NOAA/ARL/ATDD sUAS Metadata for VORTEX-SE Spring, 2017

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1.0 Data Set Overview:

This dataset is from the NOAA Air Resources Laboratory, Atmospheric Turbulence and Diffusion Division (NOAA/ARL/ATDD) DJI S-1000 small Unmanned Aerial System (sUAS) and the Microdrone MD4-1000 sUAS. These aircraft are instrumented to make measurements of air temperature, relative humidity, and atmospheric pressure while in flight. The DJI S-1000 is also equipped to measure the Earth's surface temperature while in flight.

The period of this dataset is for VORTEX-SE 2017 between March 1 and May 8, 2017. The dataset contains data for flights made with the DJI S-1000 on March 25, March 27, April 5, and April 28, 2017. Flights with the MD4-1000 were made on April 28, 2017.

A total of 19 flights were made with the DJI S-1000 sUAS as shown in the table below:

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

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

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 2017/04/28 were made simultaneously with the Microdrone MD4-1000 and the DJI S-1000. The takeoff and landing coordinates for Cullman are shown below:

Location	Latitude	**Longitude**	Elevation (m MSL)
Cullman, AL	34.193896° North	86.796645° West	245

2.0 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 below:

	Humidity Sensor	**Temperature Sensor**	**Pressure Sensor**
Type	Capacitive	Bead Thermistor	Piezoresistive
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 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.

FLIR Tau 2 Camera Specifications	
Resolution	336 x 256 VOx Microbolometer
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 was collected and stored during flight to measure the aircraft's position, velocity, and attitude. Data from the autopilot was 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 was stored at 192 Hz during flight.

A GoPro Hero 3 camera was used to transmit video data in the visible wavelength band during flight. Data from the camera was downlinked using a DJI iOSD Mk II system to a ground station that was monitored during flight. Video data was not recorded for any flight this year.

Data from the Microdrone autopilot was collected and stored during flight to measure the aircraft's position, velocity, and attitude. Data from the autopilot was processed using Microdrone's MDCockpit 3.5 to convert the binary files into comma separated value (CSV) files for easier post-processing. Data from the Microdrone autopilot was stored at 1 Hz during flight.

3.0 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 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) was downloaded to 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 was 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 was properly collected.

Next, time series data from the DJI barometric altitude was plotted and the data files trimmed to match the exact moment of liftoff and touchdown of the vehicle. A sanity check was then performed to verify the number of data points in the DJI file was close to that expected for the duration of the flight. The frequency of the DJI data was found experimentally to be 192±1 Hz and this value has been consistent throughout the experiment period.

The FLIR data files were then processed using TeAx ThermoViewer software. The original files from the TeAx device are stored in a compressed binary format in blocks of 1000 frames. The FLIR data are taken continuously from the moment the aircraft lifts off until it touches down. As with the DJI and iMet-XQ data, the first and last files are trimmed to the exact moment of liftoff and touchdown. After initial trimming, each file is concatenated into a single compressed binary file that contains all FLIR frames from the exact moment of liftoff until the exact moment of touchdown. As with the DJI data, a sanity check of the number of frames in the entire flight is performed to ensure there are no missing data. The frequency of the TeAx/FLIR data was found experimentally to be 1 Hz and has remained consistent throughout the experiment period.

After the single TeAx binary flight file was created, each frame was then 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 is 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.

Files in this archive include the trimmed iMet-XQ data for each device, each FLIR file for the entire flight, and the DATA file that contains the integrated, time tagged data for the DJI A2 autopilot, the iMet-XQ, and the FLIR index. The archive also contains MATLAB scripts that were used to perform the data processing and visualization.

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 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.

4.0 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:

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.

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:

	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 reported in 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 DATA file has the following columns for the DJI S-1000:

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.

The marker (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:

	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						

The MKR file defines areas in the data that are scientifically useful and provides a "snapshot" of the maneuvers performed during the flight. 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, 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 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 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 meters/sec.

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

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

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

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:

	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						

5.0 Data Remarks:

For the most part, the data were recovered completely and correctly from both aircraft. Below is a table of known problems with the DJI S-1000 data and comments afterward:

Date (YYYY/MM/DD)	Location	Flight	DJI	iMet-XQ Dev 4	iMet-XQ Dev 5	FLIR	GoPro Video	Notes
2016/03/25	Cullman	1	Yes	Yes	Yes	Yes	No	
2016/03/25	Cullman	2	Yes	Yes	Yes	Yes	No	
2016/03/27	Cullman	1	Yes	Yes	Yes	Yes	No	
2016/03/27	Cullman	2	Yes	Yes	Yes	Yes	No	
2016/03/27	Cullman	3	Yes	Yes	Yes	Yes	No	
2016/04/05	Cullman	1	Yes	Yes	Yes	Yes	No	
2016/04/05	Cullman	2	Yes	Yes	Yes	Yes	No	Simultaneous flight with tethersonde
2016/04/05	Cullman	3	Yes	Yes	Yes	Yes	No	Simultaneous flight with tethersonde. Balloon launch at 17:15:00 GMT
2016/04/05	Cullman	4	Yes	Yes	Yes	Yes	No	Simultaneous flight with tethersonde
2016/04/05	Cullman	5	Yes	Yes	Yes	Yes	No	Simultaneous flight with tethersonde
2016/04/05	Cullman	6	Yes	Yes	Yes	Yes	No	
2016/04/28	Cullman	1	Yes	Yes	Yes	Yes	No	
2016/04/28	Cullman	2	Yes	Yes	Yes	Yes	No	Simultaneous flight with MD4-1000 flight 3.
2016/04/28	Cullman	3	Yes	Yes	Yes	Yes	No	Simultaneous flight with MD4-1000 flight 4.
2016/04/28	Cullman	4	Yes	Yes	Yes	Yes	No	Simultaneous flight with MD4-1000 flight 5.
2016/04/28	Cullman	5	Yes	Yes	Yes	Yes	No	Simultaneous flight with MD4-1000 flight 6.
2016/04/28	Cullman	6	Yes	Yes	Yes	Yes	No	
2016/04/28	Cullman	7	Yes	Yes	Yes	Yes	No	
2016/04/28	Cullman	8	Yes	Yes	Yes	Yes	No	

Below is a table of known problems with the MD4-1000 data and comments afterward. Note that flights 1 and 2 with the MD4-1000 were performed for pilot checkout and orientation. No data was collected during those flights:

Date (YYYY/MM/DD)	Location	Flight	MD4	iMet-XQ Dev 3	iMet-XQ Dev 6	Notes
2016/04/28	Cullman	3	Yes	Yes	Yes	Simultaneous flight with DJI S-1000 flight 2.
2016/04/28	Cullman	4	Yes	Yes	Yes	Simultaneous flight with DJI S-1000 flight 3.
2016/04/28	Cullman	5	Yes	Yes	Yes	Simultaneous flight with DJI S-1000 flight 4.
2016/04/28	Cullman	6	Yes	Yes	Yes	Simultaneous flight with DJI S-1000 flight 5.
2016/04/28	Cullman	7	Yes	Yes	Yes	
2016/04/28	Cullman	8	Yes	Yes	Yes	

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 during each climb at the same time.

Included with this dataset are a set of MATLAB scripts that 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. 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.

Any questions about the data set should be directed to Edward J. Dumas (ed.dumas@noaa.gov).

6.0 References:

No publications exist at this time for this dataset.

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