



HAL
open science

Estimation of Spatial Distribution of Leaf Area Density in Canopies from Terrestrial LiDAR Point Clouds

Maxime Soma, François Pimont, Sylvie Durrieu, Jean-Luc Dupuy

► **To cite this version:**

Maxime Soma, François Pimont, Sylvie Durrieu, Jean-Luc Dupuy. Estimation of Spatial Distribution of Leaf Area Density in Canopies from Terrestrial LiDAR Point Clouds. *Silvilaser 2021*, Sep 2021, Vienna, Austria. <hal-03624811>

HAL Id: hal-03624811

<https://hal.inrae.fr/hal-03624811v1>

Submitted on 30 Mar 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization



ESTIMATION OF SPATIAL DISTRIBUTION OF LEAF AREA DENSITY IN CANOPIES FROM TERRESTRIAL LIDAR POINT CLOUDS

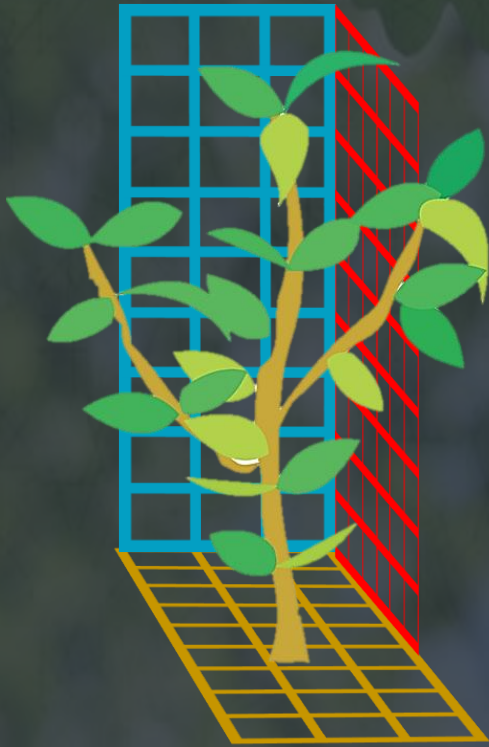
SILVILASER, VIENNA, 28TH – 30TH SEPTEMBER 2021

Maxime Soma^{1,2},
François Pimont¹,
Sylvie Durrieu²,
Jean-Luc Dupuy¹

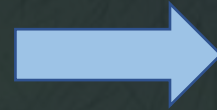
1. ÉCOLOGIE DES FORÊTS MÉDITERRANÉENNES (URFM)
INRAe, AVIGNON
2. TERRITOIRES, ENVIRONNEMENT, TÉLÉDÉTECTION ET
INFORMATION SPATIALE (TETIS), INRAe, MONTPELLIER



WHAT IS LEAF AREA DENSITY ?



3D distribution of the one-sided leaves area
($\text{m}^2 \cdot \text{m}^{-3}$)

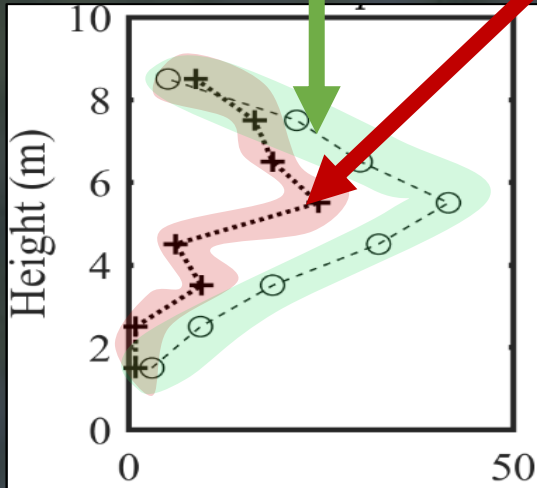


$$LAI(x, y) = \int_0^H LAD(x, y, z) dz$$

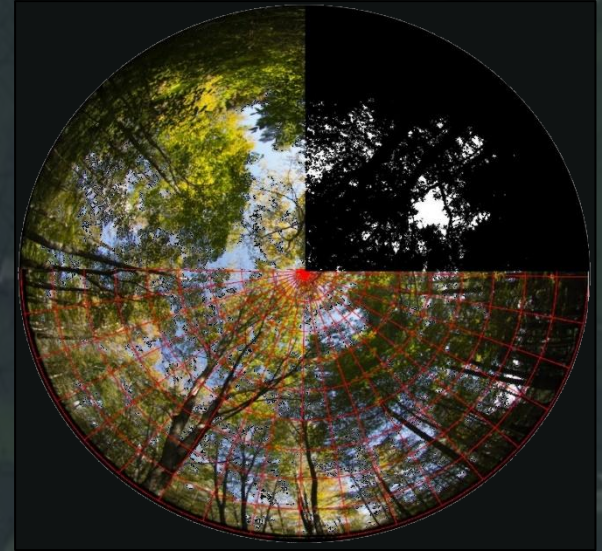
Leaf Area Index (LAI) ($\text{m}^2 \cdot \text{m}^{-2}$)

HOW TO MEASURE LEAF AREA ?

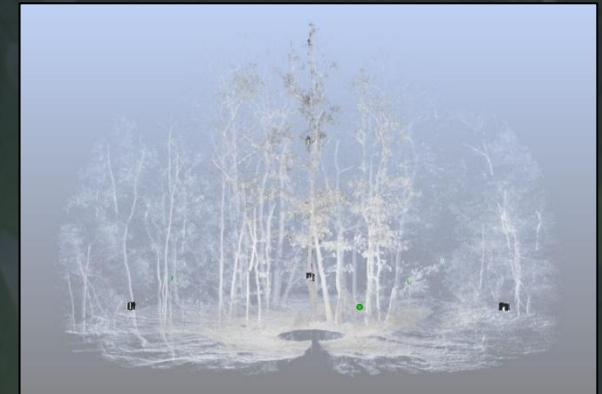
Destructively



Gap fraction theory
(passive measurement - 2D)



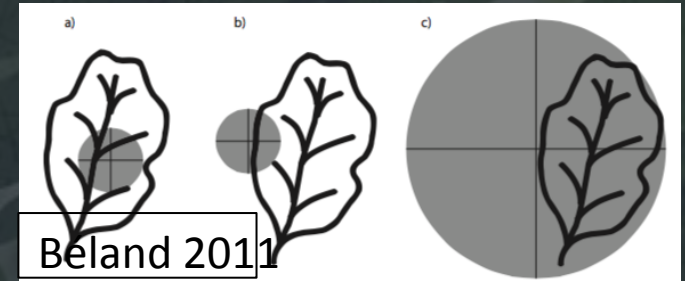
Full 3D
description
(active sensor)
→ Terrestrial
LiDAR





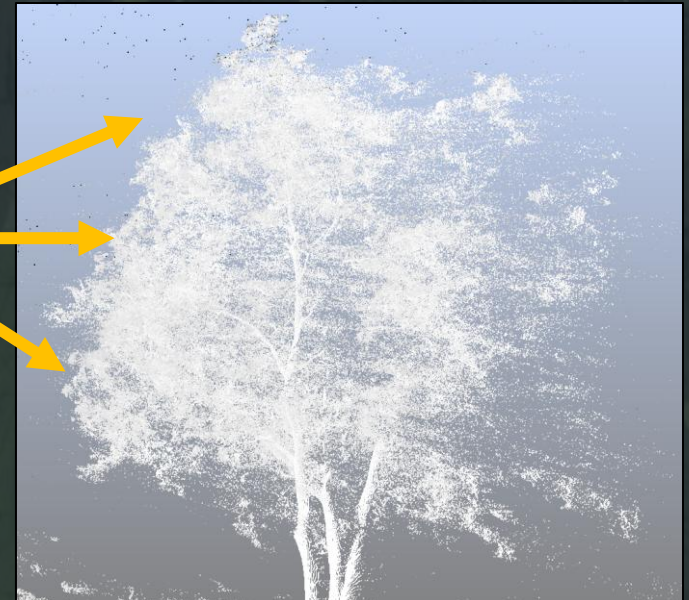
LIMITS OF TERRESTRIAL LiDAR DATA

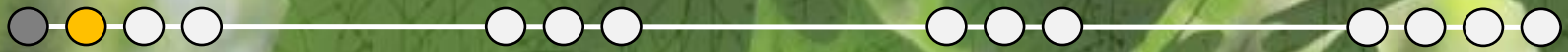
LiDAR beams footprint is not infinitely thin and diverge with distance to targets



Heterogeneous sampling

Interactions with vegetation elements





OBJECTIVE OF THE STUDY

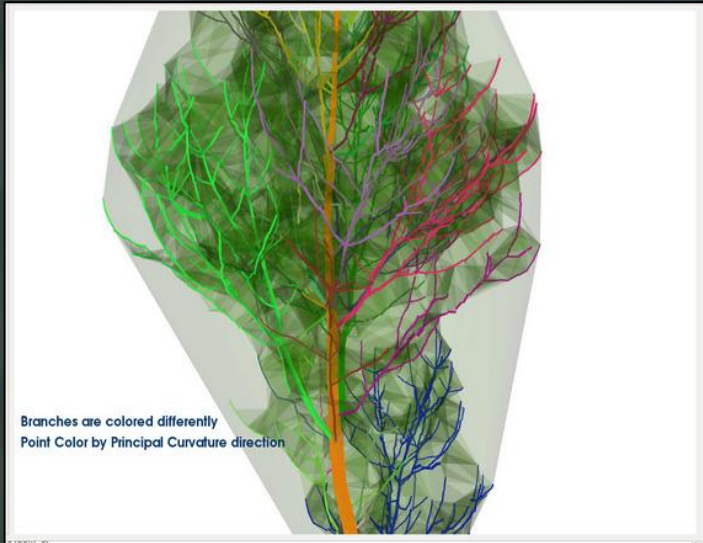
How to relate a terrestrial LiDAR point cloud to Leaf Area Density with:

- **field vegetation elements (i.e. heterogenous)**
- **sampling limitations of instruments**
- **various scales of measures (branch, tree, stand)**



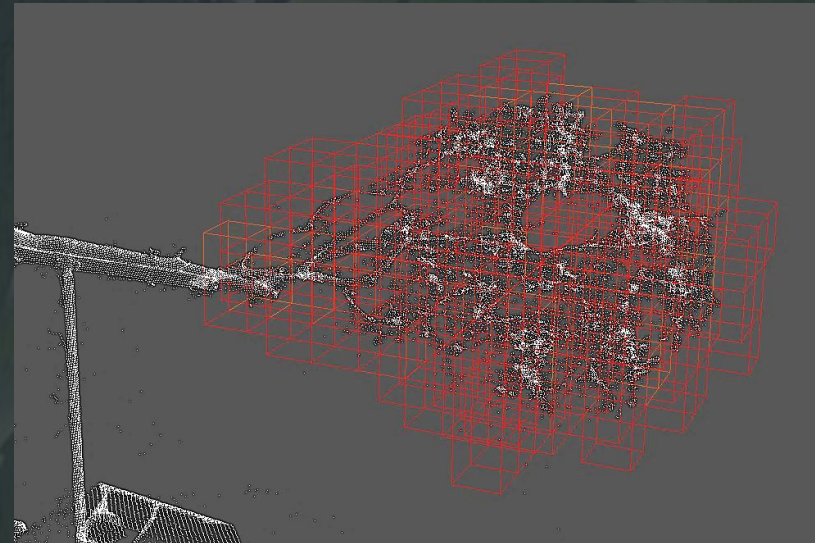
POINT CLOUDS ANALYSIS METHODS

Object-based / reconstruction

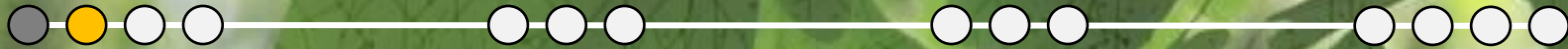


→ Wood volume,
branch levels etc.

Statistics



→ Leaf area



THEORETICAL RELATIONS BETWEEN POINTS AND LEAF AREA

Leaf fraction

$$LAD = F \frac{1}{G} \lambda$$

Leaf projection factor

with λ the coefficient of attenuation

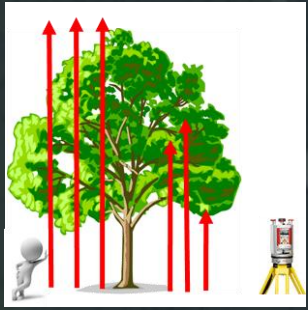
Beer-Lambert

$$Transmittance = e^{-\lambda \delta}$$

$$RDI = \frac{N_i}{N_i + N_g}$$

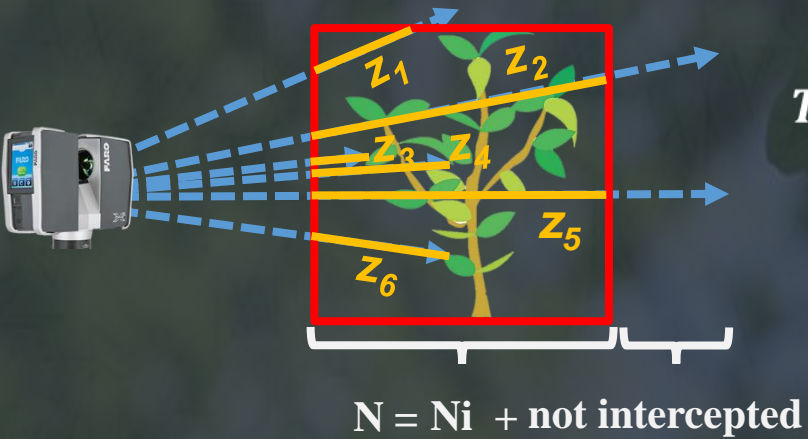
$$= 1 - Transmittance$$

Contact frequency



$$\hat{\lambda} = -\frac{\ln(1 - RDI)}{\delta}$$

$$\tilde{\lambda} = \frac{RDI}{\bar{z}}$$



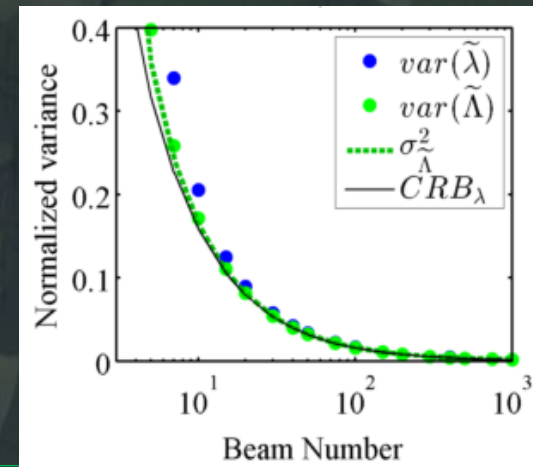
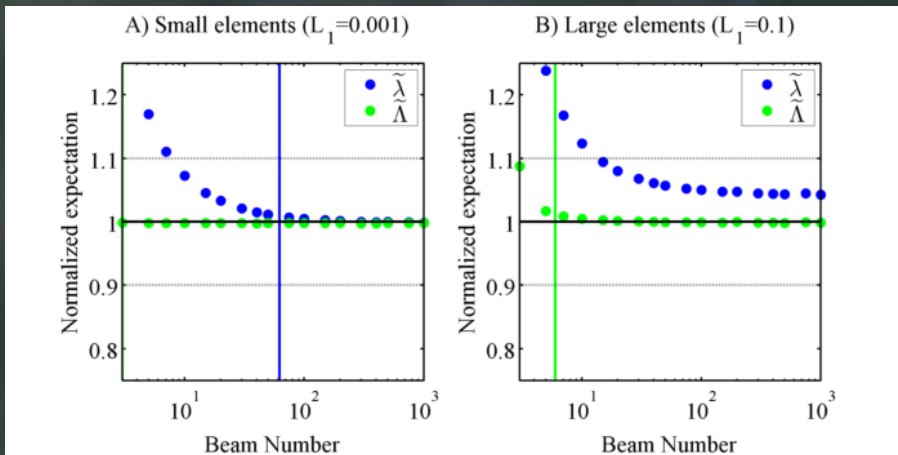
BUILDING UNBIASED ESTIMATORS USING NUMERICAL EXPERIMENT

Size of vegetation elements?

Low number of beams?

Unequal beams path length?

Bringing confidence intervals



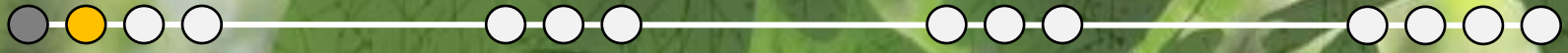
CRB bound reached : there is no best unbiased estimator from this information

Validation of corrections

→ Selection of the corrected contact frequency estimator (Maximum Likelihood Estimator - MLE) for attenuation coefficient

$$\widetilde{LAD} = \frac{H}{G} \tilde{\Lambda} = \frac{H}{G \sum z_e} \left(Ni - \frac{\sum hits z_e}{\sum z_e} \right)$$

Pimont et al.



VALIDATION OF ESTIMATOR WITH ACTUAL VEGETATION AT LABORATORY

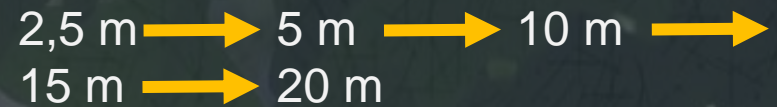
Indoor measurements at branch scale



Scans followed by destructive measurements of leaf areas

- Fully foliated
- Half-foliated
- Defoliated

at various distances:



Quercus
pubescens



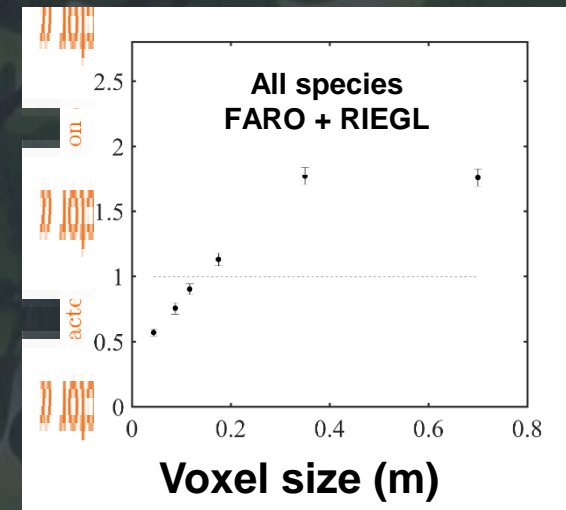
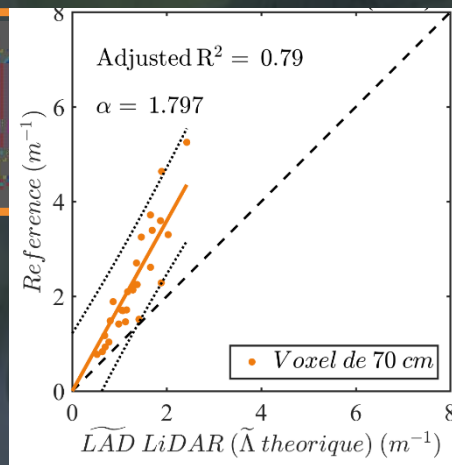
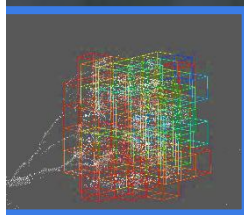
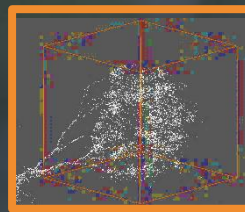
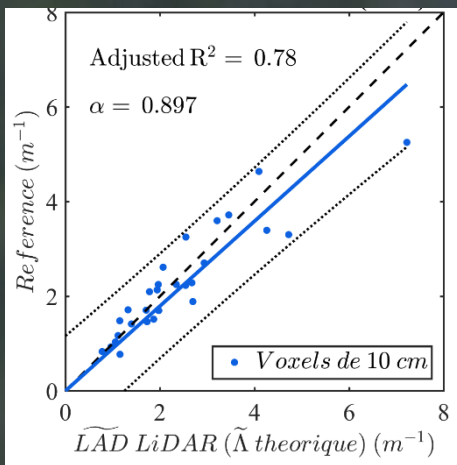
Quercus
ilex



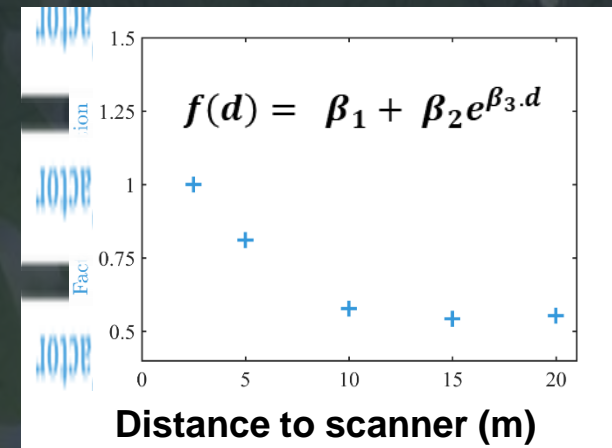
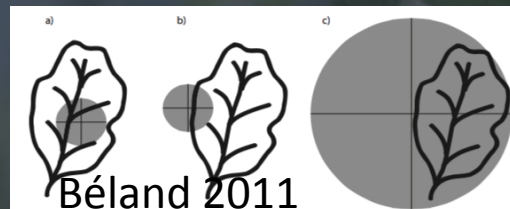
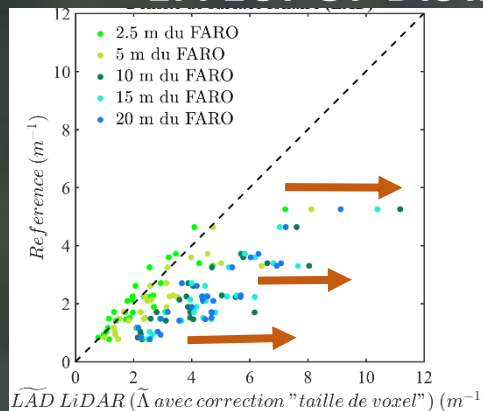
Pinus
halepensis

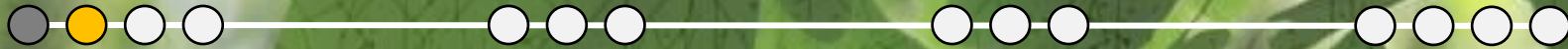
VALIDATION OF ESTIMATOR WITH ACTUAL VEGETATION AT LABORATORY

EFFECT OF VEGETATION HETEROGENEITY



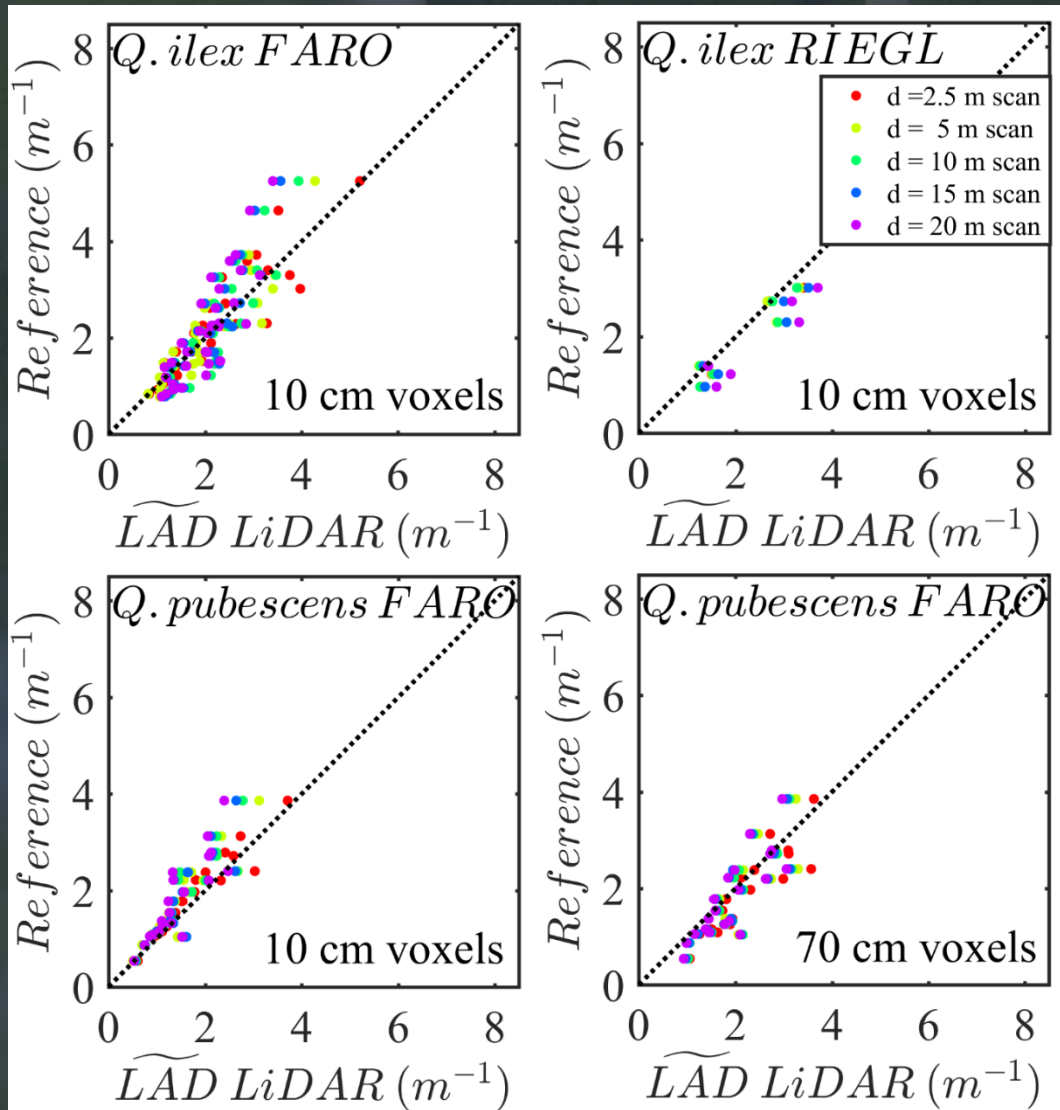
EFFECT OF DISTANCE TO FARO INSTRUMENT



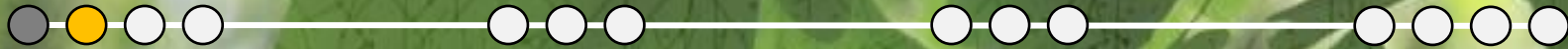


VALIDATION OF ESTIMATOR WITH ACTUAL VEGETATION AT LABORATORY

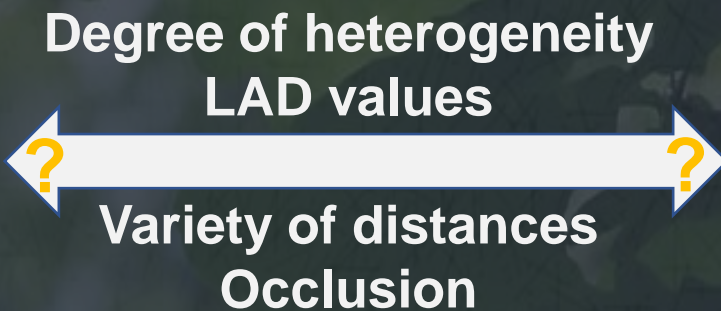
- unbiased
- 20% mean absolute error



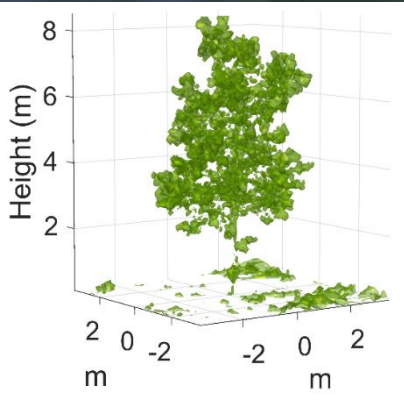
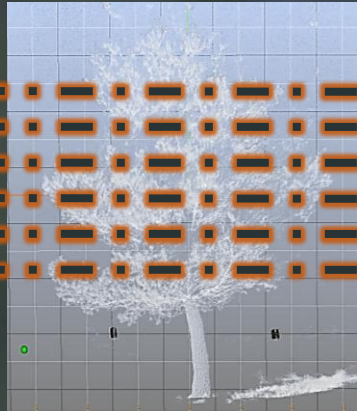
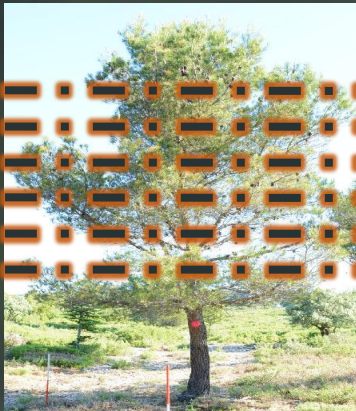
Soma et al., 2018



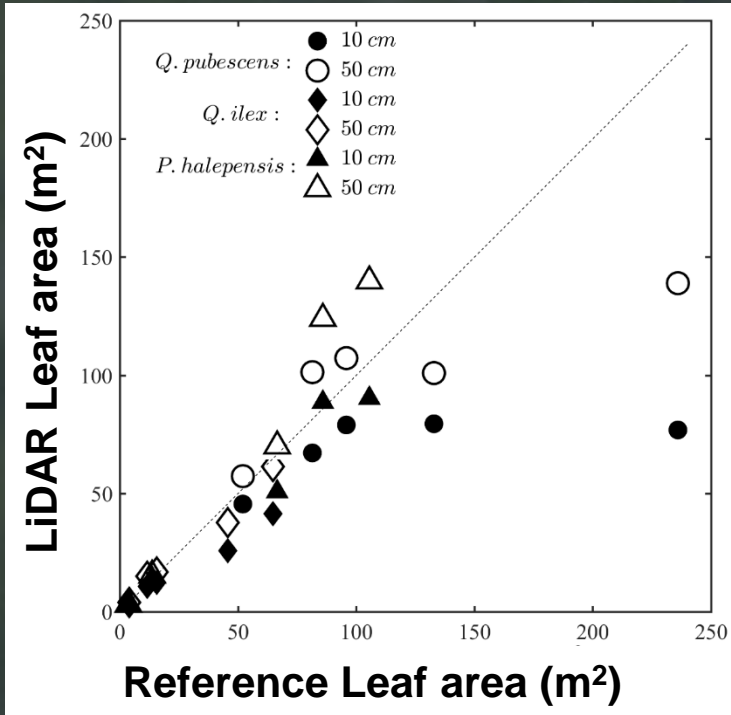
VALIDATION OF APPROACH AT TREE SCALE



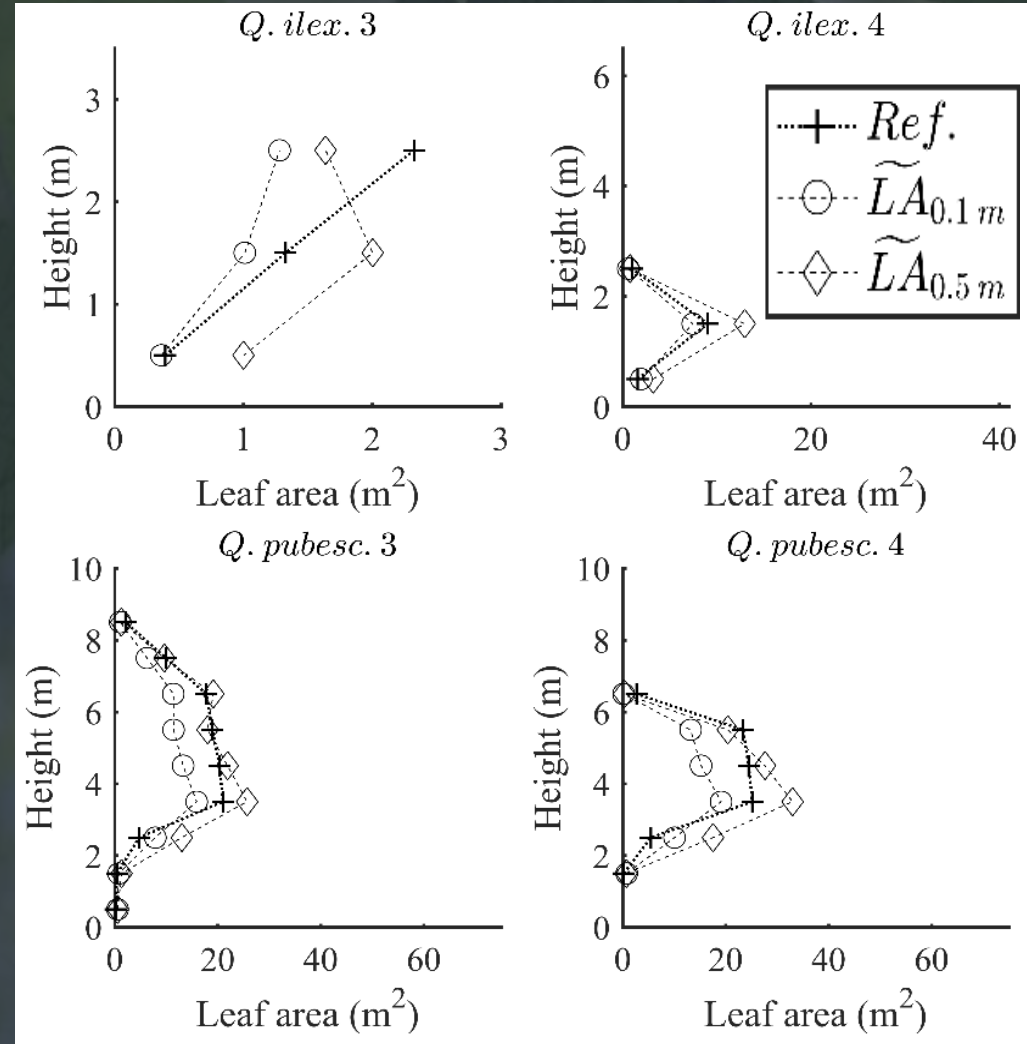
SCANS + DESTRUCTIVE VALIDATION ON 15 TREES

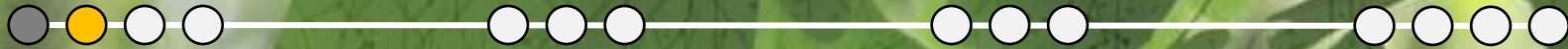


VALIDATION OF APPROACH AT TREE SCALE

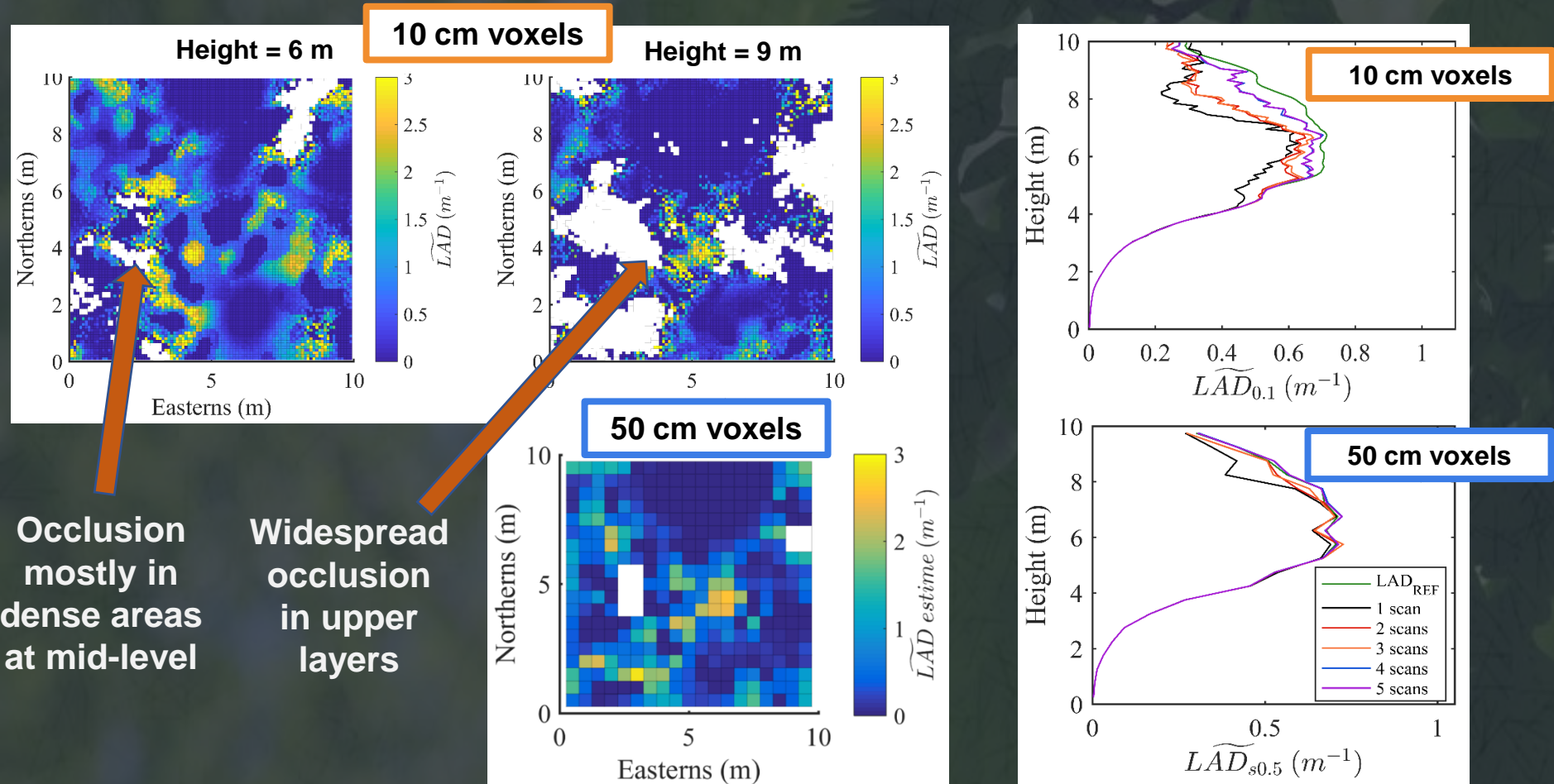


- RMSE < 25% in most cases
- Larger errors with largest trees

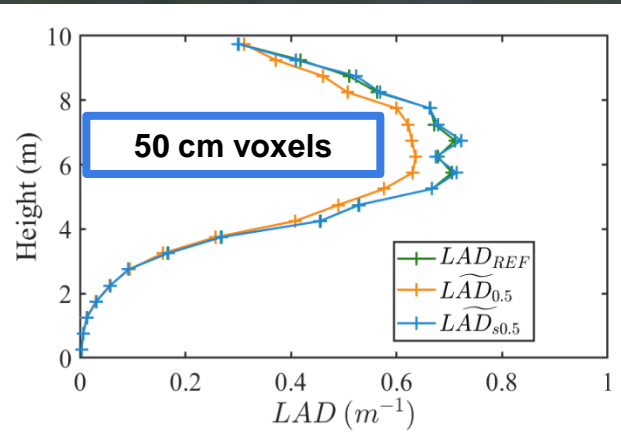




INVESTIGATING INFLUENCE OF SAMPLING LIMITATIONS AT LARGER SCALE IN A VIRTUAL CANOPY



INVESTIGATING INFLUENCE OF SAMPLING LIMITATIONS AT LARGER SCALE IN A VIRTUAL CANOPY



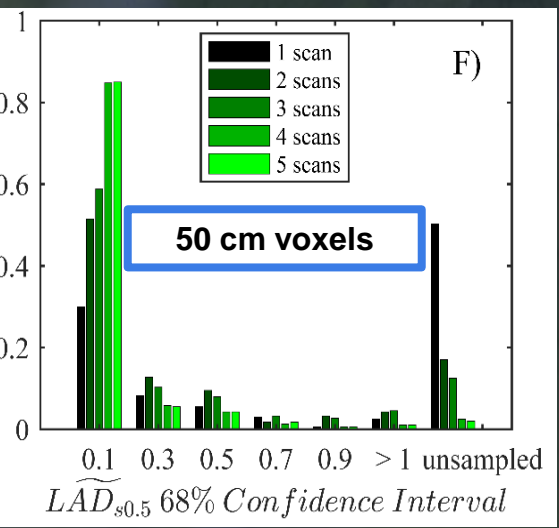
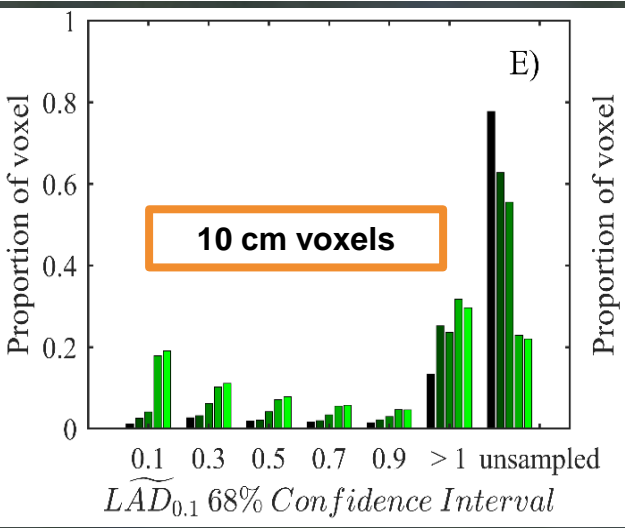
→ Correction for vegetation heterogeneity (i.e. voxel size) is necessary but spatially homogenous (calibration possible)

Soma et al., 2021

The main bias results from spatial correlation of occluded areas with dense LAD

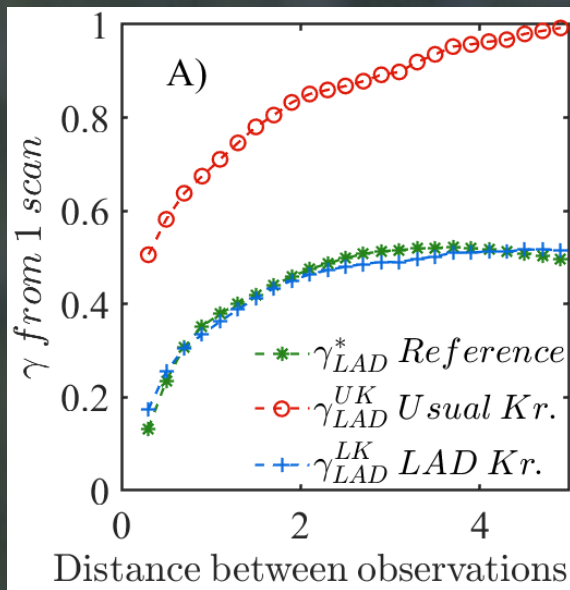


Difficult to correct
→ Best choice to limit occlusion and correct heterogeneity (0.5 voxels)



COMBINATION OF MLE ESTIMATOR AND VEGETATION STRUCTURE : A NEW KRIGING METHOD TO LIMIT BIAIS AND ERRORS IN LOW SAMPLING CONDITIONS

ENHANCING USUAL KRIGING WITH THE MLE ESTIMATOR



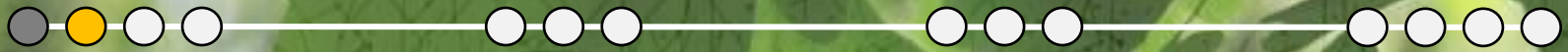
Usual estimator of variogram:

$$\sum_{\|x_k - x_l\|=h} (\overline{LAD}_k - \overline{LAD}_l)^2$$

Estimator of variogram « LAD »:

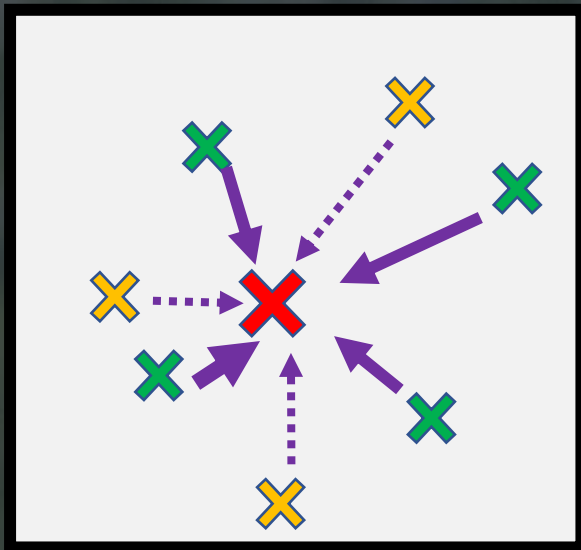
$$\sum_{\|x_k - x_l\|=h} (\overline{LAD}_k - \overline{LAD}_l)^2 - \sigma_k^2 - \sigma_l^2$$

Level 1 : Correcting for noise through variances allows to retrieve the actual spatial correlation in vegetation



COMBINATION OF MLE ESTIMATOR AND VEGETATION STRUCTURE : A NEW KRIGING METHOD TO LIMIT BIAIS AND ERRORS IN LOW SAMPLING CONDITIONS

Level 2 : Integrating sampling criteria in kriging weights



N low

N high

Usual kriging:

$$LAD_x = \beta_1(d_{1,x})LAD_1 + \dots + \beta_i(d_{i,x})LAD_i$$

Si $d_{1,x} \approx d_{i,x}$ alors, $\beta_1 = \beta_i$

« LAD » Kriging :

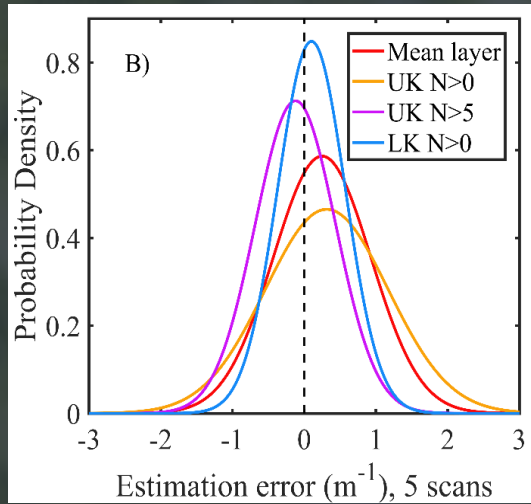
$$LAD_x = \beta_1(d_{1,x}, N_1)LAD_1 + \dots + \beta_i(d_{i,x}, N_i)LAD_i$$

Si $d_{1,x} \approx d_{i,x}$ et $N_1 \ll N_i$,

alors, $\beta_1 \ll \beta_i$

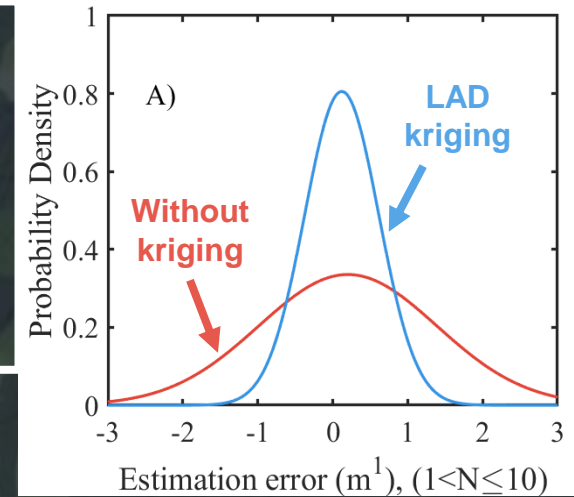
VALIDATION OF THE NEW KRIGING METHOD FOR LAD

VALIDATION OF THE METHOD ON A VIRTUAL REFERENCE CANOPY



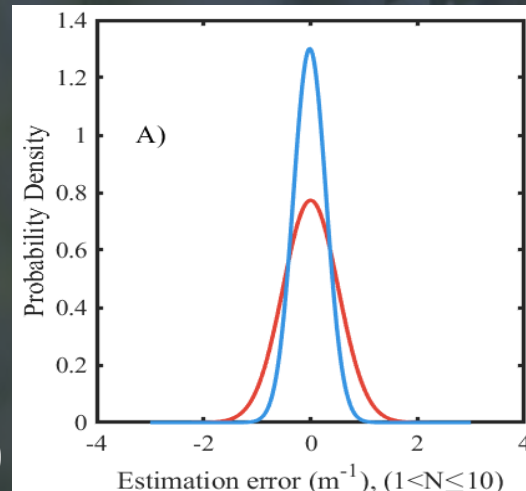
Lowest errors method in unexplored voxel

Potential to reduce errors in poorly sampled voxels

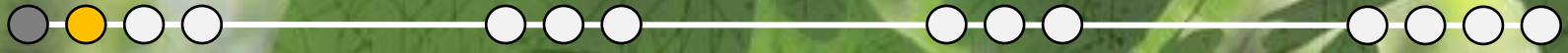


EXAMPLE APPLICATION TO FIELD DATA

Soma et al., 2020



- Drop of RMSE from 0.72 m⁻¹ to 0.48 m⁻¹ in unexplored voxels
- 0.92 m⁻¹ to 0.42 m⁻¹ in poorly explored voxels
- No additional information or any threshold required



CONCLUSIONS OF THE STUDY AND PERSPECTIVES OF THE DEVELOPPED APPROACHES