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Precipitation and Hydrology Experiment Counter-Flow Spectrometer and Impactor Field Campaign Report

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ARM CLIMATE RESEARCH FACILITY

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Acronyms and Abbreviations

ACE	Advanced Composition Explorer
ARM AAF	Atmospheric Radiation Measurement Aerial Facility
ARM	Atmospheric Radiation Measurement Climate Research Facility
CSI	counter-flow spectrometer and impactor
DOE	U.S. Department of Energy
IPHEX	Integrated Precipitation and Hydrology Experiment
NASA	National Aeronautics and Space Administration
NPOL	NASA Polerametric radar site in Rutherford County, North Carolina
UTC	Coordinated Universal Time
M-D	mass-dimension
HVPS-3	high-volume precipitation spectrometer 3

Contents

1.0 Background

The U.S. Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) Climate Research Facility Aerial Facility (ARM AAF) counter-flow spectrometer and impactor (CSI) probe was flown on the University of North Dakota Cessna Citation research aircraft during the Integrated Precipitation and Hydrology Experiment (IPHEX). The field campaign took place during May and June of 2014 over North Carolina and its coastal waters as part of a National Aeronautics and Space Administration (NASA) Global Precipitation Measurement validation campaign. The CSI was added to the Citation instrument suite to support the involvement of Jay Mace through the NASA Advanced Composition Explorer (ACE) satellite program and flights of the NASA ER-2 aircraft, which is a civilian version of the Air Force's U2-S reconnaissance platform. The ACE program funded extra ER-2 flights to focus on clouds that are weakly precipitating, which are also of interest to the Atmospheric System Research program sponsored by DOE.

2.0 Data

The CSI probe is designed to measure total water content (liquid plus ice), which provides a reference for water mass estimates derived from particle size distributions. The instrument is a counter-flow design, in which back pressure is applied to the sampling inlet using dry air to allow only water condensate (i.e., no vapor) to enter the sampling chamber. The condensate is vaporized and the resulting water vapor content is used to calculate the mass concentration of the condensate.

The Citation flew over 55 science mission hours during the campaign. Summaries of the missions are provided in Appendix A. The CSI raw data files have been archived,[1] and are in the directory named /arm-iop/2014/osc/iphex/poellot-csi/. The metadata file, found in the archive, is attached to this report as Appendix B. Complementary data from other cloud microphysics instruments carried on the Citation can be found at the NASA Distributed Active Archive Center.[2]

3.0 Data Issues

An initial issue with the data was discovered after completion of the campaign. The probe was operated during IPHEX with a back-pressure flow somewhat higher than desired, which prevented smaller water and ice particles from being included in the samples. Work is underway to obtain a reasonable estimate of the mass fraction that was missed as a result. Over the past couple of months, Jason Tomlinson from the ARM AAF has gathered additional data with the instrument as flown on the U.S. Department of Energy's Gulfstream-1. His preliminary finding is that the cut size for liquid spheres was approximately 19 μm, which is higher than originally expected. A preliminary report is provided in Appendix C. This will need to be considered when interpreting CSI measurements. Estimates of cloud water content from particles smaller than 19 μm may be obtained from particle size distributions measured by a cloud droplet probe that was part of the Citation microphysics instrument suite for NASA.[2]

[1] http://iop.archive.arm.gov/arm-iop/0pi-data/?uid=POELLOT&st=55a3c217&home=arm-archive.
[2] ftp://gpm.nsstc.nasa.gov/gpm_validation/iphex/cloud_microphysics_Citation/UND_cloud_microphysics/.

We have since identified two other issues. One is the calibration of the CSI's internal tunable diode laser hygrometer. After performing a laboratory calibration of the tunable diode laser hygrometer in September 2015, Jason Tomlinson arrived at slightly different coefficients than those supplied by the manufacturer, which were the coefficients that had been in use up to this time. It has not yet been determined whether to apply the new or old coefficients to the IPHEX data.

The other issue is that, even with new coefficients and recognition of a larger cut size, the sampled cloud water contents (water plus ice) are still higher than estimates from a Nevzorov total water content probe and mass-dimension (M-D) estimates. The M-D estimates were provided by the National Center for Atmospheric Research using an M-D relationship developed by Heymsfield et al. (2004) applied to a combined particle size distribution derived from 2D-S (two diode-stereo) and HVPS-3 (high-volume precipitation spectrometer 3) probes. Because the other issues have been fairly well characterized, this means that the probe actually was observing erroneously high water contents. A review of possible reasons for this discrepancy has revealed that the probe was probably mounted on the aircraft in a location where particles trajectories were converging to produce higher than ambient concentrations. Studies by King (1984, 1985) and Norment and Zalosh (1974) support this conclusion. Depending on final measurements and calculations, the concentration factor looks to be in the range of something like 1.4 to possibly as high as 2.0. If this were applied as a correction to the CSI values, they would be reduced to a level more comparable to the M-D values. For the IPHEX data, development of a correction algorithm is needed. The concentration factor depends somewhat on particle size and shape, and the final calculations would be an approximation.

Ideally the probe should be mounted either on a wing location, as it is on the Gulfstream-1, or further from the fuselage. However, the moment arm of the instrument precludes any major relocation on the fuselage, and wing space is not available. The probe will be flown again during the Olympic Mountain Experiment campaign and will be mounted so that it projects ~2 inches further from the fuselage. It will be interesting to see whether that has an effect on the water content values as compared to other measured and derived values.

The end result is values that have an uncertainty due to both the concentration factor and the cut point, although cut-point effects can be offset by using cloud droplet probe data to add liquid water mass in the IPHEX data for droplets less than 19 μm in diameter. Work is still in progress for final determination of the cut point and final calibration factors.

4.0 References

Heymsfield, A, A Bansemer, C Schmitt, C Twohy, and M Poellot. 2004. "Effective ice particle densities derived from aircraft data." *Journal of Atmospheric Science* 61:982–1003, doi: http://dx.doi.org/10.1175/1520-0469(2004)061<0982:EIPDDF>2.0.CO;2.

King, WD. 1984. "Air flow and particle trajectories around aircraft fuselages. Part I: Theory." *Journal of Atmospheric and Oceanic Technology* 1:5–13, doi: http://dx.doi.org/10.1175/1520-0426(1984)001<0005:AFAPTA>2.0.CO;2

King, WD. 1985. “Air flow and particle trajectories around aircraft fuselages. Part III: Extensions to particles of arbitrary shape. *Journal of Atmospheric and Oceanic Technology* 2:539–547, doi:http://dx.doi.org/10.1175/1520-0426(1985)002<0539:AFAPTA>2.0.CO;2

Norment, HG, and RG Zalosh. 1974. Effects of Airplane Flowfields on Hydrometeor Concentration Measurement. AFCRL-TR-74-0602, Air Force Cambridge Research Laboratories, Hanscom Air Force Base, Maine.

Appendix A

Citation IPHEX Mission Summary

Map Appendix A

Citation IPHEX Mission Summary

Date	Sortie Number	Takeoff Time (UTC)	Landing Time (UTC)	Notes
05/09/2014	IPHEX-1	19:00	21:50	Step-up/step-down profile in lightly precipitating layered cloud system. Flight leg temperatures ranged from +2 to -7°C.
05/10/2014	IPHEX-2	15:53	17:58	Sampled weak convection west of Asheville. Flew step-climb profile from below the melting layer, 9,000 ft, to above the melting layer, 14,000 ft. Rain below cloud, with a mixed region of ice, super-cooled water, and mixed-phase cloud near and above the freezing level.
05/12/2014	IPHEX-3	12:24	15:24	Offshore Advanced Composition Explorer (ACE) mission. Sampled low cumulus field, then lower anvil cloud plus a few new towers at 18,000 to 22,000 ft. Coordinated with the National Aeronautics and Space Administration (NASA) ER-2 aircraft.
05/15/2014	IPHEX-4	13:08	16:48	Sampled convection east of Asheville, North Carolina. Sampled along a north-south line from 11,000 ft to 19,000 ft. Sampled along a second line near Asheville from 9,000 to 15,000 ft. Rain above freezing altitude and mixed phase below freezing altitude.
05/16/2014	IPHEX-5	12:52	15:57	Offshore mission coordinated with the ER-2 aircraft. No lightning was observed in the storm. Sampled from 11,000 to 23,000 ft. Temperature was ~0.0°C at 13,000 ft. Sampled in rain warmer than zero, below zero sampled columns and aggregates, few needles and some interesting round images at cold temperature.
5/16/2014	IPHEX-6	17:11	19:50	Offshore mission to sample storm lines. Sampled on the west side of line from 15,000 to 19,000 ft. Returned to Asheville after sampling the storm line. On descent into Asheville, sampled clouds with some icing at altitudes from 11,000 to 9,000 ft.
05/18/2014	IPHEX-7	11:12	14:35	Sampled on the east side of mountains near the NASA Polerametric (NPOL) radar site in Rutherford County, North Carolina.
05/19/2014	IPHEX-8	09:25	12:49	ER-2 aircraft flight offshore to under fly Global Precipitation Measurement satellite, with. After sampling the cloud for the overpass, proceeded south to sample cumulus clouds from 7,300 ft down to 2,000 ft.
05/23/2014	IPHEX-9	14:30	14:59	Sampled system that moved over the

Date	Sortie Number	Takeoff Time (UTC)	Landing Time (UTC)	Notes
				mountains in the morning. Sampled high crystal concentrations. No liquid water in the clouds. Many samples taken at 19,000 ft.
05/23/2014 - 05/24/2014	IPHEX-10	22:18	01:14	Sampled system that did not move as forecast in South Carolina. Mainly sampled in the anvil (east of the main updraft region) between 18,000 and 21,000 ft.
05/25/2014	IPHEX-11	19:17	22:36	Sampled storms south of Asheville between Knoxville, Tennessee, and the NPOL radar site.
05/26/2014	IPHEX-12	20:12	22:43	Sampled mostly liquid water clouds over mountains and near the NPOL radar site.
05/27/2014	IPHEX-13	13:57	15:44	Sampled over mountains near Asheville. Good mix of hydrometers; some of the largest drops sampled during the project; some pure ice and some ice with liquid water.
05/28/14	IPHEX-14	13:24	16:35	Sampled cumulus congestus clouds off coast on a line with approximate 055° heading with ~25 nm legs at altitudes of 14,000, 12,000, 10,000, 8,000, 5,000, 6,000, 10,000, 15,000, and 17,000 ft. After sampling the first storm system, we moved west ~15 nm and sampled at altitudes of 10,000 and 9,000 ft. All water (round images) except at start of 14 km leg and during the high altitudes at the end of the first leg sampling.
05/29/2014	IPHEX-15	17:35	20:51	Coordinated cloud sampling over mountains with ER-2.
06/05/2014	IPHEX-16	07:26	09:52	IPHEX mission in coordination with ER-2 sampling clouds west of Asheville over the mountains and outside of the primary study area. Altitudes of legs flown varied from 12,000 to 25,000 ft.
06/06/2014	IPHEX-17	18:34	20:10	Flew on Cumulus congestus clouds over the Achieve site. Started by going up and down the valley centered on Achieve but ended up doing repeated cloud penetrations at altitudes between 9,000 and 12,000 ft. Around the Achieve site, cloud tops and numbers were decreasing with time.
06/08/2014	IPHEX-18	18:17	21:09	Flew east of Charlotte, North Carolina, in coordination with the ER-2 at the time of a satellite overpass. Heavy rain experienced at lower altitudes and large aggregates above the melting altitude. Some difficulty in getting clearance from Air Traffic Control to get to desired areas and altitudes.
06/11/2014	IPHEX-19	16:52	20:50	Coordinated mission with the ER-2 at the time

Date	Sortie Number	Takeoff Time (UTC)	Landing Time (UTC)	Notes
				of a satellite overpass. Flew Citation at altitudes varying from 8,500 to 21,000 ft generally along the western side of a line of storms that were quite strong. Most of the time, the Citation was in precipitation along the line of cells.
06/12/2014	IPHEX-20	16:14	19:51	Coordinated mission with the ER-2 over the mountains near the Achieve trailer. Legs were flown through cumulus congestus at altitudes varying between 9,000 and 20,000 ft. Ice phase precipitation was observed and moderate precipitation was seen near cloud base.

Appendix B

IPHEX Cloud Spectrometer and Impactor Raw Data Overview

Appendix B

IPHEX Cloud Spectrometer and Impactor Raw Data Overview

Contact:

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City: Grand Forks
State: North Dakota
Zip Code: 58202-9006

Investigator(s): Michael Poellot, Jay Mace

Data Format: csv

File Naming Convention: [Data type yymmddhhmiss] based on start time of data file. Times are UTC plus 1 hour.

Directory Organization: One directory per flight [yyyymmdd_hhmiss] start time of flight (UTC)

Abstract:

The cloud spectrometer and impactor is a counter-flow virtual impactor. Dry air is applied to create back pressure at an inlet that faces into the flow. Only particles larger than a certain size (i.e., the cut point) have sufficient inertia to penetrate the counter-flow of dry air. These particles, nearly all of which are solid or liquid water, are then evaporated. This sample air is passed through a tunable diode laser hygrometer to measure the resultant water vapor content. These values are adjusted for aircraft airspeed and probe enhancement to provide cloud water content.

The instrument outputs two file types: 1) flows, settings, temperatures, and other housekeeping data along with calculated cloud water parameters and 2) housekeeping and measured water vapor values from the tunable diode laser hygrometer.

Purpose:

The CSI was flown on the University of North Dakota Cessna Citation research aircraft during the NASA IPHEX (Integrated Precipitation and Hydrology Experiment) project. The data will be used to validate Global Precipitation Measurement satellite cloud and precipitation retrievals, and to improve our understanding of cloud and precipitation processes.

Data Credit:

Data collection was funded through National Aeronautic and Space Administration Grant NNX13AM37G. Jason Tomlinson, Atmospheric Radiation Measurement Aerial Facility, is assisting with post-project instrument tests.

Site Information:

Sites North West South East
North Carolina and coastal waters

39.187290892894
-84.435911397836
32.232248143503
-71.391601562506

Content Time Range:

Began: May 9, 2014
Ended: June 13, 2014

Instrument(s):

Cloud Spectrometer and Impactor

Field Campaign Type:

Integrated Precipitation and Hydrology Experiment (IPHEX): Cloud Spectrometer and Impactor

Scientific Measurements(s):

Total cloud water

Data Quality:

Attribute Accuracy: Counter-flow values were set higher than normal. At this time, it is not known what the minimum sampled particle size (mass) or "cut point" was. Testing is expected to help determine this value.

Positional Accuracy: No formal positional accuracy tests were conducted.

Consistency and Completeness Report:

Flow controllers were calibrated prior to the project. Since these are raw instrument data, no quality assurance has been conducted at this data level.

Access Restriction:

No access constraints are associated with this data.

Use Restrictions:

No use constraints are associated with this data.

Distribution Information:

Organization Name: ARM Archive User Services
E-mail: armarchive@ornl.gov
Phone: 1-888-ARM-DATA
Street: Oak Ridge National Laboratory
City: Oak Ridge
State: Tennessee
Zip Code: 37831-6290

Appendix C

Cloud Spectrometer and Impactor Calibration Flight Report

Appendix C

Cloud Spectrometer and Impactor Calibration Flight Report

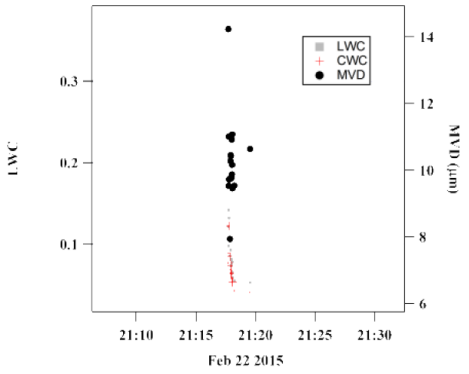
ACAPEX Calibration Flight 20150222

Wednesday, August 05, 2015 5:19 PM

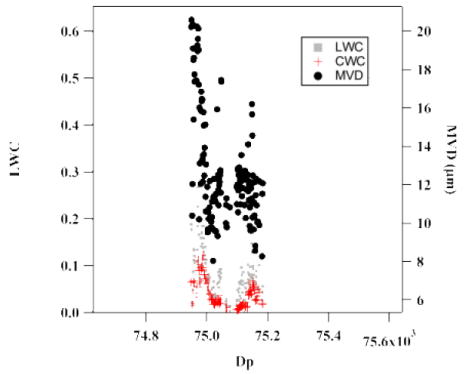
Counter Flow of 0.3 LPM

A couple of examples from Marine Layer clouds during a stratocumulus flight over the Pacific Ocean on 20150222.

Average cutsize (um) 10.3 +/- 1.3



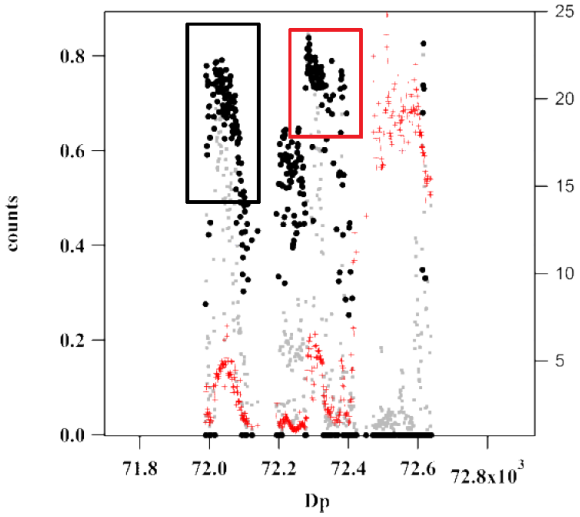
Average cutsize (um) - 11.7 +/- 1.7



I also went through this flight and picked out other causes where 90% of the distribution was smaller than 15 um and liquid water content was less than 0.2 g/m^3. This gave me more homogenous non-convective clouds to use in the analysis. For these type of clouds the cutsize was 11.6 +/- 1.9 for counterflow of 0.3 LPM. This falls in line closely to the cases shown above

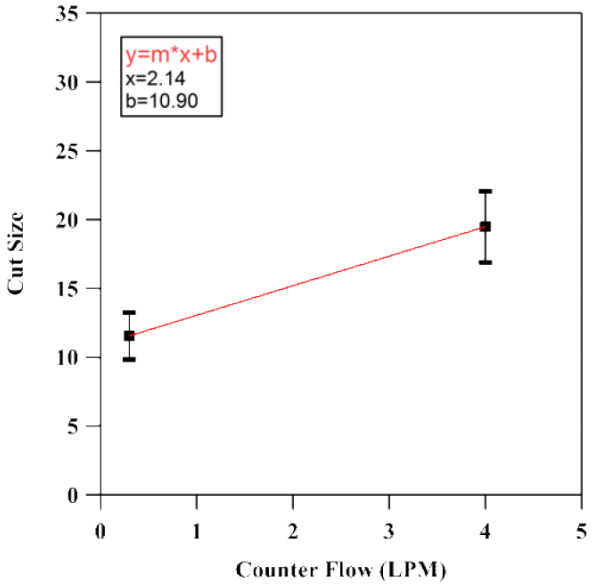
Counter Flow of 4 LPM

It was harder to find clouds to analyze the larger cute size. Around 20:00 UTC clouds with a size distribution shifted towards larger sizes was measured. I quickly kicked the counterflow up to 4 LPM.
For the Black Box: 19.5 +/- 2.0 um
For the Red Box : 19.8 +/- 3.3 um



I also went through a statistical analysis looking for cases where 50-10 % of the distribution was measured at sizes greater than 18um. During this instances the measured cutsize was 20.2 +/- 1.9 um. This agrees well with the values for the case study above.

Here is a very crude Regression analysis below. Will work on more cases tomorrow in hopes it agrees with this curve.



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