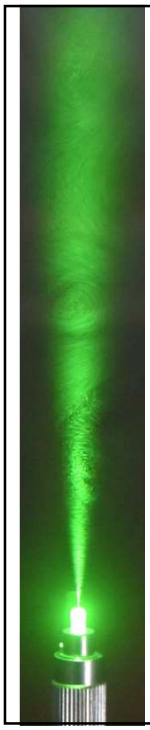

# Long-exposure digital holography applied to study mixing at the laboratory analogue of cloud top

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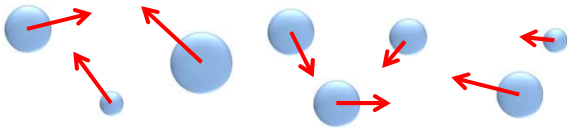
## How to simultaneously measure cloud droplet size, position and velocity ?



## What is the structure of the artificial cloud top ?

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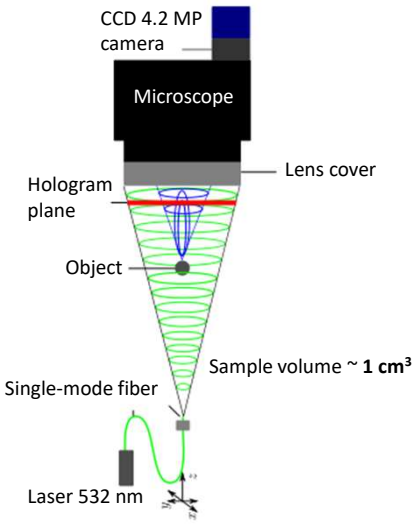
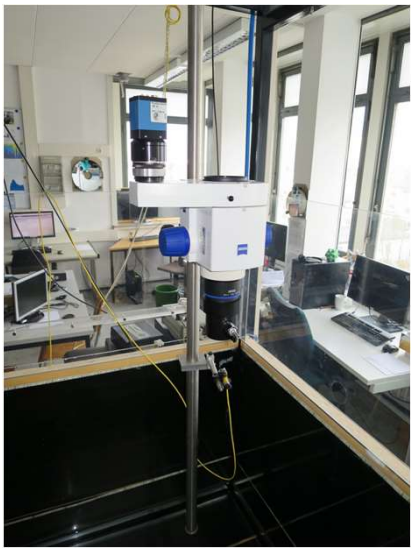
## Hologram is an interference pattern of 2 beams: reference and scattered light



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## Single long-expos. hologram contains information about particle size, position and 2C velocity

Exposure time: 5 ms
Trace length ~ 110 µm
Trace width ~ 18 µm

⇩

Diameter ~ 18 µm
Velocity ~ 1.8 cm/s

- Vertical position: depth focusing based on image gradient
- Horizontal position: center of the particle trace
- Horizontal velocity: length and orientation of the trace
- Droplet diameter: width of the trace

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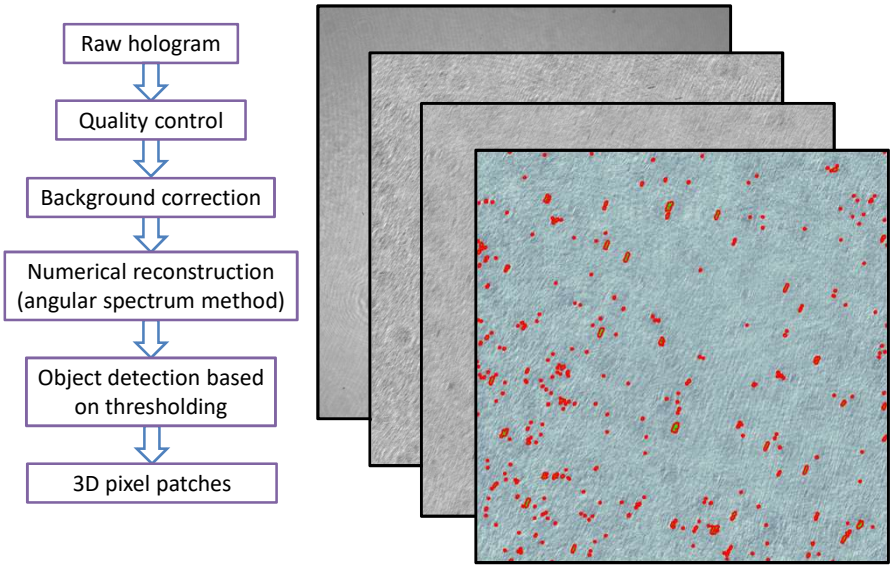
## How to find particles in the reconstructed volume ?

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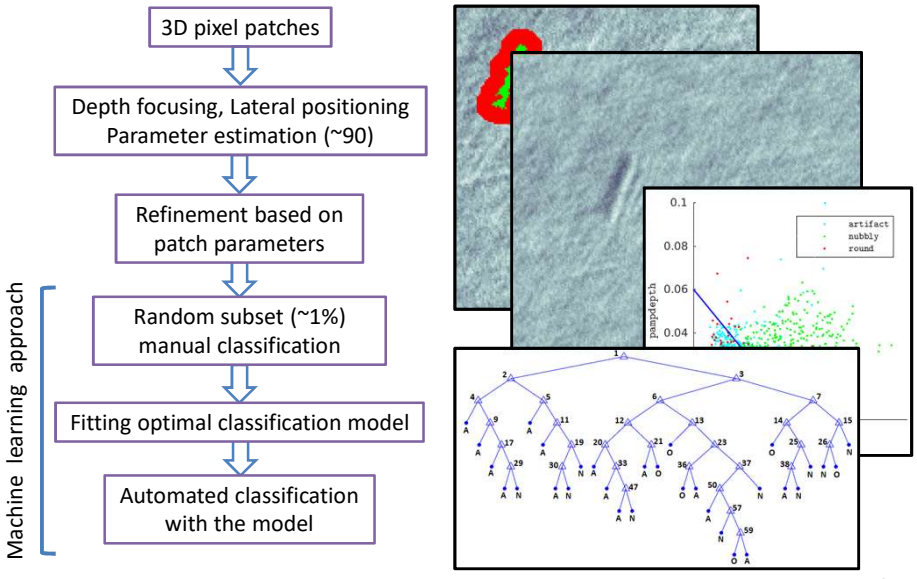
## How to distinguish between droplets and artifacts ?

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## Simpler model makes more mistakes in classification

**of objects from experimental holograms**

| Model | Detection error E |
|---|---|
| Decision tree | 31.3 % |
| Logistic regression | 26.9 % |
| Support vector machine | 23.7 % |

$$E = w_{ms}R_{ms} + w_{fa}R_{fa}$$

Miss rate — False alarm rate

$$w_{ms} = \frac{1}{3} \qquad w_{fa} = \frac{2}{3}$$

## Detection performance depends on droplet size

**according to tests on simulated holograms**

| Diameter [µm] | 5 | 10 | 15 | 20 | 25 | False |
|---|---|---|---|---|---|---|
| Overall detection rate | 11 % | 44 % | 75 % | 86 % | 87 % | 7 % |

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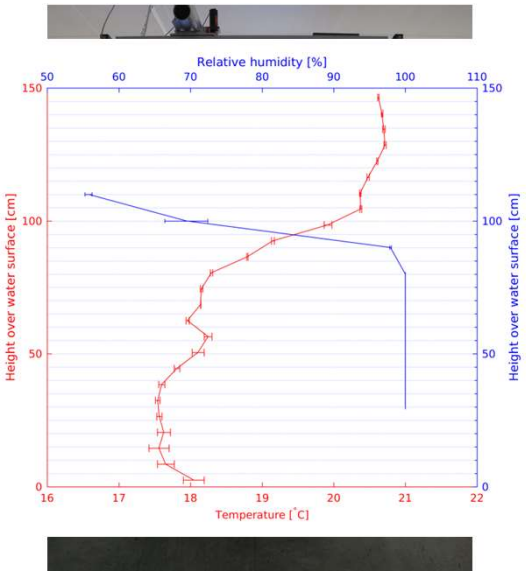
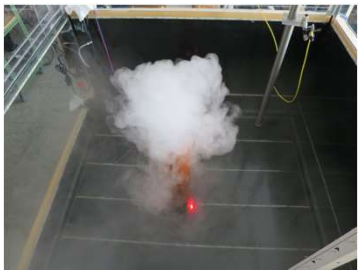
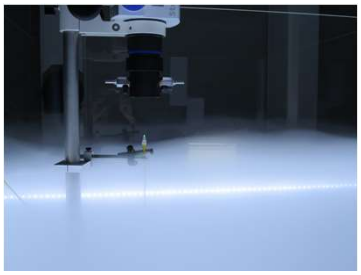
## How to produce a cloud in the lab ?





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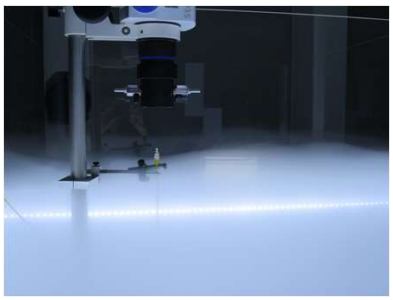
## How the laboratory cloud compares to nature ?



- ✓ cloud - clear air interface
- ✓ mixing
- ✓ temperature inversion
- ✓ droplet size
- ✓ droplet concentration

- ? spatial and temporal scales
- ? pressure changes
- ? boundary conditions
- ? droplet production

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## The cloud mixes with clear dry air from above

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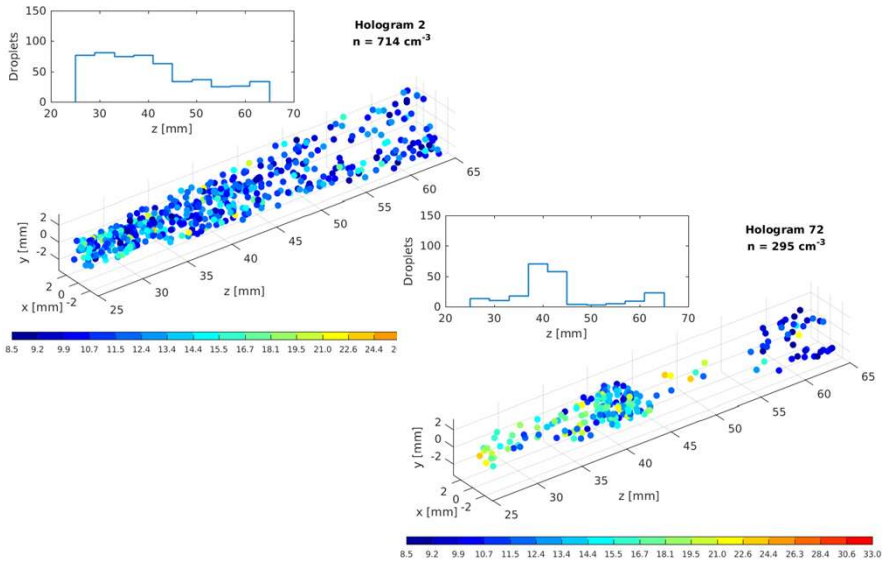
# Droplets are spatially distributed in filaments

**due to mixing and evaporation**

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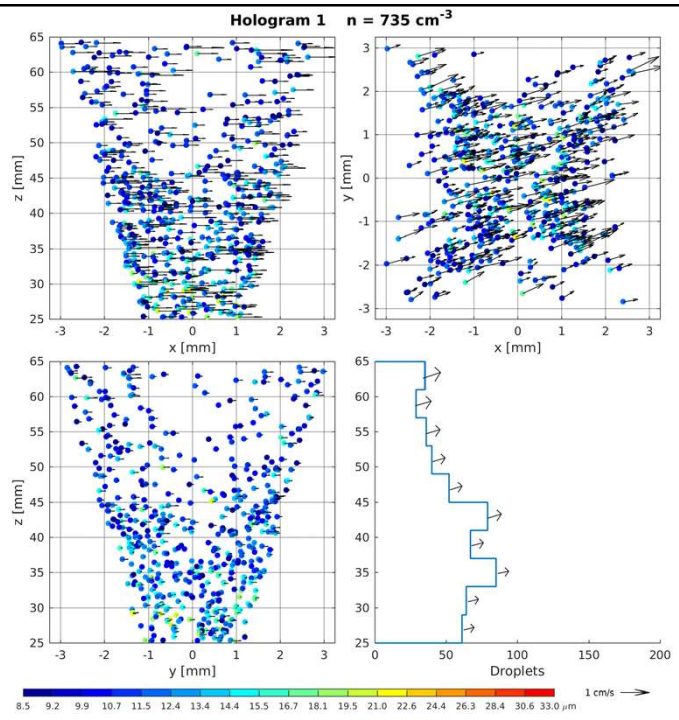


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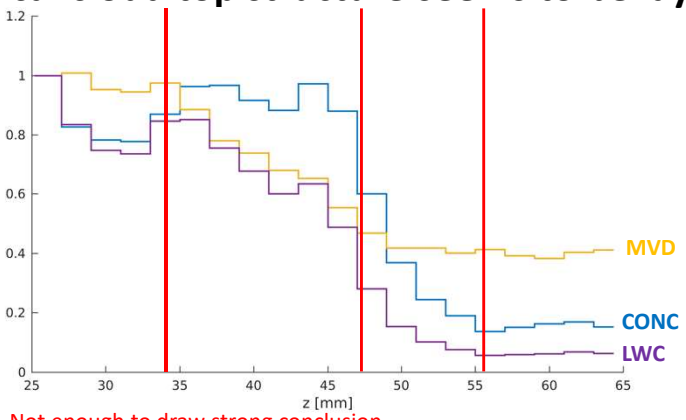
# Statistical cloud top structure seems to be layered




Not enough to draw strong conclusion

| *101 holograms* | Mean | Std | Min | Max | Error |
|---|---|---|---|---|---|
| **Concentration [cm$^{-3}$]** | 305 | 222 | 38 | 1004 | ? |
| **Horizontal velocity [mm/s]** | 6.8 | 3.9 | 0 | 25.6 | 1.8 |
| **Droplet diameter [µm]** | 12.7 | 3.2 | 8.5* | 33 | 4.5 |

* Resolution limit

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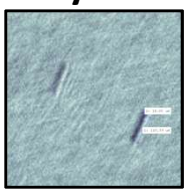
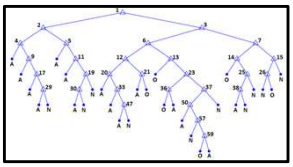
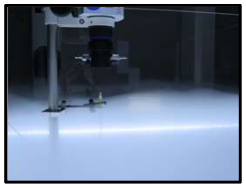
# Summary



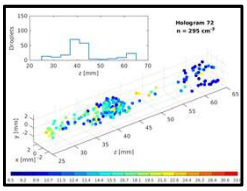
Size, position and 2C velocity estimated with one measurement



Supervised machine learning helps in particle detection



Mixing at the cloud top simulated in the laboratory chamber



Droplets at the interface spatially distributed in filaments

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