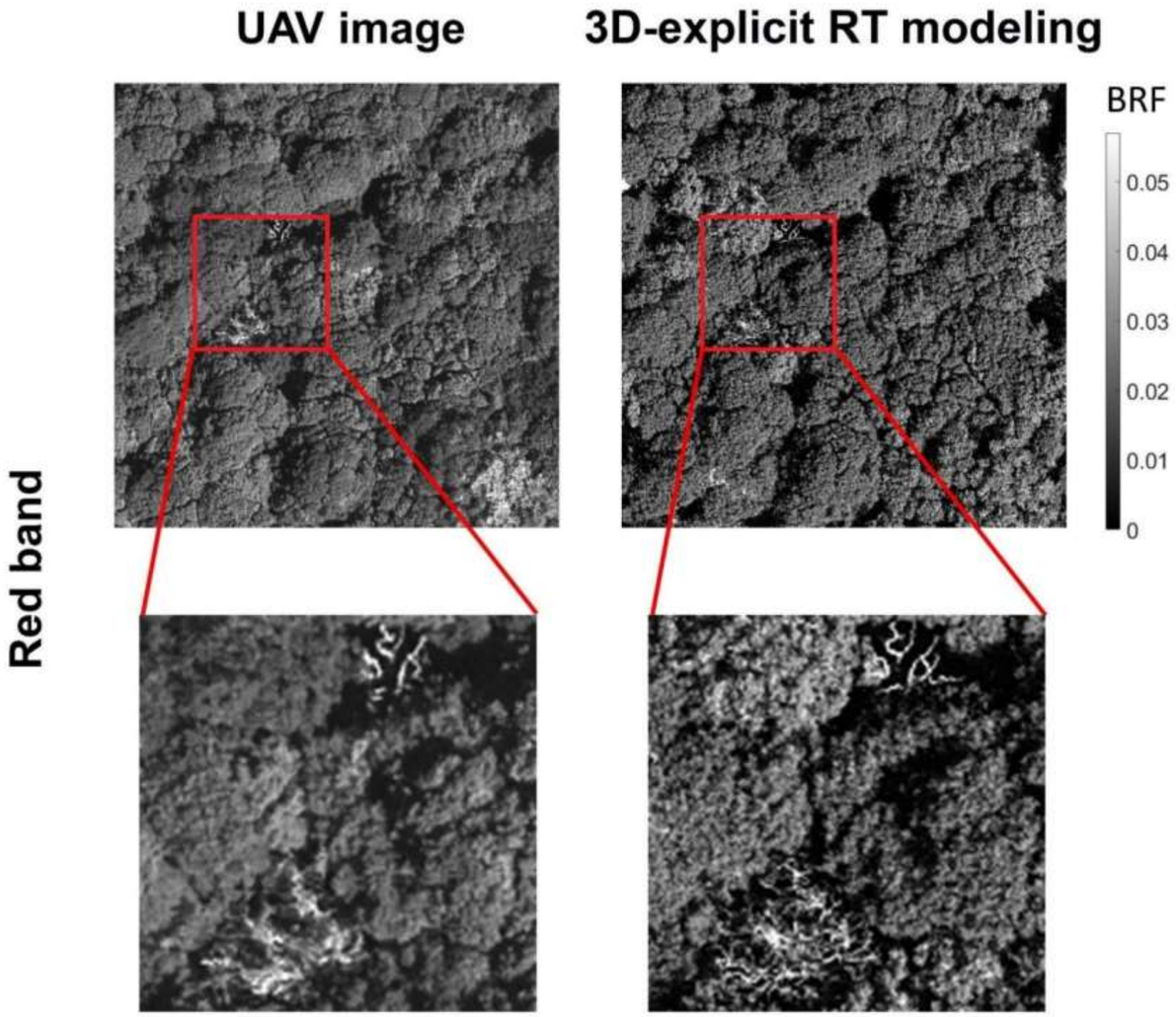
# CONCLUSIONS

- 4D-explicit radiative transfer modeling for real forest.



# CONCLUSIONS

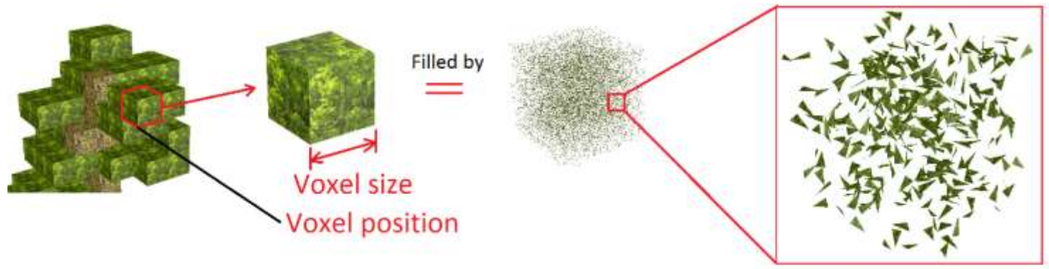
- 4D-explicit radiative transfer modeling for real forest.
- Model validation based on hyperspectral UAV images.

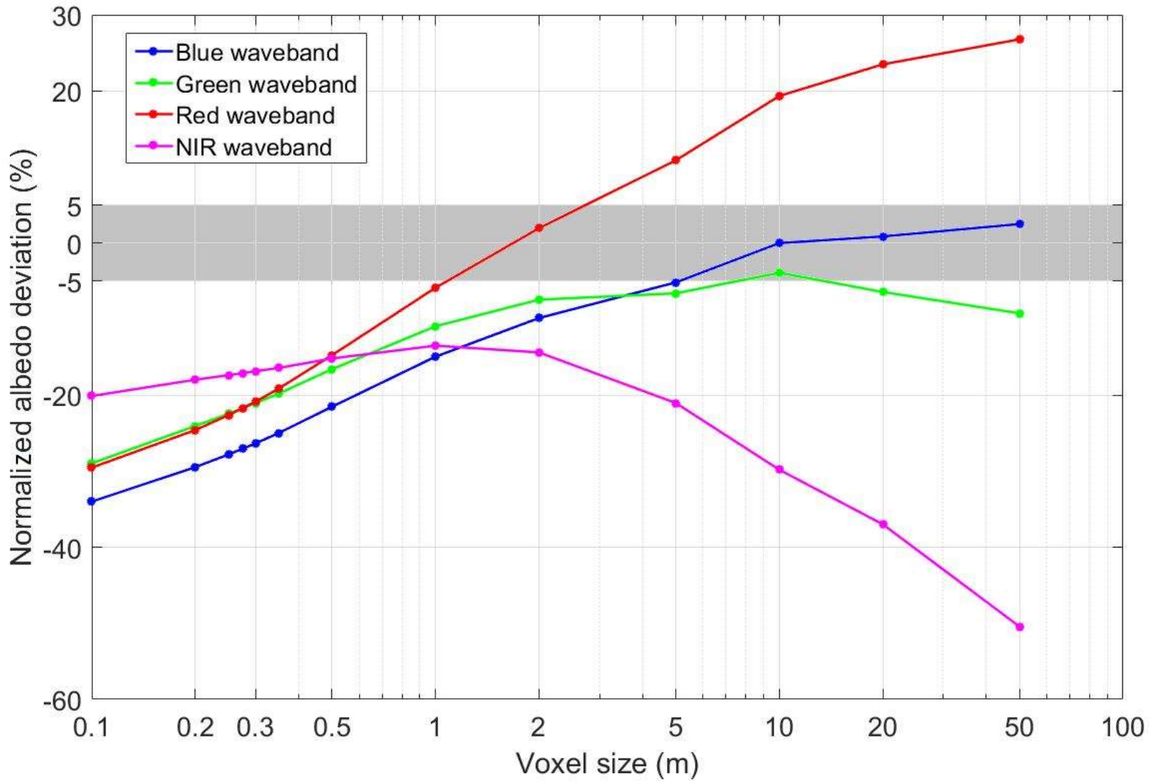



Liu, Calders, Verbeeck et. al., submitted.

# CONCLUSIONS

- 4D-explicit radiative transfer modeling for real forest.
- Model validation based on hyperspectral UAV images.
- Validating turbid medium hypothesis in forest structure.




RT deviation

# CONCLUSIONS

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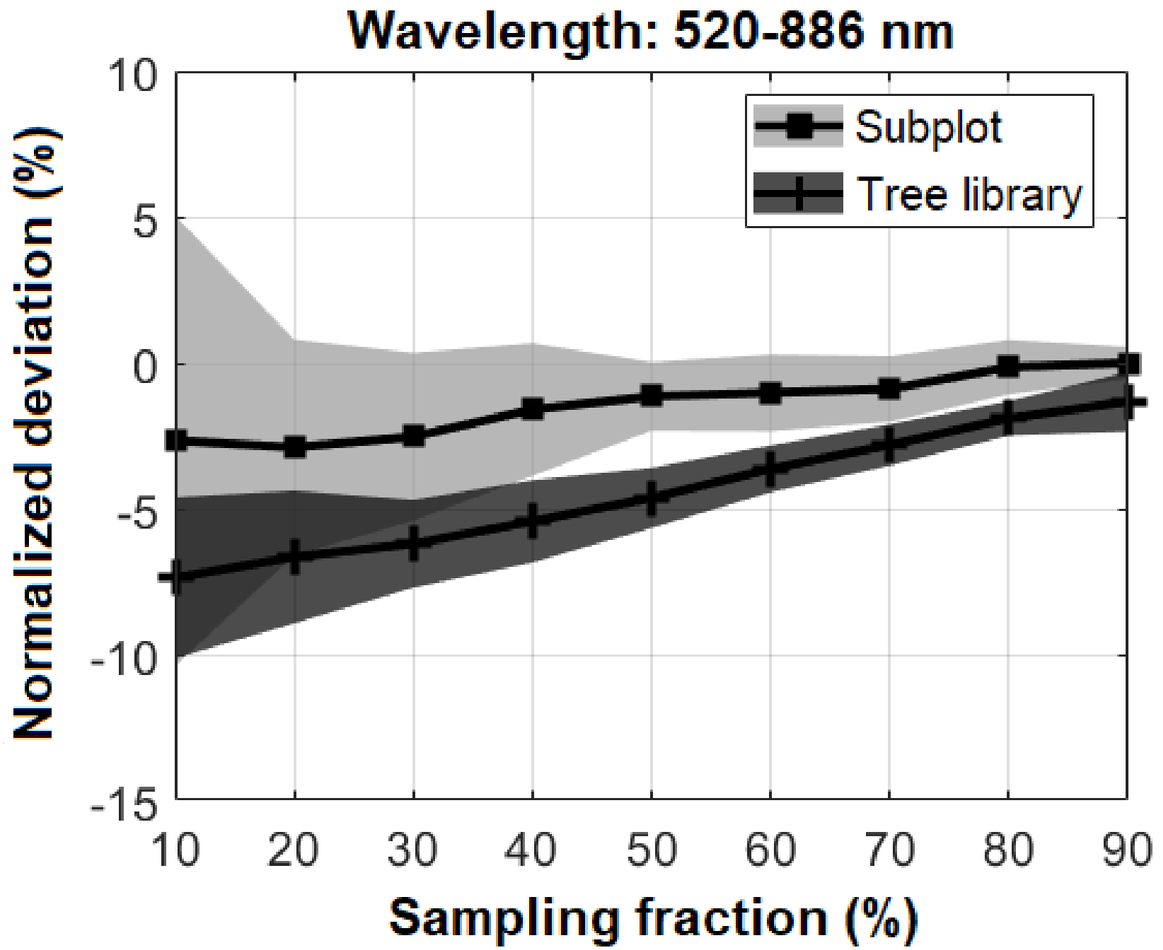
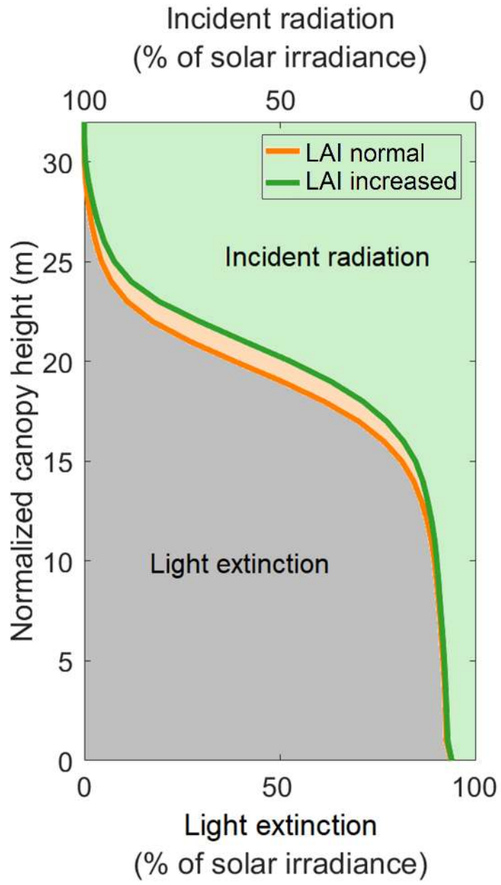


# CONCLUSIONS

- 4D-explicit radiative transfer modeling for real forest.
- Model validation based on hyperspectral UAV images.
- Validating turbid medium hypothesis in forest structure.
- Validating subsampling hypothesis in 3D reconstruction.
- Quantifying the relation between forest parametric information, radiative transfer, and remote sensing signal in a more traceable and physical way.



# Thank you.

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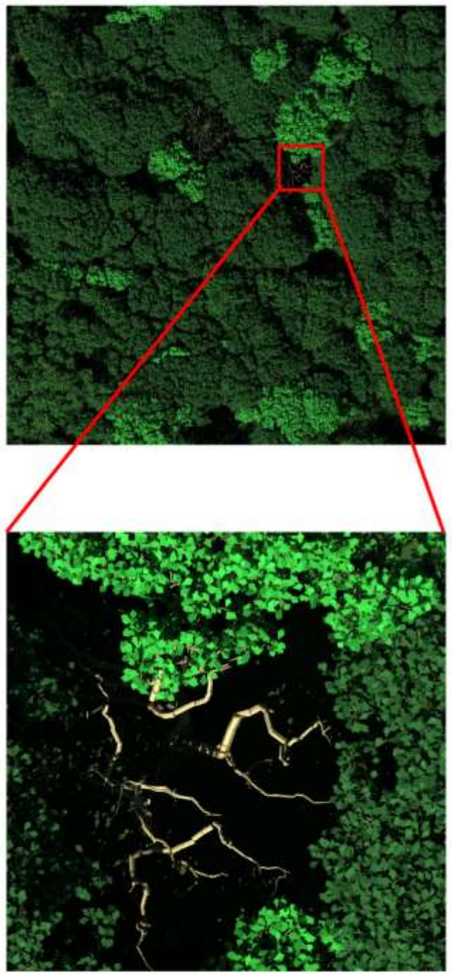

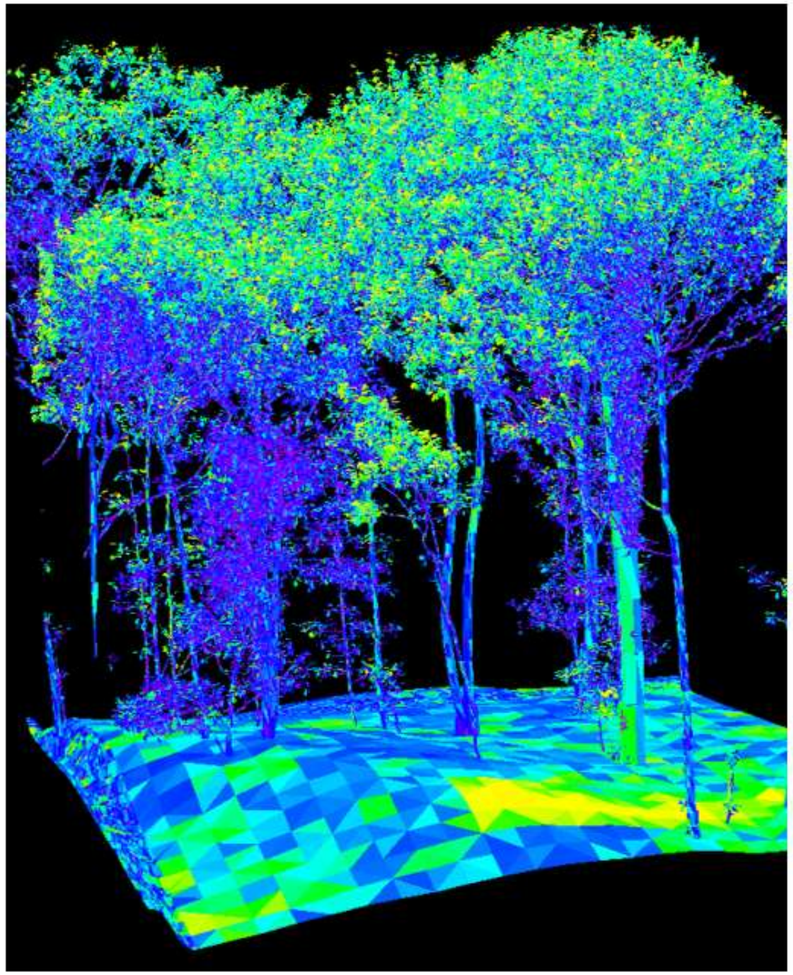

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