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Particle Size Distributions collected from NRC Convair580 during HIWC Cayenne field campaign (May 2015)

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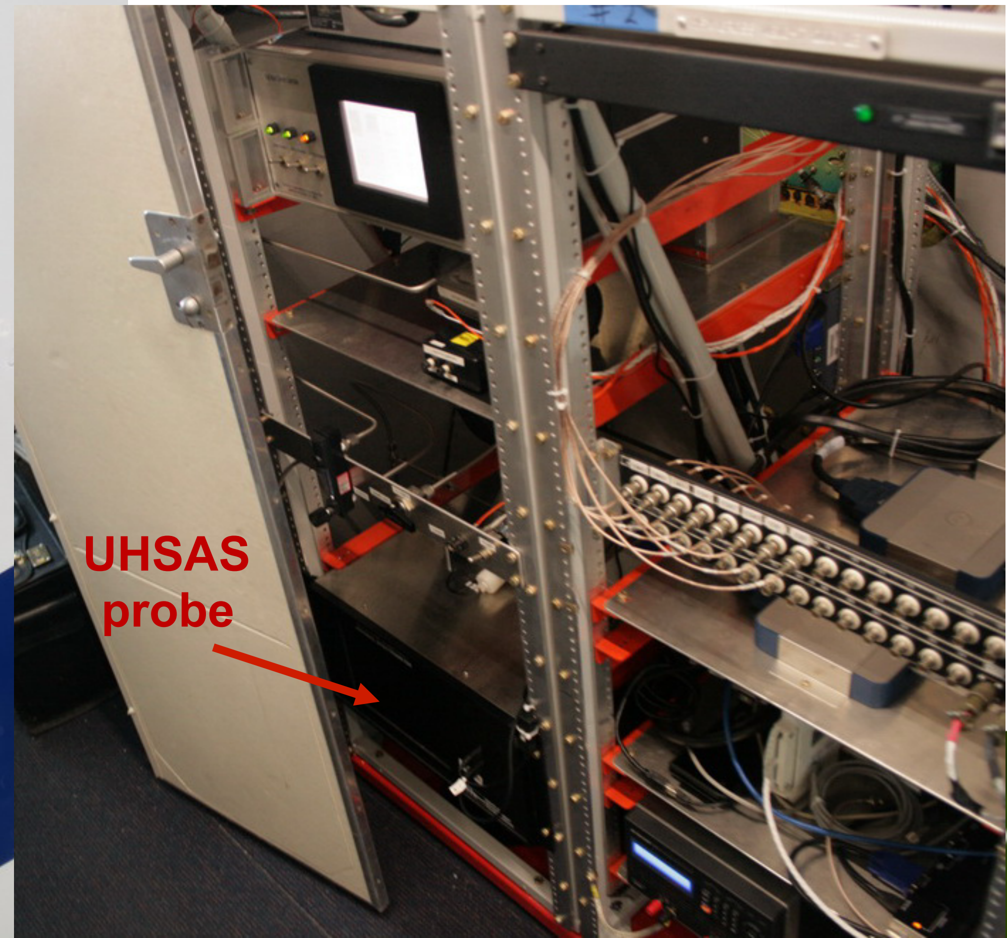
Overview

1. Aerosol PSD: PCASP
2. Cloud droplet DSD: FSSP, CDP
3. Cloud particle PSD: 2DS, PIP, CIP, 2DC

Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)

nominal size range 60nm -1μm



Particle probes performance matrix

Flight#	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Date	10-May-15	12-May-15	14-May-15	15-May-15	16-May-15	16-May-15	20-May-15	23-May-15	23-May-15	25-May-15	26-May-15	26-May-15	27-May-15	27-May-15
UHSAS	G	G	M+	G	M+	G	N	G	M+	G	N	N	N	N
FSSP	G	G	G	G	G	G	G	G	G	G	G	G	G	G
CDP	G	G	G	G	G	G	G	G	G	G	G	M	G	G
OAP-2DC	G	G	G	G	G	G	G	G	G	G	G	G	G	M
OAP-2DP	M	M	G	M	M	M	M	M	M	M	M	M	M	M
PIP	G	G	G	G	G	G	G	G	G	G	G	M	G	G
CIP	M	M	N	M	N	M	G	G	G	G	G	G	G	G
2DS-H	N	M-	M	G	G	G	M	G	M	G	G	G	G	G
2DS-V	N	M-	M	G	G	G	M	G	M	M	N	N	M	N
CPI	G	G	G	G	G	G	G	G	G	G	G	G	G	G

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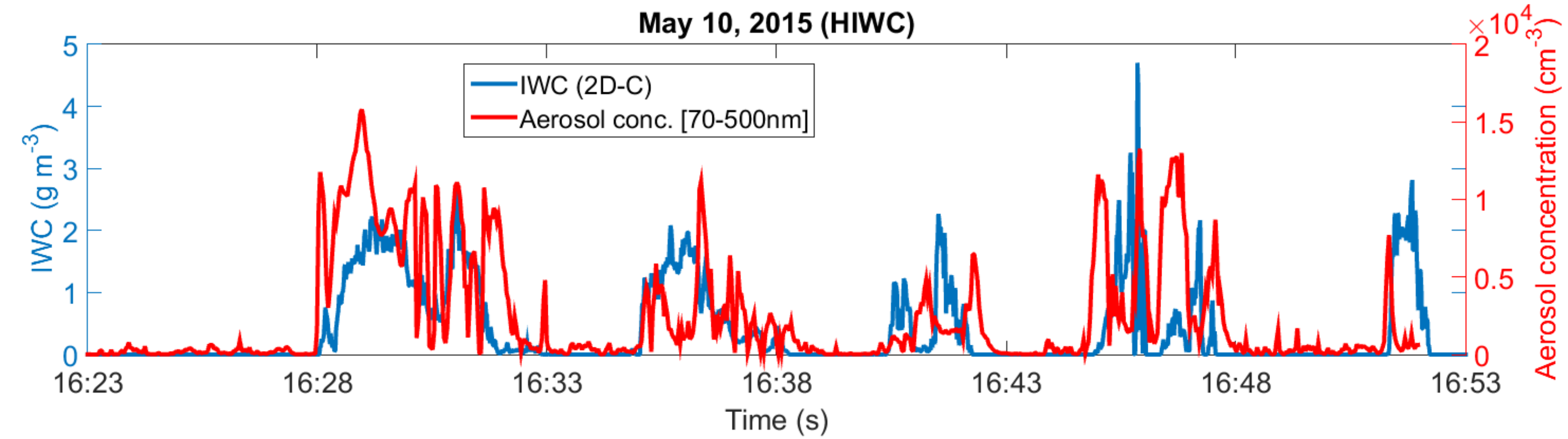
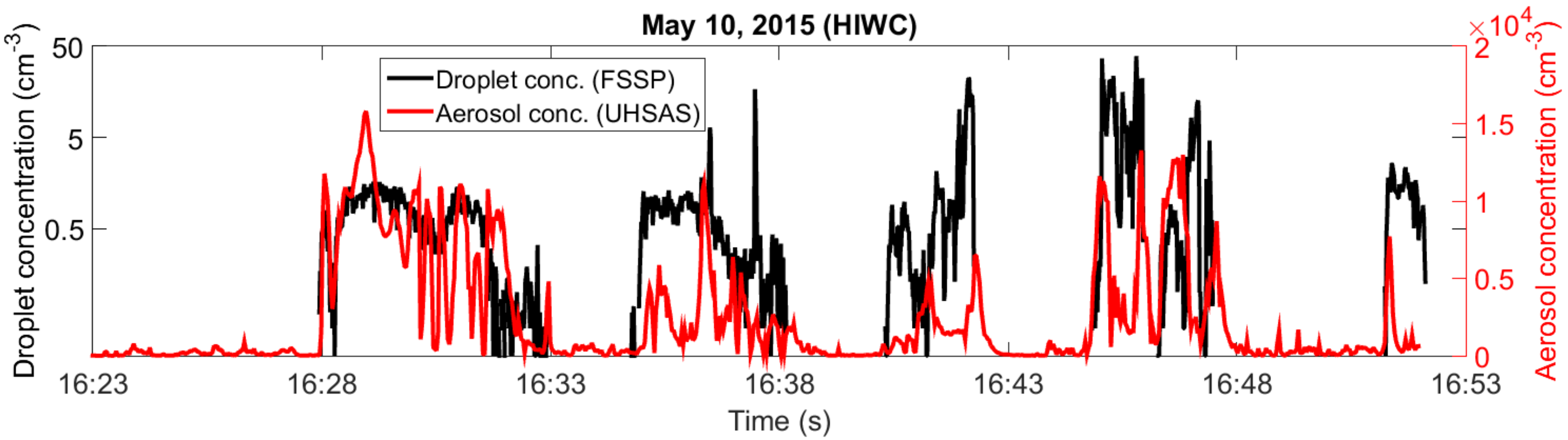
- UHSAS measurements are contaminated by artifacts, when sampling inside clouds.
- In-cloud UHSAS measurements were excluded from analysis





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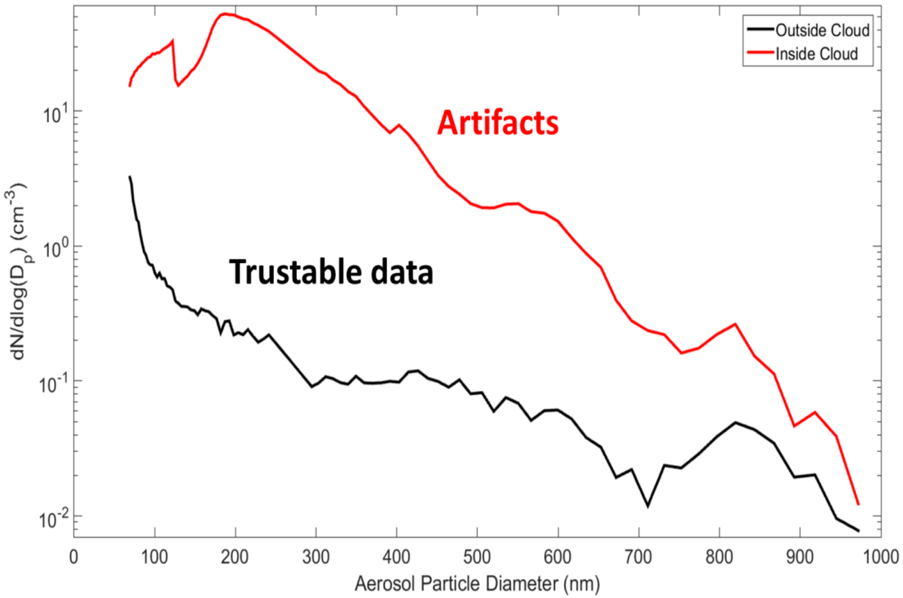
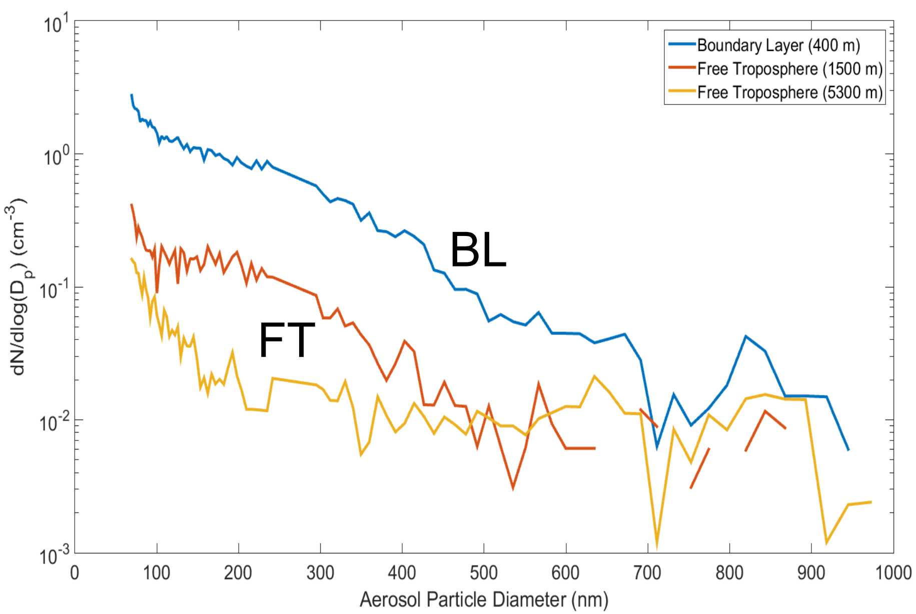


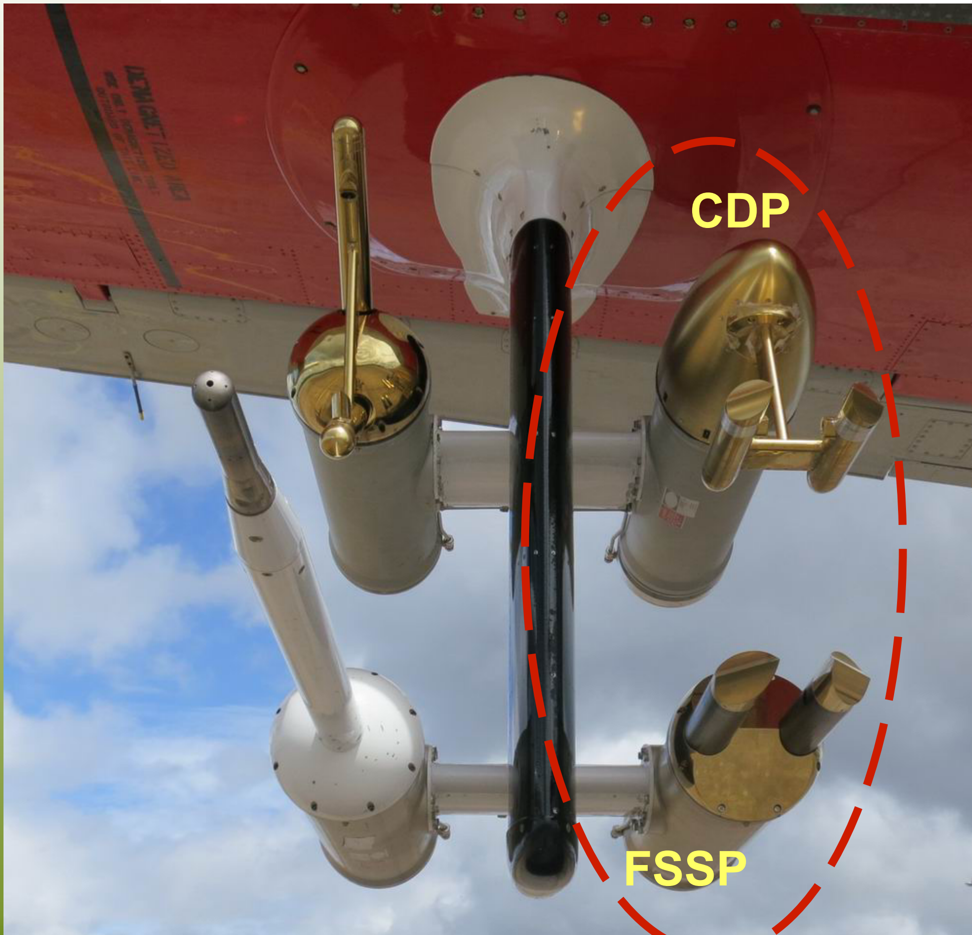
Examples of averaged aerosol particle size distributions out-side and in-side clouds.

UHSAS particle size range: 70 nm 1 μm.



Example of the aerosol size distributions measured in the boundary layer (blue) and free troposphere (red and orange).

Scattering particle probes: FSSP, CDP

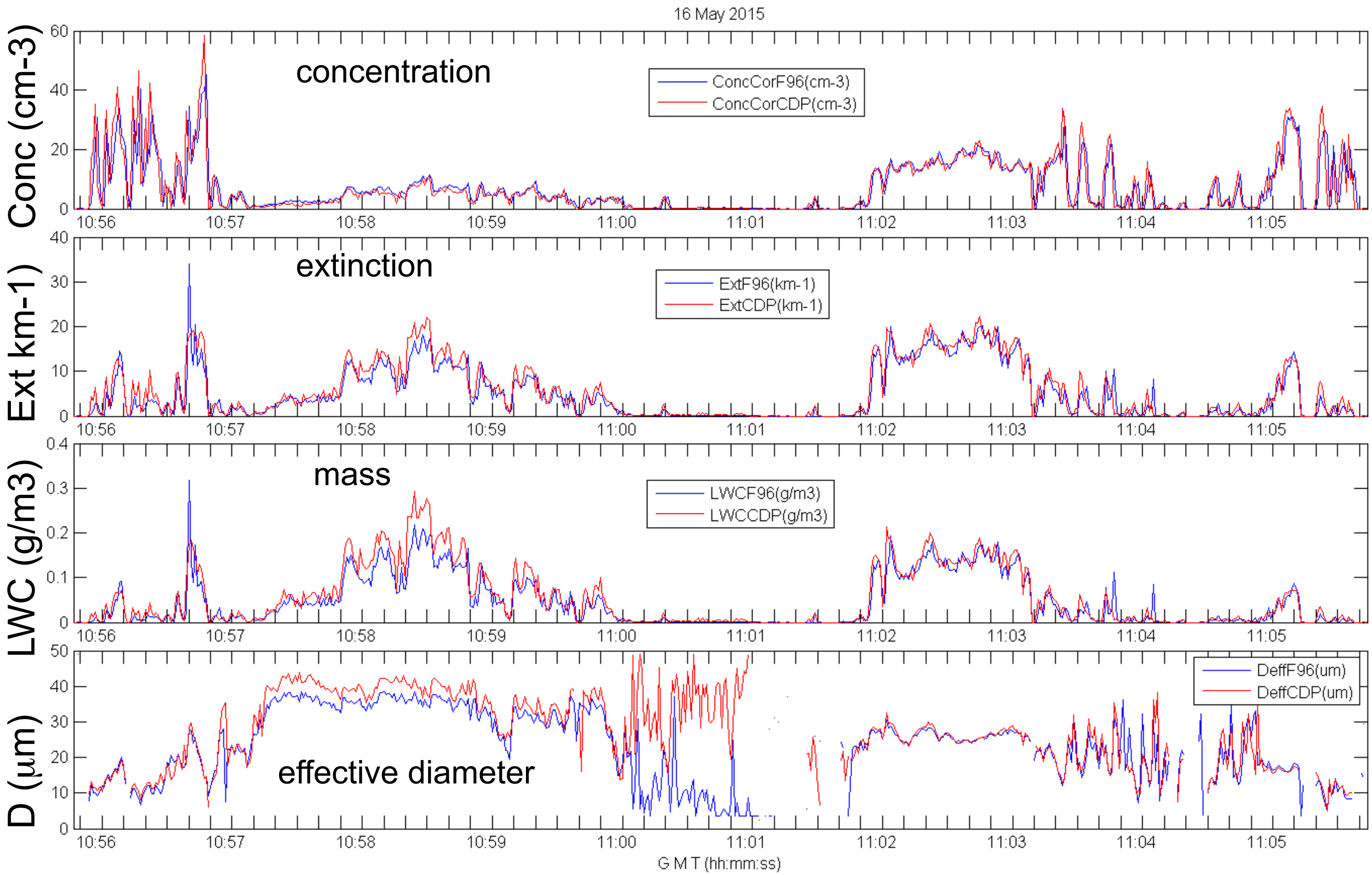


<u>nominal size ranges</u>
FSSP 2-32μm or 2-47um
CDP 2-50μm

Particle probes performance matrix

Flight#	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Date	10-May-15	12-May-15	14-May-15	15-May-15	16-May-15	16-May-15	20-May-15	23-May-15	23-May-15	25-May-15	26-May-15	26-May-15	27-May-15	27-May-15
UHSAS	G	G	M+	G	M+	G	N	G	M+	G	N	N	N	N
FSSP	G	G	G	G	G	G	G	G	G	G	G	G	G	G
CDP	G	G	G	G	G	G	G	G	G	G	G	M	G	G
OAP-2DC	G	G	G	G	G	G	G	G	G	G	G	G	G	M
OAP-2DP	M	M	G	M	M	M	M	M	M	M	M	M	M	M
PIP	G	G	G	G	G	G	G	G	G	G	G	M	G	G
CIP	M	M	N	M	N	M	G	G	G	G	G	G	G	G
2DS-H	N	M-	M	G	G	G	M	G	M	G	G	G	G	G
2DS-V	N	M-	M	G	G	G	M	G	M	M	N	N	M	N
CPI	G	G	G	G	G	G	G	G	G	G	G	G	G	G

FSSP and CDP response in liquid clouds



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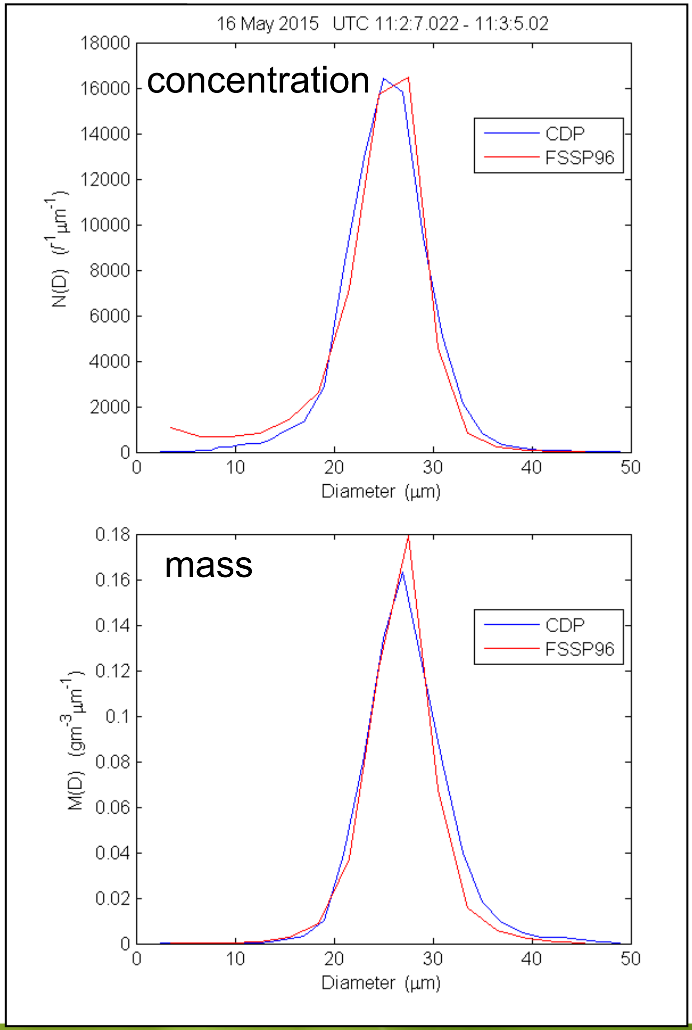
FSSP and CDP response in liquid clouds



- In liquid and mixed phase clouds the agreement between FSSP and CDP size and mass distributions appeared to be within 10-15% accuracy as long as Dmax is within the FSSP nominal size range (i.e. Dmax<47um)

- For cases with large droplets Dmax>50um the difference between the FSSP and CDP measurements may exceed 100%.

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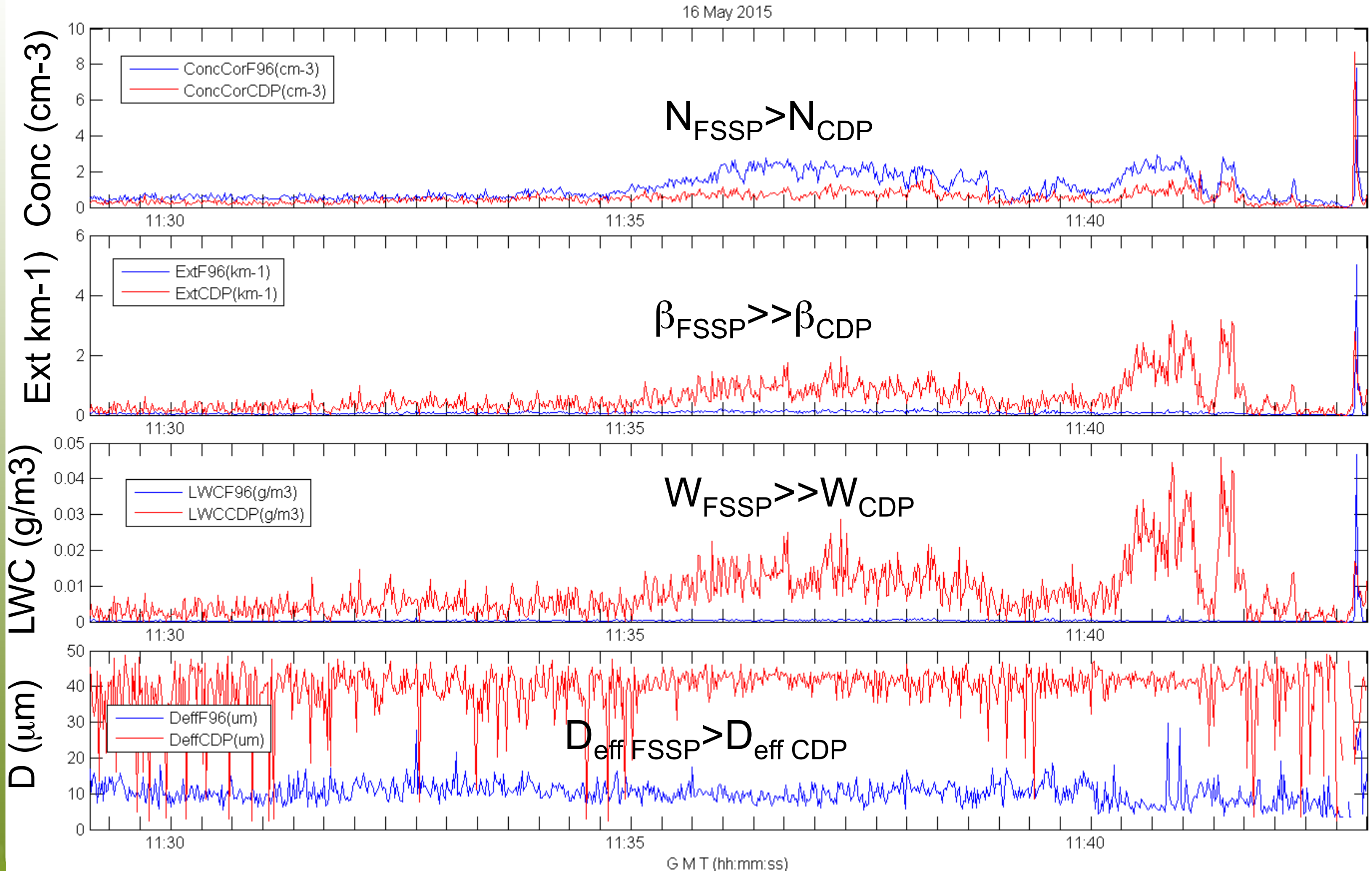
FSSP and CDP response in ice clouds



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Comparisons of PSDs measured by particle probes

Ice clouds

•FSSP has enhanced response to ice particles in 'junior' bins

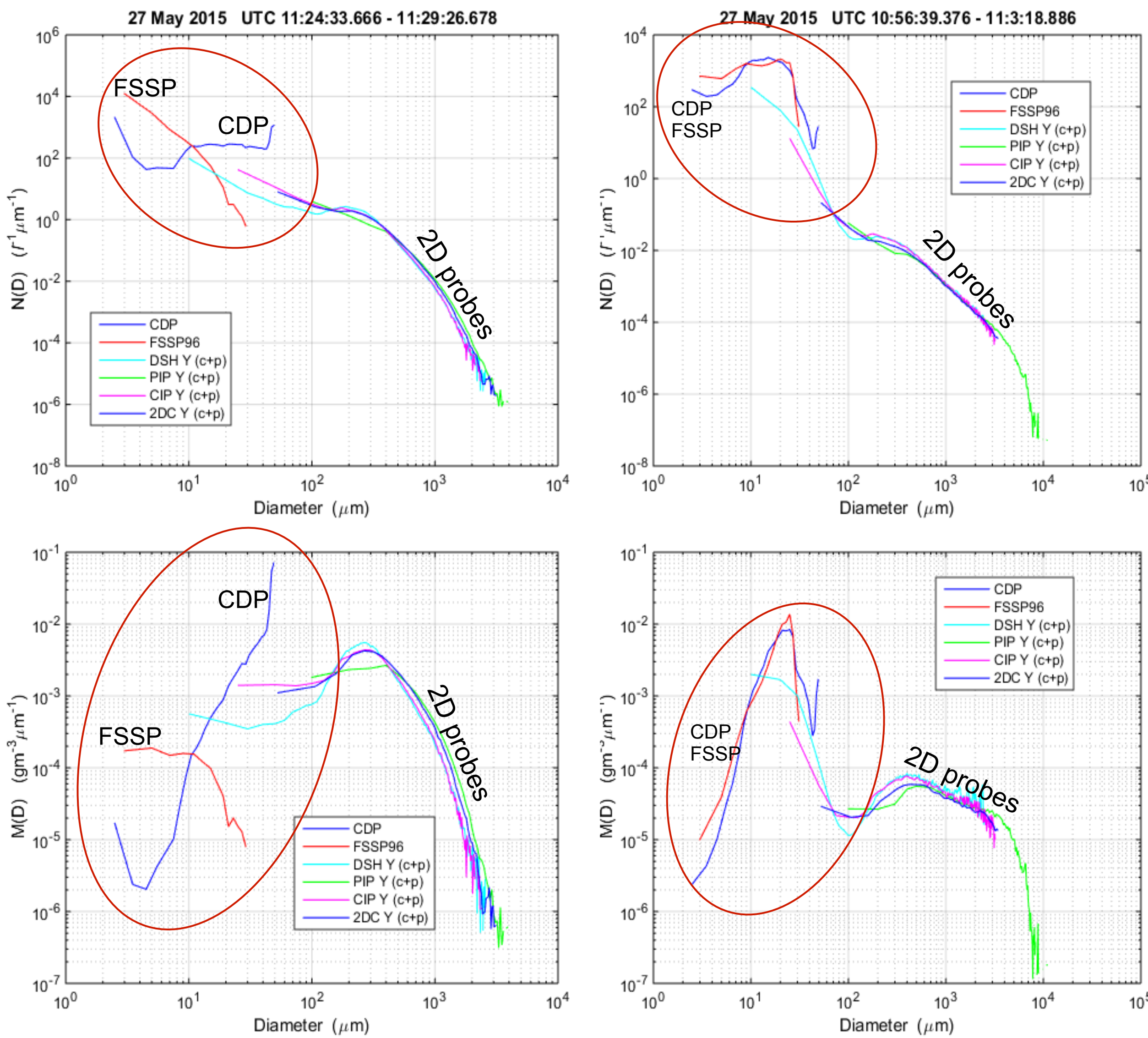
•CDP has enhanced response in 'senior' size bins

•FSSP & CDP measurements in ice clouds should not be used with caution

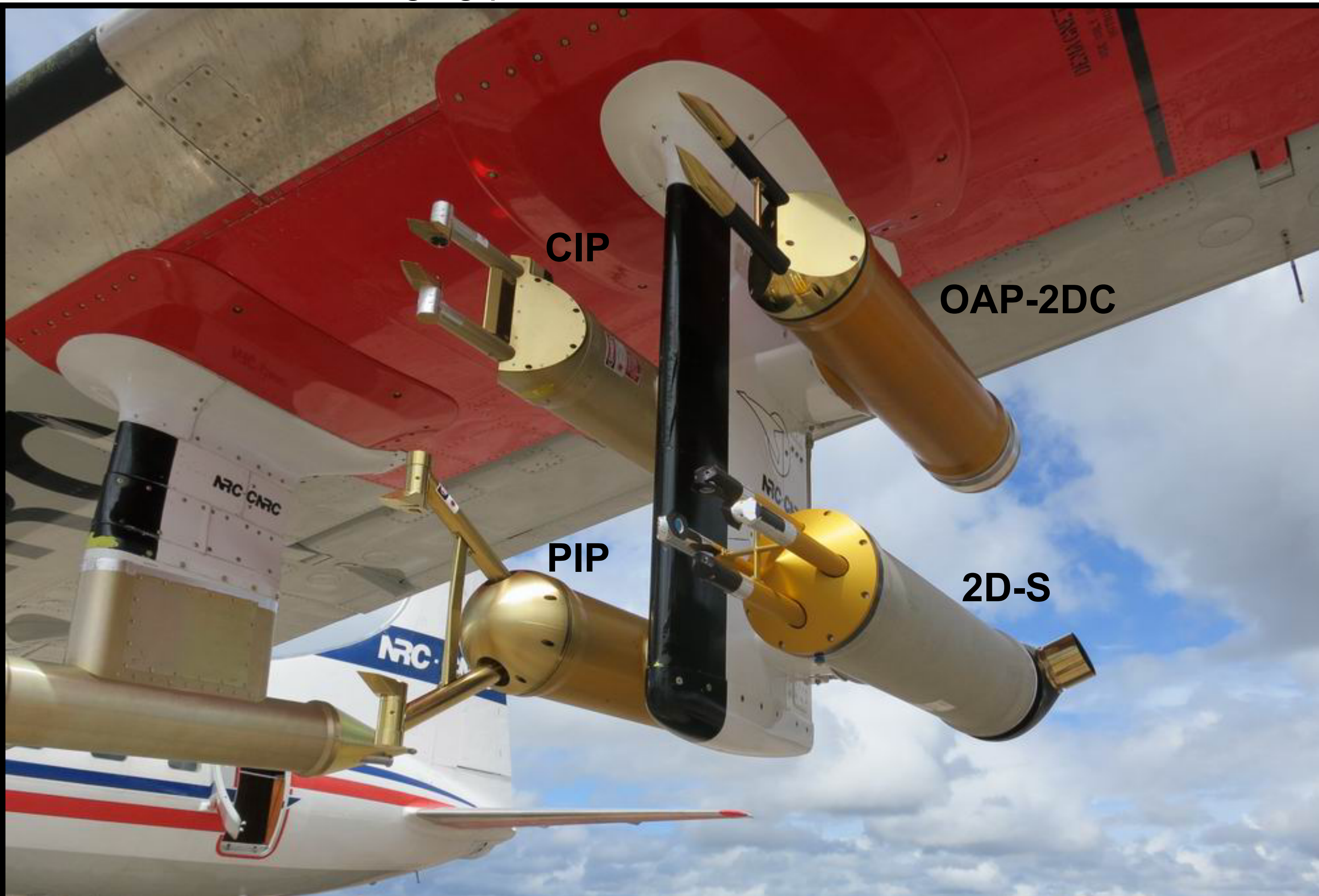
Mixed phase & liquid clouds

FSSP and CDP size distributions are consistent with 2D probes' PSDs in overlapping areas

ice cloud **mixed phase cloud**

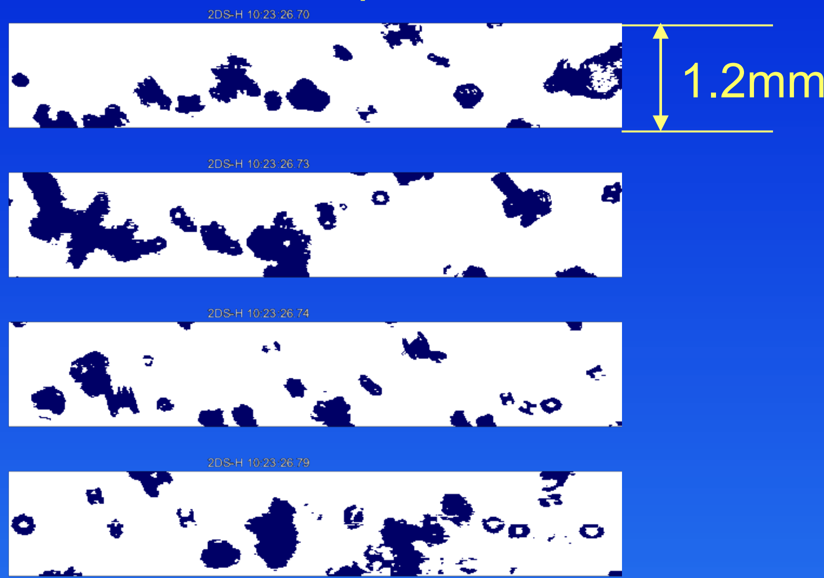


2D imaging probes: 2D-S, CIP, OAP-2DC, PIP

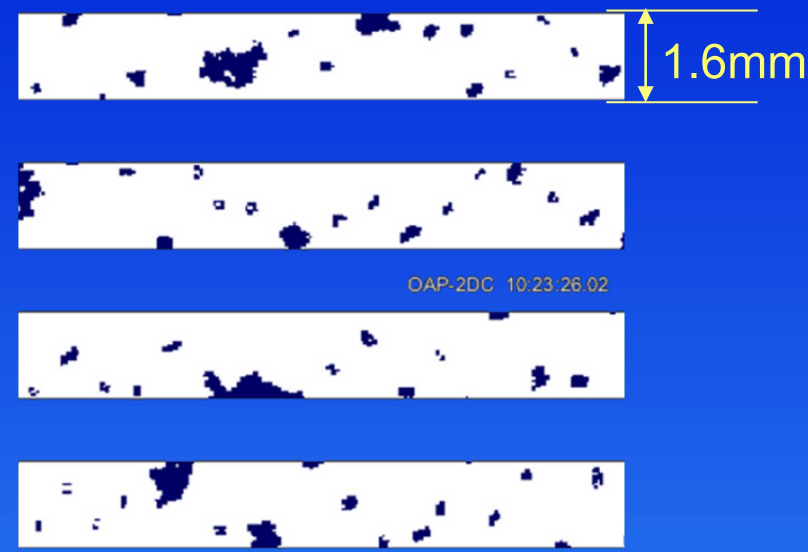


Examples of particle images registered by 2D probes

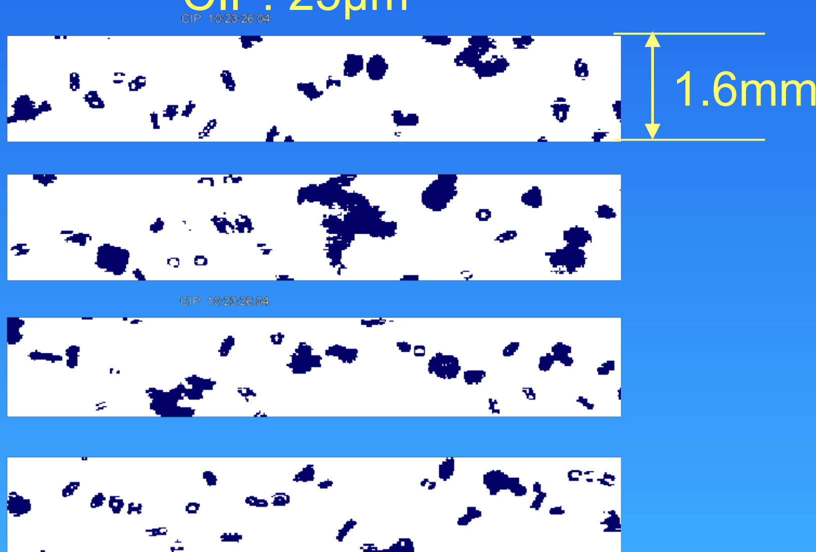
2DS: 10μm



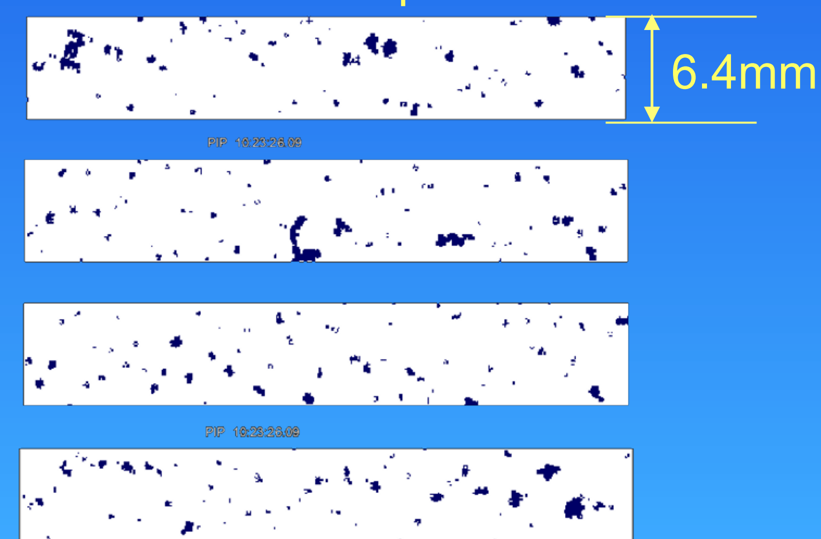
2DC: 50μm



CIP: 25μm



PIP: 100μm



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Particle probes performance matrix

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FSSP	G	G	G	G	G	G	G	G	G	G	G	G	G	G
CDP	G	G	G	G	G	G	G	G	G	G	G	M	G	G
OAP-2DC	G	G	G	G	G	G	G	G	G	G	G	G	G	M
OAP-2DP	M	M	G	M	M	M	M	M	M	M	M	M	M	M
PIP	G	G	G	G	G	G	G	G	G	G	G	M	G	G
CIP	M	M	N	M	N	M	G	G	G	G	G	G	G	G
2DS-H	N	M-	M	G	G	G	M+	G	M+	G	G	G	G	G
2DS-V	N	M-	M	G	G	G	M	G	M	M	N	N	M	N
CPI	G	G	G	G	G	G	G	G	G	G	G	G	G	G

2D image processing

1. Basic processing
2. Artifact filtering
3. Image reconstruction
4. Unresolved issues

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Artifact filtering: broken and fragmented images in single image frames

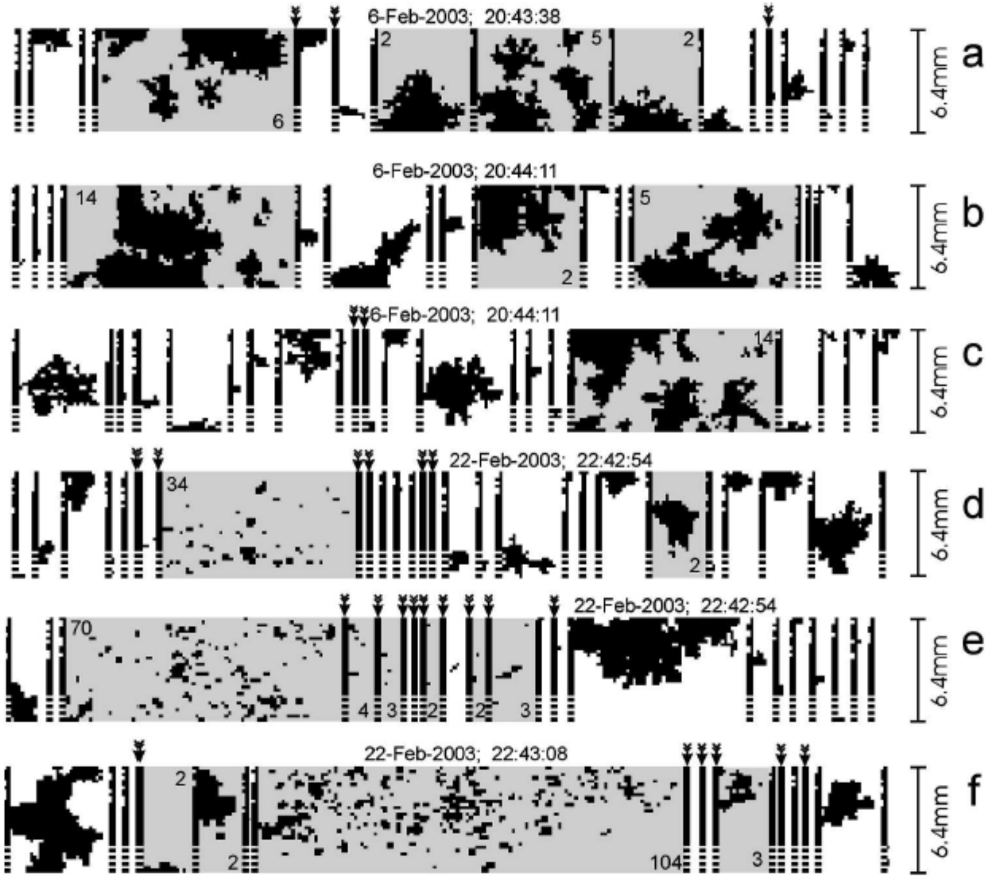


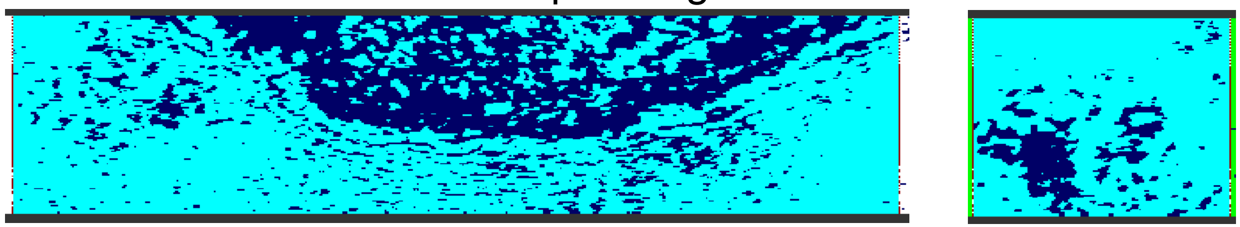
FIG. 3. Examples of shattered OAP-2DP images measured in clouds with aggregates of dendrites. Frames with multiple isolated images are highlighted in gray. The number of isolated images associated with the shattered particles is indicated inside the rectangles. Arrows indicate the time bars with zero elapsed time.

Korolev and Isaac, JTECH, 2005

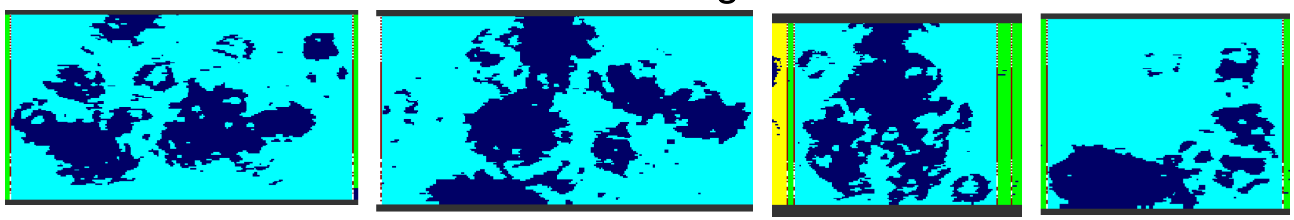
Artifact filtering: broken and fragmented images in single image frames

Rejected fragmented images

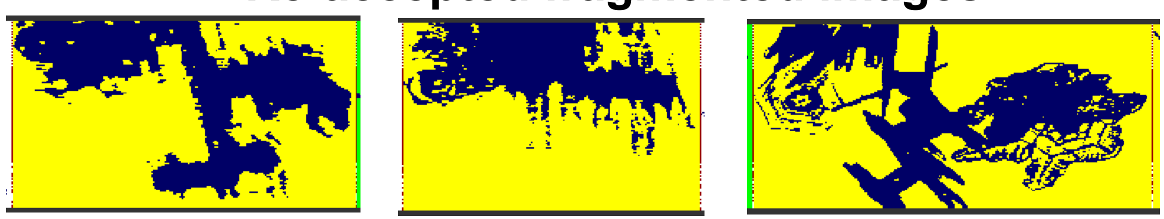
splashing



shattering



Re-accepted fragmented images



Artifact filtering: inter-arrival time algorithm

Cooper, 1977
Field et al., JTECH, 2003,2006

Assumptions:

(1) Spatial spacing of shattered particles are much smaller than that for intact ones

(2) Non-normalized inter-arrival time distribution has a bimodal distribution

(3) *All* particles associated with the short inter-arrival mode are shattered artifacts, whereas *all* particles associated to the long inter-arrival mode are intact one

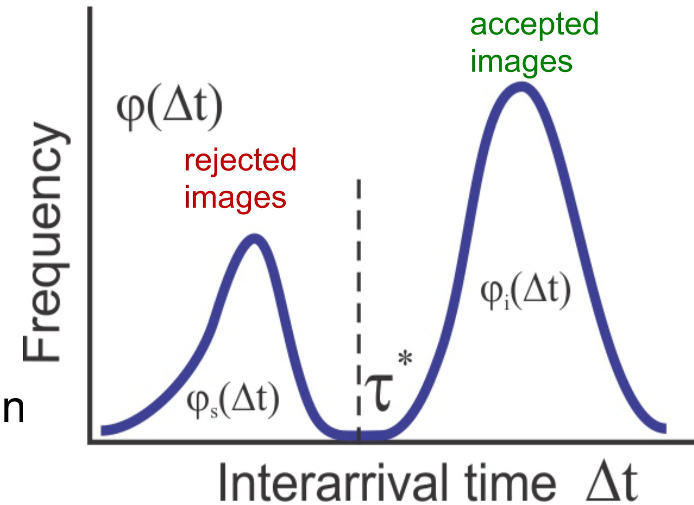
Processing:

(1)Cut-off-time τ^* was calculated as a minimum between long and short time modes

(2) τ^* was calculated at each time interval

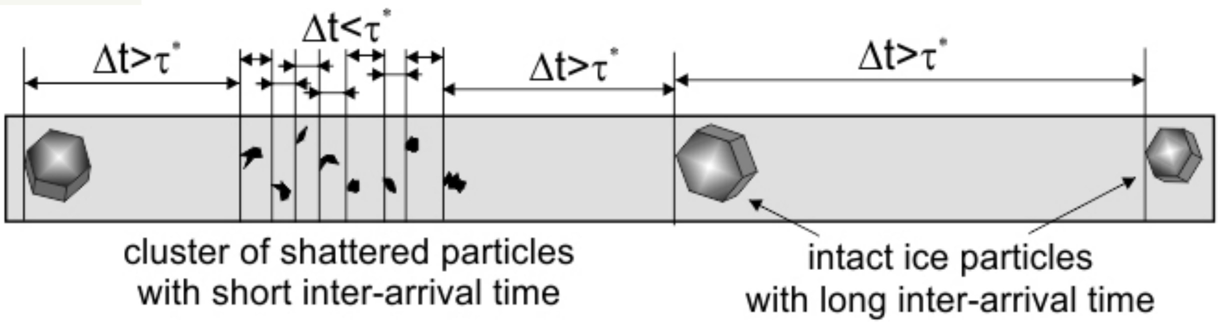
(3)Particle is accepted if $\Delta t > \tau^*$; rejected if $\Delta t \leq \tau^*$

(4)Minimum number of rejected particles per shatterin event is **2**



Artifact filtering

Efficiency of the inter-arrival time algorithm was revisited in *Korolev and Field, AMT, 2015*



Interarrival time algorithm allows effectively filter out most of the artifacts for cases with a relatively low particle concentrations, when short and long time modes are well separated

Interarrival time algorithm has fundamental and it should be used with caution

•it results in large biases at high particle concentrations

•it results in rejection of 'good' particle images at any particle concertation due to (a) statistics, (b) diffraction effects; (c) out-of-focus image fragmentation.

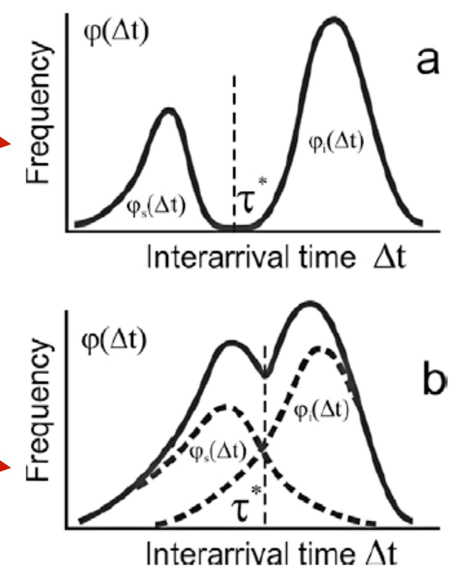


Figure 1. Conceptual diagram of the distribution of inter-arrival times $\phi(\Delta t)$ with well separated short and long inter-arrival time modes **(a)**, when shattering artifacts can be segregated from the intact particles. When the distributions of inter-arrival time associated with intact particles $\phi_i(\Delta t)$ and shattered fragments $\phi_s(\Delta t)$ have significant overlap, then segregation of intact particles and shattered artifacts is hindered **(b)**.

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Artifact filtering: cases of failure of the inter-arrival time algorithm

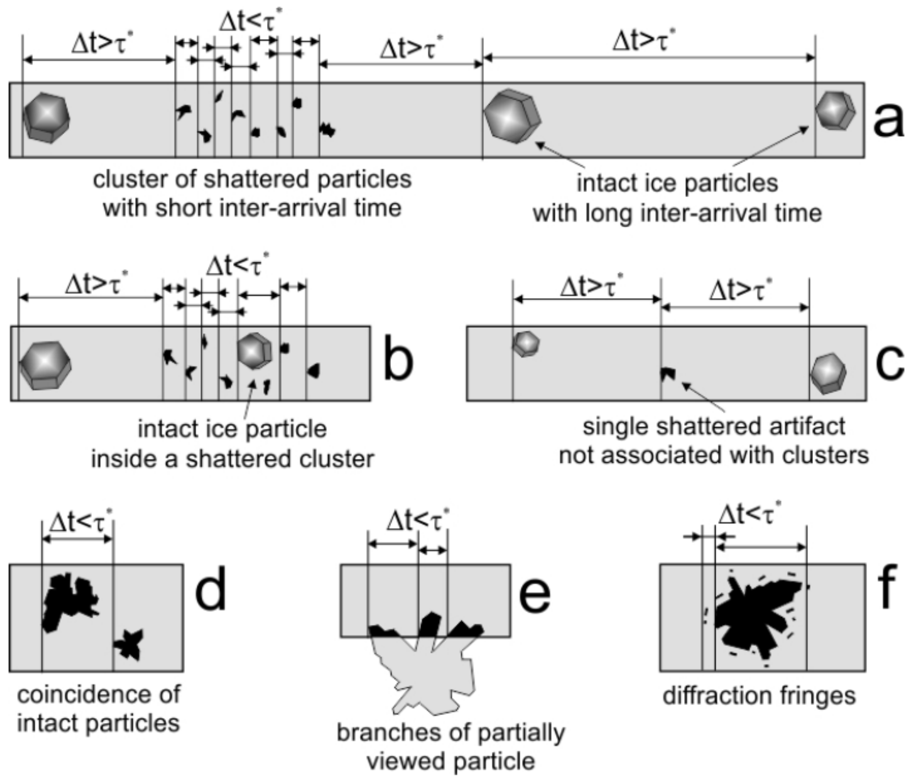


Figure 2. Conceptual diagram of **(a)** idealised spatial sequence of intact particles and shattered artifacts passing through the sample volume. Case **(c)** when the inter-arrival time algorithm may confuse shattered artifact with intact particles, and **(b, d, e, f)** when intact particles may be confused with shattering artifacts.

Korolev and Field, AMT, 2015

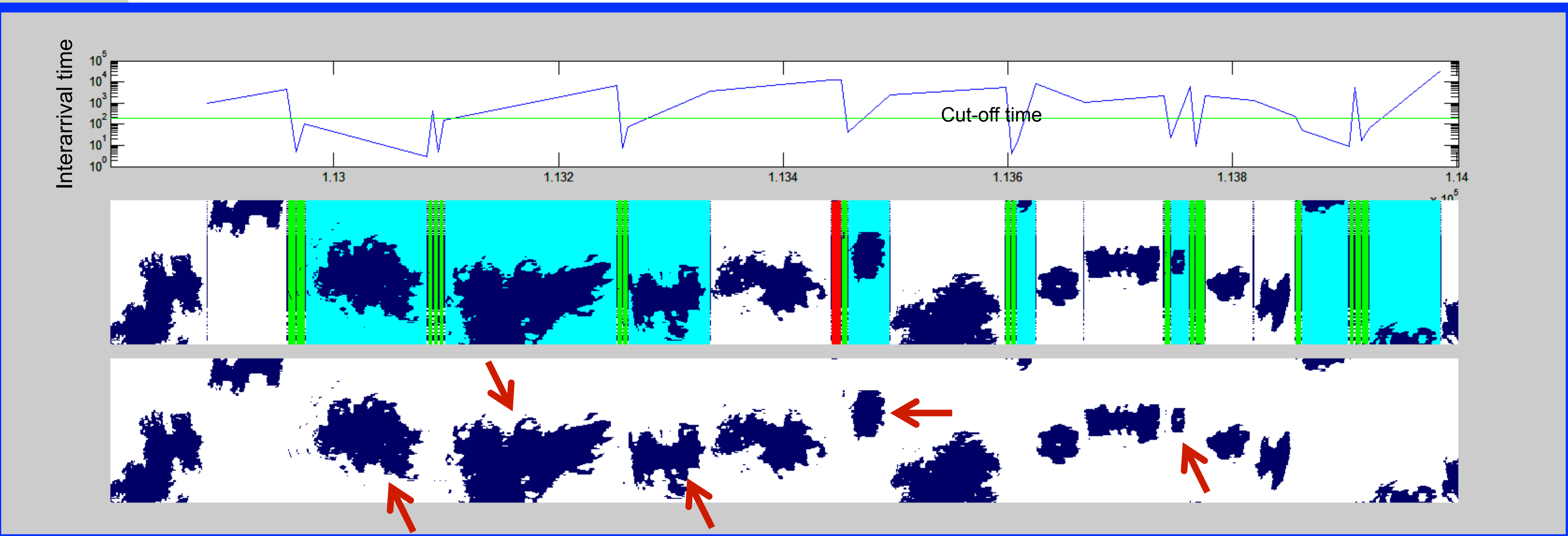
Artifact filtering

Examples of 2D-S images rejected due to short inter-arrival time caused by:

(a) diffraction effects

(b) coincidences of intact particles with a shattering events

The image processing algorithm re-accepts the rejected images indicated by red arrows

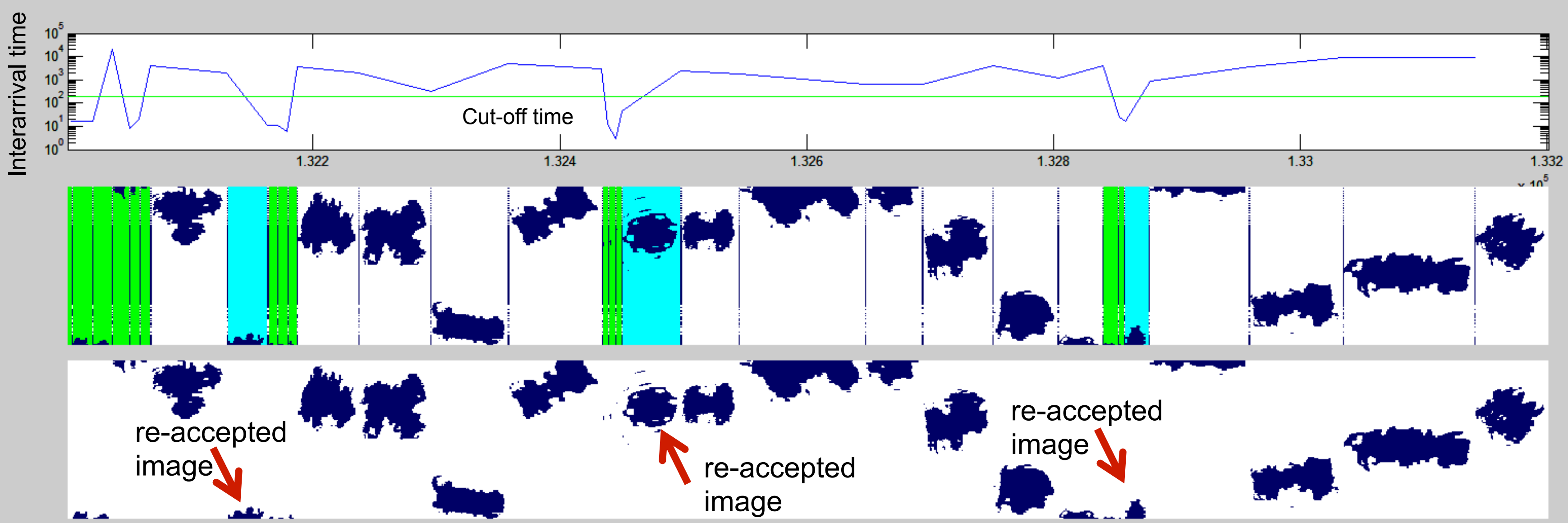


Artifact filtering

Examples of 2D-S images rejected due to short inter-arrival time caused by:

(a) diffraction effects
(b) partially viewed branched particles

The image processing algorithm re-accepts the rejected images indicated by red arrows



Artifact filtering: Cases of failure of the inter-arrival time algorithm

Examples of our-of focus fragmented images registered by 2DS probe in two or three image frames

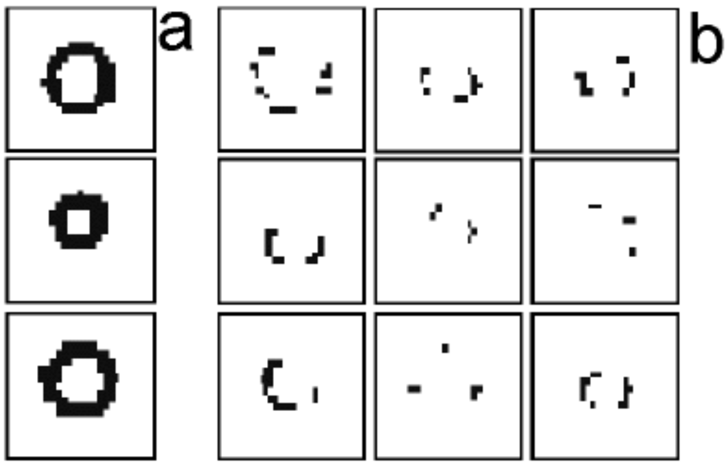


Figure 4. Examples of out-of-focus images measured by 2-D-S at 10 µm pixel resolution. **(a)** Complete circle out-of-focus images; **(b)** fragmented out-of-focus images, which were registered in two or three image frames and identified as shattering artifacts by the inter-arrival time algorithm. The fragmented out-of-focus images are related to the particles passing through the sample volume near the edge of the depth-of-field.

Korolev and Field, AMT, 2015

Artifact filtering

Examples of 2D-S images rejected due to short inter-arrival time caused by:
(a) out-of-focus fragmentation
(b) statistical coincidences

The image processing algorithm re-accepts the rejected images and convert them into single images (red squares)

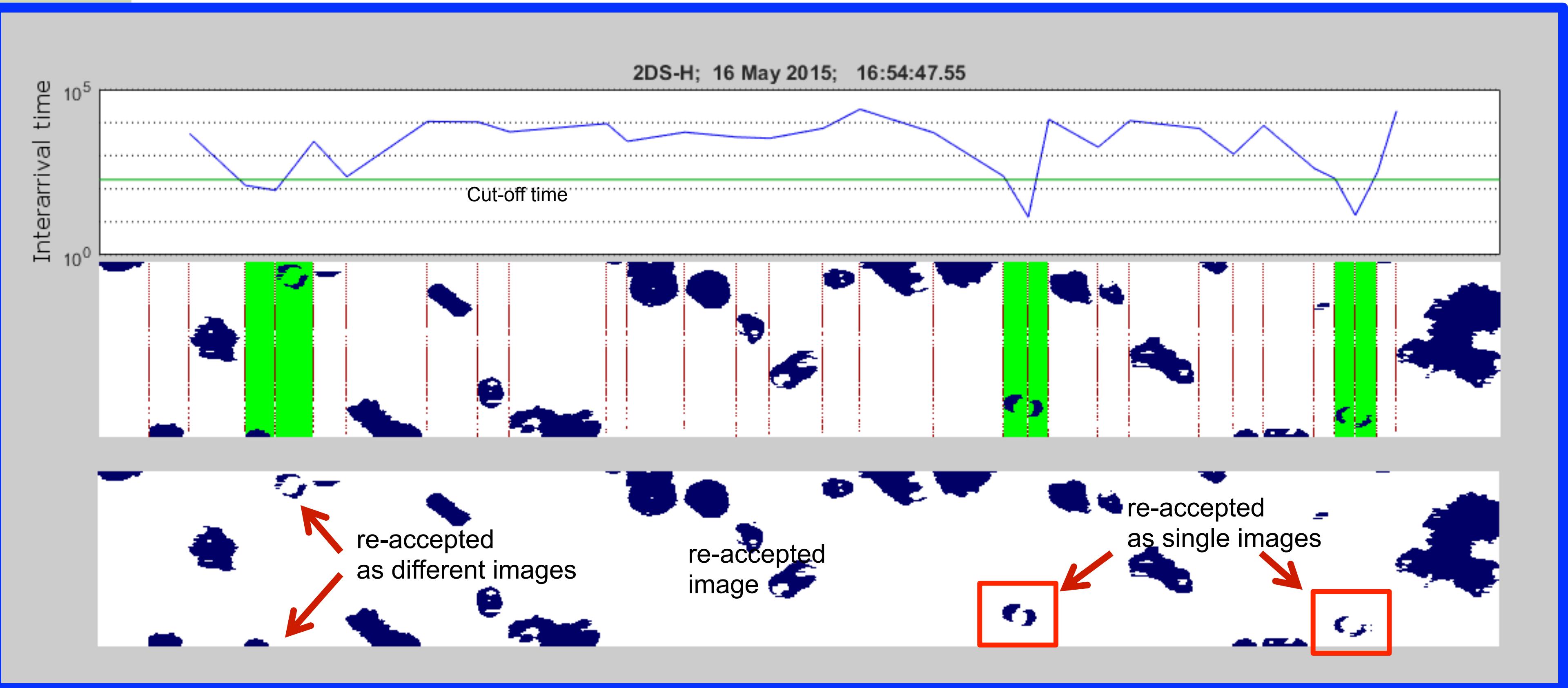


Image reconstructions

- Reconstruction of out-of-focus images based on relation between geometrical parameters of the Poisson spot and particle image

- Out-of-focus images may result in overestimation of particle size up to 80%

Korolev, JTECH, 2007

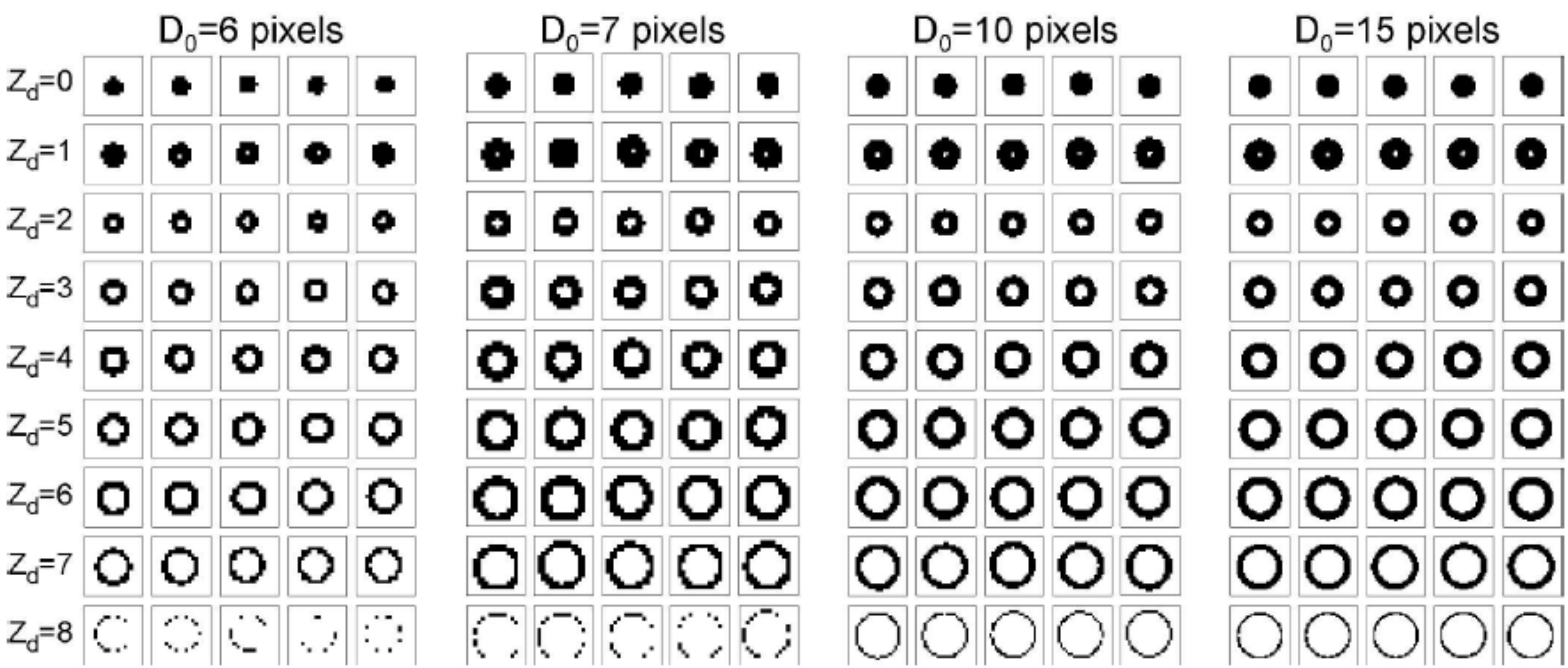


FIG. 6. Examples of modeled discrete binary diffraction images with different sizes and at different distances Z_d from the object plane. The difference in the discrete images for the same Z_d is caused by the shifts in the photodiode array with respect to the diffraction image.

Reference list for 2D data processing of the Cayenne data set:

1. Korolev A. V., J. W. Strapp, and G. A. Isaac, 1998: Evaluation of accuracy of PMS Optical Array Probes. *Journal of Atmospheric and Oceanic Technology* **,15**, 708-720.
2. Korolev, A.V. and B. Sussman, 2000: A Technique for Habit Classification of Cloud Particles. *Journal of Atmospheric and Oceanic Technology*: **17**, 8, 1048–1057
3. Korolev, A.V., and G.A. Isaac, 2005: Shattering during sampling by OAPs and HVPS. Part 1: Snow particles. *Journal of Atmospheric and Oceanic Technology* 22, 528-542
4. Korolev, A.V. 2007: Reconstruction of the Sizes of Spherical Particles from Their Shadow Images. Part I: Theoretical Considerations. *Journal of Atmospheric and Oceanic Technology* **24**, 376–389
5. Korolev A. V., E. F. Emery, J.W. Strapp, S. G. Cober, G. A. Isaac, 2013: Quantification of the effects of shattering on airborne ice particle measurements. *Journal of Atmospheric and Oceanic Technology*, **30**, 2527-2553
6. Korolev, A. and P. Field, 2015: Assessment of performance of the inter-arrival time algorithm to identify ice shattering artifacts in cloud particle probes measurements. *Atmosph. Meas. and Techn.*, 8, 761–777

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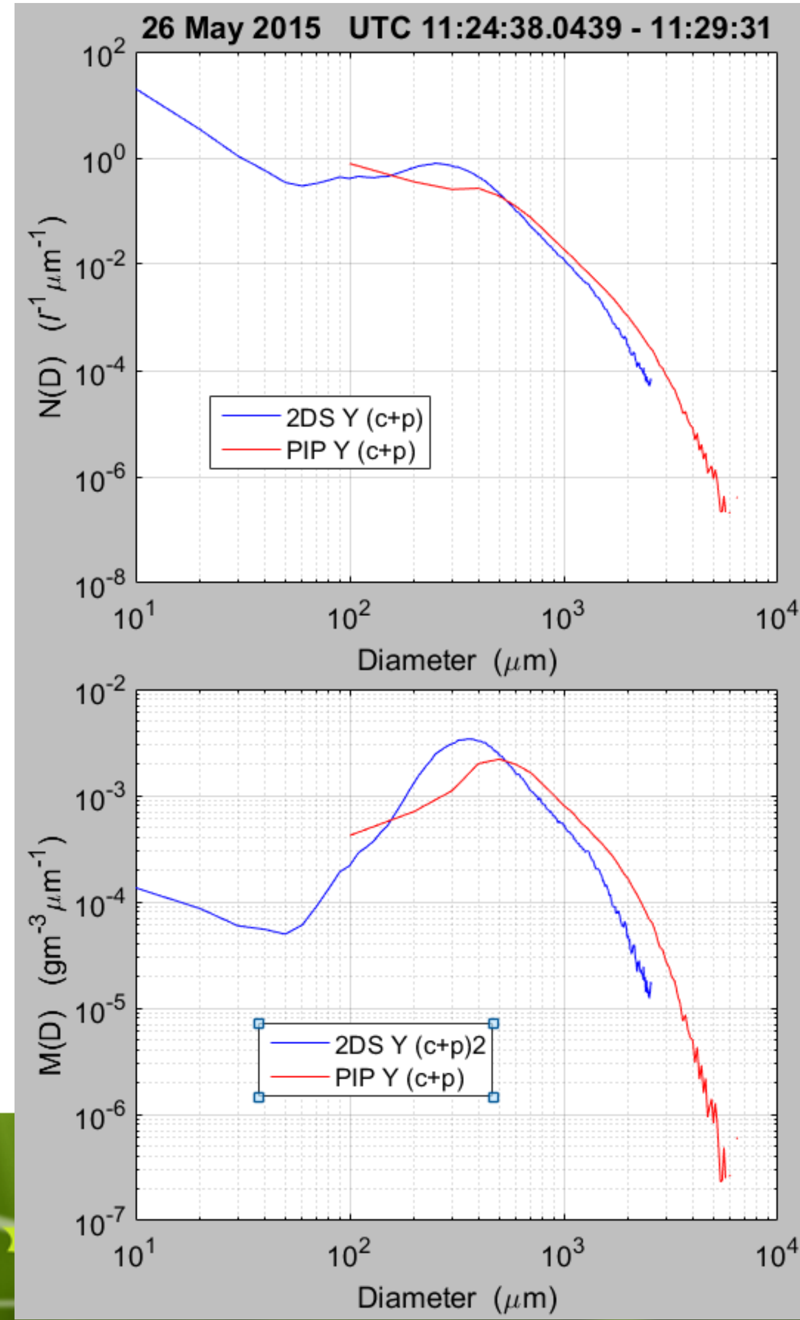
Issues in 2D processing to be resolved

1. Further developing of image processing algorithms to mitigate 2DS and PIP discrepancy in overlapping area.
2. Implementing results of laboratory calibrations in 2D-processing to improve particle sizing.
3. Refinement of size-to-mass parameterization to improve IWC assessment.



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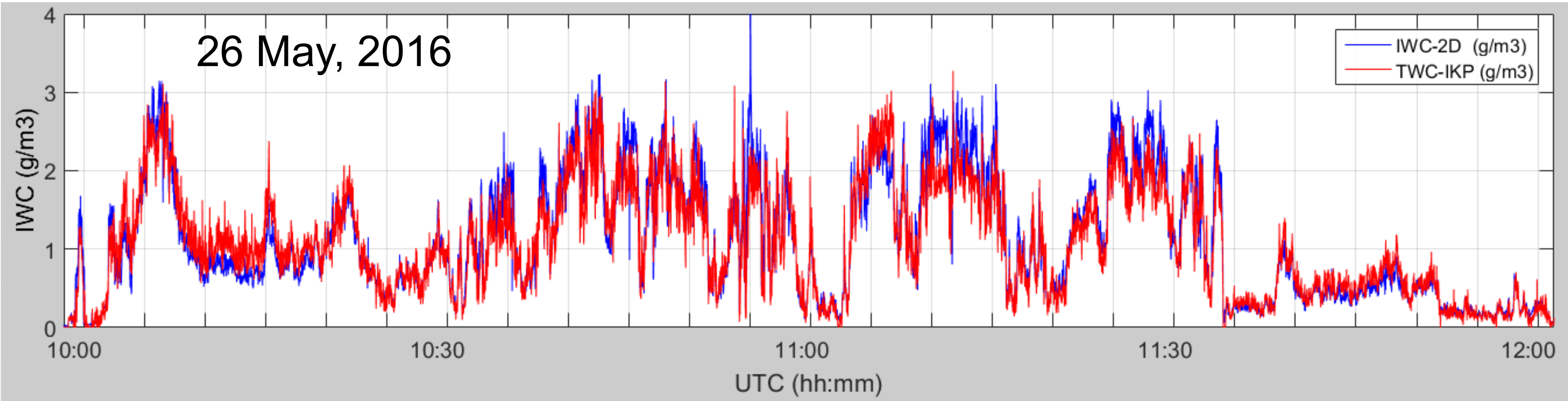
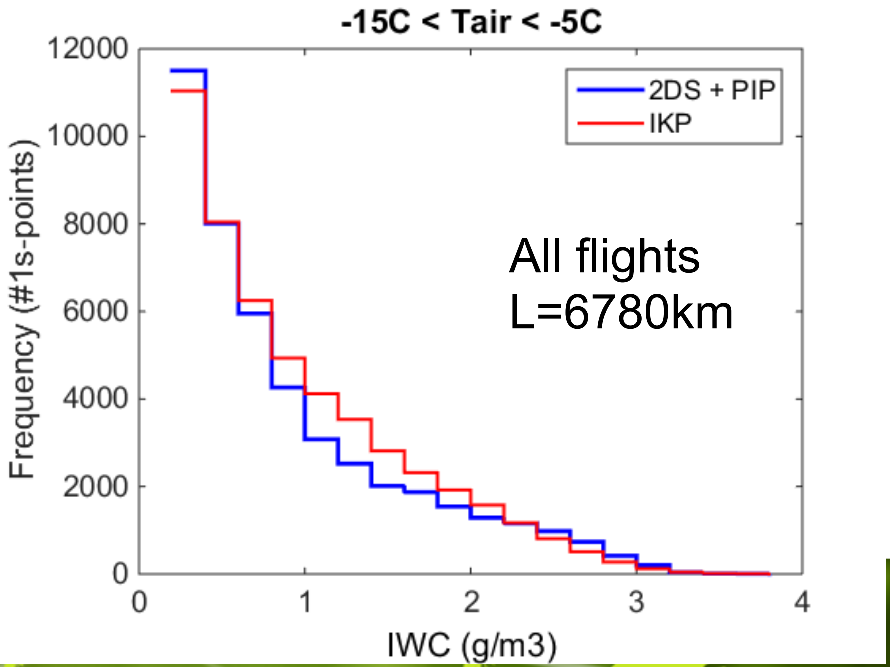
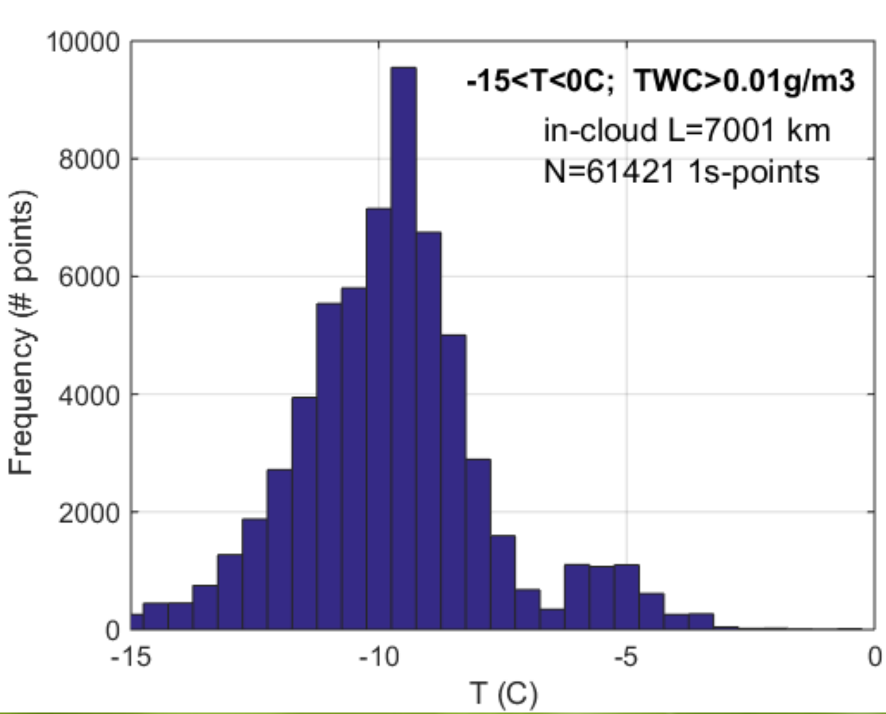
Comparisons of IWC calculated from 2D data and measured by IKP2

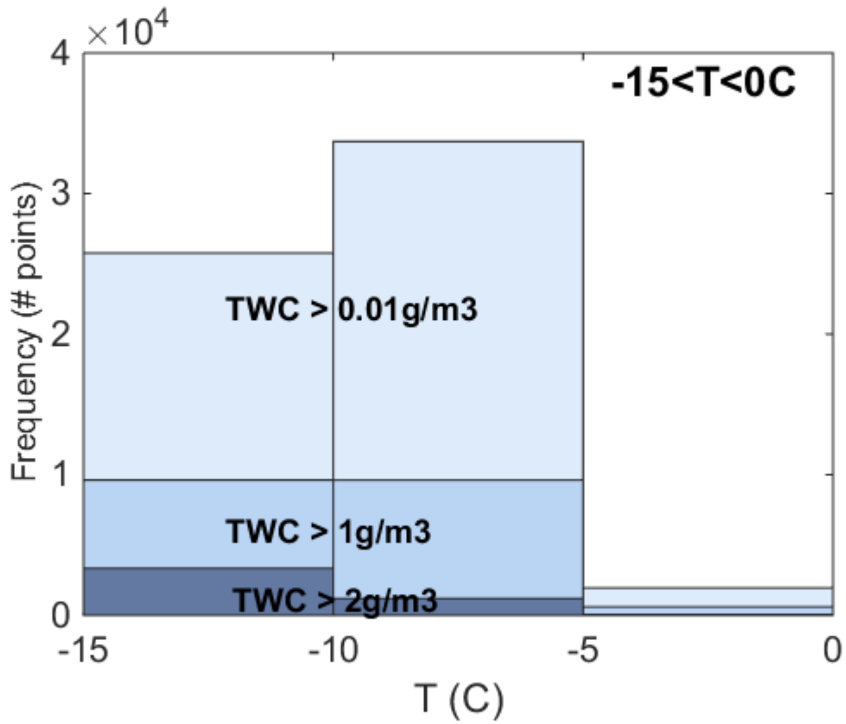




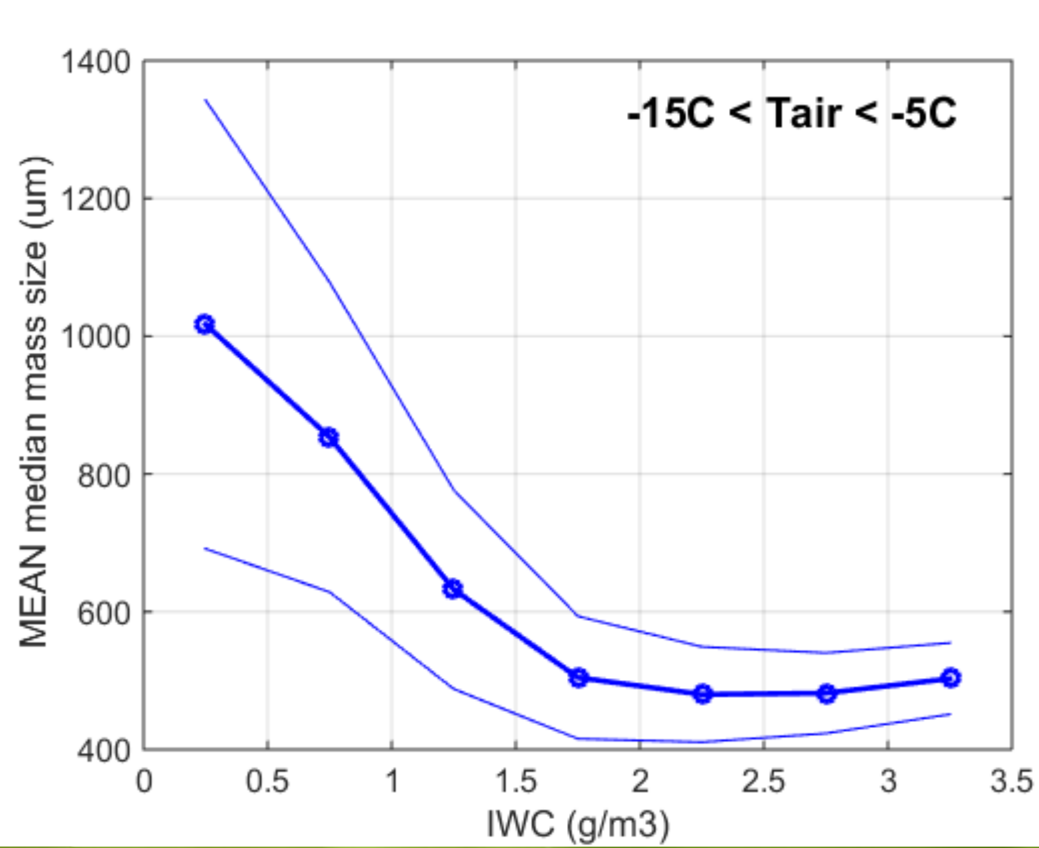
Sampling statistics of IWC vs temperature based on 2D-probes data

	-15C < T < -10C	-10C < T <-5C	-5C < T < 0C	ALL
L (IWC > 0.01g/m3)	2949 km	3831 km	221 km	**7001 km**
L (IWC > 1g/m3)	1113 km	1104 km	69 km	**2286 km**
L (IWC > 2g/m3)	390 km	140 km	6 km	**536 km**
L (IWC > 3g/m3)	16 km	7 km	0	**23 km**





Median mass size vs IWC



Median mass size decreases with increase of IWC approaching to MMD~500μm and IWC>1.5g/m^3

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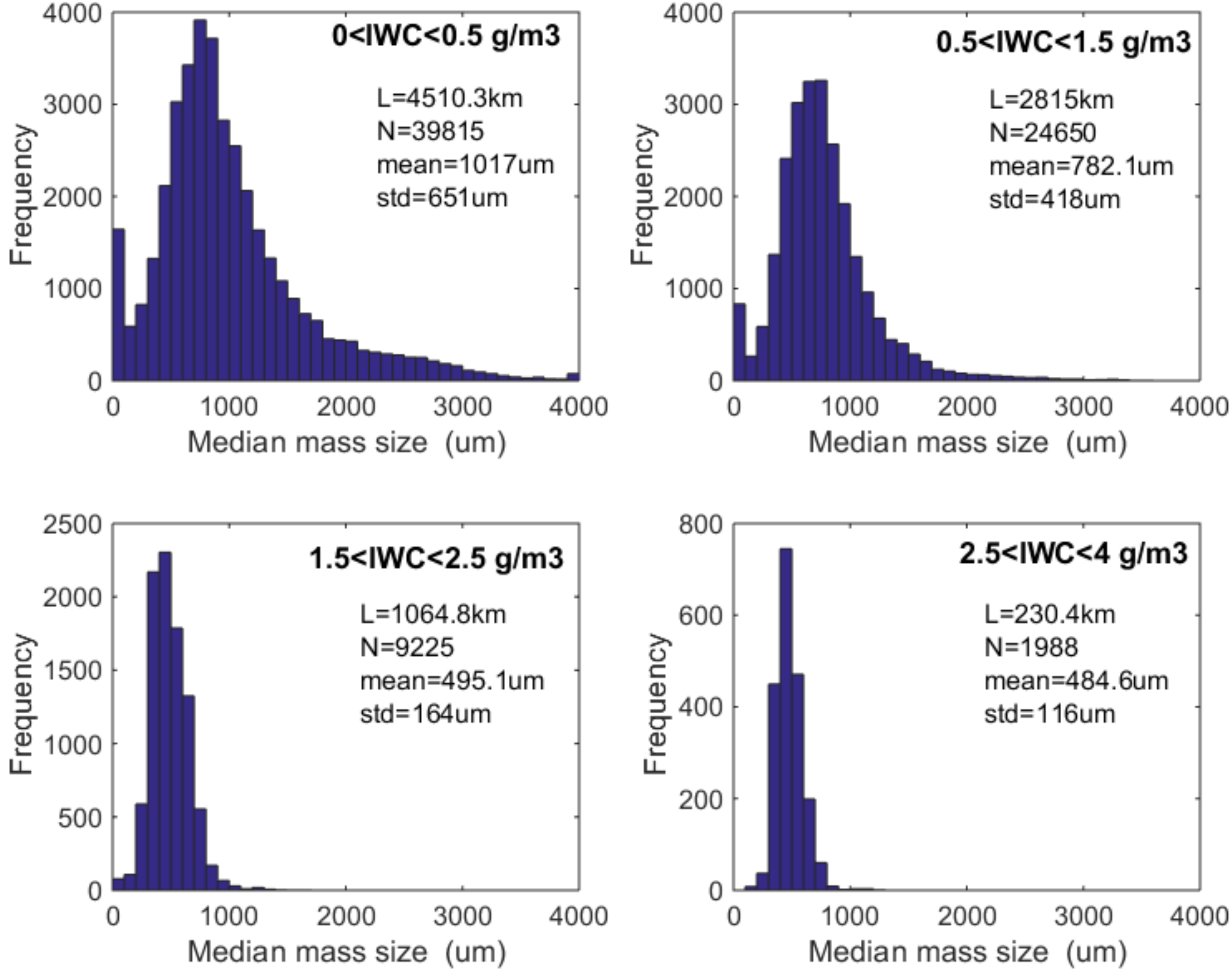
Distribution of MMD in different IWC ranges
-15C < T < -5C



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High Ice Water Content (HIWC) Program