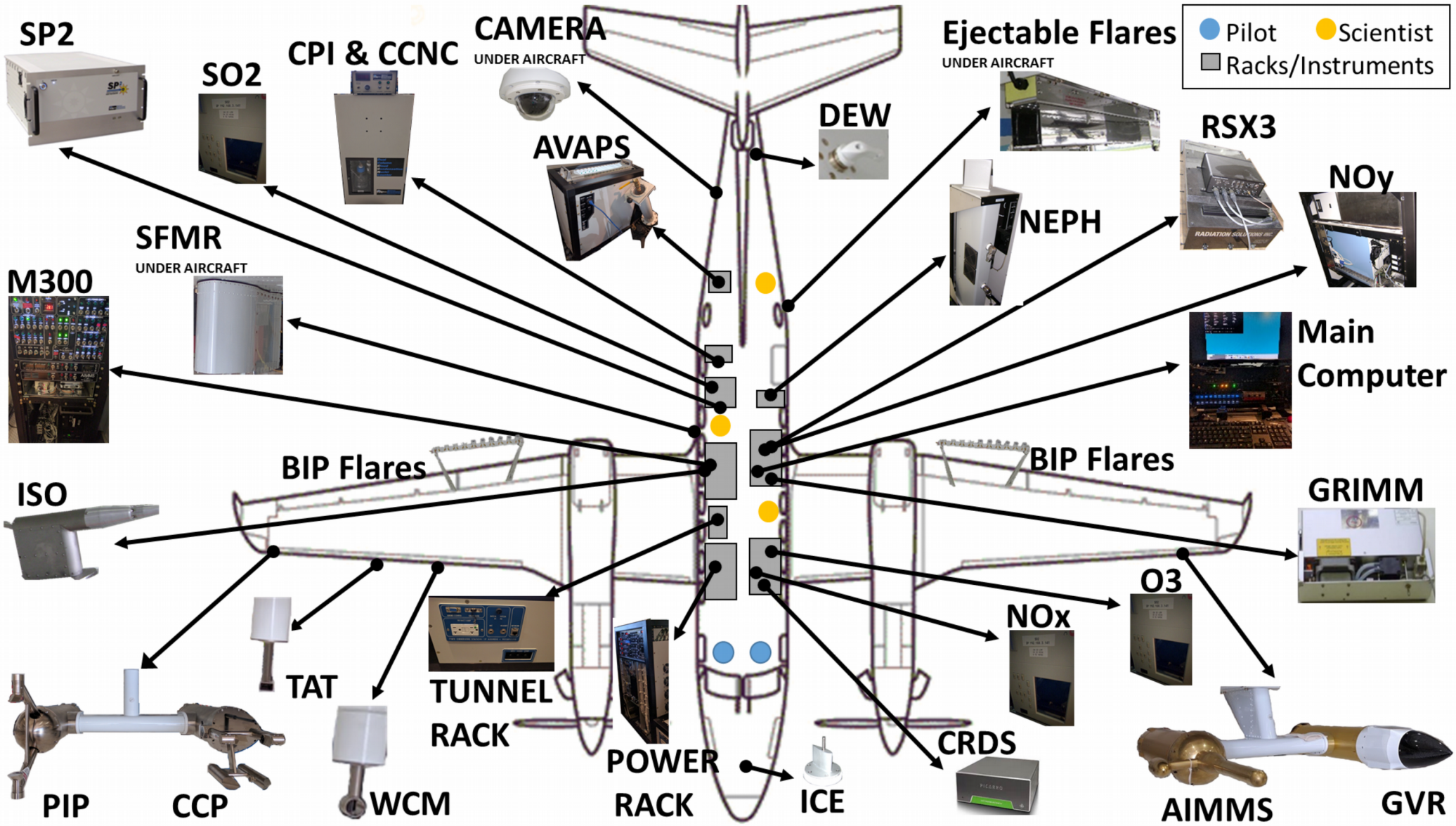
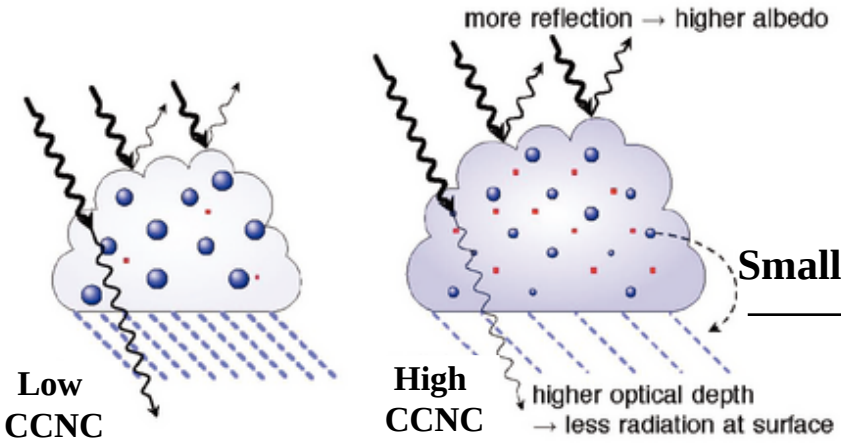
Clouds: Flights, Theory, and Data



Dr. David Delene

University of North Dakota

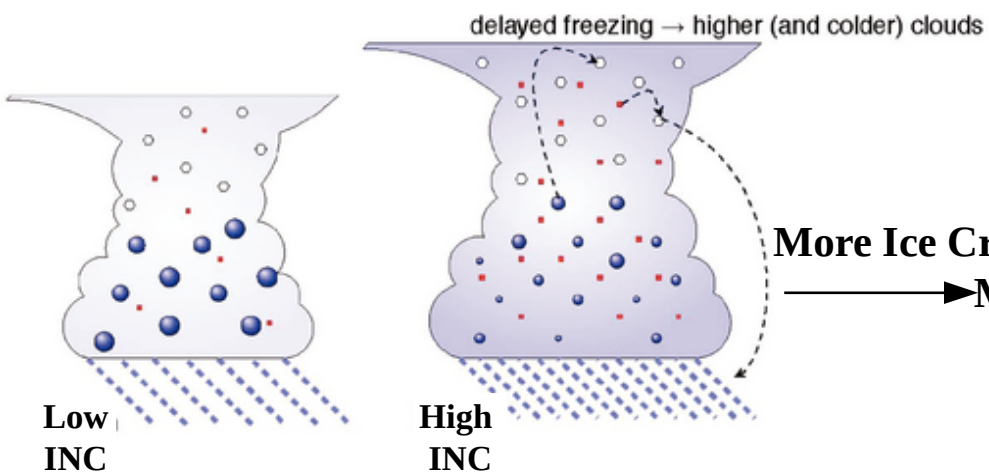
Importance of Aerosols and Clouds



Smaller Cloud Particles → Less Precipitation

Cloud Albedo and Lifetime Effect

Less Precipitation

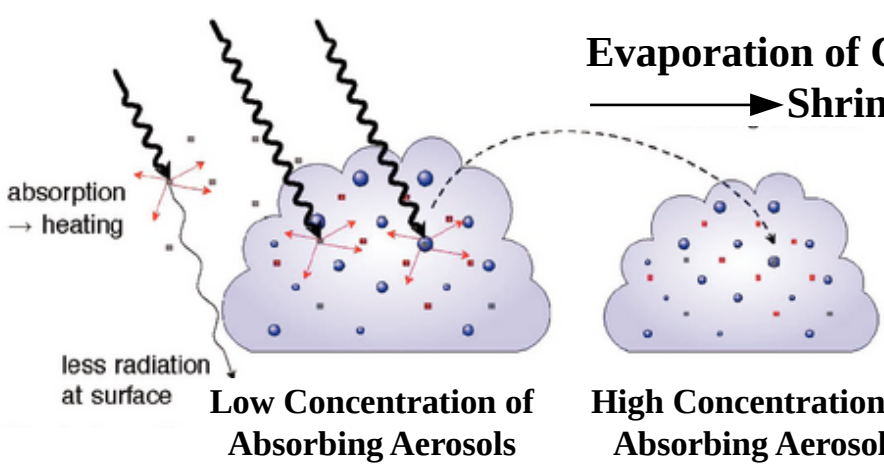


More Ice Crystals → More Precipitation

Glaciation Effect

More Precipitation

Evaporation of Cloud Droplets → Shrinking of Cloud



Semi-direct Effect

Less Precipitation

CCNC – Cloud Condensation Nuclei Concentration
INC – Ice Nuclei Concentration

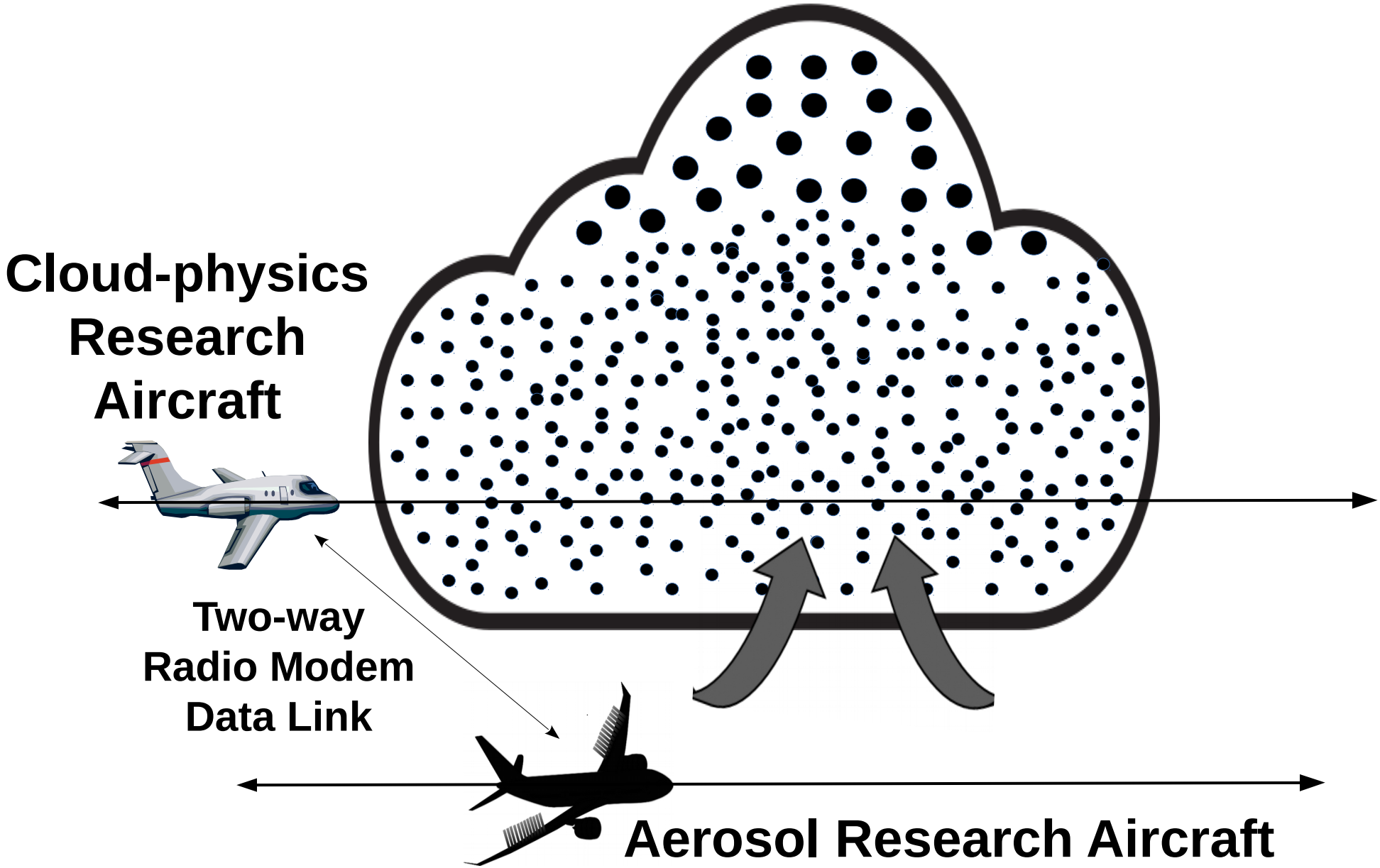
IPCC Fourth Assessment Report: Climate Change 2007: Working Group 1: The Physical Science Basis, Figure 7.20

Possible Measurement Objectives

- Determine the relationship between aerosols and cloud droplet properties.
  - Precipitation Formation
  - Aerosol Indirect Climate Affect
- Determine if cloud seeding could be beneficial (Delene 2016).
- Help determine what is the optimal seeding method for enhancing precipitation.

Delene, D. J., Suitability of North Dakota for Conducting Effective Hygroscopic Seeding, J ournal of Weather Modification, 48, 43-67, 2016.

Relationship between CCN and Droplets



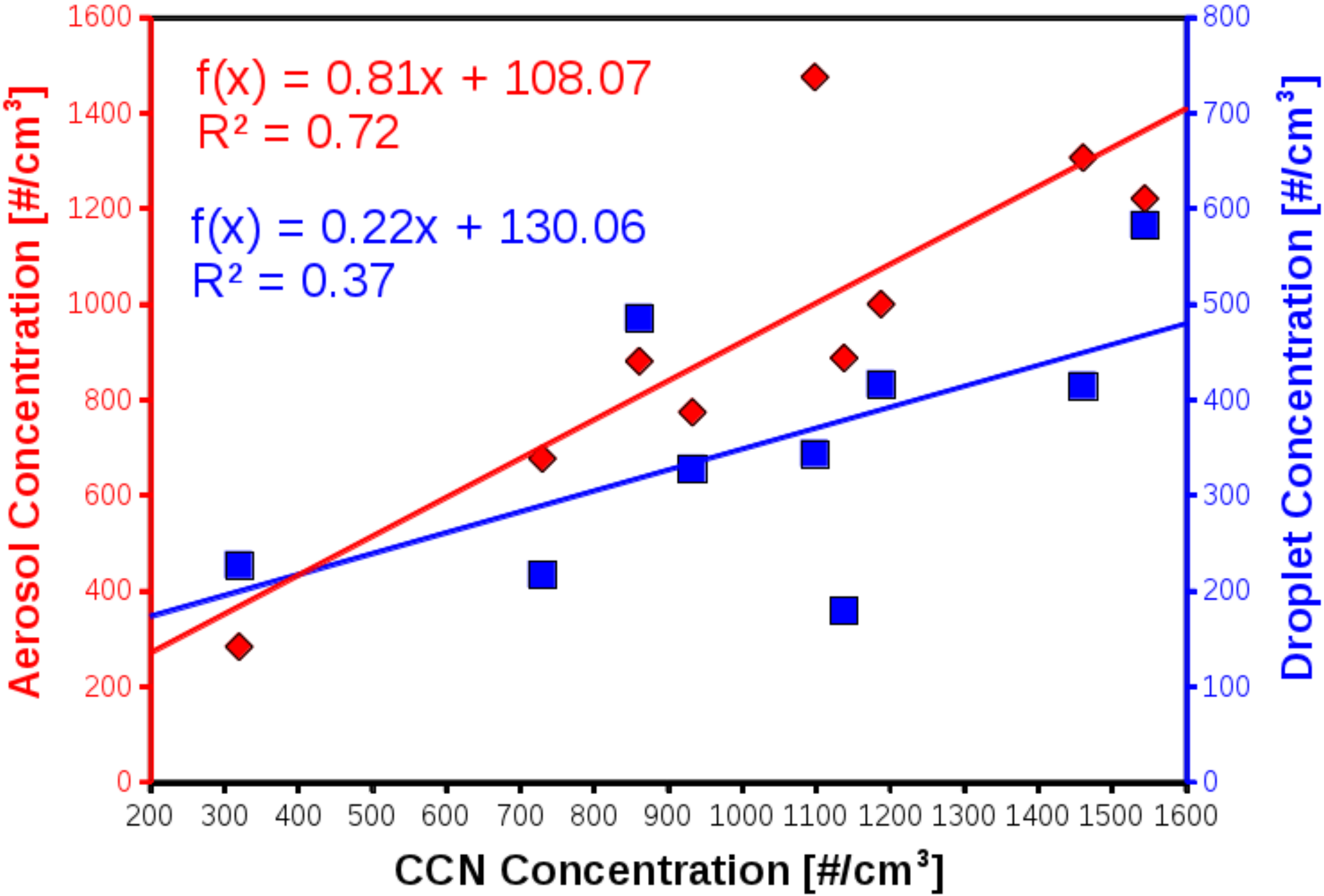


Image reproduced from Figure 8 of Delene et al., 2011.

Clouds in the Atmosphere

Clouds are made up of water droplets and/or ice crystals, much larger than typical aerosols (0.01-10 μm).

Clouds are technically aerosols but have unique properties and are typically considered separately.

East Grand Forks: 17 July 2011

Citation Flight: 14 July 2011

Rosemount Ice Rate Detector (RICE)

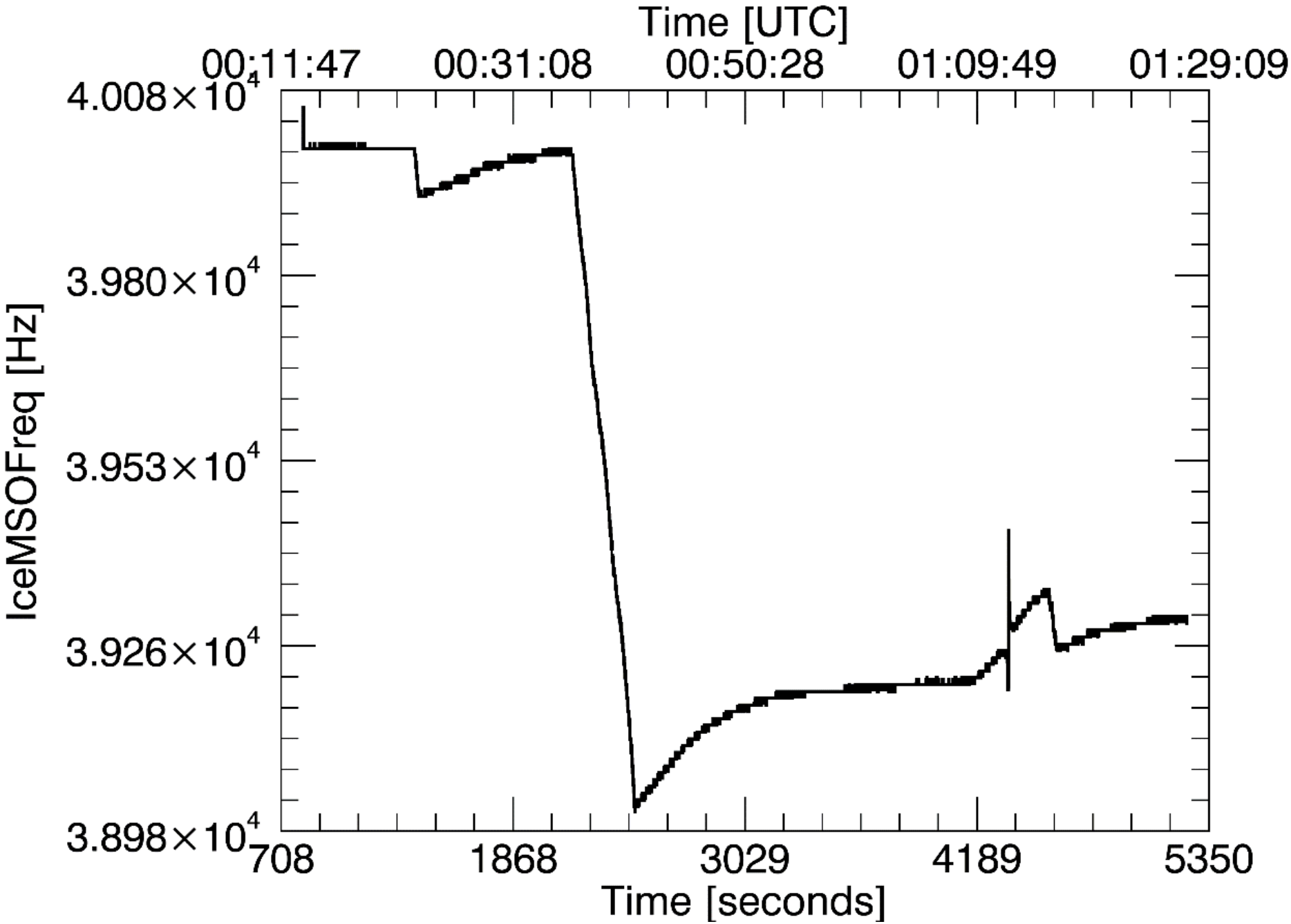
Operating Principles – Rod Frequency Change

Primary Measurements – Ice Rate Accumulation

Quality Control – Review Flight Data

Flight Profile Consideration – Icing Rate not Same as Wings

Data Acquisition – Serial Data



Time series plot of ice detector frequency during the flight on the 2 March 2017 flight near Fargo, North Dakota.

2-Dimensional Probe Aircraft Measurements

Two Dimensional Cloud (2D-C) Probe Optics

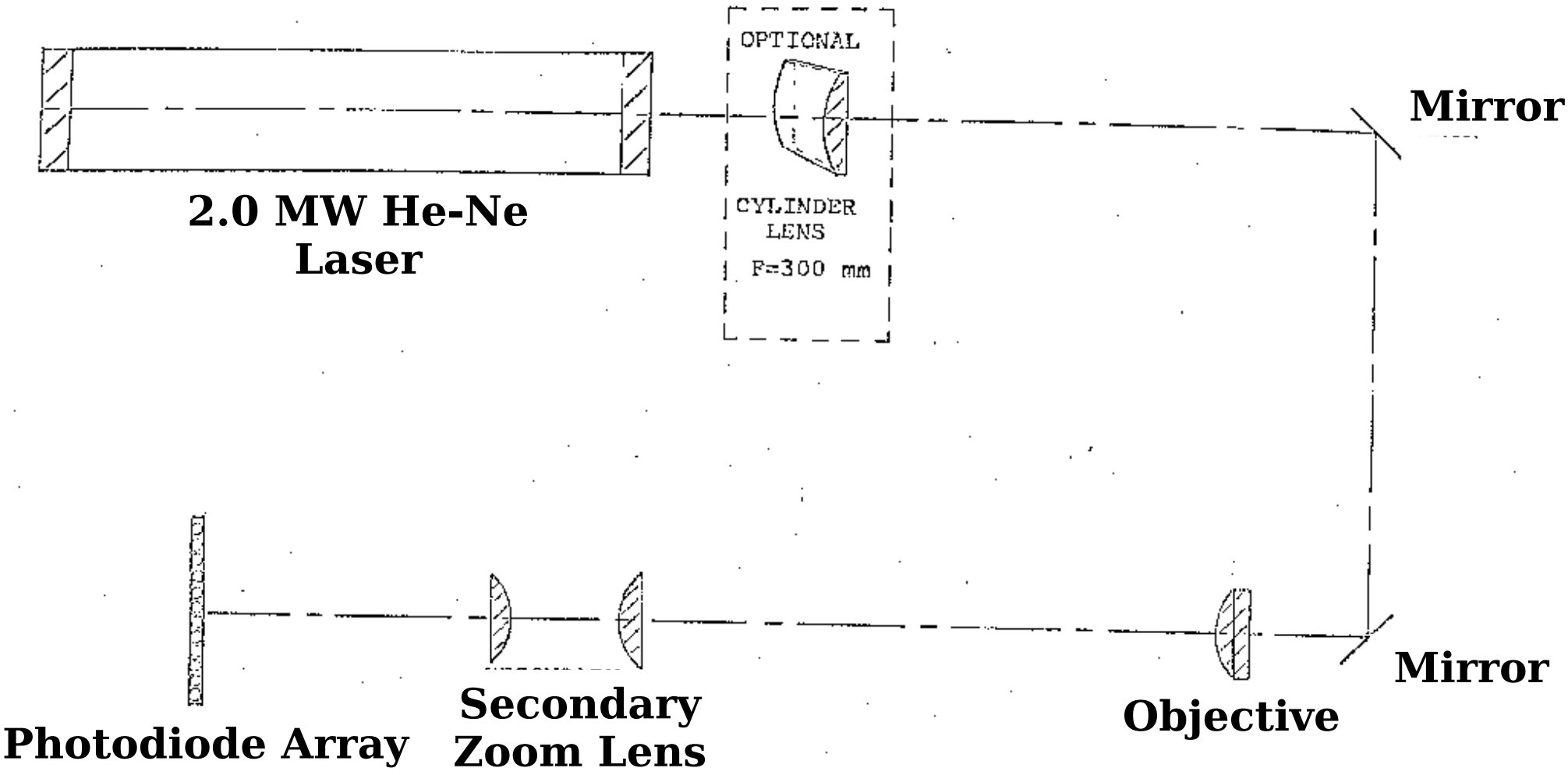
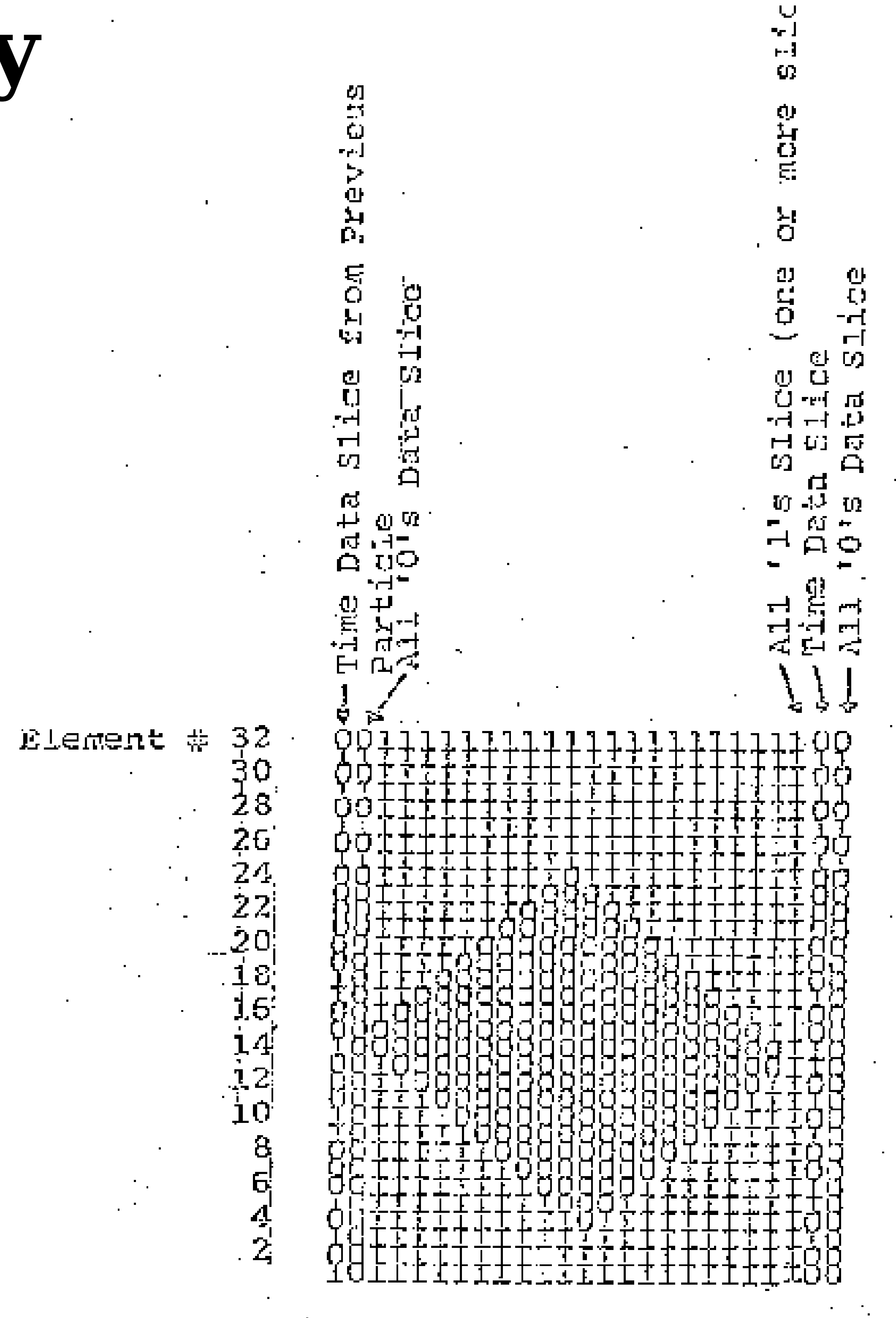


Image Array Elements



2-DC Spinning Disk

txt (0)

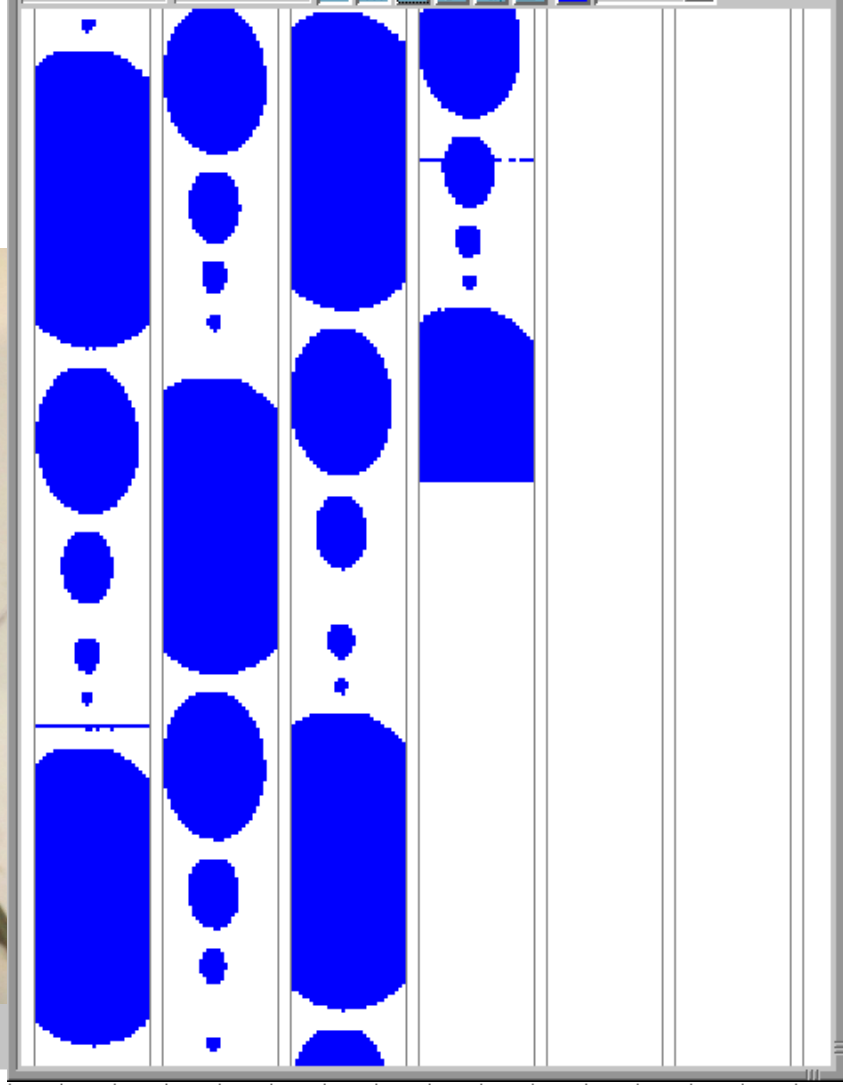
13:13:21.040 2011/12/15 x y

TAS	27	m/s
MulFac	43	
DivFac	2	
TasClk	1.075	MHz
ElapsedTime	191	0.004775 s
ElapsedTas	51	0.00474419 s
ElapsedShwOr	38	
ShwOr	7392	
House1	1426	
House2	1426	
House3	1427	
House4	1428	
House5	1425	
House6	1425	
House7	1426	
House8	1426	

0.0 -	25.0	61.5
25.0 -	50.0	0.0
50.0 -	75.0	266.5
75.0 -	100.0	881.6
100.0 -	125.0	20.5
125.0 -	150.0	61.5
150.0 -	175.0	656.1
175.0 -	200.0	451.1
200.0 -	225.0	0.0
225.0 -	250.0	0.0
250.0 -	275.0	0.0
275.0 -	300.0	20.5
300.0 -	325.0	0.0
325.0 -	350.0	574.1
350.0 -	375.0	492.1
375.0 -	400.0	20.5
400.0 -	425.0	20.5
425.0 -	450.0	0.0
450.0 -	475.0	20.5
475.0 -	500.0	0.0
500.0 -	525.0	41.0
525.0 -	550.0	0.0
550.0 -	575.0	0.0
575.0 -	600.0	0.0
600.0 -	625.0	0.0
625.0 -	650.0	20.5
650.0 -	675.0	41.0
675.0 -	700.0	307.5
700.0 -	725.0	635.6
725.0 -	750.0	20.5
750.0 -	775.0	61.5
775.0 -	800.0	1271.1

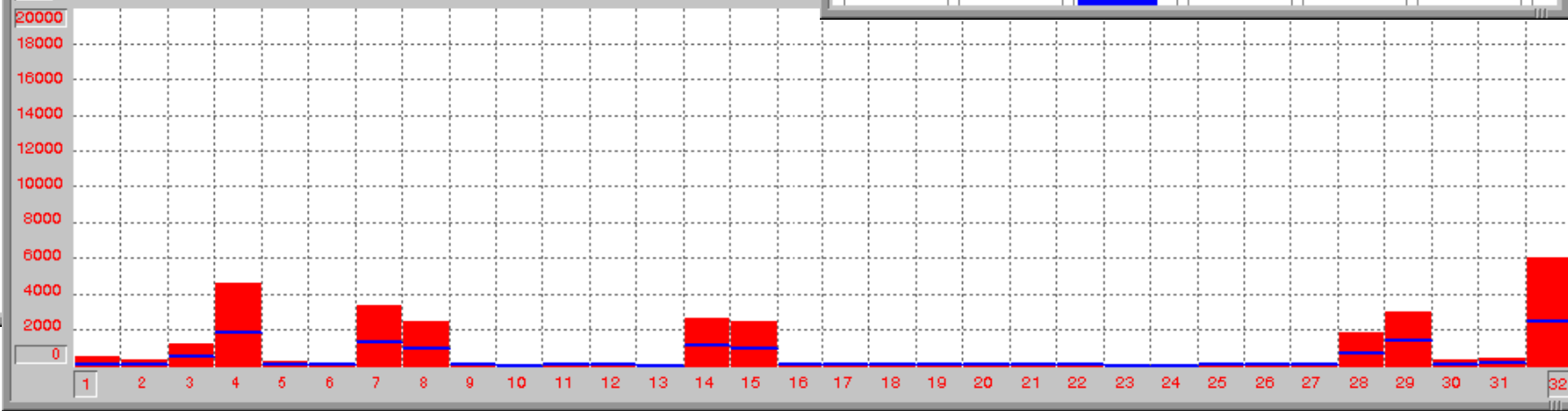
2dc (1)

13:13:18.790 2011/12/15 0x1B00 Timebars

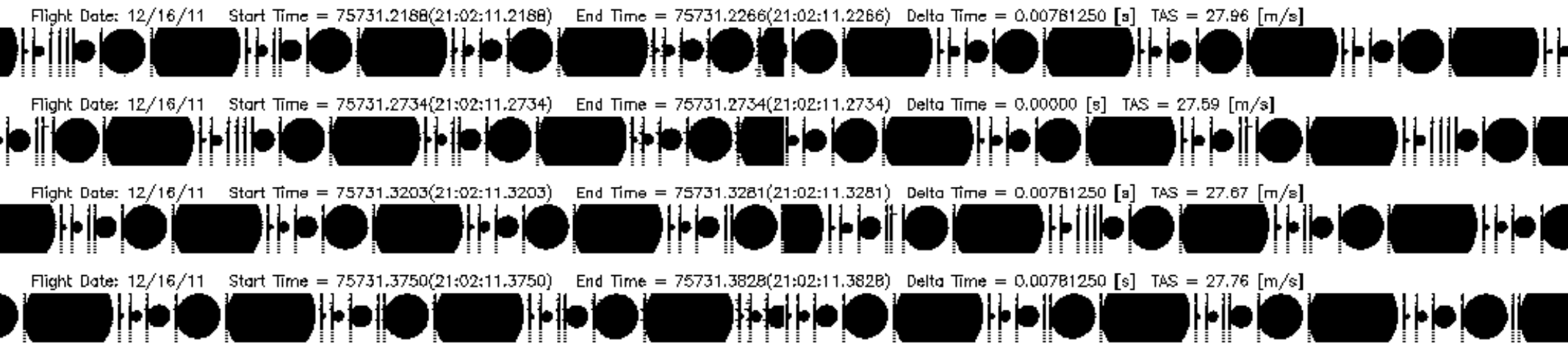


13:13:30.040 2011/12/15 Int 5 Cnt 3

2DC

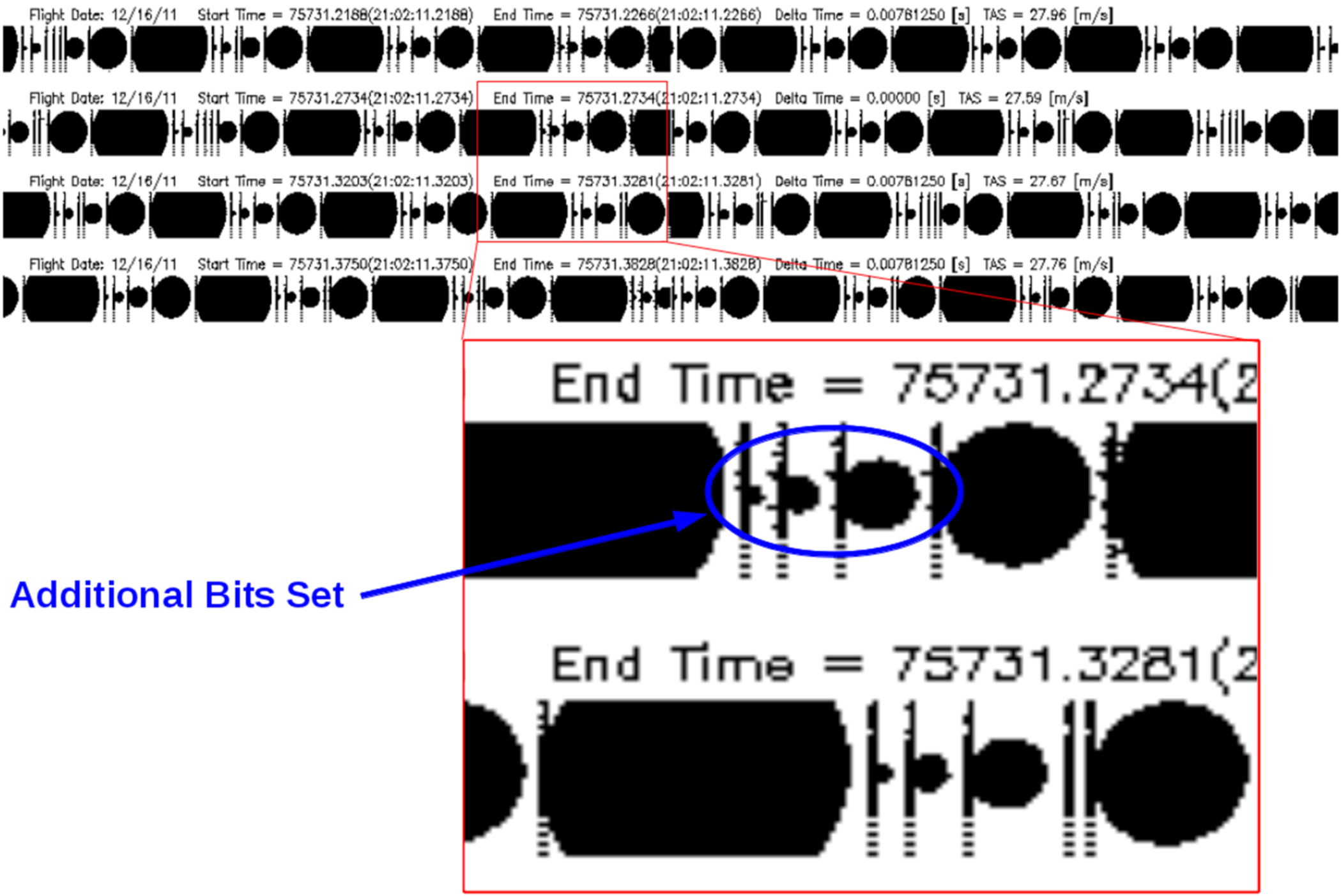


2-DC Spinning Disk

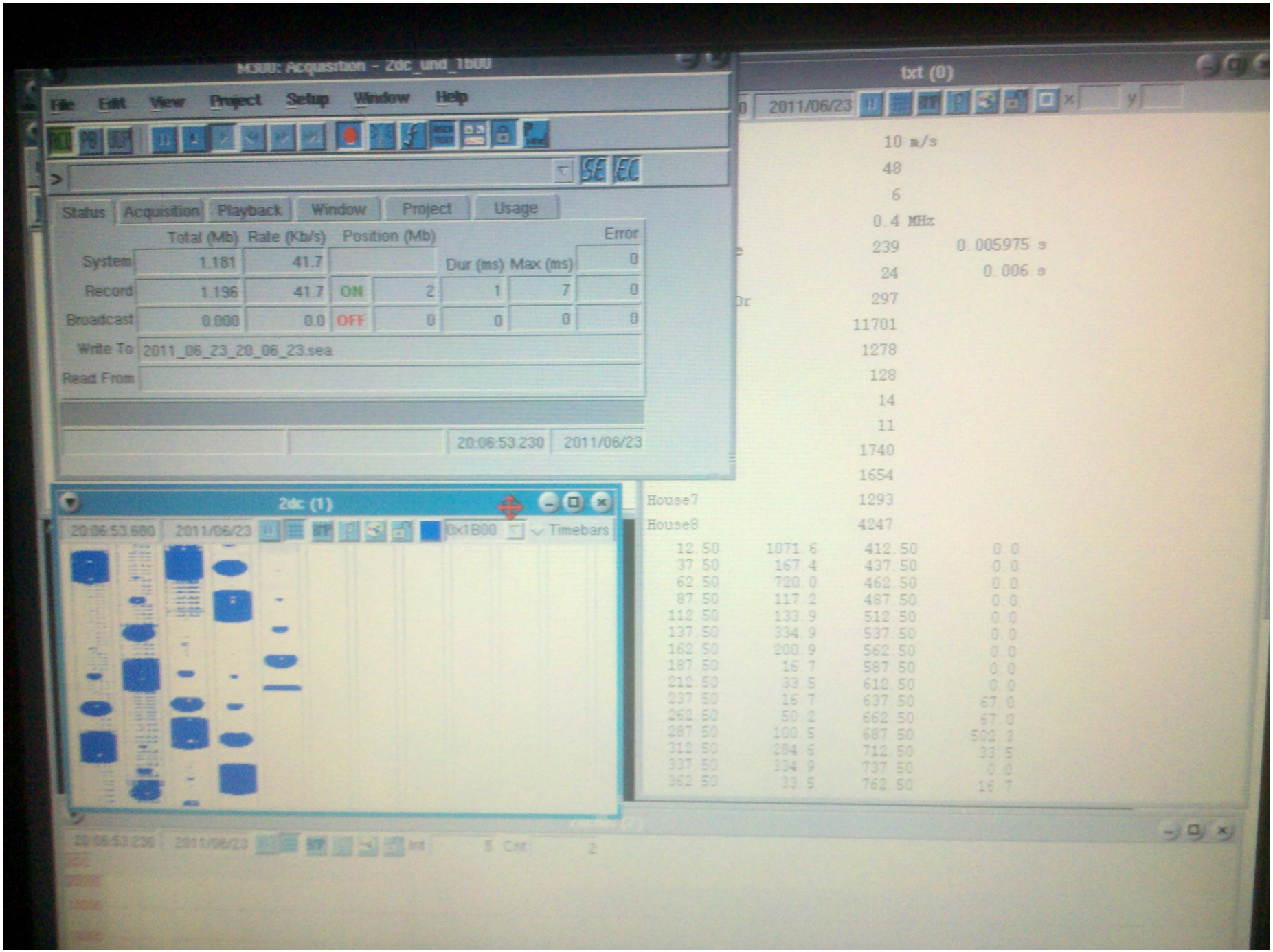


May 12, 2010 Ground Test with Spinning Disk on 2DC Probe

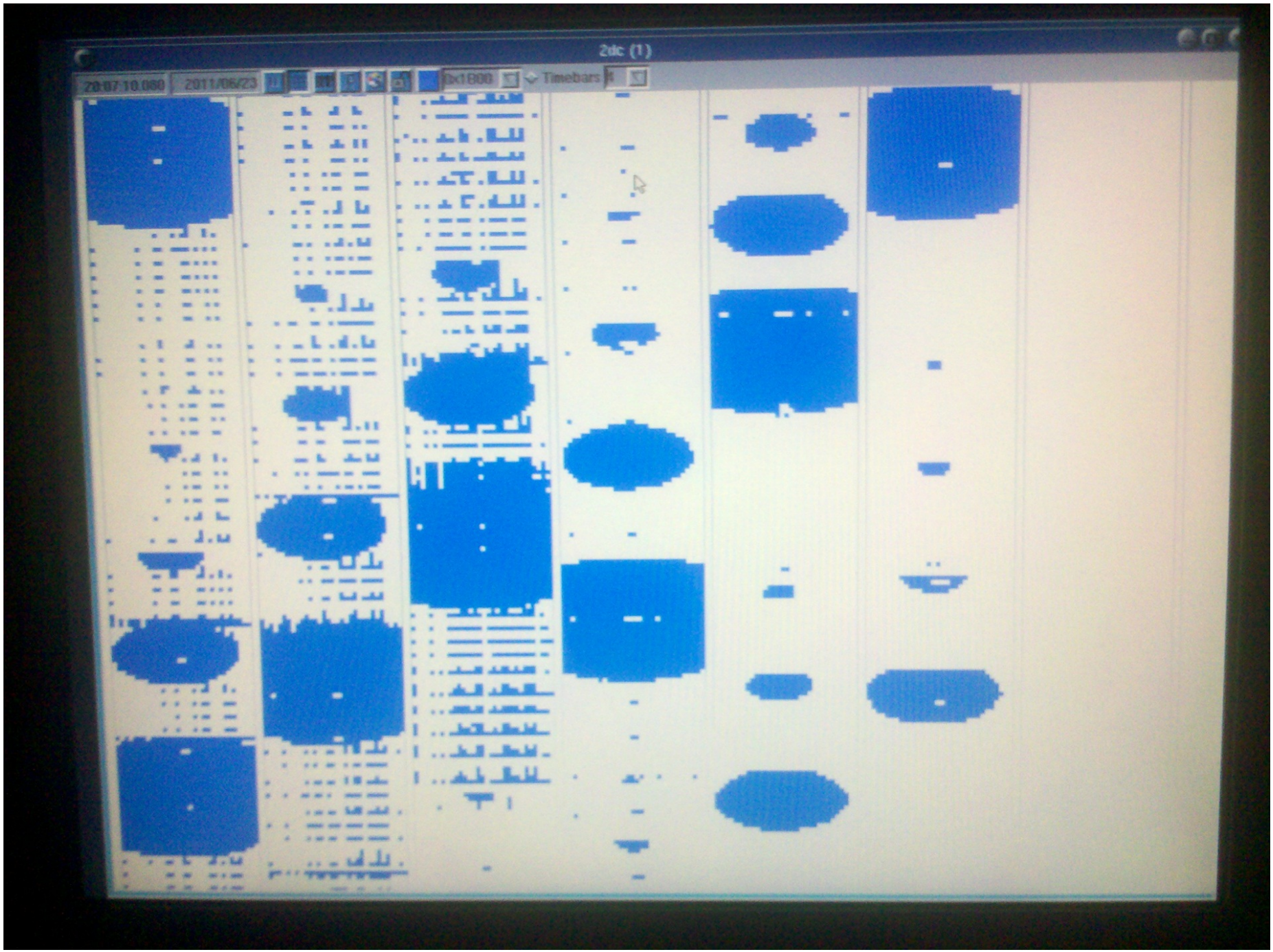
Citation Aircraft 2DC: December 16, 2011



Images from 2-DC Probe



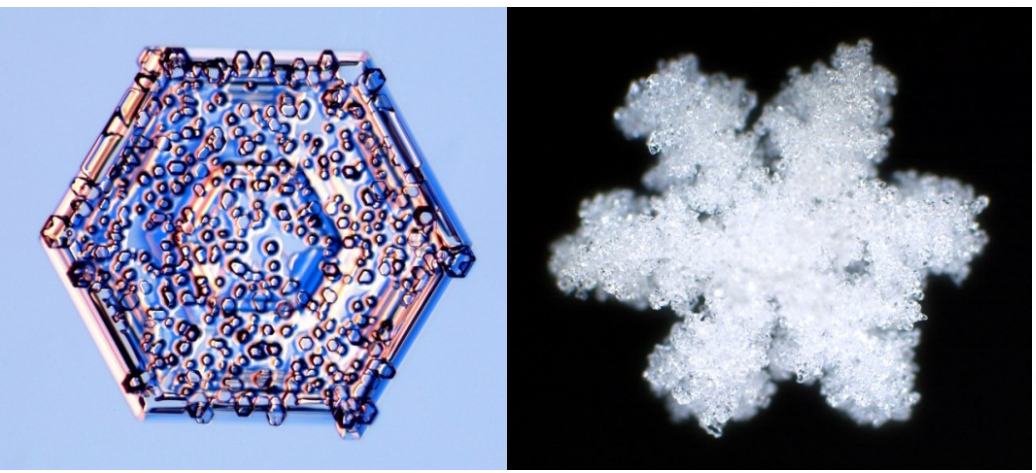
Images from 2-DC Probe



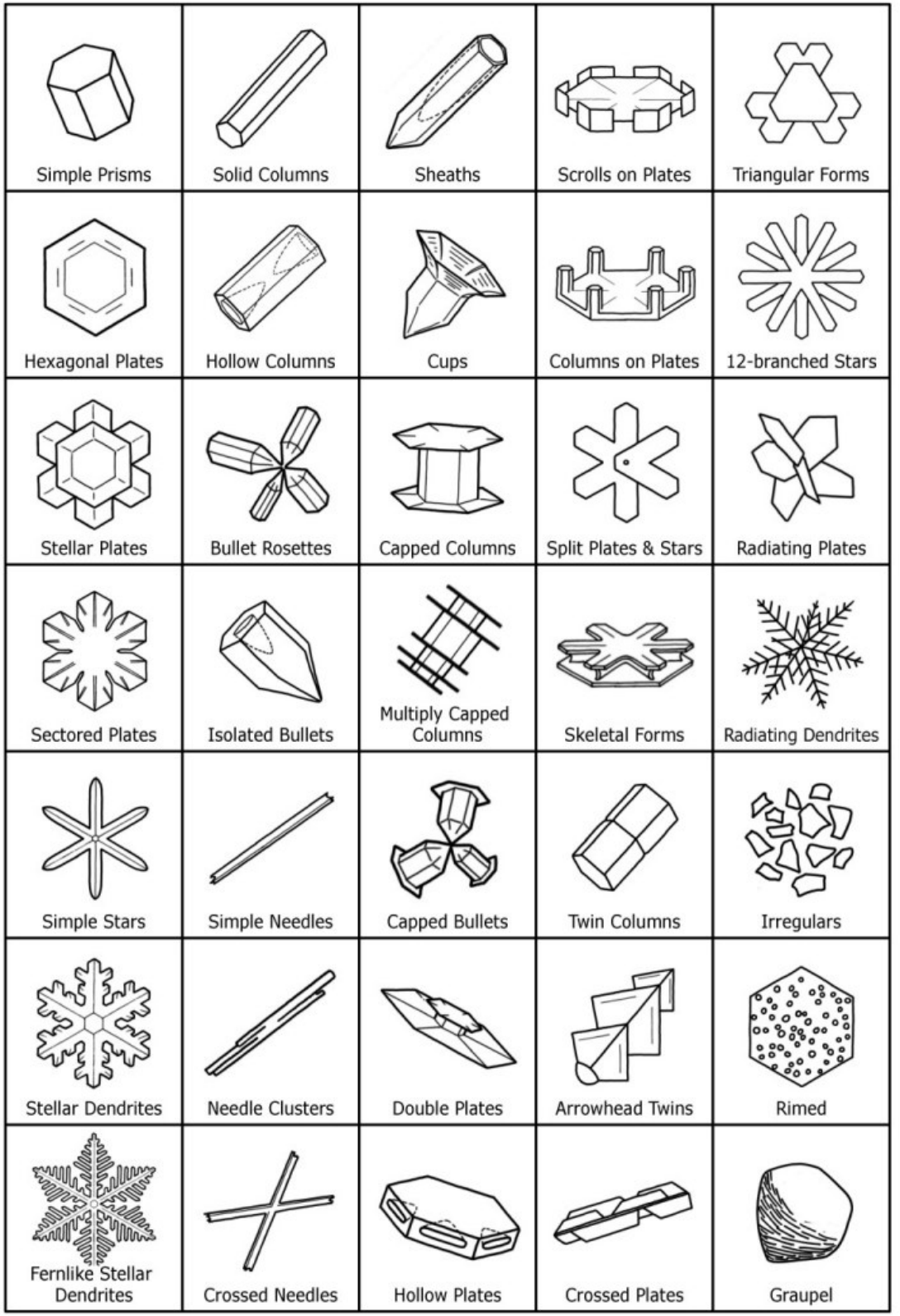
Crystal Shapes

http://www.its.caltech.edu/~atomic/snowcrystals/class/class.htm

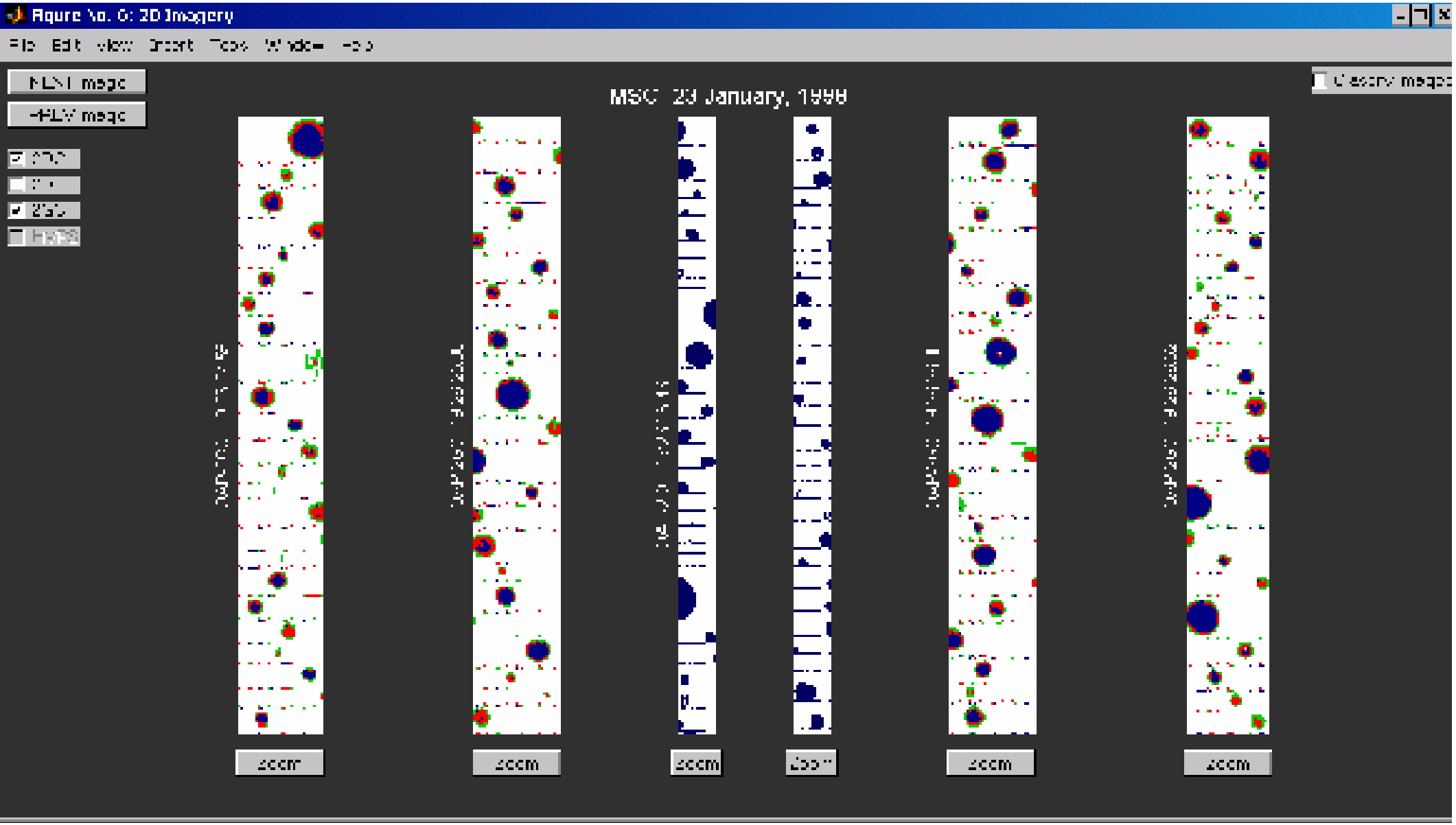
- **Spheres**
- **Needles**
- **Dendrites**
- **Irregulars**



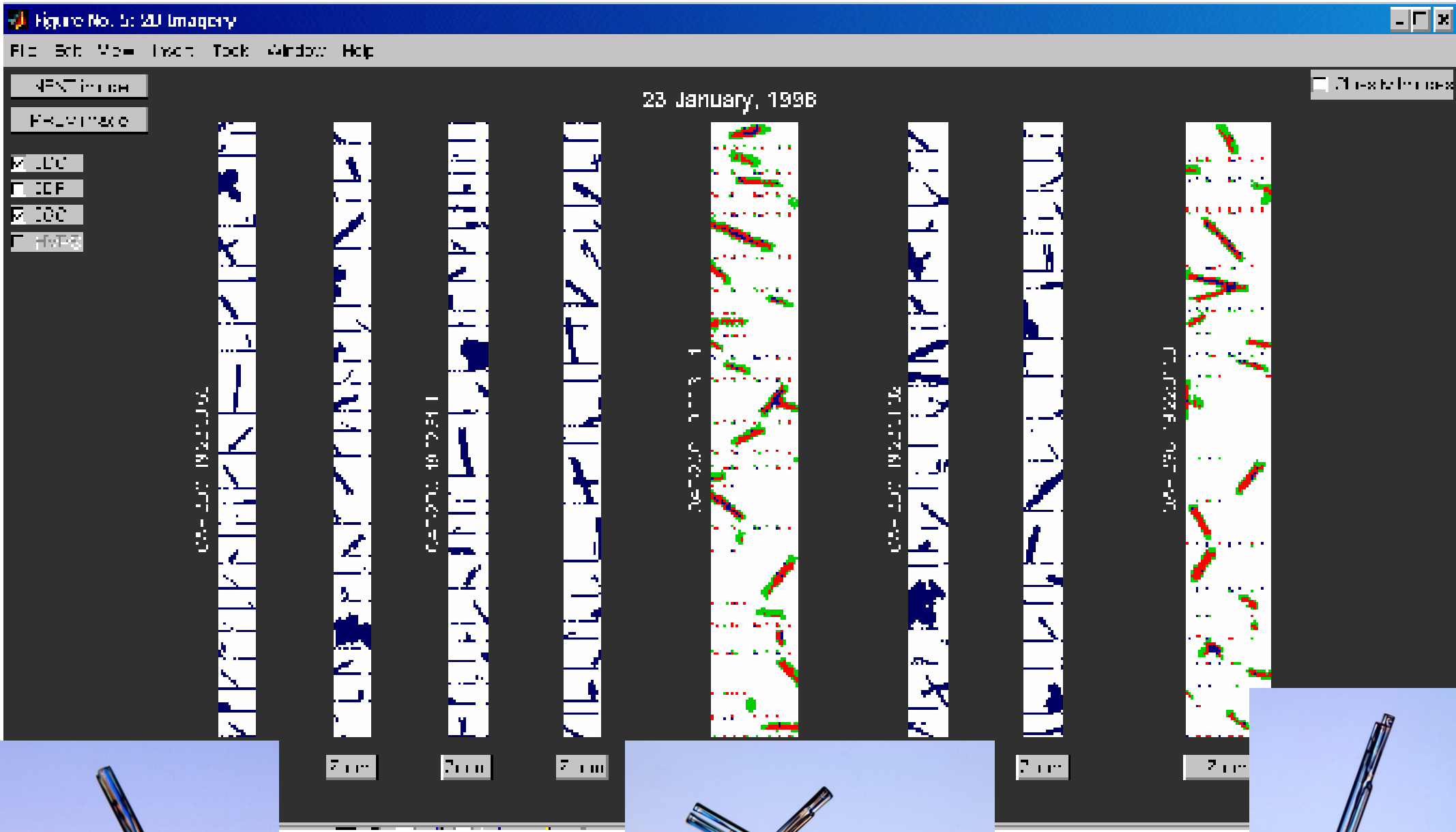
Rimed

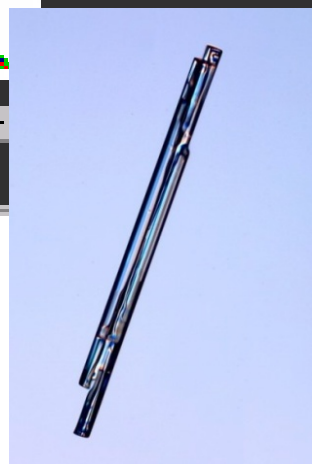


2-DC Probe: Spheres

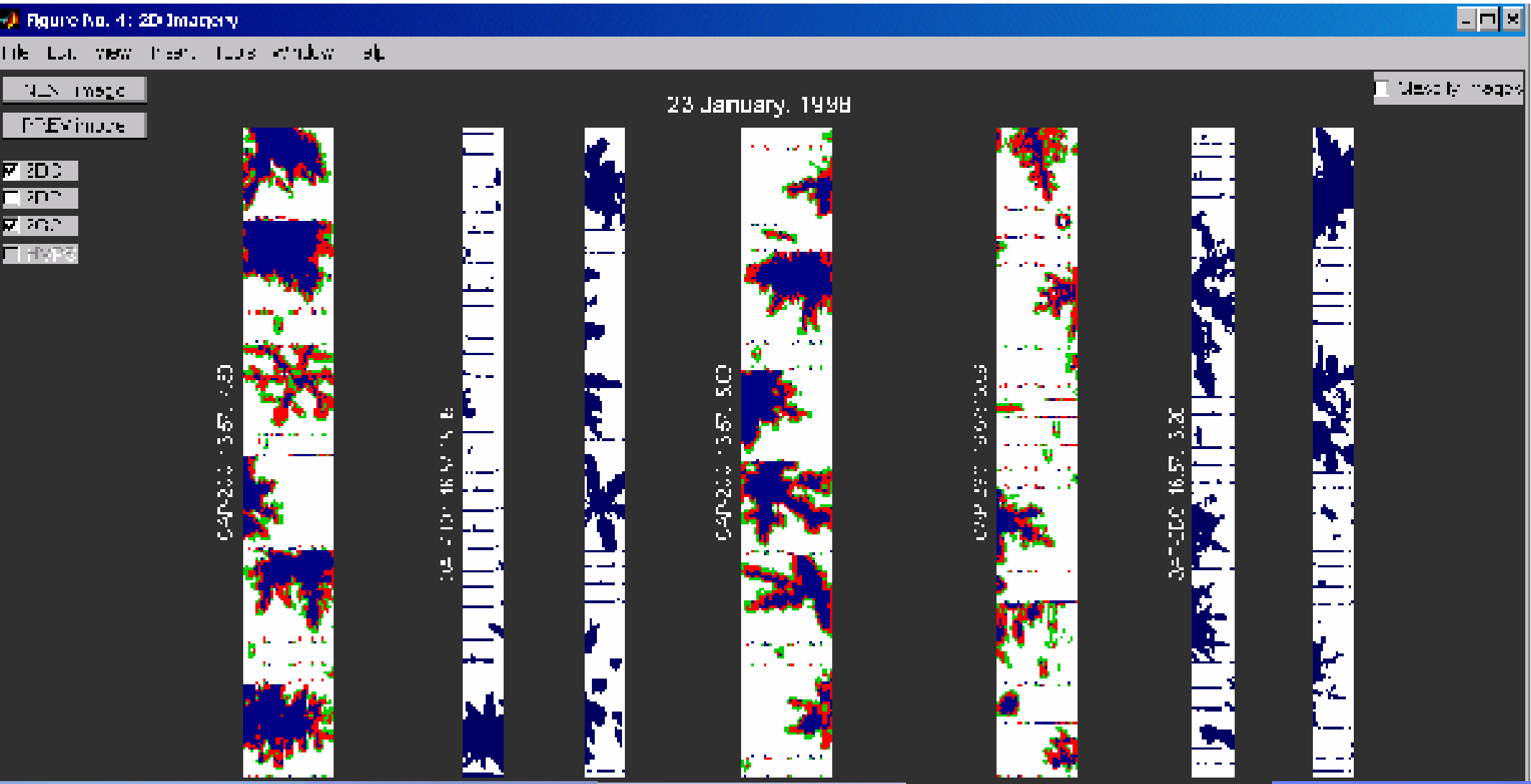


2-DC Probe: Needles

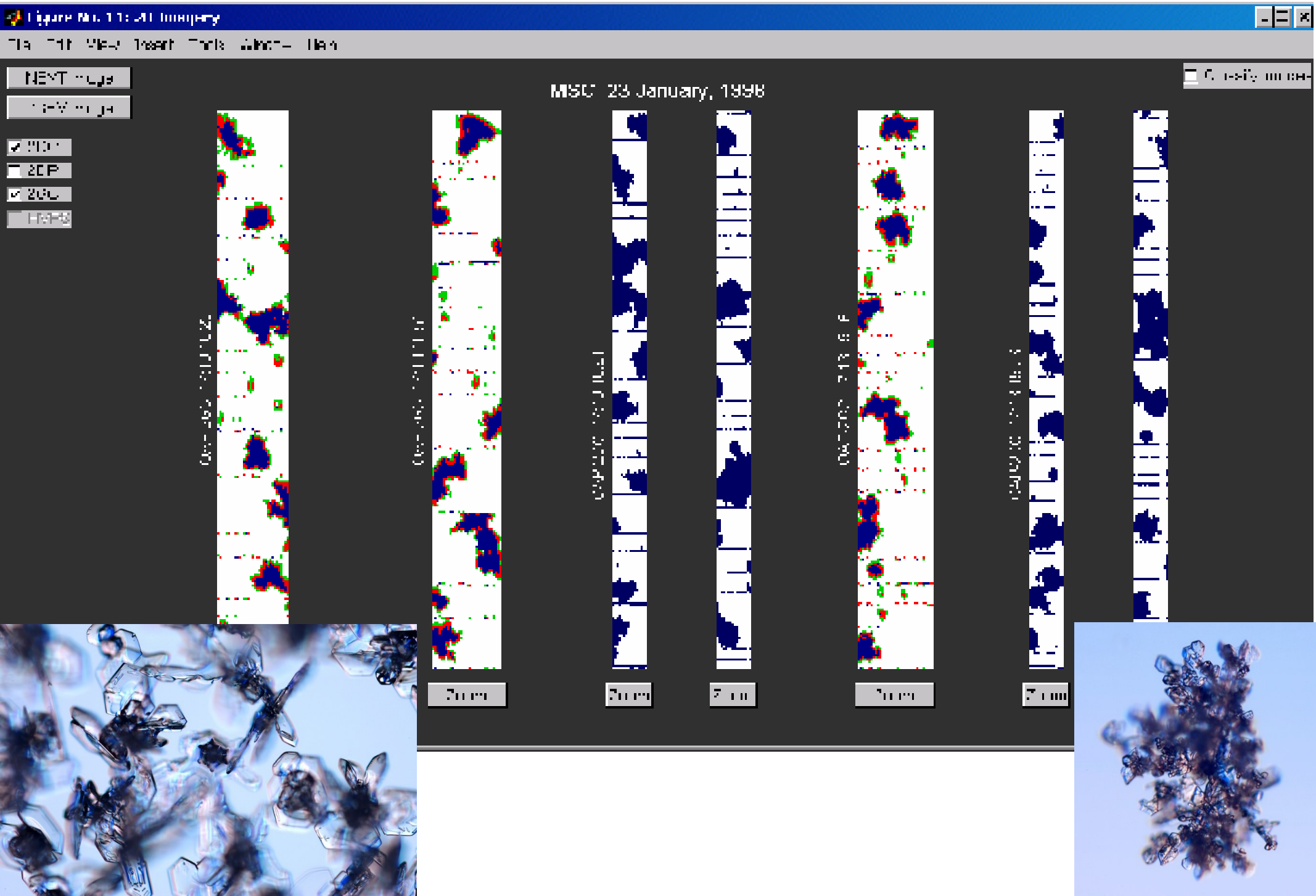




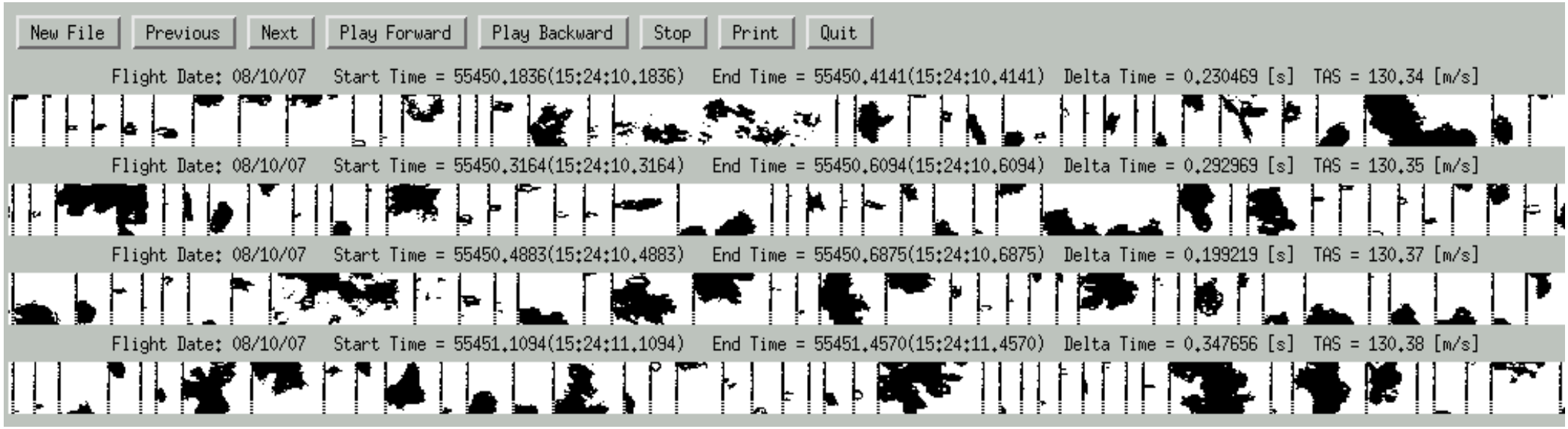
2-DC Probe: Dendrites

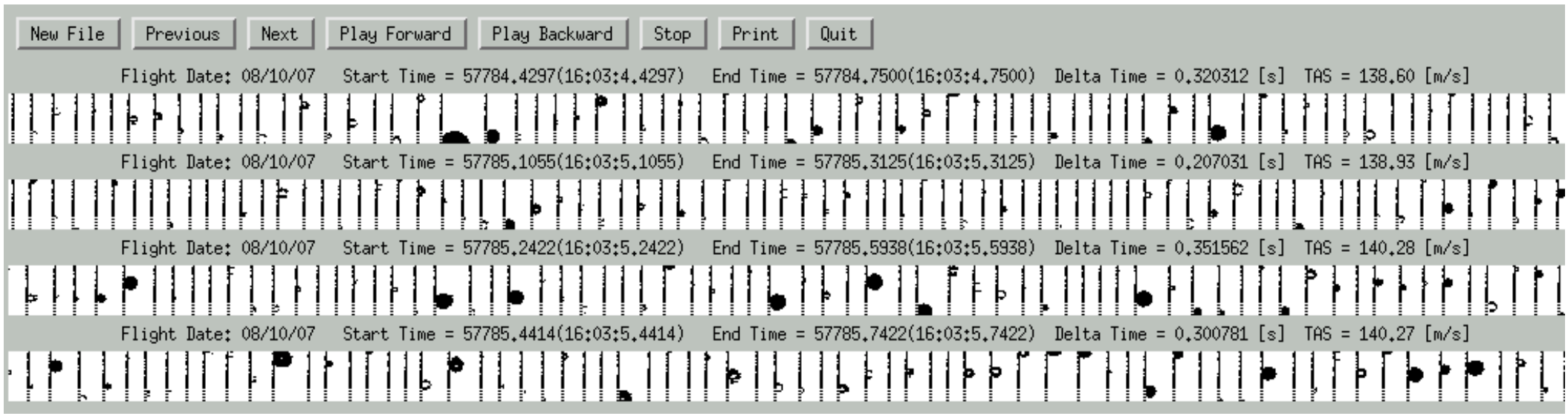


2-DC Probe: Irregulars

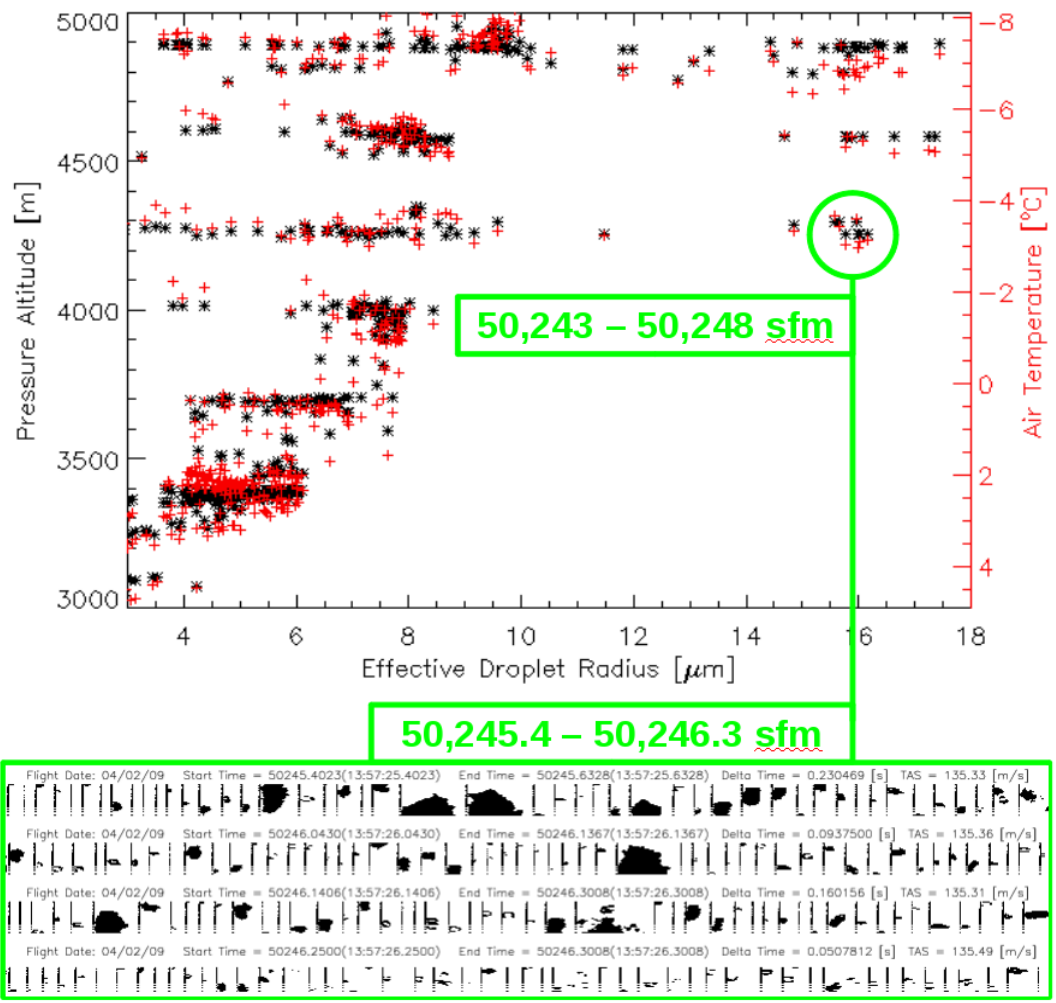


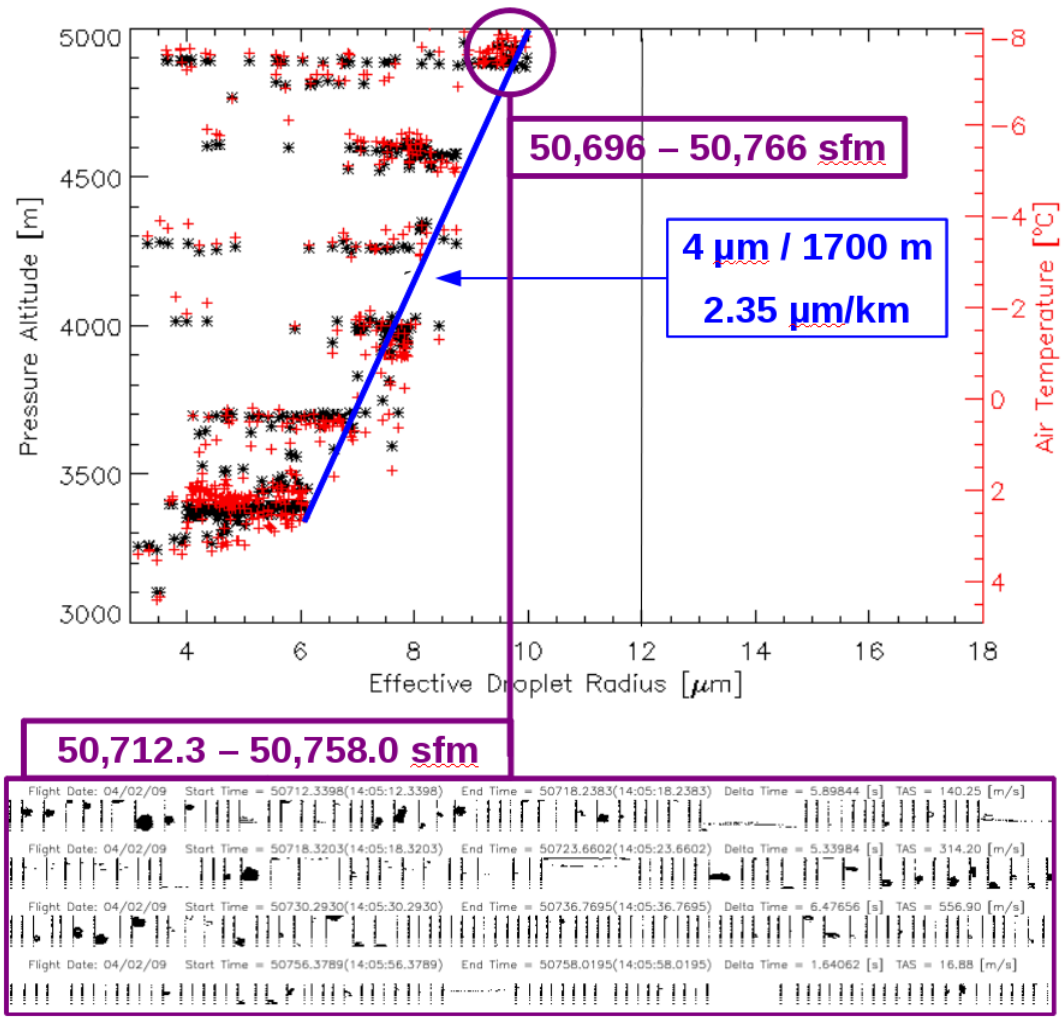
Images from 2-DC Probe





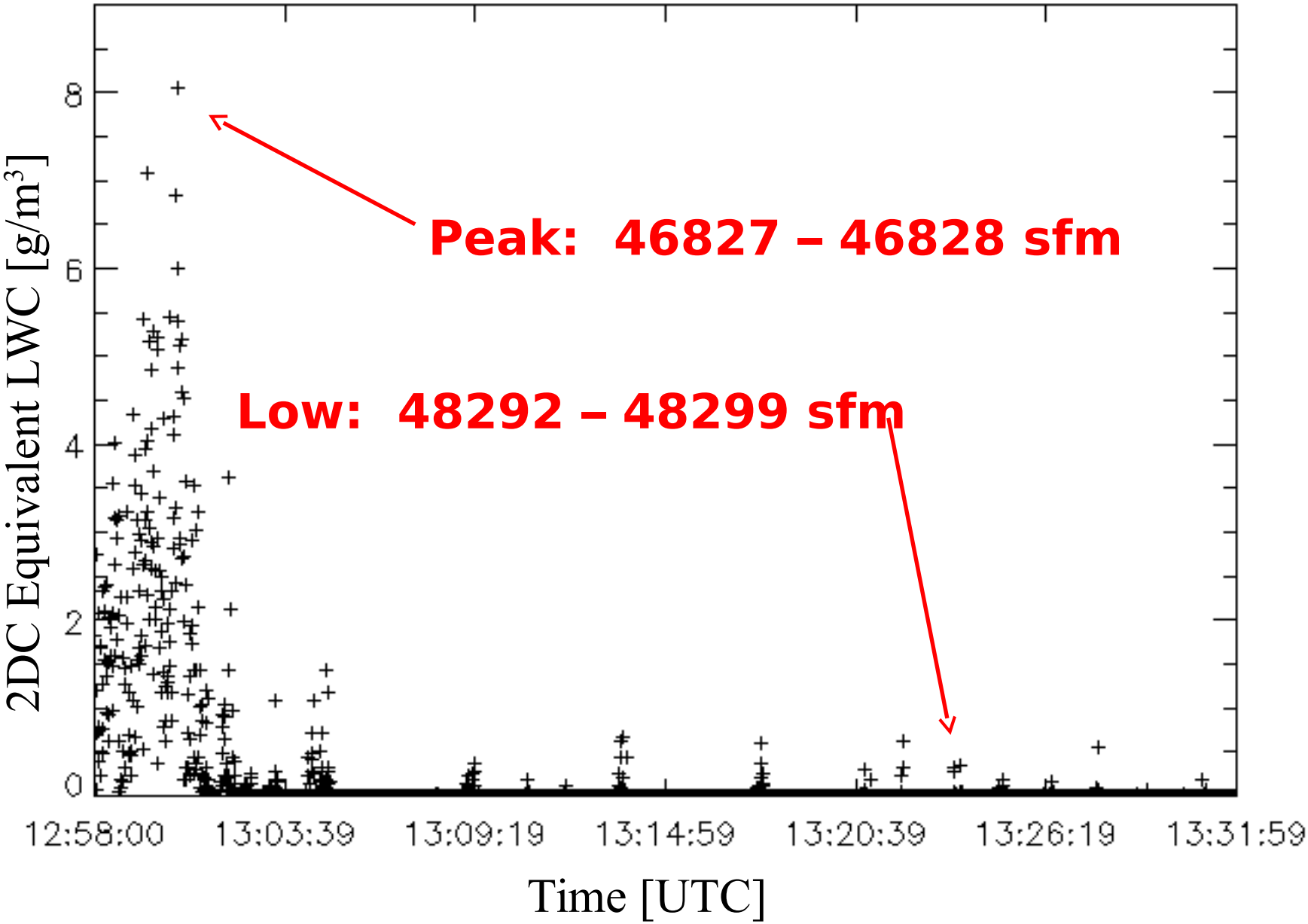
Droplet Effective Radius





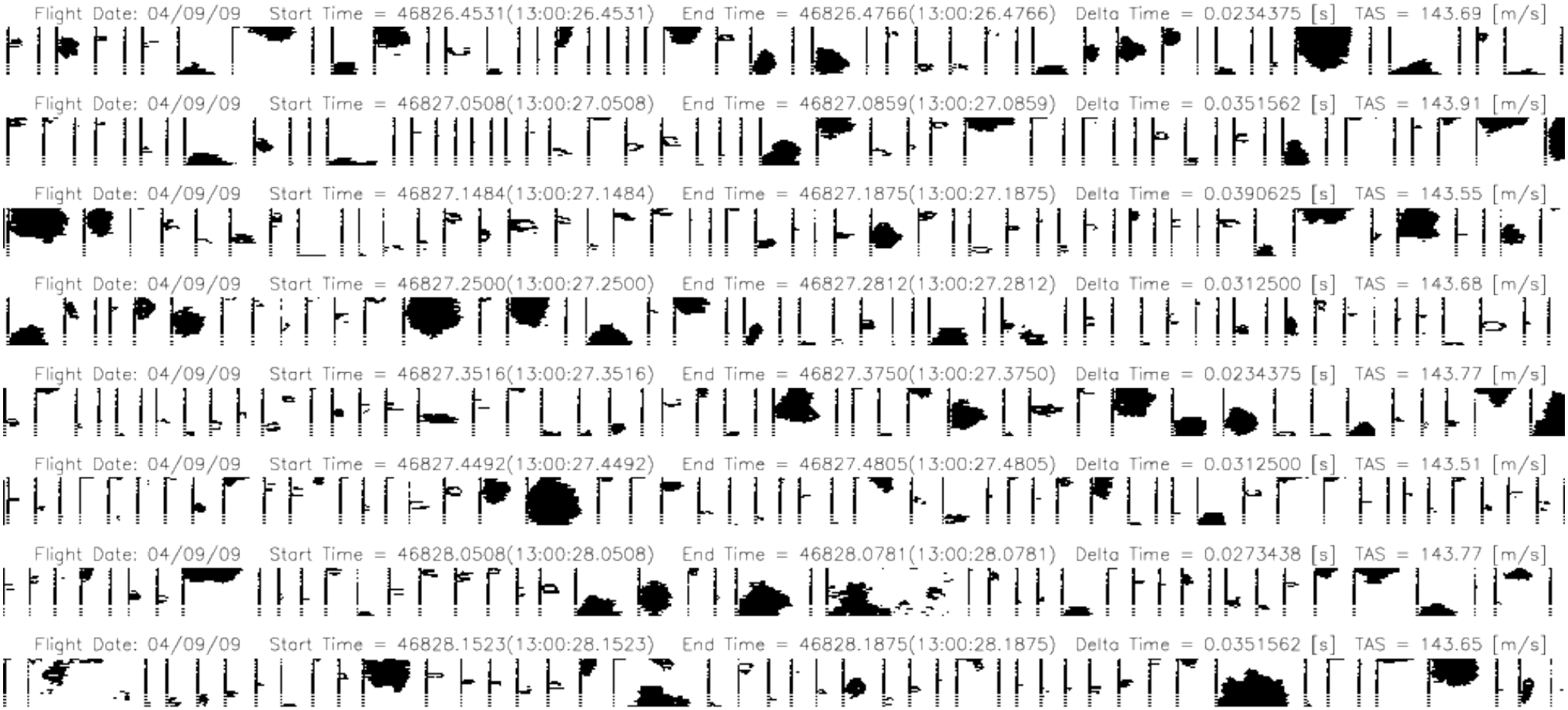
Sampling between cloud base and cloud top during time interval 49,100 to 50,800 sfm on 2 April 2008. Left panel shows all observations, while right panel only includes FSSP concentrations at STP greater than 100 #/cm^3. The blue line is the approximate rate of increase of effective droplet radius with height.

9 April 2009 Flight



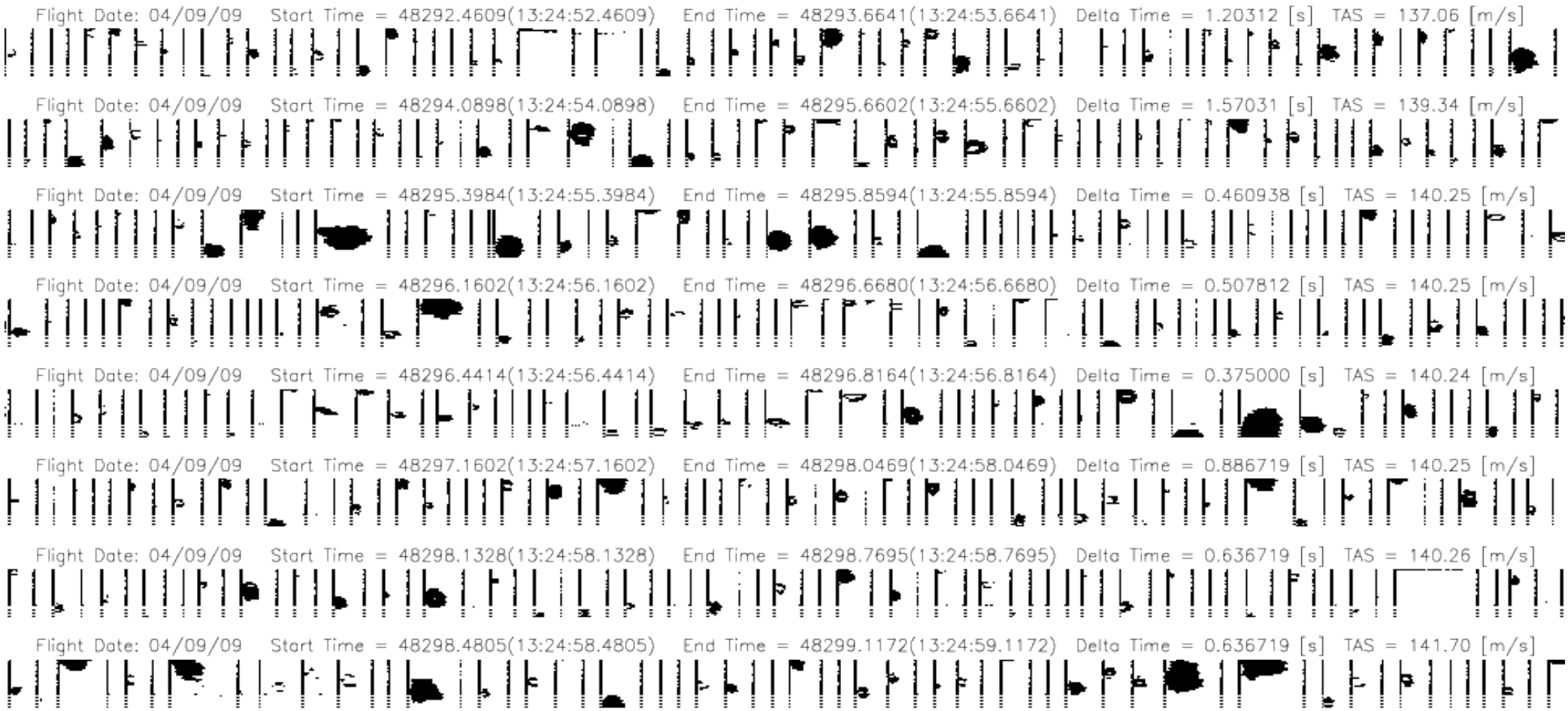
Liquid water content equivalent (1 Hz) at 18,000 ft measured by 2-DC probe on a research flight in Saudi Arabia.

9 April 2009 Flight



Images from the 2-DC between 13:00:26.45 and 13:00:28.19 (less than 2 seconds total) which correspond to the maximum liquid water content equivalent (1 Hz data) measured by 2-DC probe between on 9 April 2009 research flight in Saudi Arabia.

9 April 2009 Flight

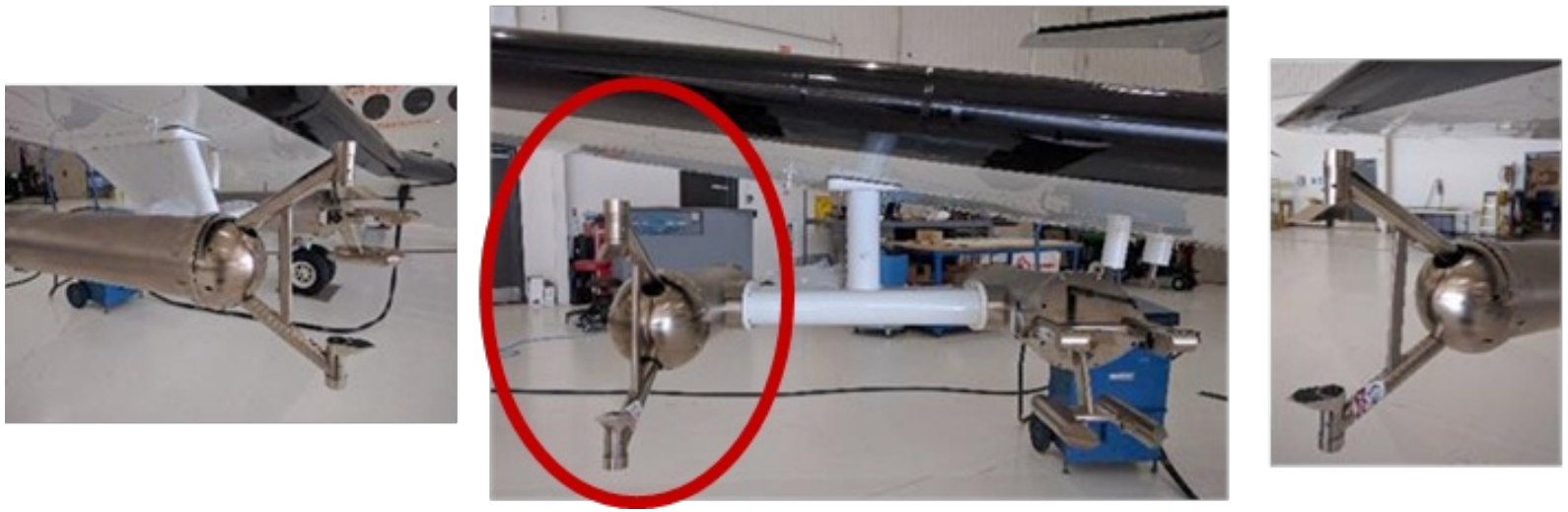


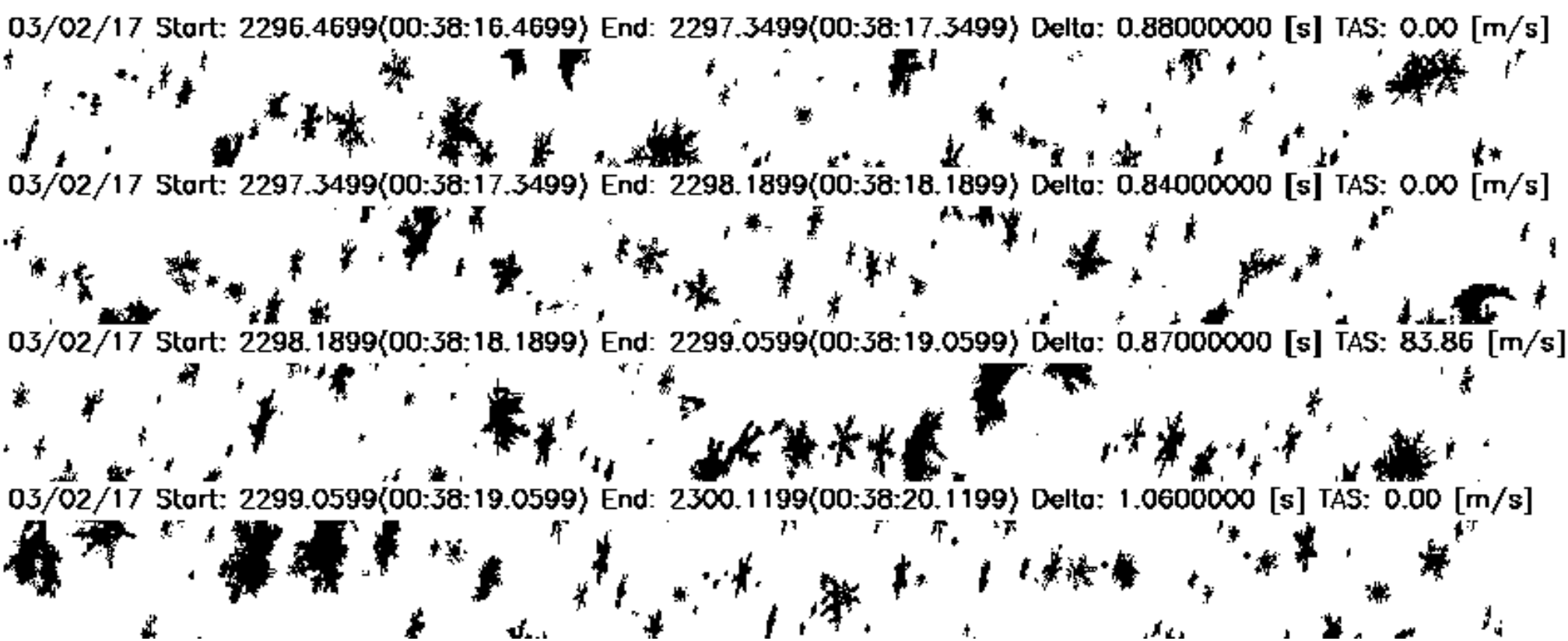
2-DC images between 13:24:52.46 and 13:24.59 (9 seconds total) which correspond to the low liquid water content equivalent (1 Hz data) measured by 2-DC probe on 9 April 2009 research flight in Saudi Arabia.

DMT Precipitation Imaging Probe (PIP)

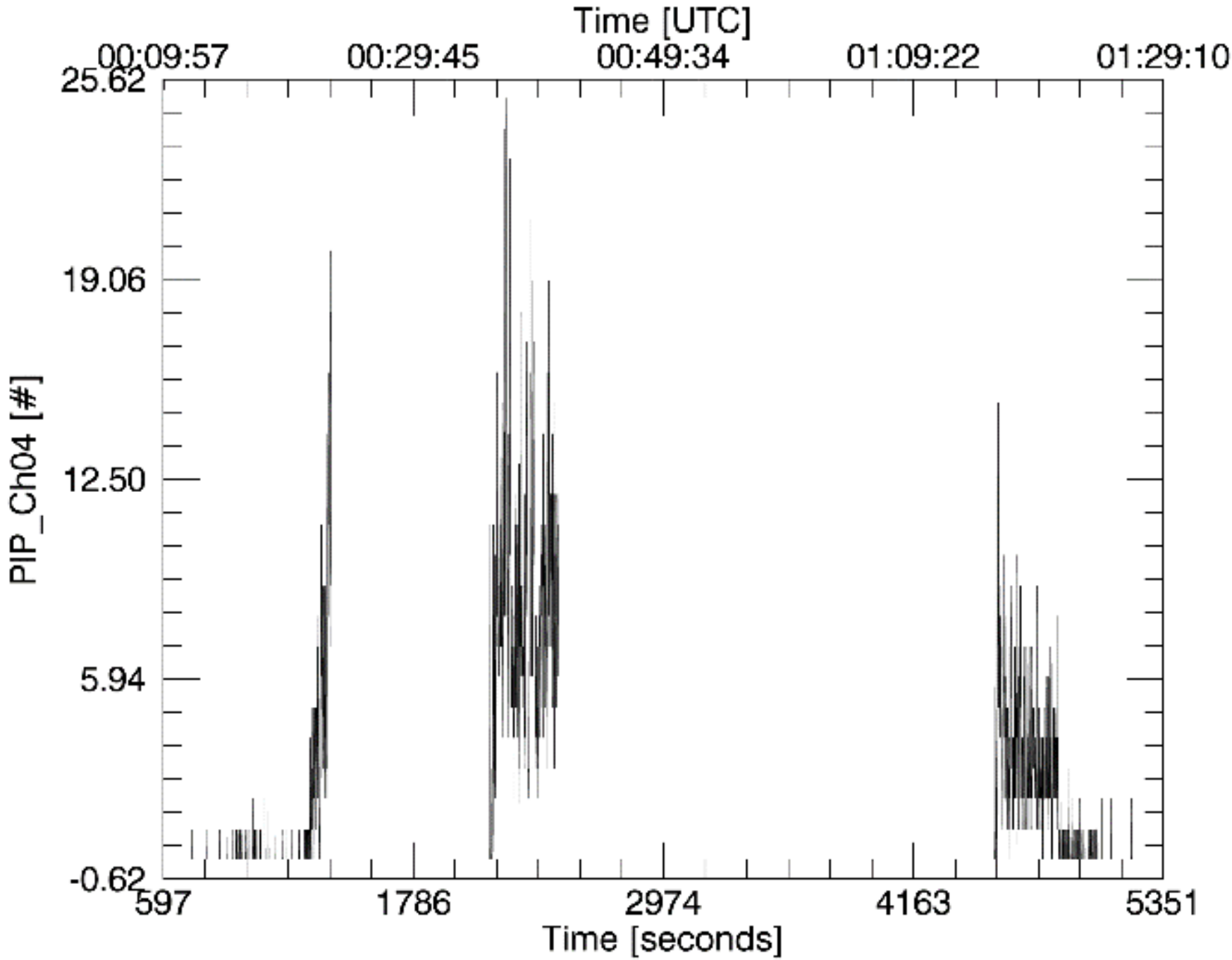
Operating Principles – Shadowing of Diodes
Primary Measurements – Cloud Droplet Concentration Spectrum (Reconstruction Gives Larger Sized Particles)
Quality Control – Size Checks with Spinning Disk (No Concentration Check Available)
Flight Profile Consideration – Icing of Probes, Requires Correct True Air Speed
Data Acquisition – Binary Image Data

Precipitation Particle Imager (PIP)



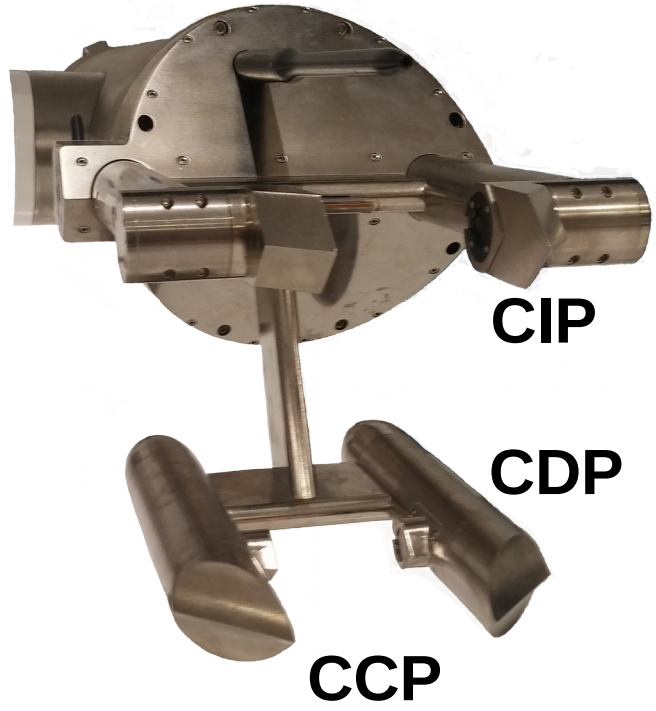


Images from the precipitation imaging probe (PIP) during 2 March 2017 flight near Fargo, North Dakota.



Time series plot of the number concentration in channel 4 of the precipitation imaging probe (PIP) during the flight on 2 March 2017 near Fargo, North Dakota.

Cloud Imaing Probe (CIP)



Operating Principles – Shadowing of Diodes

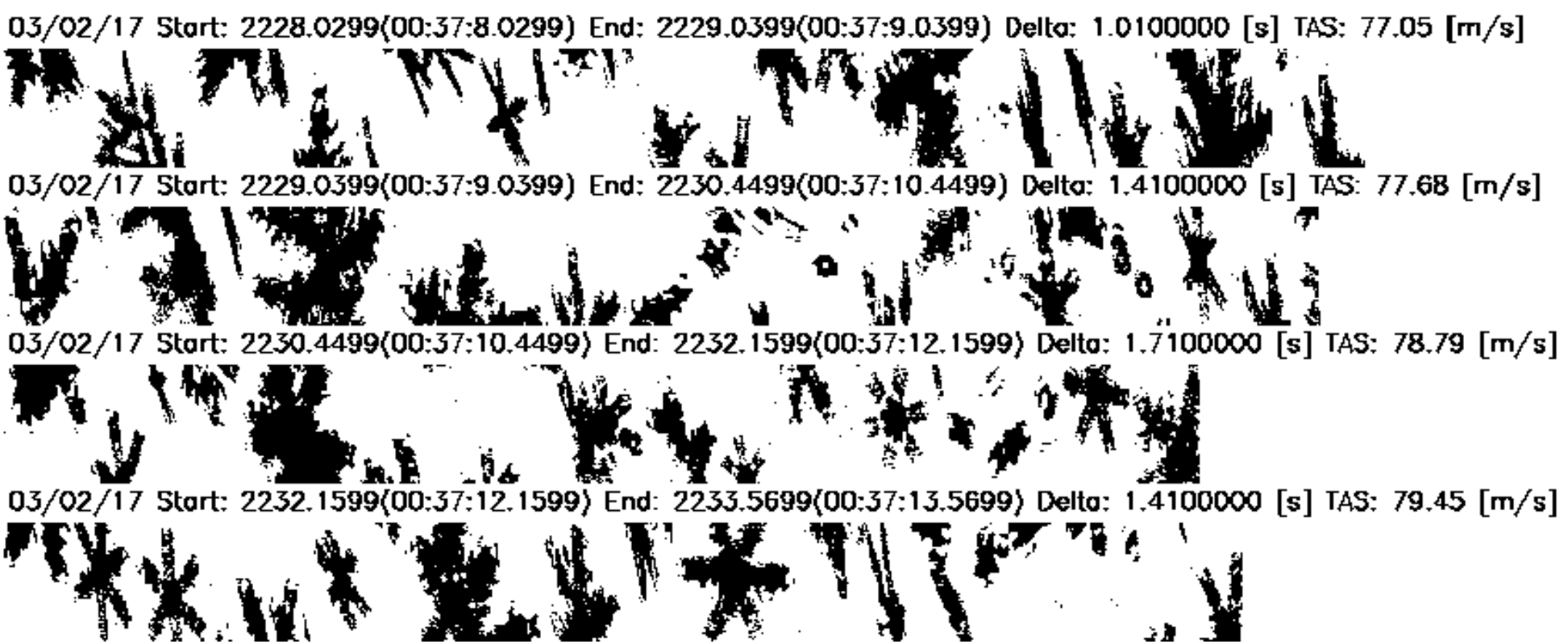
Primary Measurements – Cloud Droplet Concentration Spectrum (Reconstruction Gives Larger Sized Particles)

Quality Control – Size Checks with Spinning Disk (No Concentration Check Available)

Flight Profile Consideration – Icing of Probes, Requires Correct True Air Speed

Data Acquisition – Binary Image Data

Cloud Particle Imager (CIP)



Images from the cloud imaging probe (CIP) during the 2 March 2017 flight near Fargo, North Dakota.

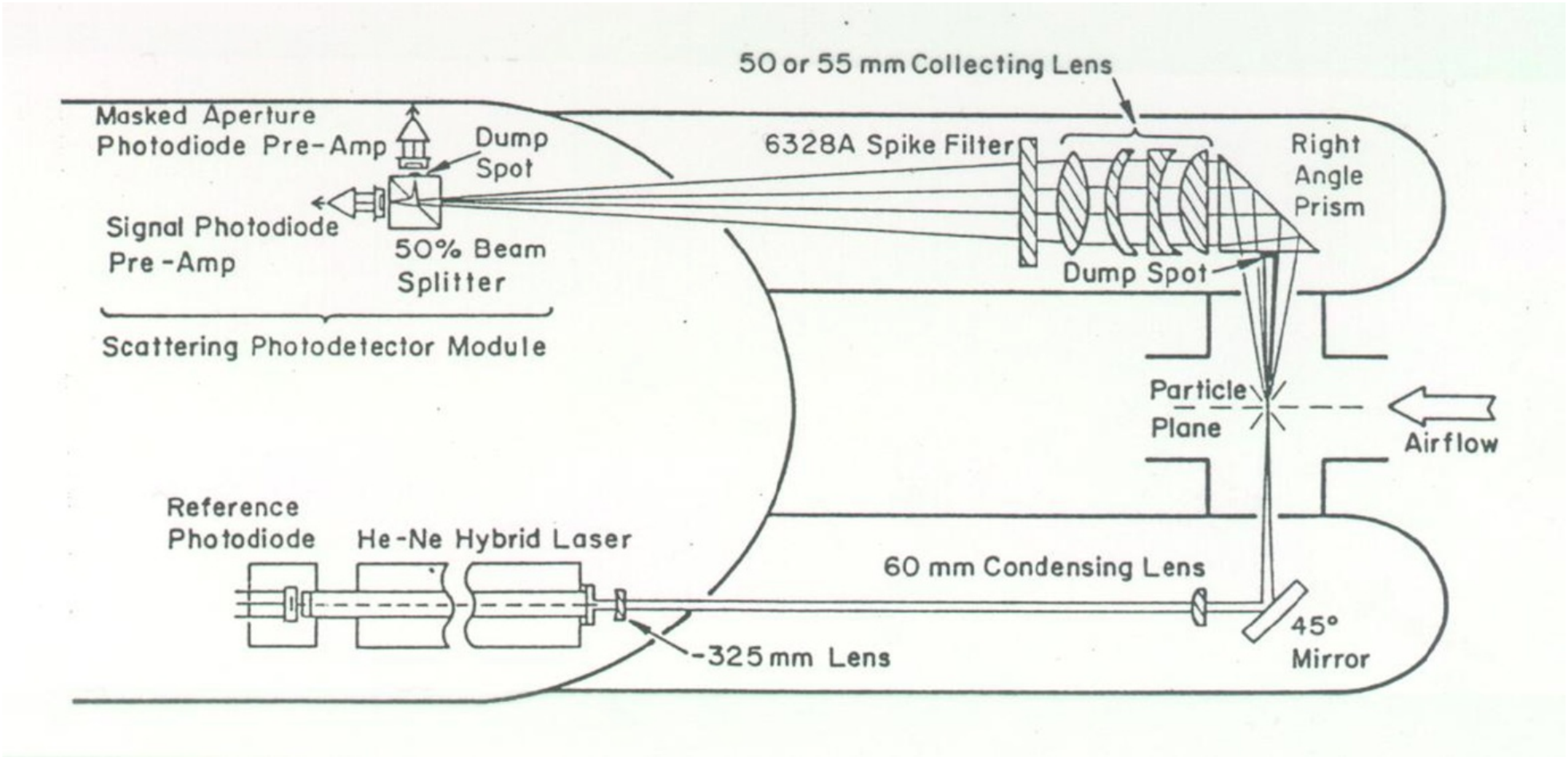
PIP/CIP Quality Control

- It is important to conduct performance test on the CIP using a spinning disk.
- It is important to clean the on cloud physics probes optics.

DMT Cloud Droplet Probe (CDP)

Operating Principles – Forward Light Scattering
Primary Measurements – Cloud Droplet Concentration Spectrum from 3 – 50 µm, 30 Channels (Liquid Water Content Derived)
Quality Control – Size Checks with Particles of Known Size (No Concentration Check Available)
Flight Profile Consideration – Icing of Probes, Requires Correct True Air Speed
Data Acquisition – Serial Data (230,400 bps) with Particle-by-particle (pbp) Data

Optical Path of the FSSP



- The beam splitter divides the scattered light onto two photodetectors.
- One photodector is optically masked to not receive scattered light from near the laser beam's center of focus.
- Droplets are rejected as being out of the depth of field when the signal from the masked detector exceeds that from the unmasked detector.

FSSP schematic is taken from Dye and Baumgarnder, [1984]

FSSP Effective Sample Volume

Sample Volume = TAS*DOF*BD*(Tc/Ts)

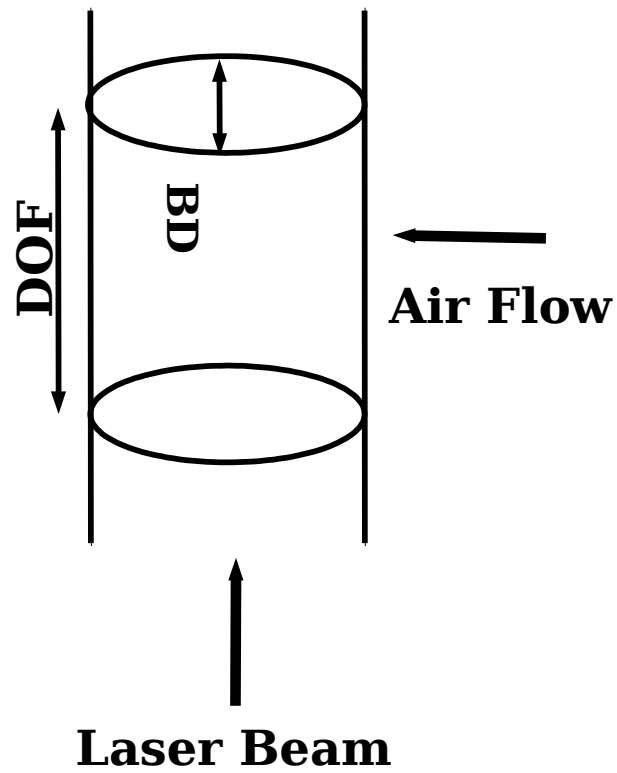
TAS – Aircraft True Air Speed (~100 m/s)

DOF – FSSP Depth of Field (~2.9 mm)

BD – Laser Beam Diameter (~0.2 mm)

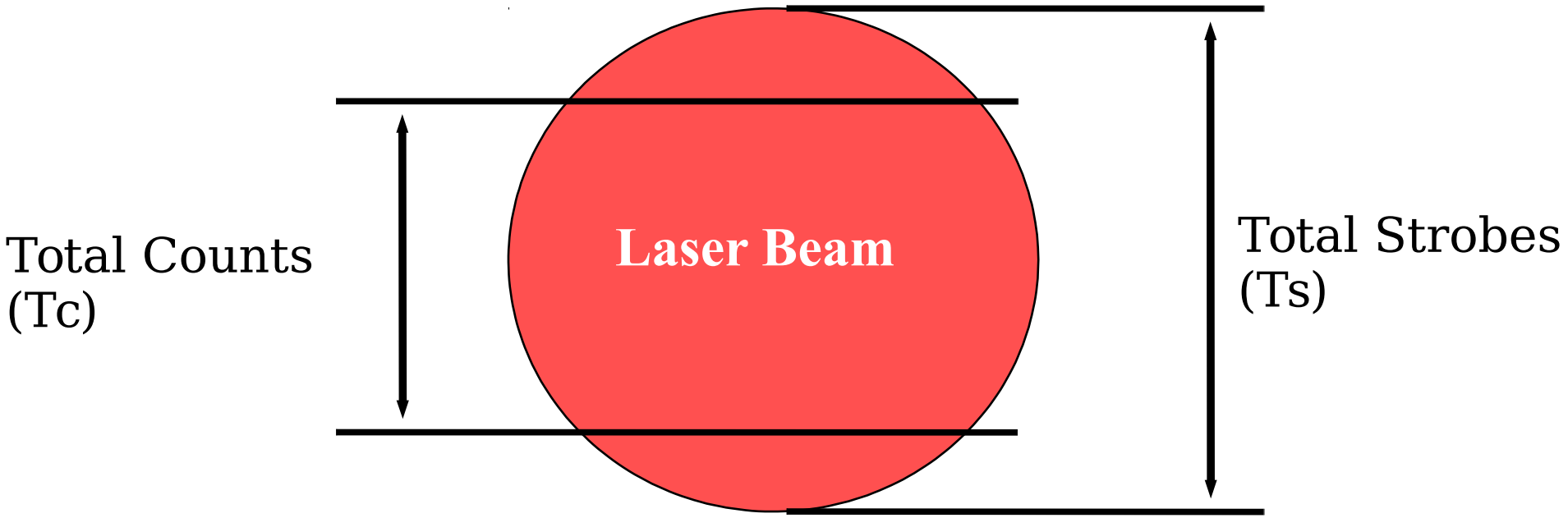
Tc – Number of Droplets Sized (Total Counts)

Ts – Number of Droplets within the DOF (Total Strobes)



Laser Beam Fraction Correction

Effective Laser Beam Diameter (Tc/Ts)



- The effective laser beam diameter is the fraction of the total diameter where droplets are within the laser beam long enough so they can be sized.
- A running average of droplet transit time through the beam is maintained. If the droplet time within the laser beam is less than the average, it is rejected from sizing but included in the running average.

Sizing Calibration: Pulse Amplitude

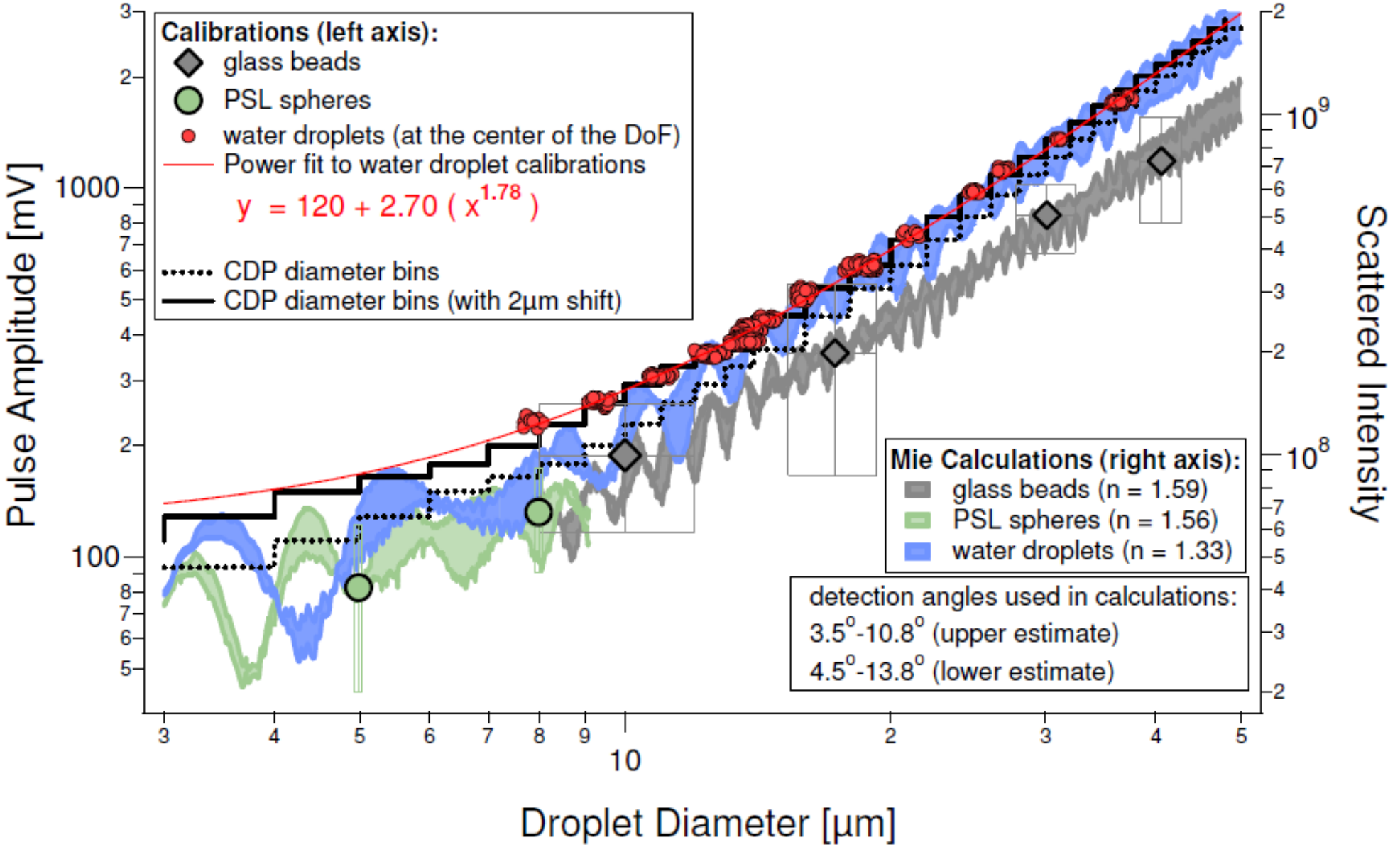
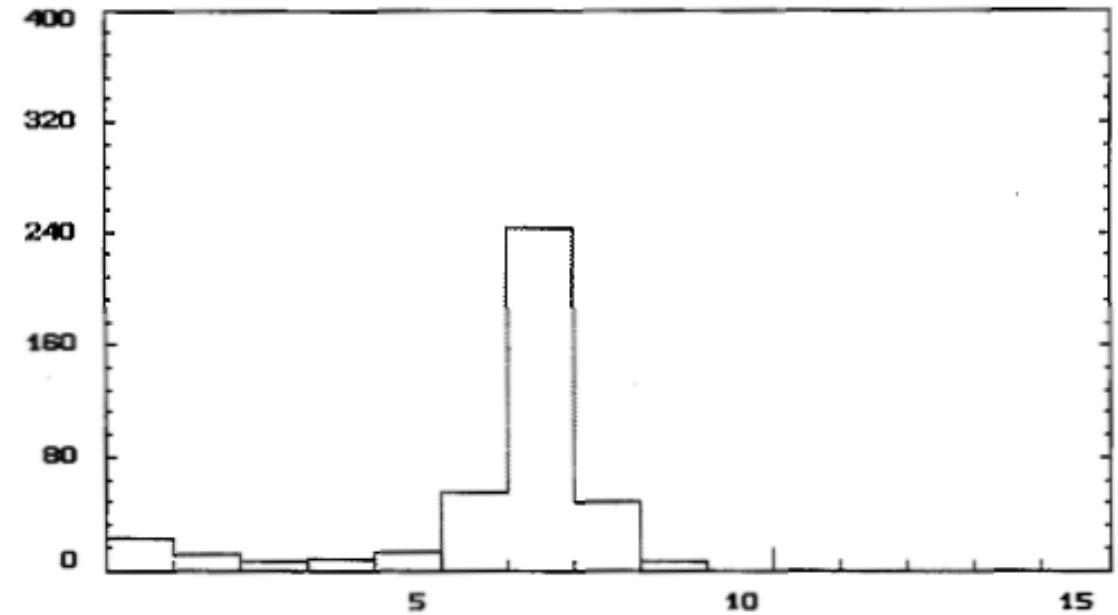


Figure is from Lance et al. [2010]: Atmos. Meas. Tech. Discuss., 3, 3133–3177, 2010, www.atmos-meas-tech-discuss.net/3/3133/2010/ doi:10.5194/amtd-3-3133-2010

Size Calibration Procedure



Chnl	Cts	Size
1	22	2.60
2	11	7.30
3	5	11.20
4	8	14.40
5	12	17.60
6	55	21.00
7	243	24.50
8	49	28.60
9	6	32.80
10	0	38.10
11	0	43.30
12	0	49.10
13	0	53.70
14	0	59.90
15	0	65.20
16		70.70

Range: 0 BeadSize: 30.200 WtrEquiv: 24.600 AvgChnl: 6.98

Probe Type: fssp

Probe S/N:
2091-0581-63
Probe Owner:
UND

Data Taken:
11:13:12.00 to
11:13:33.00
10/23/03

Processed:
10/23/03 11:13:43
Data File:
r0-30pre.cal

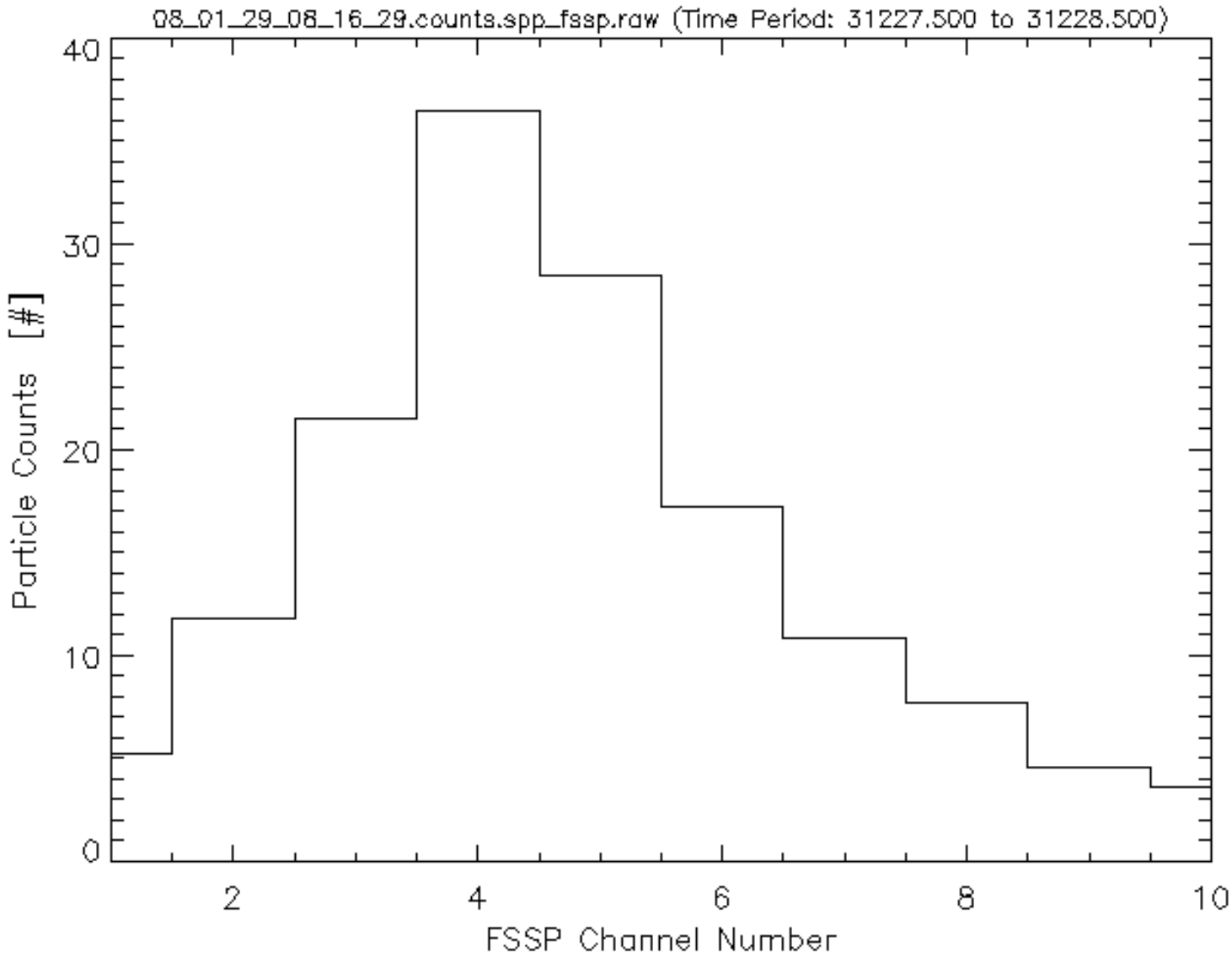
MIE Data - File,S/N,Info:
miecurve.dat
default
4.0-12.0;08/30/99

Pha Data - File,S/N,Info:
phadata.dat
default
12/92

Offset Data - File,S/N,Info:
offsets.dat
default
12/92

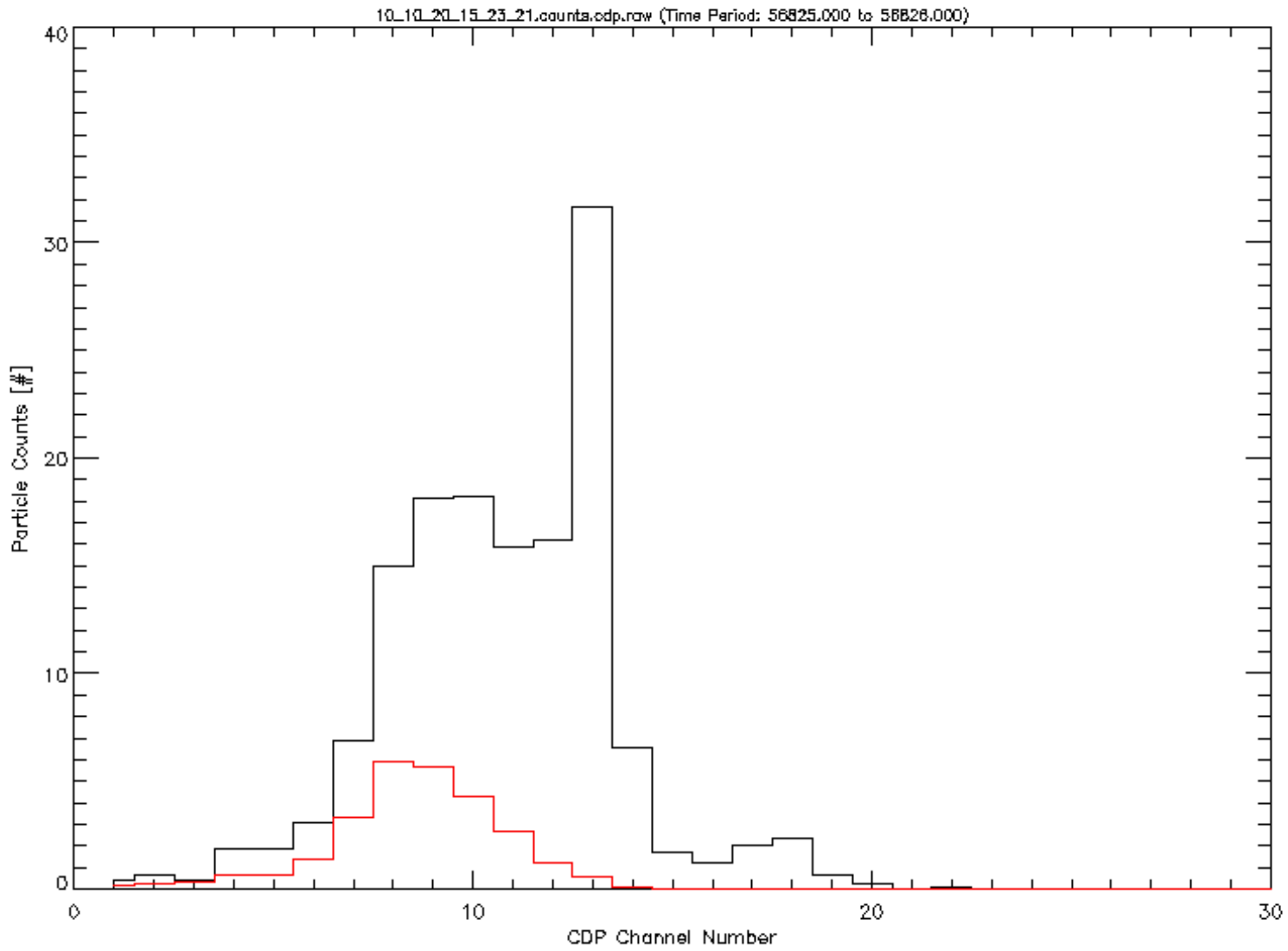
Sizing calibrated is done to determine the instrument's channel size boundaries by using the channel counts obtained from measurements on beads of known size.

Bead Performance Check



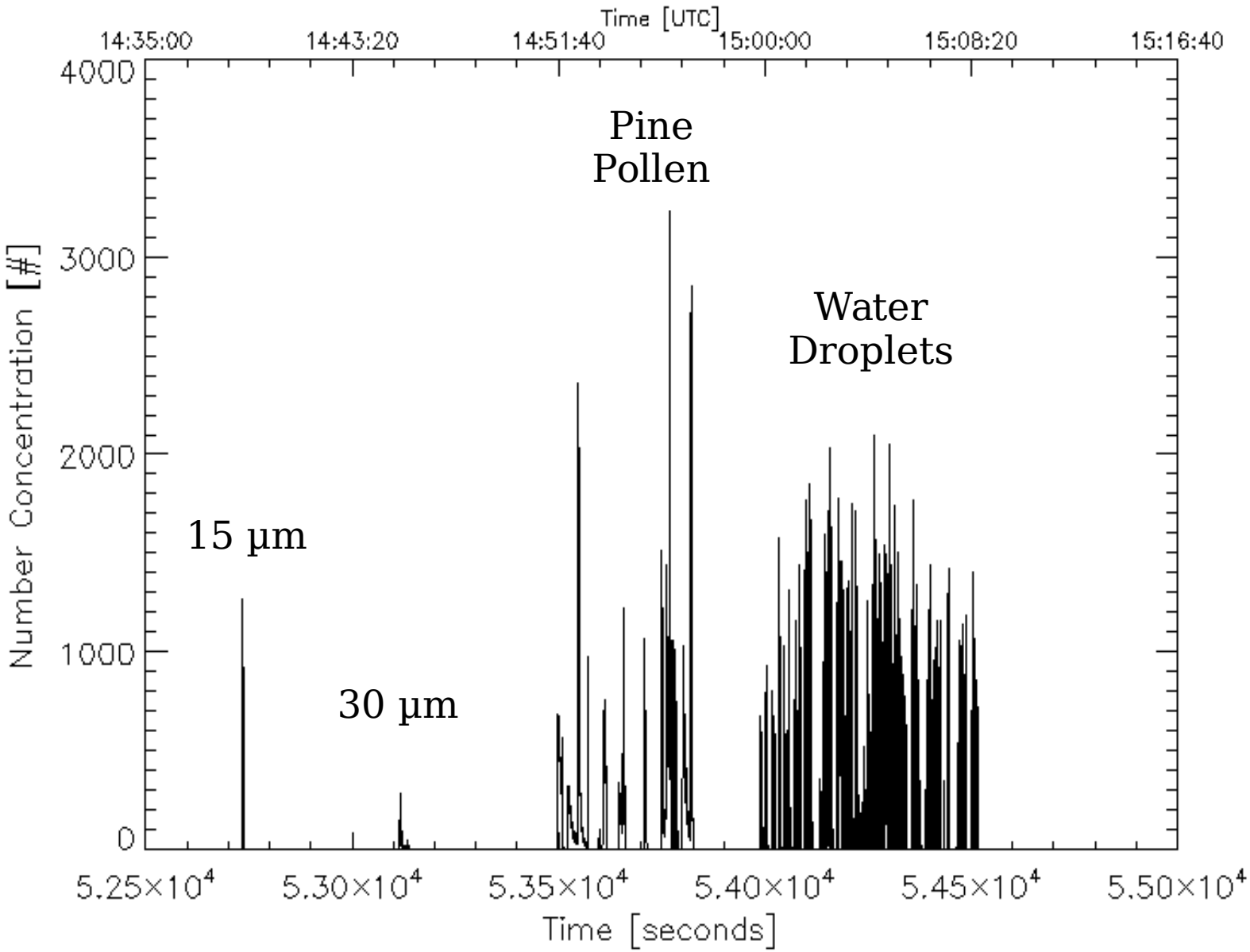
January 29, 2008 FSSP calibration check at 8:40:28 using 15 µm beads.

Good Calibration Standard?



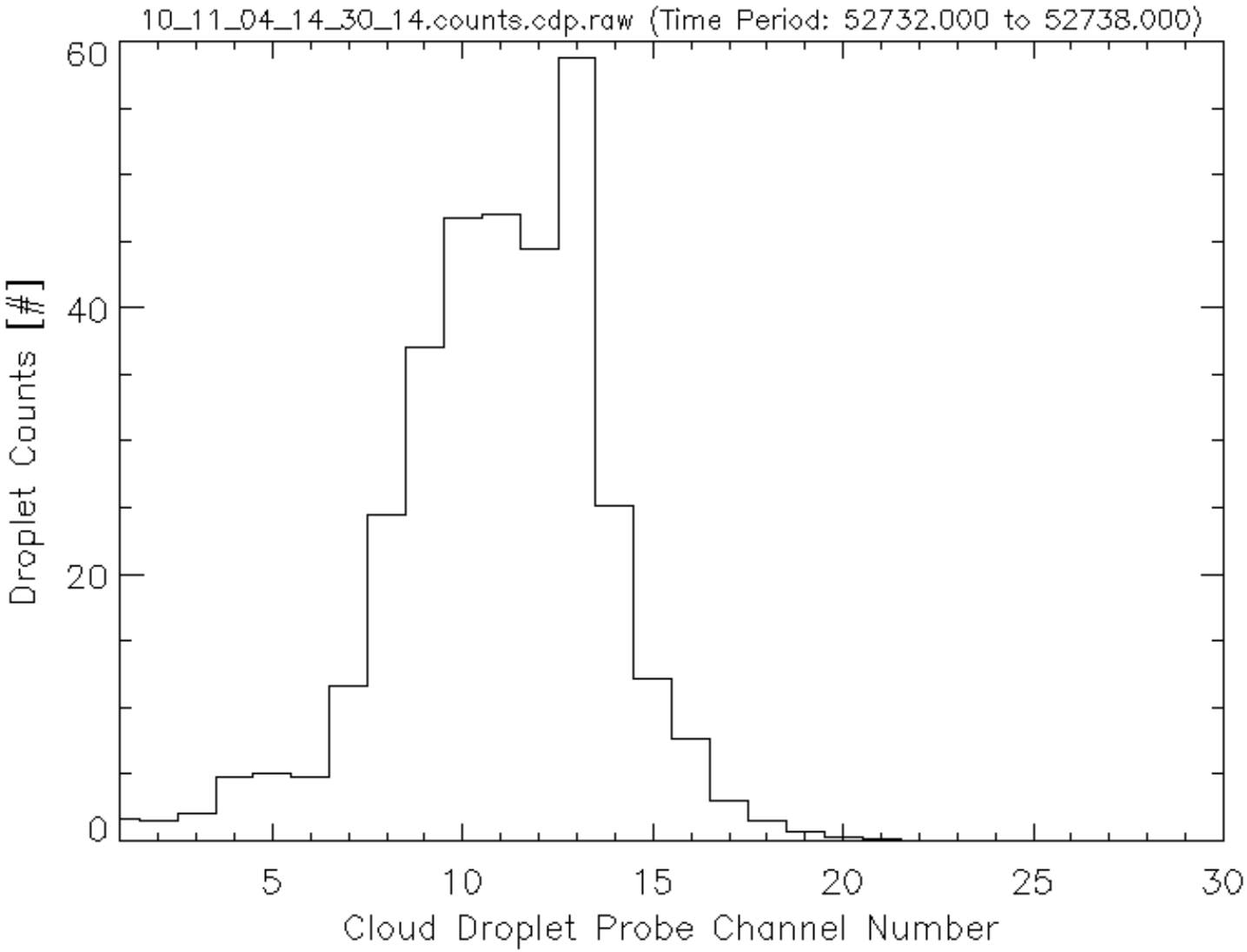
October 20, 2010 CDP performance checks using 15 µm beads. Black line 'good' size standard, red line 'poor' size standard.

CDP Performance Check



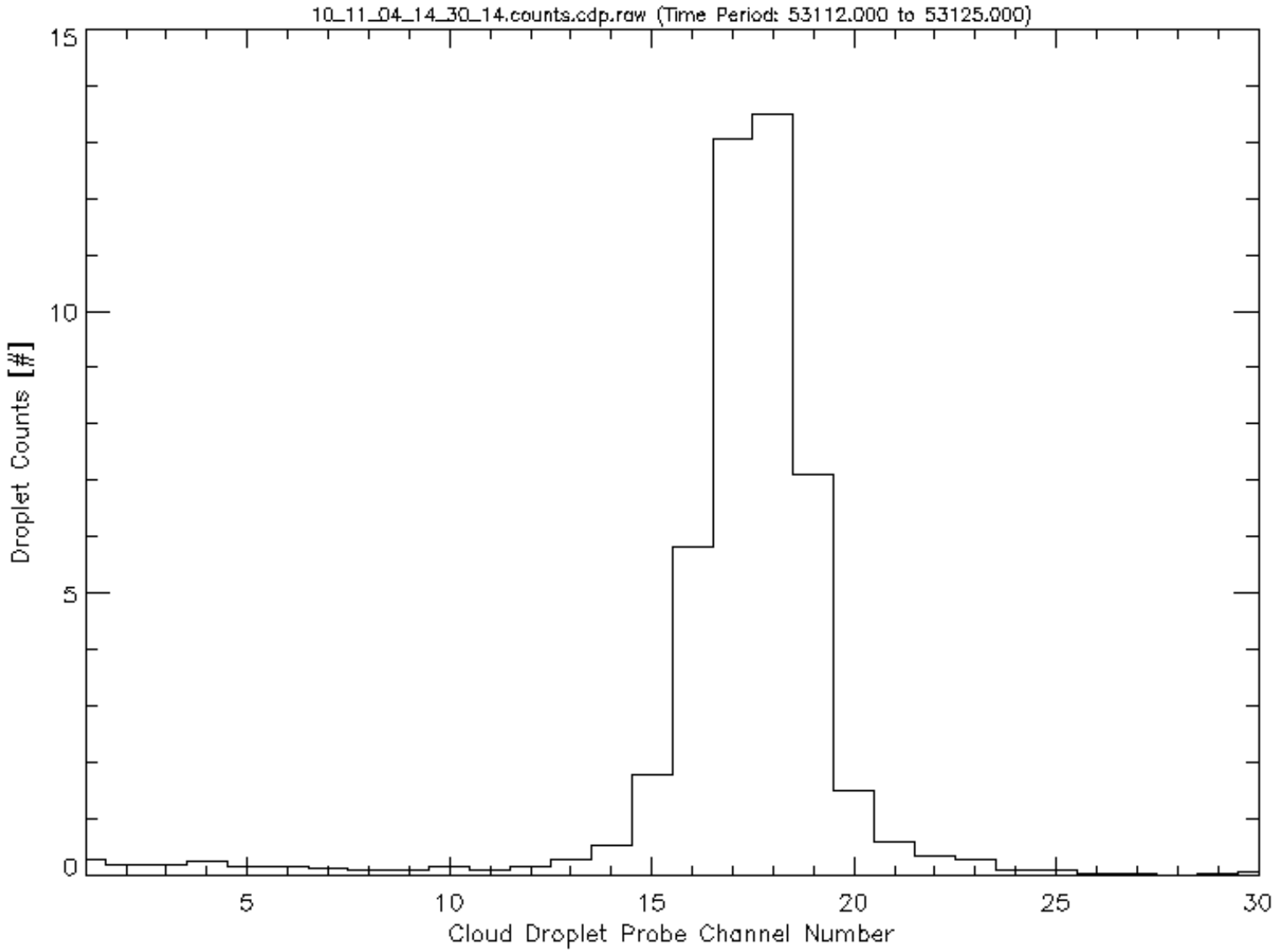
November 4, 2010 Cloud Droplet Probe (CDP) performance check.

CDP 15 µm Spectrum



Cloud Droplet Probe (CDP) spectrum from 52,732 to 52,738 sfm. The average channel value is 12.8500.

CDP 30 µm Spectrum



Cloud Droplet Probe (CDP) spectrum from 53,112 to 53125 sfm. The average channel value is 17.8234.

Saudi Spring 2009

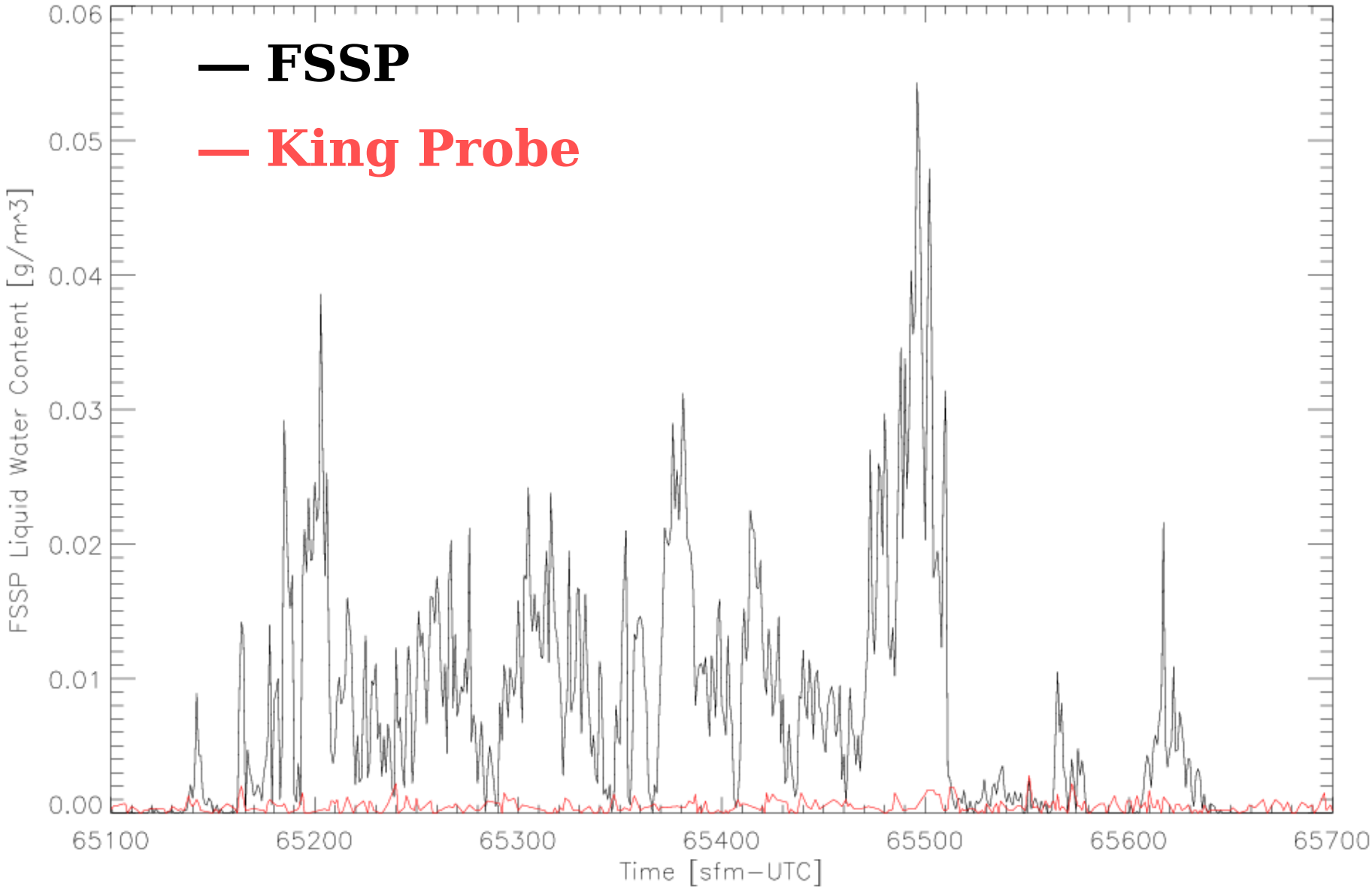
FSSP-SPP100 Performance Checks

Date	Start [SFM]	End [SFM]	Peak CH	Pre-Peak Count	Peak Count	Post-Peak Count	Mode	Bead Size[um]	Water Eq. Size	Cal. Avg CH	Std CH
09/03/19	28714	28715	11	34	37	33	0	30	24.389	10.99	11.279
09/03/19	28994	28996	5	61	66	50	0	15	12.91	4.938	5.573
09/03/20	45602.4	45603	5	7.5	9	7	0	15	12.909	4.978	5.573
09/03/20	45605.7	45606.2	4	5	15	7	0	15	12.909	4.074	5.573
09/03/20	45926	45928	4	22	23	15	0	Pine Pollen		3.88	
09/03/20	46071	46073	7	2.8	3	2.2	0	Water		6.925	
09/03/22	24773.5	24774.8	8	15	18	17	0	30	24.389	8.04	11.279
09/03/22	27006	27007	8	40	43	42	0	30	24.389	8.016	11.279
09/03/22	27283.5	27284.8	4	280	350	270	0	15	12.91	3.988	5.573
09/03/22	27288.7	27289.7	4	210	300	280	0	Pine Pollen		4.088	
09/03/22	28439.7	28441.3	10	27	33	20	0	30	24.389	9.9125	11.27
09/03/22	28622.7	28623.7	5	4.1	4.3	2.2	0	15	12.909	4.82	5.573

http://atmoswiki.aero.und.edu/atmos/citation/cals/spp/home

Ice Contamination

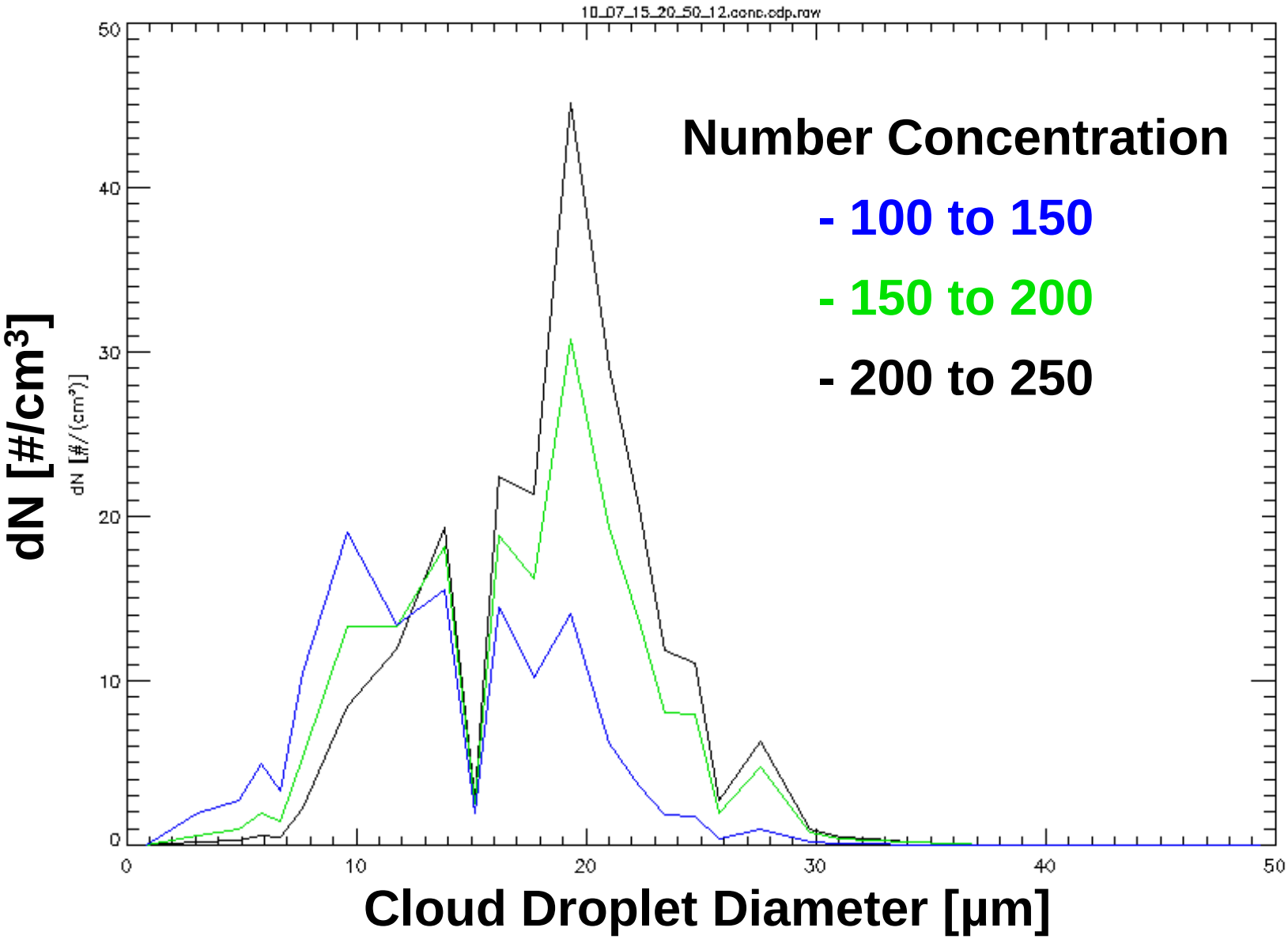
March 14, 2004 Flight



The FSSP LWC calculations assume spherical water droplets.

Cloud Droplet Probe
Number Concentration Spectrum

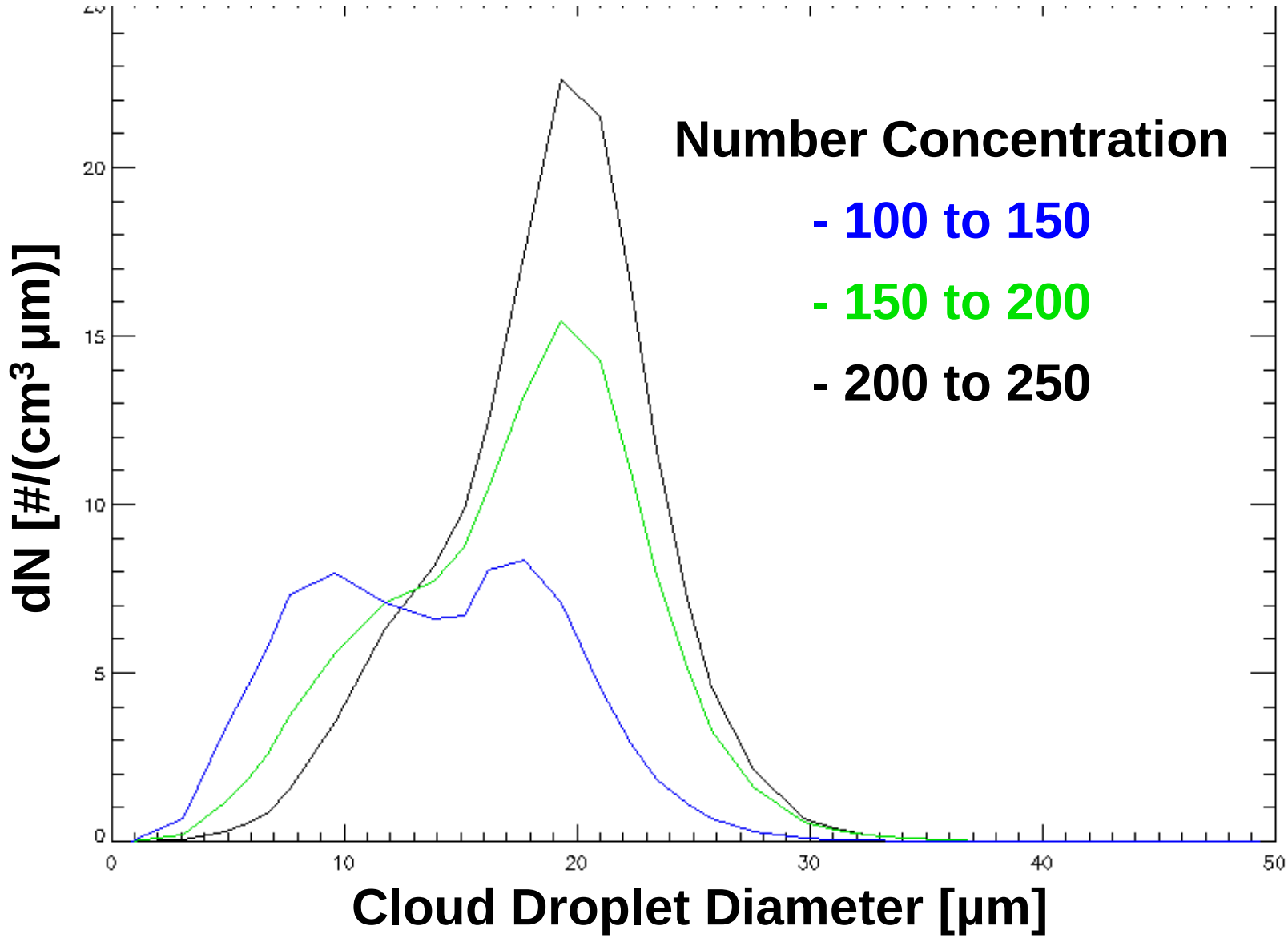
July 15, 2010 Flight



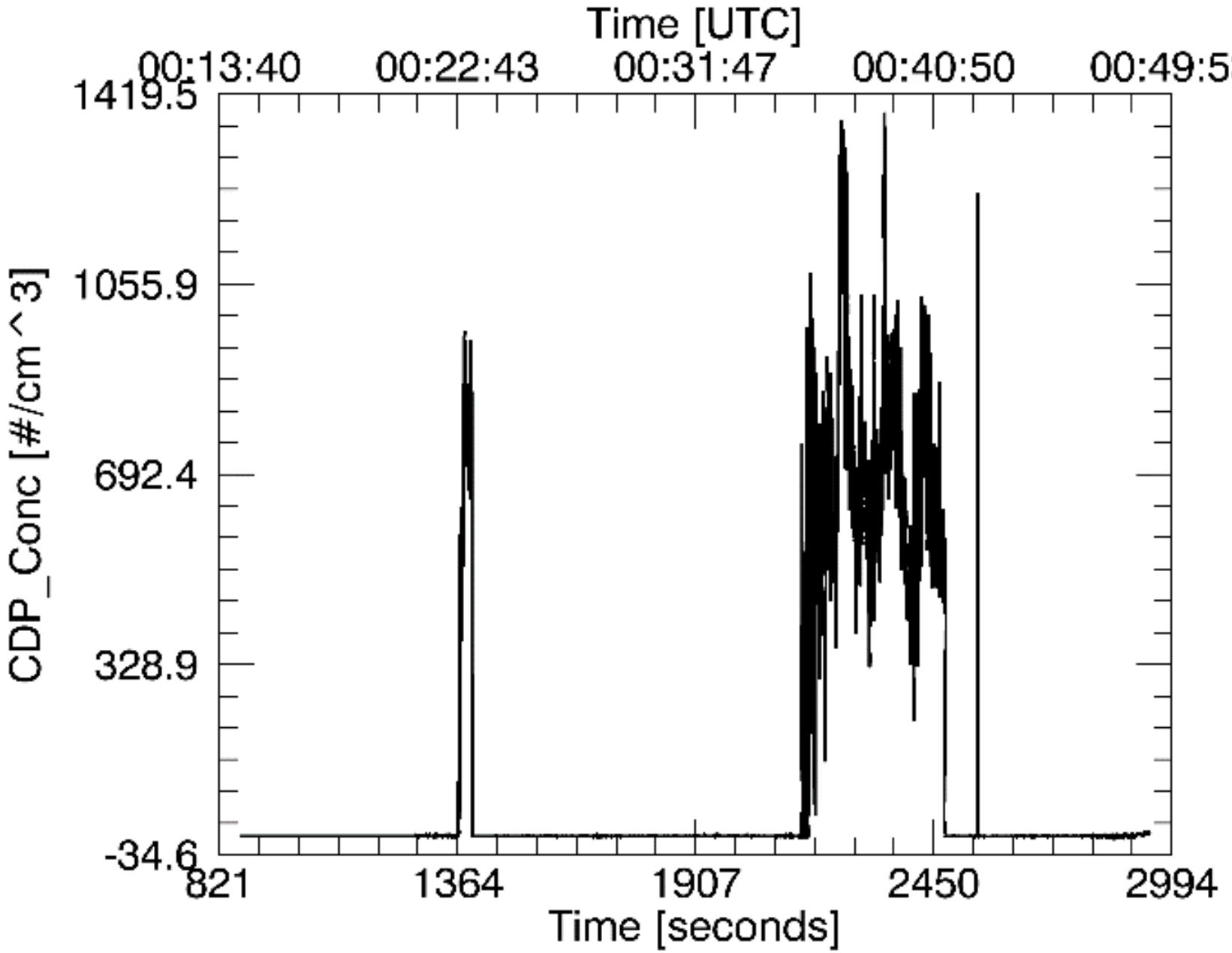
Cloud Droplet Probe

Normalized Concentration Spectrum

July 15, 2010 Flight



Cloud Droplet Probe (CDP)



Time series plot of the cloud droplet probe (CDP) concentration during the 2 March flight near Fargo, North Dakota.

Liquid Water Content Calculation

The liquid water for a given volume of air may be determined through mass integration of the cloud droplet distribution.

$$LWC = \rho w * \frac{\pi}{6} * \sum_{i=1}^{m} Ni * (d_i)^3$$

ρ_w – Density of Water

N_i – Concentration of droplets in size channel i

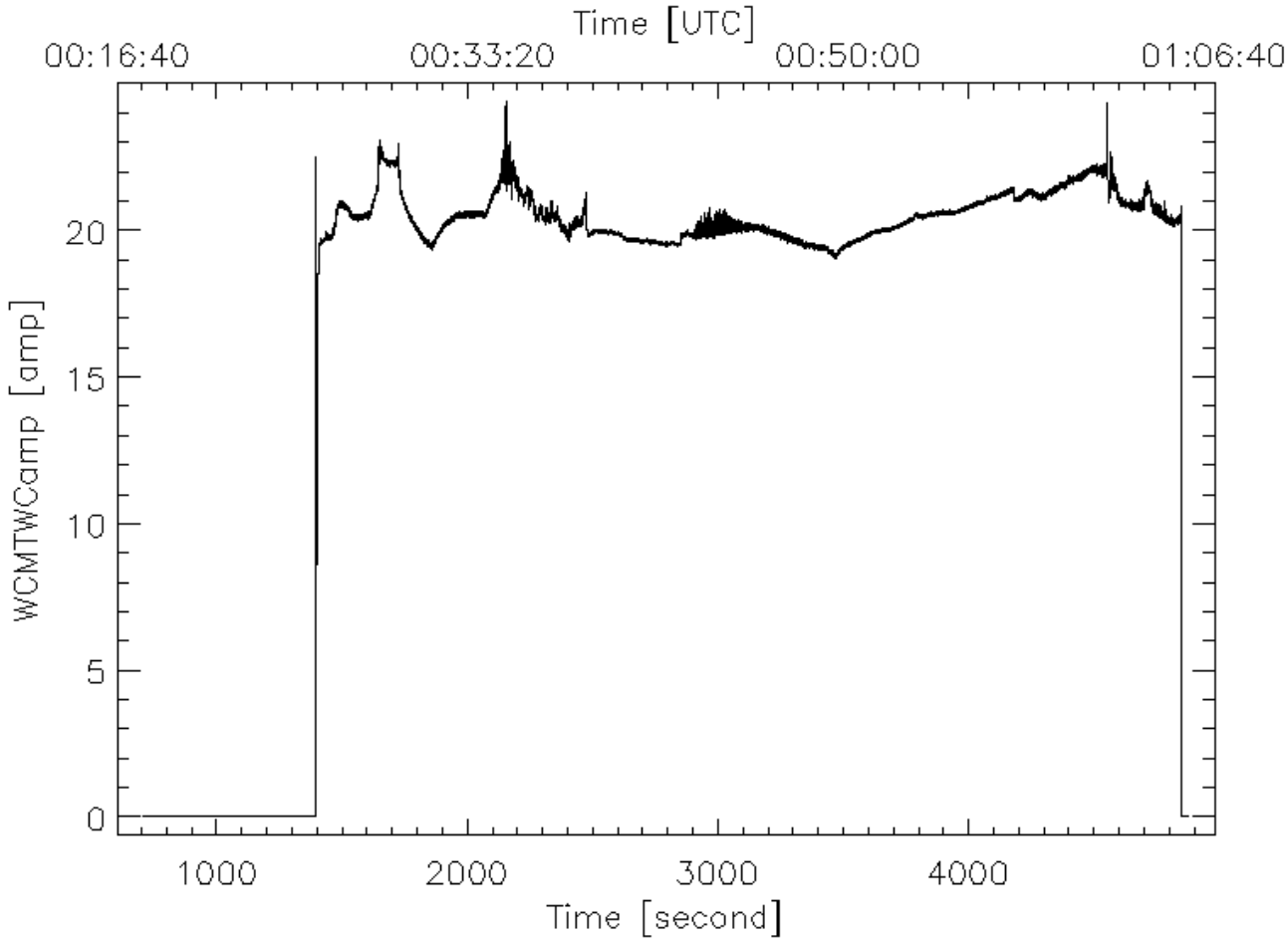
d_i – Droplet diameter in size channel i

m – Total number of channels

SEA Water Content Measurement (WCM)

Operating Principles – Hot Wire Elements
Primary Measurements – Liquid Water Content and Total Ice Water Content (Ice Water Content Derived)
Quality Control – Review Flight Data (Ensure Zero Out of Cloud Values)
Flight Profile Consideration – Icing of Probes, Clear Air Sampling
Data Acquisition – Network Data (M300)

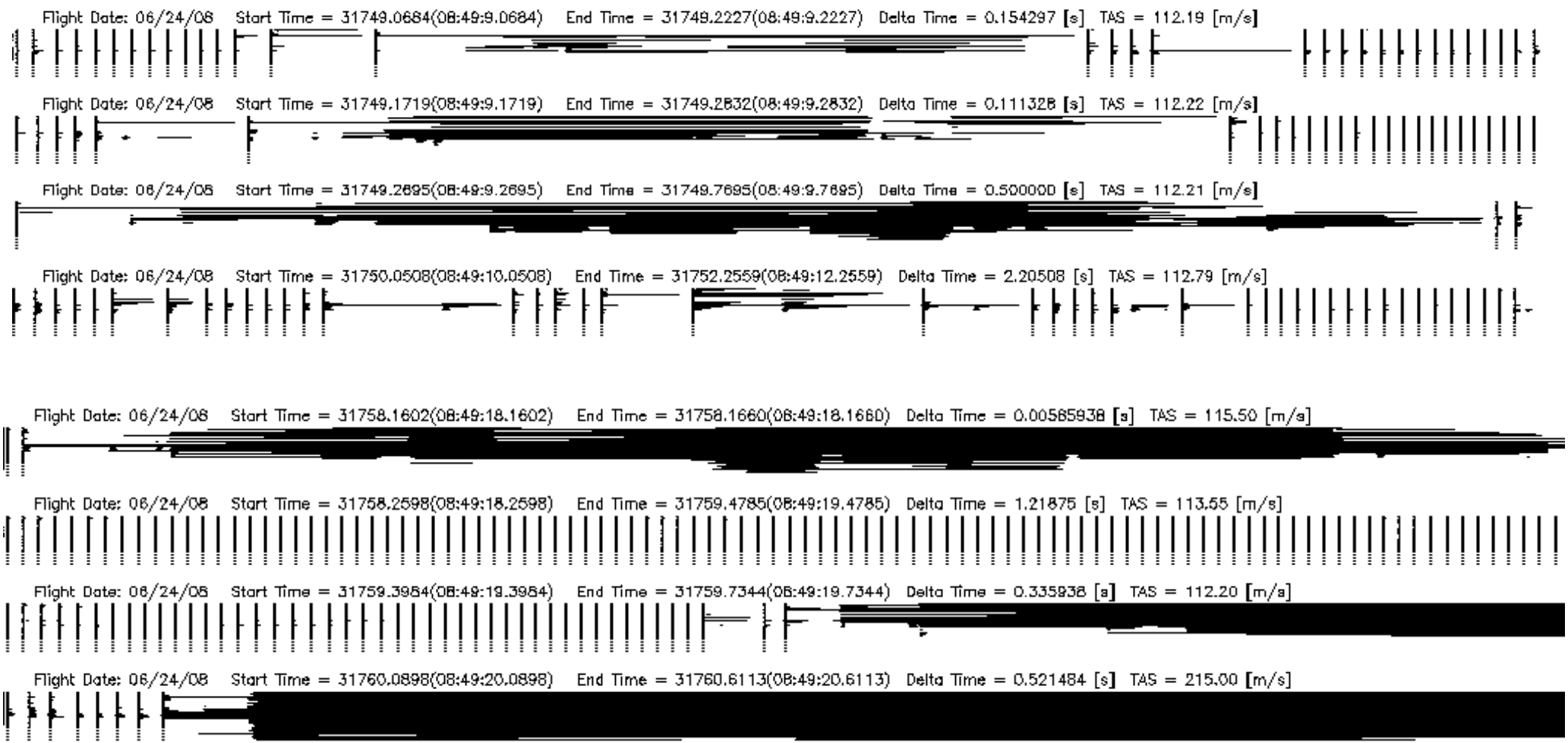
Multi Element Water Content Measurement (WCM) System



Time series plot of the total water content amps from the water content measurement (WCM) during the 2 March 2017 flight near Fargo, North Dakota.

Conclusions

Liquid Droplets are round, ice is not.



References: Clouds

Delene, D. J., C. Grainger, P. Kucera, D. Langerud, M. Ham, R. Mitchell, and C. Kruse, The Second Polarimetric Cloud Analysis and Seeding Test, Journal of Weather Modification, 43, 14-28, 2011, URL: http://www.weathermodification.org/publications/index.php/JWM/article/viewArticle/147.

Delene, D. J., Suitability of North Dakota for Conducting Effective Hygroscopic Seeding, Journal of Weather Modification, 48, 43-67, 2016.

Web Site - https://sourceforge.net/projects/adpaa/

Wiki - http://adpaa.sourceforge.net/wiki/index.php/Main_Page