Waldwachstum
Systemanalyse

Using Terrestrial Laser Scanner for Estimating Leaf Areas of Individual Trees in a Conifer Forest

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Topics

1 Conventional optical Leaf area index (LAI) determination

2 Laser scanner leaf area (LA) determination

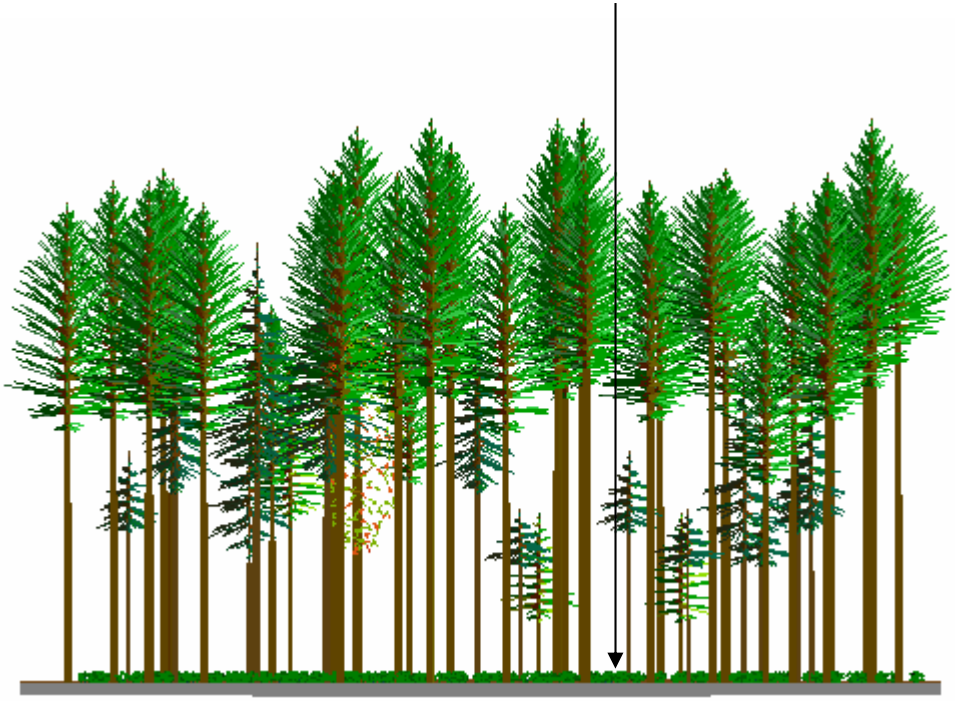
Leaf Area Index (LAI)

Watson, 1947:

- The leaf area per unit area of land
- relevant to agricultural yields

- Needle-Leaf touch number ⟶ *LAI*

A geographic position *(x,y)*



Coventional optical LAI determination

Measurement:

Light penetration

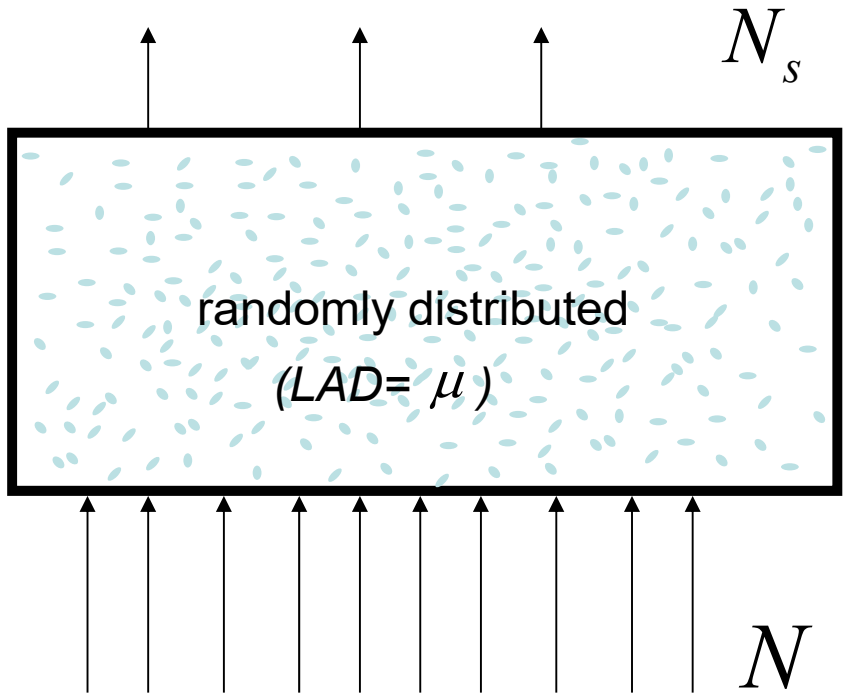
Instrument:

Fisheye camera

LAI2000 Plant Canopy Analyser

Gap fraction = $\frac{N_s}{N}$ ⇢ $\overline{LAI}$

Average over a 2D extension



Light Beams

LAI=-ln Gap fraction

- Beer–Lambert law (Monsi and Saeki,1953)
- Poisson model (Nilson, 1971)

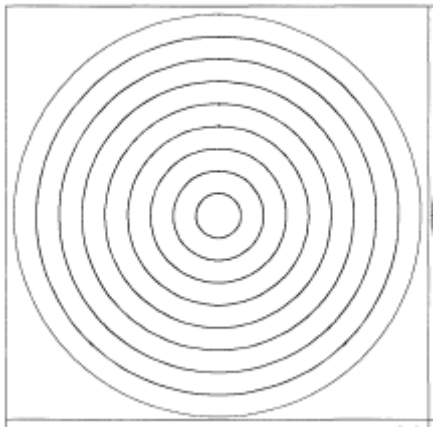
If leaves are flat and horizontal and beams are vertical

$$Gap\ fraction = \left(1 - \frac{LAI}{N}\right)^{N}$$, *N – layer (and leaf) number*

When $N \rightarrow \infty$

$$Gap\ fraction = exp\ (-LAI)$$

$$L_e = -\ln P_0(\theta) \cdot \cos\theta / G(\theta)$$

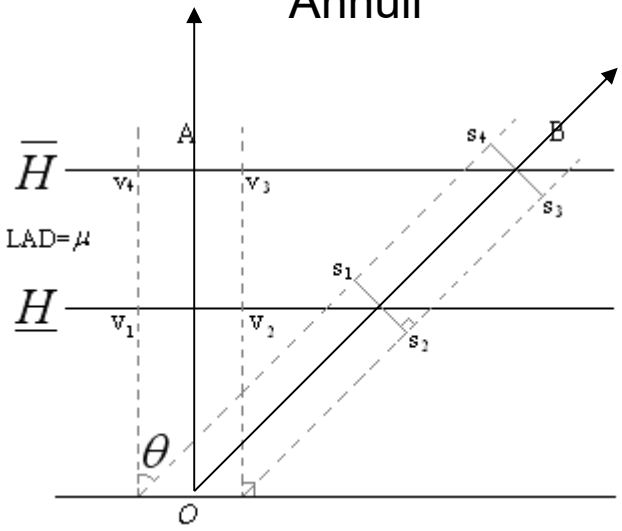


Annuli

- L_e - effective leaf area index
- P_0 - gap fraction
- G - extinction coefficient

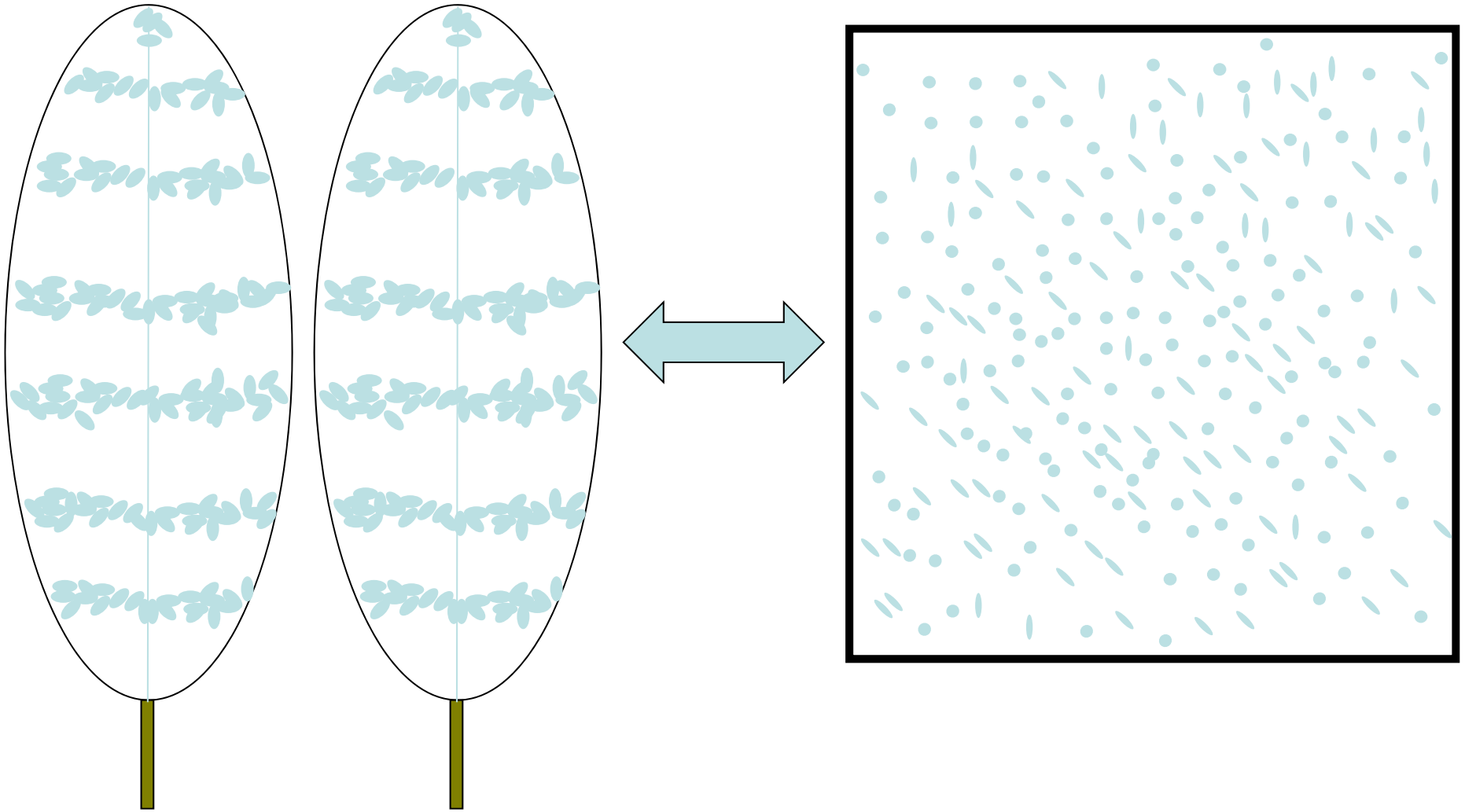
  Leaf Spherical Distribution: $G(\theta) = 0.5$

- θ - beam zenith angle

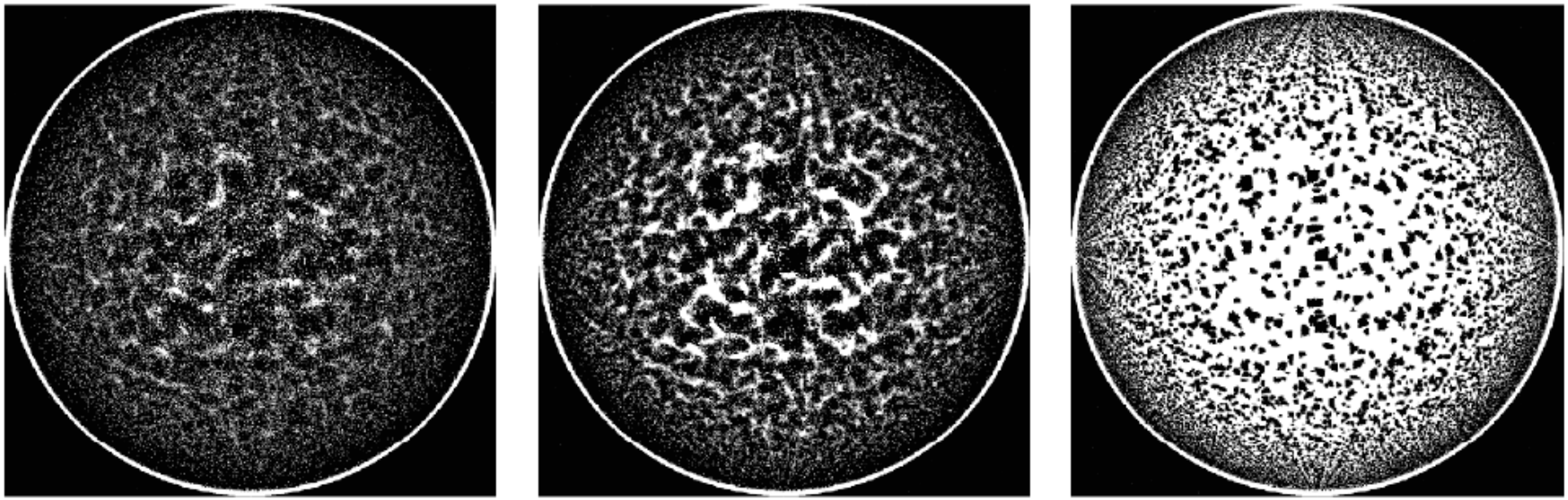


Why cos(θ) ?

Clumping Effects



Hemispherical photographs from simulated forest canopies for LAI values of 2 with fraction clumping fraction of 0.3,0.5, and 0.7

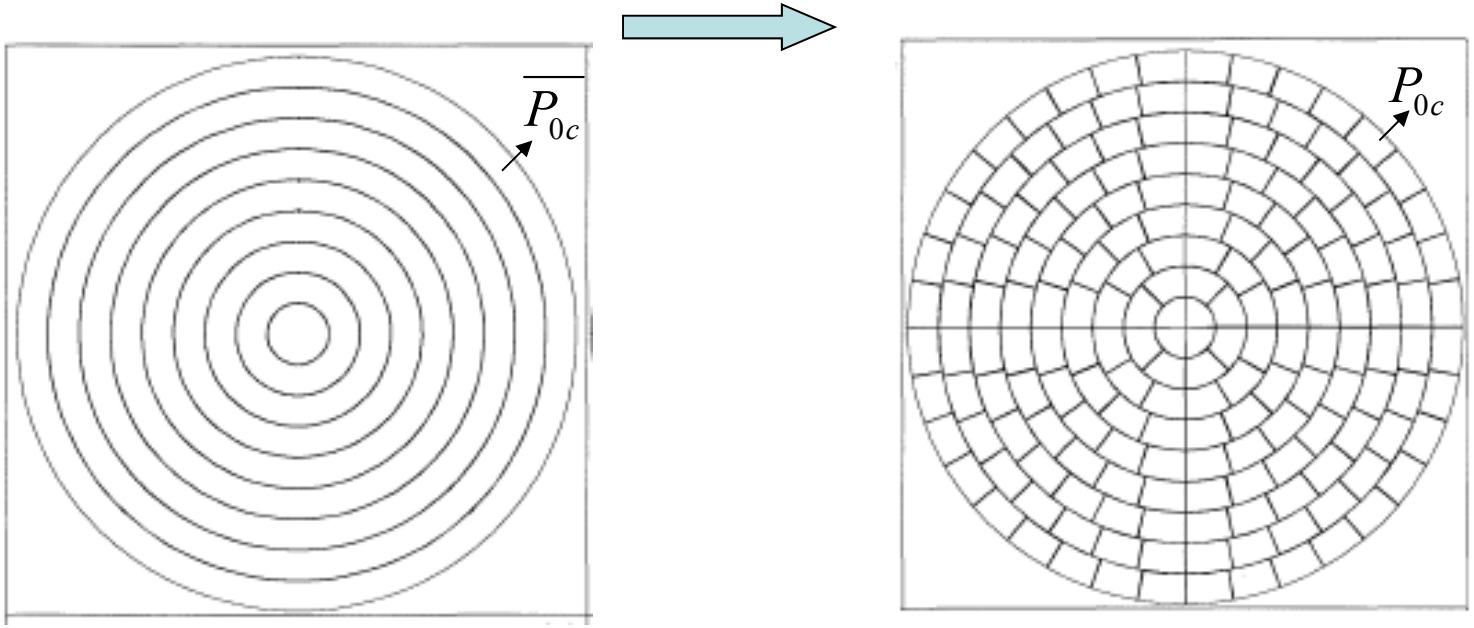


Walter et al. (2003)

Clumping Effects - Conifer

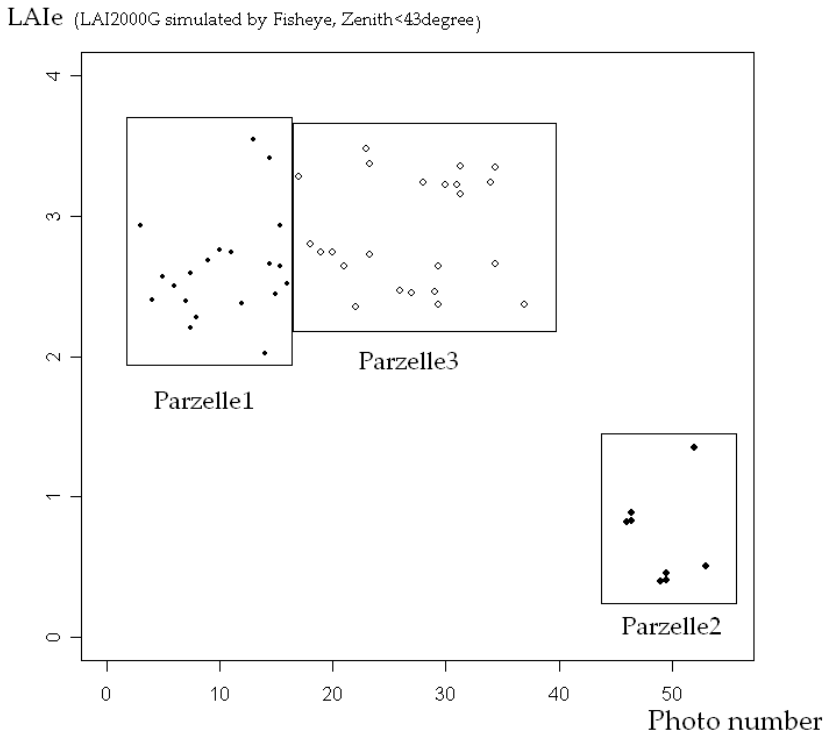
Solution – Segmentation

$$Ln\overline{P_{0c}} \qquad \overline{LnP_{0c}}$$



Problems
of conventional optical LAI determination

- Stand oriented

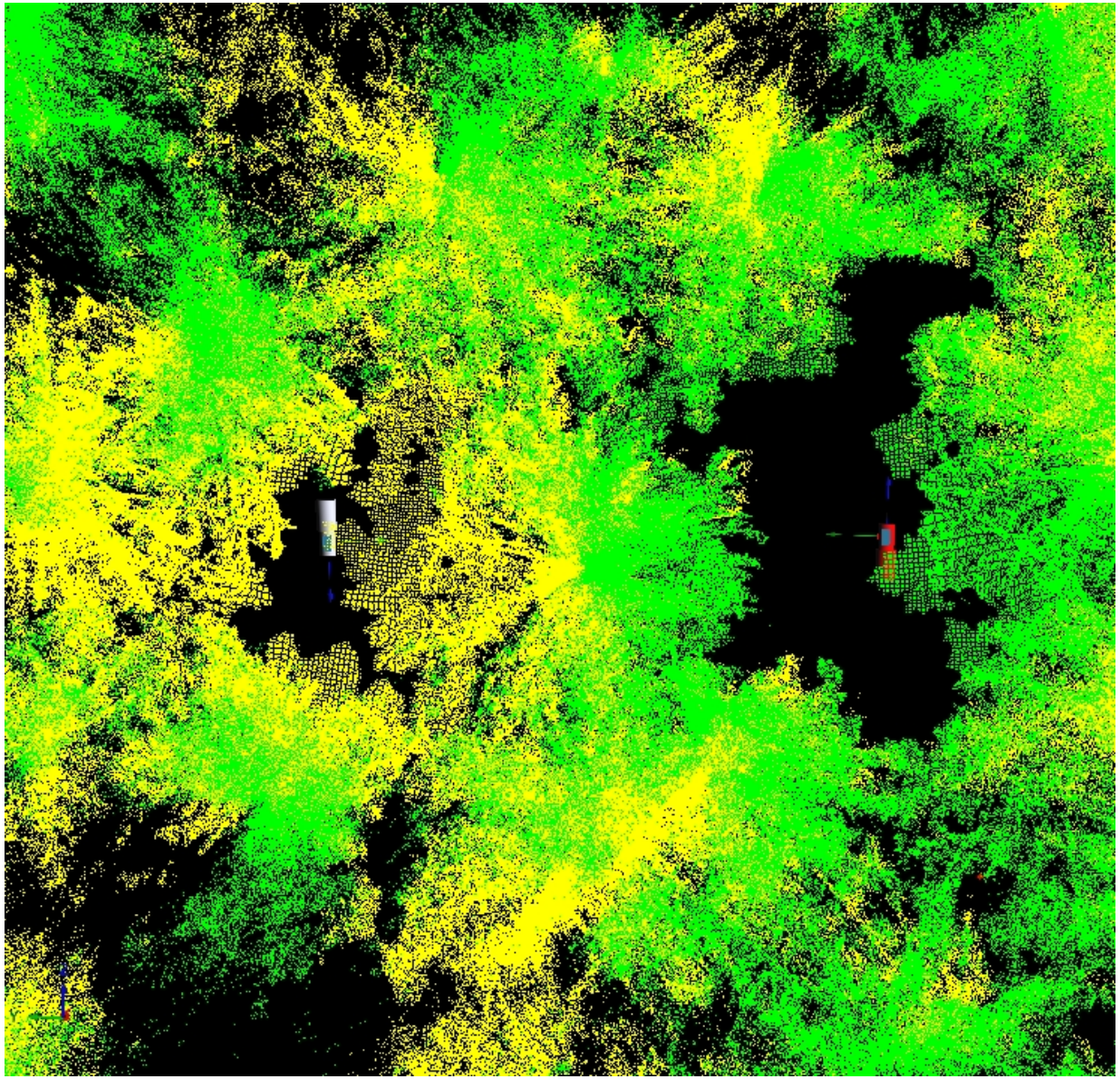


- Pure conifer or pure deciduous only
- Underestimation due to clumping
- Limit on segment size (P_{0c} !=0)
- Influence of weather condition

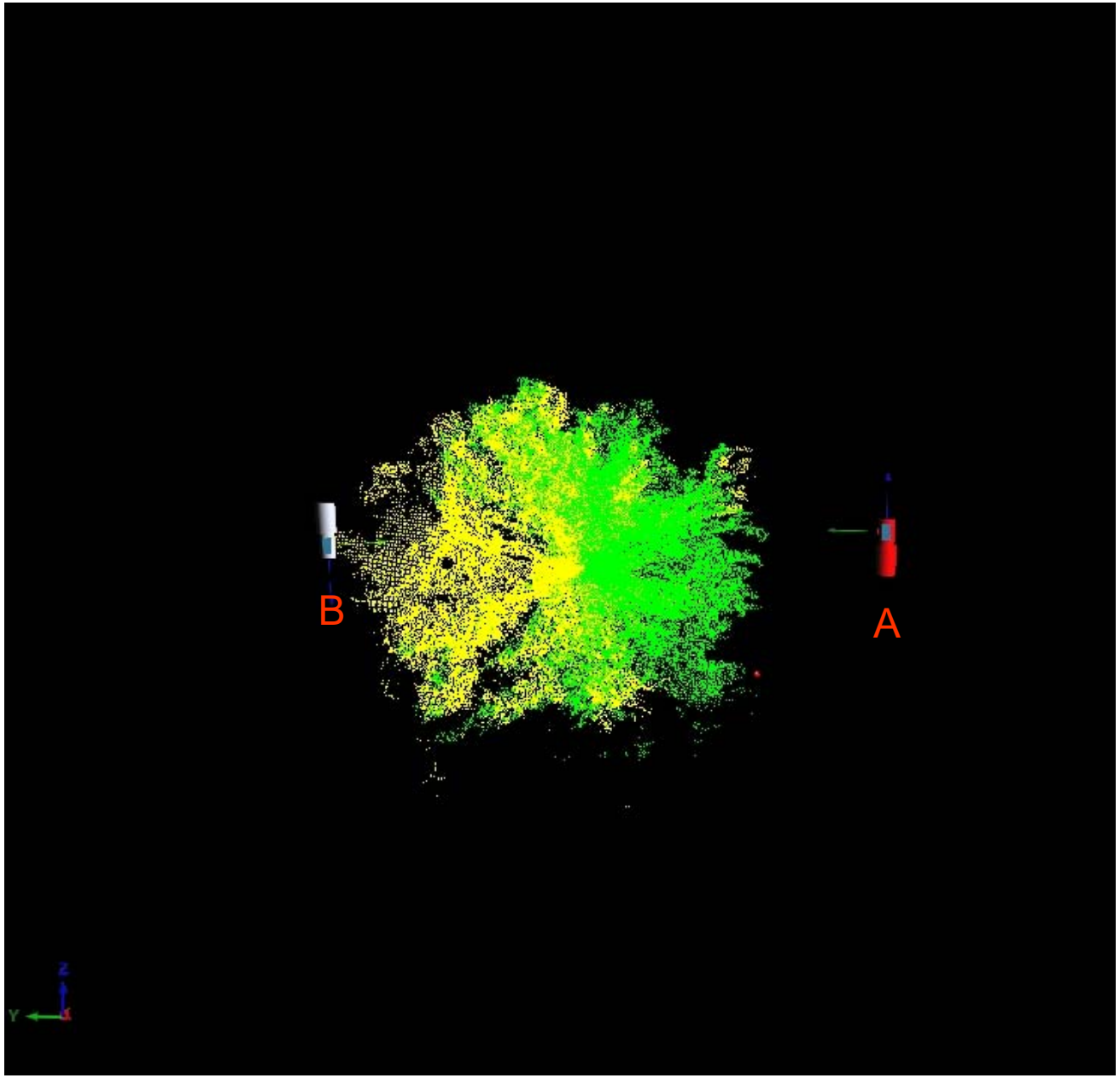
Laser Scanner for Leaf Area determination

- Individual-tree oriented
- Clumping effect above crown level eliminated
- Comparable to allometric leaf area
- No limit on segment size
- Not influenced by weather condition

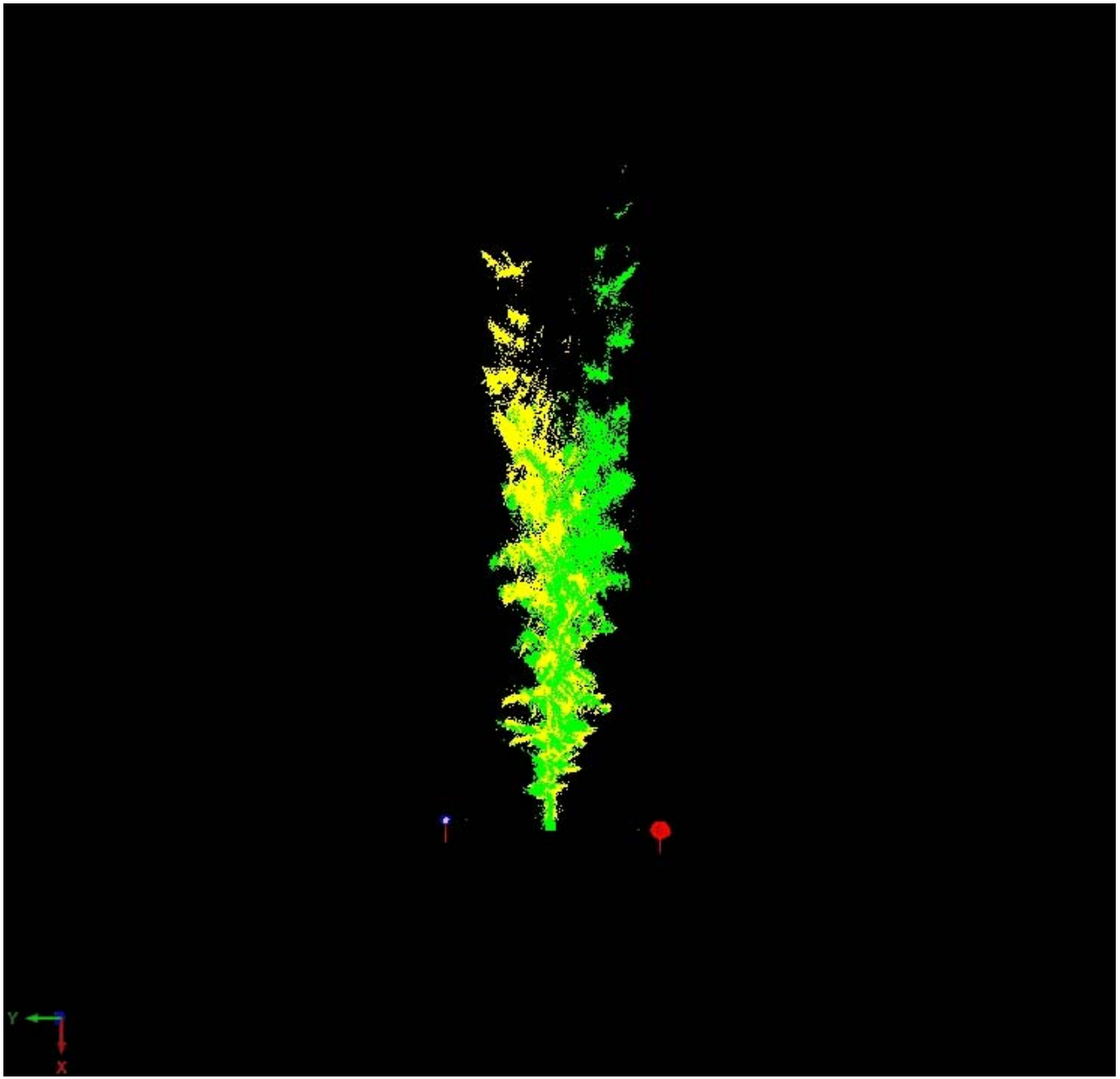
Two Scans around the objective tree



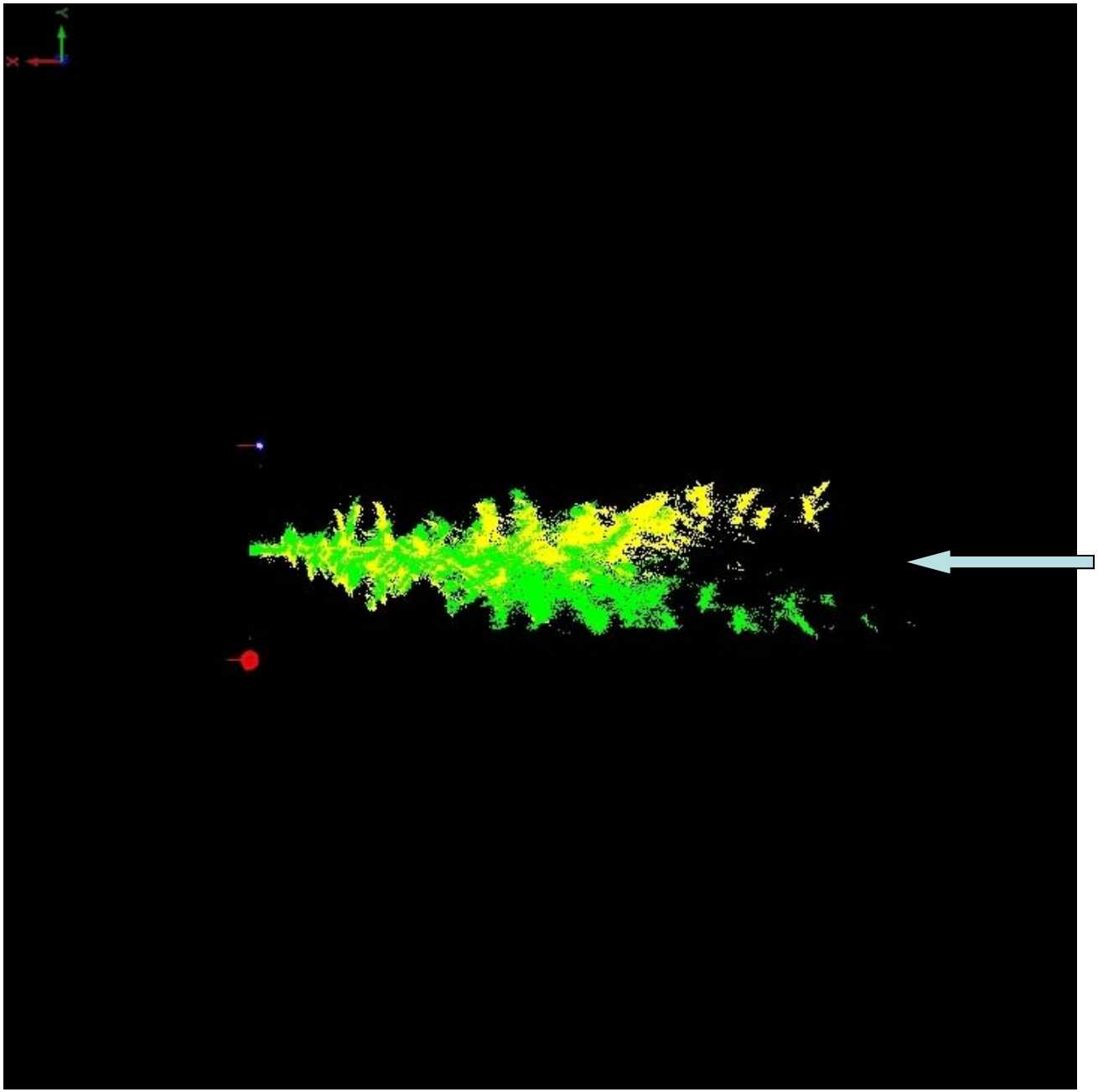
Registration and Isolation – top_down view



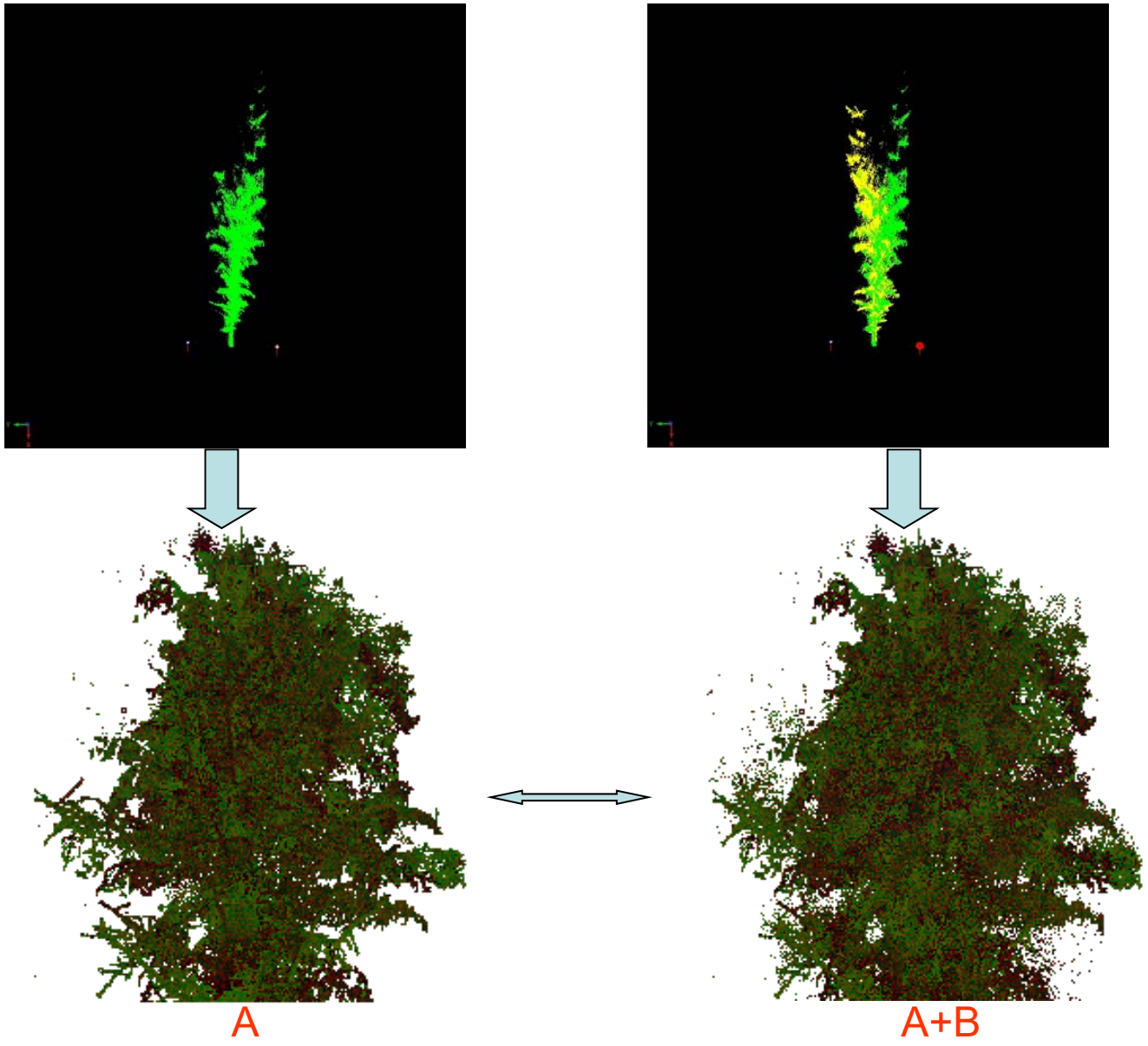
Registration and Isolation – side view



A Canopy scanned from top and down sides?



Projection



Distance-coded false color images

Projection - coordinate system transformation

Cartesian coordinate system (X, Y, and Z)

Spherical coordinate system (θ, φ)

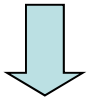
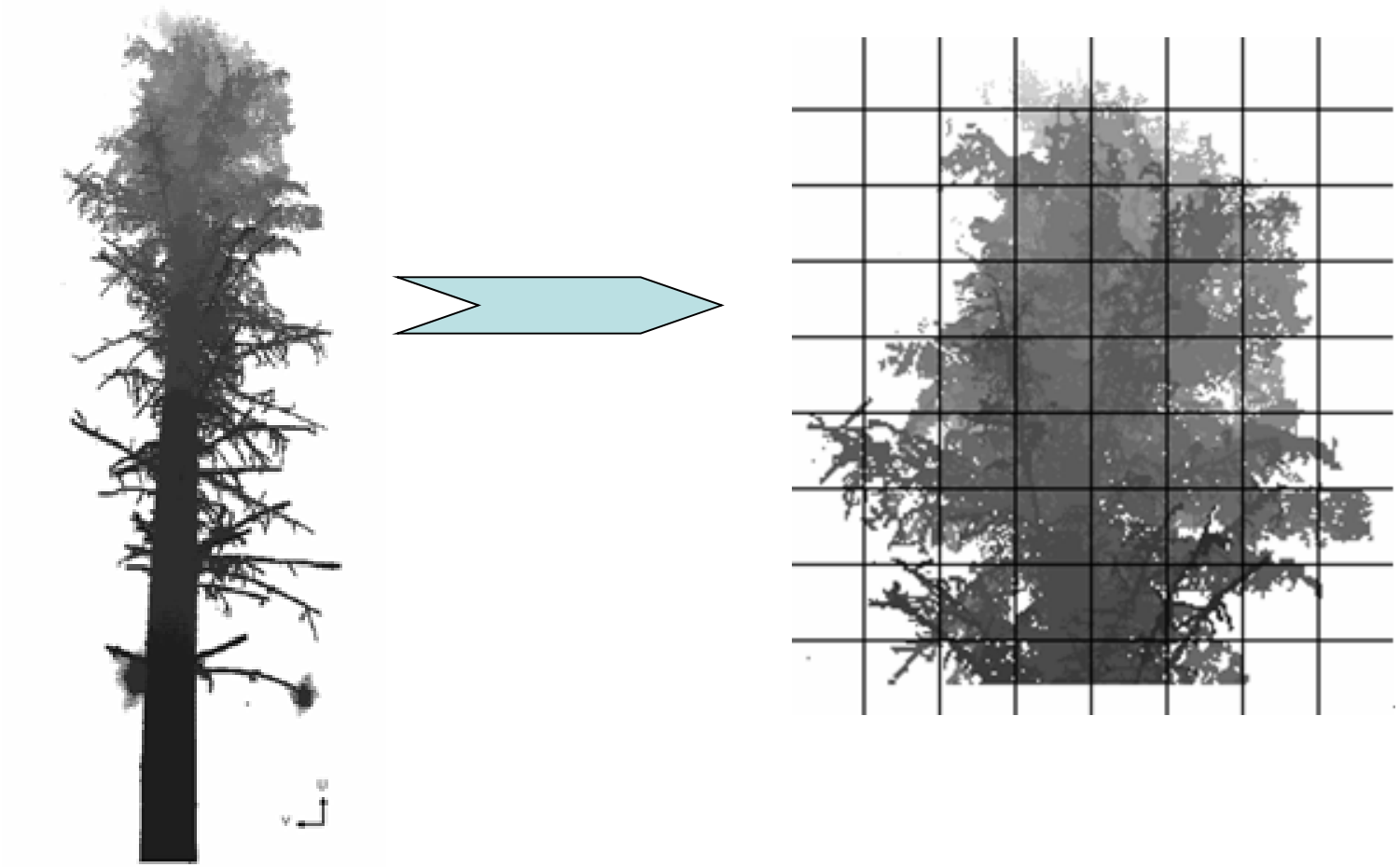


Image coordinate system (V, U)

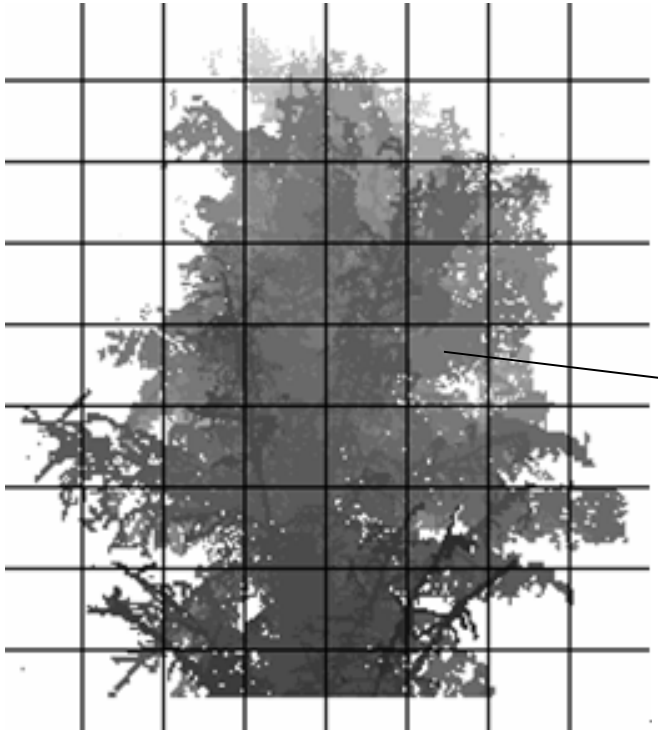
Range image after projection



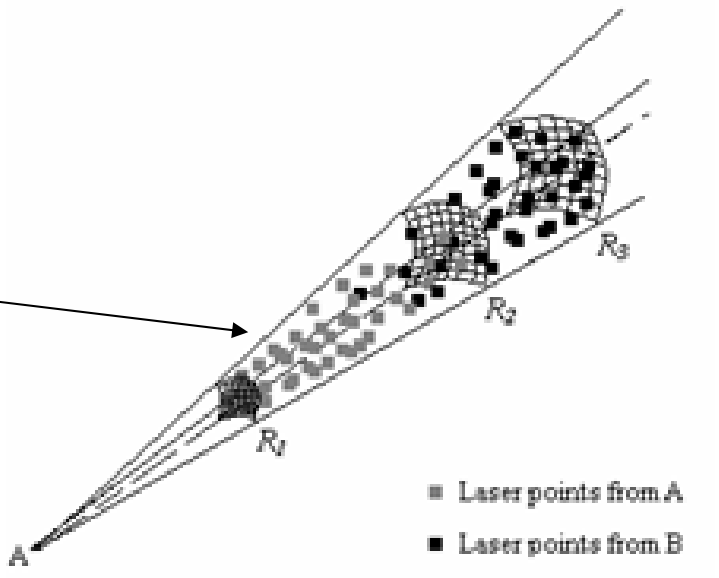
Segmented crown range image

The picture is a distance-sliced image.
The grey values represent the distance
from the scanner with white indicating the empty pixels.
In real processing, distance-coded false color images were used.

2D – 3D



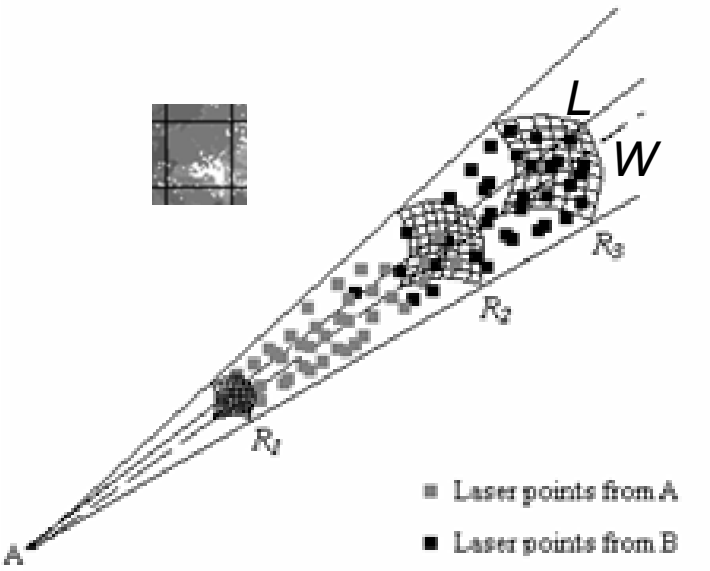
Segmented crown range image



The virtual 3D view of the space corresponding to a segment pair

Leaf area calculation for each segment

- *LA = LAD * Volume*



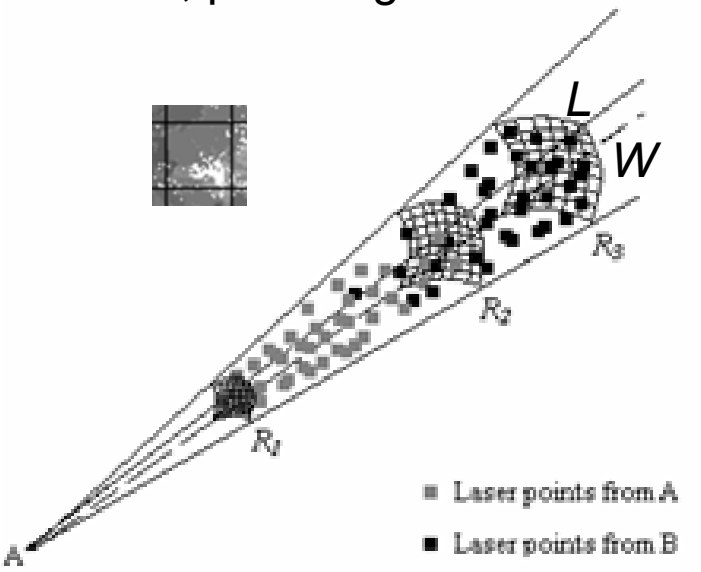
Leaf area calculation

- *LA = LAD * Volume*

Segment A+B

$$Volume = 0.002^2 \cdot L \cdot W \cdot \frac{R_3^{\,3} - R_1^{\,3}}{3}$$

rad, pixel angle width



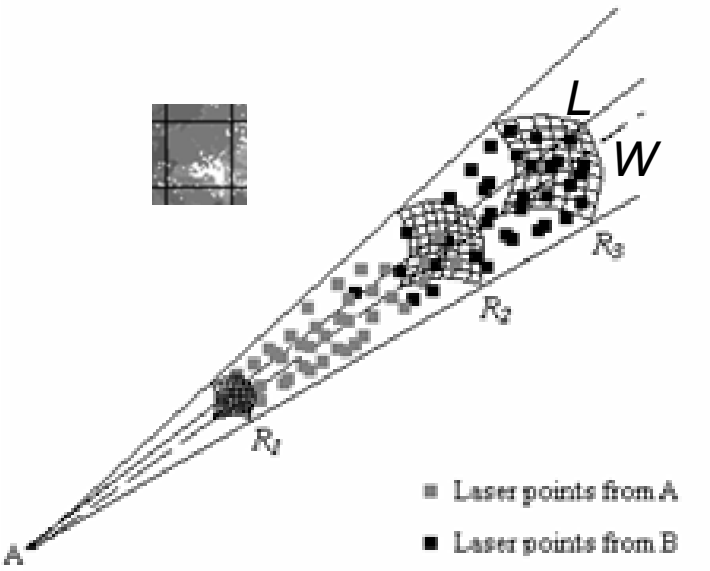
R1 and *R2* are ranges of the nearest and farthest pixel in segment A
R3 is the range of the farthest pixel in segment A+B

Leaf area calculation

- *LA = LAD * Volume*

Segment A

- *LAD = LAI / Range*

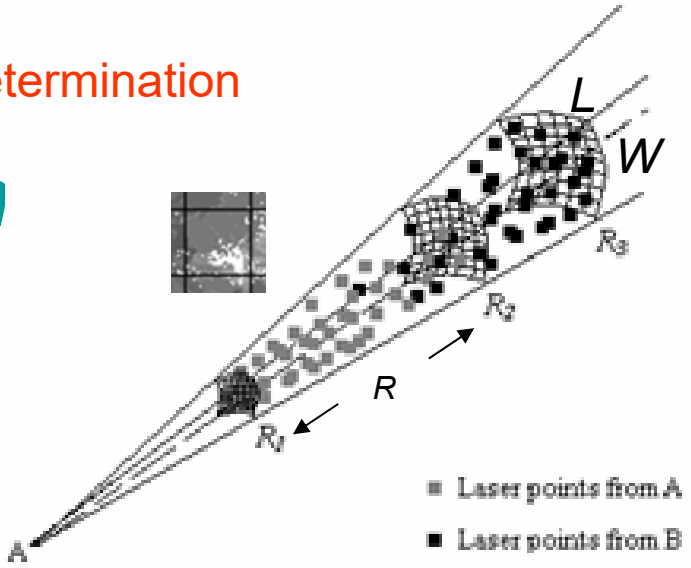


Leaf area calculation

- *LA = LAD * Volume*
- *LAD = LAI / Range*

Conventional optical LAI determination

- *LAI = -ln Gap fraction*

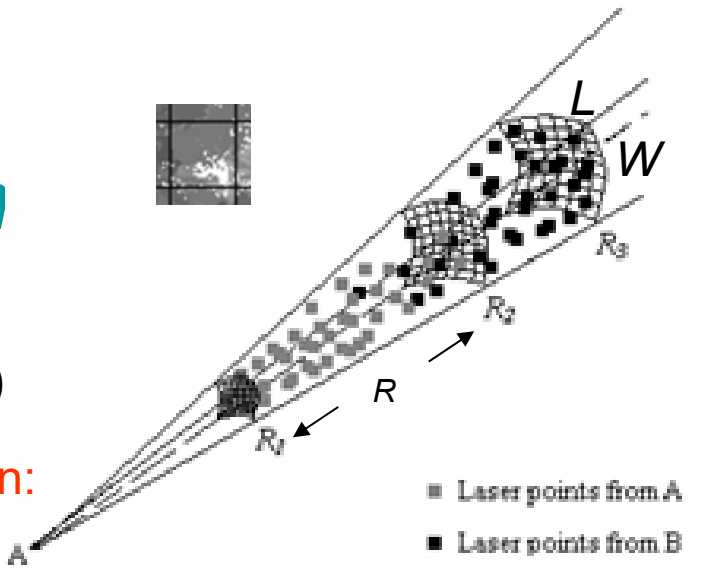


Leaf area calculation

- *LA = LAD * Volume*
- *LAD = LAI / Range*
- *LAI = -ln Gap fraction*

$R = R1 + (R2-R1) \cdot p \qquad (0<p<1)$

? But conventional optical LAI determination:
R=R2



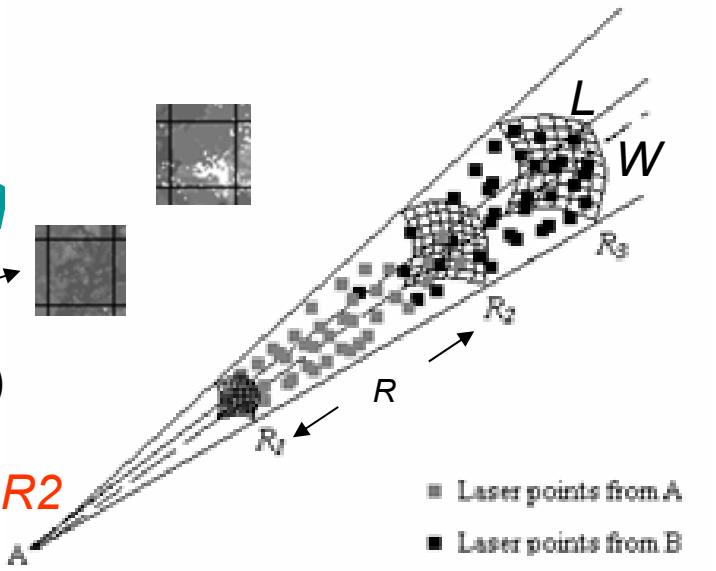
R1 and *R2* are ranges of the nearest and farthest pixel in segment A
R3 is the range of the farthest pixel in segment A+B

Leaf area calculation

- *LA = LAD * Volume*
- *LAD = LAI / Range*
- *LAI = -ln Gap fraction*

P_{0c} !=0

R = R1 + (R2-R1) ·p *(0<p<1)*



Conventional optical LAI determination:*R=R2*

R1 and *R2* are ranges of the nearest and farthest pixel in segment A

R3 is the range of the farthest pixel in segment A+B

Leaf area calculation

- *LA = LAD * Volume*

Segment A+B

$$Volume = 0.002^2 \cdot L \cdot W \cdot \frac{R_3^{\,3} - R_1^{\,3}}{3}$$

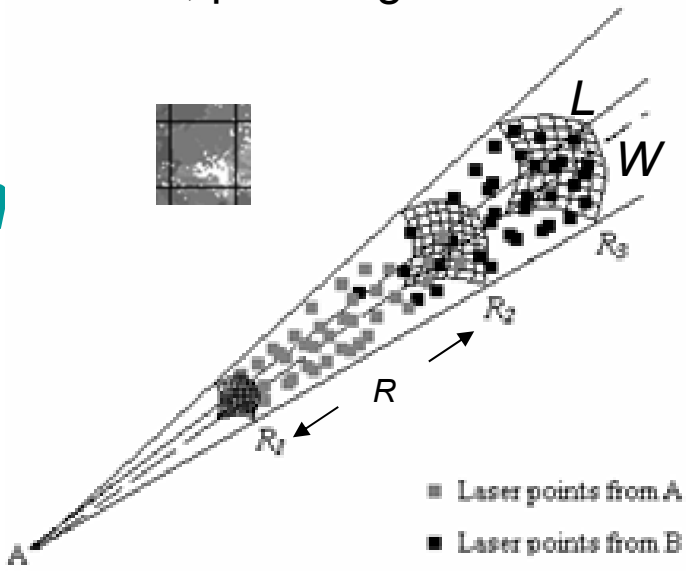
rad, pixel angle width

Segment A

- *LAD = LAI / Range*
- *LAI = -ln Gap fraction*

$$R = R1 + (R2 - R1) \cdot p \qquad (0<p<1)$$

$$P_{0R} = \frac{N_R + N_E}{L \times W}$$



N_R equals to the number of pixels whose distances to the scanner are bigger than *R*,

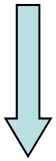
N_E equals to the number of empty pixels

R1 and *R2* are ranges of the nearest and farthest pixel in segment A

R3 is the range of the farthest pixel in segment A+B

Calculation

$$L_e = -\ln P_o(\theta) \cdot \cos\theta / G(\theta)$$



Conifer

$$LAI_R = (1-\alpha)\ LAI\ /\ \overline{SPAR}$$

$\alpha = 0.1$, the woody-to-total area ratio (Chen et al., 1997)

$\overline{SPAR}$ = 0.5, the ratio of spherically averaged shoot silhouette area to the vertically projected needle area (Stenberg et al.,1994)

Calculation 2

$$LA_n = \sum LA_s$$

LAn is one total leaf area estimate of the objective tree,
LAs is the leaf area of a segment-pair

Each tree had two estimates about its total leaf area through exchange scanA and scanB

Final result:

$$LA_a = \overline{LA_n}$$

Allometric Leaf Area

$$ln(BM) = -2.4632 + 2.7573 \cdot ln(100 \cdot DBH) - 1.1194 \cdot ln(H) \qquad (r^2 = 0.880)$$

(Seifert and Müller-Starck, 2009)

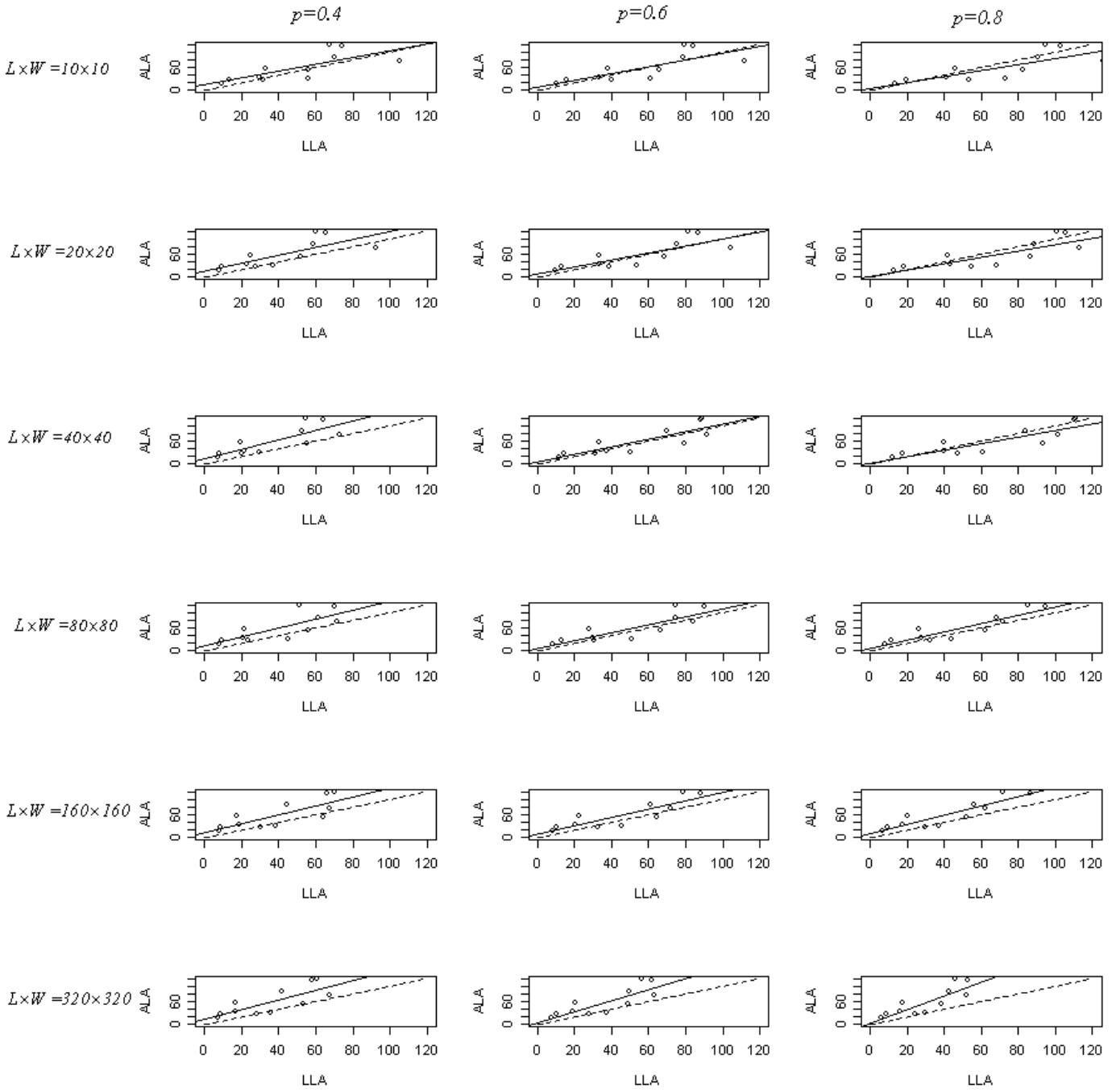
$$LA_t = BM \cdot SLA$$

LAt is the allometric leaf area of a particular tree,
BM is the leaf biomass of a particular tree,
SLA=3.5, is the specific leaf area, (Pretzsch and Mette, 2008)
DBH is the diameter at the breast height,
H is the tree height

$LA_t = \beta_0 + \beta_1 \ LA_a$

11 trees

The correlations between LLA and ALA



P_r **=9.2e-05**

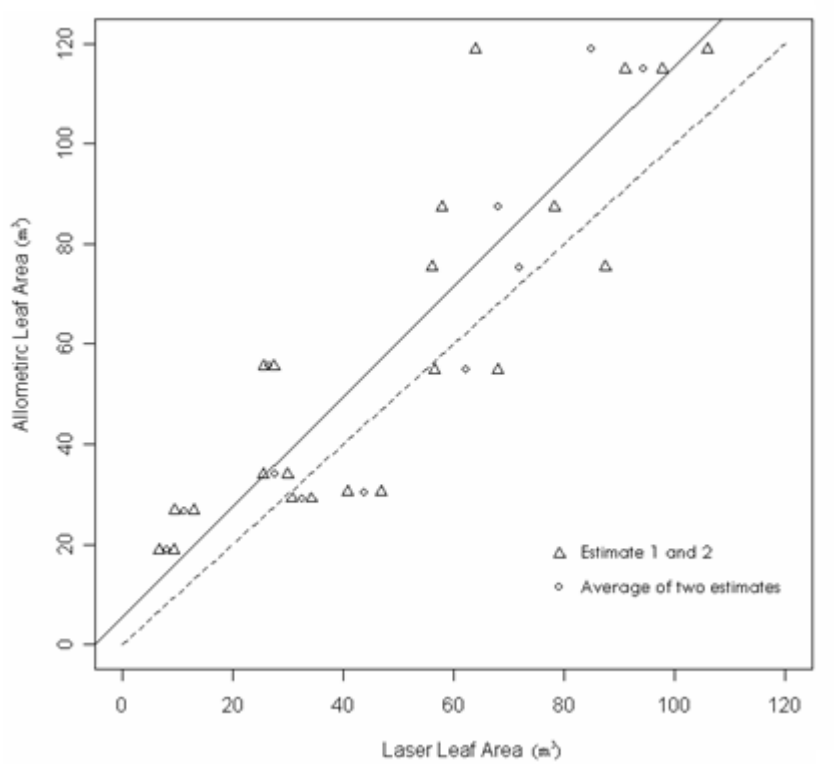
r^2 **=0.813**

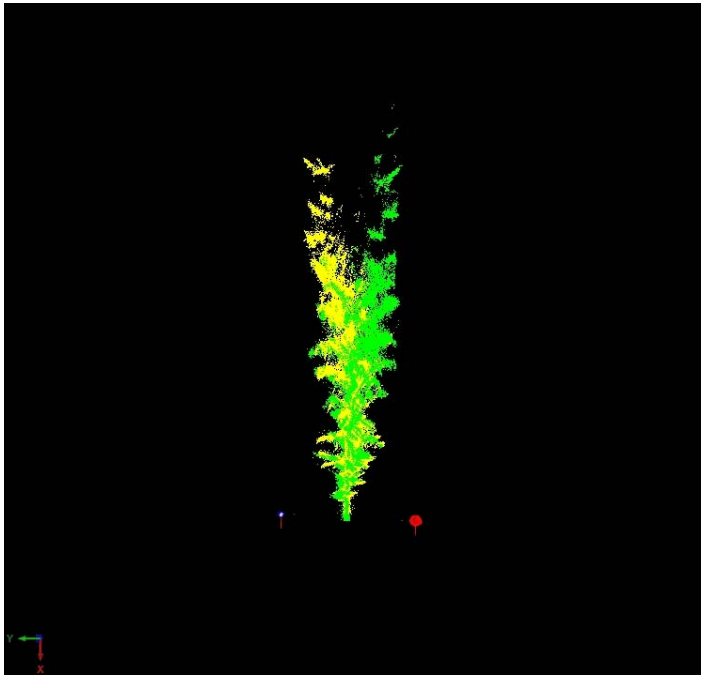
Discussions

- Should segment be set as small as possible?

The observable P_{0R} value was limited between $1/(L \times W)$ and $1\text{-}1/(L \times W)$

- Reasons for the deviation between two estimates?





Thanks!