Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering
University of California at Davis

Creating Standards and Specifications for the Use of Laser Scanning (Ground-Based LIDAR) in Caltrans Projects

Professor Bahram Ravani, Principal Investigator
Ty A. Lasky, Kin S. Yen, Jagannath Hiremagalur

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Interim Report of Contract: 65A0368 and 65A0416, Task ID 2517

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California Department of Transportation

Division of Research and Innovation

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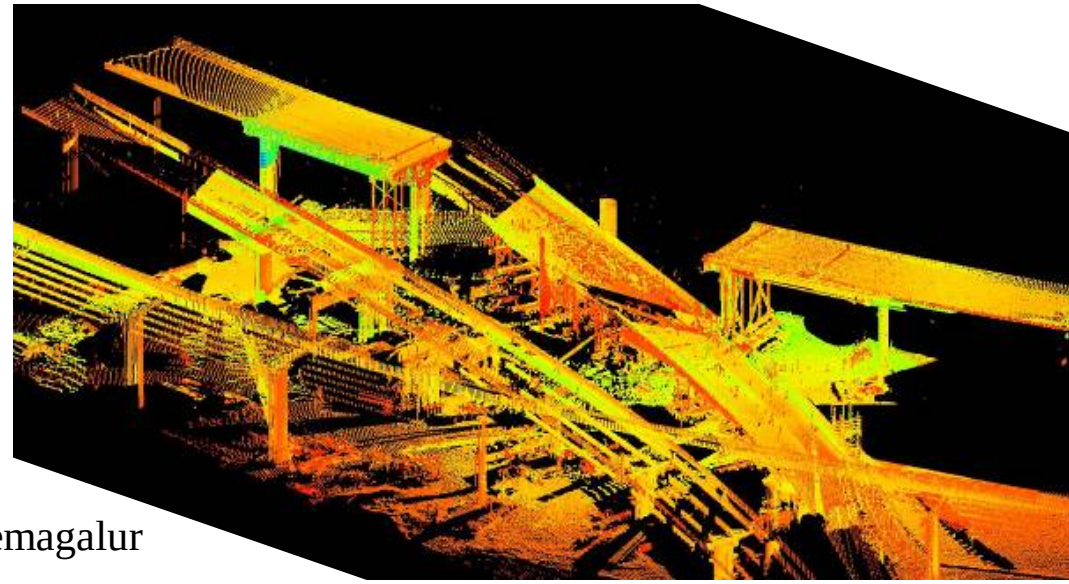
Creating Standards and Specifications for the Use of Laser Scanning (Ground-Based LIDAR) in Caltrans Projects



PI: Professor Bahram Ravani
Co-PI: Dr. Ty A. Lasky
Lead Engineer: Kin S. Yen
Development Engineer: Jagannath Hiremagalur

Caltrans Project Manager: Triet Bui, Division of Research & Innovation
Primary Caltrans Advisor: Kevin Akin, Office of Land Surveys

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Outline

- Project objectives
- Test results and conclusions
- Recommendations
  - Scanner selection guidelines
  - Software selection guidelines
  - Work-flow & QA/QC
  - Data exchange & archival format
  - Contractor deliverables
- Remaining work

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Motivation

- Difficulty in directly comparing vendor specs, e.g.:

  Accuracy:

  - Vendor 1: Position: 6 mm, at 1 – 50 m, one sigma
  - Vendor 2: Single-point: 12 mm at 100 m

  Range:

  - Vendor 1: Range: 300 m @ 90%, 134 m @ 18% albedo
  - Vendor 1: Range: 200 m @ 90%, 350 m (w. OverScan)
- Relating specs to highway applications, surveys
- Establish independent, controlled, standardized test methodology, testbed, and fixtures

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Project Goals

- Coordinated set of standards and specifications for the use of 3D laser scanning for Caltrans and its contractors
- Enable / promote increased use of 3D laser scanning in surveys to improve efficiency and safety
- Laser scanner hardware and software evaluations
  - Hard-surface accuracy requirement: 10 mm (0.03 ft) H x 7 mm (0.02 ft) V
  - Earth surface accuracy requirement: 30 mm (0.1 ft) H x 30 mm (0.1 ft) V
- Clarify common limitations of 3D laser scanners and recommend methods for their mitigation

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Literature Review

1. Schulz, T., Ingensand, H., Steiner, M., “Laser Scanning and Noise Reduction applied to 3D Road Surface Analysis”, 2005.
2. Schulz, t., Ingensand, H., Influencing Variable, “Precision and Accuracy of Terrestrial Laser Scanners”, *Proceedings of the FIG working week*, 2004.
3. W. Boehler, M. Bordas Vicent, and A. Marbs, "Investigating Laser Scanner Accuracy, Updated 2004,“ i3mainz, Institute for Spatial Information and Surveying Technology
4. G. Jacobs, "Understanding the "Useful Range" of Laser Scanners," *Professional Surveyor Magazine,* 2004.
5. 6. E.J. Jaselskis, Z. Gao, A. Welch, and D. O’Brien, "Pilot Study on Laser Scanning Technology for Transportation Projects," in *Mid-Continent Transportation Research Symposium*, Ames, Iowa, August, 2003.
7. W. Boehler and A. Marbs, "3D Scanning Instruments," in *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Corfu, Greece, 2002.
8. W. Boehler, G. Heinz, and A. Marbs, "The Potential of Non-Contact Close Range Laser Scanners for Cultural Heritage Recording," in *CIPA International Symposium*, Potsdam, Germany, 2001.

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NIST/ASTM Committee E57

Development of standards for 3D imaging systems, which include, but are not limited to laser scanners (also known as LADAR or laser radars) and optical range cameras (also known as flash LADAR or 3D range camera).

http://www.astm.org/COMMIT/SUBCOMMIT/E57.htm

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What previous studies lack

- Long-range test data (on and off pavement)
- Data on latest scanners
- DOT, surveys, and engineering perspectives
- Software evaluation
- Work-flow analysis
- Best data exchange methods
- Best practices on geo-reference target setup

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Four Vendors Participated

Intelisum
Riegl
Z-210i &
Z-420i

Optech
ILRIS-3D

Leica
ScanStation

Trimble
GX

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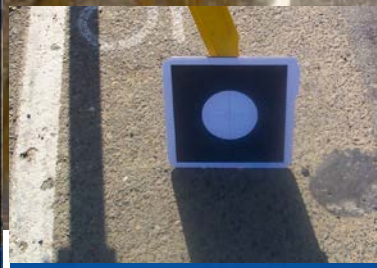



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Control Test

- "Repeatable"
- Test for useful range
  - Depends on return signal strength,
  - which depends on range, surface reflectivity, and laser incident angle
- "Resolution"
- Range Precision
- Angular precision
- Target recognition accuracy
- Compare to data measured by conventional means

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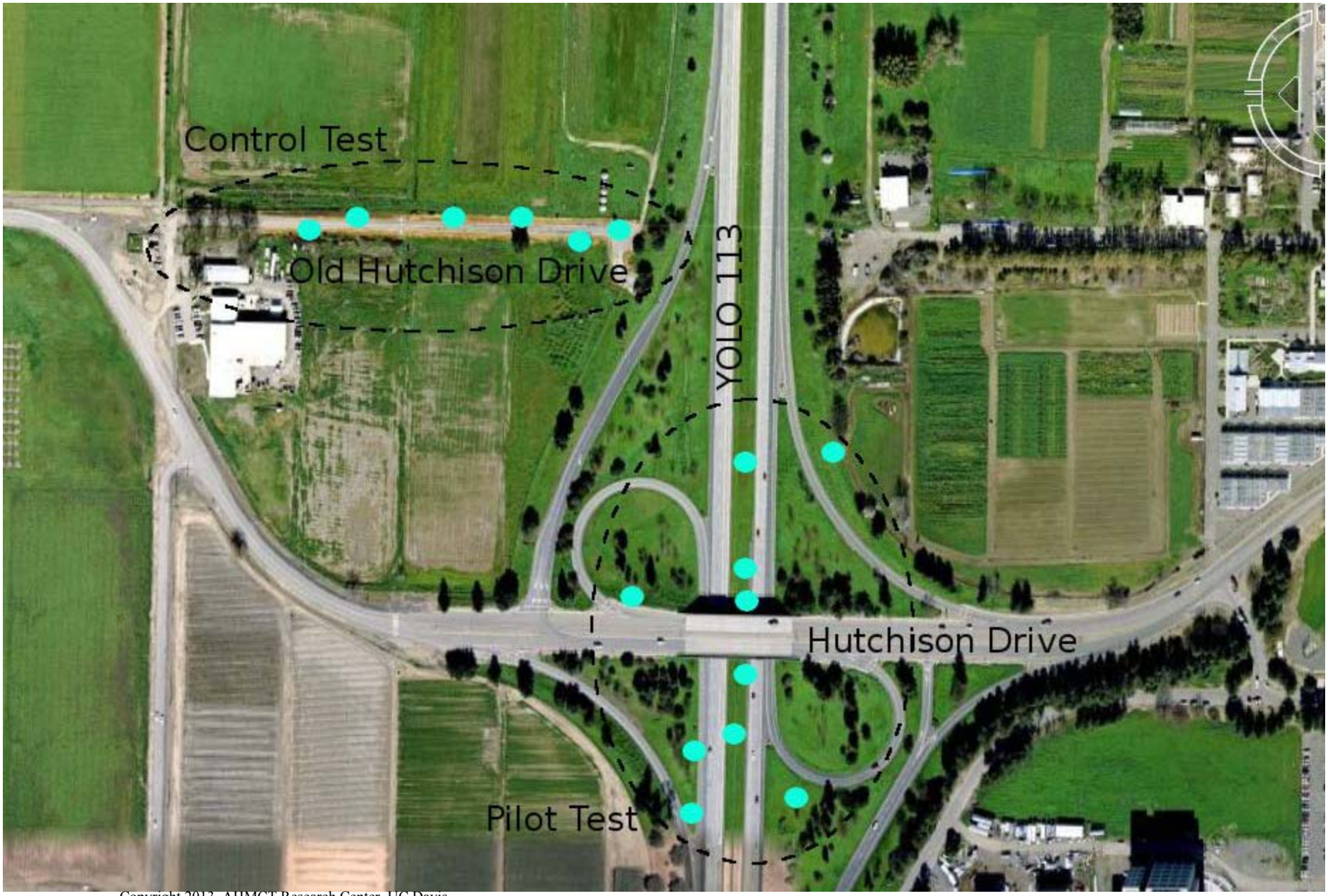

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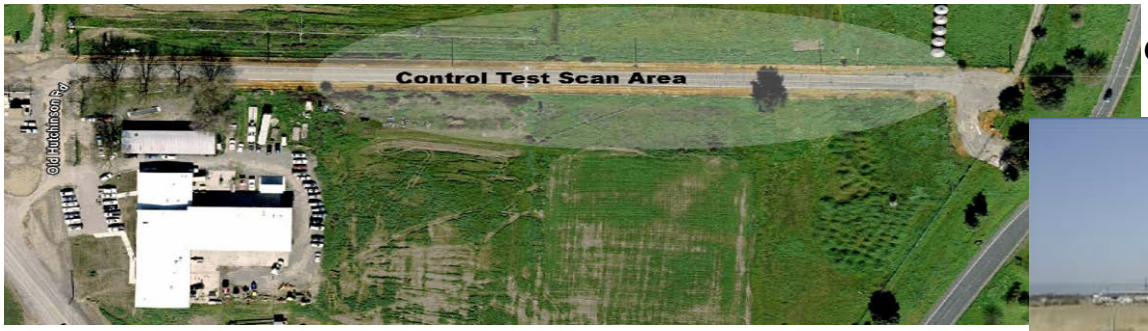
Control Tests

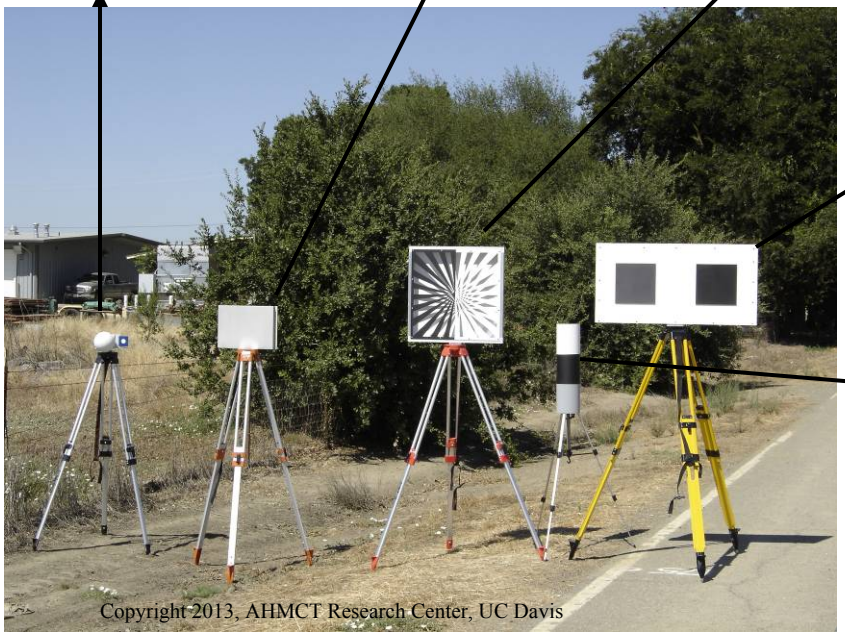


Control Test Scan Area – Old Hutch Rd, 500m of asphalt road surface

Angular Accuracy

Surface Precision/ Noise

Resolution



Range Accuracy

Incidence & Coverage Angle

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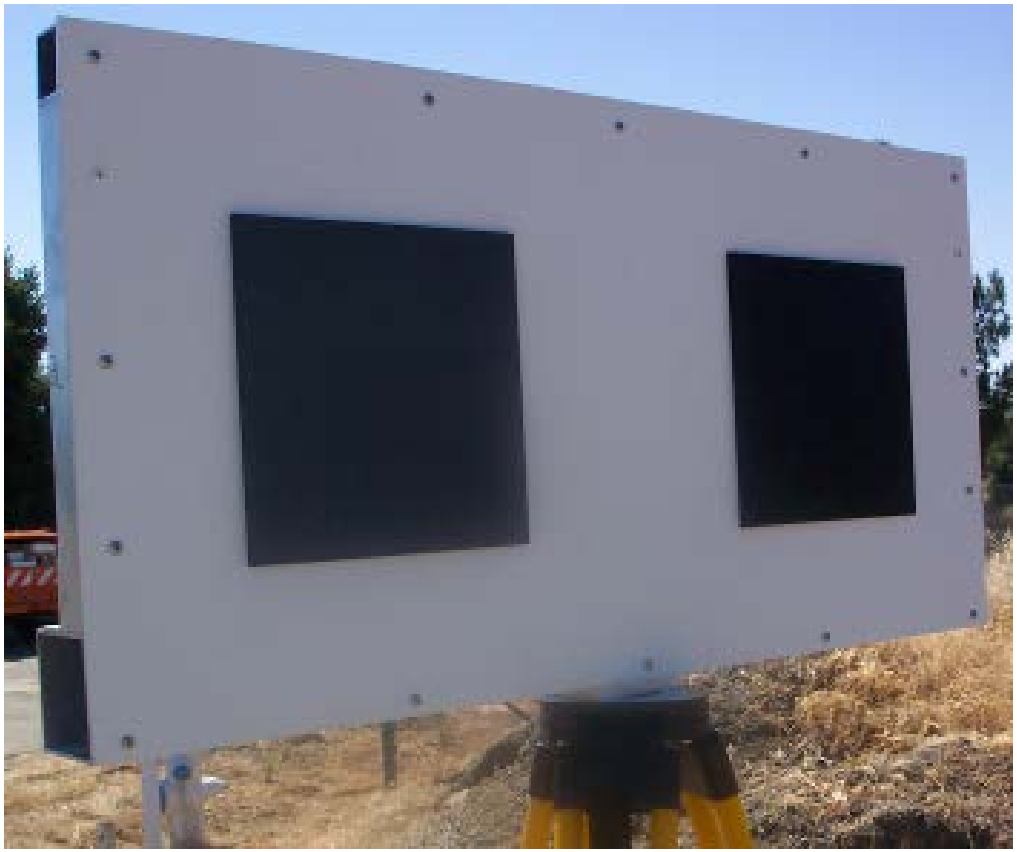
Control Tests – Range Accuracy

Test Fixture at 25, 50, 75, and 100 m.
Also scanning black asphalt pavement up to 120 m

Range Accuracy Test Fixture



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Range Accuracy RMS Results @ 95% Confidence Interval

		Range Accuracy: Root Mean Square of Residual Errors (mm)			
3D Laser Scanner Manufacturer	**Reflectivity Color**	**25 m**	**50 m**	**75 m**	**100 m**
Leica	White	4.65	3.23	3.23	4.78
	Grey	4.72	4.31	4.68	5.49
	Black	4.72	3.45	3.65	7.08
Trimble	White	2.10	1.65	2.20	1.84
	Grey	2.98	4.82	4.92	7.74
	Black	3.00	4.82	7.80	11.70
Optech	White	13.70	14.25	18.40	21.95
	Grey	13.30	14.31	16.48	21.76
	Black	13.07	14.07	18.93	18.37

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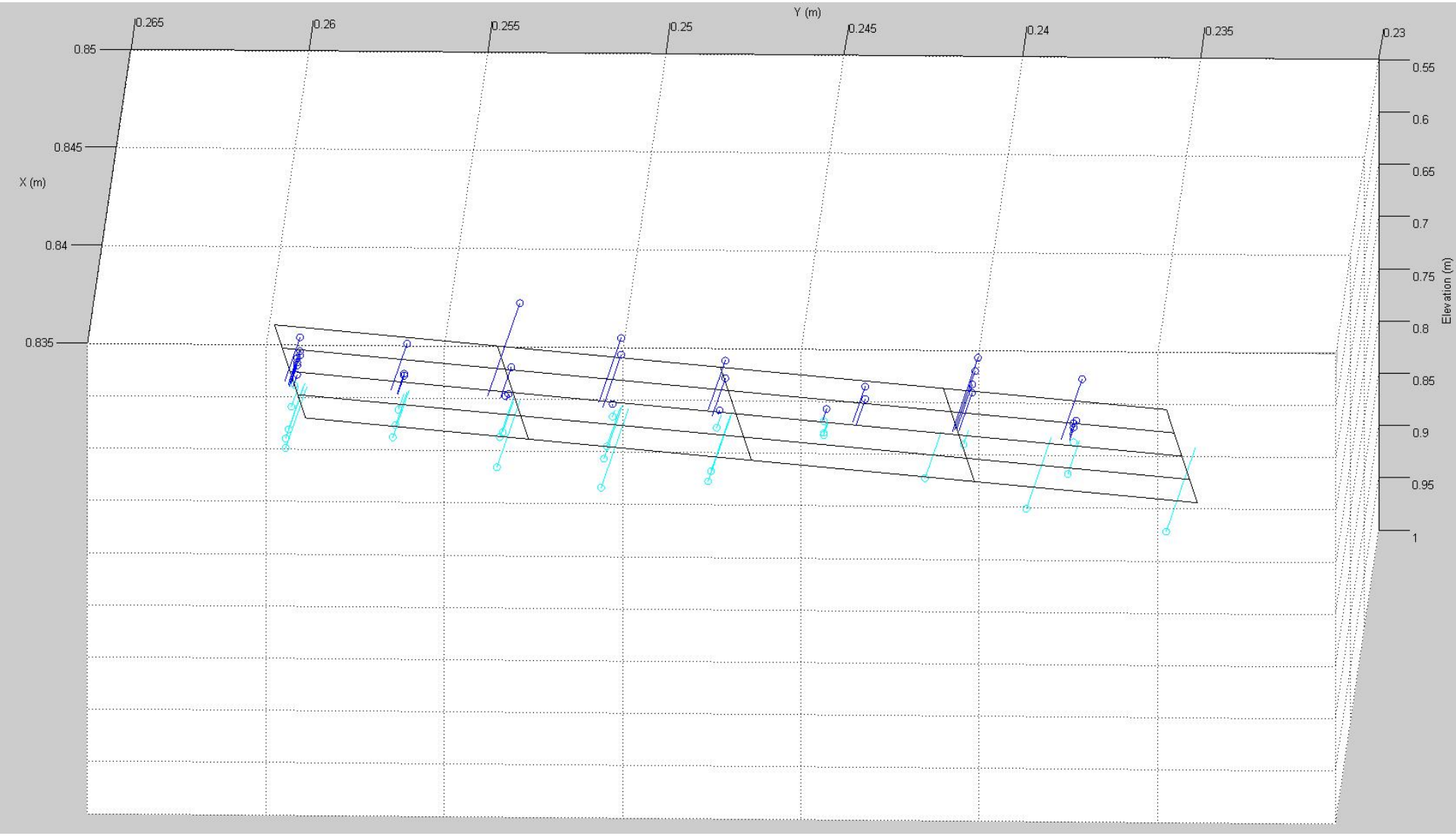

Range Errors plotted with interpolated surface and laser point cloud

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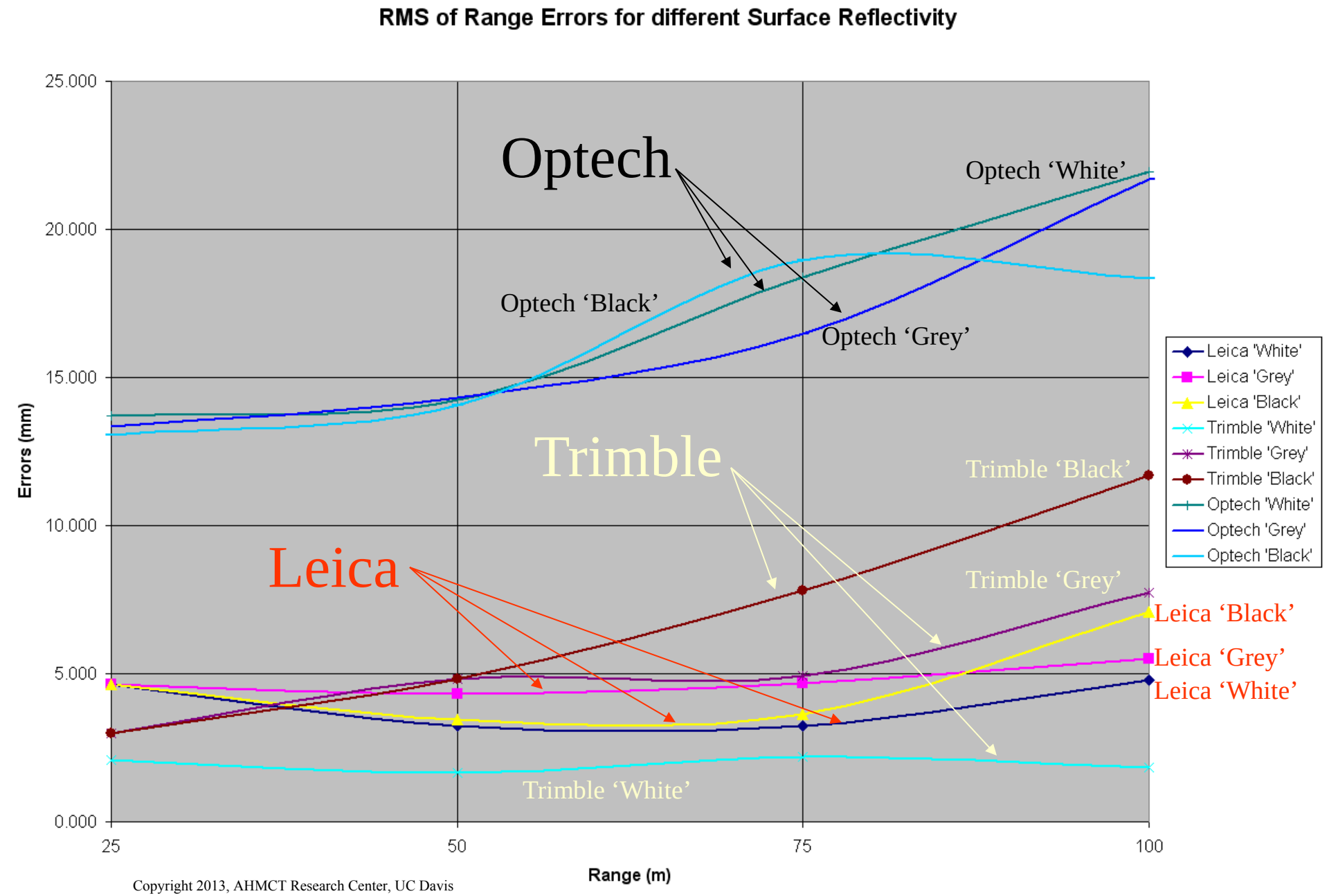

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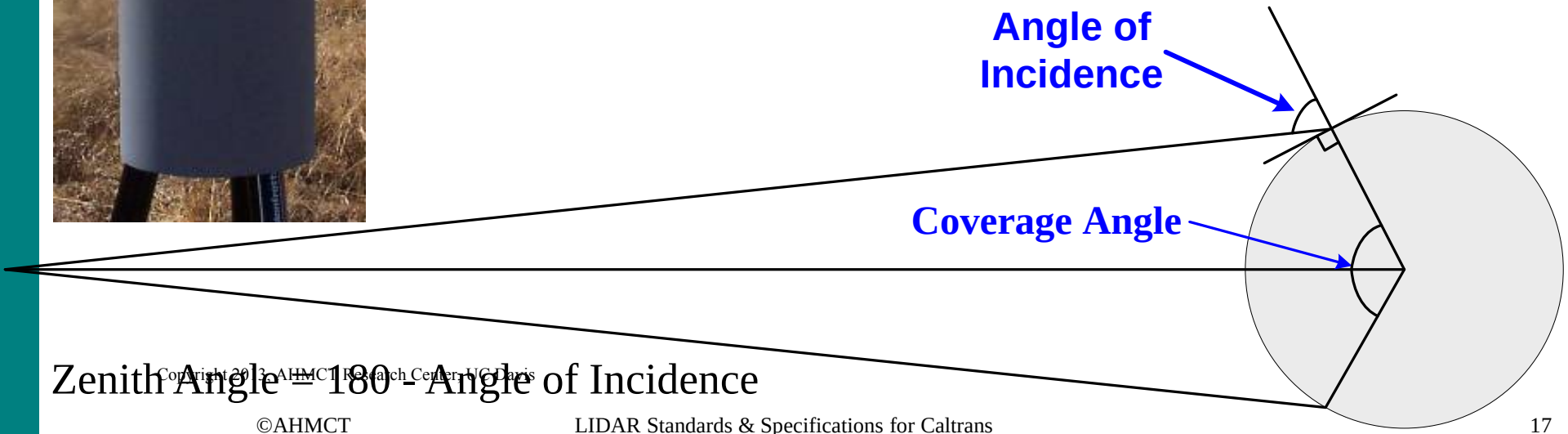
Control Tests – Incidence & Coverage Angle

Test Fixture at 25, 50, 75, and 100 m.
Three surface reflectivity levels

Incidence Angle Test Fixture



Zenith Angle = 180 - Angle of Incidence

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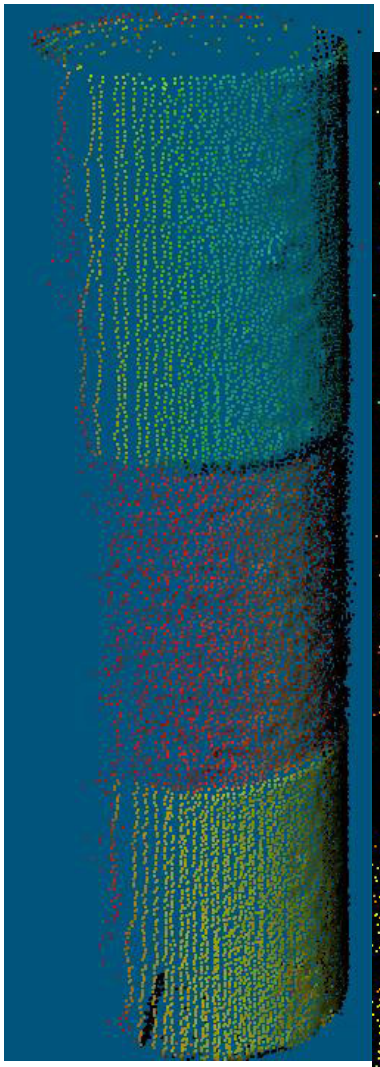
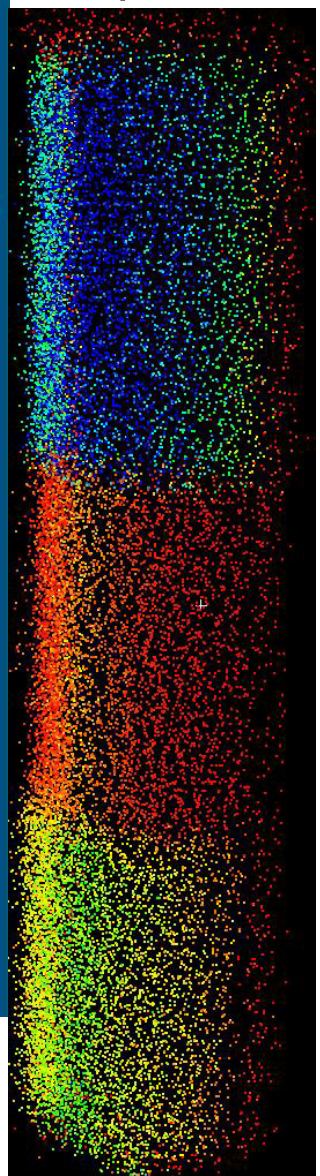
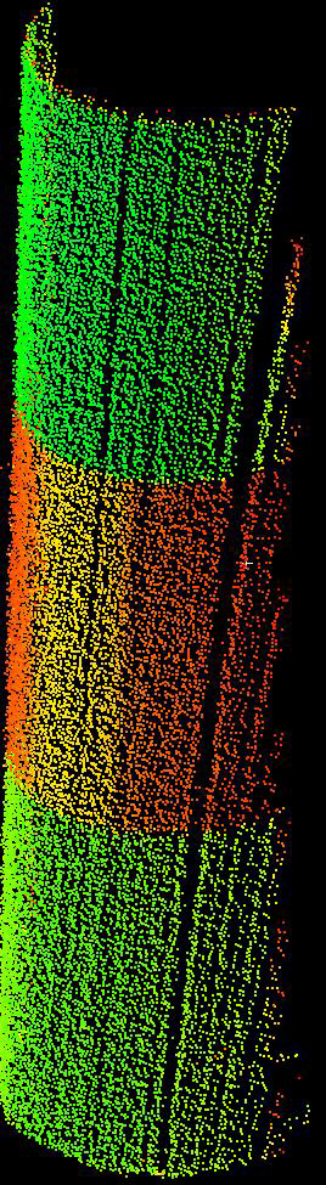
25 m

Trimble



Optech

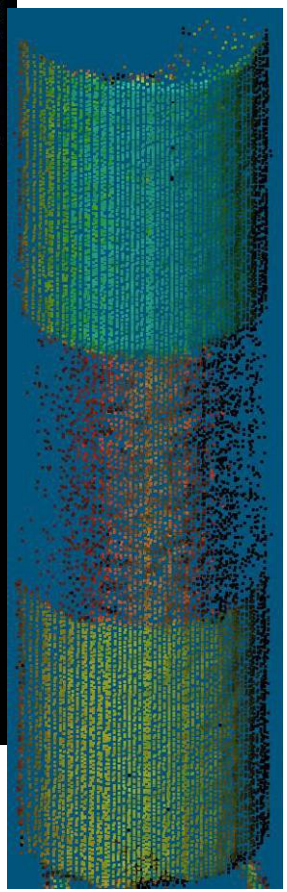


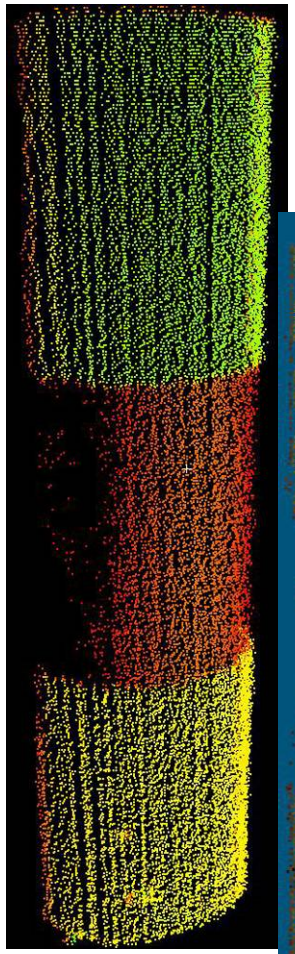


Leica

50 m

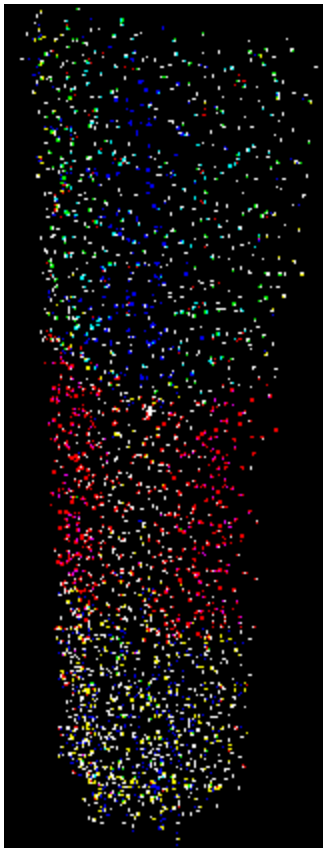
Trimble





Leica

Optech



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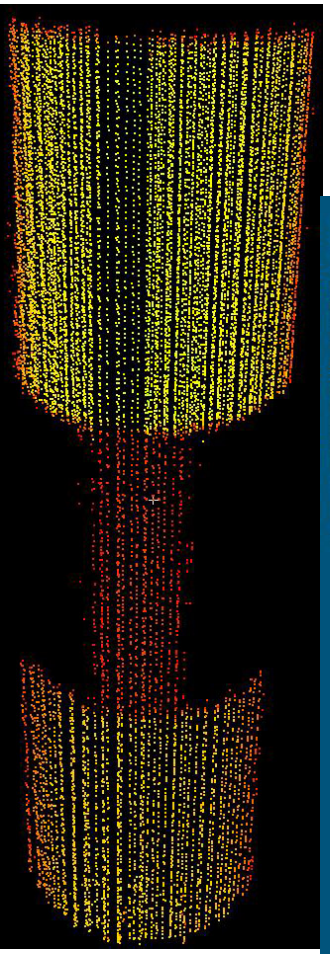
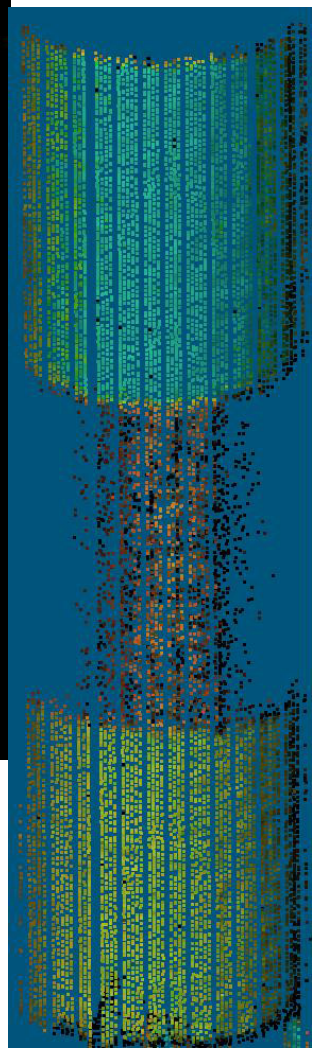
75 m

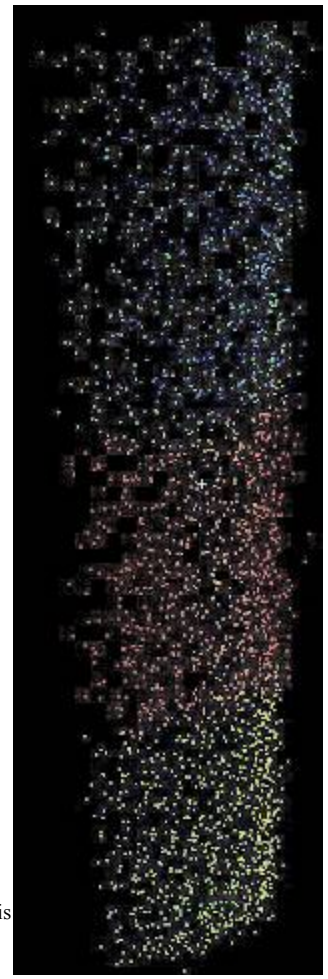
Trimble

Optech



Leica

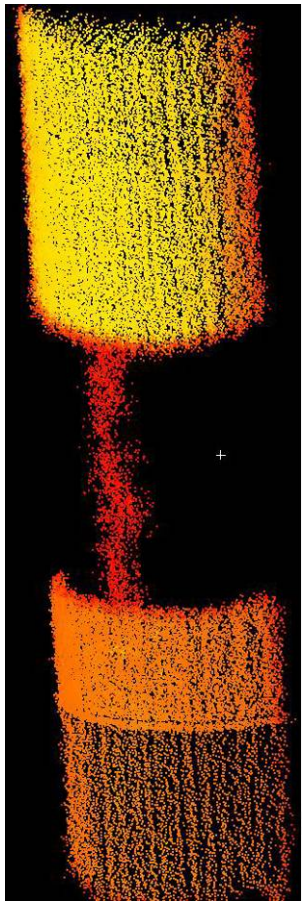




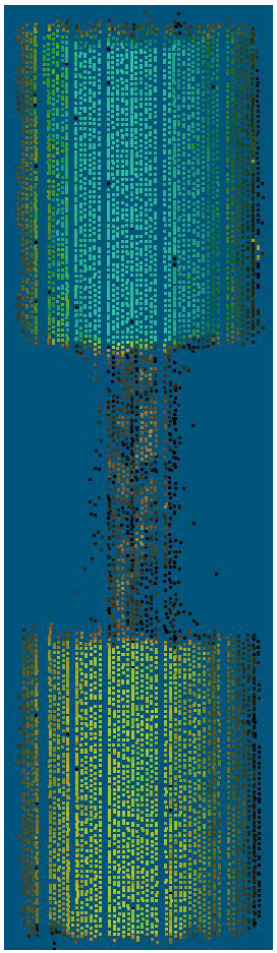
100 m

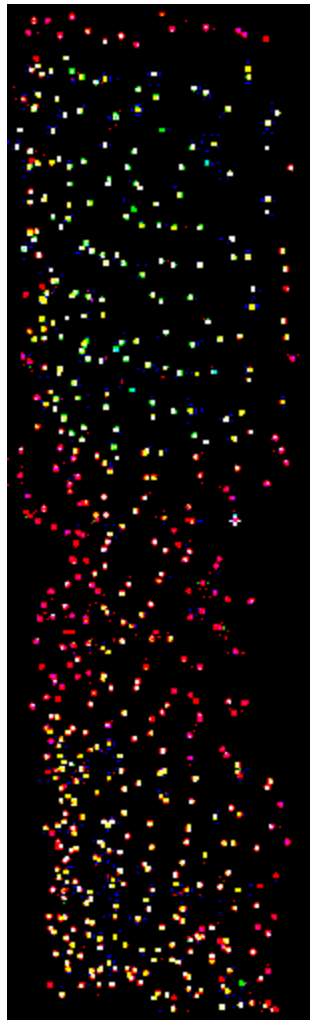
Trimble

Optech



Leica





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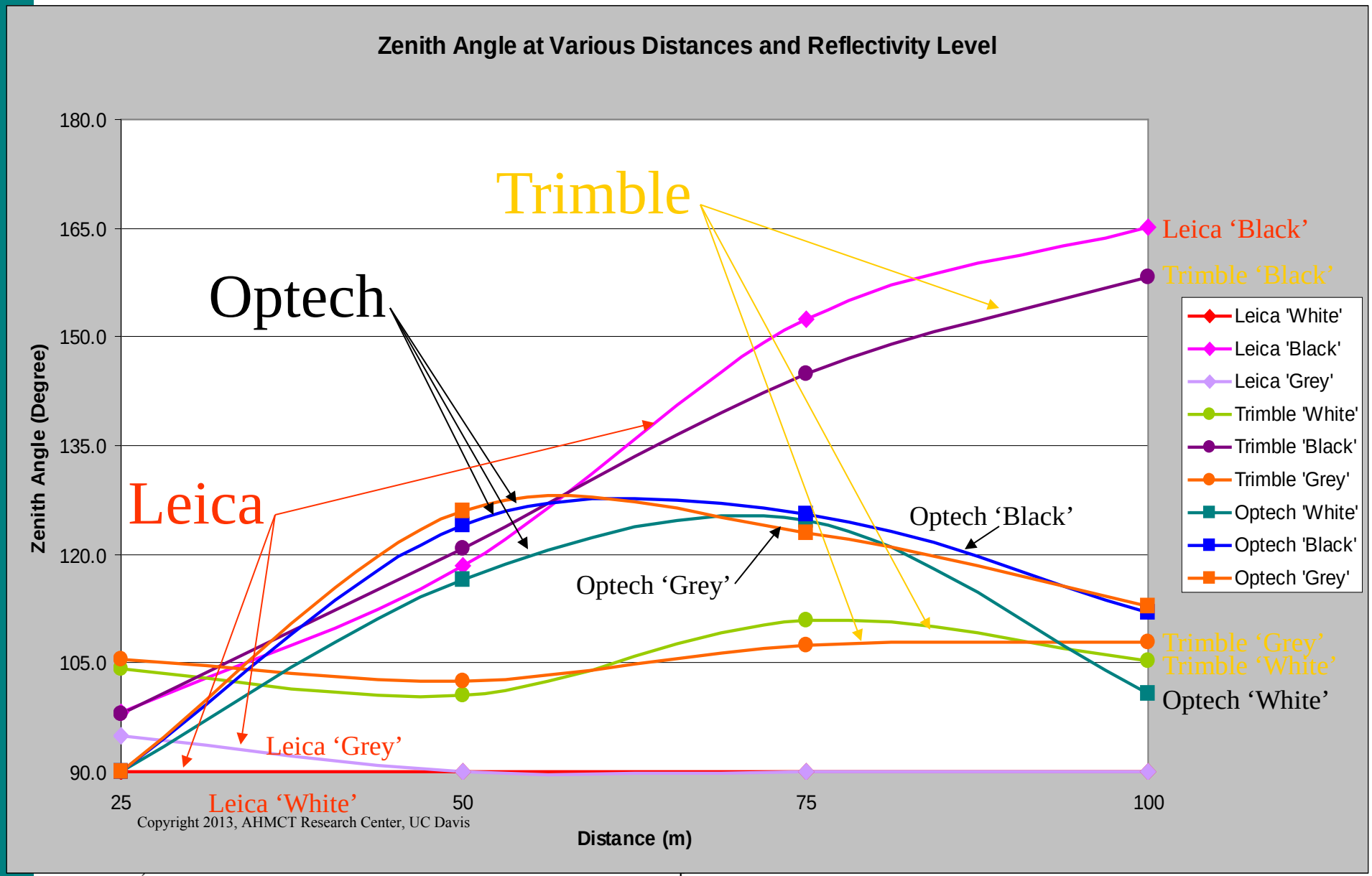
Zenith Angle at various Distances & Reflectivity Levels (surface color)



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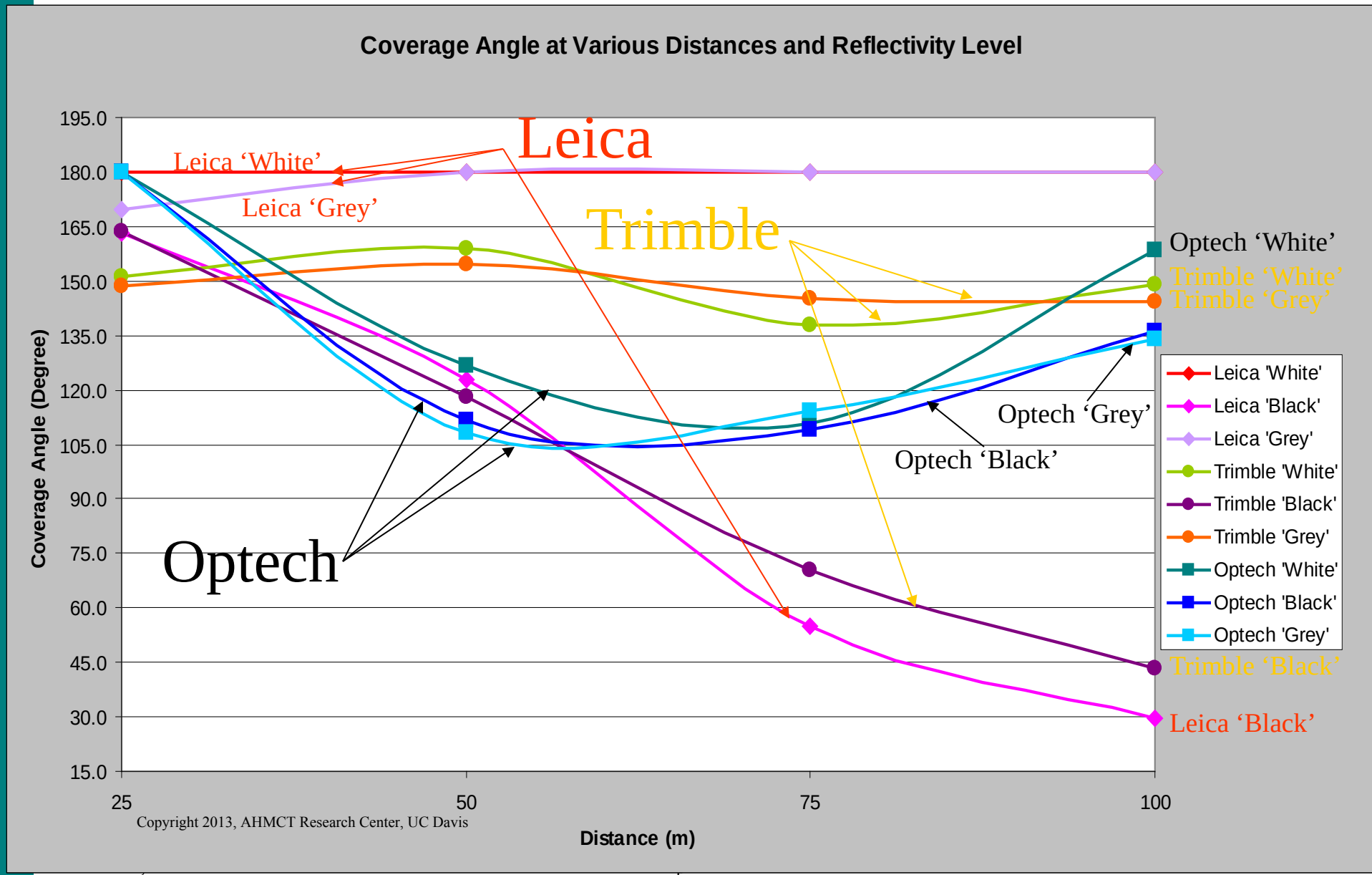
Coverage Angle at various Distances & Reflectivity Levels (surface color)



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Control Tests – Angular Accuracy

Test Fixture at 25 and 75 m.
Vendor-specific target as available.

Angular Accuracy Test Fixture

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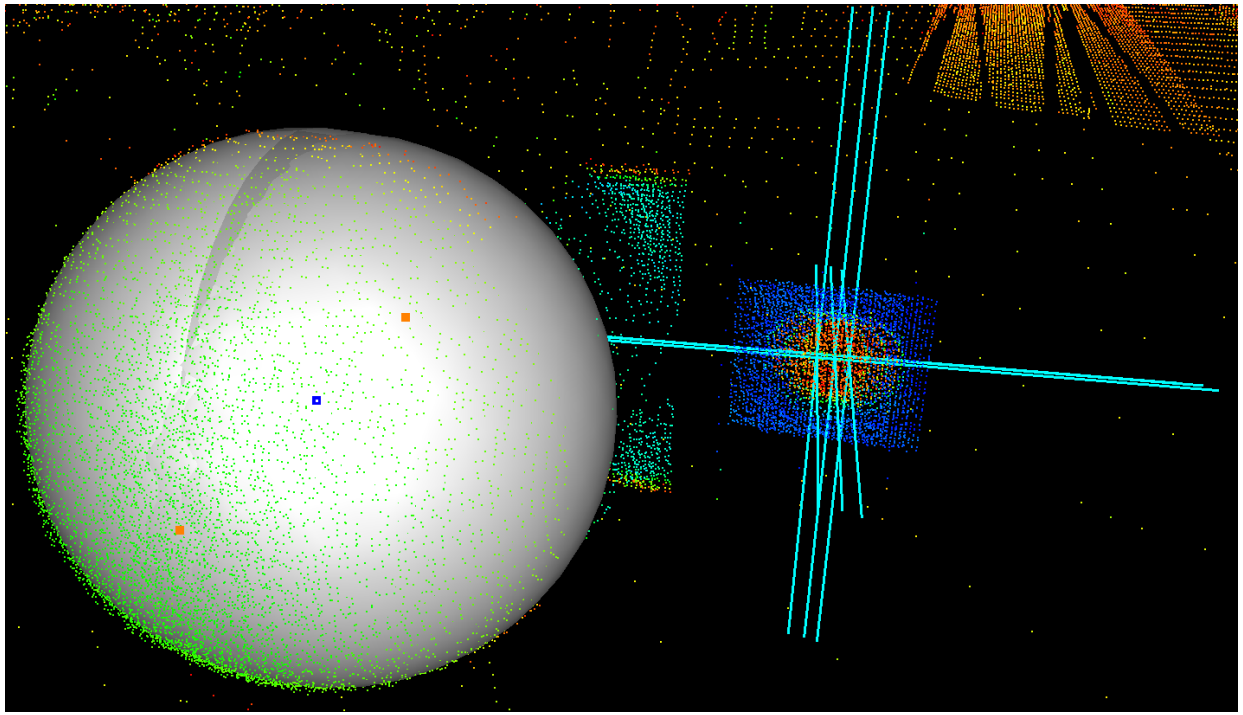
Leica Angular Accuracy Results



Error (mm)	@25 m	@75 m
Leica Target (Translation 1)	-0.67	0.43
Leica Target (Translation 2)	-0.65	0.59
6" Sphere (Translation 1)	-0.71	0.92
6" Sphere (Translation 2)	-0.72	1.15

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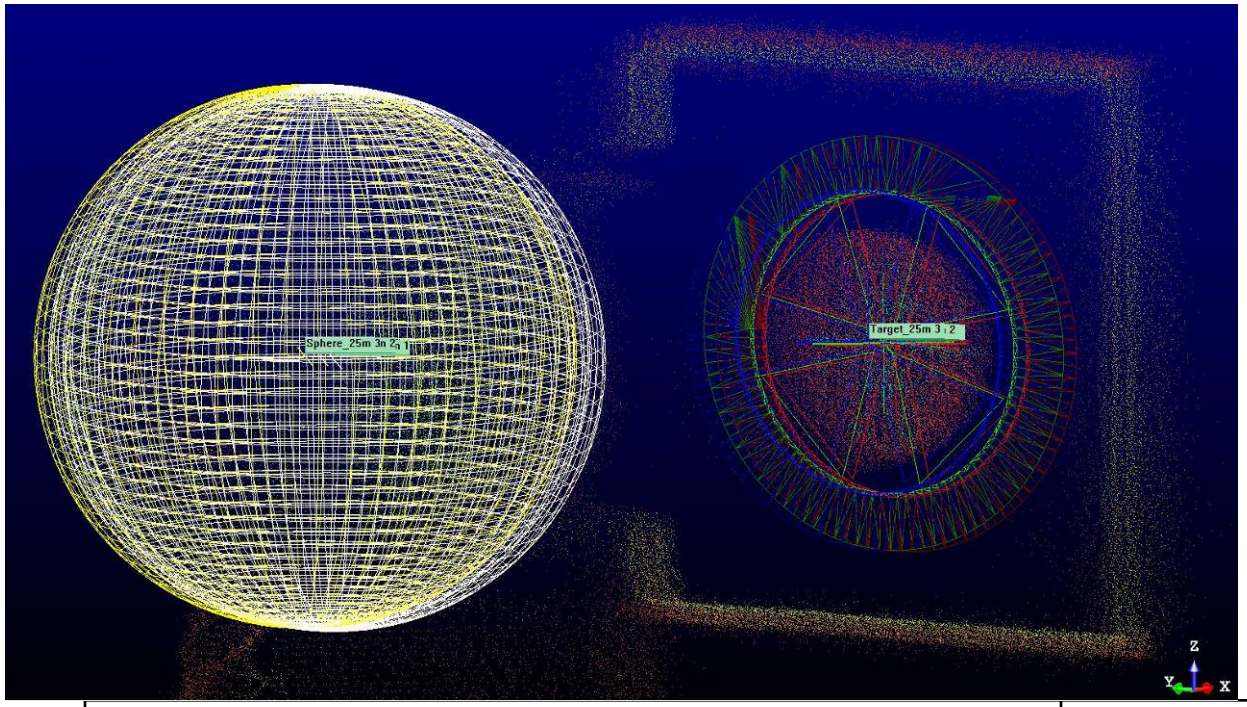
Trimble Angular Accuracy Results



Error (mm)	@25 m	@75 m
Trimble Target (Translation 1)	-0.75	0.45
Trimble Target (Translation 2)	-0.28	0.70
6" Sphere (Translation 1)	-0.51	1.73
6" Sphere (Translation 2)	-0.28	1.68

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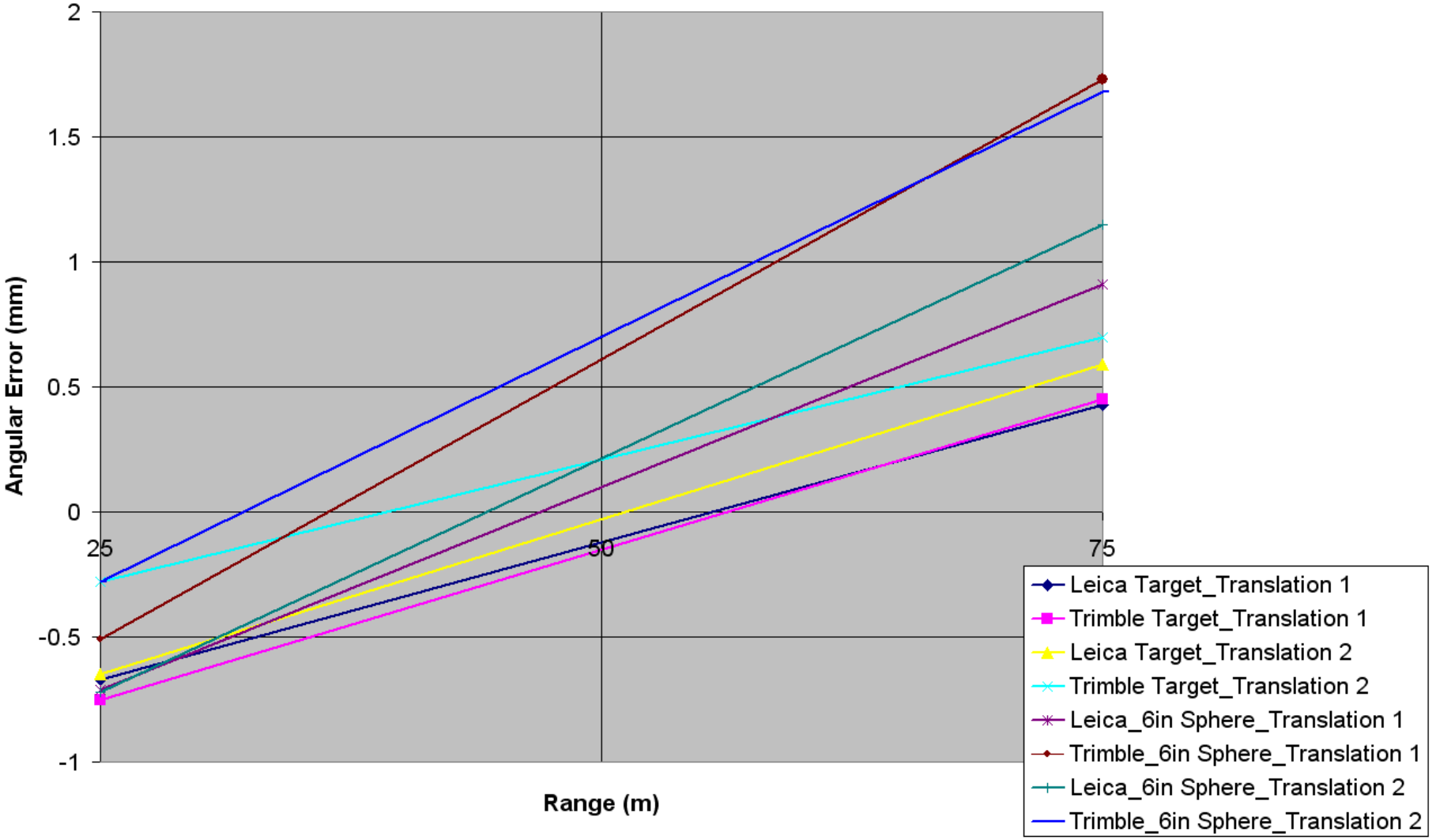
Angular Accuracy Estimates using Sphere and Vendor Targets



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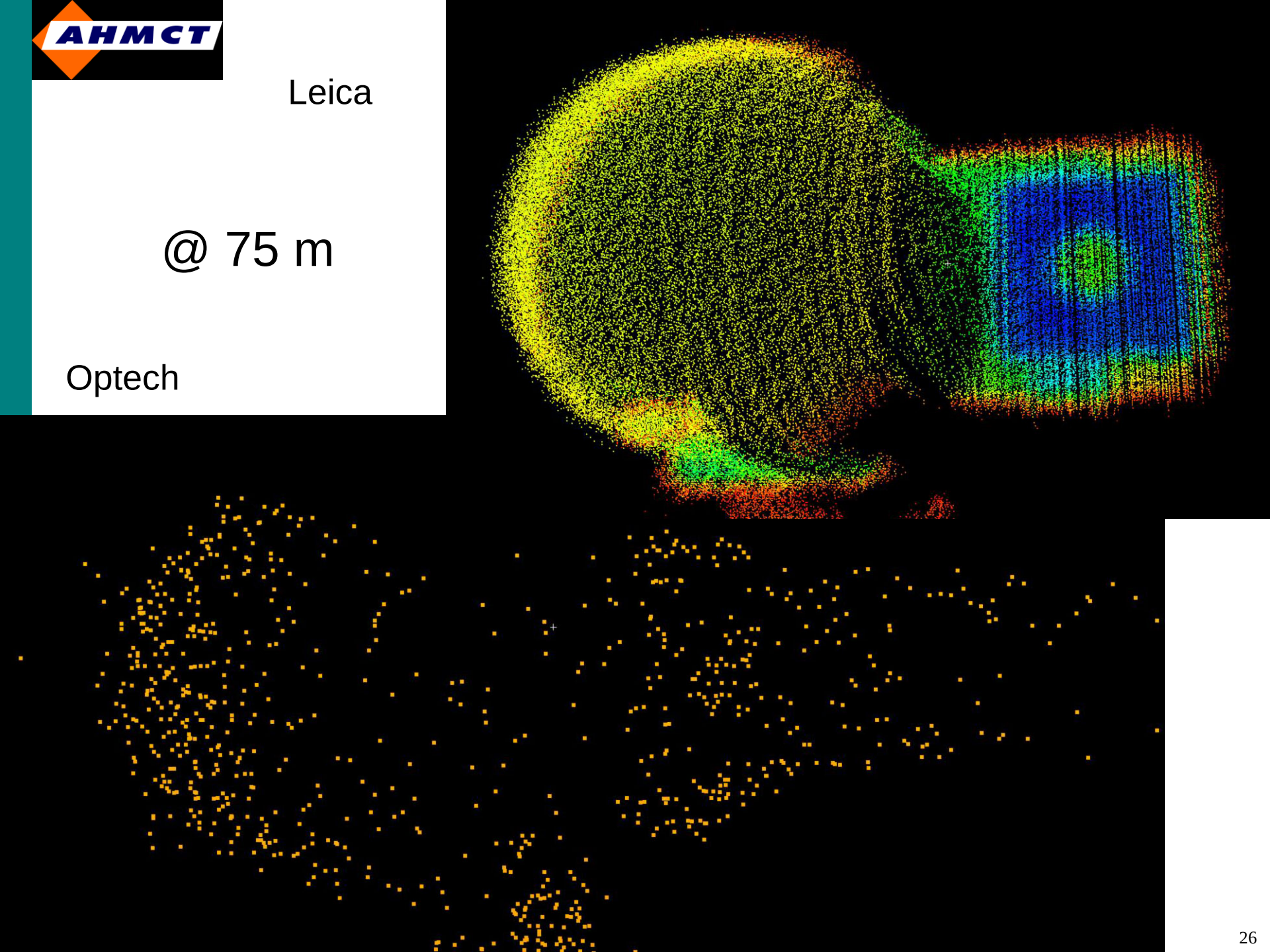
Leica

@ 75 m

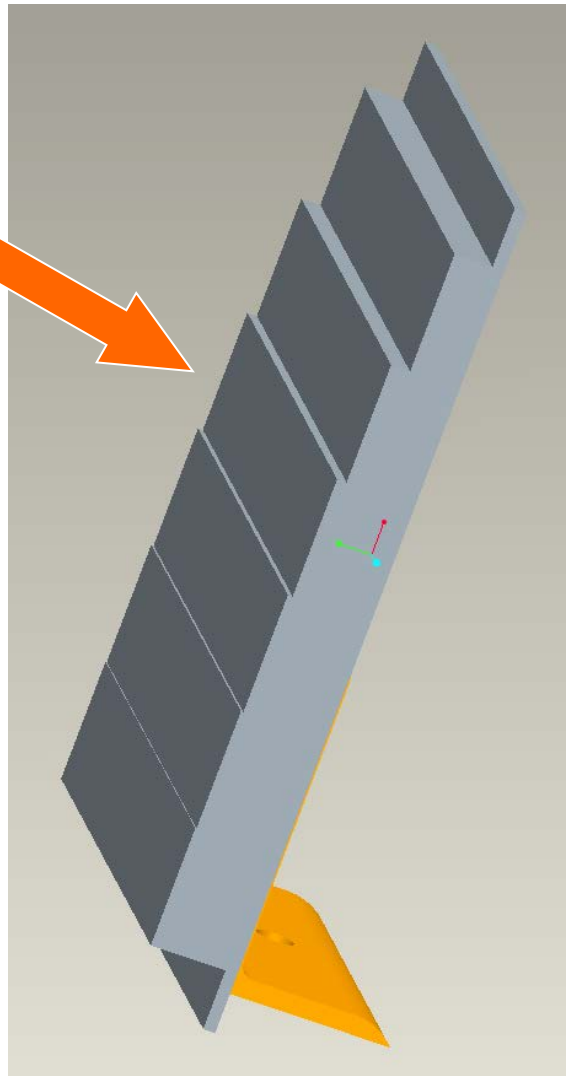
Optech



Control Tests – Surface Precision

Test Fixture at 25, 50, 75, and 100 m. Two reflectivity levels.

Line of sight of
3D Laser Scanner –
for edge effects



Point Accuracy / Surface Precision & Noise Test Fixture

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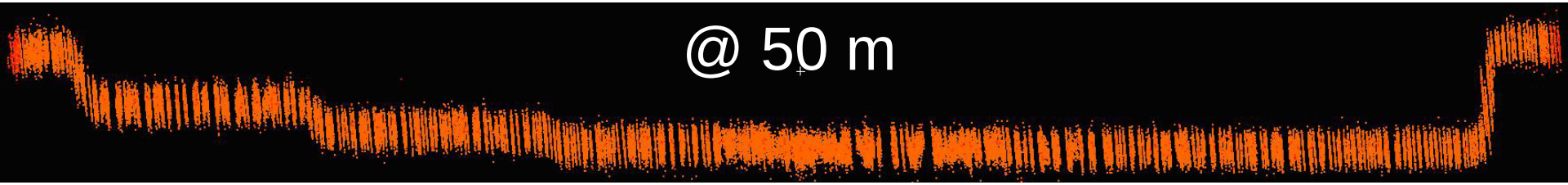
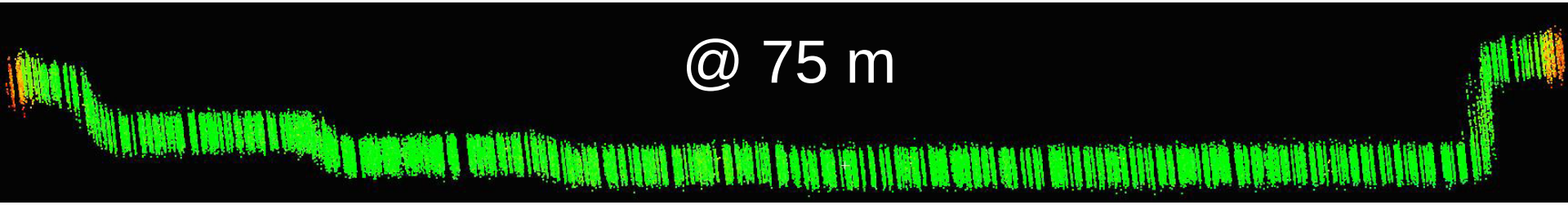
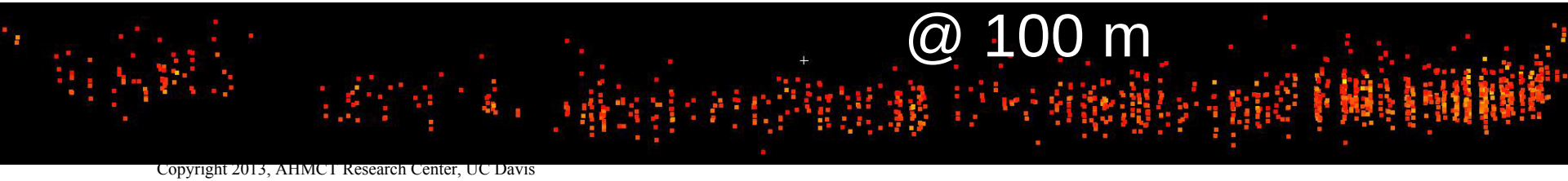
Leica ScanStation







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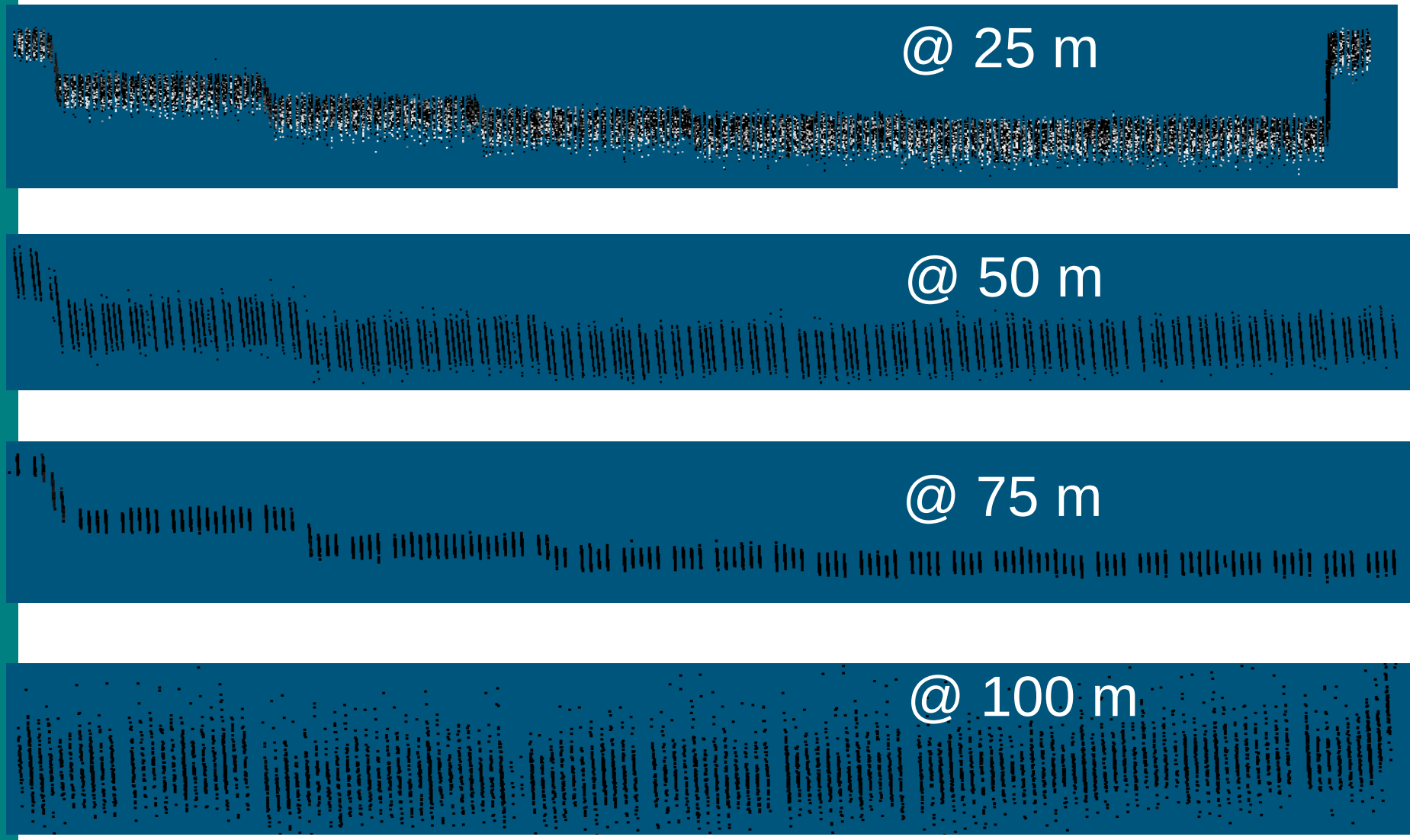
Trimble GX



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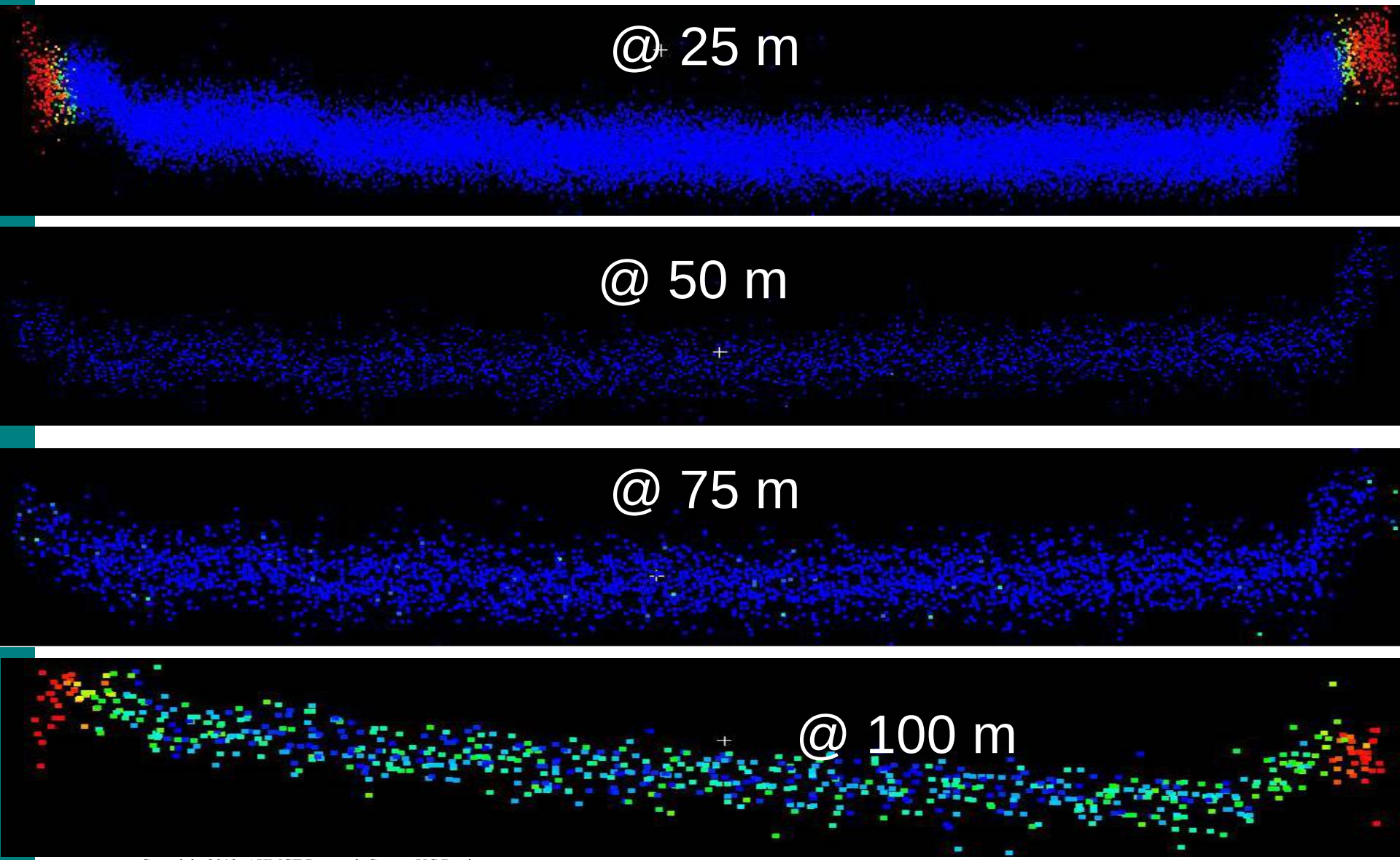

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Control Tests – Resolution

Test Fixture at 25, 50, 75, 100, and 120 m.
Measure resolution at selected ranges.
Two surface reflectivity levels

Resolution Test Fixture

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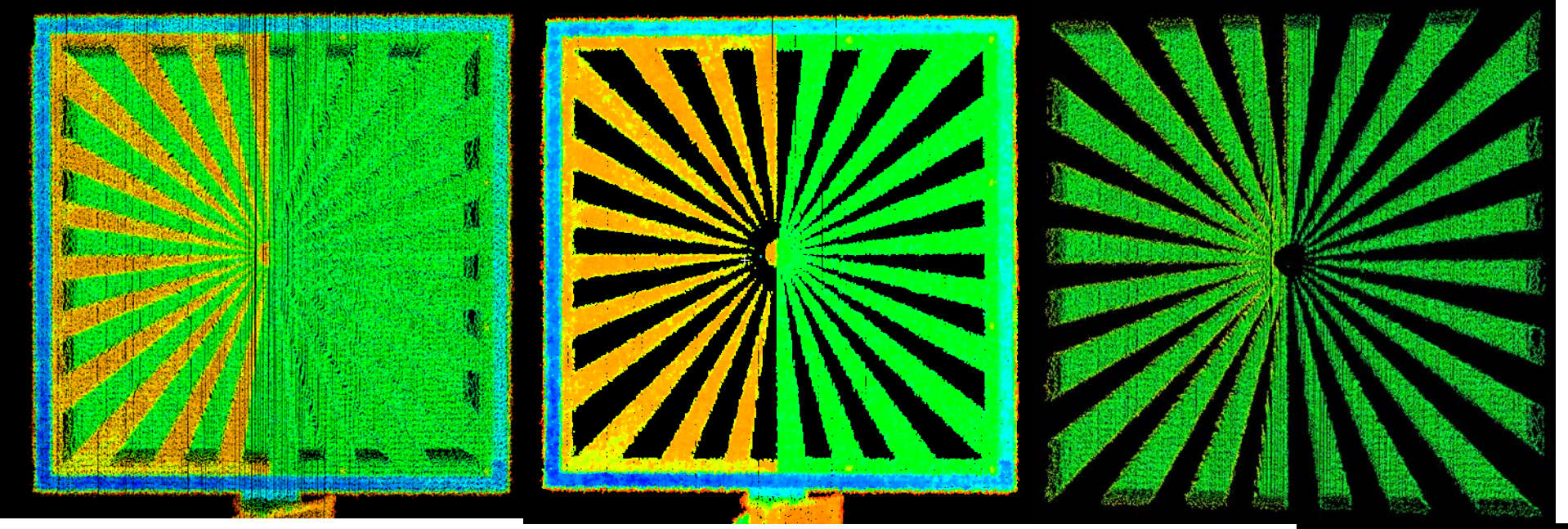
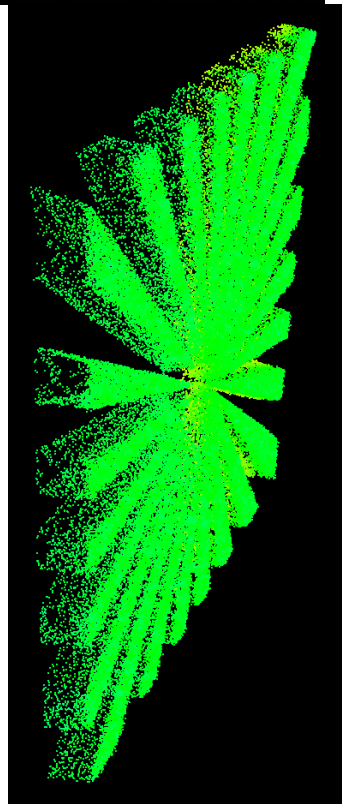


Leica, at 50 meters



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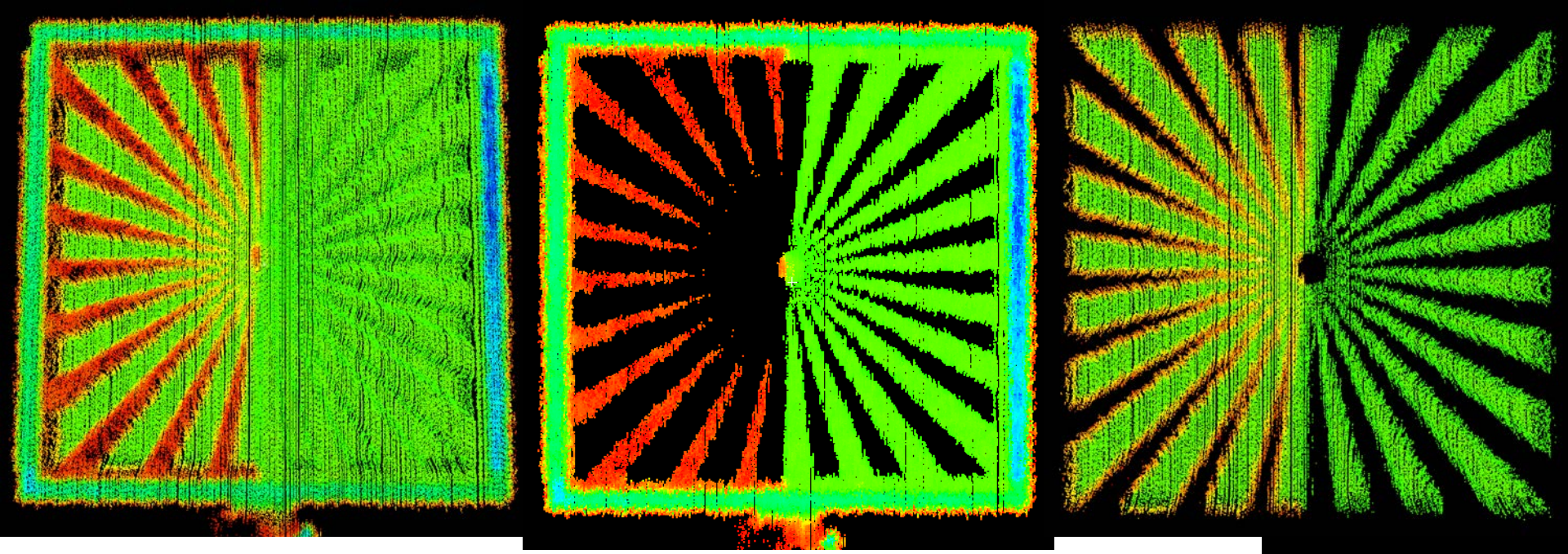
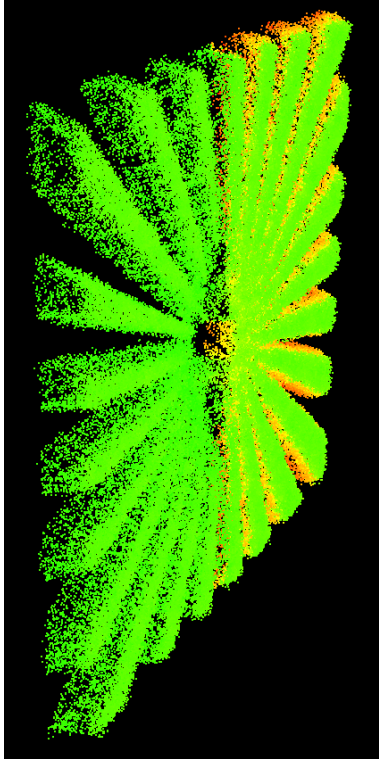


Leica, at 100 meters



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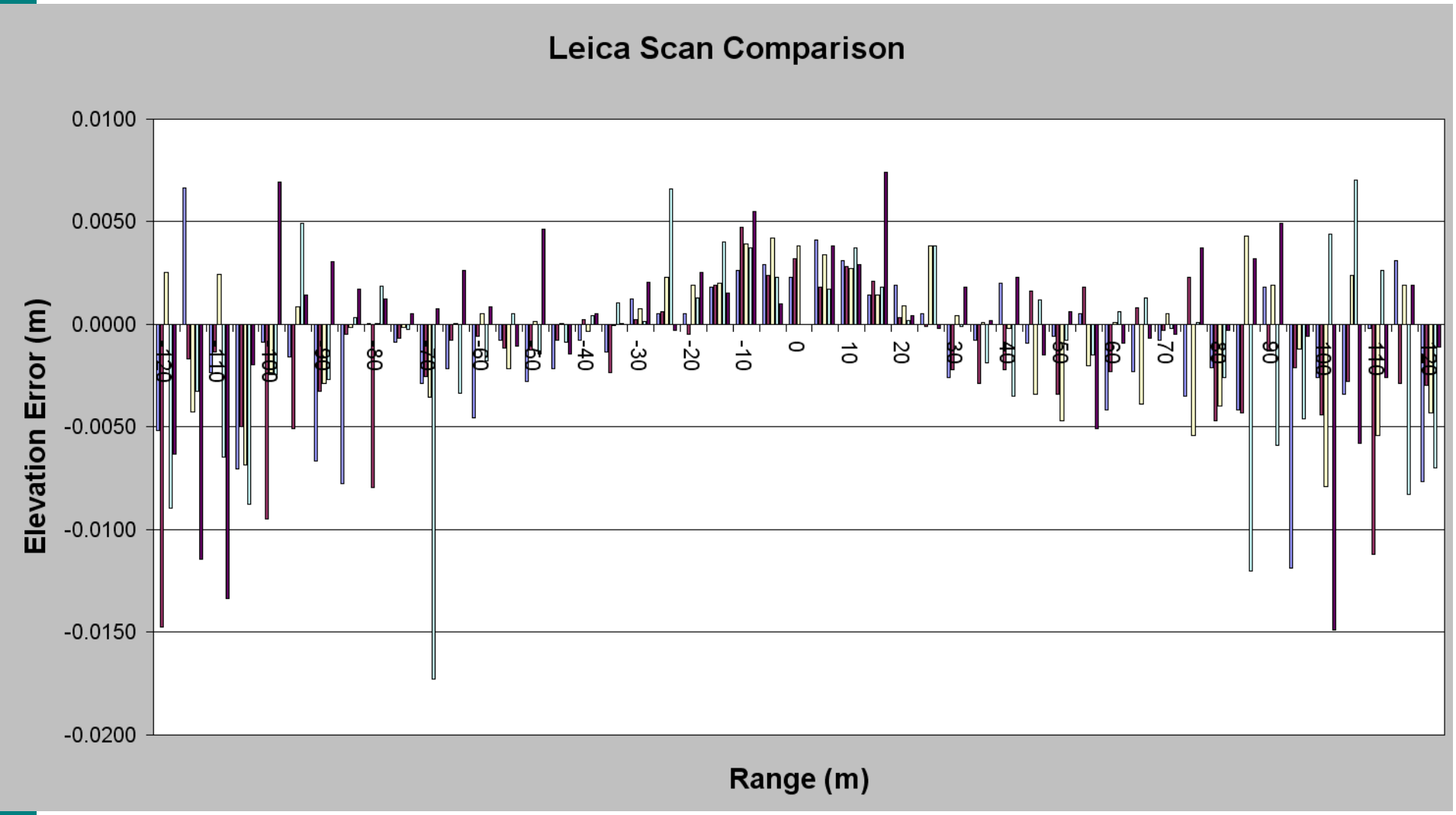
Leica, Air Temperature ~ 75° F



95% RMSE Elevation @ 90 m range = *7.2 mm*

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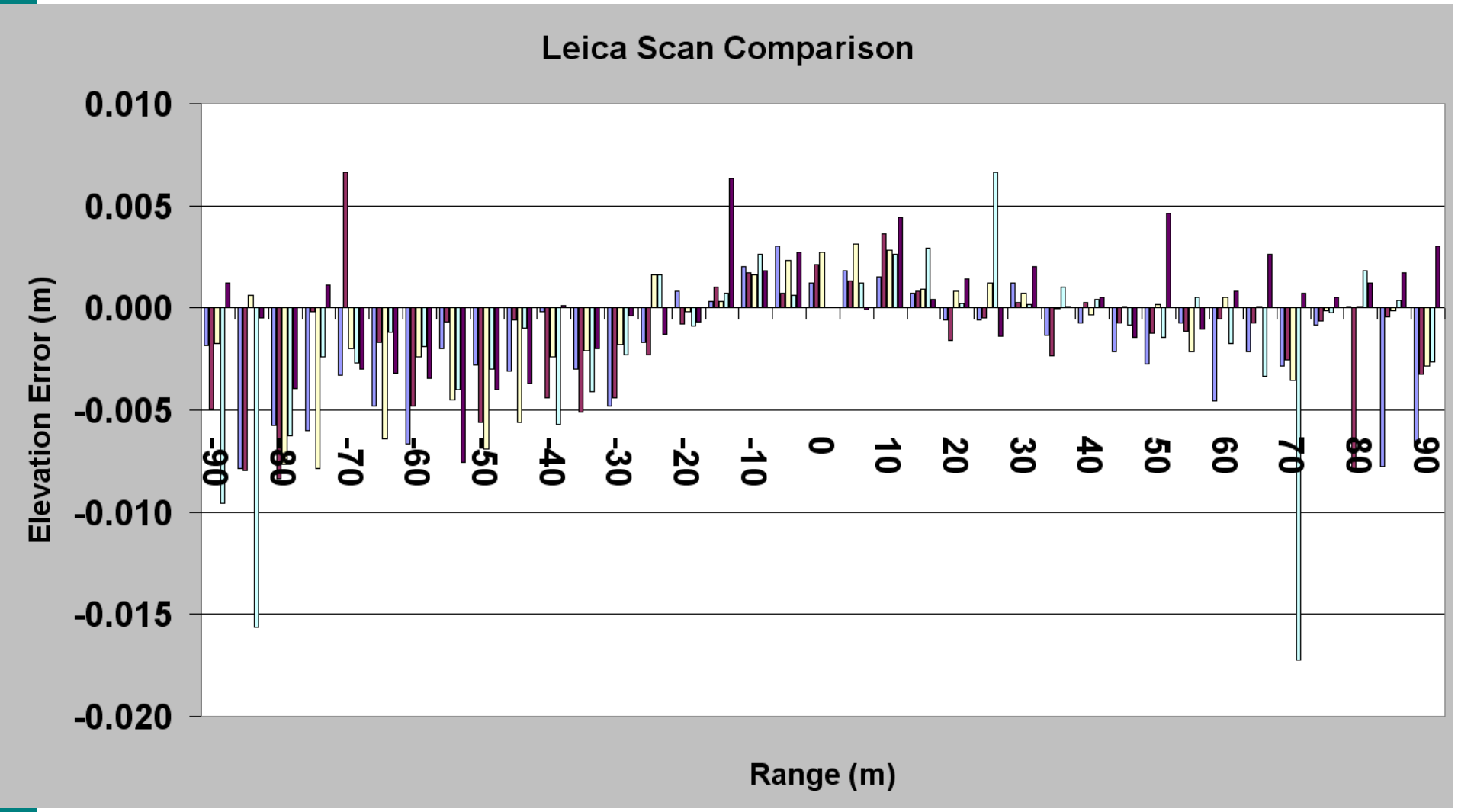
Leica, Air Temperature ~ 108° F



95% RMSE Elevation @ 90 m range = *7.0 mm*

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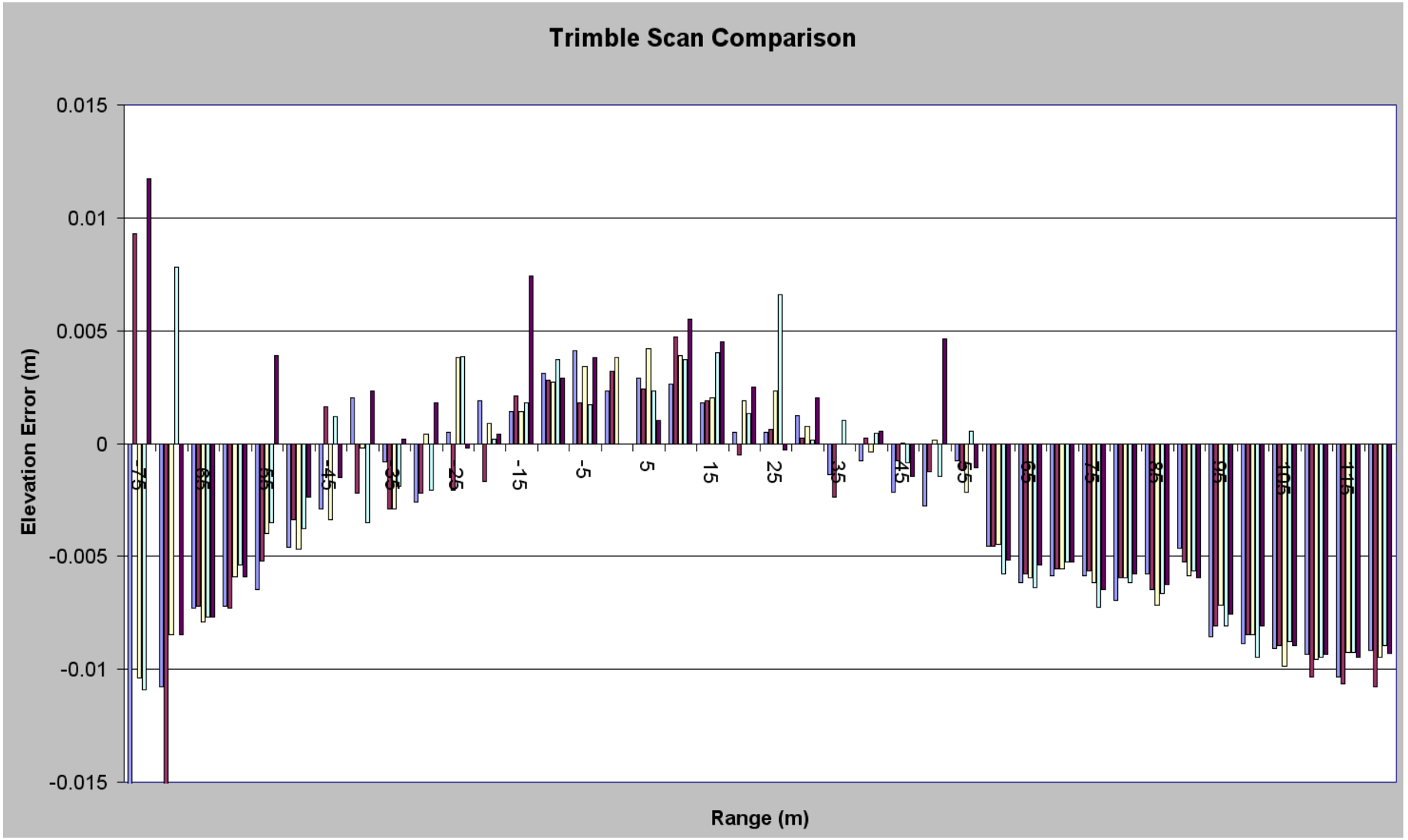
Trimble, Air Temperature ~ 108° F



95% RMSE Elevation @ 90 m range = *10.7 mm*

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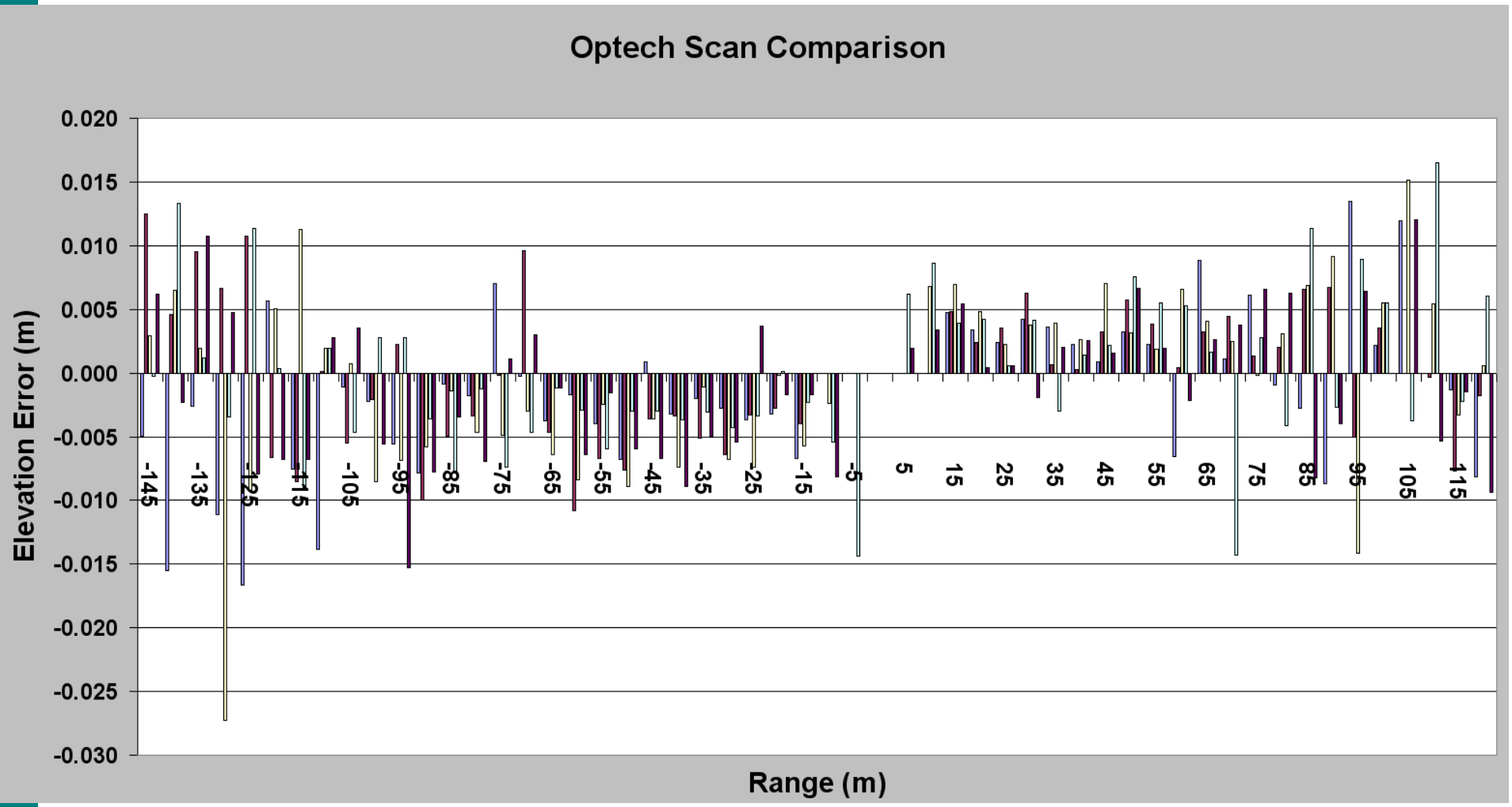
Optech, Air Temperature ~ 108° F



95% RMSE Elevation @ 90 m range = *12.0 mm*

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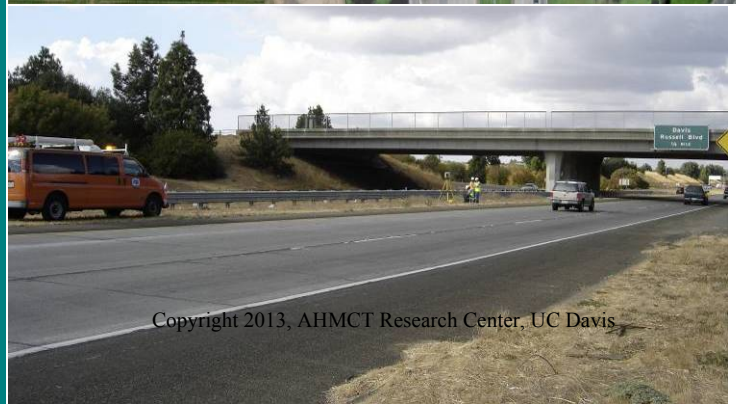
Pilot Study Test Site

3D Scan of section of Highway 113 at Hutchison Rd



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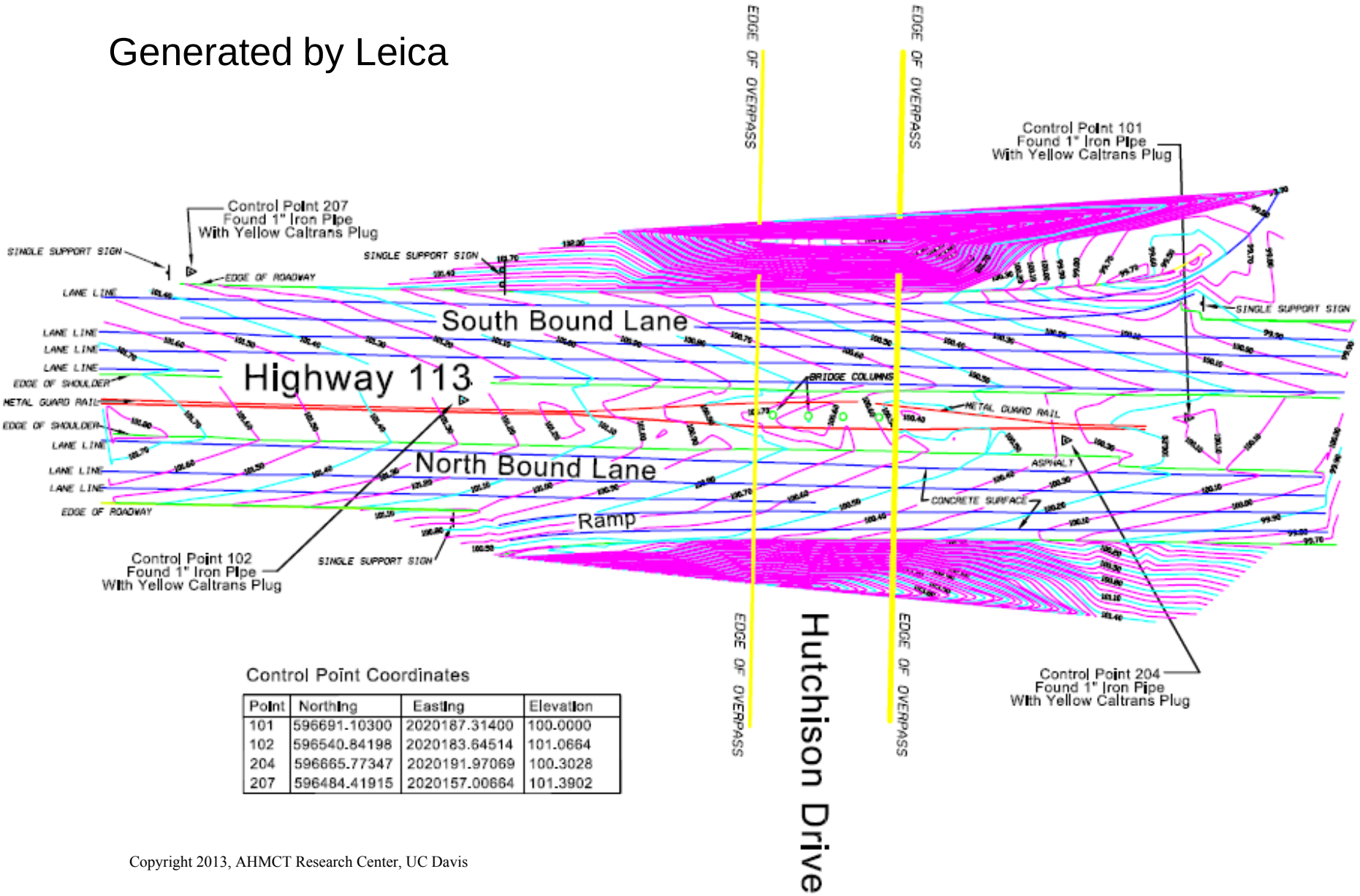
Pilot study goals:

- Evaluate pavement survey work-flow
- Compare data measured by conventional means
- Provide realistic data set for software evaluation
- Combine two point clouds
- Collect a 360 degree scan from each scan location
- Generate a Digital Terrain Model (DTM),
- Generate contour lines depicting the low-lying areas

Pilot Test Scan Area – Bridge with clover-leaf ramps and specific geo-reference points at 25 m, 50 m and 100 m on either side

Topographic map of State Highway 113 at Hutchison Drive

Generated by Leica



Control Point Coordinates

Point	Northing	Easting	Elevation
101	596691.10300	2020187.31400	100.0000
102	596540.84198	2020183.64514	101.0664
204	596665.77347	2020191.97069	100.3028
207	596484.41915	2020157.00664	101.3902

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Test Result Conclusions

- Scanner accuracy
- Scanner useful range
- Importance of accurate geo-referencing:
  - Methods
  - Redundant targets
  - Human error
- Compare to Total Station
  - With standard prism (2 mm + 2 ppm)
  - Reflectorless mode

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