DOE/SC-ARM-TR-240

Cloud Particle Imager (CPI) and 3-View Cloud Particle Imager (3V-CPI) Instrument Handbook

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Acronyms and Abbreviations

2D-S	two-dimensional stereo probe
3V-CPI	3-view cloud particle imager
ARM	Atmospheric Radiation Measurement
CACTI	Cloud, Aerosol, and Complex Terrain Interactions
CPI	Cloud Particle Imager
DOE	U.S. Department of Energy
FCDP	fast cloud droplet probe
HVPS	high-volume precipitation spectrometer
IDL	Interactive Data Language

Contents

Figures

1.0 Instrument Title

Cloud particle imager (CPI) and 3-view cloud particle imager (3V-CPI)

2.0 Mentor Contact Information

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4.0 Instrument Description

The cloud particle imager (CPI, 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 (Cloud Particle Imager 2013). Hydrometeors entering the tube will be detected by a system of two continuous wave lasers that are perpendicular to each other, monitoring the sample volume. When a hydrometeor obscures both laser beams it is inside the sample volume and a third laser is triggered to illuminate the hydrometeor and a camera records a two-dimensional image. The CPI records images with a resolution of 2.3 µm. Since the camera has 1024x1024 pixels, the maximum detectable size is 2.3 mm x 2.3 mm.

The 3V-CPI is a further development of the CPI by the same vendor (SPEC 2012). The setup is the same, but instead of the two lasers used only to detect a particle in the sample volume, the 3V-CPI combines the CPI and the two-dimensional stereo probe (2D-S). When a particle enters the sample volume, the particle is imaged additionally with two photodiode arrays with a 10 µm resolution, detecting sizes up to 1280 µm fully and particles up to 3 mm in the direction of flight. This setup of the 3V-CPI allows for three different views of the same particle, two with the detectors of the integrated 2D-S and one with the original CPI. The two-dimensional images of the 2D-S photodiode arrays consist of 128 diodes that record a one-dimensional shadowgraph image of the particle, continuously scanning along the direction of the flight.

Figure 1. The cloud particle imager (CPI).

5.0 Measurements Taken

The CPI measures the two-dimensional images of hydrometeors crossing the sample volume. For the 3V-CPI, three independent images of three detectors are simultaneously recorded. It is possible to link the channels to find images recorded by all. 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 of the CPI and 3V-CPI are saved in the format .roi and can be processed with software provided by the vendor (CPIview, Playback, and 3VCPIview). 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 CPI can be ordered from https://www.arm.gov/data/data-sources/cpi. Data are organized by measurement location/campaign.

Data from the 3V-CPI will also be available on the ARM website.

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, both the CPI and the 3V-CPI should 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 from the CPI and the 3V-CPI 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$^{\wedge 3}$.

7.2 Range

The CPI has a sensor with 1024x1024 pixels of 2.3 µm each. This relates to a resolution of 2.3 µm of particles larger than a few pixels (ca. 10 µm) up to particles of 2.3 mm.

The photodiode arrays of the 3V-CPI have 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, while larger particles of up to 3000 µm can only be sized along the direction of flight. Particles smaller 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 probe or the assumptions for determining the mass of the ice crystals are inaccurate.

7.3 Repeatability

For both the CPI and the 3V-CPI, 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 CPI measurements of sizes are sensitive to the actual size and shape of the hydrometeors as well as the location within the laser beam. If particles are outside the focus area or only partially imaged, they might be undersized. For the photodiode arrays of the 3V-CPI, 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, which would lead to an overestimate of smaller particles. The sample volume is within a tube, which heavily influences airflow and can produce shattering of particles. If the tube is not pointed exactly into the air flow, hydrometeors are not sampled correctly, and certain sizes can be missed altogether. It is important to keep in mind that this is the only ARM cloud probe with the sample volume inside a tube.

7.5 Uncertainty

The uncertainty of the CPI is determined by the pixel size, which is ±2.3 µm.

For the integrated 2D-S of the 3V-CPI, 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 of the CPI and 3V-CPI is saved in the format .roi and can be processed with software provided by the vendor (CPIview, Playback, and 3VCPIview). 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

Figure 2 shows the setup of the probes, the CPI (left) and the 3V-CPI (right). The main difference in the instrumental setup of the two probes is that the simple detectors of the CPI are replaced with photodiode arrays in the 3V-CPI that function on the same principle as the 2D-S probe and therefore effectively combines the 2D-S with the CPI.

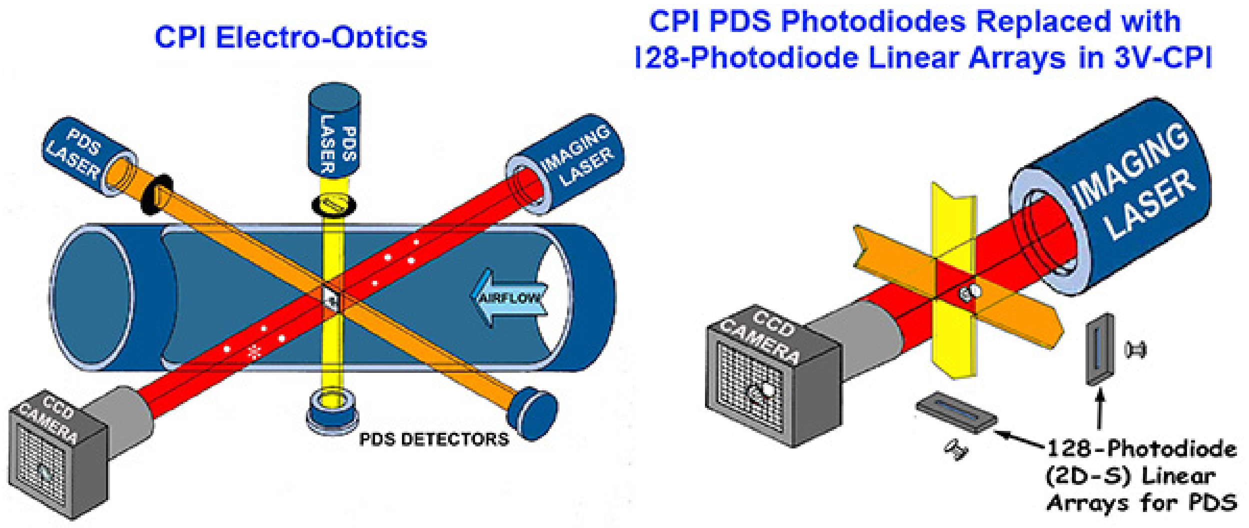

Figure 2. Design of the CPI (left) and the 3V-CPI (right). From the website http://www.specinc.com/

9.0 Instrument/Measurement Theory

The CPI is a cloud probe designed to measure the number and the size of hydrometeors in the size range 25−2300 µm (Cloud Particle Imager 2013). Two lasers continuously monitor the sample volume, and if a particle is within the sample volume, the camera and corresponding third laser are triggered to capture a detailed two-dimensional image of the passing hydrometeor with a size resolution of 2.3 µm.

For the 3V-CPI, the two monitoring lasers are additionally functioning as a setup of a 2D-S probe with photodiode arrays recording a shadowgraph image of the passing hydrometeor in two channels (with a size resolution of 10 µm), resulting in a total of three images of the same particle. 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 well as with the third camera of the CPI. 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 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 CPI and the 3V-CPI 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 ARM aircraft. The 3V-CPI 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. Both probes are mounted on the outside of the aircraft, typically below the wing (Figure 3).

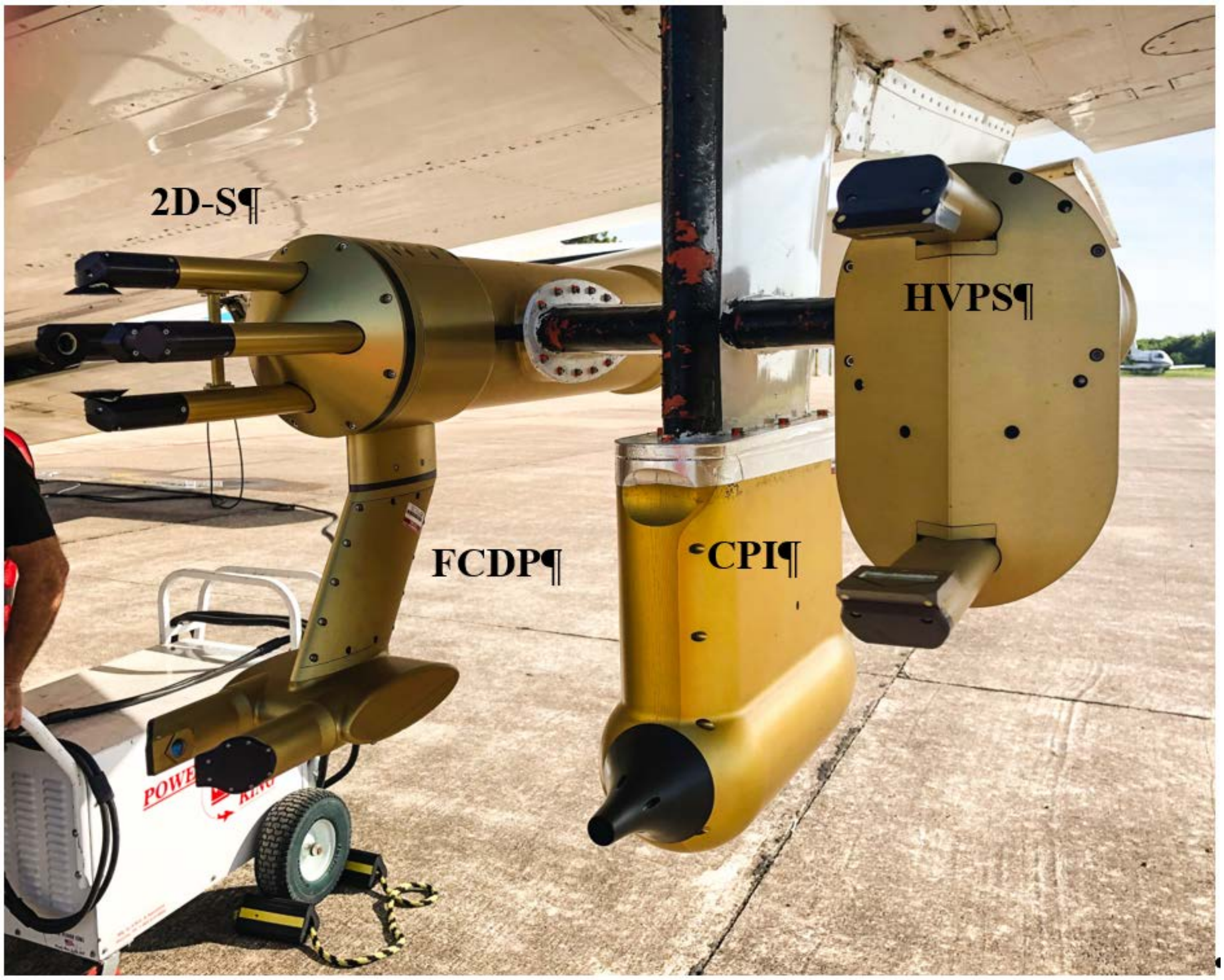

Figure 3. Mounting of several ARM cloud probes (see acronym list for names) during the Cloud, Aerosol, and Complex Terrain Interactions (CACTI) field campaign in Argentina. The CPI is located at the bottom middle. The 3V-CPI is mounted the same way.

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 choose the correct probe in the program. For further processing, the IDL (Interactive Data Language)-based programs 3VCPIview and CPIview are 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 as described by Connolly et al. 2007.

13.0 Maintenance

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

14.0 Safety

The CPI and the 3V-CPI contain a laser. During normal operation, the user is not exposed to laser radiation.

15.0 Citable References

Cloud Particle Imager CPI V2.5, User's Manual. 2013. Last accessed online November 12, 2019. http://www.specinc.com/sites/default/files/software_and_manuals/

SPEC 3V-CPI Preliminary Technical Manual. 2012. Last accessed online November 12, 2019. http://www.specinc.com/sites/default/files/software_and_manuals/

Connolly, PJ, MJ Flynn, Z Ulanowski, TW Choularton, MW Gallagher, and KN Bower. 2007. "Calibration of the cloud particle imager probes using calibration beads and ice crystal analogs: The depth of field." *Journal of Atmospheric and Oceanic Technology* 24(11): 1860−1879, https://doi.org/10.1175/JTECH2096.1

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