TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Forestry, Geosciences and Hydrosciences + Faculty of Mechanical Engineering

Parameterisation of momentum absorption in heterogeneous conifer canopies

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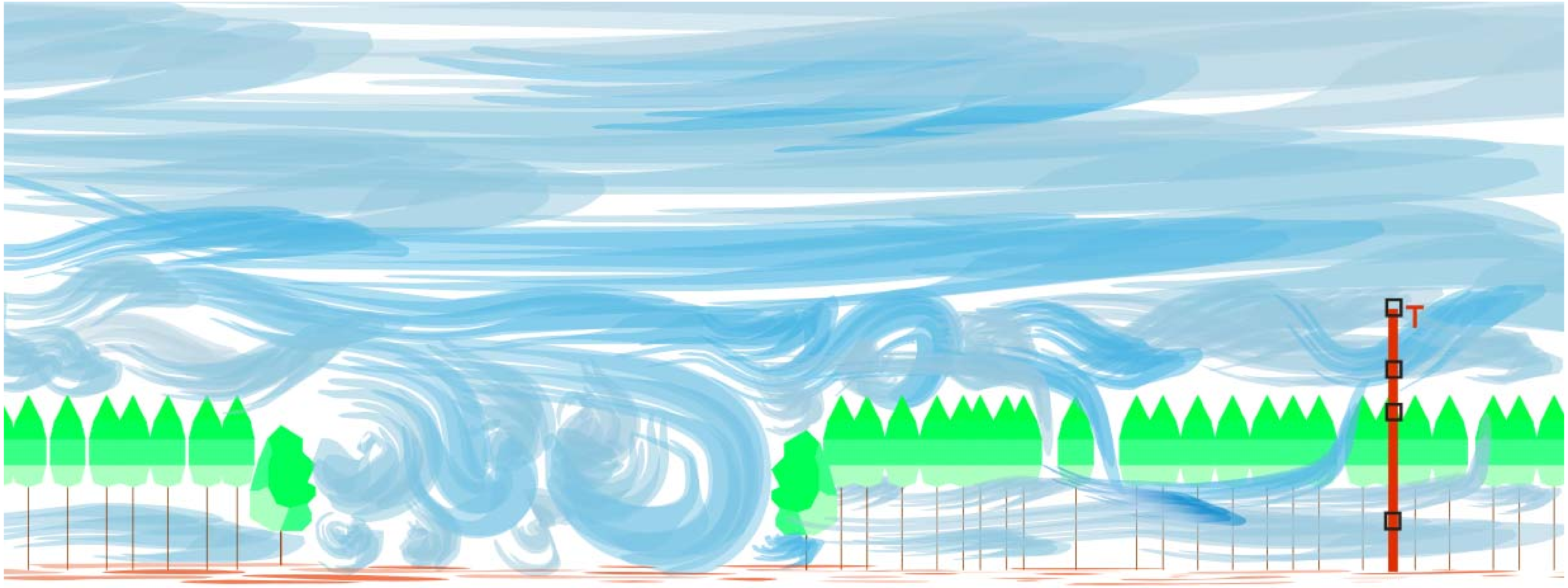
Deutsche Forschungsgemeinschaft
DFG

SPP 1276 MetStröm Conference
Berlin, 10.06.2011

Momentum Absorption

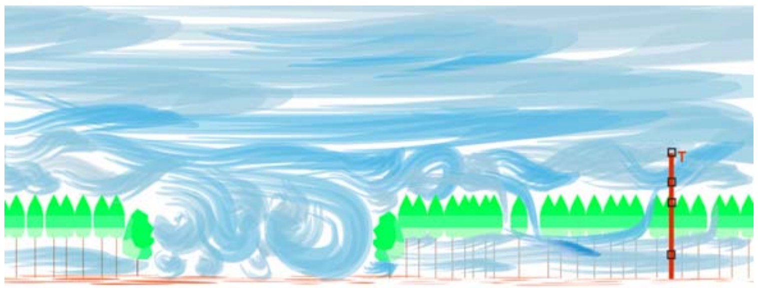
- is important to calculate realistic wind fields and thus the exchanges of energy and mass between atmosphere and land surface



Momentum Absorption

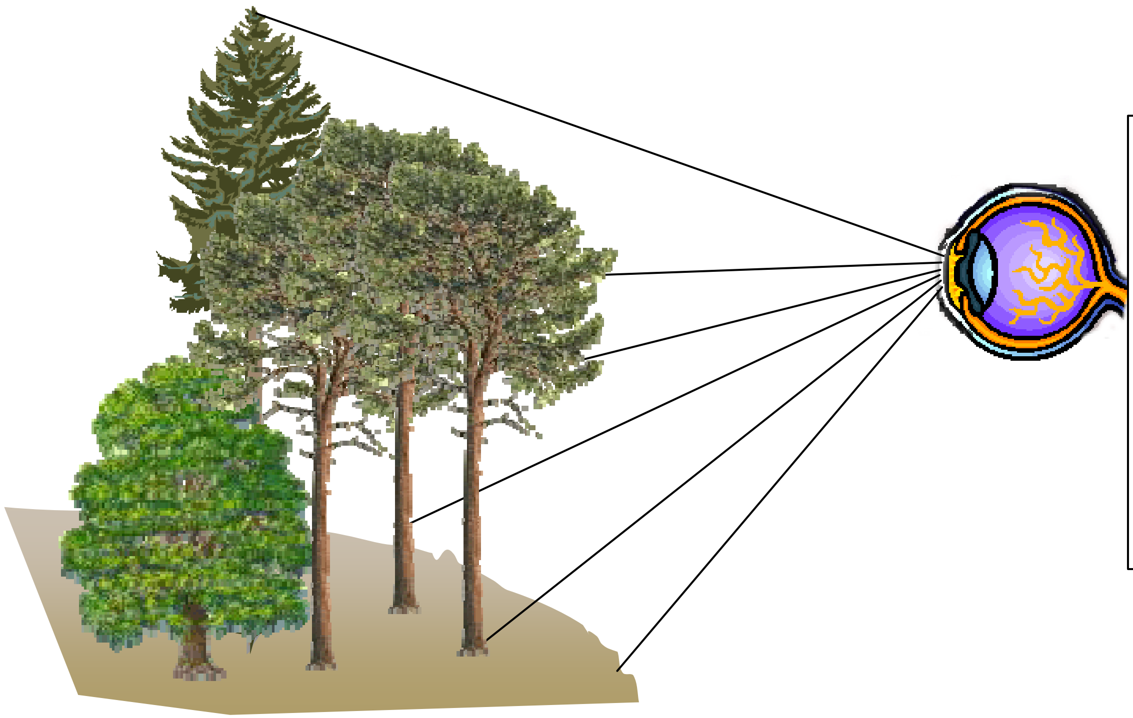
- is important to calculate realistic wind fields and thus the exchanges of energy and mass between atmosphere and land surface
- is dominated by heterogeneities in land-use and by surface structures
- must be parameterised on the basis of detailed vegetation models (each forest has other features)

Wish: A theoretically based parameterisation which can be applied on multiple scales



Challenge and Aim

- Recording 3D vegetation structure
- Parameterisation of scale dependent closure models (drag force, mixing length)



Numerical Model

...

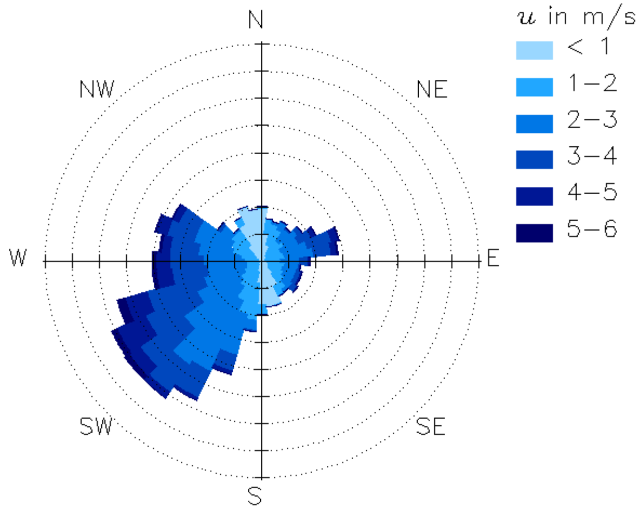
Grid Resolution

...

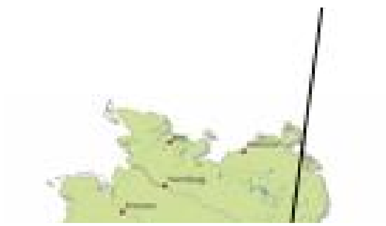
Parameters:

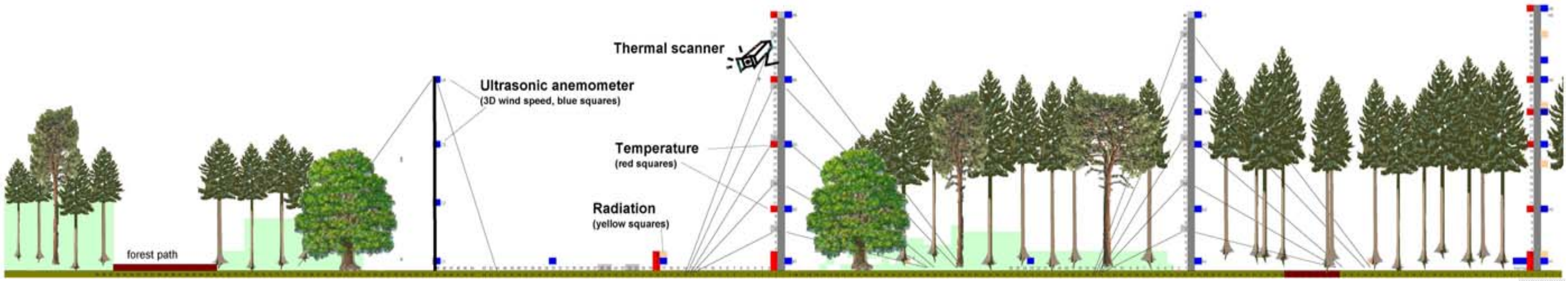
C_D, z_0, l_m, ...

Site: ASTW



Wind distribution
2008-2009



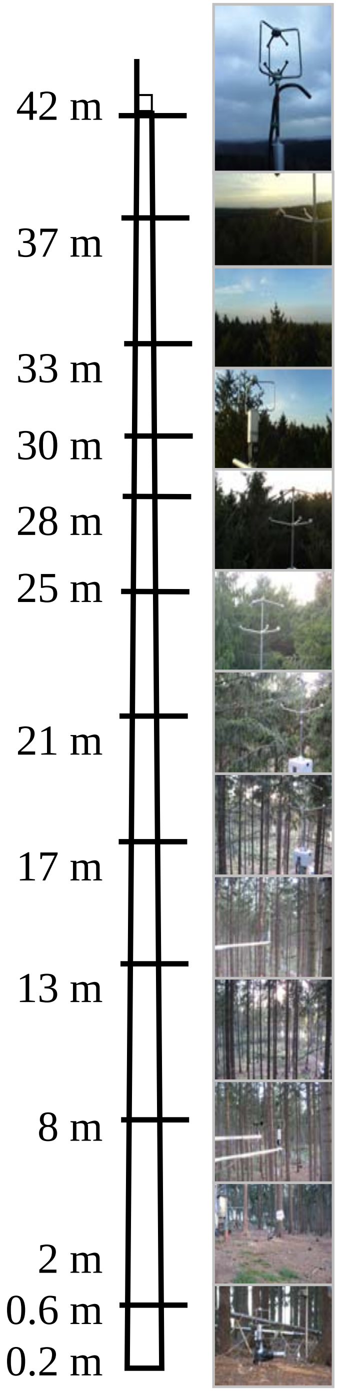


WinCanop Experiment
8/2007 - 11/2007

- Setup / Measurements:

  13 sonic anemometers over a range of 42 m, synchronous data registration (20 Hz)

  LAI2000 (vertical res. 0.5 m)



WinCanop Experiment 8/2007 - 11/2007

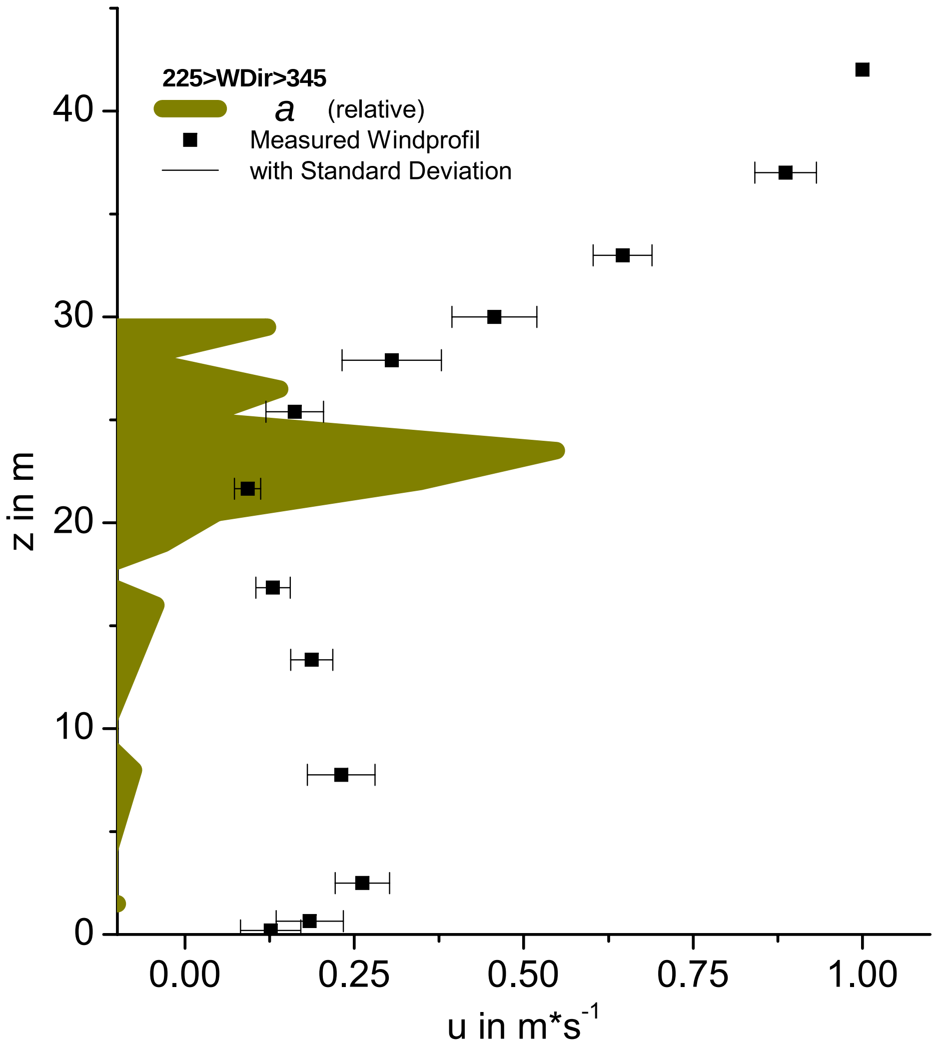
- Setup / Measurements:

  13 sonic anemometers over a range of 42 m, synchronous data registration (20 Hz)

  LAI2000 (vertical res. 0.5 m)

- Features of the horizontal wind speed:

- Inflection point with high variability at the top of the canopy
- Secondary maximum of wind speed in trunk space



Laser data

Instruments

- Riegl LMS-Z 420i (range: 800 m, resolution: 0.1°)
- Faro LSHE880 (range: 80m, resolution: 0.036°)

Used measurements

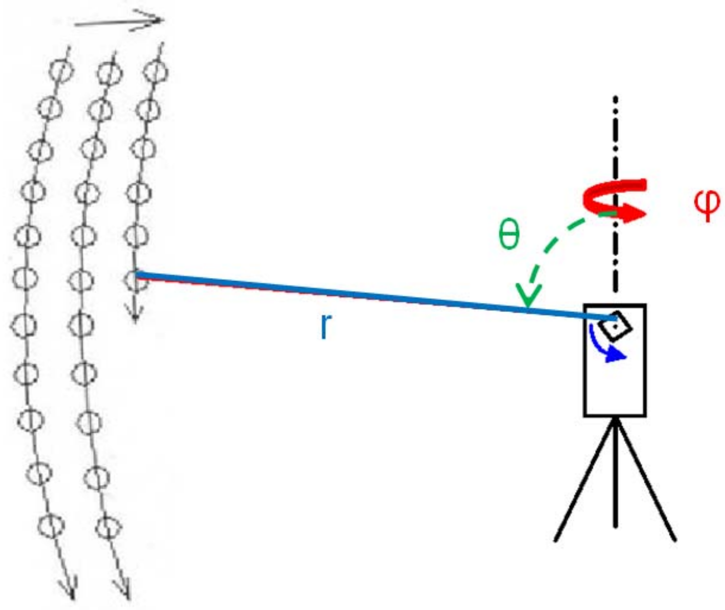
- 5 ground positions (Riegl)
- 4 ground positions (Faro)
- 2 position at 40 m (Riegl)

Data registration

- Tie points: spheres (Faro) and cylinders (Riegl)
- Transforming several scans into one coordinate system with an accuracy of: $0.0035 \text{ m} \le \sigma \le 0.0059 \text{ m}$

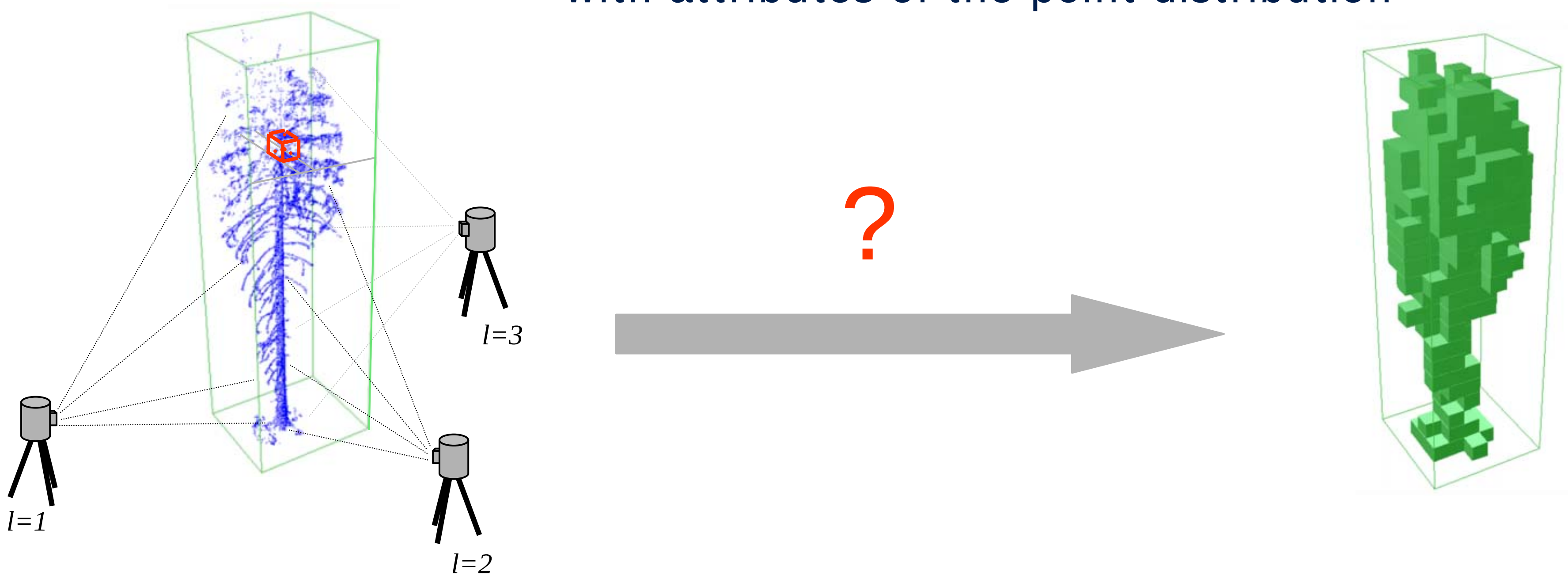
Faro

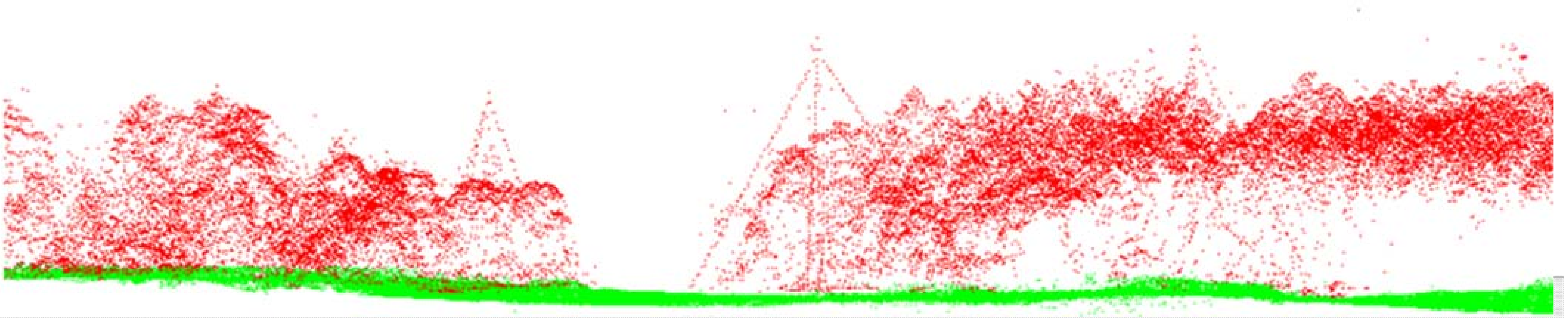
Riegl



Voxel Space

Voxel: Cubic volume at discrete position V(x,y,z) with attributes of the point distribution





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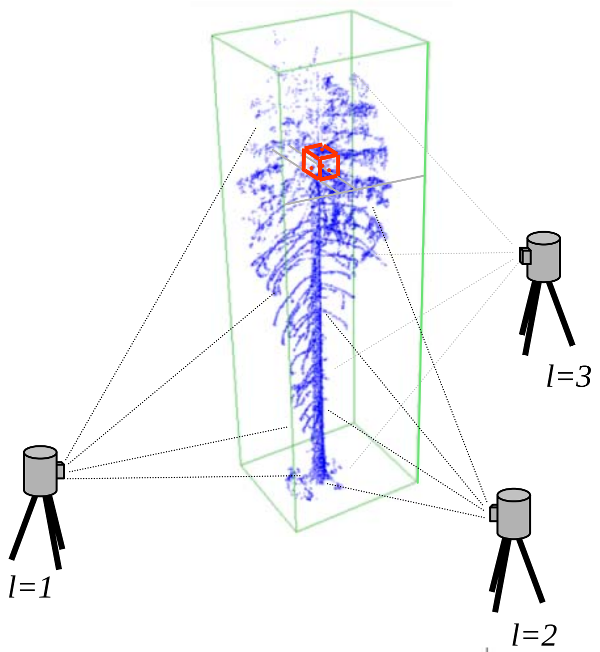
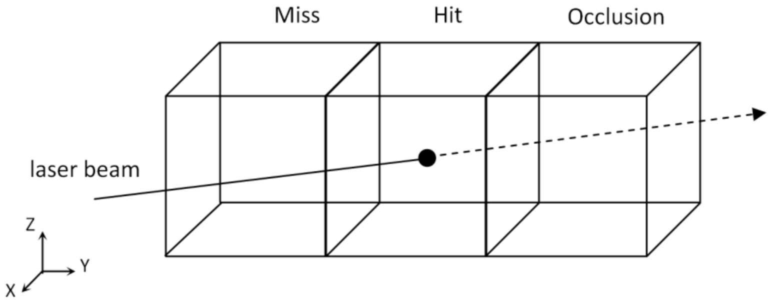
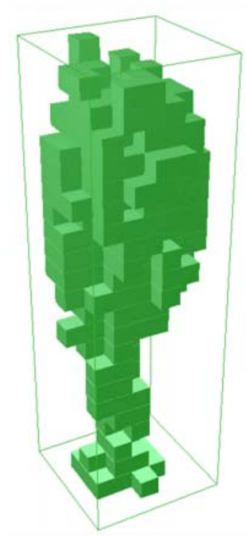
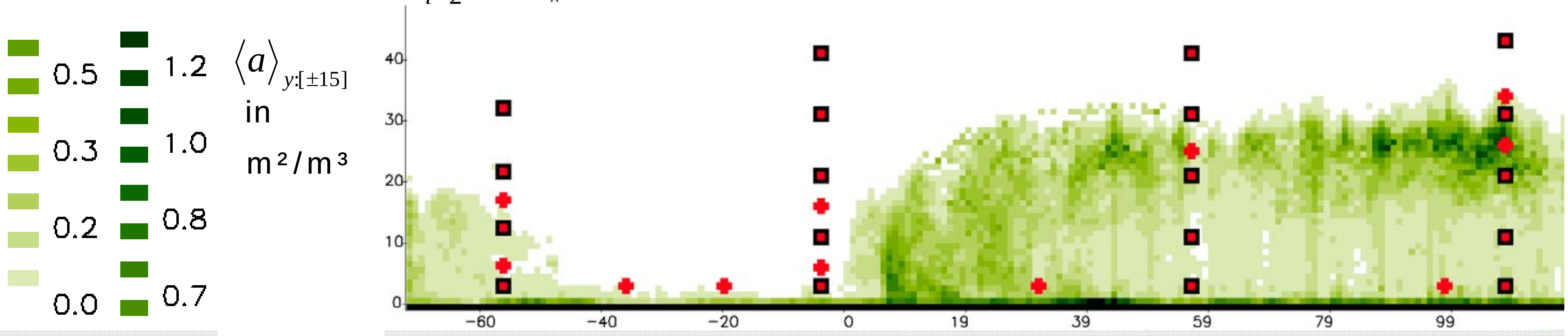


Plant Area Density (a)

$$a = F_{clump} \frac{\sum_{l=1}^{n} N_{Hit,l} / N_{\max,l}}{\sum_{l=1}^{n} \frac{N_{Hit,l} + N_{Miss,l}}{N_{\max,l}}}$$

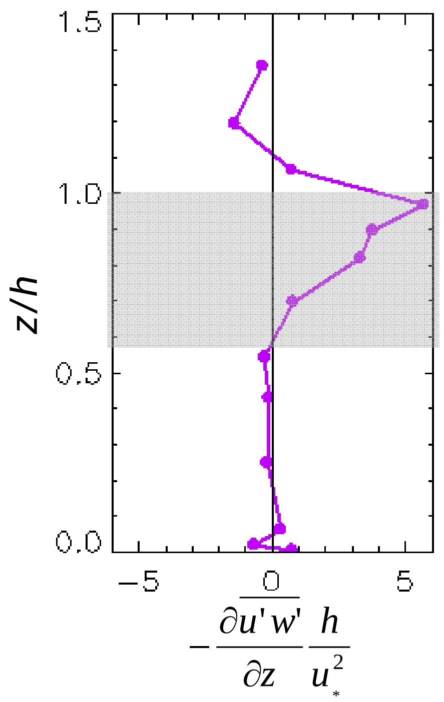




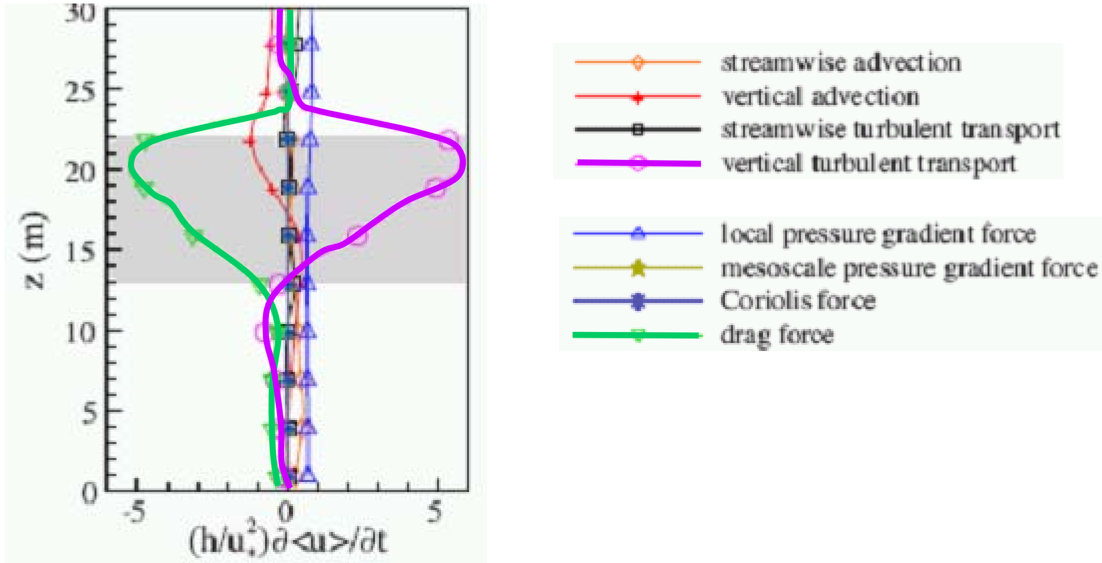


Derivation of the Drag Coefficient C_D

$$C_D \cdot a \cdot u^2 = -\frac{d\overline{u'w'}}{dz}$$



WinCanop, 2007
Main Tower
wind sector 255°-285°



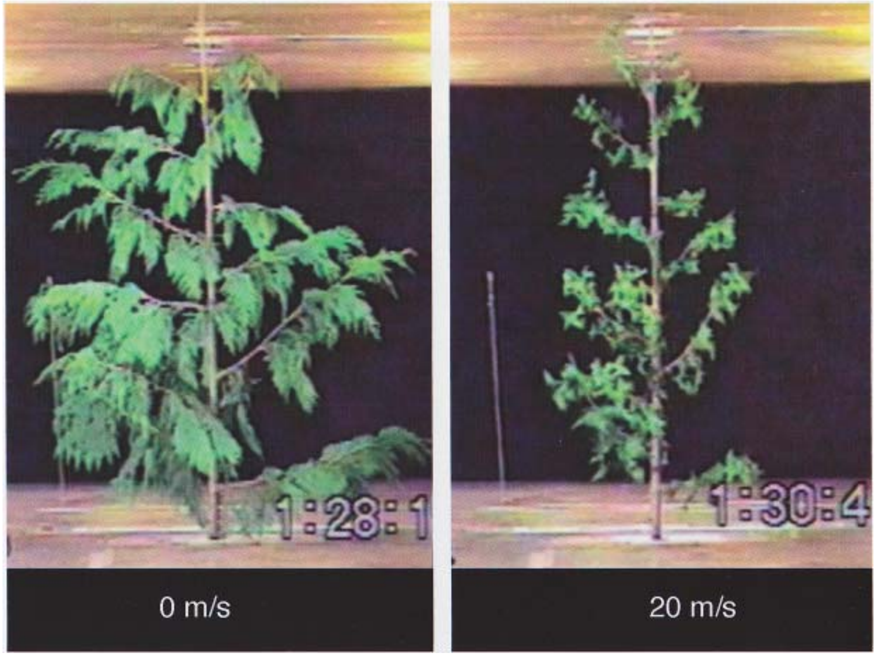
Dupont S, Bonnefond J-M, Irvine MR, Lamaud E, Brunet Y (2011) Long-distance edge effects in a pine forest with a deep and sparse trunk space: In situ and numerical experiments. Agric For Meteorol 151:328-344

C_D: Dependence on Wind Speed

- Streamlining: alignment of canopy elements
- Decreasing viscous boundary layers
- Underestimation of the drag during gusts due to the averaging

$$\bar{u}^2 \quad \rightarrow \quad \overline{Uu} = \overline{\sqrt{u^2 + v^2 + w^2} \cdot u}$$

Ayotte KW, Finnigan JJ, Raupach MR, (1999) A second-order closure for neutrally stratified vegetative canopy flows. Bound.-Layer Meteorol. 90, 189–216.

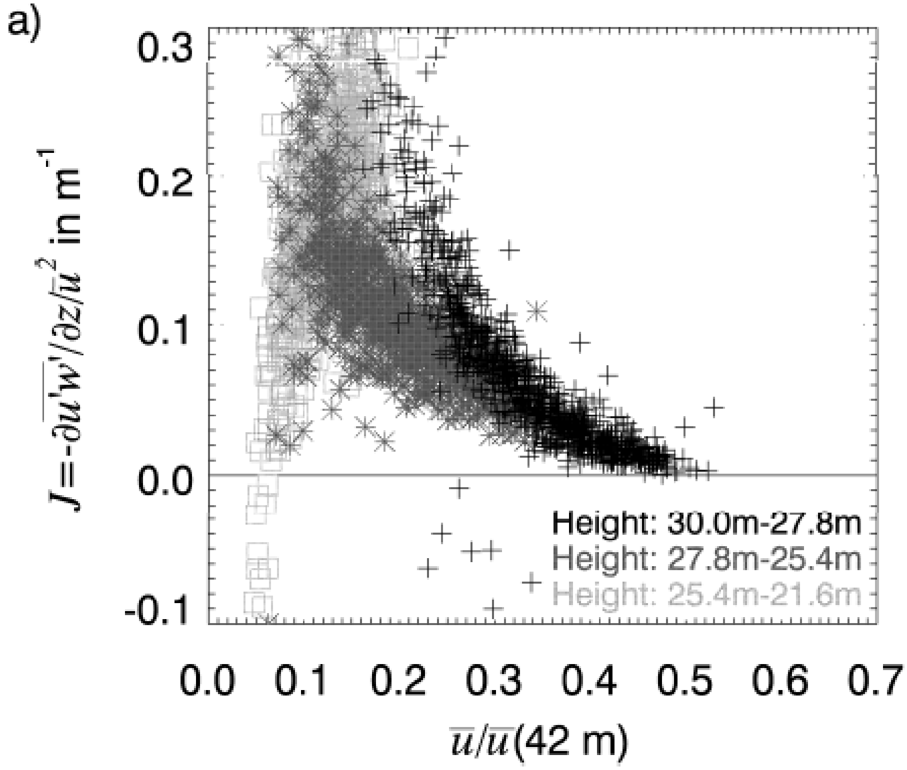


From: Monteith and Unsworth (2008) Principles of environmental physics. Academic Press, (source Rudnicki et al 2004)

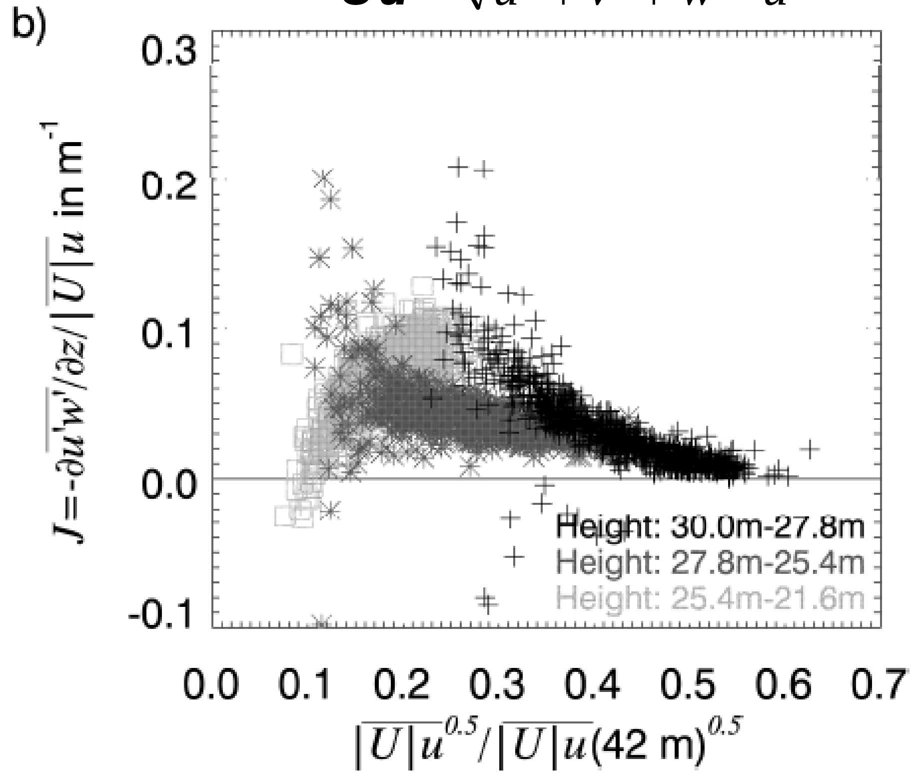
C_D: Dependence on Wind Speed

Local Drag Area $$J = -\frac{\partial \overline{u'w'}}{\partial z}\frac{1}{\overline{u}^2} = C_D \cdot a$$

$\overline{u}^2$

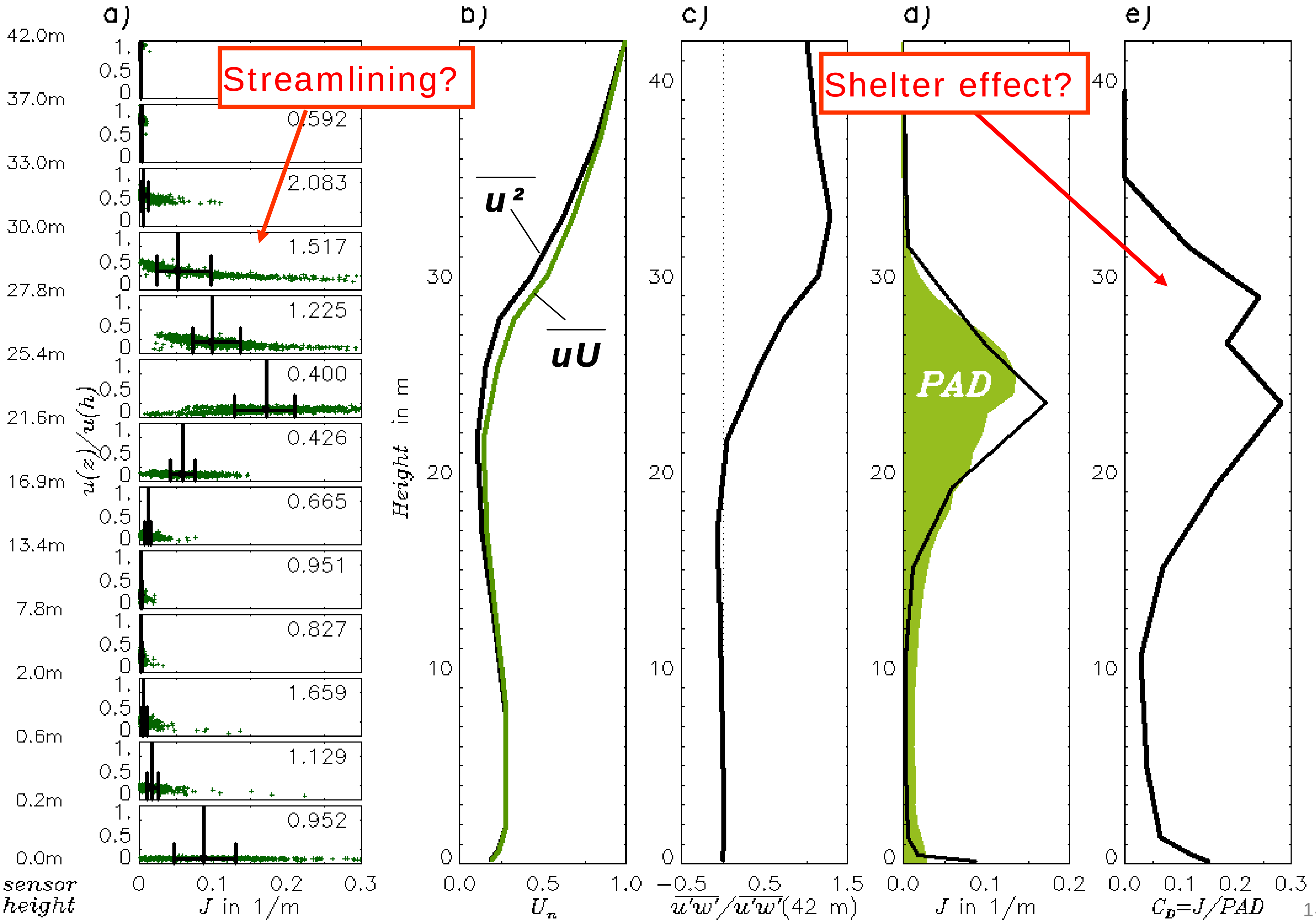


$\overline{Uu} = \sqrt{u^2 + v^2 + w^2} \cdot u$



WinCanop, 2007, main tower, wind sector 255°-285°

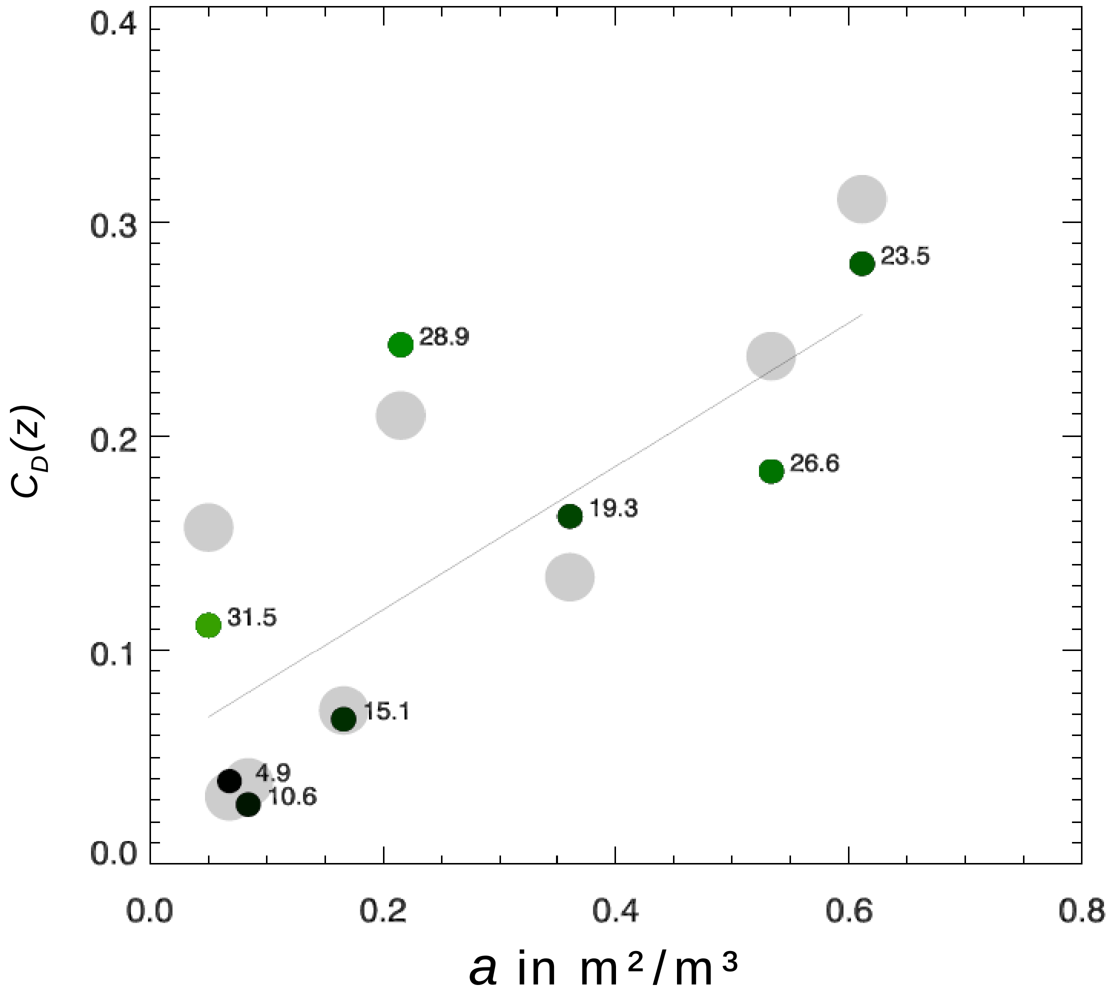
C_D: Dependence on Stand Structure



C_D: Dependence on Plant Area Density

- Additional dependence of C_D on *a*
- Smaller momentum absorption per plant area in the trunk space
- "Vegetation element" specific C_D

$$C_D(z) = \left| \frac{\partial \overline{u'w'}}{\partial z} \right| \frac{1}{a \cdot u^2}$$



Achievements

- Vegetation model from TLS
- Plant specific parameterization of the drag force F_D
- Data set for the validation of numerical models

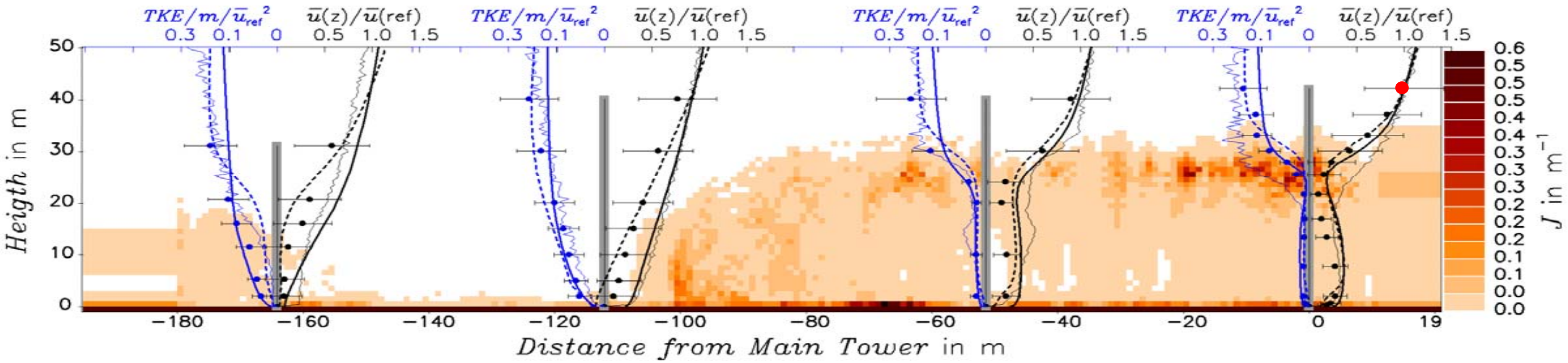
$$F_D = C_D \cdot a \cdot \overline{u}^2$$

$$C_D = C_{D0} \cdot a^n \cdot \overline{u}^m$$

Plant specific exponents for

Surface density and Streamlining

$n = 0.6$ $m = -0.8$

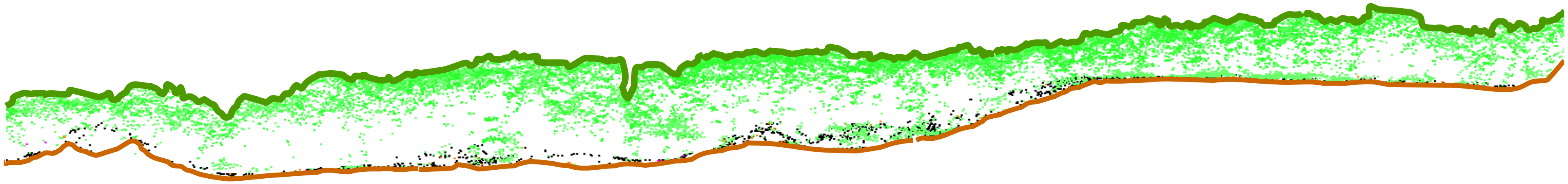


Straight thin lines: wind tunnel measurement
Straight thick lines: boundary layer model
Dashed thick lines: large eddy simulation
Dots with whiskers: measurements with standard deviation

$$J = C_{D,0} \cdot a^{1+n}$$

Next Steps

- Regarding advective and pressure terms of the momentum equation
- Classification of vegetation (stems, branches and twigs with leaves)
- Determination of the source area for local turbulence
- Scale dependent drag coefficients using Airborne Laser Scanners



Thank you