MAPPING ACCURACY ASSESSMENT OF UAS PLATFORMS

By

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OUTLINE

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- Control Field
- Imagery Flights
  - Accuracy
  - Sidelap analysis
- Orthomosaic Accuracy
- Image Point Cloud accuracy
- Initial Image Mapping Specifications
- UAV LIDAR Flights
  - Accuracy Assessments

INTRODUCTION

- The main objective of this study is to assess the accuracy of sUAS mapping accuracy and their potential to satisfy California Department of Transportation mapping requirements.
- Sensors Evaluated
  - Camera
  - LIDAR

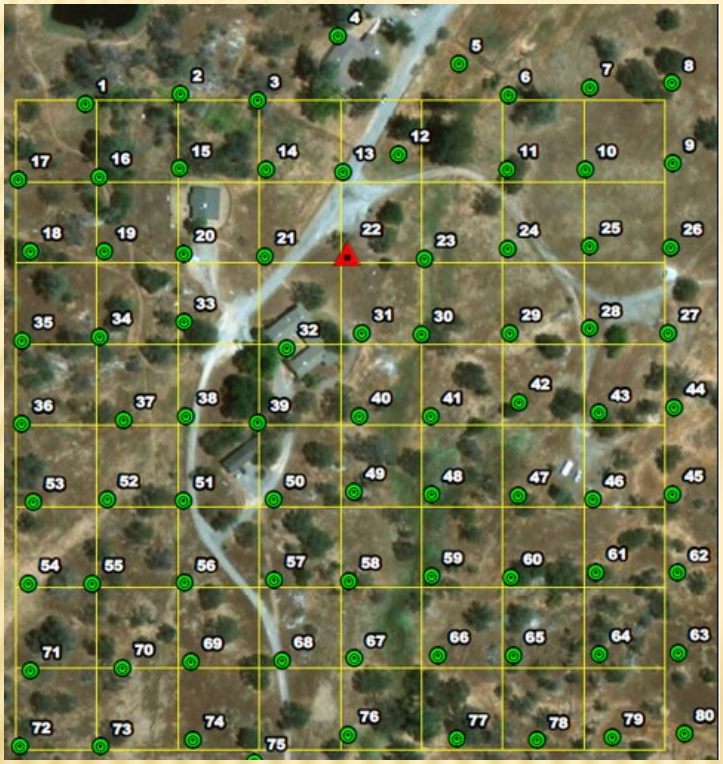
CALTRAN MAPPING REQUIREMENT

ASPRS 2014 Geo-Spatial Accuracy Requirements

Aerial Triangulation and Ground Control Accuracy Requirements, Orthoimagery and/or Planimetric Data Only And Elevation Data					
Product Accuracy (RMSEx, RMSEy) (cm)	Product Accuracy (RMSEz) (cm)	A/T Accuracy		Ground Control Accuracy	
		RMSEx and RMSEy (cm)	RMSEz (cm)	RMSEx and RMSEy (cm)	RMSEz (cm)
17.8	9.3	8.9	4.6	4.5	2.3

CONTROL FIELD

SJER Control Field



- 81 control points
- 1 cm Horizontal accuracy
- 0.5 cm vertical accuracy
- Hilly with 20m vertical relief

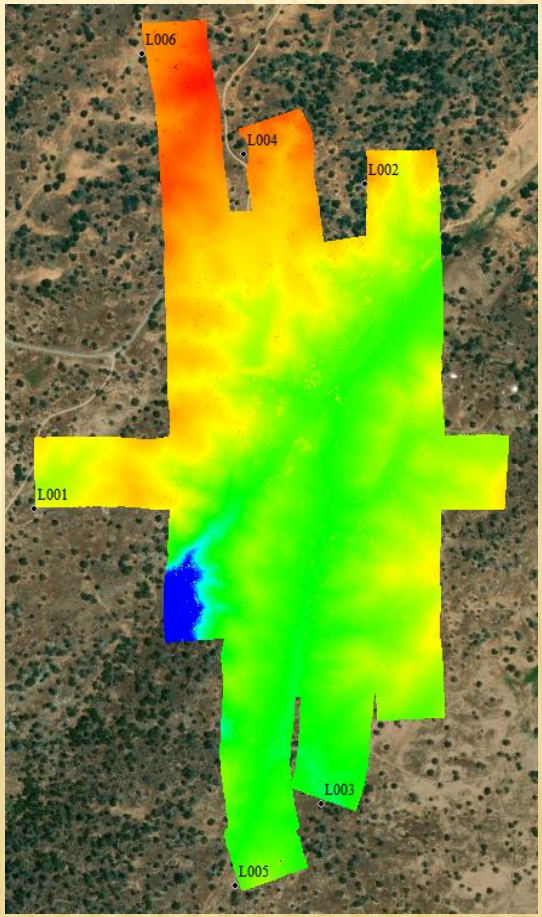
CalFire Control Field

- 30 control points
- 0.5 cm Horizontal accuracy
- 0.5 cm vertical accuracy
- Flat agricultural land

SJER HELICOPTER LIDAR DATA

Sensor	Optech Galaxy Prime
Flying Height Above Terrain	200 m
Pulse Rate	300Khz
Vertical Bias of Unadjusted Data	-8 cm
RMSEz	1 cm
RMSExy	3-5 cm
Point Density	127 pts/m^2
Average Point spacing (cm)	11
Scan Angle (deg)	43
LASER Foot print at Nader (cm)	5
LASER Foot print at Edge (cm)	9

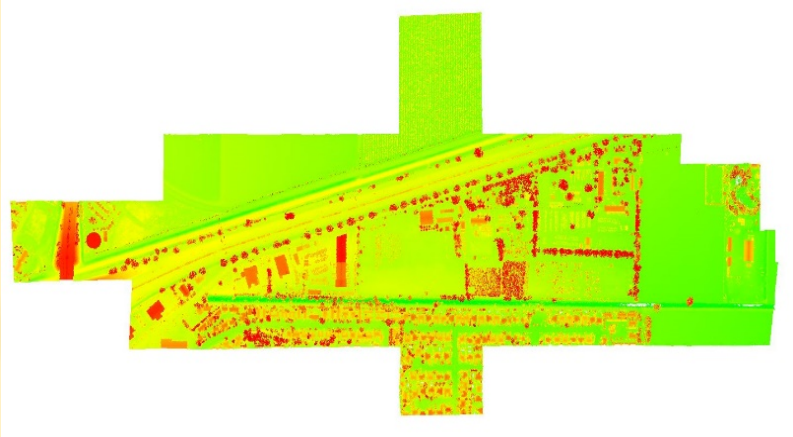
Sidelap 50%



CALFIRE HELICOPTER LIDAR DATA

Sensor	Optech Galaxy Prime
Flying Height Above Terrain	280 m
Pulse Rate	500Khz
Vertical Bias of Unadjusted Data	0.8 cm
RMSEz	0.8 cm
RMSExy	3-5 cm
Point Density	120 pts/m^2
Average Point spacing (cm)	11
Scan Swath Angle (deg)	40
LASER Foot print at Nader (cm)	5
LASER Foot print at Edge (cm)	9

Sidelap 50%



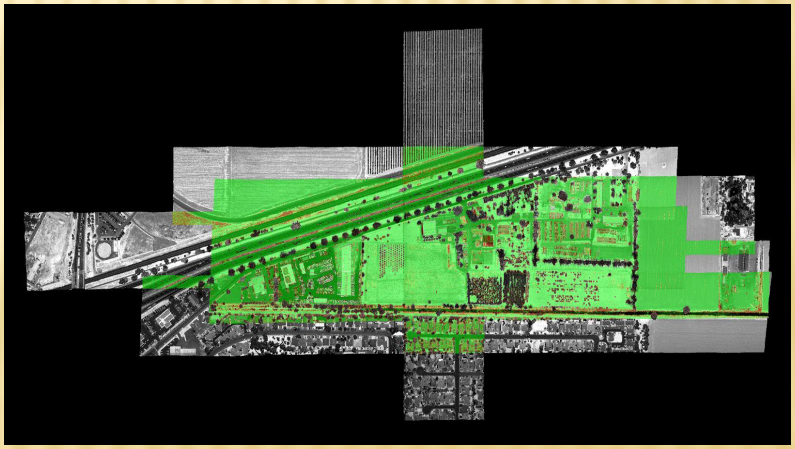


IMAGE TEST FLIGHTS

- 8 sUAS
- 6 different cameras
- 16 Flights
- Processing Software
  - Pix4D
  - AgiSoft PhotoScan

IMAGE TEST FLIGHTS

Flight	Date	Mission	Lifts	Aircraft	Site	Flying Height (m AGL)	GSD (cm)	DIR	Photos	Temp C	Wind (km/h)	Wind Dir (Deg)	Camera	Focal Length (mm)	pixel size (mm)	CCD Width (pixels)	CCD Height (pixels)	Shutter Type
A	6/25/2018	A1	2	eBee RTK (fixed-wing)	SJER	114	2.5	EW-NS	586	38	15	1.1	SODA	10.6	0.0024	5472	3648	Global
		A2	2	eBee RTK (fixed-wing)	SJER	145	3.4	EW-NS	530	38	15	1.1	SODA	10.6	0.0024	5472	3648	Global
		A3	2	eBee RTK (fixed-wing)	SJER	150	3.4	EW-NS	454	38	15	1.1	SODA	10.6	0.0024	5472	3648	Global
B	7/17/2018	B1	2	DJI Inspire With Loki System (rotor craft)	SJER	75	2.1	EW	837	39	17	349.8	FC6510	8.8	0.0024	5472	3648	Global
		B2	2	DJI Inspire With Loki System (rotor craft)	SJER	75	2.0	NS	881	39	17	349.8	FC6510	8.8	0.0024	5472	3648	Global
C	7/19/2018	C1	2	Kespri (rotor craft)	SJER	53	1.5	EW	995	40	11	351.4	ILCE-5100	16.0	0.0040	6000	4000	Global
		C2	2	Kespri (rotor craft)	SJER	110	2.9	EW	254	40	11	351.4	ILCE-5100	16.0	0.0040	6000	4000	Global
D	8/2/2018	D1	1	eBee RTK (fixed-wing)	SJER	84	1.9	EW	488	39	12	348.8	SODA	10.6	0.0024	5472	3648	Global
		D2	1	eBee RTK (fixed-wing)	SJER	84	1.9	NS	465	39	12	348.8	SODA	10.6	0.0024	5472	3648	Global
E	8/2/2018	E1	2	DJI Inspire With Loki System (rotor craft)	SJER	69	1.9	EW	801	39	12	348.8	FC6510	8.8	0.0024	5472	3648	Global
F	3/25/2019	F1	1	eBeeX RTK (fixed-wing)	SJER	105	2.4	NS	709	21	11	320.1	UMC-R10C	16.0	0.0044	5456	3632	Global
G	10/2/2019	G1	1	DJI Phantom 4 RTK	CalFire	60	1.7	EW	248	21	13	15	FC6310R	8.8	0.0024	5472	3648	Global
H	10/2/2019	H1	1	DJI Phantom 4 Pro	CalFire	120	3.4	NE/SW	113	21	13	15	FC6310	8.8	0.0024	5472	3648	Global
	10/2/2019	H2	1	DJI Phantom 4 Pro	CalFire	91	2.5	NE/SW	190	21	13	15	FC6310	8.8	0.0024	5472	3648	Global
	10/2/2019	H3	1	DJI Phantom 4 Pro	CalFire	61	1.7	NE/SW	407	21	13	15	FC6310	8.8	0.0024	5472	3648	Global
	10/2/2019	H4	1	DJI Phantom 4 Pro	CalFire	45	1.2	NE/SW	700	21	13	15	FC6310	8.8	0.0024	5472	3648	Global

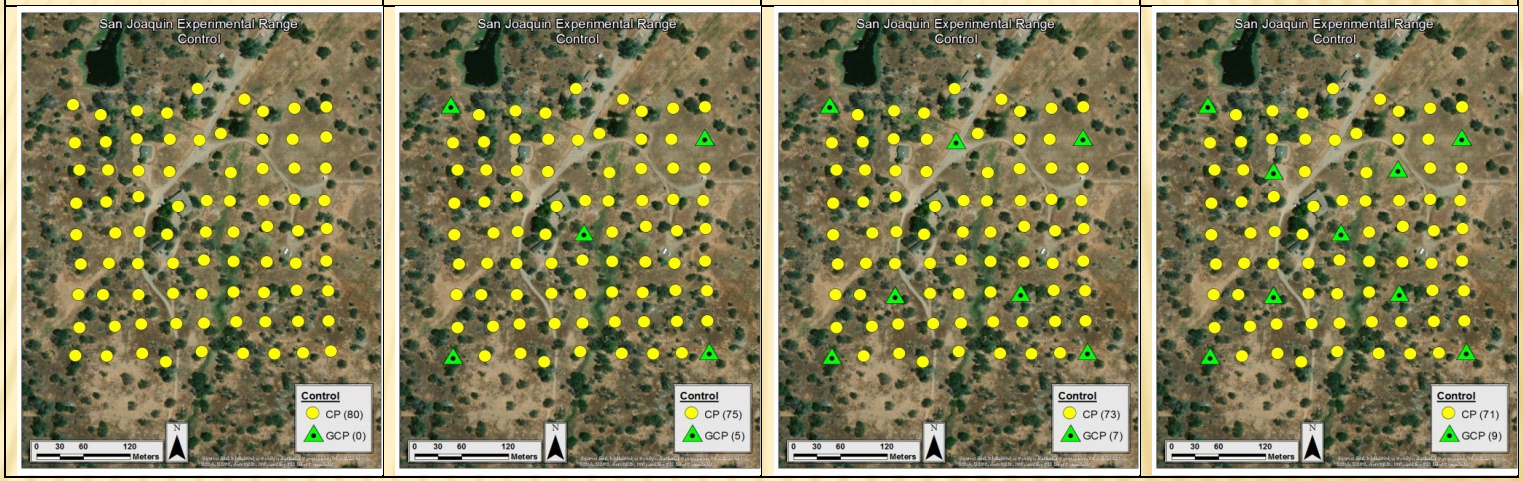
CAMERA TYPES

Camera	FC6510	FC6310R	FC6510	SODA
UAV Platform	DJI Inspire	DJI Phantom 4 RTK (Quad Rotorcraft)	DJI Phantom 4 PRO (Quad Rotorcraft)	SenseFly eBee - Plus / X
UAV GNSS Antenna	L1/L2 ,RTK,PPK,Loki	L1/L2, RTK,PPK	L1	L1/L2, RTK,PPK
Resolution	5472x3648	5472x3648	5472x3648	5472 x 3648
Pixell Size (mm)	0.0024	0.0024	0.0024	0.0024
Focal Length (mm)	8.8	8.8	8.8	10.6
Shutter type	Electronic / Global	Electronic / Global	Electronic / Global	Global

CONTROL

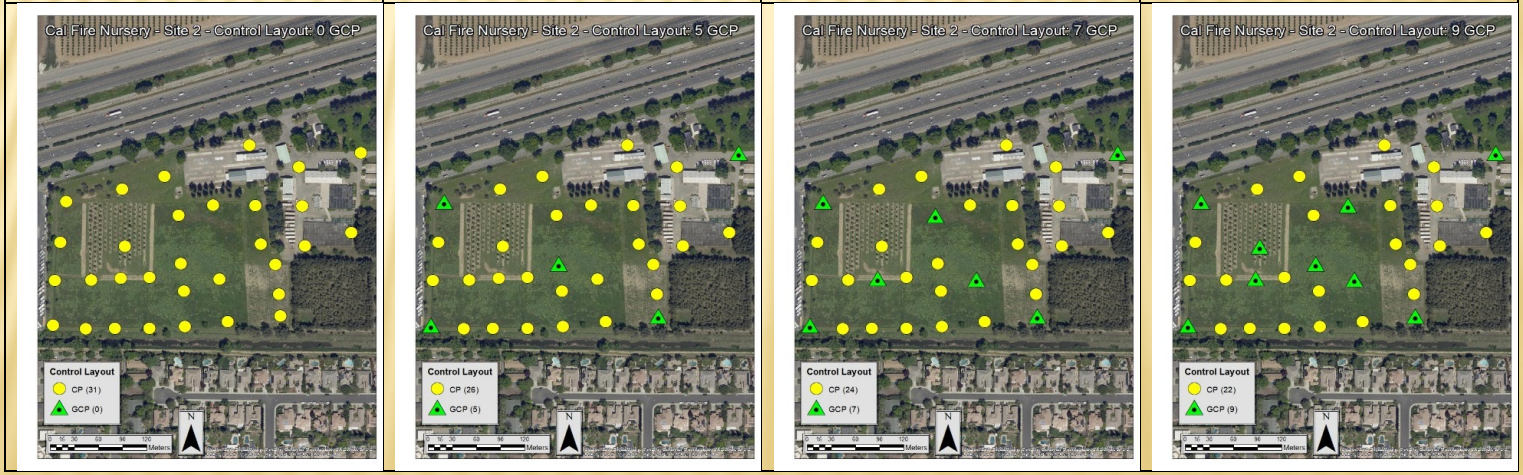
SJER

0 Ground Control	5 Ground Control	7 Ground Control	9 Ground Control



CalFire

0 Ground Control	5 Ground Control	7 Ground Control	9 Ground Control



EBEE SENSEFLY-PLUS

Pix4D AT Results (5 Control Points)

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
A1-1	114	2.59	77.3	76.4	586	75	0.85	0.80	1.15	1.17	0.8	0.8	1.1	1.1	-0.4	0.2	0.2	3.4	4.7	6.3
A1-2			51.8	76.4	293	75	1.04	0.92	1.30	1.39	1.0	0.9	1.2	1.4	-0.3	0.1	0.5	4.1	4.7	5.1
A1-3			52.1	77.3	293	75	1.17	1.19	1.63	1.67	1.1	1.2	1.6	1.6	-0.3	0.2	0.4	6.7	6.0	11.1
D1	84	1.9	59.8	84.5	488	75	1.21	1.03	1.57	1.59	1.2	1.0	1.4	1.6	0.0	0.1	0.7	5.3	5.2	7.8
D2	84	1.9	60.0	80.4	465	75	1.07	1.00	1.23	1.46	1.1	1.0	1.2	1.4	-0.1	0.3	-0.2	6.1	5.8	5.5
D3	84	1.9	80.4	84.5	953	75	0.81	0.85	1.10	1.17	0.8	0.9	1.1	1.2	0.0	0.1	-0.2	4.4	5.6	4.4

PhotoScan AT Results (5 Control Points)

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
A1-1	114	2.59	77.3	76.4	586	75	0.83	1.38	1.41	1.61	0.8	0.9	1.2	1.2	0.4	1.0	-0.8	4.2	5.5	6.5
A1-2			51.8	76.4	293	75	0.79	0.98	1.56	1.26	0.8	0.8	1.3	1.1	0.1	0.6	-0.9	3.5	4.5	5.5
A1-3			52.1	77.3	293	75	0.94	1.49	1.64	1.76	0.8	0.9	1.3	1.2	0.5	1.2	-1.0	4.5	5.1	7.6
D1	84	1.9	59.8	84.5	488	75	0.81	1.92	2.79	2.08	0.8	0.8	1.1	1.1	-0.2	1.7	2.6	3.9	5.2	4.6
D2	84	1.9	60.0	80.4	465	75	1.05	1.87	2.28	2.14	0.9	0.8	1.1	1.2	0.6	1.7	2.0	4.1	3.8	5.2
D3	84	1.9	80.4	84.5	953	75	0.80	2.06	1.25	2.21	0.8	0.8	1.1	1.1	-0.2	1.9	-0.7	4.0	5.0	5.0

DJI WITH LOKI

Pix4D AT Results (5 Control Points)

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
B1	75	2.1	89.7	86.8	837	75	0.80	0.88	0.75	1.19	0.8	0.9	0.8	1.2	-0.2	0.1	0.1	3.4	4.3	3.4
B2	75	2.0	89.5	86.0	881	75	0.92	0.80	1.21	1.22	0.9	0.8	0.8	1.2	-0.1	-0.1	-0.9	4.5	4.3	3.5
B3	75	2.0	89.45	89.7	1718	75	0.8	0.8	1.0	0.8	0.8	0.8	0.8	0.6	-0.2	-0.1	-0.6	3.7	4.8	3.9
E1	69	1.9	86.1	85.3	801	75	1.45	1.18	1.46	1.87	1.4	1.2	1.4	1.8	-0.3	-0.2	-0.6	6.4	6.2	6.4

PhotoScan AT Results (5 Control Points)

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
B1	75	2.1	89.7	86.8	837	75	0.98	1.06	1.90	1.44	0.8	1.0	1.9	1.3	-0.6	0.5	-0.4	4.2	4.4	10.1
B2	75	2.0	89.5	86.0	881	75	1.03	0.76	1.55	1.28	0.9	0.8	1.5	1.2	0.6	0.0	-0.5	3.9	4.0	7.7
B4	75	2.0	89.45	89.7	1718	75	0.8	0.9	3.3	0.8	0.7	0.9	1.0	0.6	0.3	0.1	-3.2	3.5	4.1	4.8
E1	69	1.9	86.1	85.3	801	75	1.10	1.09	1.96	1.10	1.1	1.0	1.8	0.8	-0.3	-0.4	-0.9	5.3	6.1	7.2

EBEE SENSEFLY-X

Pix4D AT Results (5 Control Points)

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
F1	105	2.4	78.6	78.2	709	75	1.42	1.28	1.37	1.91	1.4	1.3	1.4	0.9	0.1	0.1	-0.2	6.4	6.6	5.9

PhotoScan AT Results (5 Control Points)

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
F1	105	2.4	78.6	78.2	709	75	2.62	1.34	1.96	2.94	2.1	1.3	1.8	1.3	-1.6	-0.4	-0.9	8.8	6.9	8.9

DJI PHANTOM 4 RTK

Pix4D AT Results (5 Control Points)

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
G1	60	1.7	65.3	64.1	248	25	1.60	1.05	1.71	1.91	1.4	1	1.7	1.8	0.69	0.11	0.11	5.3	4.2	7.1

PhotoScan AT Results (5 Control Points)

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
G1	60	1.7	65.3	64.1	248	25	1.40	0.97	2.69	1.70	1.1	0.8	2.6	1.3	-0.91	0.6	-0.8	3.7	3.4	9.7

Weights of sensor z position relaxed to minimize correlation with self calibration parameters (focal length)

DJI PHANTOM 4 PRO

Pix4D AT Results (5 Control Points)

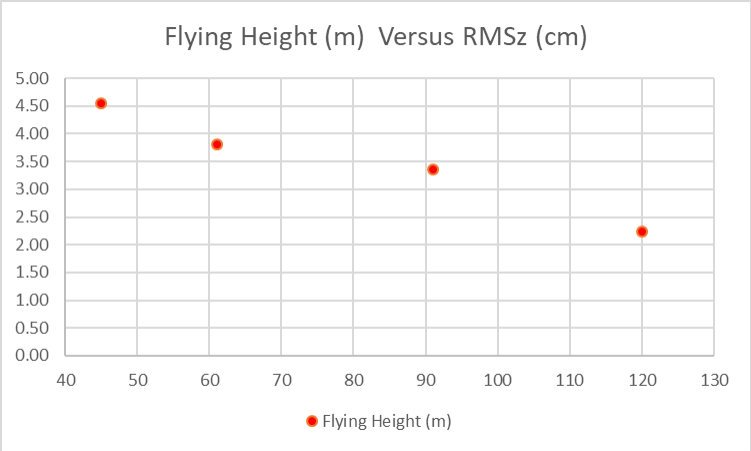
Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
H1	120	3.4	76.5	65.9	113	25	1.16	1.26	2.24	1.72	1.2	1.2	2.0	1.7	0.2	-0.3	1.1	3.4	4.3	9.1
H2	91	2.5	78.1	71.4	190	25	1.61	1.46	3.35	2.18	1.5	1.2	3.2	2.0	0.7	-0.8	1.2	6.7	4.9	15.8
H3	61	1.7	75.0	65.4	407	25	1.94	1.43	3.81	2.41	1.9	1.1	3.4	2.2	0.5	-1.0	1.9	7.3	4.8	15.8
H4	45	1.2	73.1	63.4	700	25	1.21	1.27	4.55	1.75	1.2	1.2	4.6	1.7	0.1	-0.6	0.5	4.2	6.5	24.7

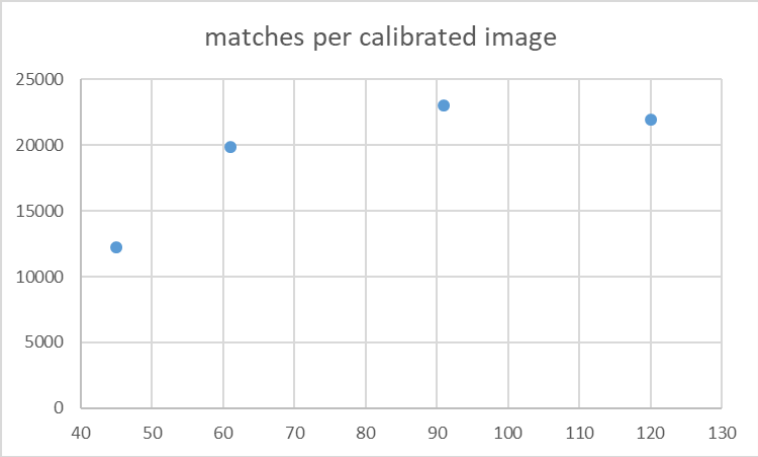
PhotoScan AT Results (5 Control Points)

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
H1	120	3.4	76.5	65.9	113	25	1.04	1.29	2.59	1.66	1.1	1.2	2.0	1.6	0.2	-0.6	1.7	3.3	4.3	7.4
H2	91	2.5	78.1	71.4	190	25	1.35	1.20	2.81	1.81	1.2	1.0	2.7	1.6	0.6	-0.7	0.9	5.0	4.3	12.7
H3	61	1.7	75.0	65.4	407	25	0.98	1.14	3.21	1.51	1.0	1.0	2.9	1.4	0.0	-0.6	1.5	3.4	4.2	14.6
H4	45	1.2	73.1	63.4	700	25	0.70	1.23	4.45	1.42	0.7	1.0	4.4	1.2	-0.1	-0.8	0.9	3.0	4.1	24.4

DJI PHANTOM 4 PRO ANALYSIS

- Single Frequency (L1)
- Matches per calibrated image increases with flying height !!!
- RMSz increases with Flying height !!!
  - Causes
    - Ground texture
    - Flat terrain with self calibration
  - Need to be investigated further
  - Both Pix4D and PhotoScan shows the same behavior
- Noisy results
- H4 does not meet Caltran spec





GENERAL NOTES FOR AT RESULTS

- All runs converged using 5 ground control points with 75 check points (CP) for site 1 and 25 points for site 2.
- Camera self-calibration (focal length, principal point, k1,k2,k3,P1,P2) was used in all runs.
- Mission A to G
  - Results are for ground sampling distance (GSD) 2.0 – 2.5 cm.
  - Pix4D RMSxy were between 0.8 and 1.91 cm.
  - PhotoScan RMSxy were between 0.8 and 2.94 cm.
  - RMSz were between 0.75 and 1.71 cm for Pix4D
  - RMSz were between 1.25 and 3.30 cm for PhotoScan
  - These results provide a comfortable safety factor for the targeted specification using Pix4D.
- Missions A and D shows similar results. These missions were flown with different SenseFly systems and on different dates. They also shows a small forward lap.

GENERAL NOTES FOR AT RESULTS

- The results do not show statistically different results when flown in different directions.
- Orthogonal flights did not contribute to the accuracy.
- Missions H1 to H4 are flown on a flat agricultural land with a single frequency (L1) GPS. The missions show increasing accuracy as the flying height increases in both software. The texture of the land might be causing this. Further research is needed to verify these results. Missions H1 to H4 show high error range that will cause a doming effect in the block.

Aerial Triangulation and Ground Control Accuracy Requirements, Orthoimagery and/or Planimetric Data Only And Elevation Data					
Product Accuracy (RMSEx, RMSEy) (cm)	Product Accuracy (RMSEz) (cm)	A/T Accuracy		Ground Control Accuracy	
		RMSEx and RMSEy (cm)	RMSEz (cm)	RMSEx and RMSEy (cm)	RMSEz (cm)
17.8	9.3	8.9	4.6	4.5	2.3

ORTHOMOSAIC

- A 2.5cm orthomosaic was created using the AT results
  - Pix4D
  - PhotoScan
  - 22 orthomosaic
- 2D check points (CP) coordinates were measured and compared with the surveyed coordinates.

PIX4D ORTHOMOSAIC ACCURACY

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
A1-1	114	2.59	77.3	76.4	586	75	1.08	1.18	2.21	0.82	1.1	1.2	1.5	0.9	0.1	-0.1	-1.6	5.6	6.5	10.8
A1-2			51.8	76.4	293	75	1.27	1.13	2.17	0.87	1.3	1.1	1.5	0.8	-0.1	-0.4	-1.6	6.1	5.2	8.9
A1-3			52.1	77.3	293	75	1.51	1.56	2.65	0.97	1.5	1.5	1.6	1.1	0.2	-0.3	-2.1	7.8	8.5	9.4
B1	75	2.1	89.7	86.8	837	75	1.96	1.17	1.25	1.01	1.2	1.2	1.2	1.0	1.6	0.0	-0.5	5.8	5.2	5.6
B2	75	2.0	89.5	86.0	881	75	1.14	1.01	1.89	0.81	1.0	0.9	1.1	0.8	-0.6	0.4	-1.5	5.2	4.8	5.4
B3	75	2.0	89.45	89.7	1718	75	1.3	1.1	1.6	0.9	1.1	1.1	1.2	0.8	0.7	0.1	-1.1	5.6	5.8	5.3
D1	84	1.9	59.8	84.5	488	75	1.53	1.20	1.48	0.92	1.5	1.2	1.3	1.0	0.2	-0.3	-0.8	7.4	5.5	5.6
D2	84	1.9	60.0	80.4	465	75	1.13	0.93	1.58	0.81	1.1	0.9	1.3	0.7	0.1	-0.1	-0.9	6.0	4.4	5.9
D3	84	1.9	80.4	84.5	953	75	1.14	0.98	1.65	0.82	1.1	0.9	1.2	0.7	0.3	-0.3	-1.2	5.3	4.0	5.5
E1	69	1.9	86.1	85.3	801	75	1.85	1.61	2.63	1.05	1.8	1.6	1.9	1.1	-0.6	-0.1	-1.8	8.2	7.3	10.1
F1	105	2.4	78.6	78.2	709	75	1.40	1.51	2.51	0.96	1.3	1.4	2.5	1.0	0.6	-0.7	0.2	6.2	6.4	14.7

PHOTOSCAN ORTHOMOSAIC RESULTS

Mission	Flying Height (m)	GSD (cm)	Lap		Photos	CP	RMSE (cm)				Std (cm)				Avg (cm)			Range (cm)		
			For	Side			x	y	z	xy	x	y	z	xy	x	y	z	x	y	z
A1-1	114	2.59	77.3	76.4	586	75	1.60	2.35	3.63	1.14	1.5	1.6	1.2	1.2	-0.5	1.7	-3.4	6.2	7.0	5.6
A1-2			51.8	76.4	293	75	1.88	1.78	1.29	1.09	1.8	1.4	1.1	1.0	-0.5	1.1	-0.7	7.7	6.1	5.0
A1-3			52.1	77.3	293	75	1.71	2.33	1.72	1.14	1.7	1.9	1.4	1.3	0.0	1.4	-1.0	8.5	9.3	6.6
B1	75	2.1	89.7	86.8	837	75	1.34	1.27	3.27	0.92	1.1	1.1	1.0	0.8	0.8	0.7	-3.1	4.6	5.5	4.2
B2	75	2.0	89.5	86.0	881	75	1.29	1.75	1.69	0.99	1.2	1.2	1.3	1.0	0.4	1.3	-1.1	5.7	6.5	6.2
B3	75	2.0	89.45	89.7	1718	75	1.3	1.3	3.3	0.9	1.1	1.1	1.0	0.8	0.8	0.7	-3.1	4.6	5.5	4.2
D1	84	1.9	59.8	84.5	488	75	2.01	1.09	1.72	1.01	1.5	1.0	1.6	1.1	-1.3	0.4	0.8	7.3	6.2	7.6
D2	84	1.9	60.0	80.4	465	75	1.87	2.24	1.98	1.17	1.8	1.2	1.2	1.1	0.7	1.9	1.6	10.2	5.7	6.4
D3	84	1.9	80.4	84.5	953	75	1.10	2.90	3.90	3.10	1.1	1.2	1.4	1.6	-0.3	2.7	-3.6	5.7	5.2	8.1
E1	69	1.9	86.1	85.3	801	75	2.05	1.14	2.36	1.03	1.5	1.1	1.9	1.1	-1.4	0.5	-1.5	7.6	6.3	8.0
F1	105	2.4	78.6	78.2	709	75	2.60	1.59	2.84	1.18	2.1	1.5	2.0	1.3	-1.6	-0.7	-2.0	8.5	8.0	8.4

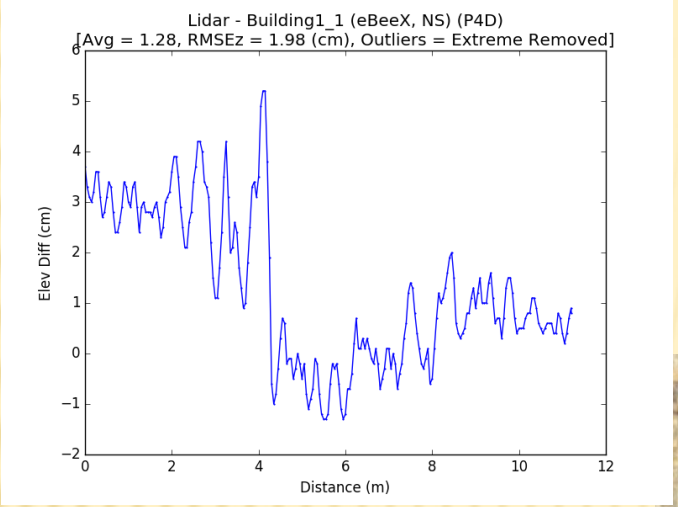
ORTHOMOSAIC SAMPLE

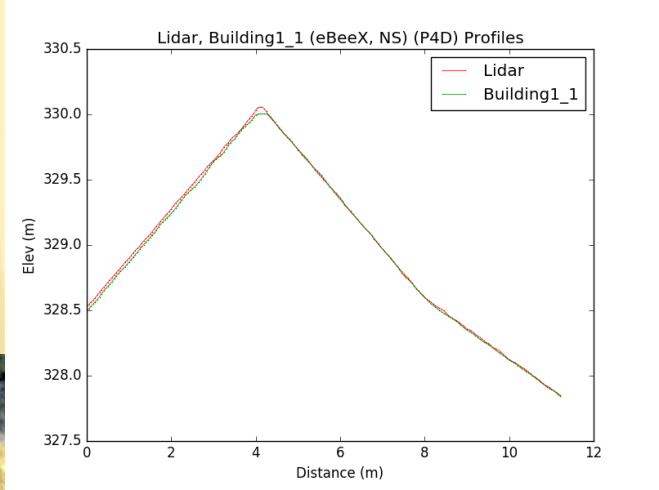
POINT CLOUD

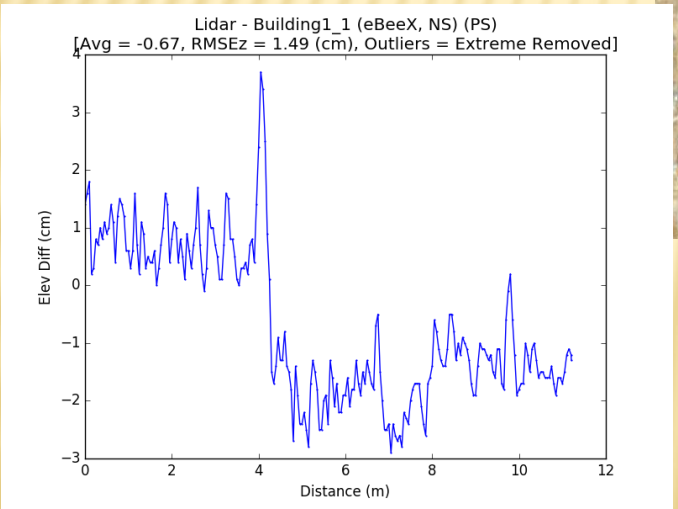
- A 5 cm DTM created from sUAS imagery point cloud
- Another 5 cm DTM created from ALS data set point cloud
- Several elevation path profiles were extracted along paths over roofs and roads, including a newly-paved driveway, from the ALS and UAS DTM's and compared .

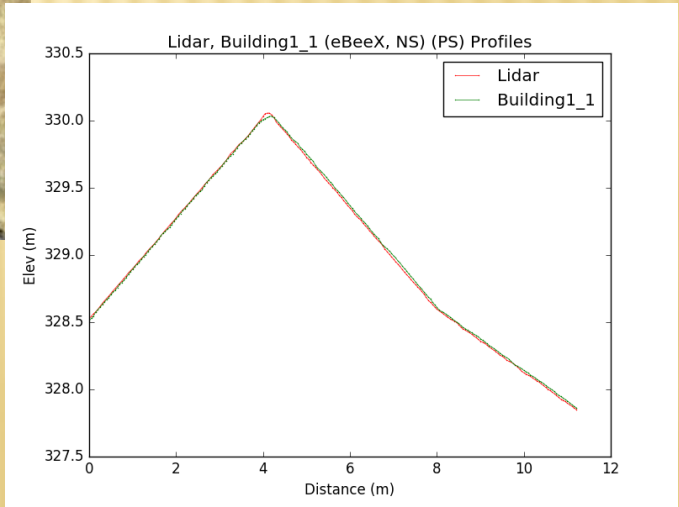
SURFACE VALIDATION ALONG PROFILES

PROFILE BUILDING 1-1

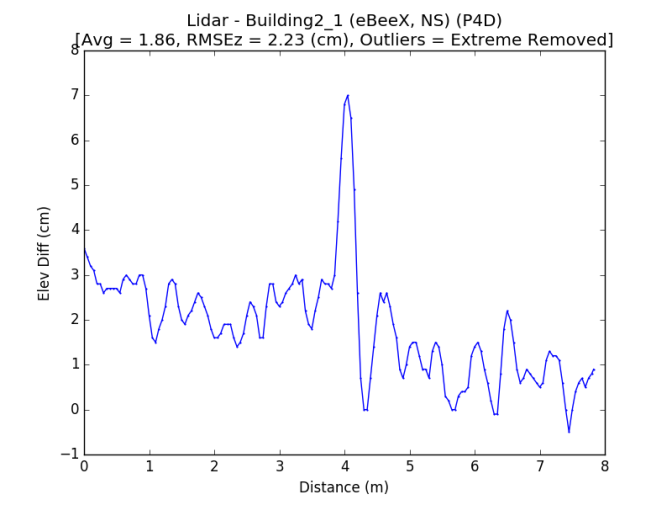


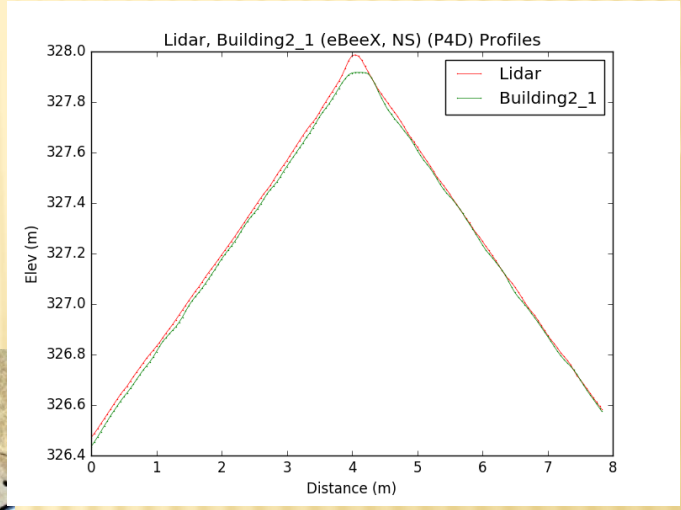


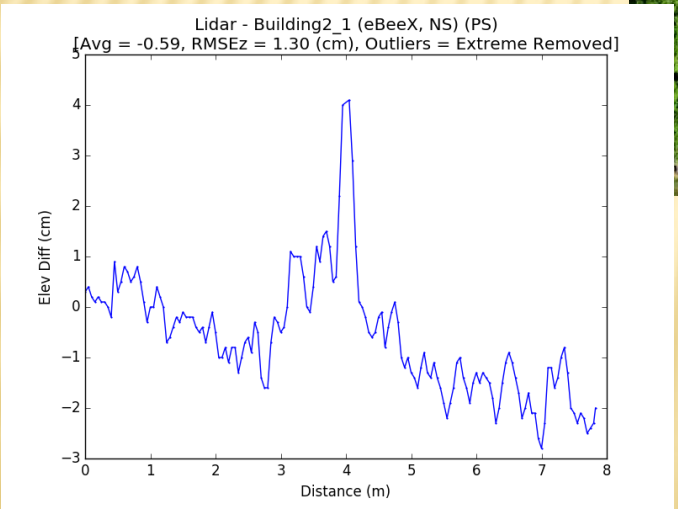


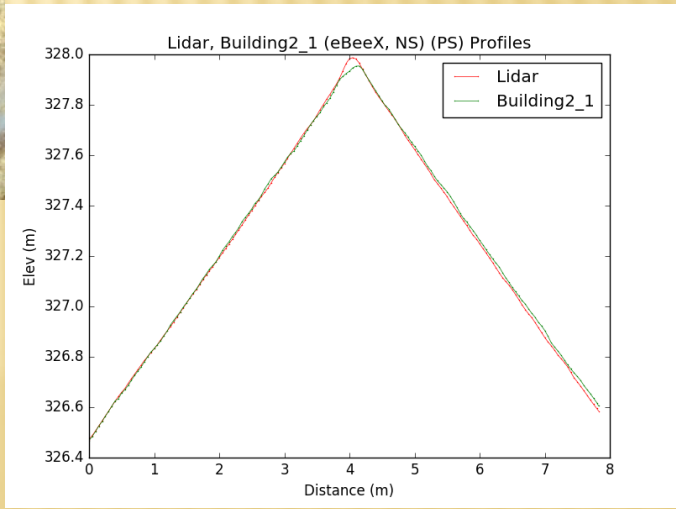


PROFILE BUILDING 2-1

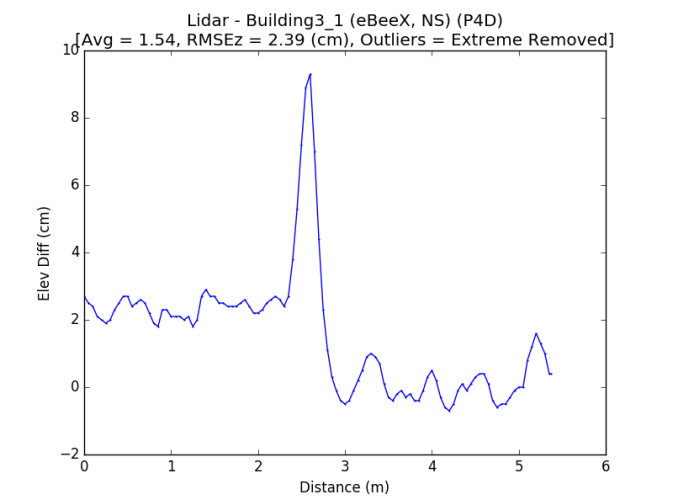


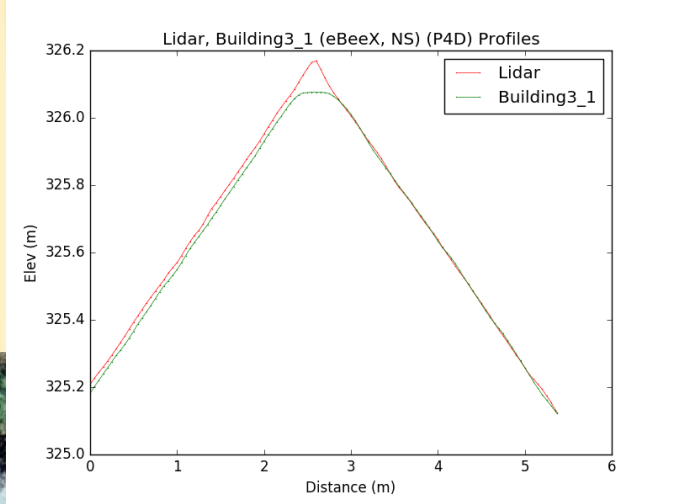


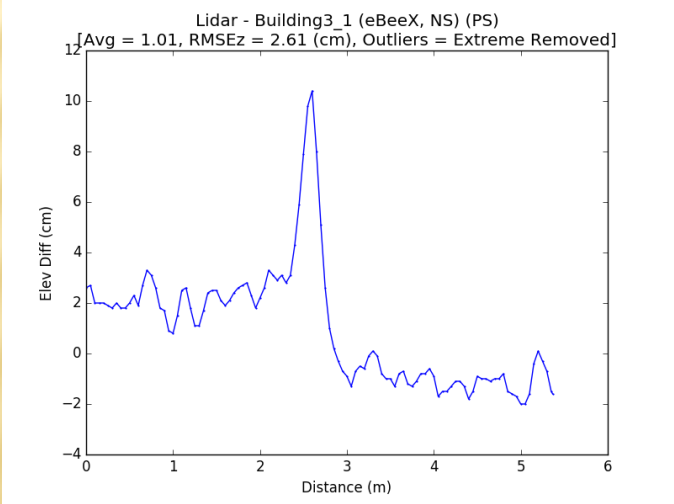


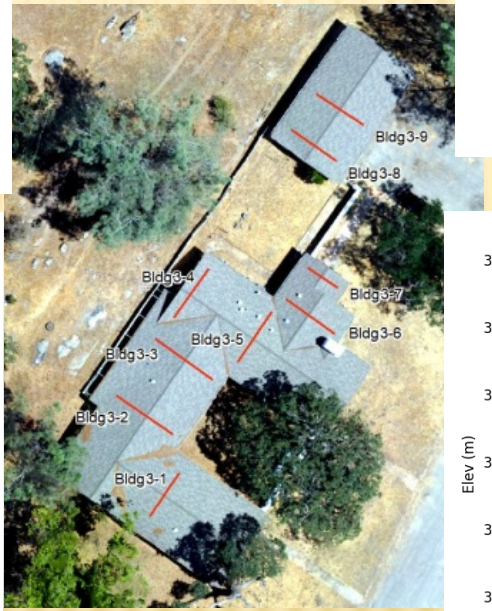


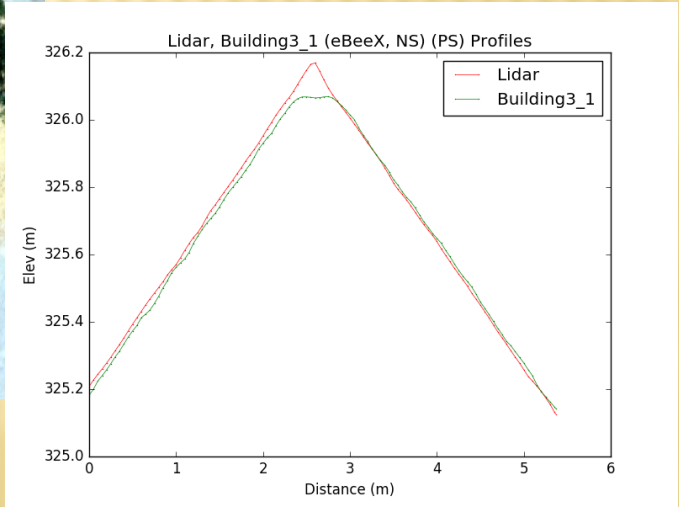
PROFILE BUILDING 3-1



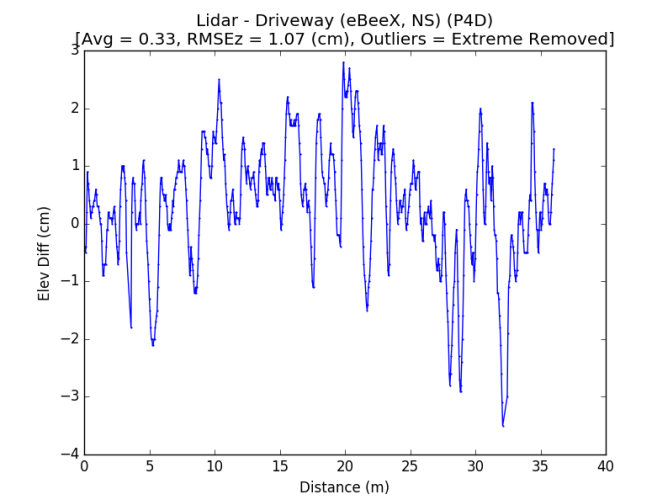


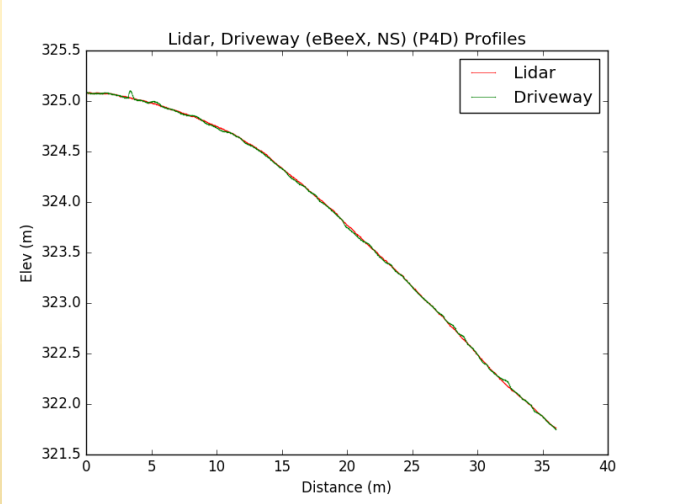


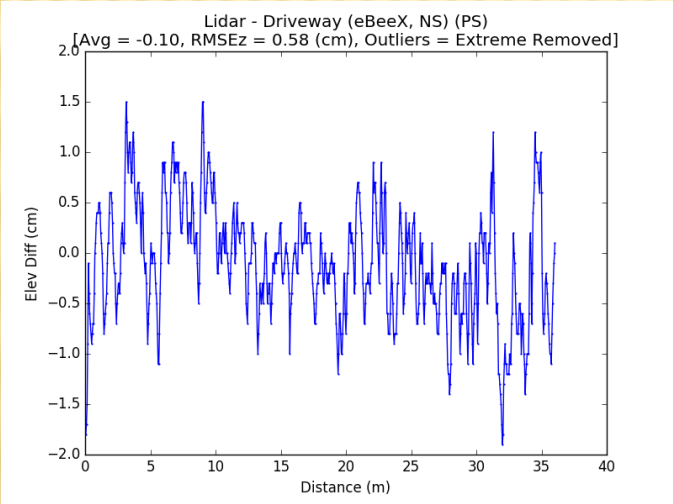


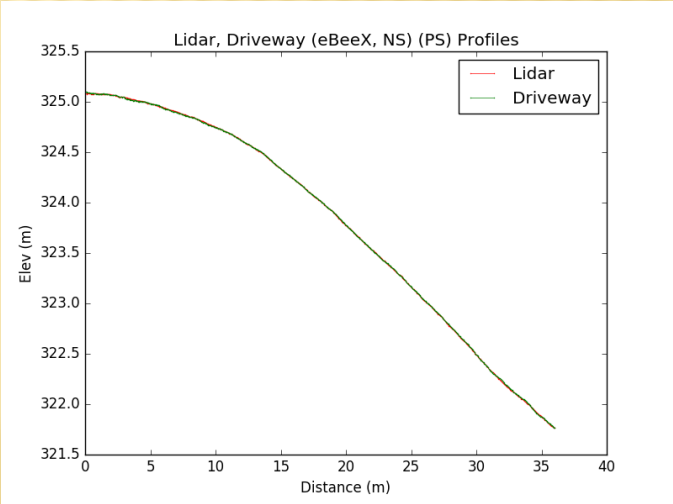


PROFILE DRIVEWAY

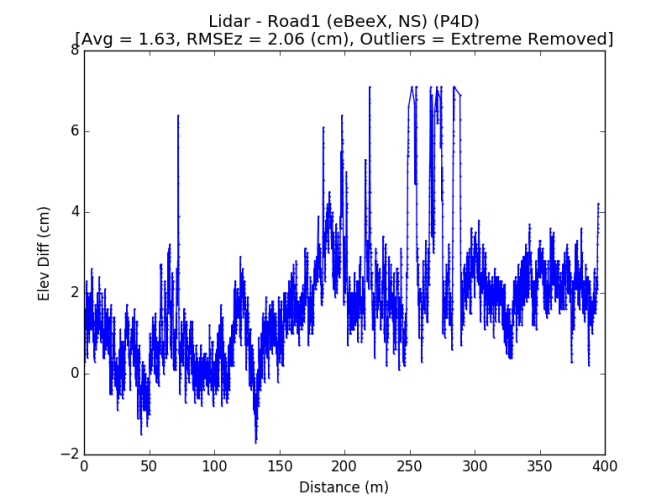


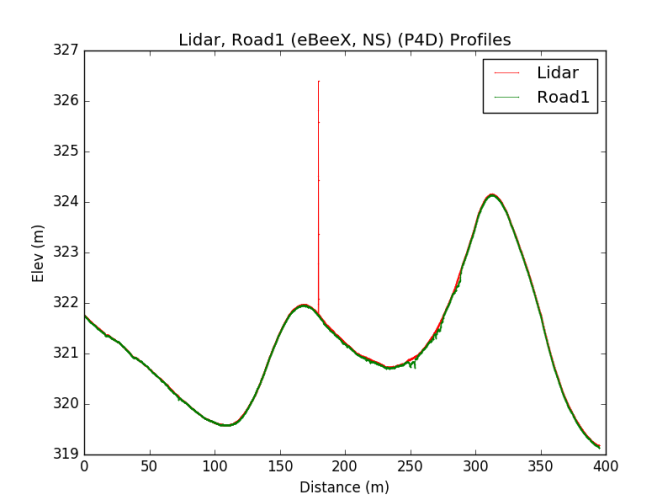


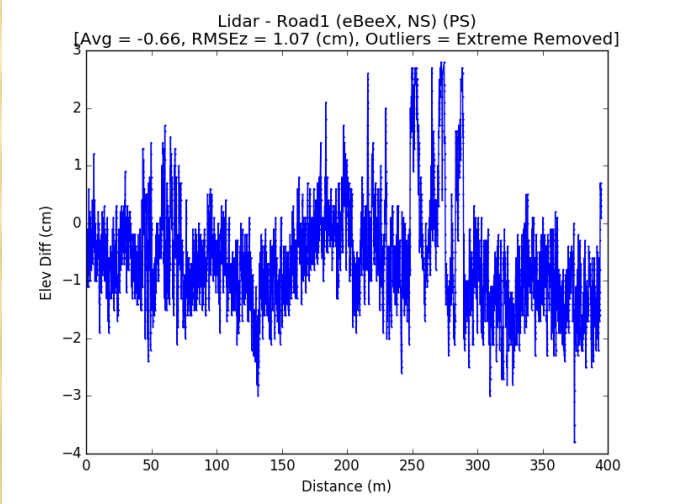


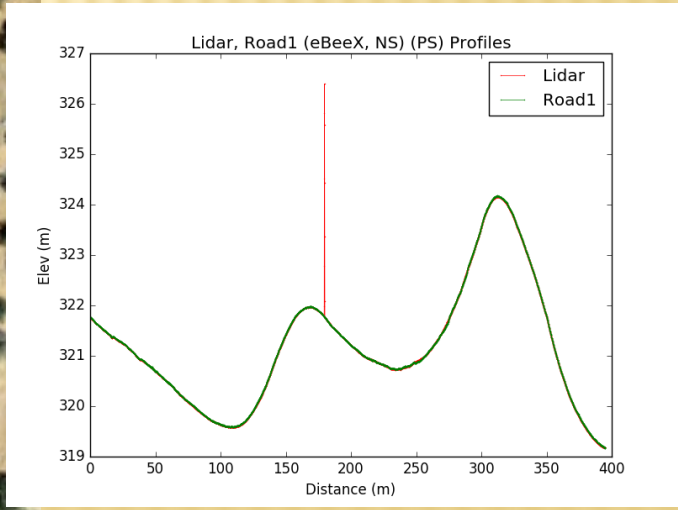


PROFILE ROAD-1

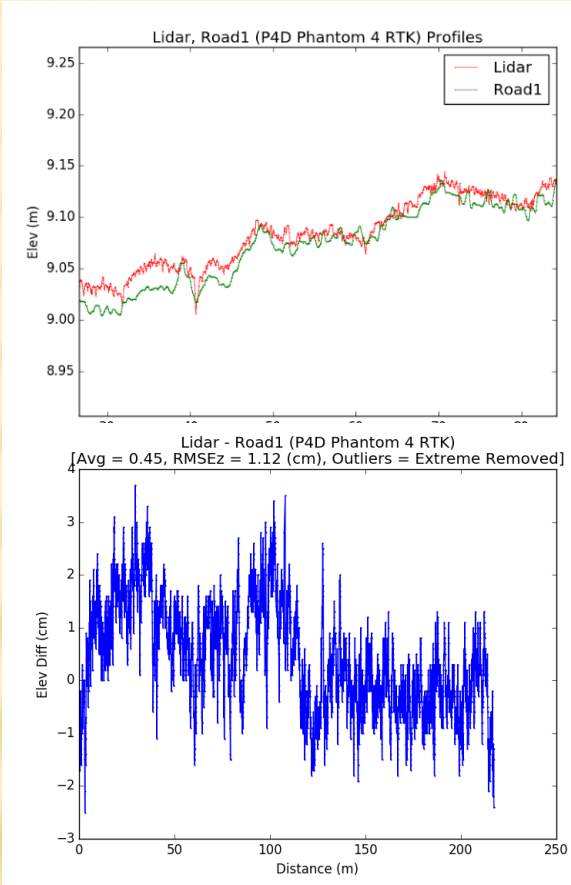


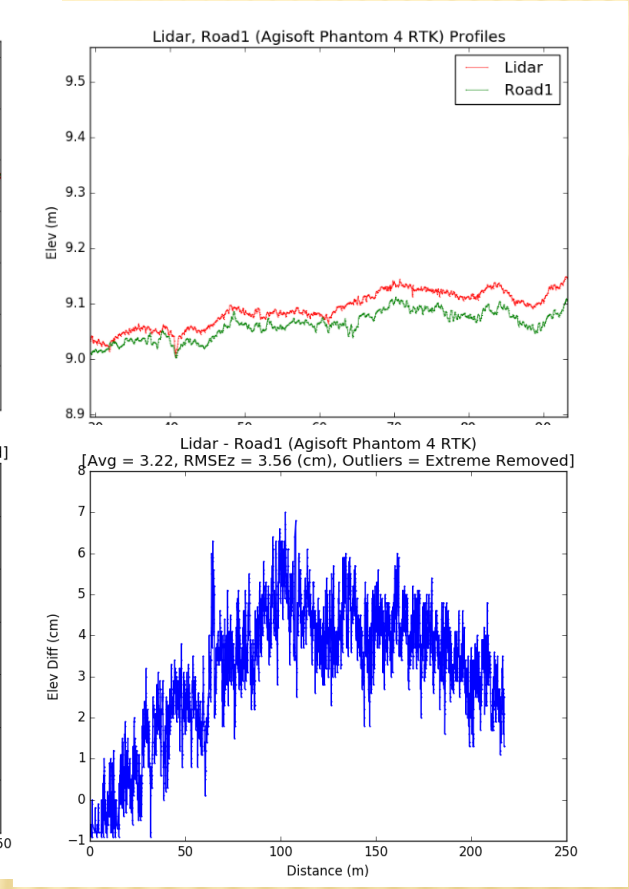






ROAD1

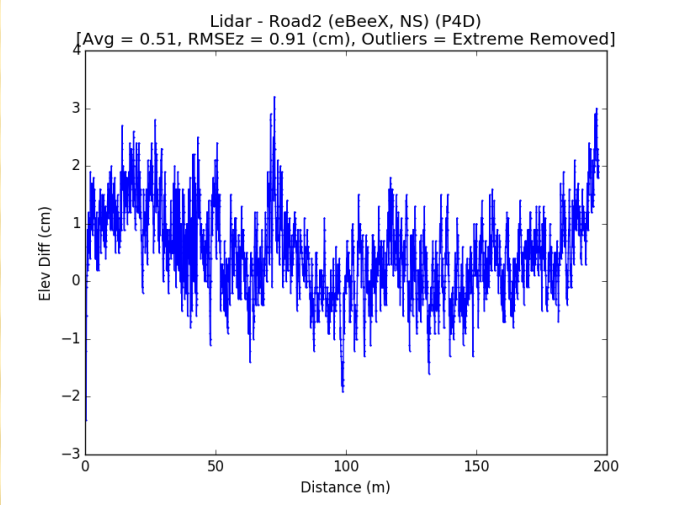


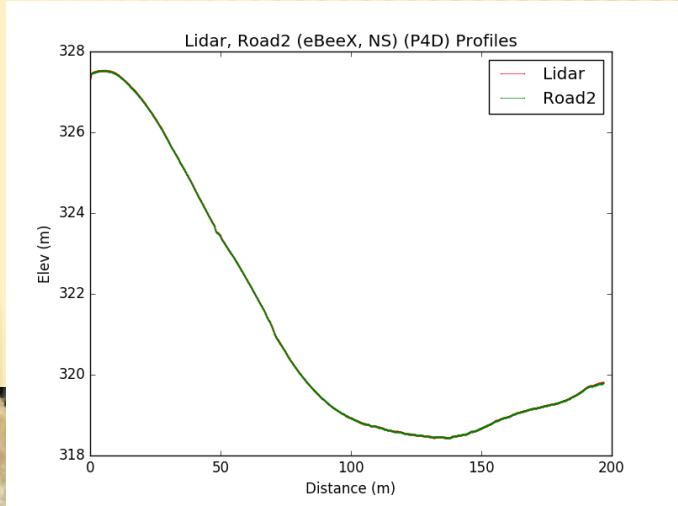


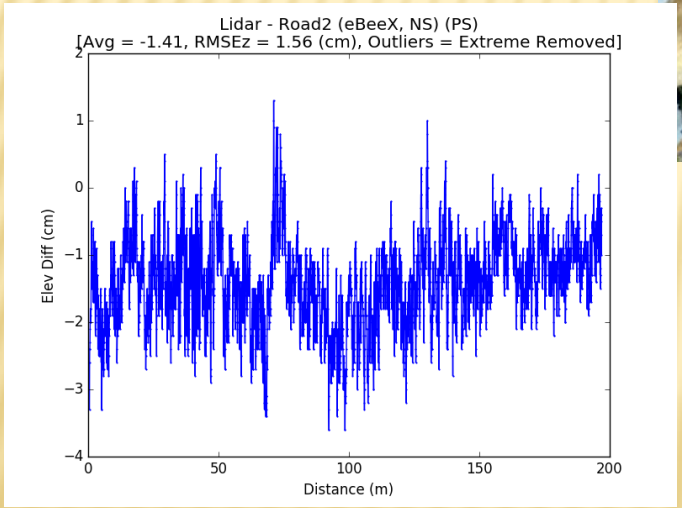
PIX4d

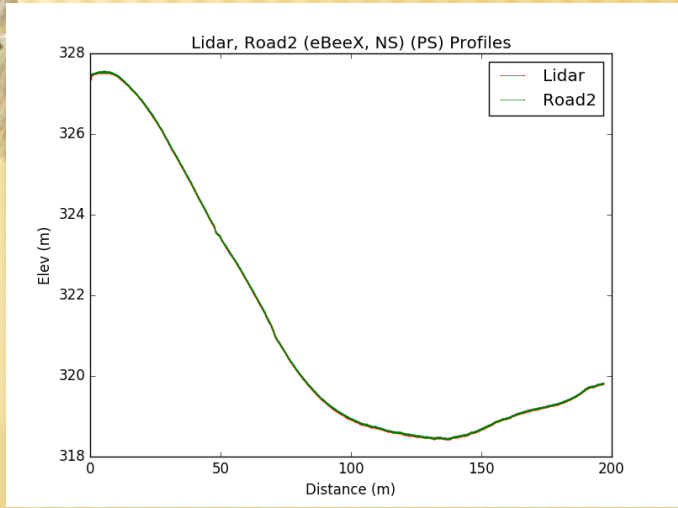
AGISOFT

PROFILE ROAD-2

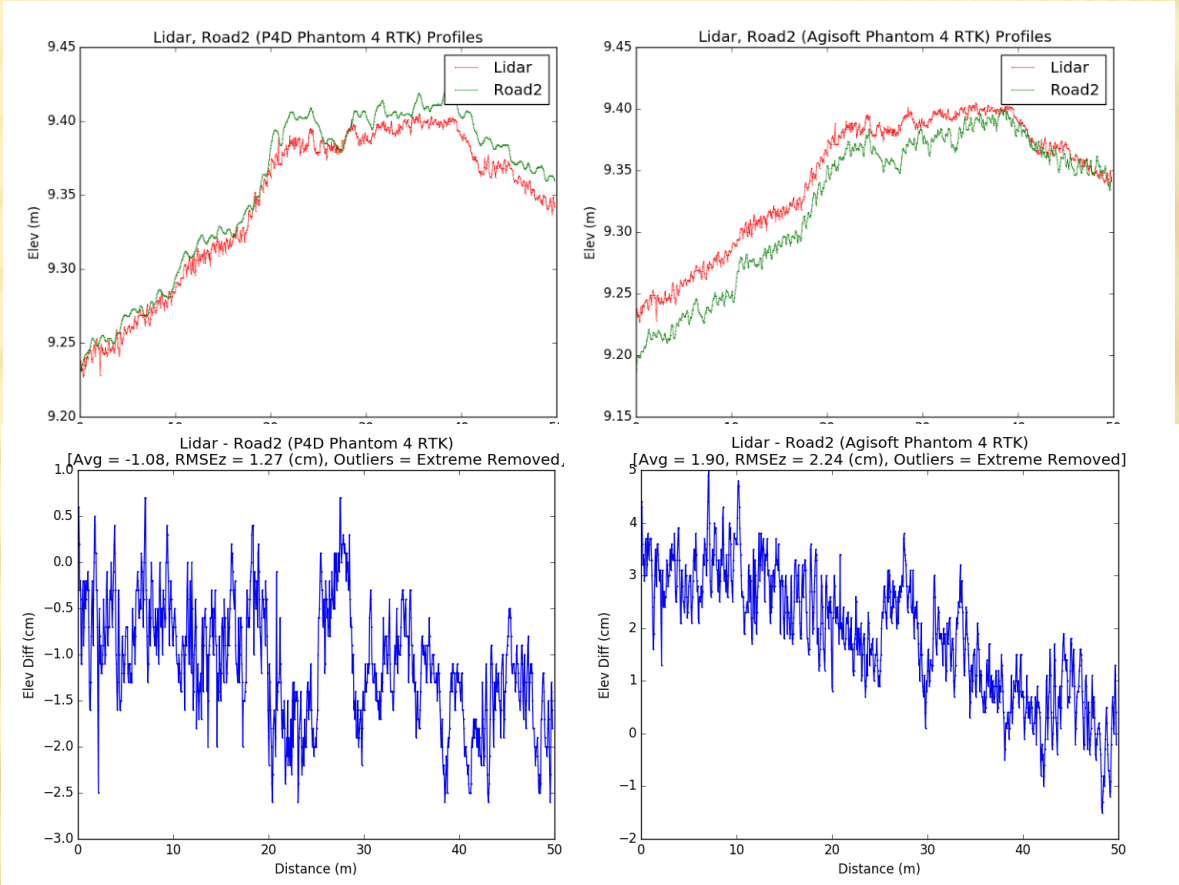








ROAD2



PIX4d AGISOFT

PIX4D PROFILE SUMMARY

Mission	Flying Height (m)	GSD (cm)	B1-1		B1-2		Driveway		Road1	
			Avg(cm)	RMSz (cm)	Avg(cm)	RMSz (cm)	Avg(cm)	RMSz (cm)	Avg(cm)	RMSz (cm)
A1-1	114	2.59	-1.6	1.8	-1.4	1.7	-0.7	1.4	-1.2	2.0
A1-2			-1.6	2.3	-0.8	2.5	-1.3	2.0	-1.3	2.1
A1-3			-0.9	1.5	-1.5	1.9	-1.1	1.7	-1.0	1.6
B1	75	2.1	-1.1	1.4	-1.3	1.5	-1.8	2.1	-0.4	1.0
B2	75	2.0	-1.5	1.9	-1.4	2.0	-2.4	2.6	-1.5	1.8
B3	75	2.0	-1.1	1.4	-1.0	1.5	-2.5	2.7	-1.1	1.6
D1	84	1.9	-0.9	1.1	-0.5	0.9	-1.2	1.9	-0.7	1.7
D2	84	1.9	-2.5	2.6	-3.2	3.3	-2.4	2.8	-0.5	1.3
D3	84	1.9	-1.9	1.9	-2.3	2.3	-2.5	2.7	-1.1	1.7
E1	69	1.9	-1.6	2.0	-1.4	1.8	-1.9	2.0	-1.5	2.7
F1	105	2.4	1.8	2.0	0.1	1.3	0.2	1.0	1.5	1.9

PHOTOSCAN PROFILE SUMMARY

Mission	Flying Height (m)	GSD (cm)	B1-1		B1-2		Driveway		Road1	
			Avg(cm)	RMSz (cm)	Avg(cm)	RMSz (cm)	Avg(cm)	RMSz (cm)	Avg(cm)	RMSz (cm)
A1-1	114	2.59	-0.6	1.0	-0.5	1.0	-0.9	1.3	0.4	1.5
A1-2			-0.5	0.7	-0.1	0.7	0.4	1.3	0.5	1.4
A1-3			-2.9	2.9	-1.7	1.9	-2.7	2.8	-2.2	2.6
B1	75	2.1	-1.6	2.0	-1.4	1.8	-1.9	2.0	-1.5	2.7
B2	75	2.0	-2.2	2.3	-2.1	2.2	-1.3	1.4	-0.7	1.5
B3	75	2.0	-1.6	2.0	-1.4	1.8	-1.9	2.0	-1.5	2.7
D1	84	1.9	1.2	1.3	0.7	0.9	1.2	1.5	1.1	2.2
D2	84	1.9	0.8	1.1	0.6	1.0	1.3	1.6	2.4	2.7
D3	84	1.9	-4.3	4.4	-4.7	4.8	4.4	4.5	-4.0	4.2
E1	69	1.9	-2.4	2.5	-2.4	2.4	-1.9	2.0	-0.8	2.4
F1	105	2.4	-0.7	1.5	-0.9	1.6	0.1	0.6	-0.7	1.1

PRELIMINARY SPECIFICATIONS FOR USING SUAS WITH AN IMAGE SENSOR TO GENERATE HIGH ACCURACY MAPPING

- Use camera with global shutter and fixed focal length
- The camera should have a well defined electronic mid exposure pulse (EMP)
- Airborne dual GPS frequency (L1 and L2) and use PPK or RTK camera positioning software
- Minimum 5 control points
- 0.5 cm planimetric and vertical accuracy
- Use Total station for horizontal control and differential leveling for vertical control

PRELIMINARY SPECIFICATIONS FOR USING SUAS WITH AN IMAGE SENSOR TO GENERATE HIGH ACCURACY MAPPING

- 80% Forward lap ± 5%
- 70% Sidelap ± 5%
- GSD of 2.5 cm or less
- Use sfm software (example Pix4D or Agisoft Metashape (PhotoScan))
- Highest accuracy will be achieved using a local base station that observes for more than two hours. Collect data for 20 mins before and after airborne data collection
- Place control outside project boundary with at least 25-m buffer
- Cover control points with at least 3 strips

SITE I (SJER) UAV LIDAR FLIGHTS

UAV LIDAR TEST FLIGHTS

Flying Parameters	
Flying Height	50
swath width	100
UAV	DJI M600 Pro
Overlap	30%
G/S (m/s)	5
Overshoot	30

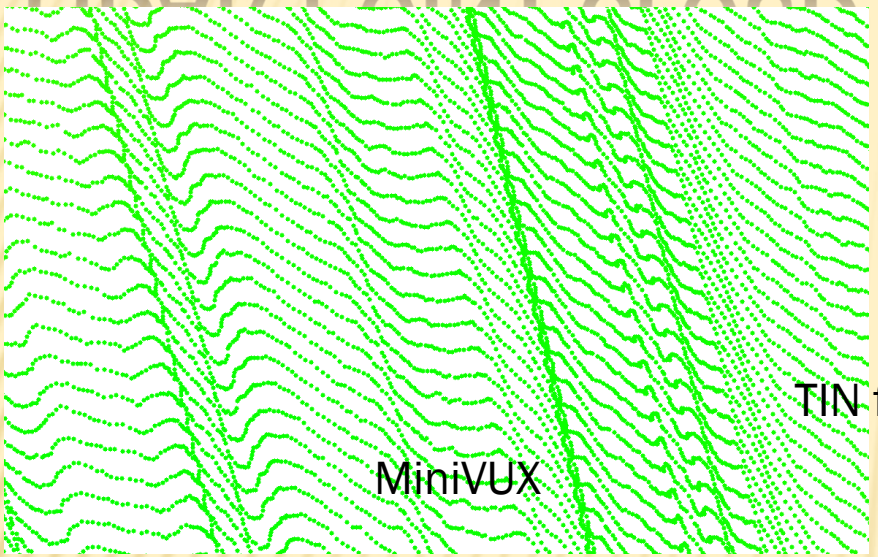
SITE I LIDAR FLIGHT PARAMETERS

LIDAR Model	Field of View (deg)		Beam Divergence (mrad)		Scan Rate (Hz)	Pulse rate (Million)	Returns	Density (pt/m^2)	Average Point Spacing (m)			Lidar Spot Size (m)	
	Horz	Vert	Horz	Vert					Average	Along Track	Cross Track	Along Track	Cross Track
Velodyne HDL32e	360	41.33 (10.67/-30.67)	3	1.2	5-20	1.39	2	392	0.05	0.05	0.05	0.12	0.30
Velodyne VLP16	360	30 (15/-15)	3	1.2	5-20	0.60	2	148	0.08	0.08	0.08	0.12	0.30
Quanergy M8	360	20 (3/-17)			5-20	1.26	3	232	0.07	0.13	0.09		
miniVUX V-series		360	1.6	0.5	100	0.10	5	50	0.14	0.35	0.11	0.05	0.16

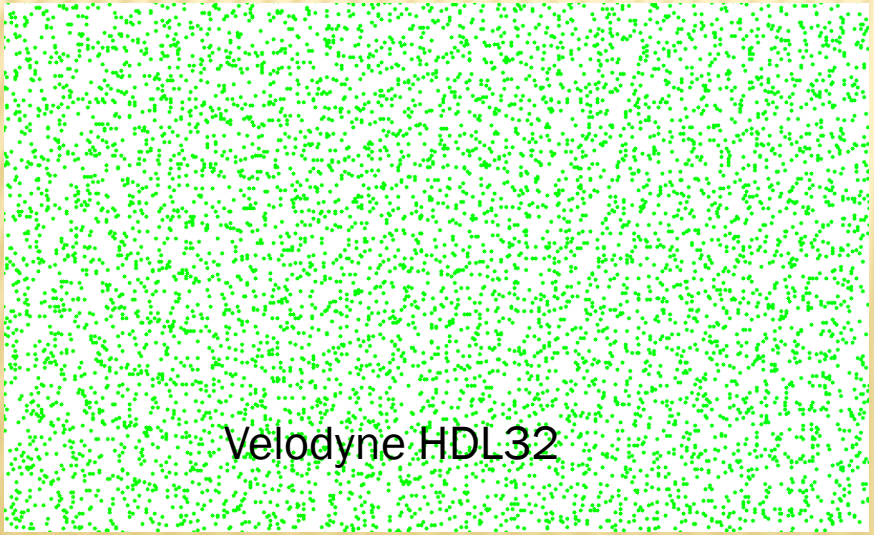
- LIDAR Spot Size > Average Point Spacing
- Multi LIDAR Beam configuration
  - LIDAR Calibration?
  - LAS Beam Tag?
- Only 75% of vertical field of view is useful

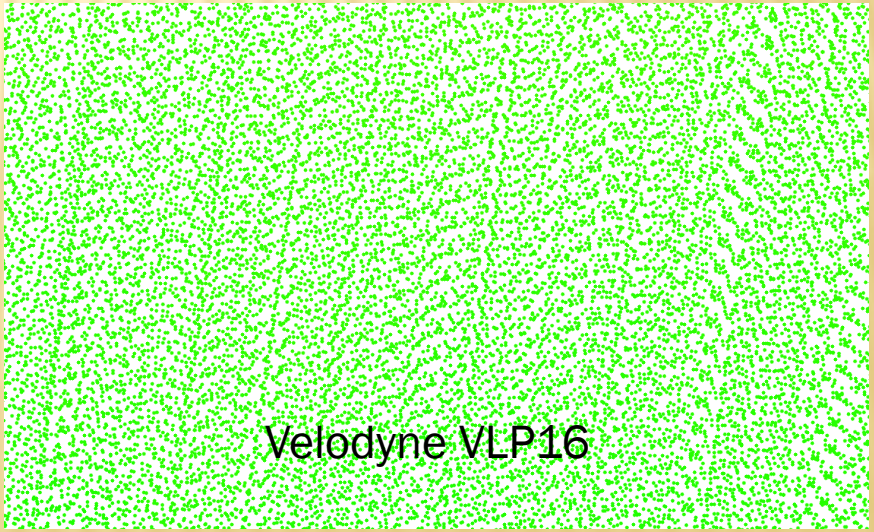
(Ref: L. Graham)

LIDAR POINT CLOUD PATTERNS



TIN formation?





SITE I LIDAR FLIGHTS RESULTS

LIDAR Model	Date	RMSE-Z (cm)	St. Err. Z (cm)	Avg-Z (cm)	Range-Z (cm)
miniVUX	3-25-2019	3.4	1.4	3.1	6.6
miniVUX	6-6-2019	8.8	2.8	-8.3	16.2
Velodyne HDL32e	6-6-2019	10.9	7.1	-8.2	30.0
Velodyne VLP16	6-6-2019	13.8	5.2	-12.8	29.2
Quanergy M8	6-6-2019	5.4	4.6	-2.9	21.6

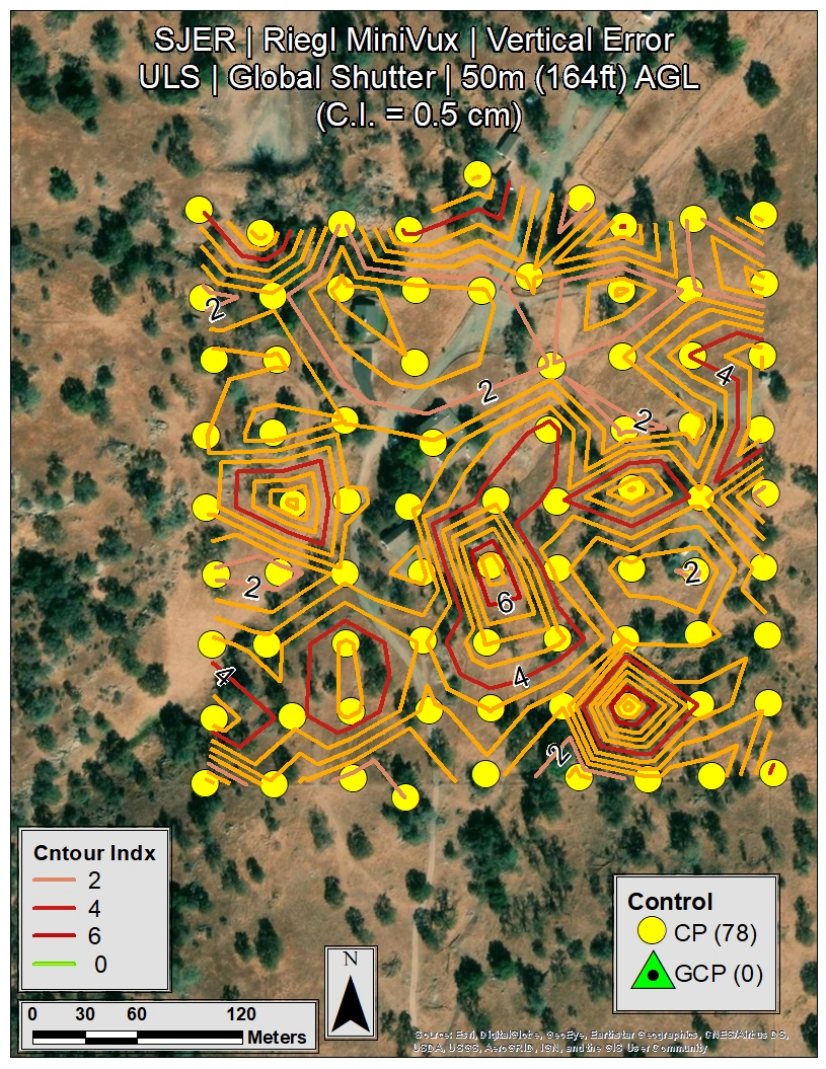
- 80 Check points
- Noisy results
- miniVUX does not show repeatability of results

ASPRS 2014 Geo-Spatial Accuracy Requirements

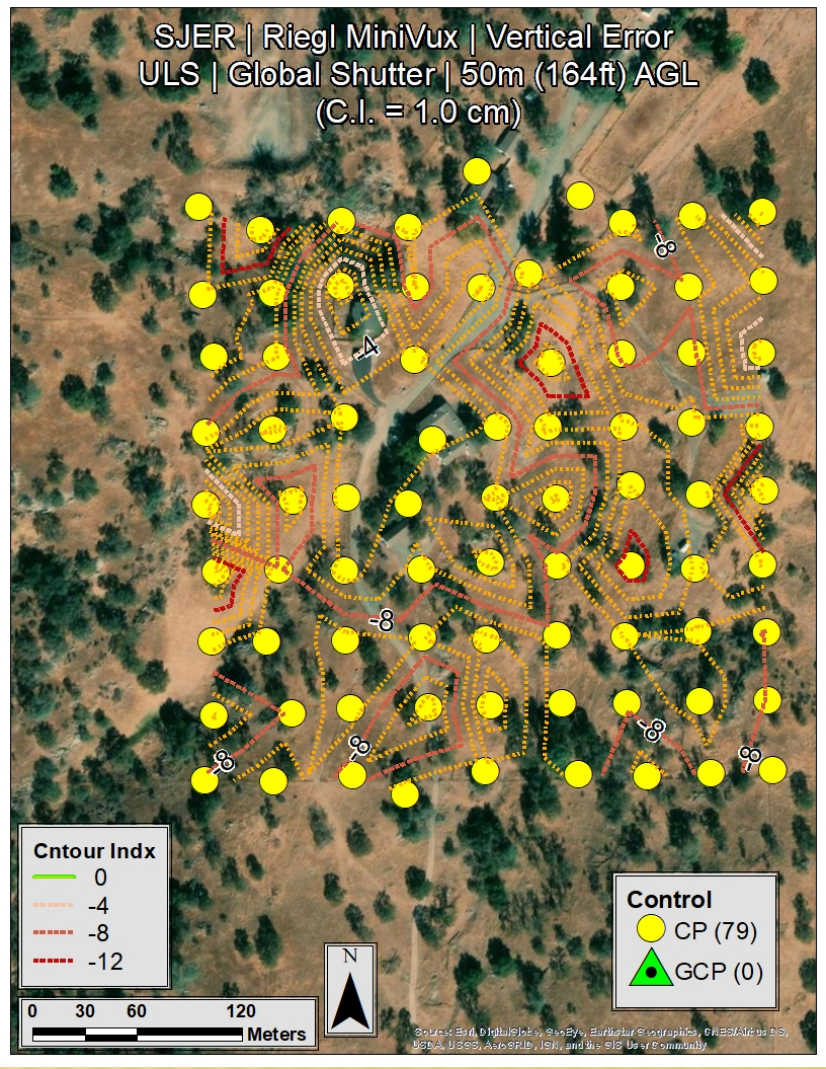
Vertical Accuracy Class (cm)	RMSEz Non-Vegetated (cm)	NVA at 95% Confidence Level (cm)	VVA at 95% (cm)
9	9.3	18.2	27.8

LIDAR POINT MINIVUX VERTICAL ERROR MAP

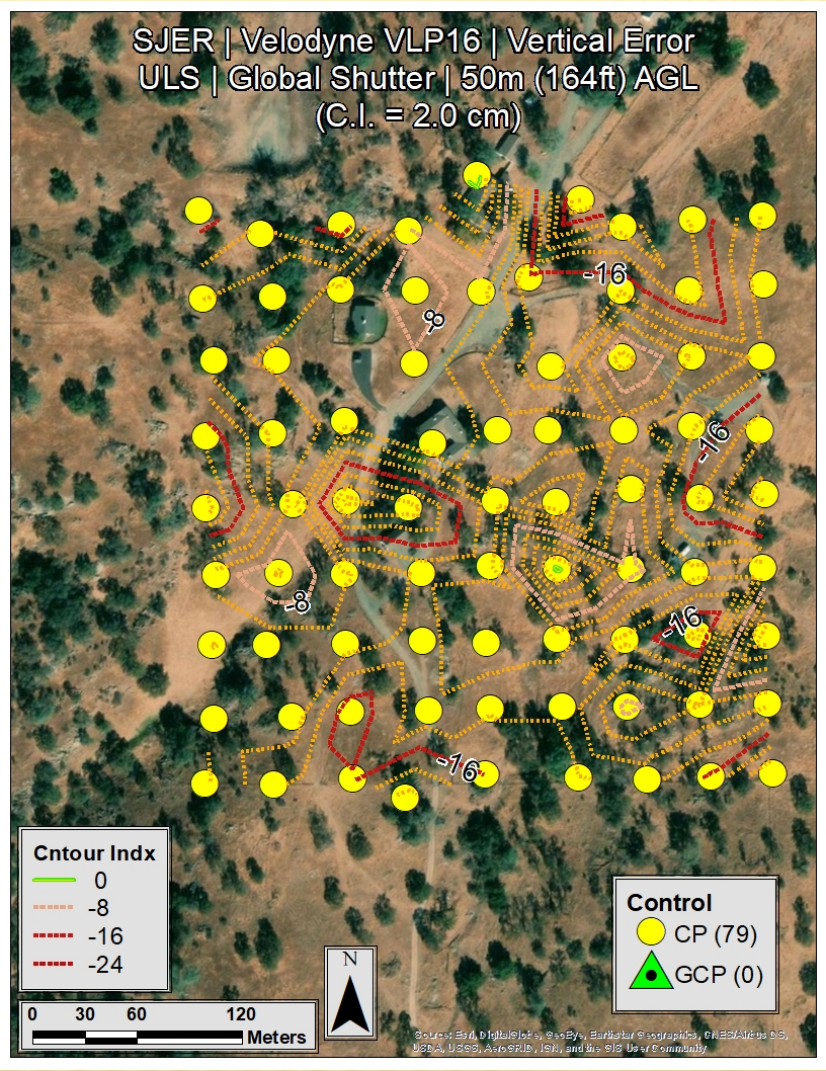
MiniVUX 3-25-2019



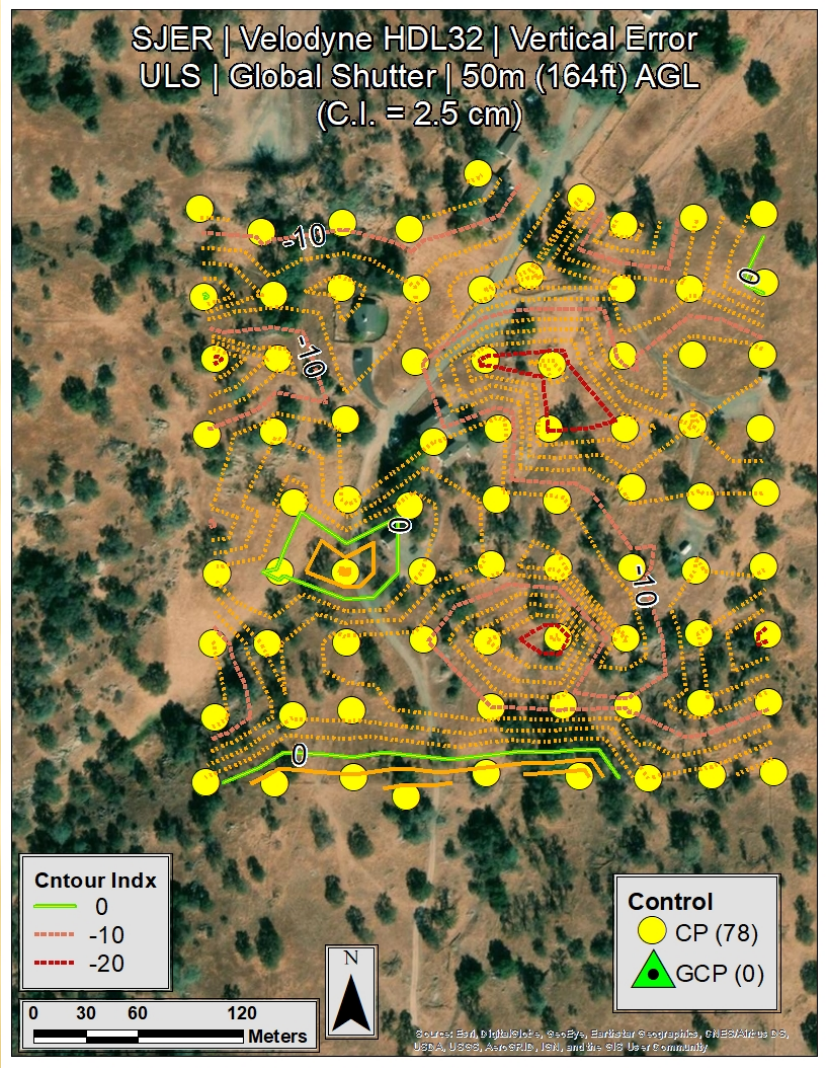
MiniVUX 6-6-2019



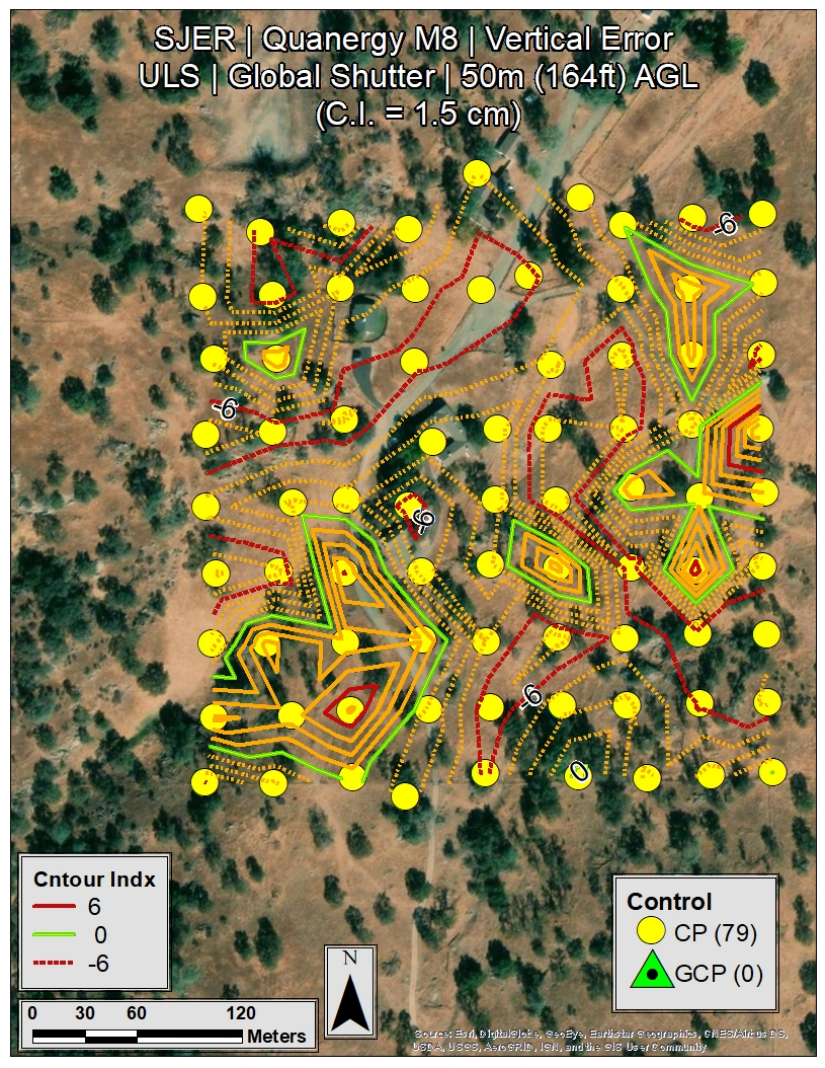
LIDAR POINT VELODYNE VLP16 VERTICAL ERROR MAP



LIDAR POINT VELODYNE HDL32 VERTICAL ERROR MAP



LIDAR POINT QUANERGY M8 VERTICAL ERROR MAP



SITE 2 CONTROL FIELD

CAL FIRE TEST SITE

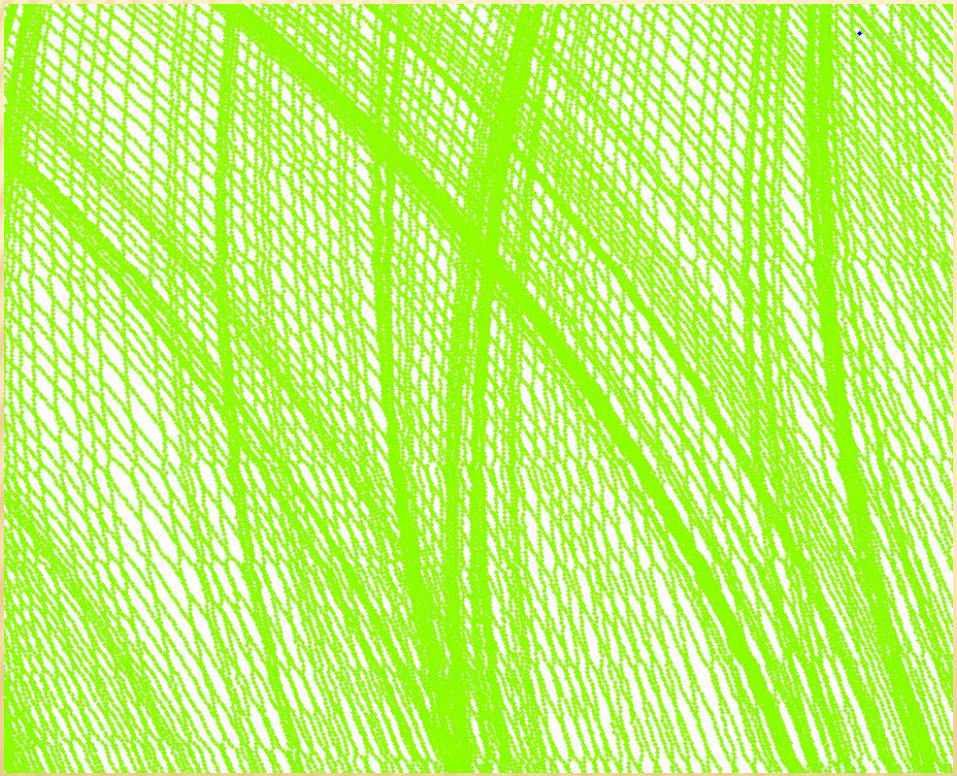
30 GCP
36 in circular B/W
5H/3V mm accuracy

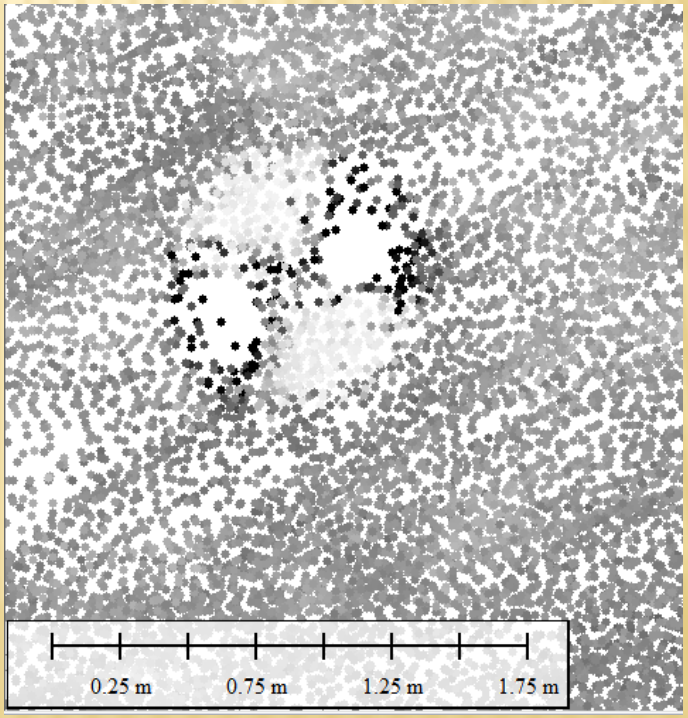
UNMANNED AERIAL SYSTEM - LIDAR

- Microdrone mdLiDAR3000DL aircraft
- Riegl miniVUX-1DL (horz 1-3cm, vert 2-4cm)
- Applanix APX-20 UAV DGL1/L2 GNSS and IMU
- Equipped with Sony RX1R II camera for co-registration and photogrammetry

MICRODRONES POINT CLOUD

- ~270 samples/ m^2
- Downward-looking circular scan pattern





ASPRS 2014 MAPPING STANDARDS

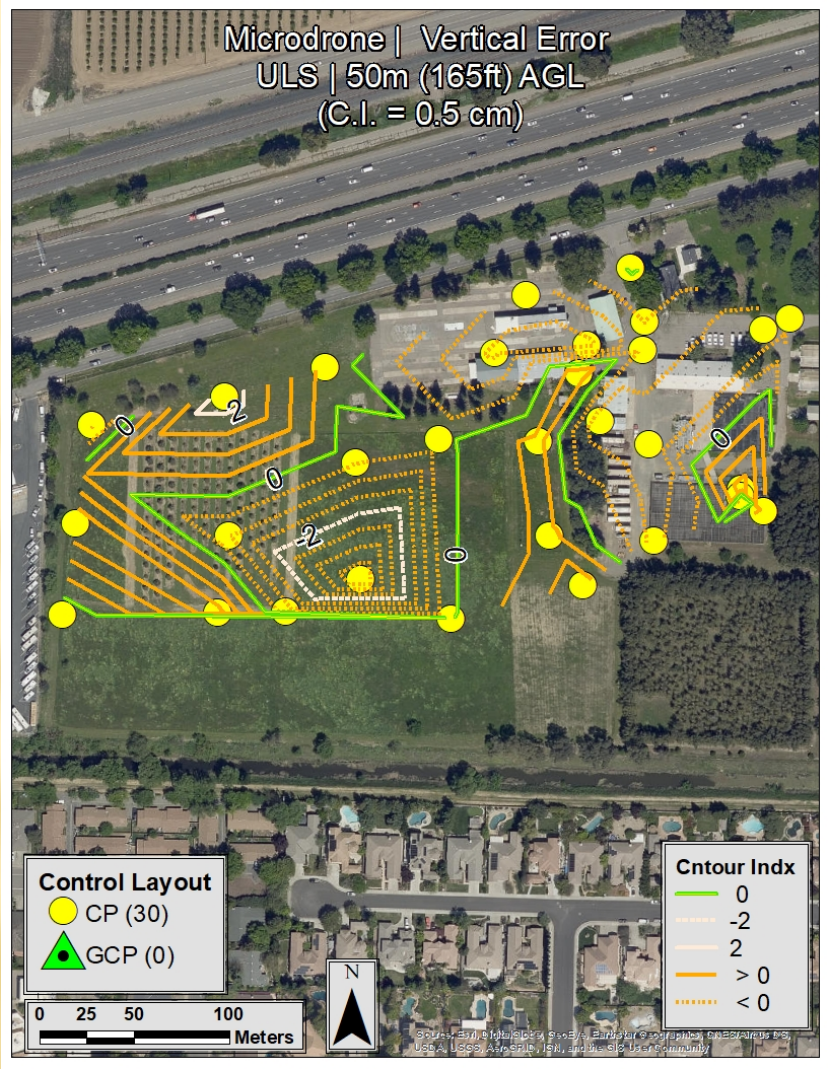
Statistic	cm
CP Sample	30
RMSEz	1.4
Std_dz	1.4
Abs Avg_dz	1.1
Avg_dz	-0.3
Median_dz	-0.5
Max_dz	2.4
Min_dz	-4.0
Range_dz	6.4

Results meets expected Caltrans standards

ASPRS 2014 Geo-Spatial Accuracy Requirements

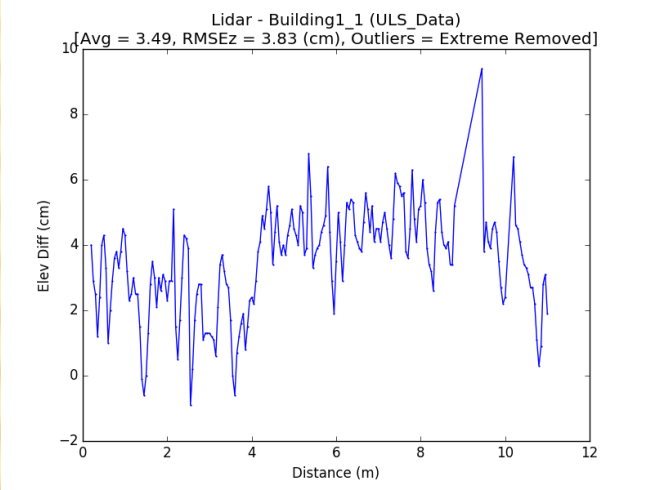
Vertical Accuracy Class (cm)	RMSEz Non-Vegetated (cm)	NVA at 95% Confidence Level (cm)	VVA at 95% (cm)
9	9.3	18.2	27.8

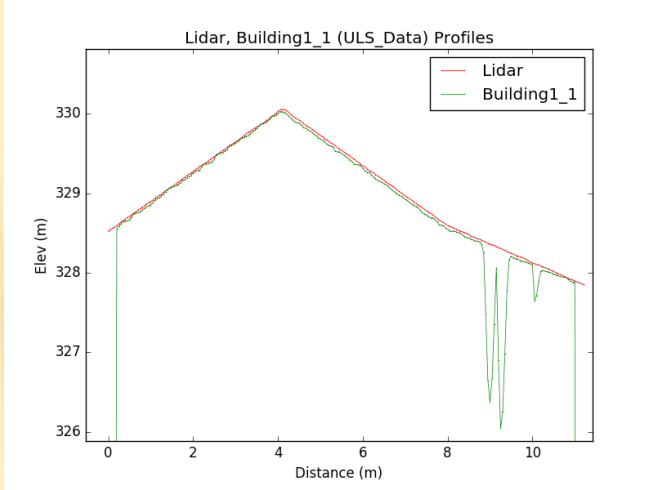
ERROR MAP

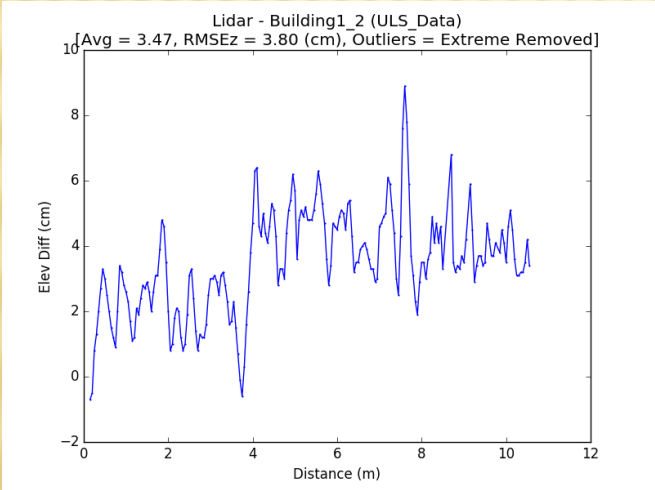

Microdrone | Vertical Error
ULS | 50m (165ft) AGL
(C.I. = 0.5 cm)
Control Layout
CP (30)
GCP (0)
0 25 50 100
Meters
N
Cntour Indx
0
-2
2
> 0
< 0

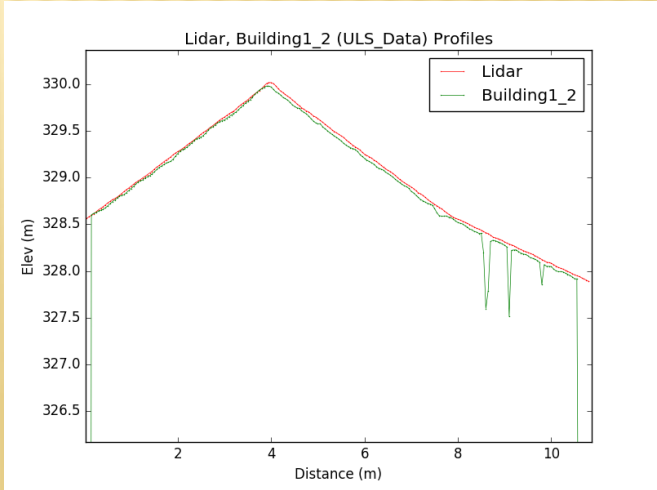
PROFILE ANALYSIS

PROFILE BUILDING 1 MINI-VUX

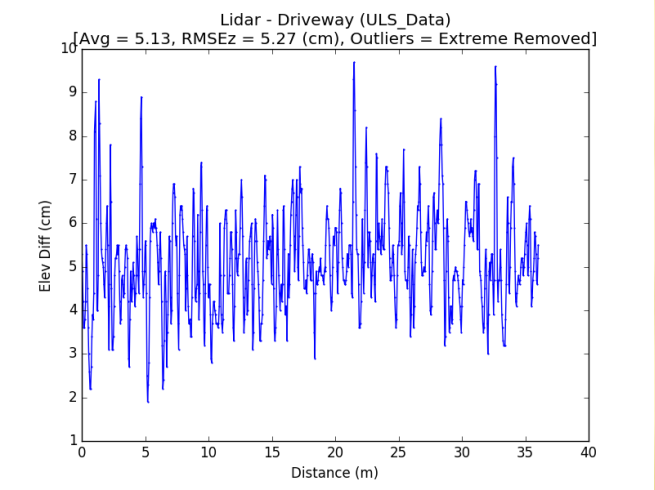


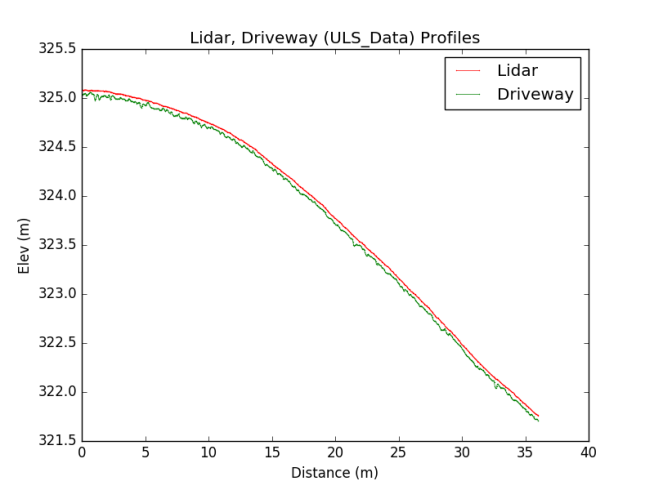




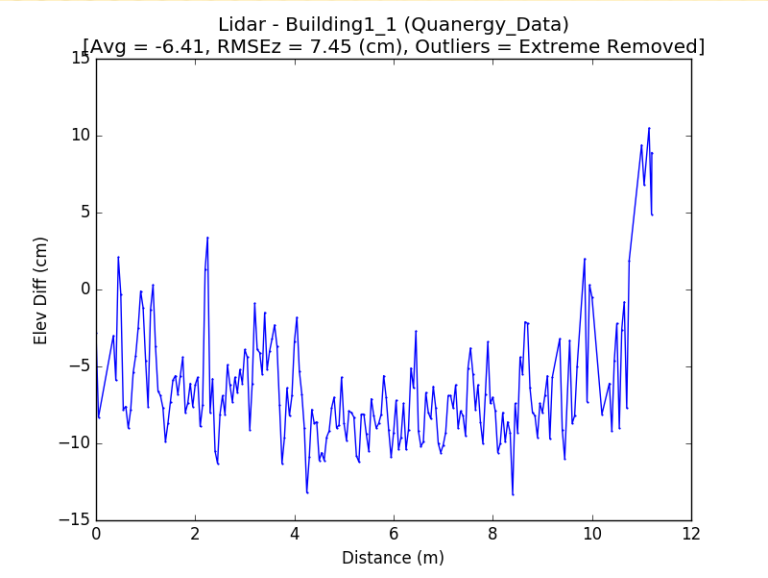


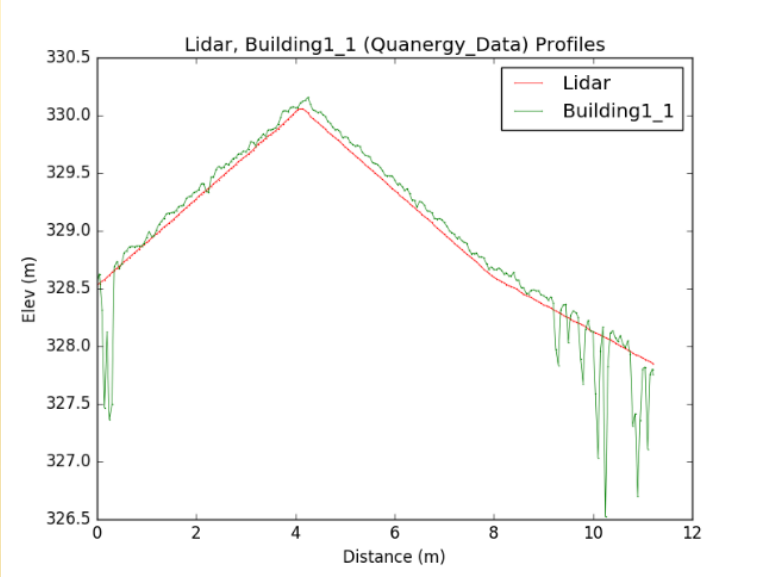
PROFILE DRIVEWAY MINI VUX



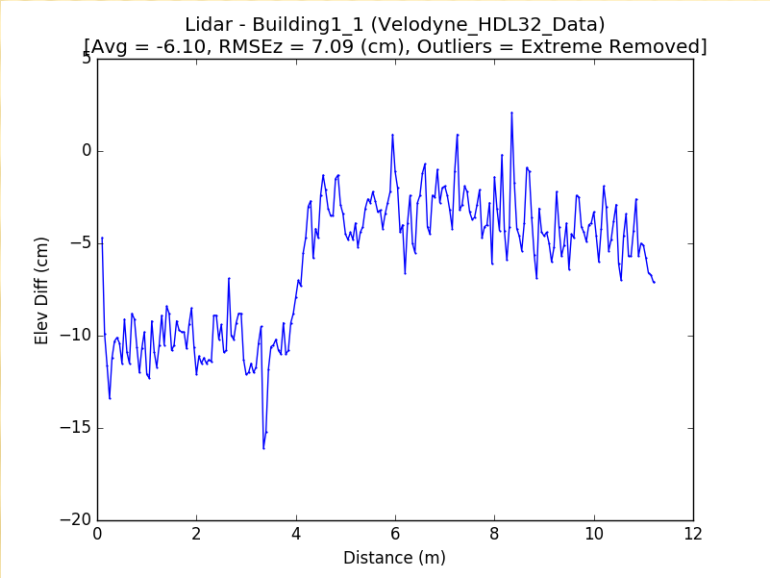


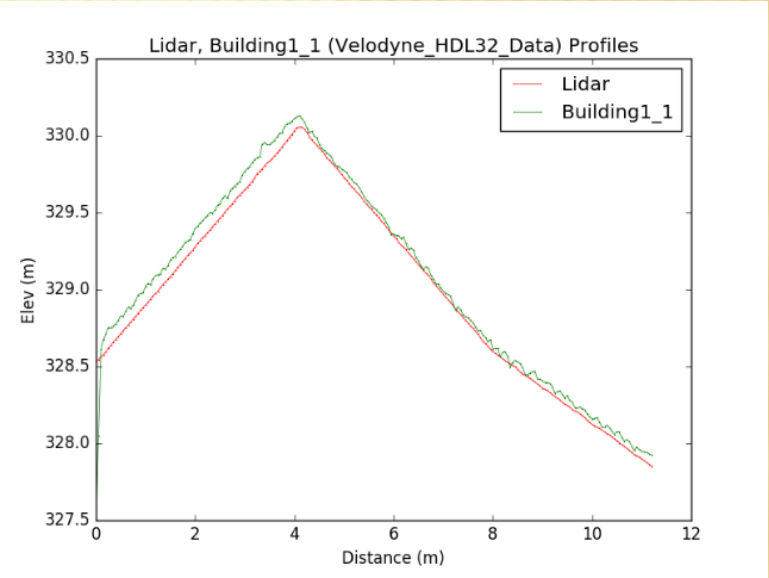
QUANERGY M8


Lidar - Building1_1 (Quanergy_Data)
[Avg = -6.41, RMSEz = 7.45 (cm), Outliers = Extreme Removed]
Elev Diff (cm)
Distance (m)
15
10
5
0
−5
−10
−15
0
2
4
6
8
10
12

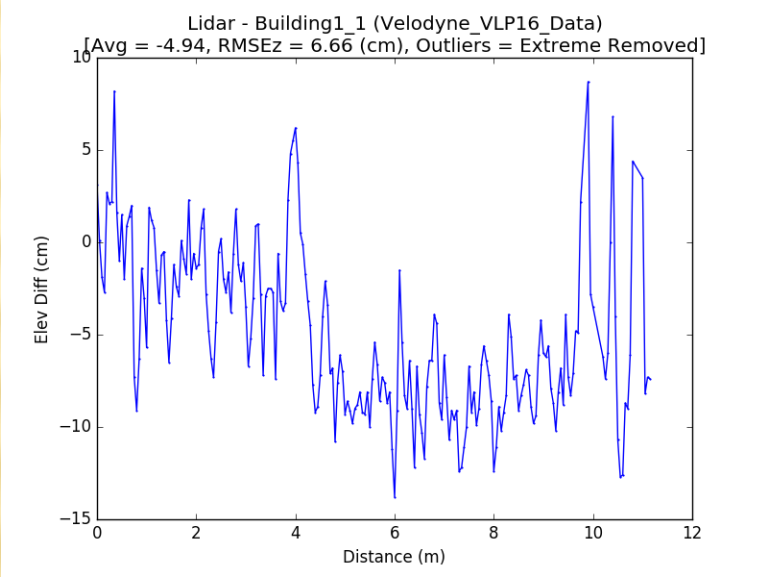

Lidar, Building1_1 (Quanergy_Data) Profiles
Lidar
Building1_1
Elev (m)
Distance (m)
330.5
330.0
329.5
329.0
328.5
328.0
327.5
327.0
326.5
0
2
4
6
8
10
12

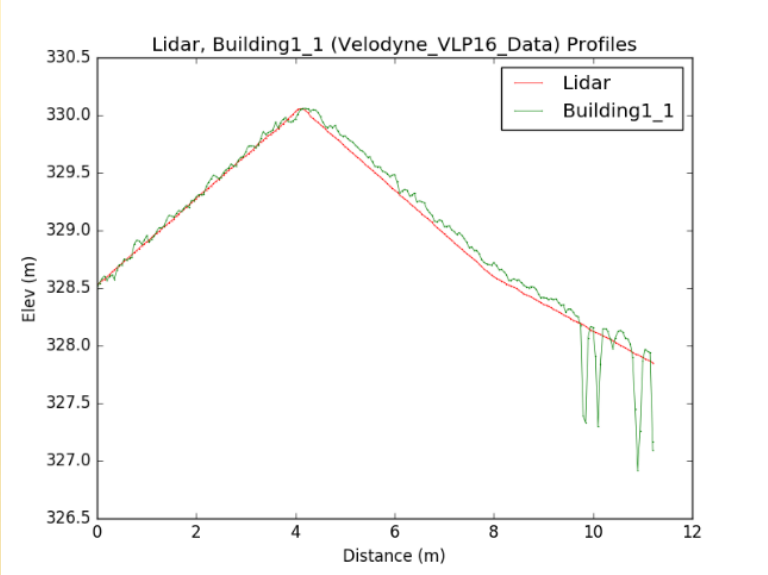
VELODYNE_HDL32



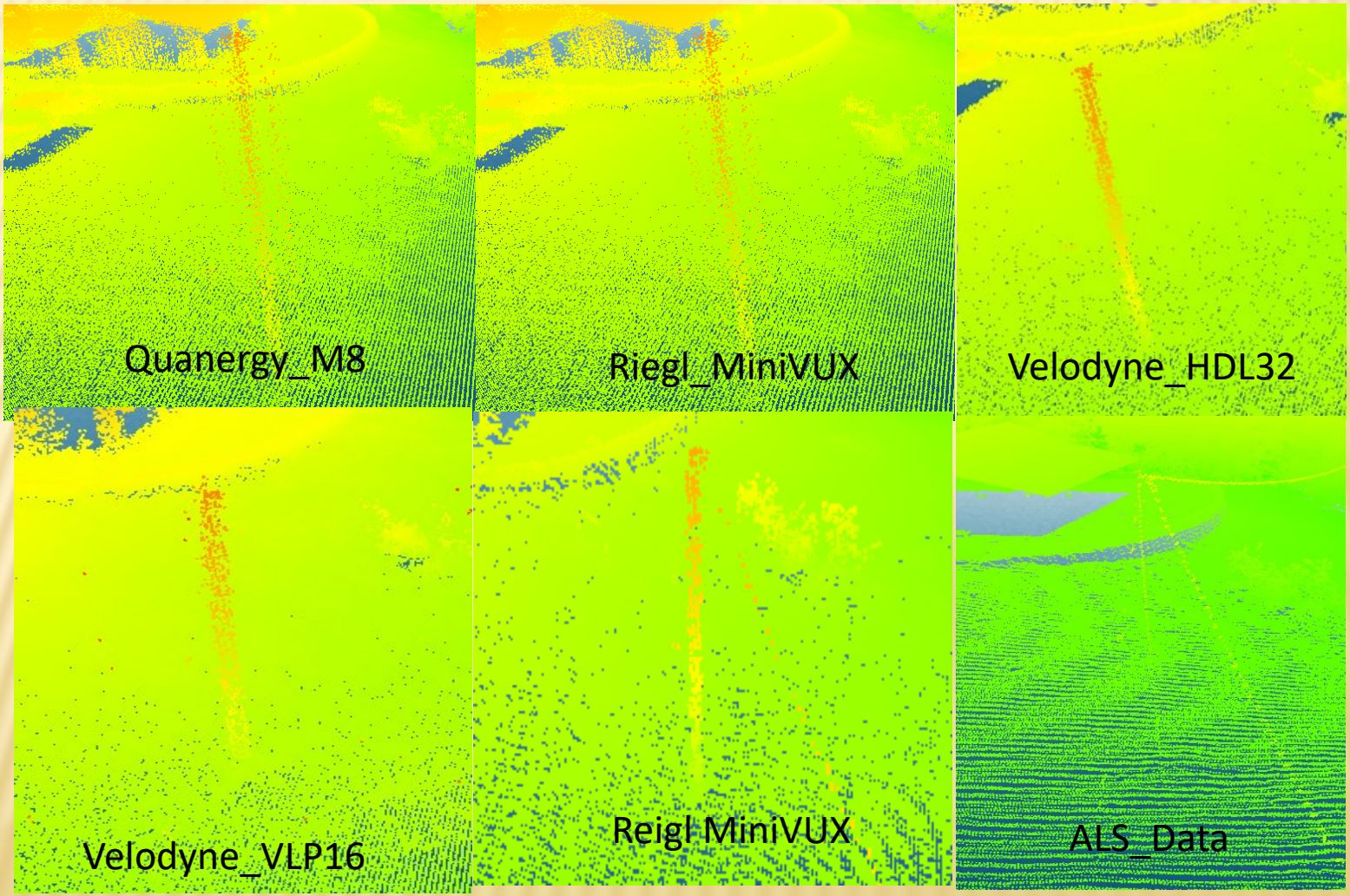


VELODYNE_VLP16

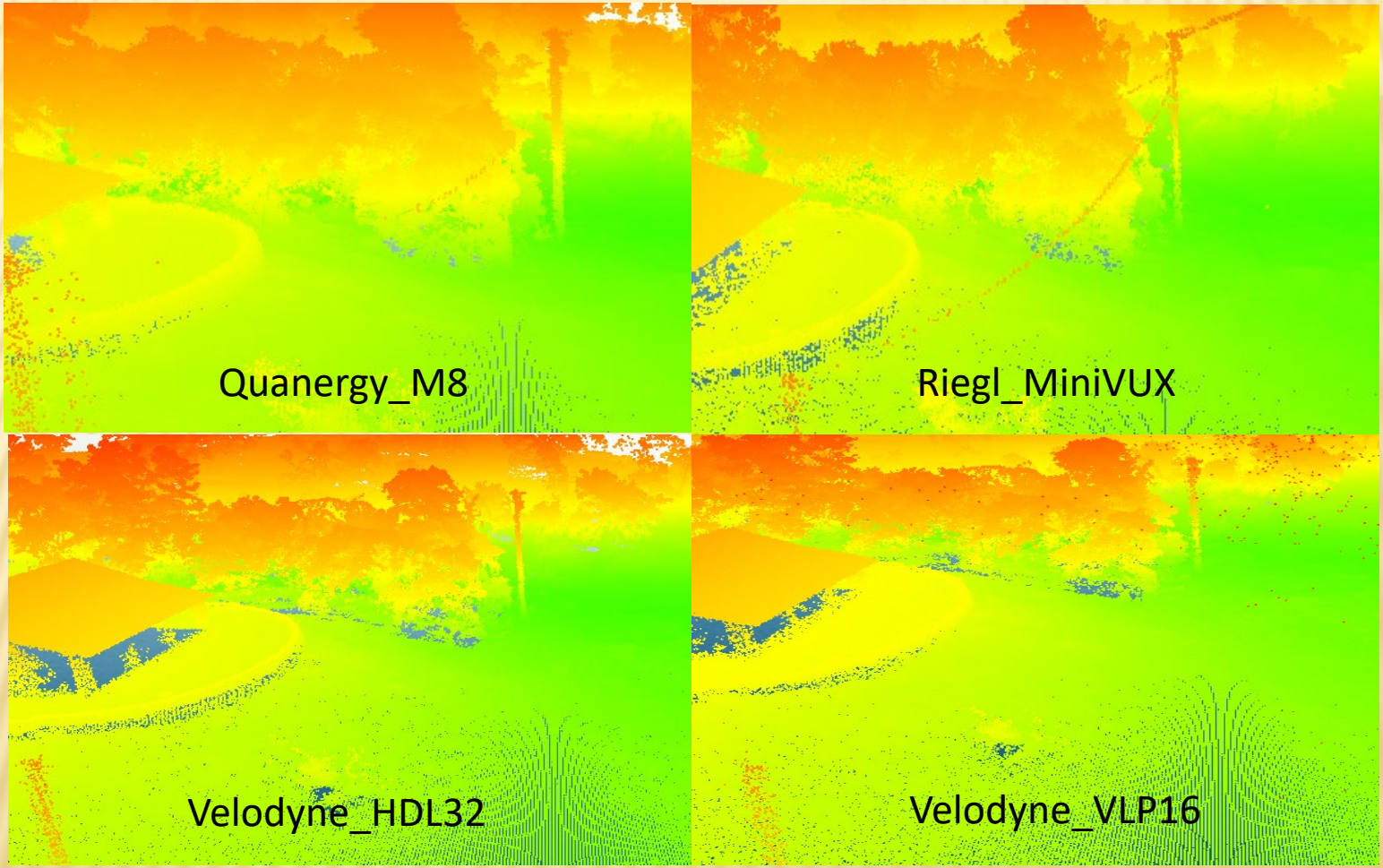




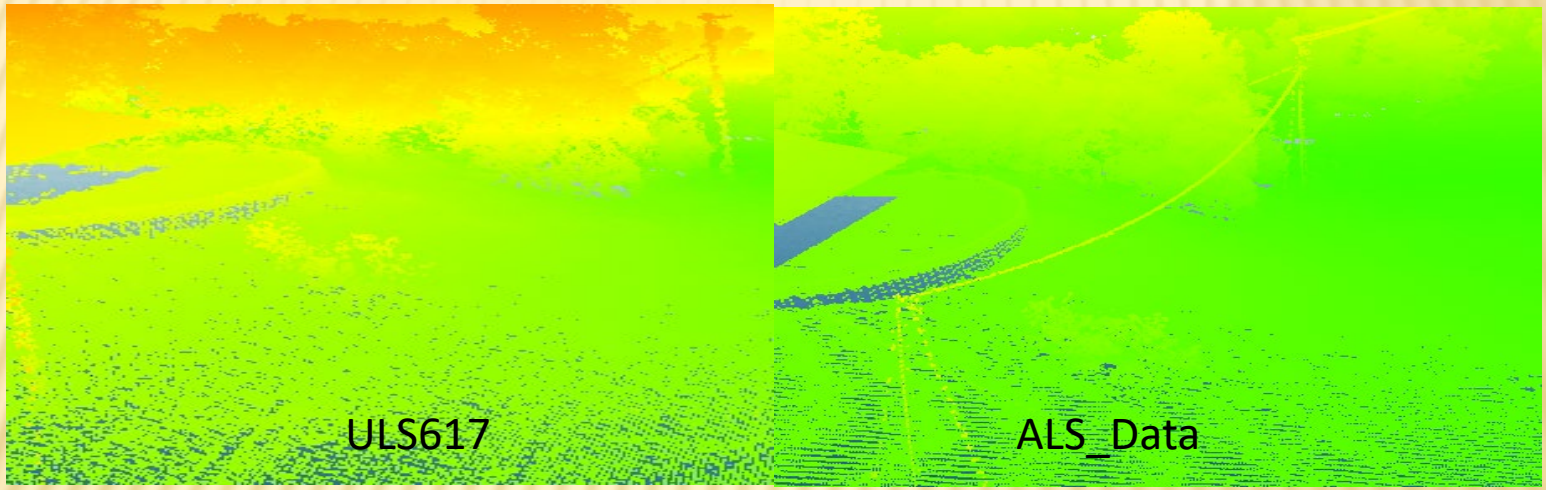
LIDAR TELEPHONE POLE RESOLUTION



LIDAR POWER LINE RESOLUTION



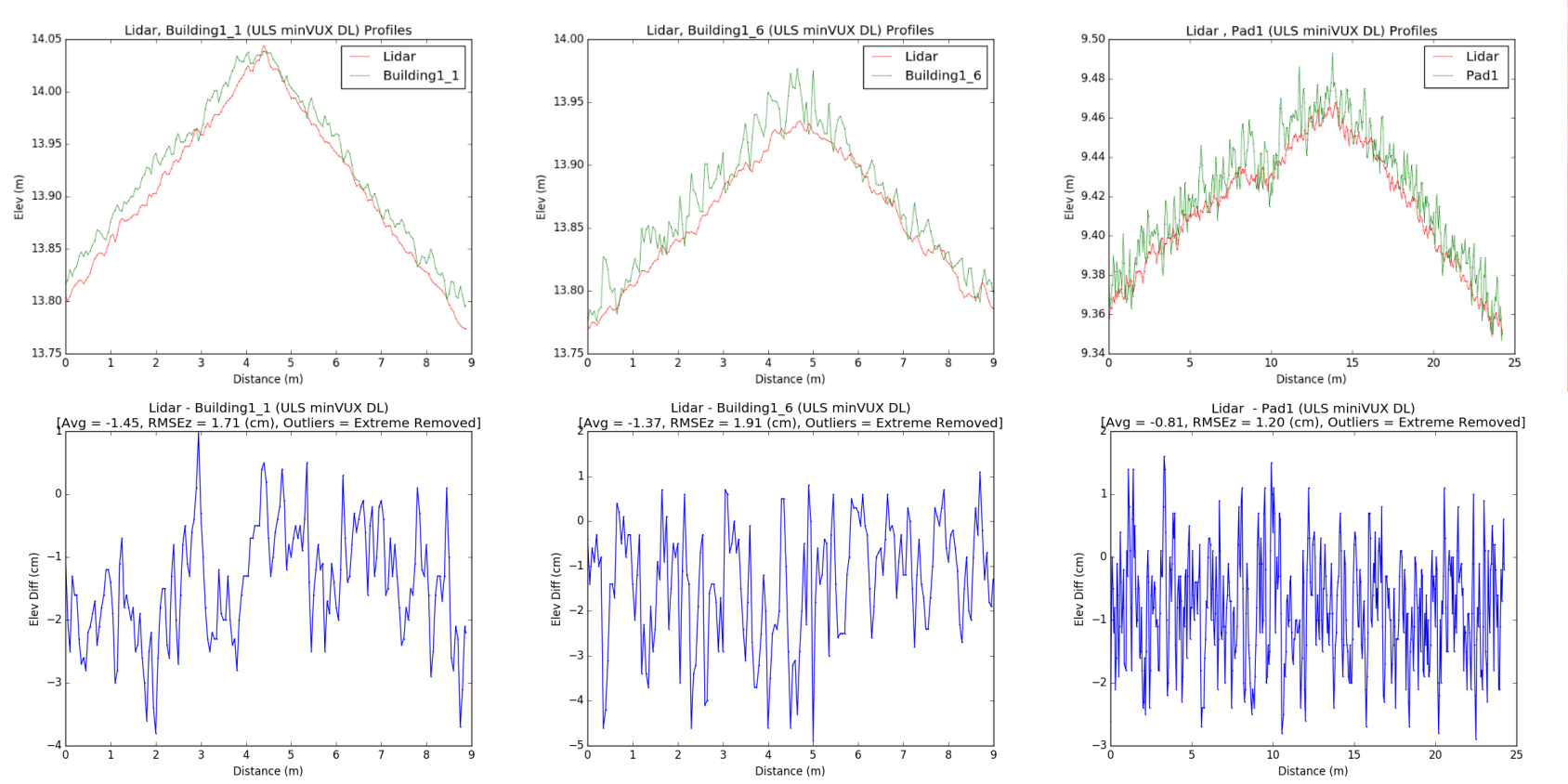
LIDAR POWER LINE RESOLUTION



PROFILES

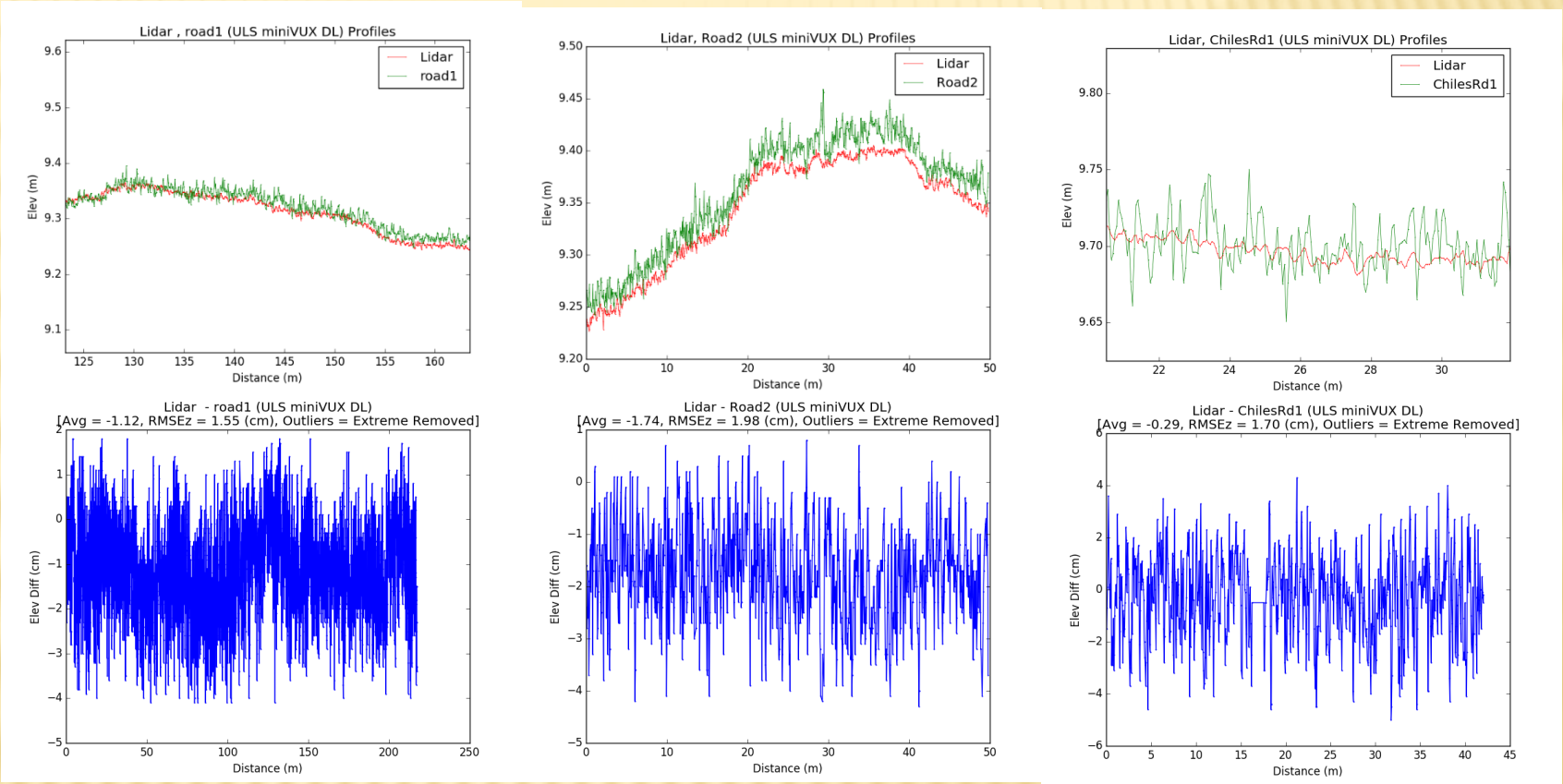
Chiles1
Pavement1_1
Pavement1_2
Pavement1_3
Pavement1_4
Pavement1_5
Building1_2
Building1_3
Building1_4
Building1_1
Building3
Building4_3
Road1
Building2
Building2
Building2
Building2
Road2
Pad1_1
Pad1_2

MICRODRONE LIDAR



Noise level in the order of 0.5 cm
Bias between -1 to -2 cm

ROAD



Noise level in the order of 0.5 cm
Bias between 0 to -2 cm

PROFILE SUMMARY

LIDAR Model	Site	Date	RMS (cm)	Std (cm)	Avg(cm)	Range(cm)
miniVUX	SJER	3-25-2019	4.3	1.7	3.9	27.1
miniVUX	SJER	6-6-2019	6.6	2.1	-6.2	23.3
Velodyne HDL32e	SJER	6-6-2019	13.8	4.2	-12.9	45.6
Velodyne VLP16	SJER	6-6-2019	11.5	3.7	-10.8	38.1
Quanergy M8	SJER	6-6-2019	5.7	3.3	-4.4	32.9
MicroDrone	CalFire	9-24-2019	1.7	1.2	-0.9	11.1

UAV LIDAR OBSERVATIONS

- Most UAV Lidar point cloud are noisy
- Different hardware produce different point patterns
- Slope has effect on LIDAR point accuracy
- Micrdrone shows very promising results

NEXT

- SJER Site
  - Fly the Microdrone sUAS
  - Fly the GeoCue True View sUAS
  - Fly the DJI Phantom 4 RTK at different flying heights

THANK YOU