OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

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FAKULTÄT FÜR VERFAHRENS- UND SYSTEMTECHNIK

DFG Deutsche Forschungsgemeinschaft

MetStröm

# Experimental investigation of two-phase flows representing cumulus cloud conditions

R. Bordás, E. Schmeyer, V. John and D. Thévenin

MetStröm Conference, 06/07/2011

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- Experiments
  - Setup
  - Methods
  - Results
- Online database
- Experiments ⇔ simulations
- Conclusions

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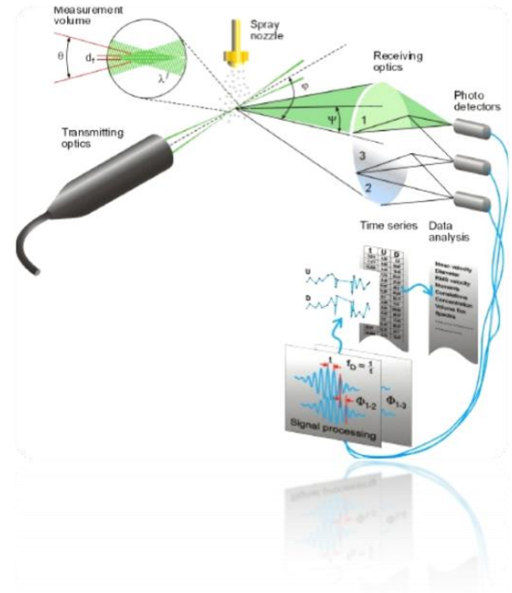
Measurement volume
Spray nozzle
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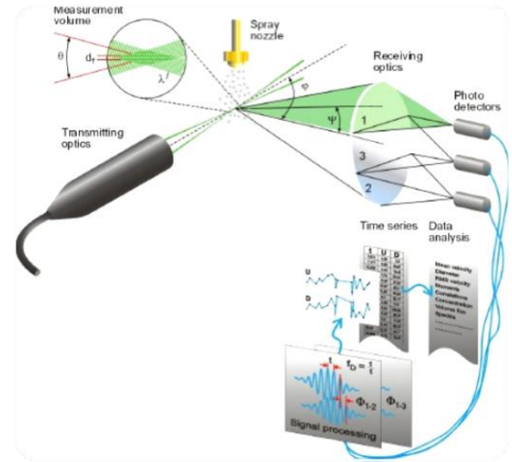


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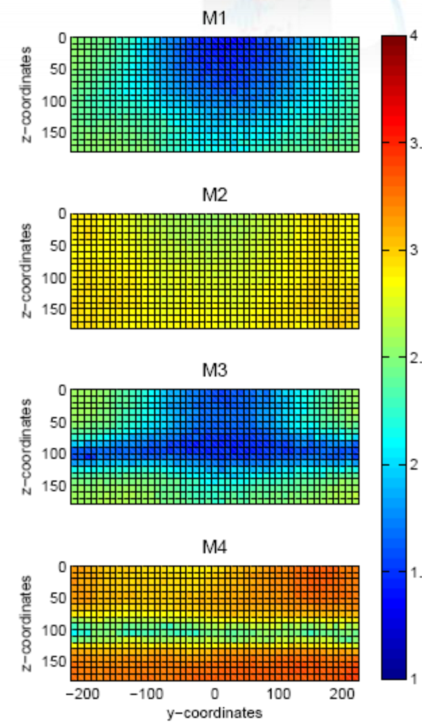

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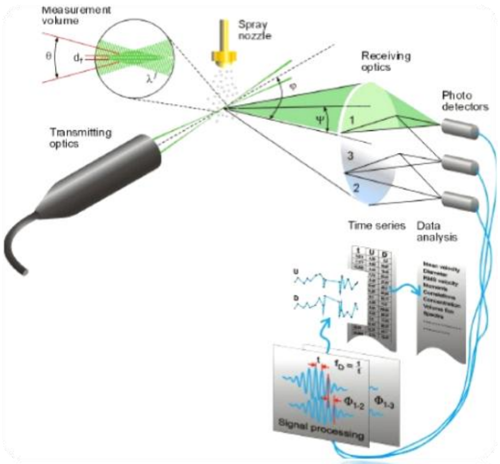


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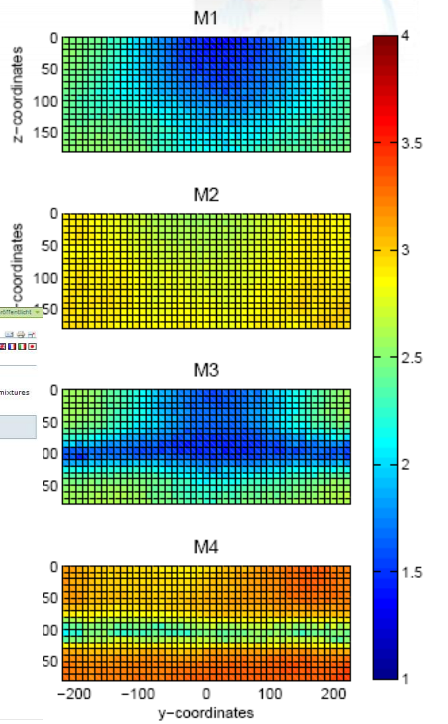

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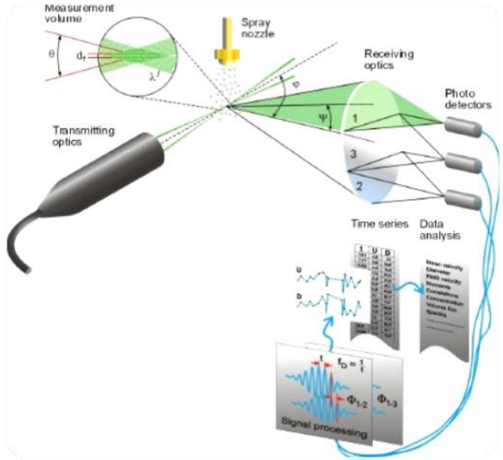


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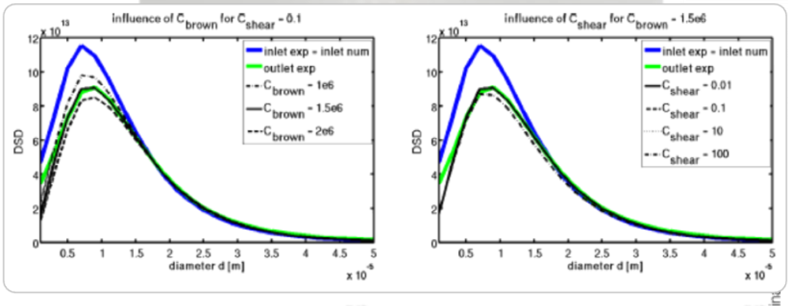
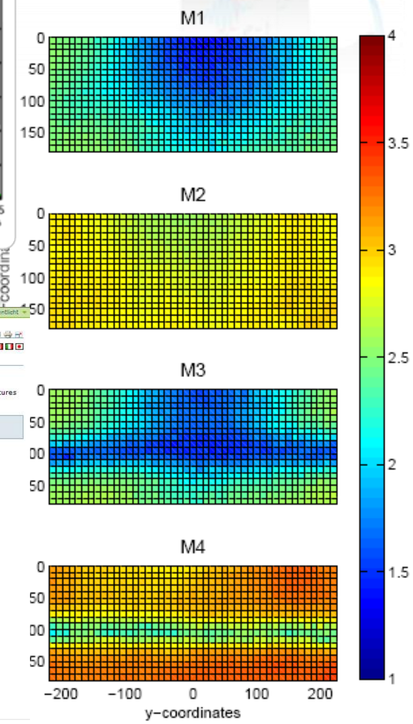
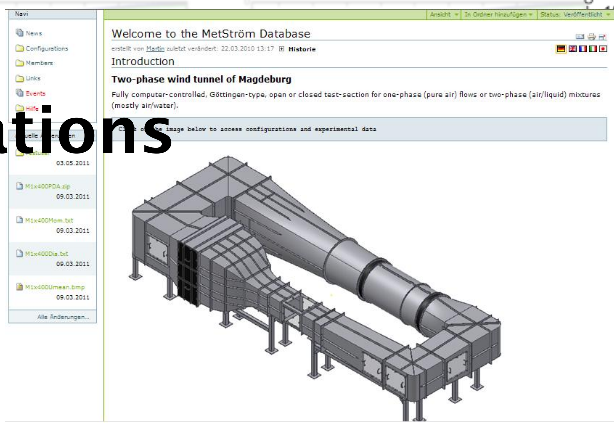



- Online database
- **Experiments ⇔ simulations**

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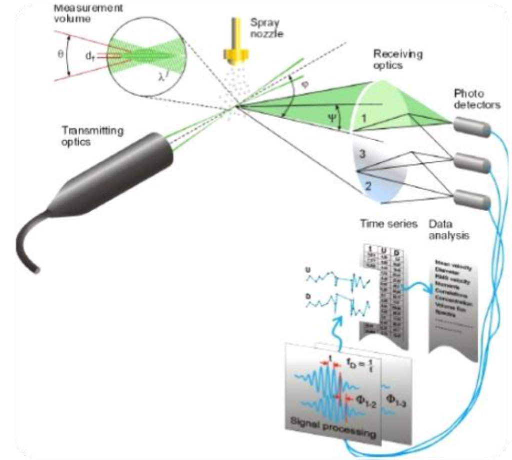


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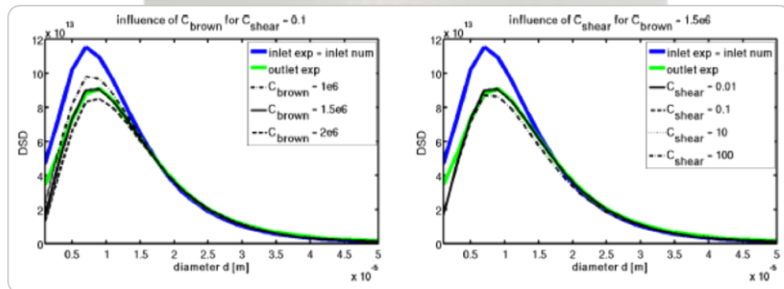
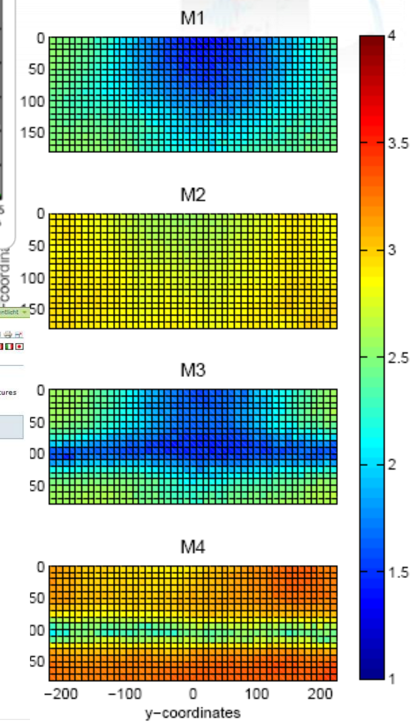


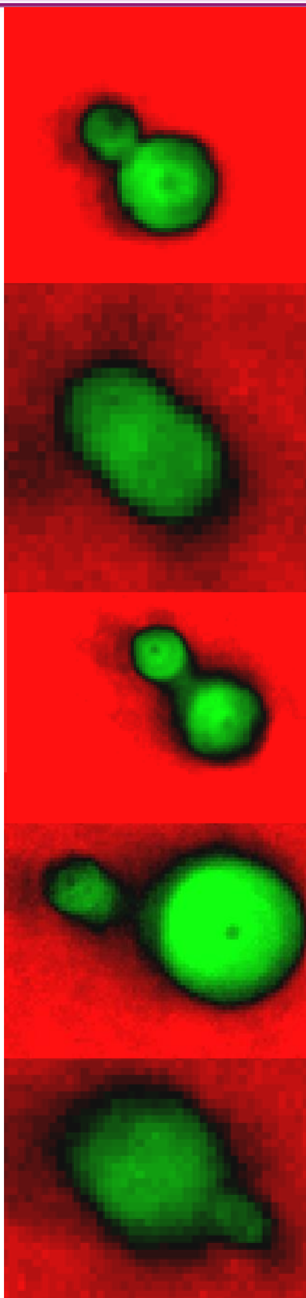




- Online database


- Experiments ⇔ simulations
- **Conclusions**

# Motivation

- Poor reliability of **precipitation forecasting**
  - In particular warm rain initiation is a mystery
- Collision–induced growth in turbulent flows
  - Theory ⇔ observations: a factor of 2 or more



# Motivation

- Poor reliability of **precipitation forecasting**
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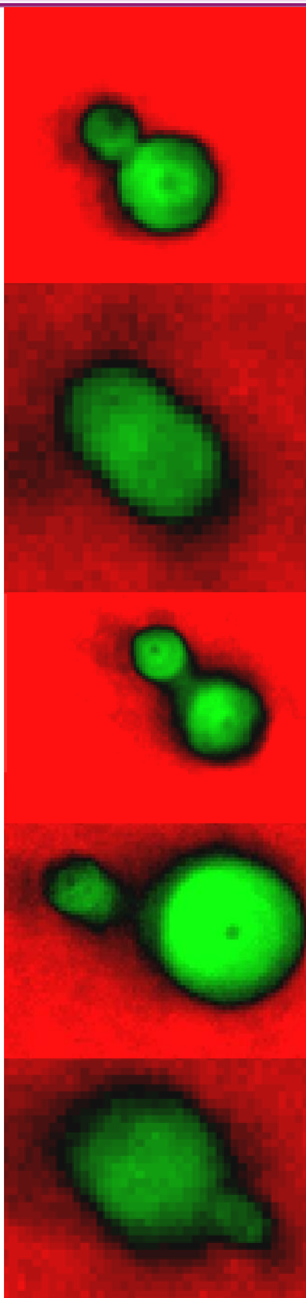
  - Theory ⇔ observations: a factor of 2 or more

↓

- Experiments in wind tunnels are essential
  - Non–intrusive measurements
  - Experimental characterization of both phases
  - Droplet–droplet interactions
  - Freely available database
- Quantifications of droplet collision rates
  - Comparison with theoretical predictions



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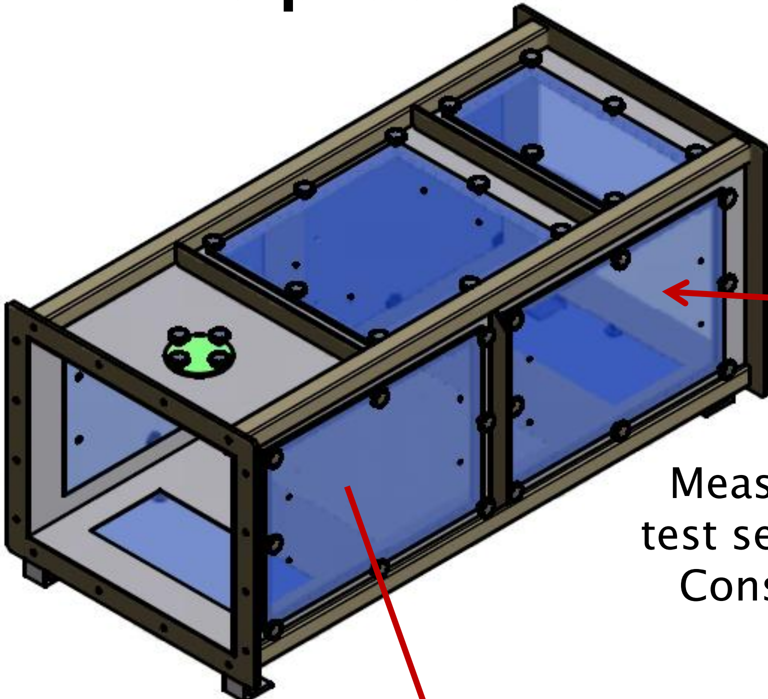
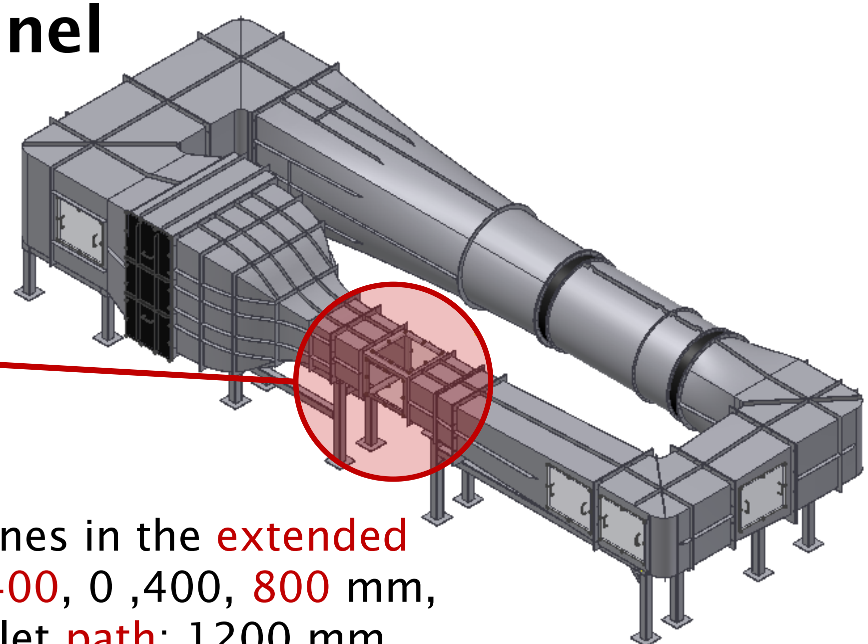
# Two-phase flow in wind tunnel

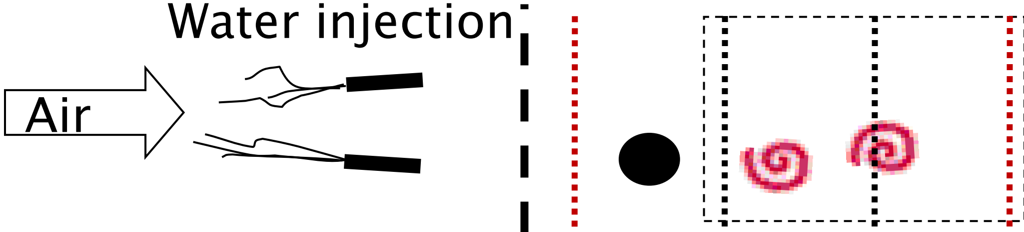




Measurement planes in the extended test section: $x$ =−400, 0 ,400, 800 mm,
Considered droplet path: 1200 mm,
Observation time: ~ 0.5 s

Grid to generate controlled turbulence

Water injection

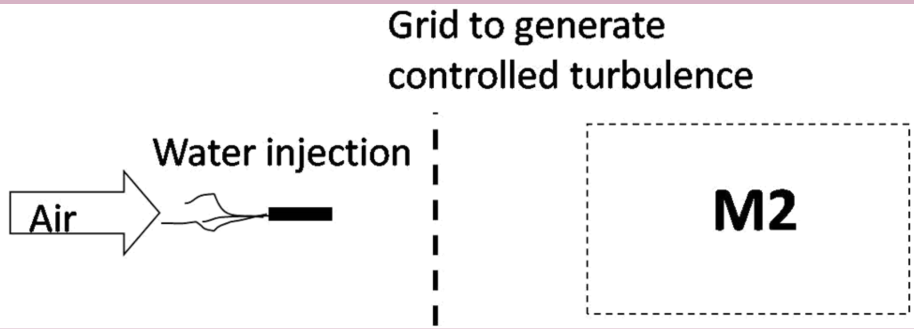



Vortex generation

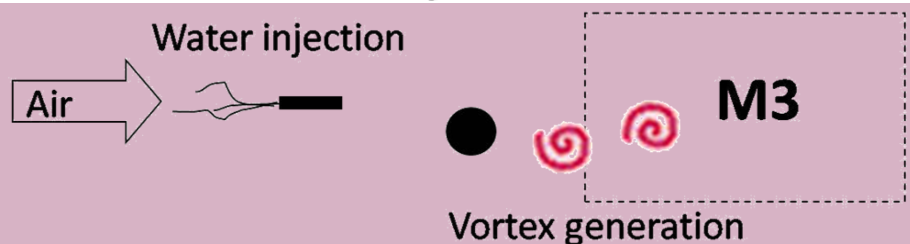
| | clouds | wind tunnel |
|---|---|---|
| Humidity | Saturated | Saturated |
| $U$ [m/s] | ~ a few m/s | ~ 2.5…3.0 |
| LWC [g/m³] | ~ 0.1–3.5 | ~ 2 |
| $d_{10}$ [µm] | 10–20 | 8.5…12.5 |
| $n$ [#/cm³] | up to 7000 | ~ 2000 |

# Configurations M1-M4

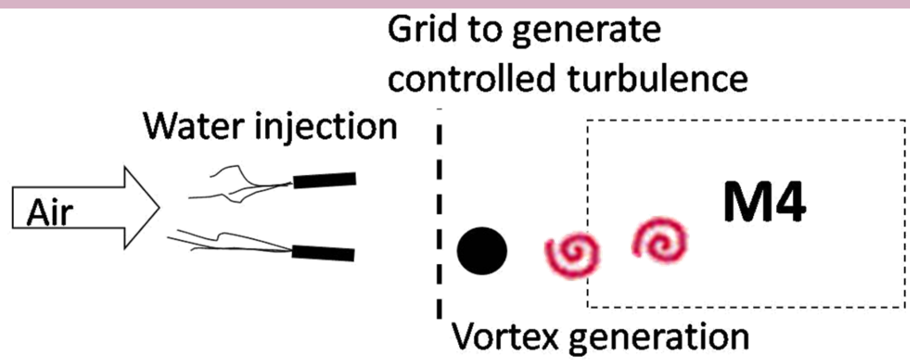

Basic configuration w/o flow structure modification




Grid to homogenize turbulence

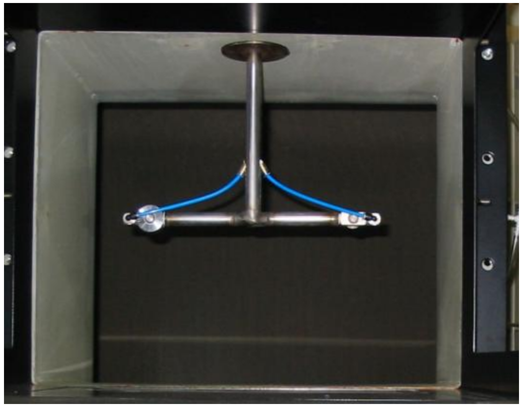


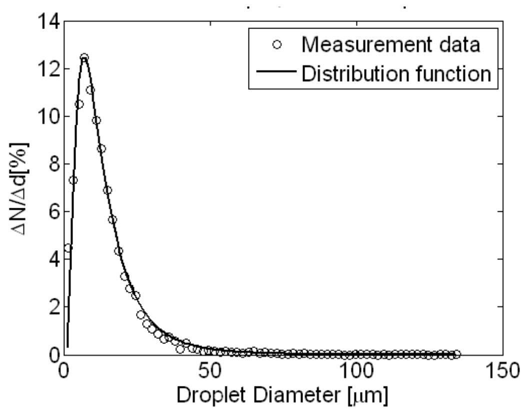

Bluff-body to generate larger coherent vortices




Double-injection configuration with different diameters and enhanced collisions

# Droplet injection





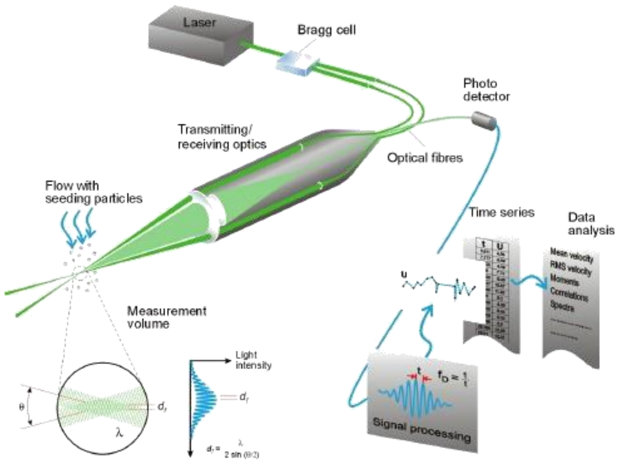

- Counter-flow direction
- Droplet distribution, measured by means of PDA
- Lognormal probability density function (PDF)

$$y = f(x|\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\frac{(-\ln(x)-\mu)^2}{2\sigma^2}}$$

- Since narrow distribution, characteristic diameters are applicable:
  - Mean diameter $d_{10} = 13.46\mu m$
  - Volume mean diameter $d_{30}=23.83\ \mu m$

# Experimental methods

| Measurement method | Measured phase | Measured quantity | Derived quantity |
|---|---|---|---|
| LDV | air | $u, u'$ | $Tu$, $TKE$ |
| PDA | drops | $u, u', d$ | $DSD, n_d, u_{rel}$ |
| PIV | air and drops | $u, v, w$ | $\varepsilon \rightarrow \eta, \tau_k$ |
| Shadowgraphy | drops | $u, w, d$ | collisions |



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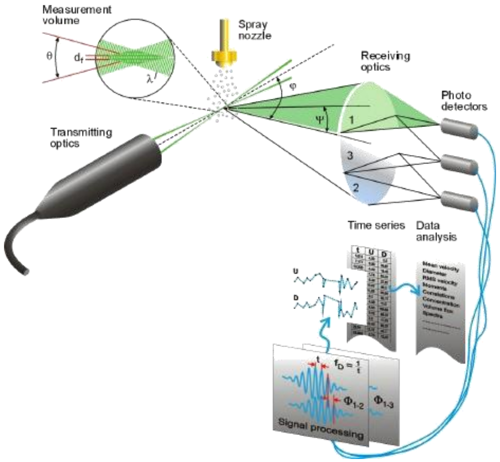

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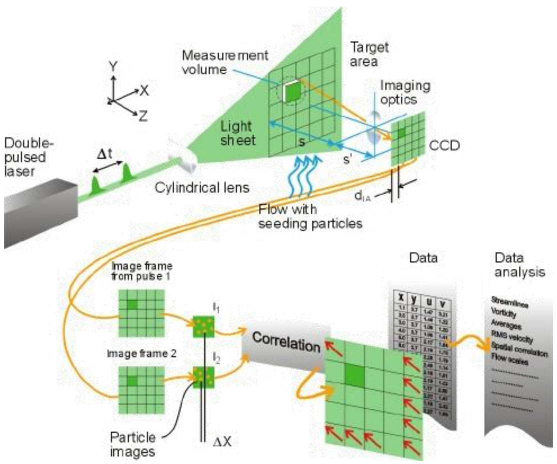

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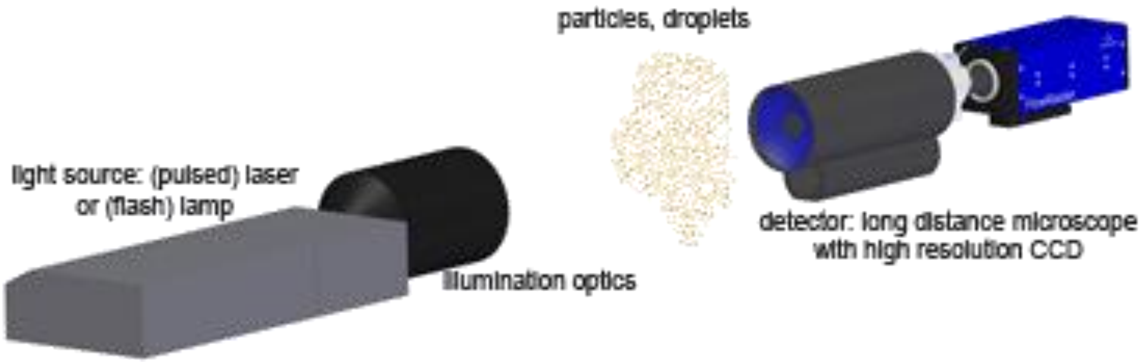
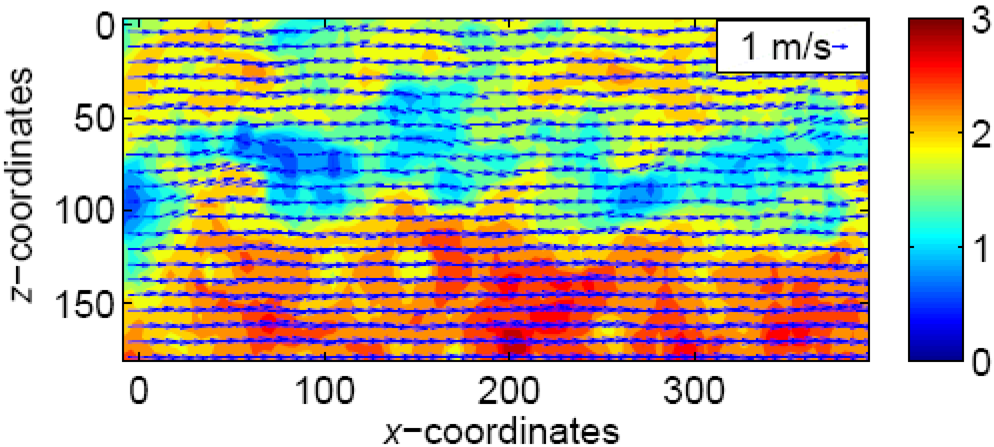


# PIV measurements

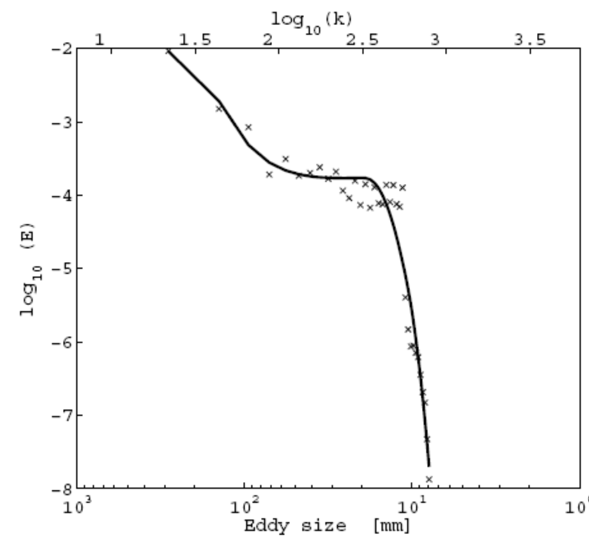
Velocity information at $y=0$, applied for the calculation of

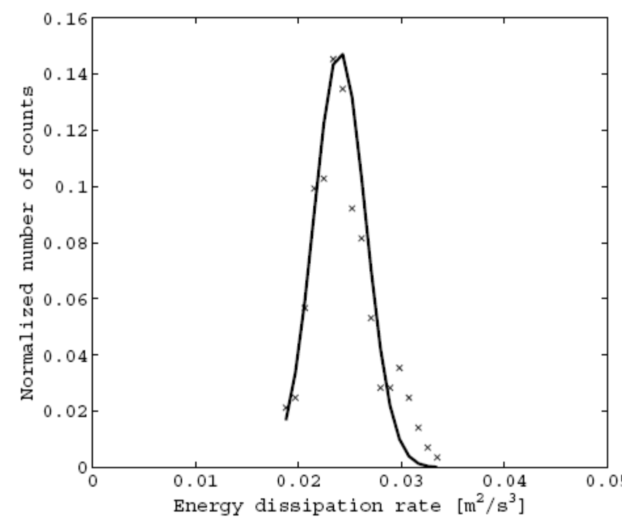
- turbulent energy spectrum and
- dissipation rate

E.g., for configuration M3:




$$\varepsilon = \nu \overline{\frac{\partial v}{\partial x}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)}$$



# Measured mean values of different configurations

| | M1 | M2 (grid) | M3 (cyl.) | M4 | Cumulus clouds |
|---|---|---|---|---|---|
| $U$ [m/s] | 2.45 | 2.93 | 2.32 | 2.92 | 1…8 |
| $u'$ [m/s] | 0.25 | 0.18 | 0.33 | 0.35 | 0.8 |
| $k$ [m²/s²] | 0.11 | 0.05 | 0.18 | 0.22 | 1 |
| $d_{10}$ [μm] | 12.61 | 11.68 | 12.44 | 8.6 | 10…20 |
| $\varepsilon$ [m²/s³] | 0.025 | 0.012 | 0.026 | 0.055 | 0.001…0.1 |
| $\tau_k$ [s] | 2.5e-2 | 3.5e-2 | 2.4e-2 | 1.7e-2 | 1e-2 |
| $\eta$ [m] | 6.2e-4 | 7.4e-4 | 6.1e-4 | 5.1e-4 | 1e-3 |
| $\lambda_g$ | 1.1e-2 | 5.6e-3 | 4.9e-3 | 9.3e-3 | 1e-1 |
| $Re_\lambda$ | 170 | 70 | 60 | 200 | 1e+5 |

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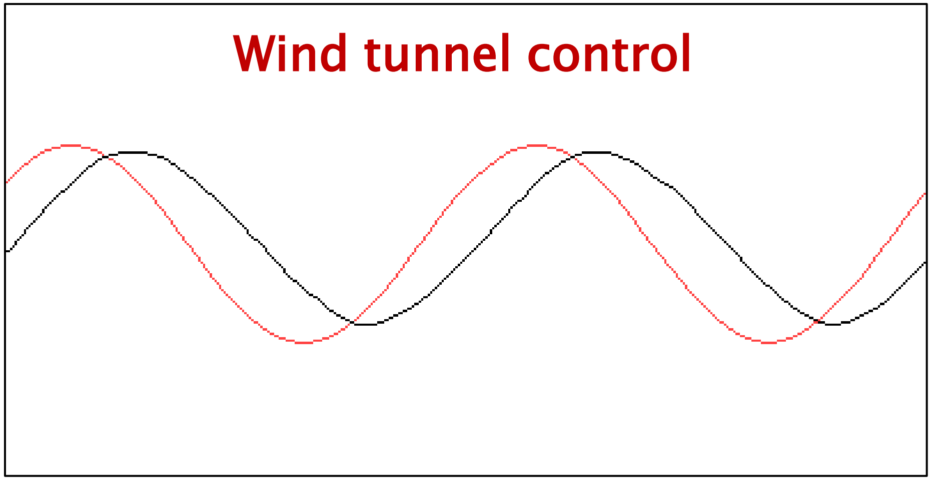
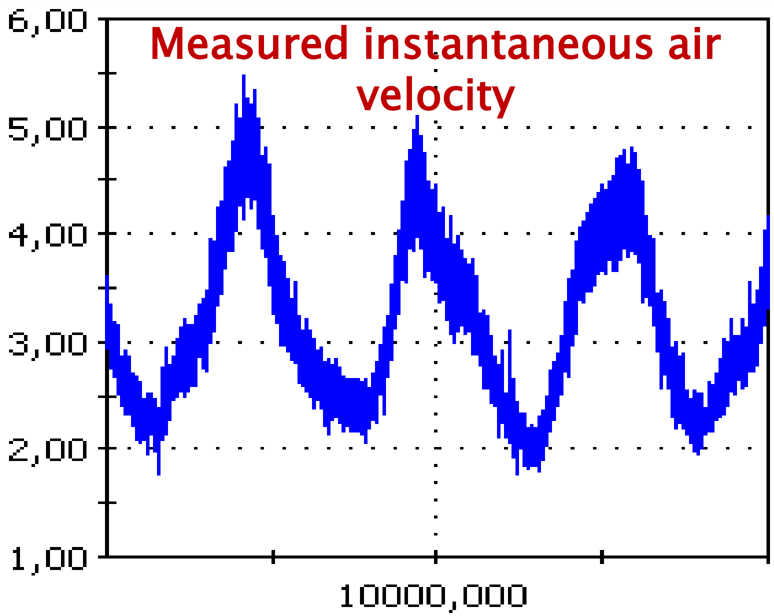
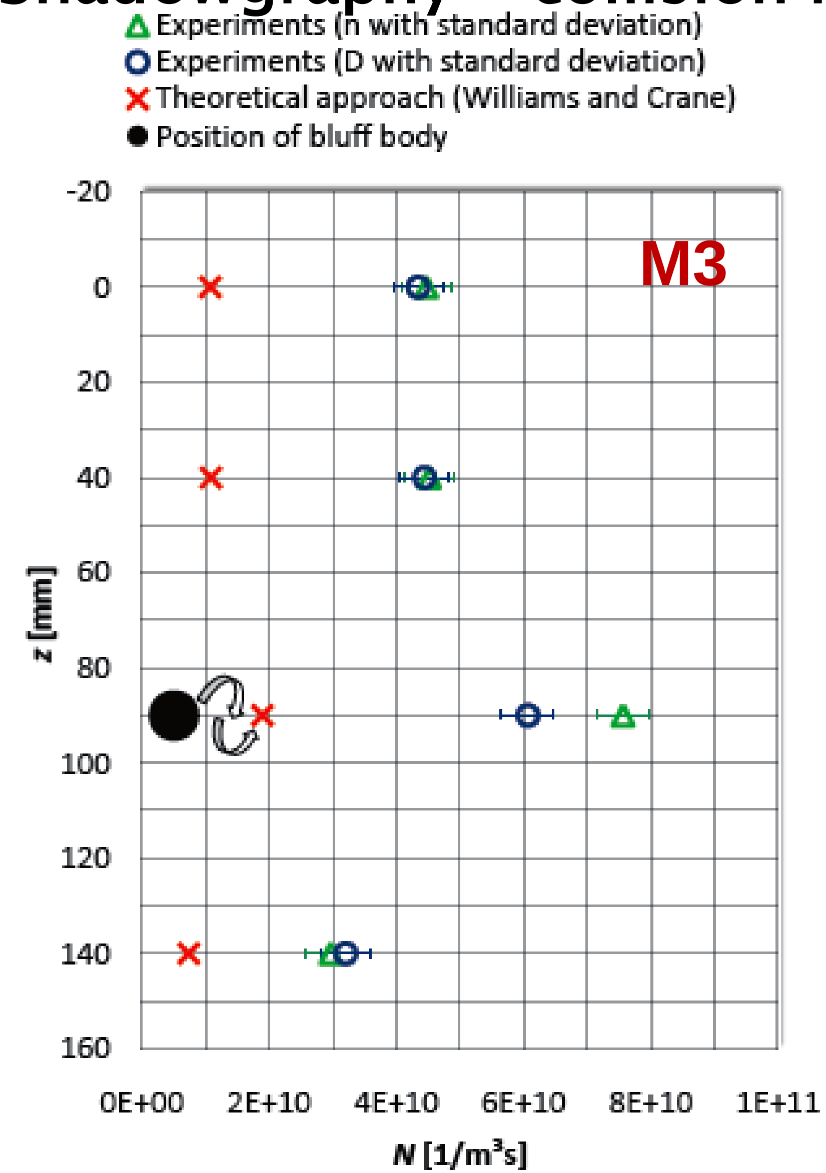
# Pulsating flow

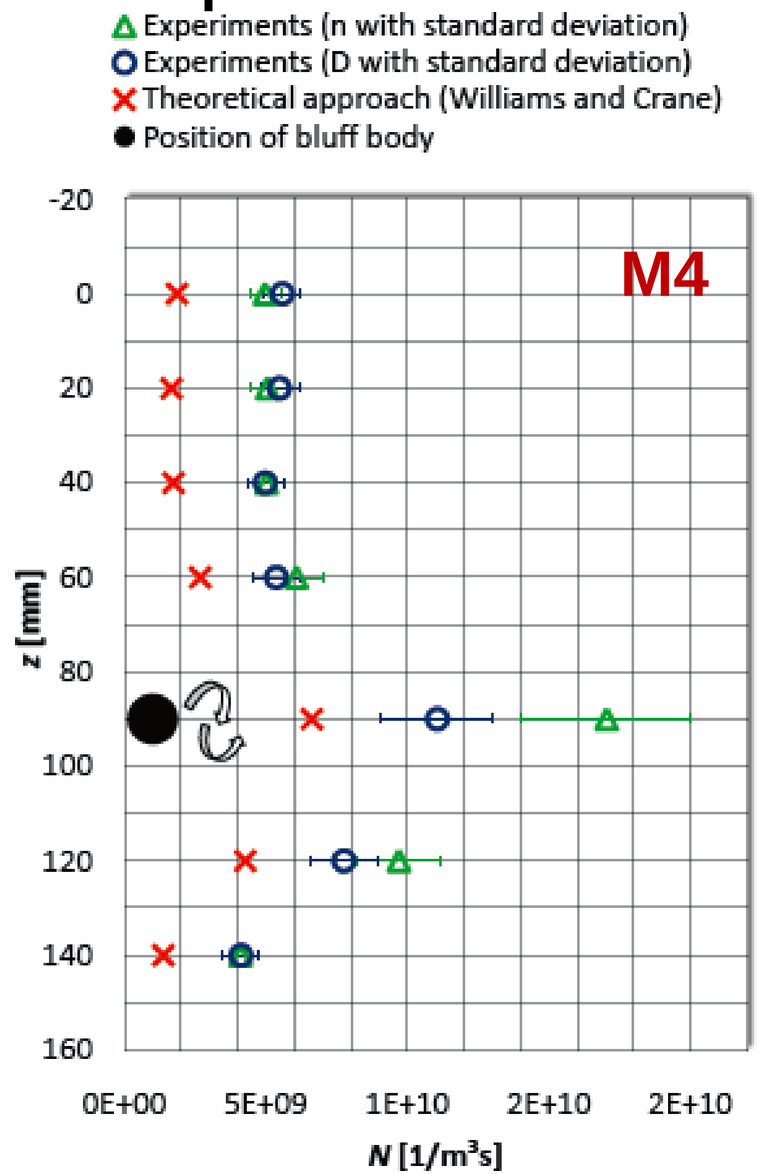



| Property | Cumulus clouds | Measured or derived by | Conf. M4 (x=0) | Pulsating flow (x=0) |
|---|---|---|---|---|
| $U$ [m/s] | 0…6 | LDV | 2.92 | 3.02 |
| Re | $10^6 \ldots 10^7$ | LDV | $10^5$ | $1.1\ 10^5$ |
| $u'$ [m/s] | 0.8 | LDV | 0.35 | 0.84 |
| $k$ [m²/s²] | 1 | LDV | 0.22 | 1.06 |
| $d_{10}$ [μm] | 10…20 | PDA | 8.5 | 9.2 |

# Shadowgraphy – collision rate: experiments vs. theory

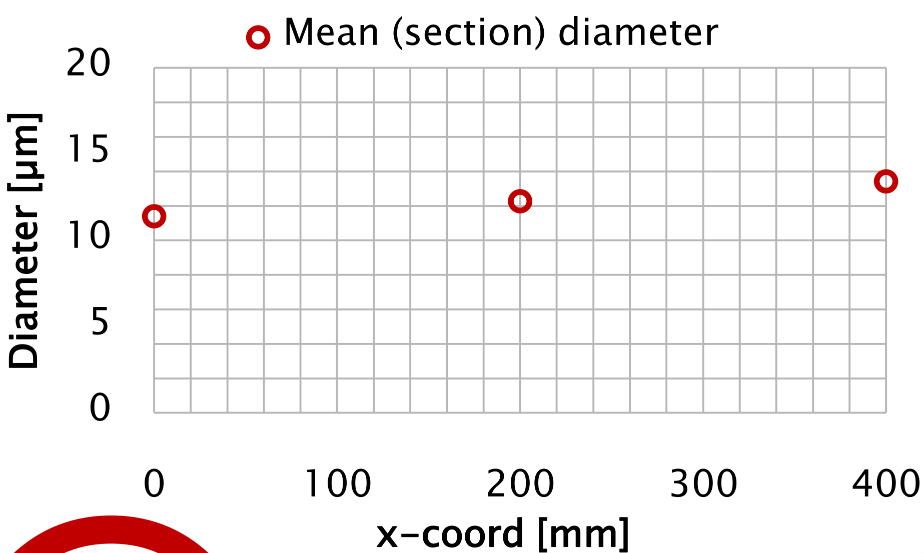



*Williams, J.J.E. and Crane, R.I. Particle collision rate in turbulent flow. *Int. J. Multiphase Flow, 1983.* ***9: p. 421.***

# Comparison (PDA ⇔ Shadowgraphy)

- Are the experimental results realistic?
- Growth rate measured by PDA ⇔ growth by droplet collision



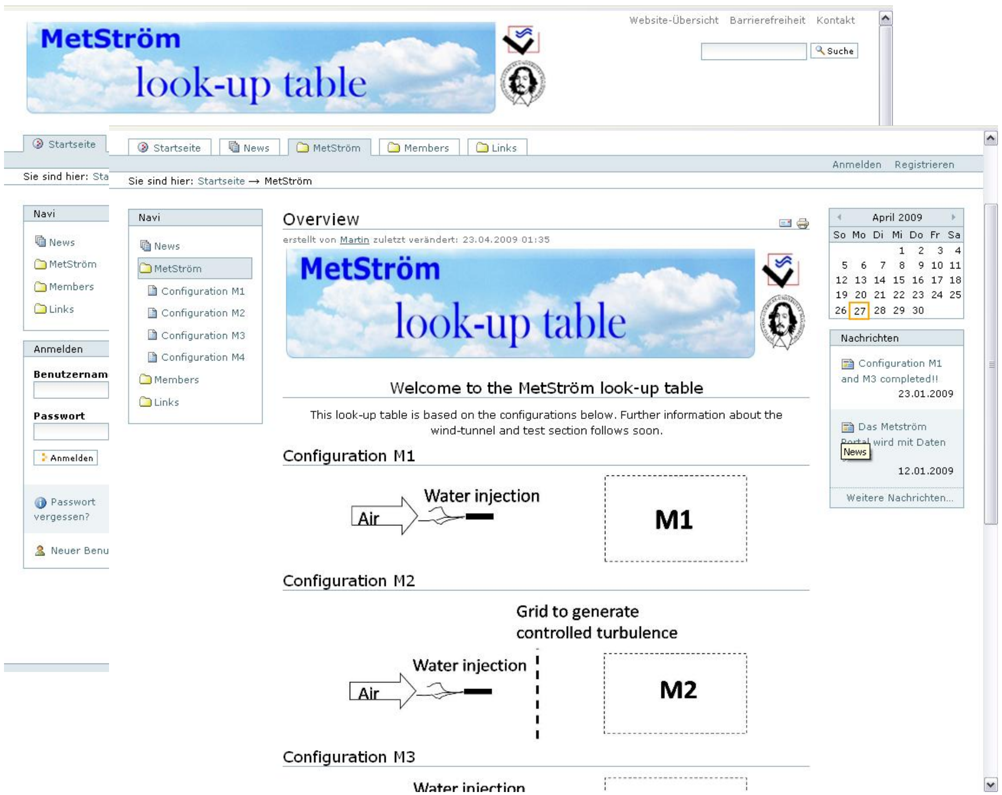

The measured 0.05% is considered here

| Property | Value |
|---|---|
| Increase in *d* [%] | 17.80 |
| Increase in *V* (PDA) [%] | 63.45 |
| Residence time [s] | 0.16 |
| **Collisions [1/cm³]** | **3810** |
| **Concentration [1/cm³]** | **5740** |
| Increase in *V* (Sha.) [%] | 66.37 |

# Online database – www.ovgu.de/isut/lss/metstroem


Continuously updated…

# Online database – www.ovgu.de/isut/lss/metstroem

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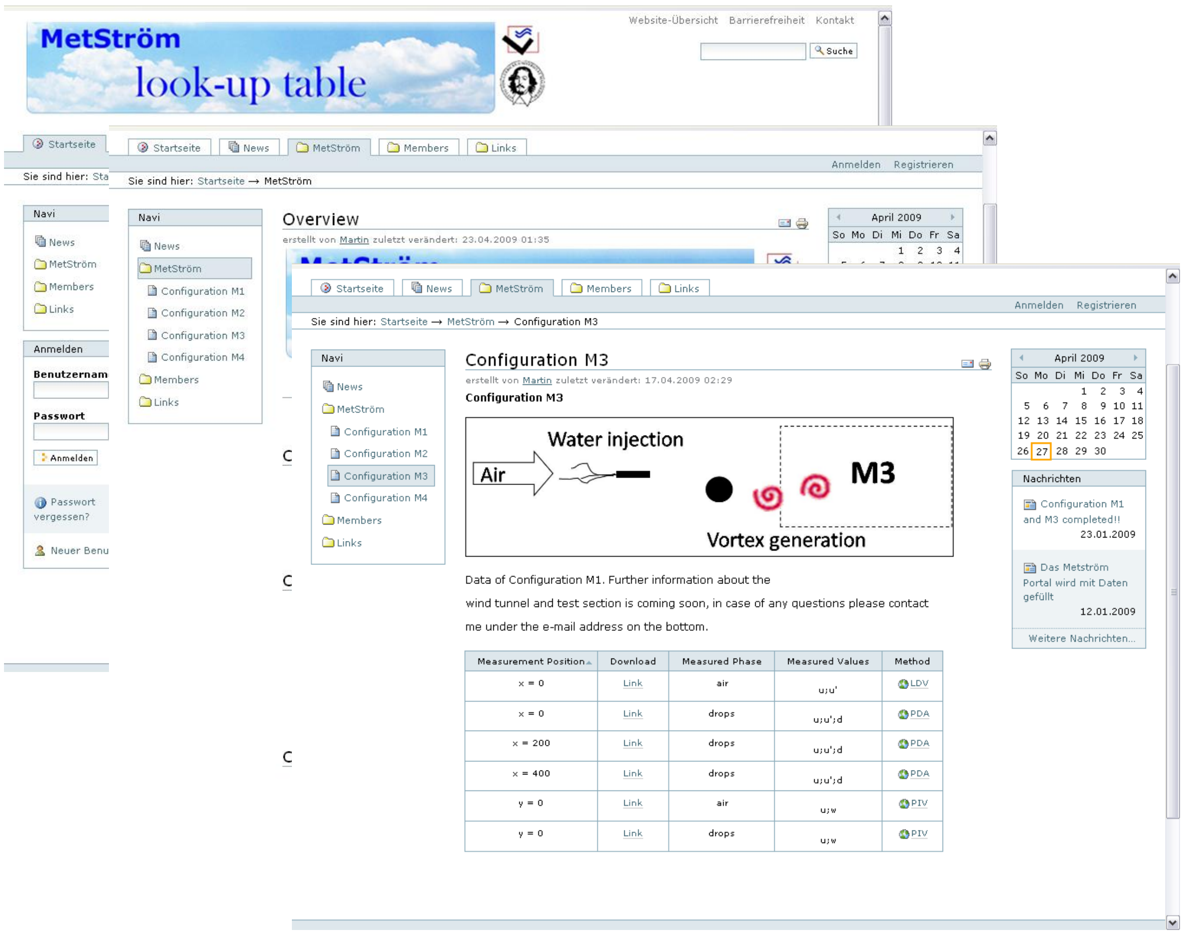


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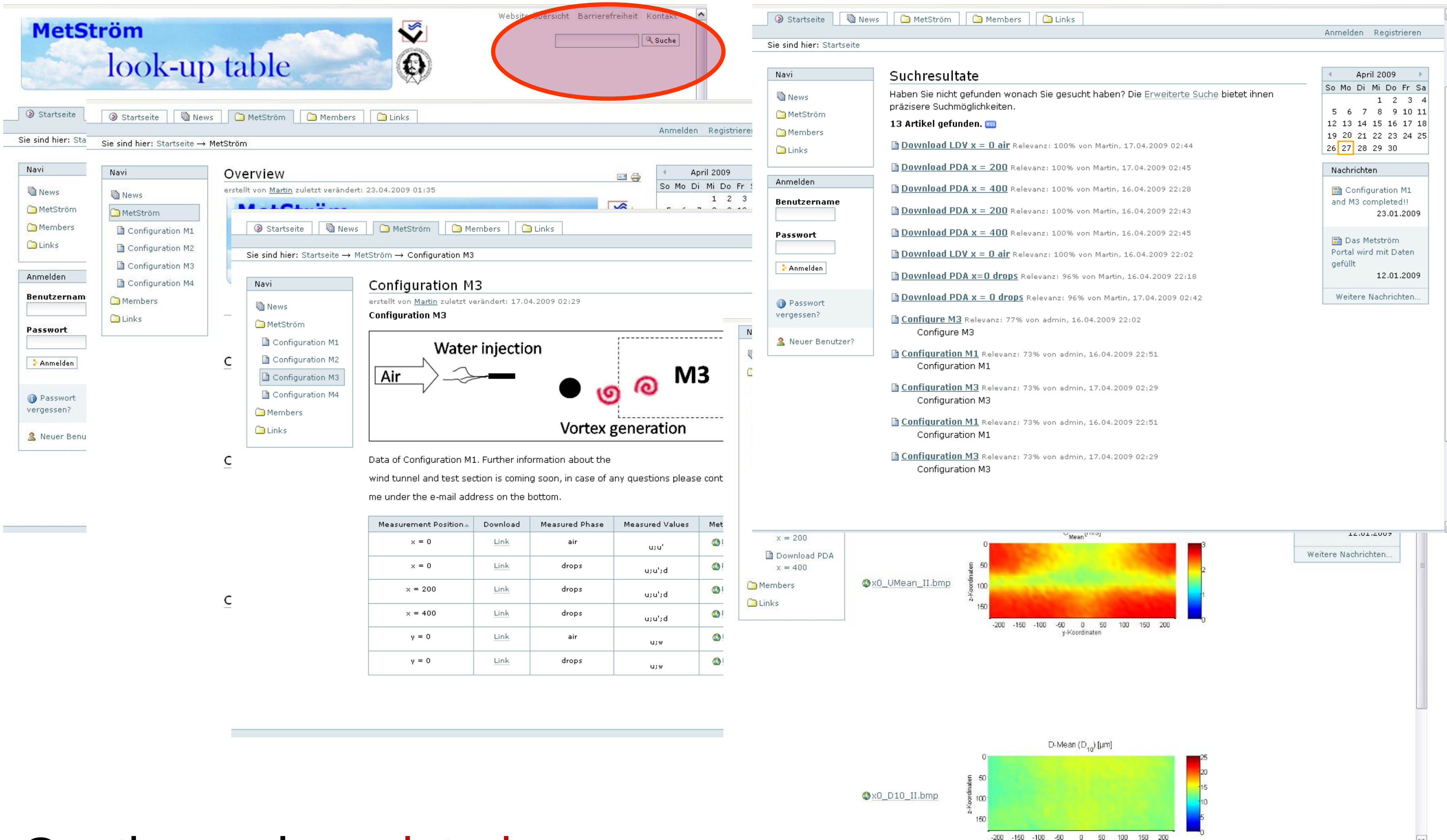


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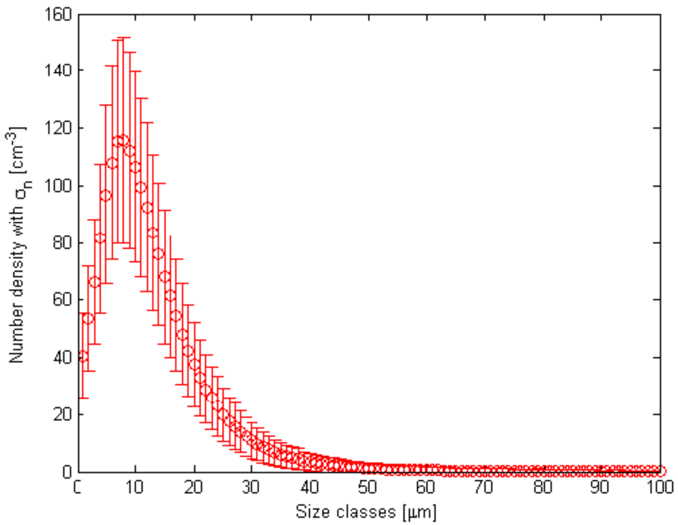
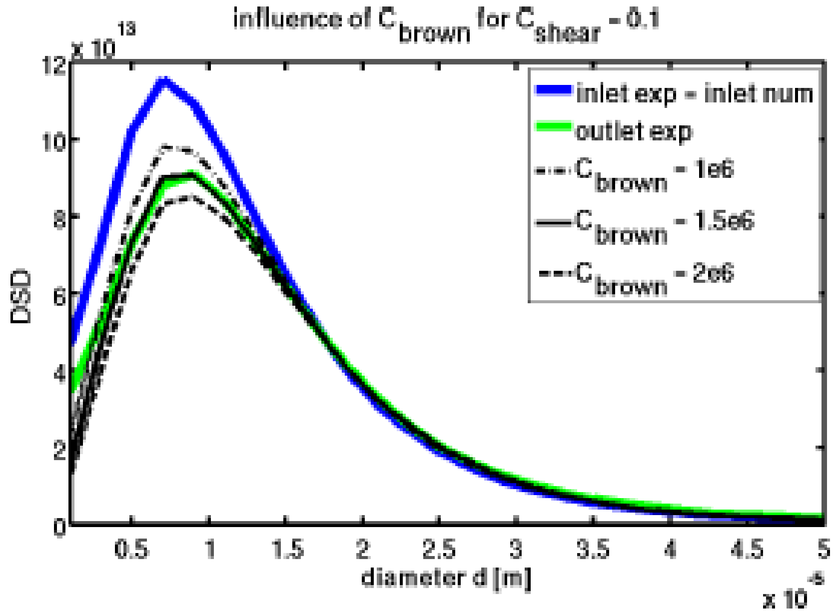
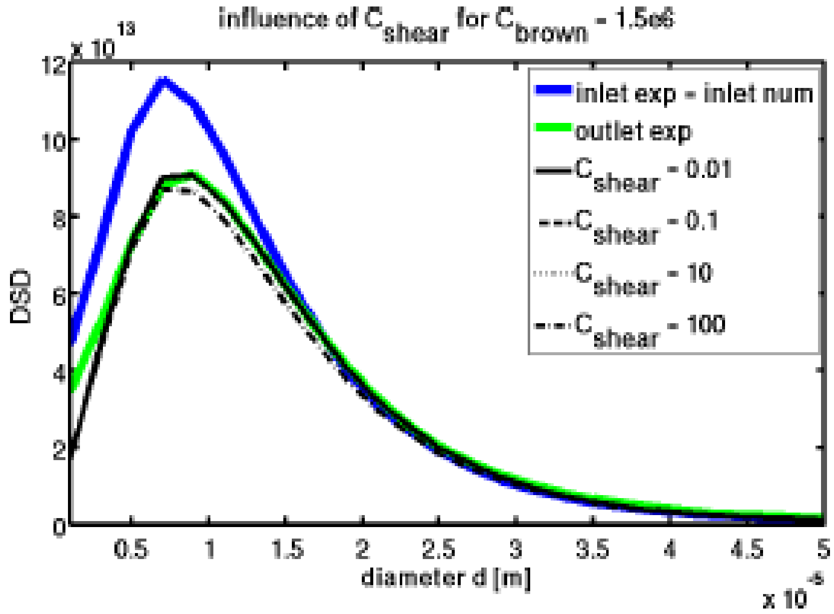
# Companion numerical simulations

Main interface between experiments and simulations: PDA measurements of droplet number density including standard deviation for each size class



# Conclusions

- Experiments in wind tunnel with key meteorological conditions
- Complete experimental characterization of the air flow and water spray
- Results freely available in a database accessible at http://www.ovgu.de/isut/lss/metstroem.
- Successful validation of companion simulations
- Experimental non-intrusive measurement of droplet collision rate
  - Comparison with theoretical predictions
  - **The measured collision rates are higher than predicted by theory, typically by a factor of 2 to 6.**

Thank you for your attention!

http://www.ovgu.de/isut/lss/metstroem
http://metstroem.mi.fu-berlin.de/

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