



UAS-Based LiDAR Mapping

Video E



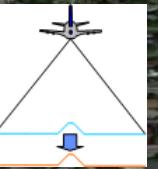
LiDAR Data Quality Control



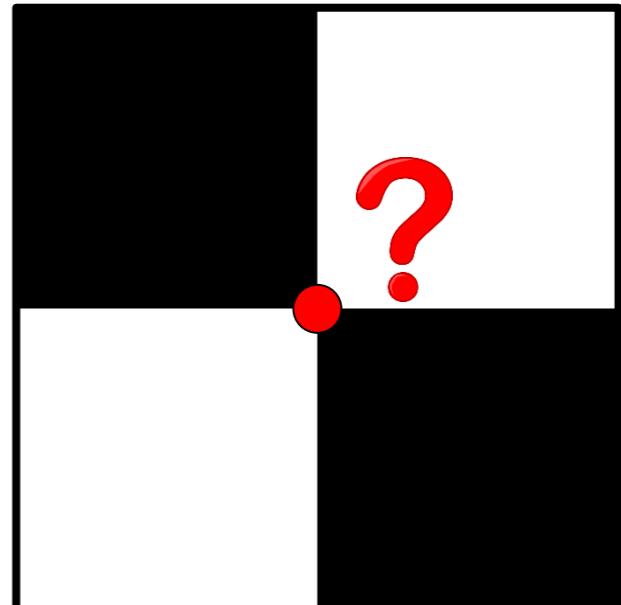
LiDAR Quality Control

- Quality control is a post-mission procedure to ensure/verify the quality of collected data.
- Quality control procedures can be divided into two main categories:
 - **External/absolute QC measures:** the LiDAR point cloud is compared with an independently collected surface (Accuracy Evaluation).
 - Check point analysis
 - **Internal/relative QC measures:** the LiDAR point clouds from different flight lines are compared with each other to ensure data coherence, integrity, and correctness (Precision Evaluation).

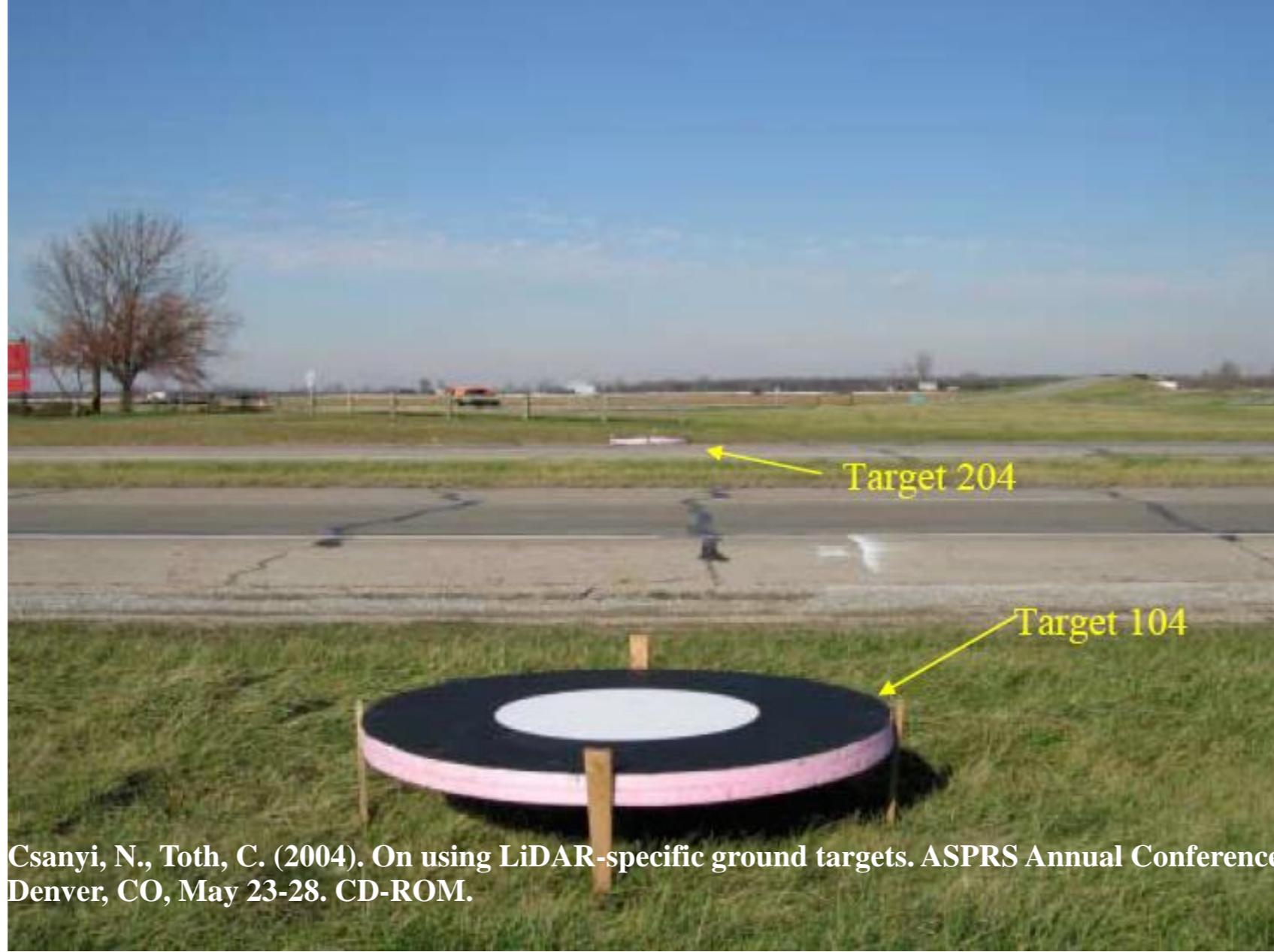
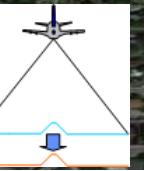
Quality Control using LiDAR Targets



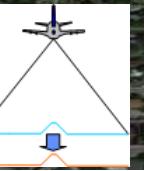
- **External/absolute quality control measures (EQC):**
 - Similar to photogrammetric quality control, the derived LiDAR coordinates can be compared with independently surveyed targets.
 - Check point analysis
 - Problem: How can we correlate the non-selective LiDAR footprints to the utilized check points?
 - Solution: Use specially designed targets.
 - The target design depends on the involved LiDAR system and collected data.
 - **Caution: the data collection should be carried out under normal operational circumstances.**
 - Same flying height, point density, etc.



EQC: LiDAR Control Targets



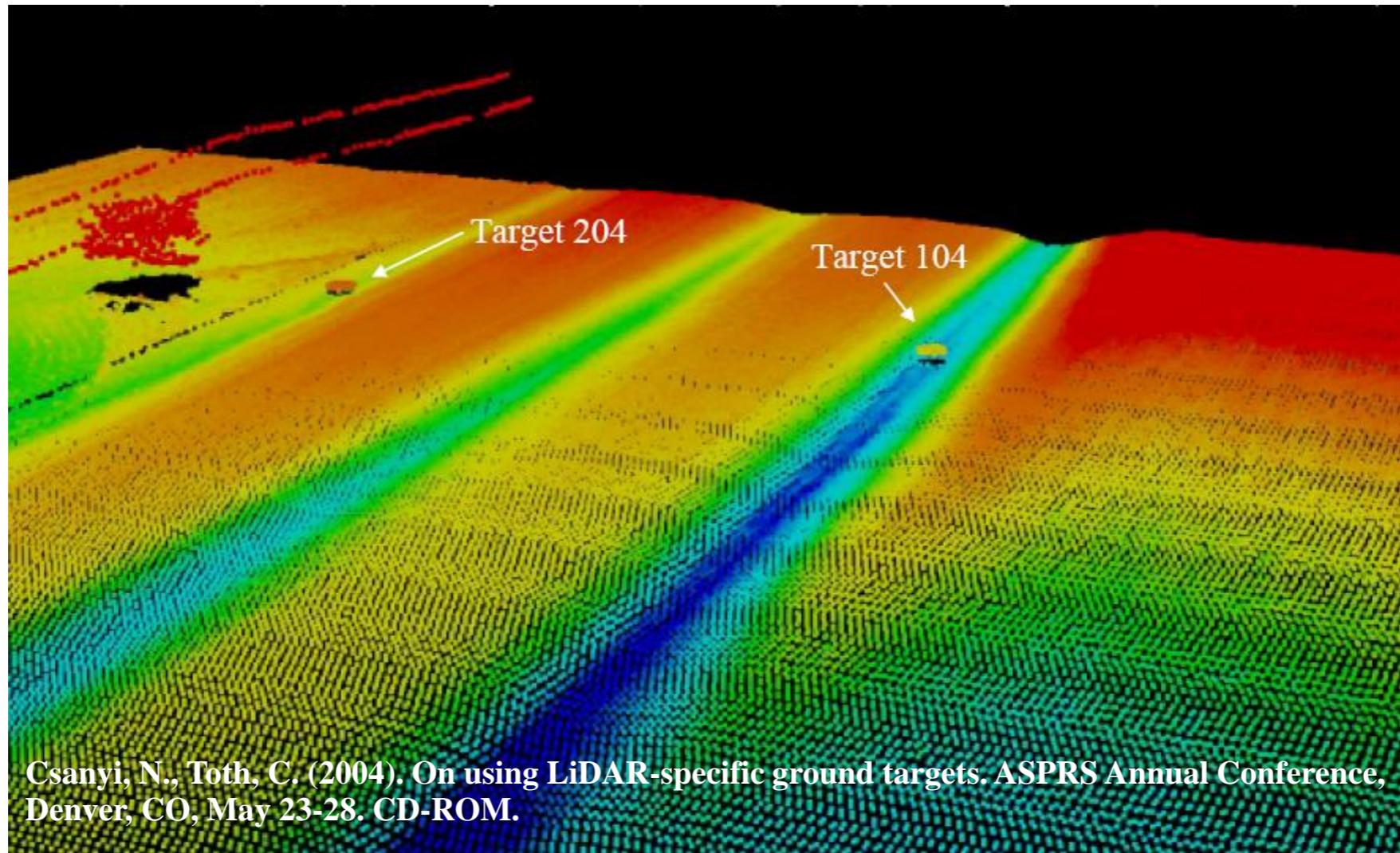
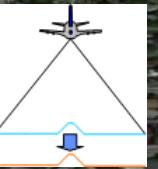
Csanyi, N., Toth, C. (2004). On using LiDAR-specific ground targets. ASPRS Annual Conference, Denver, CO, May 23-28. CD-ROM.



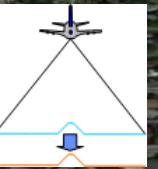
EQC: LiDAR Control Targets



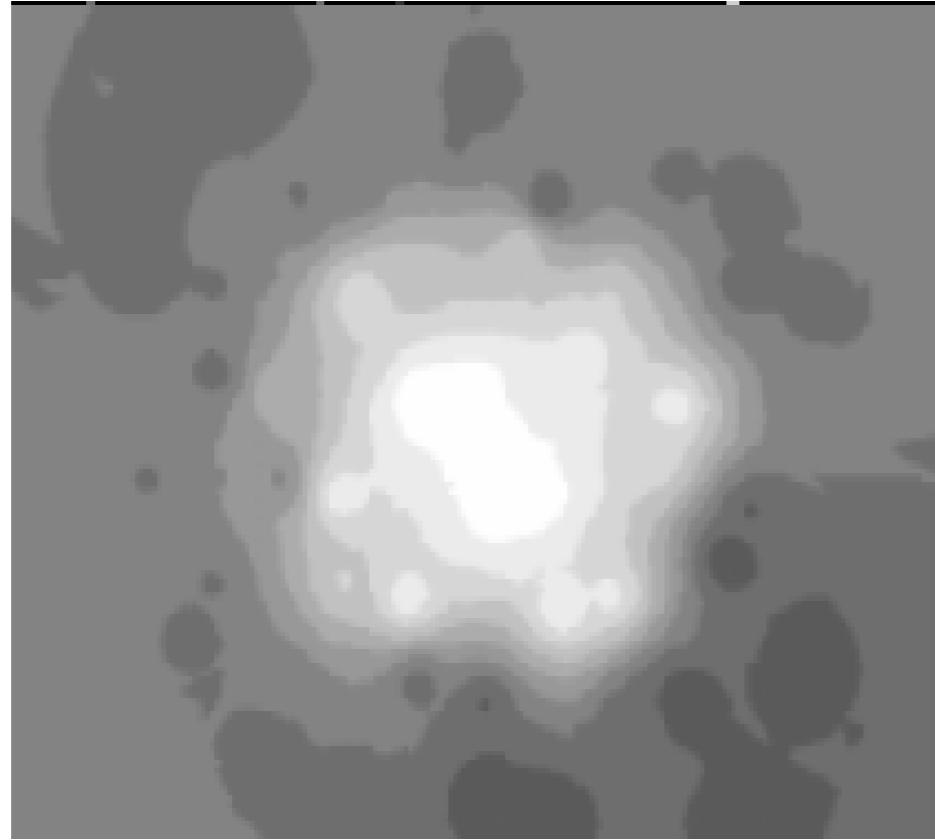
EQC: LiDAR Control Targets



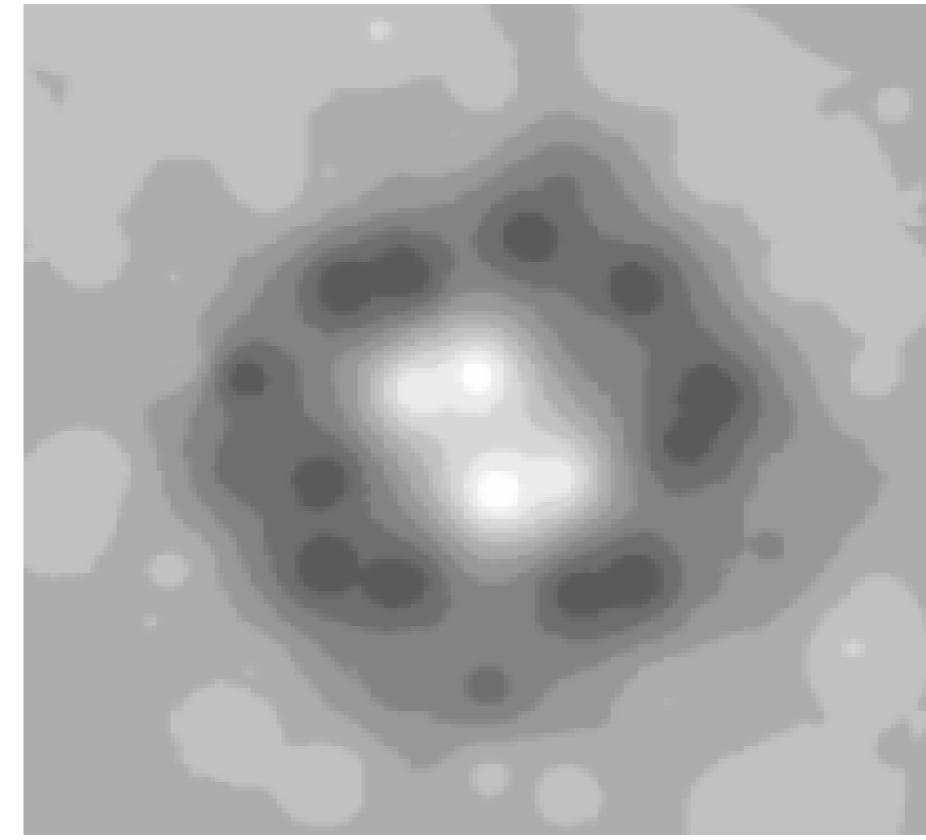
EQC: LiDAR Control Targets



Csanyi, N., Toth, C. (2004). On using LiDAR-specific ground targets. ASPRS Annual Conference, Denver, CO, May 23-28. CD-ROM.



Range Data

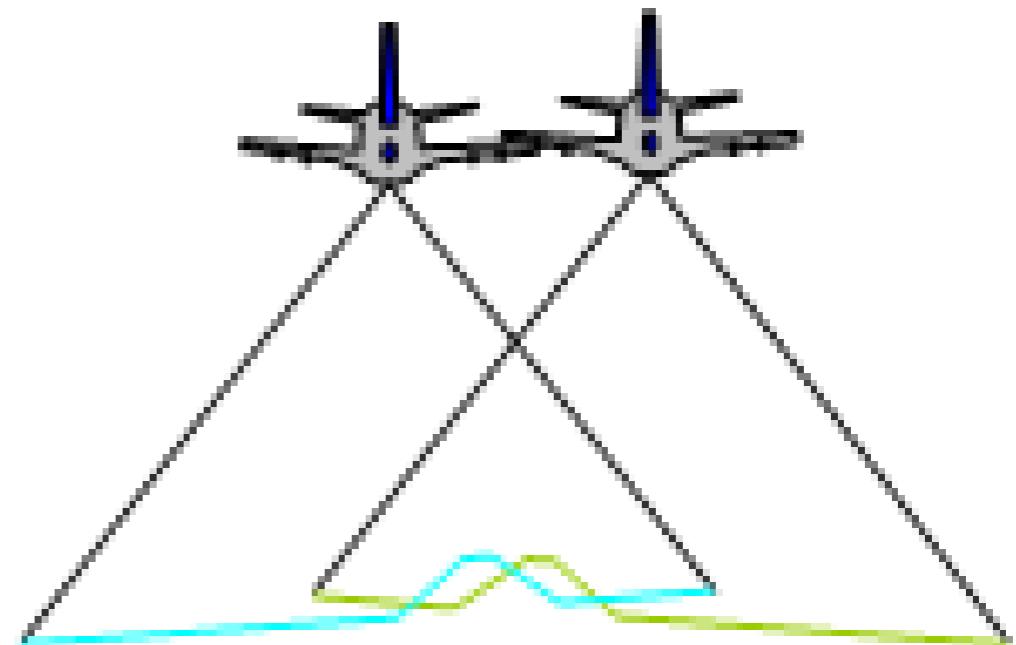


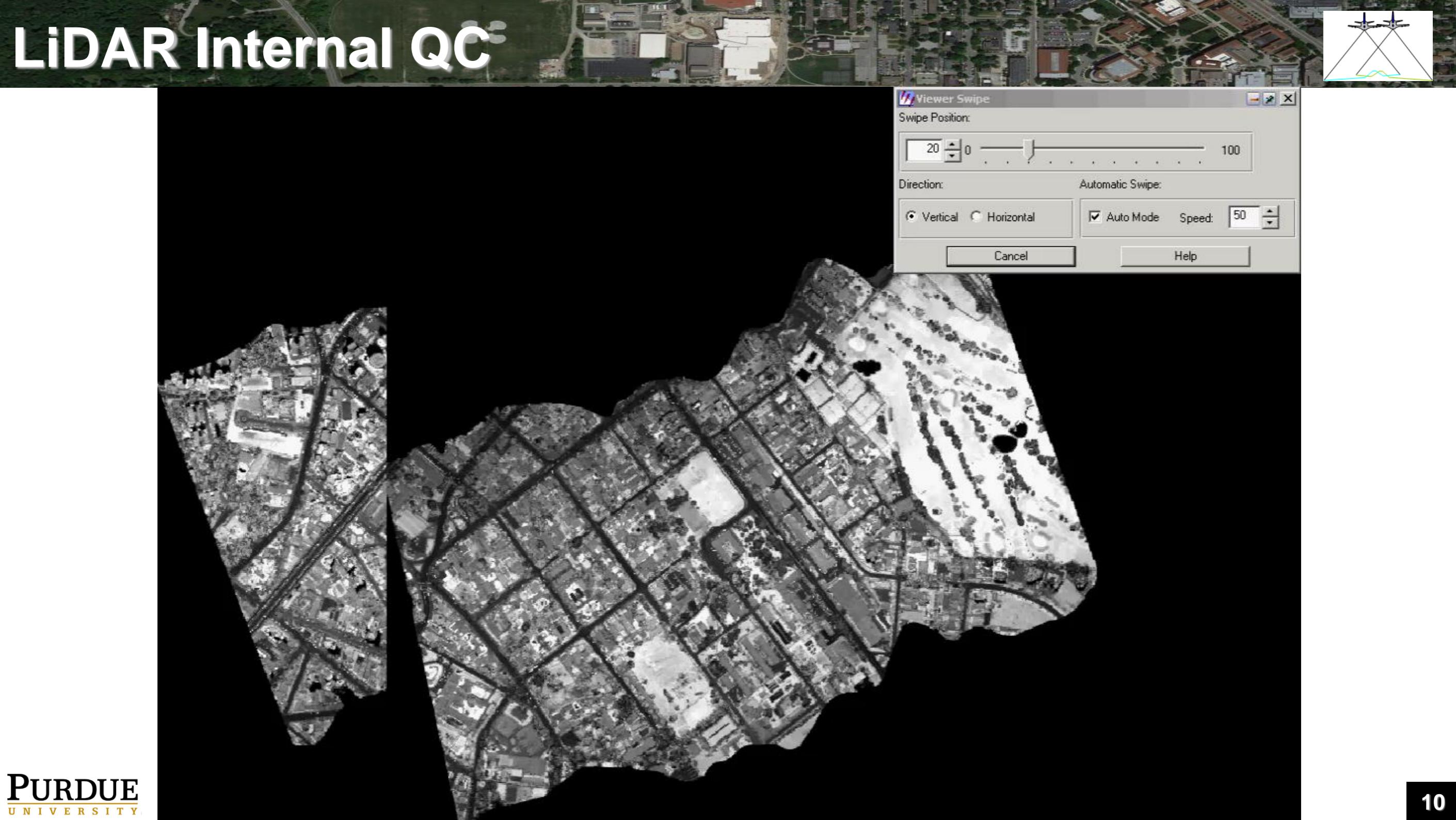
Intensity Data

- One should implement a segmentation procedure to derive the LiDAR coordinates of the target.

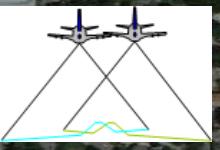
IQC: LiDAR Quality Control

- Surface reconstruction from LiDAR does not have redundancy.
 - Therefore, we do not have explicit measures in the derived surfaces to assess the quality of LiDAR-derived surfaces.
 - Neither residuals nor variance-covariance matrix is available following the reconstruction process.
- Users should have other measures to evaluate the **internal quality** of the derived LiDAR surfaces (IQC).
- Alternative methodologies are based on:
 - Coincidence of conjugate features in overlapping strips

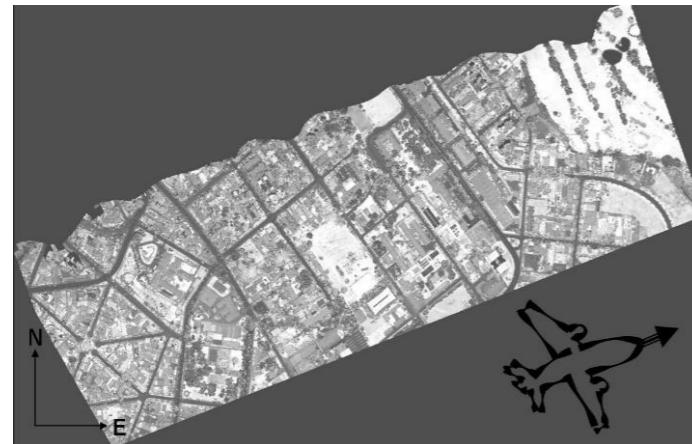




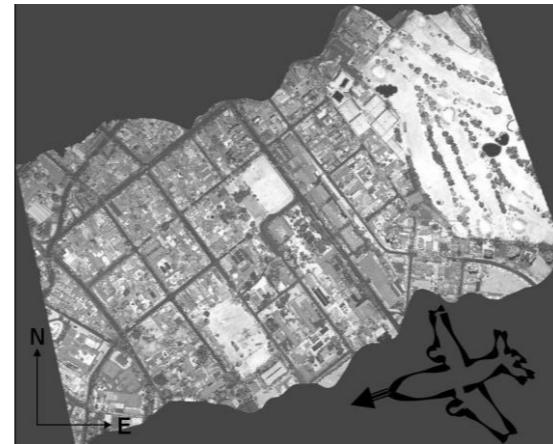
LiDAR Internal QC



- Surface reconstruction from LiDAR does not have redundancy.
 - Therefore, we do not have explicit measures to assess the quality of LiDAR coordinates.
- **Proposed Concept:** Evaluate the degree of consistency among the LiDAR footprints in overlapping strips.
 - **First approach:** quality control using extracted features from overlapping strips
 - **Second approach:** quality control using the original point cloud



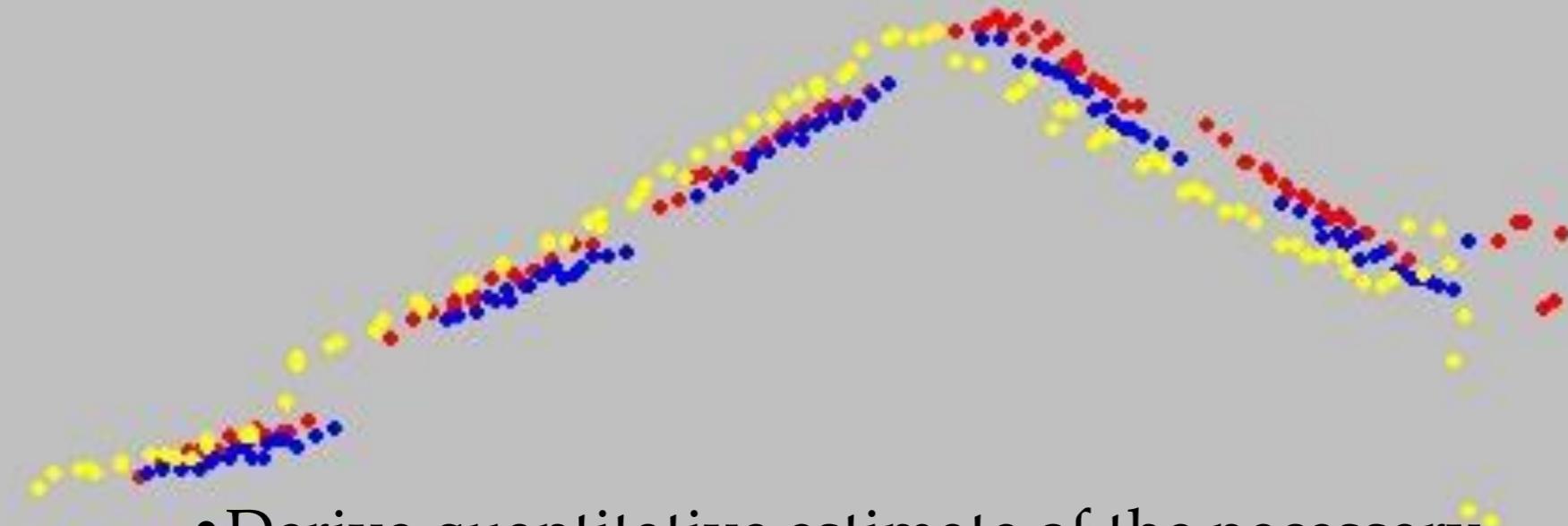
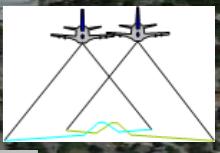
Strip 2



Strip 3



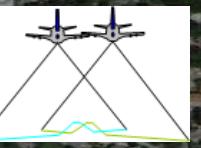
Strip 4



- Derive quantitative estimate of the necessary transformation parameters (shifts & rotations) for the co-alignment of the captured data from different flight lines.
 - For a well-calibrated system and with accurate navigation information, the transformation parameters should be very close to zero.

Check for the presence of biases

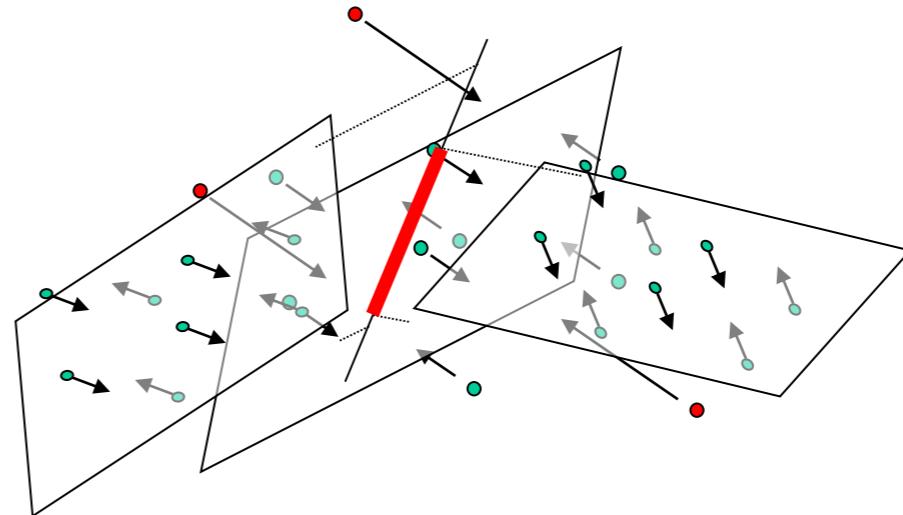
IQC: LiDAR Quality Control (Linear Features)



- The quality of the coincidence of extracted linear features from overlapping strips can be used for evaluating the internal quality of the LiDAR data.
 - The quality of coincidence can be evaluated by estimating the shifts, scale, and rotations, which are necessary for ensuring the coincidence of corresponding features.
 - The deviation from the optimal parameters (zero shifts, unit scale, and zero rotation angles) can be used as the IQC measures.

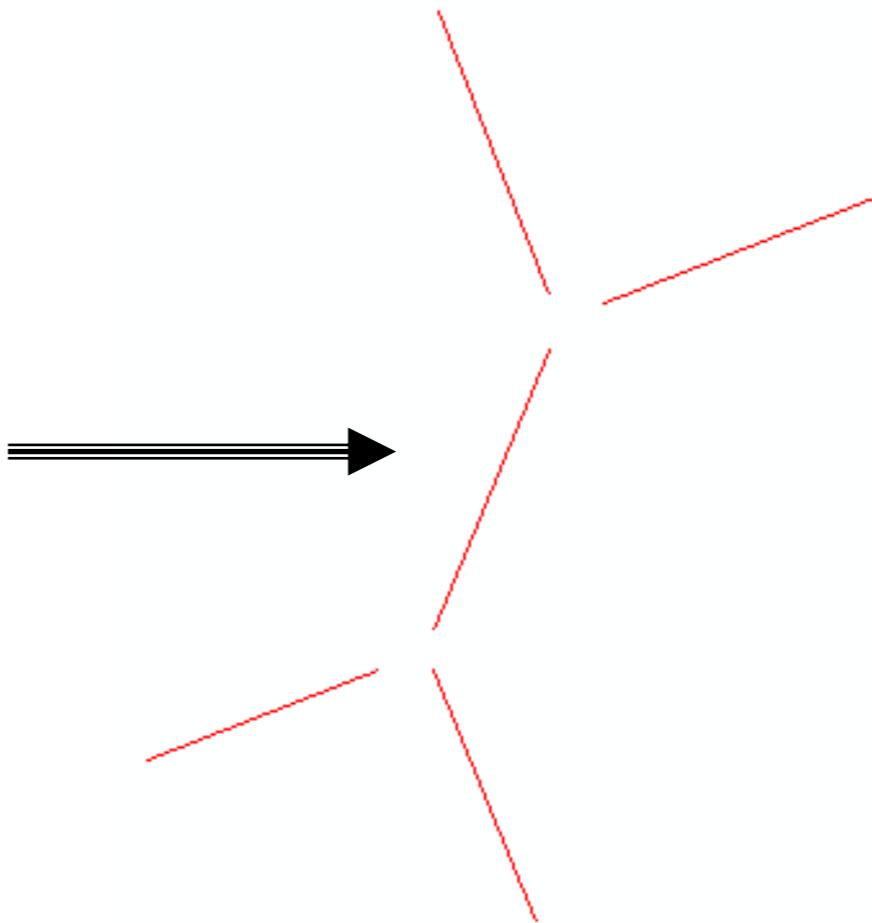
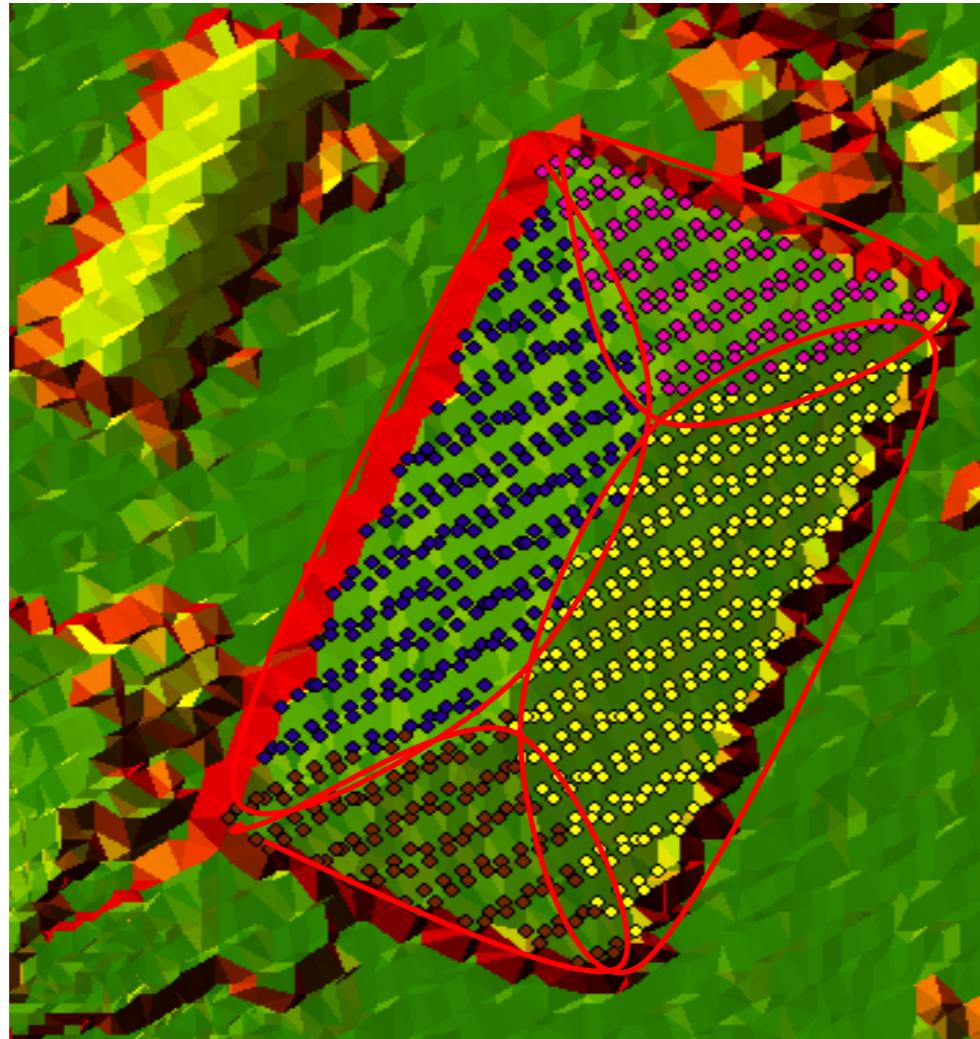
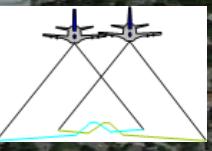


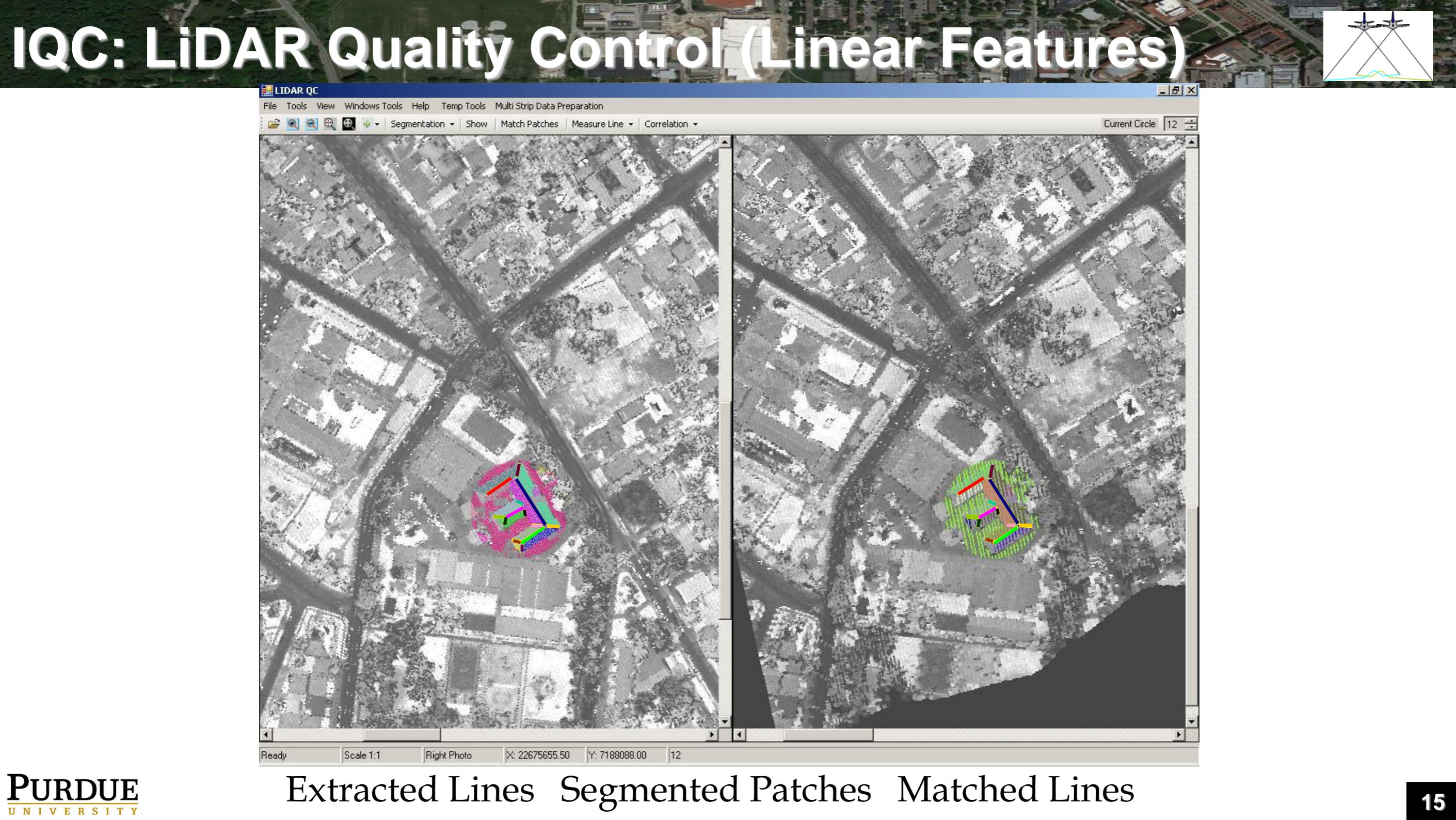
manual identification of LiDAR patches with the aid of imagery



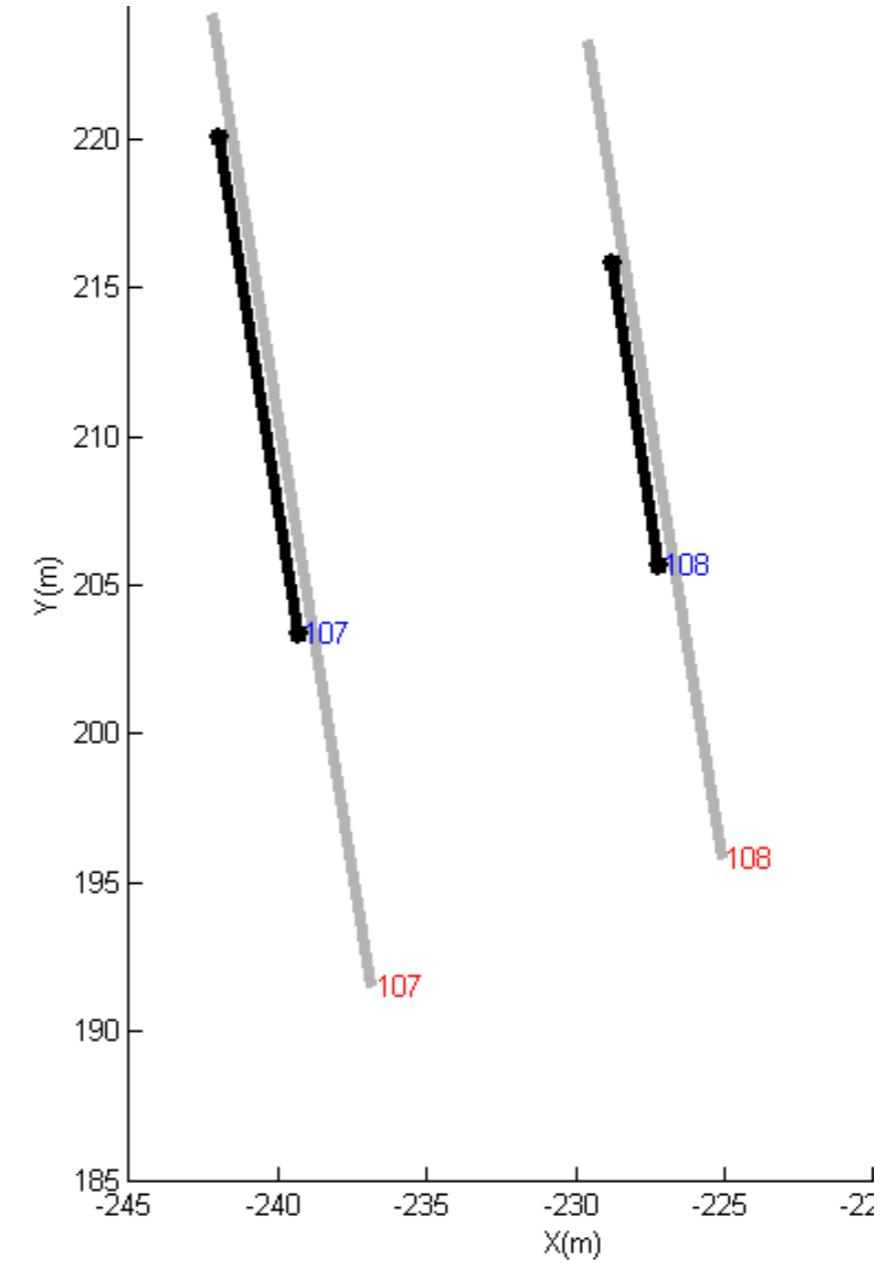
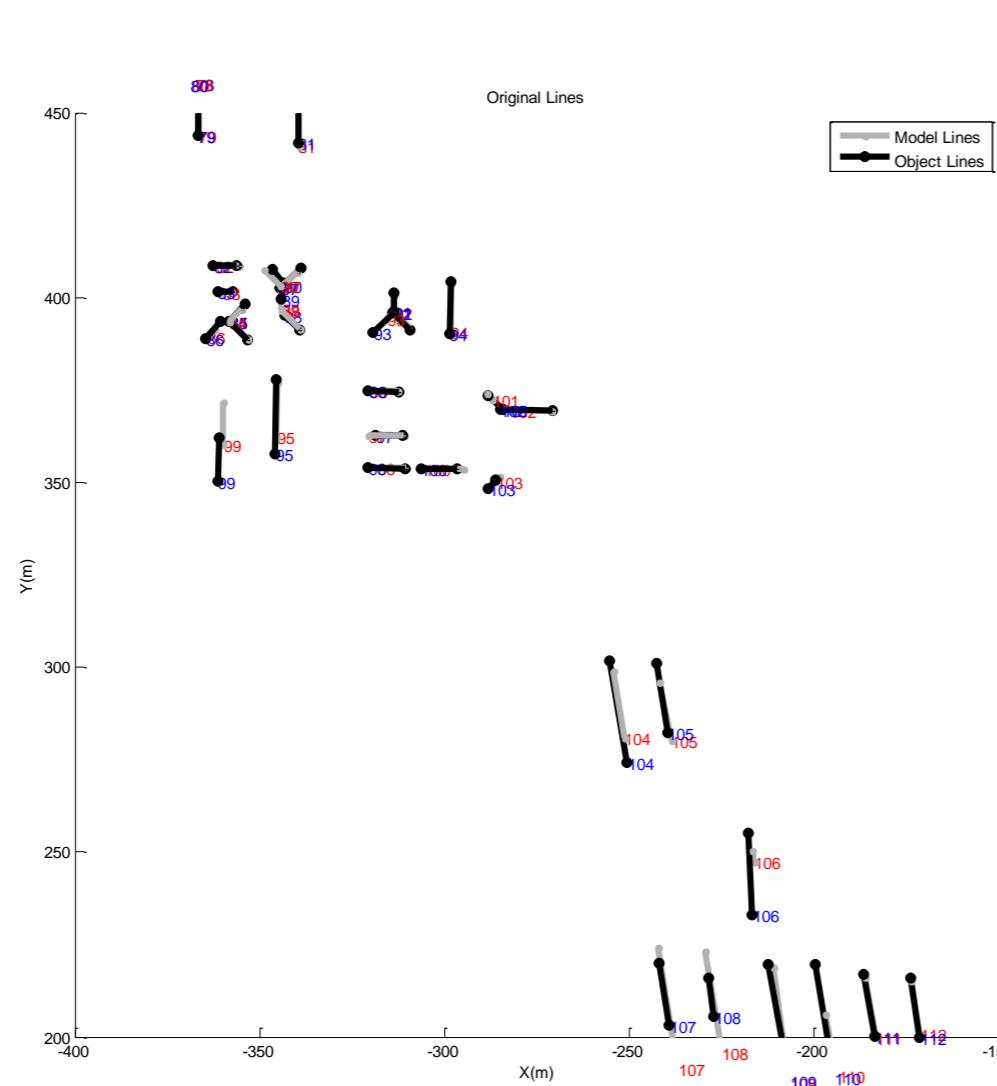
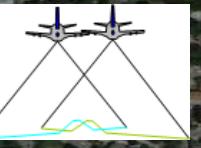
Linear Feature Extraction

IQC: LiDAR Quality Control (Linear Features)

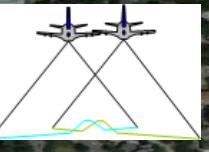




IQC: LiDAR Quality Control (Linear Features)



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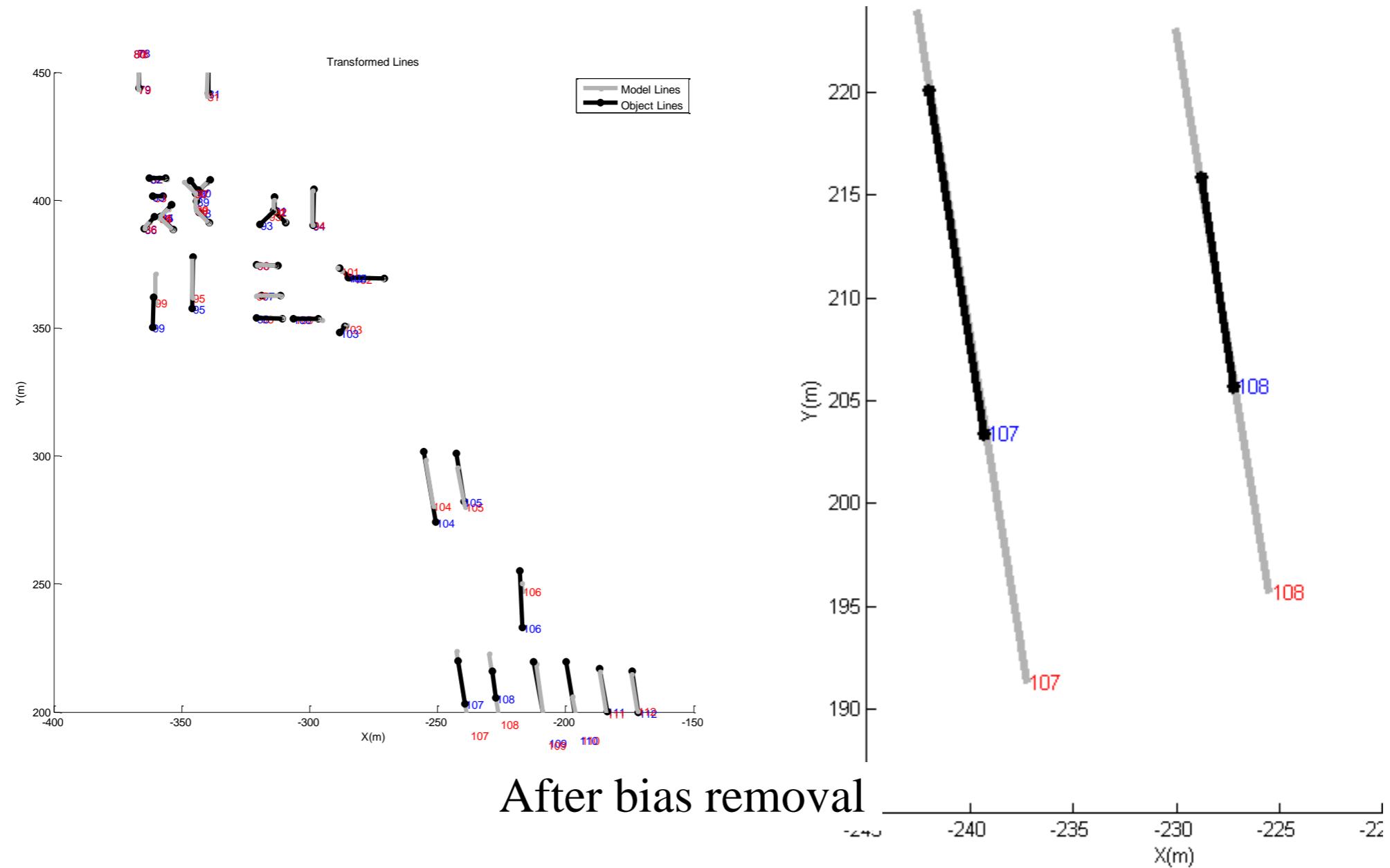
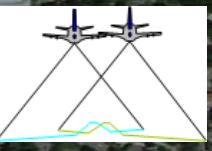


	X _T (m)	Y _T (m)	Z _T (m)	S	ω (°)	ϕ (°)	κ (°)
Optimal Para.*	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Estimated	-0.418	-0.209	-0.019	1.000	-0.010	0.017	0.003

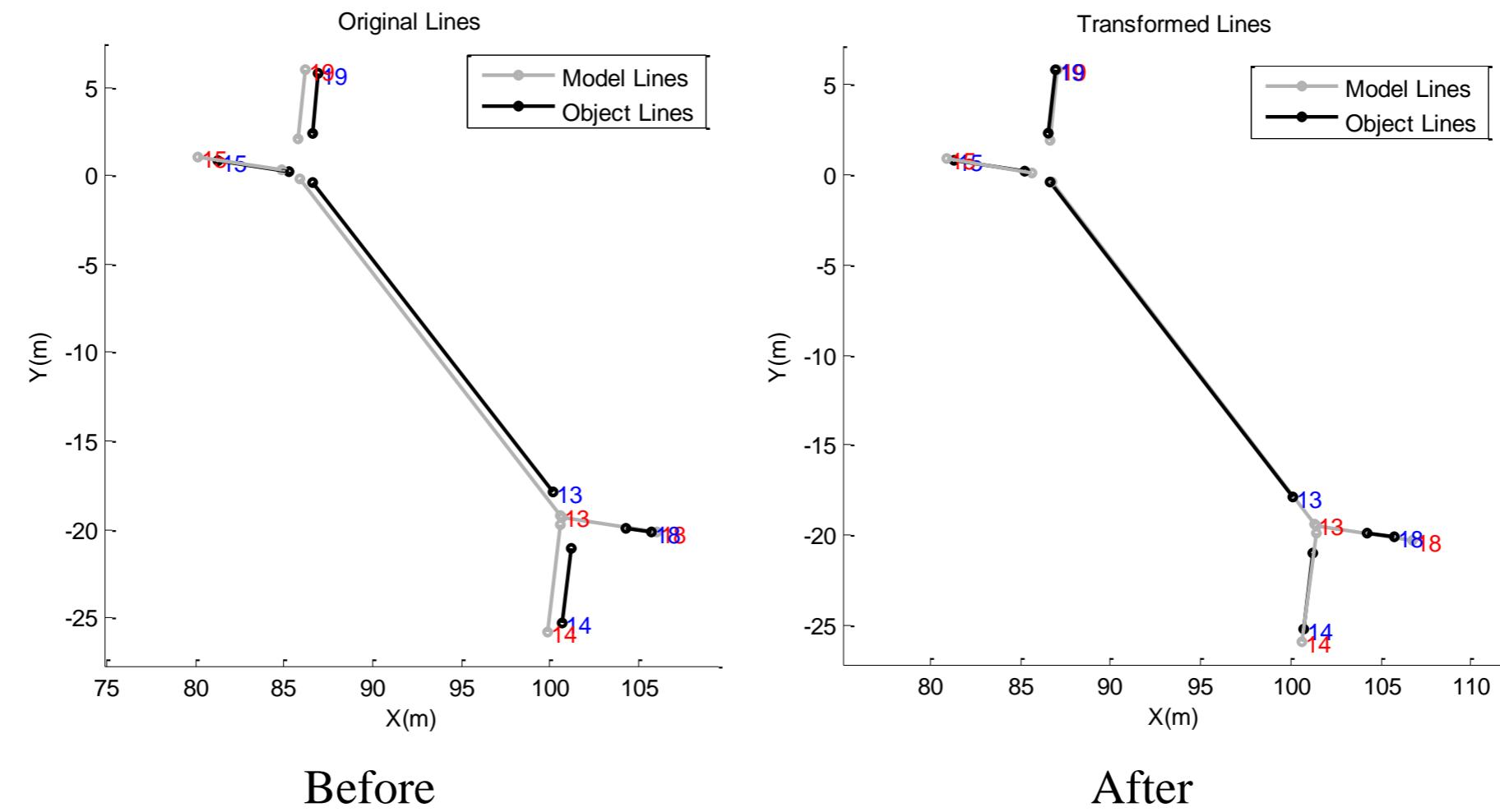
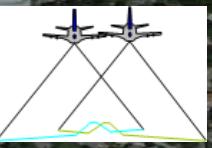
* Assuming the LiDAR data has no biases

Biases are detected

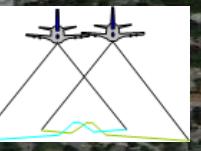
IQC: LiDAR Quality Control (Linear Features)



IQC: LiDAR Quality Control (Linear Features)

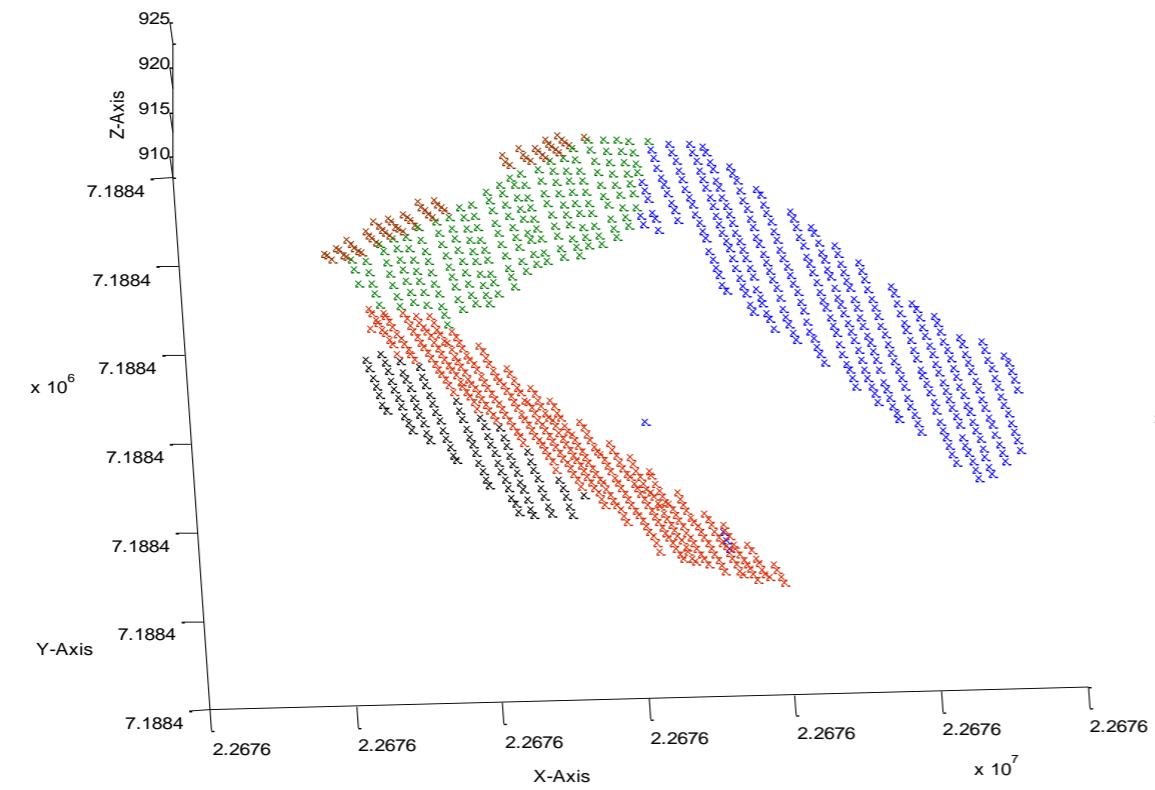
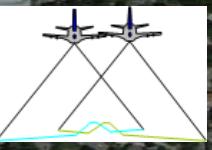


IQC: LiDAR Quality Control (Planar Features)

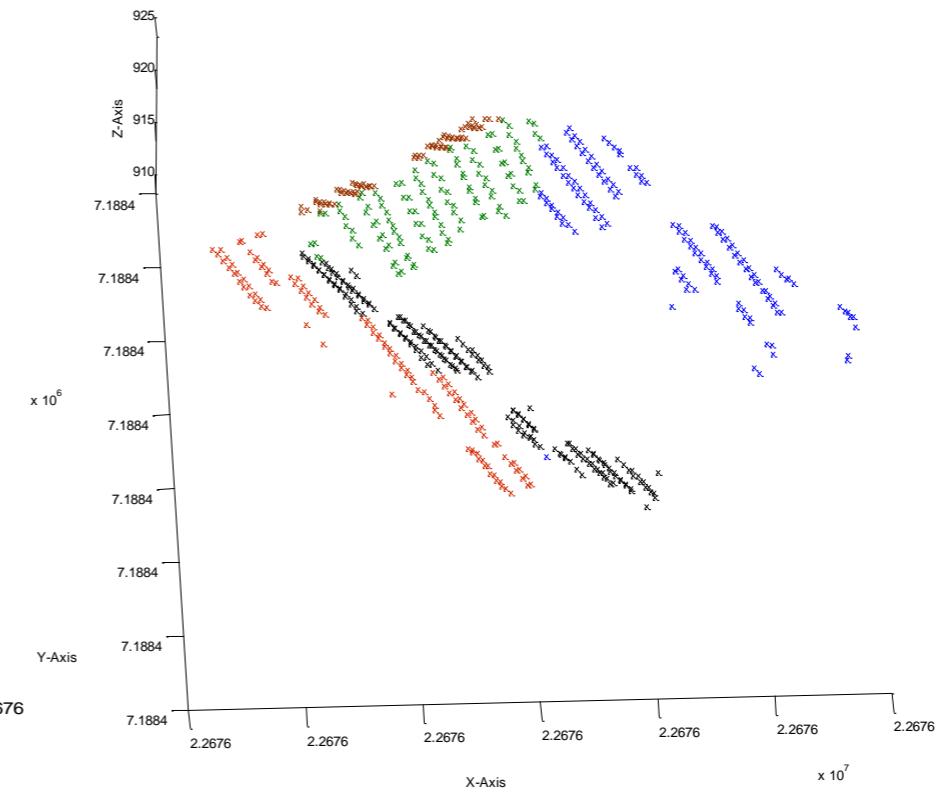


- Conceptual Basis: Check the quality of coincidence of conjugate planar patches

IQC: LiDAR Quality Control (Planar Features)

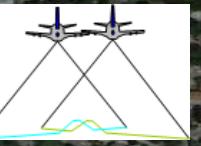


Strip # 3

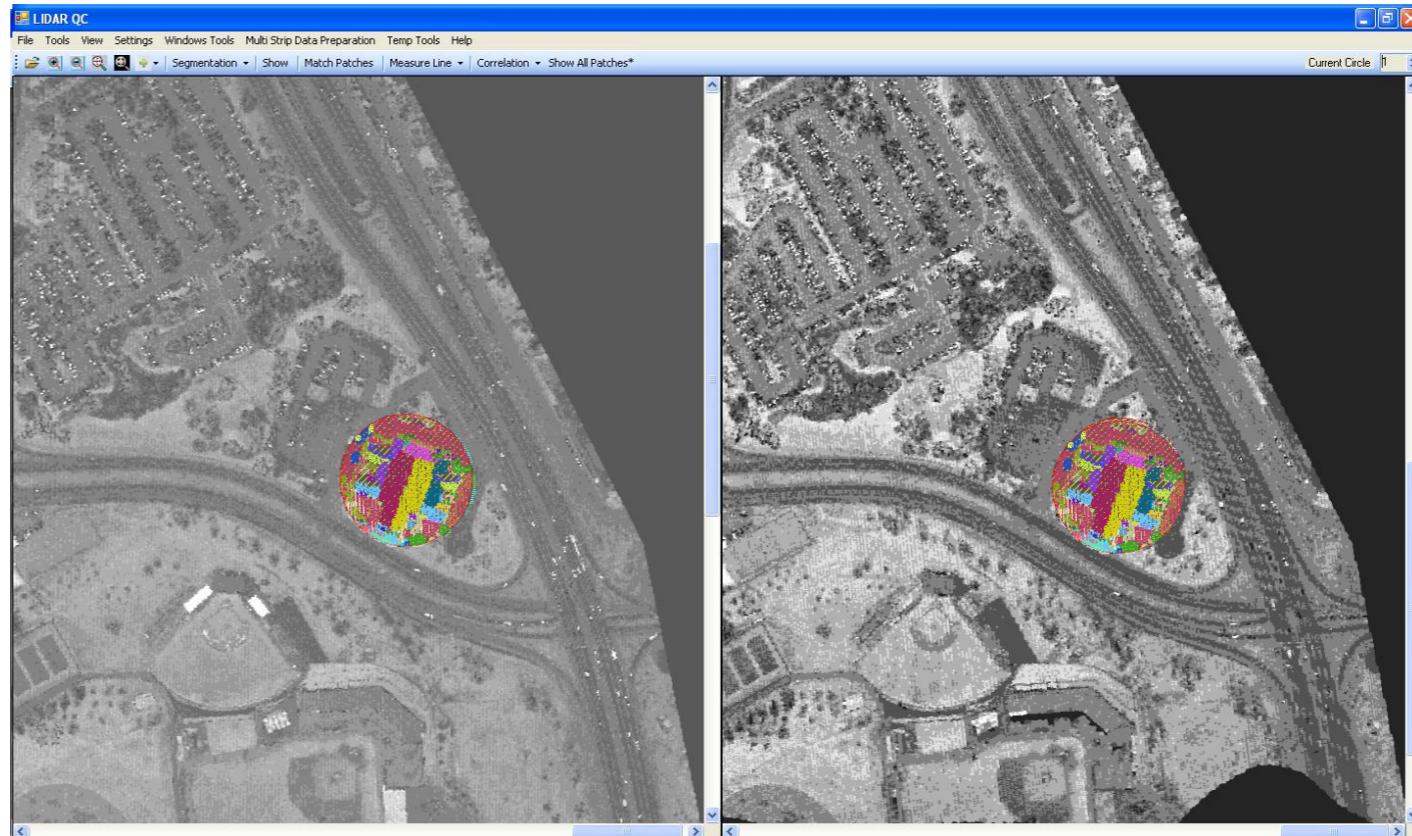
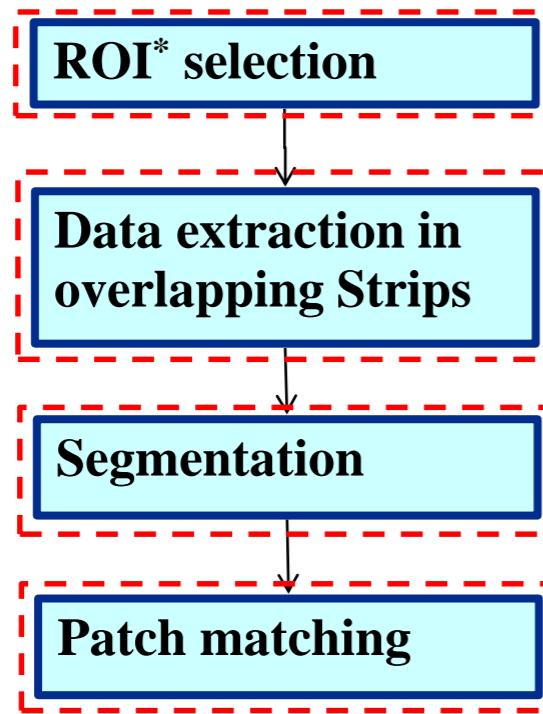


Strip # 4

IQC: LiDAR Quality Control (Planar Features)

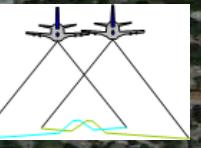


- Overlapping strips: Conjugate patch pairs



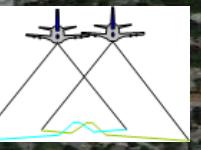
* Region of Interest

IQC: LiDAR Quality Control (Planar Features)

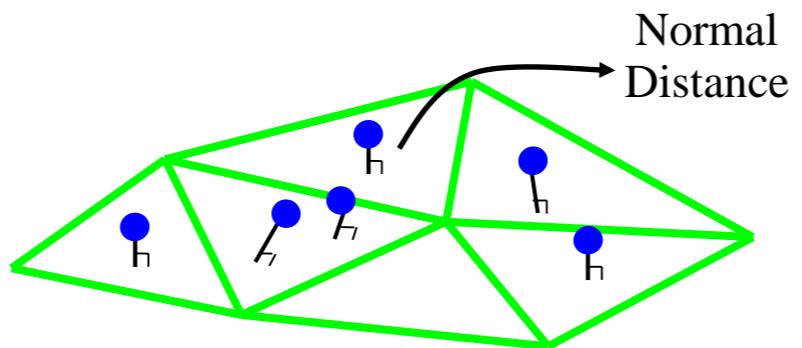


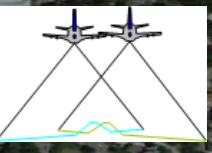
Transformation parameter	Planar-Based Approach
Scale Factor	0.9985
X_T (m)	0.75
Y_T (m)	-0.11
Z_T (m)	0.13
Ω (°)	-0.0305
Φ (°)	0.0391
K (°)	0.1950

IQC: LiDAR Quality Control (Points)

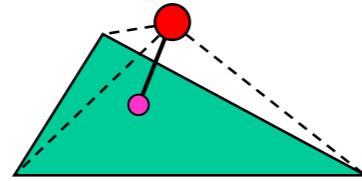


- The first surface is represented by distinct points.
- The second surface is represented by triangular patches (TIN structure).
- The similarity transformation parameters, which minimize the normal distance between points and corresponding patches, are estimated through a least squares adjustment procedure.
- Significant deviation between the estimated parameters and the optimal values ($X_T = 0.0$, $Y_T = 0.0$, $Z_T = 0.0$, $S = 1.0$, $\omega = 0.0^\circ$, $\varphi = 0.0^\circ$, $\kappa = 0.0^\circ$) indicates the presence of biases in the LiDAR system.





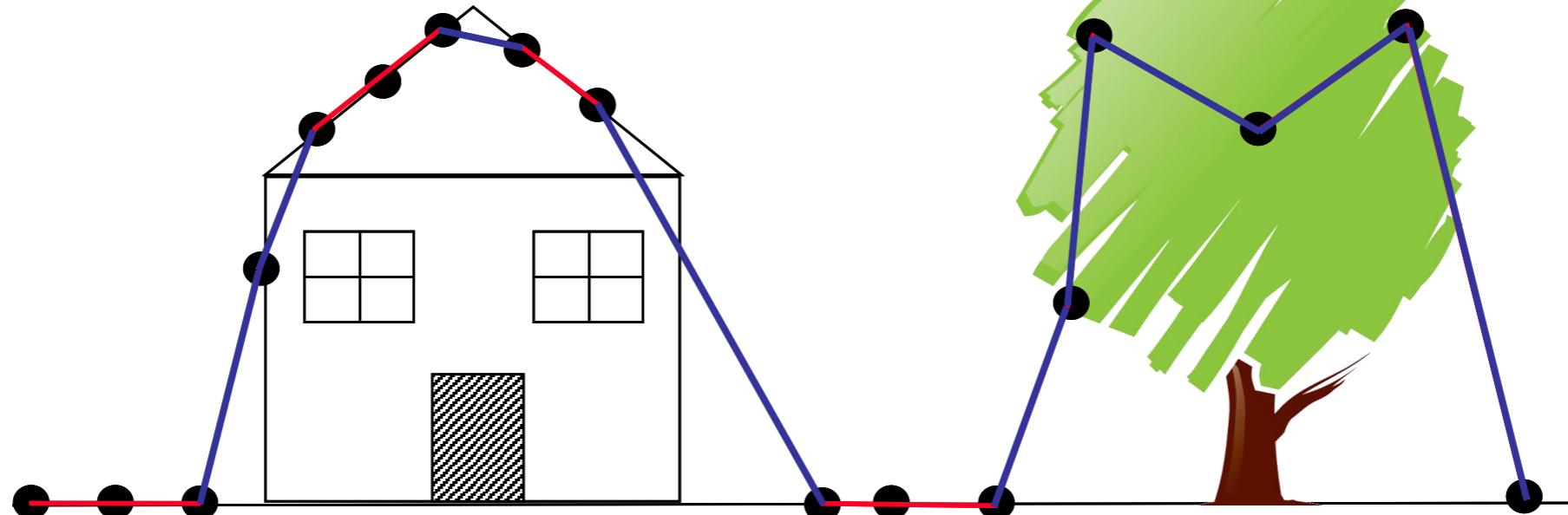
Point/Patch Pairs: Closest Patch Procedure



Conditions:

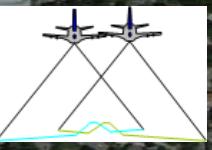
- Closest patch (within a threshold)
- Point located within the patch

Non-matches

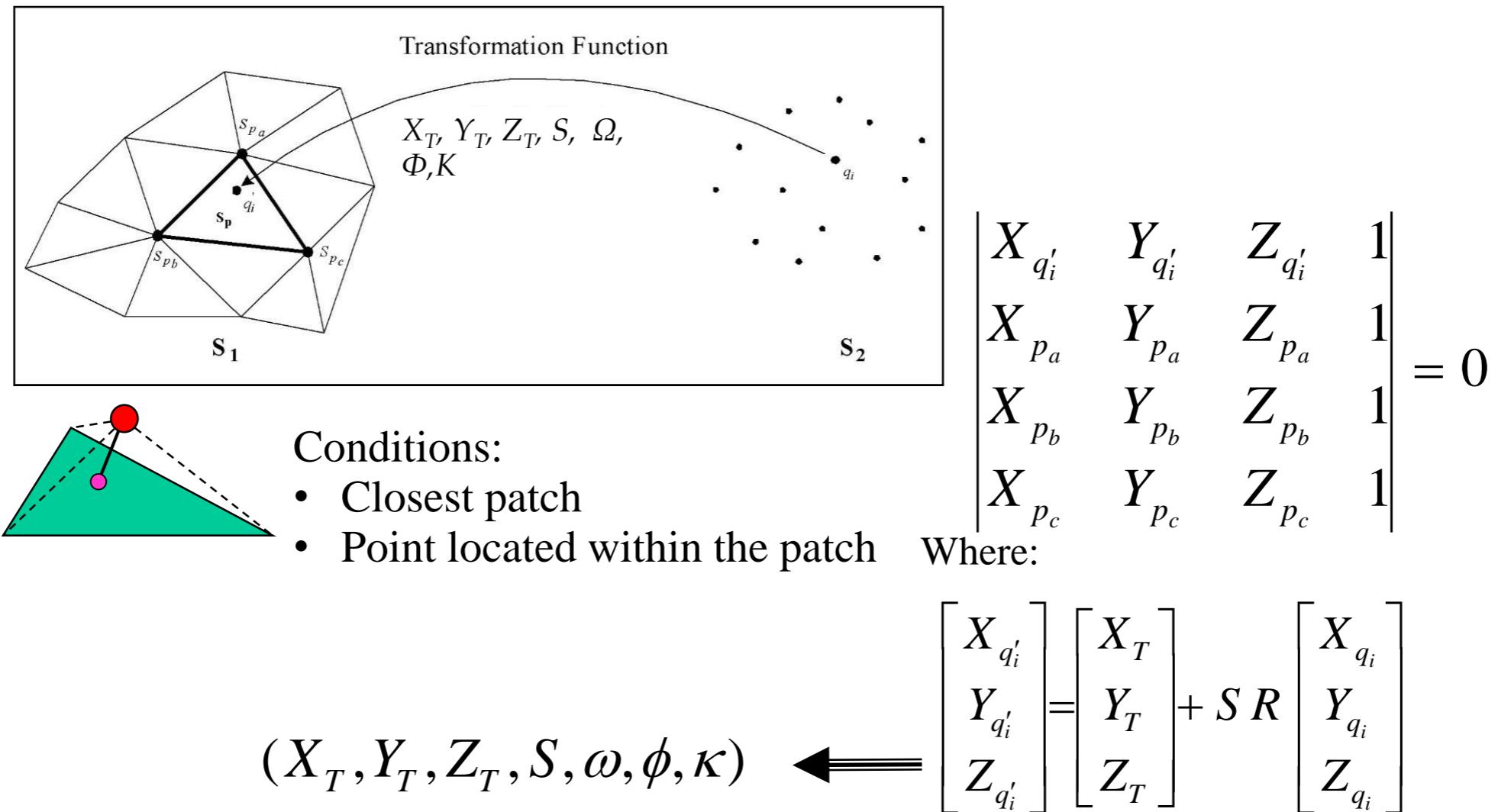


We will have conjugate point-patch pairs only whenever the TIN patches represent the physical surface.

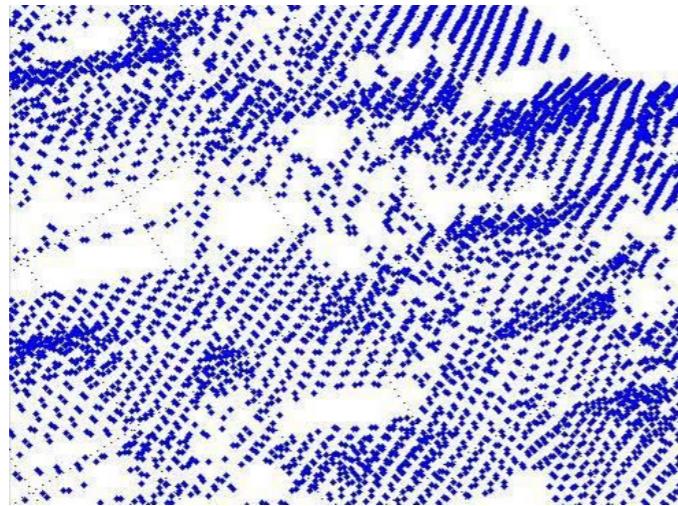
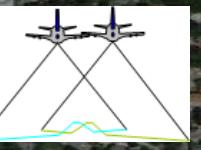
IQC: LiDAR Quality Control (Points)



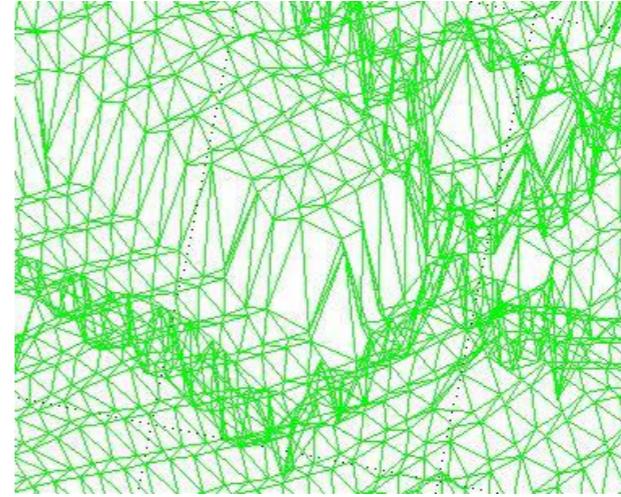
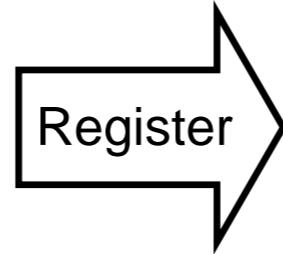
Point/Patch Pairs: Closest Patch Procedure



IQC: LiDAR Quality Control (Points)



Surface 1: 44,156 points

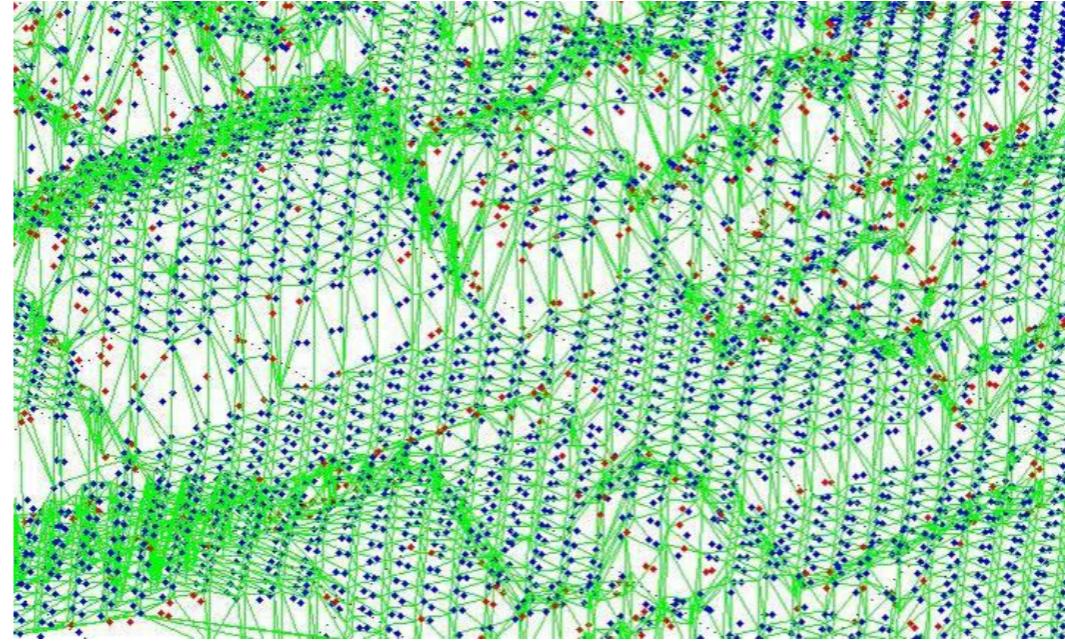
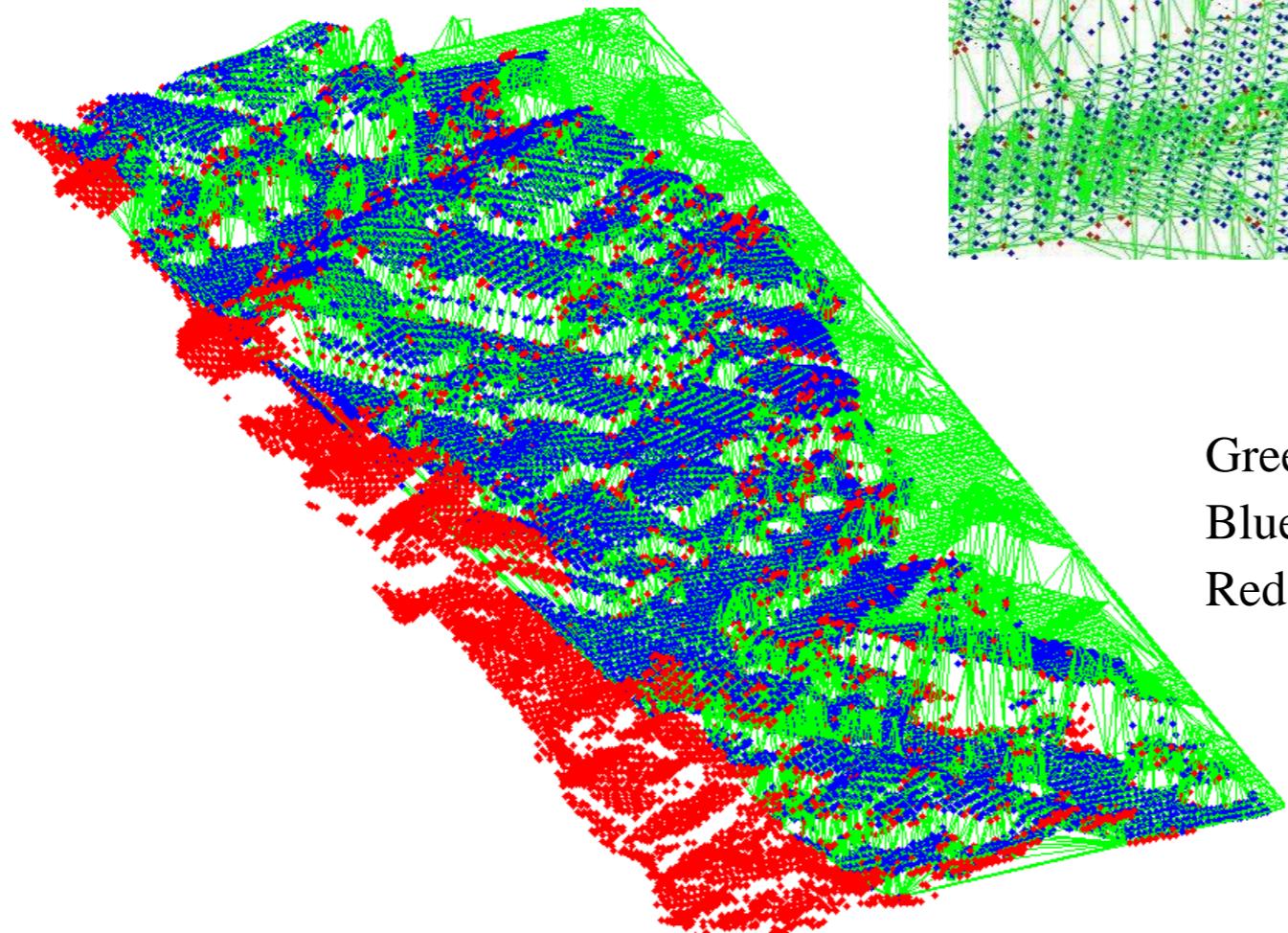
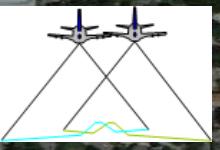


Surface 2: 45,520 patches

	X _T (m)	Y _T (m)	Z _T (m)	S	ω (°)	ϕ (°)	κ (°)
Optimal Para.*	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Estimated	-0.660	-0.367	0.007	1.001	-0.017	0.002	0.003
Estimated Variance Component	0.122						
Average Normal Distance	0.142 m						

* Assuming the LiDAR data has no biases

IQC: LiDAR Quality Control (Points)

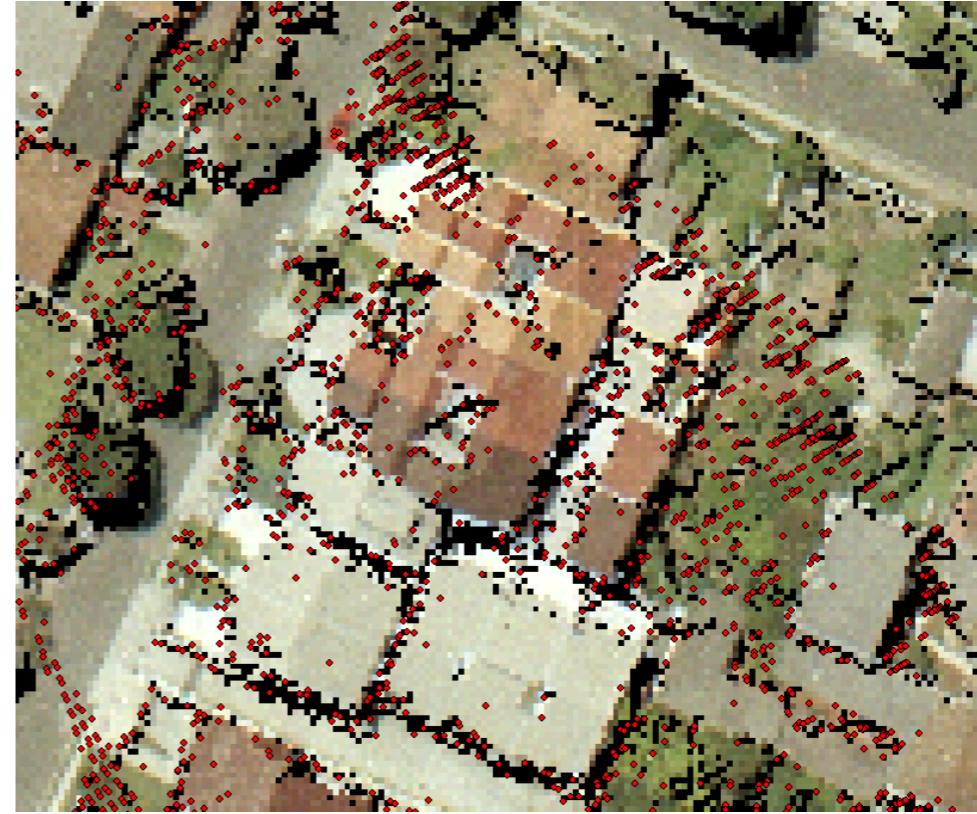
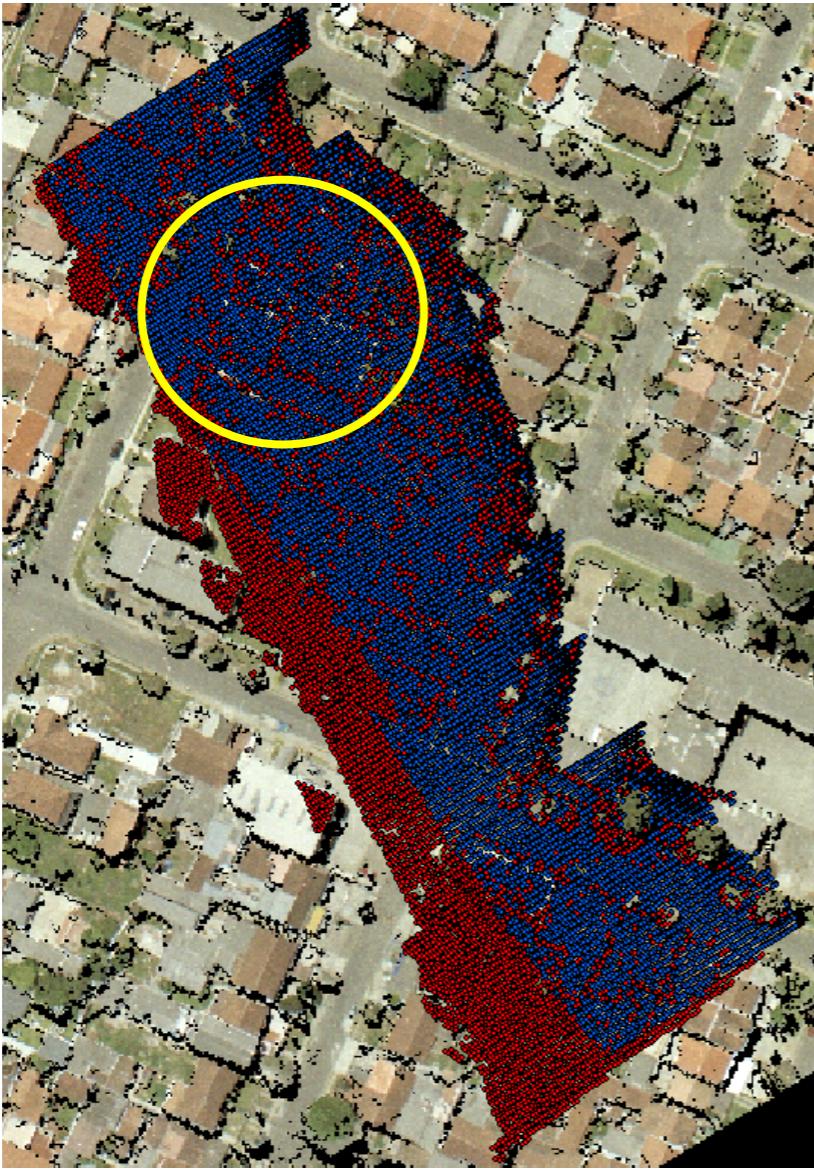
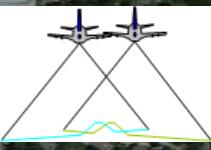


Green: Reference Surface

Blue: Matches

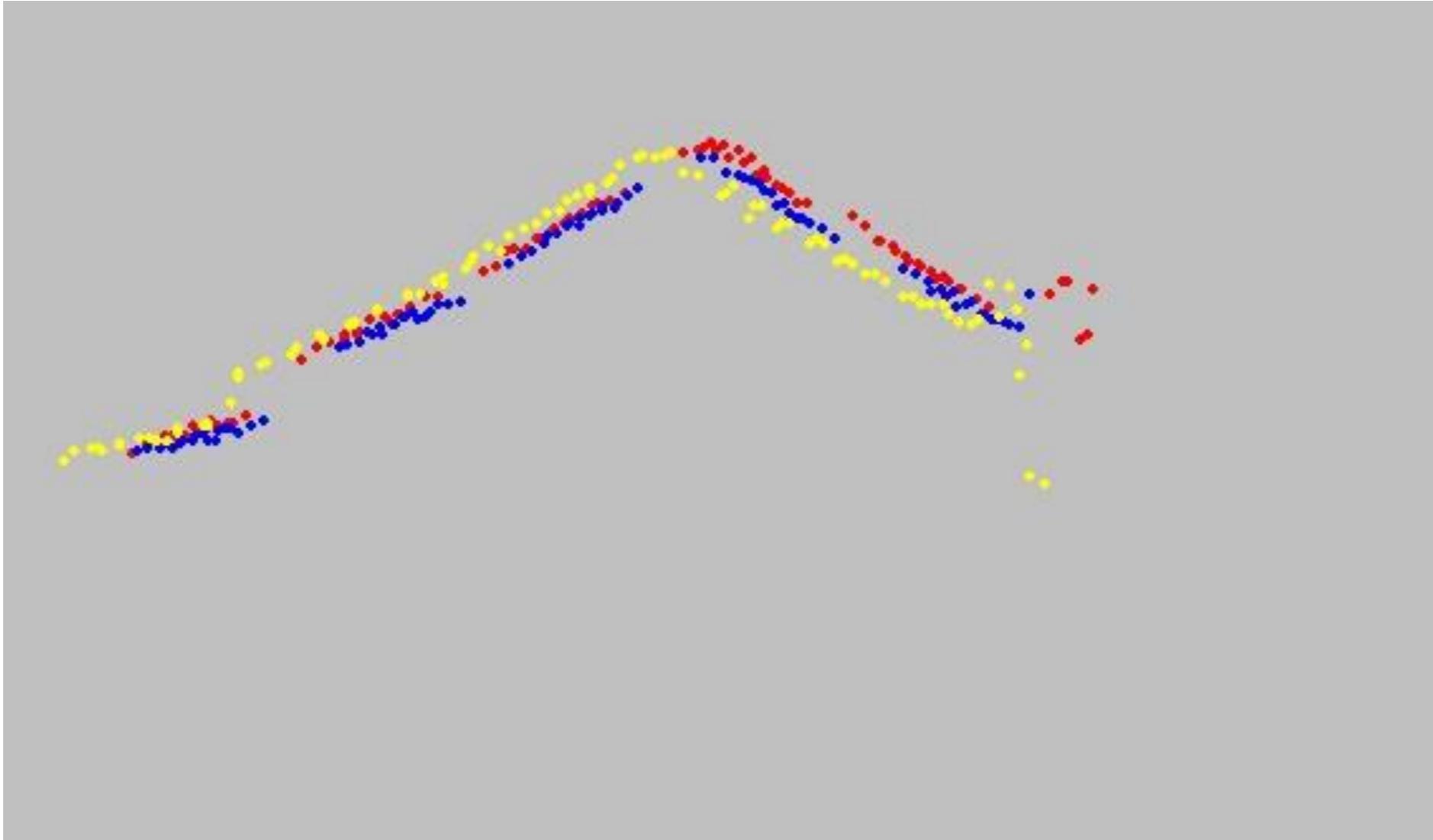
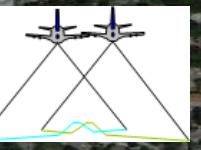
Red: Non-matches

IQC: LiDAR Quality Control (Points)



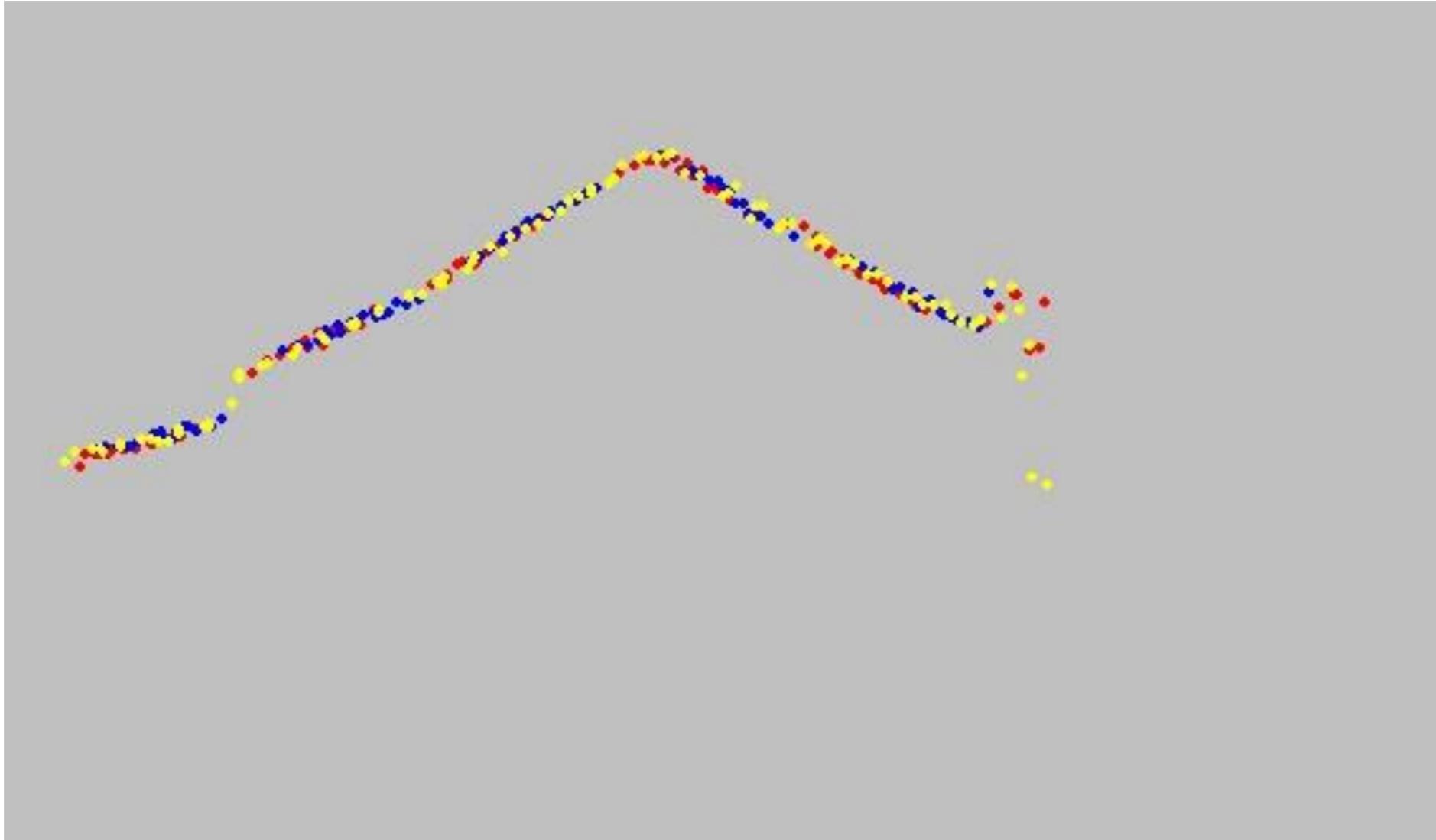
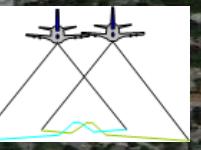
Non-matches are typically along edges of buildings and around areas with vegetations

IQC: LiDAR Quality Control (Systematic Effects)



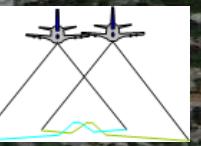
Check for the presence of biases

IQC: LiDAR Quality Control (Noise Effects)

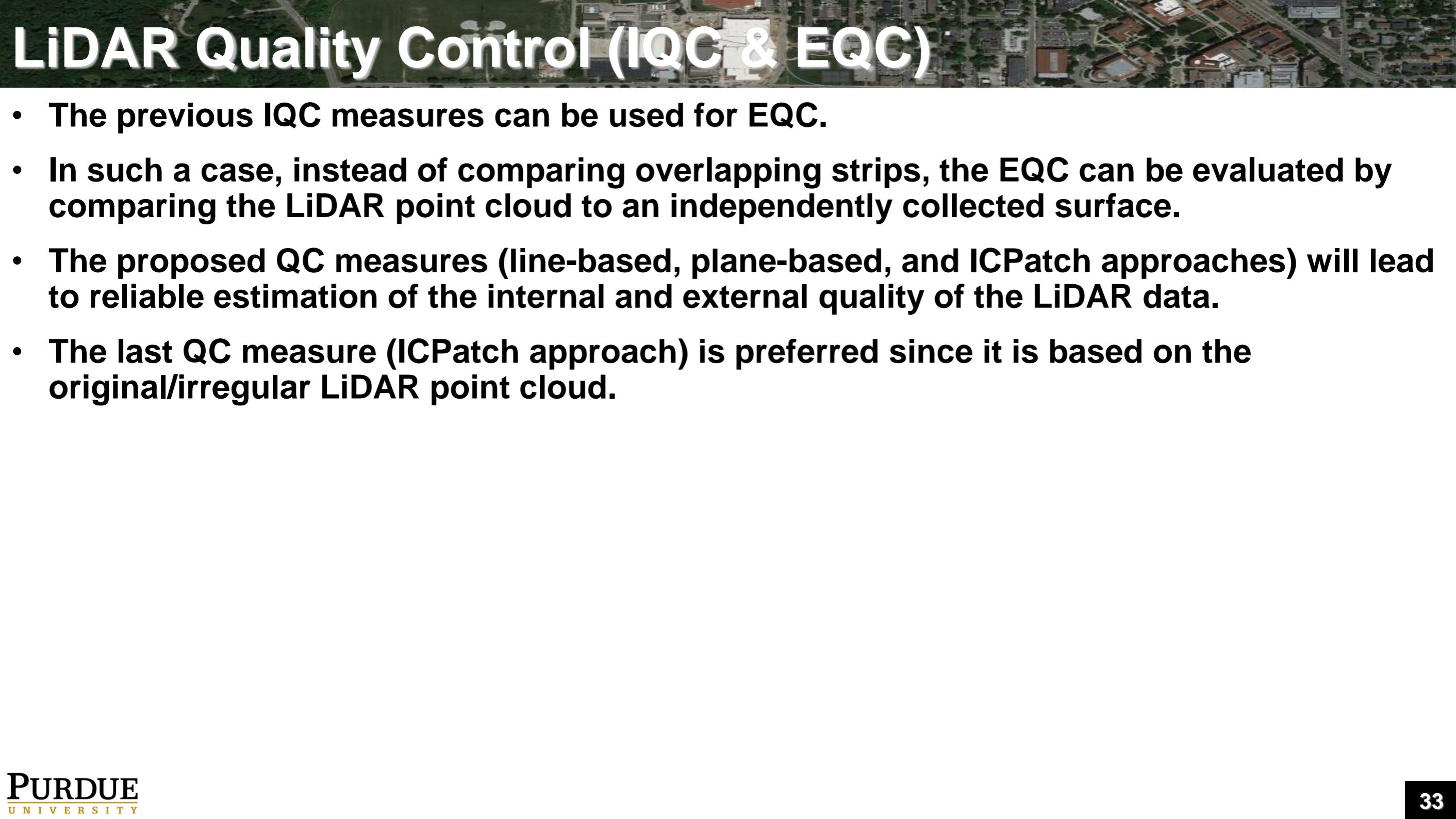


Check the noise level in the point cloud after bias removal

IQC: LiDAR Quality Control (Noise Effects)



- **Checking the noise level in the point cloud: The quality of fit between conjugate entities after removing existing biases**
 - Average normal distance between conjugate planar patches
 - Average normal distance between conjugate linear features
 - Average normal distance between conjugate point-patch pairs in the ICPatch



LiDAR Quality Control (IQC & EQC)

- The previous IQC measures can be used for EQC.
- In such a case, instead of comparing overlapping strips, the EQC can be evaluated by comparing the LiDAR point cloud to an independently collected surface.
- The proposed QC measures (line-based, plane-based, and ICPatch approaches) will lead to reliable estimation of the internal and external quality of the LiDAR data.
- The last QC measure (ICPatch approach) is preferred since it is based on the original/irregular LiDAR point cloud.

LiDAR QA/QC: Closed-Loop Approach

- **LiDAR Data in Overlapping Parallel Strips**

- ✓ Point cloud coordinates
- ✓ Raw measurements are not necessarily available

