A Comparison of Imagery Collection Methods for Rendering 3D Models of River Landscapes Using Structure-from-Motion and Small Unmanned Aerial Systems

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1. Introduction

Goal: Develop a workflow that uses structure-from-motion (SfM) photogrammetry with unmanned aerial system (UAS) imagery to study physical changes in river landscapes.

- SfM photogrammetry is a computer vision technique that uses overlapping photos taken from different perspectives to create 3D models.
- Quantifying topographic changes with this technique will help evaluate the success of restoration efforts.

When using SfM, there are many different aspects of imagery collection and processing to consider. These options can result in varying 3D models of the same scene.

Video stills and photos have different metadata that SfM software uses during processing.

Effects of including different image metadata, image quantities, and image overlap to model the same landscape are examined by comparing the resulting models against one another.

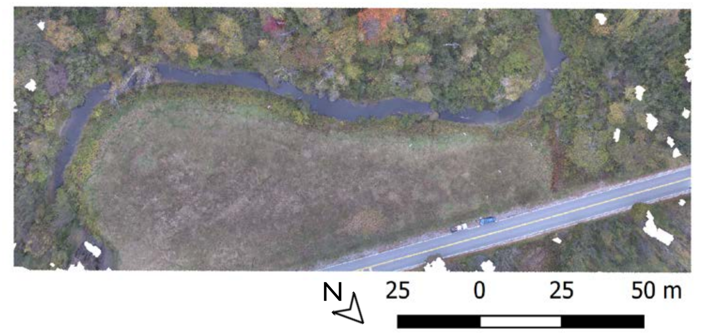
2. Methods

- Video footage and one set of photos were collected along the same two automated flight paths. One path collected nadir footage, the other collected footage at an angle.

Table 1: Flight-Related Parameters Consistent Across Photos and Video

Side Overlap Between Nadir Images:	65%
Flight Altitude:	120 feet AGL
Ground Sample Distance:	~1.6 cm
Flight Speed:	5 km/hr

Figure 1: Aerial View of Falmouth, ME Site



- Agisoft PhotoScan Professional was used to create digital elevation models (DEMs) and orthomosaics from RGB images of a stream in Falmouth, ME (Fig 1). Five different SfM run scenarios used the photo and two video still image sets (Fig 2).

Figure 2: Differences Across Image Sets

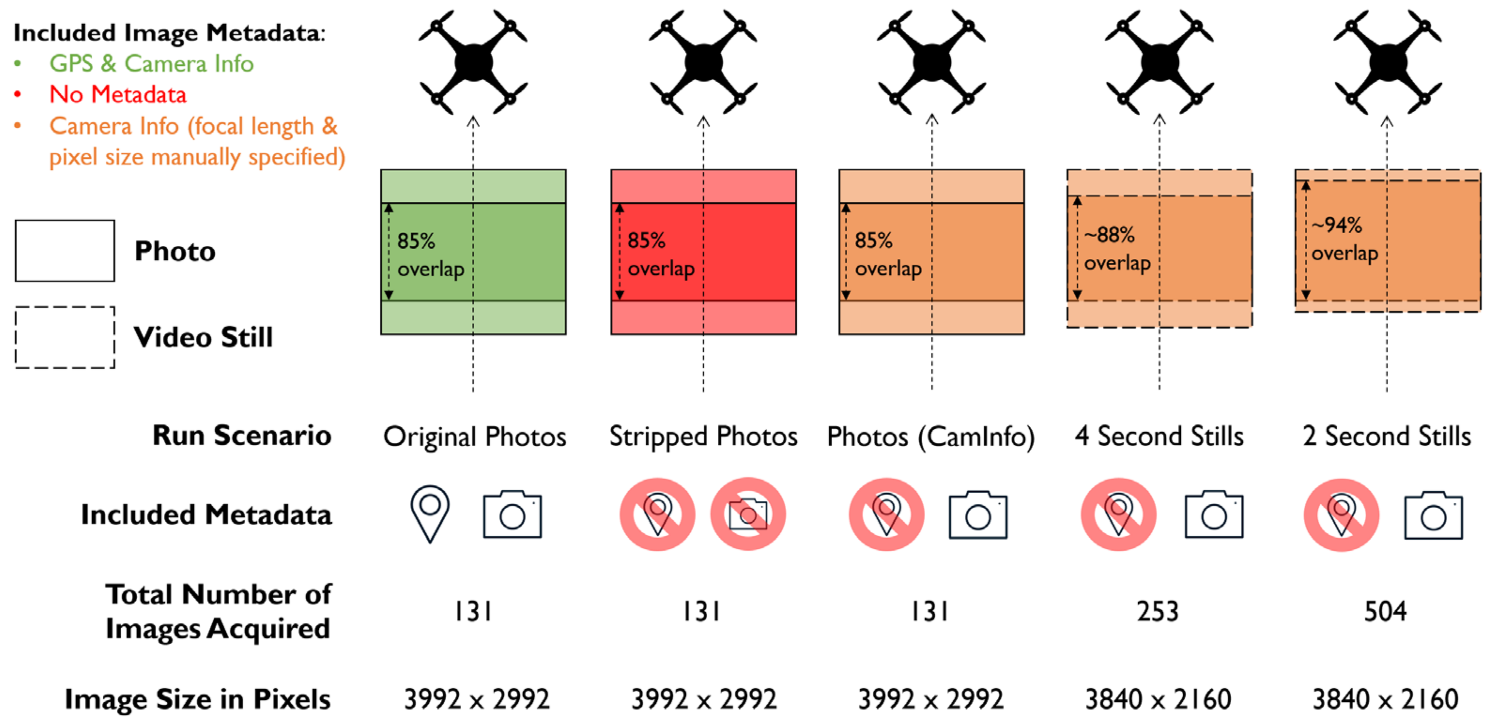


Table 2: Agisoft PhotoScan Parameters for All Run Scenarios

Workflow Step	Parameters Used
Align Photos	• Accuracy: Highest • Generic Preselection Checked (Reference Preselection checked as well for Original Photos) • Key Point Limit: 40,000 • Tie Point Limit: 4,000 • Adaptive camera model fitting checked
Georeferencing	• Same 5 GCPs and associated surveyed coordinates used • Same images used to mark GCPs (and similar video stills)
Optimize Cameras	• Did not edit sparse cloud before optimization • Left defaults checked
Build Dense Point Cloud	• Quality: Medium • Depth Filtering: Aggressive • Calculate Point Colors Checked
Build DEM	• Type: Geographic (WGS 84) • Source Data: Dense Point Cloud • Interpolation: Enabled
Color Calibration	• Source Data: Sparse Cloud • Calibrate white balance checked
Build Orthomosaic	• Surface: DEM • Blending Mode: Mosaic • Enable Hole Filling checked

3. Results

Figure 3: Comparing SfM-Estimated Camera Locations & Image Overlap

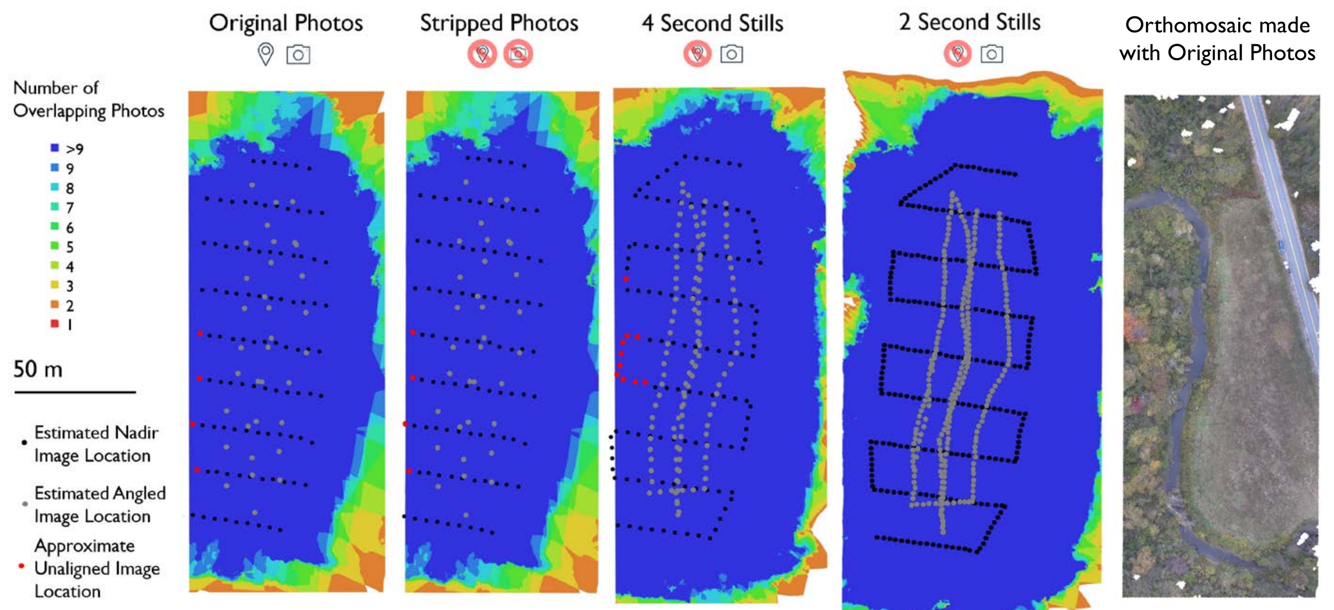
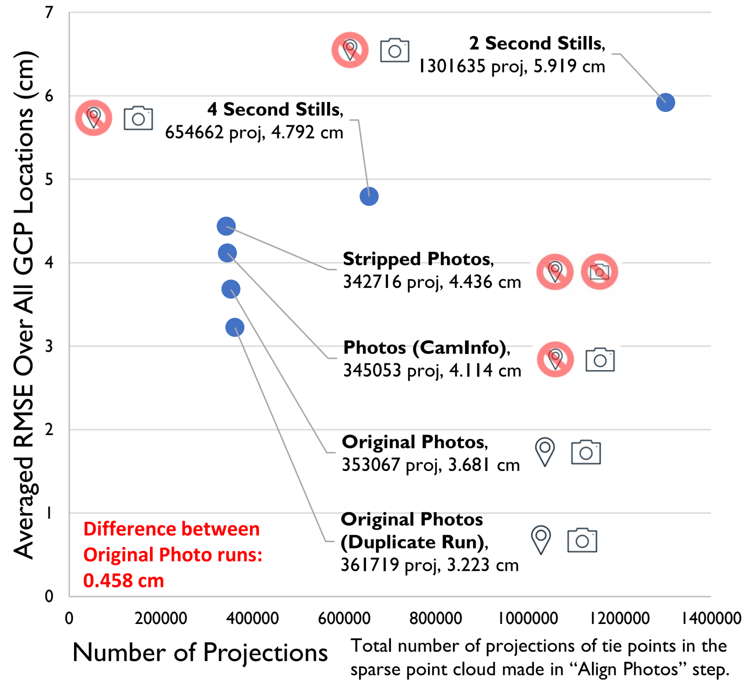
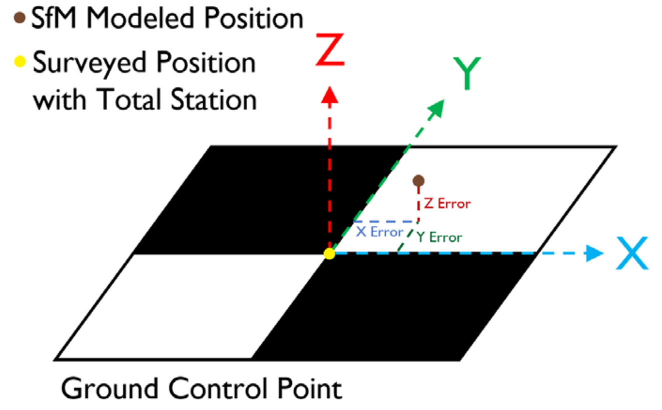


Figure 4: Projections & Total GCP RMSE



Supplement to Figure 4: Total GCP RMSE Illustrated



The total error is the root mean square error for X, Y, and Z coordinates for all images. It describes the deviation between the input positions and estimated positions of the GCP markers in the model. In this case, the input is the surveyed GCP coordinates.

From the Agisoft PhotoScan Professional Manual:

$$\text{Total error} = \text{sqrt}(\text{Sum}_{i=1}{}^{n} [(X_{i, est} - X_{i, in})^2 + (Y_{i, est} - Y_{i, in})^2 + (Z_{i, est} - Z_{i, in})^2] / n)$$

Figure 5: Absolute DEMs of Difference Between Run Scenarios

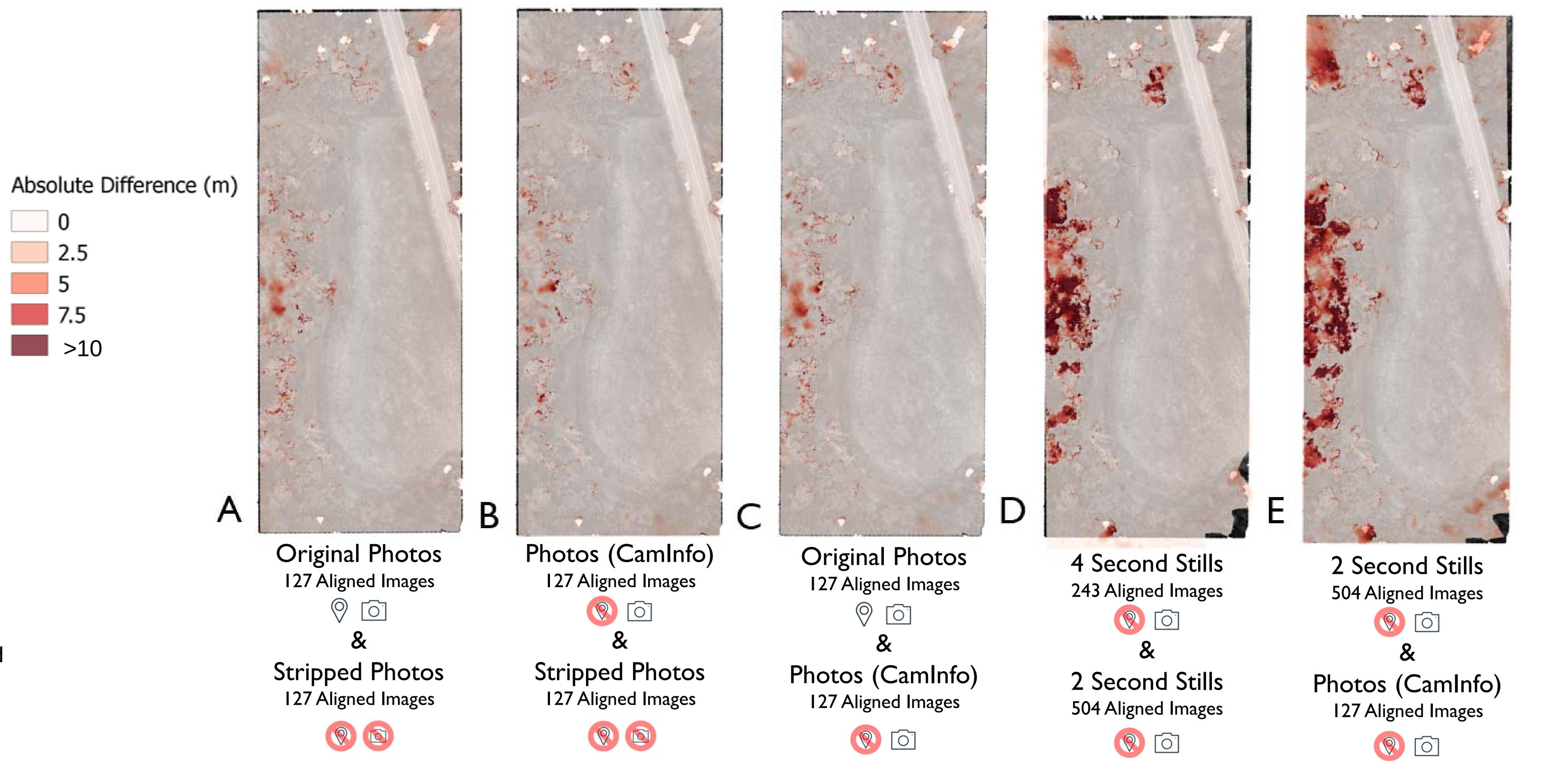


Table 3: DEM of Difference (DoD) Statistics (Absolute Values)

DoD:	A	B	C	D	E	Control
Mean Difference (m)	0.448	0.357	0.339	0.847	0.996	0.337
Median Difference (m)	0.293	0.217	0.125	0.246	0.193	0.087
Minimum Difference (m)	3.815e-6	1.907e-6	1.907e-6	1.144e-5	3.815e-6	3.815e-6
Maximum Difference (m)	10.326	13.655	13.807	23.748	18.362	10.811
Standard Deviation (m)	0.739	0.687	0.820	2.175	2.220	0.929

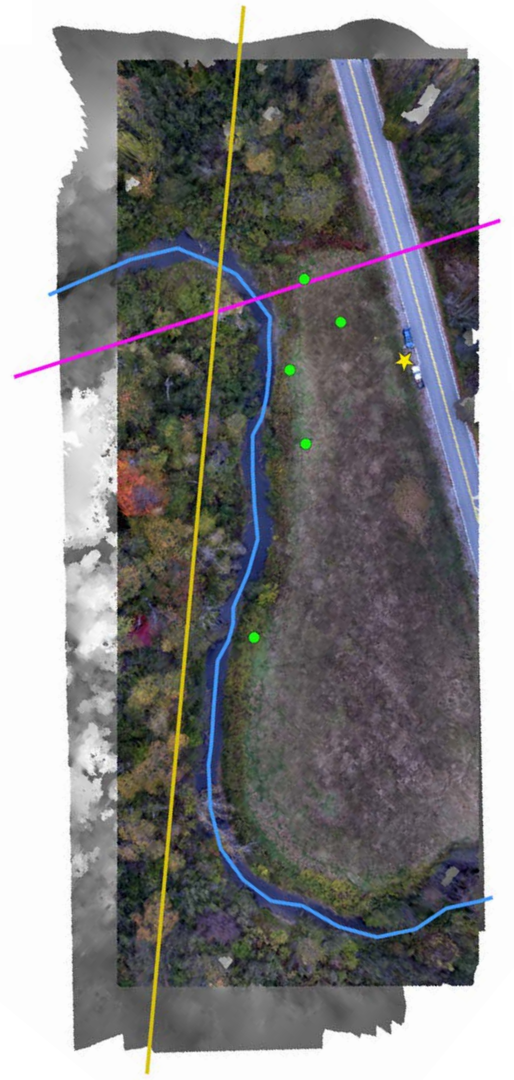
Control (Not Pictured): Original Photos & Original Photos (Duplicate Run)

Table 4: Averages Across DoDs for Terrain Types

Terrain Type*	Average Mean Difference (m)	Average Max Difference (m)	Control Mean Difference (m)
Trees	1.08	15.83	0.60
Shrubs	0.06	3.31	0.03
Grassy Field	0.06	0.16	0.05
Instream**	0.33	12.14	0.19
Water's Surface	0.22	3.96	0.12

*Representative patches manually digitized based on orthomosaics
**Includes overhanging vegetation and anomaly in Figure 6 – Stream Profile

Figure 6: Cross Sections Relative to UAV Launch Point



Pictured Left:
Original Photos Orthomosaic over 2 Second Stills DEM to illustrate differences in geographic coverage.

GCP Locations
UAV Launch Point
Cross Section 1 (113 meters long)
Cross Section 2 (238 meters long)
Stream Profile (247 meters long)

Pictured Right:
1: Cross Section 1
2: Cross Section 2
Stream: Stream Profile

Approximate Locations of Surface Types Labeled

Original Photos
Original Photos (Dup)
Stripped Photos
Photos (CamInfo)
4 Second Stills
2 Second Stills

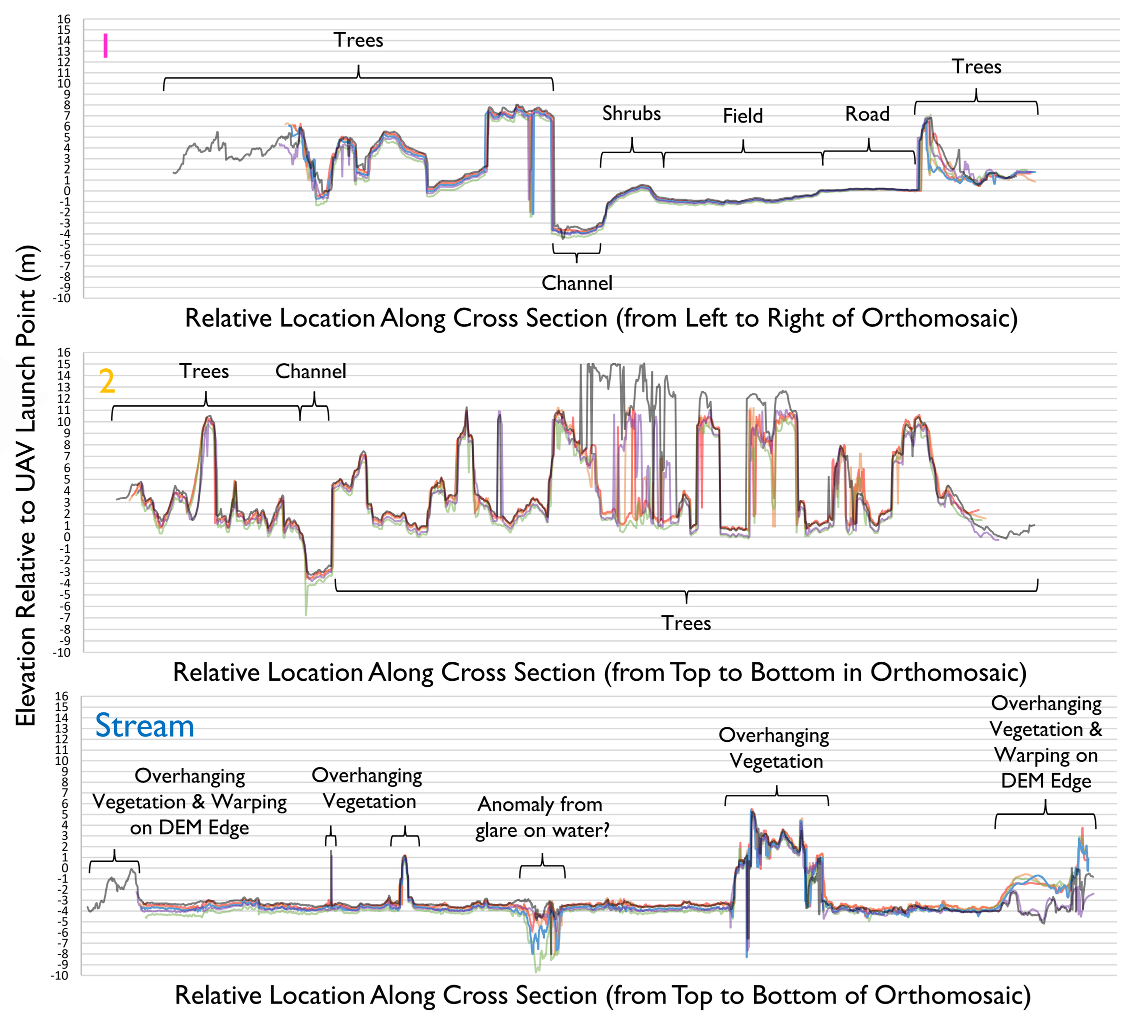


Table 5: UAS Product Summary Based on PhotoScan Processing Reports

Run Scenario	General	DEM		Orthomosaic
	Processing Time (hr:min)	Resolution (cm/pix)	Point Density (points/m²)	Resolution (cm/pix)
Original Photos	1:13	6	278	1.5
Stripped Photos	1:01	5.99	278	1.5
Photos (CamInfo)	1:05	5.99	278	1.5
2 Second Stills	13:25	6.54	234	1.63
4 Second Stills	2:46	6.75	219	1.69

Figure 7: Example Unaligned Image

4. Discussion & Conclusions

It is important to use consistent imagery collection methods for monitoring sites over time.

- Ensures that the models are comparable and any changes observed are not due to varying image collection methods.

Based on these results, the best image collection approach for our planned work is to take photos that include both GPS & camera metadata.

- The reduced total RMSE offered by this approach is significant for the measurements involving terrain types we care about, such as the channels and lightly vegetated riparian zones of newly restored rivers via dam removal.

Modeled GCP accuracy was not improved with additional images, camera perspectives, and forward overlap (Fig 4).

- GPS and camera metadata improved model GCP accuracy (see photo-based runs).
- It is uncertain why GCP total RMSE increased as the number of projections of tie points increased (e.g. 2 sec vs. 4 sec stills). This is opposite of the trend that we were expecting.

The greatest differences in DEMs occurred in heavily vegetated areas (Figs 5 & 6).

- This may be significant for those interested in creating forest canopy height models.
- The more complete image alignment of the 2 sec still run (Fig 3) may have captured branches that were missed by other runs. This comes at the cost of higher total GCP RMSE & significantly longer processing time.

Additional metadata did not improve the alignment success of tree canopy photos.

- The same 4 nadir images of tree canopy failed to align across the three photo-based runs (Fig 7).

Future work will involve UAS-independent elevation datasets.

- UAS-independent elevation datasets (e.g. a traditional survey or LiDAR) are used to verify model accuracy across the landscape (e.g. Woodget et al. 2015).

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