UAV Flight Operations for Mapping

Precision. Accuracy. Reliability

SPATIAL ANALYTIX

AGENDA

Part One:

Why is Mapping different?

Part Two:

What about accuracy and precision?

Part Three:

What is the Workflow?

Part Four:

What do the results look like?

VISION

There are **known knowns**. These are things we know we know.

There are **known unknowns**. That is to say, there are things that we know we don't know.

But there are also **unknown unknowns**. ***These are the things we don't know we don't know.***

Donald Rumsfeld
(Former) Secretary of State

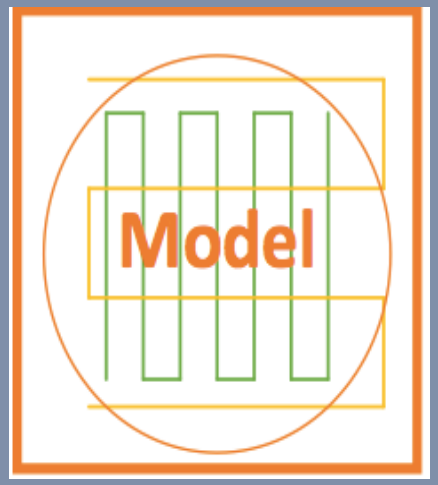
“ITS THE DATA, STUPID”

- Most vendors focus on the promise of automation.

“ITS THE DATA, STUPID”

THERE IS NO EASY BUTTON

Why Mapping is Different: Purpose

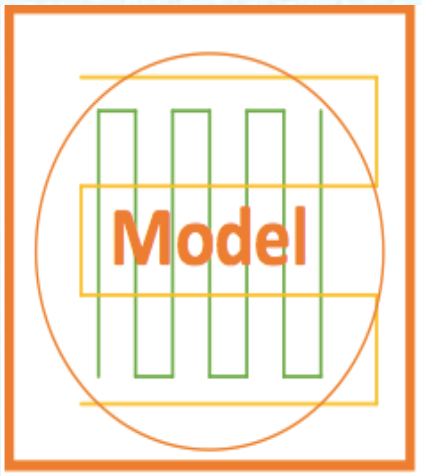


UAV MAPPING OVERVIEW

- Imagery
- Video

- Orthos
- Point Cloud*
- DSM
- DEM
- Planimetrics

- Analytics



- 3D Objects
- Point Cloud*
- Obliques

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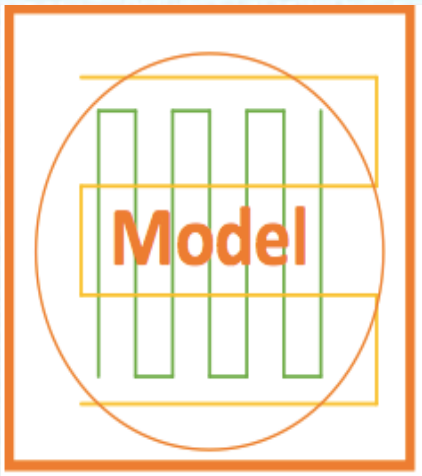
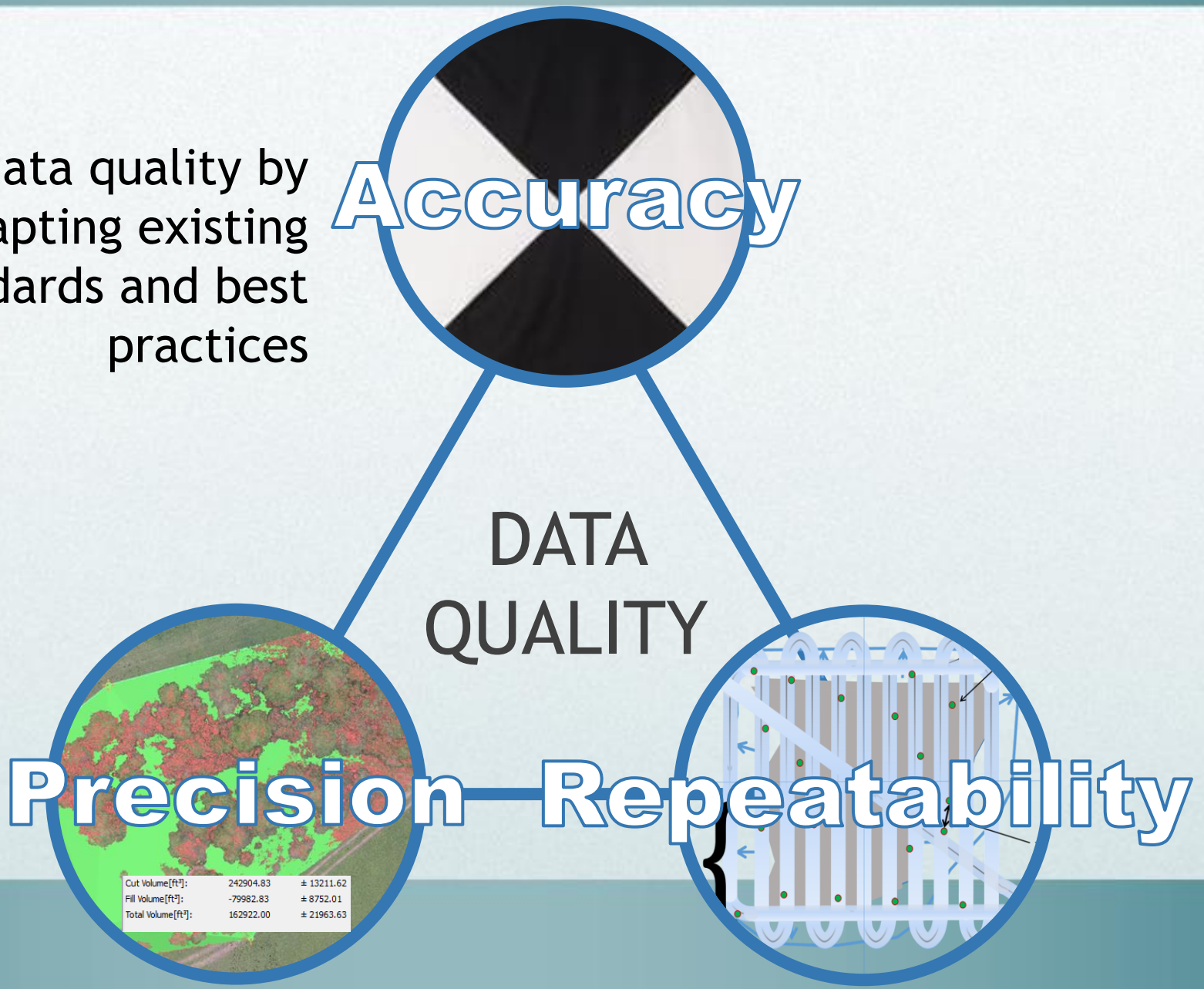
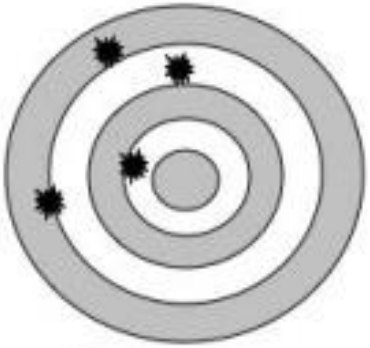


- 3D Objects
- Point Cloud*
- Obliques

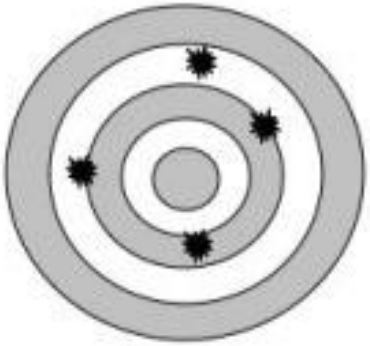
DATA QUALITY TRIANGLE

Ensure data quality by adapting existing standards and best practices



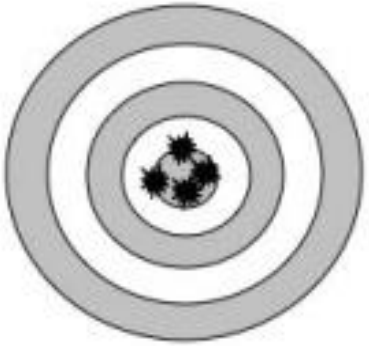


Not Accurate
Not Precise

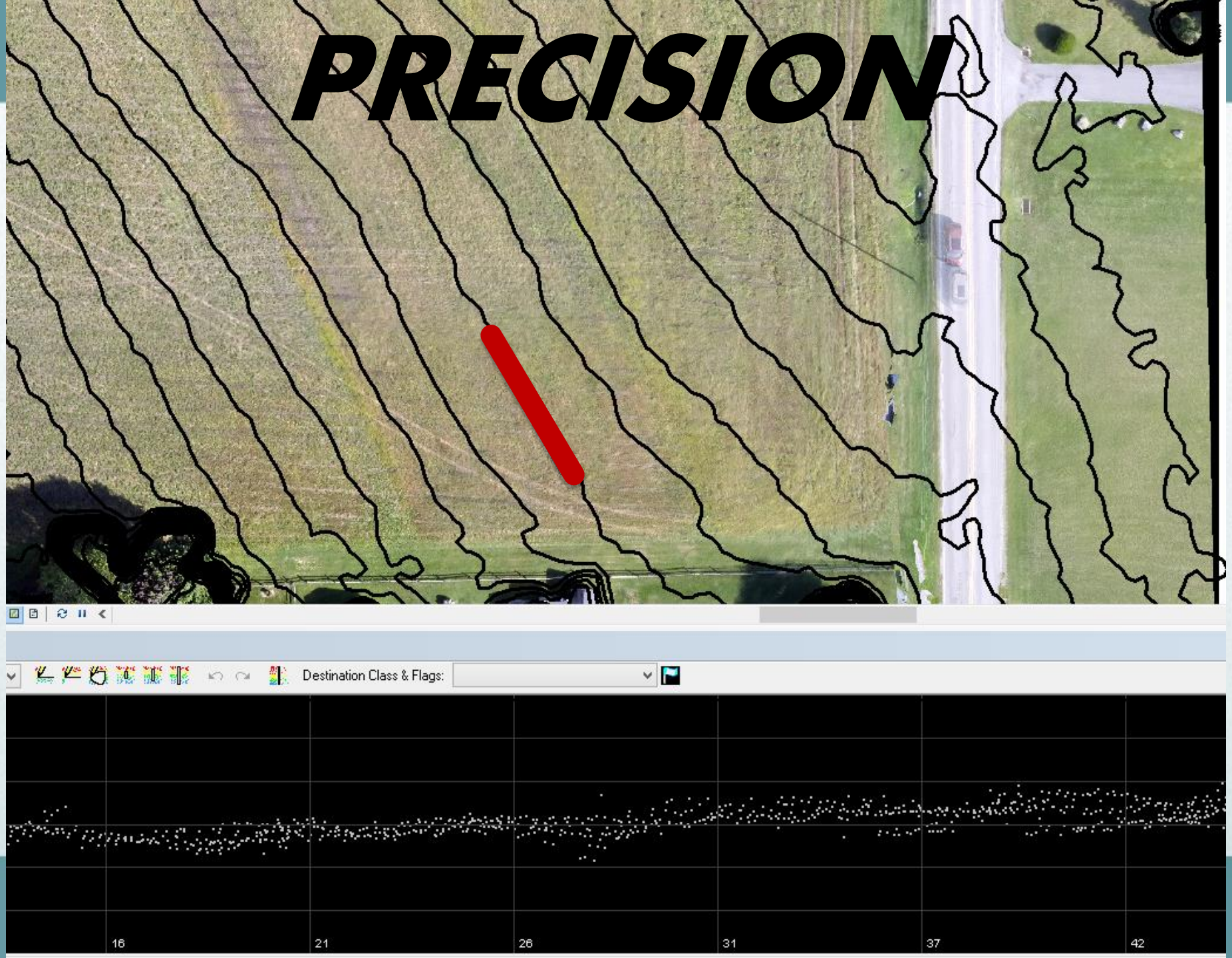


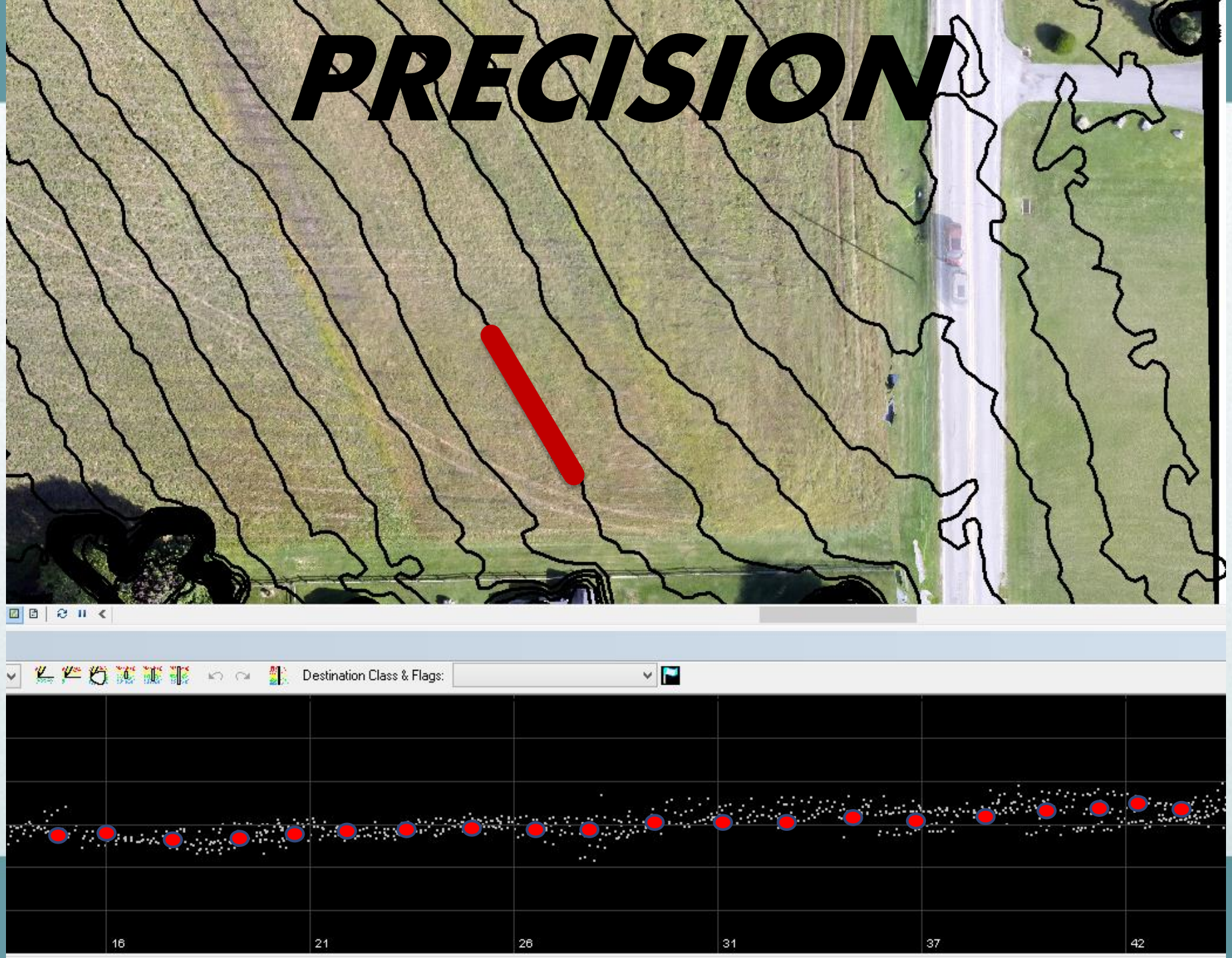
Accurate
Not Precise

Not Accurate
Precise



Accurate
Precise


PRECISION
Destination Class & Flags:
16
21
26
31
37
42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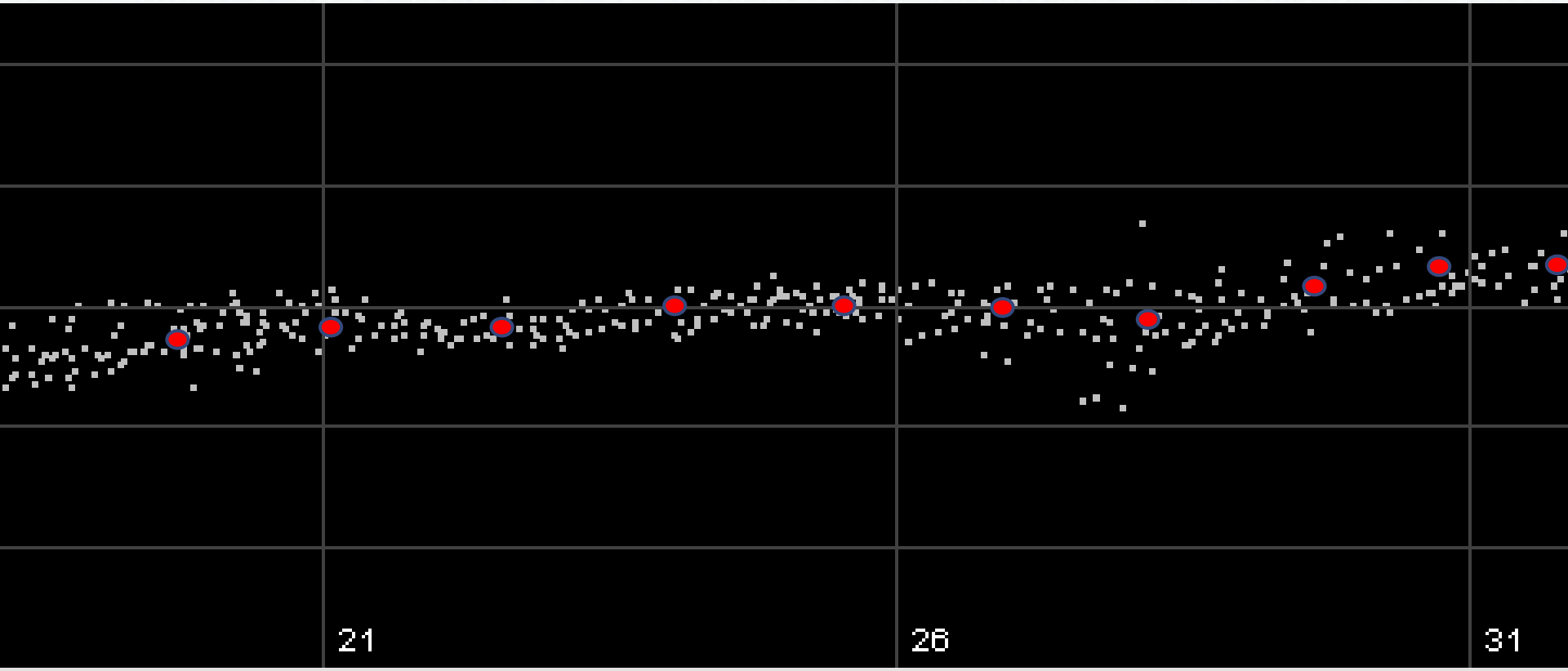
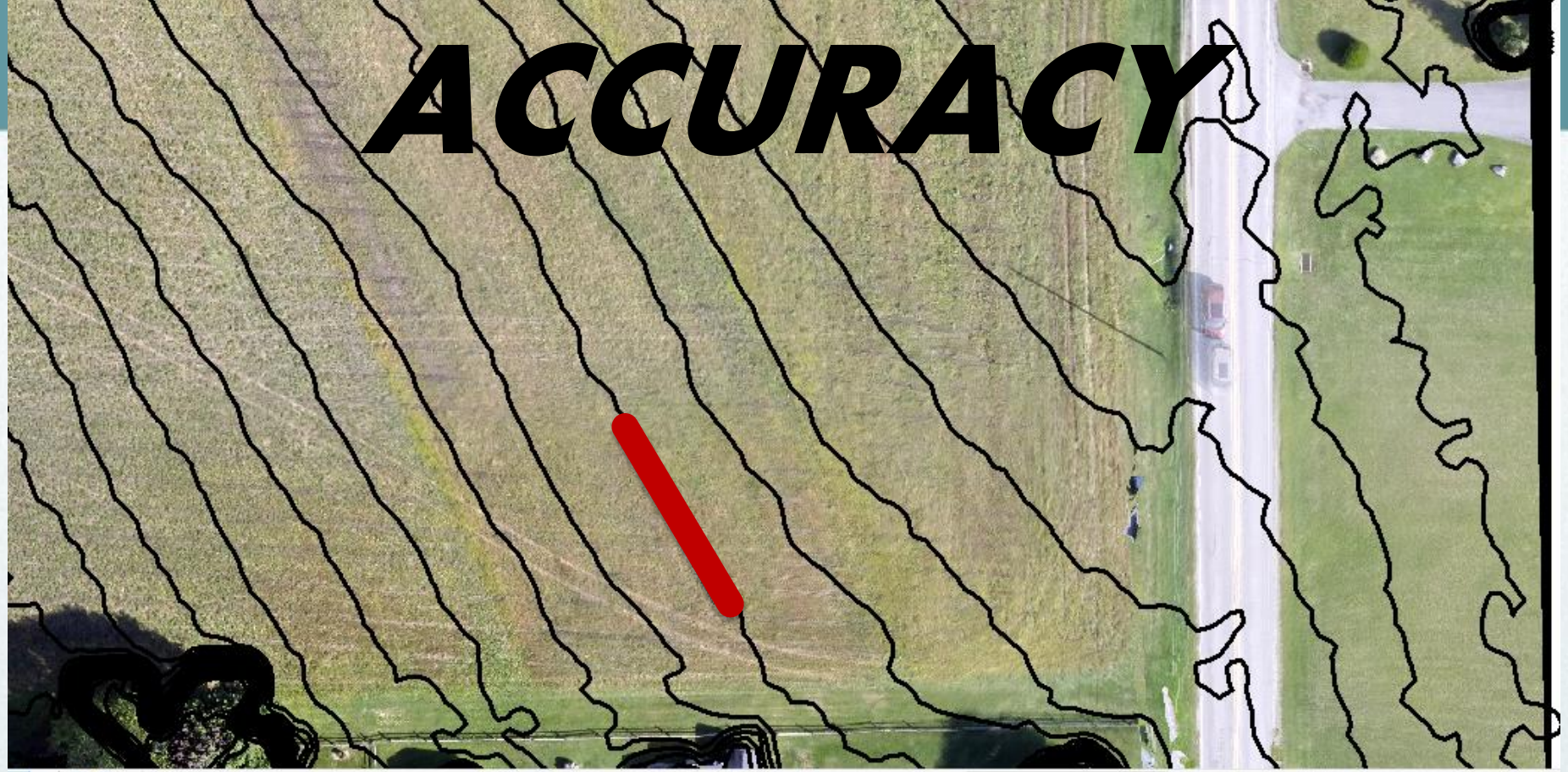
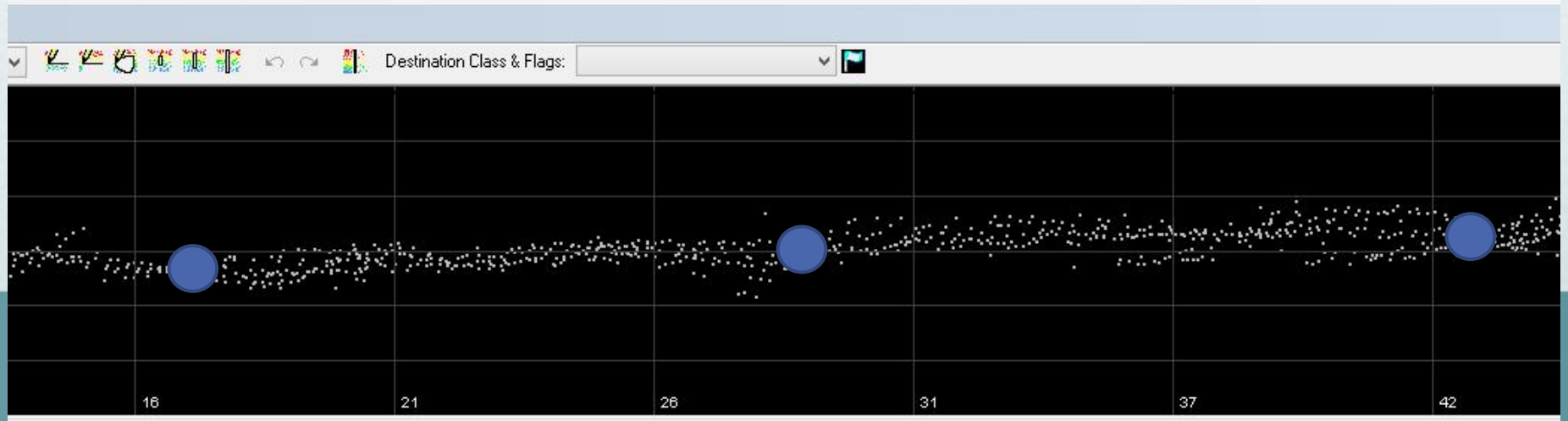
PRECISION



ACCURACY





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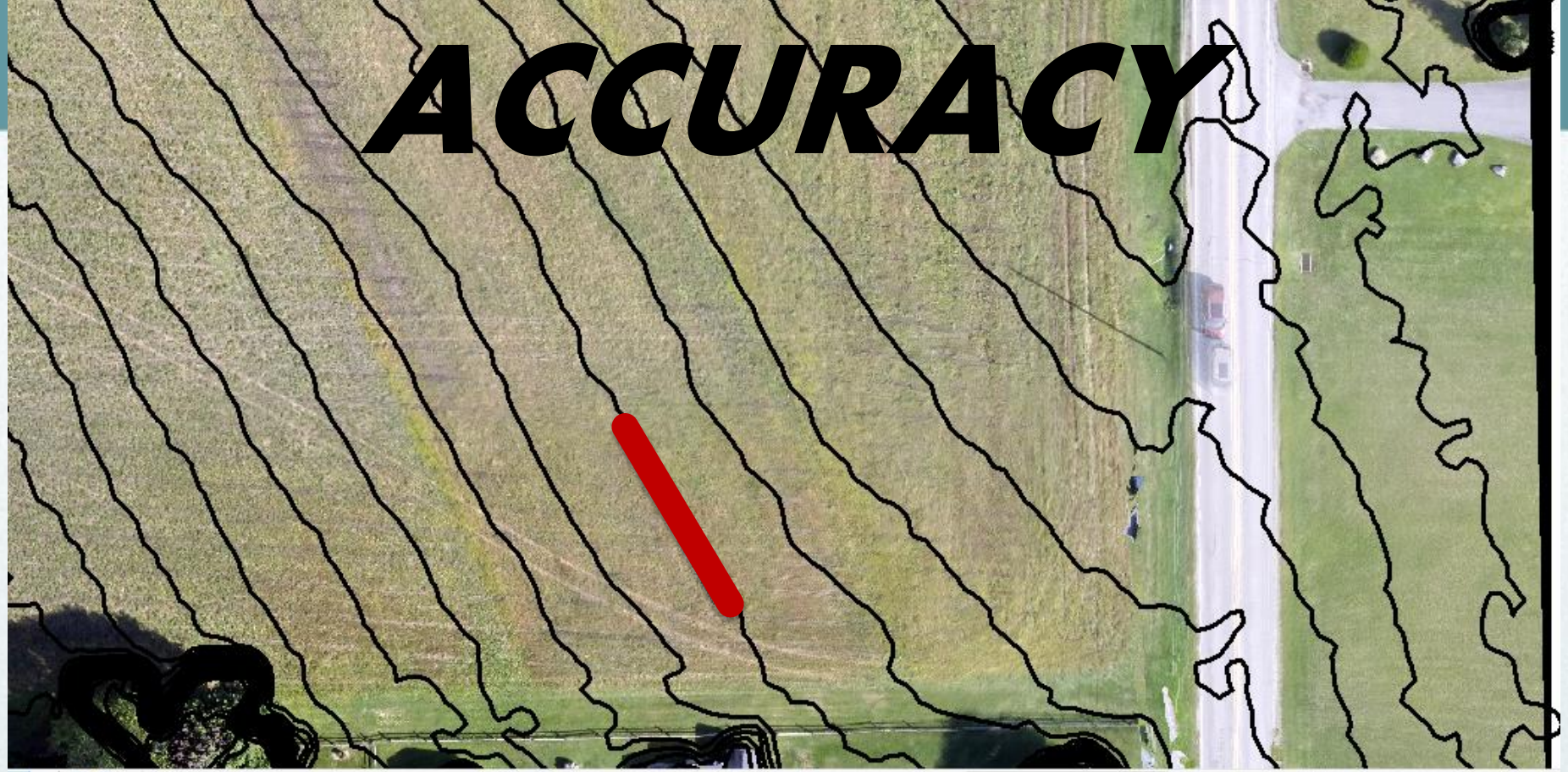
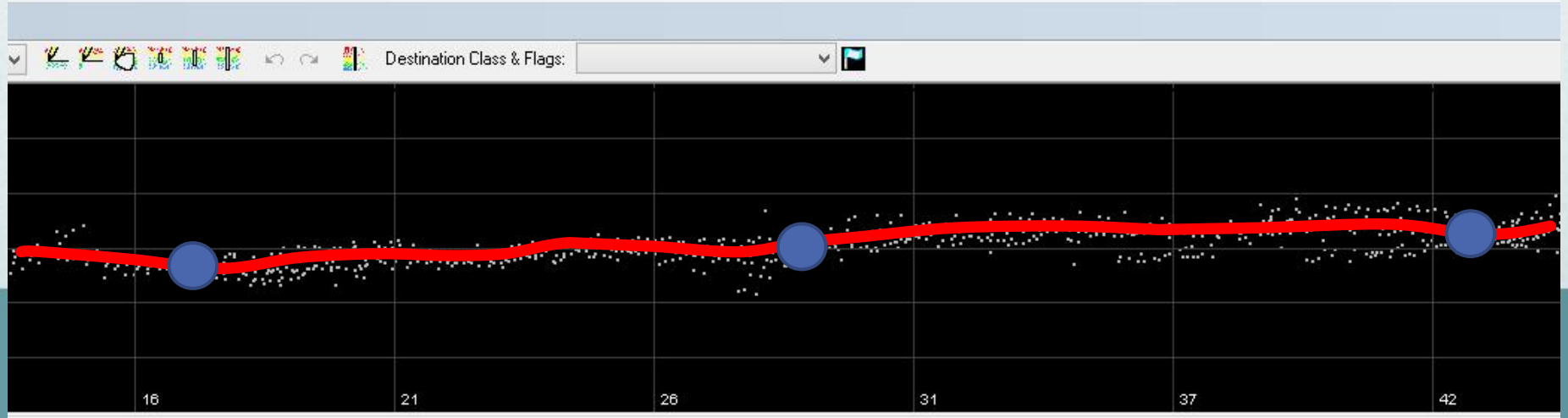
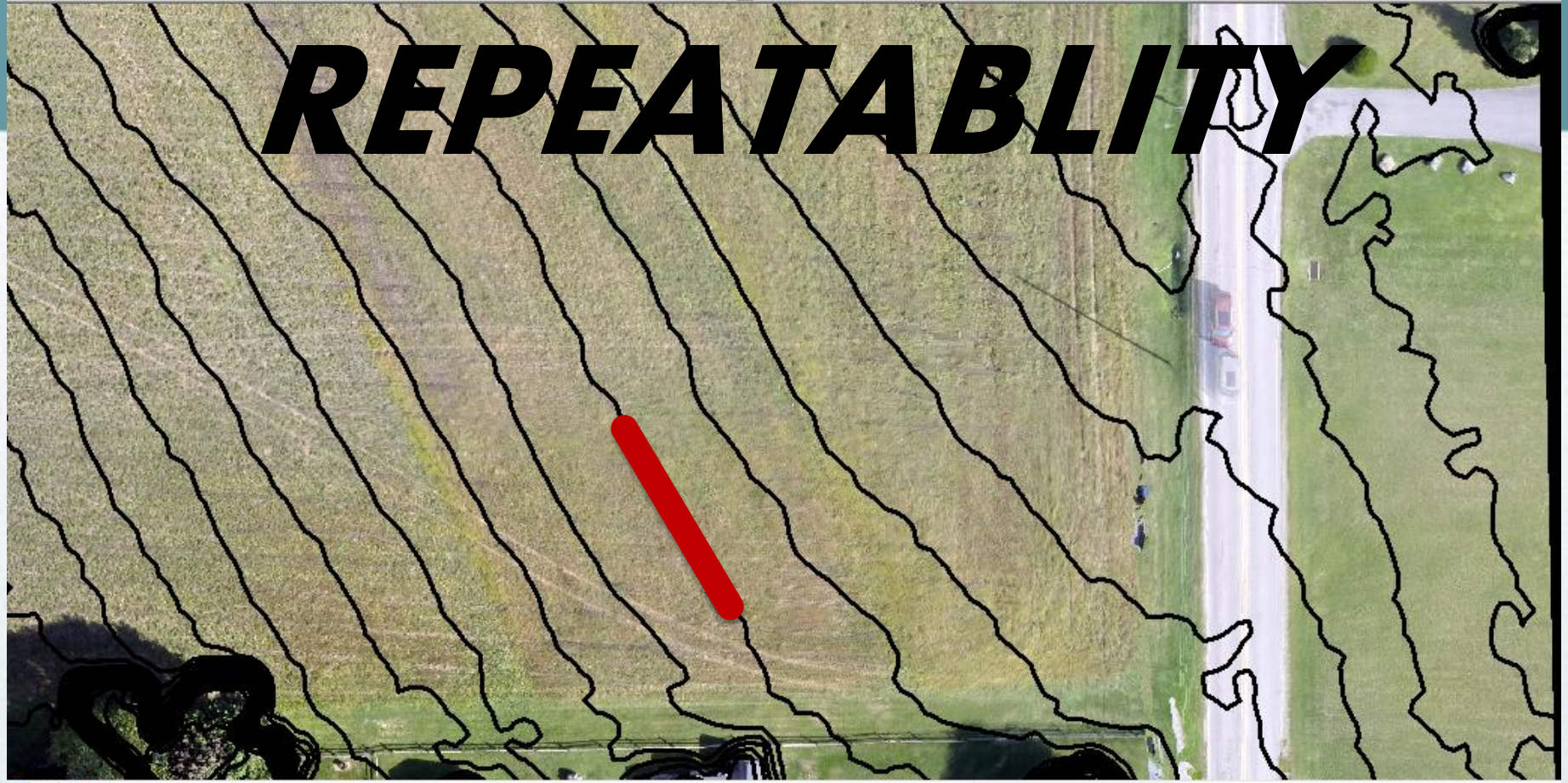
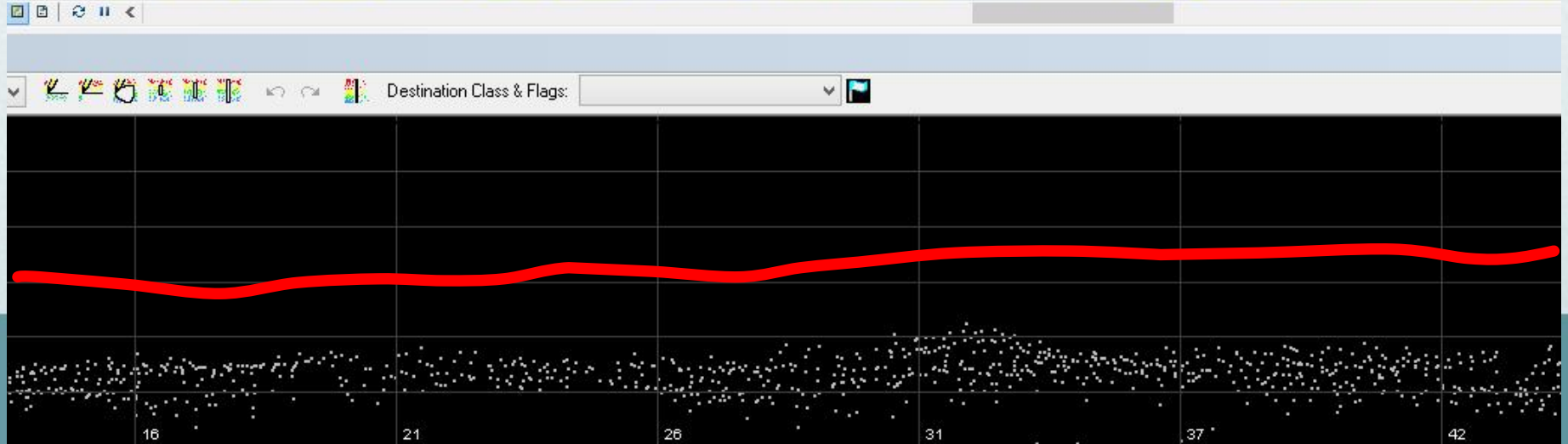




REPEATABLITY





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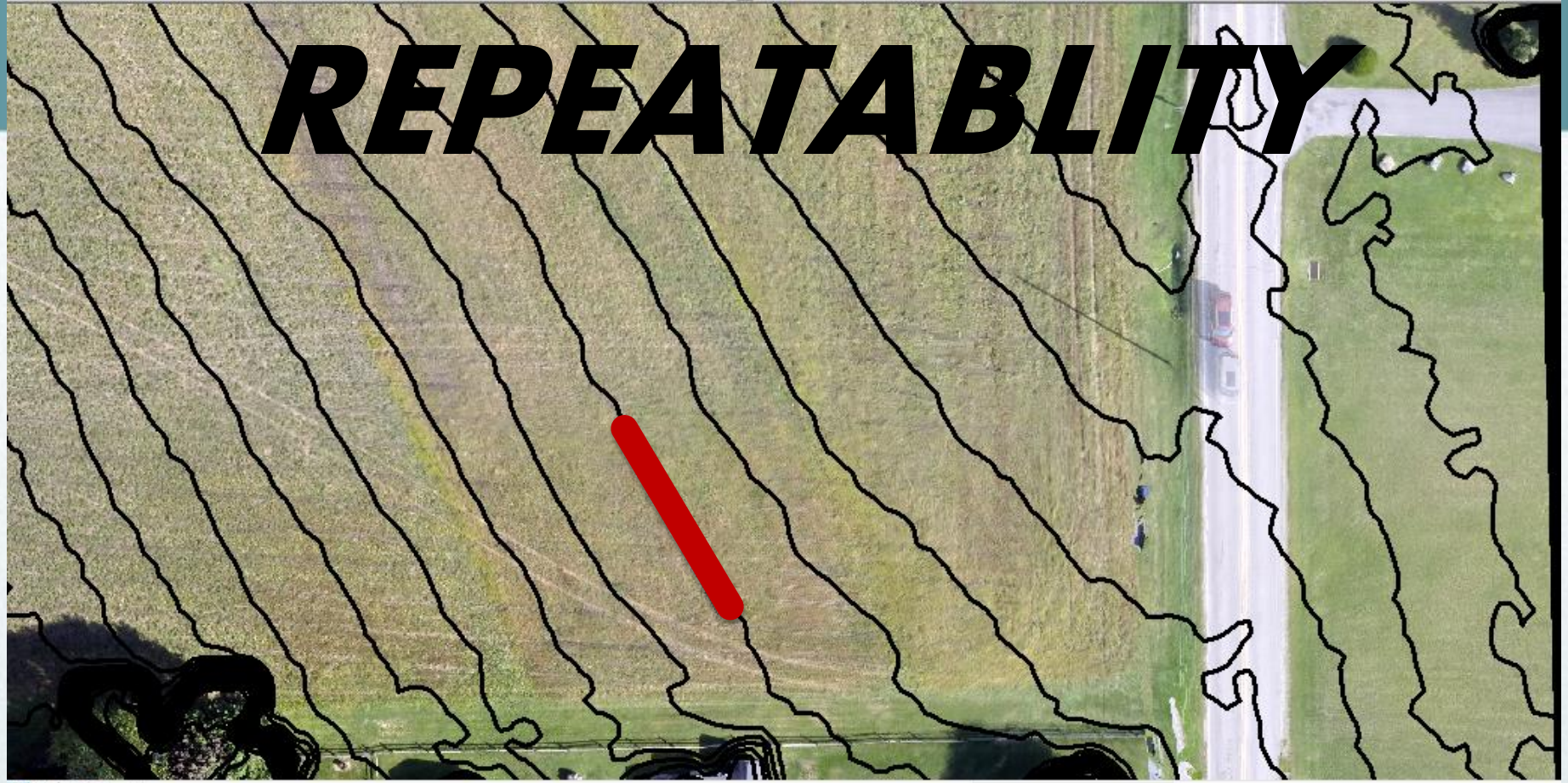
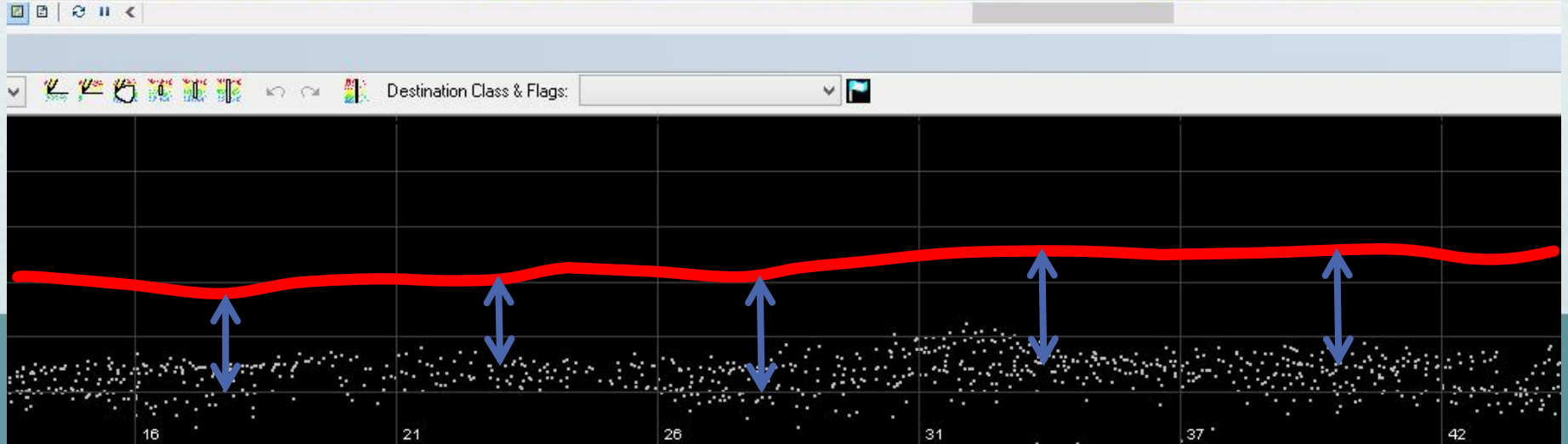




United States National Map Accuracy Standards

With a view to the utmost economy and expedition in producing maps which fulfill not only the broad needs for standard or principal maps, but also the reasonable particular needs of individual agencies, standards of accuracy for published maps are defined as follows:

1. **Horizontal accuracy.** For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as bench marks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings); etc. In general what is well defined will be determined by what is plottable on the scale of the map within 1/100 inch. Thus while the intersection of two road or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would obviously not be practicable within 1/100 inch. Similarly, features not identifiable upon the ground within close limits are not to be considered as test p
quoted, even though their positions may be scaled closely upon the map. I
timber lines, soil boundaries, etc.
2. **Vertical accuracy,** as applied to contour maps on all publication scales
more than 10 percent of the elevations tested shall be in error more tha
interval. In checking elevations taken from the map, the apparent vertical
by assuming a horizontal displacement within the permissible horizontal
scale.
3. **The accuracy of any map may be tested** by comparing the positions of
or elevations are shown upon it with corresponding positions as determine
accuracy. Tests shall be made by the producing agency, which shall also
maps are to be tested, and the extent of the testing.
4. **Published maps meeting these accuracy requirements** shall note this f
follows: "This map complies with National Map accuracy Standards."
5. **Published maps whose errors exceed those aforestated** shall omit
mention of standard accuracy.
6. **When a published map is a considerable enlargement** of a map drawi
published map, that fact shall be stated in the legend. For example, "This
of a 1:20,000-scale map drawing," or "This map is an enlargement of a 1:24,000-scale published map."
7. **To facilitate ready interchange and use of basic information for map construction** among all Federal mapmaking agencies, manuscript maps and published maps, wherever economically feasible and consistent with the uses to which the map is to be put, shall conform to latitude and longitude boundaries, being 15 minutes of latitude and longitude, or 7.5 minutes, or 3-3/4 minutes in size.

Issued June 10, 1941
Revised April 26, 1943
Revised June 17, 1947

U.S. BUREAU OF THE BUDGET

Issued June 10, 1941
Revised April 26, 1943
Revised June 17, 1947

Standards

NSSDA and NMAS

NMAS- 1947

- Paper Map produced at a certain scale
- Not appropriate to use for digital data
- “2 foot accuracy” and “1 foot accuracy” terms are still WIDELY used

NSSDA – 1998

- Applies to raster, point or vector data
- Must compare your data against a “reference”
- Reference must be 3x more accurate
- RMSE vs 95% Accuracy

More Recent (relevant) History

2003 FEMA Appendix A: Guidance for Aerial Mapping and Surveying of the Guidelines and Specifications for Flood Hazard Mapping Partners

2004 NDEP Guidelines for Digital Elevation Data

2004 ASPRS Guidelines: Vertical Accuracy Reporting for LiDAR

2009 USGS Base Lidar Specification for projects funded under ARRA

2010 Procedure Memorandum No. 61 – Standards for Lidar and Other High Quality Digital Topography

2012 USGS LiDAR Base Specification Version 1.0 (NGP)

2012 USGS National Enhanced Elevation Data Assessment

2014 ASPRS Accuracy Standards for Digital Geospatial Data

NSSDA vs NMAS

- NMAS Contour Interval = 3.2898*RMSE(z)
- NMAS Contour Interval = Accuracy(z)/0.5958

Note that Accuracy (z) is based on 95% CI, a statistical calculation.

NMAS Equivalent Contour Interval (in feet)	NSSDA RMSE(z)	NSSDA Accuracy(z)	Required Accuracy for Reference Data for "Tested to Meet"
0.5	0.15 ft or 4.60 cm	0.30 ft or 9.10 cm	0.10 ft
1	0 30 ft or 9.25 cm	0.60 ft or 18.2 cm	0.20 ft
2	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm	0.40 ft
4	1.22 ft or 37.0 cm	2.38 ft or 72.6 cm	0.79 ft
5	1.52 ft or 46.3 cm	2.98 ft or 90.8 cm	0.99 ft
10	3.04 ft or 92.7 cm	5.96 ft or 181.6 cm	1.98 ft

The fourth column in this table refers to the NSSDA Accuracy required for **Reference Data or Checkpoints** to be used in assessing data Accuracy

Standards

TABLE B.8 VERTICAL ACCURACY OF THE NEW ASPRS 2014 STANDARD COMPARED WITH LEGACY STANDARDS

Vertical Accuracy Class	$RMSE_z$ Non-Vegetated (cm)	Equivalent Class 1 contour interval per ASPRS 1990 (cm)	Equivalent Class 2 contour interval per ASPRS 1990 (cm)	Equivalent contour interval per NMAS (cm)
1-cm	1.0	3.0	1.5	3.29
2.5-cm	2.5	7.5	3.8	8.22
5-cm	5.0	15.0	7.5	16.45
10-cm	10.0	30.0	15.0	32.90
15-cm	15.0	45.0	22.5	49.35
20-cm	20.0	60.0	30.0	65.80
33.3-cm	33.3	99.9	50.0	109.55
66.7-cm	66.7	200.1	100.1	219.43
100-cm	100.0	300.0	150.0	328.98
333.3-cm	333.3	999.9	500.0	1096.49

Surface Modeling from Point Clouds

- FEMA- NPS should be equal to or less than the DEM post spacing (resolution) required

- 1-meter DEM for 1ft contours
- 2-meter DEM for 2ft contours
- 5-meter DEM for 5ft contours

- 0.7 NPS -> 1m DEM -> 1ft contours (QL 2)
- 1.4 NPS -> 2m DEM -> 2 ft contours (QL 3)

Note: Higher density data may still fail vertical RMSE test

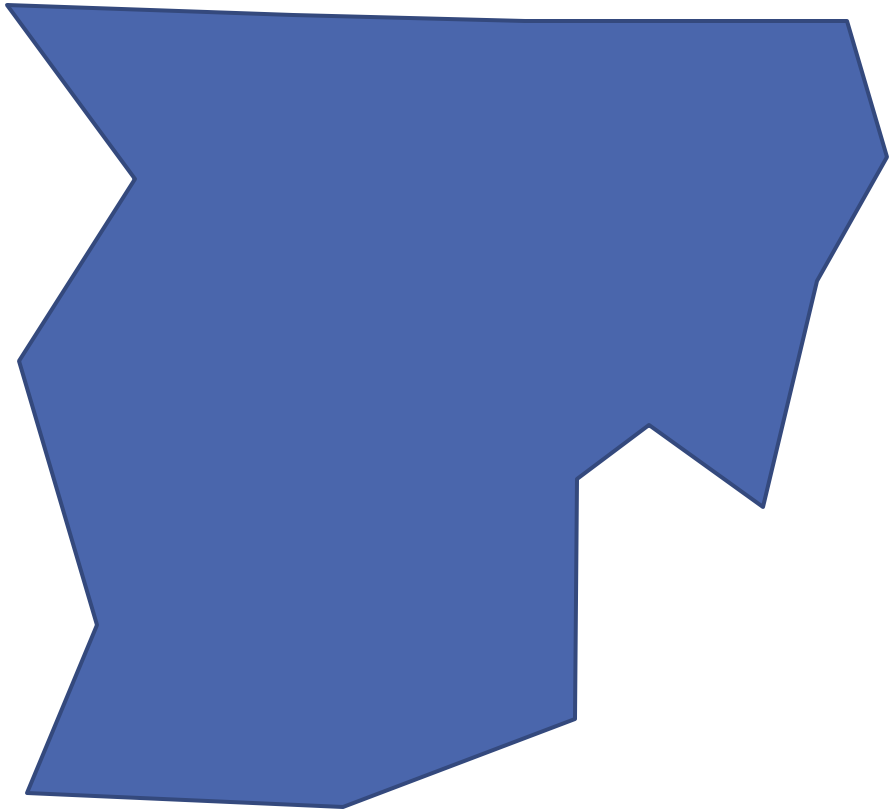
Lower density data may meet higher accuracy tests.

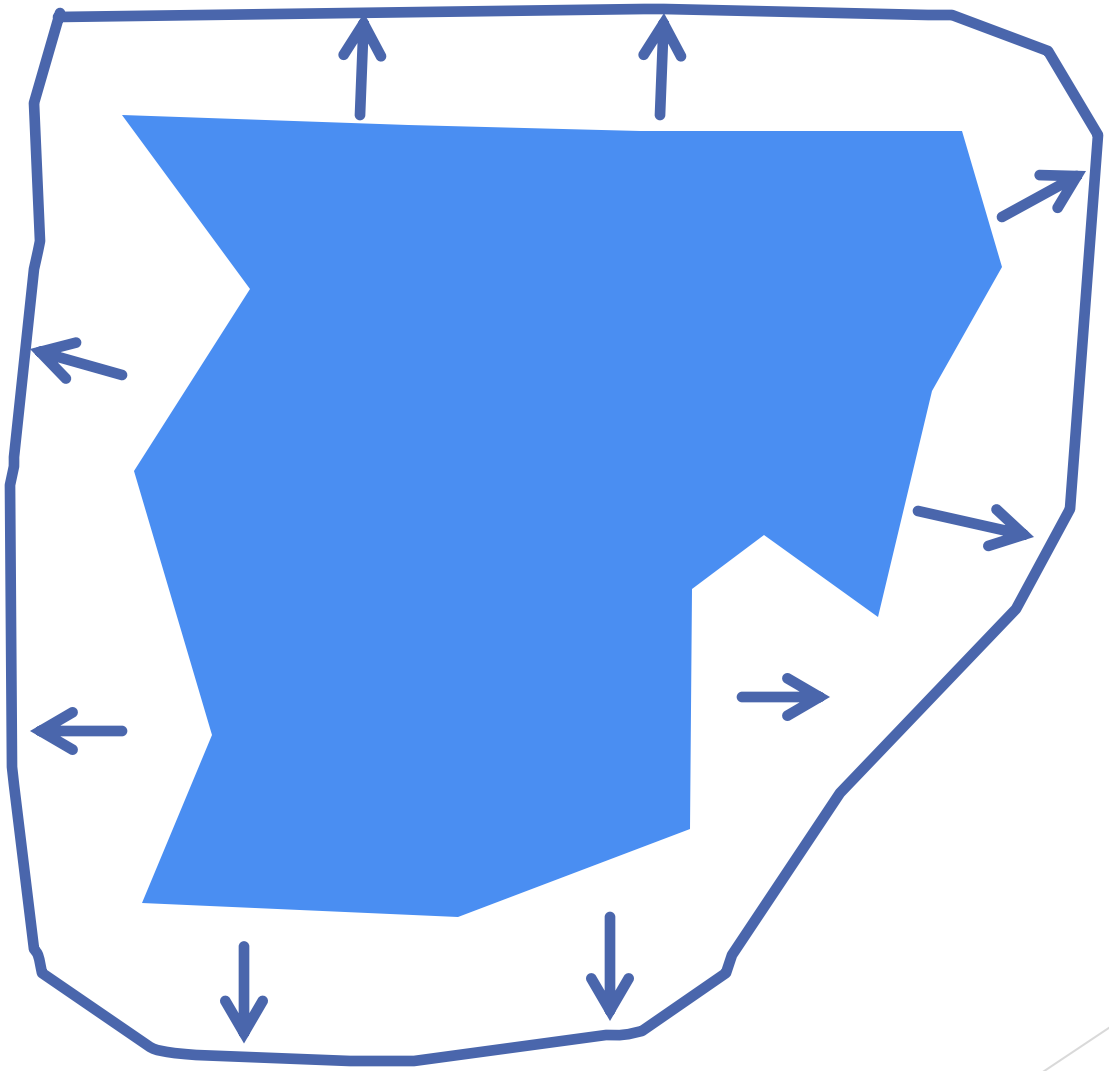
Accuracy is tested from a sample of points against the surface model, regardless of the point cloud density

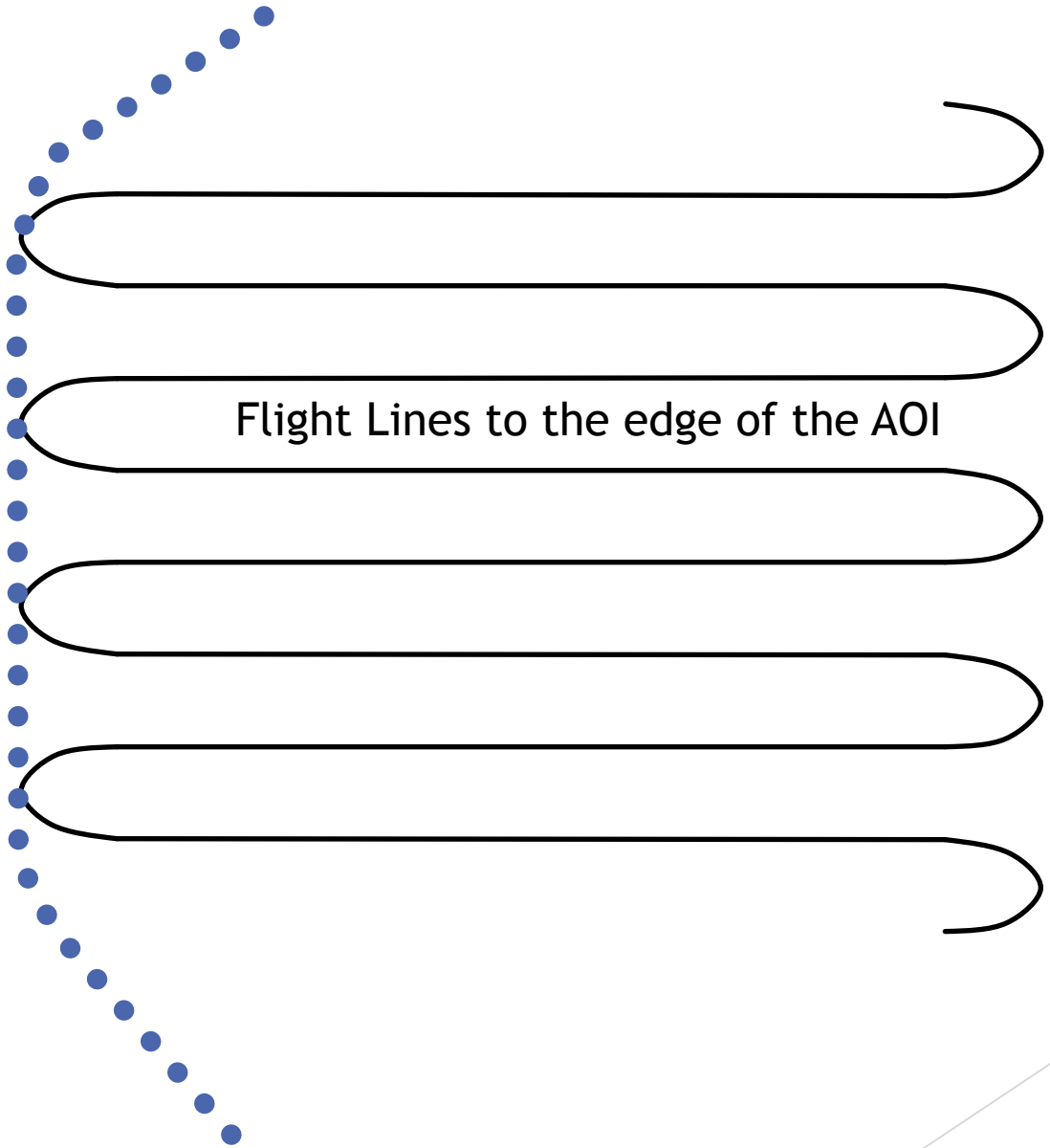
Standards

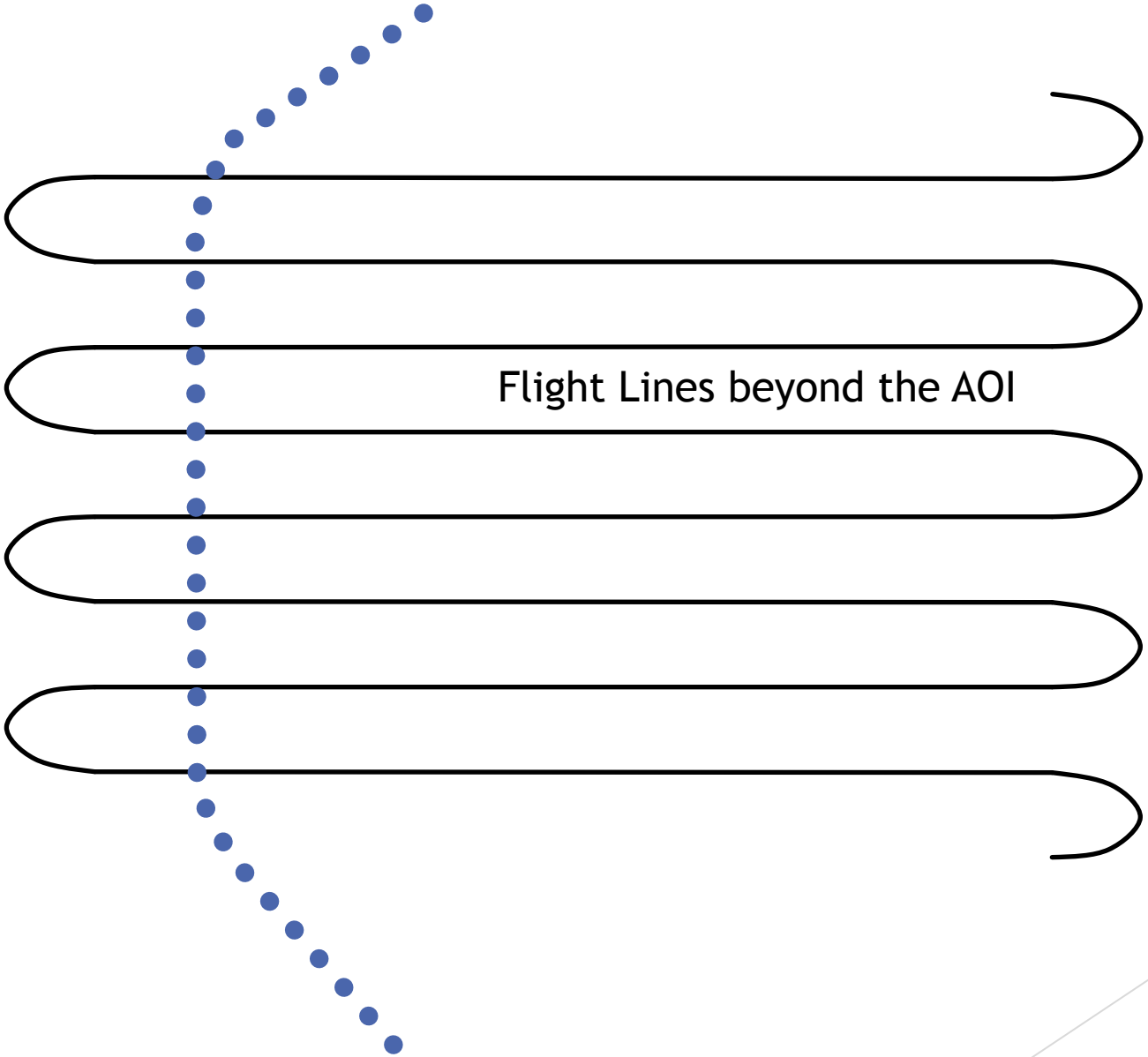
TABLE B.6 HORIZONTAL ACCURACY/QUALITY EXAMPLES FOR HIGH ACCURACY DIGITAL PLANIMETRIC DATA

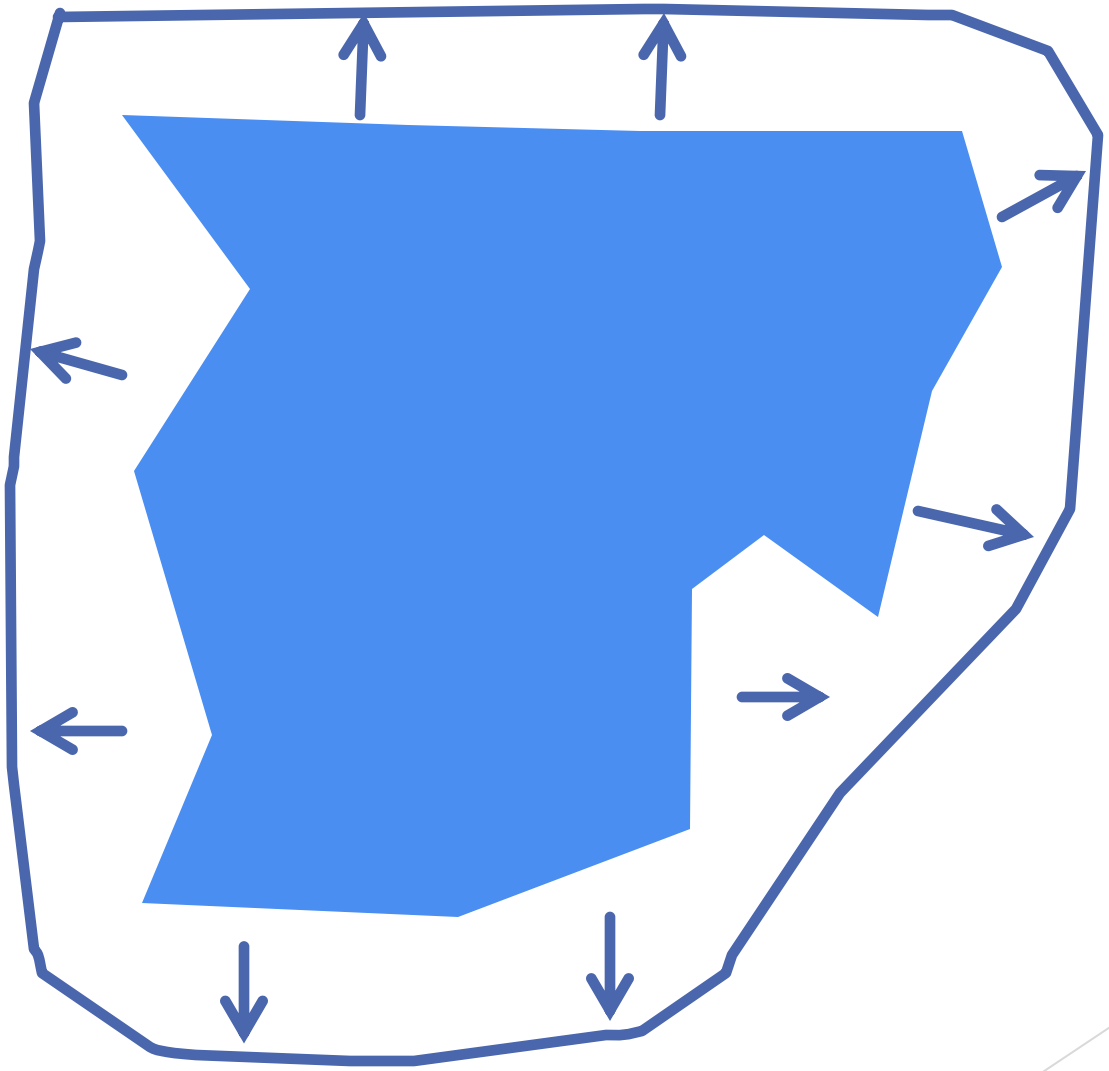
ASPRS 2014				Equivalent to map scale in		
Horizontal Accuracy Class $RMSE_x$ and $RMSE_y$ (cm)	$RMSE_r$ (cm)	Horizontal Accuracy at the 95% Confidence Level (cm)	Approximate GSD of Source Imagery (cm)	ASPRS 1990 Class 1	ASPRS 1990 Class 2	Equivalent to map scale in NMAS
0.63	0.9	1.5	0.31 to 0.63	1:25	1:12.5	1:16
1.25	1.8	3.1	0.63 to 1.25	1:50	1:25	1:32
2.5	3.5	6.1	1.25 to 2.5	1:100	1:50	1:63
5.0	7.1	12.2	2.5 to 5.0	1:200	1:100	1:127
7.5	10.6	18.4	3.8 to 7.5	1:300	1:150	1:190
10.0	14.1	24.5	5.0 to 10.0	1:400	1:200	1:253
12.5	17.7	30.6	6.3 to12.5	1:500	1:250	1:317
15.0	21.2	36.7	7.5 to 15.0	1:600	1:300	1:380
17.5	24.7	42.8	8.8 to 17.5	1:700	1:350	1:444
20.0	28.3	49.0	10.0 to 20.0	1:800	1:400	1:507
22.5	31.8	55.1	11.3 to 22.5	1:900	1:450	1:570
25.0	35.4	61.2	12.5 to 25.0	1:1000	1:500	1:634
27.5	38.9	67.3	13.8 to 27.5	1:1100	1:550	1:697
30.0	42.4	73.4	15.0 to 30.0	1:1200	1:600	1:760
45.0	63.6	110.1	22.5 to 45.0	1:1800	1:900	1:1,141

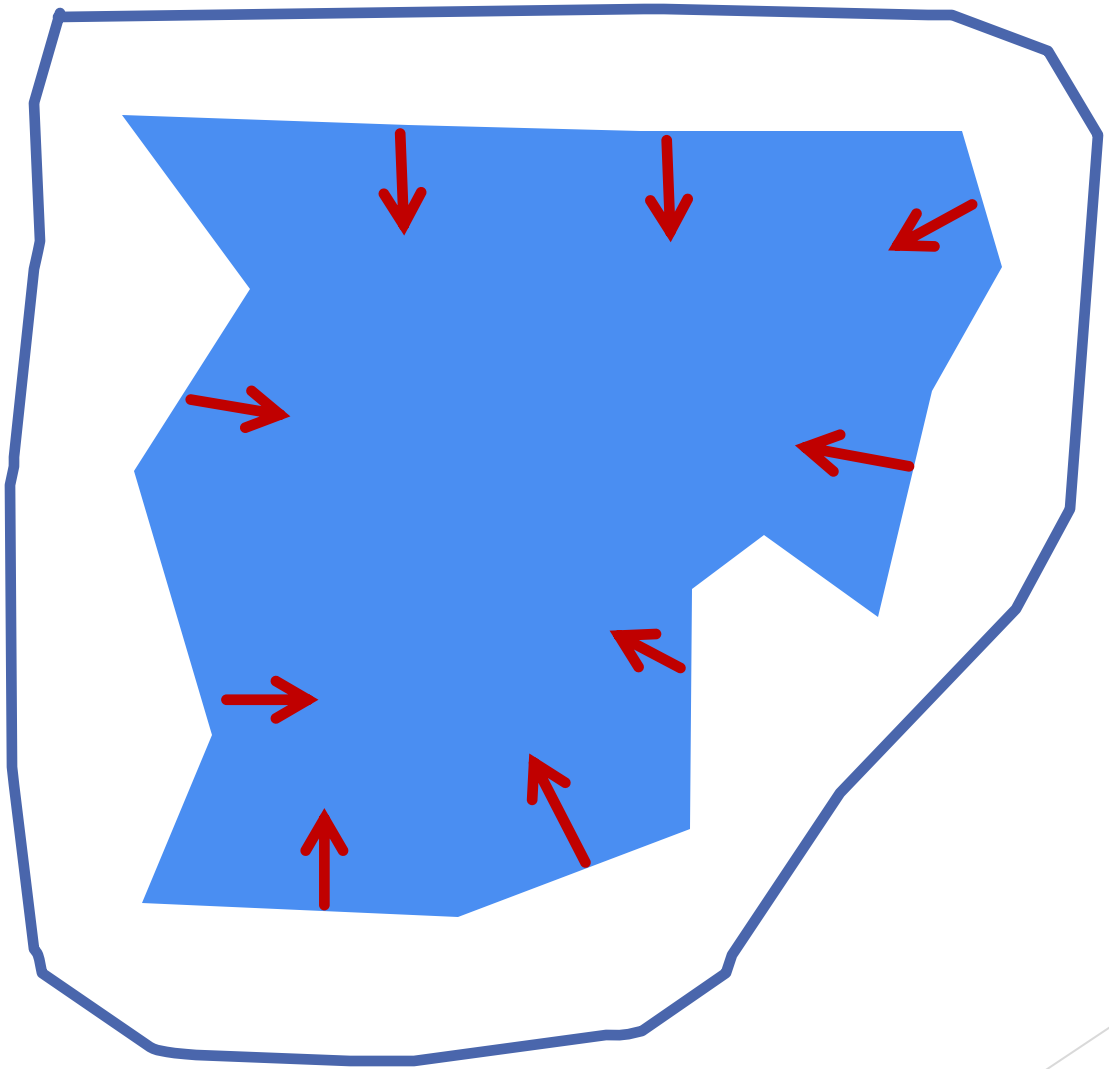


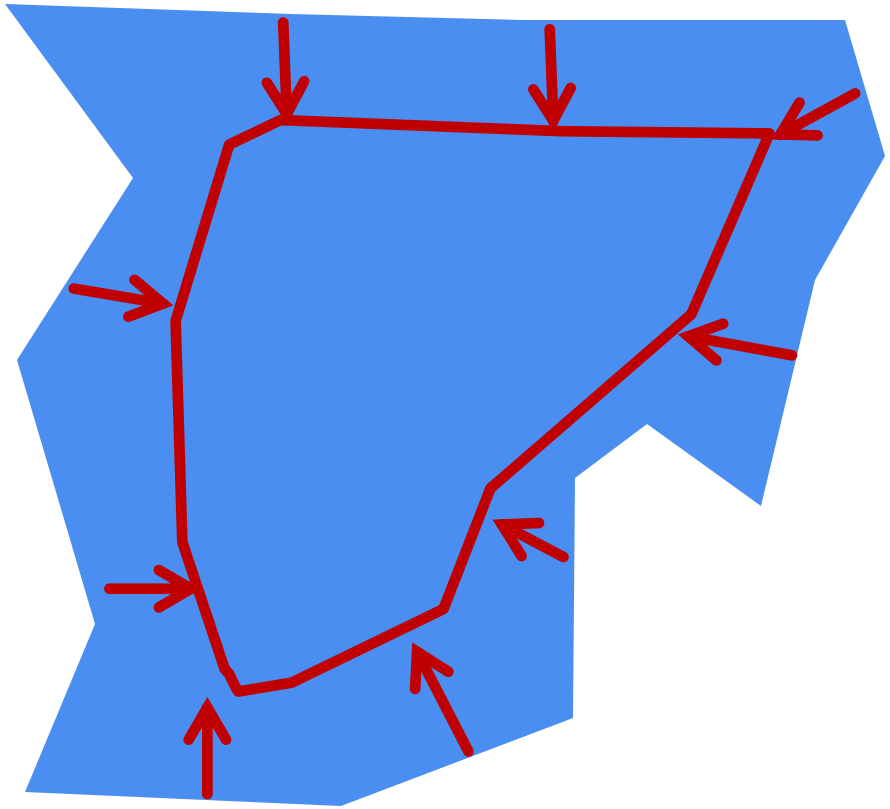


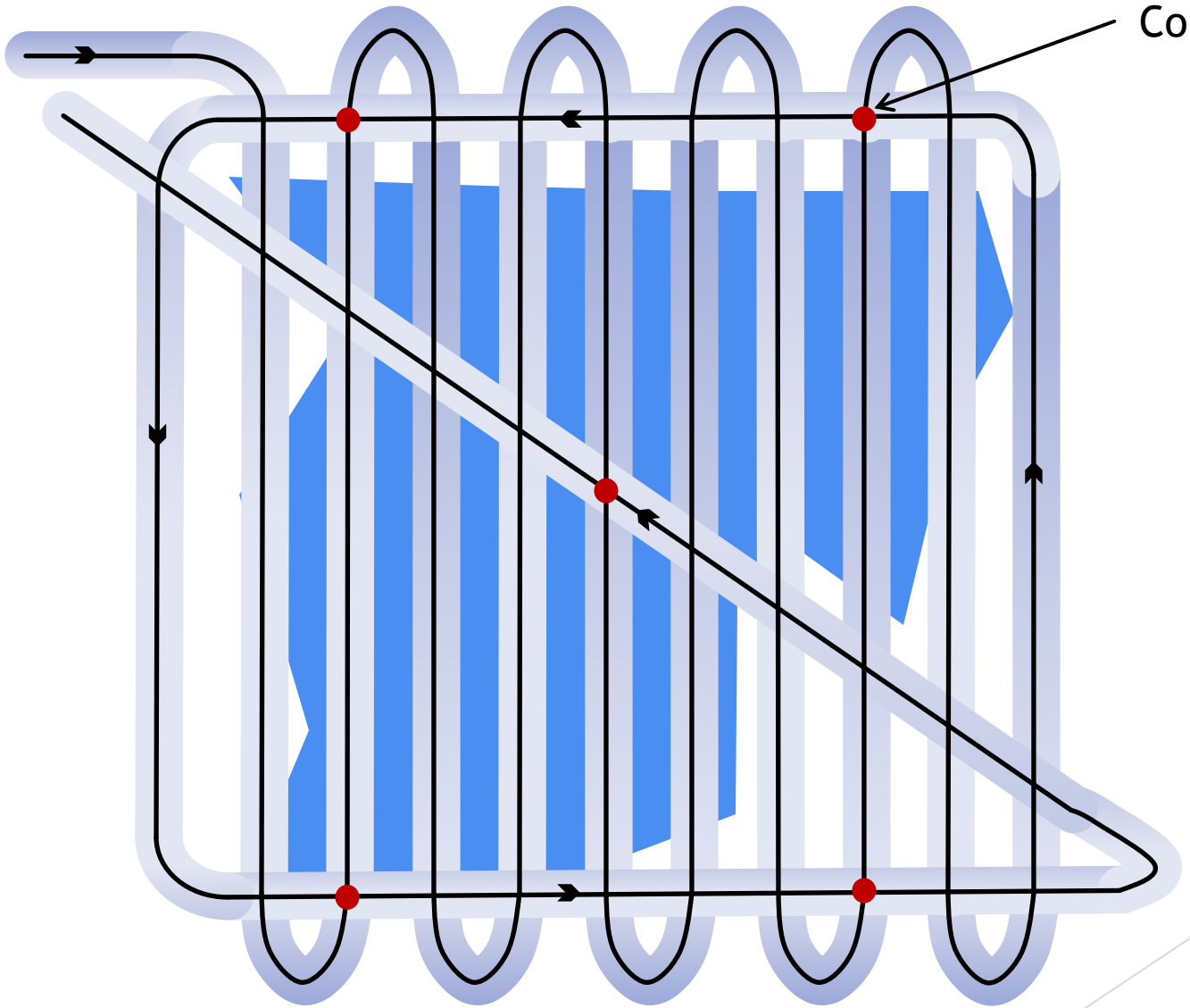

Flight Lines to the edge of the AOI

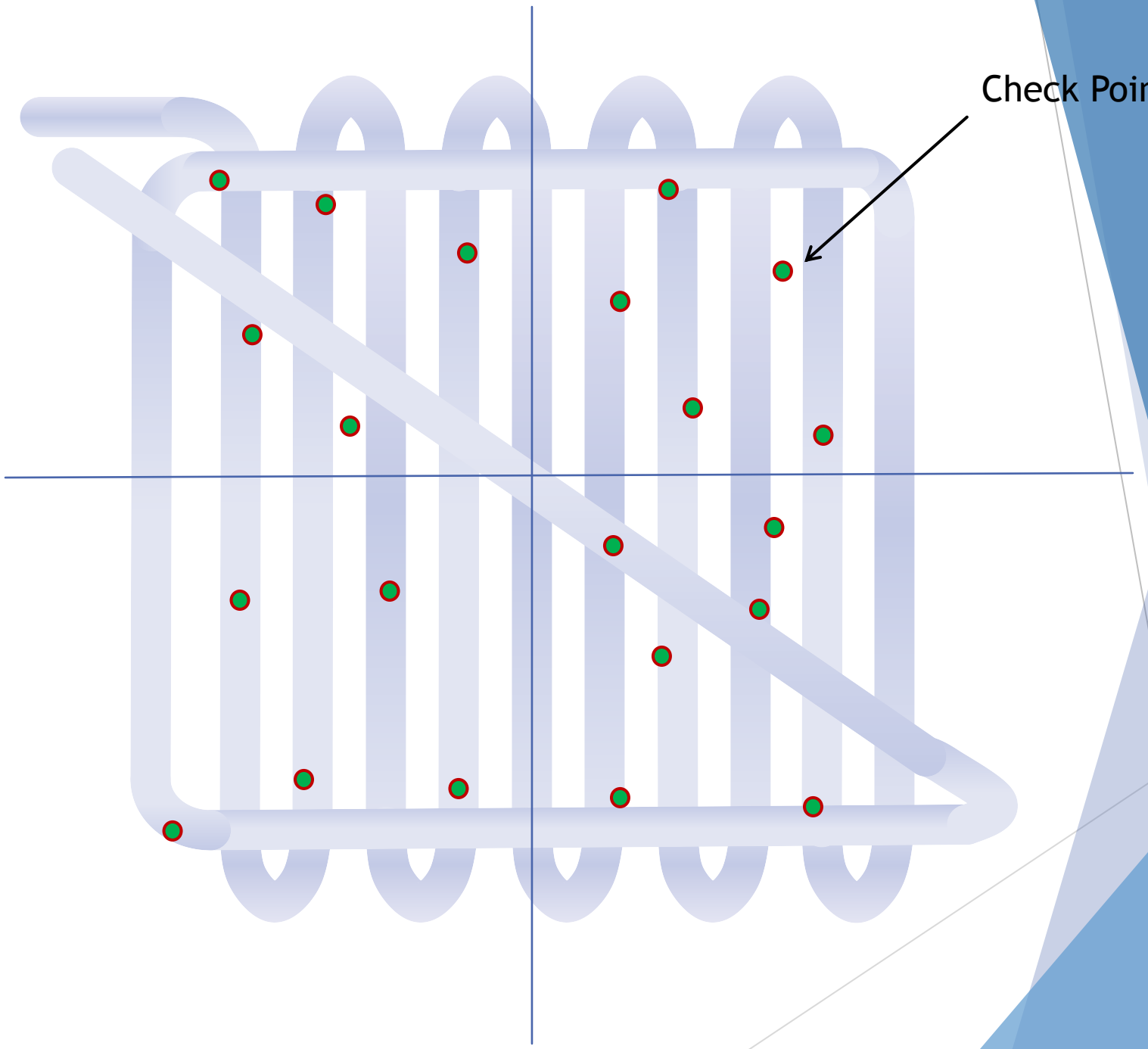

Flight Lines beyond the AOI








Control Points


Check Points

GCP Planning

- GCPs control the accuracy
- Re-use existing known control when possible
- USE A SURVEYOR IF THE JOB REQUIRES IT
- The GCP layout and the flight plan done together.
- Put GCPs in overlap areas and isolated areas
- GCP persistence-Adapt your plan over time
- Augment in areas of low confidence or obscured
- Get a report, not just a text file with XYZ coordinates

GCP Planning

- Use an appropriate target
- Include KMZ/ASCII/Shape
- Need to be visible, recoverable, numbered.
- Be Practical!

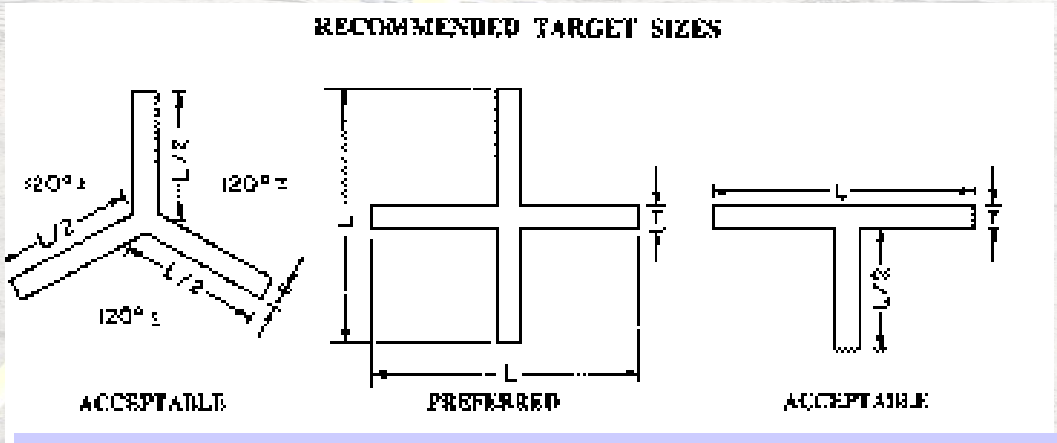


Photo. Scale	Thickness of Leg (T)	Length of Legs (L)
1:1800	6 Inches(150mm)	3 Feet(0.9m)
1:2400	6 Inches(150mm)	3 Feet(0.9m)
1:3000	6 Inches(150mm)	4 Feet(1.2m)
1:3600	6 Inches(150mm)	4 Feet(1.2m)
1:4200	6 Inches(150mm)	5 Feet(1.5m)

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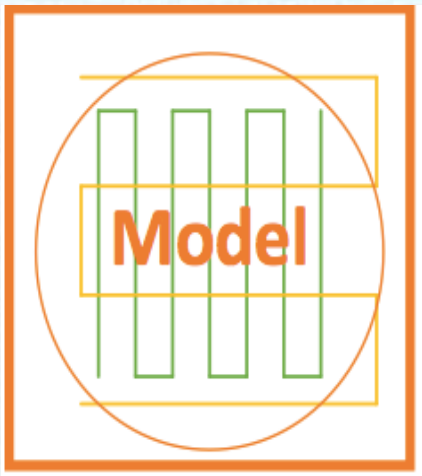

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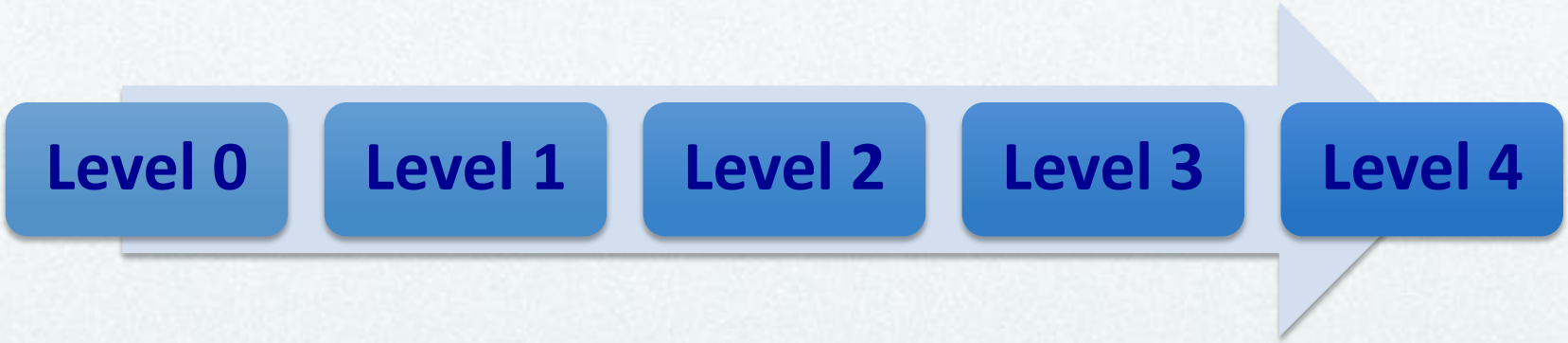

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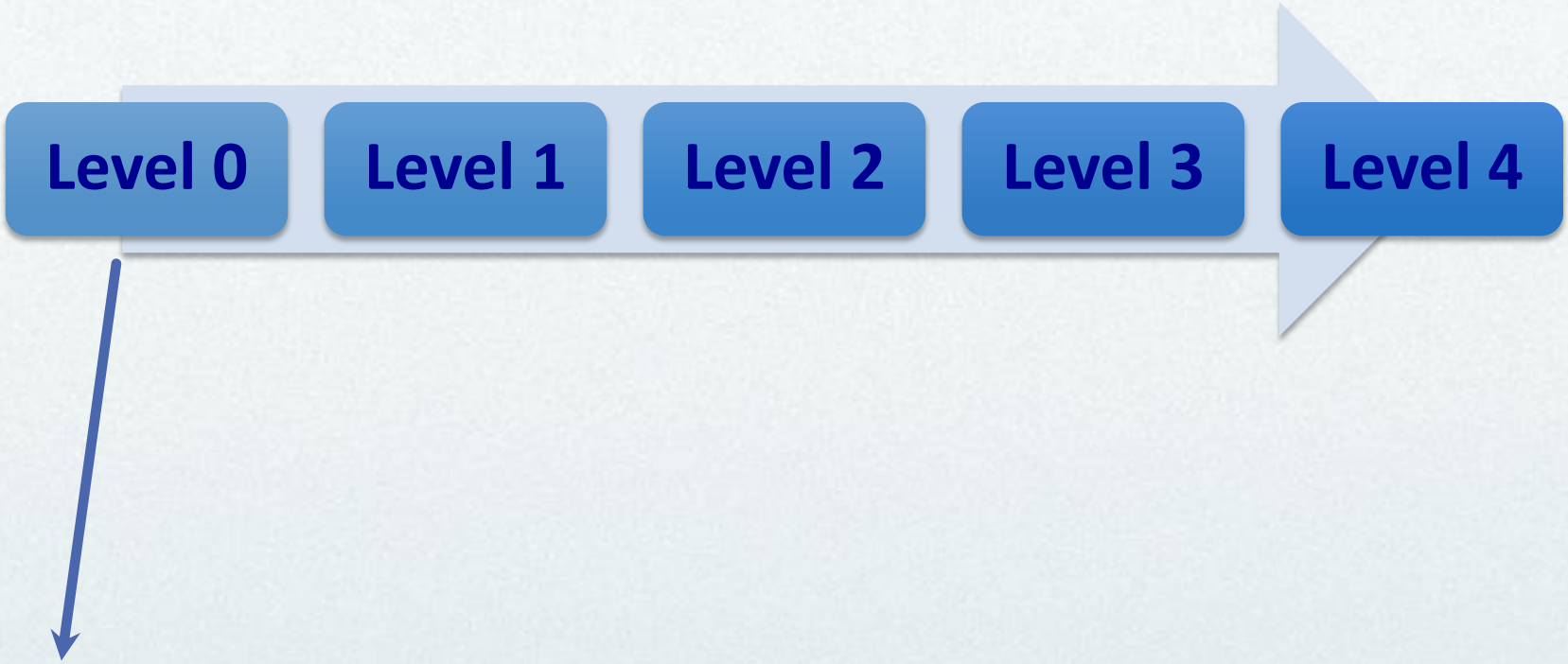
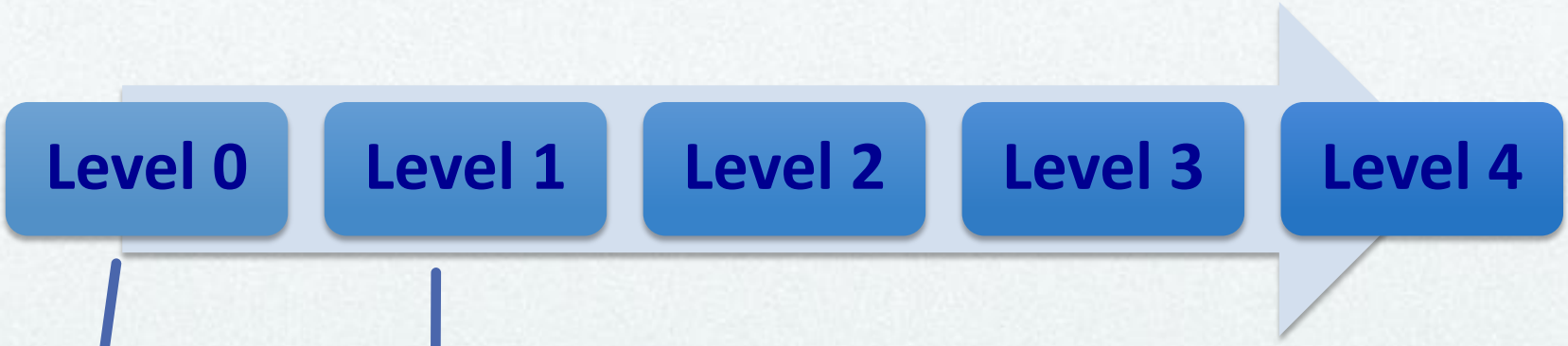


Raw Images
GPS Log
Camera Orientation

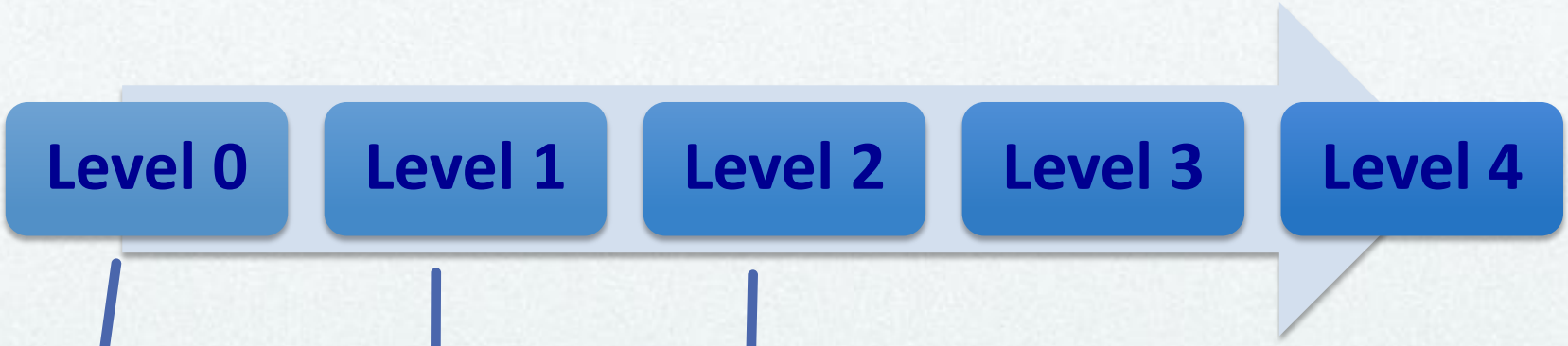
UAV MAPPING OVERVIEW



Automated Processing
QC Checks
Flight Validation

Raw Images
GPS Log
Camera Orientation

UAV MAPPING OVERVIEW

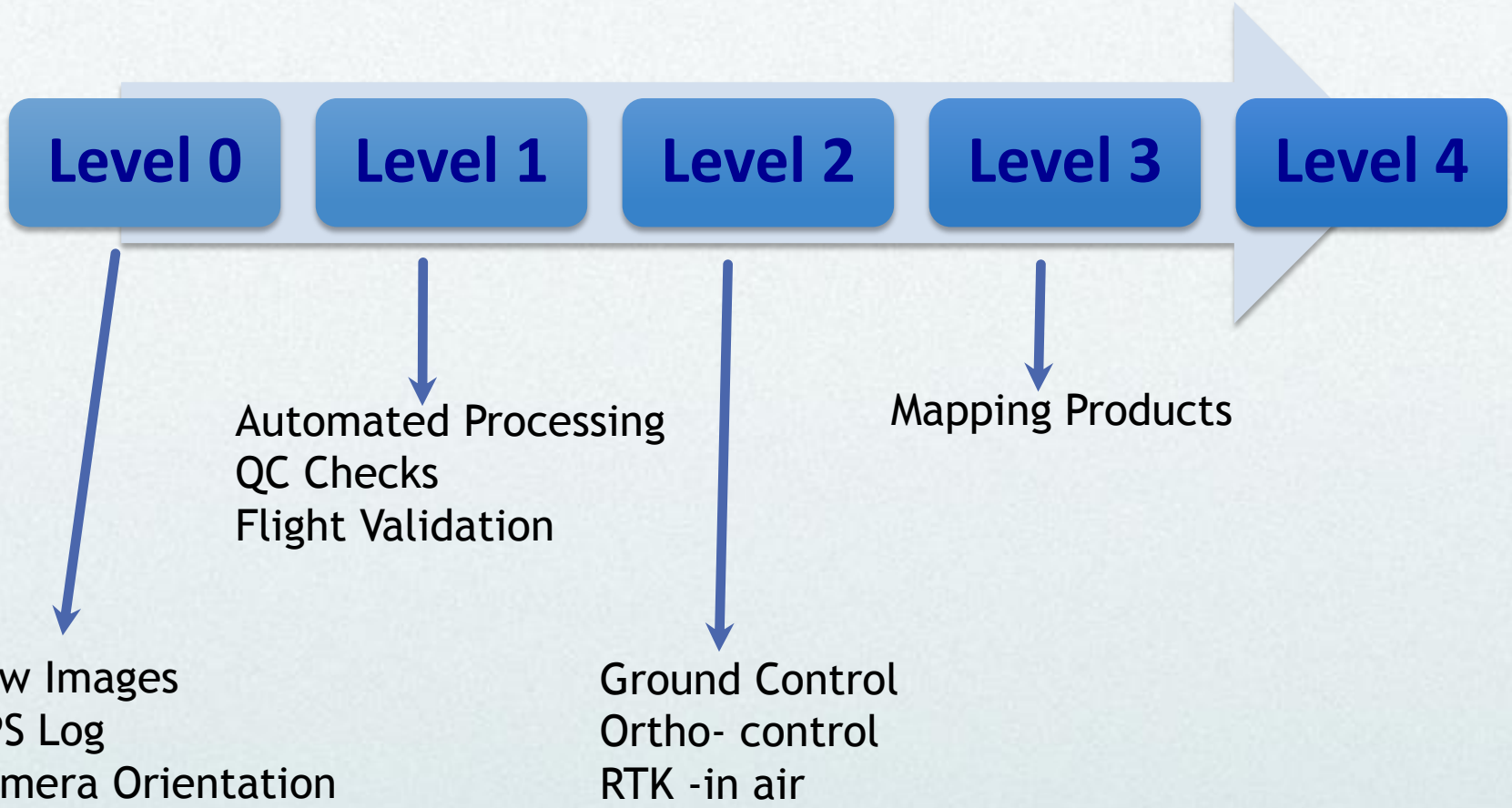


Raw Images
GPS Log
Camera Orientation

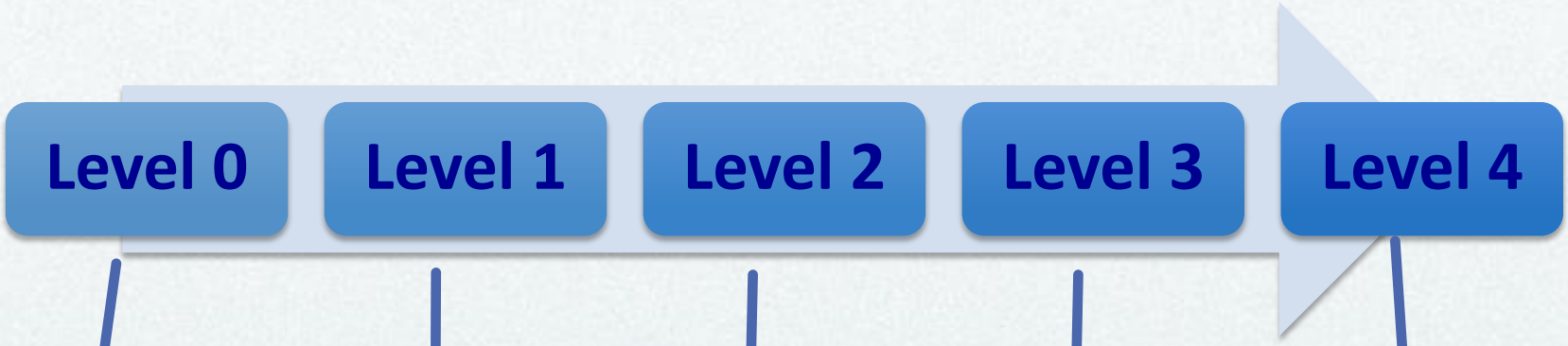
Automated Processing
QC Checks
Flight Validation

Ground Control
Ortho- control
RTK -in air

UAV MAPPING OVERVIEW



UAV MAPPING OVERVIEW



Raw Images
GPS Log
Camera Orientation

Automated Processing
QC Checks
Flight Validation

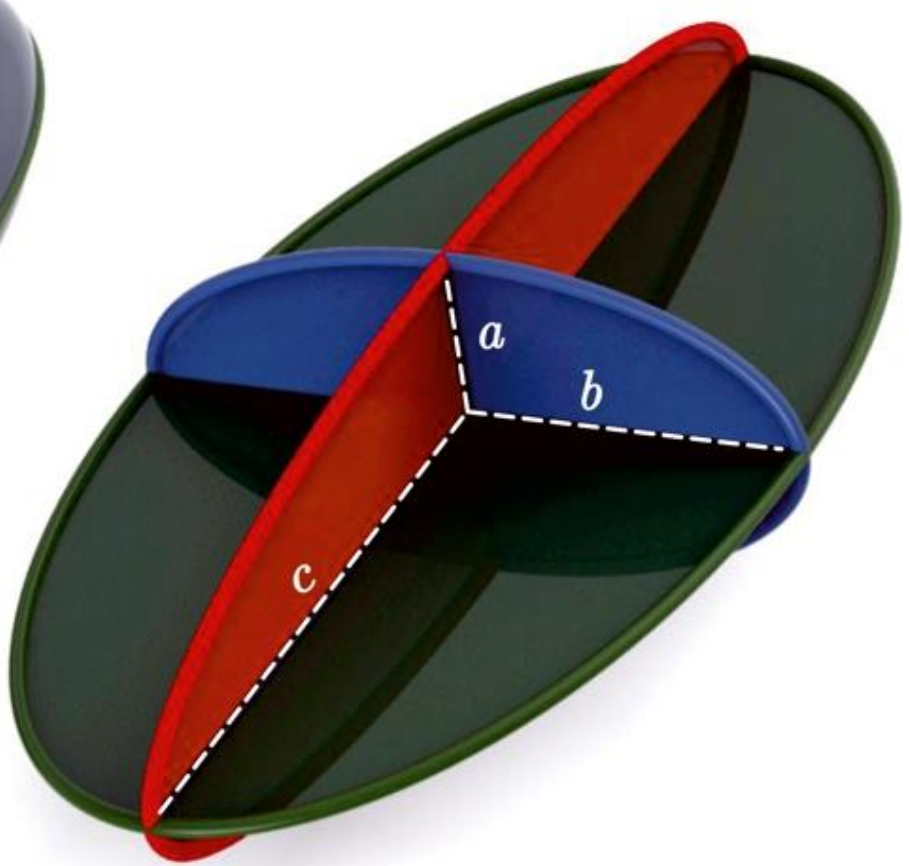
Ground Control
Ortho- control
RTK -in air

Mapping Products

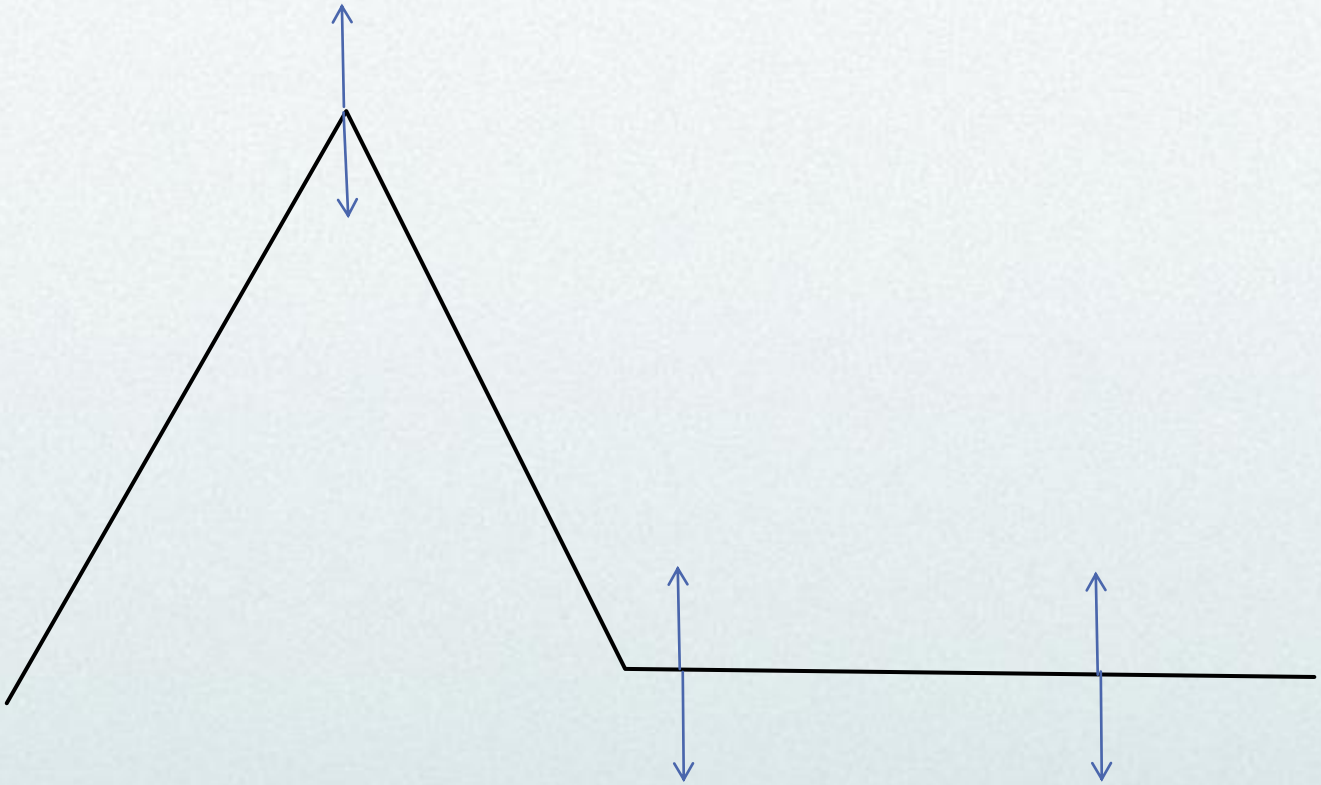
Analysis Products

Level	Description	What Do you Get?	Data Quality Triangle
Level 0	Flight Operations Raw Data	GPS Log File Flight Line Log Outline of Area Geotag Imagery	Repeatability
Level 1	Automated Processing (cloud based services)	Image mosaic Point cloud Initial Surface Model (DSM) 3D Mesh	Precision
Level 2	Ground Controlled	Survey Grade Integrated control with known accuracy	Accuracy
Level 3	Topographic Data	Point Cloud Classification Bare Earth Elevation models Contours Surface Constraints/Breaklines DSM/DEM	Stitching multiple Flights Manual Tie Points Quality Control
Level 4	Analytics	Planimetrics Volumes Change detection Habitat mapping Drainage Land Cover/Vegetation/Impervious Feature Extraction	

What is this?



ERROR



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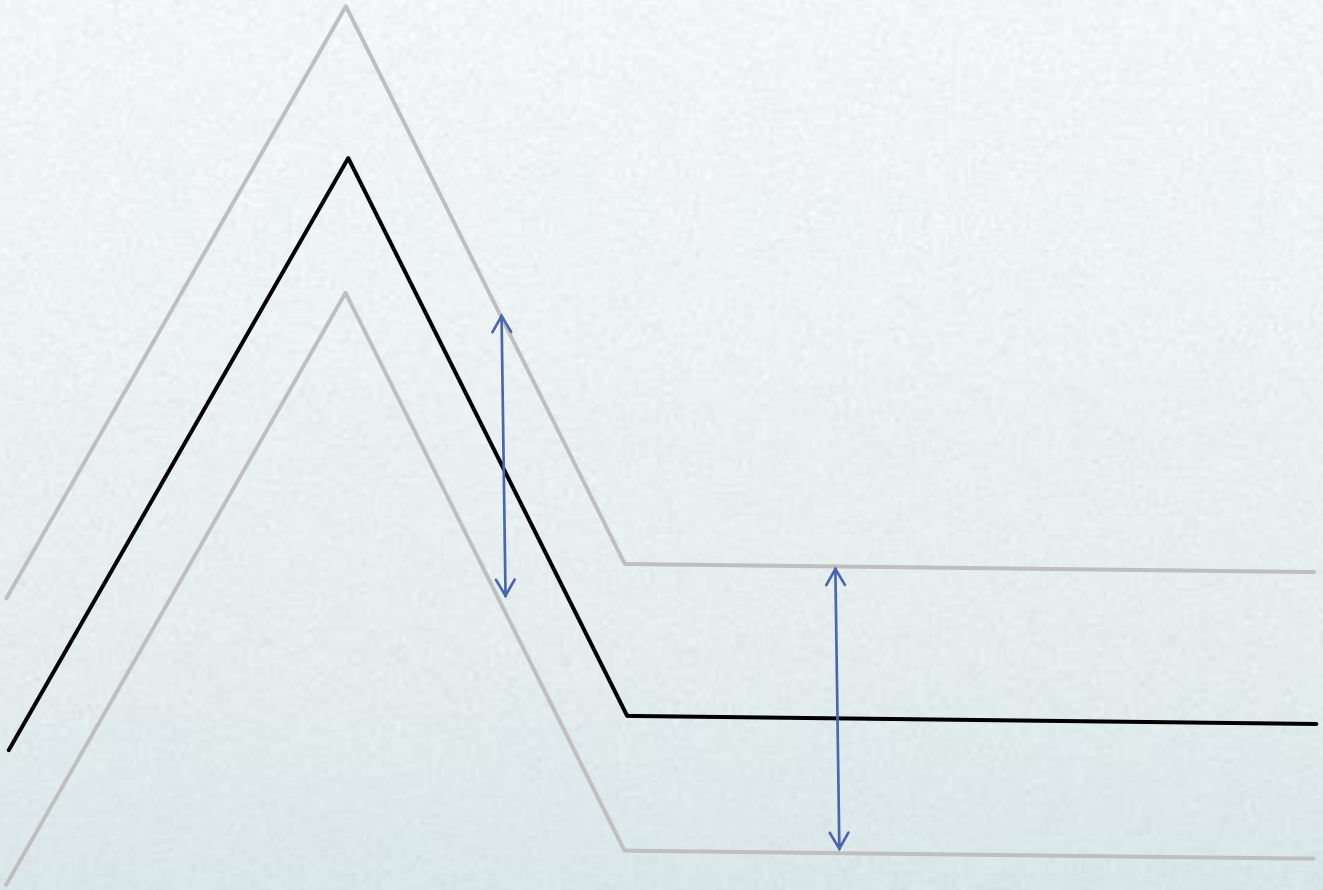

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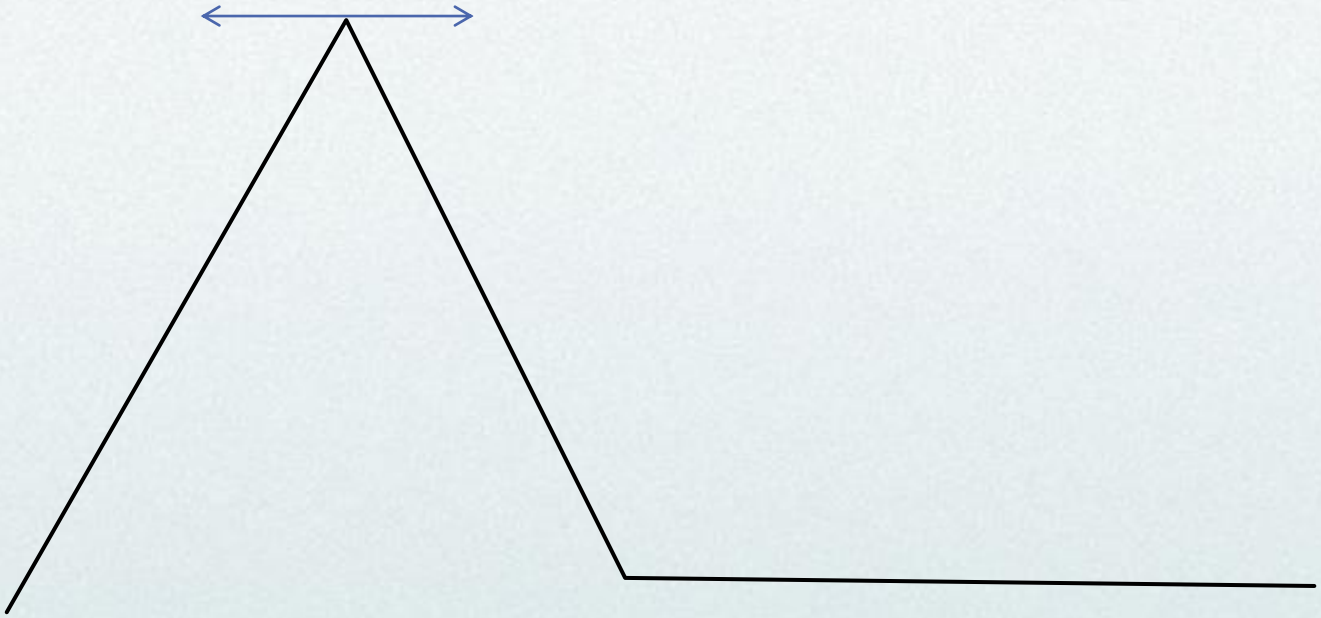

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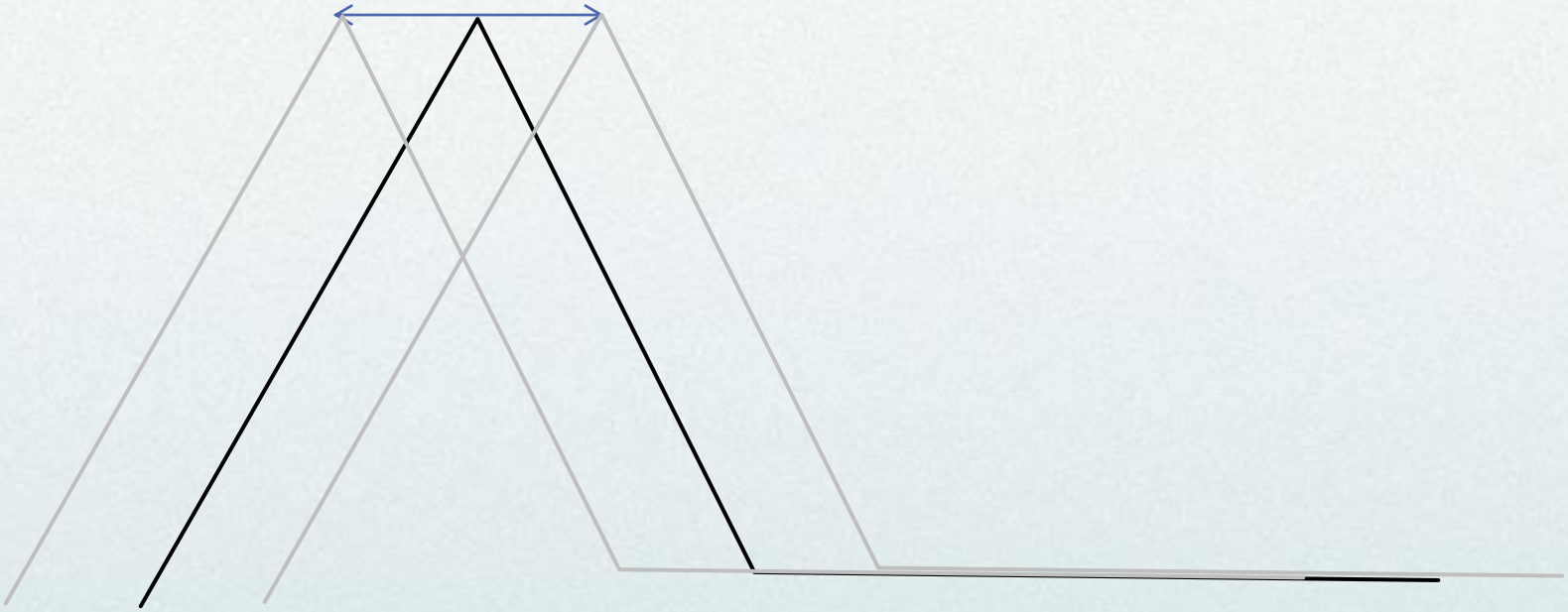

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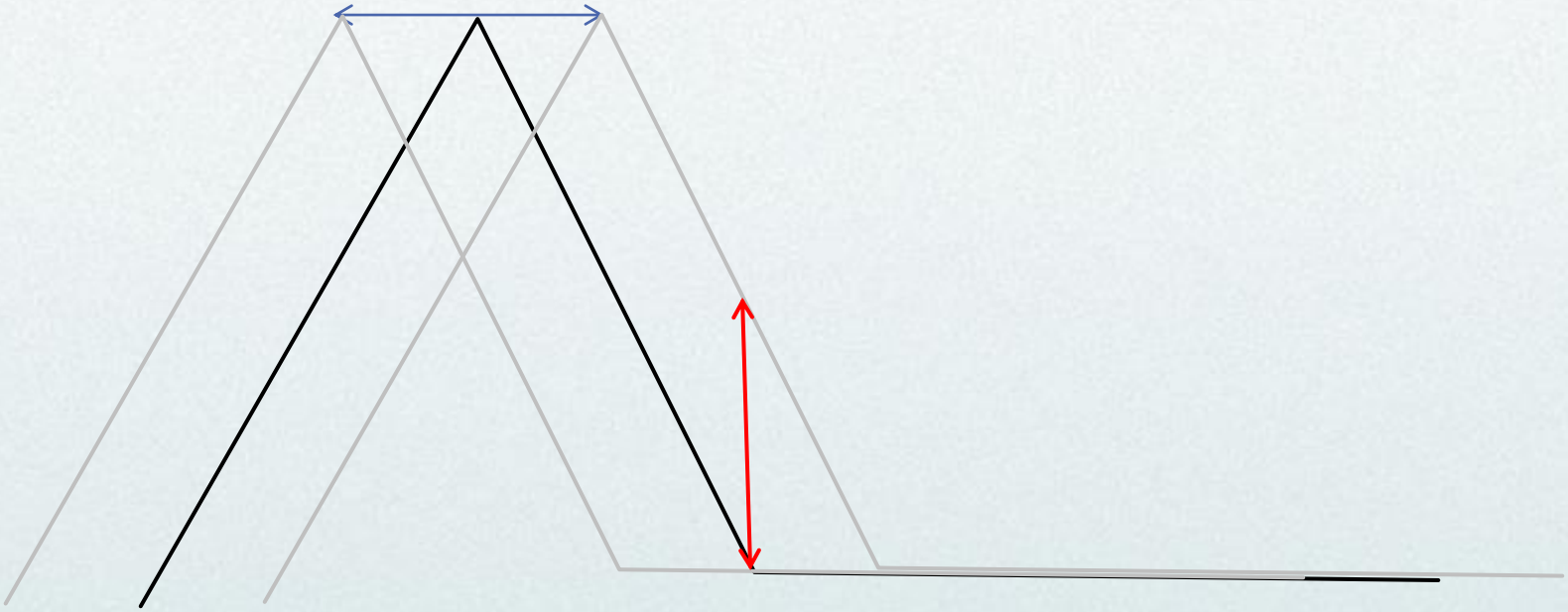
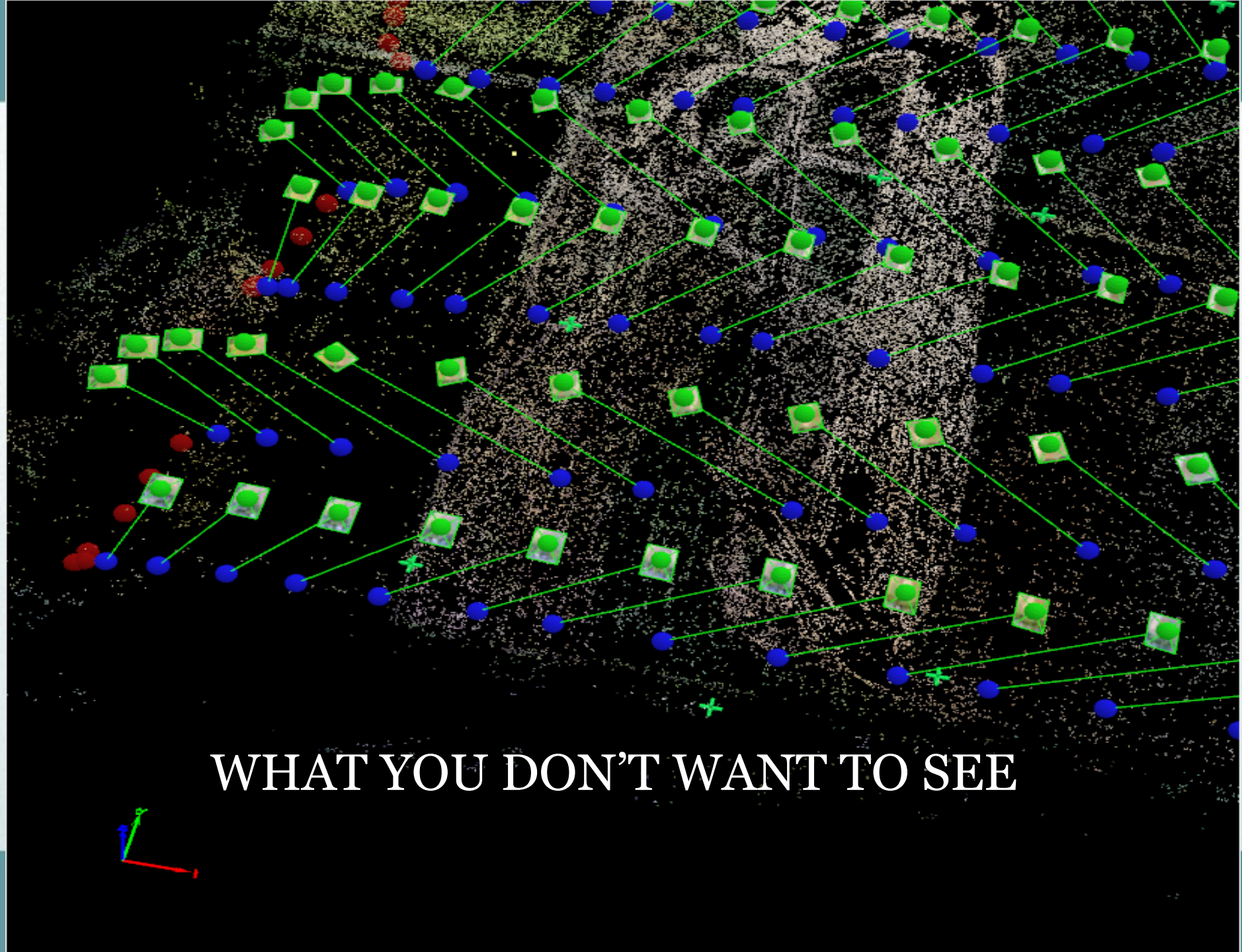
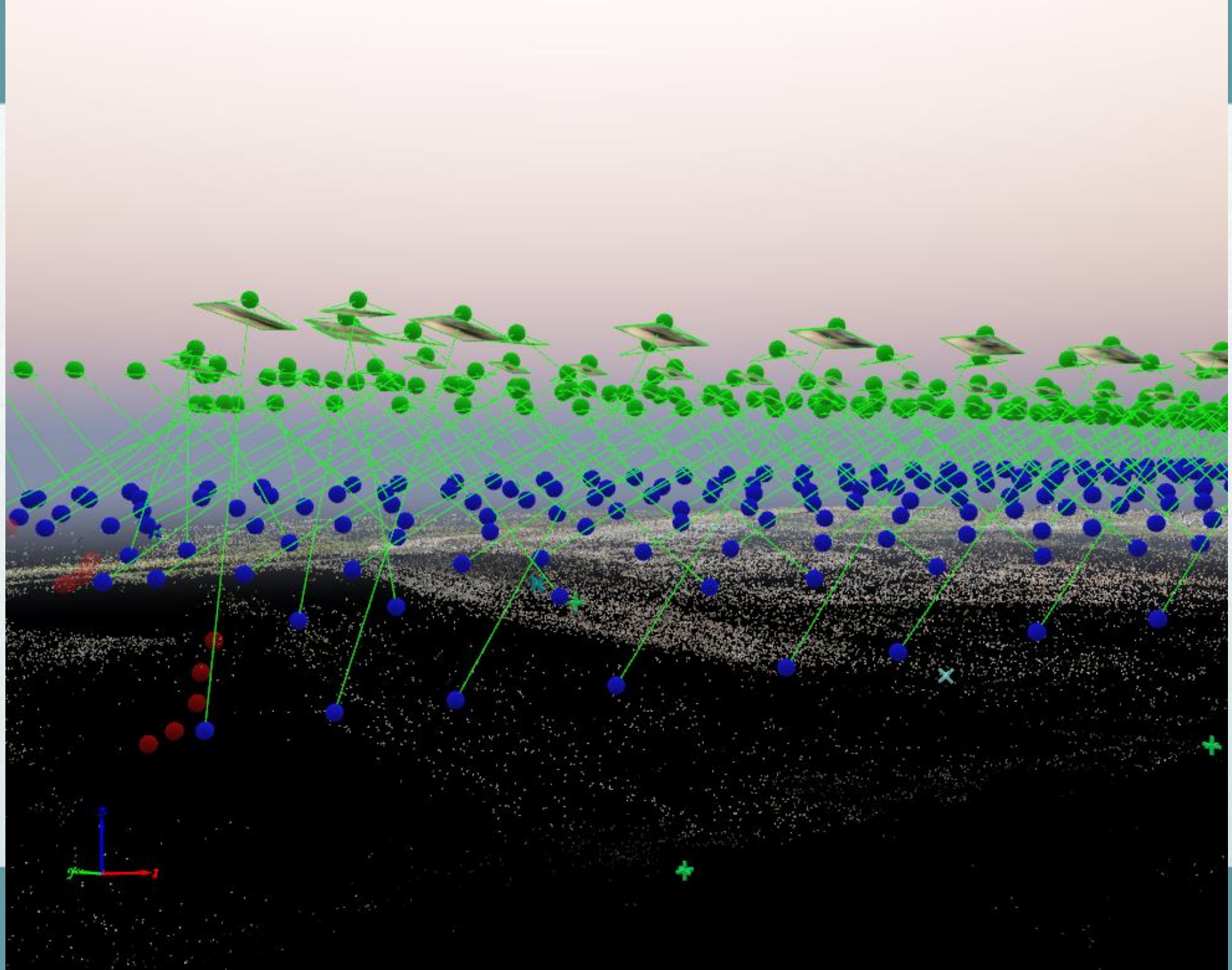
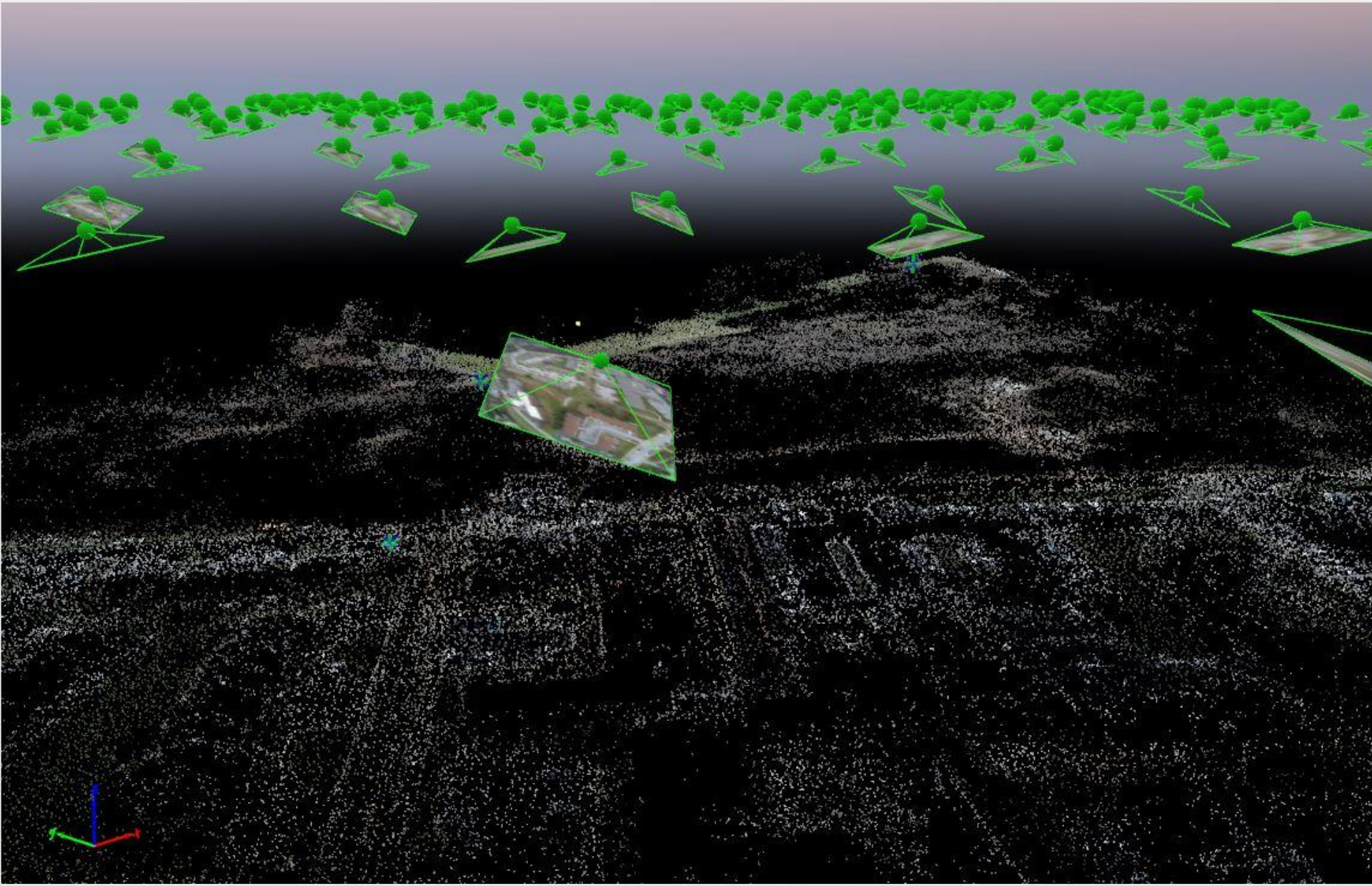


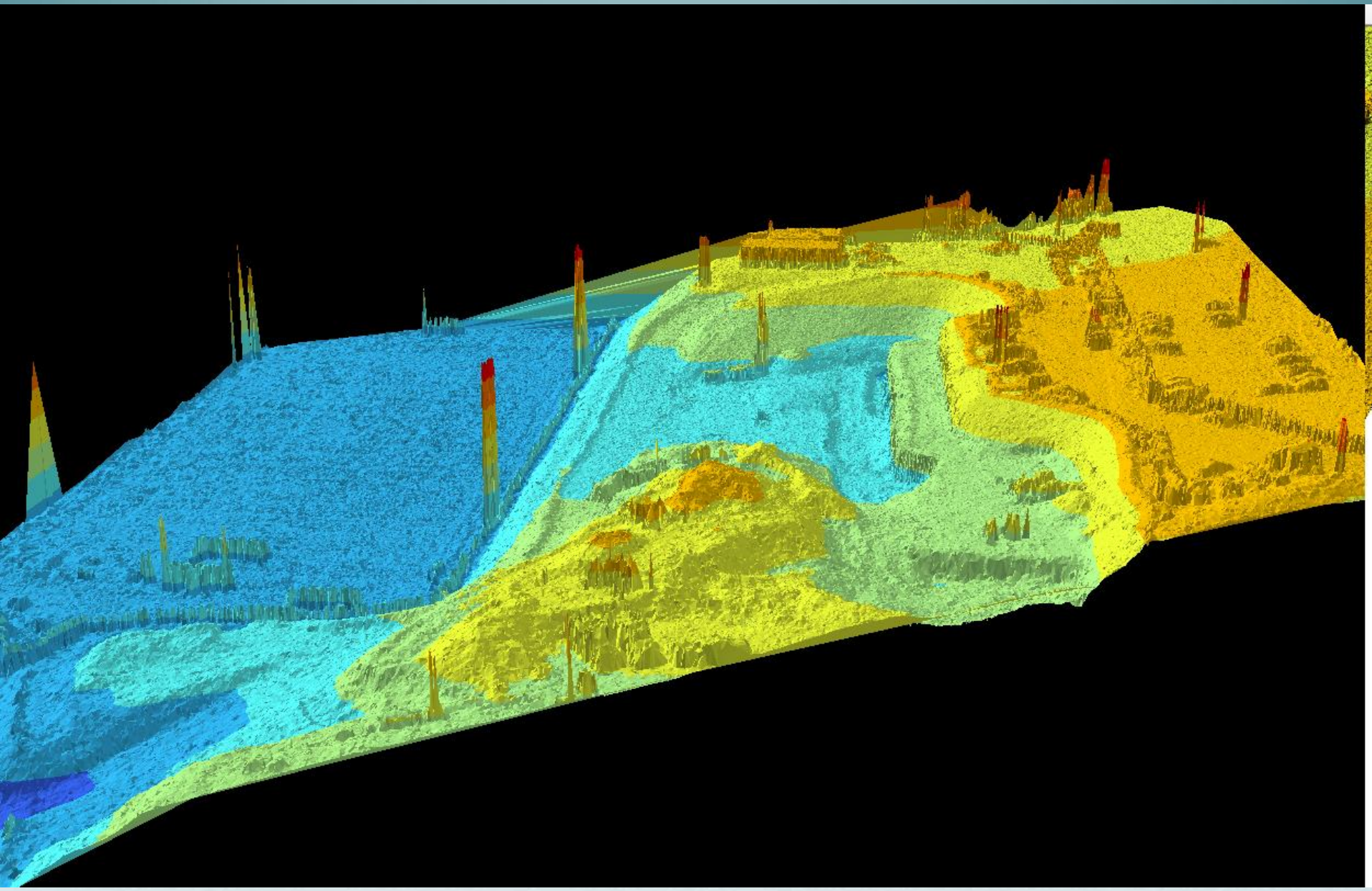
ERROR

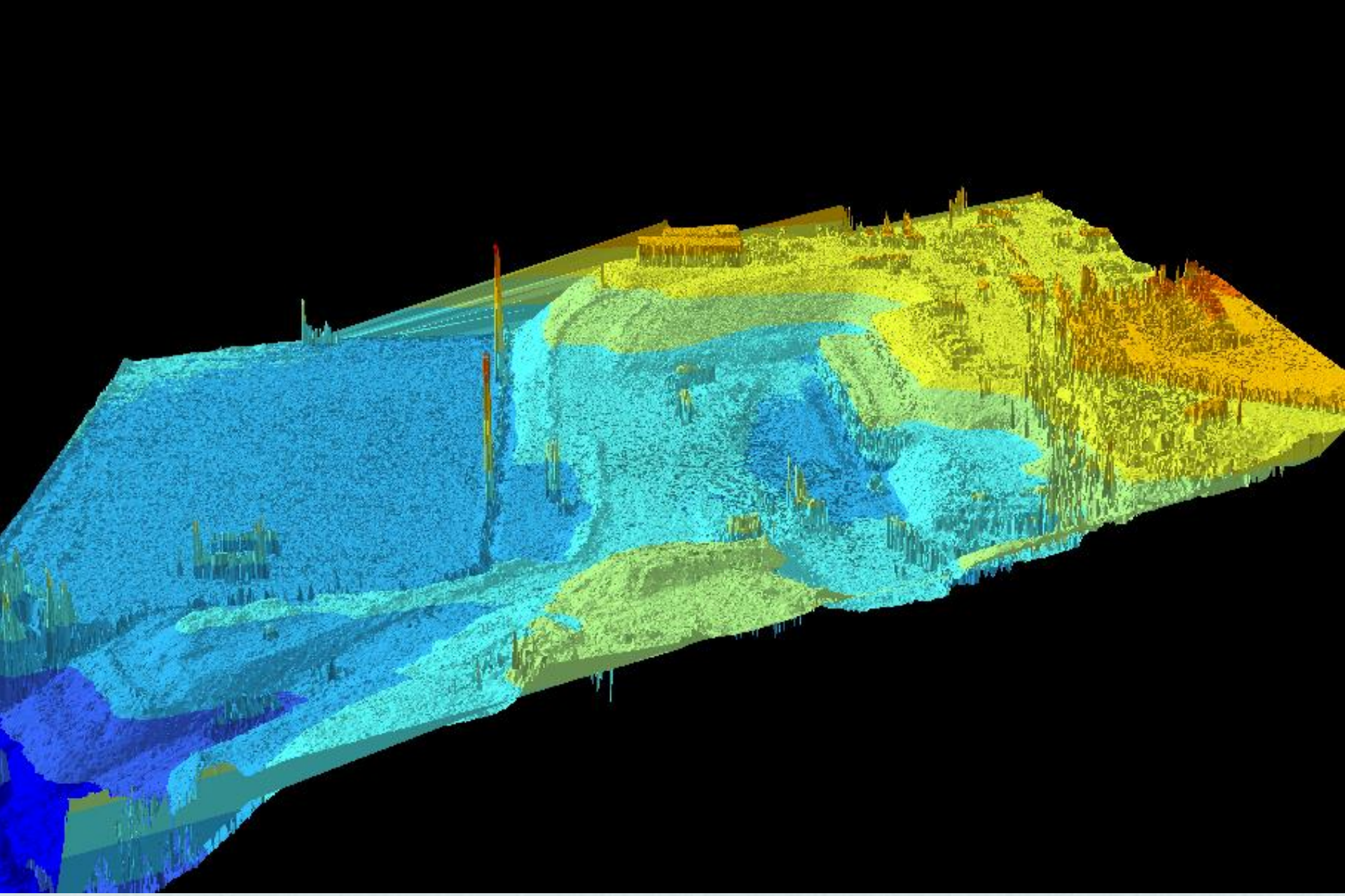
- Horizontal and Vertical Error translate to VOLUMETRIC ERROR- even when within spec
- Change detection can only be done within the accuracy limits of the sensor.
- Fly the same site twice in the same day with the same control. Check the difference.

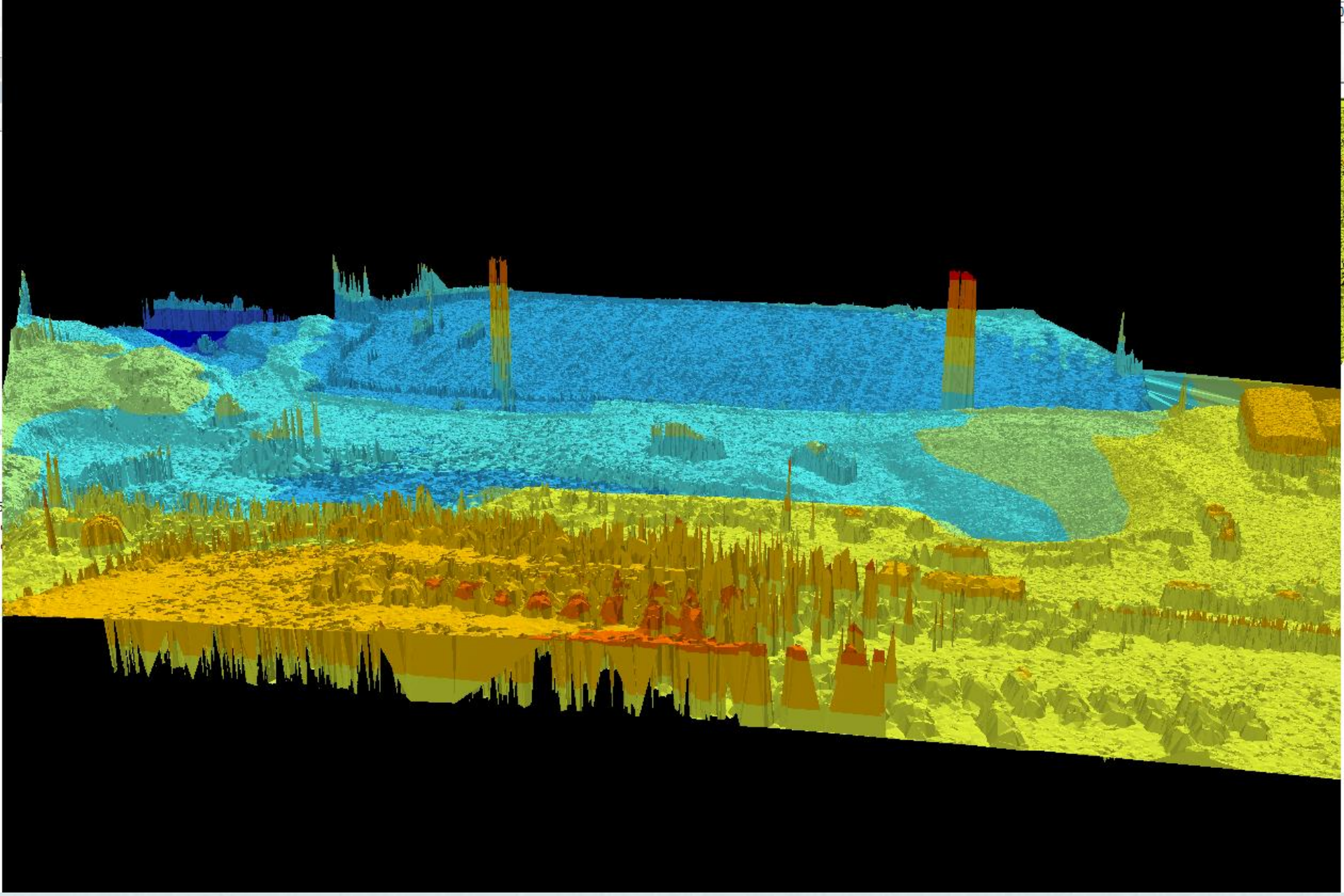

WHAT YOU DON’T WANT TO SEE



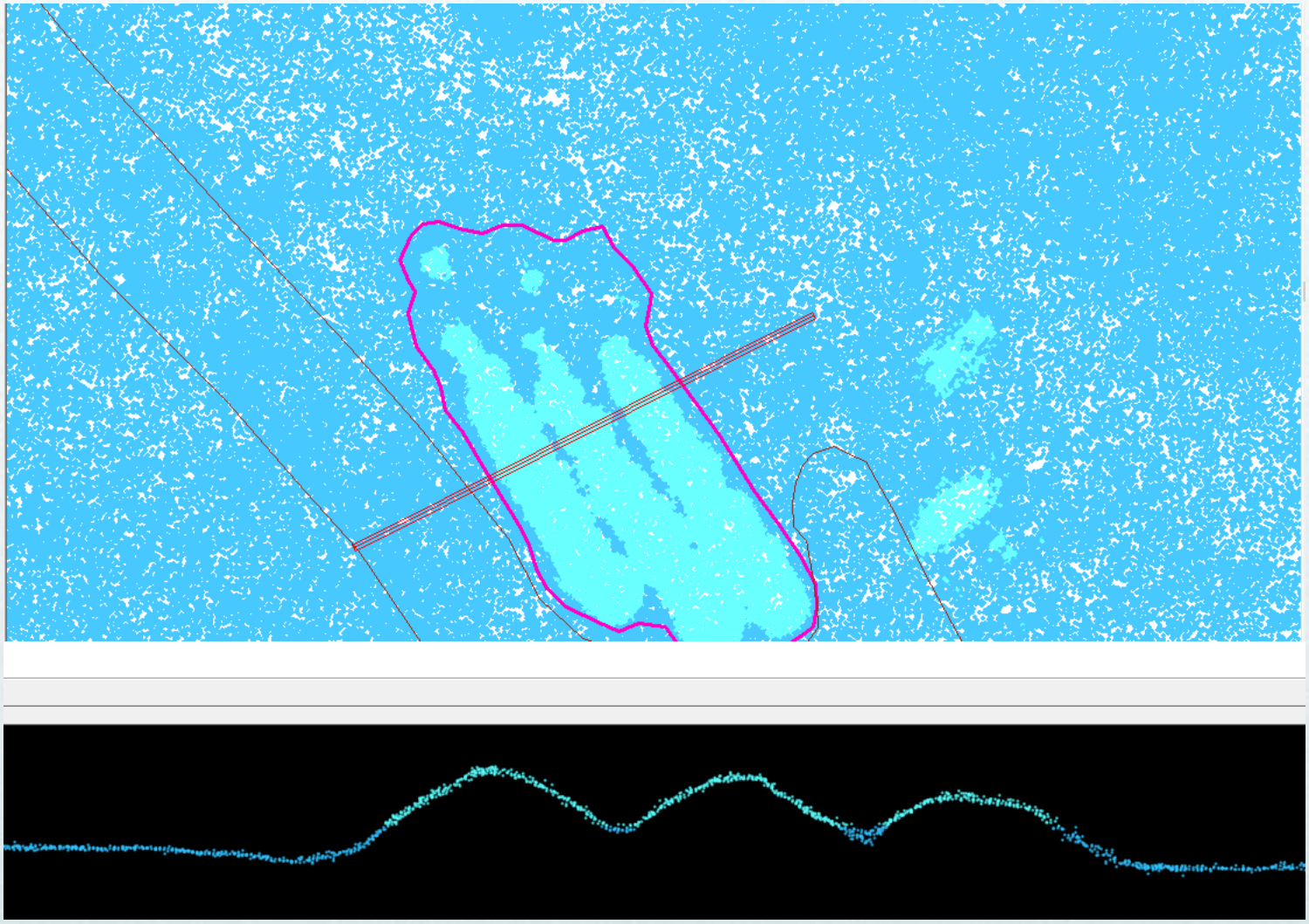


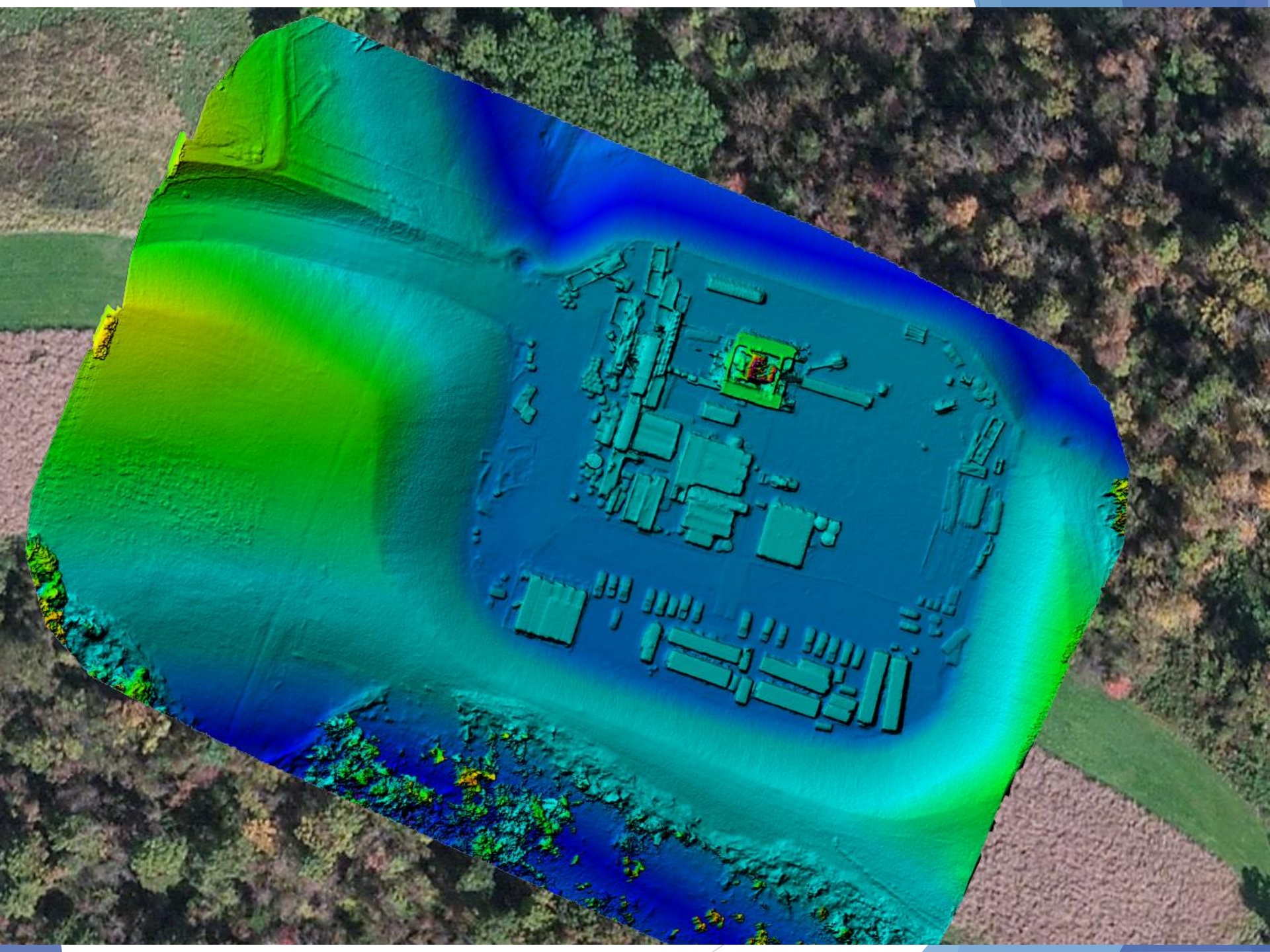


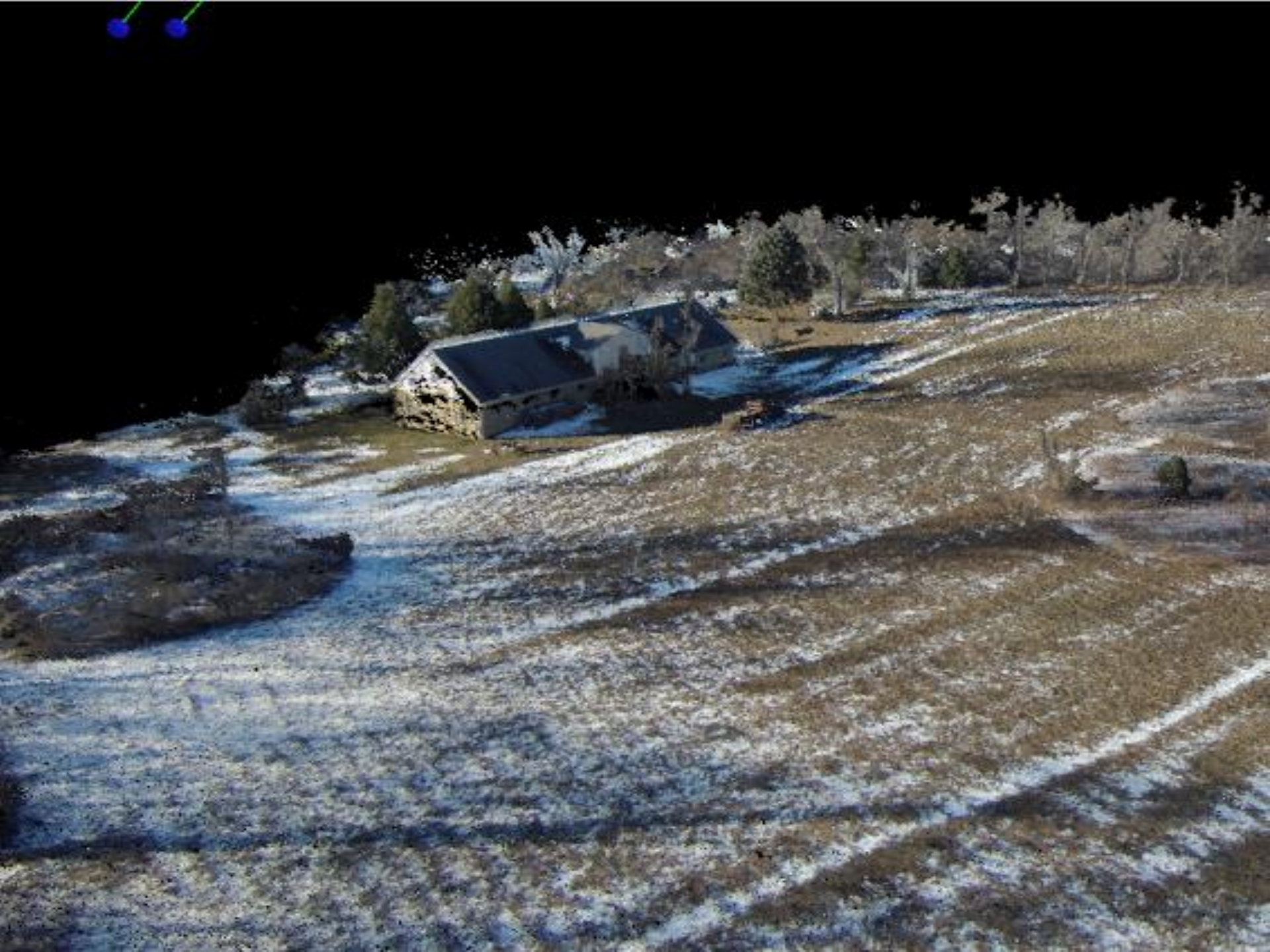




WHAT YOU **DO** WANT TO SEE







“ITS THE DATA, STUPID”

THERE IS NO EASY BUTTON

SPATIAL
ANALYTIX
Precise. Accurate. Reliable.