A Comparison of Size Distribution Calculation Methods on Single Scattering Properties of Anvil Cirrus Clouds

Shawn Wagner[1] (shawn.wagner@und.edu) and David Delene[1] (delene@aero.und.edu)
[1]University of North Dakota, Grand Forks, North Dakota

Overview

In the field of airborne cloud sampling there is currently different methods to properly handle the processing of data taken by particle imaging probes when the entire particle was unable to be captured optically. Differences in the processing of partially captured particles results in variations in the calculated properties of the clouds being sampled. One such property is the particle radiation backscatter. Backscatter is heavily dependent on the cloud particle habit and the size distribution of the cloud particles. How one handles the processing of partial particles directly affects the determined particle size distribution and thus the calculated backscatter. This study will look at three different methods of handling such particles and attempt to determine the variation in the calculations of the single scattering properties of cirrus clouds which result from utilizing the different processing methods.

The University of North Dakota's Citation Research Aircraft was used during eight flights in Florida to take in-situ measurements of high-altitude cirrus clouds during the CAPE2015 research project. Particle imaging probes onboard included a two-dimensional stereographic (2D-S) probe and a High Volume Precipitation Spectrometer version 3 (HVPS3) probe. The clouds observed were in thunderstorm anvil outflow regions between 29,000 ft and 40,000 ft, and images indicated that many of the larger crystals (over 105 micrometers in diameter) had a similar habit structure. Three different size distribution calculation algorithms are to be performed on the 2D-S data: "reconstruction", "center-of-mass", and "all-in". The "reconstruction" method involves reconstructing edge images by mirroring the observed part of the particle. The "center-of-mass" method involves only using edge images where the center of mass of the particle is known to be within the image. The "all-in" method does not use particles that are not entirely in the image. These three methods are to be evaluated by comparison with manual review of images for consistency. Each size-distribution will be used to calculate bulk single-scattering properties of the cloud, including the backscatter coefficient, mean extinction efficiency, absorption efficiency, and asymmetry factor. The uncertainty of the bulk single-scattering properties is to be evaluated from the spread of applying the three different methods. Data gathered in North Carolina of 2014 (among other data sets) can also be used for further examination.

Probes

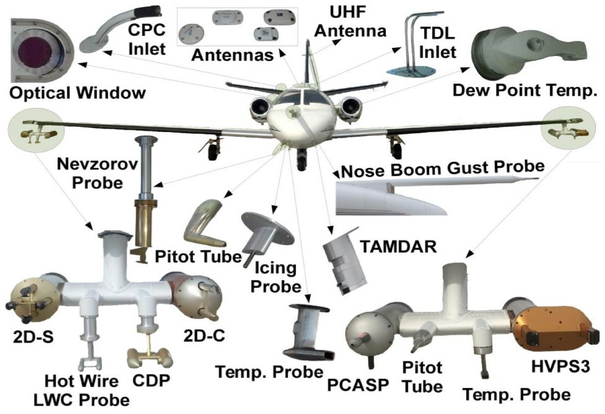


Image showing the names and locations of probes onboard the Citation Research Aircraft during the CAPE2015 research project. The probes of focus for this study are the 2D-S and HVPS3. The 2D-S provides two dimensional images of smaller particles using one vertical and one horizontal 128-photodiode laser. The HVPS3 uses the same photodiode array as the 2D-S but is geared toward one-dimensional analysis of larger particles.

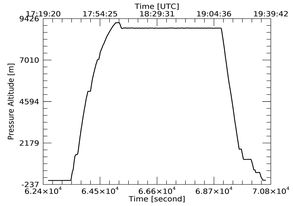
Data

Location	Year	2DC	2DS	CIP	CPI	CSI	HVPS3	NEV
Georgian Bay	2012	✓		✓	✓		✓	✓
North Carolina	2014	✓	✓		✓	✓	✓	✓
Florida	2015	✓	✓				✓	✓
North Dakota	2010	✓						
	2011	✓		✓	✓			✓
	2012	✓		✓	✓		✓	✓
	2014	✓	✓				✓	✓
	2015	✓	✓				✓	✓

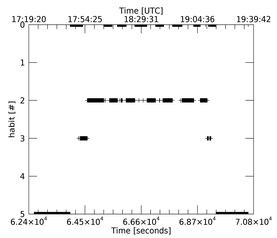
2DC = 2 Dimensional Cloud Probe
2DS = 2 Dimensional Stereo Probe
CIP = Cloud Imaging Probe
CSI = Cloud Spectrometer and Impactor
HVPS3 = High Volume Precipitation Spectromer Version 3
NEV = Nevzorov Liquid Water Content and Total Water Content Probe

Flight

Top image showing the altitude during a CAPE2015 flight on July 30th. Once at peak altitude the plane maintained a consistent height for sampling.



Bottom image showing the expected habit type during the same CAPE2015 flight on July 30th. The expected habit type is determined using environmental temperature values and the 2D-S measured area ratio of the cloud particles. The habit type is necessary for backscatter calculation.



0 = out of cloud
1 = columns
2 = plates
3 = dendrites
4 = needles
5 = liquid

2D-S Images

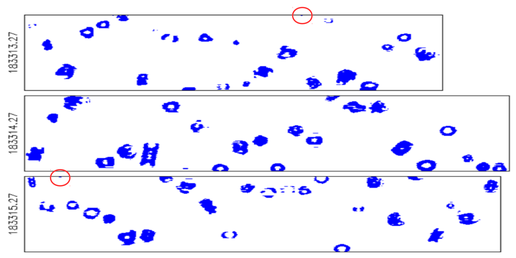


Image showing example 2D-S samples from the CAPE2015 July 30th flight at approximately 1830 UTC (mid-flight). Many of the particles are only partially captured on the edges of the images (red circles). the "reconstruction" and "all-in" processing methods will result in those partial captures particles being processed differently, which could produce significantly different size distributions.

Size Spectrum

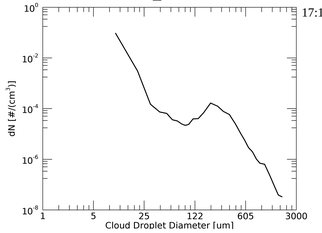


Image showing the size spectrum sampled by the 2D-S during the entirety of the CAPE2015 July 30th flight using the automated "reconstruction" processing method within the Airborne Data Processing and Analysis (ADPAA) software package [Delene, 2011].

Future Work

Process the CAPE2015 field project using "all-in" and "center-of-mass".

Use each processing methodology to calculate a size spectrum and the backscatter coefficient.

The backscatter coefficient equation [Beuth et al., 2014] is given by:

$$\beta_i(\varphi=\pi) = n_i \int_{r_{\min}}^{r_{\max}} \frac{d\sigma_i(r,\varphi=\pi)}{d\Omega} \eta_i(r) dr$$

β = backscatter coefficient
n_i = lognormal scaling factor
η_i = lognormal distribution function
$\frac{d\sigma_i(r,\varphi=\pi)}{d\Omega}$ = differential backscatter cross section
r = particle radius
φ = scattering angle

Acknowledgments

This research is being supported by a Research ND grant from the North Dakota Department of Commerce.

References

Beuth, T., et al., 2014: Calculation of backscatter coefficients for lidar systems by Mie-scattering theory and atmospheric properties. *DGaO Proceedings 2014*, Germany, DGaO Proceedings, http://www.dgao-proceedings.de/download/115/115_p33.pdf.

Delene, D.J., 2011: Airborne data processing and analysis software package. *Earth Sci Inform*, **4**, 29- 44, https://doi.org/10.1007/s12145-010-0061-4.