Rain In Cumulus over the Ocean

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NCAR science to complement investigators' research:

- ***Cloud structure, chemistry, CCN activation & droplet growth***
  - **Trace gases → air mass exchange & mixing**
  - **Cloud water chemistry (pH, fast-response real-time)**
- ***Aerosol particles***
  - **effects of cloud processing**
  - **particle production, sea-spray & droplet evaporation**
- ***Instrument operation & performance***
  - ***cloud & aerosol particle probes, air sample inlets, RDMA, CN, pH***

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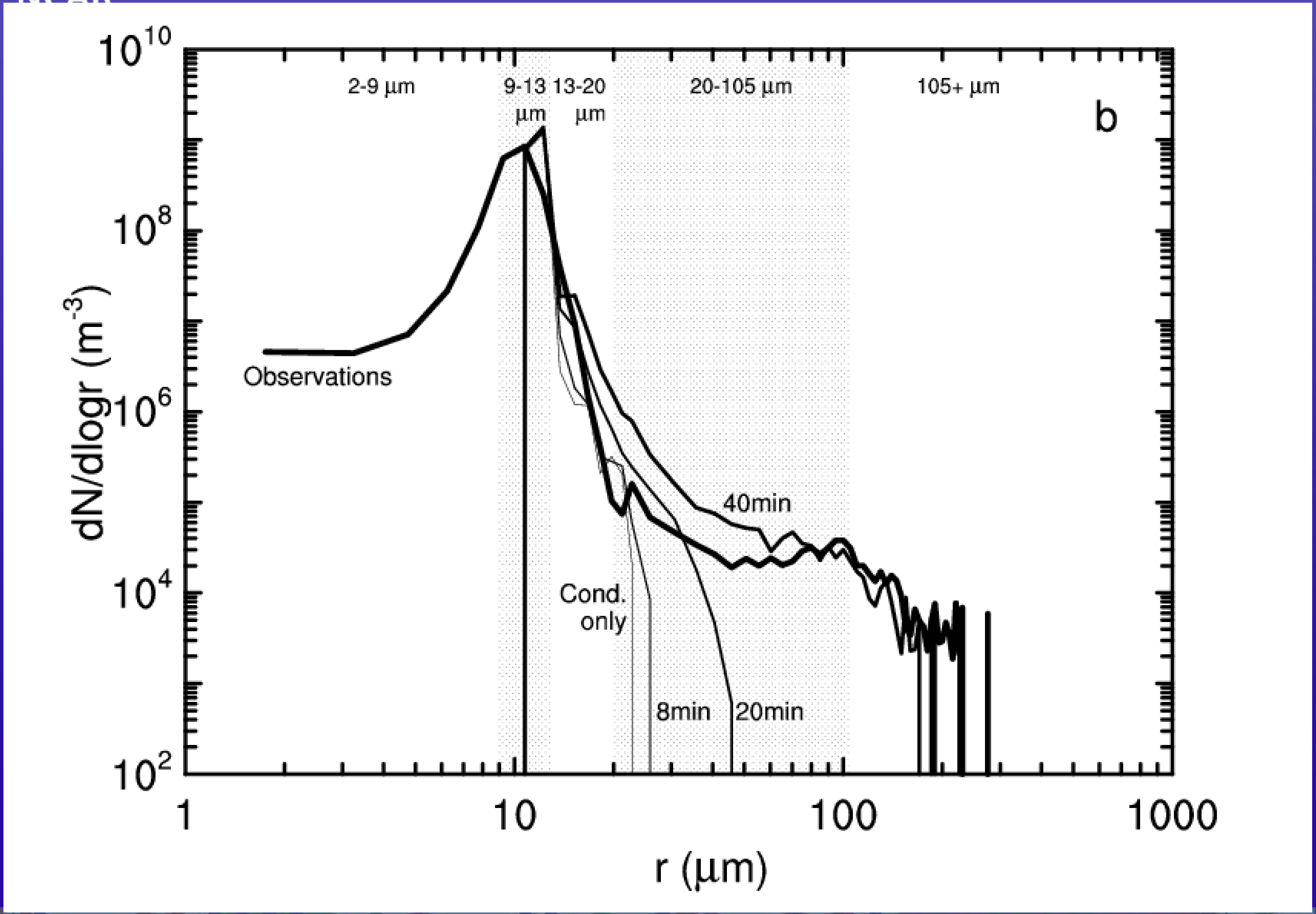
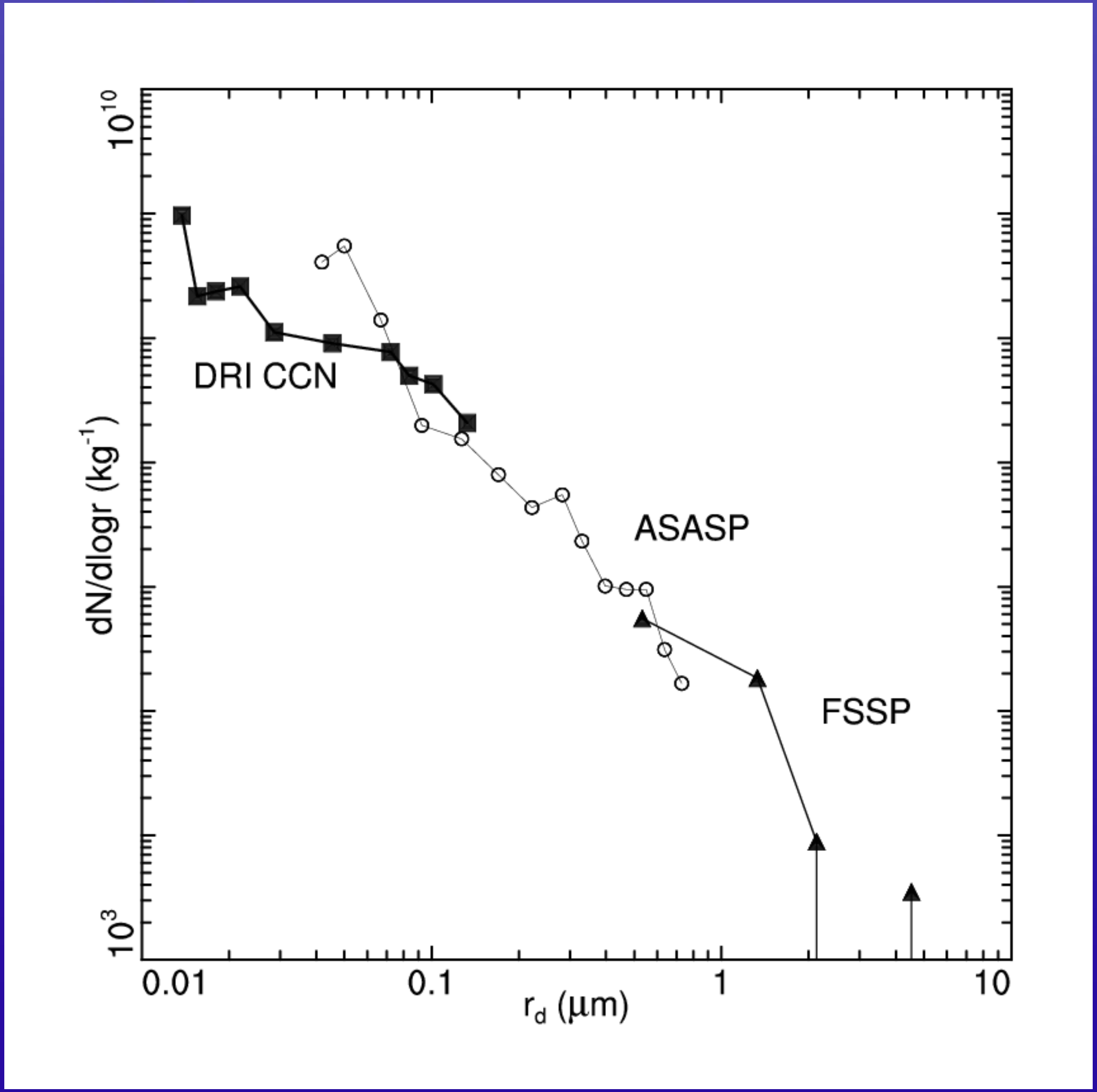
Testing coalescence rates

- *Complete aerosol spectrum*
- *Condensation + Monte-Carlo coalescence*
- *Use observed entrainment source & fraction (conserved tracer analysis)*
- *Within observed "cloud age" (reactive tracer analysis &/or radar)*
- *Tracing aerosols through multiple drop coalescence*
- *Predict aerosol size distributions in cloud-processed air*
- *What is the sea-salt balance?*

Compare observations & model results

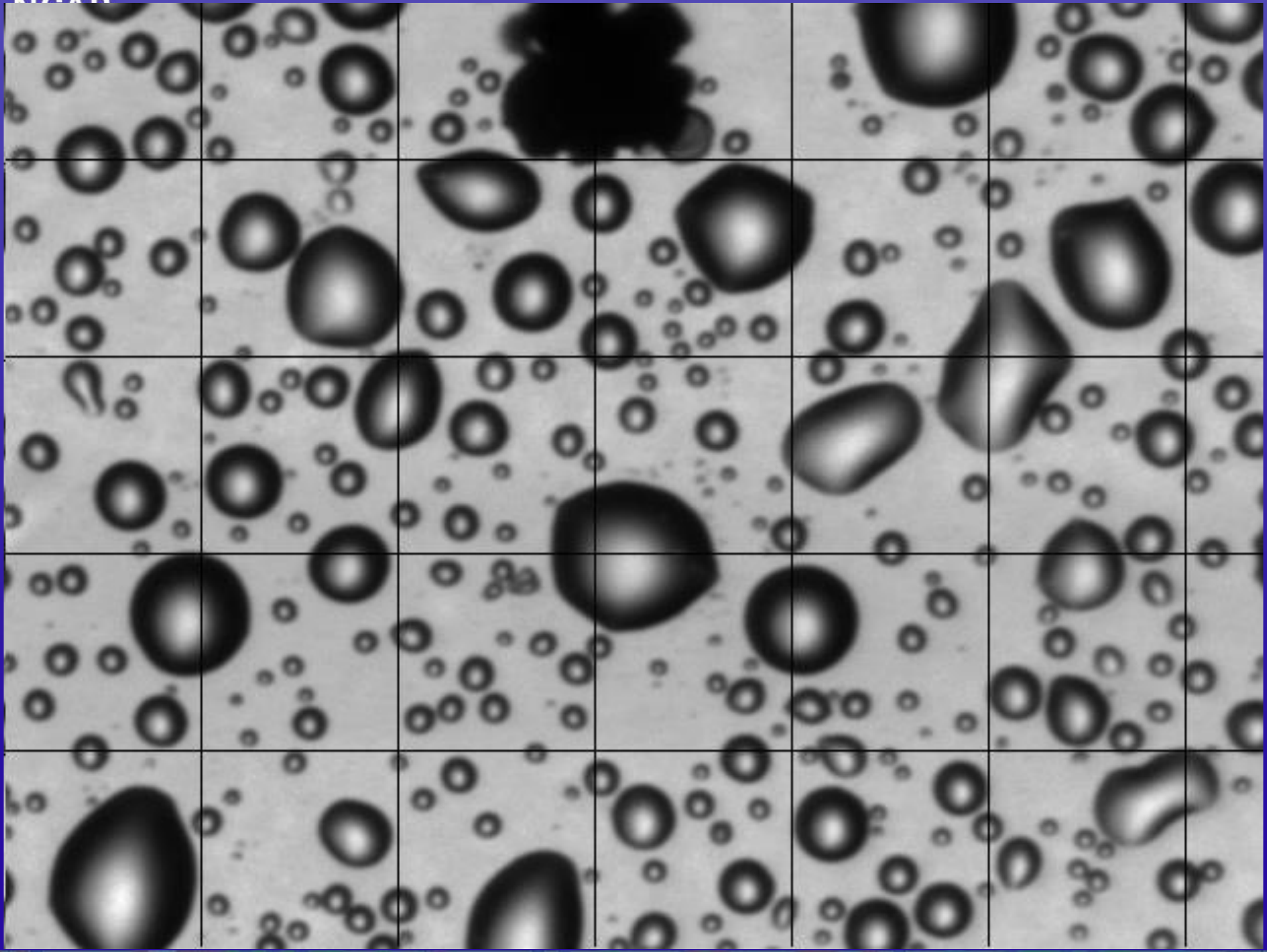


Dry aerosol size spectra

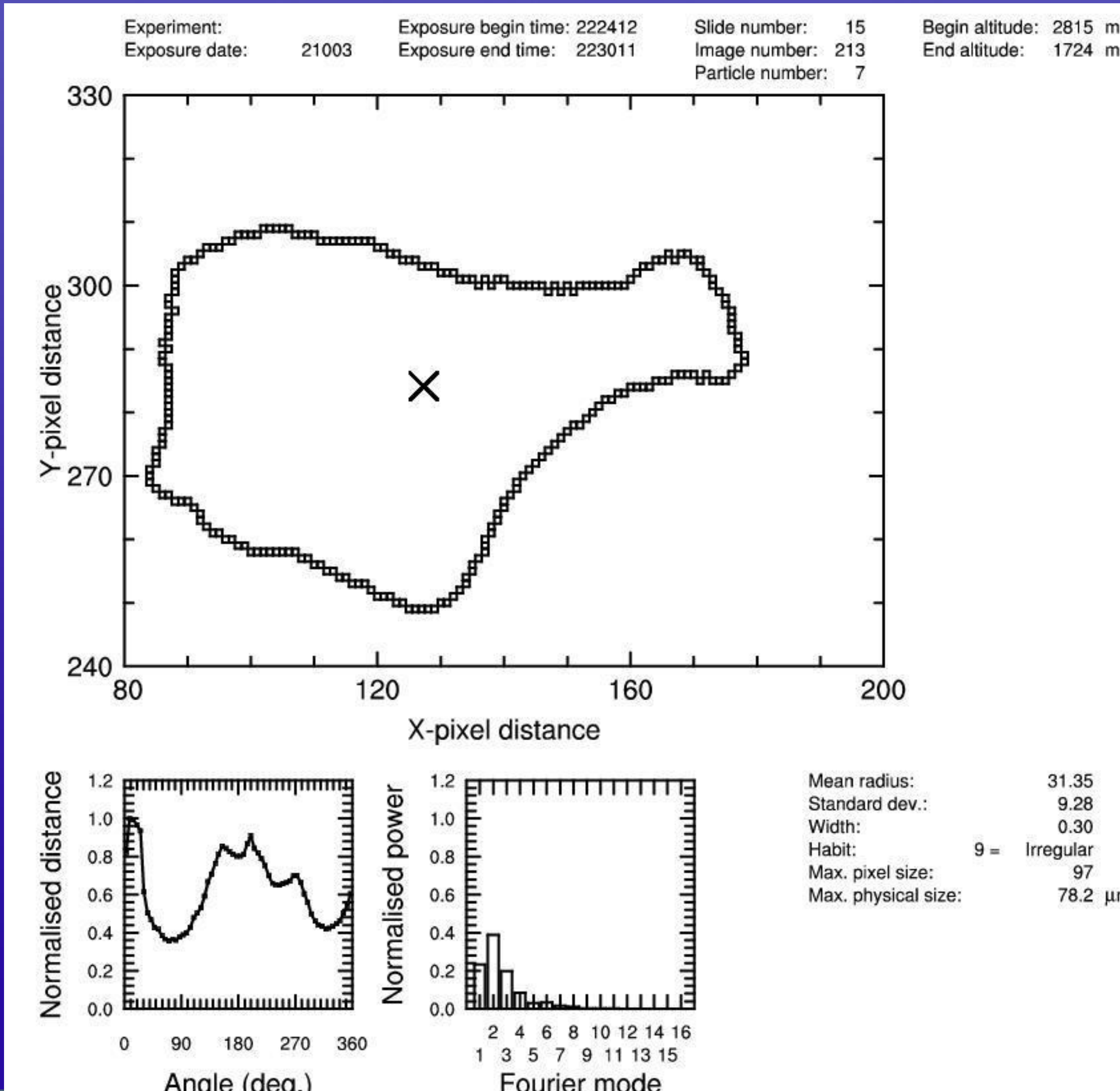


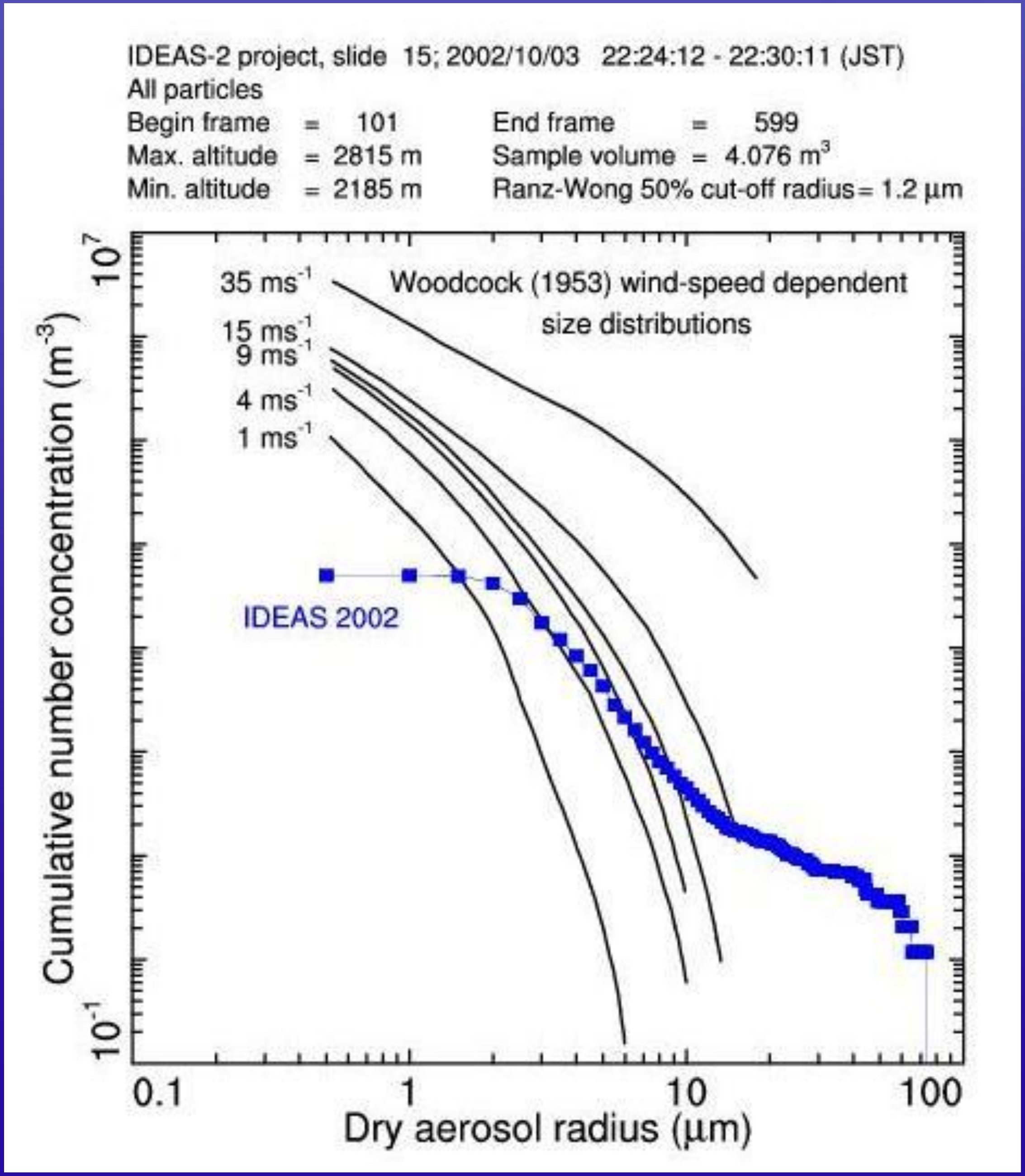
Giant Nuclei Impactor

Particle growth in humidity chamber



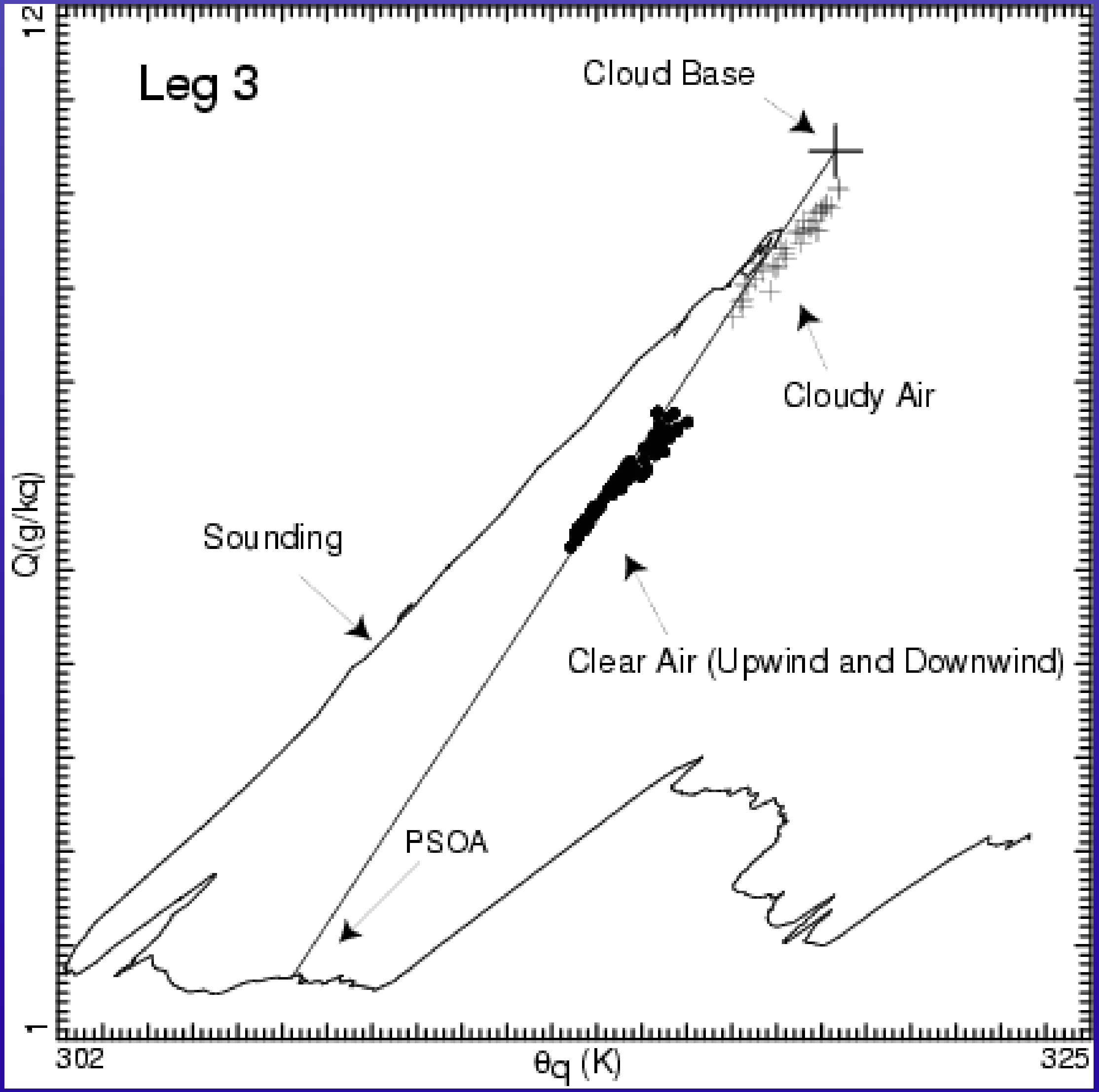
Analysis of microscope images





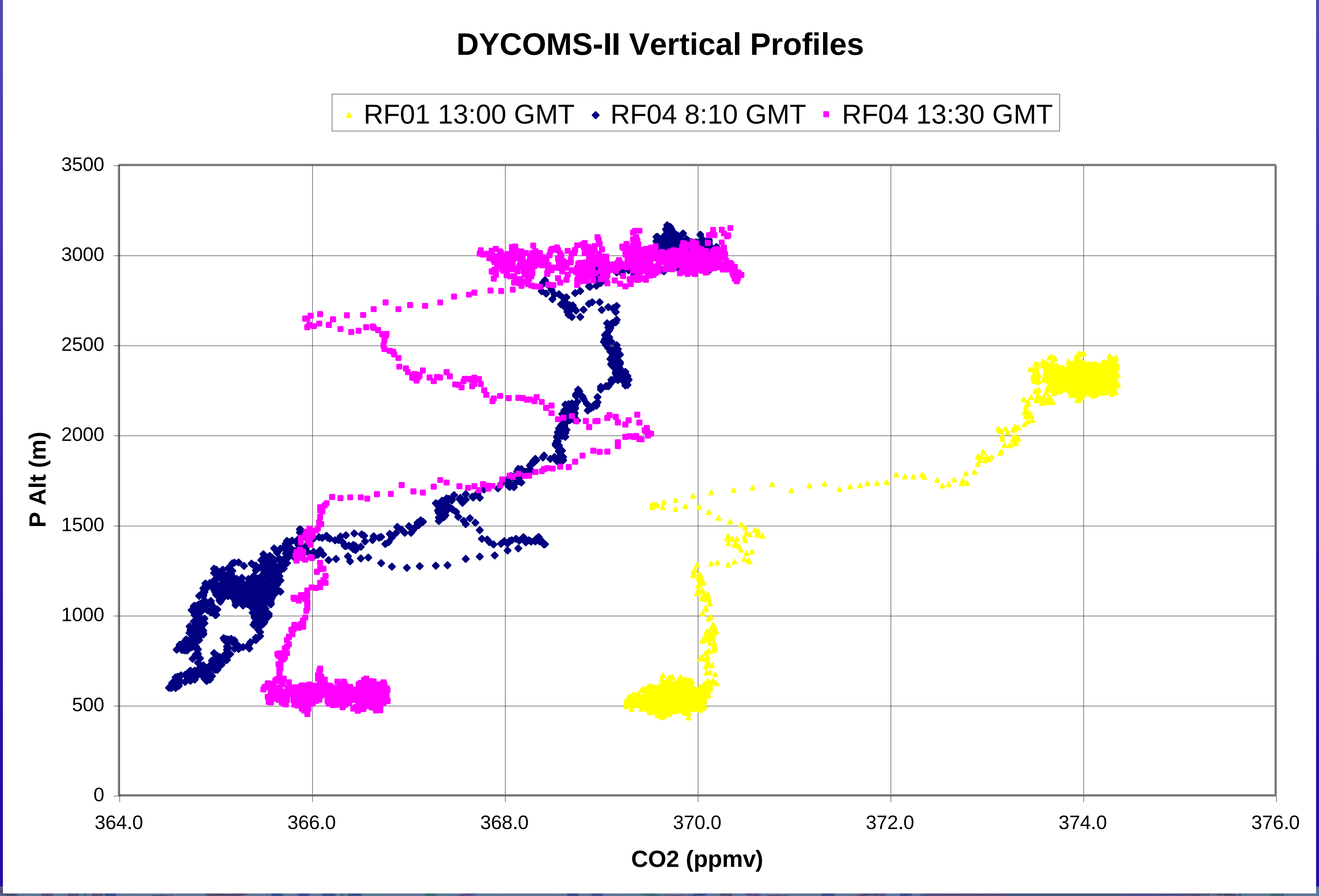
IDEAS-2 project, slide 15; 2002/10/03 22:24:12 - 22:30:11 (JST)
All particles
Begin frame = 101
End frame = 599
Max. altitude = 2815 m
Sample volume = 4.076 m³
Min. altitude = 2185 m
Ranz-Wong 50% cut-off radius = 1.2 µm
Woodcock (1953) wind-speed dependent size distributions
35 ms⁻¹
15 ms⁻¹
9 ms⁻¹
4 ms⁻¹
1 ms⁻¹
IDEAS 2002
Cumulative number concentration (m⁻³)
10⁷
10⁻¹
0.1
1
10
100
Dry aerosol radius (µm)

Trace gas analyses



fast ozone,
DMS, CO

CO variability in marine boundary layer



THE DETERMINATION OF THE "AGE OF CLOUDY AIR"

Based on mixing analysis, as simple approach is to consider the cloud development for a sample of air as:

(1) Quasi-adiabatic ascent from cloud base to mixing level

(2) Single mixing event with environmental air (linear mixing of SO_2, H_2O_2 and O_3, respectively).

(3) Quasi adiabatic descent (ascent) to the aircraft flight level (observation level).

At the observation level, match SO_2 concentration in interstitial air to that predicted by the sulfur cloud model. If pH-value is also measured, then use this as a check.

THE DETERMINATION OF THE "AGE OF CLOUDY AIR" - SULFUR MODEL

Aqueous concentrations:

$$\frac{dSO_2}{dt} = -k_1 f_1[S(IV)][H_2O_2] - k_2 f_1[S(IV)][O_3] - k_3 f_2[S(IV)][O_3]$$

$$\frac{dSO_4}{dt} = k_1 f_1[S(IV)][H_2O_2] + k_2 f_1[S(IV)][O_3] + k_3 f_2[S(IV)][O_3]$$

$$\frac{dH_2O_2}{dt} = -k_1 f_1[S(IV)][H_2O_2]$$

$$\frac{dO_3}{dt} = -k_2 f_1[S(IV)][O_3] - k_3 f_2[S(IV)][O_3]$$

where

- f_1 **is fraction of** $[S(iIV)]$ **that is** HSO_3^-
- f_2 **is fraction of** $[S(iIV)]$ **that is** SO_3^{--}
- k_1, k_2 **and** k_3 **are rate constants (Pandis and Seinfeld, 1989)**

Additional equations for ion balance with aqueous concentrations of trace gases, and for depletion of trace gases in air.

THE DETERMINATION OF THE "AGE OF CLOUDY AIR"

At beginning of calculation, the following parameters are known:

Cloud base (determined from near surface flight leg):

Conserved parameters CO, O_3, DMS and θ_q

Reactive parameters SO_2 and H_2O_2

Other: p_{base}, z_{base}, q_v, q_l and aerosol spectrum. Time $t = 0$, vary updraft speed, w.

Clear air counding (flown on upshear side of cloud band):

Conserved parameters CO, O_3, DMS and θ_q

Reactive parameters SO_2 and H_2O_2

Vary downdraft (updraft) to flight level.

Cloud penetration:

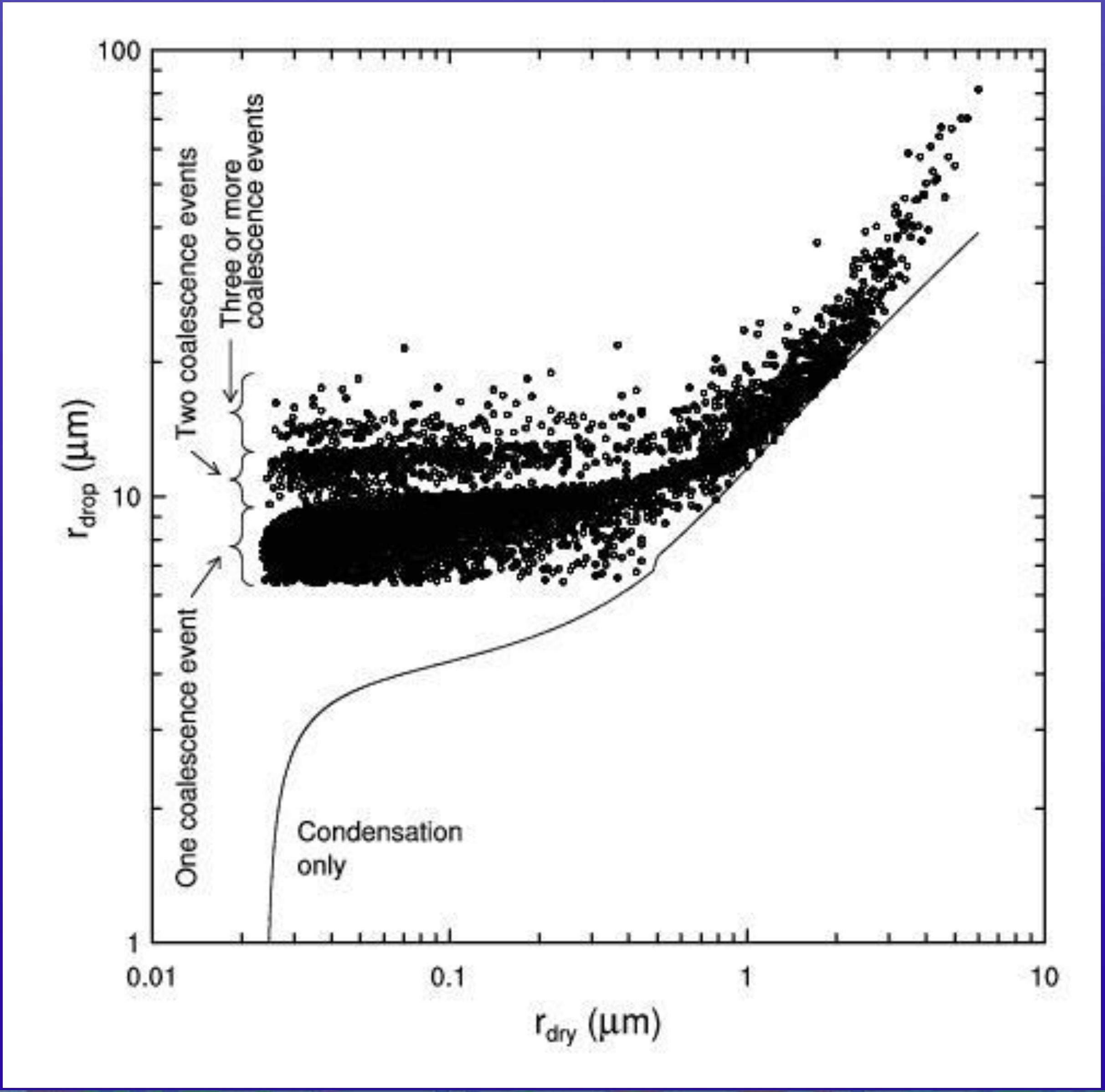
Conserved parameters CO, O_3, DMS and θ_q

Reactive parameters SO_2. No measurement of H_2O_2 needed.

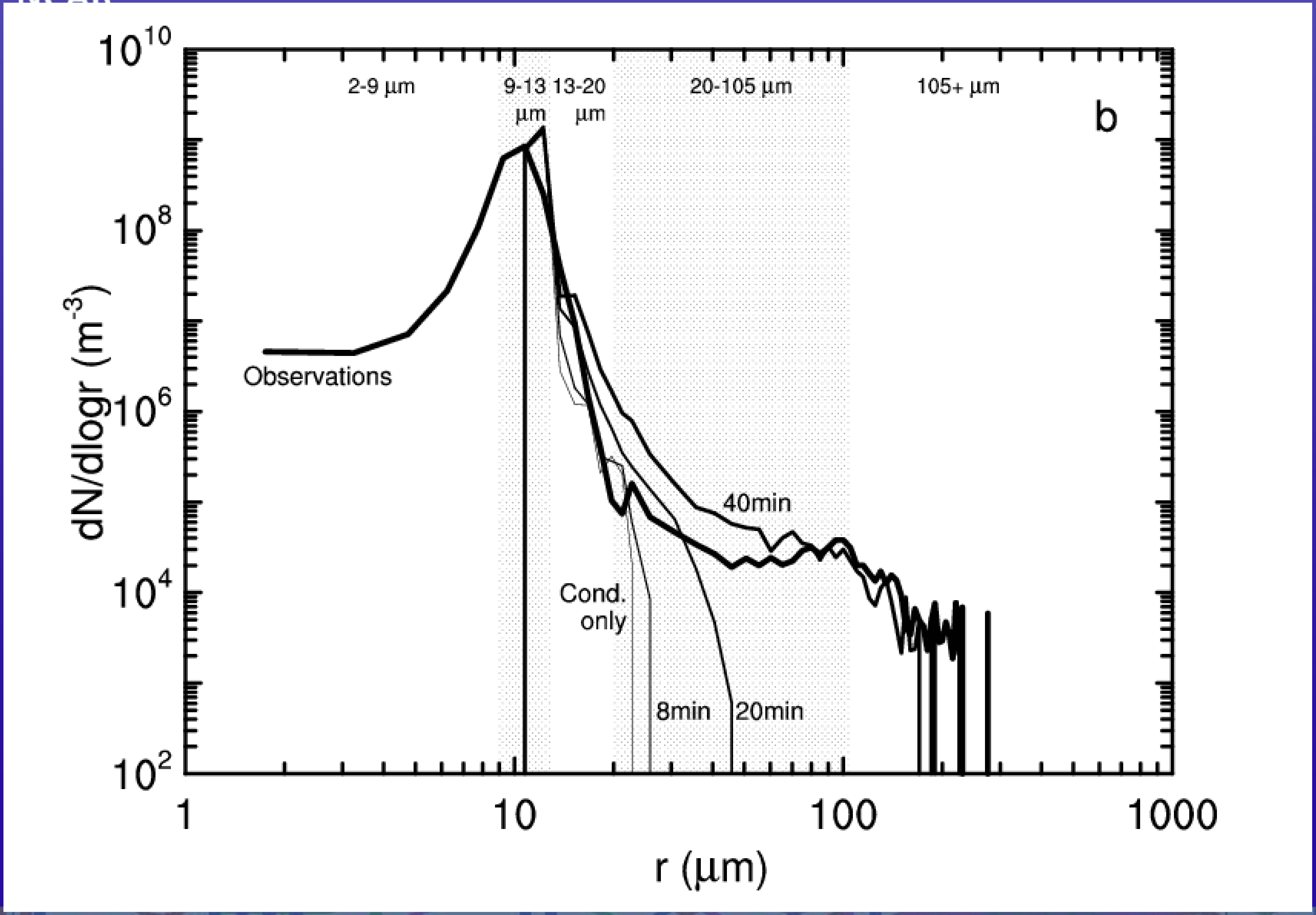
Fraction of cloud base air, F, and fraction of entrained air, $(1 - F)$. Solve the model for a range of updraft/downdraft scenarios. The key is to match the cloud penetration interstitial concentratio of SO_2. Secondary key is to match cloud penetration pH. Select the scenario(s) and use their integrated "time" as the "age of the cloudy air".

For this time, does our calculated and observed drop spectra match?

Dropsize as function of aerosol size



Compare observations & model results



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Aerosol Processing

- *How does cloud processing modify the aerosol size distribution in the detrained air ?*
  - Predict detrained size distributions based on mixing of cloud-base & entrained air
  - Compare predictions vs aerosol size distributions in detrained air

What is the sea-salt balance?

- *Generation rate = function of wind speed*
- *Observed size distribution in BL*
- *Removal through dry deposition (stability dependent)*
- *IGNORE CLOUDS & PRECIPITATION !*

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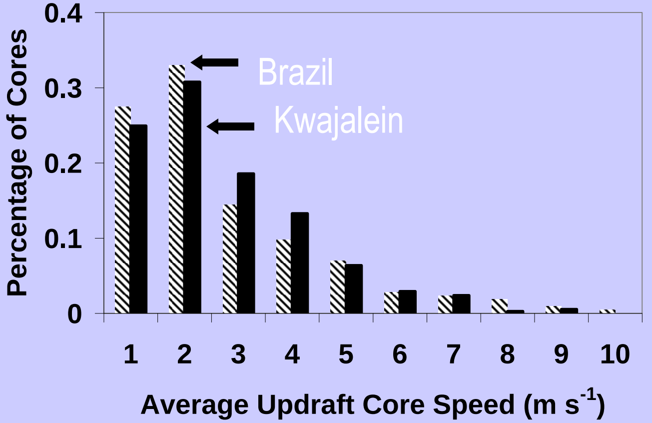
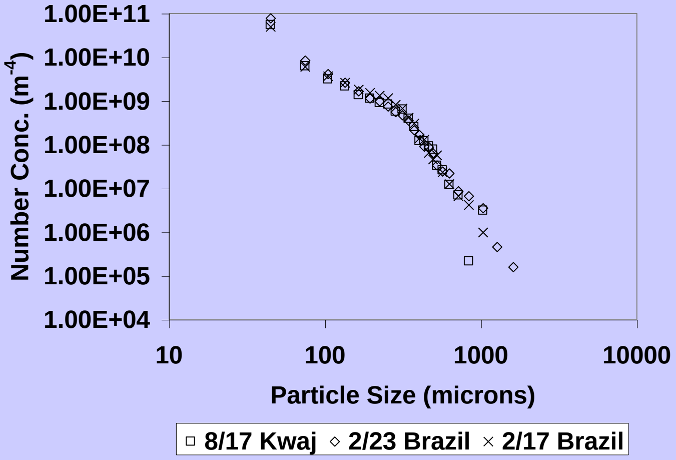
Compare clouds in other meteorological meteorological regimes



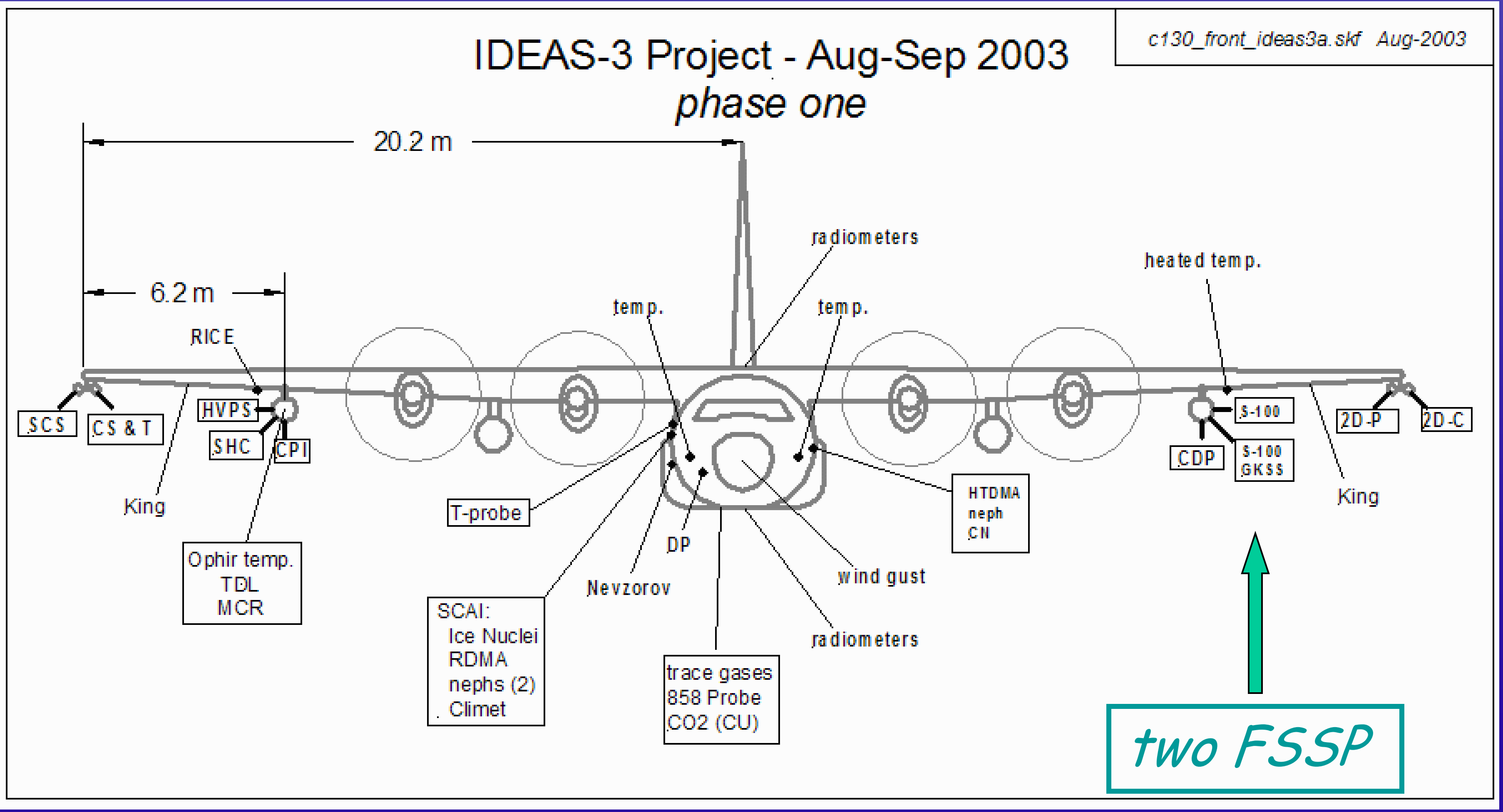


(Source Anderson et al 2004; Stith et al 2002)

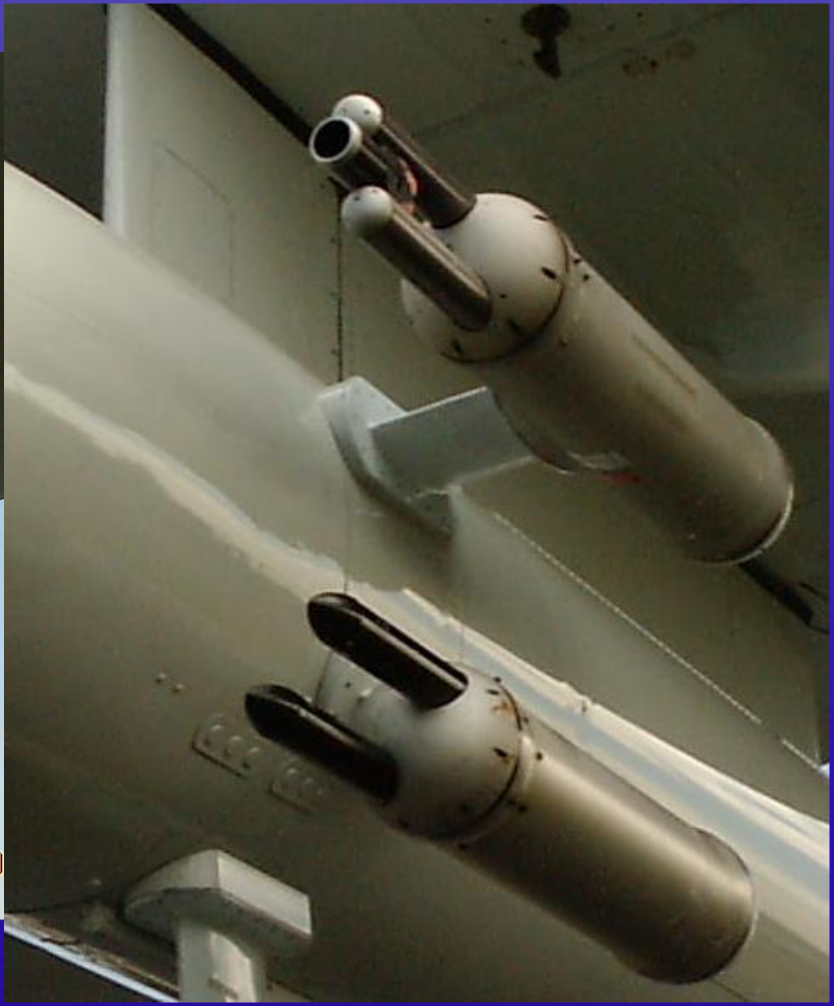
- Comparison of kinematic and microphysical properties with those of deeper tropical convection in clean regions. (Stith)
  - *Our recent studies indicate many similarities in the droplet/precipitation spectra (LWC, particle types) from clean tropical regions. These likely result from similar background levels of CCN, but are also a reflection of their similar kinematic (updraft, entrainment) properties. We hope to compare these data with that from the smaller clouds observed in RICO, which should have different kinematic properties, but similar CCN.*

FSSP comparisons

(IDEAS-3 project, with Nagel & Maixner, GKSS)



FSSP comparisons



FSSP comparisons

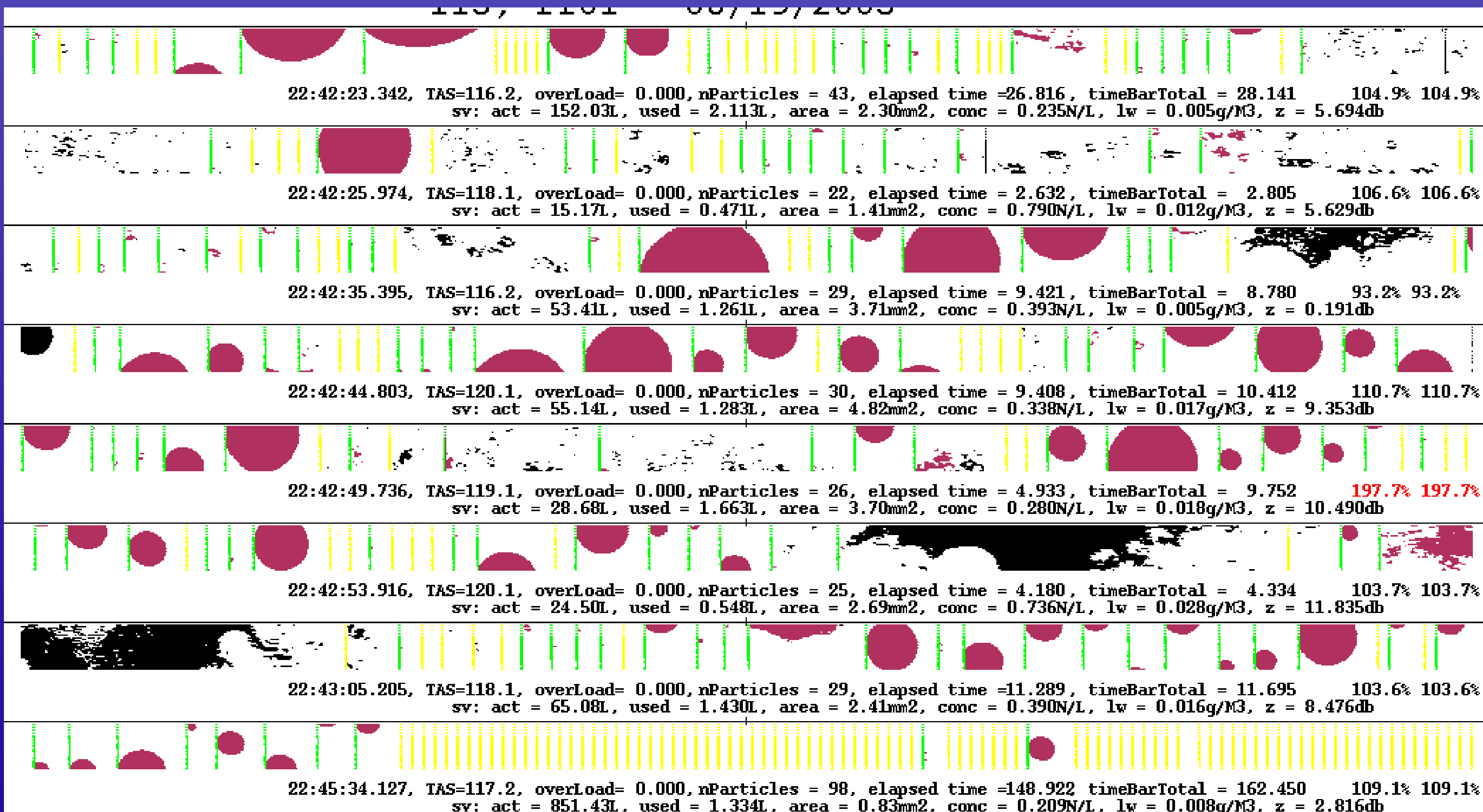
- Response to snow particles
- Effects of splash in rain

(other presentations)

- *Laser reference voltage drift*
- *Airflow:*
  - *aircraft turns in cloud*
  - *aircraft side-slip in cloud*
- *Add scarf tube (one flight)*

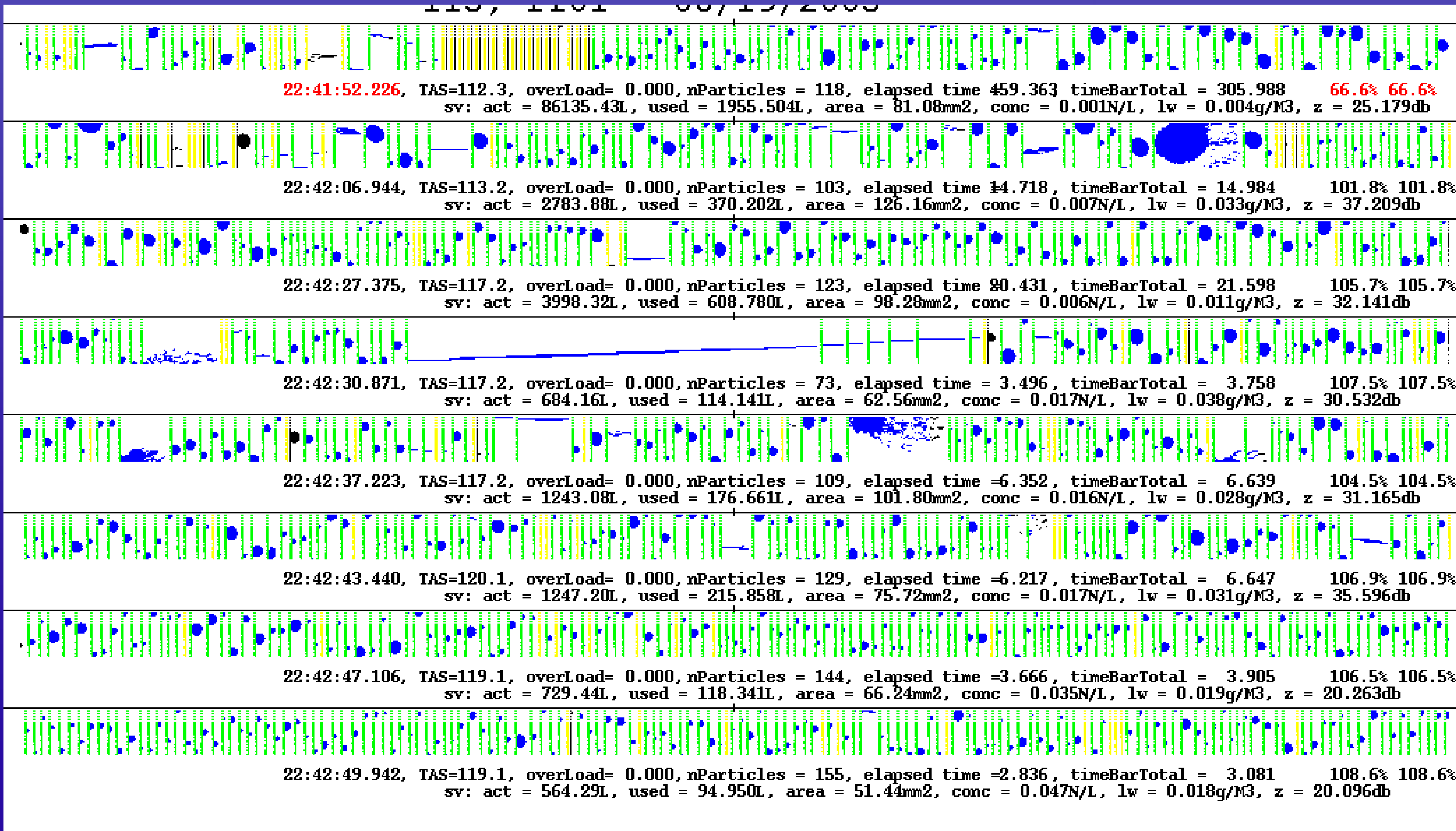
Effects of splash in rain

2DC images, 11 sec

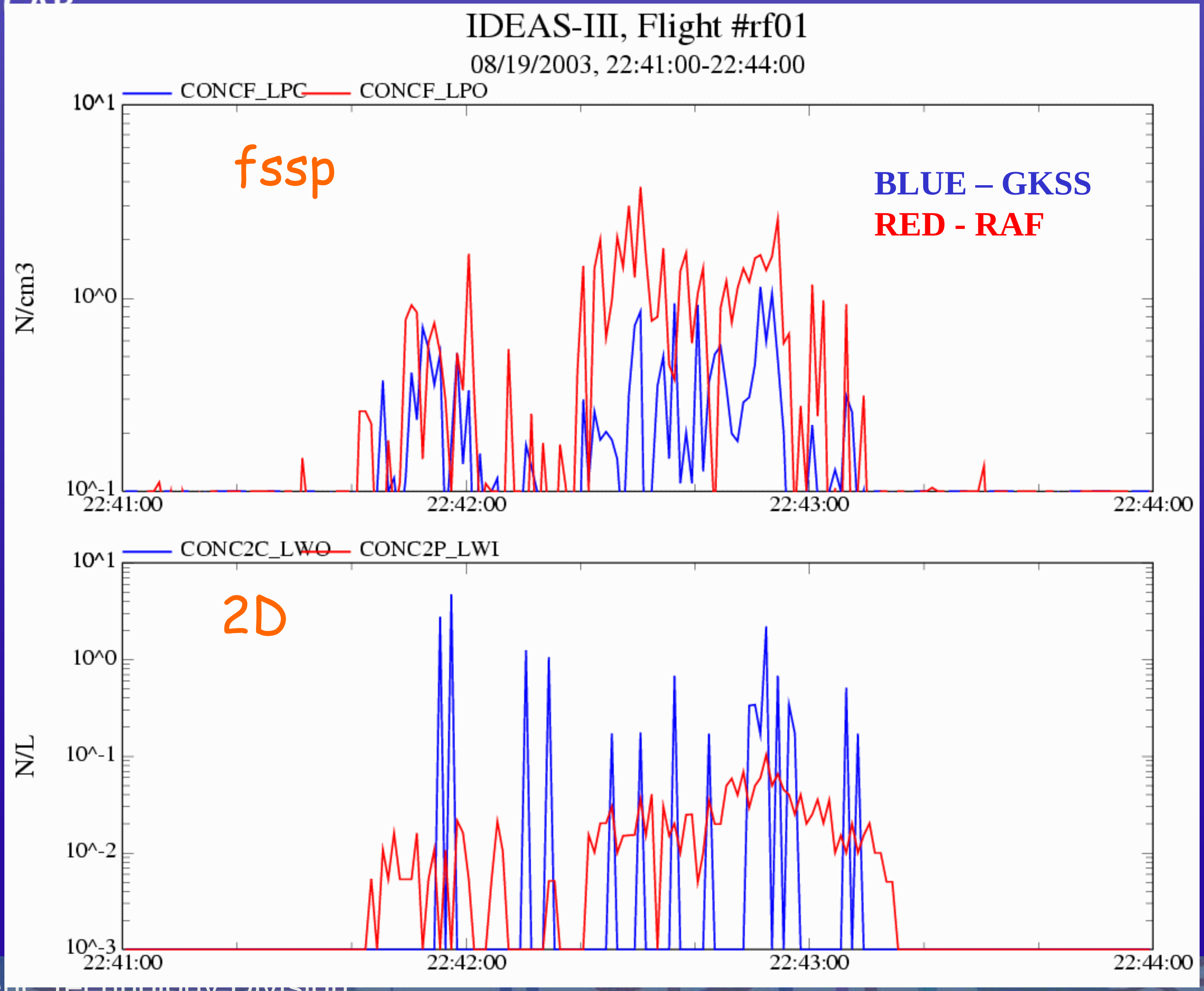


Effects of splash in rain

2DP images, 57 sec

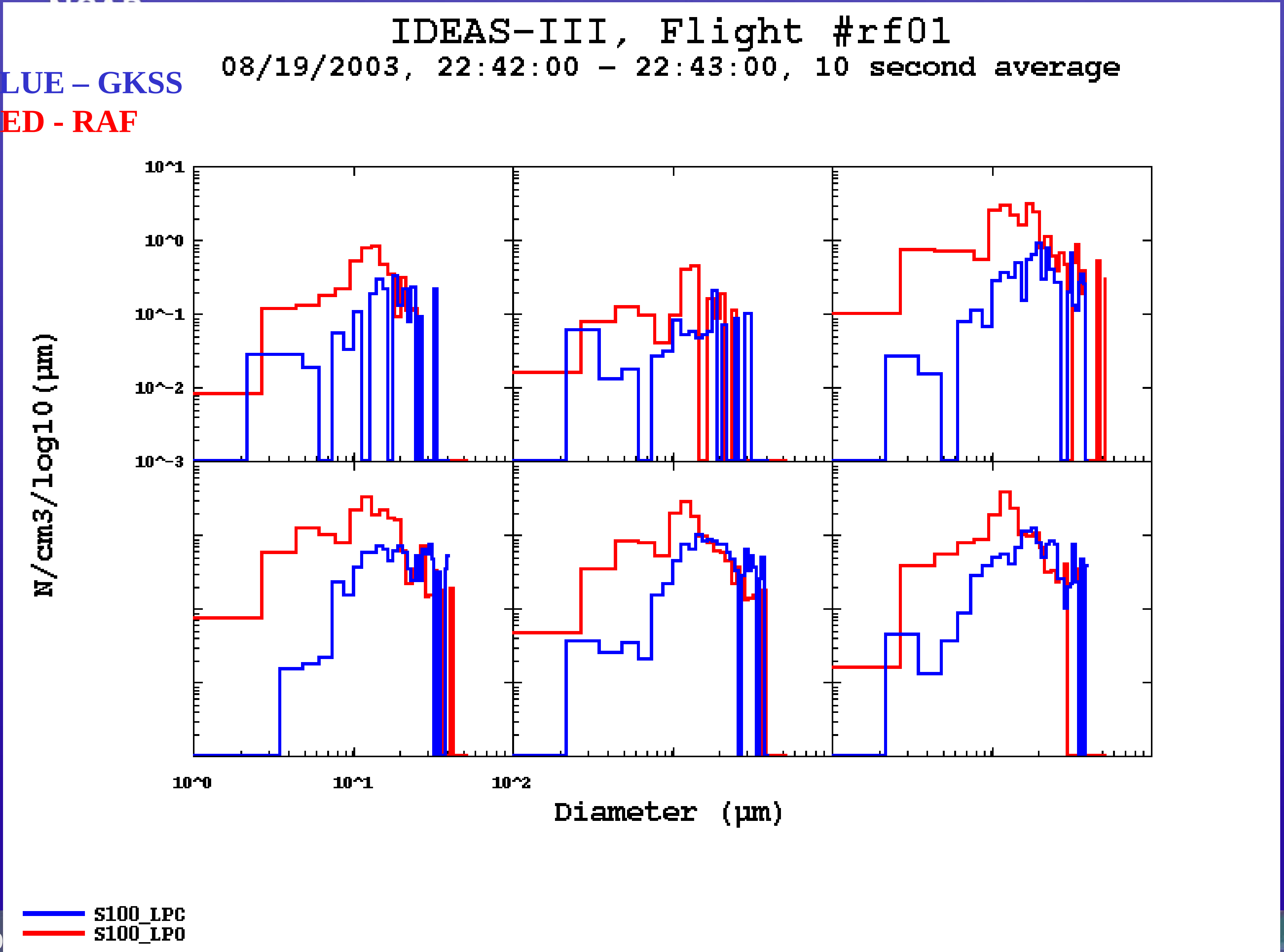


Effects of splash in rain



Effects of splash in rain

BLUE – GKSS
RED - RAF



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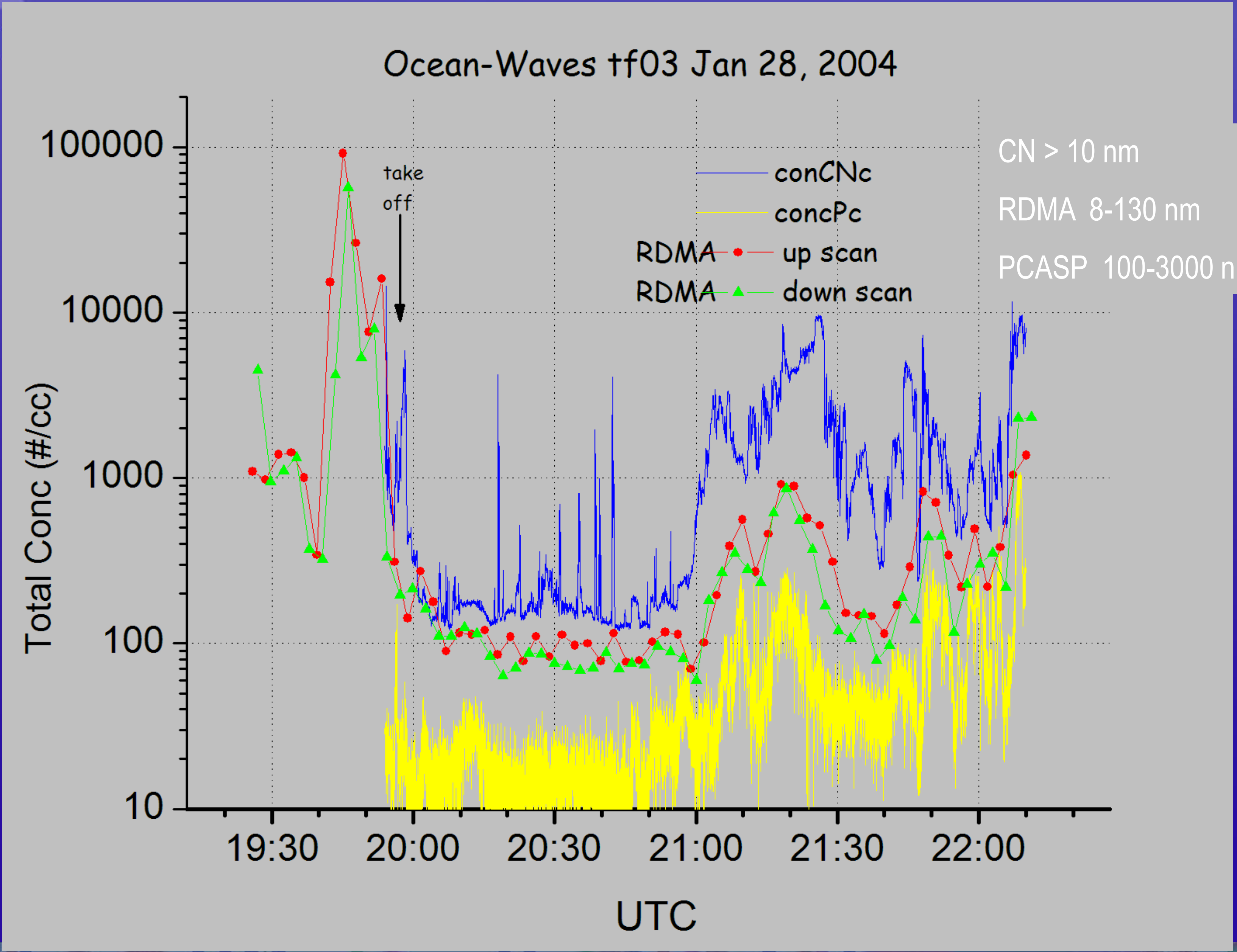
Aerosol measurements



CN > 10 nm

RDMA 8-130 nm

PCASP 100-3000 nm