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List of Abbreviations and Acronyms

Abbreviation	Acronym
AGL	Above ground level
AOC	Aircraft Operations Center
ARL	Air Resources Laboratory
ATDD	Atmospheric Turbulence and Diffusion Division
GPS	Global positioning system
HMRC	House Mountain Radio Control
iMet	International Met Systems
IOP	Intensive Operating Period
iOSD	On-screen display
IR	Infrared
KCRC	Knox County Radio Control
LDT	Local daylight time
MATLAB©	Matrix Laboratory
MSL	Mean sea level
NOAA	National Oceanic and Atmospheric Administration
OMAO	Office of Marine and Aviation Operations
sUAS	small Unmanned Aircraft System
UTC	Universal coordinated time
VORTEX-SE	Verifications of Origin of Rotations in Tornadoes Experiment in the Southeast

Abstract

This report describes the operation of NOAA/ARL/ATDD's DJI S-1000 small Unmanned Aircraft System (sUAS) in the Verifications of the Origins of Rotation in Tornadoes Experiment Southeast (VORTEX-SE) in the spring of 2017. The S-1000 was used to measure temperature and humidity profiles in the lower 213 m of the atmosphere, and to map the Earth's skin temperature during four intensive observation periods (25 March, 27 March, 05 April, and 28 April) in the VORTEX-SE experiment. ATDD and NOAA/OMAO/AOC personnel also flew the Microdrone MD4-1000 sUAS during the 28 April intensive. During this intensive, four MD4-1000 flights were flown simultaneously with the DJI S-1000. Datasets from both the DJI S-1000 and the Microdrone MD4-1000 aircraft were processed and are publicly available.

Introduction

The Verification of the Origins of Rotation in Tornadoes Experiment Southeast (VORTEX-SE) is a research program to understand the role of land surface characteristics and meteorological conditions on tornado genesis over the Southeast US. The experiment took place from 8 March through 8 May 2017 in northern Alabama and consisted of coordinated meteorological measurements among multiple NOAA labs and universities during intensive operations periods (IOPs) during which weather conditions were conducive to severe thunderstorm and tornado formation.

Data were collected using a DJI S-1000 small Unmanned Aircraft System (sUAS) owned by the NOAA Air Resources Laboratory, Atmospheric Turbulence and Diffusion Division (NOAA/ARL/ATDD). The S-1000 is an eight-rotor vehicle capable of vertical takeoff and landing. It has a span of approximately 1 m and can carry a payload of 4.5 kg for approximately 15 minutes. It is operated by a single pilot with an observer who monitors real-time video imagery transmitted to a ground station while the aircraft is in flight. The sUAS is operated within visual line of sight of the pilot and is limited to altitudes of 213 m above ground level (AGL) depending on the type of airspace at the flight location. This sUAS is instrumented to make measurements of air temperature, relative humidity, atmospheric pressure, surface temperature, and visible imagery.

The DJI S-1000 is shown in Figure 1 flying at the Knox County Radio Control (KCRC) model flying field in Knoxville, Tennessee during a test flight in preparation for the VORTEX-SE field experiment.

Figure 1: DJI S-1000 flying at Knox County Radio Control (KCRC) model flying field in Knoxville, TN.

Data were collected by the sUAS on 25 March, 27 March, 5 April, and 28 April 2017 to support IOPs designated for the VORTEX-SE program. Nineteen flights were made with the DJI S-1000 at Cullman, AL as shown in Table 1. Times used in this report will be local daylight time (LDT). It should be noted that local time changed from standard to daylight savings on 12 March 2017, the day before the S-1000 was first flown for the experiment. Local daylight time is UTC-5 hours. Additionally, GPS time is ahead of UTC time by 17 s during this experiment (GPS=UTC+17 s).

Table 1: Summary of DJI S-1000 flights made during VORTEX-SE 2017

Date (YYYY/MM/DD)	Location	Flight	Takeoff time (LDT)	Landing time (LDT)	Takeoff time (GMT)	Landing time (GMT)	Flight Time (HH:MM:SS)	Scans
2017/03/25	Cullman	1	11:05:27	11:15:33	16:05:27	16:15:33	00:10:06	606
2017/03/25	Cullman	2	13:04:25	13:16:16	18:04:25	18:16:16	00:11:51	711
2017/03/27	Cullman	1	11:59:05	12:10:44	16:59:05	17:10:44	00:11:39	699
2017/03/27	Cullman	2	13:59:22	14:10:29	18:59:22	19:10:29	00:11:07	667
2017/03/27	Cullman	3	15:42:22	15:53:25	20:42:22	20:53:25	00:11:03	663
2017/04/05	Cullman	1	07:38:45	07:44:52	12:38:45	12:44:52	00:06:07	367
2017/04/05	Cullman	3	11:28:02	11:39:20	16:28:02	16:39:20	00:11:18	678
2017/04/05	Cullman	4	12:13:43	12:25:07	17:13:43	17:25:07	00:11:24	684
2017/04/05	Cullman	5	13:23:28	13:34:17	18:23:28	18:34:17	00:10:49	649
2017/04/05	Cullman	6	14:29:59	14:40:38	19:29:59	19:40:38	00:10:39	639
2017/04/05	Cullman	7	15:27:05	15:37:39	20:27:05	20:37:39	00:10:34	634
2017/04/28	Cullman	1	11:08:14	11:19:22	16:08:14	16:19:22	00:11:08	668
2017/04/28	Cullman	2	11:41:12	11:49:31	16:41:12	16:49:31	00:08:19	499
2017/04/28	Cullman	3	12:06:34	12:14:20	17:06:34	17:14:20	00:07:46	466
2017/04/28	Cullman	4	13:06:07	13:20:17	18:06:07	18:20:17	00:14:10	850
2017/04/28	Cullman	5	15:52:43	15:06:38	19:52:43	20:06:38	00:13:55	835
2017/04/28	Cullman	6	15:58:43	16:10:46	20:58:43	21:10:46	00:12:03	723
2017/04/28	Cullman	7	16:52:21	17:04:06	21:52:21	22:04:06	00:11:45	705
2017/04/28	Cullman	8	17:30:37	17:41:35	22:30:37	22:41:35	00:10:58	658

Nineteen flights were made with the DJI S-1000 sUAS. Note that no meteorological data were collected during flight 2 on 5 April therefore this flight is not listed in Table 1 above.

Six flights were made with the Microdrone MD4-1000 sUAS as shown in Table 2 below. Note that flights 1 and 2 with the MD4-1000 were performed for pilot checkout and orientation. No meteorological data was collected during those flights.

Figure 2: The Microdrone MD4-1000 flying at the House Mountain Radio Control (HMRC) model flying field near Knoxville, TN.

Table 2: Summary of MD4-1000 flights made during VORTEX-SE 2017

Date (YYYY/MM/DD)	Location	Flight	Takeoff time (LDT)	Landing time (LDT)	Takeoff time (GMT)	Landing time (GMT)	Flight Time (HH:MM:SS)	Scans
2017/04/28	Cullman	3	11:41:28	11:50:28	16:41:28	16:50:28	00:09:00	540
2017/04/28	Cullman	4	12:06:42	12:15:20	17:06:42	17:15:20	00:08:38	518
2017/04/28	Cullman	5	13:06:15	13:21:06	18:06:15	18:21:06	00:14:51	891
2017/04/28	Cullman	6	15:52:55	16:07:29	19:52:55	20:07:29	00:14:34	874
2017/04/28	Cullman	7	16:36:10	16:45:59	21:36:10	21:45:59	00:09:49	589
2017/04/28	Cullman	8	17:59:26	18:09:55	22:59:26	23:09:55	00:10:29	629

Flights at Cullman were made primarily to measure atmospheric temperature profiles and surface temperature. No flights were made this year for tornado storm damage assessment. Note four of the flights at Cullman on 28 April 2017 were made simultaneously with the Microdrone MD4-1000 and the DJI S-1000.

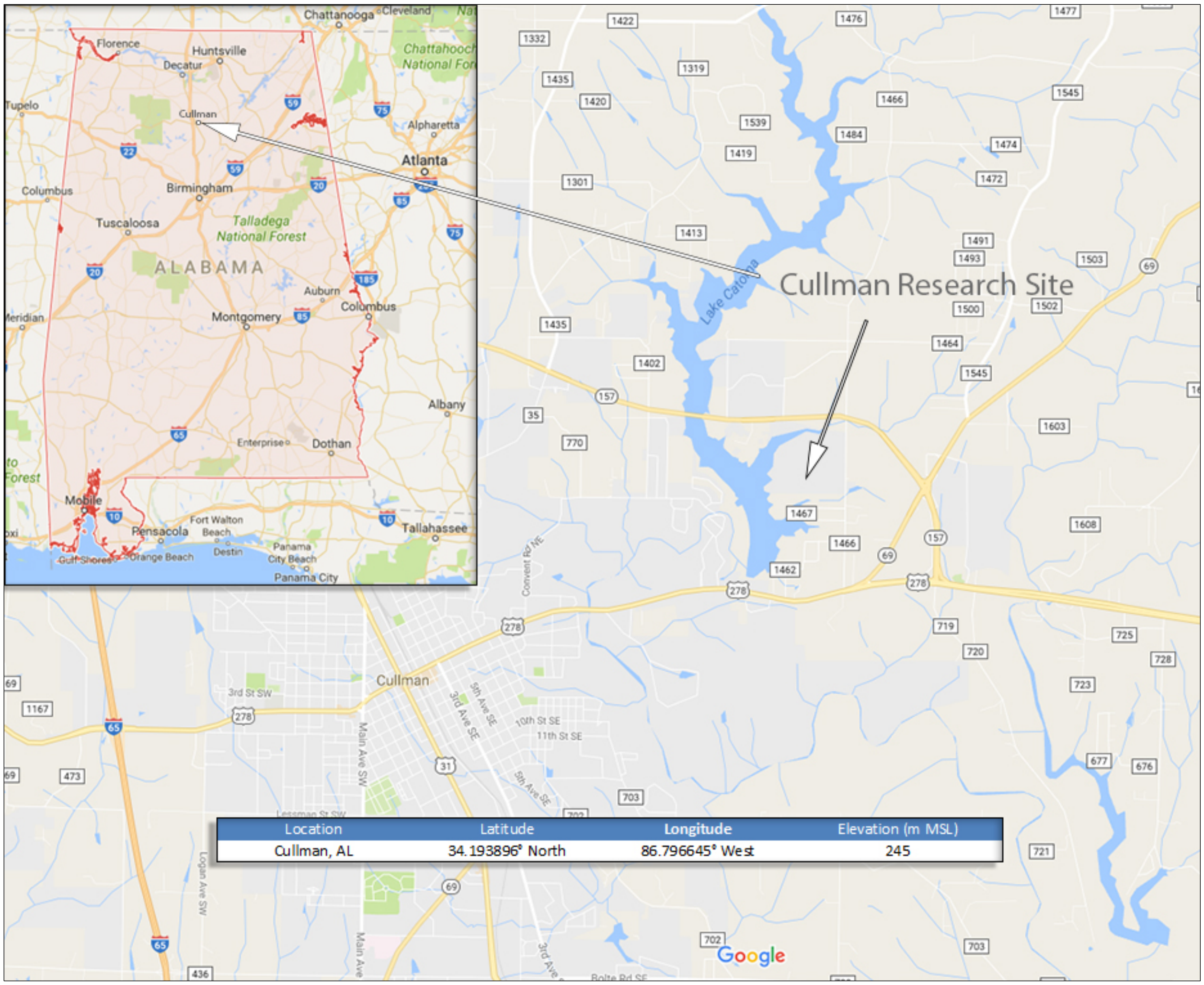

Figure 3: Map showing the S-1000 and MD4-1000 flight location in the VORTEX-SE domain with coordinates of the Cullman research site.

Instrument Description

Two International Met Systems (iMet) model XQ devices were used to measure air temperature, relative humidity, and pressure onboard the DJI-S-1000 & the Microdrone MD4-1000 aircraft. The DJI S-1000 carried two iMet devices, on the left and right sides of the aircraft respectively. Device 4 (iMet-dev4) was located on the left side, and device 5 (iMet-dev5) was located on the right side. The Microdrone MD4-1000 carried device 3 (iMet-dev3) on the left side and device 6 (iMet-dev6) on the right side of the aircraft. Each instrument is self-contained and has temperature, relative humidity, and pressure sensors with onboard GPS and data logging capability. The specifications for each sensor are shown in Table 3.

Table 3: iMet-XQ sensor specifications

	Humidity Sensor	Temperature Sensor	Pressure Sensor
Type	Capacitive	Bead Thermistor	Piezo resistive
Range	0-100% RH	-95°C to +50°C	10-1200 hPa
Response time	5 sec @ 1 m/s velocity	2 seconds	10 ms
Accuracy	±5% RH	±0.3°C	±1.5 hPa
Resolution	0.7% RH	0.01°C	0.02 hPa
Storage frequency	1 Hz	1 Hz	1 Hz

For more information please visit www.intermetsystems.com

A FLIR infrared camera was used to measure the skin temperature of the Earth's surface below the DJI S-1000 aircraft. The FLIR camera is a FLIR Tau 2 core with 336x256 pixel resolution, a 7.5 mm lens, and a TeAx Thermal Capture data acquisition system. This device stored data at 1 Hz continuously while the aircraft was being flown. This camera was mounted to the aircraft and oriented to look straight down while the aircraft was in level flight. It was not mounted on a gimbal. See Figure 4 for details.

Table 4: FLIR Tau 2 camera specifications

FLIR Tau 2 Camera Specifications	
Resolution	336 x 256 VOx Micro bolometer
Spectral band	7.5-13.5 µm
Pixel Size	17 µm
Performance	< 50 mK @ f/1.0
Scene temperature range	-40°C to +160°C
Lens field of view	45° x 35°
Storage frequency	1.0 Hz

For more information please visit www.flir.com

Data from the DJI A2 autopilot were collected and stored during flight to measure the aircraft's position, velocity, and attitude. Data from the autopilot were processed using online software from www.mapsmadeeasy.com which converted the proprietary DJI binary files into comma separated value (CSV) files for easier post-processing. Data from the A2 autopilot were stored at 192 Hz during flight.

A GoPro Hero 3 camera was used to transmit video in the visible wavelength band from the aircraft during flight. Data from the camera were downlinked using a DJI iOSD Mk II system to a portable display screen that was monitored during flight. Video data were not recorded for any flight this year. This camera, like the FLIR camera, was mounted to the aircraft and oriented to look straight down when the aircraft is in level flight. It was not mounted on a gimbal. See Figure 4 for details.

Figure 4 shows the configuration of one of the iMet-XQ sensors, the GoPro Hero 3 camera, and the FLIR infrared (IR) camera looking from the bottom of the DJI S-1000. The cameras are mounted to the carbon fiber plate attached to the bottom of the aircraft.

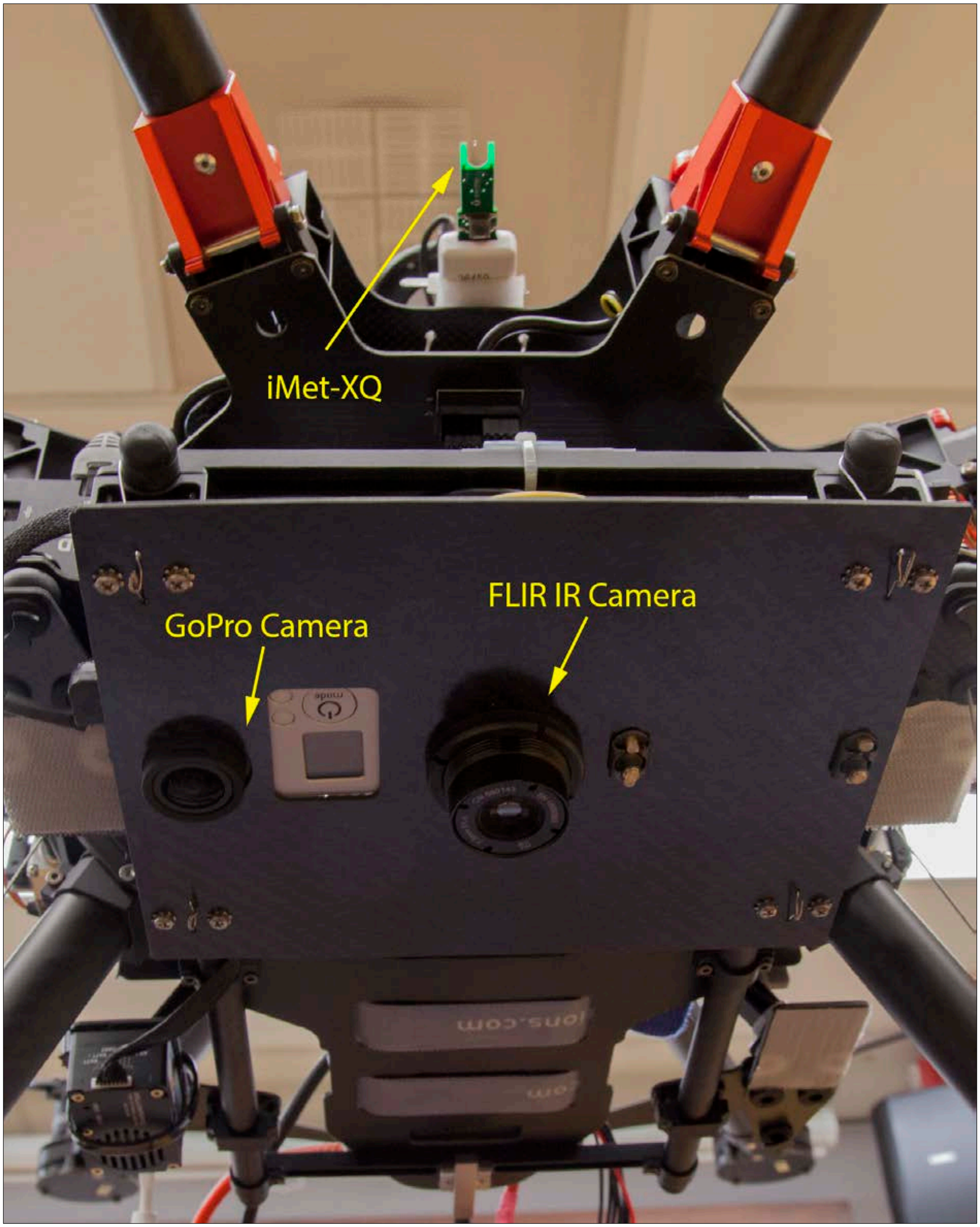

Figure 4: Instrumentation on the DJI S-1000 sUAS.

Figure 4 shows a detailed view of the iMet-XQ installation looking from the top of the S-1000. Two of these instruments were mounted on the left and right sides of the aircraft and labeled devices 4 and 5, respectively, as shown in Figure 5.

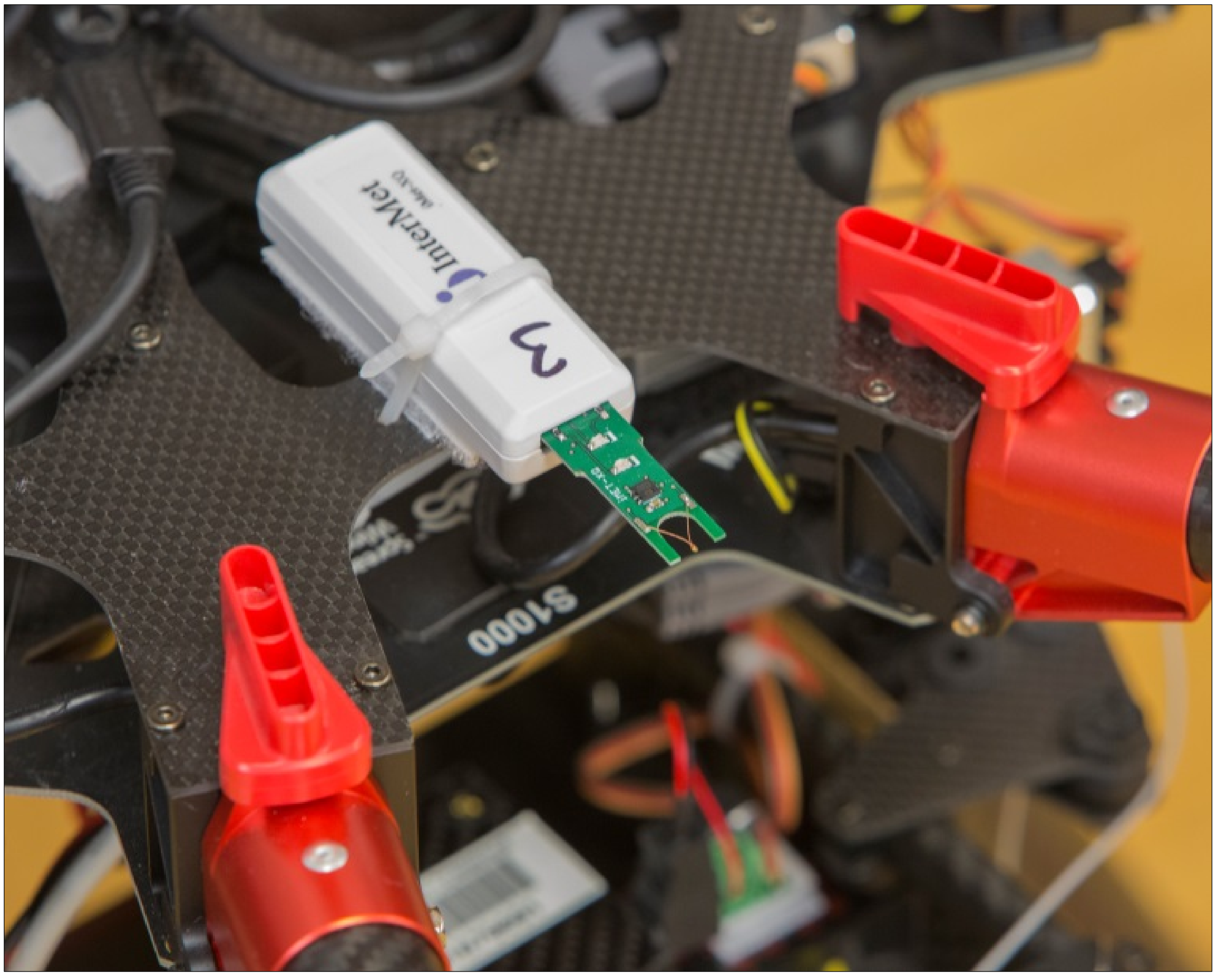

Figure 5: Detail photo of the iMet-XQ T/RH/P sensor installation on the DJI S-1000.

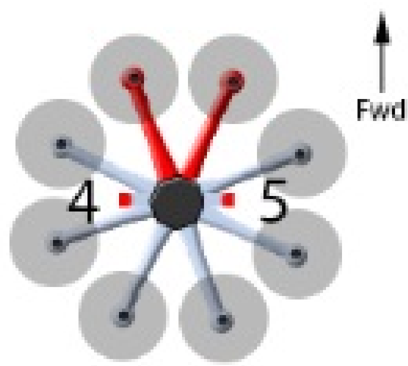

Figure 6: Schematic of iMet-XQ sensor locations on S-1000.

Data Collection and Processing

Data from the DJI A2 autopilot was stored on-board the S-1000 during flight, along with data from the iMet-XQ sensors, and the FLIR IR camera. Each device was started prior to takeoff and then stopped after landing. Following each flight day, data from each device (the DJI A2 autopilot, iMet-XQ, and FLIR IR camera) were downloaded onto a laptop computer for post-processing.

Post-processing began by converting the DJI A2 autopilot data from binary format to CSV format using online software from www.mapsmadeasy.com. Hereafter this file will be referred to as the DJI file. Following this, custom MATLAB© software was used to plot and visually inspect data from each device to provide an initial level of quality control. The iMet-XQ's GPS altitude and time were used to determine the exact time of liftoff and touchdown and the iMet-XQ files trimmed to match those times exactly. Since the iMet-XQ data were collected at 1 Hz, the exact duration of the flight could be measured both by subtracting the file's end and start time tags, as well as counting the number of lines in the file. This provided a level of redundancy to ensure the iMet-XQ data were properly collected.

Next, time series data from the DJI barometric altitude were plotted, and the data files trimmed to match the exact moment of liftoff and touchdown of the vehicle. The number of data points in the DJI file was also checked against the expected number of points based on the duration of the flight. The frequency of the DJI data was found experimentally to be 192±1 Hz, and this value was constant throughout the experiment period.

The FLIR data files were processed using TeAx ThermoViewer software. The original files from the TeAx device were stored in a compressed binary format in blocks of 1000 frames. The FLIR data were taken continuously from the moment the aircraft lifted off until it touched down. As with the DJI and iMet-XQ data, the first and last files were trimmed to the exact time of liftoff and touchdown. After initial trimming, each file was concatenated into a single compressed binary file that contained all FLIR frames from the exact time of liftoff until the exact time of touchdown. As with the DJI data, the number of FLIR frames in the entire flight was checked to ensure no data were missing. The frequency of the FLIR data was found experimentally to be 1.0 Hz and remained consistent throughout the experiment period.

After the single FLIR binary flight file was created, each frame was exported to a CSV file. The CSV file names have the following convention: YYYYMMDD-FLIR-flightX_ZZZZ.csv where YYYY=4-digit year, MM=2-digit month, DD=2-digit day as recorded at the time of the first data point in the iMet-XQ file, X=1-digit flight number and ZZZZ=4-digit frame number. Each CSV file contains 336 columns and 256 rows of temperature values in degrees Celsius. Each number in the CSV file corresponds to a temperature value for each pixel.

Finally, a new DJI file was created that included the iMet-XQ temperature, relative humidity, pressure, latitude, longitude, altitude, and number of satellites for each iMet-XQ device. Additionally, the index of the appropriate FLIR .csv frame number was added. This file was named using following convention: YYYYMMDD-DATA-flightX.csv where YYYY=4-digit year, MM=2-digit month, DD=2-digit day as recorded at the time of the first data point in the iMet-XQ file and X=1-digit flight number.

A similar process was used to process data from the Microdrone MD4-1000. Once data from the MD4-1000 autopilot was downloaded and converted, the iMet-XQ data was then trimmed to match the takeoff and landing times found in the MD4-1000 autopilot file. The data files were then merged in a similar manner to the DJI files to create a DATA file.

Data Format

The iMet-XQ filename has the following format: YYYYMMDD-iMet-devX-flightY.csv where YYYY=4-digit year, MM=2-digit month, DD=2-digit day as recorded at the time of the first data point in the iMet-XQ file, X=1-digit device number and Y=1-digit flight number. The iMet-XQ file has the following format:

Table 5: iMet-XQ file format

S/N	Device	Pressure (mb)	Temp (C)	RH (%)	GPS Date	GPS Time	Latitude (Degrees)	Longitude (Degrees)	Altitude (m)	No. Sat
00037272	XQ	+099239	+2299	+0539	2017/03/25	16:05:27	+0341938227	-0867966419	+00248648	11
00037272	XQ	+099230	+2350	+0540	2017/03/25	16:05:28	+0341938254	-0867966426	+00249080	11
00037272	XQ	+099212	+2295	+0580	2017/03/25	16:05:29	+0341938277	-0867966432	+00249620	11
00037272	XQ	+099211	+2249	+0544	2017/03/25	16:05:30	+0341938264	-0867966421	+00250143	12
00037272	XQ	+099205	+2235	+0543	2017/03/25	16:05:31	+0341938235	-0867966434	+00250647	12
…										

Scale factors: Pressure=100, Temp=100, RH=100, Latitude= 1000000, Longitude= 10000000, Altitude= 100

The sample shown above is from file 20170325-iMet-dev4-flight1.csv from the DJI S-1000. Note scale factors for the various channels shown above are applied to the raw data. Data can be converted from raw to scaled values by dividing by the appropriate scale factor, shown below Table 5.

The FLIR filename has the following format: YYYYMMDD-FLIR-flightX_ZZZZ.csv where YYYY=4-digit year, MM=2-digit month, DD=2-digit day as recorded at the time of the first data point in the iMet-XQ file, X=1-digit flight number and ZZZZ=4-digit frame number. The FLIR file has the following format:

Table 6: FLIR file format

	Column 1	Column 2	…	Column 335	Column 336
Row 1	25.77;	25.69;		25.25;	25.21;
Row 2	25.89;	25.89;		25.37;	25.25;
…					
Row 255	25.37;	25.41;		25.61;	25.65;
Row 256	25.49;	25.41;		26.37;	26.37;

Note: All values are scaled to degrees C.

The sample shown above is from file 20170325-FLIR-flight1_0001.csv.

The DATA filename has the following format: YYYYMMDD-DATA-flightX.csv where YYYY=4-digit year, MM=2-digit month, DD=2-digit day as recorded at the time of the first data point in the iMet-XQ file and X=1-digit flight number. The DJI S-1000 DATA file has the following columns:

Index, Year, Month, Day, Hour, Min, Sec, Millisecond, Latitude, Longitude, GPS Altitude, N Velocity, E Velocity, D Velocity, Velocity, Ground Speed, AccelerometerX, AccelerometerY, AccelerometerZ, GyroX, GyroY, GyroZ, Barometric Alt, QuaternionX, QuaternionY, QuaternionZ, QuaternionW, Roll, Pitch, Yaw, MagneticX, MagneticY, MagneticZ, Satellites, Main Voltage, CAN Voltage, Elec Voltage, Pres4, Temp4, RH4, Lat4, Lon4, Alt4, Sat4, Pres5, Temp5, RH5, Lat5, Lon5, Alt5, Sat5, FLIR_Index

Note that Pres4, Temp4, RH4, Lat4, Lon4, Alt4, and Sat4 are from iMet-XQ device 4 and Pres5, Temp5, RH5, Lat5, Lon5, Alt5, and Sat5 are from iMet-XQ device 5. GPS altitude is measured with respect to the GPS referenced sea level while barometric altitude is measured with respect to ground level.

To delineate which parts of a data file are useful, a marker (MKR) file is used. This is a text file that defines sections of the DATA file that are intended to be processed in a contiguous fashion. For example, the first leg of most flights started with a vertical profile followed by a horizontal transect once the aircraft reached its maximum altitude. The MKR files for each flight are listed along with the latitude and longitude plots of the flight tracks in Appendix A.

The MKR filename has the following format: YYYYMMDD-DATA-flightX.mkr where YYYY=4-digit year, MM=2-digit month, DD=2-digit day as recorded at the time of the first data point in the iMet-XQ file and X=1-digit flight number. The MKR file has the following format:

Table 7: Marker file format

	Tag	Open / Close	Scan	Time	Latitude	Longitude	Notes
Open line	File 20170325-DATA-flight1.csv OPENED at 16:05:27 GPS						
Payload line	iMet-XQ order (4 left, 5 right)						
Open 1	PRO	-1	00027	16:05:54	34.193831	-86.796646	Profile 2-225 meters up
Close 1		0	00177	16:08:24	34.193843	-86.796652	
Open 2	PRO	-1	00188	16:08:35	34.193844	-86.796649	Profile 225-2 meters down
Close 2		0	00348	16:11:15	34.193838	-86.796655	
Open 3	PRO	-1	00353	16:11:20	34.193839	-86.796649	Profile 2-168 meters up
Close 3		0	00462	16:13:09	34.193840	-86.796649	
...							
Close line	File 20170325-DATA-flight1.csv CLOSED at 16:15:33 GPS						
Total scans	Total scans 00607						

In the example above, the file 20170325-DATA-flight1.csv was opened at 16:05:27 GPS time. The payload configuration was iMet-XQ device 4 on the left, and iMet-XQ device 5 on the right side of the aircraft. There may be additional lines following the payload line to note weather conditions or other significant flight conditions, if necessary.

The first task flown was a profile that started (indicated by -1 in the open/close column) at scan 27, 16:05:54 GPS time. Note that -1 indicates the maneuver's start time and 0 indicates the maneuver's stop time. From the notes it can be seen that this profile began 2 meters above ground level (AGL) and ended at 225 meters AGL. Note the latitude and longitude of the starting and ending points. These are nearly identical and indicate that the profile was performed vertically over the same location. The profile began 27 seconds into the flight and ended 177 seconds into the flight, giving an elapsed time of 150 seconds. With the altitude gain of 223 meters, the average rate of climb was 1.49 m s^{-1}.

The remaining segments show the rest of the maneuvers during the flight. For these flights, strictly vertical ascents and descents were performed.

The abbreviation codes for all MKR files used in this experiment are as follows:

Table 8: Abbreviation codes for MKR files

Tag	Name	Description
HOV	Hover	Hovering flight at a constant altitude.
PRO	Profile	Vertical flight at a constant rate of climb or descent.

Further examples of MKR files for each flight in the VORTEX-SE study can be found in Appendix A.

The DATA filename for the MD4-1000 has the following format: YYYYMMDD-DATA-flightX.csv where YYYY=4-digit year, MM=2-digit month, DD=2-digit day as recorded at the time of the first data point in the iMet-XQ file and X=1-digit flight number. The DATA file has the following columns for the MD4-1000:

Index, Year, Month, Day, Hour, Min, Sec, Millisecond, Latitude, Longitude, Altitude, GroundSpeed, BarometricAlt, Roll, Pitch, Yaw, Temperature, MainVoltage, Pres3, Temp3, RH3, Lat3, Lon3, Alt3, Sat3, Pres6, Temp6, RH6, Lat6, Lon6, Alt6, Sat6

Note that Pres3, Temp3, RH3, Lat3, Lon3, Alt3, and Sat3 are from iMet-XQ device 3 and Pres6, Temp6, RH6, Lat6, Lon6, Alt6, and Sat6 are from iMet-XQ device 6. GPS altitude is measured with respect to the GPS referenced sea level while barometric altitude is measured with respect to ground level.

Marker files for the MD4-1000 flights were created in a manner similar to the MKR files for the DJI S-1000. An example MD4-1000 MKR file is shown below:

Table 9: Example MD4-1000 MKR File

	Tag	Open / Close	Scan	Time	Latitude	Longitude	Notes
Open line	File 20170428-DATA-flight3.csv OPENED at 16:41:28 GPS						
Payload line	iMet-XQ order (3 left, 6 right)						
Open 1	HOV	-1	00012	16:41:40	34.193863	-86.796303	Hover at 5 meters AGL
Close 1		0	00039	16:42:07	34.193858	-86.796301	
Open 2	PRO	-1	00041	16:42:09	34.193858	-86.796302	Profile 5-220 meters up
Close 2		0	00270	16:45:58	34.193984	-86.796306	
Open 3	HOV	-1	00271	16:45:59	34.193982	-86.796305	Hover at 220 meters AGL
Close 3		0	00304	16:46:32	34.193995	-86.796306	
...							
Close line	File 20170428-DATA-flight3.csv CLOSED at 16:50:28 GPS						
Total scans	Total scans 00540						

Data Remarks

For the most part, the data were recovered completely and correctly. Table 10 shows the data recovery by instrument and flight with comments afterward.

Table 10: Summary of data recovery for the DJI S-1000 for VORTEX-SE 2017

Date (YYYY/MM/DD)	Location	Daily flight number	DJI	iMet-XQ Dev 4	iMet-XQ Dev 5	FLIR	GoPro Video	Notes
2017/03/25	Cullman	1	Yes	Yes	Yes	Yes	No[1]	
2017/03/25	Cullman	2	Yes	Yes	Yes	Yes	No[1]	
2017/03/27	Cullman	1	Yes	Yes	Yes	Yes	No[1]	
2017/03/27	Cullman	2	Yes	Yes	Yes	Yes	No[1]	
2017/03/27	Cullman	3	Yes	Yes	Yes	Yes	No[1]	
2017/04/05	Cullman	1	Yes	Yes	Yes	Yes	No[1]	
2017/04/05	Cullman	3	Yes	Yes	Yes	Yes	No[1]	Simultaneous flight with tethersonde.
2017/04/05	Cullman	4	Yes	Yes	Yes	Yes	No[1]	Simultaneous flight with tethersonde. Radiosonde balloon launch at 17:15:00 GMT.
2017/04/05	Cullman	5	Yes	Yes	Yes	Yes	No[1]	Simultaneous flight with tethersonde.
2017/04/05	Cullman	6	Yes	Yes	Yes	Yes	No[1]	Simultaneous flight with tethersonde.
2017/04/05	Cullman	7	Yes	Yes	Yes	Yes	No[1]	
2017/04/28	Cullman	1	Yes	Yes	Yes	Yes	No[1]	
2017/04/28	Cullman	2	Yes	Yes	Yes	Yes	No[1]	Simultaneous flight with MD4-1000 flight 3.
2017/04/28	Cullman	3	Yes	Yes	Yes	Yes	No[1]	Simultaneous flight with MD4-1000 flight 4.
2017/04/28	Cullman	4	Yes	Yes	Yes	Yes	No[1]	Simultaneous flight with MD4-1000 flight 5.
2017/04/28	Cullman	5	Yes	Yes	Yes	Yes	No[1]	Simultaneous flight with MD4-1000 flight 6.
2017/04/28	Cullman	6	Yes	Yes	Yes	Yes	No[1]	
2017/04/28	Cullman	7	Yes	Yes	Yes	Yes	No[1]	
2017/04/28	Cullman	8	Yes	Yes	Yes	Yes	No[1]	

[1]No GoPro video data was recorded during the entire experiment.

Note that no meteorological data was collected during flight 2 on 5 April and is therefore not listed in Table 10 above.

Table 11: Summary of data recovery for the MD4-1000 for VORTEX-SE 2017

Date (YYYY/MM/DD)	Location	Daily flight number	MD4	iMet-XQ Dev 3	iMet-XQ Dev 6	FLIR	GoPro Video	Notes
2017/04/28	Cullman	3	Yes	Yes	Yes	No[1]	No[2]	Simultaneous flight with DJI S-1000 flight 2.
2017/04/28	Cullman	4	Yes	Yes	Yes	No[1]	No[2]	Simultaneous flight with DJI S-1000 flight 3.
2017/04/28	Cullman	5	Yes	Yes	Yes	No[1]	No[2]	Simultaneous flight with DJI S-1000 flight 4.
2017/04/28	Cullman	6	Yes	Yes	Yes	No[1]	No[2]	Simultaneous flight with DJI S-1000 flight 5.
2017/04/28	Cullman	7	Yes	Yes	Yes	No[1]	No[2]	
2017/04/28	Cullman	8	Yes	Yes	Yes	No[1]	No[2]	

[1]FLIR instrument was not installed on this aircraft. [2]GoPro video was not installed on this aircraft.

A total of 6 flights were made with the Microdrone MD-1000 sUAS as shown in Table 11. Note that flights 1 and 2 with the MD4-1000 were performed for pilot checkout and orientation. No meteorological data were collected during those flights.

During the simultaneous flights, each aircraft was stationed 100 feet apart prior to flight. Each aircraft maintained its position directly over its takeoff spot while performing their profiles. Each pilot coordinated efforts to maintain the same climb rate and hit target altitudes at the same time during each climb.

It should be noted that during the last 2 MD4-1000 flights wind shear was encountered at altitudes > 180 meters AGL that caused the flight track of the aircraft to vary significantly from the planned track. These tracks are shown in figures 30 and 31.

Several MATLAB© scripts were built to visualize and manipulate data from the DJI S-1000 instruments. The MATLAB© script *uasDisplay.m* displays time series data from the DJI files (e.g. 20170325-DATA-flight1.csv), as well as the latitude and longitude plot of the flight track. It is a GUI application that can also display marker data and calculate statistics for various segments defined by the MKR files. Additionally, data from both the iMet-XQ and FLIR can be brought in and displayed in the time series. Controls to execute the *process_iMet.m* and *process_FLIR.m* scripts are included as well.

The MATLAB© script *process_iMet.m* displays data from the iMet-XQ files (e.g. 20170325-iMet-dev4-flight1.csv). The user can select various series of iMet-XQ data to plot from up to 5 different data files on the same set of axes. Statistics can be calculated for various combinations of data using this script.

The MATLAB© script *process_FLIR.m* is designed to display data from the FLIR files (e.g. 20170325-FLIR-flight1_0001.csv) for quick-looks of the FLIR data. These scripts and all data for each of the VORTEX-SE flights are available at the following ftp site: ftp://ftp.atdd.noaa.gov/CI/djis1000/

Acknowledgements

ATDD wishes to thank Mark Rogers of NOAA/AOML/AOC for flying the Microdrone MD4-1000 aircraft during the VORTEX-SE 2017 field campaign.

Appendix A – Catalog of DJI S-1000 flight tracks and marker files from the 2017 VORTEX-SE campaign

```
File 20170325-DATA-flight1.csv OPENED at 16:05:27 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00027 16:05:54 34.193831 -86.796646 Profile 2-225 meters up
     0 00177 16:08:24 34.193843 -86.796652
PRO -1 00188 16:08:35 34.193844 -86.796649 Profile 225-2 meters down
     0 00348 16:11:15 34.193838 -86.796655
PRO -1 00353 16:11:20 34.193839 -86.796649 Profile 2-168 meters up
     0 00462 16:13:09 34.193840 -86.796649
PRO -1 00464 16:13:11 34.193840 -86.796648 Profile 168-2 meters down
     0 00586 16:15:13 34.193833 -86.796650
File 20170325-DATA-flight1.csv CLOSED at 16:15:33 GPS
Total scans 00607
```

Figure 7: DJI S-1000 Flight 1, Saturday, 25 March 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170325-DATA-flight2.csv OPENED at 18:04:25 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00023 18:04:48 34.193867 -86.796655 Profile 2-228 meters up
     0 00174 18:07:19 34.193866 -86.796652
PRO -1 00179 18:07:24 34.193867 -86.796652 Profile 228-2 meters down
     0 00363 18:10:28 34.193869 -86.796654
PRO -1 00365 18:10:30 34.193869 -86.796653 Profile 2-228 meters up
     0 00509 18:12:54 34.193865 -86.796653
PRO -1 00514 18:12:59 34.193866 -86.796652 Profile 228-2 meters down
     0 00694 18:15:59 34.193861 -86.796650
File 20170325-DATA-flight2.csv CLOSED at 18:16:16 GPS
Total scans 00712
```

Figure 8: DJI S-1000 Flight 2, Saturday, 25 March 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170327-DATA-flight1.csv OPENED at 16:59:05 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00055 17:00:00 34.193889 -86.796651 Profile 2-220 meters up
     0 00203 17:02:28 34.193890 -86.796651
PRO -1 00208 17:02:33 34.193890 -86.796649 Profile 220-2 meters down
     0 00358 17:05:03 34.193889 -86.796649
PRO -1 00362 17:05:07 34.193889 -86.796647 Profile 2-220 meters up
     0 00506 17:07:31 34.193891 -86.796654
PRO -1 00513 17:07:38 34.193891 -86.796653 Profile 220-2 meters down
     0 00661 17:10:06 34.193889 -86.796649
File 20170327-DATA-flight1.csv CLOSED at 17:10:44 GPS
Total scans 00700
```

Figure 9: DJI S-1000 Flight 1, Monday, 27 March 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170327-DATA-flight2.csv OPENED at 18:59:22 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00038 19:00:00 34.193902 -86.796697 Profile 2-220 meters up
     0 00181 19:02:23 34.193907 -86.796700
PRO -1 00189 19:02:31 34.193906 -86.796696 Profile 220-2 meters down
     0 00334 19:04:56 34.193900 -86.796697
PRO -1 00338 19:05:00 34.193900 -86.796693 Profile 2-220 meters up
     0 00482 19:07:24 34.193900 -86.796697
PRO -1 00489 19:07:31 34.193899 -86.796695 Profile 220-2 meters down
     0 00636 19:09:58 34.193894 -86.796691
File 20170327-DATA-flight2.csv CLOSED at 19:10:29 GPS
Total scans 00668
```

Figure 10: DJI S-1000 Flight 2, Monday, 27 March 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170327-DATA-flight3.csv OPENED at 20:42:22 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00031 20:42:53 34.193869 -86.796630 Profile 2-220 meters up
     0 00177 20:45:19 34.193872 -86.796635
PRO -1 00185 20:45:27 34.193872 -86.796632 Profile 220-2 meters down
     0 00333 20:47:55 34.193868 -86.796630
PRO -1 00339 20:48:01 34.193868 -86.796633 Profile 2-220 meters up
     0 00482 20:50:24 34.193871 -86.796633
PRO -1 00491 20:50:33 34.193871 -86.796632 Profile 220-2 meters down
     0 00634 20:52:56 34.193867 -86.796630
File 20170327-DATA-flight3.csv CLOSED at 20:53:25 GPS
Total scans 00664
```

Figure 11: DJI S-1000 Flight 3, Monday, 27 March 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170405-DATA-flight1.csv OPENED at 12:38:45 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00031 12:39:16 34.193908 -86.796675 Profile 2-220 meters up
     0 00176 12:41:41 34.193907 -86.796678
PRO -1 00184 12:41:49 34.193910 -86.796676 Profile 220-2 meters down
     0 00336 12:44:21 34.193906 -86.796675
File 20170405-DATA-flight1.csv CLOSED at 12:44:42 GPS
Total scans 00358
```

Figure 12: DJI S-1000 Flight 1, Wednesday, 5 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170405-DATA-flight3.csv OPENED at 16:28:02 GPS
Simultaneous flight with tethersonde
iMet-XQ order (4 left, 5 right)
PRO -1 00027 16:28:29 34.193840 -86.796738 Profile 2-220 meters up
     0 00174 16:30:56 34.193838 -86.796741
PRO -1 00182 16:31:04 34.193840 -86.796739 Profile 220-2 meters down
     0 00331 16:33:33 34.193836 -86.796741
PRO -1 00332 16:33:34 34.193837 -86.796739 Profile 2-220 meters up
     0 00476 16:35:58 34.193840 -86.796740
PRO -1 00482 16:36:04 34.193841 -86.796742 Profile 220-2 meters down
     0 00629 16:38:31 34.193840 -86.796741
File 20170405-DATA-flight3.csv CLOSED at 16:39:20 GPS
Total scans 00679
```

Figure 13: DJI S-1000 Flight 3, Wednesday, 5 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170405-DATA-flight4.csv OPENED at 17:13:43 GPS
Simultaneous flight with tethersonde and simultaneous balloon launch at 17:15:00 GMT
iMet-XQ order (4 left, 5 right)
PRO -1 00076 17:14:59 34.193822 -86.796715 Profile 2-220 meters up
     0 00220 17:17:23 34.193826 -86.796716
PRO -1 00225 17:17:28 34.193827 -86.796715 Profile 220-2 meters down
     0 00371 17:19:54 34.193823 -86.796716
PRO -1 00372 17:19:55 34.193824 -86.796716 Profile 2-220 meters up
     0 00516 17:22:19 34.193824 -86.796715
PRO -1 00522 17:22:25 34.193825 -86.796715 Profile 220-2 meters down
     0 00673 17:24:56 34.193823 -86.796714
File 20170405-DATA-flight4.csv CLOSED at 17:25:07 GPS
Total scans 00685
```

Figure 14: DJI S-1000 Flight 4, Wednesday, 5 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170405-DATA-flight5.csv OPENED at 18:23:28 GPS
Simultaneous flight with tethersonde
iMet-XQ order (4 left, 5 right)
PRO -1 00026 18:23:54 34.193843 -86.796718 Profile 2-220 meters up
     0 00172 18:26:20 34.193842 -86.796716
PRO -1 00179 18:26:27 34.193844 -86.796715 Profile 220-2 meters down
     0 00325 18:28:53 34.193840 -86.796719
PRO -1 00327 18:28:55 34.193842 -86.796719 Profile 2-220 meters up
     0 00471 18:31:19 34.193841 -86.796716
PRO -1 00474 18:31:22 34.193840 -86.796713 Profile 220-2 meters down
     0 00623 18:33:51 34.193838 -86.796718
File 20170405-DATA-flight5.csv CLOSED at 18:34:17 GPS
Total scans 00650
```

Figure 15: DJI S-1000 Flight 5, Wednesday, 5 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170405-DATA-flight6.csv OPENED at 19:29:59 GPS
Simultaneous flight with tethersonde
iMet-XQ order (4 left, 5 right)
PRO -1 00026 19:30:25 34.193839 -86.796713 Profile 2-220 meters up
     0 00171 19:32:50 34.193843 -86.796709
PRO -1 00179 19:32:58 34.193844 -86.796713 Profile 220-2 meters down
     0 00325 19:35:24 34.193842 -86.796709
PRO -1 00327 19:35:26 34.193843 -86.796709 Profile 2-220 meters up
     0 00467 19:37:46 34.193838 -86.796713
PRO -1 00473 19:37:52 34.193843 -86.796710 Profile 220-2 meters down
     0 00621 19:40:20 34.193838 -86.796711
File 20170405-DATA-flight6.csv CLOSED at 19:40:38 GPS
Total scans 00640
```

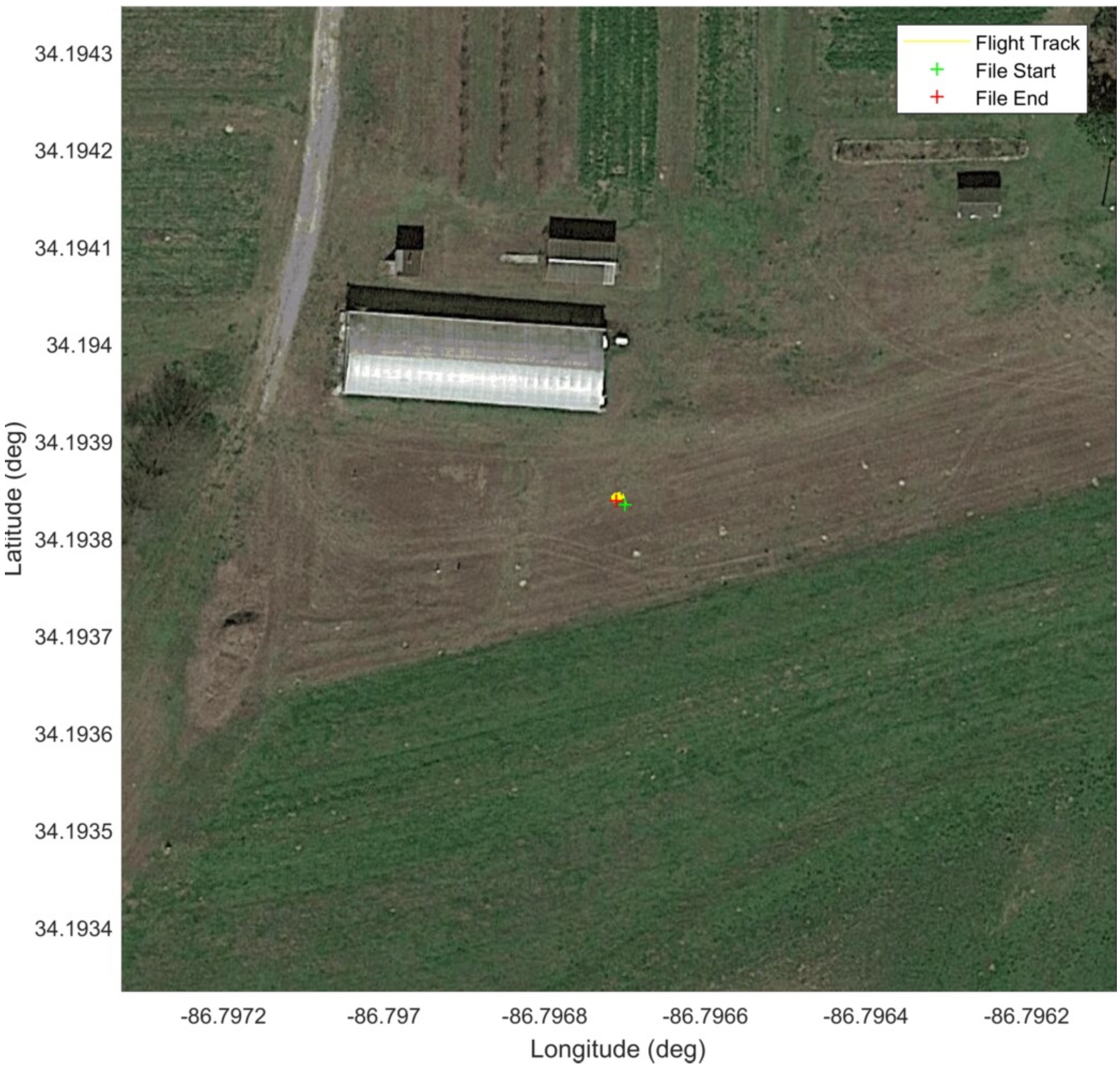

Figure 16: DJI S-1000 Flight 6, Wednesday, 5 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170405-DATA-flight7.csv OPENED at 20:27:05 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00026 20:27:31 34.193837 -86.796722 Profile 2-220 meters up
     0 00169 20:29:54 34.193843 -86.796714
PRO -1 00176 20:30:01 34.193843 -86.796714 Profile 220-2 meters down
     0 00324 20:32:29 34.193837 -86.796715
PRO -1 00326 20:32:31 34.193836 -86.796717 Profile 2-220 meters up
     0 00471 20:34:56 34.193846 -86.796714
PRO -1 00477 20:35:02 34.193846 -86.796714 Profile 220-2 meters down
     0 00628 20:37:33 34.193835 -86.796718
File 20170405-DATA-flight7.csv CLOSED at 20:37:39 GPS
Total scans 00635
```

Figure 17: DJI S-1000 Flight 7, Wednesday, 5 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight1.csv OPENED at 16:08:14 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00025 16:08:39 34.193860 -86.796656 Profile 2-220 meters up
     0 00169 16:11:03 34.193866 -86.796656
PRO -1 00180 16:11:14 34.193868 -86.796655 Profile 220-2 meters down
     0 00329 16:13:43 34.193861 -86.796654
PRO -1 00331 16:13:45 34.193863 -86.796655 Profile 2-220 meters up
     0 00468 16:16:02 34.193862 -86.796653
PRO -1 00475 16:16:09 34.193864 -86.796653 Profile 220-2 meters down
     0 00626 16:18:40 34.193858 -86.796659
File 20170428-DATA-flight1.csv CLOSED at 16:19:22 GPS
Total scans 00669
```

Figure 18: DJI S-1000 Flight 1, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight2.csv OPENED at 16:41:12 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 3!
HOV -1 00020 16:41:32 34.193787 -86.796752 Hover at 2 meters AGL
     0 00033 16:41:45 34.193783 -86.796751
HOV -1 00050 16:42:02 34.193783 -86.796752 Hover at 20 meters AGL
     0 00058 16:42:10 34.193785 -86.796751
HOV -1 00076 16:42:28 34.193785 -86.796754 Hover at 40 meters AGL
     0 00083 16:42:35 34.193784 -86.796749
HOV -1 00097 16:42:49 34.193787 -86.796749 Hover at 60 meters AGL
     0 00102 16:42:54 34.193787 -86.796750
HOV -1 00116 16:43:08 34.193788 -86.796748 Hover at 80 meters AGL
     0 00127 16:43:19 34.193789 -86.796749
HOV -1 00143 16:43:35 34.193789 -86.796755 Hover at 100 meters AGL
     0 00150 16:43:42 34.193791 -86.796751
HOV -1 00164 16:43:56 34.193789 -86.796751 Hover at 120 meters AGL
     0 00169 16:44:01 34.193787 -86.796750
HOV -1 00183 16:44:15 34.193790 -86.796755 Hover at 140 meters AGL
     0 00191 16:44:23 34.193791 -86.796752
HOV -1 00205 16:44:37 34.193786 -86.796751 Hover at 160 meters AGL
     0 00210 16:44:42 34.193787 -86.796751
HOV -1 00224 16:44:56 34.193788 -86.796750 Hover at 180 meters AGL
     0 00237 16:45:09 34.193791 -86.796750
HOV -1 00253 16:45:25 34.193786 -86.796749 Hover at 200 meters AGL
     0 00258 16:45:30 34.193788 -86.796748
HOV -1 00274 16:45:46 34.193791 -86.796748 Hover at 220 meters AGL
     0 00291 16:46:03 34.193792 -86.796750
PRO -1 00293 16:46:05 34.193790 -86.796750 Profile 220-3 meters down
     0 00477 16:49:09 34.193781 -86.796754
File 20170428-DATA-flight2.csv CLOSED at 16:49:31 GPS
Total scans 00500
```

Figure 19: DJI S-1000 Flight 2, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight3.csv OPENED at 17:06:34 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 4!
HOV -1 00027 17:07:01 34.193810 -86.796717 Hover at 2 meters AGL
     0 00048 17:07:22 34.193810 -86.796718
PRO -1 00050 17:07:24 34.193810 -86.796718 Profile 2-220 meters up
     0 00253 17:10:47 34.193817 -86.796719
HOV -1 00255 17:10:49 34.193818 -86.796719 Hover at 220 meters AGL
     0 00286 17:11:20 34.193821 -86.796719
PRO -1 00288 17:11:22 34.193820 -86.796720 Profile 220-2 meters down
     0 00449 17:14:03 34.193808 -86.796718
File 20170428-DATA-flight3.csv CLOSED at 17:14:20 GPS
Total scans 00467
```

Figure 20: DJI S-1000 Flight 3, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight4.csv OPENED at 18:06:07 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 5!
PRO -1 00031 18:06:38 34.193796 -86.796726 Profile 2-220 meters up
     0 00233 18:10:00 34.193799 -86.796726
HOV -1 00235 18:10:02 34.193800 -86.796723 Hover at 220 meters AGL
     0 00250 18:10:17 34.193802 -86.796723
PRO -1 00253 18:10:20 34.193801 -86.796723 Profile 220-2 meters down
     0 00406 18:12:53 34.193790 -86.796728
HOV -1 00410 18:12:57 34.193792 -86.796728 Hover at 10 meters AGL
     0 00436 18:13:23 34.193792 -86.796726
PRO -1 00440 18:13:27 34.193792 -86.796722 Profile 10-220 meters up
     0 00630 18:16:37 34.193799 -86.796725
HOV -1 00631 18:16:38 34.193799 -86.796726 Hover at 220 meters AGL
     0 00646 18:16:53 34.193795 -86.796726
PRO -1 00649 18:16:56 34.193793 -86.796725 Profile 220-10 meters down
     0 00825 18:19:52 34.193794 -86.796726
File 20170428-DATA-flight4.csv CLOSED at 18:20:17 GPS
Total scans 00851
```

Figure 21: DJI S-1000 Flight 4, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight5.csv OPENED at 19:52:43 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 6!
PRO -1 00030 19:53:13 34.193814 -86.796673 Profile 2-220 meters up
     0 00217 19:56:20 34.193822 -86.796675
PRO -1 00226 19:56:29 34.193821 -86.796675 Profile 220-2 meters down
     0 00405 19:59:28 34.193814 -86.796675
HOV -1 00408 19:59:31 34.193813 -86.796675 Hover at 12 meters AGL
     0 00465 20:00:28 34.193816 -86.796673
PRO -1 00468 20:00:31 34.193815 -86.796675 Profile 12-220 meters up
     0 00607 20:02:50 34.193823 -86.796677
HOV -1 00610 20:02:53 34.193824 -86.796677 Hover at 220 meters AGL
     0 00624 20:03:07 34.193825 -86.796674
PRO -1 00626 20:03:09 34.193826 -86.796674 Profile 220-12 meters down
     0 00805 20:06:08 34.193816 -86.796675
File 20170428-DATA-flight5.csv CLOSED at 20:06:38 GPS
Total scans 00836
```

Figure 22: DJI S-1000 Flight 5, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight6.csv OPENED at 20:58:43 GPS
iMet-XQ order (4 left, 5 right)
HOV -1 00019 20:59:02 34.193849 -86.796667 Hover at 2 meters AGL
     0 00079 21:00:02 34.193845 -86.796670
PRO -1 00082 21:00:05 34.193843 -86.796670 Profile 2-220 meters up
     0 00221 21:02:24 34.193848 -86.796669
HOV -1 00223 21:02:26 34.193849 -86.796667 Hover at 220 meters AGL
     0 00233 21:02:36 34.193844 -86.796668
PRO -1 00235 21:02:38 34.193843 -86.796666 Profile 220-2 meters down
     0 00385 21:05:08 34.193837 -86.796667
PRO -1 00390 21:05:13 34.193838 -86.796667 Profile 2-220 meters up
     0 00537 21:07:40 34.193853 -86.796666
PRO -1 00545 21:07:48 34.193849 -86.796668 Profile 220-2 meters down
     0 00698 21:10:21 34.193842 -86.796668
File 20170428-DATA-flight6.csv CLOSED at 21:10:46 GPS
Total scans 00724
```

Figure 23: DJI S-1000 Flight 6, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight7.csv OPENED at 21:52:21 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00025 21:52:46 34.193840 -86.796678 Profile 2-220 meters up
     0 00167 21:55:08 34.193844 -86.796673
HOV -1 00169 21:55:10 34.193845 -86.796673 Hover at 220 meters AGL
     0 00208 21:55:49 34.193852 -86.796675
PRO -1 00212 21:55:53 34.193850 -86.796674 Profile 220-2 meters down
     0 00361 21:58:22 34.193840 -86.796673
PRO -1 00366 21:58:27 34.193841 -86.796672 Profile 2-220 meters up
     0 00511 22:00:52 34.193847 -86.796676
PRO -1 00523 22:01:04 34.193852 -86.796674 Profile 220-2 meters down
     0 00673 22:03:34 34.193841 -86.796677
File 20170428-DATA-flight7.csv CLOSED at 22:04:06 GPS
Total scans 00706
```

Figure 24: DJI S-1000 Flight 7, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight8.csv OPENED at 22:30:37 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00026 22:31:03 34.193816 -86.796692 Profile 2-220 meters up
     0 00172 22:33:29 34.193816 -86.796692
PRO -1 00181 22:33:38 34.193817 -86.796689 Profile 220-2 meters down
     0 00330 22:36:07 34.193814 -86.796691
PRO -1 00335 22:36:12 34.193814 -86.796692 Profile 2-220 meters up
     0 00479 22:38:36 34.193819 -86.796690
PRO -1 00490 22:38:47 34.193818 -86.796690 Profile 220-3 meters down
     0 00640 22:41:17 34.193816 -86.796691
File 20170428-DATA-flight8.csv CLOSED at 22:41:35 GPS
Total scans 00659
```

Figure 25: DJI S-1000 Flight 8, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

Appendix B – Catalog of MD4-1000 flight tracks and marker files from the 2017 VORTEX-SE campaign

```
File 20170428-DATA-flight3.csv OPENED at 16:41:28 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 2!
HOV -1 00012 16:41:40 34.193863 -86.796303 Hover at 5 meters AGL
     0 00039 16:42:07 34.193858 -86.796301
PRO -1 00041 16:42:09 34.193858 -86.796302 Profile 5-220 meters up
     0 00270 16:45:58 34.193984 -86.796306
HOV -1 00271 16:45:59 34.193982 -86.796305 Hover at 220 meters AGL
     0 00304 16:46:32 34.193995 -86.796306
PRO -1 00306 16:46:34 34.194017 -86.796301 Profile 220-20 meters down
     0 00467 16:49:15 34.193857 -86.796303
HOV -1 00469 16:49:17 34.193858 -86.796303 Hover at 20 meters AGL
     0 00498 16:49:46 34.193860 -86.796306
File 20170428-DATA-flight3.csv CLOSED at 16:50:28 GPS
Total scans 00540
```

Figure 26: MD4-1000 Flight 3, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight4.csv OPENED at 17:06:42 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 3!
HOV -1 00013 17:06:55 34.193915 -86.796232 Hover at 7.5 meters AGL
     0 00045 17:07:27 34.193910 -86.796235
PRO -1 00047 17:07:29 34.193913 -86.796236 Profile 7.5-220 meters up
     0 00258 17:11:00 34.194228 -86.796235
HOV -1 00261 17:11:03 34.194237 -86.796233 Hover at 220 meters AGL
     0 00288 17:11:30 34.194331 -86.796235
PRO -1 00290 17:11:32 34.194330 -86.796235 Profile 220-2 meters down
     0 00489 17:14:52 34.193937 -86.796241
File 20170428-DATA-flight4.csv CLOSED at 17:15:20 GPS
Total scans 00518
```

Figure 27: MD4-1000 Flight 4, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight5.csv OPENED at 18:06:15 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 4!
HOV -1 00014 18:06:29 34.193913 -86.796233 Hover at 4 meters AGL
     0 00040 18:06:55 34.193910 -86.796230
PRO -1 00042 18:06:57 34.193910 -86.796228 Profile 20-220 meters up
     0 00252 18:10:27 34.193914 -86.796231
HOV -1 00254 18:10:29 34.193913 -86.796233 Hover at 220 meters AGL
     0 00273 18:10:49 34.193971 -86.796235
PRO -1 00275 18:10:51 34.193968 -86.796235 Profile 220-20 meters down
     0 00416 18:13:12 34.193912 -86.796235
HOV -1 00417 18:13:13 34.193911 -86.796234 Hover at 10 meters AGL
     0 00453 18:13:49 34.193908 -86.796235
PRO -1 00455 18:13:51 34.193909 -86.796232 Profile 20-220 meters up
     0 00634 18:16:50 34.194005 -86.796236
HOV -1 00636 18:16:52 34.193999 -86.796233 Hover at 220 meters AGL
     0 00659 18:17:15 34.193910 -86.796231
PRO -1 00662 18:17:18 34.193908 -86.796231 Profile 220-20 meters down
     0 00820 18:19:56 34.193910 -86.796232
HOV -1 00823 18:19:59 34.193908 -86.796232 Hover at 20 meters AGL
     0 00855 18:20:31 34.193898 -86.796264
File 20170428-DATA-flight5.csv CLOSED at 18:21:06 GPS
Total scans 00891
```

Figure 28: MD4-1000 Flight 5, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight6.csv OPENED at 19:52:55 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 5!
HOV -1 00017 19:53:12 34.193929 -86.796110 Hover at 6 meters AGL
     0 00037 19:53:32 34.193928 -86.796113
PRO -1 00040 19:53:35 34.193927 -86.796110 Profile 2-220 meters up
     0 00222 19:56:37 34.193938 -86.796109
HOV -1 00224 19:56:39 34.193932 -86.796111 Hover at 220 meters AGL
     0 00242 19:56:57 34.193931 -86.796109
PRO -1 00244 19:56:59 34.193932 -86.796110 Profile 220-12 meters down
     0 00429 20:00:04 34.193928 -86.796112
HOV -1 00431 20:00:06 34.193928 -86.796111 Hover at 9 meters AGL
     0 00472 20:00:47 34.193929 -86.796109
PRO -1 00476 20:00:51 34.193930 -86.796110 Profile 12-220 meters up
     0 00622 20:03:18 34.193997 -86.796111
HOV -1 00624 20:03:20 34.193988 -86.796110 Hover at 220 meters AGL
     0 00645 20:03:41 34.193953 -86.796110
PRO -1 00647 20:03:43 34.193972 -86.796111 Profile 220-6 meters down
     0 00846 20:07:02 34.193919 -86.796149
File 20170428-DATA-flight6.csv CLOSED at 20:07:29 GPS
Total scans 00874
```

Figure 29: MD4-1000 Flight 6, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight7.csv OPENED at 21:36:10 GPS
iMet-XQ order (3 left, 6 right)
PRO -1 00030 21:36:40 34.193849 -86.796660 Profile 5-215 meters up
     0 00163 21:38:53 34.194456 -86.796851
PRO -1 00283 21:40:53 34.195420 -86.797526 Profile 215-10 meters down
     0 00547 21:45:18 34.193729 -86.796738
File 20170428-DATA-flight7.csv CLOSED at 21:45:59 GPS
Total scans 00589
```

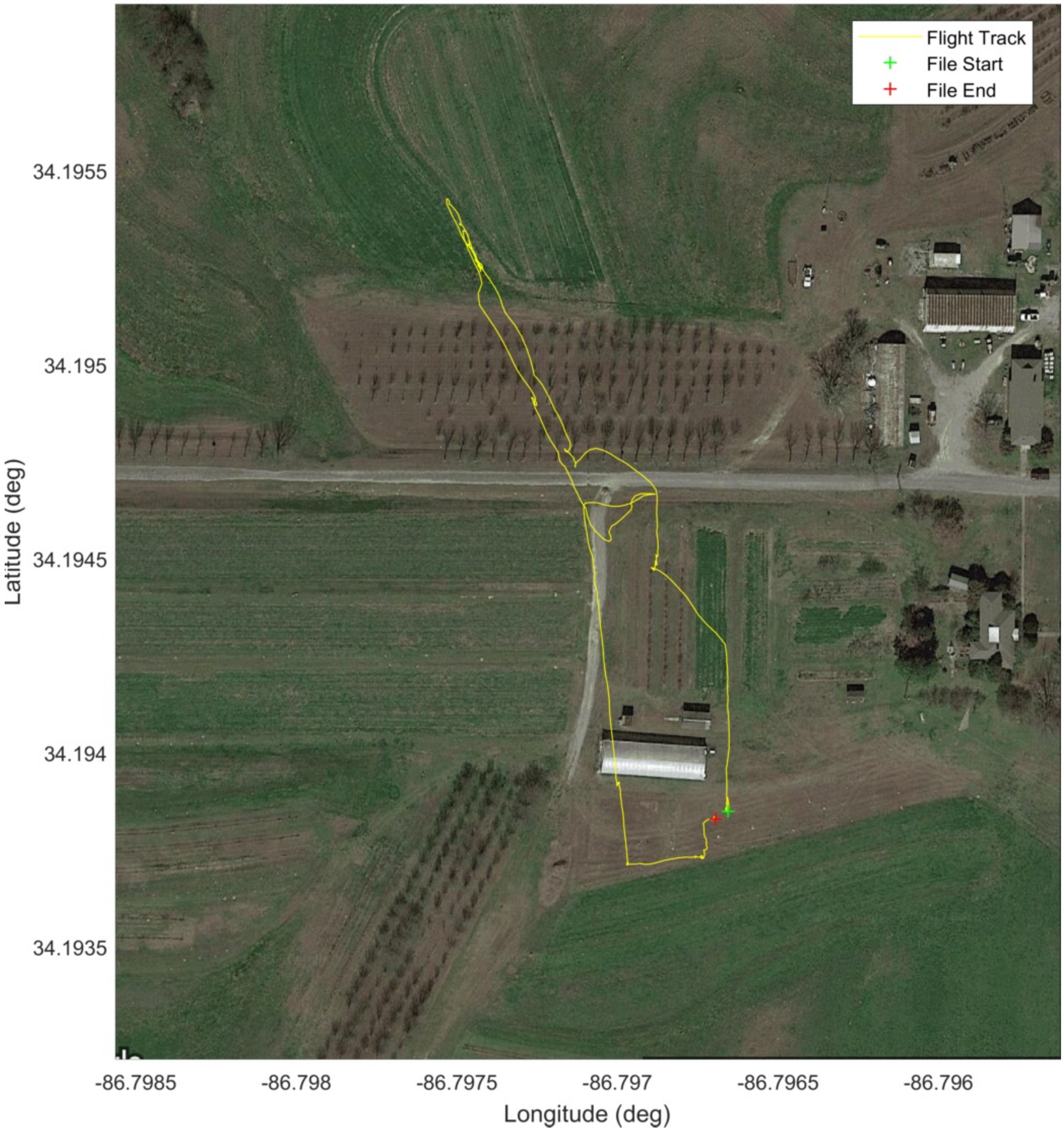

Figure 30: MD4-1000 Flight 7, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

```
File 20170428-DATA-flight8.csv OPENED at 22:59:26 GPS
iMet-XQ order (3 left, 6 right)
PRO -1 00024 22:59:50 34.193822 -86.796667 Profile 2-220 meters up
     0 00140 23:01:46 34.193828 -86.796666
PRO -1 00151 23:01:57 34.193827 -86.796668 Profile 220-2 meters down
     0 00291 23:04:17 34.193819 -86.796667
PRO -1 00299 23:04:25 34.193823 -86.796665 Profile 2-190 meters up
     0 00421 23:06:28 34.194227 -86.796832
PRO -1 00433 23:06:40 34.194441 -86.796892 Profile 190-15 meters down
     0 00590 23:09:17 34.193691 -86.796680
File 20170428-DATA-flight8.csv CLOSED at 23:09:55 GPS
Total scans 00629
```

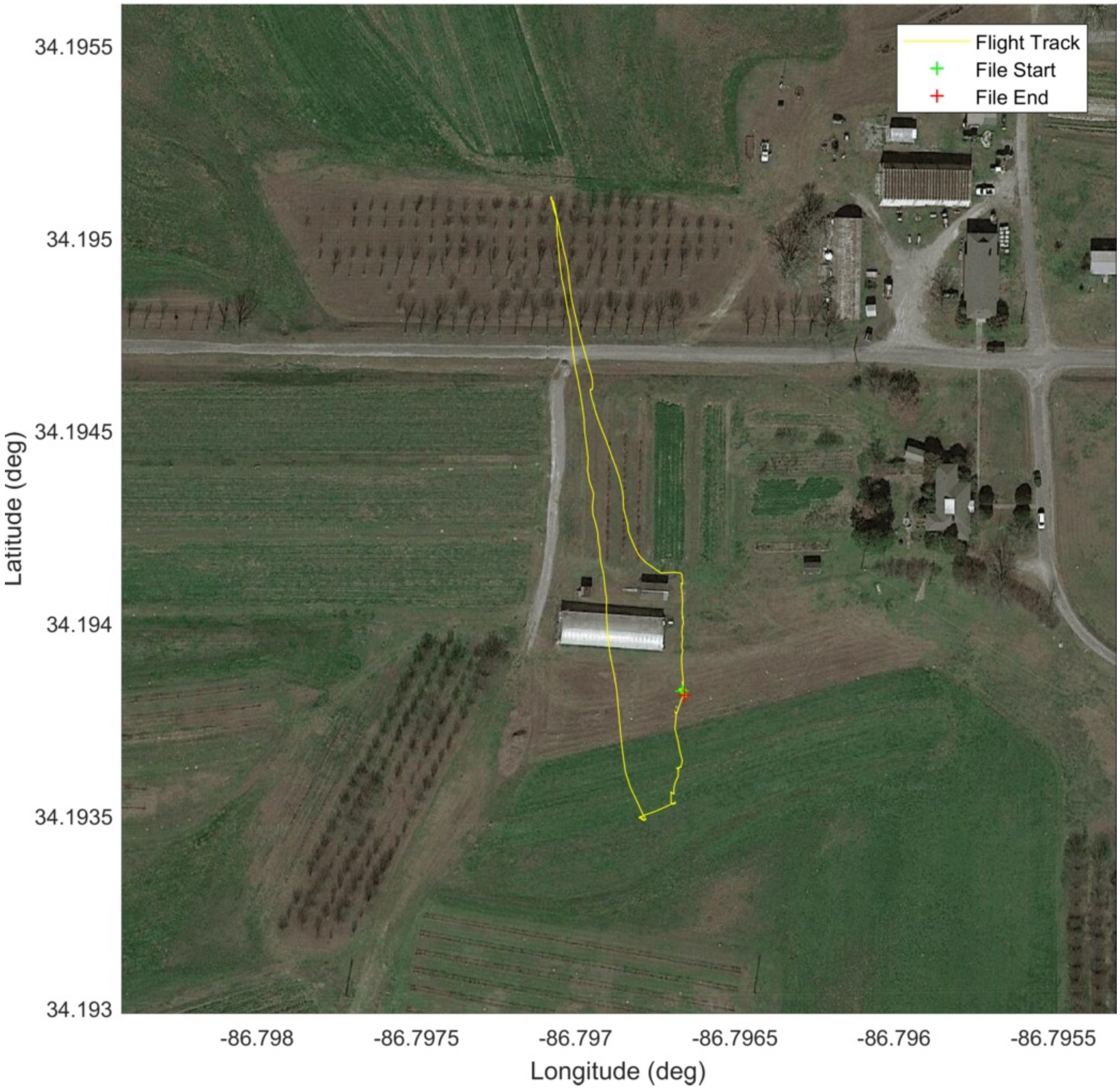

Figure 31: MD4-1000 Flight 8, Friday, 28 April 2017 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the SUAS flight, respectively.

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