POSITIONING AND APPLICATIONS

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     4.0           ANNOUNCEMENT                               RINEX VERSION / TYPE
POSITIONING AND APPLICATION SYMPOSIUM        IAG COM. 4      EVENT NAME / AGENCY
WUELS          WROCLAW          POLAND                        LOCATION / CITY / COUNTRY
  2016    09    04             2016    09    07               TIME START / END
51.11283  17.063761  3835751.626  1177249.744  4941605.054    APPROX POSITION B / L / XYZ
1 Emerging Positioning Technologies                           SESSION NO / TOPIC
2 Geospatial Mapping and  Engineering Applications            SESSION NO / TOPIC
3 Atmosphere Remote Sensing                                   SESSION NO / TOPIC
4 Multi-Constellation GNSS                                    SESSION NO / TOPIC
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Efficient geo-referencing and analysis of terrestrial laser scanning data for slope stability assessments

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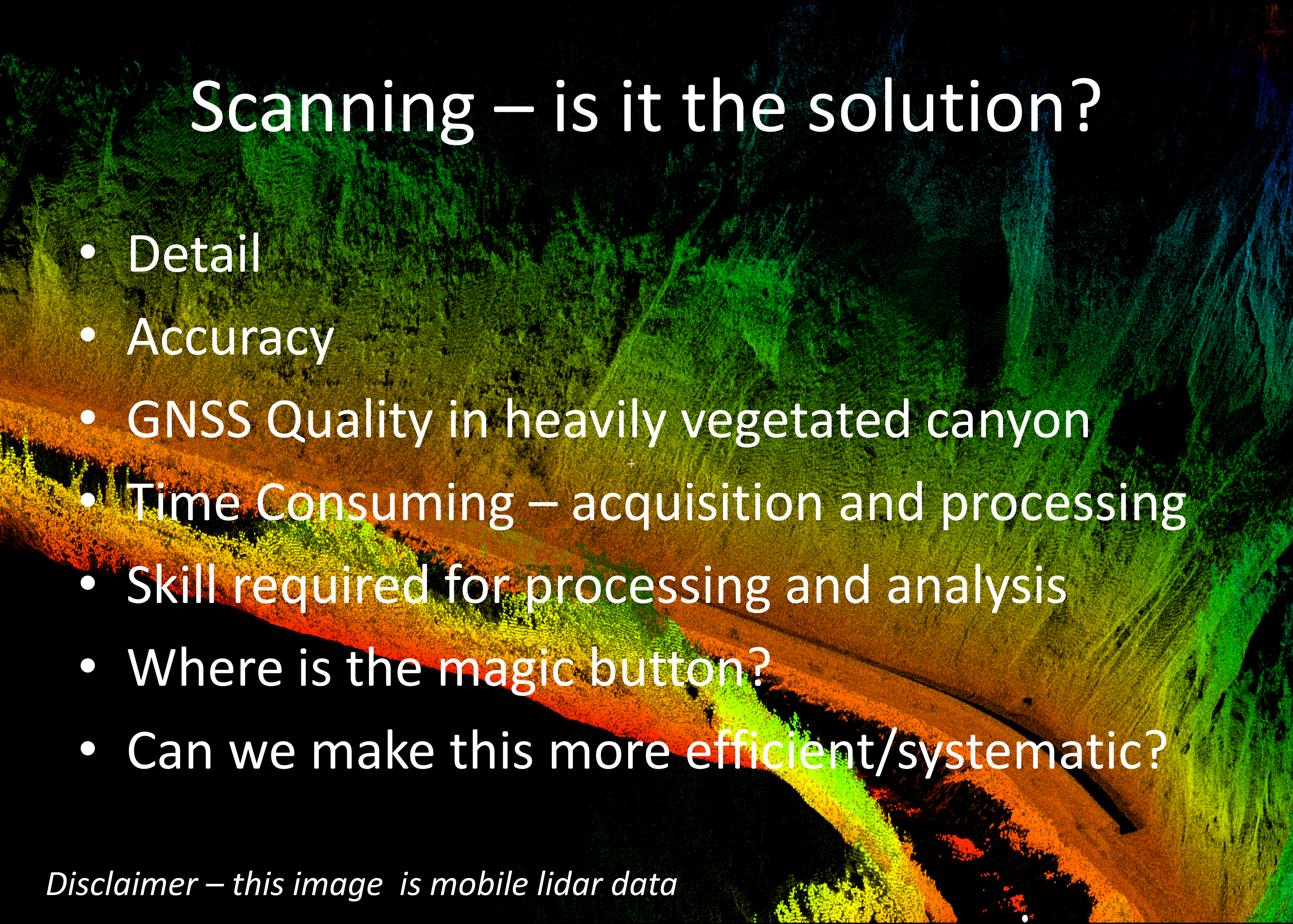
Motivation

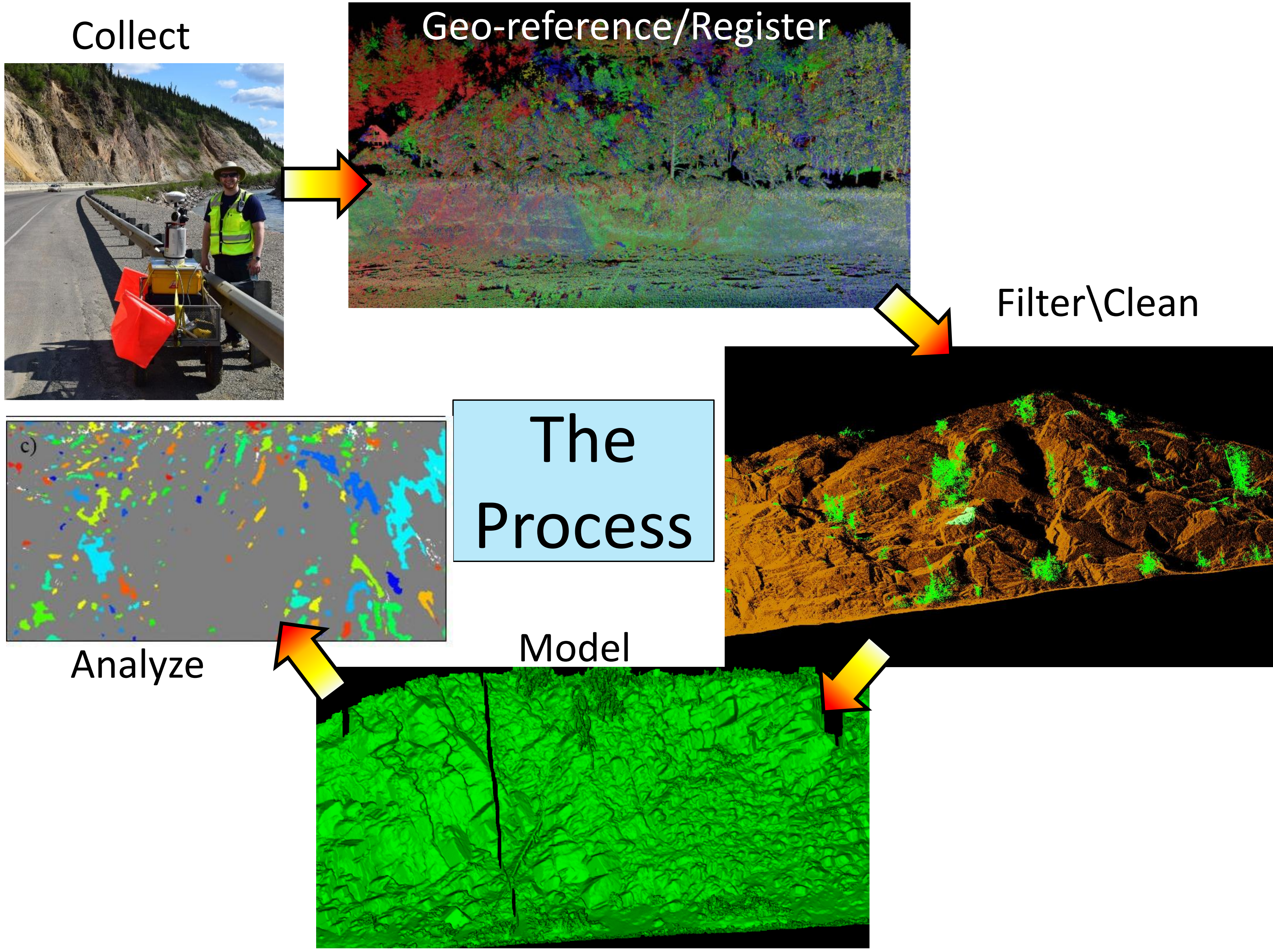
- Long, isolated highways
- Proactive Risk Assessment – Performance-based Asset Management
- Identify priority locales for remediation, detailed monitoring
- Limited personnel
- Less money

Scanning – is it the solution?



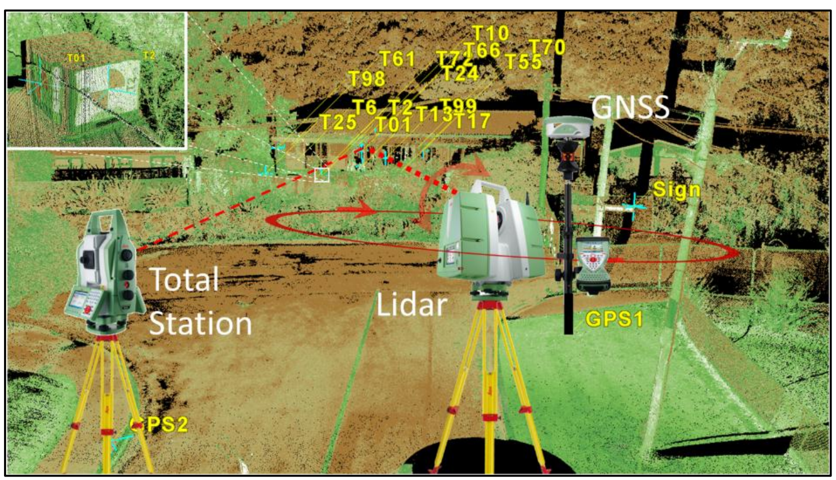
- Detail
- Accuracy
- GNSS Quality in heavily vegetated canyon
- Time Consuming – acquisition and processing
- Skill required for processing and analysis
- Where is the magic button?
- Can we make this more efficient/systematic?

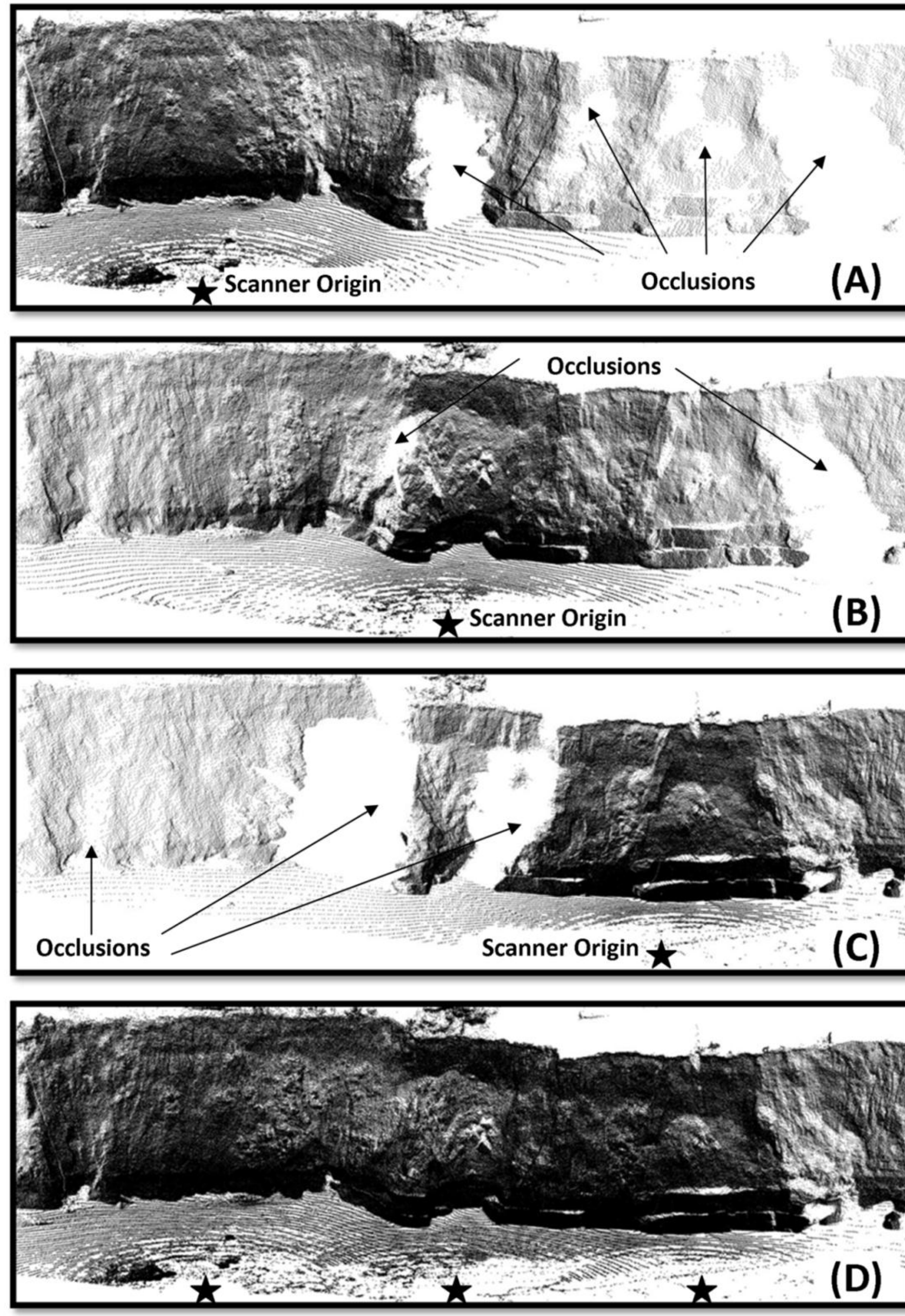
Disclaimer – this image is mobile lidar data


The Process
Collect
Geo-reference/Register
Filter\Clean
Model
Analyze
c)

Point Cloud Registration

- Direct Geo-reference
- Target-based
- Iterative Closest Point
- Feature-based
- Mixed



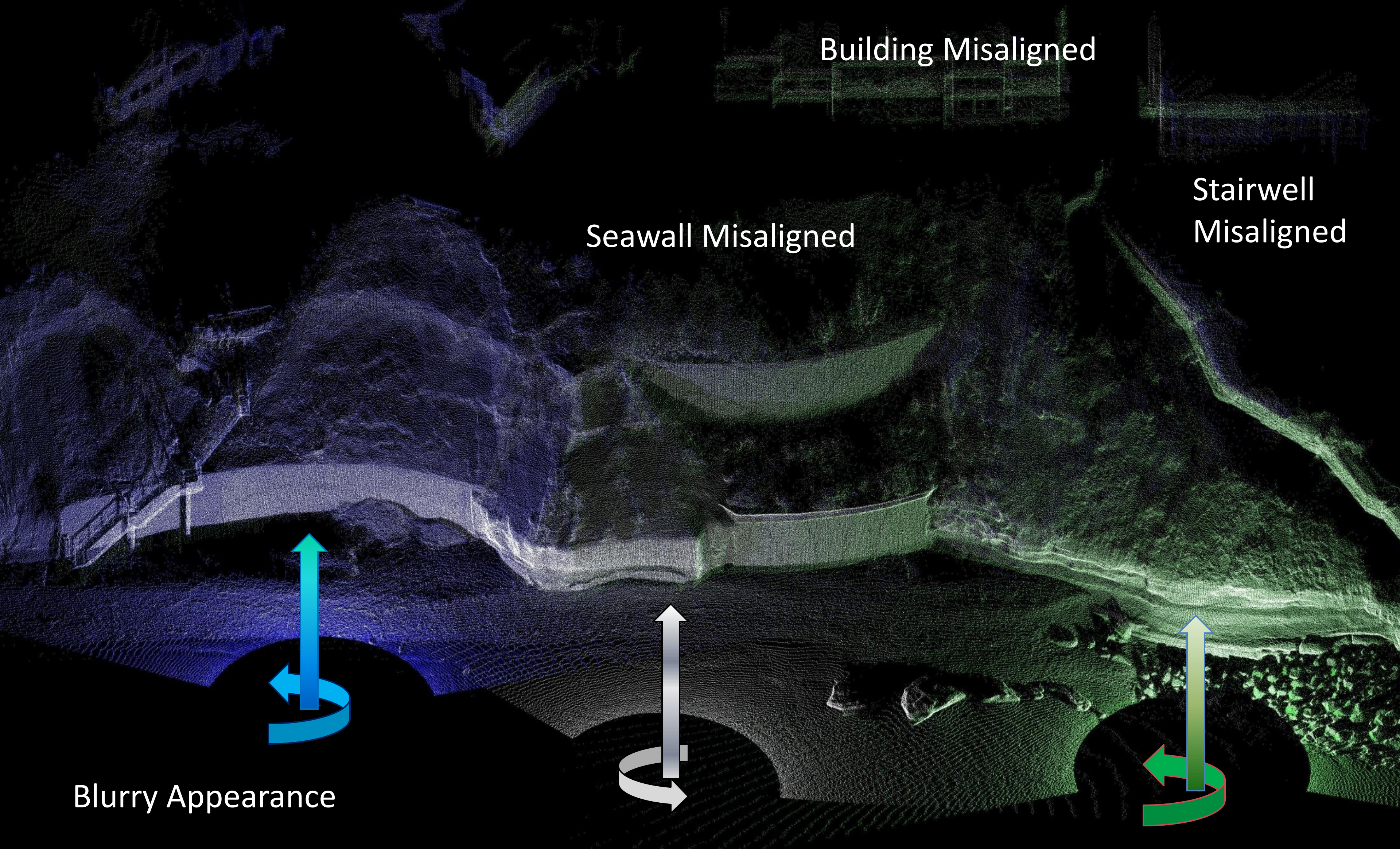


6 DOF

- GNSS coordinate at each scan location (translation X,Y,Z)
- Dual Axis Tilt/Level Compensator (rotation X,Y)
- Digital compass reading or back-sight
(~ rotation Z)
- *Point Reg*- Registration to improve rotation Z and translation Z estimates.

Olsen et al. (2009, 2011)

Registered only using estimated rotation



Least squares solution

Formulation:

$$\begin{Bmatrix} v_{x1} & v_{y1} \\ v_{x2} & v_{y2} \\ & \vdots \\ v_{xn} & v_{yn} \end{Bmatrix} = \begin{Bmatrix} x_{B1} - X_{B0} & y_{B1} - Y_{B0} \\ x_{B2} - X_{B0} & y_{B2} - Y_{B0} \\ & \vdots \\ x_{Bn} - X_{B0} & y_{Bn} - Y_{B0} \end{Bmatrix} \begin{bmatrix} \cos \propto_B & \sin \propto_B \\ -\sin \propto_B & \cos \propto_B \end{bmatrix} + \begin{Bmatrix} X_{B0} & Y_{B0} \\ X_{B0} & Y_{B0} \\ & \vdots \\ X_{B0} & Y_{B0} \end{Bmatrix} - \begin{Bmatrix} x_{A1} & y_{A1} \\ x_{A2} & y_{A2} \\ & \vdots \\ x_{An} & y_{An} \end{Bmatrix}$$

Sum of the squares of the errors:

$$V_{SS}^2 = v_{x1}^2 + v_{y1}^2 + v_{x2}^2 + v_{y2}^2 + \cdots + v_{xn}^2 + v_{yn}^2$$

Minimizing the sum of the squares of the errors:

$$\frac{\partial V_{SS}^2}{\partial \propto_B} = \frac{\partial v_{x1}^2}{\partial \propto_B} + \frac{\partial v_{y1}^2}{\partial \propto_B} + \frac{\partial v_{x2}^2}{\partial \propto_B} + \frac{\partial v_{y2}^2}{\partial \propto_B} + \cdots + \frac{\partial v_{xn}^2}{\partial \propto_B} + \frac{\partial v_{yn}^2}{\partial \propto_B} = 0$$

Solution:

$$\propto_B = -\tan^{-1}\left(\frac{\overline{\Delta y}}{\overline{\Delta x}}\right) = -atan2(\overline{\Delta x}, \overline{\Delta y})$$

$$\overline{\Delta y} = \sum_{i=1}^{n} x_{Ai} y_{Bi} - \sum_{i=1}^{n} y_{Ai} x_{Bi} + y_{BO}(\sum_{i=1}^{n} x_{Bi} - \sum_{i=1}^{n} x_{Ai}) + x_{BO}(\sum_{i=1}^{n} y_{Ai} - \sum_{i=1}^{n} y_{Bi})$$

$$\overline{\Delta x} = \sum_{i=1}^{n} x_{Ai} x_{Bi} + \sum_{i=1}^{n} y_{Ai} y_{Bi} - y_{BO}(\sum_{i=1}^{n} y_{Ai} + \sum_{i=1}^{n} y_{Bi})$$

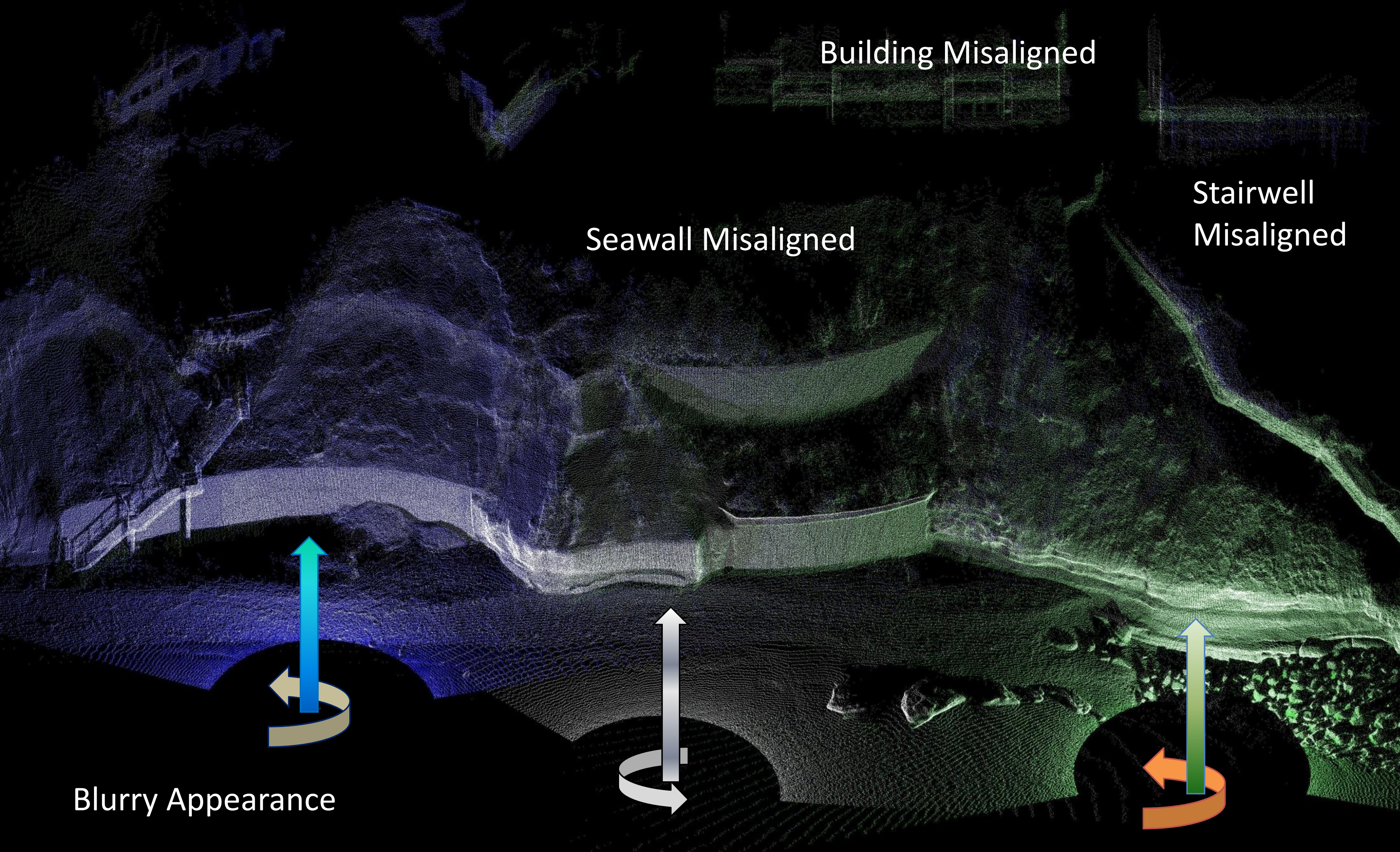
$$-x_{BO}(\sum_{i=1}^{n} x_{Ai} + \sum_{i=1}^{n} x_{Bi}) + n(y_{BO}^2 + x_{BO}^2)$$

Revised from Olsen et al. (2011)

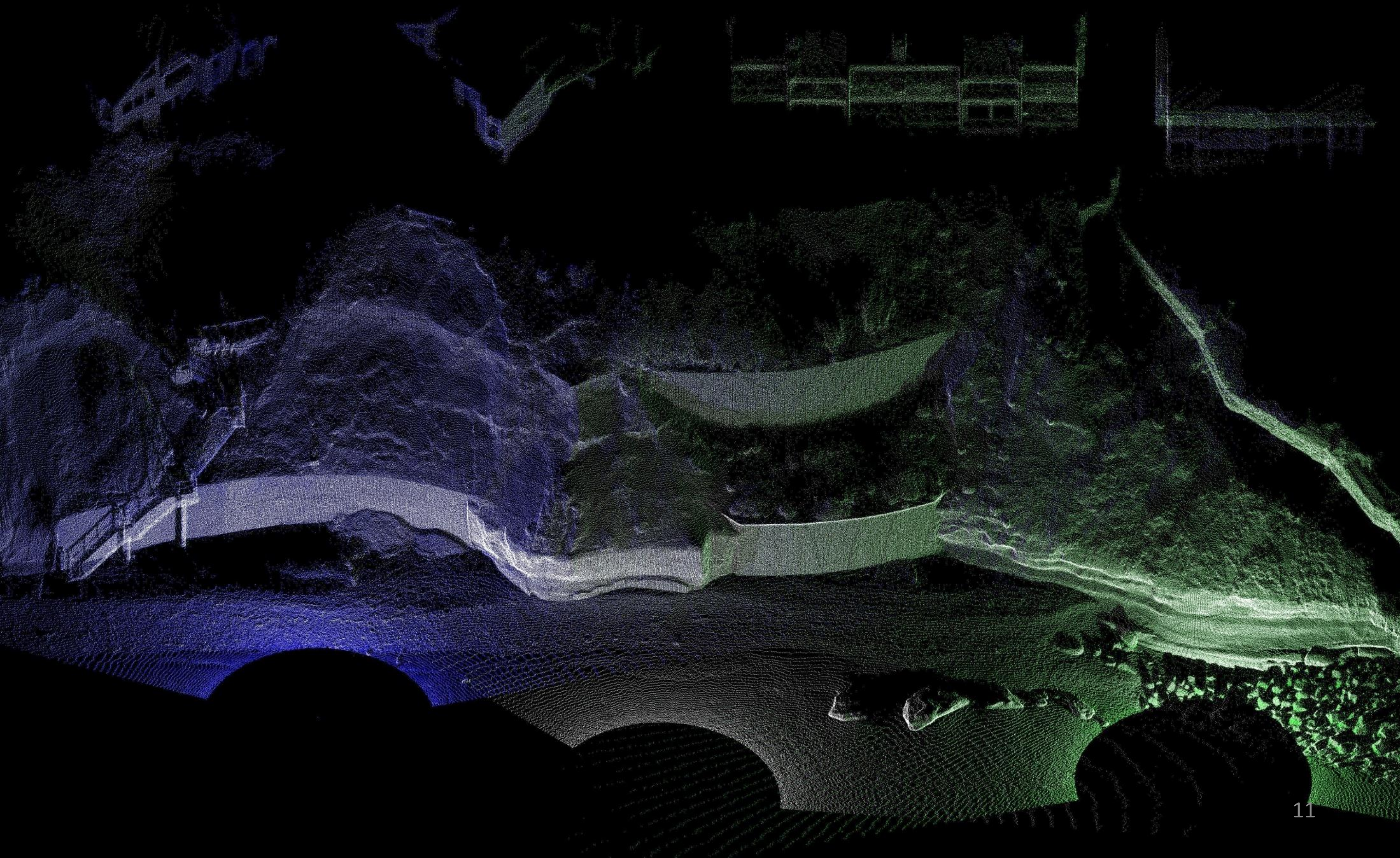
Elevation Adjustments

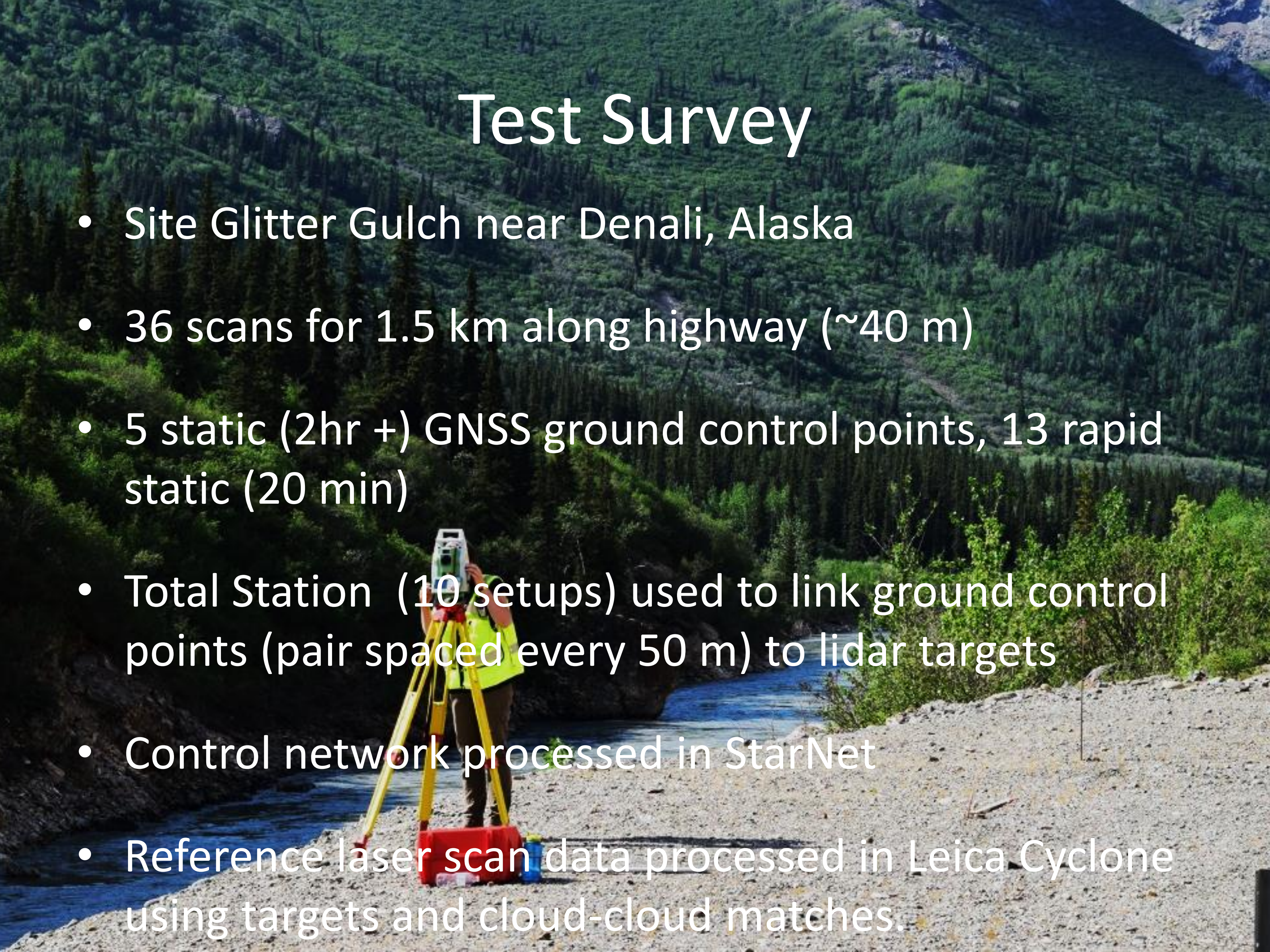
- Before matching scans, the X,Y,Z position of the scanner origin is adjusted for an out of level setup.
- Weighted least squares adjustment to allow each scan to move in Z, proportional to a weight ($1/\sigma_z^2$) comparing all its neighboring scans Iterate

Registered only using estimated rotation



Geo-referenced by *PointReg*





Test Survey

- Site Glitter Gulch near Denali, Alaska
- 36 scans for 1.5 km along highway (~40 m)
- 5 static (2hr +) GNSS ground control points, 13 rapid static (20 min)
- Total Station (10 setups) used to link ground control points (pair spaced every 50 m) to lidar targets
- Control network processed in StarNet
- Reference laser scan data processed in Leica Cyclone using targets and cloud-cloud matches.

Coordinate Comparison

Statistics	OPUS-RS* (m)				RTK-Lib# (m)			
	ΔX	ΔY	ΔZ	Δ3D	ΔX	ΔY	ΔZ	Δ3D
N	32	32	32	32	29	29	29	29
Average	[illegible]	[illegible]	[illegible]	0.0723	**0.0186**	**0.0071**	**0.0009**	**0.0260**
Std Dev	0.0088	[illegible]	0.0309	0.0313	0.0078	0.0125	0.0112	0.0073
Min	-0.0127	[illegible]	-0.1153	0.0139	-0.0057	-0.0353	-0.0239	0.0128
Max	0.0261	0.0581	-0.0099	0.1200	0.0308	0.0341	0.0242	0.0432
RMS	[illegible]	[illegible]	[illegible]	0.0786	**0.0201**	**0.0142**	**0.0110**	**0.0270**
95%conf	0.0254	0.0362	**0.1475**	0.1270	**0.0394**	**0.0279**	**0.0216**	**0.0437**

L2C

- *L2C on Trimble Receivers (R8) affects P2 data such that it won't work in OPUS-RS (Smith et al. 2014).
- #Results in Leica Geo-Office (exporting Rinex 3.03, not 2.11) were very similar. Rinex 2.11 did not process in LGO.
- Some stations would process in LGO but not RTK-lib and vice-versa.
- Base Station located within 0.1 to 2.0 km of points
- RTK-lib processing against CORS GRNX (15km) Yields Δ3D = 0.06 m @95% Conf.

Ground Control Point Comparison

Statistics	OPUS-RS (18)				RTKLib (14)			
	ΔX	ΔY	ΔZ	Δ3D	ΔX	ΔY	ΔZ	Δ3D
Average	-0.0034	-0.0057	0.0087	0.0254	-0.0158	-0.0072	-0.0057	0.0213
Std. Dev	0.0081	0.0091	0.0271	0.0181	0.0082	0.0071	0.0085	0.0077
Min	-0.0168	-0.0211	-0.0617	0.0030	-0.0298	-0.0209	-0.0210	0.0077
Max	0.0130	0.0140	0.0572	0.0636	-0.0001	0.0058	0.0080	0.0339
RMS	**0.0086**	**0.0105**	**0.0277**	**0.0309**	**0.0176**	**0.0099**	**0.0099**	**0.0226**
95%conf	**0.0168**	**0.0207**	**0.0543**	**0.0499**	**0.0345**	**0.0195**	**0.0195**	**0.0365**

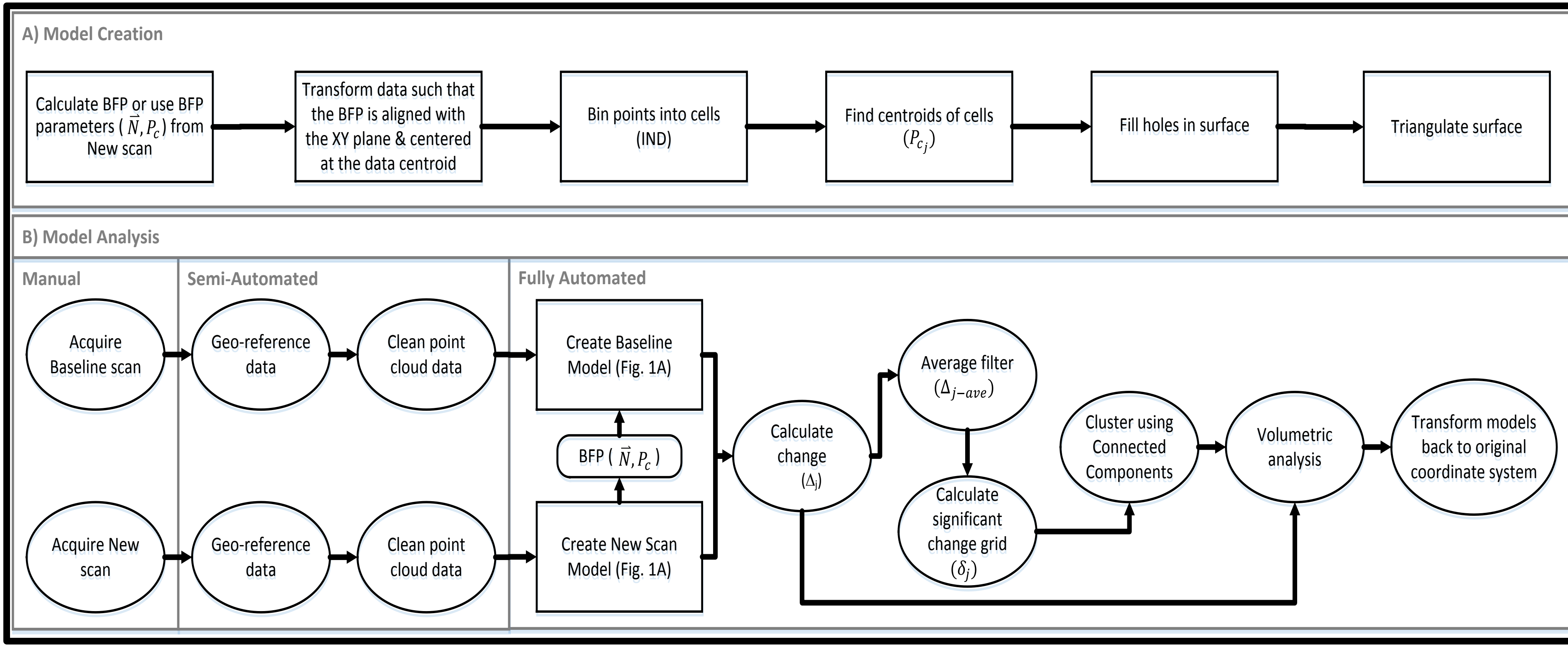
- RTK-lib results are GPS+Glonass, OPUS is GPS-only
- RTK-lib results with GPS-only are very similar
- Base Station within 0.1-2.0 km, nearest CORS – 15km

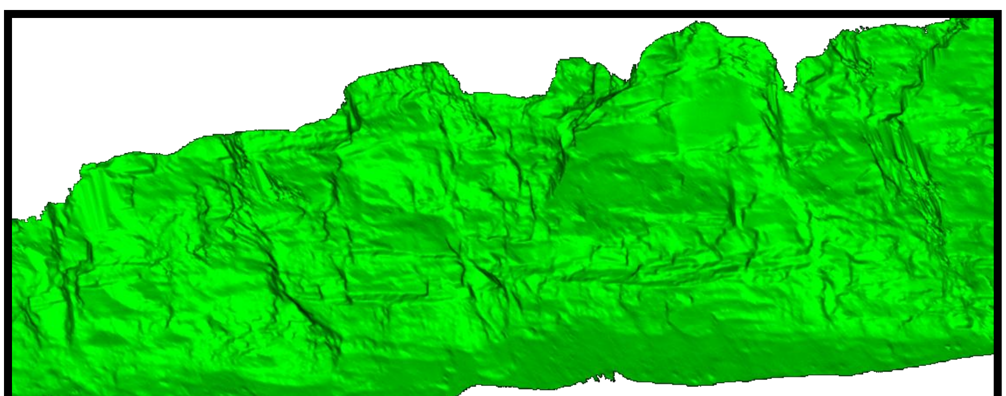
Point Reg Results

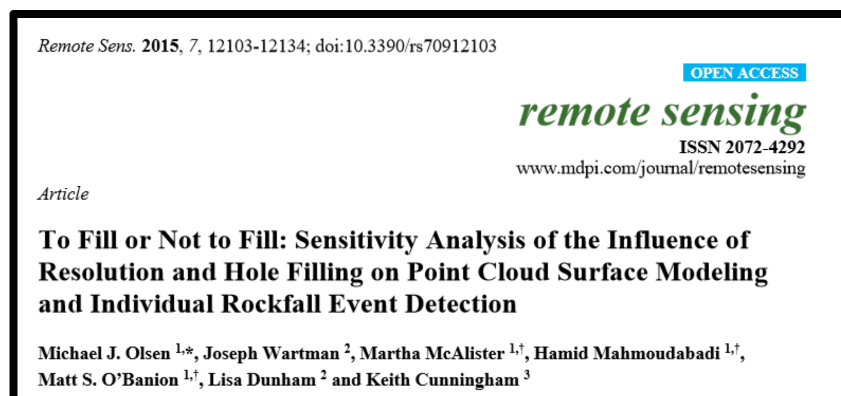
Statistics	Point Reg (OPUS-RS)*				Point Reg (RTK-Lib)#			
	ΔRx	ΔRy	ΔRz	ΔZ	ΔRx (º)	ΔRy(º)	ΔRz (º)	ΔZ (m)
N	30	30	30	30	29	29	29	29
Average	-0.0007	0.0008	-0.0043	0.0718	-0.0003	0.0015	-0.0055	**-0.0026**
Std. Dev	0.0067	0.0065	0.0099	**0.0161**	0.0072	0.0067	0.0184	**0.0065**
Min	-0.0322	-0.0250	-0.0331	0.0281	-0.0322	-0.0250	-0.0789	-0.0138
Max	0.0085	0.0132	0.0154	0.1099	0.0121	0.0132	0.0290	0.0101
RMS	0.0066	0.0064	0.0106	0.0735	0.0071	0.0067	0.0188	0.0068
95%conf	0.0130	0.0126	**0.0209**	0.1441	0.0138	0.0132	**0.0369**	**0.0134**

- For OPUS, reduction of Std. Dev by ½ to 0.0161 m
- Reduction of ΔZ @95% confidence by ½ to 0.0134 m for RTKlib
- Rz agrees within 0.0209 - 0.0369 degrees, which is near the approximate sampling of the scanner (0.022º)

Modeling Secret Sauce







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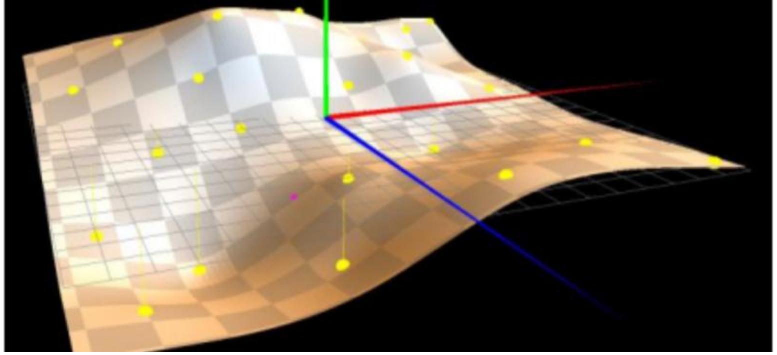
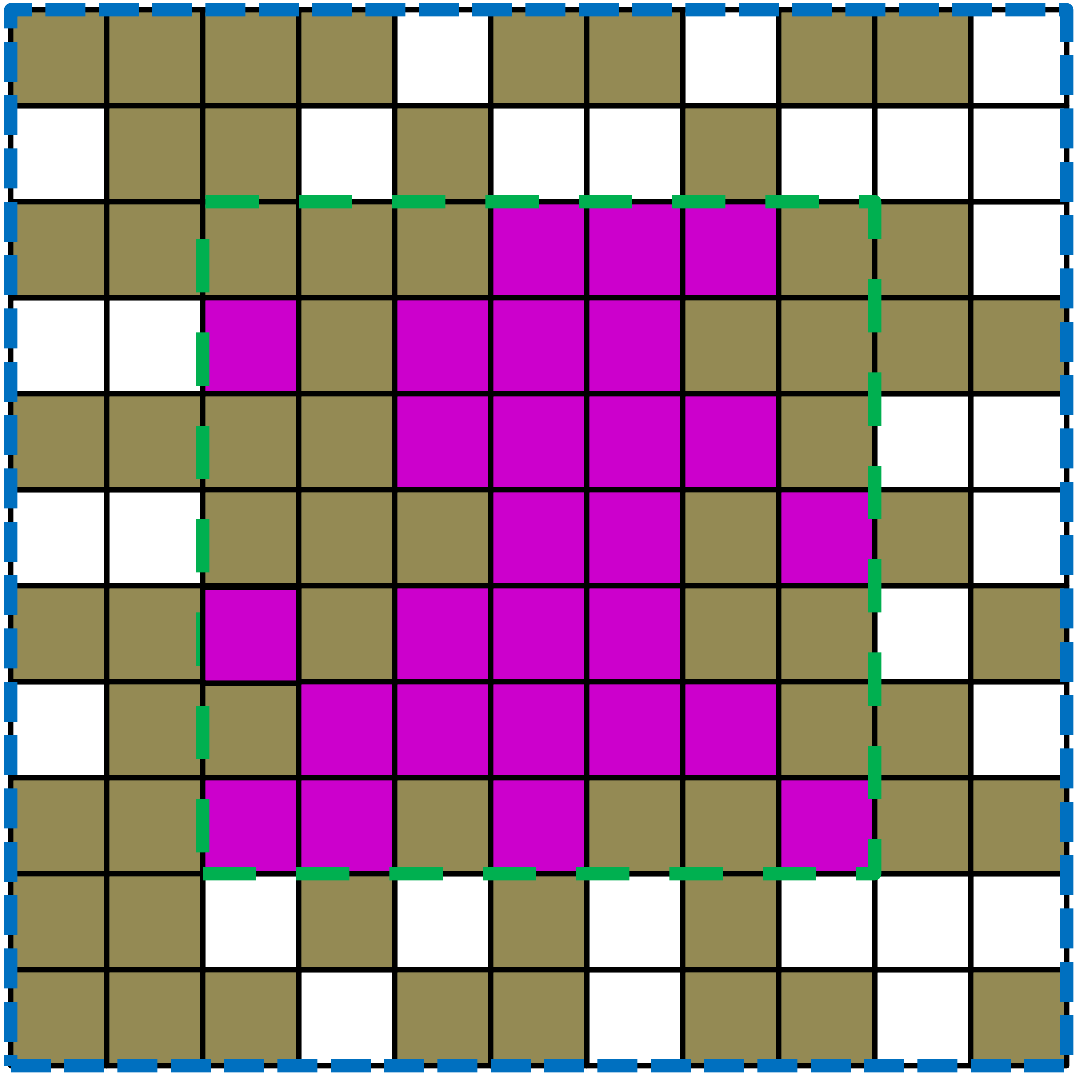
Article

To Fill or Not to Fill: Sensitivity Analysis of the Influence of Resolution and Hole Filling on Point Cloud Surface Modeling and Individual Rockfall Event Detection

Michael J. Olsen [1,*], Joseph Wartman [2], Martha McAlister [1,†], Hamid Mahmoudabadi [1,†], Matt S. O'Banion [1,†], Lisa Dunham [2] and Keith Cunningham [3]

Hole Filling Process

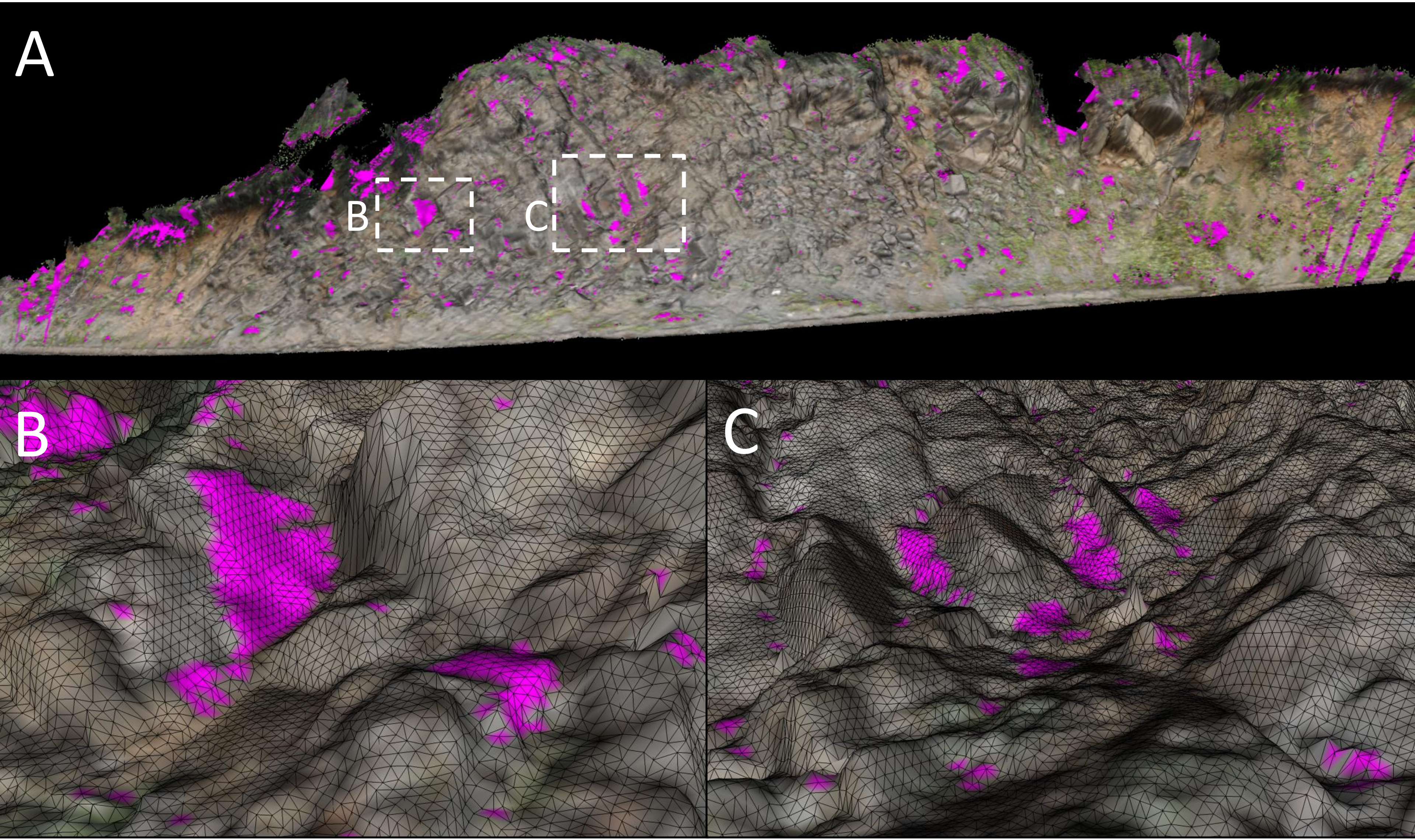




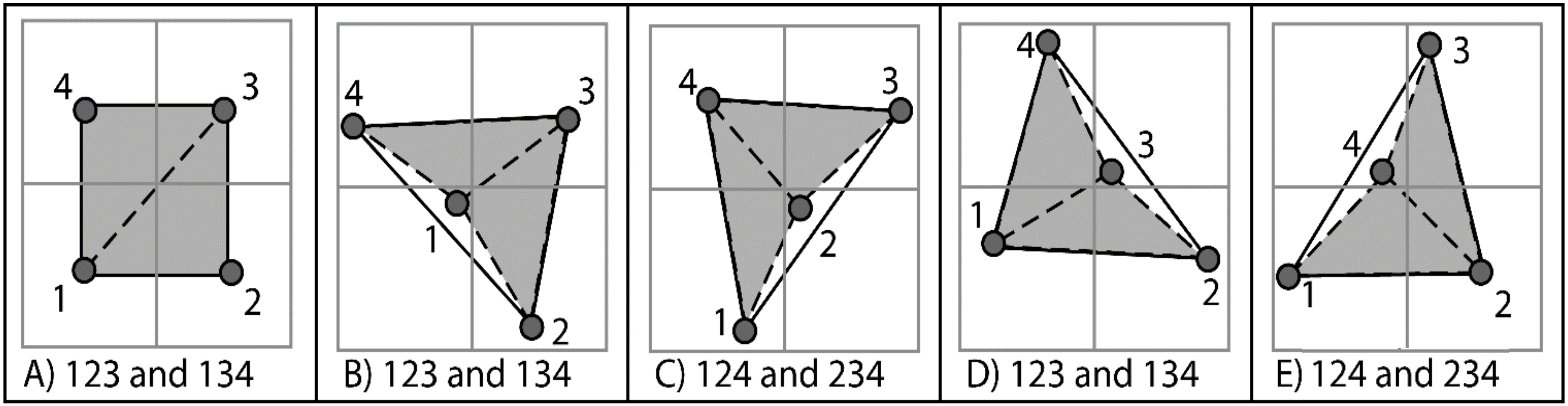
Legend

- Cell with data whose centroid is used to compute the TPS
- Cell with no data where a "centroid" is interpolated from the TPS
- Cell with no data that is not filled with this TPS but will likely be filled with the TPS computed from the next overlapping search window.
- Search window for centroid points to compute the TPS
- Search window for cells to fill with the TPS

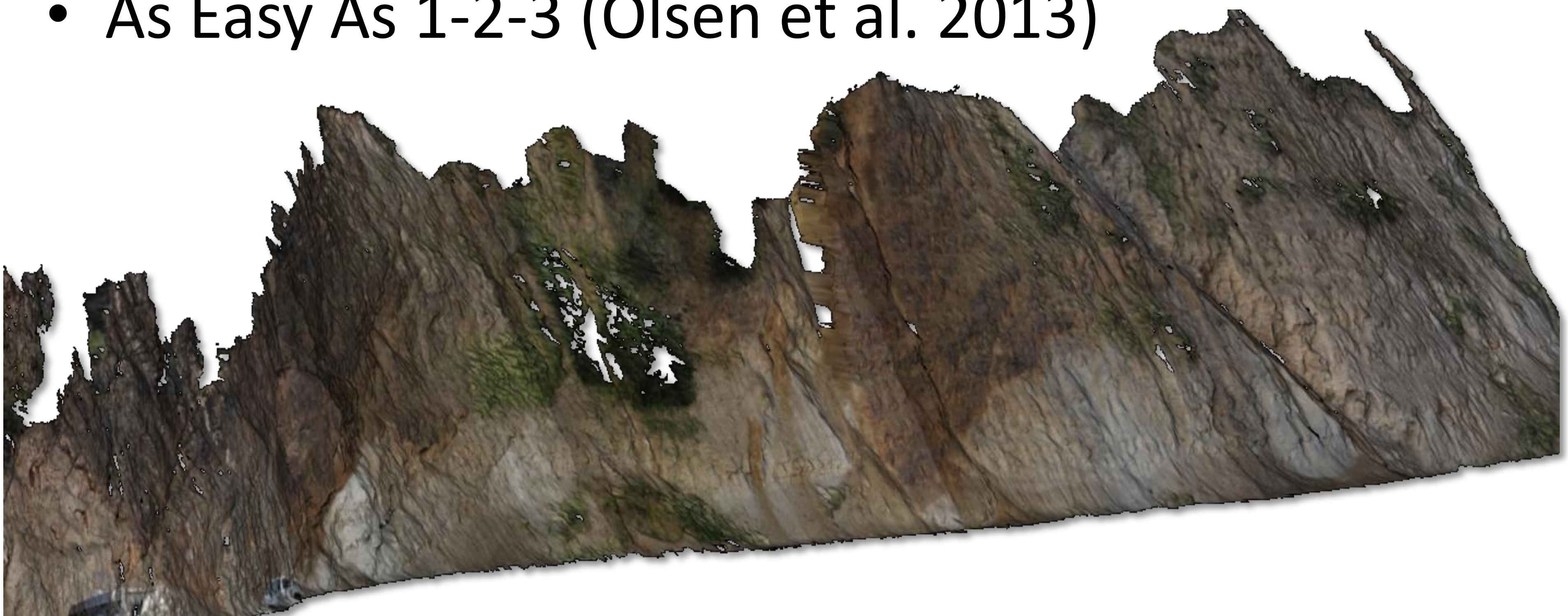
Hole Filling



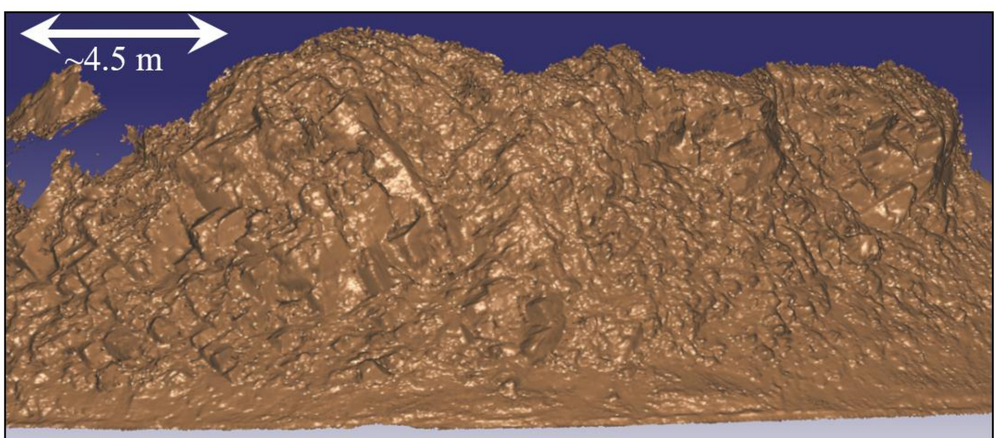
Triangulation rules

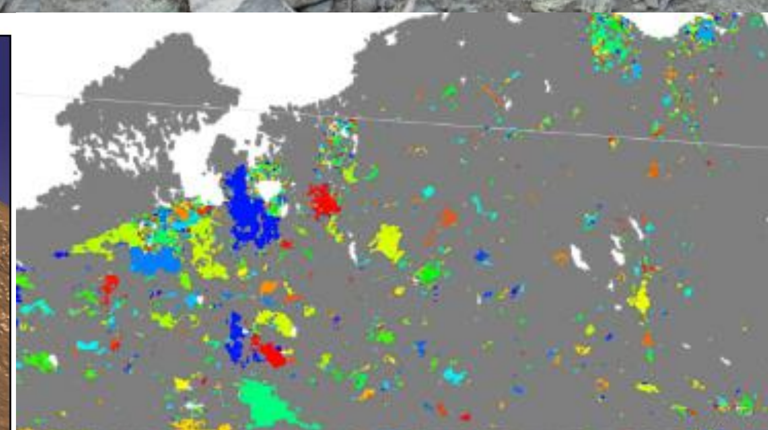


- As Easy As 1-2-3 (Olsen et al. 2013)

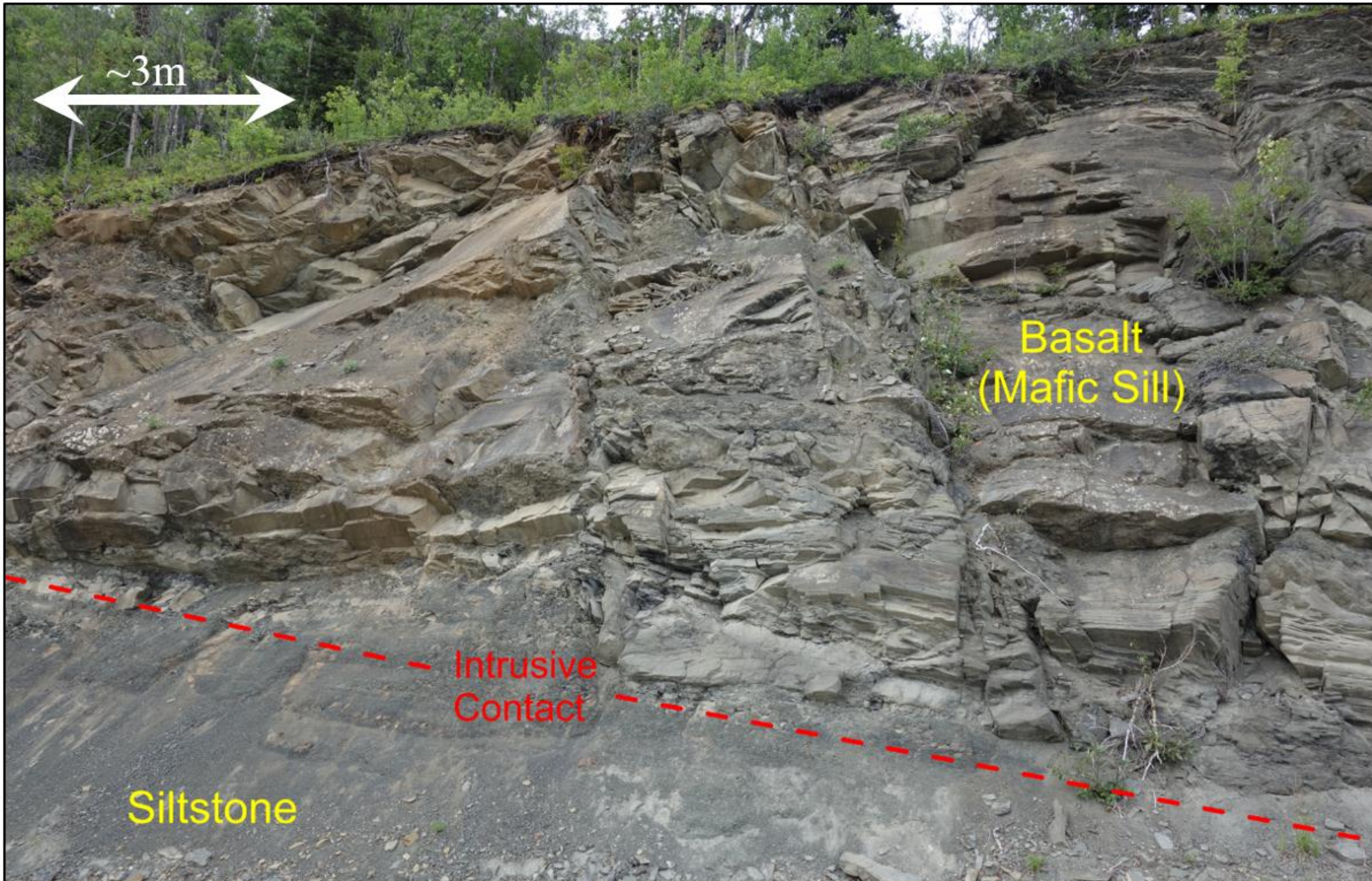


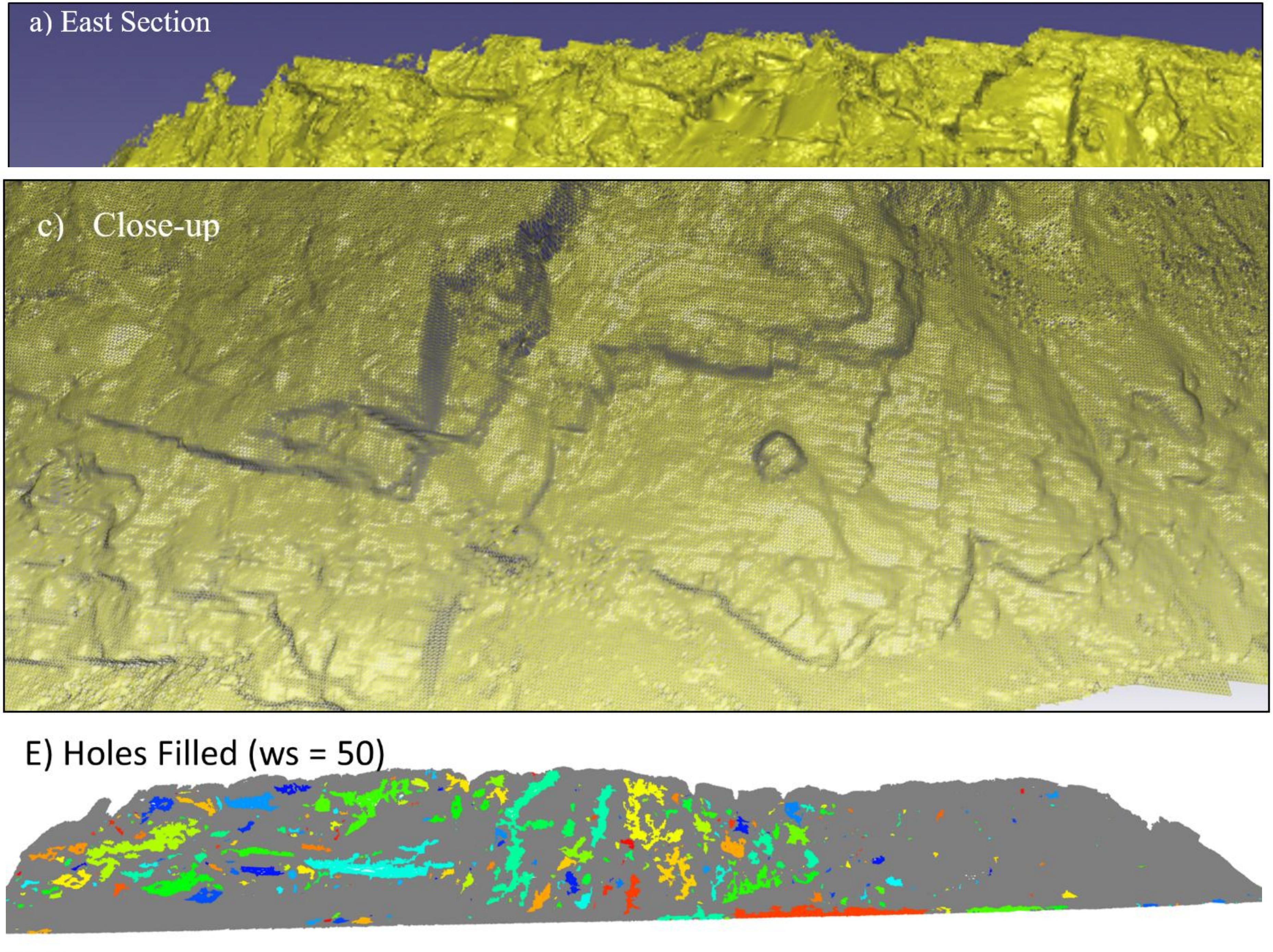
Site A (LL85.5)



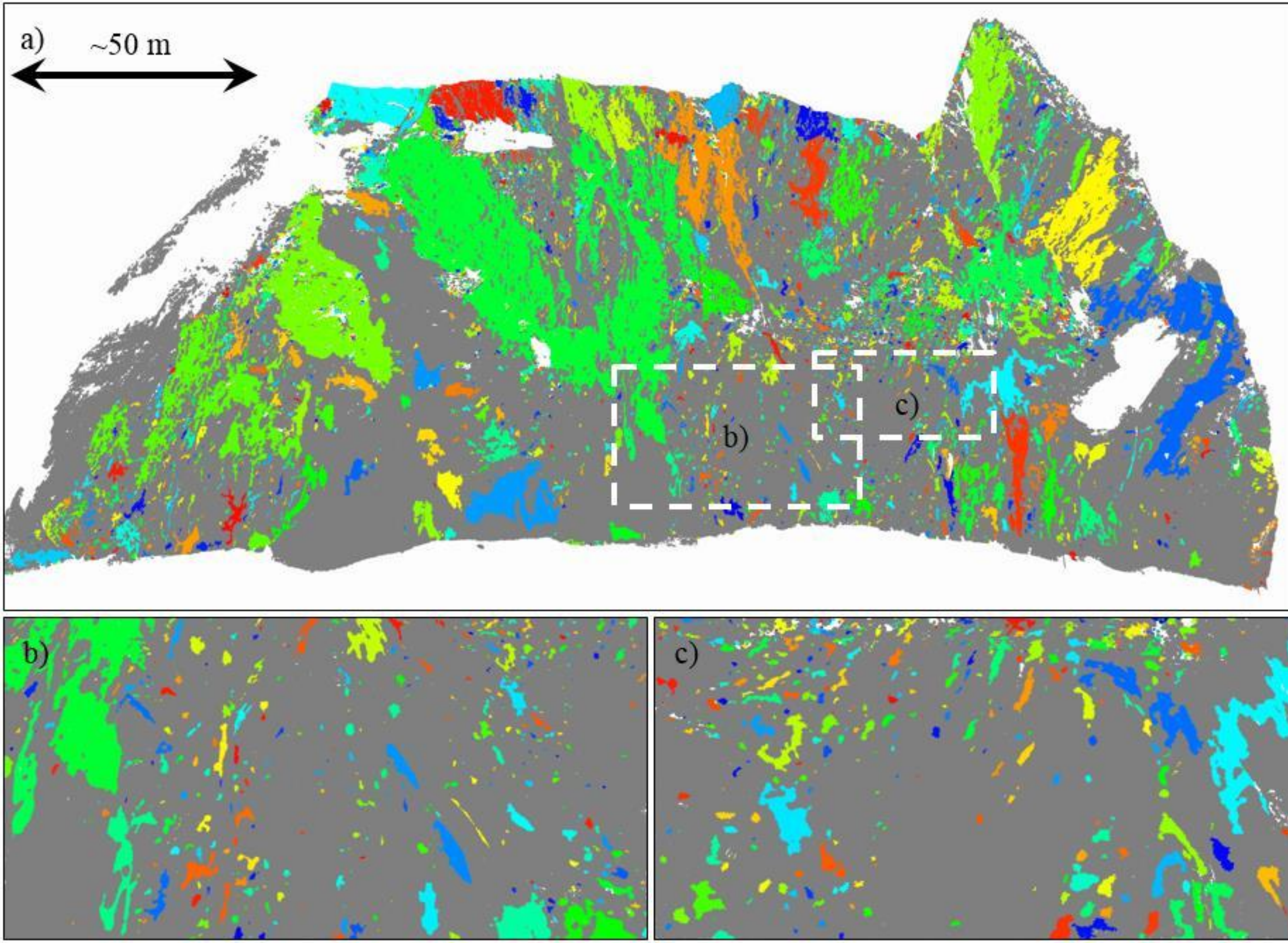


Site B (LL87)



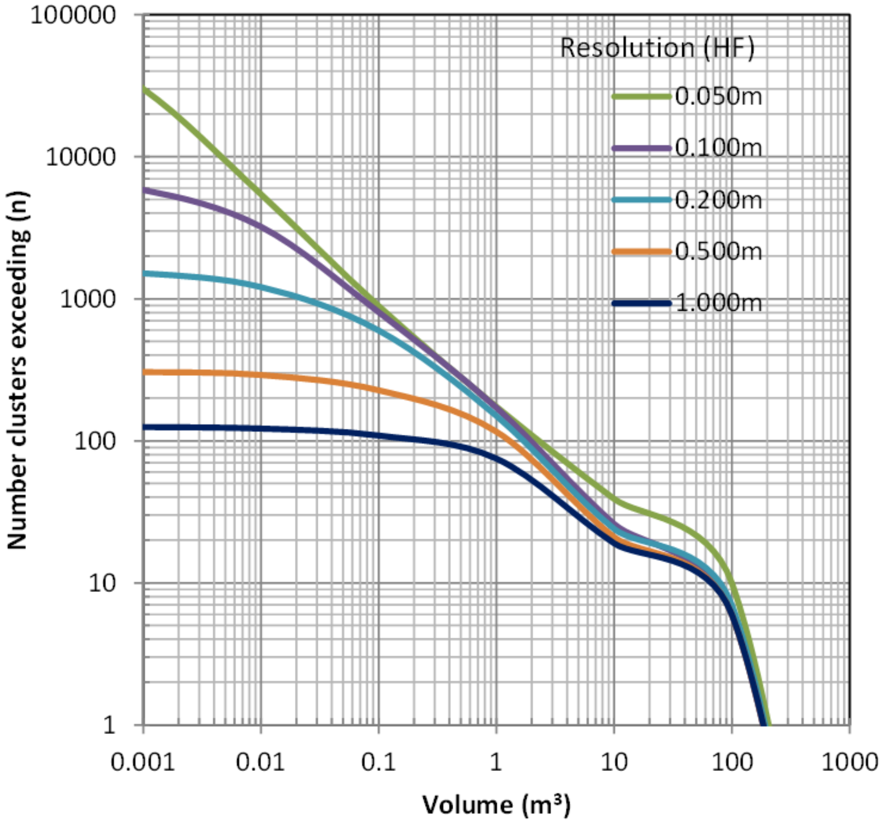

a) East Section
c) Close-up
E) Holes Filled (ws = 50)

Site C (GG239)

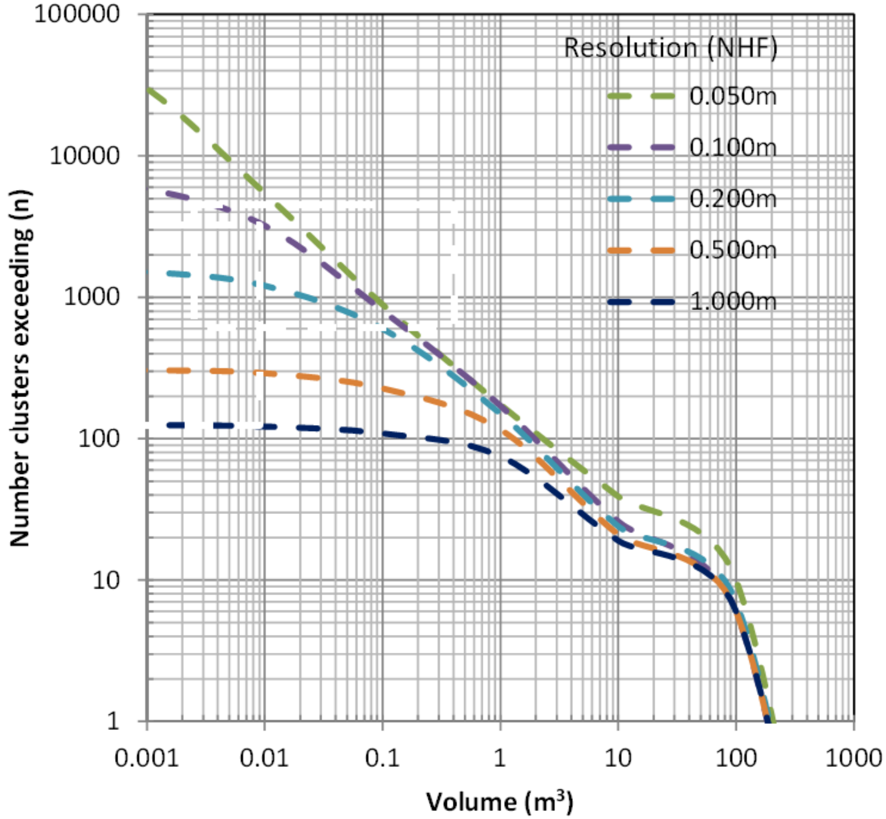


a)
~50 m
b)
c)
b)
c)

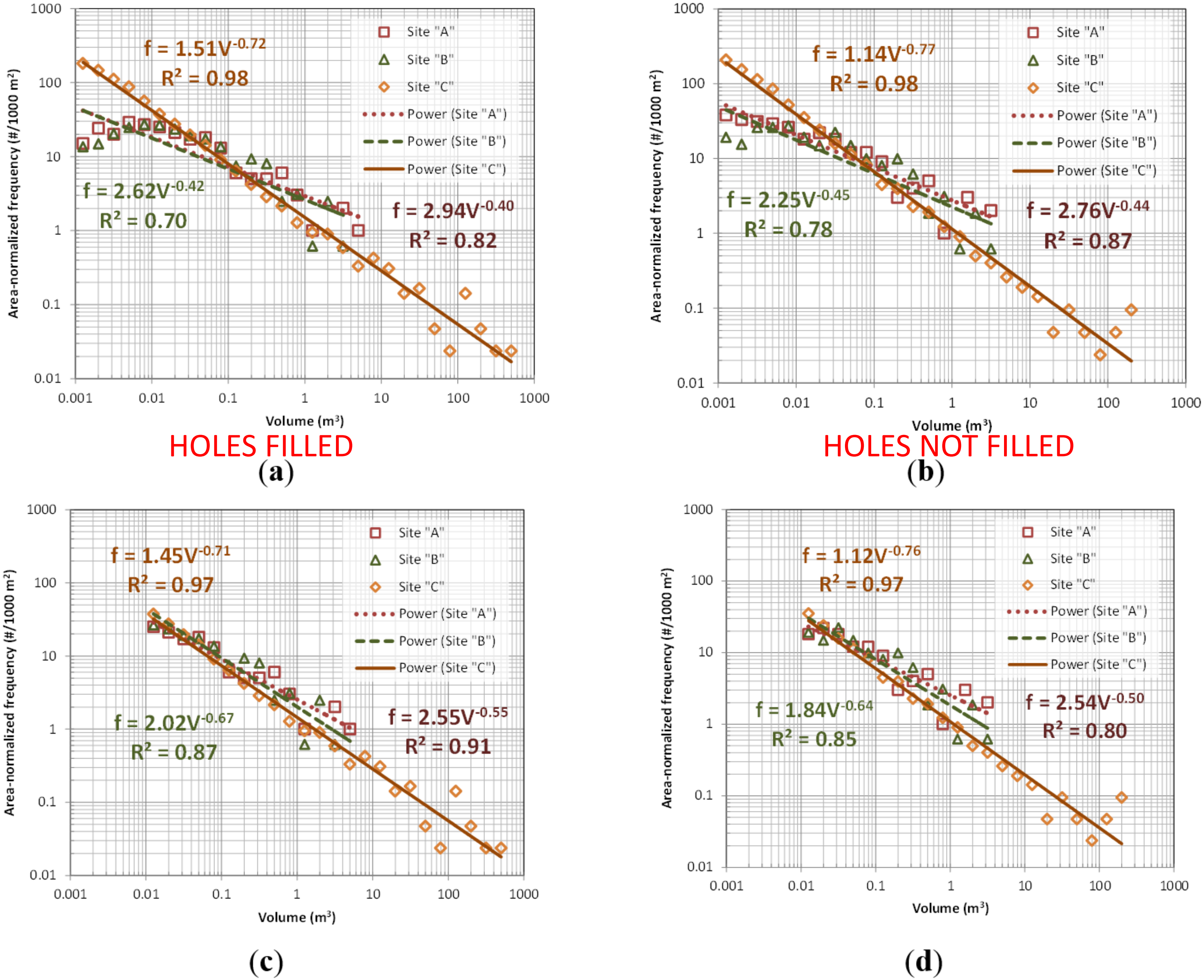
Cumulative Mag-Freq Relationships (1 year)



(a)



(b)



(a)
HOLES FILLED
Site "A"
Site "B"
Site "C"
Power (Site "A")
Power (Site "B")
Power (Site "C")
f = 1.51V^-0.72
R² = 0.98
f = 2.62V^-0.42
R² = 0.70
f = 2.94V^-0.40
R² = 0.82
Area-normalized frequency (#/1000 m²)
Volume (m³)
(b)
HOLES NOT FILLED
f = 1.14V^-0.77
R² = 0.98
f = 2.25V^-0.45
R² = 0.78
f = 2.76V^-0.44
R² = 0.87
(c)
f = 1.45V^-0.71
R² = 0.97
f = 2.02V^-0.67
R² = 0.87
f = 2.55V^-0.55
R² = 0.91
(d)
f = 1.12V^-0.76
R² = 0.97
f = 1.84V^-0.64
R² = 0.85
f = 2.54V^-0.50
R² = 0.80

Key Observations

- Caution with L2C!!!
- Point Reg GNSS solution compares well with target based approach with much less effort
- Clustering approach captures rockfall events well
- Mag-freq curves highly dependent on modeling resolution
- Modest hole filling with TPS tended to improve the magnitude frequency relationships, but can result in poorer fit for small volumes.

Acknowledgements