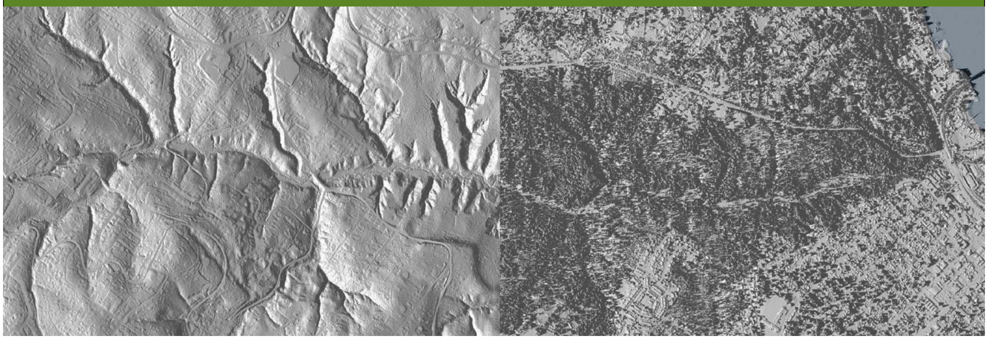
Light Detection and Ranging (LiDAR)



http://m.mtv.com/news/article.rbml?id=1590929

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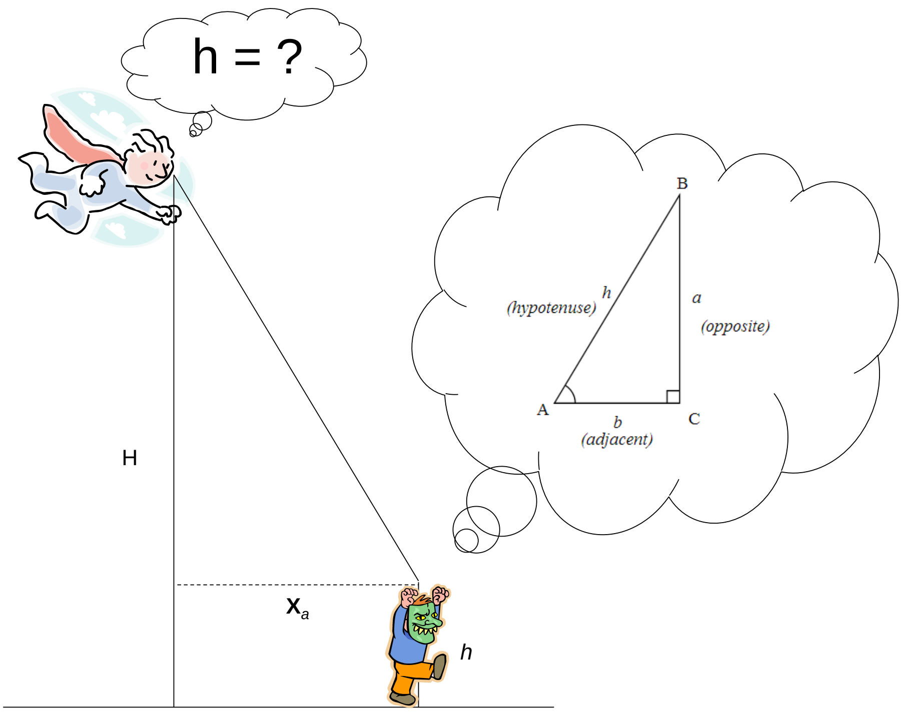
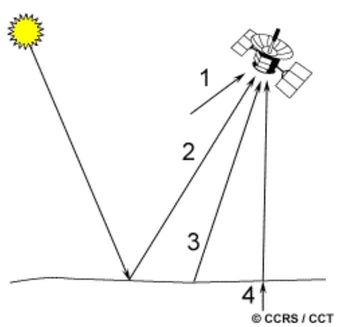
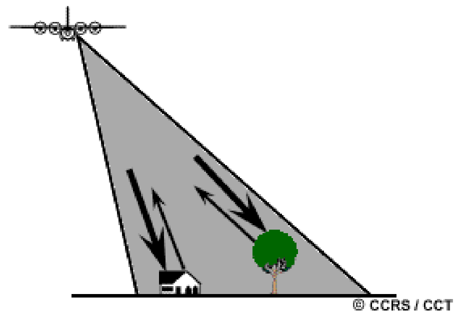


Types of aerial sensors



passive



active

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Active sensors for mapping terrain

- Radar
  - transmits microwaves in pulses
  - determines distance to objects and their angular position (from side)
- LiDAR
  - transmits optical laser light in pulses
  - determines distance to objects

History of LiDAR

- laser ranging developed in the 1960s
- LiDAR terrain mapping began in 1970s
- initial systems were “single beam”, profiling devices
- early use for terrain mapping limited by lack of accurate geo-referencing
- early systems used for bathymetry
- development of global positioning systems and inertial navigation (measurement) systems improved accuracy

LiDAR Platforms

- aerial
  - for highly detailed, local elevation data
- satellite
  - covers large areas with less detail

LIDAR Operational Theory

- A pulse of light is emitted and the precise time is recorded.
- The reflection of that pulse is detected and the precise time is recorded.
- Using the constant speed of light, the delay can be converted into a “slant range” distance.
- Knowing the position and orientation of the sensor, the XYZ coordinate of the reflective surface can be calculated.

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Components of a LiDAR system

- Laser scanner
- High-precision clock
- GPS
- IMU – Inertial navigation measurement unit
- Data storage and management systems
- GPS ground station

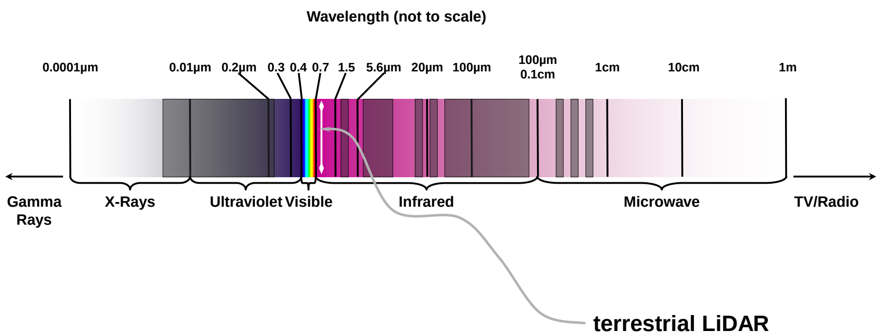
Components of a LiDAR system - Laser

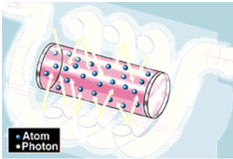
- Frequency: 50,000 (50k) to 200,000 (200k) pulses per second (Hz) (slower for bathymetry)

- Wavelength:
  - infrared (1500 – 2000 nm) for meteorology – Doppler LiDAR
  - near-infrared (1040 - 1060 nm) for terrestrial mapping
  - blue-green (500 – 600 nm) for bathymetry
  - ultraviolet (250 nm) for meteorology

- eye-safe; low wattage (<1w)

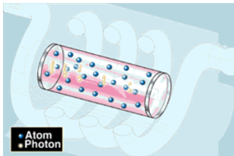
Electro-magnetic Spectrum





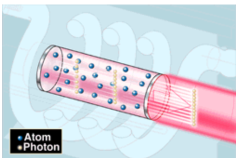
How a laser works:

High-voltage electricity causes a quartz flash tube to emit an intense burst of light, exciting some of the atoms in a cylindrical ruby crystal to higher energy levels.



At a specific energy level, some atoms emit particles of light called photons. At first the photons are emitted in all directions. Photons from one atom stimulate emission of photons from other atoms and the light intensity is rapidly amplified.

Mirrors at each end reflect the photons back and forth, continuing this process of stimulated emission and amplification.



The photons leave through the partially silvered mirror at one end. This is laser light. The emitted light waves are in phase with one another and are so nearly parallel that they can travel for long distances without spreading.

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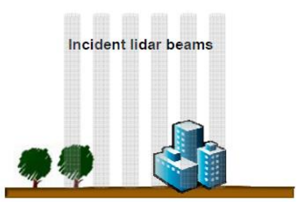
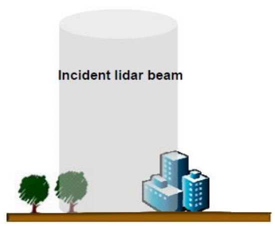
LiDAR – FOV (or footprint) Large or Small?

- FOV related to beam divergence (0.1 to 1 milliradian)
- Small FOV for detailed local mapping
- Large FOV for more complete ground sampling and more interactions with multiple vertical structures
- Large FOV usually results in a lower S/N





Components of a LiDAR system

- Scanner
  - mirror spins or scans to project laser pulses to the surface
  - scanning angles up to 75 degrees; scanner measures the angle at which each pulse was fired
  - receives reflected pulse from surface (“return”)

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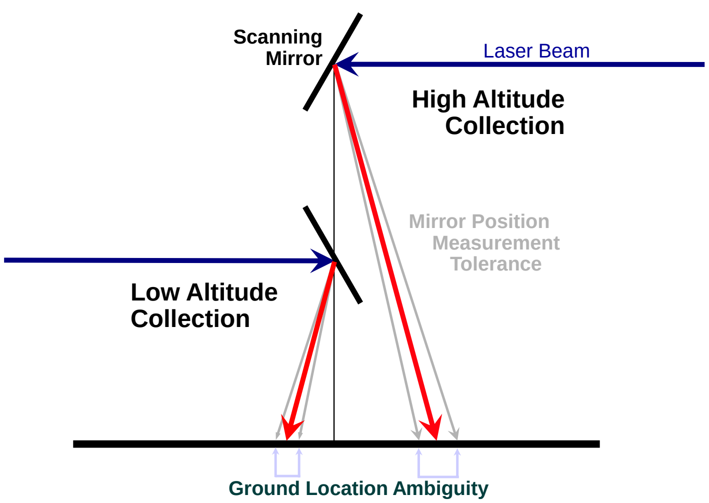

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Components of a LiDAR system

- global positioning system (GPS)
  - records the x,y,z location of the scanner
  - surveyed ground base stations in the flight area
- inertial measurement unit (IMU)
  - measures the angular orientation of the scanner relative to the ground (pitch, roll, yaw)

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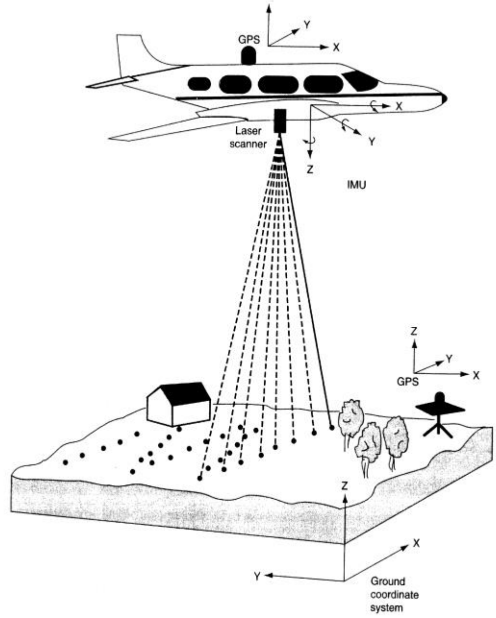
Components of a LiDAR system

- clock
  - records the time the laser pulse leaves and returns to the scanner



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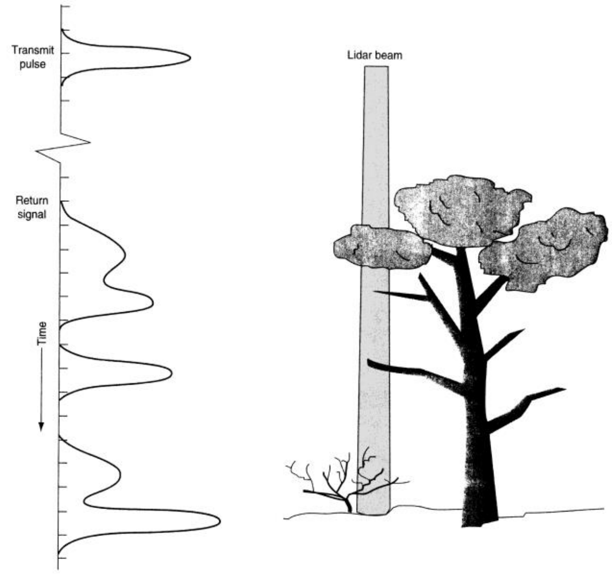
Principles of Airborne LiDAR – Flight Planning

- cannot penetrate clouds
- are often flown at night
- overlap of 30 to 50% in steeper terrain
- multiple passes at different angles in urban areas (to avoid LiDAR "shadow")
- flying elevation typically 200 to 300 meters (higher in urban areas)
- multiple "returns" are received for each laser pulse fired from the scanner
- modern systems are capable of recoding up to 5 returns for each pulse



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Principles of LiDAR -- Returns

- the *range distance* between the sensor and surface object is calculated by comparing the time the pulse left the scanner to the time each return is received

Pulse laser
Range distance (R) and range resolution (ΔR)

$$R = c\frac{t}{2} \qquad \Delta R = c\frac{\Delta t}{2}$$

where:

c: speed of light (~299,792,458 meters/second)

t: time interval between sending/receiving the pulse (ns)

Δt: resolution of time measurement (ns)

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Laser pulse travel time

$$t = \frac{2(R)}{c}$$

example:

- flight altitude of 300m, object is 10 meters high directly below sensor. What's the laser pulse travel time?

1.93467 X 10^{-6} seconds (or 1,935 nanoseconds)

Continuous-wave Laser
Range distance (R) and range resolution (ΔR)

$$R = \frac{c}{2}\frac{\varphi}{2\pi f} \qquad \Delta R = \frac{c}{2}\frac{\Delta\varphi}{2\pi f}$$

where:

c: speed of light (~299,792,458 meters/second)

φ: phase (radian)

Δφ: phase resolution (radian)

f: frequency (Hz) – number of wave cycles per unit time

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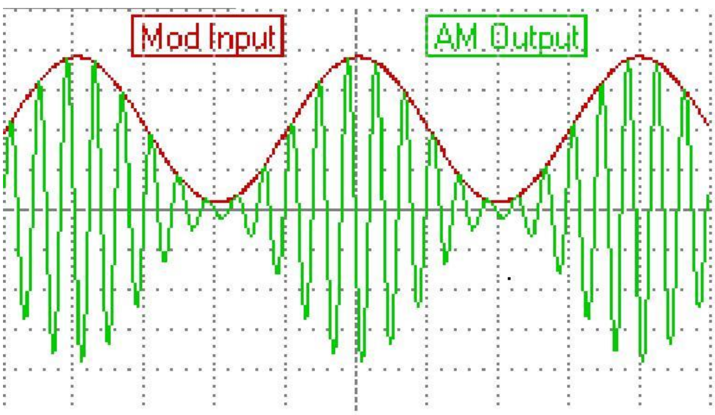
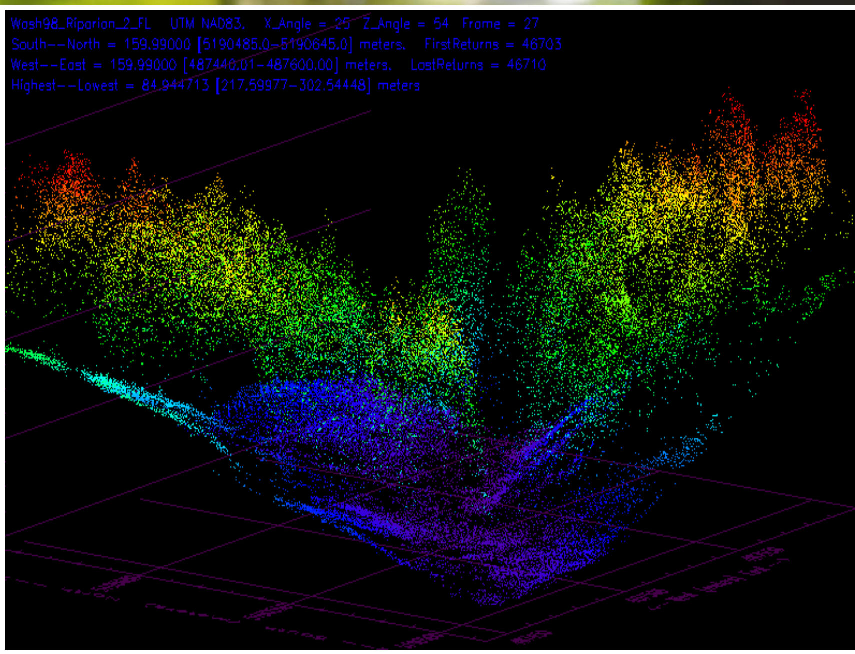
Continuous-wave laser implementation



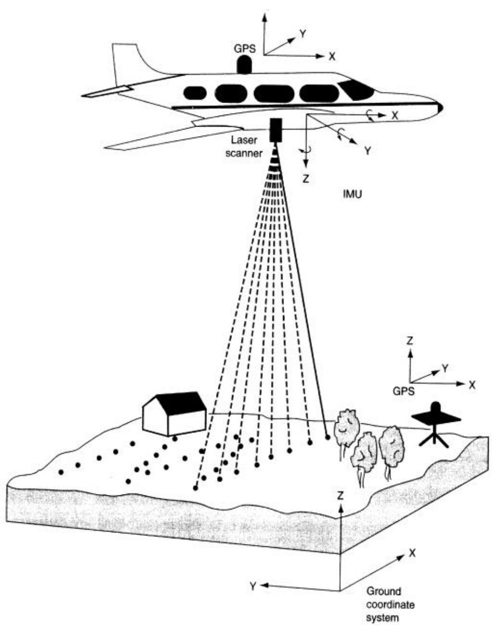
Principles of LiDAR -- Returns

- the x/y/z coordinate of each return is calculated using the location and orientation of the scanner (from the GPS and IMU), the angle of the scan mirror, and the range distance to the object
- the collection of returns is known as a *point cloud*

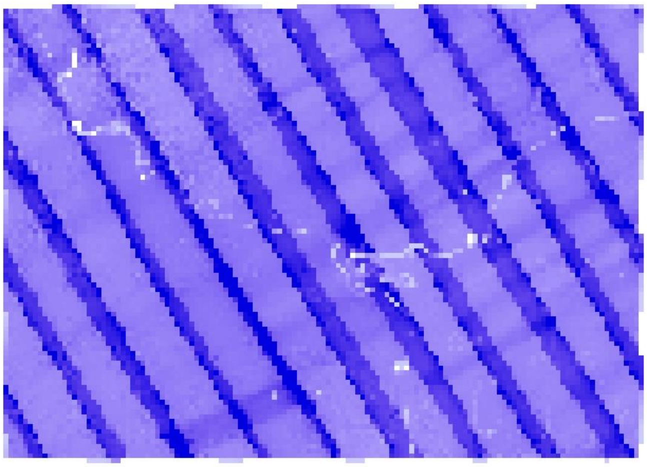


Principles of LiDAR – “Resolution”

- number of pulses per unit area
- current systems capable of 20 + pulses/square meter
- resolution determined by aircraft speed, flying altitude field of view (FOV), rate of pulse emission
- points are not evenly spaced



LiDAR point count pattern



* Darker color indicates more counts

Maximum Unambiguous Range (Pulse Laser)

- Laser energy
- Pulse rate (none-overlapping pulses)

Pulse Rate (Hz)	Max Unambiguous Range
10 K	14990 m / 49179 ft
71 K	2111 m / 6927 ft
100 K	1499 m / 4918 ft
167 K	898 m / 2945 ft

Principles of LiDAR – “Resolution”

- higher resolution and a narrow FOV is needed to penetrate dense vegetation
- higher resolutions allow the surface and features on the surface to be better resolved, but at cost of larger datasets and slower processing times

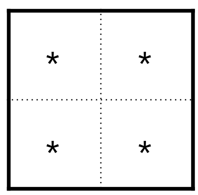
Lidar density and DEM resolution

- average of 1 Lidar pulse per DEM pixel

- Point density (e.g., 8 pulses per square meter)

- Point spacing (e.g., 50 cm)

PS = SQRT(1/PD)



Example: 8 pulses / meter^2 = 0.35 meters

Principles of LiDAR – "Resolution"

for the Portland City Boundary...

	20 pulses/sq meter	8 pulses/sq meter	1 pulse/sq meter
number of points	15,060,000,000	6,024,000,000	753,000,000

for the UGB...

	20 pulses/sq meter	8 pulses/sq meter	1 pulse/sq meter
number of points	45,180,000,000	18,072,000,000	2,259,000,000

Principles of LiDAR – Accuracy

- vertical accuracy typically 15 to 20 cm (~6 inches)
- horizontal accuracy 1/3 to 1 meter
- accuracy improved by flying low and slow, with a narrow FOV

Principles of LiDAR -- Intensity

- strength of returns varies with the composition of the surface object reflecting the return
- reflective percentages are referred to as *LiDAR intensity*
- can be used to identify land cover types
- intensity values need to be normalized among flights

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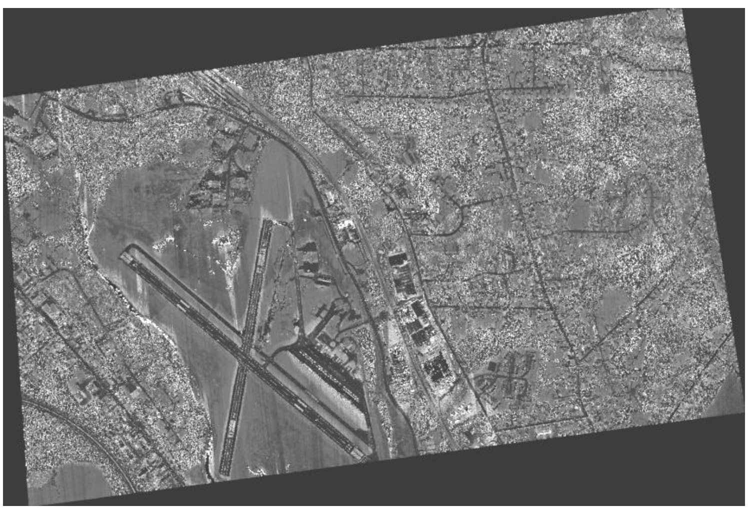

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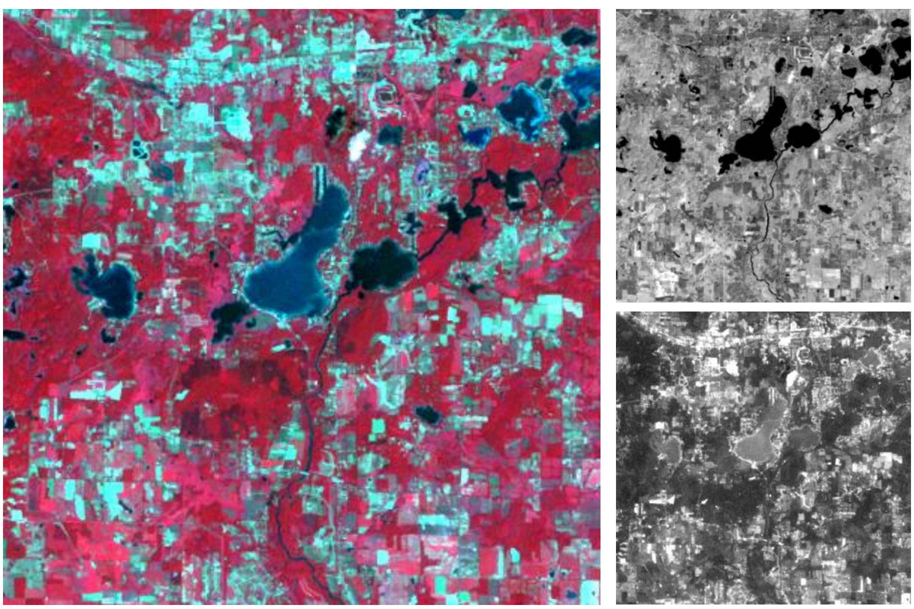
LiDAR reflectivity examples

White Paper	up to 100%
Snow	80-90%
Beer Foam	88%
Deciduous Trees	~ 60%
Coniferous Trees	~ 30%
Dry Sand	57%
Wet Sand	41%
Asphalt with Pebbles	17%
Black Neoprene	5%
Clear Water	< 5%

ETM+: CIR False Color Composite Image



Advantages of LiDAR

- all data geo-referenced from inception
- high level of accuracy
- ability to cover large areas quickly
- quicker turnaround, less labor intensive, and lower costs than photogrammetric methods
- can collect data in steep terrain and shadows
- can produce DEM and DSM

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Disadvantages of LiDAR

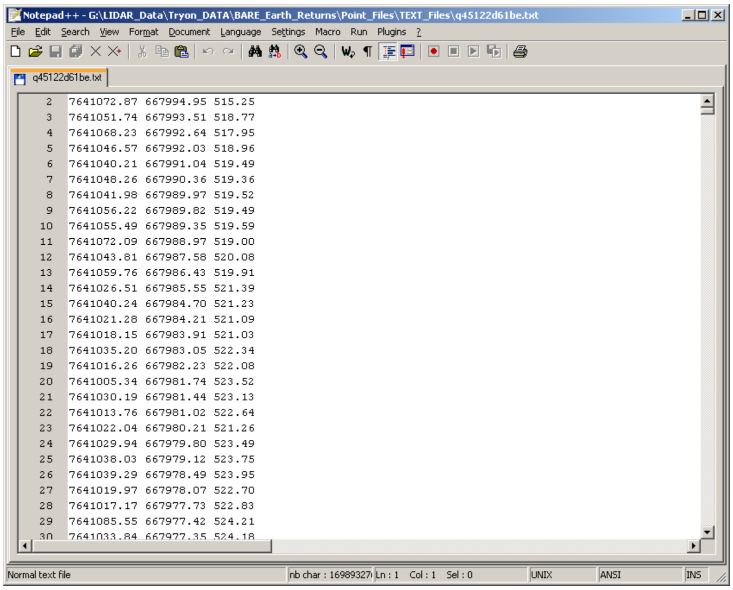
- inability to penetrate very dense canopy leads to elevation model errors
- very large datasets that are difficult to interpret and process
- no international protocols
- cost
  - $200 - $300 / sq mile – 3 meters resolution
  - $350 - $450 / sq mile – 1 meter resolution

LiDAR Data Pre-processing

- data collected by onboard computer in formats proprietary to the system vendor
- post-processed to calibrate multiple flight lines, filter erroneous values and noise
- returns are classified and separated by category: first returns, last (or bare-earth) returns, etc.

LiDAR Data Formats

- point values are usually delivered by vendor as either ASCII point files or in LAS format



7641072.87	667994.95	515.25
7641051.74	667993.51	518.77
7641068.23	667992.64	517.95
7641046.57	667992.03	518.96
7641040.21	667991.04	519.49
7641048.26	667990.36	519.36
7641041.98	667989.97	519.52
7641056.22	667989.82	519.49
7641055.49	667989.35	519.59
7641072.09	667988.97	519.00
7641043.81	667987.58	520.08
7641059.76	667986.43	519.91
7641026.51	667985.55	521.39
7641040.24	667984.70	521.23
7641021.28	667984.21	521.09
7641018.15	667983.91	521.03
7641035.20	667983.05	522.34
7641016.26	667982.23	522.08
7641005.34	667981.74	523.52
7641030.19	667981.44	523.13
7641013.76	667981.02	522.64
7641022.04	667980.21	521.26
7641029.94	667979.80	523.49
7641038.03	667979.12	523.75
7641039.29	667978.49	523.95
7641019.97	667978.07	522.70
7641017.17	667977.73	522.83
7641085.55	667977.42	524.21
7641033.84	667977.35	524.18

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LAS format

- LiDAR data exchange format standard
- public binary file format that maintains information specific to the LIDAR nature of the data while not being overly complex
- maintained by ASPRS
- http://www.lasformat.org/

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LAS Point Data Record format

Item	Format	Size	Required
X	long	4 bytes	*
Y	long	4 bytes	*
Z	long	4 bytes	*
Intensity	unsigned short	2 bytes	
Return Number	3 bits (bits 0, 1, 2)	3 bits	*
Number of Returns (given pulse)	3 bits (bits 3, 4, 5)	3 bits	*
Scan Direction Flag	1 bit (bit 6)	1 bit	*
Edge of Flight Line	1 bit (bit 7)	1 bit	*
(1.1) Classification	unsigned char	1 byte	*
(1.1) `Scan Angle Rank (-90 to +90) – Left side	char	1 byte	*
(1.1) User Data	unsigned char	1 byte	
(1.1) Point Source ID	unsigned short	2 bytes	*

http://liblas.org/raw-attachment/wiki/WikiStart/asprs_las_format_v11.pdf

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LiDAR Processing Software

- QT Modeler
- TerraScan
- ArcGIS (Workstation, LiDAR Analyst, 3D Analyst, LP360)
- Leica Photogrammetry Suite
- ENVI LiDAR

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Typical LiDAR to DEM Processing Steps

1) Import "raw" points into a GIS format

2) Convert points to a TIN model of the surface

3) Convert TIN model to a raster model of the surface

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Step 1 – Import Points

- the multiple LiDAR x/y/z returns are converted into individual GIS datasets
- usually use function typical of "generate"
- large datasets can overwhelm many GIS applications

bare earth point returns

Step 2 – Create TIN model

- triangulated irregular network
- typically created using *Delauney triangulation*, where all points are connected to the nearest two points
- Delauney triangles are as equi-angular as possible
- ensures that any point on the surface is as close as possible to a triangle node

Step 2 – Create TIN model

- the x/y/z return points become the nodes of the TIN model triangles
- the slope of the triangle sides and face is therefore known
- TIN model allows for the linear interpolation of elevation values between the triangle nodes
- maintains “edges” better than if point returns were converted directly to raster data

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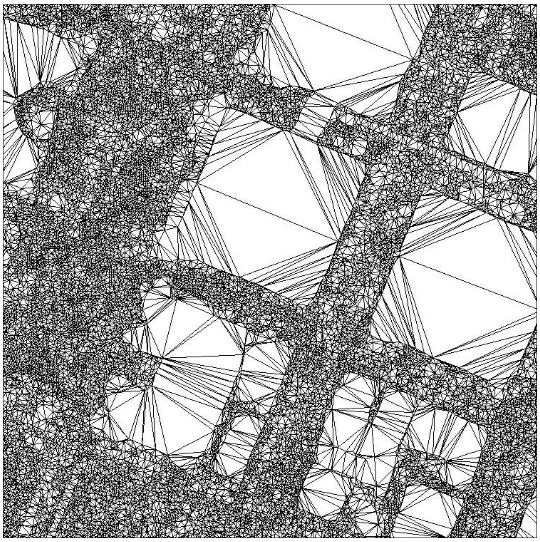
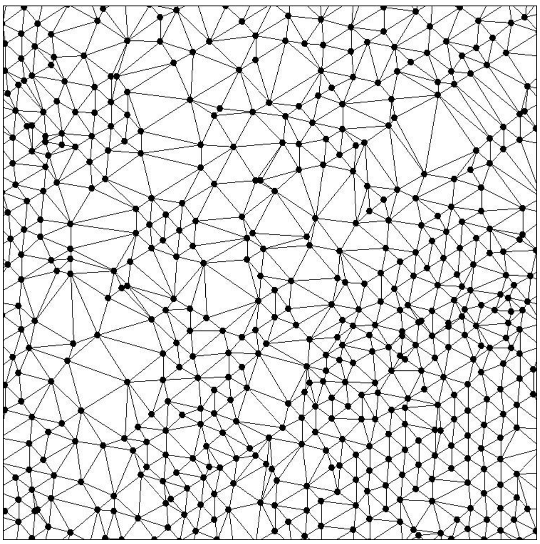
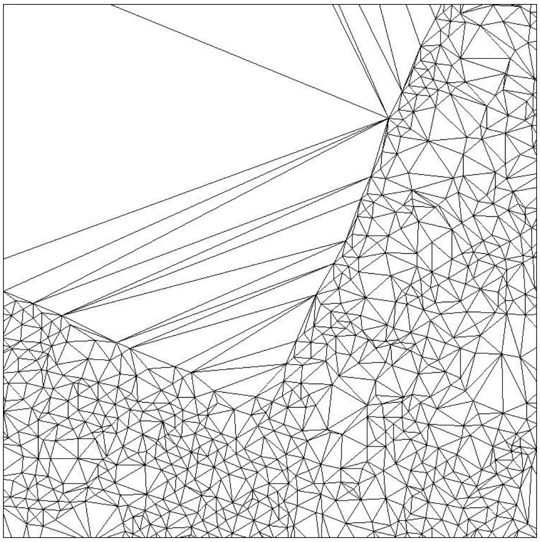
bare earth point returns



TIN model



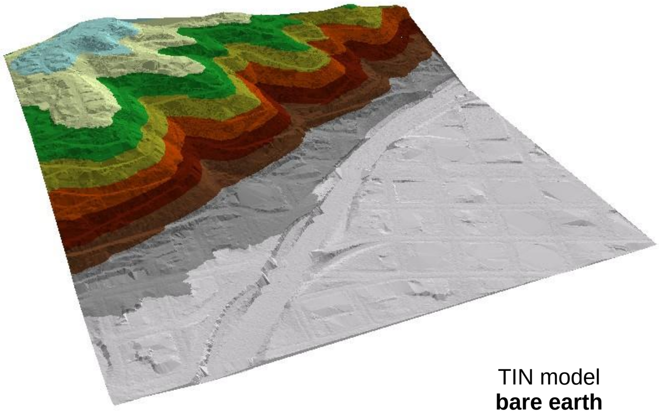
TIN model



TIN "edges"

Step 2 – Create TIN model

- the TIN model is a useful representation of the surface
- for LiDAR data, a raster model is generally preferred as a final product due to its lower complexity and faster drawing speeds



TIN model
bare earth

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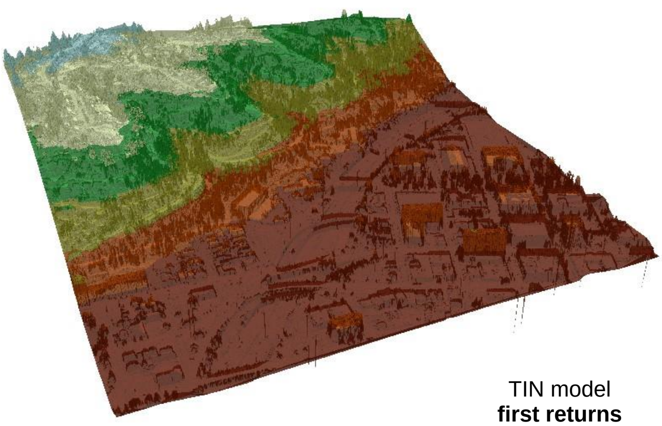


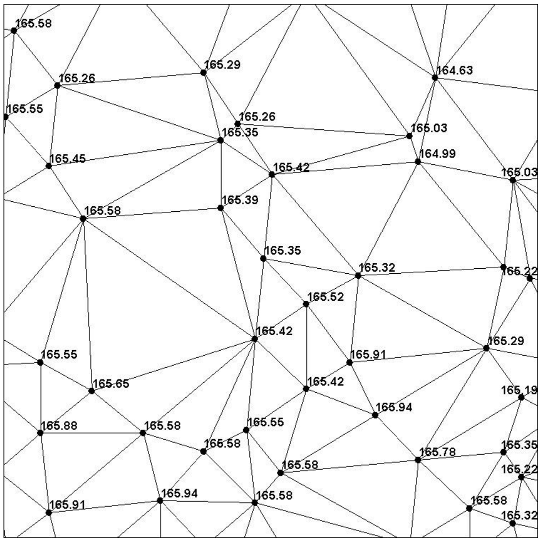
TIN model
first returns

Step 3 – Create a Raster Model

- raster data stores elevation values in a regularly-spaced series of uniform data units (pixels)
- raster-based models of the surface are known as *digital elevation models* (DEM)
- raster based models of features above the surface are often referred to as *digital surface models* (DSM)

Step 3 – Create a Raster Model

- raster data can be created from the TIN model by by interpolating the elevation value for each pixel's center point using linear interpolation
- the minimum resolution depends on the LiDAR return resolution
- rule of thumb: **average of 1 pulse per pixel**



TIN model

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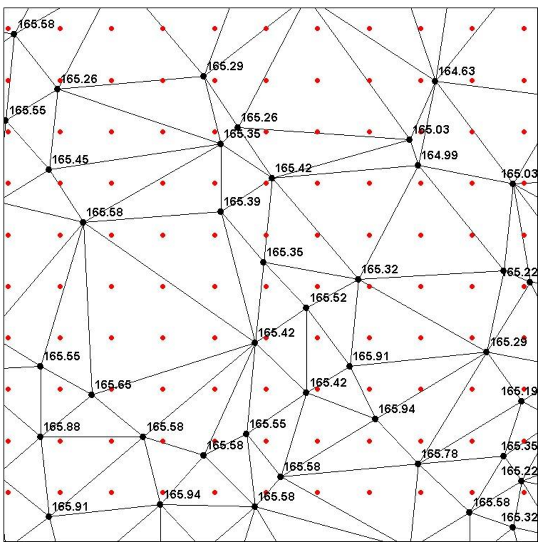
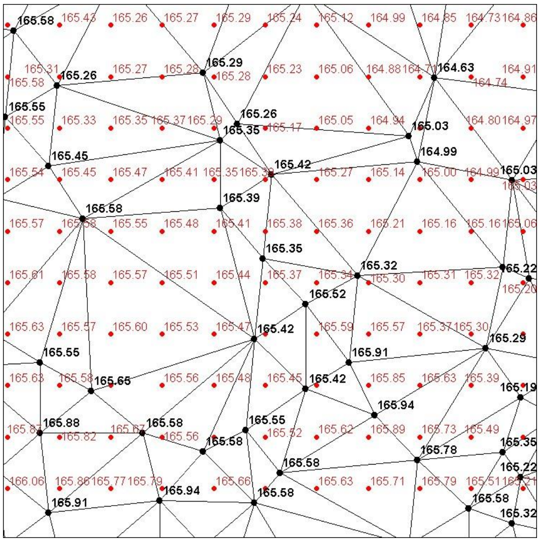
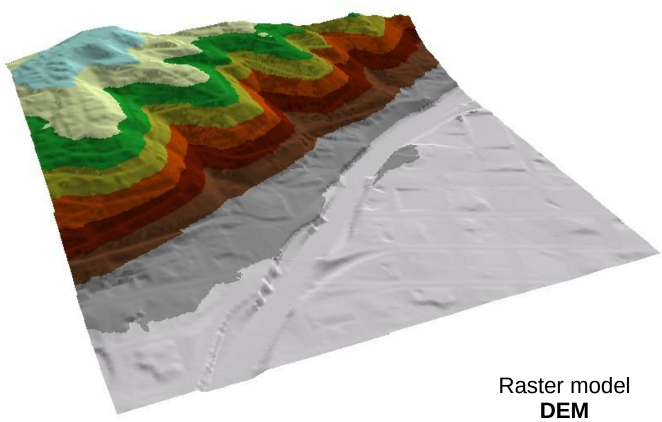


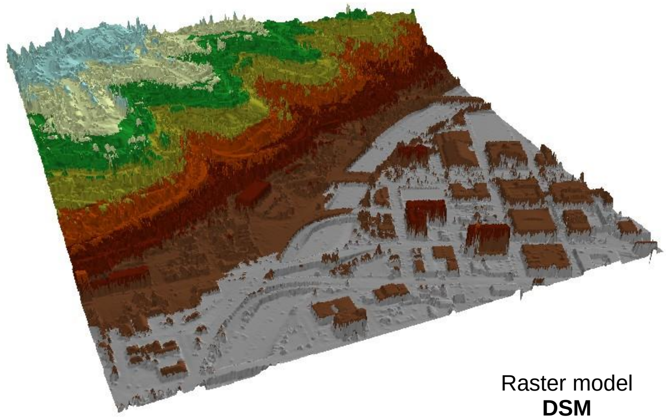
TIN model with pixel center points



TIN model with pixel center points



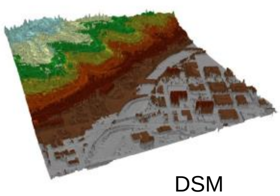
Raster model
DEM



Raster model
DSM

Other products – Height Image

- created by subtracting the bare earth returns from the first returns
- creates a raster image of tree, building, and other surface feature heights



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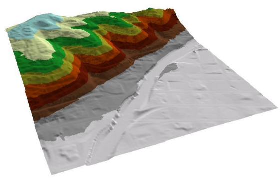

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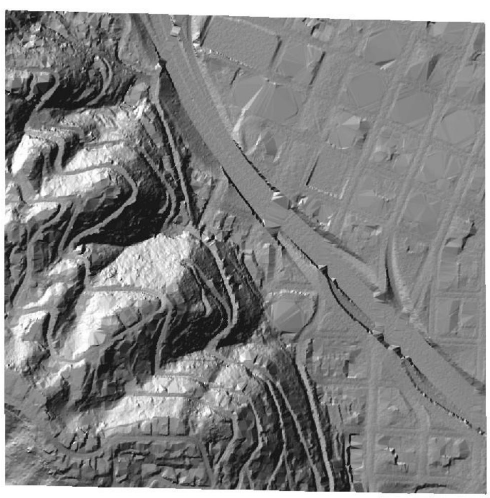
DSM DEM Height

Raster model
feature heights

Other products -- Hillshades

- shaded relief image created by considering the illumination angle of the sun and shadows
- used to view 3D models in 2D
- the source of light is usually from the north; this produces the most visually-appealing image



bare earth hillshade

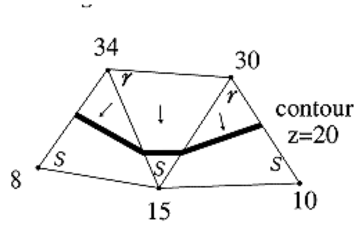
first return hillshade

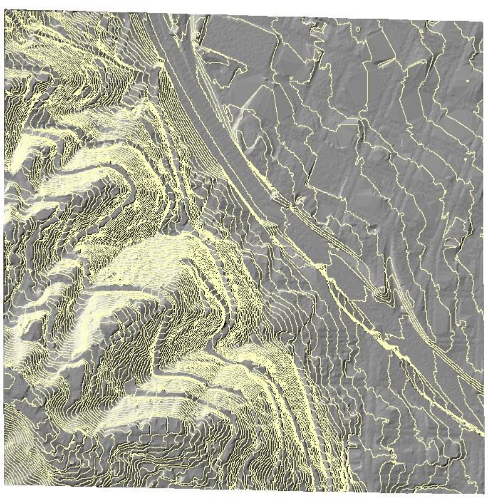
Other products -- Contours

- can be created from the TIN or raster model
- appropriate interval depends on the vertical accuracy of the LiDAR data.

  (contour interval should be at least twice the vertical accuracy, i.e.,

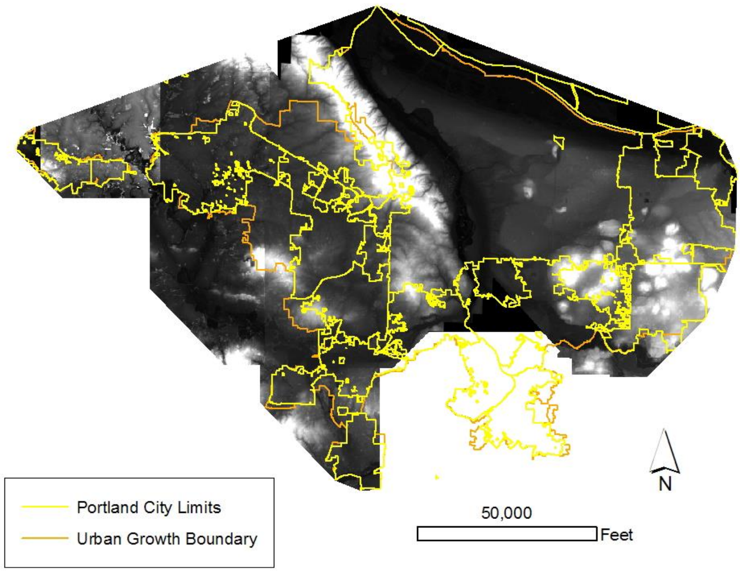
Other products -- Contours





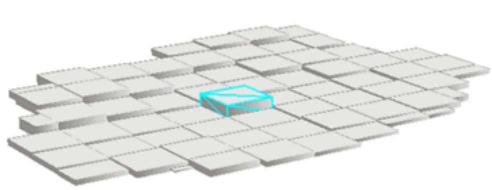
5' contours

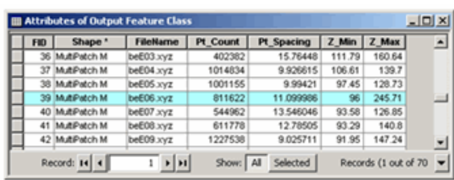
Geography CSAR ArcGIS Server (http://atlas.geog.pdx.edu)



Public Domain LiDAR in Oregon

- http://www.blm.gov/or/gis/lidar.php
- USGS NED (3m DEM) and Earth Explorer (las)
- ESRI ArcGIS
  - ArcGIS Point file information tool
  - ArcGIS LAS Dataset tools





Attributes of Output Feature Class

FID	Shape *	FileName	Pt_Count	Pt_Spacing	Z_Min	Z_Max
36	MultiPatch M	beE03.xyz	402382	15.76448	111.79	160.64
37	MultiPatch M	beE04.xyz	1014834	9.926615	106.61	139.7
38	MultiPatch M	beE05.xyz	1001155	9.99421	97.45	128.73
39	MultiPatch M	beE06.xyz	811622	11.099986	96	245.71
40	MultiPatch M	beE07.xyz	544962	13.546046	93.58	126.85
41	MultiPatch M	beE08.xyz	611778	12.78505	93.29	140.8
42	MultiPatch M	beE09.xyz	1227538	9.025711	91.95	147.24

Record: 1 Show: All Selected Records (1 out of 70

ArcGIS 10.1 LAS Dataset

A LAS dataset can be:

- Used in ArcGIS in both 2D and 3D using ArcMap and ArcScene.
- Displayed as either points using elevation or point attribute renderers based on certain Lidar filters applied to the point cloud.
- Rendered as a triangulated surface model.
- Visualized using elevation, slope, aspect, or contour lines based on certain Lidar filters.
- Used to make updates to the source LAS files.