Vertical microphysical profiles and closure calculations

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Closure between aerosols and cloud base drop size distribution (DSD): This can be done by combining measured CCN supersaturation (S) activation spectrum below cloud base, with the measured cloud drop number concentrations (Nd) and updrafts measured (Wb) at the non-precipitating base of the same cloud cluster.

To be presented by Ramon Braga
2. **Vertical evolution of cloud and hydrometeor DSD, thermodynamics and updrafts.**

Flying through the developing cloud tops prevents contamination by precipitation falling from above.
First time measurements of cloud aerosol interactions in mixed phase and ice convective clouds in the Amazon.
Growing                         Mature                                         Dissipating

The relation between $r_e$ and depth cloud depth above its base (D) is uniquely related to CCN.

Rosenfeld and Woodley, CAIPEEX-2 Final report to IITM.
How sensitive is the threshold value?

Rain initiates at 10-12 µm, but accelerates strongly above 14 µm.

\[ r_{ec} \approx 14 \mu m \]

R is rain water content in drops with diameters of 0.1-0.25 mm, as measured by the Cloud Imaging Probe (CIP).

R > 0.01 – 0.1 g/m³ raises the precipitation flag.
Height, m  | Temp, °C
--- | ---
7,073 m,  | -12.2 °C
6,793 m,  | -11.8 °C
6,124 m,  | -8.7 °C
5,816 m,  | -6.8 °C
4,406 m,  | +1.3 °C

Aircraft measured images of vertical development of cloud and rain drops in the cloud
Why do we need the vertical profiles of cloud drop size distributions?

Aerosol composition + size distribution $\rightarrow$ CCN(S)
CCN(S) + Updrafts $\rightarrow$ Cloud base drop concentrations ($N_{db}$)
$N_{db}$ $\approx$ adiabatic drop concentrations ($N_{da}$)

$Re_a$ $\approx$ $Re$, due to nearly inhomogeneous cloud mixing.

$LWC_a \alpha Re_a^3 N_{da}$
$LWC_a \alpha$ Cloud depth above its base ($D$)

Coalescence rate $\alpha Re^5$ $\rightarrow$ Rain initiates at $Re \approx 13\text{–}14 \, \mu m$

The critical $D$ for rain initiation ($D_c$) is $D$ where $Re$ reaches 14 $\mu m$
$\rightarrow D_c \alpha N_{db}$
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CCN(S) + Updrafts $\rightarrow$ Cloud base drop concentrations ($N_d_b$)

$N_d_b \approx$ adiabatic drop concentrations ($N_d_a$)

$Re_a \approx Re$, due to nearly inhomogeneous cloud mixing.

$LWC_a \propto Re_a^3 N_d_a$
$LWC_a \propto$ Cloud depth above its base (D)

Coalescence rate $\propto Re^5 \rightarrow$ Rain initiates at $Re \approx 13-14 \, \mu m$

The critical D for rain initiation ($D_c$) is D where Re reaches 14 $\mu m$

$\rightarrow D_c \propto N_d_b$
CAIPEEX flights, India 2009+2010
Konwar et al., JGR 2012

\[ y = 0.0035x + 1.2, \ R = 0.79, \ p < 0.0001 \]

ACRIDICON, Amazon 9/2014

\[ D_c = 0.65 + 0.0035N_d \quad R = 0.97 \]
FLIGHT: AC09  DATE: 2014/09/11

NIXE

Cloud drop diameter [μm]

CAS-DPOL

Number of droplets (cm⁻³ μm⁻¹)

Height [m]

Number of droplets (cm⁻³ μm⁻¹)
FLIGHT: AC18  TIME: 17:08  SAMPLE: 424

CAS-DPOL

TEMPERATURE [°C]

LWC [gm⁻³]

CAS–DPOL
ADIABATIC
Which cloud probe to believe?

• CDP appears to have double Nd and LWC with respect to both CAS probes.
• CAS DSD is distorted badly at sizes < 10 µm, and has a poor size resolution above 10 µm.
• While CAS LWC looks unrealistically low, CDP Nd looks unrealistically high.

Conclusion: additional calibration and QC required
Water cloud  Mixed phase  Ice
FIG. 6. Flight tracks for all scientific missions (AC07 to AC20).
First rain
FLIGHT: AC09  DATE: 2014/09/11 16:07:01

MEAN_ND=291 cm⁻³  MEAN_CWC=0.530 gm⁻³  DWC=0.000 gm⁻³
MAX_ND=568 cm⁻³  MAX_CWC=1.122 gm⁻³  RWC=0.00 gm⁻³

AF=0.63  H=1709 m  WMAX=4.39 ms⁻¹  Re=7.92  T=17.0 °C

Height [m]

Number of droplets (cm⁻³ µm⁻¹)

LWC (gKg⁻¹ µm⁻¹)

CCP-CDP + NIXE-CAPS + PIP Droplet Diameter (µm)

MEAN_ND=121 cm⁻³    MEAN_CWC=0.946 gm⁻³
MAX_ND=165 cm⁻³    MAX_CWC=1.317 gm⁻³

DWC=0.055 gm⁻³    AF=0.23    H=4790 m
RWC=0.33 gm⁻³    Re=13.48    T=−1.9 °C

WMAX=0.10 ms⁻¹

Height [m]

WTMAX=5.66 ms⁻¹
AF=0.14  H=6424 m
Re=16.36  T=−9.6 °C

MEAN_ND=51 cm⁻³  MEAN_CWC=0.646 gm⁻³
MAX_ND=78 cm⁻³  MAX_CWC=0.936 gm⁻³

DWC=0.111 gm⁻³  RWC=1.12 gm⁻³

Height [m]

Number of droplets (cm⁻³ µm⁻¹)

LWC (g Kg⁻¹ µm⁻³)

CCP-CDP + NIXE-CAPS + PIP Droplet Diameter (µm)
FLIGHT: AC09  DATE: 2014/09/11  18:1

MEAN_ND=3333 cm^{-3}  MEAN_CWC=0.888 gm^{-3}  DWC=0.0005 cm^{-3}  MAX_CWC=0.888 gm^{-3}  RWC=0.005 gm^{-3}  Re=6565  T=306.666°C

CAS-NIXE

Height [m]

0  2  4  6  8

Number of droplets (cm^{-3} \mu m^{-1})

0.0  10.0  20.0  30.0  40.0  50.0

NIXE-CAPS Droplet Diameter (\mu m)

0.0  0.0001  0.001  0.01  0.1  1.0  10.0  100.0

LWC (g kg^{-1})

0.000001  0.0001  0.001  0.01  0.1  1.0  10.0  100.0  1000.0

The graphs show the number of droplets in different sizes and their concentration as a function of droplet diameter and height.
FIG. 6. Flight tracks for all scientific missions (AC07 to AC20).
First rain
FLIGHT: AC07  DATE: 2014/09/06 18:34:08

- MEAN ND = 837 cm⁻³
- MEAN CWC = 0.624 gm⁻³
- MAX ND = 1255 cm⁻³
- MAX CWC = 0.923 gm⁻³
- DWC = 0.000 gm⁻³
- RWC = 0.00 gm⁻³
- WMAX = 4.52 ms⁻¹
- AF = 0.87
- H = 2341 m
- Re = 5.85
- T = 14.2 °C

**Graphs:**
- Number of droplets (cm⁻³ µm⁻³)
- LWC (g kg⁻¹)

**Axes:**
- X-axis: CCP-CDP + NIXE-CAPS + PIP Droplet Diameter (µm)
- Y-axis: Height [m]
FLIGHT: AC07  DATE: 2014/09/06 20:14:50  WMAX=7.91 ms⁻¹
MEAN_ND=116 cm⁻³  MEAN_CWC=0.556 gm⁻³  DWC=0.032 gm⁻³  AF=0.16  H=6449 m
MAX_ND=181 cm⁻³  MAX_CWC=0.925 gm⁻³  RWC=5.47 gm⁻³  Re=11.92  T=−9.3 °C

Graphs showing the distribution of droplet counts and liquid water content (LWC) over different droplet diameters.
FLIGHT: AC07  DATE: 2014/09/06 19:34:44

WMAX=13.09 m/s
AF=0.10  H=9023 m
Re=12.50  T=-25.6 °C

Mean ND=44 cm⁻³  Mean CWC=0.271 gm⁻³
Max ND=98 cm⁻³  Max CWC=0.607 gm⁻³

DWC=0.220 gm⁻³  RWC=19.53 gm⁻³

Number of droplets (cm⁻³ μm⁻¹)

LWC (g/kg)

CCP-CDP + NIXE-CAPS + PIP Droplet Diameter (μm)
Fig. 6. Flight tracks for all scientific missions (AC07 to AC20).

WMAX = 1.64 m/s⁻¹
AF = 0.24  H = 2369 m
Re = 11.97  T = 11.0 °C

Mean ND = 93 cm⁻³  Mean CWC = 0.462 gm⁻³  DWC = 0.003 gm⁻³
Max ND = 209 cm⁻³  Max CWC = 1.019 gm⁻³  RWC = 0.00 gm⁻³

Graphs show:
- Number of droplets (cm⁻³ µm⁻³)
- LWC (g/kg)

CCP-CDP + NIXE-CAPS + PIP Droplet Diameter (µm)

Height [m]
Technical Summary

Further scientific advancements require to:

• Calibrate and reconcile the cloud drop probes
• Obtain images of the CIP (PHIPS is not a replacement), as was done in India, Israel, California and most other cloud physics campaigns.
• Classify the hydrometeors to rain and ice.
• Unmask and QC the BAHAMAS updrafts within the clouds.
2009 08 24, 10:14 UT, 6720 m, -8.1ºC. Max HWLWC=1.66 gm-3. N of Bareilly. The cloud has supercooled rain drops.
2009 08 24, 10:03 UT, 7350 m, -11.8°C. Max HWLWC=0.87 gm-3. N of Bareilly. The cloud has small raindrops and larger freezing rain drops.
The cloud has small rain drops, large freezing rain drops, and small graupel.
2009 08 24, 9:57 UT, 8130 m, -17.1°C. Max HWLWC=0.49 gm-3. N of Bareilly. The cloud is glaciating, with frozen rain drops, small graupel and ice crystals.
Scientific Summary

• Height for rain initiation (Dc) increases linearly with cloud base drop concentrations (Nd)

• Increasing Dc from 50 to $\sim$500 cm$^{-3}$ incurs warm cloud invigoration due to reducing the large S at low Nd and advanced coalescence.

• Further increase of Nd incurs mixed phase cloud invigoration due to less rainout and thus more latent heat release of freezing.

• Rain initiates at Re $> 12$ to $13 \ \mu m$ and is fully developed for Re $> 14 \ \mu m$, as in other studies.

• Supercooled cloud water extend to colder temperatures with more Nd and smaller Re.
Thank you for flying with us!
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