NOAA Technical Memorandum OAR ARL-273

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Notice

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List of Abbreviations and Acronyms

Abbreviation	Acronym
AGL	Above ground level
ARL	Air Resources Laboratory
ATDD	Atmospheric Turbulence and Diffusion Division
GPS	Global positioning system
iOSD	On-Screen Display
IR	Infrared
LDT	Local daylight time
MATLAB©	Matrix Laboratory
MSL	Mean sea level
NOAA	National Oceanic and Atmospheric Administration
sUAS	Small unmanned aircraft system
UTC	Universal coordinated time

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 2016. The S-1000 was used to measure temperature and humidity profiles in the lower 125-213 m of the atmosphere, and map the Earth's skin temperature during three intensive observation periods (13 March, 24 March, and 27 April) in the VORTEX-SE experiment. Additionally, the S-1000 was used to perform a damage survey from an EF-2 tornado that occurred within the VORTEX-SE domain on 31 March 2016.

Introduction

The Verification of the Origins of Rotation in Tornadoes Experiment Southeast (VORTEX-SE) is a research program to understand the formation, intensity, structure, and path of tornadoes in the southeast region of the United States. The experiment took place from 1 March through 1 May 2016 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 either 125 m or 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 13 March, 24 March, 5 April, and 27 April 2016 that correspond roughly to IOPs designated for the VORTEX-SE program. A total of 11 flights were made in six locations 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 13 March 2016, the first day the S-1000 was 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).

Table 1: Summary of DJI S-1000 flights made during VORTEX-SE 2016

Date (YYYY/MM/DD)	Location	Flight	Takeoff time (LDT)	Landing time (LDT)	Takeoff time (GPS)	Landing time (GPS)	Flight Time (HH:MM:SS)	Scans
2016/03/13	Belle Mina	1	18:04:23	18:17:19	23:04:40	23:17:36	00:12:56	776
2016/03/13	Belle Mina	2	18:26:47	18:39:31	23:27:04	23:39:48	00:12:44	764
2016/03/13	Belle Mina	3	19:01:59	19:16:13	00:02:16	00:16:30	00:14:14	854
2016/03/24	Cullman	1	14:20:54	14:26:58	19:21:11	19:27:15	00:06:04	364
2016/04/05	Priceville1	1	11:56:27	12:07:37	16:56:44	17:07:54	00:11:10	670
2016/04/05	Priceville[2]	2	13:41:08	13:53:53	18:41:25	18:54:10	00:12:45	765
2016/04/05	Priceville[3]	3	14:18:45	14:31:23	19:19:02	19:31:40	00:12:38	758
2016/04/05	Priceville[4]	4	15:16:43	15:29:45	20:17:00	20:30:02	00:13:02	782
2016/04/27	Cullman	1	15:10:04	15:25:13	20:10:21	20:25:30	00:15:09	909
2016/04/27	Cullman	2	16:05:28	16:20:21	21:05:45	21:20:38	00:14:53	893
2016/04/27	Cullman	3	18:13:59	18:27:49	23:14:16	23:28:06	00:13:50	830

Flights at Belle Mina and Cullman were made primarily to measure atmospheric temperature and moisture profiles and surface temperature. The Priceville flights were conducted at four different locations to survey damage along the path of the 31 March 2016 Priceville EF-2 tornado. The flight at Cullman on 24 March 2016 was shorter than the other flights due to rain. The takeoff and landing coordinates as well as the elevation and maximum flight altitude for each flight area are shown in Table 2.

Table 2: Locations of DJI S-1000 flights in Alabama during VORTEX-SE 2016

Location	Coordinates	Elevation (m MSL)	Max altitude (m AGL)
Belle Mina	34.689136 N, 86.884254 W	189	125
Cullman	34.193924 N, 86.796586 W	245	213
Priceville[1]	34.473306 N, 86.925149 W	178	213
Priceville[2]	34.517659 N, 86.858952 W	263	125
Priceville[3]	34.517287 N, 86.857099 W	257	125
Priceville[4]	34.505696 N, 86.876620 W	251	125

A map of each location identified in Table 2 is shown in Figure 2.

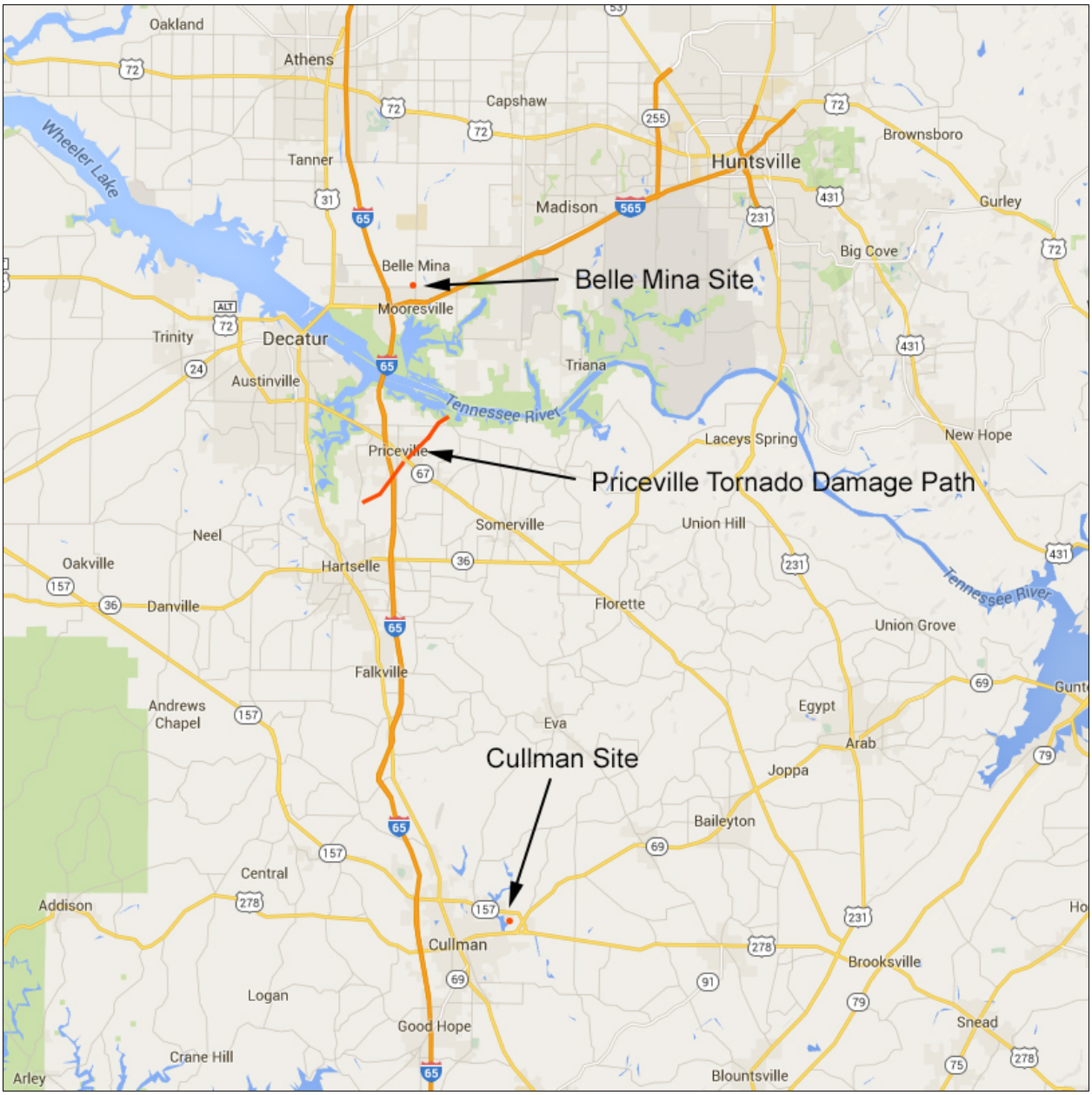

Figure 2: Map showing S-1000 flight locations in the VORTEX-SE domain.

Instrument Description

Two International Met Systems iMet-XQ sensors were used to measure air temperature, relative humidity, and pressure (T/RH/P) onboard the aircraft. One device (iMet-dev4) was located on the left side and the other (iMet-dev5) on the right side of the aircraft. The instruments are self-contained 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	±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 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 7.5 Hz continuously while the aircraft was being flown. This 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 3 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	7.5 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 record video in the visible wavelength band during flight. Data from the camera were downlinked using a DJI iOSD Mk II system to a ground station that was monitored during flight. Video data were simultaneously recorded on a microSD card inside the GoPro camera. 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 3 for details.

Figure 3 shows the configuration of the iMet-XQ sensor, 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.

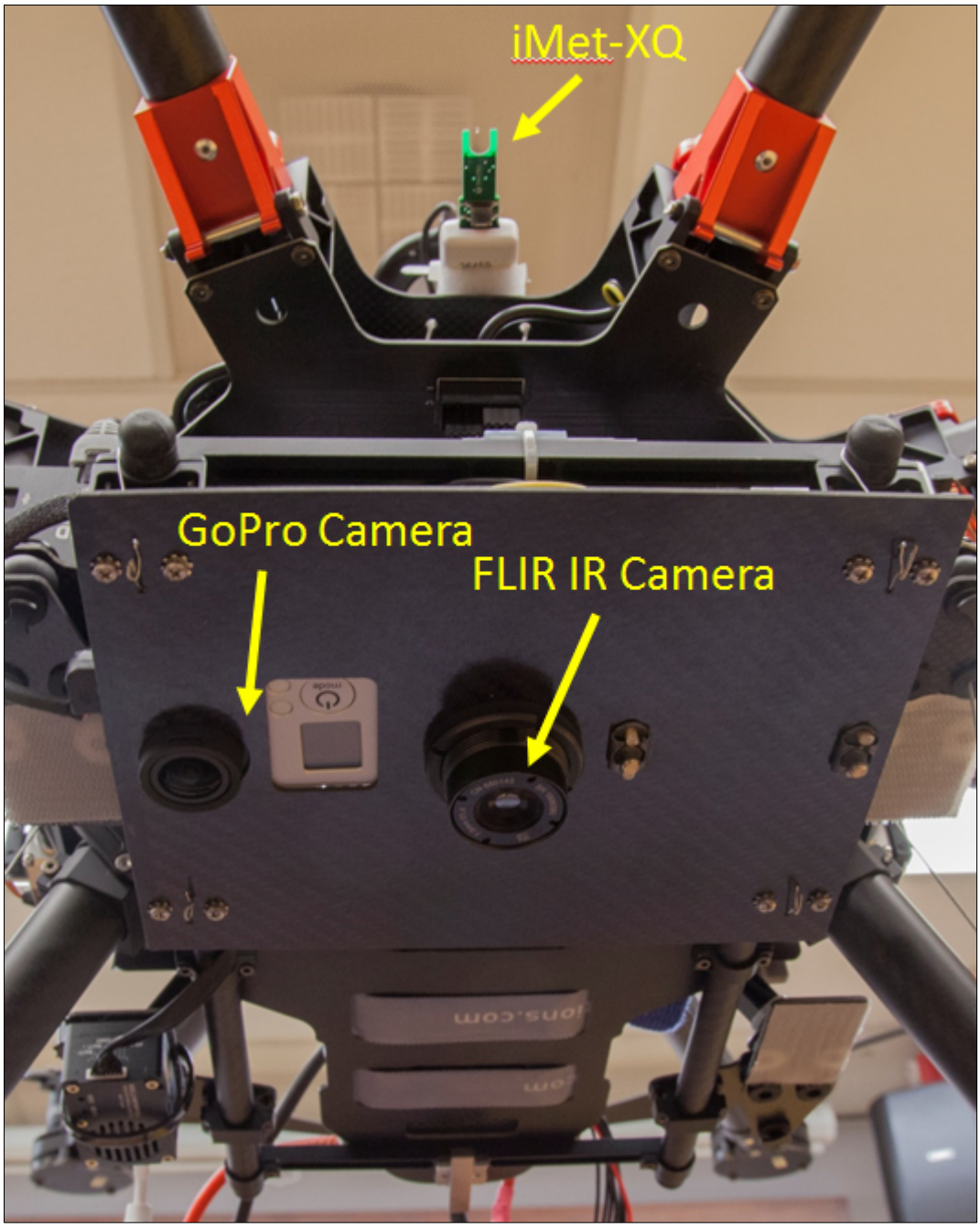

Figure 3: Instrumentation on the DJI S-1000 sUAS.

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.

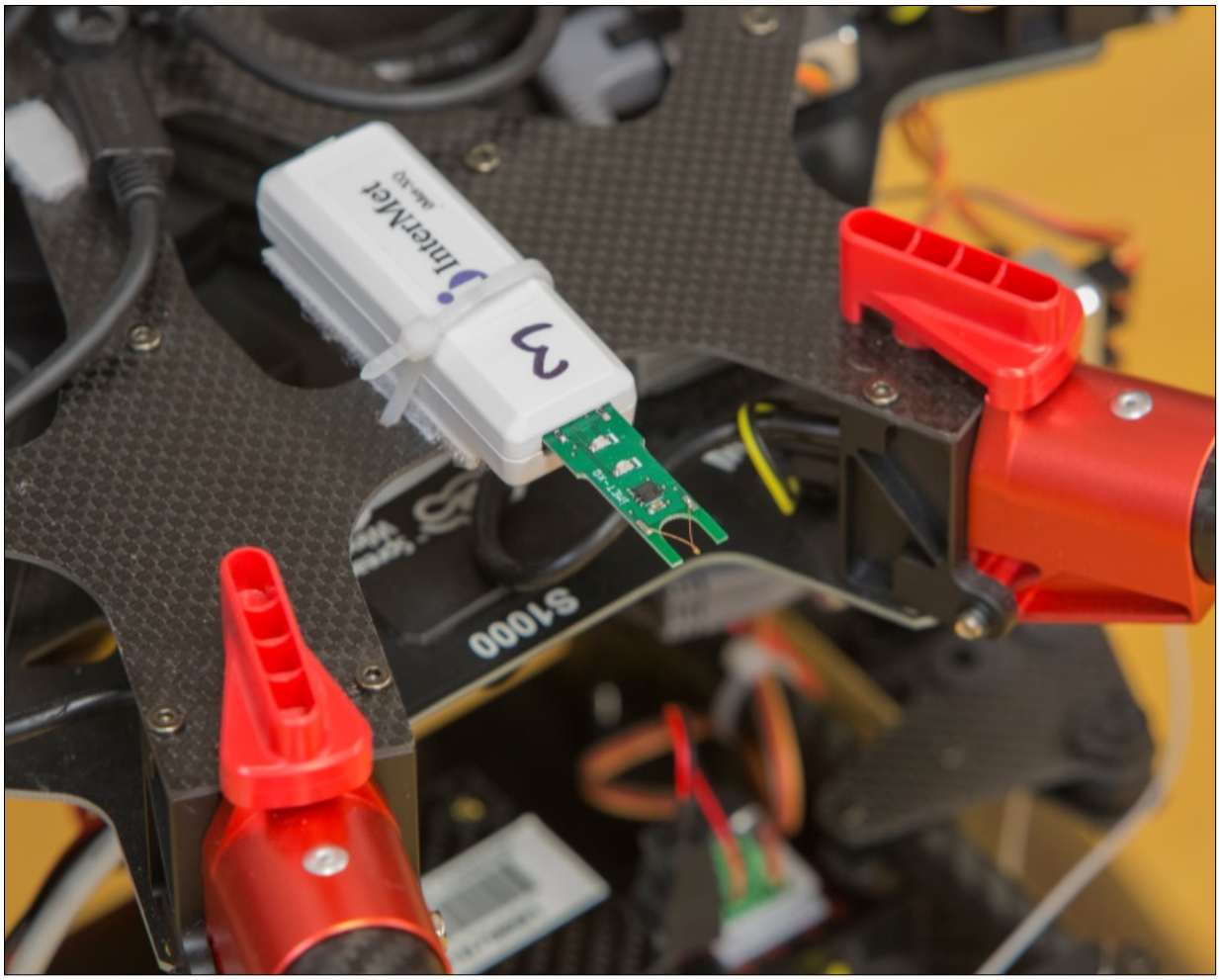

Figure 4: Detail of the iMet-XQ T/RH/P sensor installation on the DJI S-1000.

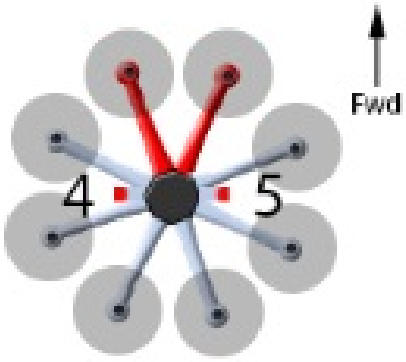

Figure 5: Schematic of iMet-XQ sensor locations on S-1000

Data Collection and Processing

Data from the DJI A2 autopilot was stored on-board the aircraft during flight, along with data from the iMet-XQ sensors, the FLIR IR camera, and the GoPro Hero 3 camera. Each device was powered on prior to takeoff and then powered off after landing. Following the flight, data from each device (the DJI A2 autopilot, iMet-XQ, FLIR IR camera, and GoPro Hero 3 video 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 7.5 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 appropriate iMet-XQ T, RH, and P data for each line, as well as the index of the appropriate FLIR .csv frame number for each line. 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.

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	+098837	+2028	+0632	2016/03/13	23:04:40	+0346890920	-0868842459	+00187320	14
00037272	XQ	+098827	+2031	+0635	2016/03/13	23:04:41	+0346890940	-0868842456	+00187878	14
00037272	XQ	+098810	+2040	+0632	2016/03/13	23:04:42	+0346890962	-0868842446	+00188455	14
00037272	XQ	+098811	+2054	+0631	2016/03/13	23:04:43	+0346890975	-0868842443	+00188827	14
00037272	XQ	+098811	+2040	+0626	2016/03/13	23:04:44	+0346890976	-0868842451	+00189084	14
…										

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

The sample shown above is from file 20160313-iMet-dev4-flight1.csv. 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	20.53;	20.49;		20.33;	20.21;
Row 2	20.57;	20.45;		20.17;	20.37;
…					
Row 255	20.33;	20.41;		21.09;	21.09;
Row 256	20.25;	20.29;		20.93;	20.93;

Note: All values are scaled to degrees C.

The sample shown above is from file 20160313-FLIR-flight1_0001.csv.

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 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 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 20160313-DATA-flight1.csv OPENED at 23:04:40 GPS						
Payload line	iMet-XQ order (4 left, 5 right)						
Open 1	PRO	-1	00011	23:04:51	34.689099	-86.884253	Profile 5-125 meters up
Close 1		0	00086	23:06:06	34.689100	-86.884251	
Open 2	TRS	-1	00090	23:06:10	34.689100	-86.884253	Transect Southwest at 125m
Close 2		0	00193	23:07:53	34.687100	-86.885228	
Open 3	TRS	-1	00200	23:08:00	34.687101	-86.885230	Transect Northwest at 125m
Close 3		0	00239	23:08:39	34.687271	-86.885487	
…							
Close line	File 20160313-DATA-flight1.csv CLOSED at 23:17:36 GPS						
Total scans	Total scans 00776						

In the example above, the file 20160313-DATA-flight1.csv was opened at 23:04:40 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, if necessary.

In the example file in Table 7, the first task flown was a profile that started (indicated by -1 in the open/close column) at scan 11, 23:04:51 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 5 m AGL and ended at 125 m AGL and went up. 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 11 s into the flight and ended 86 s into the flight, giving an elapsed time of 75 s. With the altitude gain of 120 m, the average rate of climb was 1.6 ms^{-1}.

The next segment is a transect that went to the southwest at a constant altitude of 125 m AGL. This transect began 90 s into the flight and ended 193 s into the flight, taking a total of 103 s. Another transect was started 200 s into the flight, again at 125 m AGL, and took 39 s, flying in a northwesterly direction.

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

Table 8: Abbreviation codes for MKR files

Tag	Name	Description
PRO	Profile	Vertical flight at a constant rate of climb or descent.
TRS	Transect	Forward flight at a constant altitude.

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

Data Remarks

For the most part, the data were recovered completely and correctly. Table 9 shows the data recovery by instrument and flight with comments afterward.

Table 9: Summary of data recovery for VORTEX-SE 2016

Date (YYYY/MM/DD)	Location	Daily flight number	DJI	iMet-XQ Dev 4	iMet-XQ Dev 5	FLIR	GoPro Video	Notes
2016/03/13	Belle Mina	1	Yes	Yes	Yes	Yes	No	
2016/03/13	Belle Mina	2	Yes	Yes	Yes	Yes	No	
2016/03/13	Belle Mina	3	Yes	Yes	Yes	Yes	No	Graw rawinsonde launch
2016/03/24	Cullman	1	Yes	No	Yes	Yes	Yes	iMet did not initialize
2016/04/05	Priceville[1]	1	Yes	Yes	Yes	Yes	Yes	
2016/04/05	Priceville[1]	2	Yes	Yes	Yes	Yes	Yes	
2016/04/05	Priceville[1]	3	Yes	Yes	Yes	No	Yes	FLIR did not record
2016/04/05	Priceville[1]	4	Yes	Yes	Yes	Yes	Yes	
2016/04/27	Cullman	1	Yes	Yes	Yes	Yes	Yes	
2016/04/27	Cullman	2	Yes	Yes	Yes	No	Yes	FLIR did not record
2016/04/27	Cullman	3	Yes	Yes	Yes	Yes	Yes	

[1]Priceville flights didn't include MKR files because the flights were primarily for storm damage assessment. Note that YES indicates data were recovered completely and correctly while NO indicates data were not recovered.

The missing GoPro data from flights 1-3 on 13 March 2016 was due to a full microSD card on the GoPro camera. The flights that evening were primarily to assess vertical profiles of temperature and relative humidity on the rapidly stabilizing boundary layer in the hour preceding sunset. A simultaneous launch of a Graw radiosonde was performed at the beginning of the last flight of the day at 19:02:00 local time.

iMet-XQ sensor number 4 did not initialize during the flight at Cullman on 24 March 2016. This flight was performed under overcast skies and began with a profile to 213 m AGL. Flights at Cullman are allowed to fly to 213 m AGL under an agreement between NOAA and the FAA for sUAS operation in certain types of Class G airspace. During this flight, near the top of the profile, rain began at the surface and rapidly increased in intensity. The aircraft was near the top of the profile at the time and a descent was begun immediately. By the time the aircraft landed it had been exposed to approximately 45 s of heavy rain. It should be noted that the aircraft continued to perform well, excellent flight control was maintained, and the aircraft landed without incident.

The purpose of flights on 5 April 2016 was to survey damage caused by the Priceville EF2 tornado. The primary goal of these flights was to record visual images from the aircraft although the iMet and FLIR were also carried and operated. FLIR data were not obtained on flight 3 due to the FLIR data record switch not being actuated.

Flights on 27 April 2016 at Cullman were performed primarily to obtain vertical profiles of T/RH and spatial distribution of heat flux over the test site. Unfortunately, FLIR data were not obtained on flight 2 due to the FLIR data record switch not being actuated.

Several MATLAB© scripts were built to visualize and manipulate data from the DJI S-1000 instruments. These scripts are described briefly below:

The MATLAB© script *uasDisplay.m* displays time series data from the DJI files (e.g. 20160313-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. 20160313-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. 20160313-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/

Vertical Profiles of Temperature and Relative Humidity

The data shown in the following figures was taken on 13 March 2016 during the first VORTEX-SE 2016 IOP. Three vertical profiles were made with the S-1000 from the surface to 125 m AGL within 1 hour of sunset and allowed detailed observation of the development of an inversion layer in the lower 50 m of the boundary layer, as shown in Figure 6. The profiles also show a more gradual cooling of about one degree in the layer between 50 and 125 m AGL over approximately a one-hour period. The sky conditions were clear and the visibility > 10 miles. Turbulence was negligible. Evening civil twilight ended on 13 March 2016 at 00:18 UTC (19:18 LDT).

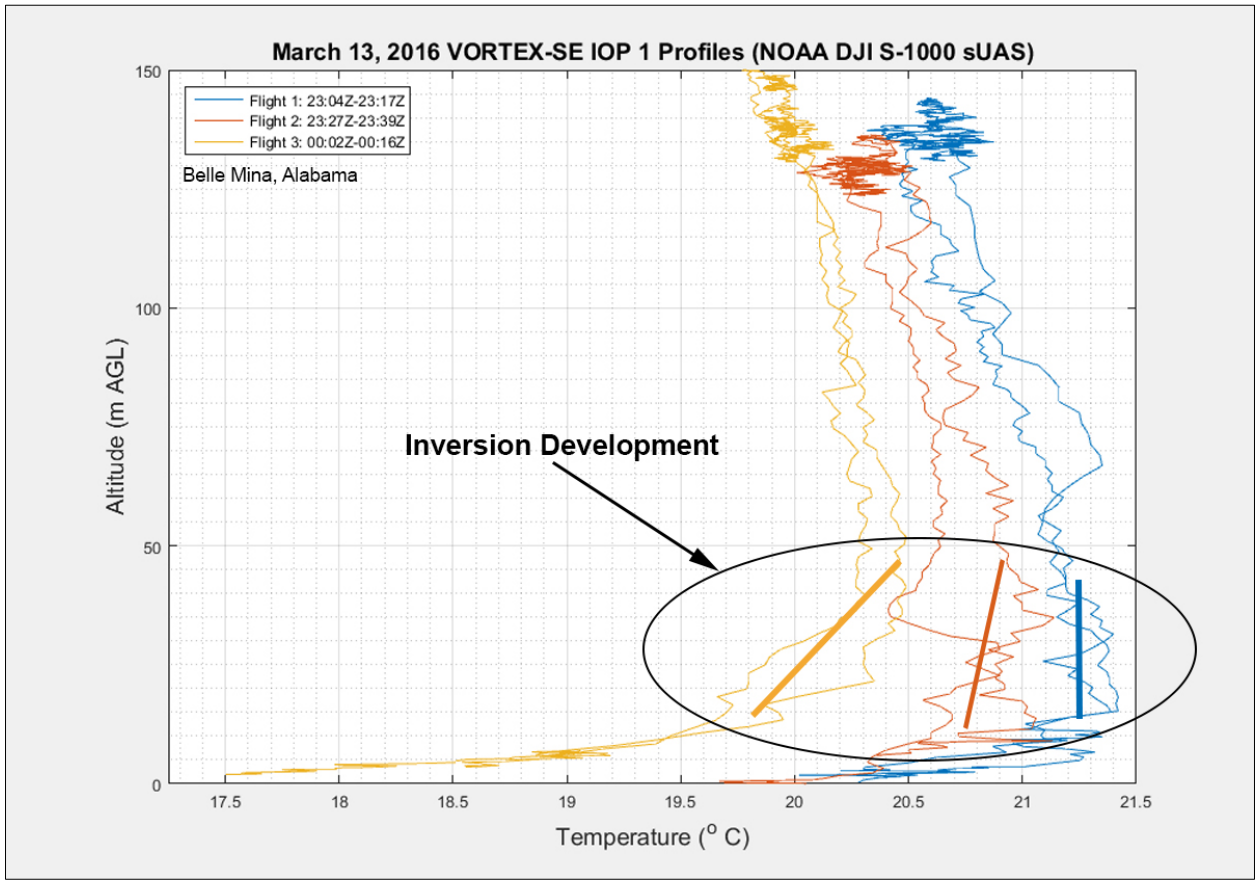

Figure 6: Vertical profiles from 13 March 2016. Blue, orange, and yellow lines correspond with flights 1, 2, and 3, respectively.

Air temperatures measured by the 10 m ATDD flux tower at Belle Mina, which was located approximately 1250 m to the east-northeast of the launch and landing point for the S-1000, show generally good agreement with the profiles measured by the S-1000, except for more rapid cooling noted by the aircraft during flight 3. A detailed view of these temperatures is shown in Figure 7. Figure 8 shows the vertical profiles of moisture for the same series of flights.

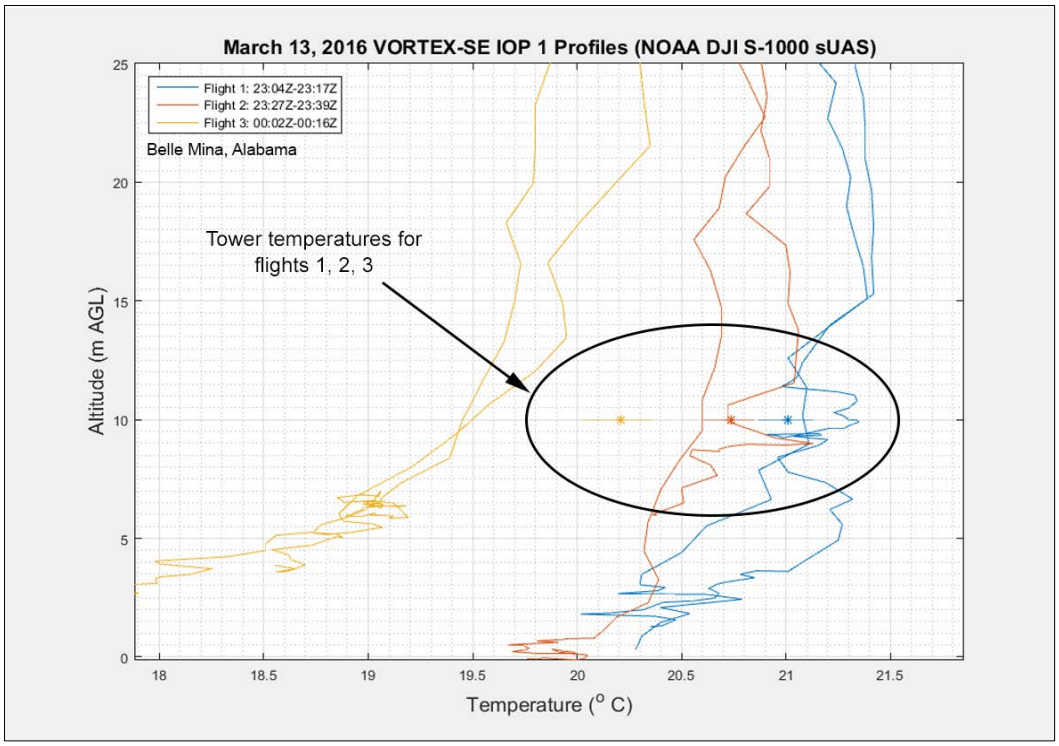

Figure 7: Tower temperatures in relation to S-1000 vertical profiles. Blue, orange, and yellow lines correspond with flights 1, 2, and 3, respectively.

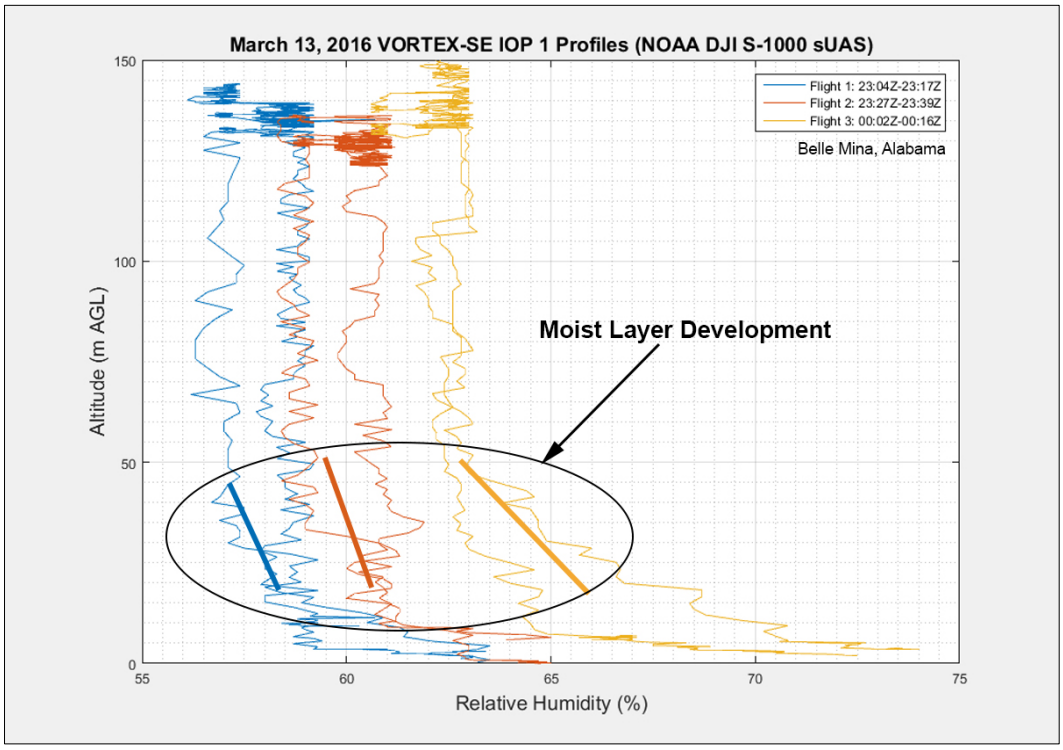

Figure 8: Vertical RH profiles from 13 March 2016 show a moist layer of air near the surface. Blue, orange, and yellow lines correspond with flights 1, 2, and 3, respectively.

Tornado Damage Assessment

The Priceville tornado occurred on 31 March 2016 between 2200 and 2215 LDT and followed the path shown in Figure 9 in orange. The tornado started in the southwest corner near the yellow pushpin and traveled northeast toward the Tennessee River. The damage assessment was performed on 5 April 2016 and included flights in the four areas shown below. The flight tracks for flights 1, 2, 3 and 4 are shown in blue, red, green, and yellow, respectively.

Figure 9: EF-2 tornado damage path (thick orange line) near Priceville on 31 March 2016 and sUAS flights on 5 April 2016. Flights 1, 2, 3, and 4 correspond with blue, green, yellow, and red lines, respectively.

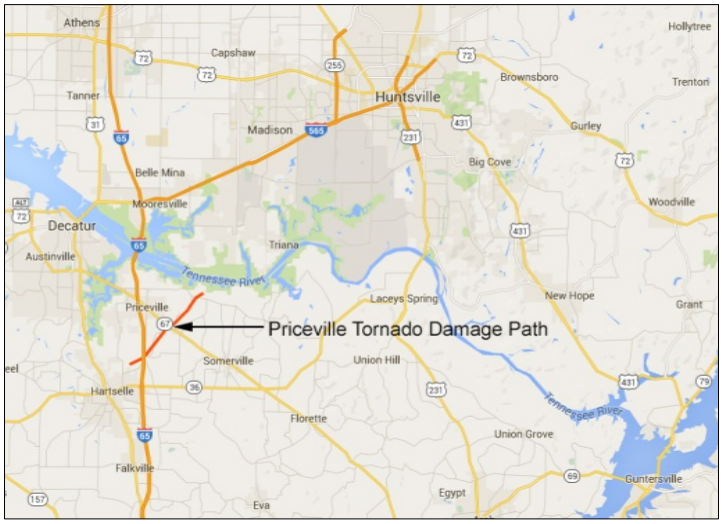

Figure 10: Map of the Priceville tornado damage path in the VORTEX-SE study area.

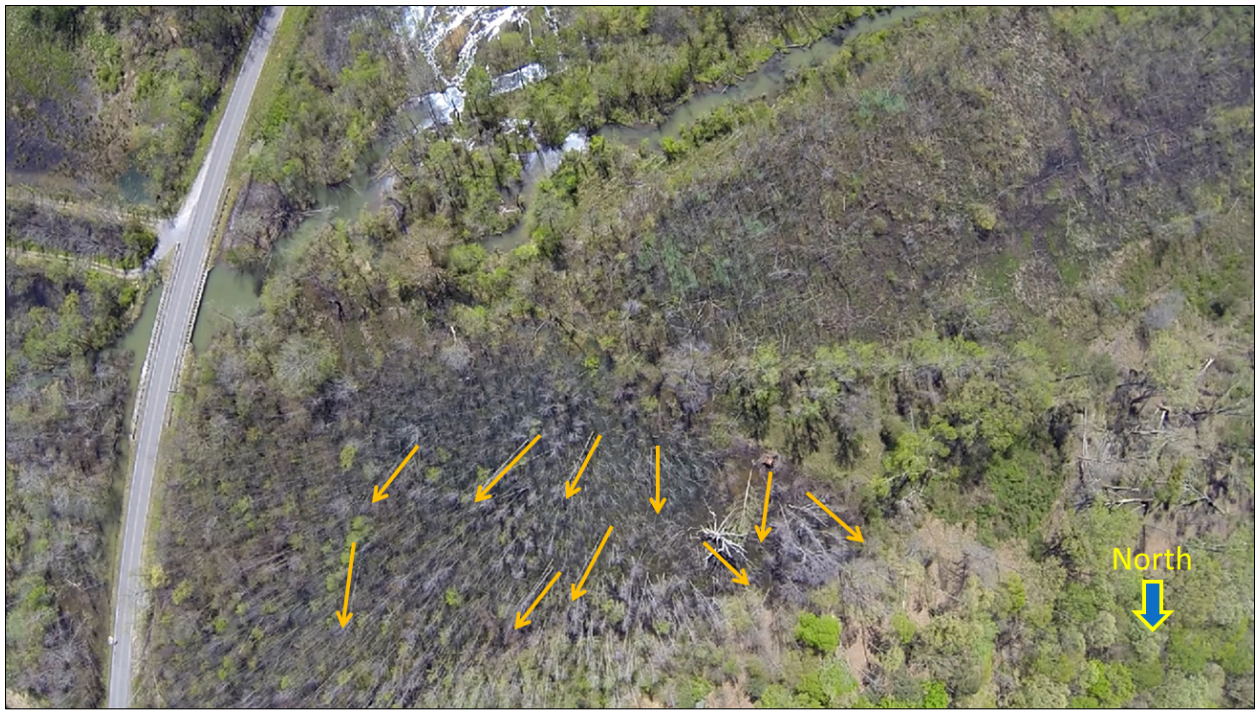

Figure 11: Damage near the SW end of the Priceville tornado track on 5 April 2016 from Flight 1. Orange arrows indicate direction trees fell. North arrow indicated in bottom right.

Figure 12: Damage near the middle of the Priceville tornado track on 5 April 2016 from Flight 2. Orange arrows indicate direction trees fell; red arrow indicates roof damage. North arrow indicated in bottom right.

Figure 13: Damage near the middle of the Priceville tornado track on 5 April 2016 from Flight 3. Orange arrows indicate direction trees fell. North arrow indicated in bottom right.

Figure 14: Damage near the middle of the Priceville tornado track on 5 April 2016 from Flight 4. Orange arrows indicate direction trees fell. North arrow indicated in bottom right.

Appendix A – Catalog of DJI S-1000 flight tracks and marker files from the 2016 VORTEX-SE campaign

```
File 20160313-DATA-flight1.csv OPENED at 23:04:40 GPS
iMet-XQ order(4 left, 5 right)
PRO -1 00011 23:04:51 34.689099 -86.884253 Profile 5-125 meters up
     0 00086 23:06:06 34.689100 -86.884251
TRS -1 00090 23:06:10 34.689100 -86.884253 Transect Southwest at 125 meters
     0 00193 23:07:53 34.687100 -86.885228
TRS -1 00200 23:08:00 34.687101 -86.885230 Transect Northwest at 125 meters
     0 00239 23:08:39 34.687271 -86.885487
TRS -1 00253 23:08:53 34.687306 -86.885496 Transect North at 125 meters
     0 00352 23:10:32 34.691141 -86.885307
TRS -1 00362 23:10:42 34.691184 -86.885301 Transect West at 125 meters
     0 00392 23:11:12 34.691132 -86.886206
TRS -1 00405 23:11:25 34.691036 -86.886173 Transect South at 125 meters
     0 00517 23:13:17 34.687316 -86.886759
TRS -1 00543 23:13:43 34.687414 -86.886633 Transect Northeast at 125 meters
     0 00617 23:14:57 34.688766 -86.884629
PRO -1 00620 23:15:00 34.688767 -86.884620 Profile 125-5 meters down
     0 00727 23:16:47 34.688776 -86.884619
File 20160313-DATA-flight1.csv CLOSED at 23:17:36 GPS
Total scans 00776
```

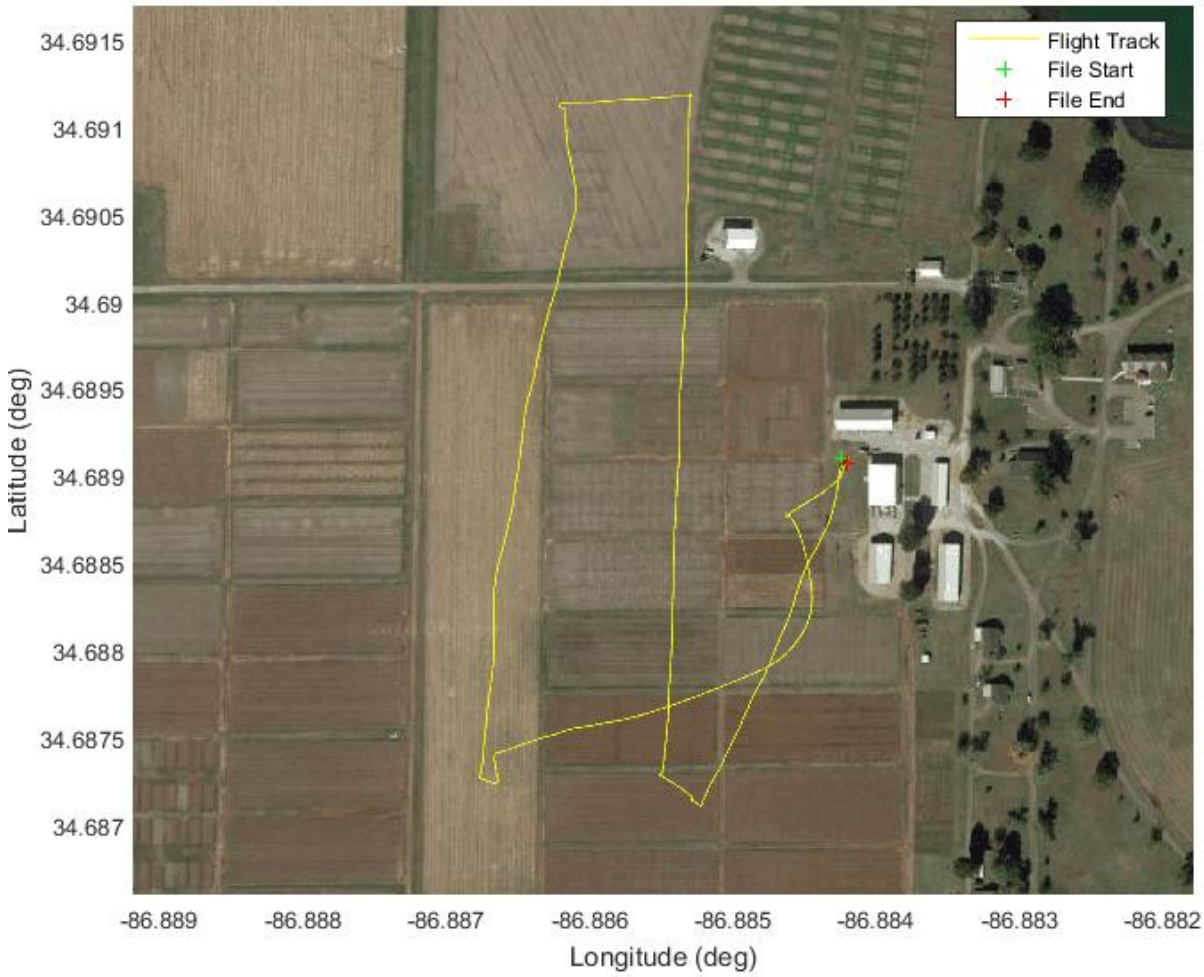

Figure 15: Flight 1, Sunday, 13 March 2016 in Belle Mina, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively.

```
File 20160313-DATA-flight2.csv OPENED at 23:27:04 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00012 23:27:16 34.689082 -86.884204 Profile 5-125 meters up
     0 00101 23:28:45 34.689083 -86.884209
TRS -1 00127 23:29:11 34.689051 -86.884204 Transect South at 125 meters
     0 00181 23:30:05 34.686631 -86.884131
TRS -1 00203 23:30:27 34.686563 -86.884166 Transect West at 125 meters
     0 00221 23:30:45 34.686453 -86.884996
TRS -1 00236 23:31:00 34.686471 -86.885005 Transect North at 125 meters
     0 00320 23:32:24 34.691712 -86.885309
TRS -1 00329 23:32:33 34.691694 -86.885301 Transect West at 125 meters
     0 00339 23:32:43 34.691738 -86.885619
TRS -1 00379 23:33:22 34.691795 -86.885514 Transect South at 125 meters
     0 00499 23:35:23 34.686658 -86.885813
TRS -1 00524 23:35:48 34.686691 -86.885804 Transect Northeast at 125 meters
     0 00621 23:37:25 34.688868 -86.884336
PRO -1 00640 23:37:44 34.688861 -86.884350 Profile 125-5 meters down
     0 00739 23:39:23 34.688864 -86.884339
File 20160313-DATA-flight2.csv CLOSED at 23:39:48 GPS
Total scans 00764
```

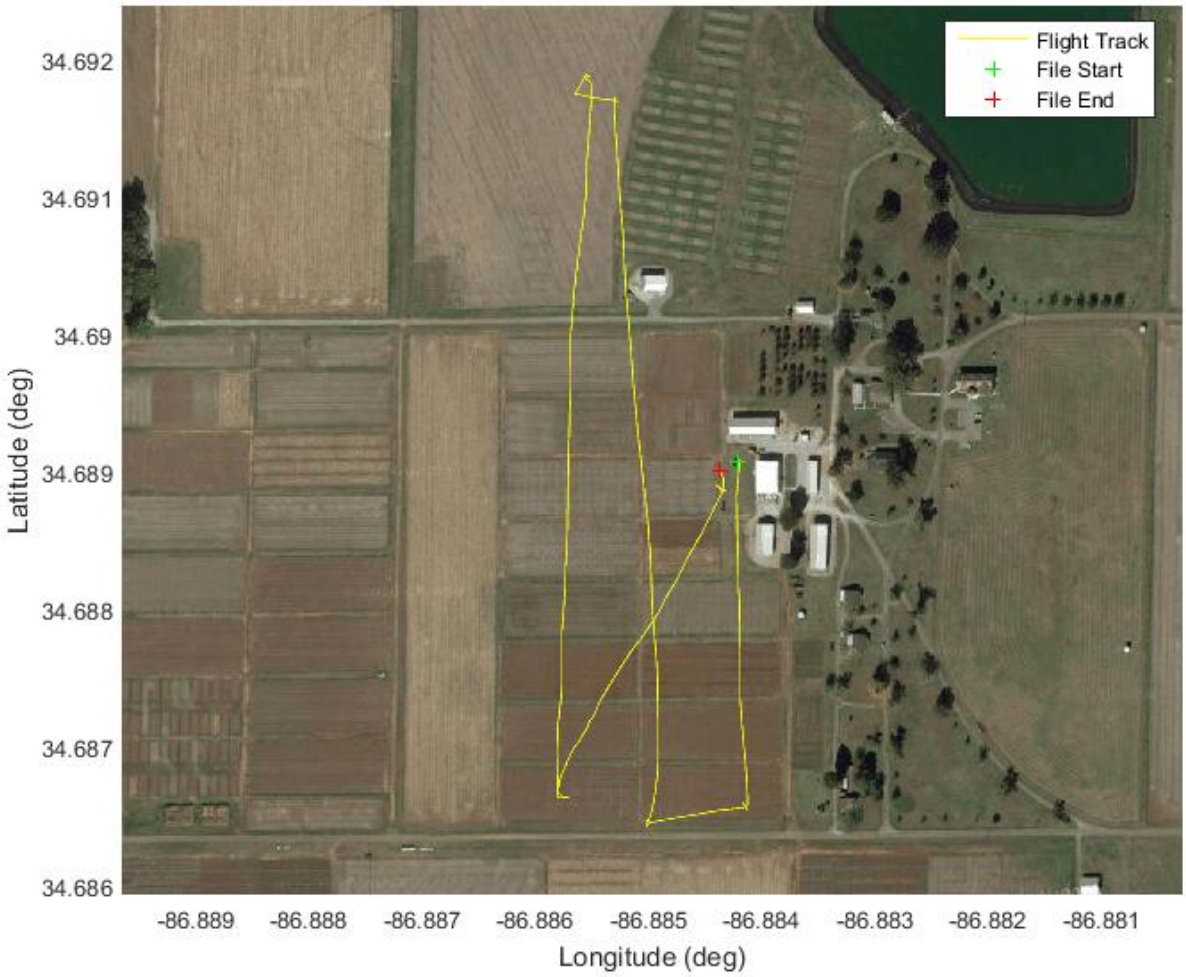

Figure 16: Flight 2, Sunday, 13 March 2016 in Belle Mina, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively.

```
File 20160313-DATA-flight3.csv OPENED at 00:02:16 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00019 00:02:35 34.689012 -86.884343 Profile 5-125 meters up
     0 00106 00:04:02 34.689013 -86.884341
TRS -1 00126 00:04:22 34.688978 -86.884344 Transect South at 125 meters
     0 00173 00:05:09 34.686257 -86.884521
TRS -1 00194 00:05:30 34.686174 -86.884573 Transect West at 125 meters
     0 00208 00:05:44 34.686065 -86.885066
TRS -1 00220 00:05:56 34.686130 -86.885062 Transect North at 125 meters
     0 00309 00:07:25 34.691780 -86.884642
TRS -1 00319 00:07:35 34.691798 -86.884662 Transect West at 125 meters
     0 00338 00:07:54 34.691888 -86.885652
TRS -1 00363 00:08:19 34.691803 -86.885670 Transect South at 125 meters
     0 00449 00:09:45 34.686459 -86.885859
TRS -1 00481 00:10:17 34.686415 -86.885823 Transect North at 125 meters
     0 00561 00:11:37 34.691486 -86.885770
TRS -1 00588 00:12:04 34.691223 -86.885779 Transect Southeast at 125 meters
     0 00631 00:12:47 34.688913 -86.884321
TRS -1 00638 00:12:54 34.688819 -86.884348 Transect Southwest at 125 meters
     0 00669 00:13:25 34.688194 -86.884800
TRS -1 00679 00:13:35 34.688207 -86.884777 Transect Northeast at 125 meters
     0 00699 00:13:55 34.688641 -86.884523
PRO -1 00702 00:13:58 34.688640 -86.884521 Profile 125-5 meters down
     0 00782 00:15:18 34.688638 -86.884523
File 20160313-DATA-flight3.csv CLOSED at 00:16:30 GPS
Total scans 00854
```

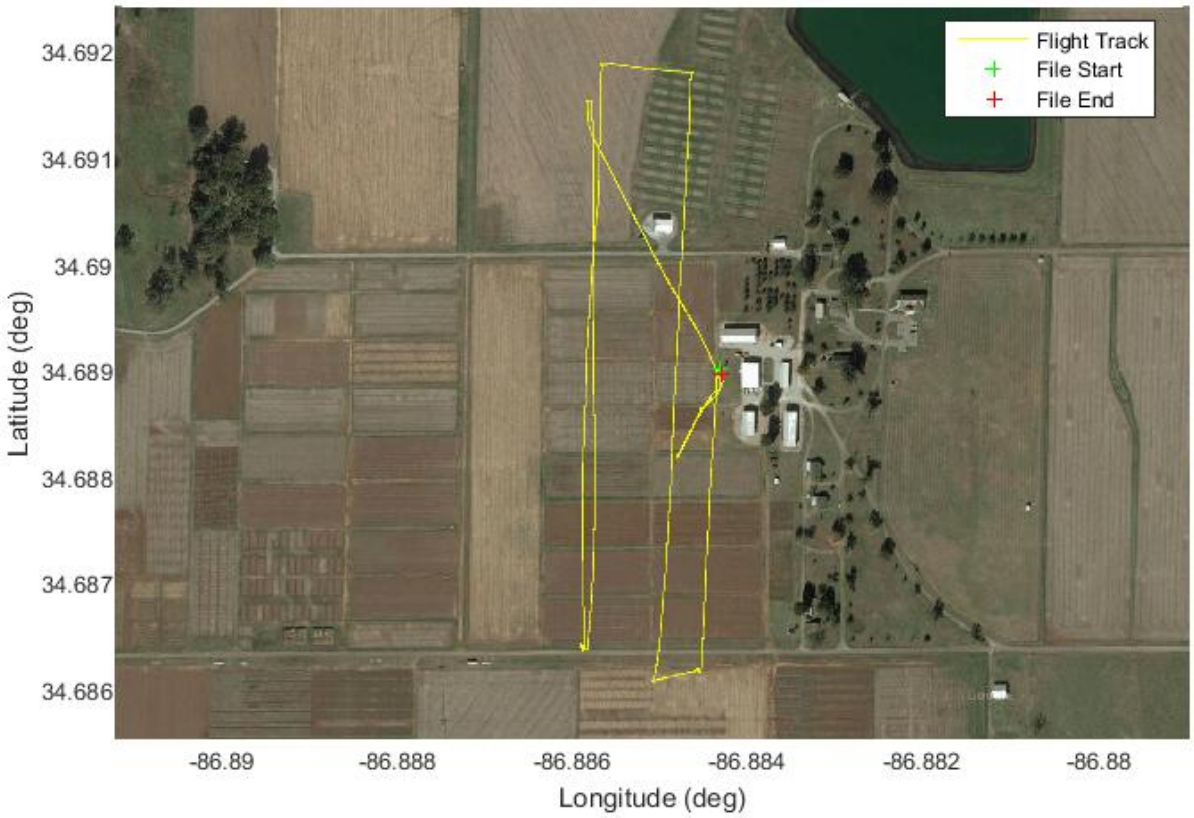

Figure 17: Flight 3, Sunday, 13 March 2016 in Belle Mina, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively.

```
File 20160324-DATA-flight1.csv OPENED at 19:21:11 GPS
iMet-XQ order (4 left, 5 right).  Device 4 did not work this flight.
Weather: Overcast, rain started approximately scan 300.
PRO -1 00010 19:21:21 34.193908 -86.796580 Profile 5-212 meters up
     0 00124 19:23:15 34.193916 -86.796586
PRO -1 00138 19:23:29 34.193909 -86.796579 Profile 212-5 meters down
     0 00343 19:26:54 34.193905 -86.796582
File 20160324-DATA-flight1.csv CLOSED at 19:27:15 GPS
Total scans 00364
```

Figure 18: Flight 1, Thursday, 24 March 2016 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively.

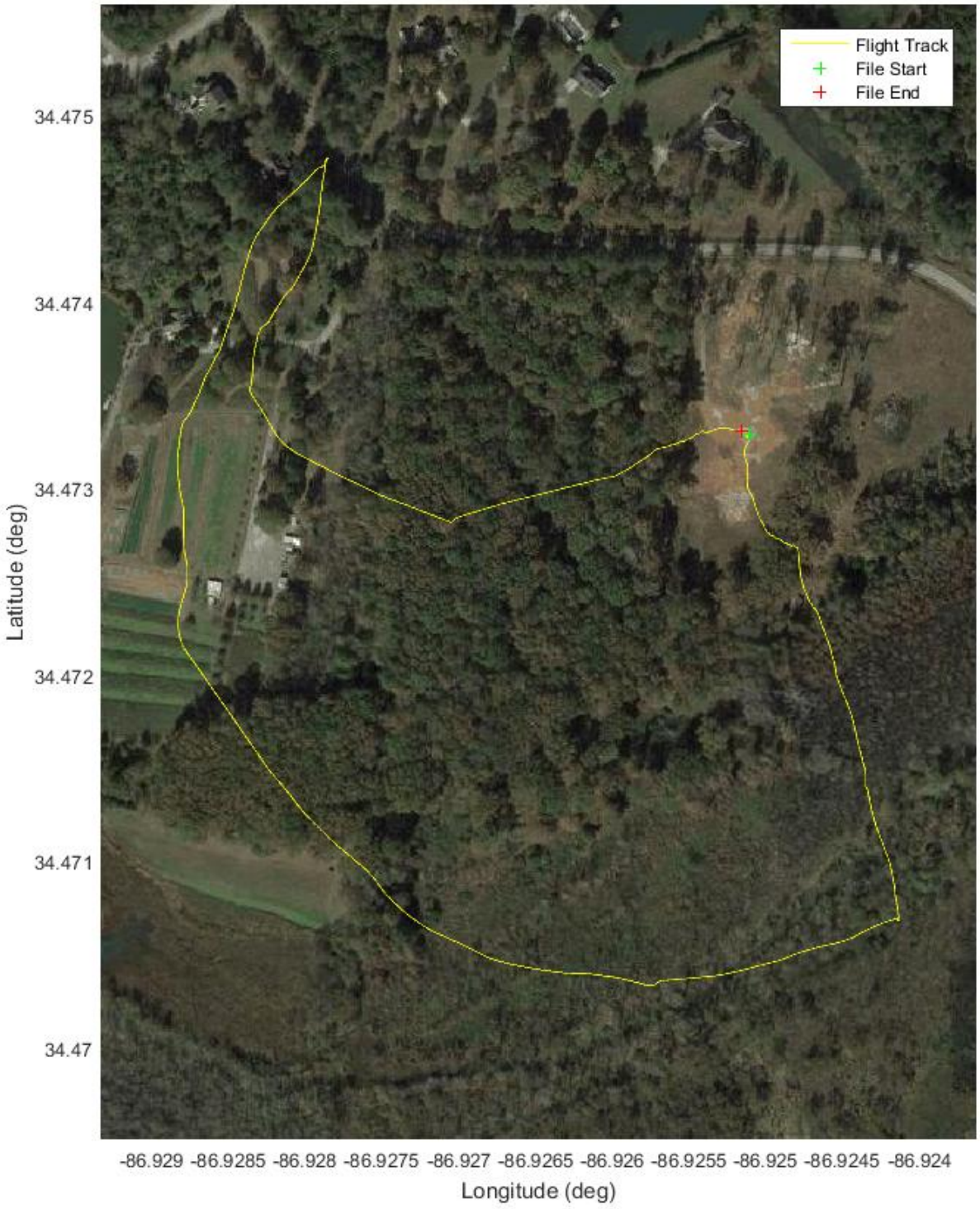

Figure 19: Flight 1, Tuesday, 5 April 2016 near Priceville, Alabama for storm damage assessment. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively.

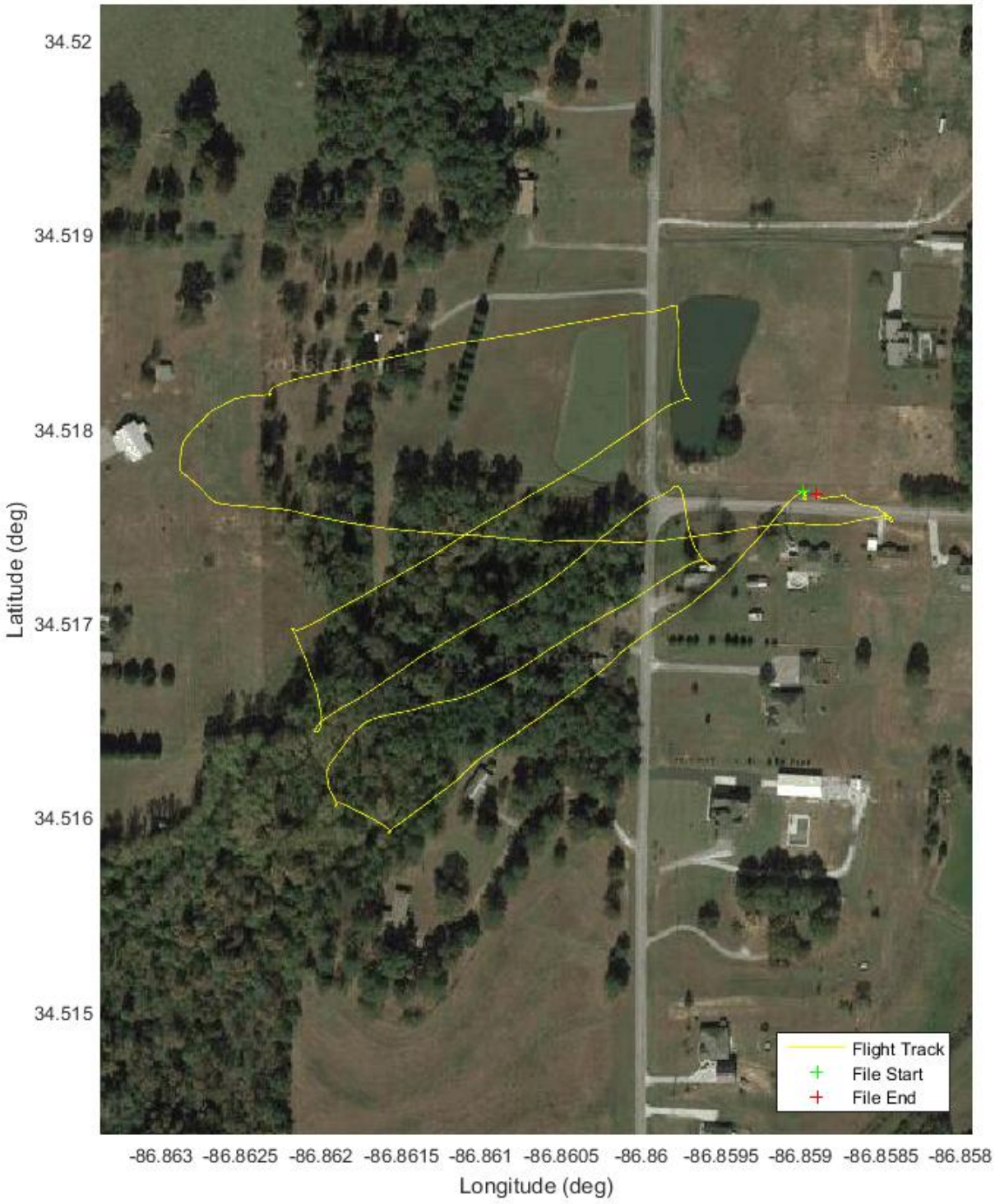

Figure 20: Flight 2, Tuesday, 5 April 2016 near Priceville, Alabama for storm damage assessment. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively.

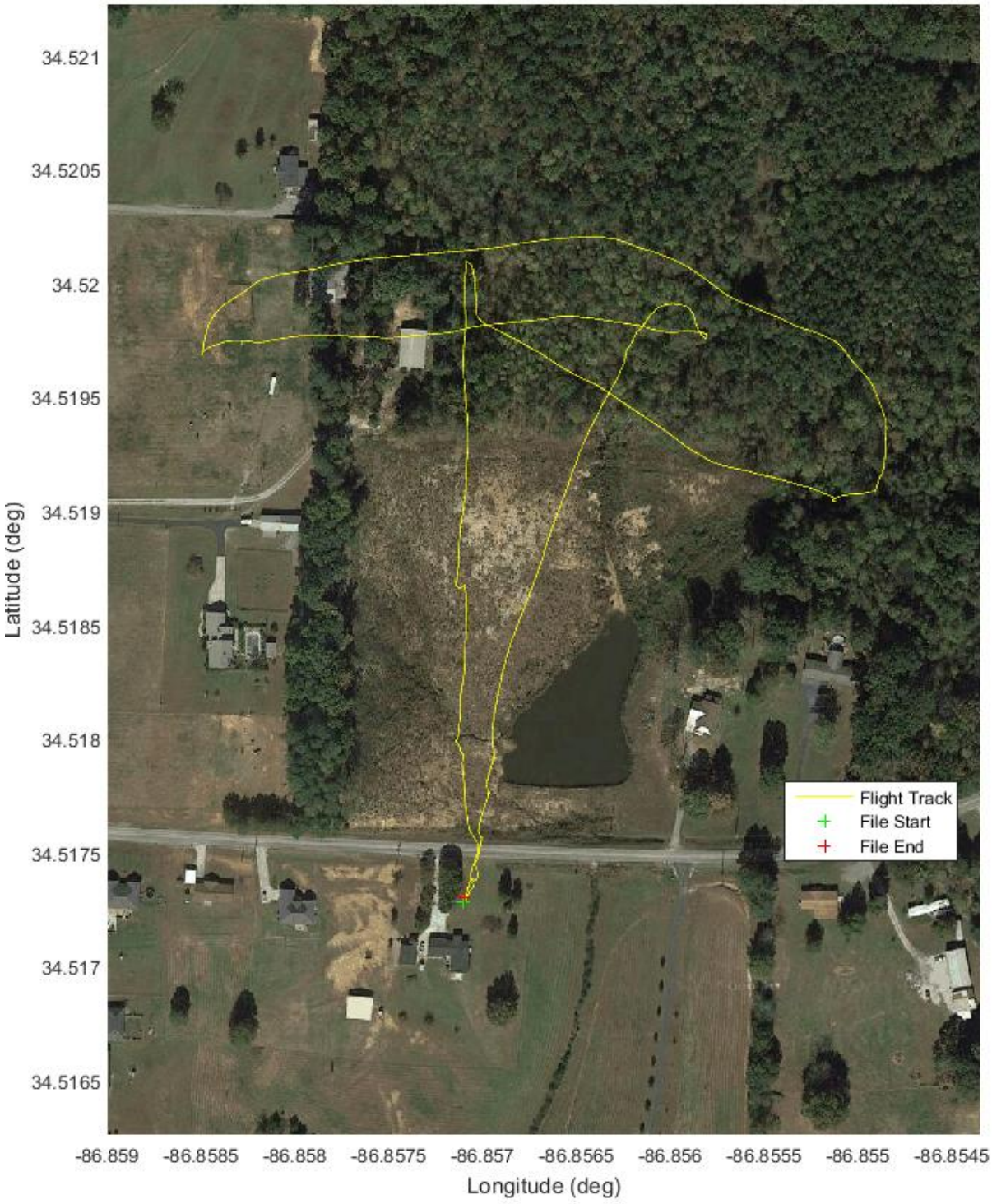

Figure 21: Flight 3, Tuesday, 5 April 2016 near Priceville, Alabama for storm damage assessment. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively.

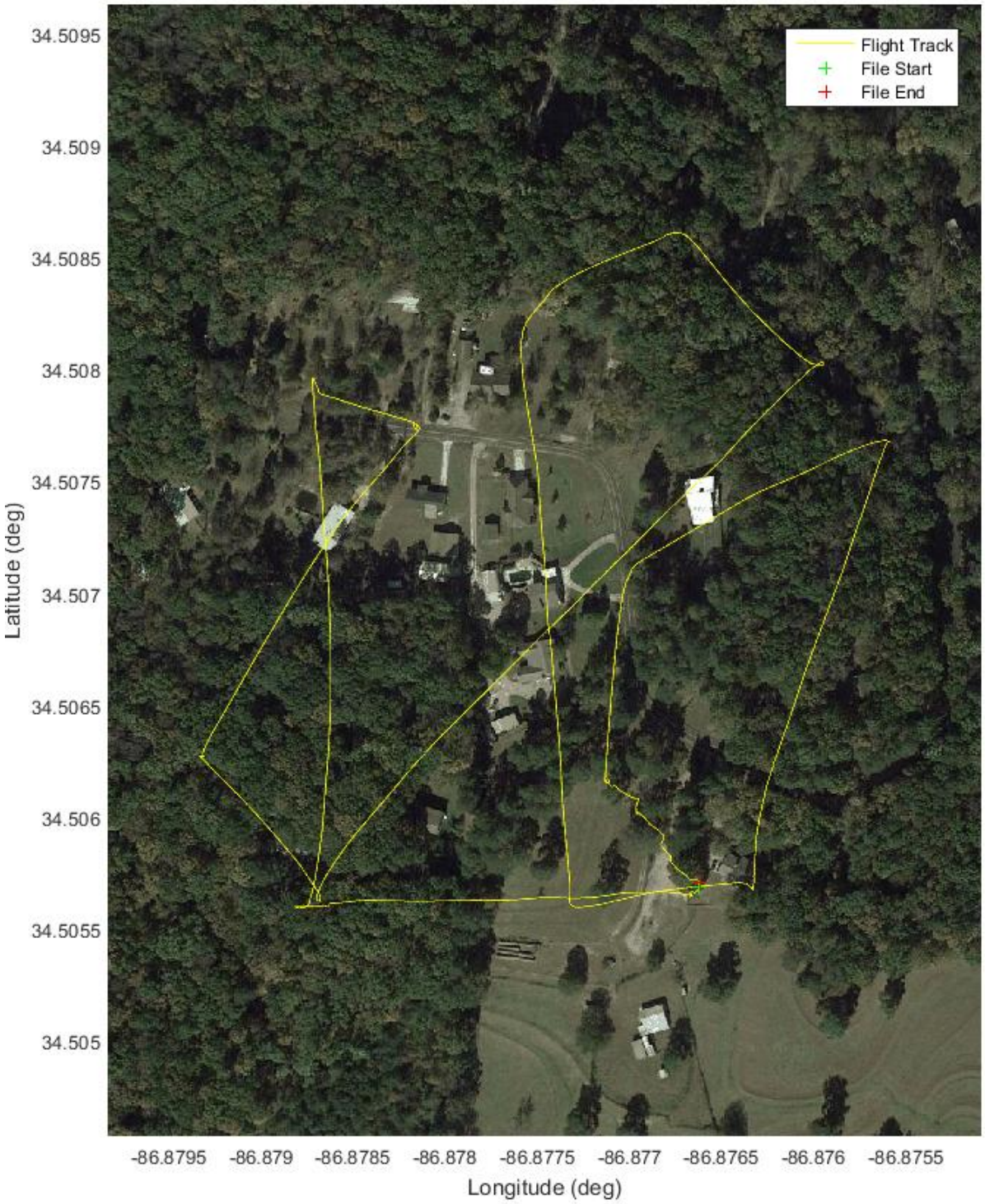

Figure 22: Flight 4, Tuesday, 5 April 2016 near Priceville, Alabama for storm damage assessment. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively.

```
File 20160427-DATA-flight1.csv OPENED at 20:10:21 GPS
iMet-XQ order(4 left, 5 right)
PRO -1 00006 20:10:27 34.193945 -86.796512 Profile 5-214 meters up
     0 00149 20:12:50 34.193948 -86.796514
TRS -1 00151 20:12:52 34.193948 -86.796515 Transect Southwest at 214 meters
     0 00253 20:14:34 34.193344 -86.800101
TRS -1 00285 20:15:06 34.193082 -86.800233 Transect South at 214 meters
     0 00320 20:15:41 34.191337 -86.799940
TRS -1 00341 20:16:02 34.191388 -86.799723 Transect Northeast at 214 meters
     0 00435 20:17:36 34.192657 -86.793074
TRS -1 00473 20:18:14 34.192805 -86.793307 Transect Northwest at 214 meters
     0 00567 20:19:48 34.195773 -86.798745
TRS -1 00586 20:20:07 34.195707 -86.798798 Transect South at 214 meters
     0 00636 20:20:57 34.193613 -86.799957
TRS -1 00670 20:21:31 34.193512 -86.799914 Transect Northeast at 214 meters
     0 00722 20:22:23 34.194111 -86.796538
PRO -1 00731 20:22:32 34.194110 -86.796483 Profile 214-5 meters down
     0 00851 20:24:32 34.194114 -86.796456
File 20160427-DATA-flight1.csv CLOSED at 20:25:30 GPS
Total scans 00909
```

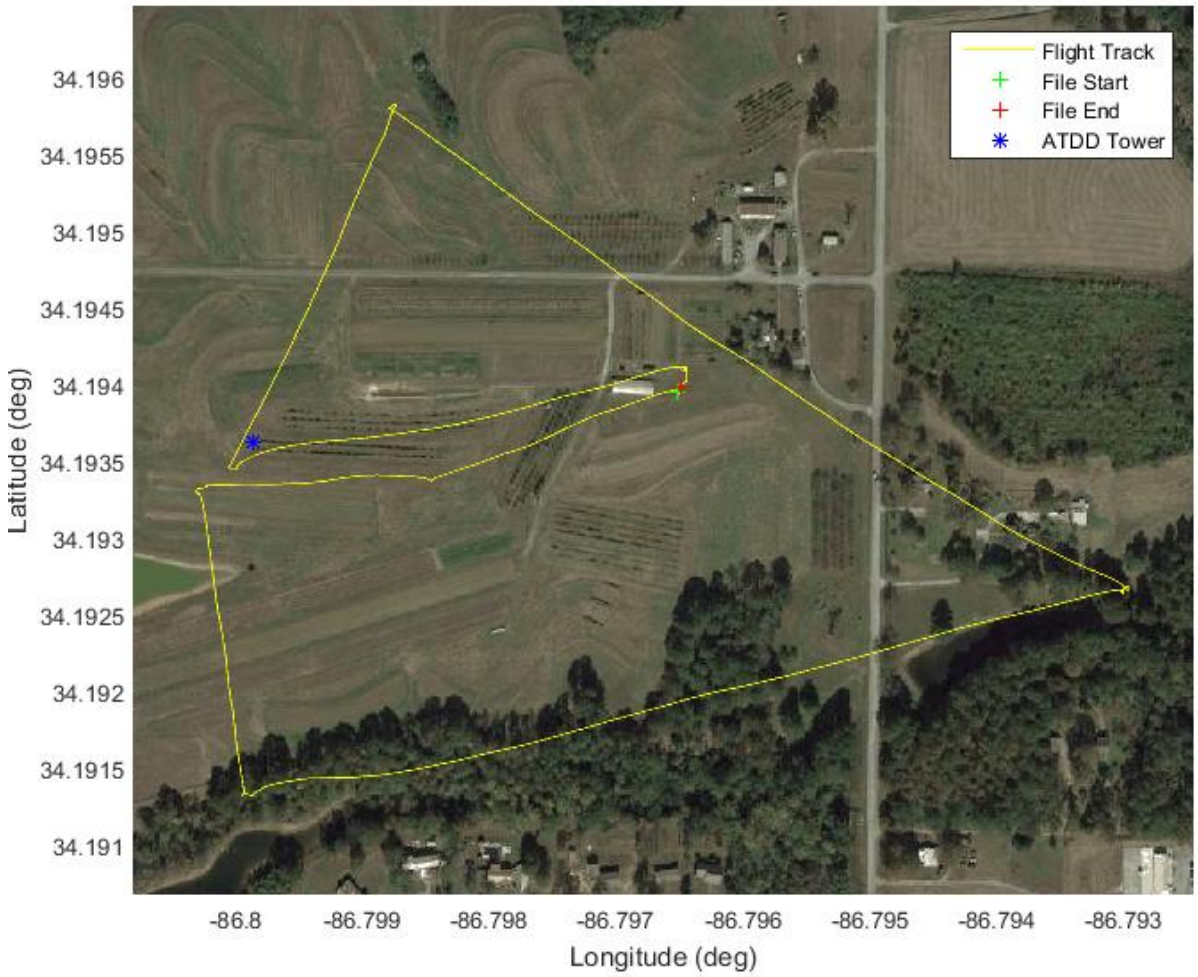

Figure 23: Flight 1, Wednesday, 27 April 2016 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively. Blue star indicates ATDD 10 m flux tower.

```
File 20160427-DATA-flight2.csv OPENED at 21:05:45 GPS
iMet-XQ order(4 left, 5 right)
PRO -1 00006 21:05:51 34.193928 -86.796517 Profile 5-214 meters up
     0 00142 21:08:07 34.193933 -86.796517
TRS -1 00162 21:08:27 34.193910 -86.796681 Transect Southwest at 214 meters
     0 00210 21:09:15 34.193164 -86.799873
TRS -1 00233 21:09:38 34.193078 -86.799965 Transect South at 214 meters
     0 00267 21:10:12 34.191562 -86.799937
TRS -1 00278 21:10:23 34.191546 -86.799879 Transect East at 214 meters
     0 00378 21:12:03 34.191406 -86.792963
TRS -1 00402 21:12:27 34.191451 -86.792968 Transect Northeast at 214 meters
     0 00500 21:14:05 34.196209 -86.800269
TRS -1 00519 21:14:24 34.196135 -86.800232 Transect South at 214 meters
     0 00577 21:15:22 34.192486 -86.799733
TRS -1 00607 21:15:52 34.192407 -86.799723 Transect Northeast at 214 meters
     0 00655 21:16:40 34.193635 -86.796221
PRO -1 00670 21:16:55 34.193664 -86.796050 Profile 214-12 meters down
     0 00802 21:19:07 34.193660 -86.796043
File 20160427-DATA-flight2.csv CLOSED at 21:20:38 GPS
Total scans 00893
```

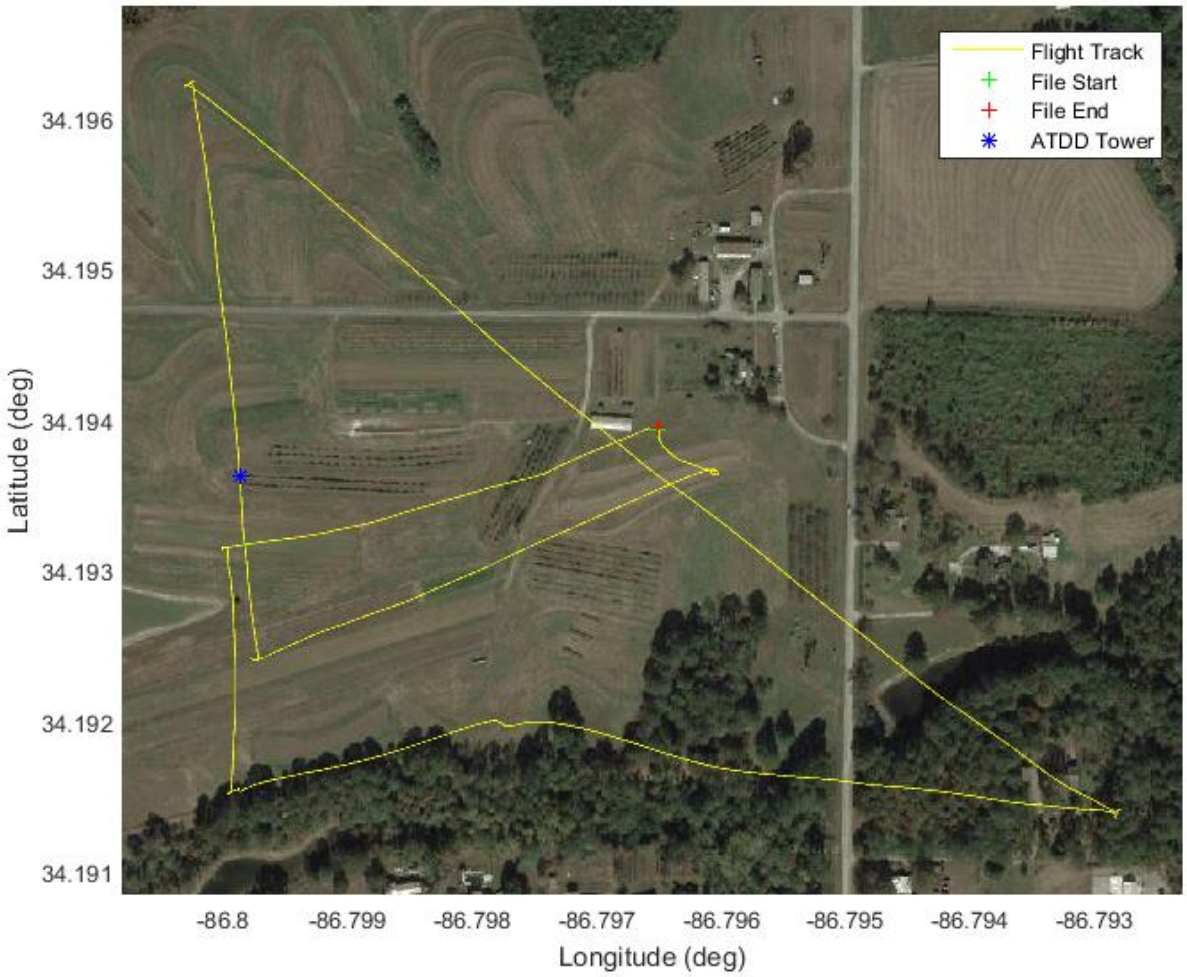

Figure 24: Flight 2, Wednesday, 27 April 2016 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively. Blue star indicates ATDD 10 m flux tower.

```
File 20160427-DATA-flight3.csv OPENED at 23:14:16 GPS
iMet-XQ order(4 left, 5 right)
PRO -1 00005 23:14:21 34.193927 -86.796583 Profile 5-214 meters up
     0 00148 23:16:44 34.193924 -86.796588
TRS -1 00180 23:17:16 34.193843 -86.796830 Transect Southwest at 214 meters
     0 00226 23:18:02 34.192456 -86.800089
TRS -1 00245 23:18:21 34.192394 -86.800165 Transect South at 214 meters
     0 00275 23:18:51 34.190997 -86.799598
TRS -1 00293 23:19:09 34.190937 -86.799457 Transect Northeast at 214 meters
     0 00368 23:20:24 34.191920 -86.793077
TRS -1 00392 23:20:48 34.191966 -86.792962 Transect Northwest at 214 meters
     0 00487 23:22:23 34.196613 -86.801187
TRS -1 00504 23:22:40 34.196618 -86.801246 Transect Southwest at 214 meters
     0 00531 23:23:07 34.195219 -86.801664
TRS -1 00541 23:23:17 34.195128 -86.801675 Transect Southeast at 214 meters
     0 00577 23:23:53 34.193519 -86.800667
TRS -1 00588 23:24:04 34.193468 -86.800574 Transect Northeast at 214 meters
     0 00638 23:24:54 34.194006 -86.796658
PRO -1 00652 23:25:08 34.193987 -86.796525 Profile 214-3 meters down
     0 00793 23:27:29 34.193969 -86.796489
File 20160427-DATA-flight3.csv CLOSED at 23:28:06 GPS
Total scans 00830
```

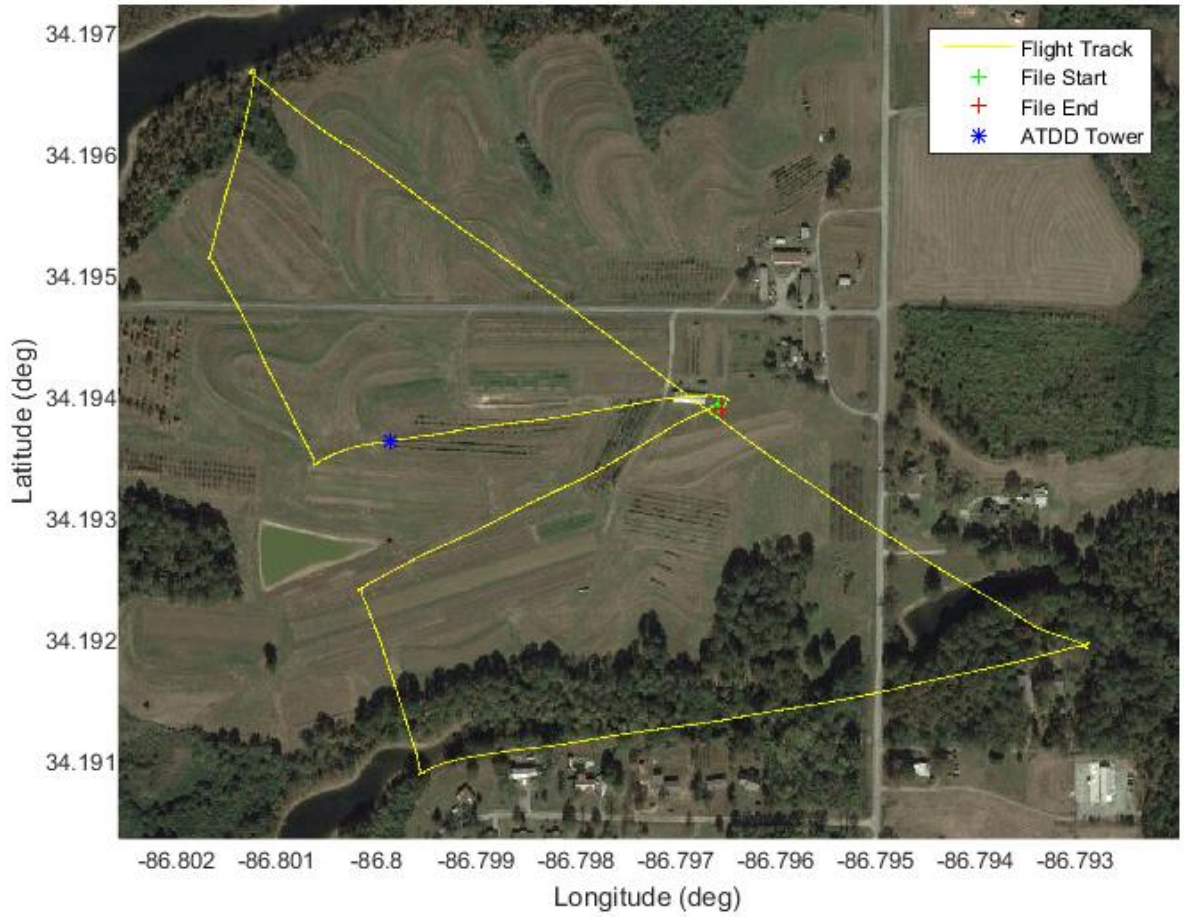

Figure 25: Flight 3, Wednesday, 27 April 2016 in Cullman, Alabama. Green plus sign and red plus sign indicate the starting location and ending location of the UAV flight, respectively. Blue star indicates ATDD 10 m flux tower.

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