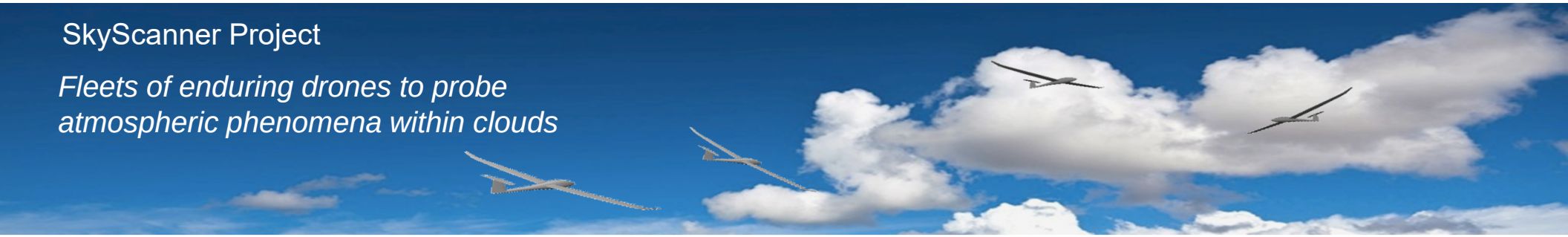


3D in-situ measurements of entrainment-related cumulus clouds properties using a swarm of unmanned aerial vehicles

Fayçal Lamraoui[1], Greg Roberts[1,2], Frédéric Burnet[1], Simon Lacroix[3]

1 Météo-France/CNRS, CNRM/GMEI/MNPCA
2 Scripps Institution of Oceanography
3 LAAS, CNRS

4th Conference of the International Society for Atmospheric Research using Remotely-piloted Aircraft

Toulouse, France May 23-25

1. Motivation
2. Numerical experiment
3. Macroscopic model & LES-based cloud microphysics
4. 3D Sampling strategy

Shallow convective clouds

- Significant role in controling Earth's global energy budget

- A proper parametrization of shallow cumulus is necessary to accurately model the global radiation balance in General Circulation Models

- NWP and climate models have coarse resolution to resolve cumulus process ===> Need => LES (sub-grid processes)

Determination of cloud properties still a persistant challenge for cloud modelling

Problem/Challenge

What is the dominant mixing mechanism ?
The Dilution of cloudy updraft is mainly cause by ?

Entrainment

⇩

Long-lasting controversy

Entrainment/Detrainment → is still an active field of research problem for > half a century

The existing **mixing models** are very diverse

Lateral mixing models

.
.

Cloud-top mixing models

.
.

The lack of **observations** of cumulus clouds properties has caused a divergence in the formulation of cloud models

Studies of shallow cumulus

Field experiments

ARM Atmospheric Radiation Measurement	Diurnal Cycle Cumulus
BOMEX Barbados Oceanographic and Meteorological Experiment	Steady state Trade wind cu
ATEX Atlantic Trade-wind Experiment	Trade wind cu topped with Scu
RICO Rain in cumulus over the Ocean experiment	Precipitating trade wind cu

LES (Large Eddy Simulation)

Cloud

Single

Ensemble

Parametrization

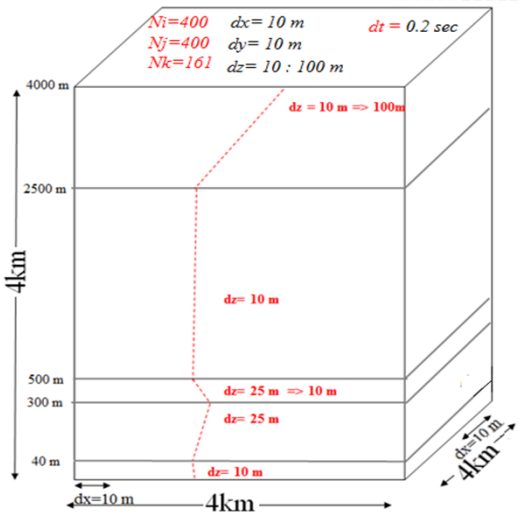
Climate/NWP Models

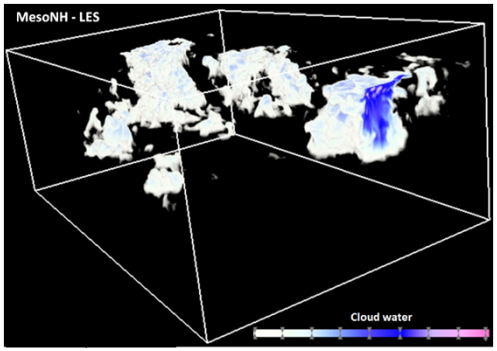
MesoNH (LES simulation) – Shallow convective clouds

Fields & forcings

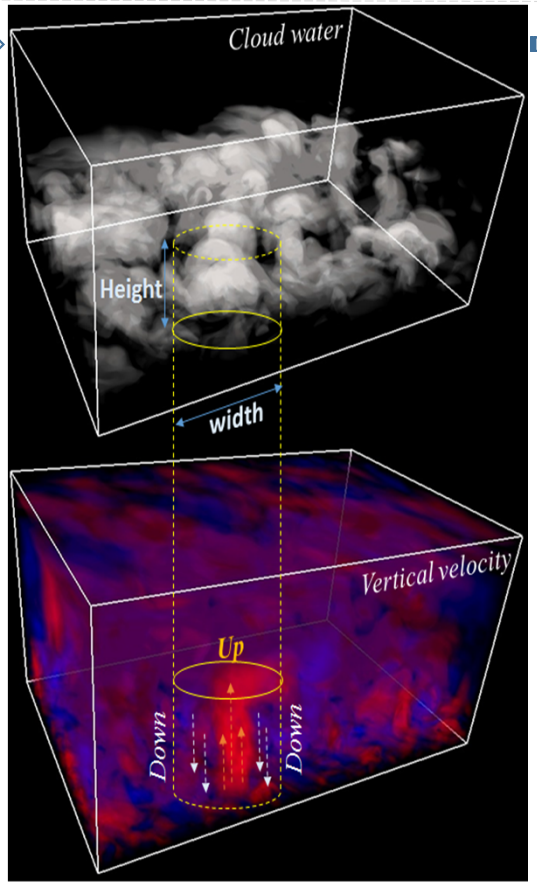
Field campaign
ARM-SGP
Brown et al 2002

Grid setup





Output



Post-processing (output/second)

Macroscopic Model

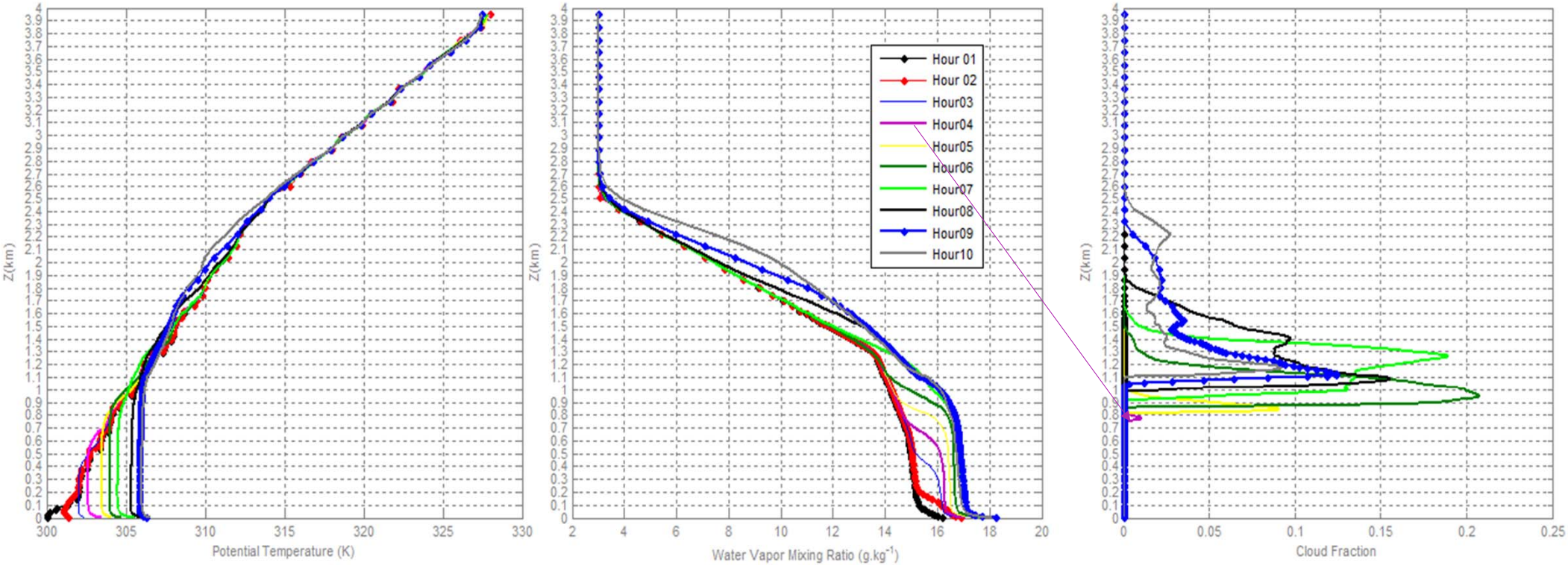
- Cloud Geometry Vs Vertical velocity
- Cloud Tracking
- Cumulus Microphysics

Objective

Locate sensitive zones
(within and around the cloud)

Adaptive sampling
using drones

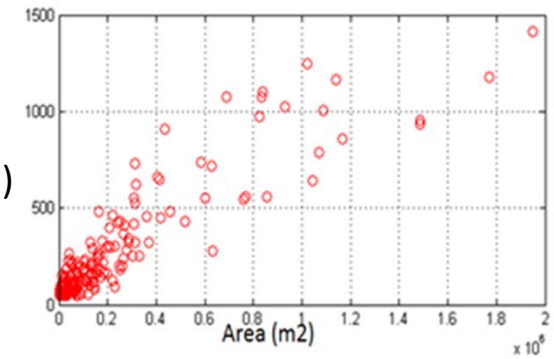
Mean profiles (15 hrs simulation) Start time (LT): **05:30 AM**



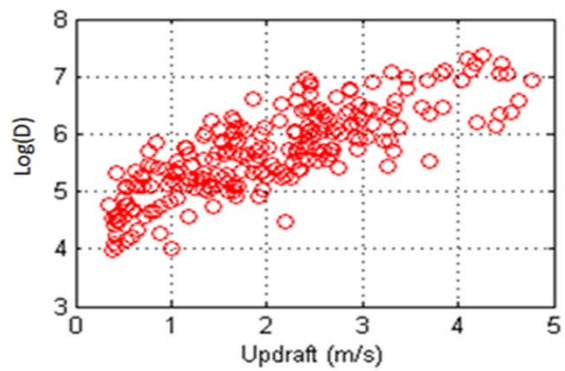
Geometry vs **W cloud base**

376 individual clouds

H(m)

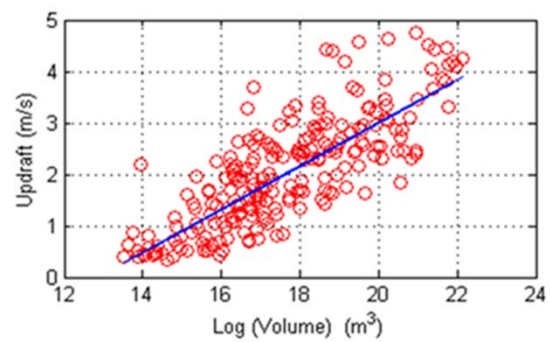


$$H = a_1 . D^2 + b_1$$



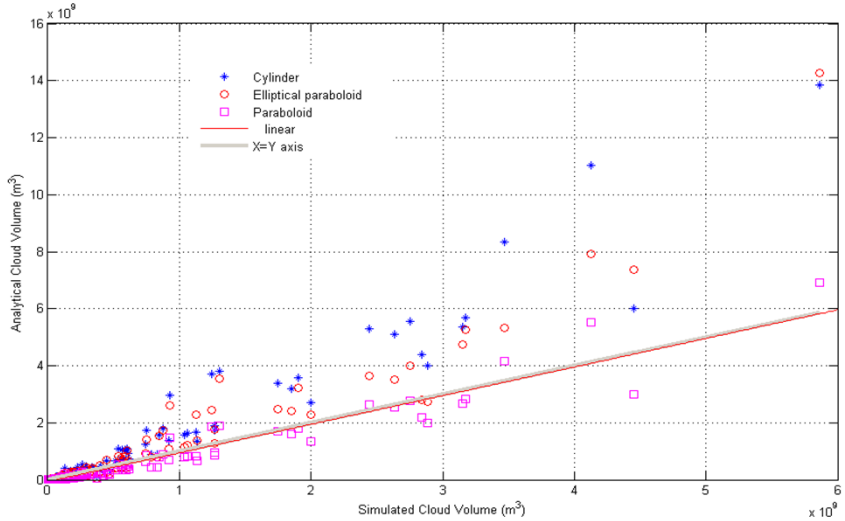
$$\log(D) = a_2 . W + b_2$$

$$W = a_3 . \log(\sqrt{H}) + b_3$$

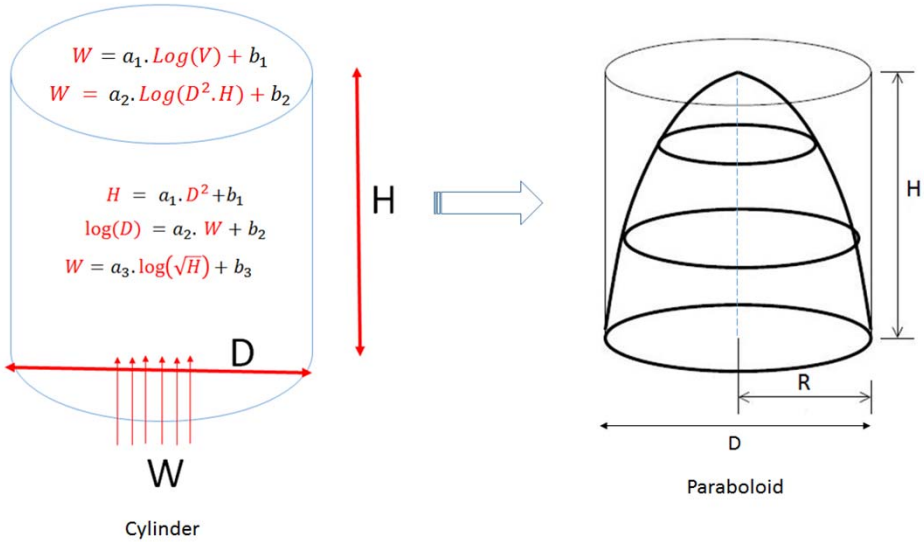


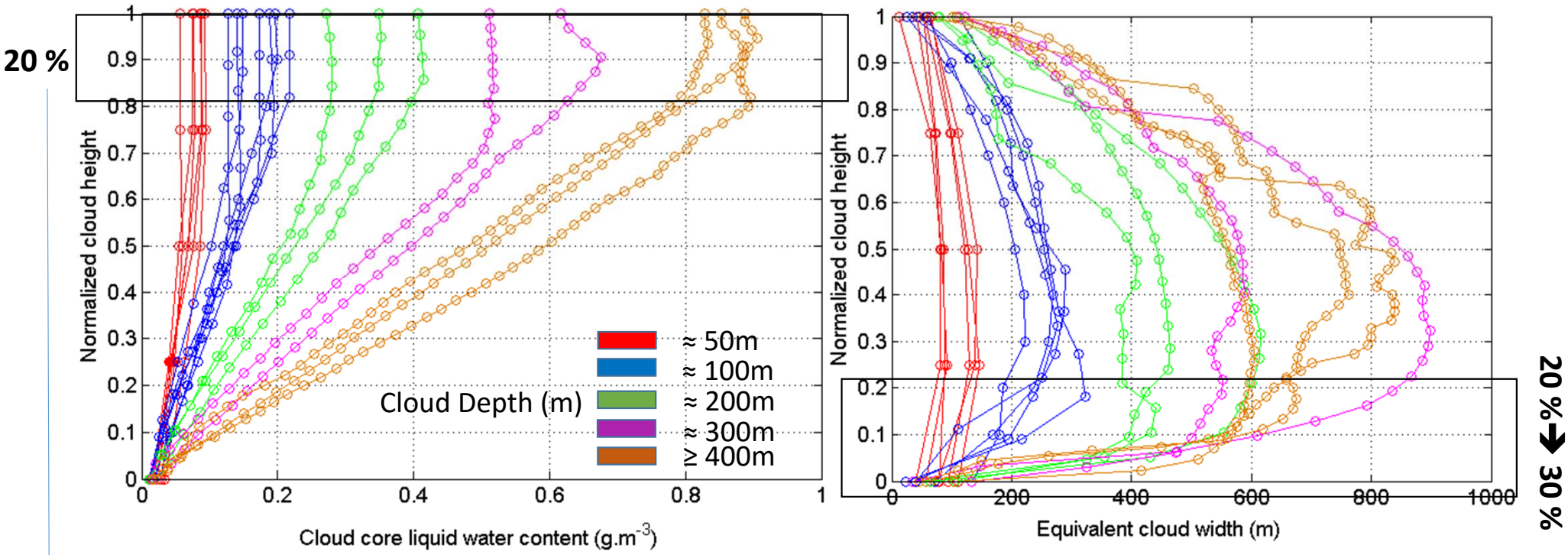
$$W = a_1 . Log(V) + b_1$$

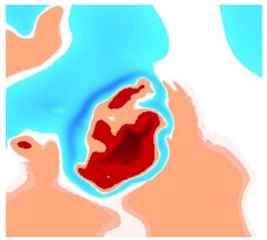
$$W = a_2 . Log(D^2 . H) + b_2$$



Shallow cumulus clouds (over land) can be represented by **Paraboloid**





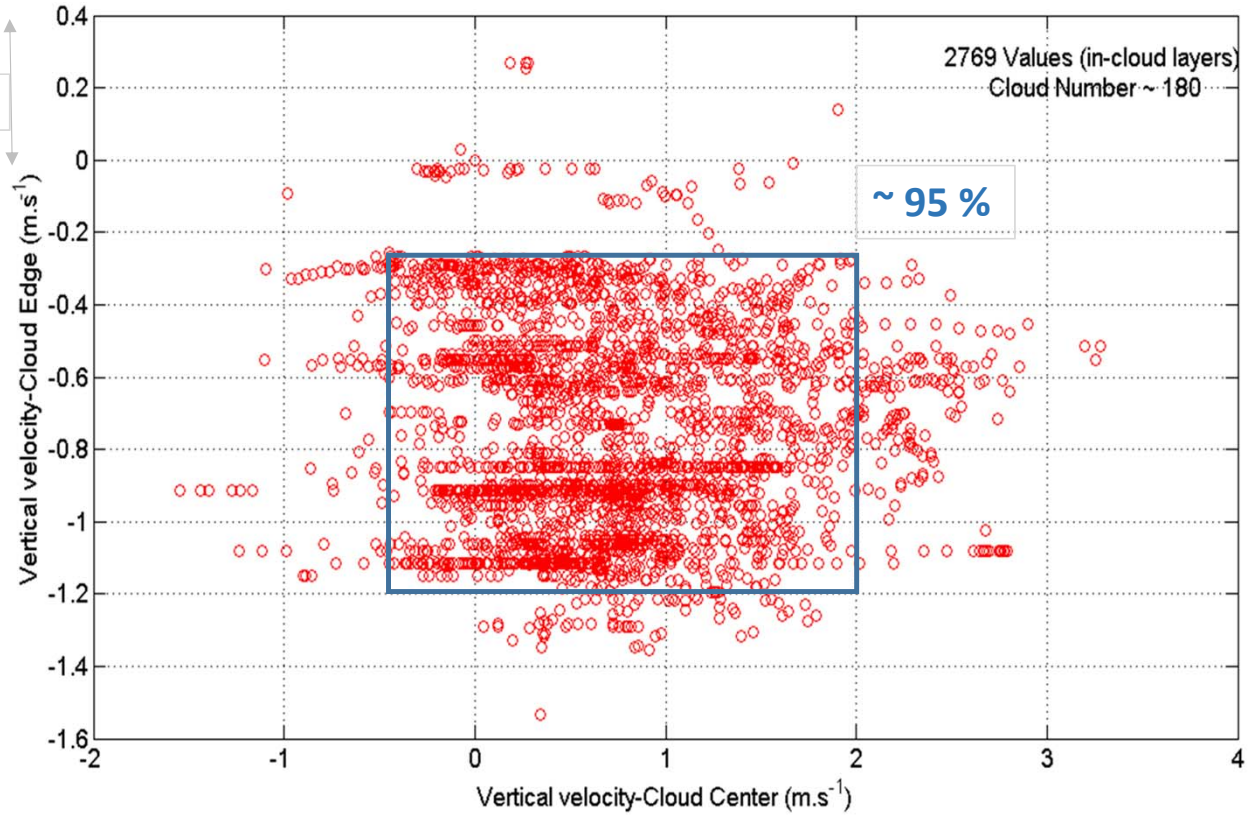


Vertical velocity (upper 20% of cloud height)

Subsiding shell

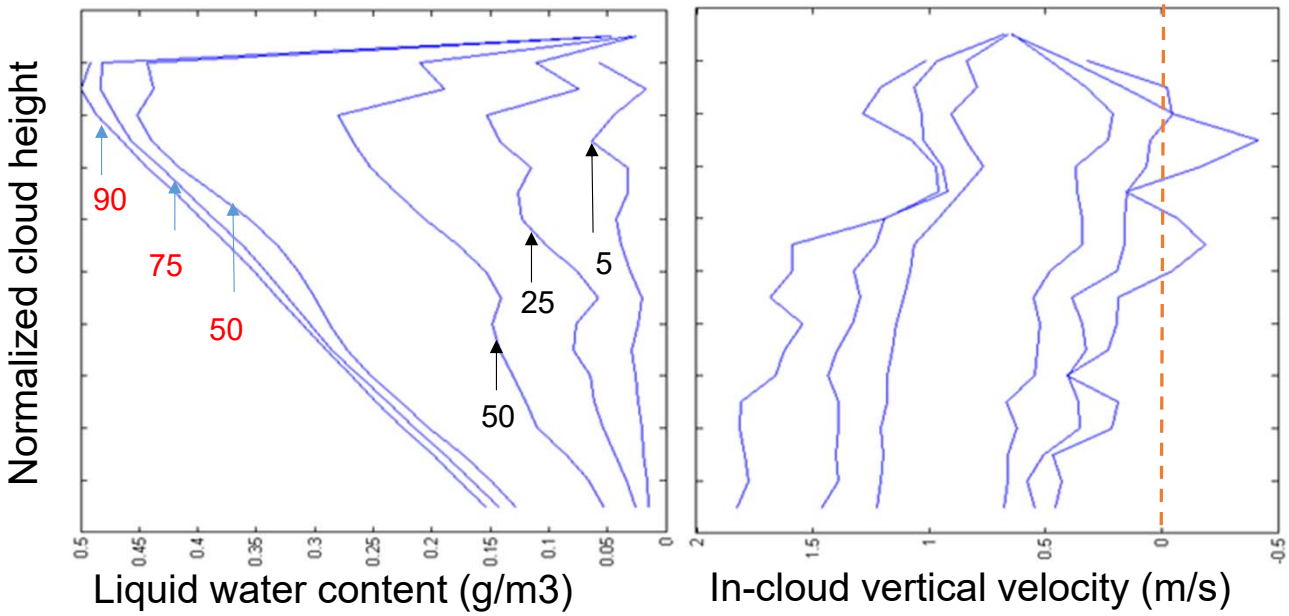
In-cloud Vertical Velocity
(Cloud center Vs Cloud Edge)

W_edge >0 ➔ 0.22 %



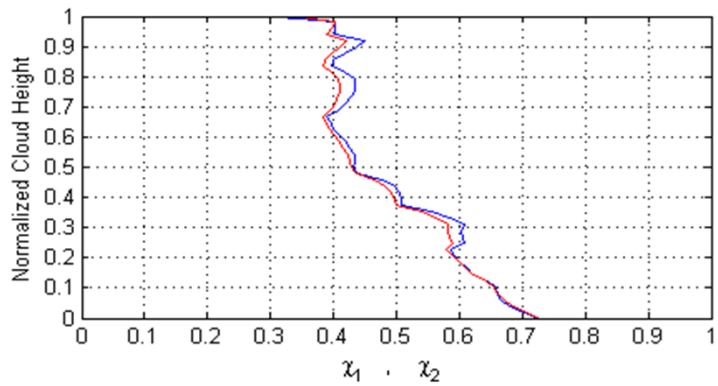
W Center<0 ~ 14 %

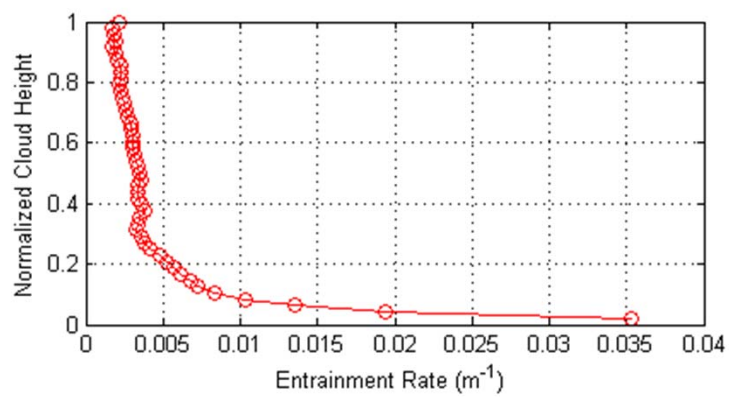
W Center>0 ~ 86 %

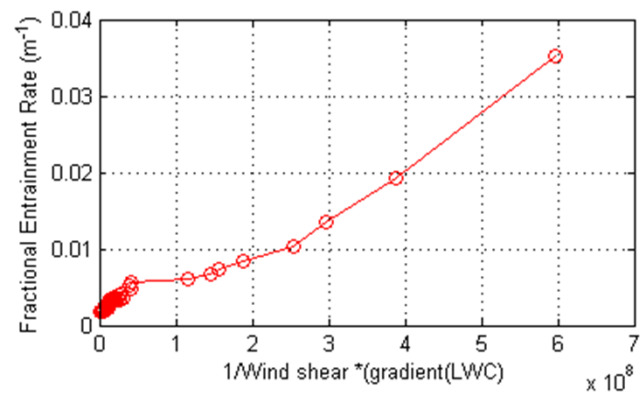

Normalized cloud height
90
75
50
50
25
5
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Liquid water content (g/m3)
2
1.5
1
0.5
0
-0.5
In-cloud vertical velocity (m/s)

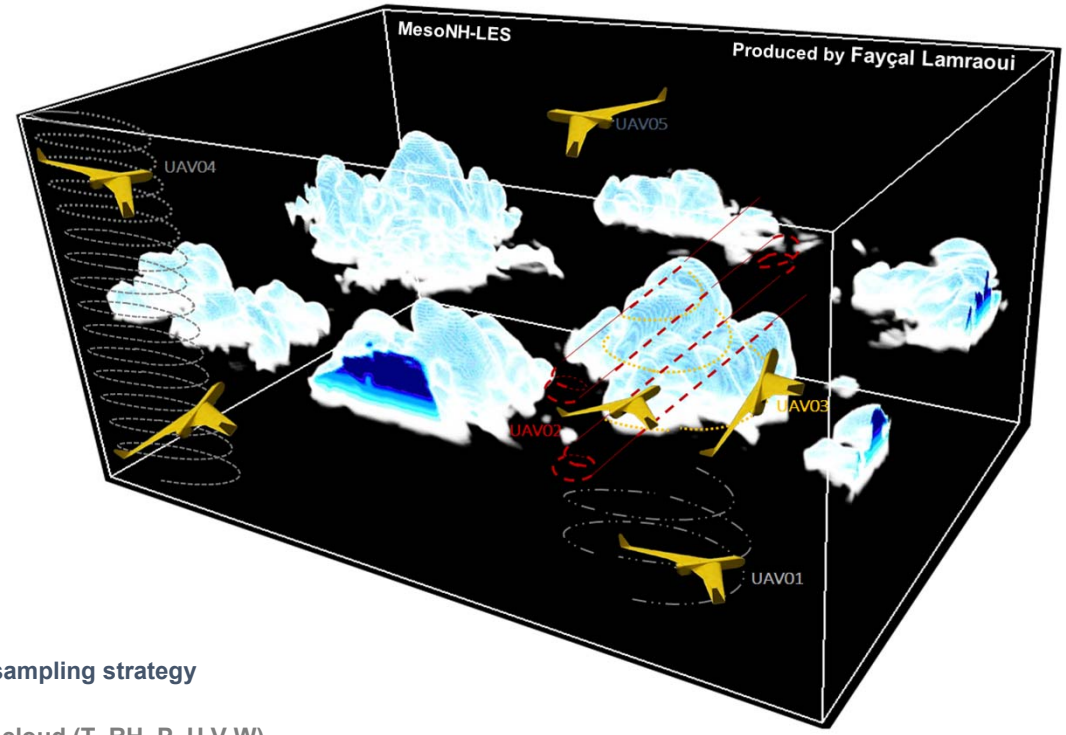
Conservation
- Moist static energy
- Mass

⇨ Mixing ratio ⇨ Fractional Entrainment Rate









Multi-UAVs cumulus cloud sampling strategy

- **UAV01: Below-cloud (T, RH, P, U,V,W)**
- **UAV02: In-cloud and near-cloud environment (LWC, T, P, U, V, W)**
- **UAV03: In-cloud edge and geometry tracking**
- **UAV04: Cloud free atmosphere (T, RH, P, U, V, W)**
- **UAV05: Cloud field sampling (LWC, T, RH, P, U, V, W)**