



ICE Initiation - proposed field experiment  
*Wave/Layer clouds*  
(Ice-Initiation Steering Committee)

**Outline:**

*Clouds of interest*

*Recent field studies*

*New studies - Why now? What's new?*

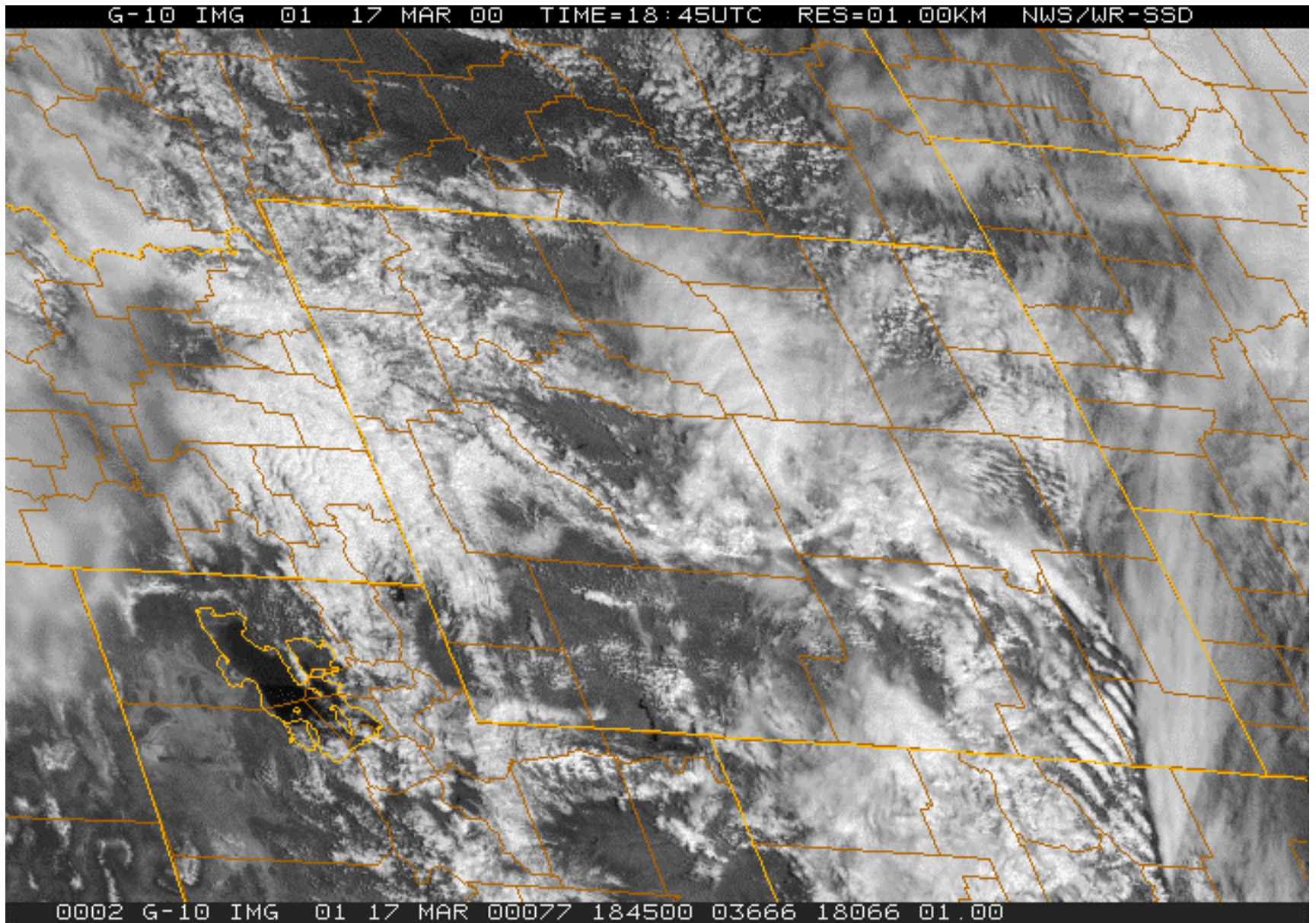
*Next steps*

*Scientific goals, Study methods*

*Critical measurements, Field project*

*June 7-8, 2004 Ice Initiation Workshop*

# Wave clouds - *March 17, 2000*



# Wave clouds

- Gravity waves created during forced ascent of stable layer at about ridge level, winds  $>20$ kt, shear.
- Clouds form when lifting  $>$  LCL
- Horizontal and vertical dimensions  $\sim$  underlying mountains
- ( $\sim 10$ - $30$  km wavelength,  $\sim 0.5$ - $1$  km amplitude)
- Temperature range  $\sim 0$  to  $-50^{\circ}\text{C}$
- Common in Colorado-Wyoming during winter
- Quasi-steady state, suitable for Lagrangian studies

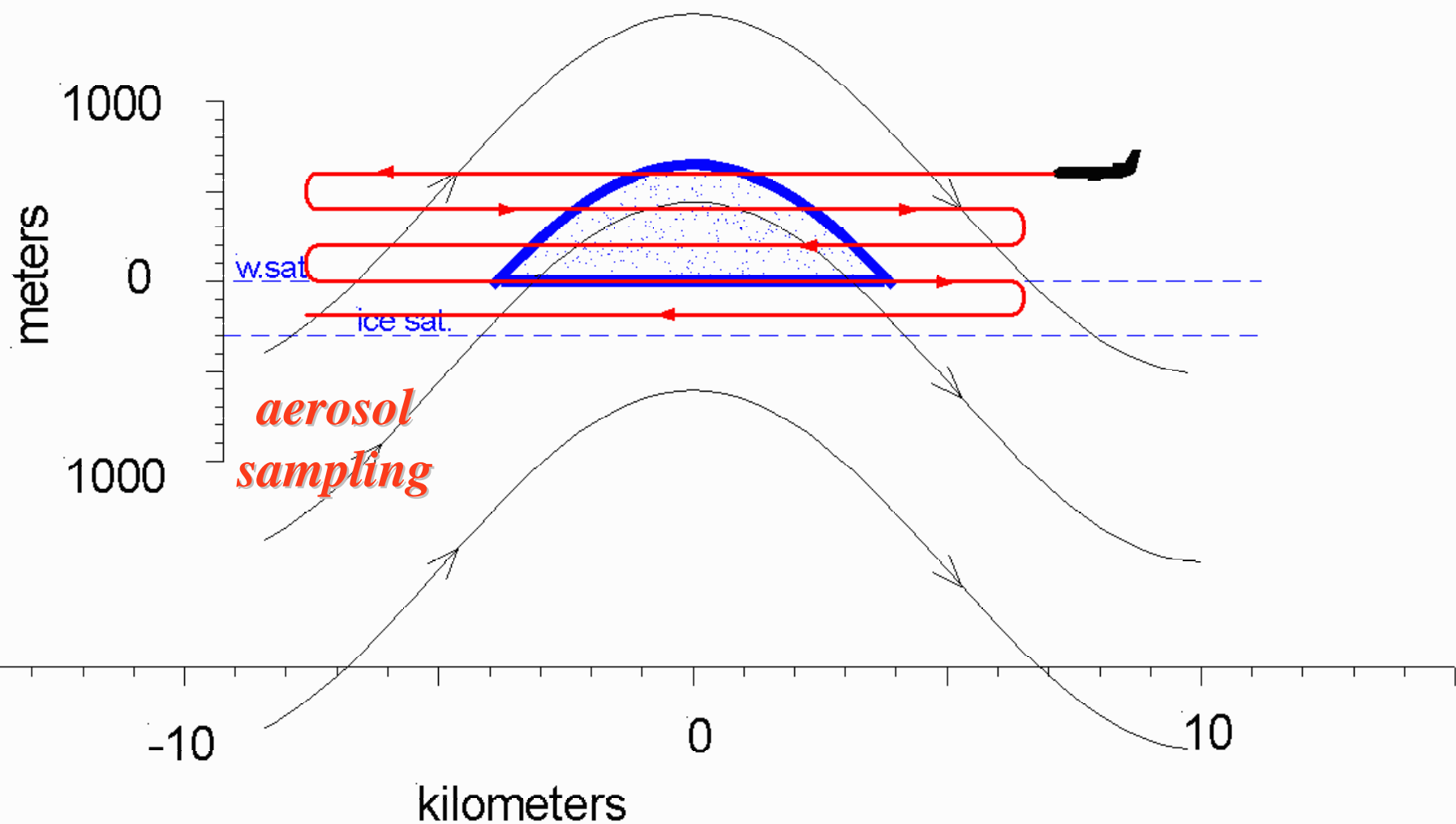
# Previous wave cloud studies

- UWyo, Queen Air (1972-5)
- NCAR, King Air (1988-89)
- UWyo, King Air (1999)
- NASA SUCCESS, DC-8 (1996, one case)
- CSU, Wyoming King Air (2000)
- SPEC, Lear Jet (2000-present)
- MidCiX, NASA WB-57 (2004)

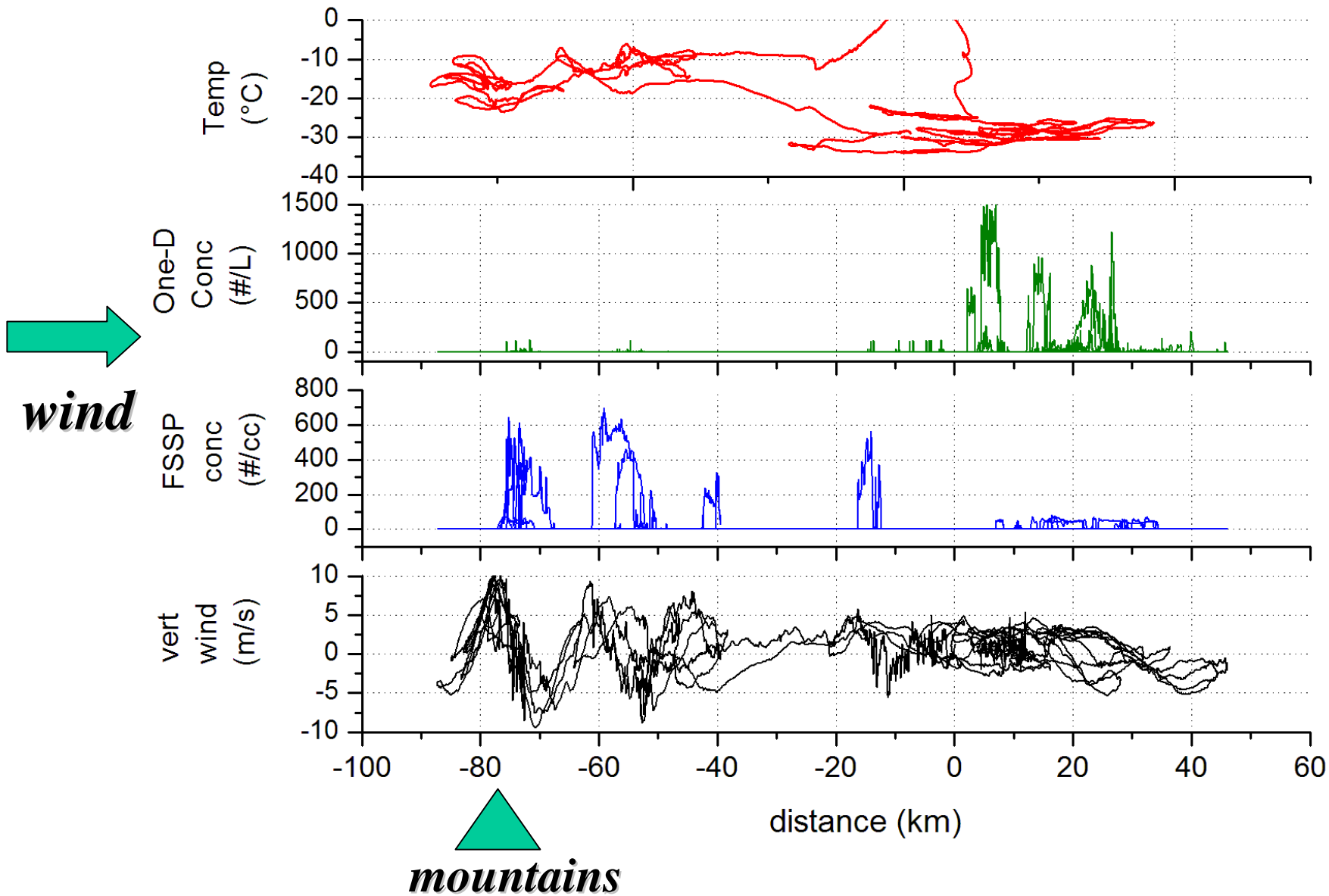
# *CSU, Wyoming King Air (2000)*

- *March 2000 - Wyoming King Air*
- *CSU ice nuclei instrument*
- *9 flights, cloud temperatures -3 to -40°C*
- *vertical motion +10 to -9 m s<sup>-1</sup>*

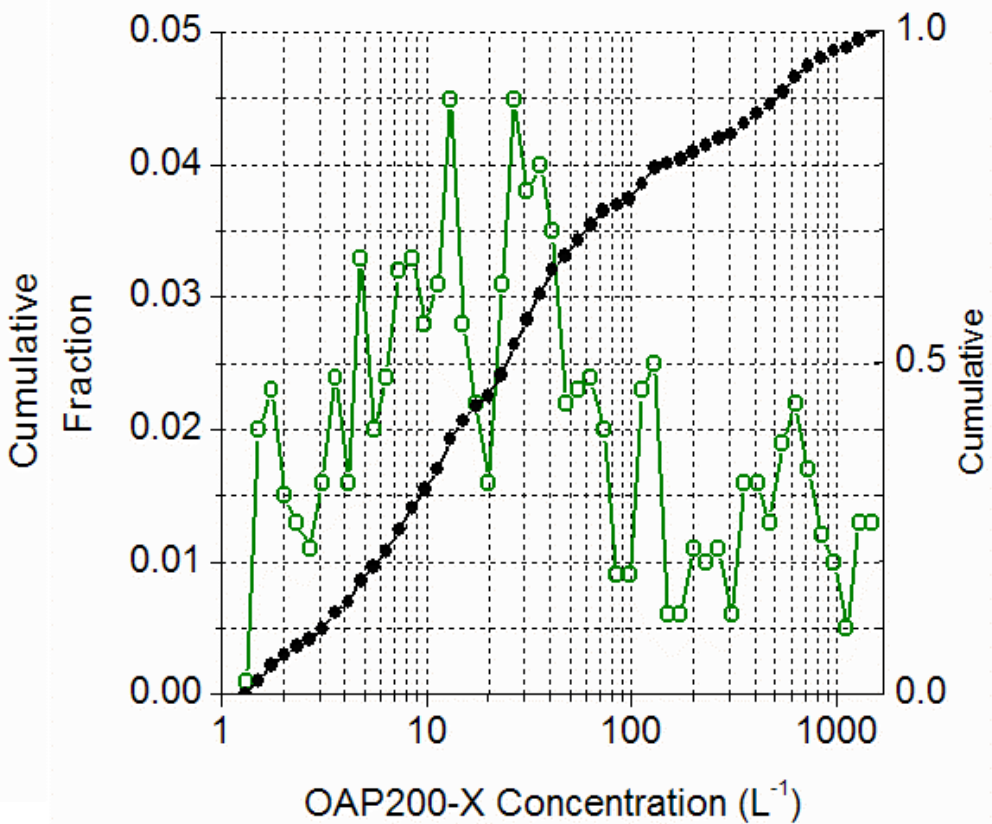
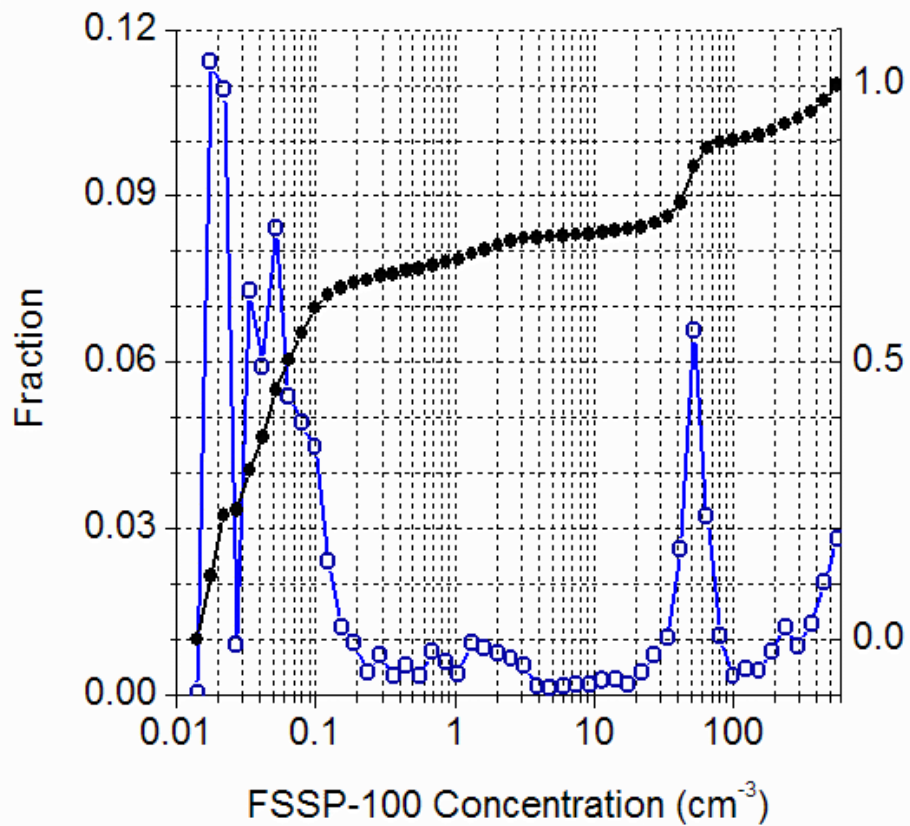
# flight passes to profile cloud + aerosols



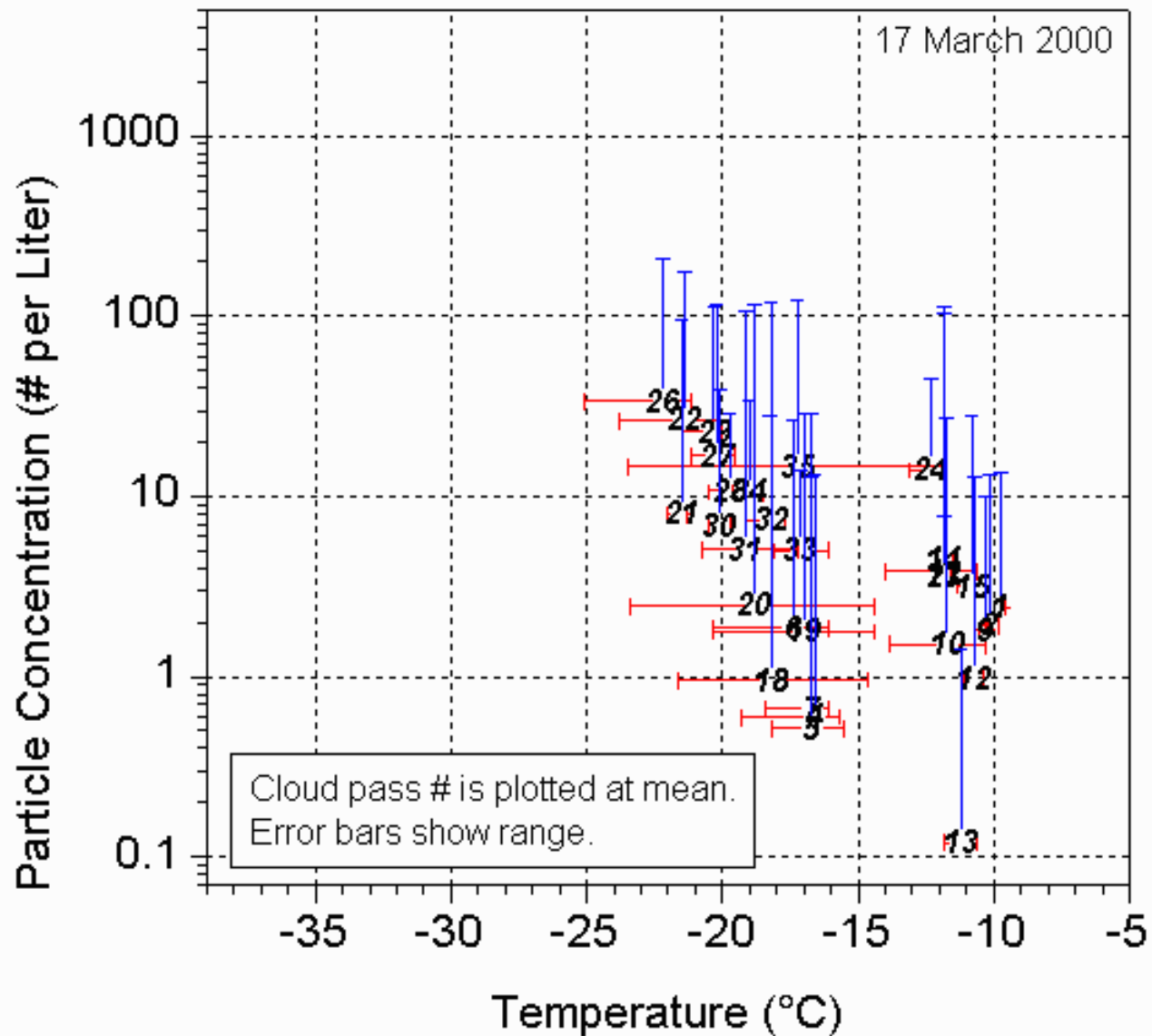
# Wave Clouds - March 14, 2000



*March 14, 2000*

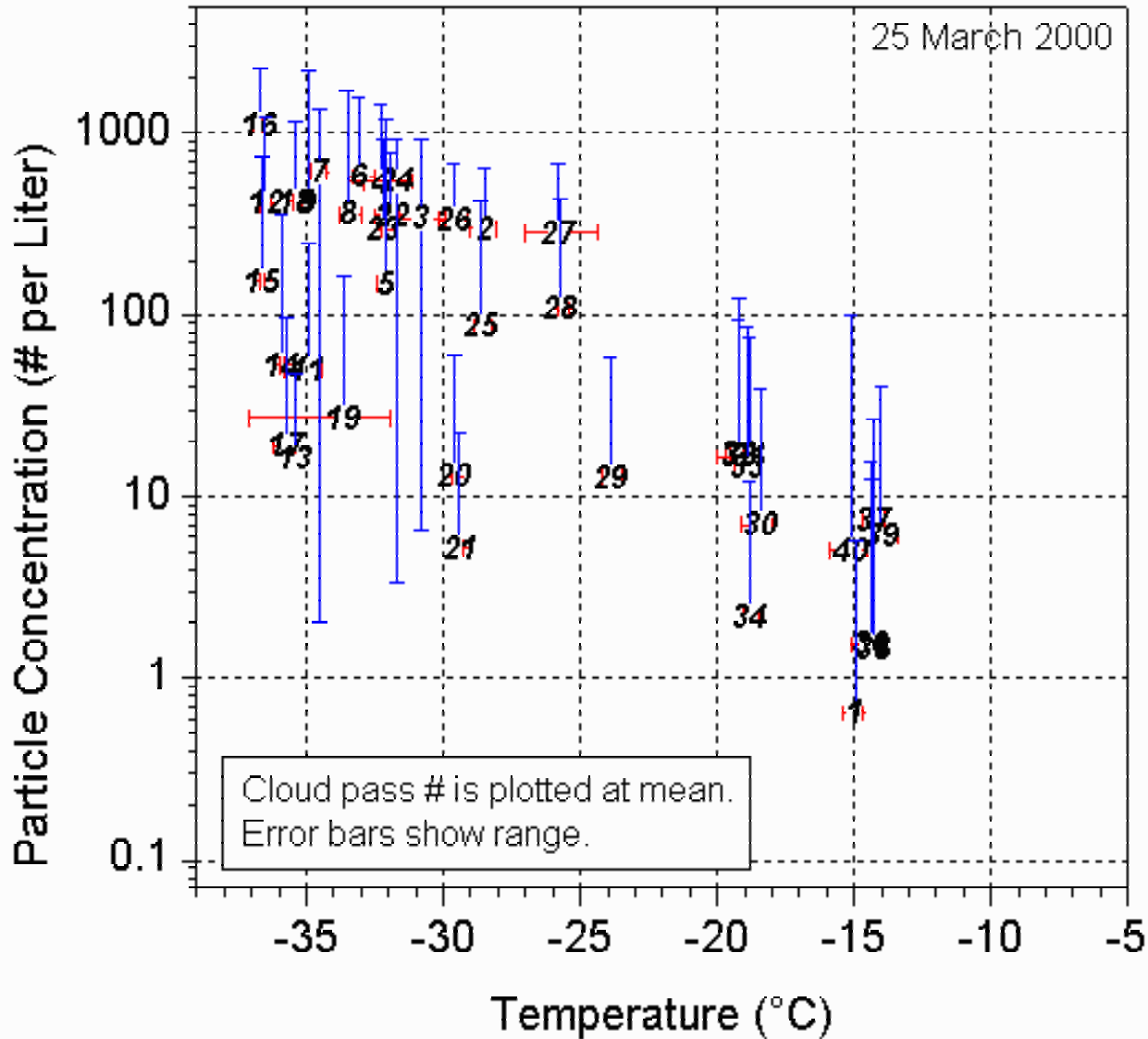


*March 17, 2000*



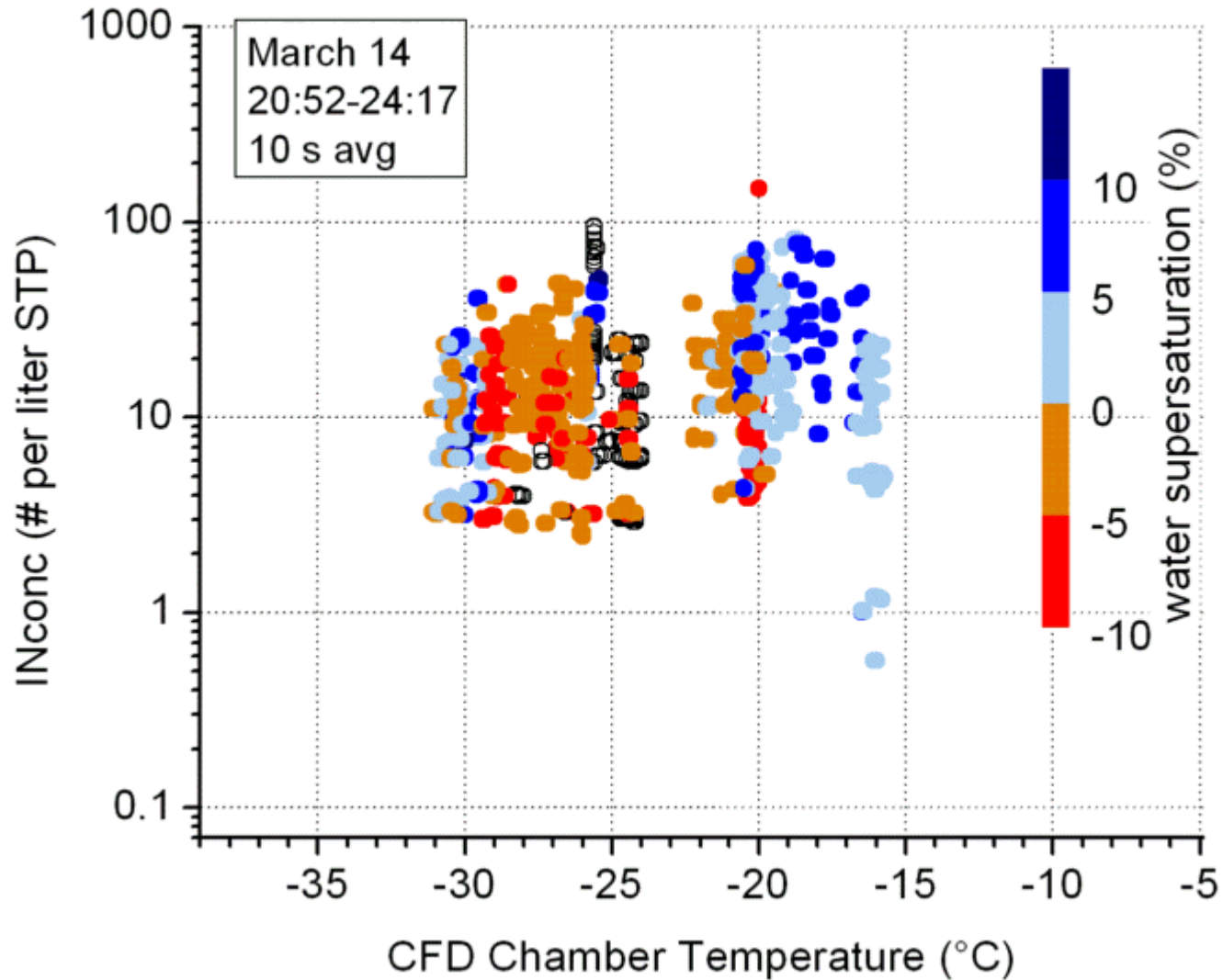
*OAP-200X probe*

*March 25, 2000*



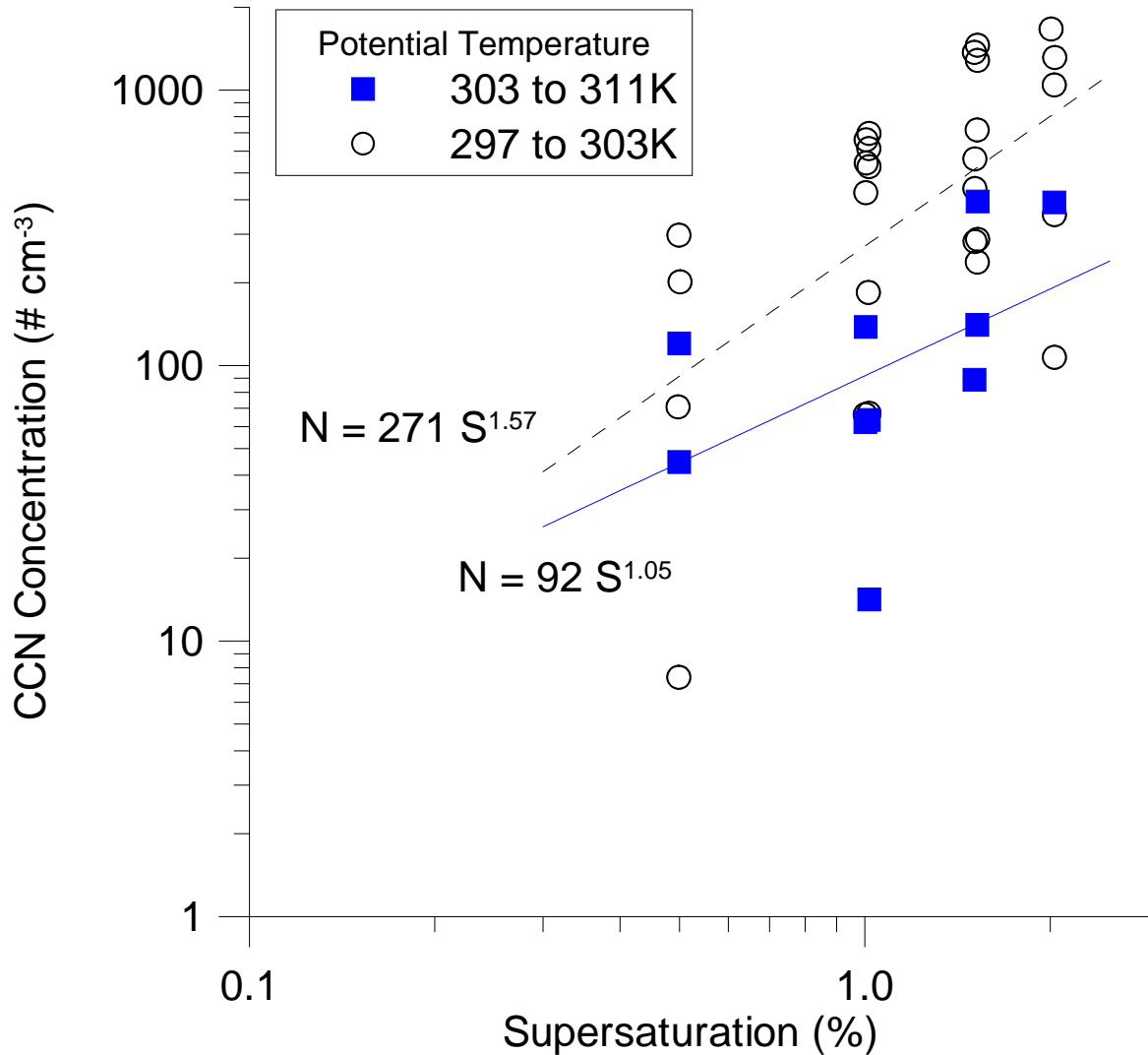
*OAP-200X probe*

# Ice nuclei data



# March 17 CCN Activation Spectra

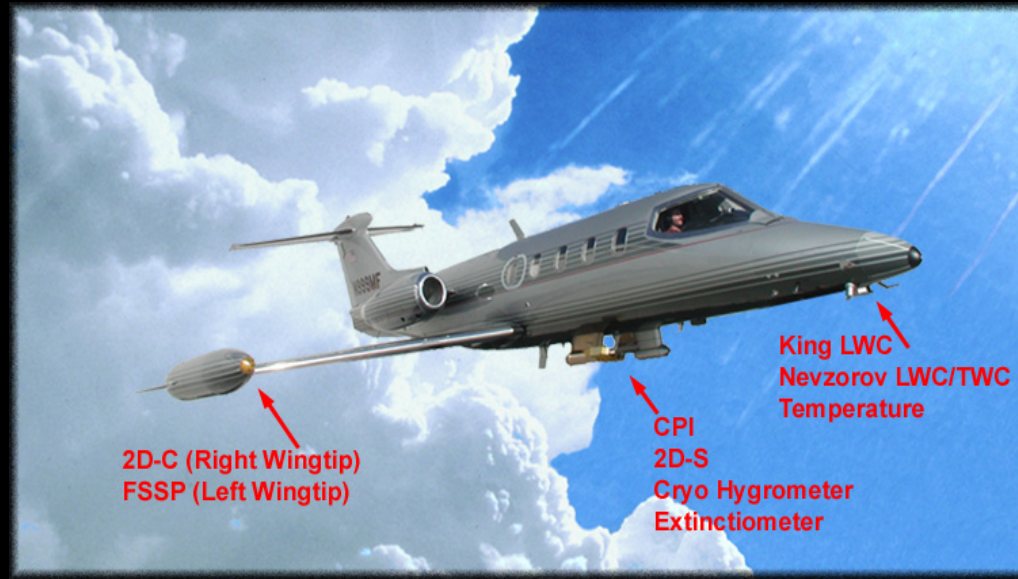
16:22-16:50



**CLOUD:**  
**700 drops cm<sup>-3</sup>**  
**(max 1000)**

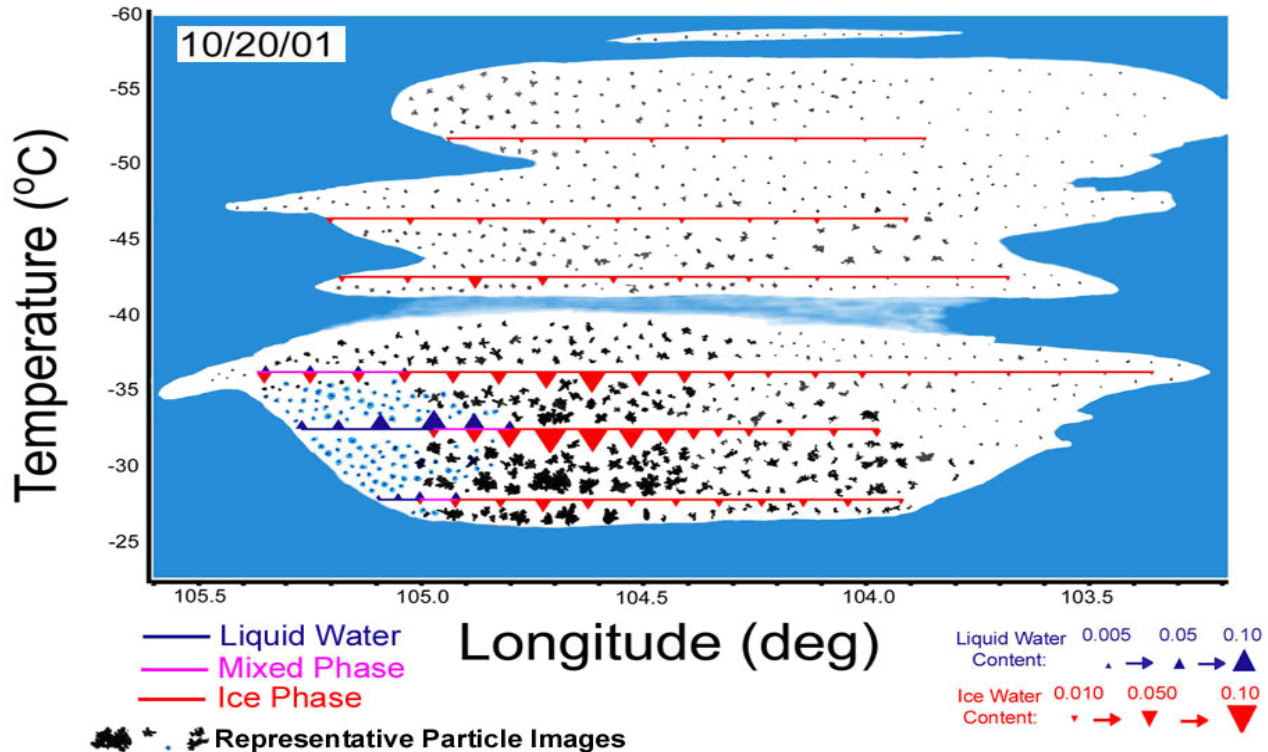
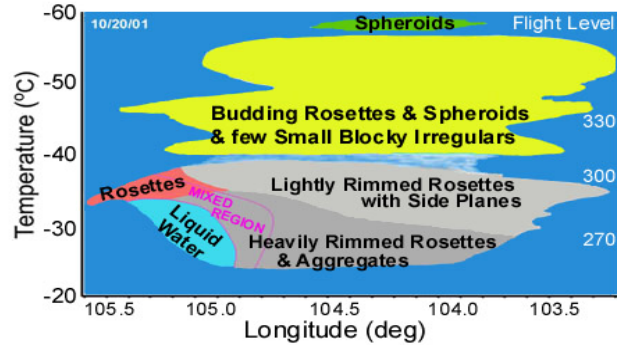
**→ 1.8% SSw peak**

# SPEC Learjet



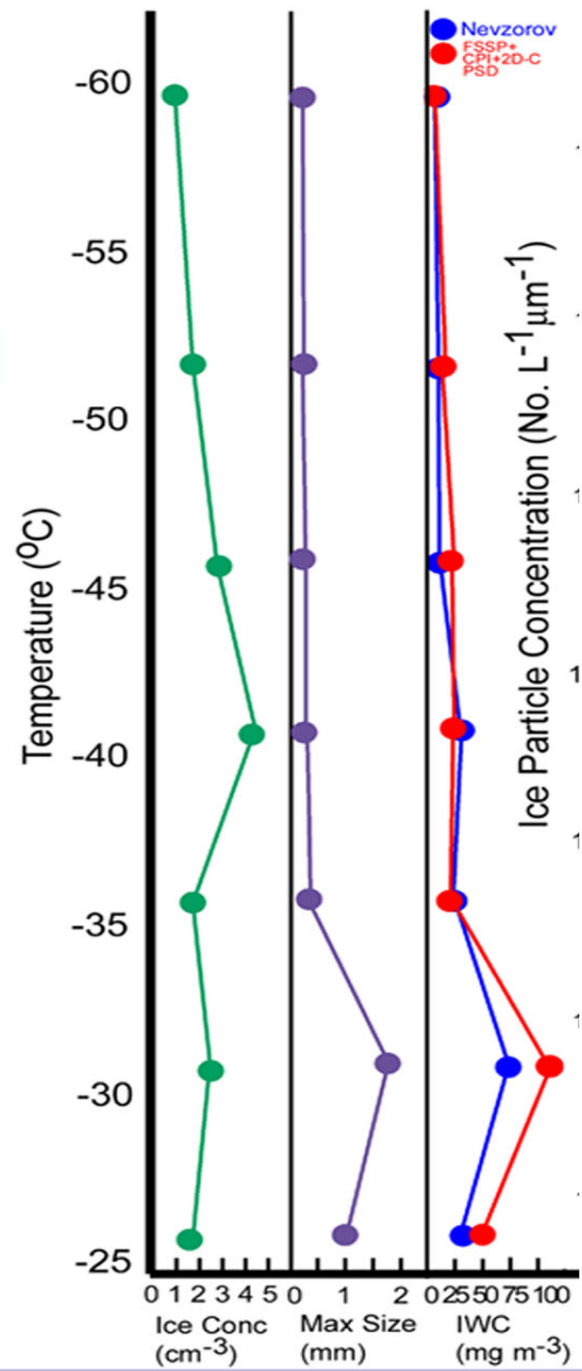
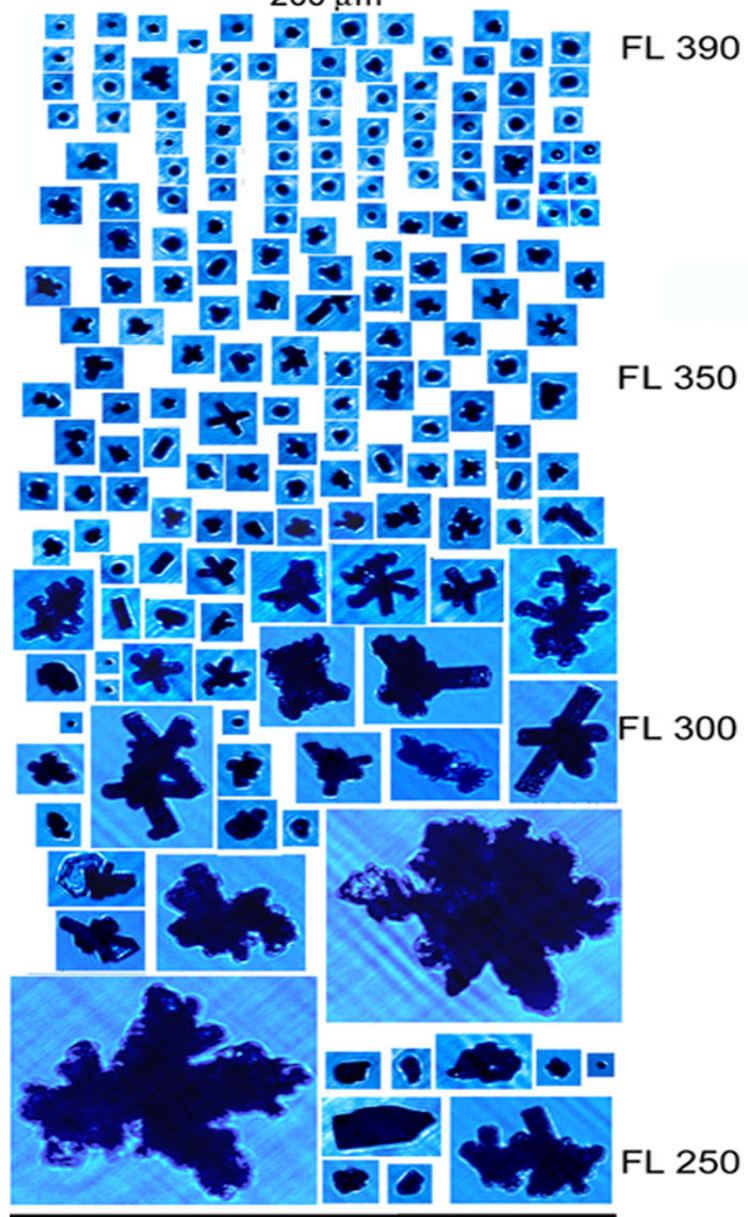
- 133 Legs flown in 17 wave clouds over the past four years.
- Already partially funded by NSF for wave cloud flights.
- Instrumentation includes CPI and new 2D-S (stereo) imaging probes.

# 20 October 2001 Wave Cloud



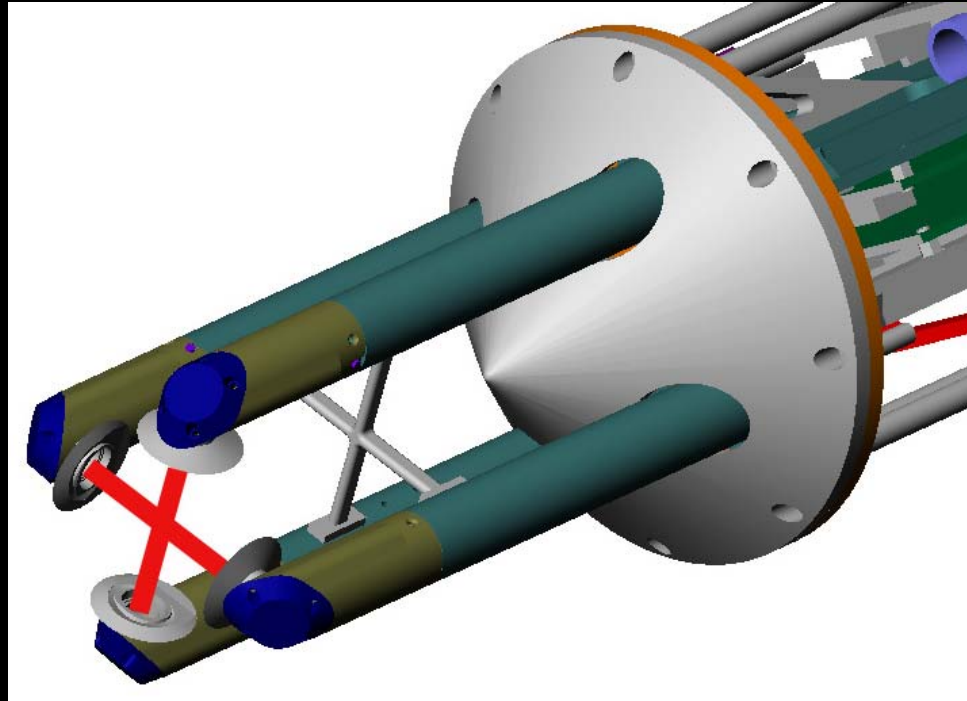
EXAMPLES OF CPI IMAGES

200  $\mu\text{m}$



# SPEC 2D-S probe

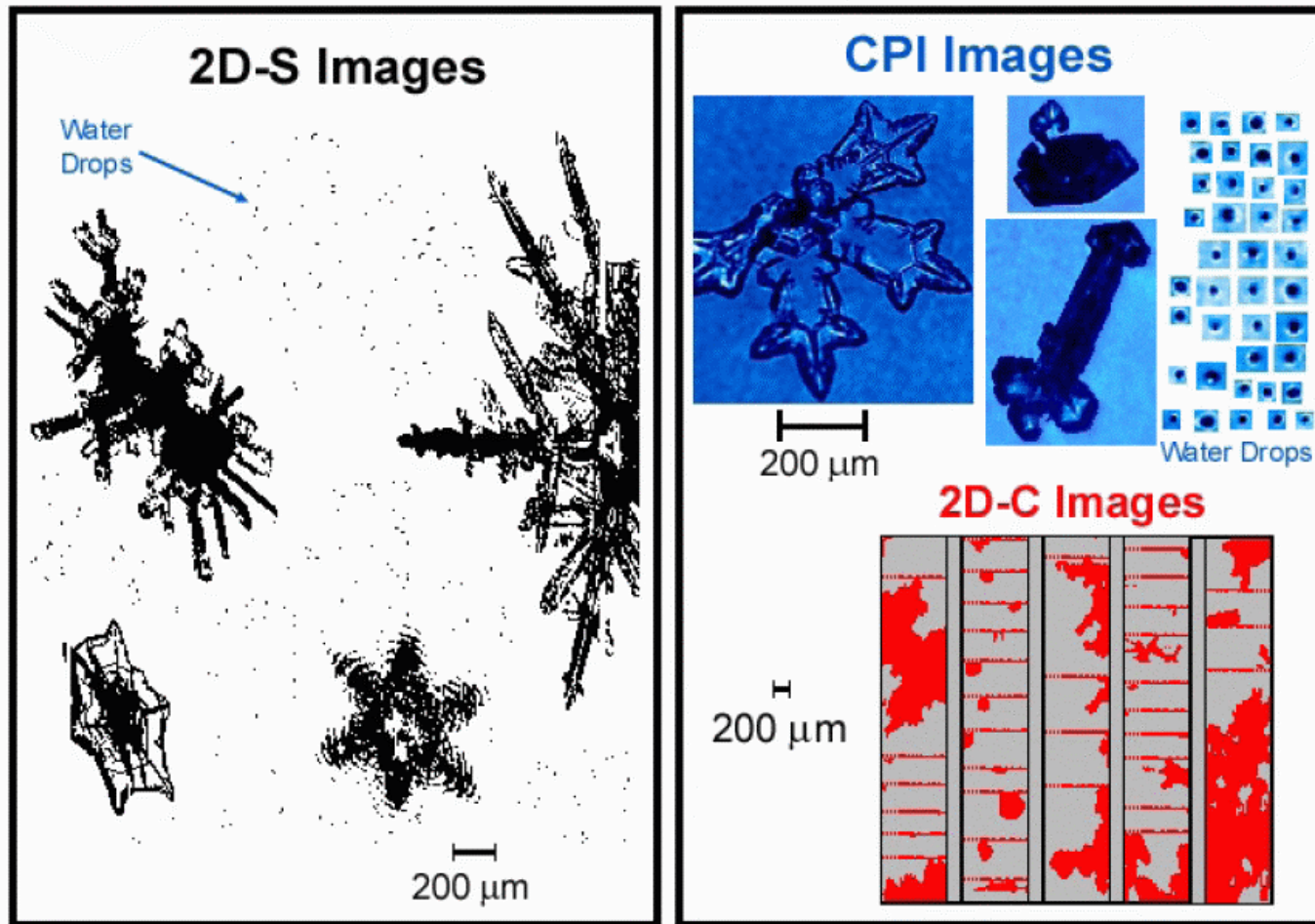
Navy SBIR Phase II Contract



- Laser beams illuminate dual high-speed linear arrays with 128 photodiodes each
- 10  $\mu\text{m}$  pixel resolution at 250 m/s
- Overlap region defines sample volume for small particles and provides a region with stereo pairs of images to improve determination of particle habit and IWC.

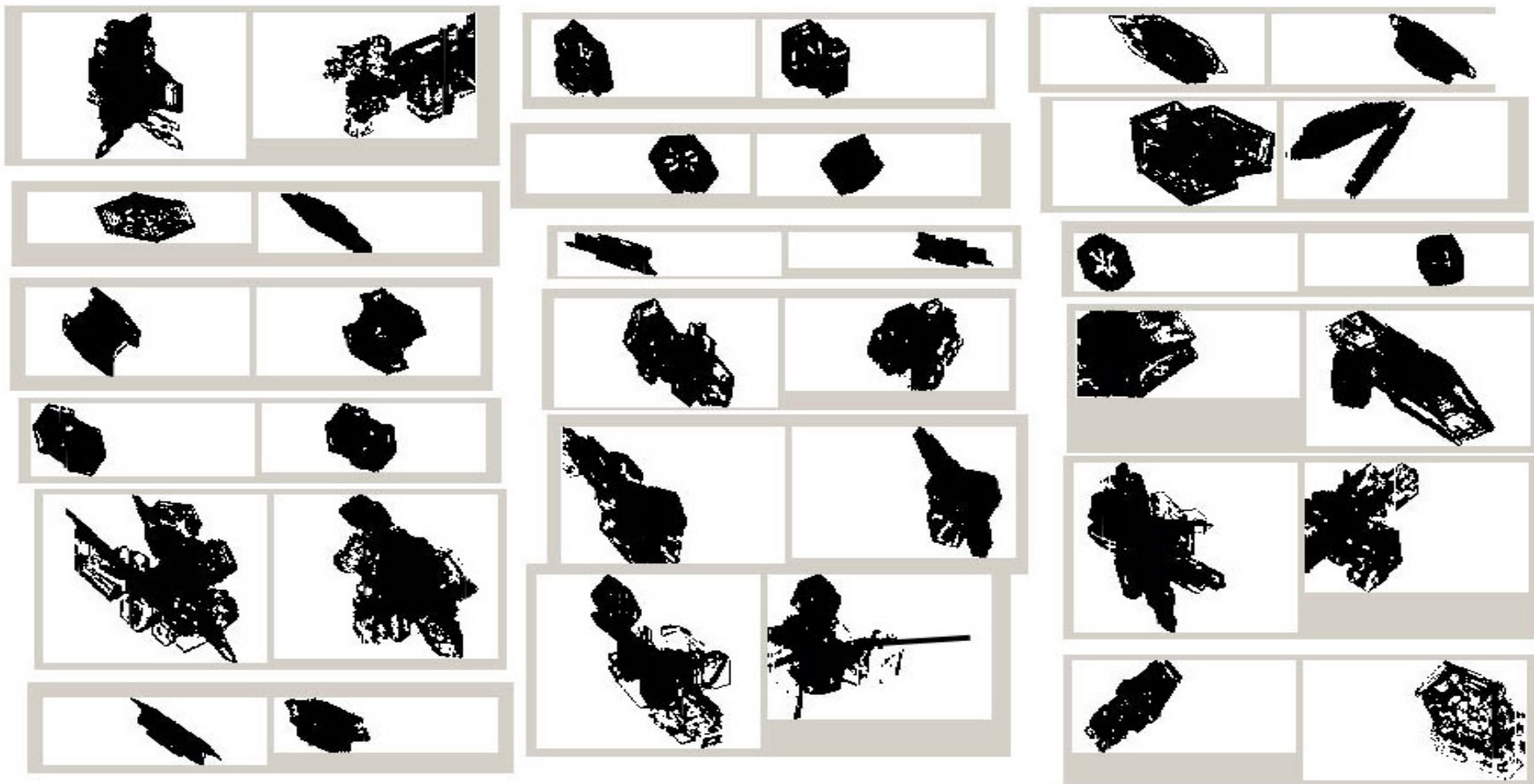
# Particle Imaging Probes

## Comparison of 2D-S, CPI and 2D-C images in a Mixed-Phase (Upslope) Cloud



**Figure 6.** Examples of images from the 2D-S, CPI and 2D-C probes in a mixed-phase upslope cloud investigated by the SPEC Learjet.

# Examples of Stereo Pairs of Images from the 2D-S Probe



# NEW Wave/Layer Cloud Studies

## *Why now? What's new?*

- New instruments, new capabilities:
  - *Aerosols: airborne IN, CCN, aerosol composition, hydration*
  - *SID, CPI, 2D-S, ..*
  - *Lab facilities - AIDA, CSU, U.Wash, PennState, ..*
  - *Airborne millimeter radar*
  - *Polarization lidar, ground & airborne*
- Improved understanding of Homogeneous-Freezing
  - *Theory, lab studies, & observations*
- Greater modeling complexity
  - *Aqueous phase chemistry, aerosol tracking, small scales*
- Agency interest, field programs
  - *NASA CRYSTAL-FACE, MidCiX*
  - *NCAR Initiatives, UT/LS*
- U.S. Research aircraft capabilities
  - *High altitude: HIAPER, NASA WB-57, SPEC Lear jet, UND Citation*
  - *mid-trop: NCAR C-130, UWyo King Air*

# Field project

Address Heterogeneous-Fz & Homog-Fz

Field site locations

- *Colorado-Wyoming Front Range*

Timing

- *time of year; one project or several?*

Forecast & modeling guidance

Couple with agency activities

Couple observations to events ?

- *Dust plume production*
- *Add cloud seeding experiment ?*



# Scientific goals

Identify ice formation mechanisms:

*Primary, secondary, deposition, evaporation, imm-fz, homog-fz, ..*

*Dominant mechanism ? Absent mechanisms ? Pre-activation?*

*Role of aerosols ?*

Understand sensitivity of cloud properties to aerosols

*Improve descriptions in cloud models*

Where does ice first form, and how does it propagate?

Role of evaporation on ice formation/propagation

Effect of cloud cycling

*→ cloud properties & aerosol chemistry*

Improve microphysics instruments & methods

# Study methods

remote sensing aircraft:

*airborne W-band*

*airborne doppler pol.*

in-situ aircraft:

*cloud particle probes*

Ground-based:

*k-band radar*

*Polarization lidar*

Laboratory

satellite

modeling

*Closely coupled*



# Critical measurements

## Aerosol - CCN, IN, GN

- *Vertical profiles, faster sample rates, real-time*

## Air motion & mixing

## Thermodynamics

- *Water vapor*
- *Temperature in cloud*

## Cloud microphysics

- *Presence of supercooled liquid water*
- *First appearance of ice phase*
- *High resolution droplet & crystal measurements*

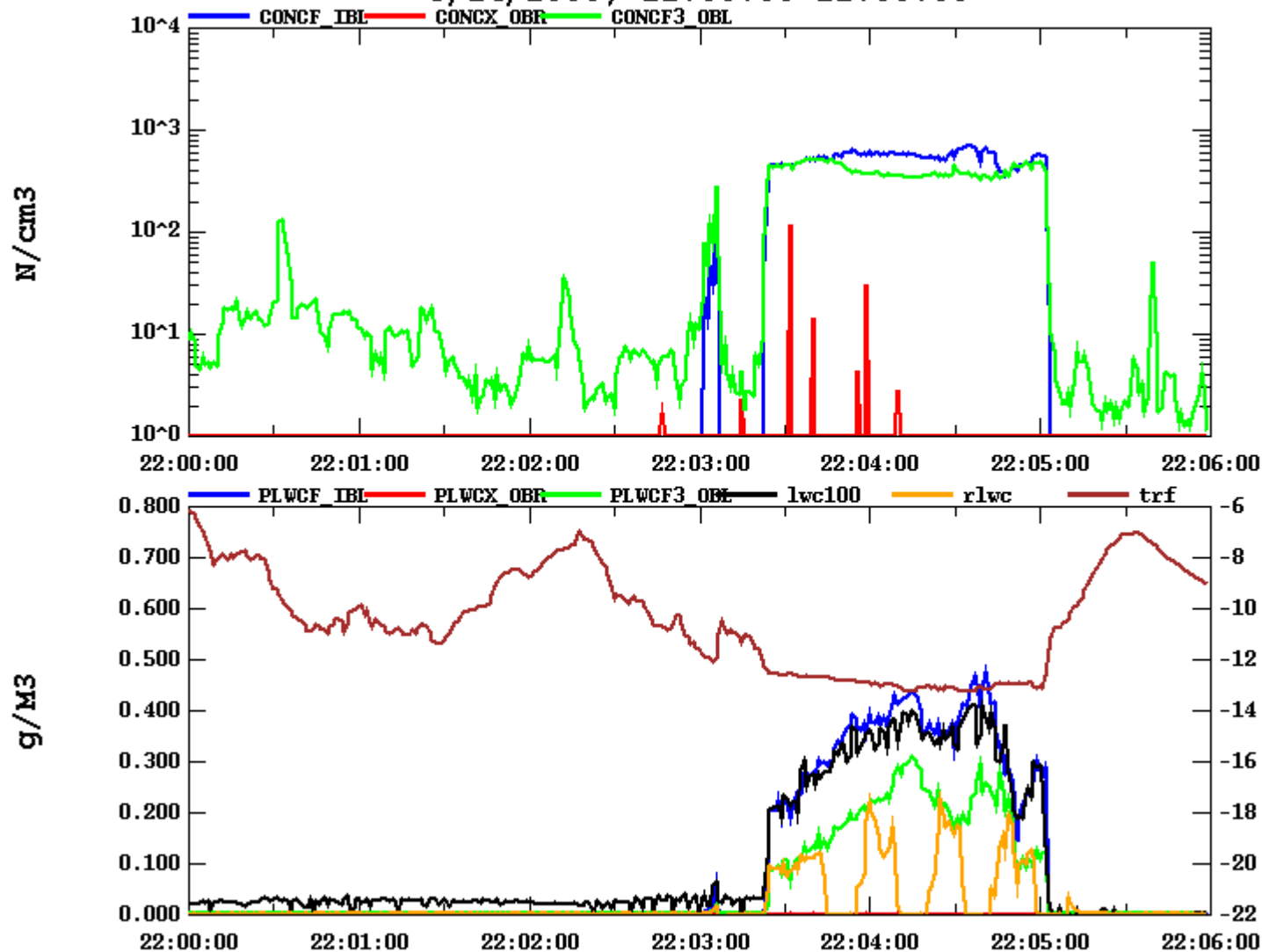
## Cloud structure

END



# Typical cloud pass, $-13^{\circ}\text{C}$

Wave Ice, Flight #0  
3/14/2000, 22:00:00-22:06:00



# Advantages for research

- ◆ *Simple airflow, cloud and precipitation forming processes*
  - ◆ *Airflow smooth, predominantly horizontal with small vertical extent*
  - ◆ *Narrow temperature range along parcel trajectory*
  - ◆ *Change sampling altitude to sample in a different temperature regime*
- ◆ *Stationary w.r.t. ground*
- ◆ *Often occur as series of wave clouds downwind of the first*
- ◆ *Quasi steady-state. Lifetime:*
  - Cloud ~ hours*
  - Cloud parcels ~ few hundred seconds*

*Every few hundred seconds, the cloud is completely replaced (re-formed) with new air; each subsequent aircraft penetration obtains a new, uncontaminated and independent microphysical sample.*
- ◆ *Simple relation between the Lagrangian and Eulerian frames of reference - very useful for analysis and modeling:*
  - $$\text{parcel time} = \text{aircraft time} * (\text{TAS} + \text{Wind})/\text{Wind}$$

*(where Wind > 0 for tailwind; Wind < 0 for headwind)*
- ◆ *Highly suitable for numerical modeling*