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WINTRE-MIX Cloud Microphysics Data Release : Scattering and Optical Array Probe Datasets

Prepared by: Dr. Leonid Nichman (Leonid.Nichman@nrc-cnrc.gc.ca), Dr. Keyvan Ranjbar (Keyvan.Ranjbar@nrc-cnrc.gc.ca), Mr. Kenny Bala (Kliti.Bala@nrc-cnrc.gc.ca)

Reviewed by: Dr. Leonid Nichman

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Dataset Description

This document accompanies the uploaded imaging and scattering probe data collected during the WINTREMIX flight campaign (February – March 2022) onboard NRC's Convair-580 aircraft.This document provides basic information about the sensors and brief notes on data processing, data structure, and quality assurance that can aid the users in the analysis of cloud microphysics data.

The dataset contains measurements collected by 4 optical probes (Table 1). The instruments and their detection size ranges are shown in **Table 1.**

Table 1. Optical probes and their detection size ranges.

Instrument Name	Detection Size Range (um)	Manufacturer	Detection method	Reference
Cloud Droplet Probe (CDP-2)	2-50	DMT	Light Scattering	Lance et al., 2010
2D-Stereo probe (2DS, H and V channels)	10-1280	SPEC	Optical Array Probe	Lawson et al., 2006
Precipitation Imaging Probe (PIP)	100-6400	DMT	Optical Array Probe	Baumgardner et al., 2001
High Volume Precipitation Spectrometer (HVPS-3)	150-19200	SPEC	Optical Array Probe	Glienke & Mei, 2020

The uploaded dataset is comprised of nine flights, each at 1Hz resolution. The flight numbers and intensive operational period (IOP) numbers differ due to the mismatch of ground and air operational portions of the campaign, days with multiple flights, and an additional shared flight for the FAA TAIWIN demonstration. The flight times and the corresponding IOP numbers are shown in **Table 2.**

Table 2. Summary of WINTRE-MIX flights information with a FAA TAIWIN flight.

NRC Flight Number	WINTREMIX IOP Number	Start Date (UTC)	Start Time (UTC)	End Time (UTC)	Flight Duration
F01	IOP1	03-Feb-22	02:00	06:30	4.5
F02	IOP3	12-Feb-22	00:21	05:06	4.75
F03	IOP4	18-Feb-22	03:20	07:04	3.7
F04	IOP5	22-Feb-22	23:44	03:43	4
F04 (TAIWIN)	IOP6	25-Feb-22	08:52	13:01	4
F05	IOP7	01-Mar-22	20:45	01:09	4.4
F06	IOP8	06-Mar-22	13:10	17:12	4
F07	IOP9a	07-Mar-22	16:11	20:04	4
F08	IOP9b	07-Mar-22	21:40	01:40	4
F09	IOP10	12-Mar-22	03:45	07:50	4.1

The data provided for each flight is composed of separate datasets from three probes. This includes the CDP, the 2DS(H channel by default, V channel if H channel is of poor data quality) and finally the HVPS3, except for IOP4 where the PIP is provided instead, due to poor data quality from HVPS3. The provided data is thus intended to provide the broadest size spectrum possible for microphysical measurements, including overlapping size spectra for redundant measurements.

Instrument Placement On The Aircraft

In **Figure 1**, a frontal view of the NRC Convair-580 aircraft is shown with labeled locations indicating placement of probes. **Table 3** provides a list of the cloud microphysics probe locations on the aircraft exterior. **Figure 2** contains a photograph of the Convair during flight, with the underwing probes in view.

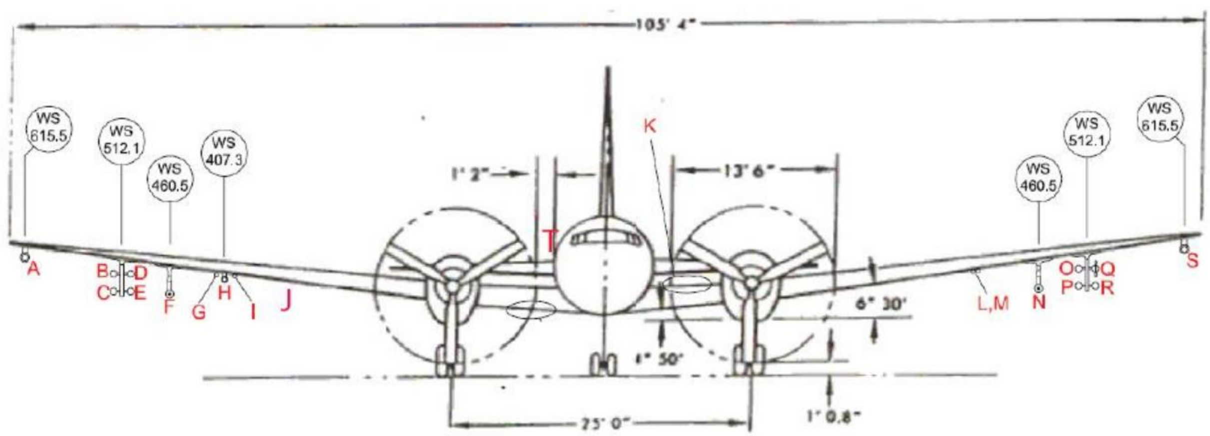

Figure 1. A diagram of the NRC Convair with instrumentation locations labeled.

Table 3. List of instruments located on the aircraft wing and fuselage as indicated in Figure 1.

Diagram Label	Instrument	Location acronym
D	CDP-2	Starboard Inner Upper (SIU)
E	NRC 2D-S & FCDP combo	Starboard Inner Lower (SIL)
P	SPEC HVPS -3	Port Inner Lower (PIL)
Q	PIP	Port Outer Lower (POL)

Figure 2. NRC Convair-580 research aircraft instrumented with underwing cloud probes.

Instrument Theory of Operation

Scattering Probes

The Cloud Droplet Probe (CDP) is designed to measure cloud droplet size distribution from 2 μm to 50 μm. This is a forward-scattering instrument that accepts and sizes only particles that pass through a region of the laser beam with uniform power. Forward-scattered light is directed through a 50/50 optical beam splitter, then measured by photodetectors to determine size and depth of field. More specifically, the CDP consists of two arms, which house the optical components of the system. A 658 nm diode laser is directed out of a sapphire window and between the two arms across an open sample area. In the sample area, particles suspended in an air sample pass through the beam, scatter laser radiation, and detected by the forward scattering detector (Lance et al., 2010).

Optical Array Probes

Optical Array Probes (OAPs) use a photodiode array illuminated by a laser as the method of imaging cloud hydrometeors. Hydrometeors which enter the probe sample volume obscure the illumination source, thus causing the voltage to drop on sections of the shadowed photodiode array. For more details please consult (Brenguier et. al. 2013).

Data Collection and Processing

Data Collection

The data from each instrument is collected through a real-time *Data Acquisition System (DAS)*.

Data Processing Description

Scattering Probe Data Processing Summary

The procedure for CDP data processing is performed as per the steps described in (Droplet Measurement Technologies, 2009).

Imaging Probe Data Processing Summary

The data from the imaging probes is processed in an identical manner for all OAPs, as seen below.

Particle Sizing

Particle sizing involves computing a diameter from a photodiode image which is sufficiently representative of a particle's size. For this data release all subsequent quantities are computed using D_s and D_{eq} as the particle diameter definitions (McFarquhar et. al. 2017)[1].

D_s refers to the diameter of the circle which encloses all of the shadowed pixels in an image, with an example shown in **Figure 3** .

D_{eq} is defined as the diameter of a circle with an area identical to the particle in an image. Note that for perfect circles, $D_s = D_{eq}$, but for noncircular images, these two diameters can differ significantly. An example may be seen in **Figure 4** below where a fictitious image four pixels wide would yield $D_s = 4px$, but $D_{eq} = 2\sqrt{\frac{A}{\pi}} = \frac{4}{\pi}px$ where A is the area of the total number of pixels, in this case $A = 4px$

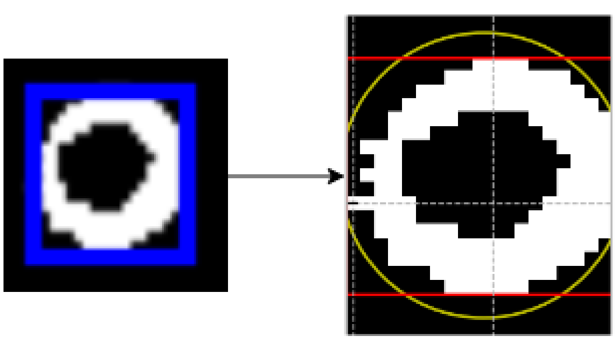

Figure 3. An example of particle sizing. In this case, the particle is being sized using D_s

[1] Please note that in the referenced text, D_{eq} is referenced as D_{area}. Additionally, some works refer to D_s as D_{max} . Please note that for a true Dmax , only the highest Dmax value between all the probes with different size ranges should be taken.

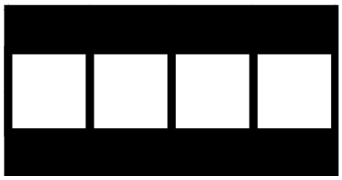

Figure 4. A fictitious four-pixel wide photodiode image

Photodiode Array Separation

Due to different data analysis approaches, the population of detected particles is separated into two classes. One classified as “all-in” and another one classified as “center-in”. For further details, please consult (Heymsfield and Parrish 1978). The two types of categories are depicted in **Figure 5**.

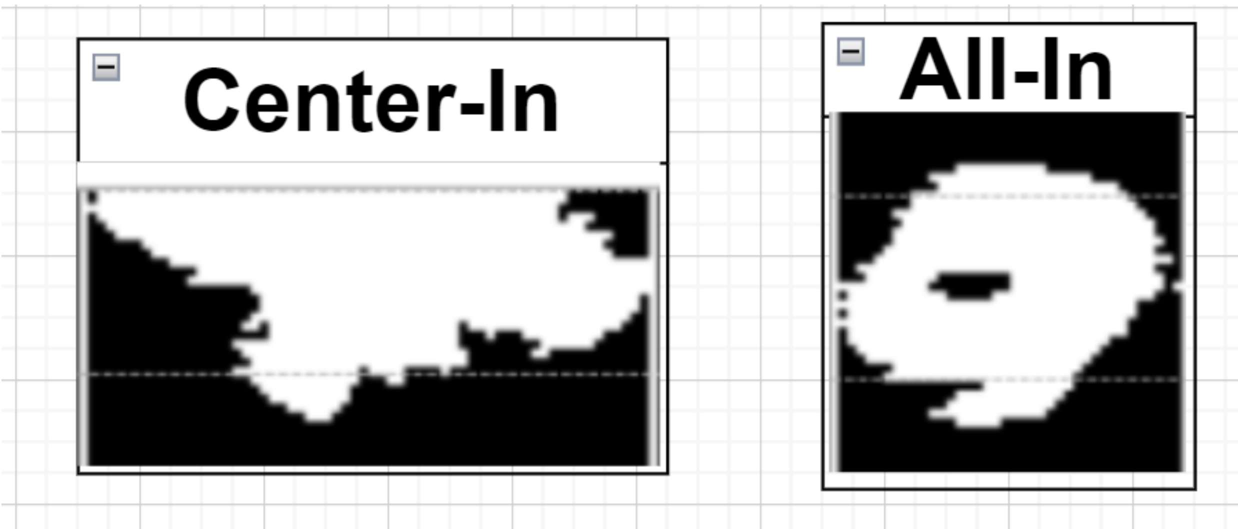

Figure 5. An example of a center-in and all-in image

Data Filtering

Filtering of undesirable images is performed with the following criteria:

1. **Interarrival Time :** Particles with an inter-arrival time less than $1\mu s$ are filtered out. This is a common threshold used for analysis of non natural small artifact particles originating from shattering on the impact with the probe arms(Korolev et. al. 2013)
2. **Area Ratio :** The area ratio refers to the ratio of the particle area in pixels, compared to the area enclosed by a sphere with diameter D_{max}. The threshold used for this dataset is 0.1. Only particles with area ratios above this threshold are accepted (McFarquhar et. al. 2017).
3. **Dimension Ratio :** The dimension ratio refers to the ratio of the maximum particle size along the photodiode dimension, divided by the maximum particle size along the time dimension. The threshold used for this dataset is 0.1. Only particles with dimension ratios above this threshold are accepted. This filtering criteria is meant to remove “streakers”, meaning photodiodes which turn off spuriously without the presence of a particle(McFarquhar et. al. 2017).
4. **Maximum number of objects per image :** Images with lots of diffraction or other artifacts like splashing are rejected. This means that only images with one complete particle are accepted.

Particle Size Distribution Computation

After data filtering, there are two separate particle populations which both go through an identical data filtering procedure. These are the “all-in” population and the “center-in” population. In each case, the D_{max} and D_{eq} diameters of each particle are used to construct a particle count distribution, with dimensions of particle diameter and time. Thus, four total particle count distributions are produced.

Once this step is complete, the sample volume for each unit of time, for each bin in the PSD is computed using the following formula (McFarquhar et. al. 2017).

$$SV = TAS \cdot SA = TAS \cdot EAW \cdot \min(Sep, DOF)$$

Where SV is the sample volume, TAS is the aircraft True Airspeed, SA is the probe sample area, EAW is the probe effective array width, Sep is the probe arm separation, and DOF is the probe Depth of Field.

The filtered particle populations(all-in and center-in) are then binned into a particle count distribution.

Diameter Percentile Computations

The statistics of diameter percentile (99th percentile and 100th percentile) are also computed separately for each particle population. In this case, the particle population is separated by time, and percentile statistics are computed for each second of flight.

Quality Control and Assurance Procedures

Data quality control and assurance has been achieved by selecting the most reliable collection of probes for data release. In cases of instrument failure, the default probe is switched with data of another probe which was functional during that flight. For the 2DS, the H-channel is provided as the default channel, replaced with the V-channel in cases of channel failure(indicated in **Table 4**). Data from the HVPS3 is instead replaced with the PIP for one flight where the HVPS3 is non-functional.

Data Format

The data is separated in between three separate files, all in the NETCDF4 format. The CDP-2, 2DS, and HVPS3/PIP are each stored in their own file. The scattering probe dataset contains only one root group, where both the global attributes and data is located. The imaging probe files on the other hand have a root group containing all the relevant global attributes, followed by two sub-groups, each containing the data derived using $D_s$and D_{eq} respectively. A visual representation of the structures described may be seen in **Figure 6**.

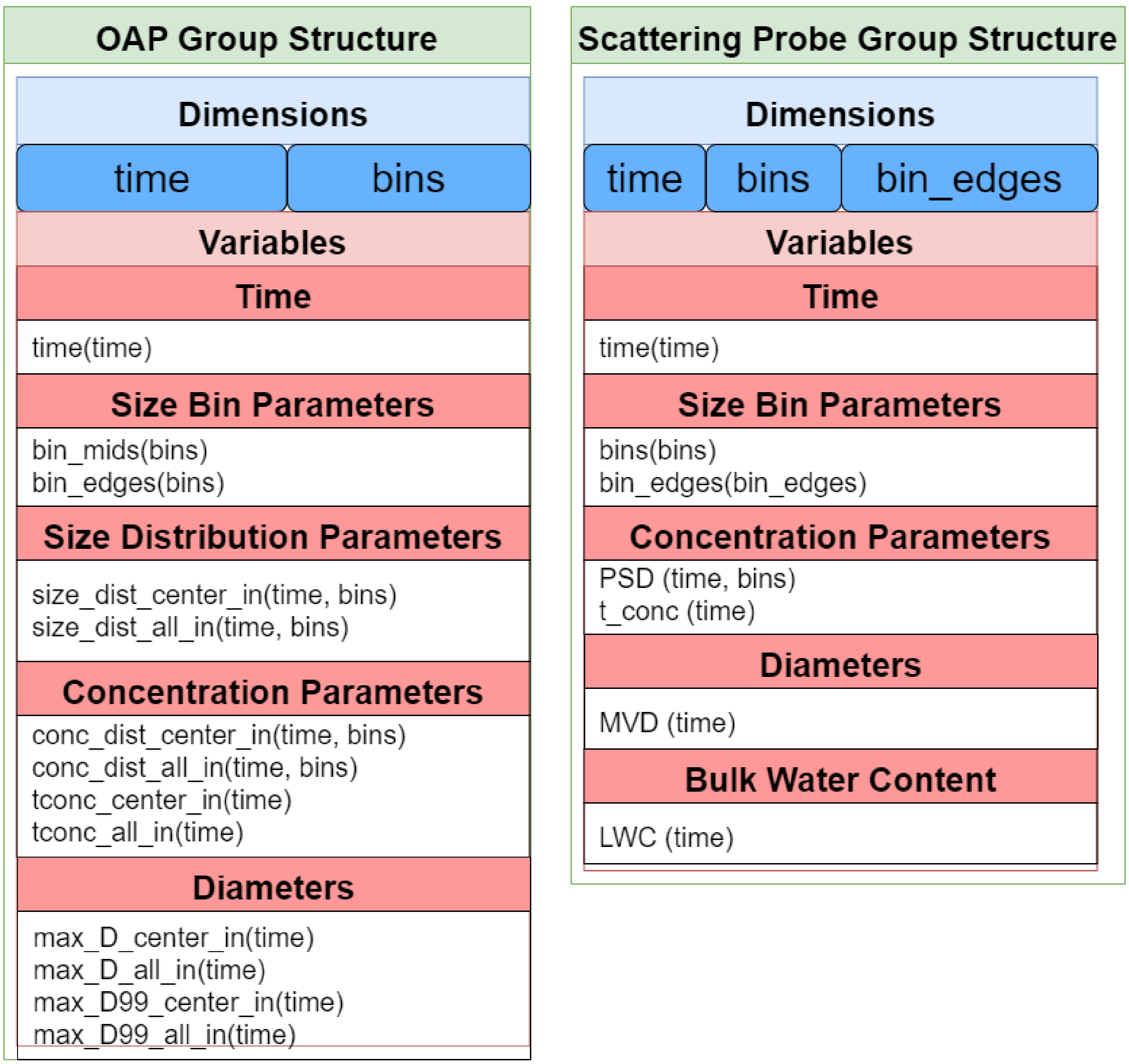

Figure 6 – A diagram describing the data structure of both OAP and scattering probe datasets in the provided data

Data Remarks

Table 4 describes data availability and quality. Due to the harsh icing flight conditions there might be some data gaps remaining.

Table 4. Summary of data quality per flight, per core probe

WINTREMIX IOP Number	NRC Flight Number	CDP Availability	2DS Availability	PIP Availability	HVPS3 Availability
IOP1	F01		2DS-H		
IOP3	F02		2DS-H		
IOP4	F03		2DS-V		
IOP5	F04		2DS-H	HVPS substitute	
IOP6	N/A	Delivered for TAIWINdemo (contact FAA for data)			
IOP7	F05		2DS-H		
IOP8	F06		2DS-H		
IOP9a	F07		2DS-H		
IOP9b	F08		2DS-V		
IOP10	F09		2DS-H		

**Orange color indicates minor issues or possible minor gaps in data. Redundant probe data provided for a more complete information as much as possible.

References

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