Some Results from Aircraft Microphysical Measurements during the March 2000 Cloud IOP

Chunsong Lu and Yangang Liu

Brookhaven National Laboratory (clu@bnl.gov)

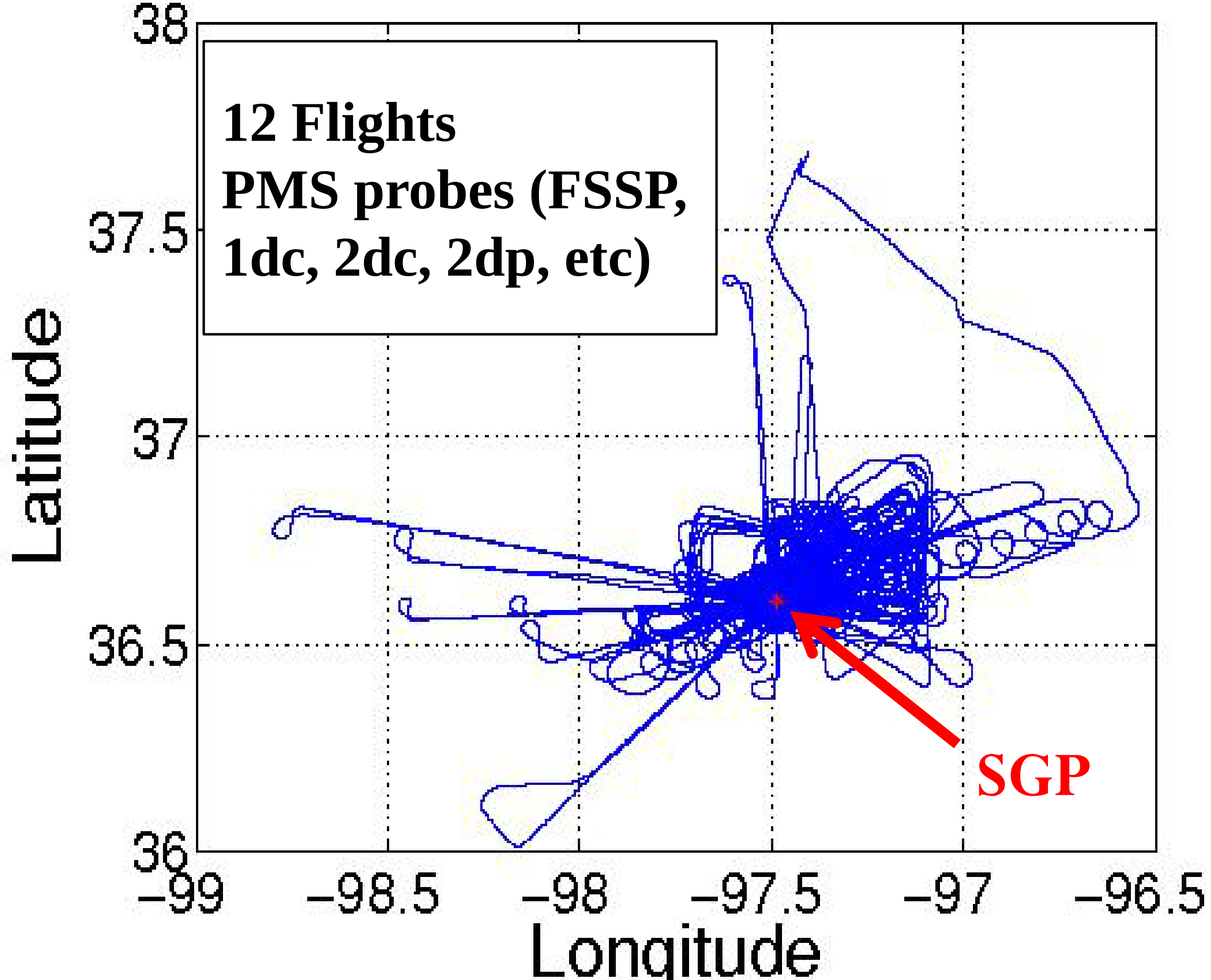
Thanks to Prof. Michael Poellot, University of North Dakota, for help with the data

Objectives

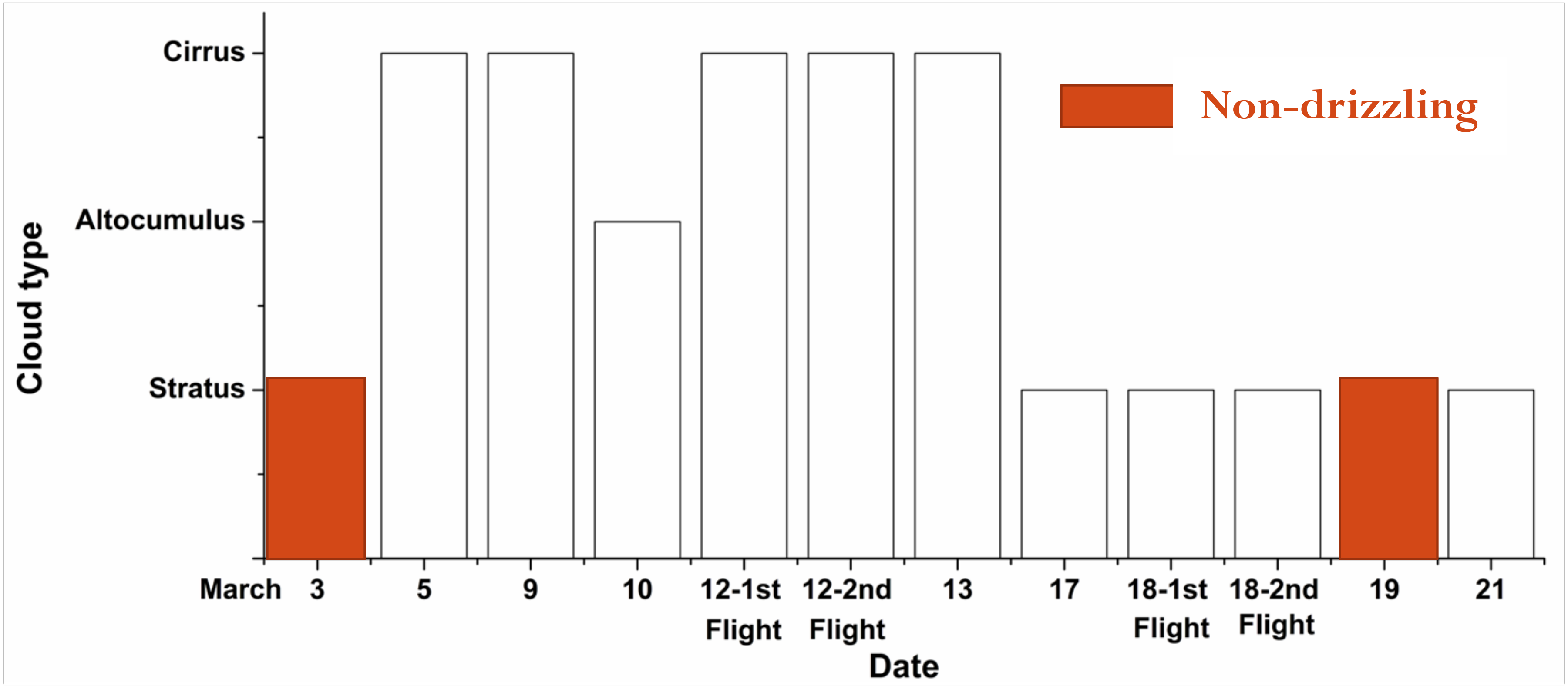
- Survey and examine aircraft measurements collected during March 2000 Cloud IOP for FASTER warm-up investigation
- Examine the relationships between key cloud microphysical properties critical for Z-L relation:

  $Z = \alpha L^{\gamma}$
- Dissect physical mechanisms responsible for these relationships
- Explore ways to improve retrieval of microphysics

Summary of flights (1)



Summary of flights (2)



Theoretical Analysis (1)

- Z can be expressed as

$$Z = 64\int r^6 n(r)dr = 64Nr_6^6$$

$$Z = \frac{36}{\rho^2\pi^2}\frac{\beta_6^6}{N}L^2$$

$$Z = \frac{3\times 64}{4\pi\rho}\beta_6^6 r_v^3 L$$

where **ρ**, N, r_v are water density, number concentration, and volume-mean radius, respectively, and β_6 the ratio of the 6-th mean radius r_6 to r_v:

$$\beta_6 = \frac{r_6}{r_v}$$

Theoretical Analysis (2)

- For adiabatic clouds with constant N and β_6 (Atlas 1954):

$$Z \propto \frac{\beta_6^6}{N} L^2 = BL^2$$

- For special inhomogeneous mixing with constant r_v and β_6 (Paluch et al. 1996):

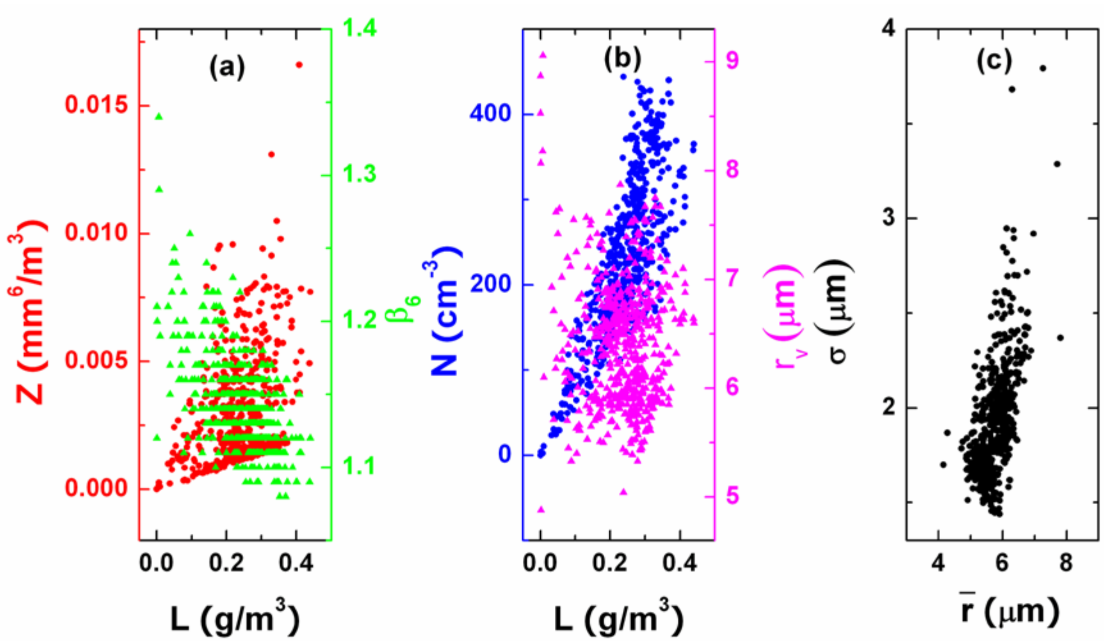
$$Z \propto \beta_6^6 r_v^3 L = AL$$

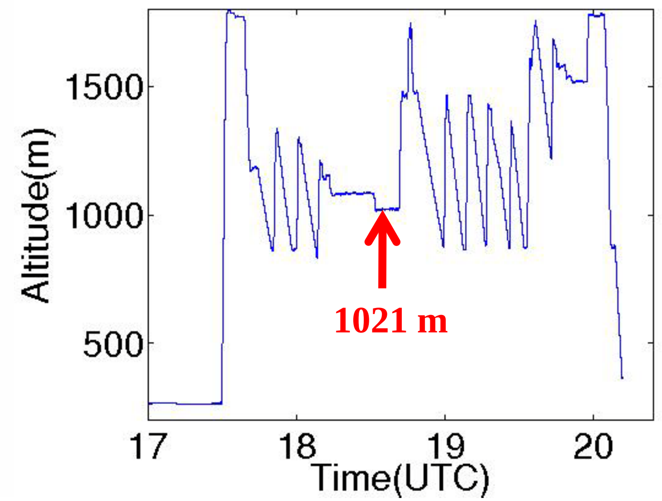
- The relationships of r_v, β_6, and N to L determine the specific Z-L relationship.

Example One: Height – 1021 m

$Z=0.0075L^{0.78}$ ($\gamma=0.78 < 1$)

inhomogeneous entrainment-mixing ?



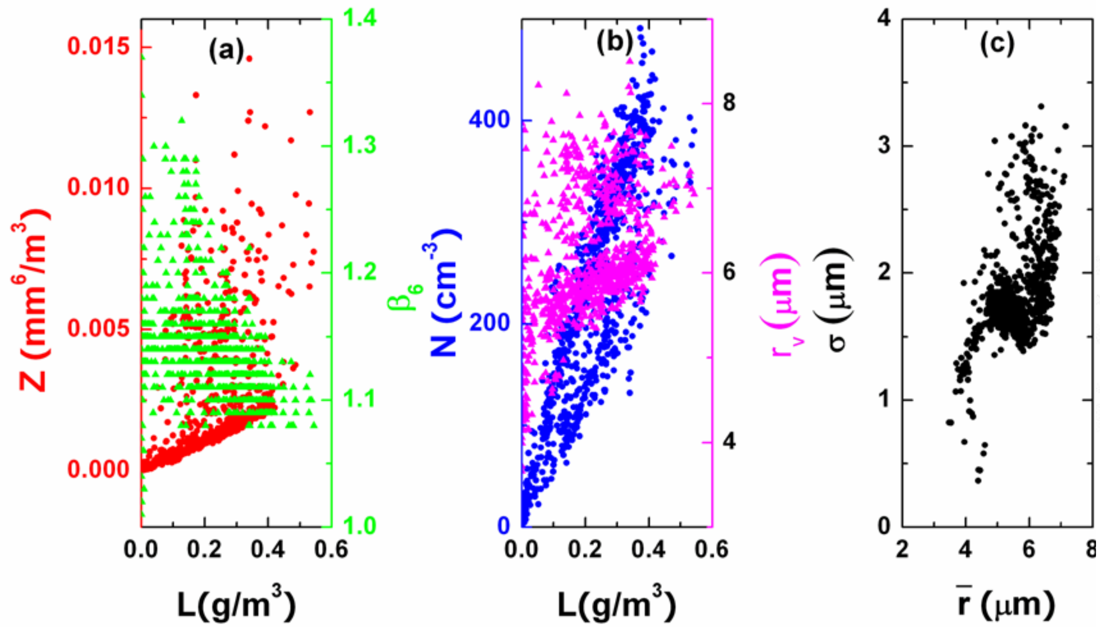


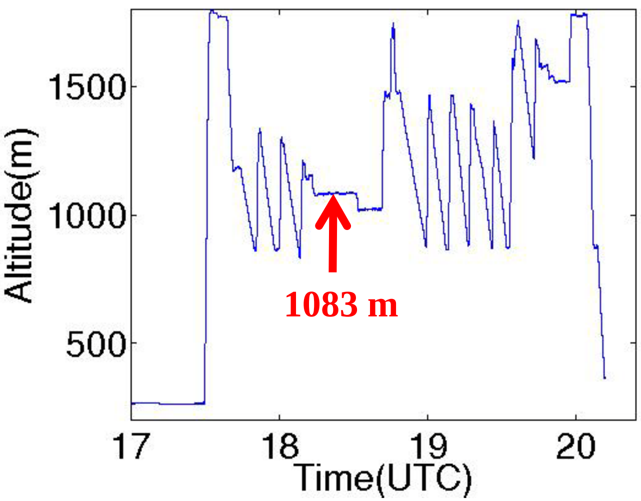
(a) Radar reflectivity (Z) and β_6 as a function of liquid water content (L), (b) number concentration (N) and volume-mean radius (r_v) as a function of L, and (c) standard deviation (σ) as a function of mean radius ($\bar{r}$) at H = 1021 m of 3 Mar 2000 flight.

Example Two: Height – 1083 m

$Z=0.0098L^{1.15}$ (γ=**1.15** > 1)

Combination of homogeneous Entrainment-mixing and other mechanisms ?



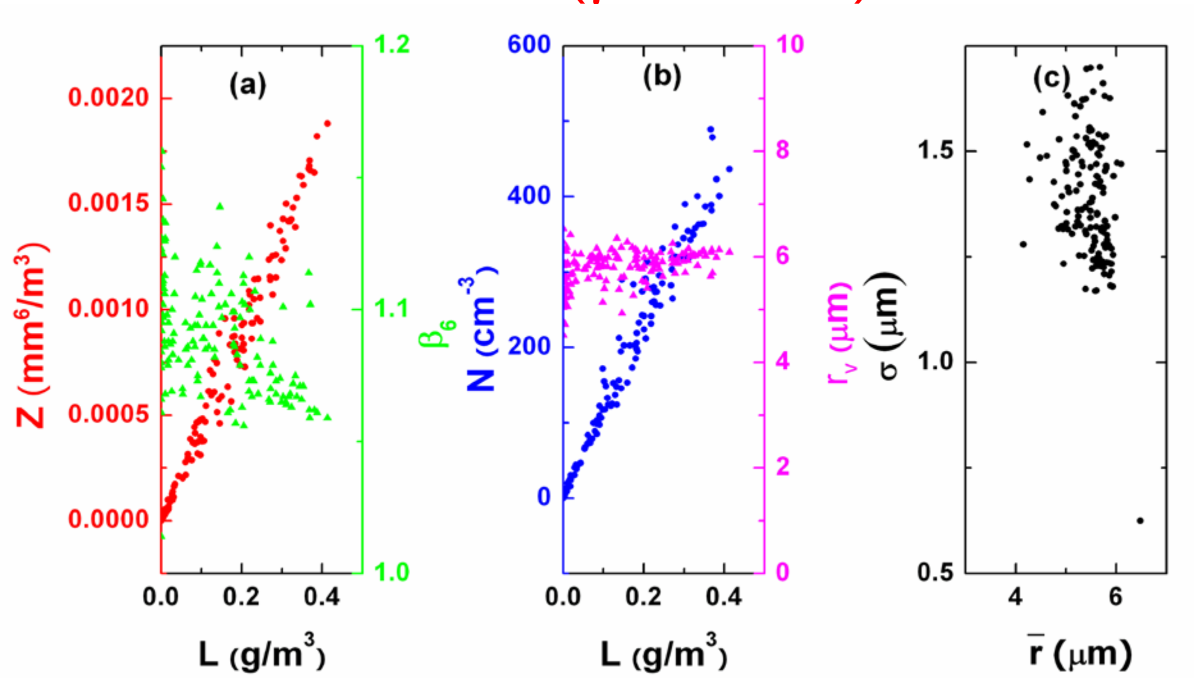


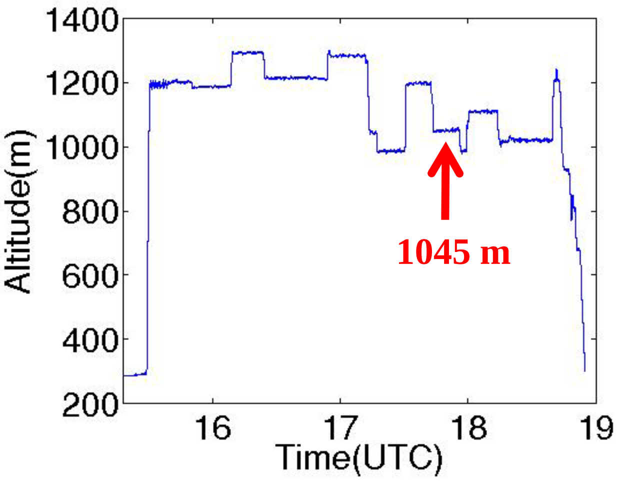
(a) Radar reflectivity (Z) and β_6 as a function of liquid water content (L), (b) number concentration (N) and volume-mean radius (r_v) as a function of L, and (c) standard deviation (σ) as a function of mean radius ($\bar{r}$) at H = 1083 m of 3 Mar 2000 flight.

Example Three: Height – 1045 m

$Z=0.0046L^{1.02}$ ($\gamma=1.02\sim1$)

close to the special-inhomogeneous entrainment-mixing assumed in Paluch et al (1996).



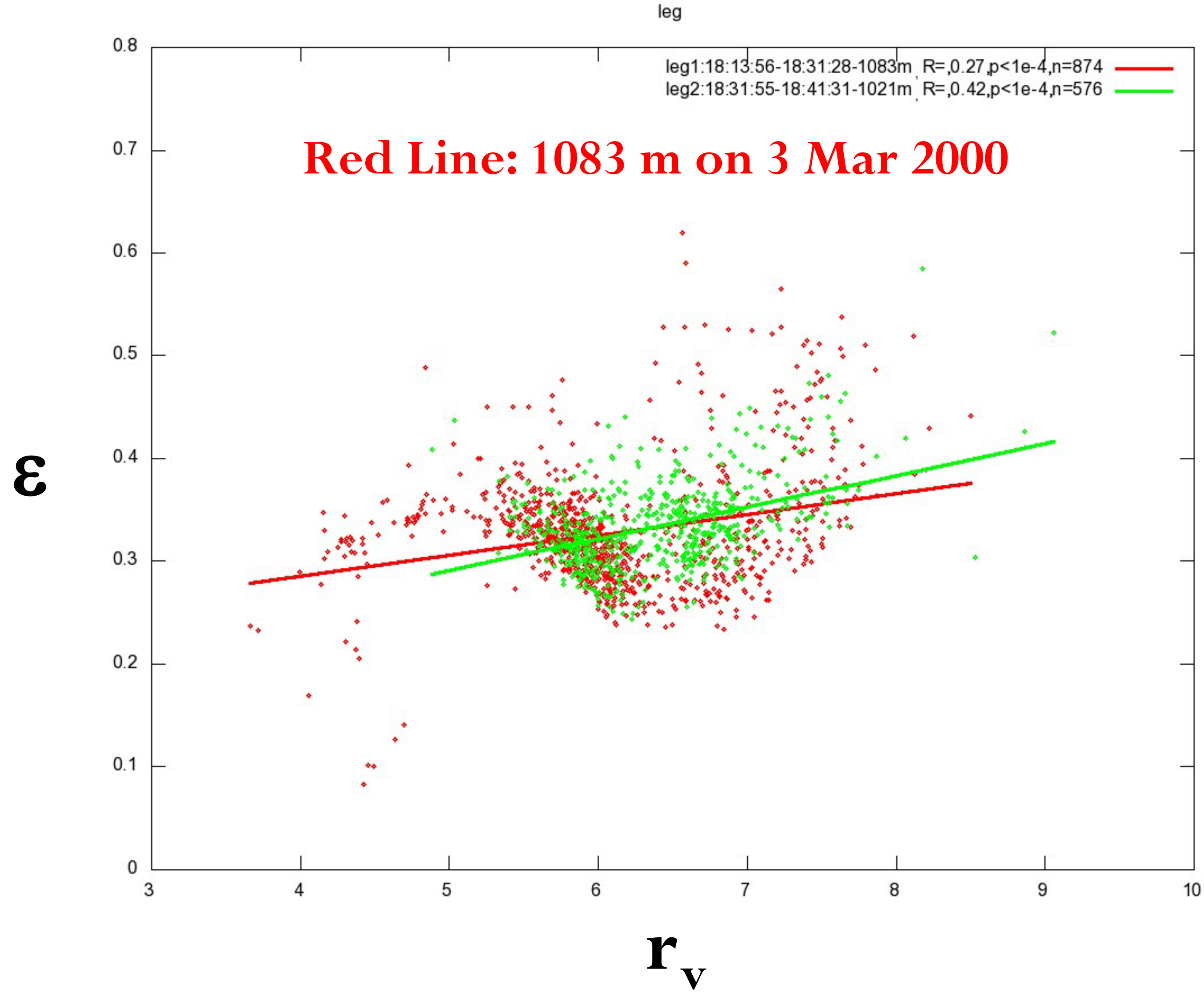


(a) Radar reflectivity (Z) and β_6 as a function of liquid water content (L), (b) number concentration (N) and volume-mean radius (r_v) as a function of L, and (c) standard deviation (σ) as a function of mean radius ($\bar{r}$) at H = 1045 m of 19 Mar 2000 flight.

Summary

- Z-L relationship depends on the combined dependences of r_v, β_6, and N on L, which in turn depends on the specific physical processes shaping the cloud, e.g., entrainment-mixing.

- Implications for radar retrievals?



leg
leg1:18:13:56-18:31:28-1083m R=,0.27,p<1e-4,n=874
leg2:18:31:55-18:41:31-1021m R=,0.42,p<1e-4,n=576
Red Line: 1083 m on 3 Mar 2000
ε
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3
4
5
6
7
8
9
10
r_v

Inhomogeneous Entrainment

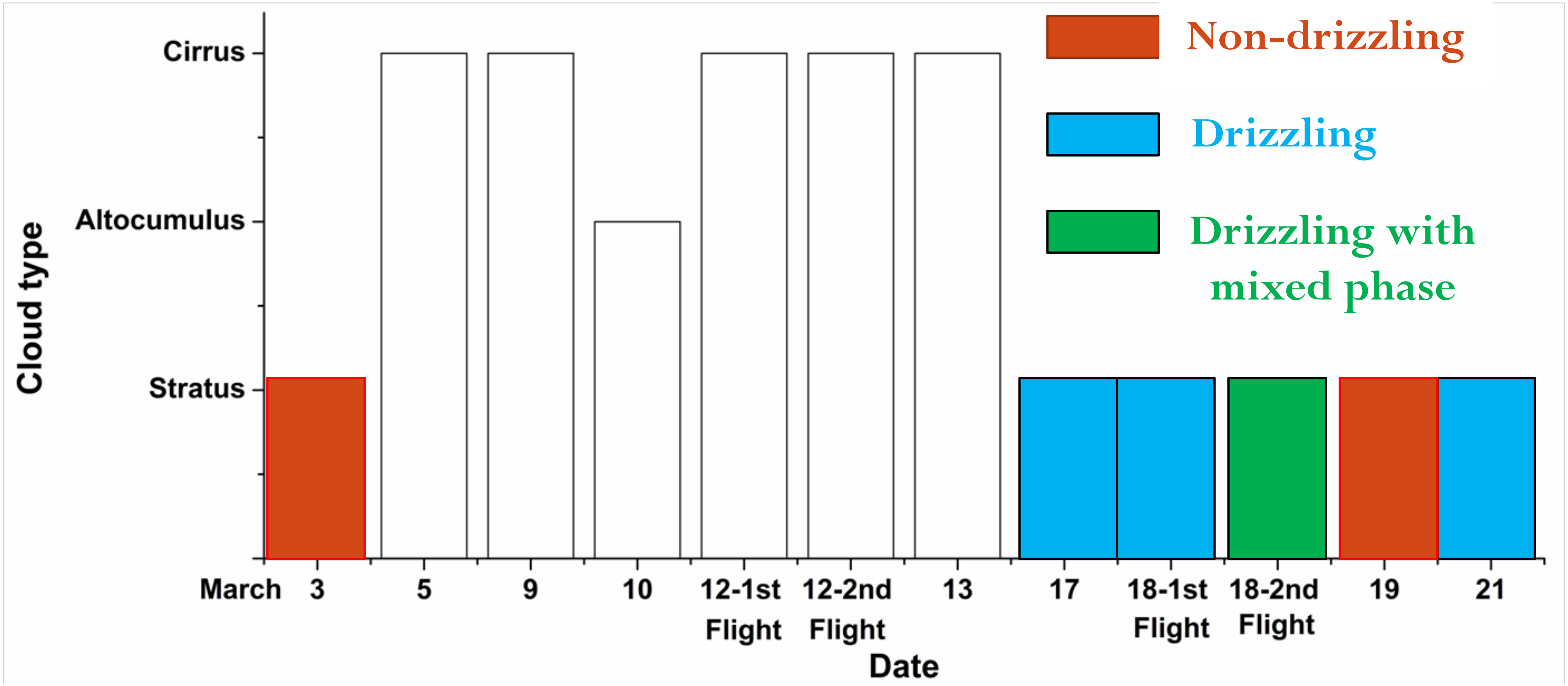
- **Entrainment of dry air from aloft and the subsequent mixing evaporates cloud droplets, decreasing N and L; at the same time entrainment and mixing also lead to continued growth of some favored droplets increasing r_v and ε (Daum et al., 2010).**

Homogeneous Entrainment

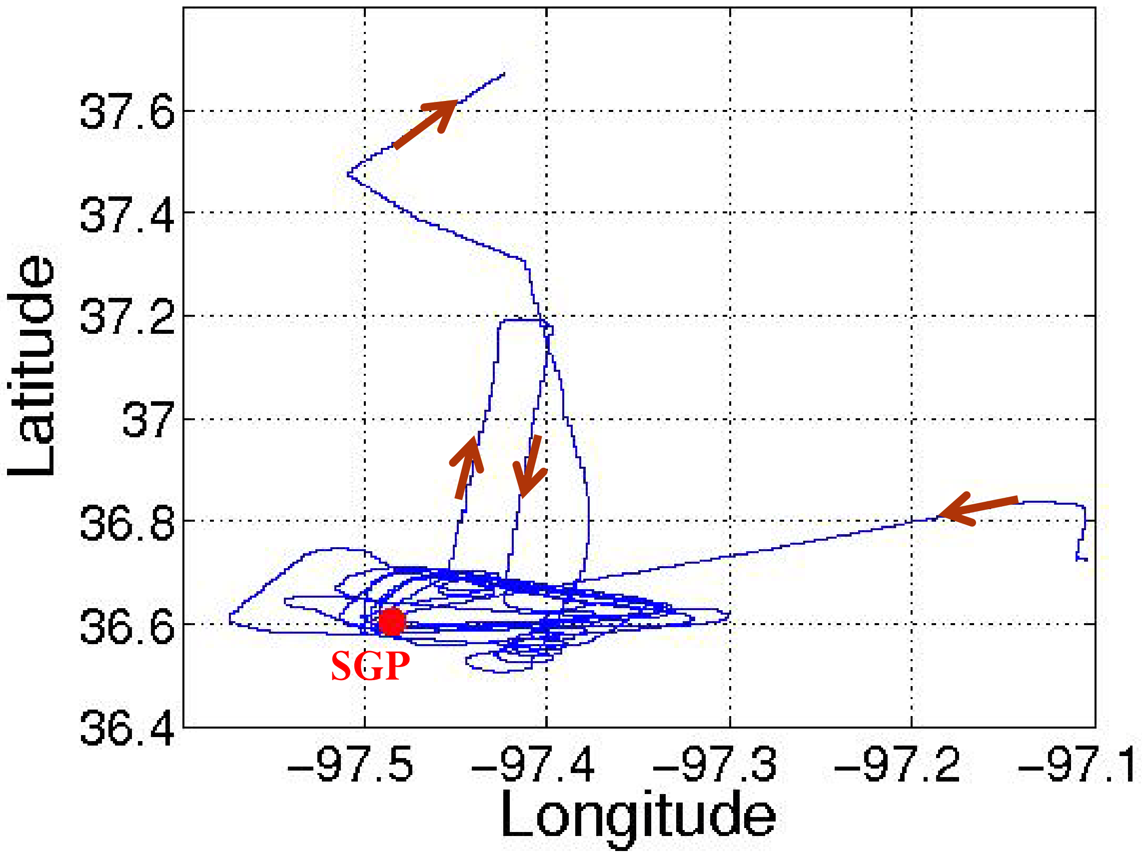
- **The clear and cloudy air mix homogeneously, then evaporation occurs simultaneously from all droplets until saturation is achieved uniformly in the mixed volume (Warner, 1973; Mason and Jonas, 1974).**

Future Work

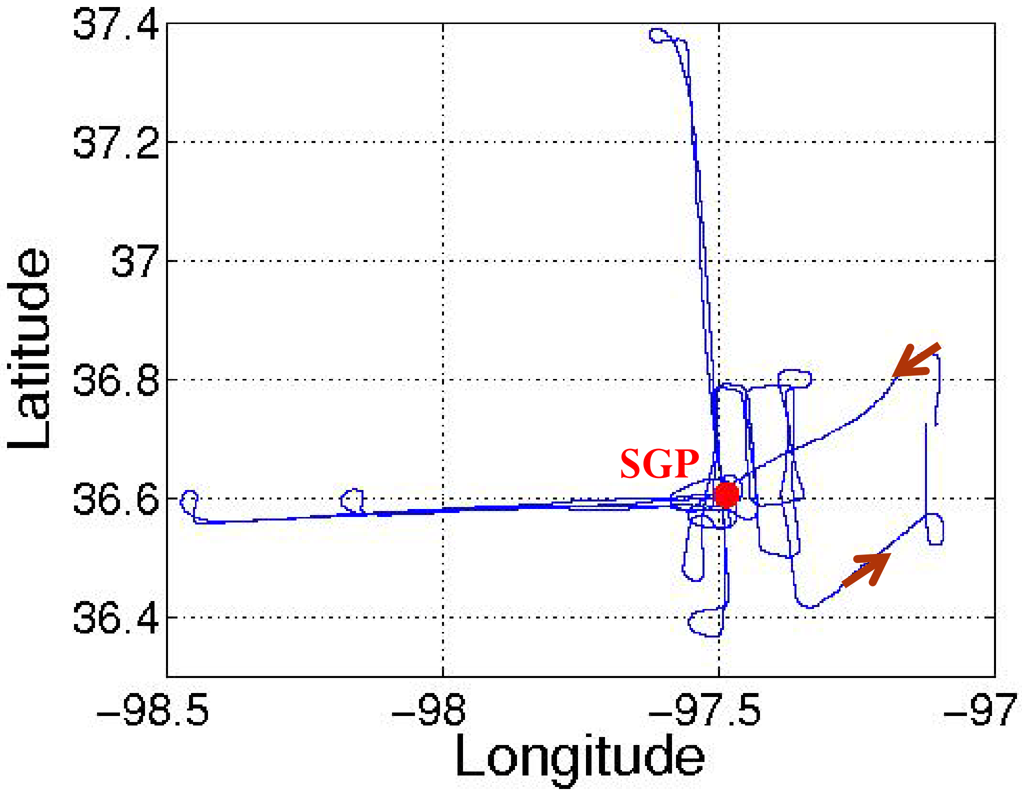
- **Focusing on Drizzling flights**



Case Studies --- 3 March 2000

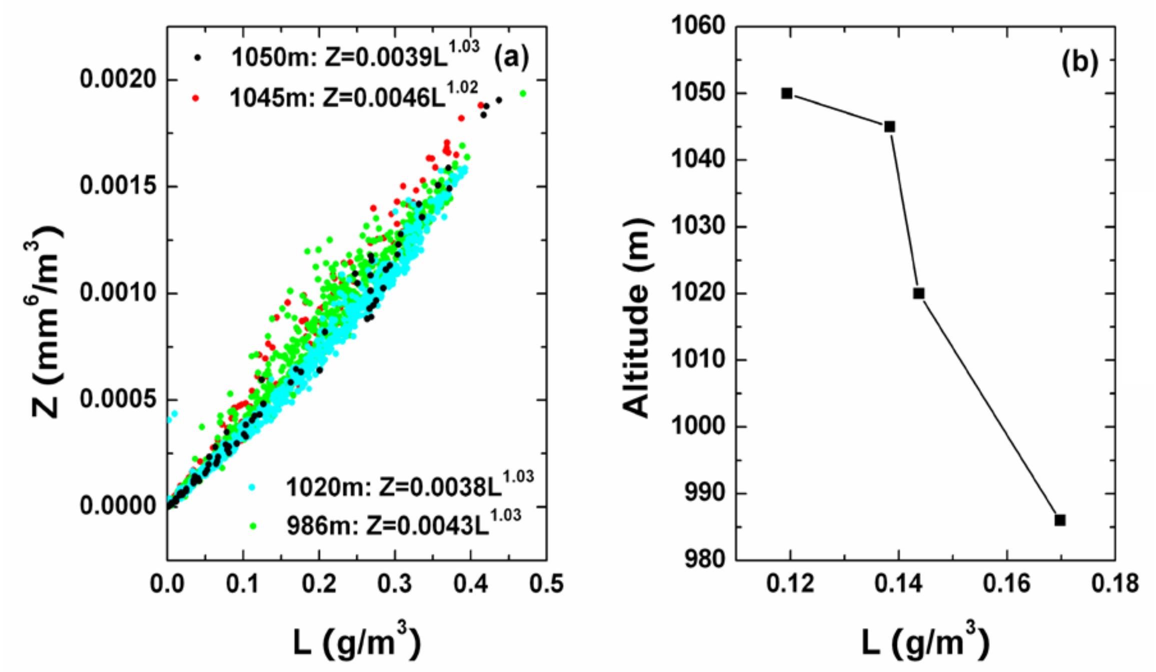


Case Studies---Case Two: 19 March 2000



Case Studies---Case Two: 19 March 2000

- **The cloud was at dissipation stage, gradually becoming thin with fluctuating decrease of cloud top (Dong et al., 2002).**



Sampled at cloud top

(a) Radar reflectivity (Z) as a function of liquid water content (L) and (b) Vertical profile of L of four legs in Case 19 Mar 2000.