DOE/SC-ARM-TR-239

High-Volume Precipitation Spectrometer (HVPS) Instrument Handbook

S Glienke F Mei

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S Glienke
F Mei
Both at Pacific Northwest National Laboratory

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Acronyms and Abbreviations

2D-S	two-dimensional stereo probe
AC	alternating current
ACAPEX	ARM Cloud Aerosol Precipitation Experiment
ACE-ENA	Aerosol and Cloud Experiments in the Eastern North Atlantic
ARM	Atmospheric Radiation Measurement
CACTI	Cloud, Aerosol, and Complex Terrain Interactions
DC	direct current
DOE	U.S. Department of Energy
HVPS	high-volume precipitation spectrometer
ICARTT	International Consortium for Atmospheric Research on Transport and Transformation
IDL	Interactive Data Language
NetCDF	Network Common Data Form
PMS	particle measuring system

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High-volume precipitation spectrometer (HVPS)

2.0 Mentor Contact Information

Fan Mei
Pacific Northwest National Laboratory
902 Battelle Boulevard
P.O. Box 999, MSIN K4-28
Richland, Washington 99352
Ph: 509-375-3965
fan.mei@pnnl.gov

3.0 Vendor/Developer Contact Information

SPEC Inc. (Stratton Park Engineering)
3022 Sterling Circle, #200, Boulder, Colorado 80301
Ph: (303)449-1105
www.specinc.com

4.0 Instrument Description

The high-volume precipitation spectrometer (HVPS, Figure 1) is a U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility instrument for measuring hydrometeors larger than 150 µm (HVPS 2010, SPEC 2013). It is an open-path instrument located on the outside of the aircraft, typically below the wing. A laser sheet throws a shadowgraph image of the hydrometeor (cloud droplets or ice crystals) in the sample volume on a photodiode array. As the hydrometeor moves through the sample volume, this optical array records the moving shape and a two-dimensional picture can be recorded. At an air speed of 100 m/s, the sample volume is 310 l/s. The recorded images can be analyzed for size distributions, number concentrations, and further cloud properties detailed below. Hydrometeors in the range of 0.3−19.2 mm can be fully recorded at a 150 µm resolution; larger particles can only be sized along the direction of flight.

Figure 1. The high-volume precipitation spectrometer (HVPS).

5.0 Measurements Taken

The HVPS measures the two-dimensional images of hydrometeors crossing the sample volume. From the recorded images, key cloud properties such as hydrometeor number concentration, hydrometeor size distribution, and ice and liquid water content are derived.

6.0 Links to Definitions and Relevant Information

6.1 Data Object Description

The raw data is saved in files with the ending .HVPS, which have to be post-processed with software provided by the vendor (Playback and HVPSview). Two types of data are provided through the ARM Data Center. Cloud particle number concentration and cloud particle size distribution can be downloaded in two formats: ICARTT and NetCDF format. Processed image files are also available for each flight. Each image recorded has a timestamp as well as ice and/or droplet size. The options of the derived parameters and methods for the data processing are detailed in the HVPS post-processing manual (HVPS 2010). Two main algorithms are applied during the data process: the algorithm to reconstruct the sizes of spherical particles from their shadow images (McFarquhar 2017) and the algorithm to remove the spurious effects, such as from precipitation shattering (Korolev 2007, McFarquhar 2017).

Data Ordering

Data from the HVPS can be ordered from https://www.arm.gov/capabilities/instruments/hvps. Data are organized by measurement location/campaign.

6.2 Data Plots

Figures 2 and 3 show data from the HVPS after post-processing. Figure 2 shows the total number concentration of sampled hydrometeors as well as a size distribution by time. Gaps in the data are periods outside clouds; the highest and lowest altitudes were above and below cloud, respectively, and show no cloud droplet concentration. Figure 3 shows the flight path colored with the total number concentration, which was relatively low for this case. These plots were generated using the ARM Data Quality Diagnostic Plot Browser (https://dq.arm.gov/dq-plotbrowser/). Figure 4 shows example images from the HVPS.

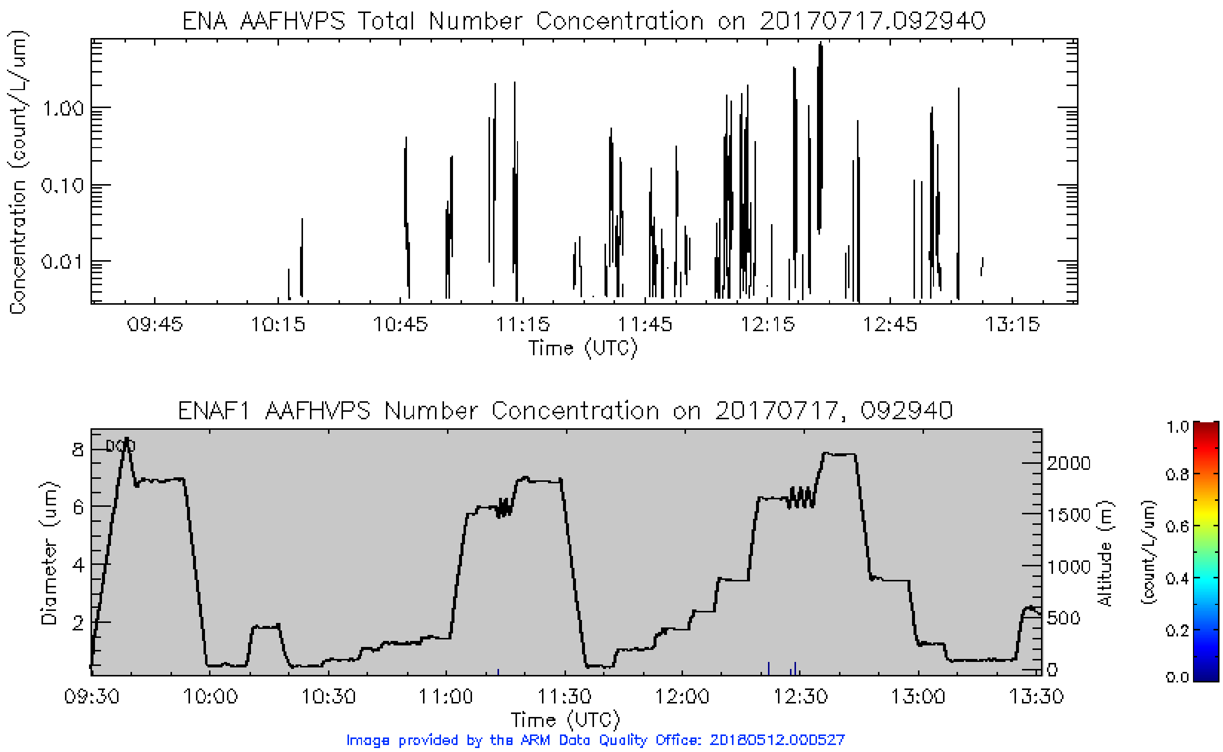

Figure 2. Total cloud droplet number concentration as measured by the HVPS on July 18, 2018 during the Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) field campaign, Azores, Portugal. Top: Total number concentration throughout the flight. Bottom: Number concentration per size from HVPS, also shown is the altitude.

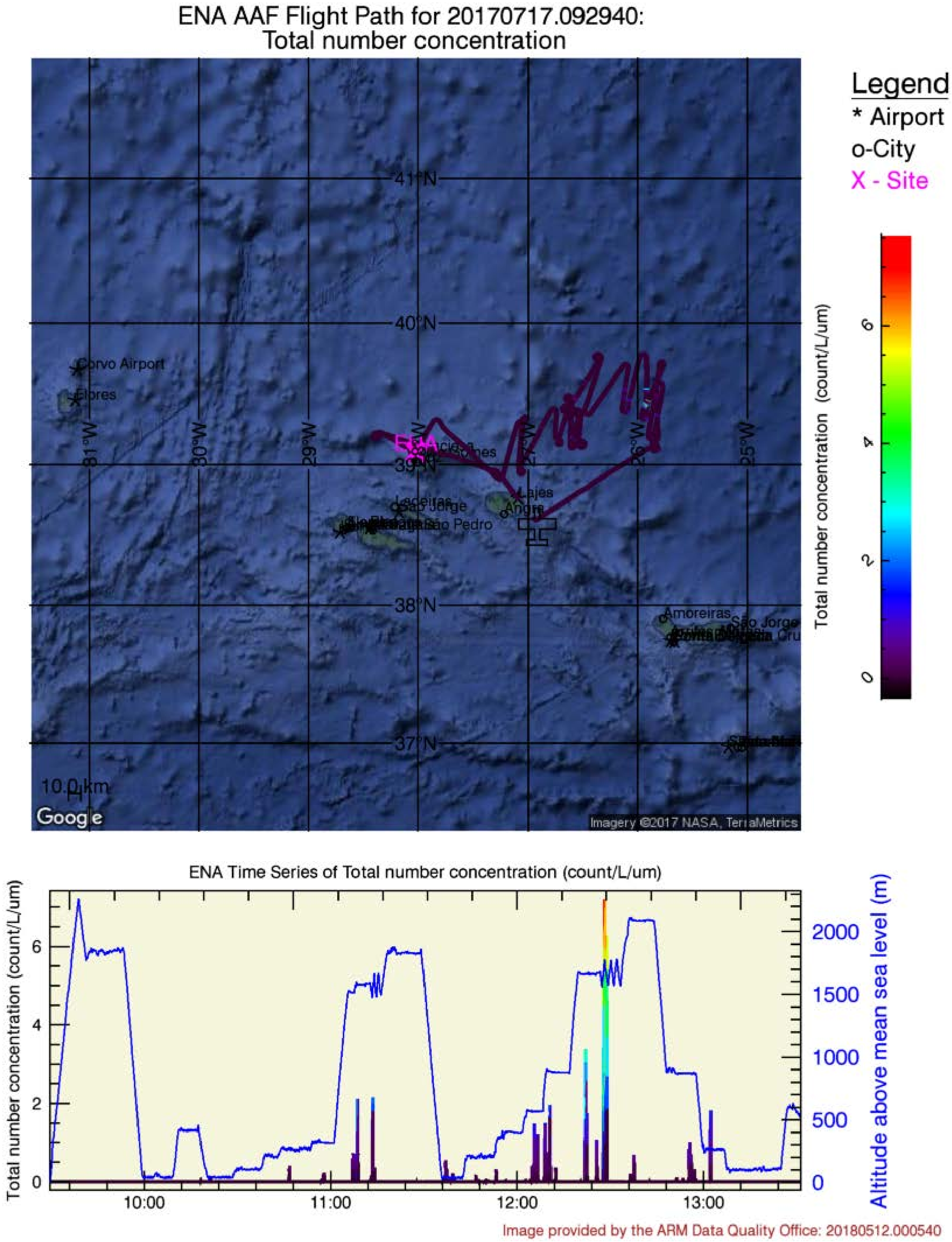

Figure 3. The flight path plot colored by the total cloud droplet number concentration measured by the HVPS on July 18, 2017 during the ACE-ENA field campaign, Azores, Portugal.

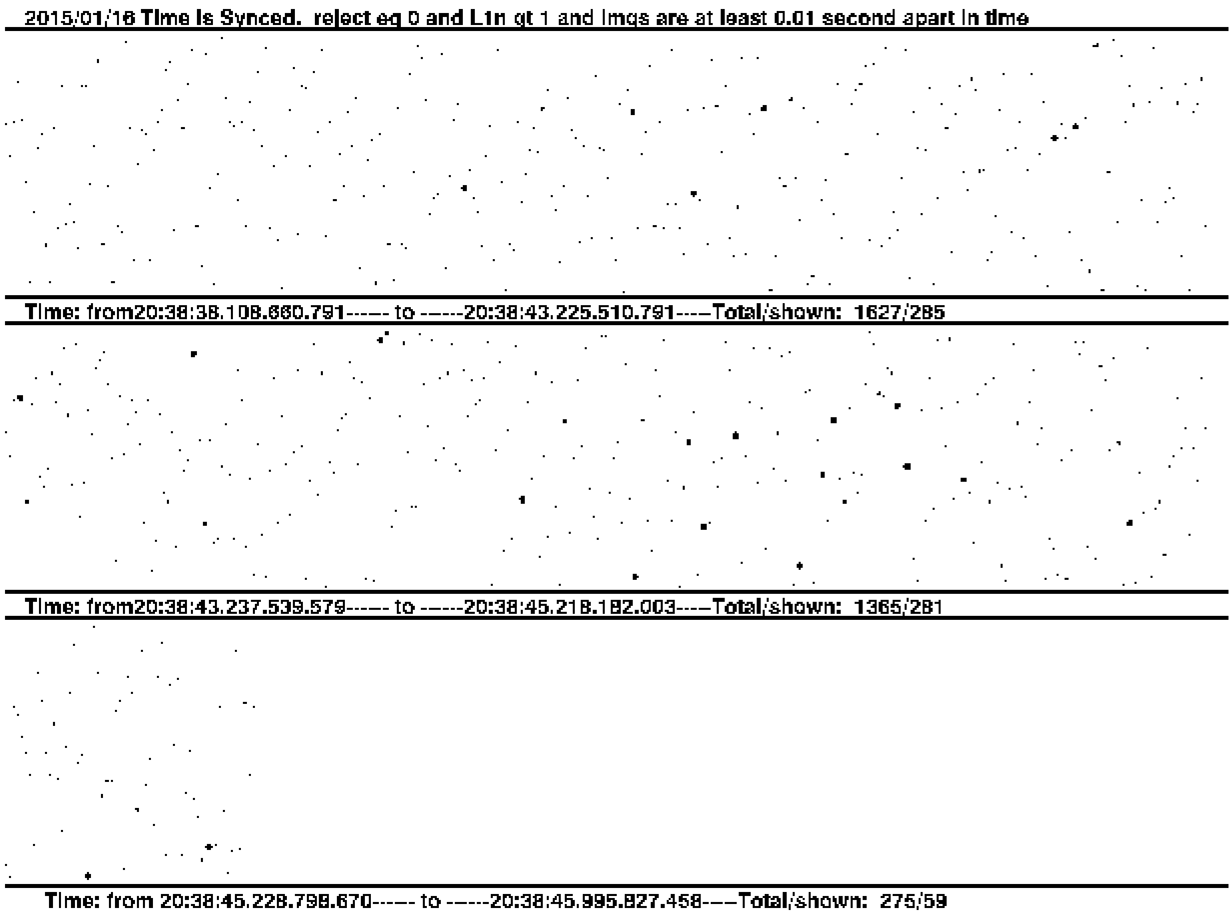

Figure 4. Hydrometeor images from the ARM Cloud Aerosol Precipitation Experiment (ACAPEX) in California on January 16, 2015. Hydrometeors of various sizes and shapes can be detected.

6.3 Data Quality

Good data quality is ensured by a comparison with other measurements. During sections of the flight that are known not to contain clouds or precipitation, the HVPS should also not record any images. Number concentrations and sizes should be comparable to other cloud probe measurements and deviations should be investigated.

7.0 Technical Specification

7.1 Units

The processed data has the following units:

- Cloud particle number concentration: #/liter
- Cloud particle size distribution: #/liter/µm for each bin (61 bins)
- Ice and liquid water content: g/m^3.

7.2 Range

The HVPS has 128 diodes in each array with an effective pixel size of 150 µm. Hence, hydrometeors in the range of 0.3−19.2 mm can be fully recorded at a 150 µm resolution; larger particles can only be sized along the direction of flight. Smaller particles than 300 µm can be detected, but their shadowgraph image would only cover one or two pixels and is therefore not considered reliable.

Since liquid and ice water content are derived from the measured size distributions, the range depends on the size of the hydrometeors. Water content will be inaccurate if mostly cloud droplets are present, which are below the range of the HVPS or the assumptions for determining the mass of the ice crystals are inaccurate.

7.3 Repeatability

For the HVPS, it is important to size the same objects consistently. This is tested regularly during calibration. If especially small hydrometeors are detected but are not in the depth of field, they produce diffraction patterns that are larger than their original size with a bright area in the middle. These rings can still be recorded but are often broken due to the individual pixels. The diffraction pattern of the same object can look different depending on the exact location with respect to the pixels of the photodiode array.

7.4 Sensitivity

The HVPS measurements of sizes are sensitive to the actual size and shape of the hydrometeors as well as the location within the laser beam. Small hydrometeors up to 19.2 mm can be detected as a full two-dimensional image but might be undersized if they are close to the edge of the optical array and only part of the shadowgraph image is recorded. The size along the flight path relies on an accurate determination of the speed of flight. The correct air speed is especially important for hydrometeors larger than 19.2 mm since they are solely sized on grounds of the air speed. Hydrometeors that are outside the depth of field will not produce an in-focus shadowgraph image but will depict diffraction patterns. This can be a source of uncertainty if not accounted for in post-processing.

Shattering of hydrometeors on the housing of the probe will produce a multitude of smaller particles. The sharp leading edges for the HVPS minimize shattering into the sample volume, but nevertheless it can contribute to an overestimate of smaller particles or particles not being detected at all.

7.5 Uncertainty

The uncertainty for the size measurements is determined by the size of the pixels of the photodiode array, which corresponds to ±150 µm.

For number concentrations, the uncertainty is in most cases within Poisson counting statistics, and therefore ±sqrt(N), with N being the number of particles. Coincidence can lead to an underestimate of the number concentration.

7.6 Input Values

During post-processing, the user has to specify the environmental conditions (ice/liquid water), shatter-removal methods, and the methods used to obtain sizes from out-of-focus particles.

7.7 Output Values

The raw data is saved in files with the ending .HVPS. Each image recorded has a timestamp, and data products such as hydrometeor number concentration, hydrometeor size distribution, and ice and liquid water content are determined during post-processing.

8.0 Instrument System Functional Diagram

Figures 5 and 6 show the setup of the probe. Figure 5 shows the location of the sample volume and the electrical components of the probe. Figure 6 shows the system block diagram.

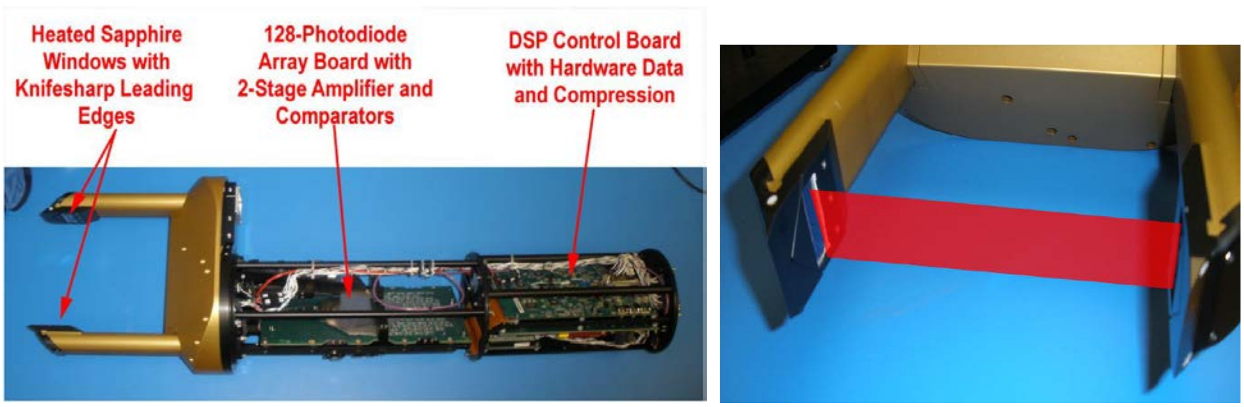

Figure 5. Photograph of HVPS showing the probe (top left), the sample volume and laser beams (top right). Adapted from the probe manual (SPEC 2007).

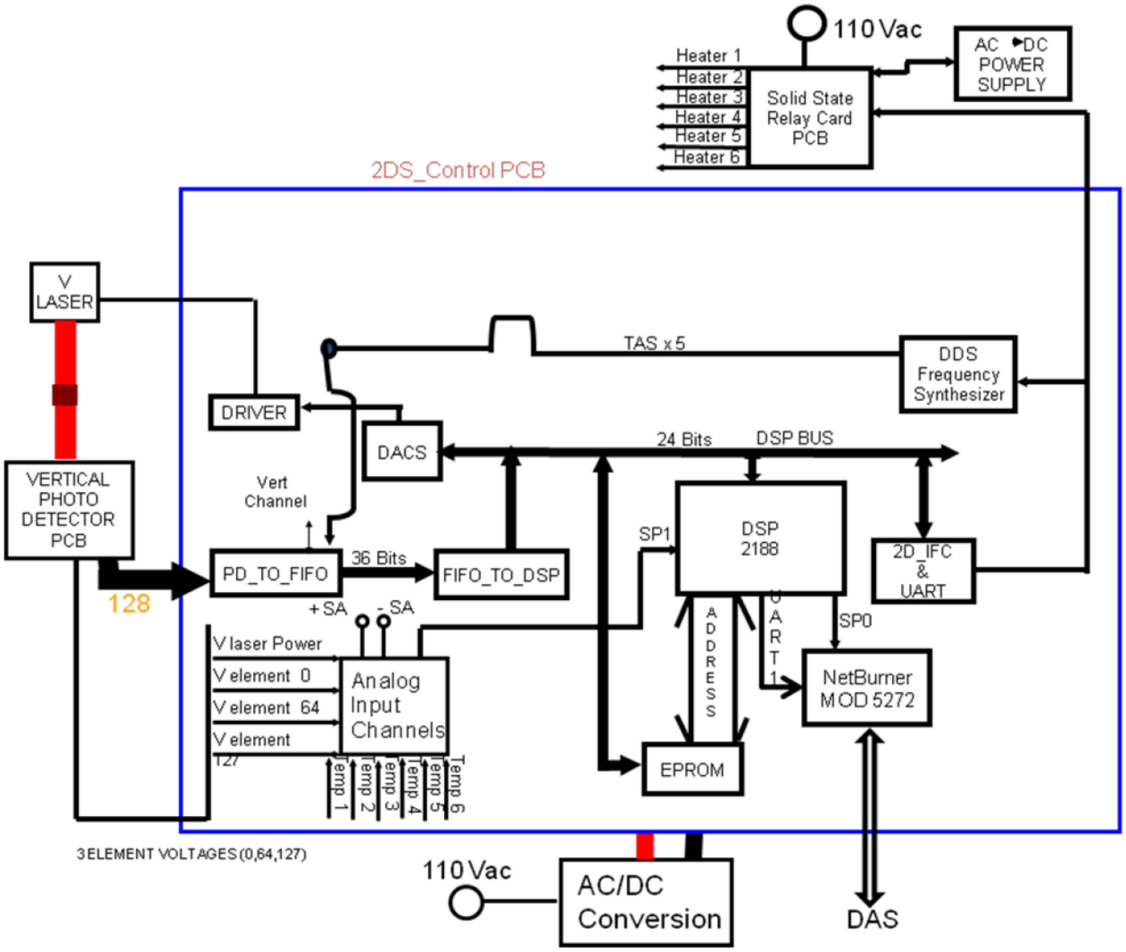

Figure 6. System block diagram provided by the vendor. Taken from the probe manual (SPEC 2007).

9.0 Instrument/Measurement Theory

The HVPS is an open-path cloud probe designed to measure the number and the size of hydrometeors in the size range 0.3-19.2 mm (HVPS 2010). If a particle is within focus, a laser will illuminate the particle and a shadow is cast on a photodiode array. As a particle moves through the laser beam, the optical array continuously records the shadow of the moving object, which will create a two-dimensional image. To determine the size along the flight path, one has to know the speed of the air. Small particles are not fully captured by the diode array, whereas larger particles greater than 19.2 mm can only be judged according to the flight speed because they cover more than the size of the total array. At an air speed of 100 m/s, the sample volume is 310 l/s.

To determine the size of the particles as well as the water content, the user has to differentiate between ice and liquid water. Liquid water forms round droplets for smaller sizes and slightly deformed spheres for larger sizes, which makes it easy to determine sizes of even half-imaged droplets as well as to determine the mass of the droplet for liquid water content. If ice is present, the shapes are much more irregular and the post-processing has to make assumptions about the shape in the third dimension. For ice water content derivation, a value for the density of the ice, which is highly variable, is assumed.

10.0 Setup and Operation of Instrument

The Fast Cloud Droplet Probe (FCDP) can only measure correct values for number concentrations if the sample volume is defined. Therefore, an air speed greater than 10 m/s is necessary, which is a given for ARM aircraft. The probe is mounted in a standard particle measuring system (PMS) below the wing of the aircraft (Figure 7).

Figure 7. Mounting of several ARM cloud probes (see acronym list for names) during the Cloud, Aerosol, and Complex Terrain Interactions (CACTI) field campaign in Argentina. The HVPS is located at the right.

11.0 Software

For both data acquisition and processing, software is provided by the manufacturer. For acquisition and initial processing, the executable SPEC 2D-S is used as Real-Time Acquisition program and as Playback.

It is important to change the software into HVPS mode, since the software was designed for the two-dimensional stereo (2D-S) probe. For further processing, the IDL (Interactive Data Language)-based program HVPSview is used (HVPS 2010).

12.0 Calibration

For calibration and laser alignment, the probe is sent to the vendor. No calibration is typically needed during deployment. A spinning disk with known hole sizes is also used to check the size resolution. This calibration procedure is routinely performed in the laboratory before and after a field campaign.

13.0 Maintenance

Maintenance of the probe during deployment consists of cleaning the probe windows to remove dirt before each flight.

14.0 Safety

The 2D-S contains a laser.

The anti-shattering tips are sharp and have to be handled with care.

15.0 Citable References

HVPS Post-Processing Using HVPSview Software, User Manual. 2010. Last accessed online November 6, 2019. http://www.specinc.com/sites/default/files/software_and_manuals/

SPEC HVPS V3 Technical Manual (Rev. 1.2). 2013. Last accessed online November 11, 2019. http://www.specinc.com/sites/default/files/software_and_manuals/

Korolev, A. 2007. "Reconstruction of the Sizes of Spherical Particles from Their Shadow Images. Part I: Theoretical Considerations." *Journal of Atmospheric and Oceanic Technology* 24(3): 376−389, https://doi.org/10.1175/JTECH1980.1

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