NOAA/ARL/ATDD DJI S-1000 sUAS Metadata for VORTEX-SE Spring, 2016

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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). This sUAS is instrumented to make measurements of air temperature, relative humidity, atmospheric pressure, surface temperature, and visible imagery while in flight.

The period of this dataset is for VORTEX-SE 2016 between March 1 and May 1, 2016. The dataset contains data for flights made on March 13, March 24, April 5, and April 27, 2016.

A total of 11 flights were made in six locations 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
2016/03/13	Belle Mina	1	18:04:40	18:17:36	23:04:40	23:17:36	00:12:56	776
2016/03/13	Belle Mina	2	18:27:04	18:39:48	23:27:04	23:39:48	00:12:44	764
2016/03/13	Belle Mina	3	19:02:16	19:16:30	00:02:16	00:16:30	00:14:14	854
2016/03/24	Cullman	1	14:21:11	14:27:15	19:21:11	19:27:15	00:06:04	364
2016/04/05	Priceville1	1	11:56:44	12:07:54	16:56:44	17:07:54	00:11:10	670
2016/04/05	Priceville[2]	2	13:41:25	13:54:10	18:41:25	18:54:10	00:12:45	765
2016/04/05	Priceville[3]	3	14:19:02	14:31:40	19:19:02	19:31:40	00:12:38	758
2016/04/05	Priceville[4]	4	15:17:00	15:30:02	20:17:00	20:30:02	00:13:02	782
2016/04/27	Cullman	1	15:10:21	15:25:30	20:10:21	20:25:30	00:15:09	909
2016/04/27	Cullman	2	16:05:45	16:20:38	21:05:45	21:20:38	00:14:53	893
2016/04/27	Cullman	3	18:14:16	18:28:06	23:14:16	23:28:06	00:13:50	830

Flights at Belle Mina and Cullman were made primarily to measure atmospheric temperature profiles and surface temperature. The Priceville flights were conducted at four different locations to survey damage along the path of the Priceville, AL EF2 tornado. Note the flight at Cullman on 2016/03/04 was cut short due to rain. The takeoff and landing coordinates for each flight area are shown below:

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

2.0 Instrument Description:

Two International Met Systems T/RH/P sensors XQ devices were used to measure air temperature, relative humidity, and pressure 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 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 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.

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	7.5 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 record video 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 simultaneously recorded on a microSD card inside the GoPro camera.

3.0 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) 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 7.5 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.

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	+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.

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	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.

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:

Index, Year, Month, Day, Hour, Min, Sec, Millisecond, Latitude, Longitude, GPS Altitude, N Velocity, E Velocity, D Velocity, Velocity, Ground Speed, Accelerometer X, Accelerometer Y, Accelerometer Z, Gyro X, Gyro Y, Gyro Z, Barometric Alt, Quaternion X, Quaternion Y, Quaternion Z, Quaternion W, Roll, Pitch, Yaw, Magnetic X, Magnetic Y, Magnetic Z, Satellites, Main Voltage, CAN Voltage, Elec Voltage, Pres 4, Temp 4, RH 4, Pres 5, Temp 5, RH 5, FLIR Index

Note that Pres 4, Temp 4, RH 4 are from iMet-XQ device 4 and Pres 5, Temp 5, RH 5 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 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						

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 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.

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 meters above ground level (AGL) and ended at 125 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 11 seconds into the flight and ended 86 seconds into the flight, giving an elapsed time of 75 seconds. With the altitude gain of 120 meters, the average rate of climb was 1.6 meters/sec.

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

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

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

5.0 Data Remarks:

For the most part, the data were recovered completely and correctly. Below is a table of known problems with comments afterward:

Date (YYYY/MM/DD)	Location	Flight	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 balloon launch
2016/03/24	Cullman	1	Yes	No	Yes	Yes	Yes	iMet didn't 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 didn't 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 didn't 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.

The missing GoPro data from flights 1-3 on 2016/03/13 was due to a full microSD card on the GoPro camera. The flights that evening were primarily to assess the 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 balloon was performed at the beginning of the last flight of the day at 19:02:00 local time.

The iMet-XQ sensor number 4 didn't initialize during the flight at Cullman. This flight was performed under gray, overcast skies and began with a profile to 700 feet AGL. Flights at Cullman are allowed to fly to 700 feet 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 seconds 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 2016/04/05 was to survey damage caused by the Priceville EF2 tornado and the primary purpose of the flight was deemed to be to record visual images from the aircraft although the iMet and FLIR were carried and operating during the flights. FLIR data was not obtained on flight 3 due to the FLIR data record switch not being actuated.

Flights on 2016/04/27 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 was not obtained on flight 2 due to the FLIR data record switch not being actuated.

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. 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.

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.