# Shape shows more than pictures

## *An introduction to lidar*


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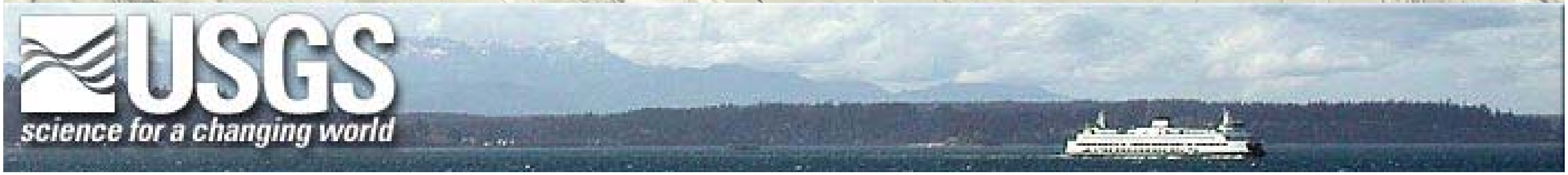
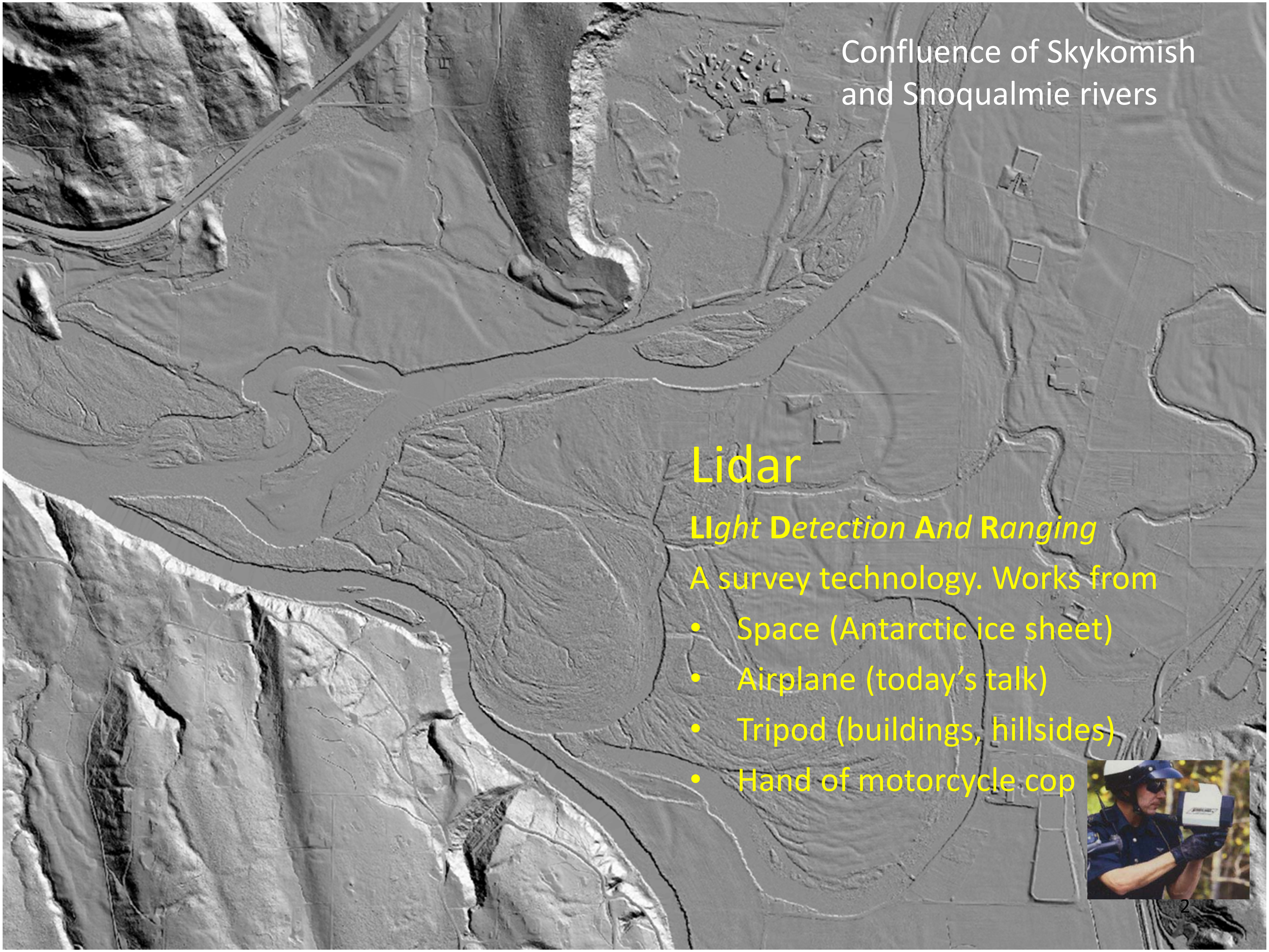
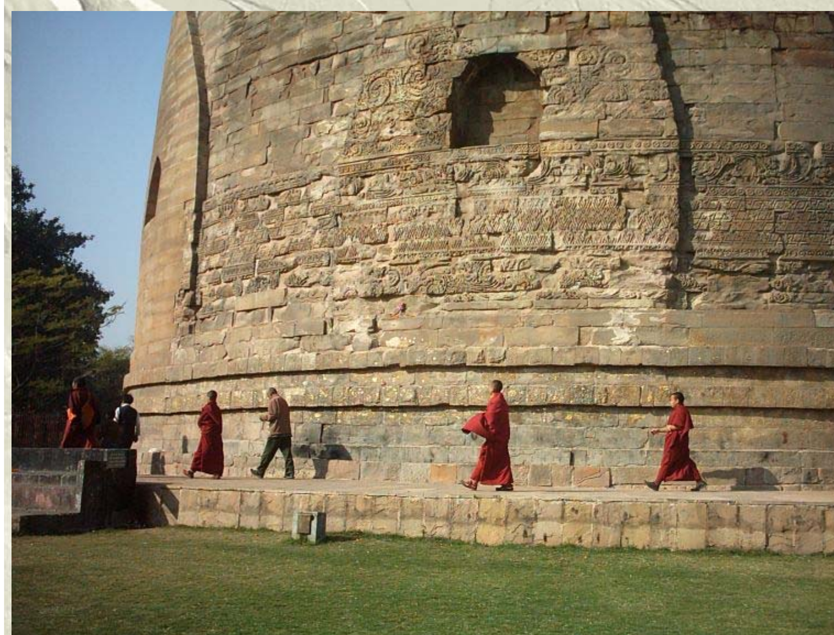



Confluence of Skykomish and Snoqualmie rivers
Lidar
LIght Detection And Ranging
A survey technology. Works from
• Space (Antarctic ice sheet)
• Airplane (today's talk)
• Tripod (buildings, hillsides)
• Hand of motorcycle cop

# outline

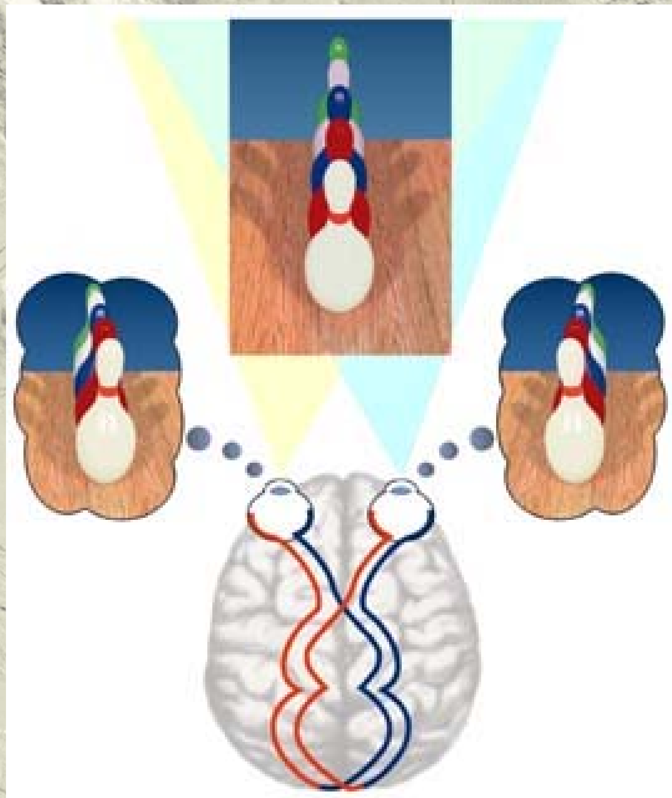
- How we experience the spatial world
- Lidar: a primer
- Examples of environmental studies with lidar
  a) Oso landslide: response and analysis
  b) A forest canopy mapping exercise

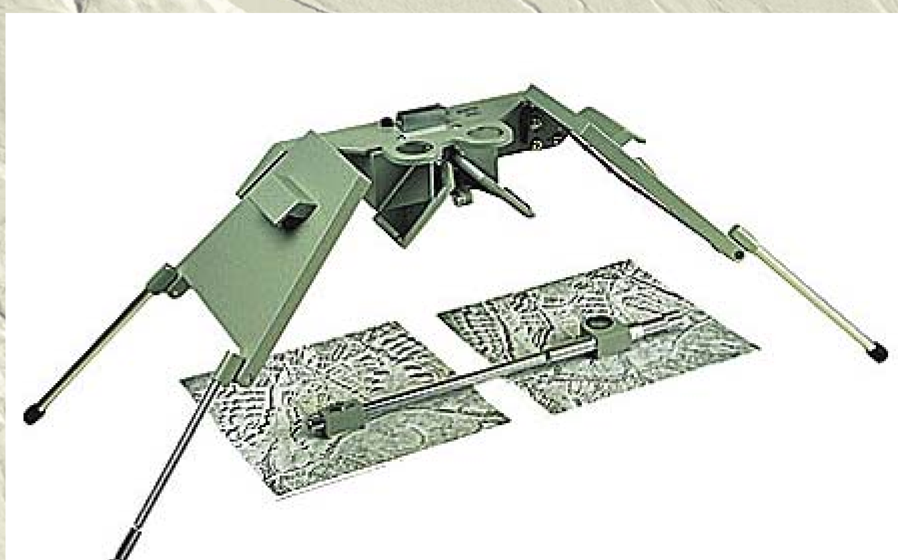
We directly experience the shape of the world by touching it and by moving through it (kinesthesia).

www.pinkstripeysocks.com
www.museodelprado.es
www.verywell.com/how-to-walk-uphill-3435575
www.columbia.edu/itc/mealac/pritchett/00fwp/


With one eye we comprehend the relative positions of features in the image plane. Space is 2-dimensional.

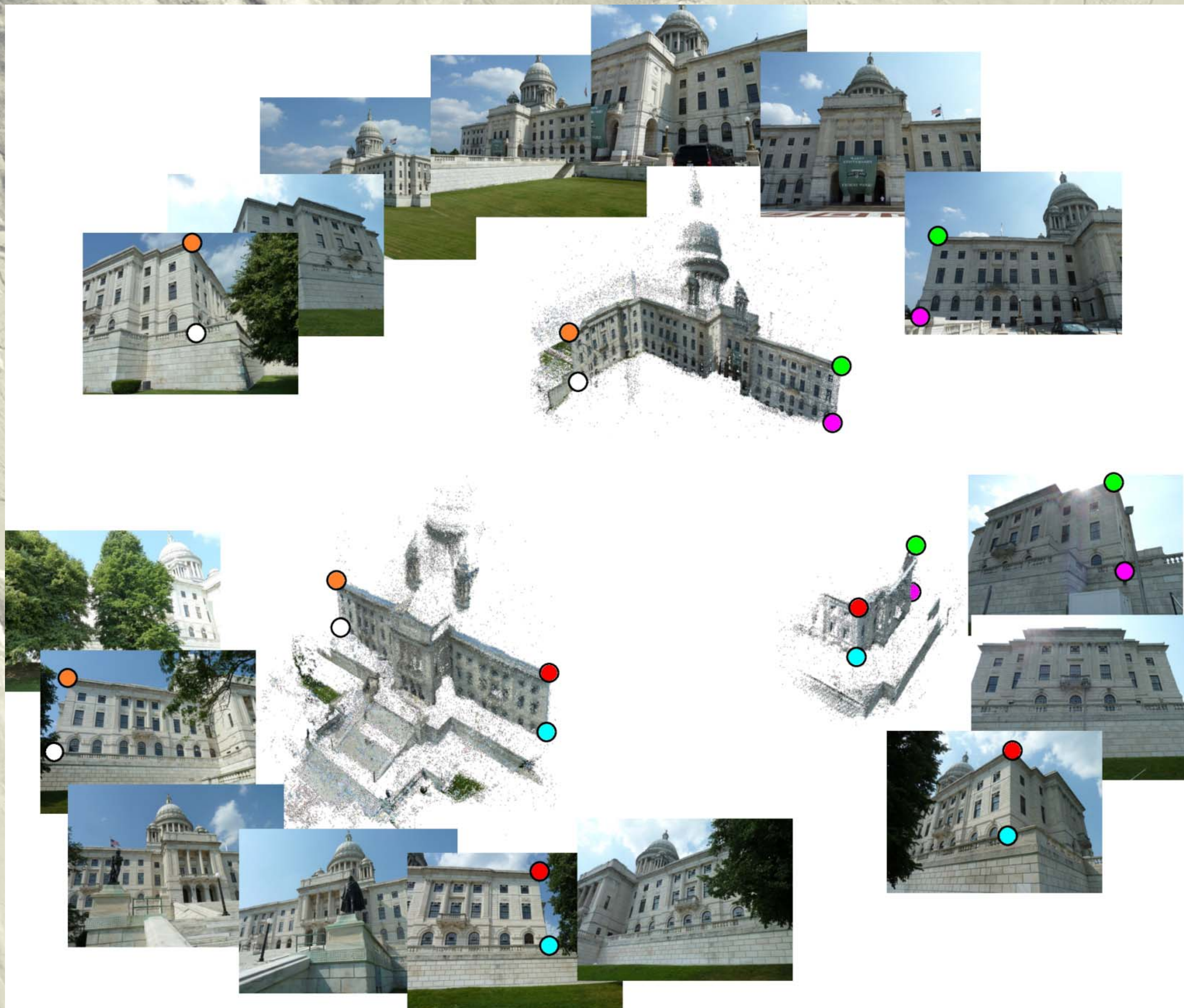


With both eyes open our brain applies the principle of parallax, fuses two images, and figures out the 3rd dimension.
This only works for close views.



With a stereoscope and aerial photographs, our effective inter-eye distance is thousands of feet and we see the landscape in 3D.

vision3d.com
benmeadows.com



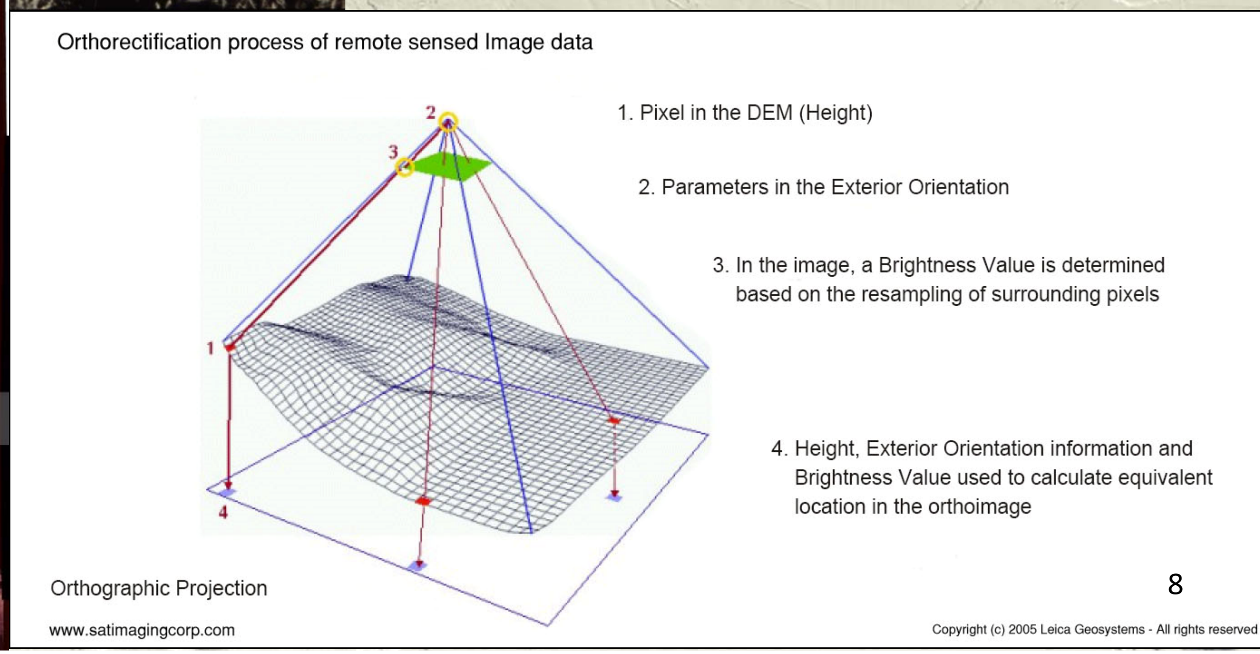
We fuse our kinesthetic sense and sight to understand the spatial world.

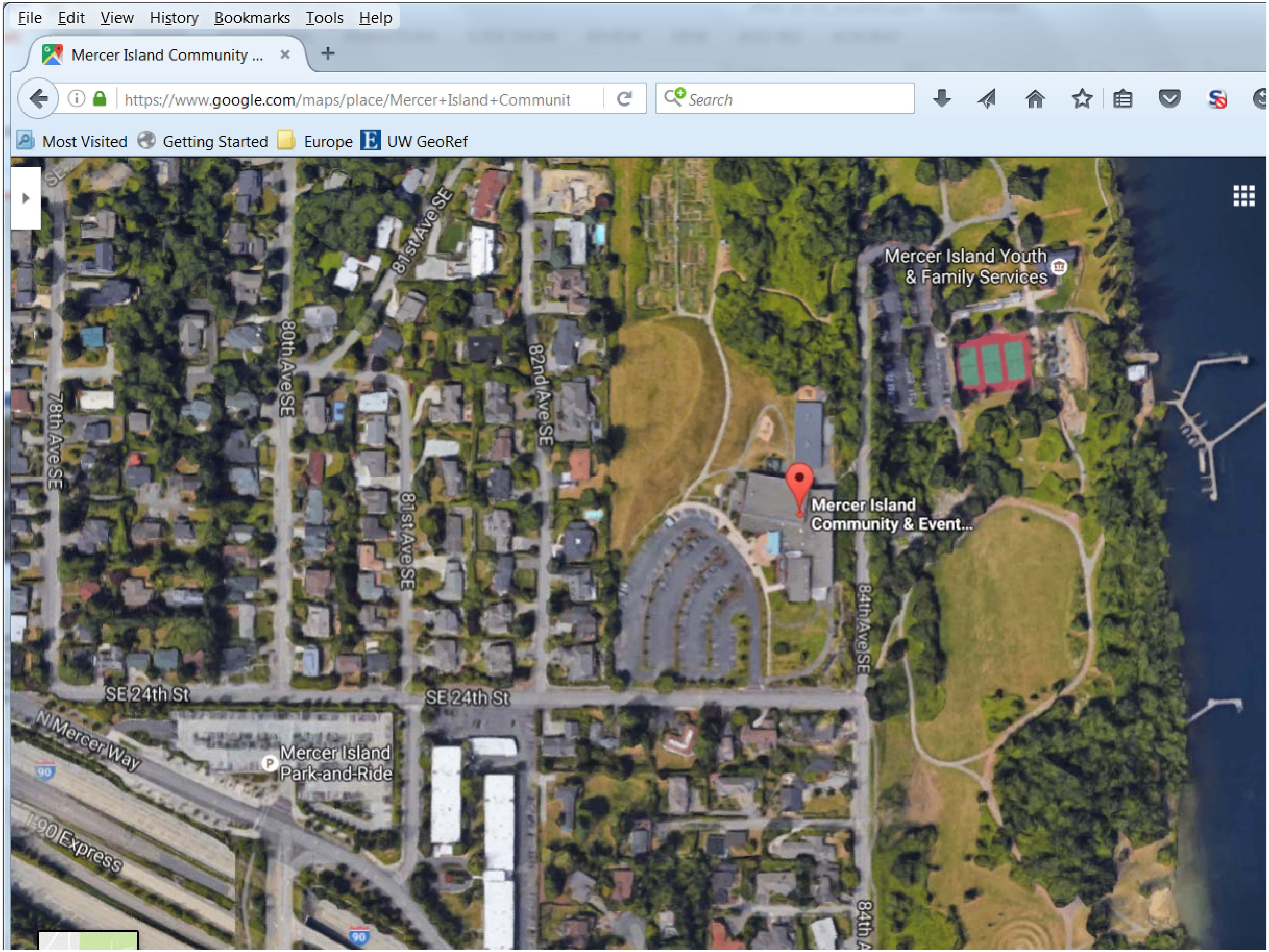
Most of the details come from sight.

https://www.ordnancesurvey.co.uk/about/news/2014/mapping-war-peace.html
http://media.gettyimages.com
http://www.satimagingcorp.com/services/orthorectification/

To understand (map) the spatial world we commonly:

- Survey to create a sparse geometric framework
- or use photogrammetry to create a denser, though still sparse, geometry
- Project image data onto this framework
- Map from the rectified image


File Edit View History Bookmarks Tools Help
Mercer Island Community ...
https://www.google.com/maps/place/Mercer+Island+Communit
Search
Most Visited
Getting Started
Europe
UW GeoRef
81st Ave SE
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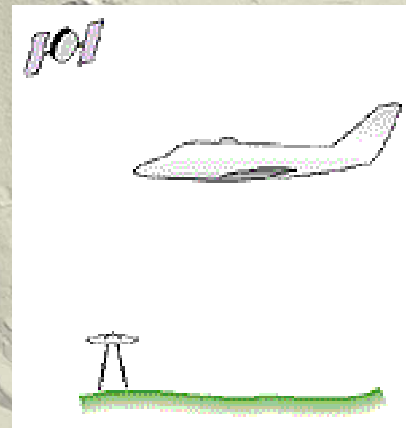
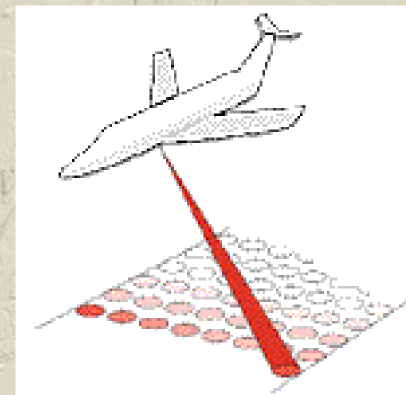
Mercer Island Youth & Family Services
Mercer Island Community & Event...
84th Ave SE
SE 24th St
SE 24th St
N Mercer Way
Mercer Island Park-and-Ride
I-90 Express
90
90

Our mapping technology—which roughly mirrors our senses—has predisposed us to study the world with pictures

- Remote sensing has been the study of color across the map
- Environmental map data are raster (pictures)

# Lidar:
# a primer





*graphic courtesy Natural Resources Canada*

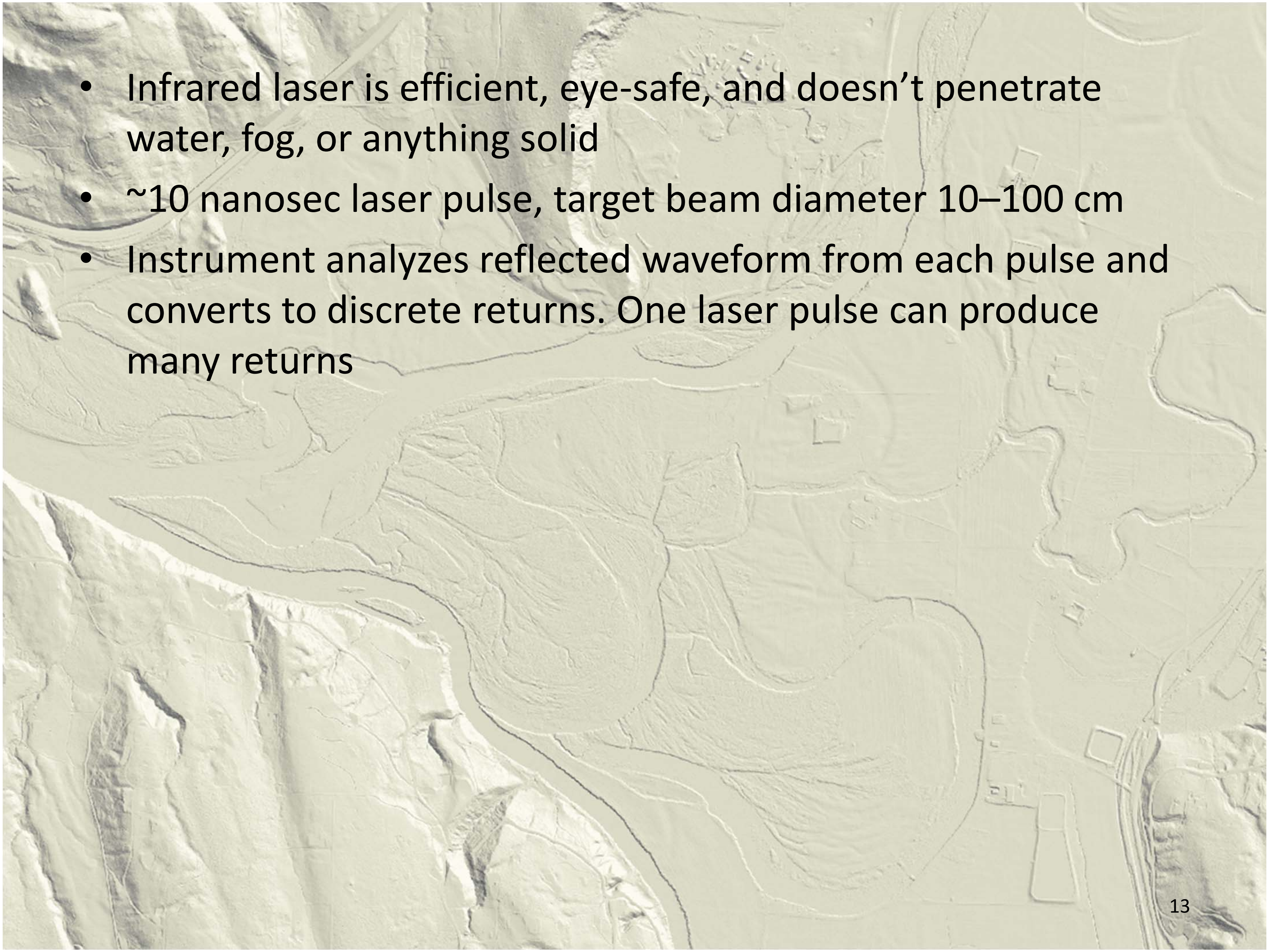
Mapping technology has changed. We now routinely measure dense geometry.

- Differential GPS—aircraft position
- Inertial Measurement Unit (IMU)—aircraft orientation
- Scanning laser rangefinder— scan angle, distance
- 3 data streams
  - GPS @ 1–2 Hz
  - IMU @ 1–200 Hz
  - rangefinder @ 20 kHz – 1,000 kHz
- Extensive processing to get ground coordinates

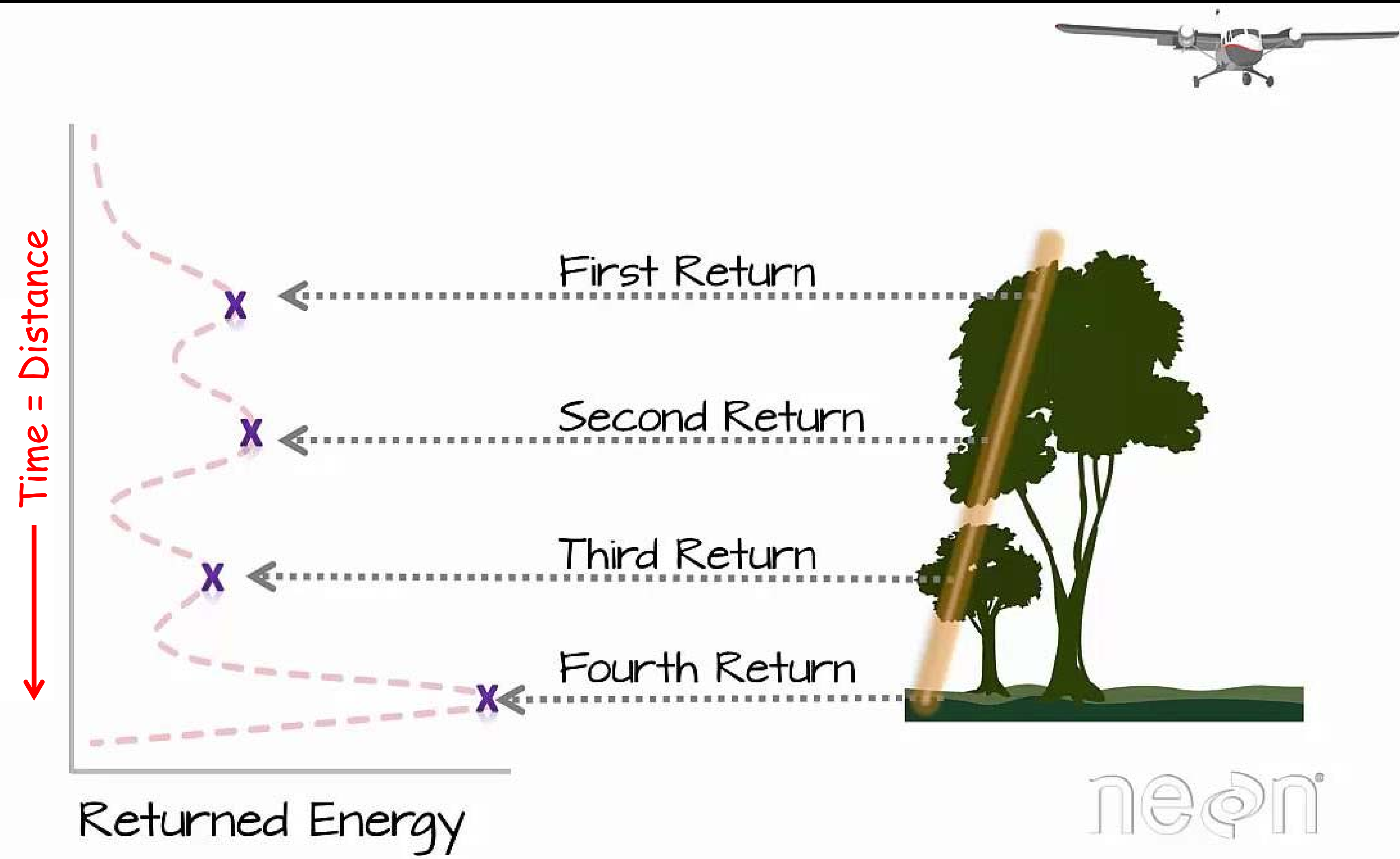

*Power supply, electronics*

*Laser scanner*

Lidar instrument mounted inside a small aircraft



- Infrared laser is efficient, eye-safe, and doesn’t penetrate water, fog, or anything solid
- ~10 nanosec laser pulse, target beam diameter 10–100 cm
- Instrument analyzes reflected waveform from each pulse and converts to discrete returns. One laser pulse can produce many returns



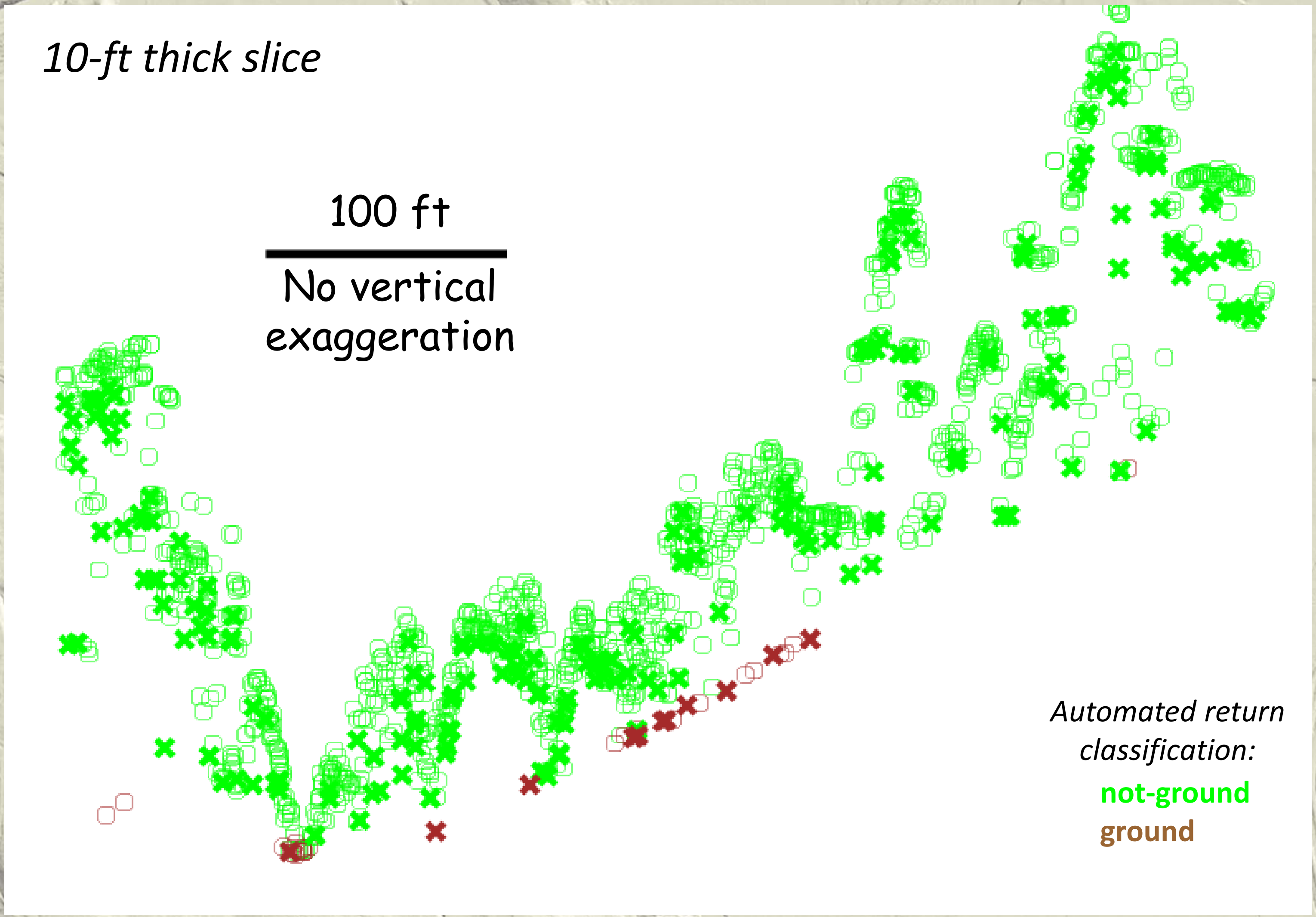

National Ecological Observatory Network, Inc. / youtube.com

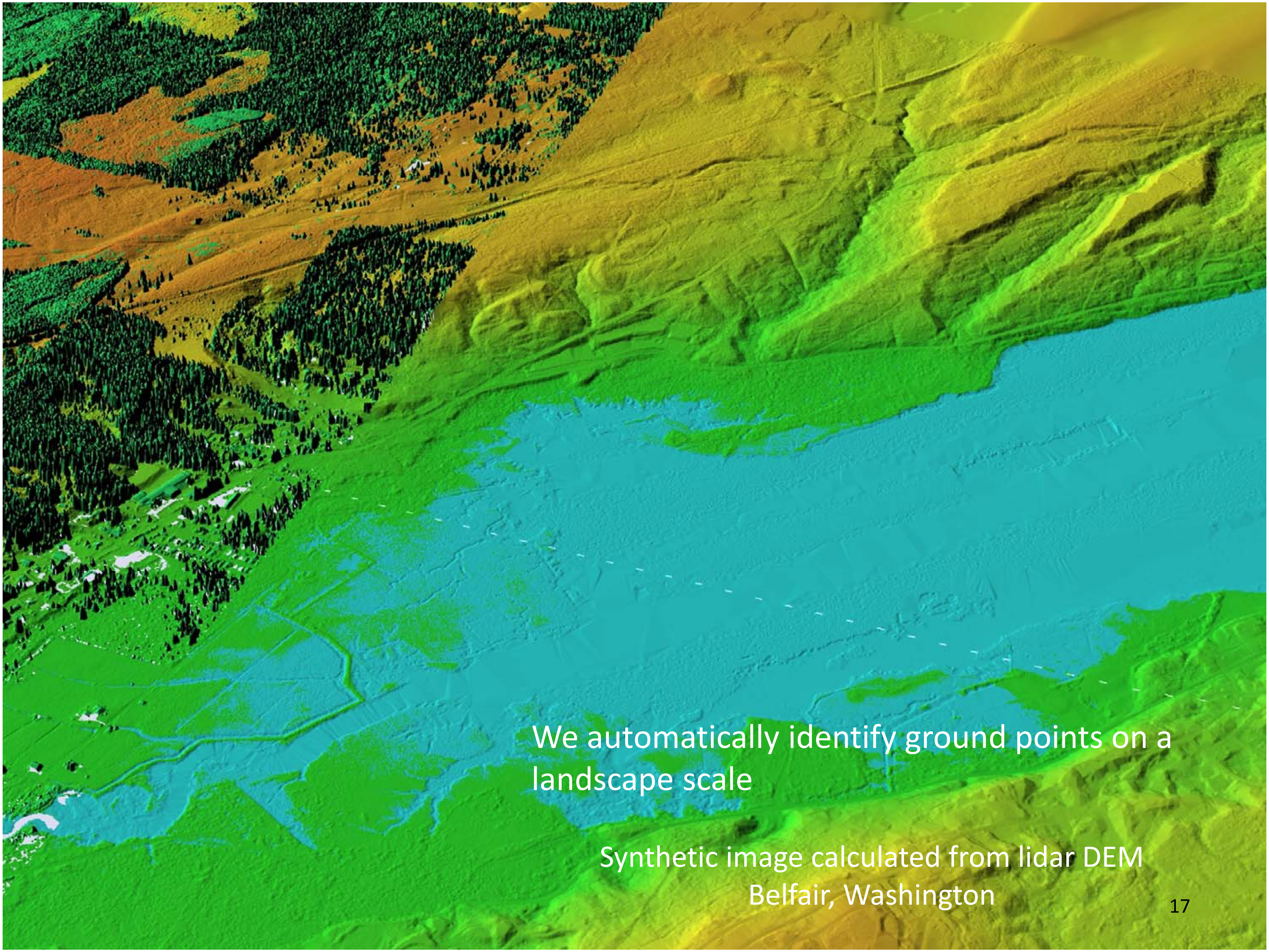
- Infrared laser is efficient, eye-safe, and doesn’t penetrate water, fog, or anything solid
- 10 nanosec laser pulse, target beam diameter 10–100 cm
- Instrument analyzes reflected waveform from each pulse and converts to discrete returns. One laser pulse can produce many returns
- Measure positions on everything: trees, ground, buildings, water, ducks, clouds, …
- Return position accuracies
  - 2–20 cm Z
  - 20–100 cm XY
- Prime determinant of quality is pulse density
  - Nominal on-ground pulse spacing: 2 m–0.1 m
  - 0.25–100 pulse/$m^2$
  - Denser data have more information and are more accurate

**PSLC**
***0.3 m***
***8 pulse/$m^2$***

Many positions => shape

# A lidar point cloud—pure XYZ position *in profile view*






Synthetic image calculated from lidar DEM
Belfair, Washington

# Components of a lidar data set

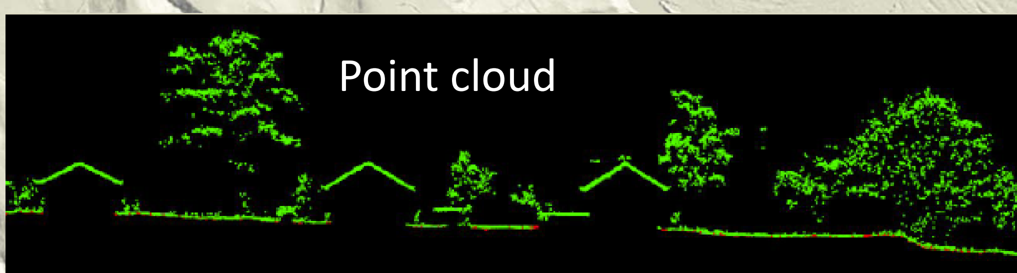
WA DNR Lands
Puget Sound LiDAR Consortium

Technical Data Report

**Puget Sound LIDAR Consortium (PSLC)**
Attn: Christy Lam
1011 Western Ave., Suite 500
Seattle, WA 98104

**QSI Environmental**
517 SW 2nd St., Suite 400
Corvallis, OR 97333
PH: 541-752-1204

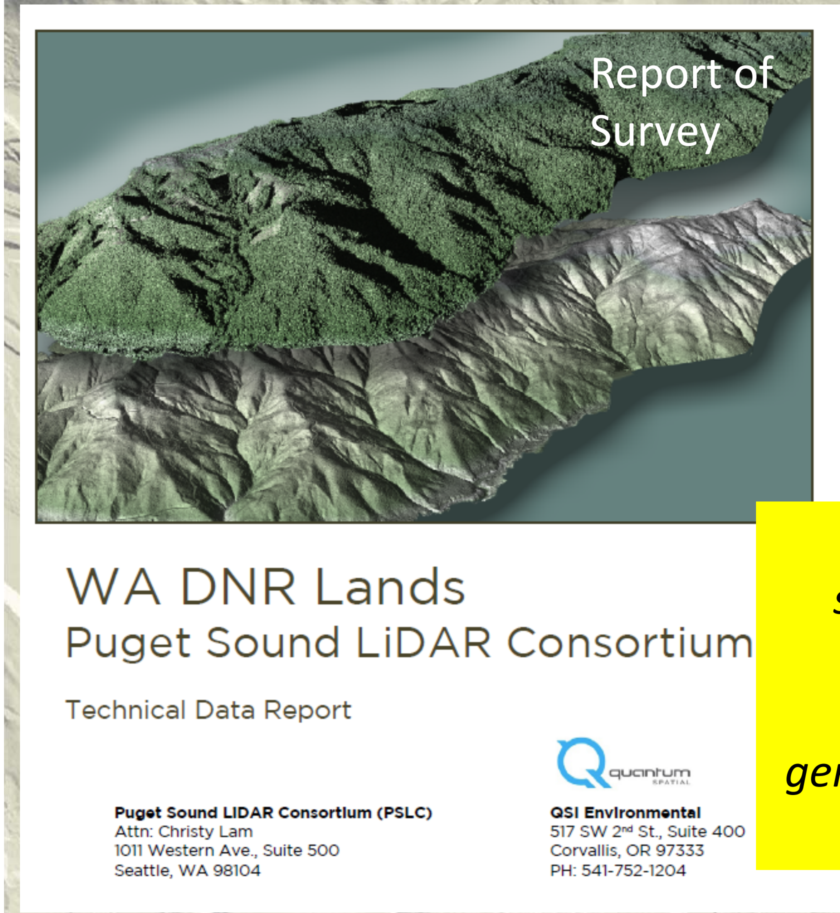
*Where, when, how. Documentation of ground control survey. Completeness and accuracy assessments. Description of deliverables*




*X, Y, Z, t, return#, classification*
*± other per-point data*
*Humongous binary files*

| Name | Size |
|---|---|
| q46123e6102.las | 635,755 KB |
| q46123e6103.las | 595,530 KB |
| q46123e6104.las | 637,497 KB |
| q46123e6105.las | 680,371 KB |
| q46123e6106.las | 574,786 KB |
| q46123e6107.las | 732,325 KB |
| q46123e6108.las | 774,355 KB |
| q46123e6109.las | 671,371 KB |
| q46123e6110.las | 628,186 KB |
| q46123e6111.las | 683,069 KB |

# Components of a lidar data set

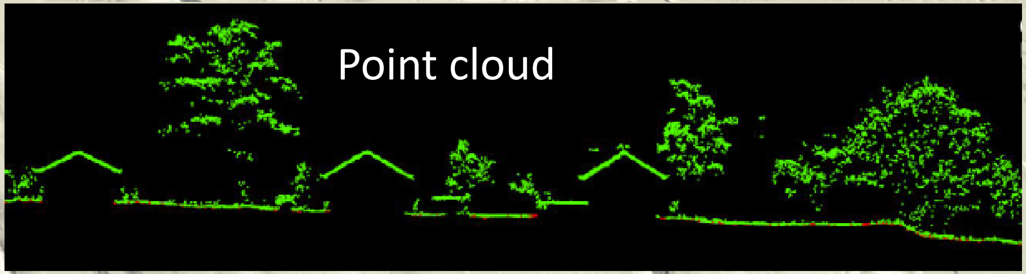



Bare-earth DEM
*hillshade image*

*Elevation raster: world without trees, buildings, bridges. Unfortunately often all that is available*

*Raster file format suggests DEMs are pictures—but they represent shapes generated from point positions*

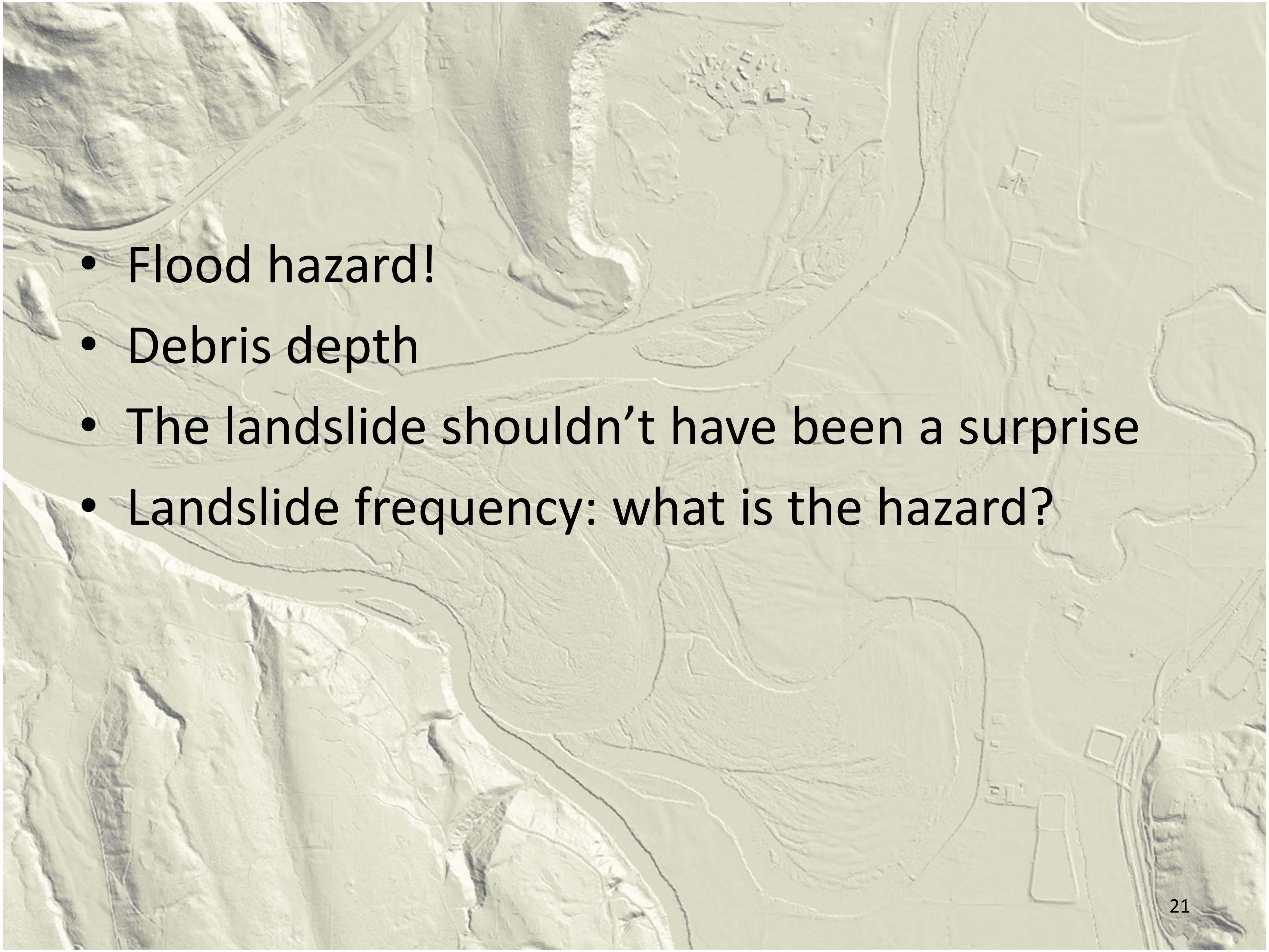
Highest-hit DEM
*hillshade image*



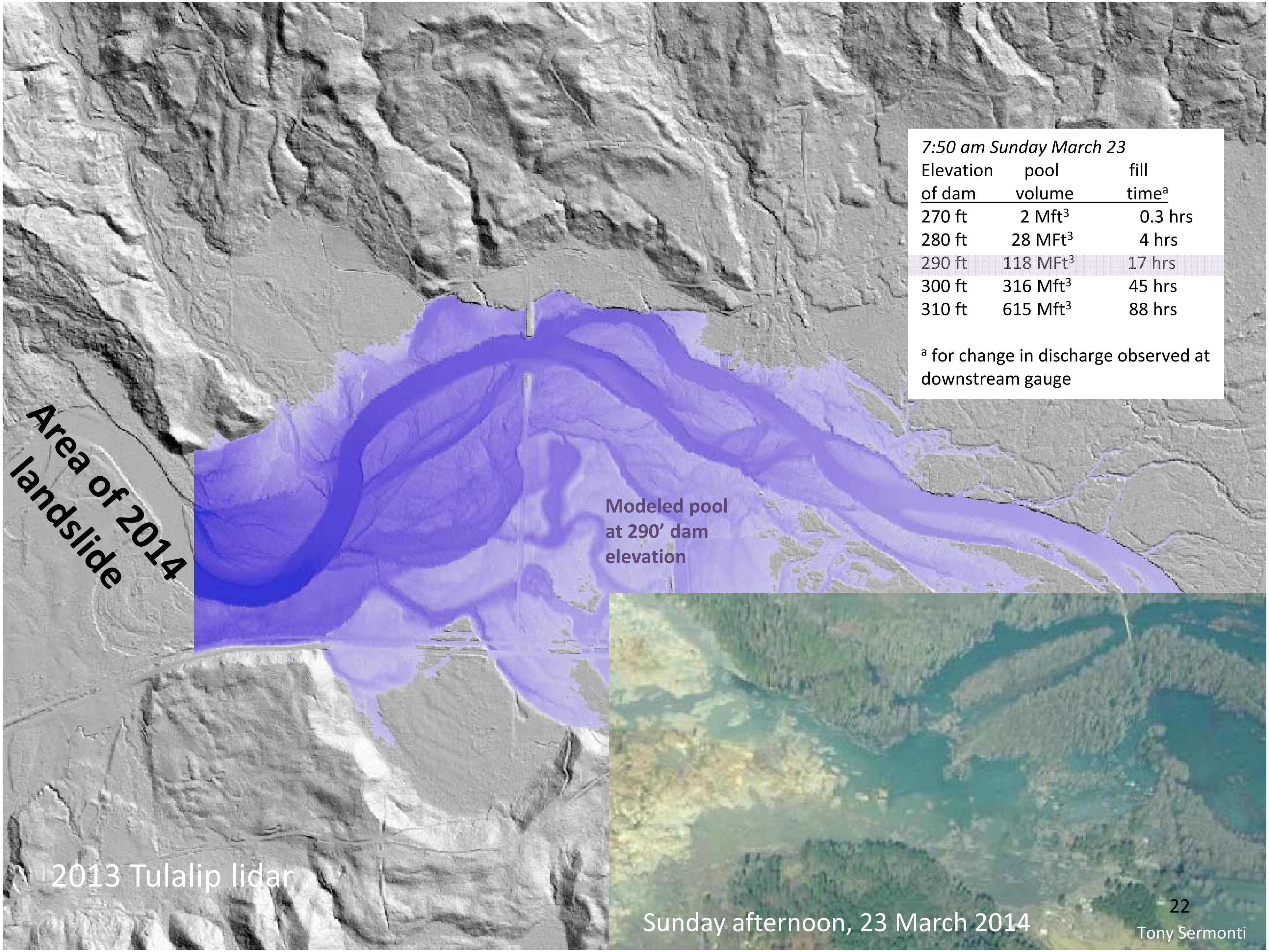
# Oso landslide: response and analysis

- 2003 NASA lidar survey
- 2013 Tulalip lidar survey
- Landslide, 10:37 am March 22, 2014
- 2014 WSDOT post-slide lidar survey

gallery.usgs.gov



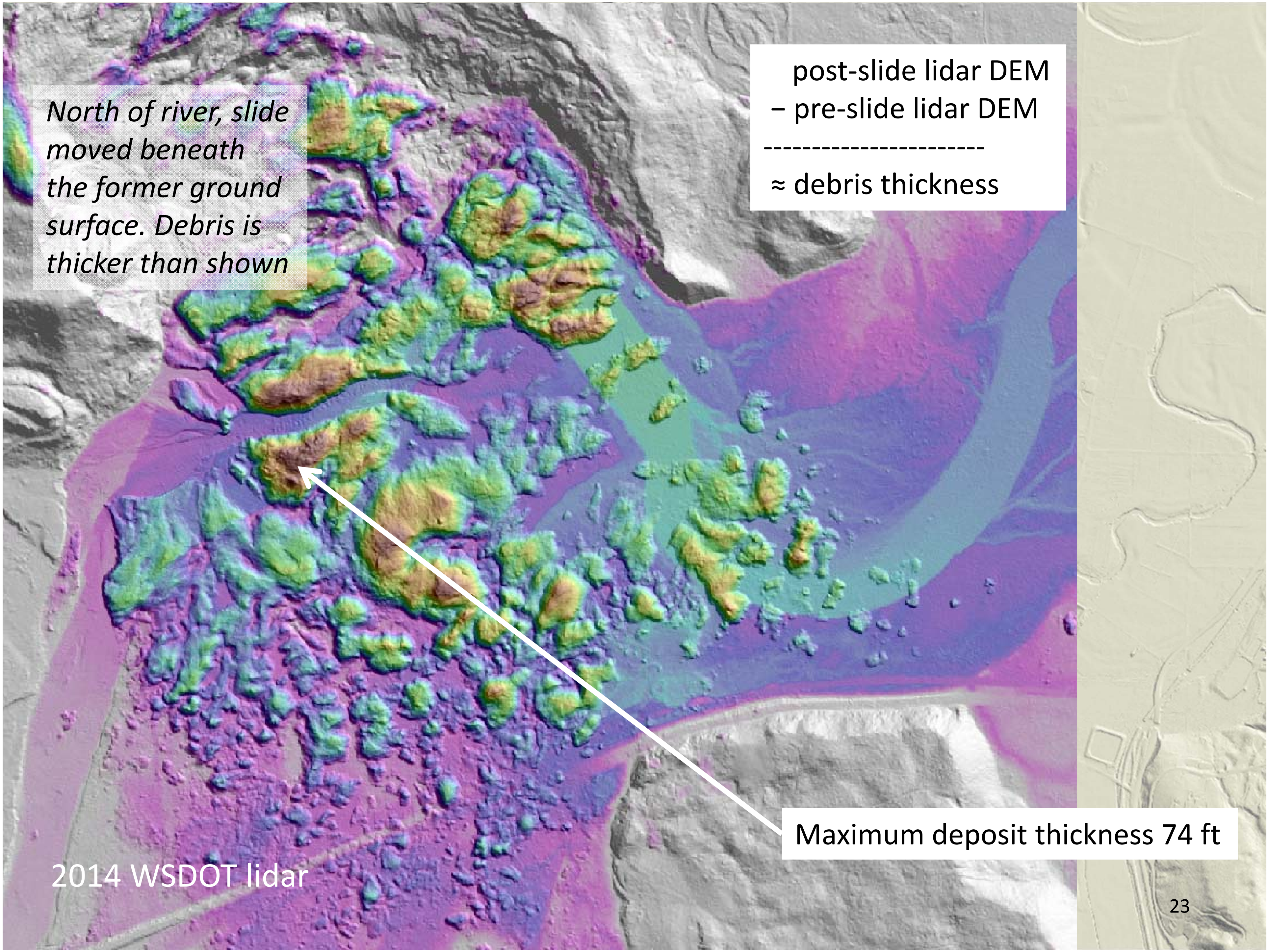
- Flood hazard!
- Debris depth
- The landslide shouldn’t have been a surprise
- Landslide frequency: what is the hazard?




*7:50 am Sunday March 23*

| Elevation of dam | pool volume | fill time[a] |
|---|---|---|
| 270 ft | 2 $Mft^3$ | 0.3 hrs |
| 280 ft | 28 $MFt^3$ | 4 hrs |
| 290 ft | 118 $MFt^3$ | 17 hrs |
| 300 ft | 316 $Mft^3$ | 45 hrs |
| 310 ft | 615 $Mft^3$ | 88 hrs |

[a] for change in discharge observed at downstream gauge


North of river, slide moved beneath the former ground surface. Debris is thicker than shown
post-slide lidar DEM
− pre-slide lidar DEM
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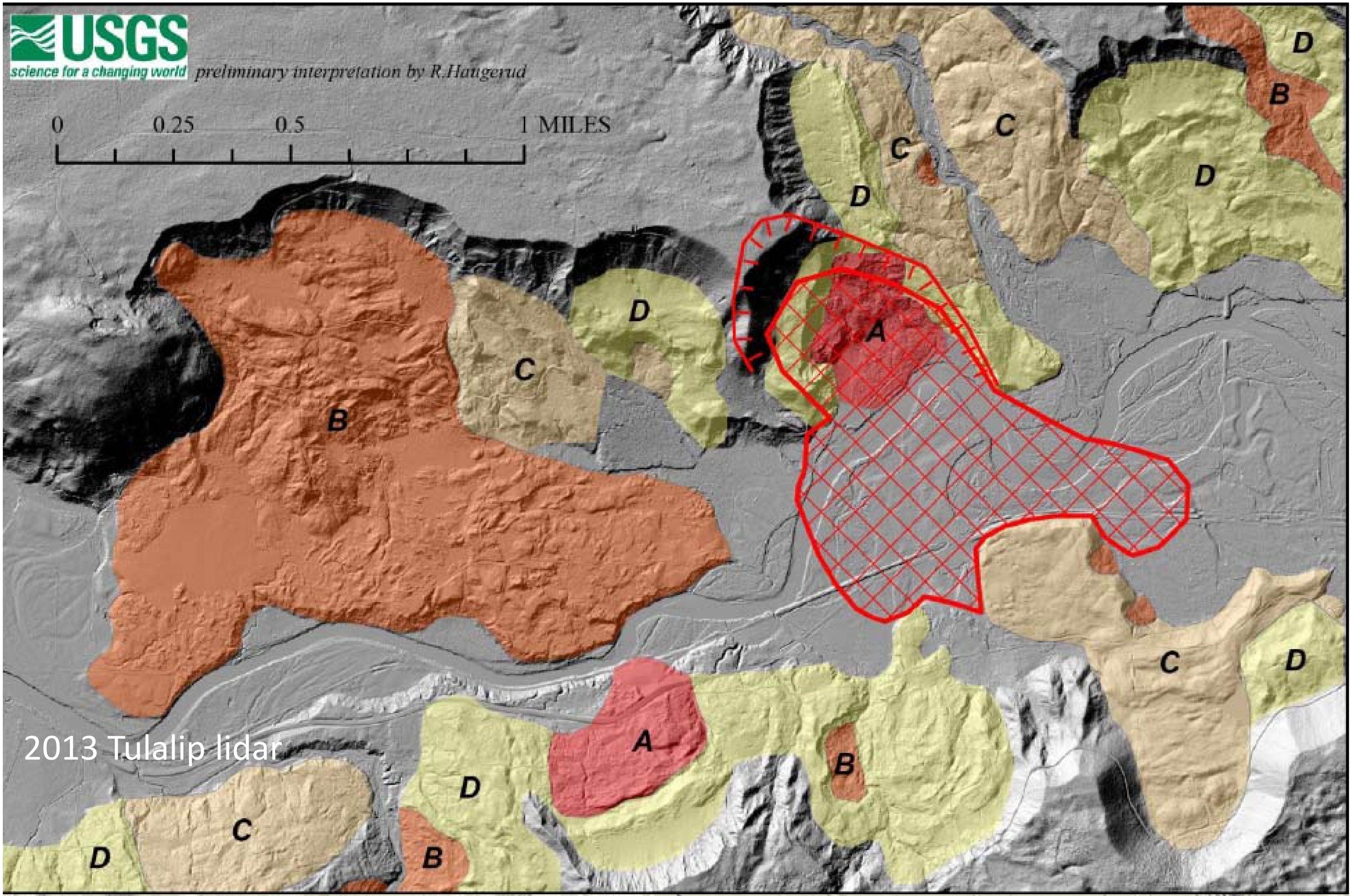
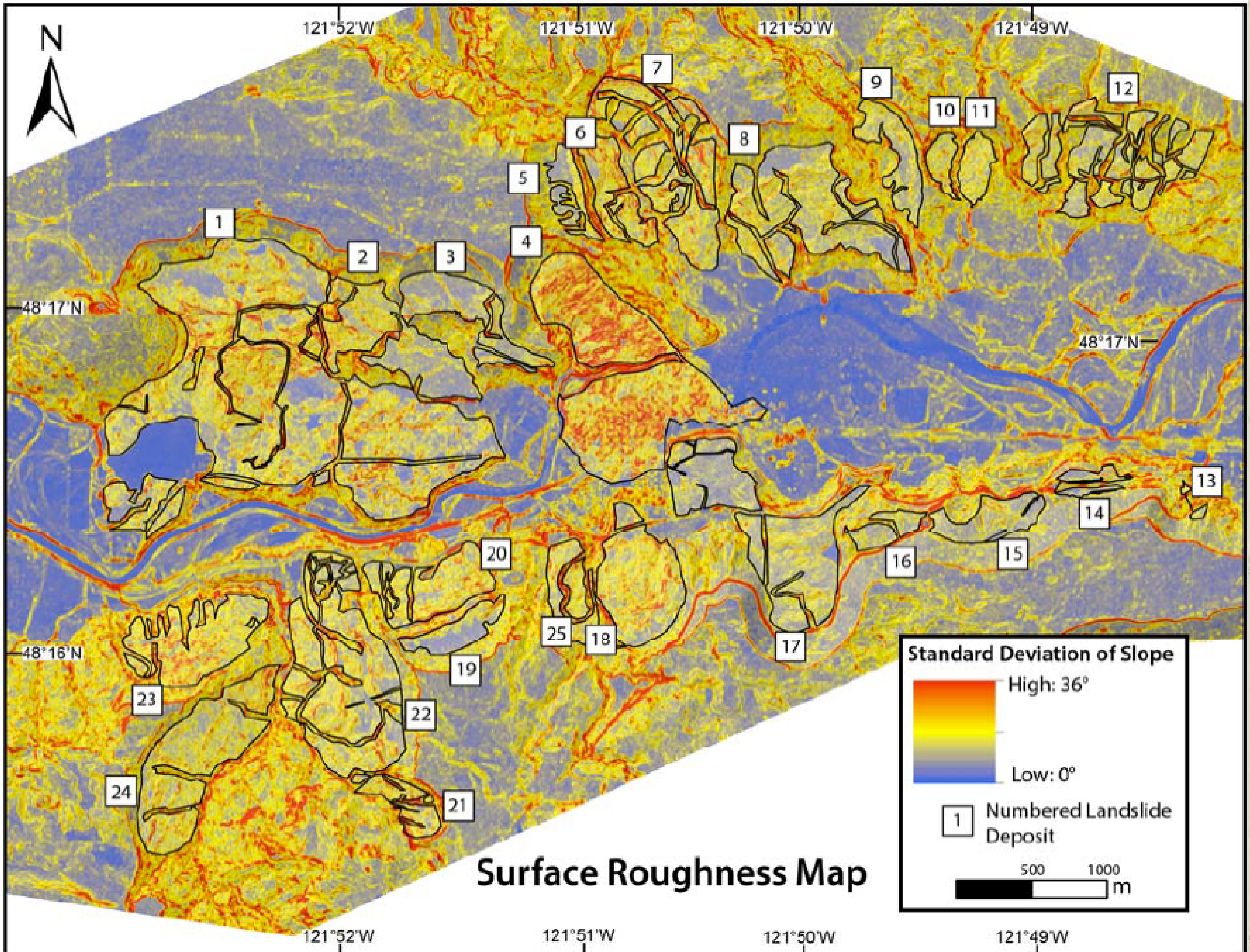
≈ debris thickness
Maximum deposit thickness 74 ft
2014 WSDOT lidar




Colored areas show older landslide deposits, distinguished by their relative age: A, youngest to D, oldest.
The red cross-hatched area marks the approximate extent of deposits from the March 22, 2014 landslide.

pubs.usgs.gov/of/2014/1065/

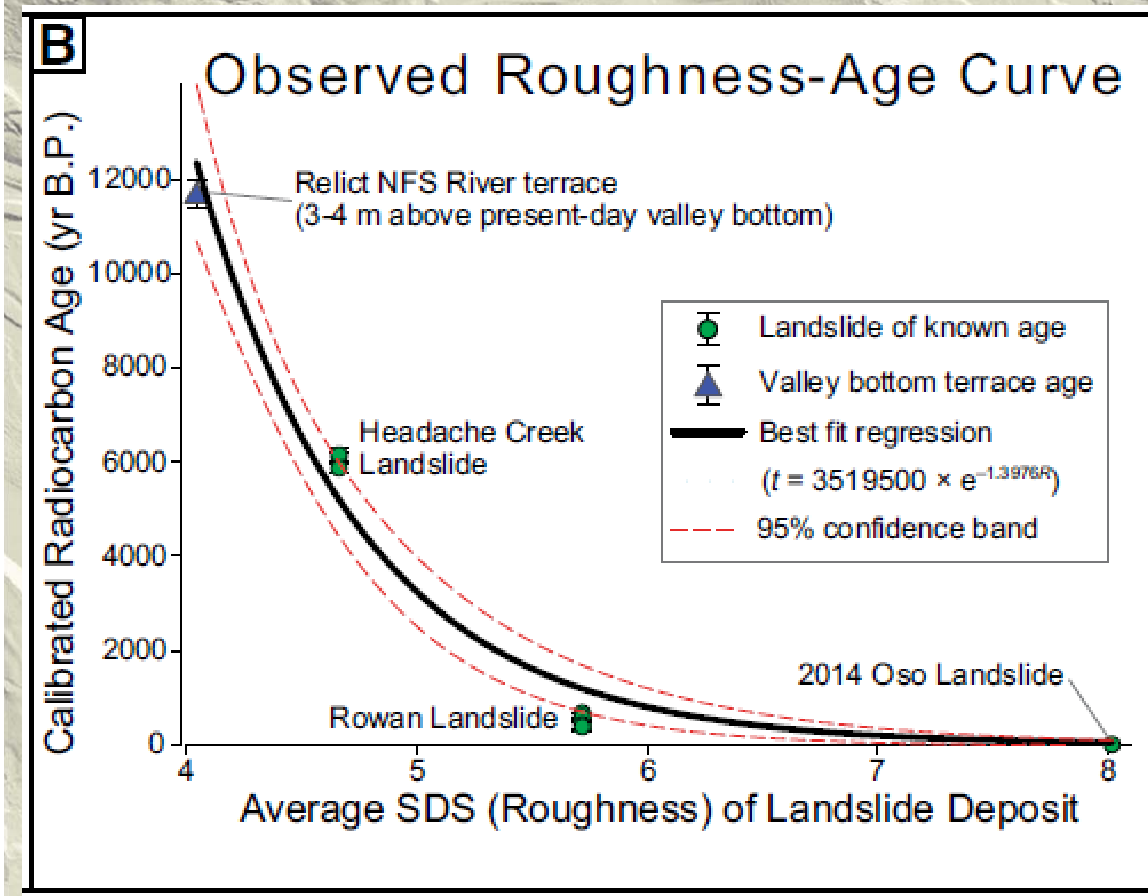



2014 WSDOT
post-side lidar

1. Map surface roughness from lidar topography

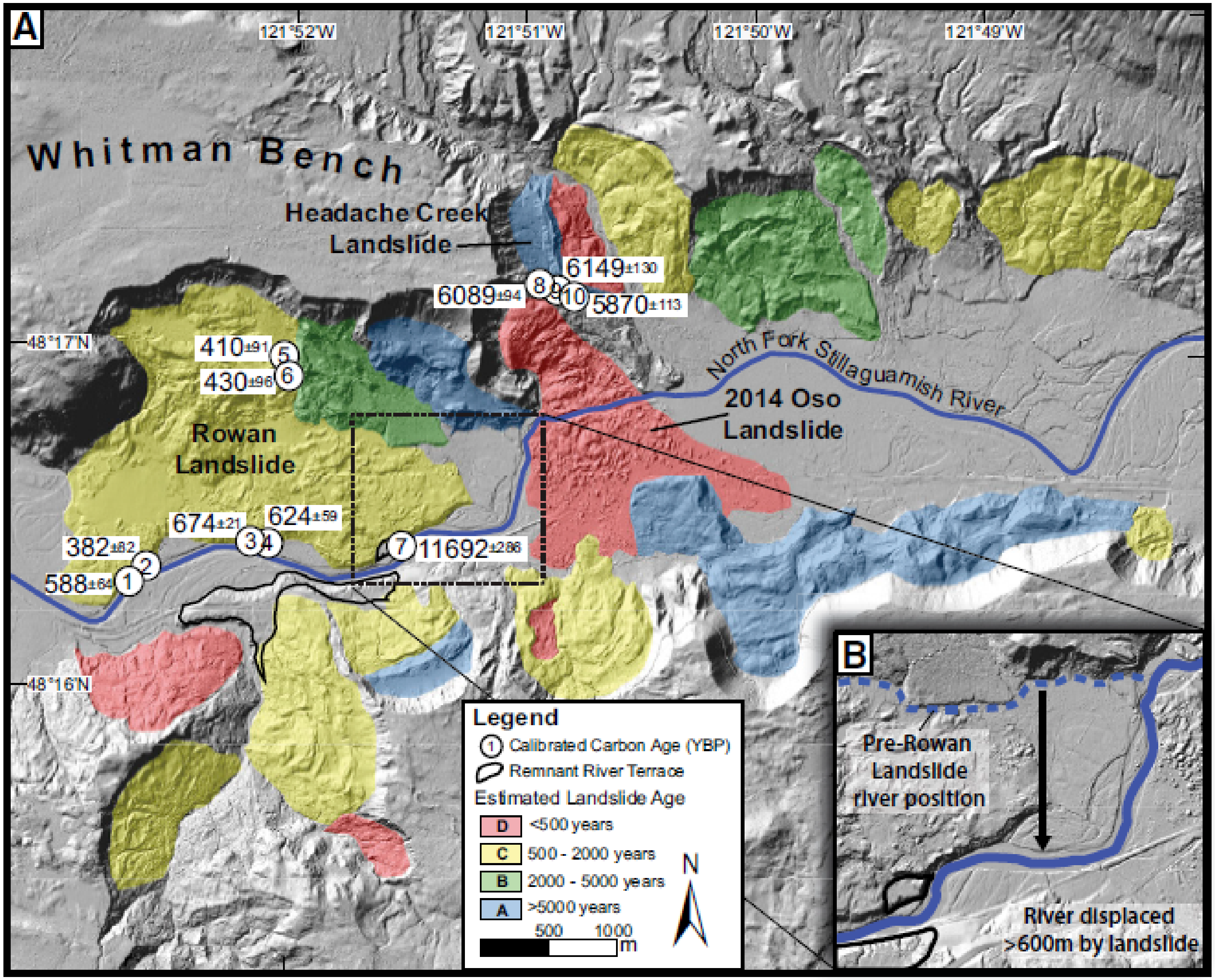
*Underlying principle: raindrops, frost, worms, and gophers make topography smoother with time*

Geology, 2016, *Surface roughness dating of long-runout landslides near Oso, Washington (USA), reveals persistent postglacial hillslope instability*, Sean LaHusen, Alison Duvall, Adam Booth, and David Montgomery




2. Fieldwork to find datable wood for three features
3. Use radiocarbon ages to calibrate a roughness-age curve

Geology, 2016, *Surface roughness dating of long-runout landslides near Oso, Washington (USA), reveals persistent postglacial hillslope instability*, Sean LaHusen, Alison Duvall, Adam Booth, and David Montgomery




4. Use roughness-age relation to estimate ages of undated landslides

**Conclusion: In this part of North Fork Stillaguamish valley, 1 large landslide every 140-500 years.**

Geology, 2016, *Surface roughness dating of long-runout landslides near Oso, Washington (USA), reveals persistent postglacial hillslope instability*, Sean LaHusen, Alison Duvall, Adam Booth, and David Montgomery

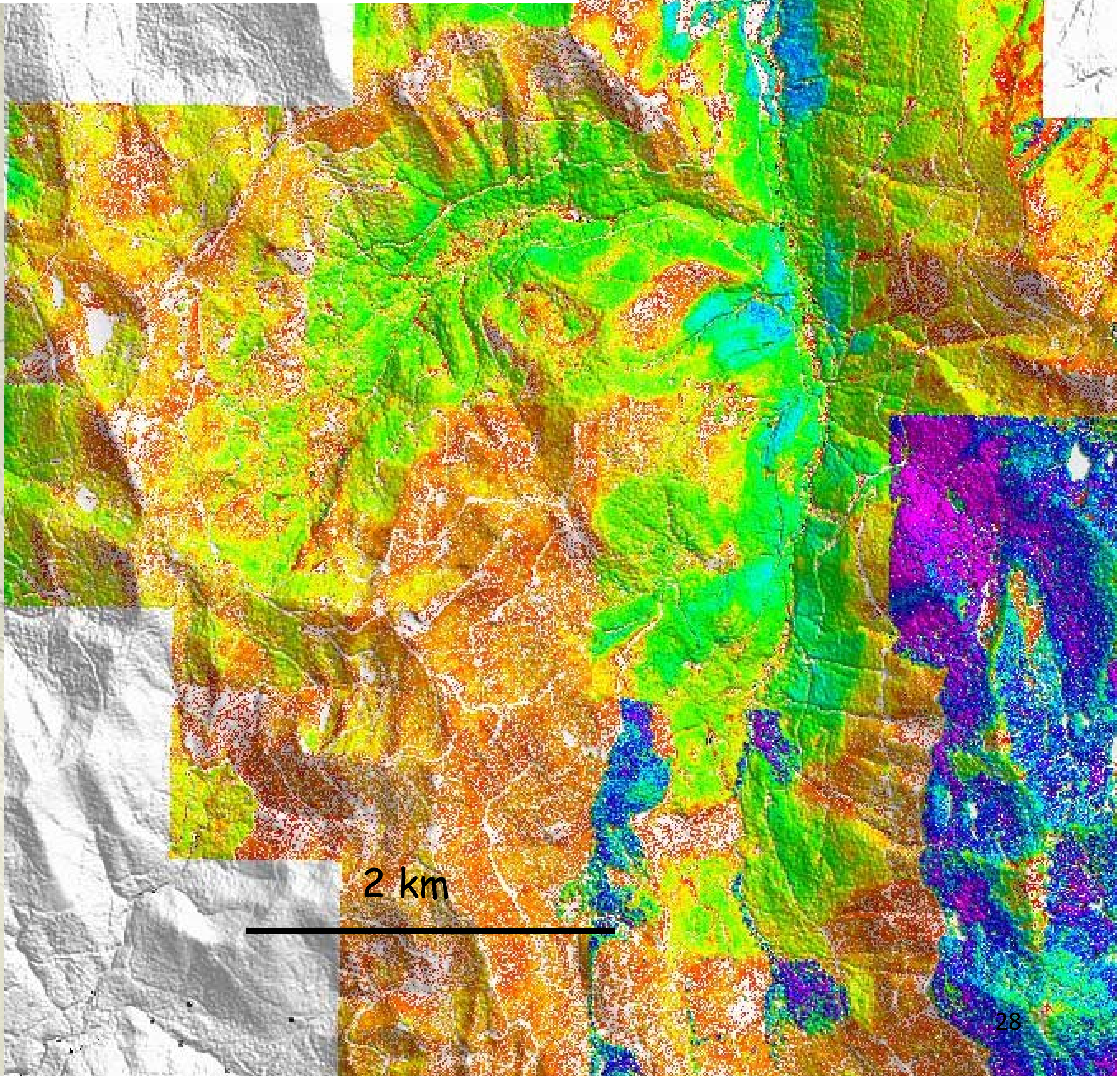
# A forest canopy mapping exercise

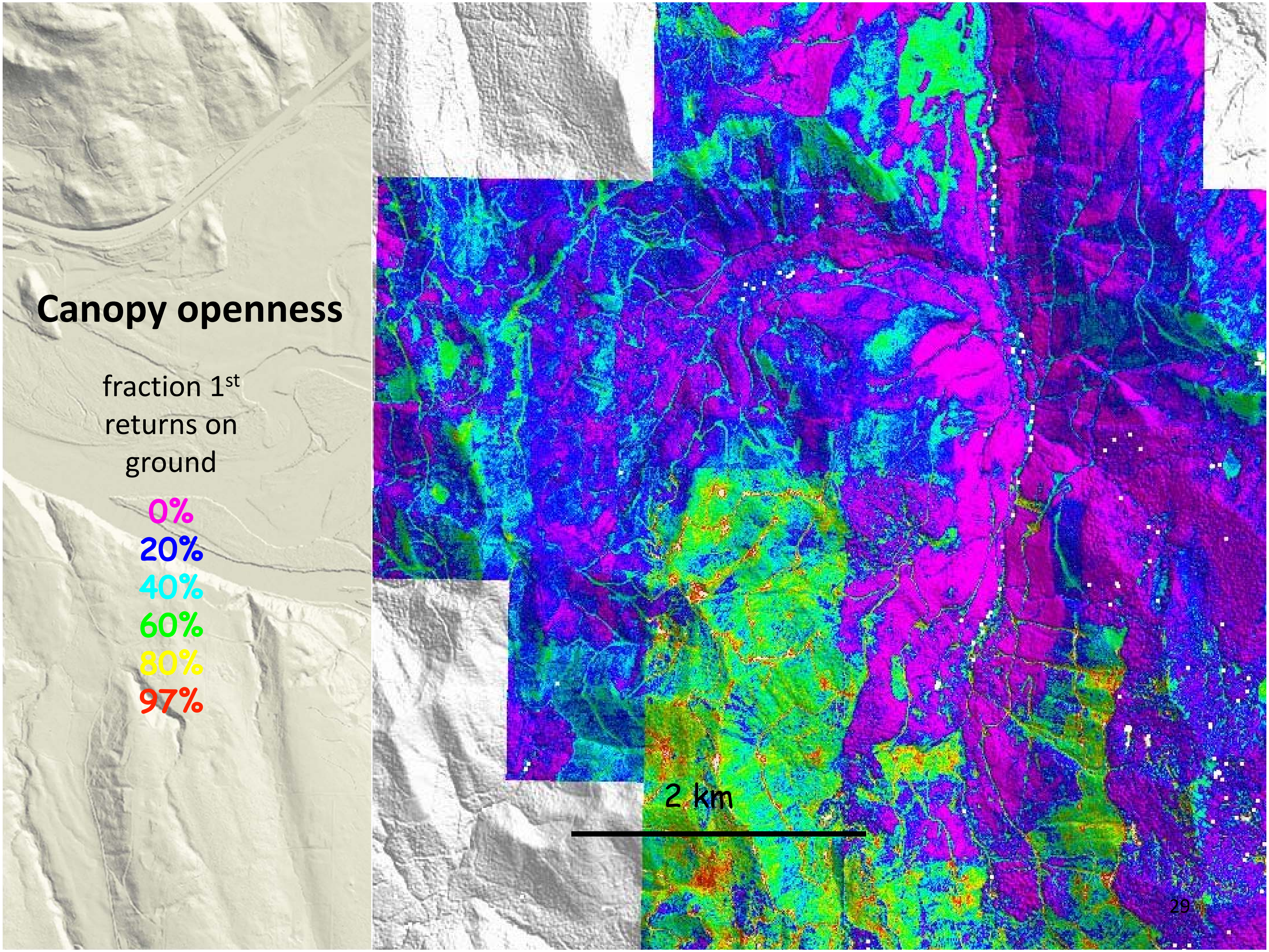
- 1+ pulse/$m^2$ data
- 30-ft cells
- 90+ 1st returns in each cell

**Canopy height**

90th percentile height: ≥150′ 120′ 90′ 60′ 30′ 5′

*fully automated calculations*

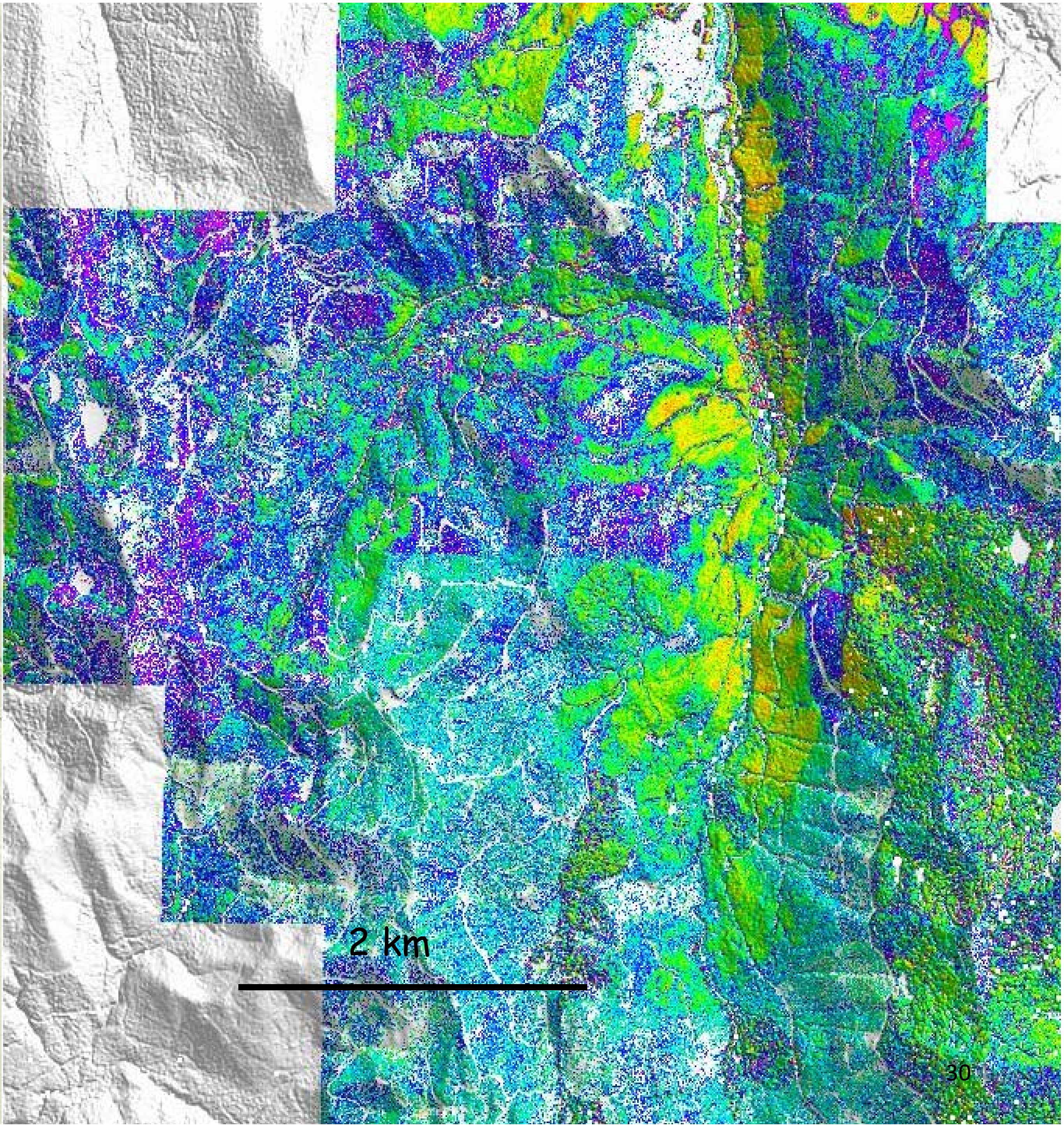



Canopy openness
fraction 1st returns on ground
0%
20%
40%
60%
80%
97%
2 km

## Canopy raggedness

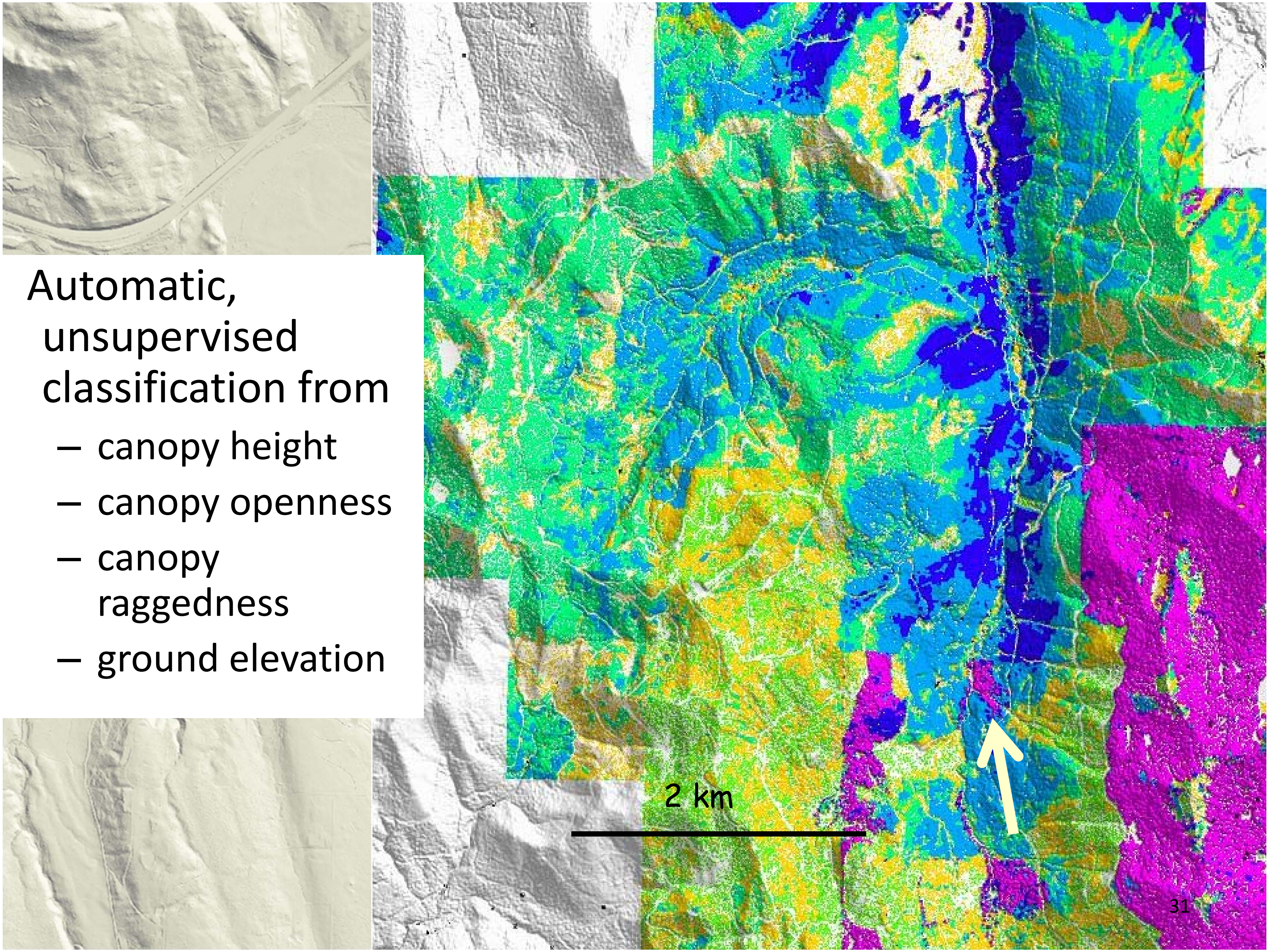
$$\frac{\left(75^{th}\text{ percentile height} - 25^{th}\text{ percentile height}\right)}{90^{th}\text{ percentile height}}$$

>=0.75
0.60
0.45
0.30
0.15
0.02



Automatic, unsupervised classification from

- canopy height
- canopy openness
- canopy raggedness
- ground elevation

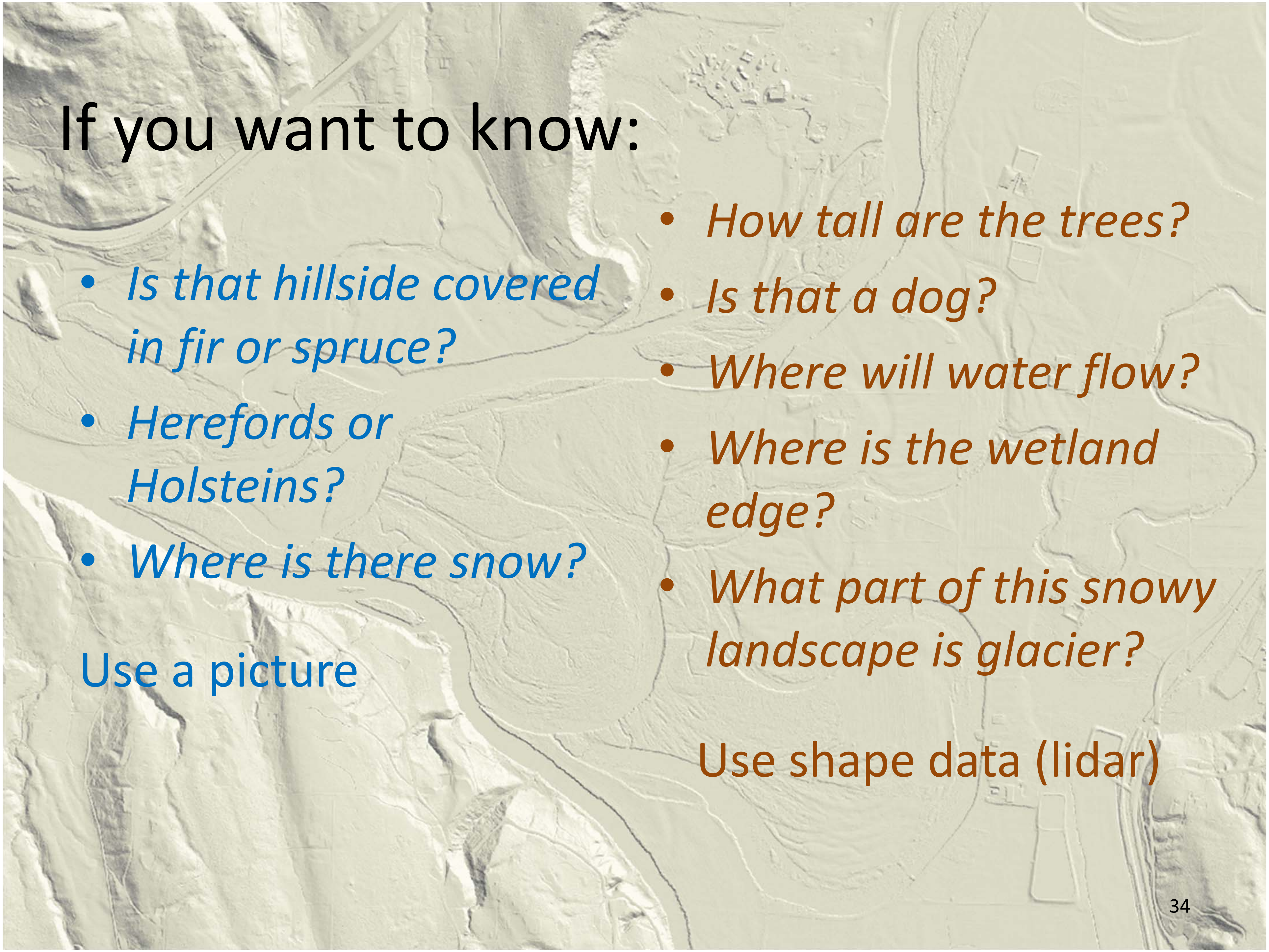


# What makes lidar special?

- Unsurpassed shape data over large areas
- Data are born digital, ready for manipulation and analysis
- Measures the ground through holes in forest canopy

1:24K color stereo air photos ~ 6 byte/$m^2$

6ft lidar DEM ~ 1 byte/$m^2$ ***<= lower information content, but more useful!***



# If you want to know:

- *Is that hillside covered in fir or spruce?*
- *Herefords or Holsteins?*
- *Where is there snow?*

Use a picture

- *How tall are the trees?*
- *Is that a dog?*
- *Where will water flow?*
- *Where is the wetland edge?*
- *What part of this snowy landscape is glacier?*

Use shape data (lidar)