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DOE/SC-ARM-TR-233

Two-Dimensional Stereo (2D-S) Probe Instrument Handbook

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ARM

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Acronyms and Abbreviations

2D-S	two-dimensional stereo probe
ACE-ENA	Aerosol and Cloud Experiments in the Eastern North Atlantic
ARM	Atmospheric Radiation Measurement
CACTI	Cloud, Aerosol, and Complex Terrain Interactions
DOE	U.S. Department of Energy
IDL	Interactive Data Language
PMS	Particle Measurements Systems

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The two-dimensional stereo (2D-S) probe.

2.0 Mentor Contact Information

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4.0 Instrument Description

The two-dimensional stereo (2D-S) probe (Figure 1) is a U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility instrument for measuring the concentration and size of cloud droplet and ice crystals (1). It is an open-path instrument with two laser beams mounted perpendicular to each other. Each laser beam 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. If the hydrometeor is in the cross-section of the two beams, both optical arrays record the object and a stereo image can be detected. If the hydrometeor is outside the cross-section and only shadows one beam, the image will also be recorded. Therefore, the 2D-S records images for two channels, labeled “horizontal” and “vertical,” which can be analyzed for size distributions, number concentrations, and further cloud properties detailed below. Hydrometeors in the range of 25-1280 μm can be fully recorded at a 10 μm resolution; larger particles of up to 3000 μm can only be sized along the direction of flight.

Figure 1. The two-dimensional stereo (2D-S) probe.

5.0 Measurements Taken

The 2D-S measures the two-dimensional images of hydrometeors crossing the sample volume. It is possible to link the two channels to find images recorded by both, which results in stereo images. From the recorded images key cloud properties such as cloud particle number concentration, cloud particle 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 .2DS, which have to be post-processed with software provided by the vendor (Playback and 2DSView). Each image recorded has a timestamp, and data products such as cloud particle number concentration, cloud particle size distribution, and ice and liquid water content are determined during post-processing.

6.2 Data Ordering

Data from the 2D-S can be ordered from https://www.arm.gov/data/data-sources/2d-s. Data are organized by measurement location/campaign.

6.3 Data Plots

Figures 2 and 3 show data from the 2D-S after post-processing the data. 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 2D-S.

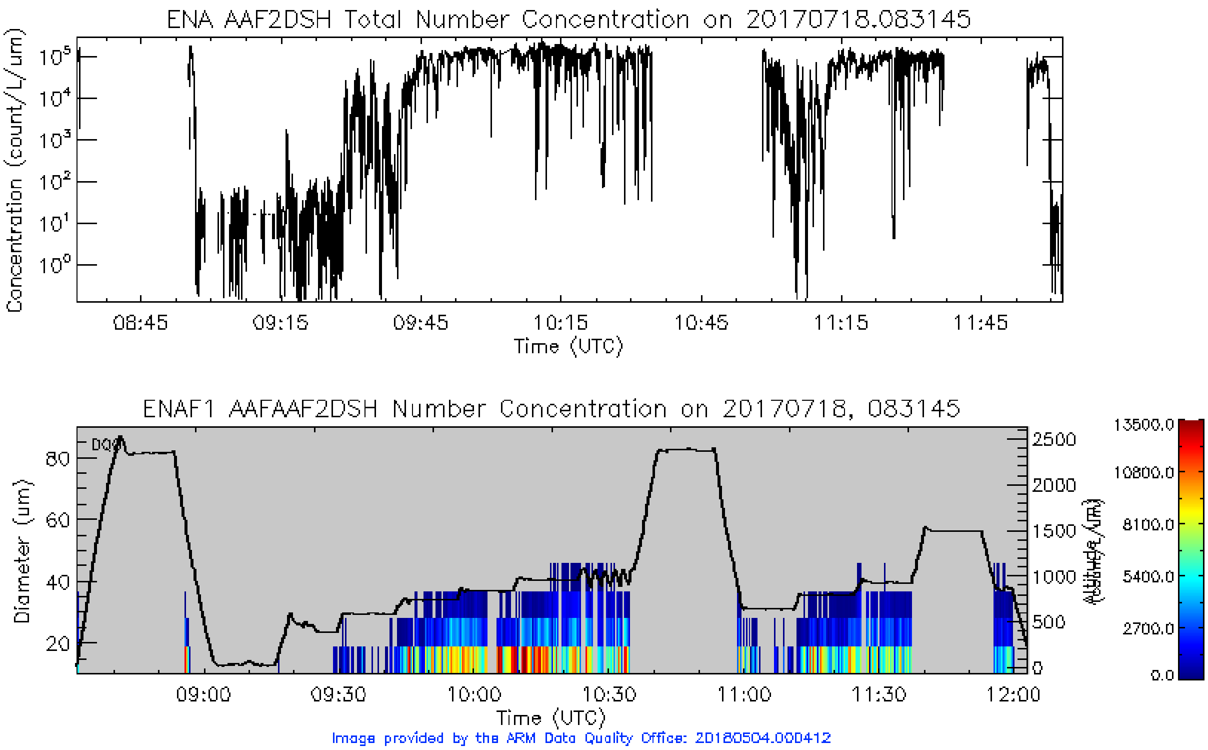

Figure 2. Total cloud droplet number concentration as measured by the 2D-S on July 18, 2018 during the Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) field campaign, Azores, Portugal. Top: Total number concentration throughout the flight. Bottom: Number concentration per size from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

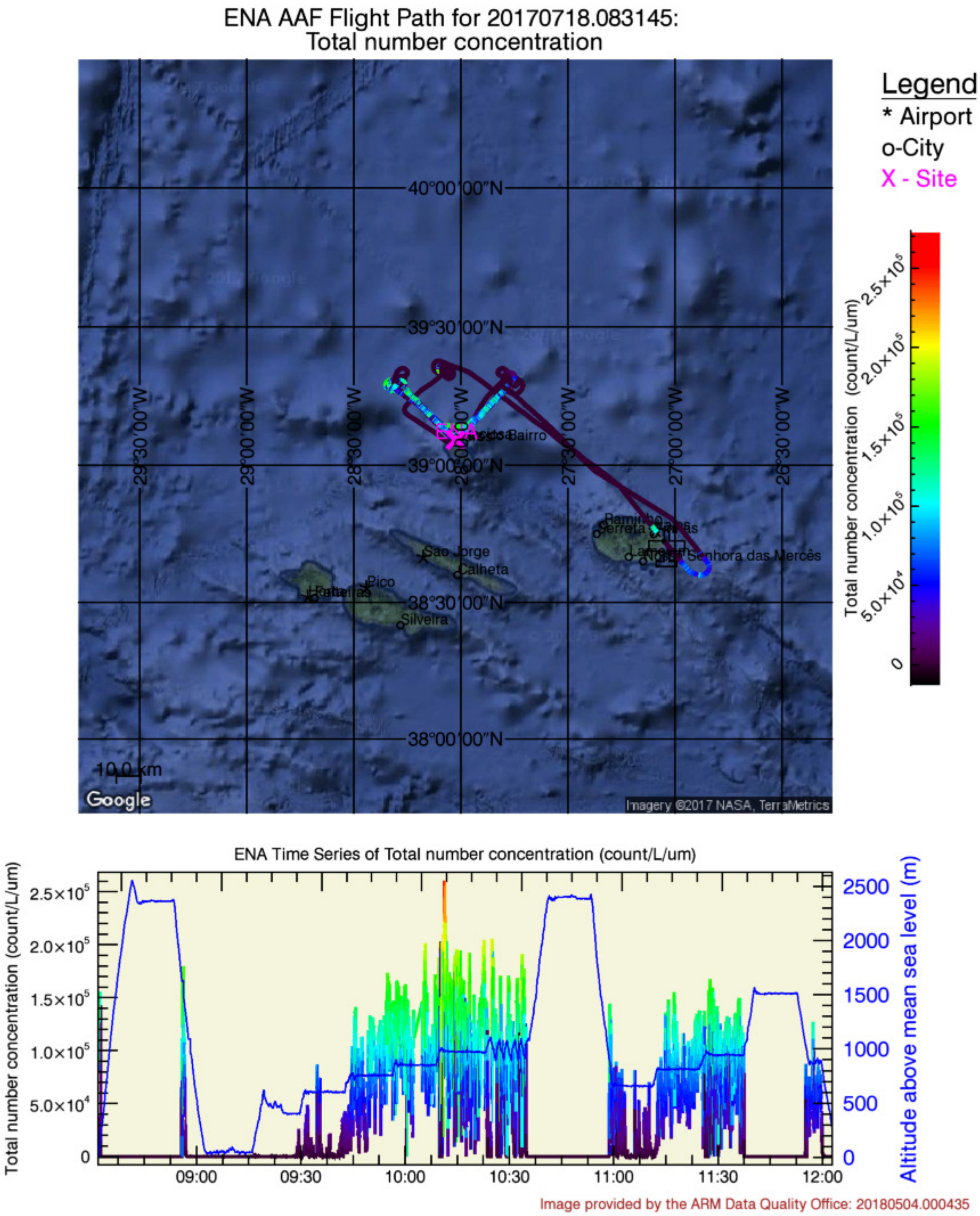

Figure 3. The flight path plot colored by the total cloud droplet number concentration measured by the 2D-S on July 18, 2017 during the ACE-ENA field campaign, Azores, Portugal.

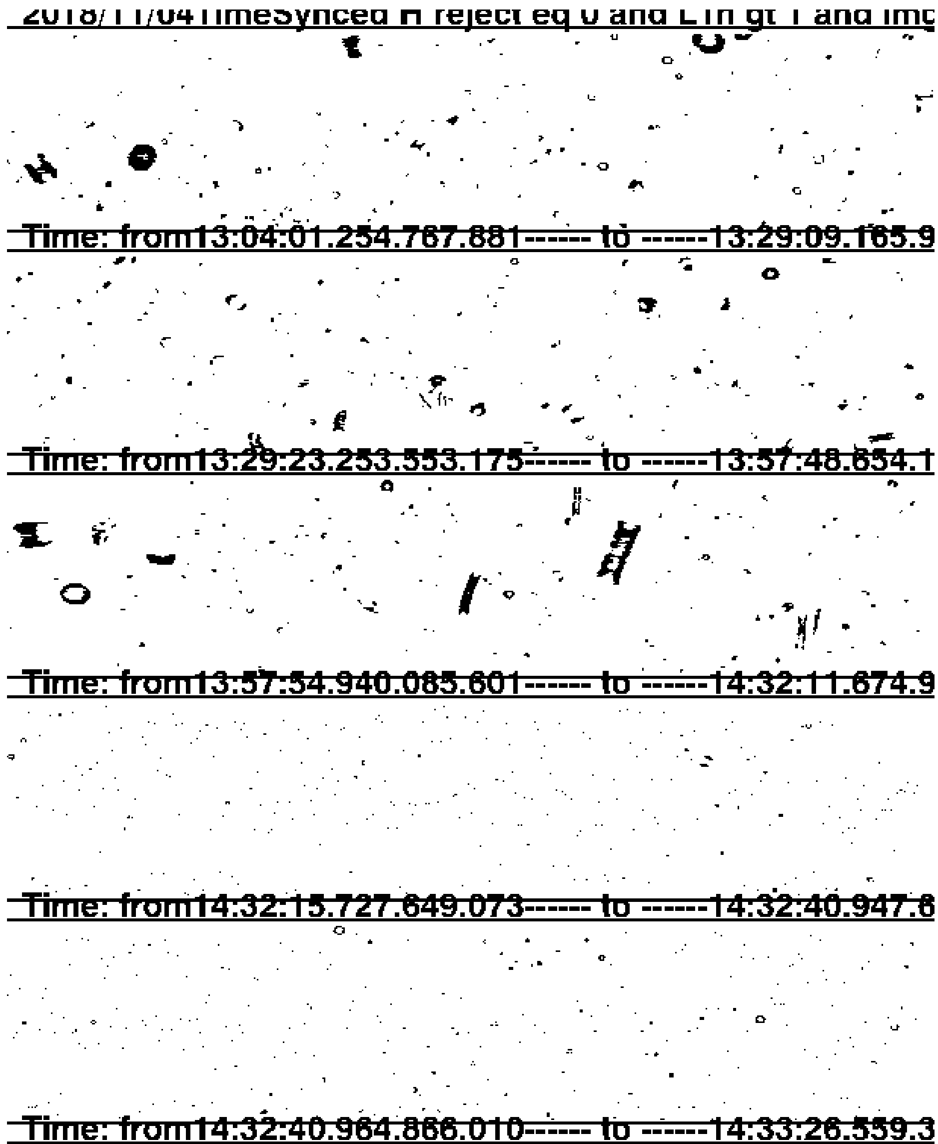

Figure 4. Hydrometeor images from the Cloud, Aerosol, and Complex Terrain Interactions (CACTI) field campaign on November 4, 2018. Both columns and capped columns, as well as cloud droplets, can be detected. Rings are particles that are out of focus.

6.4 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 2D-S 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 2D-S has 128 diodes in each array with an effective pixel size of 10 µm. Hence, hydrometeors in the range of 25-1280 µm can be fully recorded at a 10 µm resolution, larger particles of up to 3000 µm can only be sized along the direction of flight. Smaller particles than 25 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 very small cloud droplets are present that are below the range of the 2D-S or the assumptions for determining the mass of the ice crystals are inaccurate.

7.3 Repeatability

For the 2D-S, 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 2D-S 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 1280 µm 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 1280 µm 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 2D-S minimize shattering into the sample volume but nevertheless it can contribute to an overestimate of smaller particles.

7.5 Uncertainty

The uncertainty for the size measurements is determined by the size of the pixels of the photodiode array, which corresponds to ±10 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) as well as 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 .2DS. Each image recorded has a timestamp, and data products such as cloud particle number concentration, cloud particle 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, the electrical components of the probe, and the illumination of the photodiode array by the laser beam. Figure 6 shows the system block diagram.

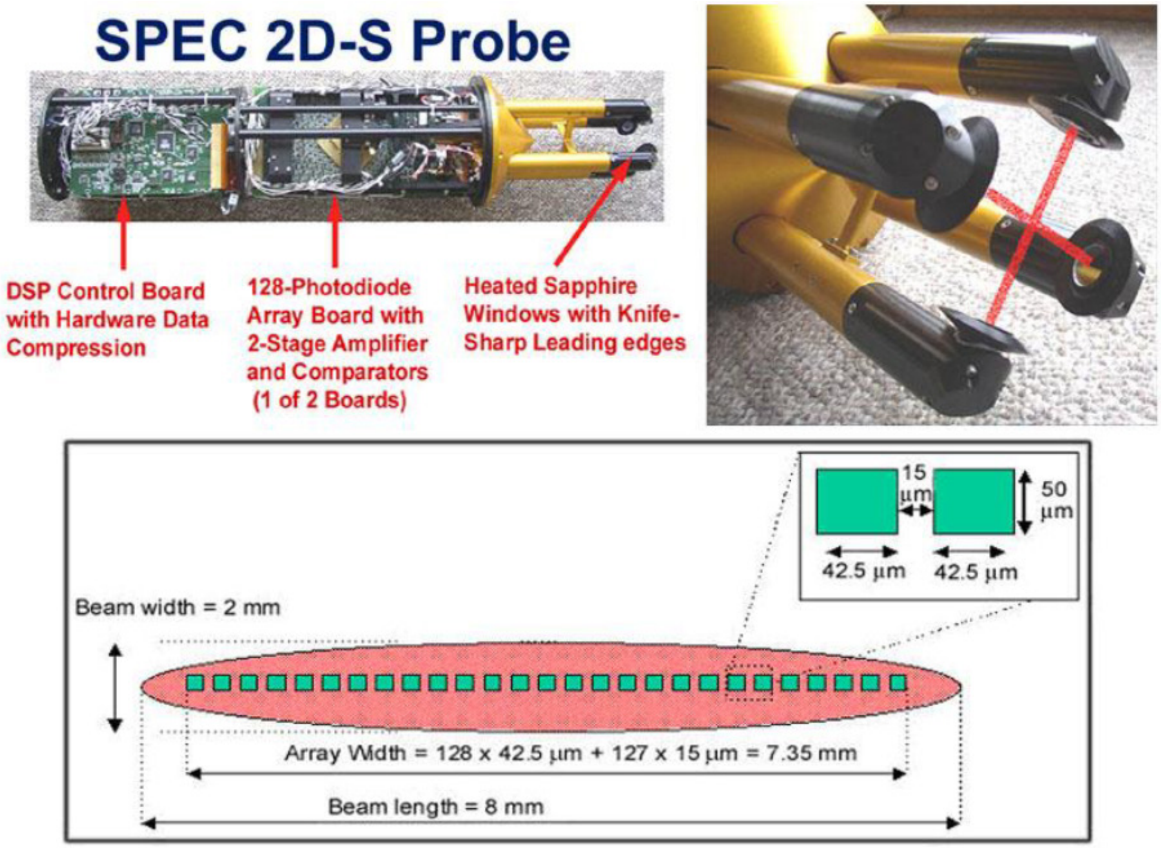

Figure 5. Photograph of 2D-S showing the probe (top left), the sample volume and laser beams (top right), and the setup of the beam illuminating the photodiode array (bottom). From the probe manual. (2)

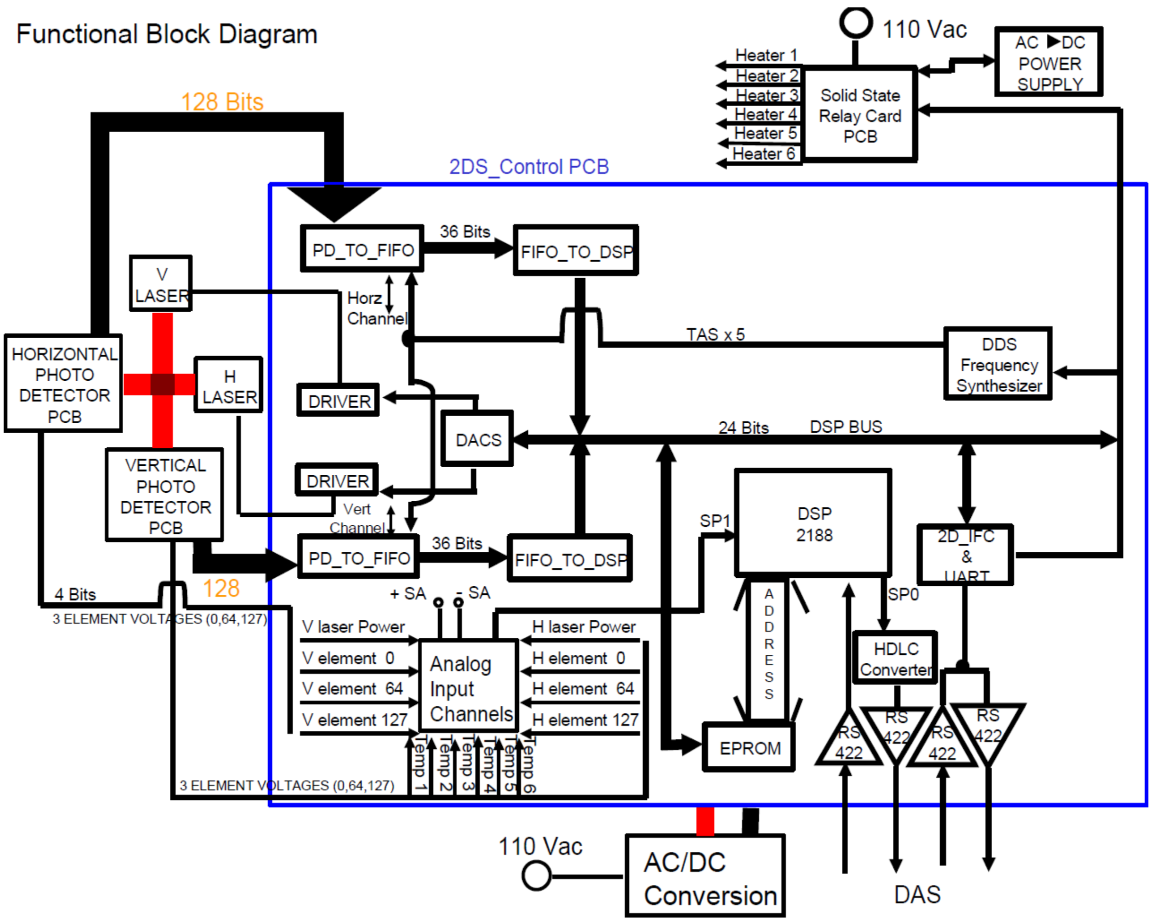

Figure 6. System block diagram provided by the vendor. Taken from the probe manual (2).

9.0 Instrument/Measurement Theory

The 2D-S is an open-path cloud probe designed to measure the number and the size of hydrometeors in the size range 25-3000 µm (1). If a particle is within focus, a laser will illuminate the particle and a shadow is cast on a photodiode array. Particles within the volume created by the crossing of the two beams of the two identical setups perpendicular to each other will be imaged with both arrays and recorded as stereo images. 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 1280 µm can only be judged according to the flight speed because they cover more than the size of the total array.

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 determining 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 2D-S can only measure correct values for number concentrations if the sample volume is defined. Therefore, an air speed greater than 0 m/s is necessary, which is a given for our aircrafts. The probe has two channels that are sampling independently, labeled "horizontal" (H) and "vertical" (V), with an overlap region in the center. These labels are arbitrary, depending on the exact orientation of the probe. The probe is mounted in a standard Particle Measuring Systems (PMS) can below the wing of the aircraft (Figure 7).

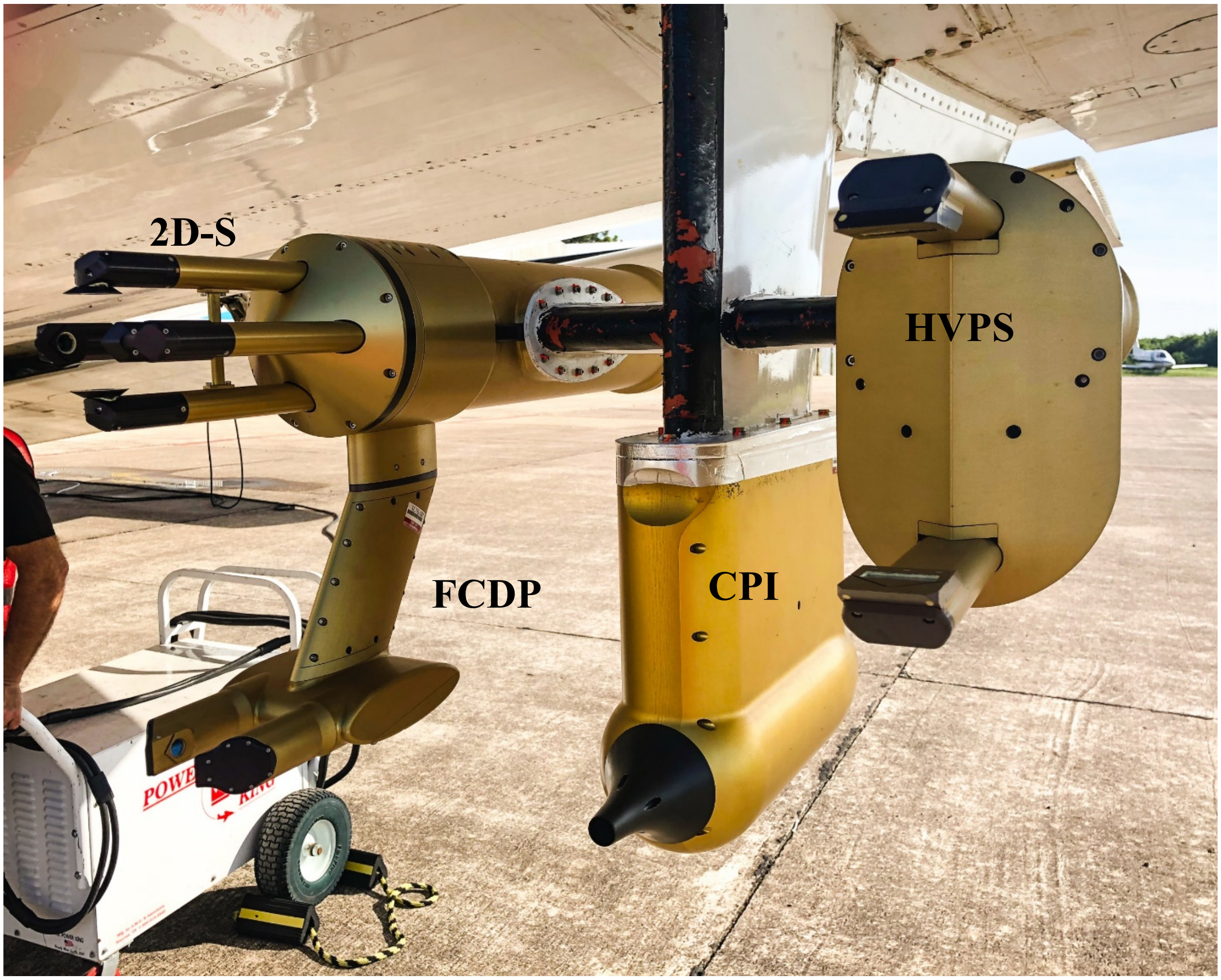

Figure 7. Mounting of several ARM cloud probes during CACTI. The 2D-S is located at the top left.

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. For further processing, the IDL (Interactive Data Language)-based program 2DSView is used.

12.0 Calibration

For calibration and laser alignment the probe is sent to the vendor. No calibration is typically needed during deployment. Calibration can be done by using sized glass beads.

13.0 Maintenance

Necessary 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 must be handled with care.

15.0 Citable References

(1) Lawson, RP, D O'Connor, P Zmarzly, K Weaver, B 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(11): 1462–1477, https://doi.org/10.1175/JTECH1927.1

(2) SPEC 2D-S Technical Manual (Rev.3.1), February 2011. Last accessed online on November 6, 2019, http://www.specinc.com/sites/default/files/software_and_manuals/

www.arm.gov

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