

Multi-Angle Snowflake Camera Instrument Handbook

M Stuefer
J Bailey

July 2016



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.

Multi-Angle Snowflake Camera Instrument Handbook

M Stuefer
J Bailey
both University of Alaska – Fairbanks

July 2016

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AC	alternating current
AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement Climate Research Facility
C	Celsius
CCD	change-coupled device
cm	centimeter
DMF	ARM Data Management Facility
DOE	U.S. Department of Energy
DQ	data quality
Fps	frames per second
GUID	A camera definition's unique identifier
IEEE	Institute of Electrical and Electronics Engineers
ID	identification
IIDC	Instrumentation & Industrial Digital Camera
IR	infrared
kg	kilogram
LED	light-emitting diode
MASC	Multi-Angle Snowflake Camera
Mbps	megabytes per second
mm	millimeter
PC	personal computer
PNG	Portable Network Graphics image format
RF	radio frequency
USB	universal serial bus
V	volt
VAP	value-added product
W	watt

Contents

Acronyms and Abbreviations	iii
1.0 General Overview.....	1
2.0 Contacts	2
2.1 Mentor	2
2.2 Instrument Developer.....	2
3.0 Deployment Locations and History	2
4.0 Near-Real-Time Data Plots	3
5.0 Data Description and Examples	4
5.1 Data File Contents.....	4
5.1.1 Primary Variables and Expected Uncertainty	4
5.1.2 Secondary/Underlying Variables	4
5.1.3 Diagnostic Variables	5
5.1.4 Data Quality Flags.....	7
5.1.5 Dimension Variables	7
5.2 Annotated Examples	7
5.2.1 Example Image Data File	7
5.2.2 Example Fall Speed Data File.....	8
5.3 User Notes and Known Problems	8
6.0 Data Quality.....	9
6.1 Data Quality Health and Status	9
6.2 Data Reviews by Instrument Mentor.....	9
6.3 Data Assessments by Site Scientists/Data Quality Office.....	9
7.0 Value-Added Procedures and Quality Measurement Experiments	9
8.0 Instrument Details.....	10
8.1 Detailed Description.....	10
8.1.1 List of Components	12
8.1.2 System Configuration and Measurement Methods	13
8.1.3 Specifications	15
8.2 Theory of Operations	17
8.3 Calibration.....	17
8.4 Operations and Maintenance	17
8.4.1 User Manual	17
8.4.2 Routine and Corrective Maintenance Documentation	18
8.4.3 Software Documentation.....	19
9.0 References	19

Figures

1	Exterior of the MASC.....	1
2	AMF-3 deployment of the ARM MASC in March, 2015.....	3
3	MASC hydrometeor fall speed data plot available operationally at http://plot.dmf.arm.gov/plotbrowser/	3
4	MASC original image triplet from November 29, 2015, showing an example of a snowflake as captured by camera 1 (left), the center camera, 2(center), and camera 3 (right).....	7
5	Schematic of basic components of MASC (image courtesy of Garrett et al. 2012). The hatched region represents the cross-section for triggering of the IR motion detector system.....	10
6	MASC with lid removed, exposing the three Unibrain cameras and electronics.....	13
7	Firewire and USB cables are guided through washer and nut.....	16
8	Firewire and USB cables connected.....	16
9	MASC with calibration target installed.....	17

Tables

1	MASC status log responses.....	5
2	More MASC status log responses.....	5
3	Individual camera status log responses.....	6
4	MASC image output identification responses.....	7
5	MASC fall speed output responses.....	8
6	MASC scheme for naming directories and image file names.....	14
7	MASC run-time commands.....	15

1.0 General Overview

The Multi-Angle Snowflake Camera (MASC) takes 9- to 37-micron resolution stereographic photographs of free-falling hydrometers from three angles, while simultaneously measuring their fall speed. Information about hydrometeor size, shape orientation, and aspect ratio is derived from MASC photographs.

The instrument consists of three commercial cameras separated by angles of 36°. Each camera field of view is aligned to have a common single focus point about 10 cm distant from the cameras. Two near-infrared emitter pairs are aligned with the camera's field of view within a 10-angular ring and detect hydrometeor passage, with the lower emitters configured to trigger the MASC cameras. The sensitive IR motion sensors are designed to filter out slow variations in ambient light. Fall speed is derived from successive triggers along the fall path.

The camera exposure times are extremely short, in the range of 1/25,000th of a second, enabling the MASC to capture snowflake sizes ranging from 30 micrometers to 3 cm.

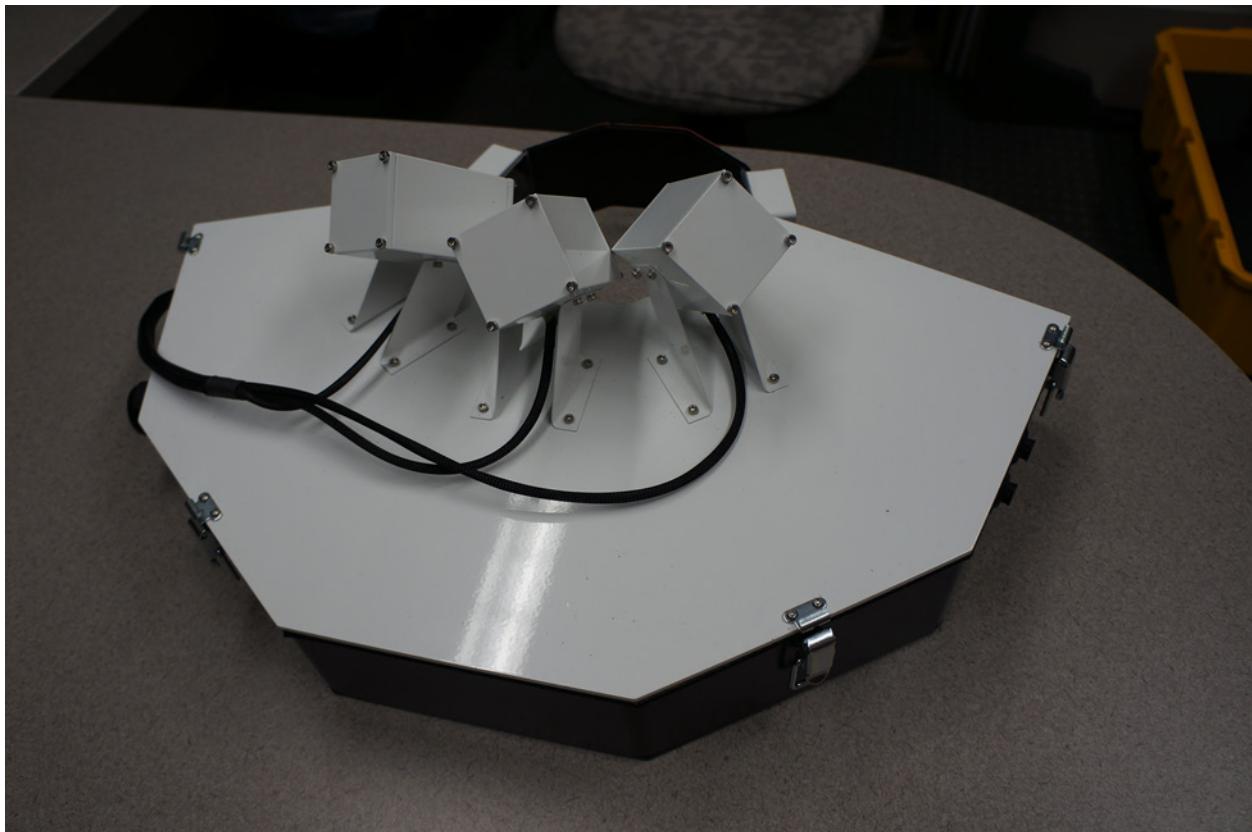


Figure 1. Exterior of the MASC.

2.0 Contacts

2.1 Mentor

Martin Stuefer
Geophysical Institute
University of Alaska – Fairbanks
Fairbanks, Alaska 99775-7320
Ph.: (907) 474-6477
Email: mstuefer@alaska.edu

2.2 Instrument Developer

MASC engineering, maintenance, and manufacturing will be provided by:

Particle Flux Analytics in collaboration with the:

Center for Engineering Innovation
University of Utah
Salt Lake City, Utah 84112
Web.: <http://particleflux.net/>
Email: info@particleflux.net

Former vendor (before January 2016):

Fallgatter Technologies
7953 Ponderosa Circle
Salt Lake City, Utah 84094
Phone +1 (801) 581-5768

3.0 Deployment Locations and History

The MASC has been deployed originally for testing at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility North Slope of Alaska site (NAS C-1) in Barrow, Alaska, in spring, 2014. The instrument was then re-located to the third ARM Mobile Facility (AMF-3) at Oliktok Point, Alaska in February, 2015.



Figure 2. AMF-3 deployment of the ARM MASC in March, 2015.

Other current and former non-ARM MASC deployment locations are:

- Alta Ski Area, Utah

<http://www.alta.com/pages/snowflakeshowcase.php>

- Greenland Summit

<http://www.geosummit.org/>

- Mammoth Mountain, California

<http://fiesta.bren.ucsb.edu/~nbair/>

4.0 Near-Real-Time Data Plots

Overview data collected by the MASC can be viewed at the ARM plotbrowser website at <http://plot.dmf.arm.gov/plotbrowser/>. By selecting the ‘OLI’ site and the datastream named ‘olimasc’, the plotbrowser provides an interactive web-based tool for plotting daily and monthly hydrometeor fall speeds and for browsing through MASC raw image data that are received and stored at ARM’s Data Management Facility (DMF).

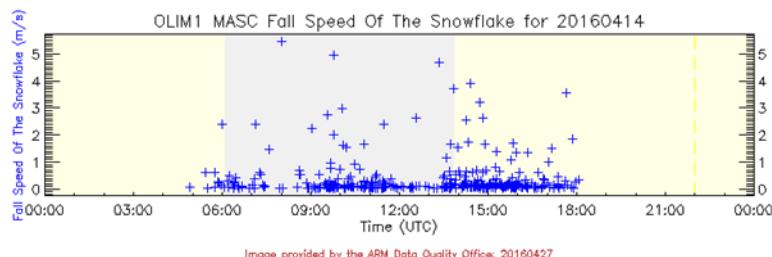


Figure 3. MASC hydrometeor fall speed data plot available operationally at <http://plot.dmf.arm.gov/plotbrowser/>.

5.0 Data Description and Examples

Any number of images, from zero to thousands, may be collected in a single day. These images are recorded in threes, one for each camera. They show monochrome (black and white) views of hydrometeors separated by 36 degrees. Fall speed of the hydrometeors, in meters per second, is recorded in the dataInfo.txt file. See details in the Output Values section below.

5.1 Data File Contents

Particle images acquired by the MASC can support the analysis of solid hydrometeors microphysical characteristics with an emphasis on precipitating snow crystals. Snow crystal size, shape, and constitution play an important part in determining the climate in subarctic to Polar regions. However, observations of snow particle properties are incomplete and often performed with proxy methods resulting in empirical data with an inherent lack of accuracy. Particle properties depend on the particle growth process and their modification during the settling and depositional processes. Ice/snow crystal growth occurs through 1) accretion (growth of an ice particle when it captures super-cooled liquid droplets, 2) deposition (growth by water vapor depositing on the ice particle in a liquid form and immediately freezing, or directly depositing as a solid), and 3) aggregation (merging of multiple ice particles to form one main snowflake; i.e., snowflakes sticking together). Surfaces of ice crystals become sticky at temperatures above -5° C. Aggregation maximizes near 0° C.

5.1.1 Primary Variables and Expected Uncertainty

The primary MASC instrument products are Portable Network Graphics (png) format images. Single hydrometeors passing through the MASC ring trigger the cameras that capture image triplets. Each image has a timestamp. The three images are separated by 36 degrees on the horizontal plane. The fall speed is recorded in meters per second.

5.1.1.1 Definition of Uncertainty

While the main primary data products are image data with uncertainty relating to the image analysis methods, there are generic estimates of uncertainty of the measured fall speed data. The fall speed is calculated from the time interval between two successive triggers, vertically separated by 32 mm, which allows only for a trajectory from the top to the bottom of the triggering arrays. The automated calculation is verified for repeatability and accuracy in the laboratory. This is done by measuring the length of photographed motion blur of a small bead, captured at a slow camera shutter speed.

Experiments with spherical metal beads were conducted, and the uncertainty of the fall speed was conservatively estimated with +10% of the fall speed in meters per second.

5.1.2 Secondary/Underlying Variables

In addition to the images, the time lag of each hydrometeor passing by the vertical stacks of infrared (IR) motion sensors is directly translated into fall speed.

5.1.3 Diagnostic Variables

The diagnostic information can be found in the status log file. The status log contains all of the status output collected to date. It is specified by the –fslOut command line parameter. The output is rather wide, so it is broken into several tables following each other.

Table 1. MASC status log responses.

Time	timestamp	ERR_CR	MCR_DISCNCNT	MCR_WAIT	MCR_PWR	MCR_BRWN
"2013/10/25, 10:04:59.048277 7"	130271906990482771	-	-	X	-	-

These columns can be deciphered as follows:

- **Time** shows the human-readable time of status response
- **TimeStamp** shows the machine time of status response
- **ERR_CR** corresponds to whether there was a critical MASC error (X) or not (_). Not set, so can be ignored
- **MCR_DISCNCNT** corresponds to whether the MASC USB is disconnected (X) or (_)
- **MCR_WAIT** corresponds to whether we are still waiting on MASC status response (X) or not (_)
- **MCR_PWR** corresponds to whether MASC was just powered on (X) or not (_)
- **MCR_BRWN** corresponds to whether MASC experienced a dip in power restarting the microcontroller (X) or not (_)

Table 2. More MASC status log responses.

MCR_SFTWR	MCR_EXTR	MCR_WTCHDG	BUS_RST	IMG_QFULL	IMG_BADFRAME	FS_QFULL
-	-	-	0	0	0	0

These columns can be deciphered in the following manner:

- **MCR_SFTWR** corresponds to whether MASC microcontroller has just been reset via software (X) or not (_)
- **MCR_EXTR** corresponds to whether MASC experienced an external reset (X) or not (_)
- **MCR_WTCHDG** corresponds to whether the MASC microcontroller experienced a watchdog timer reset (X) or not (_)
- **BUS_RST** corresponds to the number of camera (Firewire 800) bus resets
- **IMG_QFULL** corresponds to the number of dropped images due to the image queue being full

- **IMG_BADFRAME** corresponds to the number of dropped images due to badly formed frames
- **FS_QFULL** corresponds to the number of dropped fall speeds due to speed queue being full

Finally, we have status output for each camera that is detected. The status consists of two columns per camera: one for whether the camera is connected (X) or (_), and the other for the bit-composited representation of errors.

Camera connectedness title include camera identification (ID), followed by the GUID (camera definition's unique identifier). All of the rows below match the camera GUID to ensure correctness.

Table 3. Individual camera status log responses.

Cam 0 (08:14:43:65:00:01:00:11)	Detected errors
X	00000000000000000000000000000000

The errors can be deciphered in the following manner (reading from left to right corresponds to top to bottom order below). These are defined within the Instrumentation & Industrial Digital Camera (IADC) standard 1.31:

1. Capture image quality for Format_6
2. Capture image size for Format_6
3. Optical Filter Control
4. Tilt Control
5. Pan Control
6. Zoom Control
7. Frame Rate Control
8. White Shading Compensation Control
9. Trigger Delay Control
10. Trigger Control
11. Temperature Control
12. Focus Control
13. IRIS Control
14. Gain Control
15. Shutter Speed Control
16. Gamma Control
17. Saturation Control
18. Hue Control
19. White Balance Control
20. Sharpness Control
21. Auto Exposure Control
22. Brightness Control

5.1.4 Data Quality Flags

MASC blank images or distorted image data might be produced under certain conditions by false alarms or radio frequency (RF) pollution interfering with the MASC electronics. The image data itself are not flagged. An image status file is generated, which might show errors in the data acquisition. Images might be filtered based upon respective excessive fall speeds, or using image size information.

5.1.5 Dimension Variables

Primary MASC data are png-type images. Fall speeds are indicated in meters per second.

5.2 Annotated Examples

5.2.1 Example Image Data File

MASC image data allow determining the morphologies of snowflakes that are characteristic for each precipitation event. Images of the different snowflake types from dendrites to a variety of plates, needles, or columns are shown elsewhere (i.e., Garrett et al. 2012). Figure 3 gives an example of a raw image triplet directly derived from MASC image acquisition.



Figure 4. MASC original image triplet from November 29, 2015, showing an example of a snowflake as captured by camera 1 (left), the center camera, 2 (center), and camera 3 (right).

Table 4. MASC image output identification responses.

Flake ID	Camera ID	Date (mm.dd.yyyy)	Time (hh:mm:ss)	Image name
4064	0	11.29.2015	15:30:29	oliMASCM1.a0.20151129.153029.id_4064_cam_0.png
4064	1	11.29.2015	15:30:29	oliMASCM1.a0.20151129.153029.id_4064_cam_1.png
4064	2	11.29.2015	15:30:29	oliMASCM1.a0.20151129.153029.id_4064_cam_2.png

Each column can be described as follows:

- **image name** shows the image that this specific camera has taken (i.e., oliMASC1). The path to the file is not included, but the images should be located in the same folder as the data file.
- **date (mm.dd.yyyy)** shows the date of the capture with format: mm-month, dd-day, yyyy-year
- **time (hh:mm:ss)** shows the timestamp of the capture with format: hh-hour, mm-minute, ss-second
- **flake id** shows the id of the snowflake captured
- **camera id** shows the id of the camera that captured the image

Please note that a perfect acquisition run will have each snowflake ID repeat three times, once for each camera. If one of these is missing, that particular image has been dropped.

5.2.2 Example Fall Speed Data File

This file describes how to correlate snowflake ids with the measured fall speed. This file is the one specified by the –fdout command line parameter.

Table 5. MASC fall speed output responses.

snowflake id	date (mm.dd.yyyy)	time (hh:mm:ss:mmmmmm)	fall speed (m/s)
1	10.25.2013	10:05:50.336211	0.314453
2	10.25.2013	10:06:12.744492	0.673613
3	10.25.2013	10:06:13.318525	1.02842
4	10.25.2013	10:06:13.718548	0.863711

Each column can be described in the following ways:

- **snowflake id** shows the id of the snowflake captured
- **date (mm.dd.yyyy)** shows the date of the capture with format: mm-month, dd-day, yyyy-year
- **time (hh:mm:ss.mmmmmm)** shows the timestamp of the capture with format: hh-hour, mm-minute, ss-second, mmmmmm-microseconds
- **fall speed (m/s)** shows the recorded fall speed of the flake

5.3 User Notes and Known Problems

Originally, the ARM MASC experienced trigger sensitivity issues due to RF interference from a radar instrument adjacent to the location of the MASC at the AMF-3 site. Installation of RF chokes to increase the electromagnetic interference protection, and new firmware, fixed the false triggering of the instrument due to the RF pollution. Notes of the issues were kept within a deployment log at https://nanuna.gi.alaska.edu/wiki/index.php/MASC_Log.

6.0 Data Quality

The [DQ-Explorer](#) site includes quality control metrics and data-quality plots allowing for visual inspection of MASC data. Weekly data quality assessment reports are disseminated for the MASC by the ARM Data Quality Office at the University of Oklahoma.

6.1 Data Quality Health and Status

The MASC Status output is a response whenever image data is returned or whenever automatic status checks are performed at defined regular time intervals. Portions of the status check for the microcontroller behavior. The checks also deliver messages about critical errors, resets of power or software, or if images are dropped. The dropped images message contains information if there are images generated by the MASC at a rate faster than they are saved to the disk. The dropped image message also identifies the number of image triplets that is lost due to a mis-formed or mis-transmitted image data.

6.2 Data Reviews by Instrument Mentor

The instrument mentor conducts comprehensive data reviews weekly and monthly in conjunction with the generation of the weekly site status report.

6.3 Data Assessments by Site Scientists/Data Quality Office

All DQ Office and most site scientist techniques for checking have been incorporated within [DQ HandS](#) and can be viewed there.

7.0 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of the ARM Program are met through the analysis and processing of existing data products into "value-added" products or VAPs. Despite extensive instrumentation deployed at the ARM sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely.

A new datastream is in development for a hydrometeor microphysics VAP derived from the Multi-Angle Snowflake Camera (MASC) image data. The MASC vendor developed Matlab- and Python-based software to derive snowflake microphysical characteristics. Software is in development status to implement MASC image data analysis operationally and in near-real time. The following parameters describing hydrometeor microphysics are calculated:

- hydrometeor size: the maximum dimension along the major particle axis.
- aspect ratio relative to the minimum dimension along the minor axis.
- hydrometeor cross-section.
- hydrometeor orientation.

- equivalent radius defined as the radius of an equivalent cross-section circle.
- Complexity of the perimeter defined as the ratio between the hydrometeor perimeter and the perimeter of an equivalent cross-section circle.

The Python-based scripts will be implemented at the ARM-DMF to create the snowflake microphysics VAP operationally whenever the MASC delivers useful data.

8.0 Instrument Details

The MASC was developed to address the need for high-resolution multi-angle imaging of hydrometeors in free fall, while simultaneously measuring their fall speed. The instrument was developed at the University of Utah. A MASC description was published by Garret et al (2012); an excerpt of this description follows below.

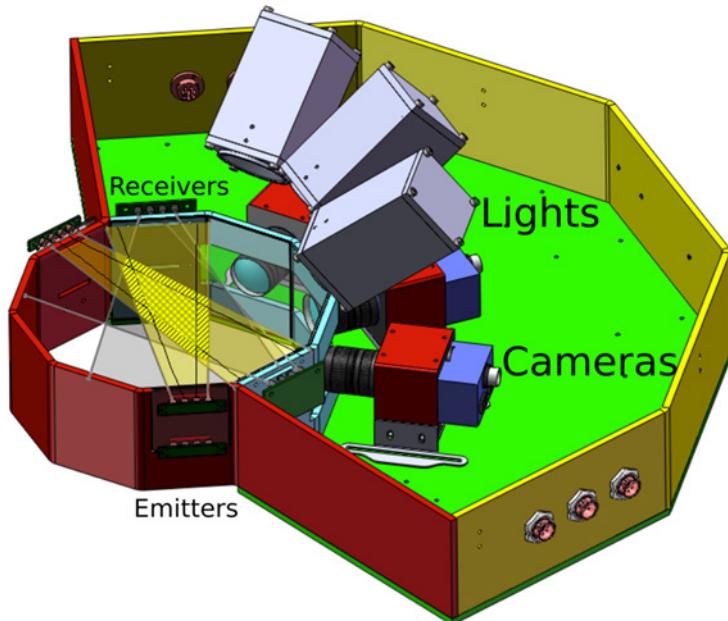


Figure 5. Schematic of basic components of MASC (image courtesy of Garrett et al. 2012). The hatched region represents the cross-section for triggering of the IR motion detector system.

8.1 Detailed Description

The MASC consists of three cameras, separated by 36°, each pointing at an identical focal point approximately 10 cm away. The focal point itself lies within a ring through which hydrometeors fall. The ring houses a system of near-infrared emitter-detector pairs, arranged in two arrays that are separated vertically by 32 mm. Hydrometeors passing through the lower array simultaneously trigger each of the three cameras as well as a bank of lights aimed at the center of the camera depth of field. Fall speed is calculated from the time it takes to traverse the distance between the upper and lower IR-triggering array.

The cameras and lenses are commercially available. The ARM MASC is furnished with three Unibrain Fire-I 980b (grayscale) 2448x2048 pixel cameras arranged within one center and two outer positions.

Paragraph 8.1.1 below summarizes the camera parameters, along with their respective values for depth of field and image resolution as determined using a calibration target. Shorter lenses have the disadvantage of lower resolution, but the advantage of a larger depth of field and horizontal field of view. Conversely, the 35 mm lens begins to approximate the 9 cm object distance. This “macro” perspective constrains the depth of field with the advantage that the pixel resolution is just 9 μm . While it might seem that a 16 mm lens on a 5MP camera body would offer the optimal mix of high resolution and a large depth of field, this is not in fact the case. Rather, for a fixed lens and digital sensor size, swapping a 1.2 MP body with a 5 MP body merely doubles the field of view while maintaining a constant image resolution in μm units.

The camera exposure time required to capture fine details in falling hydrometeors at close range is extremely short. Typically, a 1/25,000th of a second is chosen. This speed is sufficiently fast to capture a vertical resolution of 40 μm in a hydrometeor falling at 1 m s^{-1} while allowing for adequate light from the MASC’s three 2700 lumen light-emitting diodes (LEDs). LEDs were chosen over a traditional xenon flash system because they require much lower voltages, are longer lived, and are technically easier to implement where images might be collected at a rate of once per second, in cold conditions, and continuously over long periods. Upgrades are underway to enable higher-powered and more concentrated light, with the expectation that it will allow for shorter exposure times and larger depths of field.

The near-infrared motion sensor device used for triggering the cameras and measuring fall speed has been designed to detect the smallest hydrometeors, whether liquid or ice. Each sensor array contains two near-infrared emitter/detector pairs, with an intersection point that spans the horizontal domain occupied by the camera depth of field. Each emitter/detector pair consists of a set of four near-infrared LEDs facing four opposite photodiodes. Each emitter subtends a 6° angle and each photodiode a 15° viewing angle. The intersection point of the two pairs occupies a maximum cross section of 3100 mm^2 .

With this setup, a 35 mm field of view and 10 mm camera depth of field corresponds to just 11 % of the trigger depth of field, implying that just one in nine photographed images are expected to be in sharp focus. One option for increasing the in-focus fraction is to physically block part of the lower emitter array. For example, if the two outermost emitters are blocked, then the trigger depth of field is reduced from 3100 to 1400 mm^2 . This does not change the number of in-focus images collected, but it does reduce the number of images that must ultimately be processed as rejects.

Falling hydrometeors larger than approximately 0.1 mm in maximum dimension (representing approximately 1/100000th of the trigger cross-section) are detected. The MASC microprocessor electronics are designed to accept only very rapidly varying fluctuations in the detected emission, which occur when something occults the beam quickly. The goal is to filter out ambient light fluctuations associated with varying sunlight and shadows. The instrument works equally well under all natural lighting conditions, including darkness. The capture interval can be as fast as the hydrometeor inter-arrival times, or limited to a desired frequency. Typically it is set to once per second in order to limit excessive flashes.

The MASC microprocessor controls the camera and communications via personal computer (PC) using a FireWire 800 Line for image data and one USB-RS232 Converter for camera control. Unibrain supplies the camera driver that is for use with Microsoft Windows. Software has been developed for data acquisition of images, fall speeds, timestamps, and housekeeping variables.

8.1.1 List of Components

8.1.1.1 Cameras

The MASC uses three Fire-i980b cameras manufactured by Unibrain, Inc. These are high-speed industrial cameras. The Fire-i980b monochrome camera incorporates a high-end, Dual Tap 2/3" sensor, 5 Megapixels, Progressive Scan Sony charge-coupled device (CCD) and achieves up to 15 frames per second (fps) at maximum resolution.

By using the IEEE 1394b interface that supports the IIDC protocol, users can transfer images to a host PC at speeds of up to 800 Mbps. Multiple cameras can be connected in a daisy-chain configuration perfectly suited for operation in a multi-camera system like the MASC. The camera specifications from the manufacturer are:

- Model: Unibrain Fire-I 980b
- Part number: 4610
- Image Sensor: 2/3" progressive scan Sony ICX-625ALA 2/3" CCD
- 3.45 x 3.45 um pixel size
- Effective pixels: 5,054,448, 2456(H) x 2058(V)
- Fast hardware or software asynchronous trigger
- Picture sizes: 2448x2048, 1600x1200, 1280x960, 800x600, 640x480
- Data path: 8 bit or 12 bit b/w
- CELL size: 3.45 um x 3.45 um
- Scanning system: Progressive scan
- Frame rates: 15, 7.5, 3.75, 1.875 fps
- Synchronization: External trigger or software trigger
- Control functions: Auto-Exposure, Auto-Shutter, Brightness, Sharpness
- Lens Mount: C-mount
- Digital interface: 2x 1394b 9 pin ports with screw lock support at 800 Mbps
- Binning mode (b/w): 2x2, 1x2
- Gain: 0-18 dB
- Multicamera sync: -144 us ~+144 us at 15, 7.5 frame rate
- Shutter speed: 5 usec – 3600 sec
- Gamma: 0.4-2.5
- External trigger: Mode 0,1,2,4,5,15
- Strobe output signal: Active high, normal or trigger mode
- S/N ratio: 56 dB or better
- Power requirements: 310 mA max @+12V DC, 3.8 W
- Compact housing (50 x 50 x 49 mm) - weight 230 gram
- Operating temperatures: -5 to +45 C
- Regulations: FCC, CE, MIC, RoHS
- Accessories: Lens cover, Unibrain Fire-I drivers and Fire-I API SDK, 4.5m 1394b cable.
- High shock and vibration resistance.

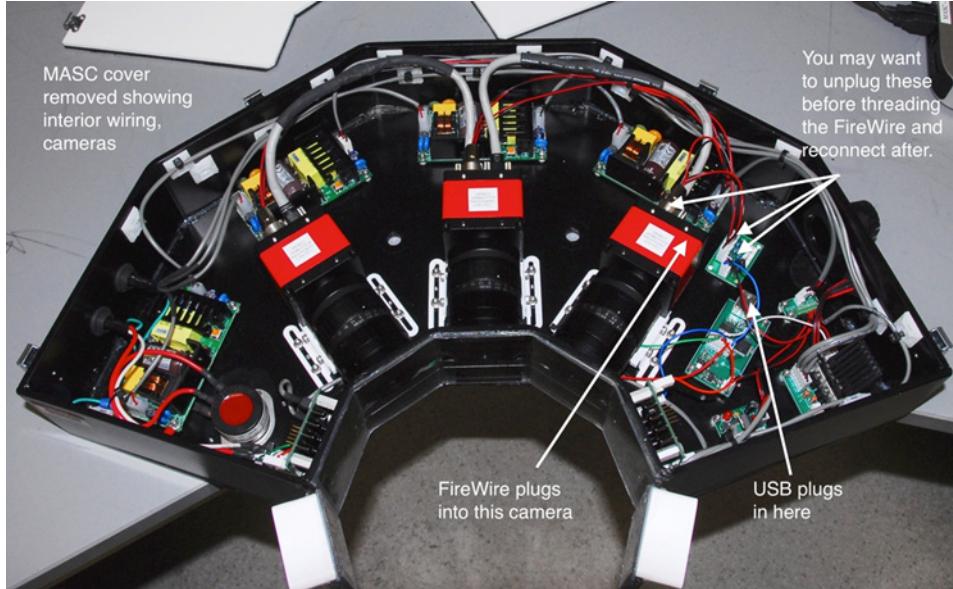


Figure 6. MASC with lid removed, exposing the three Unibrain cameras and electronics.

8.1.1.2 Lights

A bank of lights illuminates the passing hydrometeors at the center of the camera depth of field. The MASC uses three 40W LED lights rated at 2700 lumens each to illuminate the snowflake images. The lights are controlled simultaneously with the camera triggers by the infrared motion sensors.

8.1.1.3 Data Acquisition

The snowflake images and fall speeds are collected using universal serial bus (USB) and Firewire 800 cables connected to a PC operating on a Microsoft Windows 7 environment.

8.1.1.4 Anti-Riming

Anti-riming is accomplished through a 100W silicon heating pad mounted on the collection plate and additional heating pads at the bottom of the main housing in order to keep the electronics and cameras within the operating temperature ranges.

8.1.2 System Configuration and Measurement Methods

8.1.2.1 Generating Configuration File

The configuration file is generated by using a windows command line utility. The following command needs to be run from the same directory as the command file `simpleDataAcquisition.exe`.

```
simpleDataAcquisition.exe -v -comp COM1 -fslOut statusLog.txt -  
slWait 10 -fdOut dataInfo.txt -fiOut imgInfo.txt -diOut
```

```
.\Data\%d\%h\ -iNam %d_%T_flake_%f_cam_%c.png -wCfg
acquisitionConfig.xml
```

The command line will generate the acquisitionConfig.xml configuration file that will be loaded when the bat file shown in the following section will be run.

The tables below show the scheme for naming directories and image file names.

Table 6. MASC scheme for naming directories and image file names.

Character	Meaning
%d	Date (yyyy.mm.dd format) Shortcut for %Y.%M.%D
%Y	Year (yyyy format)
%M	Month (mm format) range: (01---12)
%D	Day (dd format) range: (01---31)
%T	Time stamp (hh.mm.ss format) Shortcut for %h.%m.%s – suggested not to use this because directories should be created less frequently than images. Suggested use is %h instead to split by hours.
%h	Hour (hh format) range: (00---23)
%m	Minute (mm format) range: (00---59)
%s	Second (ss format) range: (00---59)
%u	Microsecond (uuuuuu format) range: (000000-999999)
%f	Snowflake ID (n format) range: (1-4,294,967,295) Once the maximum number is reached, it will overflow to 0.
%c	Camera ID (n format) range: (0-2)

8.1.2.2 Example Batch File

Once the configuration file has been created in the preceding step, the following batch file can be created and run to start MASC measurements.

```
: set this to be the base directory where to store images
SET localBaseDir=OliSnowflakeImages_%%d_Hr_%%h

: set this to be the location of the folder to put images/data
SET MainFlakeDir=C:\Users\Pictures\AMF3

CD %MainFlakeDIR

: start data acquisition

simpleDataAcquisition.exe -rCfg -diOut %MainFlakeDir%\%localBaseDir%\ -
autoappend
```

This batch file can be created and saved in the same directory as the config file and simpleDataAcquisition.exe file. When executed, the batch file will set up where and how to store the captured images. The batch will also load the configuration file contained in the same

directory. The images will be placed in a designated directory (i.e.: C:\Users\Pictures\Barrow\BarrowSnowflakeImages_date_Hr_hour).

8.1.2.3 Measurement Methods

To measure or collect images, run the above batch file in a command prompt within Windows. The table below shows run-time commands that can be executed during the program operation.

Table 7. MASC run-time commands.

Runtime control option	Description
Help	Prints the help message below
Stop	Stops the acquisition and exits
Lightson #	Turns on the lights for a specified number of seconds (followed after the command line). There is a request for confirmation to make sure of intent, Note: it may be possible to burn the lights out by running them too much. For now, the time is limited to 3 minutes.
Lightoff	Turn the lights off
Trigger	Triggers the cameras, takes pictures, and saves them
Status	Gets the status of the MASC and it will be written out on the screen and status log
Reset	Performs a software reset for the MASC

After each command is executed, a message confirming the command is displayed. These messages can still be interrupted by acquisition output.

8.1.3 Specifications

8.1.3.1 Physical Dimensions

Weight and size: 10kg, 43.5cm x 58cm x 21.5cm.

Cameras: 3 high-speed 5 Megapixel, 2/3" sensor, industrial cameras, each with C-mount 12.5mm lenses (swappable)

Lights: Three 40W LEDs rated at 2700 lumens each

Snowflake detection range: 40 micrometers to 3 centimeters

Detection region: about 2.5 cm²

8.1.3.2 Electrical Specifications

The AC power receptacle for the MASC is rated at 13A. Max power 240W at 115-240VAC.

The MASC contains four 60W power supplies. Each power supply has built-in protection for excessive current.

The MASC has a separate AC receptacle for the ice prevention heat pads. The heat pads are resistive and current is passively regulated. There are two 50W heat pads and one 38W heat pad, all wired to one power terminal.

The MASC and ice control both need to be plugged into a panel that is equipped with both over current and ground fault protection circuitry. Cable and plug termination need to be in a water-resistant enclosure.

The Heating system will automatically turn on at 7°C and off at 16°C, which indicates hysteresis. The system will heat from a freezing temp until it reaches 16°C and will turn off until it cools to 7°C, at which point the thermostat resets and starts heating again.



Figure 7. Firewire and USB cables are guided through washer and nut.

Attaching the Firewire and USB cables (Figure 6) to the MASC require removal of the MASC lid. The cables are guided through a hole to the side of the case to their sockets inside the MASC (Figure 7). This preparation is preferably performed prior to delivering the instrument to the outdoor location.

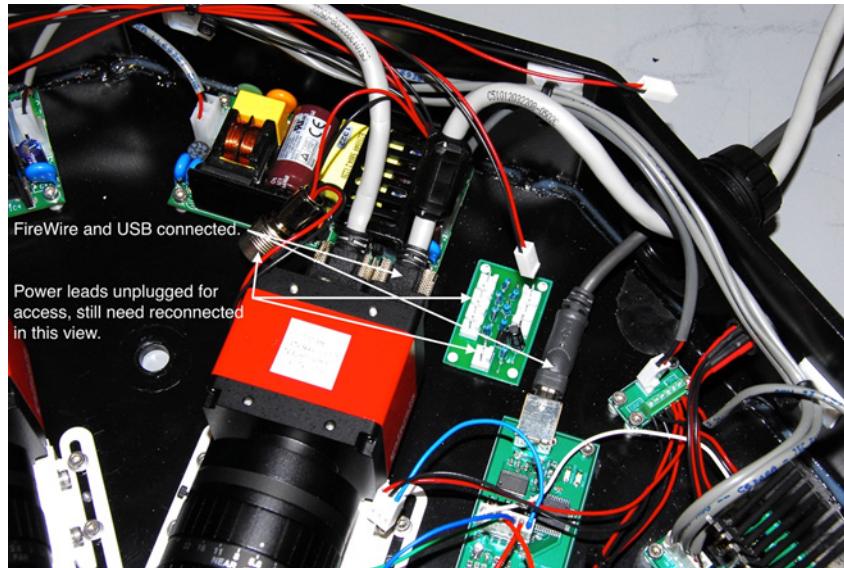


Figure 8. Firewire and USB cables connected.

8.2 Theory of Operations

The MASC includes a bank of IR pyroelectric sensors containing crystalline material that generates a surface electric charge when exposed to infrared radiation. When the amount of radiation striking the crystal changes, the amount of charge also changes and can then be measured. Hydrometeors emit enough infrared radiation to alter the surface electric charge and thus activate the motion sensors, which then trigger the MASC cameras and LED lights. The photographs are obtained at a speed up to 1/40,000th of a second. The fall speed is measured from concurrent triggers of vertical stacks of motion sensors.

8.3 Calibration

Whenever new cameras are installed, or cameras are moved within the MASC housing, calibration procedures have to be performed to ensure that all of the MASC cameras cover the field of view. The MASC ‘Getting Started Guide’, available through the MASC vendor, describes the various steps of the calibration procedure for each single camera. Prior to starting calibration using a vendor-supplied calibration target (see Figure 8), all cameras are set to the correct video mode. Typically the MASC is connected to a portable laptop nearby for checking the camera video stream in real time while performing camera adjustments.

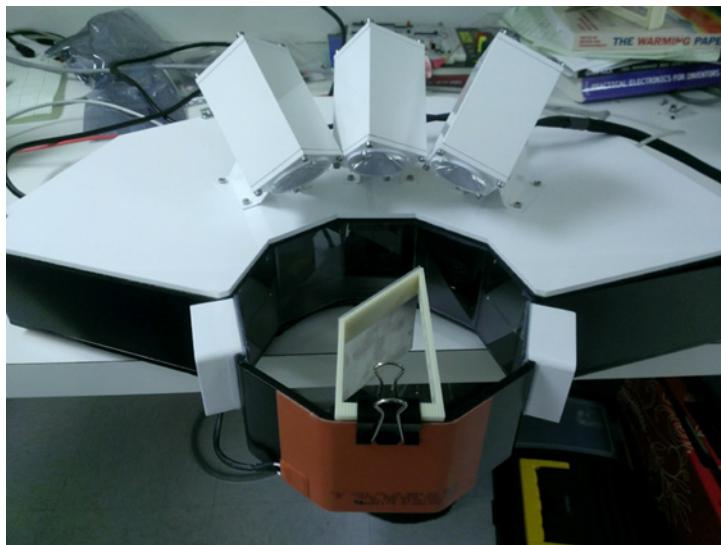


Figure 9. MASC with calibration target installed.

8.4 Operations and Maintenance

8.4.1 User Manual

A ‘Getting Started’ guide is provided by the MASC vendor at the University of Utah.

8.4.1.1 Initial Setup of MASC

The first time the MASC is set up on a new PC, this procedure needs to be followed:

1. Connect the MASC's USB cable to the computer.
2. Start Device Manager and go to the Ports (COM & LPT) item.
3. Select the appropriate device (USB Serial Port). This can be ensured by finding out which device is the newly connected one. Right click on it and select properties.
4. When the properties window opens, go to Port Settings tab and set the following values: Bits per second: **38400**, Data Bits: **8**, Parity: **None**, Stop Bits: **2**, and Flow Control: **Hardware**.

8.4.1.2 Power-On Sequence

This procedure should be followed whenever power is removed from the system.

1. With all devices powered off, connect USB and Firewire cords from the MASC to the PC.
2. Plug in the power cords (MASC Power and Anti-riming power) to power source.
3. Power on the PC.

8.4.1.3 Power-off Sequence

1. Power down the PC.
2. Unplug the MASC from the power source.

8.4.1.4 Operating the MASC

Once the MASC has been powered on and configured according to the steps above, the data collection can be started by running the batch file created in the instruments section. This batch file can be placed in the windows startup directory so it will run automatically in case of lost power to the PC.

8.4.2 Routine and Corrective Maintenance Documentation

Any snow and frost build-up on the instrument needs to be removed. MASC maintenance includes periodic cleaning of the camera and IR motion detector windows. These windows are made of polycarbonate and scratch easily. Best practice is to use a soft cotton cloth for cleaning. Do not use paper towels on the windows!

Note that the MASC lid should only be removed in dry, non-dusty conditions. The inside of the instrument must be clean and dry at all times.

8.4.2.1 Clean Camera Lens Cover

To clean the camera lenses, use a soft cloth and glass cleaner. Do not use any scraping instrument or rough cloth that will scratch the clear plastic lens cover.

8.4.2.2 Remove Snow Build-Up

Excess snow build up on the instrument might block the LED lights or cover the camera lenses. Removing the snow from the instrument may be required. The anti-riming heat pads should remove the excess snow and ice from the front of the instrument.

8.4.3 Software Documentation

The MASC's firmware controls the actual snowflake acquisition. Updating the firmware is expected to be required only very infrequently. The MASC vendor performs firmware upgrades. The general procedure is documented in the MASC 'Getting Started Guide'.

The Unibrain Firewire 800 driver (ubCore 6.0) is responsible for correct operation of the cameras within the MASC. It can be downloaded from <http://www.unibrain.com/downloads/>.

The Unibrain Fire-I and FireI IDC software (Fire-I 4.0 drivers and applications) are used to set up the cameras and troubleshoot Firewire connections. It can be downloaded from <http://www.unibrain.com/downloads/>.

The PICkit 2.0 programmer software (PICkit 2 v2.61) is used to program and update the firmware, which drives the MASC. It can be downloaded from

<http://ww1.microchip.com/downloads/en/DeviceDoc/PICkit%202%20v2.61.00%20Setup%20A.zip>

A data acquisition executable file (*simpleDataAcquisition.exe*) is available to configure the MASC for operations. This utility allows defining the COM port settings, setting the locations of the files and specifying the header and names for the PNG image data.

For seamless operational data acquisition, a batch file (i.e., *runMASC.bat*) is created including the *simpleDataAcquisition.exe* routine in order to configure the data acquisition parameters consistently.

9.0 References

Garrett, TJ, C Fallgatter, K Shkurko, and D Howlett. 2012."Fall speed measurement and high-resolution multi-angle photography of hydrometeors in freefall." *Atmospheric Measurement Techniques* 5: 2625-2633, [doi:10.5194/amt-5-2625-2012](https://doi.org/10.5194/amt-5-2625-2012).

MASC technical specification at http://particleflux.net/data/MASC_Spec_Sheet.pdf

Multi-Angle Snowflake Camera Getting Started Guide available through the vendor Particle Flux Analytics, University of Utah, UT 84112, Email: info@particleflux.net.

