Examination of Turbulent Entrainment-Mixing Mechanisms Using a Combined Approach

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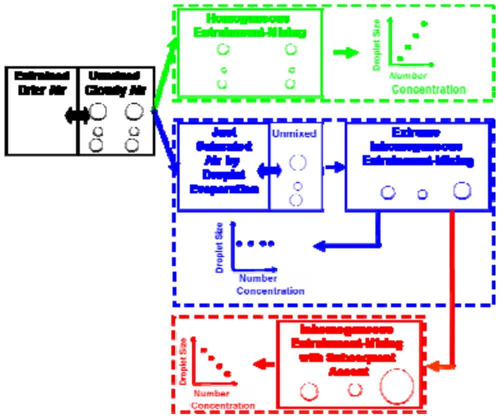
1. Objectives

- To examine turbulent entrainment-mixing processes occurring in the mid-latitude continental stratocumulus clouds;
- To seek the connection between microphysical, thermodynamic and dynamical properties associated with entrainment-mixing processes;
- To explore and use an integrative approach that combines analyses of microphysical, thermodynamic and dynamical relationships.

2. Data

- **Cloud type:** Stratocumulus.
- **Time:** March 2000 cloud Intensive Observation Period (IOP).
- **Site:** Southern Great Plains (SGP), USA.
- **Aircraft:** Citation research aircraft of the University of North Dakota.
- **Instruments:**
  Cloud droplet spectra --- Forward Scattering Spectrometer Probe (FSSP);
  Drizzle drop spectra --- Optical array probe 1D-C;
  Air temperature --- Rosemount Model 102.

3. Types of Entrainment-Mixing Mechanisms



The relationship between droplet size and number concentration is closely related to different entrainment-mixing mechanisms.

Figure 1. Schematic illustration of three types of entrainment-mixing (e.g., Baker et al., 1984; Yum, 1998)

4. Method One: Microphysics

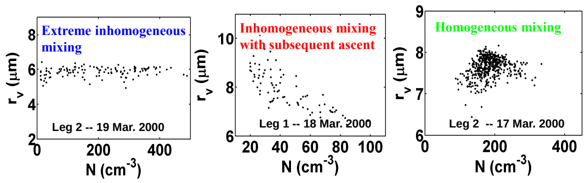


Figure 2. Relationship between the volume-mean radius (r_v) and the number concentration (N).

The inhomogeneous entrainment-mixing mechanism, especially the extreme scenario, dominates over the homogeneous mechanism.

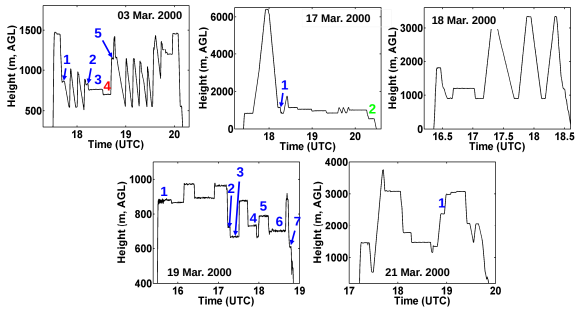


Figure 3. Temporal evolution of the aircraft height in the five cases. The numbers in the figures are horizontal leg numbers and different colors represent different mechanisms.
Blue: extreme inhomogeneous entrainment-mixing mechanism;
Red: inhomogeneous entrainment-mixing with subsequent ascent;
Green: homogeneous entrainment-mixing mechanism.

5. Method Two: Thermodynamics
--- *Filament Structure*

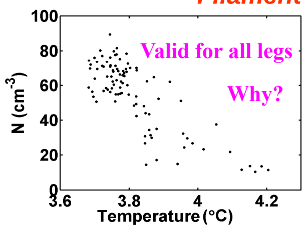


Figure 4. Relationship between the air temperature and the number concentration (N) along Leg 1 of the 17 March 2000 case.

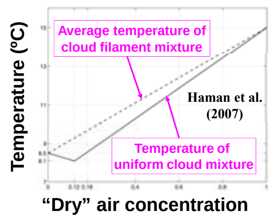


Figure 5. Mixing diagram of the air from the cloud top and from above the inversion.

Filament structure is partially responsible for the observed dominance of the extreme inhomogeneous mechanism.

6. Method Three: Dynamics
--- *Transition Scale Number*

NEW!

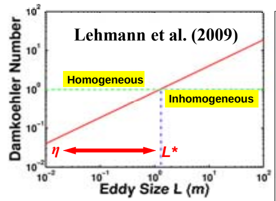


Figure 6. Damkohler number as a function of entrained eddy size (an example).

We define transition scale number (N_L) as:

$$N_L = \frac{L^*}{\eta} = \frac{\xi^{1/2}\tau_{react}^{3/2}}{\eta}$$

where
L^*: transition length derived by Lehmann et al. (2009);
η: Kolmogorov scale;
ξ: turbulent dissipation rate;
τ_{react}: the time needed for droplets to evaporate in a subsaturated blob or a blob to obtain saturation.

A larger value of transition scale number indicates a higher probability of the homogeneous process.

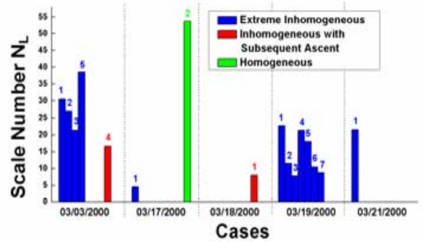


Figure 7. Bar plot for the average scale number (N_L) along different legs in the five cases. The numbers in the figure are horizontal leg numbers.

7. Conclusions

- Microphysical analysis shows that the inhomogeneous entrainment-mixing process occurs much more frequently than the homogeneous counterpart, and most cases of the inhomogeneous entrainment-mixing process are close to the extreme scenario.
- Thermodynamic analysis shows that sampling average of filament structures partially contributes to the dominance of inhomogeneous entrainment-mixing mechanism.
- A new dimensionless number, scale number, is introduced as a dynamical measure for different entrainment-mixing processes, with a larger scale number corresponding to a higher degree of homogeneous entrainment-mixing.
- The combined microphysical-dynamical-thermodynamic analysis sheds new light on developing parameterization of entrainment-mixing processes and their microphysical and radiative effects in large scale models.

References

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Acknowledgments

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