Topic 11: Calibration Techniques and Standards

Sara Lance
Darrel Baumgardner, Paul Lawson, Patrick Chuang, Linea Avallone, Markus Petters, Walter Strapp

June 25, 2010
Calibration Methods Outline

Fundamental Calibrations of
1. particle size
2. particle concentration
3. particle shape/ aspect ratio
4. CCN concentrations (SS)
5. IN concentrations (RH,T)
6. liquid water content
7. ice water content

Methods to illuminate in-flight biases
1. Coincidence
2. Electronic response time – *Topic 10*
3. Particle shattering – *Topic 13*
4. Airflow distortions – *Topic 12*

Field Calibration/In-Flight Validation
1. “Housekeeping” variables
2. In-flight instrument intercomparisons
3. Internal sizing calibration from Mie oscillations
4. Field calibration methods

Standardization of Calibration Methods
1. Centralized calibration facility
2. Reporting of calibration methods
Calibration techniques for single particle measurements

1. **Particle size**
   - glass beads, PSL spheres, water droplets, spinning disk w/ diffraction dots

2. **Particle concentration**
   - micropositioning with spinning wire, spinning pinhole, static obstruction, jet of single water droplets, etc in the beam. In-flight or wind tunnel intercomparison to other instruments like PCASP with known sample volumes.
   - Strapp et al, 2001; Feingold et al, 2006; Nagel et al, 2007; Lance et al, in prep

3. **Particle shape**
   - Ice analogues
   - Ulanowskiet al., 2003, 2006
Calibration techniques for single particle measurements

4. CCN
dry NaCl or (NH$_4$)$_2$SO$_4$ particles of known size, to calibration instrument supersaturation of water vapor and thermal properties of the CCNc column. Lance et al, 2006; Rose et al, 2008

Calibration of the optical particle counter with glass beads, PSL particles, water droplets... Does anybody ever do this?

5. IN
Is there a standard ice nucleating compound? What properties would a representative compound exhibit? Would calibration of column RH and T be sufficient (in addition to optical particle counter calibration)?
Particle Size Calibration using Glass Beads

A powder that is blown directly across the instrument sample volume.

**PROS**
- Easy to use in the field (especially for sizes > 10 um)

**CONS**
- Uncontrolled trajectories, velocities and concentrations
- Short bursts of data
- Potential for large coincidence errors
- Different refractive index/shape than water droplets

*Nagel et al, 2007*
Particle Size Calibration using PolyStyrene Latex (PSL) spheres

**PROS**
- Fairly easy to use in the field
- Steady flow of particles allows some control of concentrations

**CONS**
- Difficult to generate/transmit PSL particles > 3 um
- Potential for large coincidence errors
- Different refractive index than water droplets

*Fischer Scientific*
Droplet generation methods

3-150um, produced by tapping

Technique for producing uniform small droplets by capillary waves excited in a small meniscus

Hafldi Jonsson
Department of Atmospheric Science, State University of New York at Albany, Albany, New York 12222

Bernard Vonnegut
Atmospheric Sciences Research Center, State University of New York at Albany, Albany, New York 12222
(Received 8 March 1982; accepted for publication 2 August 1982)

6-240+ um, produced by flinging

FSSP Characterization with Monodisperse Water Droplets

M. Wendisch and A. Keil
Physics Department, Institute for Tropospheric Research, Leipzig, Germany

A. V. Korolev
Cloud Physics Research Division, Atmospheric Environment Service, Toronto, Ontario, Canada
(Manuscript received 2 January 1996, in final form 25 April 1996)
Generating Standardized Water Droplets using InkJet Technology

40 um drops

Commercial Piezo-Electric device (MicroFab, MicroDrop)
- Produces a jet of single droplets
- Reproducible Size AND Concentration

USA Germany
Evaporation Flow Tube

Control of droplet size by varying residence time

Lance et al, in prep
Evaporation Flow Tube

Control of droplet size by varying residence time

\[ \Delta t \approx 2 \text{ second} \]

Lance et al, in prep
Droplets in the sample volume of the CDP
Gives the “True”
drop size
Independent Verification of Drop Sizing *(within the CDP sample volume)*

Lance et al, in prep

**Fig. A2.** Ratio of glare distance $d_{glare}$ and droplet diameter $d_{true}$ in dependence of the angle of observation $\delta$. 

**FSSP Characterization with Monodisperse Water Droplets**

M. WENDISCH AND A. KEIL  
*Physics Department, Institute for Tropospheric Research, Leipzig, Germany*

A. V. KOROLEV  
*Cloud Physics Research Division, Atmospheric Environment Service, Toronto, Ontario, Canada*  
(Manuscript received 2 January 1996, in final form 25 April 1996)
Calibration of CDP Sizing with Water Drops, PSL and Glass Beads

Calibrations (left axis):
- glass beads
- PSL spheres
- water droplets (at the center of the DoF)
- Power fit to water droplet calibrations

\[ y = 120 + 2.70 \left( x^{1.78} \right) \]

Mie Calculations (right axis):
- glass beads (n = 1.59)
- PSL spheres (n = 1.56)
- water droplets (n = 1.33)

Detection angles used in calculations:
- 3.5° - 10.8° (upper estimate)
- 4.5° - 13.8° (lower estimate)

Lance et al, in prep
Sizing Calibration for Optical Array Probes

using large water drops

using spinning disk with diffraction dots

Strapp et al, 2001

Korolev et al, 1991
Sample Area Calibration

The “sample area” of an open path single-particle instrument is defined by the optical and electronic systems.
Drops inside the Sample Area

The CAS, CDP and some FSSPs are like this.

Similar, but slightly different situation for the original FSSP.
Drops outside the Sample Area

[Image of diagram showing laser beam, Qualifier, Sizer, beam dump, open path length, and a graph with voltage vs. time in microseconds.]
Drops outside the Sample Area

![Diagram showing laser, beam dump, Sizer, Qualifier, and open path length.](image)
CDP Sample Area Results:
Calibration with Water Droplets

Calibrated Sample Area agrees well with the instrument specs (0.3 mm²)

Lance et al, in prep
~22 um Drops

Lance et al, in prep
~12 um Drops

Lance et al, in prep
Particle Shape “Calibration”

- Using ice analogues
  - e.g. sodium hexafluorosilicate, $\text{Na}_2\text{SiF}_6$ crystals (which have very similar refractive index to ice at visible wavelengths)

- Growing ice crystals reproducibly?
  - How to transmit them?

Kenneth G. Libbrecht, Caltech
SnowCrystals.com
Calibration techniques for bulk measurements

4. Liquid water content
   Wind tunnel experiments, using icing cylinder(s) or liquid mass conservation for comparison. Collection/evaporation of droplets, and analysis of H$_2$O vapor using Lyman-α hygrometer. In-flight comparison to drop size distribution measurements.
   

5. Ice water content
   Collection/evaporation of crystals, and analysis of H$_2$O vapor using tunable diode laser, Lyman-α hygrometer or other hygrometer technique
   
   Twohy et al, 1997; Hallar et al, 2004; Davis et al, 2007
Wind tunnel calibrations of King-LWC for various sized water droplets

Biter et al, 1987

Strapp et al, 2003
Potential Method for Wind Tunnel Calibration of Ice Water Content

Using Lyman-α hygrometer to analyze H₂O vapor obtained by evaporation of ice crystals collected by Countert Flow Virtual Impactor (CVI) or subsisokinetic inlet

Lawson et al, 2010
Twohy et al, 1997
need for wind-tunnel / other calibration methods mimicking in-flight conditions to illuminate biases that arise only in-flight

1. **coincidence**
   when the sample area of one or more detectors is too great (or droplet concentrations are too high). Leads to oversizing, undercounting and size-spectrum broadening.
   *Baumgardner et al, 1985; Cooper, 1988; Brenguier et al, 1998; Lance et al, in prep*

2. **electronic response time** - *Topic 10*
   when electronic response is too slow relative to aircraft velocity, both counting and sizing errors are possible.
   *Baumgardner et al, 1985; Lawson et al, 2006; Nagel et al, 2007; Lawson et al, 2010; Strapp et al, 2003*

3. **particle shattering** - *Topic 13*

4. **airflow distortions** - *Topic 12*
CDP and King-LWC In-Flight Intercomparison

Lance et al, in prep

Mixed-Phase Clouds:
Intercept = -37.69 ± 1.43
Slope = 0.366 ± 0.010

Liquid-Only Clouds:
Intercept = -10.07 ± 4.46
Slope = 0.2467 ± 0.0164

Measured CDP-LWC bias [%]

Measured Droplet Concentration [cm⁻³]
Calibration of the “Extended Sample Area” with Water Droplets

Lance et al, in prep
Monte Carlo Simulations of the CDP response
(Constrained by the Calibrations)

\[ \tau_Q = \left( \frac{1}{N_D} \right) \]

\[ \tau_U = \left( \frac{SA}{N_D \cdot SA_{ext}} \right) \]

Lance et al, in prep
Model/Measurement
CDP-LWC bias comparison

Simulations assuming spatial homogeneity in $n_d$ at 100m scales:
- (5-9 um droplets, 1.5-2.0 us pulse widths)
- (4.9 um, 2.0 us) - Linear fit (4.9 um, 2.0 us)
- (6.4 um, 1.8 us) - Linear fit (6.4 um, 1.8 us)
- (12.6 um, 1.5 us) - Linear fit (12.6 um, 1.5 us)

Simulations with sub-100m spatial variability in $n_d$:
- (7-9 um droplets, 1.2-1.3 us pulse widths, $L = 50$ m)
- (6.9 um droplets, 1.0 us pulse widths, $L = 33$ m)

Lance et al, in prep
Simulated and measured droplet size distributions

- Consistency between measured CDP-King LWC bias and simulated LWC bias
- Consistency between simulated and measured droplet concentrations

Lance et al, in prep
Laboratory Calibration of the CDP Extended Sample Area

Modified CDP

Extended sample area after installing 800 um pinhole on sizer

Qualified sample area

Standard CDP

Extended sample area

Qualified sample area

modified to reduce “coincidence errors”, which occur when multiple droplets pass through the sensitive region of the laser beam at the same time

Lance et al, in prep
CDP Intercomparison (Standard v. Modified)

Droplet Concentrations [cm\(^{-3}\)]

- **Modified CDP (10 Hz)**
- **Modified CDP (Averaged to 1 Hz)**
- **Standard CDP (1 Hz)**

UTC

5/16/2010
Verifying Improved CDP Performance In-Flight: Very Recent Results from Calnex campaign

Undercounting error is a function of droplet size.

Lance et al, in prep
Sample Area Calibration using a High Speed Rotating Disk with Wire

FIG. 11. Schematic of the high-speed tool with spinning disk in the probe laser sample volume.

FIG. 12. Oscilloscope signals of a water droplet of 70-μm diameter, a glass fiber, and a tungsten wire, as produced by the FSSP electronics and as measured at the PHA input.

Nagel et al, 2007
Advancements in Techniques for Calibration and Characterization of In Situ Optical Particle Measuring Probes, and Applications to the FSSP-100 Probe

DAGMAR NAGEL
Geesthacht, Germany

UWE MAIXNER
Barum, Germany

WALTER STRAPP AND MOHAMMED WASEY
Environment Canada, Downsview, Ontario, Canada

Fig. 15. (a) FSSP DOF and (b) probe sizing for a 70-µm particle, as function of airspeed, simulated with a rotating glass fiber. The “static DOF size” measured with frosted tape as the scattering source is included. (c) In addition, the normalized liquid water content is given.

spinning disk with pinhole, wire or diffraction dots in high-speed calibrations to determine limitations in the instrument time-response
Sample Area Calibration for Optical Array Probes using spinning disk with diffraction dots

Strapp et al., 2001
Field Calibration and In-Flight Validation

• **Methods for tracking changes to In-Flight performance during a project:**
  – “Housekeeping” variables
    • PBP transit time (pulse width) for both qualifier and sizer, interparticle arrival time, baseline voltages, laser block temperature, laser current monitor... ?

  – Comparison between in-flight size distribution measurements (droplets, ice crystals, CVI residuals) and bulk measurements (LWC/IWC/TWC).

• **Standardized field calibration methods:**
  - Single particle instruments
    1. Sample Area
    2. Sizing
    3. Shape/Aspect Ratio
    4. CCN
    5. IN
  - Bulk measurements
    1. LWC
    2. IWC
Water droplet calibrations in the field?

- **Droplet generator („Piezodropper“)***
  - adjustable for 25-60µm droplets
  - micro-positioned (5µm resolution)
  - compact, possible to move into FSSP inlet

- arbitrary repetition rate (up to ~KHz)
- for good parameters stable operation for hours
**CDP Sample Area**

- **Sample Area measurement:**
  - Positions recorded where count rate almost drops to zero
  - 50µm steps along the laser beam (Plot: x-axis)
  - 5µm accuracy for each line (along plot y axis)

- **Results:**
  - Sample Area = 0,217 mm$^2$ +/- 8%
  - Lower limit 0,197mm$^2$, upper limit 0,237mm$^2$
  - Sharp sample area borders (counts fall to zero within 5µm displacement)
CDP and FSSP Calibrations

- 35µm water droplets generated (no precise independent droplet size measurement)
- Droplet speed of 1.5 m/s
- Stable trajectory (within a few µm at the sample volume)
- Compact, portable system is possible (for use in the field)
Standardization of Calibrations

• Centralized calibration facilities
  – Using ARM radiation measurement calibration facility in Oklahoma as a working precedent.
  – Prerequisite before field programs?
  – Where should they be located?
  – What are the critical parameters?
  – Static (laboratory) or dynamic (wind tunnel) calibration?

• Standardized calibration methods/techniques, especially for use in the field

• **Reminder: Always report calibration methods!**