STANDARD OPERATION PROCEDURE FOR THE IAGOS-CORE CLOUD INSTRUMENT (BCP)

Revision by Karl Beswick, December 2014

1 Rationale

The Backscatter Cloud Probe was commissioned by IAGOS as a near-real-time cloud detector, primarily as a means to facilitate data quality control of trace gas instruments developed for the climate monitoring instrument packages. At the time of development there were no commercially available instruments suitable for the purpose: the IAGOS partner airlines needed to optimize long-term running costs by minimizing drag due to IAGOS instrumentation, with instruments capable of providing the required data all being of considerable bulk. As a result, Droplet Measurement Technologies developed a new type of probe which could be mounted entirely within the aircraft fuselage, using light backscattered from a laser directed through a small window.

2 Description of Method

2.1 The Backscatter Cloud Probe (BCP)

The BCP uses Mie Scattering theory to determine the size of particles passing through the sample volume of the instrument. Particles pass through a laser beam and scatter light in all directions. To allow all parts of the instrument to be located inside the aircraft, the BCP uses backscattered light in the 144° to 156° range (Figure 1). The depth of field (DOF) of the laser beam, where scattered light is focused onto the photodetector, is defined by a threshold signal level, below which a droplet is deemed to be outside the DOF. The BCPs used by IAGOS are currently configured to detect particles in the optical-equivalent range 5-75µm diameter, assuming spherical water droplets of refractive index 1.33.

In the current configuration the BCP creates a ten-channel size spectrum, although 20, 30 or 40 channels are configurable as options. The sizing information, however, can only be estimated following a full calibration of the laser beam and sample area: without this, the probe can only be used to give an indication of particle number concentration. It should be emphasised that the BCP was only ever intended as a qualitative indicator of cloud presence, and that any sizing information, when used with appropriate caution, can still assist in the interpretation of other data.

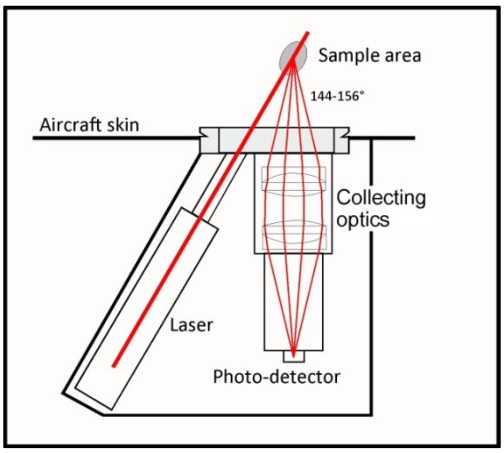

Figure 1 The BCP is contained within the body of the aircraft

The location of the particle in the beam is a critical piece of information needed to interpret the measurement. The intensity of the scattered light will depend upon the size, composition and shape of the particle, as well as the intensity and wavelength of the incident laser light. The amount of light collected will depend upon how far the particle is from the collecting optics when it passes through the beam. Particles can pass through the full width of the laser beam, but since the power density of the laser beam is of Gaussian shape, particles passing through the heart of the beam will scatter more light than those passing through the edge of the beam. To account for this disparity, a correction algorithm, commonly called an “inversion routine”, must be used in post-processing data analysis, mathematically making an estimate of the sizing correction for the final output. This will be discussed fully in Section 3.

The BCP uses a class 3b laser and can only be used once the aircraft is airborne, as the laser is only eye-safe at a distance of a few metres. The sample volume of the BCP is only 4 cm outside the aircraft, within the aircraft boundary layer, compared with the 6 cm used for the pitot tubes used by the aircraft to determine of true air speed.

The instrument comprises two main parts, the optical head and the electronics interface. The optical head is attached to the IAGOS inlet plate via an “optics cap”, a mount which protrudes slightly from the aircraft skin and which has a channel to divert water on the aircraft skin away from the sapphire window when in flight. The electronics interface acts as a combined power and data unit, and is mounted on the IAGOS Package 1 rack. Both parts of the instrument are extremely compact compared to other cloud instruments, with the optical head weighing only 0.5 kg and measuring 0.1x0.1x0.04 m. Since the BCP has no moving parts, and uses electronics systems that have been proven over long periods in other instruments, it is expected to require a minimum of maintenance and to operate for extended periods without failure.

2.2 Operators

The operation of BCPs as part of IAGOS is carried out by a number of groups. There are four main institutions and companies involved:

- University of Manchester (known as UNIMAN within IAGOS): based in the UK; responsible for long-term maintenance and calibration; documentation relating to quality assurance, data processing
- enviscope and Gomolzig Flugzeug- und Maschinenbau: based in Germany; responsible for maintenance and certification
- CNRS: based in France; responsible for package development, installation and certification; database management
- Droplet Measurement Technologies (DMT): BCP manufacturer, based in the USA

Full contact details can be found in Appendix A.

2.3 Installation

The BCP for any given IAGOS package is prepared for installation by enviscope, and fitted to the aircraft in conjunction with engineers from the airline involved. The procedures for fitting the instrument to the aircraft are covered by enviscope and the airlines, and are beyond the scope of this document.

Prior to preparation by enviscope, a BCP will either be used for the first time since manufacture and calibration by DMT, or will have been returned following calibration or repair by either UNIMAN or DMT. Following a satisfactory final visual inspection, it will be assumed that an instrument is fit to fly.

The final visual check is focussed on the external physical state of the instrument. The condition of the cables is checked, as is the state of the external window. Experience has shown that the window is the weakest point of the BCP system, so particular attention is required to ensure that the instrument is handled carefully.

It is not possible to make a check on the electronics of the instrument immediately preceding installation: the BCP laser is not eye-safe, and the instrument should only be powered on the ground in controlled laboratory conditions.

2.4 Instrument Operation

The BCP is fully autonomous, requiring only a 28 VDC power supply and an RS232 data connection to the IAGOS logging system. Since the laser used is not eye-safe, power is supplied from the aircraft through a weight-on-wheels signal to ensure operation begins once the aircraft is airborne. Data is polled from the BCP by the logging system every four seconds.

The BCP will only give reliable data if the window is kept clean. It is the responsibility of the airline to ensure that the window is regularly inspected, particularly if there is likely to be contamination from de-icing fluids. There is currently no documented procedure for the airlines to carry out regular checks of the window, and there is no method for determining automatically the state of the window. There will therefore always be a chance that data may be compromised in some way by not knowing the operational state of the window. The risk entailed is minimised by keeping regular checks on the output from each instrument.

All data files from the BCP are uploaded to the CNRS database within a day of the flight. These files are subject to a preliminary analysis within 7-14 days by UNIMAN. This process is described in more detail in section 3.1, but includes a check on the housekeeping data for the individual instrument as well as looking at the cloud information. Output from all files is looked at manually, ensuring that any faults with a particular instrument will be detected at an early stage.

2.5 Measured and Derived Parameters

For the purposes of IAGOS, the principle measured parameter is the total particle number concentration within the specified diameter limits. These limits can be defined in the probe initialisation, but IAGOS uses the range 5-75µm, covering the majority of expected cloud conditions. The BCP outputs raw counts measured during the current sampling period, which for the IAGOS logging system is 4 seconds. The processed output corrects these values for the sample area, the true air speed of the aircraft and for the record length to give units of particles per cm^3.

The BCP is capable of size-discrimination of liquid droplets, and can output up to 40 channels of information: IAGOS uses a set-up of 10 channels, giving size bins of 7 µm width. Assuming an appropriate calibration is available, the following parameters can be calculated from the spectral information:

- liquid water content, LWC, in units of grammes of water per m^3;
- mean volume-weighted diameter, MVD, calculated in units µm
- effective diameter, ED, calculated in units of µm, and defined as the ratio of the cube of the mean volume diameter to the square of the surface weighted diameter

IAGOS requires an indication of the presence of cloud, and this is done through the derived parameter liquid water content, LWC. The following values for cloud presence are assigned:

- 0 for LWC < 0.001 gm^{-3}
- 1 for LWC between 0.001 and 0.1 gm^{-3}, analogous to nominally sub-visible cloud
- 2 for nominally visible cloud with LWC > 0.1 gm^{-3}

As well as cloud information, the BCP also outputs housekeeping information, which gives a picture of the electronic condition of the instrument. This information comprises:

- 1st stage monitor (volts) – increases if the instrument is pointing at the sun, or if stray light increases for some reason
- ADC overflow (number) – the number of particles detected but rejected because they were oversized
- Baseline monitor (volts) – this should have a value of 3V ± 0.2V
- Electronics temperature (°C) – the temperature of the electronics box, which should stay above 10°C and below 60°C
- Optics temperature (°C) - the temperature of the optical head which houses the receiving optics, which should stay below 60°C
- Average transit time (µs) – the average time, over 128 particles, that the laser illuminated a particle

2.6 Removal

There are a number of reasons for the removal of a BCP:

- scheduled calibration and maintenance
- request from UNIMAN, CNRS or enviscope as a result of concerns about data quality
- aircraft servicing
- damage to the instrument
- removal of the entire IAGOS package.

The removal of a BCP from an aircraft is undertaken by the airline engineers, usually in conjunction with enviscope. If the BCP is the only instrument to be removed then it will be replaced with a blanking plate, to enable the IAGOS package to continue in use. As with installation, the processes involved are not within the scope of this document.

The airline will then pass the instrument to enviscope who will carry out basic visual checks, as described in section 2.2. If there are no issues, then the BCP will either be returned to operation at a suitable point, or sent to DMT or UNIMAN.

If any faults are noted during the visual checks, and depending on the reason for removal, then a number of options are available:

- If the instrument has been removed due to total failure, then it will be returned to DMT for repair and recalibration
- If there has been damage to the external window then this can be repaired by enviscope
- Cable damage can be remedied by enviscope, who keep a supply of spare parts.

- If there have been data quality issues with the instrument then it is sent to UNIMAN – the processes carried out are described in section 3.1 below.

3 Maintenance and Calibration

3.1 Test Procedure

There is no facility for testing a BCP whilst it is still installed on an aircraft, due to the non-eye-safe nature of the laser used. All testing, maintenance and calibration is therefore carried out in the laboratory, either by enviscope, UNIMAN, or DMT.

The BCP is expected to run for extended periods of between six and twelve months without requiring maintenance. Prior to deployment each BCP will be factory calibrated by DMT, or a two-stage calibration will be carried out by UNIMAN.

For the purposes of certification, the work carried out at the University of Manchester is prescribed by the document "IAGOS-BCP_Calibration Manual_IR.doc" in conjunction with the document "IAGOS-BCP_Calibration Report_IR.xls". These documents ensure that a consistent and safe method is applied in compliance with EASA rules, and that any work carried out is properly recorded and checked. The documents are available on request from UNIMAN (see Appendix A – Contacts), but the following list comprises the main elements:

- On receiving a BCP from enviscope a visual check is carried out: parts received; state of window (no cleaning required at this point); cable check
- Check functioning of laser: whilst using laser safety goggles check for diffuse scattering of the beam. If the laser is inoperative, the BCP is returned to DMT for repair.
- Check communications: connect the BCP to a suitable computer and ensure that data is received from the probe. If communication cannot be established, the probe is returned to DMT for repair.
- Check functioning of heater circuits: allow a few minutes for the probe to warm up, and then ensure that the electronics box and optical black temperatures are within the 10°C to 60°C range. If the heater circuits are not working correctly then then BCP is returned to DMT for repair
- Carry out a brief glass bead calibration using two bead sizes (see section 3.2.1 for further details). This calibration should be similar to previous glass bead calibrations carried out for the same probe.
- If necessary, the external window should be cleaned and the glass bead calibration repeated
- If the two-size glass bead calibration is unsatisfactory, then the calibration should be repeated with five different sizes.
- If the full glass bead calibration is satisfactory, then a beam map can then be undertaken (see section 3.2.2 for further details), otherwise the probe should be returned to DMT for repair.

3.2 Calibration Methodology and Standards

Unlike for the trace gas instruments used by IAGOS, there is no clearly defined and consistent absolute standard for calibrating laser-based cloud instruments. Coupled with the fact that the response from individual BCP instruments shows a great deal of variation, it is difficult to calibrate a BCP in a formally traceable manner.

There are three main calibration methods used for the IAGOS BCP instruments: calibration using glass beads of a known size; beam mapping using a custom-built facility at the University of Manchester; calibration by comparison with a co-located, scientific-grade instrument at DMT. An individual probe should undergo at least one of these calibrations in each twelve-month period of operation.

3.2.1 Glass bead calibration

Glass beads of up to four known sizes are used to carry out an initial calibration of a BCP. The glass beads are manufactured by Duke Scientific and are supplied with a NIST-traceable certificate indicating the exact size and standard deviation of the sample provided. Although these have a different refractive index to that of water, Mie scattering theory calculations can determine the water-equivalent size to be expected for each size. The particles are dispensed from a 10 cm^3 sample bottle using a compressed air supply, and are directed into the sample volume of the instrument. Each sample bottle is used only for one size of particles to prevent signal contamination from other sizes. Data are then checked against the expected results to confirm the probe is working correctly.

3.2.2 Beam mapping

One of the largest sources of error in BCP data is the size of the sample area. This can be determined very accurately using “beam mapping”: a stream of liquid water droplets of well-known size can be positioned with a precision of 2 µm within the sample area of the probe through the use of computer-controlled micro-positioners. By moving the droplet stream in two dimensions through the laser beam, a sample area map is defined by all positions at which the instrument responds. By using droplets of different sizes, a comprehensive picture of the instrument response is built up which can be used along with other data to help create an inversion matrix which can be applied to each particle spectrum measured by the BCP (see section 4).

The droplets are created using a piezo-electric droplet dispenser similar to those used in ink-jet printers. The absolute size of the droplets is determined using a direct optical method, the “glare” technique, in which specular reflections off the front and back face of droplets are observed by a camera. A full description of the beam mapping process can be found in Lance *et al*, 2010.

3.2.3 DMT Calibration

AWAITING INFORMATION FROM DMT

4 Data Flow

4.1 Original logging system files

Data are recorded to the main IAGOS logger at 4 second intervals, and are offloaded to the CNRS database within 1-2 hours of the end of each flight. CNRS carry out some initial processing to create files for each instrument: the BCP data are stored to ASCII files which are saved to the CNRS server. Data analysis is then carried out by UNIMAN using analysis software custom written in Igor.

4.2 Calculation of Results

4.2.1 Sample volume correction

The number concentration of particles is determined by counting the number of cloud particles detected within the size range of the BCP over a selected time period and dividing by the volume of air which passes through the sample area. The volume V of air is calculated as:

V = sample area x true air speed x sampling time

The sample area is determined through the beam mapping procedure (see section 3.2.2) or from a DMT factory calibration and the true air speed (TAS) is provided from the aircraft instrumentation.

4.2.2 Size retrieval using data inversion

This description of the use of the inversion technique is taken from Beswick *et al,* 2014.

The derivation of size distributions from the backscatter measurement involves the procedure, best known as inversion, in which we assume that the operating principle of the measurement system is well known and can be modelled such that we can predict how it will reproduce the actual size distribution.

Mathematically, the actual size distribution, with n size bins, is represented by the row vector **A**. The measured size distribution, with m size bins is represented by the column vector, **M**. The n x m matrix, **T**, is a probabilistic description of how the instrument will actually measure a particle of size i. Stated differently, the matrix **T** describes the probability that a particle in size element i will actually be placed by the measurement into size element j, where $j < i$. The relationship between **A** and **M** is expressed as:

$\mathbf{M} = \mathbf{TA}$ (1)

This is solved analytically by multiplying both sides of (1) by the inverse of **T**, $\mathbf{T}^{-1}$:

$\mathbf{T}^{-1}\mathbf{M} = \mathbf{T}^{-1}\mathbf{TA} = \mathbf{A}$ (2)

This can be done only if the inverse of **T** can be calculated. For the BCP, this is done by implementing an iterative process in which we propose a value for the actual distribution, calling it **A***, multiply it by our transformation matrix, **T**, and obtain a size distribution, **M***, that we compare with our measured distribution, **M**. If **M*** = **M**, then **A*** = **A**. Otherwise we need to adjust our value of **A*** and recalculate **M***. We continue this iteration until we obtain an **M*** that is a reasonable approximation to **M**, i.e. when the difference between the two vectors is within a preset value.

In order to create the transformation matrix, **T**, we need the probability distribution that predicts which fraction of the particles that fall in bin j should have actually been placed in bin i, as a result of the Gaussian intensity distribution of the laser beam. We also have to take into account that some particles with different sizes have the same scattering cross section due to the light scattering properties. When the BCP measures the light scattered by particles in some size ranges, they will be classified in smaller size intervals. This response must also be part of the model and included in the transformation matrix.

The transformation matrix that describes the response of an individual BCP is generated by calculating the scattering cross section, with Mie scattering theory, of droplets from 5 µm to 90 µm, in 1 µm intervals, then multiplying by the normalized intensity map of the laser beam in order to determine into which size cells, *j*, a particle of size, *i*, will fall.

4.3 Data processing

4.3.1 File Handling

Final data processing for BCP data is undertaken by UNIMAN. A suite of software has been written in IgorPro which allows each file to be individually analysed. Files for all BCPs are downloaded from the CNRS database and separated by month and airline. In line with IAGOS file naming conventions, the original data files are named BCPyyyyyMMddhhmmssbb.txt, where yyyy is the year, MM is the month, dd is the day, hhmmss is the start time of the file and bb is the base unit for the package. Processed files use the same root name, but the file extension is changed to .NAS, reflecting the NASA AMES format of the file.

UNIMAN keep a register of all BCPs which can be used to determine which BCP has been used on a particular aircraft at a given time, and to ensure that the correct calibration and quality criteria are applied to each file. The register includes details of: deployment dates; airline; calibration details; data quality; IAGOS base unit.

4.3.2 Analysis

Each flight with BCP data is processed manually using custom-written software. This software gives the user a number of diagnostic tools and graphical output, as well as providing a final output file in NASA AMES 1001 format to be uploaded to the CNRS database.

The following are details of the main features of the analysis:

- Initial processing, during which the user chooses which BCP/airline/IAGOS base unit combination is being processed, and selects whether to have (and optionally save) graphical output
- If the user does not choose graphical output then the file is processed and only the NASA AMES file is written.
- If the user chooses graphical output then a number of graphs will be plotted automatically:
  - BCP housekeeping diagnostic which includes: 1st stage monitor; optics temperature; baseline monitor; electronics temperature; ADC overflow; average transit time; altitude; mean and effective diameters; liquid water content; particle number concentration.
  - General flight diagnostic which includes: route; altitude profiles during ascent, cruise and descent of temperature, particle number concentration and mean volume diameter; time series of particle number concentration, liquid water content, particle size spectrum
  - Up to 144 5-minute averaged spectra, labelled with time and altitude
  - Separate altitude profiles for ascent, cruise and descent; each profile includes temperature, mean volume diameter, liquid water content, particle number concentration
  - “Faults” diagnostic which includes time series of: altitude; altitude change rate; recovered temperature; true air speed; heading change rate; particle number concentration
- If the user has chosen to save the graphical output, then all but the “Faults” diagnostic are saved. In practice, this option is used for the first analysis of every file, to give “quick look” output for each flight

- If any of the graphical output gives an indication of an "interesting" event during a flight then further diagnostic graphs can be used. Examples of an interesting event include:
  - A deviation from a normal flight route, either by a change of heading or by altitude change – this can be determined by comparing the flight plan with previous flights
  - A deviation in the temperature and/or true air speed signals – this may indicate that the pitot tube from which the signals are taken has ingested ice
  - Problems with data such as: missing points; housekeeping data that is not within normal limits; instrument reset; lower concentrations than might normally be expected – this may indicate an instrument fault if it persists over a number of flights
  - high concentration events, perhaps indicating unusual conditions such as deep convective clouds
  - deep cloud profiles of at least 20 kft
- A summary of the flight is saved to a spreadsheet including: filename; file data version; start and end dates and times; flight duration; cumulative operating hours; departure and arrival airports; notes on the flight, including information about interesting events and the presence of significant clouds; indication of cloud presence during the ascent, cruise and descent phases of the flight; quality indicator (see section 5); other indicators and flags for organisational purposes.
- The software always writes an output file in NASA AMES 1001 format – see section 4.3.3. This file is uploaded to the CNRS database, and should always represent the most up-to-date analysis of the data.

4.3.3 Products

The principal product for the BCP data analysis is the NASA AMES 1001 format file which is uploaded to the CNRS database. The metadata for this format sets out when the file was processed, what parameters are included, what values are used for missing data, measurement units, quality indicators and other information including the route flown.

4.3.4 Time-scale

Initial analysis of a data file takes place within 14 days of the flight to which it corresponds. Dependent upon the type of sample area calibration available at the time of the data processing, this initial analysis may not be considered as the final version, and this is indicated in the NASA AMES file. If better calibration information becomes available then the data will be reprocessed and resubmitted to the CNRS database within 18 months of the original flight.

The spectral data may only be considered final if a full beam-mapping calibration has been carried out and the results applied to the data. This calibration process may not have taken place prior to an individual instrument being operationally deployed, but when the data has become available it can be retrospectively applied, and the affected data files will be re-analysed and submitted to the CNRS database within 18 months of the original flight.

5 Uncertainty Analysis

5.1 Uncertainty in data products

As previously noted, the BCP was only ever intended as a qualitative indicator of the presence of cloud. Experience has, however, shown that the BCP is capable of making good quality measurements of total particle number concentration. Total N is therefore considered the most reliable part of the output from the BCP, and has an uncertainty which is dependent on the nature of the calibration data available. A full description of the error analysis for the BCP is given by Beswick *et al*, 2014.

The major sources of error in determining total number concentration within the defined particle size range for the BCP are the sample area and the true air speed. The smallest error for the sample area is achieved using the beam-mapping procedure, and this gives an error estimated at ±8%.

The true air speed is measured at a distance of 6 cm from the aircraft skin, whilst the BCP samples air 4-5cm from the aircraft. This gives rise to an error in the TAS as applied to the sample volume correction of ±20%. Combined with the error in the sample area, this gives a root mean squared error of ±22% in the total N from a beam-mapped BCP.

If a beam-mapped sample area is not available, then the latest DMT factory calibration is used. This has an error of XXX%, which would give a combined total error of XXX%. In cases where a factory calibration is also not available, a default value of 0.35 mm^2 is used, with an error of ±0.25 mm^2 (representing the spread of sample areas on IAGOS BCPs).

At the present time, due to the design of the BCP and in particular the characteristics of the sample area, the errors in the size distribution data are a complicated function of the number of channels in the measured size distribution, the fraction of the actual size distribution with concentrations in optical diameters smaller than about 15 µm, the width of the actual distribution, the refractive index of the particles and their shape. With no independent measurement of the actual size distribution, confidence in the retrieved spectra is variable. However, this should not detract from the qualitative information that the BCP can provide. For any given instrument, its characteristic behaviour will be apparent over a period of time, and relative changes between flights are capable of adding positively to the interpretation of the IAGOS dataset.

Table 1 Summary of uncertainties

Quantity	Source of uncertainty	Uncertainty
Sample area	Positioning accuracy when using beam-mapping calibration	±8%
	Factory calibration	±X%
	Default value of 0.35 mm^2, based on operational data of all IAGOS BCPs	±0.25 mm^2 or ±71%
True air speed	Measurement not co-located with BCP	±20%
N	RMS combination of errors for beam-mapped sample area and true air speed	±22%
	RMS combination of errors for factory calibrated sample area and true air speed	±X%
	RMS combination of errors for default sample area and true air speed	±74%

5.2 Response to non-spherical particles

The calibration applied to a BCP only holds true in operational conditions if the particles being sampled are spherical water droplets. In the case of non-spherical particles, for example ice or aerosol, the instrument will respond to the particle, but will not make an accurate determination of the particle size. With the current generation of BCP, there is no independent measure to indicate the phase or type of particle and other IAGOS signals such as altitude or temperature must be used to determine if the size information is applicable.

5.3 QA/QC levels

Each data record is given a quality flag with a value between 0 and 6, according to the following:

- 0 - no BCP
- 1 - BCP error, e.g. during a reset
- 2 - default sample volume correction, with the largest expected error in total N
- 3 - factory calibrated sample volume correction
- 4 - beam-mapped sample volume correction
- 5 - beam-mapped sample volume correction with inversion applied
- 6 - potentially obscured windows

This flag will be replaced with two WMO-GAW compatible quality indicators in the near future, at which point all data will be re-analysed. Previous versions of the data analysis have used a more limited system, with only three values specified in the NASA AMES files:

- 0 - Invalid data
- 1 - no inversion applied: valid parameters are total counts and cloud presence
- 2 - inversion applied: all cloud parameters valid

Files with this method of data flagging should not be considered as final versions of the data.

6 BCP Specifications

The specifications given below are taken from the DMT BCP Manual.

Item	**Value**
Typical sample area	0.35 mm^2
Size Range	5 µm to 75 µm
Number Concentration Range	0 - 1000 cm^{-3}
Air Speed Range	10 - 250 m s^{-1}
Number of Size Bins	10 or 20
Sampling Frequency	0.1 sec. to 10 sec
Refractive Index	1.30 - 1.70
Light Collection Angles	150º, +/-6º
Laser Wavelength	658 nm
Laser Power	77mW or less
Data System Interface	RS-232 or RS-422 serial interface
Temp	-40 to +40 °C
Altitude	0 - 15000 m
Humidity	0 - 100%

Weight	1.5 kg
Probe	11.7 x 10.7 x 4.5 cm with 5.9 cm diameter mounting flange
Electronics	21.6 x 12 x 5.7 cm
Power Requirement	28VDC, 5A

7 References

Beswick, K., Baumgardner, D., Gallagher, M., Volz-Thomas, A., Nedelec, P., Wang, K.-Y., and Lance, S.: The backscatter cloud probe – a compact low-profile autonomous optical spectrometer, Atmos. Meas. Tech., 7, 1443-1457, doi:10.5194/amt-7-1443-2014, 2014

Lance, S., Brock, C.A., Rogers, D., and Gordon, J.A.: Water droplet calibration of the Cloud Droplet Probe (CDP) and in-flight performance in liquid, ice and mixed phase clouds during ARCPAC, Atmos. Meas. Tech., 3, 1683-1706, doi:10.5194/amt-3-1683-2010, 2010.

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