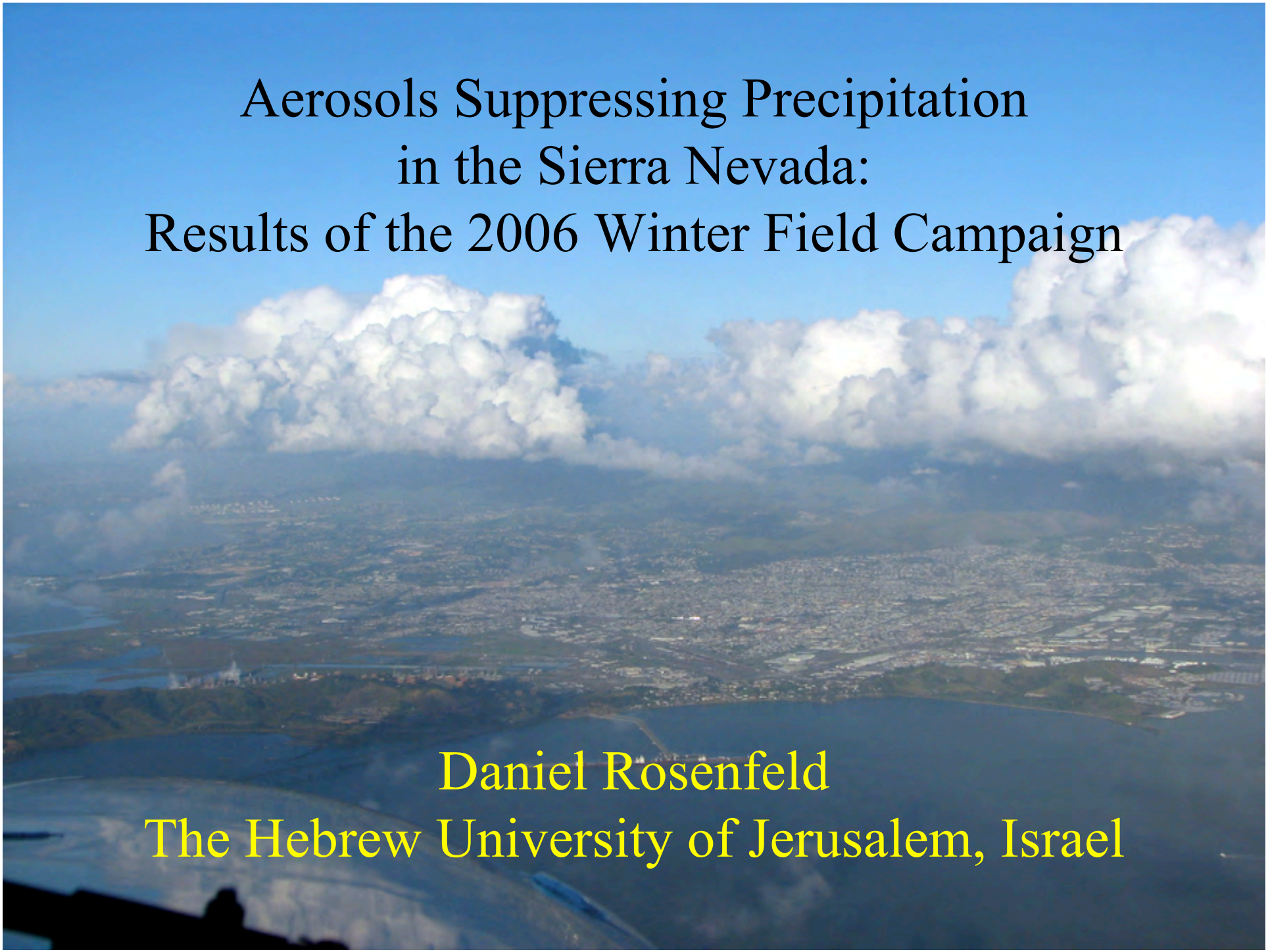


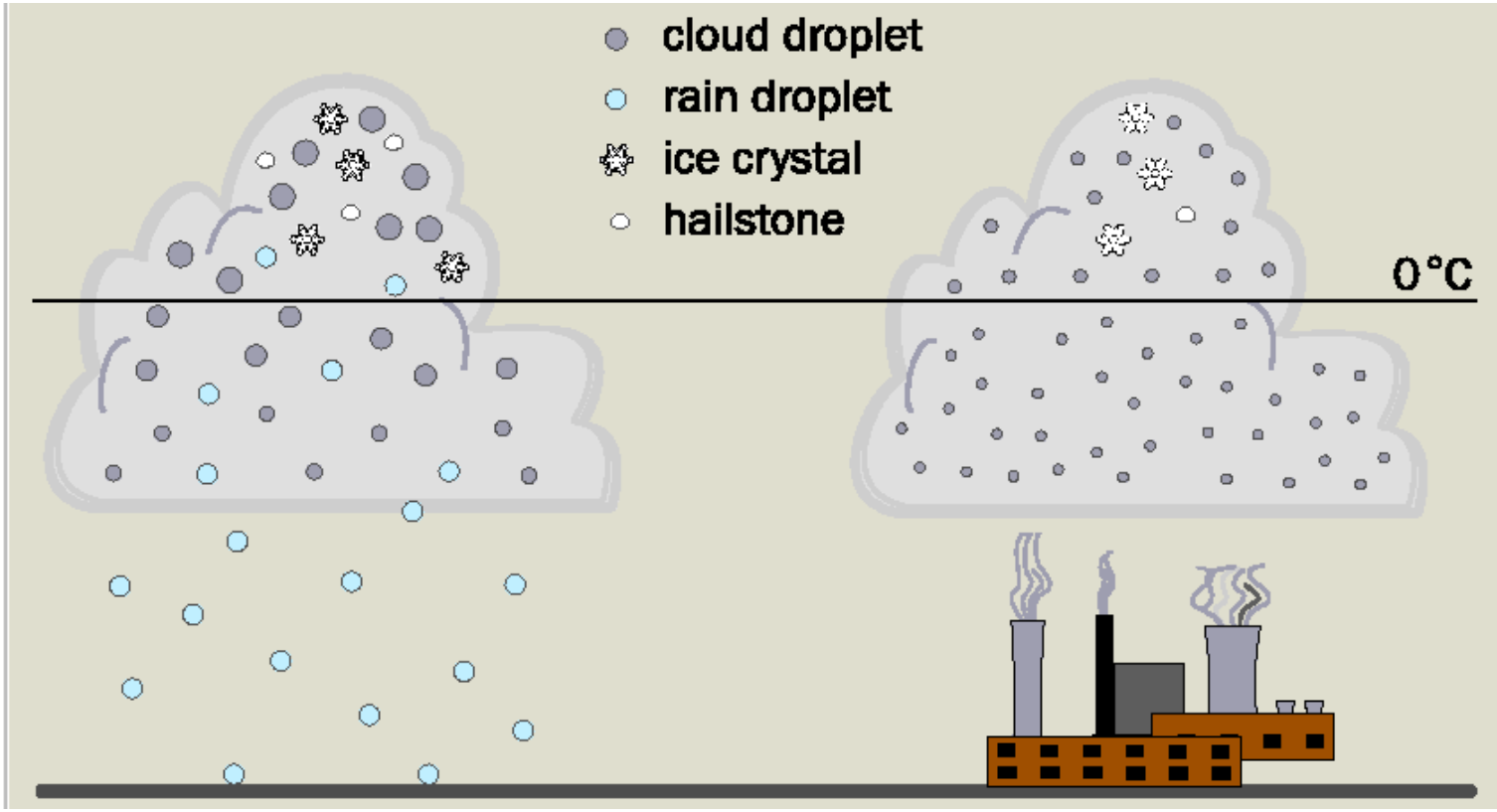
Aerosols Suppressing Precipitation in the Sierra Nevada: Results of the 2006 Winter Field Campaign

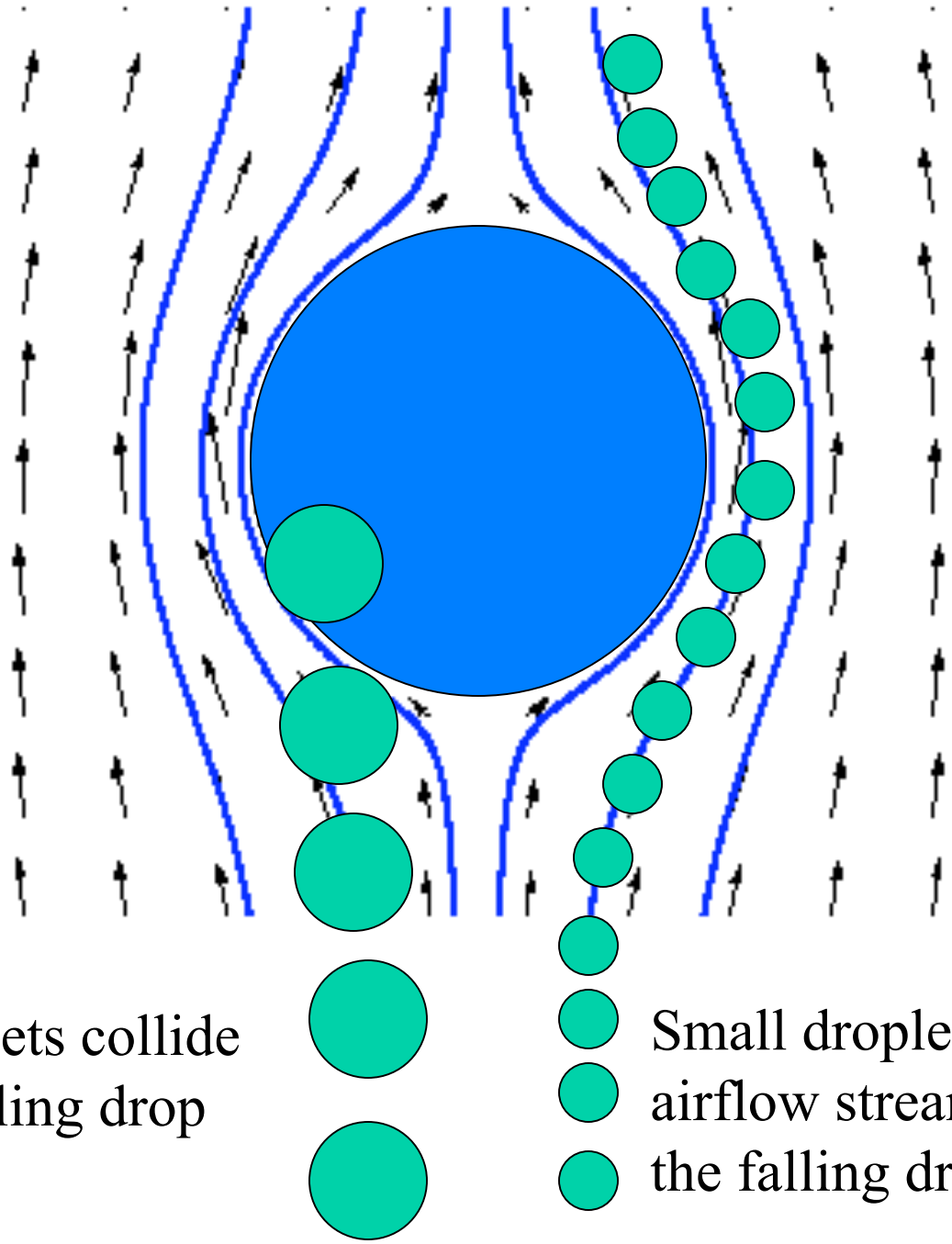
Daniel Rosenfeld
The Hebrew University of Jerusalem, Israel

Suppression of Rain and Snow by Urban and Industrial Air Pollution

Daniel Rosenfeld

Direct evidence demonstrates that urban and industrial air pollution can completely shut off precipitation from clouds that have temperatures at their tops of about −10°C over large areas. Satellite data reveal plumes of reduced cloud particle size and suppressed precipitation originating from major urban areas and from industrial facilities such as power plants. Measurements obtained by the Tropical Rainfall Measuring Mission satellite reveal that both cloud droplet coalescence and ice precipitation formation are inhibited in polluted clouds.

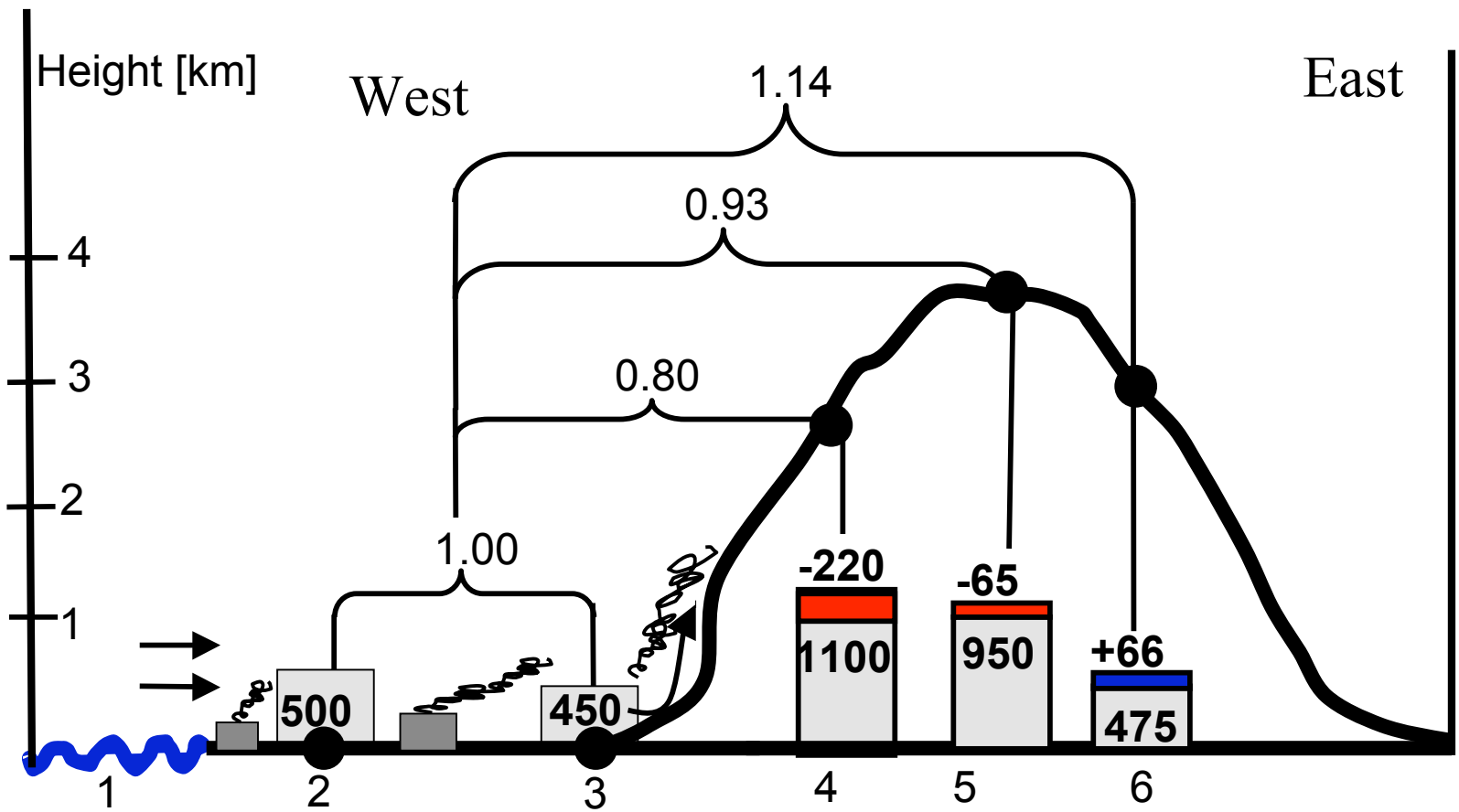




Large droplets collide with the falling drop

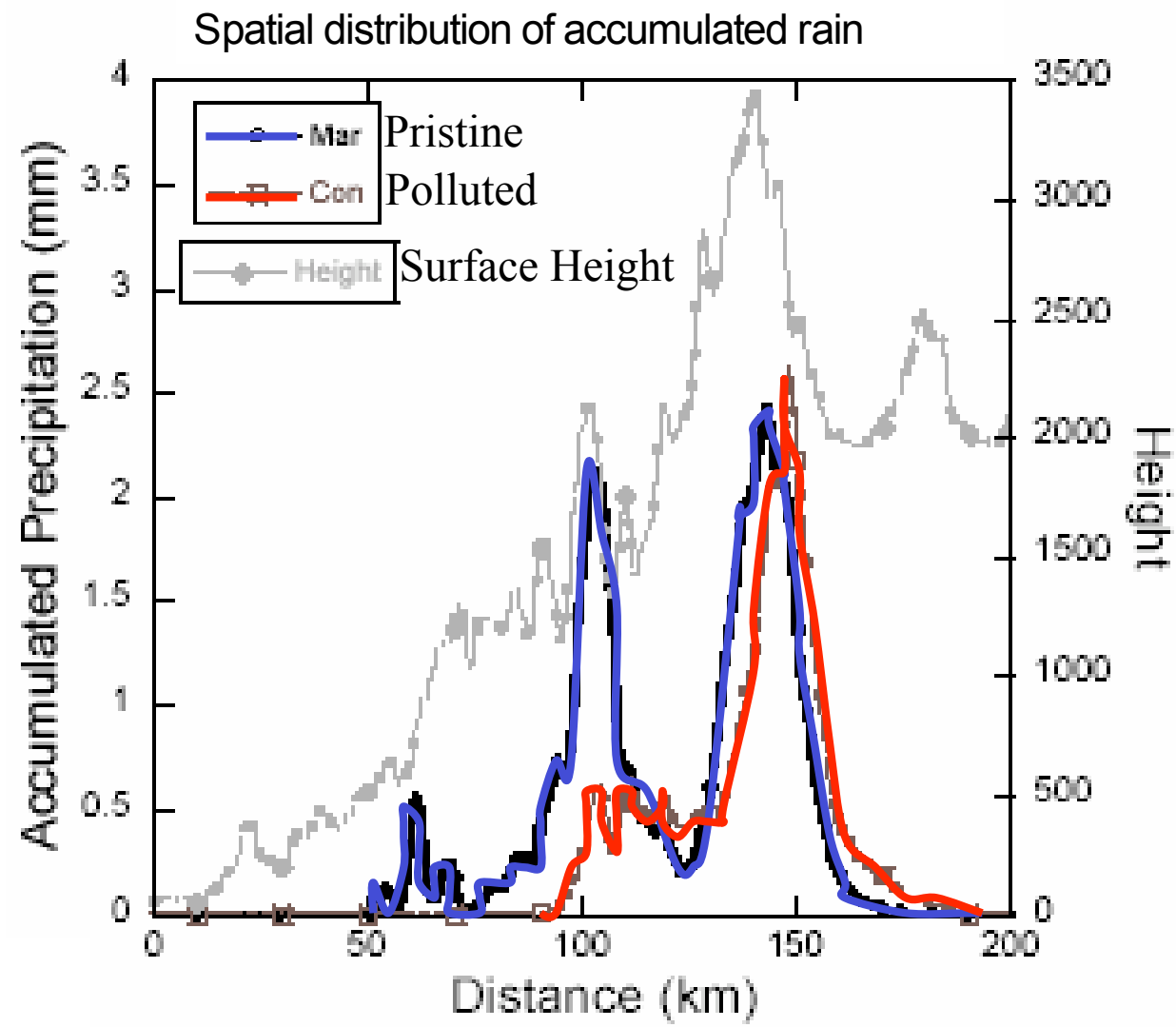
Small droplets follow the airflow streamlines and bypass the falling drop

Topographic cross section of the central Sierra Nevada showing the effects of urban air pollution on precipitation as the clouds moves from west to east across the mountains.



Givati and Rosenfeld, J. Applied Meteorology, 2004

Explicit 2D cloud simulations of cross section of the Sierra Nevada

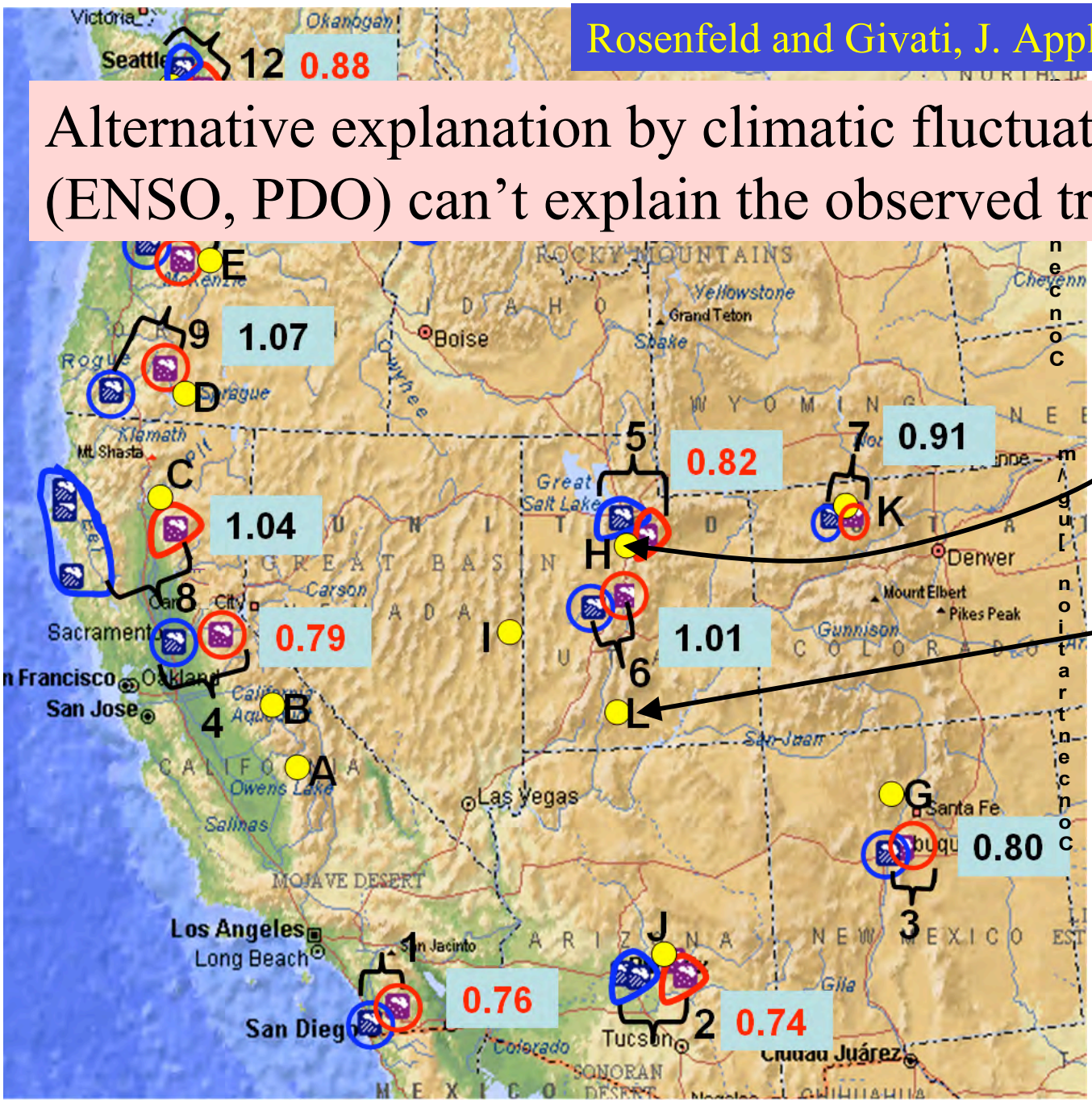


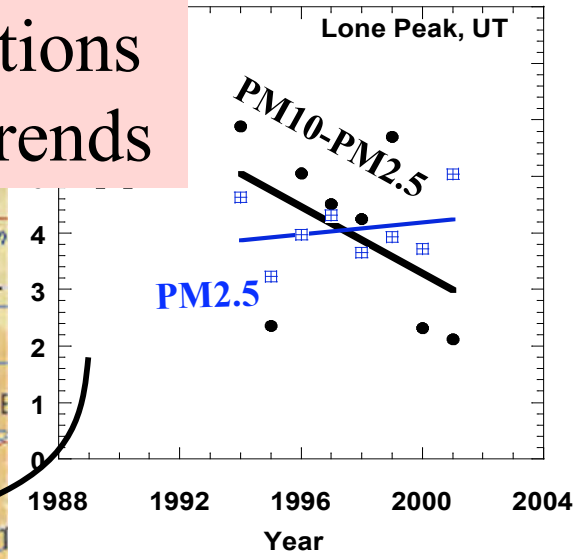
B. Lynn, A. Khain, D. Rosenfeld, W. L. Woodley, 2006. Effects of aerosols on precipitation from orographic clouds. In press, JGR.

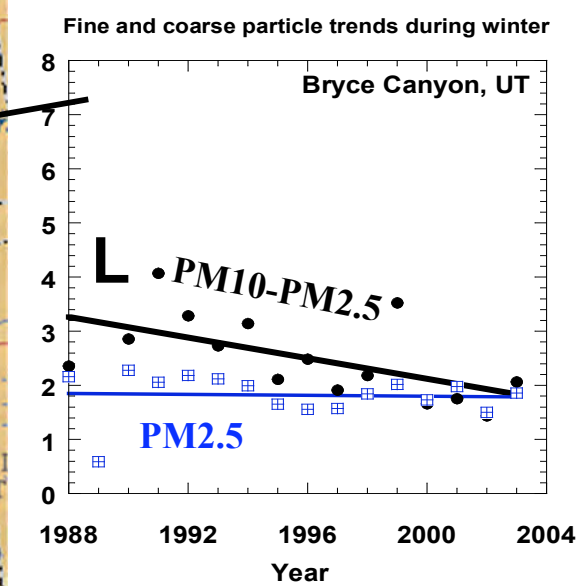
Trends of orographic precipitation linked to the trends in aerosols

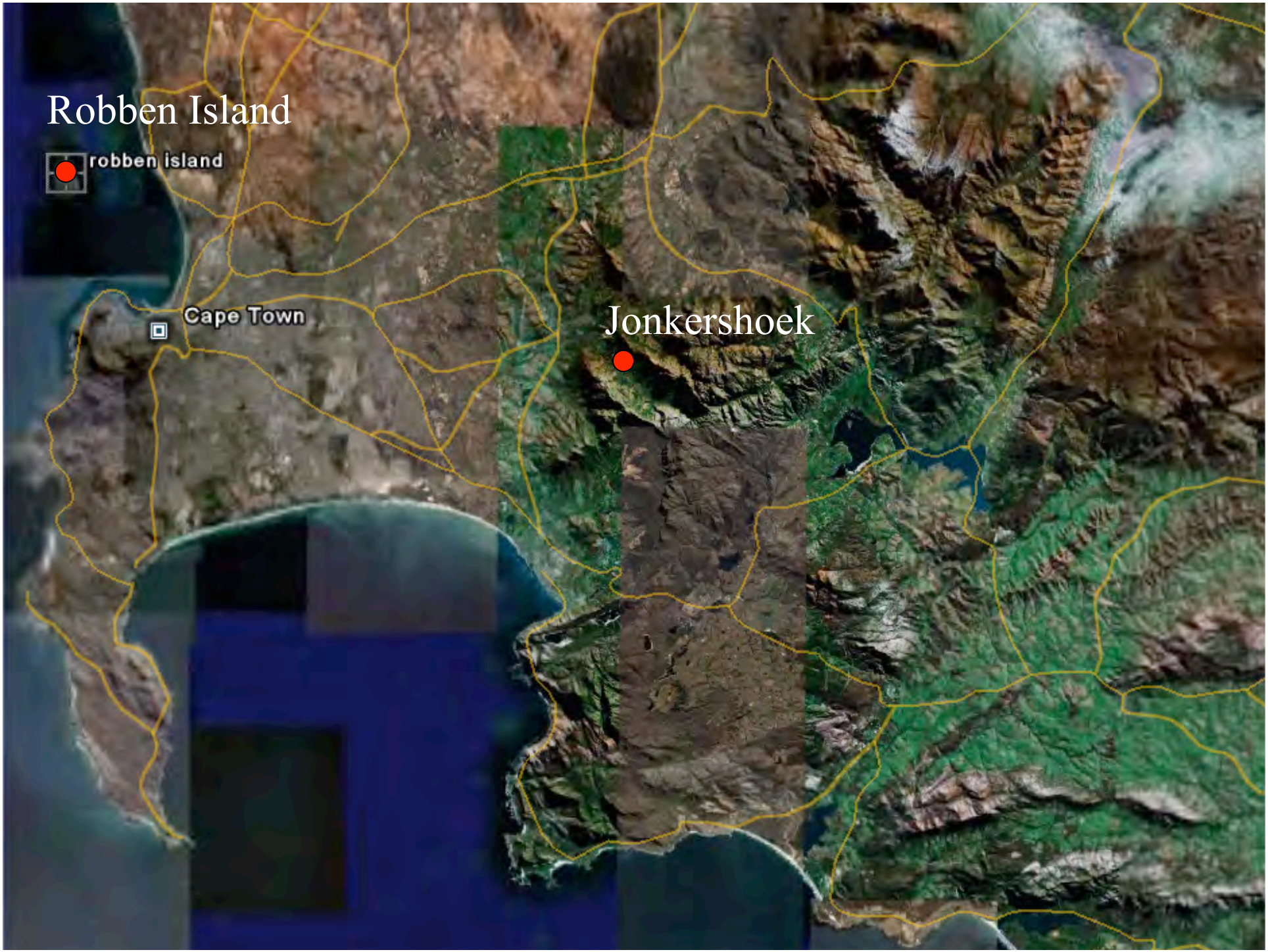
Rosenfeld and Givati, J. Applied Meteorology, 2006

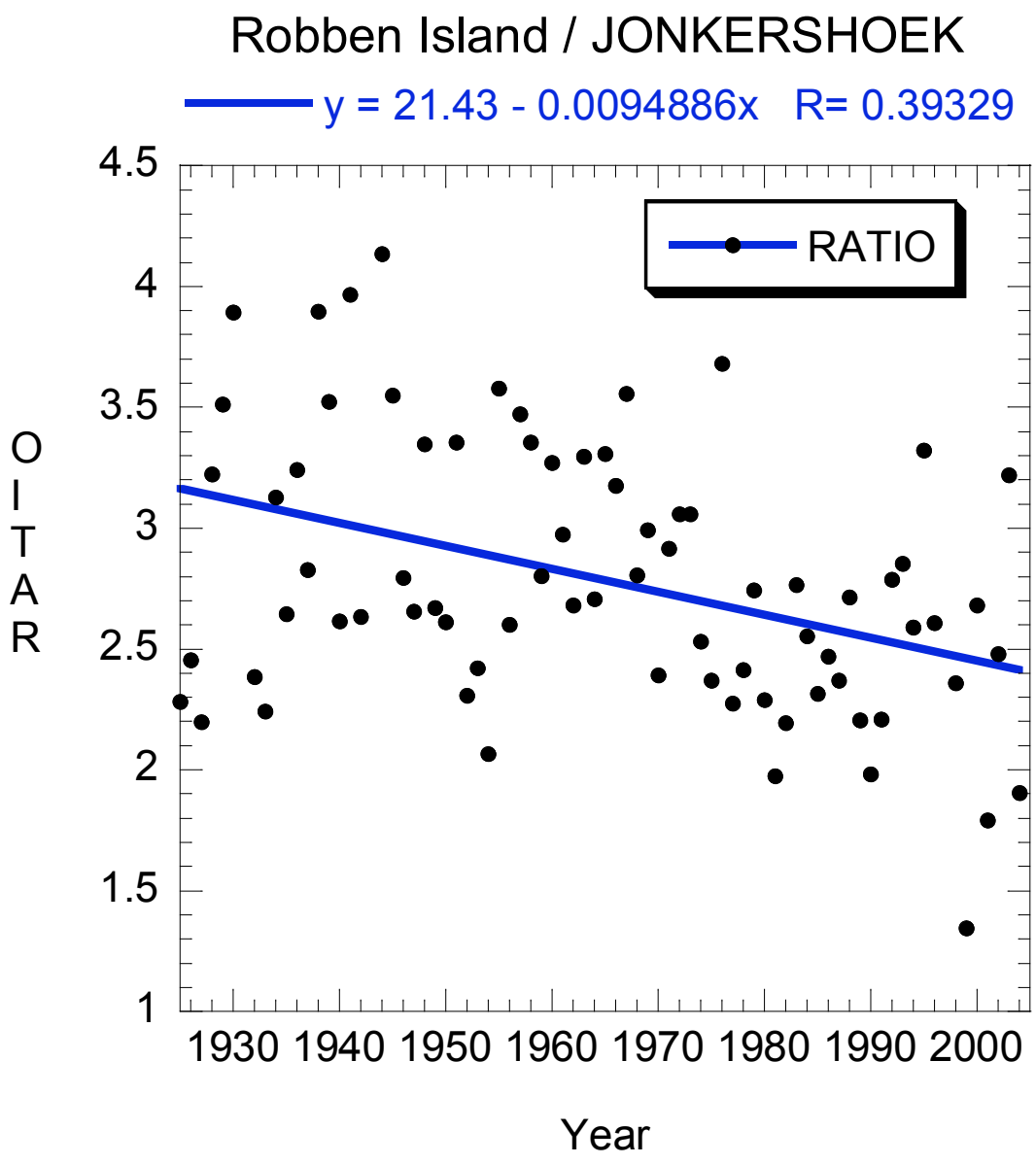
Alternative explanation by climatic fluctuations (ENSO, PDO) can't explain the observed trends








Robben Island
robben island
Cape Town
Jonkershoek

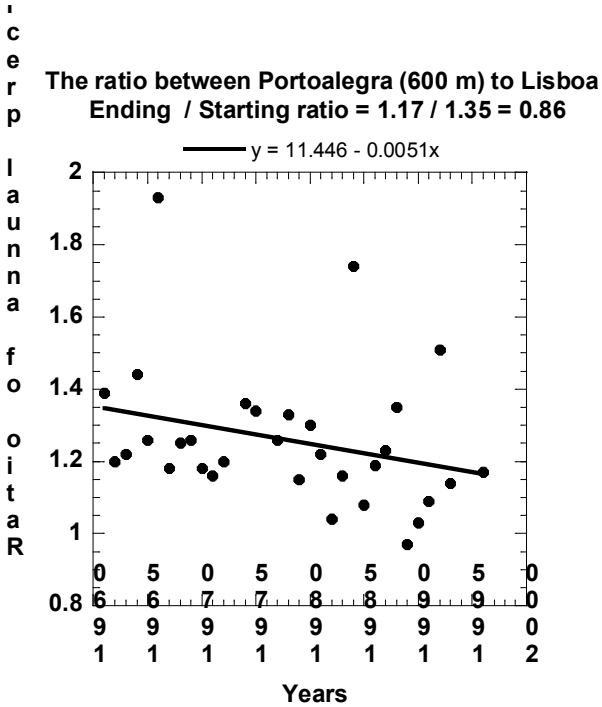

Robben Island / JONKERSHOEK
y = 21.43 - 0.0094886x R= 0.39329
RATIO
4.5
4
3.5
3
2.5
2
1.5
1
O I T A R
1930 1940 1950 1960 1970 1980 1990 2000
Year

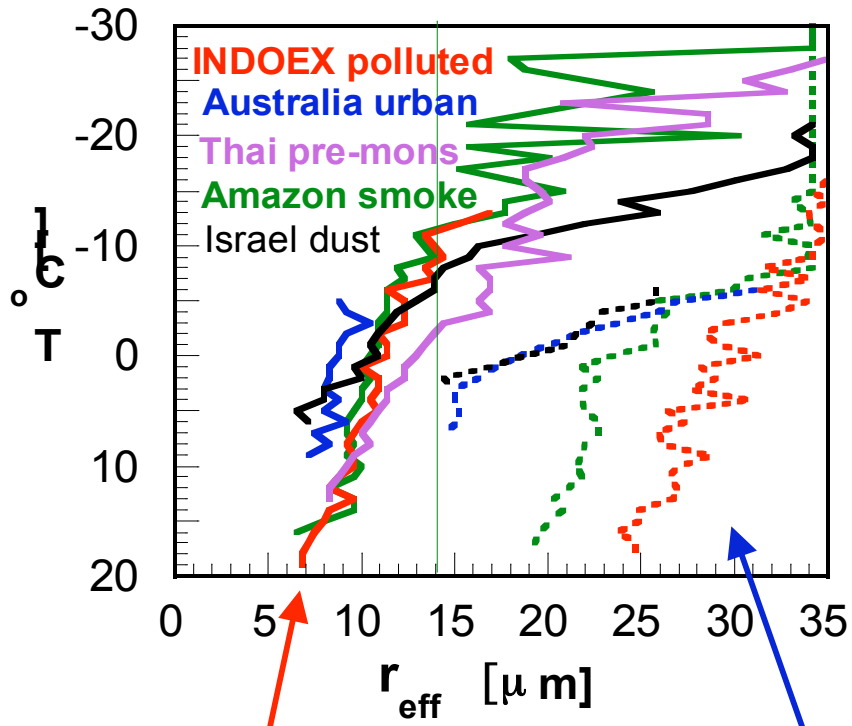
Western Portugal

Also found in:

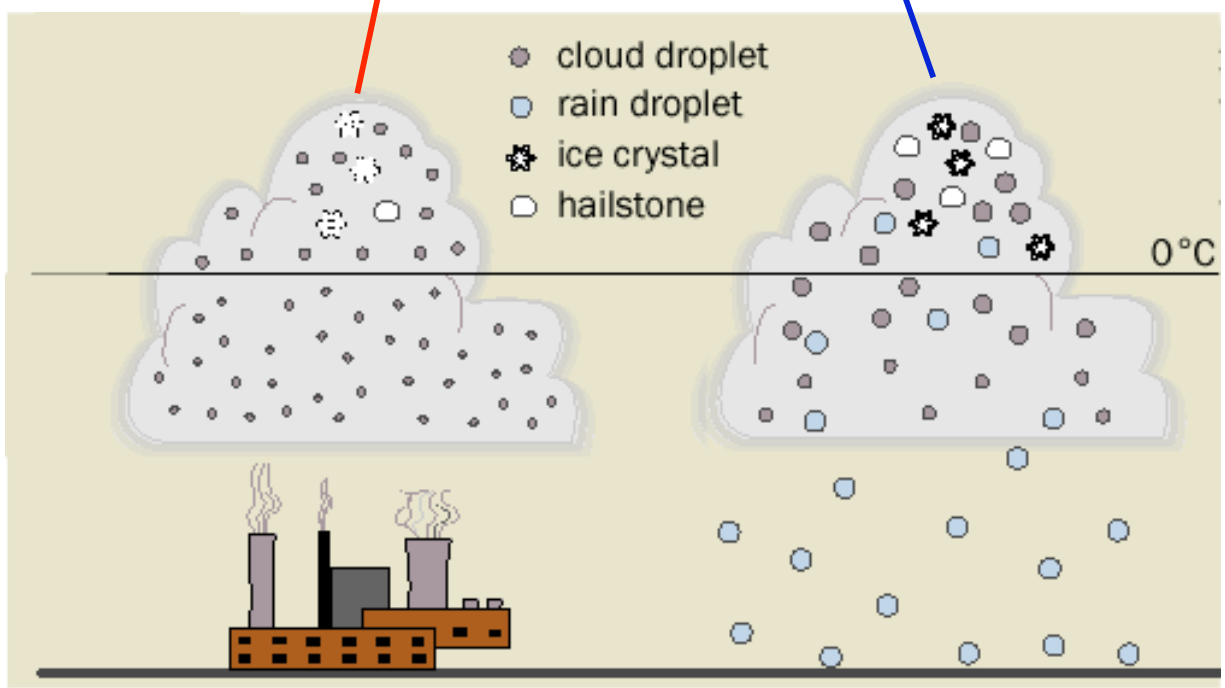
Israel, France, Morocco, Swiss, China, Puerto Rico, Canada, Greece, Spain, …

Not found in New Zealand, Hawaii big island

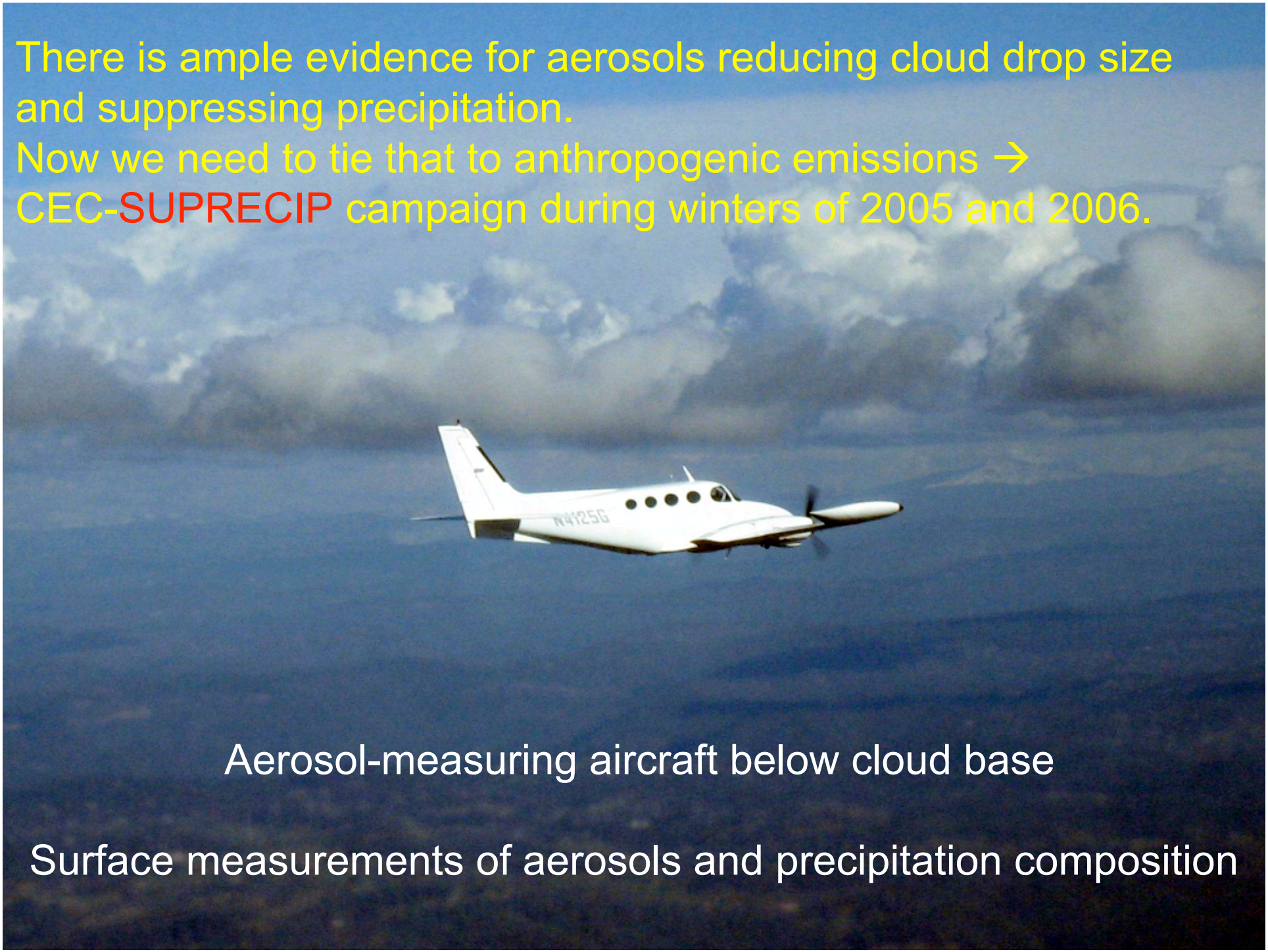




Ramanathan, V., P. J. Crutzen, J. T. Kiehl, and D. Rosenfeld, 2001: Aerosols, Climate and the Hydrological Cycle. *Science*, 294, 2119-2124.

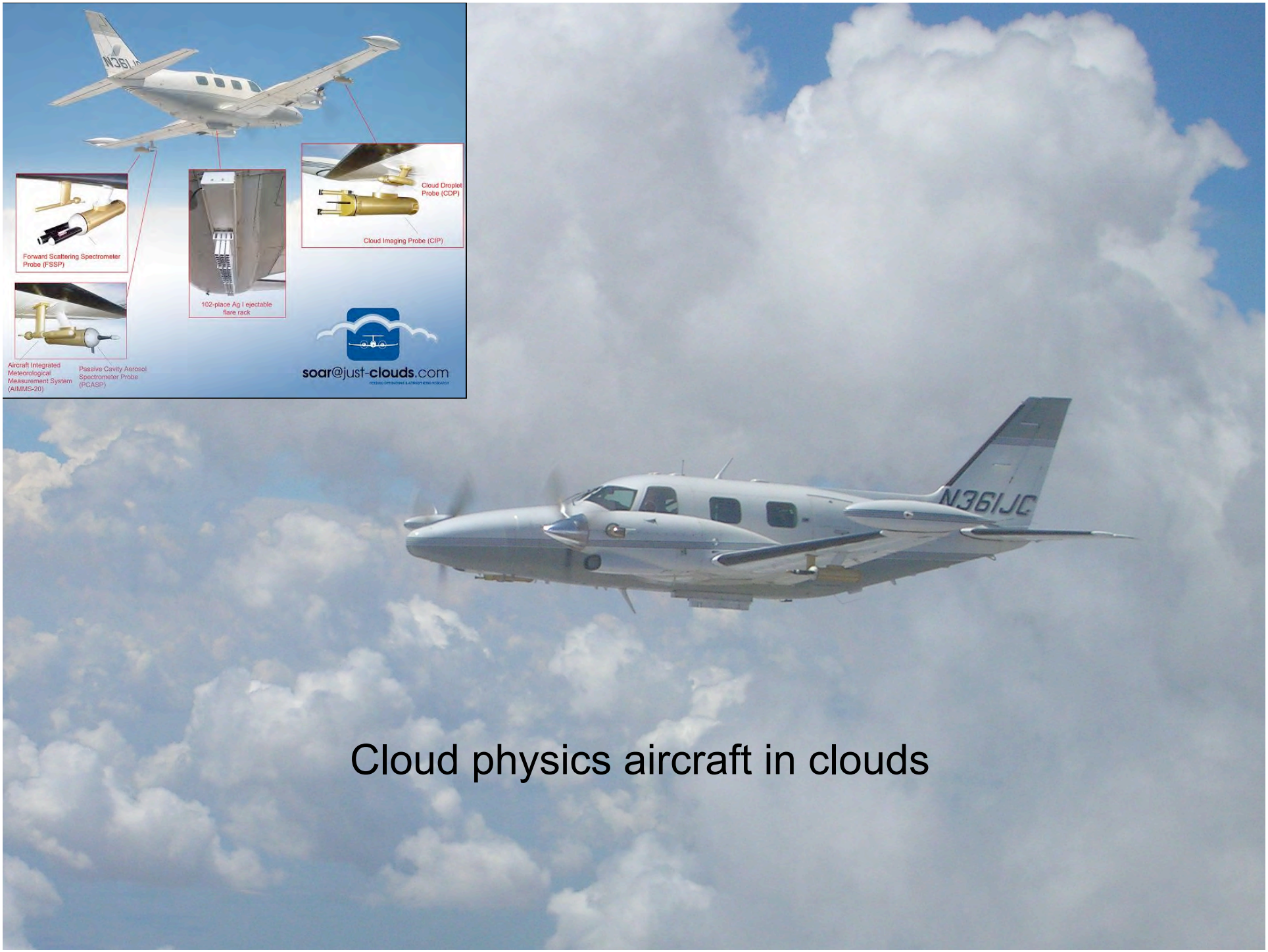


There is ample evidence for aerosols reducing cloud drop size and suppressing precipitation.
Now we need to tie that to anthropogenic emissions →
CEC-SUPRECIP campaign during winters of 2005 and 2006.



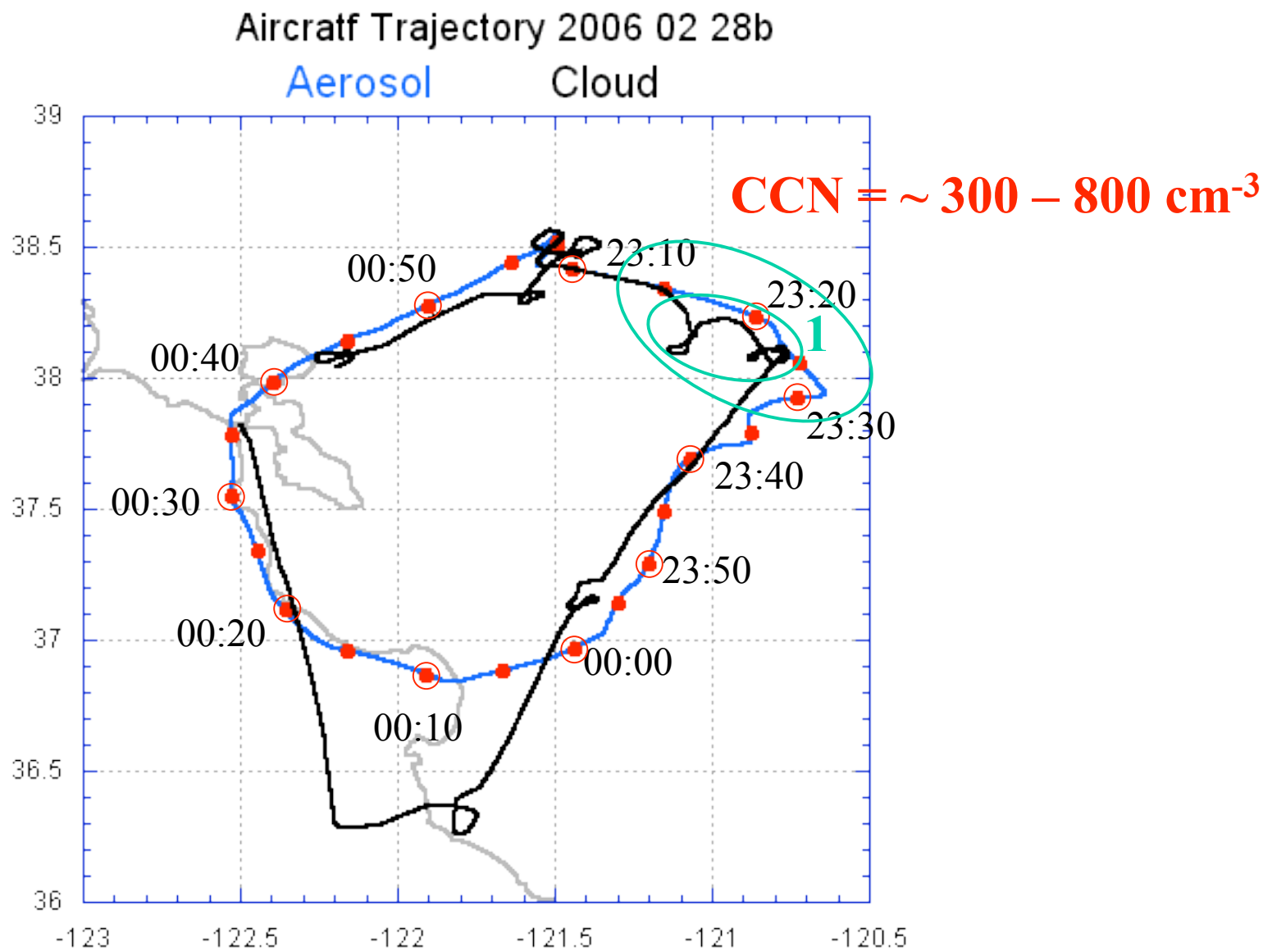
Aerosol-measuring aircraft below cloud base

Surface measurements of aerosols and precipitation composition



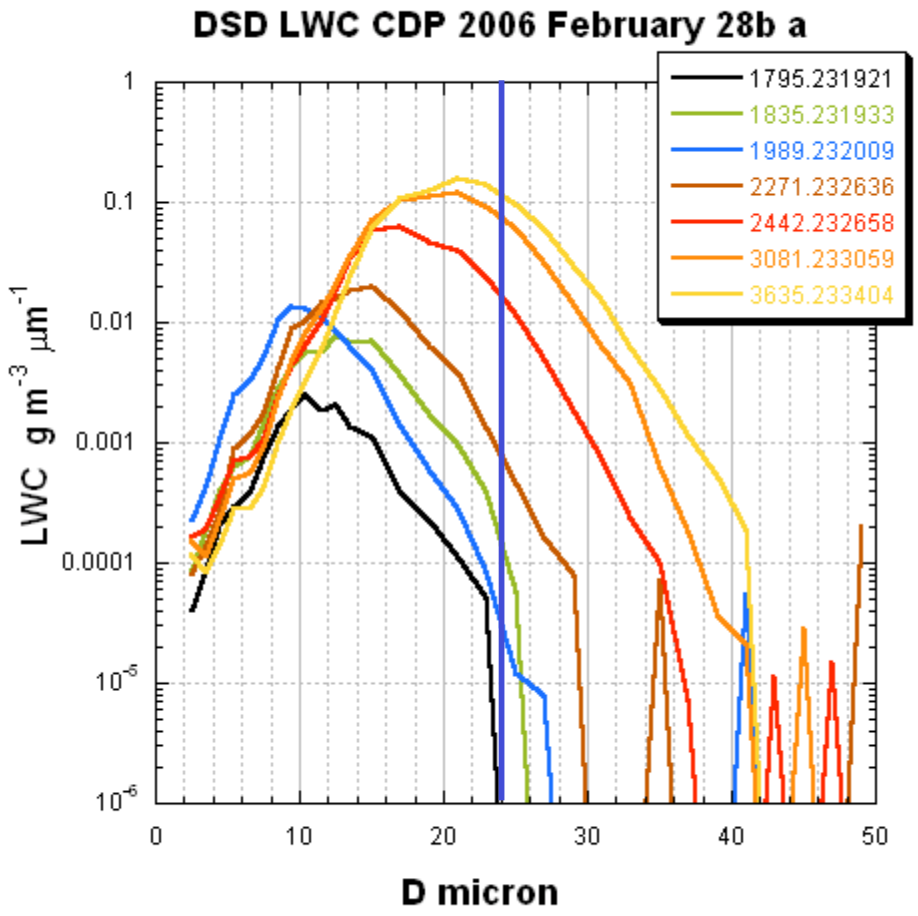
Cloud physics aircraft in clouds

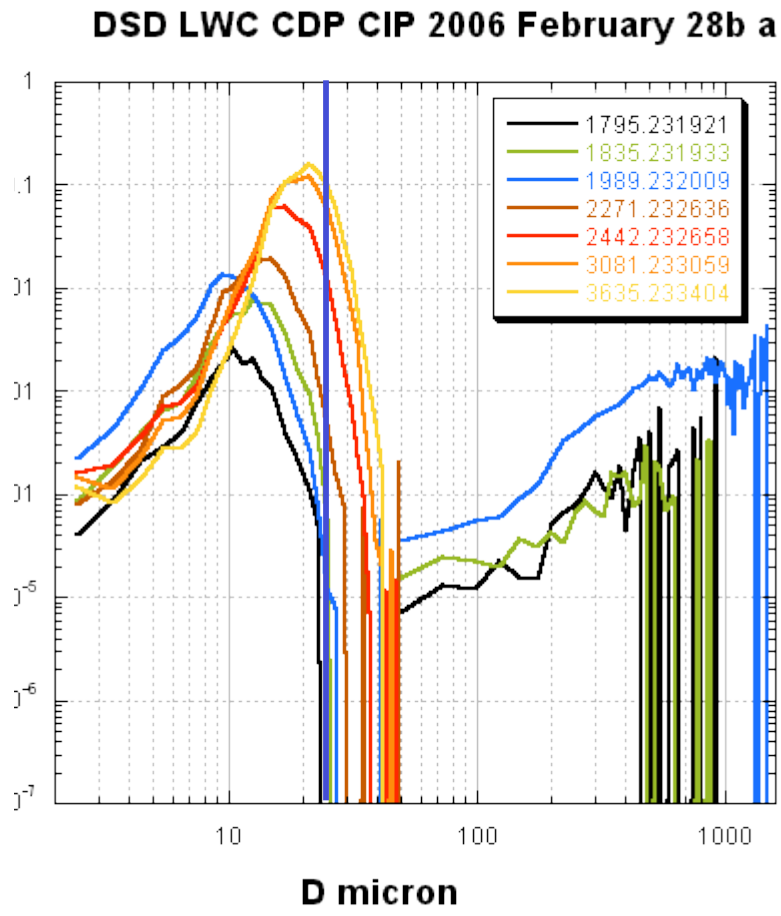
Forward Scattering Spectrometer Probe (FSSP)
102-place Ag I ejectable flare rack
Cloud Droplet Probe (CDP)
Cloud Imaging Probe (CIP)
Aircraft Integrated Meteorological Measurement System (AIMMS-20)
Passive Cavity Aerosol Spectrometer Probe (PCASP)
soar@just-clouds.com


Aircratf Trajectory 2006 02 28b
Aerosol
Cloud
CCN = ~ 300 – 800 cm-3
1
00:50
23:10
23:20
00:40
23:30
23:40
00:30
23:50
00:20
00:00
00:10
39
38.5
38
37.5
37
36.5
36
-123
-122.5
-122
-121.5
-121
-120.5

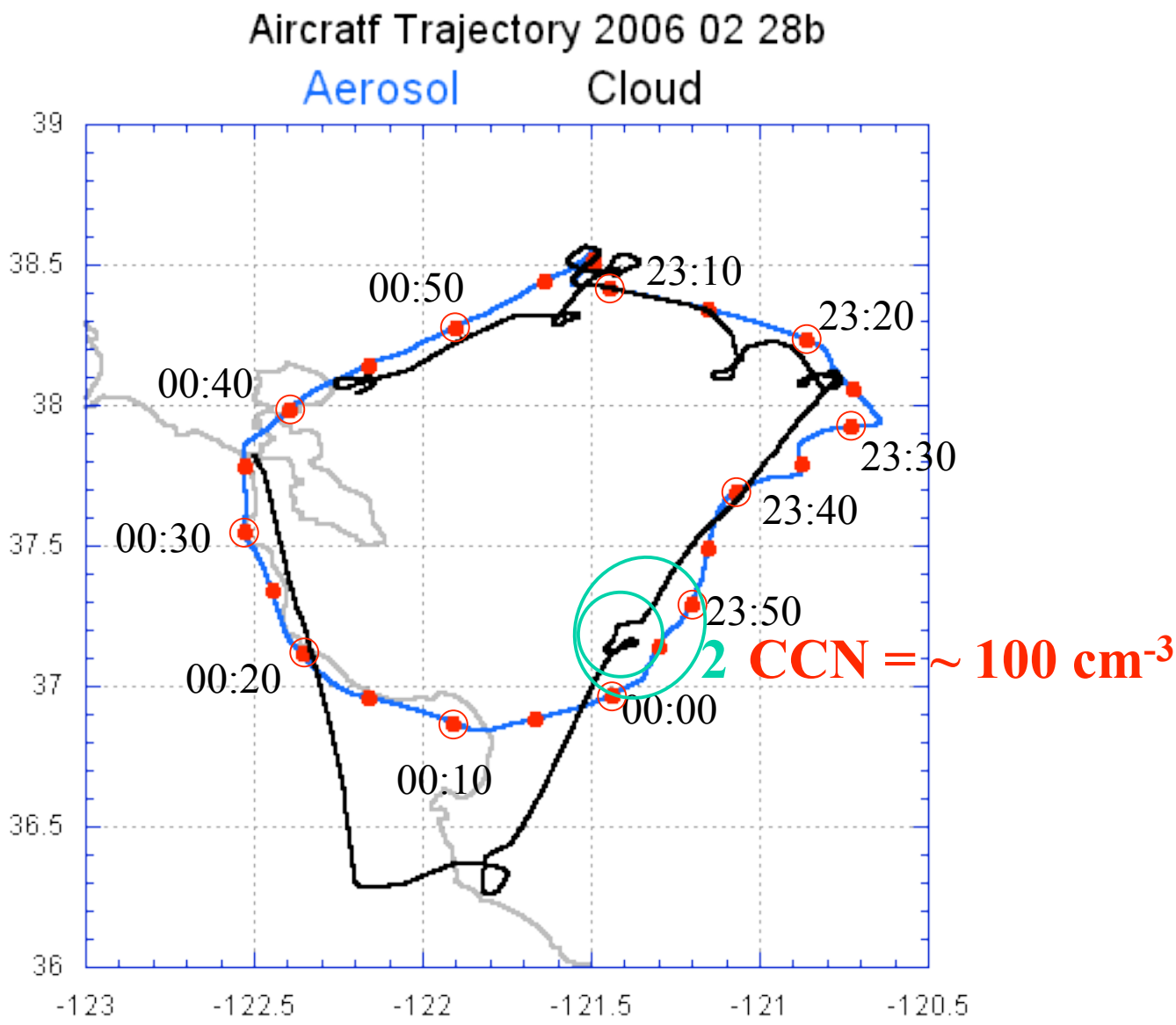
Cloud 1
2006 02 28 23:17 1600 m -1°C
CCN = ~ 300 – 800 cm-3

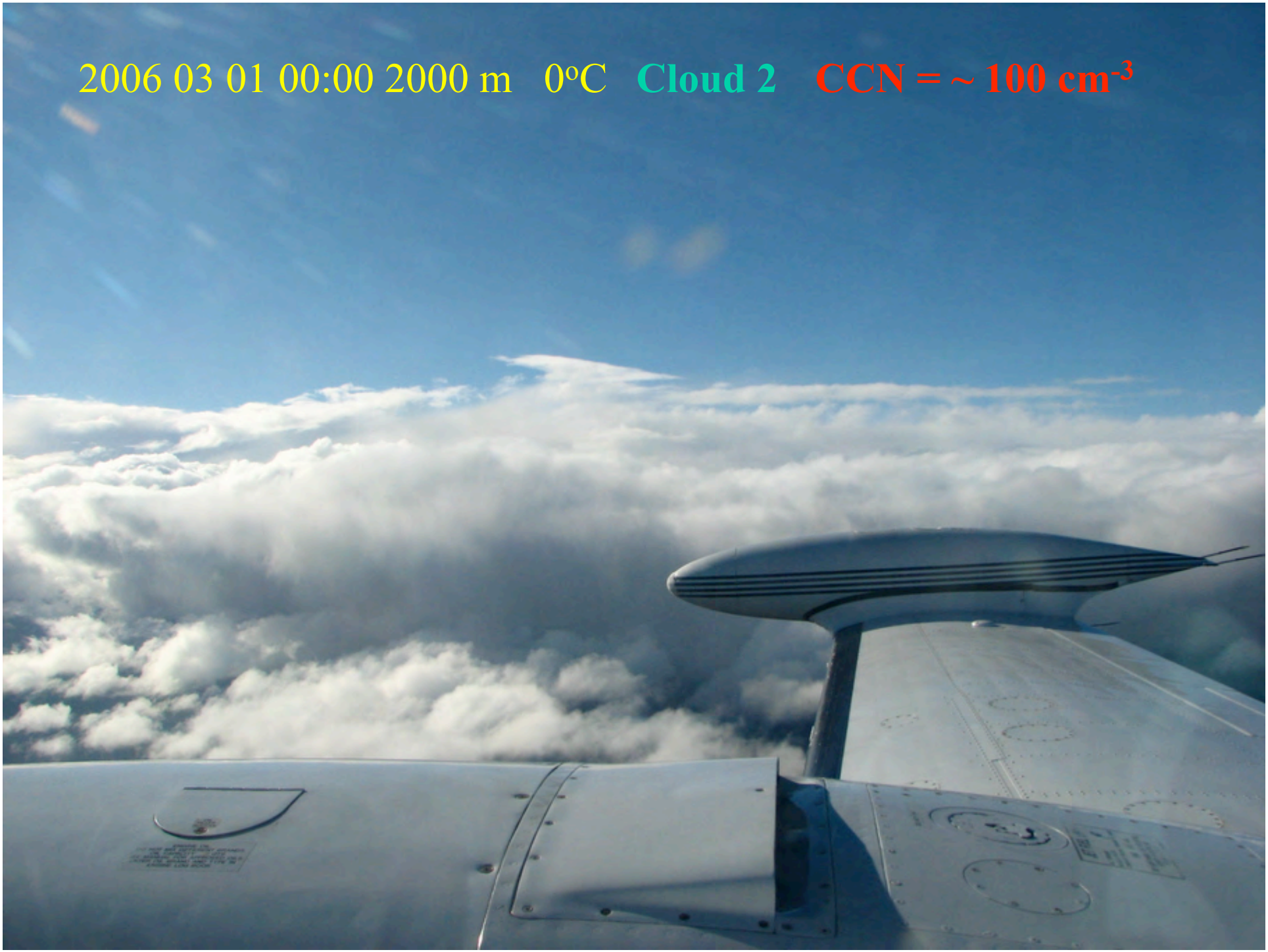
Cloud 1



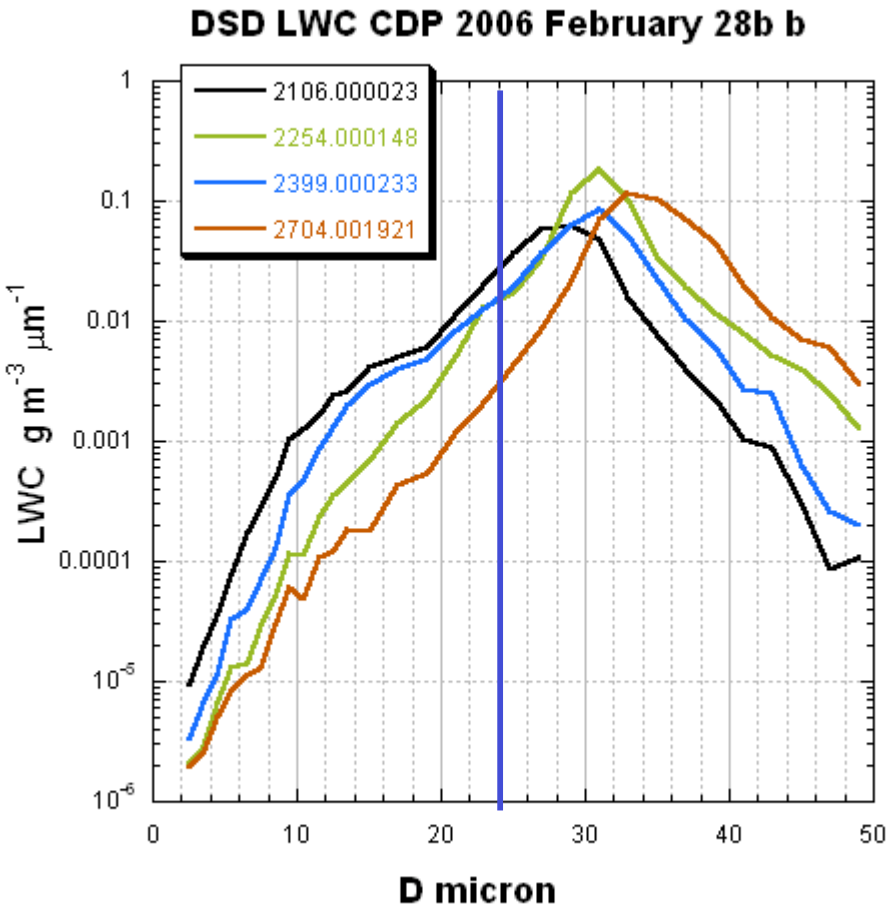


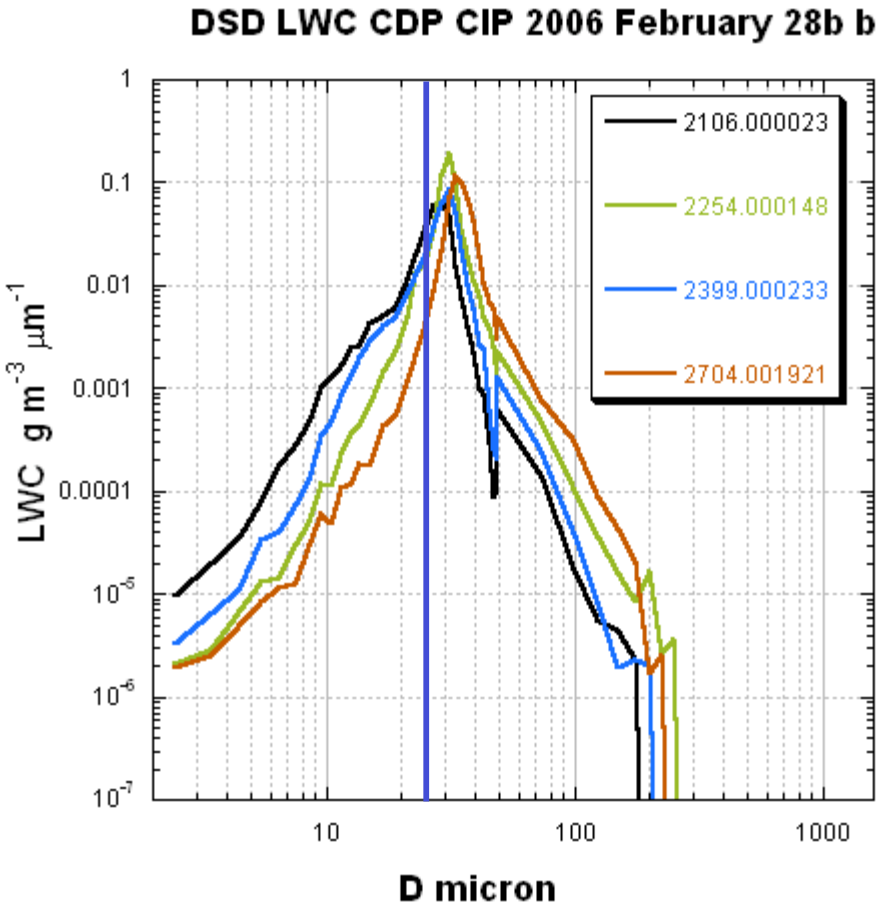
CCN = ~ 300 – 800 cm^{-3}


Aircratf Trajectory 2006 02 28b
Aerosol
Cloud
39
38.5
38
37.5
37
36.5
36
-123
-122.5
-122
-121.5
-121
-120.5
00:50
23:10
23:20
00:40
23:30
23:40
00:30
23:50
2 CCN = ~ 100 cm-3
00:20
00:00
00:10

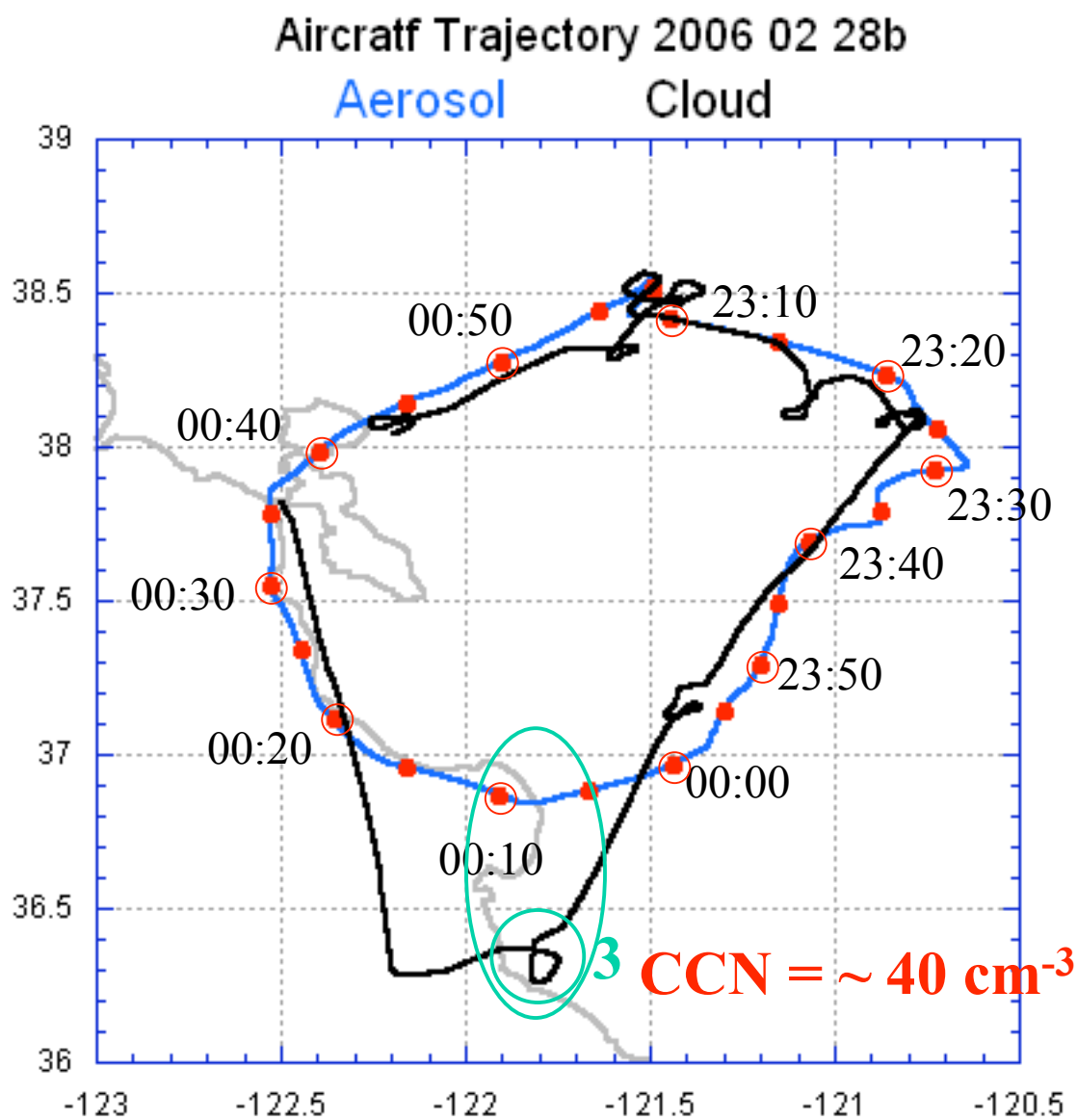

2006 03 01 00:00 2000 m 0°C Cloud 2 CCN = ~ 100 cm-3

Cloud 2

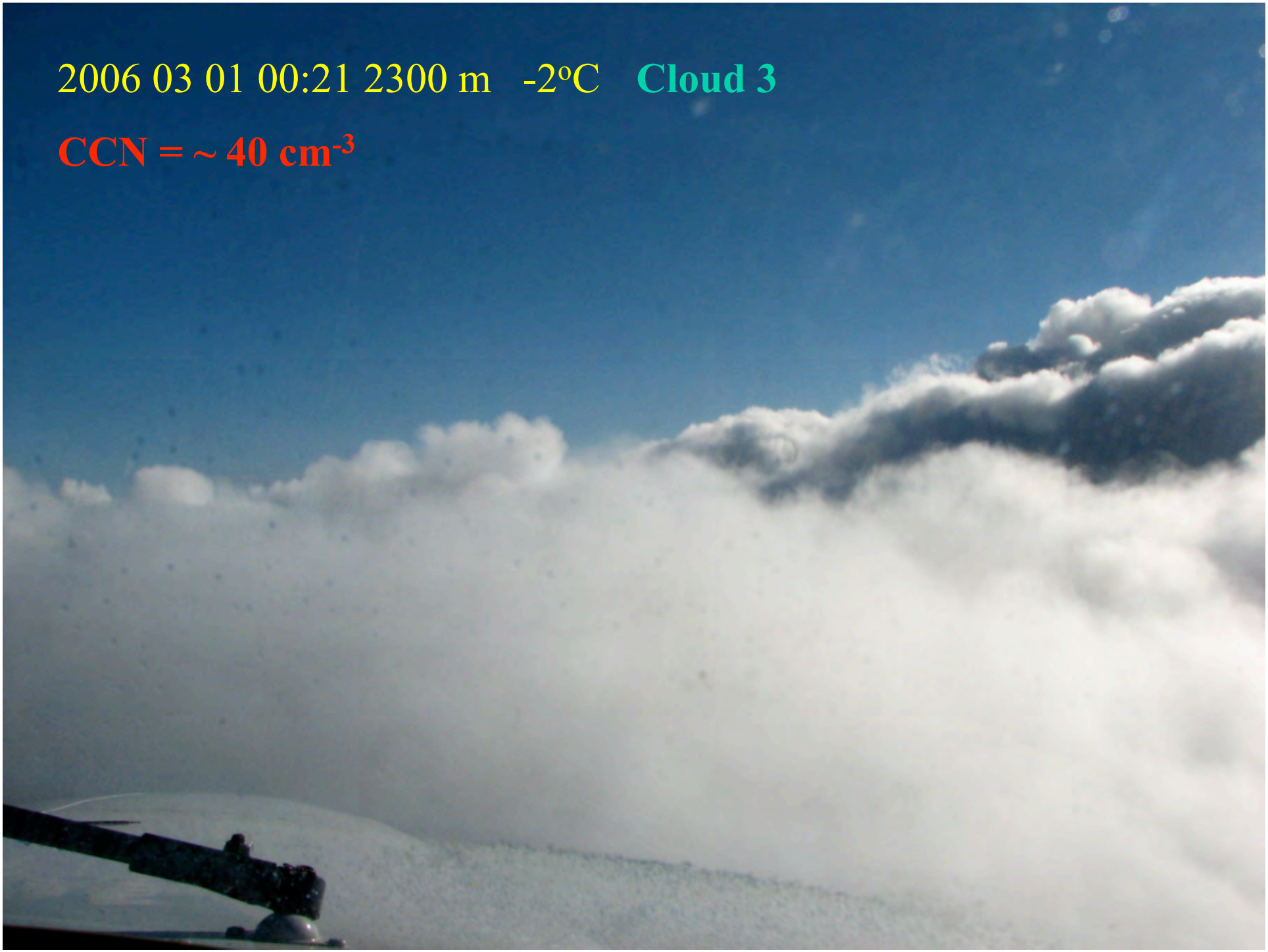


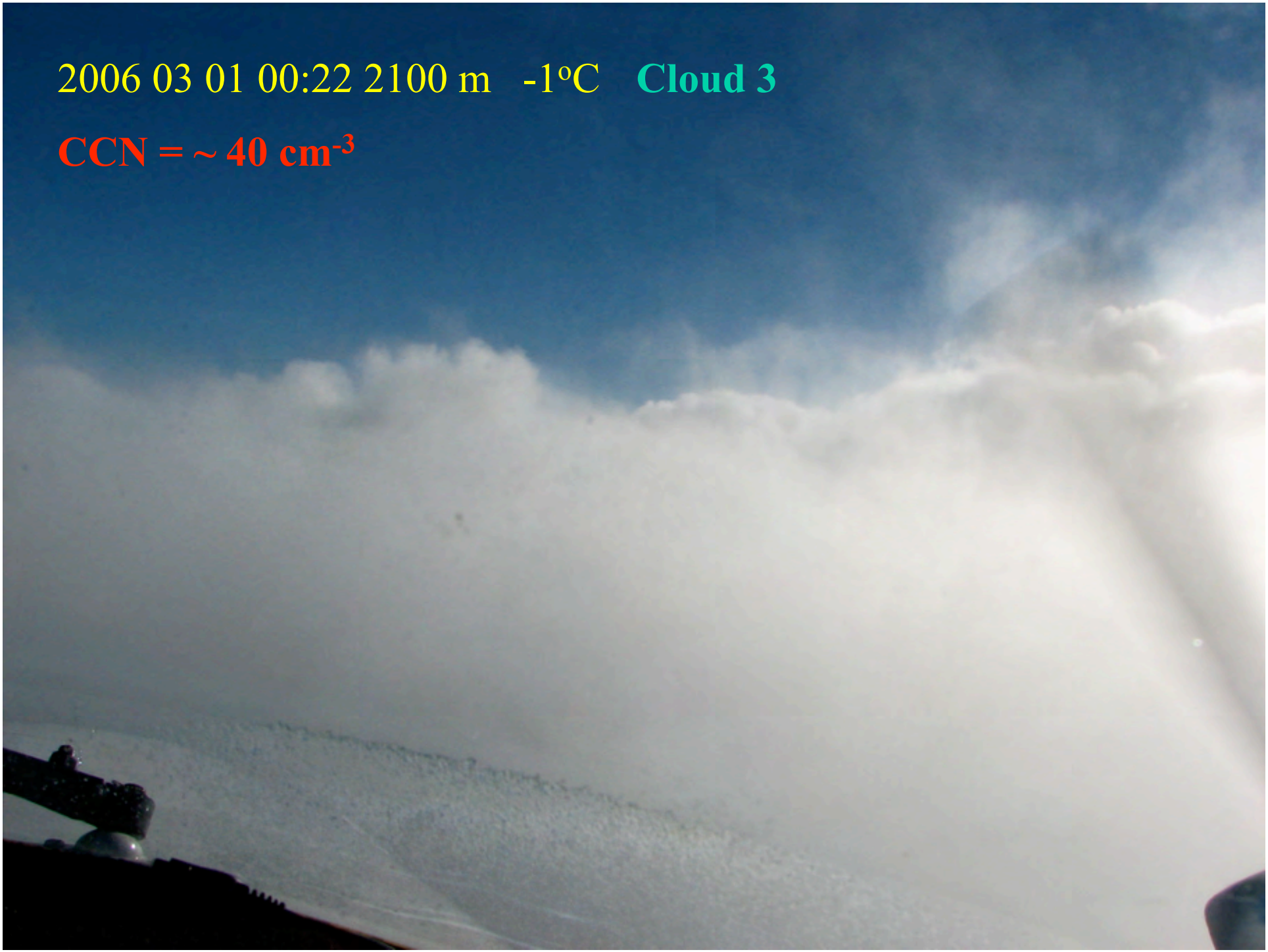


CCN = ~ 100 cm^{-3}

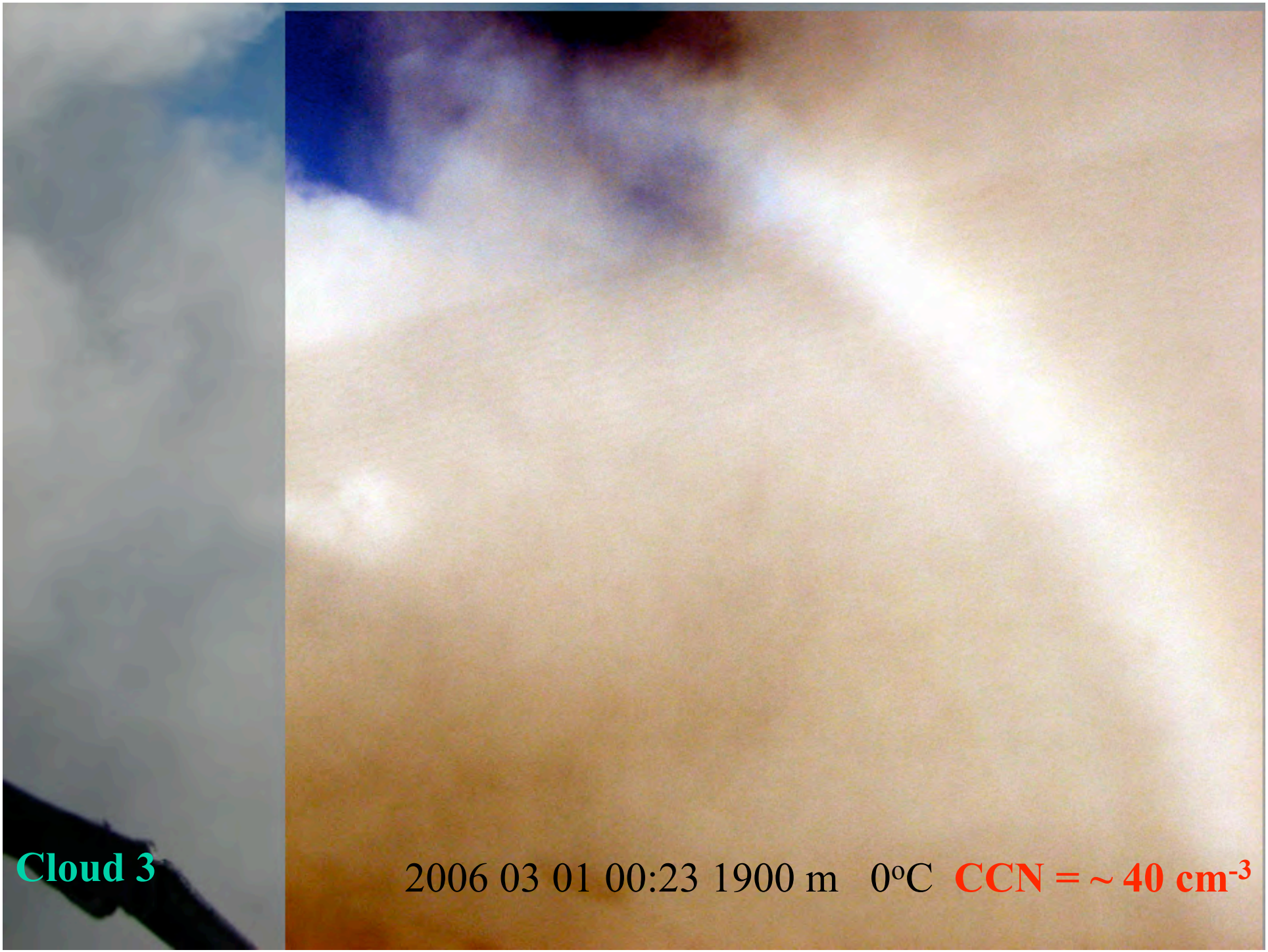

Aircratf Trajectory 2006 02 28b
Aerosol
Cloud
39
38.5
38
37.5
37
36.5
36
-123
-122.5
-122
-121.5
-121
-120.5
00:50
23:10
23:20
00:40
23:30
23:40
00:30
23:50
00:20
00:00
00:10
3
CCN = ~ 40 cm-3

Cloud 3
CCN = ~ 40 cm-3
2006 03 01 00:18 2800 m -3oC


2006 03 01 00:21 2300 m -2°C Cloud 3
CCN = ~ 40 cm-3

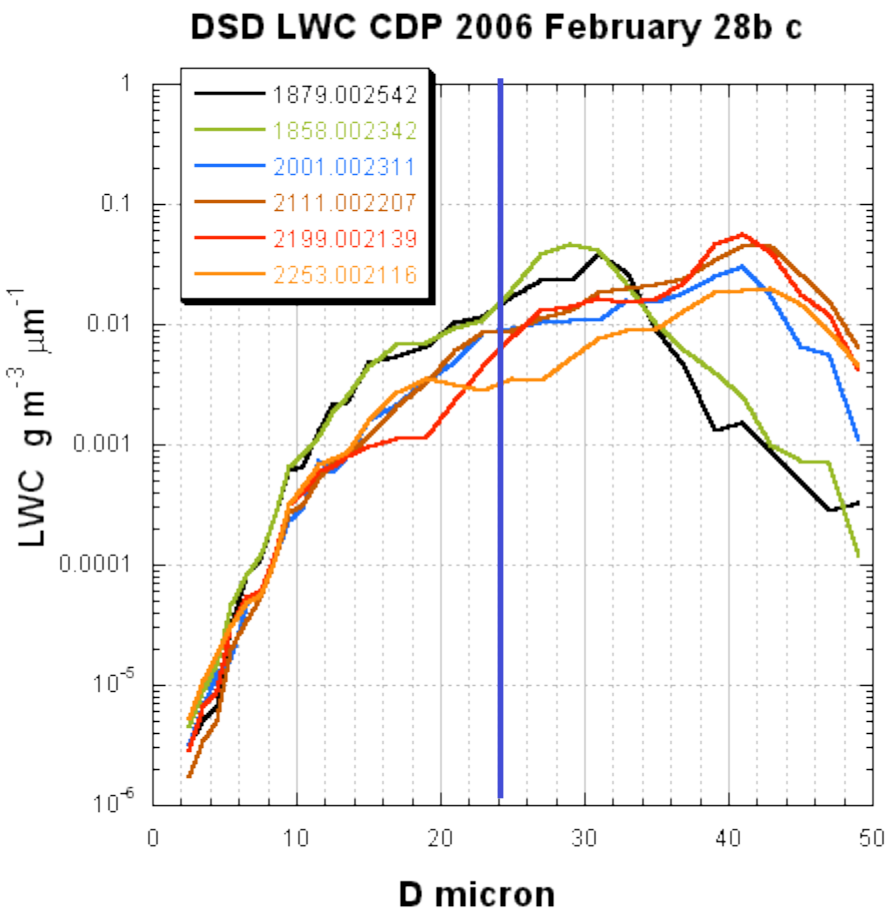

2006 03 01 00:22 2100 m -1°C Cloud 3
CCN = ~ 40 cm-3

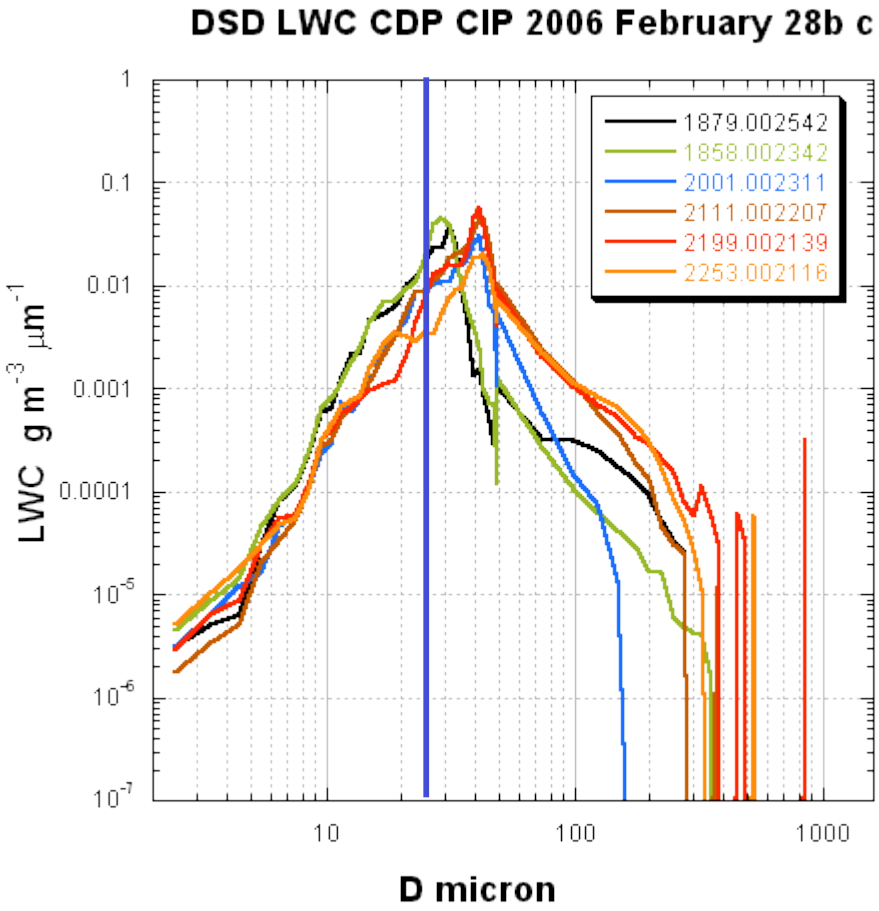
Cloud 3
2006 03 01 00:23 1900 m 0°C CCN = ~ 40 cm-3


Cloud 3
2006 03 01 00:23 1900 m 0°C CCN = ~ 40 cm-3

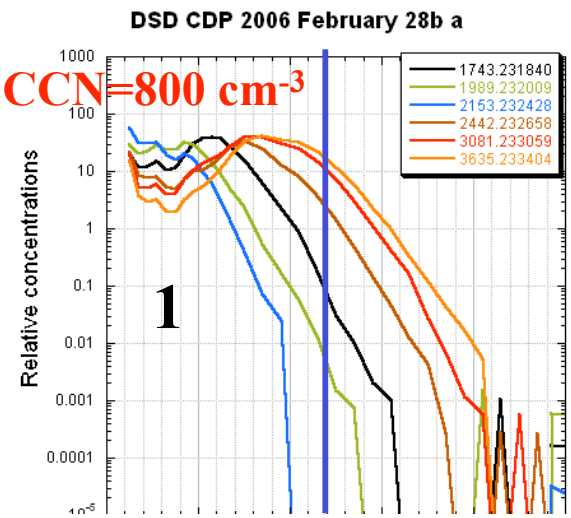
Cloud 3
CCN = ~ 40 cm-3
2006 03 01 00:30 1800 m 2°C

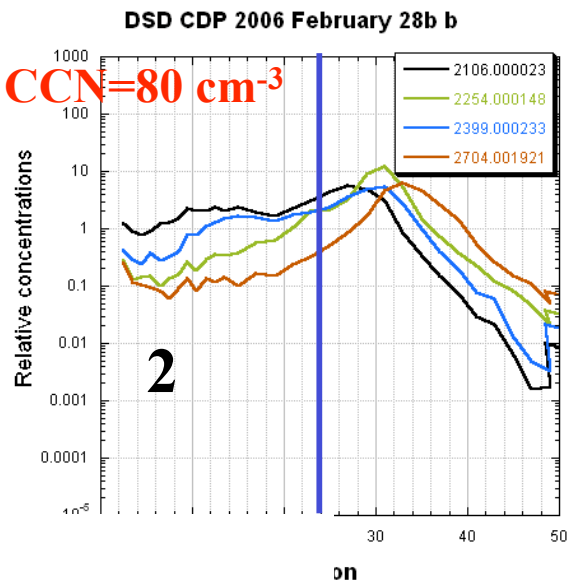
Cloud 3

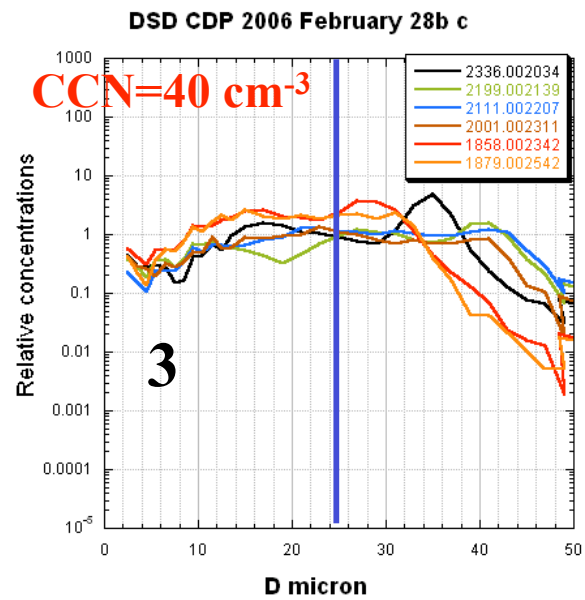


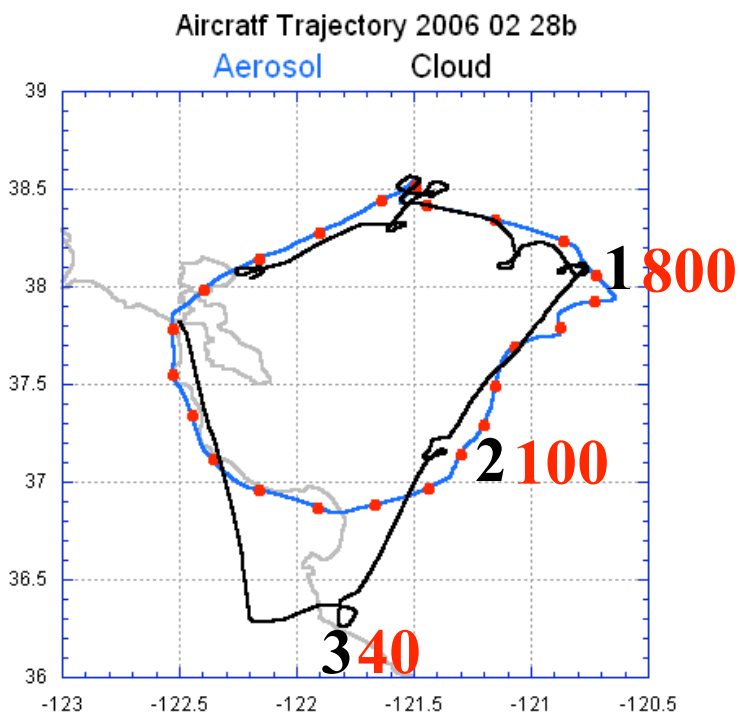


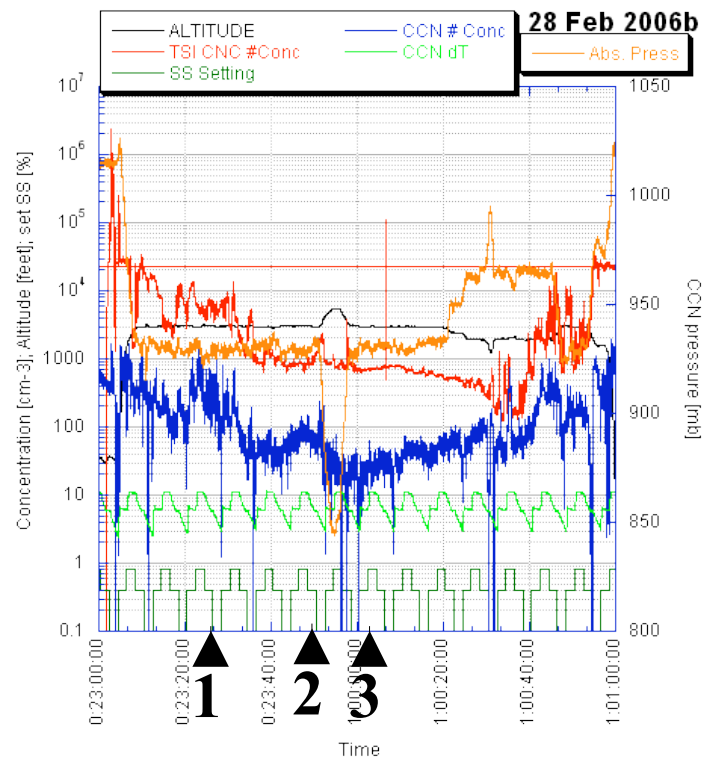
CCN = ~ 40 cm^{-3}

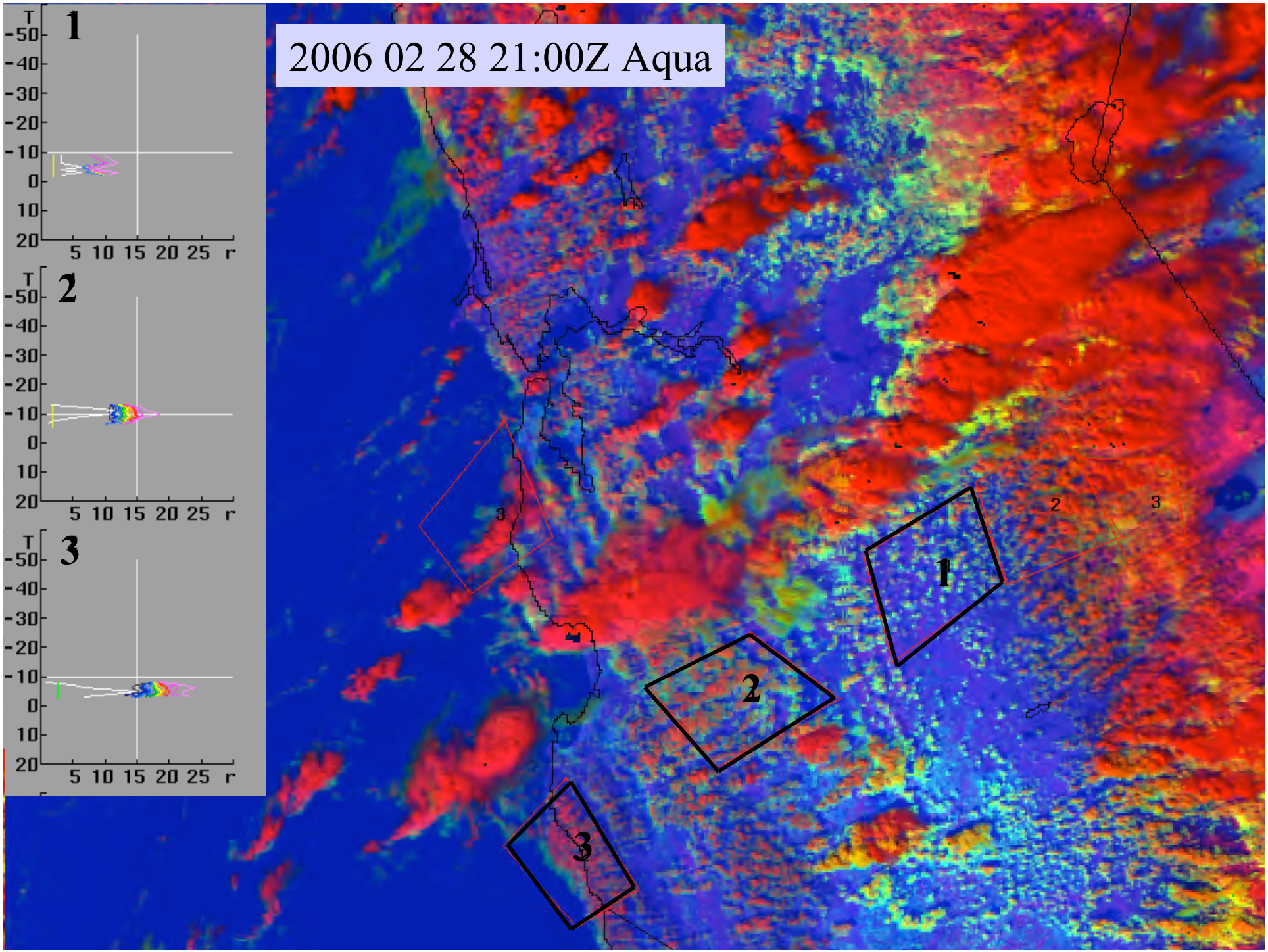

DSD CDP 2006 February 28b a
CCN=800 cm-3
1743.231840
1989.232009
2153.232428
2442.232658
3081.233059
3635.233404
Relative concentrations
1

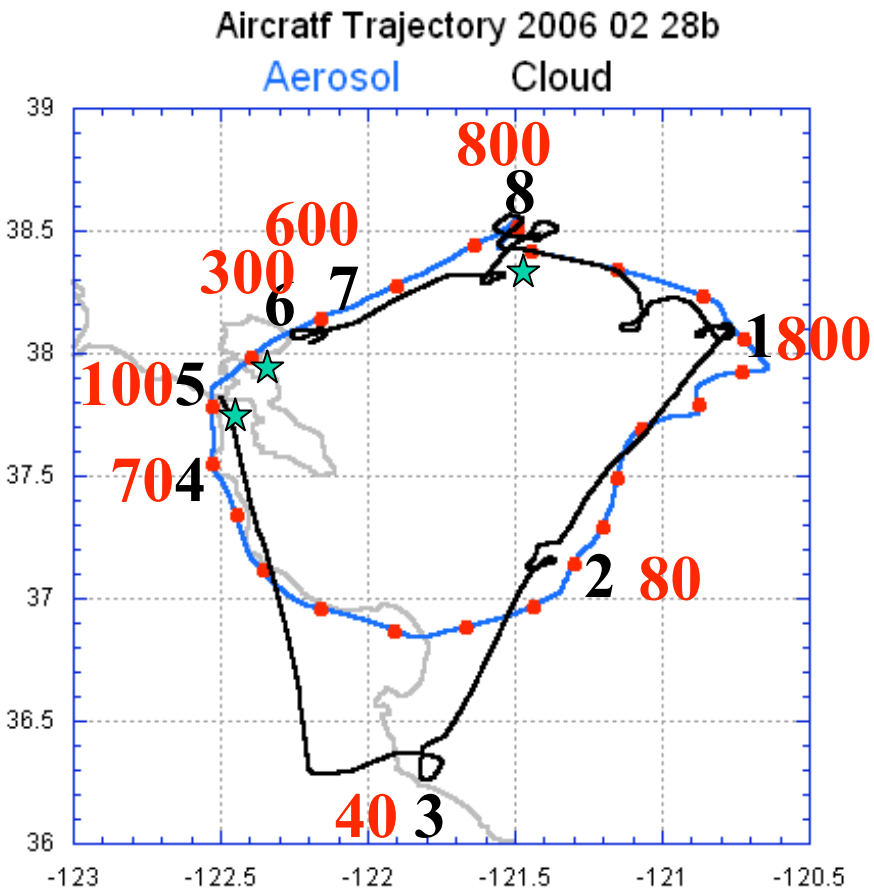

DSD CDP 2006 February 28b b
CCN=80 cm-3
2106.000023
2254.000148
2399.000233
2704.001921
Relative concentrations
2

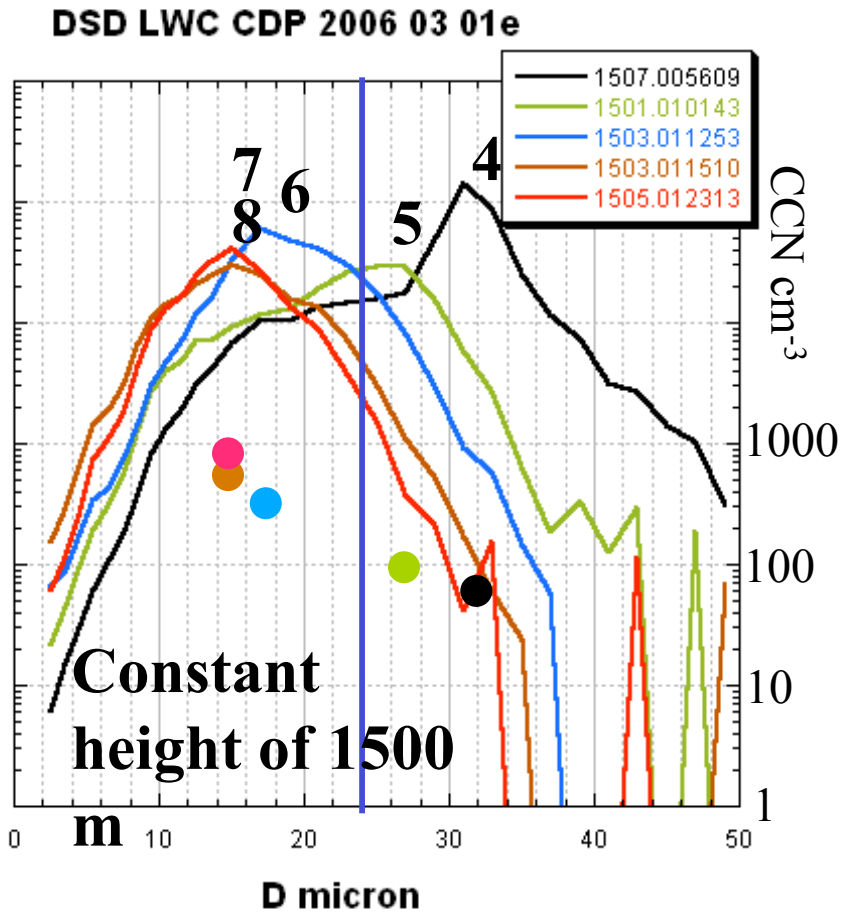

DSD CDP 2006 February 28b c
CCN=40 cm-3
2336.002034
2199.002139
2111.002207
2001.002311
1858.002342
1879.002542
Relative concentrations
3
D micron

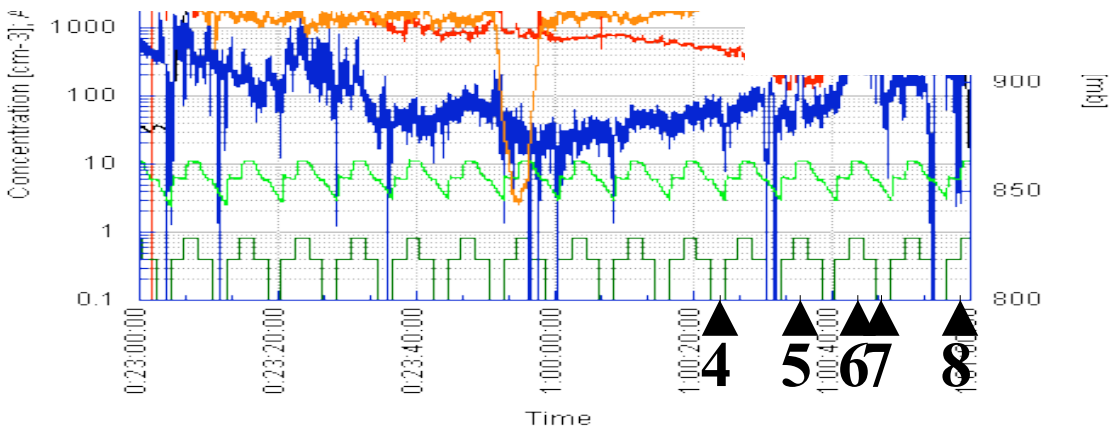

Aircratf Trajectory 2006 02 28b
Aerosol
Cloud
1 800
2 100
3 40

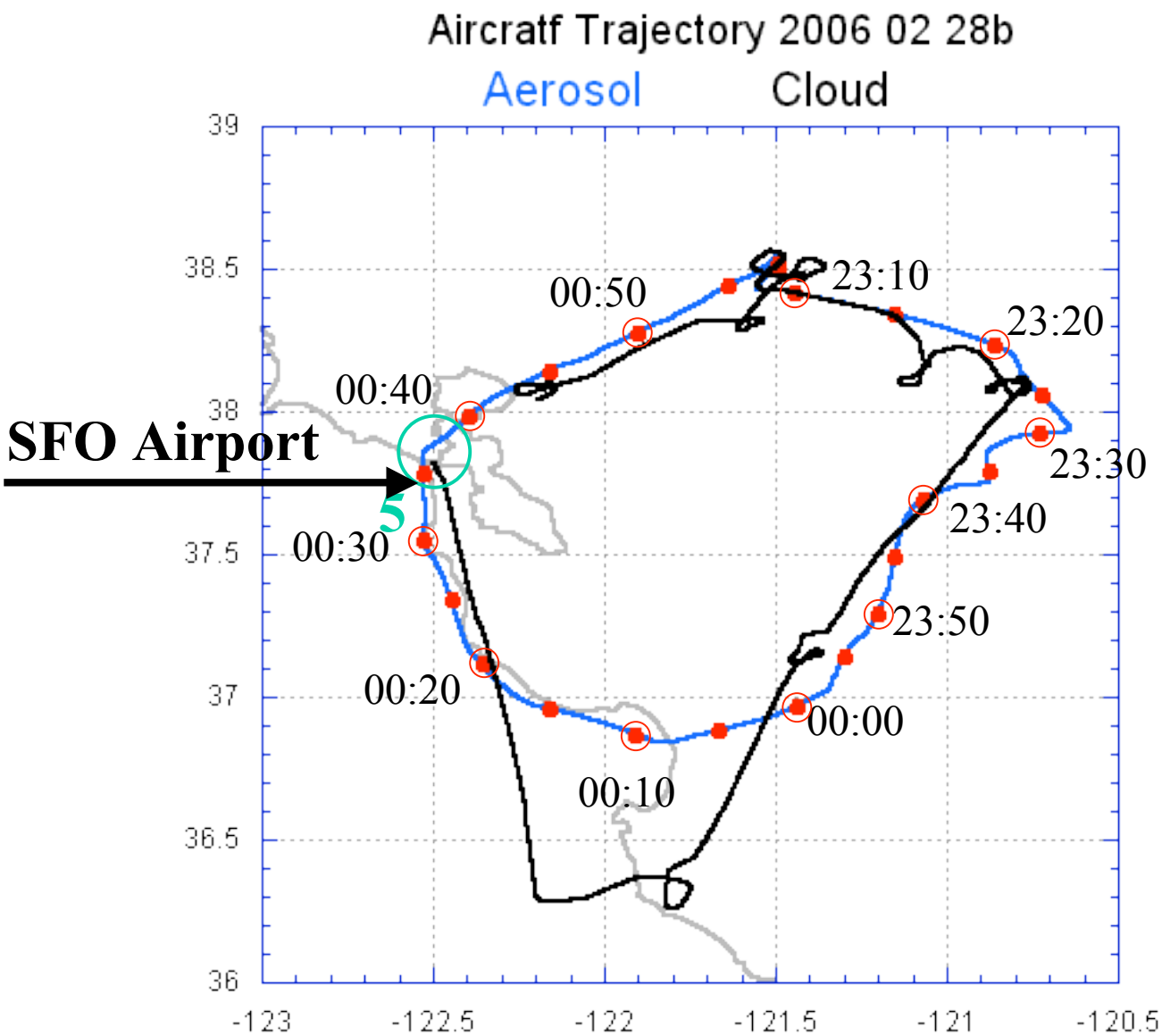

28 Feb 2006b
ALTITUDE
TSI CNC #Conc
SS Setting
CCN # Conc
CCN dT
Abs. Press
Concentration [cm-3], Altitude [feet], set SS [%]
CCN pressure [mb]
Time
1
2
3

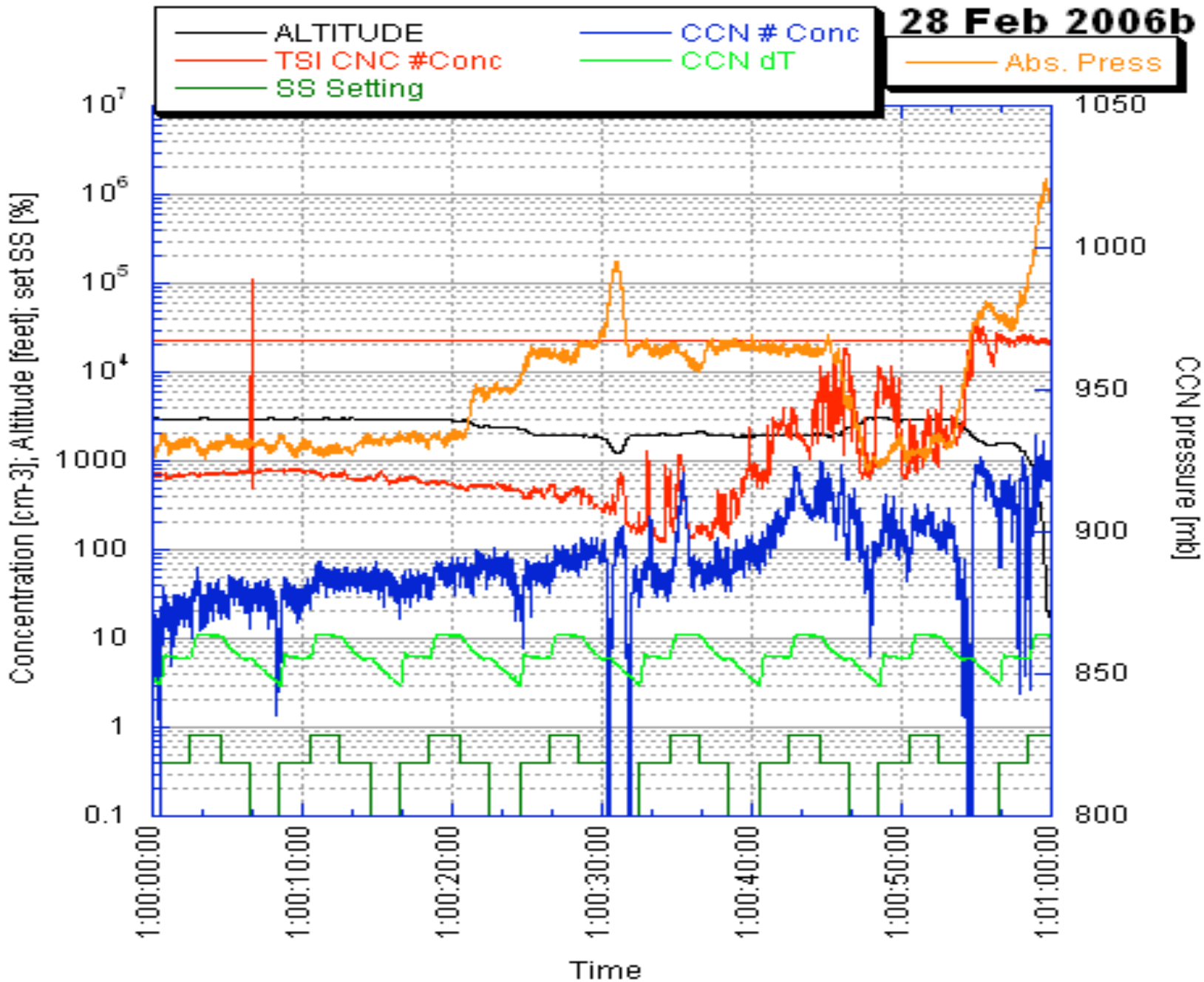

2006 02 28 21:00Z Aqua
1
2
3
T
-50
-40
-30
-20
-10
0
10
20
5 10 15 20 25 r


Aircratf Trajectory 2006 02 28b
Aerosol
Cloud
800
8
600
300
6
7
1800
1005
704
2
80
40
3
39
38.5
38
37.5
37
36.5
36
-123
-122.5
-122
-121.5
-121
-120.5


DSD LWC CDP 2006 03 01e
1507.005609
1501.010143
1503.011253
1503.011510
1505.012313
7
6
8
5
4
CCN cm-3
1000
100
10
1
Constant
height of 1500
m
0
10
20
30
40
50
D micron


Concentration [cm-3]
1000
100
10
1
0.1
900
850
800
[mb]
0:23:00:00
0:23:20:00
0:23:40:00
1:00:00:00
1:00:20:00
1:00:40:00
4
5
67
8
Time


Aircratf Trajectory 2006 02 28b
Aerosol
Cloud
SFO Airport
5
00:50
23:10
23:20
00:40
23:30
23:40
00:30
23:50
00:20
00:00
00:10
39
38.5
38
37.5
37
36.5
36
-123
-122.5
-122
-121.5
-121
-120.5


28 Feb 2006b
ALTITUDE
TSI CNC #Conc
SS Setting
CCN # Conc
CCN dT
Abs. Press
Concentration [cm-3]; Altitude [feet]; set SS [%]
CCN pressure [mb]
Time
10^7
10^6
10^5
10^4
1000
100
10
1
0.1
1050
1000
950
900
850
800
1:00:00:00
1:00:10:00
1:00:20:00
1:00:30:00
1:00:40:00
1:00:50:00
1:01:00:00

Aerosol aircraft: 2006 03 01 01:03Z 900 m

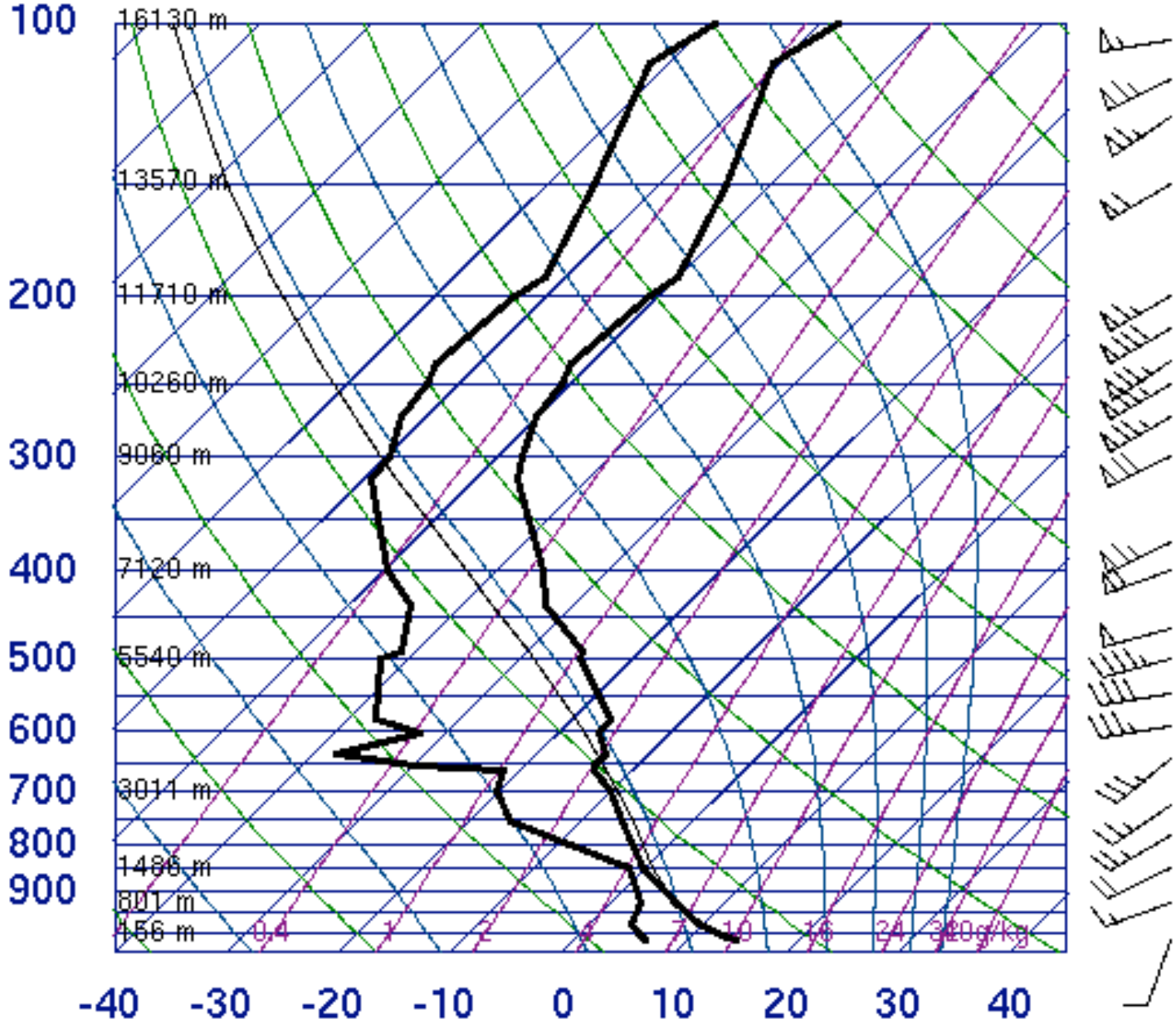
2006 03 01 01:03Z 1500 m 3°C

2006 03 01 01:05Z 1500 m 3°C

2006 03 01 01:03Z 1500 m 3°C

Cloud 6
2006 03 01 01:03Z 1500 m 3°C

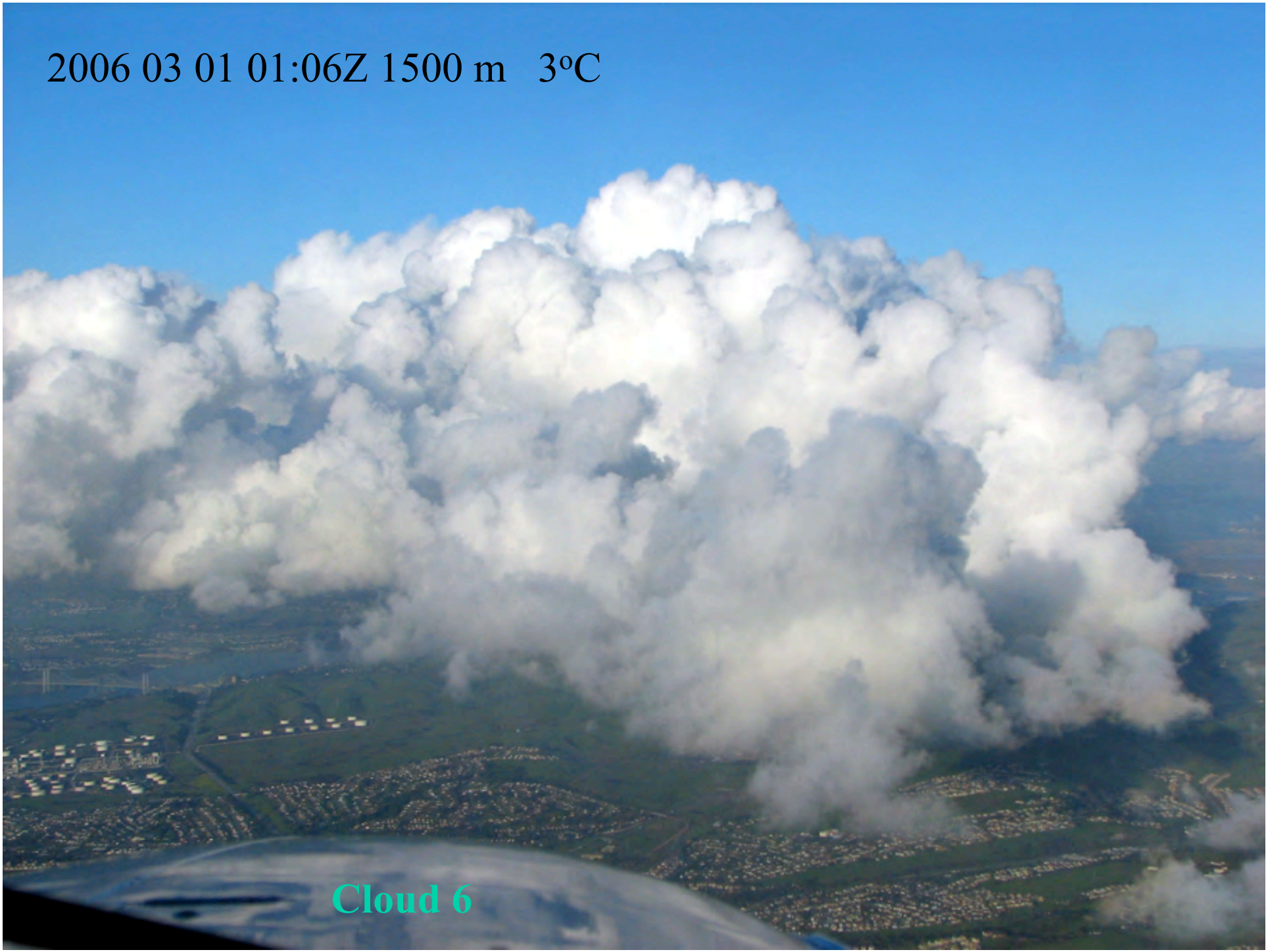
72493 OAK Oakland Int

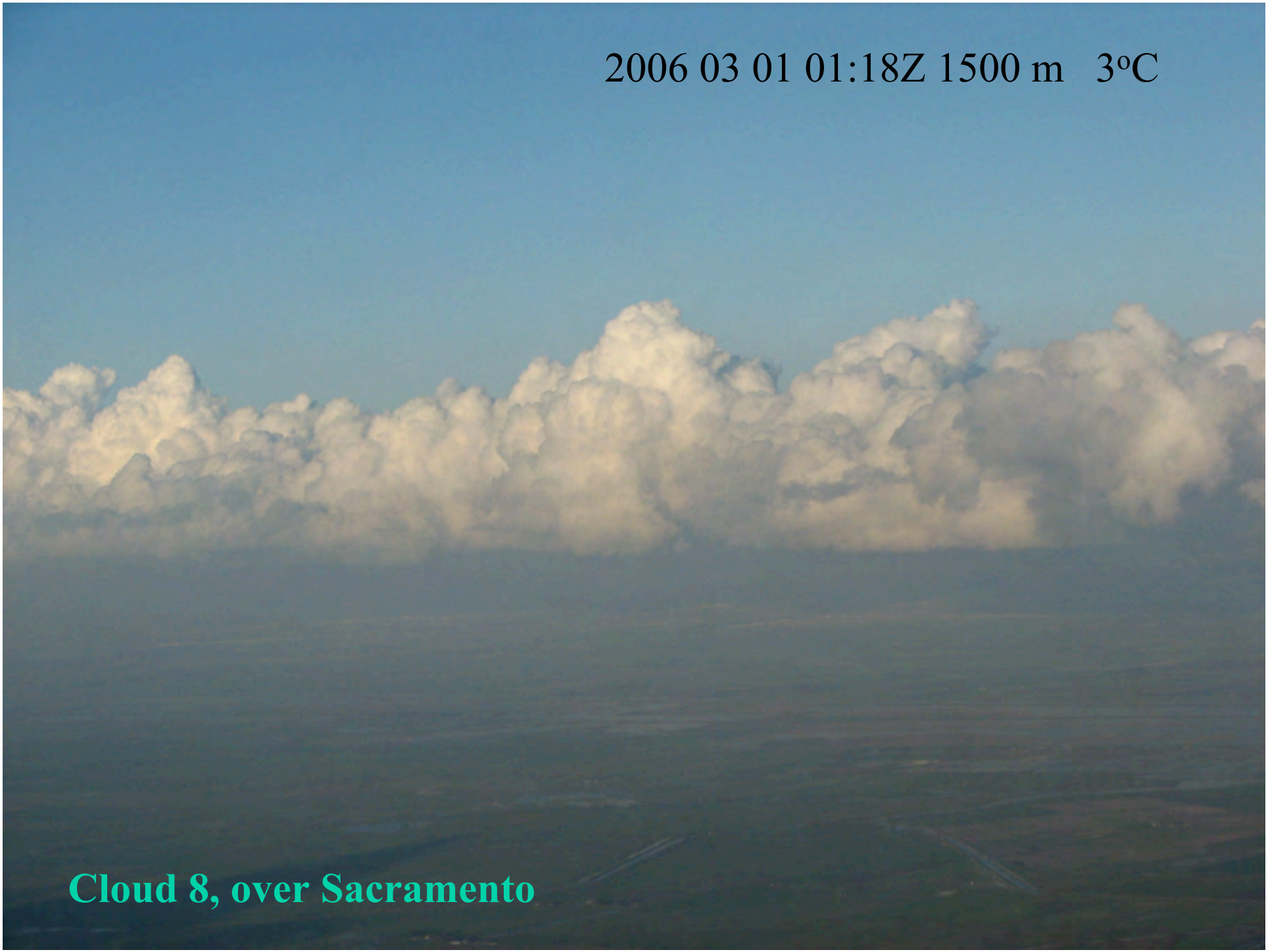


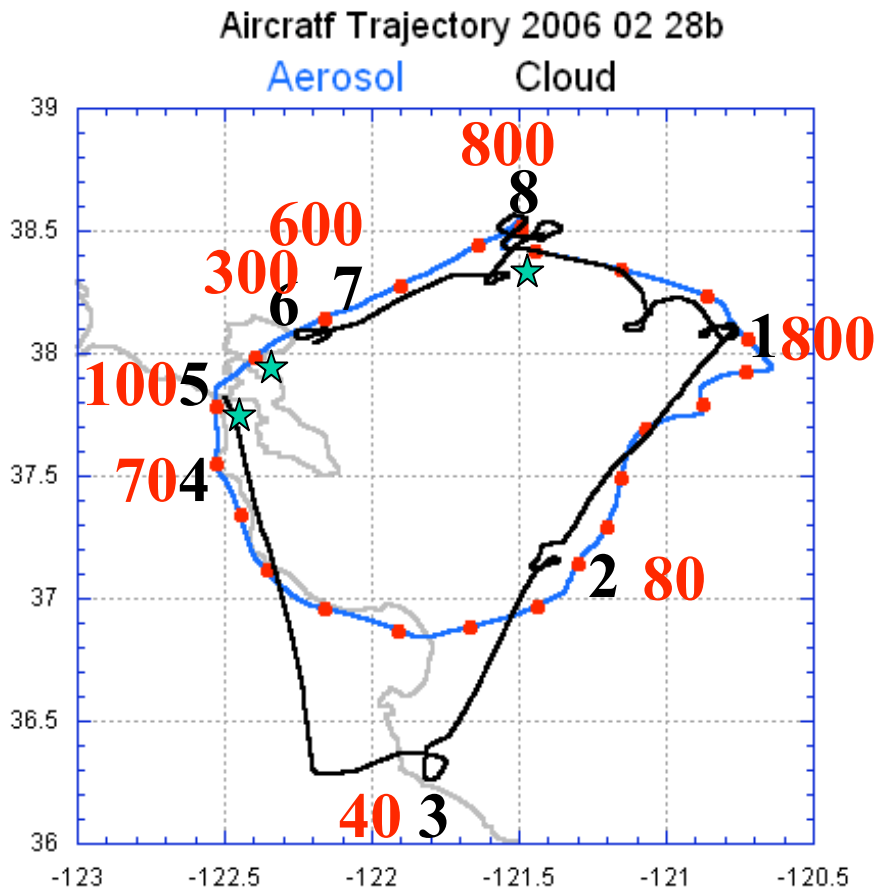
SLAT	37.73
SLON	-122.
SELV	3.00
SHOW	6.21
LIFT	4.24
LFTV	4.16
SWET	126.7
KINX	12.70
CTOT	23.00
VTOT	24.20
TOTL	47.20
CAPE	75.02
CAPV	97.44
CINS	-1.25
CINV	-0.30
EQLV	643.9
EQTV	640.8
LFCT	885.2
LFCV	889.9
BRCH	1.98
BRCV	2.57
LCLT	276.2
LCLP	895.4
MLTH	285.0
MLMR	5.37
THCK	5384.
PWAT	13.09

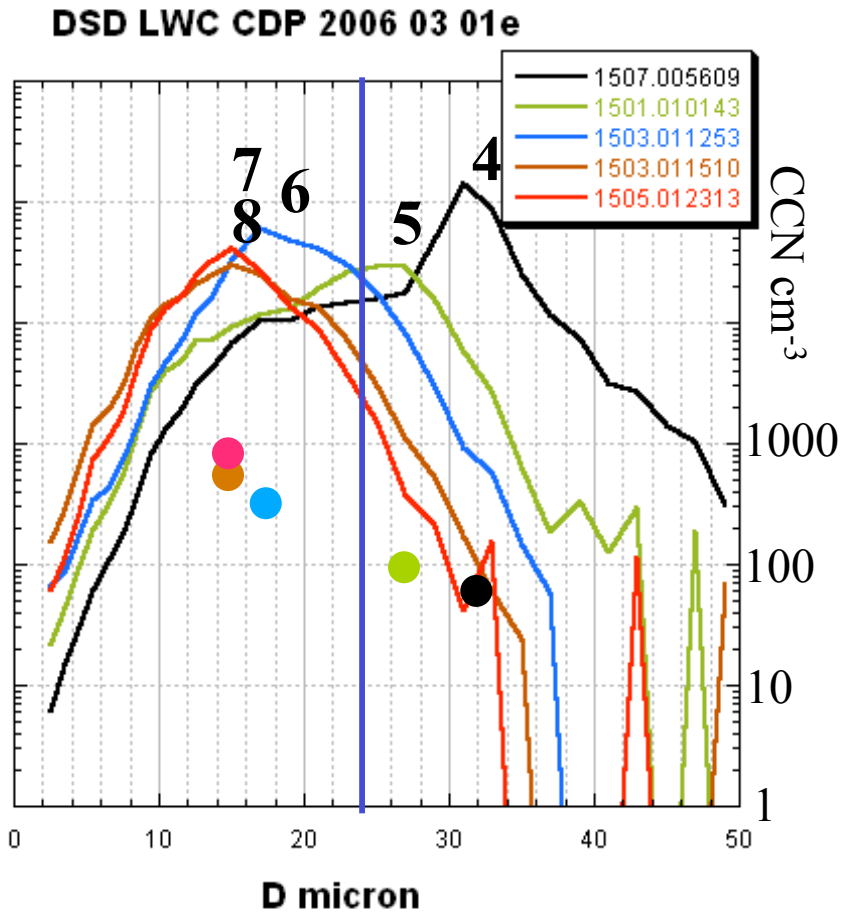
00Z 01 Mar 2006

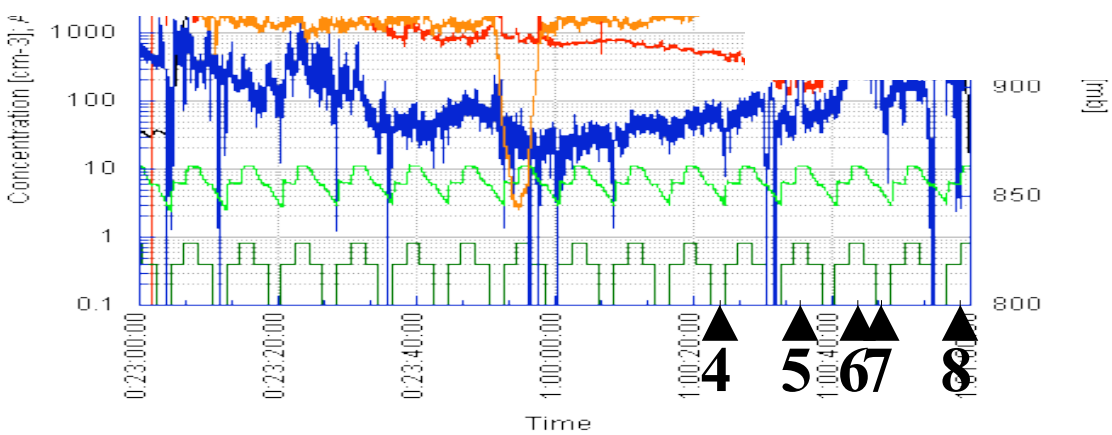
University of Wyoming


2006 03 01 01:06Z 1500 m 3°C
Cloud 6

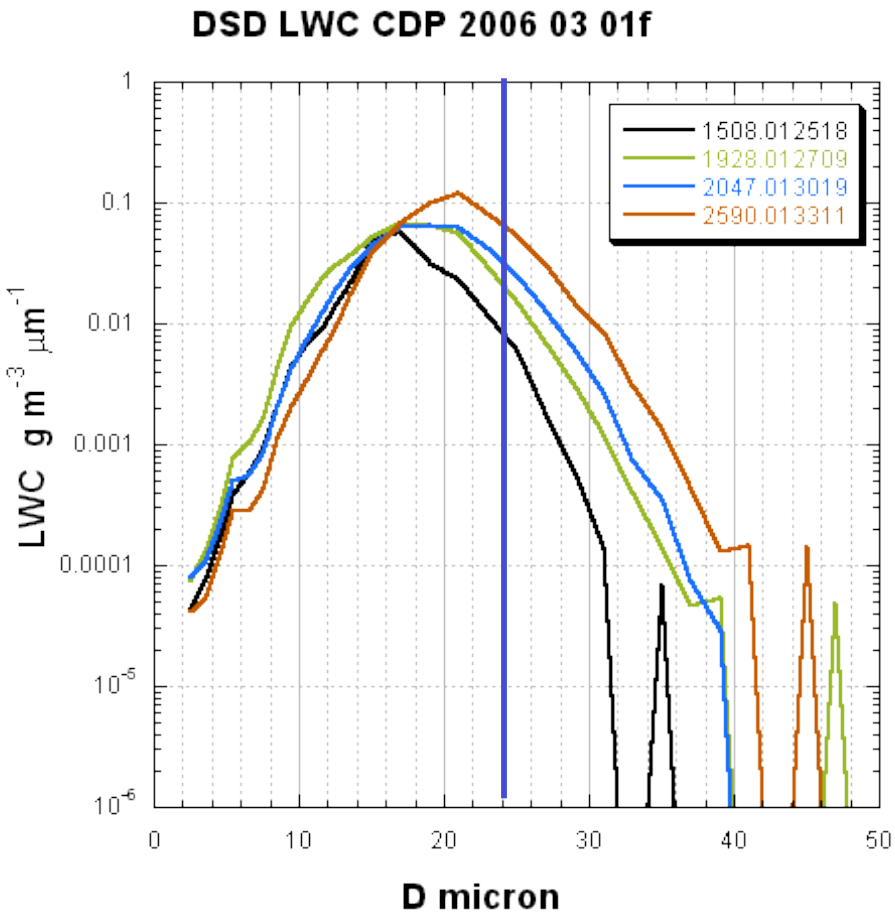

2006 03 01 01:18Z 1500 m 3°C
Cloud 8, over Sacramento


Aircratf Trajectory 2006 02 28b
Aerosol
Cloud
39
38.5
38
37.5
37
36.5
36
-123
-122.5
-122
-121.5
-121
-120.5
800
8
600
300
6
7
1800
1005
704
2
80
40
3


DSD LWC CDP 2006 03 01e
1507.005609
1501.010143
1503.011253
1503.011510
1505.012313
CCN cm-3
1000
100
10
1
0
10
20
30
40
50
D micron
7
6
8
5
4

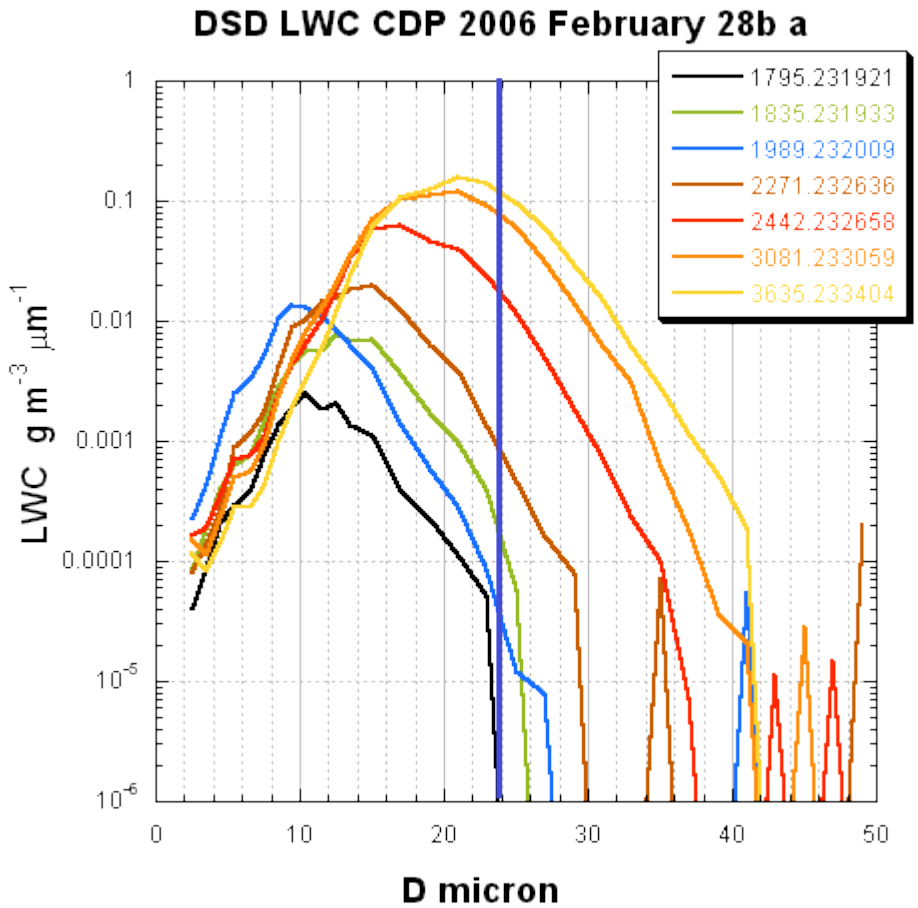

Concentration [cm-3], A
1000
100
10
1
0.1
900
850
800
[mb]
0:23:00:00
0:23:20:00
0:23:40:00
1:00:00:00
1:00:20:00
1:00:40:00
Time
4
5
67
8

Cloud 8

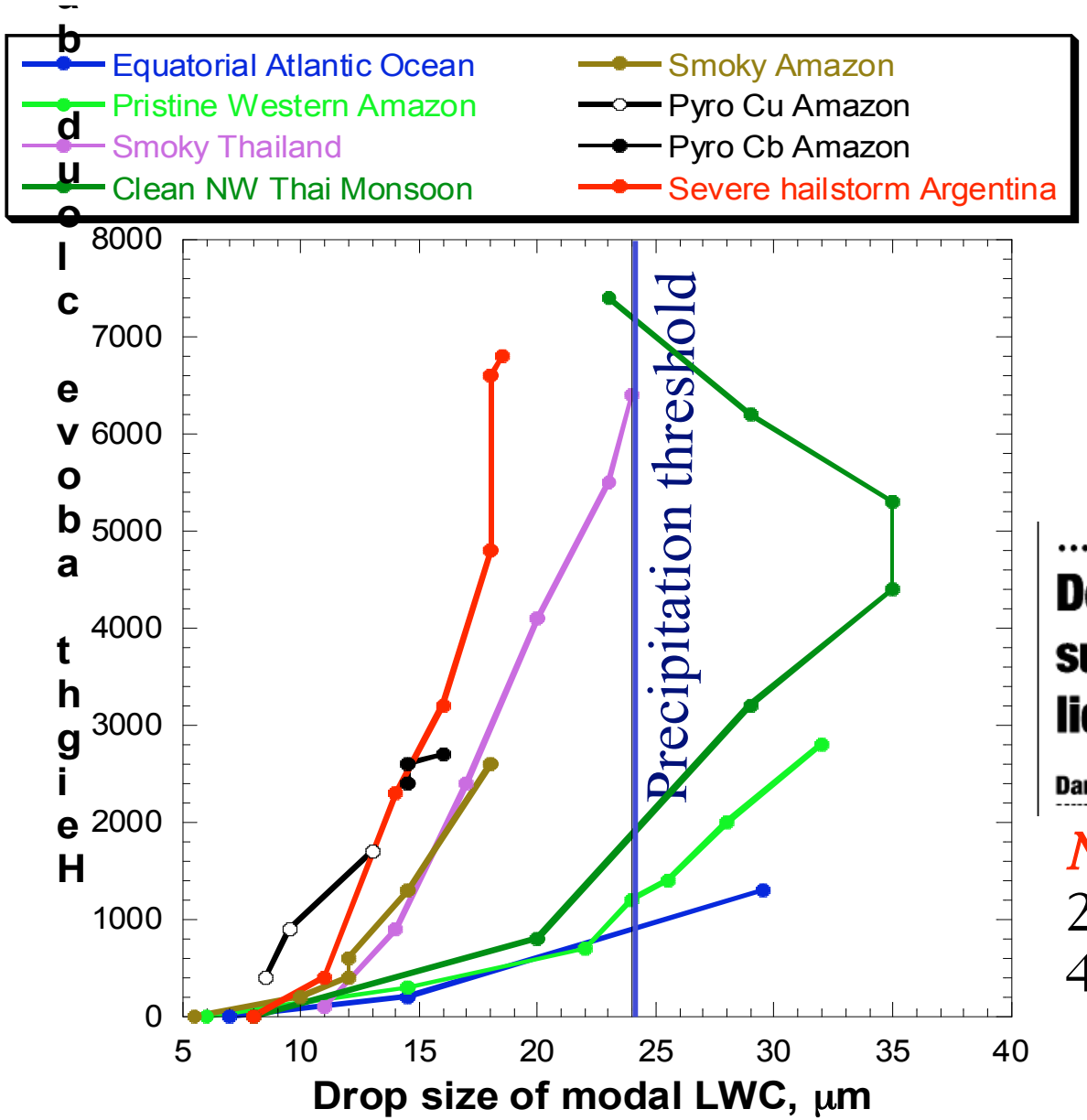


CCN = ~ 800 cm^{-3}

Cloud 1



CCN = ~ 300 – 800 cm^{-3}



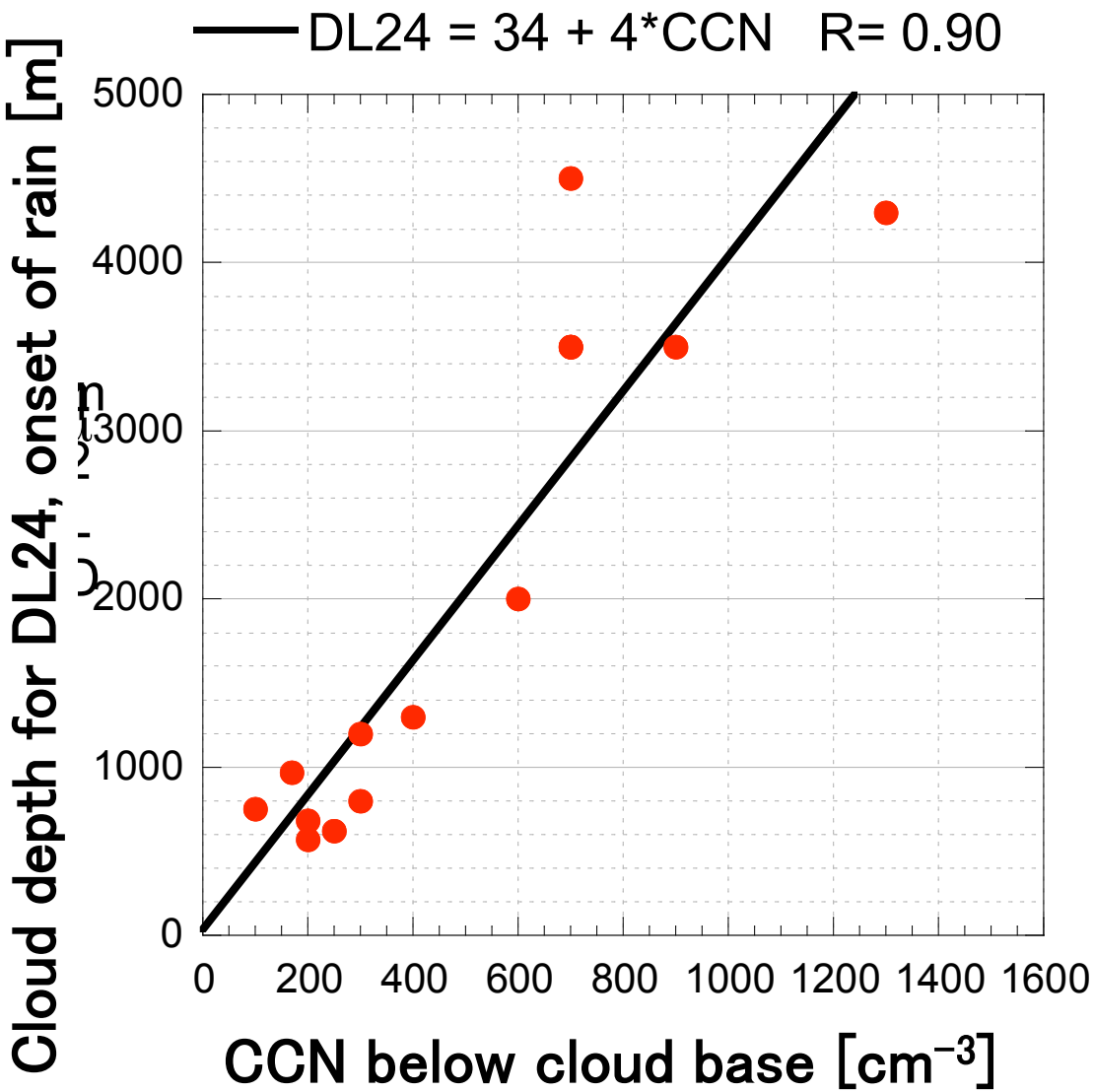
Andreae, M. O., D. Rosenfeld, P. Artaxo et al., 2004: Smoking rain clouds over the Amazon. *Science*, 303, 1337-1342.

Deep convective clouds with sustained supercooled liquid water down to –37.5 °C

Daniel Rosenfeld* & William L. Woodley†

Nature, 25 May 2000, 405, 440-442.

Aircraft measured Modal LWC cloud drop diameter as a function of height above cloud base, for the various aerosol regimes in Brazil [Thailand].



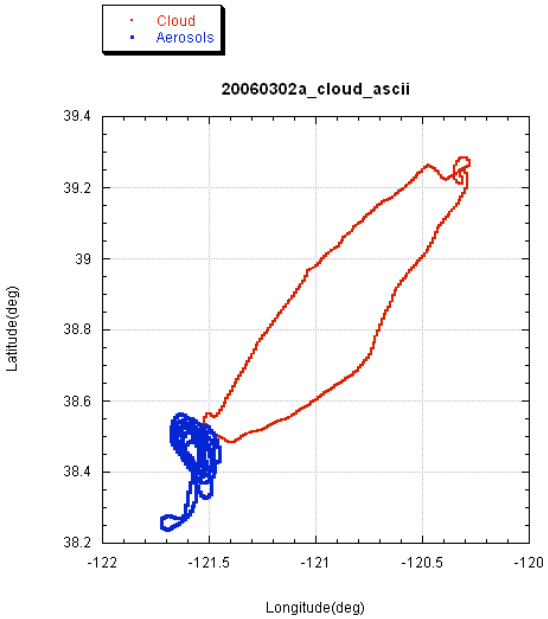
Based on the flights from:
2006 02 28a
2006 02 28b
2006 03 01
2006 03 02a
2006 03 02b
2006 03 02c

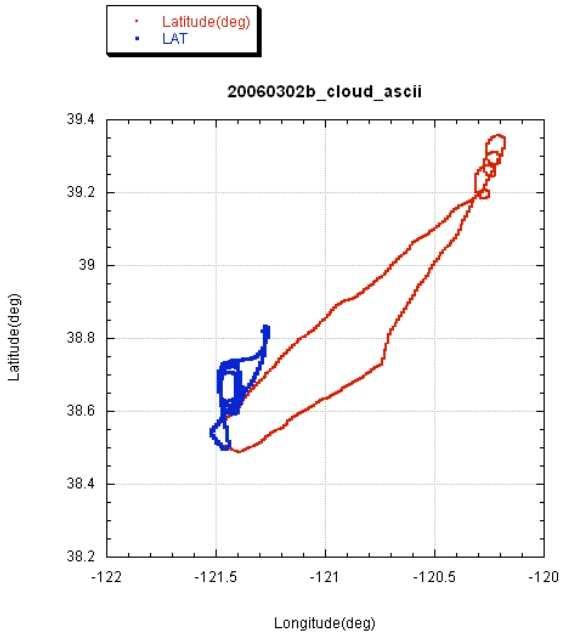
Yet unanalyzed data exists for up to 13 additional flights

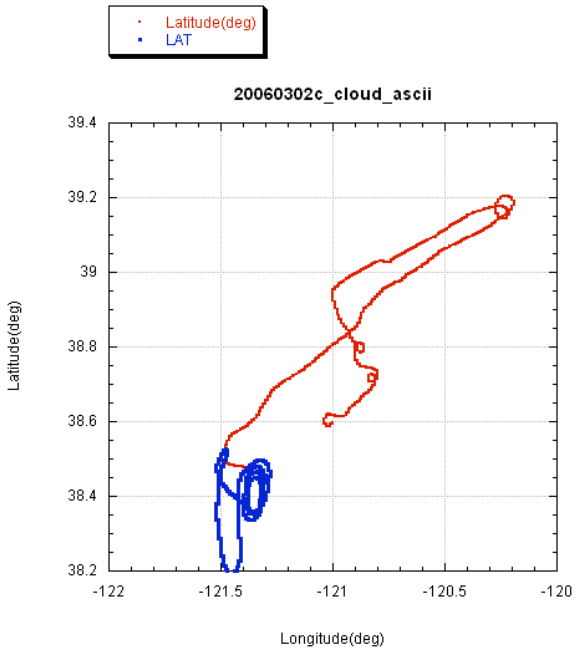
Three flights on March 2, 2006

Cloud physics aircraft tracks

Aerosols aircraft tracks



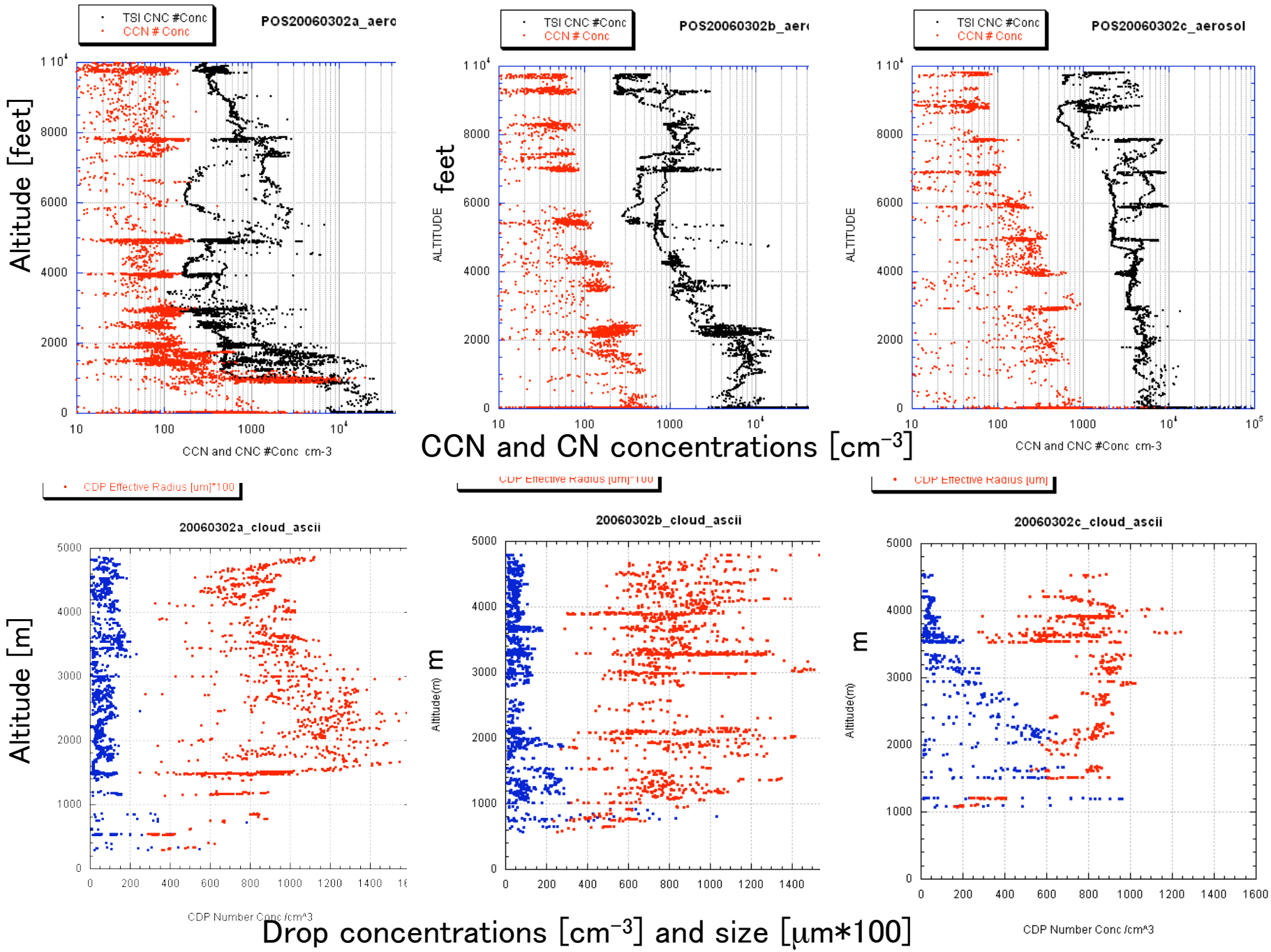




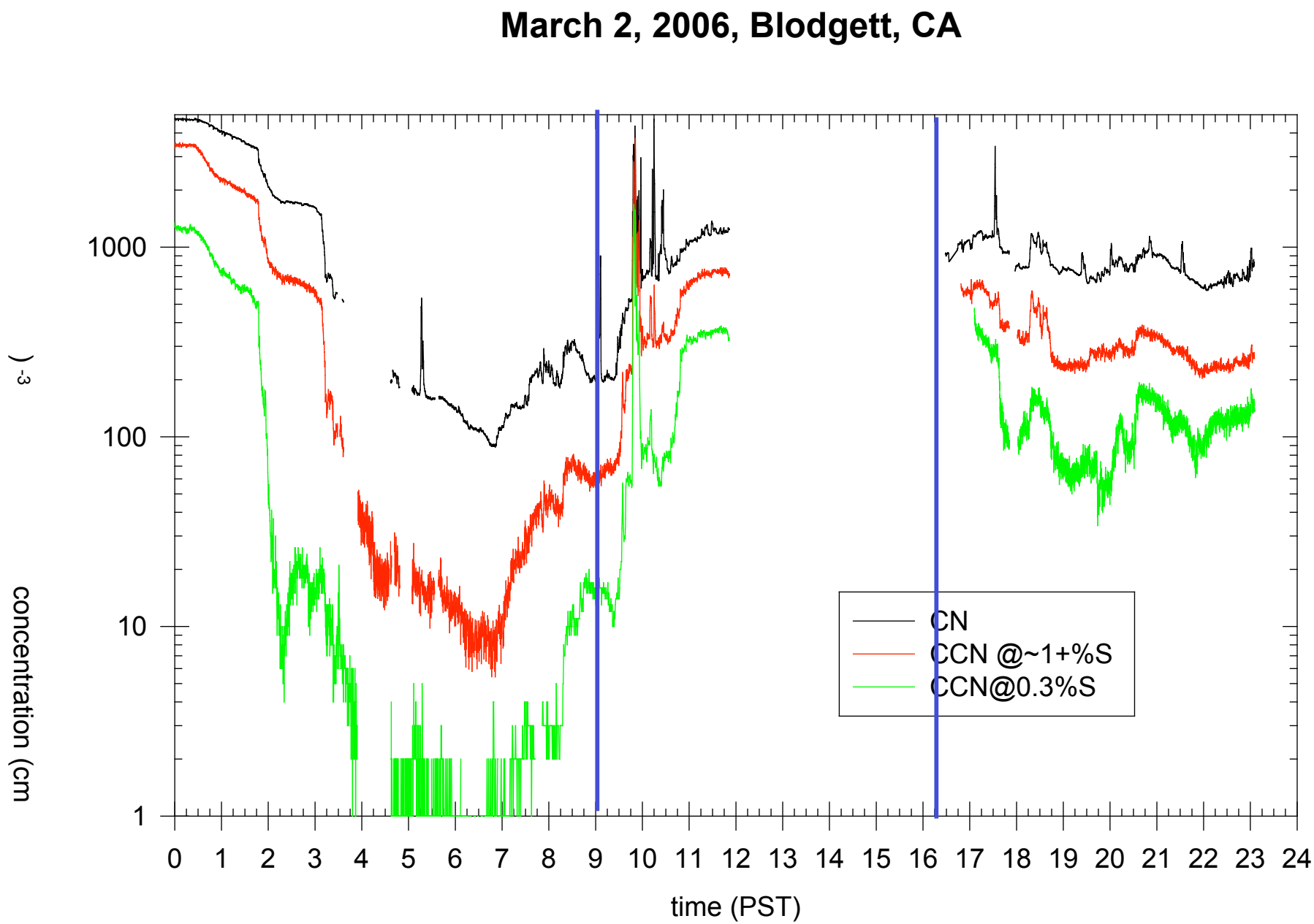
Morning
9-10 PST

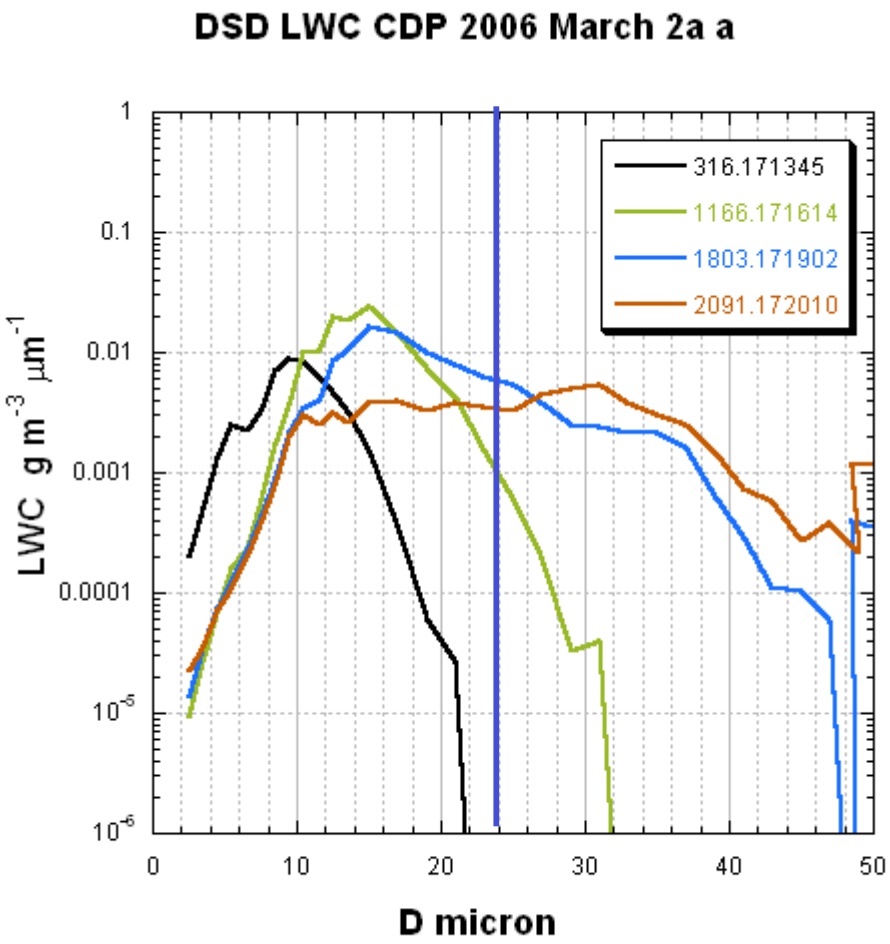
Noon
12-13 PST

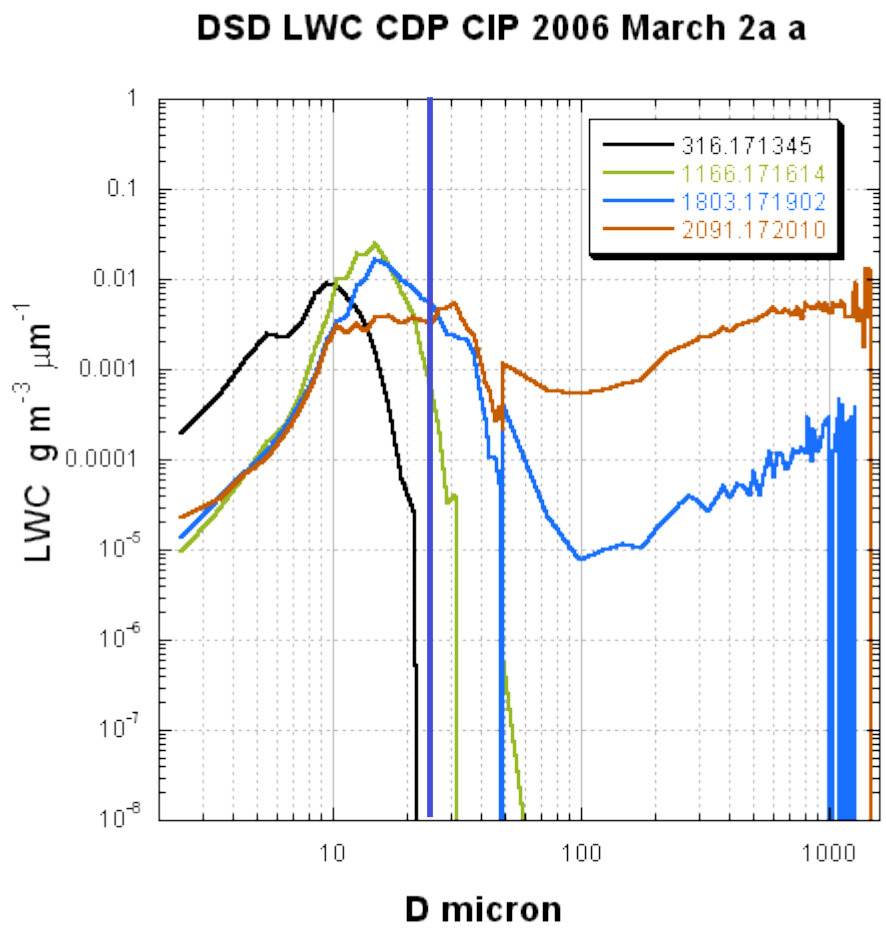
Afternoon
15-16 PST



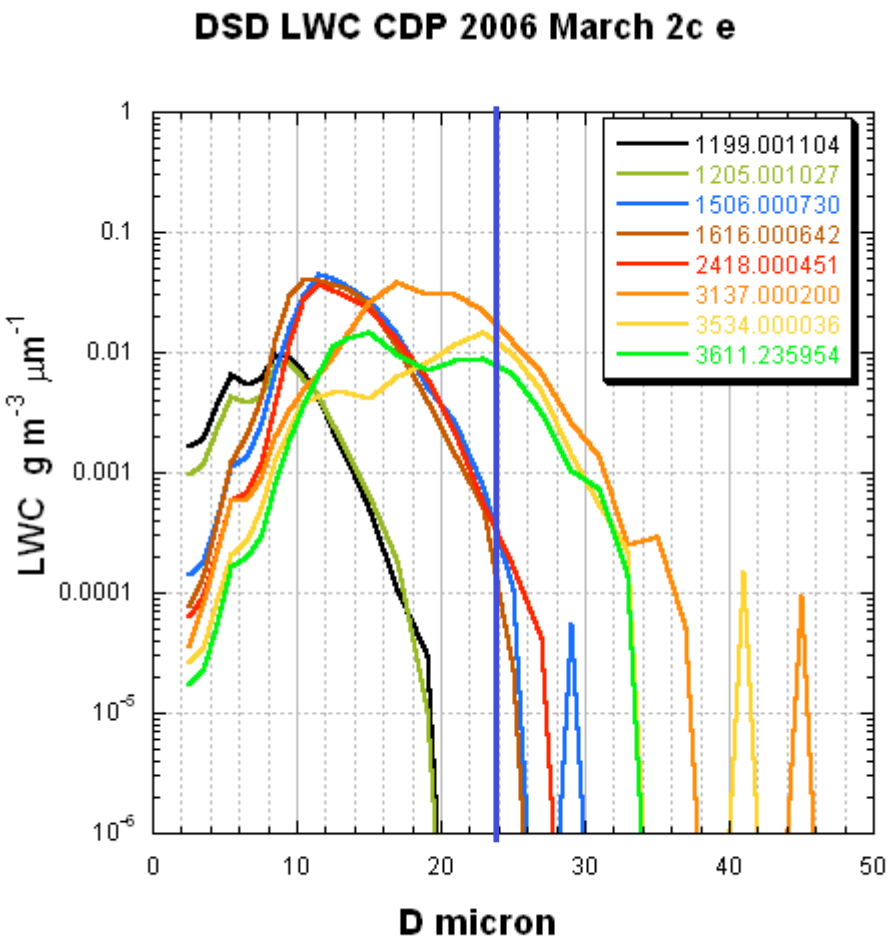
Morning Noon Afternoon

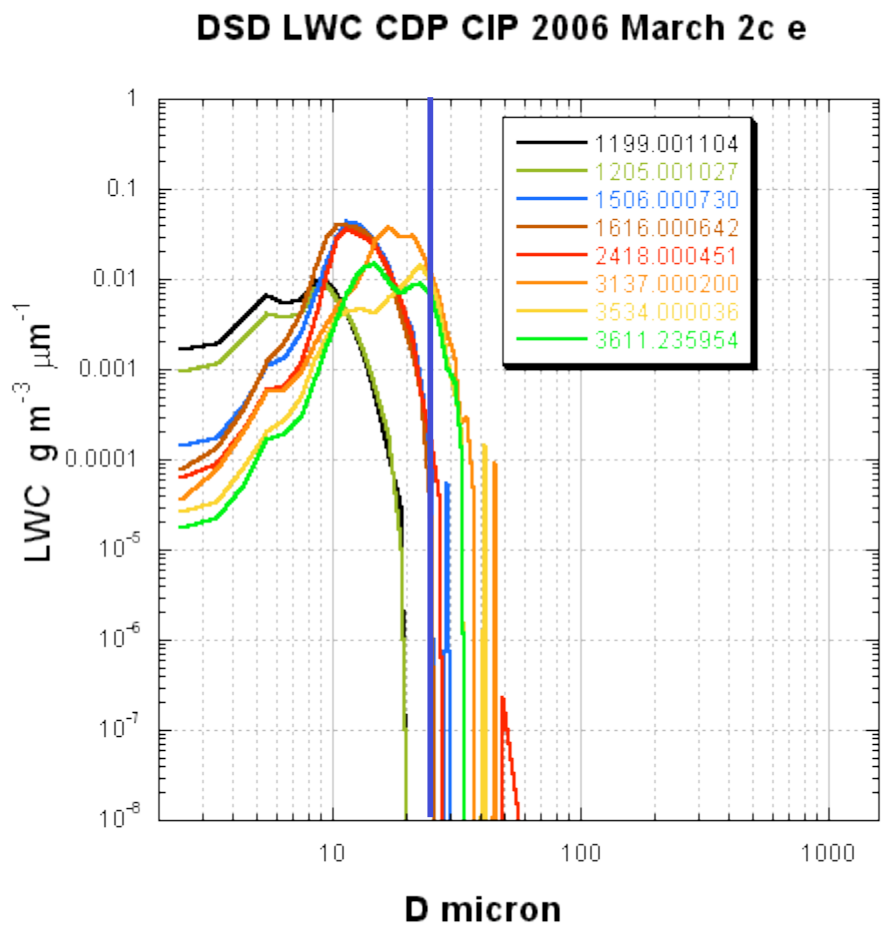

March 2, 2006, Blodgett, CA
concentration (cm -3)
1000
100
10
1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
time (PST)
CN
CCN @~1+%S
CCN@0.3%S


DSD LWC CDP 2006 March 2a a
316.171345
1166.171614
1803.171902
2091.172010
LWC g m-3 µm-1
D micron

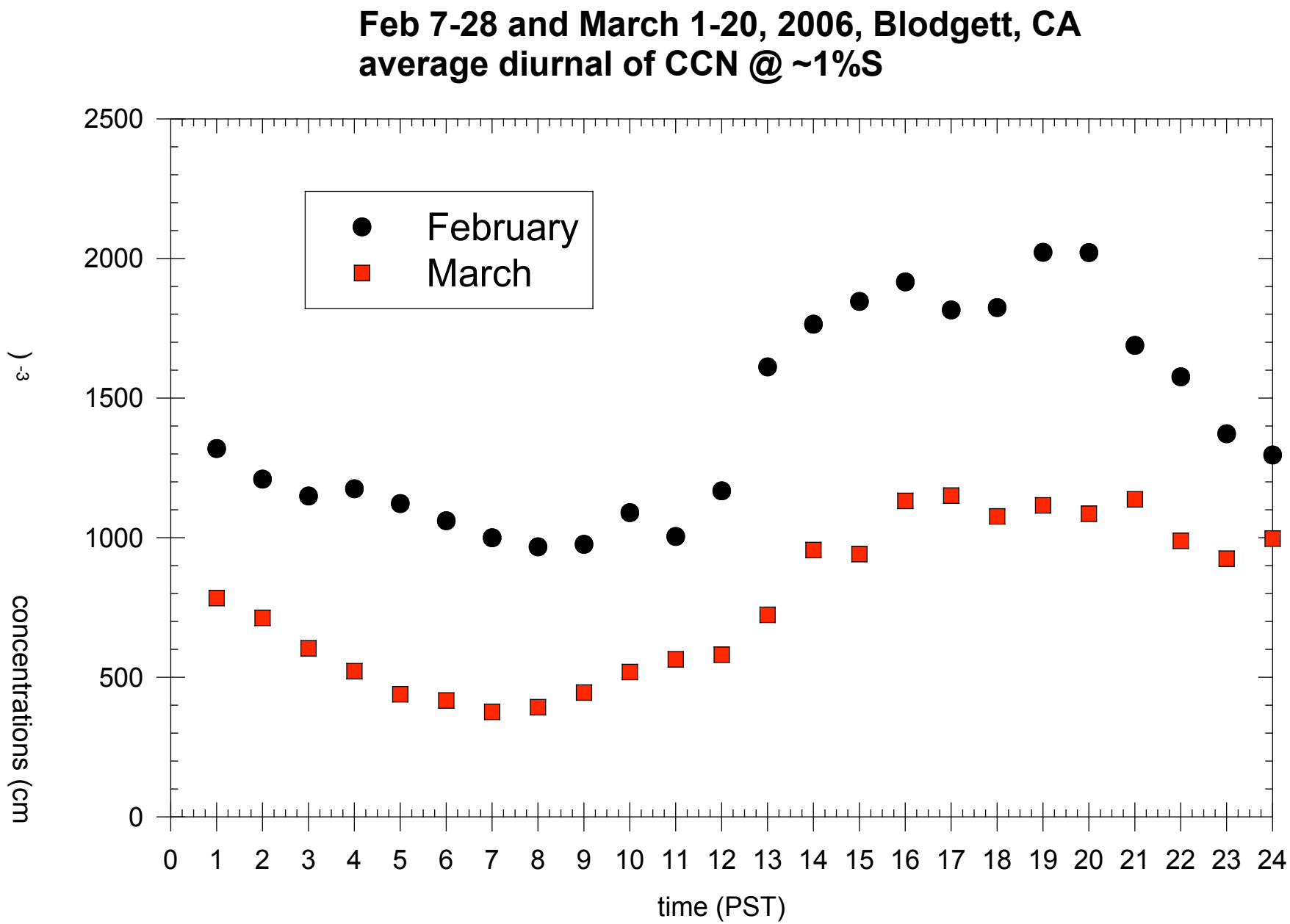

DSD LWC CDP CIP 2006 March 2a a
316.171345
1166.171614
1803.171902
2091.172010
LWC g m-3 µm-1
D micron

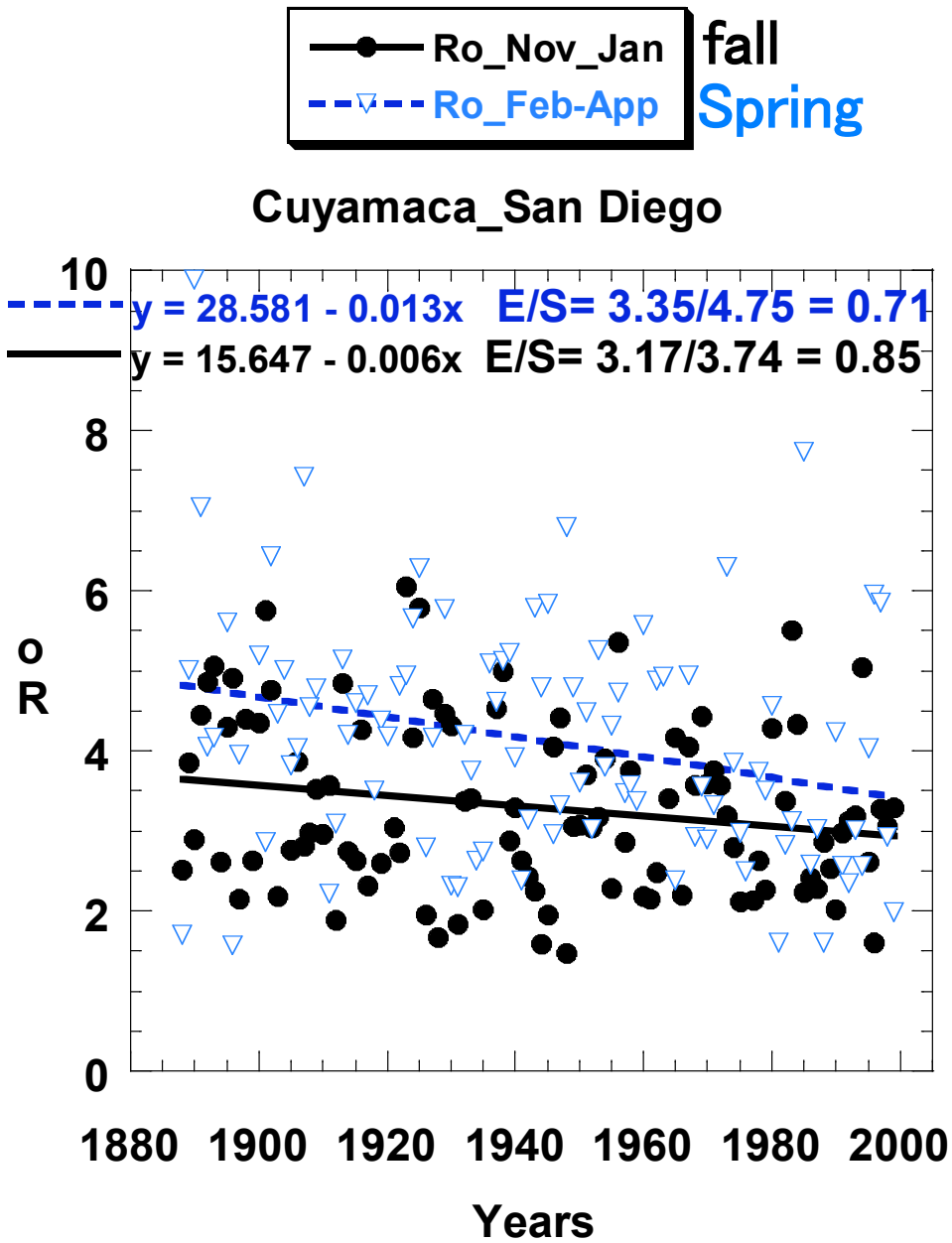
CCN < 100 cm^{-3}


DSD LWC CDP 2006 March 2c e
LWC g m-3 µm-1
D micron
1199.001104
1205.001027
1506.000730
1616.000642
2418.000451
3137.000200
3534.000036
3611.235954


DSD LWC CDP CIP 2006 March 2c e
LWC g m-3 µm-1
D micron
1199.001104
1205.001027
1506.000730
1616.000642
2418.000451
3137.000200
3534.000036
3611.235954

CCN = ~ 600 cm^{-3}


Feb 7-28 and March 1-20, 2006, Blodgett, CA
average diurnal of CCN @ ~1%S
February
March
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
time (PST)
concentrations (cm -3)



Greater decreasing trend occurs in spring, when the sun is stronger.

Conclusions

1. Enhanced CCN aerosols is associated with smaller cloud drops and deeper cloud depth for onset of rain in the cloud.
2. Cloud depth for onset of rain [m] = 4*CCN [cm^{-3}]
3. Enhanced CCN concentrations and precipitation suppression are clearly linked to urban areas.
4. Clouds triggered at the Sierra foothills ingest the aerosols that inhibit precipitation mostly in the afternoon and evening.
5. The solar control is suggested to occur by increasing the:
   - Vertical mixing of the aerosols;
   - Photochemical production of CCN;
   - Drying the boundary layer and greater cloud base updrafts that nucleate more CCN into cloud drops.
6. The solar control is supported by greater observed suppressed precipitation during spring compared to fall.