A Comparison of Microphysical Properties of Wave, Cirrus and Anvil Clouds

NASA CRYSTAL-FACE Workshop – Salt Lake City
24 - 28 February 2003
OUTLINE

- **WAVE CLOUDS**: Composite of 12 SPEC Learjet flights over the Front Range of the Rockies

- **CIRRUS CLOUDS**: Composite of 10 SPEC Learjet flights in Utah, Colorado and Oklahoma

- **ANVIL CLOUDS**: Examples of Data:
  - SPEC Learjet in Colorado
  - UND Citation near Cape Kennedy (ABFM Project)
  - ARA Egrett - Darwin, Australia
  - WB-57 and UND Citation (CRYSTAL- FACE)
IWC Improvement

PHOTOGRAPHED CRYSTALS

EQUIVALENT MELTED DROPS

More Parameters are used in the New Image Processing Technique

OLD TECHNIQUE
(Mitchell et al. 1990)

\[ \text{Mass} = \alpha \times X^\beta \]

where: \( X = L = \text{Length} \)

NEW TECHNIQUE
(SPEC 2002)

\[ \text{Mass} = \alpha \times X^\beta \]

where: \( X = A \times W \times 2(L + W)/P \)

\( L = \text{Length} \quad \) \( W = \text{Width} \) 

\( A = \text{Area} \quad \) \( P = \text{Perimeter} \)
Wave Cloud
Investigated by the SPEC Learjet
VERTICAL PROFILE OF CRYSTAL HABITS FOR 75 WAVE PASSES IN 11 CLOUDS (~$10^5$ particles)

Wave Cloud Habits % by Mass

11 Flights
75 Regional Legs
88,390 Total Particles

Mixed Phase

Glaciated Region

-55 C
-45 C
-35 C
-30 C
-25 C

West

East
CIRRUS CLOUDS

VERTICAL PROFILE OF CRYSTAL HABITS FOR 66 PASSES IN 13 MID-LATITUDE CLOUDS (> 250,000 particles)

Cirrus Cloud Habits
% by Mass

13 Flights
66 Extended Legs
256,559 Total Particles
WAVE vs CIRRUS

Wave Clouds
(Glaciated Region)

Conc= 10,270 L⁻¹
IWC= 0.016 g m⁻³
\( r_{\text{eff}} = 8.40 \, \mu \text{m} \)
\( \beta_{\text{ext}} = 2.45 \, \text{Km}⁻¹ \)

43% Rosettes

Conc= 640 L⁻¹
IWC= 0.003 g m⁻³
\( r_{\text{eff}} = 18.4 \, \mu \text{m} \)
\( \beta_{\text{ext}} = 0.25 \, \text{Km}⁻¹ \)

18% Rosettes

Cirrus Clouds

Conc= 14,005 L⁻¹
IWC= 0.023 g m⁻³
\( r_{\text{eff}} = 12.6 \, \mu \text{m} \)
\( \beta_{\text{ext}} = 3.41 \, \text{Km}⁻¹ \)

37% Rosettes

Conc= 755 L⁻¹
IWC= 0.006 g m⁻³
\( r_{\text{eff}} = 25.0 \, \mu \text{m} \)
\( \beta_{\text{ext}} = 0.76 \, \text{Km}⁻¹ \)

40% Rosettes

Conc= 6,050 L⁻¹
IWC= 0.030 g m⁻³
\( r_{\text{eff}} = 18.2 \, \mu \text{m} \)
\( \beta_{\text{ext}} = 3.17 \, \text{Km}⁻¹ \)

30% Rosettes

Conc= 3,200 L⁻¹
IWC= 0.022 g m⁻³
\( r_{\text{eff}} = 36.7 \, \mu \text{m} \)
\( \beta_{\text{ext}} = 0.83 \, \text{Km}⁻¹ \)

63% Rosettes
16 July C-F Anvil Mission

WB-57  FL = 460  T = -65°C

Computed From (SPP-CPI-CIP) PSD:

- CONC = 7,700 L^{-1}
- IWC = 0.13 gm^{-3}
- \beta_{ext} = 9 Km^{-1}
- r_{eff} = 20 \mu m

- IWC (Harv.)= 0.16 gm^{-3}
- IWC (CU) = N/A
- \beta_{ext} (CIN) = N/A

--

Citation  FL = 390  T = -49°C

Computed From CPI PSD:

- CONC = 9,600 L^{-1}
- IWC = 0.25 gm^{-3}
- \beta_{ext} = 47 Km^{-1}
- r_{eff} = 32 \mu m

- IWC (CIN) = 0.28 gm^{-3}
- \beta_{ext} (CIN) = 37 Km^{-1}
- r_{eff} (CIN+CVI) = 12 \mu m

---

Particle Size (microns)

Number/Liter/\mu m

→ 200 \mu m
13-JUN-00 Anvil: 21:29:30 - 21:29:40

**Composite FSSP & 2D-C Particle Size Distribution**

- **MASS**
- **NUMBER**

Computed from Composite PSD:

- **IWC=0.57 g m\(^{-3}\)**
- **Total Conc= 24,000 L\(^{-1}\)**
- **2D-C Conc= 4,000 L\(^{-1}\)**
- **\(\beta_{\text{ext}}= 43 \text{ Km}^{-1}\)**
- **\(r_{\text{eff}}= 98 \mu m\)**

**CPI Images**

- Scale: 200 \(\mu m\)

**2D-C Images**

- Scale: 1000 \(\mu m\)
ALLIED/BAE FLIGHT IN ARKANSAS
ANVIL ON 16 JUNE 1997 (Strapp et al. 1999)

FSSP CONCENTRATION

IWC (g/m^3)

NEVZOROV
FSSP + 2D-C

CUMMULATIVE MASS FRACTION

MASS (g m^-3 μm^-1)

SIZE (μm)
Examples of Likely Influence of E-Field on Aggregation

CRYS TALS IN 100 KV m$^{-1}$ ELECTRIC FIELD
(Saunders & Wahab 1975)
MAJOR FINDINGS

**WAVE CLOUDS:**

- Ice Particle Concentrations: 1 - 20 cm\(^{-3}\) (Typ.)
- Bullet Rosettes dominate particle habits from about –25 to about –45 C. Small spheroidal particles and budding rosettes found from –45 to –55 C.
- Highest IWC found just downwind of region with supercooled water (T > -37 C)
- Rimming, sideplane growth and (lastly) aggregation found downwind of region with supercooled water.
- \(\beta_{\text{ext}}\) values from about 1 to 10 (in SLW), \(r_{\text{eff}}\) from about 5 to 30, IWC < 0.2 g m\(^{-3}\)

**CIRRUS CLOUDS:**

- Ice Particle Concentrations: 0.1 - 5 cm\(^{-3}\) (Typ.)
- Bullet Rosettes dominate particle habits from about –25 to about –45 C. Small spheroidal particles and budding rosettes found from –45 to –55 C.
- PSDs similar to downwind part of wave cloud
- Aggregates of Bullet Rosettes found in moderately deep cirrus. Sideplane growth and riming found in some deep cirrus
- \(\beta_{\text{ext}}\) values from 0.1 to 1 Km\(^{-1}\), \(r_{\text{eff}}\) from 10 to 50, IWC < 0.05 g m\(^{-3}\)
MAJOR FINDINGS (Continued)

- **ANVIL CLOUDS:**
  - Ice Particle Concentrations: 1 to > 100 cm\(^{-3}\) (Typ.)
  - Particle habits mainly irregular shapes, aggregates, plates and some columns (virtually no bullet rosettes)
  - Aggregates occasionally observed in “Chains”, which are likely formed as a result of high electric fields.
  - \(\beta_{\text{ext}}\) values from 1 to 50, \(r_{\text{eff}}\) from 10 to 100 \(\mu\text{m}\), IWC 0.1 to > 1 g m\(^{-3}\)
  - Particle Concentration, IWC, \(\beta_{\text{ext}}\), \(r_{\text{eff}}\) all decrease with distance from center of convection and increasing altitude.
NEXT STEPS…

- Piece together relative location of storm from radar, satellite and video relative to WB-57 and Citation flight tracks
- Construct vertical and horizontal profiles of anvil microphysics from WB-57 and Citation measurements
- Construct, if possible, quasi-3D pictures of the storm/anvil profile with microphysical properties.
- Compare microphysical properties with remote measurements.
CPI Images of Cirrus Ice Crystals

Data Collected on 1 June 1999 over the Facility for Atmospheric Remote Sensing in Utah