ESCAPE Data Documentation Readme File for SPEC Instrumentation onboard Learjet

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
DM: Qixu Mo, mo@specinc.com
Stipulations on Use: Users are strongly encouraged to consult PI and/or DM prior to use.
Author(s): Paul Lawson, SPEC Inc., plawson@specinc.com; Qixu Mo, SPEC Inc, Mo@specinc.com; Roelof Bruintjes, NCAR, roelof@ucar.edu

1.0 Data Set Description

Data Version: R0 (Final), August, 2022
Project: ESCAPE, June 1-20 2022, https://www.eol.ucar.edu/field_projects/escape
Platform(s): SPEC Learjet
Instrumentation: State and Cloud microphysics (from Learjet), as listed below. Further information on the cloud microphysics instrumentation and additional project photos can be found at www.specinc.com.

2.0 Instrument Description

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 and Fast 2D-S (Stereo) Optical Array Spectrometer*	SPEC Model OAP 2D-S or Fast 2D-S with upgraded electronics	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 (HVPS4)*	SPEC Version-4 HVPS	50 μm to 2 cm	50um and 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)
Forward Camera	Allied Vision Guppy F-080 Camera	N/A	N/A
Up/Down Ka-Band Radar	Prosensing KPR	0.1 to 10 km	N/A

***CPI images in archive, OAP images available from SPEC on request.**

**** Radar data available on request**

3.0 Data Collection, Processing and Cloud Probe Analysis Guidelines

Note: Page0 files 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, HVPS4) 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.

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. 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 Qixu Mo (Mo@specinc.com).

All of the ESCAPE 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 unknown). M4 has been updated in recent years to also use the longest length scale in any direction as the original particle size prior to resizing, so that the same length scale is used across the combination of M4 and M7.

4.0 Data Format

All data files follow the standard ICARTT data format (https://www-air.larc.nasa.gov/missions/etc/IcarttDataFormat.htm). Please see individual data file headers for lists of specific parameters, units, etc. All sampling is reported at 1 Hz. For faster sampling products, please email PI or DM with specific requests. OAP imagery is also available by request.

5.0 Data Remarks

Hawk2D50 & HVPS4: Be aware of possible splashers in the dataset (drops that have hit and splashed on the instrument windows) at the largest sizes when flying through precipitation.

HawkCPI Imagery: Note that at times the instrument was run in “fishing” mode, where it is set to capture images of larger particles only. During this project it was also run in an automated fishing mode, where it samples in standard mode for 1 second, then fishing mode for 3 seconds. 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, HVPS4) imagery. Please contact PI or DM for specific guidance on imagery analysis.

Notes on Bulk Properties contained in individual instrument files:

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.

6.0 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)

Baumgardner, D. and A. Rodi, 1989: Laboratory and Wind Tunnel Evaluations of the Rosemount Icing Detector. *J. Tech.*, 970-979, doi.org/10.1175/1520-0426(1989)006<0971:LAWTEO>2.0.CO;2

Beswick, K. M., M. W. Gallagher, A. R. Webb, E. G. Norton, and F. Perry, 2008: Application of the Aventech AIMMS20AQ airborne probe for turbulence measurements during the Convective Storm Initiation Project. *Atmos. Chem. Phys*., 8, 5449–5463, doi:10.5194/acp-8-5449-2008.

Brenguier, J.-L., T. Bourrianne, A. de Araujo Coelho, J. Isbert, R. Peytavi, D. Trevarin, and P. Wechsler, 1998: Improvements of droplet size distribution measurements with the Fast-FSSP. *J. Atmos. Oceanic Technol.*, 15, 1077–1090, doi:10.1175/1520-0426(1998)015,1077:IODSDM.2.0.CO;2.

Cober, S. G., G. A. Isaac, A. V. Korolev, and J. W. Strapp, 2001: Assessing Cloud-Phase Conditions. *J. Appl. Meteor.,* 40, 967-1983, doi.org/10.1175/1520-0450(2001)040<1967:ACPC>2.0.CO;2

DMT PCASP Manual, DOC-0228, Rev C. http://www.dropletmeasurement.com/resources/manuals-guides.

Korolev, A. V., Strapp, J. W., Isaac, G. A., & Nevzorov, A. N., 1998: The Nevzorov Airborne Hot-wire LWC-TWC Probe: Principle of operation and performance characteristics. *Journal of Atmospheric and Oceanic Technology*, *15*(6), 1495–1510. https://doi.org/10.1175/1520-0426(1998)015<1495:TNAHWL>2.0.CO;2

Knollenberg, R. G., 1981: Techniques for probing cloud microstructure. Clouds: Their Formation, Optical Properties, and Effects. P.V. Hobbs and A. Deepak, Eds., *Academic Press*, 15–91, doi:10.1016/B978-0-12-350720-4.50007-7.

Lawson, R. P. and W. A. Cooper, 1990: Performance of some airborne thermometers in clouds. *J. Atmos. Oceanic Technol*., 7, 480–494, doi:10.1175/1520-0426(1990)007,0480:POSATI.2.0.CO;2.

Lawson, R. P., R. E. Stewart, J. W. Strapp, G. A. Isaac, 1993: Aircraft observations of the origin and growth of very large snowflakes. *Geophys. Res. Lett.*, 20(1), doi.org/10.1029/92GL02917.

Lawson, R. P., R. E. Stewart, and L. J. Angus, 1998: Observations and numerical simulations of the origin and development of very large snowflakes. *J. Atmos. Sci*., 55, 3209–3229.

Lawson, R. P., B. A. Baker, C. G. Schmitt, and T.L. Jensen, 2001: An overview of microphysical properties of Arctic stratus clouds observed during FIRE.ACE. *J. Geophys. Res.*, **106(D14)**, 14989-15014.

Lawson, R. P., D. O'Connor, P. Zmarzly, K. Weaver, B. A. Baker, Q. Mo, and H. Jonsson, 2006a: The 2D-S (stereo) probe: Design and preliminary tests of a new airborne, high speed, highresolution particle imaging probe. *J. Atmos. Oceanic Technol*., 23, 1462–1477, doi:10.1175/JTECH1927.1.

Lawson, R. P., B. A. Baker, P. Zmarzly, D. O'Connor, Q. Mo, J. F. Gayet, and V. Shcherbakov, 2006b: Microphysical and Optical Properties of Atmospheric Ice Crystals at South Pole Station. *Journal of Applied Meteorology & Climatology*, 45, 1505-1524.

Lawson, R. P., C. Gurganus, S. Woods, and R. Bruintjes, 2017: Aircraft Observations of Cumulus Microphysics Ranging from the Tropics to Midlatitudes: Implications for "New" Secondary Ice Process. *J. Atmos. Sci.***, 74,** 2899-2920.

Liu, W., S. L. Kaufman, B. L. Osmondson, G. J. Sem, F. R. Quant, D. R. Oberreit, 2006: Water-based Condensation Particle Counters for Environmental Monitoring of Ultrafine Particles, *Journal of Air and Waste Management Association*, 56(4):444-455.

O'Connor, D., B. Baker, and R. P. Lawson, 2008: Upgrades to the FSSP-100 Electronics. 15th. Int. Conf. on Clouds and Precipitation. Cancun, Mexico, Universidad Nacional Autónoma deMéxico, P13.6. [Available online at http://cabernet.atmosfcu.unam.mx/ICCP-2008/abstracts/Program_on_line/Poster_13/OConnor_extended_final.pdf.]

Woods, S., P. Lawson, E. Jensen, T. Thornberry, A. Rollins, P. Bui, L. Pfister, M. Avery, 2018: Microphysical Properties of Tropical Tropopause Layer Cirrus. *J. Geophys. Res. Atmos.*, doi: 10.1029/2017JD028068.