Flow Through Decidious Tree Crowns

Comparison of Measurements and High Resolution Numerical Modelling

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Overview

- Introduction
- Description of the measuring site
- Results of measurements
- The numerical model MISCAM
  - Basic equations
  - Parameterization of vegetation
- Results of numerical simulations
- Discussion

Introduction

- Project background (measurements)
  - Analysis of the particle (PM_{10}) filtering potential of vegetation
  - Deposition as a boundary layer phenomenon (pathways, parameters)
  - Parameterization of flow through vegetation
  - Process understanding
  - Comparison with microscale modelling

Introduction

- Project background (modelling)
  - Effects of different types of vegetation on microscale flow
  - Impacts on pollutant dispersal, esp. deposition
  - Contribution to model evaluation
  - Extension of range of applicability

The measurement site

- Open space in an urban setting
- UCL, irregular flow, even at night
- Next to a busy road
- Single tree (within a row of similar specimens)

The measurement site

Instrumentation

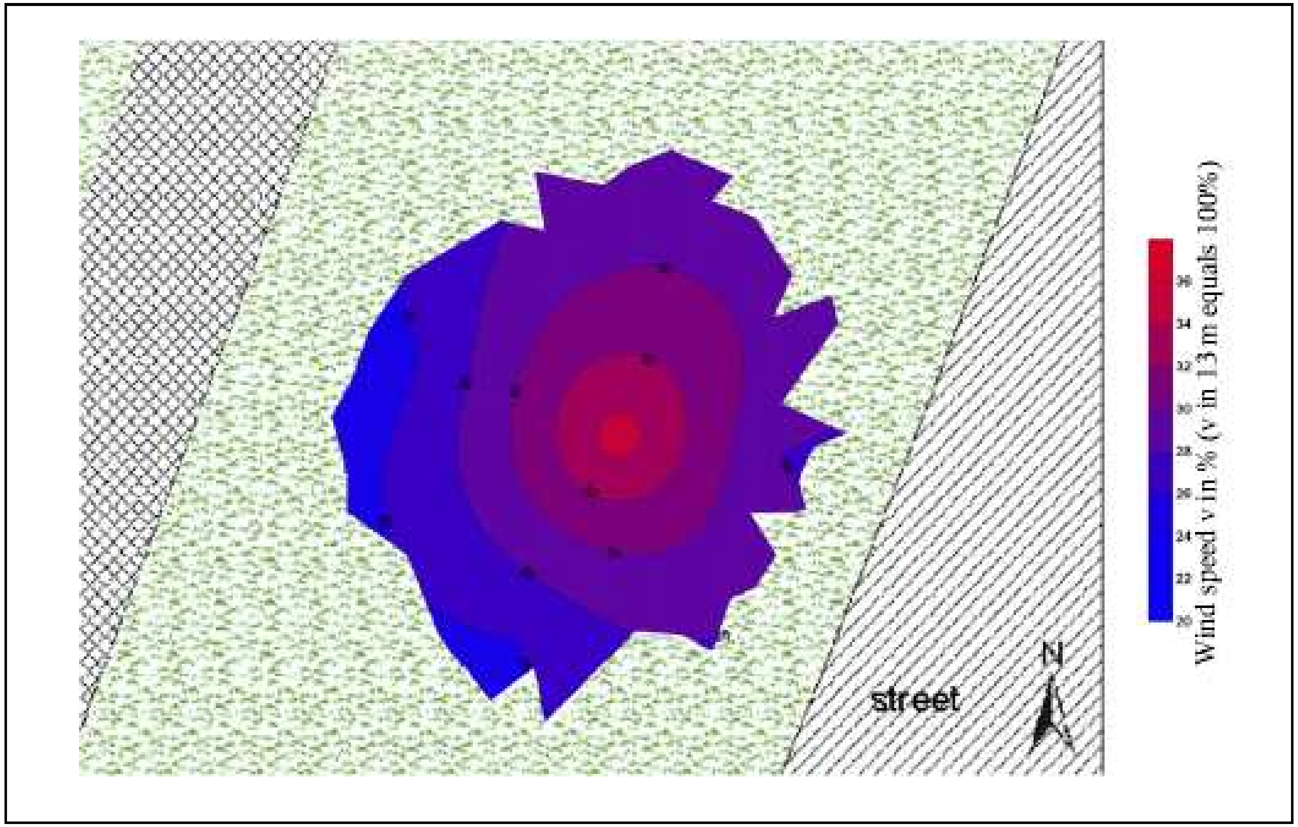
- Wind speed measurements
  - Ultrasonic anemometers
  - Wind vane and cup anemometer
  - Thermal globe anemometers

Measuring setup

- Cross-sectional registration of wind speed at 5.5 m above ground
- Registration of wind speed in the lower part of the crown
- Continuous registration at 13 m above ground
- Vertical wind profile south of the tree (1-6 m)
- Linear extrapolation of the wind speed distribution

Results of measurements

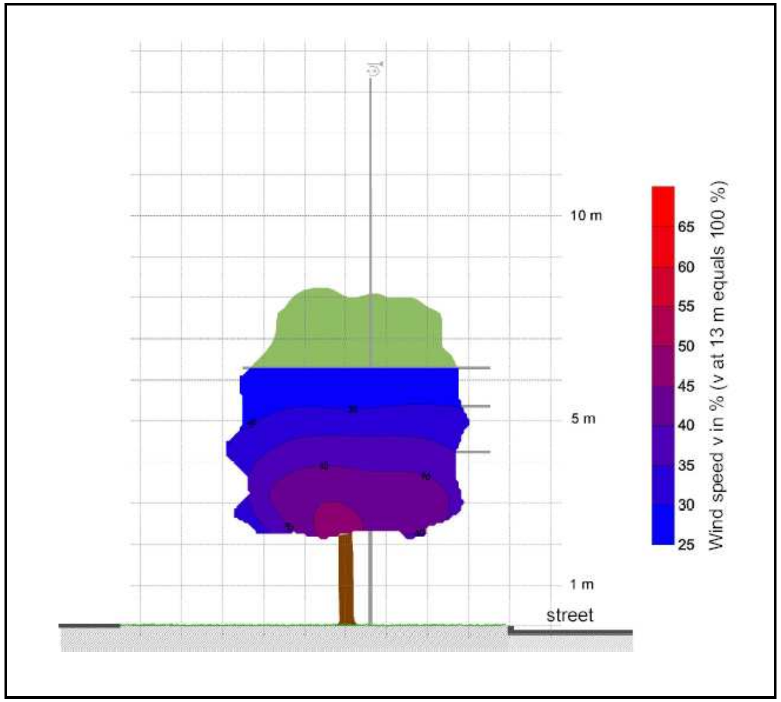
Horizontal wind speed distribution at $z = 5.5$ m.

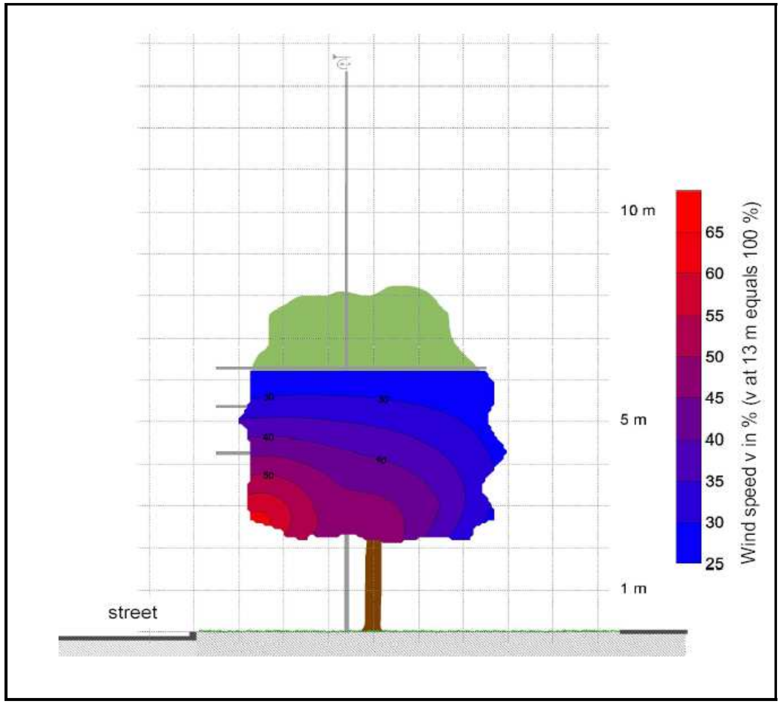


Results of measurements

Vertical wind speed distribution

as seen from S (left) and N (right)





The numerical model MISCAM

- Microscale climate and air pollution model
- Three-dimensional non-hydrostatic flow model
- Explicit modeling of buildings
- Modified k-ε model of turbulence
- Eulerian pollutant dispersal model (optional)
- Parameterization of vegetation following Green (1992)

The numerical model MISCAM

Basic equations - turbulence model

$$\frac{\partial k}{\partial t} + \frac{\partial u_j k}{\partial x_j} = \frac{\partial}{\partial x_j}\left(c_\mu \frac{k^2}{\varepsilon}\frac{\partial k}{\partial x_j}\right) + P_{m,k} + P_h - \varepsilon \qquad (1)$$

$$\frac{\partial \varepsilon}{\partial t} + \frac{\partial u_j \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{c_\mu}{\sigma}\frac{k^2}{\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right) + c_1 \frac{\varepsilon}{k}(P_{m,\varepsilon} + P_h) - c_2 \frac{\varepsilon^2}{E} \qquad (2)$$

The numerical model MISCAM

Basic equations - production rates

$$P_{m,k} = 0.5 c_\mu \frac{k^2}{\varepsilon} \sqrt{\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\left(\frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i}\right)} \quad (3)$$

$$P_{m,\varepsilon} = 0.5 c_\mu \frac{k^2}{\varepsilon} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \quad (4)$$

$$P_h = -1.35 c_\mu \frac{k^2}{\varepsilon} \frac{g}{\Theta_0} \frac{\partial \Theta}{\partial x_j} \delta_{3j} \quad (5)$$

The numerical model MISCAM

Basic equations - flow field

$$\frac{\partial \tilde{u}_i}{\partial t} = -\frac{\partial u_j u_i}{\partial x_j} + \frac{\partial}{\partial x_j}\left[c_\mu \frac{k^2}{\varepsilon}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \quad (6)$$

$$\frac{\partial^2 p'}{\partial x_i^2} = -\frac{\rho}{\Delta t}\frac{\partial \tilde{u}_i}{\partial x_i} \quad (7)$$

$$u_i = \tilde{u}_i - \frac{\Delta t}{\rho}\frac{\partial p'}{\partial x_i} \quad (8)$$

$$\hookrightarrow \frac{\partial u_i}{\partial x_i} = 0 \quad (9)$$

The numerical model MISCAM

Parameterization of vegetation

$$\left(\frac{\partial \tilde{u}_i}{\partial t}\right)_{veg} = \left(\frac{\partial \tilde{u}_i}{\partial t}\right)_{old} - c_d n L \mathbf{v} u_i \qquad (10)$$

Drag force dependant on stand density n, leaf area density L, total velocity **v** and velocity component under concern.

$c_d = 0.2n^2$: empirical drag coefficient

The numerical model MISCAM

Parameterization of vegetation

$$\left(\frac{\partial k}{\partial t}\right)_{veg} = \left(\frac{\partial k}{\partial t}\right)_{old} + c_d n L \mathbf{v}^3 - 4 c_d n L \mathbf{v} k \quad (11)$$

$$\left(\frac{\partial \varepsilon}{\partial t}\right)_{veg} = \left(\frac{\partial \varepsilon}{\partial t}\right)_{old} + \frac{3}{2}\frac{\varepsilon}{k} c_d n L \mathbf{v}^3 - 6 c_d n L \mathbf{v} \varepsilon \quad (12)$$

Increased production rates implied by Eq. (10)

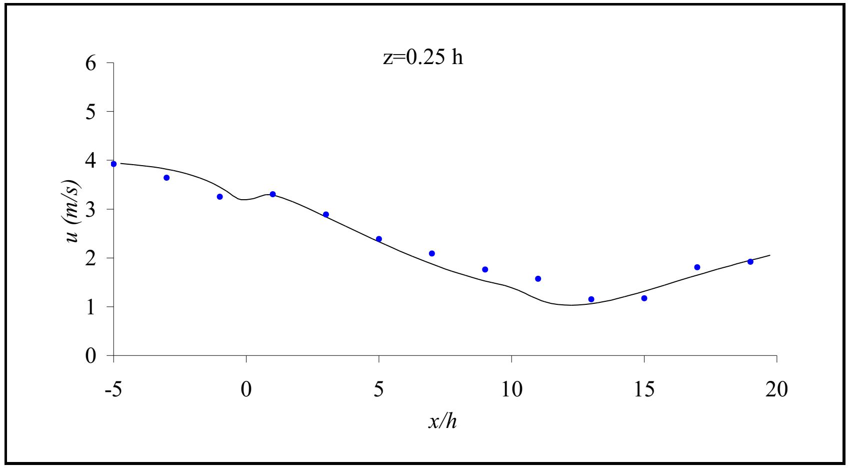
Reduction of k, ε as proposed by Green (1992)

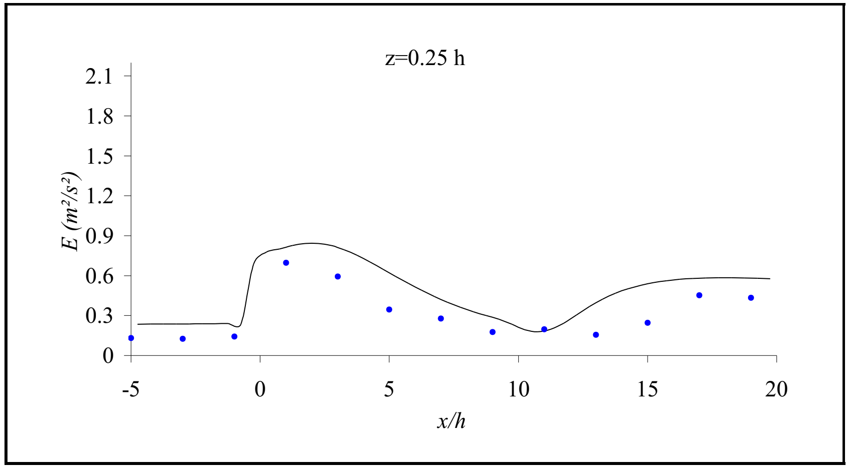
Results (1)

- Two-dimensional flow through a homogeneous tree stand
- Comparison to wind tunnel data (Green, 1992)
- Results already published (Ries & Eichhorn, 2001)

Comparison to wind tunnel data

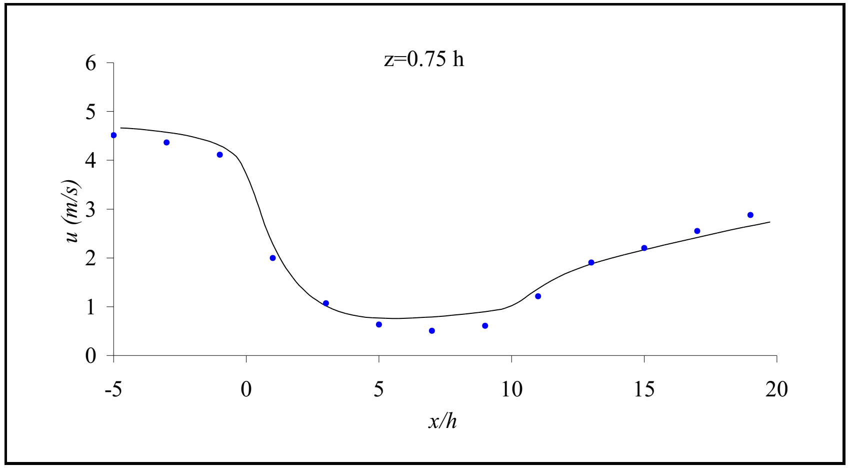
Horizontal wind speed (m/s, left) and turbulent kinetic energy (m^2/s^2, right) at $z = 0.25\ h$ (h: height of trees)

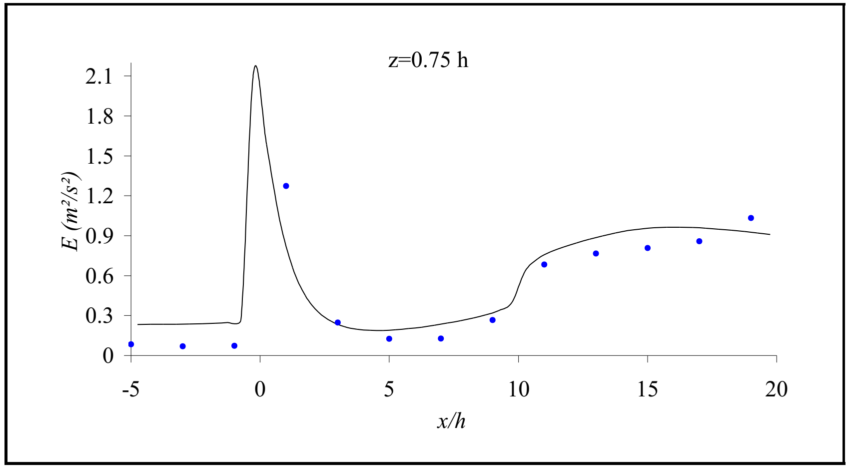




Comparison to wind tunnel data

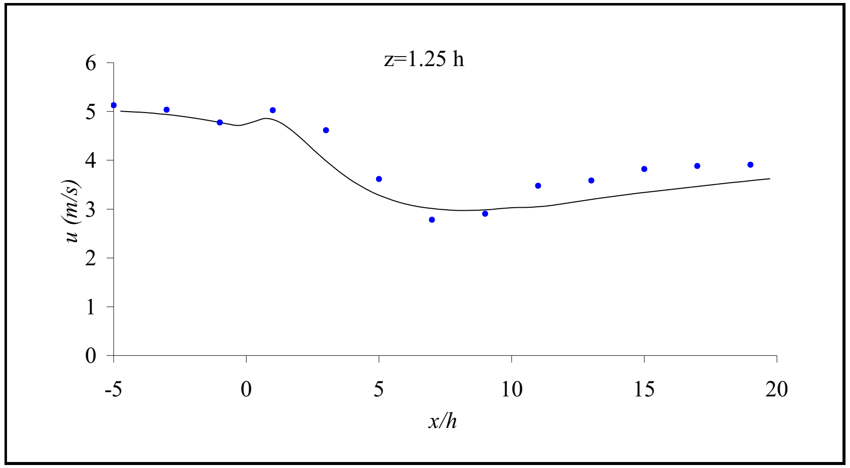
Horizontal wind speed (m/s, left) and turbulent kinetic energy (m^2/s^2, right) at $z = 0.75\ h$ (h: height of trees)

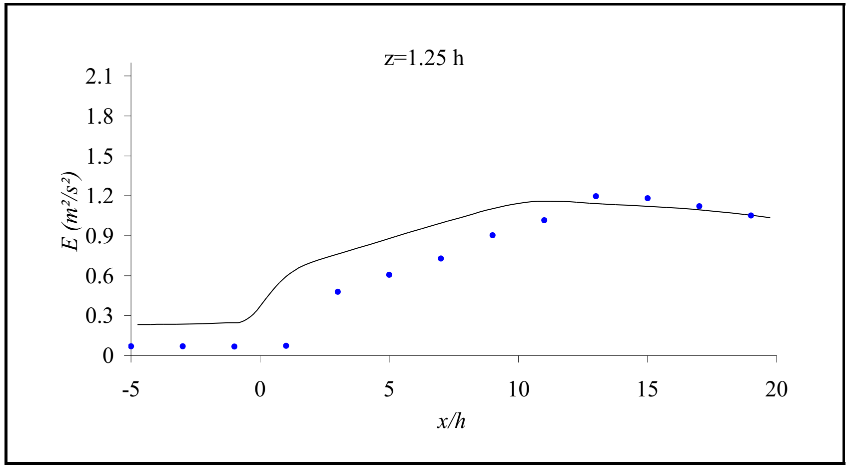




Comparison to wind tunnel data

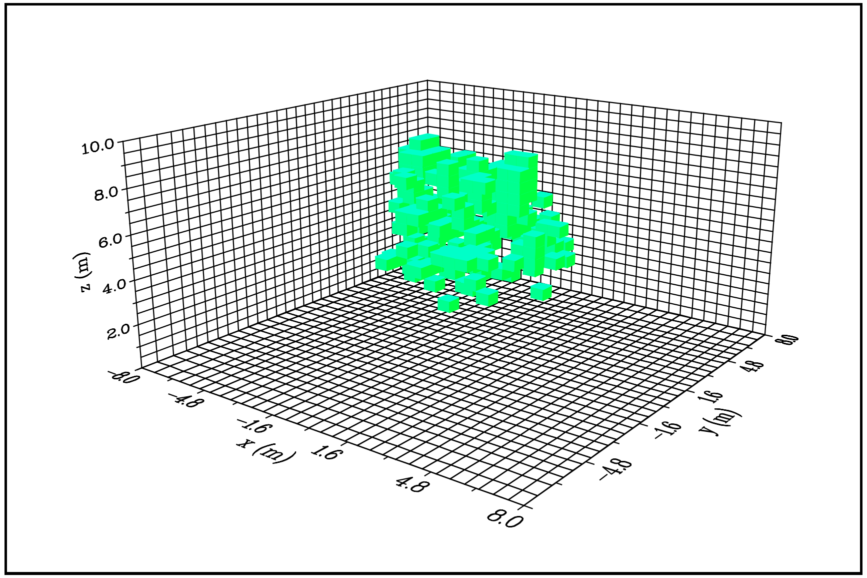
Horizontal wind speed (m/s, left) and turbulent kinetic energy (m^2/s^2, right) at $z = 1.25\ h$ (h: height of trees)





Results (2)

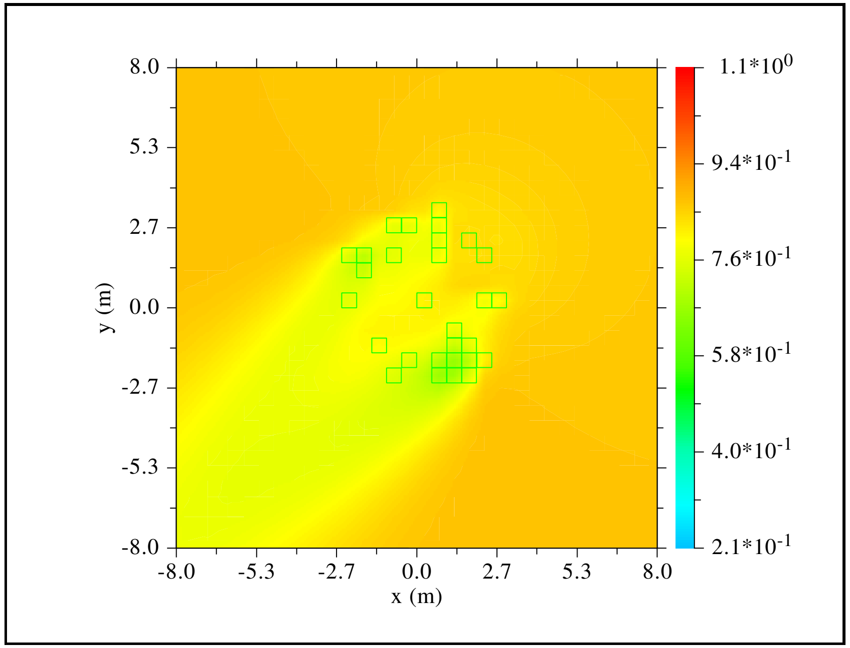
- Flow through a single tree
- Leaf area density (L) from measuring site, grid resolution 0.5 m
- Neighboring trees neglected
- Inflow direction 45° (NE)
- Inflow velocity 1 m/s at $z = 13$ m

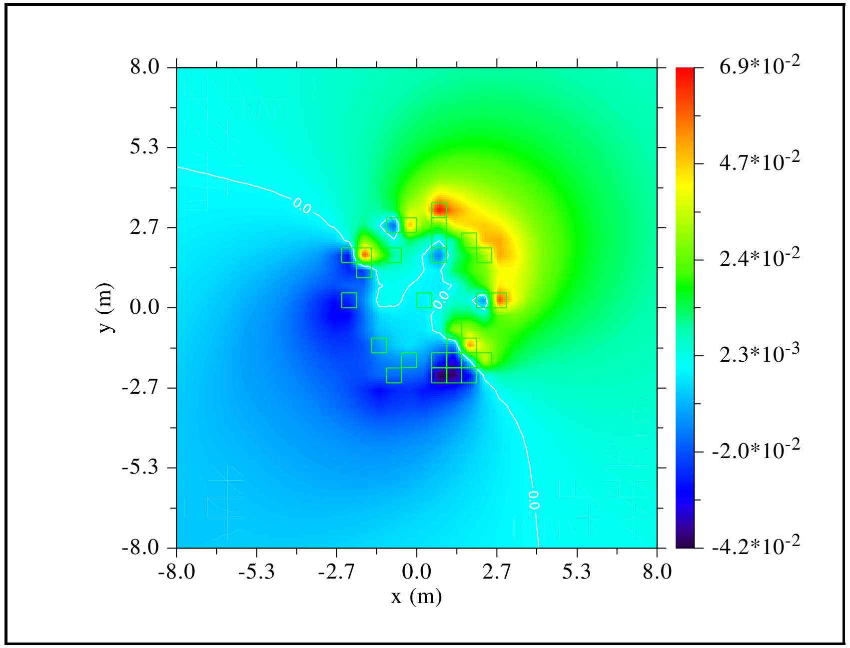


Flow through a single tree

Normalized wind speed (left) and
pressure perturbation (hPa, right)

horizontal cross-section at $z = 5.25$ m

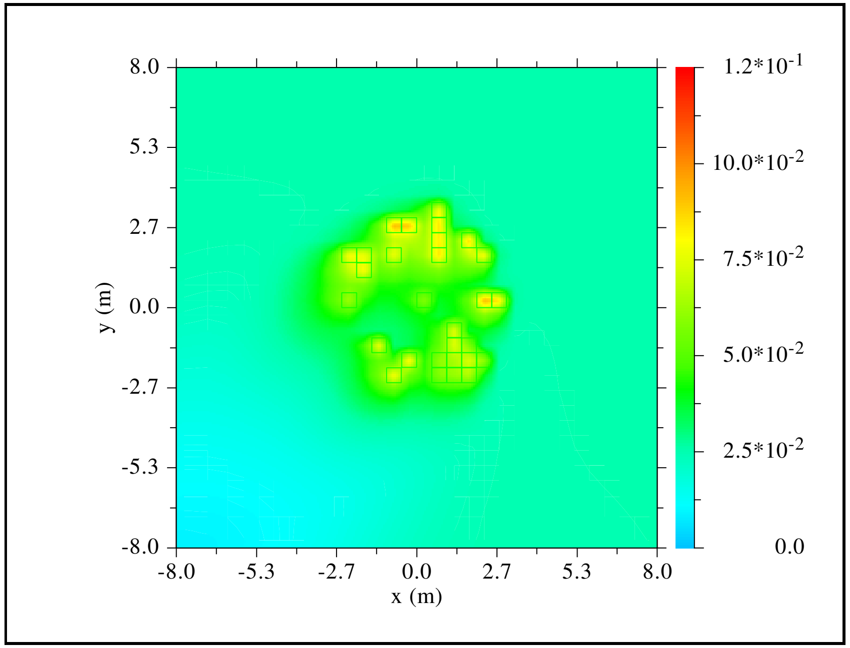


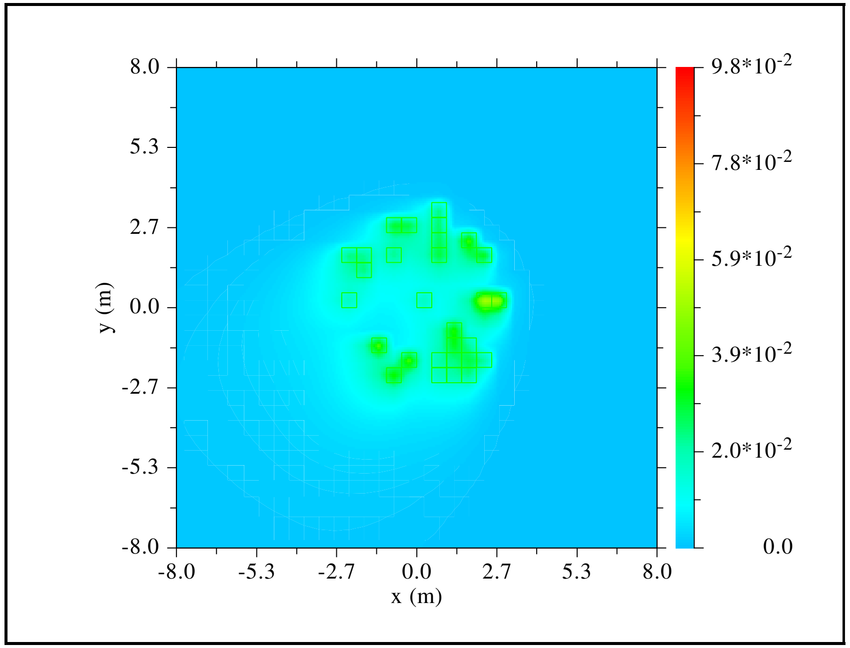


Flow through a single tree

Turbulent kinetic energy (m^2/s^2, left) and turbulent energy dissipation (m^2/s^3, right),

horizontal cross-section at $z = 5.25$ m

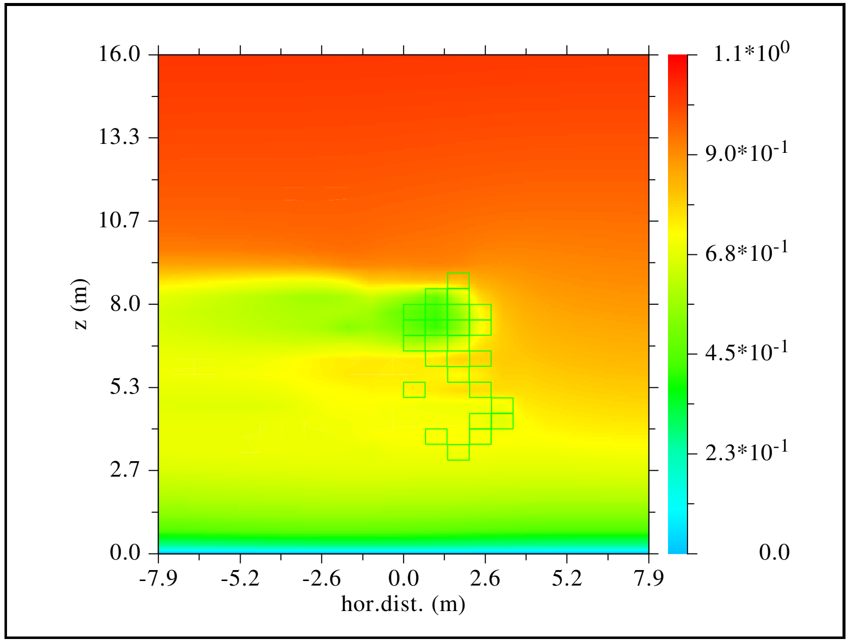


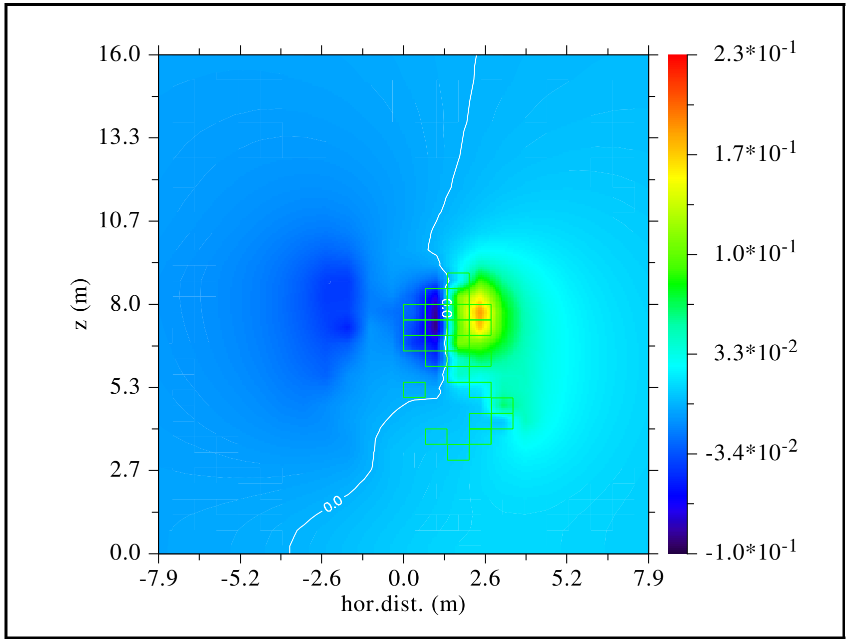


Flow through a single tree

Normalized wind speed (left) and
pressure perturbation (hPa, right),

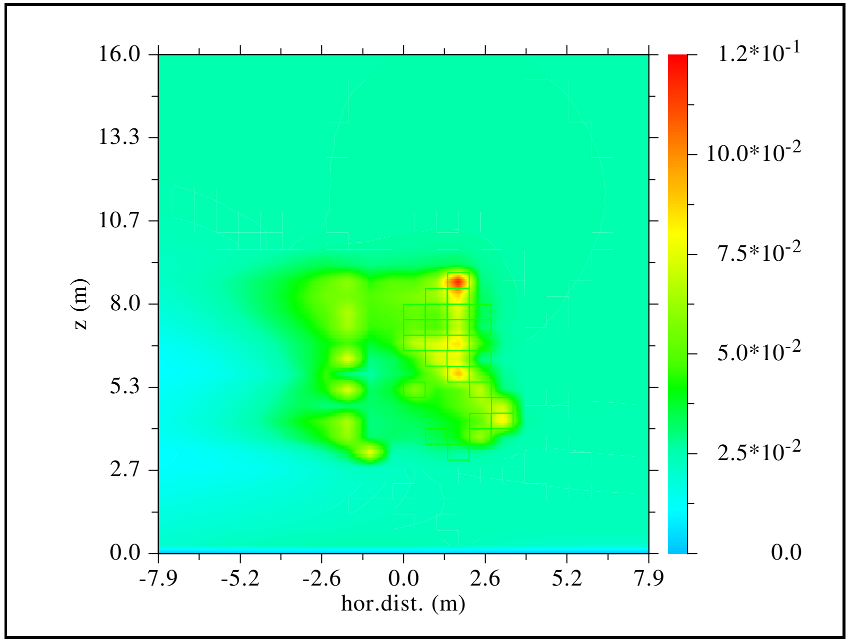
vertical cross-section SW — NE

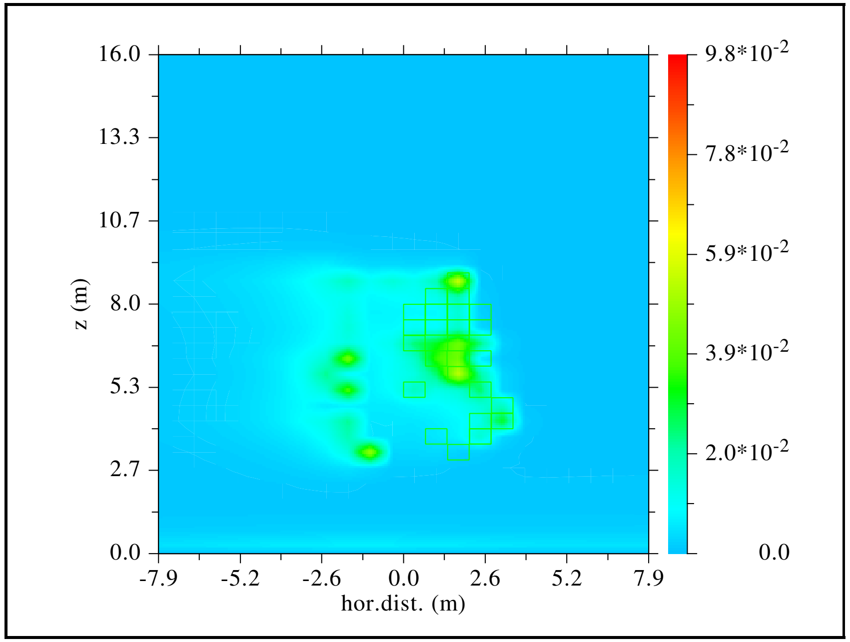




Flow through a single tree

Turbulent kinetic energy (m^2/s^2, left) and turbulent energy dissipation (m^2/s^3, right), vertical cross-section SW — NE





Discussion

- Wind measurements within tree crown yield some interesting results
- Numerical model MISCAM extended to account for vegetation effects
- Numerical simulations reproduce significant speed reduction within crown as well as local acceleration near trunk
- Quantitative agreement unsatisfactory
- Influence of neighboring trees as well as traffic induced turbulence neglected!

Future work

- More measurements required
- Comparison of computed and observed turbulence quantities (in progress)
- Dispersal simulations, including dry deposition on leaf surfaces
- A lot more . . .