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UAV pattern testing design, methods, data analysis and results from UAV spray drift studies conducted in 2023 and 2024 for the Unmanned Aerial Pesticide Application System Task Force (UAPASTF)

Tim Dupuis, Aaron Rice, Ben Brayden, Brent Toth

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Introduction

Study Team

- The Unmanned Aerial Pesticide Application System Task Force (UAPASTF) contracted with the Stone Environmental field team to conduct nine GLP UAV drift deposition field trials.
- We partnered with local personnel whenever possible. This included local farmers, CROs, spray drone experts, academic personnel, government authorities, and in-country industry folks.

Study Location

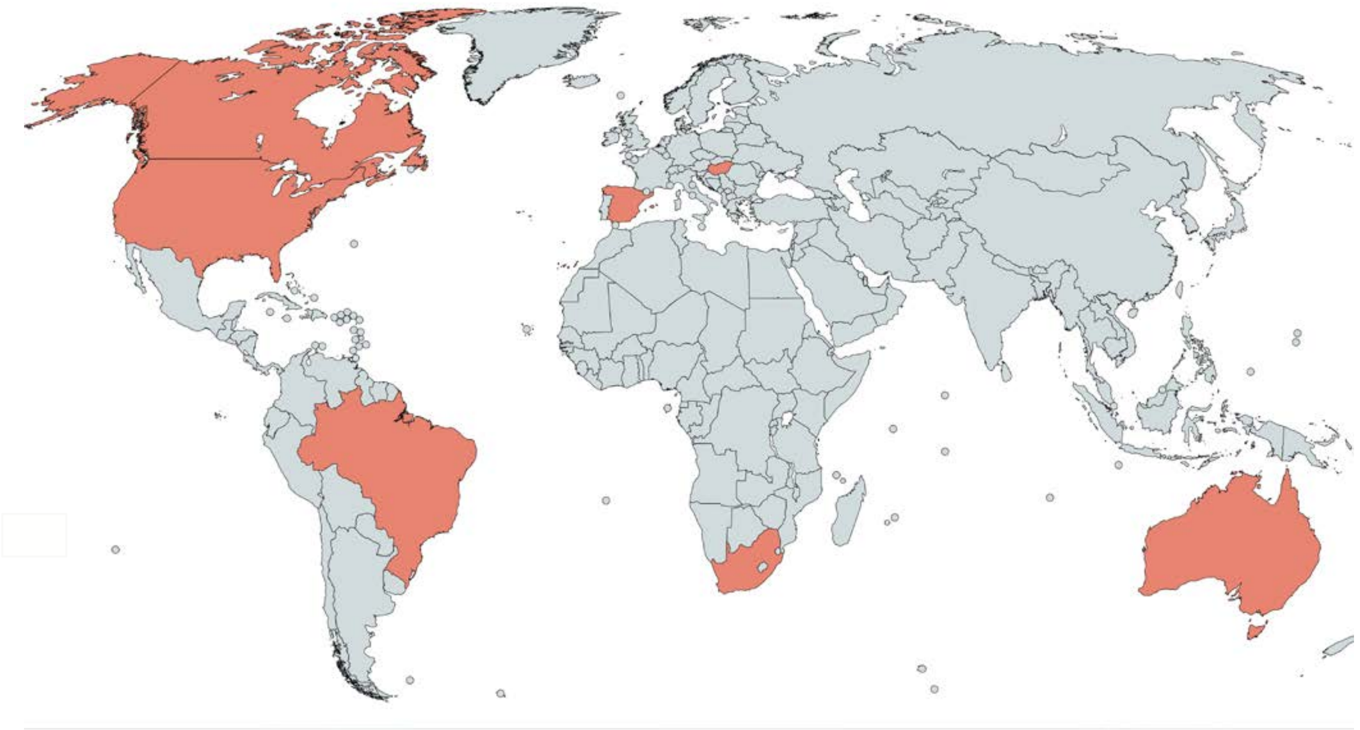
- Studies were conducted in seven countries around the world, and in five continents.

Study Timeframe

- Pilot Study (non-GLP) was conducted February 2023.
- The first GLP study was in Canada conducted May 2023.
- The ninth and final GLP study was conducted in South Africa September 2024.

Study Locations and Timeline

- Robstown, Texas, USA – February 2023 (Non-GLP)
- Katy, Texas, USA – April 2023 (Pattern Testing study only)
- Saint-Jean-sur-Richelieu, Quebec, Canada – May/June 2023
- Santa Helena de Goiás, Goiás, Brazil – August/September 2023
- Bugac, Bács-Kiskun, Hungary – October 2023
- Oropesa, Toledo, Spain – November 2023
- Robstown, Texas, USA – December 2023
- Castro, Paraná, Brazil – March 2024
- Clifton, Queensland, Australia – April 2024
- Delmas, South Africa –September 2024
- Hertzogville, South Africa – September 2024



Observational and Participatory Stakeholders Present

- Partners throughout the GLP studies
  - Drone Spray Canada
  - DJI
  - Application Insight, LLC
- Texas, USA (non-GLP) – USDA, HSE-UAV
- Texas, USA (Pattern Testing) – Application Insight, LLC
- Canada – PMRA, Agriculture and Agri-food Canada
- Goiás, Brazil – São Paulo State University, AgIdea
- Hungary – Hungarian Ministry of Agriculture, Ministry of Agriculture and Rural Development of the Slovak Republic, Central Controlling and Testing Institute in Agriculture (CCTIA; Slovakia), National Forest Center (NFC; Slovakia), MyActionCam
- Spain – Spanish Ministry of Health, ACRE Solutions
- Texas, USA – USDA
- Paraná, Brazil – Federal University of Santa Maria
- Australia – APVMA, University of Queensland
- South Africa (2x) – September 2024

Study Design

Study design followed the UAPASTF guidance protocol.

Verification and Calibration

- Sprayer speed verification
- Nozzle verification and pressure verification

Pattern Testing

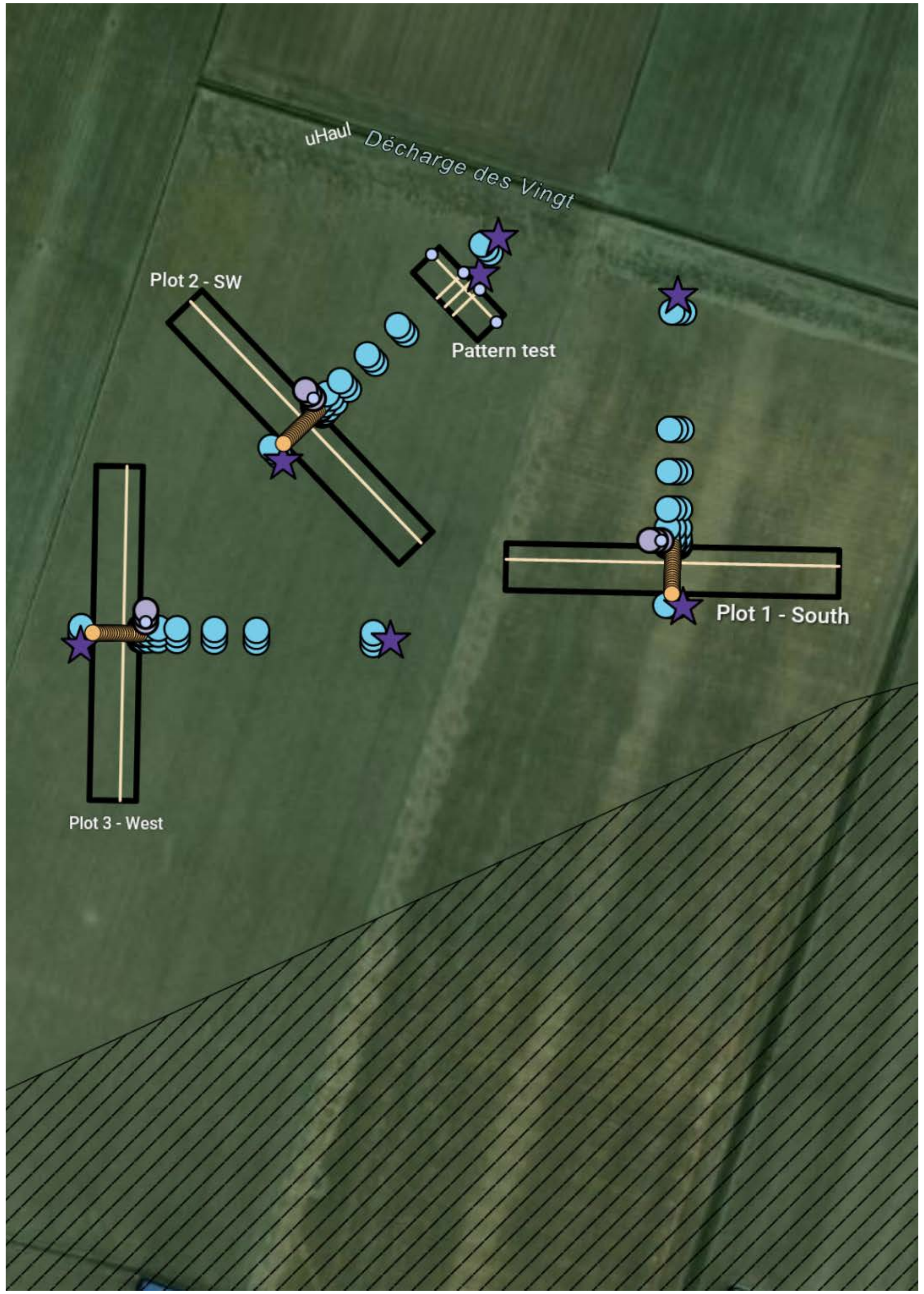
- Three replicates per nozzle for a total of nine passes.
- Determination of swath width and displacement for Event Applications.

Event Applications

- Three replicates of each nozzle droplet classification pairing (XR110015/XR11003, TT11001/TT11003, AIXR110015/AIXR11003).
- Nine UAV and nine reference ground applications in total.

Quality Control Samples

- Photostability samples
- Transit stability samples
- Tank mix samples
- Source water characterization samples



UAV – T30

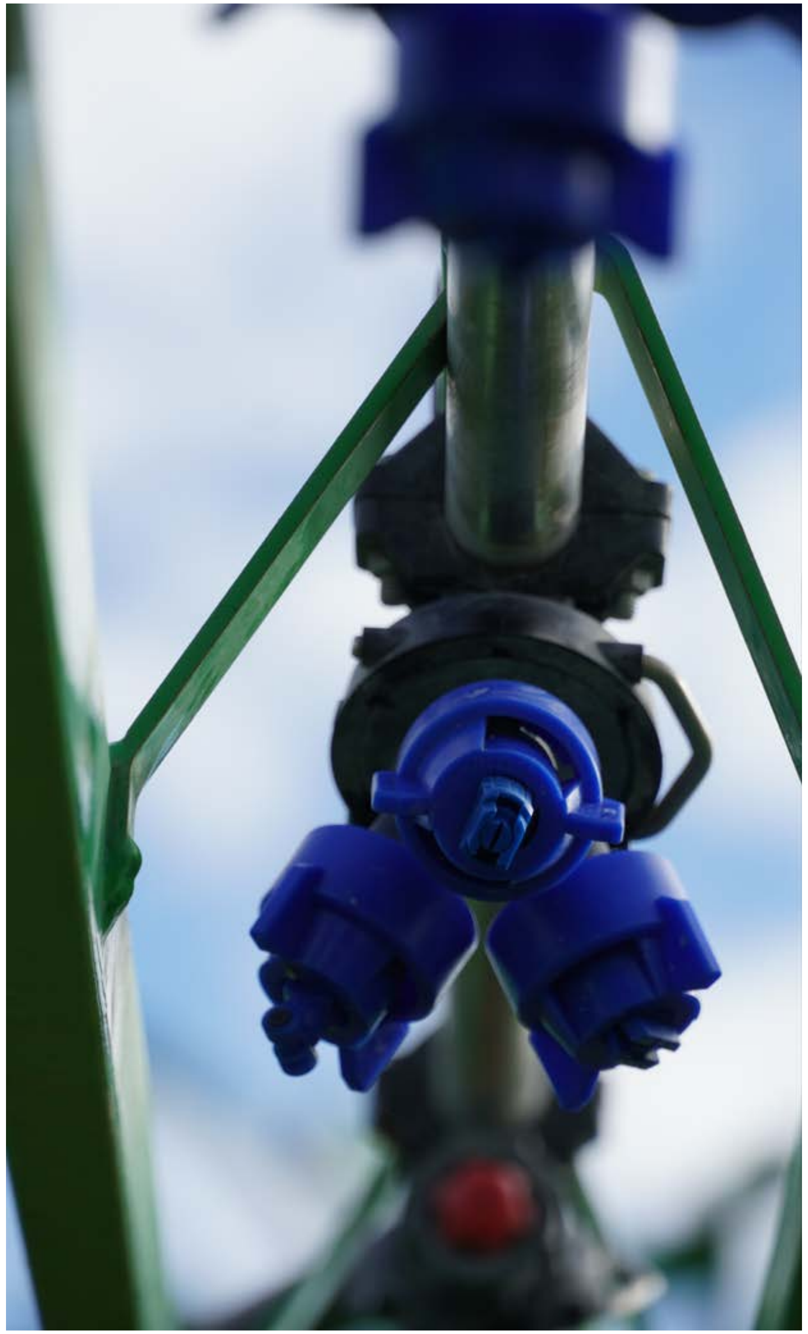
The DJI T30 was used for all studies to achieve a consistent benchmark/ comparator.

- The T30 uses traditional hydraulic nozzles which allows comparison to conventional spray application technology.
- UAV technology is moving fast, and we wanted to have a consistent dataset across all studies. The T30 was chosen as this benchmark.
- At the time of study initiation, the T30 had significant global market share, and was in the mid-range of existing and anticipated UAVs in terms of weight and payload capacity.

Nozzles

Three nozzles were used to achieve a fine, medium and coarse droplet spectrum.

- The XR nozzles were targeting a fine droplet, the TT nozzles were targeting a medium droplet, and the AIXR nozzles were targeting a coarse droplet
- For the UAV XR110015, TT11001*, and AIXR110015 nozzles were used at a target pressures of 30, 40, and 30 psi, respectively.

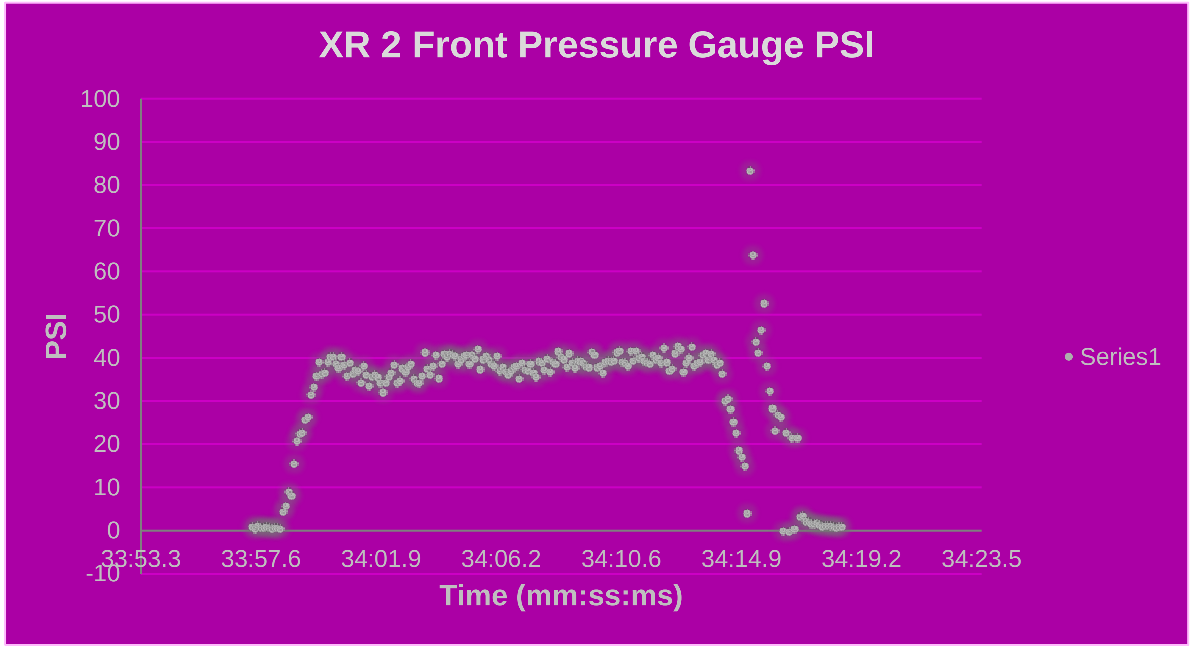


*In the Texas non-GLP study, the Texas pattern test study, and in the Canada study TT110015 nozzles were used.

UAV pressure monitoring

UAV pressure was monitored during nozzle verification, pattern testing, and multi-swath applications

- T30 application rate is controlled by the internal computer which controls two pumps via flow rate controllers.
- To verify the pressure, we installed two inline pressure loggers recording at 0.1 second intervals.



Calibration and Verification

The nozzle flow rate was verified for the UAV and ground sprayer

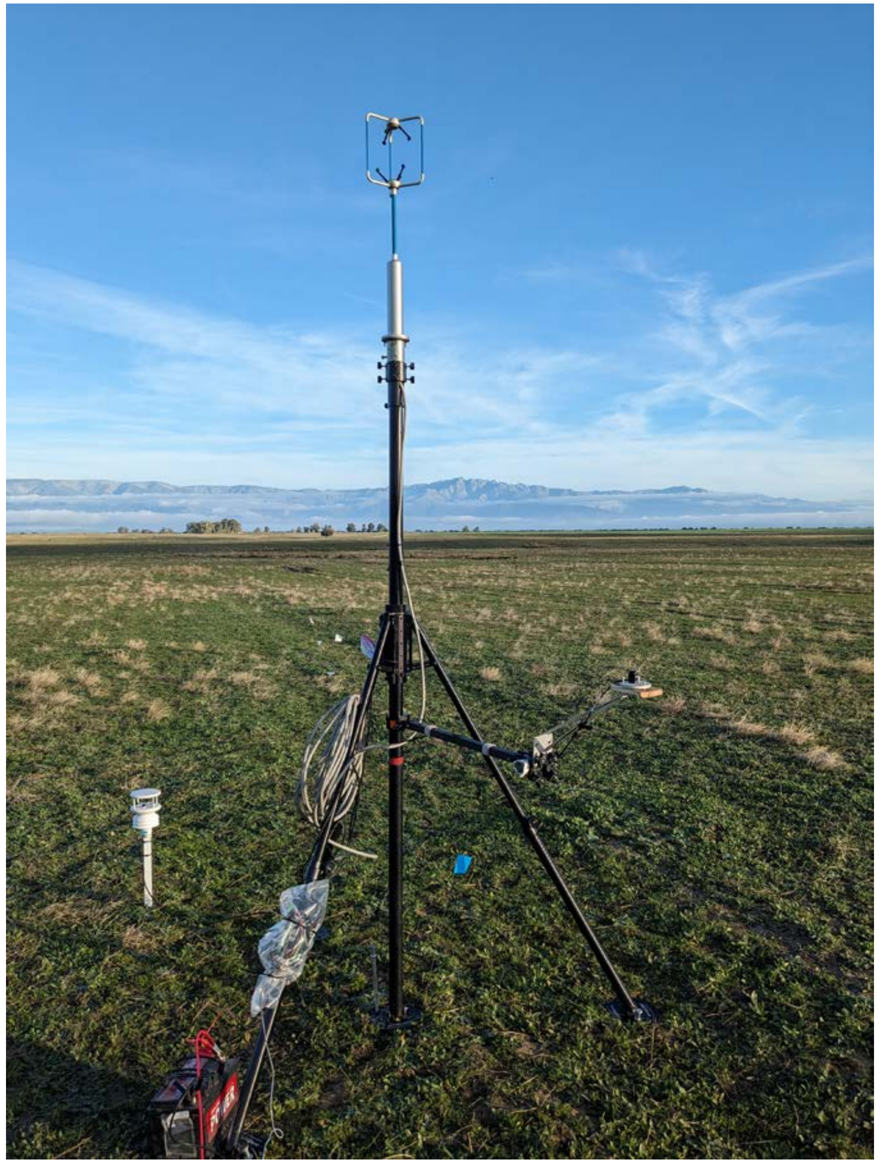
- Verification was performed using SpotOn® SC-1 calibrators.
- Pressure was verified with inline Track-It™ pressure loggers.
- Inconsistencies were addressed by swapping out defective nozzles, documenting the actual versus target pressure, adjusting the sprayer speed, and/or contacting the nozzle manufacturer.

Meteorological Stations

Application ranges

- The target wind speed during testing was 2.0 – 5.0 m/s (4.5 – 11.2 mph) at boom height
- The target wind direction was within 30 degrees of the field orientation

Parameter	Height Above Ground on Upwind Met Station	Height Above Ground on Downwind Met Station
3D Wind Speed and Direction	3 m	NA
2D Wind Speed and Direction	51 cm	51 cm, 3 m
Temperature	51 cm	51 cm, 3 m
Relative Humidity	51 cm	51 cm, 3 m
Barometric Pressure	51 cm	51 cm, 3 m

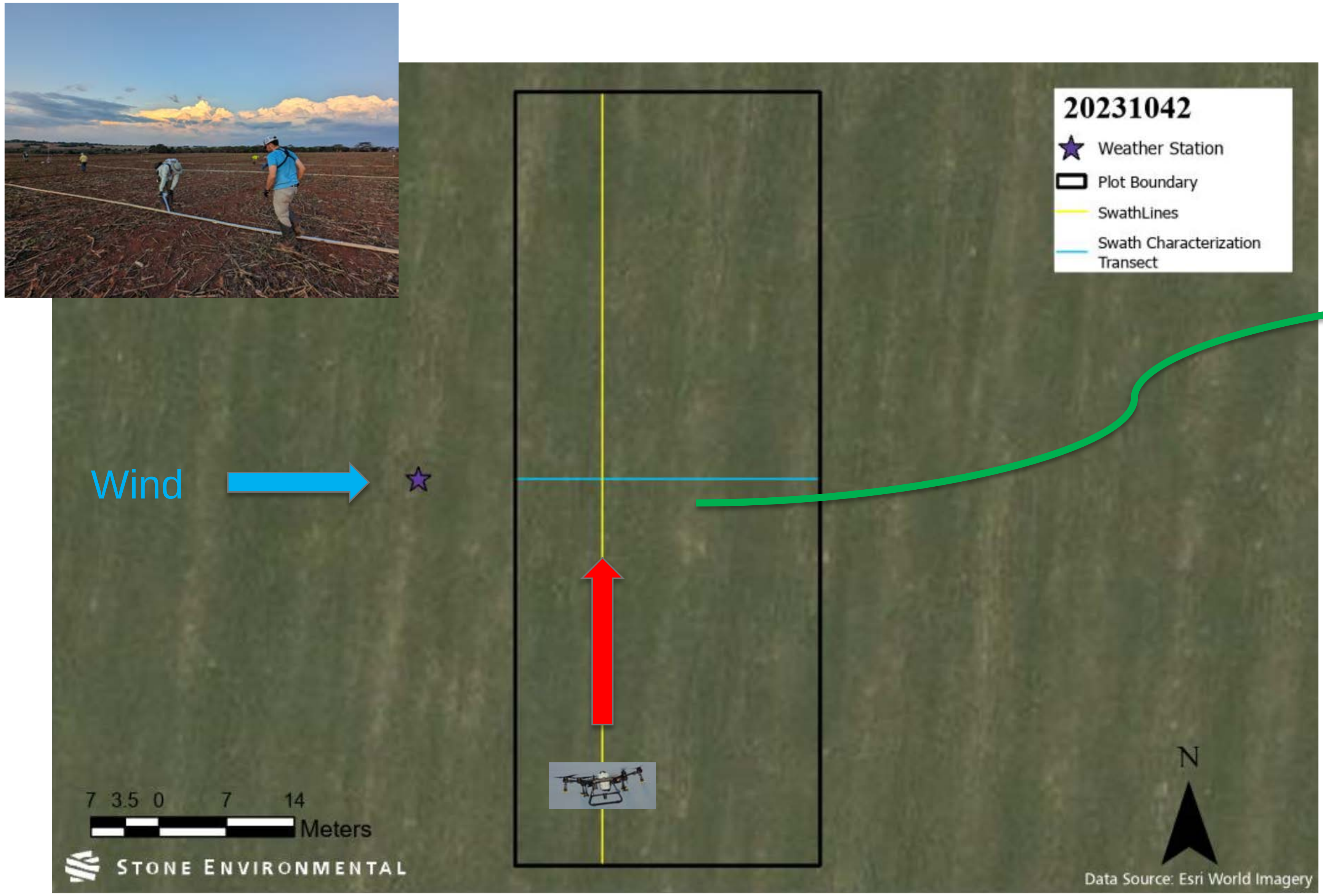


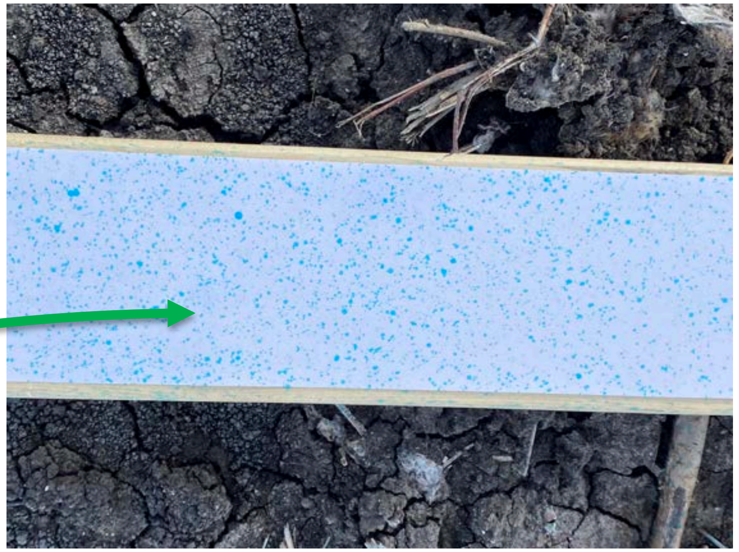
Pattern Testing

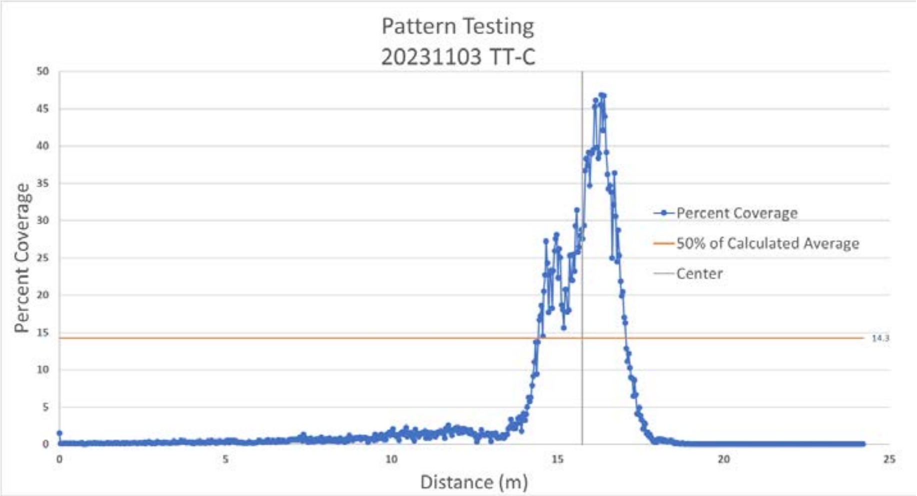
UAV spray pattern was measured for the UAV release height, nozzle, forward speed, and environmental conditions

- Tests were performed in a crosswind. This has not been the industry standard, since results are more variable. However, we saw the need to perform pattern testing in the same environmental conditions as we would be performing the off target drift tests.
- Three transects of media was collected for each nozzle.
- Deposition of FD&C blue dye was initially collected on Kromekote cards and analyzed with AccuPatt. Starting with the first Brazil study, only receipt paper was collected and run through the Swath Gobbler™.
- Swath width and swath displacement were calculated based on average percent coverage.

Pattern Testing







Data Retrieval

Receipt Paper

Swath Gobbler Analysis

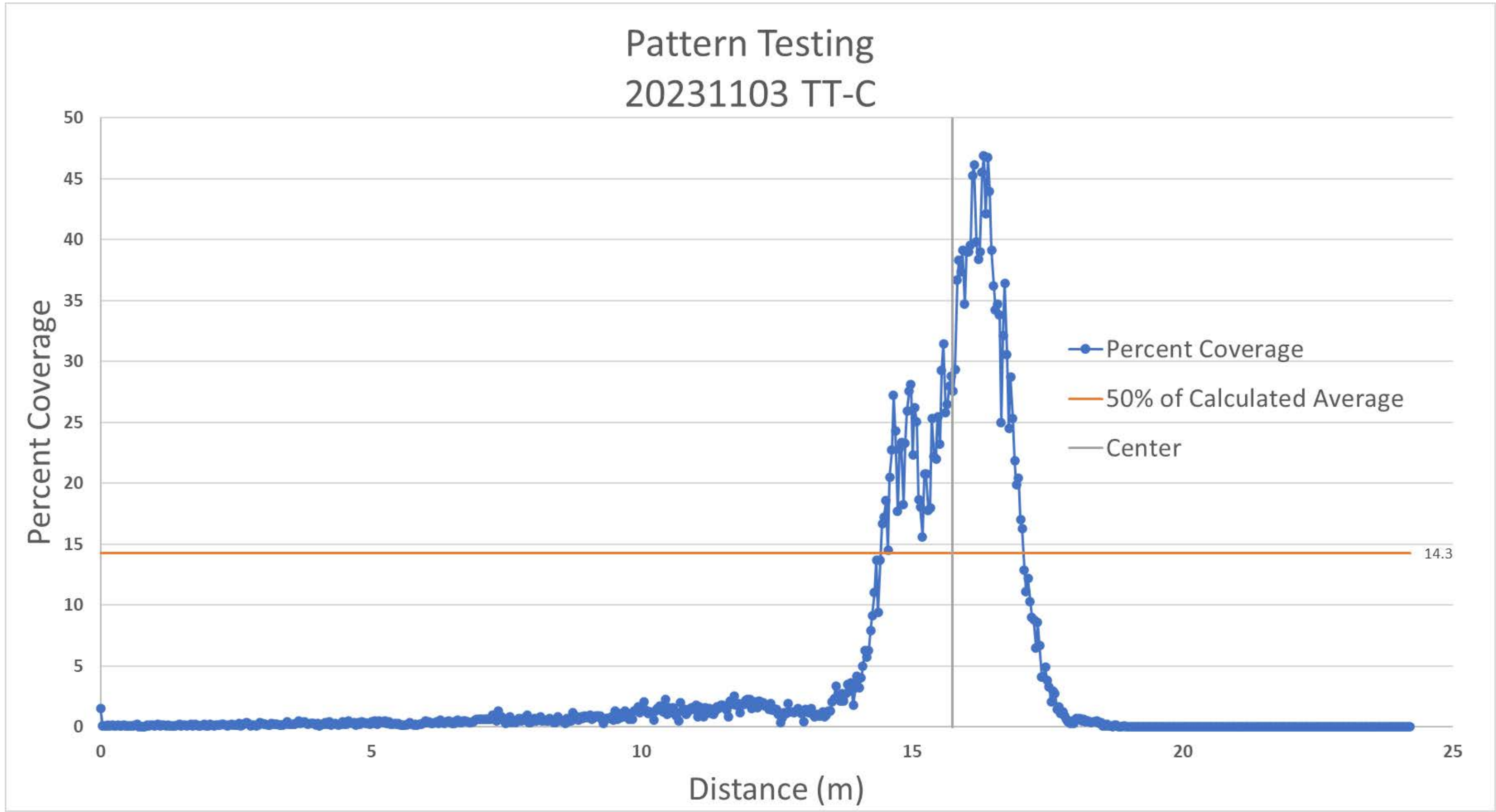
Swath Gobbler Coverage Values

Image Number	Postion (mm)	Percent Coverage (%)	Hits Per cm^2
0	0	2.260795234	50.87776333
1	35.5	0.800902028	6.014304291
2	71	0.921478248	5.933029909
3	106.5	0.691562047	4.957737321
4	142	0.561740821	4.388816645
5	177.5	1.242955572	8.940182055
6	213	1.007812386	6.420676203
7	248.5	1.220091959	9.224642393
8	284	1.213335993	7.964889467
9	319.5	1.063958022	9.062093628
10	355	1.190223477	11.05331599
11	390.5	1.277908808	8.980819246
12	426	1.174969216	9.224642393
13	461.5	0.718941489	6.095578674
14	497	1.031849403	8.330624187
15	532.5	1.01289714	6.948959688
16	568	0.758410556	4.876462939
17	603.5	0.82330339	5.648569571
18	639	0.945799727	7.599154746
19	674.5	1.134753437	8.696358908
20	710	1.016061777	8.168075423

Pattern Testing Analysis

Swath width was determined as width of swath at ½ of average percent coverage

- Added variability with crosswind methodology.
- An iterative process using an excel worksheet and outlier analysis was used to determine the swath width.
- Swath displacement calculated by determining the difference between the flight path center and the calculated swath center.



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Analytical Sheet

Step 1

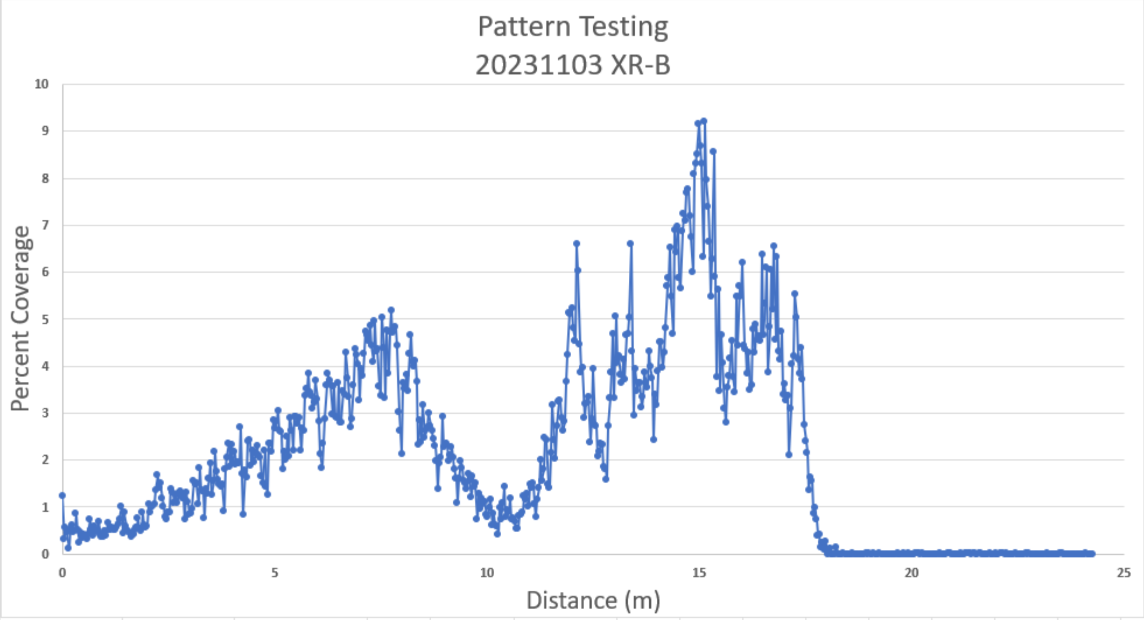
- Import raw data from Swath Gobbler or other source

Step 2

- Add data to pre-labeled analysis tab

Position (m)	Percent Coverage (%)			average	1/2 average
0	1.240395416			0	0.0
0.0355	0.310667777			0	0.0
0.071	0.570025769			0	0.0
0.1065	0.465272733			0	0.0
0.142	0.117696045			0	0.0
0.1775	0.527747643			0	0.0
0.213	0.603272235			0	0.0
0.2485	0.457912286			0	0.0
0.284	0.490696501			0	0.0
0.3195	0.856052048			0	0.0
0.355	0.522413985			0	0.0
0.3905	0.249046253			0	0.0
0.426	0.47497999			0	0.0
0.4615	0.331540158			0	0.0
0.497	0.42356353			0	0.0
0.5325	0.373533822			0	0.0
0.568	0.322579613			0	0.0
0.6035	0.407278096			0	0.0
0.639	0.742125121			0	0.0
0.6745	0.510217688			0	0.0
0.71	0.400699918			0	0.0
0.7455	0.599254212	0	0	0	0.0
0.781	0.487922999			0	0.0
0.8165	4.85E-01			0	0.0
0.852	0.701233746			0	0.0
0.8875	0.414887447			0	0.0
0.923	0.370120281			0	0.0
0.9585	0.367240106			0	0.0
0.994	0.495816812			0	0.0
1.0295	0.388076928			0	0.0
1.065	0.676521132			0	0.0
1.1005	0.527605412			0	0.0
1.136	0.512102247			0	0.0
1.1715	0.5710925			0	0.0
1.207	0.511071073			0	0.0
1.2425	0.519782714			0	0.0
1.278	0.563163129			0	0.0
1.3135	0.643416898			0	0.0
1.349	0.741129505			0	0.0
1.3845	1.021039857			0	0.0
1.42	0.449058414			0	0.0
1.4555	0.88296924			0	0.0
1.491	0.59025811			0	0.0
1.5265	0.50644857			0	0.0
1.562	0.475904491			0	0.0
1.5975	0.431706248			0	0.0
1.633	0.368449068			0	0.0
1.6685	0.421145606			0	0.0
1.704	0.504990703			0	0.0
1.7395	0.567287824			0	0.0

Swath Width(m)	Width(ft)			
0.0	0.0			
1/2 Swath				
0				
Center(distance)		Theoretical Center		Displacement
0.0		17.5	DW to UW	0.0



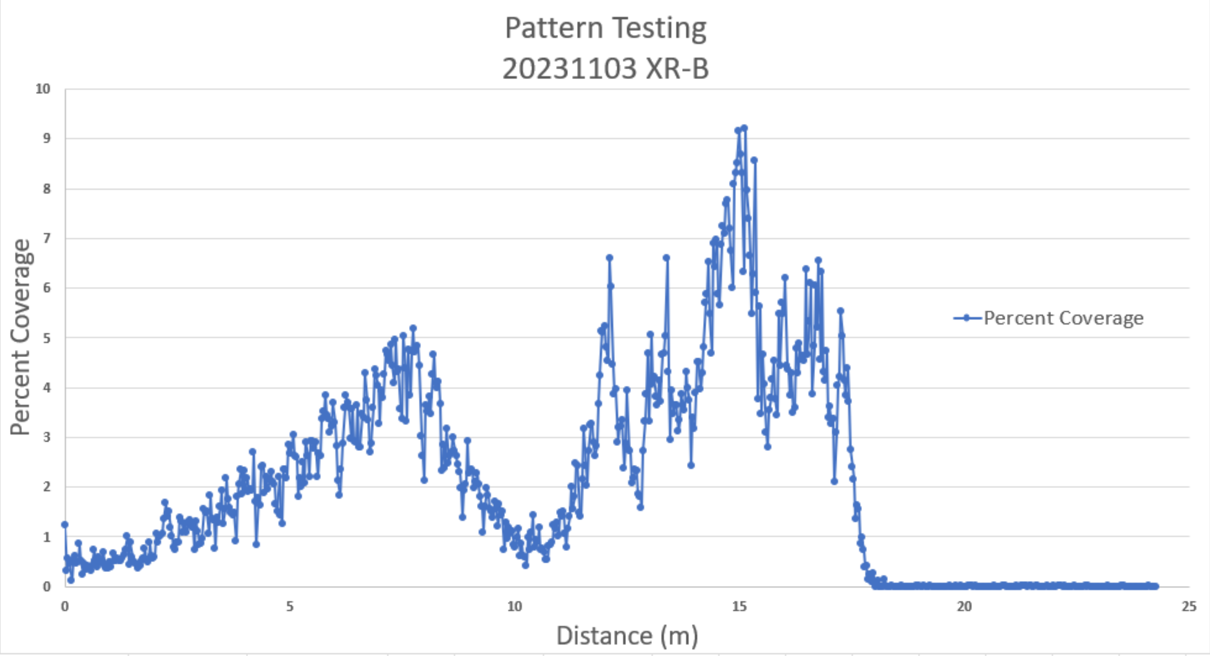
Analytical Sheet

Step 3

- Iterative Calculation of average

Position (m)	Percent Coverage (%)			average	1/2 average
0	1.240395416			4.491141005	2.2
0.0355	0.310667777			4.491141005	2.2
0.071	0.570025769			4.491141005	2.2
0.1065	0.465272733			4.491141005	2.2
0.142	0.117696045			4.491141005	2.2
0.1775	0.527747643			4.491141005	2.2
0.213	0.603272235			4.491141005	2.2
0.2485	0.457912286			4.491141005	2.2
0.284	0.490696501			4.491141005	2.2
0.3195	0.856052048			4.491141005	2.2
0.355	0.522413985			4.491141005	2.2
0.3905	0.249046253			4.491141005	2.2
0.426	0.47497999			4.491141005	2.2
0.4615	0.331540158			4.491141005	2.2
0.497	0.42356353			4.491141005	2.2
0.5325	0.373533822			4.491141005	2.2
0.568	0.322579613			4.491141005	2.2
0.6035	0.407278096			4.491141005	2.2
0.639	0.742125121			4.491141005	2.2
0.6745	0.510217688			4.491141005	2.2
0.71	0.400699918			4.491141005	2.2
0.7455	0.599254212	2.074909998	4.491141005	4.491141005	2.2
0.781	0.487922999	3.120251067		4.491141005	2.2
0.8165	4.85E-01	4.384311551		4.491141005	2.2
0.852	0.701233746	4.491141005		4.491141005	2.2
0.8875	0.414887447	4.491141005		4.491141005	2.2
0.923	0.370120281			4.491141005	2.2
0.9585	0.367240106			4.491141005	2.2
0.994	0.495816812			4.491141005	2.2
1.0295	0.388076928			4.491141005	2.2
1.065	0.676521132			4.491141005	2.2
1.1005	0.527605412			4.491141005	2.2
1.136	0.512102247			4.491141005	2.2
1.1715	0.5710925			4.491141005	2.2
1.207	0.511071073			4.491141005	2.2
1.2425	0.519782714			4.491141005	2.2
1.278	0.563163129			4.491141005	2.2
1.3135	0.643416898			4.491141005	2.2
1.349	0.741129505			4.491141005	2.2
1.3845	1.021039857			4.491141005	2.2
1.42	0.449058414			4.491141005	2.2
1.4555	0.88296924			4.491141005	2.2
1.491	0.59025811			4.491141005	2.2
1.5265	0.50644857			4.491141005	2.2
1.562	0.475904491			4.491141005	2.2
1.5975	0.431706248			4.491141005	2.2
1.633	0.368449068			4.491141005	2.2
1.6685	0.421145606			4.491141005	2.2
1.704	0.504990703			4.491141005	2.2
1.7395	0.567287824			4.491141005	2.2

Swath Width(m)	Width(ft)			
0.0	0.0			
1/2 Swath				
0				
Center(distance)		Theoretical Center		Displacement
0.0		17.5	DW to UW	0.0



Analytical Sheet

Step 4

- Assign Swath Width, Center and Displacement based on calculation

Position (m)	Percent Coverage (%)			average	1/2 average
0	1.240395416			4.491141005	2.2
0.0355	0.310667777			4.491141005	2.2
0.071	0.570025769			4.491141005	2.2
0.1065	0.465272733			4.491141005	2.2
0.142	0.117696045			4.491141005	2.2
0.1775	0.527747643			4.491141005	2.2
0.213	0.603272235			4.491141005	2.2
0.2485	0.457912286			4.491141005	2.2
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0.3195	0.856052048			4.491141005	2.2
0.355	0.522413985			4.491141005	2.2
0.3905	0.249046253			4.491141005	2.2
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0.4615	0.331540158			4.491141005	2.2
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0.639	0.742125121			4.491141005	2.2
0.6745	0.510217688			4.491141005	2.2
0.71	0.400699918			4.491141005	2.2
0.7455	0.599254212	2.074909998	4.491141005	4.491141005	2.2
0.781	0.487922999	3.120251067		4.491141005	2.2
0.8165	4.85E-01	4.384311551		4.491141005	2.2
0.852	0.701233746	4.491141005		4.491141005	2.2
0.8875	0.414887447	4.491141005		4.491141005	2.2
0.923	0.370120281			4.491141005	2.2
0.9585	0.367240106			4.491141005	2.2
0.994	0.495816812			4.491141005	2.2
1.0295	0.388076928			4.491141005	2.2
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1.42	0.449058414			4.491141005	2.2
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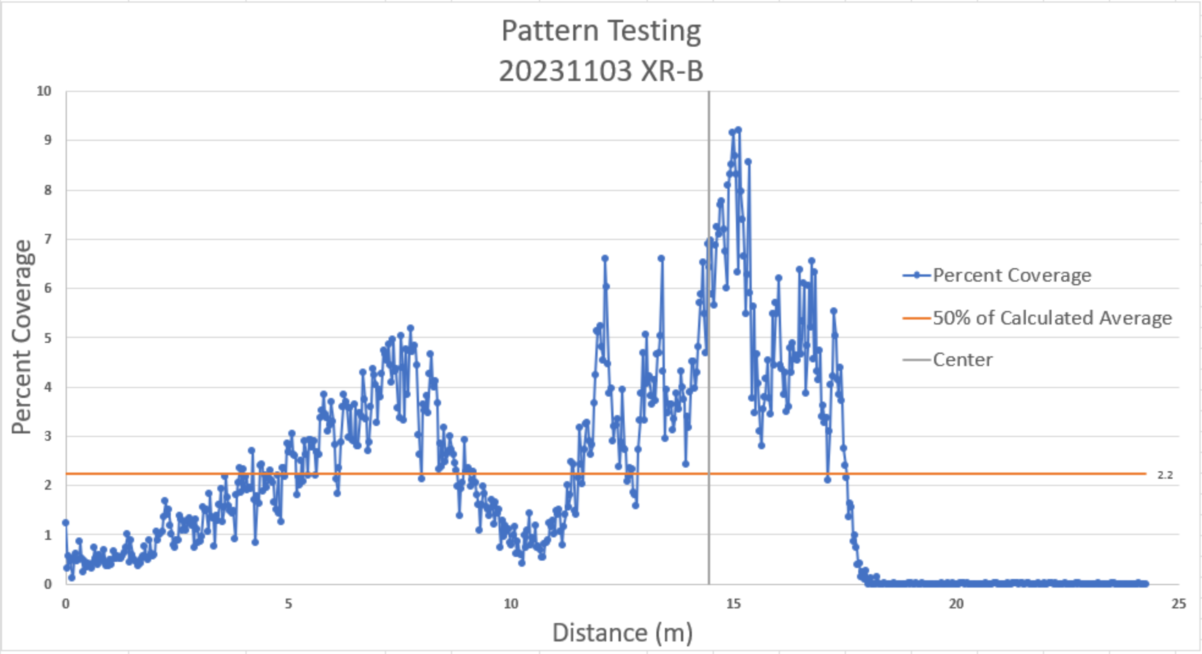
1.6685	0.421145606			4.491141005	2.2
1.704	0.504990703			4.491141005	2.2
1.7395	0.567287824			4.491141005	2.2

Swath Width(m)	Width(ft)
6.1	20.1

1/2 Swath
3.07075

Center(distance)	Theoretical Center		Displacement
14.4	17.5	DW to UW	3.1



Stone's Analytical Method

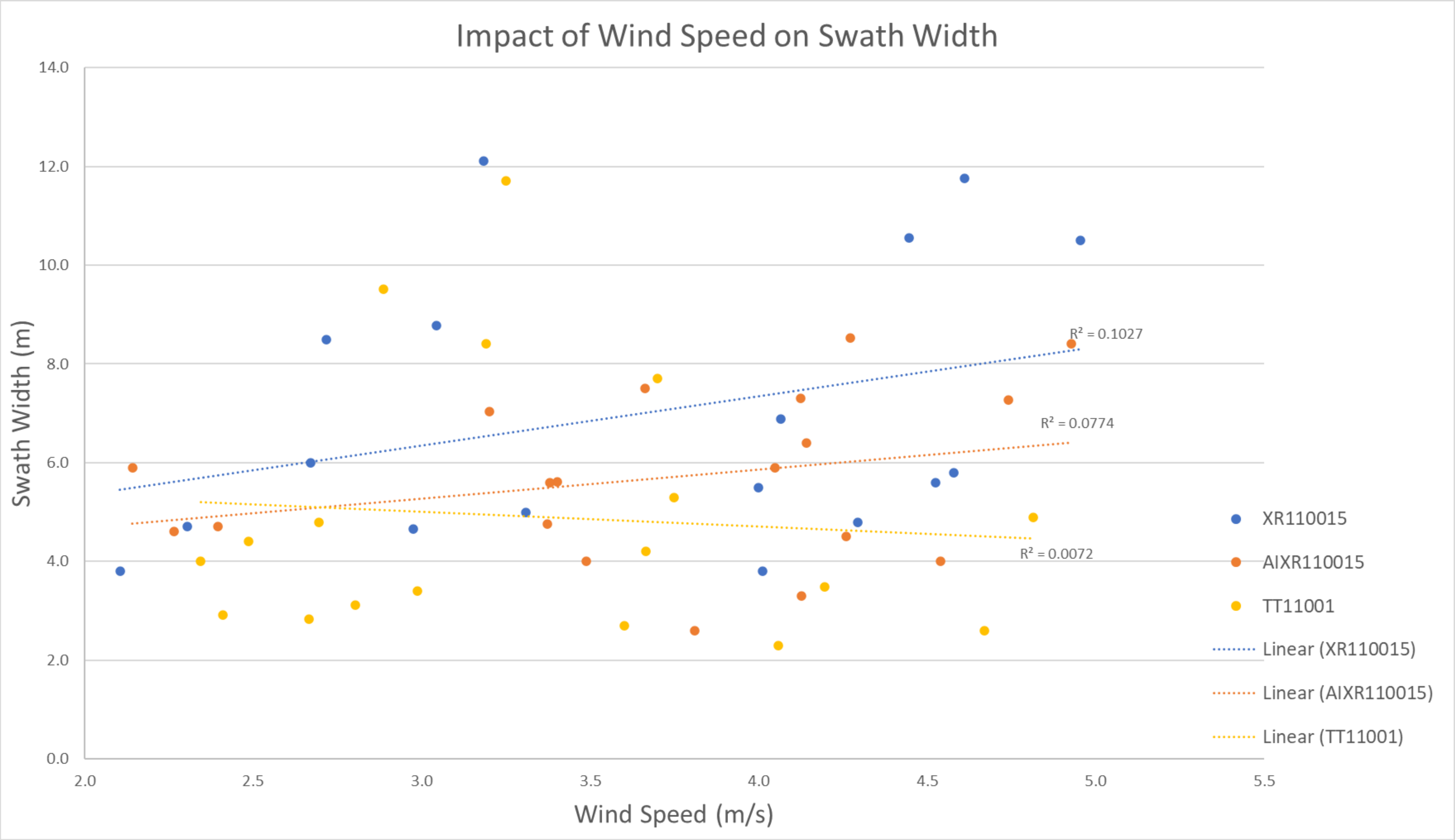
Unique Testing Conditions

- Operating in a crosswind led to some challenging analytical situations

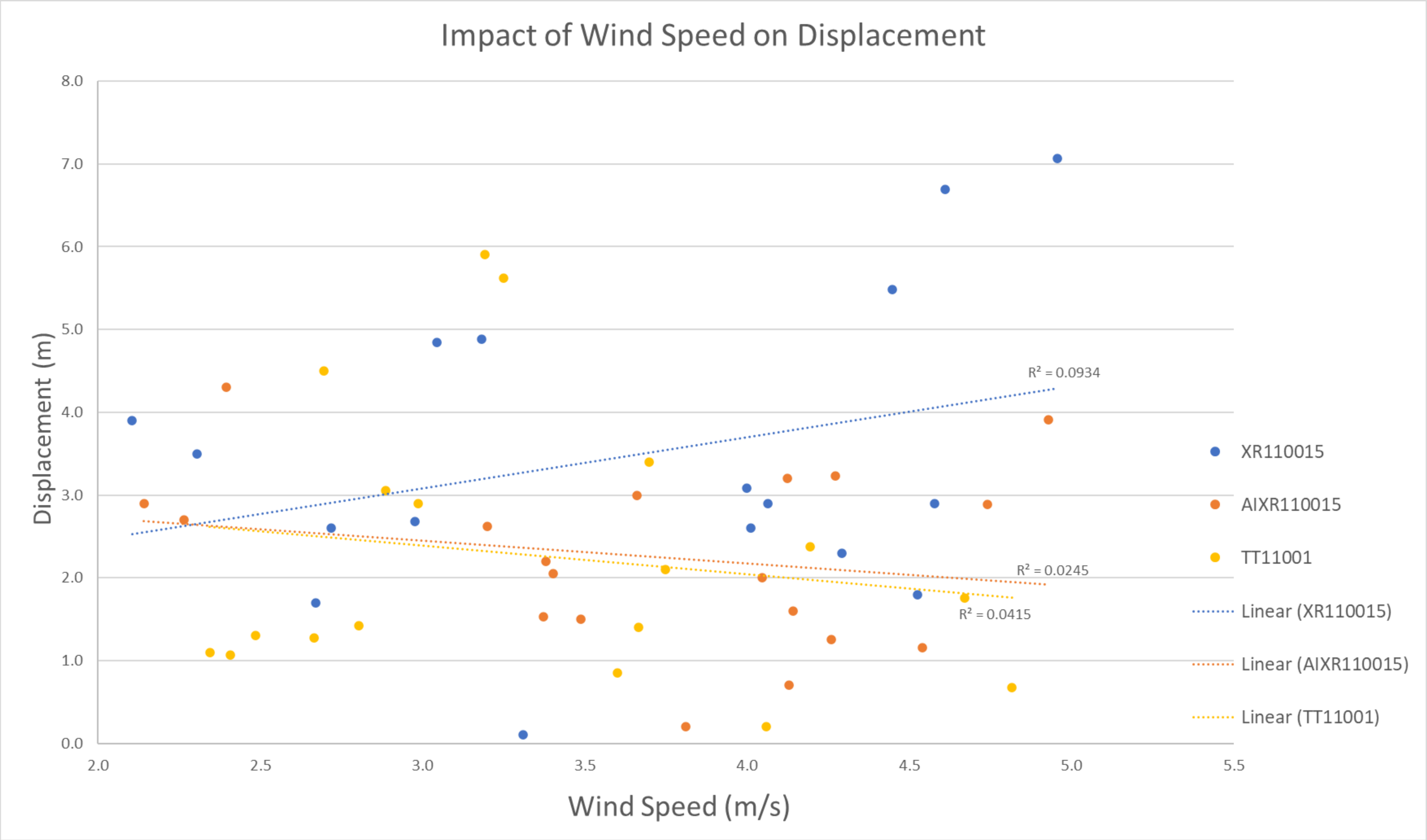
Iterative Average vs CV(coefficient of variation)

- Ultimately decided based on crosswind testing approach
- Accounts for inherent unevenness of data

Swath Width vs Wind Speed



Displacement vs Wind Speed



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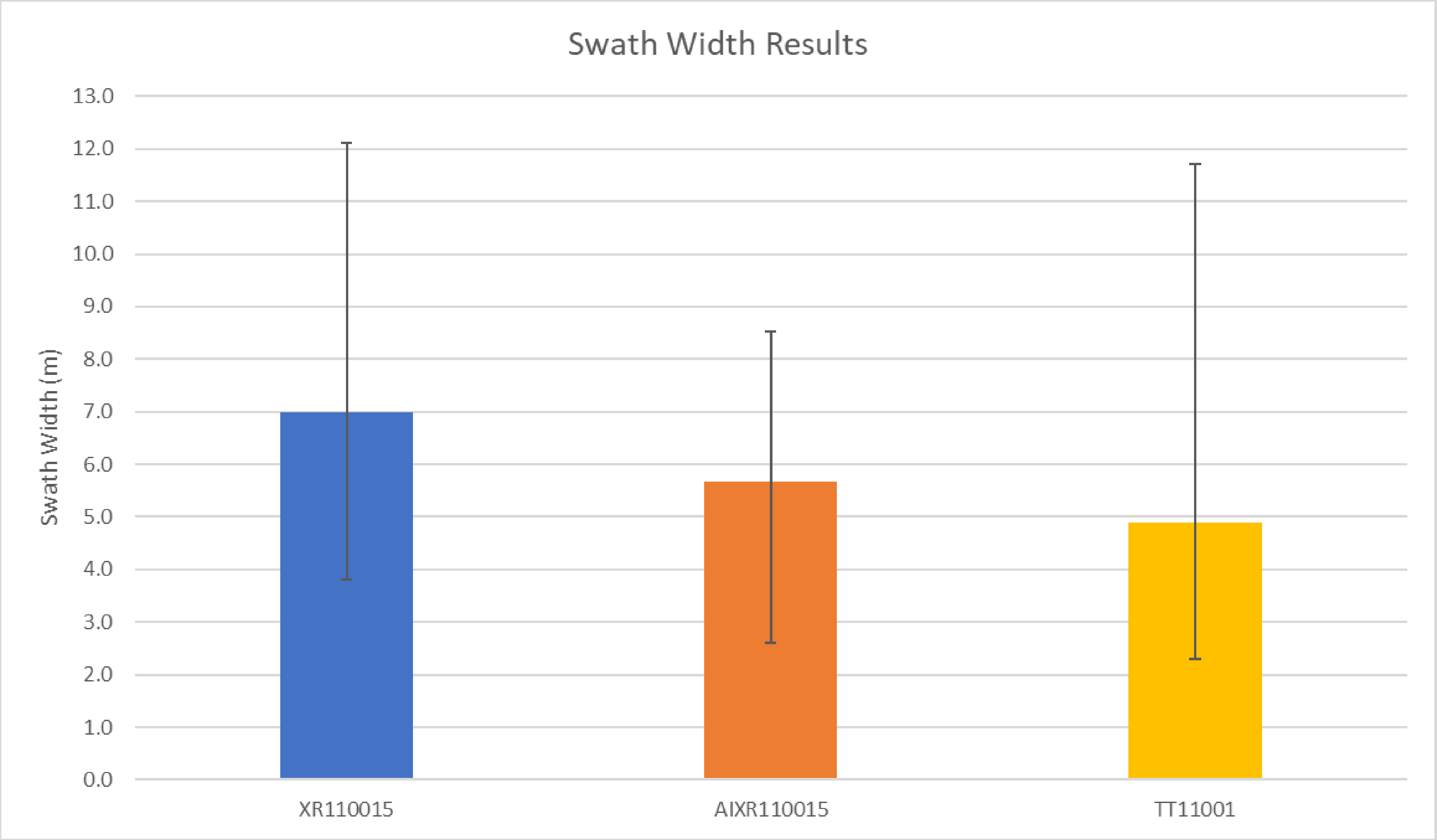
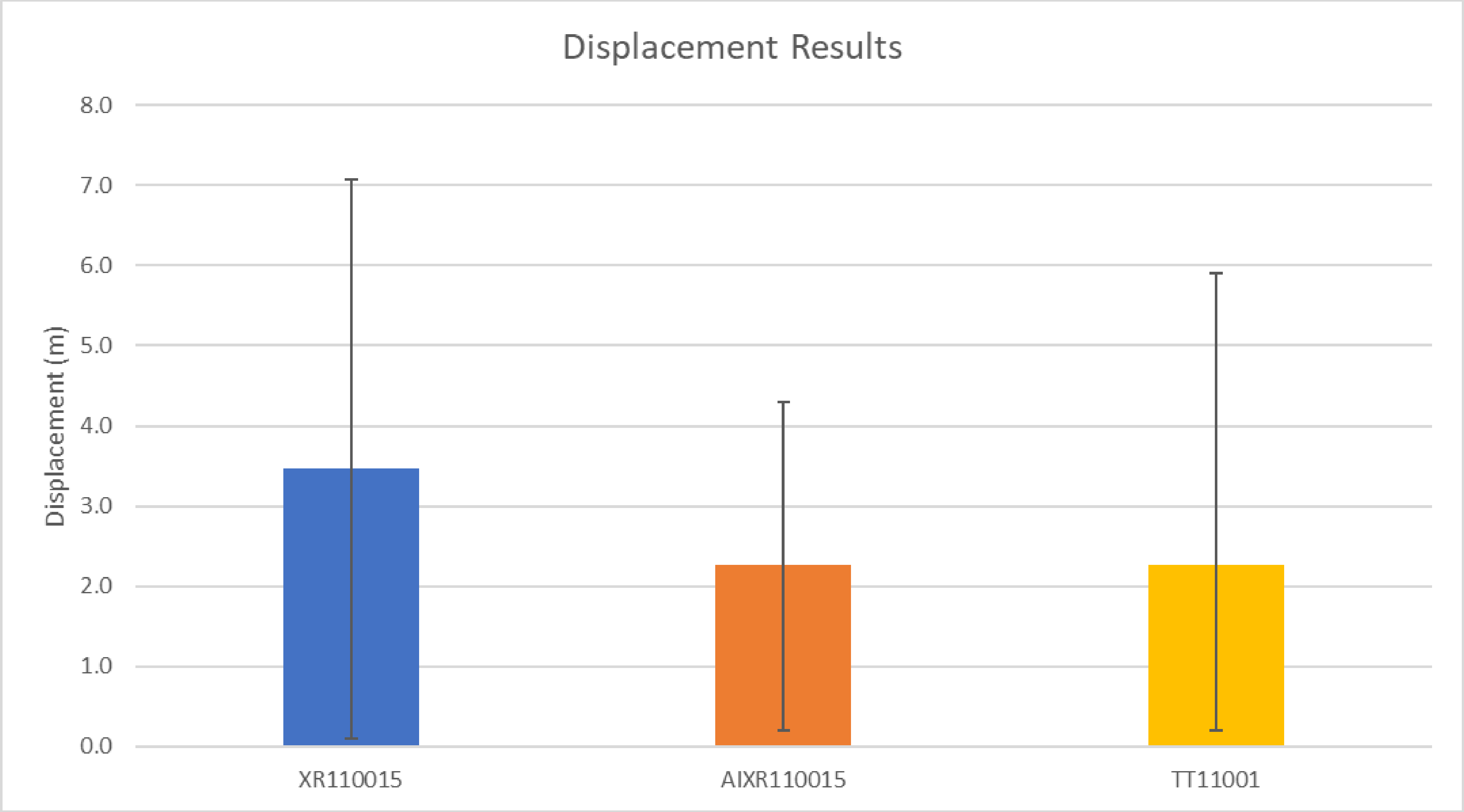
Swath Width Results Summarized



Displacement Results Summarized



Potential Factors in Results

Environmental Conditions

- Wind speed/direction
- Wind Gusts and/or turbulence
- 3D Wind Vectors
- Humidity

Applicator (UAV)

- Pressure
- Nozzle Technology
- Nozzle Angle
- Rotor downwash
- Proprietary DJI spray systems

Additional Questions to Investigate

The goal of the UAPASTF and the studies discussed is to generate regulatory information and data.

These studies including but not limited to the pattern testing data have created a baseline from which further research could be done.

Additional research topics or ideas…

- Increased number of data collected within a given time period
- Wind speed goals beyond the 2-5 m/s
- Rotary atomizers vs hydraulic nozzles
- Comparison to other makes and models of UAV
- Wind tunnel testing

Thank you.

Contact / tdupuis@stone-env.com

Note: All data generated by this study protocol is proprietary to the UAPASTF and its member companies.