CAMP2Ex Data Documentation Readme File for SPEC Instrumentation onboard both Learjet and P3-B

PI: Paul Lawson
Organization: SPEC (Stratton Park Engineering Company), Inc.
Contact: 3022 Sterling Cir, Ste. 200, Boulder, CO 80301, (303)449-1105, plawson@specinc.com
Platforms: NASA P3-B and SPEC Learjet 35
Stipulations on Use: Users are strongly encouraged to consult PI and/or DM prior to use.

Learjet Instrumentation: State and Cloud Microphysics

Equipment	*Manufacturer/Model*	*Range*	*Accuracy*
Temperature	Rosemount Model 102 & 510BH	-50 to +50 °C	0.5 °C
Altitude	West Star Aviation RVSM Certification	45,000 ft (13.7 km)	60 ft (18.3 m)
Airspeed	West Star Aviation RVSM Certification	0 to 220 m s^{-1}	1 m s^{-1}
Dew Point Temperature	EdgeTech Chilled Mirror C-137	-50 to + 50°C	1°C
Liquid Water/Total Water	Sky Tech Nevzorov LWC/TWC	0 to 4 g m^{-3}	0.1 g m^{-3}
Icing Rate	Rosemount Icing Rod 871LM5	N/A	Sensitivity ~0.01 g m^{-3}
Aircraft Position	Aventech AIMMS-20 Dual GPS	N/A	10 m
Aircraft Heading	Learjet Sperry Directional Gyro	0 to 360°	1°
Horizontal Wind	Aventech AIMMS - 20	0 to 360° 1 to 100 m s^{-1}	1° 1 m s^{-1}
Vertical Wind	Aventech AIMMS - 20	0 to 50 m s^{-1}	0.5 m s^{-1}
2D-S (Stereo) Optical Array Spectrometer	SPEC Model OAP 2D-S	10 μm to 3 mm	10 μm
Fast Forward Scattering Spectrometer Probe (FFSSP)	SPEC Model FFSSP	2 to 50 μm	2 μm
Fast Cloud Droplet Probe (FCDP)	SPEC Model FCDP-100	2 to 50 μm	2 μm
High Volume Precipitation Spectrometer (HVPS)	SPEC Version-3 HVPS	150 μm to 2 cm	150 μm
Combination FCDP, 10 and 50 μm 2D-S, V 2.5 CPI	SPEC Hawkeye	1 μm to 6,400 μm	1 μm (FCDP) 10-50 μm (2D-S) 2.3 μm (CPI)
Passive Cavity Aerosol Spectrometer (PCASP)	PMS	0.1 to 3 μm	0.05 μm
Condensation Particle Counter (CPC)	TSI Water-based aerosol CPC	Down to 10 nm in size	
Forward Camera	Allied Vision Guppy F-080 Camera	N/A	N/A

P3-B Instrumentation: Cloud Microphysics

Instrument	*Resolution*	*Size Range*	*Measurement*
PCASP 100X	Variable: 10nm, 100nm, 200nm	0.1-3 µm	Aerosol concentration and size outside of cloud; reverse flow inlet
FCDP and HawkFCDP	~1-3 µm	1-50 µm	Cloud droplets, forward scattering
2D-S (2D10, 2-channels)	10 µm	10-1280 µm	Drops/Ice, 2D-imagery
Hawk2D-S (Hawk2DS10, Hawk2DS50)	10/50 µm	10-6400 µm	Drops/Ice, 2D-imagery
HawkCPI	2.3 µm	9-2000 µm	Drops/Ice, High res-imagery
HVPS (1-channel)	150 µm	150-19200 µm	Precip/Ice, 2D-imagery

Cloud Probe Analysis Guidelines

Note: Page0 for the Learjet contains all state information from the aircraft and a summary of the in situ data (concentration or LWC) from each instrument.

The suite of in situ cloud microphysics probes on each aircraft should be used together in order to provide the most complete picture of the clouds sampled. Together, the suite provides concentration, area, and mass particle size distributions (PSDs), from which bulk properties such as total concentration, liquid water content (LWC), ice water content (IWC), total water content (TWC), effective radius (Reff), extinction, etc. may be calculated.

Within the cloud microphysics suite, the scattering probes (FFSSP, FCDP, HawkFCDP) cover the droplet size range (1-50 µm). The Optical Array Probes (OAPs: 2D-S, Hawk2D10, Hawk2D50, HVPS) cover droplet to precipitation sizes depending on the individual OAP's pixel resolution (see chart above for specifics).

In order to provide measurement across the full size range of cloud particles, the measurements from the individual instruments need to be combined. There is some overlap in the size ranges covered by each instrument, so combining their individual instruments is not a simple matter of addition of bulk properties, but rather first the individual size distributions must be blended, taking into account temporal averaging to acquire good sampling statistics, probe sizing uncertainties, etc. in order to choose appropriate size cutoffs for combining the instrument PSDs. Thus, in order to combine PSDs from the individual instruments, it is recommended to first average the 1 Hz individual instrument PSDs over the time period of interest. The individual PSDs should then be plotted up to assess the overlay of the PSDs. Typically, cutoffs are chosen such that they provide the best continuous size distribution across all sizes. This choice also takes into account that the OAPs generally have higher uncertainties in the smallest bins, and may also be assisted by looking at the OAP imagery. These cutoffs may vary from cloud to cloud (or even within a single cloud pass) depending on the cloud particle spectra, influenced by such factors as cloud age, location within cloud, cloud type, particle phase, etc. Two cumulus congestus case studies from 19 and 25 of September flights, utilizing data from both aircraft, have been posted on LaRC for helpful reference in combining PSDs and providing examples of the spatial and temporal variability in these tropical warm clouds: https://www-air.larc.nasa.gov/cgi-bin/DocXhg/CAMP2EXDocs#ShowAll.

In regard to choice of forward scattering probes onboard the Learjet, the FFSSP and FCDP often contain discrepancies for sizes smaller than about 30 µm, but agree quite well for D > 30 µm. These differences in the smaller sizes are due to differences in instrument design and data collection. Further laboratory and field research is needed to better constrain these measurement sensitivities and uncertainties at the smallest sizes. The FFSSP has a more extensive field history, and is typically held to be the observation of choice between the two for measuring cloud droplets. To address this discrepancy, the R1 FCDP & HawkFCDP data has had a correction applied to bring it closer in line with the FFSSP data, see details in the data concerns section below. Note that the FCDP appears to be more sensitive to coarse mode aerosol particles than the FFSSP, and FCDP observations are often utilized for such.

For specific guidance on which probes to use, how to combine data from multiple instruments, imagery questions, etc., please email Paul Lawson (plawson@specinc.com) or Sarah Woods (swoods@specinc.com).

All of the CAMP2Ex 2D-S data is processed with M4M7. The various lengthscales will not make a big difference in the liquid clouds, but they are of particular importance for ice clouds, since the particles are of varying shape and orientation. M7 defines the particle size as the longest length in any direction across the particle image. M4 applies Korolev re-sizing of out-of-focus particles, which is important for the smaller particles of both phases, but will introduce larger uncertainties in ice clouds since it assumes the original particle was spherical (original shape is unkown). M4 has been updated in recent years to also use the longest lengthscale in any direction as the original particle size prior to resizing, so that the same lengthscale is used across the combination of M4 and M7.

Possible data concerns with specific instruments:

2D10 (mostly P3): Intermittent time jumps were found in the 1 Hz processed preliminary data (RA). We have worked hard to rectify these jumps in post-processing QC and analysis, but user should be aware of issue and contact DM if they notice additional timing issues in the final (R0) data.

HawkFCDP (P3 only): Post-deployment calibration gives a bit of shift toward better size distribution agreement, but standalone FCDP most reliable of the two droplet probes. Recommend primary use of FCDP, with HawkFCDP as a backup should FCDP be missing data/inoperable.

Hawk2D50 (P3 & Learjet): Be aware of some splashers in this dataset (drops that have hit and splashed on the instrument windows) at the largest sizes.

HVPS (P3 & Learjet): Be aware of a lot of splashers in this dataset (drops that have hit and splashed on the instrument windows): size distributions will sometimes need to be truncated when the splashers extend the size distribution to unrealistic sizes (D > ~3-5 mm).

HVPS (mostly P3): Some intermittent time jumps were found in the 1 Hz processed preliminary data (RA). We have worked hard to rectify these jumps in post-processing QC and analysis, but user should be aware of issue and contact DM if they notice additional timing issues in the final (R0) data.

HawkCPI Imagery: Note that at times the instrument was run in "fishing" mode, where it is set to capture images of larger particles only. When not in "fishing" mode, the max frame rate is about 400 fps, so caution should be used when interpreting the HawkCPI imagery as certain times may be overrun with smaller or larger particles depending on the mode of operation. These images should be analyzed in the context of the OAP (2D10, Hawk2D10, Hawk2D50, HVPS) imagery. Please contact PI or DM for specific guidance on imagery analysis.

Scattering Probe Data (FCDP & HawkFCDP on P3 & Learjet): During our analysis of the scattering probe data, we observed that the small particle concentrations (D<30µm) for the FCDP instruments were anomalously large in comparison to that of the FFSSP. We have not been able to determine the cause of this discrepancy to date, and further laboratory studies are warranted. To mitigate this issue, we have applied a correction factory to all FCDP and HawkFCDP data in an attempt to adjust the FCDP particle size distributions to match the complimentary FFSSP instrument that was deployed on the Learjet during this campaign. The correction factor is a function of particle size (detailed in ICT header): FCDP Conc (#/L/um) = FCDP Conc * [Bin Center /30 ^ 0.3]. In practice, this correction may reduce the reported FCDP concentration by ~30% in some cases, though the impact on the reported water content is minimal since the small particles typically contribute a small proportion of the total observed water content. This change has been applied and archived as R1 for all FCDP and HawkFCDP files. The R0 files did not include this correction.

Notes on Bulk Products:

Reff:

The effective particle radius is computed using two methods: $Reff_a$ is computed by assuming the particles are spherical (based on their maximum dimension) and divides the third moment (radius cubed) by the second moment (radius squared). This calculation is most applicable for measurements that are composed of all water drops. $Reff_b$ is computed from dividing particle mass, using the formula from Baker and Lawson (2006), by the projected area of the particle. This calculation is most applicable for measurements that are composed of all ice particles.

WC

The water content (WC) here is reported as the liquid water content (LWC) or ice water content (IWC) for the forward scattering and OAP probes. This value is the result of integrating across the drop or particle size distribution. For a given instrument file, this value is only valid for the size range covered by that specific instrument. As with the other properties, note that there is overlap in instrument size ranges, so the grand total for the full size distribution cannot be found by simply summing the individual instrument WC values. For the Learjet Nevzorov observations, the TWC = IWC + LWC. Please see the Analysis Guidelines section and LaRC cumulus congestus case studies for further details of how to compute the total liquid or ice water content across all cloud particle sizes.

Ext:
Extinction = 2*cross sectional area. Again, specific to the individual instrument's size range.

Instrumentation Reference Information

Parameter	Instrument	PI	Reference
Learjet State			
Temperature	Rosemount Model 102 & 510BH	Lawson (SPEC)	Lawson and Cooper (1990)
Altitude	Royal Air FAA RVSM Certification	Lawson (SPEC)	
Airspeed	Royal Air FAA RVSM Certification	Lawson (SPEC)	
Dew Point Temperature	EdgeTech Chilled Mirror C-137	Lawson (SPEC)	
Liquid Water/Total Water	Sky Tech Nevzorov LWC/TWC	Lawson (SPEC)	Korolev et al. (1998)
Icing Rate	Rosemount Icing Rod 871LM5	Lawson (SPEC)	Baumgardner and Rodi (1989); Cober et al. (2001)
Aircraft Position	Aventech AIMMS-20 Dual GPS	Lawson (SPEC)	Beswick et al. (2008)
Aircraft Heading	Learjet Sperry Directional Gyro	Lawson (SPEC)	
Horizontal & Vertical Winds	Aventech AIMMS - 20	Lawson (SPEC)	Beswick et al. (2008)
Microphysics (Concentration, Area, Mass, Size, etc)			
Cloud droplets (2-50 µm)	SPEC Fast Forward Scattering Spectrometer Probe (FFSSP)	Lawson (SPEC)	Knollenberg (1981), Brenguier et al. (1998), Lawson et al. (2017)
Cloud droplets (2-50 µm)	SPEC Fast Cloud Droplet Probe (FCDP)	Lawson (SPEC)	Knollenberg (1981), O'Connor et al. (2008), Lawson et al. (2017)
Cloud particles (10 µm – 3 mm)	SPEC 2D-S (Stereo) Optical Array Spectrometer	Lawson (SPEC)	Lawson et al. (2006a)
Cloud particles (2-50 µm)	SPEC Hawkeye-FCDP	Lawson (SPEC)	Knollenberg (1981), Lawson et al. (2017); Woods et al. (2018)
Cloud particles (10 µm – 3 mm)	SPEC Hawkeye-2DS	Lawson (SPEC)	Lawson et al. (2006a), Woods et al. (2018)
Cloud particle habit, high res imagery	SPEC Hawkeye-CPI	Lawson (SPEC)	Lawson et al. (2001, 2006b); Woods et al. (2018)
Precipitation (150 µm – 2 cm)	SPEC High Volume Precipitation Spectrometer (HVPS-3)	Lawson (SPEC)	Lawson et al. (1993, 1998)
Aerosol concentration (down to 10 nm in size)	TSI Water-based Condensation Particle Counter (CPC)	Lawson (SPEC)	Liu et al. (2006), additional references, see bibliography at: https://www.tsi.com/discontinued-products/water-based-

			condensation-particle-counter-3782/
Aerosol (0.1 - 3 µm)	DMT Passive Cavity Aerosol Spectrometer (PCASP)	Lawson (SPEC)	DMT PCASP Manual, DOC-0228, Rev C. http://www.dropletmeasurement.com/resources/manuals-guides.

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