Vertical variation of turbulent entrainment mixing processes in marine stratocumulus clouds over ENA using digital holography

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HOLODEC (Holographic Detector for Clouds)
A joint development between Michigan Technological University, Mainz University, and NCAR

- Conventional
  - 1 particle in beam at a time

- Holodec
  - 13 cc ~10^3 droplets
  - 30-60 m
  - Instantaneous cm scale cloud properties
  - No spatial/temporal averaging
  - Current focus on warm clouds IOP1

Raymond Shaw, MTU
Objectives:

1. How does entrainment mixing behavior vary with altitude in a stratocumulus layer?

2. Can we explain this behavior using turbulence measurements?
Mixing diagrams attempt to display the mixing regimes

Extreme in-homogenous mixing

\[ Y \text{ - Mean droplet volume} \]

\[ V = \text{constant, } N < N_a \]

Dry air entrained

Homogenous mixing

\[ V < V_a, \ N = \text{constant} \]

Dry air entrained

- Normalized by the adiabatic value

Yum et al. 2015 JGR
Mixing Diagram observations

- Each data point is a hologram and colored by the relative dispersion of the hologram.
- Cloud top shows primarily inhomogeneous type mixing (IM)
- Cloud base shows primarily homogeneous type mixing (HM)
- Confirms that mixing proceeds from IM near cloud top to HM near cloud base (Yum et al. 2015 JGR)
Damkohler No.

\[ Da = \frac{\tau_t}{\tau_r} \]

\( \tau_t \) – Turbulence mixing time scale  
\( \tau_r \) – Microphysical time scale

Large \( Da \) – Fast microphysics - IM  
Small \( Da \) – Slow microphysics - HM

\[ \tau_t = \frac{u'^2}{\varepsilon} \quad \tau_{phase} = \frac{1}{4\pi D n r} \]

\( \varepsilon \) - dissipation rate  
\( u' \) – velocity fluctuation  
\( D \) – diffusivity

\[ \tau_{evap} = -\frac{r_a^2}{2A S_0} \]

A – growth parameter,  
\( S_0 \) – supersaturation deficit
Which microphysical time scale to use?

\[ \tau_{phase} = \frac{1}{4\pi Dn r} \]

Considers ensemble of droplets, \( n \) is important

\[ \tau_{evap} = -\frac{r_a^2}{2AS_0} \]

Considers each droplet individually

\( S_0 \) – Above cloud saturation deficit (-45%)

\( S_0 \) is important

For Cloud top, mid and base,

\( \tau_{evap} \) assumes \( S_0 = \) constant?

As parcel descends, mixing and droplet evaporation will bring it closer to saturation

\( S_0 = -45\% \)

\( RH = 100\% \)
Considering variation of $S_0$ with height

$$T_{evap}^* = -\frac{r_a^2}{2A S_0(z)}$$

$S_0(z)$ – Saturation deficit as a function of cloud height

- $S_0(1.0) = 1.0 \times S_0$ at cloud top
- $S_0(0.5) = 0.5 \times S_0$ at cloud middle
- $S_0(0.0) = 0.0 \times S_0$ at cloud base

$T_{evap}$ now agrees with mixing diagram observations and $T_{phase}$

Variation of $S_0$ with height needs to be considered
Conclusions

1. Mixing: inhomogeneous near cloud top, homogeneous near base.

2. Damkohler number measurements can explain this behavior.

3. $T_{\text{evap}}$ needs to consider variability of $S_0$ with height within stratocumulus cloud layer.
Future work/collaborations

1. Effect of aerosols on mixing and drizzle formation.
   - Size and concentration

2. Flight legs parallel and perpendicular to mean wind direction show considerable difference.