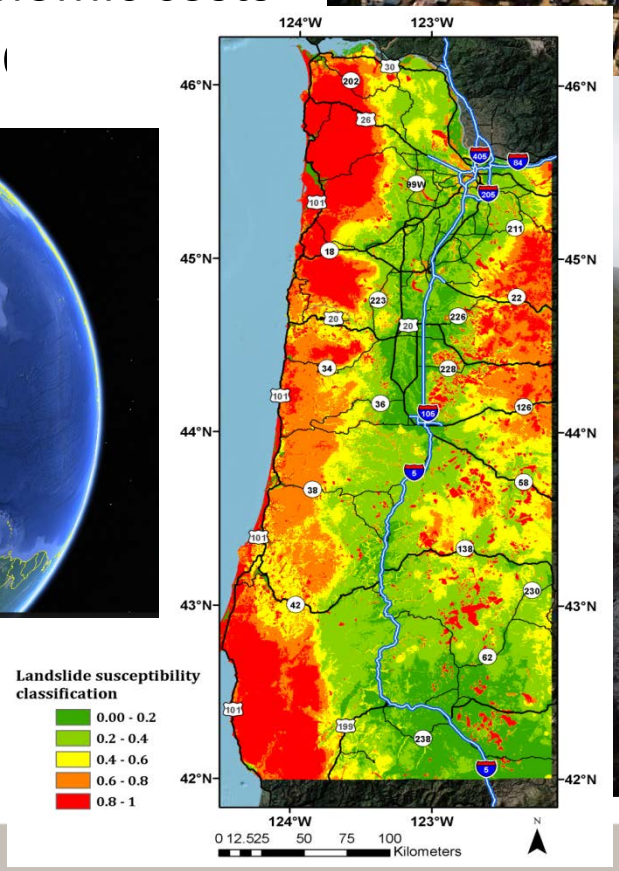
Advanced change analysis algorithms for landslide and erosion evaluation

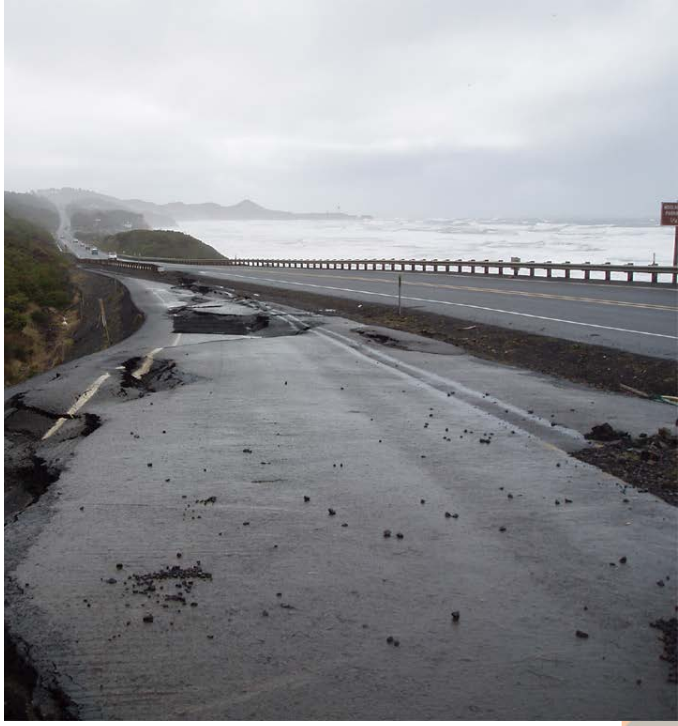
Michael J. Olsen
Eric HI and Janice Hoffman Faculty Scholar
School of Civil and Construction Engineering
Oregon State University

JALBTCX 2015

Landslides

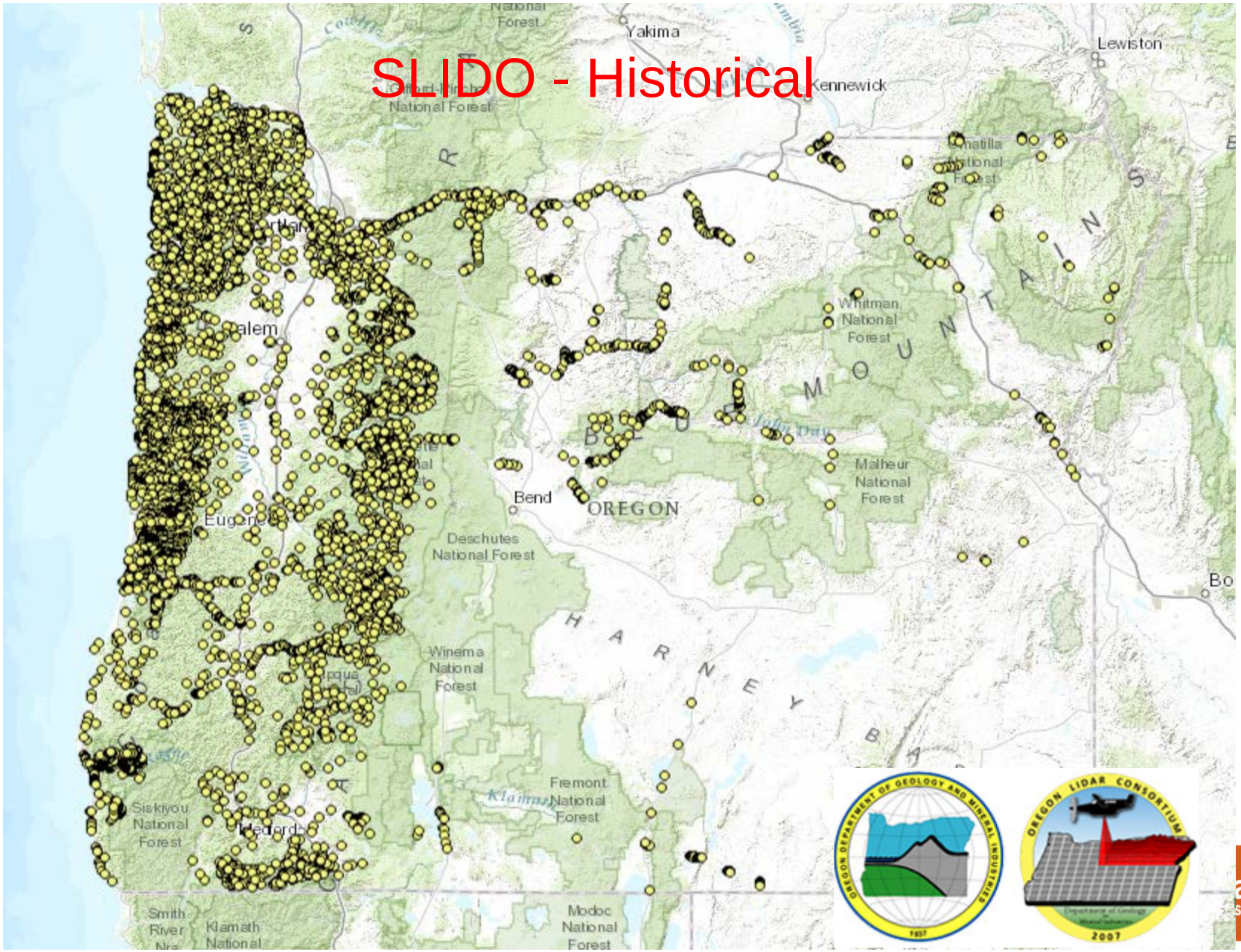
- A persistent problem that results from downward sliding of earth mass causing:
- Loss of life, home, & property
- Infrastructure instability
- Significant annual economic costs
- Earthquake? Rainfall?

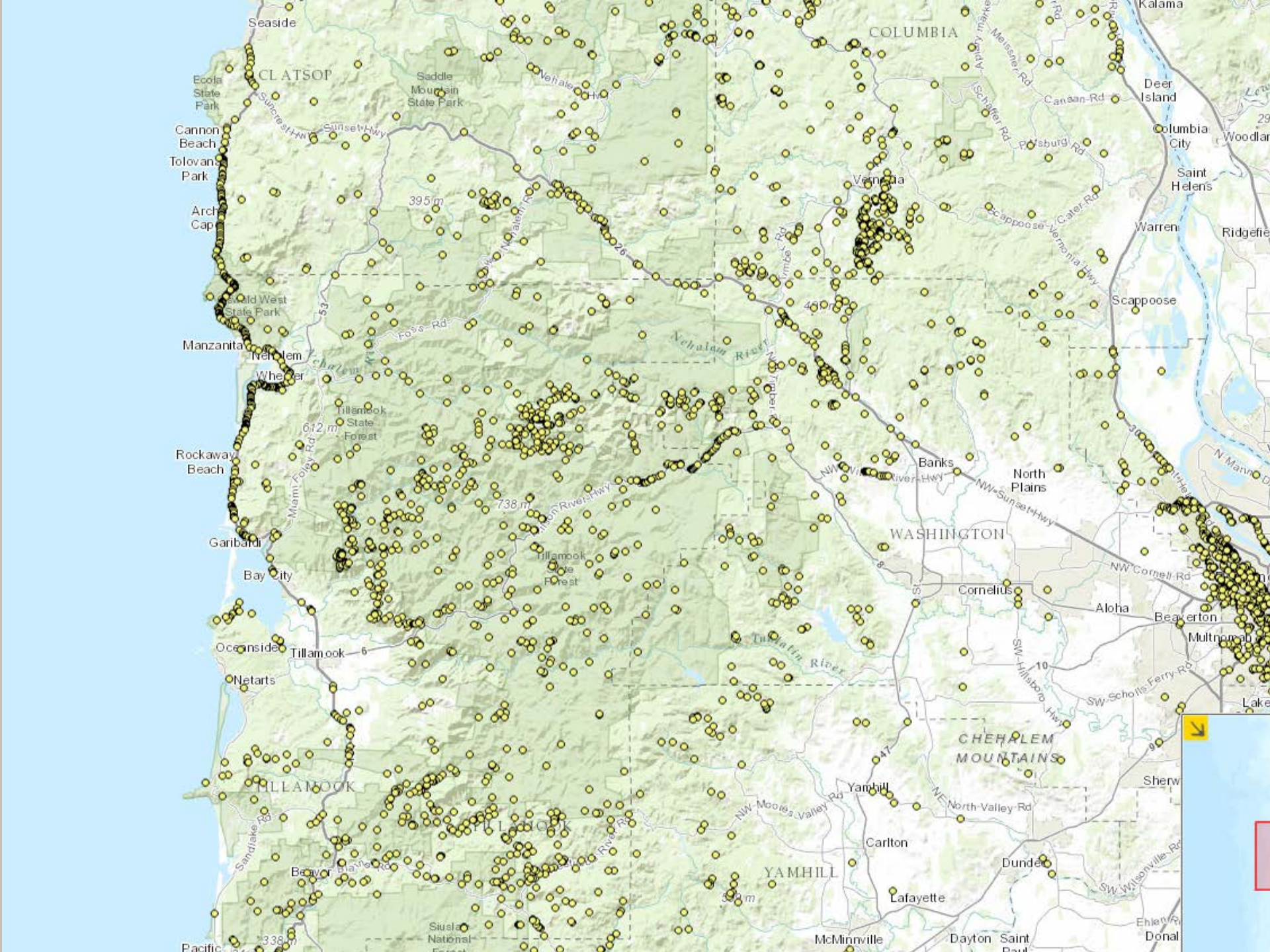




http://landslides.usgs.gov

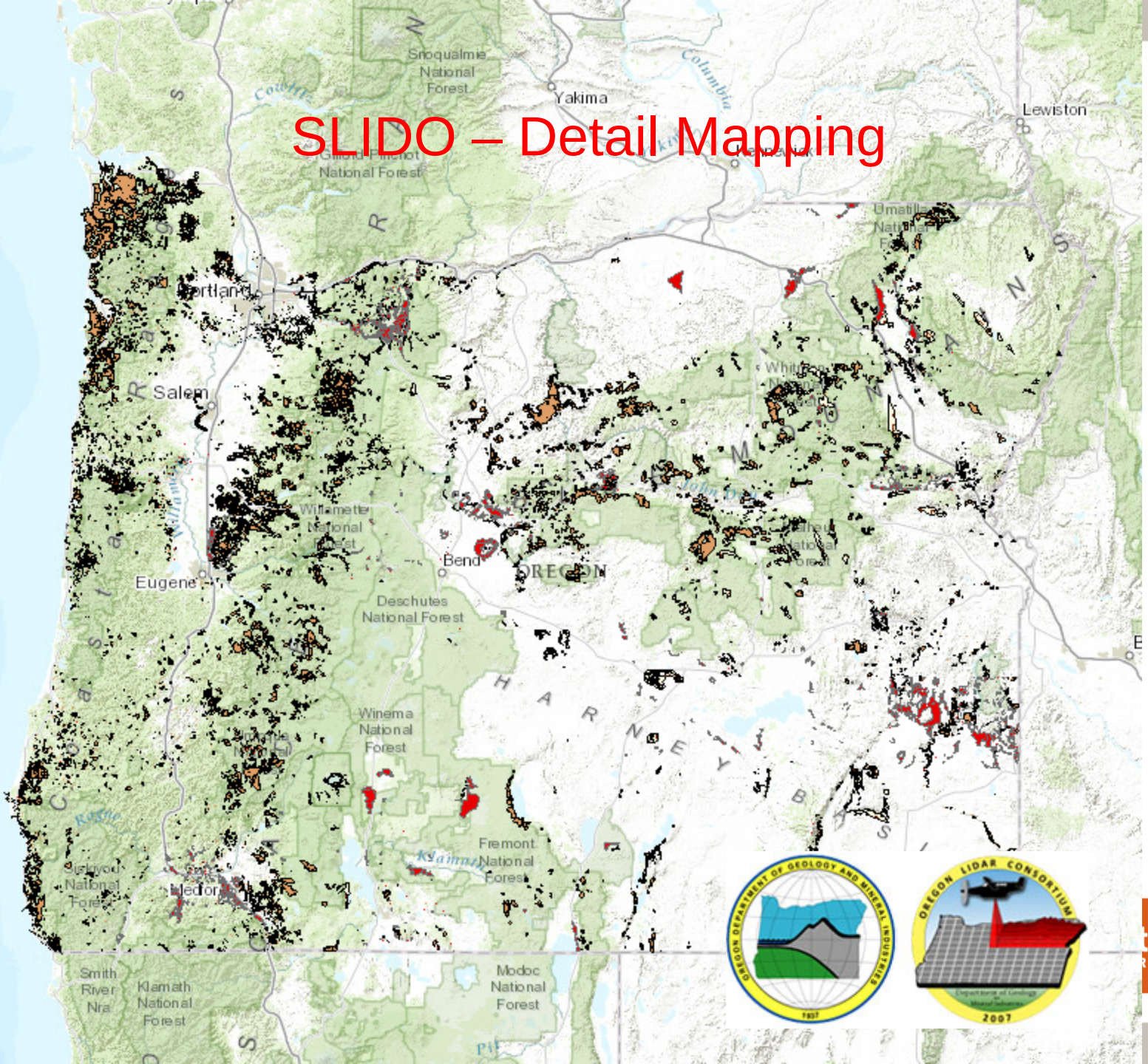
SLIDO - Historical

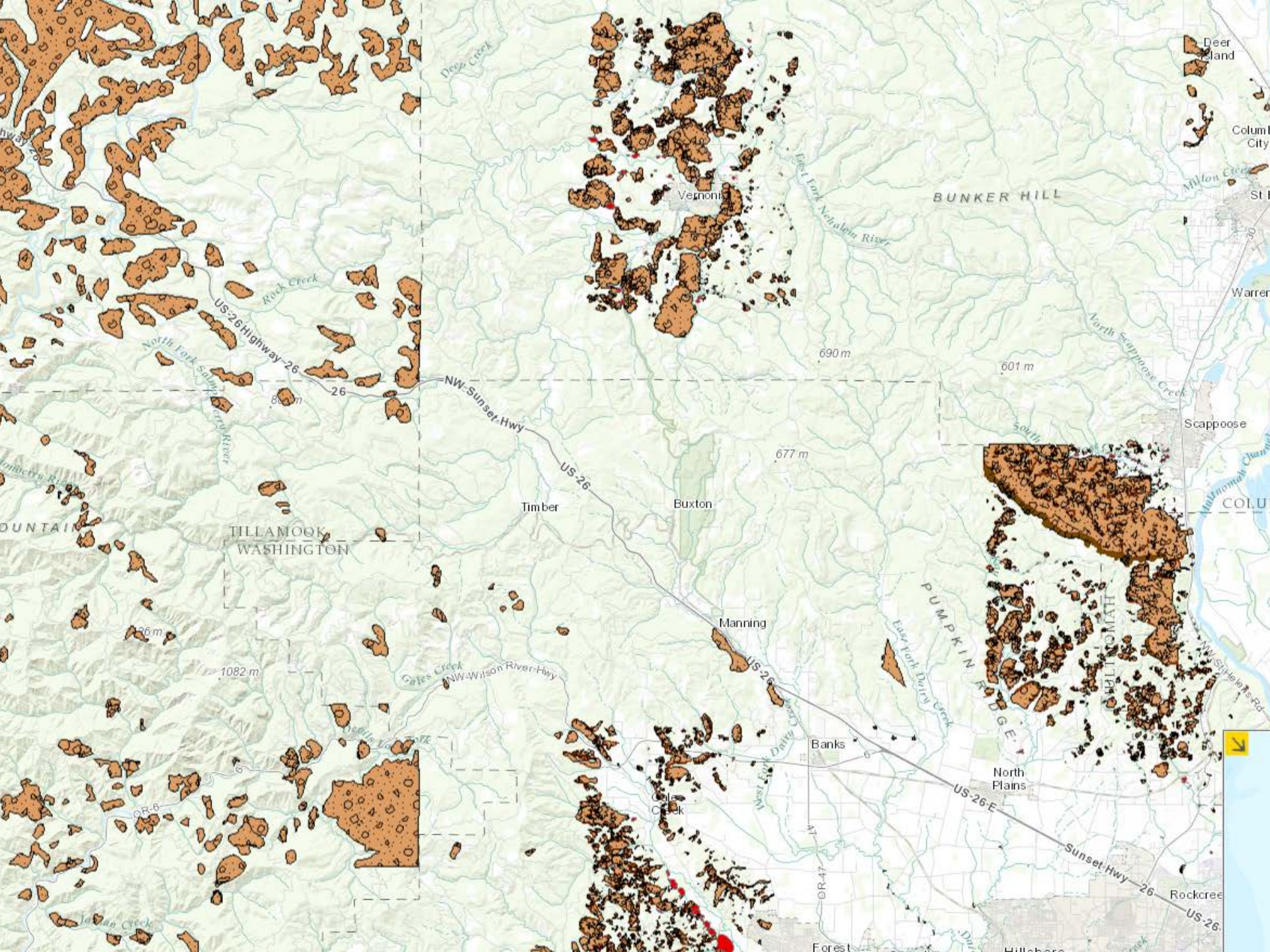




Seaside
CLATSOP
Ecola State Park
Saddle Mountain State Park
Cannon Beach
Tolovana Park
Arch Cape
Manzanita
Nehalem
Wheeler
Rockaway Beach
Garibaldi
Bay City
Oceanside
Tillamook
Netarts
TILLAMOOK
Beaver
Pacific
Tillamook State Forest
Siuslaw National Forest
Nehalem River
Tualatin River
COLUMBIA
Vernonia
Banks
North Plains
WASHINGTON
Cornelius
Aloha
Beaverton
Multnomah
Yamhill
Carlton
YAMHILL
Lafayette
McMinnville
Dayton
Saint Paul
Dundee
CHEHALEM MOUNTAINS
Scappoose
Warren
Saint Helens
Columbia City
Deer Island
Kalama
Woodlan
Ridgefie
Sherw
Donal
Sunset Hwy
Nehalem Hwy
Foss Rd
Miami Foley Rd
Tillamook River Hwy
NW Sunset Hwy
NW Cornell Rd
SW Hillsboro Hwy
SW Scholls Ferry Rd
NW Mooies Valley Rd
NE North Valley Rd
SW Wilsonville Rd
Canaan Rd
Scappoose-Vernonia Hwy
Meissner Rd
Schaffer Rd
395 m
612 m
738 m
338 m

SLIDO – Detail Mapping




Deer Island
Deep Creek
Vernonia
East Fork Nehalem River
BUNKER HILL
Milton Creek
Warren
Rock Creek
US-26 Highway-26
North Fork Salmon River
26
NW-Sunset-Hwy
690 m
601 m
North Scappoose Creek
Scappoose
677 m
US-26
Timber
Buxton
TILLAMOOK
WASHINGTON
Manning
PUMPKIN RIDGE
East Fork Dairy Creek
1082 m
Gales Creek
NW-Wilson River-Hwy
Banks
North Plains
US-26-E
Sunset-Hwy
26
Rockcree
OR-6
OR-47
Forest

Landslide Monitoring Techniques

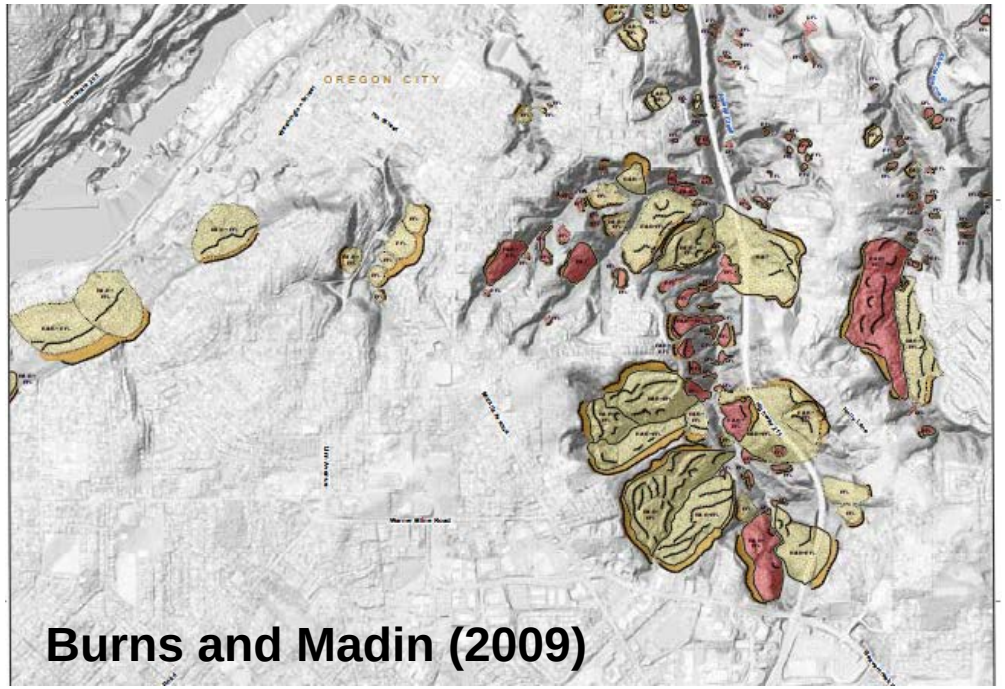
- Methods of monitoring landslide techniques
  - Total station markers
  - Inclinometers
    - Subsurface detail, limited spatially
  - GPS
    - Surface detail, limited spatially
  - Interferometer Synthetic Aperture Radar (InSAR)
    - Surface detail, limited temporally and by forest
  - LIDAR

http://www.itm-soil.com.au/content/in-place-inclinometer-0

Wang, 2011

LIDAR Applications for Landslides

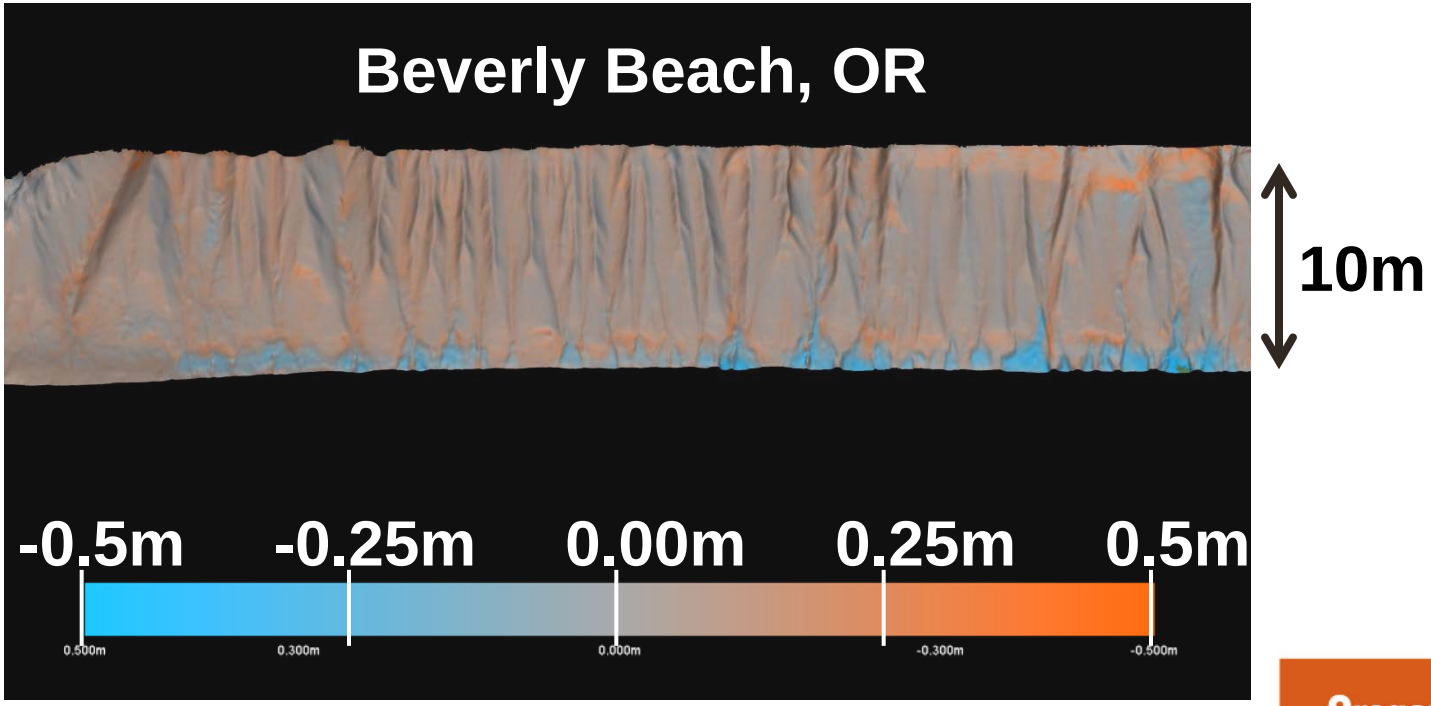
1. Detection and characterization of mass movements
2. Hazard assessment and susceptibility mapping
3. Modeling (Dunning, Himalaya)
4. Monitoring



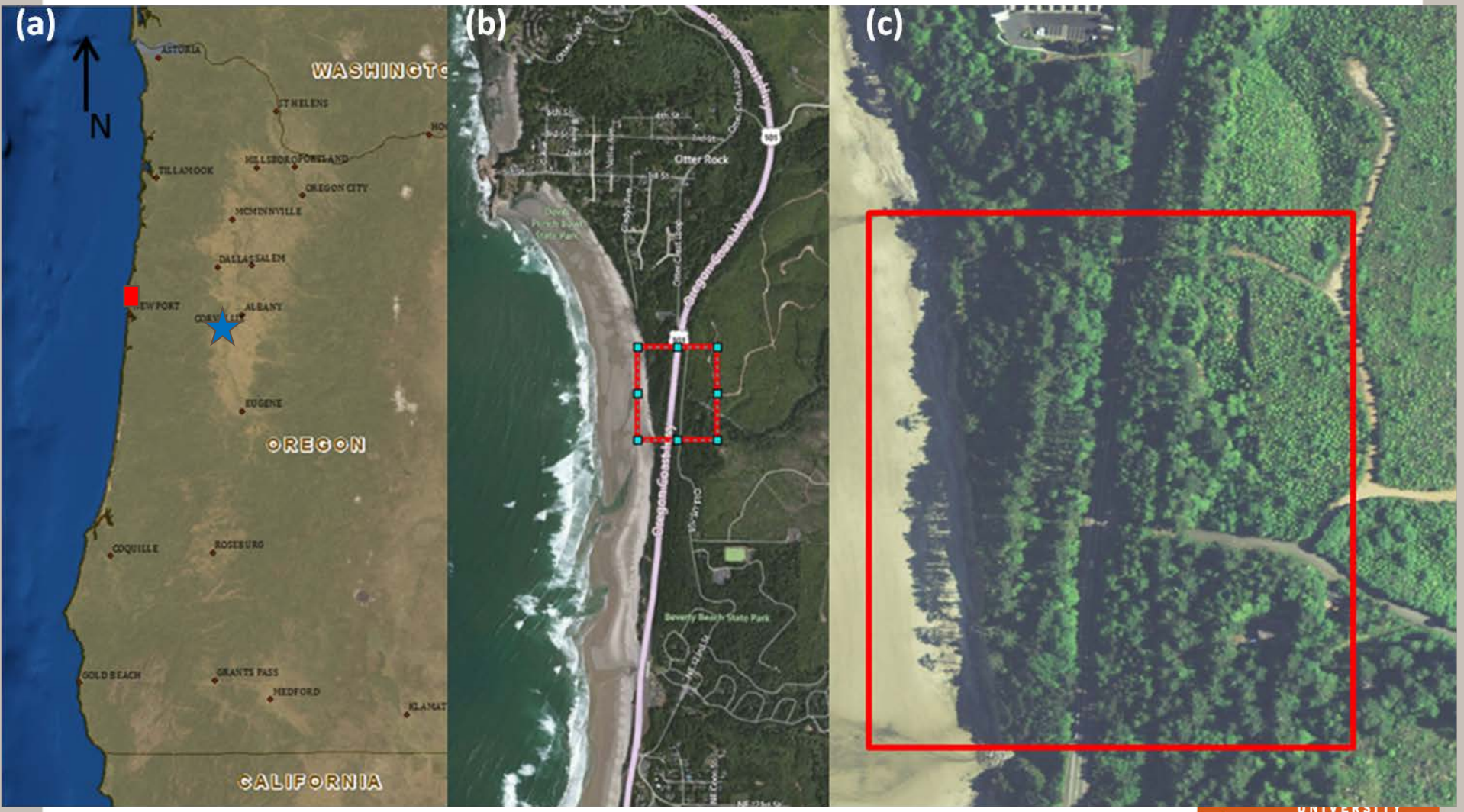
Burns and Madin (2009)

Erosion Monitoring (e.g. Collins, Lim, Rosser, Olsen, Young)

- Displacement mapping
- Volume determination
- Cliff failure & stability

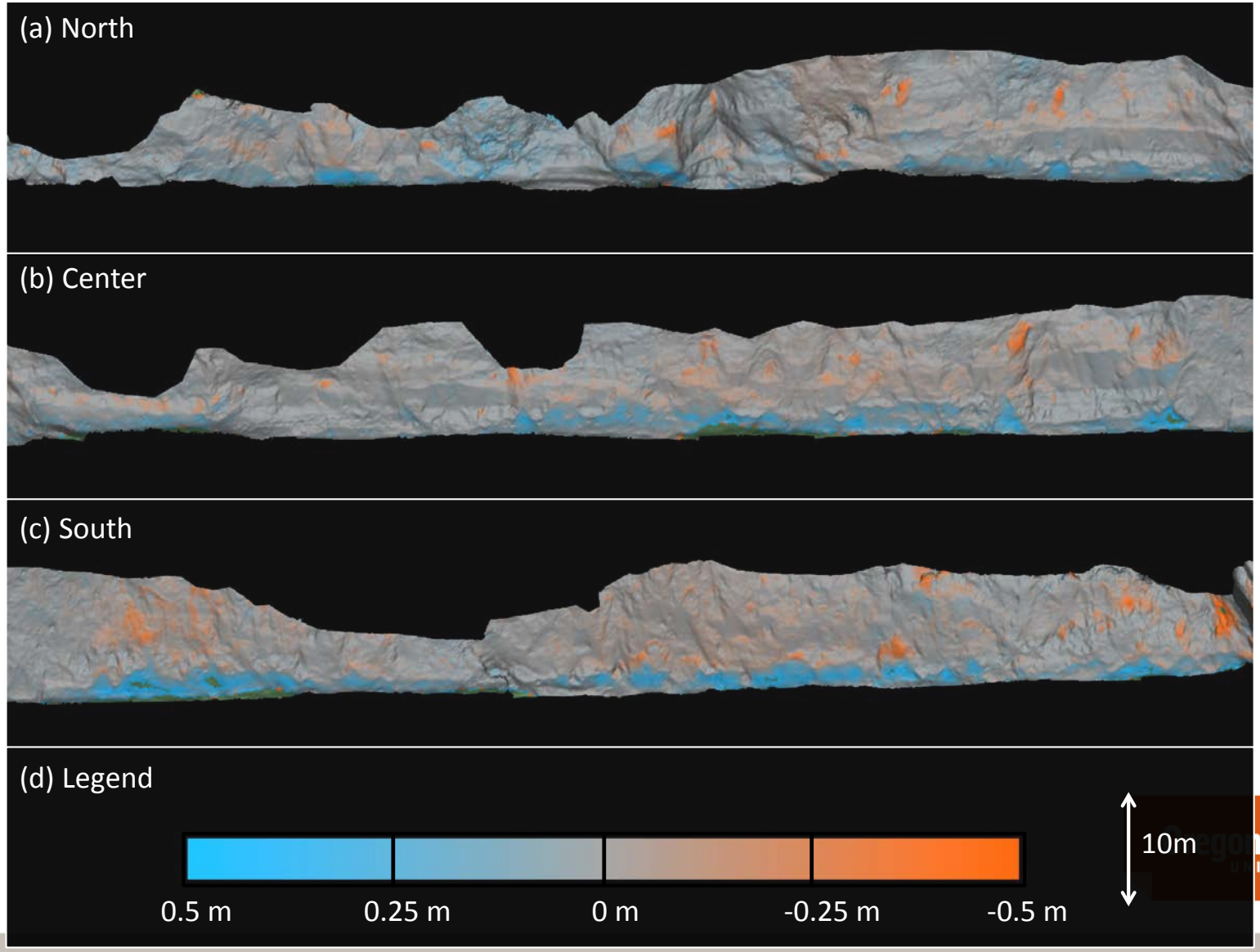


Study Area

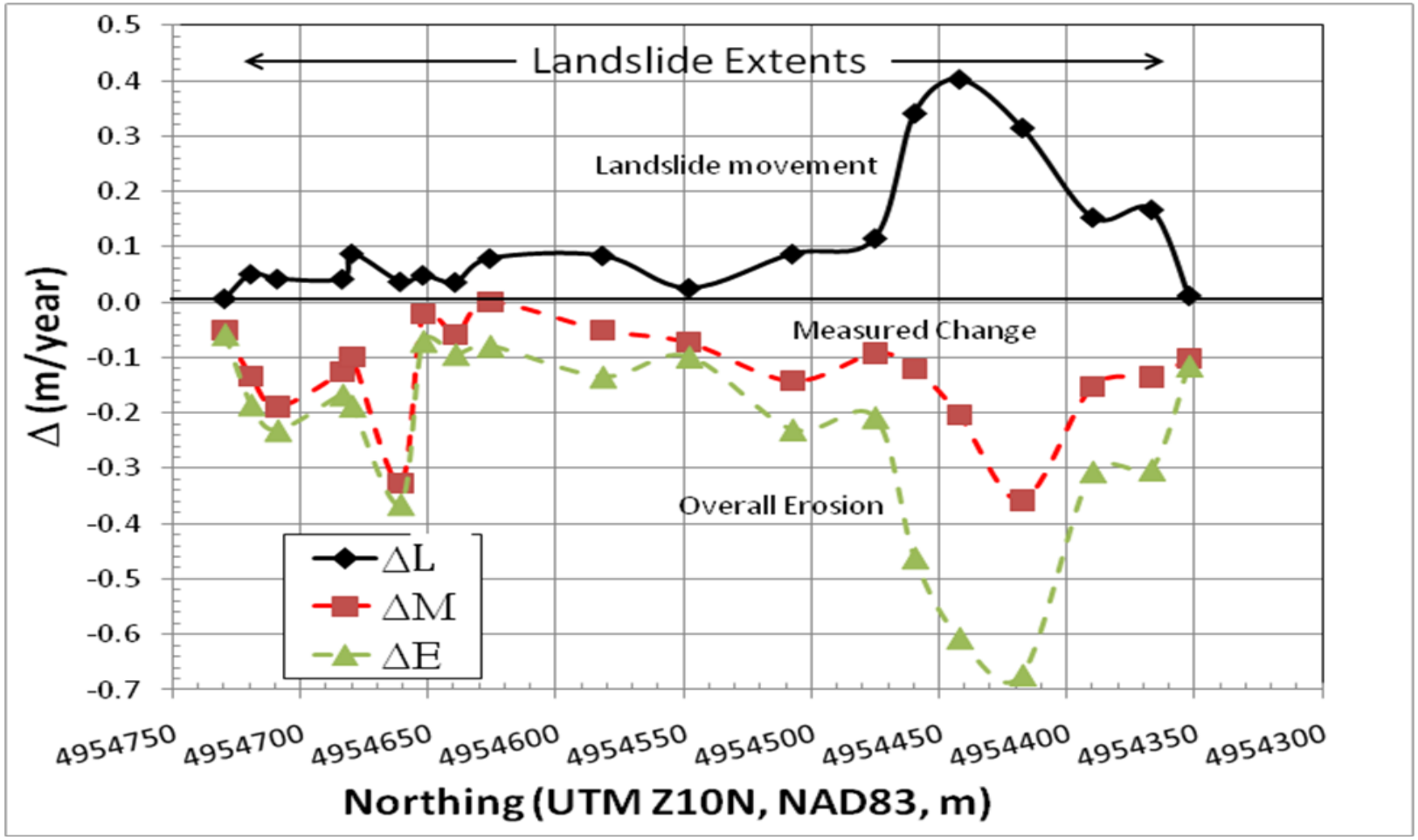


Highly active coastal landslide with rigid natural features on top of bluff.

Bluff face change Apr12 to Nov12



Landslide movement (2007 to 2011)



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Presentation Outline & Bibliography

- Olsen, M.J., (2015). "In-Situ change analysis and monitoring through terrestrial laser scanning," *Journal of Computing in Civil Engineering*, 29(2), 04014040, ASCE. doi:10.1061/(ASCE)CP.1943-5487.0000328

- Conner, J., & Olsen, M.J., (2014). "Automated quantification of distributed landslide movement using circular tree trunks extracted from terrestrial laser scan data," *Computers and Geosciences,* 67, 31-39. doi:10.1016/j.cageo.2014.02.007

- Leshchinsky, B., Olsen, M.J., & Tanyu, B. (2015). "Contour Connection Method for Automated Identification and Classification of Landslide Deposits," *Computers and Geosciences, 74, 27-38*. doi:10.1016/j.cageo.2014.10.007

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In-situ change detection using 3D Laser Scanning (Part I)

Olsen, M.J., (2015). “In-Situ change analysis and monitoring through terrestrial laser scanning,” Journal of Computing in Civil Engineering, 29(2), 04014040, ASCE. doi:10.1061/(ASCE)CP.1943-5487.0000328

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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Typical Change Analysis Approach

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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Presented 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 & registration)

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

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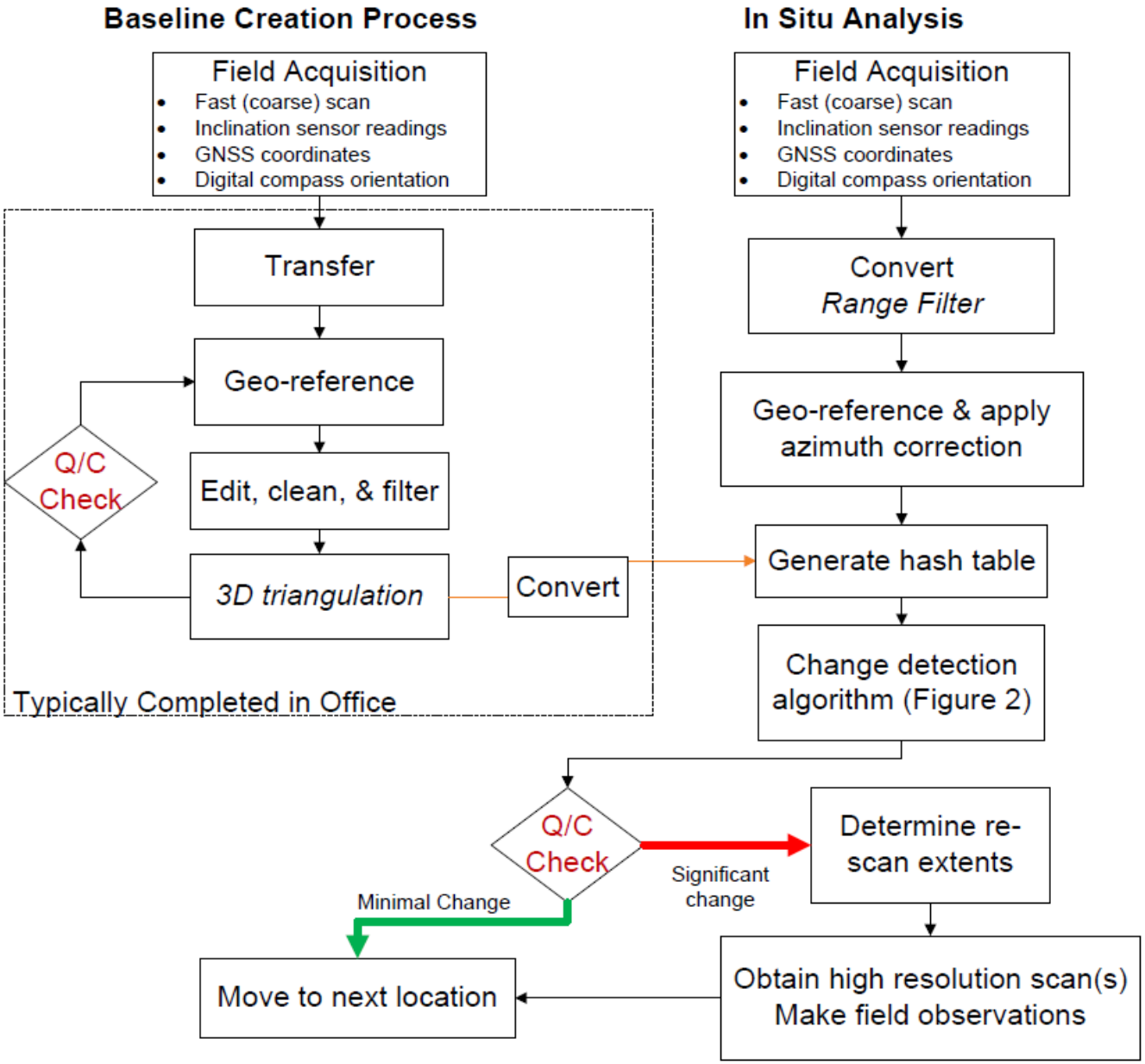
Liscan Workflow v1.1 10.22.2012



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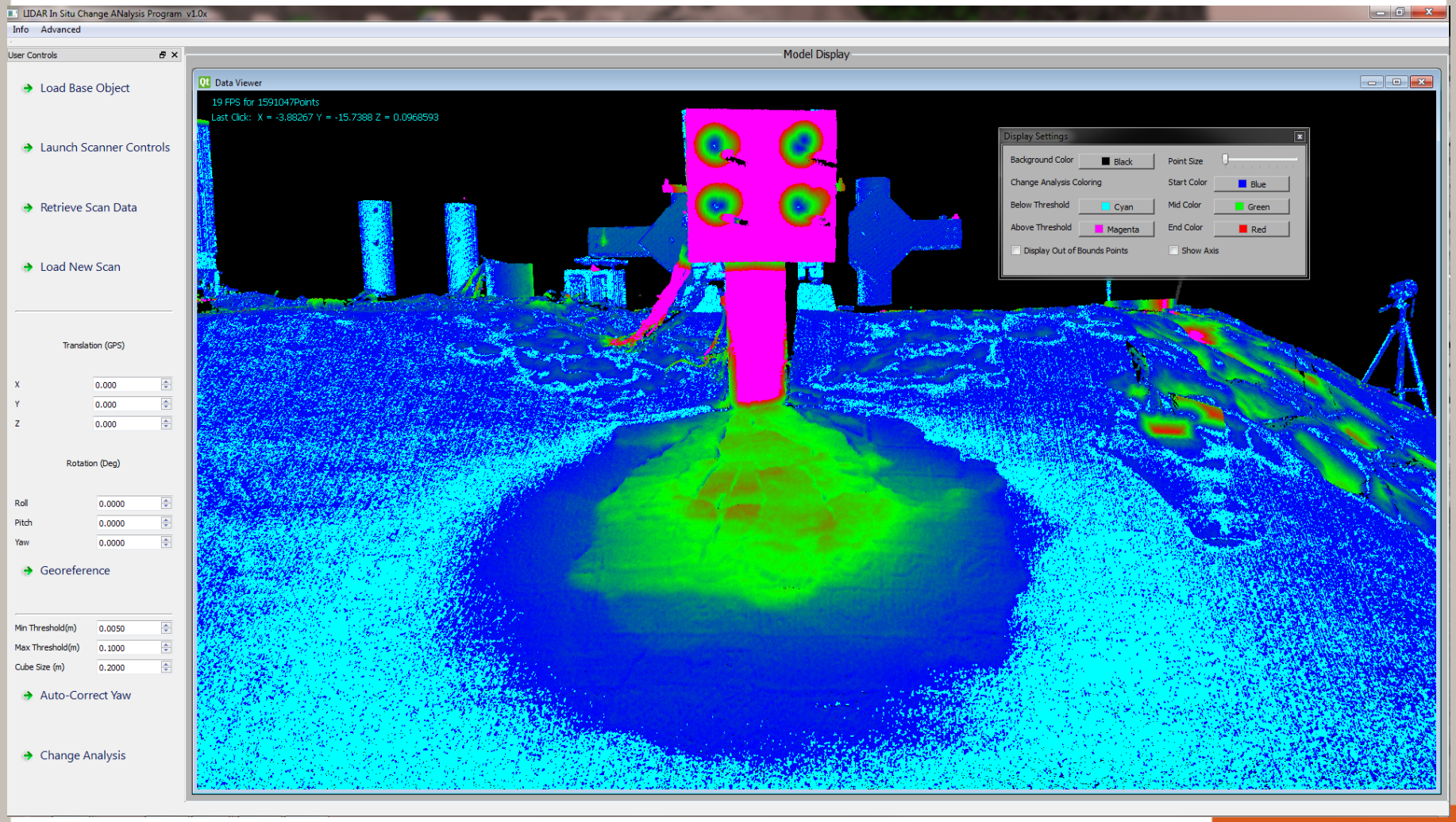
Liscan v1.0



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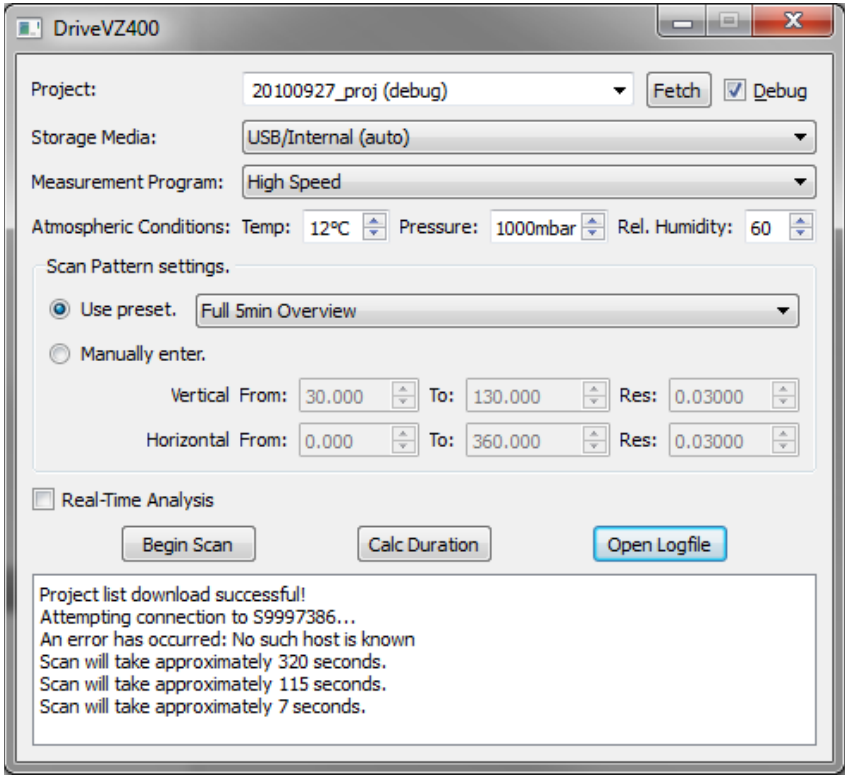
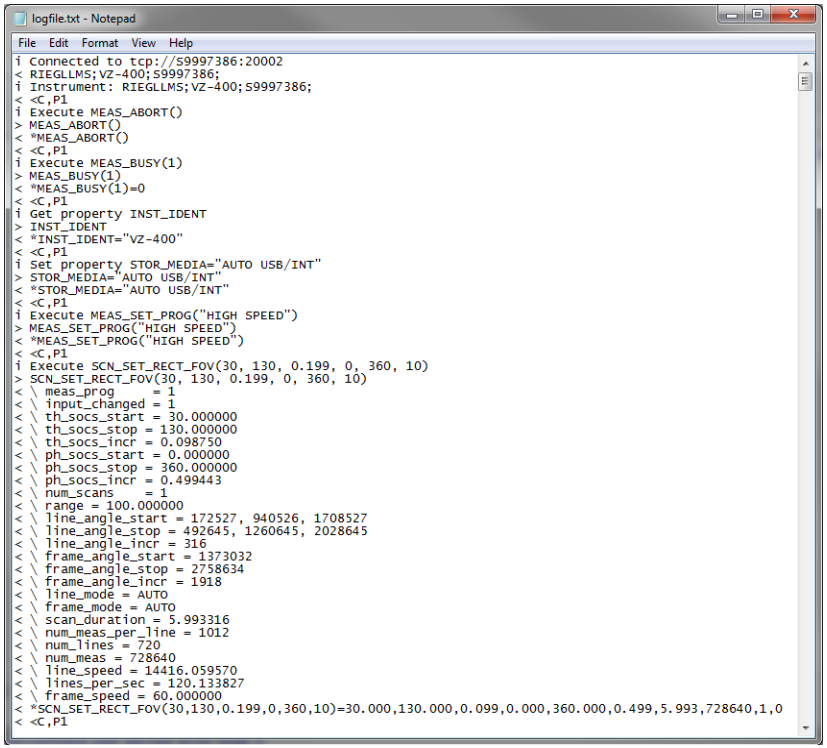
Scanner Controls GUI and Output





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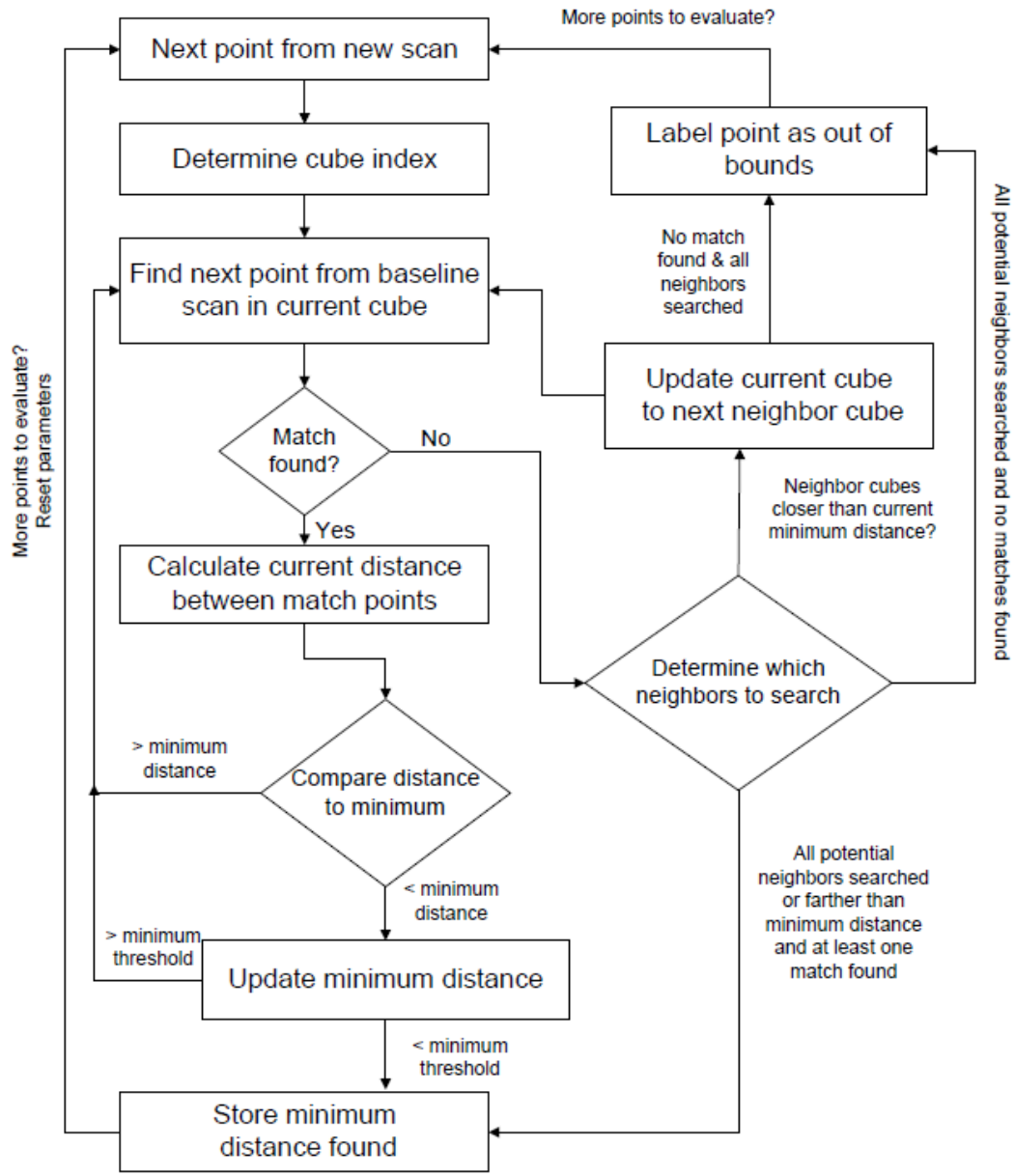
Geo-referencing

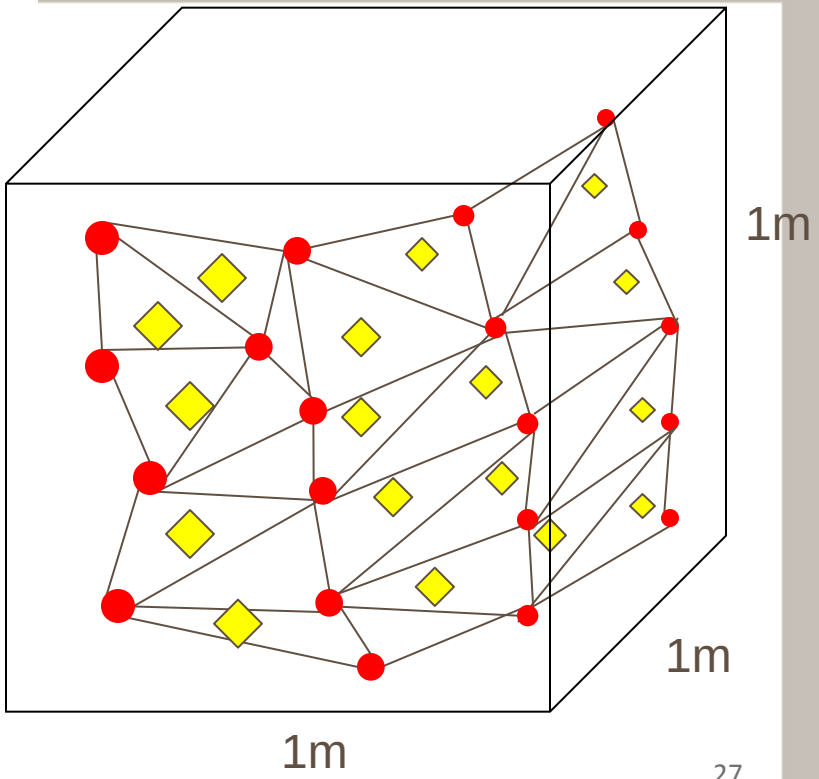
6 DOF

- 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)

Olsen, M., Johnstone, E., Kuester, F., Driscoll, N., and Ashford, S. (2011). ”New Automated Point-Cloud Alignment for Ground-Based Light Detection and Ranging Data of Long Coastal Sections.” *J. Surv. Eng.*, 137(1), 14–25.

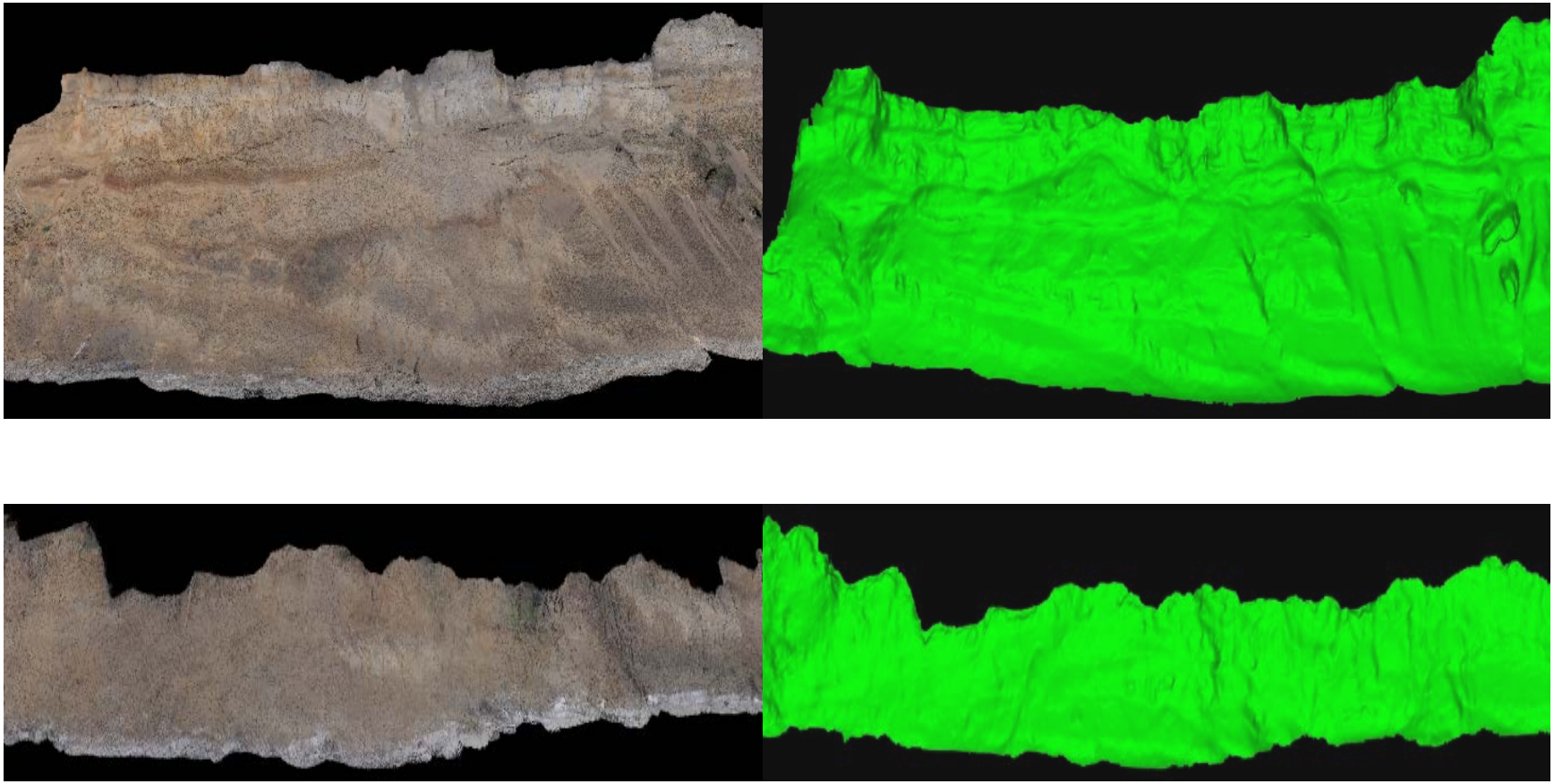
Change Detection Algorithm





Research Sites – Johnson Creek Landslide

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



Olsen, M.J., Johnstone E., & Kuester F. (2013). "Hinged, pseudo-grid triangulation method for long, near linear cliff analysis," *Journal of Surveying Engineering*, ASCE, 139(2), 105-109.

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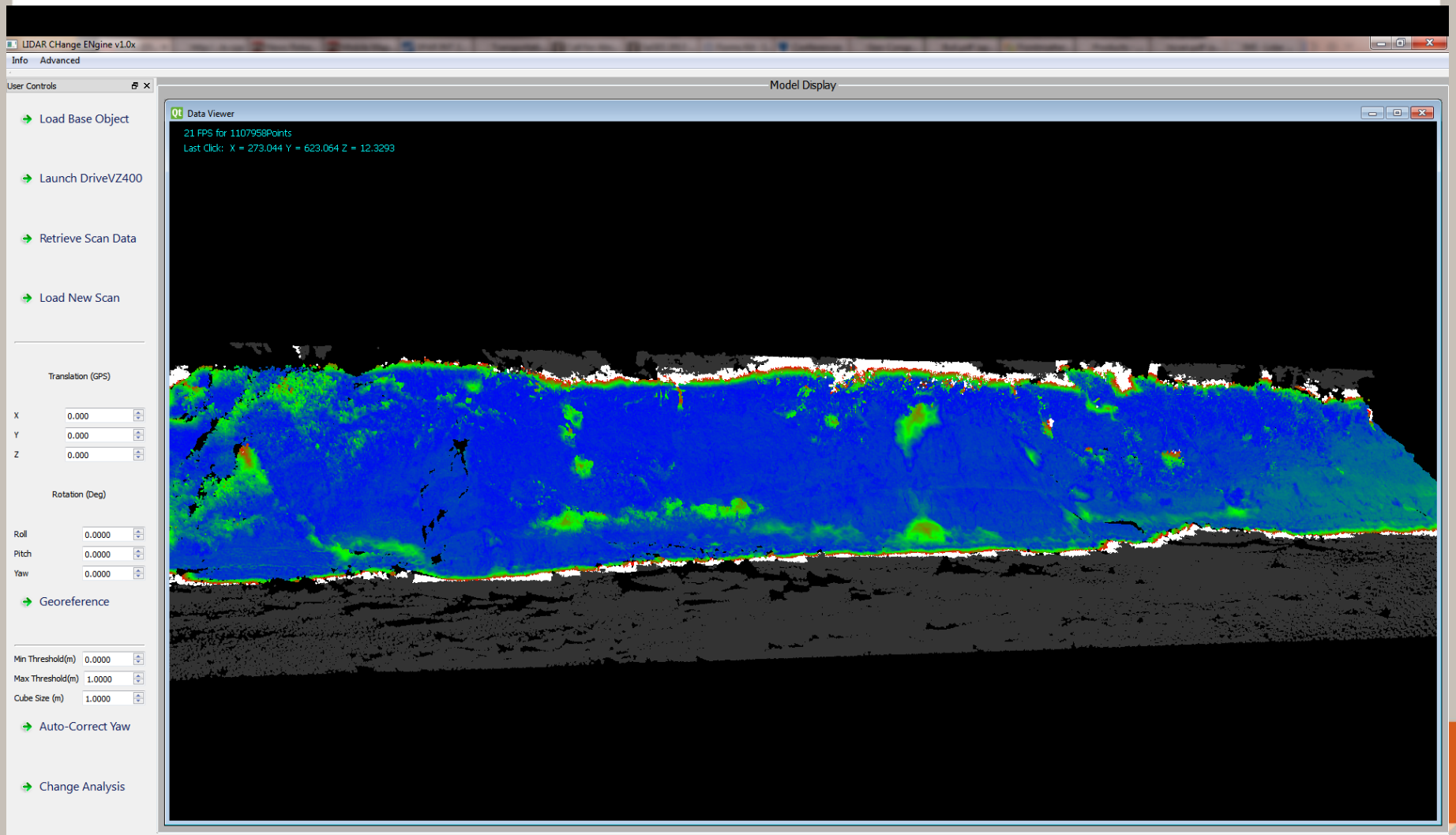
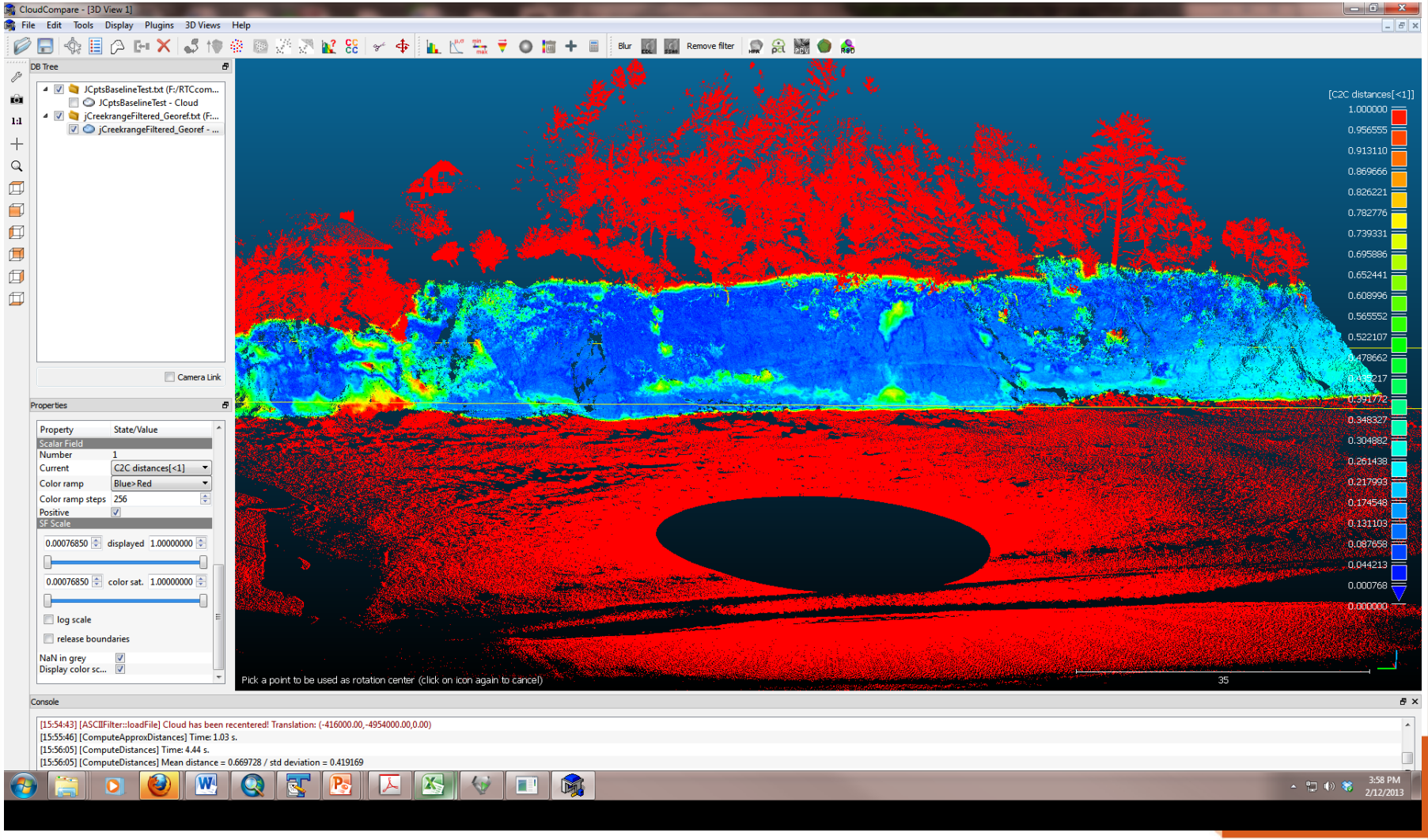
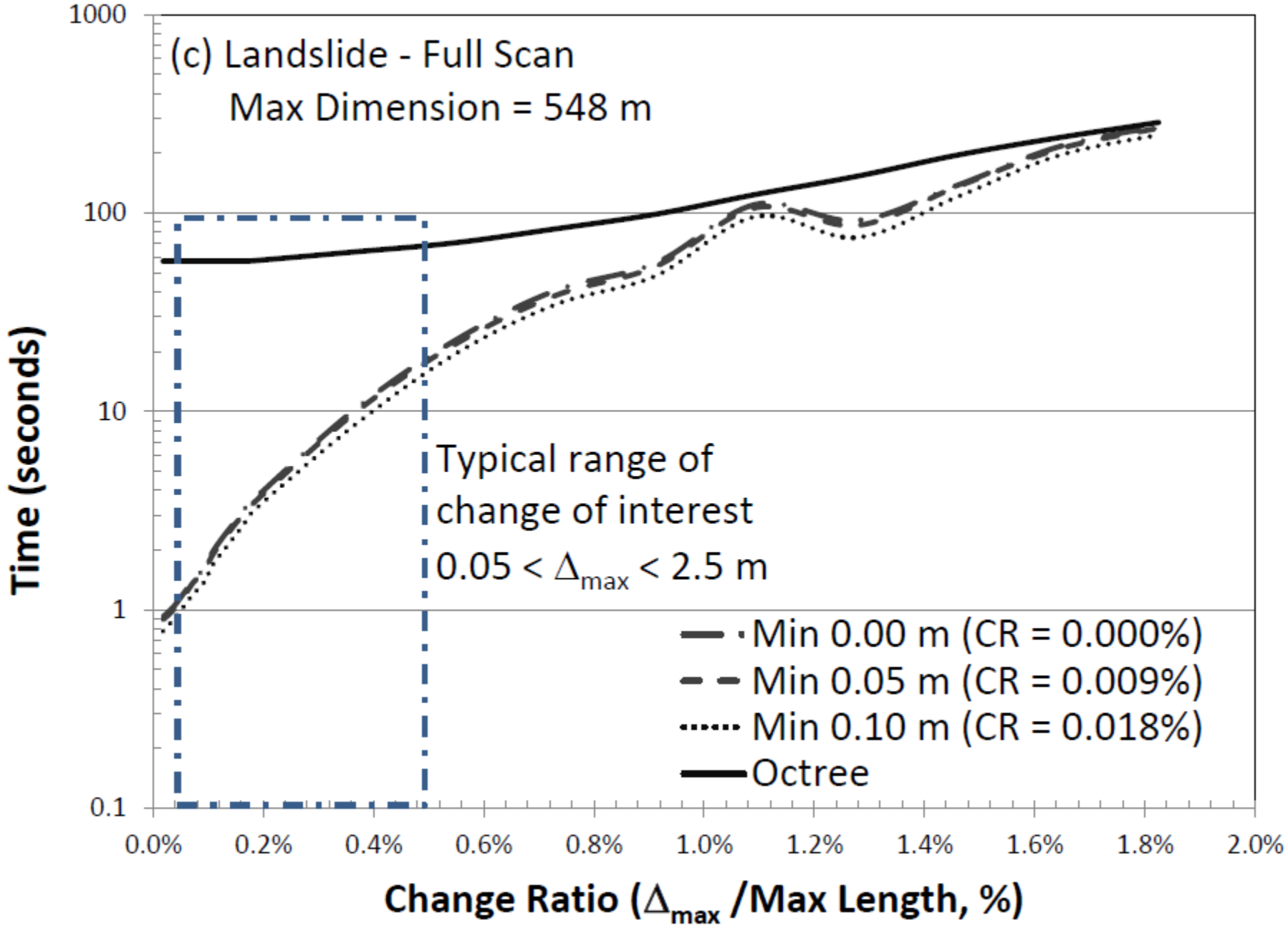
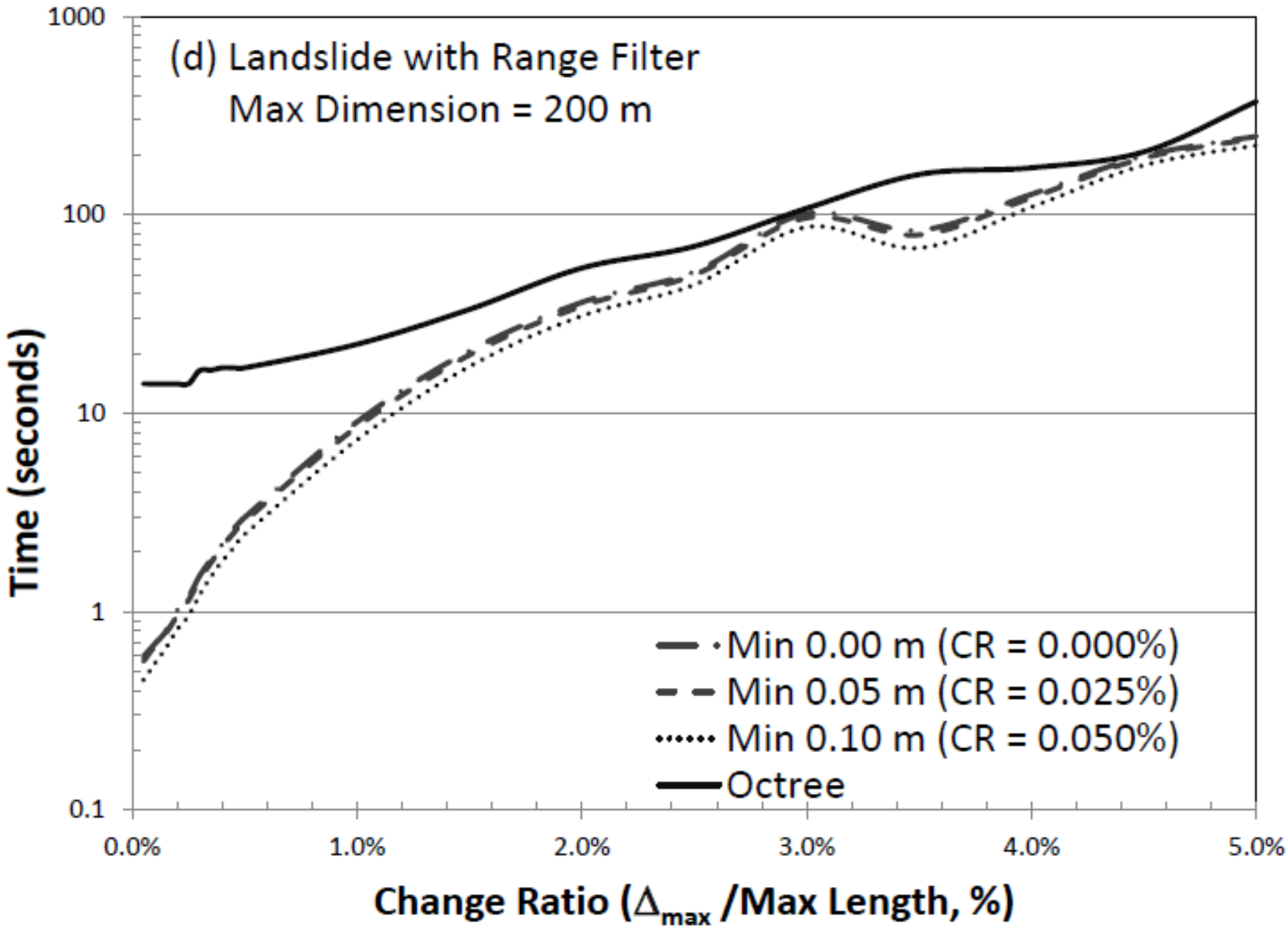
LISCAN (In-Situ Change)



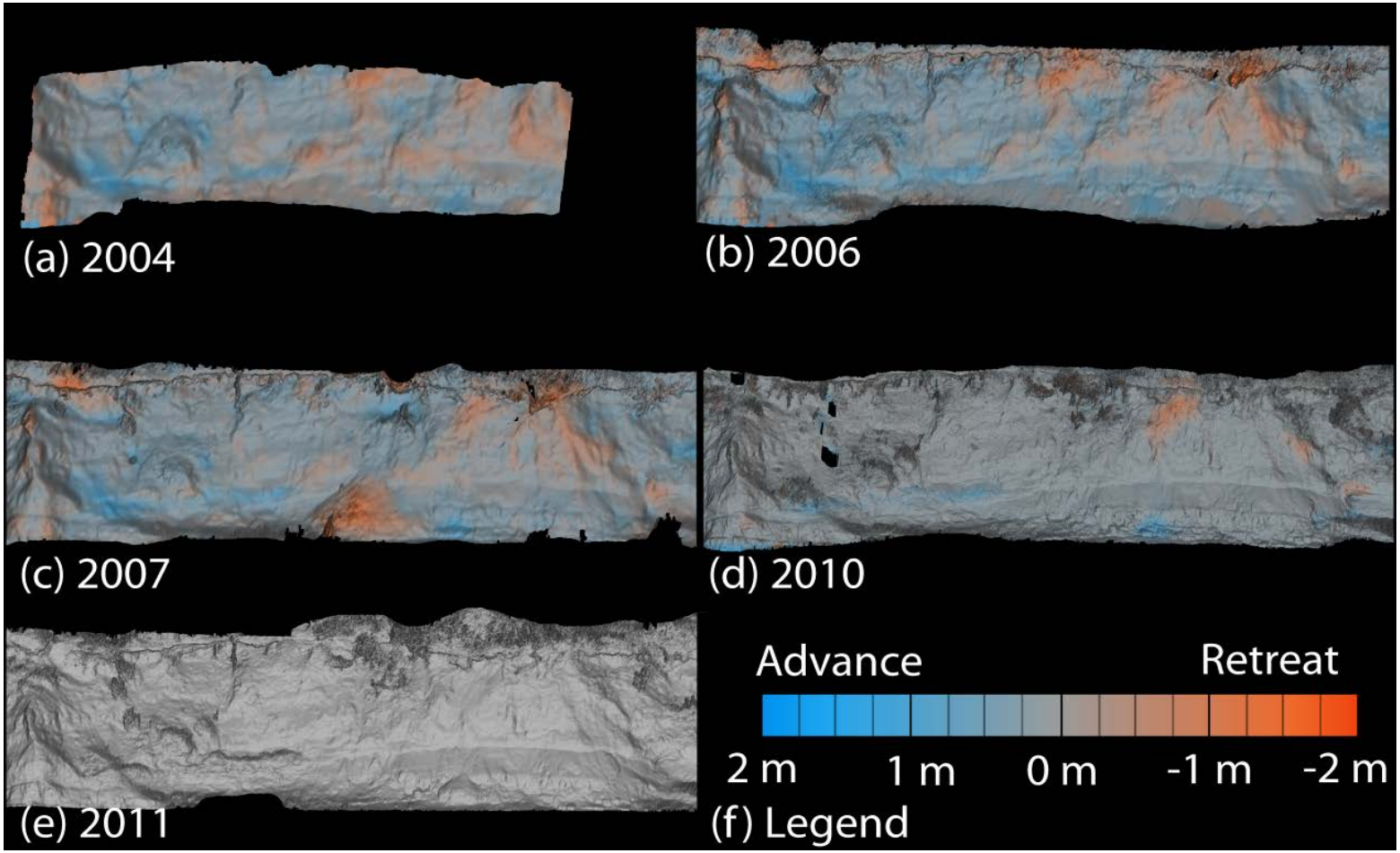
Cloud Compare




(c) Landslide - Full Scan
Max Dimension = 548 m
Typical range of
change of interest
0.05 < Δmax < 2.5 m
Min 0.00 m (CR = 0.000%)
Min 0.05 m (CR = 0.009%)
Min 0.10 m (CR = 0.018%)
Octree
Time (seconds)
1000
100
10
1
0.1
0.0%
0.2%
0.4%
0.6%
0.8%
1.0%
1.2%
1.4%
1.6%
1.8%
2.0%
Change Ratio (Δmax /Max Length, %)


(d) Landslide with Range Filter
Max Dimension = 200 m
1000
100
10
1
0.1
Time (seconds)
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
Change Ratio (Δ_{max} /Max Length, %)
Min 0.00 m (CR = 0.000%)
Min 0.05 m (CR = 0.025%)
Min 0.10 m (CR = 0.050%)
Octree

JCL – Post-processed results



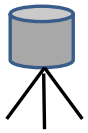
Change analysis between LiDAR surveys showing advance and retreat of the cliff face at the North Section (Northing 4,954,580 m to 4,954,650m).

Part II - Quantification of Landslide Movement in a Forested Environment

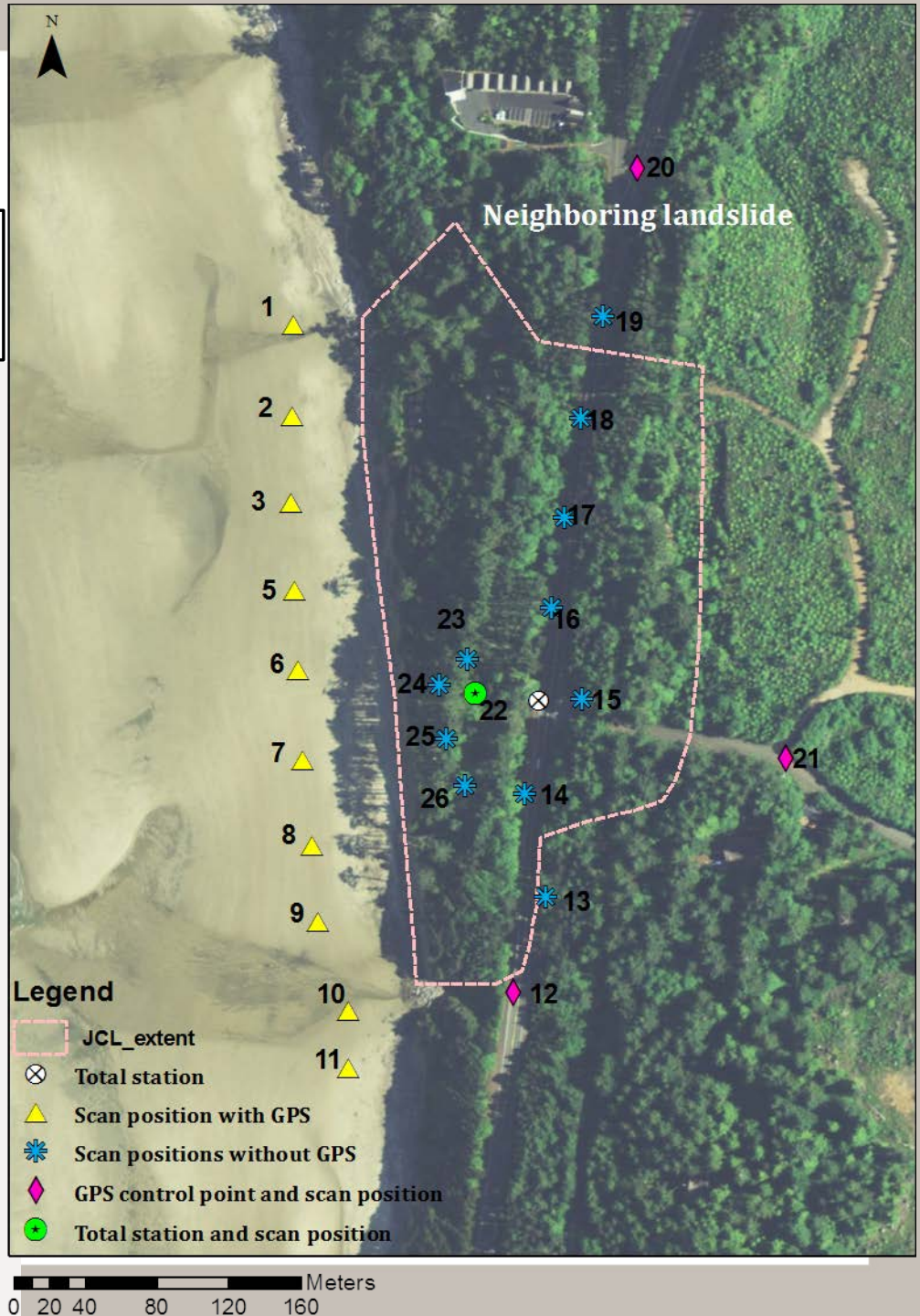
Conner, J., & Olsen, M.J., (2014). “Automated quantification of distributed landslide movement using circular tree trunks extracted from terrestrial laser scan data,” *Computers and Geosciences,* 67, 31-39. doi:10.1016/j.cageo.2014.02.007

Methodology

1. Perform Surveys (Field Collection)
   - Terrestrial laser scanning
   - Total station & GPS control network



- RTK GPS\ORGN
  - H: 2.0 cm, V: 5.0 cm
  - PDOP: 1.3 to 3.5
- TPS1200+ total station
  - H: 2.5 cm, V: 5.0 cm
- Riegl VZ-400 TLS
  - 4 cm RMS
- ~700 mil pts / survey
- ~27.5 mil pts / scan



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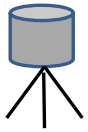
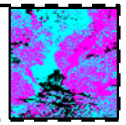
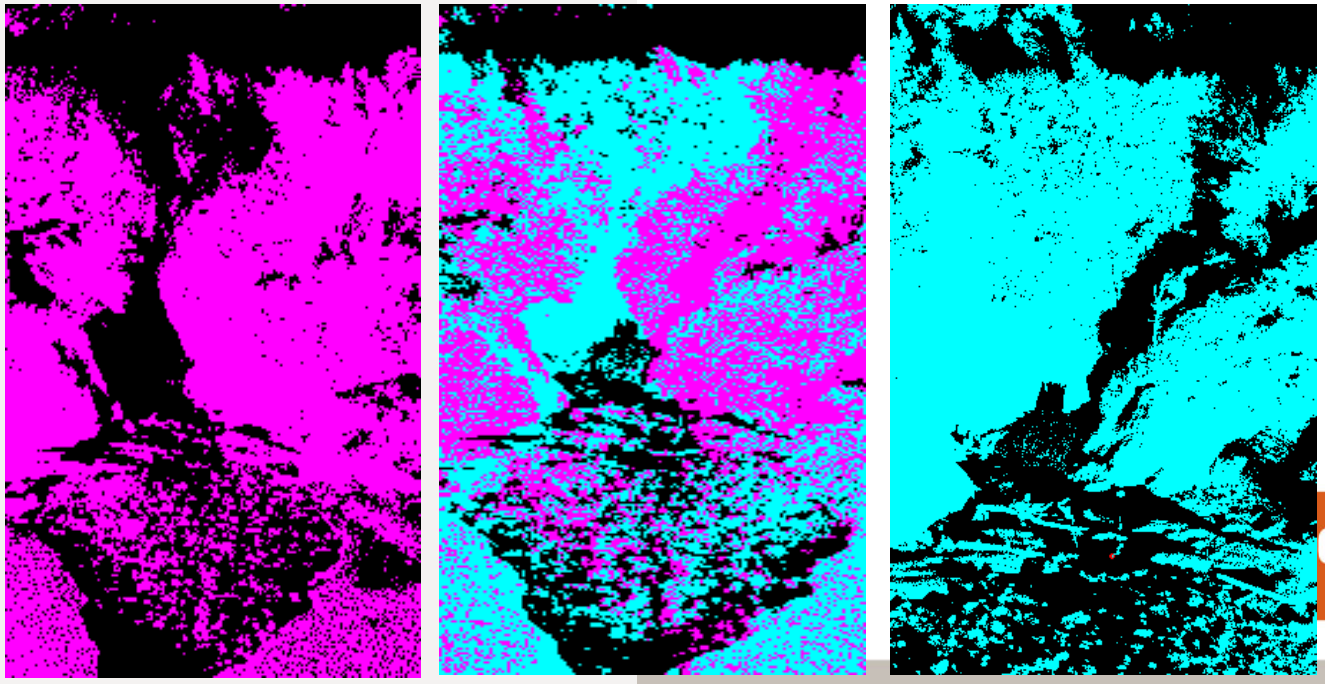


2. Georeference Scans
   - Using Olsen et al. (2011)



- PointReg –least sq. adjustment of Yaw
- X, Y, & Z from scan origins
- Roll and pitch from inclination sensors



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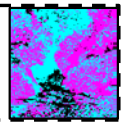
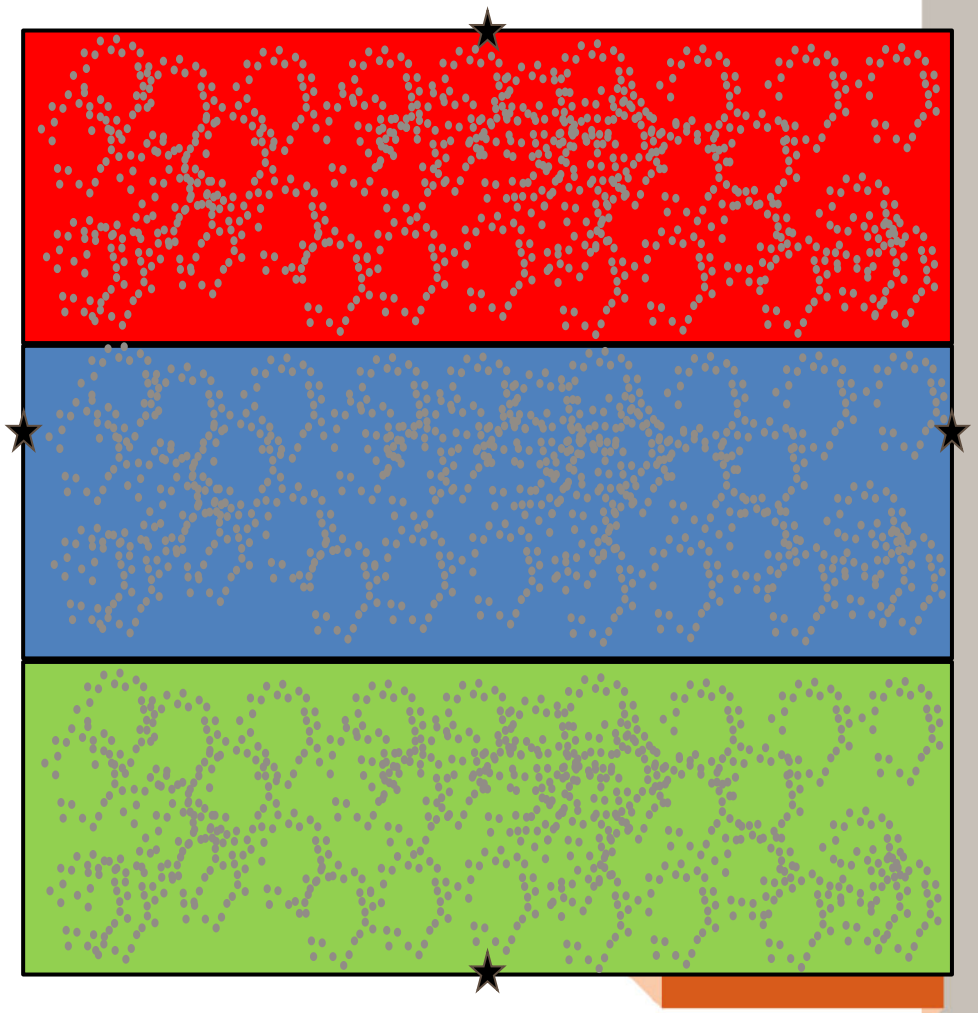


3. If needed, divide the dataset into tiles for workability



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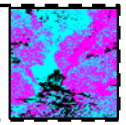
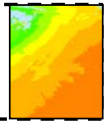
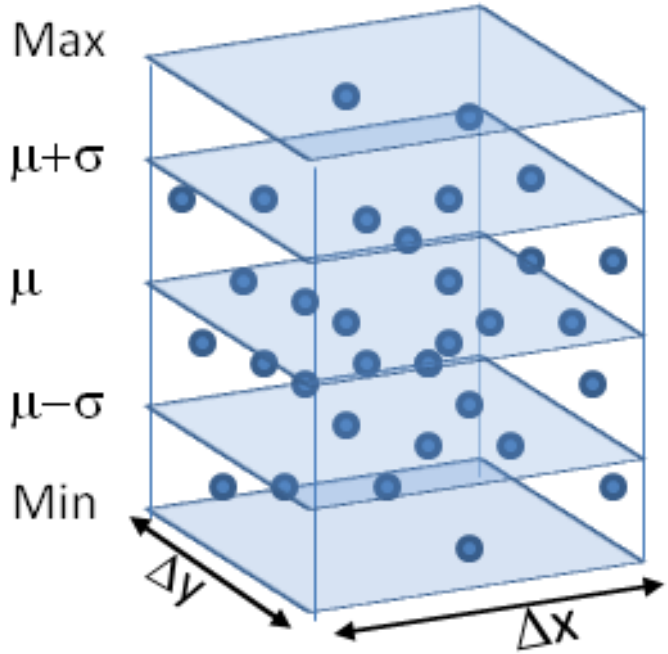


3. If needed, divide the dataset into tiles for workability

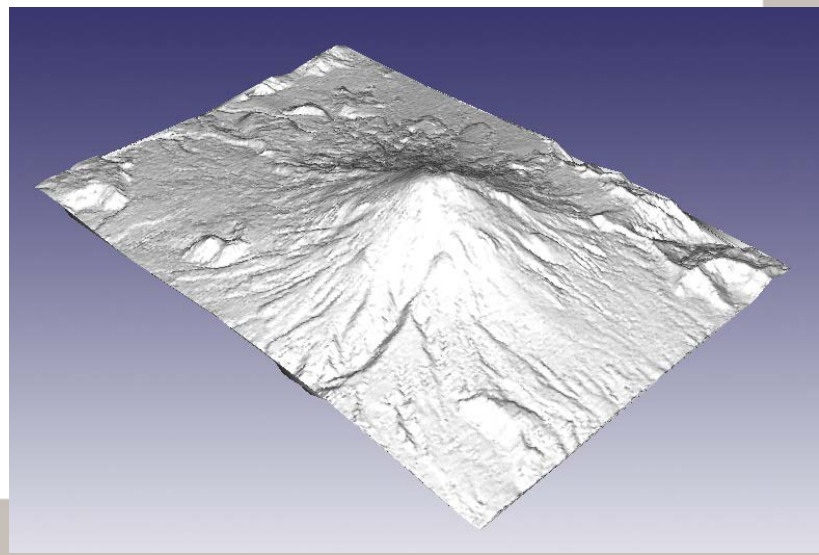
4. Generate Digital Terrain Model (DTMs) for each tile and merge





http://www.lidarnews.com/content/view/8378/136/

•Statistically filter 2m X 2m grids to minimum value for each tile.
•Merge tiles together for DTM of entire test area.



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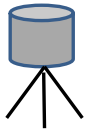

2. Georeference Scans
   - Using Olsen et al. (2011)

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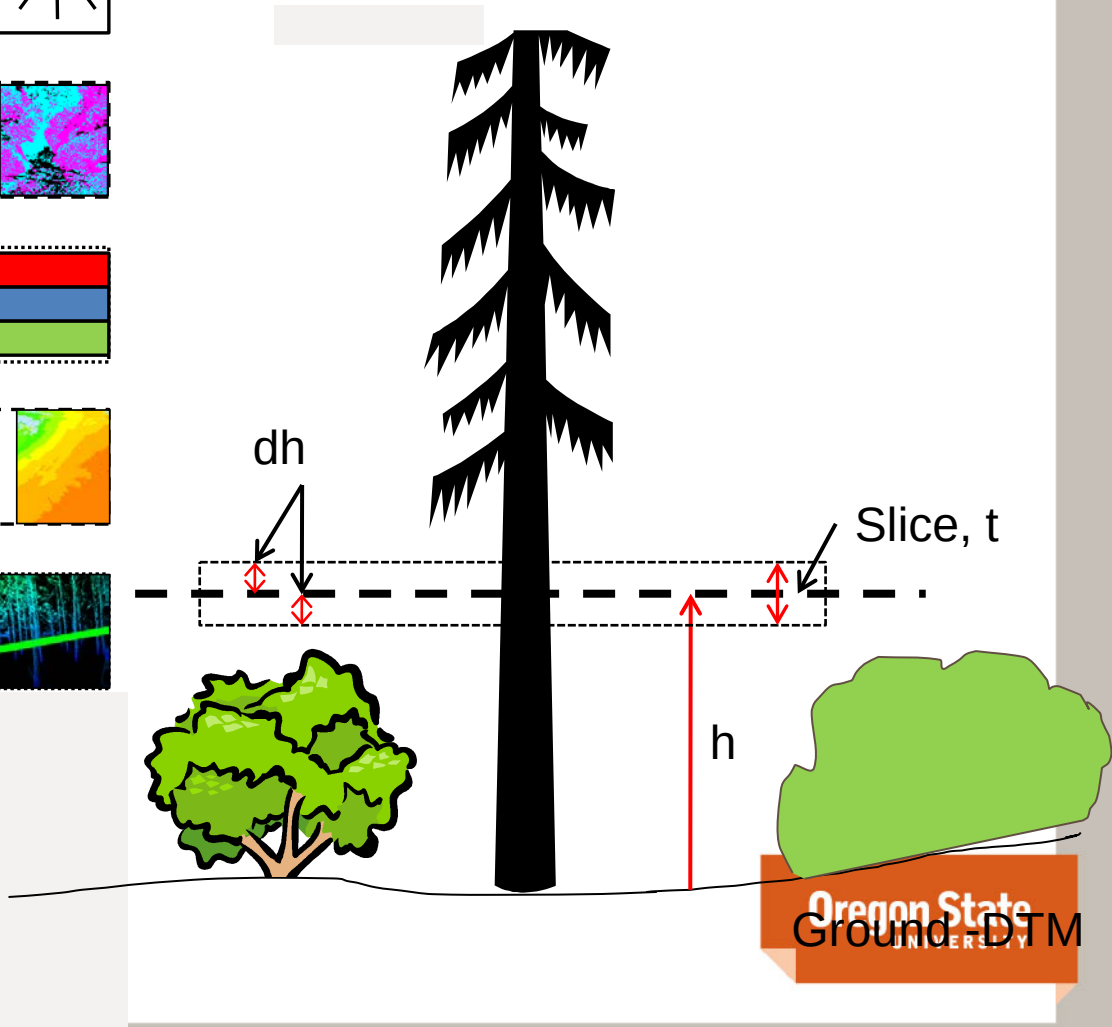
4. Generate Digital Terrain Model (DTMs) for each tile and merge

5. Extract slice of point cloud above DTM

- $h - \Delta h < (h(i) = z(i) - z(DTM)) < h + \Delta h$
  - Above vegetation, below canopy



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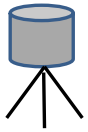

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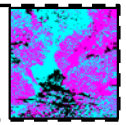

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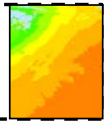
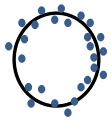
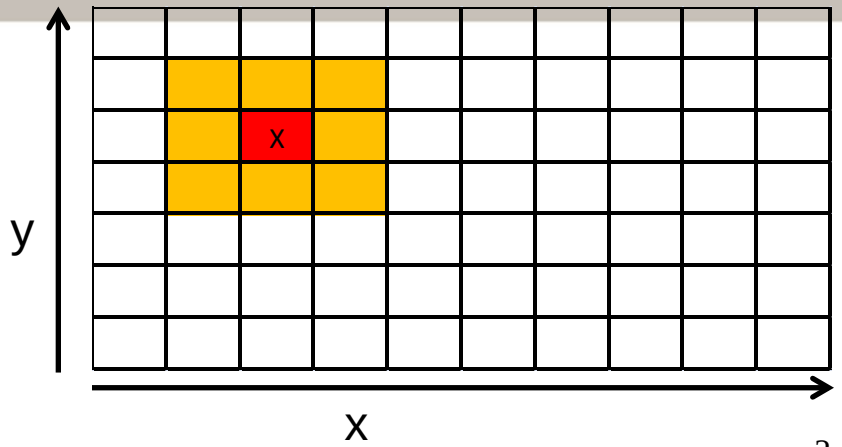


5. Extract slice of point cloud above DTM

6. Find trees in datasets
   - Least-Squares Fit Circles to Points on Individual Trees





$$S = \sum_i \left((x_i - x_c)^2 + (y_i - y_c)^2 - r^2 \right)^2$$

- Minimize the summation of residuals, S
- Partial derivative and set = to 0

$$\begin{pmatrix} S_{xx} & S_{xy} \\ S_{xy} & S_{yy} \end{pmatrix} \begin{pmatrix} x_c \\ y_c \end{pmatrix} = \begin{pmatrix} 0.5(S_{xxx} + S_{xyy}) \\ 0.5(S_{yyy} + S_{yxx}) \end{pmatrix}$$

- Determines circle parameters Xc, Yc and r
- Calculates RMS for circle fit

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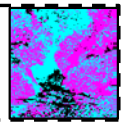
Methodology

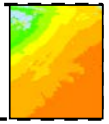
1. Perform Surveys (Field Collection)
   - Terrestrial laser scanning
   - Total station & GPS control network

2. Georeference Scans
   - Using Olsen et al. (2011)



3. If needed, divide the dataset into tiles for workability

4. Generate Digital Terrain Model (DTMs) for each tile and merge



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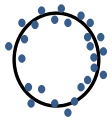

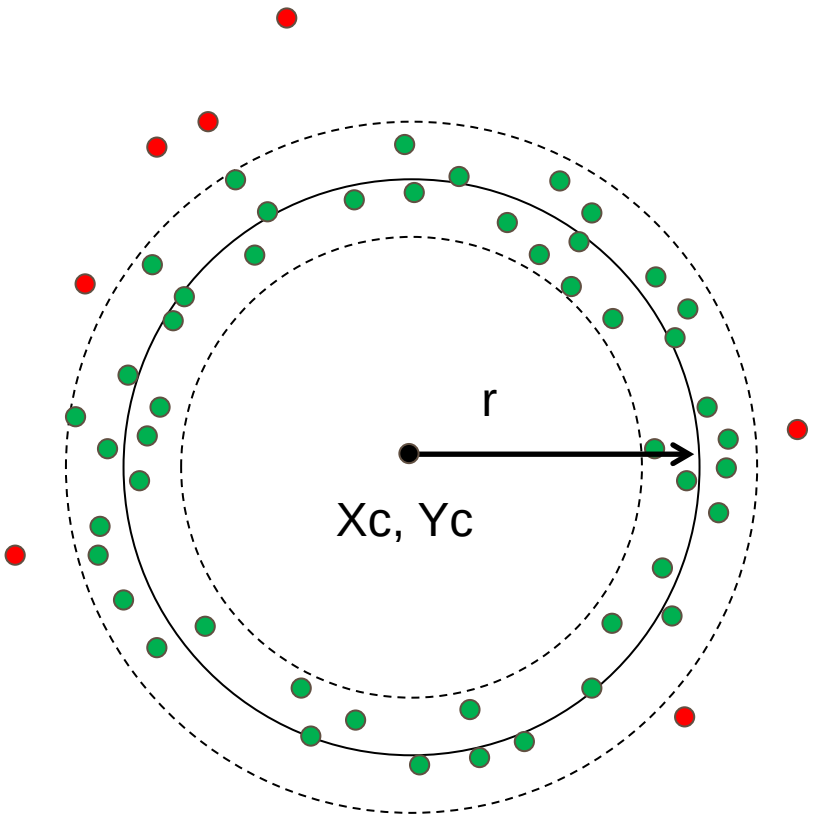

- Uses r ± 2 x RMS for outlier detection

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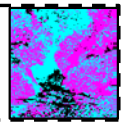

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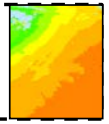

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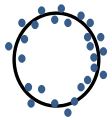
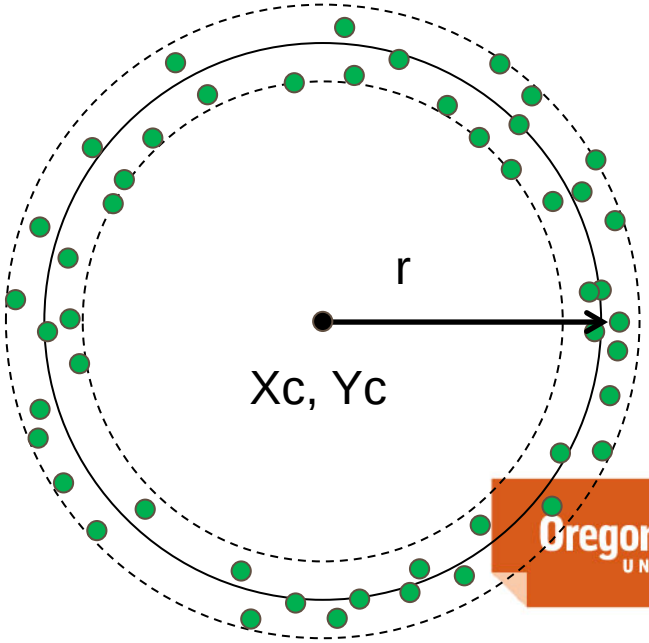


- Removes outliers
- Refits circle
- Recalculates RMS
- Circle is only used if Xc, Yc are in the center grid



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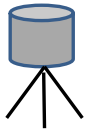

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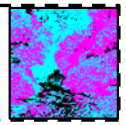

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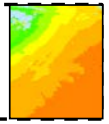

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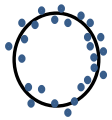
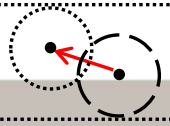
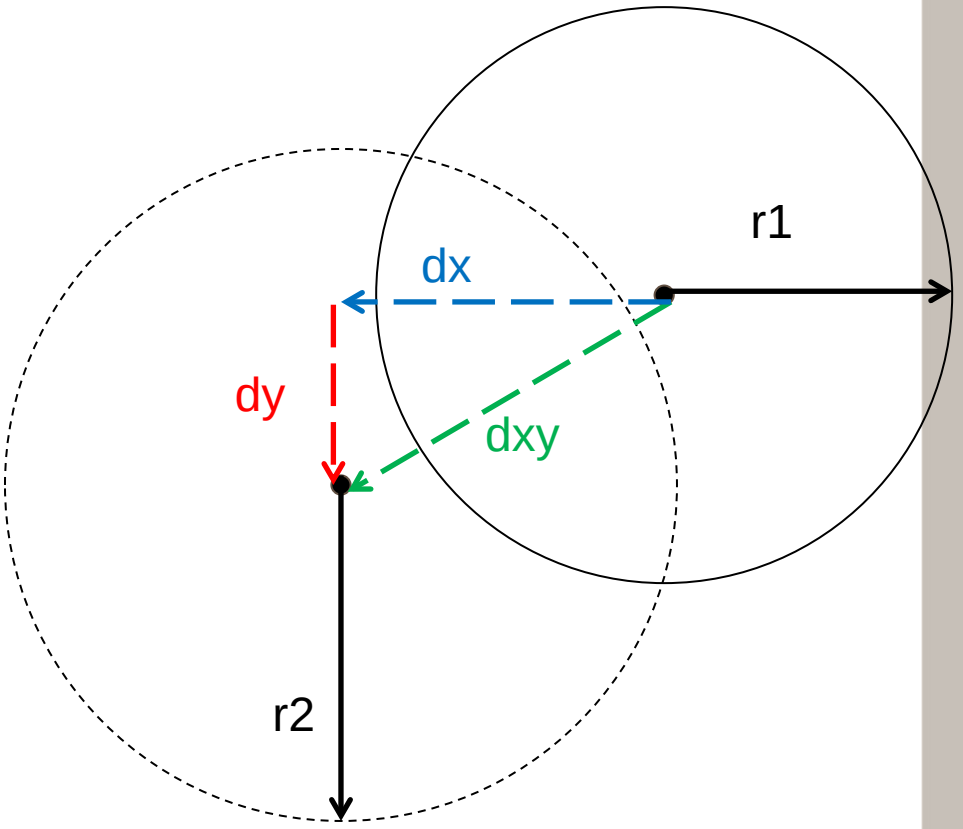


7. Compare tree locations between surveys to extract movement





$\Delta r = abs(r1 - r2)$

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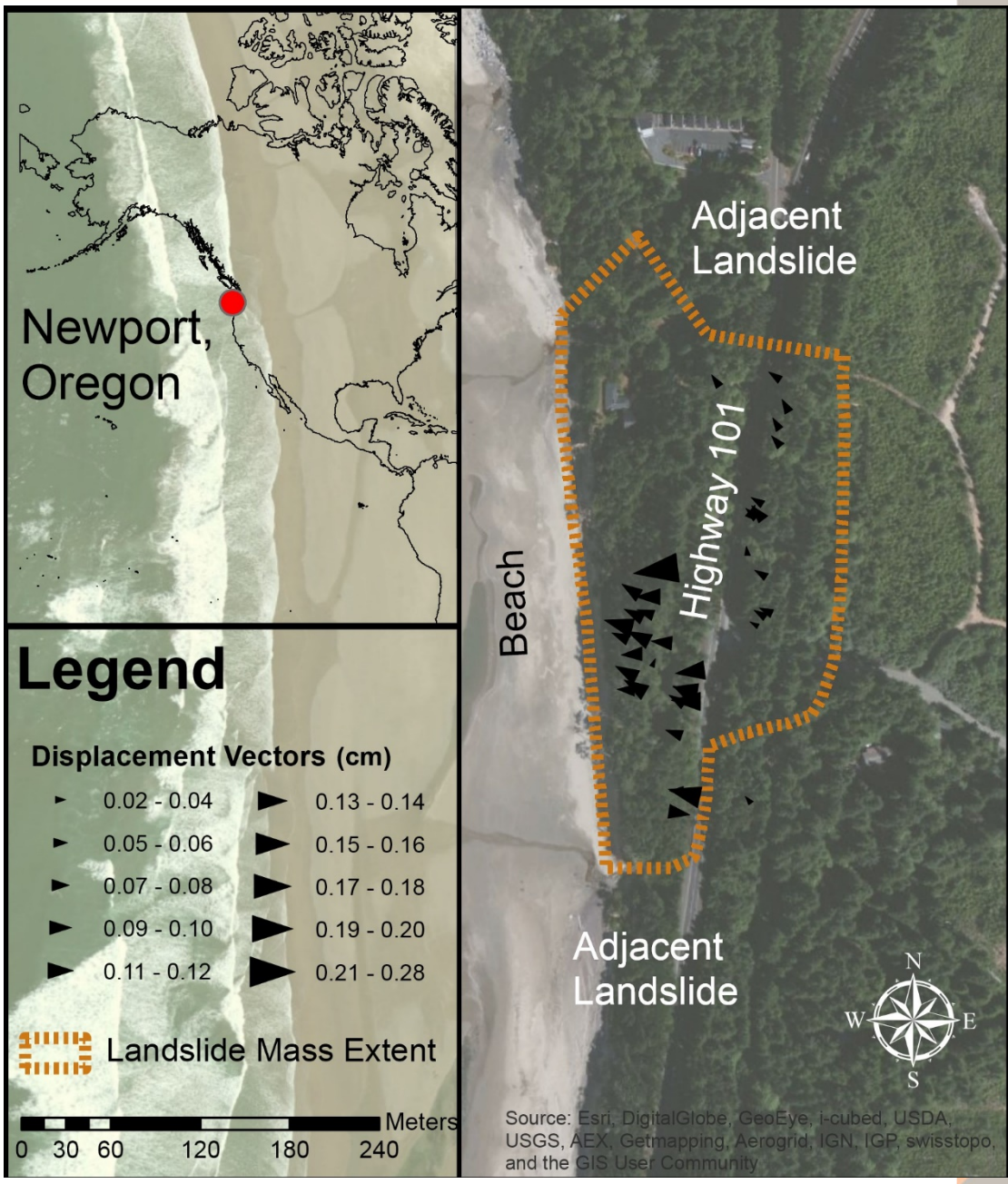
Results

- 71 trees detected, 93% have expected results if:
  - 0 > dx > -0.14
  - 0 > dy > -0.1
  - dxy < 0.15
- Reliability is:
  - # trees with expected results / total # trees



Comparison to Conventional Methods

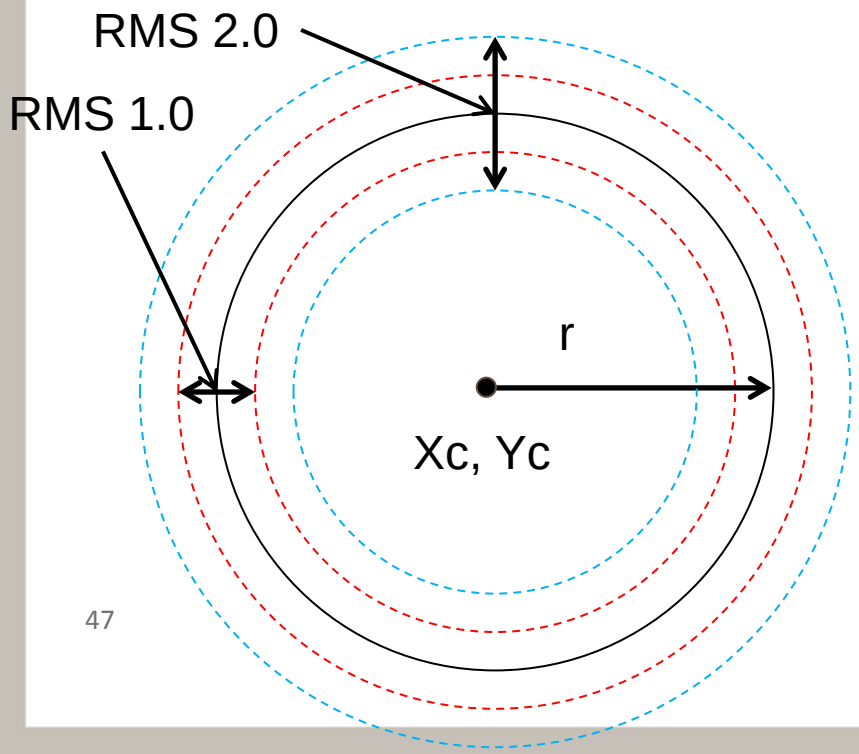
Conventional survey				Closest tree			Absolute Difference		
Point	Dx (m)	Dy (m)	Dxy (m)	Dx (m)	Dy (m)	Dxy (m)	Dx (m)	Dy (m)	Dxy (m)
14	-0.067	-0.036	0.076	-0.082	-0.028	0.087	0.015	0.008	0.011
15	-0.056	-0.042	0.070	-0.053	-0.025	0.059	0.003	0.017	0.011
16	-0.081	-0.036	0.089	-0.083	-0.039	0.092	0.002	0.003	0.004
18	-0.082	-0.050	0.096	-0.045	-0.039	0.060	0.037	0.011	0.036
19	-0.107	-0.038	0.114	-0.091	-0.053	0.105	0.016	0.015	0.009
20	-0.129	-0.034	0.133	-0.098	-0.065	0.117	0.031	0.031	0.016
22	-0.082	-0.037	0.090	-0.085	-0.007	0.085	0.003	0.030	0.005
23	-0.082	-0.021	0.085	-0.118	-0.025	0.121	0.036	0.005	0.036
24	-0.105	-0.024	0.108	-0.105	-0.039	0.112	0.000	0.015	0.004
25	-0.122	-0.059	0.135	-0.146	-0.015	0.147	0.024	0.044	0.012

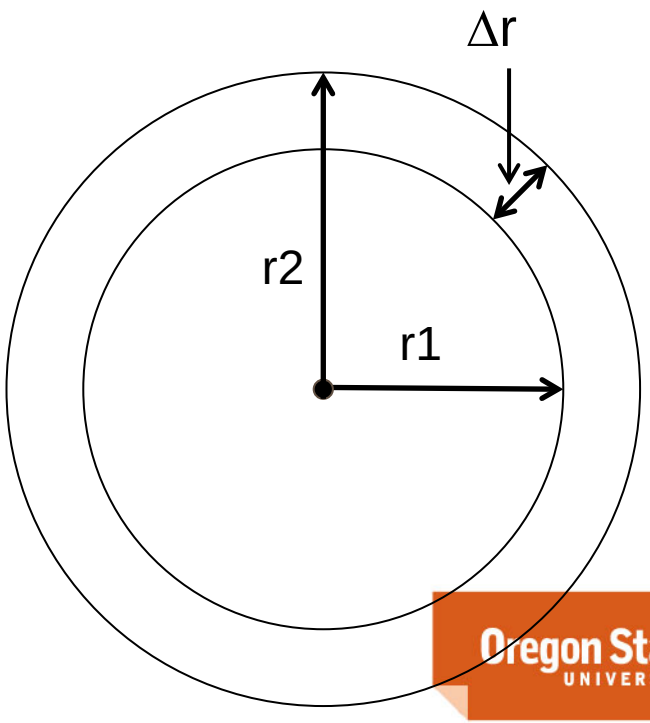
Summary Table

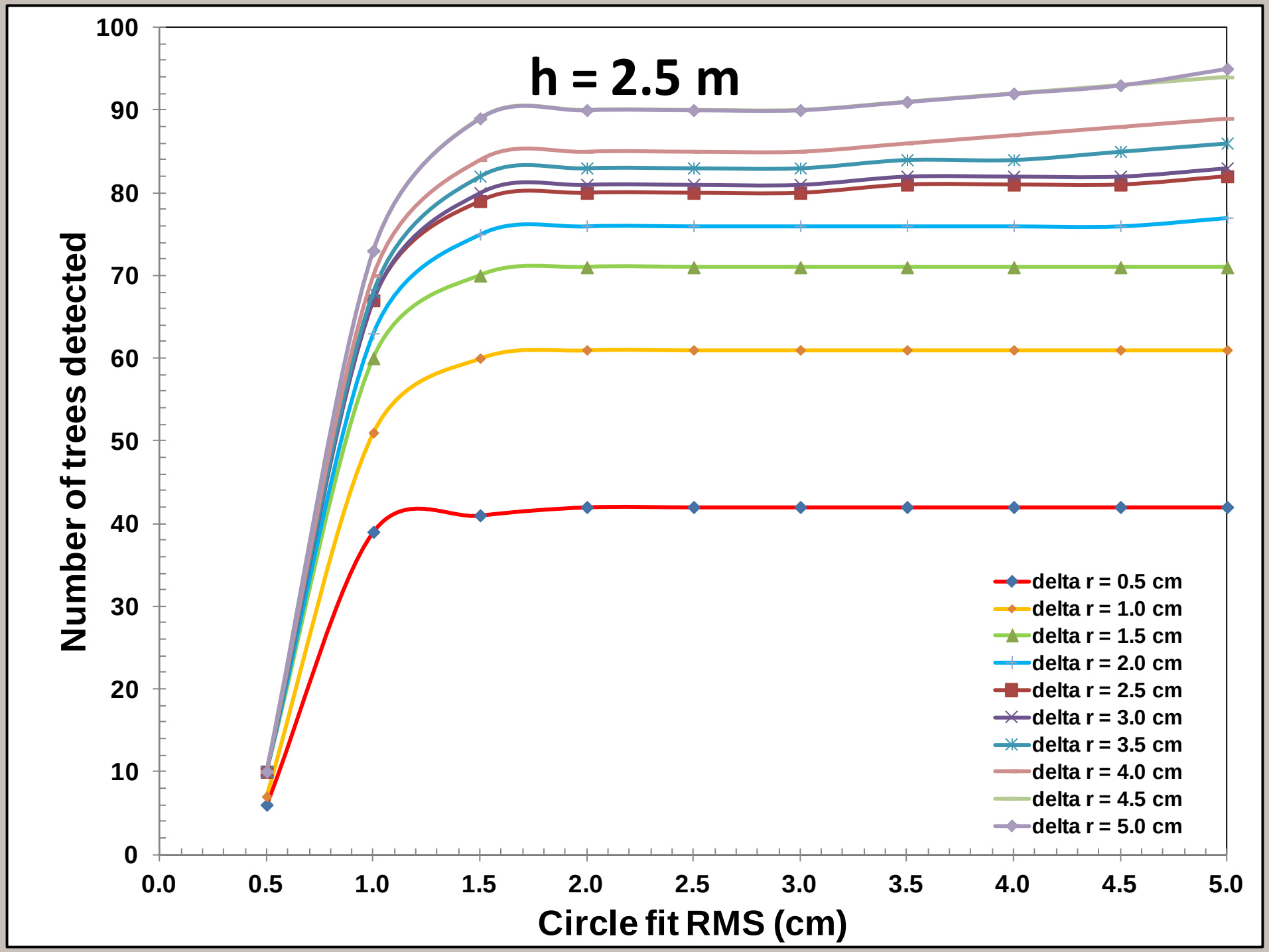
Max	0.037	0.044	0.036
Min	0.000	0.003	0.004
Average	**0.017**	**0.018**	**0.014**
Std dev	**0.015**	**0.013**	**0.012**

Parameter Analysis

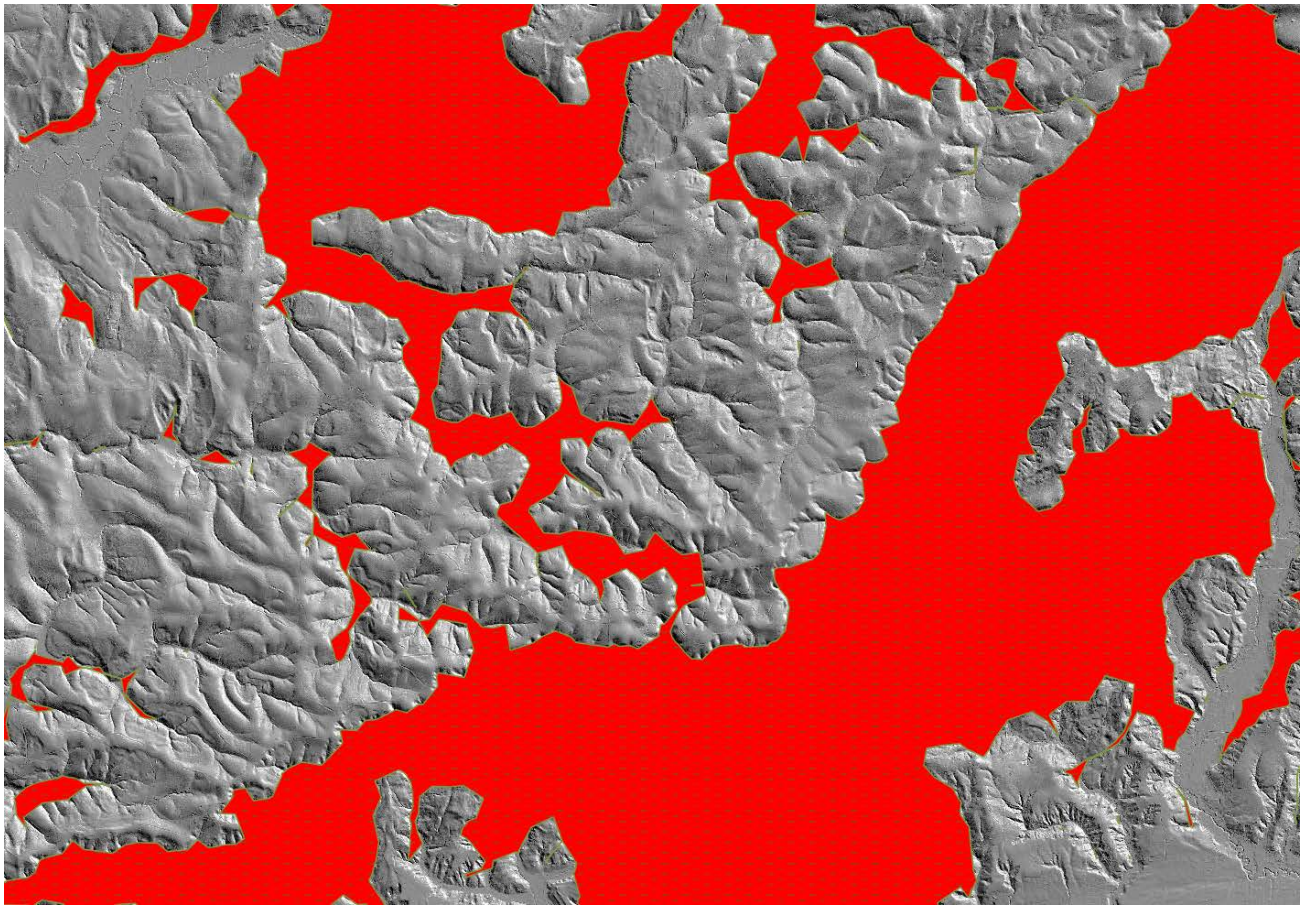
- As circle fit RMS increases usable points are farther from circle
- Δr difference in tree radii between surveys






h = 2.5 m
Number of trees detected
Circle fit RMS (cm)
0
10
20
30
40
50
60
70
80
90
100
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
delta r = 0.5 cm
delta r = 1.0 cm
delta r = 1.5 cm
delta r = 2.0 cm
delta r = 2.5 cm
delta r = 3.0 cm
delta r = 3.5 cm
delta r = 4.0 cm
delta r = 4.5 cm
delta r = 5.0 cm

Contour Connection Method for airborne LIDAR landslide mapping



Leshchinsky, B., Olsen, M.J., & Tanyu, B. (2015). "Contour Connection Method for Automated Identification and Classification of Landslide Deposits," *Computers and Geosciences, 74, 27-38*. doi:10.1016/j.cageo.2014.10.007

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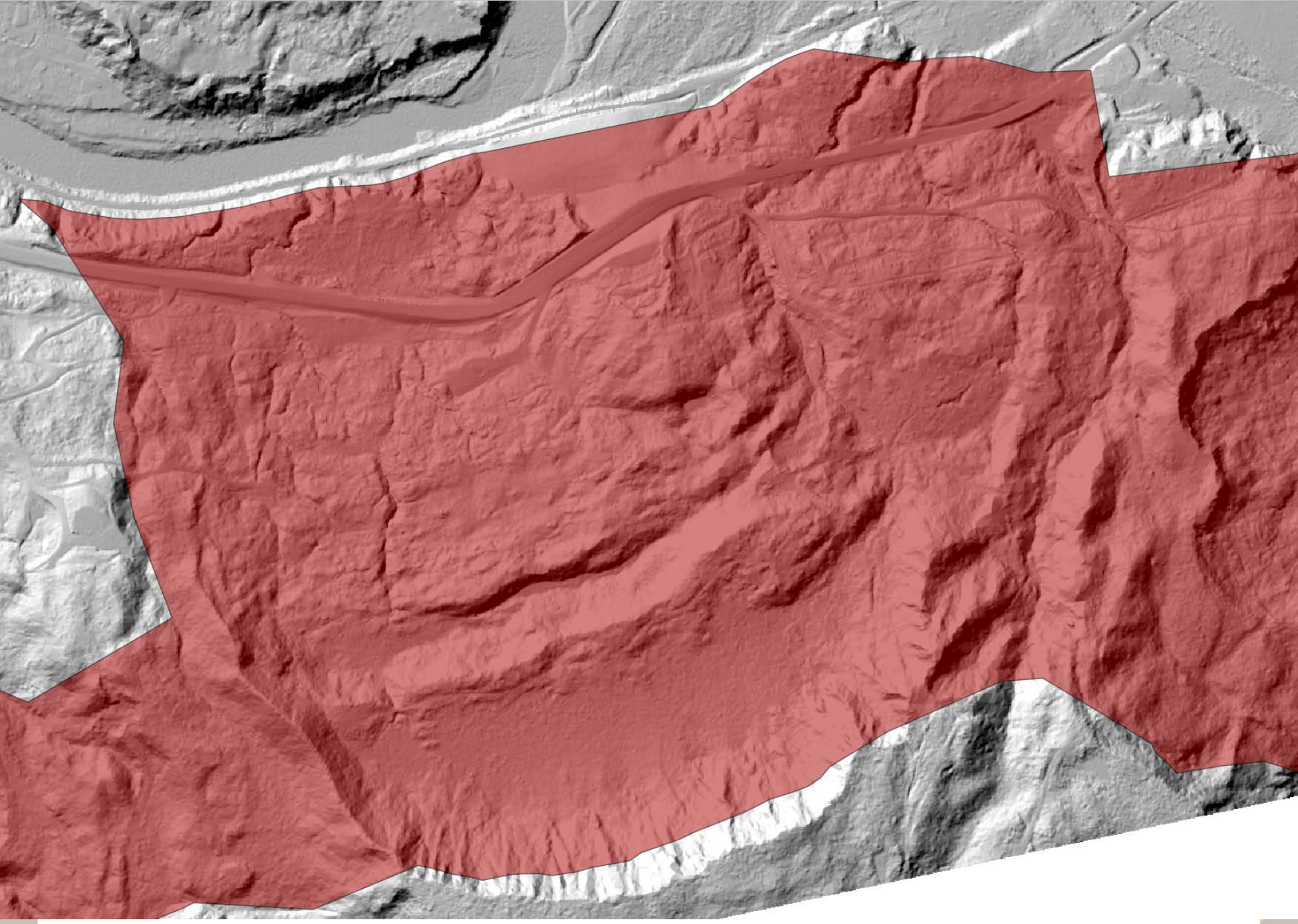


Satellite Image: Pre-Landslide, Oso, WA
© 2013 Google Images

Do you see the landslides and deposits scattered across this landscape?

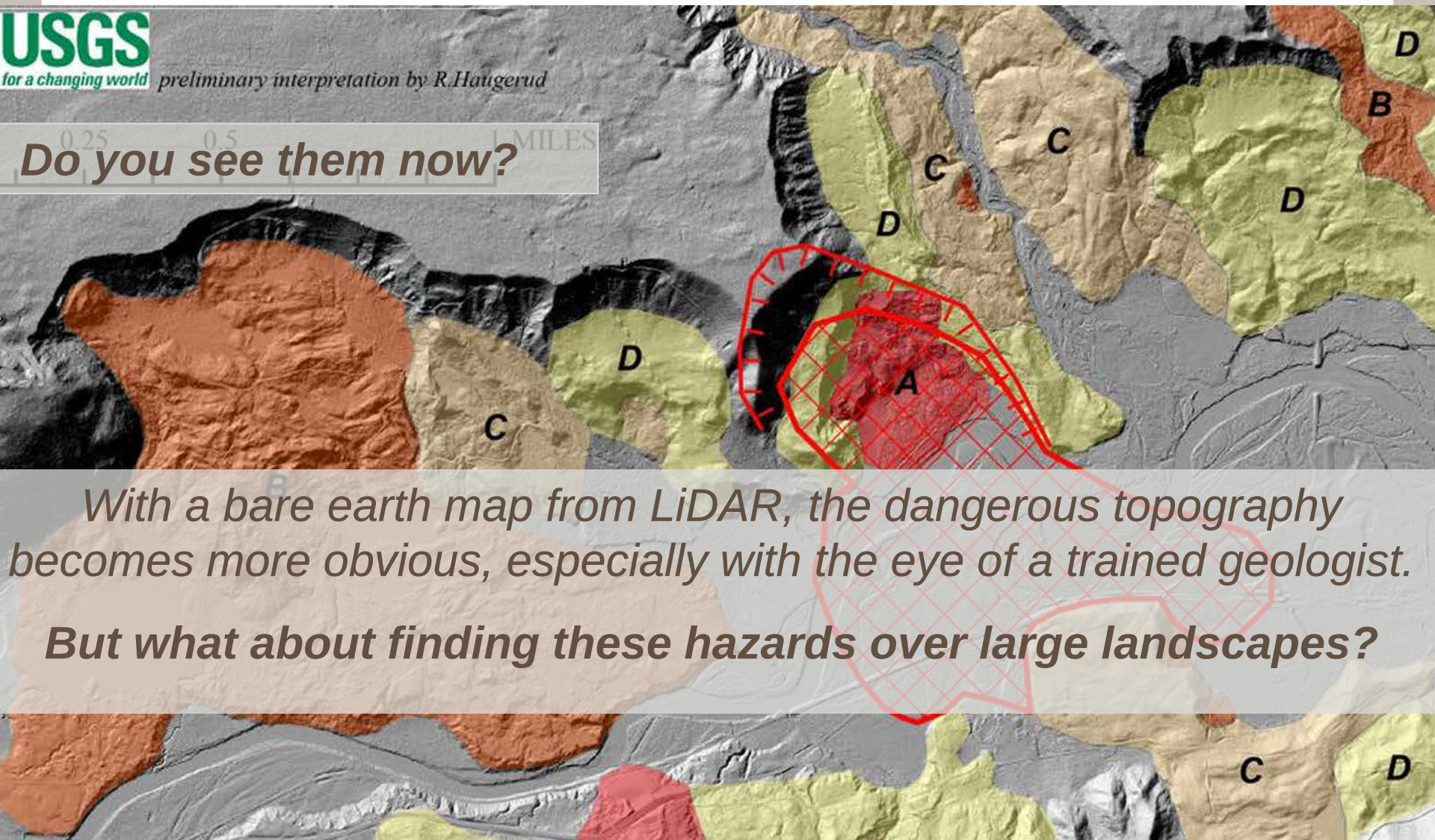
Maybe you see this headscarp from a slide in 2006?

Anything else?

LiDAR Bare Earth Map: Landslide Inventory

Credit: 2014 USGS, R. Haugerud

A – D (youngest – oldest)



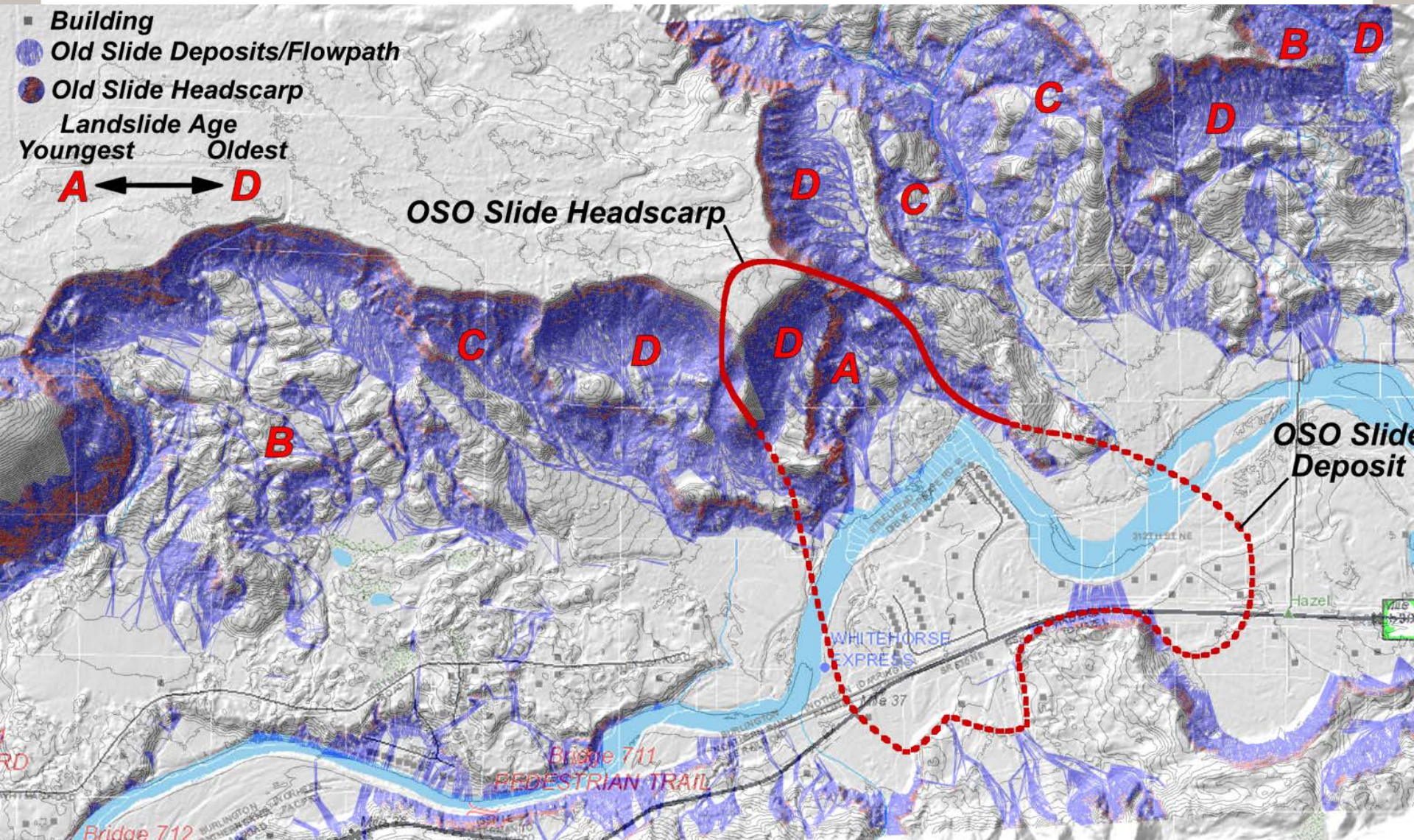
Do you see them now?

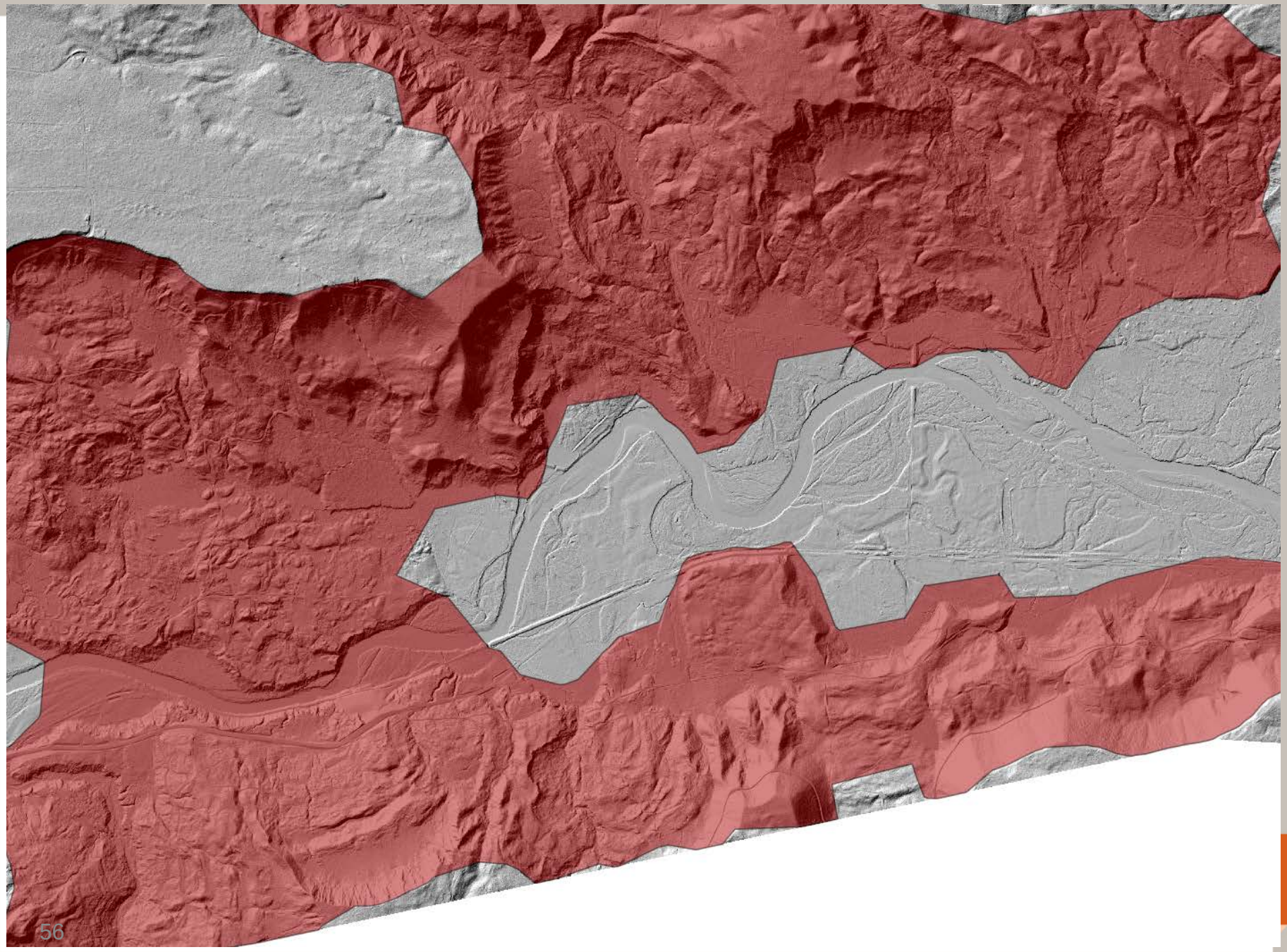
With a bare earth map from LiDAR, the dangerous topography becomes more obvious, especially with the eye of a trained geologist.

But what about finding these hazards over large landscapes?

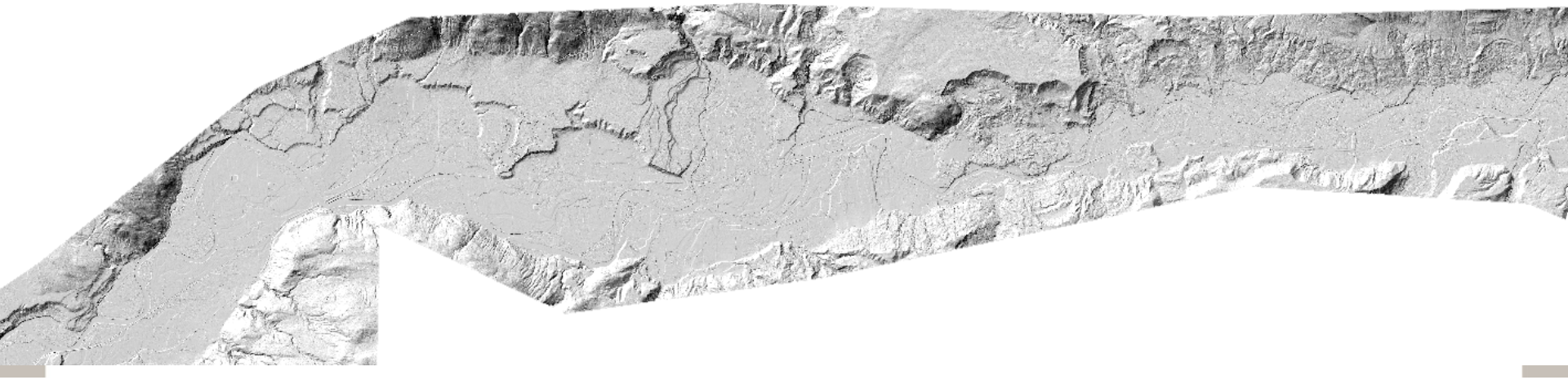
Automated Landslide Detection Algorithm - Current Research

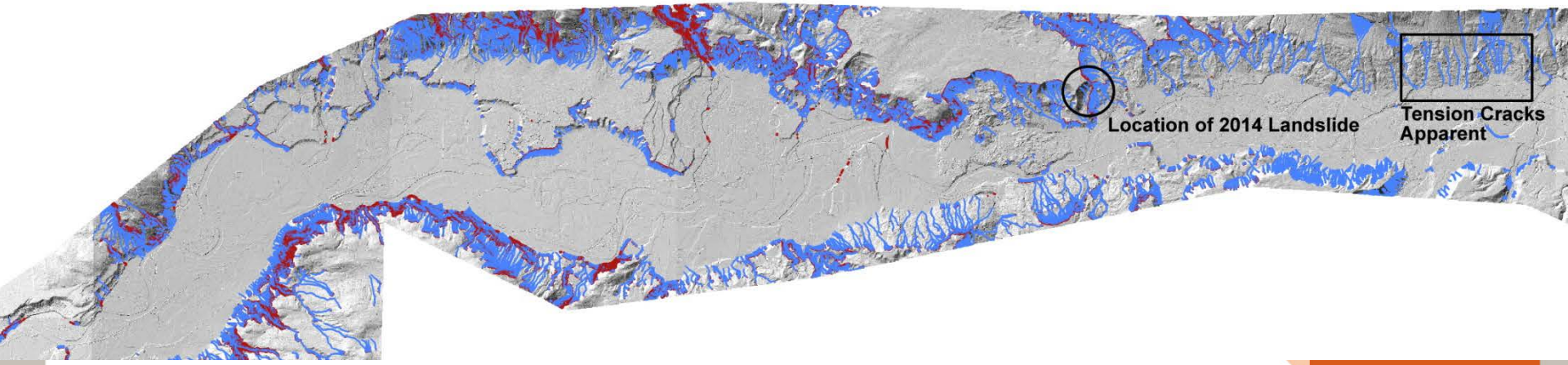
Highlighted Scarps in Red, Deposits in Blue





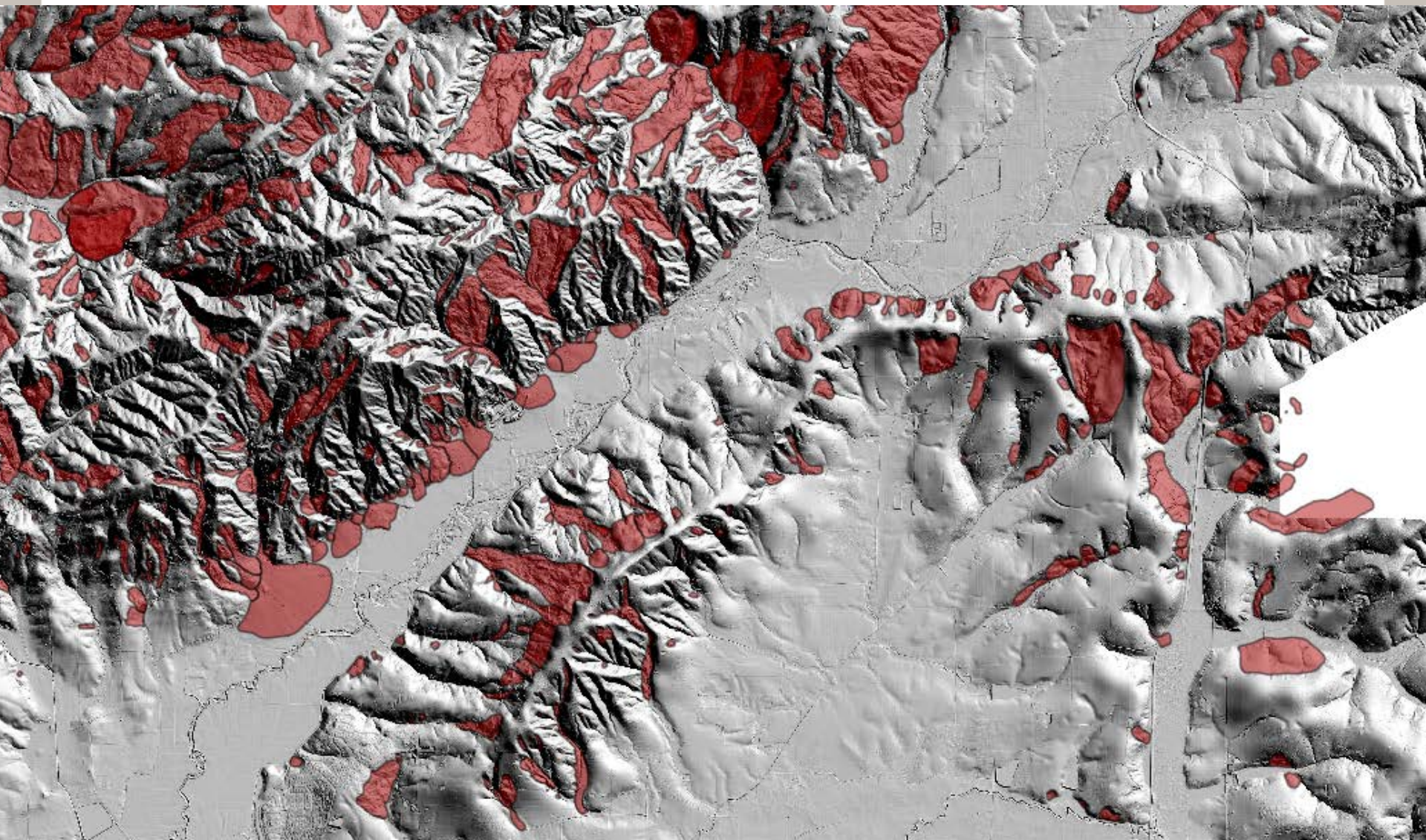
The whole valley is littered with landslides.





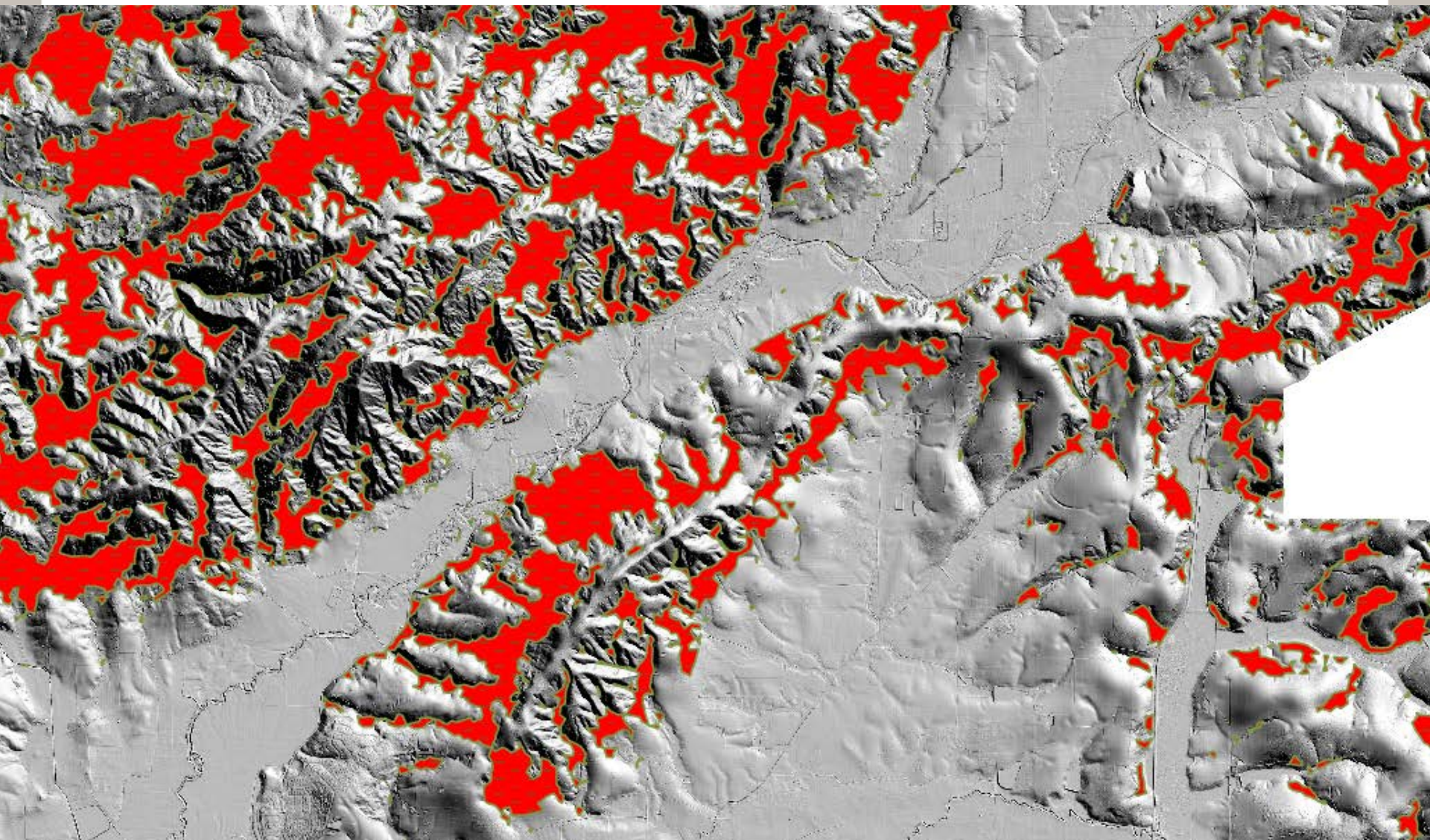
Pittsburg Quadrangle – Geologist Inventory

55 Square Miles, over 750 manually inventoried landslides



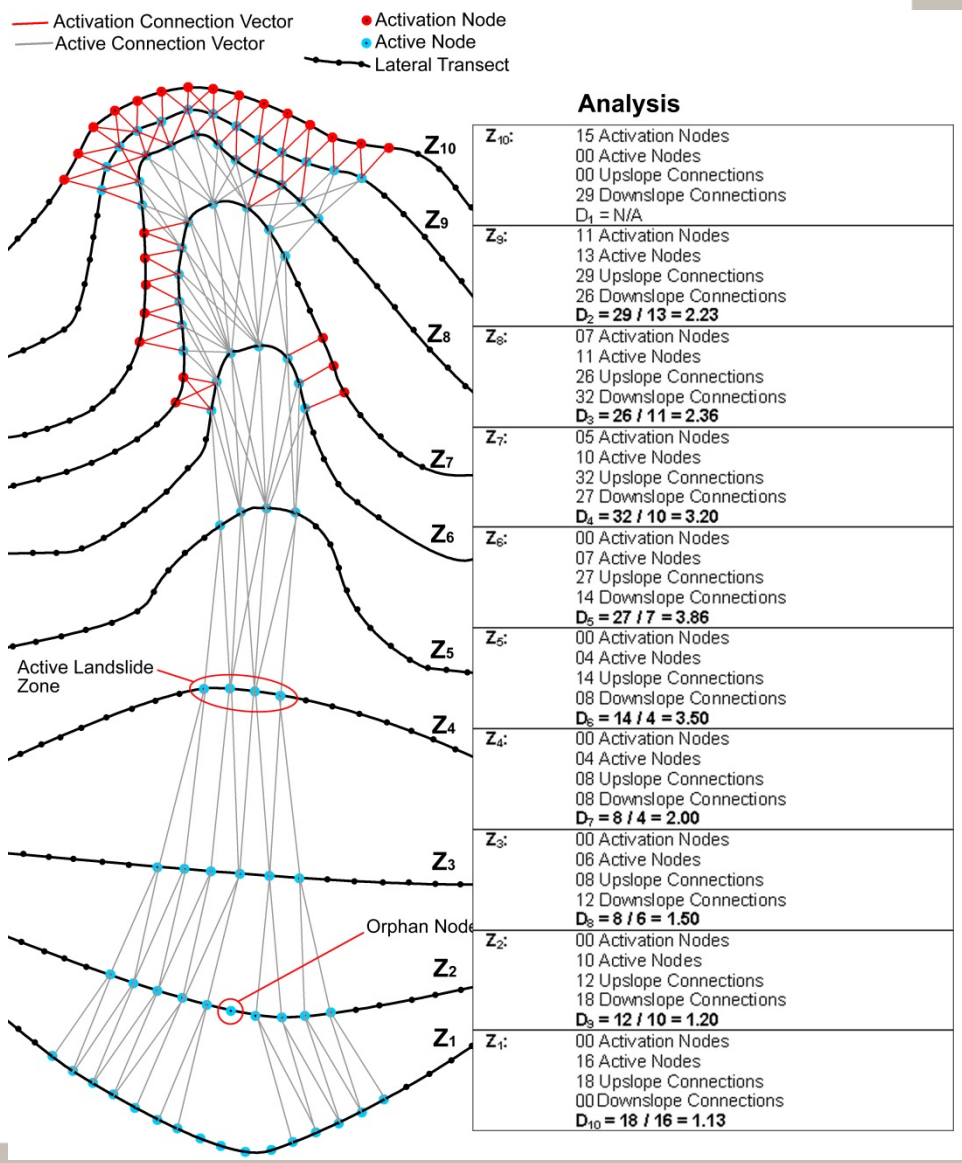
Pittsburg Quadrangle – Geologist CCM

One processor, 20 minutes of analysis, 91% agreement (pixel-pixel)



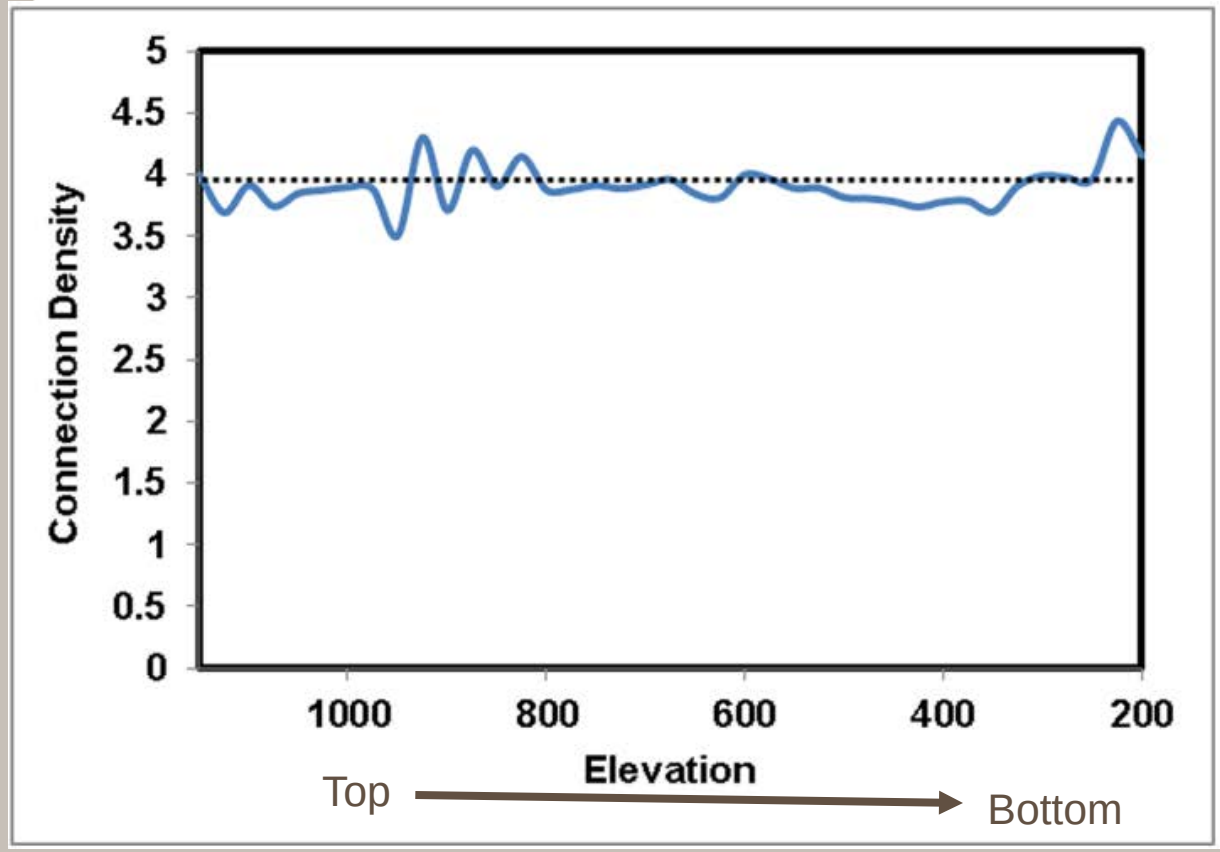
Signatures

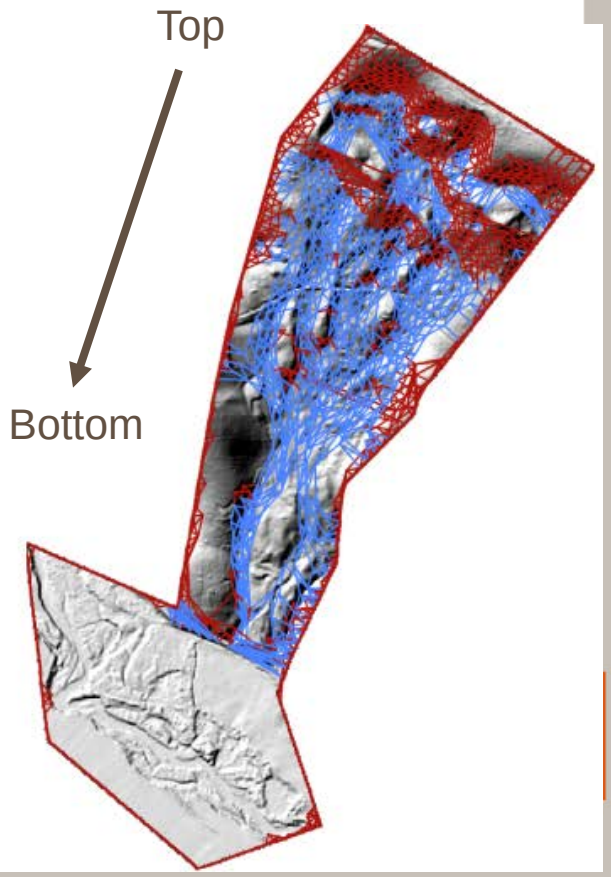
- Density of connections on each layer is indicative of concavity, convexity, roughness
- Change in density over layers yields a unique signature for a given landslide
- Can be used for classification of age, risk, erosion potential, etc.
- An “index” property



Signatures – Earth Flow

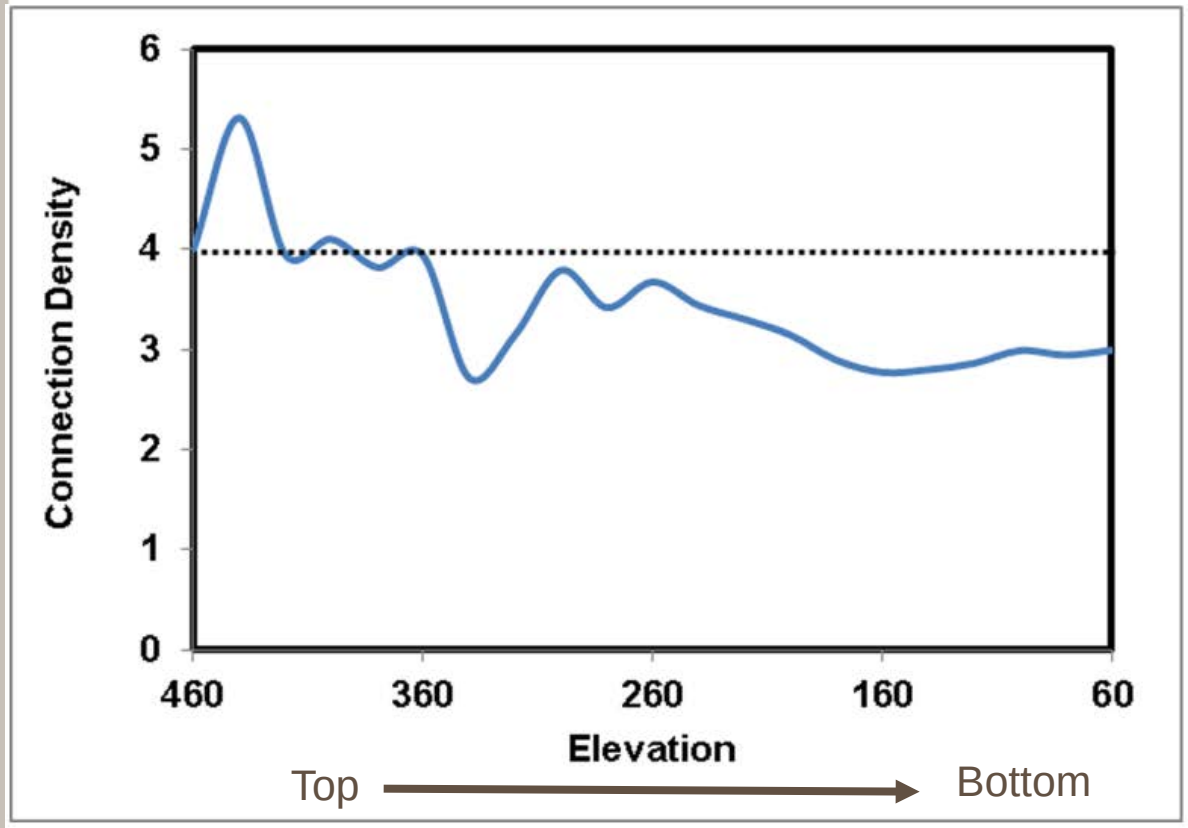
- Little change in convexity/concavity
- Erratic nature implies roughness, i.e. “young” feature

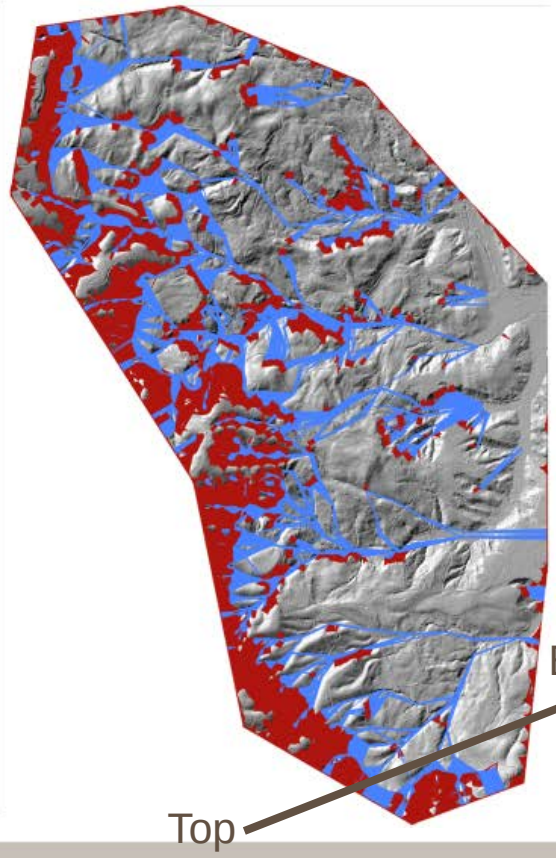




Signatures – Complex

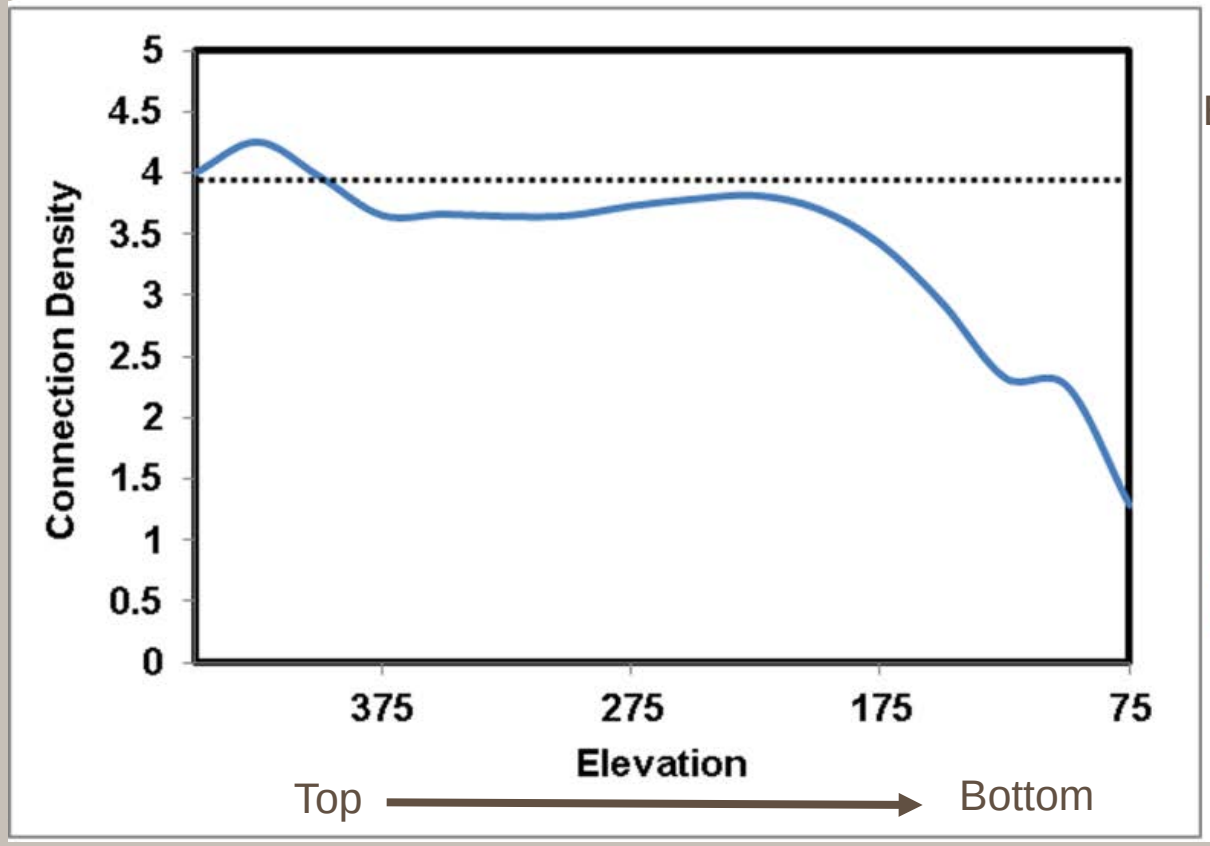
- Initial concave behavior, outward flow at base
- Again erratic nature implies “young” feature

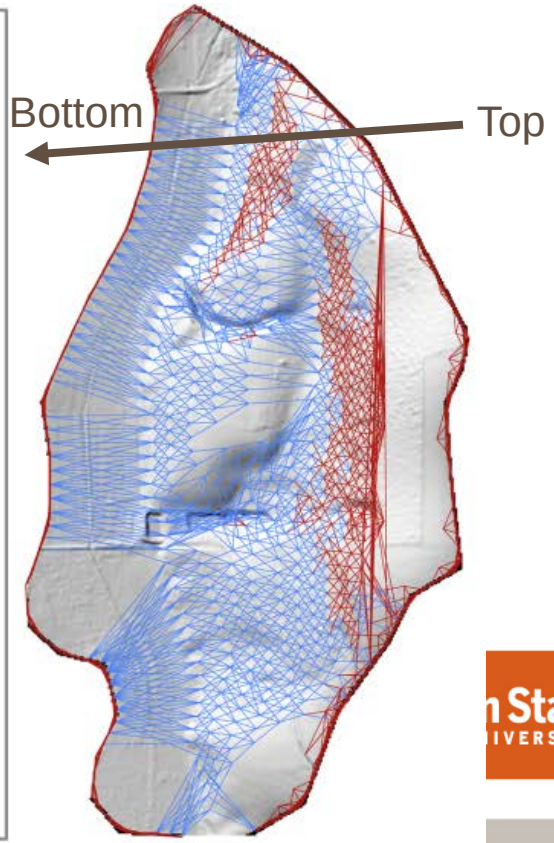




Signatures – Slide

- Initial concavity followed by convexity suggests outward flow, typically associate with slides
- Smooth nature suggests an older feature





Conclusions

- In-situ change analysis leads to a more effective and efficient filed investigation
- Slow-moving landslides in forested terrain can be analyzed by evaluating tree movement
- The CCM algorithm effectively delineates landslides in airborne lidar data

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  - Jonathan Allan (DOGAMI)
  - Alan Blair (FHWA)

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LASER MEASUREMENT SYSTEMS

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