ARCSIX SPEC Data ReadMe File

1.0 Introduction

This document provides a comprehensive list of the instruments SPEC installed on the NASA P-3 and SPEC Learjet, the data files they produced (shown in parentheses after the instrument name), the size range of each instrument, potential measurement errors and methodologies for utilizing the data.

The Fast Cloud Droplet Probe (FCDP) counts and sizes individual cloud drops from about 2 to 50 microns using forward-scattering technology based on Mie theory, which is not applicable to non-spherical particles. It is subject to measurement errors commonly known from single-particle forward-scattering instruments (e.g., FSSP and FCDP). Measurement uncertainties are described in several papers available from search engines or using AI.

Both the P-3 and Learjet carried several optical array probes (OAPs) that each imaged particles within a distinct size range. In order to construct a "combined" particle size distribution (PSD) that covers the entire size range of cloud particles from cloud-droplet to precipitation sizes, the PSDs from multiple probes must be combined in an eclectic manner. For example, it may be necessary to combine portions of the FCDP, F2D-S, HVPS (50-micron channel) and HVPS4 (150-micron channel) PSDs to cover the sizes of all the particles in a cloud pass. Since only portions of each probe's size range is used, the remainder of the PSD from that is not used must be deleted. Under some circumstances, use of a PSD from only a single probe can result in an order of magnitude error in the computation of bulk properties (e.g., Concentration, LWC, IWC, Extinction, Equivalent Radar Reflectivity). Examples showing how to combine PSDs from multiple probes is presented in this document. Since the .ICT files provided for each probe cover the entire size range from that individual probe, it is up to the user to develop code to properly combine PSDs from the various probes. SPEC has a Matlab app that performs this function and is available upon request, but this app is not a commercial product and only very limited support is available from SPEC.

Both the P-3 and Learjet flew hot-sensor devices to measure LWC and Total Water Content (TWC = IWC plus LWC). The P-3 flew an SAE WCM-2000 with three sensors: a 0.5 mm hot-wire and a 2 mm hot-wire to each measure LWC, and a 4-mm cylinder to measure TWC. The Learjet flew a Nevzorov probe with three sensors: a 2-mm hot-wire and a 3-mm hot-wire to each measure LWC, and a 8-mm cone to measure TWC. Dr. Alexei Korolev (alexei.korolev@ec.gc.ca) processed both the P-3 and Learjet hot-sensor data. Dr. Korolev should be consulted for advice on how best to interpret the data.

Both aircraft flew a Rosemount icing rod (Rice) that is not heated and changes frequency when it accumulates ice upon impact with supercooled liquid water. The probe does not respond to cloud drops that are not supercooled. Also, the temperature of the icing rod is close to the dynamic temperature of the aircraft, which is a function of the total temperature measured by the Rosemount total temperature probe and recovery coefficient. The total temperature of the aircraft can be 5 to 15 °C higher than the static temperature, and the recovery coefficient of the icing rod is about 0.6

(see Lawson and Cooper 1990 for a more complete explanation). In clouds where the static temperature of the air is within a few degrees below 0 °C, the temperature of the icing rod may not be below 0 °C and may not indicate that the aircraft is in a supercooled liquid water regime.

The Learjet few a Ka-band precipitation radar (KPR) developed by ProSensing, Inc, (Pazmany and Haimov 2018), which was installed on the left wing of the aircraft. It extended in front of the wing of the Learjet and switched from zenith to nadir views at 5 Hz with interleafed short radio frequency (RF) and linear frequency modulation (FM) pulses. It has a "deadband" that extends 150 m in both zenith and nadir directions from the aircraft, but the porpoising maneuvers provide complete cloud coverage when the aircraft descended/ascended in a slant direction. The KPR is insensitive to low concentrations of small cloud droplets (i.e., < ~ 30 μm diameter), but registers returns from drizzle and ice particles in sufficient concentrations that are larger than about 100 μm. The Learjet KPR data have been processed by Dr. Alexei Korolev and are available in the archives under Dr. Korolev's name. See the KPR NetCDF header for an explanation of the data products and contact Dr. Korolev (alexei.korolev@ec.gc.ca) for details on how the data were processed.

A very useful product (called Page0), which lists 1-hz data from state and position sensors along with measurements from the scattering, OAP, hot-sensor and CPI probes is an Excel spreadsheet that is available upon request from SPEC for each P-3 and Learjet mission. It is not uploaded because NASA archives do not support CSV spreadsheets. A snippet from a Page0 spreadsheet is shown in the example below.

Time (HMS)	Time (s)	TAS (m/s)	Palt (ft)	Hdg (dg)	Temp (C)	Dew (C)	LWC1 (g/m3)	LWC2 (g/m3)	FCDP (g/m3)	LWTA (g/m3)	Rice (dHz)	FCDP (#/CC)	2DS (#/L)	2DS (#/L)	2D-Gray (#/L)	PPS (#/L)	HK10 (#/L)	HK50 (#/L)	H50 (#/L)	V50 (#/L)	H150 (#/L)	V150 (#/L)	CPI (#/s)	Lat (deg)	Long (deg)	
135300	49980	116	1788.1	282	-2.25	-5	0	0	0	0	76.9	0	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	CLEAR AIR
135301	49981	116	1774.9	282	-2.33	-5	0	0	0	0	77	0.2	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135302	49982	116	1758.5	282	-2.39	-5.1	0	0	0	0	77.1	0.1	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135303	49983	115	1742.1	282	-2.45	-5.1	0	0	0	0	77.1	0.1	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135304	49984	115	1732.3	282	-2.62	-5.1	0	0	0	0	77.1	0	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135305	49985	114	1712.6	282	-2.73	-5.1	0	0	0	0	77.2	0.1	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135306	49986	113	1699.5	282	-2.89	-5.1	0	0	0	0	77.3	0	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135307	49987	113	1683.1	282	-3.4	-5.2	0	0	0	0	76.6	0.5	0	0	0	0	0	0	0	0	0	0	20	73.1	-74	
135308	49988	113	1660.1	282	-3.62	-5.2	0	0	0	0	79.1	0.4	252.465	282.147	0	0	0	0	0	0	0	0	187	73.1	-74	
135309	49989	113	1643.7	282	-3.78	-5.2	0	0	0	0.005	84.6	1.4	4602.49	5630.13	109.9	19079	8549	0	0.03	0.2	0	0	240	73.1	-74	IN CLOUD
135310	49990	113	1627.3	283	-3.95	-5.2	0.02	0.02	0	0.024	88	17.5	28641.4	33191.3	16014	1E+05	20968	0	0	0.2	0	0	204	73.1	-74	
135311	49991	113	1614.2	283	-4.14	-5.2	0.08	0.08	0.01	0.091	89.8	42.1	53528.4	58551.8	40692	2E+05	79343	0.24	0.31	0	0.02	0	209	73.1	-74	
135312	49992	112	1591.2	283	-4.26	-5.2	0.11	0.11	0.02	0.117	91.5	59.8	47785	55556.5	43437	1E+05	72275	0.06	0.12	0.1	0	0	200	73.1	-74	
135313	49993	112	1578.1	283	-4.38	-5.2	0.1	0.09	0.02	0.096	91.5	54.8	30088.7	36267.1	22056	1E+05	47517	0	0	0.2	0	0	200	73.1	-74	
135314	49994	112	1558.4	283	-4.38	-5.1	0.06	0.05	0.02	0.058	91	49	24828.1	29137.7	26018	74901	26571	0	0	0.6	0	0	211	73.1	-74	
135315	49995	112	1538.7	283	-4.43	-5.1	0.06	0.05	0.02	0.056	90.9	63	8430.33	10201.5	9850.1	22923	16681	0.03	0	0	0	0	20	73.1	-74	
135316	49996	112	1528.9	283	-4.46	-5.1	0.02	0.02	0.01	0.021	90.9	46.3	1371.87	1424.39	1665.2	15356	2930	0	0	0	0	0	7	73.1	-74	
135317	49997	112	1509.2	283	-4.38	-5.1	0.01	0.01	0.01	0.008	90.5	34.4	642.2	739.116	44.424	11376	128.7	0	0	0	0	0	7	73.1	-74	
135318	49998	112	1486.2	283	-4.36	-5	0.01	0.01	0	0.007	90.2	13.4	454.329	881.38	20.592	2514	1373	0.25	0	0	0.01	0.02	0	73.1	-74	
135319	49999	112	1469.8	283	-4.32	-5	0	0	0.01	0.005	89.8	46.4	13.66	34.189	20.592	110.3	86.93	0	0.03	0	0	0	0	73.1	-74	
135320	50000	112	1456.7	283	-4.27	-5	0	0	0	0	89.5	4.6	13.66	0.165	4.69	0	0	0	0.07	0	0	0	0	73.1	-74	CLEAR AIR
135321	50001	112	1437	283	-4.25	-5	0	0	0	0.001	89.2	2	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135322	50002	112	1420.6	283	-4.23	-5	0	0	0	0.001	88.8	1.4	0	0	0	0	0	0.03	0	0	0	0	0	73.1	-74	
135323	50003	112	1407.5	283	-4.12	-5	0	0	0	0	88.5	1.2	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135324	50004	112	1384.5	283	-4.15	-5.1	0	0	0	0	88.2	0.9	0	0.451	0	0	0	0	0	0	0	0	0	73.1	-74	
135325	50005	112	1368.1	283	-4.12	-5.1	0	0	0	0	87.8	0.9	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135326	50006	112	1348.4	283	-4.08	-5.1	0	0	0	0	87.5	0.7	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135327	50007	112	1332	283	-4.03	-5.1	0	0	0	0	87.1	0.4	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	
135328	50008	112	1318.9	284	-3.95	-5.1	0	0	0	0	86.9	0	0	0	0	0	0	0	0	0	0	0	0	73.1	-74	

SLW

Example of a page0 Excel file

2.0 Instruments installed on the P-3 and Learjet

FCDP (ARCSIX-FCDP_P3B_...ICT). Scattering probe with a size range of 2-50 microns.

Fast2D-S –OAP probe consisting of two identical channels (on vertical and horizontal axes). (Not installed on Learjet)

F2D-S 10-micron V (vertical) channel (ARCSIX-F2DS10V_P3B_...ICT). 10-micron resolution optical array probe, capable viewing particles between 10 and 1280 microns and measuring the size of particles out to about 3 mm.

F2D-S 10-micron H (horizontal) channel (ARCSIX-F2DS10H_P3B_...ICT). 10-micron resolution optical array probe, capable viewing particles between 10 and 1280 microns and measuring the size of particles out to about 3 mm.

2D-S –OAP probe consisting of two identical channels (on vertical and horizontal axes). (Not installed on P3B)

2D-S 10-micron V (vertical) channel (ARCSIX-2DS10V_Learjet_...ICT). 10-micron resolution optical array probe, capable viewing particles between 10 and 1280 microns and measuring the size of particles out to about 3 mm.

2D-S 10-micron H (horizontal) channel (ARCSIX-2DS10H_Learjet_...ICT). 10-micron resolution optical array probe, capable viewing particles between 10 and 1280 microns and measuring the size of particles out to about 3 mm.

2D-Gray (standalone instrument) (ARCSIX-2DGRAY50_P3B...ICT, Images: ARCSIX-2DGRAY50-Images_P3B_...zip). 10-micron resolution optical array probe, capable of viewing particles between 10 and 1280 microns and recording particles out to about 3 mm with three gray levels (30%, 50% and 70%). A gray level of 50% (approximately equivalent to black and white probes) is used for ICT files, all levels visible in images.

HVPS-4 – Combination probe featuring 4 different channels of data (i. e., 4 independent probes).

HVPS-4 50-micron V channel (ARCSIX-HVPS4V50_P3B…ICT, Images: ARCSIX-HVPS4-V50-Images_...zip). 50-micron resolution optical array probe, capable of viewing particles between 50 and 6400 microns and recording the size of particles out to about 1 cm.

HVPS-4 50-micron H channel (ARCSIX-HVPS4H50_P3B…ICT, Images: ARCSIX-HVPS4-H50-Images_...zip). 50-micron resolution optical array probe,

capable of viewing particles between 50 and 6400 microns and recording the size of particles out to about 1 cm.

HVPS-4 150-micron V channel (ARCSIX-HVPS4V150_P3B…ICT, Images: ARCSIX-HVPS4-V150-Images_...zip). 150-micron resolution optical array probe, capable of viewing particles between 150 and 19200 microns and recording the size of particles out to about 3 cm.

HVPS-4 150-micron H channel (ARCSIX-HVPS4H150_P3B…ICT, Images: ARCSIX-HVPS4-H150-Images_...zip). 150-micron resolution optical array probe, capable of viewing particles between 150 and 19200 microns and recording the size of particles out to about 3 cm.

NOTE 1: Particles passing within the 50-µm overlap region (6.4 mm x 6.4 mm) are imaged by both 50-µm channels and both 150-µm channels. Particles passing within the 150-µm overlap region (19.2 mm x 19.2) are imaged by both 150-µm channels. All four channels run continuously and image particles, regardless of their position in the fields of view.

NOTE 2. If a channel is not operating properly or is experiencing excessive noise it is not archived

Hawkeye – Combination instrument consisting of 4 probes, 3 of which are archived (not installed on the Learjet).

FCDP – data not archived as of now

2D-S 10-micron OAP V channel (ARCSIX-Hawk2DS10_P3B_...ICT). 10-micron resolution optical array probe, capable viewing particles between 10 and 1280 microns and measuring the size of particles out to about 3 mm.

2D-S 50-micron OAP H channel (ARCSIX-Hawk2DS50_P3B_...ICT). 50-micron resolution optical array probe, capable of viewing particles between 50 and 6400 microns and recording the size of particles out to about 1 cm.

Cloud Particle Imager (CPI) (Images: ARCSIX-HawkCPI-images_P3B_...zip) with 2.3-micron pixel size at 877x2600 pixel grid with 256 gray levels.

NOTE: Since the Hawkeye has an inlet tube instead of arms, it is more prone to artifacts generated by particles shattering on the inlet tube. Also, the tube has a larger influence on flow distortion than the OAP probes with arms (i.e., 2D-S, 2D-Gray and HVPS). It is recommended to use particle size distributions from the 2D-S and HVPS-4 unless those probes are not operating properly.

SEA WCM-2000 LWC/TWC Probe (ARCSIX-Lwc123_P3B…R0) installed only on the P-3 is a combination instrument with three sensors: LWC1 is a 2.0-mm diameter hot-wire and LWC2 is a 0.5-mm diameter hot-wire, each sensor measures LWC. LWTA is a 4-mm heated cylinder to measure total water content (TWC). See Lillie et al. 2005 for more information).

SkyTech Nevzorov LWC/TWC Probe (ARCSIX-NevLwc123_Learjet…ICT) installed only on the Learjet is a combination instrument with three sensors: LWCA1 a 2-mm hot-wire and LWCA2 is a 3-mm diameter hot-wire, each sensor measures LWC. LWTA is an 8-mm heated cone to measure TWC. See Korolev et al. (1998 for more information).

Prosensing Precipitation Radar (KPR). The Learjet KPR data have been processed by Dr. Alexei Korolev and are available in the archives under Dr. Korolev's name. See the header for an explanation of the data products and contact Dr. Korolev for details on how the data were processed.

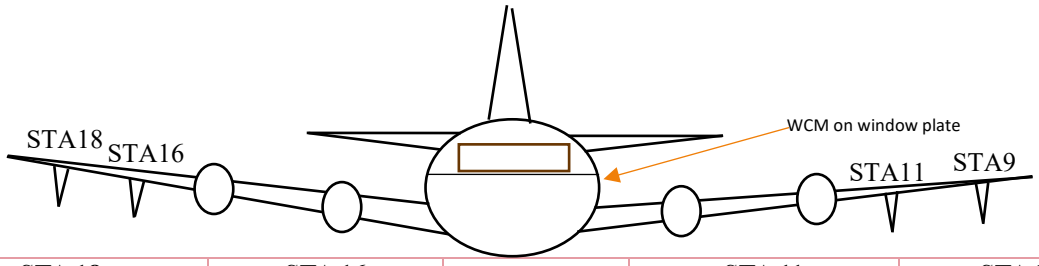
Particle Phase Spectrometer (PPS) – Combination instrument consisting of two probes.

> **2D-Gray 5-micron OAP** (ARCSIX-PPS2DGRAY50_P3B_...ICT). 5-micron resolution optical array probe, capable of viewing particles between 5 and 640 microns with three gray levels (30%, 50% and 70%). A gray level of 50% (equivalent to black and white probes) is used for ICT files, all levels visible in images.
>
> **Cloud Particle Imager (CPI)** with 0.73-micron pixel size at an 877x2600 pixel resolution and 256 gray levels, images available upon request

NOTE: The PPS is a new instrument. This is the first time it has been flown. It was designed to provide higher resolution images of water drops and ice particles than the current CPI and 2D-Gray probe. Data from the gray OAP portion of the probe is not yet processed. The PPS images are available. The PPS on the Lear was more mature than the P-3 instrument.

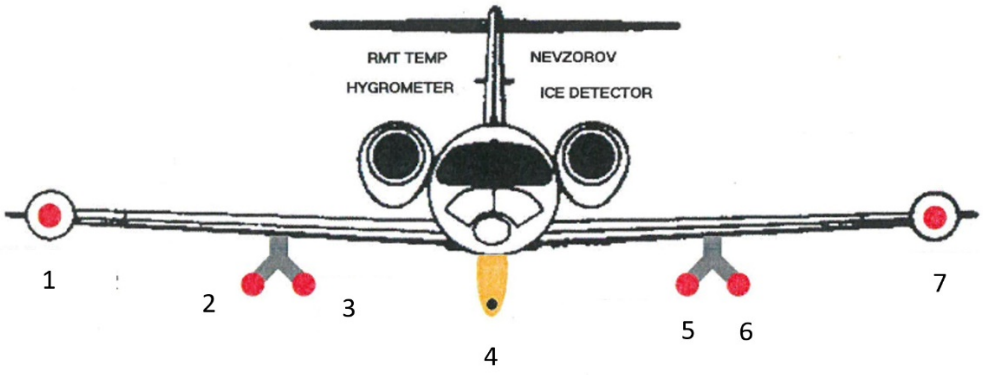
Instrument Locations

P-3



STA 18	STA 16		STA 11	STA 9
Probe	**Probe**		**Probe**	**Probe**
PCASP	Hawkeye		F2D-S & FCDP	PPS
HVPS-4			2D-Gray	

Learjet

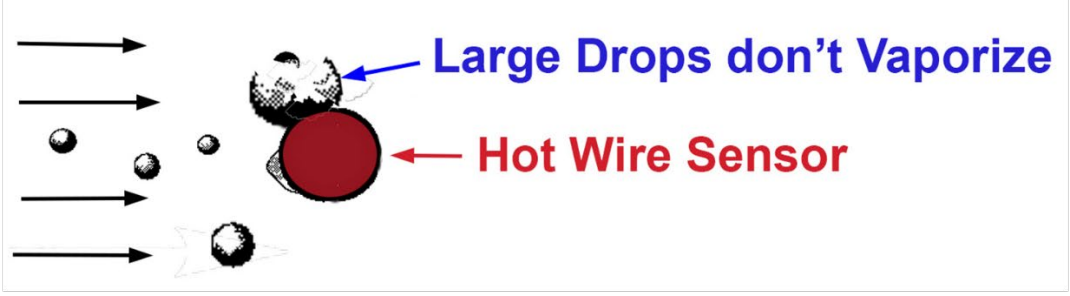


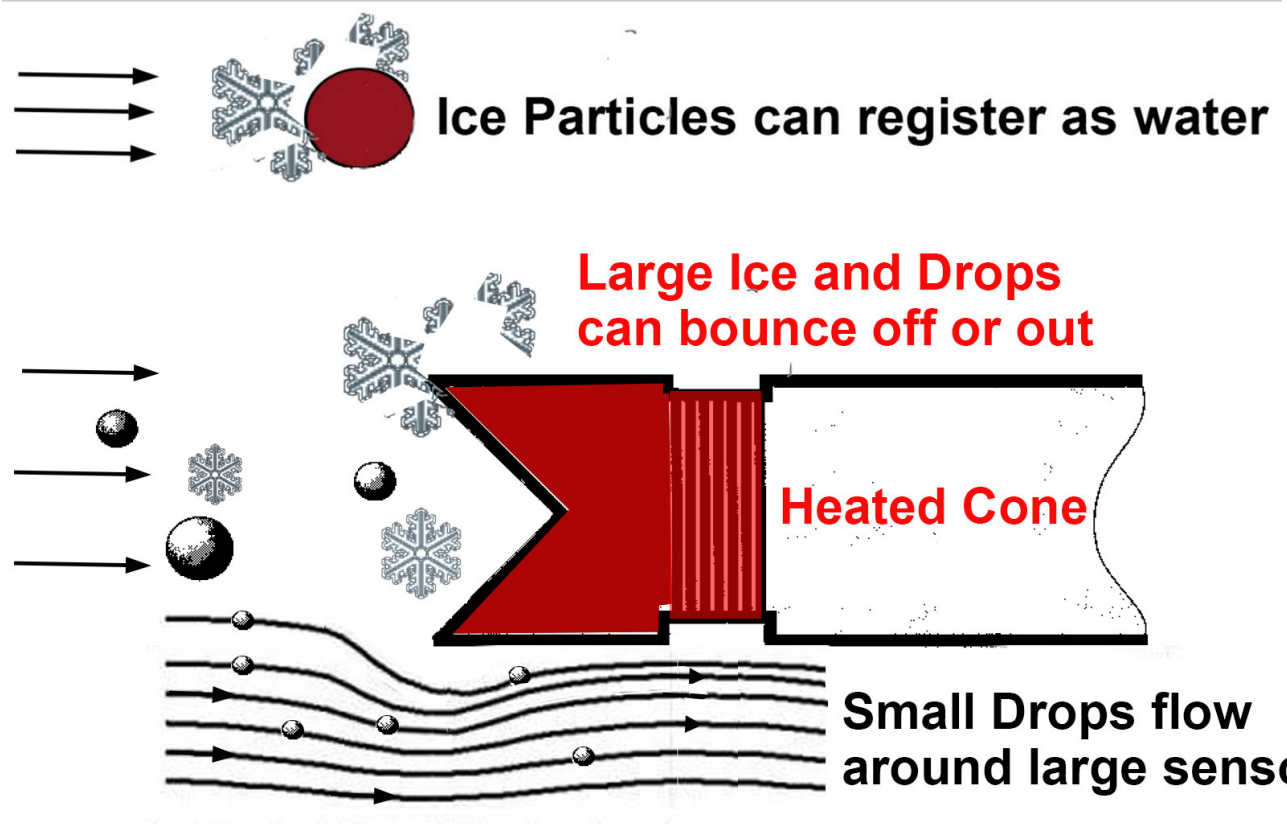
1	2	3	4	5	6	7
Probe	**Probe**	**Probe**	Probe	**Probe**	**Probe**	**Probe**
AIMMS & FCDP	2D-S	2D-Gray	PPS	HVPS-4	KPR	FFSSP

NOTE: The AIMMS air motion sensing probe was inoperative. The FFSSP and PCASP probes did not perform well and data have not been archived.

3.0 Errors Inherent in Various Instruments

3.1 Hot-Sensors for Measuring LWC and TWC (WCM and Nevzorov)





3.2 FCDP

- Suffers from errors associated with single-particle measurement, e.g., very small sample volume, particle coincidence in the sample volume artificially broadens drop size distribution.
- Sizing limited to about 50 microns.
- Large drops outside the sample volume can register as small drops.
- Error in sizing drops is cubed in LWC calculation.
- Sizing is predicated on spherical particles (Mie scattering theory).

3.3 OAP Probes

- The depth of field increases as a function of the square of particle size. Thus, the depth of field (and sample volume) increases until it reaches the distance between the probe arms. The concentration of particles up to about 110 μm in maximum dimension are adjusted based on their depth of field, i.e., sample volume (Lawson et al. 2006).
- Particles shattering from inlets and arms are mostly rejected in post-processing (Lawson 20011; Korolev et al. 2011).
- In general, particle concentration in the first two size bins are less reliable than larger bins.
- Images of out of focus particles that appear as "donuts", are resized using the diffraction-based correction found in Korolev (1997).

How to use the Archived Data files

4.1 Overview

- Starting with the page0 spreadsheet gives a good overview of output from all of the instruments, including time, position, state parameters and particle probe data.
- Viewing particle images from the 2D-GRAY and HVPS-4 probes will provide visual information of particle characteristics, i.e., whether cloud is all-liquid or mixed-phase, contains drizzle, etc. CPI and PPS images are also useful, but both probes have a small sample volume and will go into overload in high particle concentrations, (i.e., cloud drops), so larger (ice) particles may not be imaged.
- Due to occasional instrument problems, data collected by a specific probe may not be included for portions of a mission, or in rare cases, data may be omitted from the archives for an entire mission. There are multiple probe redundancies to avoid a lack of data in specific size ranges. If you have questions about data not in the archive, please reach out to Parker Morris (parker@specinc.com).
- Combining size distributions from multiple instruments will be essential throughout most of the mission due to size limitations of each instrument.

4.2 Calculating LWC in All-liquid clouds

The hot-wire probes provide the best estimate of LWC in all-liquid clouds with cloud drops < ~ 50 microns in diameter. In all-liquid clouds with drops > 50 microns the WCM and Nevzorov TWC hot-sensors can be used, but due to errors shown in Section 3.1 the TWC value may not be the most accurate method. LWC computed from integrating the FCDP drop size distribution (DSD) is also archived and may be used for comparison with the hot-wire probes.

An alternative method involves "stitching" together DSDs from multiple probes. An example is shown in the **Figure 4.1**. The FCDP DSD is used from 2 to 40 microns, the 2D-S DSD is added to the FCDP from 40 to 250 microns and the HVPS-4 is incorporated from 250 to 350 microns. Bulk properties listed to the right of the combined DSD show that LWC is doubled when the 2D-S DSD is added in the presence of drizzle. Drop

concentration and extinction are increased slightly. Radar reflectivity is increased by orders of magnitude when the large drop portion of the DSD is incorporated.

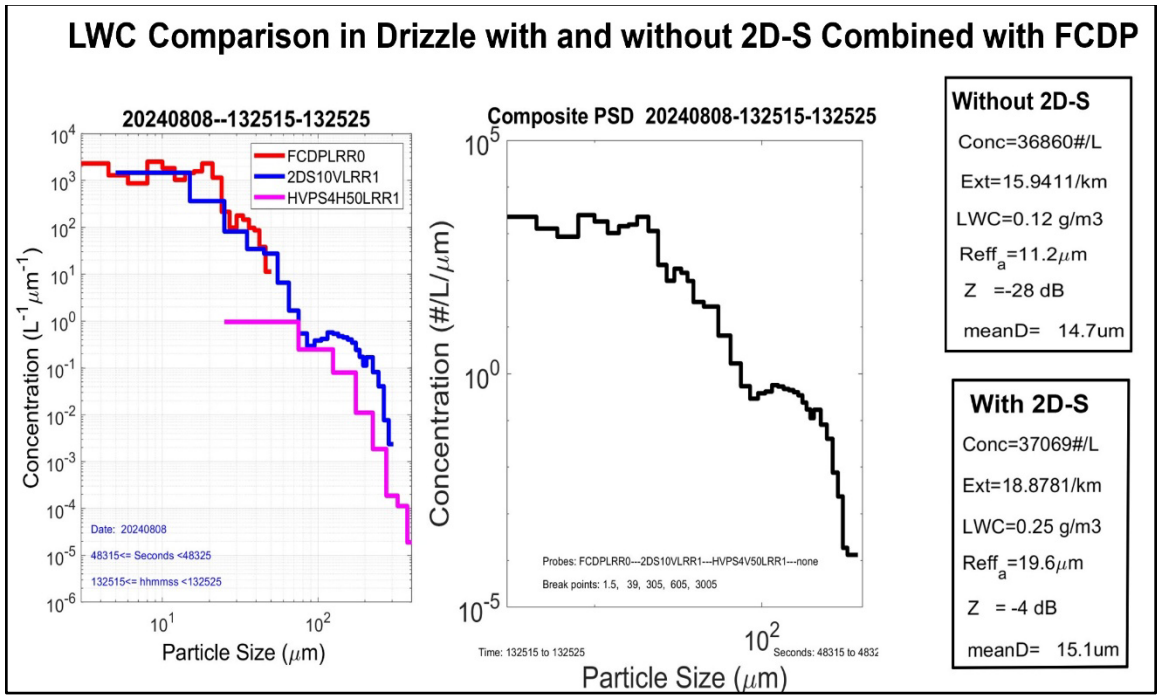


Figure 4.1. Example of DSDs in all-liquid cloud with drizzle and computation of bulk properties with and without incorporating 2D-S and HVPS-4 data.

4.3 Calculating LWC and IWC in Mixed-phase Clouds

4.3.1 Mixed-phase with Cloud Drops < 50 microns

In several of ARCSIX mixed-phase clouds the drop size spectrum does not exceed 50 microns, i.e., the size limit of the FCDP and hot-wire probes. These mixed-phase clouds can generally be distinguished from OAP and CPI images. Both sets of images should be examined. An example of images in this regime is shown in **Figure 4.2**. In these cases the LWC can be estimated from the hot-wire probes and/or FCDP. However, both instruments have a partial response to ice particles.

IWC can be estimated in this mixed-phase regime from the combined particle size distribution. This is demonstrated in the **Figure 4.3** that shows all the PSDs from the FCDP and OAP probes (top), and the combined PSD (bottom). The portion of the combined size distribution from the size of the largest drops out to the maximum particle size is then used to compute IWC, which is accomplished using a power-law relating particle size-to-mass, such as found in Brown and Francis (1995). Code to compute IWC and other bulk properties using the combined particle size distribution needs to be developed by the user. Alternatively, Matlab code is available from SPEC on request that does this function, but is not supported by SPEC.

An alternative method for estimating IWC in this regime is to use the .ICT file that contains IWC from the 50-micron channel of the HVPS-4 probe. This file uses the particle-by-particle IWC power law for particle area-to-mass (Baker and Lawson 2006), which is considered more accurate for columnar ice particles. However, the caveat is that the first bin of the 50-micron channel extends from 25 to 75 microns, so some cloud drops may also be included. That said, the first bin will miss some ~ 50-micron ice particles due to the discrete spacing of the photodiode array, so there are competing errors. Both techniques, using the combined PSD and the HVPS-4 50-micron IWC .ICT file should be compared as a sanity check.

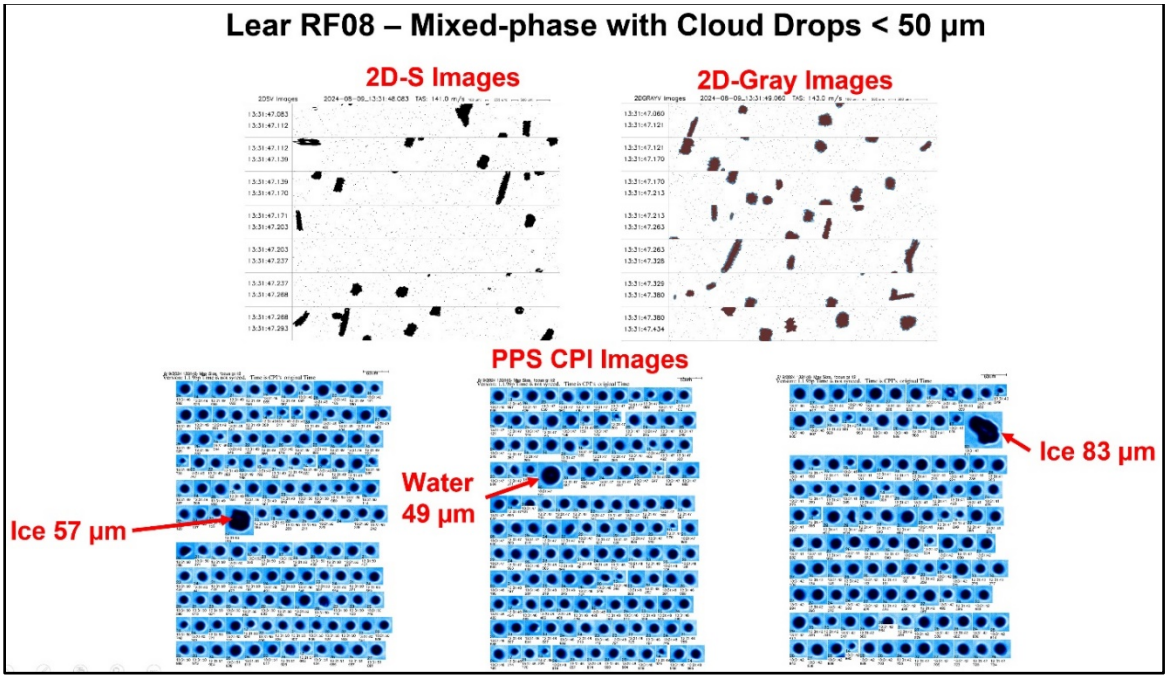


Figure 4.2. Example of 2D-S, 2D-Gray and CPI images in mixed-phase cloud where cloud drops are < 50 microns in diameter.

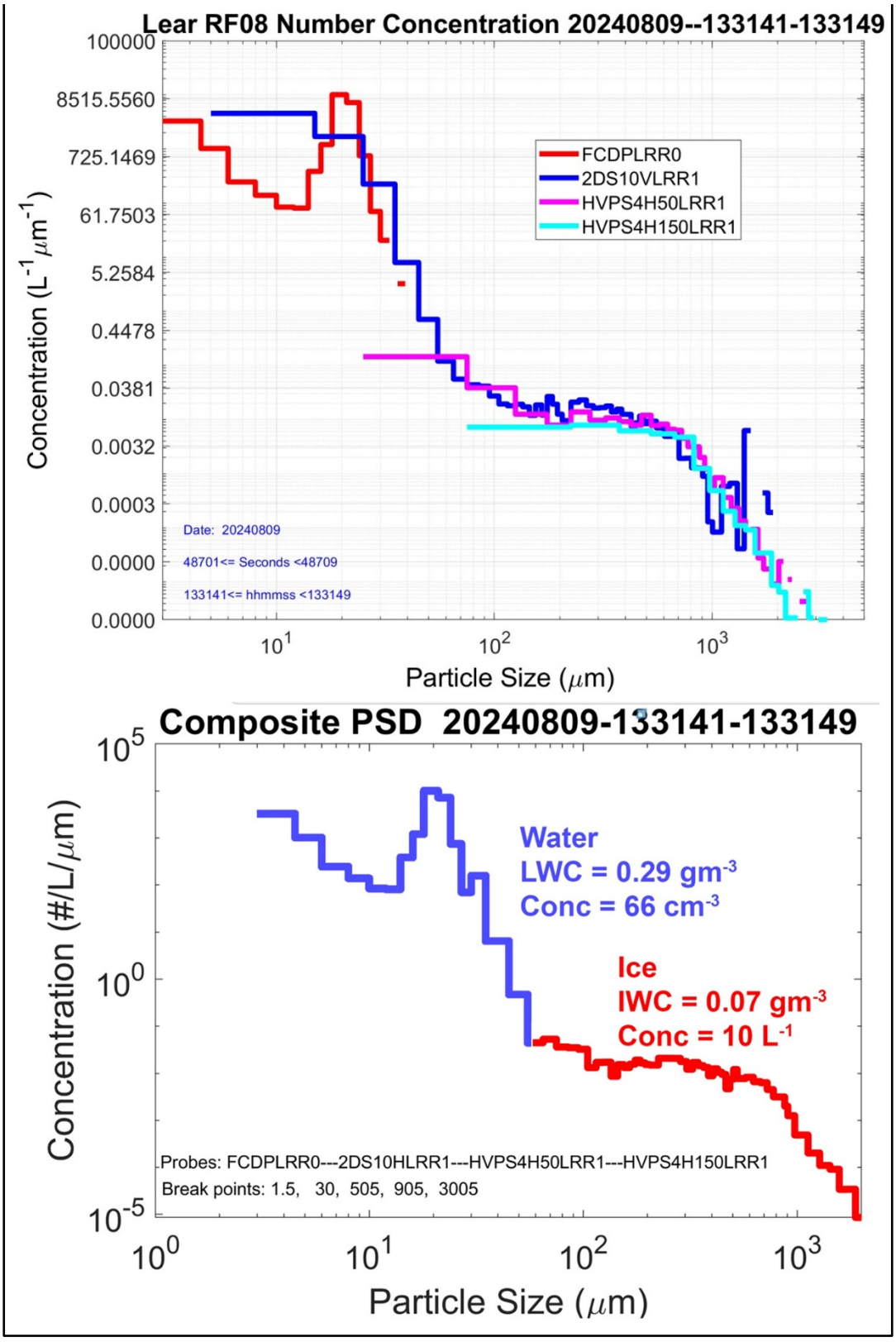


Figure 4.3. Example of (top) FCDP, 2D-S and HVPS-4 PSDs in mixed-phase cloud with drops < 50 microns, and (bottom) combined PSD with water separated from ice.

4.3.2 Mixed-phase with Cloud Drops > 50 microns (i.e., Drizzle)

Separating water and ice size distributions in mixed-phase clouds where the size of drizzle drops overlaps with the size of ice particles is more difficult than clouds where the size of water and ice do not overlap. An example of 2D-Gray images with overlapping sizes of ice and water drops is shown in **Figure 4.4** along with PSDs from the OAP probes and a combined PSD.

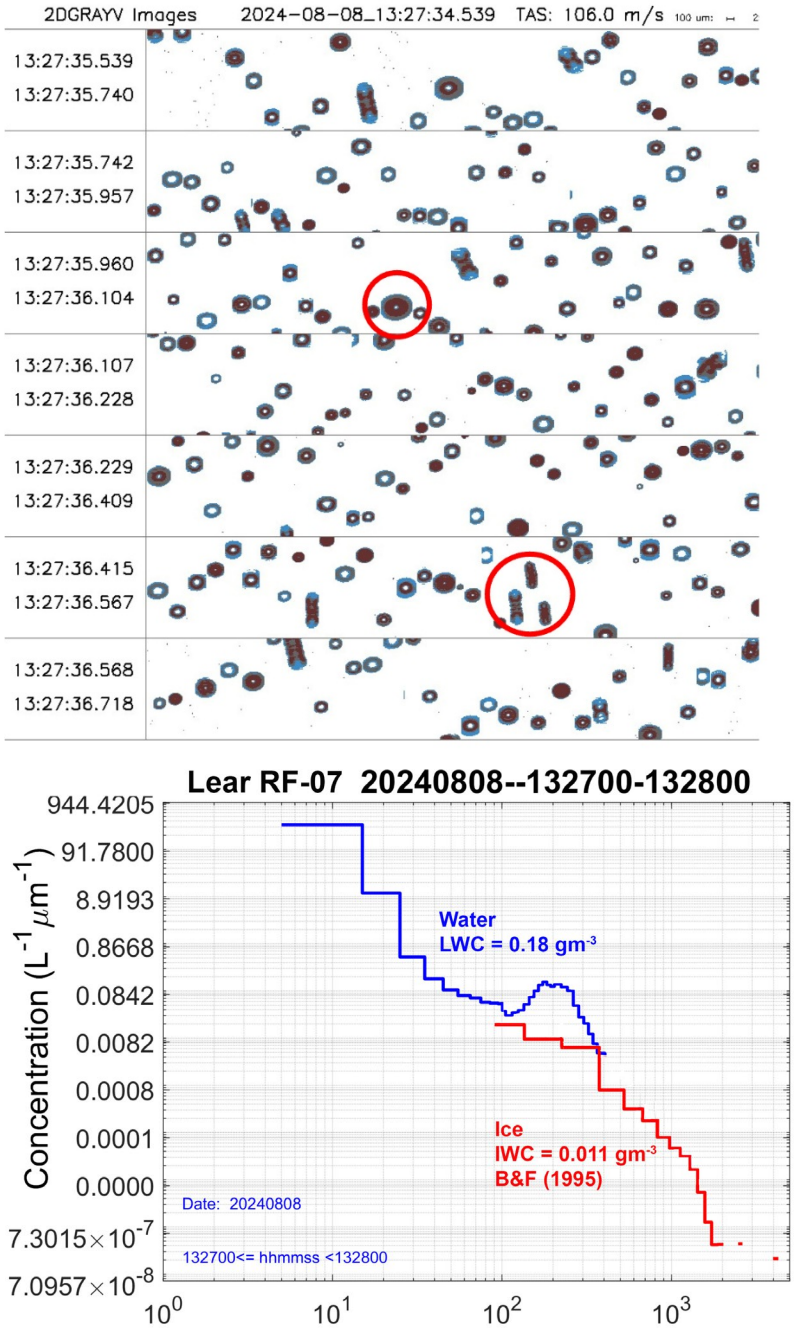


Figure 4.4. Example of (top) 2D-Gray images and (bottom) ice and water PSDs in mixed-phase where the sizes of drizzle drops and ice particles overlap.

In this case, separate water and ice size distributions are determined by a visual inspection of the 2D-Gray images. The percentage of water drops and ice particles is estimated for each size bin and then plotted separately. Bulk properties for the water DSD are computed assuming spherical drops and the ice portion is estimated using a size-to-mass power law. This is a very manually intensive process and requires some familiarity with 2D-Gray images. As shown in **Figure 4.5**, some images are clearly water drops (blue circles) or ice particles (red circles), others are questionable (black circle with ??). Using the gray probe instead of the black and white 2D-S has the advantage that typically each gray color is circular, even when the drop is out of focus (i.e., a donut). However, as irregular-shaped ice with an aspect ratio close to one becomes increasingly out of focus, the diffraction pattern becomes more and more circular, making it difficult to separate phase. Also, if two water drops are within proximity, they can look like an out-of-focus columnar ice particle (see example with a question mark in **Figure 4.5**).

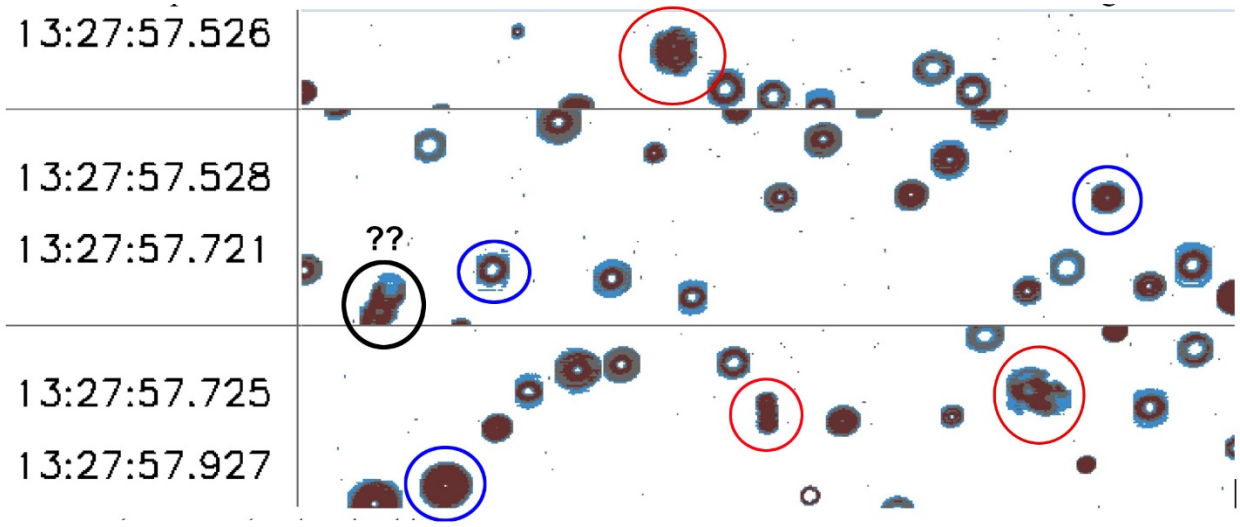


Figure 4.5. 2D-Gray images showing examples of water drops (blue circles) and ice particles (red circles) estimated from the shapes of the images. Black circle illustrates ambiguity where the image may be out-of-focus columnar ice or two water drops.

References

Brown, P.R.A. and P.N. Francis.: Improved measurements of the ice water content in cirrus using a total-water probe. Journal of Atmospheric and Oceanic Technology, 12, 410-414, 1995

Korolev, A. V., Emery, E. F., Strapp, J. W., Cober, S. G., Isaac, G. A., Wasey, M., and Marcotte, D.: Small Ice Particles in Tropospheric Clouds: Fact or Artifact? Airborne Icing Instrumentation Evaluation Experiment, Bulletin of the American Meteorological Society, 92, 967–973, https://doi.org/10.1175/2010BAMS3141.1, 2011.

Korolev, A. V., Strapp, J. W., Isaac, G. A., and Nevzorov, A. N.: The Nevzorov Airborne Hot-

Wire LWC–TWC Probe: Principle of Operation and Performance Characteristics, J. Atmos. Oceanic Technol., 15, 1495–1510, https://doi.org/10.1175/1520-0426(1998)015<1495:TNAHWL>2.0.CO;2, 1998.

Lawson, R. P. and Cooper, W. A.: Performance of Some Airborne Thermometers in Clouds, J. Atmos. Oceanic Technol., 7, 480–494, https://doi.org/10.1175/1520-0426(1990)007<0480:POSATI>2.0.CO;2, 1990.

Lawson, R. P., and. Baker, B. A.: Improvement in determination of ice water content from two-dimensional particle imagery. Part II: Applications to collected data. Journal of Applied Meteorology, 45, 1291-1303, 2006

Lawson, R. P., D. O'Connor, P. Zmarzly, K. Weaver, B. A. Baker, Q. Mo, and H. Jonsson, 2006: The 2D-S (Stereo) Probe,: Design and preliminary tests of a new airborne, high speed, high-resolution particle imaging probe. Journal of Atmospheric and Oceanic Technology, 23, 1462-1477, 2006

Lawson, R. P.: Effects of ice particles shattering on the 2D-S probe, Atmospheric Measurement Techniques, 4, 1361–1381, https://doi.org/10.5194/amt-4-1361-2011, 2011.

Lilie, L., Emery, E., Strapp, J., and Emery, J.: A Multiwire Hot-Wire Device for Measurement of Icing Severity, Total Water Content, Liquid Water Content, and Droplet Diameter, in: 43rd AIAA Aerospace Sciences Meeting and Exhibit, 43rd AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, https://doi.org/10.2514/6.2005-859. 2005

Pazmany, A. L. and Haimov, S. J.: Coherent Power Measurements with a Compact Airborne Ka-Band Precipitation Radar, Journal of Atmospheric and Oceanic Technology, 35, 3–20, https://doi.org/10.1175/JTECH-D-17-0058.1, 2018.