

Investigations of turbulence statistics in the laboratory model of an atmospheric cloud

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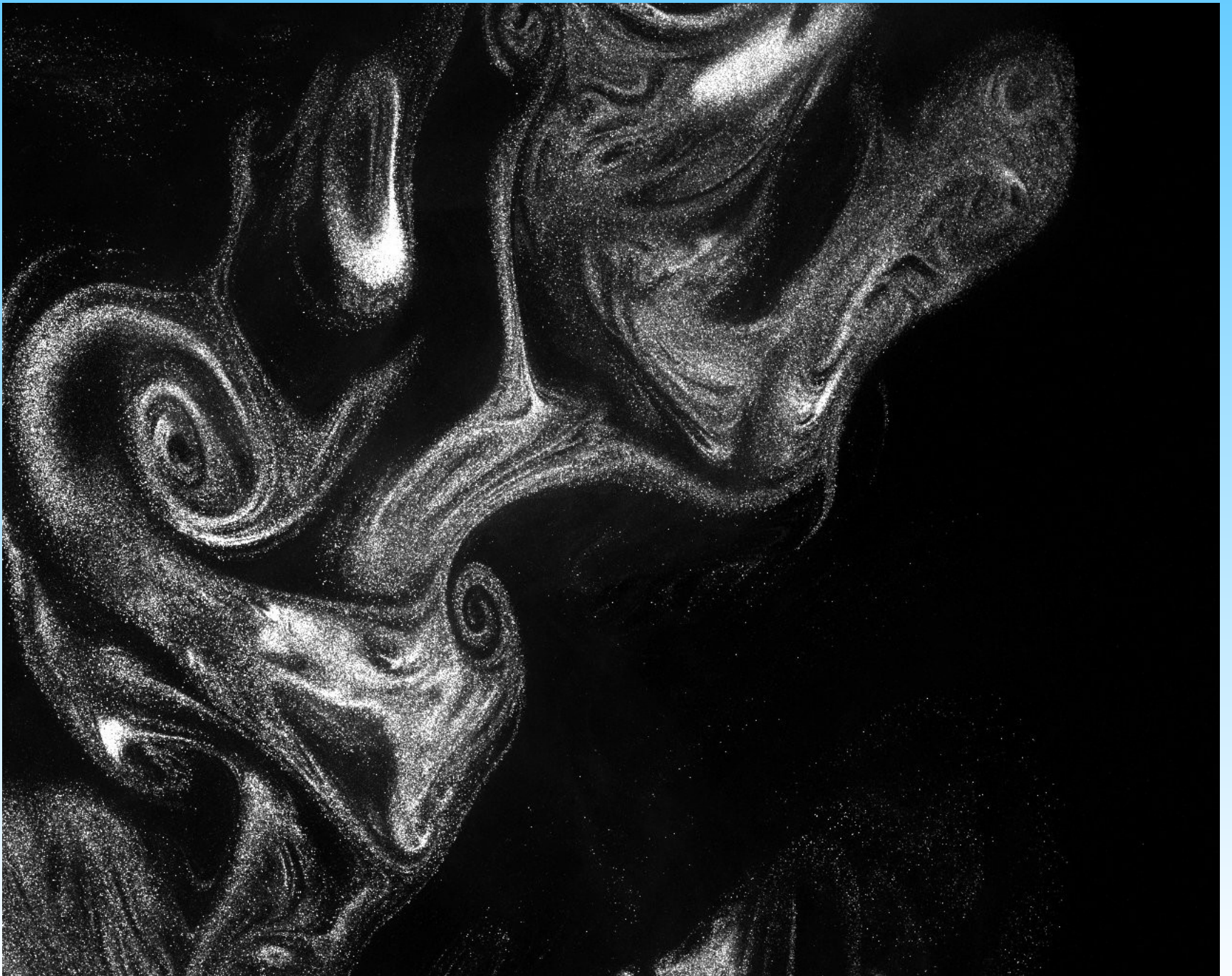


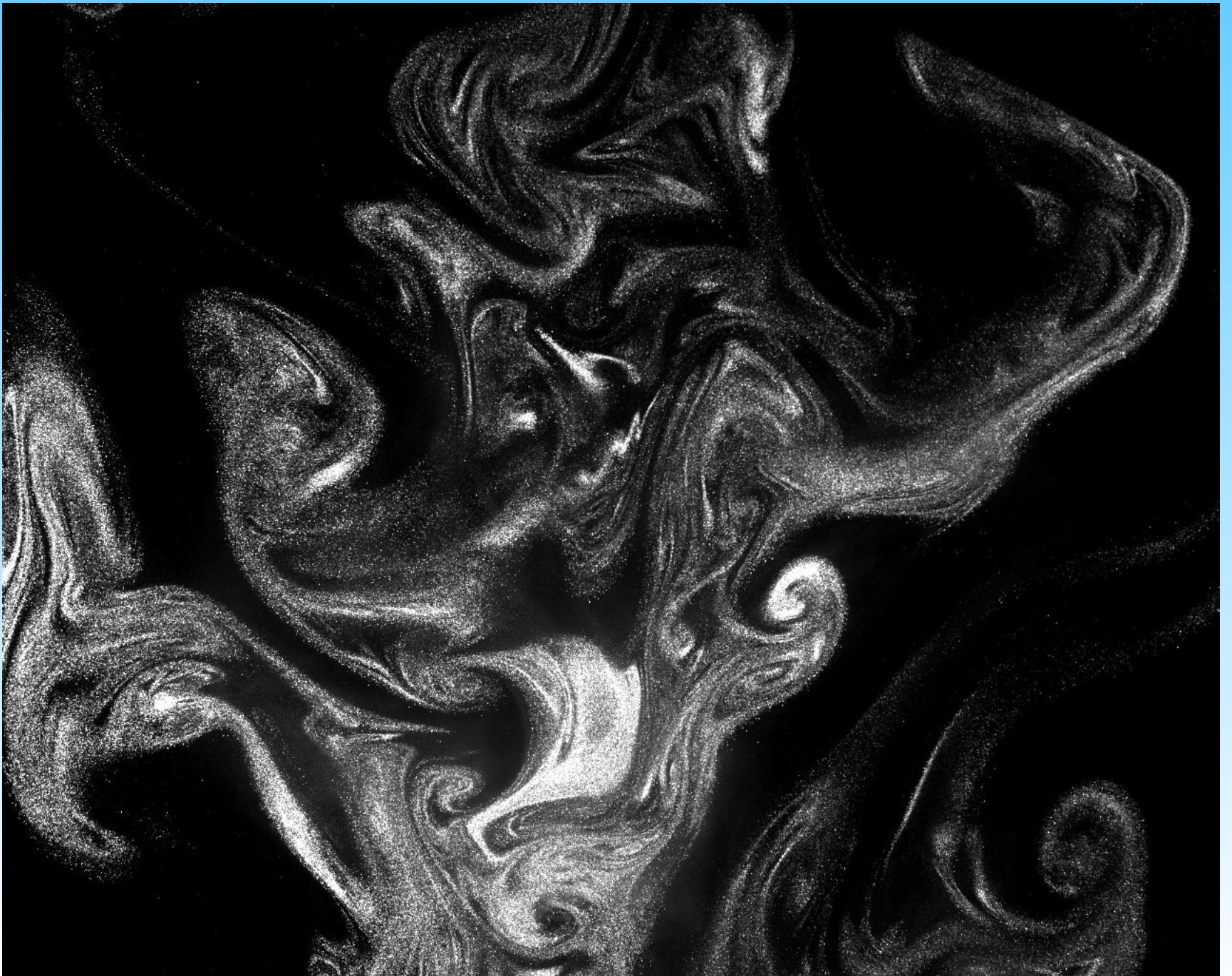
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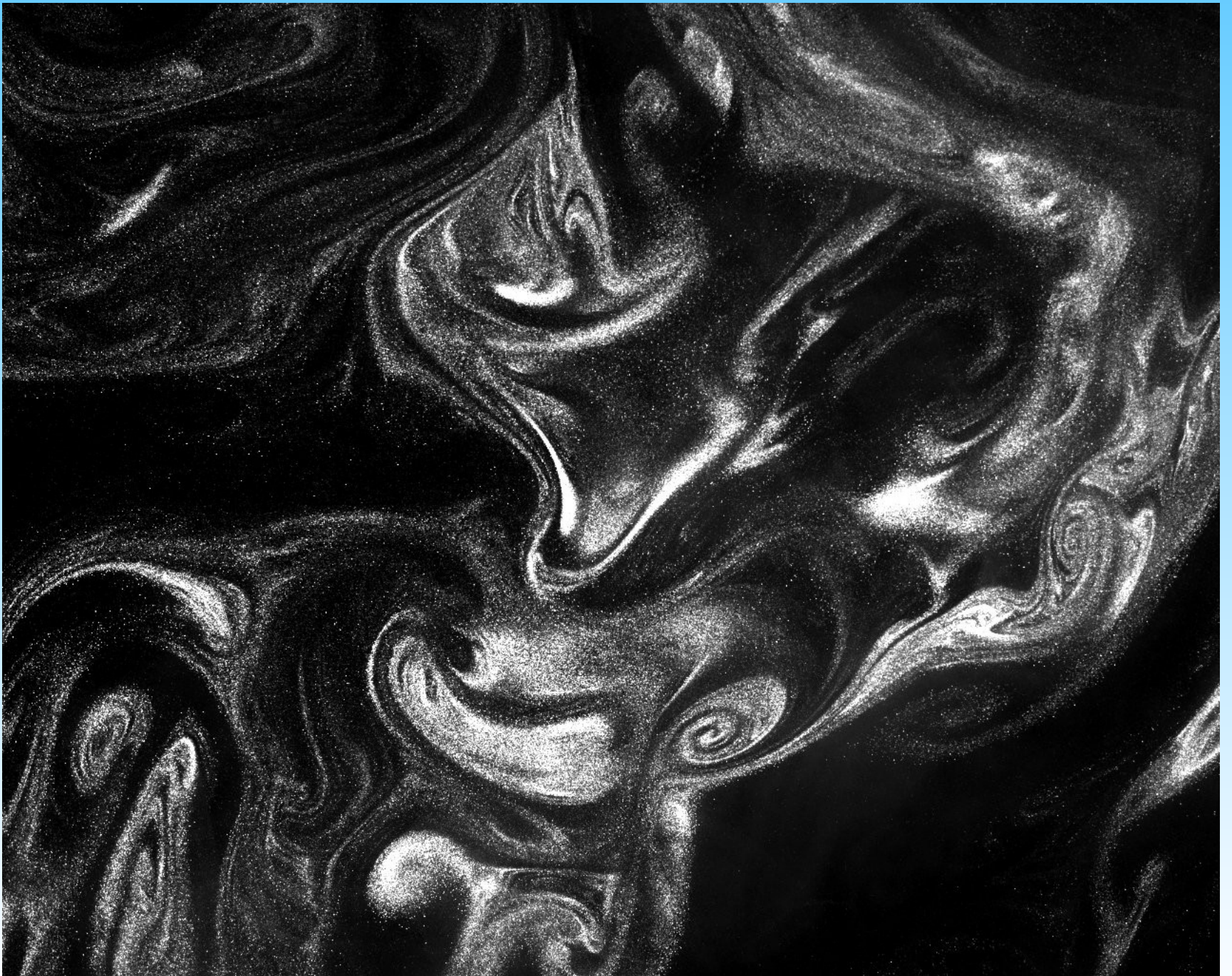
Motivation

- „Warm rain initiation problem” – formation of rain in clouds without ice crystals – how is it possible?
- Is turbulence responsible for higher aggregation rate?
- Lack of high resolution measurements of cloud droplets turbulence interactions.
- The aim – measurement of the velocity fields down to Kolmogorov scale for the laboratory model of a cloud

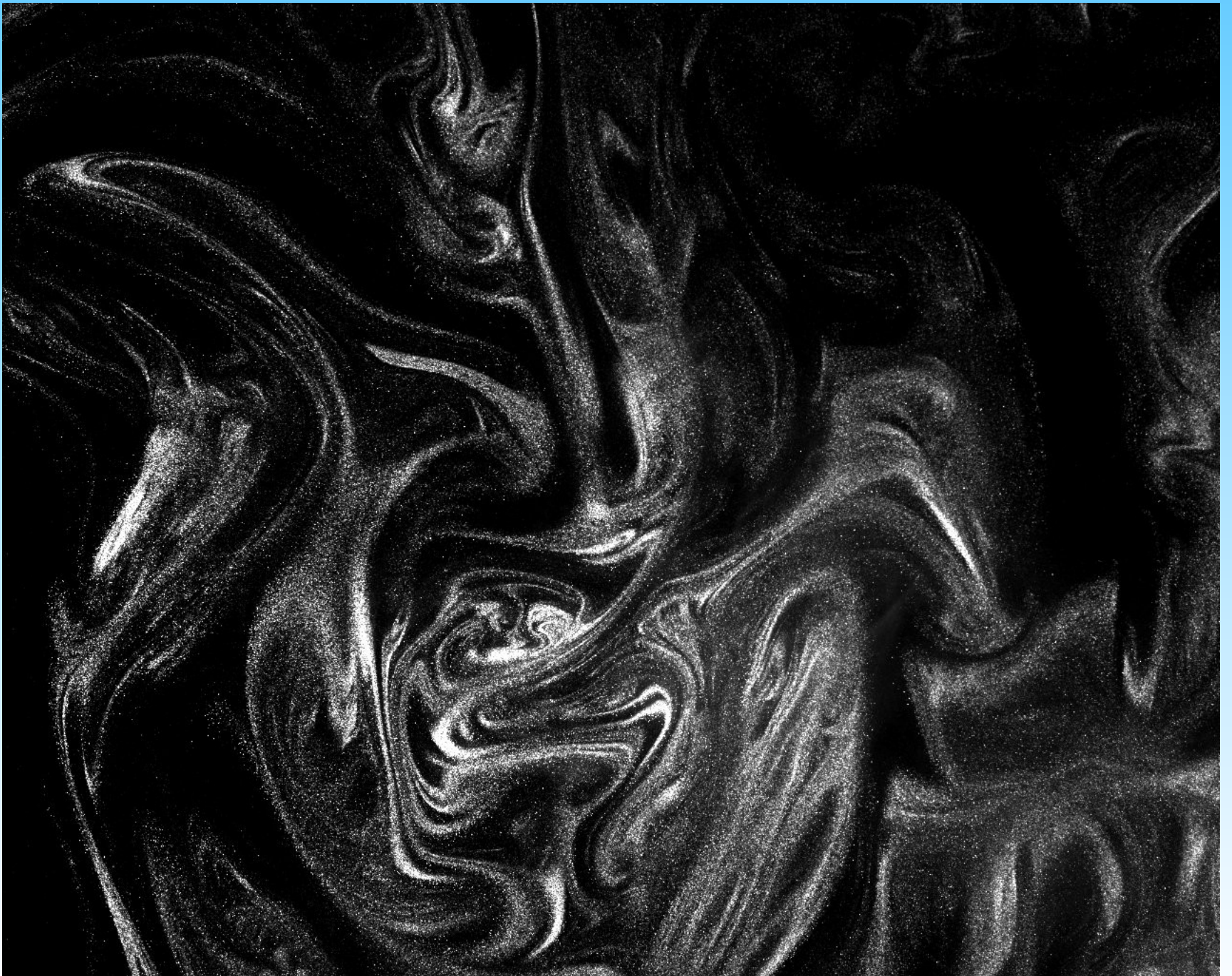


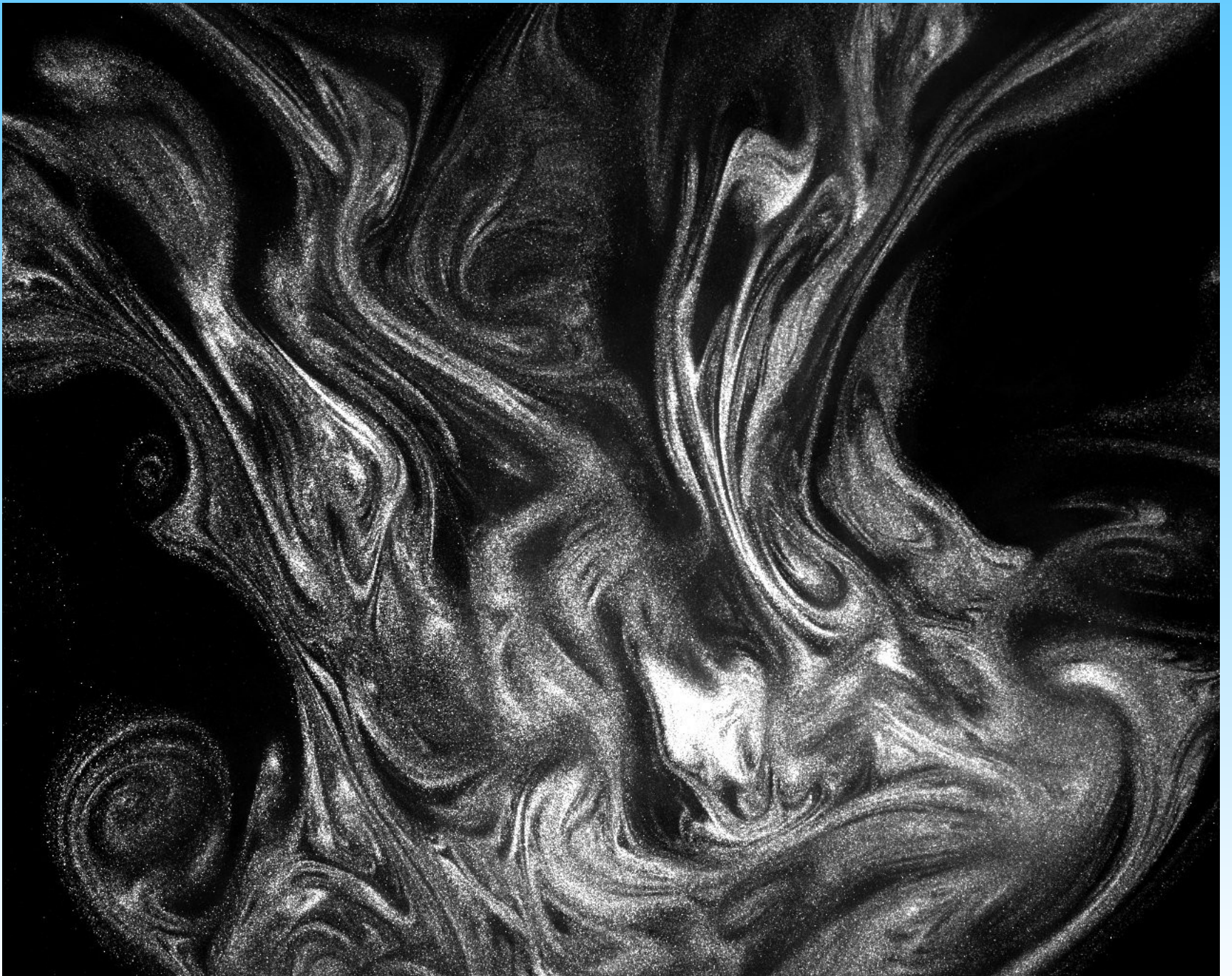


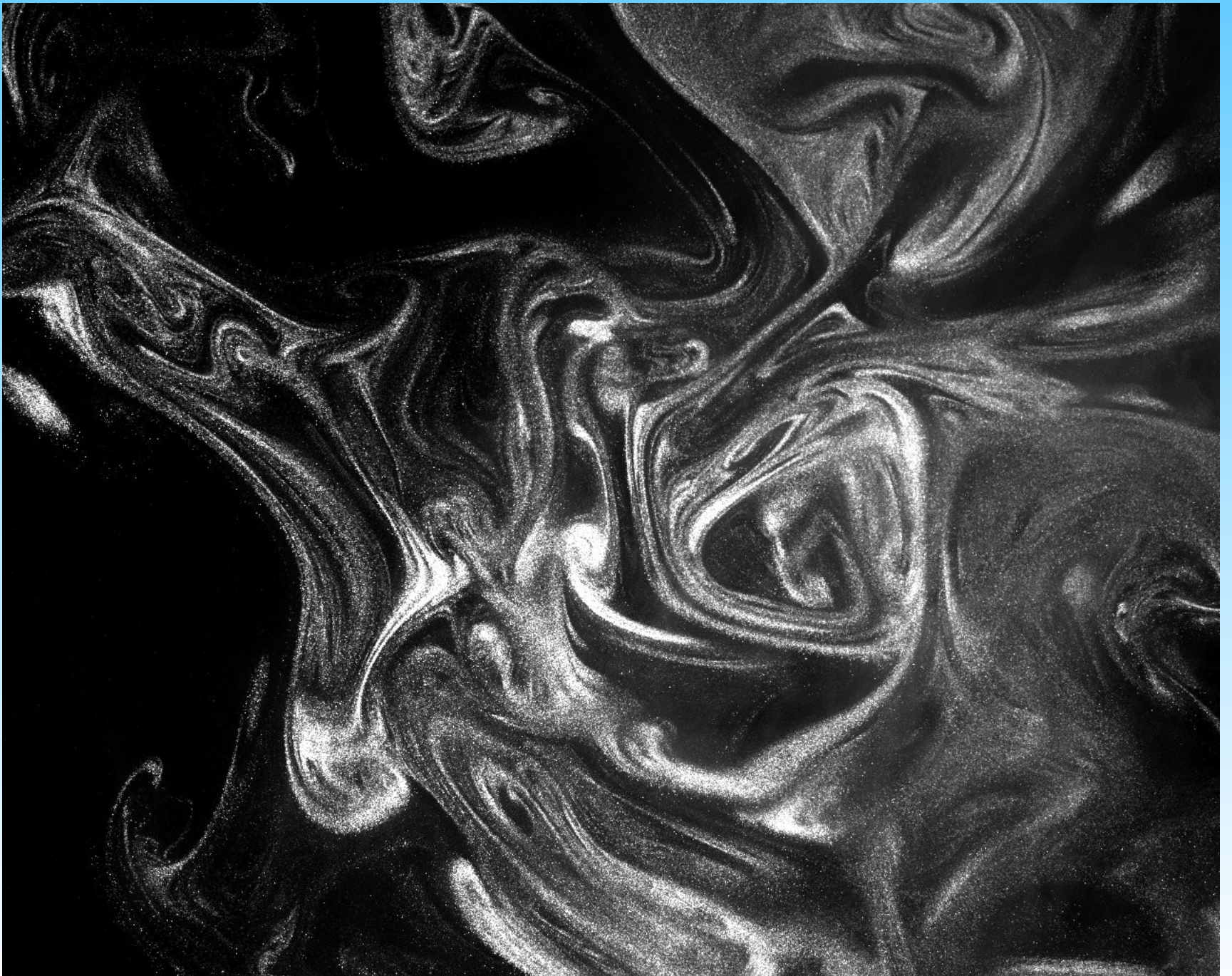










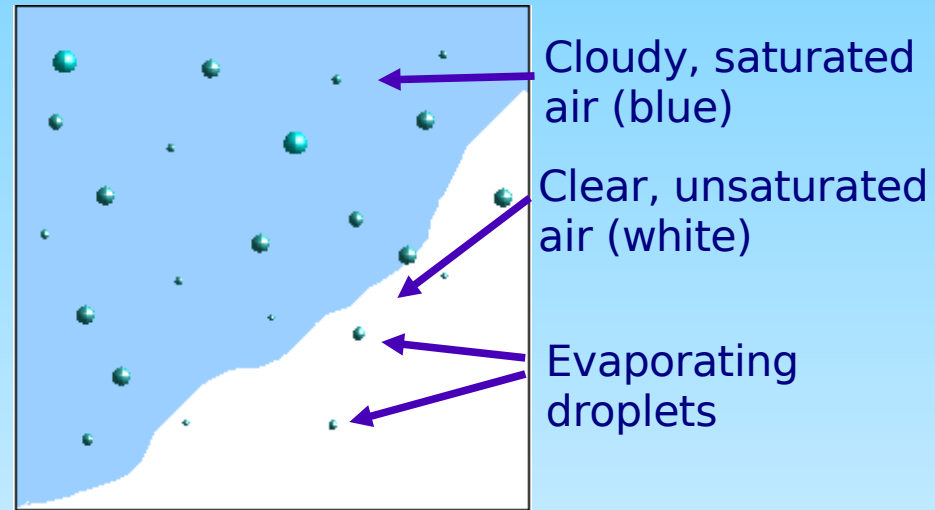




Mixing of cloud and clear air

Transport mechanisms of water across the interface:

- molecular diffusion (vapour),
- gravitational sedimentation of droplets



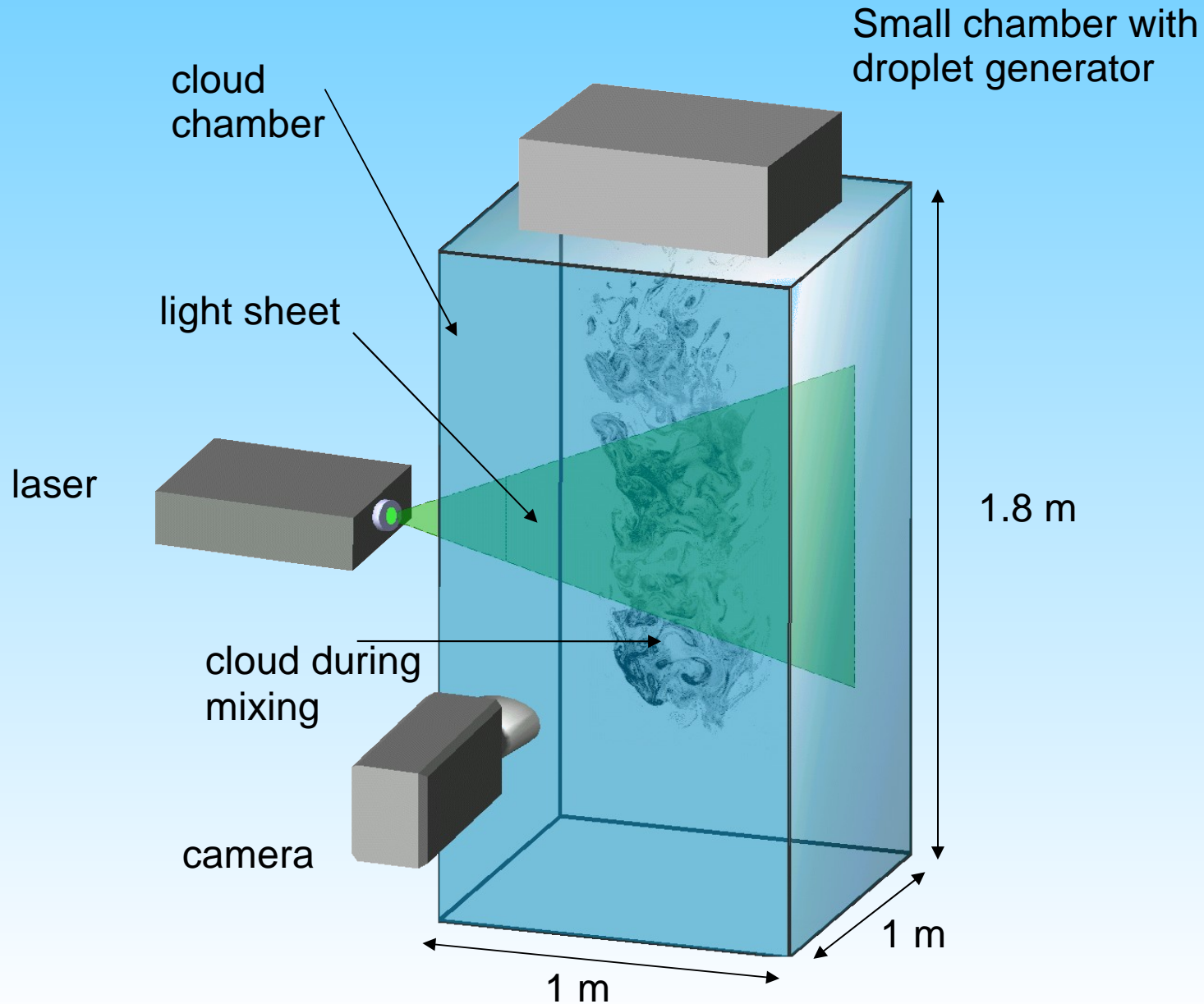
At the interface:

- evaporation of droplets,
- evaporative cooling,
- negative buoyancy

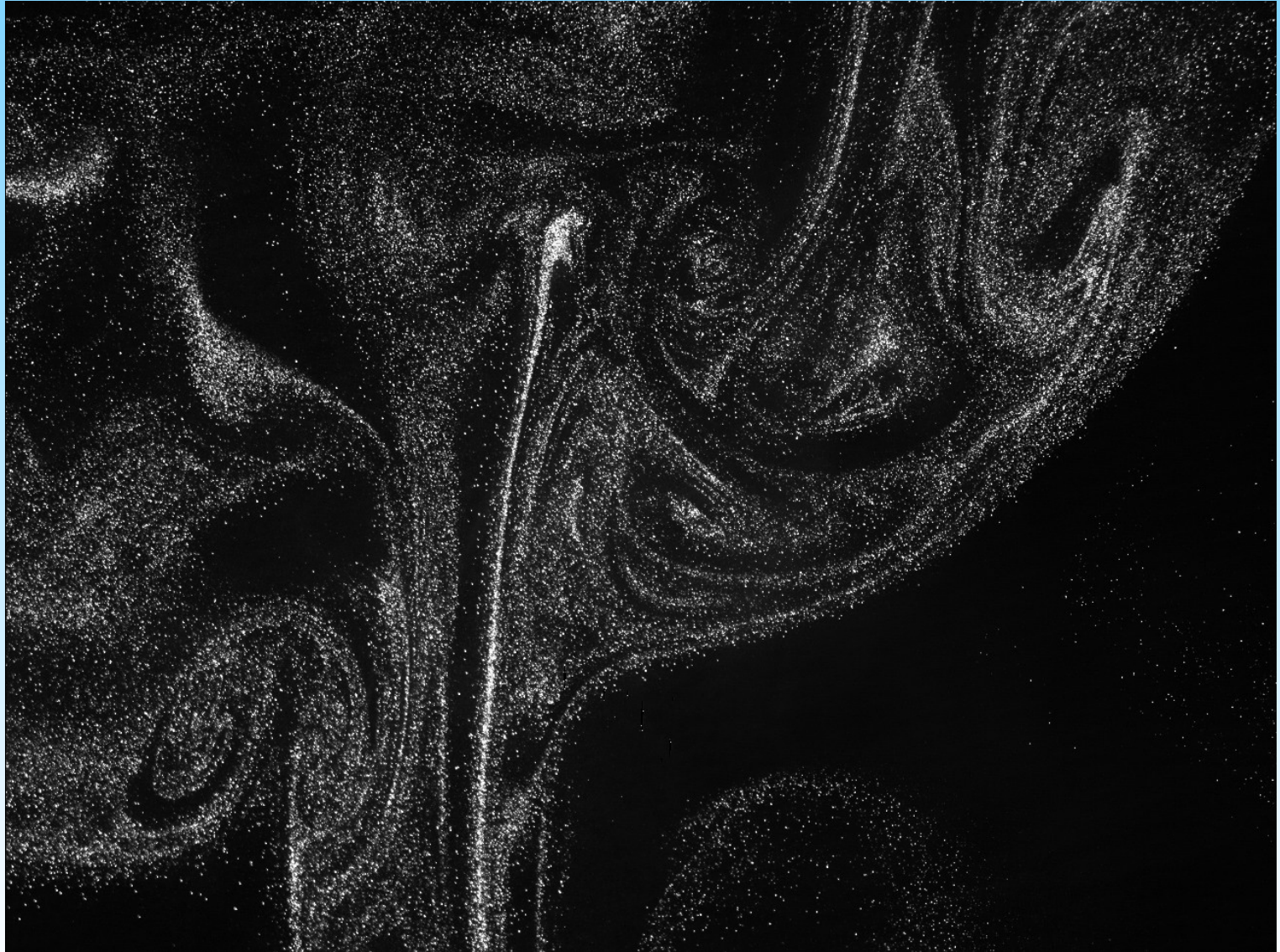
Processes possibly important for:

- droplet collisions,
- evolution of droplet spectra
- warm rain formation

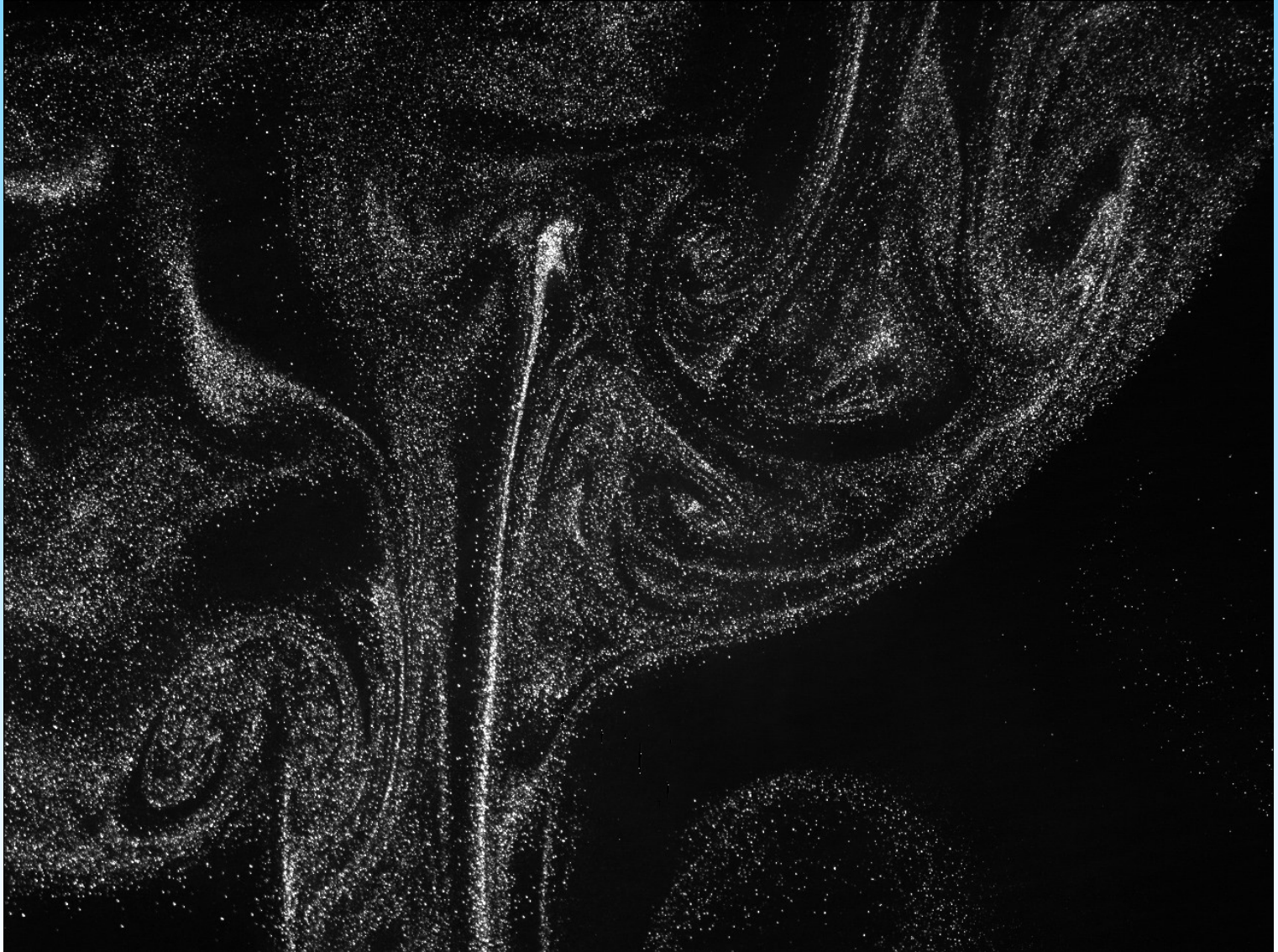
Experimental setup



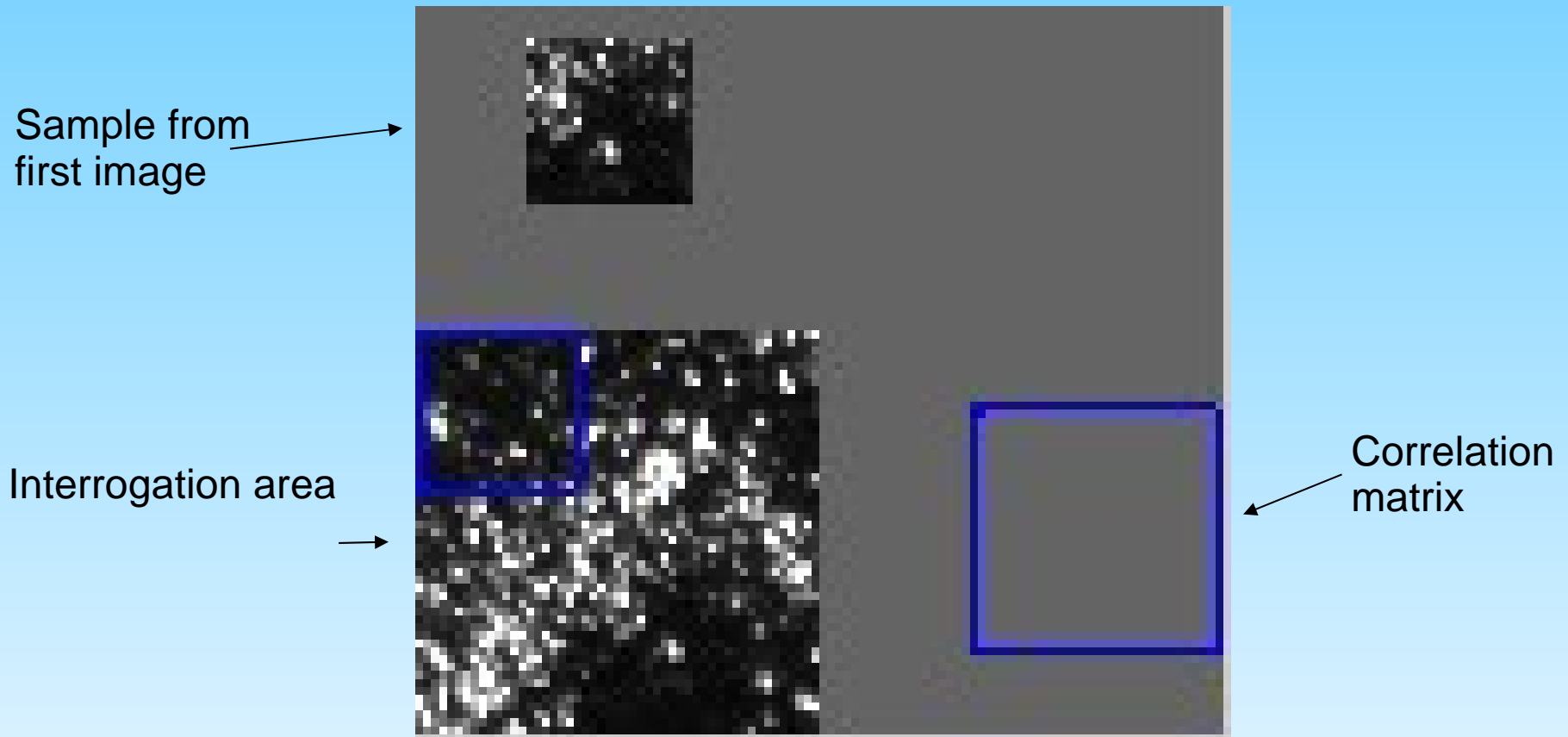
Images from the experiment



Images from the experiment

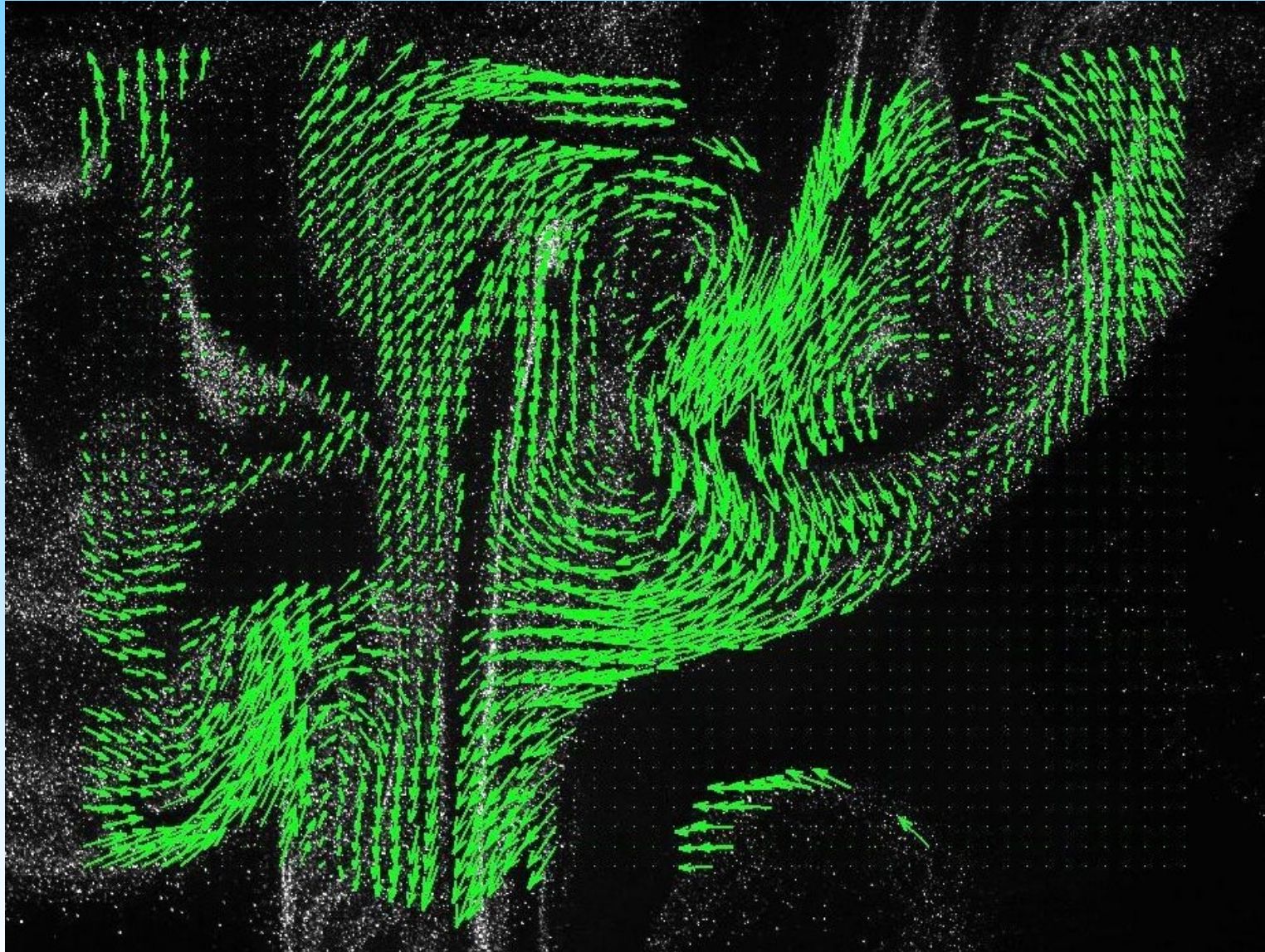


Particle Image Velocimetry

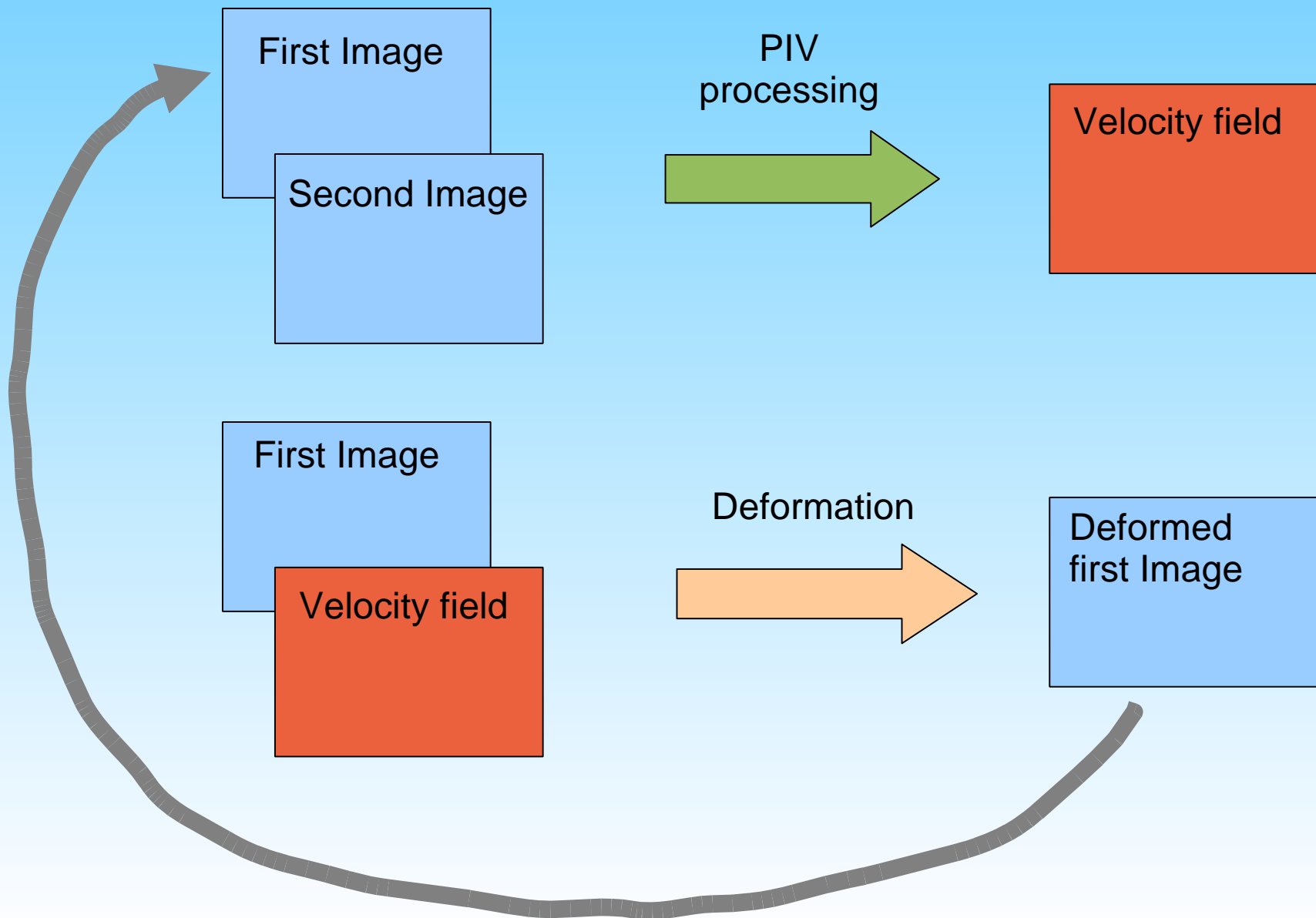


$$c(A, B) = \frac{\sum_{i=1}^M \sum_{j=1}^M [A(i, j) - \langle A \rangle][B(i, j) - \langle B \rangle]}{\sqrt{\left(\sum_{i=1}^M \sum_{j=1}^M [A(i, j) - \langle A \rangle] \right) \left(\sum_{i=1}^M \sum_{j=1}^M [B(i, j) - \langle B \rangle] \right)}}$$

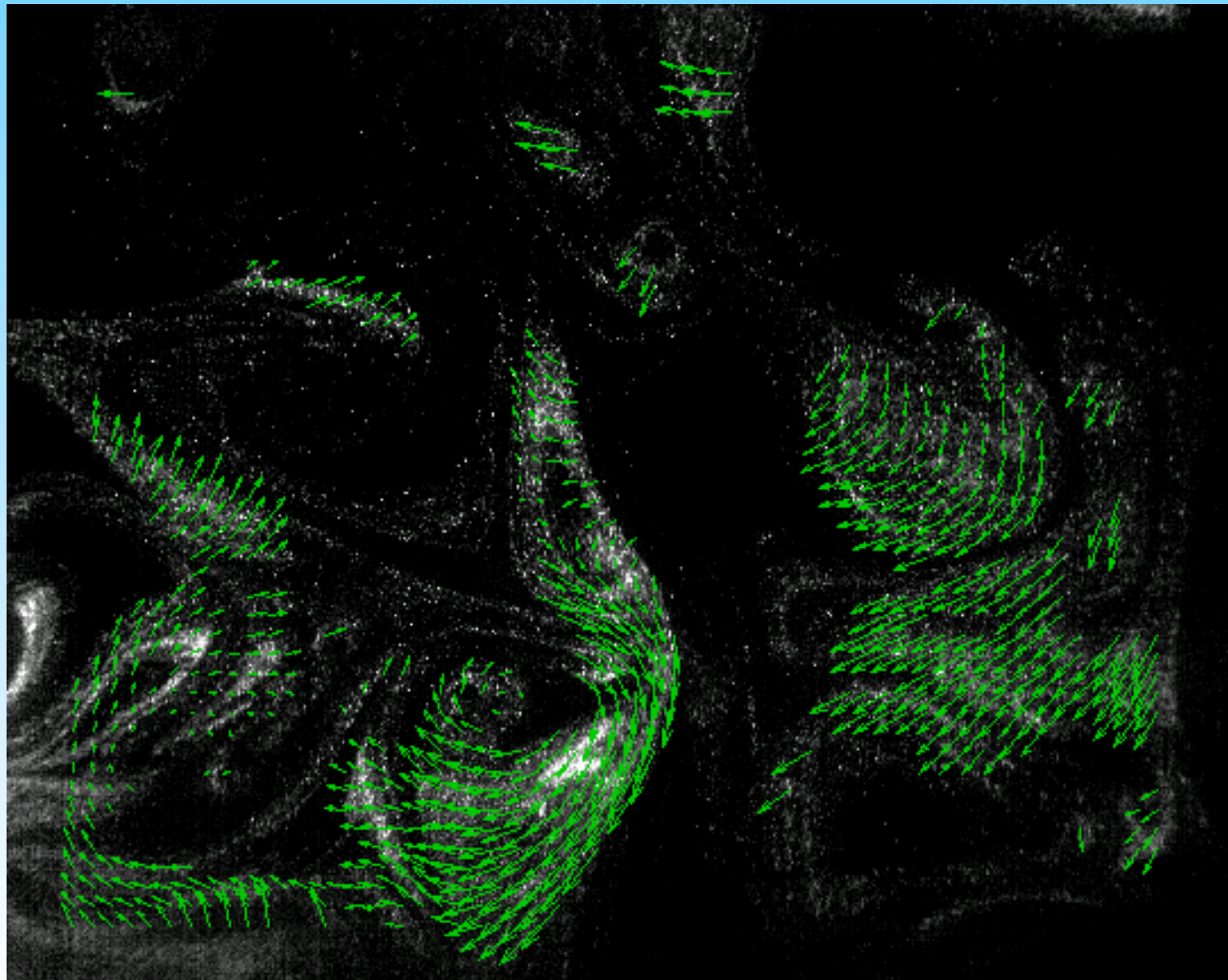
Velocity field – sequences of pairs



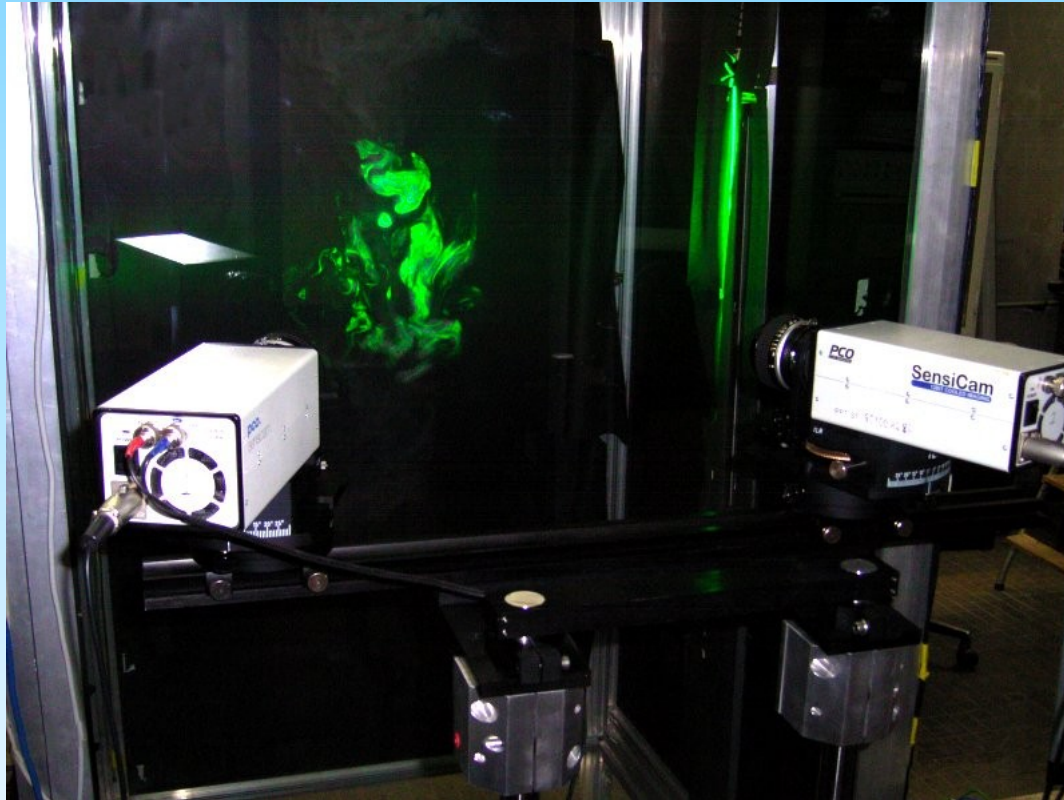
Particle Image Velocimetry - deformations



Long sequence PIV (1000x5ms)



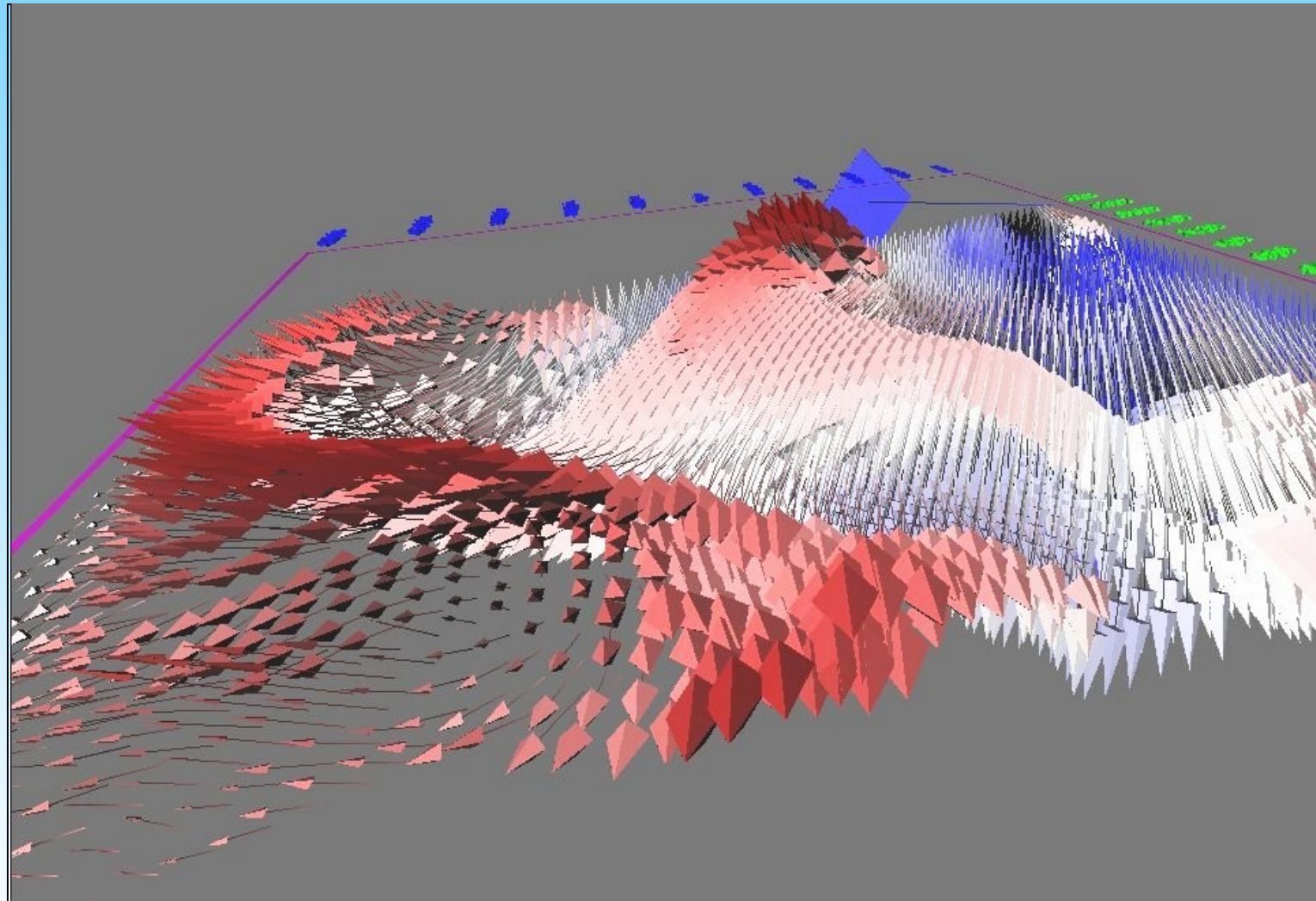
Stereo PIV - experiment



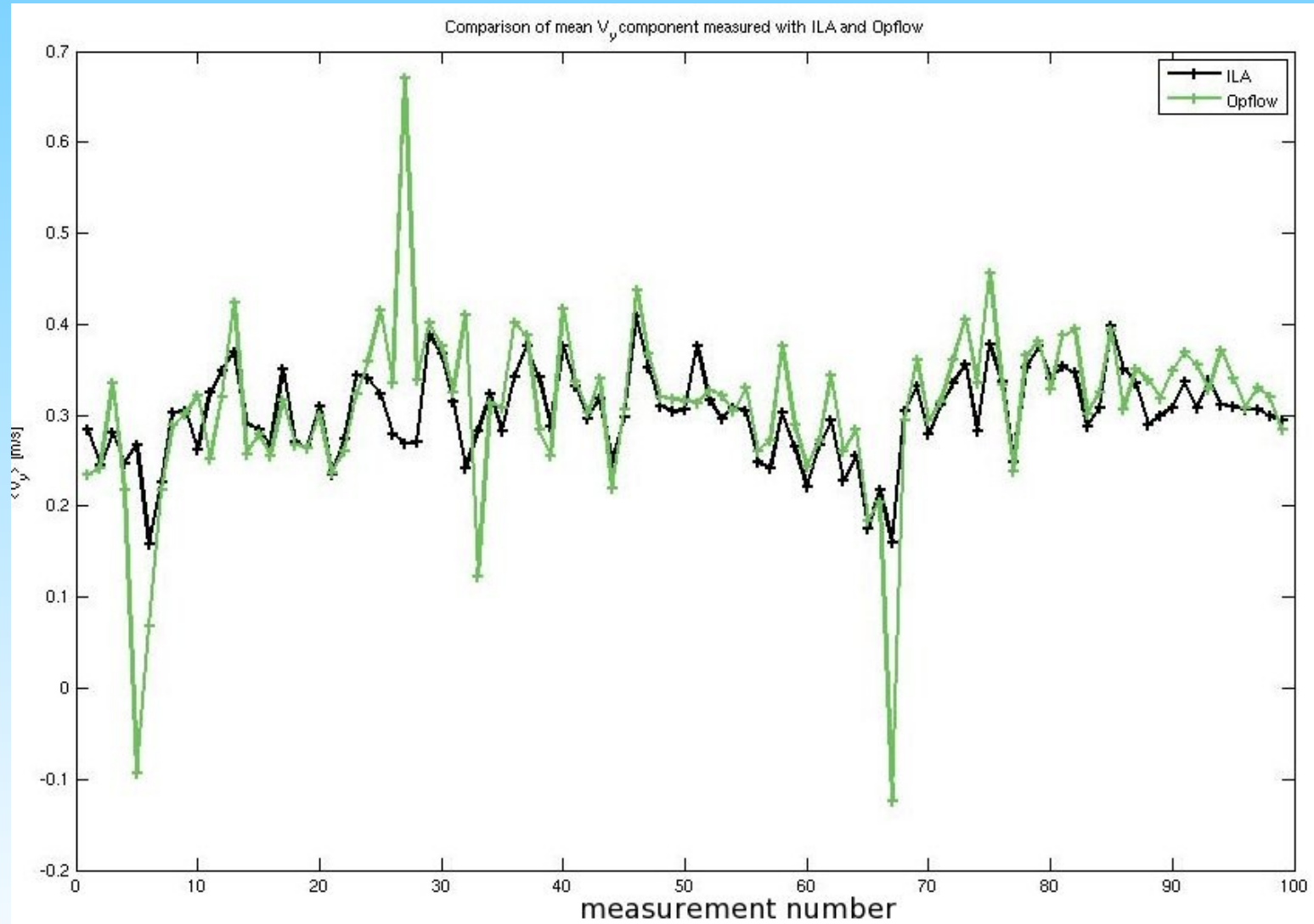
Evaluation using VidPIV and Optical Flow (Opflow)

Stereo PIV – velocity field

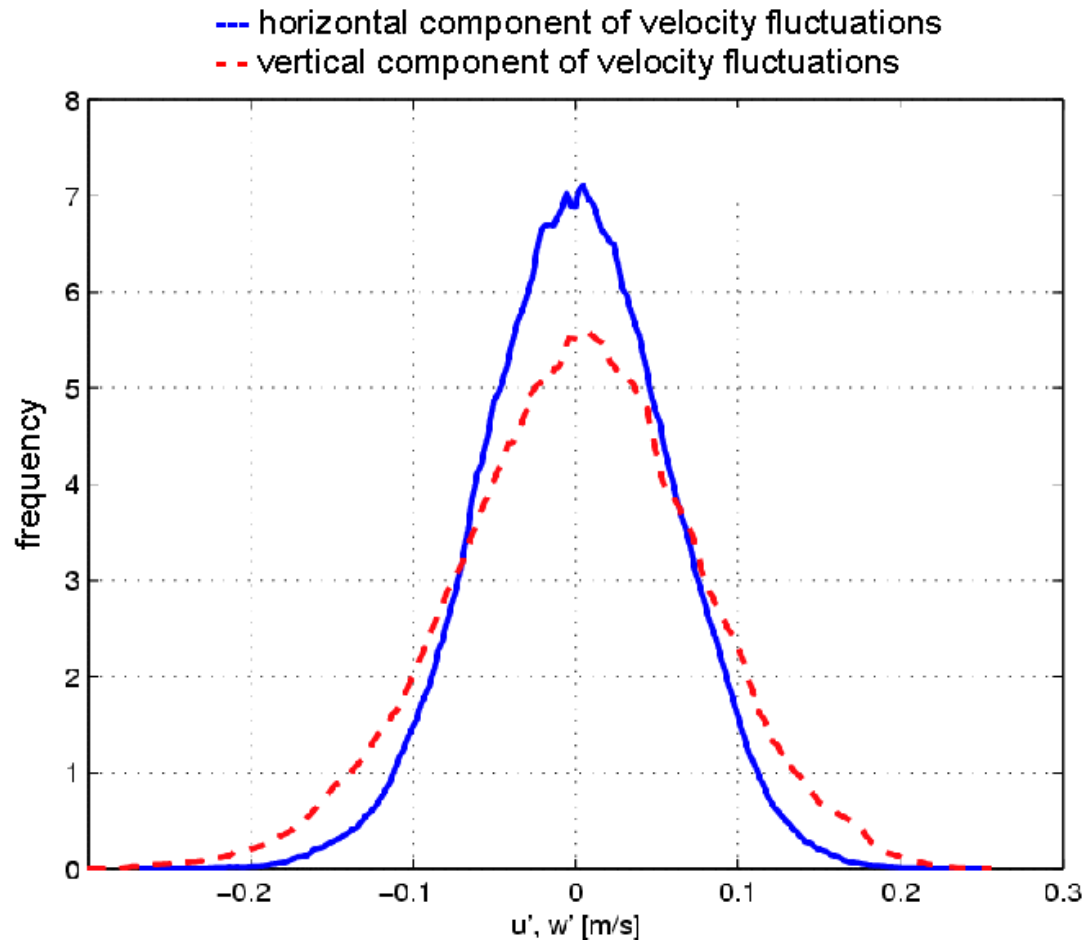
VidPIV ILA



Stereo PIV – comparison of VidPIV and Opflow



Statistics of fluctuations for 1000 samples

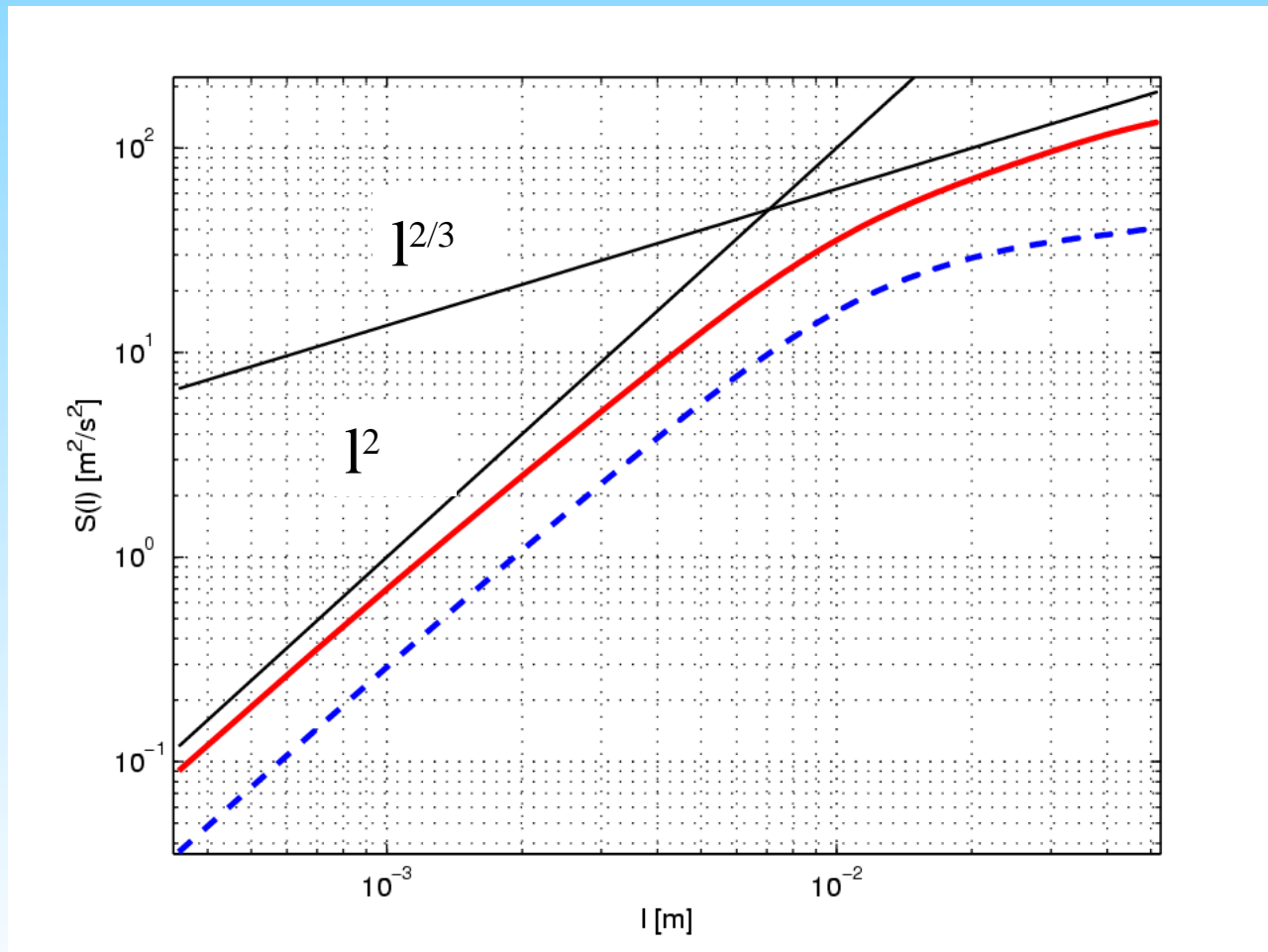


	<i>Standard deviation</i> [cm/s]	<i>Skewness</i>	<i>Kurtosis</i>
Horizontal component of velocity	5.4	-0.01	3.2
Vertical component of velocity	8.0	-0.2	3.1

Second order longitudinal structure function

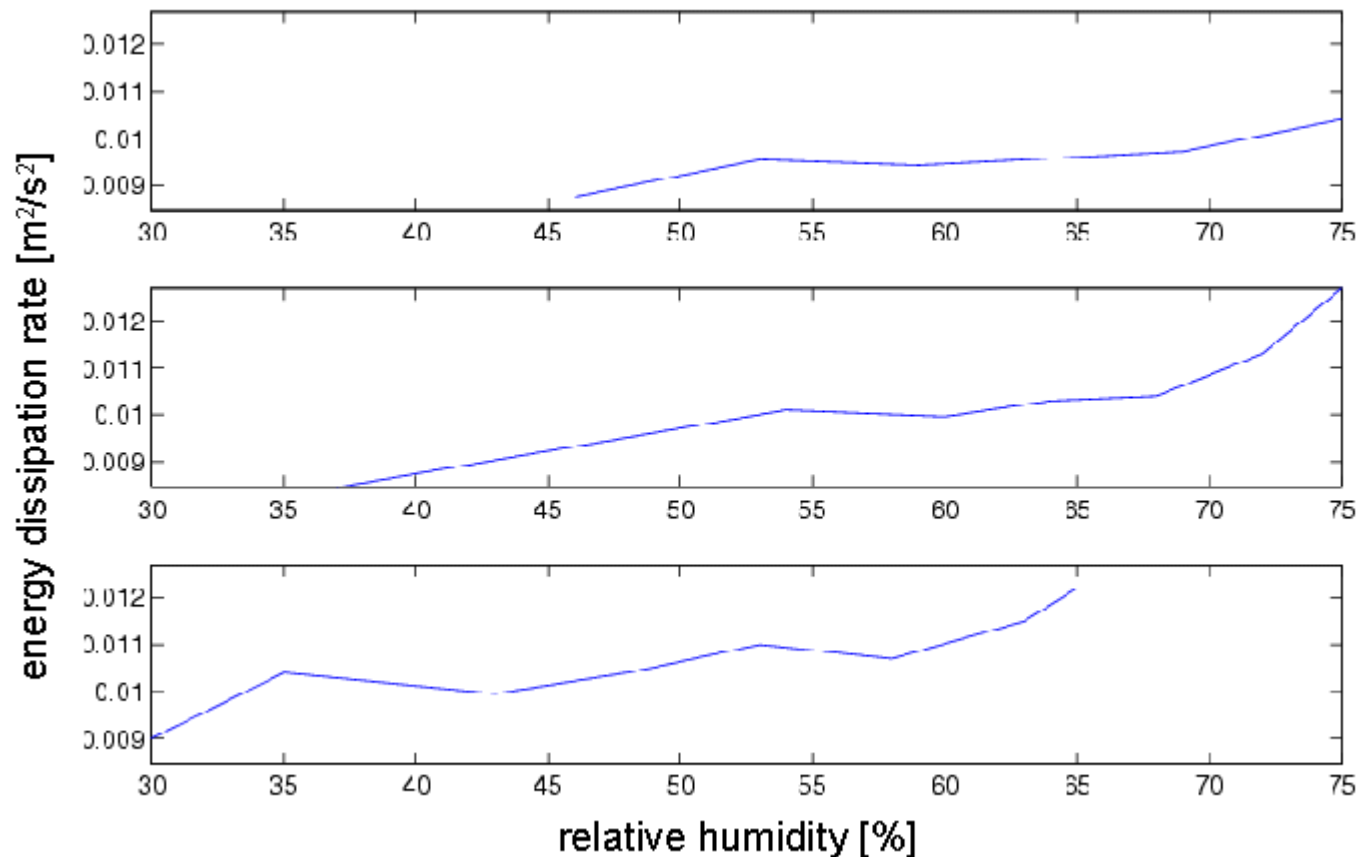
— $S_u^{\parallel}(l) = \langle [u(x+l, z) - u(x, z)]^2 \rangle$

— $S_w^{\parallel}(l) = \langle [w(x, z+l) - w(x, z)]^2 \rangle$



Energy dissipation rate calculated from PIV

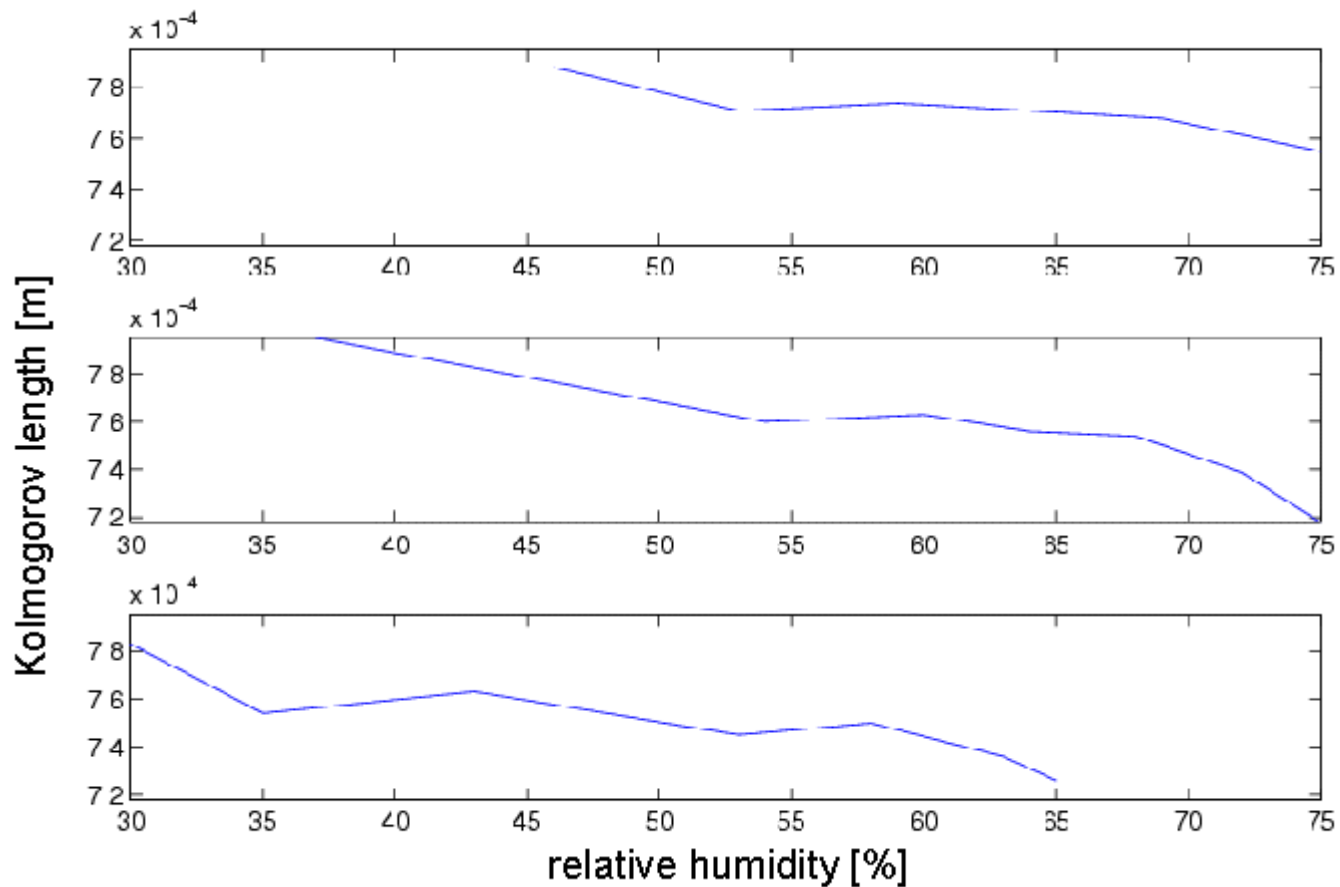
$$\varepsilon = \nu \left\langle \left(\frac{\partial u_i}{\partial x_j} \right)^2 \right\rangle$$



Starting from different initial humidity

Kolmogorov length calculated from PIV

$$\eta = \left(\frac{\nu^3}{\varepsilon} \right)^{1/4}$$



Starting from different initial humidity

Conclusions

- Our study demonstrates the possibility of using Particle Image Velocimetry for quantitative analysis of cloud droplets motion inside the cloud chamber
- Statistical analysis of the retrieved velocity field confirms suggestion of earlier numerical simulations, that small scales anisotropy of the turbulence takes place in regions of entrainment and mixing of cloud filaments with clean air.
- Structure of turbulence in small scales seems to be sensitive to humidity – evaporation efficiency.