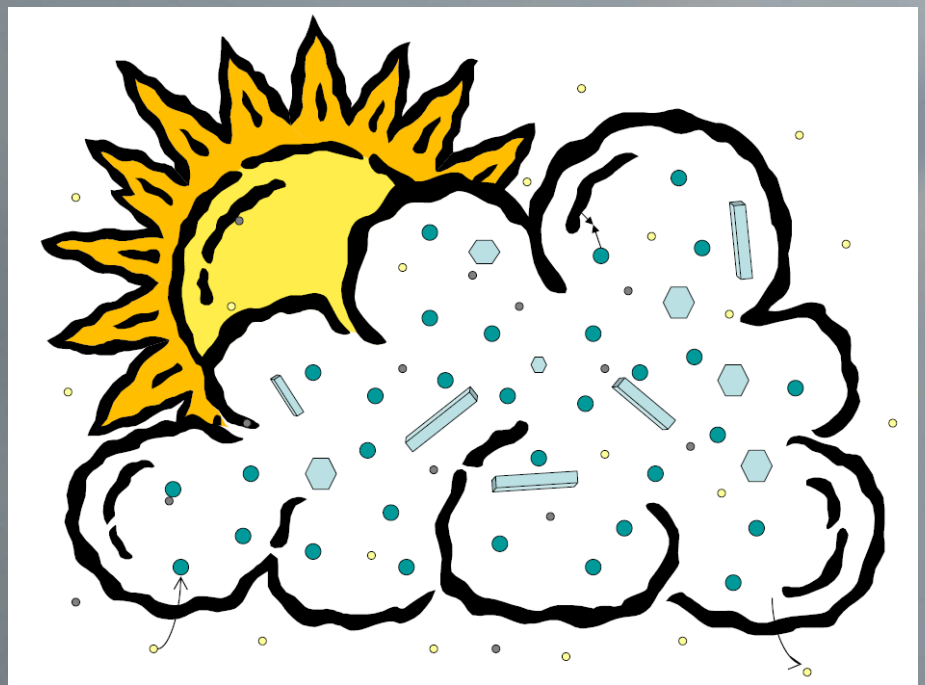
Indirect & Semi-Direct Aerosol Campaign Cloud Observations: A new look at arctic clouds

Greg McFarquhar[1], Alexei Korolev[2], Walter Strapp[2], Paul Lawson[3], Matt Freer[1], Kenny Bae[1], Robert Jackson[1] and Gong Zhang[1]



[1]University of Illinois

[2]Environment Canada

[3]SPEC Inc.

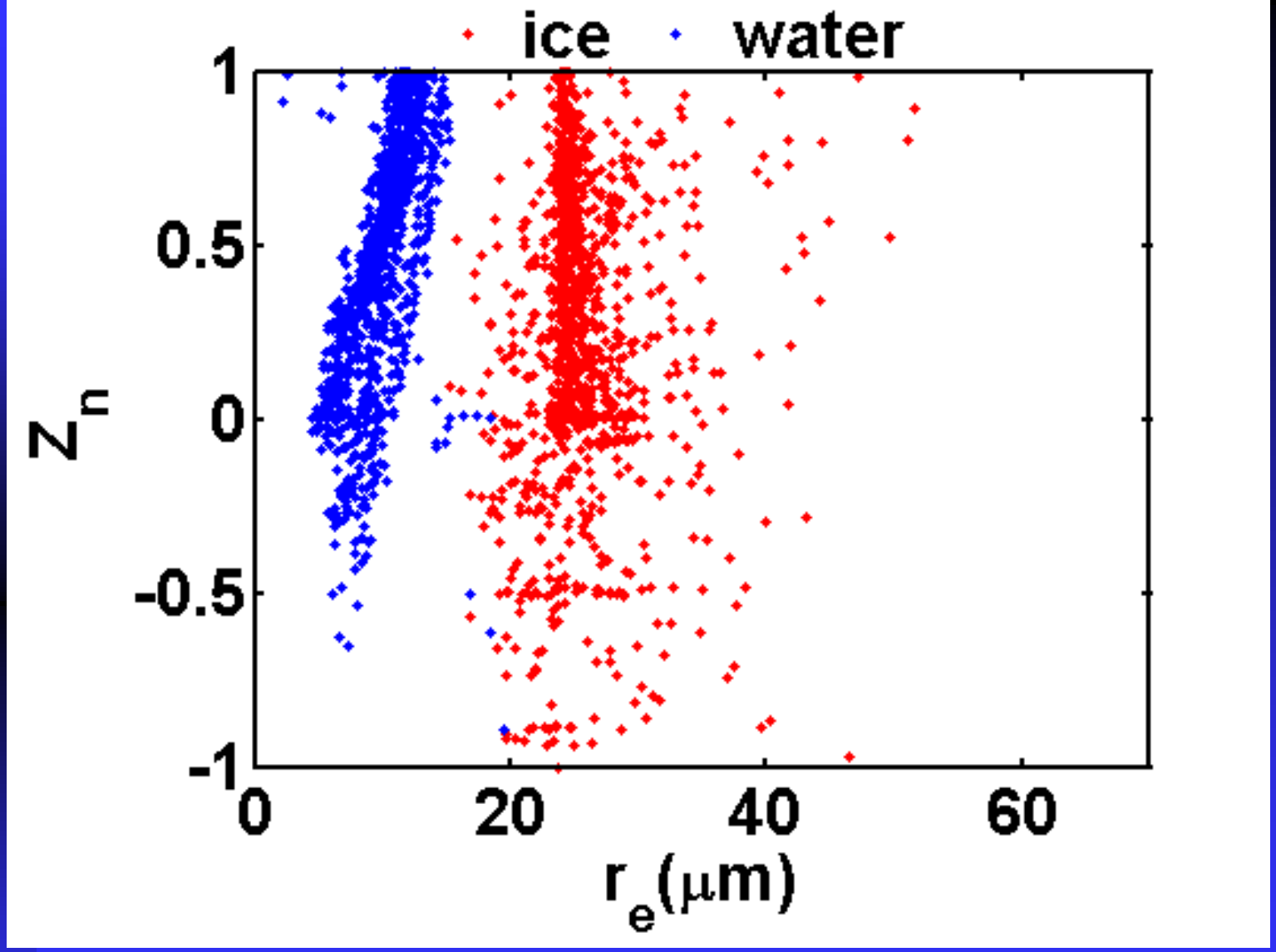
Overview

1. Motivation: what we need
2. What we got
3. Current investigations: understanding measurements
4. Available data & preliminary value added products

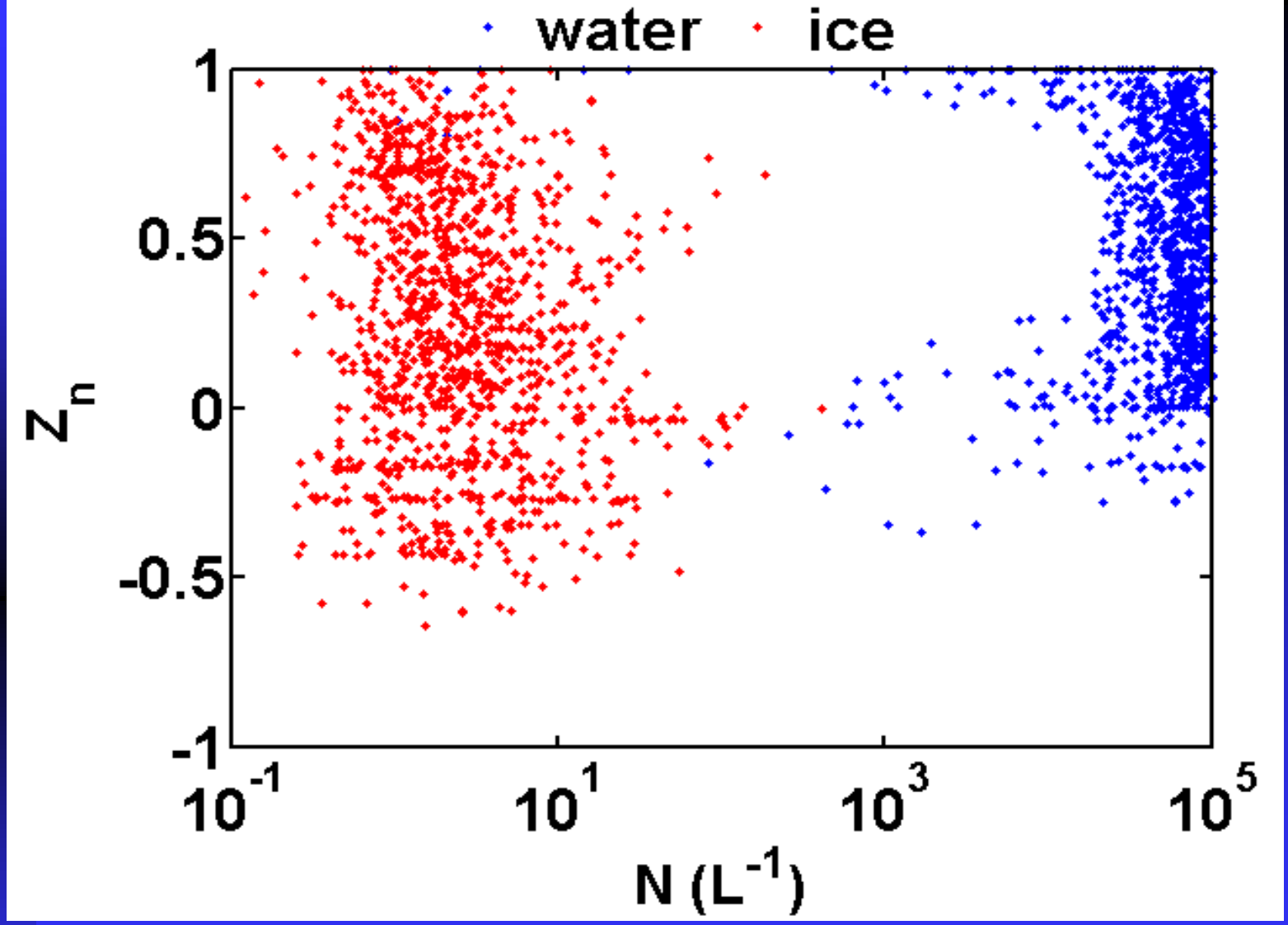
Motivation: what do we need?

- To study cloud-aerosol interactions in mixed-phase clouds, we need horizontal & vertical profiles of cloud properties in variety of aerosol conditions

- During M-PACE, we used aircraft data to derive 101 vertical profiles of cloud microphysical properties using observed size & habit distributions over Oliktok and Barrow



For M-PACE vertical profiles of r_{ei} and r_{ew} were generated from cloud measurements as function of normalized altitude



These, and other data such as N_i and N_w were helpful for developing/evaluating models and remote sensing retrievals

Motivation: what do we need?

- **Wanted similar data from ISDAC**
  - **to describe how differences between spring and fall arctic aerosols produce differences in cloud properties & surface energy balance**
  - **to evaluate performance of cloud & climate models and parameterizations, and long-term retrievals of aerosols, clouds, precipitation and radiative heating from surface-based measurements**
  - **To perform process-oriented studies to understand how aerosol characteristics affect cloud properties**

What did we get?

- 27 project sorties representing 103.6 hours of data on 12 different flight days
- Golden days with single-layer stratocumulus on 8 and 26 April when 3 sorties flown; heavily polluted data on 19 April

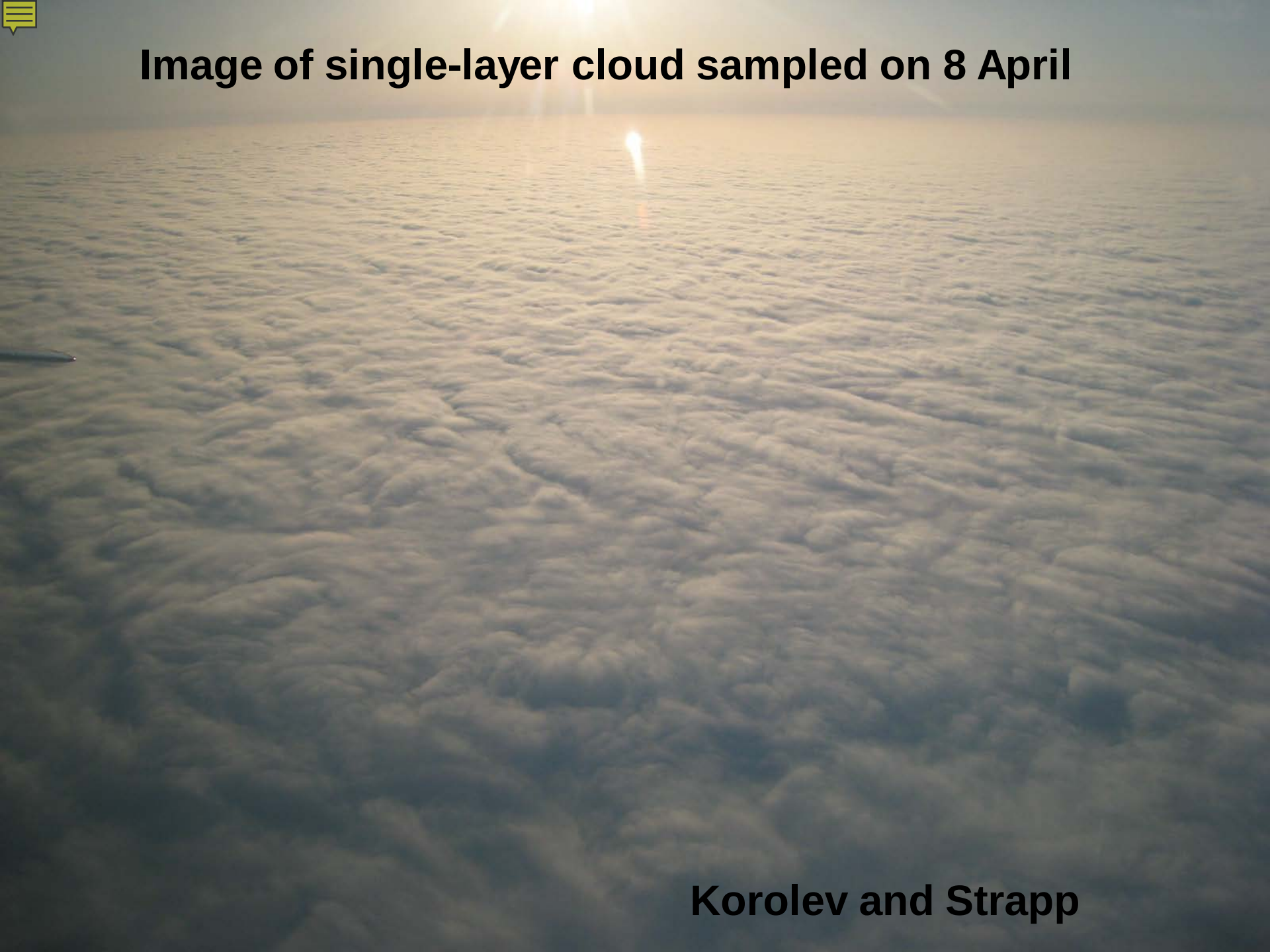


Image of single-layer cloud sampled on 8 April
Korolev and Strapp

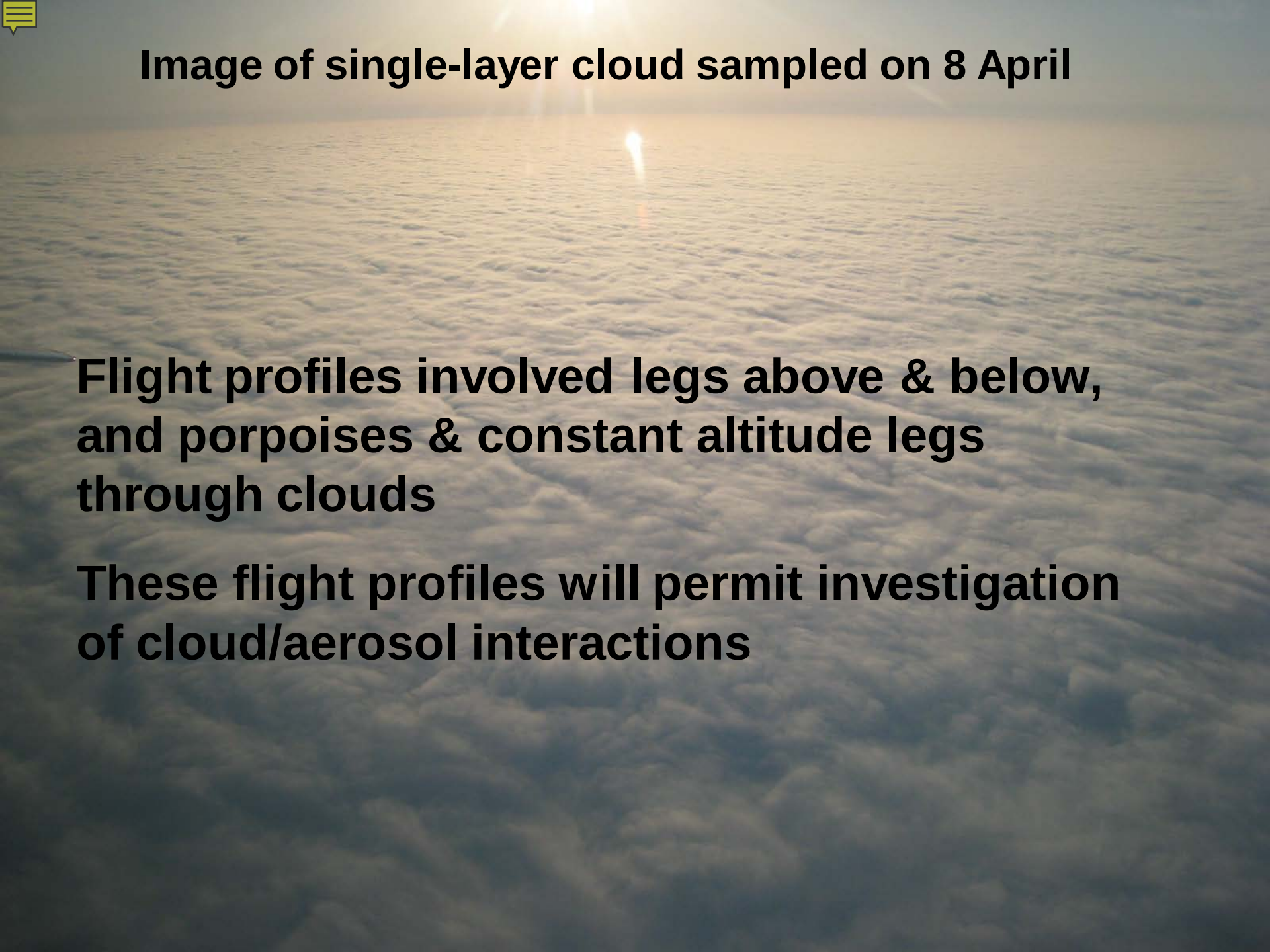


Image of single-layer cloud sampled on 8 April

Flight profiles involved legs above & below, and porpoises & constant altitude legs through clouds

These flight profiles will permit investigation of cloud/aerosol interactions

Understanding Measurements

Primary observation platform for ISDAC was National Research Council of Canada Convair

Equipped by Environment Canada, NRC, universities and private companies with instruments to measure aerosol and cloud particles from 1 nm to > 10 mm in size


➔ Need wide variety of probes to measure sizes & bulk properties of clouds

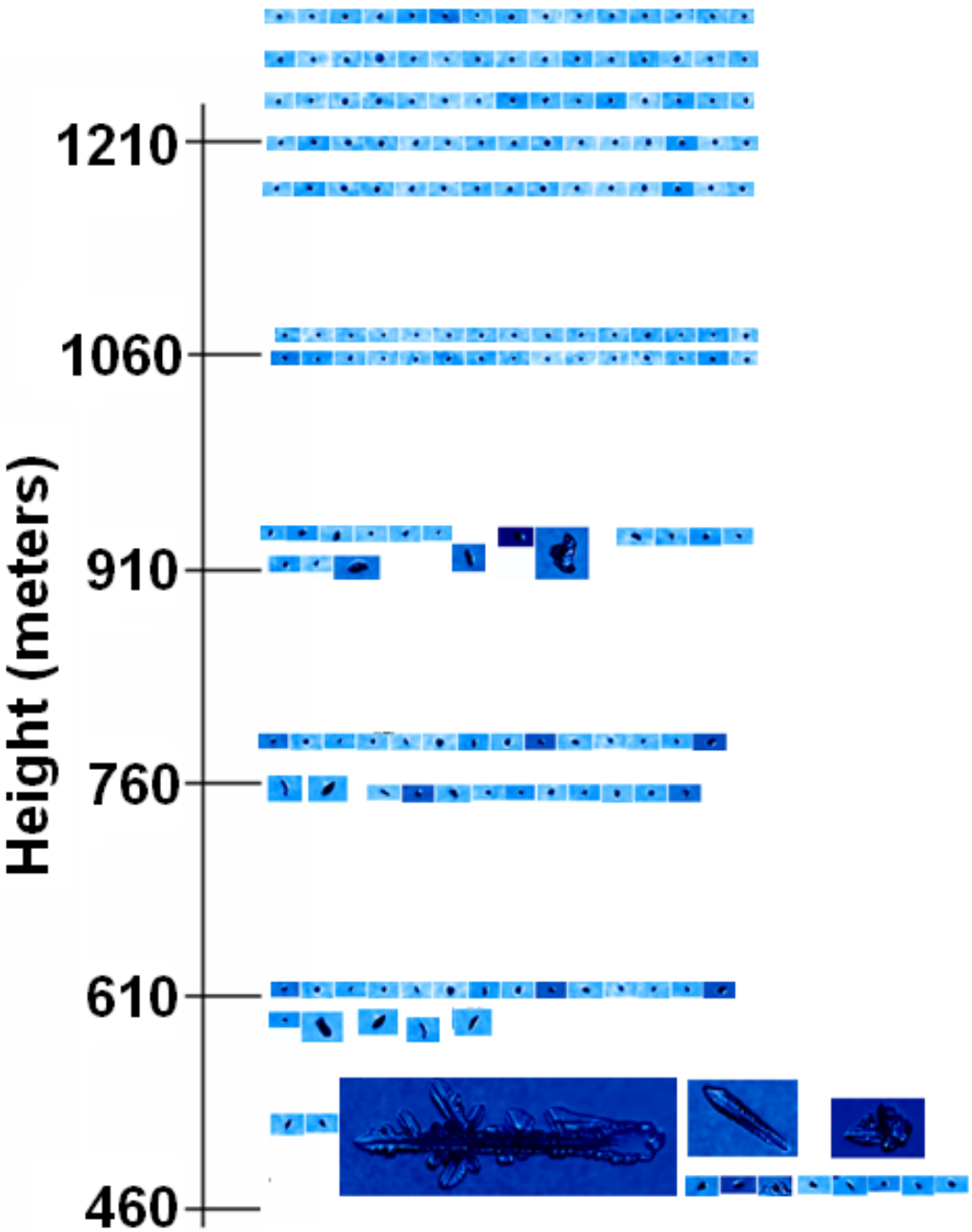
What did we measure in cloud?

- Size distributions:
  - Forward scattering probes (3 < D < 50 μm)
  - Optical array probes over complete range of sizes (50 μm < D < 10 mm)
- High-resolution images of hydrometeors
- Bulk parameters
  - Liquid & total water content, extinction
  - Presence of supercooled water
- Redundancy key to microphysical measurements
  - Allows us to assess consistency & performance of multiple probes

Uncertainties in Cloud Observations

- Before providing library of derived parameters like r_{ei}, r_{ew}, N_i, N_w, we need to:
  - Calibrate probes
  - Remove shattering artifacts in calculation of concentrations
  - Automated habit recognition
  - Determine which combination of probes to use in which size ranges
- CLOSURE tests of bulk and size-resolved mass & extinction can reduce these uncertainties

How do we go from raw data to something useful for models/ remote sensing retrievals/radiative transfer studies?



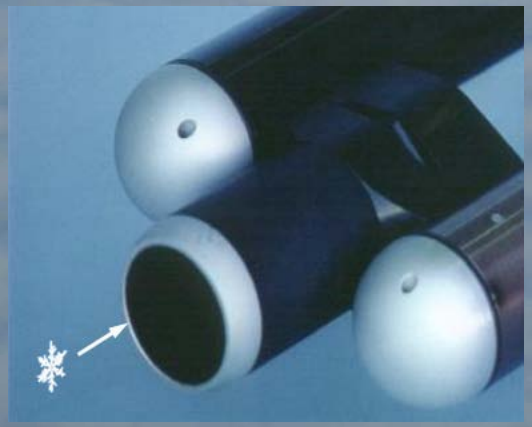
Shattering Effect: CAS vs CDP vs FSSP

Cloud and Aerosol Spectrometer

Shroud

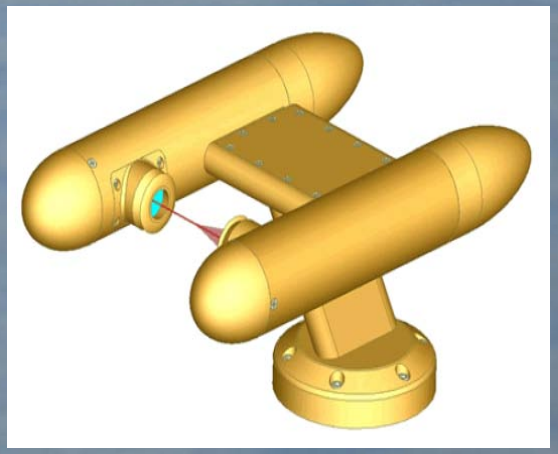
Inlet

Forward Scattering Spectrometer Probe



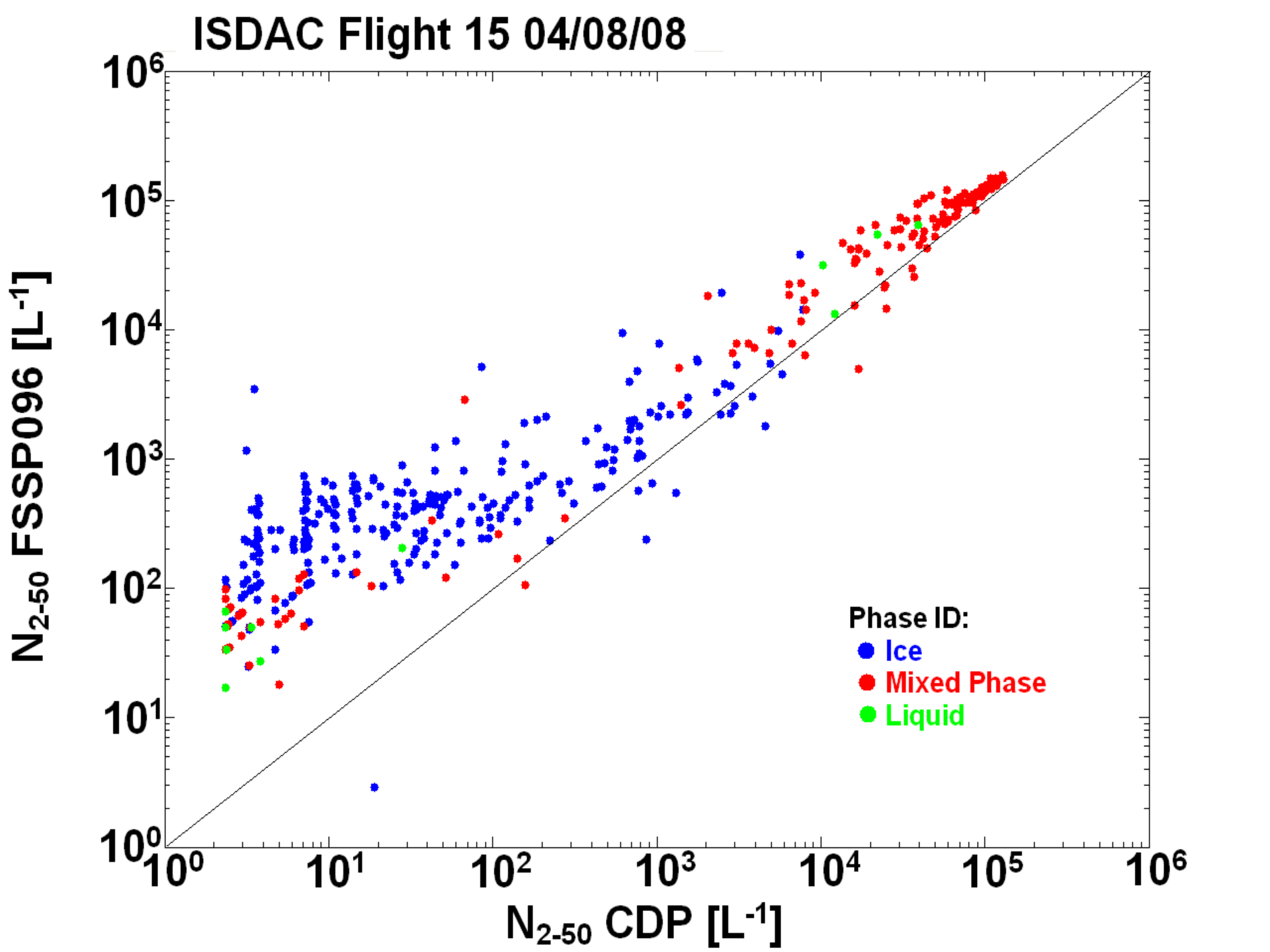
-Surfaces for shattering

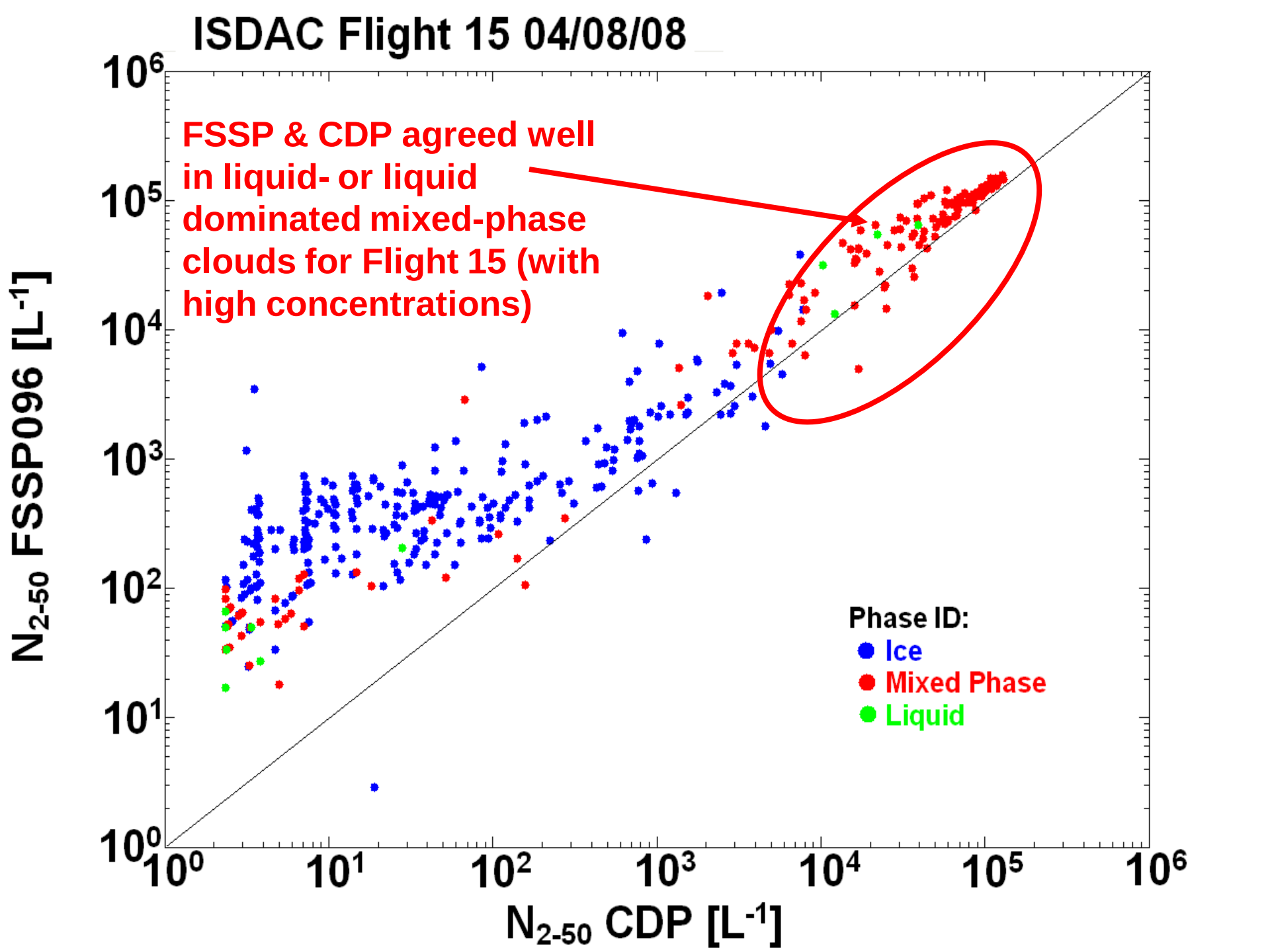
Cloud Droplet Probe

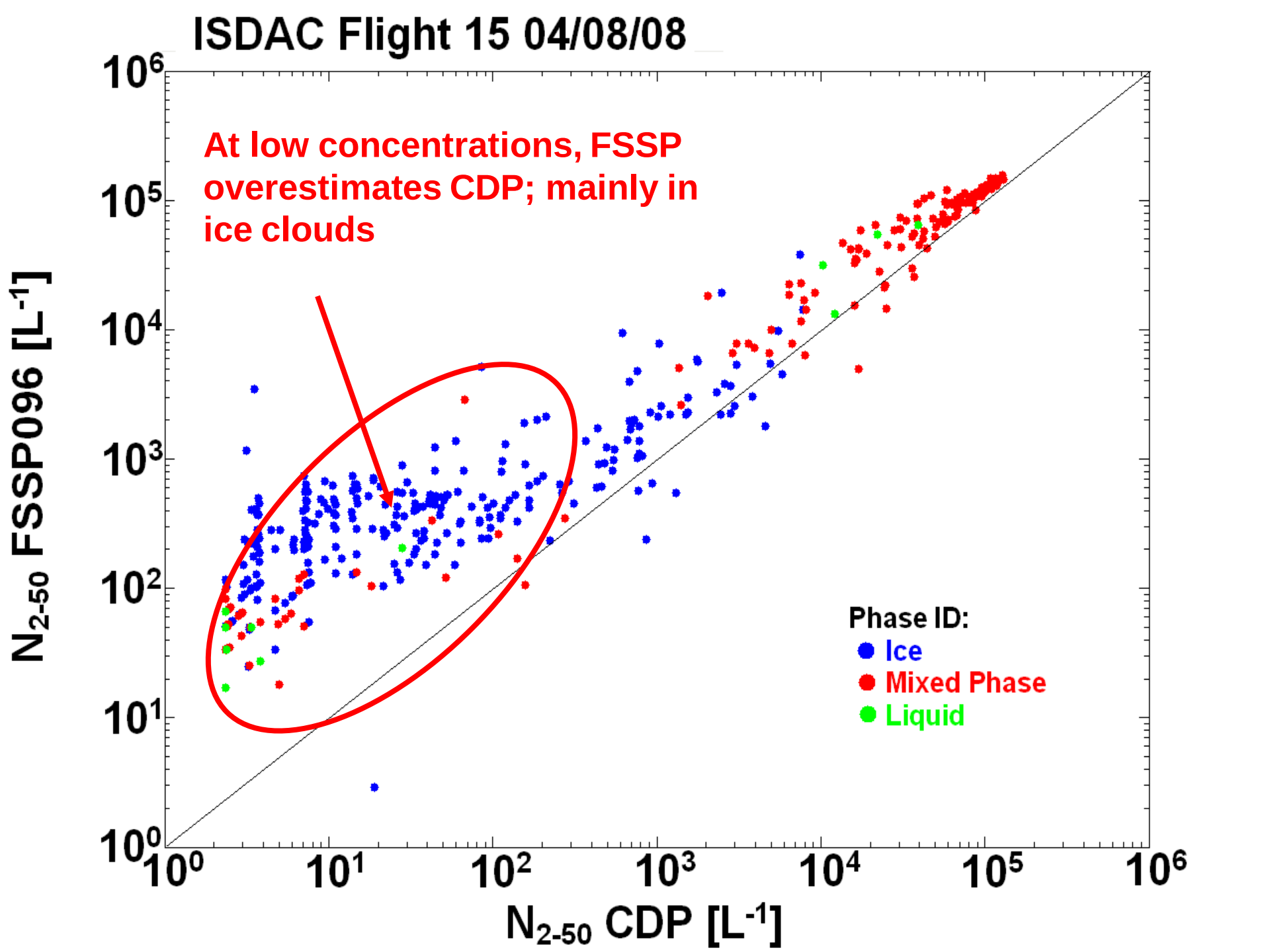


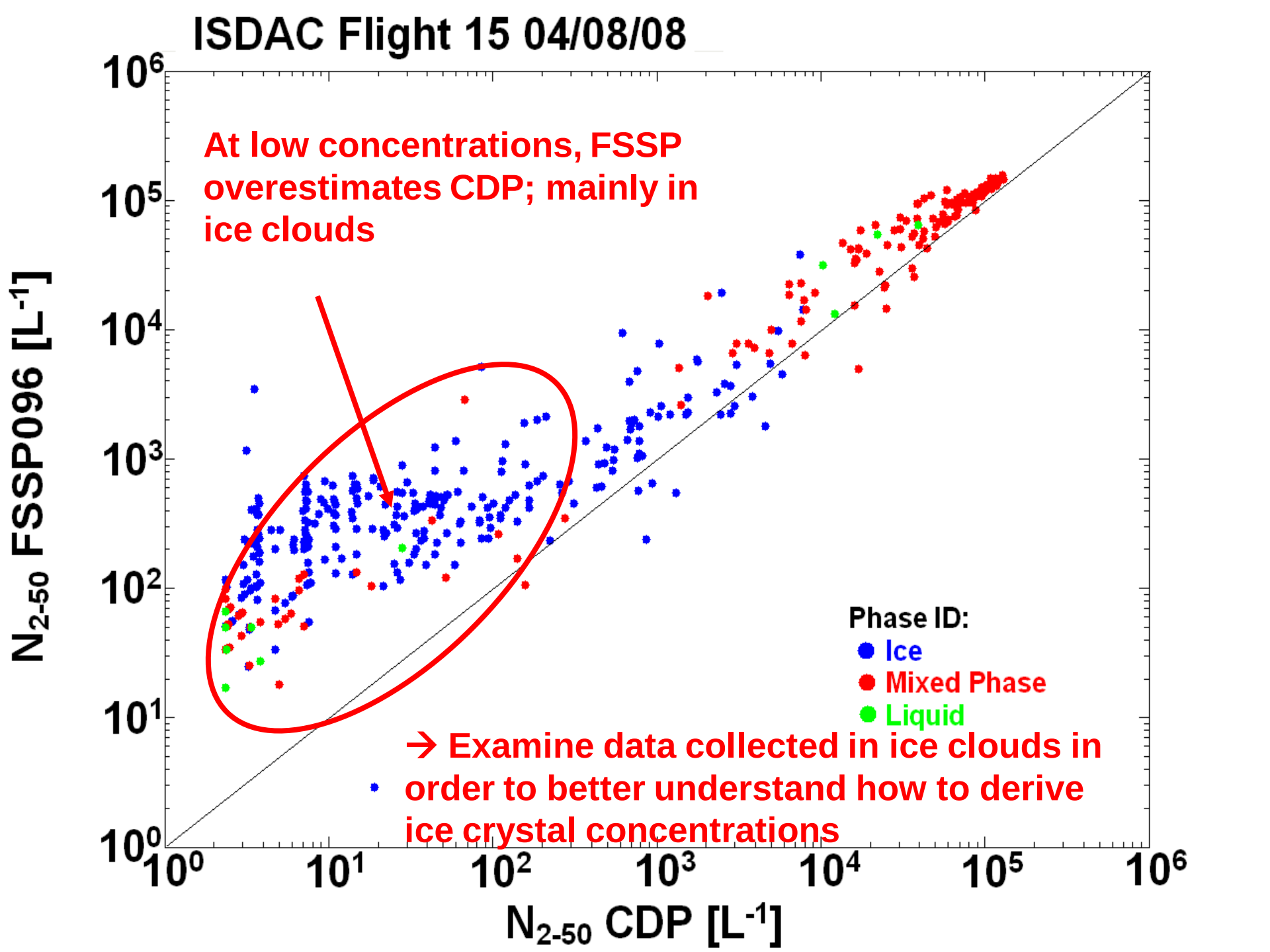
- No inlet or shroud

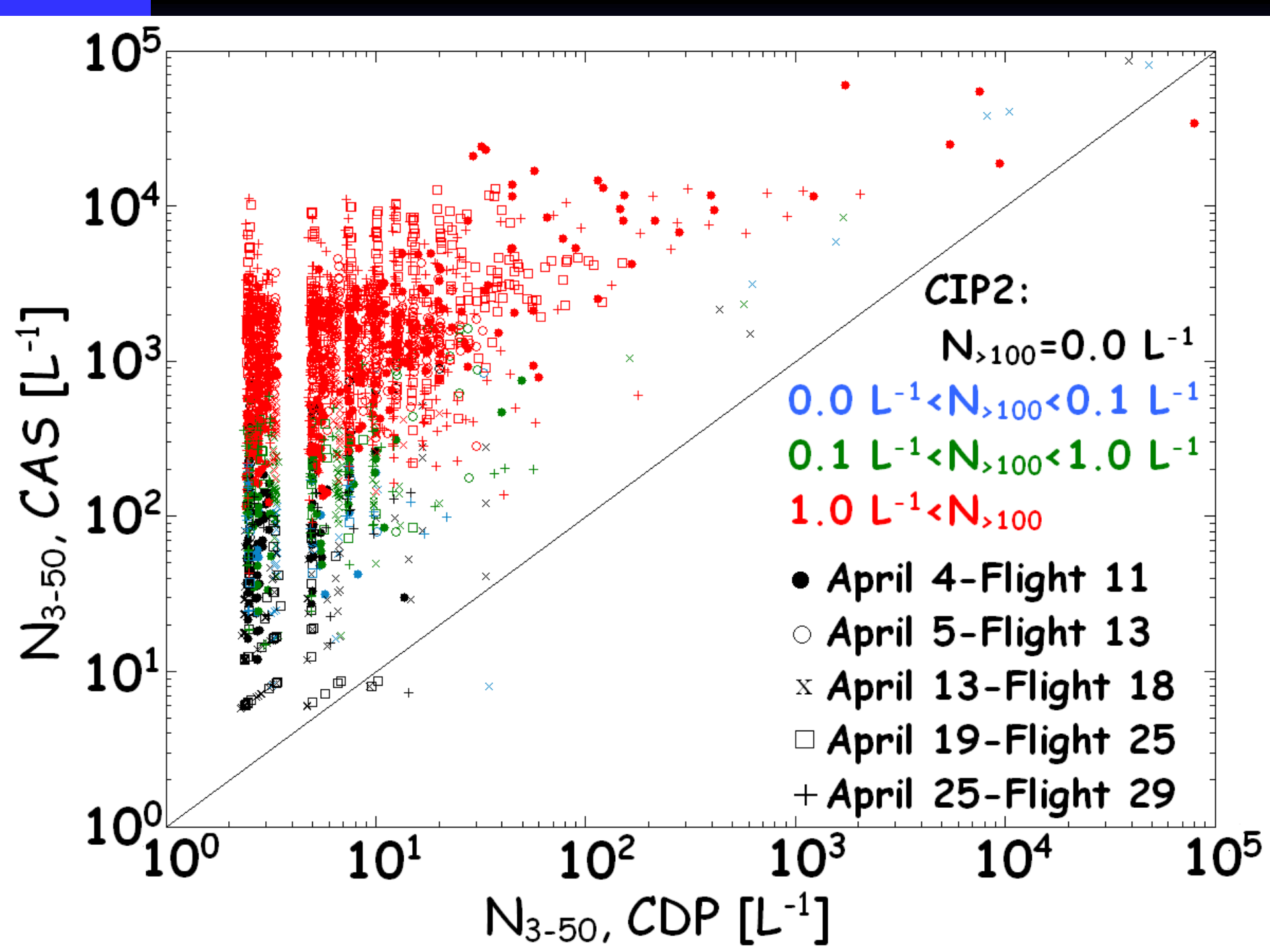
- ✓ **The same working principle and look-up table**
- ✓ **Can we see shattering on FSSP or CAS?**

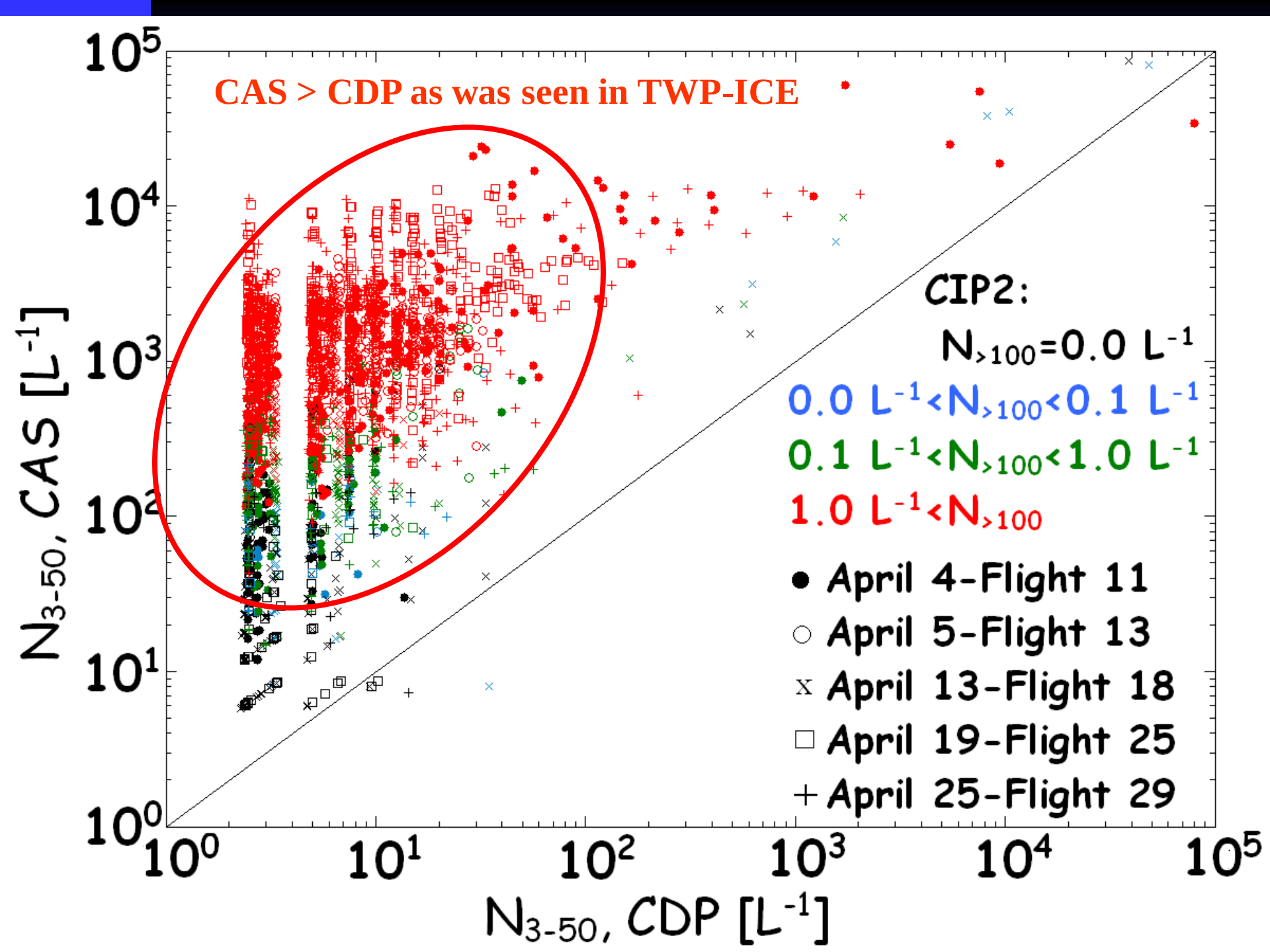

ISDAC Flight 15 04/08/08
$N_{2\text{-}50}$ FSSP096 [L^{-1}]
$N_{2\text{-}50}$ CDP [L^{-1}]
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Phase ID:
Ice
Mixed Phase
Liquid

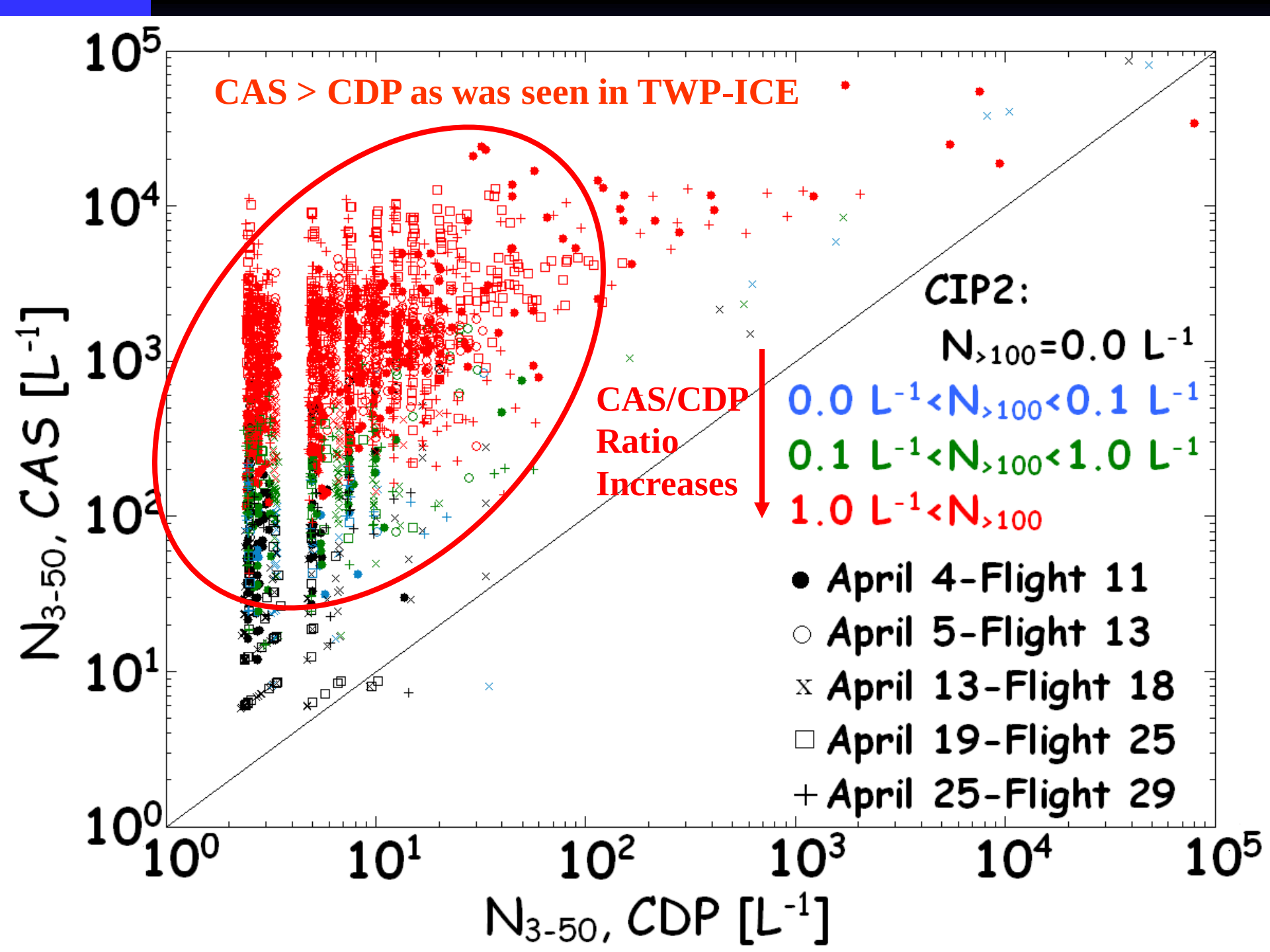

ISDAC Flight 15 04/08/08
FSSP & CDP agreed well in liquid- or liquid dominated mixed-phase clouds for Flight 15 (with high concentrations)
Phase ID:
Ice
Mixed Phase
Liquid
N2-50 FSSP096 [L-1]
N2-50 CDP [L-1]
10^0
10^1
10^2
10^3
10^4
10^5
10^6

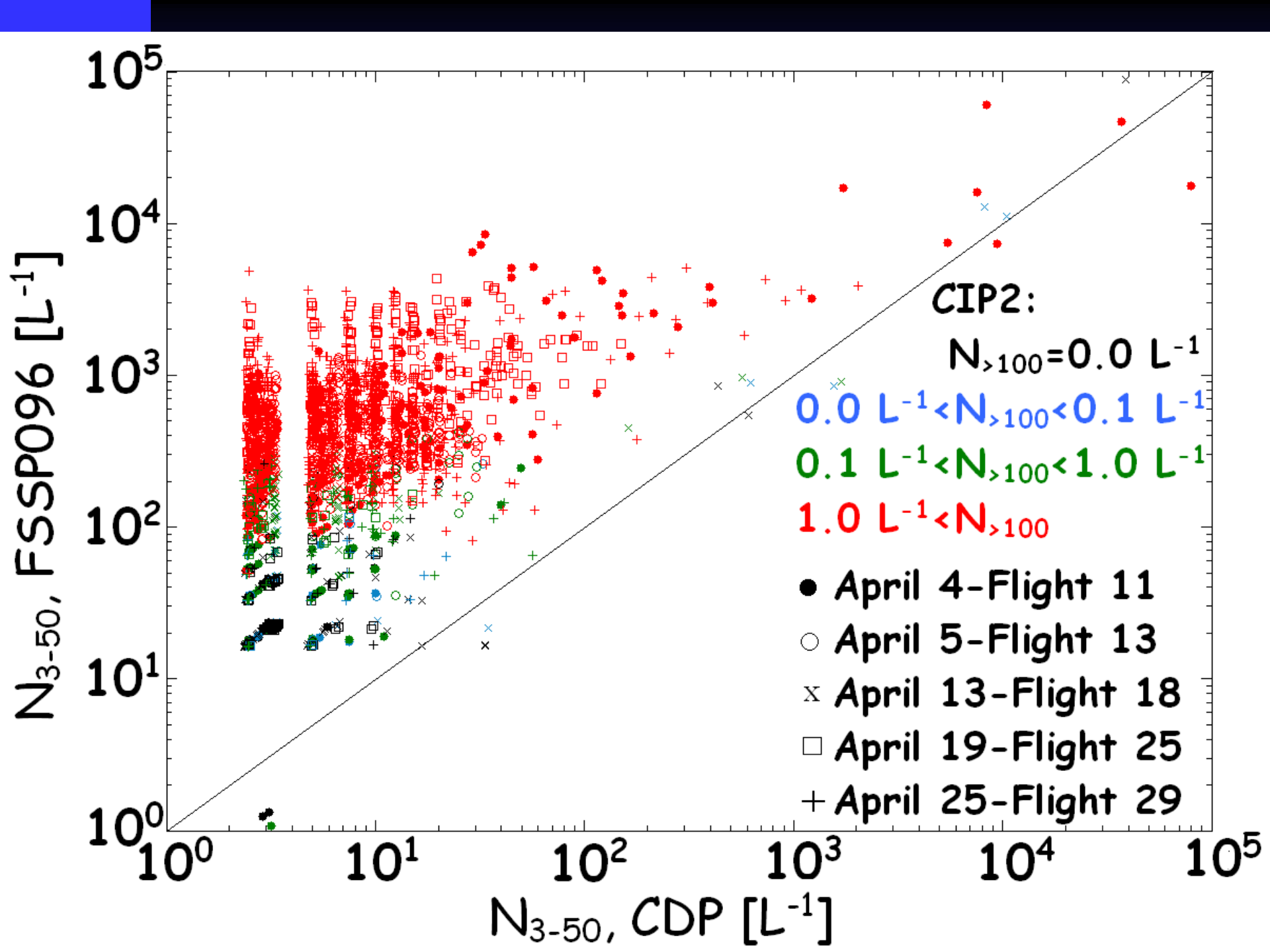

ISDAC Flight 15 04/08/08
At low concentrations, FSSP overestimates CDP; mainly in ice clouds
Phase ID:
Ice
Mixed Phase
Liquid
$N_{2\text{-}50}$ FSSP096 [L^{-1}]
$N_{2\text{-}50}$ CDP [L^{-1}]
10^0
10^1
10^2
10^3
10^4
10^5
10^6

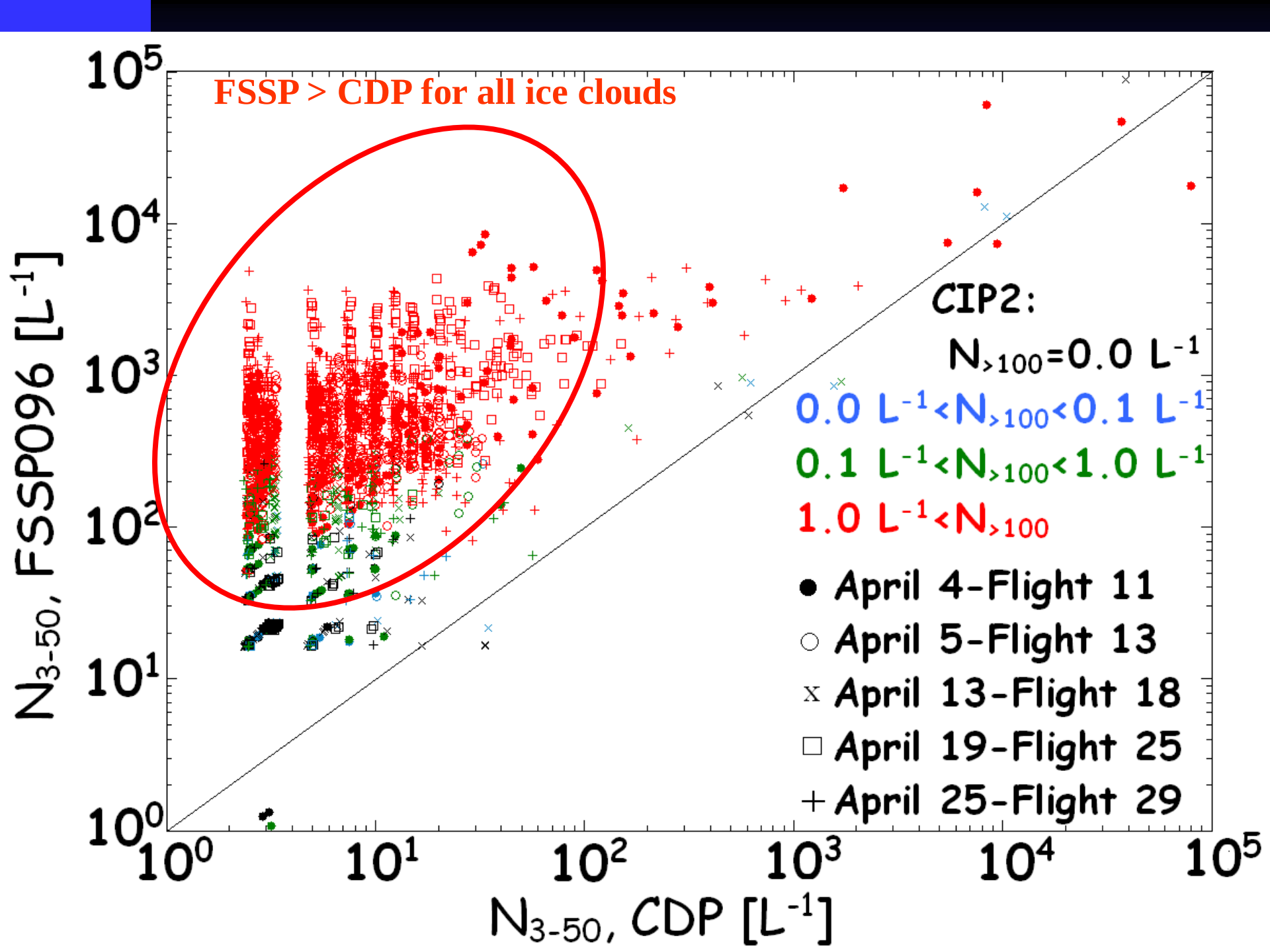

ISDAC Flight 15 04/08/08
At low concentrations, FSSP overestimates CDP; mainly in ice clouds
Phase ID:
Ice
Mixed Phase
Liquid
→ Examine data collected in ice clouds in order to better understand how to derive ice crystal concentrations
$N_{2\text{-}50}$ FSSP096 [L^{-1}]
$N_{2\text{-}50}$ CDP [L^{-1}]
10^0
10^1
10^2
10^3
10^4
10^5
10^6

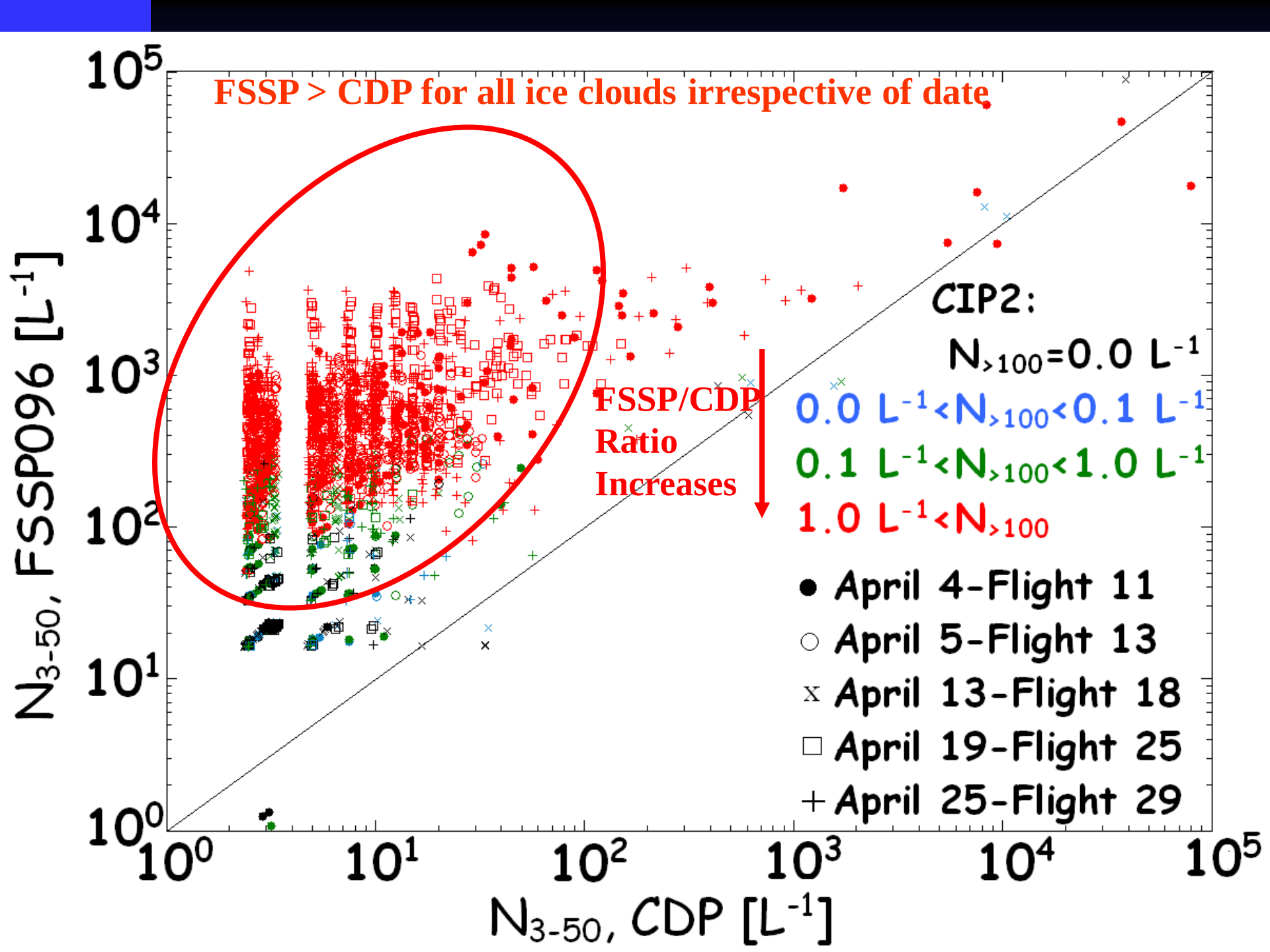

10^5
10^4
10^3
10^2
10^1
10^0
$N_{3\text{-}50}$, CAS [L^{-1}]
10^0
10^1
10^2
10^3
10^4
10^5
$N_{3\text{-}50}$, CDP [L^{-1}]
CIP2:
$N_{>100}$=0.0 L^{-1}
0.0 L^{-1}<$N_{>100}$<0.1 L^{-1}
0.1 L^{-1}<$N_{>100}$<1.0 L^{-1}
1.0 L^{-1}<$N_{>100}$
April 4-Flight 11
April 5-Flight 13
April 13-Flight 18
April 19-Flight 25
April 25-Flight 29


CAS > CDP as was seen in TWP-ICE
CIP2:
$N_{>100}$=0.0 L^{-1}
0.0 L^{-1}<$N_{>100}$<0.1 L^{-1}
0.1 L^{-1}<$N_{>100}$<1.0 L^{-1}
1.0 L^{-1}<$N_{>100}$
April 4-Flight 11
April 5-Flight 13
April 13-Flight 18
April 19-Flight 25
April 25-Flight 29
$N_{3\text{-}50}$, CAS [L^{-1}]
$N_{3\text{-}50}$, CDP [L^{-1}]
10^0
10^1
10^2
10^3
10^4
10^5


CAS > CDP as was seen in TWP-ICE
CAS/CDP Ratio Increases
CIP2:
N>100=0.0 L-1
0.0 L-1<N>100<0.1 L-1
0.1 L-1<N>100<1.0 L-1
1.0 L-1<N>100
April 4-Flight 11
April 5-Flight 13
April 13-Flight 18
April 19-Flight 25
April 25-Flight 29
N3-50, CAS [L-1]
N3-50, CDP [L-1]
10^0
10^1
10^2
10^3
10^4
10^5

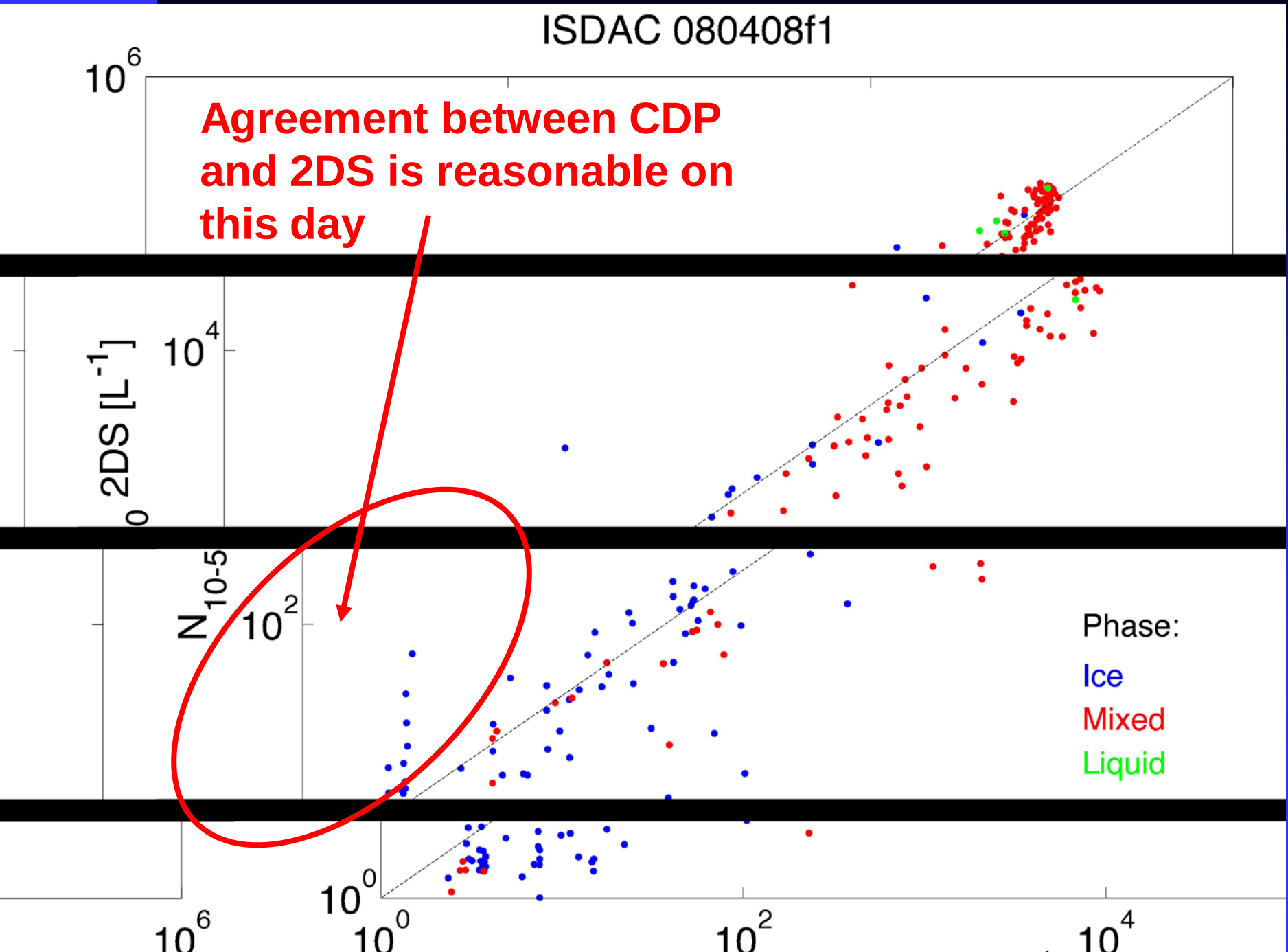

10^5
10^4
10^3
10^2
10^1
10^0
$N_{3\text{-}50}$, FSSP096 [L^{-1}]
10^0
10^1
10^2
10^3
10^4
10^5
$N_{3\text{-}50}$, CDP [L^{-1}]
CIP2:
$N_{>100}$=0.0 L^{-1}
0.0 L^{-1}<$N_{>100}$<0.1 L^{-1}
0.1 L^{-1}<$N_{>100}$<1.0 L^{-1}
1.0 L^{-1}<$N_{>100}$
April 4-Flight 11
April 5-Flight 13
April 13-Flight 18
April 19-Flight 25
April 25-Flight 29

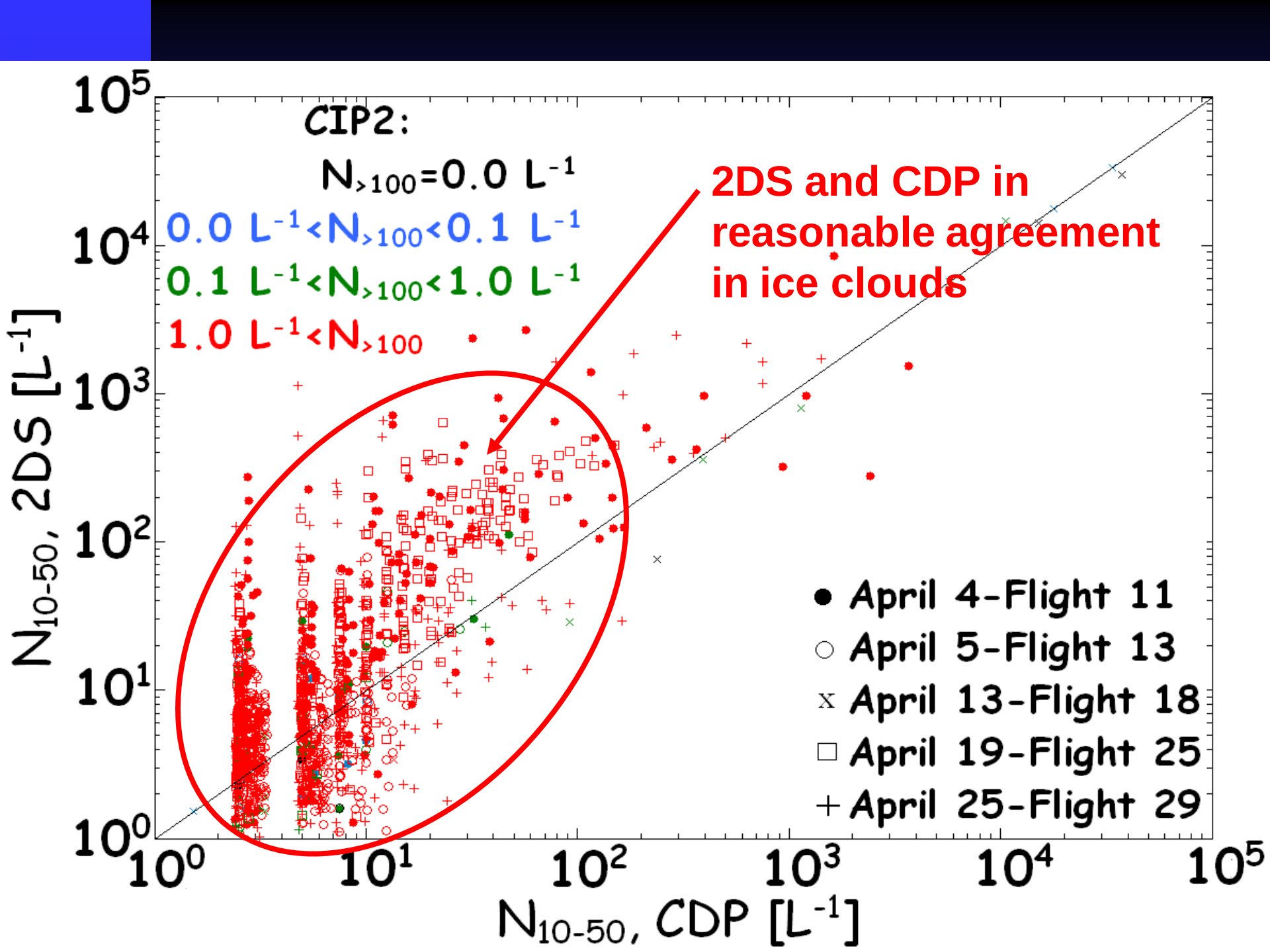

FSSP > CDP for all ice clouds
CIP2:
N>100=0.0 L-1
0.0 L-1<N>100<0.1 L-1
0.1 L-1<N>100<1.0 L-1
1.0 L-1<N>100
April 4-Flight 11
April 5-Flight 13
April 13-Flight 18
April 19-Flight 25
April 25-Flight 29
N3-50, FSSP096 [L-1]
N3-50, CDP [L-1]
10^0
10^1
10^2
10^3
10^4
10^5

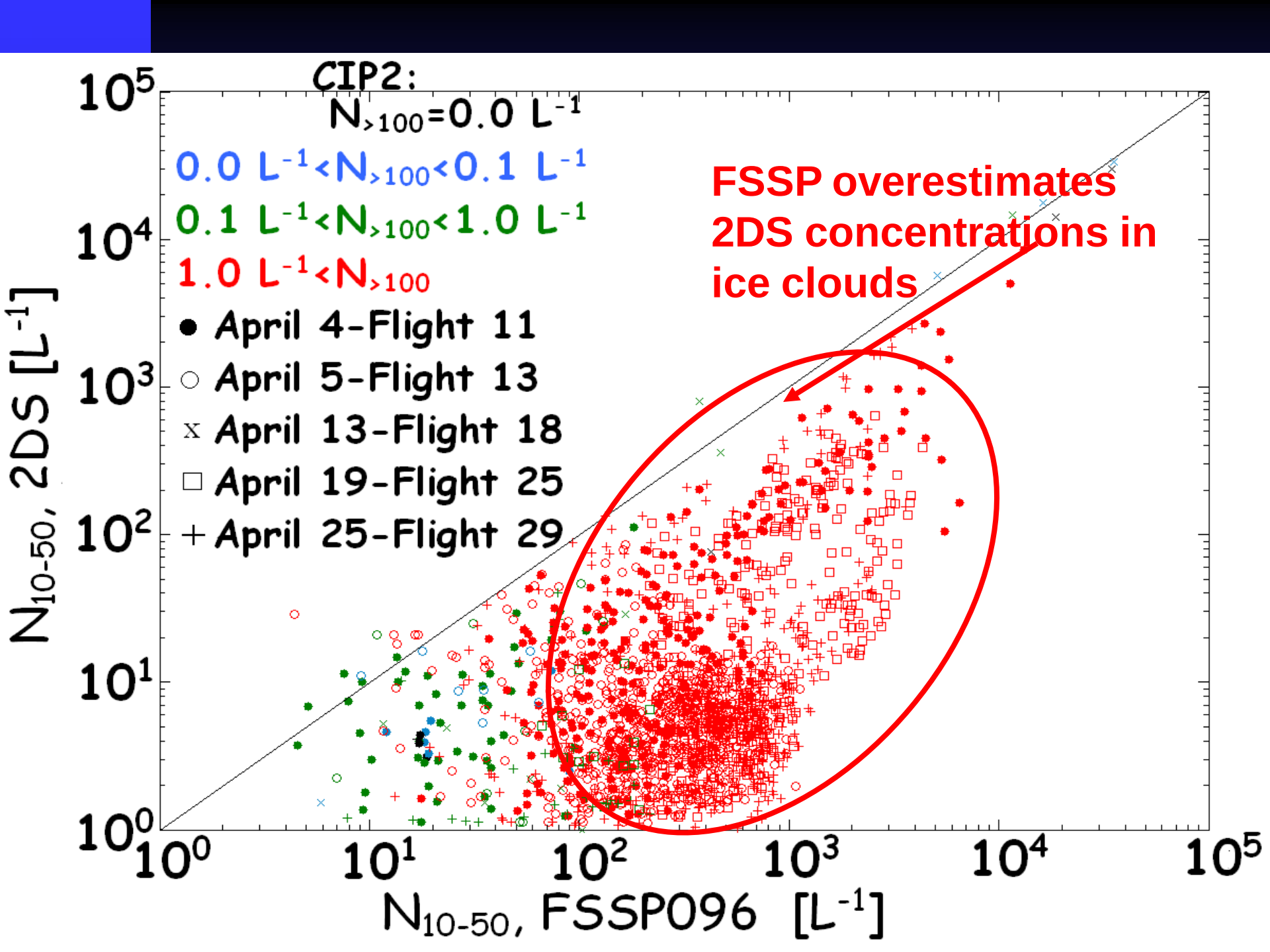

FSSP > CDP for all ice clouds irrespective of date
FSSP/CDP Ratio Increases
CIP2:
N>100=0.0 L-1
0.0 L-1<N>100<0.1 L-1
0.1 L-1<N>100<1.0 L-1
1.0 L-1<N>100
April 4-Flight 11
April 5-Flight 13
April 13-Flight 18
April 19-Flight 25
April 25-Flight 29
N3-50, FSSP096 [L-1]
N3-50, CDP [L-1]
10^0
10^1
10^2
10^3
10^4
10^5

SPEC Inc. 2-D Stereo Probe

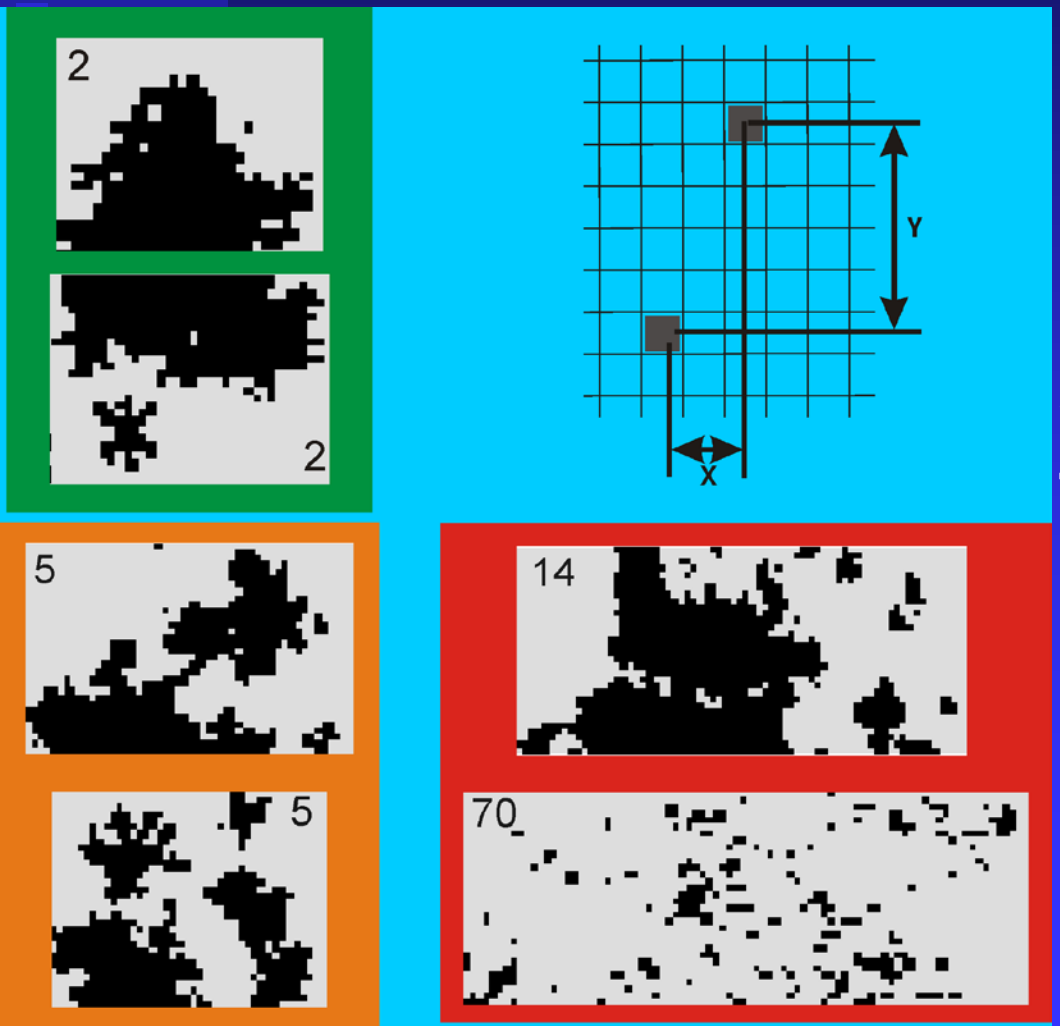
- Two photodiode arrays capture 2-d images of ice particles with D > 10 μm
- Fills void between 50 < D < 125 μm from conventional OAPs
- May help quantify small ice concentrations by resolving shattering debate


ISDAC 080408f1
Agreement between CDP and 2DS is reasonable on this day
10^6
10^4
10^2
10^0
$N_{0\text{-}2DS}$ [L^{-1}]
$N_{10\text{-}5}$
10^6
10^0
10^2
10^4
Phase:
Ice
Mixed
Liquid


CIP2:
$N_{>100}$=0.0 L^{-1}
0.0 L^{-1}<$N_{>100}$<0.1 L^{-1}
0.1 L^{-1}<$N_{>100}$<1.0 L^{-1}
1.0 L^{-1}<$N_{>100}$
2DS and CDP in reasonable agreement in ice clouds
April 4-Flight 11
April 5-Flight 13
April 13-Flight 18
April 19-Flight 25
April 25-Flight 29
$N_{10\text{-}50}$, 2DS [L^{-1}]
$N_{10\text{-}50}$, CDP [L^{-1}]
10^0
10^1
10^2
10^3
10^4
10^5


CIP2:
$N_{>100}$=0.0 L^{-1}
0.0 L^{-1}<$N_{>100}$<0.1 L^{-1}
0.1 L^{-1}<$N_{>100}$<1.0 L^{-1}
1.0 L^{-1}<$N_{>100}$
April 4-Flight 11
April 5-Flight 13
April 13-Flight 18
April 19-Flight 25
April 25-Flight 29
FSSP overestimates 2DS concentrations in ice clouds
$N_{10\text{-}50}$, 2DS [L^{-1}]
$N_{10\text{-}50}$, FSSP096 [L^{-1}]
10^0
10^1
10^2
10^3
10^4
10^5

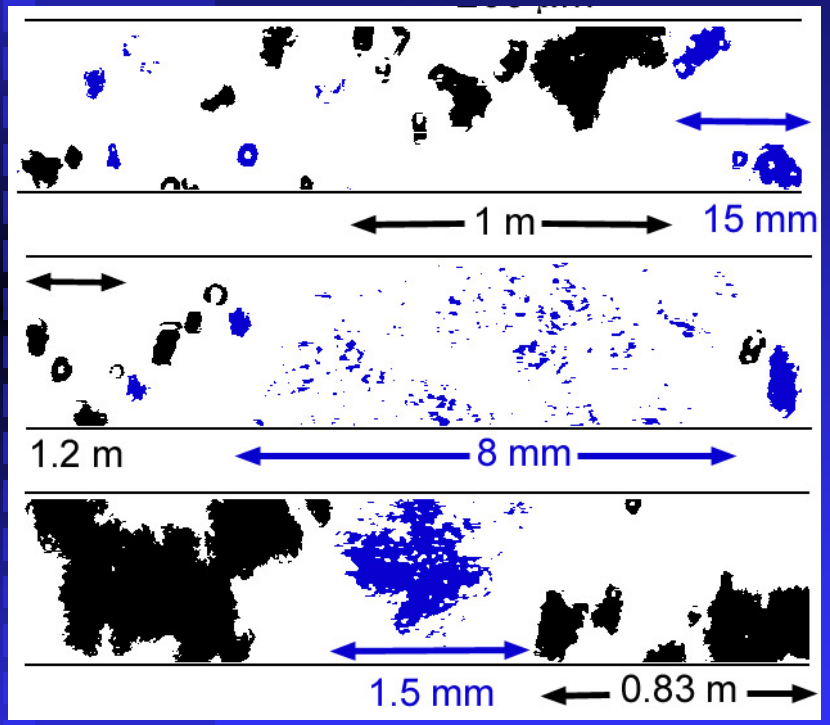
Shattering can also have impact on optical array probe data:
-Set of criteria for identifying images of shattered particles



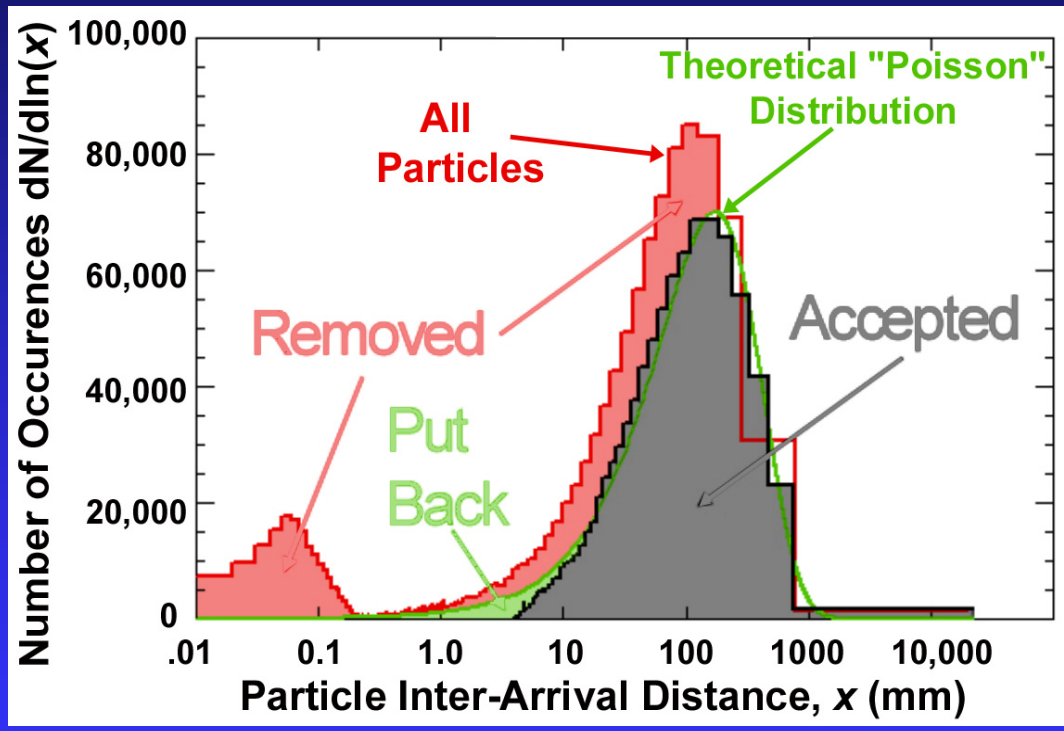
1. Number of fragments
2. Relative size of fragments
3. Gaps in X and Y directions
4. Area density

Korolev et al.

Technique to Adjust Measurements for the Effects of Shattered Ice Particles (i.e., Artifacts)

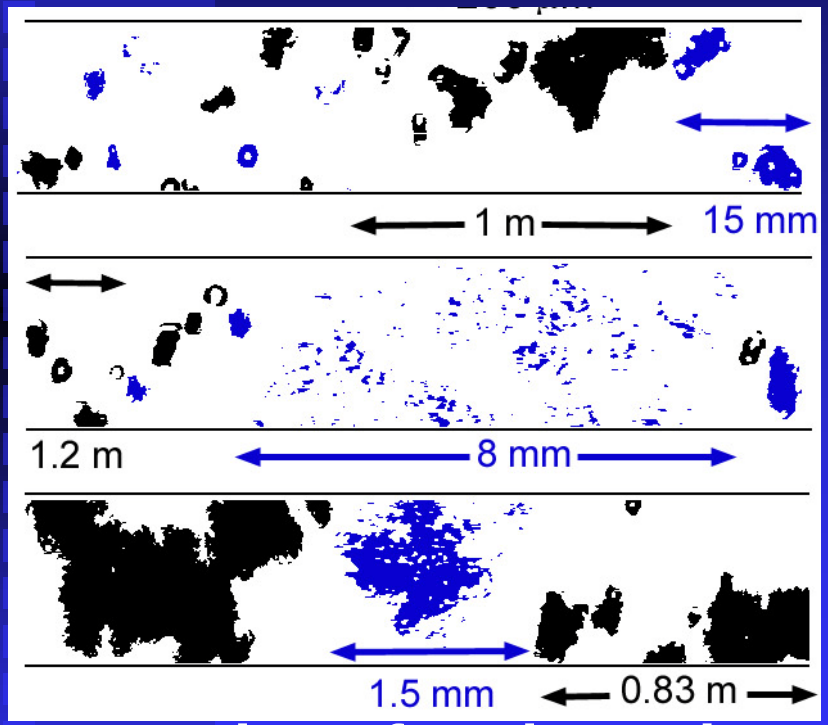


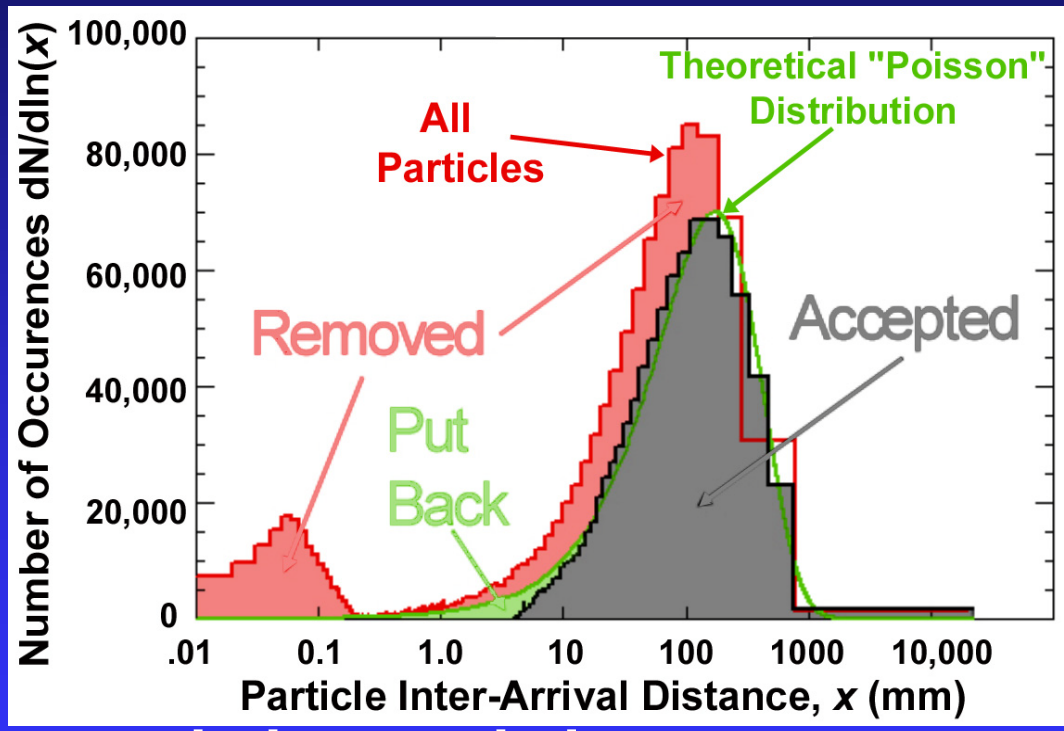
Lawson et al.



Technique to Adjust Measurements for the Effects of Shattered Ice Particles (i.e., Artifacts)

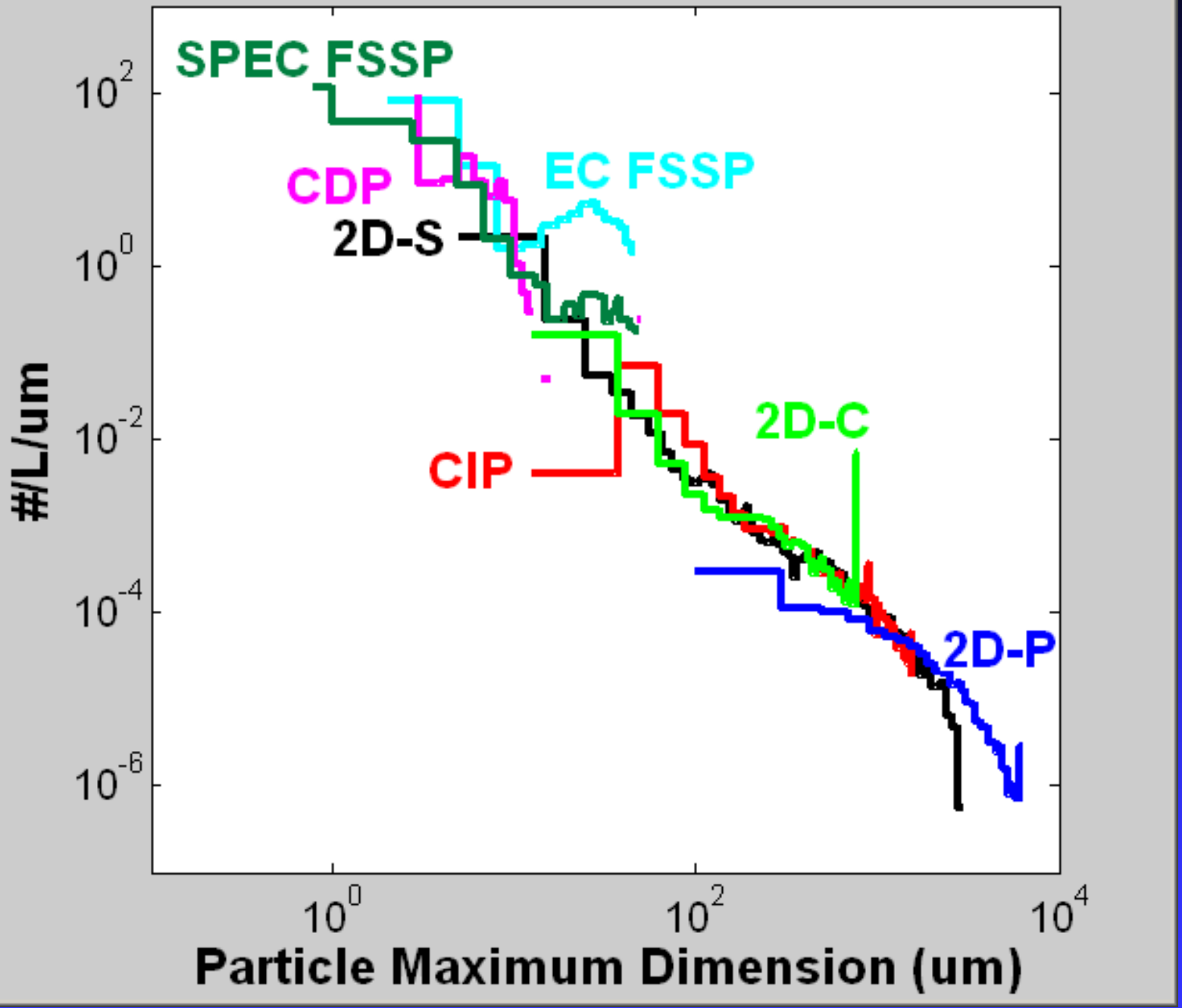
Lawson et al.



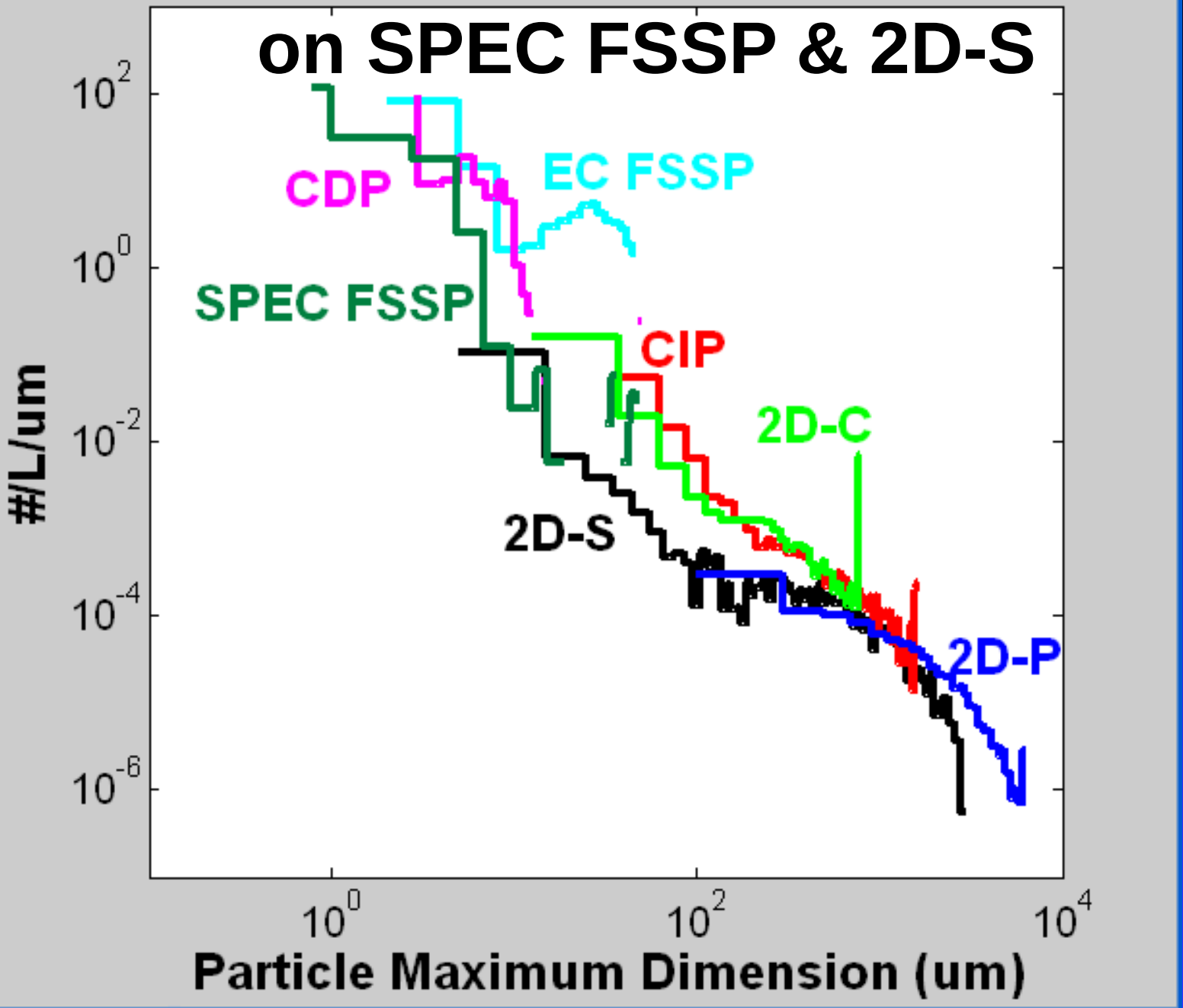


Corrections for shattering events being made by ISDAC PIs (Korolev, Lawson, McFarquhar) for imaging probes; SPEC FSSP records interarrival times and also permits shattering events to be removed

Shattered Particles are Included



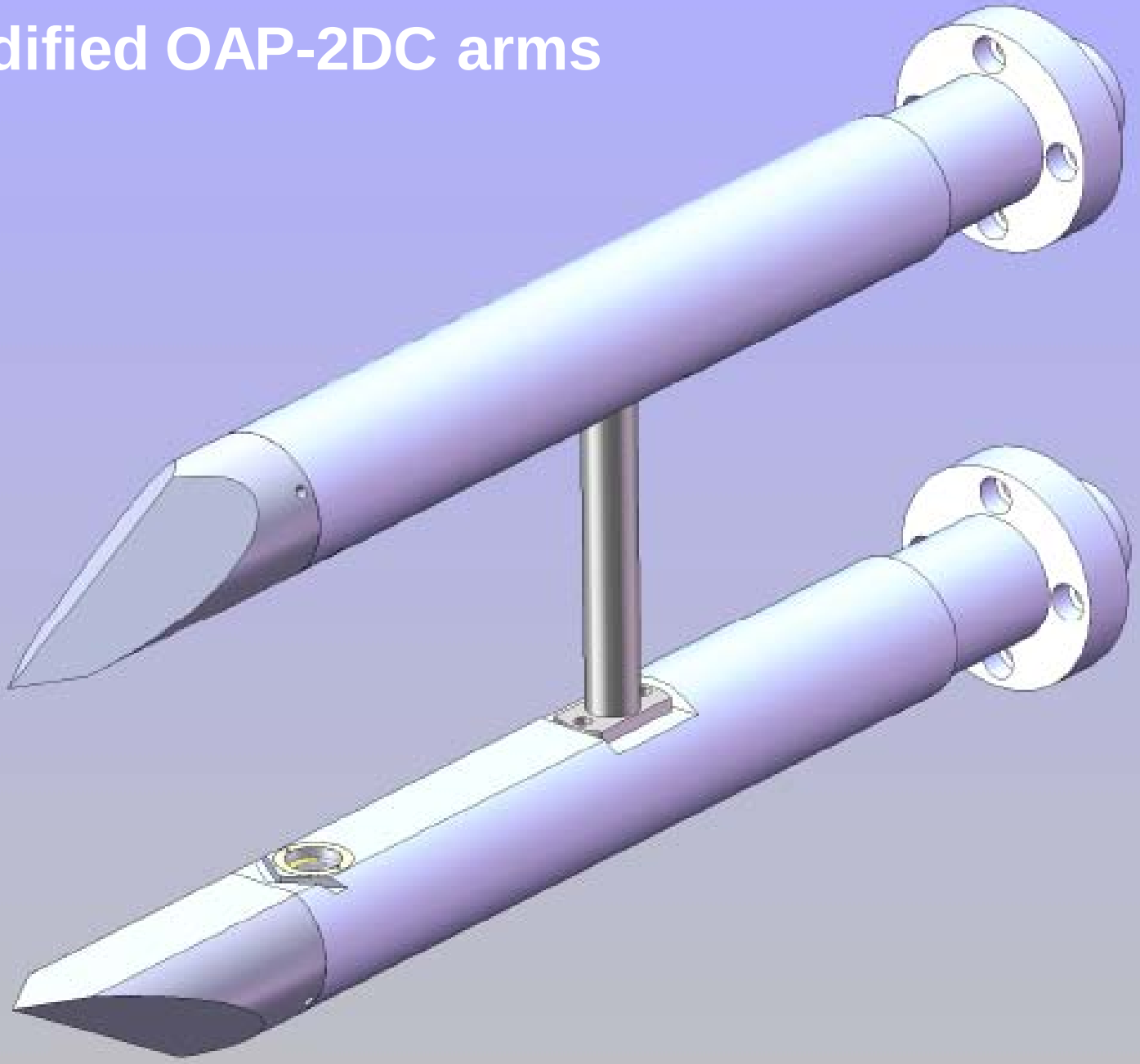
Shattered Particles are Removed on SPEC FSSP & 2D-S



Comparison of Bulk Properties with/without Shattering

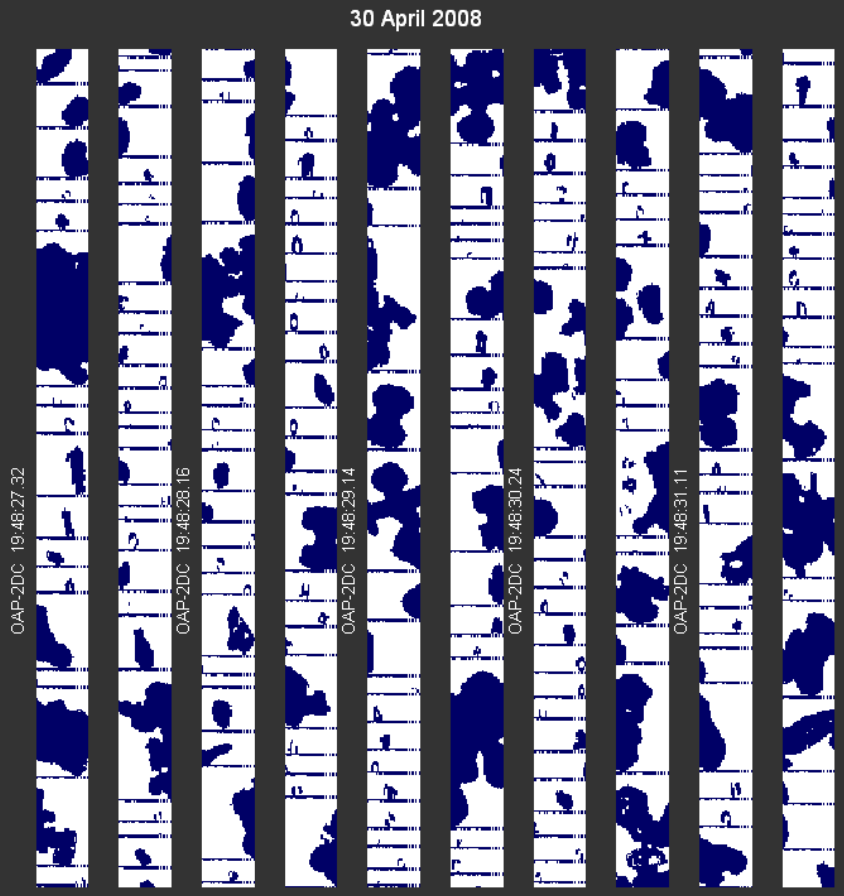
	Conc. (L^{-1})	Ext. (Km^{-1})	TWC ($g\ m^{-3}$)	R_{EFF} (um)	dBz
With Shatter	81.2	0.14	0.006	71.5	-2.61
Shatter Remove	36.6	0.09	0.004	79.5	-3.97
CSI TWC			0.008		
Nev. LWC TWC			0.003 0.001		
Trans. Ext.		1.69			

Modified OAP-2DC arms

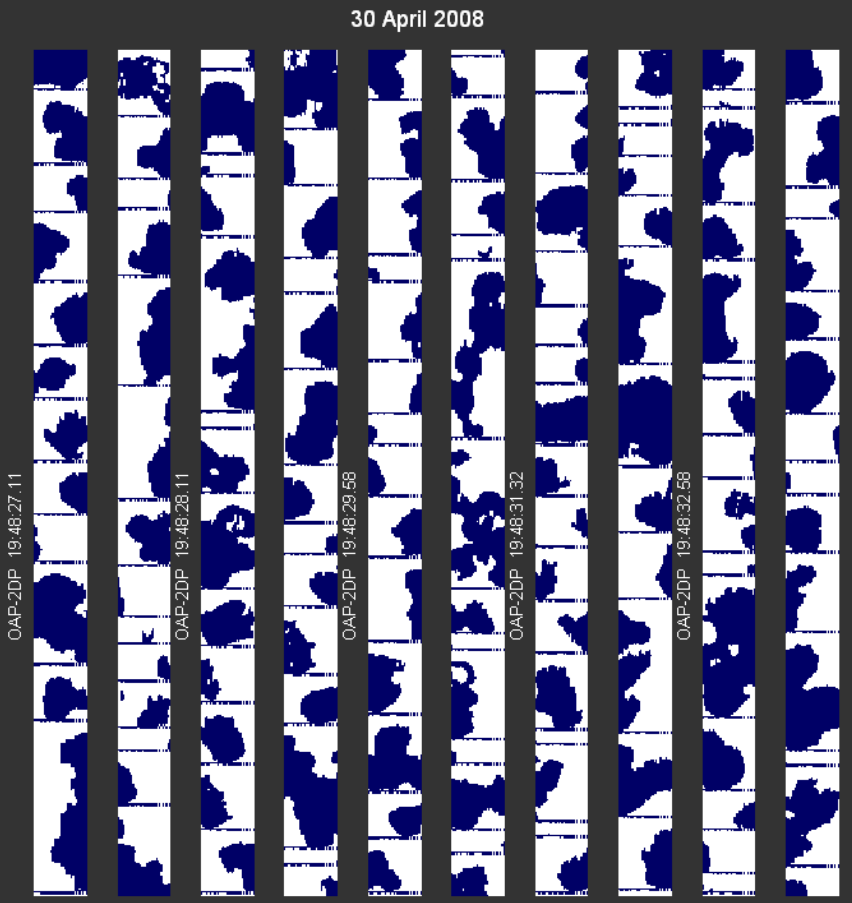


30 April 2008, NRC Convair 580, ISDAC, Fairbanks

Standard OAD-2DC arms



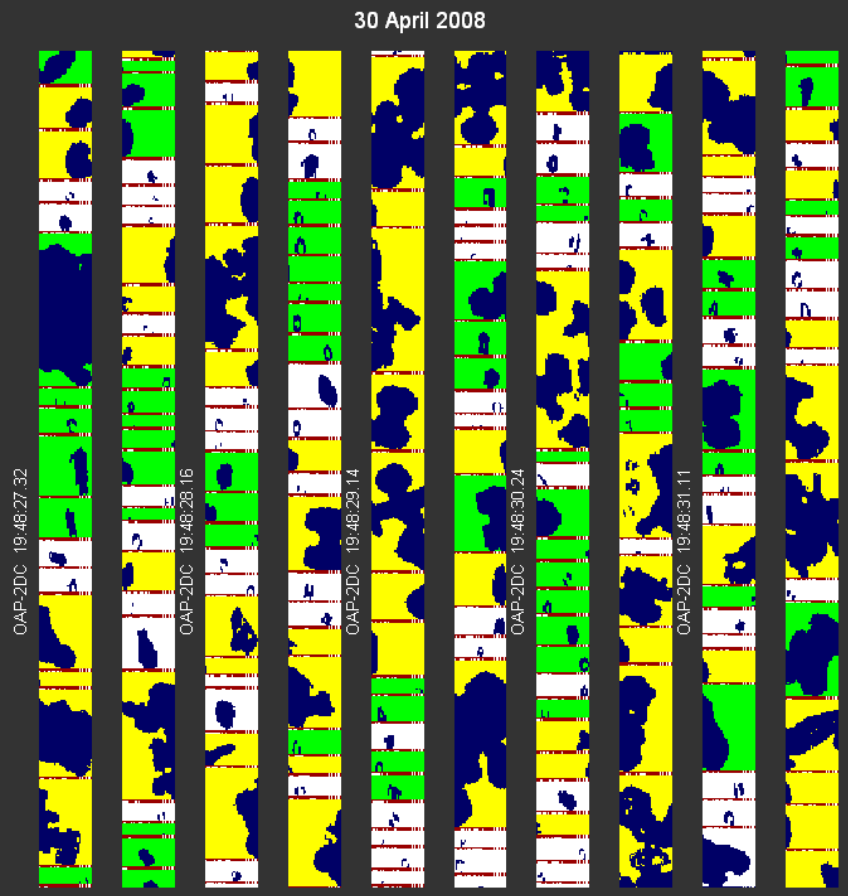
Modified OAD-2DC arms



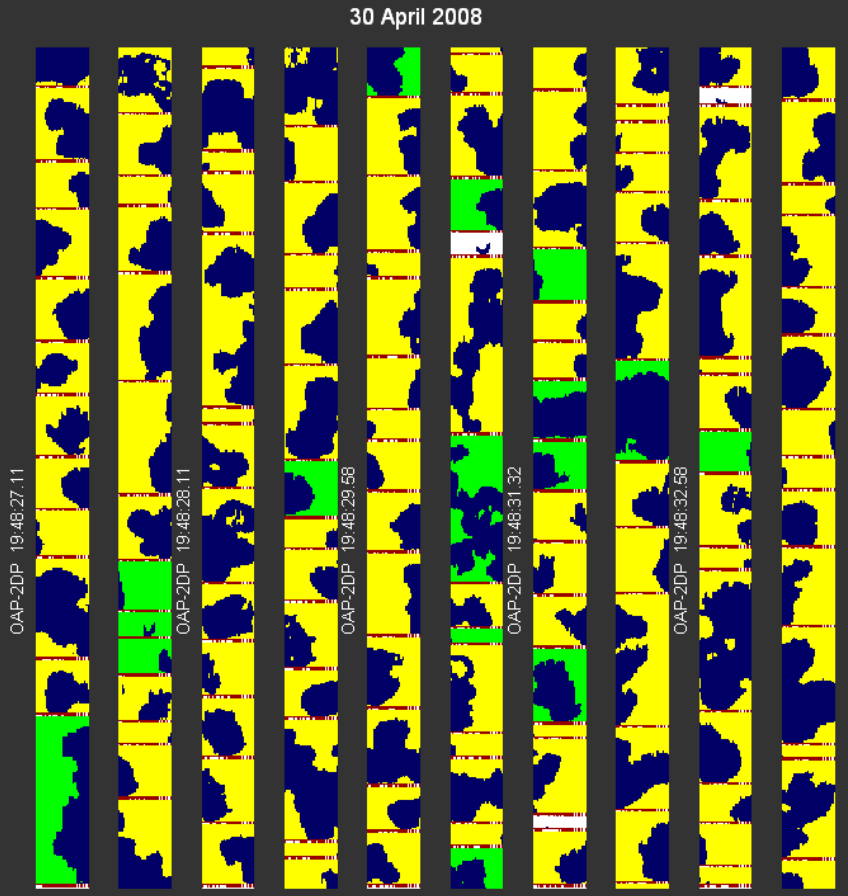
Rejected and accepted OAP-2DC images

τ_{rej}=1000 tics ⇔ ΔX=2.5cm

Standard OAD-2DC arms



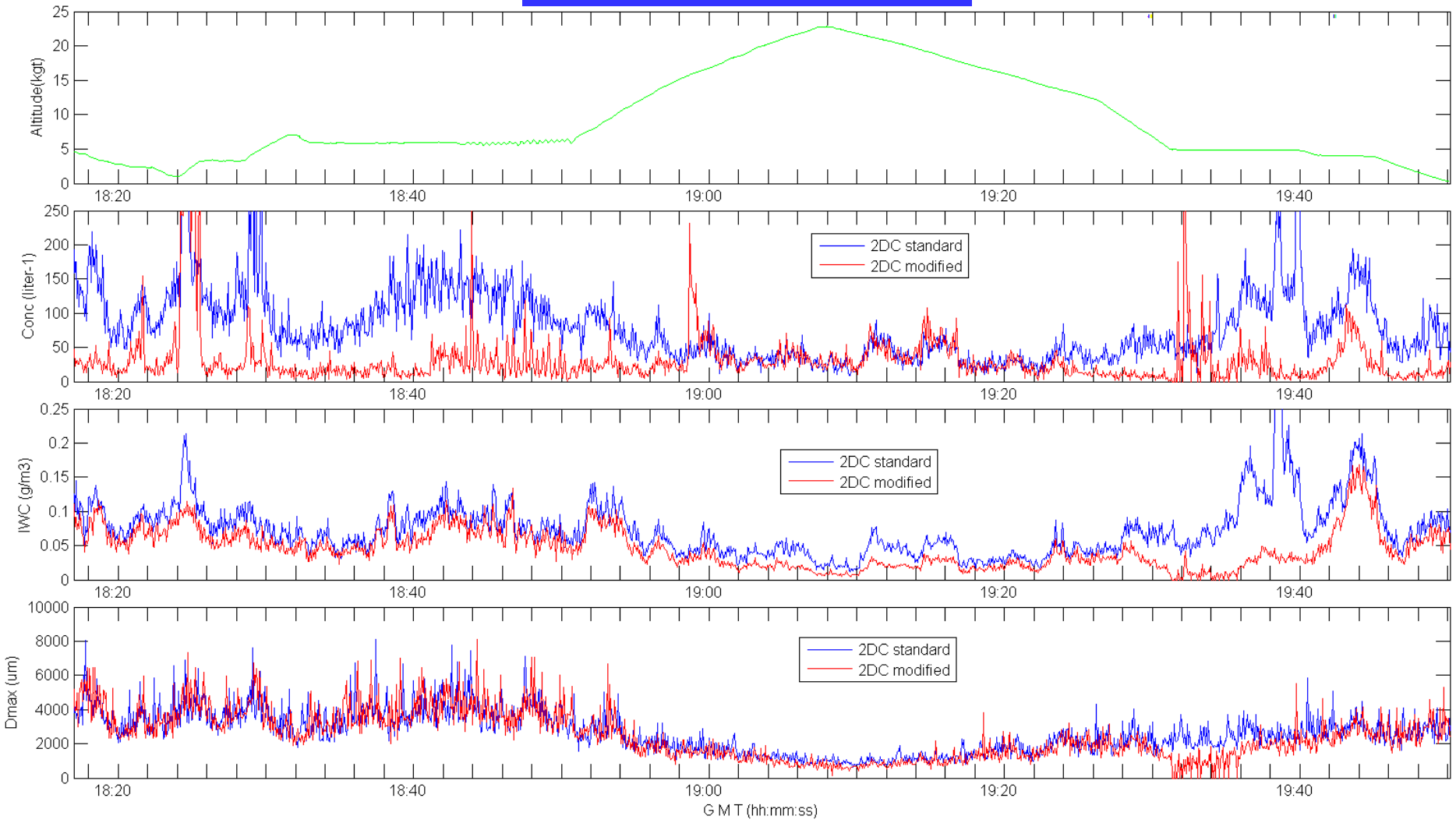
Modified OAD-2DC arms



interarrival time aspect ratio partial images complete images

Comparison of OAP-2DC with modified and standard arms

30 April 2008, ISDAC, Fairbanks



Korolev et al.

ISDAC - NRC Convair-580 Flight Hours

Date	Flight	From	To	Start	End	hrs
03/21/08	F01-Test-01	Ottawa	Ottawa	16:15Z	18:15Z	2.2
03/22/08	F02-Test-02	Ottawa	Ottawa	12:45Z	15:50Z	3.3
03/28/08	F03-Transit-01	Ottawa, ON	Kenora, ON	12:23Z	15:44Z	3.6
03/28/08	F04-Transit-02	Kenora, ON	Calgary, AB	16:30Z	19:36Z	3.3
03/28/08	F05-Transit-03	Calgary, AB	Comox, BC	20:24Z	22:17Z	2.1
03/29/08	F06-Transit-04	Comox, BC	Whitehorse, YK	17:43Z	20:50Z	3.3
03/29/08	F07-Transit-05	Whitehorse, YK	Fairbanks	21:51Z	23:42Z	2.1
03/31/08	F08-Test-03	Fairbanks	Fairbanks	20:00Z	22:30Z	2.7
04/01/08	F09-Project-01	Fairbanks	Barrow	20:00Z	23:46Z	4
04/01/08	F10-Project-02	Barrow	Fairbanks	00:33 Z	03:33Z	3.2
04/04/08	F11-Project-03	Fairbanks	Barrow	17:36Z	21:23Z	4
04/04/08	F12-Project-04	Barrow	Fairbanks	22:46Z	03:25Z	4.9
04/05/08	F13-Project-05	Fairbanks	Barrow	17:37Z	21:35Z	4.2
04/05/08	F14-Project-06	Barrow	Fairbanks	22:34Z	02:59Z	4.6
04/08/08	F15-Project-07	Fairbanks	Barrow	15:00Z	18:48Z	4
04/08/08	F16-Project-08	Barrow	Barrow	19:54Z	23:36Z	3.9
04/09/08	F17-Project-09	Barrow	Fairbanks	00:12Z	01:58Z	2
04/13/08	F18-Project-10	Fairbanks	Barrow	15:21Z	18:57Z	3.8
04/13/08	F19-Project-11	Barrow	Fairbanks	20:08Z	00:24Z	4.7
04/14/08	F20-Project-12	Fairbanks	Barrow	18:03Z	22:17Z	4.4
04/14/08	F21-Project-13	Barrow	Fairbanks	23:25Z	02:58Z	3.8
04/18/08	F22-Project-14	Fairbanks	Barrow	15:10Z	19:16Z	4.3
04/18/08	F23-Project-15	Barrow	Barrow	20:16Z	00:26Z	4.4
04/19/08	F24-Project-16	Barrow	Fairbanks	01:21Z	03:08 Z	2.0
04/19/08	F25-Project-17	Fairbanks	Barrow	19:37Z	23:41Z	4.3
04/20/08	F26-Project-18	Barrow	Fairbanks	00:37Z	04:31Z	4.1
04/24/08	F27-Project-19	Fairbanks	Barrow	17:18Z	21:12Z	4.1
04/24/08	F28-Project-20	Barrow	Barrow	22:17Z	01:32Z	3.5
04/25/08	F29-Project-21	Barrow	Fairbanks	02:16Z	05:54Z	3.8
04/26/08	F30-Project-22	Fairbanks	Barrow	18:49Z	22:36Z	4.0

Lots of data were collected during ISDAC

Not just on golden days, but many other days

Explore the data!!

Data Availability

- Most data sets have been placed on archive
- A very few are awaiting final calibrations before being released on archive
- Determining higher order data products is subject of some ARM science team proposals
- More details will be discussed at the ISDAC Breakout Session