TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät für Maschinenwesen, Institut für Strömungsmechanik

LES von Strömungen in inhomogenen Wäldern mit Hilfe hochauflösender terrestrischer Laserscans

Fabian Schlegel und Jörg Stiller

MetStröm Workshop, Tharandt 2010

Dresden, 10.09.2010

Outline

1. Introduction
   - Chair of Fluid Dynamics
   - DFG SPP 1276 MetStröm

Outline

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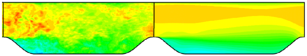
Chair of Fluid Dynamics

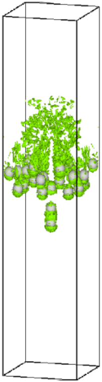
Professor: Dr.-Ing. habil. Jochen Fröhlich

Research topics:

- Turbulent flows (LES, DNS)
- Statistical and hybrid turbulence modelling
- Multiphase flows
- Reactive flows
- Magnetohydrodynamics
- Flows with cavitation
- Optimization



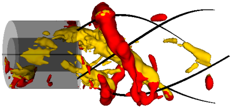
Hybrid LES-RANS modelling



Sedimentation of particles

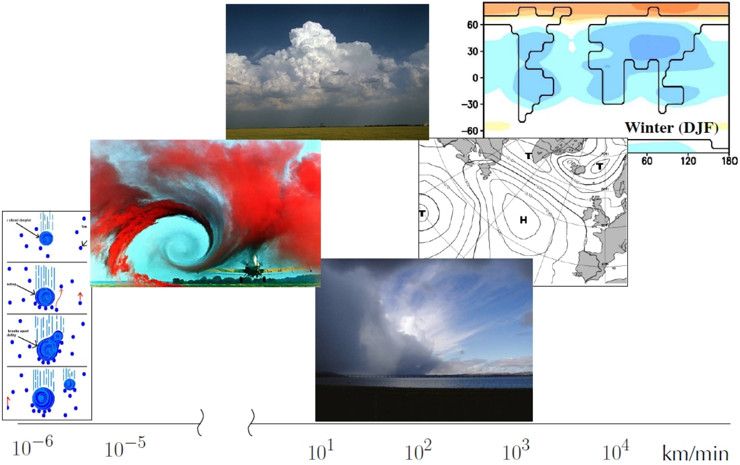
Ressources:

- CFD-Codes: LESOCC2, PRIME, Semtex, OpenFoam and commercial software
- Workstations, clusters, access to High Performance Computing
- Various water channels equipped with laser measurement systems



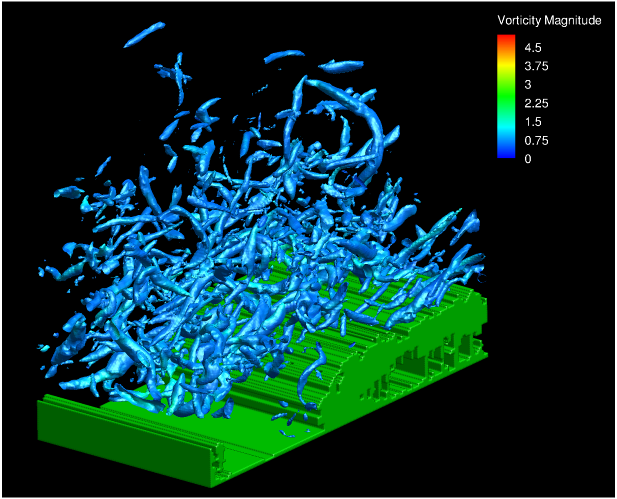
Swirling flow

DFG SPP 1276 MetStröm



T. von Larcher and R. Klein, EULAG Workshop 2008

Numerical Method



SGS-Model

Filtered Navier-Stokes-Equation (FNSE) with vegetation:

$$\partial_t \bar{u}_i + \partial_{x_j} \left(\bar{u}_i \bar{u}_j \right) + \partial_{x_i} \bar{p} = \partial_{x_j} \nu \bar{S}_{ij} - \partial_{x_j} \tau_{ij} + F_i$$

with:

$$F_i = -c_d a \sqrt{\bar{u}_i^{\,2}}\, \bar{u}_i = -\frac{\bar{u}_i}{\tau}$$

Transport equation for unresolved turbulent kinetic energy (TKE):

$$\partial_t K_\tau + \partial_{x_j} \left(\bar{u}_j K_\tau \right) - \partial_{x_j} \left(2\nu_\tau \partial_{x_j} K_\tau \right) = \frac{4}{5} \frac{\left(1 - c_{GM}\right)}{c_{Rm} c_{3m}} \nu_\tau \bar{S}_{ij} \bar{S}_{ij} - \frac{c_{\epsilon m}}{\Delta} K_\tau^{\frac{3}{2}} - \frac{2K_\tau}{\tau}$$

with:

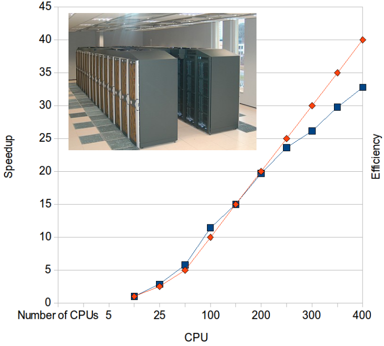
$$\nu_\tau = \frac{5}{6} c_{3m} \Delta \sqrt{K_\tau}$$

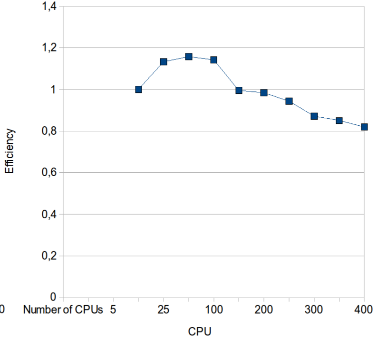
[R. Shaw and U. Schumann, Boundary-Layer Meteorology **61**: 47-64, 1992]

Solver

- OpenFOAM® C++ libraries (Version 1.6)
- Finite Volume Method
- Scheme of 2nd order accuracy in space
- 2nd order Euler backward scheme in time
- Pressure-implicit splitting operator algorithm (PISO) for pressure-velocity coupling
- Unstructured, nonorthogonal, hexahedral mesh

Solver

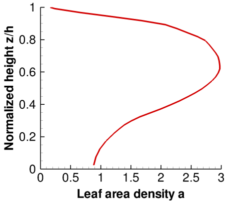




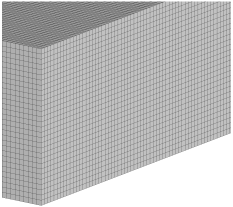
Performance test with OpenFOAM® 1.6 on SGI Altix 4700
→ Mesh with 2 mil. cells on 200 CPUs has an efficiency of 99%

Validation with Homogeneous Forest

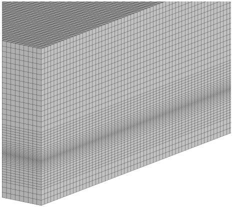
- Domain dimensions: 192 m x 96 m x 60 m
- 20 m tall forest with a bulk velocity of 2 m/s
- BC: free slip at top, no slip at bottom, periodic for both lateral directions
- 10,000 s for startup and 10,000 s for averaging



Leaf area density for LAI = 2

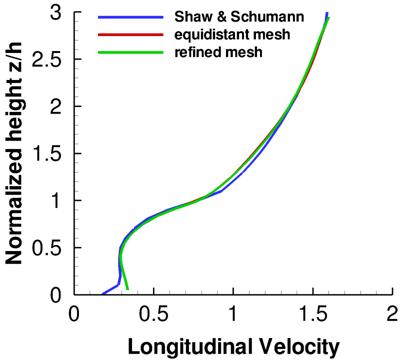


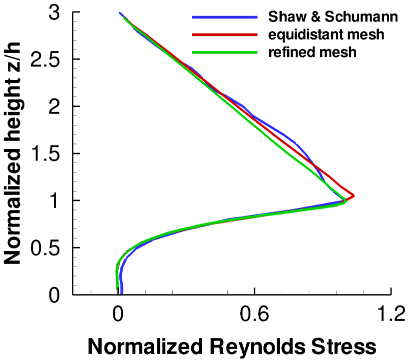
equidistant mesh with $\Delta = 2\,\text{m}$



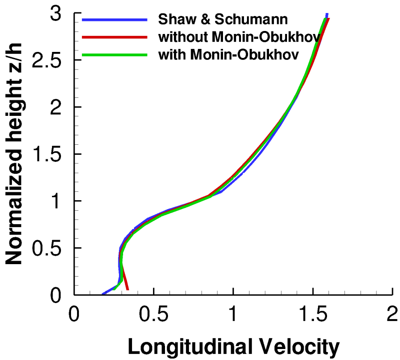
refined mesh within the crown section with $\Delta_{\text{min}} = 0.28\,\text{m}$

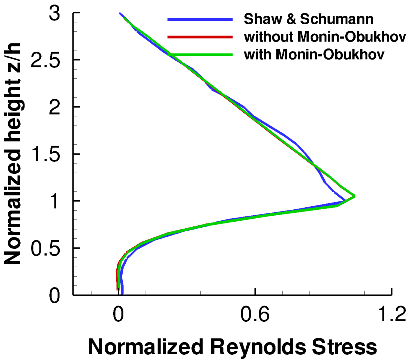
Validation with Homogeneous Forest





Validation with Homogeneous Forest



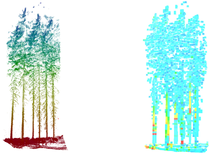


[H. Schmidt and U. Schumann, Journal of Fluid Mechanics **200**: 511-562, 1989]

Determination of Leaf Area Density

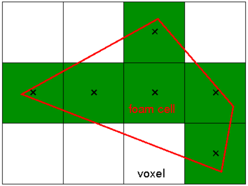
Terrestrial laser scanning

point cloud resulting from terrestrial laser scans

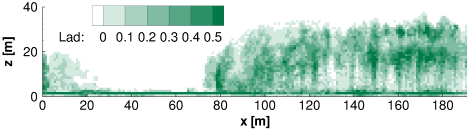


Point cloud (left) and corresponding voxel representation (right)

Numerical simulation



Averaging of voxel for hexahedral foam mesh



Leaf area density (averaged over 30 m width in y-direction)

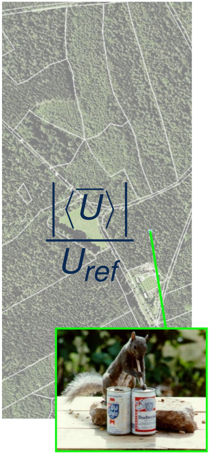
Simulations for “Wildacker”
Setup

Name	Domain size	PAD	Spacing
Simulation C	$191 \times 96 \times 175\,\mathrm{m}$	$a(z)$	$\Delta = 1\,\mathrm{m}$
Simulation D	$191 \times 96 \times 175\,\mathrm{m}$	$a(x,z)$	$\Delta = 1\,\mathrm{m}$
Simulation E	$191 \times 96 \times 175\,\mathrm{m}$	$a(x,z)$	$\Delta \approx 2\,\mathrm{m}$
Simulation F	$760 \times 380 \times 210\,\mathrm{m}$	$a(z)$	$\Delta_{min} = 2\,\mathrm{m}$
Simulation G	$760 \times 380 \times 210\,\mathrm{m}$	$a(x,z)$	$\Delta_{min} = 2\,\mathrm{m}$
Simulation H[1]	$760 \times 380 \times 210\,\mathrm{m}$	$a(z)$	$\Delta_{min} = 2\,\mathrm{m}$

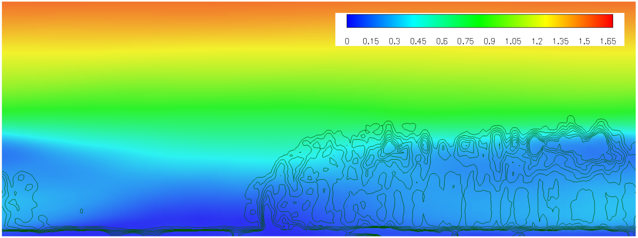
- BC: free slip at top, no slip at bottom, periodic for both lateral directions
- Logarithmic overlap law for rough walls at lower boundary
- Constant mass flux through the inflow boundary of 6 m/s

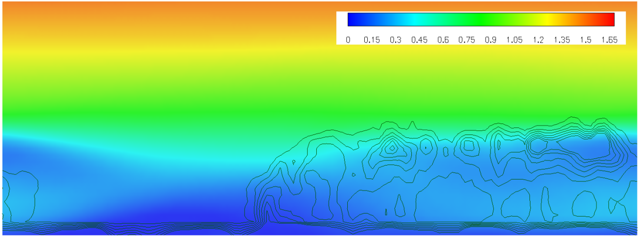
[1] reference case for homogenous forrest without a clearing

Simulations for “Wildacker”

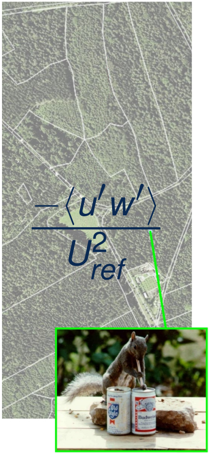


$$\frac{|\langle \overline{U} \rangle|}{U_{ref}}$$

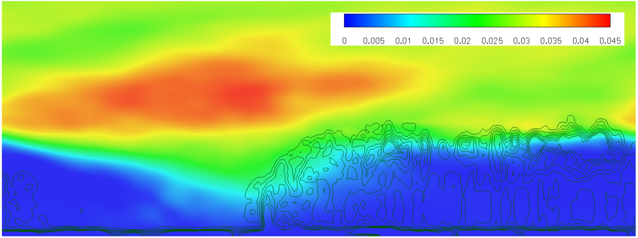


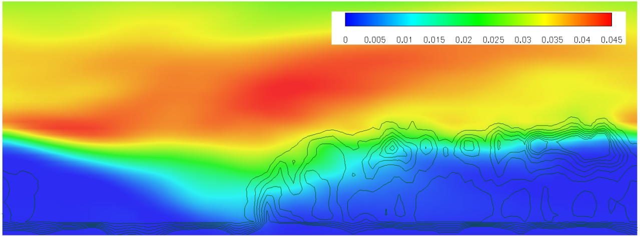


Simulations for “Wildacker”

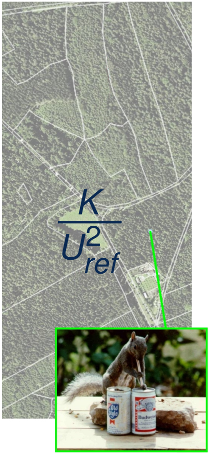


$$\frac{-\langle u' w' \rangle}{U_{ref}^2}$$

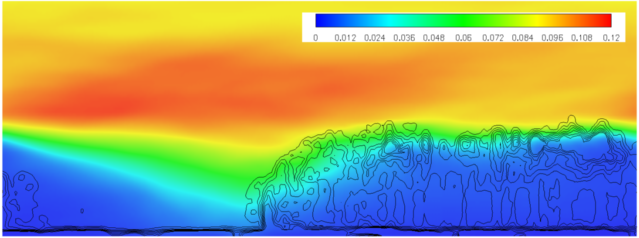


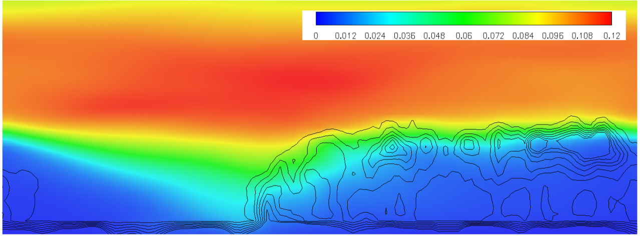


Simulations for “Wildacker”



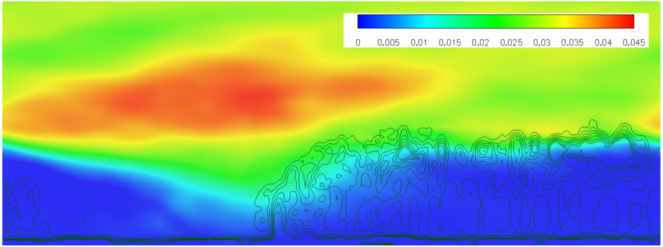
$$\frac{K}{U_{ref}^2}$$



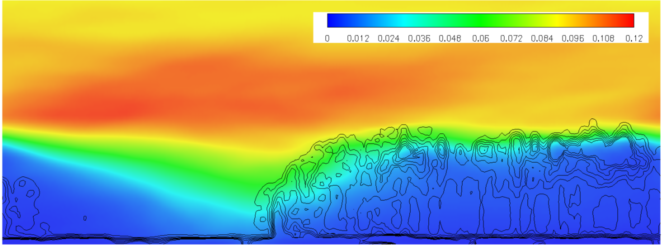


Simulations for “Wildacker”

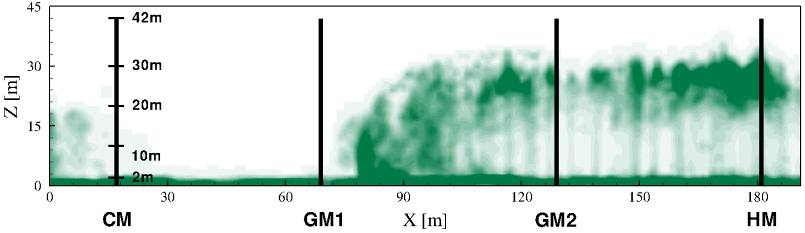
$$-\frac{\langle u' w' \rangle}{U_{ref}^2}$$



$$\frac{K}{U_{ref}^2}$$



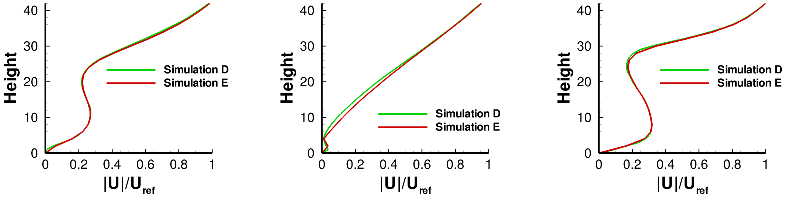
Simulations for “Wildacker”



- Clark tower (CM) bei x = 17 m
- Scaffolding tower 1 (GM1) bei x = 69 m
- Scaffolding tower 2 (GM2) bei x = 129 m
- Permanent scaffolding tower (HM) bei x = 181 m

Simulations for “Wildacker”

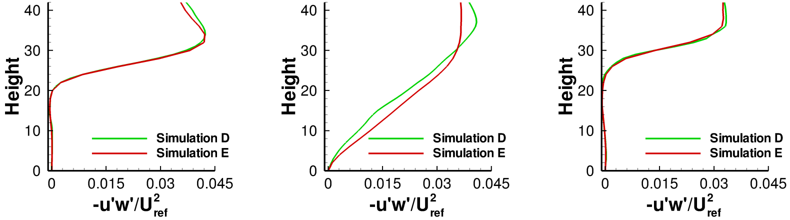
Profiles of normalized mean velocity $\left|\langle\overline{U}\rangle\right| / U_{ref}$ for CM, GM1 and HM:



- CM and HM shows typical velocity profile for forrested areas
- Clearing visible in velocity profile for GM1
- Resolution has no significant effect on mean flow

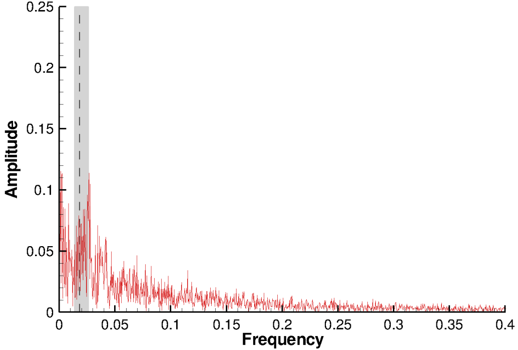
Simulations for “Wildacker”

Profiles of normalized Reynolds stress $-\langle u' w' \rangle / U_{ref}^2$ for CM, GM1 and HM:



- CM and HM shows typical velocity profile for forrested areas
- Within the forrest nearly no turbulent flux compared to the profile over the clearing (GM1)
- Resolution may effects the profile right infront of the forrest edge

Simulations for “Wildacker”

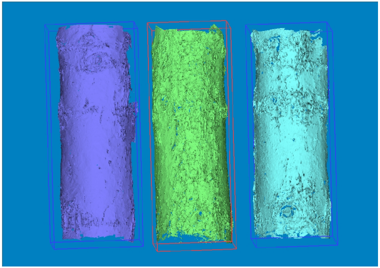


Frequency spectra for HM at 42 m height

- Characteristic peaks at high wavelength, especially for domain length
- Spectra for all tower positions at 2, 10, 20, 30, 40 m height available
- Still work in progress

Outlook

- Extension to 3D leaf area density
- Comparison with boundary layer model
- Improvement of subgrid-scale model by investigation of vegetation details



Idea of rough cylinder represented by point cloud for LES
Pictures by A. Bienert

SAVE A TREE

Eat a beaver.