ESCAPE Data Documentation Readme File for SPEC Instrumentation onboard Learjet

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1.0 Data Set Description

Data Version: R0 (Final), August, 2022 Project: ESCAPE, June 1-20 2022, <u>https://www.eol.ucar.edu/field_projects/escape</u> Platform(s): SPEC Learjet Instrumentation: State and Cloud microphysics (from Learjet), as listed below. For cloud microphysics instrumentation, additional photos, descriptions, and details 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° |
| | | 1 to 100 m s ⁻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) | SPEC Model OAP 2D-S or Fast 2D-S | 10 µm to 3 | 10 µm |
| Optical Array Spectrometer | with upgraded electronics | mm | |
| Fast Forward Scattering | SPEC Model FFSSP | 2 to 50 μm | 2 μm |
| Spectrometer Probe (FFSSP) | | | |

| 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 |

3.0 Data Collection and Processing and Cloud Probe Analysis Guidelines

Note: PageOfiles 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 μ m). 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 μ m, but agree quite well for D > 30 μ m. 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 (<u>plawson@specinc.com</u>) or Qixu Mo (<u>Mo@specinc.com</u>).

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 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.

4.0 Data Format

All data files follow the standard ICARTT data format (https://www-

<u>air.larc.nasa.gov/missions/etc/lcarttDataFormat.htm</u>). 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 & | Lawson | Lawson and Cooper (1990) |
| | 510BH | (SPEC) | |
| Altitude | Royal Air FAA RVSM | Lawson | |
| | Certification | (SPEC) | |
| Airspeed | Royal Air FAA RVSM | Lawson | |
| | Certification | (SPEC) | |
| Dew Point Temperature | EdgeTech Chilled Mirror C- | Lawson | |
| | 137 | (SPEC) | |
| Liquid Water/Total Water | Sky Tech Nevzorov | Lawson | Korolev et al. (1998) |
| | LWC/TWC | (SPEC) | |
| Icing Rate | Rosemount Icing Rod | Lawson | Baumgardner and Rodi (1989); |
| | 871LM5 | (SPEC) | Cober et al. (2001) |
| Aircraft Position | Aventech AIMMS-20 Dual | Lawson | Beswick et al. (2008) |
| | GPS | (SPEC) | |
| Aircraft Heading | Learjet Sperry Directional | Lawson | |
| | Gyro | (SPEC) | |
| Horizontal & Vertical | Aventech AIMMS - 20 | Lawson | Beswick et al. (2008) |
| Winds | | (SPEC) | |
| | | | |
| Microphysics | | | |
| (Concentration, Area, | | | |
| Mass, Size, etc) | | | |
| Cloud droplets (2-50 µm) | SPEC Fast Forward | Lawson | Knollenberg (1981), Brenguier et |
| | Scattering Spectrometer | (SPEC) | al. (1998), Lawson et al. (2017) |
| | Probe (FFSSP) | | |
| Cloud droplets (2-50 µm) | SPEC Fast Cloud Droplet | Lawson | Knollenberg (1981), O'Connor et al. |
| | Probe (FCDP) | (SPEC) | (2008), Lawson et al. (2017) |
| Cloud particles (10 µm – | SPEC 2D-S (Stereo) Optical | Lawson | Lawson et al. (2006a) |
| 3 mm) | Array Spectrometer | (SPEC) | |
| Cloud particles (2-50 µm) | SPEC Hawkeye-FCDP | Lawson | Knollenberg (1981), Lawson et al. |
| | | (SPEC) | (2017); Woods et al. (2018) |
| Cloud particles (10 µm – | SPEC Hawkeye-2DS | Lawson | Lawson et al. (2006a), Woods et al. |
| 3 mm) | | (SPEC) | (2018) |
| Cloud particle habit, high | SPEC Hawkeye-CPI | Lawson | Lawson et al. (2001, 2006b); |
| res imagery | | (SPEC) | Woods et al. (2018) |
| Precipitation (150 µm – 2 | SPEC High Volume | Lawson | Lawson et al. (1993, 1998) |
| cm) | Precipitation | (SPEC) | |
| | Spectrometer (HVPS-3) | | |

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