Fast Cloud Droplet Probe (FCDP) Instrument Handbook

S Glienke   F Mei

January 2020

DISCLAIMER

This report was prepared as an account of work sponsored by the U.S. Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

Fast Cloud Droplet Probe (FCDP) Instrument Handbook

S Glienke
F Mei
Both at Pacific Northwest National Laboratory

January 2020

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
CPI	Cloud Particle Imager
DOE	U.S. Department of Energy
FCDP	fast cloud droplet probe
HVPS	high-volume precipitation spectrometer
ICARTT	International Consortium for Atmospheric Research on Transport and Transformation
NetCDF	Network Common Data Form

Contents

Figures

1.0   Instrument Title

Fast cloud droplet probe (FCDP)

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 fast cloud droplet probe (FCDP; 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 droplets in the diameter size range 1.5-50 µm (Lance et al. 2010, SPEC 2013, 2019). It is an open-path instrument mounted on the outside of the aircraft (typically below the wing). When a droplet passes through the sample volume, light from a laser source is scattered, which is used to detect and size the droplet. The sample volume is a focused area of the laser beam that is continuously monitored along the flight path. If a droplet crosses the laser beam but is outside the sample volume, a separate detector will reject the droplet. Only single droplets at a time will be detected and sizes measured over one second have to be averaged to obtain a size distribution. When measuring ice clouds, the FCDP will not yield useful information, since the measurement method, which assumes spherical particles to obtain size and scattering, is very different for ice crystals.

Figure 1.   The fast cloud droplet probe (FCDP).

5.0   Measurements Taken

The FCDP measures the amount of light scattered forward when a droplet crosses the focused section of the laser beam. The raw data from the FCDP shows the voltages at two different sensors, the "sizer" and the "qualifier". Only droplets that pass the qualifying requirement are within the sample volume and correctly sized. The voltage of the sizer can be correlated to the size of the droplet. From the recorded sizes, key cloud properties such as cloud particle number concentration, cloud particle size distribution, and liquid water content are derived.

6.0   Links to Definitions and Relevant Information

6.1   Data Object Description

The raw data are saved in five different files:

- "hk" contains housekeeping data

- "log" keeps track of the settings used during data acquisition

- "scat.bin" contains information for each particle event

- "qual.bin" as well as "sig.bin" contain information for a subset of particles, currently only saved for testing and debugging.

These files have to be post-processed with software provided by the vendor (FCDP GUI and SP3C).

Two main algorithms are applied during the data process: the algorithm to remove the spurious effects, such as from precipitation shattering, and the algorithm to correct the coincidence, which used the mask on the qualifier optics to reject the coincident particles. (SPEC 2019, McFarquhar et al. 2017, Baumgardner et al. 2017)

The final data files are provided through the ARM Data Center in both ICARTT and NetCDF format, which contain cloud particle number concentration and cloud particle size distribution.

6.2 Data Ordering

Data from the FCDP can be ordered from https://www.arm.gov/data/data-sources/fcdp. Data are organized by measurement location/campaign.

6.3 Data Plots

Figures 2 and 3 show data from the FCDP after post-processing. Figure 2 shows the total number concentration of sampled droplets 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/).
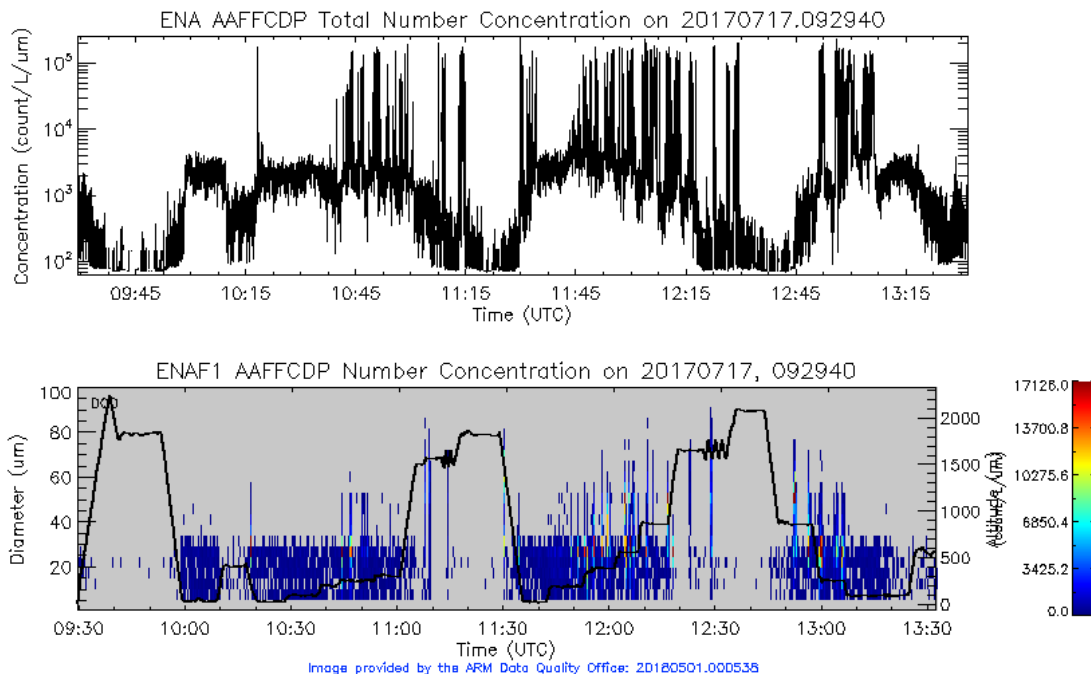

Figure 2. Total cloud droplet number concentration is measured by the FCDP on July 17, 2018 during the Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) field campaign, Azores, Portugal. Top: Total number concentration throughout the flight. Bottom: Number concentration per size from FCDP; also shown is the altitude.
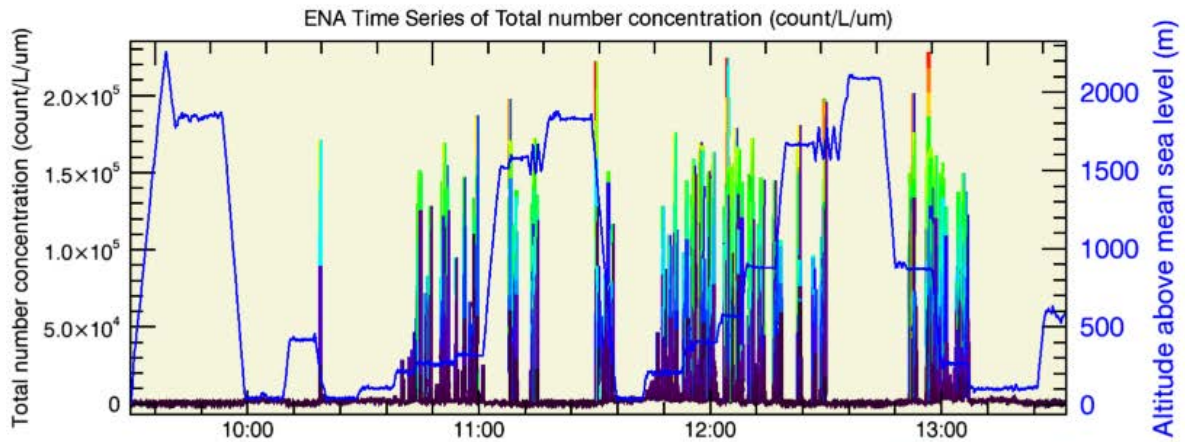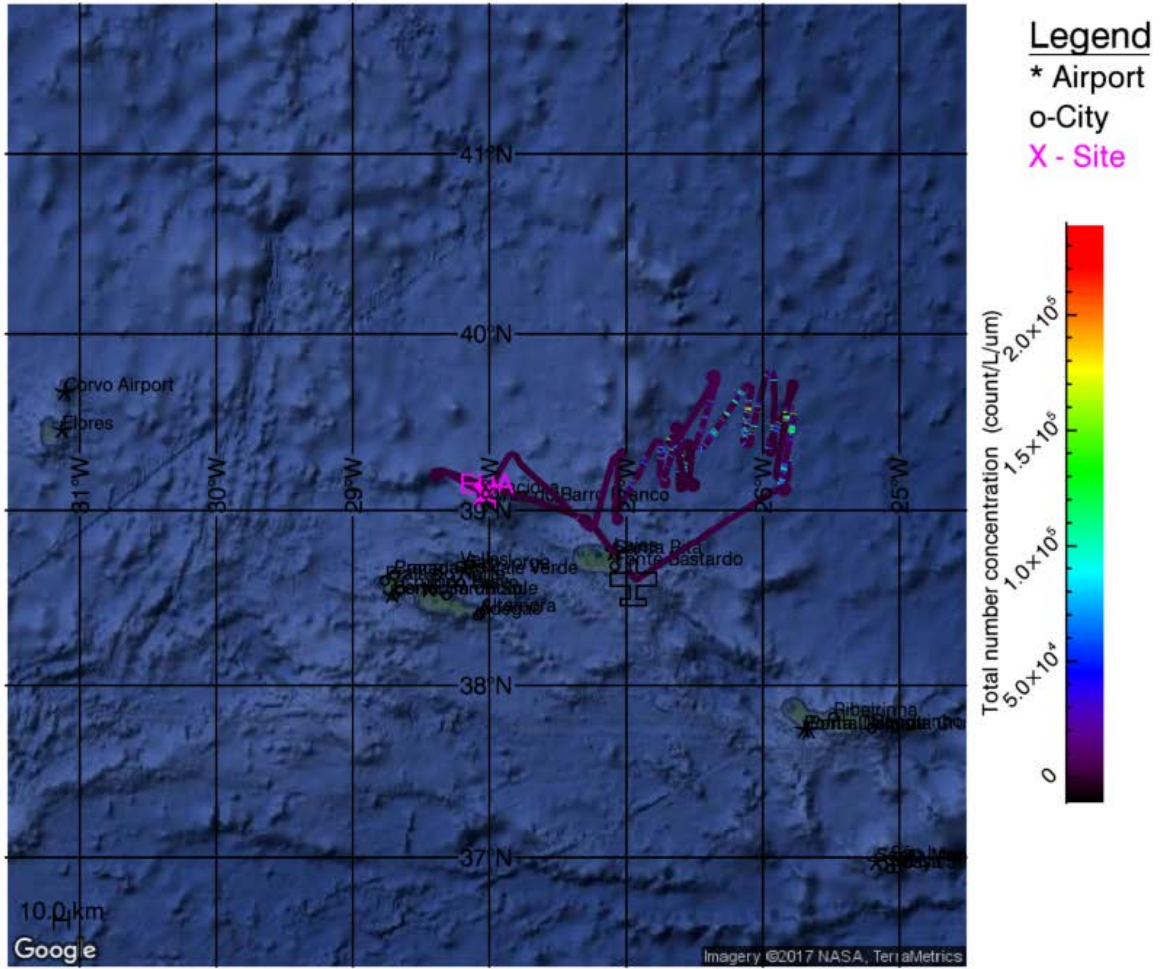
Figure 3.   The flight path plot colored by the total cloud droplet number concentration measured by the FCDP on July 17, 2017 during the ACE-ENA field campaign, Azores, Portugal.

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, the FCDP should also not record data. 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 (22 bins)
- Liquid water content: g/m^3.

7.2 Range

Droplets with sizes of 1.5−50 µm can be measured by the FCDP. Smaller droplets will not scatter enough light to be detected and larger droplets will not be reliably sized due to the change in the scattering. Larger droplets are also typically found in lower concentrations and the sample volume can be too small for those.

7.3 Repeatability

For the FCDP, it is important to size the same droplets consistently. This is tested regularly during calibration, which is done once a week during deployment. Also, bin sizes should be chosen to ensure unambiguous correlation between scattering and size despite the non-monotony of Mie scattering.

7.4 Sensitivity

The measurements of the FCDP are very sensitive to the air speed, since it is needed for the calculation of the sample volume. The FCDP is designed for air speeds of 10−200 m/s to correctly sample droplets.

Coincidence is important to consider, since it has two effects. First, two droplets will be counted as one, resulting in a wrong number of droplets, and second, the scattered light will be different for two droplets than for one and it will be incorrectly sized.

Shattering of hydrometeors on the housing of the probe will produce a multitude of smaller particles. The sharp leading edges for the FCDP minimize shattering into the sample volume but nevertheless it can contribute to an overestimate of smaller droplets. Shattering can at least partially be removed during post-processing by an interarrival time analysis. Shattered particles have lower interarrival times than non-shattered particles.

7.5   Uncertainty

The uncertainty for the size measurements is roughly 3 µm. Size bins vary for different sizes, with a higher resolution for smaller droplets. The bin sizes have to be chosen carefully because of the non-monotony of Mie scattering with size. Mie scattering exhibits bumps where the same scattering intensity can be related to more than one size. These should be narrower than the chosen bin sizes to ensure that one scattering intensity can be related to only one bin size.

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

7.6   Input Values

The FCDP is started with a setup file containing all important information.

7.7   Output Values

The raw data is saved in five different files with information about housekeeping, logging, individual particle events, and two files containing information for a subset of particles for testing and debugging.

Data products such as cloud particle number concentration, cloud particle size distribution, and liquid water content are determined during post-processing.

8.0   Instrument System Functional Diagram

Figure 4 shows the measurement principle and how the light that is scattered by droplets is detected and recorded.
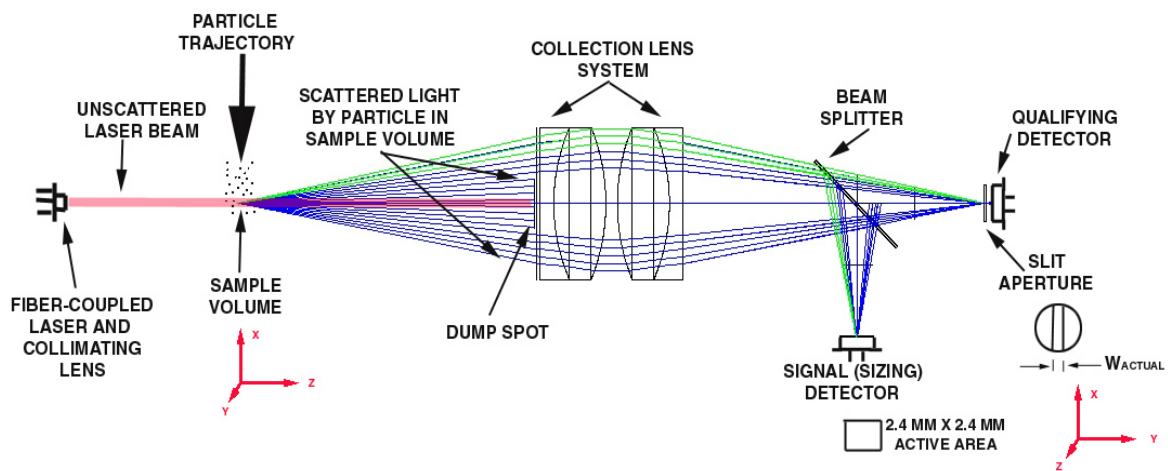

Figure 4.   Functional diagram provided by the vendor. Shown is the optical path and measurement principle. Taken from the probe manual (SPEC 2019).

9.0 Instrument/Measurement Theory

The FCDP is an open-path instrument mounted on the outside of the aircraft. The sample volume lies between the two forward pointing arms of the probe. A laser is focused on the sample volume, which is continuously monitored along the flight path. When a droplet passes through the sample volume, the laser light is scattered, which is used to detect and size the droplet. Within the probe, there are two detectors, the "sizer" and the "qualifier". Both detectors measure the light scattered at ca. 4–12 degrees in a forward direction, but the qualifier is masked whereas the sizer is not. In a regular droplet event, the qualifier is set up to measure a higher signal than the sizer, which is the criterion for accepting and counting the droplet. If the droplet is out of focus, the scattered light is more diffuse and the qualifier signal will be less than the sizer signal, therefore rejecting the event.

Only single droplets at a time will be detected and sizes measured over one second have to be averaged to obtain a size distribution. When measuring ice clouds, the FCDP will not yield useful information, since the measurement method, which assumes spherical particles to obtain size and scattering, is very different for ice crystals.

10.0 Setup and Operation of Instrument

The 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 below the wing of the aircraft (Figure 5). In Figure 5, the FCDP is mounted with a collar provided by the vendor to be mounted in conjunction with the two-dimensional stereo (2D-S) probe.
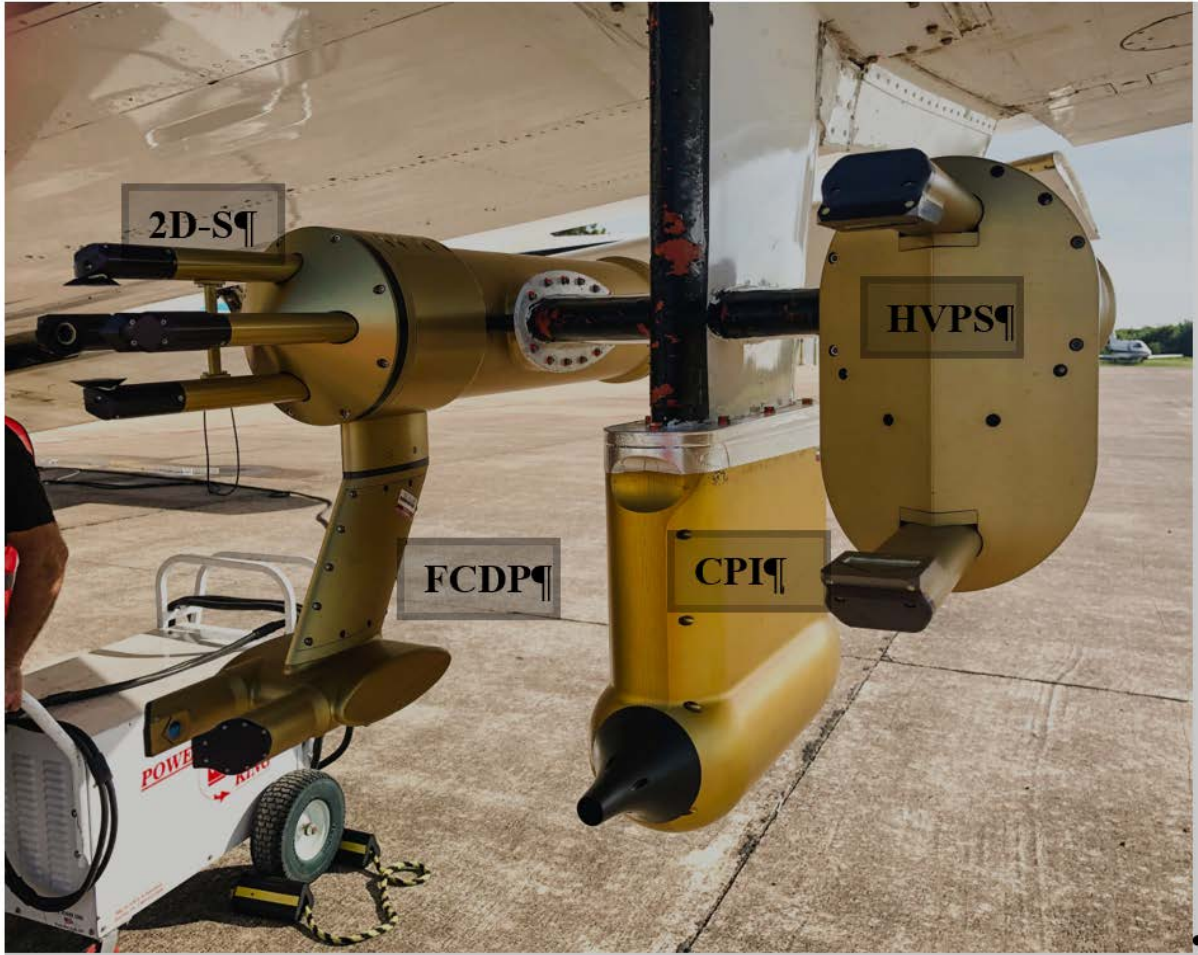
Figure 5.   Mounting of several ARM cloud probes (see acronym list for names) during the Cloud, Aerosol, and Complex Terrain Interactions CACTI field campaign, in Argentina. The FCDP is located at the bottom left.

11.0 Software

For processing the data, software provided by the vendor (FCDP GUI and SP3C) is used. The version used is slightly modified to correct for errors.

12.0 Calibration

The laser alignment and the estimation of the sampling area were performed by the vendor. Regular calibration of the size measurements is typically performed weekly during a field campaign with six sizes of glass beads (8, 15, 20, 30, 40, 50 µm).

13.0 Maintenance

Maintenance of the probe during deployment is necessary:

- Cleaning of the probe windows to remove dirt before each flight
- Regular calibration with glass beads about once a week.

14.0 Safety

The FCDP contains a continuous-wave laser.

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

15.0 Citable References

Lance, S, CA Brock, D Rogers, and JA Gordon. 2010. "Water droplet calibration of the Cloud Droplet Probe (CDP) and in-flight performance in liquid, ice and mixed-phase clouds during ARCPAC." *Atmospheric Measurement Techniques* 3(6): 1683–1706, https://doi.org/10.5194/amt-3-1683-2010

SPEC FCDP Technical Manual (Rev.1.0 - Preliminary). 2013.

SPEC FCDP Technical Manual (Rev.2.0). 2019. Last accessed online November 7, 2019. http://www.specinc.com/sites/default/files/software_and_manuals/

McFarquhar, GM, D Baumgardner, A Bansemer, SJ Abel, J Crosier, J French, P Rosenberg, A Korolev, A Schwarzoenboeck, D Leroy, J Um, W Wu, AJ Heymsfield, C Twohy, A Detwiler, P Field, A Neumann, R Cotton, D Axisa, and J Dong. 2017. "Processing of ice cloud in situ data collected by bulk water, scattering, and imaging probes: fundamentals, uncertainties, and efforts toward consistency." In *Ice Formation and Evolution in Clouds and Precipitation: Measurement and Modeling Challenges*, *American Meteorological Society Monographs* 58: 11.1−11.33, https://doi.org/10.1175/AMSMONOGRAPHS-D-16-0007.1

Baumgardner, D, SJ Abel, D Axisa, R Cotton, J Crosier, P Field, C Gurganus, A Heymsfield, A Korolev, M Kraemer, and P Lawson. 2017. "Cloud ice properties: In situ measurement challenges." In *Ice Formation and Evolution in Clouds and Precipitation: Measurement and Modeling Challenges, American Meteorological Society Monographs* 58: 9.1−9.23, https://doi.org/10.1175/AMSMONOGRAPHS-D-16-0011.1