SkyScanner Project

Fleets of enduring drones to probe atmospheric phenomena within clouds

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

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

- Significant role in controlling 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
  \[\Rightarrow\] Need \[\Rightarrow\] LES (sub-grid processes)

Determination of cloud properties still a persistent challenge for cloud modelling
Problem/Challenge

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

LES (Large Eddy Simulation)

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

Cloud

Single

Ensemble

Parametrization

Climate/NWP Models
MesoNH (LES simulation) – Shallow convective clouds

Fields & forcings

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

Field campaign
ARM-SGP
Brown et al 2002
Mean profiles  (15 hrs simulation)  Start time (LT): **05:30 AM**
Geometry vs W cloud base

376 individual clouds

\[ H = a_1 \cdot D^2 + b_1 \]
\[ \log(D) = a_2 \cdot W + b_2 \]
\[ W = a_3 \cdot \log(\sqrt{H}) + b_3 \]

\[ W = a_1 \cdot \text{Log}(V) + b_1 \]
\[ W = a_2 \cdot \text{Log}(D^2 \cdot H) + b_2 \]
Shallow cumulus clouds (over land) can be represented by **Paraboloid**

\[
\begin{align*}
W &= a_1 \cdot \log(V) + b_1 \\
W &= a_2 \cdot \log(D^2, H) + b_2 \\
H &= a_3 \cdot D^2 + b_3 \\
\log(D) &= a_4 \cdot W + b_4 \\
W &= a_5 \cdot \log(\sqrt{H}) + b_5
\end{align*}
\]
Cloud Depth (m)

Cloud core liquid water content (g.m$^{-3}$)

Vertical velocity (upper 20% of cloud height)

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

W_edge >0  \(\rightarrow\)  0.22 %

W Center<0  \(~\)  14 %

W Center>0  \(~\)  86 %

\(\sim 95\%\)
Conservation

- Moist static energy
- Mixing ratio
- Fractional Entrainment Rate

Mass

\[ \text{Normalized Cloud Height} \]

\[ \chi_1, \chi_2 \]

\[ \text{Entrainment Rate (m}^{-1}) \]

\[ \text{Fractional Entrainment Rate (m}^{-1}) \]

\[ \frac{1}{\text{Wind shear}} \text{ (gradient (LWC))} \times 10^6 \]
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)