

Point Cloud to Raster

LAStools to ArcGIS

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SURVEY



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THE UNIVERSITY OF UTAH

Tutorial notes

*Applications of High Resolution Topography to Geologic Hazards in Utah
September, 2017, Salt Lake City, Utah*

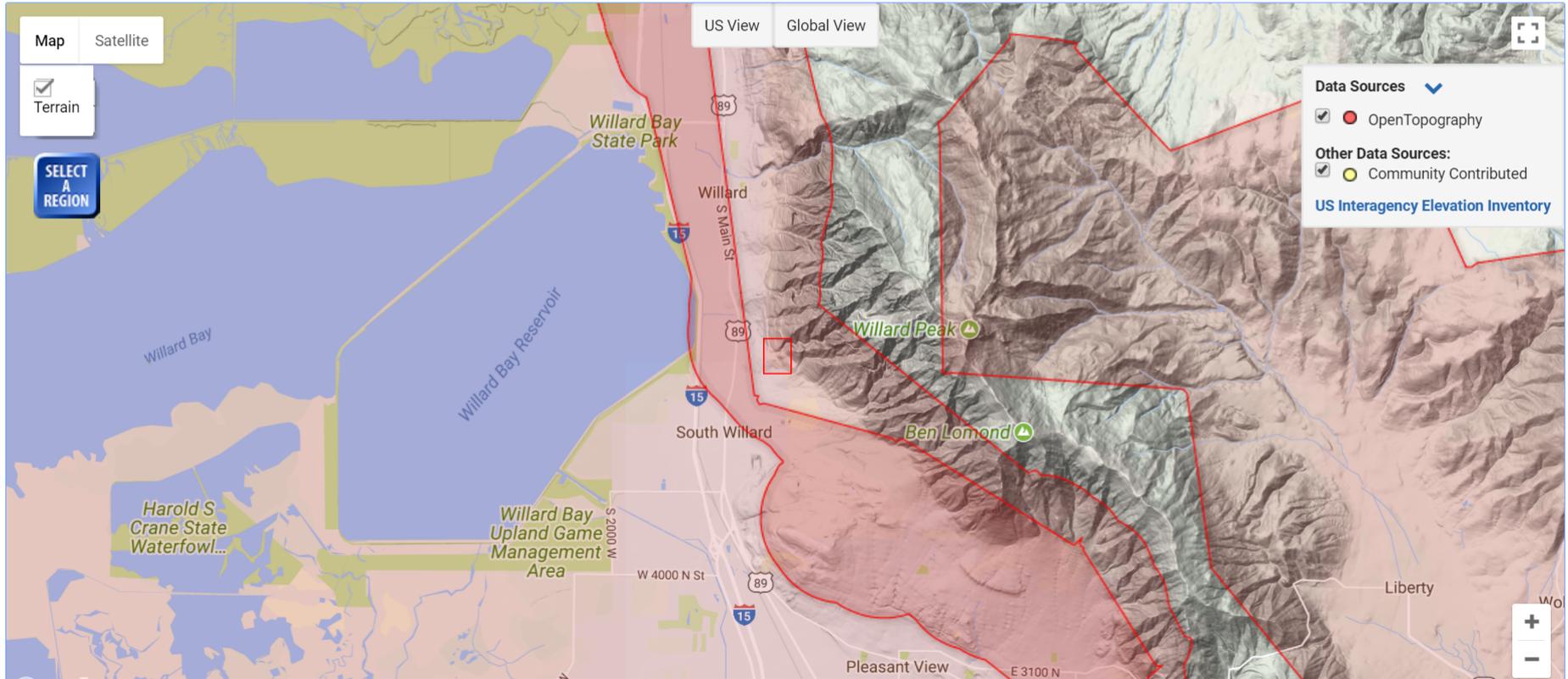


OpenTopography

High-Resolution Topography Data and Tools

Find Topography Data

Instructions



High Resolution Data

Global Data

1 State of Utah Acquired LiDAR Data - Wasatch Front

Raster Data

Point Cloud Data

State of Utah Acquired Lidar Data - Wasatch Front

1a. Select area of data to download or process



3A. DEM Generation (Streaming TIN)

- Gridding Method
- Calculate TIN

Unselect

1. Coordinates & Classification

Horizontal Coordinates: UTM Zone 12N, NAD83 (2011) [EPSG: 26912]
Vertical Coordinates: NAVD88 (GEOID12A) [EPSG: 5703]

Data Selection Coordinates: Manually enter selection coordinates (in the horizontal coordinate system listed above)

$X_{min} = 414200.283785$ $Y_{min} = 4580776.748503$ $X_{max} = 414794.803033$ $Y_{max} = 4581560.787511$

The selection area contains approximately 15,254,000 points.

Choose Return Classification Ground Unclassified

2. Point Cloud Data Download

- Point cloud data in LAS format
- Point cloud data in LAZ format
- Point cloud data in ASCII format

For now, don't select anything else

Job Description

These options allow users to describe and keep track of their jobs. Information entered below is archive accessed via myOpenTopo (available only to registered OpenTopography users).

Job title (up to 100 characters)

Job description (up to 500 characters)

Enter your e-mail address for notification upon completion of processing

SUBMIT

Point Cloud Job Report

[Modify and resubmit this job](#)
[Full job metadata report](#)

[Download Job Metadata](#)
[View Job Configuration](#)

Job Id	Dataset	Title	Submission	Completion	Duration	Num points	Final Status
pc1505615743550	UGS_Wasatch	UGS Pearsons Canyon demo	2017-09-16 19:35:44	2017-09-16 19:36:04	20 secs	14,014,140	Done ✓

Download Job Results

Point Cloud Results

- Download point cloud data in LAZ format [points.laz \(63.3 MB\)](#)

Rename it so you can remember

[Share These Job Results](#)

LAStools

- Open source and commercial tools for processing and analyzing lidar point cloud data in LAS/LAZ format
- <https://rapidlasso.com/lastools/>
- Native GUI, command line, ArcGIS, QGIS & ERDAS Imagine toolboxes.



The screenshot shows a web browser window displaying the website for rapidlasso GmbH. The browser's address bar shows the URL <https://rapidlasso.com/lastools/>. The website header features the company name "rapidlasso GmbH" with the tagline "fast tools to catch reality" below it. A navigation menu includes links for Products, LAStools, BLAST, LASzip, PulseWaves, Blog, Events, Support, and Contact. The main content area is titled "LAStools" and contains the following text:

Our flagship product is the **LAStools** software suite, which is an easy [download](#) (28 MB) and is available for licensing (see [pricing](#)). It is a collection of highly efficient, batch-scriptable, multicore command line tools. We have tools to classify, tile, convert, filter, raster, triangulate, contour, clip, and polygonize LiDAR data (to name just a few functions). All of the tools can also be run via a native GUI and are available as a LiDAR processing toolboxes for **ArcGIS** versions 9.3, 10.0, 10.1, 10.2, or 10.3, for **QGIS** versions 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, or 2.10, and for **ERDAS IMAGINE** versions 14.0 and 15.1.

LAStools are the fastest and most memory efficient solution for batch-scripted multi-core LiDAR processing and can turn billions of LiDAR points into useful products at blazing speeds and with low memory requirements. For seamless processing of large amounts of LiDAR we further offer the **BLAST** extension of LAStools.

Below the text, there is a "Share this:" section with social media sharing buttons for Twitter and Facebook (showing 67 shares).

At the bottom of the page, it says "Blog at WordPress.com."

PearsonDemopoints.laz

browse ...

- \
- \.
- \2017 OT short course
- \BorahPeak
- \LASTools
- \OldTalks to build from
- \Papers
- PearsonDemopoints.laz

wildcard: *.laz add

directory: E:\ go

- .las
- .laz
- .bin
- .asc
- .bil
- .dtm

ASCII files ... +

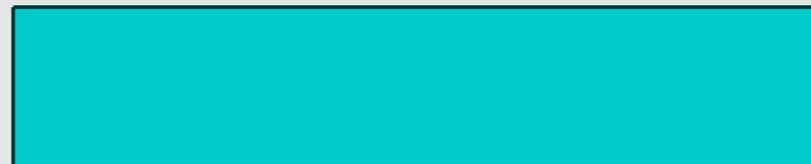
filter ... +

transform ... +

projection ... +

overlays ... +

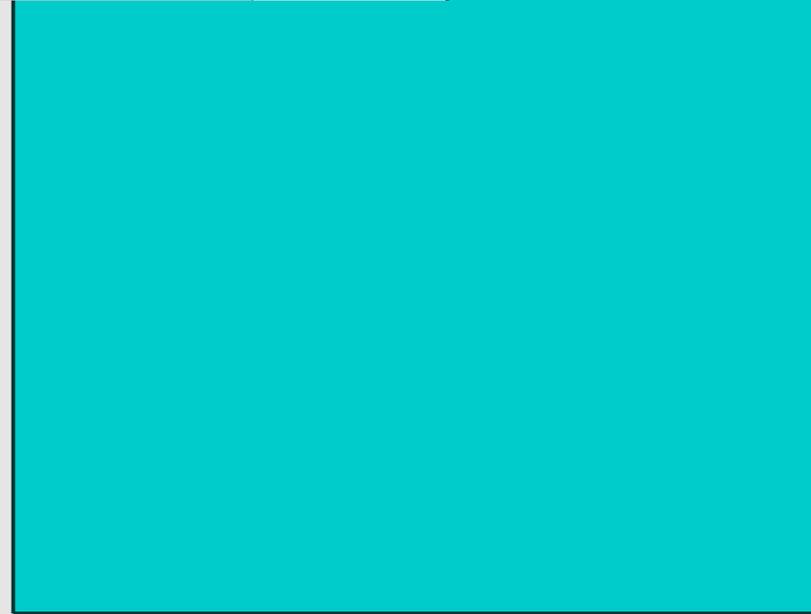
LAS version: 1.2
 source ID: 0 created: 258/2017
 'LASTools (c) by rapidlasso GmbH'
 'las2las (version 140403) + OT'
 # of points: 14014140
 point type: 3 point size: 34



RUN

```
lasview -i "C:\Users\ramon\Google Drive\+S_Active_Items\2017UGS_OT\PearsonDemopoints.laz"
```

START
 COPY
 CANCEL



- selected file only
- process all files
- verbose

render only +

color by +

window size +

VIEW

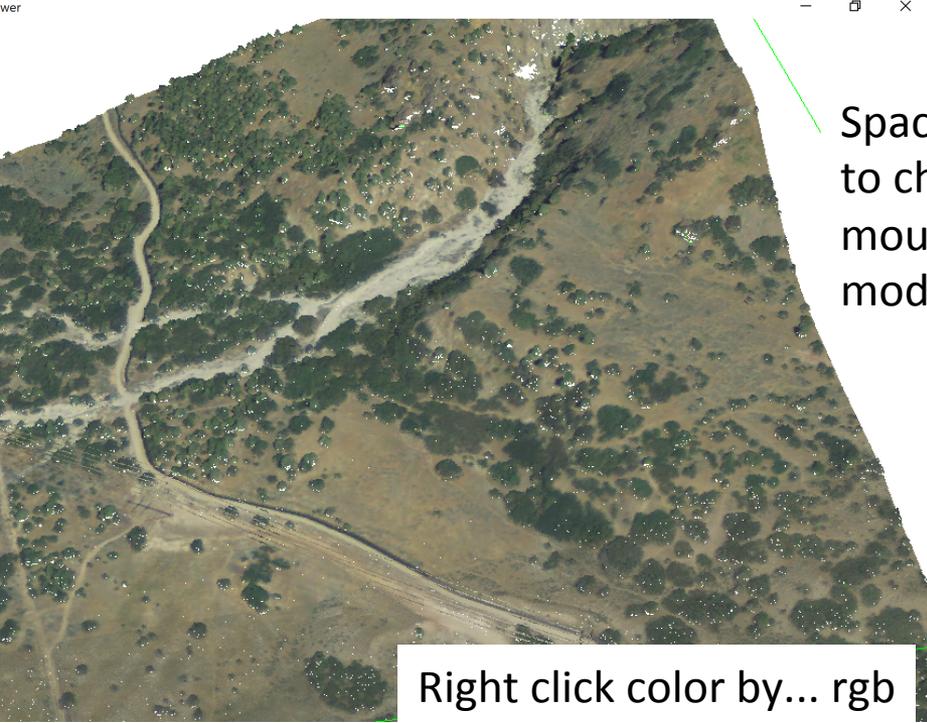
sample points: 5000000

files are flightlines

apply file source ID

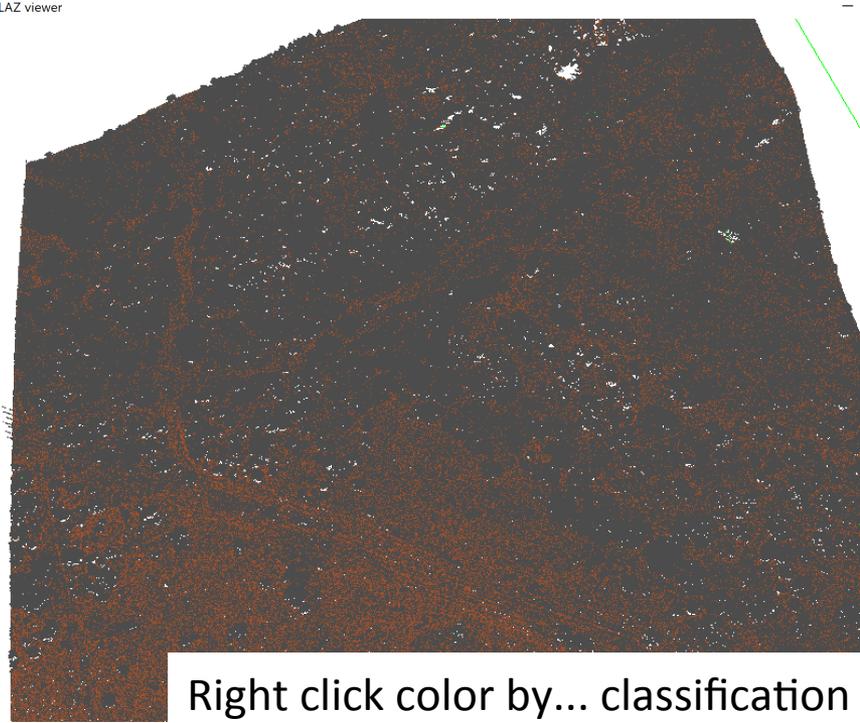
concavity: 50

README <Q>UIT

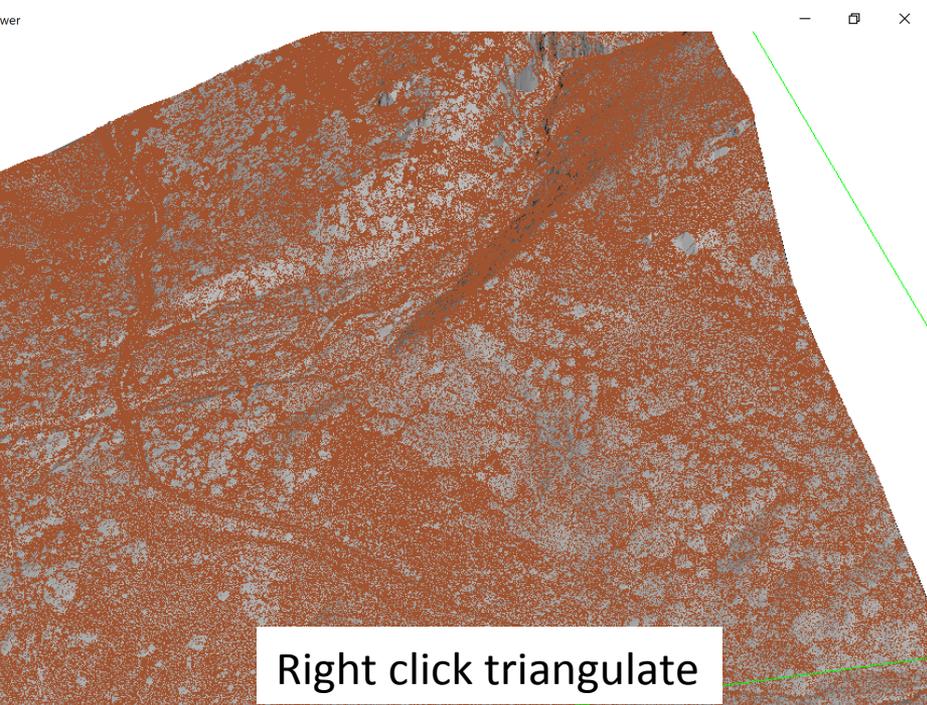


Space bar
to change
mouse
mode

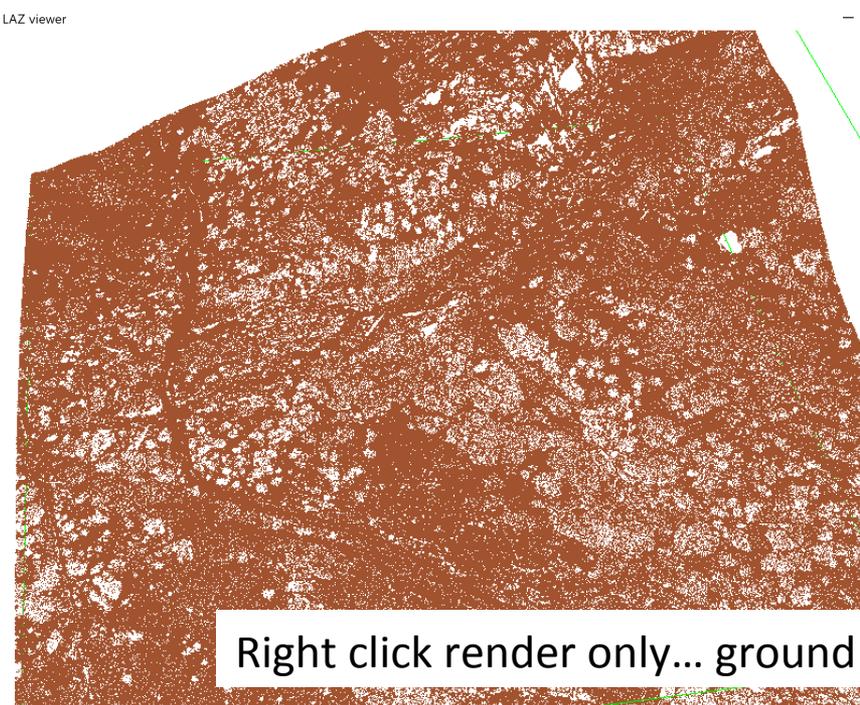
Right click color by... rgb



Right click color by... classification



Right click triangulate



Right click render only... ground

ASPRS LAS(er) Format

- Binary public format for exchange of 3D point cloud data. Owned & maintained by ASPRS.
- Airborne lidar-oriented. v. 1.0 (2003) – v 1.4 (2011)

<i>Classification Value (bits 0:4)</i>	<i>Meaning</i>
0	Created, never classified
1	Unclassified ¹
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building
7	Low Point (noise)
8	Model Key-point (mass point)
9	Water

- .LAZ = LASzip – open source library for lossless compression of LAS lidar data. Developed by Martin Isenburg of LAStools.

Overview

Starting with an LAS/LAZ file, let's explore the contents of the file, do some manipulation and filtering, and then maybe reproject the file. Next we'll make elevation and other rasters using Lastools and visualize and examine them in Google Earth and ArcGIS.

Outline

1. LASinfo to see what's in the file (attributes etc)
2. LAS2txt to look at contents in human readable form
3. LASboundary to make an outline of the file and plot it on a map
4. LASground to classify ground vs vegetation points
5. LAS2LAS for filtering on attributes and reprojection
6. Lasgrid point density
7. Lecture burst on generating DEMs from points
8. Neighborhood approach for DSM and DTM (Lasgrid DEM)
9. Tinning approach with tiling for DSM and DRM (lastile and blast2dem)
10. ArcGIS DEM visualization, manipulation, and simple raster math

LASinfo – reports contents of LAS file

lasinfo - prints out a quick overview of the LiDAR content of a LAS/LAZ/BIN/ASCII file

The screenshot displays the lasinfo application interface. On the left, a file browser shows the selected file 'PearsonDemopoints.laz'. The main window contains a command prompt with the following command: `lasinfo -i "C:\Users\ramon\Google Drive\S\Active_Items\2017UGS_OT\PearsonDemopoints.laz" -otxt`. The 'RUN' dialog box is open, with the 'START' button highlighted. On the right, the 'output options' section is expanded, and the '*.txt' option is selected. A red circle highlights this section, and a red arrow points to the 'START' button with the text: *Run button is down here --collapse the upper choices*. The bottom status bar shows the following information: LAS version: 1.2, source ID: 0, created: 258/2017, 'LASinfo (c) by rapidlasso GmbH', 'las2las (version 140403) + OT', # of points: 14014140, point type: 3, point size: 34.

LASinfo – reports contents of LAS file

PearsonDemopoints - Notepad

File Edit Format View Help

reporting all LAS header entries:

```
file signature:      'LASF'  
file source ID:     0  
global_encoding:    1  
project ID GUID data 1-4: 00000000-0000-0000-5455-484100000000  
version major.minor: 1.2  
system identifier:  'LAStools (c) by rapidlasso GmbH'  
generating software: 'las2las (version 140403) + OT'  
file creation day/year: 258/2017  
header size:        227  
offset to point data: 1487  
number var. length records: 3  
point data format:  3  
point data record length: 34  
number of point records: 14014140  
number of points by return: 13428282 578830 6177 846 5  
scale factor x y z:  0.01 0.01 0.01  
offset x y z:        0 0 0  
min x y z:           414200.29 4580776.75 1355.91  
max x y z:           414794.80 4581560.78 1599.66
```

Header summary

variable length header record 1 of 3:

```
reserved           43707  
user ID            'LASF_Projection'  
record ID          34735  
length after header 96  
description        'GeoTIFF GeoKeyDirectoryTag'
```

Georeferencing information

GeoKeyDirectoryTag version 1.1.0 number of keys 11

```
key 1024 tiff_tag_location 0 count 1 value_offset 1 - GTModelTypeGeoKey: ModelTypeProjected  
key 1025 tiff_tag_location 0 count 1 value_offset 1 - GTRasterTypeGeoKey: RasterPixelIsArea  
key 1026 tiff_tag_location 34737 count 31 value_offset 9102  
key 2049 tiff_tag_location 34737 count 6 value_offset 3102  
key 2054 tiff_tag_location 0 count 1 value_offset 9102  
key 3072 tiff_tag_location 0 count 1 value_offset 26912  
key 3076 tiff_tag_location 0 count 1 value_offset 9001  
key 4096 tiff_tag_location 0 count 1 value_offset 5703  
key 4097 tiff_tag_location 34737 count 14 value_offset  
key 4098 tiff_tag_location 0 count 1 value_offset 5103
```

```
X 41420029 41479480  
Y 458077675 458156078  
Z 135591 159966  
intensity 0 255  
return_number 1 5  
number_of_returns 1 5  
edge_of_flight_line 0 0  
scan_direction_flag 0 1  
classification 1 7  
scan_angle_rank -16 20  
user_data 0 0  
point_source_ID 6165 12218  
gps_time 67454341.779927 68227738.997013  
Color R 7424 61440  
G 8192 61696  
B 10752 59648  
number of first returns: 13428282  
number of intermediate returns: 7035  
number of last returns: 13428388  
number of single returns: 12849565  
overview over number of returns of given pulse: 12849565 114517 16008 3368 22 0 0  
histogram of classification of points:  
10625129 unclassified (1)  
3388321 ground (2)  
690 noise (7)
```

*Summary of file contents -
Min/max & histogram -
from scan of file*

LAS2TXT – points in ascii

las2txt - turns LiDAR into human-readable, easy-to-parse ASCII

The screenshot shows the las2txt application interface. On the left, a file list contains 'PearsonDemopoints.laz'. Below it, a file browser shows the same file selected in the 'E:\' directory. The main window is a large cyan rectangle. On the right, a settings panel includes a 'VIEW' button, 'sample points: 5000000', and a list of attributes with checkboxes. A red circle highlights the attribute list, and a red arrow points from a text box to the 'parse string' field.

Attributes list (circled in red):

- (x)
- (y)
- (z)
- (i)ntensity
- (r)eturn number
- (n)umber of returns
- (c)lassification
- scan (a)ngle
- (u)ser data
- (p)oint source ID
- GPS (t)ime
- (k)eypoint flag
- with(h)old flag
- (o)verlap flag
- scanner channe(l)
- (R)GB color
- (w)ave packet index
- (W)ave packet
- wa(v)e form

parse string: xyzirncapt
separator: comma

Parse string & delimiter

LAS2TXT – points in ascii

414248.13,4580776.87,1363.64,134,1,1,1,5,0,6165,67454341.779927,22528,23
414248.04,4580776.97,1363.51,148,1,1,1,5,0,6165,67454341.782320,23040,23
414246.79,4580776.96,1363.12,192,1,1,1,5,0,6165,67454341.800585,27904,28
414247.00,4580777.40,1363.19,185,1,1,1,5,0,6165,67454341.800597,29184,29
414246.90,4580777.54,1363.31,162,1,1,1,5,0,6165,67454341.803013,29440,29
414246.68,4580777.08,1363.20,170,1,1,1,5,0,6165,67454341.803025,31488,32
414245.40,4580776.88,1363.18,199,1,1,1,5,0,6165,67454341.821231,29696,29
414245.62,4580777.35,1363.11,221,1,1,2,5,0,6165,67454341.821243,33024,33
414245.84,4580777.80,1363.14,230,1,1,2,5,0,6165,67454341.821255,31488,31
414246.05,4580778.24,1363.22,205,1,1,1,5,0,6165,67454341.821266,33792,32
414245.98,4580778.42,1363.16,233,1,1,2,5,0,6165,67454341.823683,35072,34
414245.74,4580777.94,1363.15,236,1,1,1,5,0,6165,67454341.823695,31488,30720,25088
414245.51,4580777.45,1363.18,231,1,1,1,5,0,6165,67454341.823707,32512,32512,26624
414245.27,4580776.96,1363.20,206,1,1,1,5,0,6165,67454341.823718,28416,28160,22272
414244.14,4580777.17,1363.16,235,1,1,1,5,0,6165,67454341.841924,26624,24576,23040
414244.36,4580777.63,1363.17,202,1,1,2,5,0,6165,67454341.841936,27904,26368,23296
414244.58,4580778.09,1363.19,236,1,1,1,5,0,6165,67454341.841948,28672,27392,23040
414244.80,4580778.53,1363.25,213,1,1,1,5,0,6165,67454341.841960,28928,27648,23040
414245.01,4580778.98,1363.24,236,1,1,1,5,0,6165,67454341.841971,29440,27648,23296
414245.23,4580779.44,1363.22,237,1,1,1,5,0,6165,67454341.841983,29184,27648,23552
414244.97,4580779.17,1363.20,237,1,1,1,5,0,6165,67454341.844376,28672,27136,22784
414244.73,4580778.69,1363.22,215,1,1,1,5,0,6165,67454341.844388,29184,27648,23296

- (x)
- (y)
- (z)
- (i)ntensity
- (r)eturn number
- (n)umber of returns
- (c)lassification
- scan (a)ngle
- (u)ser data
- (p)oint source ID
- GPS (t)ime
- (k)eypoint flag
- with(h)old flag
- (o)verlap flag
- scanner channe(l)
- (R)GB color
- (w)ave packet index
- (W)ave packet
- wa(v)e form

attributes ... +

parse string: xyzirncapt

separator: comma

LASboundary – generate outline of point data

lasboundary - computes the exact boundary polygon for massive amounts of LiDAR points

The screenshot displays the lasboundary application interface. On the left, a file list shows 'PearsonDemopoints.laz' selected. Below it, a filter section is visible with the text 'keep_random_fraction 25' circled in red. The main window shows a 3D visualization of a point cloud with a cyan-colored boundary polygon overlaid. A red arrow points from the text 'Larger the value, the less detailed the outline' to the cyan boundary. On the right, a settings panel includes options for '1 job on 4 cores', 'selected file only', 'process all files', 'merge files into one', 'output ...', and 'verbose'. The 'VIEW' section has 'sample points: 5000000' and radio buttons for 'use points', 'use bounding box', 'use tile bounding box', and 'use LAX information'. The 'output: kml' dropdown is also visible. At the bottom, a Google Earth Pro window shows a 3D view of the terrain with a yellow boundary polygon overlaid. The bottom status bar of the Google Earth window shows coordinates: 'Imagery Date: 3/15/2013 3780798.00° N 1194447.21° W elev. 1495 ft eye at 8427 ft'.

Filter to use fraction (25%) of points = faster!

Larger the value, the less detailed the outline

Output format

LAS version: 1.2
source ID: 0 created: 258/2017
LAStools (c) by rapidlasso GmbH
las2las (version 140403) + OT
of points: 14014140
point type: 3 point size: 34
x: 414200.29 414794.8
y: 4500730.75 4501500.70

LAS2LAS – filtering, clipping, coordinate transformation

The screenshot shows the las2las application window. On the left, a file browser shows the file 'D17_SJER_AOI_points.laz' selected. Below the browser, a list of file formats is shown, with 'ASCII files ...' circled in red. The main area is a large cyan rectangle. On the right, a settings panel includes options for 'selected file only', 'process all files', 'merge files into one', 'output ...', and 'verbose'. Below these are 'VIEW', 'sample points: 5000000', 'files are flightlines', and 'apply file source ID'. Further down are 'options:', a dropdown menu, 'number/value: 0', 'ADD', 'target projection ...', 'format: laz', 'RUN', 'README', and '<Q>UIT'. At the bottom, there are controls for 'clip input' (pick, disable), coordinate fields (lower left x, upper right x, lower left y, upper right y), 'use square tile', and 'tile size: 1000'. The bottom status bar shows 'selected file: C:\geospatial\D17_SJER_AOI_points.laz'. A red arrow points from the 'projection ...' option in the settings panel to the 'target projection ...' field.

Lots of options for filtering (attribute, coordinates, other...). Can also transform coordinates & rescale values

Reprojection: set a target. File MUST have CRS set in header to define new output CRS. If not set, use "projection" option at left to define input projection.

```
las2las -i "C:\geospatial\D17_SJER_AOI_points.laz" -keep_classification 2 -target_sp83 CA_IV -olaz
```

LAS version: 1.3
source ID: 751 created: 269/2016
'LASStools (c) by Martin Isenburg'
'las2las (version 120628)'
of points: 8455153
point type: 3 point size: 34
x: 255529.29 256108.99
y: 41110595.88 41113028.47
z: 385.78 541.75

LICENSE
LASStools (c) 2016
= open license =
by Martin Isenburg
(version 160606)

Reset Rotate Move Zoom

clip input
pick lower left x: 0 upper right x: 0 use square tile
disable lower left y: 0 upper right y: 0 tile size: 1000

selected file: C:\geospatial\D17_SJER_AOI_points.laz

Lecture burst:
Point cloud classification



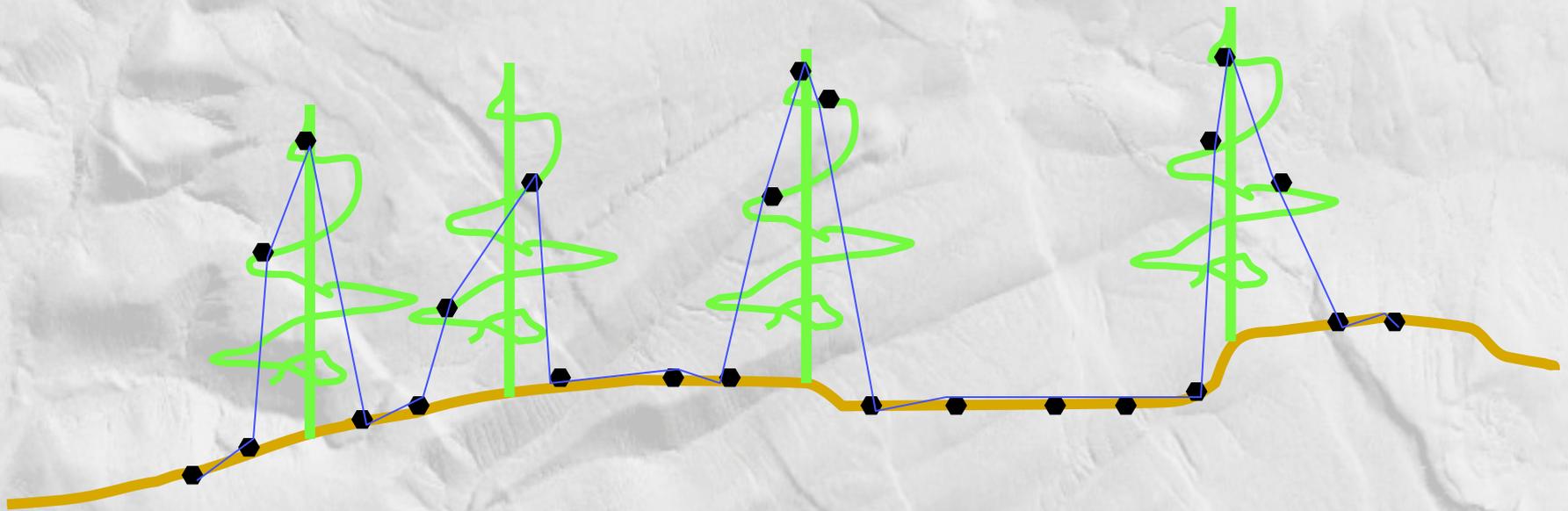
Lidar ground classification

...simplified...

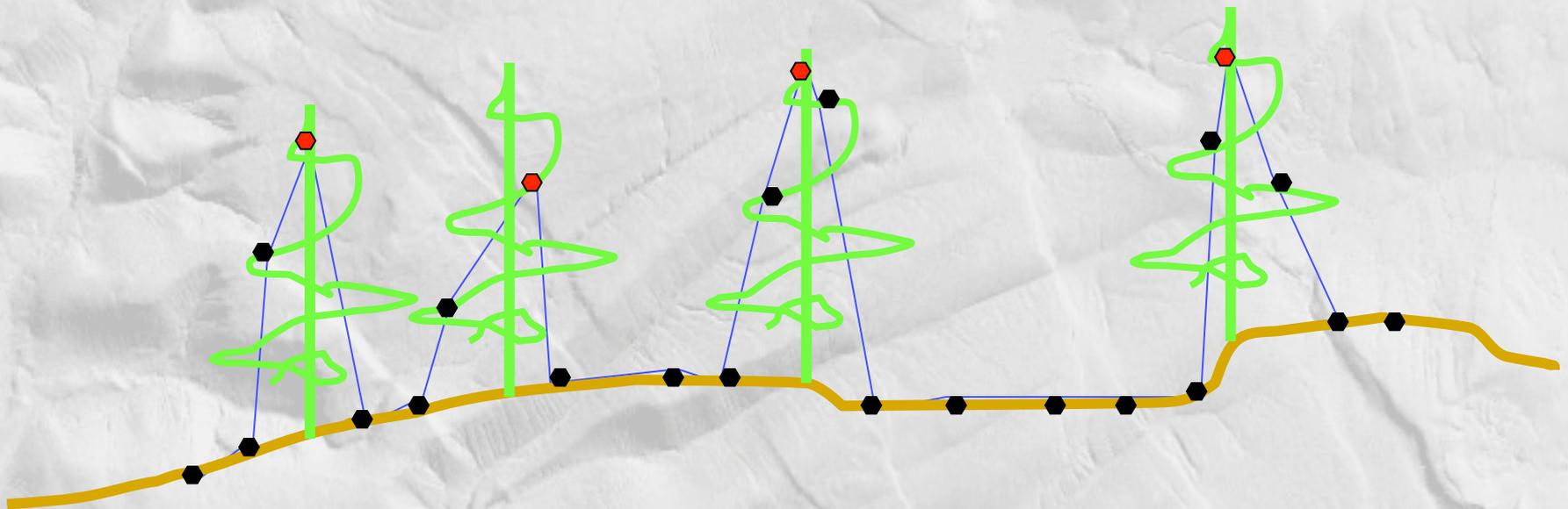
Three assumptions:

1. Ground is smooth
 - Assumption: high curvature is not a point on the ground
2. Ground is continuous (single-valued)
3. Ground is lowest surface in vicinity

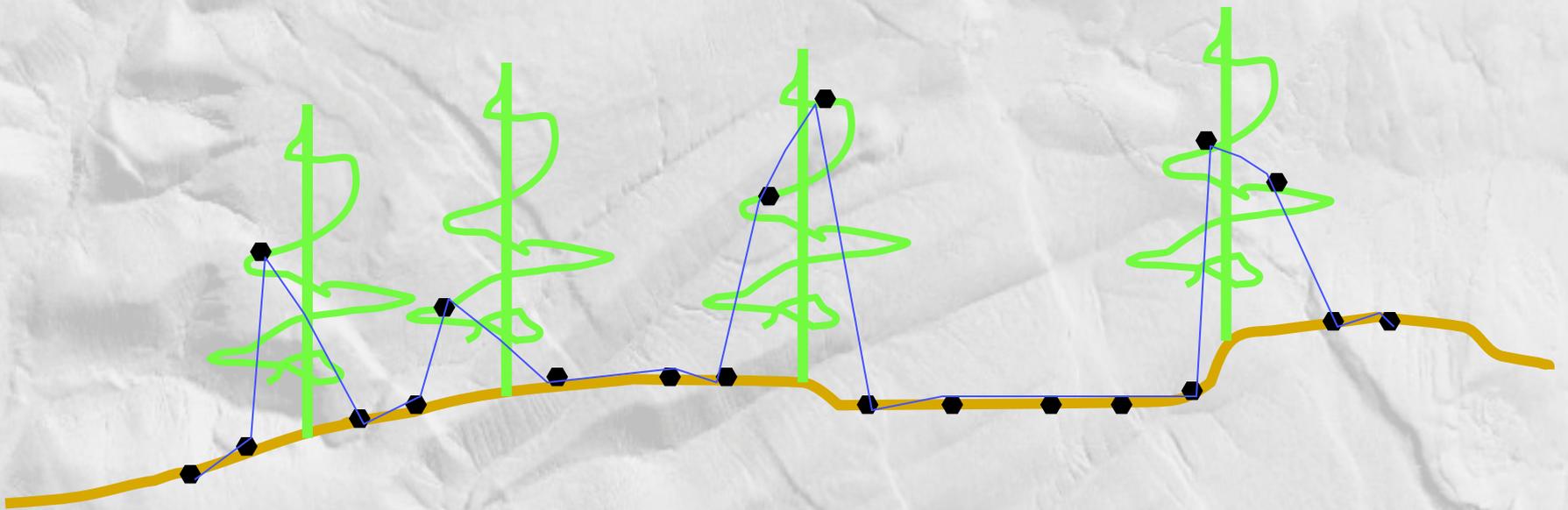
Start with mixed ground and canopy returns (e.g. last-return data), build TIN



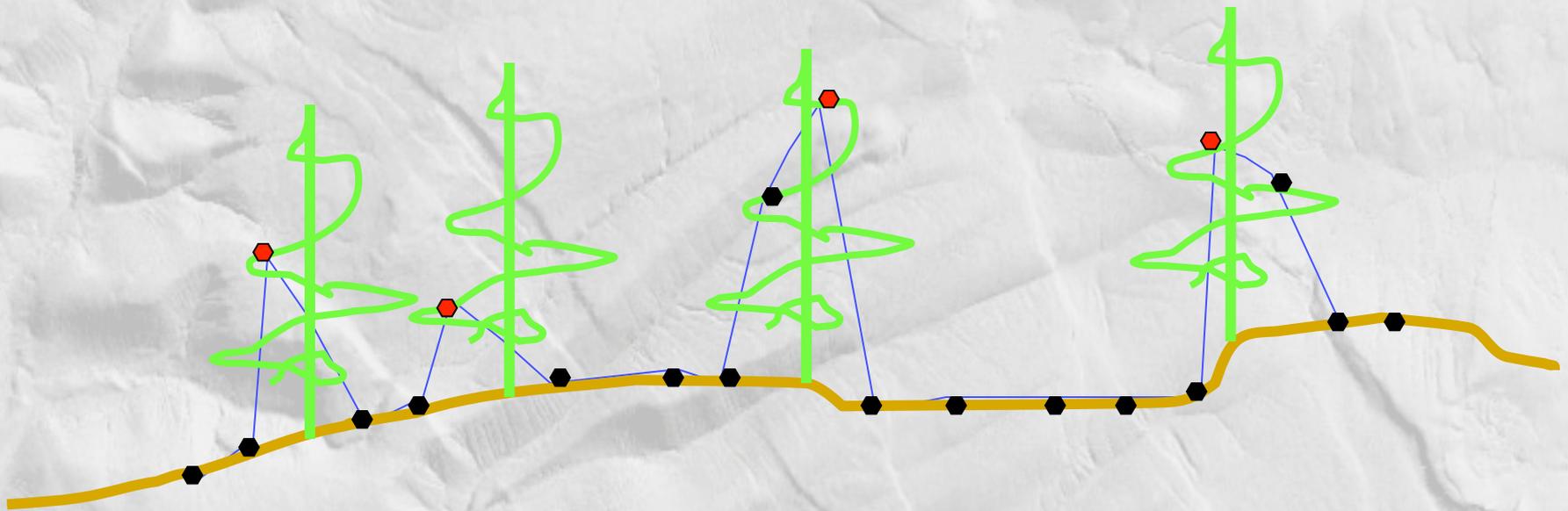
Flag points that define spikes (strong convexities)



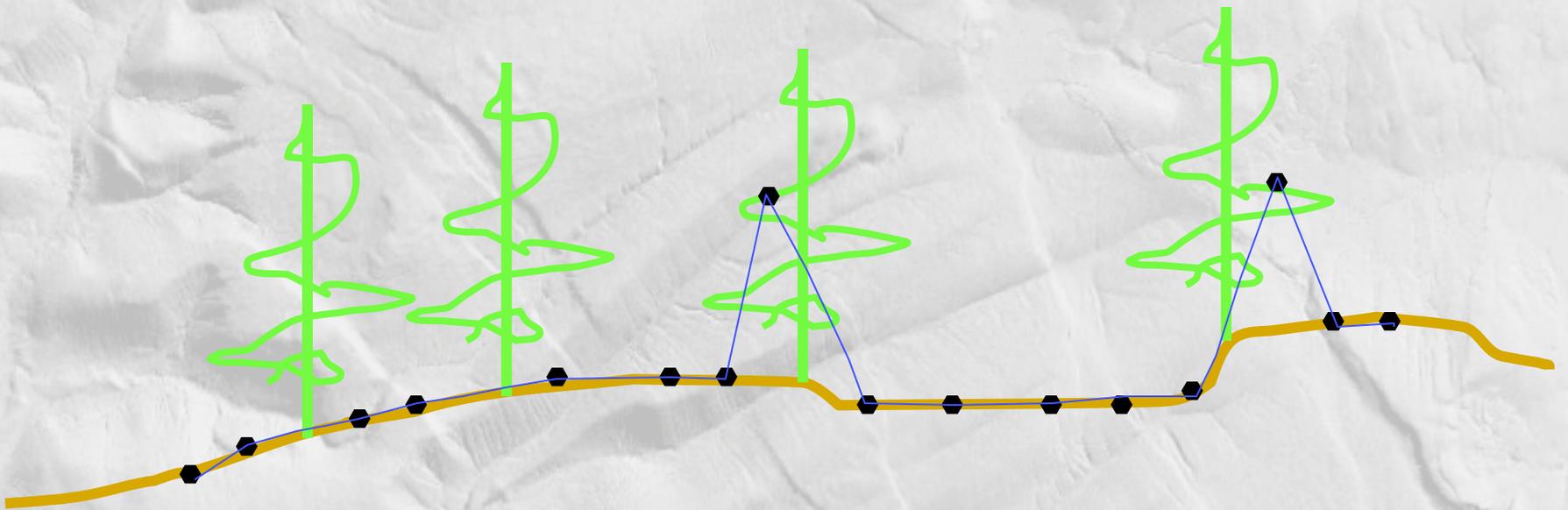
Rebuild TIN



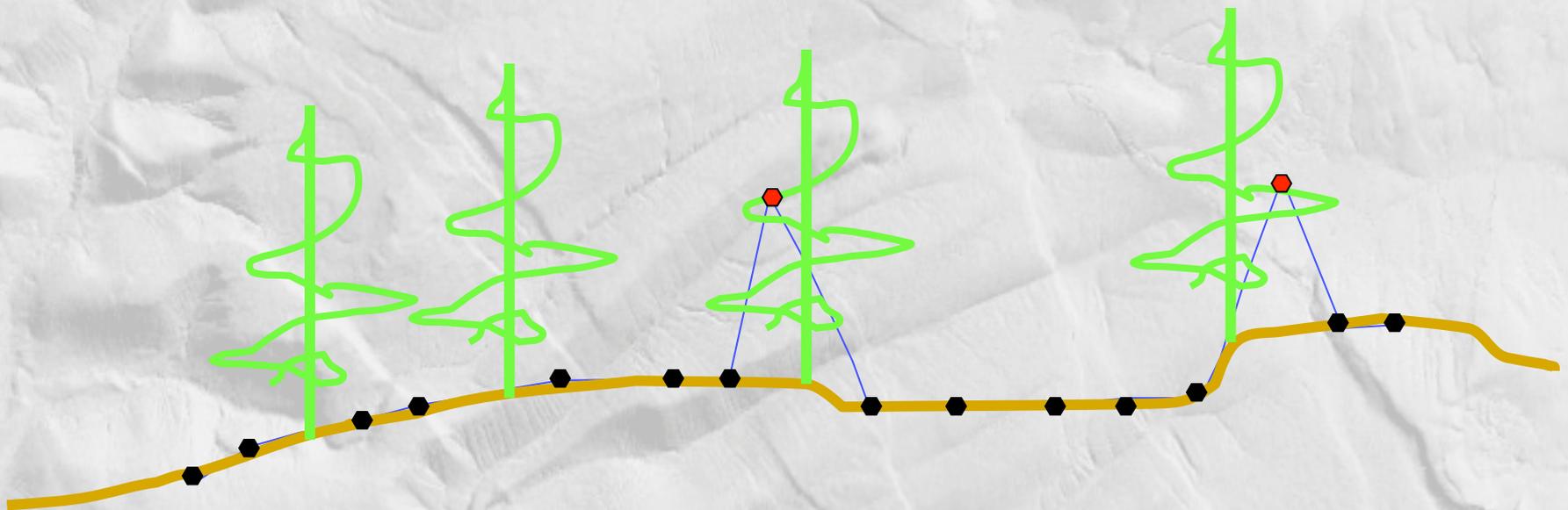
Flag points that define spikes (strong convexities)



Rebuild TIN



Flag points that define spikes (strong convexities)



Rebuild TIN

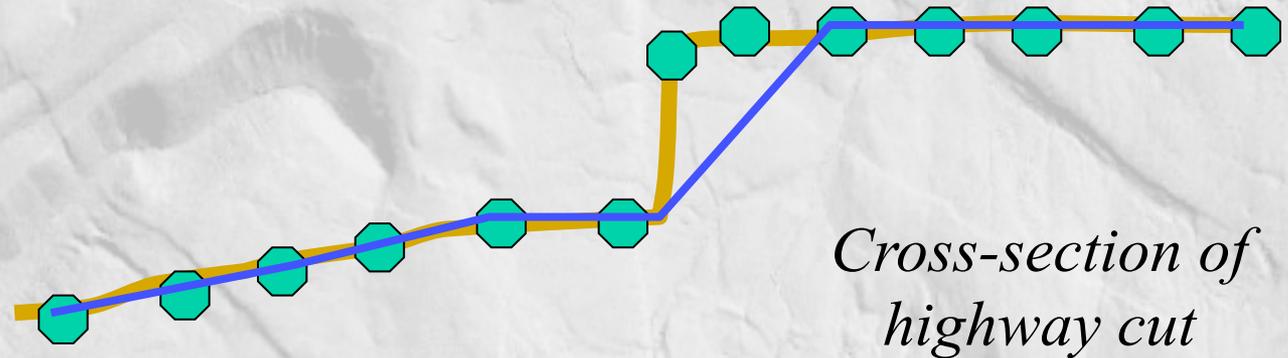


Despike algorithm

Benefits:

- It works
- It's automatic
 - Cheap
 - All assumptions explicit
- It can preserve breaklines
- It appears to retain more ground points than other algorithms

Despike algorithm

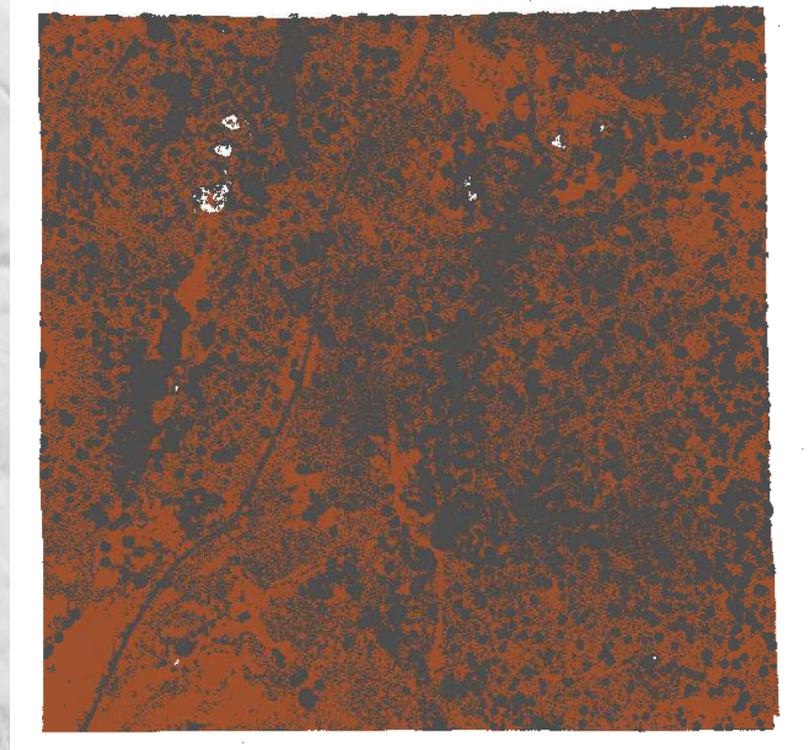
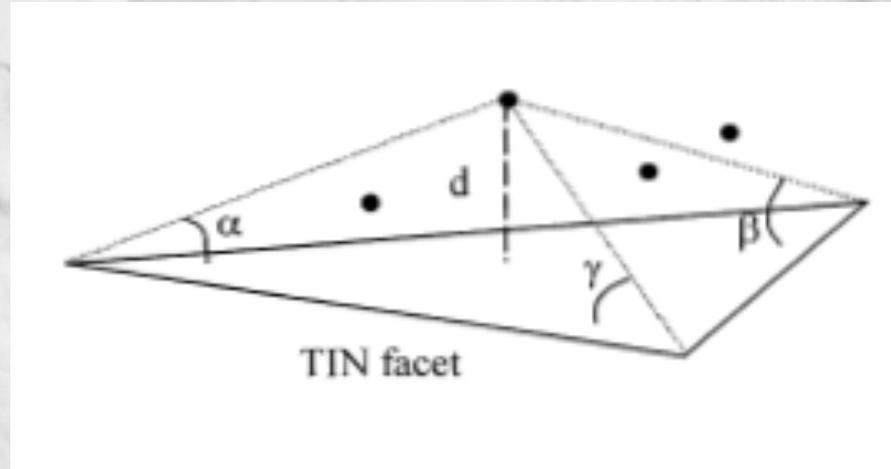


Problems:

- Removes some corners
- Sensitive to negative blunders
- Computationally intensive
- Makes rough surfaces
 - Real? Measurement error? Misclassified vegetation?

Point cloud classification

- LAStools LASground
- Other software:
 - Terrascan
 - QT Modeler
 - ENVI lidar
 - Global Mapper
 - MCCLidar
 - CANUPO (CloudCompare)
- Still an area of active research
- Based on algorithm in Axellson (2000)*, with some modifications



LASground – identify bare-earth (ground) points

The screenshot displays the LASground application window. The title bar reads "lasground - extracts the bare-earth from LiDAR by classifying all ground points".

Input: Unclassified point cloud file (indicated by a red circle around the file list):

- File list: PearsonDemopoints_uncl (selected)
- Wildcard: *.laz
- Directory: C:\
- File types: .las, .laz, .bin (checked)

Ground classification settings: Output filename, landcover type, processing level (indicated by a red circle around the settings panel):

- Jobs: 1 job on 8 cores
- Processing: process all files (selected)
- Output: dir: C:\OTd, appendix: _be, filename: (empty)
- Verbose:
- VIEW button
- Sample points: 5000000
- Options: no bulge, no stddev, in horizontal feet, in vertical feet, by flightline (unchecked)
- Landcover type: wilderness (selected), nature, town or flats, city or warehouses, metropolis, custom
- Settings: default, fine, extra (selected), ultra
- Ignore points: (empty)
- compute height: ; replace z:
- Output: laz
- RUN button

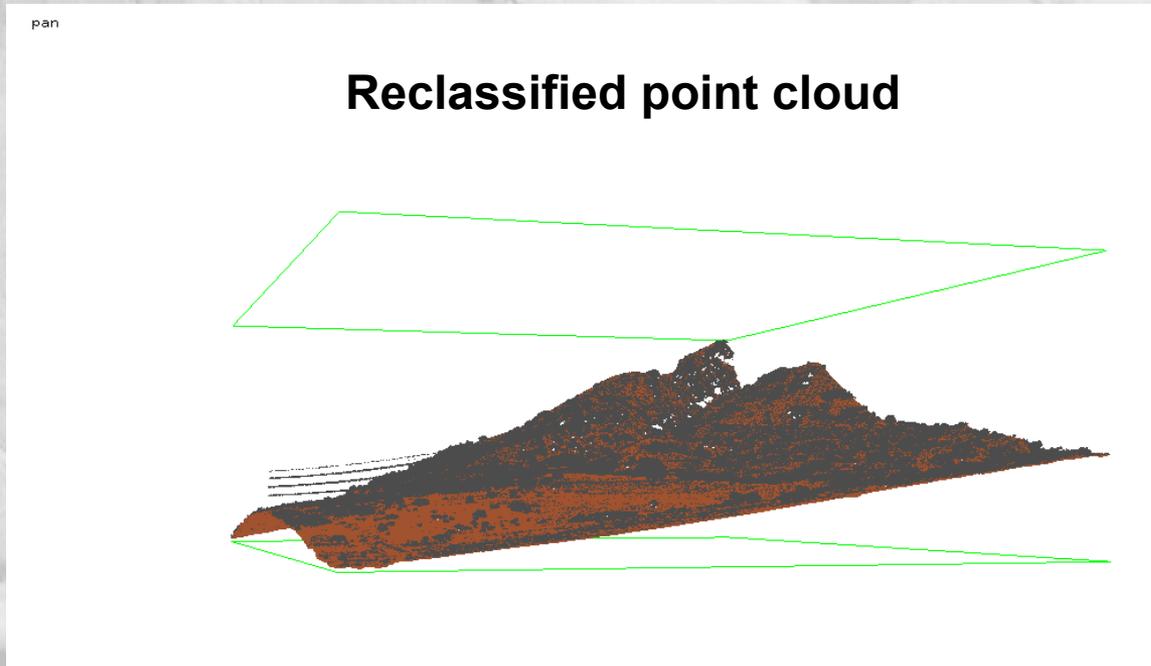
Software Information:

- LAS version: 1.2
- source ID: 0 created: 258/2017
- 'LAStools (c) by rapidlasso GmbH'
- 'las2las (version 170528)'
- # of points: 14014140
- point type: 3 point size: 34
- x: 414200.29 414794.8
- y: 4580776.75 4581560.78

License and Tools:

- LICENSE: LAStools (c) 2017 == unlicensed == by Martin Isenburg (version 170528)
- Tools: Reset, Rotate, Move, Zoom
- clip input: pick, disable, lower left x: 0, upper right x: 0, use square tile, lower left y: 0, upper right y: 0, tile size: 1000
- selected file: C:\OTdata\17Utah\PearsonDemopoints_unclass.laz

LASground – identify bare-earth (ground) points



```
X          41420029  41479480
Y          458077675 458156078
Z           135591   159966
intensity   0         255
return_number 1         5
number_of_returns 1       5
edge_of_flight_line 0     0
scan_direction_flag 0     1
classification 1         7
scan_angle_rank -16      20
user_data   0         0
point_source_ID 6165     12218
gps_time 67454341.779927 68227738.997013
Color R 7424 61440
      G 8192 61696
      B 10752 59648
```

Original point cloud classification

```
number of points of given pulse: 41438282
number of returns of given pulse: 13428388
number of last returns: 13428388
number of single returns: 12849565
overview over number of returns of given pulse: 12849565 1145177 16008 3368 22 0 0
histogram of classification of points:
10625129 unclassified (1)
3388321 ground (2)
690 noise (7)
```

```
x          41420027  41479482
Y          458077673 458156080
Z           135590   159964
intensity   0         0
return_number 1         5
number_of_returns 1       5
edge_of_flight_line 0     0
scan_direction_flag 0     1
classification 1         2
scan_angle_rank -16      20
user_data   0         0
point_source_ID 0         0
gps_time 0.000000 0.000000
Color R 7424 61440
      G 8192 61696
      B 10752 59648
```

After point cloud (re)classification

```
WARNING: number of points of given pulse is larger than header_max_x
number of returns of given pulse: 12849565
number of intermediate returns: 7035
number of last returns: 13428388
number of single returns: 12849565
overview over number of returns of given pulse: 12849565 1145177 16008 3368
histogram of classification of points:
5315758 unclassified (1)
8698382 ground (2)
```

point density

lasgrid - rasters huge LiDAR collections into elevation/intensity/density/... grids

PearsonDemopoints.laz

browse ...

\\
\\.
\\2017 OT short course
\\BorahPeak
\\LAsTools
\\OldTalks to build from
\\Papers
PearsonDemopoints.laz

wildcard: *.laz

directory: E:\

.las .laz .bin

.asc .bil .dtm

ASCII files ...

filter ...

transform ...

projection ...

overlays ...

LAS version: 1.2

source ID: 0 created: 258/2017

'LAsTools (c) by rapidlasso GmbH'

'las2las (version 140403) + OT'

of points: 14014140

point type: 3 point size: 34

RUN

```
lasgrid -i "C:\Users\ramon\Google Drive\+S_Active_Items\2017UGS_OT\PearsonDemopoints.laz" -point_density -otif
```

START

COPY

CANCEL

1 job on 4 cores

selected file only

process all files

merge files into one

output ...

verbose

VIEW

sample points: 5000000

1m²

pixel/step size: 1

item: point_density

op: lowest

fill n pixels: 0

color options

subsample

large rasters

use bounding box

use tile bounding box

specify size of raster

ncols: 512

nrows: 512

specify lower left

llx:

lly:

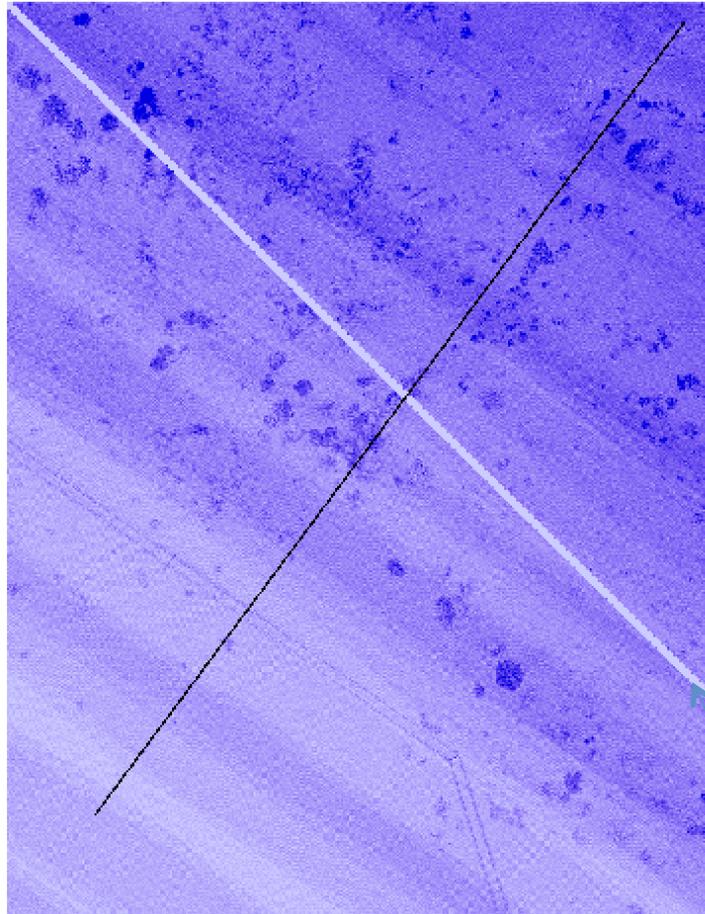
format: tif

RUN

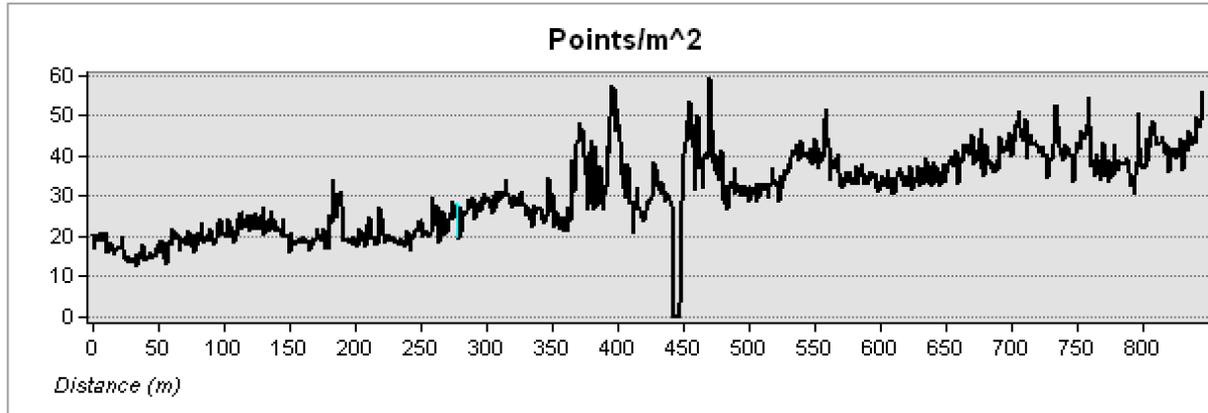
README

<Q>UIT

point density



Profile Graph Title



Load .tif into ArcMap, change color map, use 3D Analyst to profile density

Slash of no data is telling us that we have exceeded the license limit

Digital Elevation Models

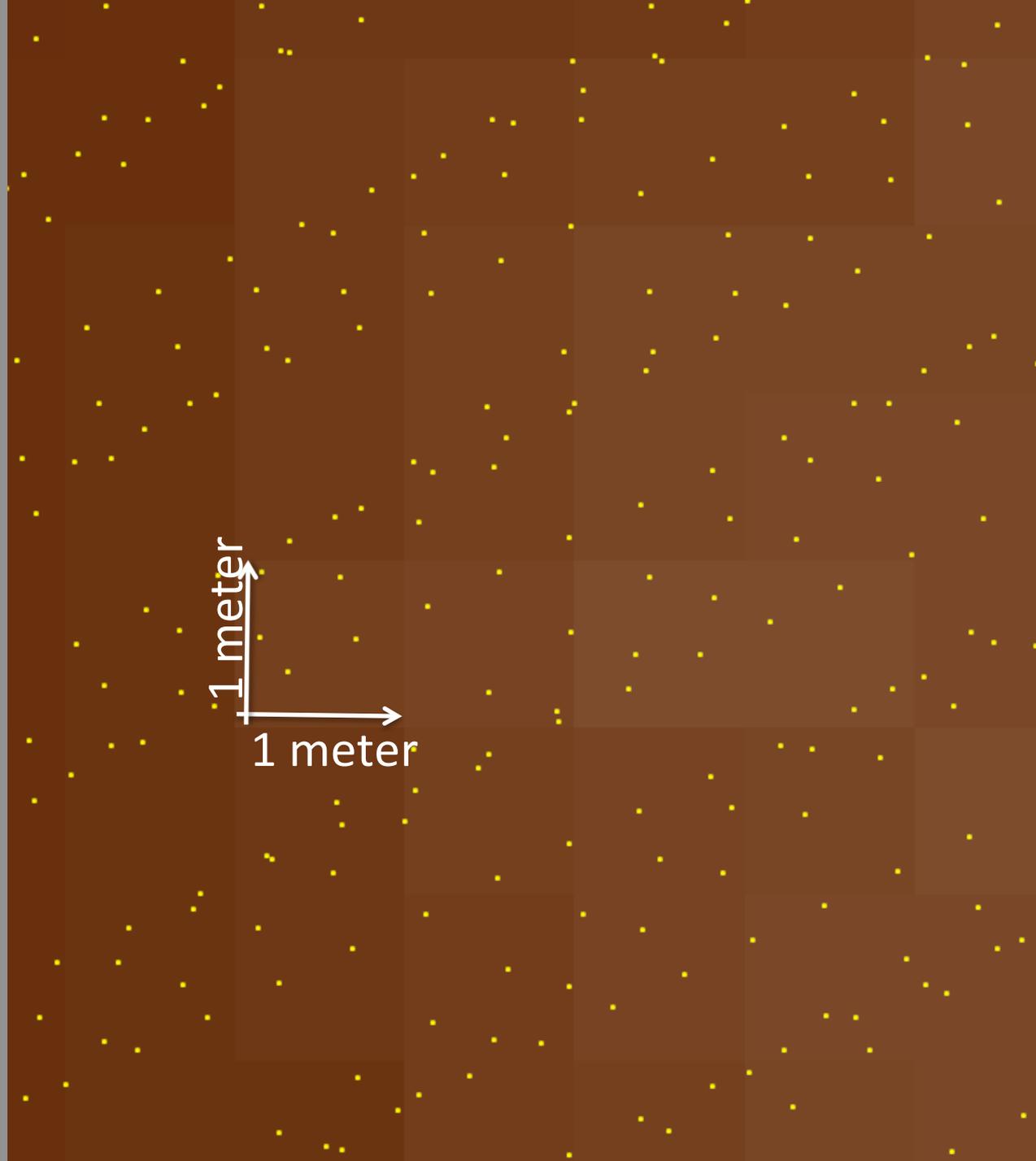
- Digital representation of topography / terrain
 - “Raster” format – a grid of squares or “pixels”
 - Continuous surface where Z (elevation) is estimated on a regular X,Y grid
 - “2.5D”

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	0	
0	50	100	100	100	100	100	100	100	100	100	100	100	100	100	50	0	
0	50	100	150	150	150	150	150	150	150	150	150	150	150	150	100	50	0
0	50	100	150	200	200	200	200	200	200	200	200	200	200	150	100	50	0
0	50	100	150	200	250	250	250	250	250	250	250	250	200	150	100	50	0
0	50	100	150	200	250	300	300	300	300	300	300	250	200	150	100	50	0
0	50	100	150	200	250	300	350	350	350	300	250	200	150	100	50	0	0
0	50	100	150	200	250	300	350	400	350	300	250	200	150	100	50	0	0
0	50	100	150	200	250	300	350	350	350	300	250	200	150	100	50	0	0
0	50	100	150	200	250	300	300	300	300	300	250	200	150	100	50	0	0
0	50	100	150	200	250	250	250	250	250	250	250	200	150	100	50	0	0
0	50	100	150	200	200	200	200	200	200	200	200	200	150	100	50	0	0
0	50	100	100	100	100	100	100	100	100	100	100	100	100	100	50	0	0
0	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

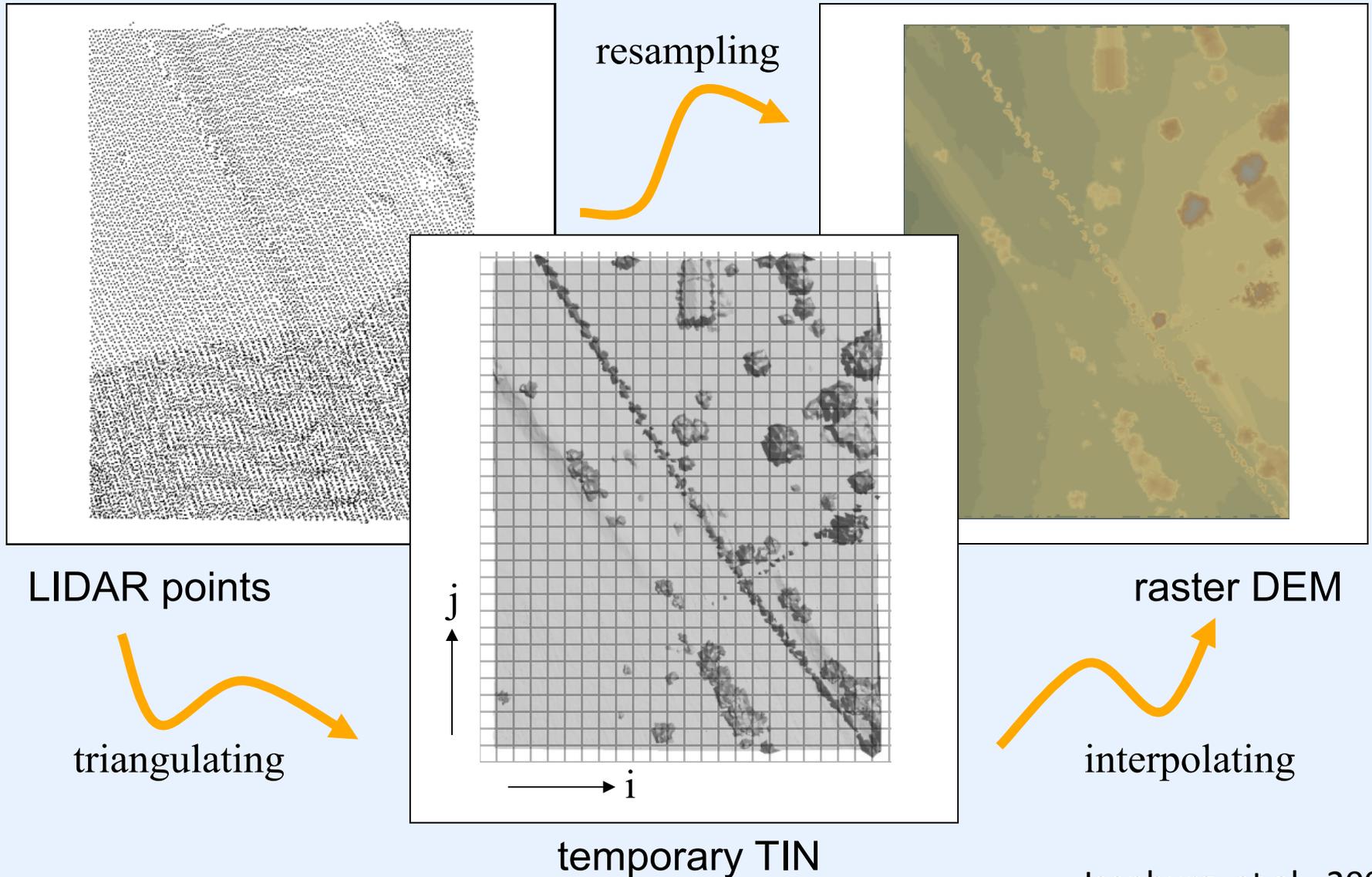
Source: <http://www.ncgia.ucsb.edu/giscc/extra/e001/e001.html>

- Grid resolution is defined by the size in the horizontal dimension of the pixel
 - 1 meter DEM has pixels 1 m x 1m assigned a single elevation value.

- 1 meter grid
- LiDAR returns from EarthScope data collection
- Example from flat area with little or no vegetation so ground is sampled approx. 5+ times per square meter
- How do we best fit a continuous surface to these points?
- Ultimately wish to represent irregularly sampled data on a regularized grid.

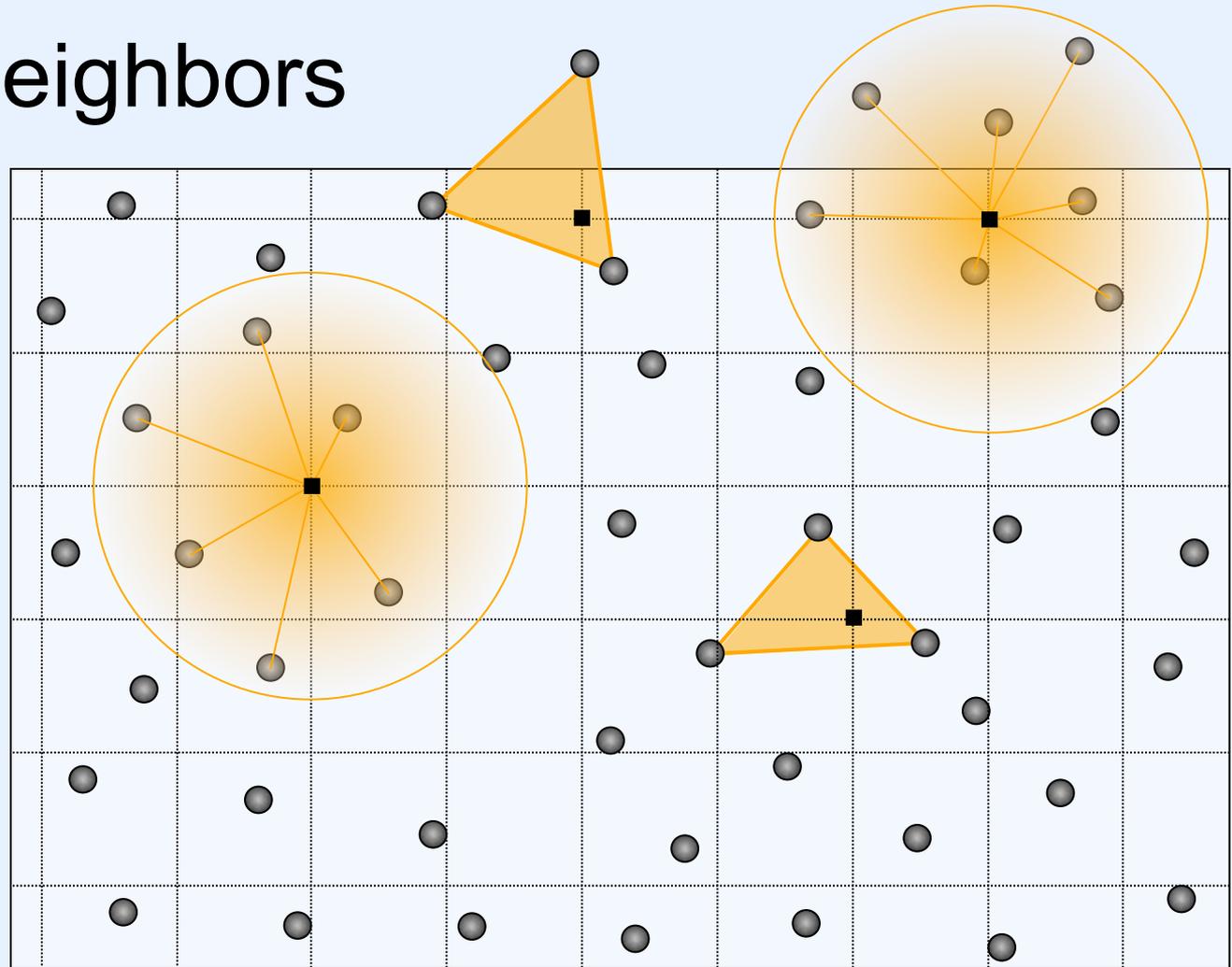


Generating DEMs from LIDAR

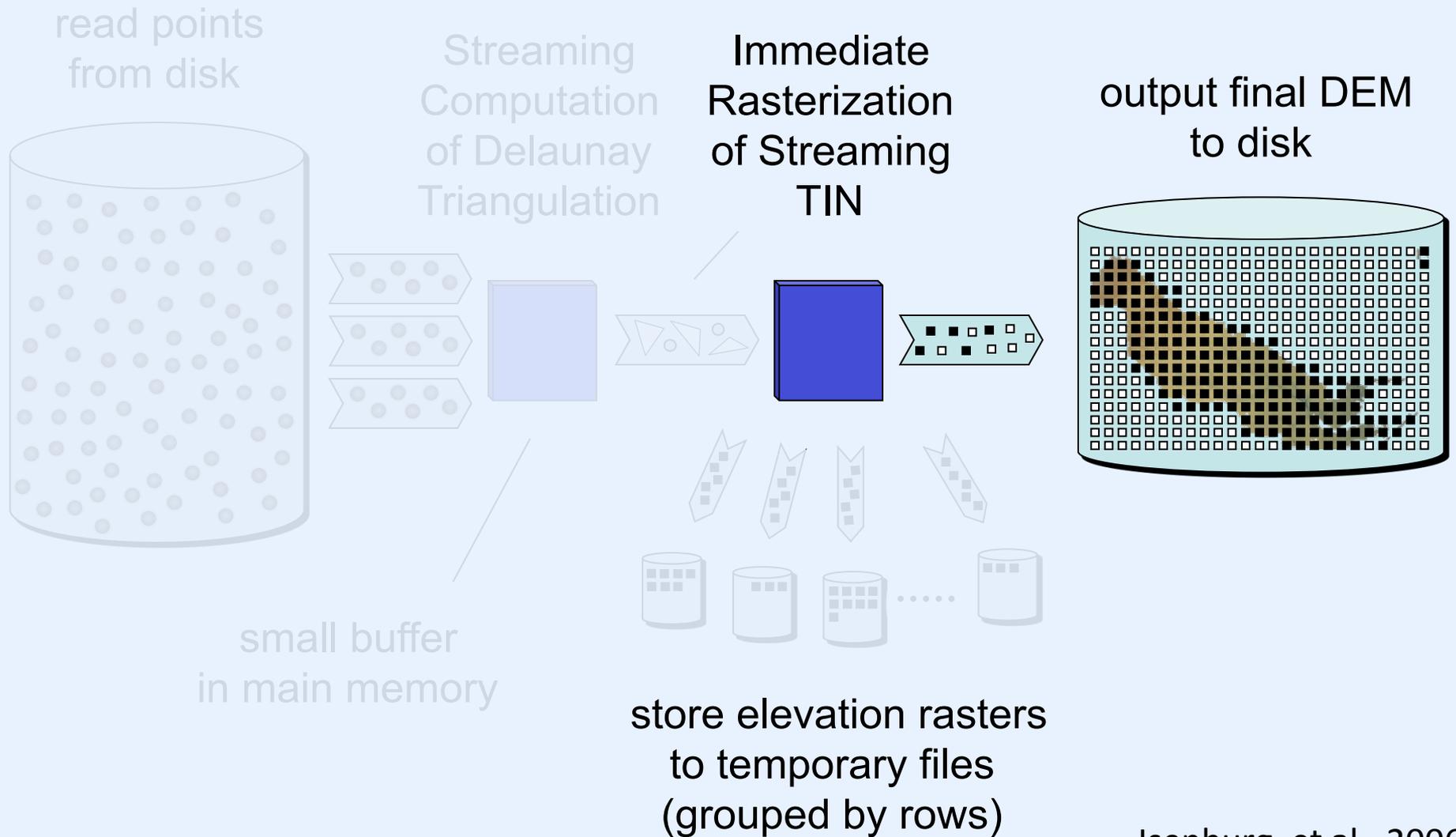


Interpolation Methods

- Inverse Distance Weighting (IDW)
- Natural Neighbors
- Kriging
- Splines
- TIN
- linear
- quintic
- ...



DEM Generation via TIN Streaming



Example Result

500,141,313 Points

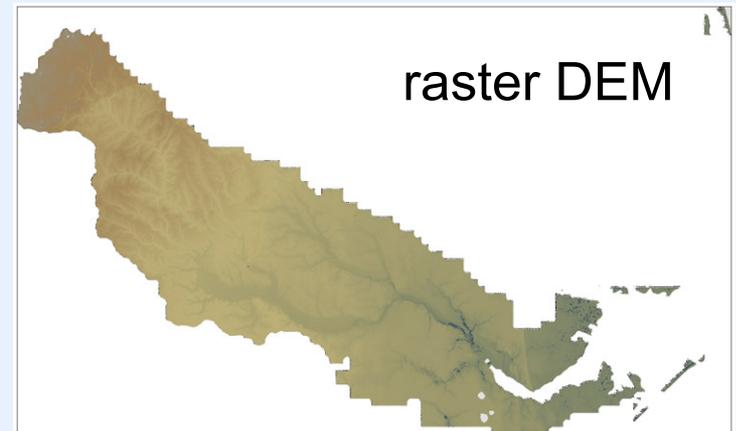
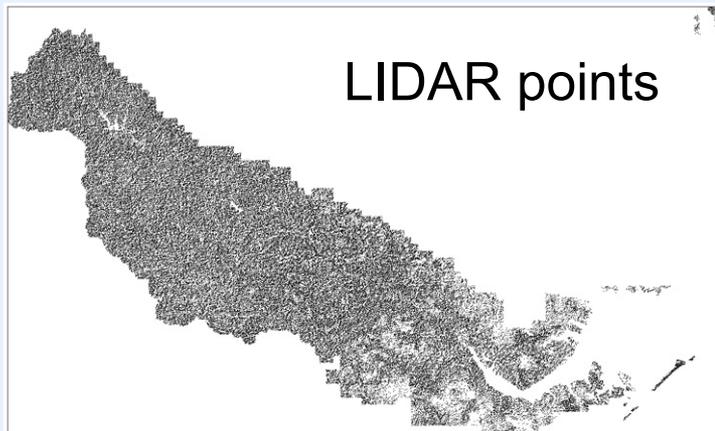
11 GB

(binary, xyz, doubles)

50,394 × 30,500 DEM

3 GB

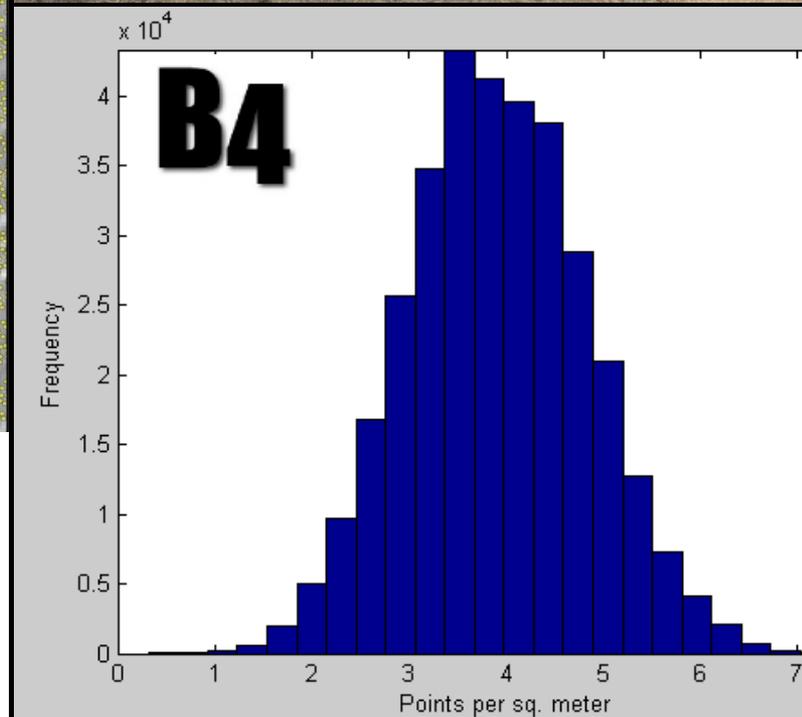
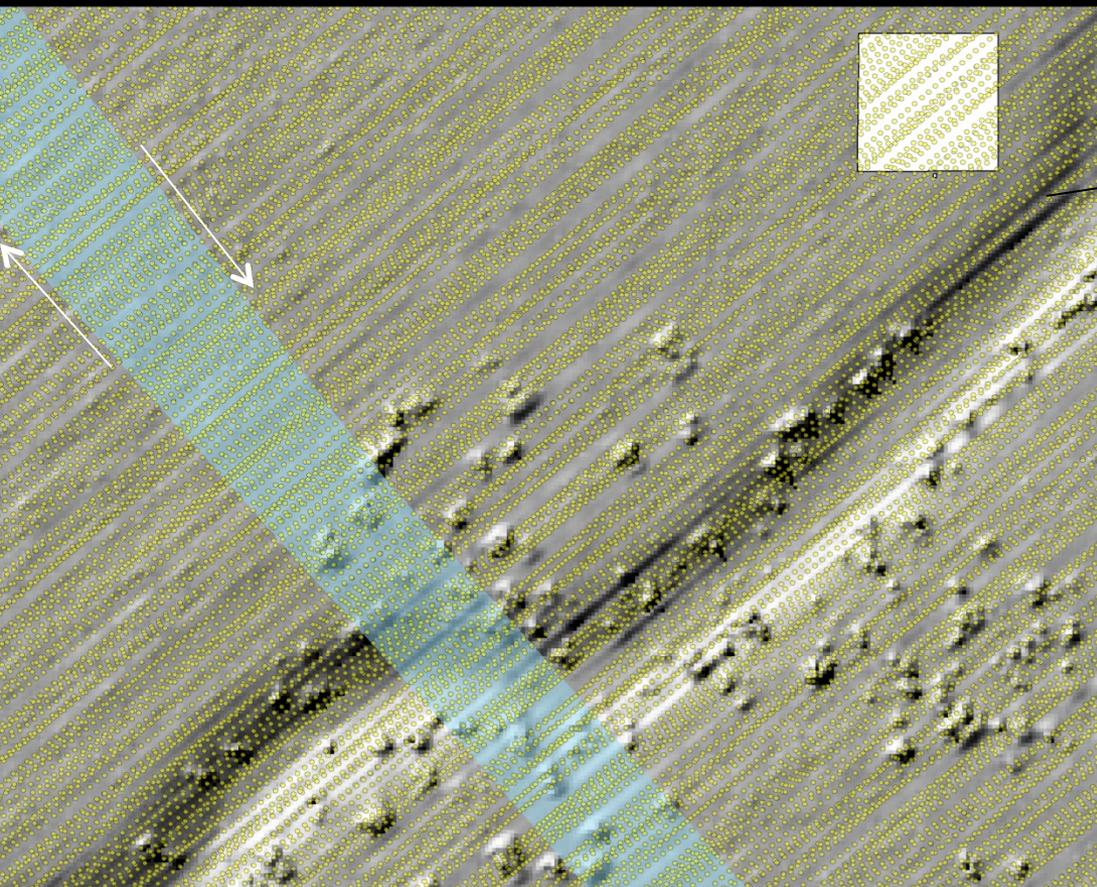
(binary, BIL, 16 bit, 20 ft)



- on a household laptop with two harddisks □
 - in 67 minutes □
 - 64 MB of main memory □
 - 270 MB temporary disk space □

Measure fault slip at the appropriate scale

B4 LiDAR topography 0.25 m DEM



Mean ~ 4 shots/sq. m

of the DEM. A common method for determining the cell size of a DEM has been defined by Hu (2003). The grid size of a DEM can be estimated by:

Langridge, et al. 2014

$$s = \sqrt{\frac{A}{n}} \quad \text{Sqrt}(1\text{m}^2/4) = 0.5 \text{ m/pix} \quad (1)$$

where s is the estimated cell size (typically in m), n is the number of sample points and A is the area containing the sample points. The

LASGRID is neighborhood approach for DEM computation

lasgrid - rasters huge LiDAR collections into elevation/intensity/density/... grids

PearsonDemopoints.laz

browse ...

- \
- \.
- \2017_OT short course
- \BorahPeak
- \LAStools
- \OldTalks to build from
- \Papers
- PearsonDemopoints.laz

wildcard: *.laz add

directory: E:\ go

.las .laz .bin
 .asc .bil .dtm

ASCII files ...

filter ...

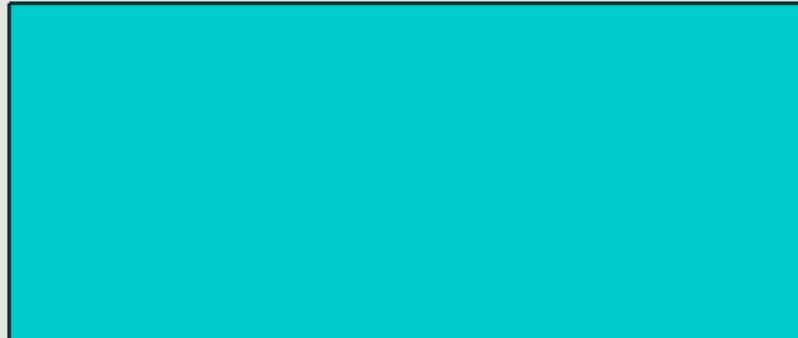
transform ...

projection ...

overlays ...

LAS version: 1.2
source ID: 0 created: 258/2017
LAStools (c) by rapidlasso GmbH
las2las (version 140403) + OT
of points: 14014140
point type: 3 point size: 34

Digital surface model—all points



```
lasgrid -i "C:\Users\ramon\Google Drive\  
+S_Active_Items\2017UGS_OT  
\PearsonDemopoints.laz" -elevation -average -  
odix "_DSM" -otif
```



1 job on 4 cores +

selected file only
 process all files
 merge files into one

output ...

dir:

appendix:

filename:

verbose

VIEW

sample points:

pixel/step size:

item:

op:

fill n pixels:

color options +

subsample +

large rasters +

use bounding box
 use tile bounding box
 specify size of raster

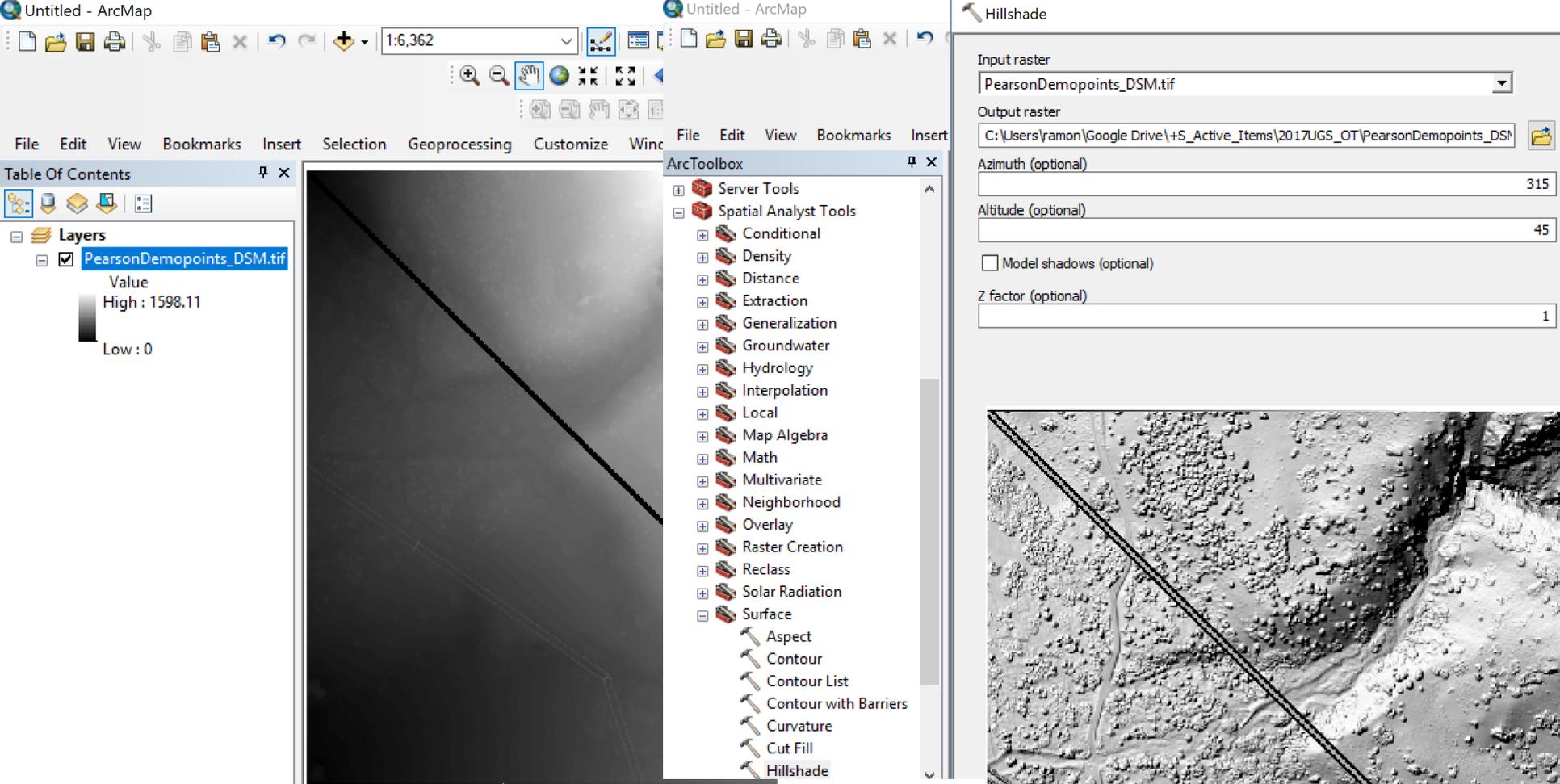
ncols:
nrows:

specify lower left

llx:
lly:

format:

RUN



Open lasgrid produced 1 m pixel Digital Surface Model and compute hillshade using Spatial Analyst toolbox

LASGRID is neighborhood approach for DEM computation

lasgrid - rasters huge LiDAR collections into elevation/intensity/density/... grids

PearsonDemopoints.laz

browse ... +

filter ... -

by coordinates:

by classification or return:

by various criteria:

number or value: 2

ADD

keep_classification 2

transform ... +

projection ... +

overlays ... +

LAS version: 1.2
source ID: 0 created: 258/2017
LASools (c) by rapidlasso GmbH
las2las (version 140403) + OT
of points: 14014140
point type: 3 point size: 34
x: 414200.29 414794.8

Digital terrain model—ground points

```
lasgrid -i "C:\Users\ramon\Google Drive\  
+S_Active_Items\2017UGS_OT  
\PearsonDemopoints.laz" -keep_classification  
2 -elevation -average -odix "_DTM" -otif
```

Under filter, select –
keep_classification and
number or value 2;
ADD

1 job on 4 cores +

selected file only
 process all files
 merge files into one

output ...

dir:

appendix:

filename:

verbose

VIEW

sample points:

pixel/step size:

item:

op:

fill n pixels:

color options +

subsample +

large rasters +

use bounding box
 use tile bounding box
 specify size of raster

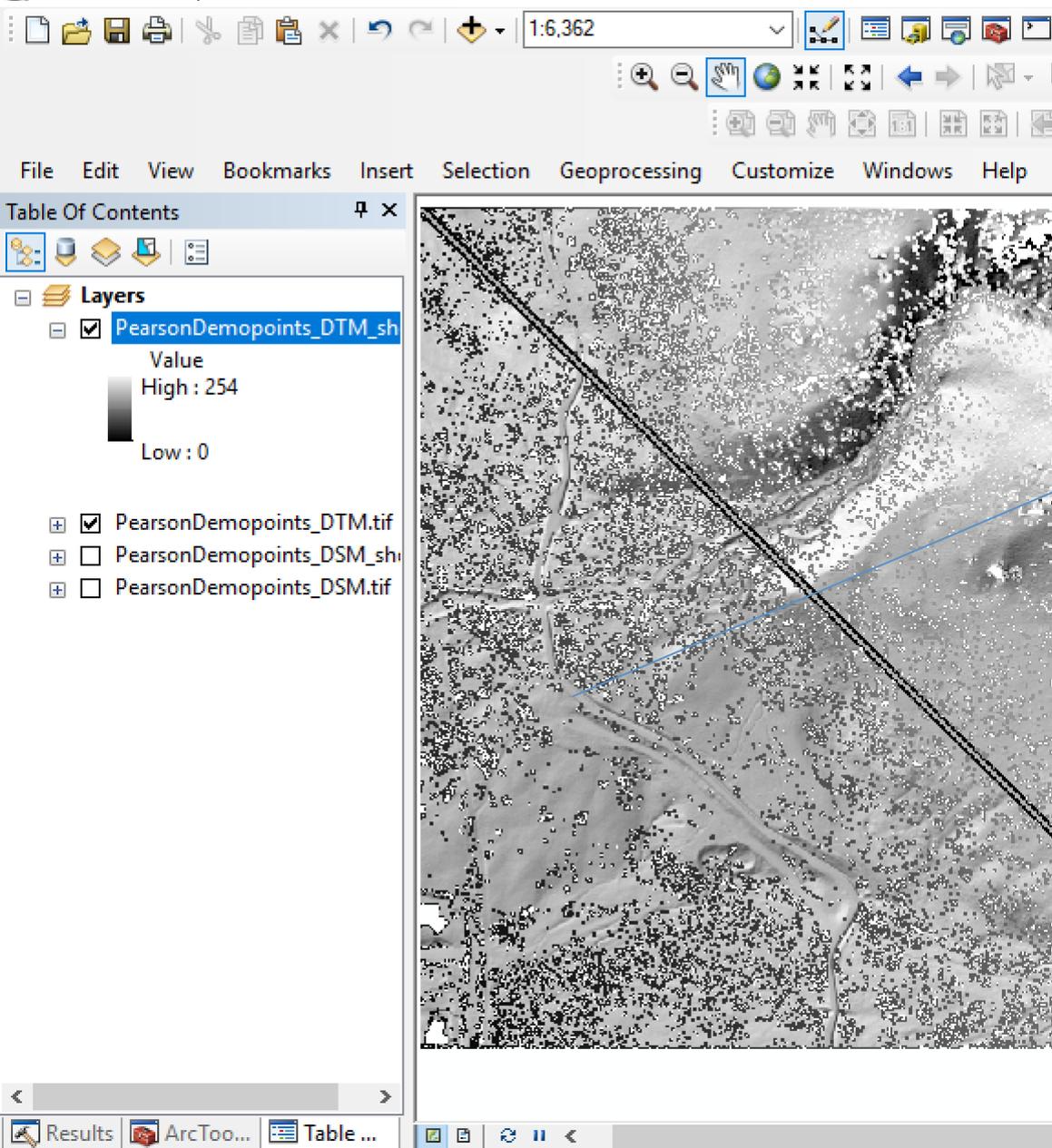
ncols:
nrows:

specify lower left

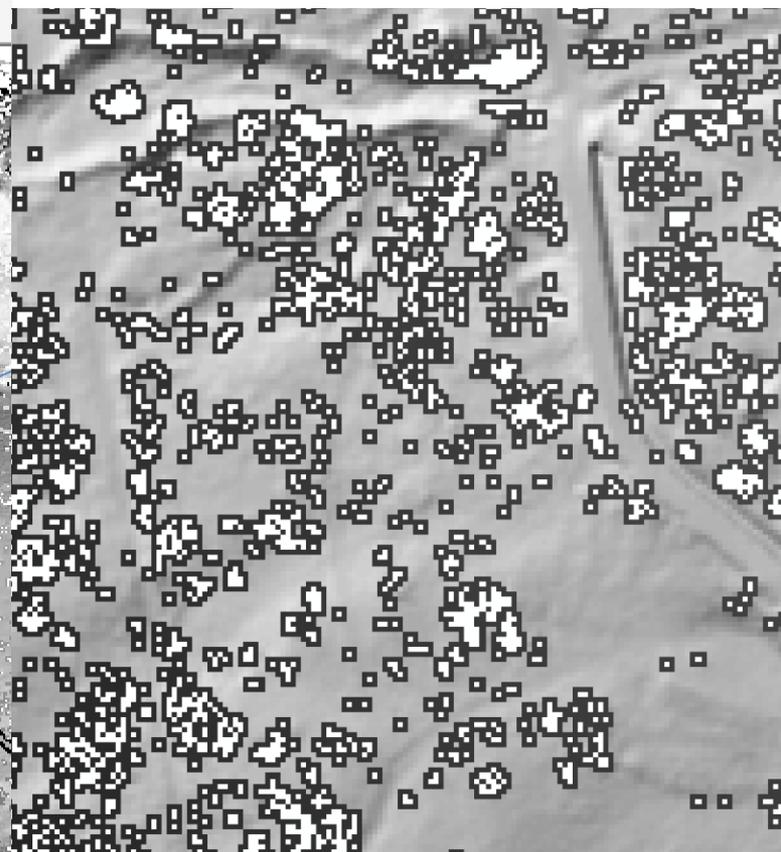
llx:
lly:

format:

RUN



Digital terrain model—ground points



Open lasgrid produced 1 m pixel Digital Terrain Model and view as hillshade. No ground returns under the trees!

BLAST2DEM is TIN approach for DEM computation

blast2dem - rasters billions of LiDAR points via a streaming TIN to elevation, intensity, slope, or RGB grids

PearsonDemopoints.laz

browse ...

- \
- \..
- \2017 OT short course
- \BorahPeak
- \LAStools
- \OldTalks to build from
- \Papers
- PearsonDemopoints.laz

wildcard: *.laz add

directory: E:\ go

.las .laz .bin
 .asc .bil .dtm

ASCII files ... +

filter ... +

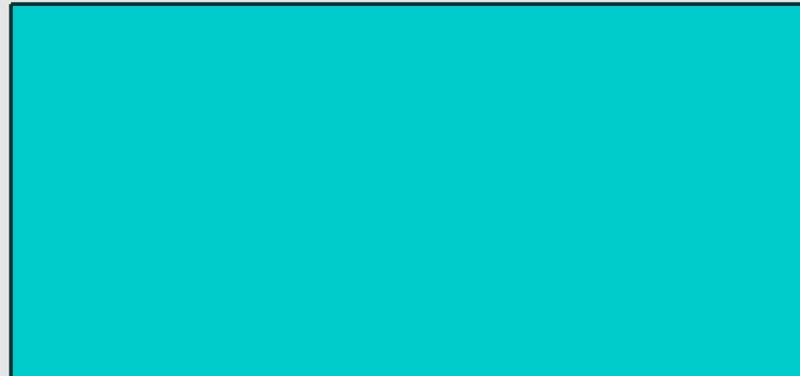
transform ... +

projection ... +

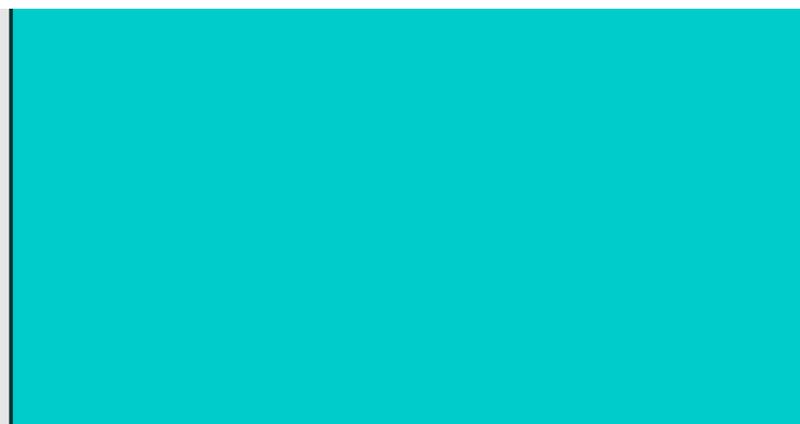
overlays ... +

LAS version: 1.2
source ID: 0 created: 258/2017
LAStools (c) by rapidlasso GmbH
las2las (version 140403) + OT
of points: 14014140
point type: 3 point size: 34

Digital surface model—all points (13.4M)



```
blast2dem -i "C:\Users\ramon\Google Drive\  
+S_Active_Items\2017UGS_OT  
\PearsonDemopoints.laz" -elevation -odix  
"blastDSM" -otif
```



1 job on 4 cores +

selected file only
 process all files
 merge files into one

output ... +

verbose

VIEW

sample points: 5000000

step: 1

kill triangles > 100

item: elevation ▾

actual values
 hillside shading
 gray ramp
 false colors

set min max
min: 0
max: 0

invert ramp:

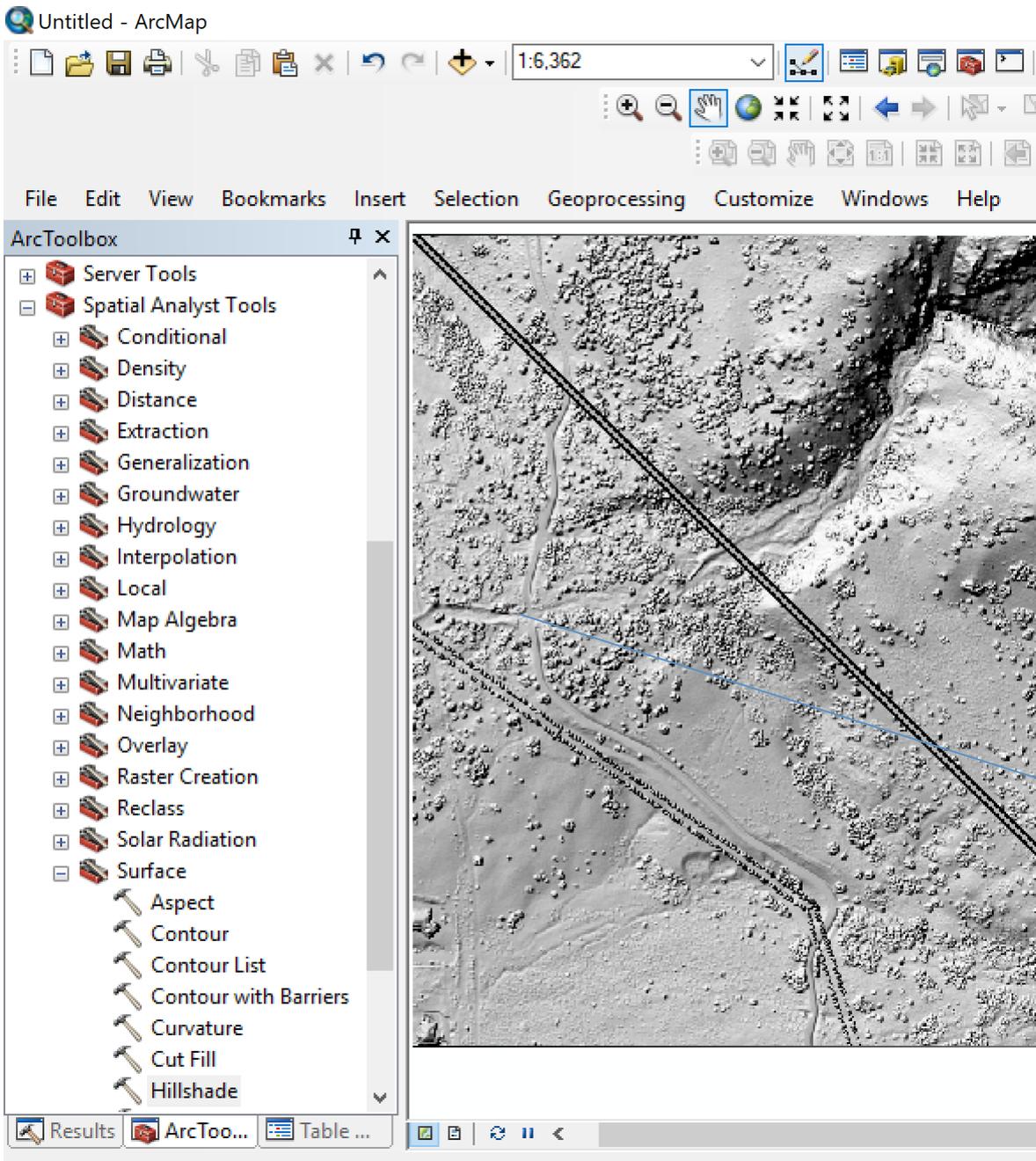
use tile bounding box
 specify size of raster
ncols: 512
nrows: 512

specify lower left
llx:
lly:

format: tif ▾

RUN

README <Q>UIT



Looks good but what is that white slash?
We exceeded the unlicensed limit for blast2dem of 5M points!



We need to tile the data – be sure to make a folder to capture the tiles

The screenshot shows the 'lastile' application window. On the left, a file browser lists 'PearsonDemopoints.laz'. The central area displays a 3D visualization of a LiDAR point cloud with a cyan grid overlay. On the right, a control panel includes a job configuration section with '3 jobs on 4 cores' selected, a 'process all files' option, and an 'output' section with 'dir: C:\User'. Below the visualization, a white text box contains the following command:

```
lastile -i "C:\Users\ramon\Google Drive\+S_Active_Items\2017UGS_OT\PearsonDemopoints.laz" -o "tile.laz" -tile_size 250 -buffer 10 -faf -cores 3 -odir "C:\Users\ramon\Google Drive\+S_Active_Items\2017UGS_OT\250m_tiles" -olaz
```

At the bottom left, the application status is shown: 'LAS version: 1.2', 'source ID: 0 created: 258/2017', 'LASools (c) by rapidlasso GmbH', 'las2las (version 140403) + OT', '# of points: 14014140', and 'point type: 3 point size: 34'.

Now let's blast again

blast2dem - rasters billions of LiDAR points via a streaming TIN to elevation, intensity, slope, or RGB grids

file_list.8852.txt

- tile_414000_4580750.laz
- tile_414000_4581000.laz
- tile_414000_4581250.laz
- tile_414000_4581500.laz
- tile_414250_4580750.laz
- tile_414250_4581000.laz
- tile_414250_4581250.laz

browse ...

file_list.8852.txt

- tile_414000_4580750.laz
- tile_414000_4581000.laz
- tile_414000_4581250.laz
- tile_414000_4581500.laz
- tile_414250_4580750.laz
- tile_414250_4581000.laz

wildcard: *.laz add

directory: E:\ go

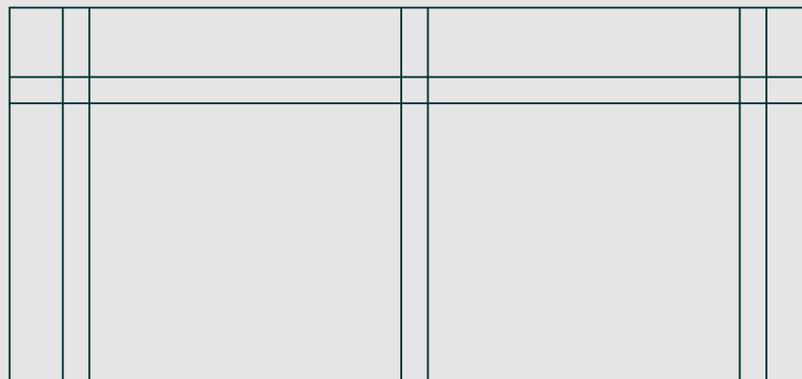
.las .laz .bin
 .asc .bil .dtm

ASCII files ... +

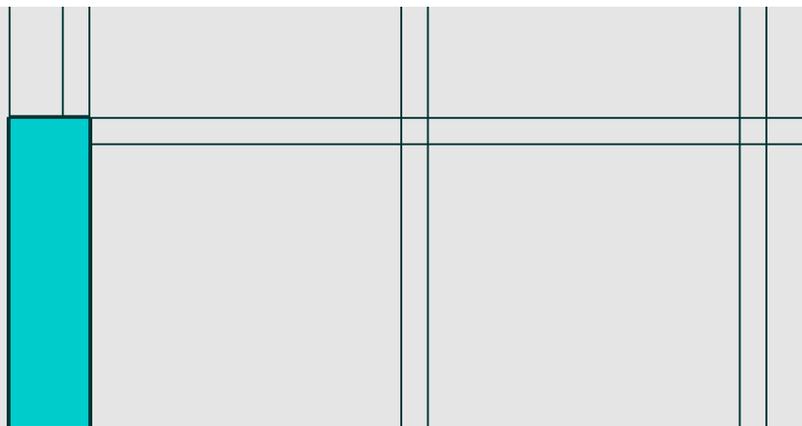
filter ... +
transform ... +
projection ... +
overlays ... +

LAS version: 1.2
source ID: 0 created: 258/2017
'LASools (c) by rapidlasso GmbH'
'lastile (170915) unlicensed'
of points: 254569
point type: 3 point size: 34

Digital surface model—all points



```
blast2dem -lof file_list.8852.txt -cores 3 -  
elevation -odir "C:\Users\ramon\Google Drive\  
+S_Active_Items\2017UGS_OT\250m_DSM" -  
otif
```



3 jobs on 4 cores +

selected file only
 process all files
 merge files into one

output ... +

verbose

VIEW

sample points: 5000000

step: 1

kill triangles > 100

item: elevation ▾

actual values
 hillside shading
 gray ramp
 false colors

set min max
min: 0
max: 0

invert ramp:

use tile bounding box
 specify size of raster
ncols: 512
nrows: 512

specify lower left
llx:
lly:
format: tif ▾

RUN

README <Q>UIT

Mosaic the tiles (with their buffers) into a seamless DSM in ArcGIS

Arctoolbox

- Data Management Tools
 - Archiving
 - Attachments
 - Data Comparison
 - Distributed Geodatabase
 - Domains
 - Feature Class
 - Features
 - Fields
 - File Geodatabase
 - General
 - Generalization
 - Geodatabase Administration
 - Geometric Network
 - Graph
 - Indexes
 - Joins
 - LAS Dataset
 - Layers and Table Views
 - Package
 - Photos
 - Projections and Transformations
 - Raster
 - Mosaic Dataset
 - Raster Catalog
 - Raster Dataset
 - Copy Raster
 - Create Random Raster
 - Create Raster Dataset
 - Download Rasters
 - Mosaic
 - Mosaic To New Raster

Mosaic To New Raster

Input Rasters

- C:\Users\ramon\Google Drive\+S_Active_Items\2017UGS_OT\250m_DSM\tile_4

Output Location

C:\Users\ramon\Google Drive\+S_Active_Items\2017UGS_OT\250m_DSM

Raster Dataset Name with Extension

250m_DSM_mosaic.tif

Spatial Reference for Raster (optional)

Pixel Type (optional)

32_BIT_FLOAT

Cellsize (optional)

Number of Bands

1

Mosaic Operator (optional)

LAST

Mosaic Colormap Mode (optional)

FIRST

OK Cancel Environments... << Hide Help Tool Help

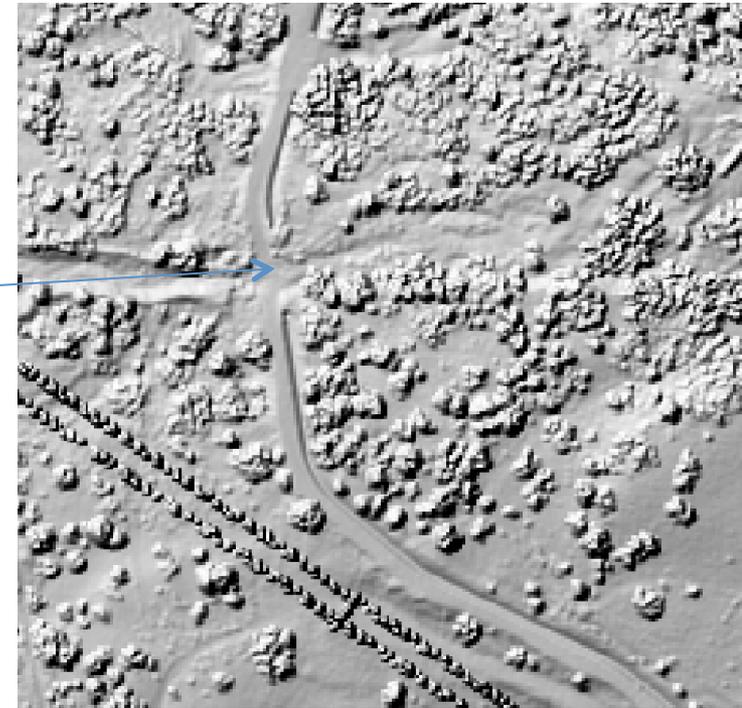
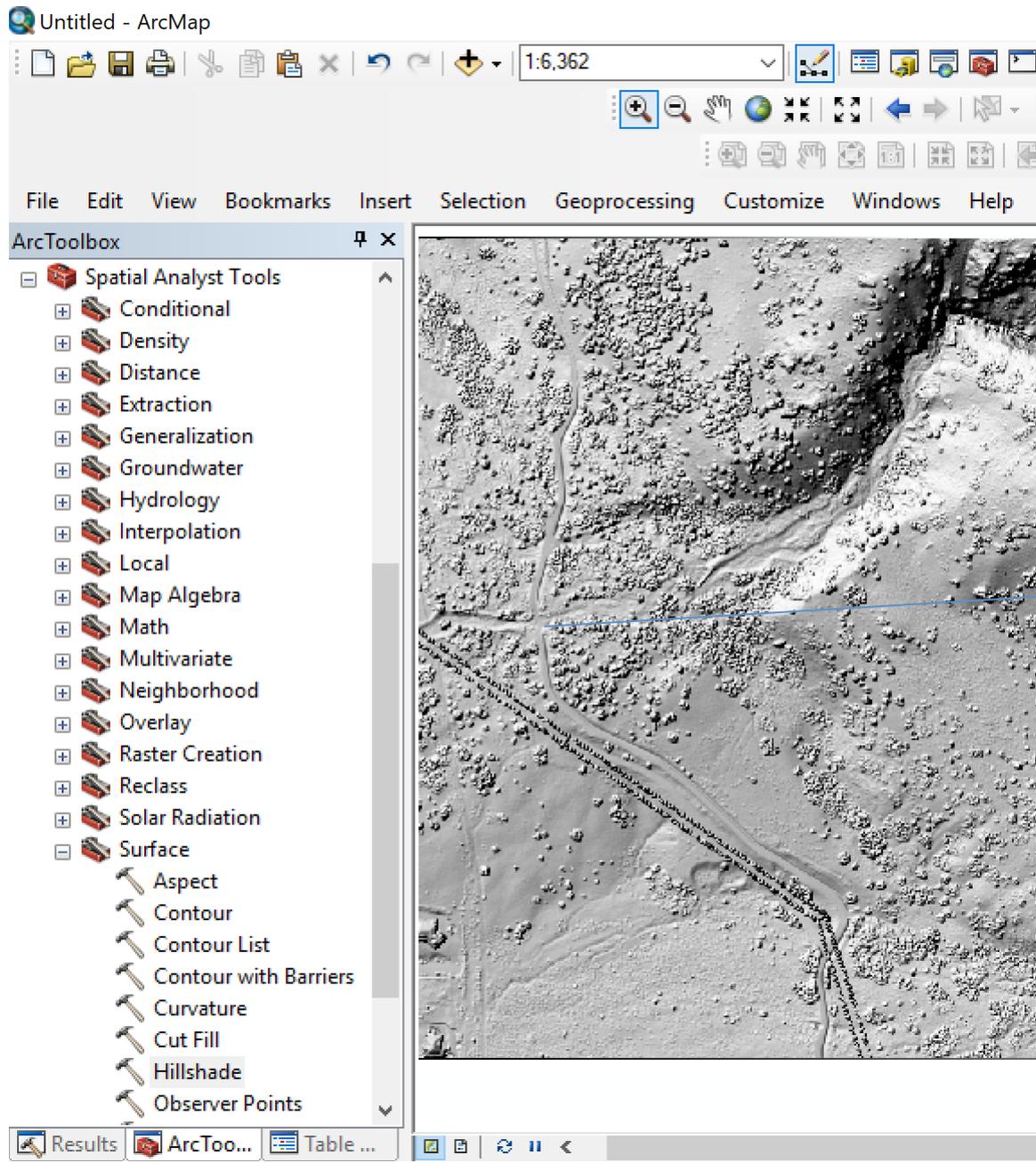
Mosaic To New Raster

Mosaics multiple raster datas

Load all the tiles with a shift-select

These do matter

Visualize the seamless DSM in ArcGIS as a hillshade



Now let's blast again

blast2dem - rasters billions of LiDAR points via a streaming TIN to elevation, intensity, slope, or RGB grids

file_list.3140.txt

- tile_414000_4580750.laz
- tile_414000_4581000.laz
- tile_414000_4581250.laz
- tile_414000_4581500.laz
- tile_414250_4580750.laz
- tile_414250_4581000.laz
- tile_414250_4581250.laz

browse ...

..

- tile_414000_4580750.laz
- tile_414000_4581000.laz
- tile_414000_4581250.laz
- tile_414000_4581500.laz
- tile_414250_4580750.laz
- tile_414250_4581000.laz

wildcard: *.laz add

directory: E:\ go

.las .laz .bin

.asc .bil .dtm

ASCII files ...

filter ...

by coordinates:

by classification or return:

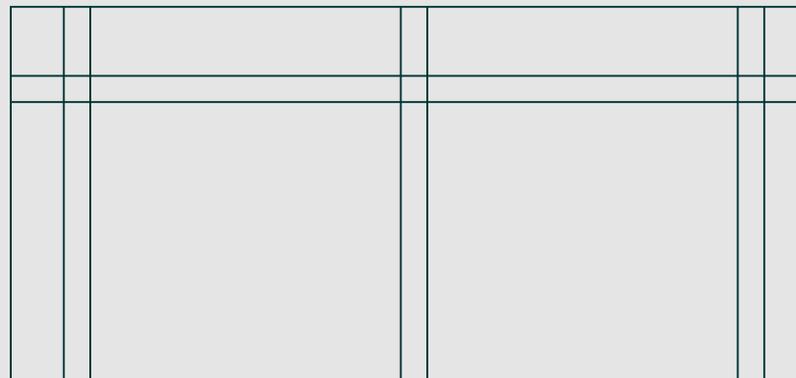
by various criteria:

number or value: 2

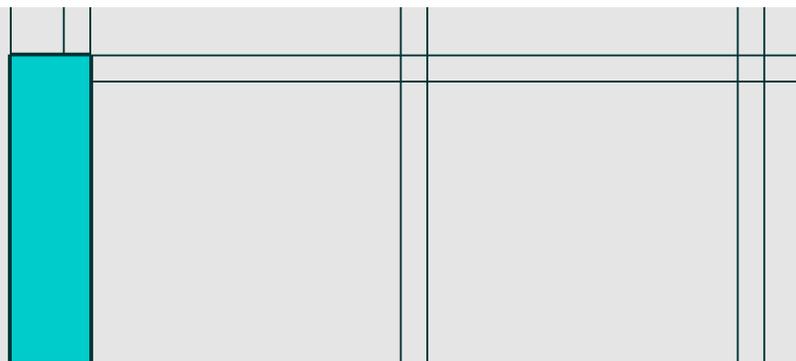
ADD

keep_classification 2

Digital terrain model—ground points



```
blast2dem -lof file_list.3140.txt -cores 3 -  
keep_classification 2 -elevation -odir "C:\Users  
\ramon\Google Drive\+S_Active_Items  
\2017UGS_OT\250m_DTMv2" -otif
```



3 jobs on 4 cores +

selected file only

process all files

merge files into one

output ... +

verbose

VIEW

sample points: 5000000

step: 1

kill triangles > 100

item: elevation

actual values

hillside shading

gray ramp

false colors

set min max

min: 0

max: 0

invert ramp

use file bounding box

specify size of raster

ncols: 512

nrows: 512

specify lower left

llx:

lly:

format: tif

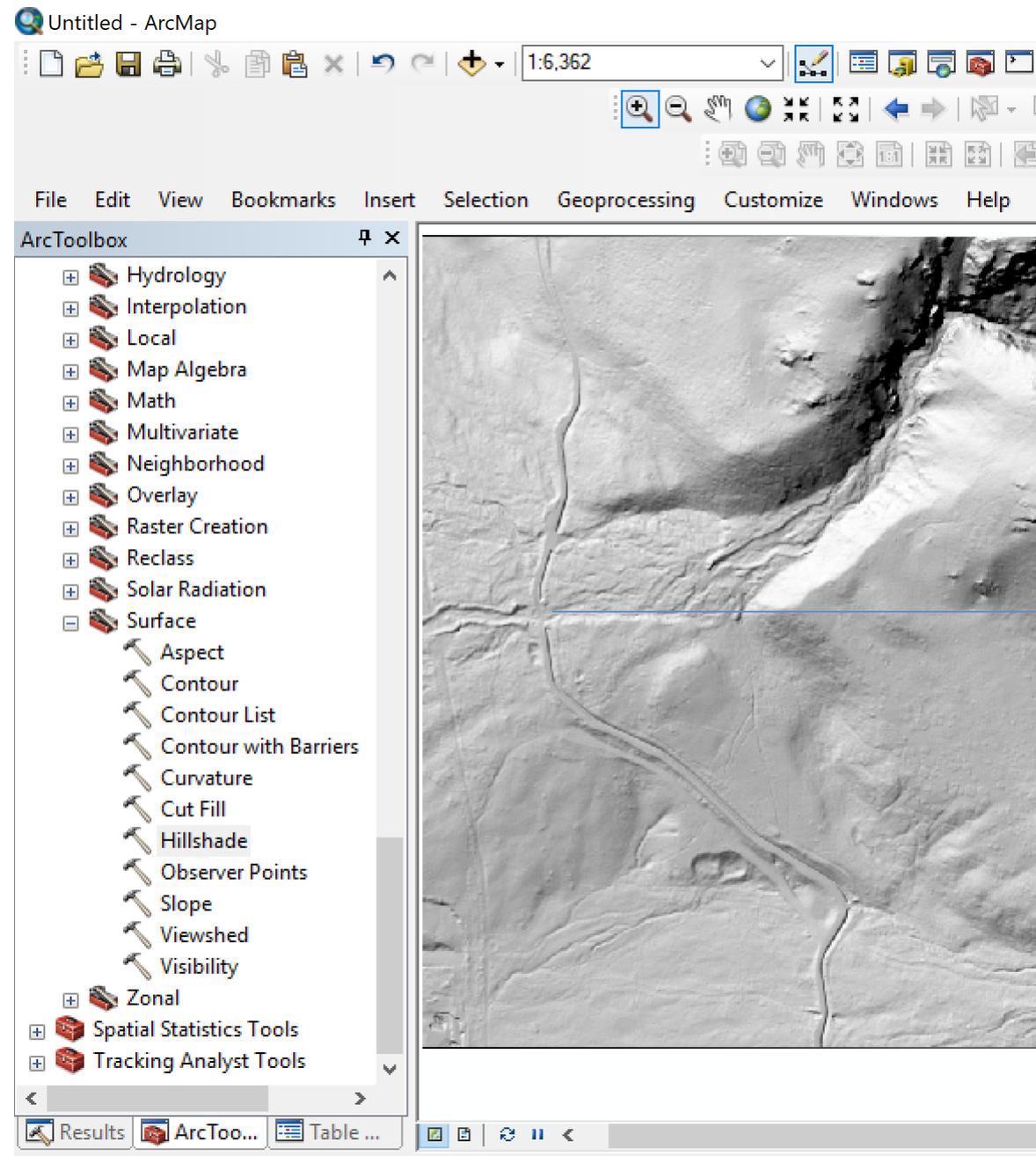
RUN

README <Q>UIT

Under filter, select `-keep_classification` and number or value 2; ADD

Visualize the seamless DTM in ArcGIS as a hillshade

(mosaic as we did for the DSM)



DEMs in ArcMap and ArcScene

Basic visualization and colorization

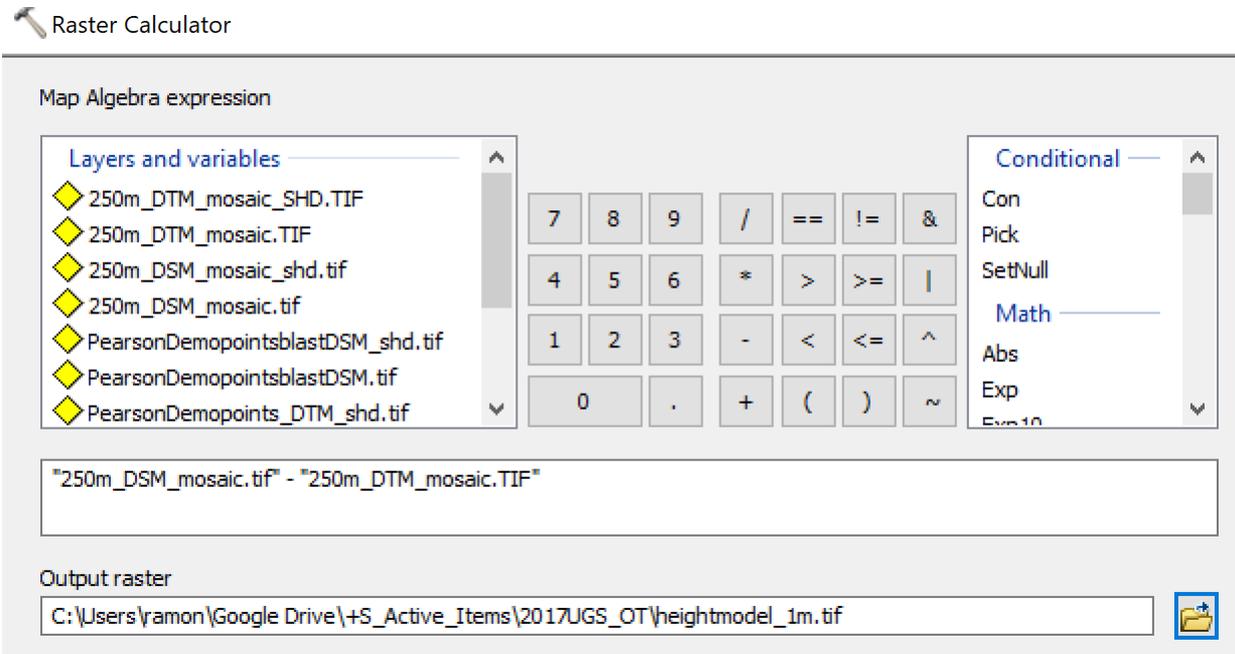
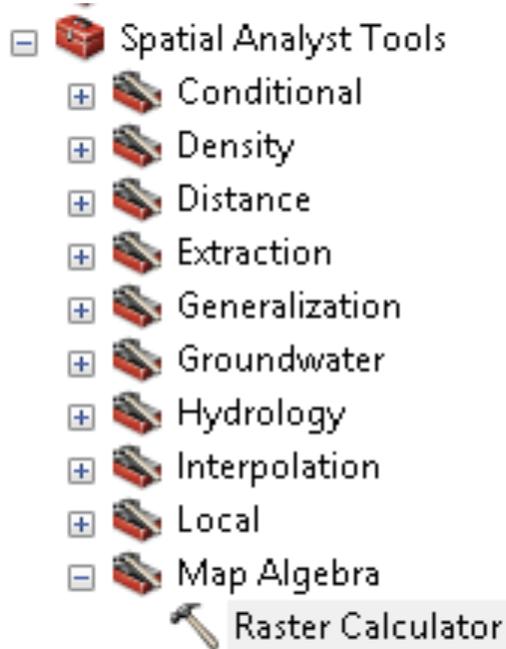
Point and profile measurements

Raster Math (difference and conditional)

Canopy

3D viewing in ArcScene

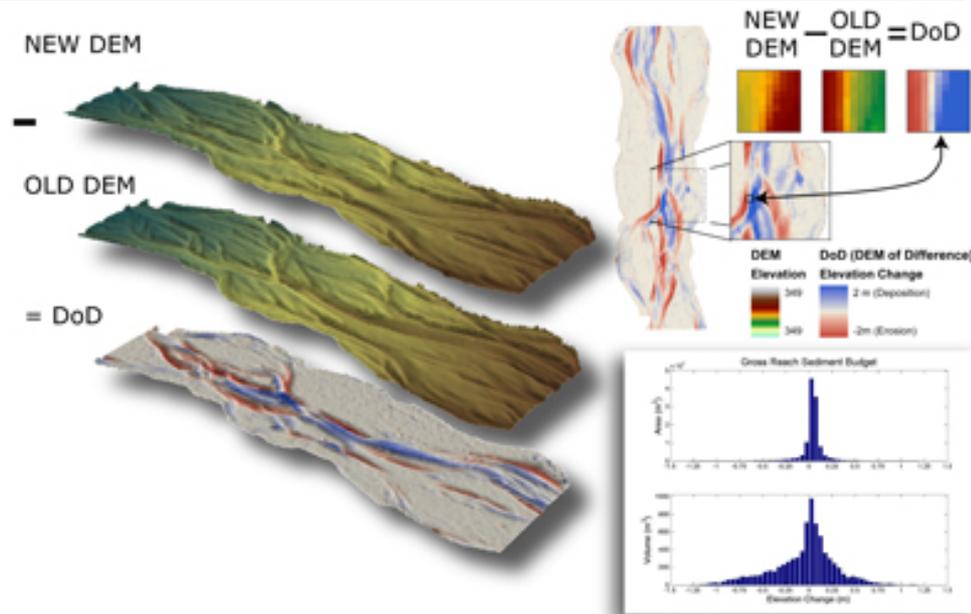
Raster math!



Note that is the beginning of other sorts of topographic differencing e.g., Morphological sediment budgeting

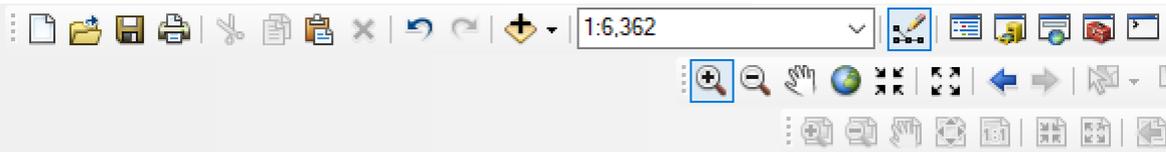
JOSEPH M. WHEATON
Research Linking Fluvial Geomorphology & Ecohydraulics

<http://www.joewheaton.org/>



Simple Canopy Height Map

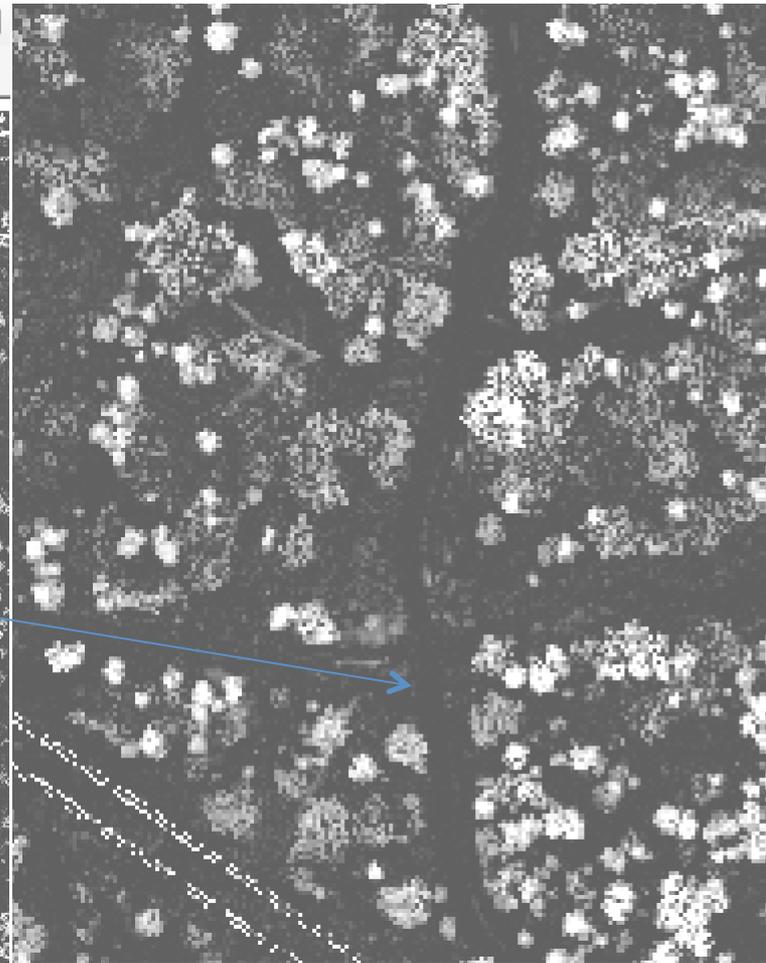
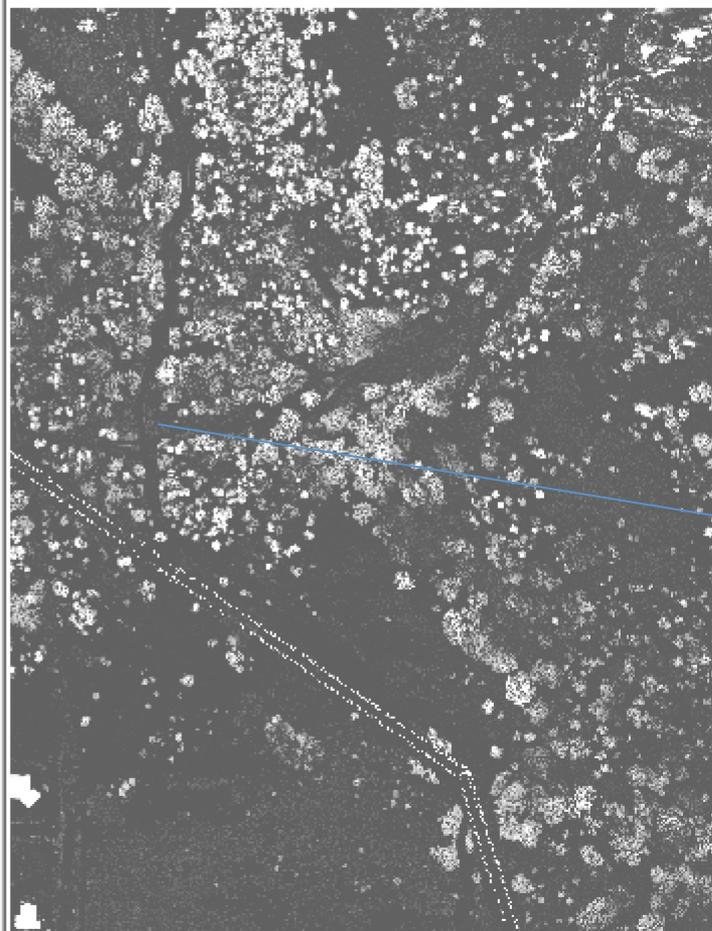
Untitled - ArcMap



File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help

Table Of Contents

Layers	
<input checked="" type="checkbox"/>	heightmodel_1m.tif Value High : 43.75 Low : -2.59009
<input checked="" type="checkbox"/>	250m_DTM_mosaic_SHD.TIF
<input type="checkbox"/>	250m_DTM_mosaic.TIF
<input type="checkbox"/>	250m_DSM_mosaic_shd.tif
<input type="checkbox"/>	250m_DSM_mosaic.tif
<input type="checkbox"/>	PearsonDemopointsblastDSM
<input type="checkbox"/>	PearsonDemopointsblastDSM
<input type="checkbox"/>	PearsonDemopoints_DTM_sh
<input type="checkbox"/>	PearsonDemopoints_DTM.tif
<input type="checkbox"/>	PearsonDemopoints_DSM_sh
<input type="checkbox"/>	PearsonDemopoints_DSM.tif



Canopy higher than 1 m

Map Algebra expression

Con: Performs a conditional if/else evaluation on each of the input cells of an input raster. Really powerful!!!

Layers and variables

- ◆ heightmodel_1m.tif
- ◆ 250m_DTM_mosaic_SHD.TIF
- ◆ 250m_DTM_mosaic.TIF
- ◆ 250m_DSM_mosaic_shd.tif
- ◆ 250m_DSM_mosaic.tif
- ◆ PearsonDemopointsblastDSM_shd.tif
- ◆ PearsonDemopointsblastDSM.tif

Conditional

7	8	9	/	==	!=	&
4	5	6	*	>	>=	
1	2	3	-	<	<=	^
0	.	+	()	~	

Math

- Abs
- Exp
- Exp10

Con("heightmodel_1m.tif" >= 1,"heightmodel_1m.tif")

Layer Properties

General Source Key Metadata Extent Display Symbology

Show: Unique Values Classified **Stretched** Discrete Color

Stretch values along a color ramp

Color	Value	Label	Labeling
	43.75	High : 43.75	
	1	Low : 1	

Color Ramp:

Display Background Value: 0 as

Use hillshade effect Z: 1 Display NoData as

Stretch Type: Standard Deviations Histograms

n: 2.5 Invert

Apply Gamma Stretch: 1

OK Cancel Apply

Untitled - ArcMap

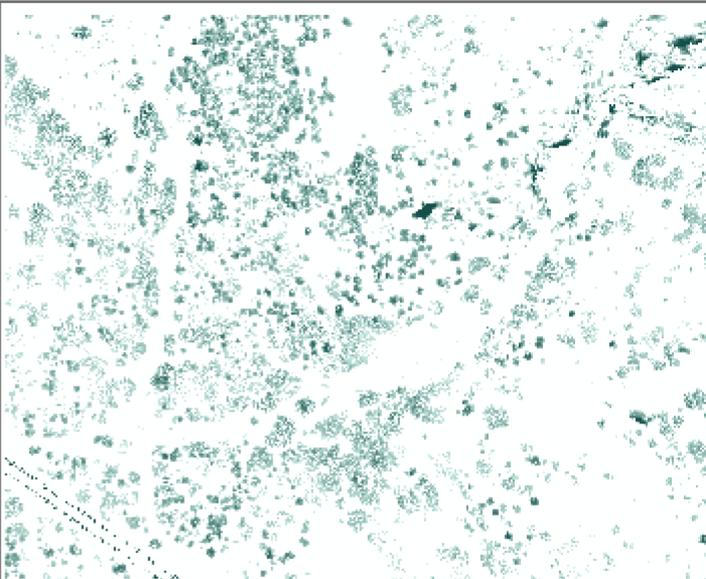
1:6,362

File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help

Table Of Contents

Layers

- canopy_ge1m_1m.tif
 - Value
 - High : 43.75
 - Low : 1
- heightmodel_1m.tif
- 250m_DTM_mosaic_SHD.TIF
- 250m_DTM_mosaic.TIF
- 250m_DSM_mosaic_shd.tif
- 250m_DSM_mosaic.tif
- PearsonDemopointsblastDSM
- PearsonDemopointsblastDSM



Properties-> Symbology -> Change the color ramp

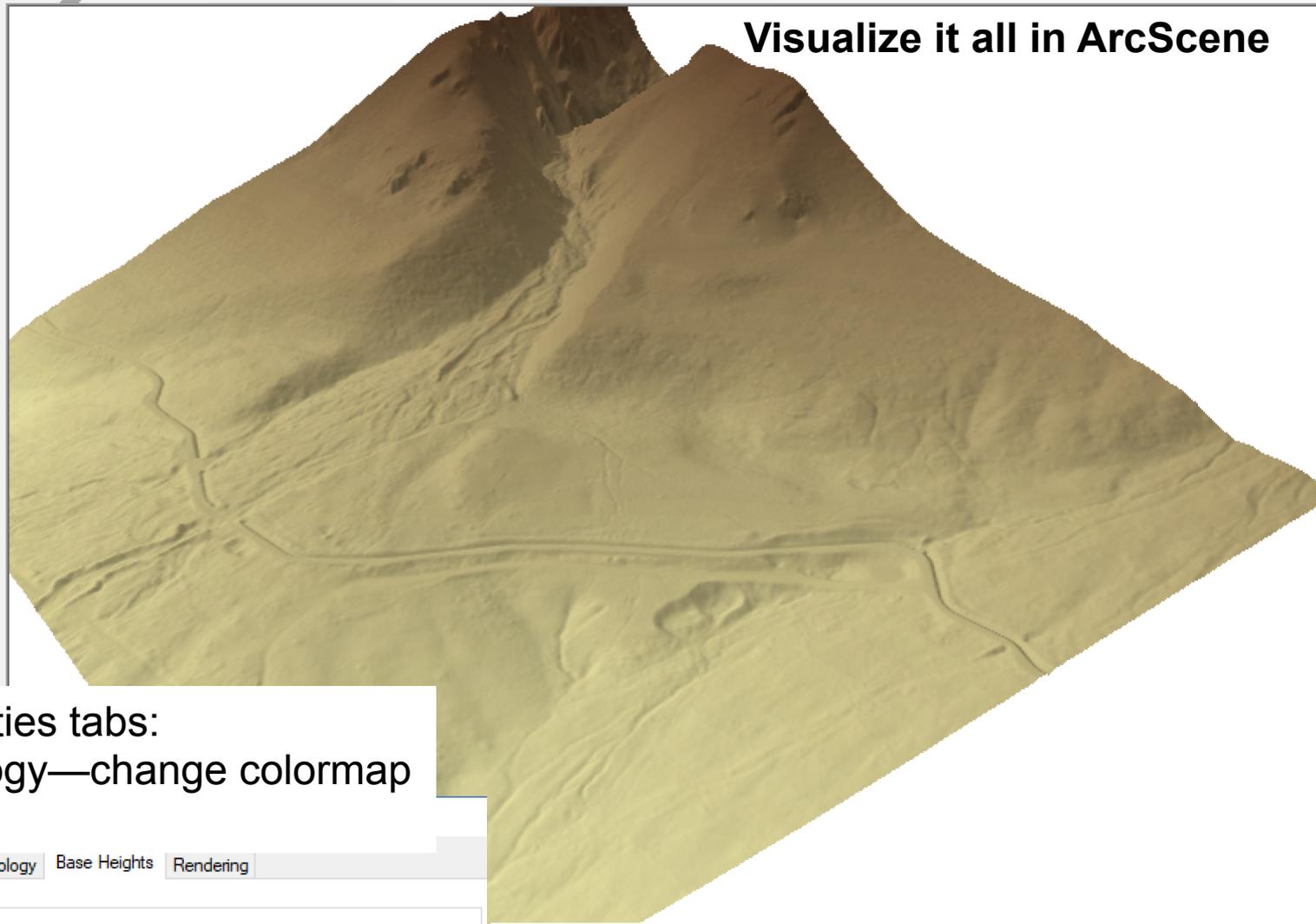


250m_DTM_mosaic.TIF

Table of Contents

Scene layers

- 250m_DTM_mosaic.TIF
 - Value
 - High : 1596.87
 - Low : 1357.22



Visualize it all in ArcScene

ArcScene Properties tabs:
Symbology—change colormap

General Source Extent Display Symbology Base Heights Rendering

Elevation from surfaces

No elevation values from a surface

Floating on a custom surface:

C:\Users\ramon\Google Drive\+S_Active_Items\2017UGS_OT\250m_DTMv2\250m_DTM

Raster Resolution... 1 m cell size

Rendering
Shade areal features
High quality enhancement



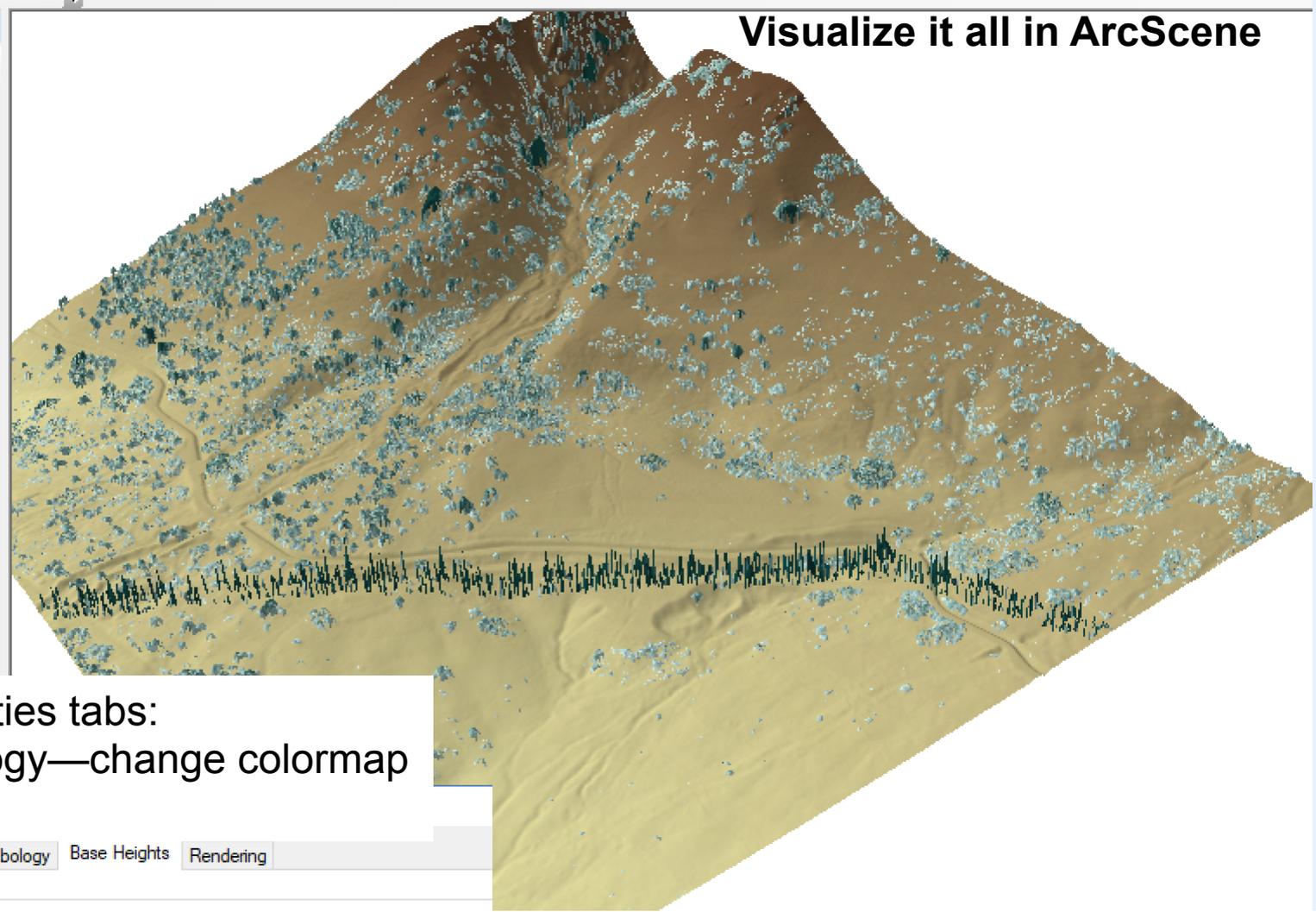
250m_DTM_mosaic.TIF

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Scene layers

- canopy_ge1m_1m.tif
 - Value
 - High : 43.75
 - Low : 1
- 250m_DTM_mosaic.TIF
 - Value
 - High : 1596.87
 - Low : 1357.22

Visualize it all in ArcScene



ArcScene Properties tabs:
Symbology—change colormap

General Source Extent Display Symbology Base Heights Rendering

Elevation from surfaces

No elevation values from a surface

Floating on a custom surface: **Drape it on the DSM**

C:\Users\ramon\Google Drive\+_S_Active_Items\2017UGS_OT\250m_DSM\250m_DSM_r

Raster Resolution... **1 m cell size**

Rendering
Shade areal features
High quality enhancement