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# Small Unmanned Aircraft System (sUAS) measurements during the 2017 Land-Atmosphere Feedback Experiment (LAFE)

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# List of Abbreviations and Acronyms

| Abbreviation | Acronym |
|---|---|
| **AGL** | Above ground level |
| **AOC** | Aircraft Operations Center |
| **ARL** | Air Resources Laboratory |
| **ARM** | Atmospheric Radiation Measurement |
| **ATDD** | Atmospheric Turbulence and Diffusion Division |
| **DOE** | Department of Energy |
| **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 |
| **LAFE** | Land-Atmosphere Feedback Experiment |
| **LDT** | Local daylight time |
| **MATLAB©** | Matrix Laboratory |
| **MSL** | Mean sea level |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **OMAO** | Office of Marine and Aviation Operations |
| **PBL** | Planetary Boundary layer |
| **SGP** | Southern Great Plains |
| **sUAS** | small Unmanned Aircraft System |
| **UTC** | Universal coordinated time |

# Abstract

This report describes the operation of small Unmanned Aircraft Systems (sUAS) by NOAA's Air Resources Laboratory, Atmospheric Turbulence and Diffusion Division (NOAA/ARL/ATDD) in the Land-Atmosphere Feedback Experiment (LAFE) that was conducted in the summer of 2017 near Lamont, Oklahoma. Both the DJI S-1000 and the Microdrone MD4-1000 were used to measure temperature and humidity profiles in the lower 300 m of the atmosphere, and the S-1000 was used to map the Earth's skin temperature during three intensive observation periods (14 August, 15 August, and 17 August) in the LAFE experiment. NOAA/OMAO/AOC personnel also flew the Microdrone MD4-1000 sUAS during the 14 and 15 August intensives. During these intensives, fourteen 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 Land-Atmosphere Feedback Experiment (LAFE) was a research program to study the effect of land surface interactions on the planetary boundary layer (PBL) under quiescent fair weather meteorological conditions. The experiment took place from 1 August through 31 August 2017 in central Oklahoma near the town of Lamont at the Department of Energy's (DOE) Southern Great Plains (SGP) Atmospheric Radiation Measurement (ARM) facility. The experiment consisted of coordinated meteorological measurements among multiple NOAA laboratories and universities during intensive operations periods (IOPs) during which weather conditions were relatively benign in the LAFE research domain. For more details on the experimental setup, see Wulfmeyer et al. (2017).

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 was operated within visual line of sight of the pilot and was 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 LAFE field experiment.

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

Data were collected on August 14, 15, and 17, 2017 to support designated LAFE IOPs, as shown in Table 1 below:

**Table 1: Summary of DJI S-1000 flights made during LAFE 2017**

| Date (YYYY/MM/DD) | Flight | Takeoff time (LDT) | Landing time (LDT) | Takeoff time (GPS) | Landing time (GPS) | Flight Time (HH:MM:SS) | Scans |
|---|---|---|---|---|---|---|---|
| **2017/08/11** | 01 | 12:47:27 | 12:56:37 | 17:47:45 | 17:56:55 | 00:09:10 | 550 |
| **2017/08/14** | 01 | 12:39:47 | 12:49:40 | 17:40:05 | 17:49:58 | 00:09:53 | 593 |
| **2017/08/14** | 02 | 12:59:44 | 13:09:31 | 18:00:02 | 18:09:49 | 00:09:47 | 587 |
| **2017/08/14** | 03 | 13:40:28 | 13:50:15 | 18:40:46 | 18:50:33 | 00:09:47 | 587 |
| **2017/08/14** | 04 | 13:59:35 | 14:10:07 | 18:59:53 | 19:10:25 | 00:10:32 | 632 |
| **2017/08/14** | 05 | 14:59:13 | 15:09:23 | 19:59:31 | 20:09:41 | 00:10:10 | 610 |
| **2017/08/14** | 06 | 15:18:36 | 15:28:41 | 20:18:54 | 20:28:59 | 00:10:05 | 605 |
| **2017/08/14** | 07 | 15:59:47 | 16:10:28 | 21:00:05 | 21:10:46 | 00:10:41 | 641 |
| **2017/08/14** | 08 | 16:20:23 | 16:31:06 | 21:20:41 | 21:31:24 | 00:10:43 | 643 |
| **2017/08/14** | 09 | 16:59:51 | 17:10:33 | 22:00:09 | 22:10:51 | 00:10:42 | 642 |
| **2017/08/14** | 10 | 17:20:11 | 17:30:35 | 22:20:29 | 22:30:53 | 00:10:24 | 624 |
| **2017/08/14** | 11 | 17:40:00 | 17:50:05 | 22:40:18 | 22:50:23 | 00:10:05 | 605 |
| **2017/08/14** | 12 | 18:09:55 | 18:20:29 | 23:10:13 | 23:20:47 | 00:10:34 | 634 |
| **2017/08/15** | 01 | 12:09:27 | 12:20:03 | 17:09:45 | 17:20:21 | 00:10:36 | 636 |
| **2017/08/15** | 02 | 15:09:32 | 15:19:57 | 20:09:50 | 20:20:15 | 00:10:25 | 625 |
| **2017/08/15** | 03 | 15:40:53 | 15:51:36 | 20:41:11 | 20:51:54 | 00:10:43 | 643 |
| **2017/08/15** | 04 | 16:09:34 | 16:20:53 | 21:09:52 | 21:21:11 | 00:11:19 | 679 |
| **2017/08/15** | 05 | 16:40:54 | 16:51:49 | 21:41:12 | 21:52:07 | 00:10:55 | 655 |
| **2017/08/15** | 06 | 17:09:46 | 17:20:52 | 22:10:04 | 22:21:10 | 00:11:06 | 666 |
| **2017/08/15** | 07 | 17:41:21 | 17:52:16 | 22:41:39 | 22:52:34 | 00:10:55 | 655 |
| **2017/08/15** | 08 | 18:09:40 | 18:20:43 | 23:09:58 | 23:21:01 | 00:11:03 | 663 |
| **2017/08/17** | 01 | 11:39:48 | 11:50:34 | 16:40:06 | 16:50:52 | 00:10:46 | 646 |
| **2017/08/17** | 02 | 12:09:34 | 12:20:44 | 17:09:52 | 17:21:02 | 00:11:10 | 670 |
| **2017/08/17** | 03 | 12:39:49 | 12:50:37 | 17:40:07 | 17:50:55 | 00:10:48 | 648 |
| **2017/08/17** | 04 | 13:09:57 | 13:20:33 | 18:10:15 | 18:20:51 | 00:10:36 | 636 |
| **2017/08/17** | 05 | 13:39:47 | 13:50:28 | 18:40:05 | 18:50:46 | 00:10:41 | 641 |
| **2017/08/17** | 06 | 14:09:43 | 14:20:17 | 19:10:01 | 19:20:35 | 00:10:34 | 634 |
| **2017/08/17** | 07 | 14:40:04 | 14:50:29 | 19:40:22 | 19:50:47 | 00:10:25 | 625 |
| **2017/08/17** | 08 | 15:10:03 | 15:21:12 | 20:10:21 | 20:21:30 | 00:11:09 | 669 |
| **2017/08/17** | 09 | 15:39:47 | 15:50:31 | 20:40:05 | 20:50:49 | 00:10:44 | 644 |
| **2017/08/17** | 10 | 16:09:39 | 16:20:32 | 21:09:57 | 21:20:50 | 00:10:53 | 653 |
| **2017/08/17** | 11 | 16:40:05 | 16:51:07 | 21:40:23 | 21:51:25 | 00:11:02 | 662 |
| **2017/08/17** | 12 | 17:09:56 | 17:20:29 | 22:10:14 | 22:20:47 | 00:10:33 | 633 |
| **2017/08/17** | 13 | 17:39:42 | 17:46:21 | 22:40:00 | 22:46:39 | 00:06:39 | 399 |
| **2017/08/17** | 14 | 18:09:40 | 18:20:26 | 23:09:58 | 23:20:44 | 00:10:46 | 646 |

A total of 35 flights were made with the DJI S-1000 sUAS. Note that no meteorological data were collected during the test flight on 11 August, which was made for demonstration purposes. Note that times in this table are local daylight time (LDT), which lags Universal Coordinated Time (UTC) by 5 hours (LDT=UTC-5 h). Additionally, GPS time is ahead of UTC time by 18 s during this experiment (GPS=UTC+18 s).

The Microdrone MD4-1000 quadcopter was also used in the LAFE experiment. This aircraft is owned by the Cooperative Center for Unmanned Technologies (CCUT) in Santa Barbara, California and was on loan to ATDD for the LAFE experiment. The MD4-1000 is a four-rotor vehicle capable of vertical takeoff and landing. It has a wingspan of approximately 1 m and can carry a payload of 1.2 kg for approximately 20 minutes. It is operated by a single pilot with an observer. The sUAS was operated within visual line of sight of the pilot and was instrumented to make measurements of air temperature, relative humidity, and atmospheric pressure. The MD4-1000 is shown in Figure 2 flying at the House Mountain Radio Control (HMRC) model flying field in Corryton, Tennessee during a test flight in preparation for the LAFE field experiment.

**Figure 2: The Microdrone MD4-1000 flying at House Mountain Radio Control (HMRC), Corryton, TN.**

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

**Table 2: Summary of MD4-1000 flights made during LAFE 2017**

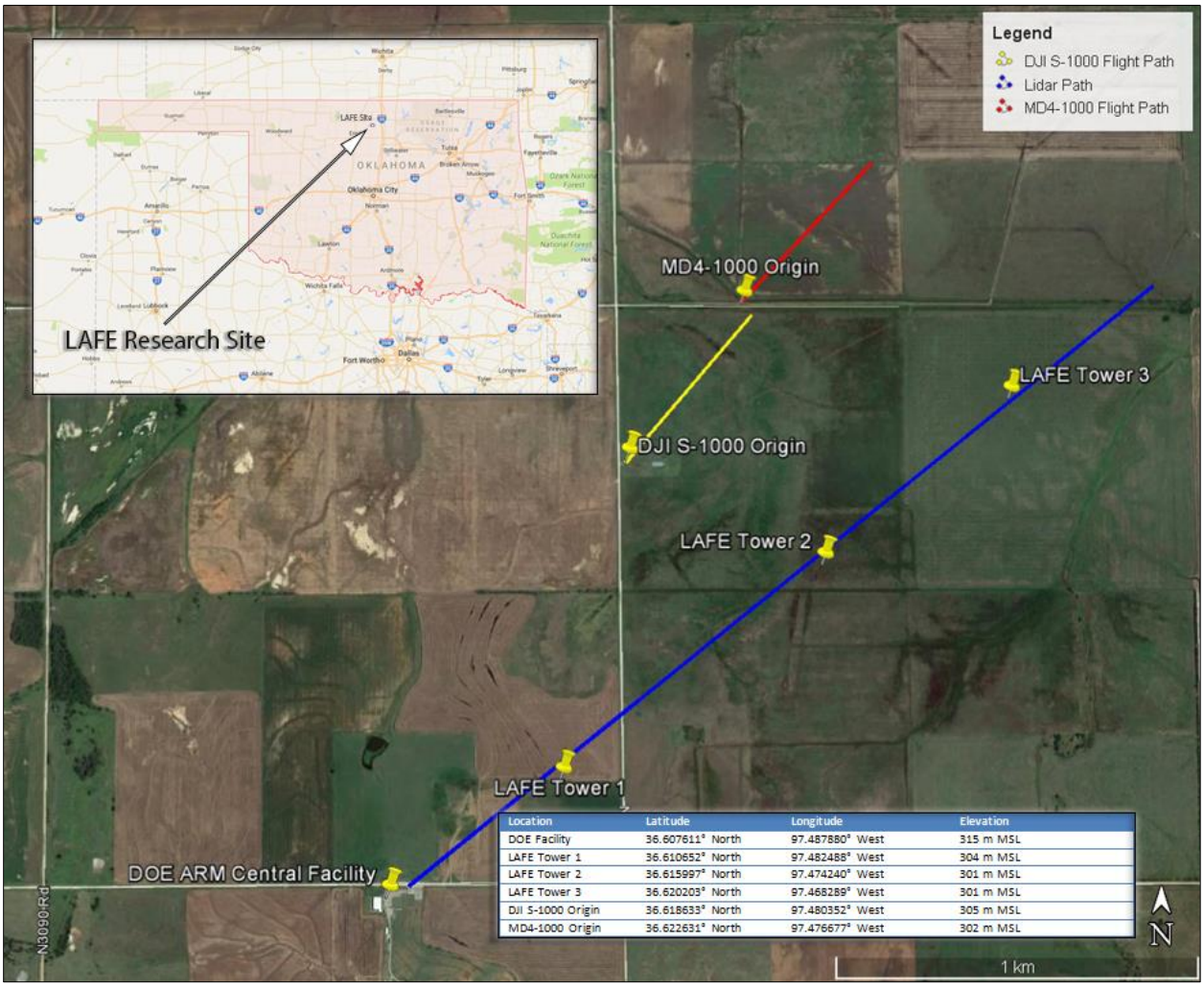
| Date (YYYY/MM/DD) | Flight | Takeoff time (LDT) | Landing time (LDT) | Takeoff time (GMT) | Landing time (GMT) | Flight Time (HH:MM:SS) | Scans |
|---|---|---|---|---|---|---|---|
| **2017/08/14** | 01 | 12:01:37 | 12:07:21 | 17:01:55 | 17:07:39 | 00:05:44 | 344 |
| **2017/08/14** | 02 | 12:07:46 | 12:09:15 | 17:08:04 | 17:09:33 | 00:01:29 | 89 |
| **2017/08/14** | 03 | 12:39:27 | 12:53:22 | 17:39:45 | 17:53:40 | 00:13:55 | 835 |
| **2017/08/14** | 04 | 13:00:05 | 13:12:57 | 18:00:23 | 18:13:15 | 00:12:52 | 772 |
| **2017/08/14** | 05 | 13:40:06 | 13:52:20 | 18:40:24 | 18:52:38 | 00:12:14 | 734 |
| **2017/08/14** | 06 | 15:00:01 | 15:10:37 | 20:00:19 | 20:10:55 | 00:10:36 | 636 |
| **2017/08/14** | 07 | 15:40:18 | 15:53:14 | 20:40:36 | 20:53:32 | 00:12:56 | 776 |
| **2017/08/14** | 08 | 16:59:41 | 17:12:06 | 21:59:59 | 22:12:24 | 00:12:25 | 745 |
| **2017/08/14** | 09 | 17:38:31 | 17:53:02 | 22:38:49 | 22:53:20 | 00:14:31 | 871 |
| **2017/08/14** | 10 | 18:07:43 | 18:23:20 | 23:08:01 | 23:23:38 | 00:15:37 | 937 |
| **2017/08/15** | 01 | 12:13:19 | 12:23:56 | 17:13:37 | 17:24:14 | 00:10:37 | 637 |
| **2017/08/15** | 02 | 15:08:09 | 15:22:31 | 20:08:27 | 20:22:49 | 00:14:22 | 862 |
| **2017/08/15** | 03 | 15:38:12 | 15:53:39 | 20:38:30 | 20:53:57 | 00:15:27 | 927 |
| **2017/08/15** | 04 | 16:08:14 | 16:21:47 | 21:08:32 | 21:22:05 | 00:13:33 | 813 |
| **2017/08/15** | 05 | 16:39:29 | 16:52:30 | 21:39:47 | 21:52:48 | 00:13:01 | 781 |
| **2017/08/15** | 06 | 17:07:52 | 17:21:35 | 22:08:10 | 22:21:53 | 00:13:43 | 823 |
| **2017/08/15** | 07 | 17:37:48 | 17:53:08 | 22:38:06 | 22:53:26 | 00:15:20 | 920 |

Note that the MD4-1000 only measured air temperature, relative humidity, and air pressure. It did not measure surface temperature or visible imagery.

The LAFE experiment consisted of a synergy between ground-based LIDAR systems making measurements of wind speed, temperature, and relative humidity along a line originating at the DOE SGP ARM site extending along a heading of approximately 51° true north. Adjacent to this line, three eddy-covariance flux towers were installed and operated by NOAA/ATDD. These were stationed approximately 500, 1500, and 2000 meters northeast of DOE SGP ARM central facility. For more information on the LAFE experiment, please see:

https://www.eol.ucar.edu/field_projects/lafe

The sUAS were used to extend the temperature and relative humidity measurements made by the towers to a larger spatial extent. Figure 3 shows the locations of various entities in the LAFE experiment. Included are the DOE SGP ARM facility, the locations of ATDD's flux towers (Tower 1, Tower 2, and Tower 3), and the starting locations and approximate flight paths for the DJI S-1000 and the MD4-1000 sUAS's, as well as line along which LIDAR measurements were made, shown in blue.




| Location | Latitude | Longitude | Elevation |
|---|---|---|---|
| DOE Facility | 36.607611° North | 97.487880° West | 315 m MSL |
| LAFE Tower 1 | 36.610652° North | 97.482488° West | 304 m MSL |
| LAFE Tower 2 | 36.615997° North | 97.474240° West | 301 m MSL |
| LAFE Tower 3 | 36.620203° North | 97.468289° West | 301 m MSL |
| DJI S-1000 Origin | 36.618633° North | 97.480352° West | 305 m MSL |
| MD4-1000 Origin | 36.622631° North | 97.476677° West | 302 m MSL |

**Figure 3: Map showing the LAFE domain with coordinates of various places in the LAFE 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 except for one flight where it carried device 7 on the left side. 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. The specifications for the FLIR camera are shown in Table 4.

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. 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. For more details on the experimental setup, see Dumas et al (2016, 2017).

## 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 next step was to ensure the data from the iMet-XQ were properly time-aligned with the DJI data. This was done by examining the difference between the GPS altitudes measured by each device. Because of the changes in altitude during the flight, time lag differences could easily be seen and corrected manually. An example of the plots generated during this procedure is shown in Figure 4. Note that the times shown in Figure 4 are in UTC.

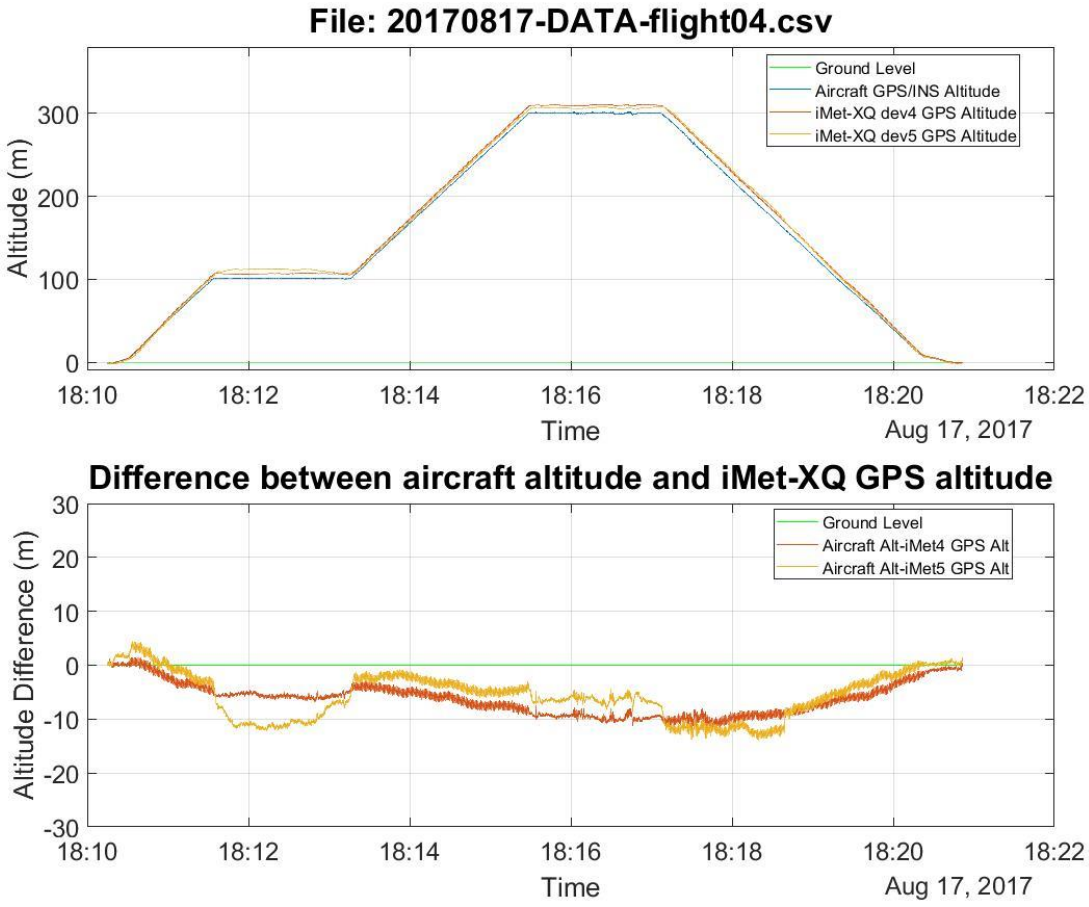



**Figure 4: Comparison of DJI S-1000 and iMet-XQ GPS altitudes for file 20170817-DATA-flight04.csv.**

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 0.93±0.01 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-flightXX_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, XX=2-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-flightXX.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 XX=2-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-flightYY.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 YY=2-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 | +097557 | +3473 | +0588 | 2017/08/14 | 17:40:05 | +0366186403 | -0974803354 | +00300576 | 16 |
| 00037272 | XQ | +097553 | +3276 | +0606 | 2017/08/14 | 17:40:06 | +0366186402 | -0974803353 | +00300605 | 16 |
| 00037272 | XQ | +097555 | +3179 | +0600 | 2017/08/14 | 17:40:07 | +0366186403 | -0974803353 | +00300661 | 16 |
| 00037272 | XQ | +097550 | +3168 | +0612 | 2017/08/14 | 17:40:08 | +0366186401 | -0974803352 | +00300720 | 16 |
| 00037272 | XQ | +097547 | +3177 | +0611 | 2017/08/14 | 17:40:09 | +0366186399 | -0974803360 | +00300878 | 16 |
| … | | | | | | | | | | |

Scale factors: Pressure=100, Temp=100, RH=10, Latitude= 10000000, Longitude= 10000000, Altitude= 1000

The sample shown above is from file 20170814-iMet-dev4-flight01.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-flightXX_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, XX=2-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 | 38.73; | 37.81; | | 39.37; | 38.81; |
| Row 2 | 40.29; | 38.61; | | 39.05; | 38.01; |
| … | | | | | |
| Row 255 | 38.53; | 40.29; | | 43.65; | 43.97; |
| Row 256 | 37.89; | 39.53; | | 39.65; | 39.65; |

Note: All values are scaled to degrees C.

The sample shown above is from file 20170814-FLIR-flight01_0001.csv.

The DATA filename has the following format: YYYYMMDD-DATA-flightXX.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 XX=2-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-flightXX.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 XX=2-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 20170814-DATA-flight01.csv OPENED at 17:40:05 GPS | | | | | | |
| Payload line | iMet-XQ order (4 left, 5 right) | | | | | | |
| Comment Line | This flight flown simultaneously with MD4-1000 flight 3! | | | | | | |
| Open 1 | PRO | -1 | 00007 | 17:40:12 | 36.618659 | -97.480344 | Profile 1m-100m |
| Close 1 | | 0 | 00076 | 17:41:21 | 36.618657 | -97.480341 | |
| Open 2 | TRS | -1 | 00078 | 17:41:23 | 36.618657 | -97.480342 | Transect |
| Close 2 | | 0 | 00157 | 17:42:42 | 36.622158 | -97.476390 | |
| Open 3 | PRO | -1 | 00160 | 17:42:45 | 36.622161 | -97.476392 | Profile 100m-300m |
| Close 3 | | 0 | 00289 | 17:44:54 | 36.622159 | -97.476382 | |
| … | | | | | | | |
| Close line | File 20170814-DATA-flight01.csv CLOSED at 17:49:58 GPS | | | | | | |
| Total scans | Total scans 00594 | | | | | | |

In the example above, the file 20170814-DATA-flight01.csv was opened at 17:40:05 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 7, 17:40:12 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 10 meters above ground level (AGL) and ended at 100 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 7 seconds into the flight and ended 76 seconds

into the flight, giving an elapsed time of 69 seconds. With the altitude gain of 99 meters, the average rate of climb was 1.43 m $s^{-1}$.

The remaining segments show the rest of the maneuvers during the flight. For these flights, a vertical box was performed that started with a profile to 100 meters, a transect to 500 meters range at 100 meters, a vertical profile to 300 m, followed by a transect back to the starting point at 300 m altitude. Finally, a vertical profile was performed to descend near the starting point followed by landing.

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. |
| TRS | Transect | Forward flight at a constant altitude. |

A catalog of all MKR files for each flight in the LAFE study can be found in Appendix A.

The DATA filename for the MD4-1000 has the following format: YYYYMMDD-DATA-flightXX.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 XX=2-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 20170814-DATA-flight03.csv OPENED at 17:39:45 GPS | | | | | | |
| Payload line | iMet-XQ order (3 left, 6 right) | | | | | | |
| Comment Line | This flight flown simultaneously with DJI S-1000 flight 1! | | | | | | |
| Open 1 | PRO | -1 | 00039 | 17:40:25 | 36.622651 | -97.476686 | Profile 10m-100m |
| Close 1 | | 0 | 00073 | 17:40:59 | 36.622653 | -97.476688 | |
| Open 2 | TRS | -1 | 00097 | 17:41:23 | 36.622651 | -97.476687 | Transect |
| Close 2 | | 0 | 00333 | 17:45:19 | 36.625889 | -97.472761 | |
| Open 3 | PRO | -1 | 00334 | 17:45:20 | 36.625889 | -97.472761 | Profile 100m-300m |
| Close 3 | | 0 | 00382 | 17:46:08 | 36.625890 | -97.472762 | |
| … | | | | | | | |
| Close line | File 20170814-DATA-flight03.csv CLOSED at 17:53:40 GPS | | | | | | |
| Total scans | Total scans 00834 | | | | | | |

## Data Remarks

For the most part, the data were recovered completely and correctly, as shown in Table 10.

**Table 10: Summary of data recovery for the DJI S-1000 for LAFE 2017**

| Date (YYYY/MM/DD) | Daily flight number | DJI | iMet-XQ Dev 4 | iMet-XQ Dev 5 | FLIR | GoPro Video | Notes |
|---|---|---|---|---|---|---|---|
| **2017/08/11** | 01 | Yes | Yes | Yes | No | No | Demonstration flight |
| **2017/08/14** | 01 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 3 |
| **2017/08/14** | 02 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 4 |
| **2017/08/14** | 03 | Yes | Yes | Yes | No | Yes | Simultaneous with MD4-1000 flight 5 |
| **2017/08/14** | 04 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/14** | 05 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 6 |
| **2017/08/14** | 06 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/14** | 07 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/14** | 08 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/14** | 09 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 8 |
| **2017/08/14** | 10 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/14** | 11 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 9 |
| **2017/08/14** | 12 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 10 |
| **2017/08/15** | 01 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 1 |
| **2017/08/15** | 02 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 2 |
| **2017/08/15** | 03 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 3 |
| **2017/08/15** | 04 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 4 |
| **2017/08/15** | 05 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 5 |
| **2017/08/15** | 06 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 6 |
| **2017/08/15** | 07 | Yes | Yes | Yes | Yes | Yes | Simultaneous with MD4-1000 flight 7 |
| **2017/08/15** | 08 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 01 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 02 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 03 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 04 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 05 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 06 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 07 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 08 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 09 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 10 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 11 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 12 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 13 | Yes | Yes | Yes | Yes | Yes | |
| **2017/08/17** | 14 | Yes | Yes | Yes | Yes | Yes | |

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

| Date (YYYY/MM/DD) | Daily flight number | MD4 | iMet-XQ Dev 3 | iMet-XQ Dev 6 | iMet-XQ Dev 7 | Notes |
|---|---|---|---|---|---|---|
| **2017/08/14** | 01 | Yes | No | No | No | Pilot familiarization flight |
| **2017/08/14** | 02 | Yes | No | No | No | Pilot familiarization flight |
| **2017/08/14** | 03 | Yes | Yes[1] | Yes | No | Simultaneous with S-1000 flight 1 |
| **2017/08/14** | 04 | Yes | No | Yes | No | Simultaneous with S-1000 flight 2 |
| **2017/08/14** | 05 | Yes | No | No | Yes | Simultaneous with S-1000 flight 3 |
| **2017/08/14** | 06 | Yes | Yes | Yes | No | Simultaneous with S-1000 flight 5 |
| **2017/08/14** | 07 | Yes | Yes | Yes | No | |
| **2017/08/14** | 08 | Yes | Yes | Yes | No | Simultaneous with S-1000 flight 9 |
| **2017/08/14** | 09 | Yes | Yes | Yes | No | Simultaneous with S-1000 flight 11 |
| **2017/08/14** | 10 | Yes | Yes[1] | Yes | No | Simultaneous with S-1000 flight 12 |
| **2017/08/15** | 01 | Yes | Yes | Yes | No | Simultaneous with S-1000 flight 1 |
| **2017/08/15** | 02 | Yes | Yes | Yes | No | Simultaneous with S-1000 flight 2 |
| **2017/08/15** | 03 | Yes | Yes[1] | Yes | No | Simultaneous with S-1000 flight 3 |
| **2017/08/15** | 04 | Yes | Yes[1] | Yes | No | Simultaneous with S-1000 flight 4 |
| **2017/08/15** | 05 | Yes | Yes[1] | Yes | No | Simultaneous with S-1000 flight 5 |
| **2017/08/15** | 06 | Yes | Yes[1] | Yes | No | Simultaneous with S-1000 flight 6 |
| **2017/08/15** | 07 | Yes | Yes[1] | Yes | No | Simultaneous with S-1000 flight 7 |

[1]Device quit prior to end of flight.

A total of 15 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 500 meters apart prior to flight. Each pilot flew his aircraft independently of the other, although takeoff times were synchronized between aircraft to the extent possible.

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. 20170814-DATA-flight01.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. 20170814-iMet-dev4-flight01.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. 20170814-FLIR-flight01_0001.csv) for quick-looks of the FLIR data. These scripts and all data for each of the LAFE 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 LAFE 2017 field campaign.

## References

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Dumas, E. J., T. R. Lee, M. Buban, and B. Baker, 2017: Small Unmanned Aircraft System (sUAS) measurements during the 2017 Verifications of the Origins of Rotation in Tornadoes Experiment Southeast (VORTEX-SE). NOAA Technical Memorandum OAR ARL-274.

Wulfmeyer V., D. D. Turner, B. Baker, R. Banta, A. Behrendt, T. Bonin, W. A. Brewer, M. Buban, A. Choukulkar, E. Dumas, R.M. Hardesty, T. Heus, D. Lange, T. R. Lee, S. Metzendorf, T. Meyers, R. Newsom, M. Osman, S. Raasch, J. Santanello, C. Senff, F. Späth, T. Wagner, and T. Weckwerth, 2017: A new research approach for observing and characterizing land-atmosphere feedback. Submitted to the Bulletin of the American Meteorological Society.

# Appendix A – Catalog of simultaneous DJI S-1000 and MD4-1000 flight tracks and marker files

```
File 20170814-DATA-flight01.csv OPENED at 17:40:05 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 3!
PRO -1 00007 17:40:12 36.618659 -97.480344 Profile 10m-100m
     0 00076 17:41:21 36.618657 -97.480341
TRS -1 00078 17:41:23 36.618657 -97.480342 Transect
     0 00157 17:42:42 36.622158 -97.476390
PRO -1 00160 17:42:45 36.622161 -97.476392 Profile 100m-300m
     0 00289 17:44:54 36.622159 -97.476382
TRS -1 00291 17:44:56 36.622159 -97.476382 Transect
     0 00377 17:46:22 36.618281 -97.480395
PRO -1 00379 17:46:24 36.618280 -97.480399 Profile 300m-10m
     0 00572 17:49:37 36.618694 -97.480271
File 20170814-DATA-flight01.csv CLOSED at 17:49:58 GPS
Total scans 00594
```

```
File 20170814-DATA-flight03.csv OPENED at 17:39:45 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 1!
PRO -1 00039 17:40:25 36.622651 -97.476686 Profile 10m-100m
     0 00073 17:40:59 36.622653 -97.476688
TRS -1 00097 17:41:23 36.622651 -97.476687 Transect
     0 00333 17:45:19 36.625889 -97.472761
PRO -1 00334 17:45:20 36.625889 -97.472761 Profile 100m-300m
     0 00382 17:46:08 36.625890 -97.472762
TRS -1 00385 17:46:11 36.625890 -97.472762 Transect
EVT    00499 17:48:05 36.622933 -97.476507 iMet-XQ dev3 stopped
     0 00633 17:50:19 36.623193 -97.476176
PRO -1 00635 17:50:21 36.623192 -97.476175 Profile 300m-10m
     0 00790 17:52:57 36.622699 -97.476583
File 20170814-DATA-flight03.csv CLOSED at 17:53:40 GPS
Total scans 00834
```

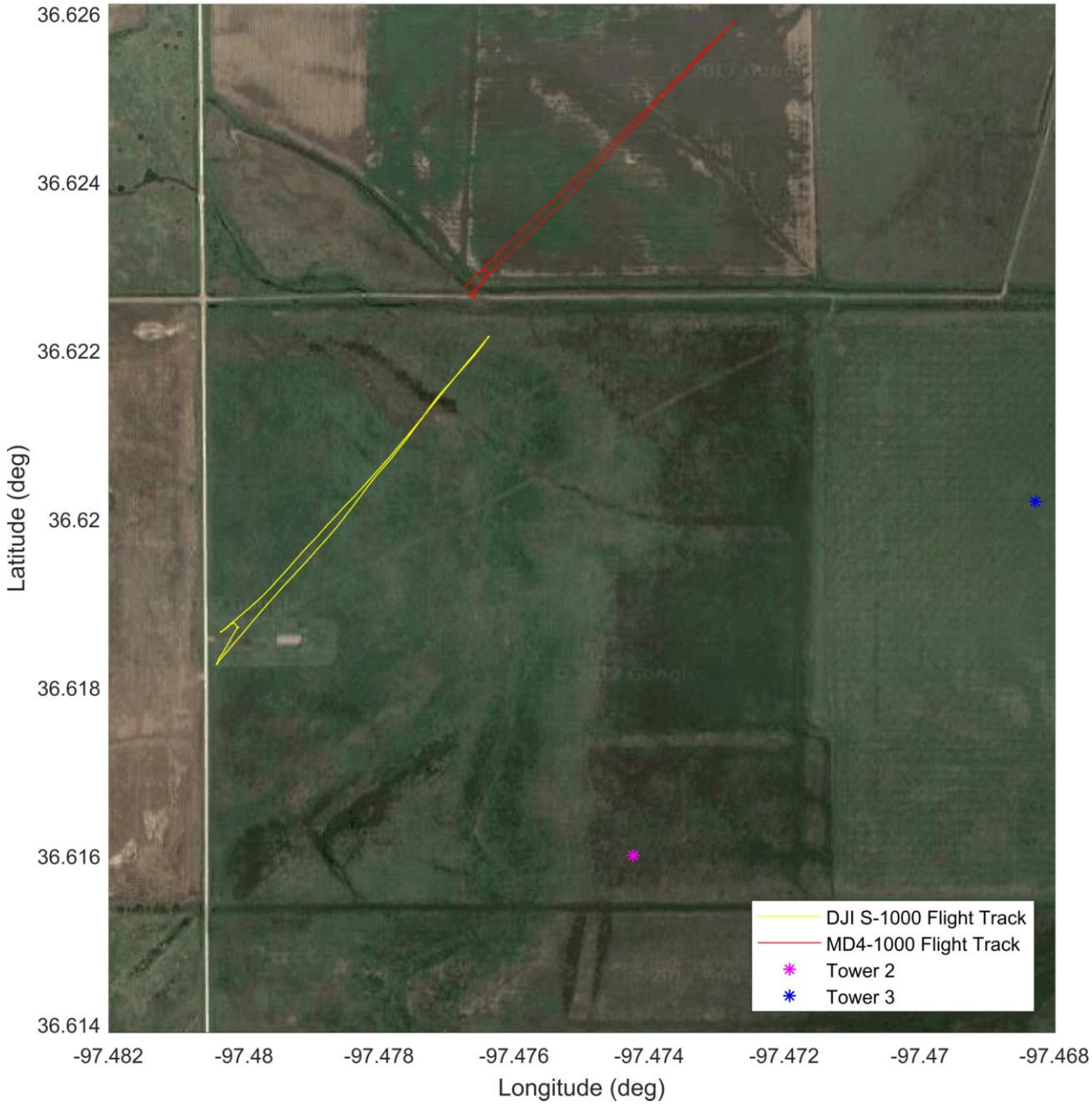


**Figure 5: DJI S-1000 Flight 1 and MD4-1000 Flight 3, Monday, 14 August 2017.**

```
File 20170814-DATA-flight02.csv OPENED at 18:00:02 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 4!
PRO -1 00007 18:00:09 36.618653 -97.480357 Profile 10m-100m
     0 00073 18:01:15 36.618650 -97.480357
TRS -1 00075 18:01:17 36.618649 -97.480356 Transect
     0 00143 18:02:25 36.621833 -97.476204
PRO -1 00145 18:02:27 36.621838 -97.476210 Profile 100m-300m
     0 00273 18:04:35 36.621840 -97.476201
TRS -1 00275 18:04:37 36.621840 -97.476201 Transect
     0 00368 18:06:10 36.618858 -97.480466
PRO -1 00370 18:06:12 36.618915 -97.480397 Profile 300m-10m
     0 00563 18:09:25 36.618717 -97.480234
File 20170814-DATA-flight02.csv CLOSED at 18:09:49 GPS
Total scans 00588
```

```
File 20170814-DATA-flight04.csv OPENED at 18:00:23 GPS
iMet-XQ order (6 right)
This flight flown simultaneously with DJI S-1000 flight 2!
PRO -1 00023 18:00:47 36.622651 -97.476673 Profile 10m-100m
     0 00050 18:01:14 36.622653 -97.476678
TRS -1 00059 18:01:23 36.622653 -97.476677 Transect
     0 00292 18:05:16 36.626286 -97.473011
PRO -1 00294 18:05:18 36.626287 -97.473011 Profile 100m-250m
     0 00342 18:06:06 36.625898 -97.473402
TRS -1 00344 18:06:08 36.625839 -97.473463 Transect
     0 00382 18:06:46 36.624533 -97.474789
PRO -1 00384 18:06:48 36.624460 -97.474856 Profile 250m-300m
     0 00400 18:07:04 36.624213 -97.475096
EVT    00418 18:07:22 36.623608 -97.475695 iMet-XQ dev 6 stopped
TRS -1 00432 18:07:36 36.623122 -97.476184 Transect
     0 00580 18:10:04 36.622799 -97.476513
PRO -1 00582 18:10:06 36.622799 -97.476513 Profile 300m-10m
     0 00728 18:12:32 36.622793 -97.476514
File 20170814-DATA-flight04.csv CLOSED at 18:13:15 GPS
Total scans 00771
```

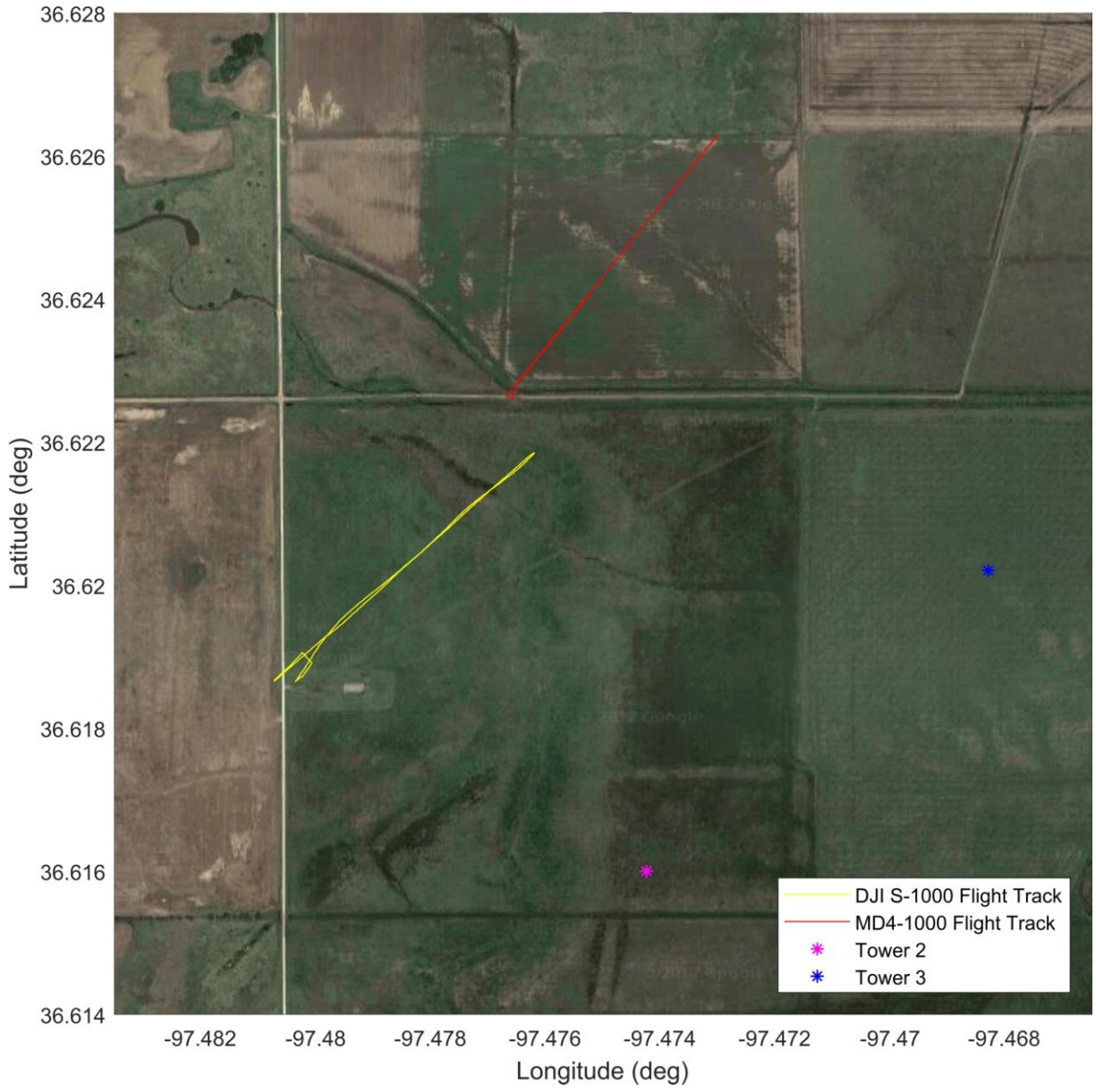


**Figure 6: DJI S-1000 Flight 2 and MD4-1000 Flight 4, Monday, 14 August 2017.**

```
File 20170814-DATA-flight03.csv OPENED at 18:40:46 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 5!
PRO -1 00009 18:40:55 36.618655 -97.480362 Profile 10m-100m
      0 00072 18:41:58 36.618660 -97.480357
TRS -1 00074 18:42:00 36.618660 -97.480358 Transect
      0 00152 18:43:18 36.622135 -97.476456
PRO -1 00154 18:43:20 36.622139 -97.476459 Profile 100m-300m
      0 00286 18:45:32 36.622144 -97.476456
TRS -1 00288 18:45:34 36.622143 -97.476457 Transect
      0 00371 18:46:57 36.618720 -97.480038
PRO -1 00373 18:46:59 36.618720 -97.480036 Profile 300m-10m
      0 00572 18:50:18 36.618678 -97.480314
File 20170814-DATA-flight03.csv CLOSED at 18:50:33 GPS
Total scans 00587
```

```
File 20170814-DATA-flight05.csv OPENED at 18:40:24 GPS
iMet-XQ order (7 right)
This flight flown simultaneously with DJI S-1000 flight 3!
PRO -1 00025 18:40:49 36.622649 -97.476652 Profile 10m-100m
      0 00057 18:41:21 36.622652 -97.476653
TRS -1 00060 18:41:24 36.622650 -97.476653 Transect
      0 00239 18:44:24 36.626115 -97.472737
PRO -1 00241 18:44:26 36.626115 -97.472737 Profile 100m-300m
      0 00288 18:45:13 36.626117 -97.472739
TRS -1 00290 18:45:15 36.626116 -97.472740 Transect
      0 00537 18:49:22 36.622730 -97.476587
PRO -1 00539 18:49:24 36.622732 -97.476588 Profile 300m-10m
      0 00685 18:51:50 36.622702 -97.476564
File 20170814-DATA-flight05.csv CLOSED at 18:52:38 GPS
Total scans 00734
```

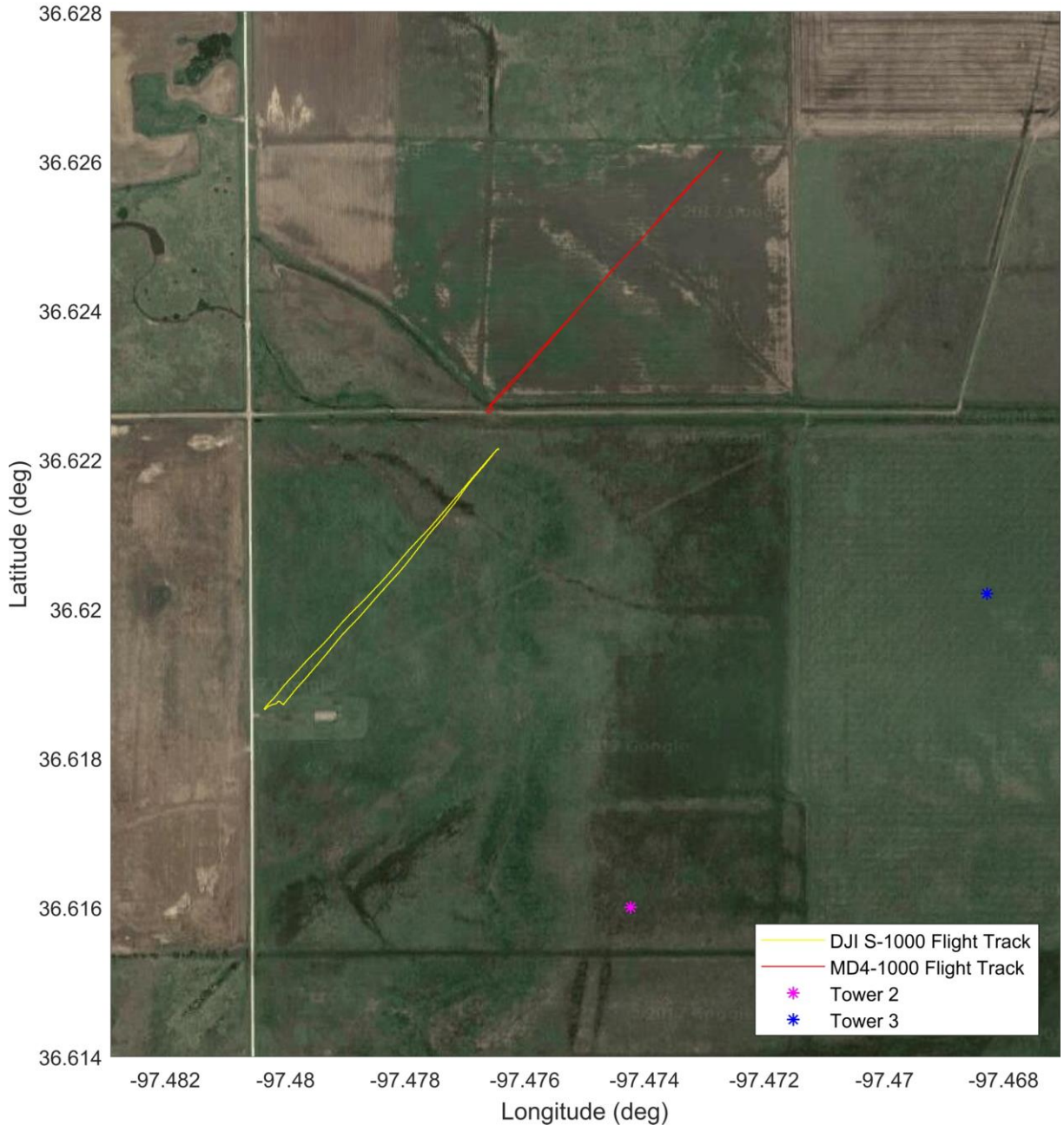


**Figure 7: DJI S-1000 Flight 3 and MD4-1000 Flight 5, Monday, 14 August 2017.**

```
File 20170814-DATA-flight05.csv OPENED at 19:59:31 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 6!
PRO -1 00017 19:59:48 36.618650 -97.480349 Profile 10m-100m
     0 00082 20:00:53 36.618650 -97.480345
TRS -1 00084 20:00:55 36.618650 -97.480346 Transect
     0 00148 20:01:59 36.622315 -97.476552
PRO -1 00150 20:02:01 36.622316 -97.476550 Profile 100m-300m
     0 00282 20:04:13 36.622313 -97.476548
TRS -1 00284 20:04:15 36.622313 -97.476547 Transect
     0 00382 20:05:53 36.618598 -97.480026
PRO -1 00384 20:05:55 36.618596 -97.480025 Profile 300m-10m
     0 00571 20:09:02 36.618745 -97.480186
File 20170814-DATA-flight05.csv CLOSED at 20:09:41 GPS
Total scans 00611
```

```
File 20170814-DATA-flight06.csv OPENED at 20:00:19 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 5!
PRO -1 00028 20:00:47 36.622659 -97.476649 Profile 10m-100m
     0 00058 20:01:17 36.622657 -97.476649
TRS -1 00071 20:01:30 36.622655 -97.476648 Transect
     0 00212 20:03:51 36.626616 -97.472346
PRO -1 00214 20:03:53 36.626615 -97.472347 Profile 100m-300m
     0 00265 20:04:44 36.626617 -97.472346
TRS -1 00267 20:04:46 36.626617 -97.472346 Transect
     0 00456 20:07:55 36.622818 -97.476495
PRO -1 00458 20:07:57 36.622818 -97.476495 Profile 300m-10m
     0 00612 20:10:32 36.622620 -97.476628
File 20170814-DATA-flight06.csv CLOSED at 20:10:55 GPS
Total scans 00636
```

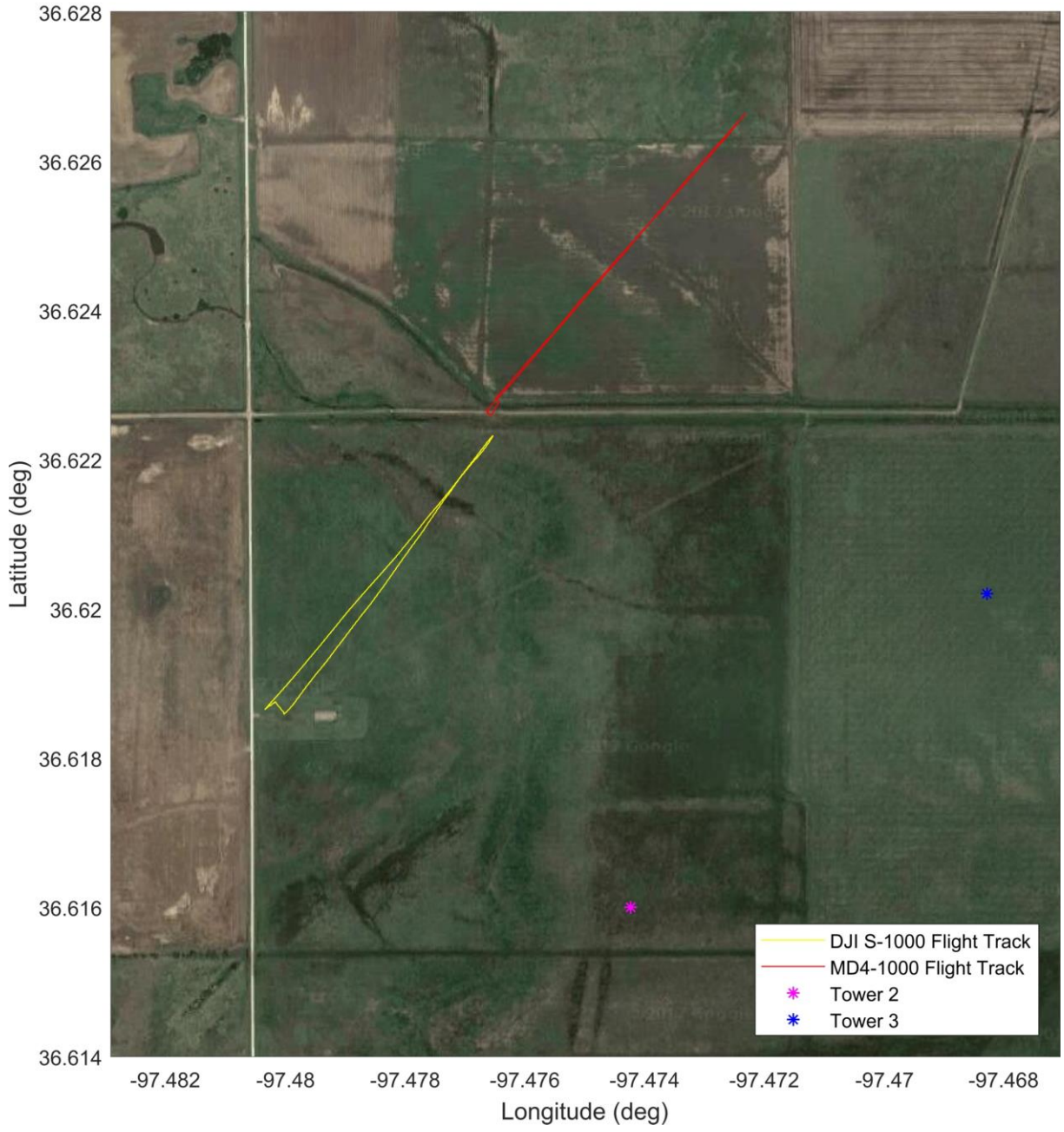


**Figure 8: DJI S-1000 Flight 5 and MD4-1000 Flight 6, Monday, 14 August 2017.**

```
File 20170814-DATA-flight09.csv OPENED at 22:00:09 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 8!
PRO -1 00012 22:00:21 36.618663 -97.480347 Profile 10m-100m
     0 00073 22:01:22 36.618665 -97.480347
TRS -1 00075 22:01:24 36.618665 -97.480347 Transect
     0 00156 22:02:45 36.622015 -97.476301
PRO -1 00158 22:02:47 36.622017 -97.476302 Profile 100m-300m
     0 00289 22:04:58 36.622018 -97.476299
TRS -1 00291 22:05:00 36.622018 -97.476299 Transect
     0 00422 22:07:11 36.618465 -97.480139
PRO -1 00424 22:07:13 36.618465 -97.480143 Profile 300m-10m
     0 00613 22:10:22 36.618714 -97.480241
File 20170814-DATA-flight09.csv CLOSED at 22:10:51 GPS
Total scans 00643
```

```
File 20170814-DATA-flight08.csv OPENED at 21:59:59 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 9!
PRO -1 00031 22:00:30 36.622663 -97.476695 Profile 10m-100m
     0 00054 22:00:53 36.622664 -97.476694
TRS -1 00066 22:01:05 36.622664 -97.476692 Transect
     0 00231 22:03:51 36.627336 -97.470974
PRO -1 00234 22:03:54 36.627334 -97.470974 Profile 100m-300m
     0 00281 22:04:41 36.627340 -97.470966
TRS -1 00297 22:04:57 36.627340 -97.470966 Transect
     0 00559 22:09:19 36.622632 -97.476621
PRO -1 00562 22:09:22 36.622633 -97.476620 Profile 300m-10m
     0 00717 22:11:57 36.622633 -97.476624
File 20170814-DATA-flight08.csv CLOSED at 22:12:24 GPS
Total scans 00745
```

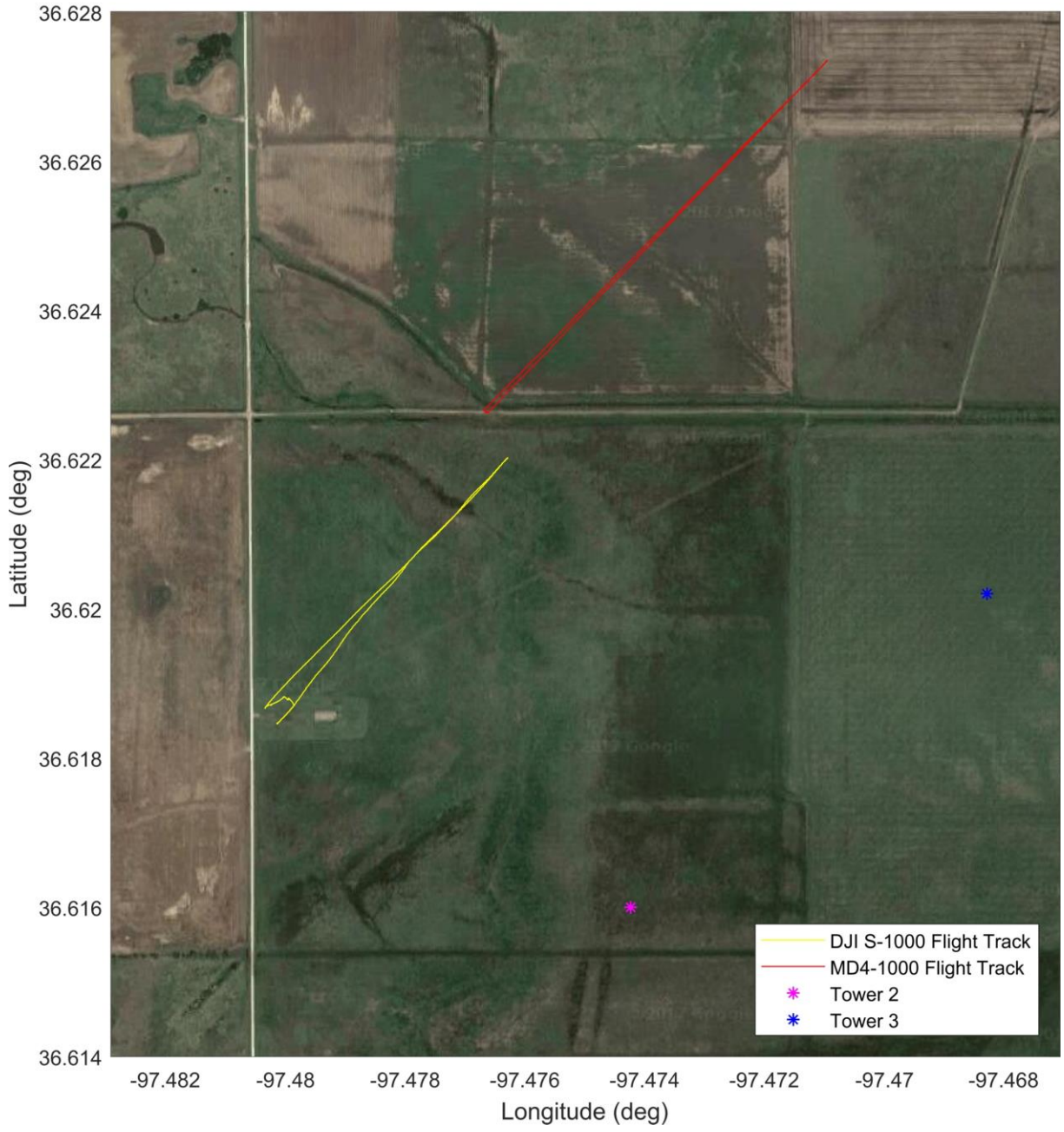


**Figure 9: DJI S-1000 Flight 9 and MD4-1000 Flight 8, Monday, 14 August 2017.**

```
File 20170814-DATA-flight11.csv OPENED at 22:40:18 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 9!
PRO -1 00009 22:40:27 36.618665 -97.480341 Profile 10m-100m
     0 00074 22:41:32 36.618666 -97.480342
TRS -1 00076 22:41:34 36.618666 -97.480342 Transect
     0 00164 22:43:02 36.622236 -97.476479
PRO -1 00166 22:43:04 36.622239 -97.476481 Profile 100m-300m
     0 00300 22:45:18 36.622240 -97.476475
TRS -1 00302 22:45:20 36.622241 -97.476475 Transect
     0 00382 22:46:40 36.618862 -97.480354
PRO -1 00384 22:46:42 36.618862 -97.480353 Profile 300m-10m
     0 00575 22:49:53 36.618714 -97.480291
File 20170814-DATA-flight11.csv CLOSED at 22:50:23 GPS
Total scans 00606
```

```
File 20170814-DATA-flight09.csv OPENED at 22:38:49 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 11!
PRO -1 00063 22:39:52 36.622680 -97.476708 Profile 10m-100m
     0 00088 22:40:17 36.622682 -97.476707
TRS -1 00106 22:40:35 36.622681 -97.476707 Transect
     0 00321 22:44:10 36.627683 -97.471285
PRO -1 00323 22:44:12 36.627683 -97.471285 Profile 100m-300m
     0 00372 22:45:01 36.627684 -97.471286
TRS -1 00399 22:45:28 36.627683 -97.471286 Transect
     0 00677 22:50:07 36.622640 -97.476680
PRO -1 00680 22:50:10 36.622642 -97.476677 Profile 300m-10m
     0 00835 22:52:45 36.622634 -97.476675
File 20170814-DATA-flight09.csv CLOSED at 22:53:20 GPS
Total scans 00871
```

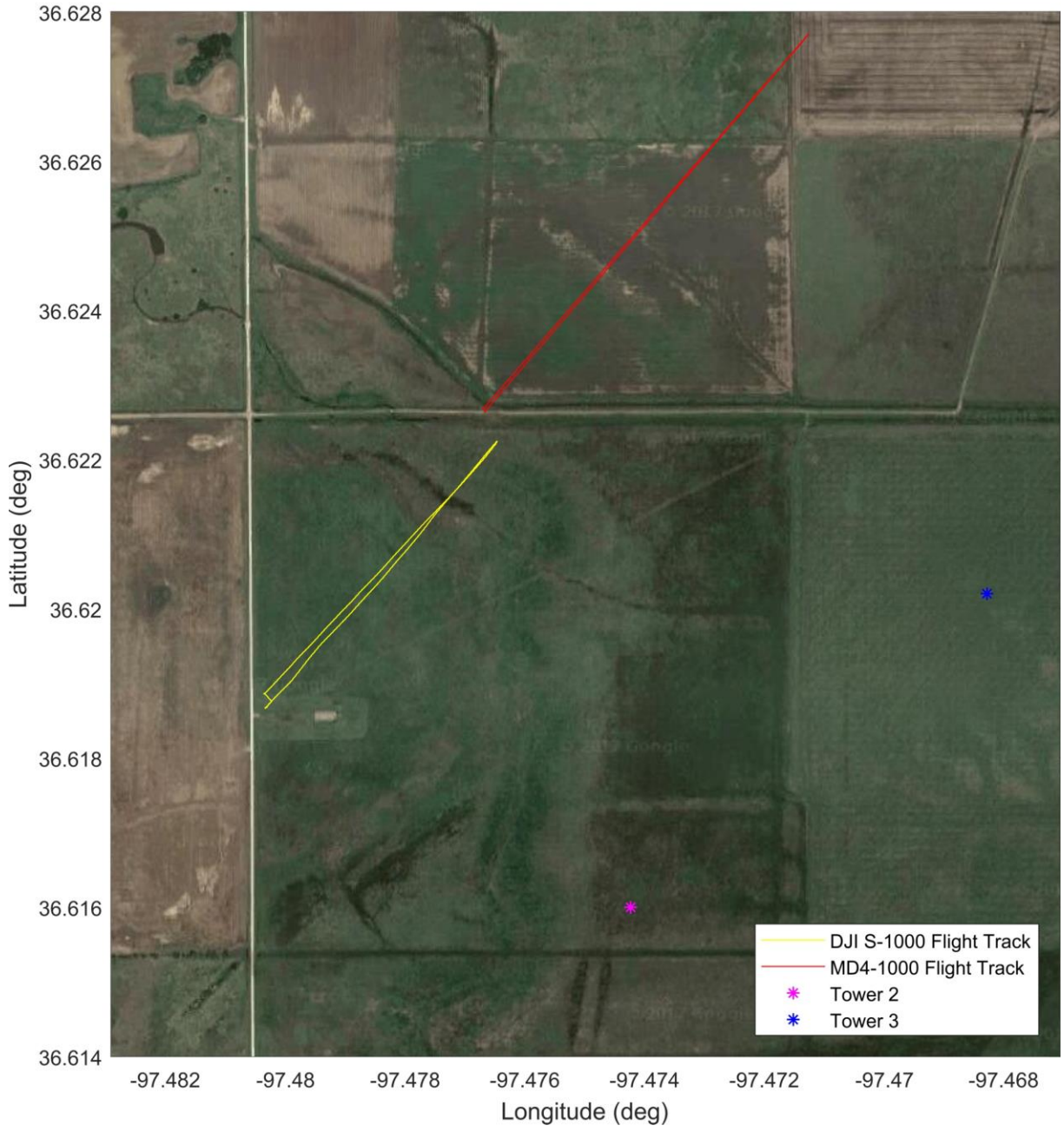


**Figure 10: DJI S-1000 Flight 11 and MD4-1000 Flight 9, Monday, 14 August 2017.**

```
File 20170814-DATA-flight12.csv OPENED at 23:10:13 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 10!
PRO -1 00015 23:10:28 36.618680 -97.480342 Profile 10m-100m
     0 00080 23:11:33 36.618683 -97.480336
TRS -1 00082 23:11:35 36.618683 -97.480336 Transect
     0 00169 23:13:02 36.621671 -97.475776
PRO -1 00171 23:13:04 36.621677 -97.475779 Profile 100m-300m
     0 00303 23:15:16 36.621682 -97.475773
TRS -1 00305 23:15:18 36.621681 -97.475774 Transect
     0 00421 23:17:14 36.618055 -97.480001
PRO -1 00423 23:17:16 36.618055 -97.480004 Profile 300m-10m
     0 00609 23:20:22 36.618702 -97.480277
File 20170814-DATA-flight12.csv CLOSED at 23:20:47 GPS
Total scans 00635
```

```
File 20170814-DATA-flight10.csv OPENED at 23:08:01 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 12!
PRO -1 00051 23:08:52 36.622674 -97.476712 Profile 10m-100m
     0 00078 23:09:19 36.622672 -97.476713
TRS -1 00092 23:09:33 36.622672 -97.476713 Transect
     0 00337 23:13:38 36.627431 -97.471018
PRO -1 00339 23:13:40 36.627431 -97.471019 Profile 100m-300m
     0 00389 23:14:30 36.627432 -97.471021
TRS -1 00394 23:14:35 36.627432 -97.471019 Transect
EVT    00461 23:15:42 36.627431 -97.471020 iMet-XQ dev3 stopped
     0 00738 23:20:19 36.622629 -97.476664
PRO -1 00742 23:20:23 36.622633 -97.476659 Profile 300m-10m
     0 00894 23:22:55 36.622639 -97.476655
File 20170814-DATA-flight10.csv CLOSED at 23:23:38 GPS
Total scans 00937
```

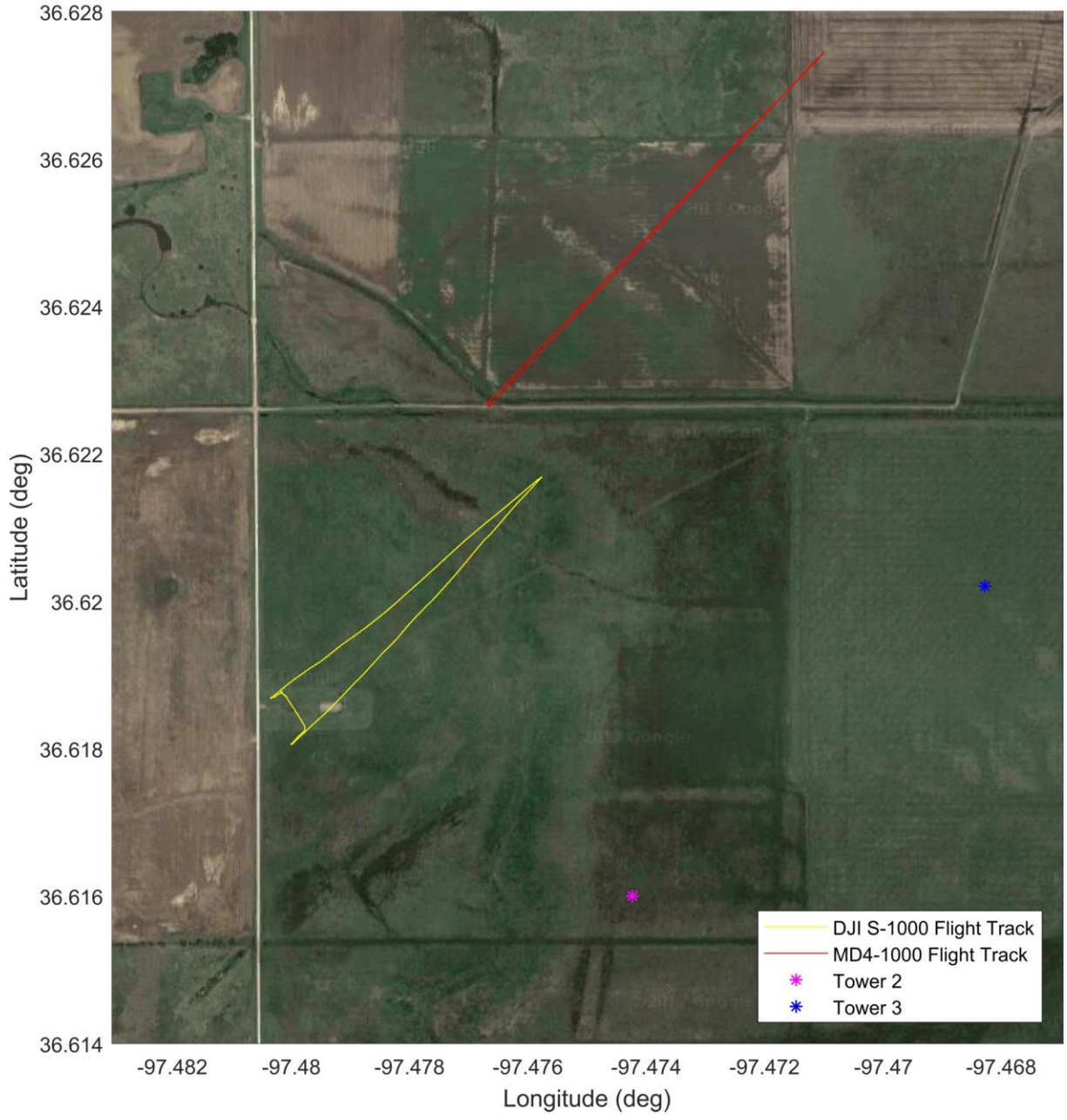


**Figure 11: DJI S-1000 Flight 12 and MD4-1000 Flight 10, Monday, 14 August 2017.**

```
File 20170815-DATA-flight01.csv OPENED at 17:09:45 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 1!
PRO -1 00013 17:09:58 36.618666 -97.480357 Profile 10m-100m
     0 00080 17:11:05 36.618668 -97.480354
TRS -1 00082 17:11:07 36.618668 -97.480352 Transect
     0 00173 17:12:38 36.621916 -97.476336
PRO -1 00175 17:12:40 36.621919 -97.476339 Profile 100m-300m
     0 00305 17:14:50 36.621920 -97.476331
TRS -1 00307 17:14:52 36.621920 -97.476332 Transect
     0 00403 17:16:28 36.618424 -97.479629
PRO -1 00405 17:16:30 36.618438 -97.479640 Profile 300m-10m
     0 00597 17:19:42 36.618716 -97.480234
File 20170815-DATA-flight01.csv CLOSED at 17:20:21 GPS
Total scans 00637
```

```
File 20170815-DATA-flight01.csv OPENED at 17:13:37 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 1!
PRO -1 00021 17:13:58 36.622658 -97.476687 Profile 10m-100m
     0 00046 17:14:23 36.622660 -97.476680
TRS -1 00049 17:14:26 36.622733 -97.476595 Transect
     0 00177 17:16:34 36.626761 -97.471694
PRO -1 00178 17:16:35 36.626793 -97.471656 Profile 100m-300m
     0 00226 17:17:23 36.626852 -97.471599
TRS -1 00229 17:17:26 36.626852 -97.471597 Transect
     0 00451 17:21:09 36.622616 -97.476680
PRO -1 00453 17:21:11 36.622615 -97.476680 Profile 300m-10m
     0 00603 17:23:41 36.622619 -97.476631
File 20170815-DATA-flight01.csv CLOSED at 17:24:14 GPS
Total scans 00637
```

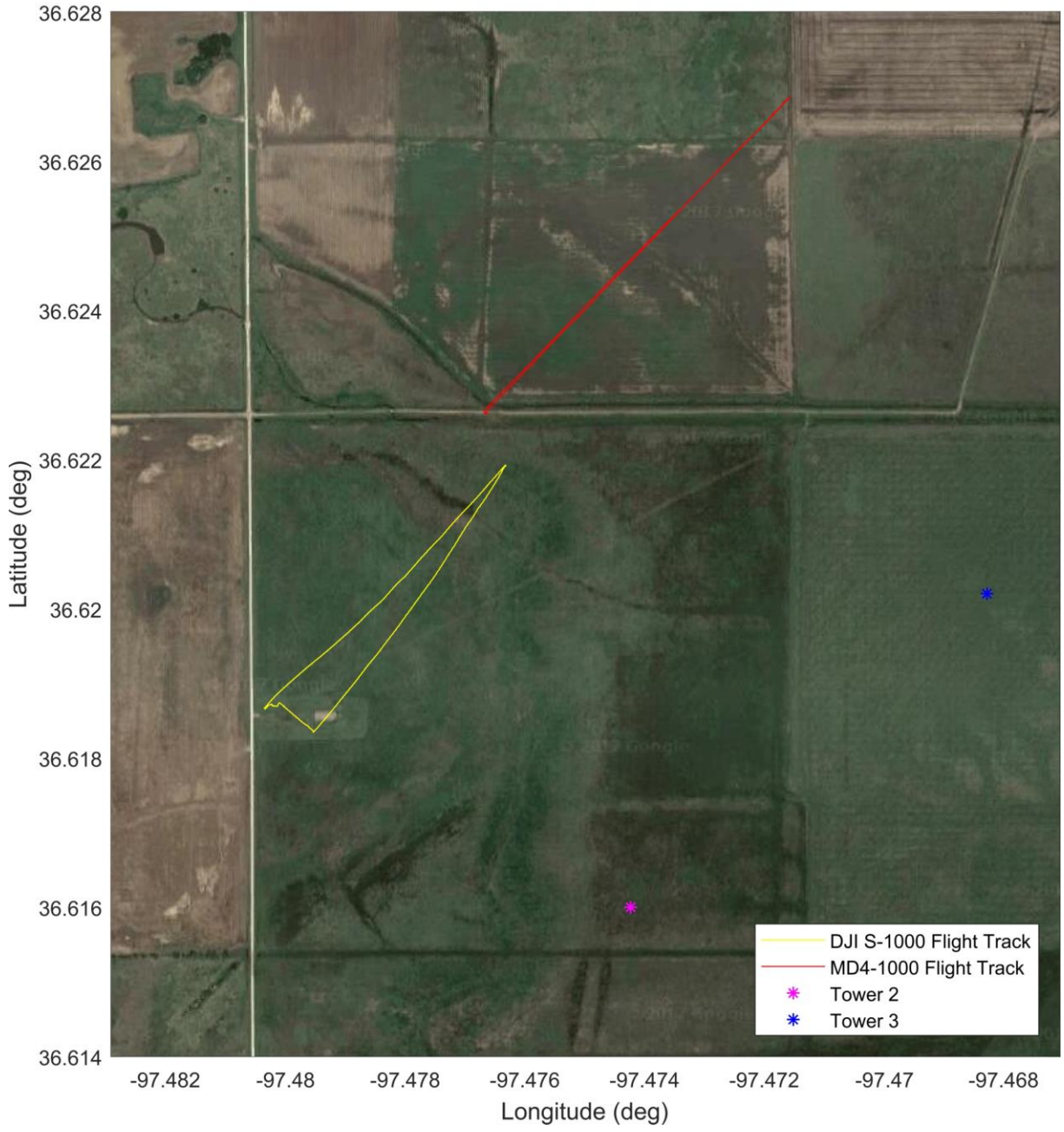


**Figure 12: DJI S-1000 Flight 1 and MD4-1000 Flight 1, Tuesday, 15 August 2017.**

```
File 20170815-DATA-flight02.csv OPENED at 20:09:50 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 2!
PRO -1 00014 20:10:04 36.618673 -97.480350 Profile 10m-100m
     0 00076 20:11:06 36.618673 -97.480351
TRS -1 00078 20:11:08 36.618677 -97.480348 Transect
     0 00169 20:12:39 36.621768 -97.476074
PRO -1 00171 20:12:41 36.621771 -97.476074 Profile 100m-300m
     0 00303 20:14:53 36.621770 -97.476070
TRS -1 00305 20:14:55 36.621770 -97.476070 Transect
     0 00397 20:16:27 36.618574 -97.479541
PRO -1 00399 20:16:29 36.618575 -97.479539 Profile 300m-10m
     0 00588 20:19:38 36.618727 -97.480251
File 20170815-DATA-flight02.csv CLOSED at 20:20:15 GPS
Total scans 00626
```

```
File 20170815-DATA-flight02.csv OPENED at 20:08:27 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 2!
PRO -1 00063 20:09:30 36.622669 -97.476689 Profile 10m-100m
     0 00087 20:09:54 36.622669 -97.476691
TRS -1 00101 20:10:08 36.622679 -97.476678 Transect
     0 00295 20:13:23 36.627177 -97.471039
PRO -1 00297 20:13:25 36.627178 -97.471038 Profile 100m-300m
     0 00345 20:14:13 36.627179 -97.471039
TRS -1 00360 20:14:28 36.627178 -97.471040 Transect
     0 00670 20:19:38 36.622626 -97.476674
PRO -1 00672 20:19:40 36.622626 -97.476674 Profile 300m-10m
     0 00823 20:22:11 36.622631 -97.476667
File 20170815-DATA-flight02.csv CLOSED at 20:22:49 GPS
Total scans 00862
```

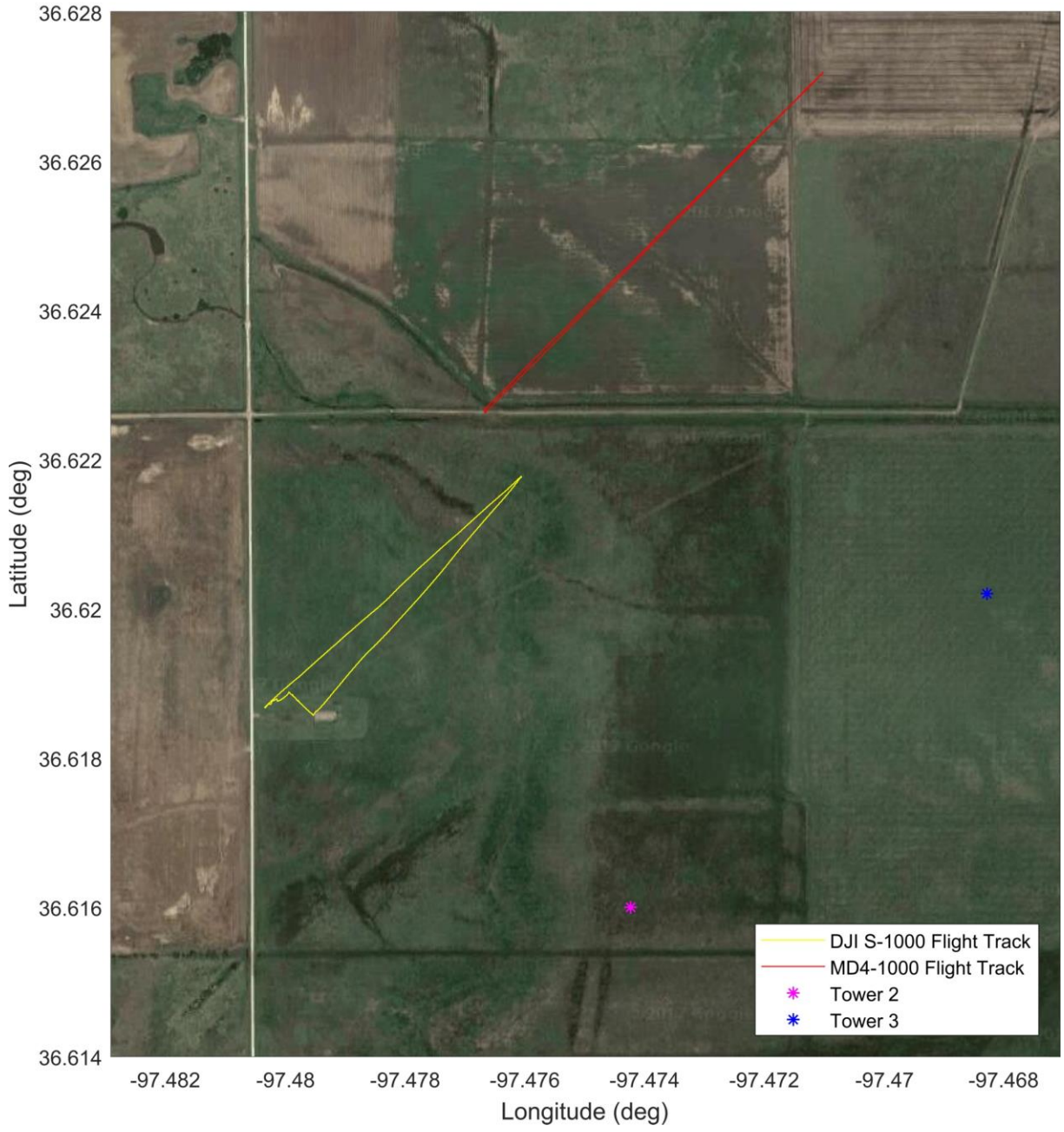


**Figure 13: DJI S-1000 Flight 2 and MD4-1000 Flight 2, Tuesday, 15 August 2017.**

```
File 20170815-DATA-flight03.csv OPENED at 20:41:11 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 3!
PRO -1 00011 20:41:22 36.618668 -97.480349 Profile 10m-100m
     0 00073 20:42:24 36.618664 -97.480351
TRS -1 00075 20:42:26 36.618664 -97.480350 Transect
     0 00171 20:44:02 36.621759 -97.476052
PRO -1 00173 20:44:04 36.621765 -97.476057 Profile 100m-300m
     0 00304 20:46:15 36.621764 -97.476051
TRS -1 00306 20:46:17 36.621763 -97.476052 Transect
     0 00402 20:47:53 36.618738 -97.480129
PRO -1 00404 20:47:55 36.618739 -97.480125 Profile 300m-10m
     0 00605 20:51:16 36.618737 -97.480256
File 20170815-DATA-flight03.csv CLOSED at 20:51:54 GPS
Total scans 00644
```

```
File 20170815-DATA-flight03.csv OPENED at 20:38:30 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 3!
PRO -1 00025 20:38:55 36.622672 -97.476694 Profile 10m-100m
     0 00051 20:39:21 36.622675 -97.476693
TRS -1 00065 20:39:35 36.622633 -97.476661 Transect
EVT    00309 20:43:40 36.627163 -97.471291 iMet-XQ dev3 stopped
     0 00354 20:44:25 36.627164 -97.471291
PRO -1 00356 20:44:27 36.627164 -97.471292 Profile 100m-300m
     0 00402 20:45:13 36.627165 -97.471293
TRS -1 00415 20:45:26 36.627163 -97.471291 Transect
     0 00739 20:50:50 36.622632 -97.476668
PRO -1 00742 20:50:53 36.622634 -97.476666 Profile 300m-10m
     0 00891 20:53:22 36.622637 -97.476663
File 20170815-DATA-flight03.csv CLOSED at 20:53:57 GPS
Total scans 00927
```

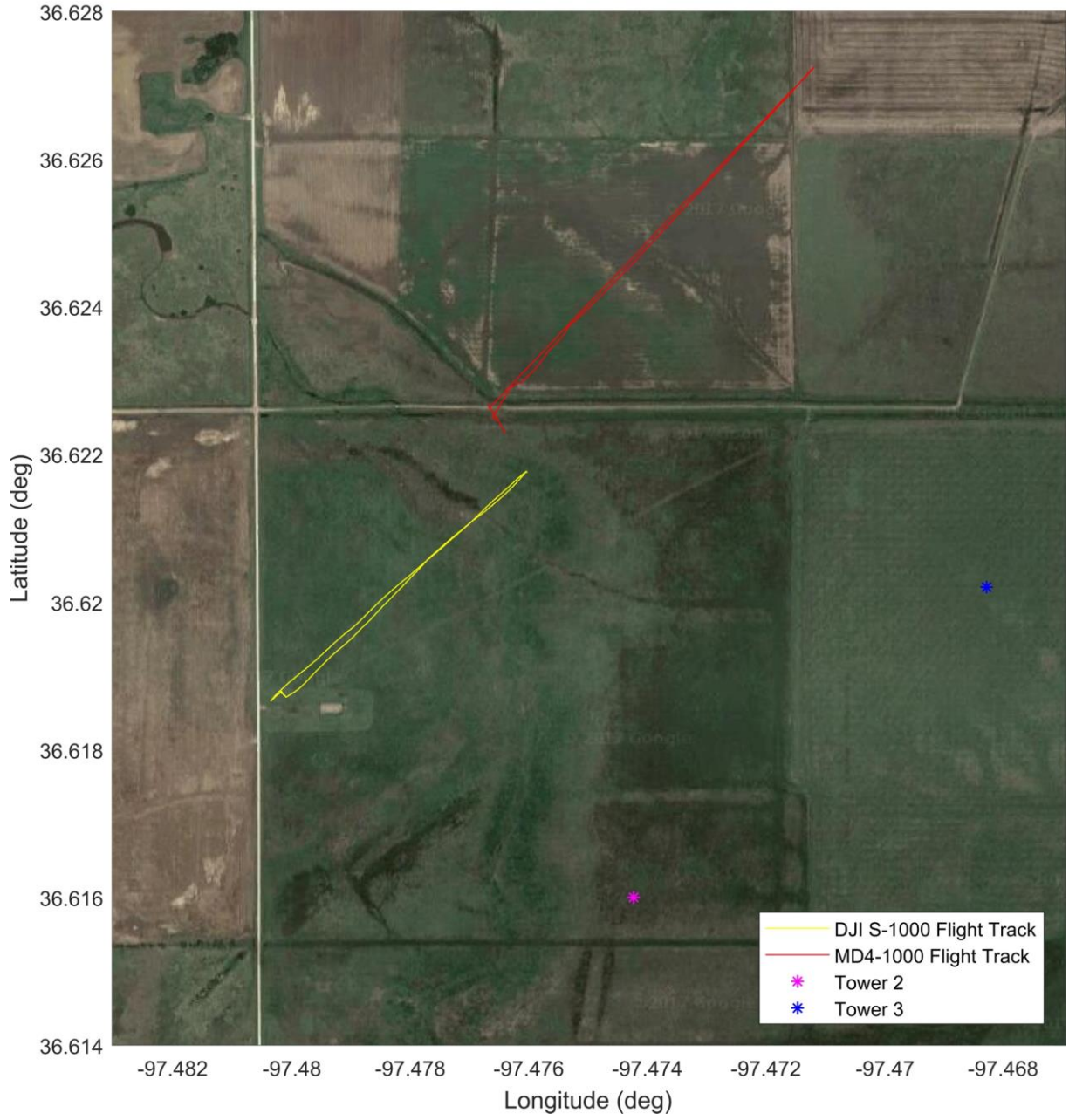


**Figure 14: DJI S-1000 Flight 3 and MD4-1000 Flight 3, Tuesday, 15 August 2017.**

```
File 20170815-DATA-flight04.csv OPENED at 21:09:52 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 4!
PRO -1 00013 21:10:05 36.618666 -97.480339 Profile 10m-100m
     0 00078 21:11:10 36.618664 -97.480342
TRS -1 00080 21:11:12 36.618665 -97.480343 Transect
     0 00180 21:12:52 36.621525 -97.475845
PRO -1 00182 21:12:54 36.621529 -97.475845 Profile 100m-300m
     0 00314 21:15:06 36.621527 -97.475840
TRS -1 00316 21:15:08 36.621529 -97.475839 Transect
     0 00441 21:17:13 36.618999 -97.480193
PRO -1 00443 21:17:15 36.618999 -97.480192 Profile 300m-10m
     0 00639 21:20:31 36.618720 -97.480228
File 20170815-DATA-flight04.csv CLOSED at 21:21:11 GPS
Total scans 00679
```

```
File 20170815-DATA-flight04.csv OPENED at 21:08:32 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 4!
PRO -1 00062 21:09:34 36.622655 -97.476710 Profile 10m-100m
     0 00088 21:10:00 36.622657 -97.476709
TRS -1 00112 21:10:24 36.622660 -97.476701 Transect
     0 00277 21:13:09 36.627288 -97.471475
PRO -1 00281 21:13:13 36.627287 -97.471476 Profile 100m-300m
     0 00329 21:14:01 36.627286 -97.471478
TRS -1 00341 21:14:13 36.627285 -97.471478 Transect
EVT    00474 21:16:27 36.624755 -97.474301 iMet-XQ dev3 stopped
     0 00615 21:18:48 36.622628 -97.476673
PRO -1 00617 21:18:50 36.622629 -97.476673 Profile 300m-10m
     0 00771 21:21:24 36.622627 -97.476672
File 20170815-DATA-flight04.csv CLOSED at 21:22:05 GPS
Total scans 00813
```

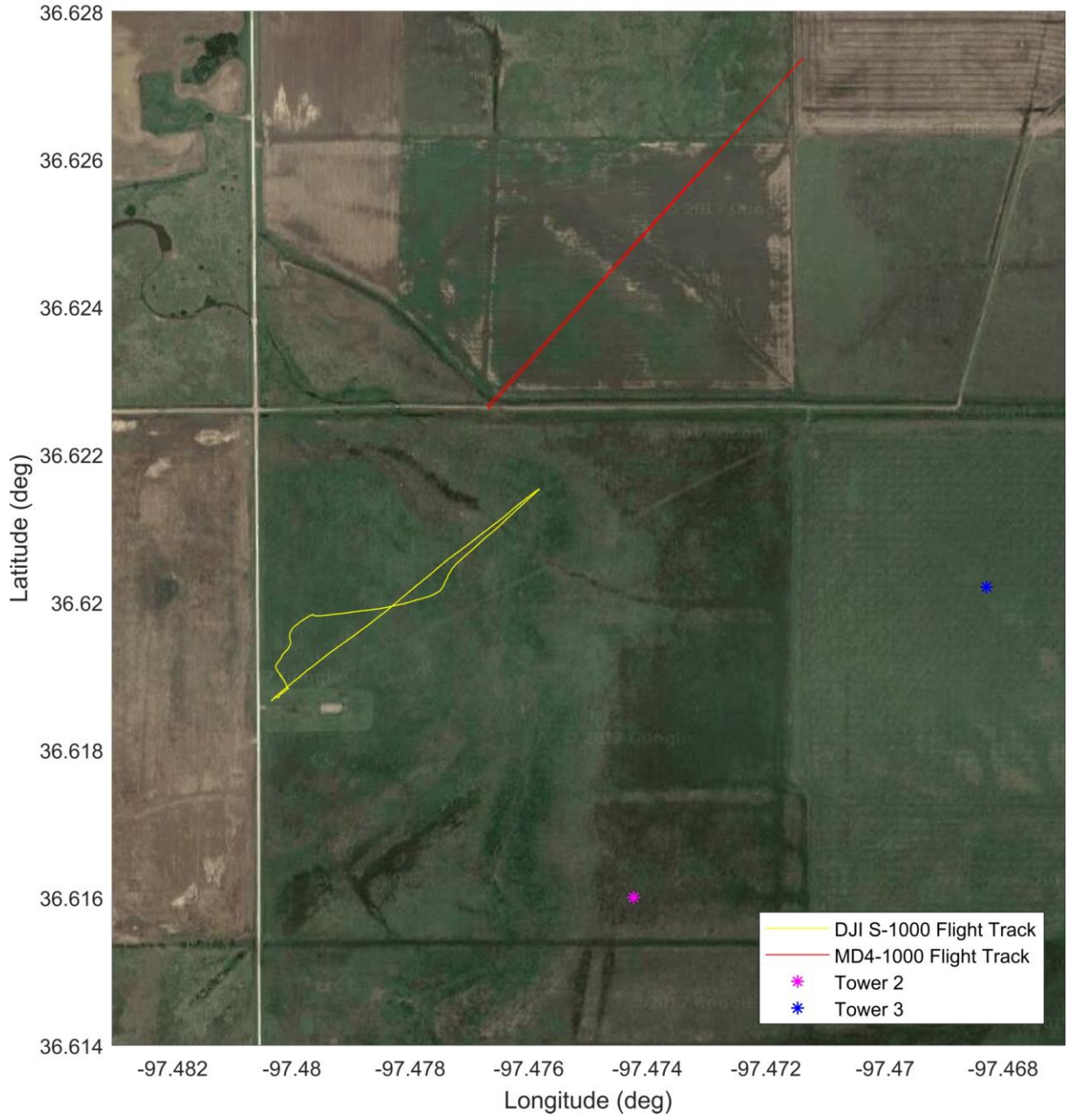


**Figure 15: DJI S-1000 Flight 4 and MD4-1000 Flight 4, Tuesday, 15 August 2017.**

```
File 20170815-DATA-flight05.csv OPENED at 21:41:12 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 5!
PRO -1 00019 21:41:31 36.618669 -97.480336 Profile 10m-100m
     0 00081 21:42:33 36.618671 -97.480336
TRS -1 00083 21:42:35 36.618672 -97.480335 Transect
     0 00185 21:44:17 36.621829 -97.476210
PRO -1 00188 21:44:20 36.621831 -97.476209 Profile 100m-300m
     0 00316 21:46:28 36.621830 -97.476201
TRS -1 00318 21:46:30 36.621830 -97.476204 Transect
     0 00418 21:48:10 36.618611 -97.479978
PRO -1 00420 21:48:12 36.618613 -97.479983 Profile 300m-10m
     0 00619 21:51:31 36.618697 -97.480293
File 20170815-DATA-flight05.csv CLOSED at 21:52:07 GPS
Total scans 00656
```

```
File 20170815-DATA-flight05.csv OPENED at 21:39:47 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 5!
PRO -1 00028 21:40:15 36.622659 -97.476685 Profile 10m-100m
     0 00049 21:40:36 36.622659 -97.476687
TRS -1 00072 21:40:59 36.622660 -97.476686 Transect
     0 00240 21:43:48 36.627046 -97.471177
PRO -1 00242 21:43:50 36.627046 -97.471177 Profile 100m-300m
     0 00284 21:44:32 36.627044 -97.471181
TRS -1 00310 21:44:58 36.627044 -97.471180 Transect
     0 00578 21:49:26 36.622624 -97.476654
PRO -1 00582 21:49:30 36.622625 -97.476656 Profile 300m-10m
     0 00736 21:52:04 36.622624 -97.476655
EVT    00758 21:52:26 36.622625 -97.476655 iMet-XQ dev3 stopped
File 20170815-DATA-flight05.csv CLOSED at 21:52:48 GPS
Total scans 00781
```

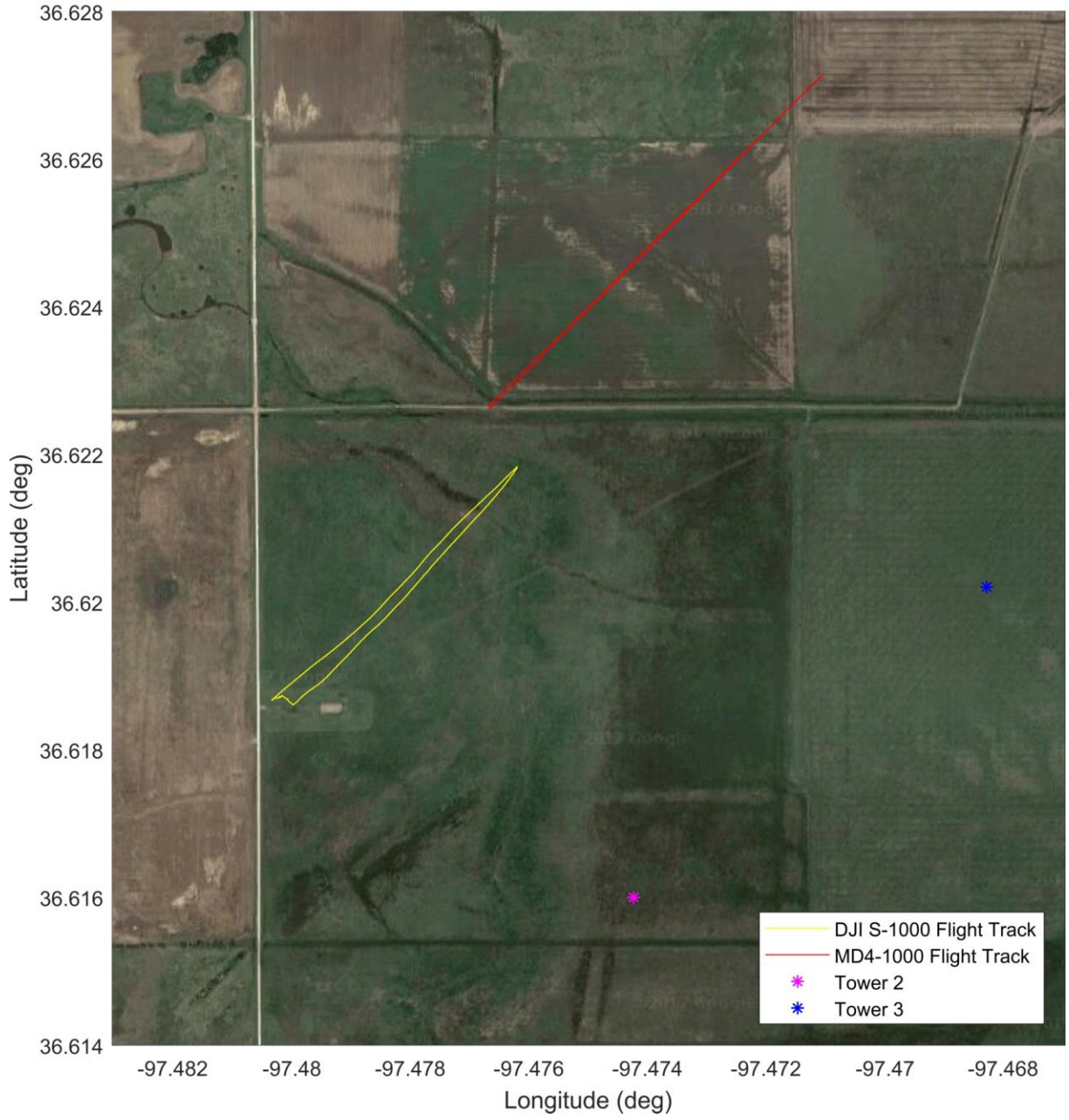


**Figure 16: DJI S-1000 Flight 5 and MD4-1000 Flight 5, Tuesday, 15 August 2017.**

```
File 20170815-DATA-flight06.csv OPENED at 22:10:04 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 6!
PRO -1 00017 22:10:21 36.618669 -97.480342 Profile 10m-100m
     0 00080 22:11:24 36.618671 -97.480343
TRS -1 00083 22:11:27 36.618672 -97.480343 Transect
     0 00187 22:13:11 36.621853 -97.476087
PRO -1 00189 22:13:13 36.621856 -97.476089 Profile 100m-300m
     0 00318 22:15:22 36.621854 -97.476086
TRS -1 00320 22:15:24 36.621854 -97.476084 Transect
     0 00425 22:17:09 36.619152 -97.480199
PRO -1 00427 22:17:11 36.619148 -97.480203 Profile 300m-10m
     0 00628 22:20:32 36.618704 -97.480294
File 20170815-DATA-flight06.csv CLOSED at 22:21:10 GPS
Total scans 00667
```

```
File 20170815-DATA-flight06.csv OPENED at 22:08:10 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 6!
PRO -1 00121 22:10:11 36.622663 -97.476694 Profile 10m-100m
     0 00151 22:10:41 36.622661 -97.476693
TRS -1 00180 22:11:10 36.622659 -97.476693 Transect
     0 00348 22:13:59 36.627292 -97.471475
PRO -1 00350 22:14:01 36.627290 -97.471479 Profile 100m-300m
     0 00393 22:14:44 36.627290 -97.471477
TRS -1 00399 22:14:50 36.627274 -97.471494 Transect
EVT    00612 22:18:23 36.623008 -97.476231 iMet-XQ dev3 stopped
     0 00634 22:18:45 36.622622 -97.476663
PRO -1 00636 22:18:47 36.622625 -97.476659 Profile 300m-10m
     0 00782 22:21:13 36.622628 -97.476653
File 20170815-DATA-flight06.csv CLOSED at 22:21:53 GPS
Total scans 00823
```

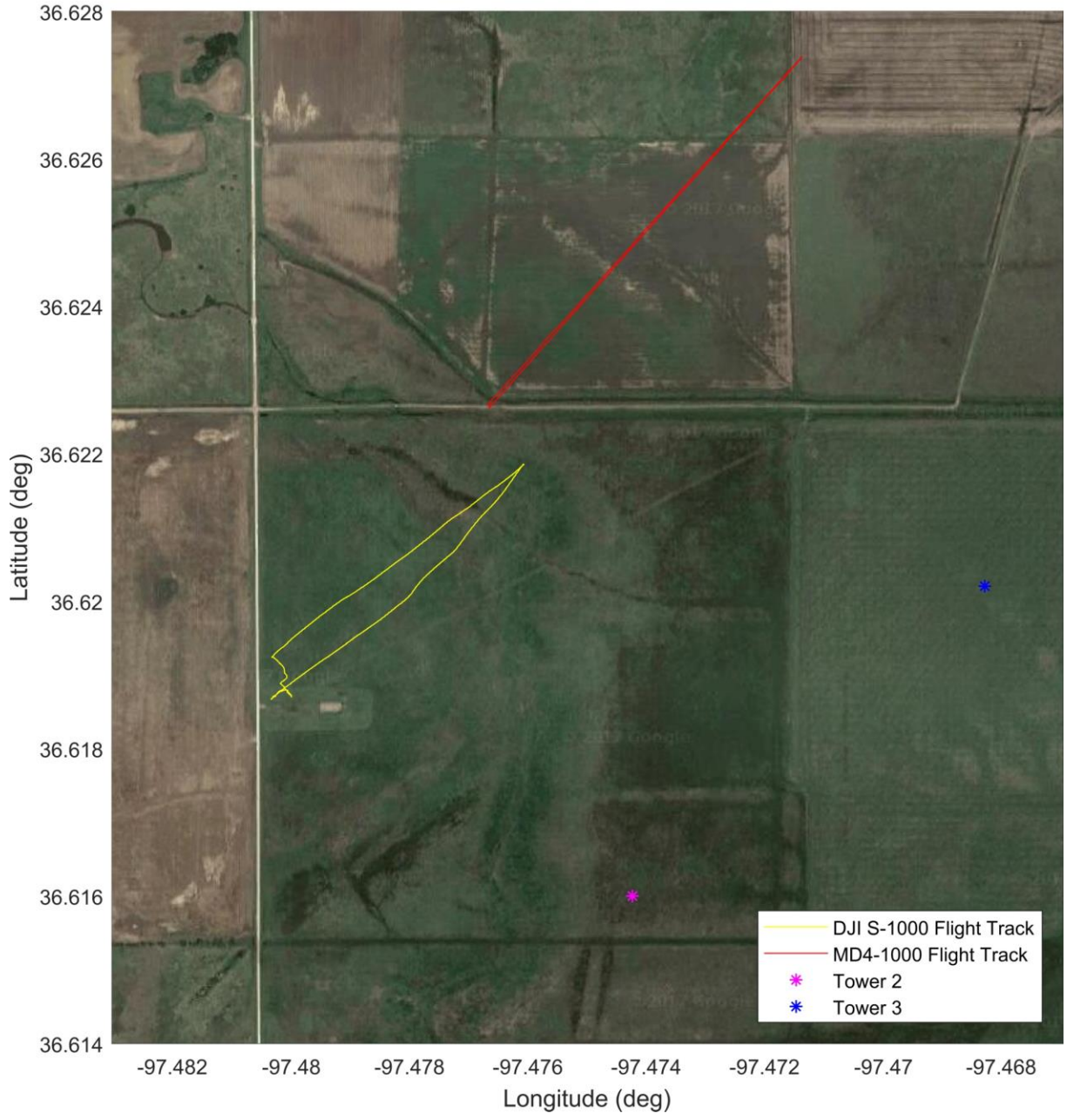


**Figure 17: DJI S-1000 Flight 6 and MD4-1000 Flight 6, Tuesday, 15 August 2017.**

```
File 20170815-DATA-flight07.csv OPENED at 22:41:39 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 7!
PRO -1 00013 22:41:52 36.618680 -97.480345 Profile 10m-100m
     0 00079 22:42:58 36.618678 -97.480346
TRS -1 00082 22:43:01 36.618726 -97.480285 Transect
     0 00174 22:44:33 36.621568 -97.475879
PRO -1 00176 22:44:35 36.621573 -97.475880 Profile 100m-300m
     0 00306 22:46:45 36.621572 -97.475872
TRS -1 00308 22:46:47 36.621571 -97.475873 Transect
     0 00410 22:48:29 36.618715 -97.480477
PRO -1 00412 22:48:31 36.618711 -97.480472 Profile 300m-10m
     0 00609 22:51:48 36.618713 -97.480268
File 20170815-DATA-flight07.csv CLOSED at 22:52:34 GPS
Total scans 00655
```

```
File 20170815-DATA-flight07.csv OPENED at 22:38:06 GPS
iMet-XQ order (3 left, 6 right)
This flight flown simultaneously with DJI S-1000 flight 7!
PRO -1 00067 22:39:13 36.622659 -97.476695 Profile 10m-100m
     0 00094 22:39:40 36.622661 -97.476695
TRS -1 00113 22:39:59 36.622664 -97.476690 Transect
     0 00400 22:44:47 36.626966 -97.471049
PRO -1 00405 22:44:52 36.626967 -97.471049 Profile 100m-300m
     0 00453 22:45:40 36.626967 -97.471048
TRS -1 00466 22:45:53 36.626966 -97.471050 Transect
     0 00700 22:49:47 36.622632 -97.476671
PRO -1 00703 22:49:50 36.622631 -97.476672 Profile 300m-10m
EVT    00818 22:51:45 36.622639 -97.476663 iMet-XQ dev3 stopped
     0 00862 22:52:29 36.622639 -97.476665
File 20170815-DATA-flight07.csv CLOSED at 22:53:26 GPS
Total scans 00920
```

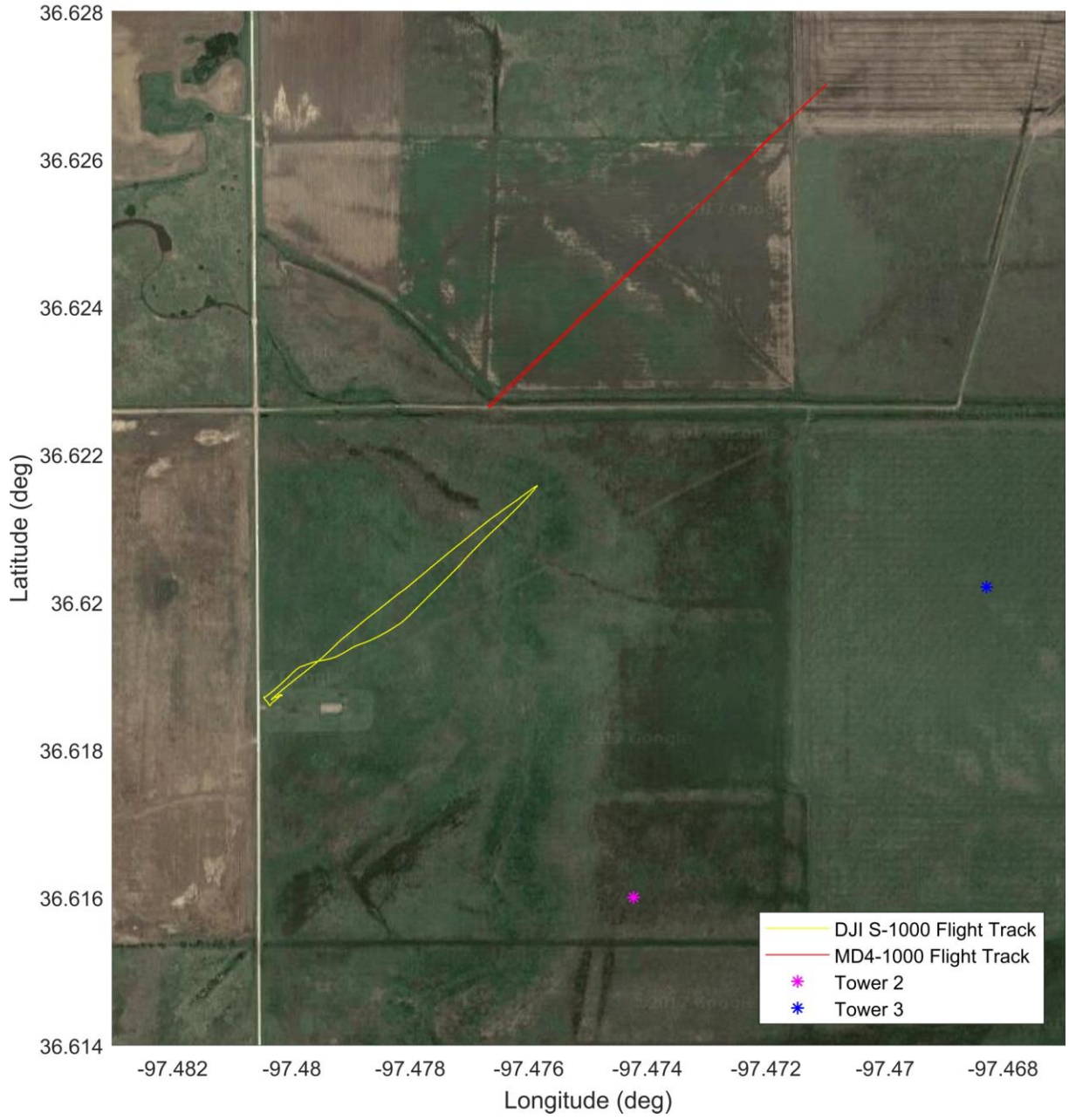


**Figure 18: DJI S-1000 Flight 7 and MD4-1000 Flight 7, Tuesday, 15 August 2017.**

# Appendix B – Catalog of DJI S-1000 flight tracks and marker files

```
File 20170811-DATA-flight01.csv OPENED at 17:47:45 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00028 17:48:13 36.621325 -97.480451 Profile 10m-365m
     0 00266 17:52:11 36.621323 -97.480449
HOV -1 00267 17:52:12 36.621324 -97.480449 Hover at 365m
     0 00276 17:52:21 36.621324 -97.480451
PRO -1 00277 17:52:22 36.621324 -97.480450 Profile 365m-10m
     0 00519 17:56:24 36.621319 -97.480459
File 20170811-DATA-flight01.csv CLOSED at 17:56:55 GPS
Total scans 00551
```

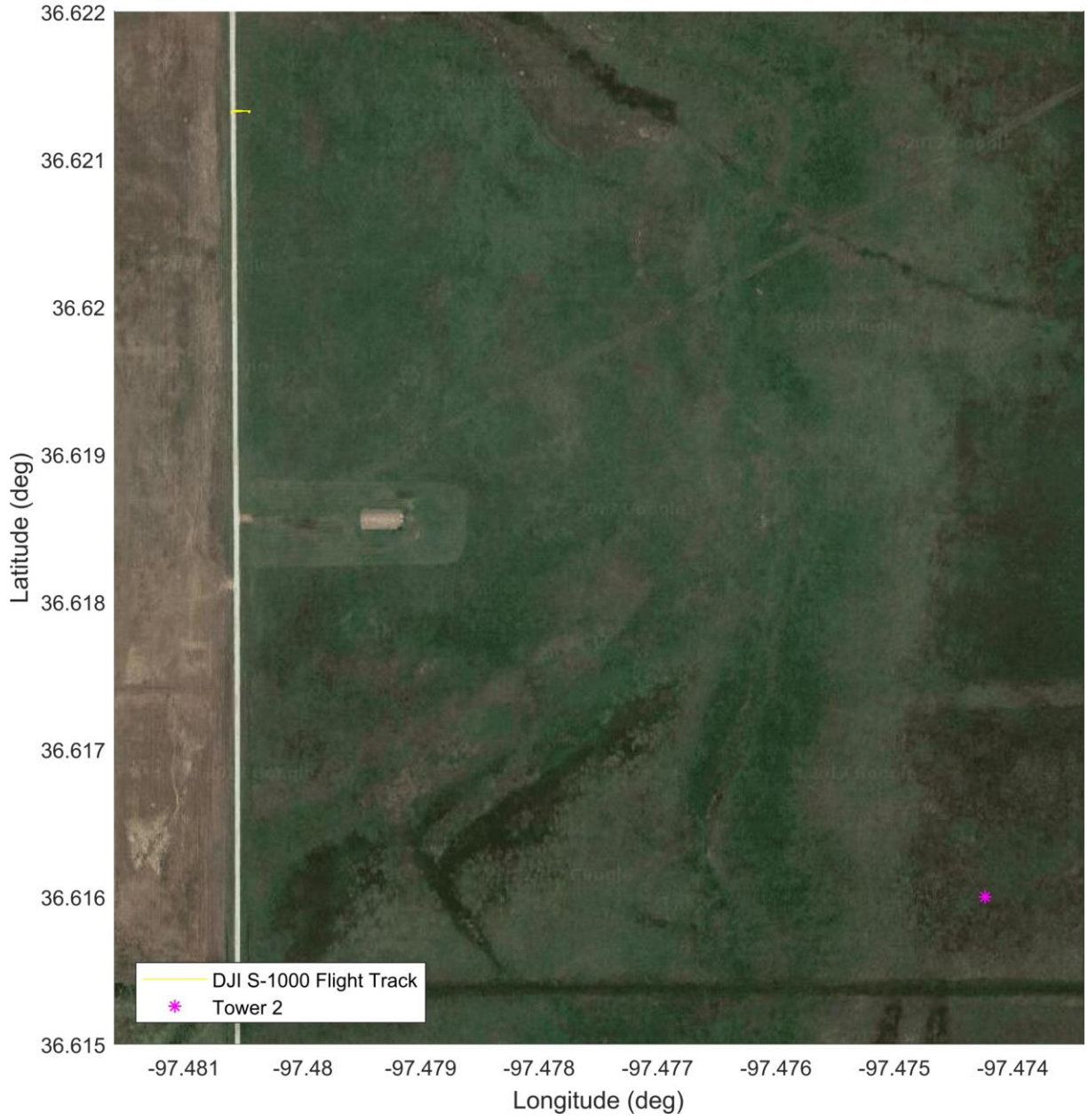


Figure 19: DJI S-1000 Flight 1, Friday, 11 August 2017.

```
File 20170814-DATA-flight04.csv OPENED at 18:59:53 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00011 19:00:04 36.618656 -97.480347 Profile 10m-100m
     0 00074 19:01:07 36.618656 -97.480346
TRS -1 00076 19:01:09 36.618656 -97.480346 Transect
     0 00132 19:02:05 36.621998 -97.476179
PRO -1 00136 19:02:09 36.621992 -97.476178 Profile 100m-300m
     0 00268 19:04:21 36.622003 -97.476176
TRS -1 00270 19:04:23 36.622000 -97.476176 Transect
     0 00388 19:06:21 36.618588 -97.479839
PRO -1 00390 19:06:23 36.618588 -97.479837 Profile 300m-10m
     0 00592 19:09:45 36.618723 -97.480242
File 20170814-DATA-flight04.csv CLOSED at 19:10:25 GPS
Total scans 00632
```

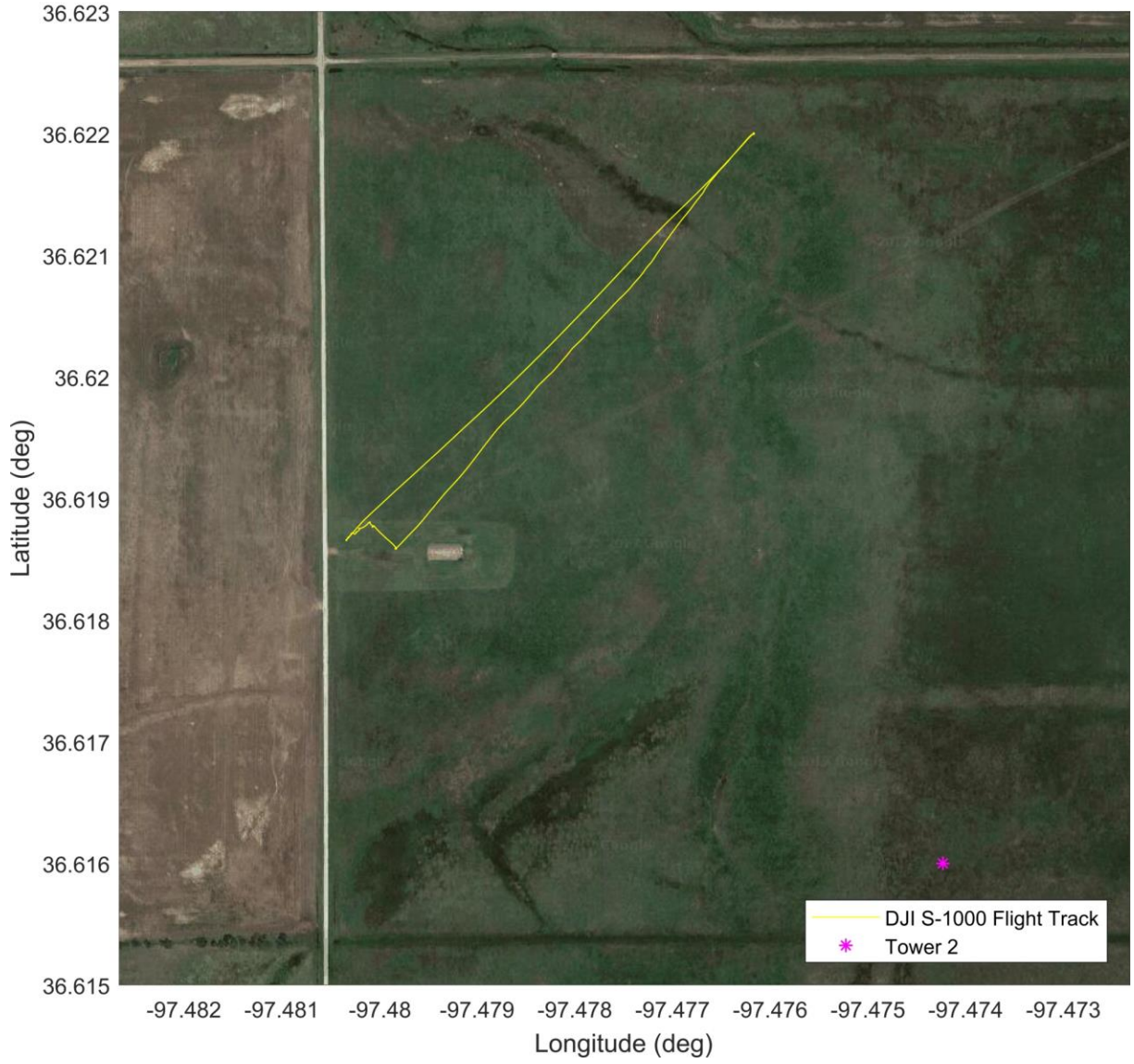


**Figure 20: DJI S-1000 Flight 4, Monday, 14 August 2017.**

```
File 20170814-DATA-flight06.csv OPENED at 20:18:54 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00009 20:19:03 36.618651 -97.480346 Profile 10m-100m
     0 00072 20:20:06 36.618649 -97.480345
TRS -1 00075 20:20:09 36.618648 -97.480345 Transect
     0 00146 20:21:20 36.622060 -97.476303
PRO -1 00148 20:21:22 36.622063 -97.476303 Profile 100m-300m
     0 00280 20:23:33 36.622060 -97.476299
TRS -1 00282 20:23:35 36.622059 -97.476300 Transect
     0 00379 20:25:12 36.618795 -97.480394
PRO -1 00381 20:25:14 36.618798 -97.480390 Profile 300m-10m
     0 00577 20:28:28 36.618752 -97.480322
File 20170814-DATA-flight06.csv CLOSED at 20:28:59 GPS
Total scans 00608
```

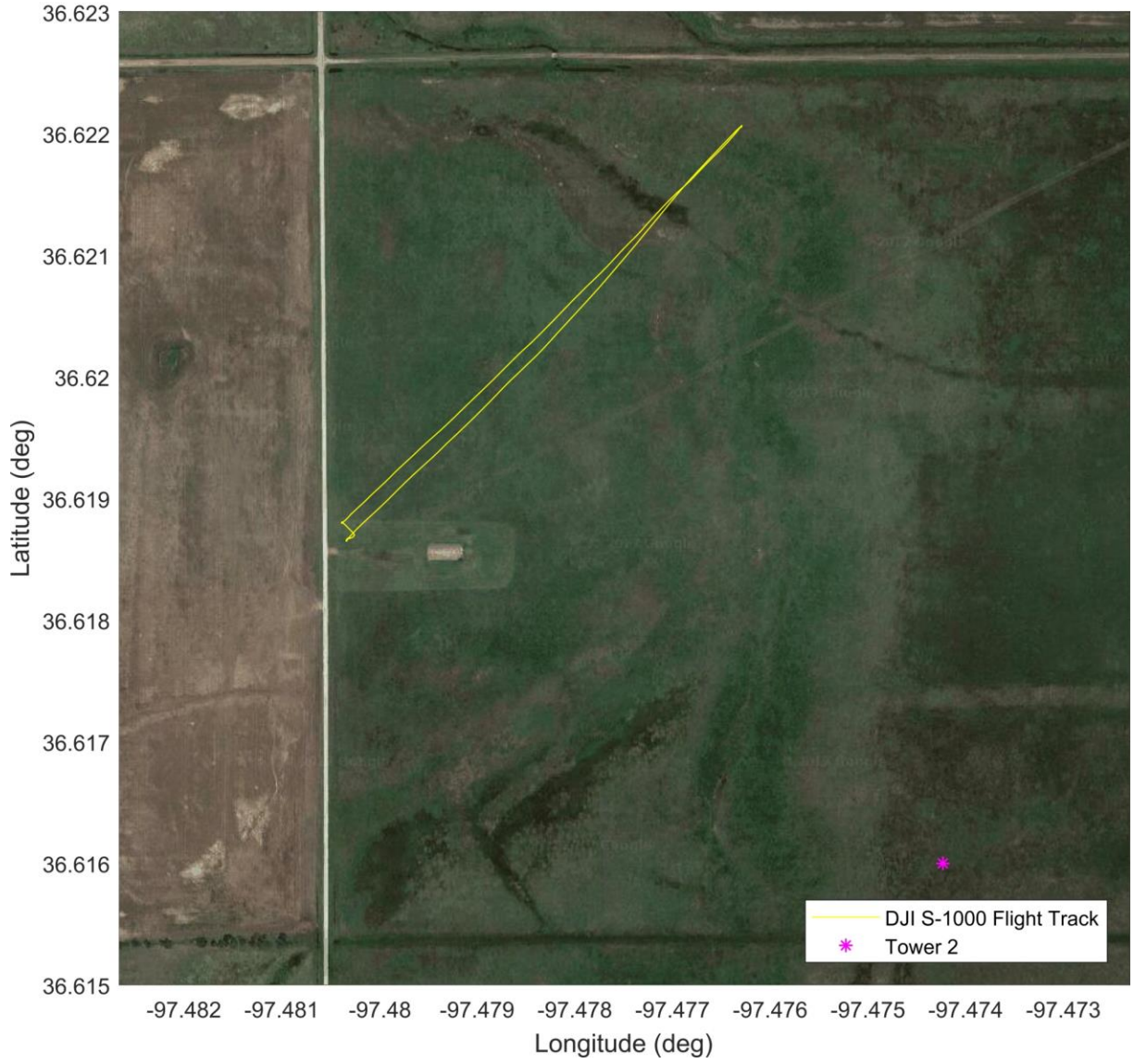


Figure 21: DJI S-1000 Flight 6, Monday, 14 August 2017.

```
File 20170814-DATA-flight07.csv OPENED at 21:00:05 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00015 21:00:20 36.618645 -97.480347 Profile 10m-100m
     0 00078 21:01:23 36.618646 -97.480346
TRS -1 00080 21:01:25 36.618646 -97.480347 Transect
     0 00158 21:02:43 36.621886 -97.476201
PRO -1 00159 21:02:44 36.621886 -97.476203 Profile 100m-300m
     0 00294 21:04:59 36.621894 -97.476196
TRS -1 00296 21:05:01 36.621895 -97.476197 Transect
     0 00404 21:06:49 36.618395 -97.480018
PRO -1 00406 21:06:51 36.618396 -97.480020 Profile 300m-10m
     0 00598 21:10:03 36.618707 -97.480259
File 20170814-DATA-flight07.csv CLOSED at 21:10:46 GPS
Total scans 00641
```

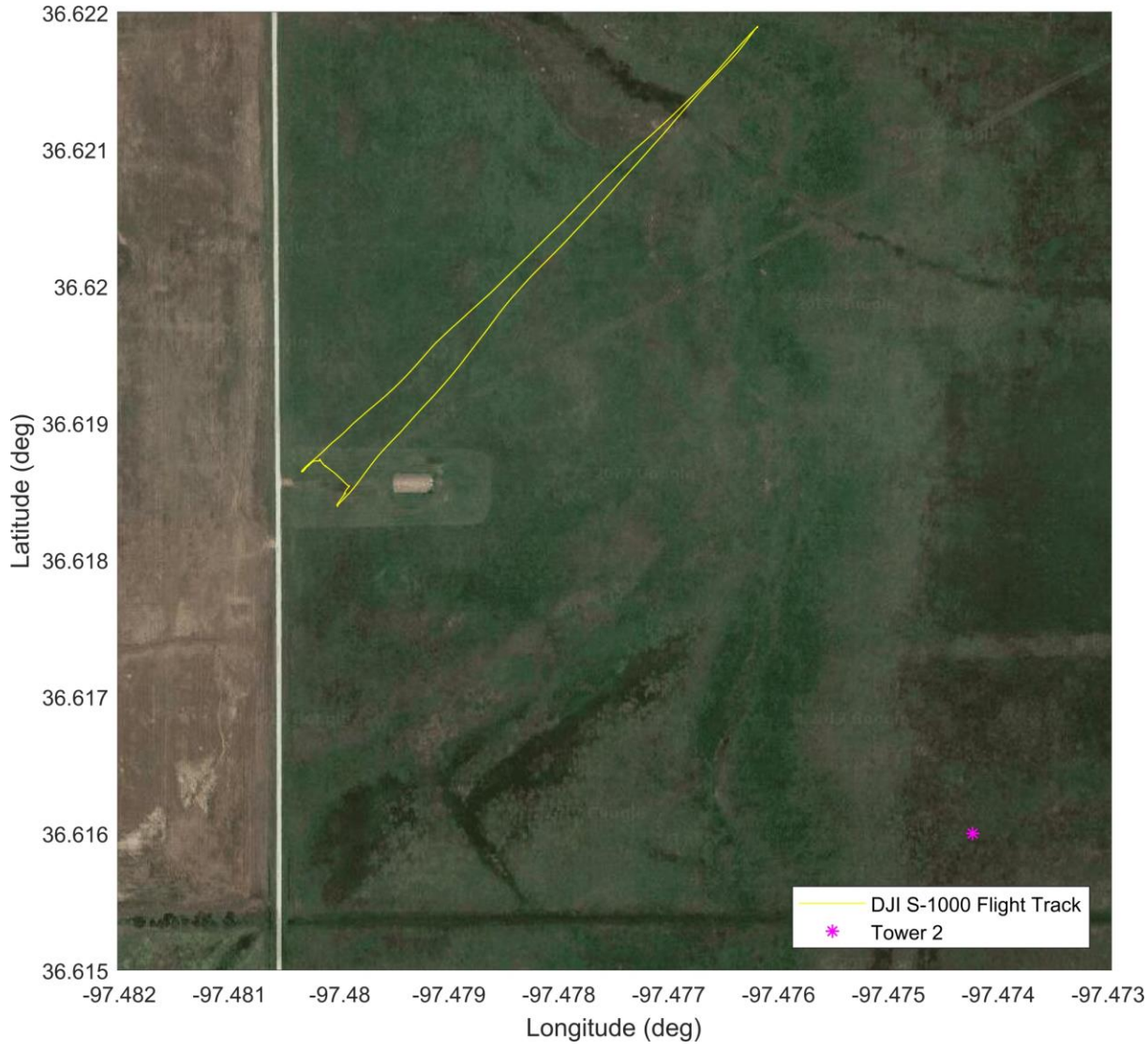


**Figure 22: DJI S-1000 Flight 7, Monday, 14 August 2017.**

```
File 20170814-DATA-flight08.csv OPENED at 21:20:41 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00018 21:20:59 36.618662 -97.480329 Profile 10m-100m
     0 00080 21:22:01 36.618659 -97.480331
TRS -1 00107 21:22:28 36.618668 -97.480317 Transect
     0 00190 21:23:51 36.621847 -97.476159
PRO -1 00192 21:23:53 36.621852 -97.476161 Profile 100m-300m
     0 00327 21:26:08 36.621852 -97.476161
TRS -1 00329 21:26:10 36.621852 -97.476159 Transect
     0 00424 21:27:45 36.618760 -97.480174
PRO -1 00426 21:27:47 36.618757 -97.480180 Profile 300m-10m
     0 00606 21:30:47 36.618714 -97.480223
File 20170814-DATA-flight08.csv CLOSED at 21:31:24 GPS
Total scans 00644
```

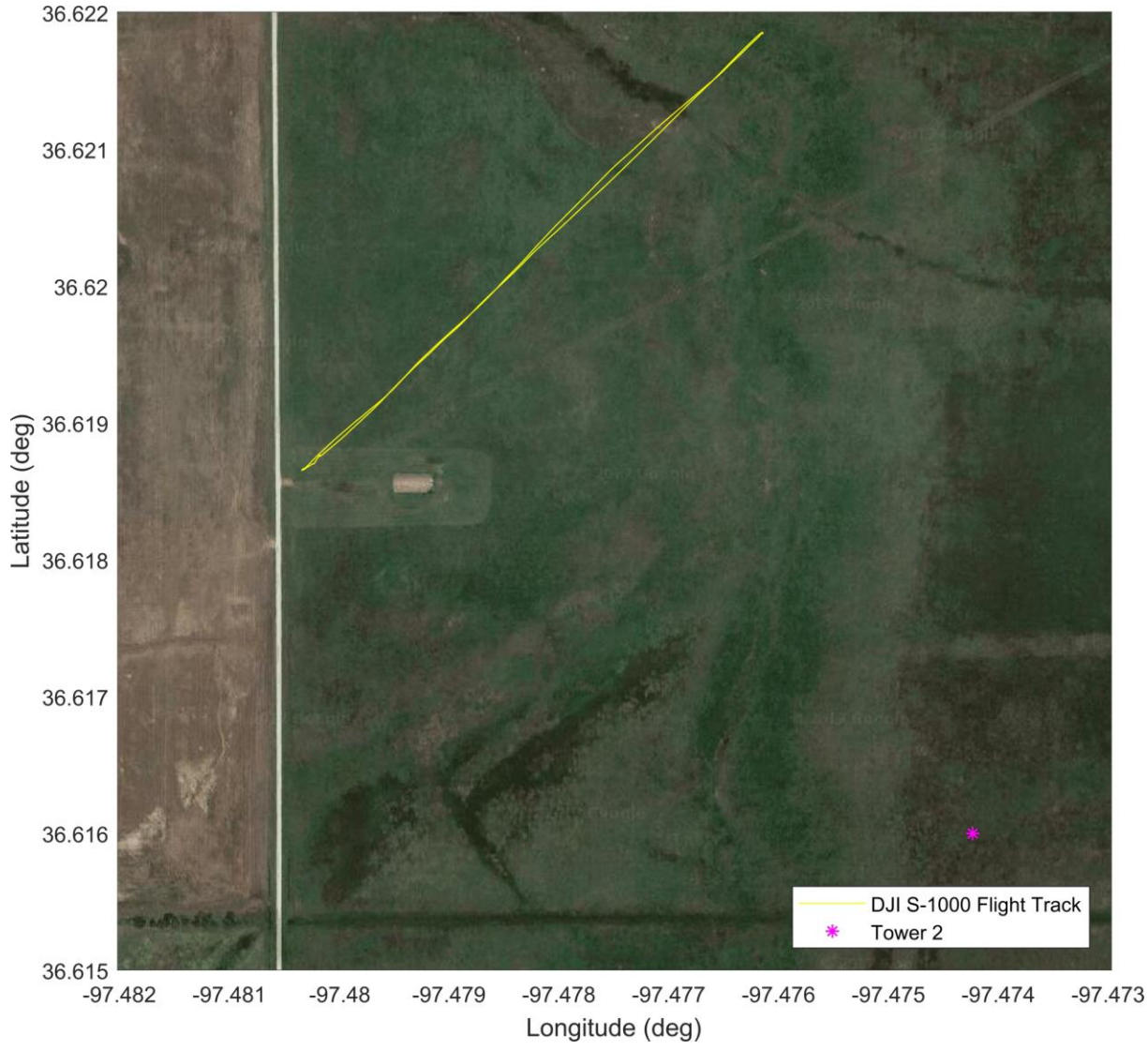


**Figure 23: DJI S-1000 Flight 8, Monday, 14 August 2017.**

```
File 20170814-DATA-flight10.csv OPENED at 22:20:29 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00015 22:20:44 36.618666 -97.480351 Profile 10m-100m
     0 00078 22:21:47 36.618670 -97.480355
TRS -1 00080 22:21:49 36.618670 -97.480353 Transect
     0 00161 22:23:10 36.622164 -97.476597
PRO -1 00163 22:23:12 36.622166 -97.476598 Profile 100m-300m
     0 00296 22:25:25 36.622165 -97.476599
TRS -1 00297 22:25:26 36.622164 -97.476600 Transect
     0 00400 22:27:09 36.618826 -97.480287
PRO -1 00403 22:27:12 36.618824 -97.480295 Profile 300m-10m
     0 00595 22:30:24 36.618694 -97.480266
File 20170814-DATA-flight10.csv CLOSED at 22:30:53 GPS
Total scans 00624
```

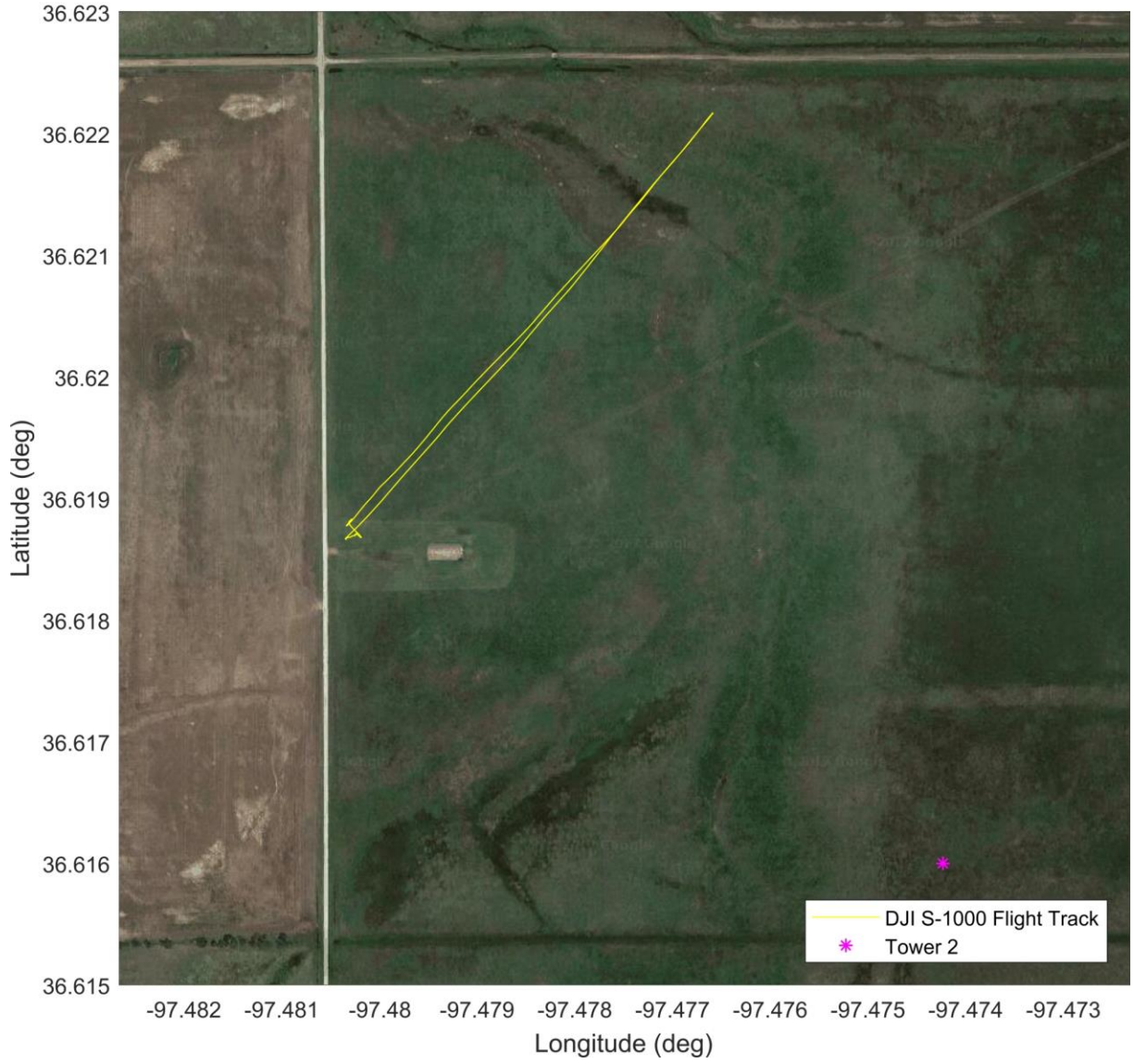


**Figure 24: DJI S-1000 Flight 10, Monday, 14 August 2017.**

```
File 20170815-DATA-flight08.csv OPENED at 23:09:58 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00013 23:10:11 36.618671 -97.480355 Profile 10m-100m
     0 00075 23:11:13 36.618676 -97.480359
TRS -1 00077 23:11:15 36.618675 -97.480361 Transect
     0 00176 23:12:54 36.621391 -97.475658
PRO -1 00178 23:12:56 36.621397 -97.475661 Profile 100m-300m
     0 00308 23:15:06 36.621396 -97.475658
TRS -1 00310 23:15:08 36.621396 -97.475658 Transect
     0 00422 23:17:00 36.618785 -97.479640
PRO -1 00424 23:17:02 36.618784 -97.479641 Profile 300m-10m
     0 00618 23:20:16 36.618707 -97.480241
File 20170815-DATA-flight08.csv CLOSED at 23:21:01 GPS
Total scans 00664
```

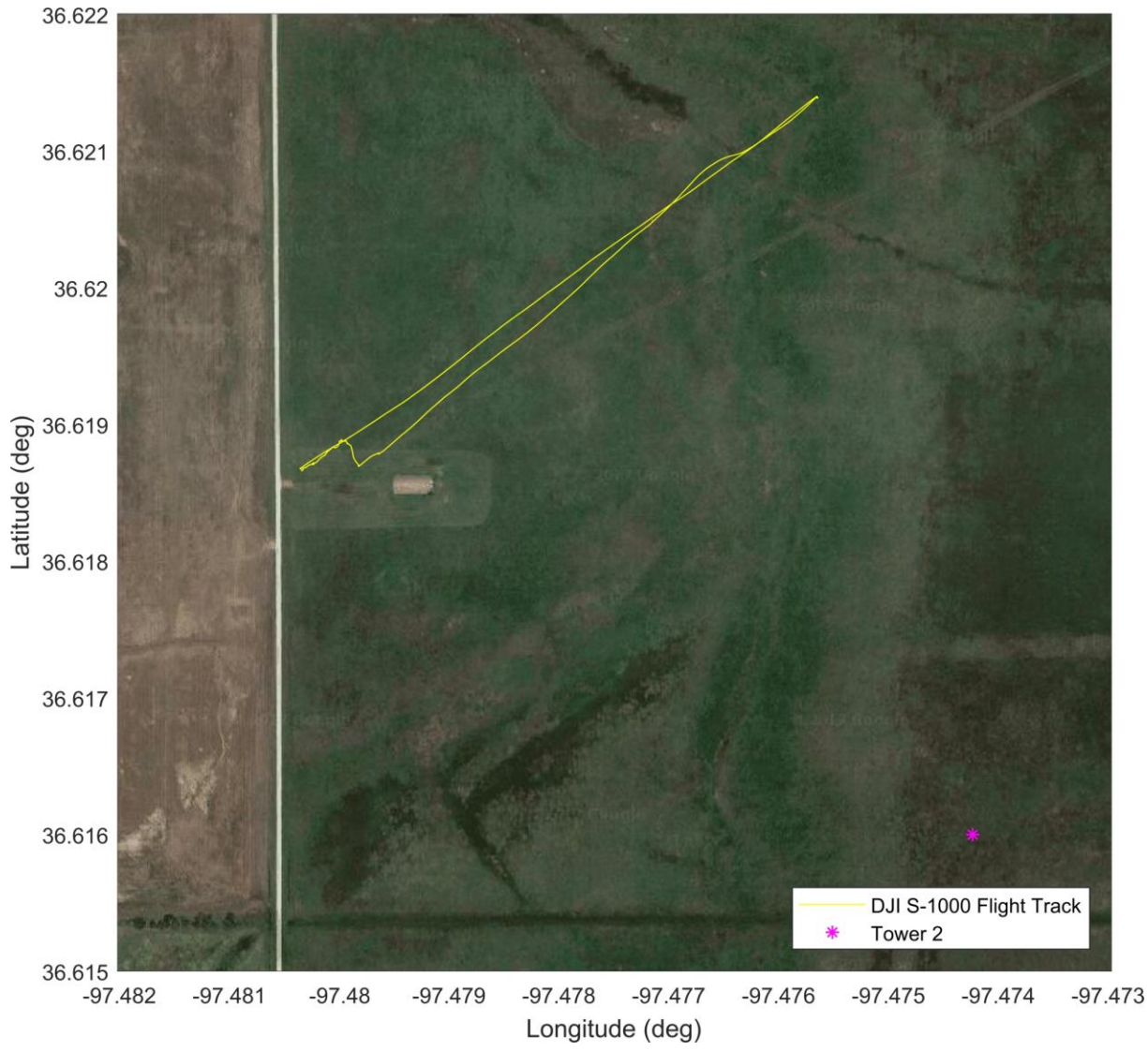


**Figure 25: DJI S-1000 Flight 8, Tuesday, 15 August 2017.**

```
File 20170817-DATA-flight01.csv OPENED at 16:40:06 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00012 16:40:18 36.618664 -97.480331 Profile 10m-100m
     0 00076 16:41:22 36.618664 -97.480327
TRS -1 00078 16:41:24 36.618663 -97.480326 Transect
     0 00176 16:43:02 36.622629 -97.477442
PRO -1 00178 16:43:04 36.622631 -97.477438 Profile 100m-300m
     0 00307 16:45:13 36.622628 -97.477439
TRS -1 00309 16:45:15 36.622630 -97.477439 Transect
     0 00416 16:47:02 36.618918 -97.480359
PRO -1 00418 16:47:04 36.618916 -97.480358 Profile 300m-10m
     0 00613 16:50:19 36.618752 -97.480258
File 20170817-DATA-flight01.csv CLOSED at 16:50:52 GPS
Total scans 00647
```

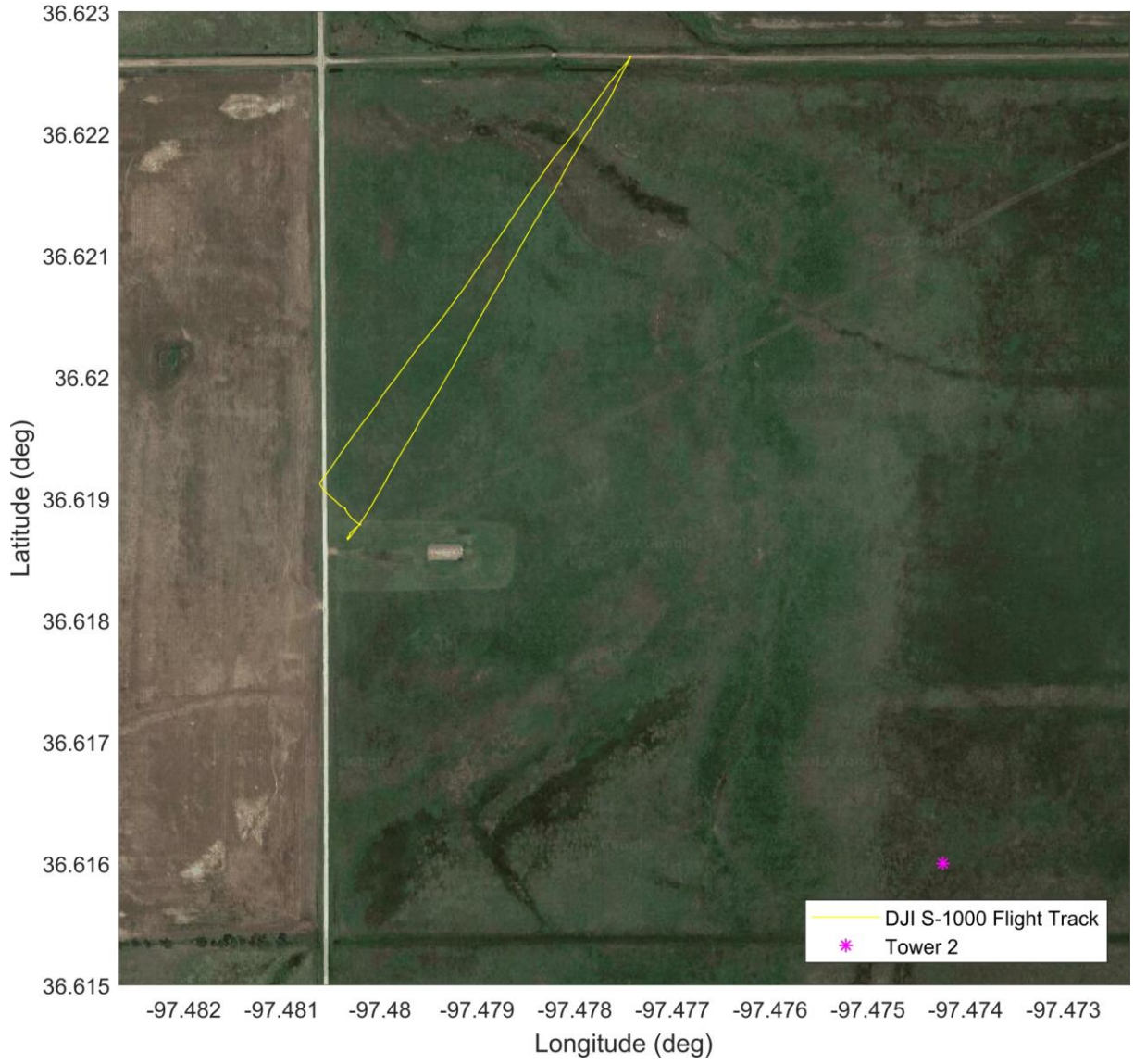


**Figure 26: DJI S-1000 Flight 1, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight02.csv OPENED at 17:09:52 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00015 17:10:07 36.618677 -97.480327 Profile 10m-100m
     0 00080 17:11:12 36.618676 -97.480320
TRS -1 00082 17:11:14 36.618676 -97.480321 Transect
     0 00180 17:12:52 36.622503 -97.477096
PRO -1 00182 17:12:54 36.622504 -97.477093 Profile 100m-300m
     0 00314 17:15:06 36.622502 -97.477098
TRS -1 00316 17:15:08 36.622504 -97.477100 Transect
     0 00432 17:17:04 36.618823 -97.480217
PRO -1 00434 17:17:06 36.618822 -97.480224 Profile 300m-10m
     0 00629 17:20:21 36.618752 -97.480261
File 20170817-DATA-flight02.csv CLOSED at 17:21:02 GPS
Total scans 00671
```

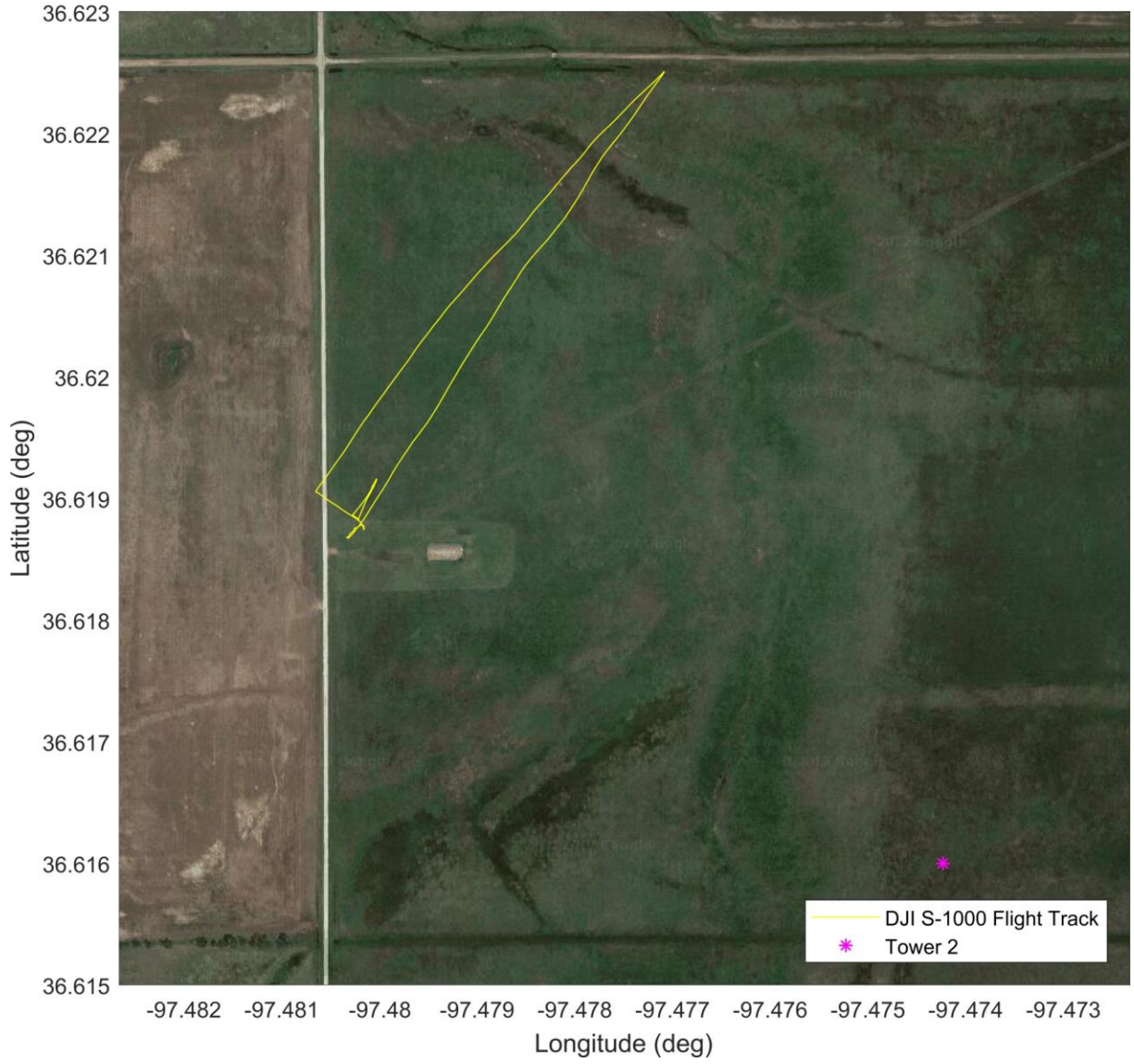


**Figure 27: DJI S-1000 Flight 2, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight03.csv OPENED at 17:40:07 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00015 17:40:22 36.618673 -97.480341 Profile 10m-100m
     0 00080 17:41:27 36.618672 -97.480338
TRS -1 00082 17:41:29 36.618672 -97.480338 Transect
     0 00180 17:43:07 36.622540 -97.477208
PRO -1 00182 17:43:09 36.622541 -97.477203 Profile 100m-300m
     0 00313 17:45:20 36.622545 -97.477205
TRS -1 00315 17:45:22 36.622546 -97.477205 Transect
     0 00423 17:47:10 36.619135 -97.480087
PRO -1 00425 17:47:12 36.619134 -97.480086 Profile 300m-10m
     0 00625 17:50:32 36.618716 -97.480288
File 20170817-DATA-flight03.csv CLOSED at 17:50:55 GPS
Total scans 00649
```

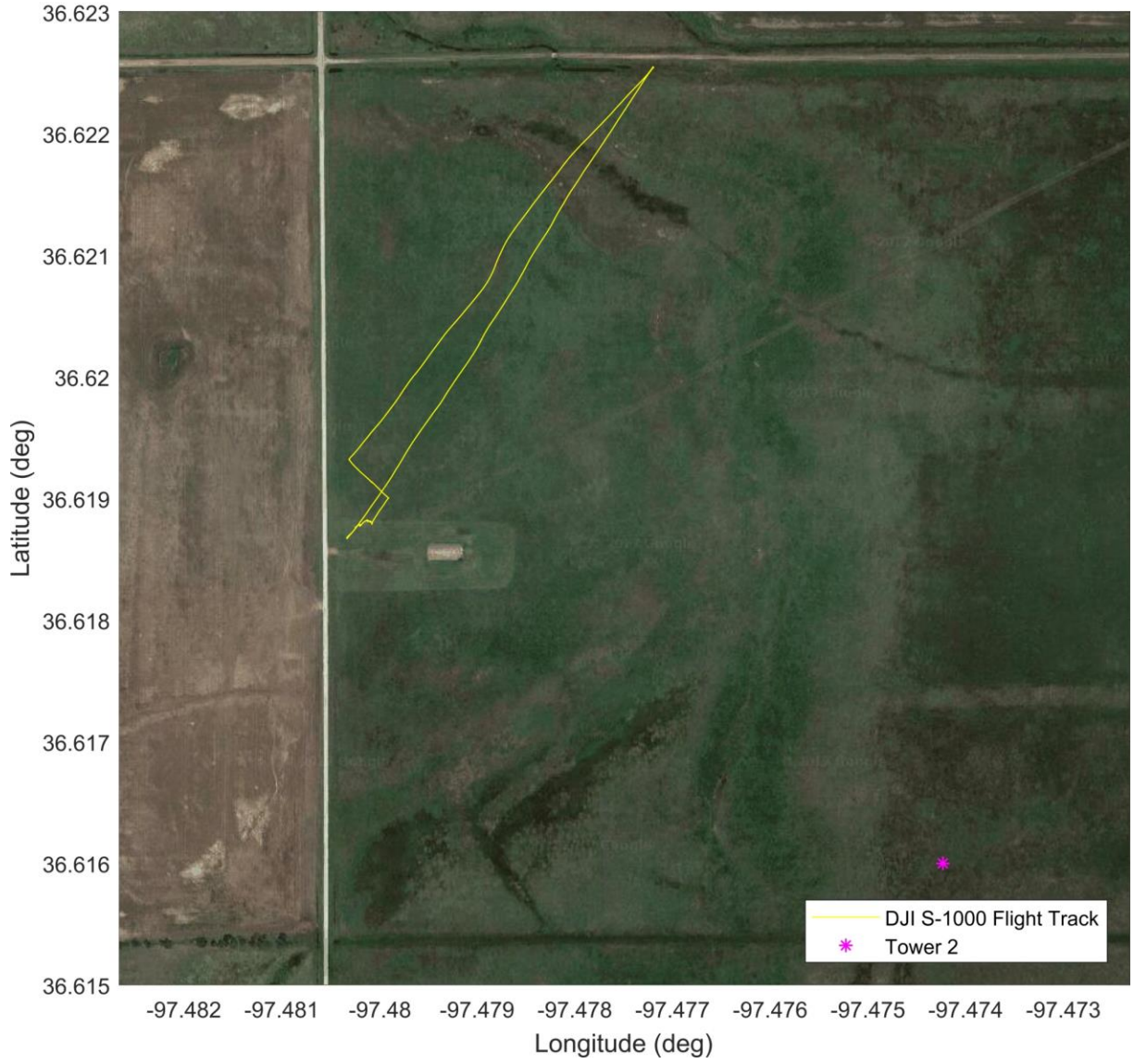


**Figure 28: DJI S-1000 Flight 3, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight04.csv OPENED at 18:10:15 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00015 18:10:30 36.618688 -97.480338 Profile 10m-100m
     0 00080 18:11:35 36.618684 -97.480335
TRS -1 00082 18:11:37 36.618684 -97.480334 Transect
     0 00180 18:13:15 36.622386 -97.476953
PRO -1 00182 18:13:17 36.622387 -97.476949 Profile 100m-300m
     0 00317 18:15:32 36.622385 -97.476953
TRS -1 00319 18:15:34 36.622384 -97.476951 Transect
     0 00411 18:17:06 36.619187 -97.480243
PRO -1 00413 18:17:08 36.619188 -97.480240 Profile 300m-10m
     0 00608 18:20:23 36.618780 -97.480234
File 20170817-DATA-flight04.csv CLOSED at 18:20:51 GPS
Total scans 00637
```

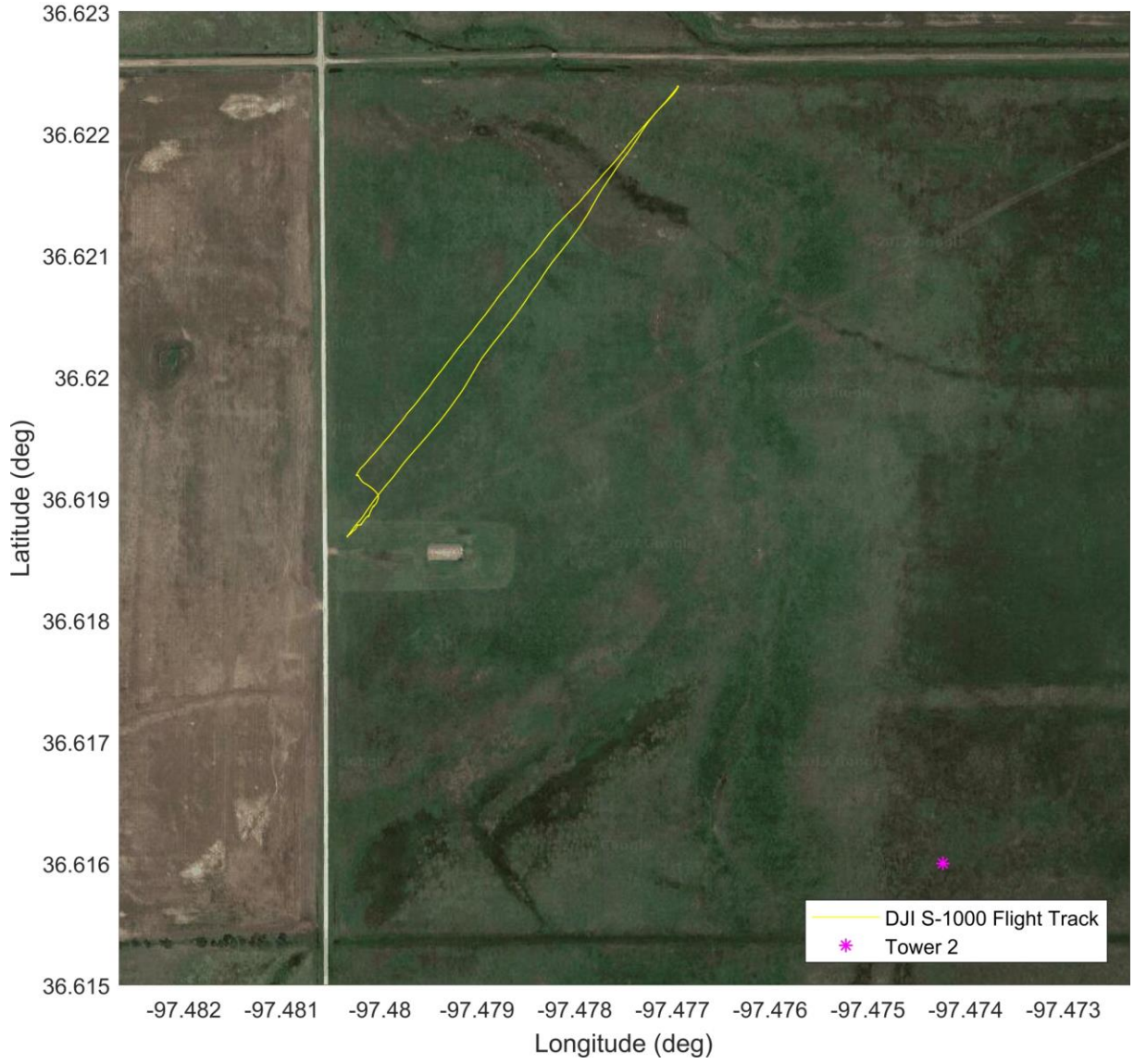


Figure 29: DJI S-1000 Flight 4, Thursday, 17 August 2017.

```
File 20170817-DATA-flight05.csv OPENED at 18:40:05 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00011 18:40:16 36.618680 -97.480340 Profile 10m-100m
     0 00075 18:41:20 36.618683 -97.480338
TRS -1 00077 18:41:22 36.618683 -97.480335 Transect
     0 00179 18:43:04 36.622492 -97.476924
PRO -1 00181 18:43:06 36.622493 -97.476922 Profile 100m-300m
     0 00313 18:45:18 36.622495 -97.476924
TRS -1 00315 18:45:20 36.622495 -97.476926 Transect
     0 00408 18:46:53 36.619345 -97.480110
PRO -1 00410 18:46:55 36.619345 -97.480113 Profile 300m-10m
     0 00604 18:50:09 36.618722 -97.480279
File 20170817-DATA-flight05.csv CLOSED at 18:50:46 GPS
Total scans 00641
```

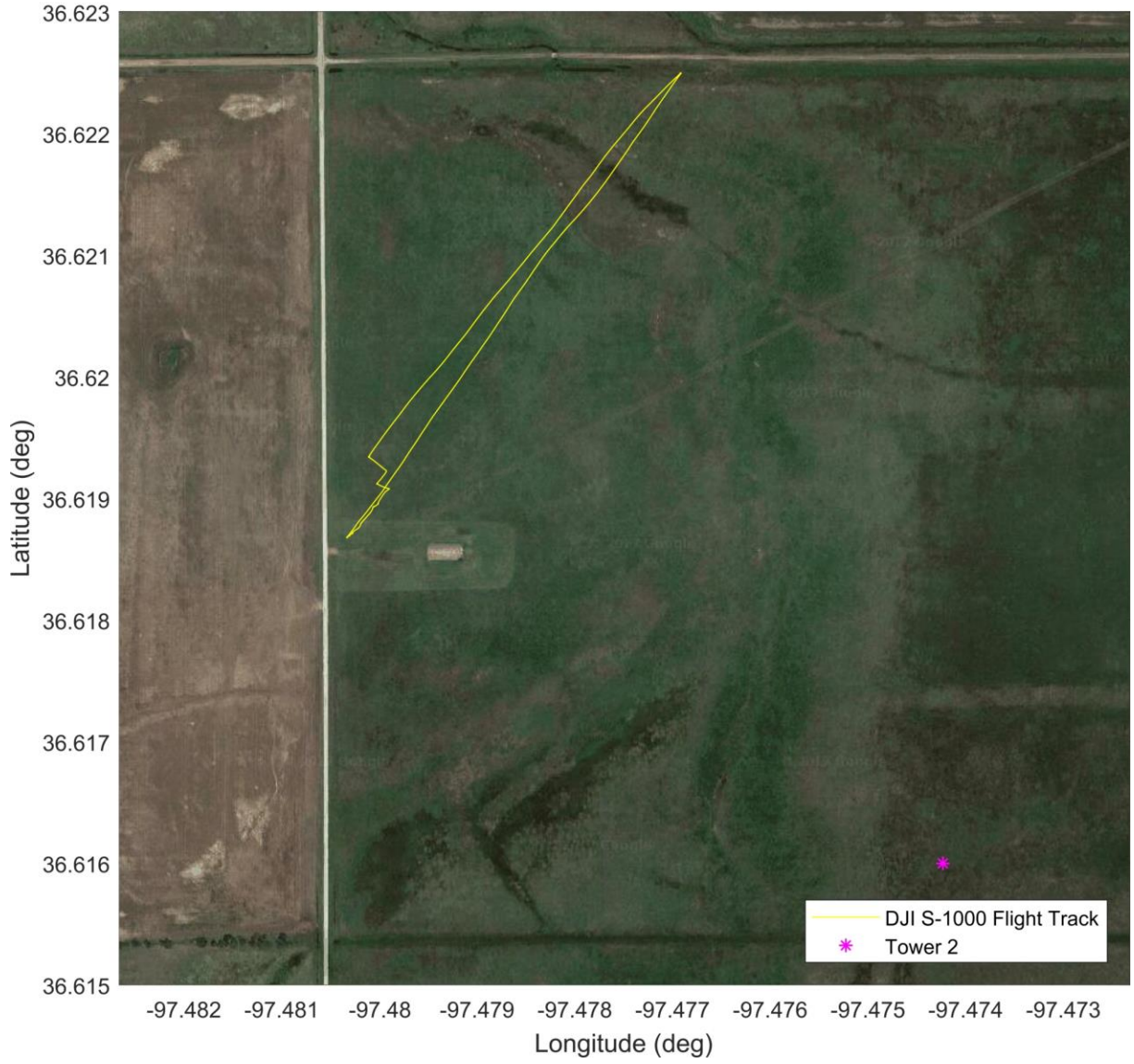


**Figure 30: DJI S-1000 Flight 5, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight06.csv OPENED at 19:10:01 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00010 19:10:11 36.618688 -97.480323 Profile 10m-100m
     0 00073 19:11:14 36.618688 -97.480321
TRS -1 00075 19:11:16 36.618687 -97.480321 Transect
     0 00180 19:13:01 36.622283 -97.476726
PRO -1 00182 19:13:03 36.622284 -97.476727 Profile 100m-300m
     0 00315 19:15:16 36.622282 -97.476724
TRS -1 00317 19:15:18 36.622279 -97.476728 Transect
     0 00405 19:16:46 36.619082 -97.479951
PRO -1 00407 19:16:48 36.619079 -97.479944 Profile 300m-10m
     0 00596 19:19:57 36.618752 -97.480266
File 20170817-DATA-flight06.csv CLOSED at 19:20:35 GPS
Total scans 00635
```

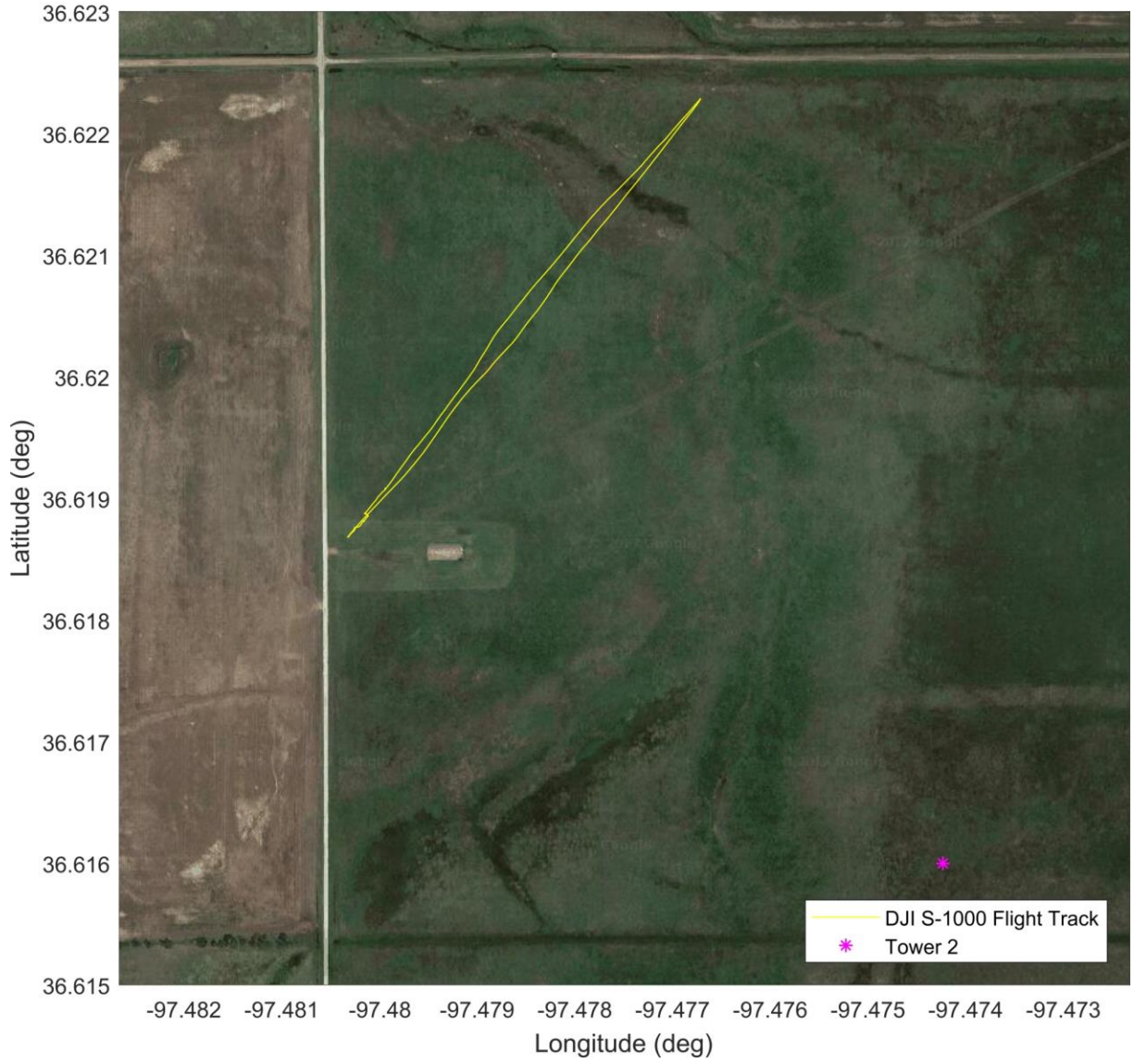


**Figure 31: DJI S-1000 Flight 6, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight07.csv OPENED at 19:40:22 GPS
iMet-XQ order (4 left, 5 right)
This flight flown simultaneously with MD4-1000 flight 7!
PRO -1 00009 19:40:31 36.618671 -97.480335 Profile 10m-100m
     0 00077 19:41:39 36.618672 -97.480334
TRS -1 00079 19:41:41 36.618672 -97.480335 Transect
     0 00173 19:43:15 36.622197 -97.476690
PRO -1 00174 19:43:16 36.622196 -97.476690 Profile 100m-300m
     0 00308 19:45:30 36.622193 -97.476686
TRS -1 00310 19:45:32 36.622193 -97.476686 Transect
     0 00409 19:47:11 36.618961 -97.480538
PRO -1 00411 19:47:13 36.618964 -97.480537 Profile 300m-10m
     0 00601 19:50:23 36.618742 -97.480244
File 20170817-DATA-flight07.csv CLOSED at 19:50:47 GPS
Total scans 00626
```

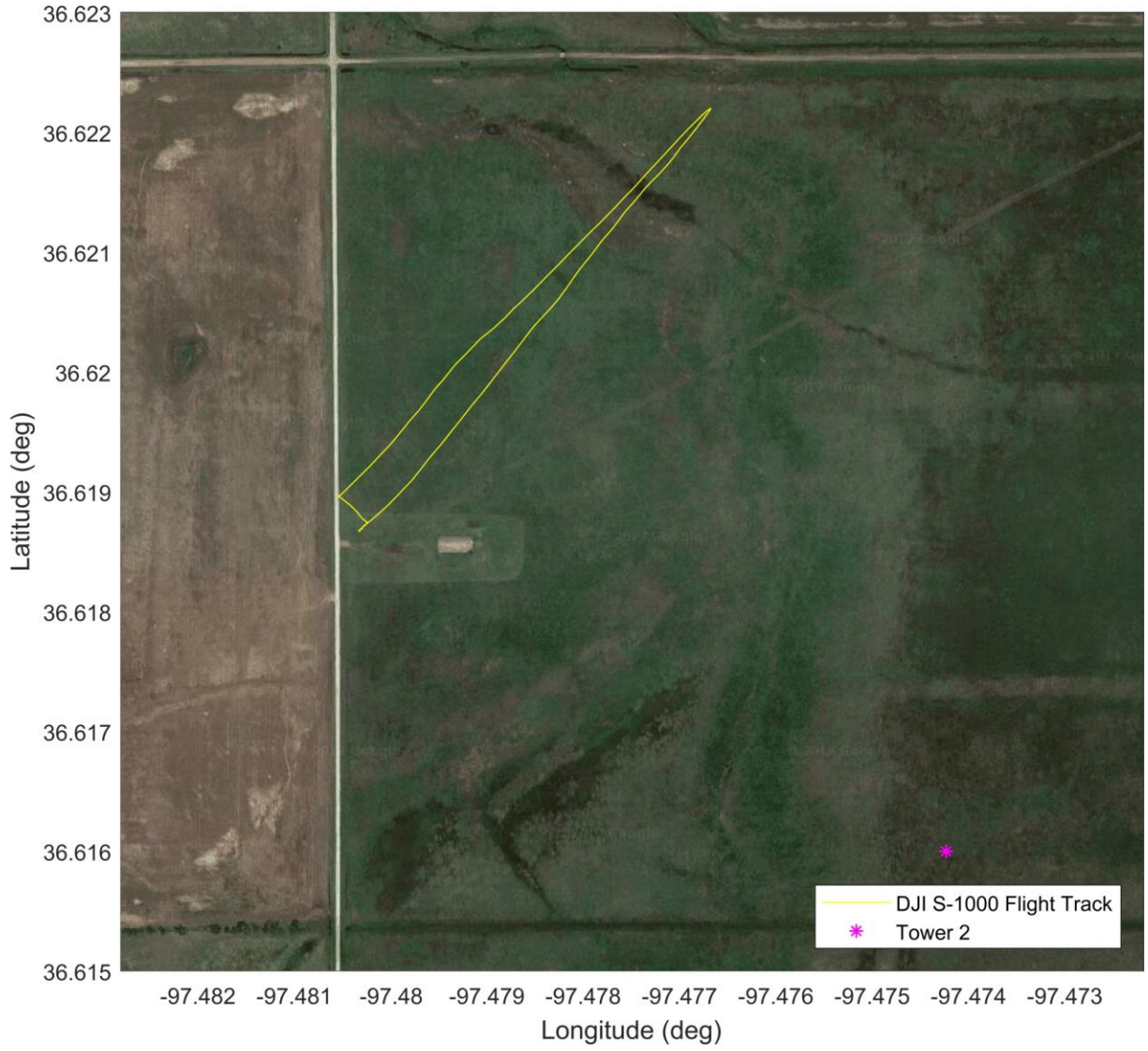


**Figure 32: DJI S-1000 Flight 7, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight08.csv OPENED at 20:10:21 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00011 20:10:32 36.618670 -97.480339 Profile 10m-100m
     0 00077 20:11:38 36.618669 -97.480339
TRS -1 00079 20:11:40 36.618674 -97.480339 Transect
     0 00178 20:13:19 36.622415 -97.477120
PRO -1 00180 20:13:21 36.622415 -97.477120 Profile 100m-300m
     0 00312 20:15:33 36.622414 -97.477121
TRS -1 00314 20:15:35 36.622415 -97.477121 Transect
     0 00431 20:17:32 36.618873 -97.480392
PRO -1 00434 20:17:35 36.618872 -97.480392 Profile 300m-10m
     0 00637 20:20:58 36.618748 -97.480226
File 20170817-DATA-flight08.csv CLOSED at 20:21:30 GPS
Total scans 00669
```

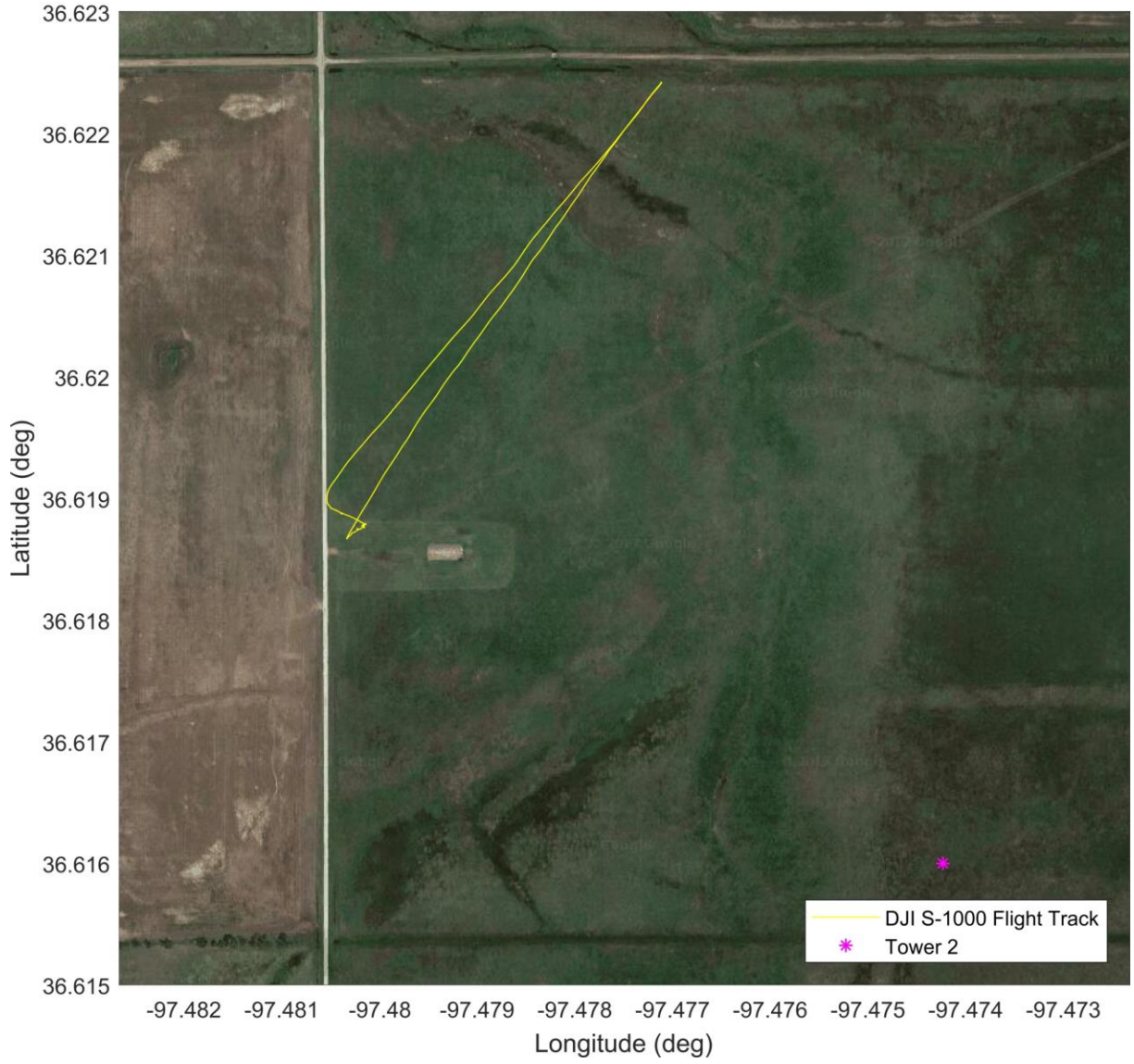


**Figure 33: DJI S-1000 Flight 8, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight09.csv OPENED at 20:40:05 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00010 20:40:15 36.618675 -97.480334 Profile 10m-100m
     0 00073 20:41:18 36.618670 -97.480333
TRS -1 00075 20:41:20 36.618670 -97.480330 Transect
     0 00171 20:42:56 36.622223 -97.476636
PRO -1 00173 20:42:58 36.622223 -97.476632 Profile 100m-300m
     0 00305 20:45:10 36.622226 -97.476633
TRS -1 00307 20:45:12 36.622227 -97.476632 Transect
     0 00412 20:46:57 36.619157 -97.480193
PRO -1 00414 20:46:59 36.619156 -97.480188 Profile 300m-10m
     0 00609 20:50:14 36.618703 -97.480264
File 20170817-DATA-flight09.csv CLOSED at 20:50:49 GPS
Total scans 00645
```

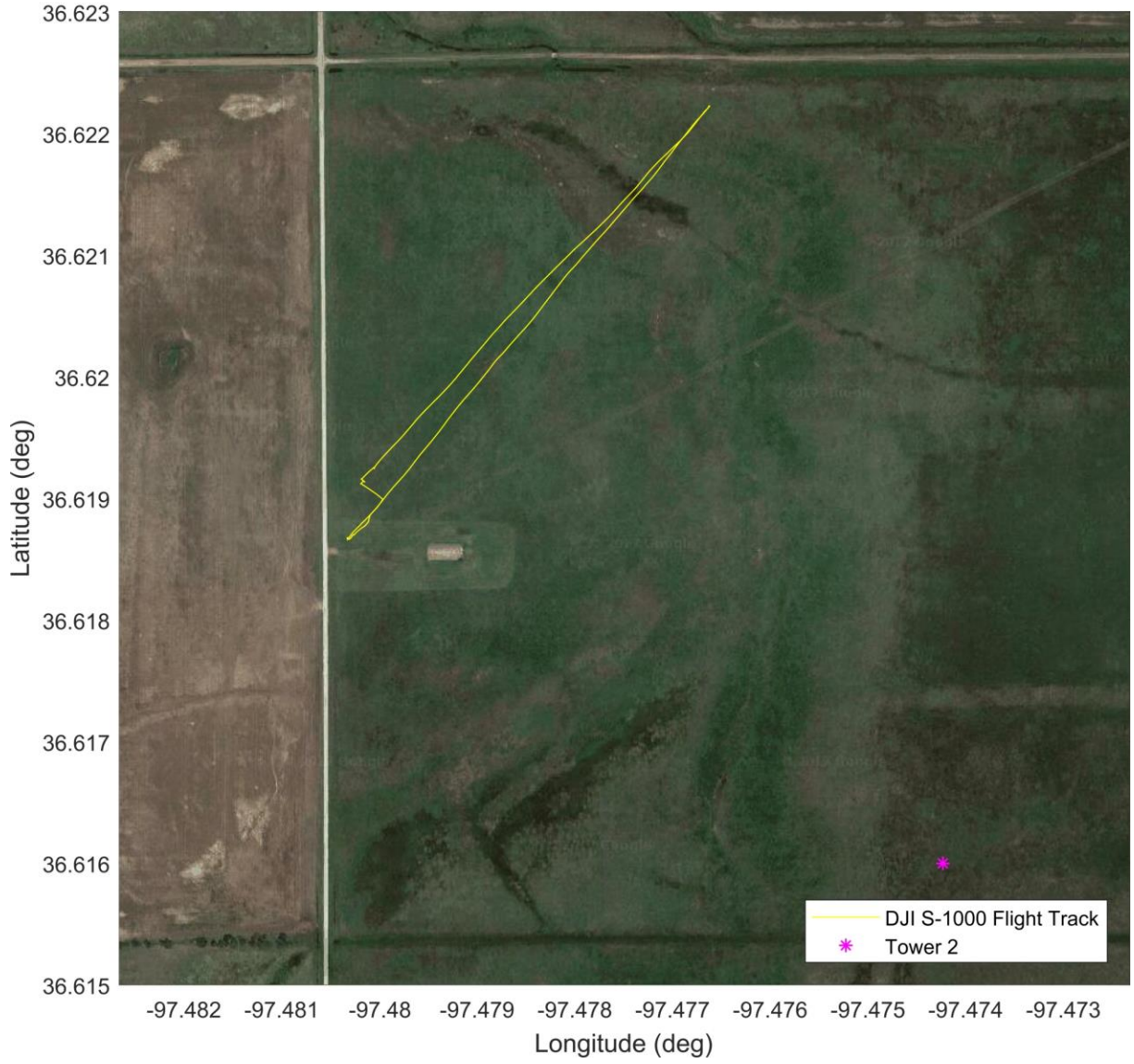


**Figure 34: DJI S-1000 Flight 9, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight10.csv OPENED at 21:09:57 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00018 21:10:15 36.618667 -97.480322 Profile 10m-100m
     0 00082 21:11:19 36.618666 -97.480322
TRS -1 00084 21:11:21 36.618666 -97.480323 Transect
     0 00179 21:12:56 36.622232 -97.476694
PRO -1 00181 21:12:58 36.622232 -97.476691 Profile 100m-300m
     0 00314 21:15:11 36.622232 -97.476692
TRS -1 00316 21:15:13 36.622232 -97.476693 Transect
     0 00424 21:17:01 36.618983 -97.480234
PRO -1 00426 21:17:03 36.618982 -97.480234 Profile 300m-10m
     0 00615 21:20:12 36.618693 -97.480277
File 20170817-DATA-flight10.csv CLOSED at 21:20:50 GPS
Total scans 00653
```

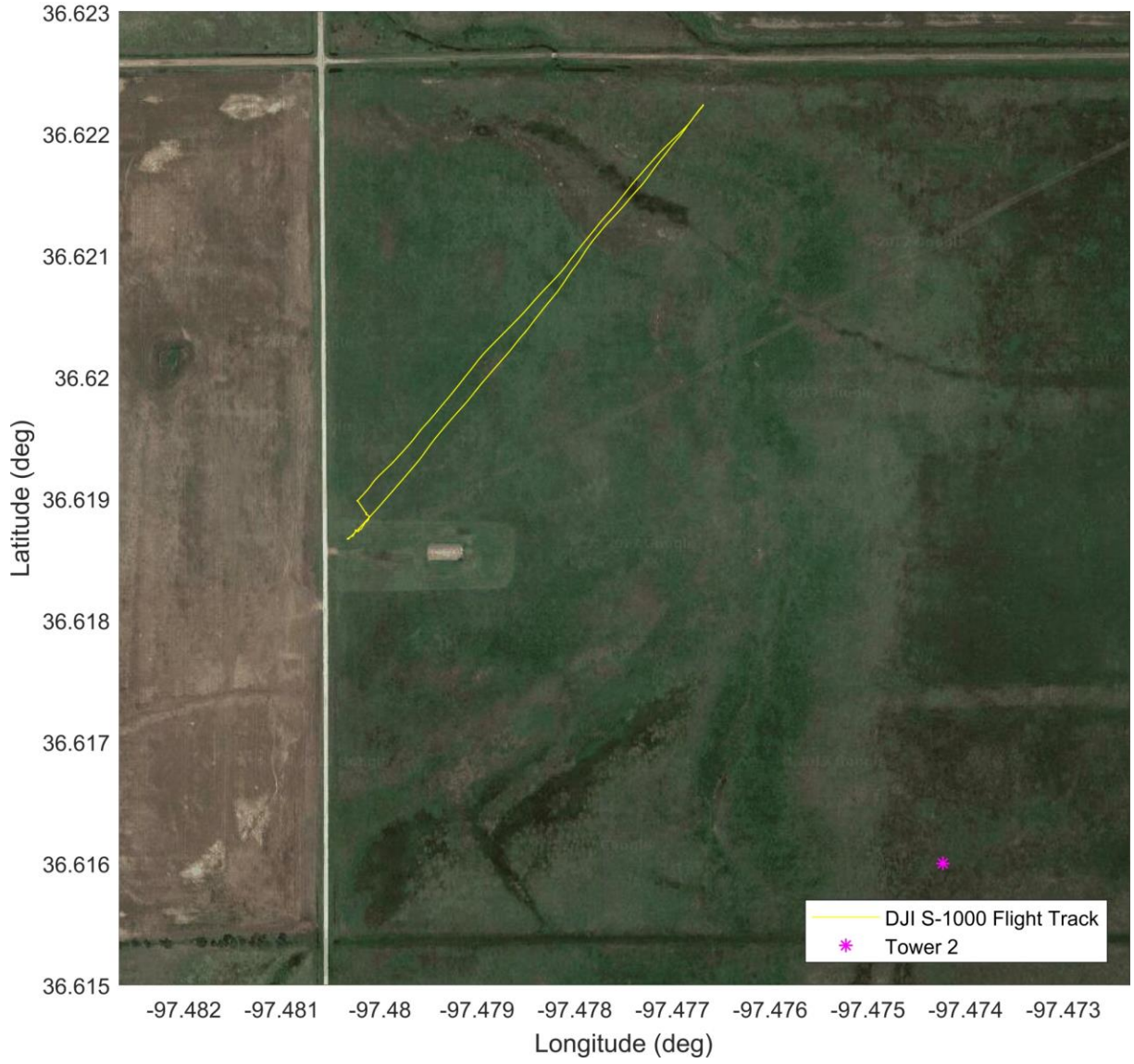


Figure 35: DJI S-1000 Flight 10, Thursday, 17 August 2017.

```
File 20170817-DATA-flight11.csv OPENED at 21:40:23 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00010 21:40:33 36.618671 -97.480343 Profile 10m-100m
     0 00073 21:41:36 36.618672 -97.480340
TRS -1 00075 21:41:38 36.618671 -97.480341 Transect
     0 00176 21:43:19 36.622182 -97.476664
PRO -1 00178 21:43:21 36.622181 -97.476662 Profile 100m-300m
     0 00307 21:45:30 36.622184 -97.476666
TRS -1 00309 21:45:32 36.622182 -97.476665 Transect
     0 00421 21:47:24 36.618983 -97.480402
PRO -1 00423 21:47:26 36.618985 -97.480403 Profile 300m-10m
     0 00617 21:50:40 36.618687 -97.480296
File 20170817-DATA-flight11.csv CLOSED at 21:51:25 GPS
Total scans 00662
```

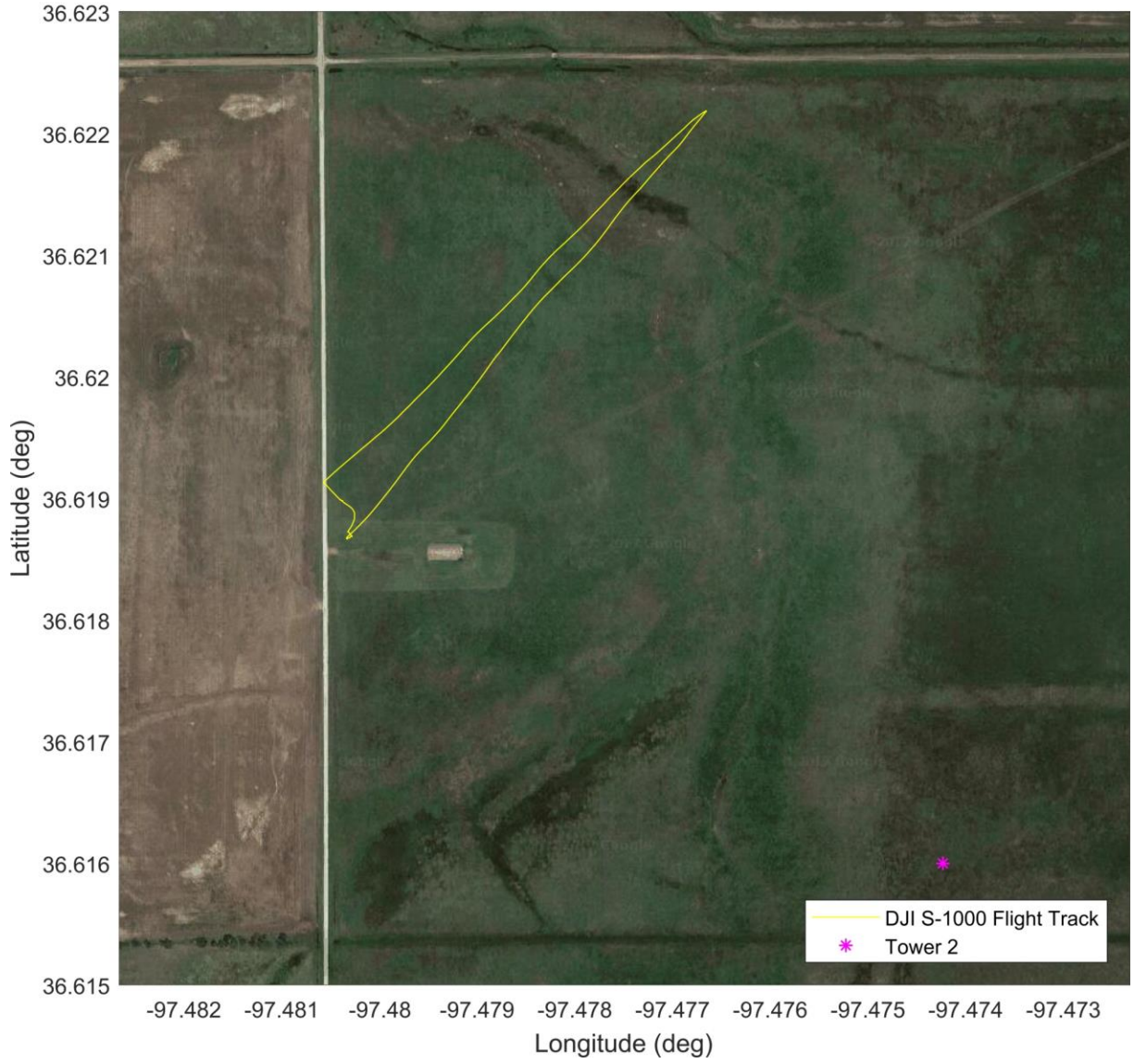


Figure 36: DJI S-1000 Flight 11, Thursday, 17 August 2017.

```
File 20170817-DATA-flight12.csv OPENED at 22:10:14 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00012 22:10:26 36.618666 -97.480339 Profile 10m-100m
     0 00078 22:11:32 36.618666 -97.480339
TRS -1 00080 22:11:34 36.618667 -97.480339 Transect
     0 00177 22:13:11 36.622314 -97.476872
PRO -1 00179 22:13:13 36.622313 -97.476870 Profile 100m-300m
     0 00311 22:15:24 36.622316 -97.476871
TRS -1 00313 22:15:26 36.622315 -97.476871 Transect
     0 00415 22:17:07 36.619005 -97.480520
PRO -1 00417 22:17:09 36.619008 -97.480521 Profile 300m-10m
     0 00612 22:20:23 36.618695 -97.480283
File 20170817-DATA-flight12.csv CLOSED at 22:20:47 GPS
Total scans 00637
```

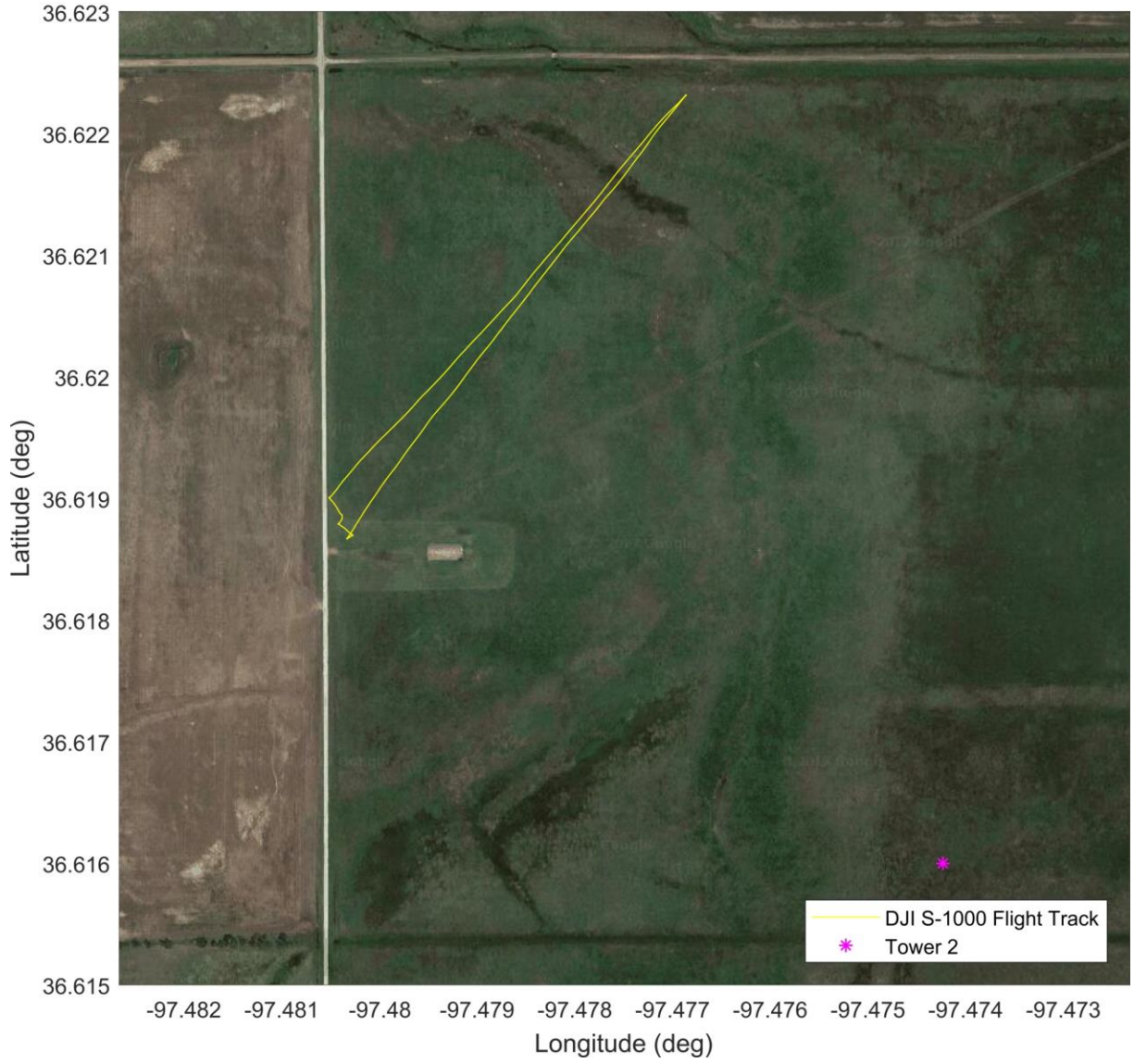


**Figure 37: DJI S-1000 Flight 12, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight13.csv OPENED at 22:40:00 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00011 22:40:11 36.618677 -97.480340 Profile 10m-100m
     0 00076 22:41:16 36.618676 -97.480337
TRS -1 00078 22:41:18 36.618675 -97.480336 Transect
     0 00176 22:42:56 36.622457 -97.477121
PRO -1 00178 22:42:58 36.622457 -97.477119 Profile 100m-160m
     0 00219 22:43:38 36.622460 -97.477119
TRS -1 00221 22:43:40 36.622397 -97.477178 Transect
     0 00292 22:44:51 36.618697 -97.480334
PRO -1 00294 22:44:53 36.618690 -97.480340 Profile 160m-10m
     0 00382 22:46:21 36.618676 -97.480347
File 20170817-DATA-flight13.csv CLOSED at 22:46:39 GPS
Total scans 00402
```

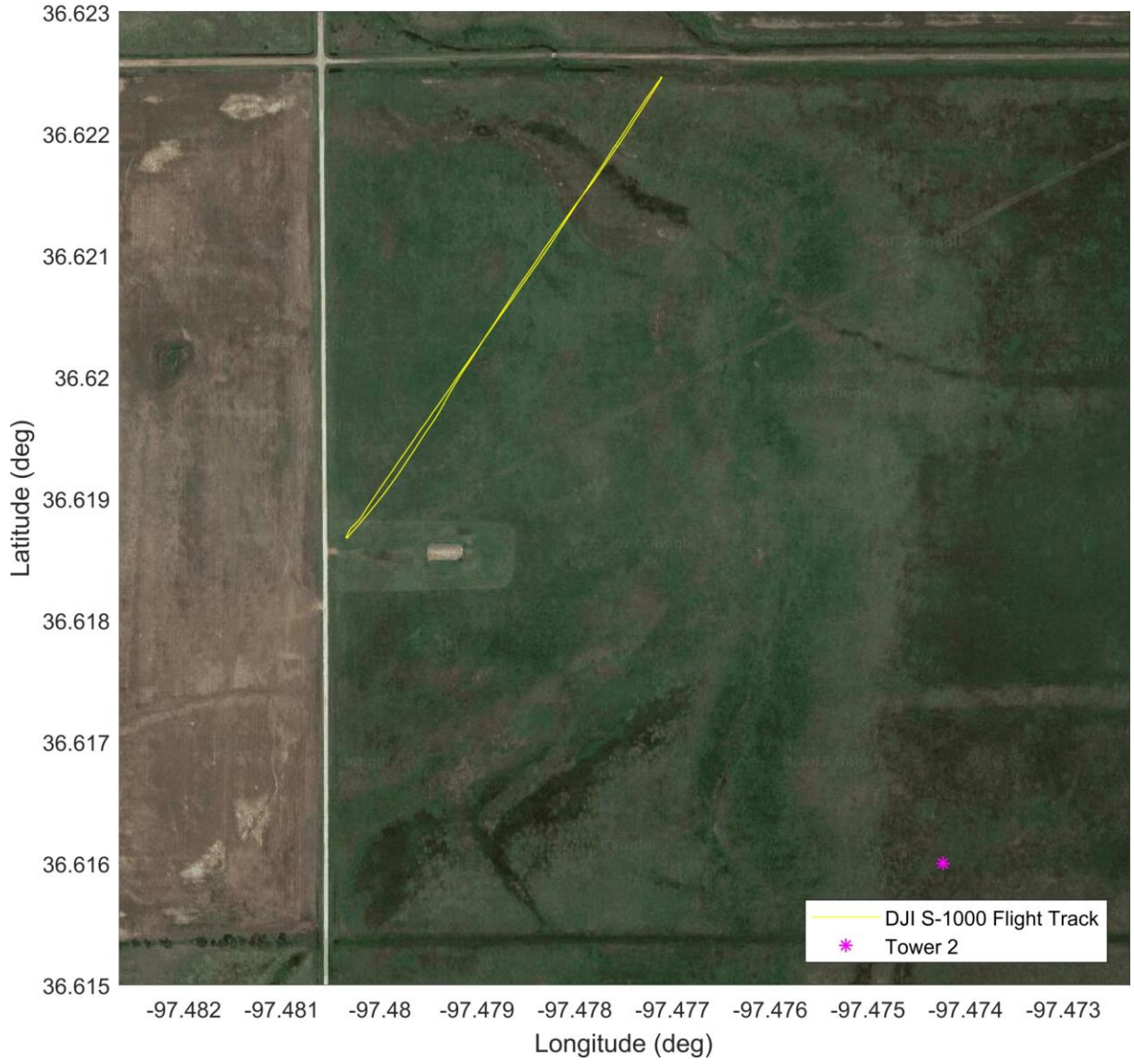


**Figure 38: DJI S-1000 Flight 13, Thursday, 17 August 2017.**

```
File 20170817-DATA-flight14.csv OPENED at 23:09:58 GPS
iMet-XQ order (4 left, 5 right)
PRO -1 00014 23:10:12 36.618689 -97.480346 Profile 10m-100m
     0 00079 23:11:17 36.618689 -97.480346
TRS -1 00081 23:11:19 36.618690 -97.480345 Transect
     0 00176 23:12:54 36.622216 -97.476686
PRO -1 00178 23:12:56 36.622216 -97.476688 Profile 100m-300m
     0 00310 23:15:08 36.622216 -97.476685
TRS -1 00312 23:15:10 36.622216 -97.476684 Transect
     0 00407 23:16:45 36.618987 -97.480350
PRO -1 00409 23:16:47 36.618988 -97.480353 Profile 300m-10m
     0 00609 23:20:07 36.618742 -97.480229
File 20170817-DATA-flight14.csv CLOSED at 23:20:44 GPS
Total scans 00646
```

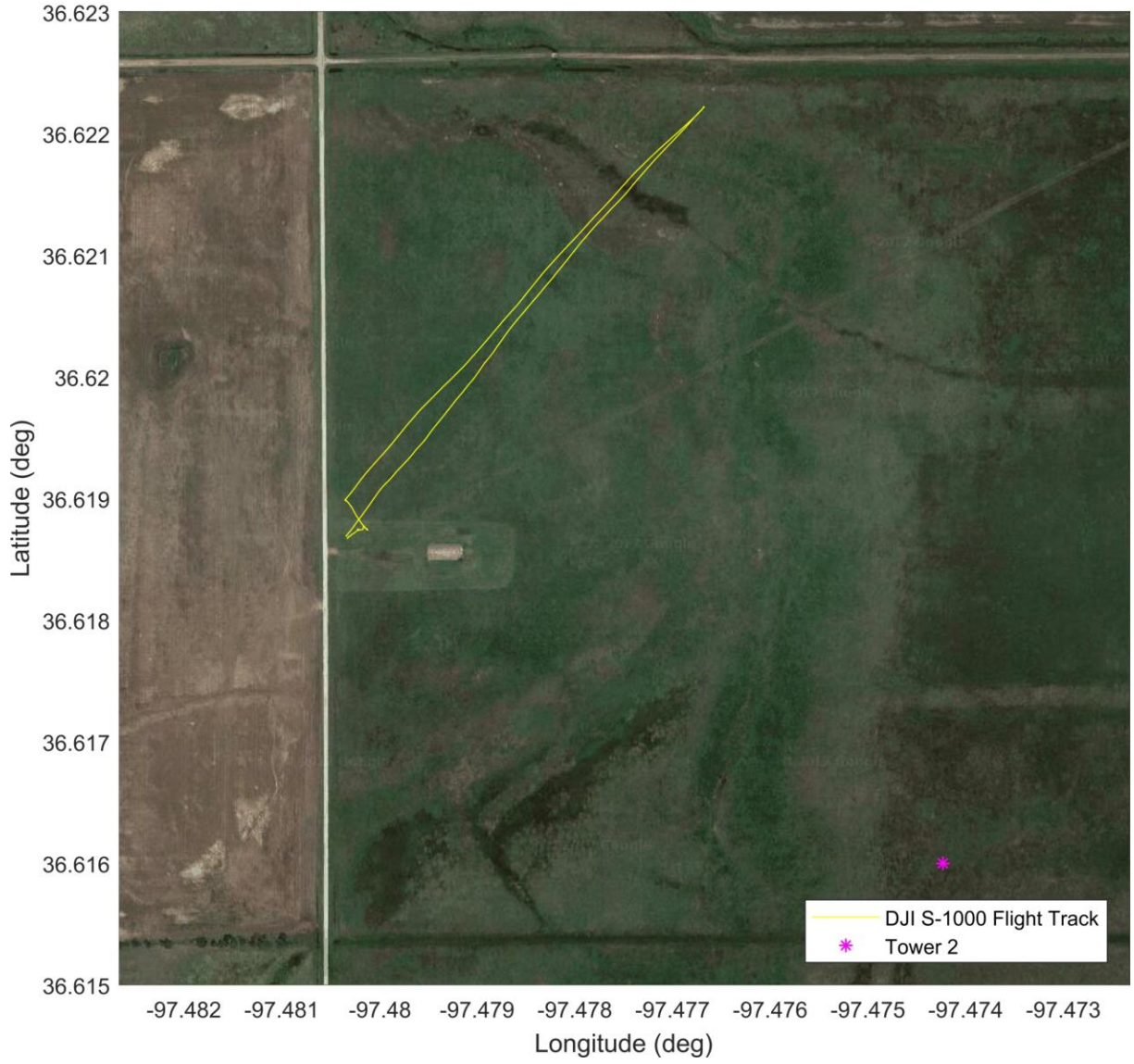


Figure 39: DJI S-1000 Flight 14, Thursday, 17 August 2017.

# Appendix C – Catalog of MD4-1000 flight tracks and marker files

```
File 20170814-DATA-flight07.csv OPENED at 20:40:36 GPS
iMet-XQ order (3 left, 6 right)
PRO -1 00021 20:40:57 36.622659 -97.476651 Profile 10m-100m
     0 00044 20:41:20 36.622660 -97.476652
TRS -1 00068 20:41:44 36.622668 -97.476636 Transect
     0 00278 20:45:14 36.627158 -97.471150
PRO -1 00284 20:45:20 36.627158 -97.471150 Profile 100m-300m
     0 00332 20:46:08 36.627158 -97.471152
TRS -1 00340 20:46:16 36.627158 -97.471150 Transect
     0 00598 20:50:35 36.622636 -97.476632
PRO -1 00601 20:50:38 36.622637 -97.476632 Profile 300m-10m
     0 00750 20:53:07 36.622636 -97.476629
File 20170814-DATA-flight07.csv CLOSED at 20:53:32 GPS
Total scans 00776
```

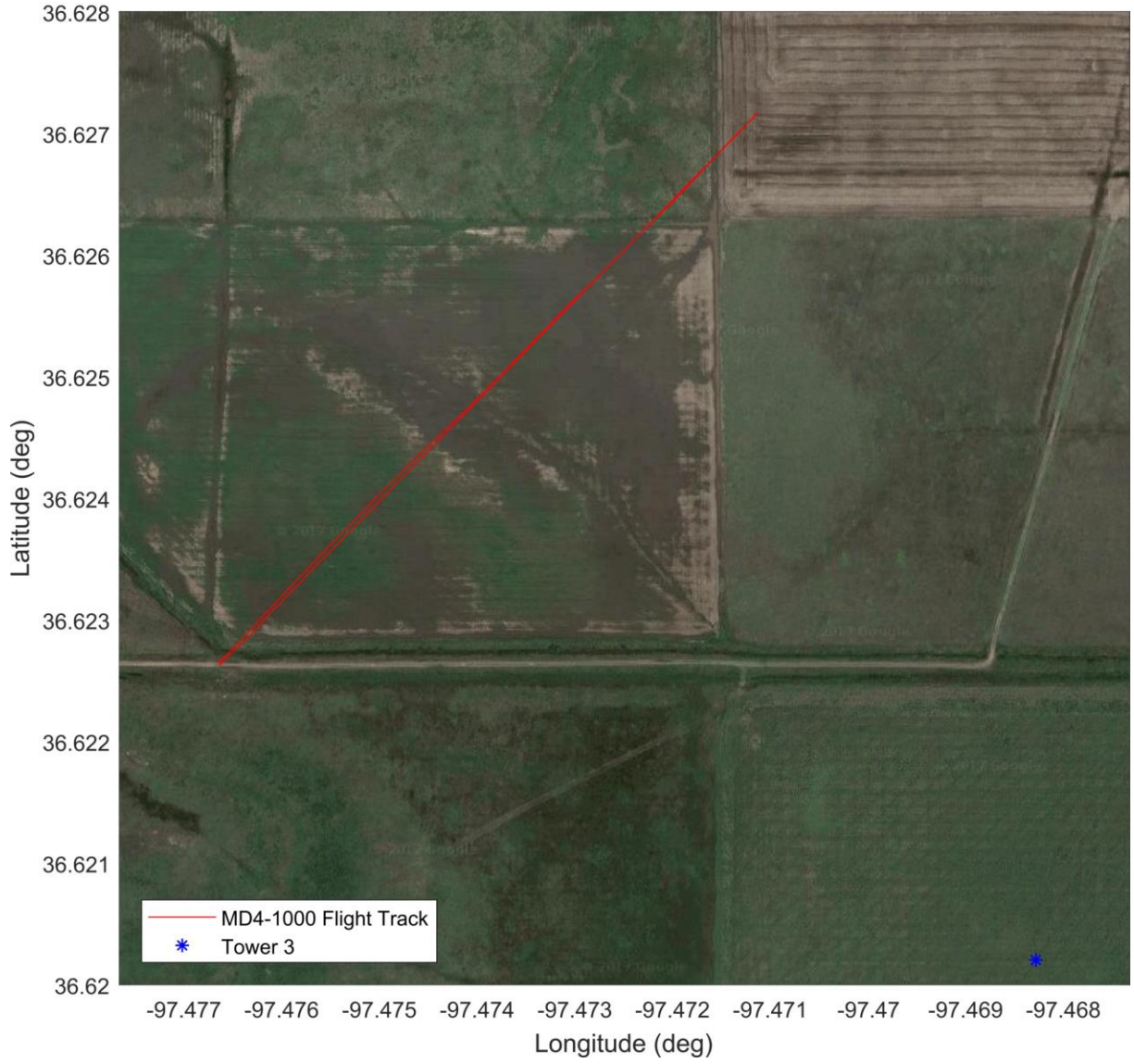


**Figure 40: Microdrone MD4-1000 Flight 7, Monday, 14 August 2017.**

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