# PARTICLE IMAGE VELOCIMETRY (PIV) FOR CLOUD DROPLETS – LABORATORY INVESTIGATIONS

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Summary: Turbulent motion of cloud droplets is observed in a laboratory chamber by means of Particle Image Velocimetry (PIV). A specially developed multi-scale PIV algorithm is used to retrieve two components of velocity of cloud droplets.

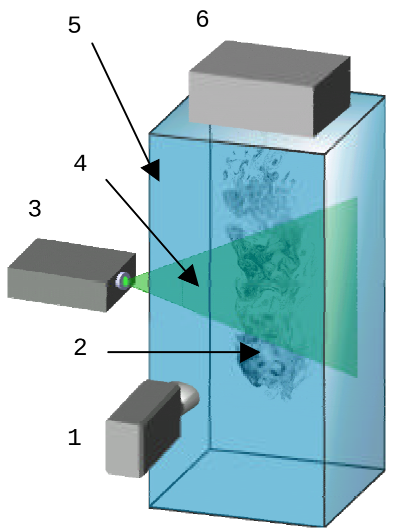



**Fig.1.** The experimental setup: 1) a camera, 2) a cloud during mixing, 3) a laser, 4) laser sheet, 5) a cloud chamber, 6) a small chamber with the droplet generator inside.

## INTRODUCTION

Interaction between small-scale turbulence and cloud particles is a key issue in warm rain formation mechanism, which is an important meteorological and climatological challenge [1],[2]. We investigate this interaction observing motion of cloud droplets in a glass walled chamber 1m deep, 1m wide and 1.8m high [3]. The second smaller chamber, placed above the main one is filled with water droplets of diameters in range from 7 to 25 micrometers. Cloudy air containing water droplets enters the main chamber forming the negatively buoyant, turbulent plume, mixing with unsaturated air in the main chamber and producing additional turbulence by evaporative cooling of droplets.

The plume is illuminated with a 1.2mm thick sheet of laser light (Nd:YAG, $\lambda$=532nm), forming the vertical cross-section through the central part of the chamber. Images, formed due to Mie scattering of laser light by cloud droplets are recorded by a high-resolution CCD camera placed outside the chamber, with the optical axis perpendicular to the light sheet. Images are recorded in pairs in order to retrieve information on droplets' velocities. Application of standard PIV algorithms to these pairs resulted in a large amount of errors and artifacts in the retrieved velocity field due to chaotic nature of motion in a chamber. Therefore a special multi-scale algorithm was developed.

## MULTI-SCALE PIV PROCESSING

In order to evaluate displacement of a droplet pattern at position (x,y) a square sample from the first exposure centered at this position is taken. Then we search the most similar sample in the second exposure within the interrogation area, also a square centered at (x,y). The size of the interrogation area depends on the expected greatest displacement and on the size of the sample. Images are matrices and each pixel is treated as an element of matrix: an integer representing grey level (brightness) of this pixel. For sample **S** of size M×M and interrogation area **A** of size L×L evaluation function used to process recordings can be defined as:

$$j\,(m,n)=\sum_{i=1}^{M}\sum_{j=1}^{M}[S(i,j)-<S>][A(i+m,j+n)-<A>]$$

where

$$<S>=\frac{1}{M^2}\sum_{i=1}^{M}\sum_{j=1}^{M}S(i,j) \qquad <A>=\frac{1}{M^2}\sum_{i=1}^{M}\sum_{j=1}^{M}A(i+m,j+n)$$

for

$$m\in[0,L-M] \qquad n\in[0,L-M]$$

The evaluation function can be written as:

$$j\,(m,n)=\sum_{i=1}^{M}\sum_{j=1}^{M}S(i,j)A(i+m,j+m)-M^2<S><A>$$

which can be efficiently calculated with use o FFT algorithm.

Maximum of $\phi$(m,n) corresponds to best similarity between samples from both exposures, from which displacement of the ensemble of droplets contained in **S** is evaluated. In standard PIV algorithms the choice of the size of the sample is a significant technical problem [4]. In the following we propose successive, multi-scale selection of smaller and smaller samples.

In a first step we look for the displacement in the whole image in order to remove the bulk motion of the plume. At the next step the size of the sample is reduced and the position of the interrogation area is determined by the displacement vector evaluated earlier. In this way the displacement is corrected. This algorithm can be repeated few times decreasing the size of the sample. Due to these operations velocity vector can be evaluated for small patterns containing small number of droplets.

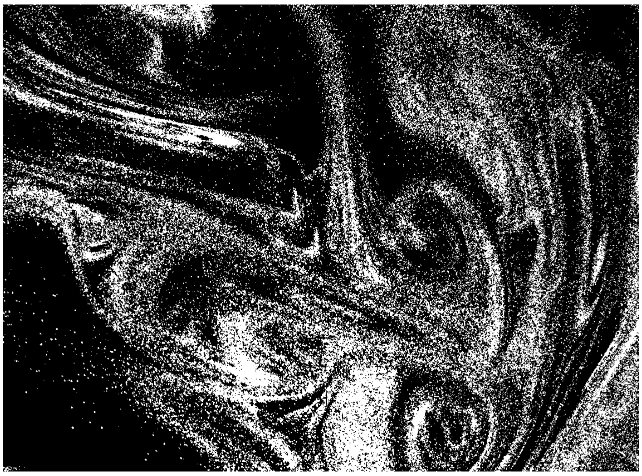
Before application to the experimental the above algorithm was verified in a benchmark pair of images [5]. It implied that average error of the displacement was about 0.5 pixels. The accuracy of retrieval, evaluated on a basis of this benchmark test is significantly better than retrieval by direct correlation.

## RESULTS

The new PIV algorithm is employed to investigate properties of a cloud model and provides insight into the cloud structure at scales of centimetres and down. Using laboratory setup consisting the cloud chamber allows us to investigate processes important for initiation of the precipitation.

Observation of the cloud structures falling down through the chamber gives opportunity to study the mixing process of the cloud with an unsaturated environmental air. Application of the multi-scale algorithm provides information on turbulent velocities of the cloud droplets. Due to it, histograms of the velocity fluctuations are acquired. Comparison of histograms of vertical and horizontal fluctuations implies that flow in regions of mixing may not be isotropic with preferred vertical direction. As suggested in [6] it may be caused by negative buoyancy forces produced by droplet evaporation.

The experimental setup and the multi-scale (PIV) algorithm are also used to investigate evolution of spatial distribution of cloud droplets. Flow structure typical for turbulence, like the vortex tube, appears to influence spatial distribution of droplets. Effect of gravity, inertia and drag forces is responsible for clustering of droplets.



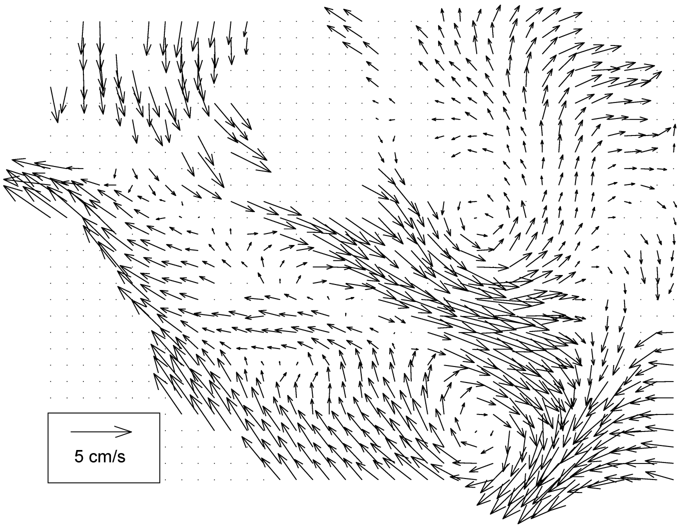



**Fig.2.** Example of experimental image visualising part of artificial cloud of size about 6cm $\times$ 4cm.
Map of velocity fluctuation obtained by processing experimental data and employing mentioned algorithm.

## SUMMARY AND FUTURE WORK

A new multi-scale algorithm was introduced and successfully employed to analyse experimental data of complex flow in the turbulent cloud chamber. Further development to increase its accuracy and resolution as well as expanded to use in other application like stereo PIV [7], allowing to retrieval of all three components of velocity vector, will be presented.

### Acknowledgments

This research was supported by a research grant No 5 T07A 052 24 of the Polish Committee for Scientific Research.

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