Beijing Forestry University

LESS

BEIJING NORMAL UNIVERSITY

2023 RAMI workshop on Radiative Transfer Modelling

LESS: a ray-tracing based 3D radiative transfer model for realistic forest canopies

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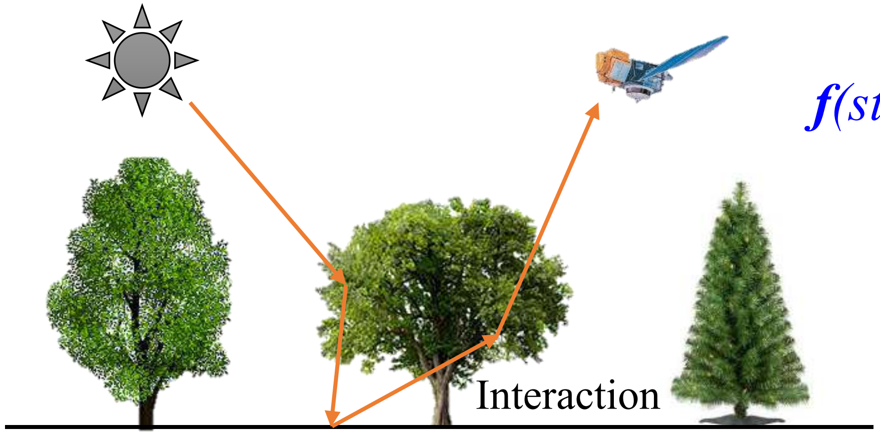
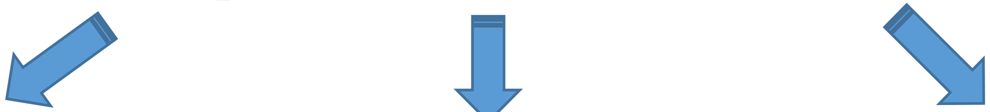
Outline

Outline

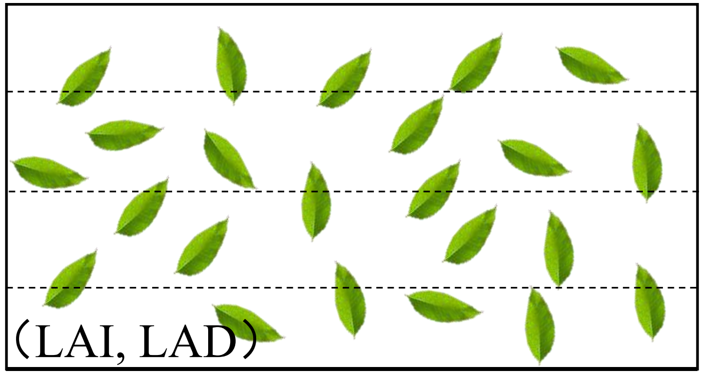
☐ Radiative transfer model



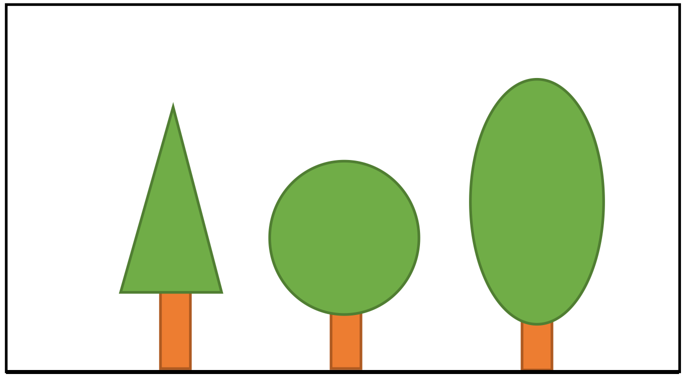
f(structure, optical,…)=BRF…



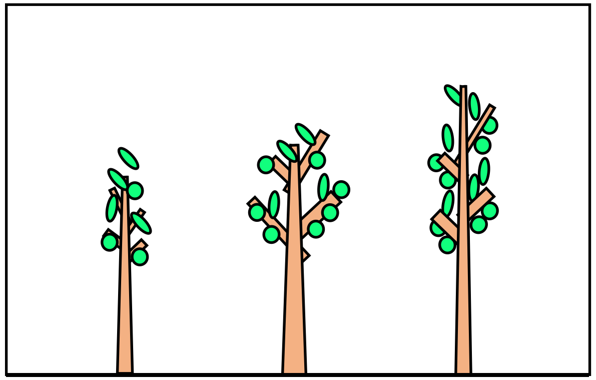
1D Radiative transfer model



Geometric-optical model



3D Radiative transfer model

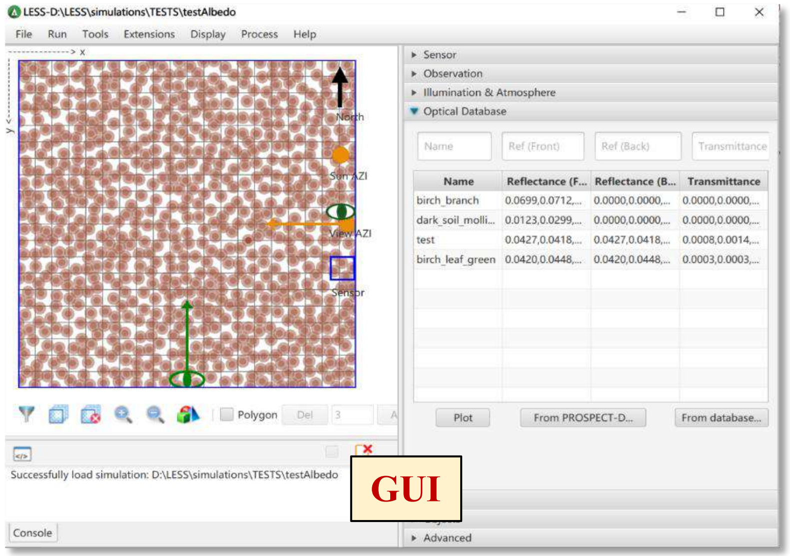


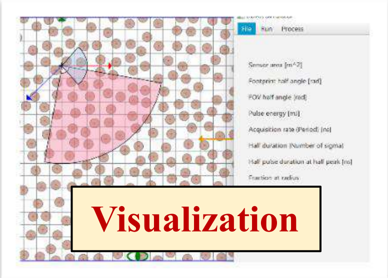
Introduction of the LESS model — The LESS model

LESS is an efficient ray-tracing based 3D radiative transfer model that can simulate:

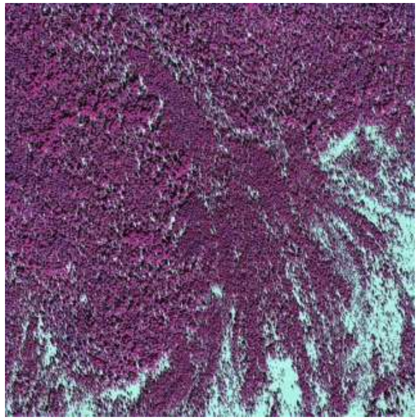
- Multispectral/Hyperspectral images
- Bidirectional Reflectance factor (BRF)
- Thermal infrared images
- LiDAR signals
- Photon recollision probability,…

It also provides an easy-to-use GUI, and Python SDK:



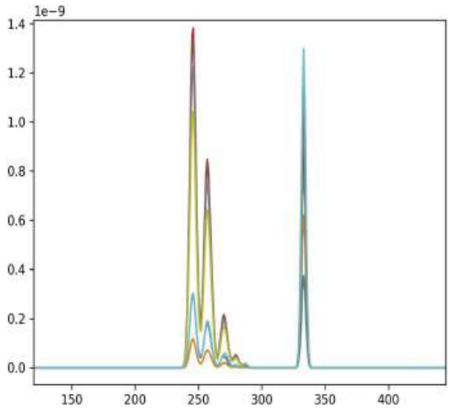


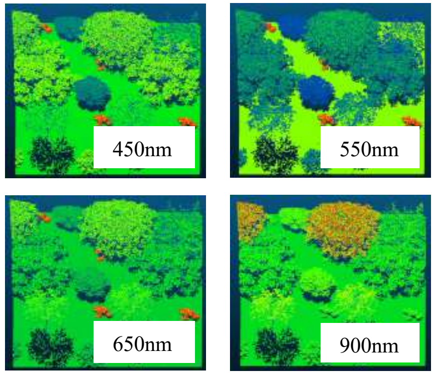
http://lessrt.org/



Multispectral images(1km)

Fisheye images

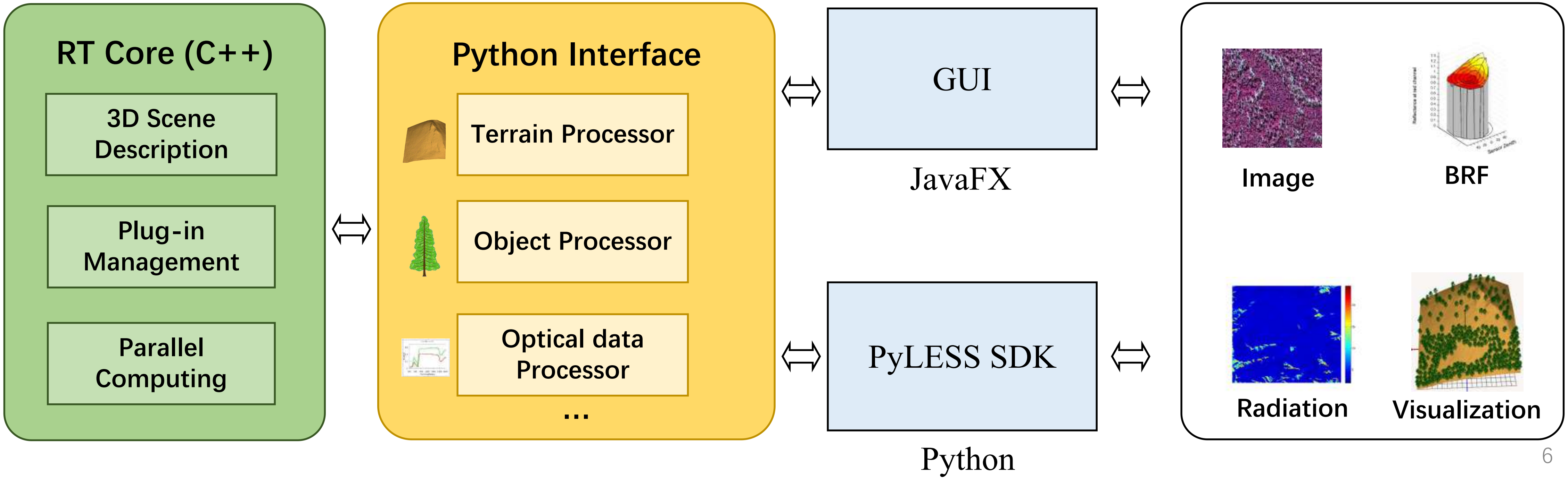




Hyperspectral LiDAR Waveform and point cloud

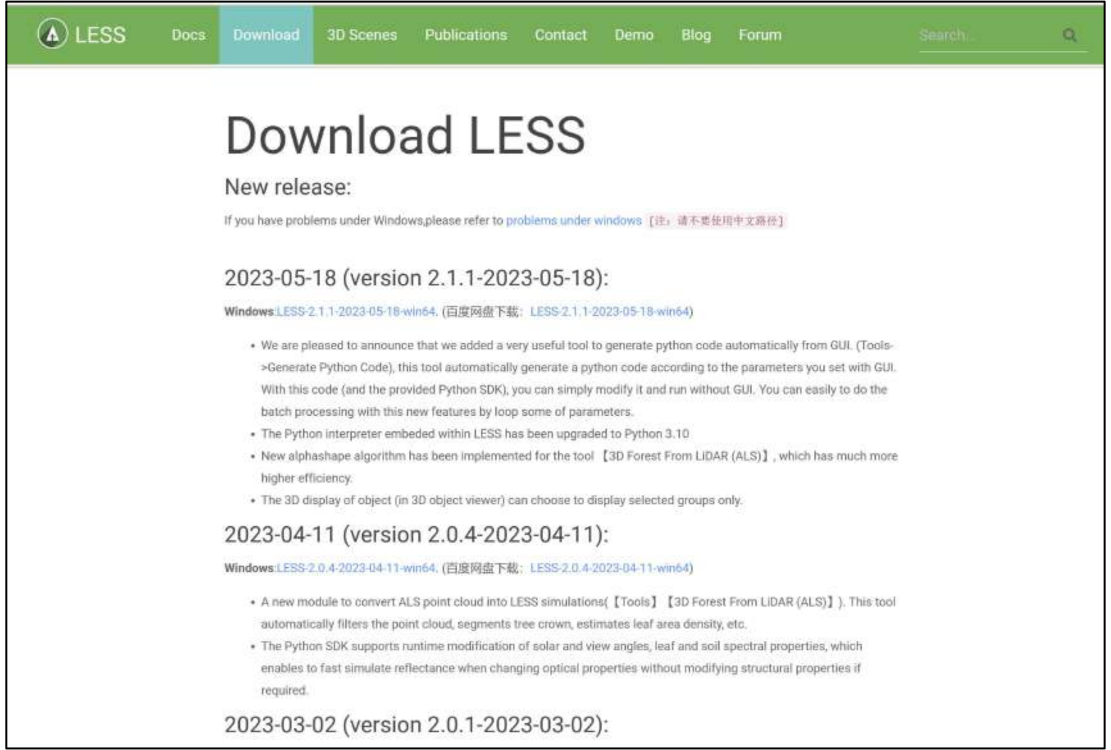
01 Introduction of the LESS model — The LESS model

- Developed since 2013 at Beijing Normal University, and formally released in 2019.
- The RT computation core is based on a heavily modified version of Mitsuba (V0.5), utilizing **the most recent technique from computer graphic community**.
- LESS has a flexible software architecture, providing **both Python SDK and Graphic User Interface (GUI).**
- LESS implements both **forward ray-tracing and backward ray-tracing** for simulating various remote sensing signals.

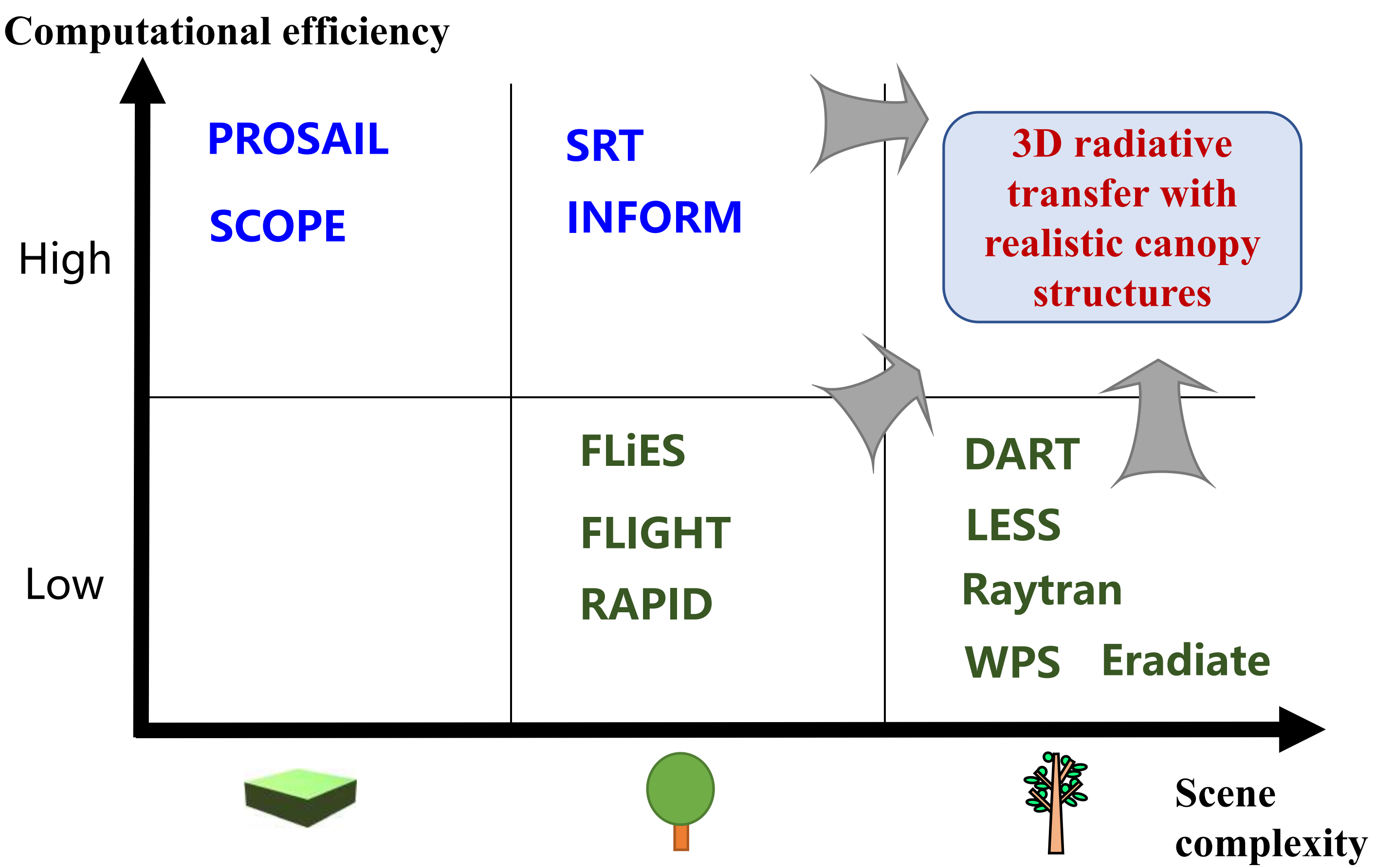


01 Introduction of the LESS model — The LESS model

- LESS new versions are released at the website: http://lessrt.org, around 1~2 month per version.
- We provide a detailed user manual for both English and Chinese, and also video courses (Chinese only now).
- We provide ready-to-use RAMI scene for LESS.



3	HET09_JBS_SUM		LAI Leaf: 3.835 LAI Wood: 1.934	0.557	百度网盘 Google Drive	PIAB shoot ACPL leaf ALGL leaf BEPE leaf FREX leaf POTR leaf TICO leaf
4	HET14_WCO_UND		LAI Leaf: 2.703 LAI Wood: 0.460	0.394	百度网盘 Google Drive	



Analytical model: Describe complex canopy structures with analytical equations (new mathematical tools)

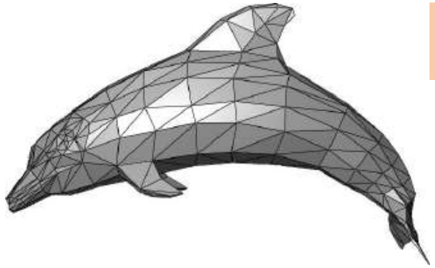
3D models: Implement computationally efficient radiative transfer simulations (acceleration, e.g., GPU, new numerical algorithms.)

How to describe 3D canopy structures? → How to realize 3D radiative transfer simulation?

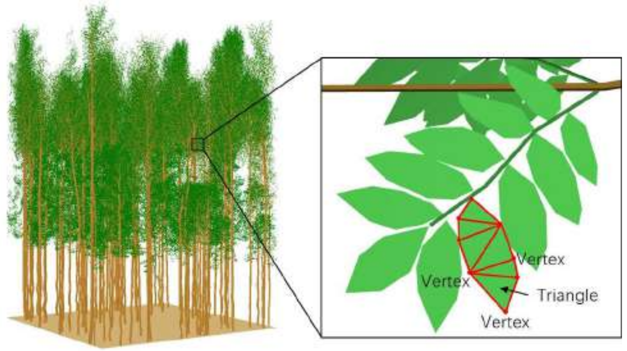
Triangle mesh

- A set of triangles to represent objects.

Example



Triangle mesh representing a dolphin (from *wikipedia*)

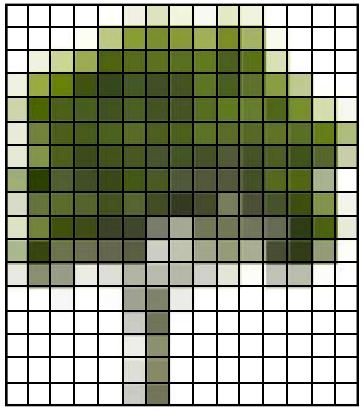


Triangle mesh representing forest

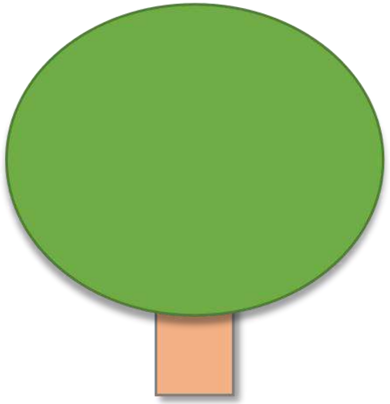
Turbid medium

- Canopy elements, such as leaves, are assumed to be infinitely small, and are described with several statistical parameters.
- Usually, turbid medium is bounded by voxels, simple geometry objects, etc.

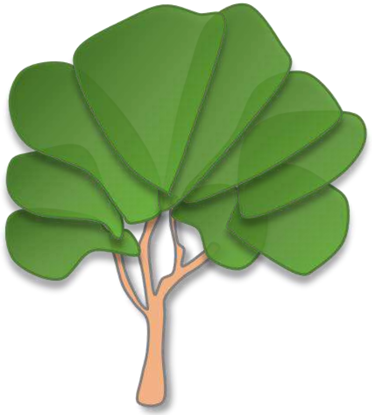
Example



Regular voxel



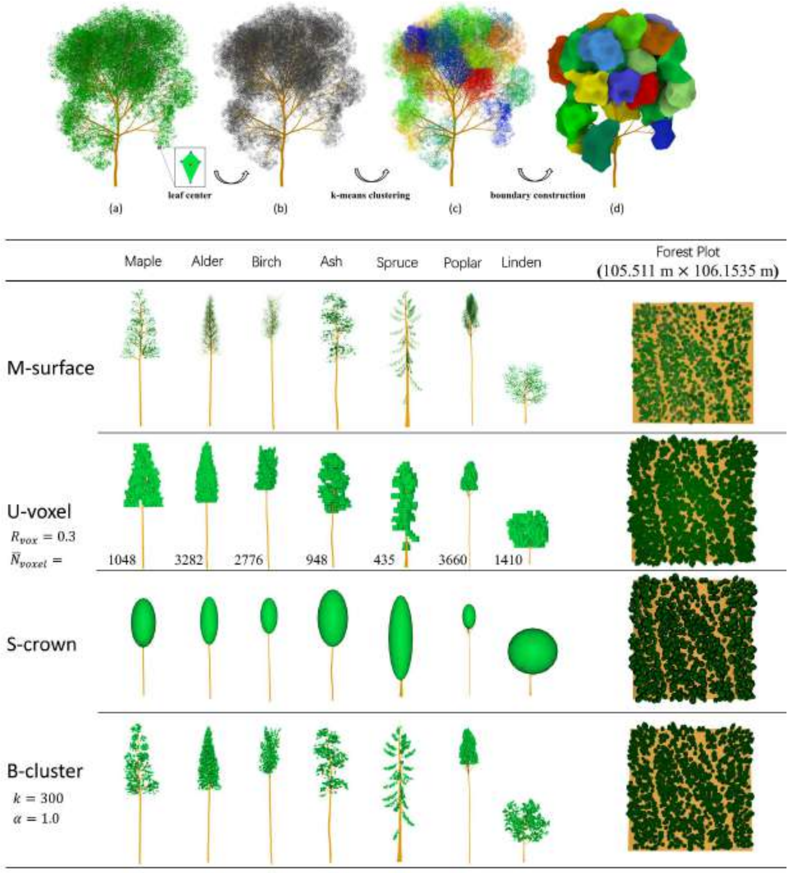
Simple objects



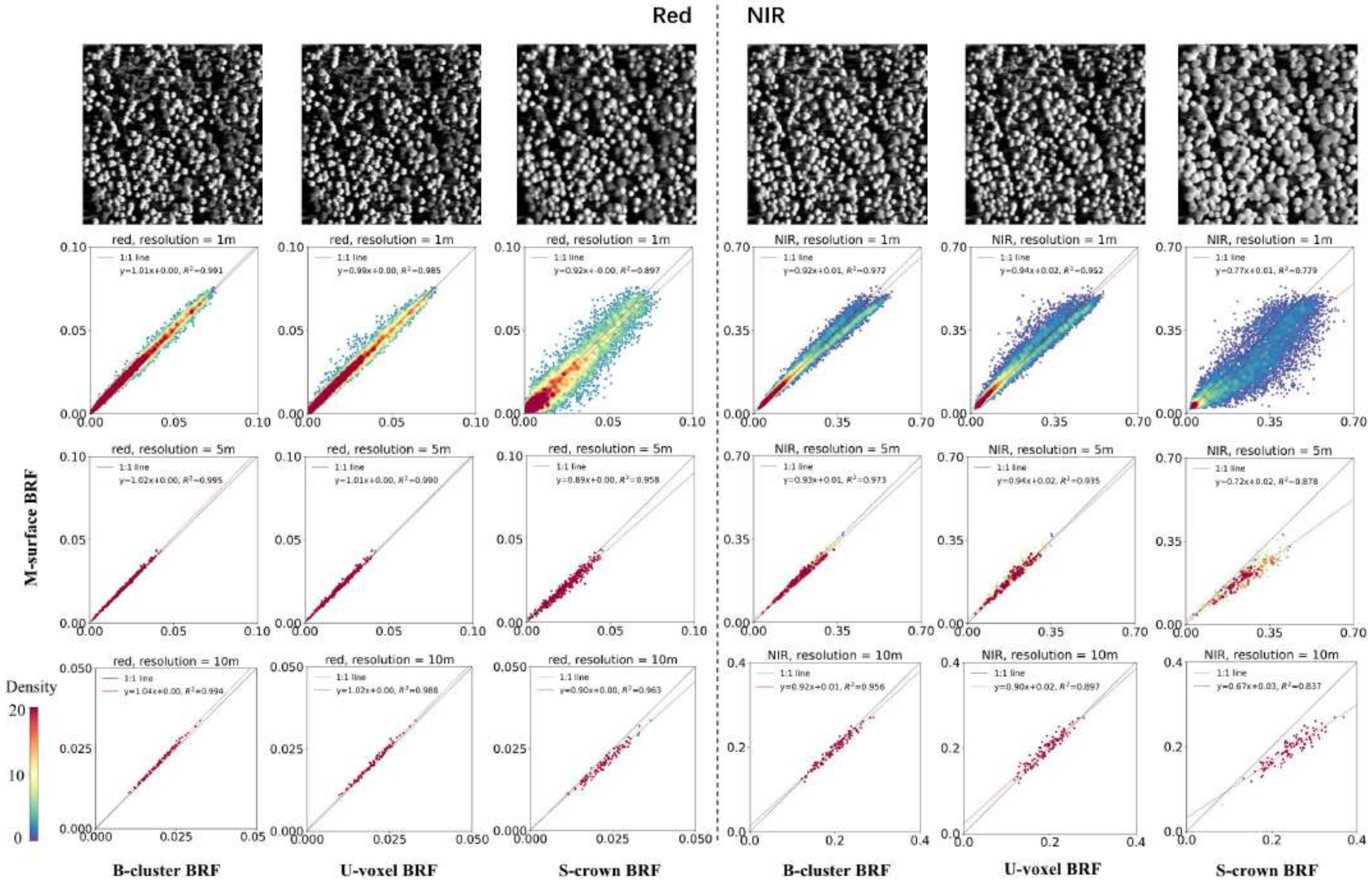
Alphashape

Turbid medium

- Comparing alphashape with triangle mesh representations.



$\bar{N}_{voxel}$ represents the averaged number of voxels for each species under a voxel resolution of 0.3 m



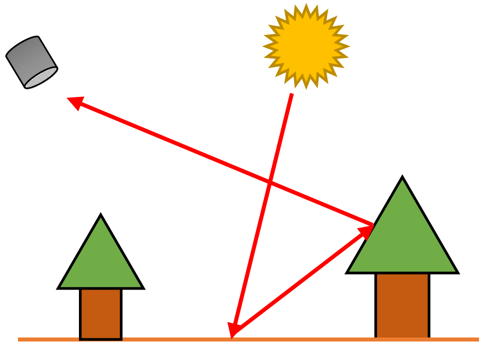
(Qi, J., RSE, 2022)*

Ray tracing in LESS

Ray Tracing

Forward ray-tracing

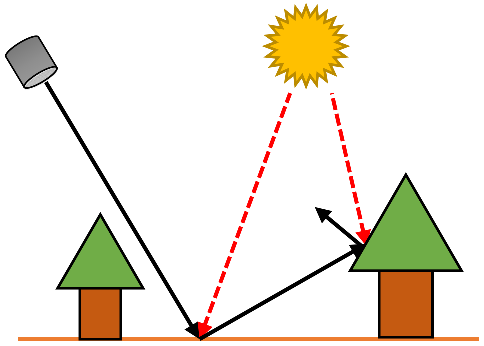
Sending rays from light sources (e.g., sun)



- Radiation are propagated through the whole canopy
- Suitable for simulating energy distribution, canopy absorption, multiple-angle BRF, etc.

Backward ray-tracing

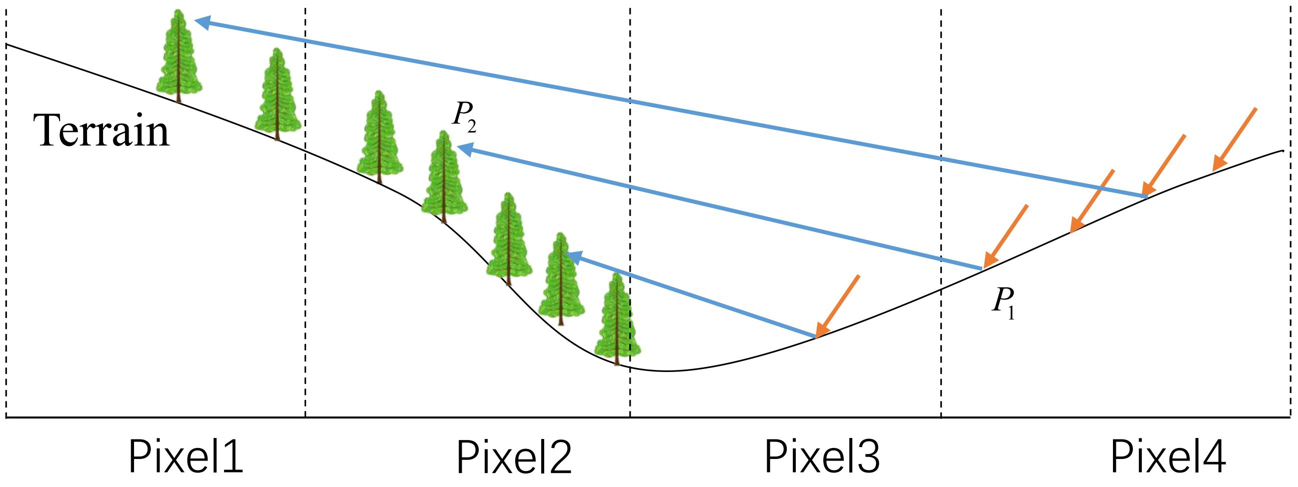
Sending rays from sensors

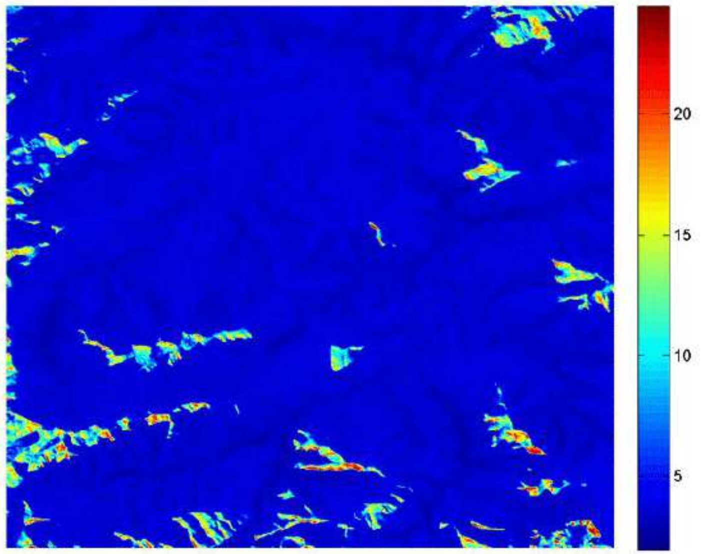


- Rays that enters the sensor only are simulated
- Suitable for simulating images, etc.

Functionalities beyond BRFs and images

- Solar radiation over rugged terrain

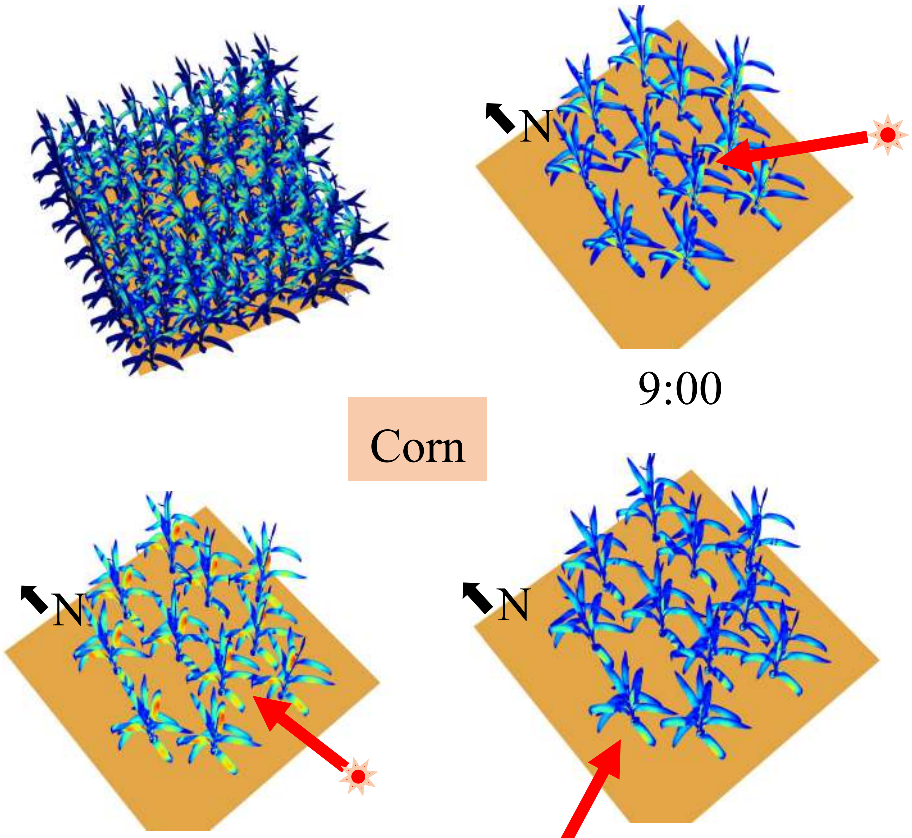




Record the incident and outgoing radiation for each pixels over rugged terrain with complex vegetation

Functionalities beyond BRFs and images

- Absorbed energy per each triangle

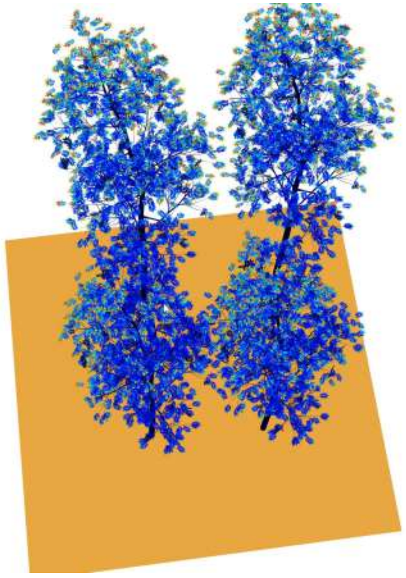


9:00

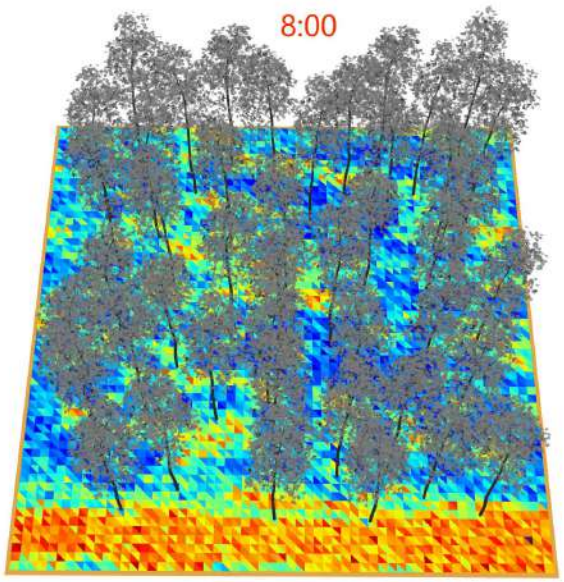
Corn

12:00

15:00



Forest



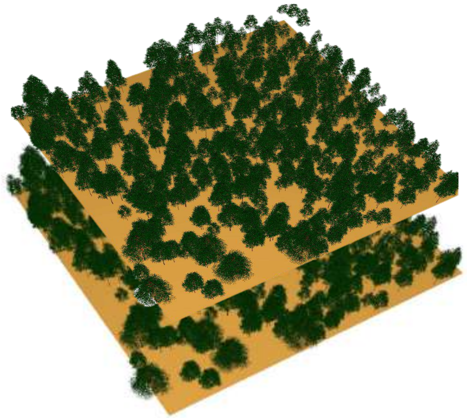
Each leaf triangle

Each ground triangle

Outline

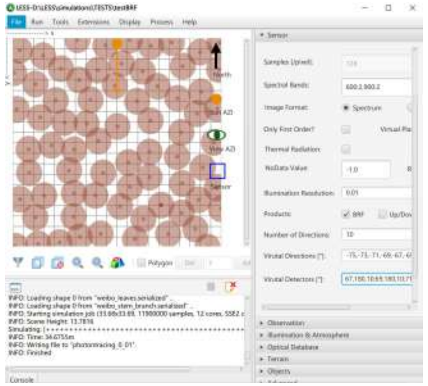
◻ Case 1: Validation of FPAR inversion algorithm

Using LESS-simulated FPAR and its corresponding BRF to validate coarse-resolution FPAR inversion algorithm, with wood absorption considered.

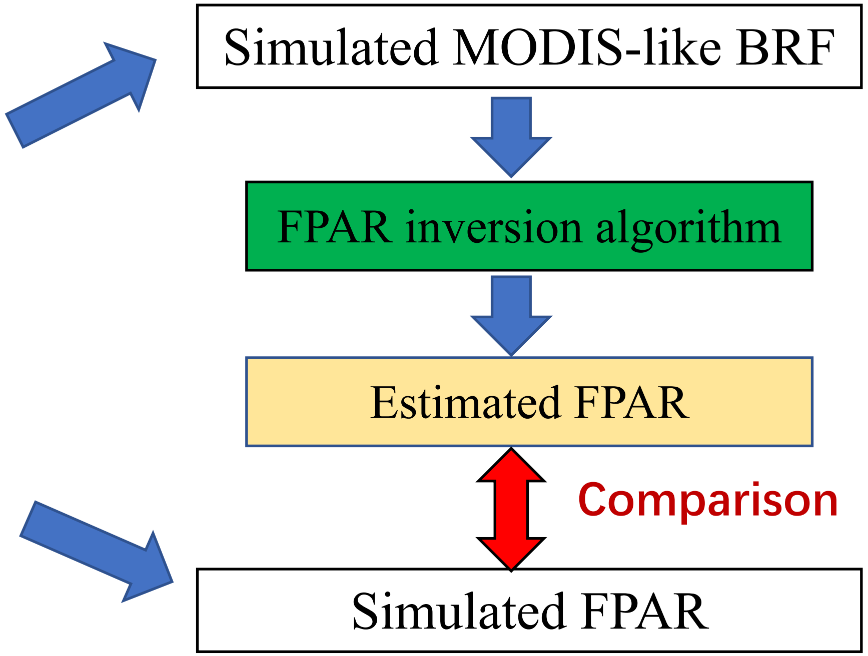


A series of scenes with varying LAIs

Input



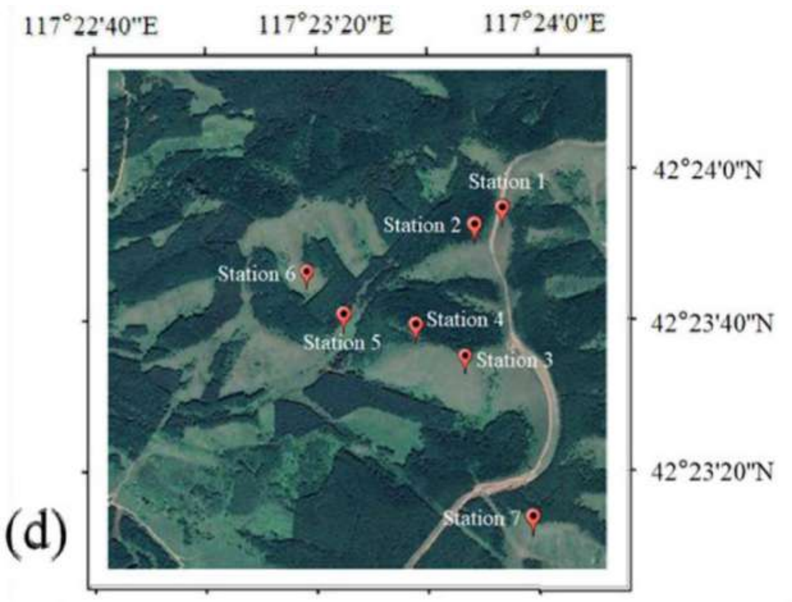
LESS

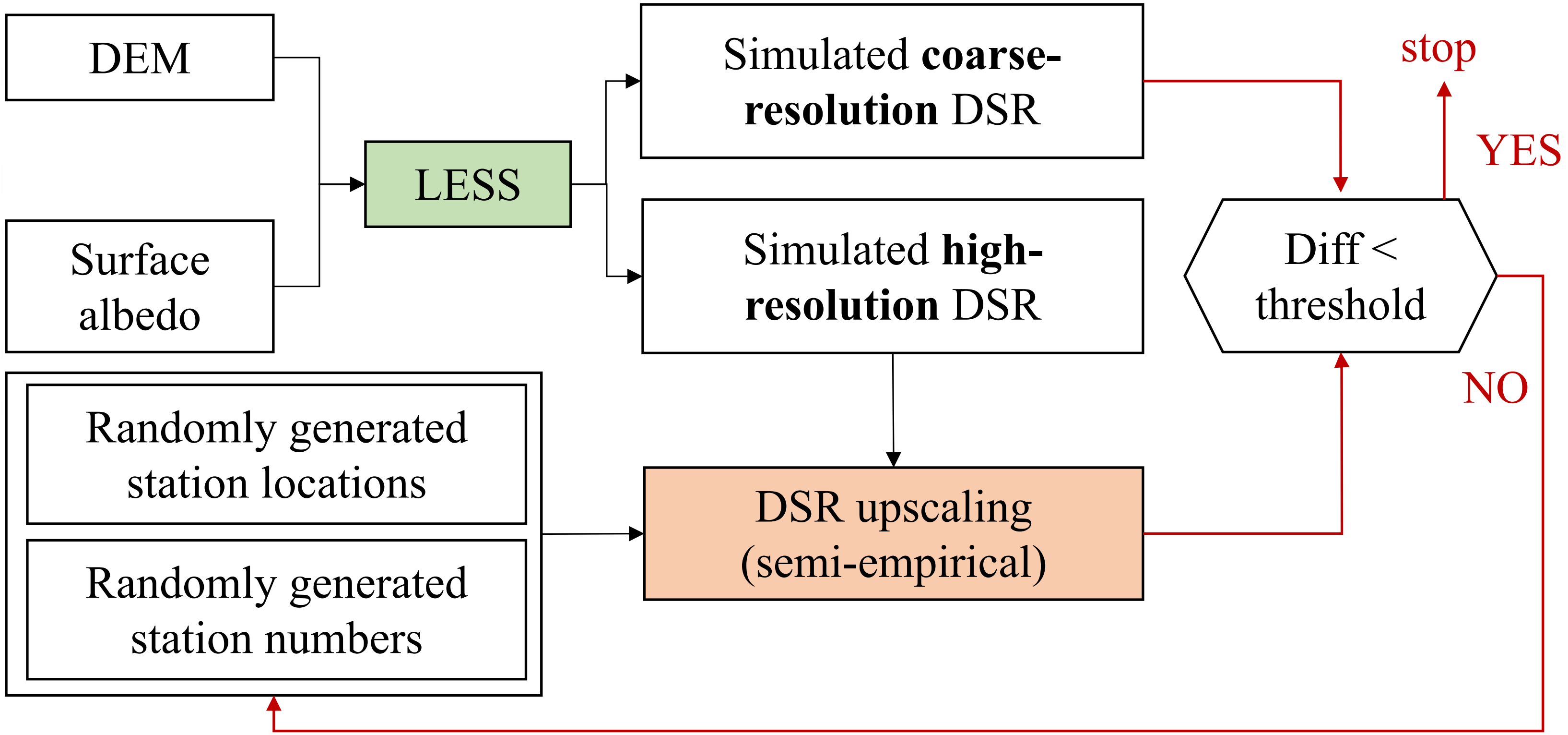


Chen, S., Liu, L., et al., 2019. Retrieval of the Fraction of Radiation Absorbed by Photosynthetic Components (FAPARgreen) for Forest using a Triple-Source Leaf-Wood-Soil Layer Approach. Remote Sensing 11, 2471.*

Case 2: Optimize DSR measurements over rugged terrains

- Validating coarse-resolution DSR is difficult because field measurements only cover a point.
- A method to choose optimized measurement ground stations (number and locations within the pixel) to upscale to pixel level is critical.

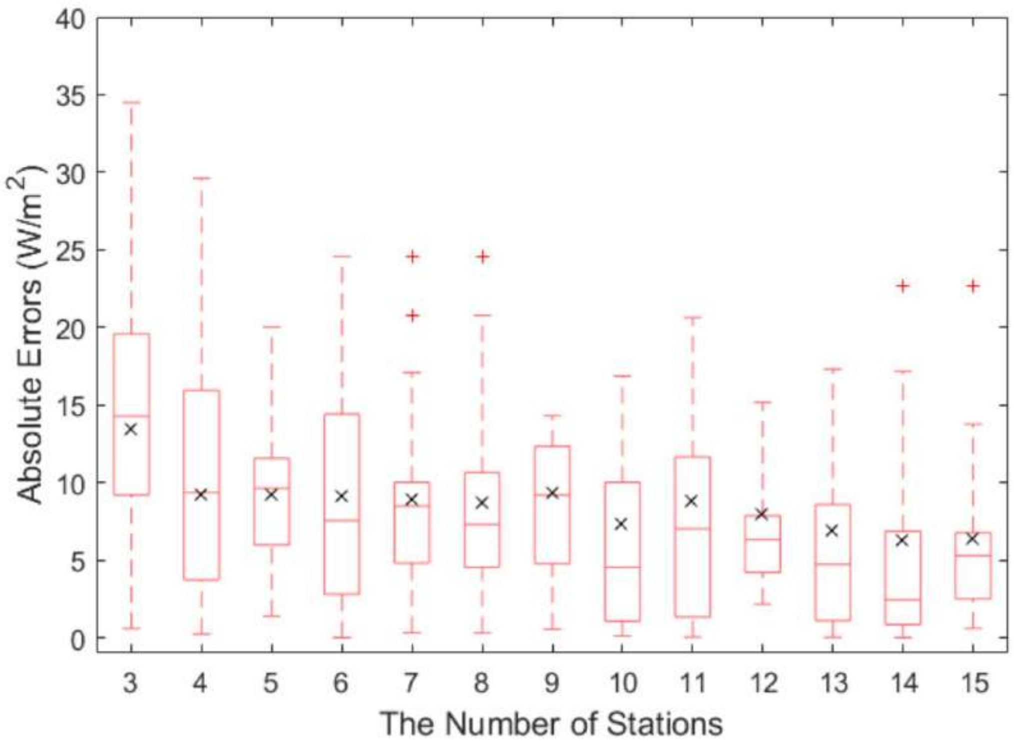




Yan, G., Chu, et al., 2020. An Operational Method for Validating the Downward Shortwave Radiation Over Rugged Terrains. IEEE Transactions on Geoence and Remote Sensing PP, 1–18.

Case 2: Optimize downward shortwave radiation (DSR) over rugged terrains

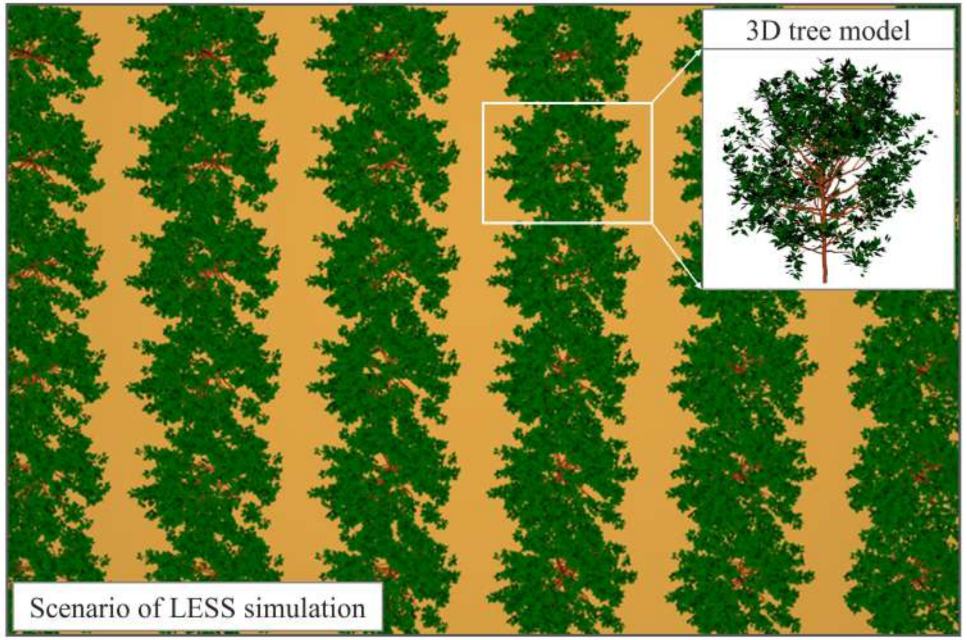
- Upscaling errors change with the number of ground stations

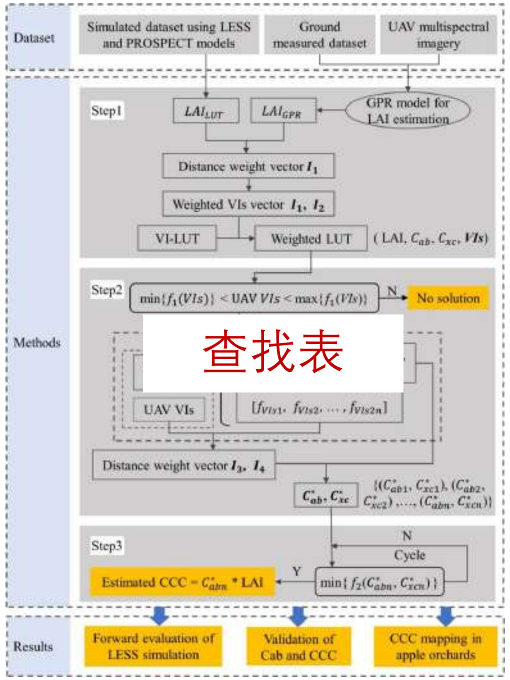


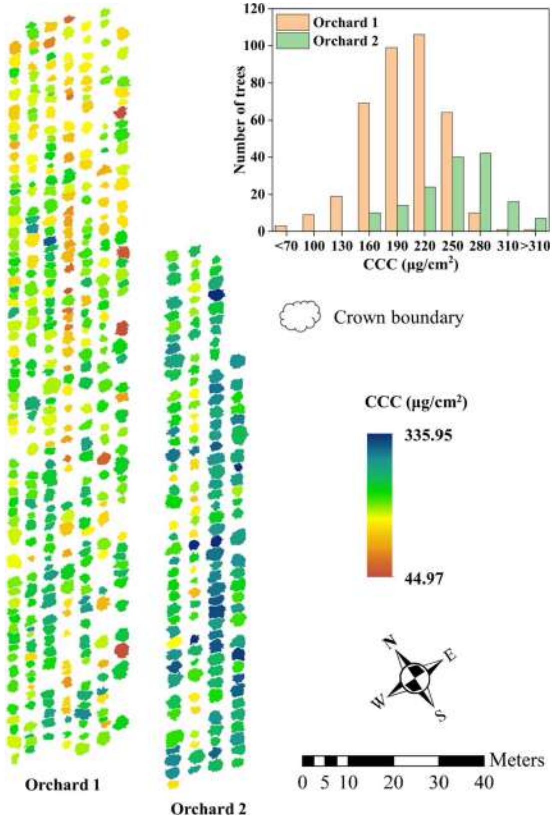
Yan, G., Chu, et al., 2020. An Operational Method for Validating the Downward Shortwave Radiation Over Rugged Terrains. IEEE Transactions on Geoence and Remote Sensing PP, 1–18.

◻ Case 3: Estimating chlorophyll content at individual tree level

- Generating look-up-tables with LESS simulated BRF over individual apple trees, considering within-crown heterogeneity.







Jinpeng Chen, Hao Yang, et al., Estimating canopy-scale chlorophyll content in apple orchards using a 3D radiative transfer model and UAV multispectral imagery, 2022, Computers and Electronics in Agriculture.

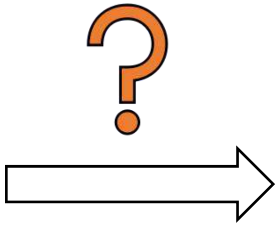
Outline

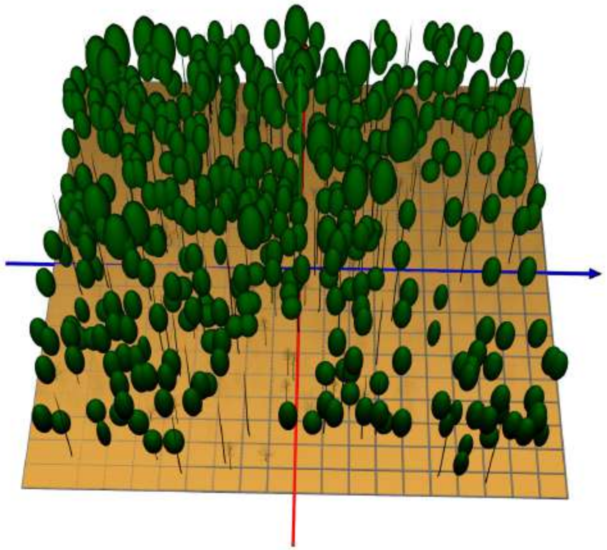
Future developments of LESS

- Computation efficiency is no longer a major difficulty.

  Increased CPU cores, Parallel computing, GPU,…

- How to construct more realistic 3D scenes matters…

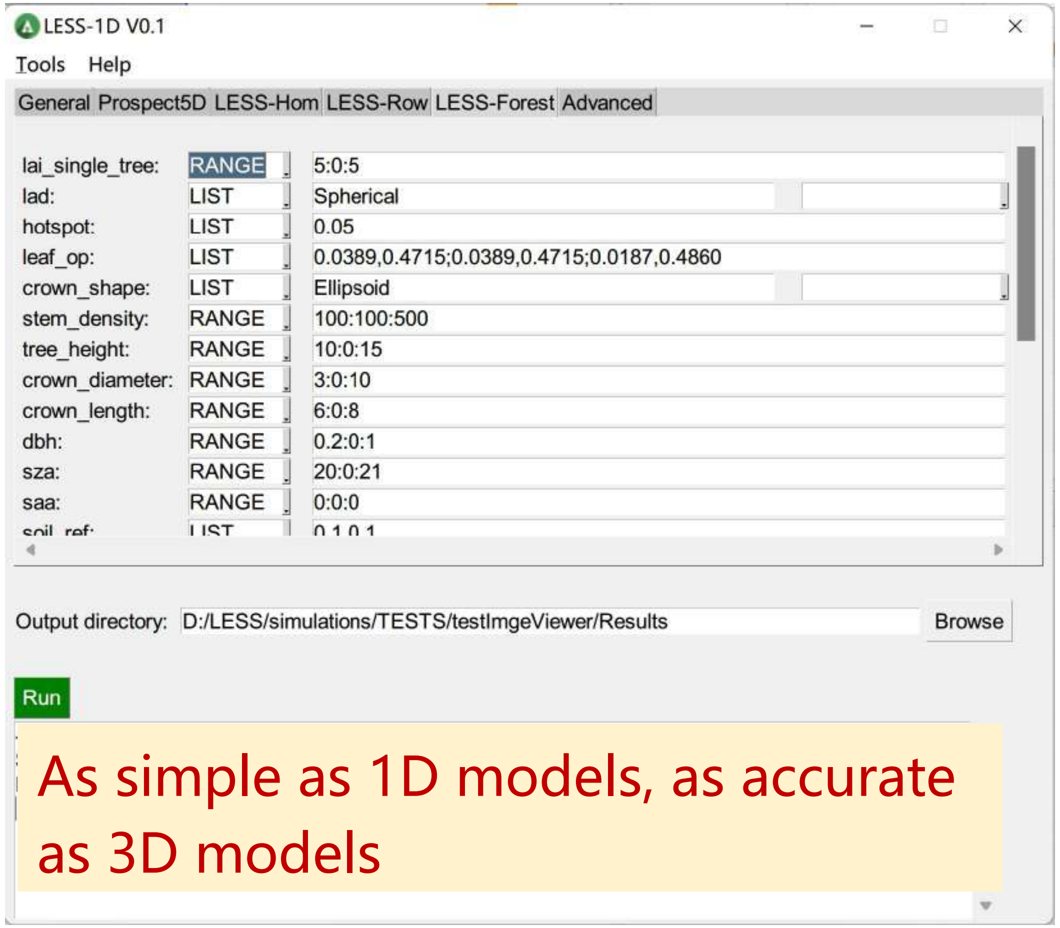




According to our users: Construction of 3D forest scenes has been a major difficulty to use 3D models

03 Future developments of LESS

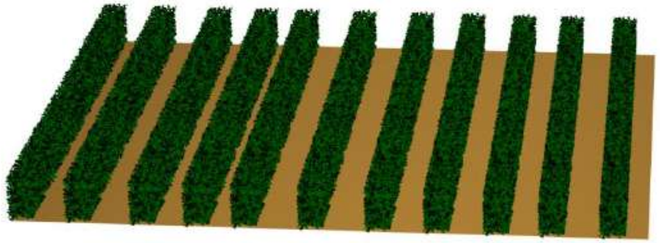
- Automatic generation of scenes according to statistical parameters that are identical to 1D models



As simple as 1D models, as accurate as 3D models

LESS-Hom

LESS-Row



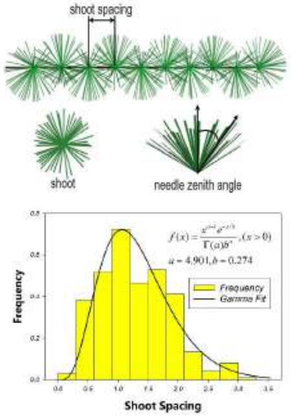
LESS-Forest

Future developments of LESS

- Generating forest scenes from LiDAR data (TLS)

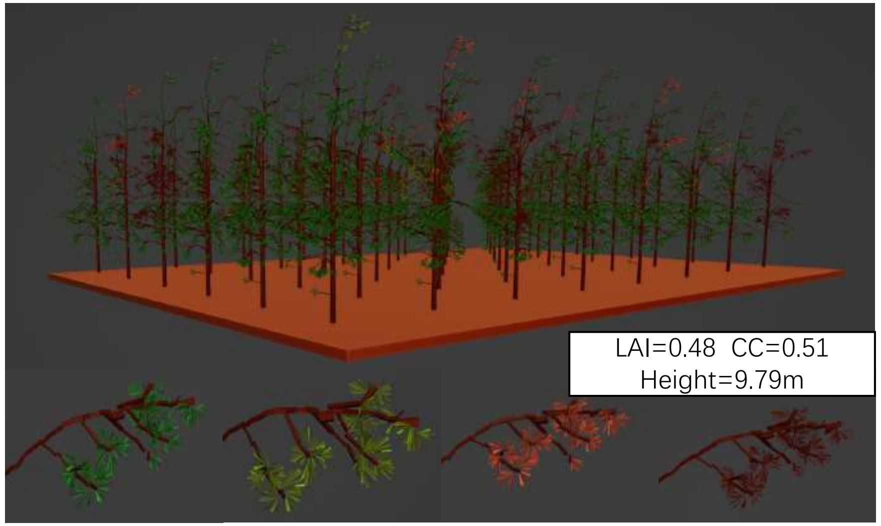
Point cloud

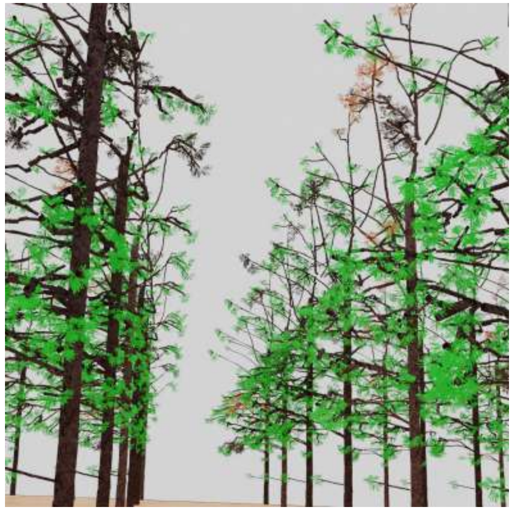
Branch reconstruction



Leaf addition

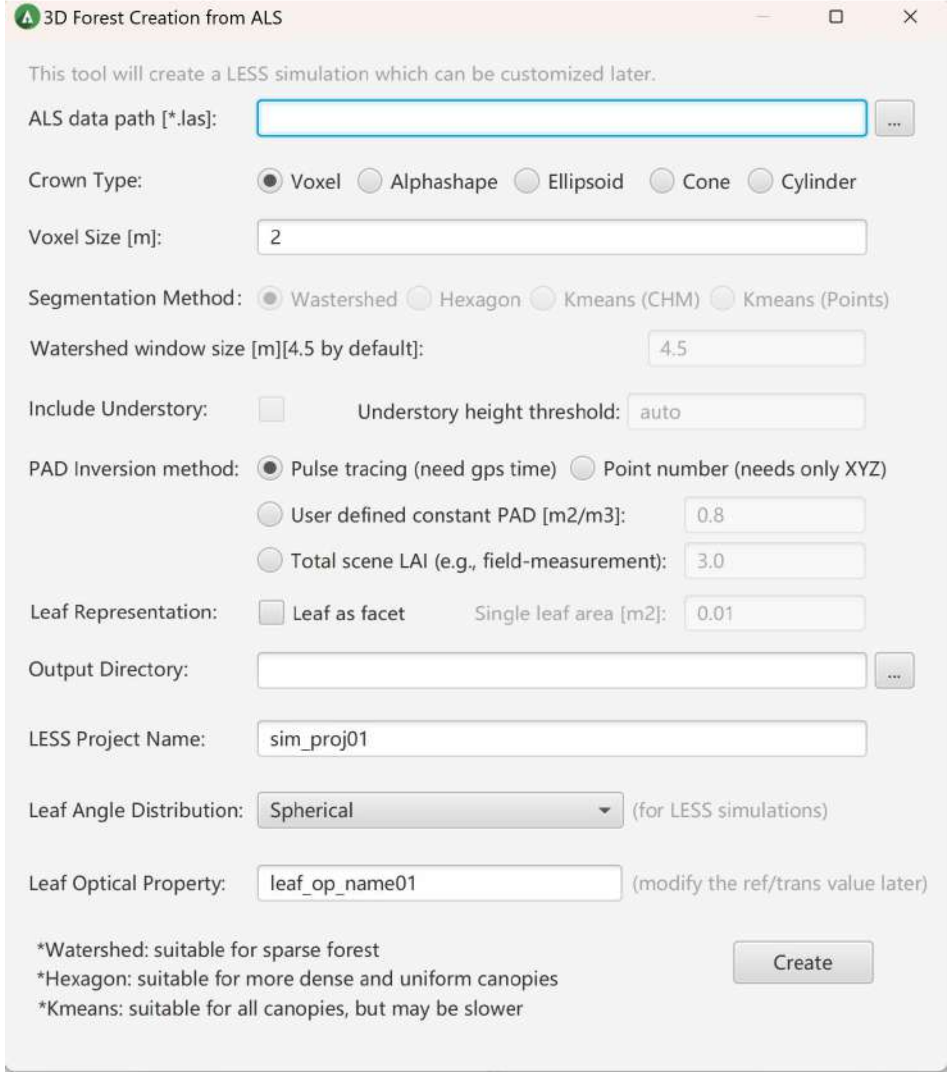
Individual trees

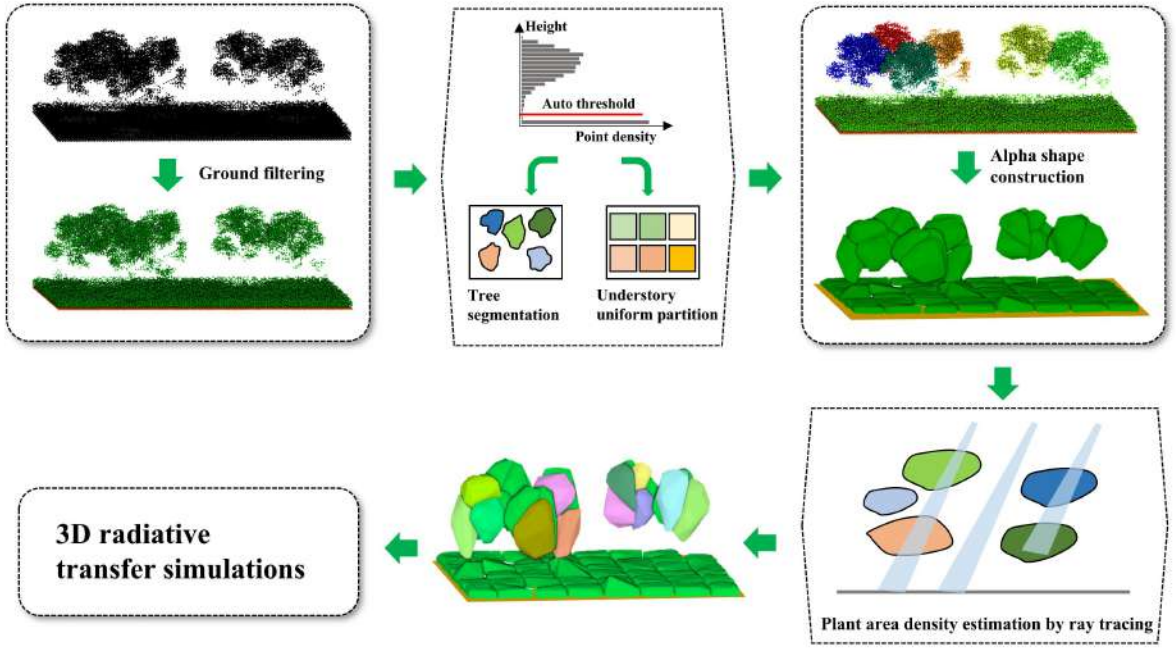


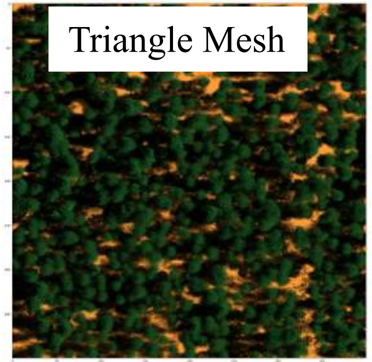


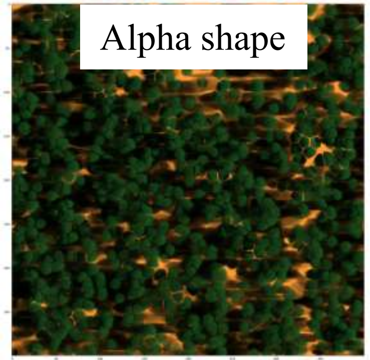
03 Future developments of LESS

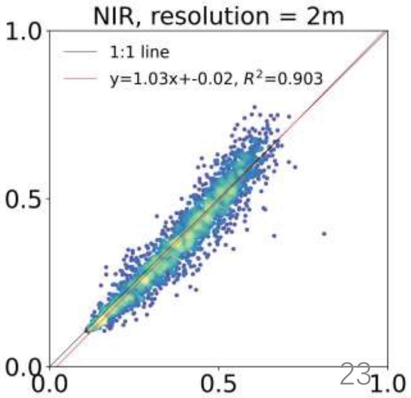
- Reconstruction from Airborne LiDAR point cloud





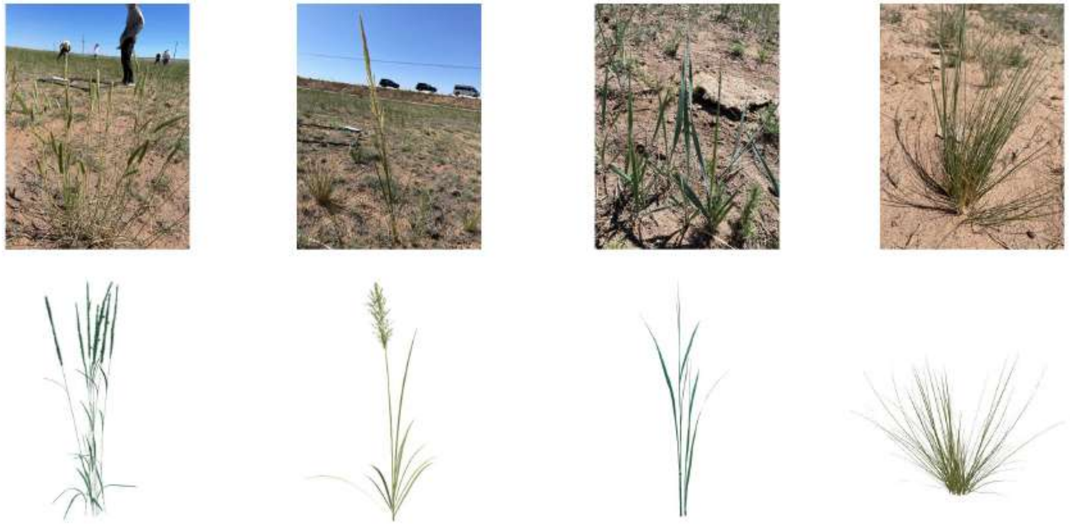


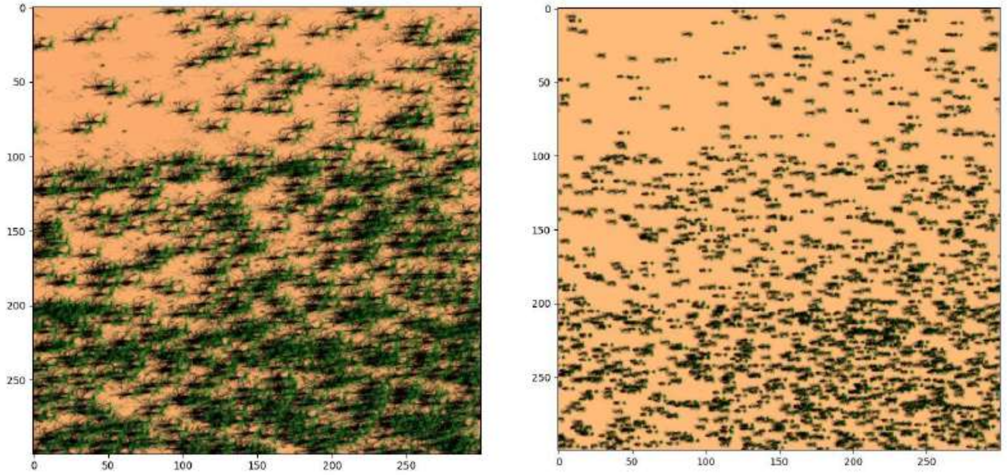




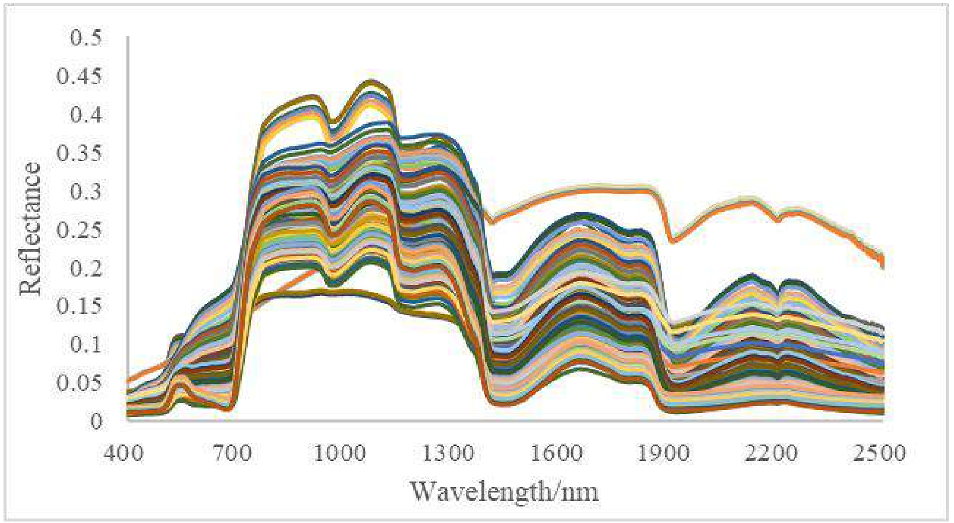
Future developments of LESS

- Generating ready-to-use database will facilitate the use of 3D RTM





LESSDB-GRASS: Around 3.7 million spectra range from 400 nm to 2500 nm with a spectral resolution 1 nm over varying grasslands. It can be used to optimize band selection, validate retrieval algorithms…



*M. X, **J. Qi****, H. Huang. (in preparation).*

03 Future developments of LESS

- Estimation of vegetation parameters using 3D RTM is now possible

  But methods are to be developed, especially for high spatial resolution applications…

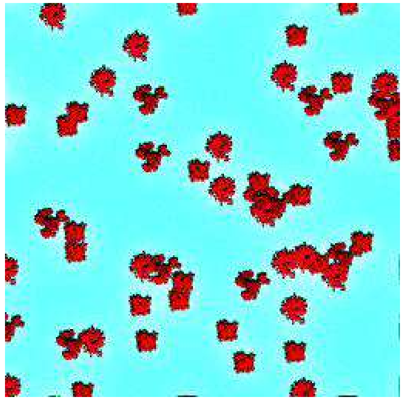
- LiDAR will be an important 3D data source

  A lot of LiDAR data are now available…

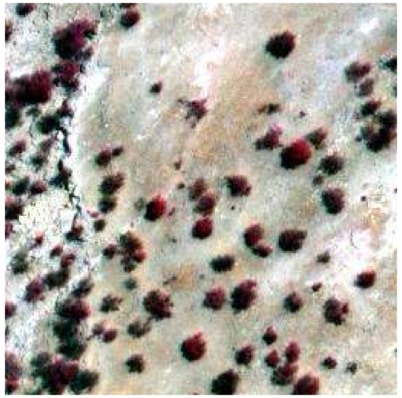
Table 2. Selected countries with airborne LiDAR dataset available for public use.

Country	Uniform Resource Locator (URL)/Helpful Links
Australia	http://www.ga.gov.au/elvis/ http://www.opentopography.org/index.php
Denmark	https://download.kortforsyningen.dk/
Finland	https://tiedostopalvelu.maanmittauslaitos.fi/tp/kartta?lang=en
Germany	https://open.nrw/
Luxembourg	https://data.public.lu/en/datasets/LiDAR-projet-pilote-dun-releve-3d-du-territoire-luxembourgeois/
Netherlands	https://www.arcgis.com/home/webmap/viewer.html?useExisting=1&layers=9039d4ec38ed444587c46f8689f0435e
Norway	https://hoydedata.no/LaserInnsyn/
Italy	http://www.pcn.minambiente.it/mattm/en/online-the-new-procedure-for-the-request-of-LiDAR-data-and_or-interferometric-ps/
Philippines	https://lipad.dream.upd.edu.ph/
Scotland	https://remotesensingdata.gov.scot/
Slovenia	http://evode.arso.gov.si/indexd022.html?q=node/12
Spain	https://b5m.gipuzkoa.eus/url5000/es/G_22485/PUBLI&consulta=HAZLIDAR http://www.murcianatural.carm.es/natmur08/descarga.html http://centrodedescargas.cnig.es/CentroDescargas/buscadorCatalogo.do?codFamilia=LIDAR http://www.icgc.cat/en/
Switzerland	https://geoweb.so.ch/map/LiDAR
United Kingdom	http://environment.data.gov.uk/ds/survey/index.jsp#/survey http://www.ceda.ac.uk/
USA	http://www.opentopography.org/index.php https://coast.noaa.gov/inventory/ https://en.wikipedia.org/wiki/National_LiDAR_Dataset_(United_States)

- Spectral heterogeneity has significant impact on 3D RTM



Simulation

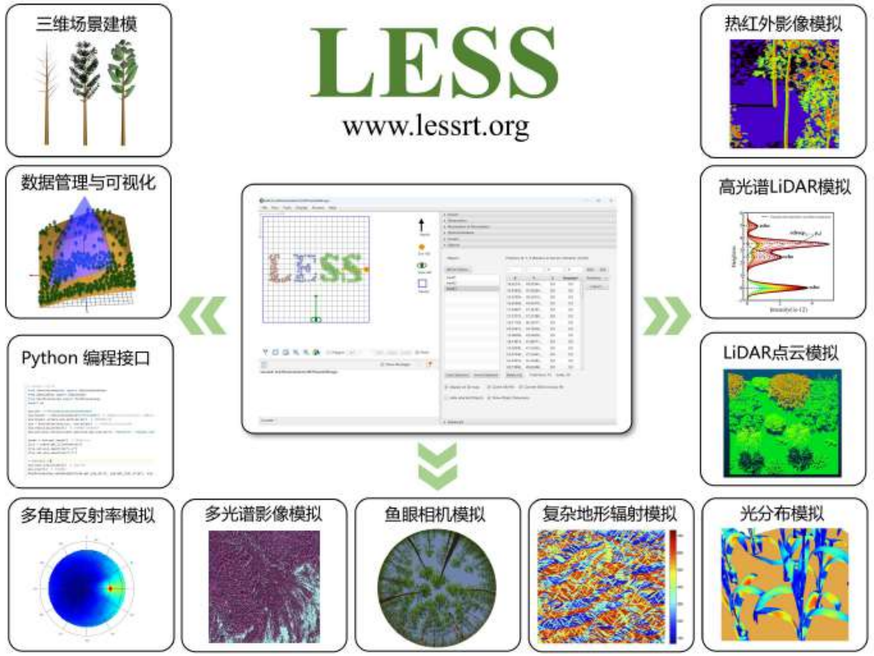


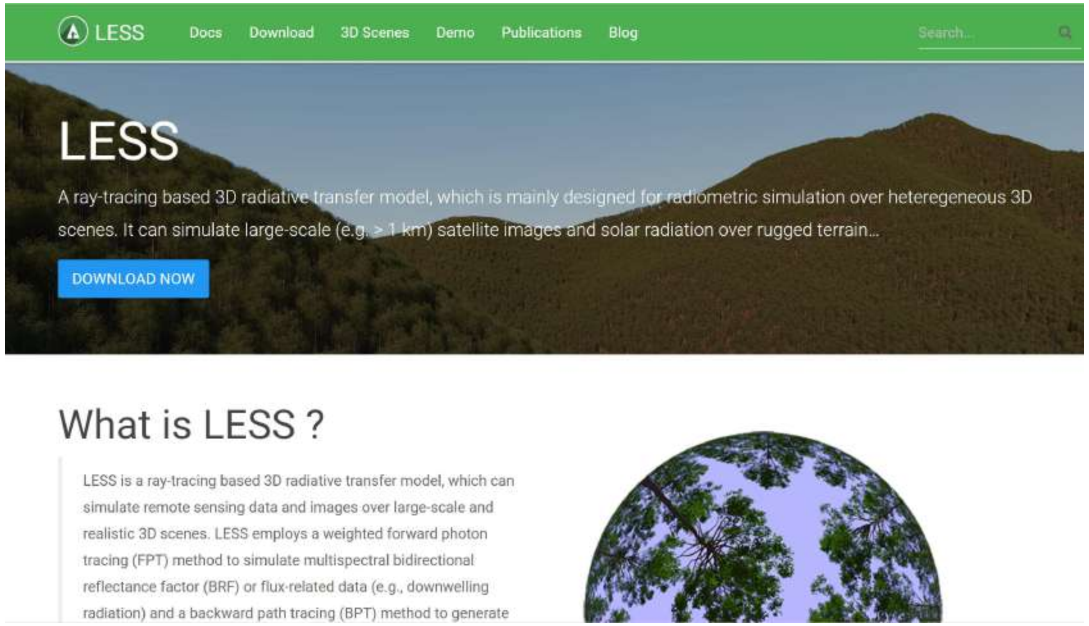
Real

Outline

04 Concluding remarks

- Radiative transfer models (RTMs) are essential to understand the interaction between solar radiation and vegetation canopies.
- LESS is a 3D RTM that supports complex canopies, and can simulate various remote sensing signals, including LiDAR and Solar-induced fluorescence…
- The application of 3D RTM will be an importance topic in the future.





Thank you!

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