Challenges in aligning aerial and terrestrial laser scans: SLAM vs RTK GPS

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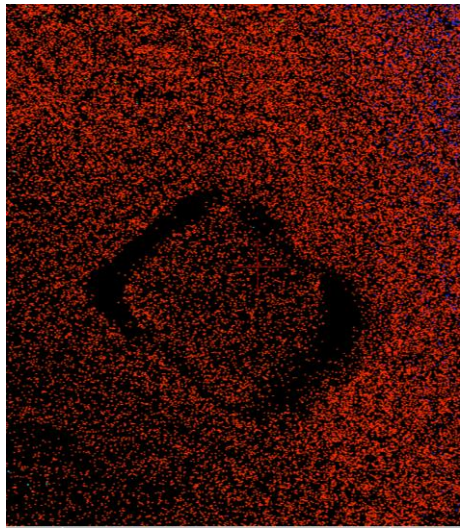
Forest Geomatics / MARS

Introduction

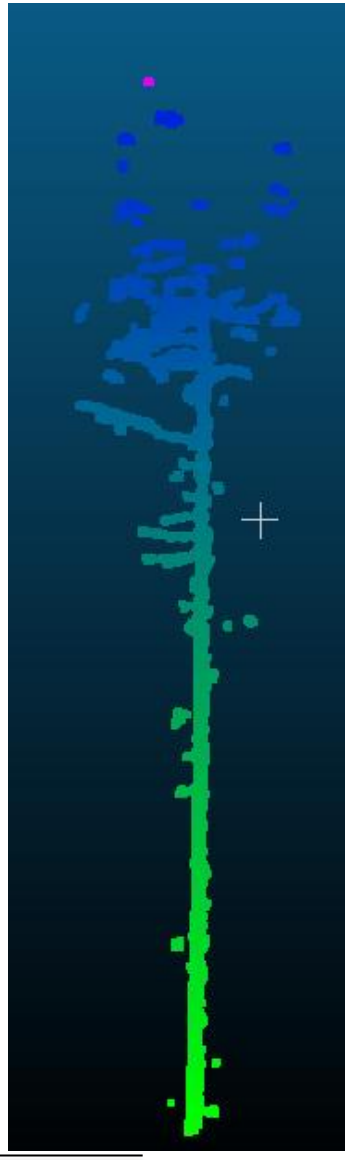
Comprehensive description of forest with lidar

- Currently registration algorithms depends
  - density
  - redundancy
  - target setting
  - feature similarity
- Need: co-registration procedure considering
  - limited positioning information
  - low density ALS
  - limited feature similarity



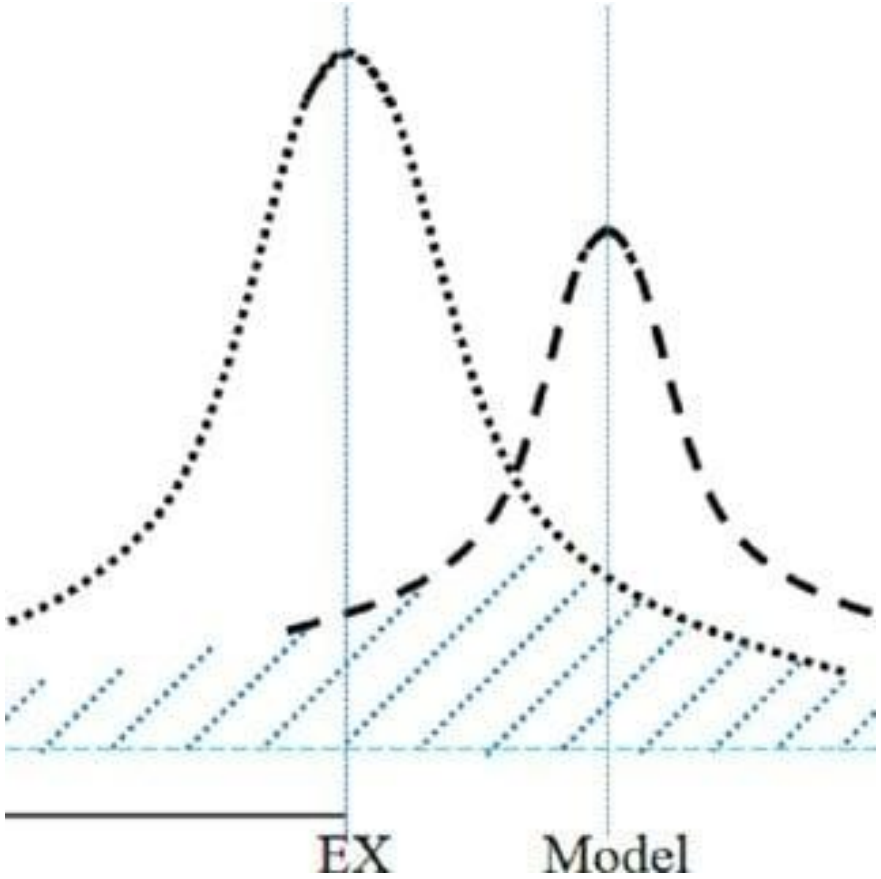
Forest description with lidar

- Lidar based inventory limited in a closed canopy forest
  - Reduced stem points from aerial
  - Reduce top from terrestrial
- Multi-platform alternative
  - Register ALS with TLS



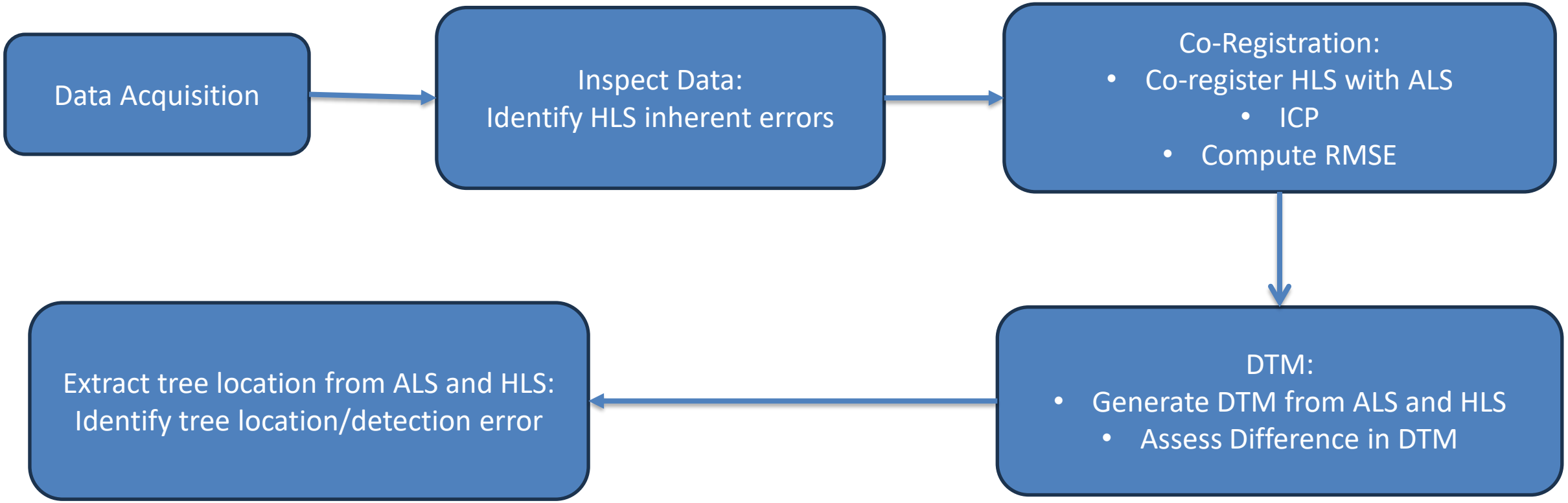
Objective

- Identify issues associated with the point cloud registration process
- Differences in tree detection from Above and Below



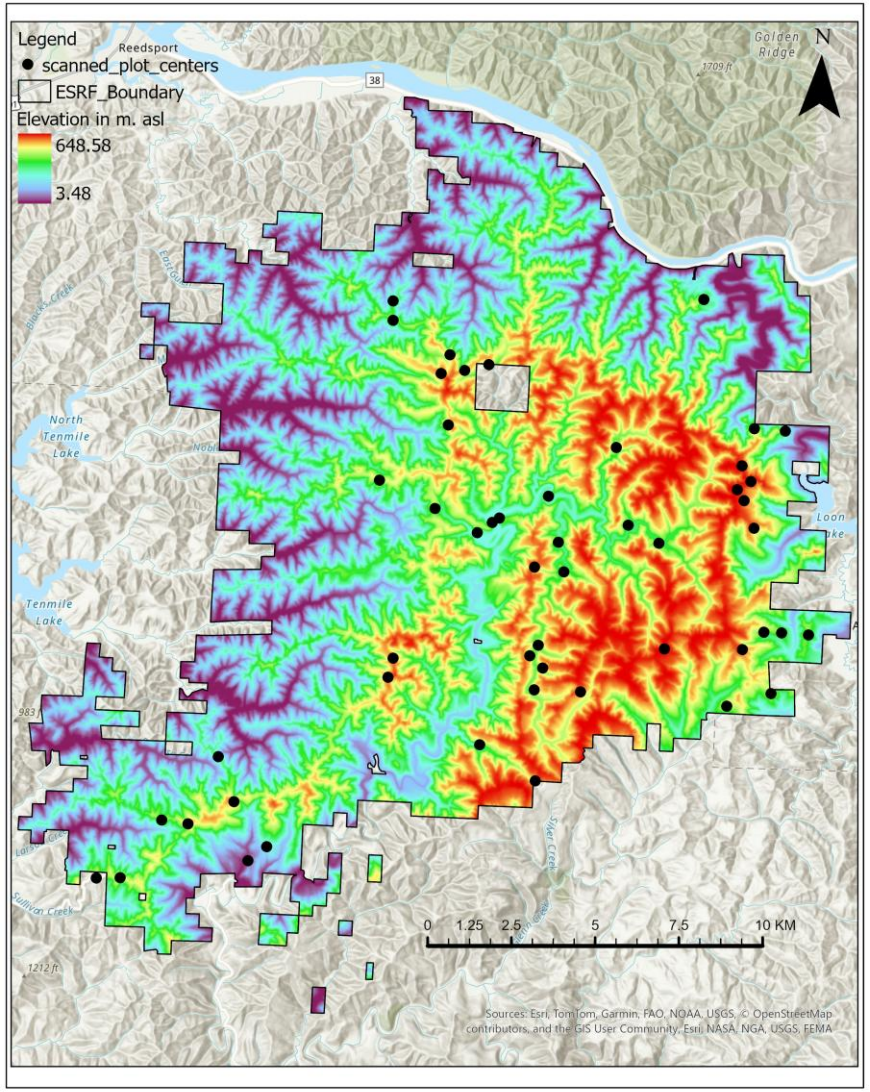
Methods

Flowchart


Data Acquisition
Inspect Data:
Identify HLS inherent errors
Co-Registration:
• Co-register HLS with ALS
• ICP
• Compute RMSE
DTM:
• Generate DTM from ALS and HLS
• Assess Difference in DTM
Extract tree location from ALS and HLS:
Identify tree location/detection error

Study Area

- Elliott State Research Forest
  - 50 plots total (All used for error identification, 5 selected for tree detection analysis)
  - Average Dimensions:
    - Height <= 80 m,
    - DBH <= 200cm
- Union county
  - 21 plots



Data acquisition: ESRF

- ALS: Fixed wing & Riegl VQ-1560ii
  - Average density: 83 ppsm
- HLS: FJ Dynamics P1
  - Average density: 13500 ppsm

Data acquisition: Union County

- ALS: rotary wing & DJI Zenmuse L1
  - Average density: 560 ppsm
- HLS: GeoSLAM ZEB Horizon
  - Average density: 2500 ppsm

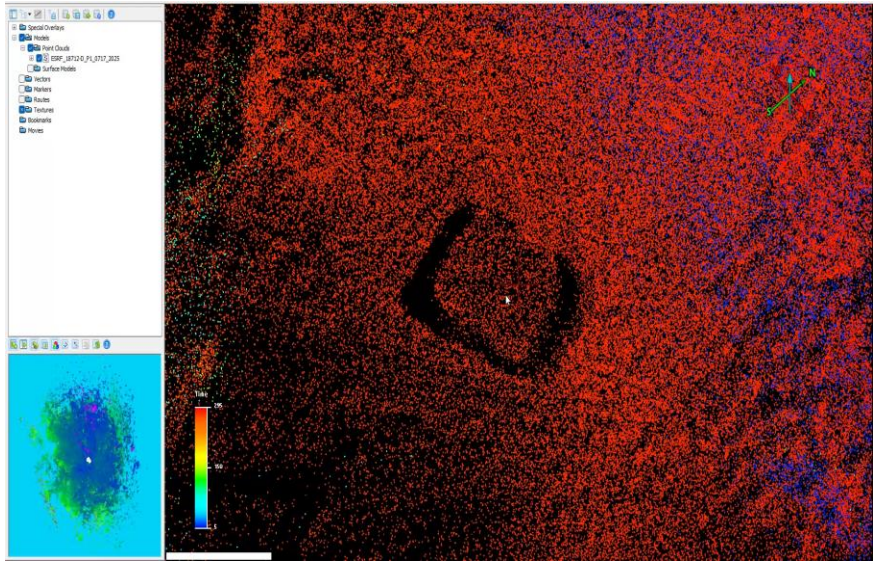
Registration: Procedure

Current Approach:

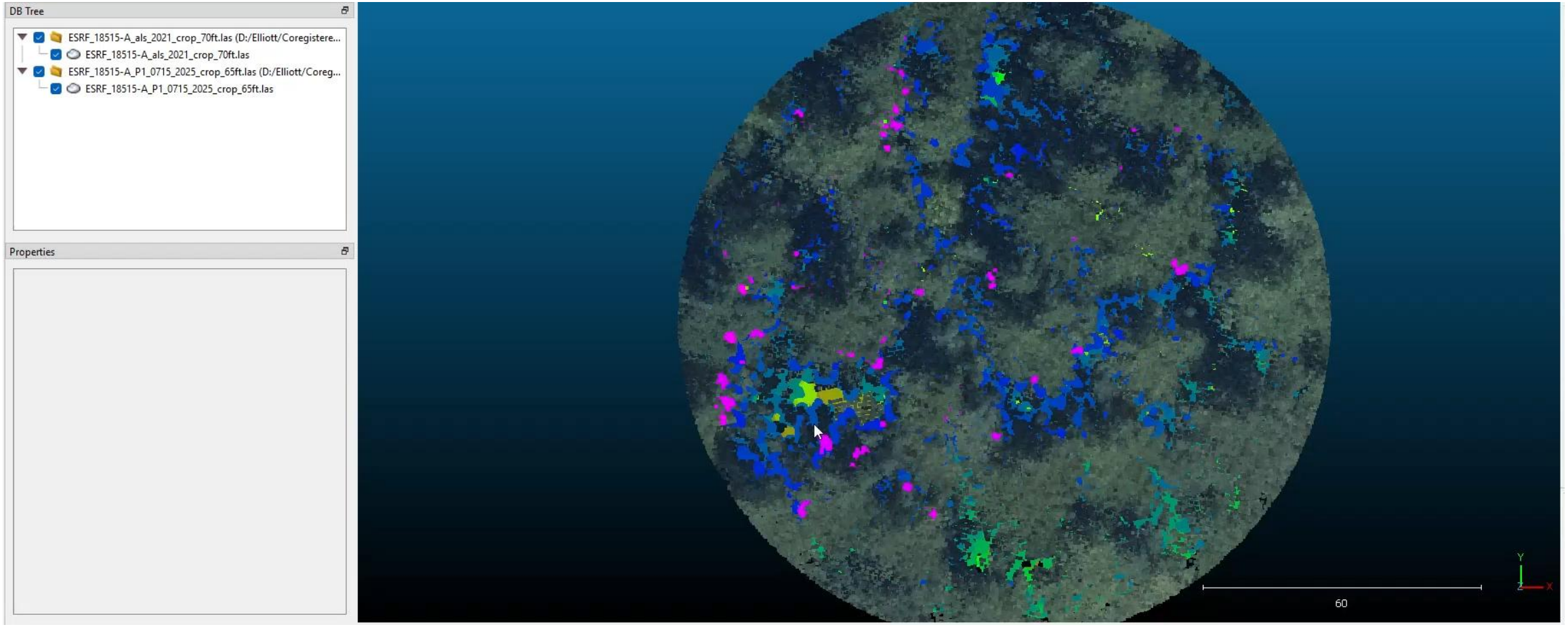
- Coarse:
  1. Point, Line, Feature Based,
  2. Deep learning methods.
- Fine: ICP, RANSAC

Our Approach:

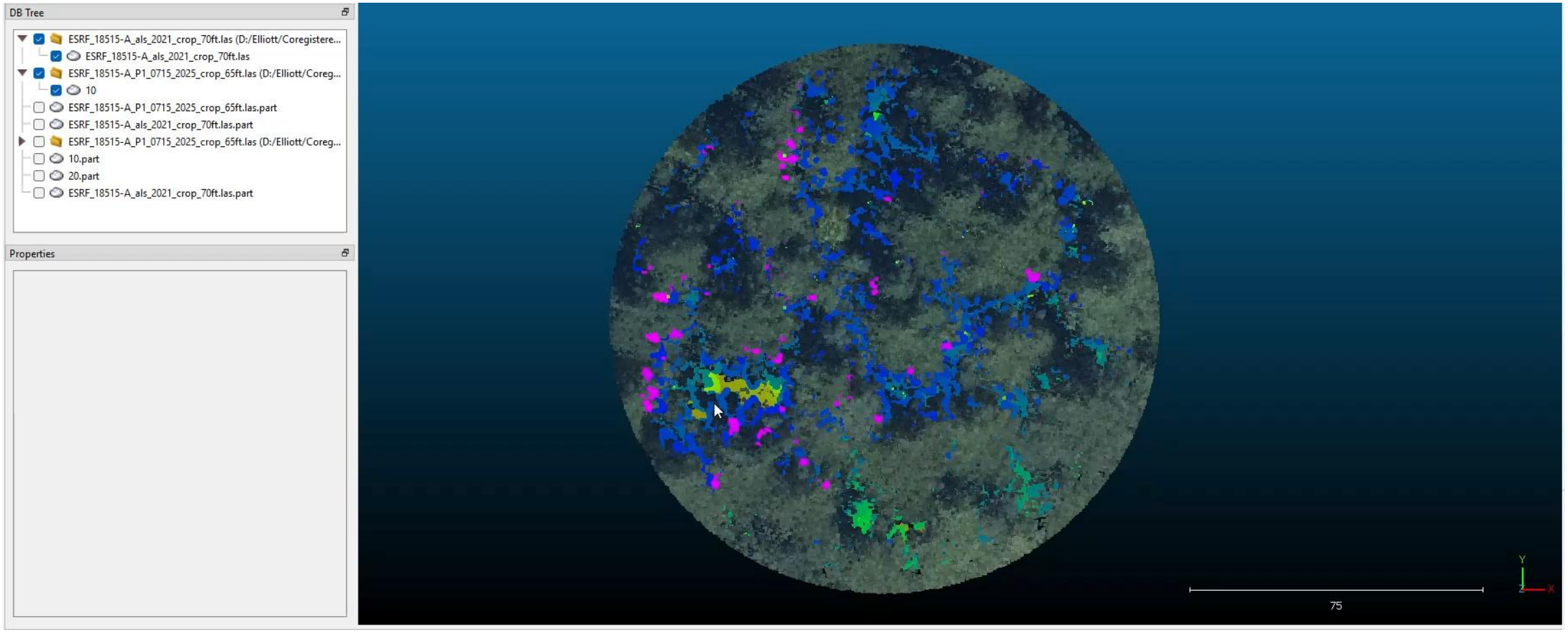
- Coarse:
  1. ‘Register-Cloud using’ plot center
     MARS code in C#
  2. Manual alignment in QTM
- Fine: ICP. n=50,000 points. Overlap=10%
  – higher overlap worse results



Registration: Coarse

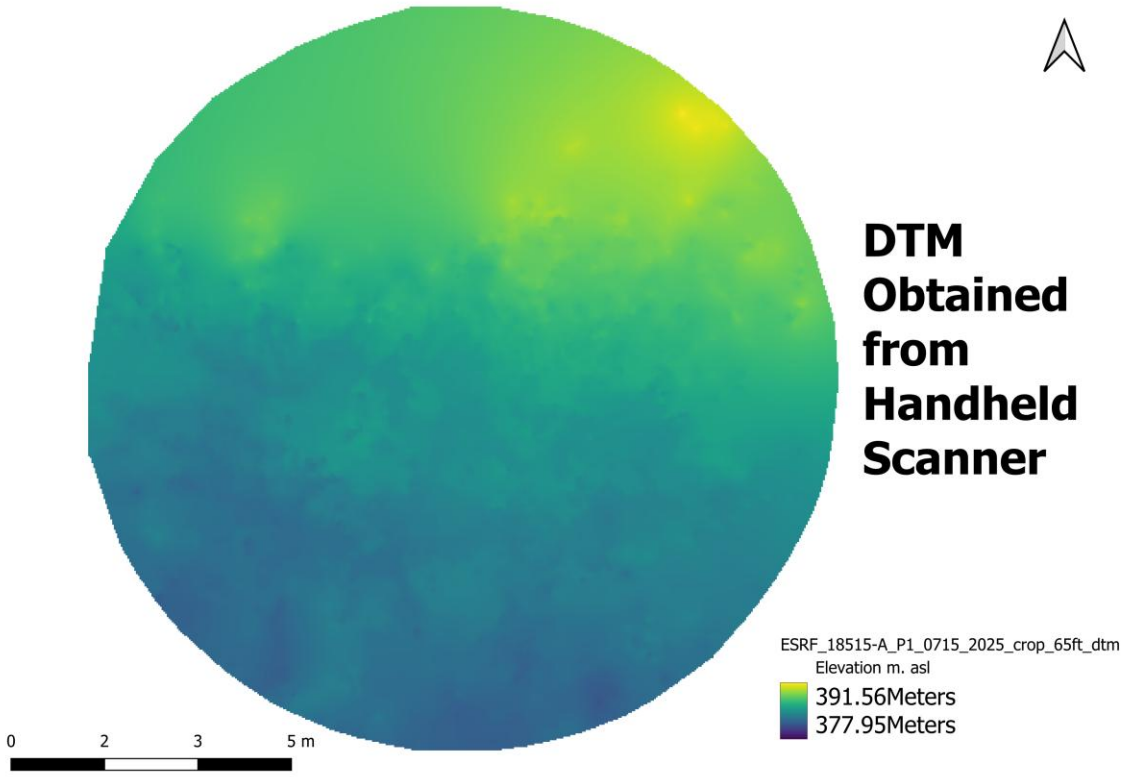


Registration: Fine

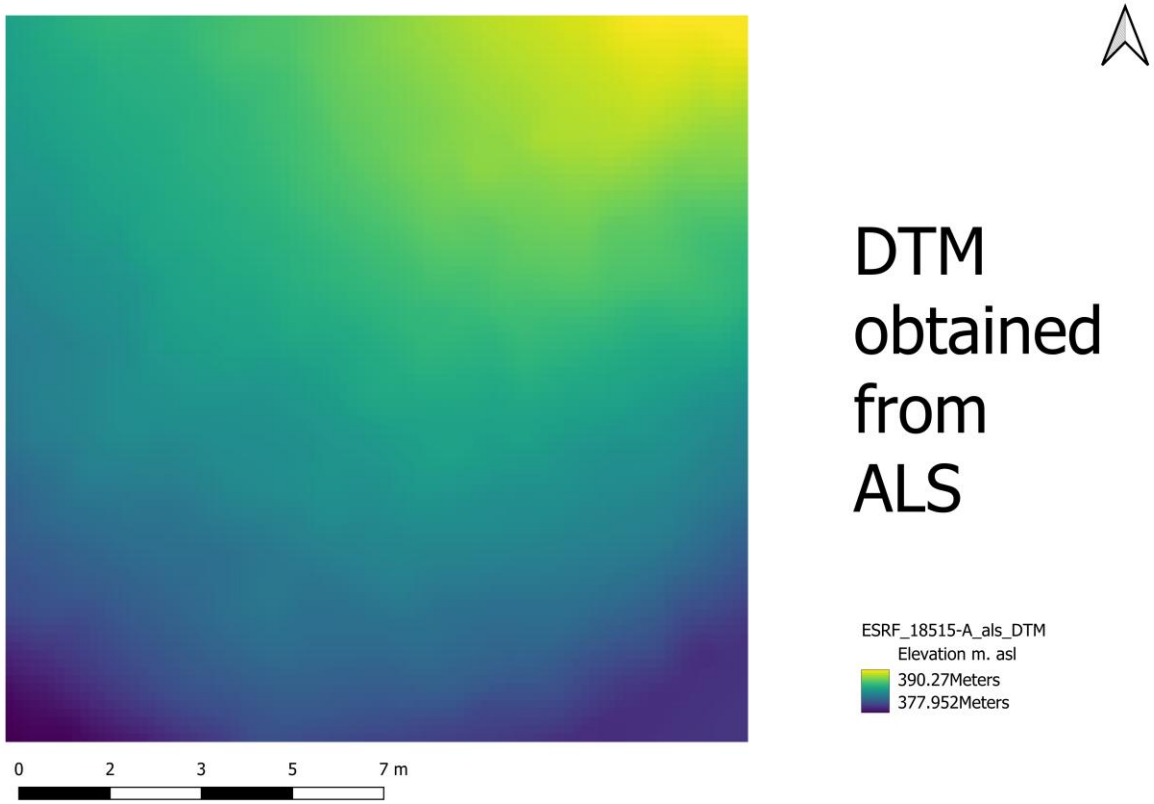


DTM generation

- ALS: TerraScan (Adaptive TIN)
- HLS: QTM (LidarSense)



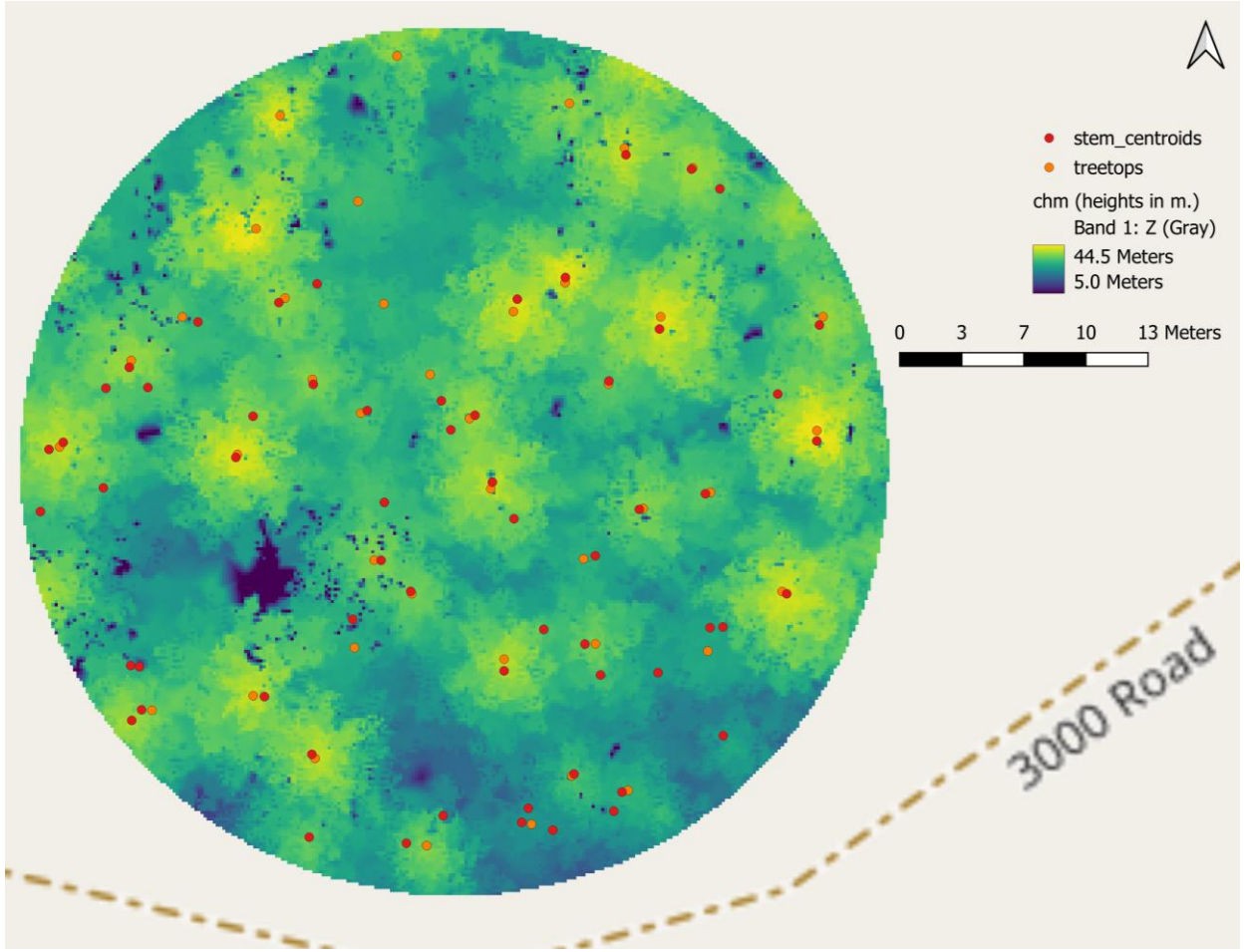
DTM Obtained from Handheld Scanner



DTM obtained from ALS

Tree Position Extraction

- ALS: CHM
  - Variable window filter
    - **ws = height × 0.05 + 2**
  - Manual check for false positives or negatives
- HLS: Tree centroid
  - Slice at breast height
  - Manual circle fit in GIS
  - Extract centroid



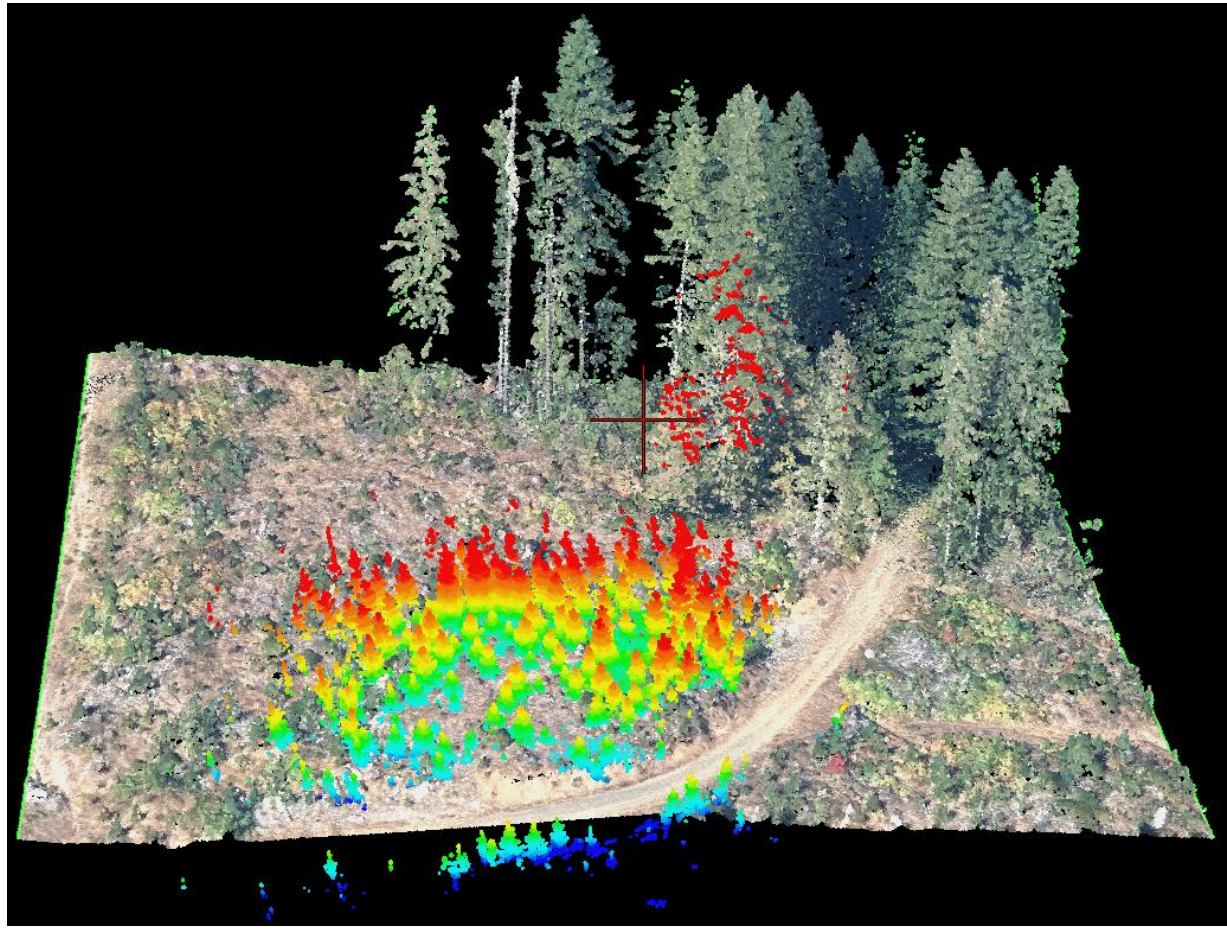
Sources of Errors

- Scan inherent errors: SLAM related errors
- DTM Difference: ground points & algorithms
- Heavy obstruction: top of the canopy
- Lack of realism of algorithm: wind and leaning
- SLAM cannot be processed: software issues

Results

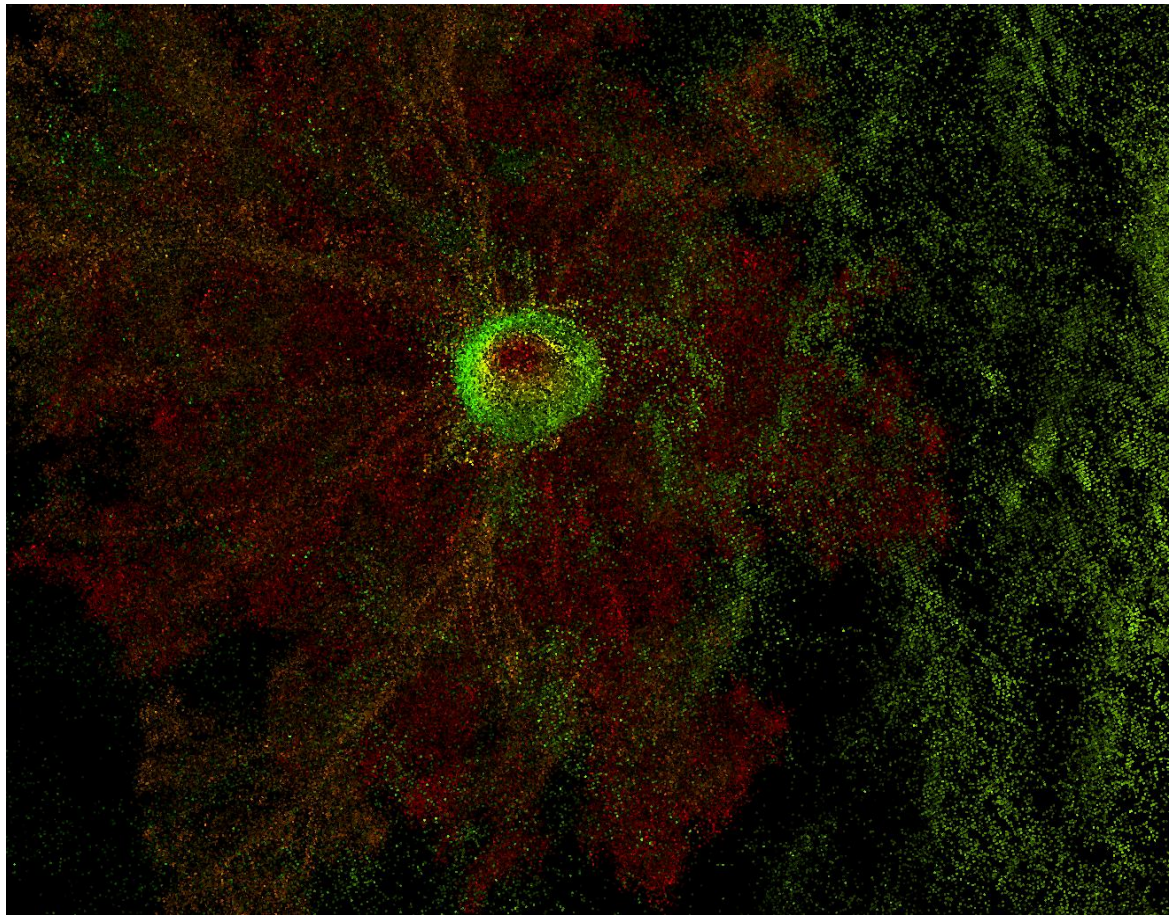
Reality change

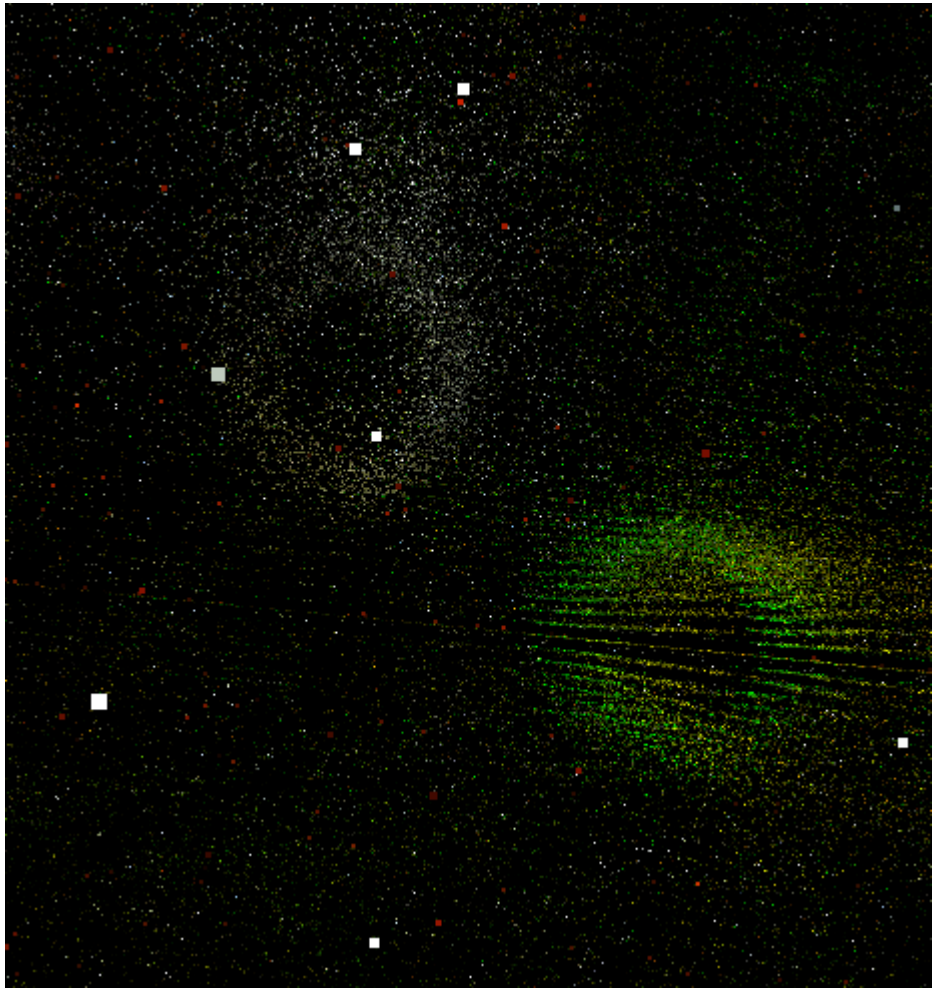
ALS in 2021 vs HLS in 2024



HLS: SLAM errors (1)

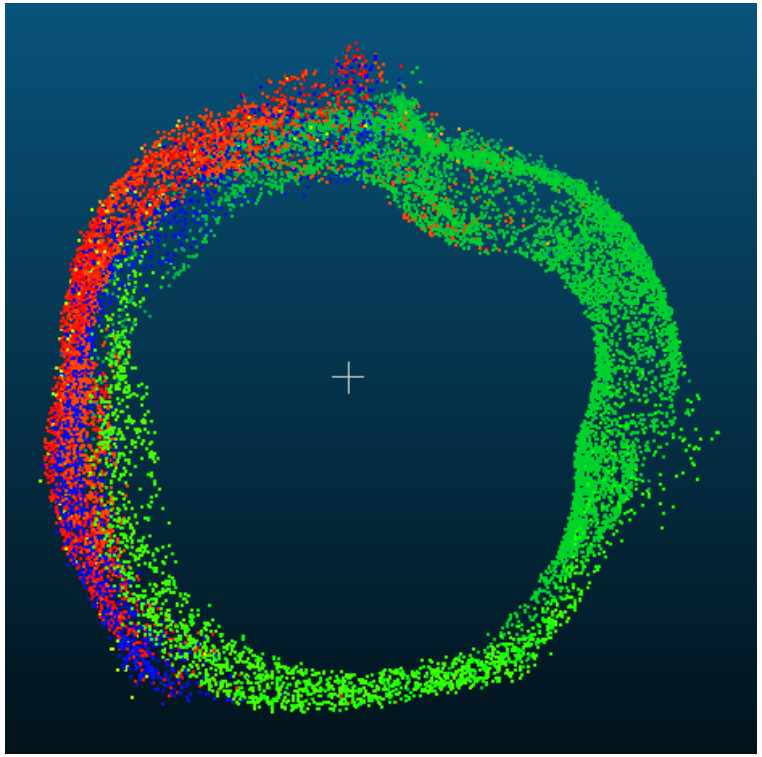
Within scan error: middle of the scan does not match



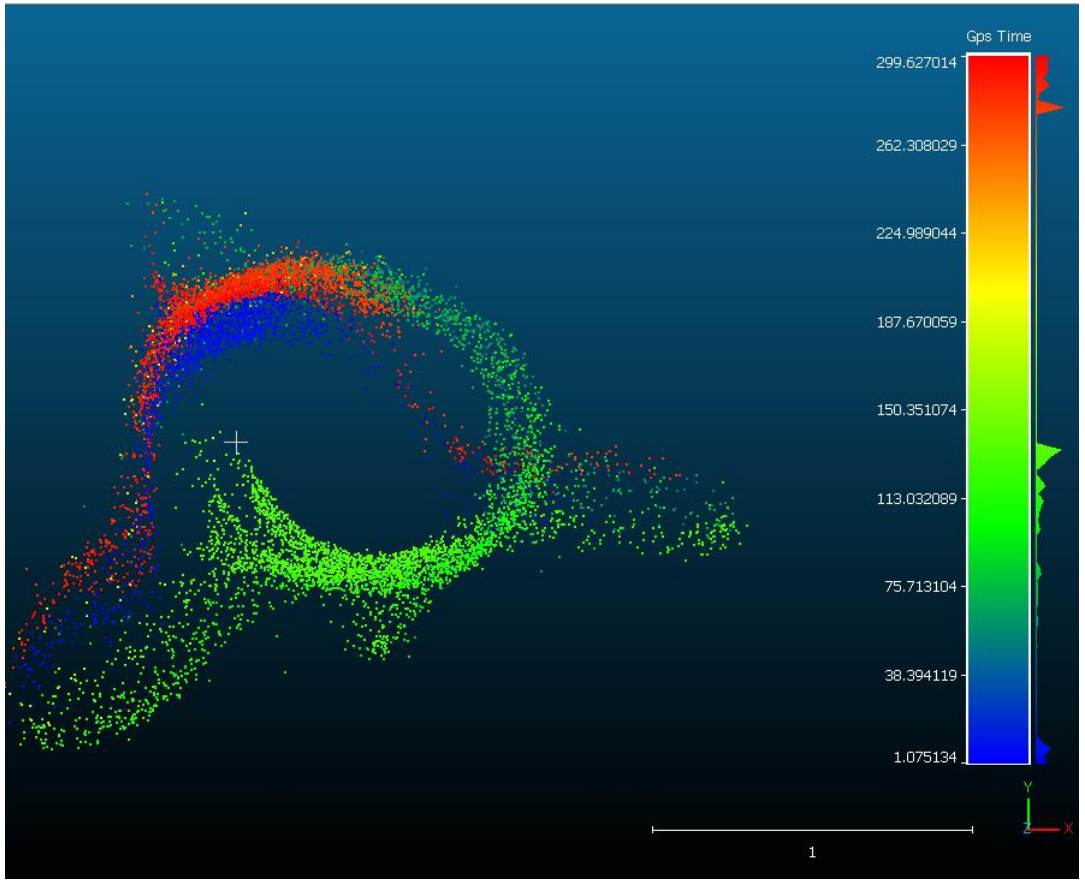


HLS: SLAM errors (2)

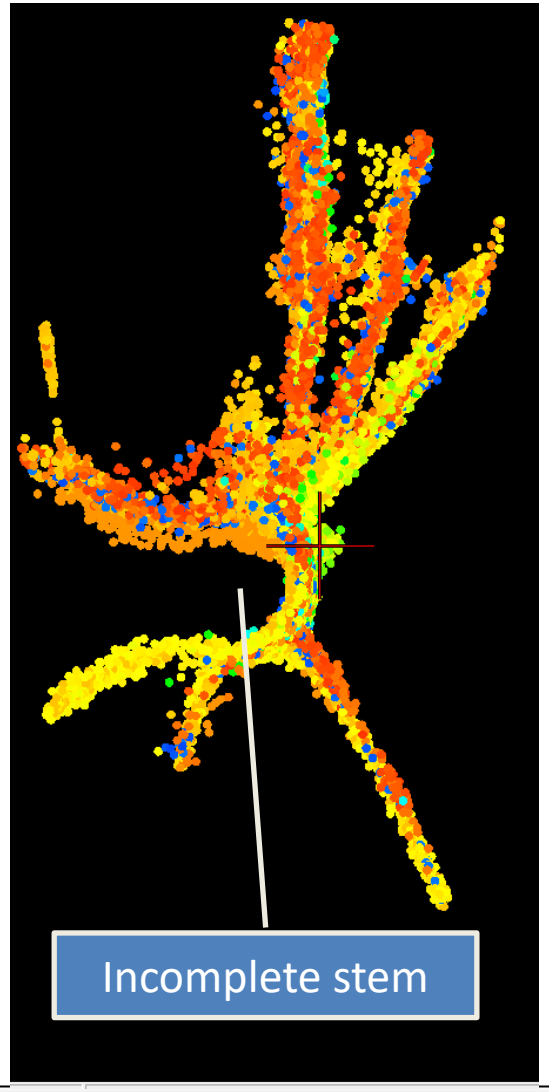
Expected point clouds

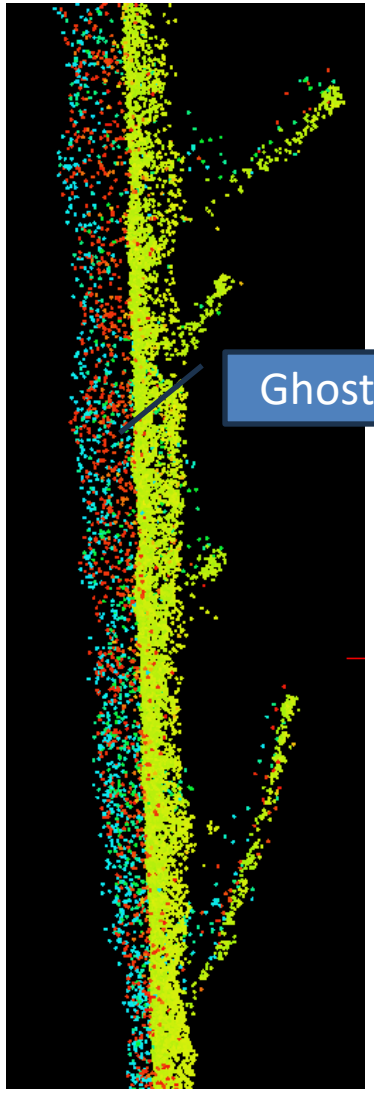


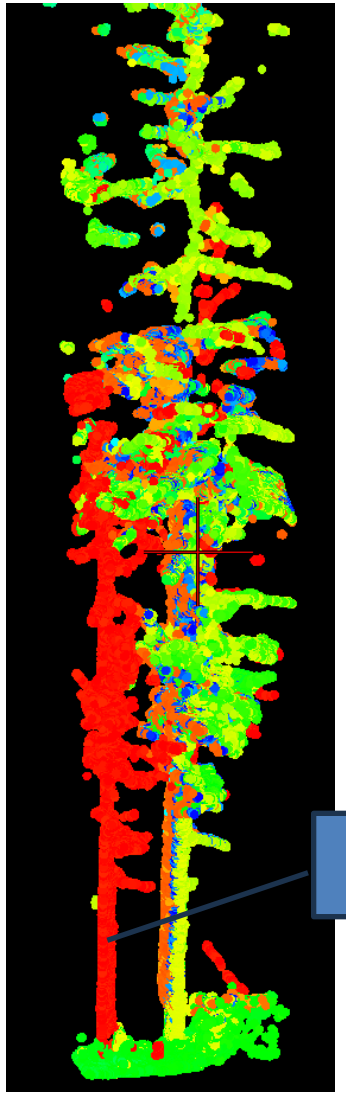
SLAM Drift & Ghost trees



HLS: SLAM errors (3)

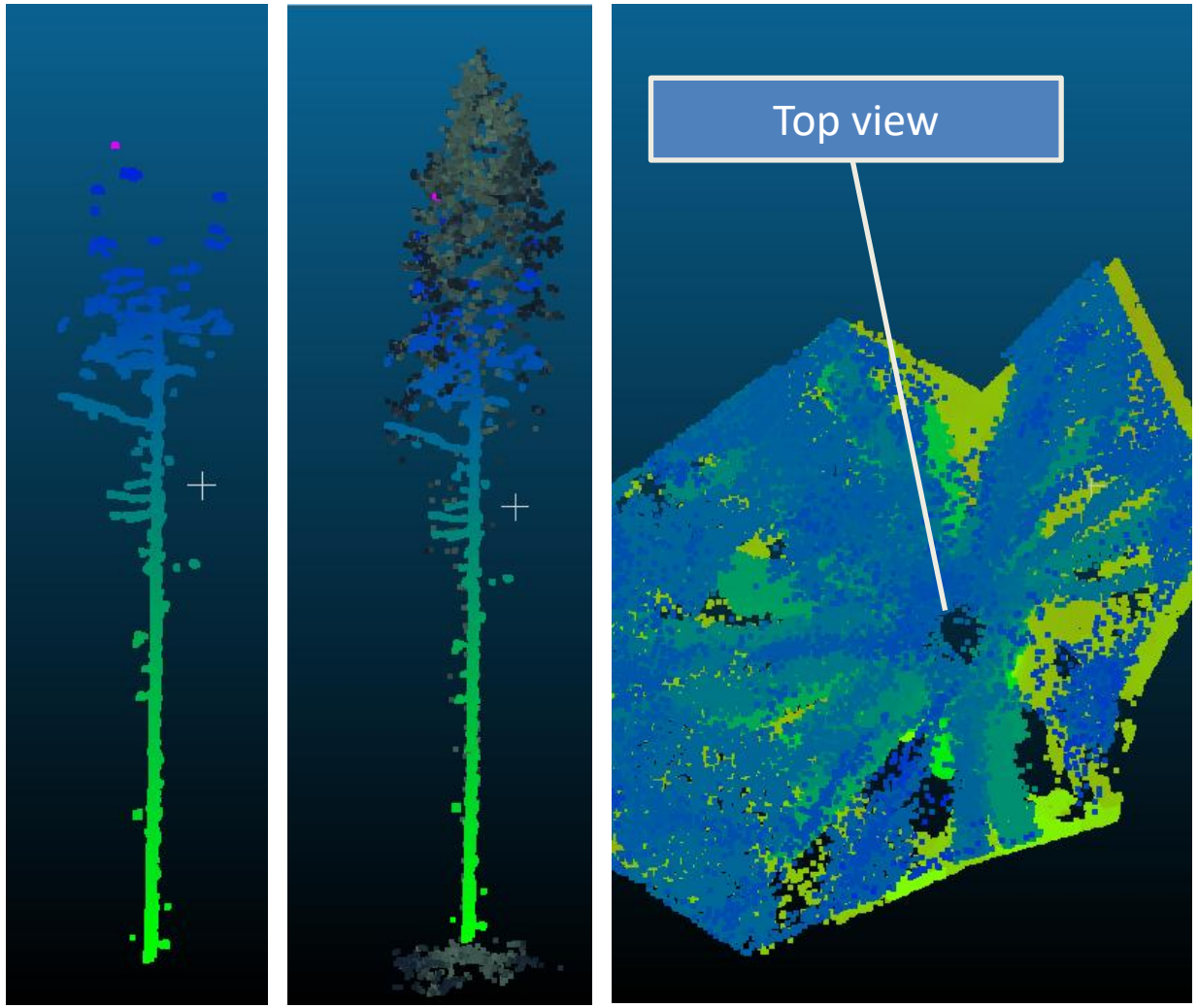




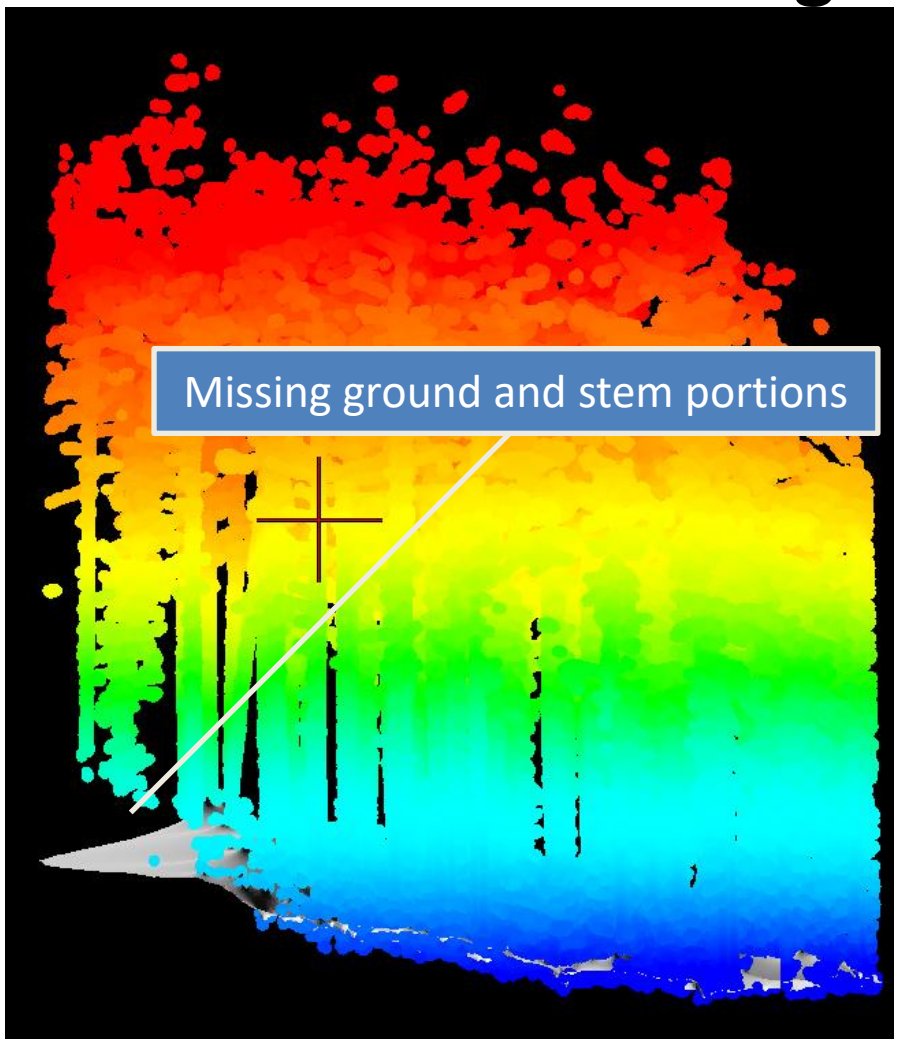


Obstructions, device & scanning pattern

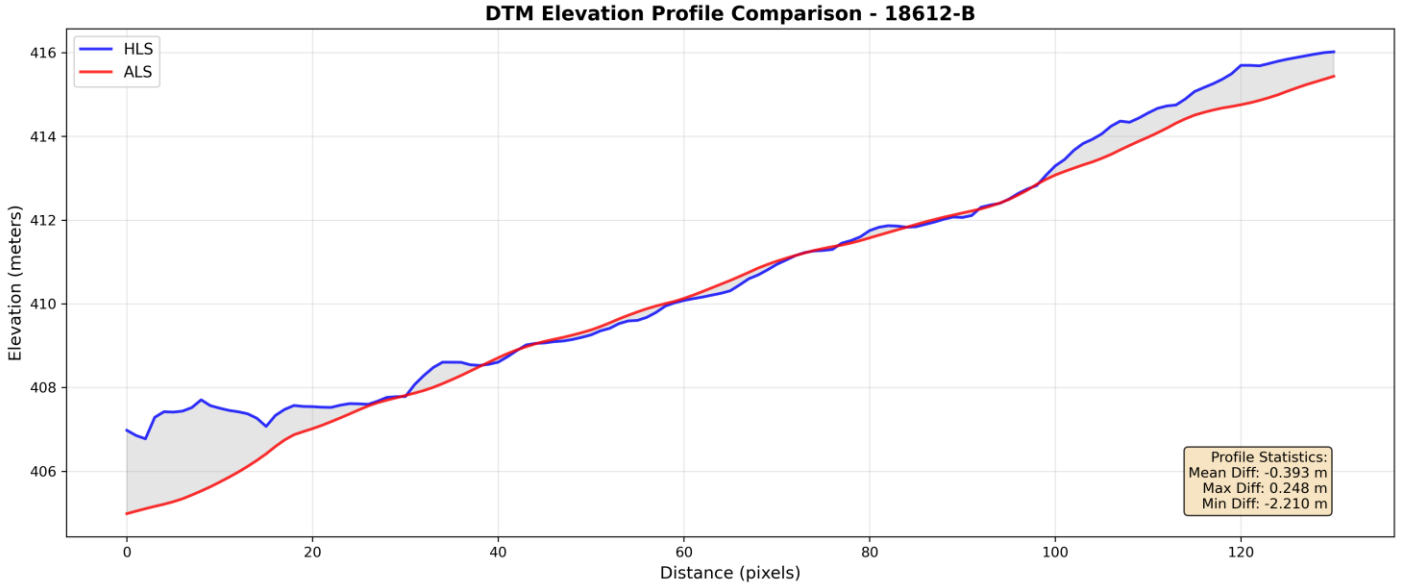
Scanner Range limit & Obstruction

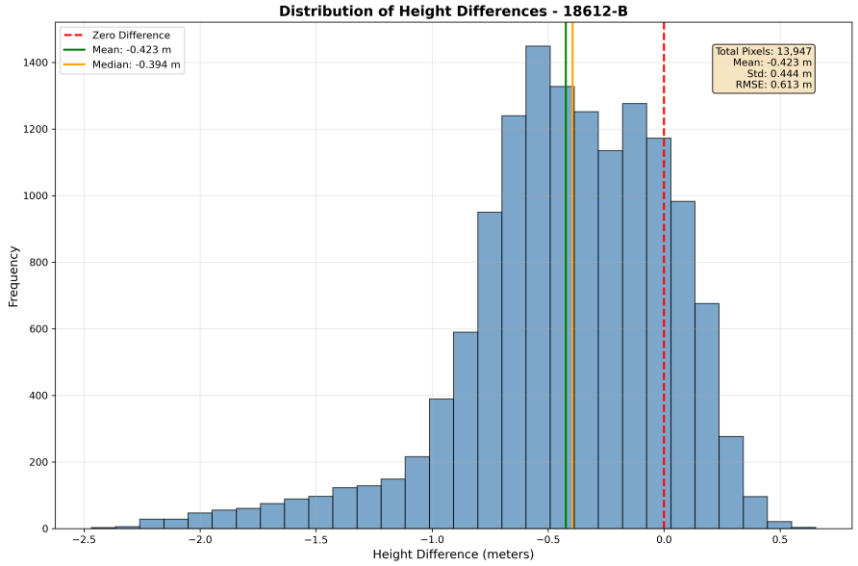


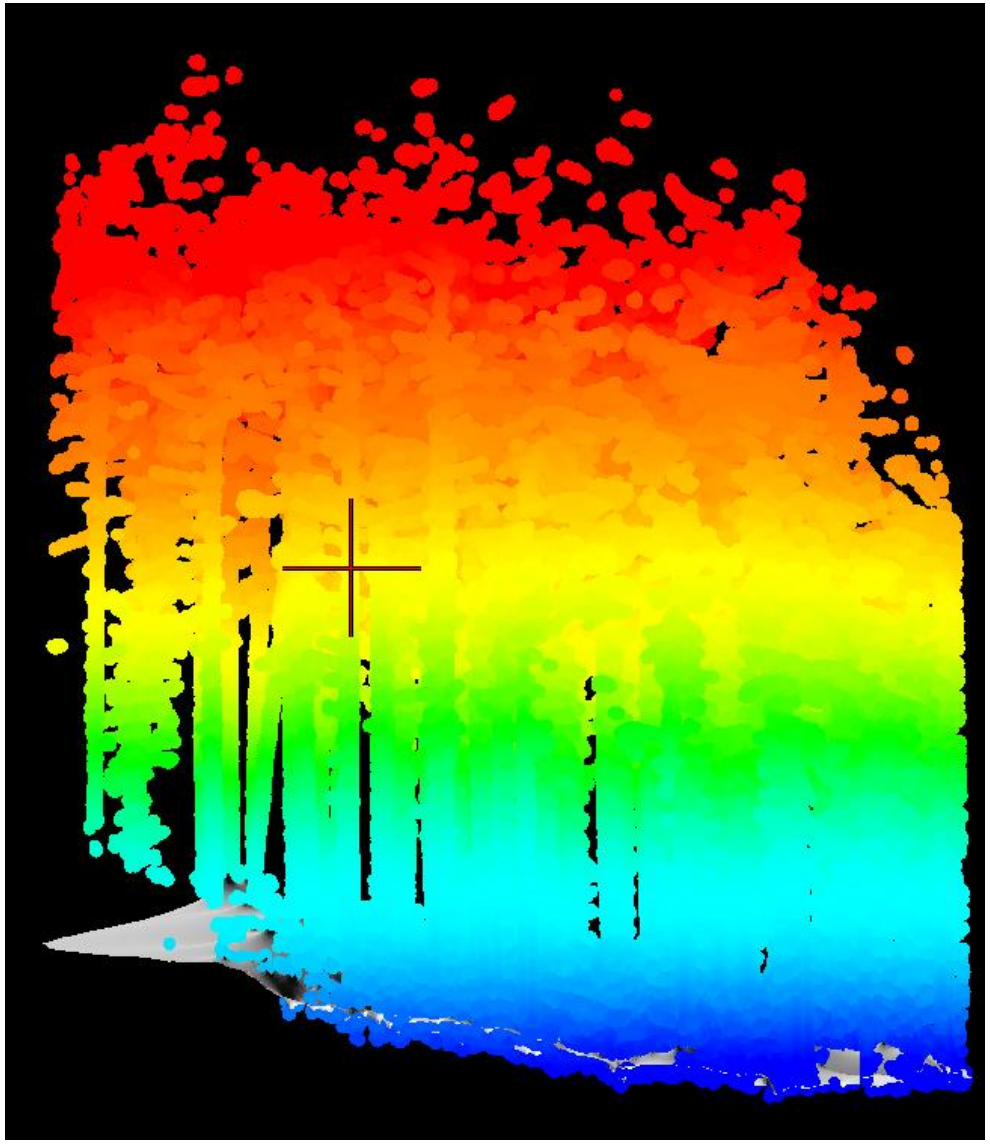
Obstruction & Line of sight



DTM differences: Example plot

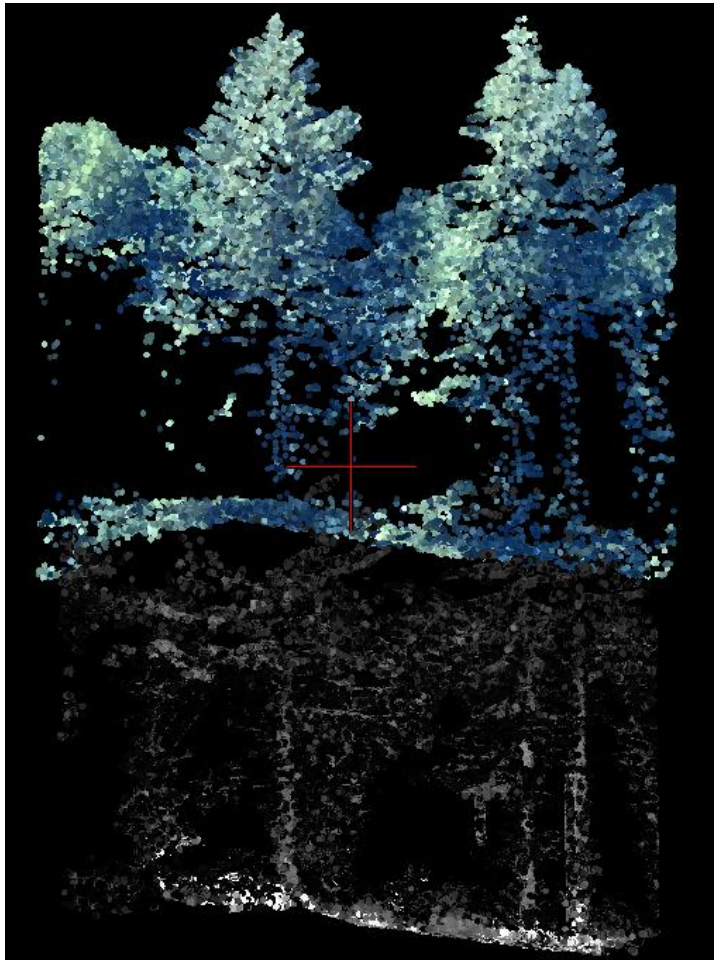


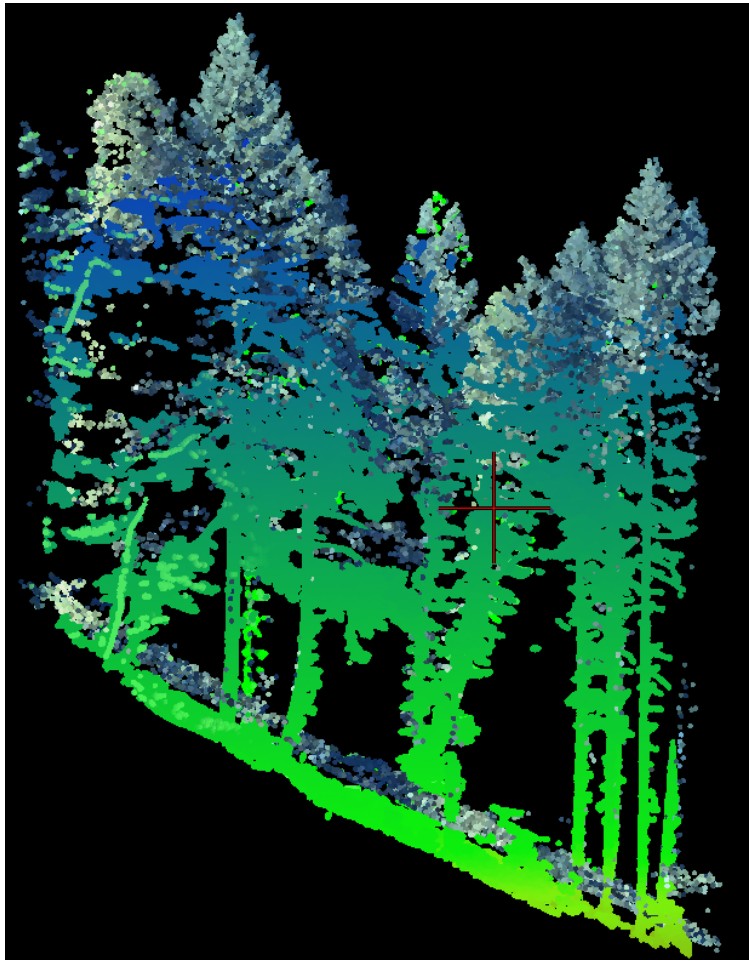




Coarse Registration Issues

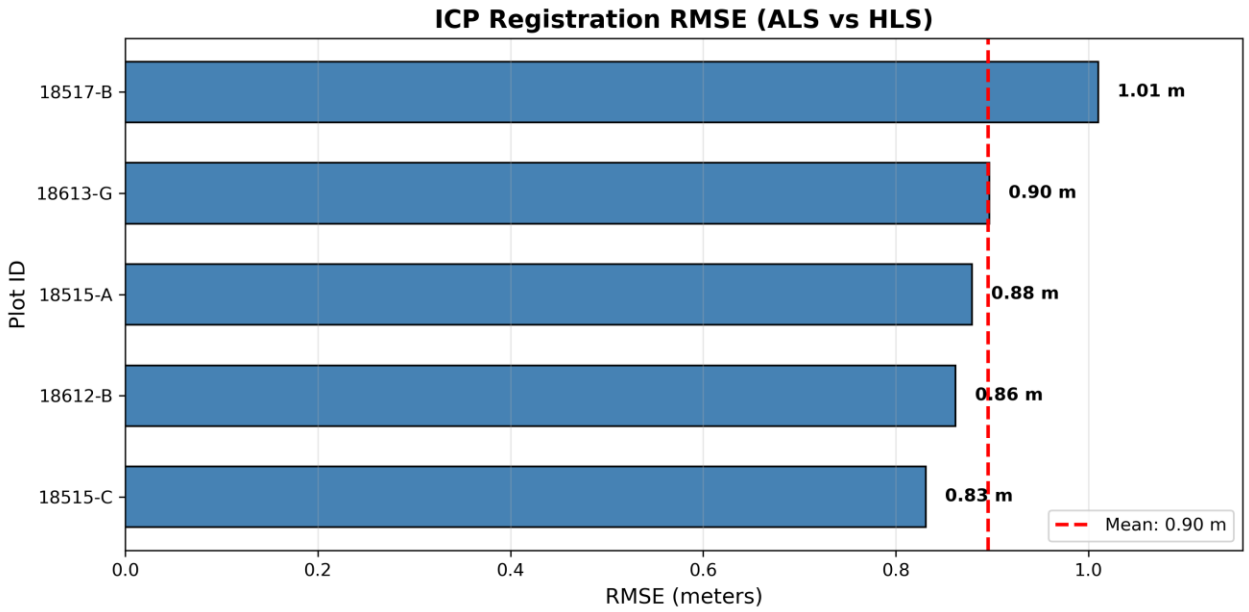
- Coarse Horizontal alignment: Register-Clouds
  - MARS lab C#
- Vertical & Rotation alignment: manually
  - QTM





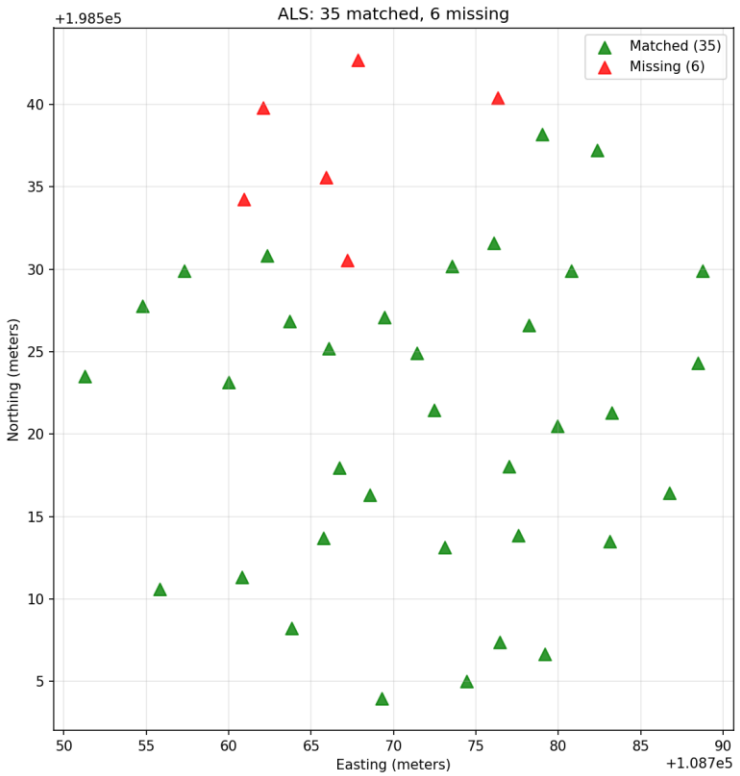
Fine co-registration ALS - HLS

- ICP: correspondence
- Parameters:
  - n=50,000 points
  - Overlap=10%
  - RMS difference: 10^{-6}
- Results sensitive to overlap.
- Increasing Overlap
  - RMSE change significantly.
  - visual inspection does not show much difference

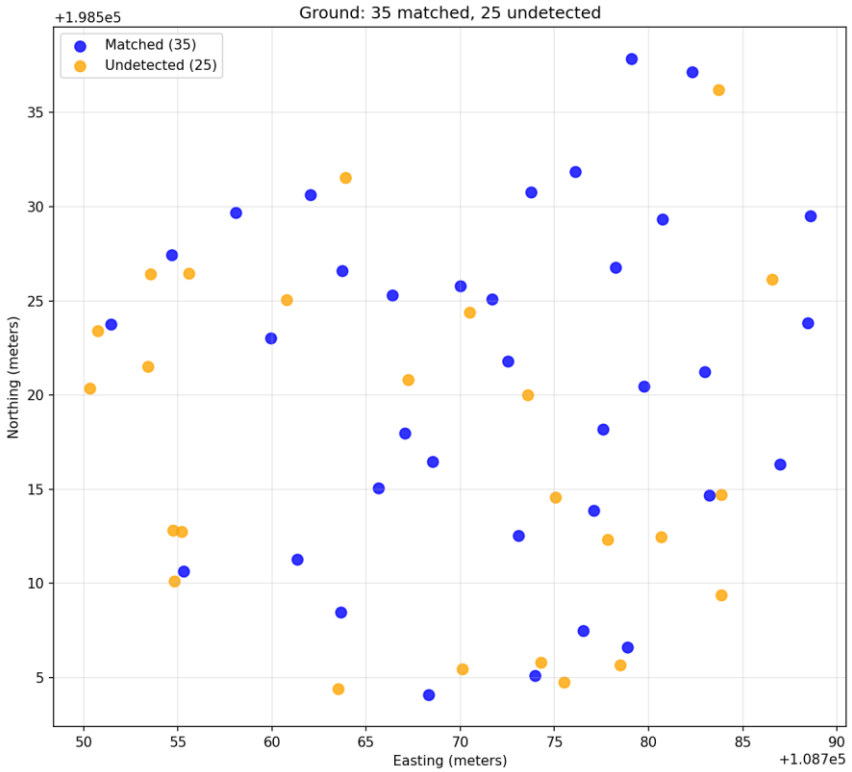


Matching of Trees with Example plot

- Coherent Point Drift Algorithm
- n_plots=5
- n_trees_ALS=304
- n_trees_HLS=335
- **76.6%** of trees from ALS found a match in HLS
- **69.6%** of trees from HLS found a match in ALS
- ALS: NO Suppressed tress
- HLS: DTM error; more trees go undetected



ALS as truth -> Match HLS to ALS



HLS as truth -> Match ALS to HLS

Conclusion

- Reality of Forests
  - Undetected understory: Error in trees per ha estimation.
  - Ground vegetation: Causes error in ground/terrain extraction
  - Lean/sweep of trees: Error in tree position
- Technology issues
  - SLAM issue and ghost trees: Error in DBH estimation
  - Difference in DTM, and Range limit: Error in Height estimation.

Acknowledgements

- Elliott State Research Forest
- OLI Meeting 2026
- College of Forestry
- Todd West
- Yang Han
- Michael Bartczyszyn

References

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Thank You!!