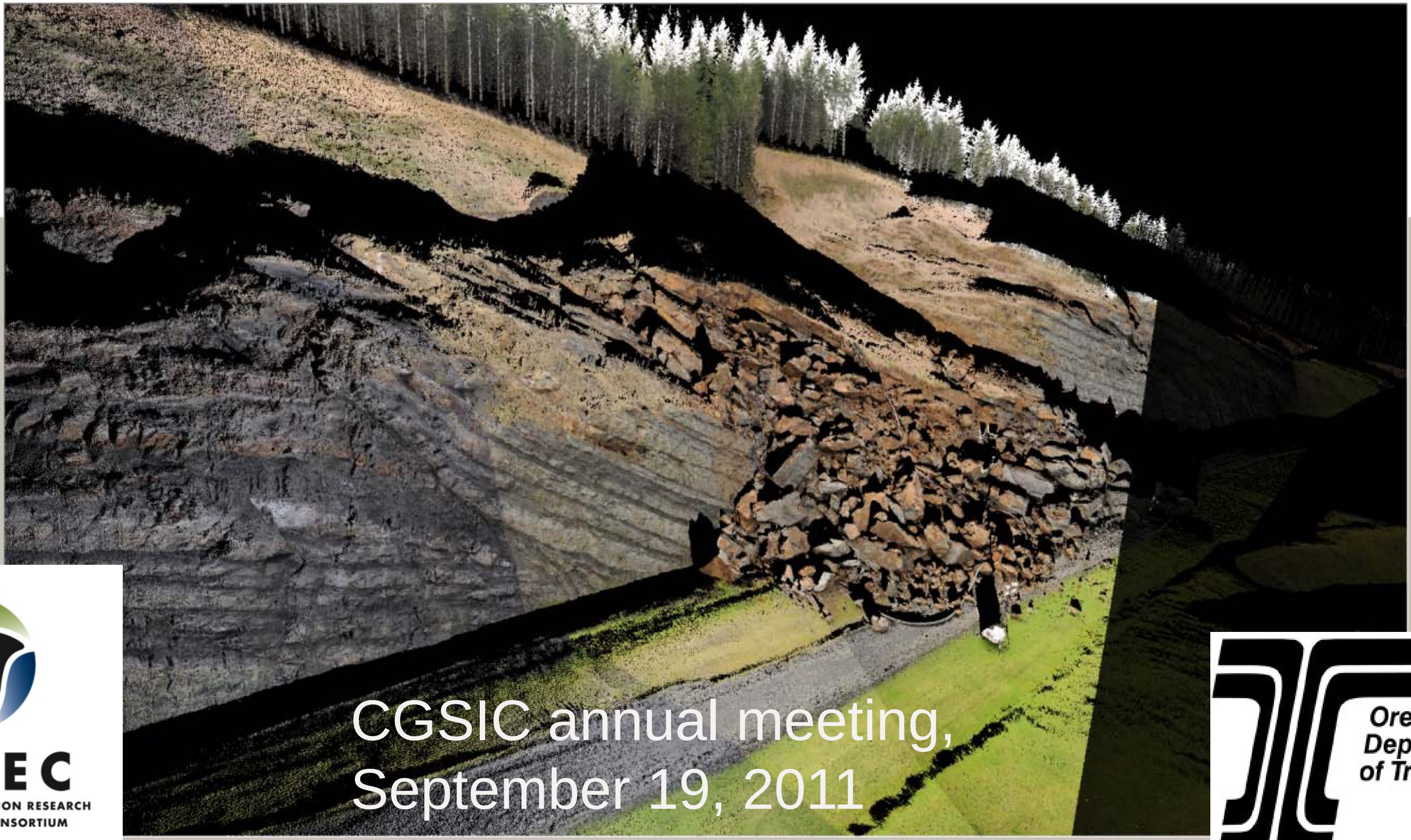
# Real-time Change detection using Laser Scanning and GNSS Real-time Networks

Michael J. Olsen



CGSIC annual meeting,
September 19, 2011

# Project Team Members

- Principal Investigator
  - Michael Olsen(CE)
- Graduate Students
  - Shawn Butcher (CE)
  - Evon Silvia (CE)
  - Keith Williams (CE)
  - Tony Rikli (CE)
  - Abby Chin (CE)
- Undergraduate Students
  - Cierra Eby (CE)
  - Amanda Olson (CE)
  - Nick Atanasov (CE)
  - Alfred Flammang (CS)
  - Andrew Johnson (CS)
  - Rebecca Pankow (CS)
  - Kris Puderbaugh (NMC)
- Technical Advisory Committee
  - Matthew Mabey (ODOT Research Coordinator)
  - Ron Singh (ODOT Geometronics)
  - Curran Mohney (ODOT)
  - Jonathan Allan (DOGAMI)
  - Alan Blair (FHWA)

Civil Engineering (geomatics and geotechnical) and Computer Science

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# Geomatics at OSU

- Growing graduate program (3MS, 1 MENG, 4 PhD)
- Recent strategic partnership with Leica Geosystems and David Evans and Associates
- Students in UG program eligible to sit for FS and FE exams.
- GPS is used in just about every geomatics course!

- New Courses
  Digital Terrain Modeling
  3D laser scanning
  BIM

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# Research Overview

- Change detection is a topic of intense interest in many fields
- Current workflows for TLS require post-processing
- Monitoring infrastructure is critical to public safety and economic operation.

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# Research Objectives

1. Obtain time-series data from multiple sites
2. Develop an in field change detection algorithm
3. Increase understanding of geologic processes
4. Improve efficiency and quality of 3D surveying
5. Improve ODOT's allocation of resources
6. Expand ODOT capacity for 3D technologies

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# Anticipated Usage

1. Rapid feedback for remediation and mitigation measures effectiveness.

2. Better prediction of infrastructure impact zones by improving the means to detect landslide movement prior to failure.

3. Greatly increase spatial information available to policy makers.

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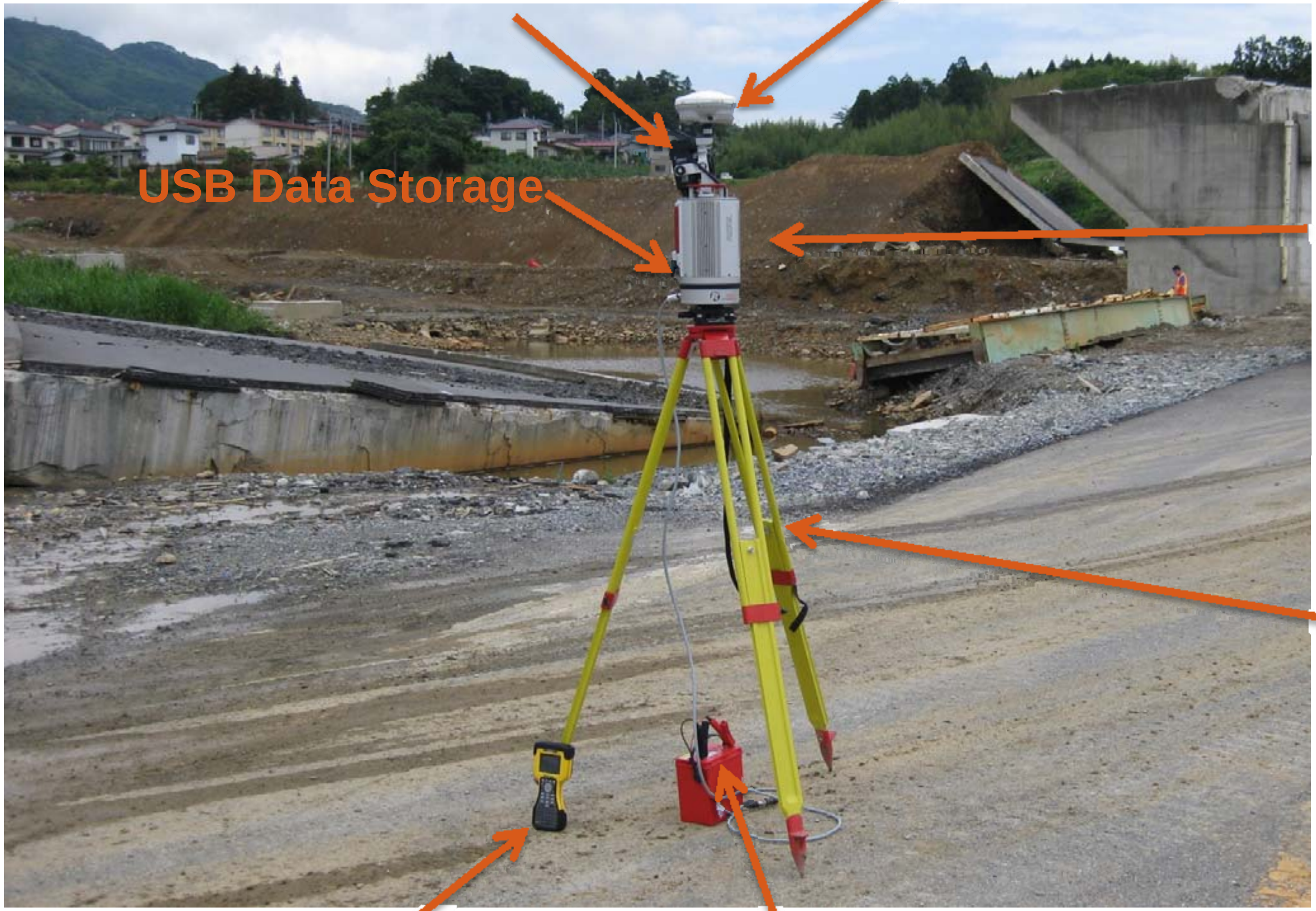
# Terrestrial Laser Scanner Components



# Field Setup Mobile

# Traditional Methodology

1. Laser scan and control data (GPS, total station, etc.) are collected in the field

2. Data processing is performed in the office
   - Time intensive process (hours, days, weeks)
   - Labor and equipment intensive
   - Must process all data collected

3. Analysis of the data is performed in the office
   - Analyses delayed until after data are processed
   - Delays discovery and usefulness of “interest” areas

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# New Methodology

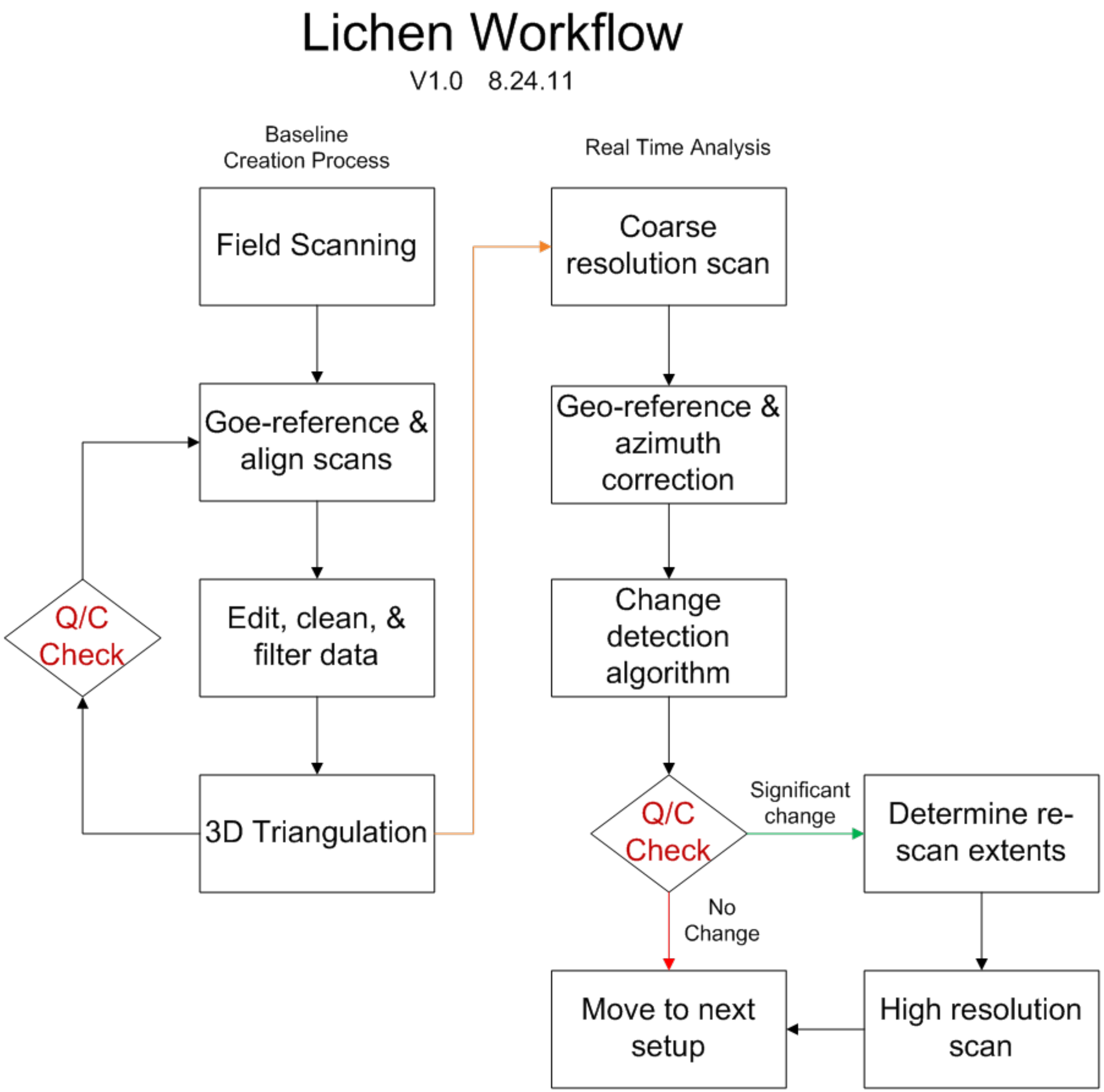
1. Laser scan and GPS data are collected in the field

2. Data processing is split between office and field
   - Introduce automation of some features
     - Geo-referencing (GPS, inclination, digital compass)
     - Visual quality control of new scans (e.g. GPS & alignments)

3. Change analysis possible immediately in the field
   - Surface comparison for change detection
   - Evaluate coarse scan and rapid GPS -> re-scan specific areas as needed

4. More efficient use of data for post-processing
   - Collect detailed, higher resolution scans where needed
   - Reduces redundant data collection
   - Data already geo-referenced

# *Lichen* (LiDAR Change Engine)



# *Lichen* - Features

1. Simple – Intuitive GUI

2. Fast – Less than a minute for file conversion, geo-referencing, and change analysis of a scan

3. Portable – Implementable from a netbook

4. Flexible - May be used with GPS or control points (monitoring projects)

5. Modular – Setup so that a controller can be integrated from any manufacturer (pending manufacturer SDK availability)

6. Small and lightweight – (<30MB for all components)

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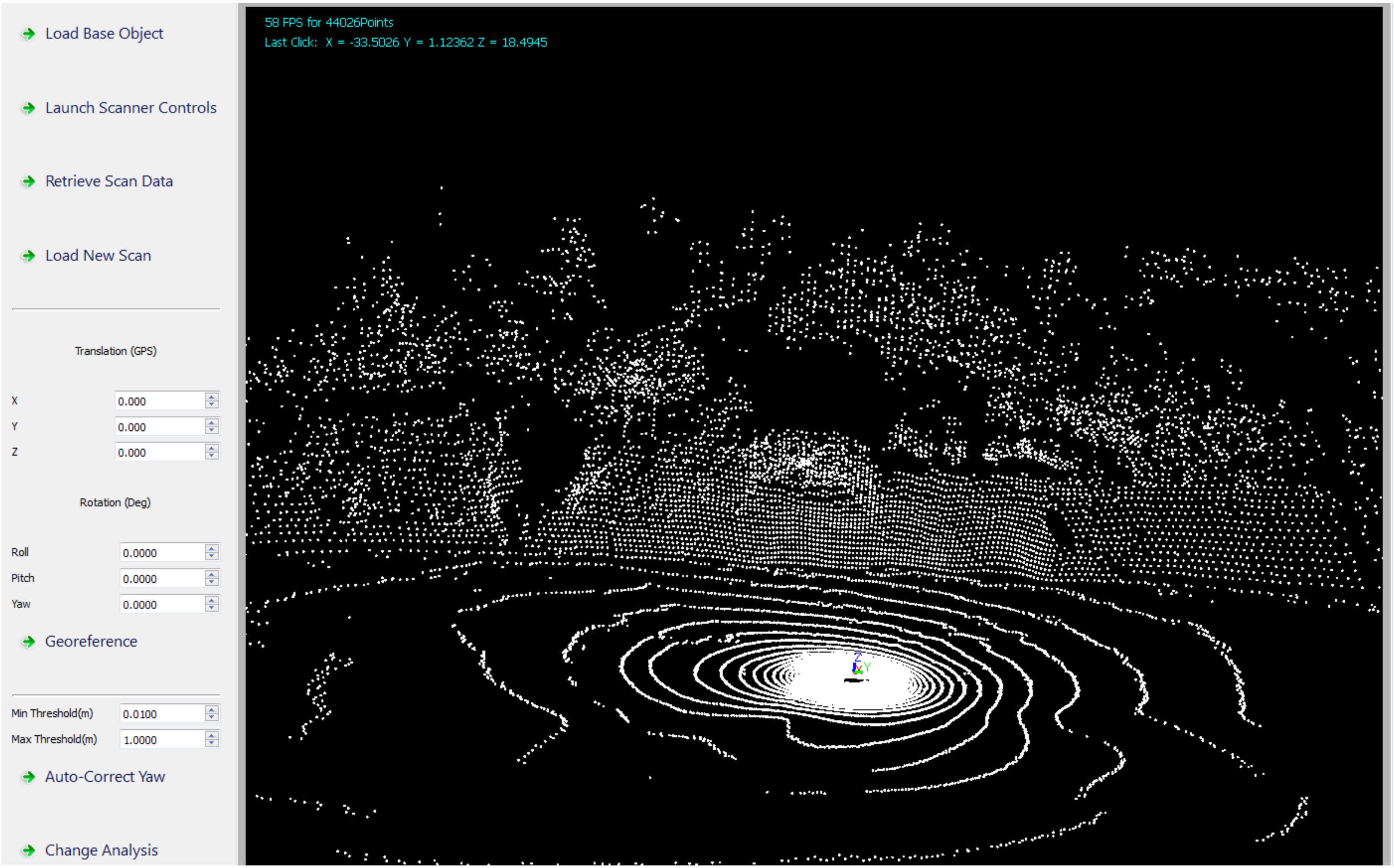
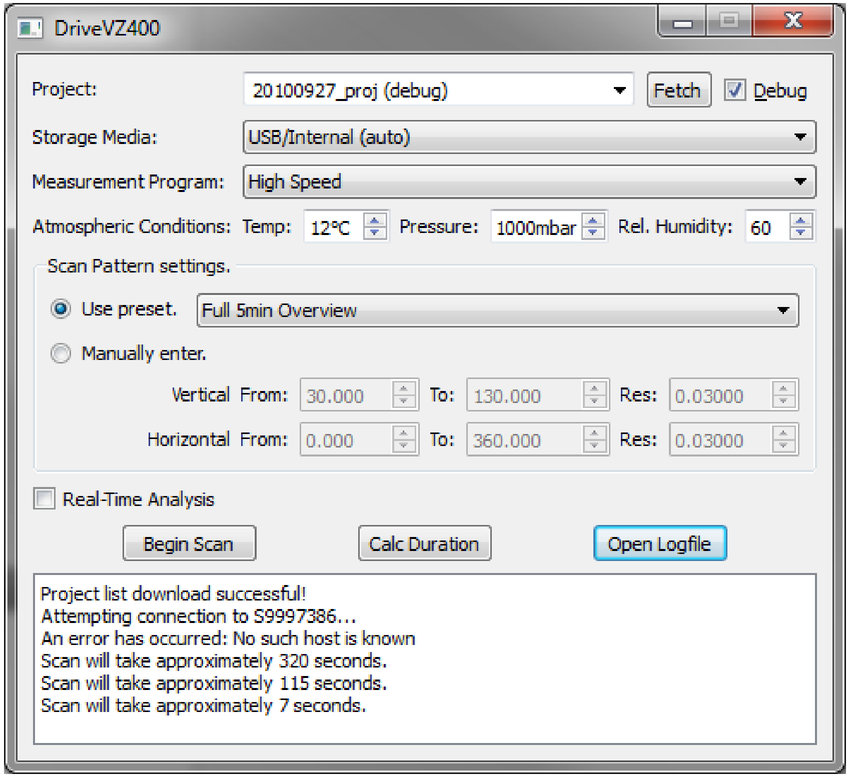
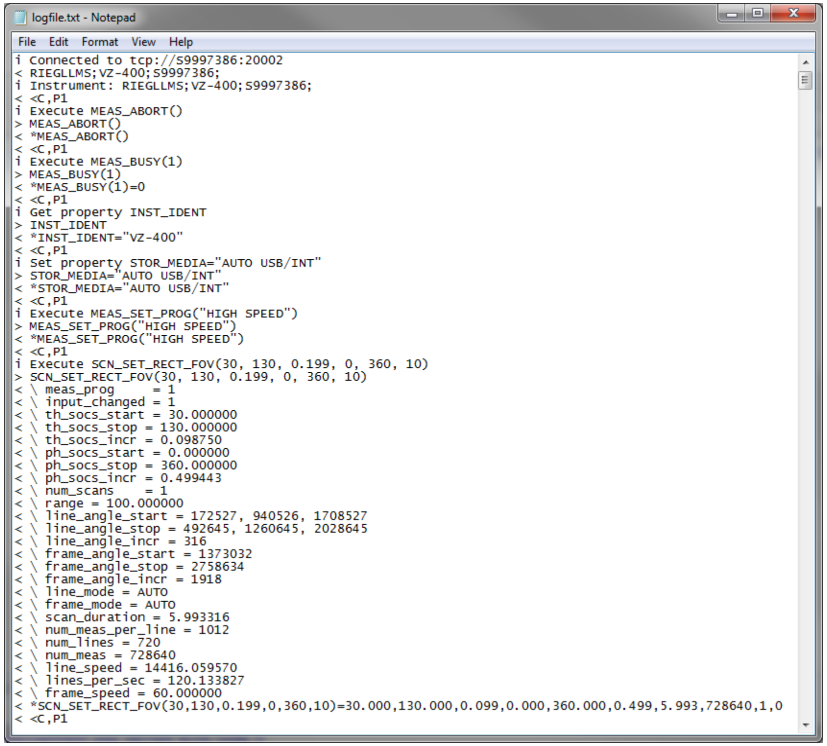
# *Lichen* v1.0



Load Base Object
Launch Scanner Controls
Retrieve Scan Data
Load New Scan
Translation (GPS)
X 0.000
Y 0.000
Z 0.000
Rotation (Deg)
Roll 0.0000
Pitch 0.0000
Yaw 0.0000
Georeference
Min Threshold(m) 0.0100
Max Threshold(m) 1.0000
Auto-Correct Yaw
Change Analysis
58 FPS for 44026Points
Last Click: X = -33.5026 Y = 1.12362 Z = 18.4945

# Drive VZ400 GUI and Output

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# Geo-referencing 6 DOF


- GPS coordinate (from ORGN) at each scan location (trans X,Y,Z)
- Dual Axis Tilt/Level Compensator (rotation X,Y)
- Digital compass reading or back-sight
( ~ rotation Z)
- Software alignment to correct for backsight error (rotation Z)

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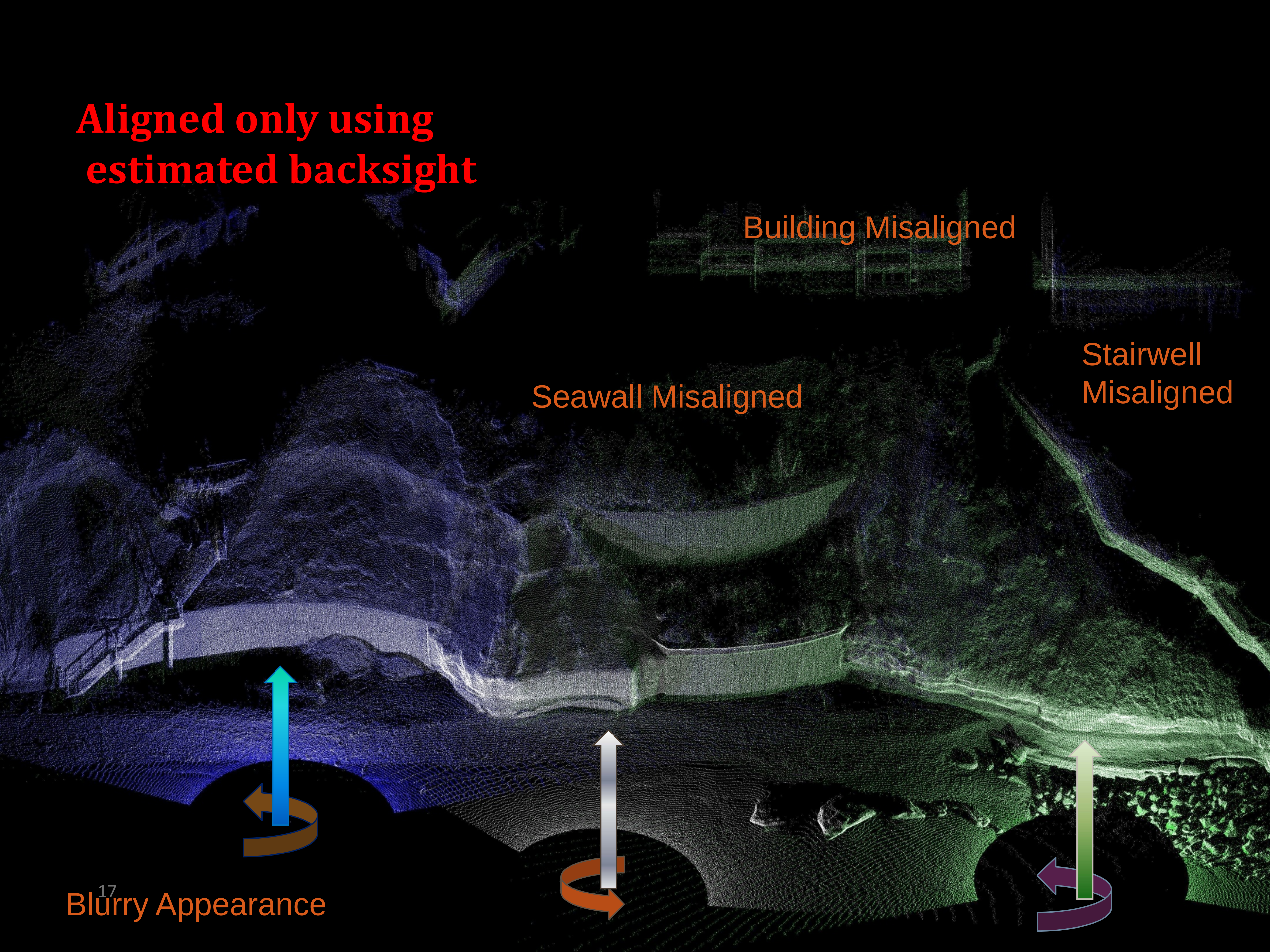
# Correct GPS data for unlevel setup

$$\begin{Bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{Bmatrix} = R \begin{Bmatrix} 0 \\ 0 \\ -(H+h) \end{Bmatrix}$$

$$R(\alpha,\beta,\gamma) = \begin{bmatrix} \cos\beta\cos\gamma & \cos\alpha\sin\gamma + \sin\alpha\sin\beta\cos\gamma & \sin\alpha\sin\gamma - \cos\alpha\sin\beta\cos\gamma \\ -\cos\beta\sin\gamma & \cos\alpha\cos\gamma - \sin\alpha\sin\beta\sin\gamma & \sin\alpha\cos\gamma + \cos\alpha\sin\beta\sin\gamma \\ \sin\beta & -\sin\alpha\cos\beta & \cos\alpha\cos\beta \end{bmatrix}$$

H = antenna height to ARP
h = phase offset


Aligned only using
estimated backsight
Building Misaligned
Stairwell
Misaligned
Seawall Misaligned
Blurry Appearance

# 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:

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

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

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

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

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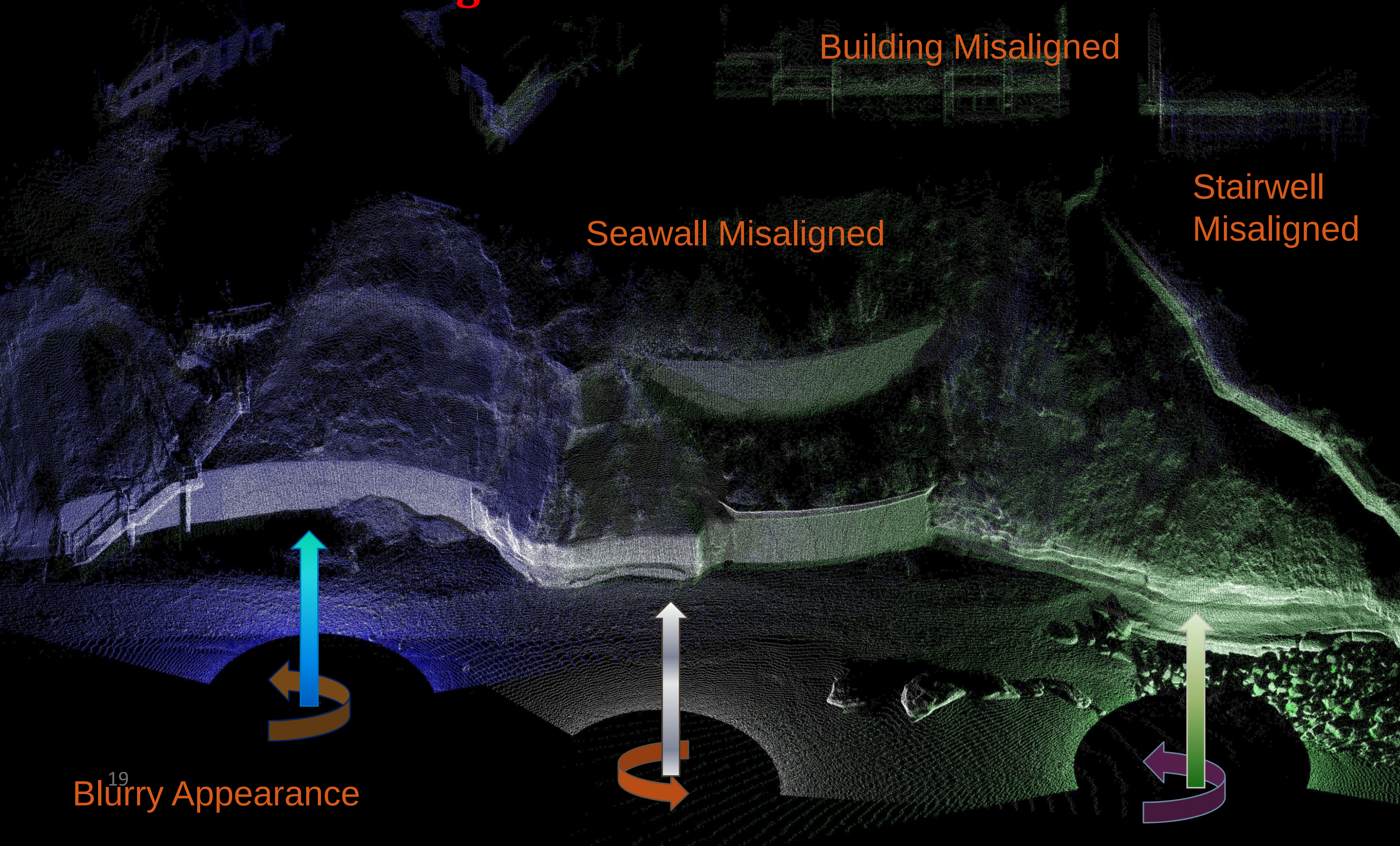
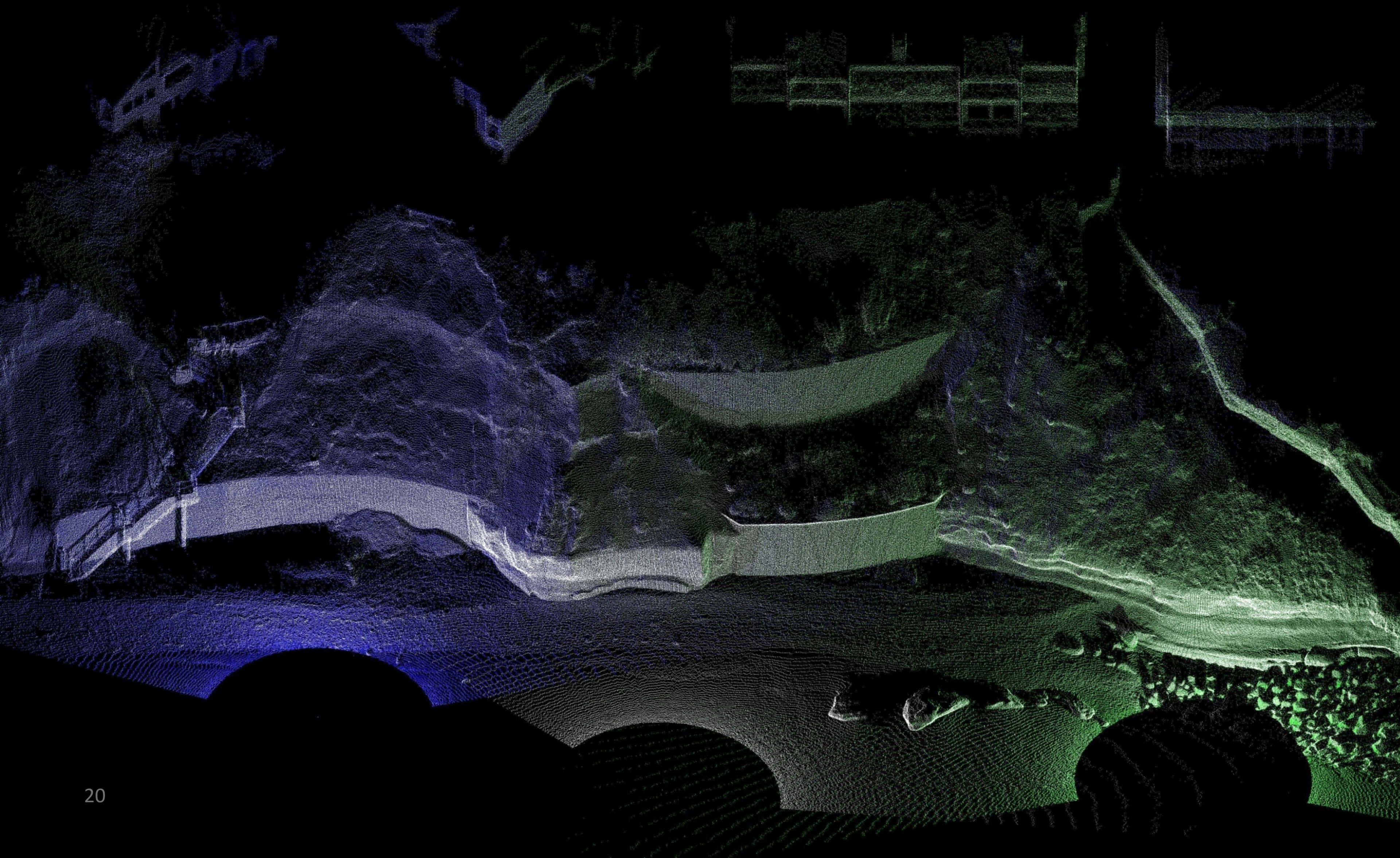
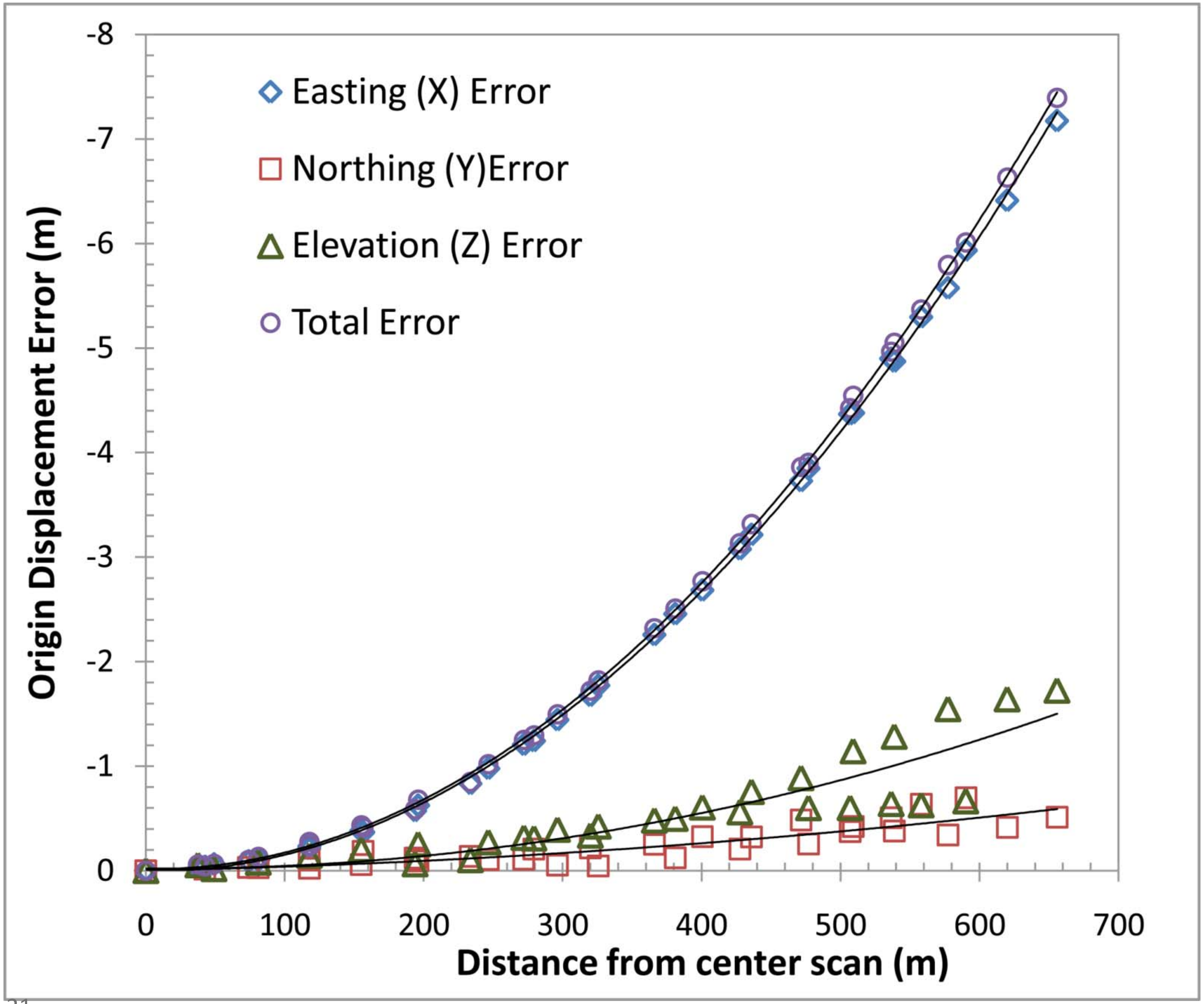
# Aligned only using estimated backsight



# Aligned by *PointReg*

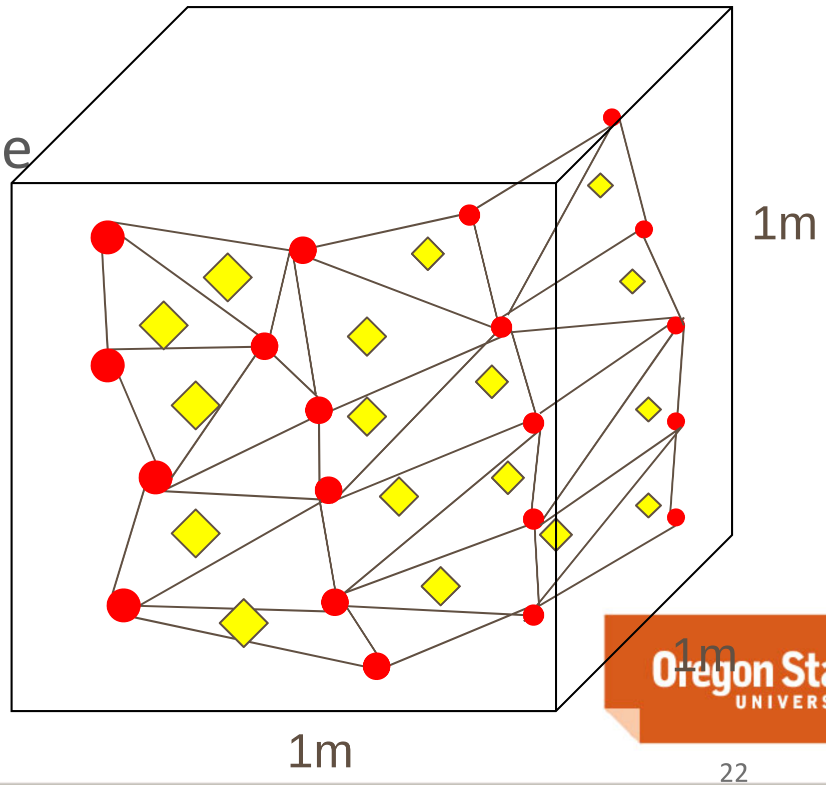


# Unconstrained Software Alignment



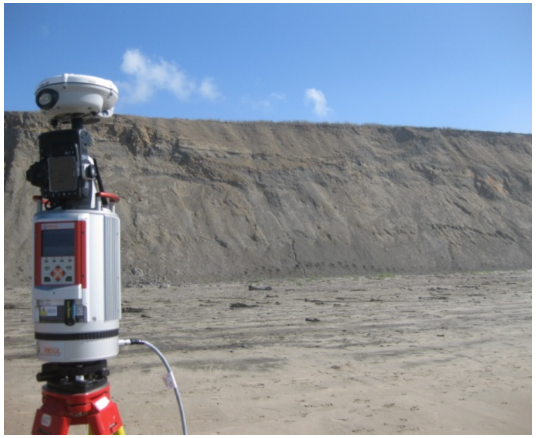
# *Change Detection* Algorithm

1. Create hash table for baseline cloud (on load)
   -> assign points to cube grid based on XYZ location
2. Import subset of new scan
3. Find distance to closest points from new scan to base scan
   i. Search in cube
   ii. If not found, search next cube
4. Color code based on distance
   (min, max thresholds)
5. Display colored results to user



# Research Sites

1. Geomatics Lab (OSU)
2. Geotechnical testing Berm (OSU)
3. Beverly Beach/Johnson Creek Landslide
4. Pioneer Mountain Eddyville (US-20)
5. MSE Wall



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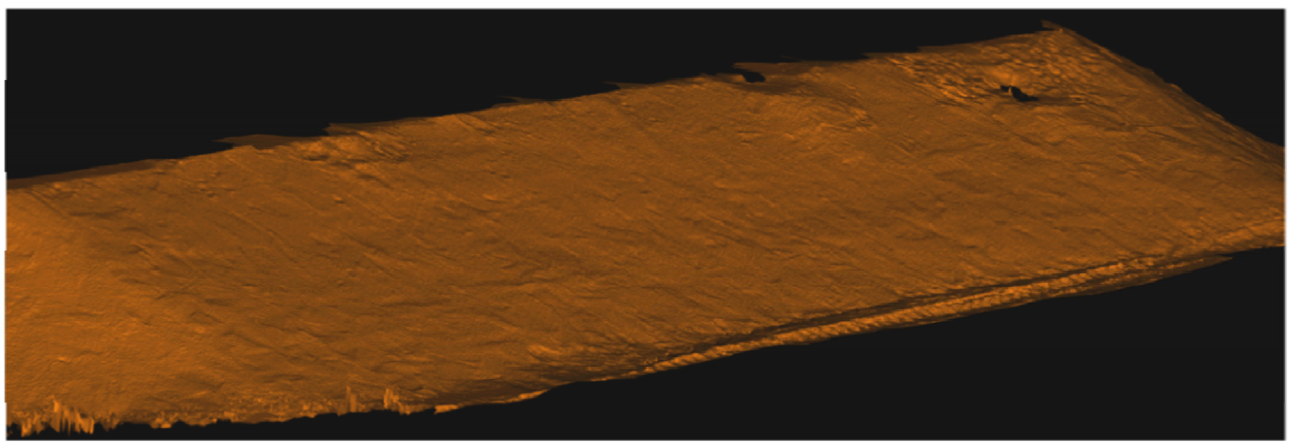
# Research Sites – Pile Testing Berm (OSU)



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# Pile Testing Berm – Monitoring Test

High resolution (0.030 degree) baseline scan taken the day of testing. For monitoring projects, post-processing may be skipped (not optimal). Total pile displacement was 10 inches.

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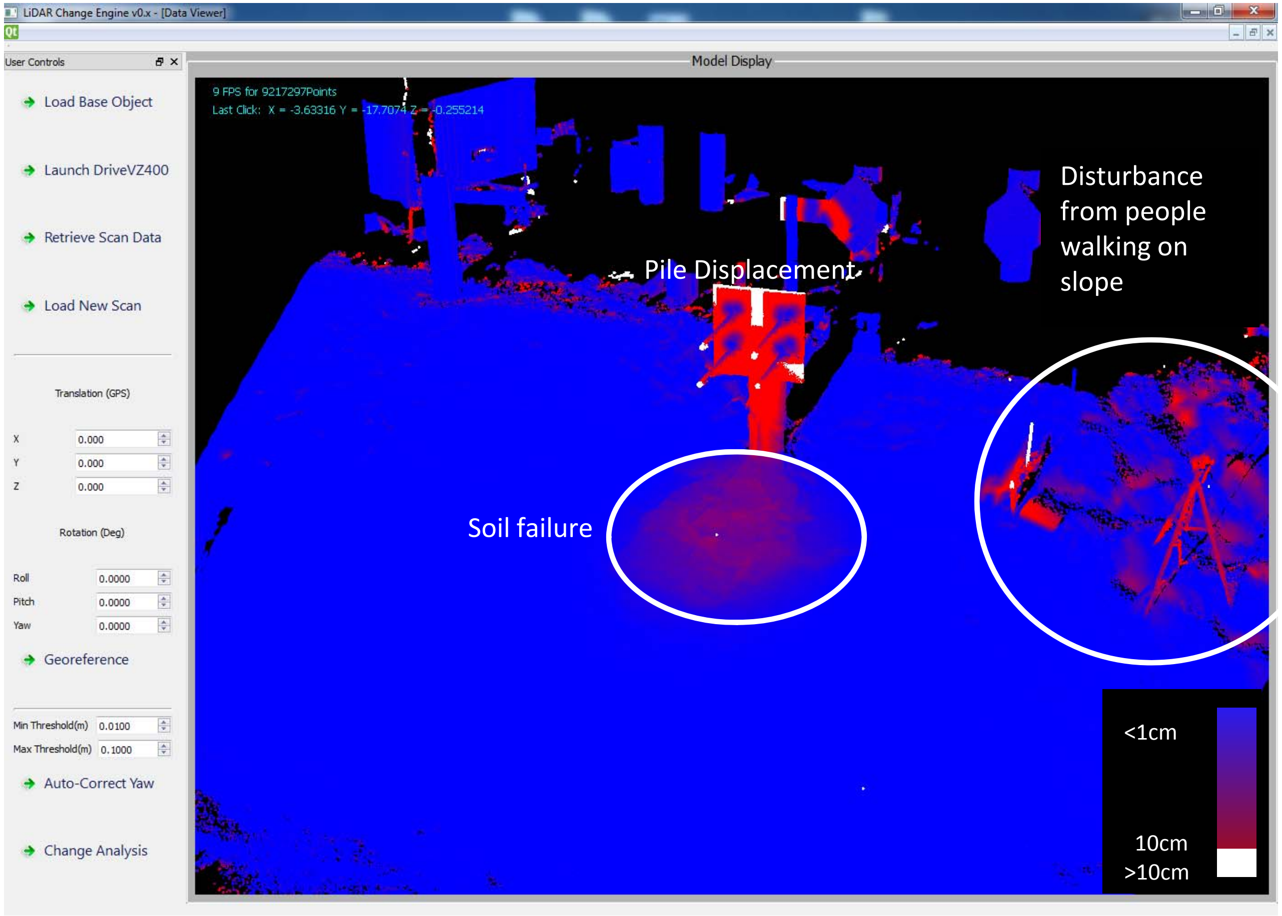
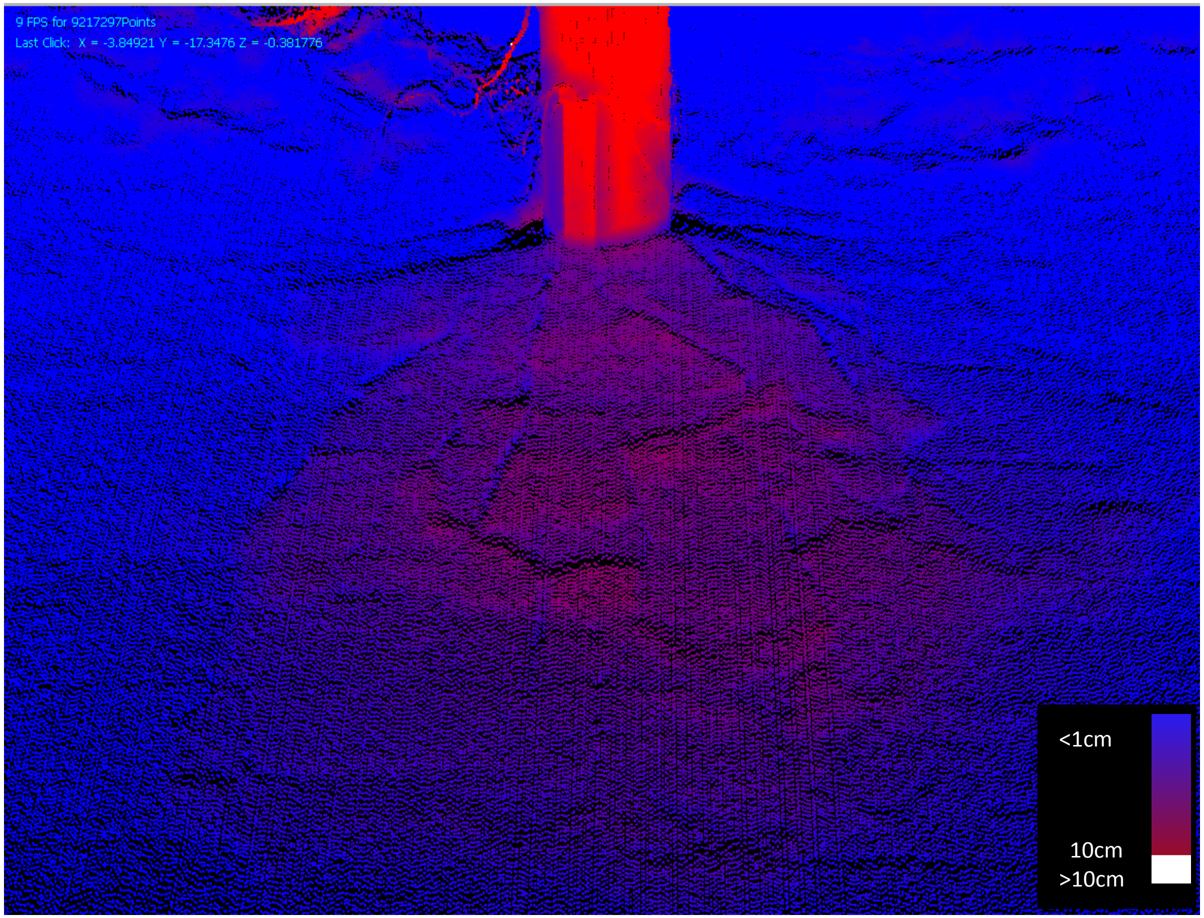
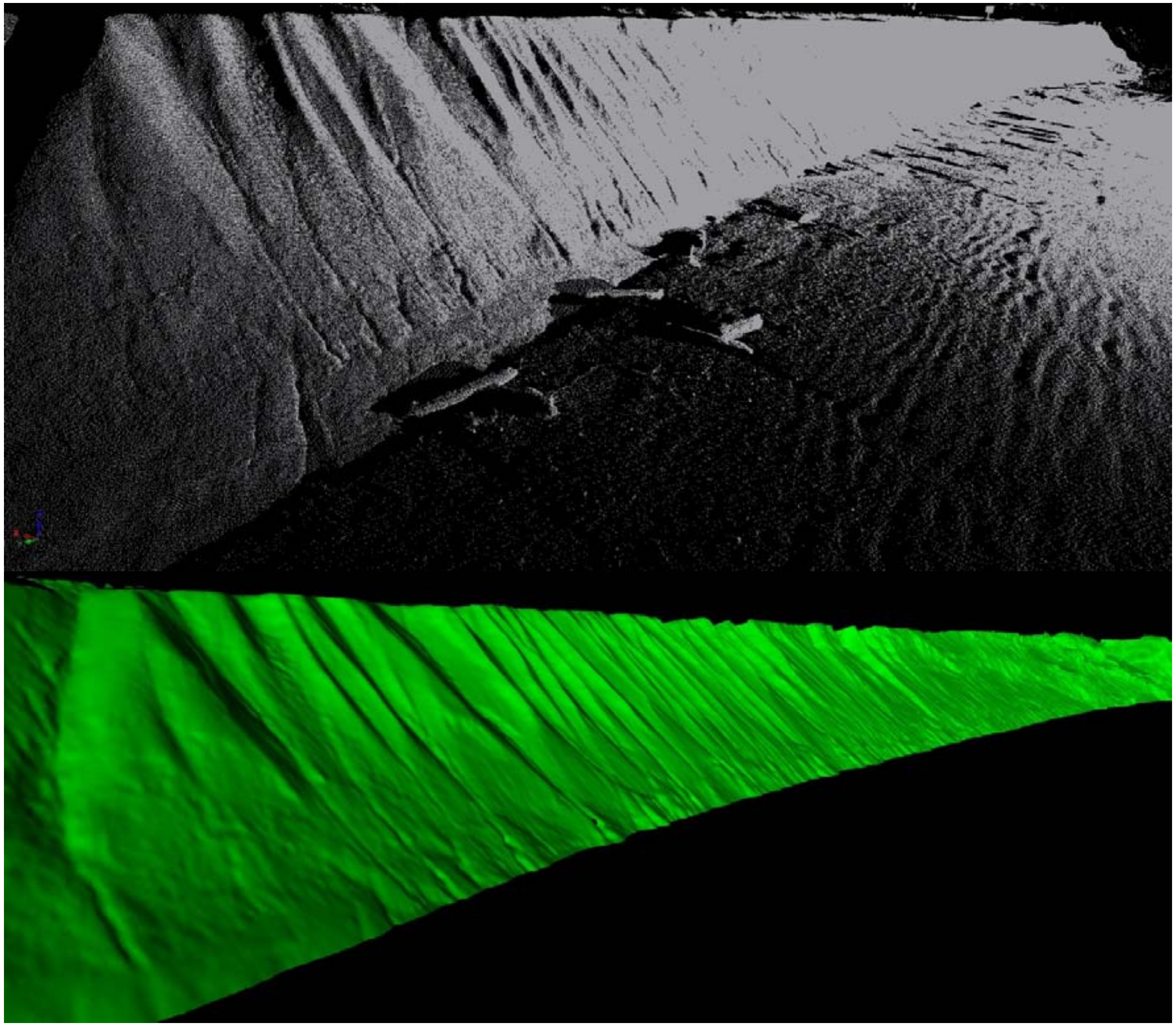
# Pile Testing Berm – Monitoring Test



# Pile Testing Berm – Monitoring Test

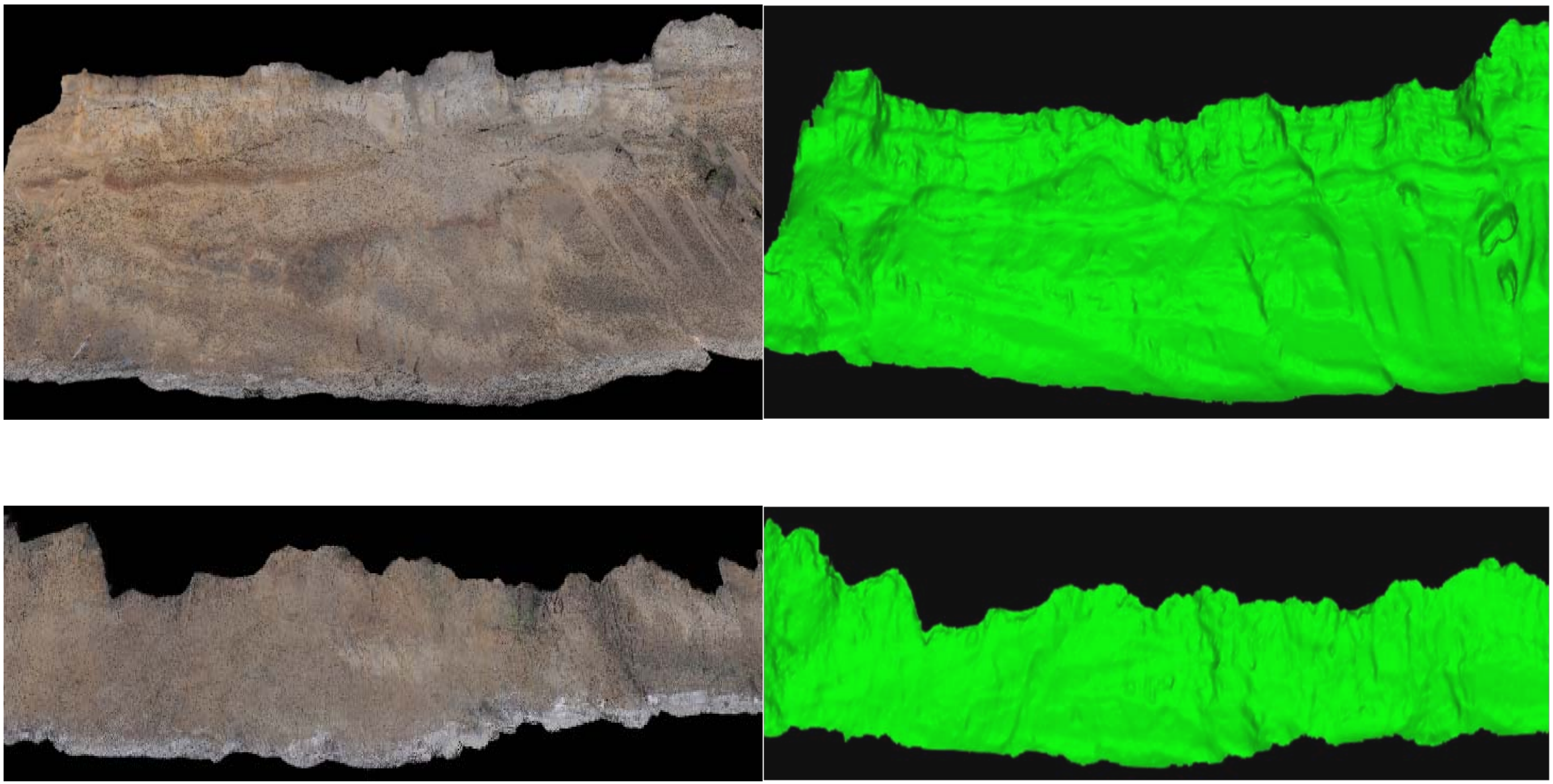


# Research Sites – Beverly Beach/Johnson Creek Landslide



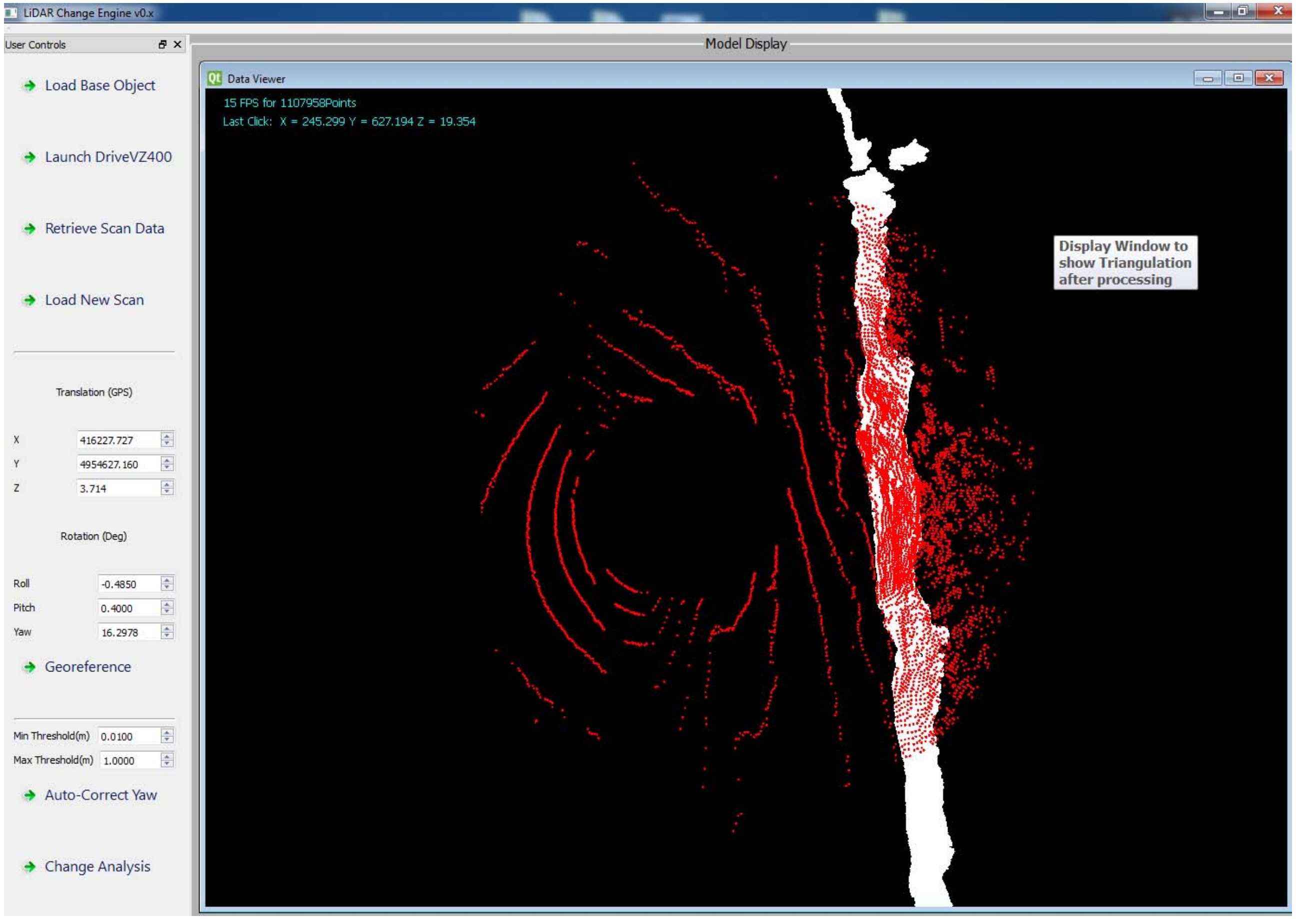
Point Cloud to 3D mesh for a section of Beverly Beach

# Research Sites – Johnson Creek Landslide



Examples of point clouds and their respective 3D triangulated meshes.

# Site Test – Johnson Creek Landslide




Geo-referencing and aligning a new scan to the baseline model in *Lichen*.

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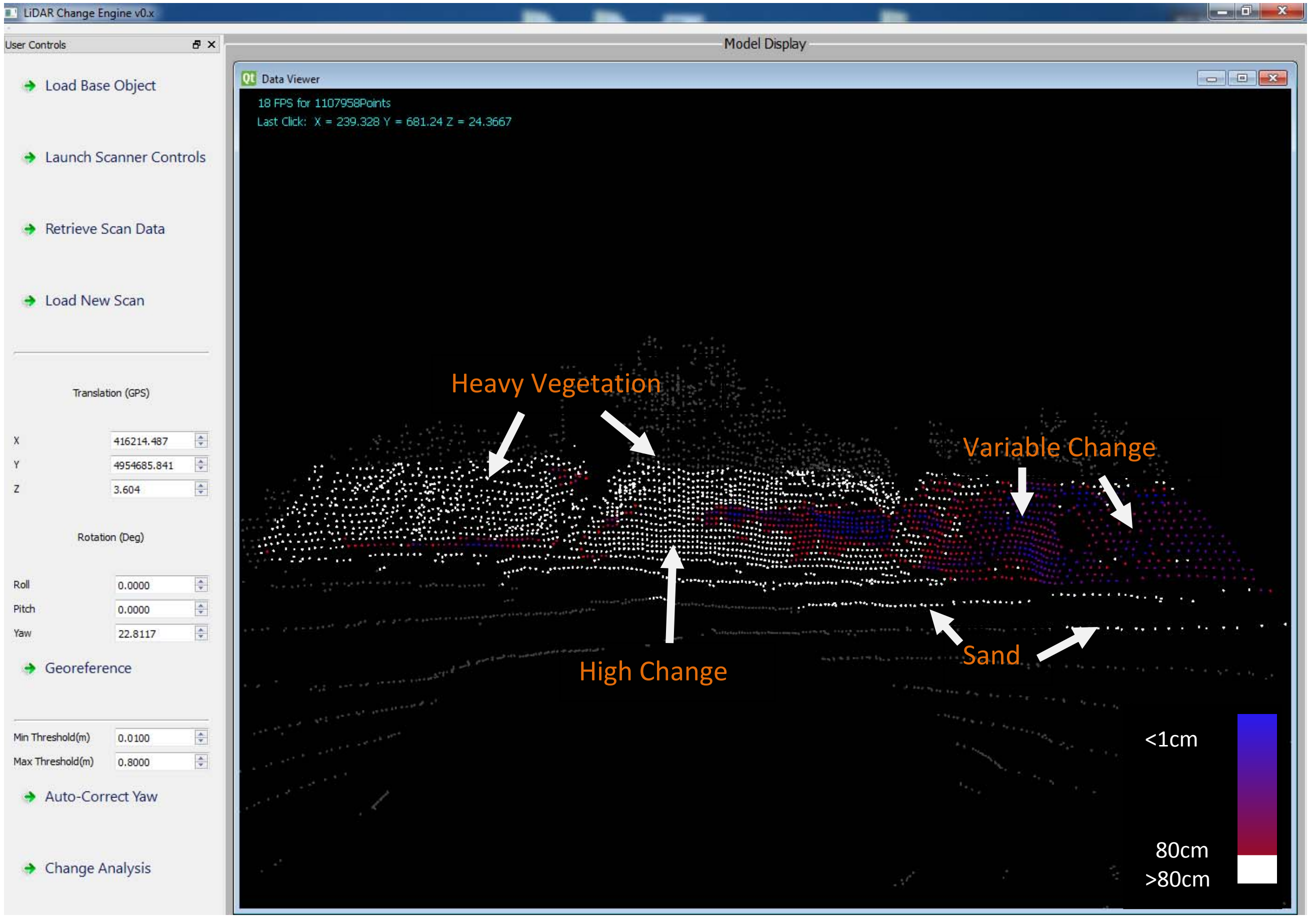
# Site Test – Johnson Creek Landslide




Change detection in the field of the new scan (August 2011 compared to baseline model (December 2010).

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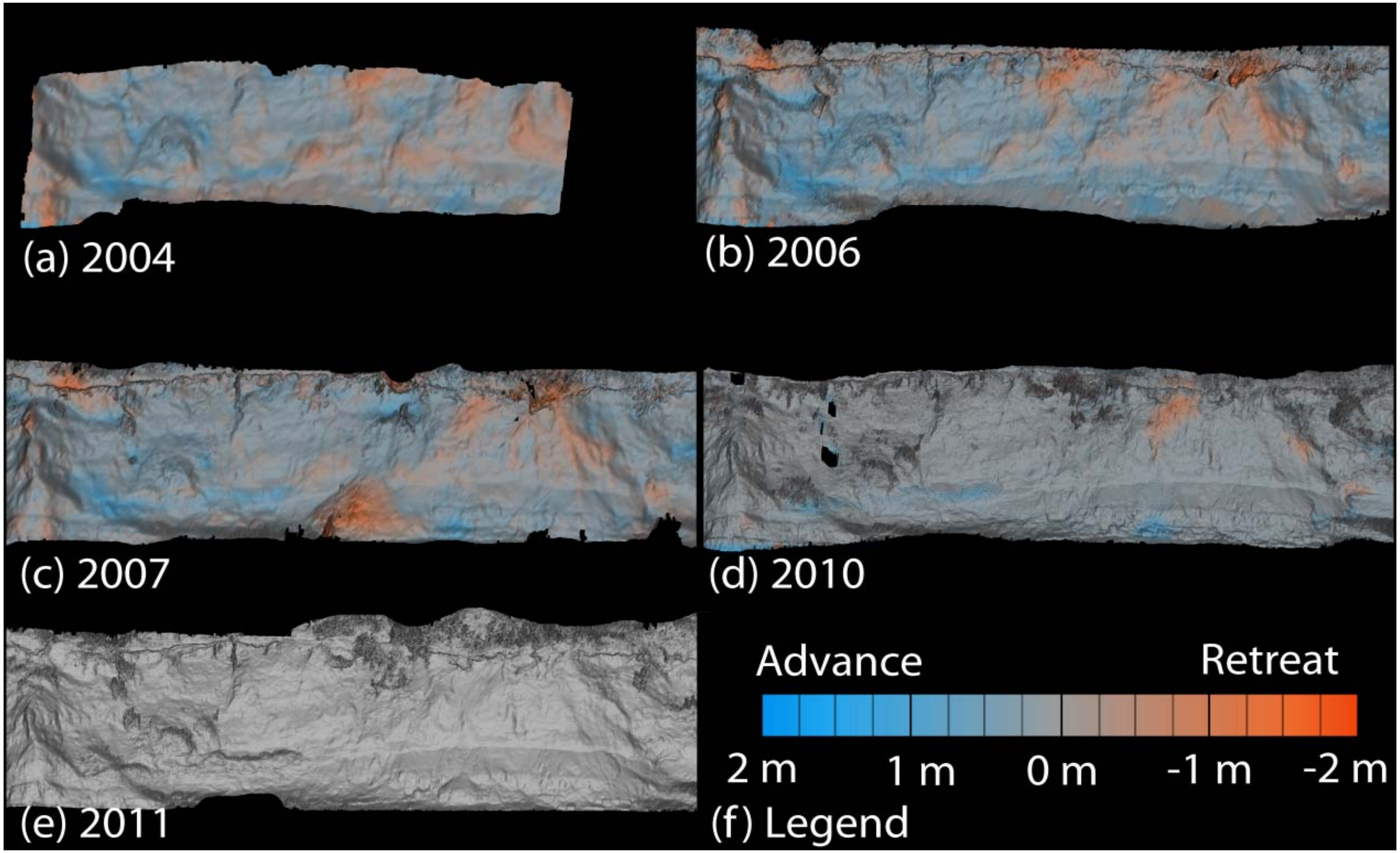
# Research Sites – Johnson Creek Landslide




Change analysis between LiDAR surveys showing advance and retreat of the cliff face at the North Section (Northing 4,954,580 m to 4,954,650m).

# Conclusions

1. Developed software that provides immediate, visual results to field crews and researchers.

2. Enabled real-time change detection for TLS systems
   a) Non-fixed position (e.g. GPS)
   b) Fixed position monitoring (e.g. control points)

3. Improved field data collection
   a) Reduced redundant data collection & processing
   b) Minimal impact to field times implementing methodology

4. Provided users with in-field quality control over new data

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# Importance of GPS real-time network technology

1. Need fast, accurate positioning information
2. Each overview scan is approximately 2 minutes
3. Sites can change substantially (e.g. Johnson Creek landslide) so survey control is unstable
4. Limited low-tide window on coast
5. Helps keep each survey independent
6. Limited field crew, resources, and survey control

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# Foreseeable Applications

1. Landslide hazard analysis

2. Coastal region monitoring projects

3. On-site monitoring of construction progress

4. Quality Control
    a) As-built
    b) 3D design to manufactured comparison

5. Disaster & Hazard Monitoring
    a) Collapsed buildings/Rescue scenarios
    b) Remediation & cleanup

# Current and Next Steps

1. Report Feedback & Modification

2. Improve *Lichen*
   a) Modify monitor file sizes
   b) Direct link to GPS data
   c) Improve customization options
   d) Increase functionality of distance & color scaling
   e) Compare additional change algorithms\evaluation. Potentially include open source versions

3. Incorporate user feedback & requests where possible

4. Disseminate findings and software

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# Special Thanks