Examination of Entrainment-Mixing Mechanisms Using a Combined Approach

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Motivation

- **Entrainment-mixing processes are important but poorly represented in models.**
- **Entrainment-mixing processes affect Z-LWC relations used in radar retrieval of LWC.**
- **Entrainment-mixing processes affect evaluation of aerosol indirect effects.**
- **Entrainment-mixing mechanisms are examined using a combination of microphysics, dynamics and thermodynamics in stratocumulus clouds.**

Data

- **Cloud:**

  Five stratocumulus cases.

- **Time:**

  The March 2000 cloud Intensive Observation Period (IOP).

- **Site:**

  Southern Great Plains (SGP), USA.

- **Aircraft:**

  Citation research aircraft of the University of North Dakota.

- **Instruments:**

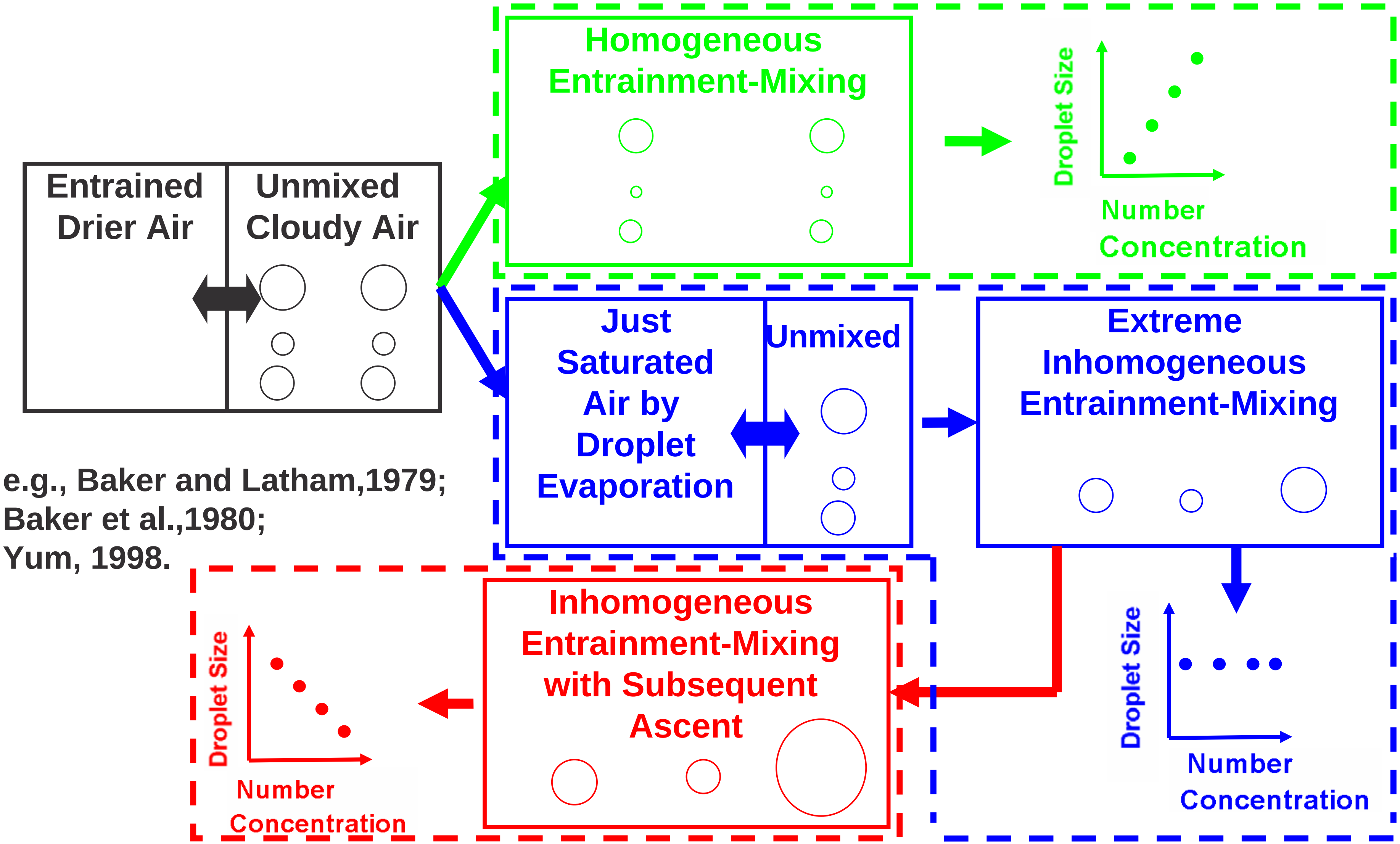
  Cloud droplet spectra --- Forward Scattering Spectrometer Probe (FSSP);

  Drizzle drop spectra --- Optical array probe 1D-C;

  Particle Image --- Cloud Particle Imager (CPI);

  Air temperature --- Rosemount Model 102.

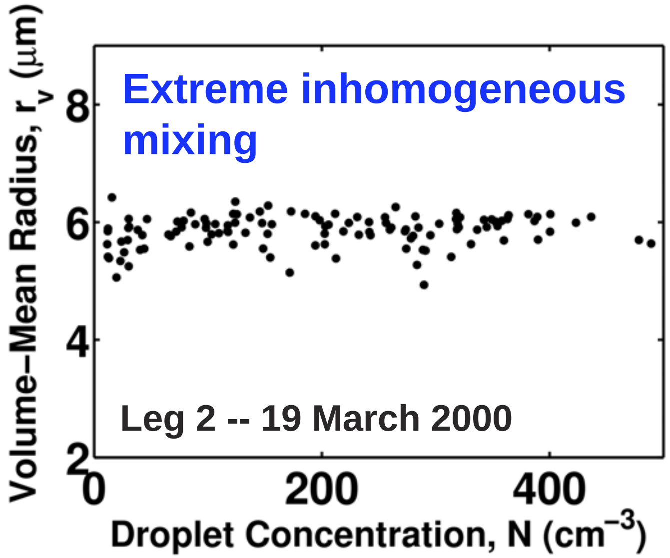
Classification of Entrainment-Mixing Mechanisms

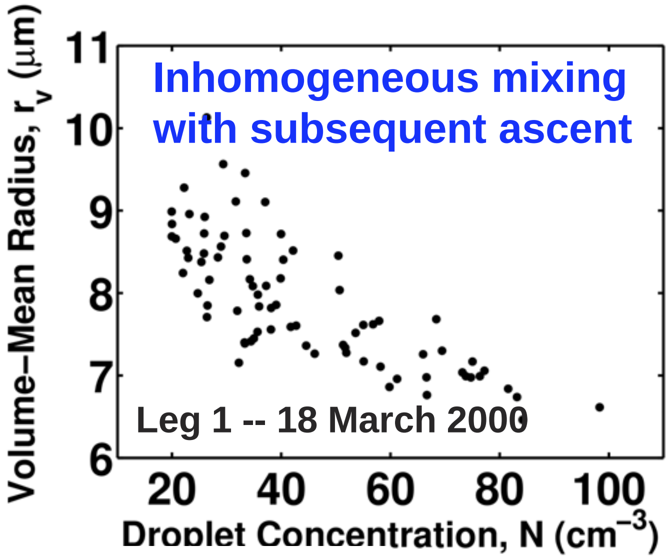


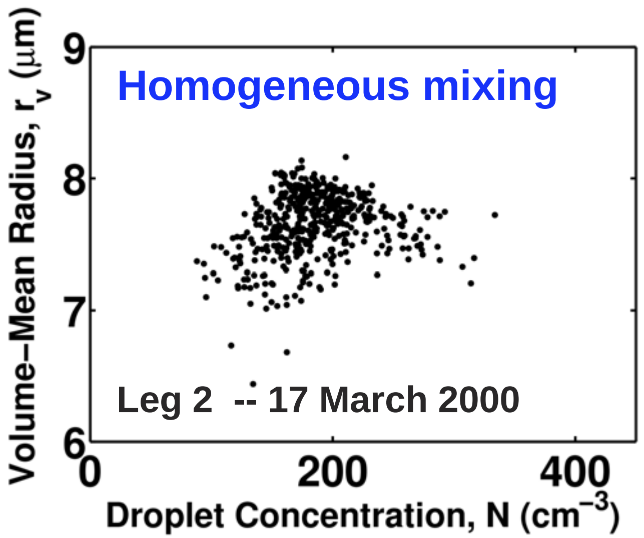
e.g., Baker and Latham,1979;
Baker et al.,1980;
Yum, 1998.

Method One: Microphysics

---Some Examples

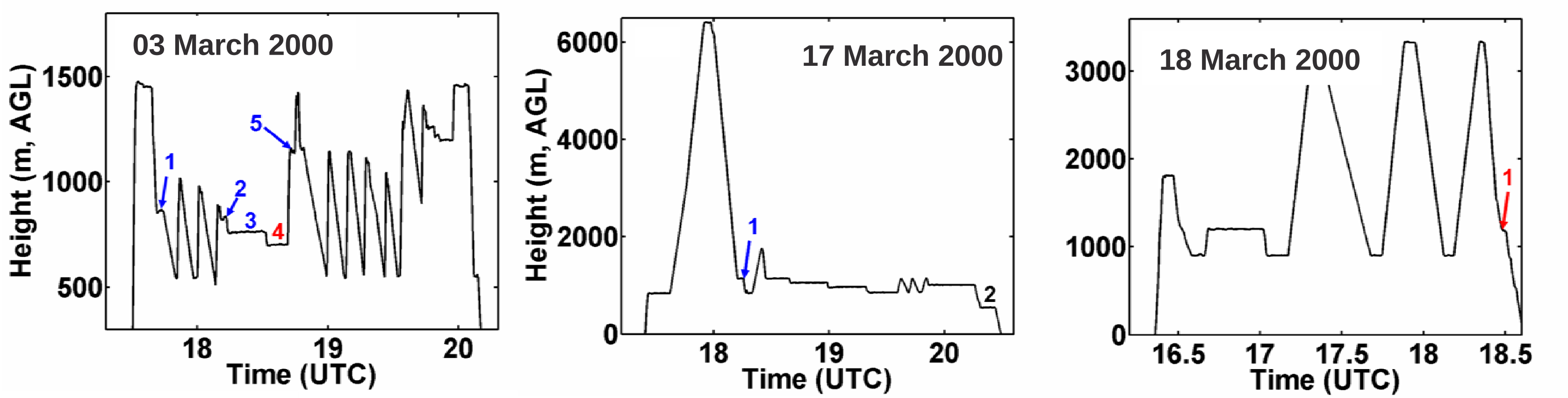


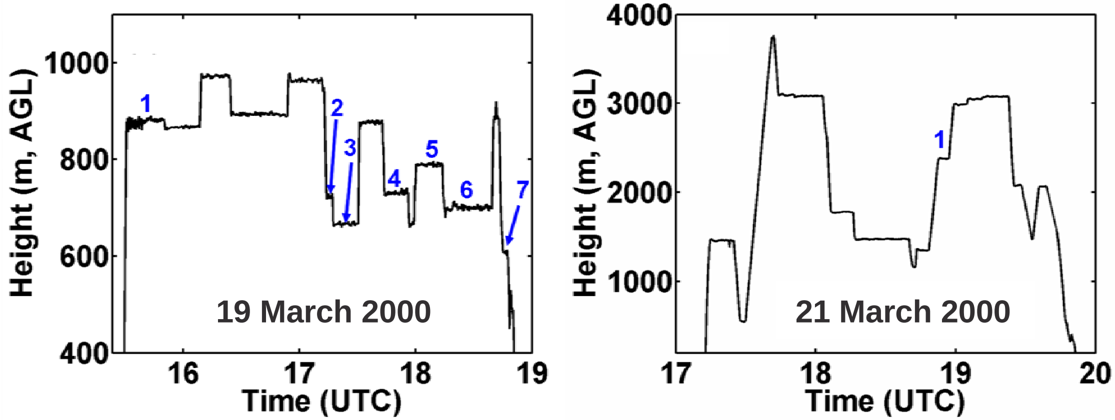




Method One: Microphysics

---Flight Summary





Leg Length > 12 km

<u>Different colors of Leg numbers:</u>

Blue: extreme inhomogeneous mixing <u>(DOMINANT)</u>;

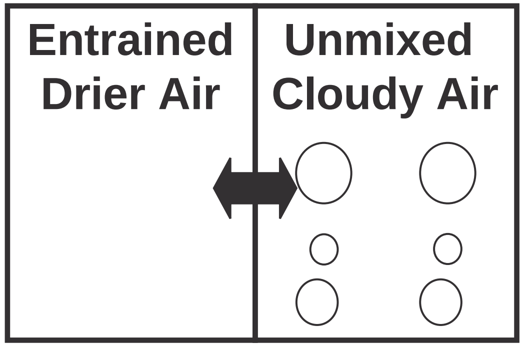
Red: inhomogeneous mixing with subsequent ascent;

Black: homogeneous mixing.

Method Two: Dynamics
---Damkoehler Number

- Damkoehler number:

$$Da = \tau_{mix} / \tau_{react}$$



- τ_{mix}: the time needed for complete turbulent homogenization of an entrained parcel of size *L* (Baker et al., 1984):

$$\tau_{mix} \sim (L^2 / \xi)^{1/3}$$

ξ : dissipation rate

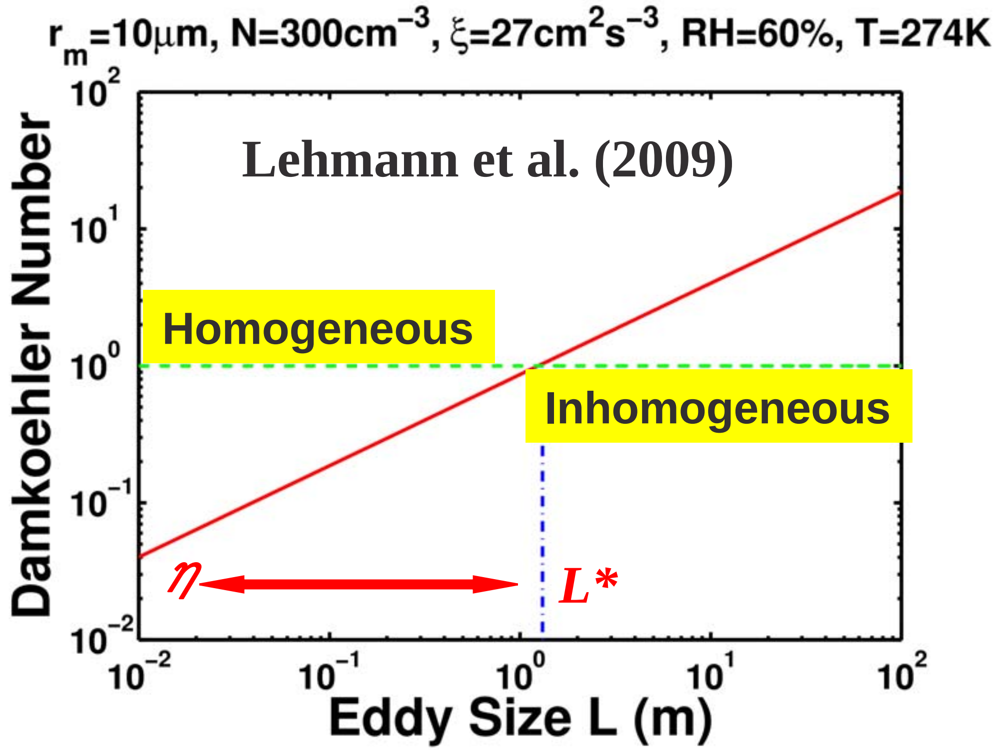
- τ_{react}: the time needed for droplets to evaporate in a subsaturated blob or a blob to be saturated (Lehmann et al. 2009):

$$\begin{cases} \dfrac{d r_m}{d t} = A \cdot \dfrac{s}{r_m} \\ \dfrac{d s}{d t} = -B \cdot s \end{cases}$$

r_m: mean radius
s: supersaturation

Method Two: Dynamics

---Transition Scale Number(1)



A larger value of N_L indicates a higher probability of homogeneous process.

Lehmann et al. (2009) defined transition length (*L) by setting Da =1.**

$$Da = \tau_{\text{mix}} / \tau_{\text{react}} = 1$$

$$\tau_{\text{mix}} \sim (L^2 / \xi)^{1/3}$$

$$L^* = \xi^{1/2} \tau_{\text{react}}^{3/2}$$

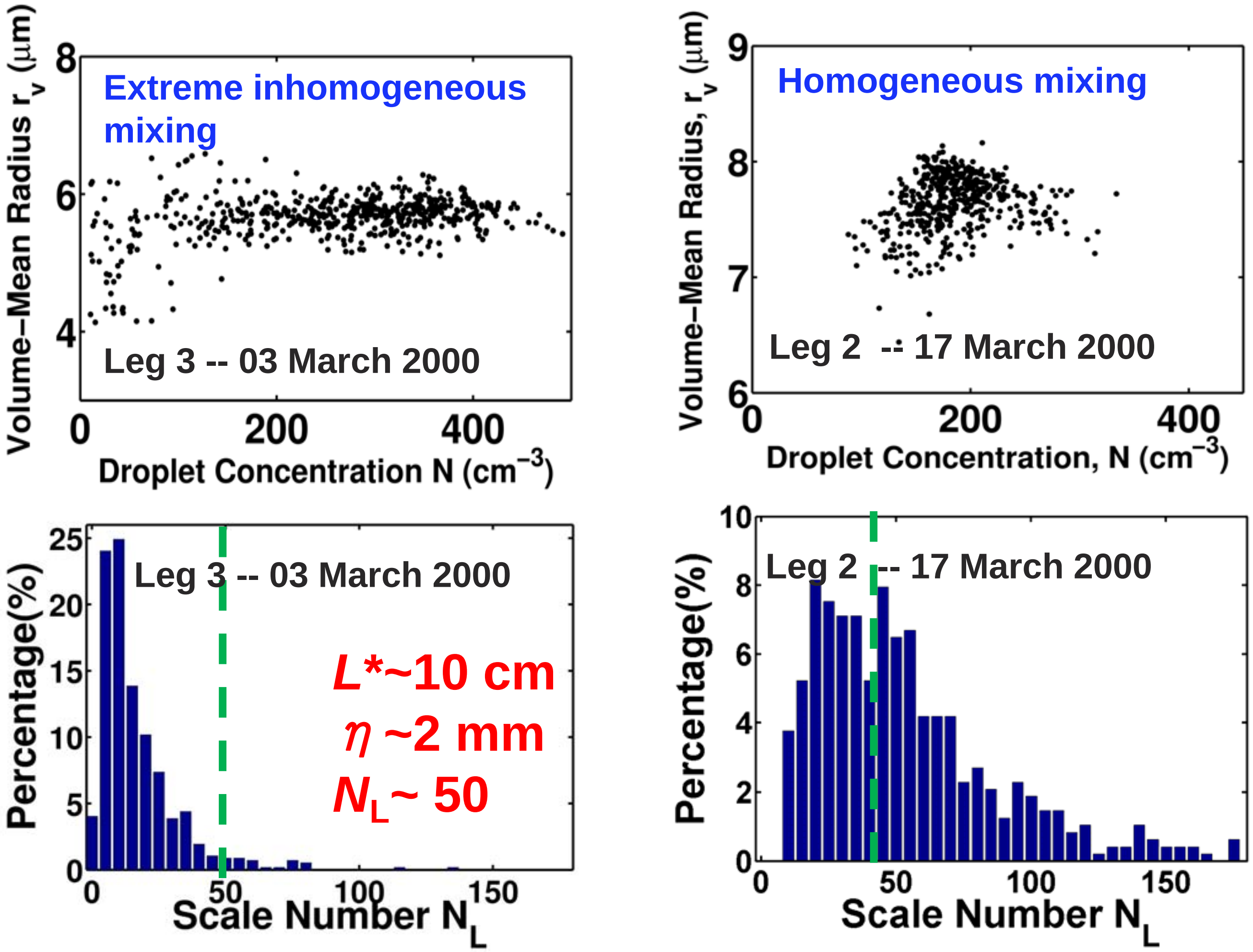
We define transition scale number (N_L) as:

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

η : Kolmogorov scale

Method Two: Dynamics

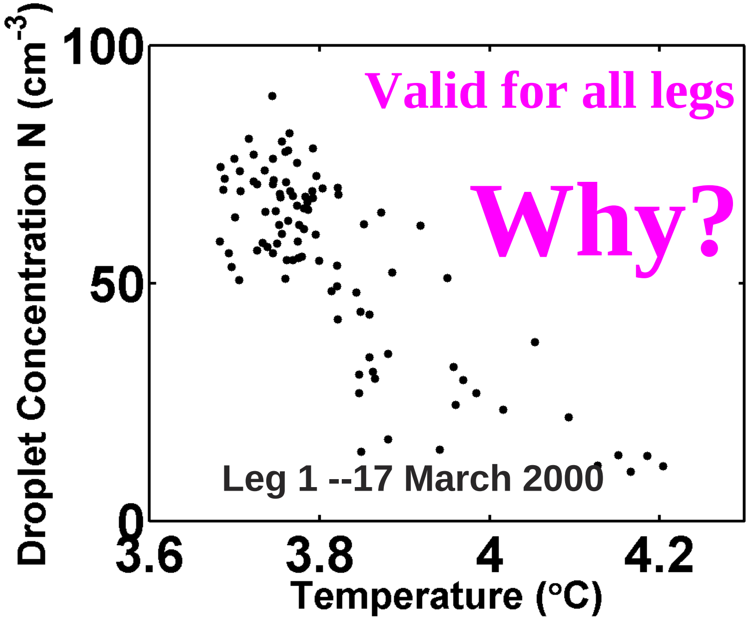
---Transition Scale Number(2)

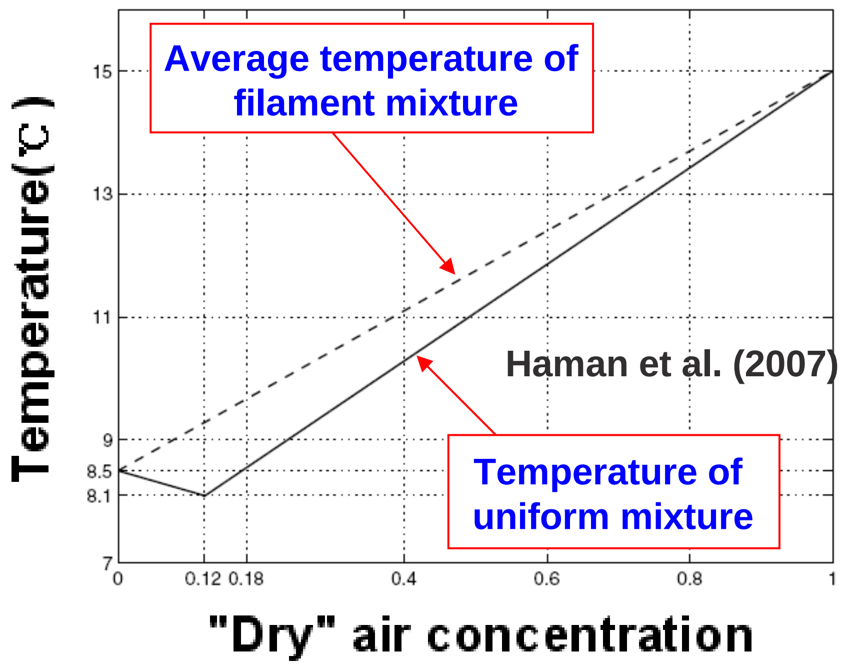


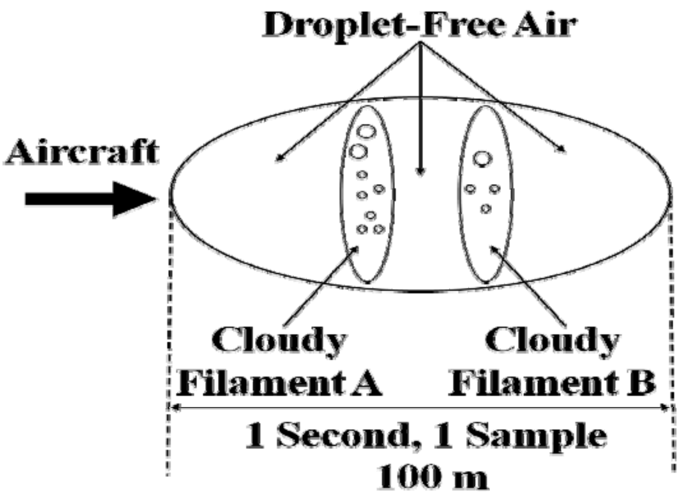
Different entrainment-mixing mechanisms tend to occur simultaneously and one dominant mechanism can not rule out the occurrence of the others.

Method Three: Thermodynamics

---Filament Structure







Filament structure is partially responsible for the observed dominance of the extreme inhomogeneous mechanism (Haman et al., 2007).

Summary

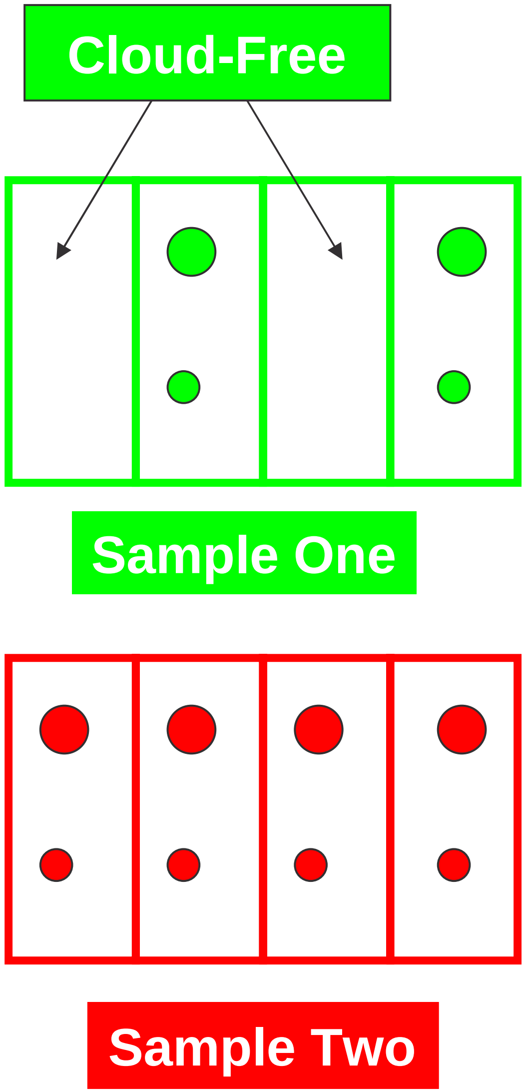
- **Microphysics:**
  - The inhomogeneous entrainment-mixing process occurs much more frequently than the homogeneous counterpart;
  - Most cases of the inhomogeneous entrainment-mixing process are close to the extreme scenario.

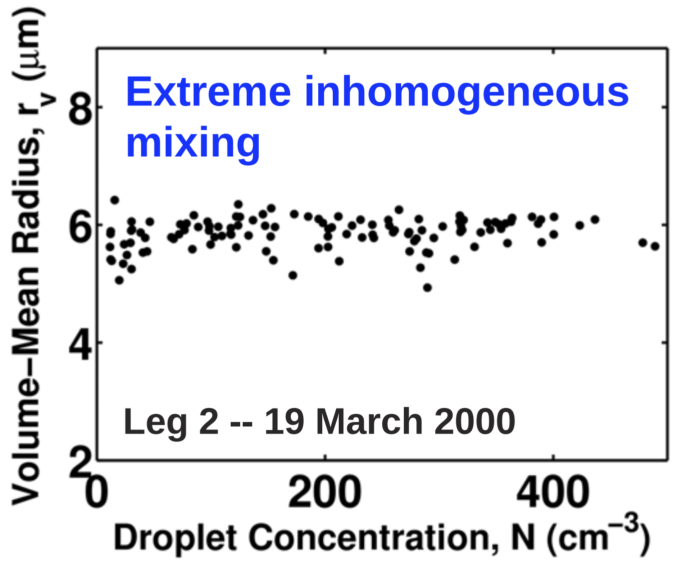
- **Dynamics:** A new dimensionless number, scale number, is introduced, with a larger value corresponding to a higher degree of homogeneous entrainment-mixing.

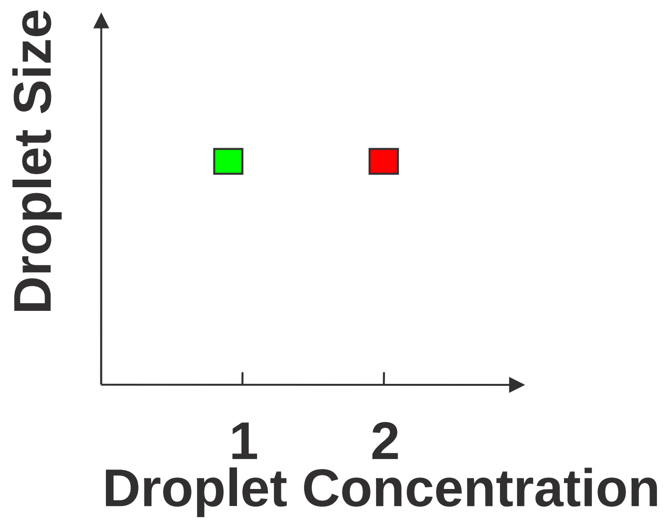
- **Thermodynamics:** Sampling average of filament structures also contributes to the dominance of inhomogeneous entrainment-mixing mechanism.

Back up

Filament Structure

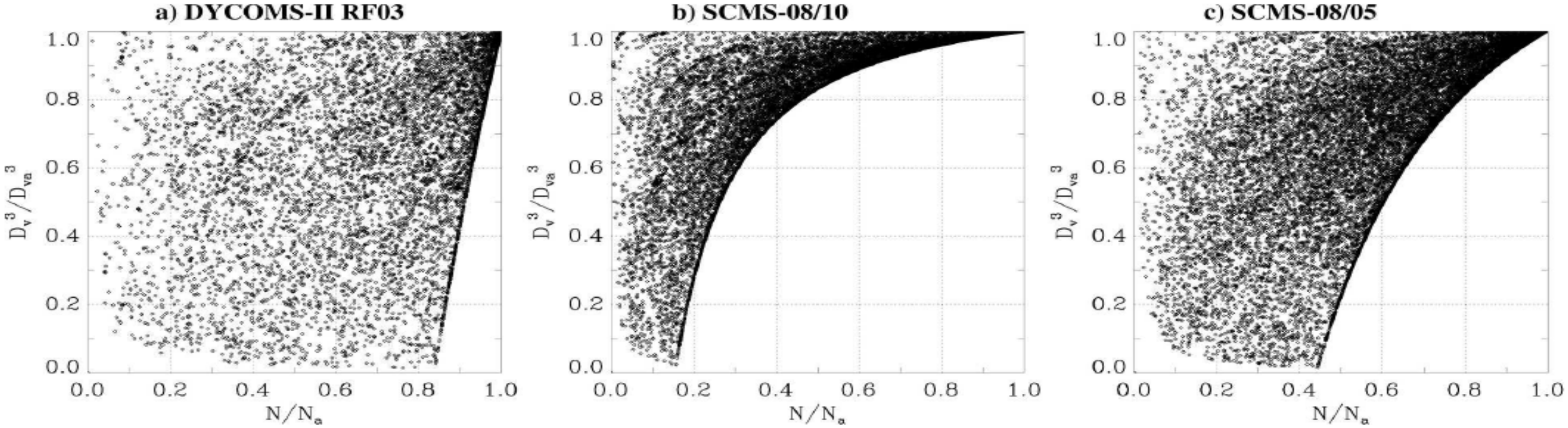






Scale-Dependence of Entrainment-Mixing Mechanism

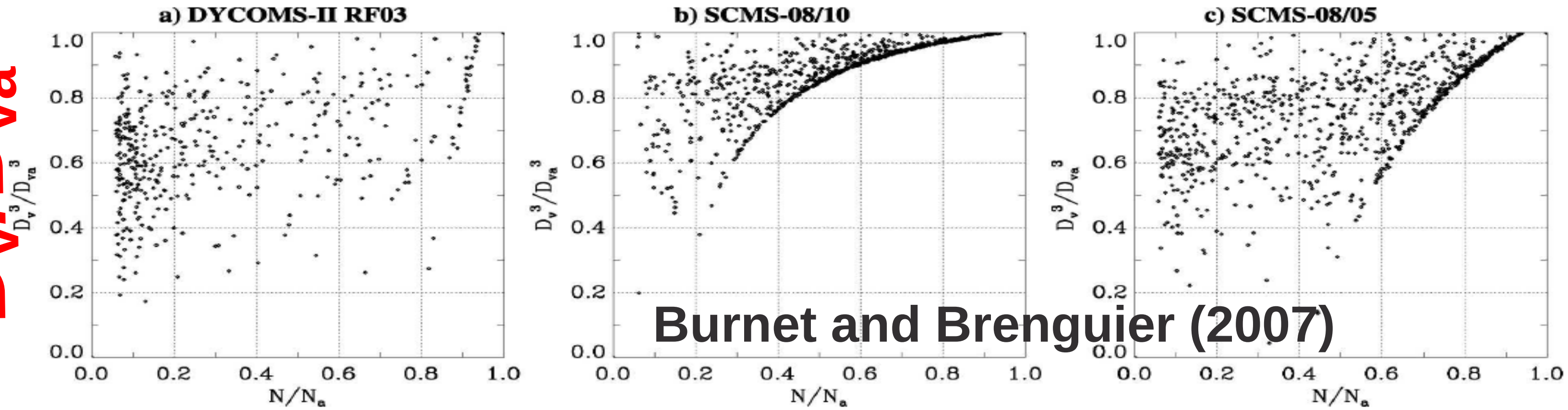
D_v/D_{va}



N/N_a

Each Point: every mixing event

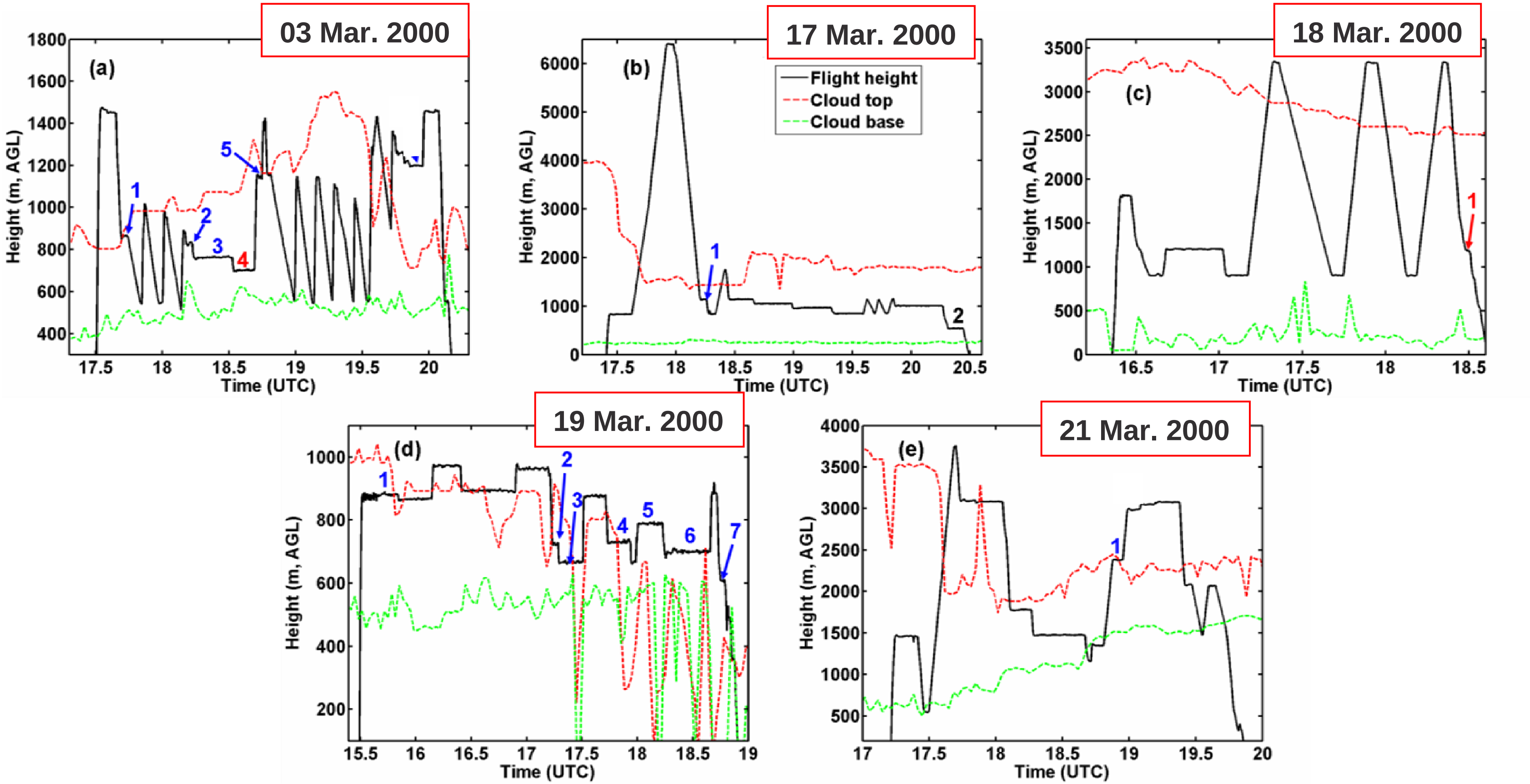
D_v/D_{va}



Burnet and Brenguier (2007)

N/N_a Each Point: average of 50 successive mixing events

Method One: Microphysics (Summary)



<u>Different colors of Leg numbers:</u>

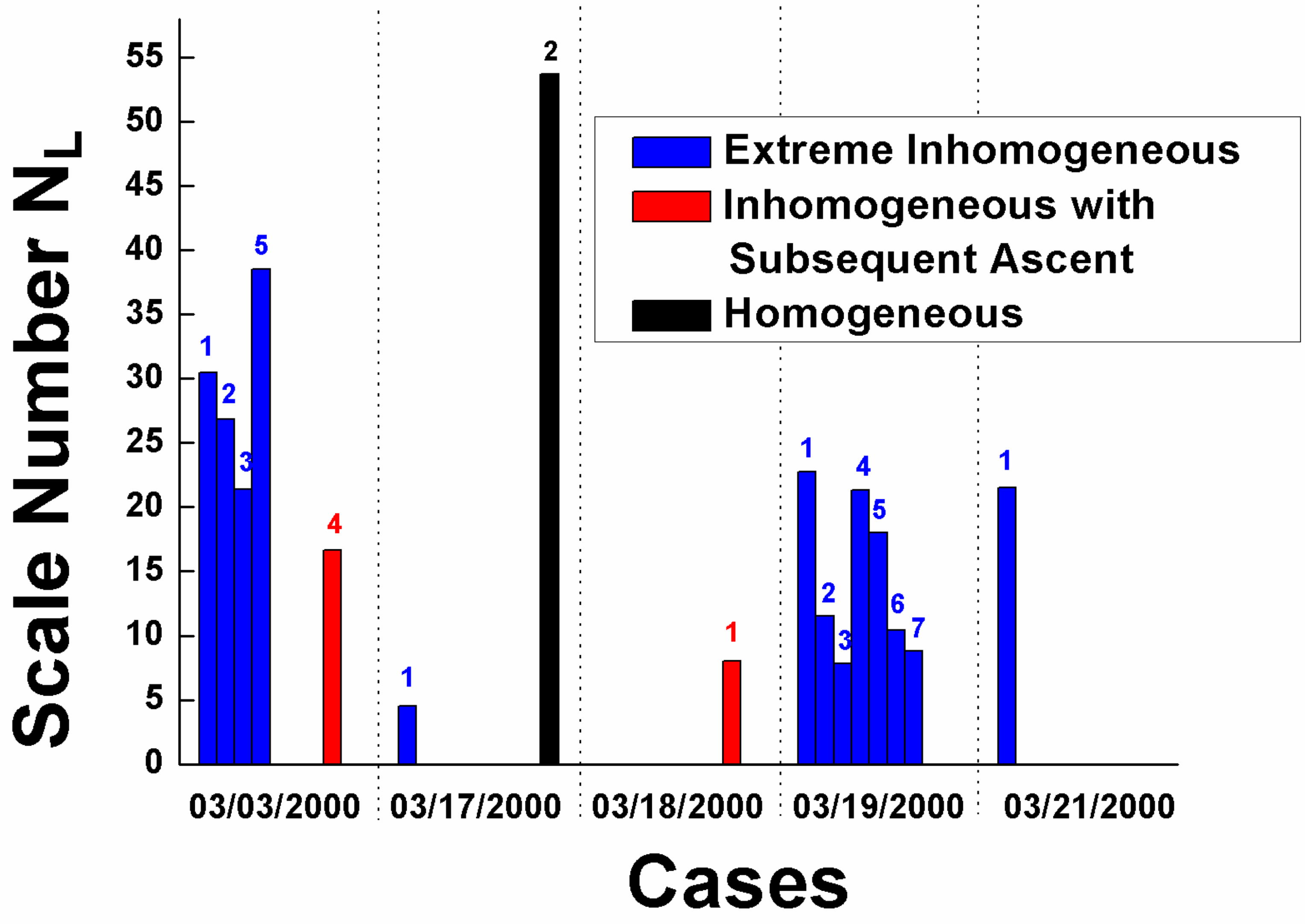
Blue: extreme inhomogeneous entrainment-mixing <u>(DOMINANT)</u>;

Red: inhomogeneous entrainment-mixing with subsequent ascent;

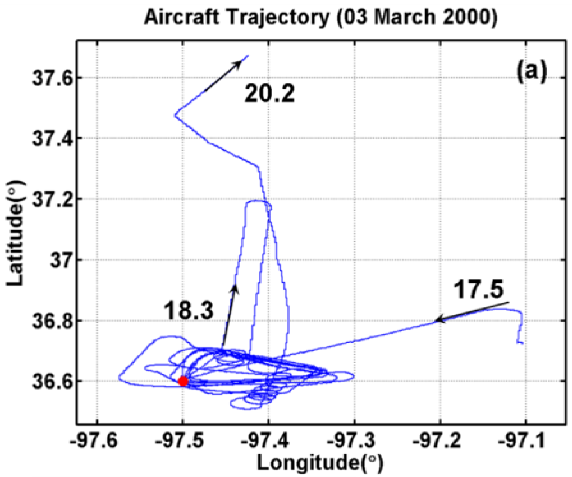
Black: homogeneous entrainment-mixing.

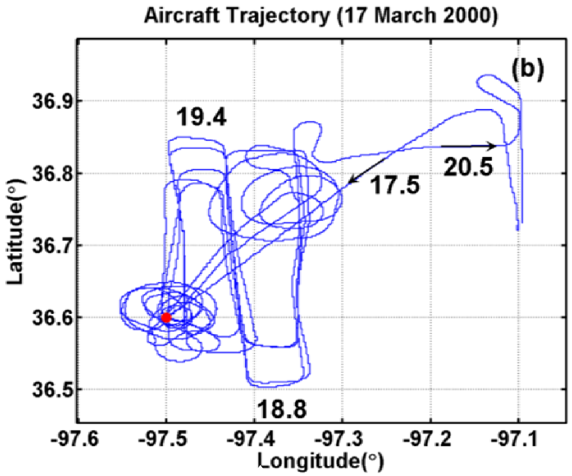
Method Two: Dynamics

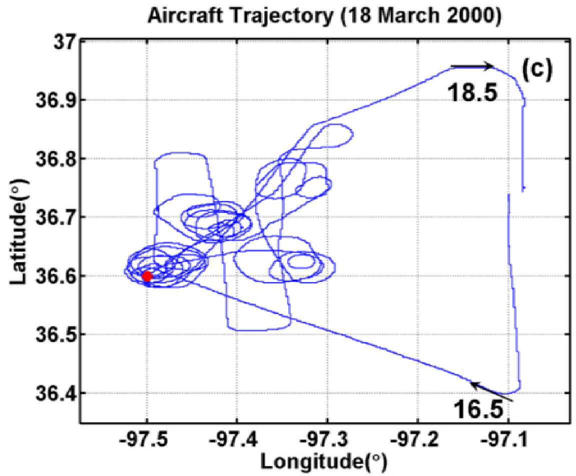
---Transition Scale Number(3)

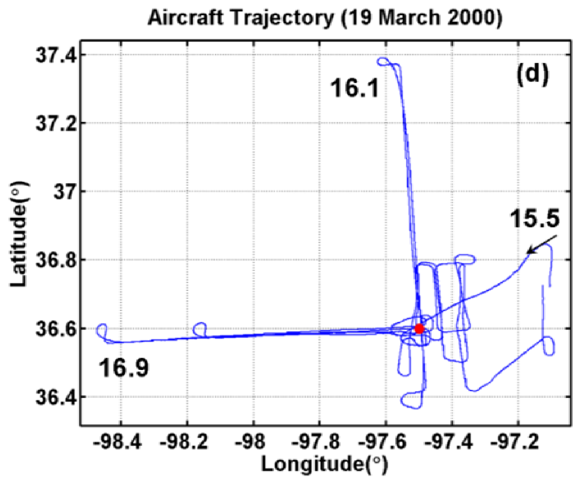


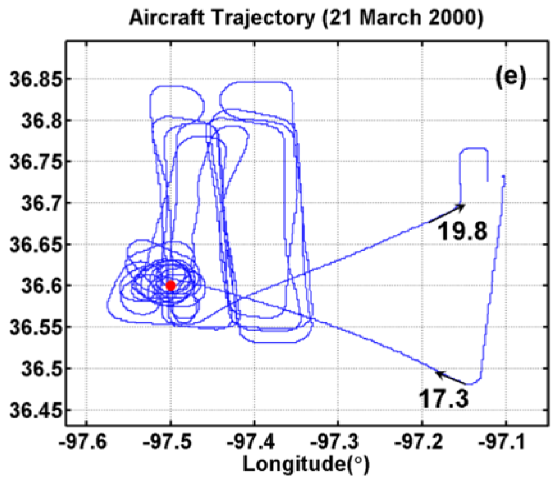
Aircraft Trajectory and Data











Period: March 2000;

Site: Southern Great Plains (SGP);

Instruments: PMS probes (FSSP, 1dc, 2dc, 2dp);

Cloud type: Stratocumulus

Summary(2)

- **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.**