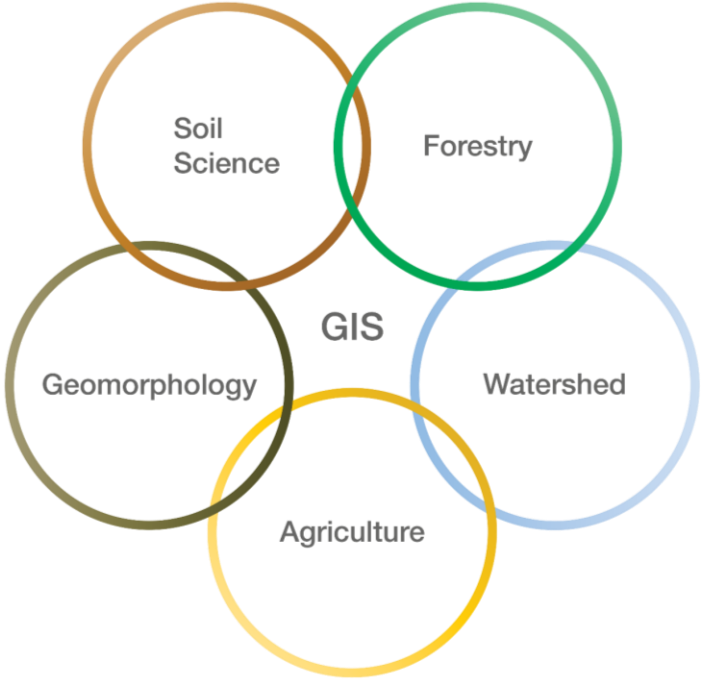
Using UAV Derived Imagery in Combination with Existing LiDAR to Map Plot-Level Forest Characteristics in Michigan

Trevor Hobbs
Soil Geomorphologist

contour geographic

- Applied geomorphology
- UAV mapping/GIS
- Web and print cartography
- Research
- Training/workshops



Past case studies- UAVs for detecting erosion in coastal dunes / mapping Pitcher's Thistle

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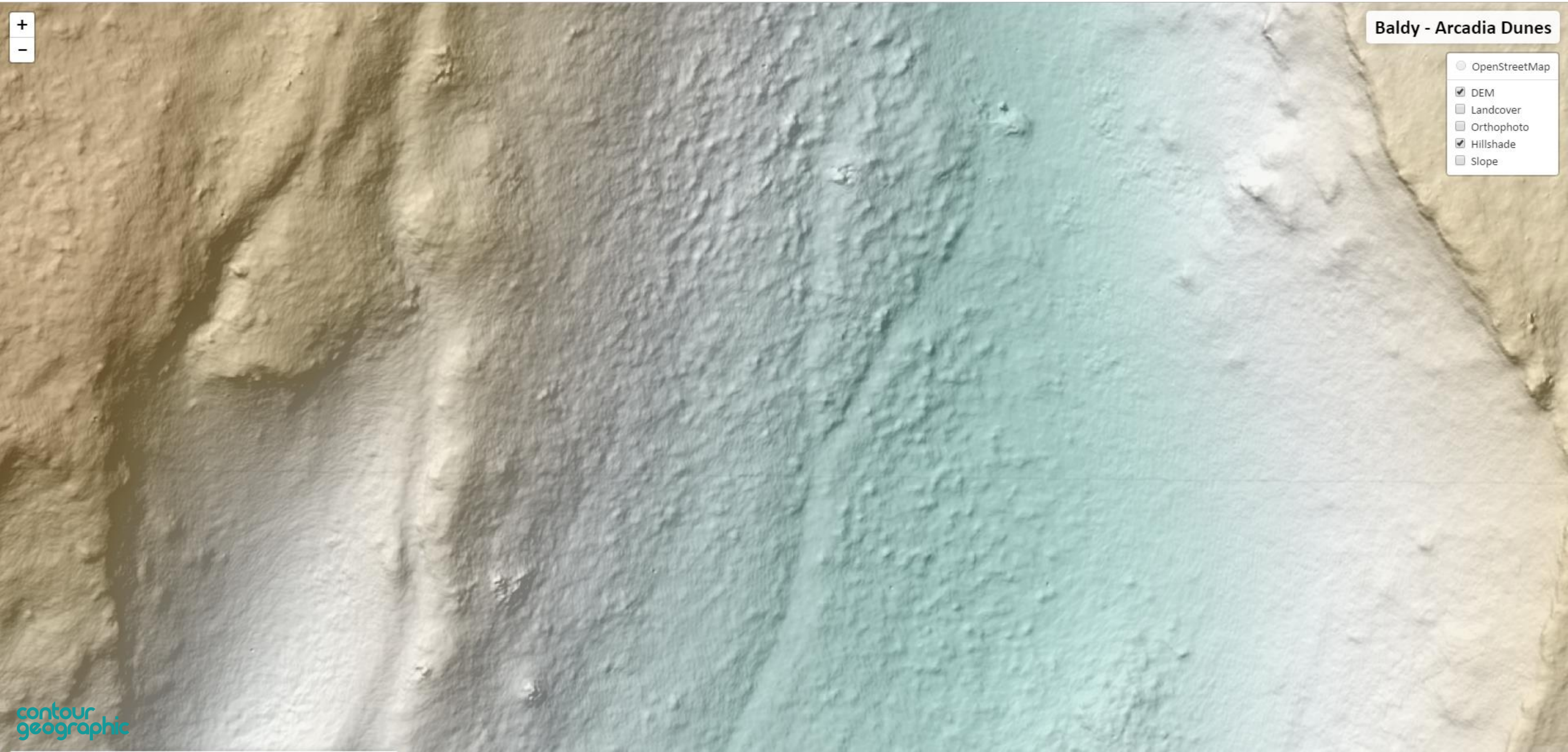
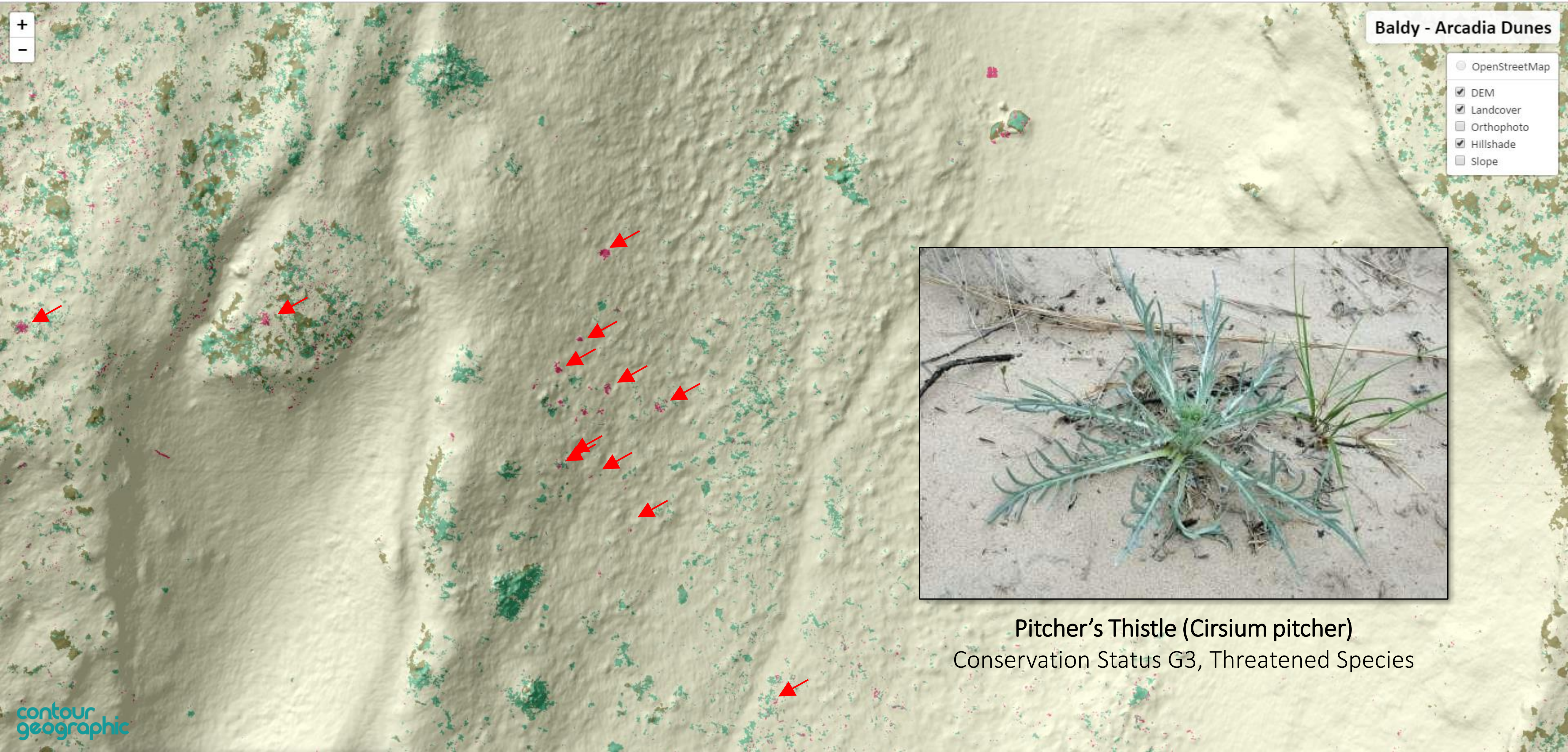
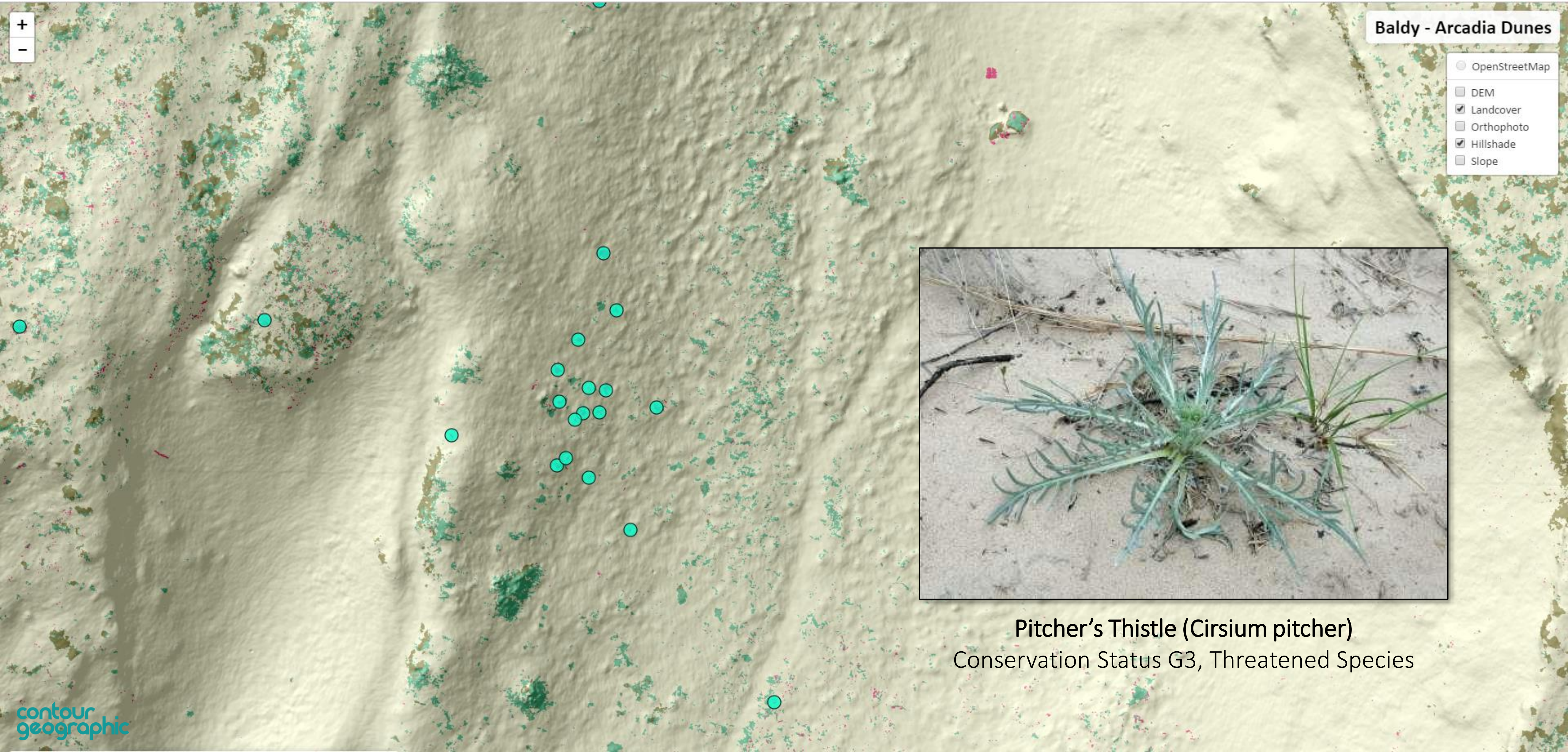


Past case studies- UAVs for detecting erosion in coastal dunes / mapping Pitcher’s Thistle



Pitcher’s Thistle (Cirsium pitcher)
Conservation Status G3, Threatened Species

Past case studies- UAVs for detecting erosion in coastal dunes / mapping Pitcher’s Thistle

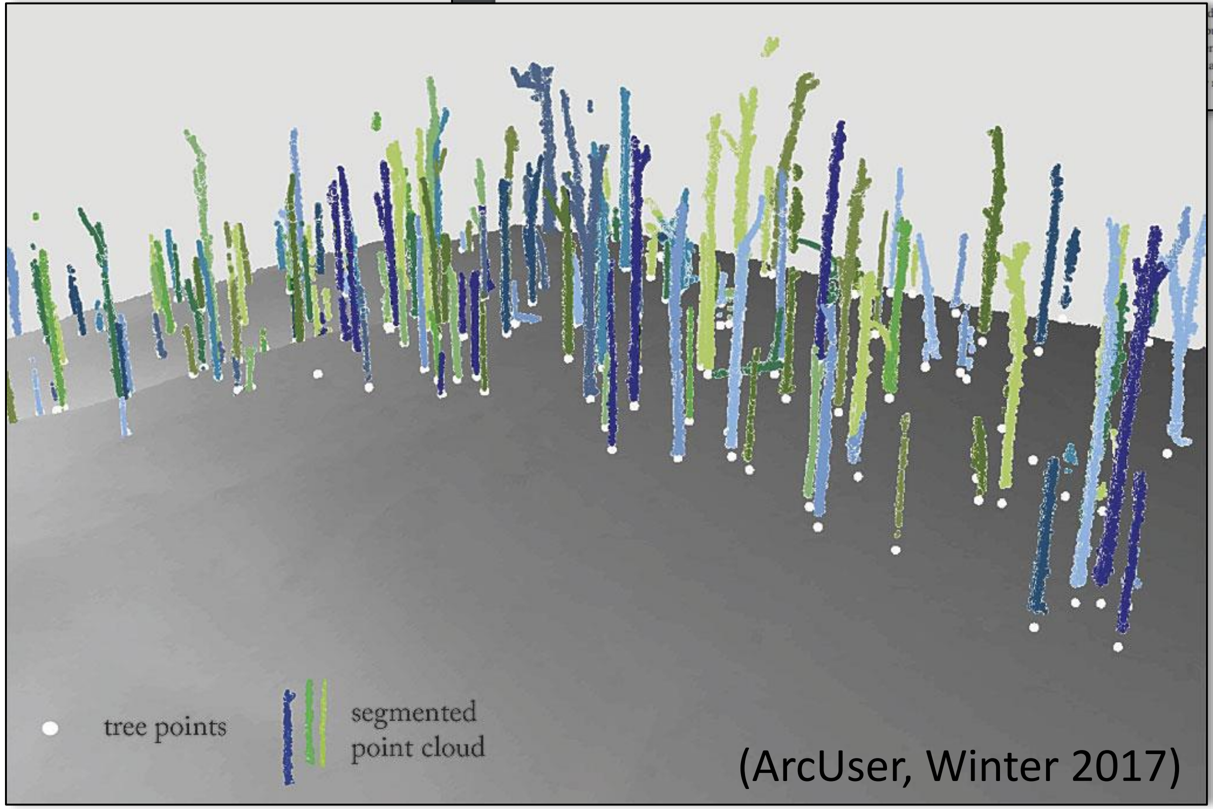


Pitcher’s Thistle (Cirsium pitcher)
Conservation Status G3, Threatened Species


ESRI World Imagery
Contour Geographic UAV imagery
contour geographic

Recent work by others using UAVs for Forestry…

- Post-harvest / post-storm damage change assessment
- Developed algorithms for mapping individual tree stems



(ArcUser, Winter 2017)

Recent work by others using UAVs for Forestry…

- Comparing UAV imagery to LiDAR

- Techniques for capturing bare earth surfaces under forest canopies using oblique ground photos + UAV photos

forests MDPI

Article

Assessment of Forest Structure Using Two UAV Techniques: A Comparison of Airborne Laser Scanning and Structure from Motion (SfM) Point Clouds

Luke Wallace [1,2,*], Arko Lucieer [1], Zbyněk Malenovský [1,3], Darren Turner [1] and Petr Vopěnka [4]

remote sensing MDPI

Article

Assessment of Image-Based Point Cloud Products to Generate a Bare Earth Surface and Estimate Canopy Heights in a Woodland Ecosystem

Jennifer L. R. Jensen [1,*] and Adam J. Mathews [2]

Received: 4 November 2015; Accepted: 31 December 2015; Published: 8 January 2016
Academic Editors: Lars T. Waser and Prasad S. Thenkabail

Questions…

- Are UAV’s useful for forest inventory and mapping? If so, what kinds of data products are possible to generate, and how can they be used?

- With all of the new LiDAR coverage in Michigan, how can that data be used to make up for where UAV imagery falls short (or vice versa)?

- Can quality data products be made with a basic (consumer-grade) UAV?

Background- LiDAR vs. UAV/structure from motion (SfM) photogrammetry

LIDAR

- Active sensor (laser)
- Penetrates forest canopy
- Ideal for mapping forest density
- Large area acquisition

UAV

- Passive sensor (photo)
- Does not penetrate forest canopy
- Ideal for mapping canopy/object surfaces
- Small areas only (<1,000 acres)

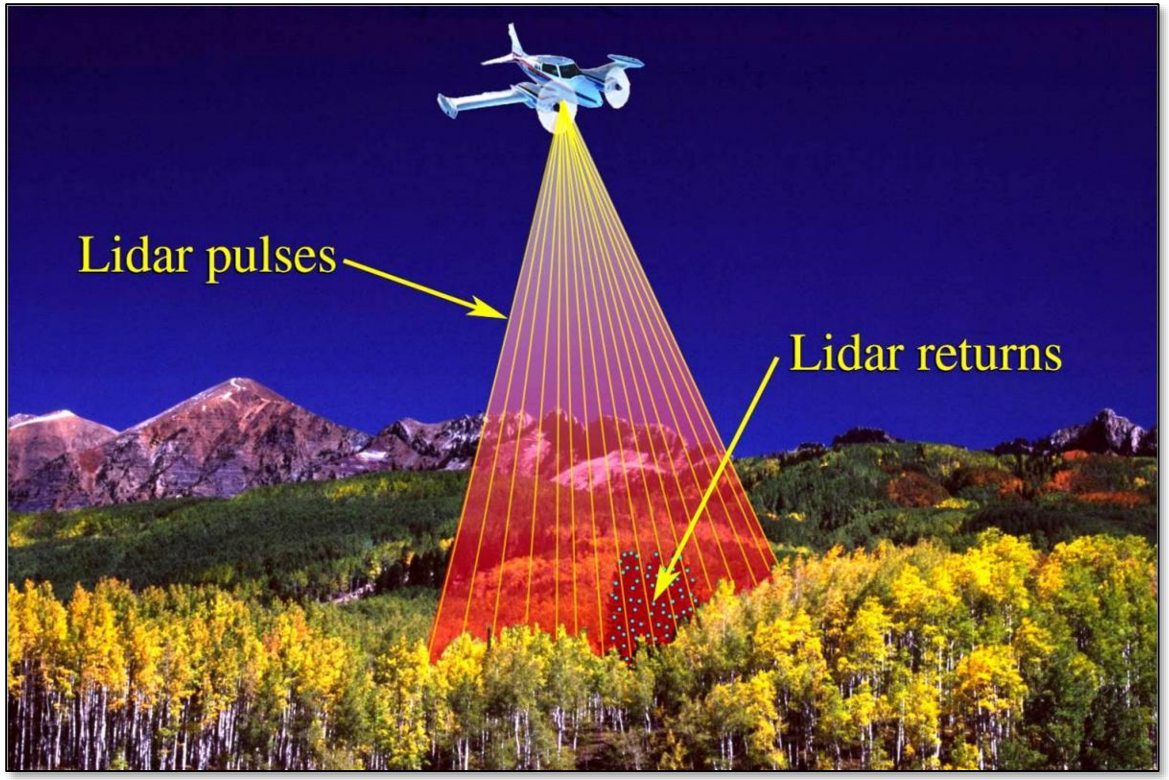
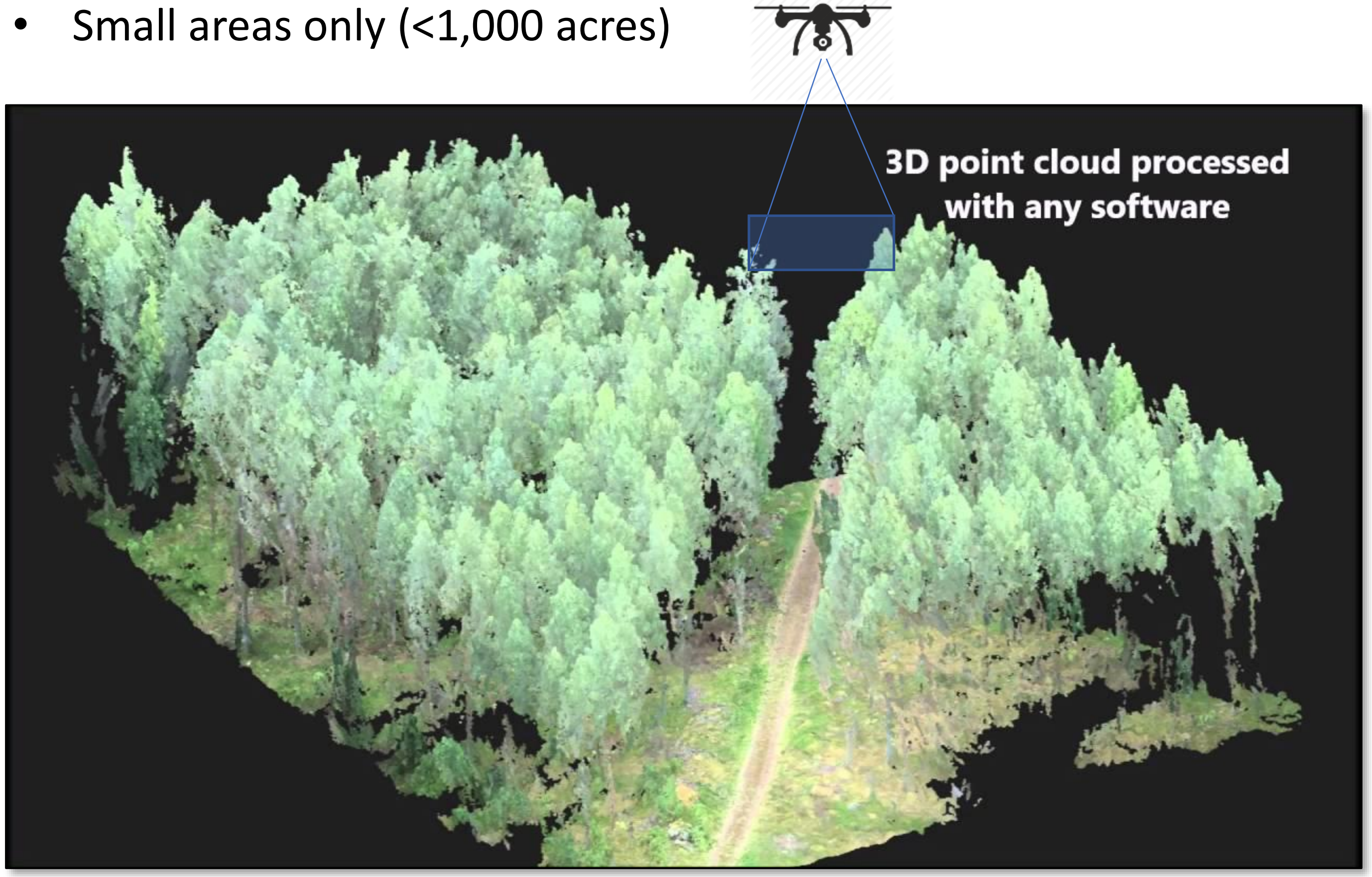


Image from VCGI Lidar http://vcgi.vermont.gov/lidar

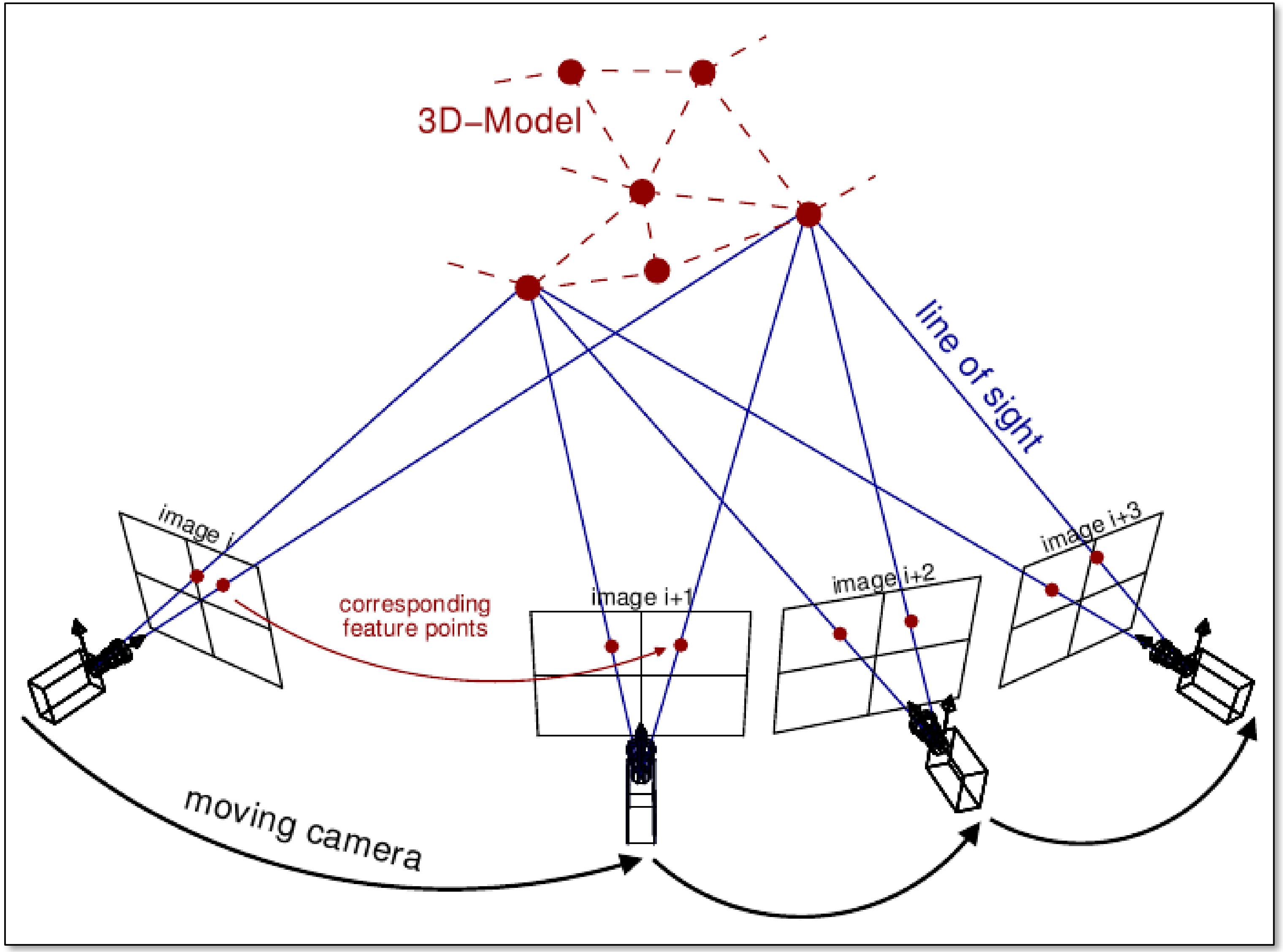


Background- UAVs and Photogrammetry

TYPICAL WORKFLOW

- Set up GPS base station to log data and transmit RTK messages to UAV and roving GPS
- Layout/survey ground control points.
- Set up flight plan to capture a series of overlapping images, such that every landscape feature appears in at least 2-3 images (60-80% frontlap/sidelap).
- UAV contains on-board camera, GPS, and Inertial Measurement Unit to record the location and 3D orientation of each image.

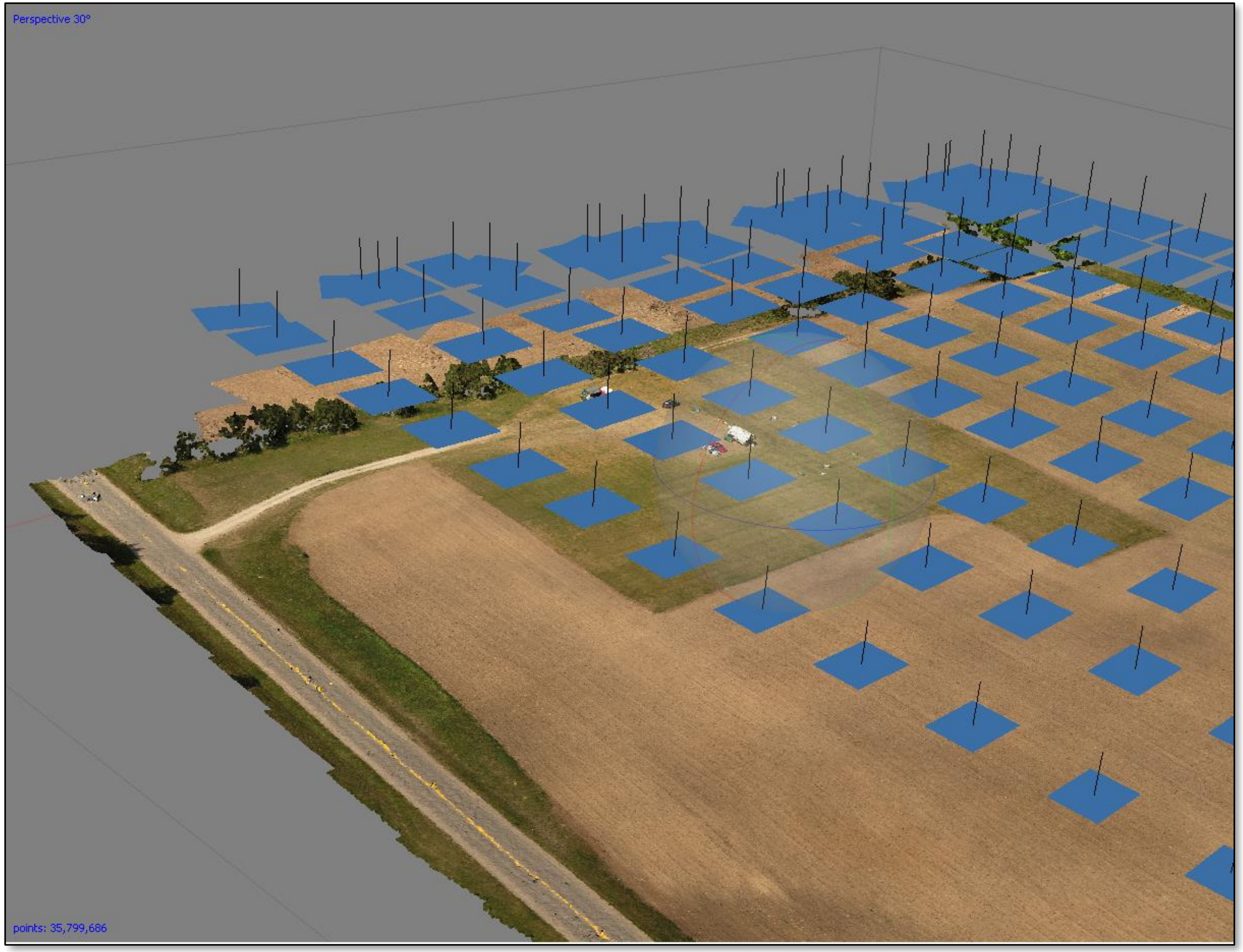
Background- UAV Image Processing



Structure From Motion (or SfM) photogrammetry…

- Similar to traditional stereo photography principals- determining object geometry based on parallax, but…

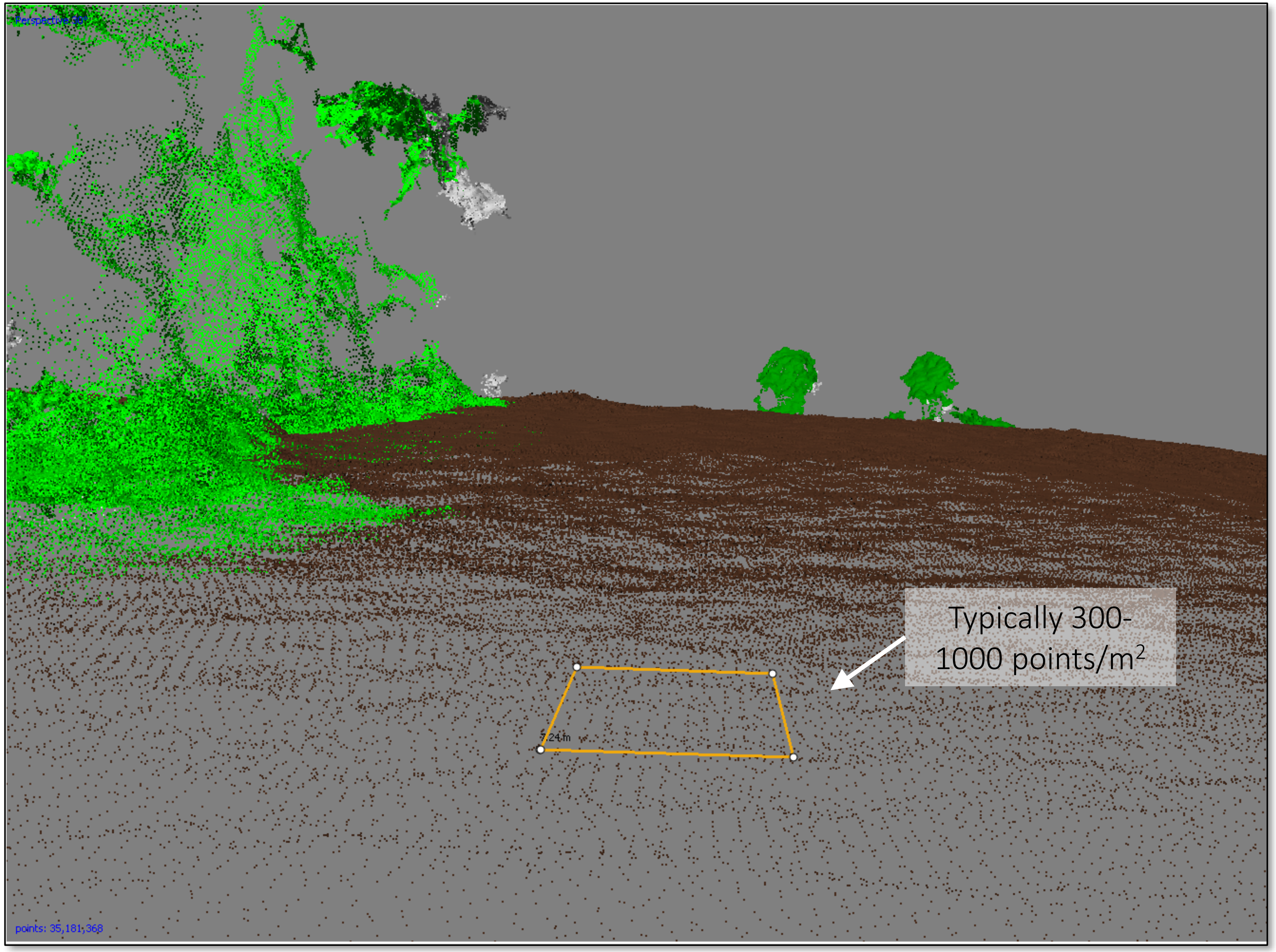
Background- UAV Image Processing



Structure From Motion (or SfM) photogrammetry…

- Similar to traditional stereo photography principals- determining object geometry based on parallax, but…
- In SfM- original camera positions are "solved" based on relative positions of corresponding feature points in adjacent photos.
- Photo-processing algorithms incorporate lens specifications (f-stop, radial distortion, etc.) and GPS locations to narrow search for matching pixels.

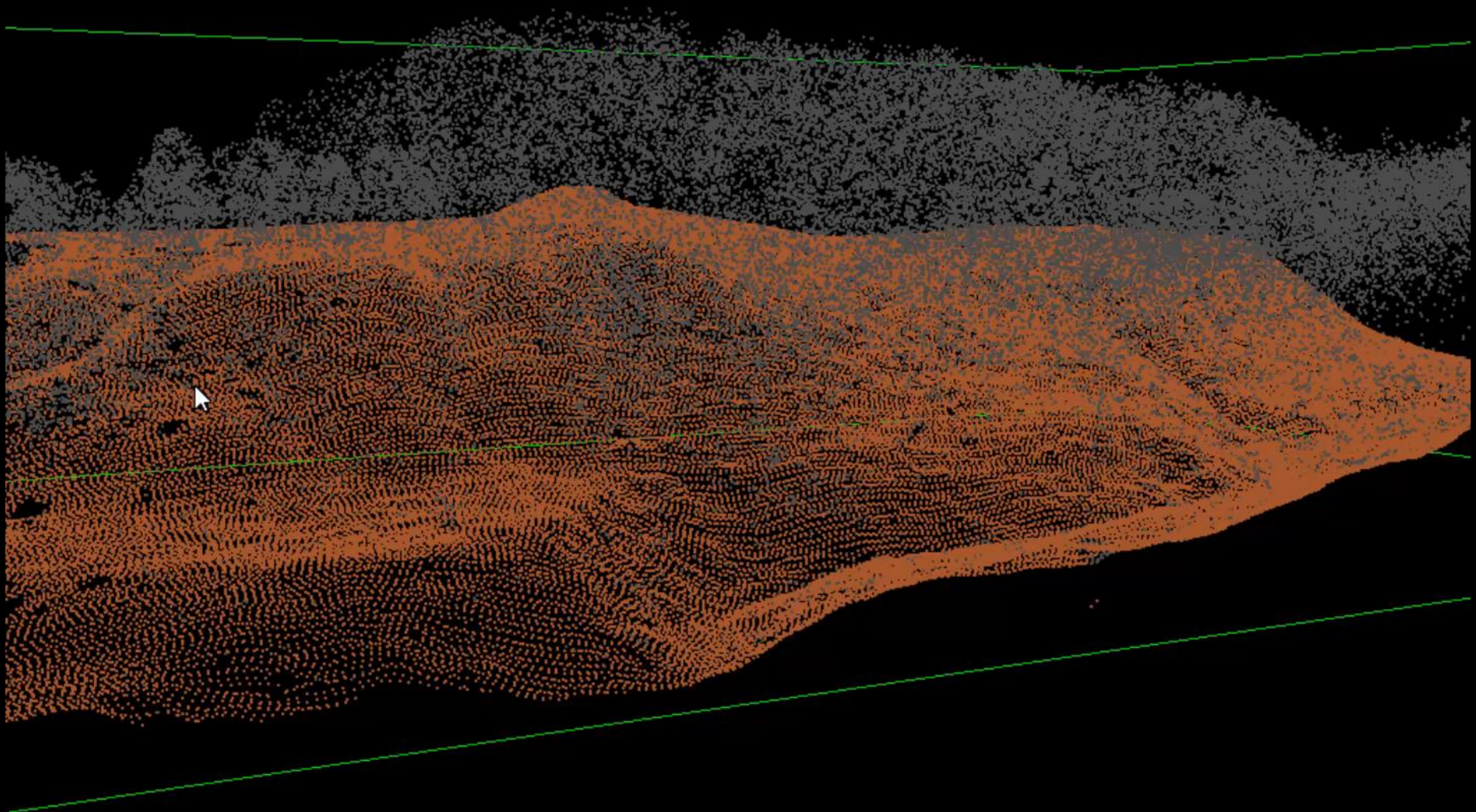
Background- UAV Resulting Point Cloud



- Each point representing the x-y-z coordinates of successfully aligned photo pixels.
- Can be classified according to ASPRS standards (.LAS) Format.
  - Examples:
    - "Ground"
    - "Vegetation"
    - "Buildings"
- Point densities are orders of magnitude higher than LiDAR data

… In Contrast- LiDAR Point Cloud

Typically 5-20 points/m^2



Challenges with using SfM/photo UAVs for mapping forests…

- Trees are in the way of the ground!

- Getting a good bare earth model is difficult, especially during leaf-on conditions.

- DEM is important if/when tree or canopy height models are needed. Typically, a bare earth DEM is needed to compute tree heights.

- Getting good ground control points (GPS) under canopy takes considerable field time.

Challenges with using SfM/photo UAVs for mapping forests…

- **Shadows!**

- Even at solar noon (time of shortest shadows), it is difficult to discern tree from shadow on sunny days

Challenges with using SfM/photo UAVs for mapping forests…

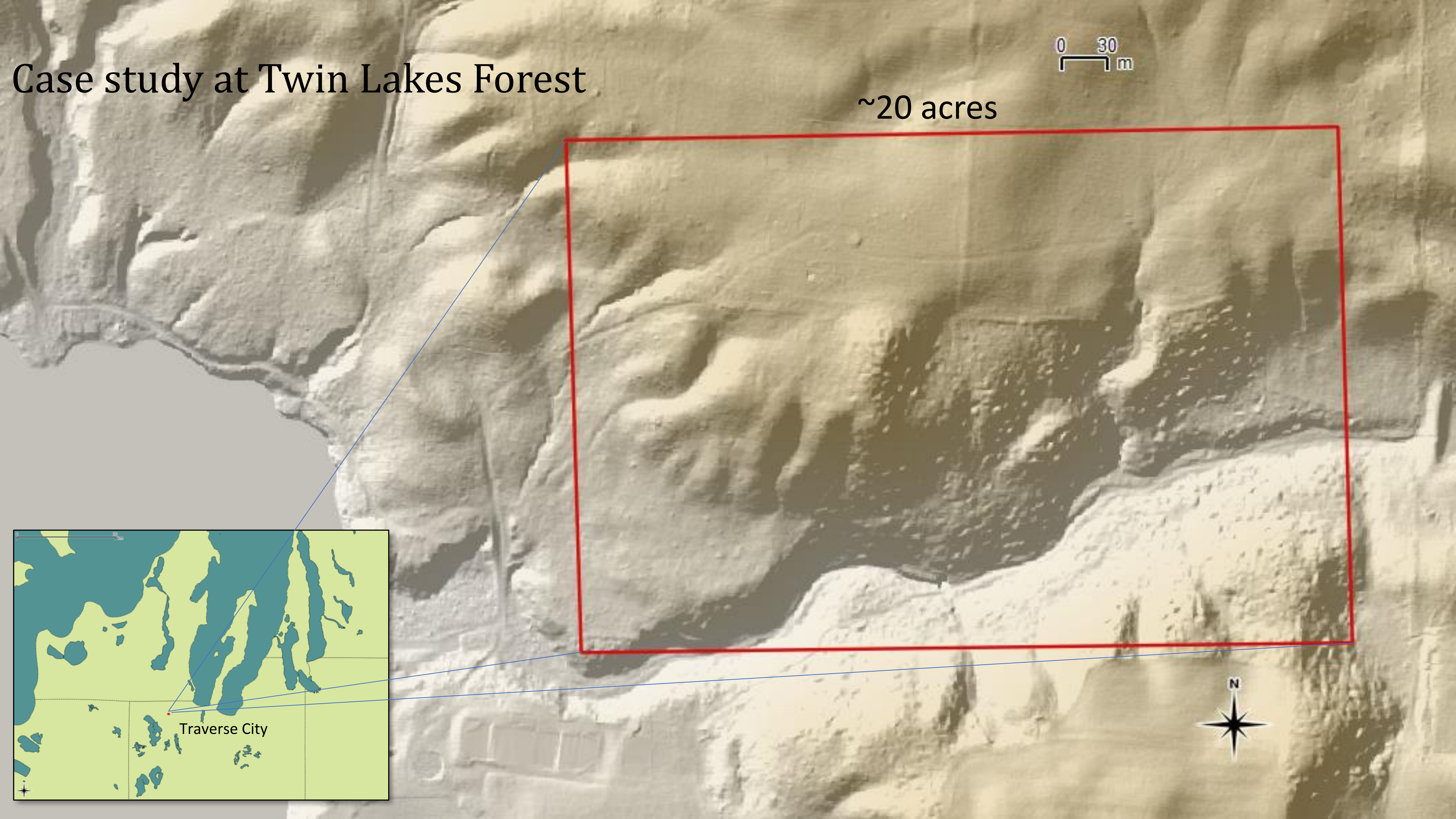
- **Must maintain line of sight with UAV (FAA regulations)!**

- Need an adjacent open field for base camp and visual contact

<u>Ideal Forest Type/Setting</u>

- Non-contiguous forests
- High value forests (hardwoods)

Case study at Twin Lakes Forest



Case study at Twin Lakes Forest

Trillium grandiflorum - Trillium

Viola canadensis - Canada Violet

Case study at Twin Lakes Forest

Sanguinaria canadensis - Bloodroot

Arisaema tropyliums - Jack-in-the-Pulpit

Case study at Twin Lakes Forest

Caulophyllum thalictroides- Blue Cohosh

Typical view along the trail

Approach - Hardware

DJI Phantom 4

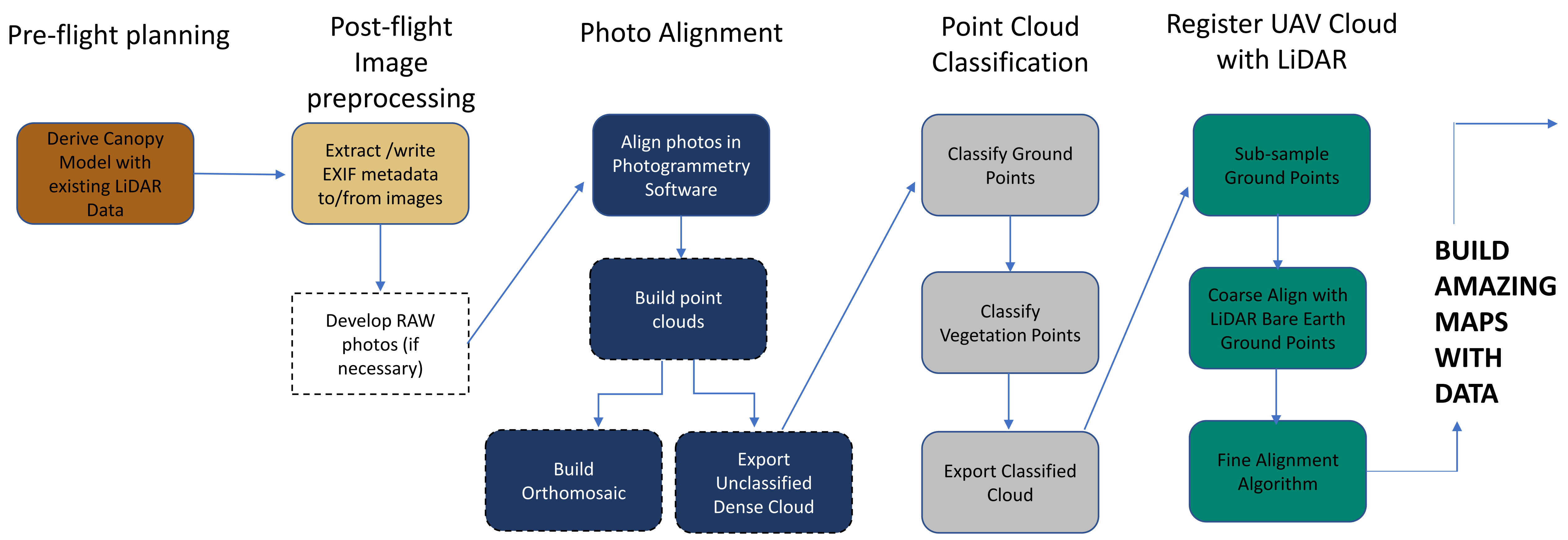
On-Board Camera Specs

- FOV 94° 20 mm (35 mm format equivalent) f/2.8 focus at ∞
- Image size 4000 x 3000 pixels
- Effective pixels: 12.4 M
- Max flight time 28 minutes (per battery)

Setup

- Shoot in RAW format (DNG)
- Captured images during Leaf-Off (Spring 2017)
- Captured images during bright overcast (good lighting, but no shadows)
- Flight speed 4 m/sec (to minimize motion blur)

WORKFLOW



SOFTWARE COCKTAIL

FUSION LiDAR Tools

EXIFtools

Agisoft Photoscan

LAStools

Cloud Compare

WORKFLOW

Pre-flight planning

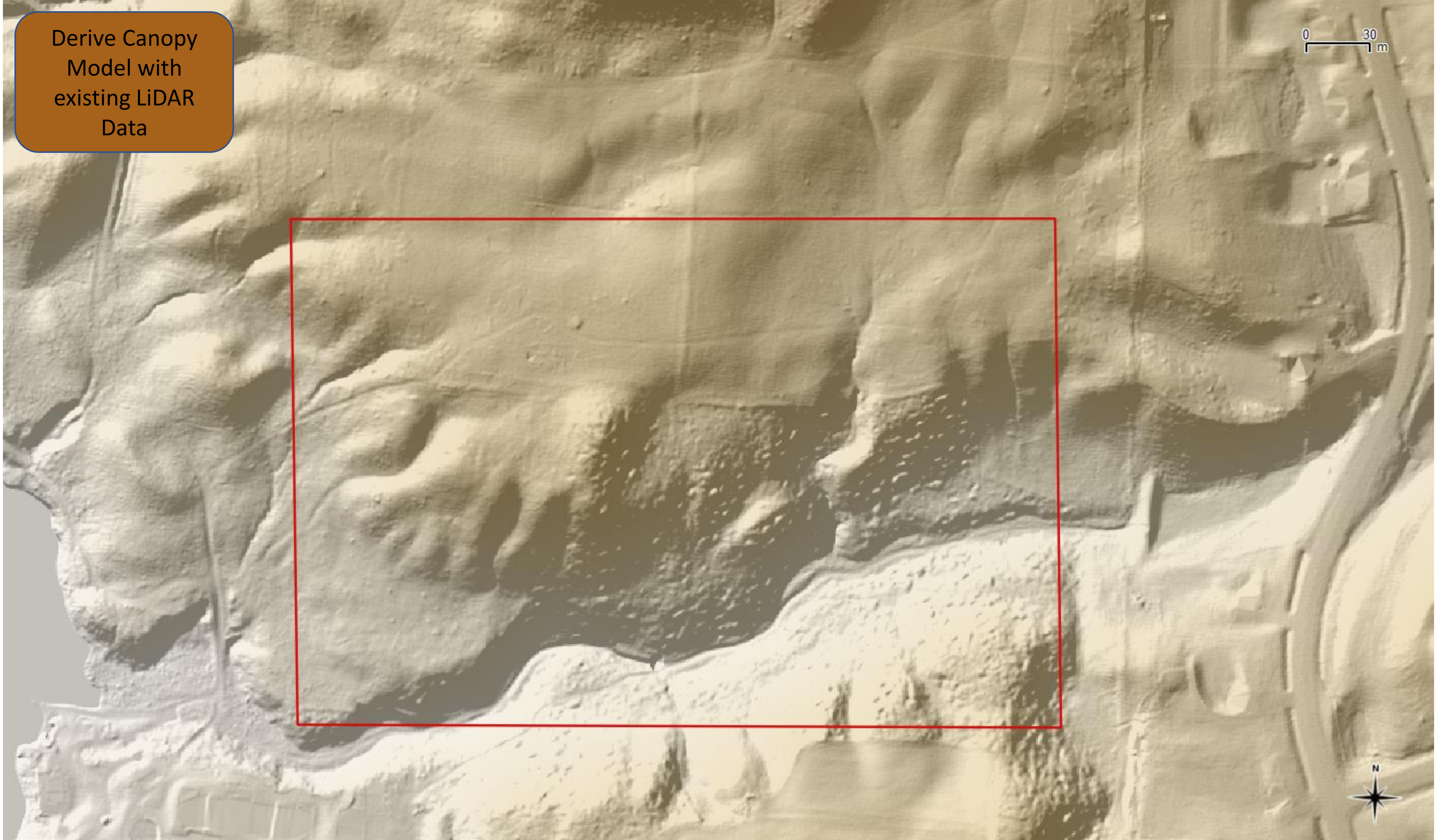
Derive Canopy Model with existing LiDAR Data

- Locate suitable base camp
- Desired marker placement
- Desired flight altitude/ground sampling distance

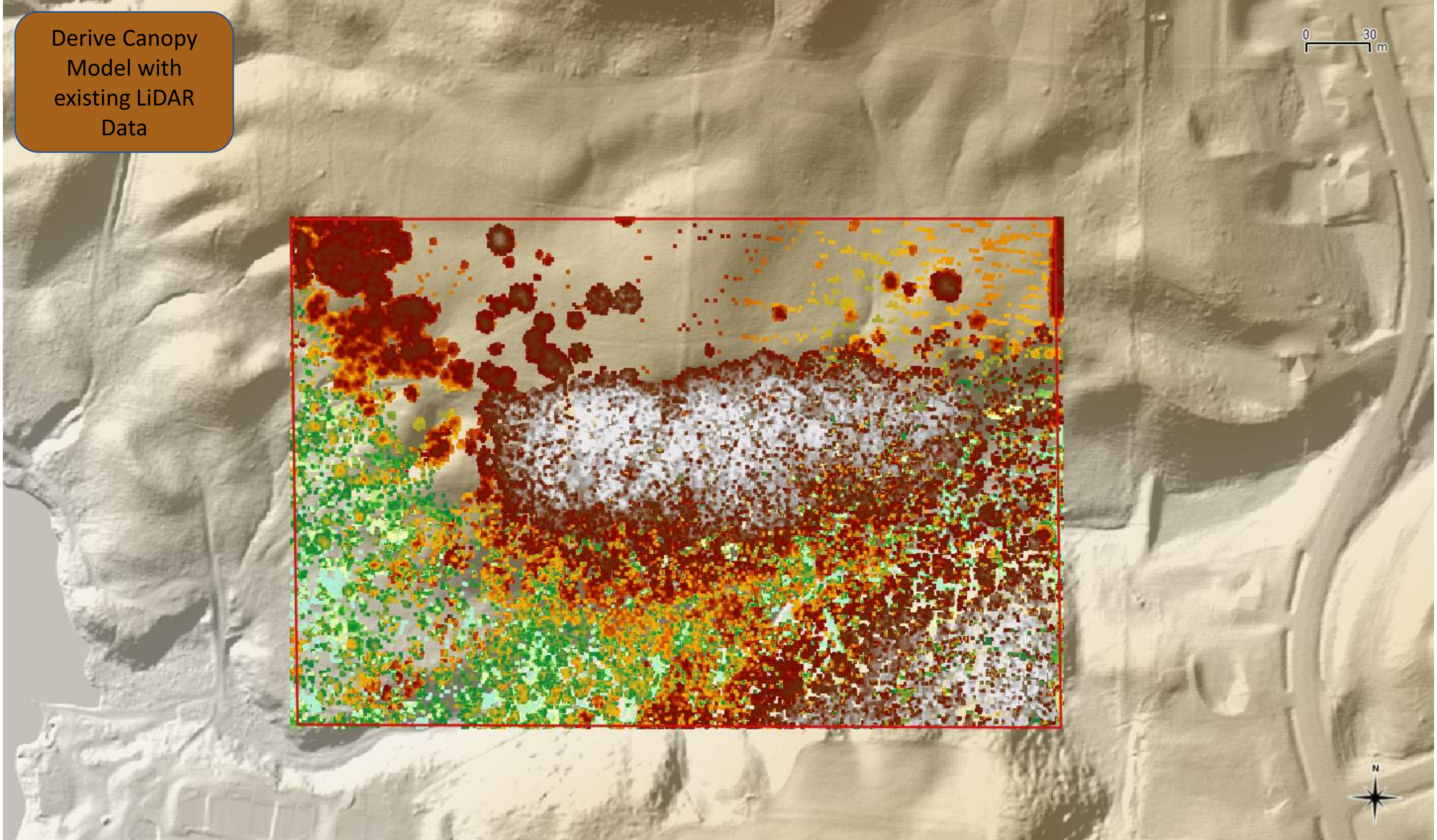
SOFTWARE COCKTAIL

FUSION LiDAR Tools

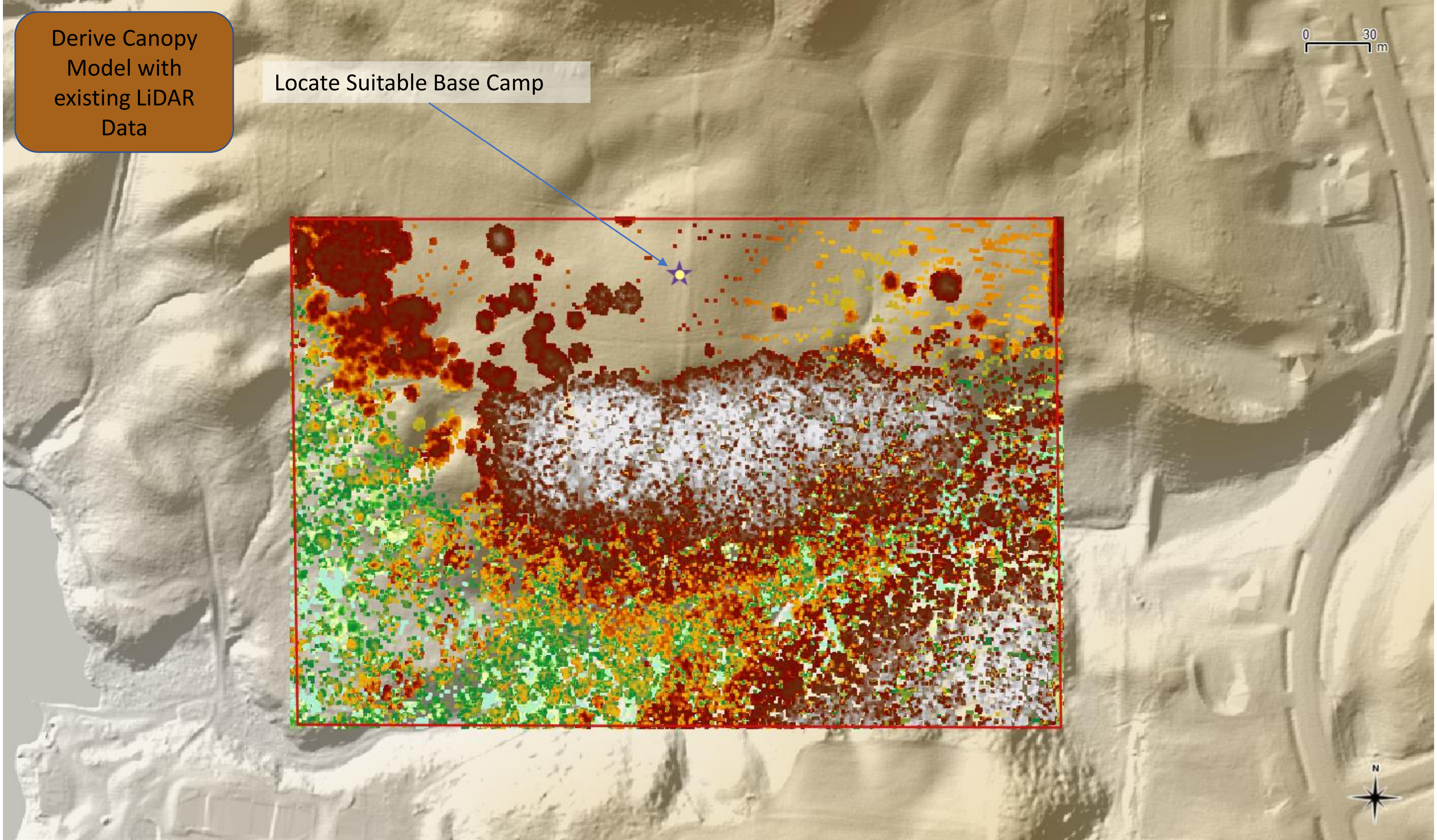
Derive Canopy Model with existing LiDAR Data



Derive Canopy Model with existing LiDAR Data

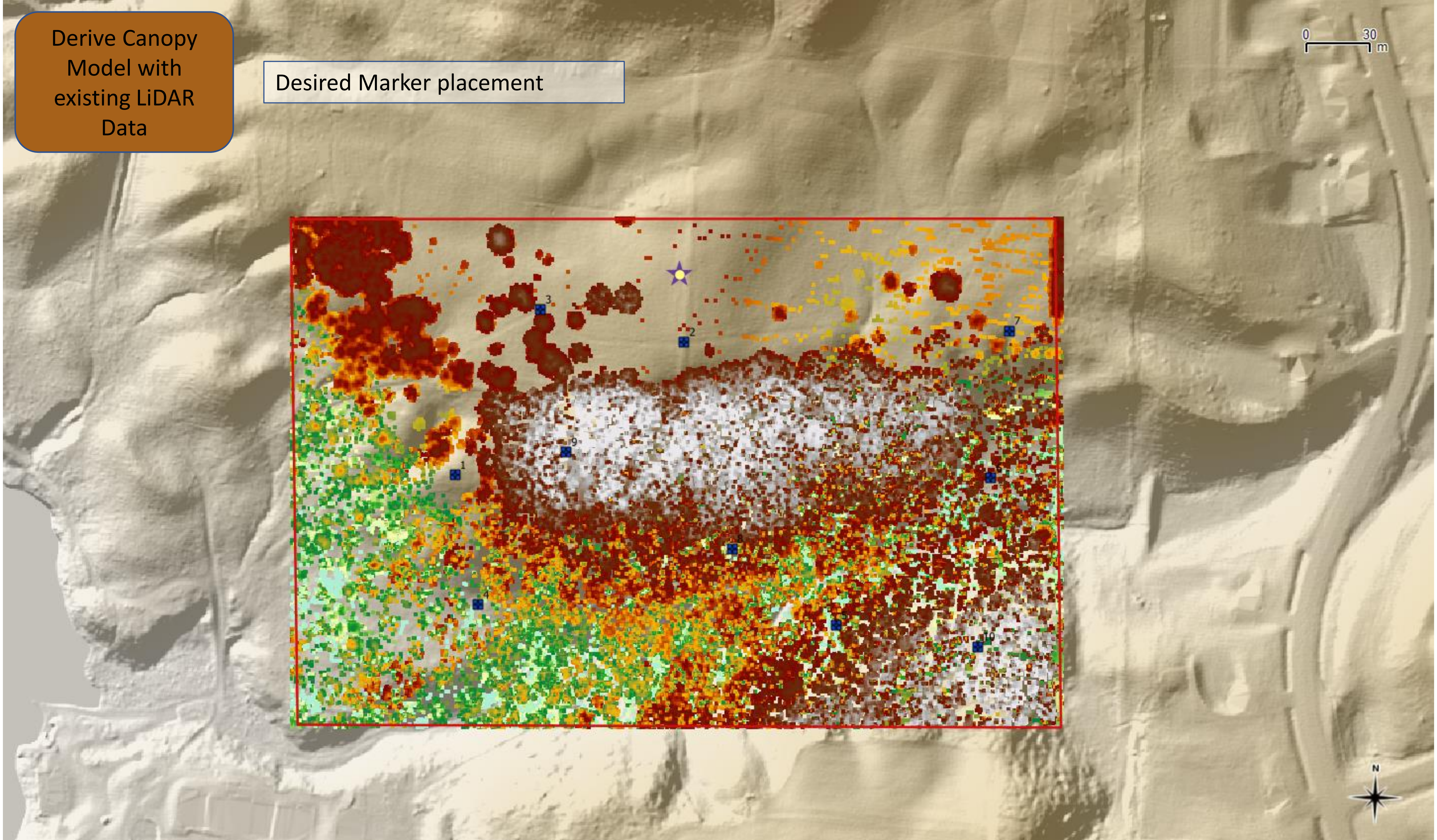


Derive Canopy Model with existing LiDAR Data



Derive Canopy Model with existing LiDAR Data

Desired Marker placement

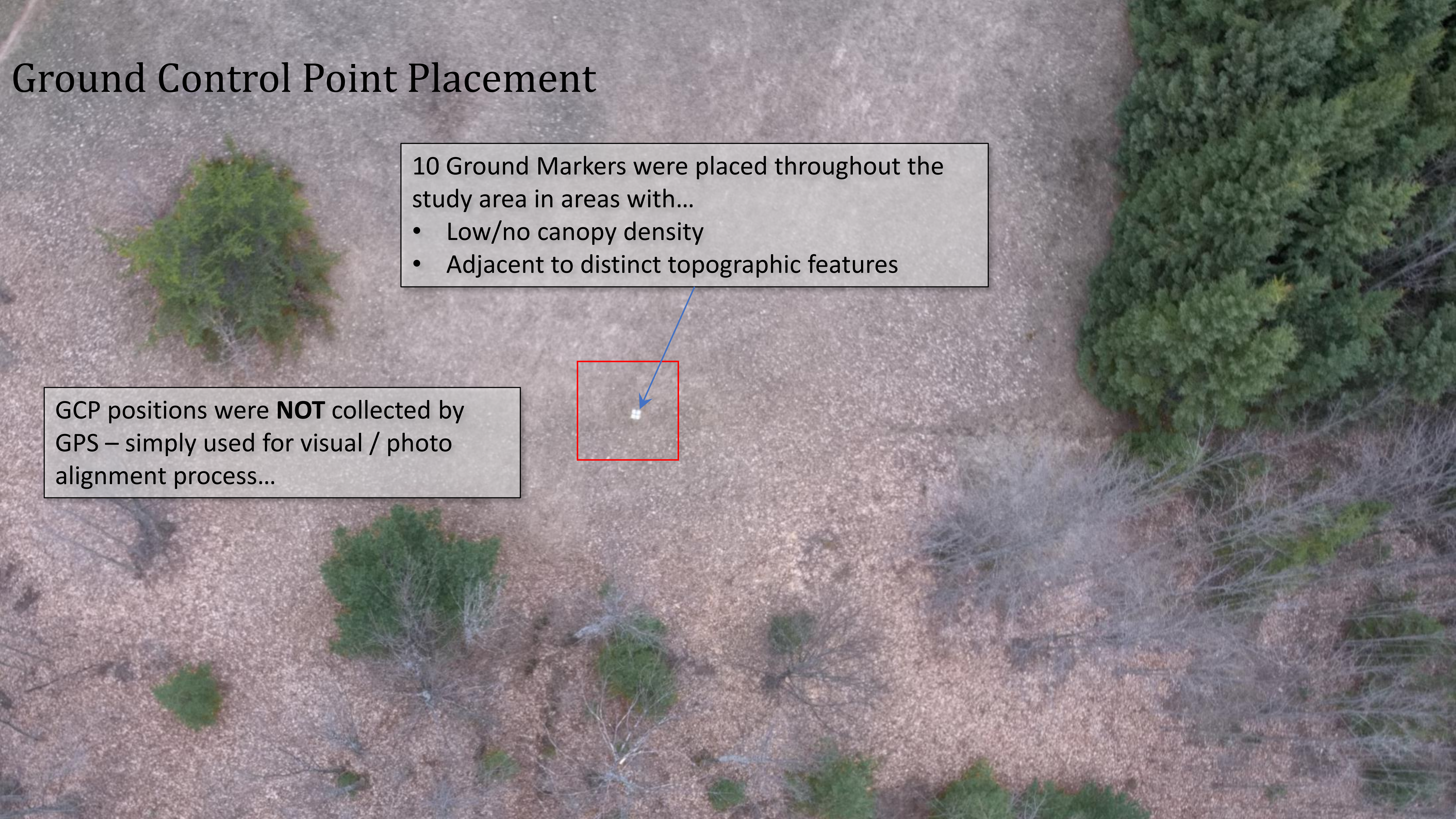


Ground Control Point Placement

10 Ground Markers were placed throughout the study area in areas with…

- Low/no canopy density
- Adjacent to distinct topographic features

GCP positions were **NOT** collected by GPS – simply used for visual / photo alignment process…



WORKFLOW

Pre-flight planning

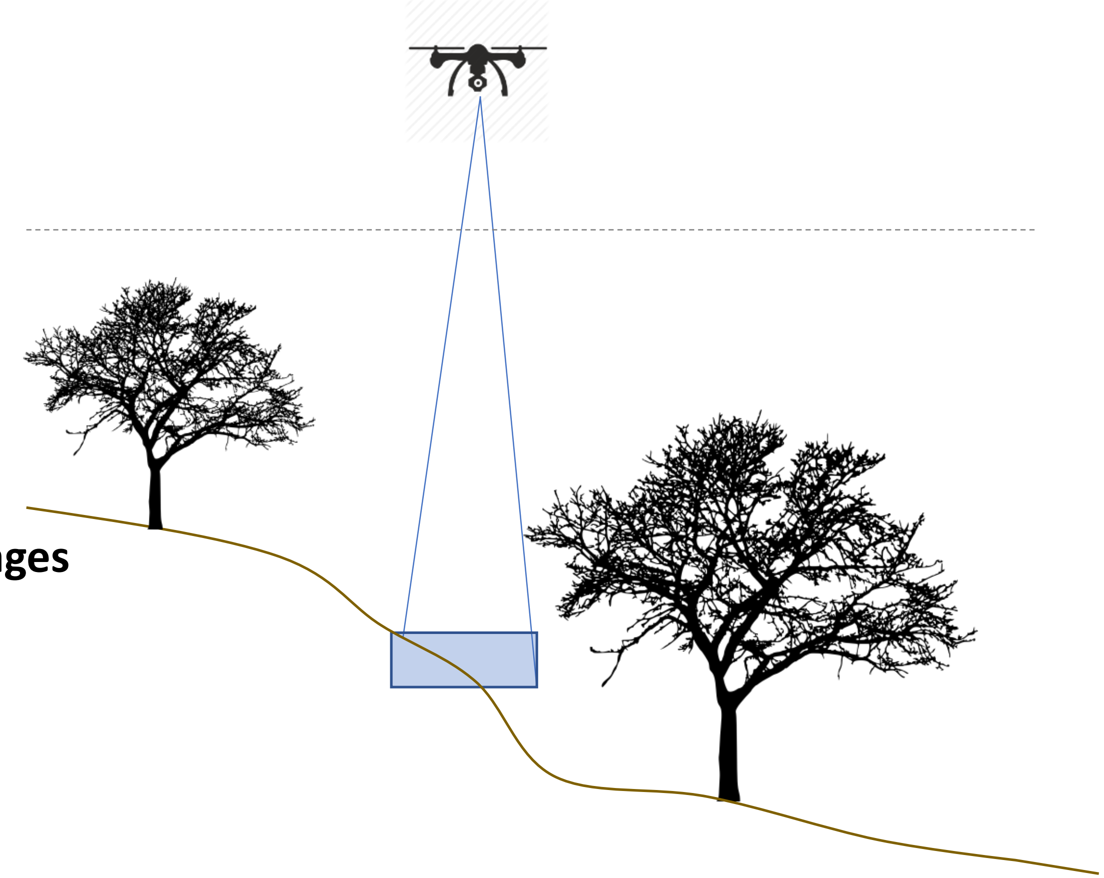
Derive Canopy Model with existing LiDAR Data

Locate suitable base camp

Desired marker placement

Desired flight altitude/ground sampling distance

- **Safe height (avoid trees)**
- **Ensuring enough overlap of canopy in images**
- **Ensuring enough ground detail**

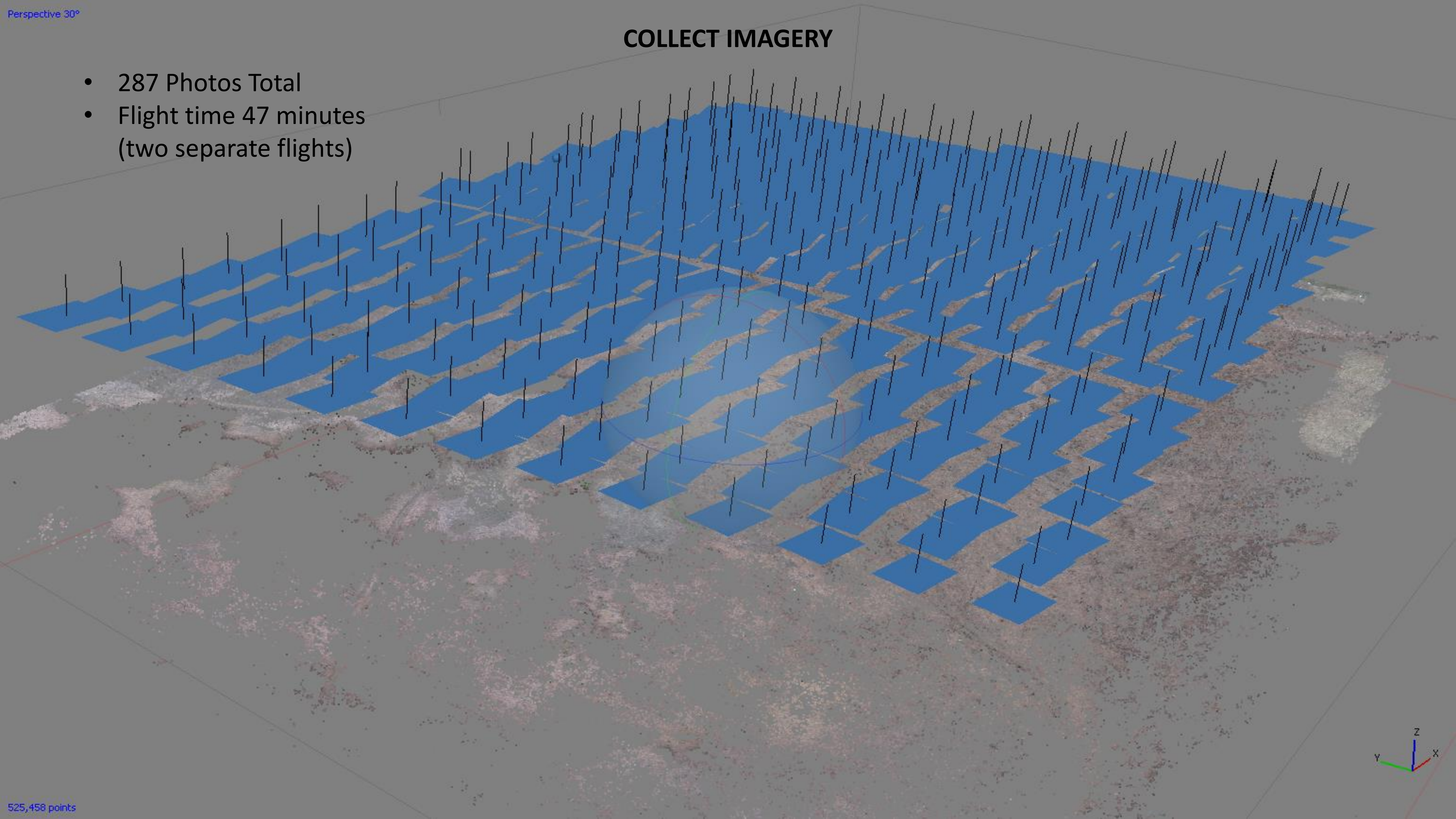


SOFTWARE COCKTAIL

FUSION LiDAR Tools

COLLECT IMAGERY

- 287 Photos Total
- Flight time 47 minutes (two separate flights)



WORKFLOW

Pre-flight planning

Post-flight
Image preprocessing

ExifTool by Phil Harvey
Read, **Write** and **Edit** Meta Information!

Derive Canopy Model with existing LiDAR Data

(collect Imagery)

Extract /write EXIF metadata to/from images

- Translate photo GPS locations to desired coordinate system **(same as LiDAR, if possible)**
- Extract Pitch, Yaw, Roll, etc.

Develop RAW photos (if necessary)

- RAW vs. JPEG? (Highest signal-to-noise ratio is desired- most of the time, RAW is best!)

SOFTWARE COCKTAIL

FUSION LiDAR Tools

EXIFtool

WORKFLOW

Pre-flight planning

Post-flight
Image preprocessing

Photo Alignment

Derive Canopy Model with existing LiDAR Data

Extract /write EXIF metadata to/from images

Develop RAW photos (if necessary)

Align photos in Photogrammetry Software

Build point clouds

Agisoft

<u>Alternatives to Agisoft Photoscan</u>

- Pix4D
- nFrames
- Micmac
- COLMAP

SOFTWARE COCKTAIL

FUSION LiDAR Tools

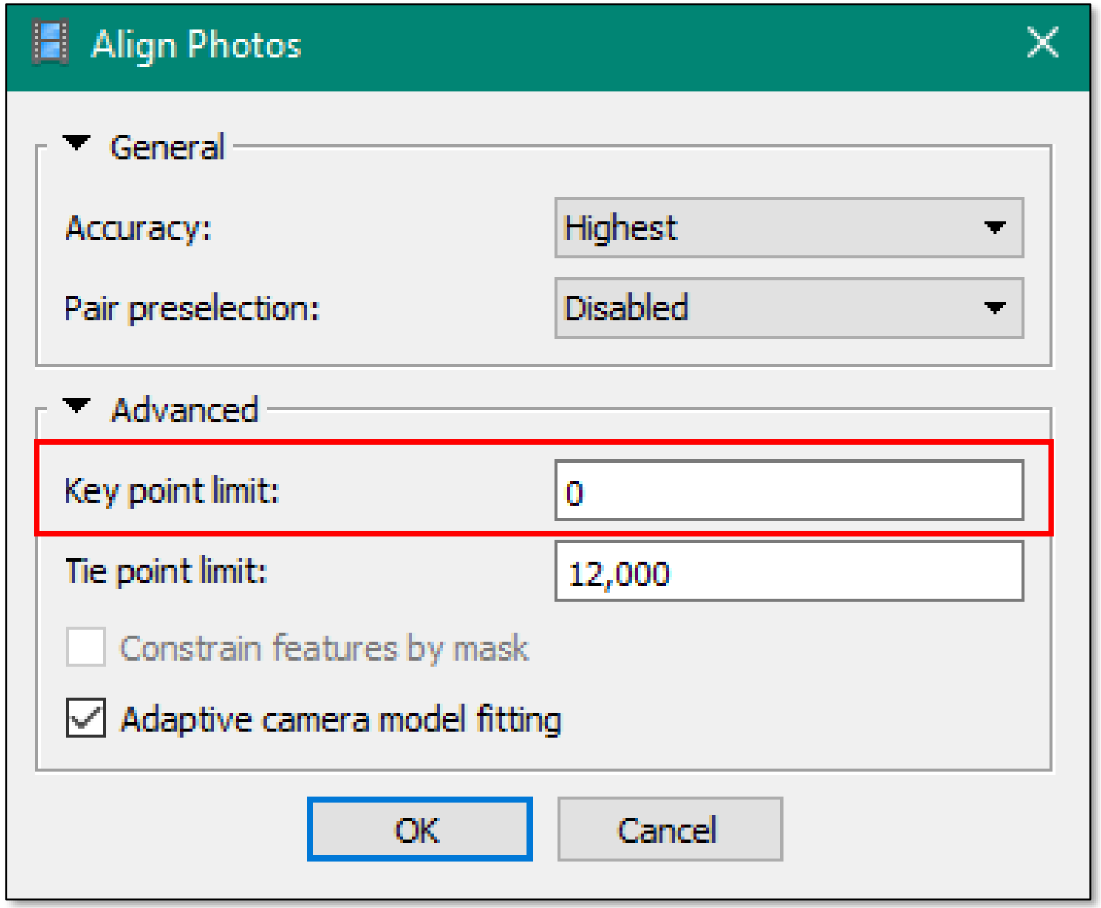
EXIFtools

Agisoft Photoscan

Agisoft Photoscan – photogrammetric software

Basic workflow

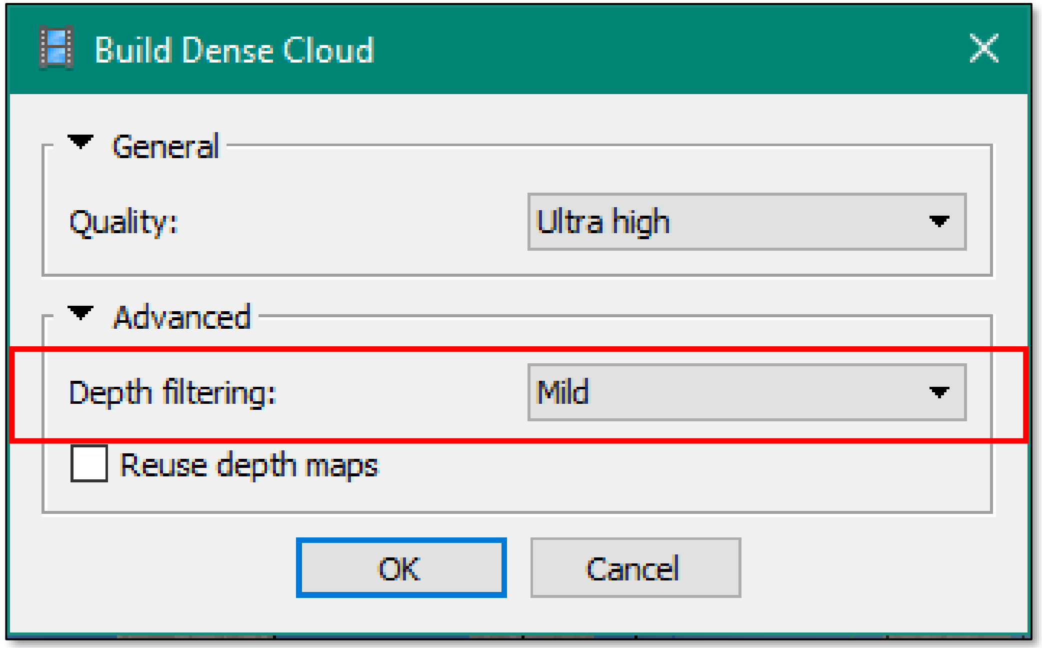
- Set desired coordinate system
- Add Photos
- Import EXIF metadata (speeds up image registration)
- **Align photos**
- **Can take several hours to days for ~300 photos**



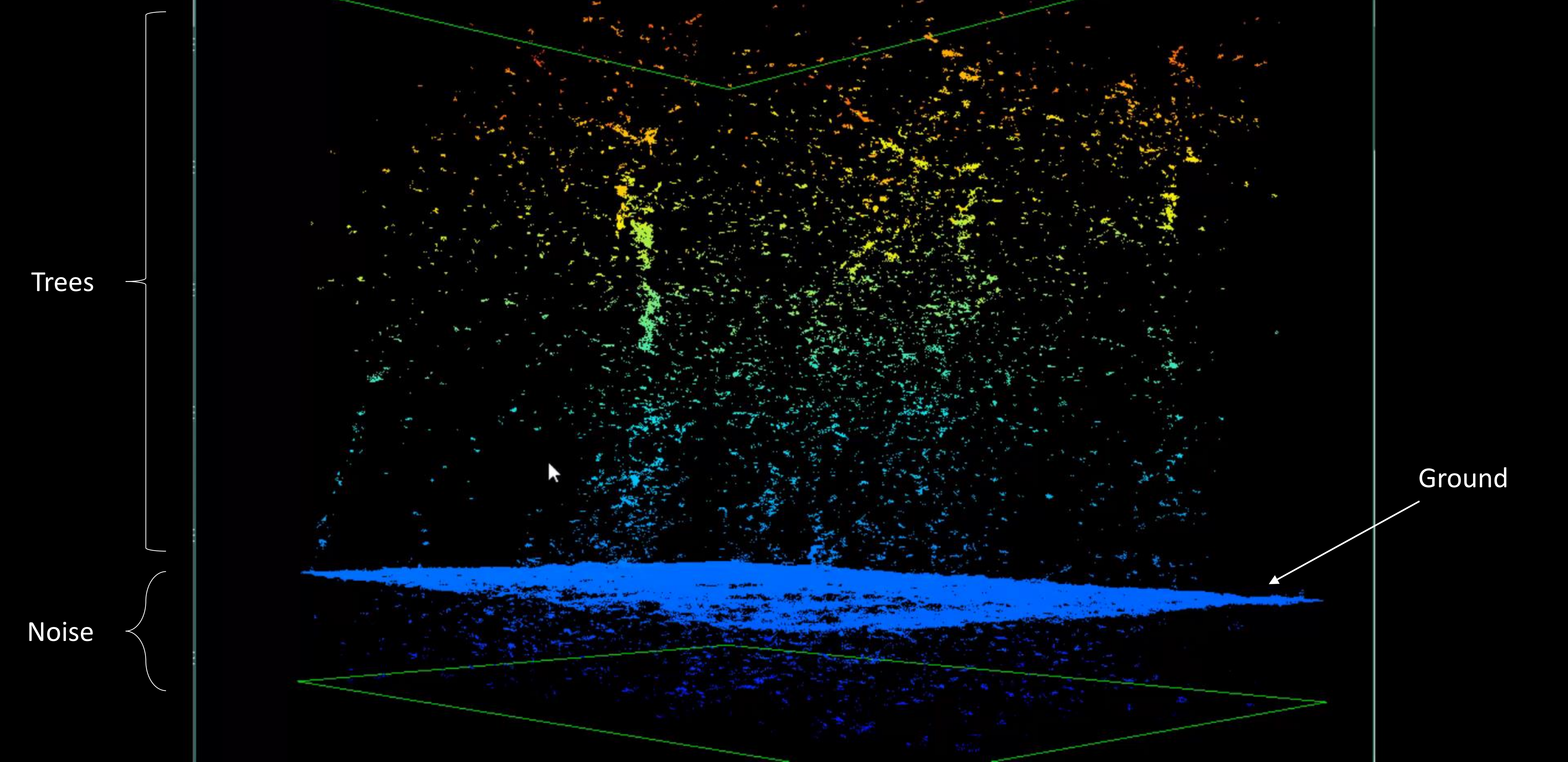
Agisoft Photoscan – photogrammetric software

Basic workflow

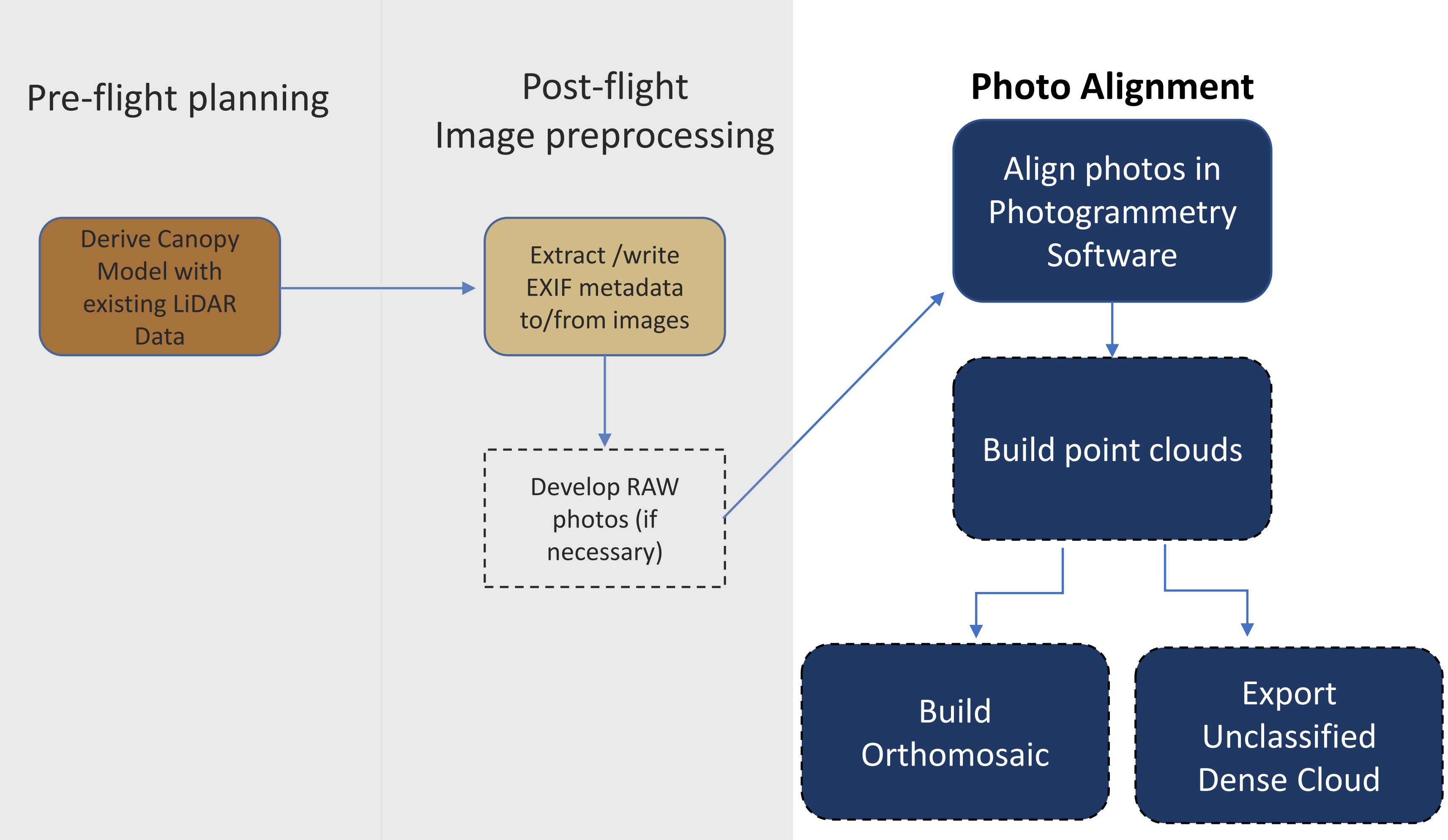
- Align Photos
- **Build Point Clouds (Sparse→Dense)**
  - **Setting depth filtering to <u>mild</u> ensures that the structure of trees are detected, yet minimizes “below ground” noise**



Example of below ground noise



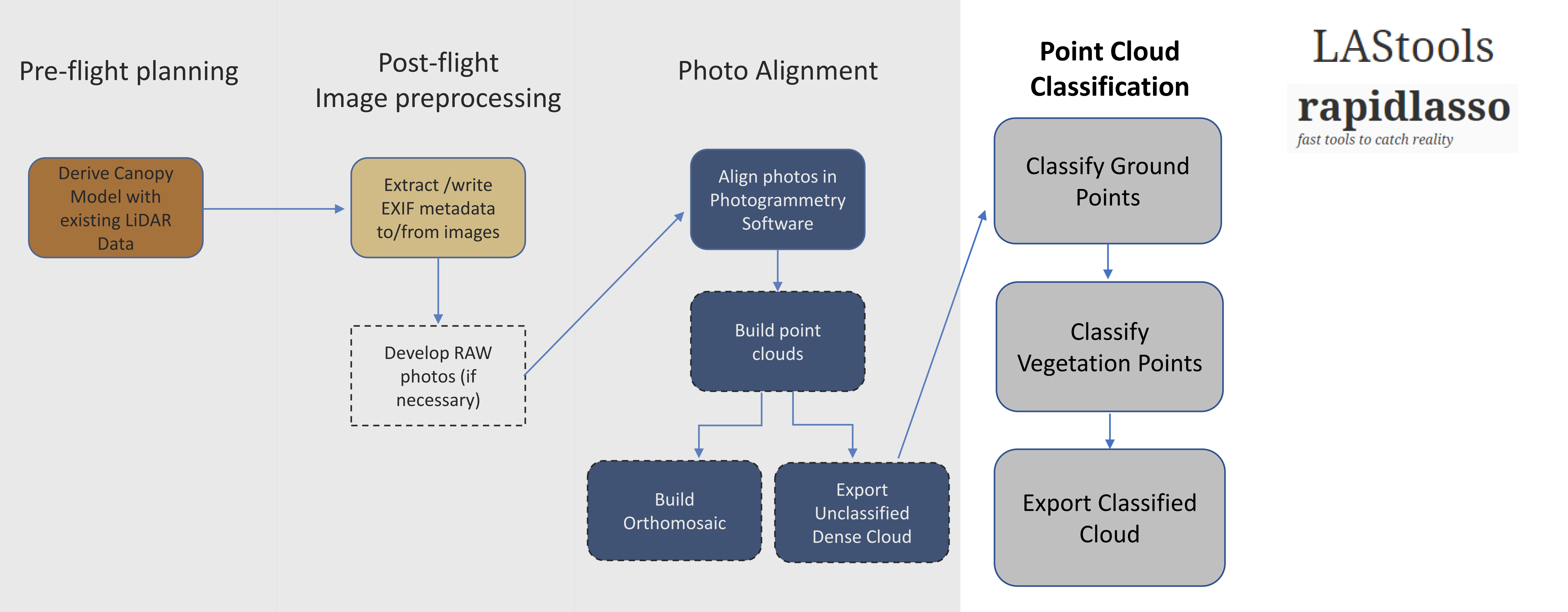
WORKFLOW



SOFTWARE COCKTAIL

- **FUSION LiDAR Tools**
- **EXIFtools**
- **Agisoft Photoscan**

WORKFLOW



SOFTWARE COCKTAIL

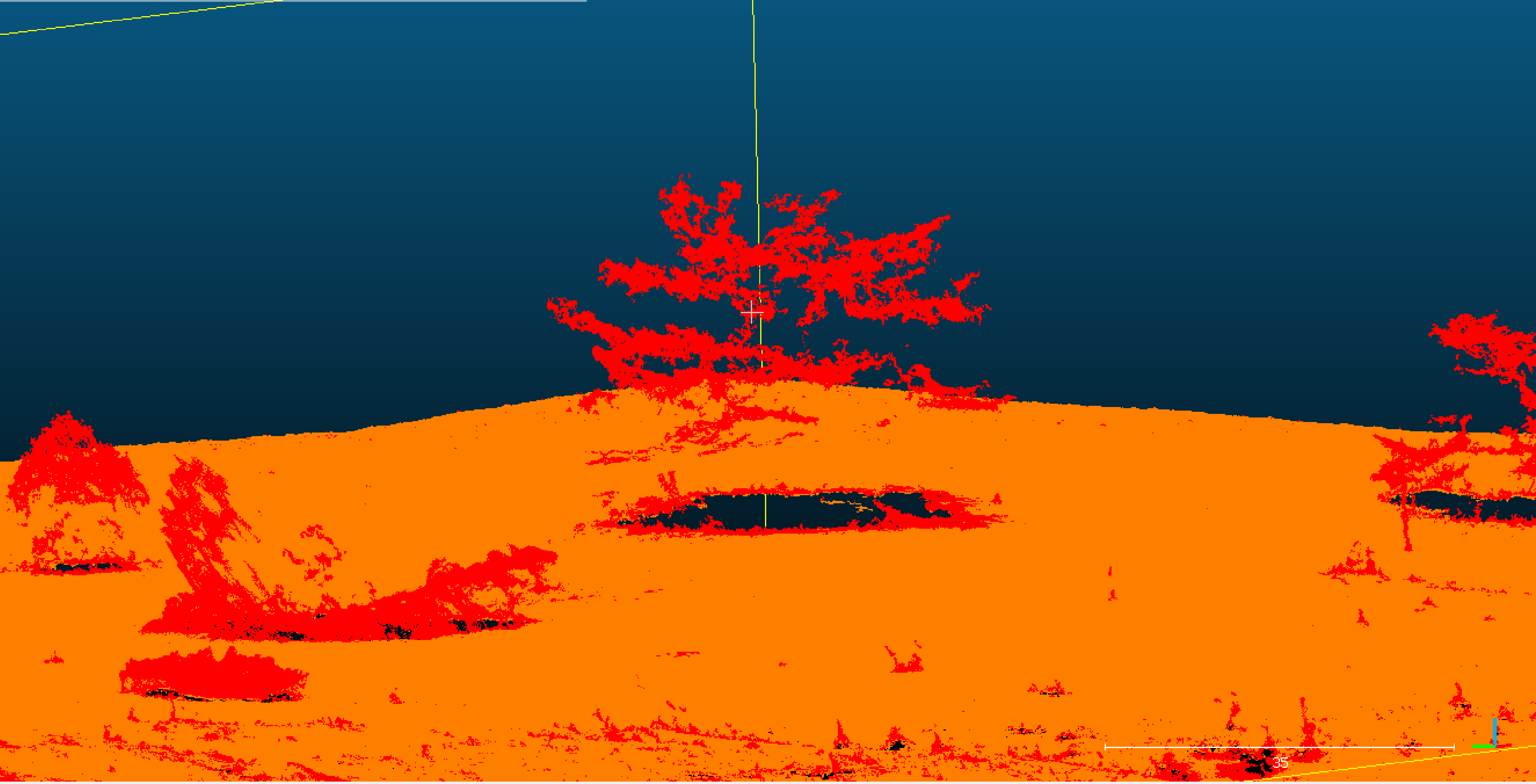
FUSION LiDAR Tools

EXIFtools

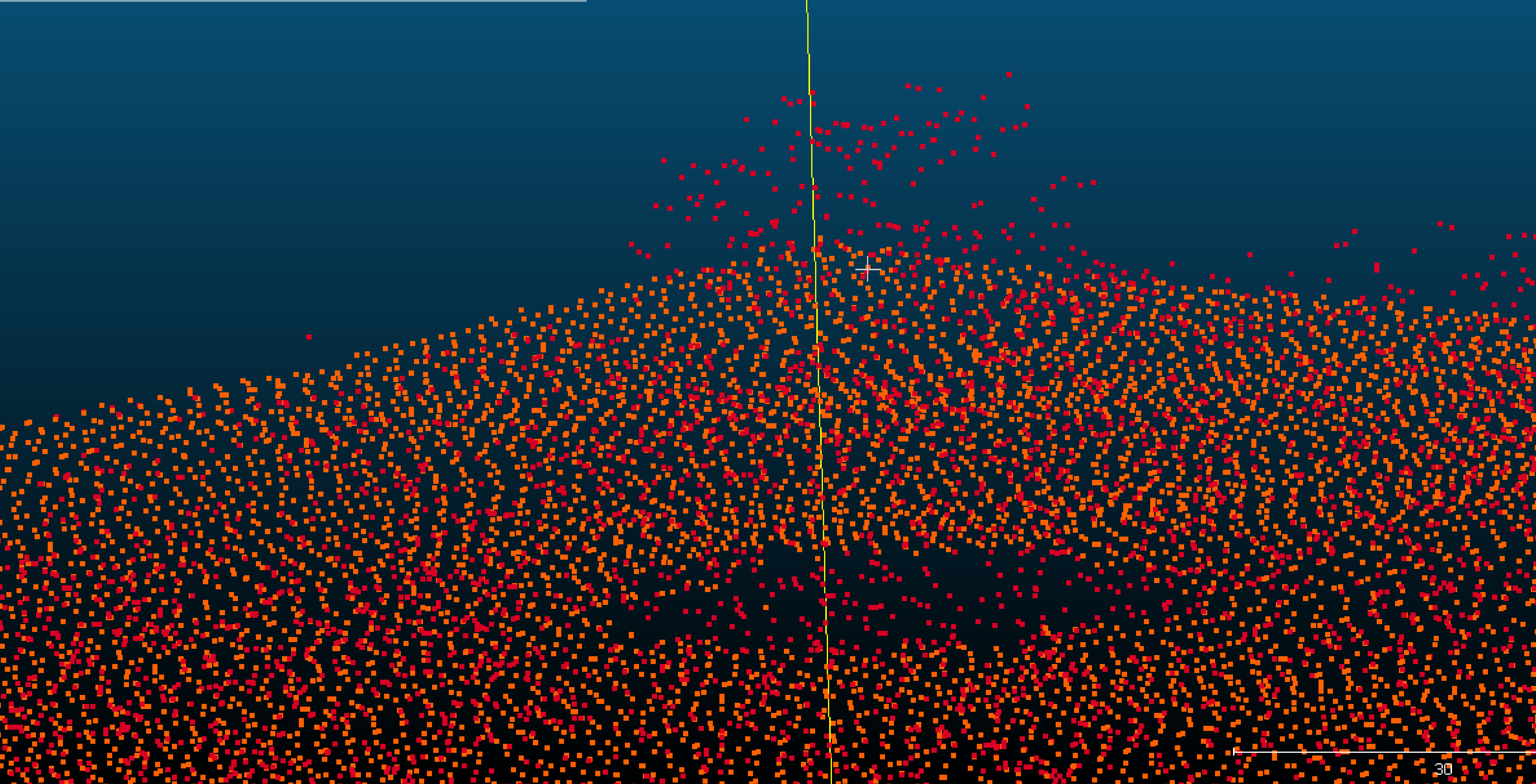
Agisoft Photoscan

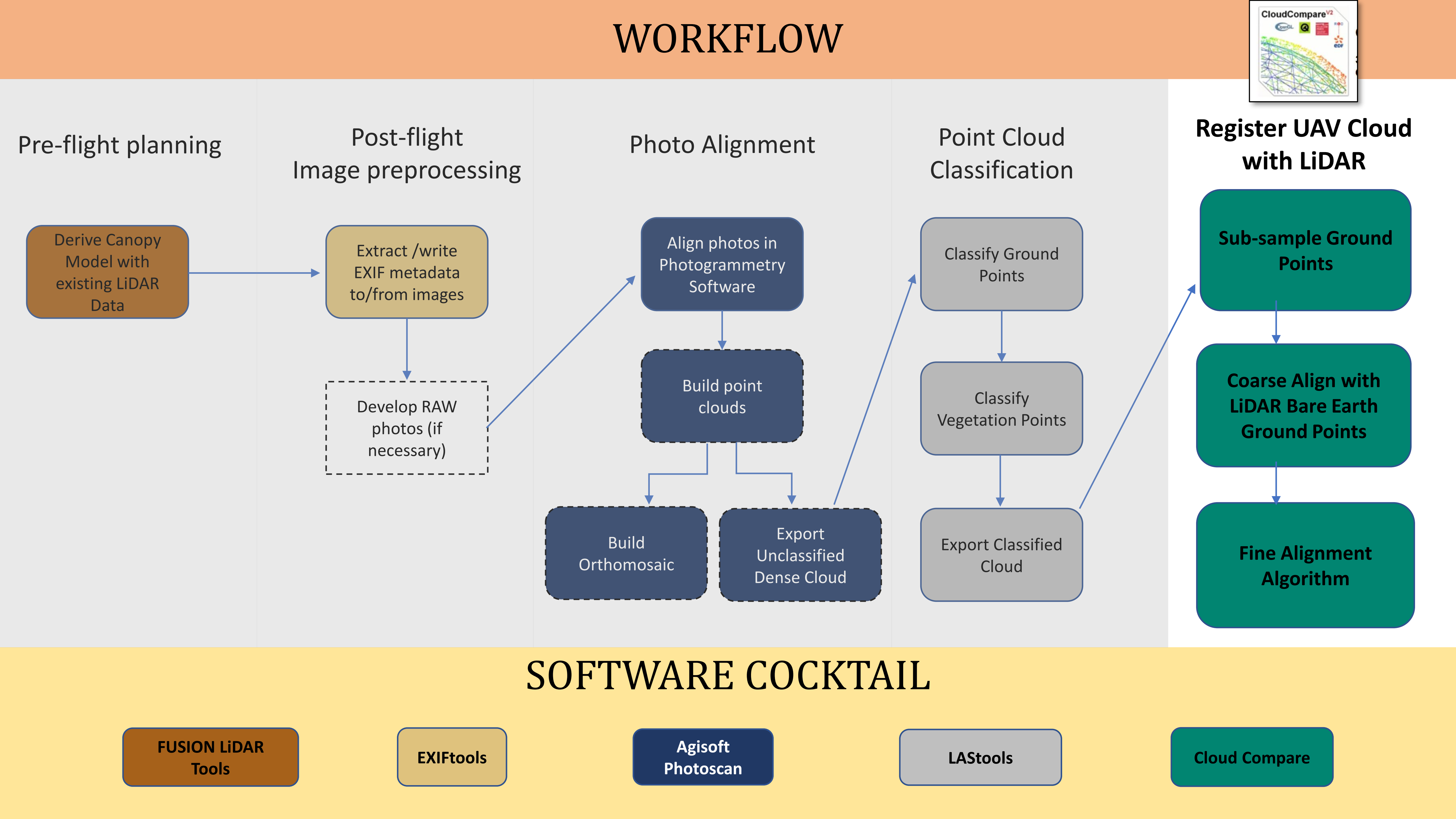
LAStools

UAV Photo Point Cloud ~254 **million** points
Or about **3,200 points/m^2**

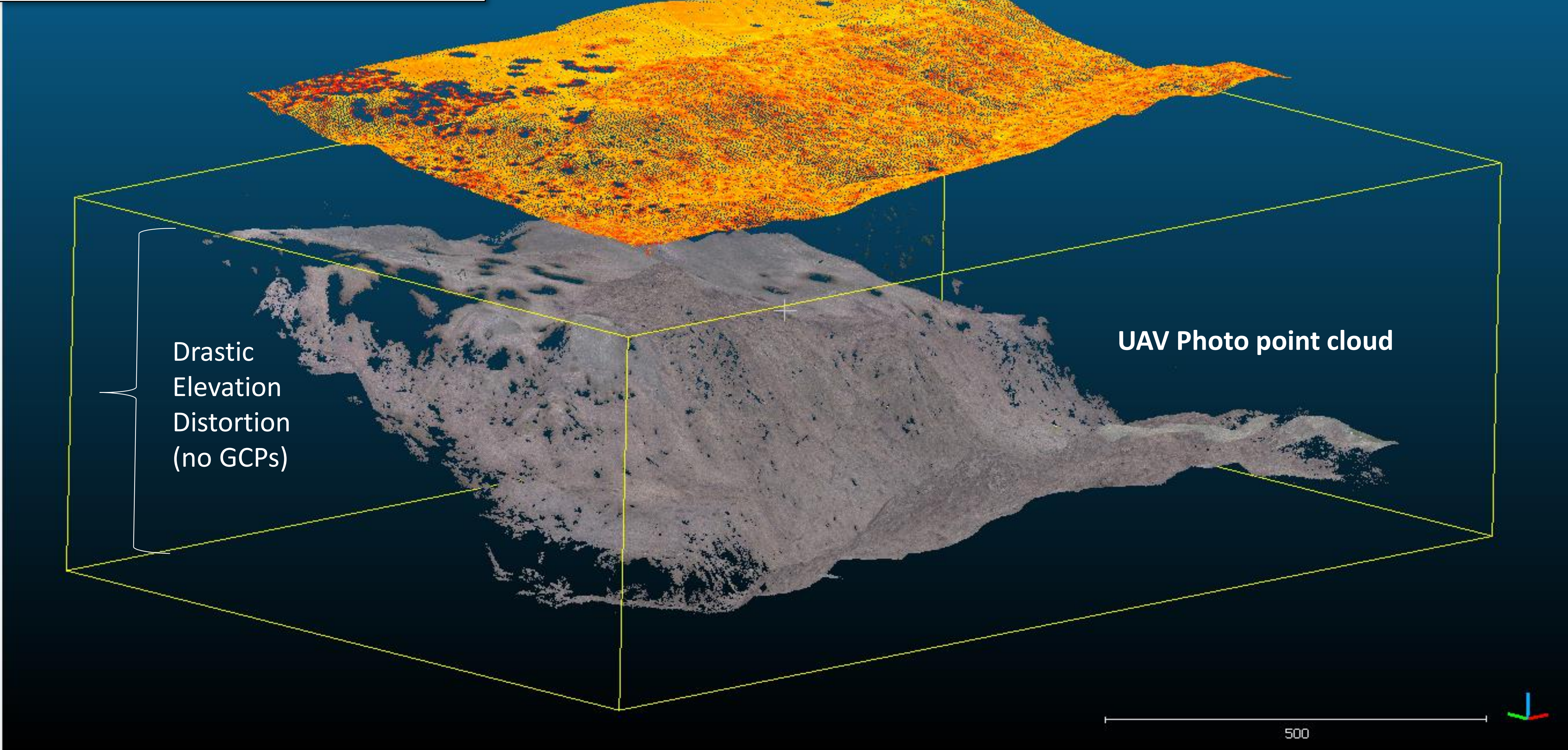


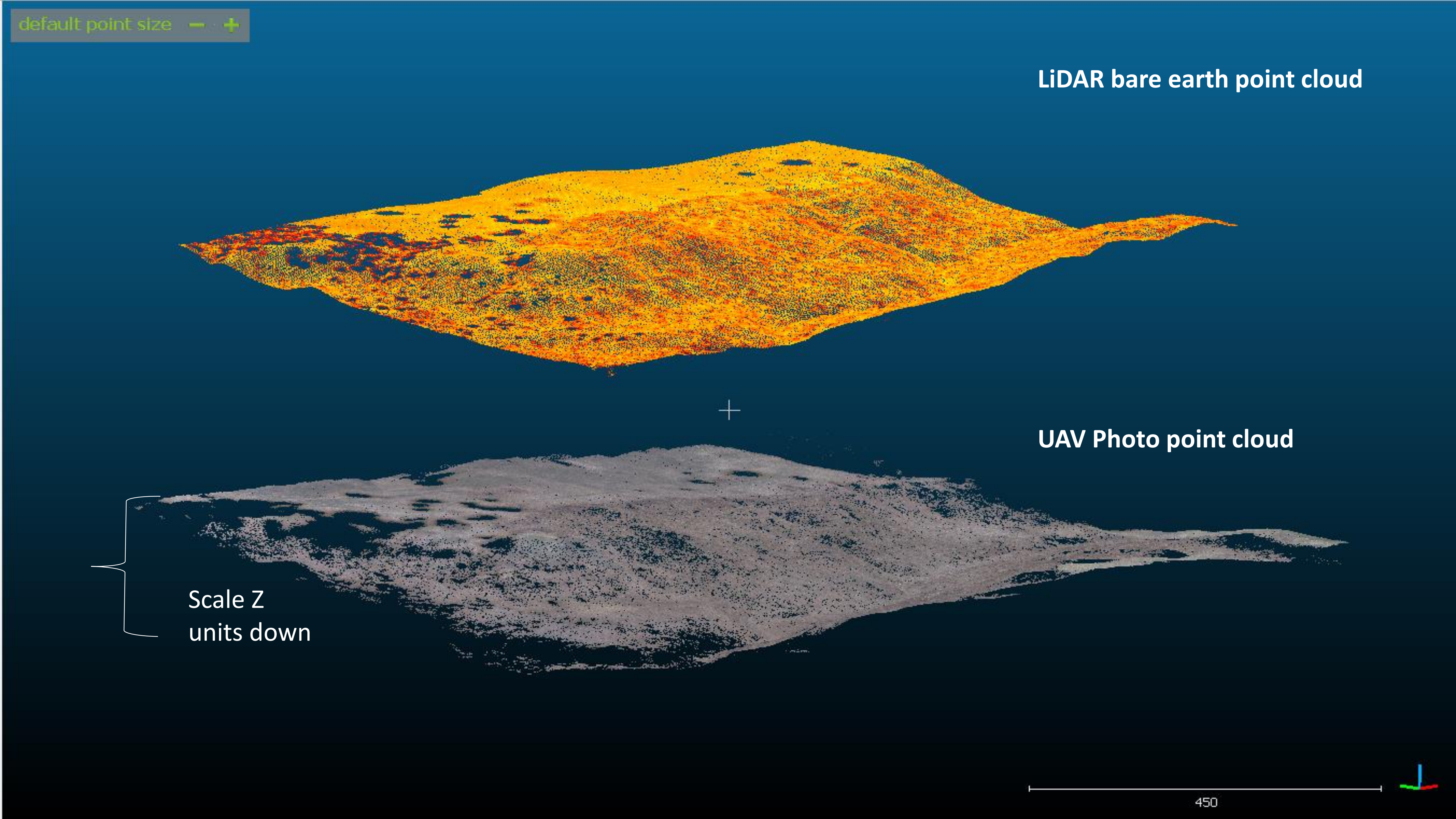
Lidar Point Cloud ~256 **thousand** points
Or about **3 points/m²**



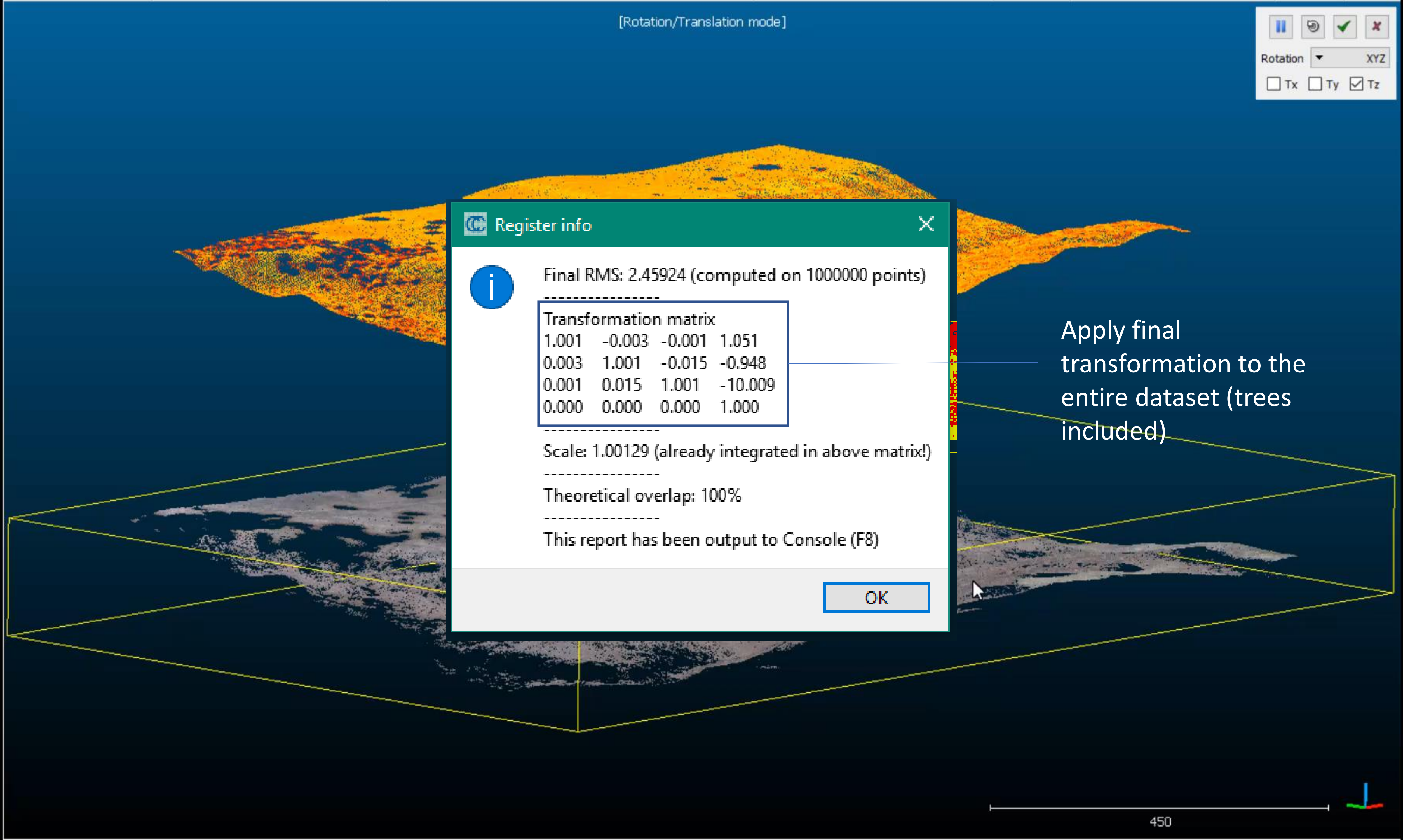

WORKFLOW
CloudCompare V2
Pre-flight planning
Derive Canopy Model with existing LiDAR Data
Post-flight Image preprocessing
Extract /write EXIF metadata to/from images
Develop RAW photos (if necessary)
Photo Alignment
Align photos in Photogrammetry Software
Build point clouds
Build Orthomosaic
Export Unclassified Dense Cloud
Point Cloud Classification
Classify Ground Points
Classify Vegetation Points
Export Classified Cloud
Register UAV Cloud with LiDAR
Sub-sample Ground Points
Coarse Align with LiDAR Bare Earth Ground Points
Fine Alignment Algorithm
SOFTWARE COCKTAIL
FUSION LiDAR Tools
EXIFtools
Agisoft Photoscan
LAStools
Cloud Compare

CloudCompare V2
CloudCompare
3D point cloud and mesh processing software
Open Source Project


LiDAR bare earth point cloud
UAV Photo point cloud
Drastic
Elevation
Distortion
(no GCPs)
500



default point size
LiDAR bare earth point cloud
UAV Photo point cloud
Scale Z
units down
450


[Rotation/Translation mode]
Rotation
XYZ
Tx
Ty
Tz
Register info
Final RMS: 2.45924 (computed on 1000000 points)
Transformation matrix
1.001 -0.003 -0.001 1.051
0.003 1.001 -0.015 -0.948
0.001 0.015 1.001 -10.009
0.000 0.000 0.000 1.000
Scale: 1.00129 (already integrated in above matrix!)
Theoretical overlap: 100%
This report has been output to Console (F8)
OK
Apply final transformation to the entire dataset (trees included)
450

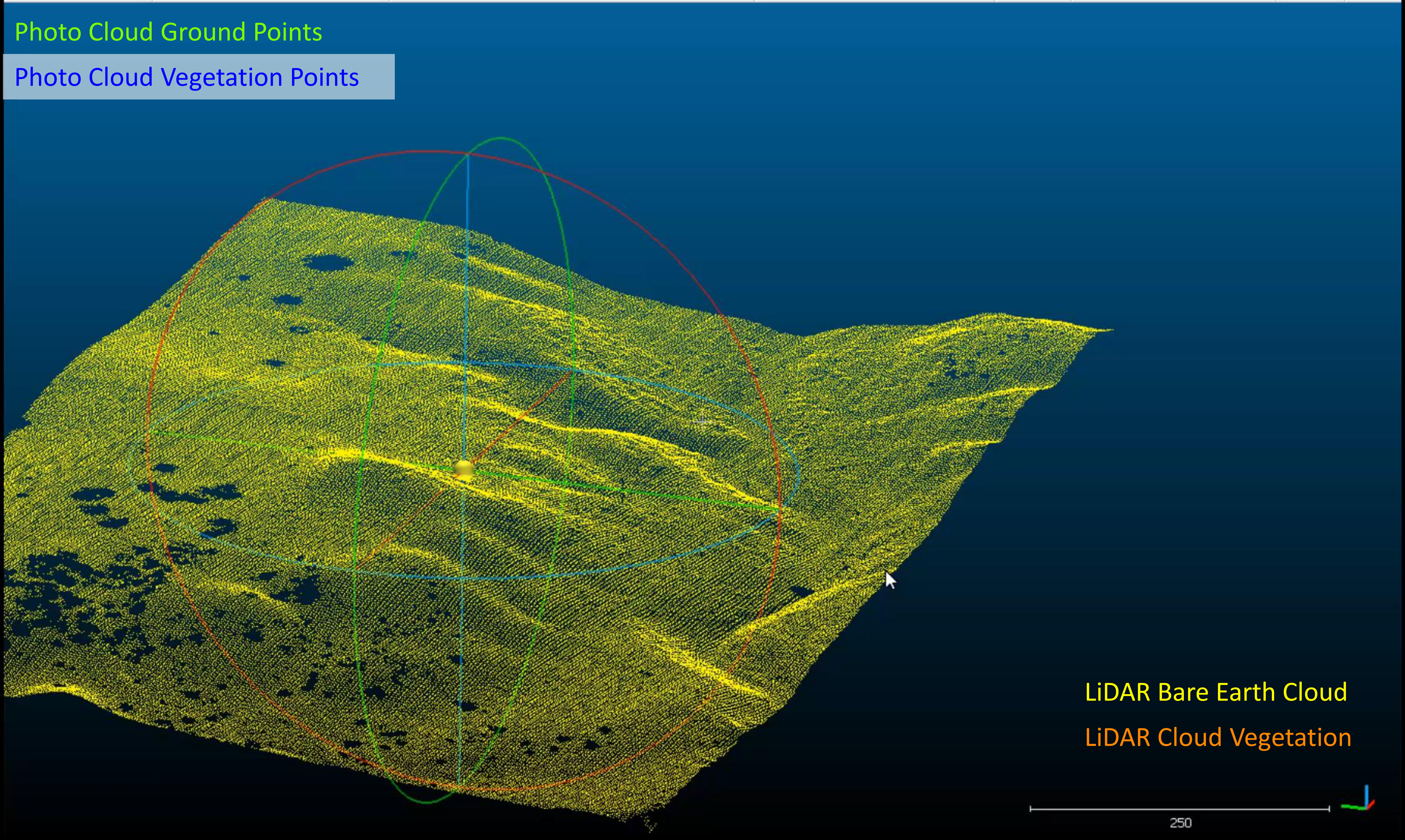
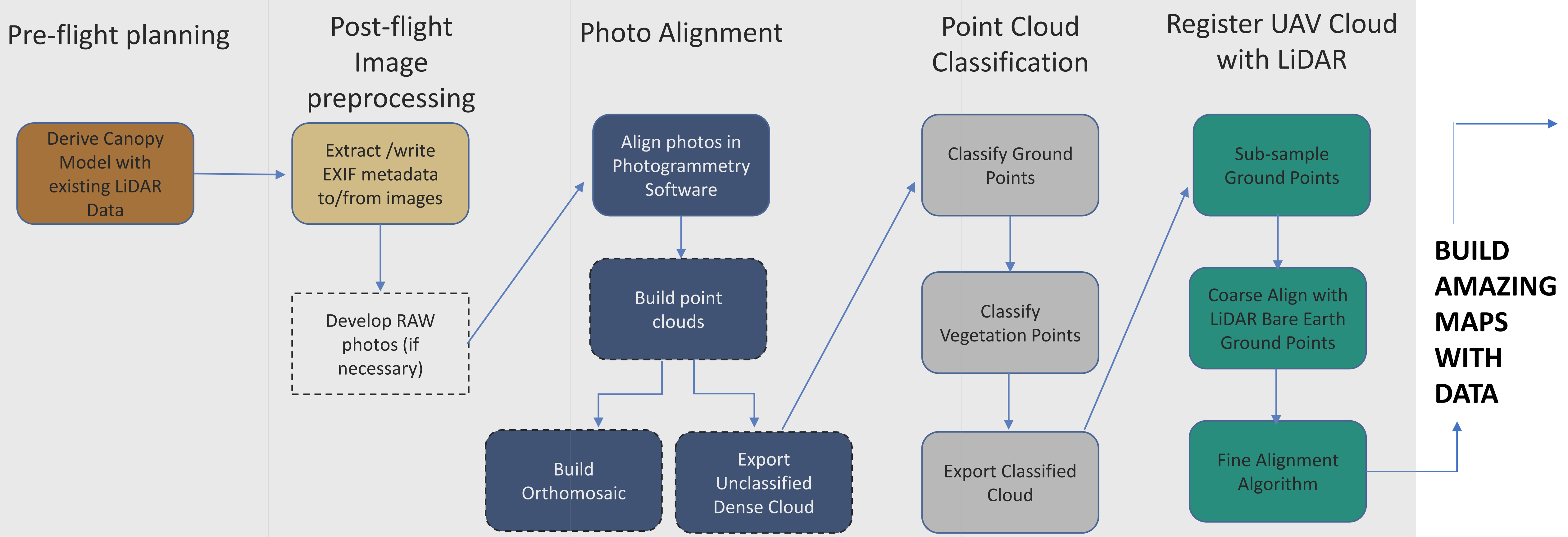


Photo Cloud Ground Points
Photo Cloud Vegetation Points
LiDAR Bare Earth Cloud
LiDAR Cloud Vegetation
250

WORKFLOW



SOFTWARE COCKTAIL

FUSION LiDAR Tools

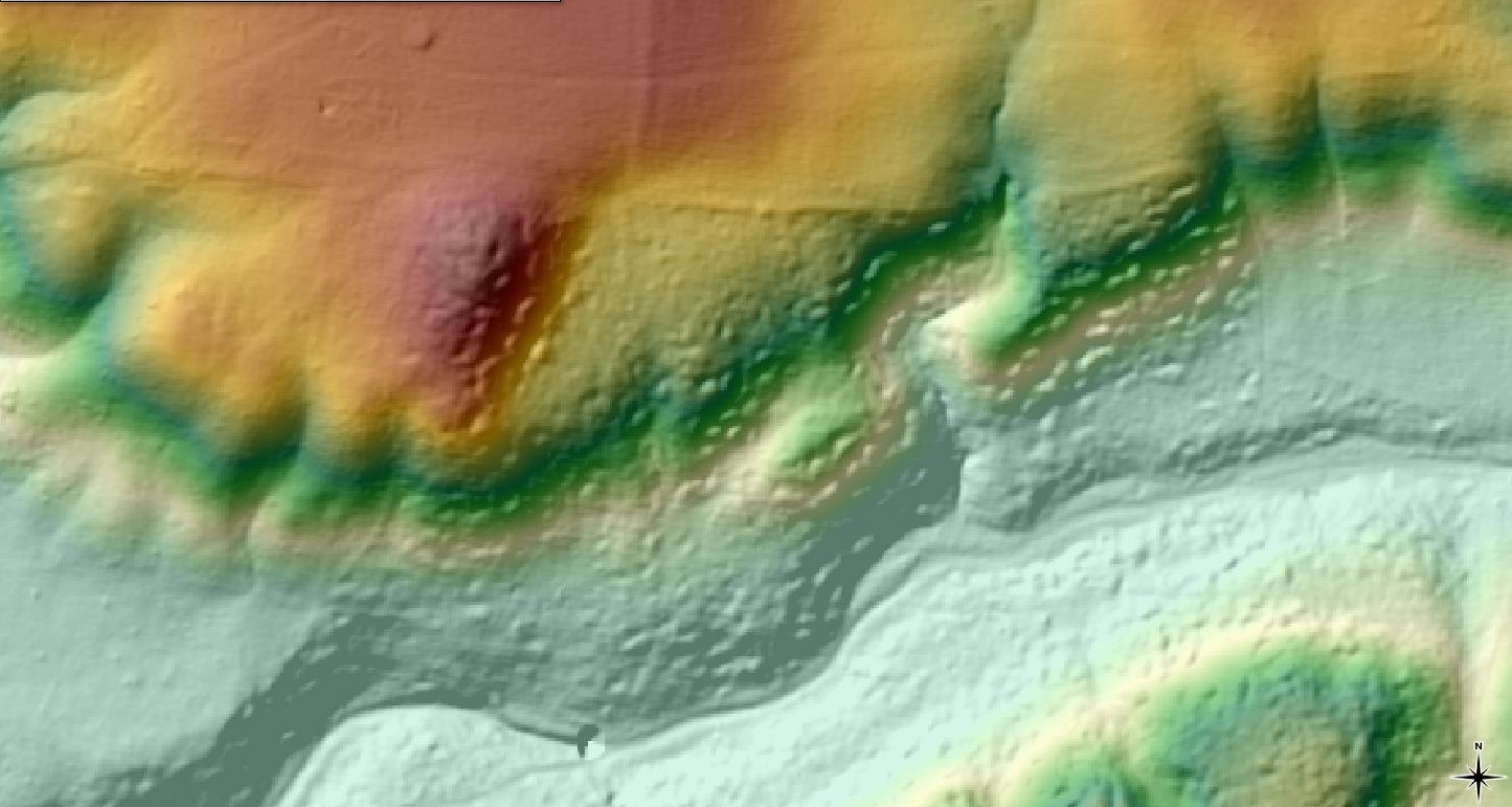
EXIFtools

Agisoft Photoscan

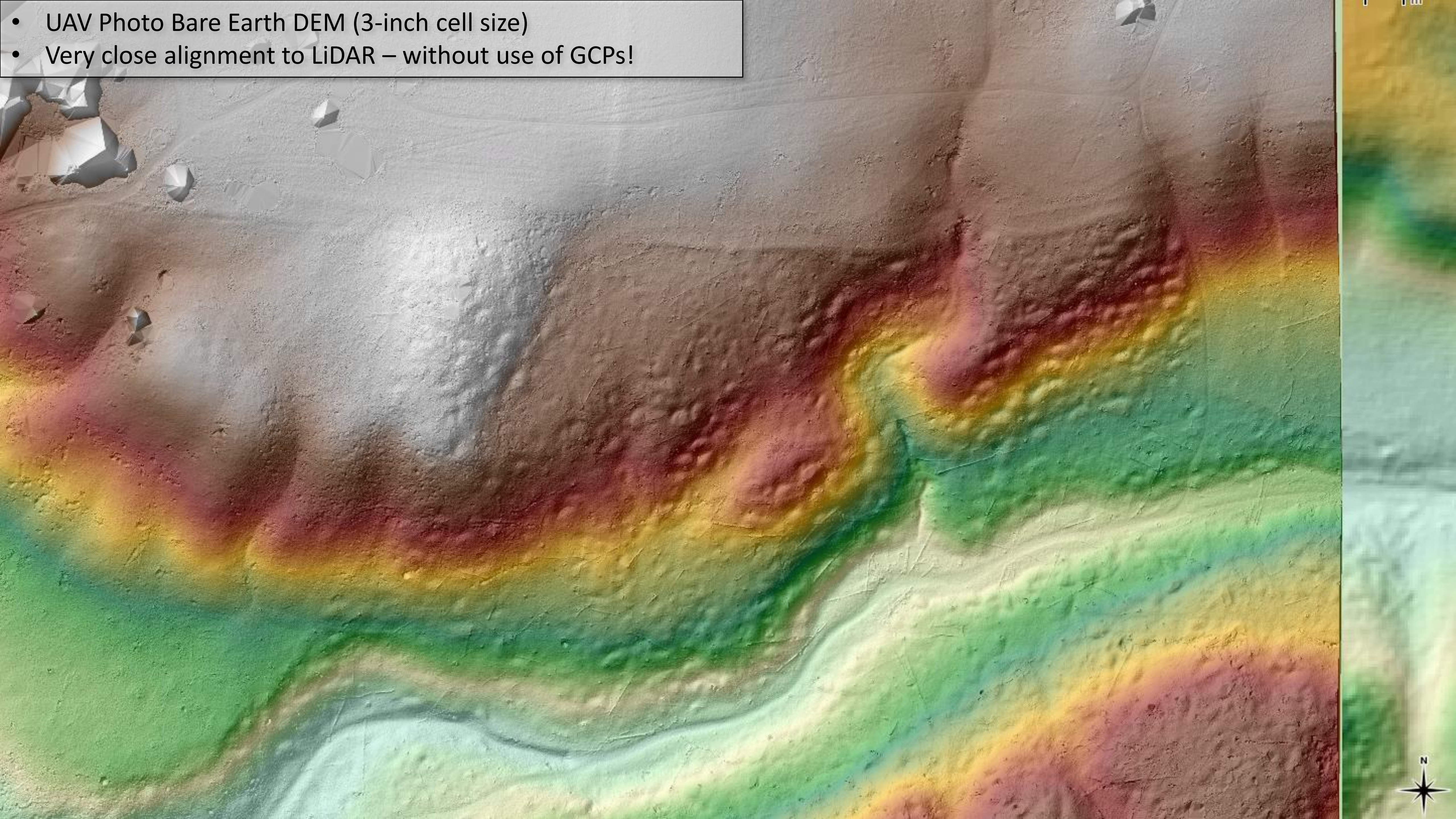
LAStools

Cloud Compare

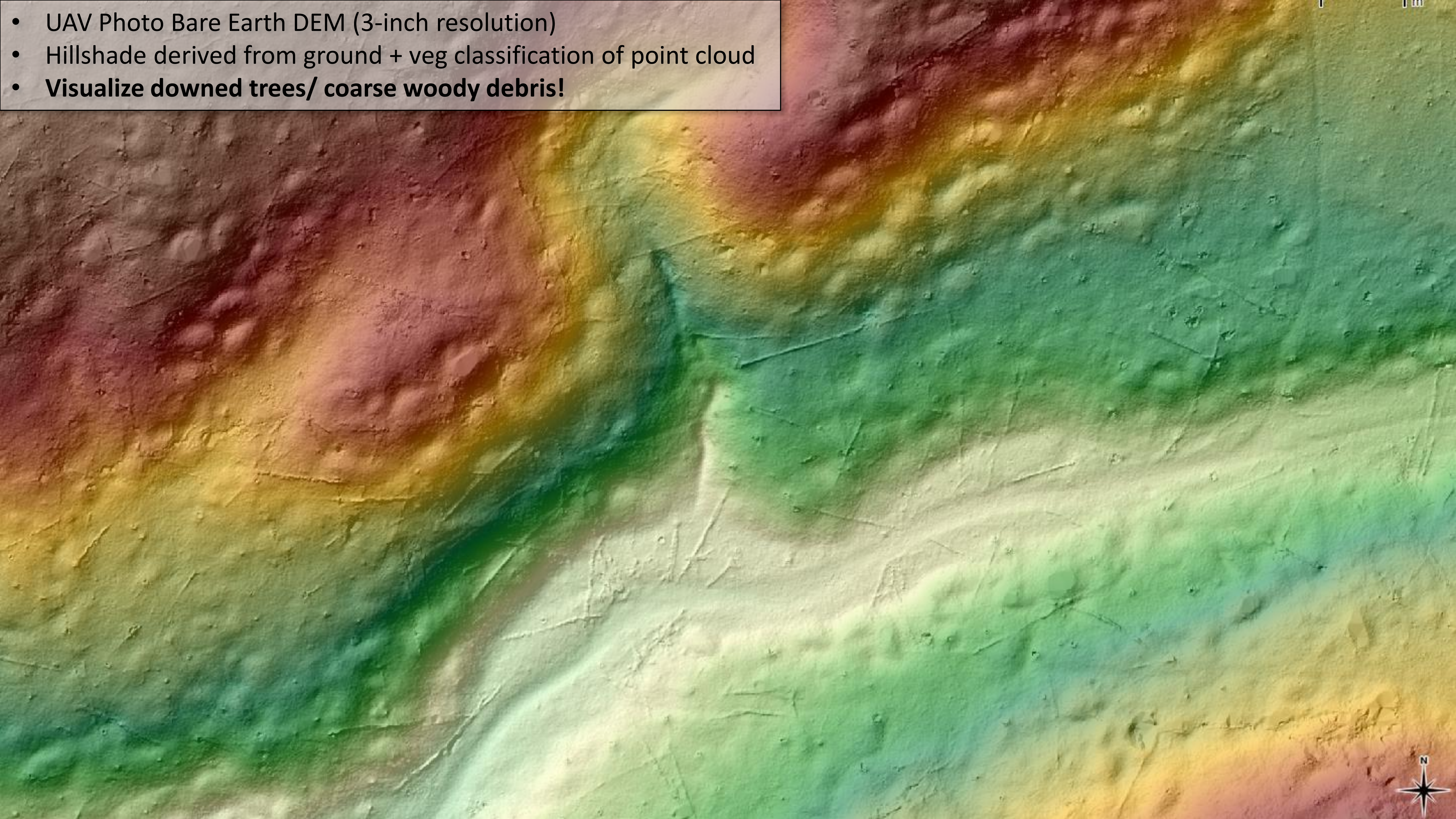
LiDAR Bare Earth DEM (2 foot cell size)

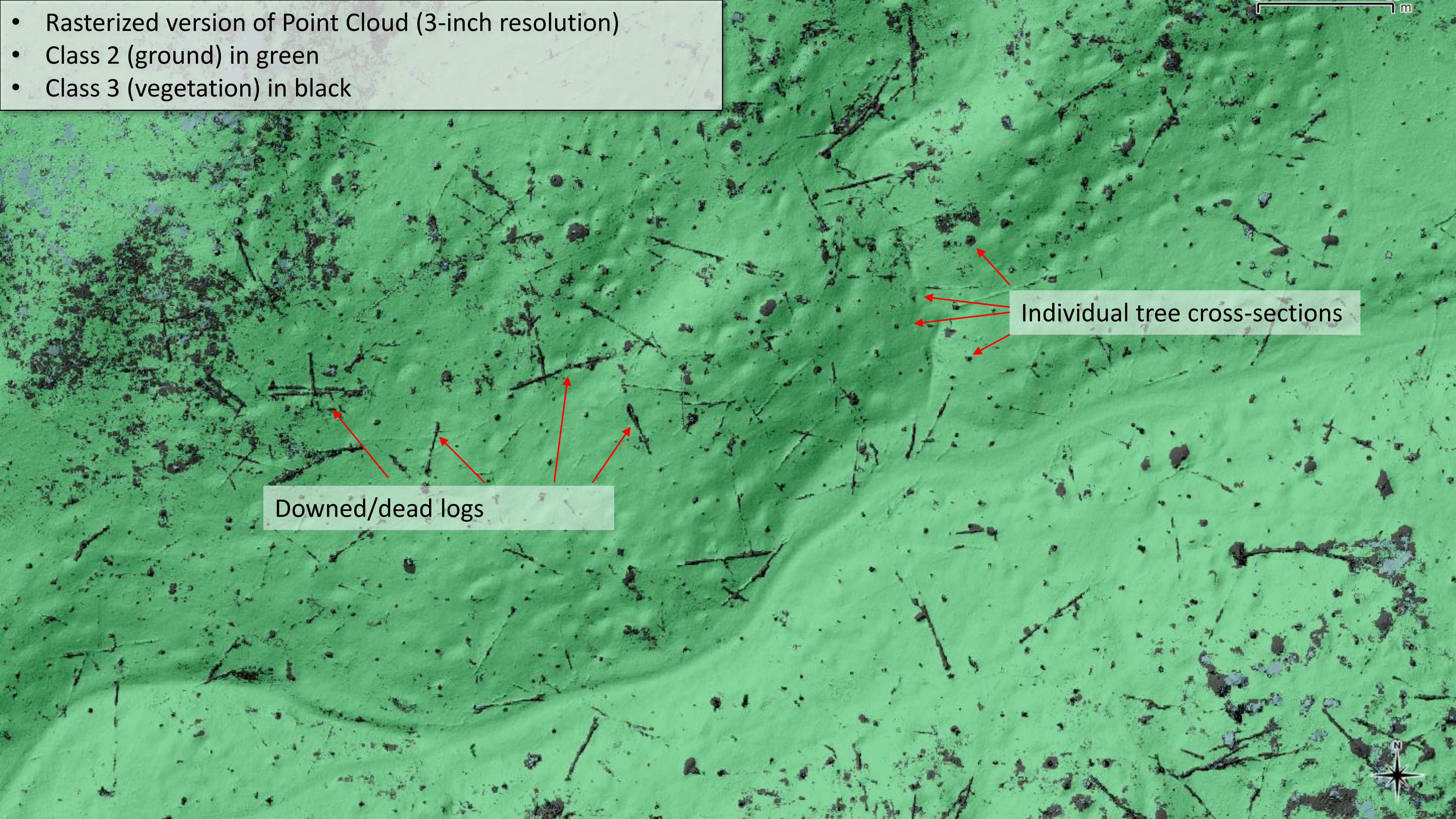


- UAV Photo Bare Earth DEM (3-inch cell size)
- Very close alignment to LiDAR – without use of GCPs!



- UAV Photo Bare Earth DEM (3-inch resolution)
- Hillshade derived from ground + veg classification of point cloud
- **Visualize downed trees/ coarse woody debris!**

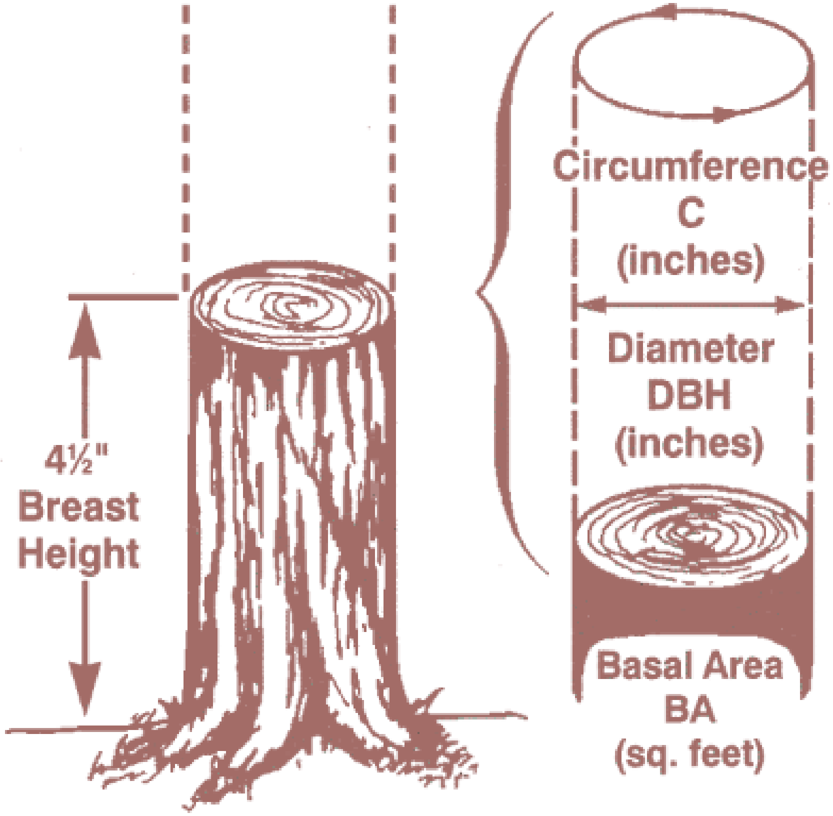




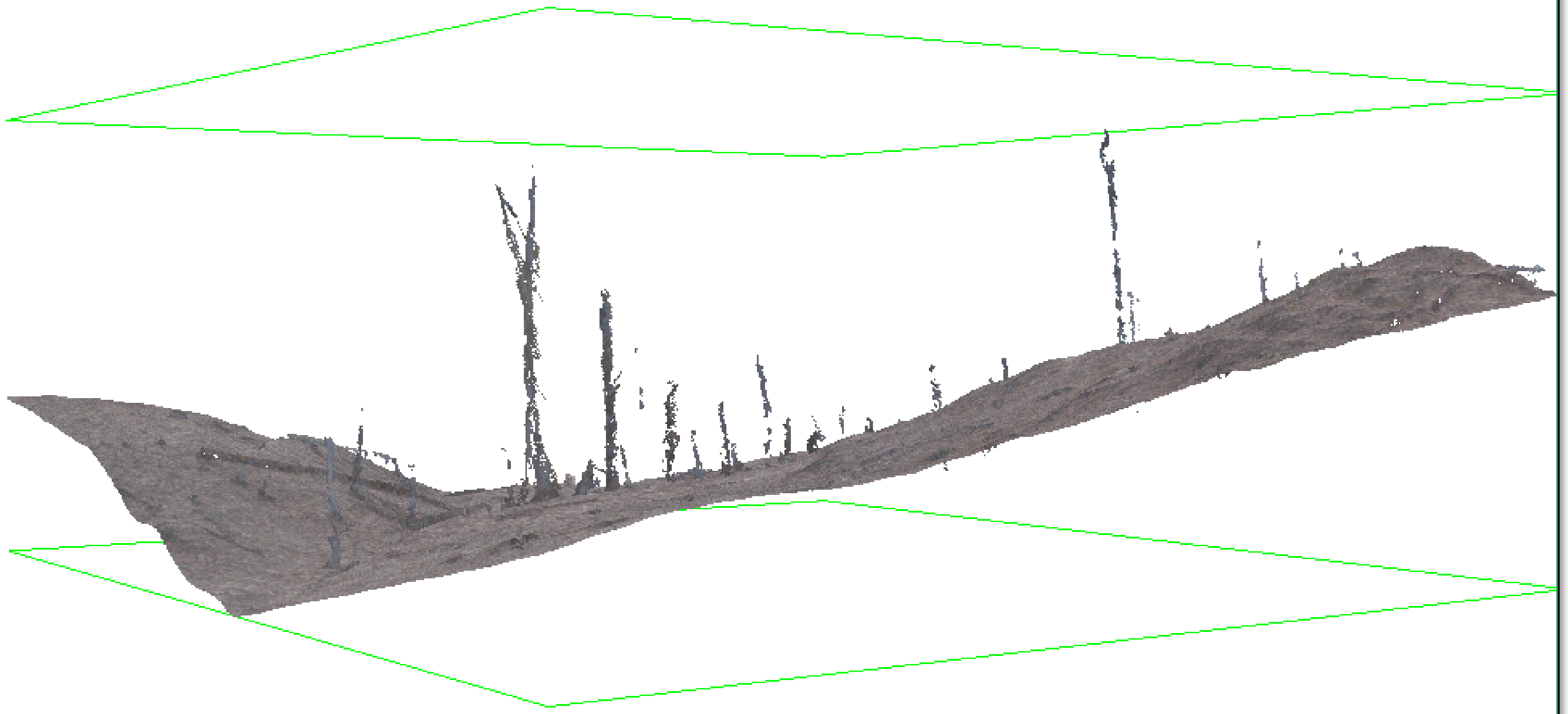
Rasterized version of Point Cloud (3-inch resolution)
Class 2 (ground) in green
Class 3 (vegetation) in black
Individual tree cross-sections
Downed/dead logs
m
N

Measuring Basal Area

- Basal area an important forest inventory measure.
- Used to estimate tree height and wood volume.
- Used in Forestry, Ecology, Timber valuation, etc.
- Typically estimated in the field on a sample of trees, then extrapolated to the entire forest stand.

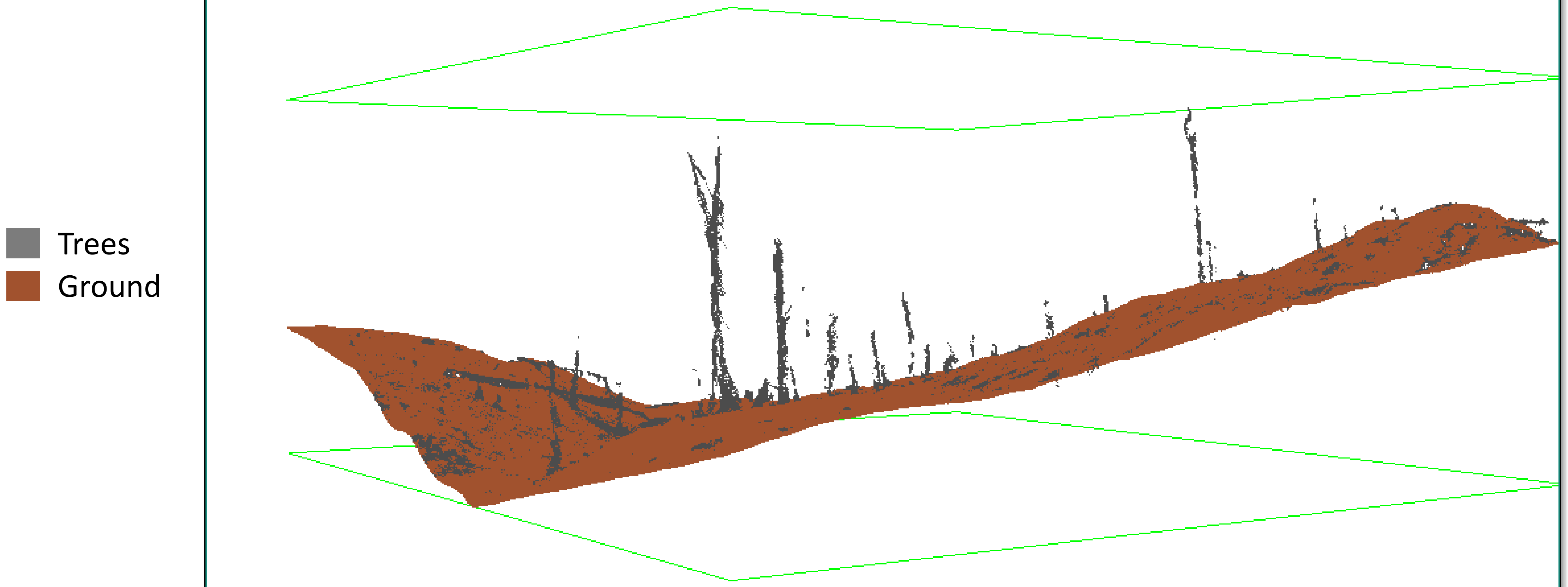


Using **LAS height** command to subtract ground elevations and obtain normalized stem heights



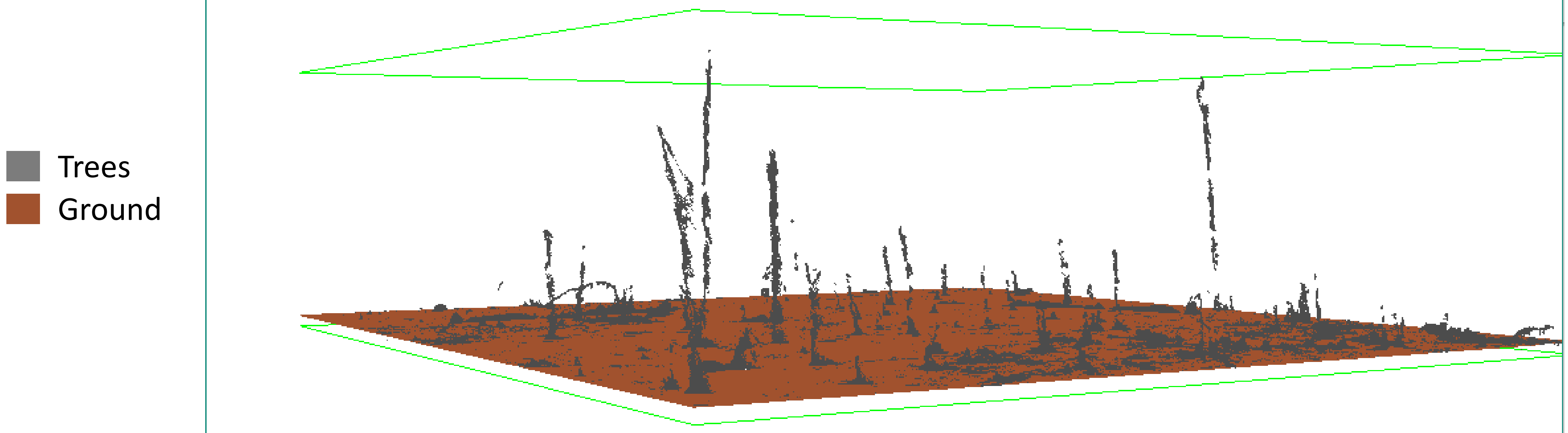
(UAV Photo cloud plot showing tree stems and terrain)

Using **LAS height** command to subtract ground elevations and obtain normalized stem heights



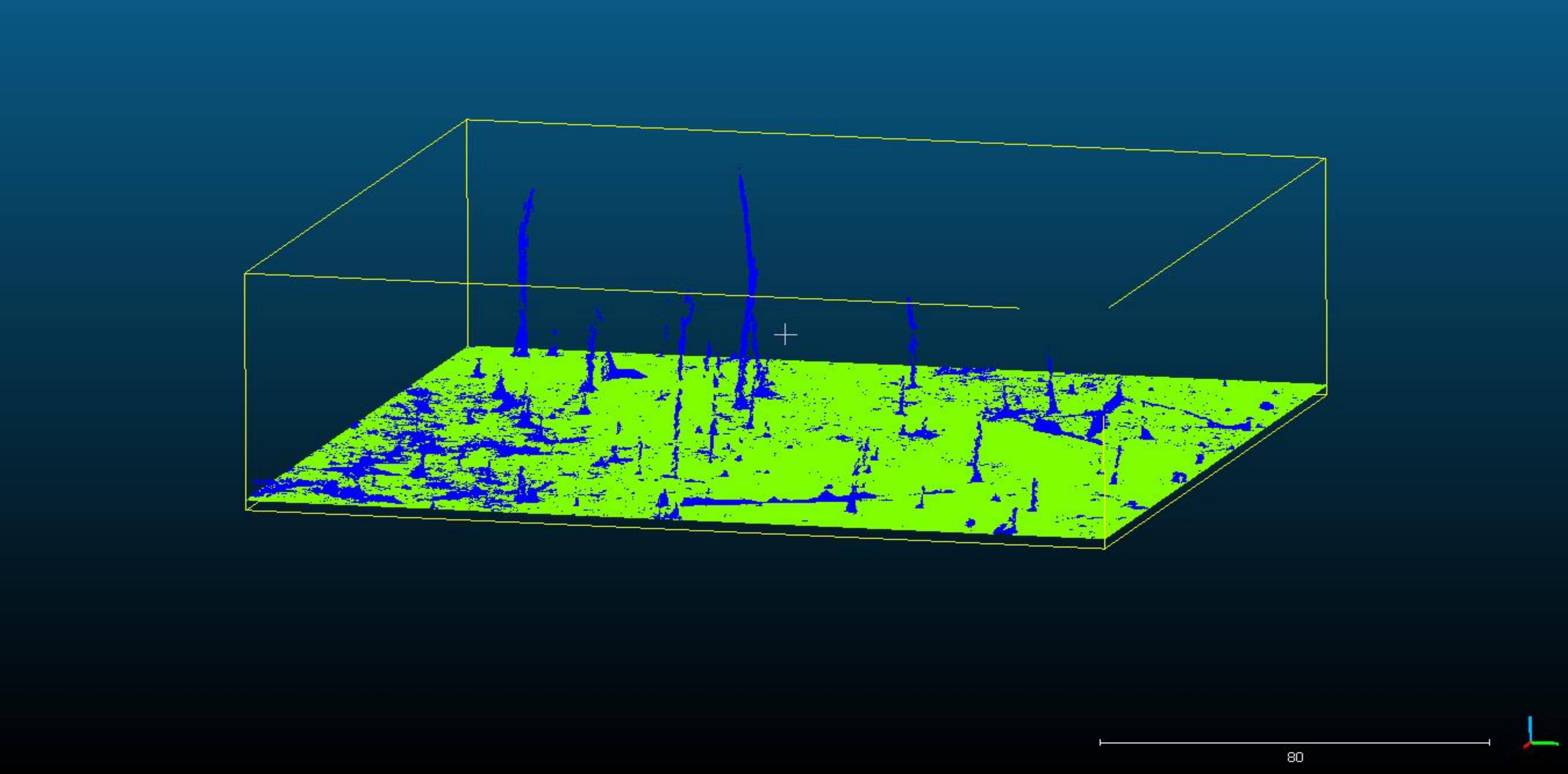
(UAV Photo cloud plot showing tree stems and terrain)

Using **LAS height** command to subtract ground elevations and obtain normalized stem heights

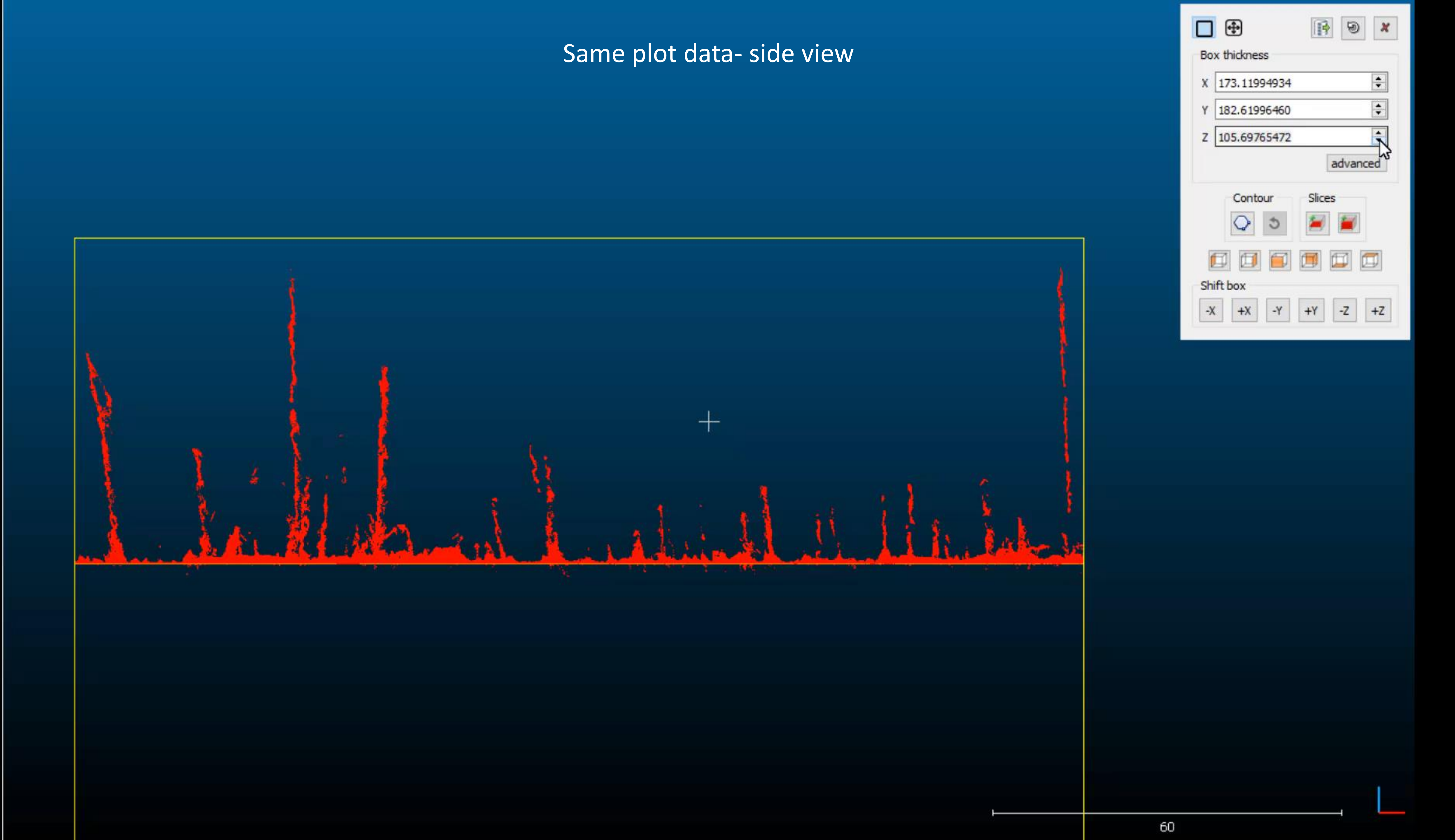


(UAV Photo cloud plot after height normalization)

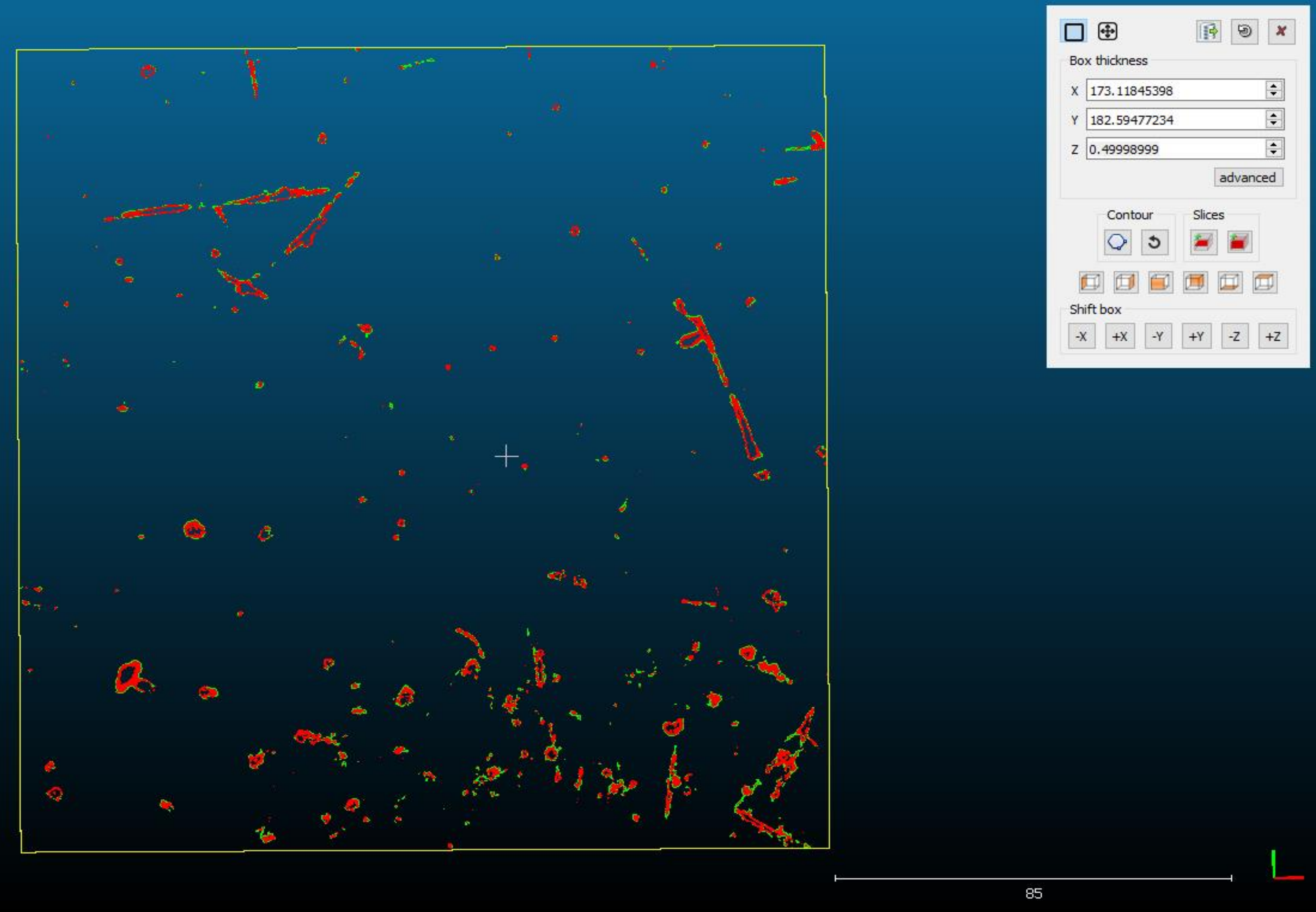
Slicing tree plots at different heights to get a direct measurement of basal area!



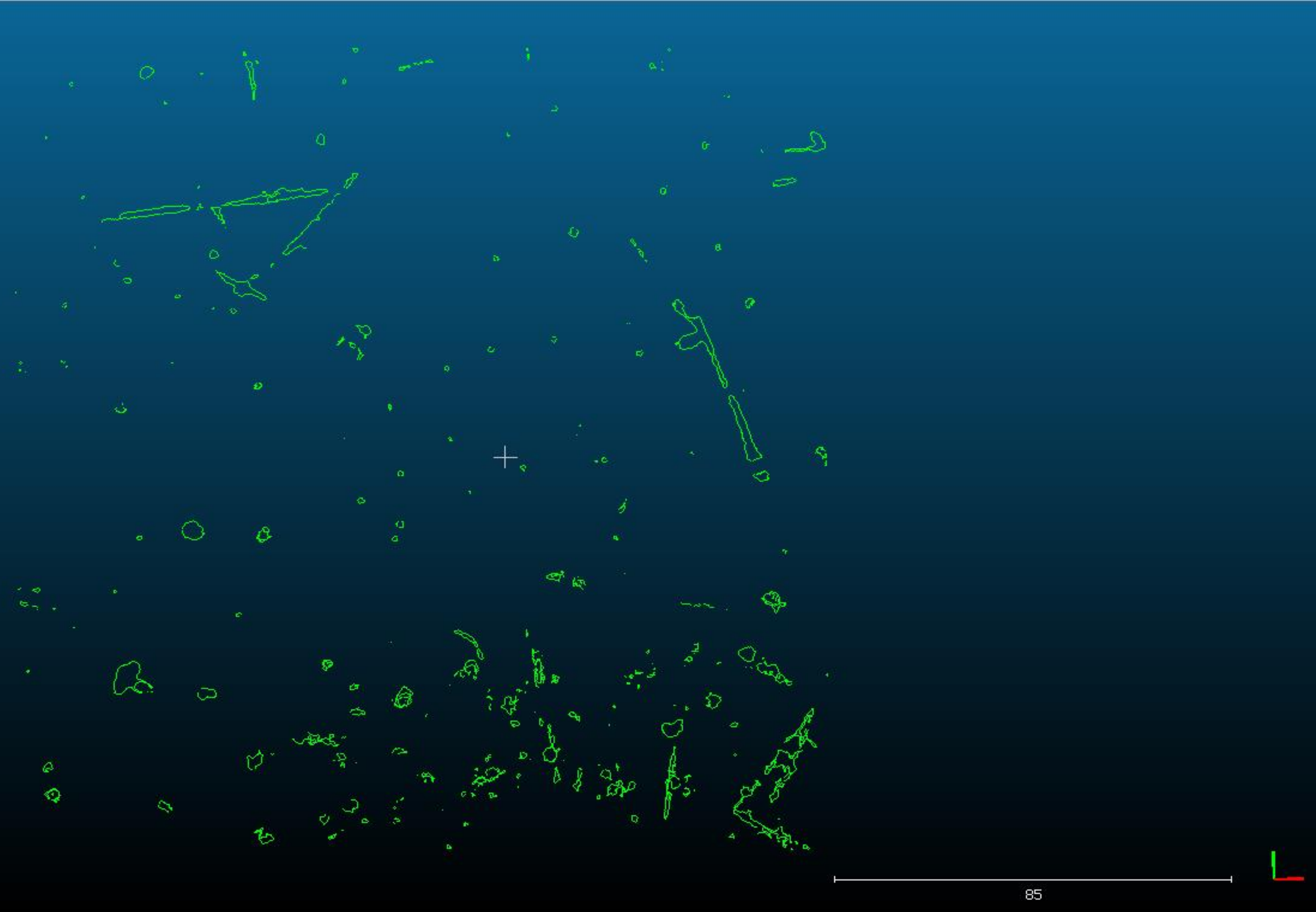
Same plot data- side view



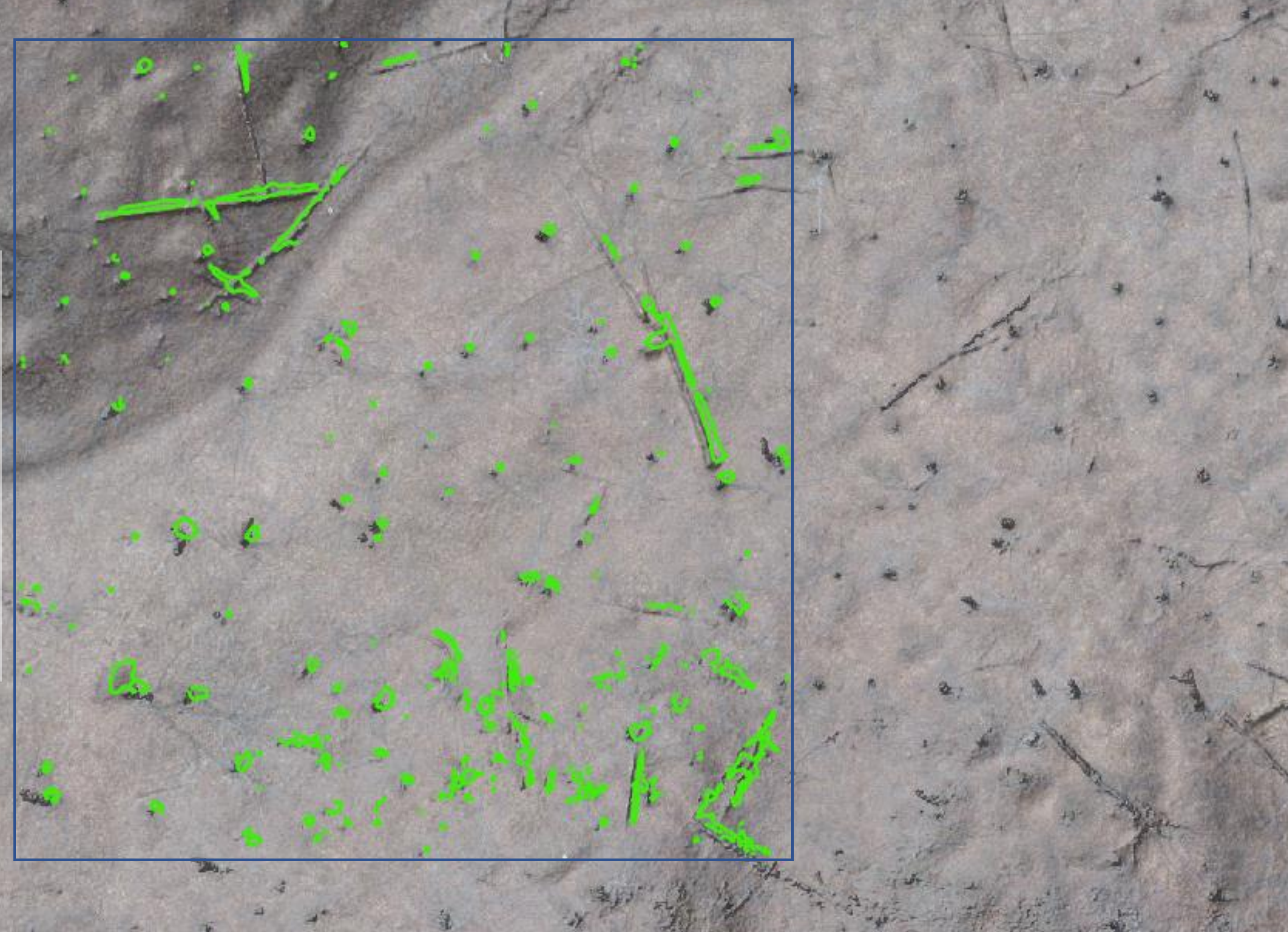
Extract contours at any given "slice" (height)

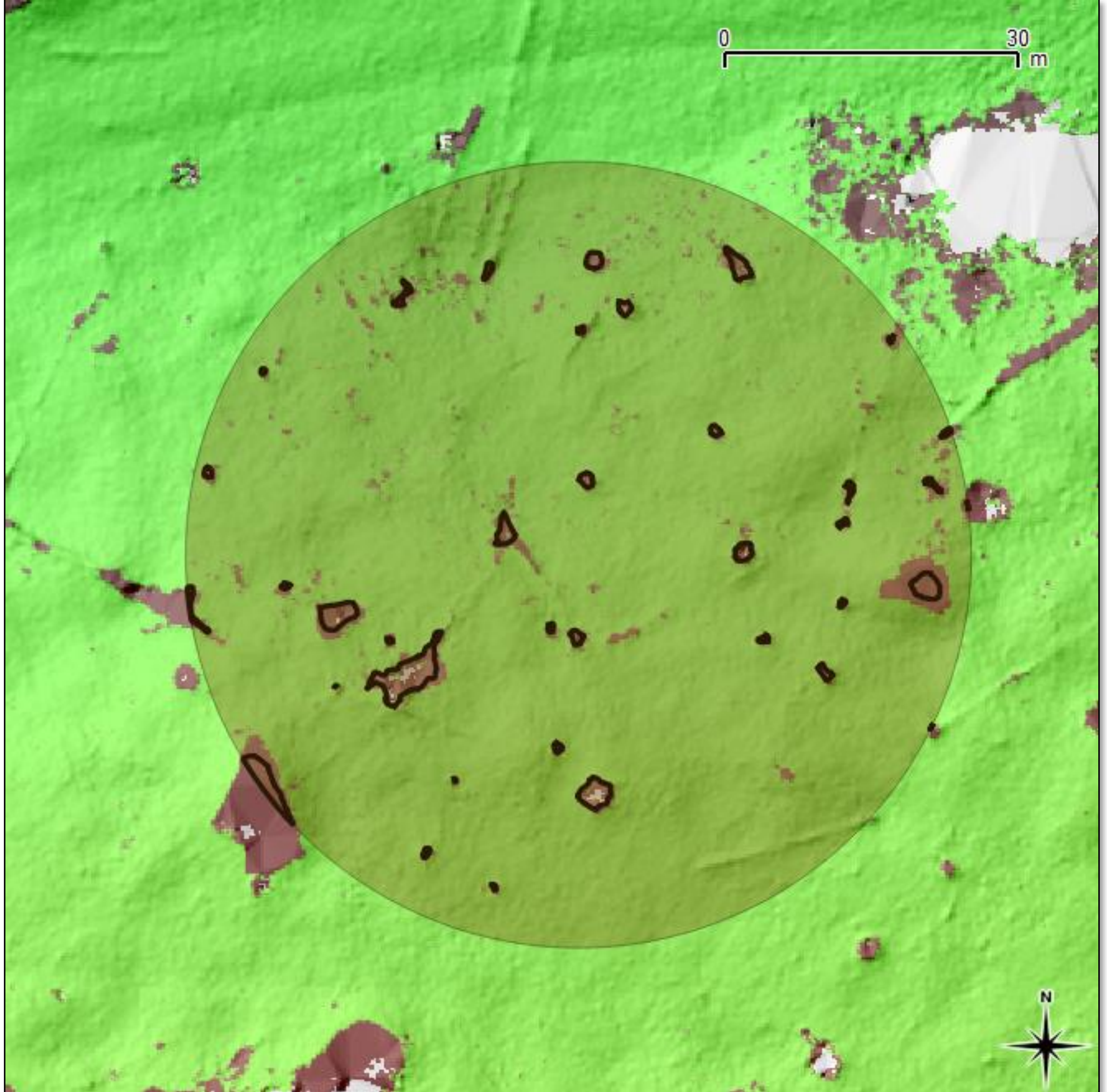


Extract contours at any given "slice" (height)→ export to shapefile



- Repair line geometry/topology
- Sort by line length to separate downed wood logs from live tree cross sections
- Calculate basal area for entire forest area

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Potential Benefits to Foresters…

- More precise measurement of Basal Area (vs. prism estimates)?
- Quick assessment of an entire forest stand (vs. a sample)
- Classification/mapping of coarse woody debris/snags (habitat value)
- Assessing forest change (with repeat measurements)

Challenges with this workflow…

- UAV-derived photo point clouds of forests are messy!

Applying common point cloud processing algorithms (i.e., classifying vegetation) across large or structurally diverse forests is cumbersome and produces unpredictable results

- Considerable time-investment in data processing/manipulation…

Relying on open-source tools/toggling between several different software programs slows efficiency

- Photo alignment and processing is computationally expensive!

Even on a robust computer workstation

- Is it really faster/better than measuring 20 acres of trees by hand?

Conclusions

Are UAV's useful for forest inventory and mapping? **YES!**

If so, what kinds of data products are possible to generate, and how can they be used?

Data Product	Use
Orthophoto	• Detailed areal assessment • Documenting existing conditions • Change assessment
Digital Elevation Model	• Hydro – soil – erosion analysis • Skid trail layout/design • Soil disturbance regime
Classified Point Cloud	• Stem count • DBH for entire forested stand • Coarse woody debris mapping • Snag analysis

Conclusions

- With all of the new LiDAR coverage in Michigan, how can that data be used to make up for where UAV imagery falls short (and vice versa)?

UAV photos can be aligned to LiDAR cloud, thereby eliminating the investment (money and field time) in high accuracy ground control point surveying.

UAV photos **add value** to existing LiDAR datasets by increasing point density → expand use beyond original intent (bare earth model)

- What can be done with basic (consumer-grade) UAVs? **A lot, but…**

The better the UAV, the less time you'll spend post-processing images and data

Questions?

Thank You