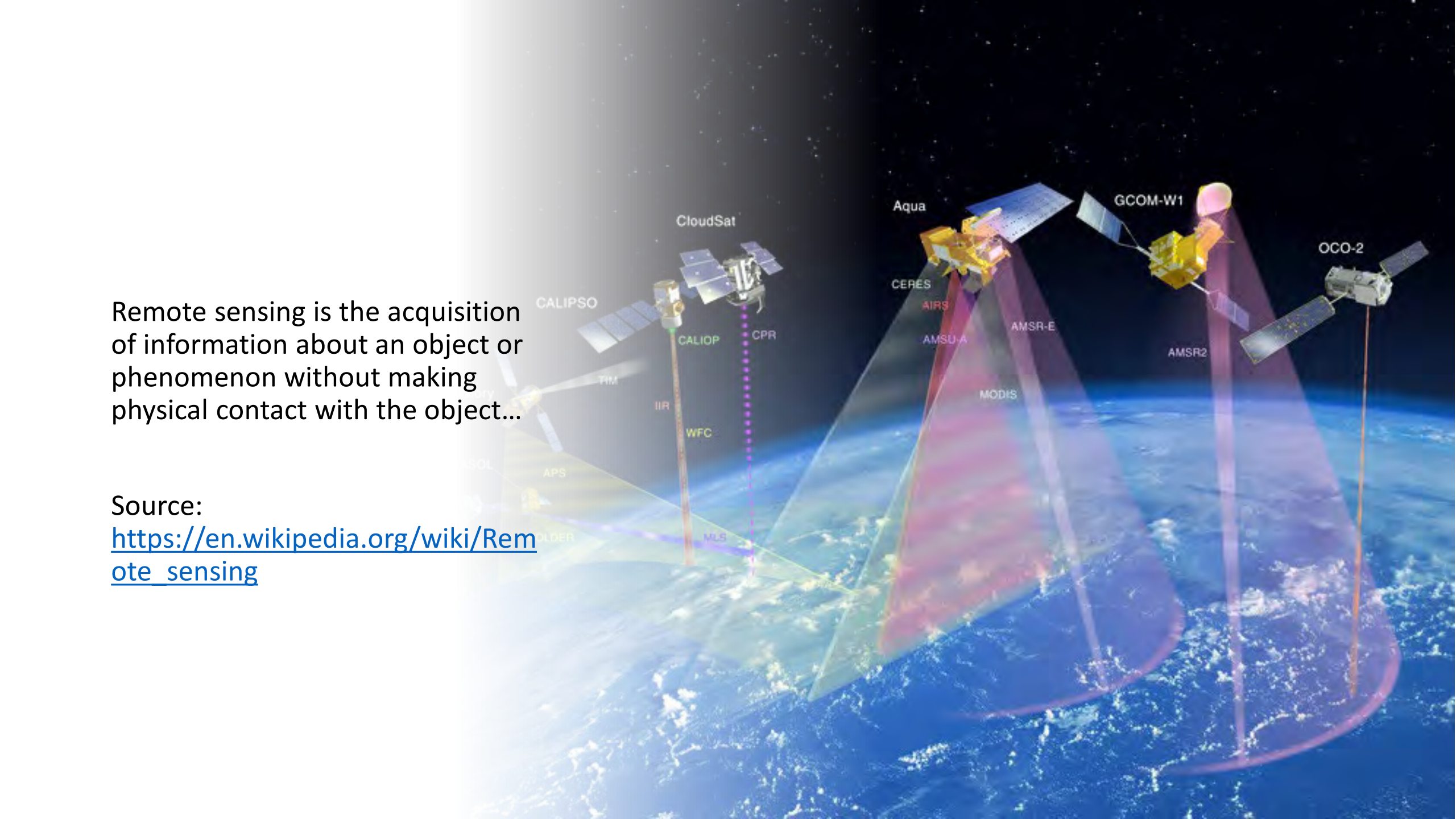
Remote Sensing

Working with Drones and LiDAR

Ralph J. Roulette Jr.

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object…

Source: https://en.wikipedia.org/wiki/Remote_sensing



Topics

- Acronyms
- Coordinate Systems
- Datums & Epochs
- GIS software
- Computer Hardware
- Google Earth
- Canada Lands Survey
- LiDAR
- PPK
- RTK
- Mapping
- Point Clouds
- Drone Safety
- Mission Planning

Purpose

Provide an introduction to:

- GIS software
- GIS terms
- GIS concepts

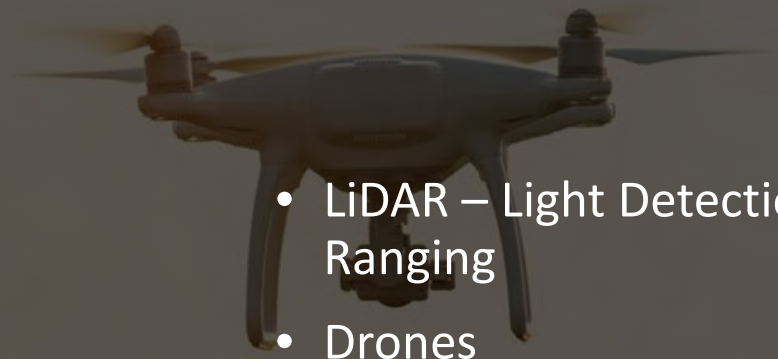
A basic overview of:

- LiDAR
- Point Clouds

For use in:

- Drone Mapping

Acronyms

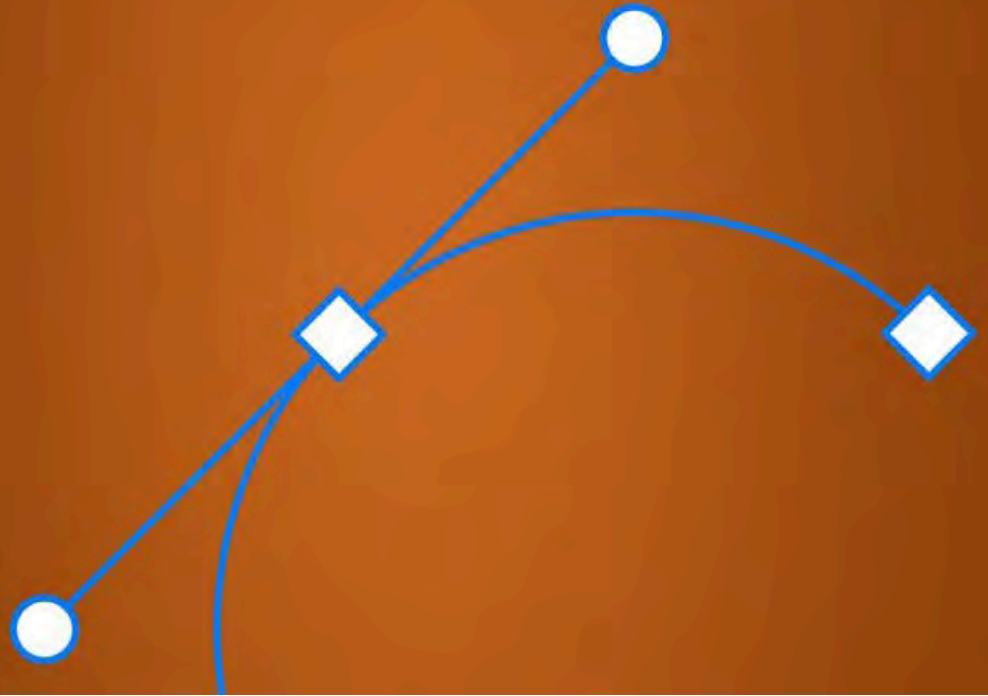


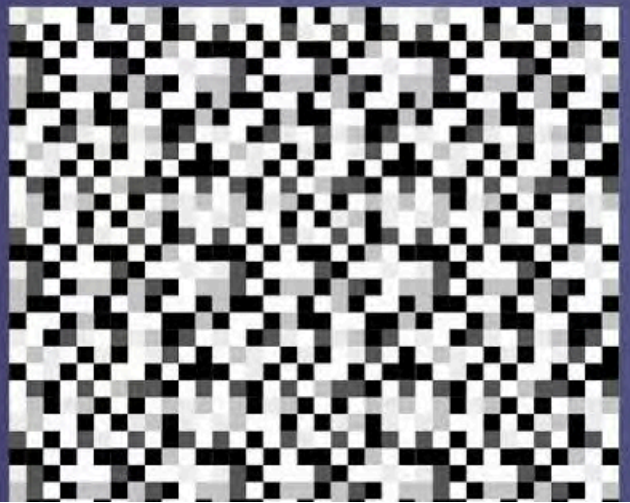
- LiDAR – Light Detection and Ranging
- Drones
  - UAV – Unmanned Aerial Vehicle
  - RPAS – Remote Piloted Aircraft System
  - VTOL – Vertical Take-Off/Landing
- RTK – Real Time Kinematics
- PPK – Post Processed Kinematic
- GSD – Ground Sampling Distance
- GCP – Ground Control Points

Geomatics

Basics

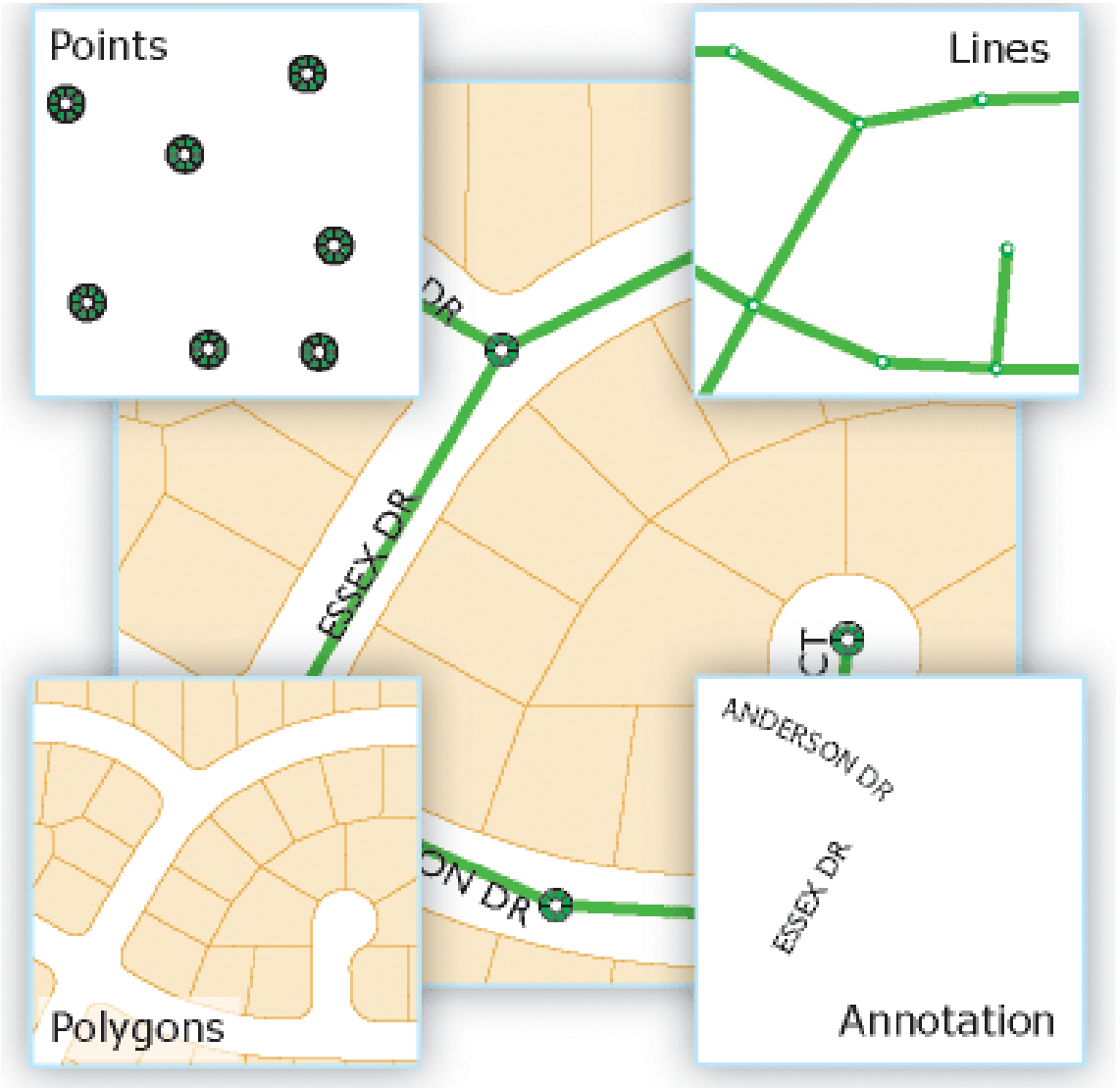
VECTOR vs RASTER



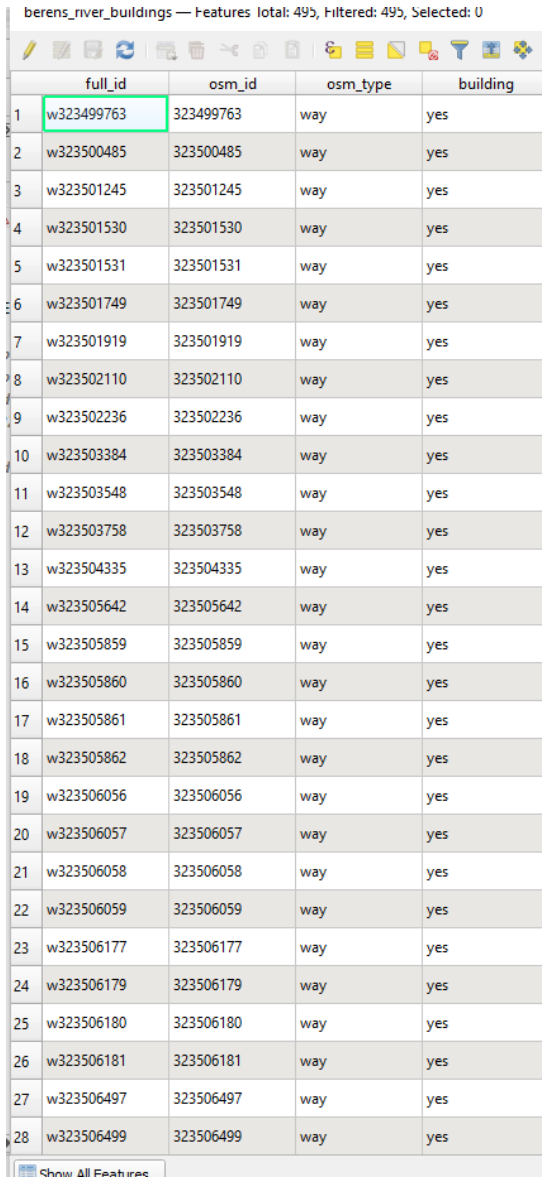


Common GIS File Formats

- Feature Class (Vectors)
  - Commonly referred as “shapefiles”
  - Can be points, lines, or polygons
  - Comprised of 3-5 files (only 3 are needed)
    - *.dbf, *.shx, *.prj, *.cpg, *.shp
- KML or KMZ
  - Key Markup Language/Key Markup Zip
  - Used by Google Earth for points, lines and polygons
  - Most drone mission planning software supports kml/kmz file format.
- WKT
  - Well Known Text

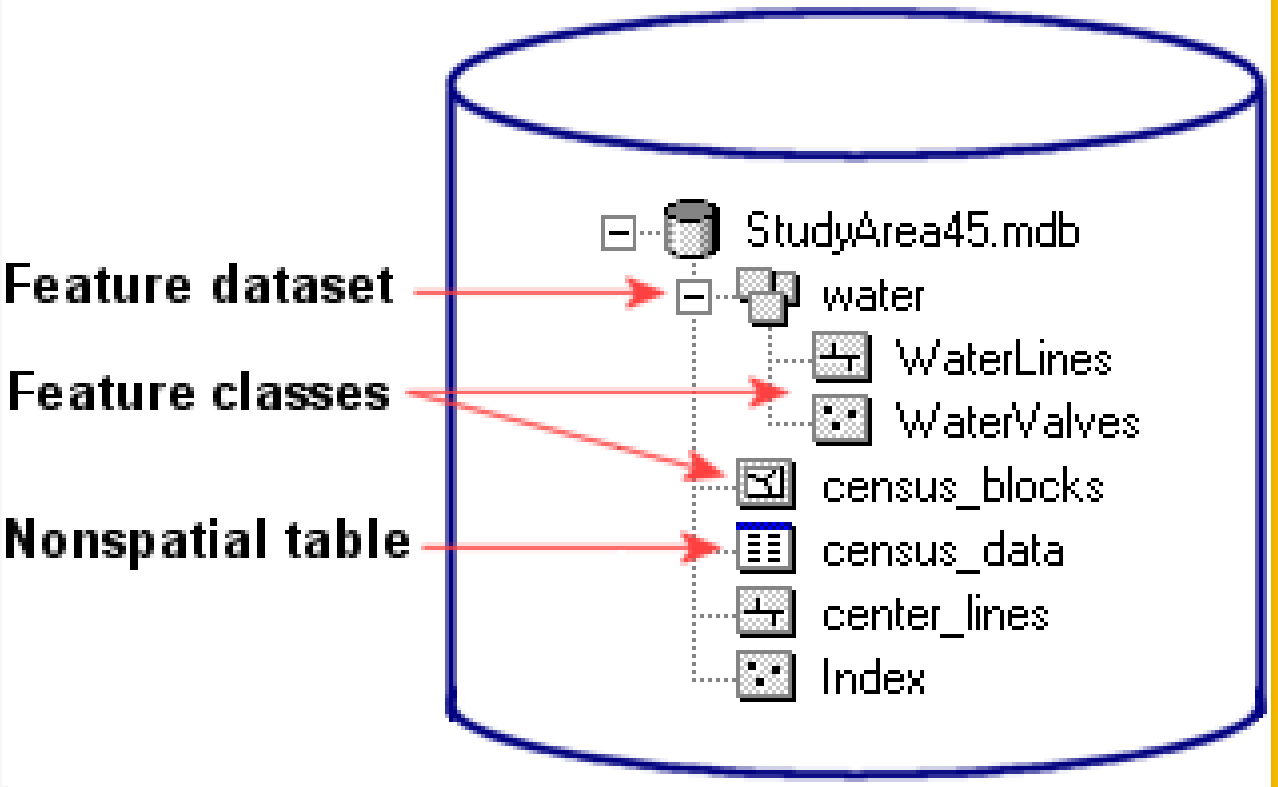


Vectors have attributes



Common GIS File Formats

- Geodatabase
  - ESRI proprietary
  - 1 file
  - Can store spatial and non-spatial data
- Geopackage
  - Opensource
  - QGIS
  - Can store spatial and non-spatial data

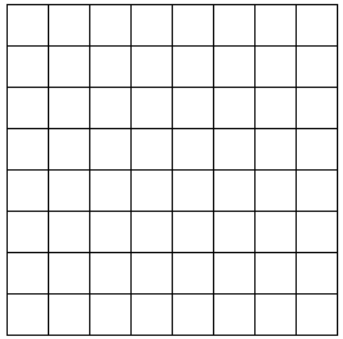


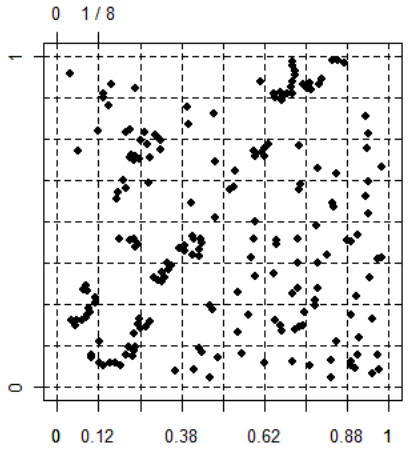
Common GIS File Formats

“In computer graphics and digital photography, a raster graphic represents a two-dimensional picture as a rectangular matrix or grid of square pixels, viewable via a computer display, paper, or other display medium.”

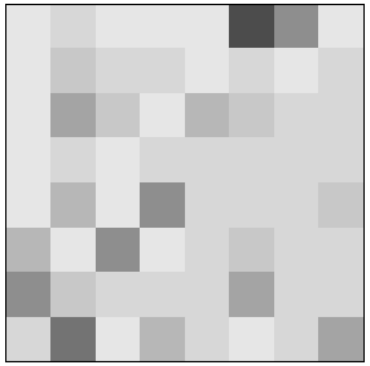
-

https://en.wikipedia.org/wiki/Raster_graphics





1	3	0	0	1	12	8	0
1	4	3	3	0	2	0	2
1	7	4	1	5	4	2	2
0	3	1	2	2	2	2	3
0	5	1	9	3	3	3	4
5	0	8	0	2	4	3	2
8	4	3	2	2	7	2	3
2	10	1	5	2	1	3	7

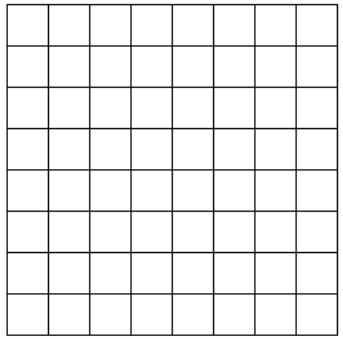


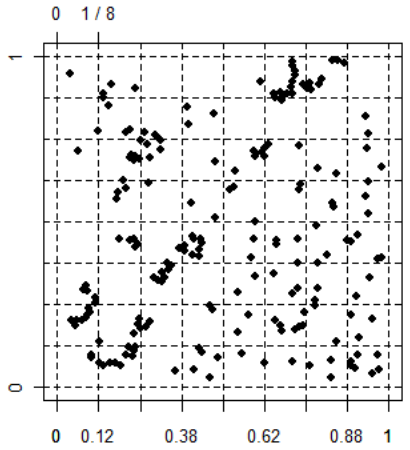
Common GIS File Formats

In GIS software, each pixel represents a spatial component. The height and width represents the raster's resolution.

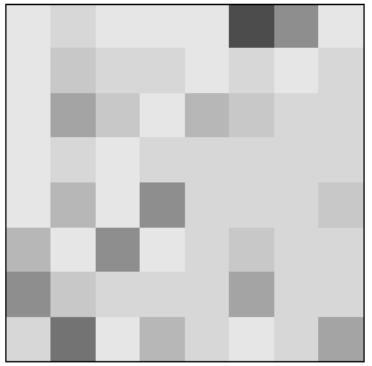
Example: 1x1 metre, 25x25 metre

Can represent elevation, population, tree species or soil type/quality. Anything that has a numerical and spatial component.



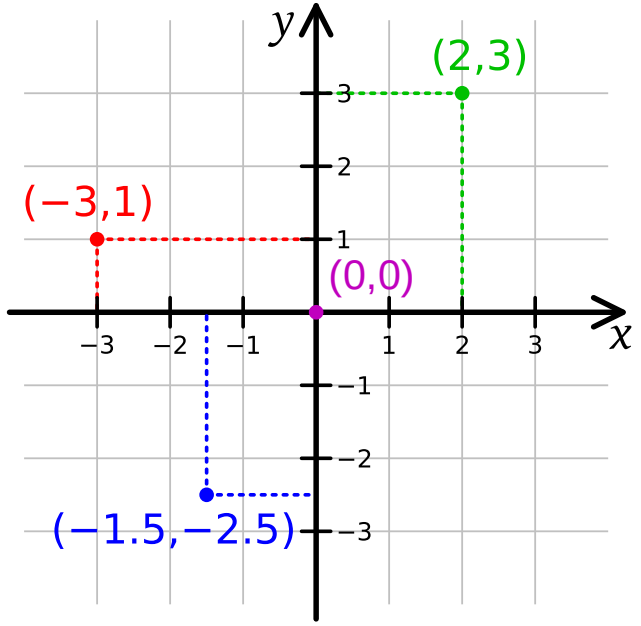


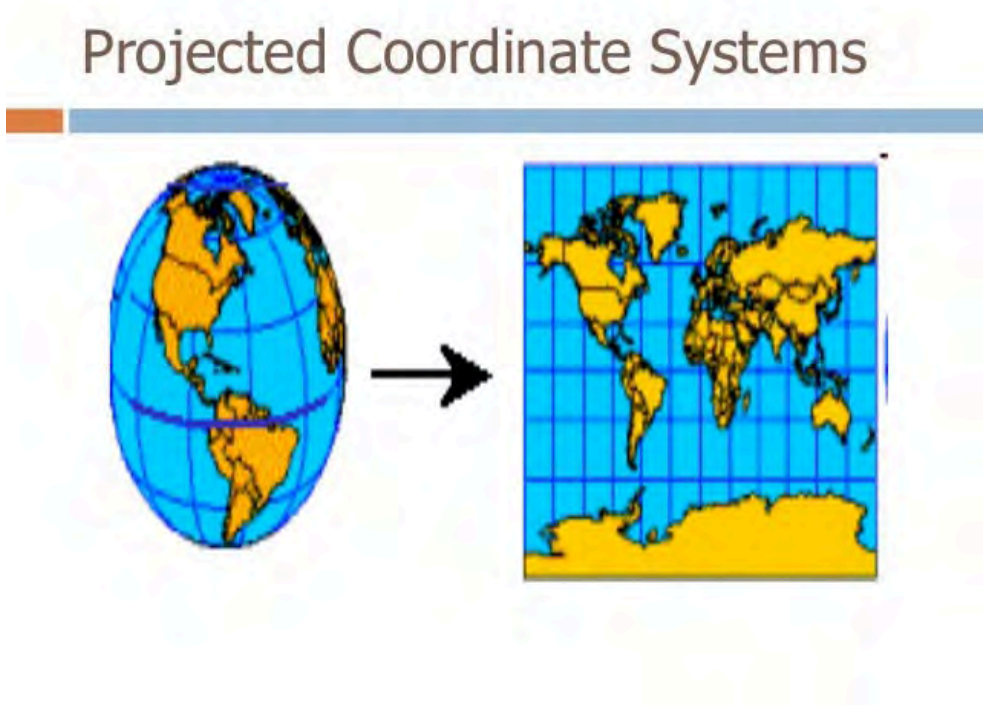
1	3	0	0	1	12	8	0
1	4	3	3	0	2	0	2
1	7	4	1	5	4	2	2
0	3	1	2	2	2	2	3
0	5	1	9	3	3	3	4
5	0	8	0	2	4	3	2
8	4	3	2	2	7	2	3
2	10	1	5	2	1	3	7



https://desktop.arcgis.com/en/arcmap/latest/manage-data/raster-and-images/what-is-raster-data.htm

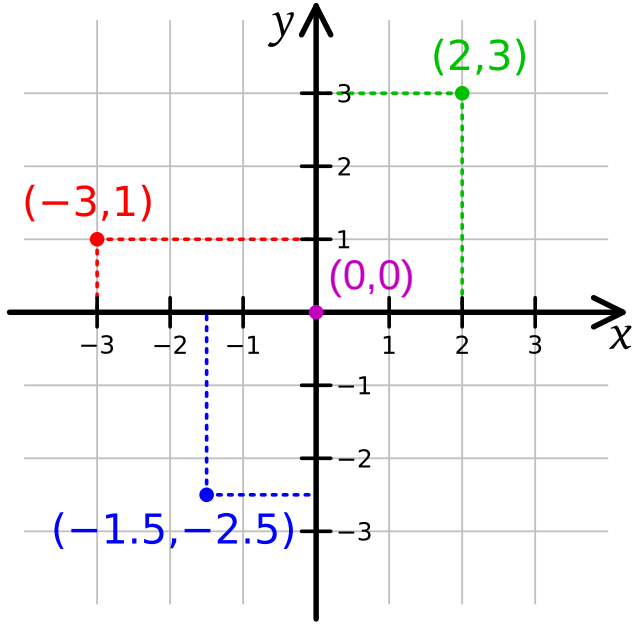
Questions?

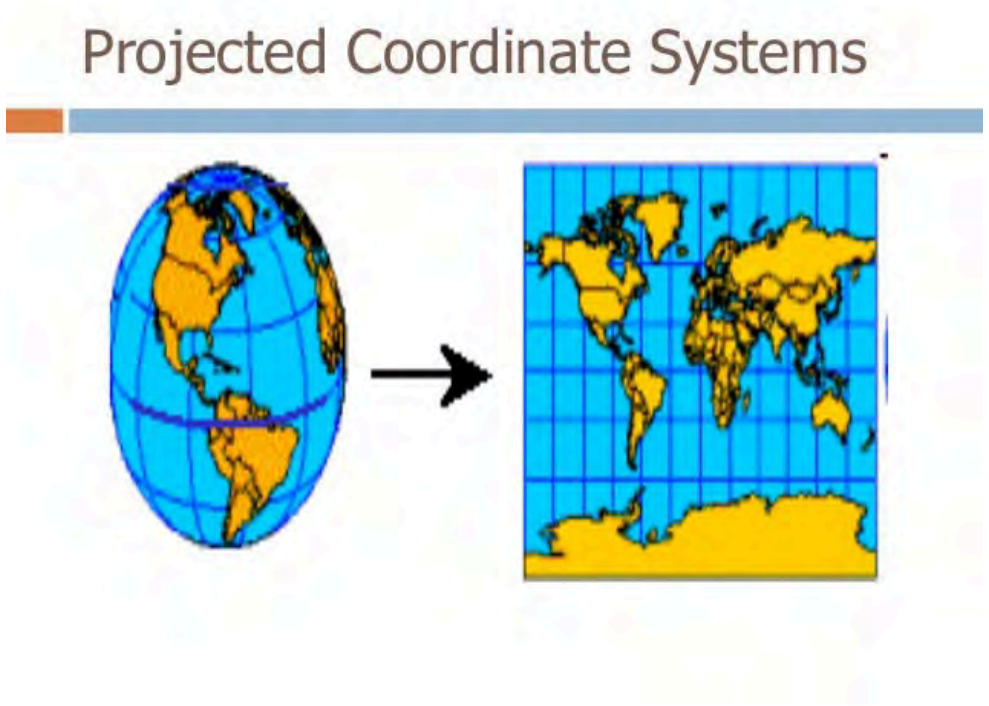




Coordinate Systems

- Cartesian Plane
- Projected Coordinate System (PCS) hint: x,y and z
- Geographic Coordinate System (GCS) hint: latitude and longitude (degrees/minutes/seconds, decimal degrees)



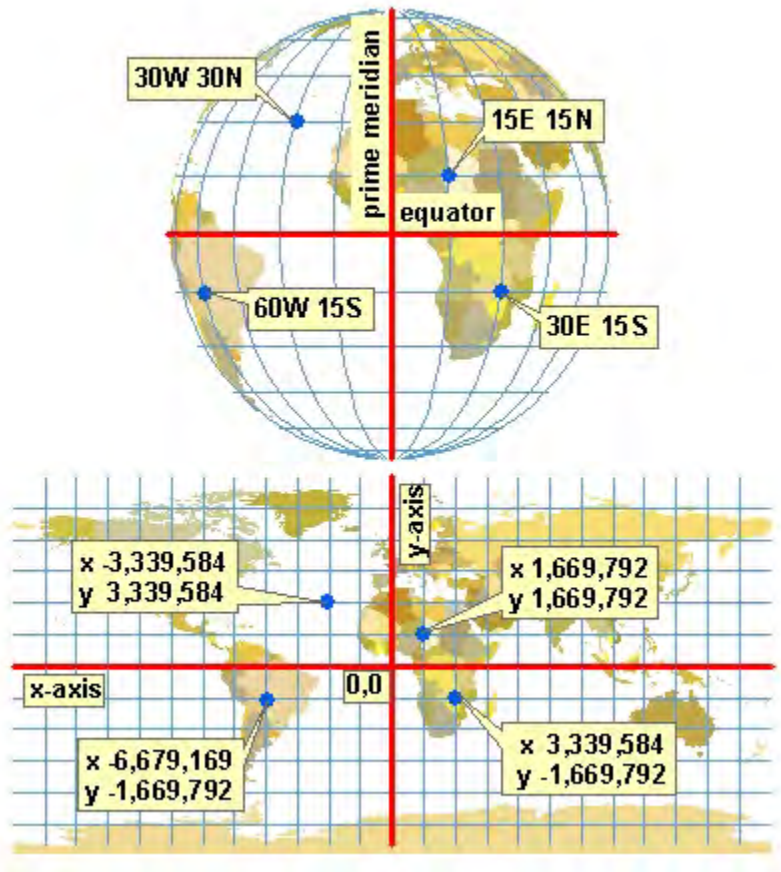


Datums

- A Reference Point
- NAD83 – North American Datum of 1983
- Refers to the North American Tectonic Plate

- A GCS defines where the data is located on the earth's surface.
- A PCS tells the data how to draw on a flat surface, like on a paper map or a computer screen.
- Geographic coordinate systems are based on a spheroid and utilize angular units (degrees).
- Projected coordinate systems are based on a plane (the spheroid projected onto a 2D surface) and utilize linear units (feet, meters, etc.).
- Geographic coordinate systems span the entire globe (e.g. latitude / longitude), while projected coordinate systems are localized to minimize visual distortion in a particular region (e.g. Robinson, UTM, State Plane)

- source: https://www.esri.com/arcgis-blog/products/arcgis-pro/mapping/gcs_vs_pcs/



Geographic coordinate system (3D)

- Coordinates in latitude and longitude
- Example : GCS_WGS_1984 (EPSG 4326)

Projected coordinate system (2D)

- Coordinates in meters or feet
- Example : WGS_1984_World_Mercator (EPSG 3395)

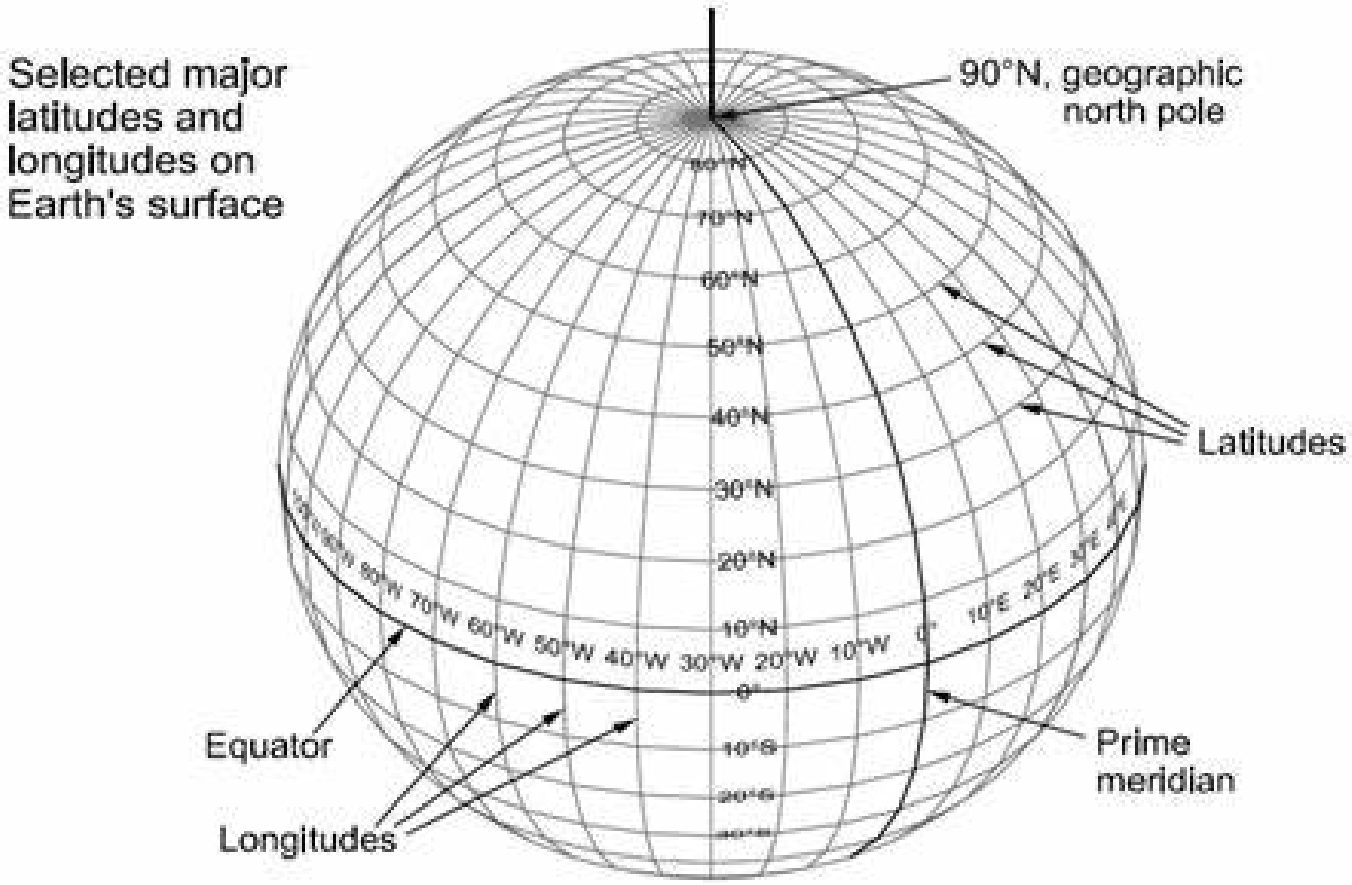
Source: https://gis.stackexchange.com/questions/347771/what-projected-or-geographic-coordinate-system-should-i-use-to-calculate-km-dist

Latitude Longitude

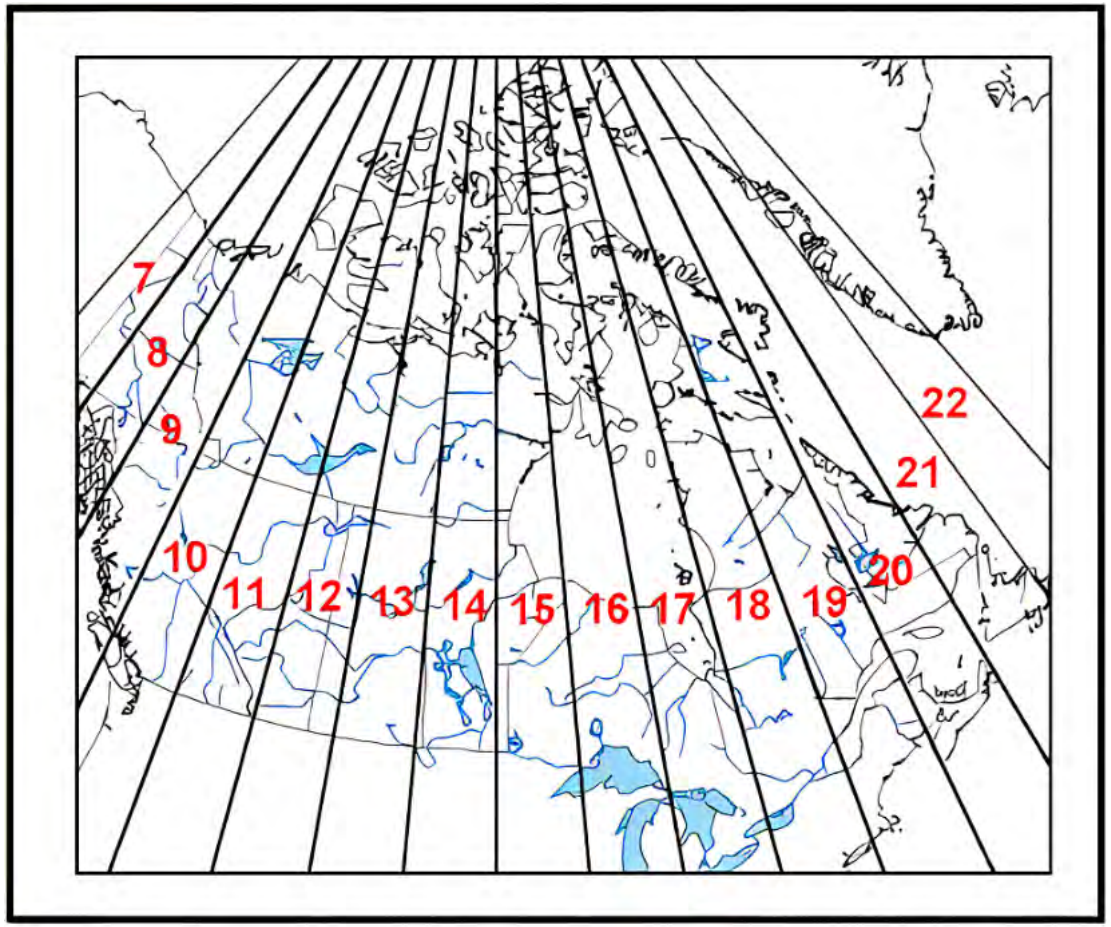
Degrees, minutes, and seconds : 40° 26’ 46” N 79° 58’ 56” W

Degrees and decimal minutes: 40° 26.767’ N 79° 58.933’ W

Decimal degrees: +40.446 -79.982



UTM Zones - Canada



Canada's Epochs

NAD83(CSRS) adopted epochs for Canada's provincial geodetic agencies	
Province	**Epoch**
British Columbia (Mainland)	2002
British Columbia (Vancouver Island)	1997
Alberta	2002
Saskatchewan	1997
Manitoba	2010
Ontario	2010
Quebec	1997
New Brunswick	1997
Prince Edward Island	2010
Nova Scotia	2010
Newfoundland and Labrador	2010
Nunavut	2010
Northwest Territories	2010
Yukon	2002

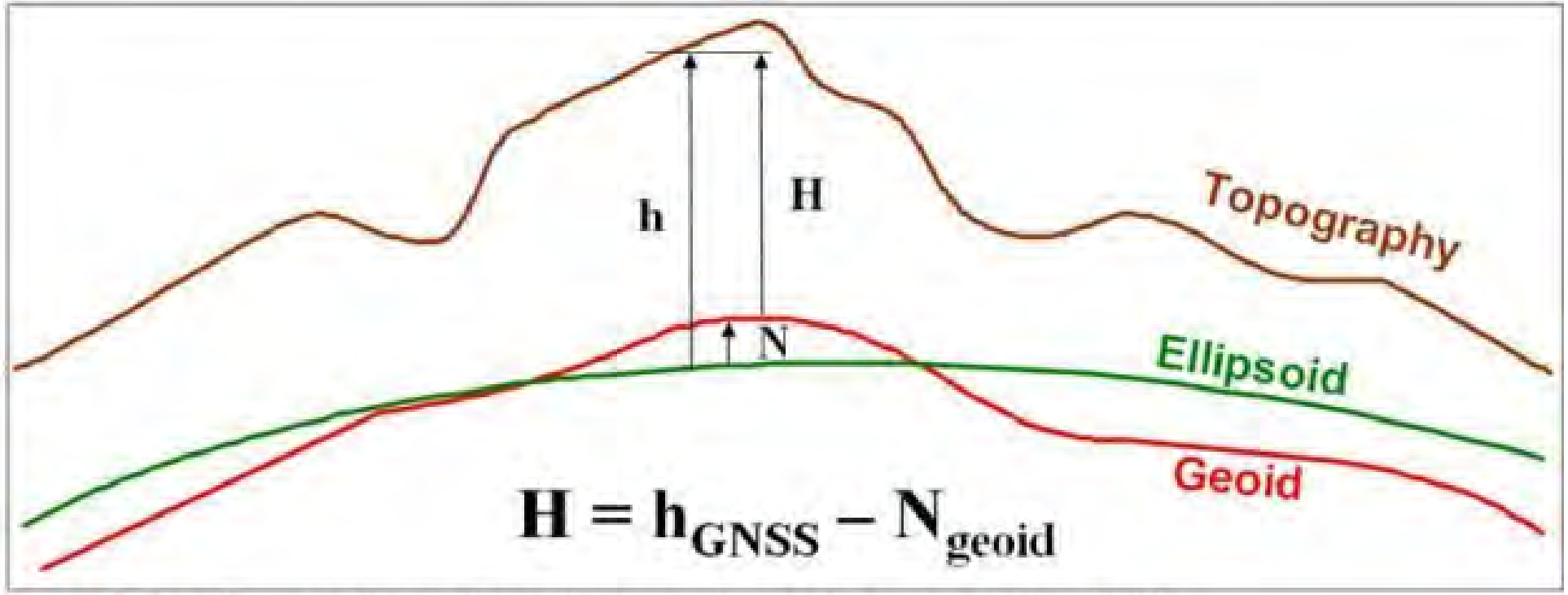


Figure 1: The ellipsoidal height (h), orthometric height (H) and geoid height (N)

Orthometric height (H), often referred as Mean Sea Level Height, can be obtained by subtracting the geoid height (N) from the GNSS ellipsoidal height (h): H = h – N. A geoid height (N) is positive (+) when the geoid is above the ellipsoid and negative (-) when it is below.

Questions?

Geomatics

Software

QGIS

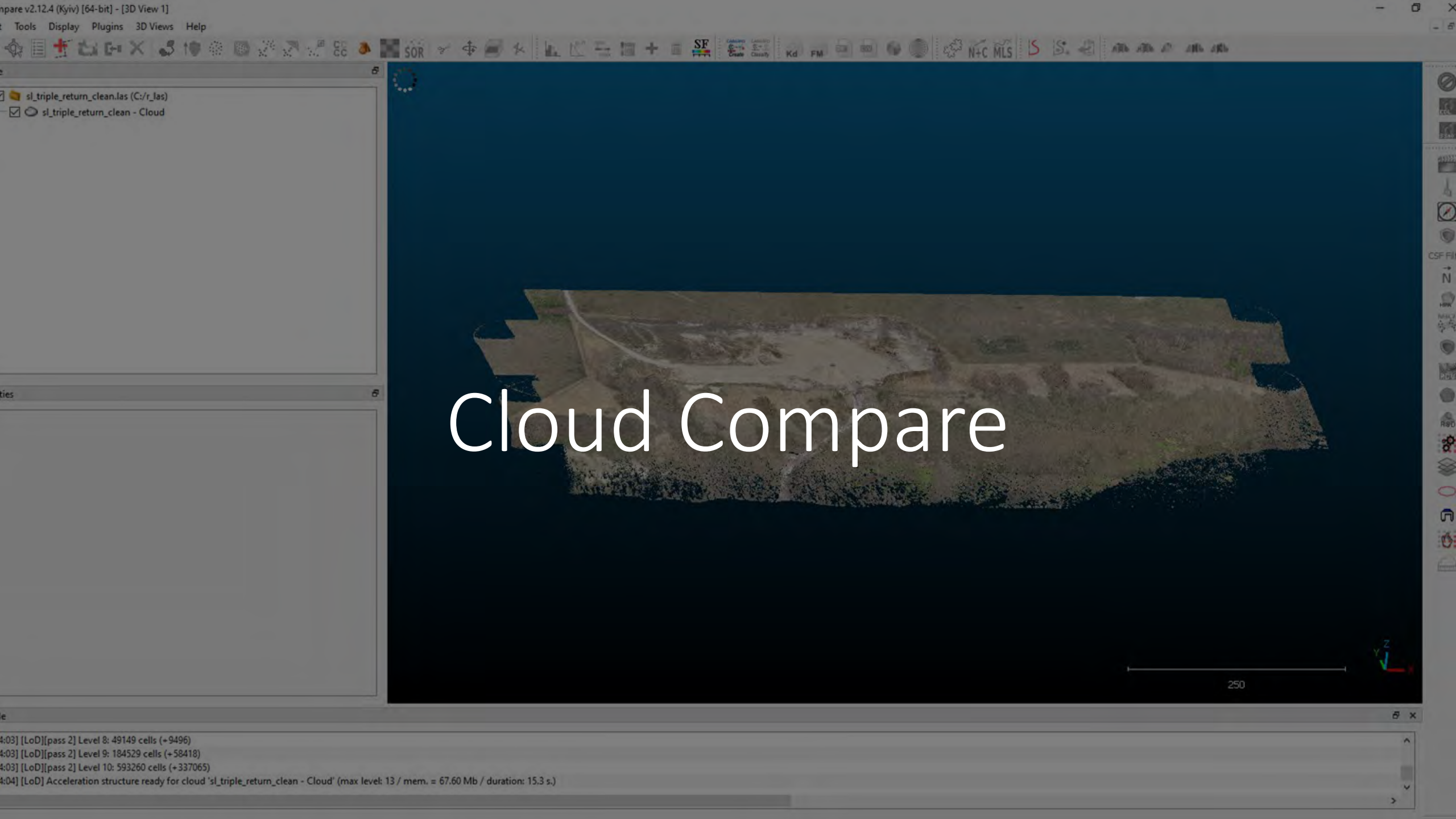
Software Download Links

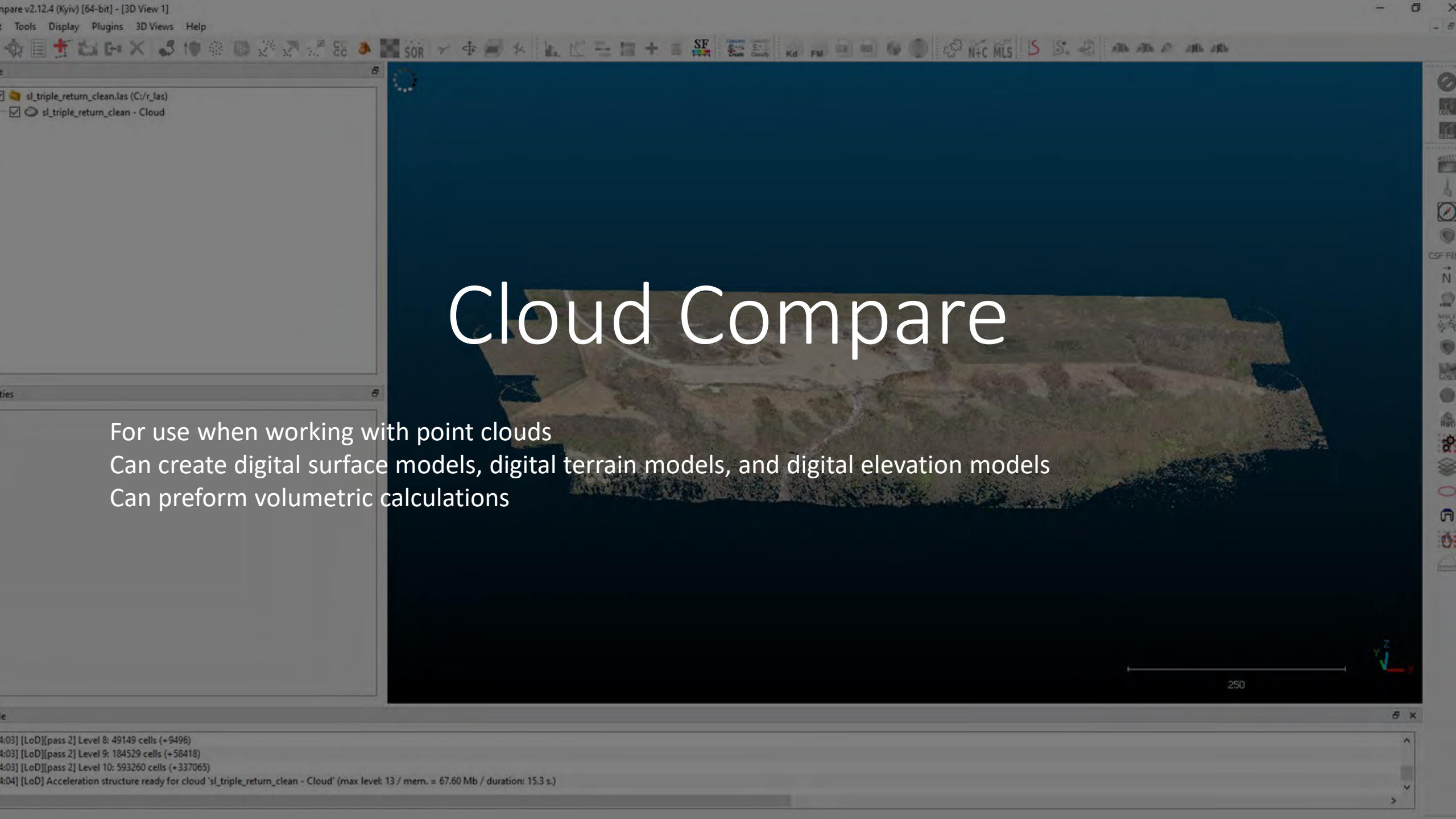
- R Studio
https://posit.co/download/rstudio-desktop/

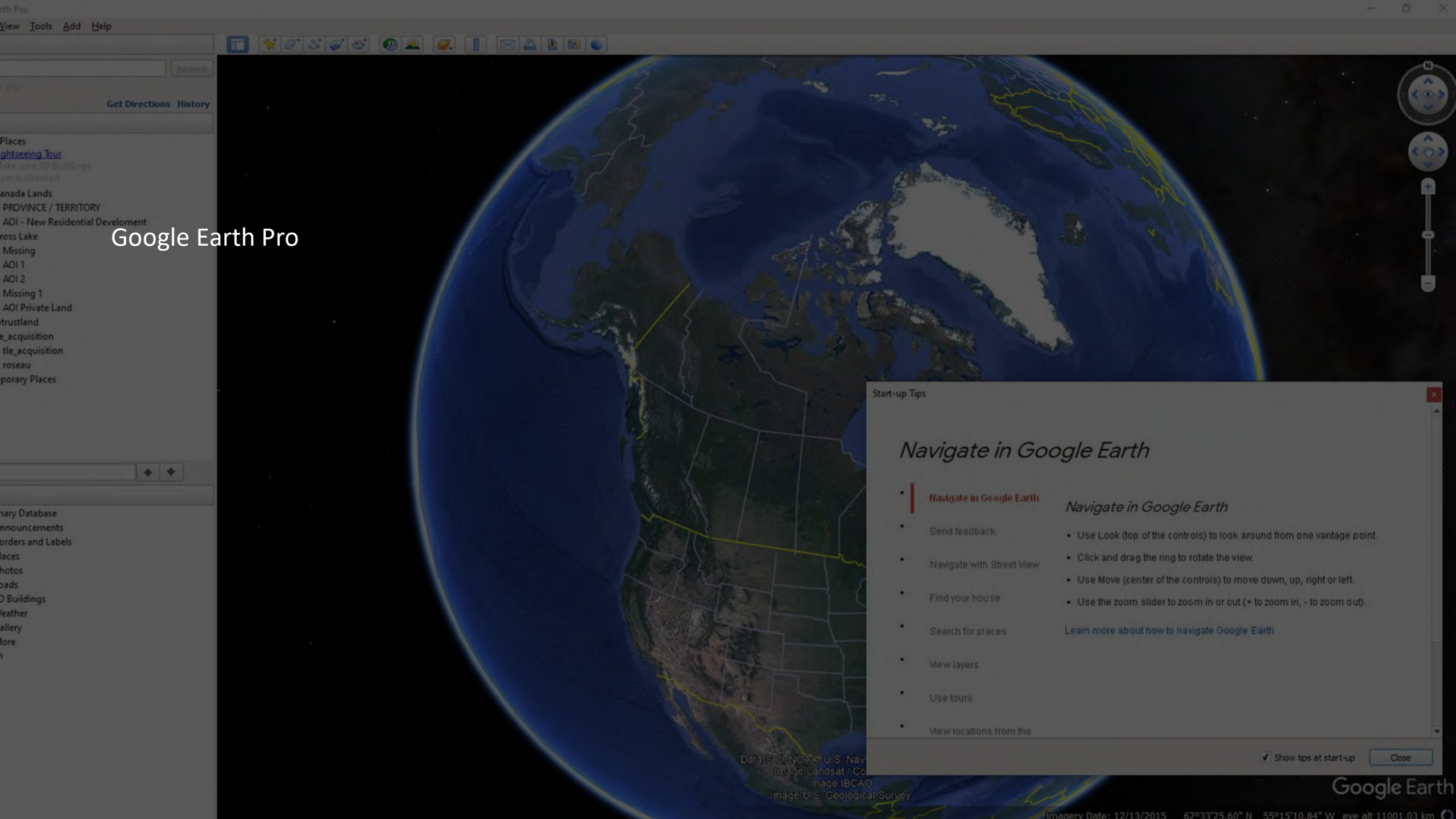
- Cloud Compare
https://www.cloudcompare.org/release/index.html

- QGIS
https://www.qgis.org/en/site/forusers/download.html

- Google Earth Pro
https://www.google.com/earth/versions/#download-pro


Cloud Compare
Tools
Display
Plugins
3D Views
Help
sl_triple_return_clean.las (C:/r_las)
sl_triple_return_clean - Cloud
250
4:03] [LoD][pass 2] Level 8: 49149 cells (+9496)
4:03] [LoD][pass 2] Level 9: 184529 cells (+58418)
4:03] [LoD][pass 2] Level 10: 593260 cells (+337065)
4:04] [LoD] Acceleration structure ready for cloud 'sl_triple_return_clean - Cloud' (max level: 13 / mem. = 67.60 Mb / duration: 15.3 s.)


Cloud Compare
For use when working with point clouds
Can create digital surface models, digital terrain models, and digital elevation models
Can preform volumetric calculations
Tools
Display
Plugins
3D Views
Help
sl_triple_return_clean.las (C:/r_las)
sl_triple_return_clean - Cloud
250
4:03] [LoD][pass 2] Level 8: 49149 cells (+9496)
4:03] [LoD][pass 2] Level 9: 184529 cells (+58418)
4:03] [LoD][pass 2] Level 10: 593260 cells (+337065)
4:04] [LoD] Acceleration structure ready for cloud 'sl_triple_return_clean - Cloud' (max level: 13 / mem. = 67.60 Mb / duration: 15.3 s.)


Google Earth Pro
View Tools Add Help
Search
Get Directions History
Places
Sightseeing Tour
PROVINCE / TERRITORY
AOI - New Residential Development
AOI 1
AOI 2
Missing 1
AOI Private Land
Start-up Tips
Navigate in Google Earth
Navigate in Google Earth
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Navigate with Street View
Find your house
Search for places
View layers
Use tours
View locations from the
Use Look (top of the controls) to look around from one vantage point.
Click and drag the ring to rotate the view.
Use Move (center of the controls) to move down, up, right or left.
Use the zoom slider to zoom in or out (+ to zoom in, - to zoom out).
Learn more about how to navigate Google Earth
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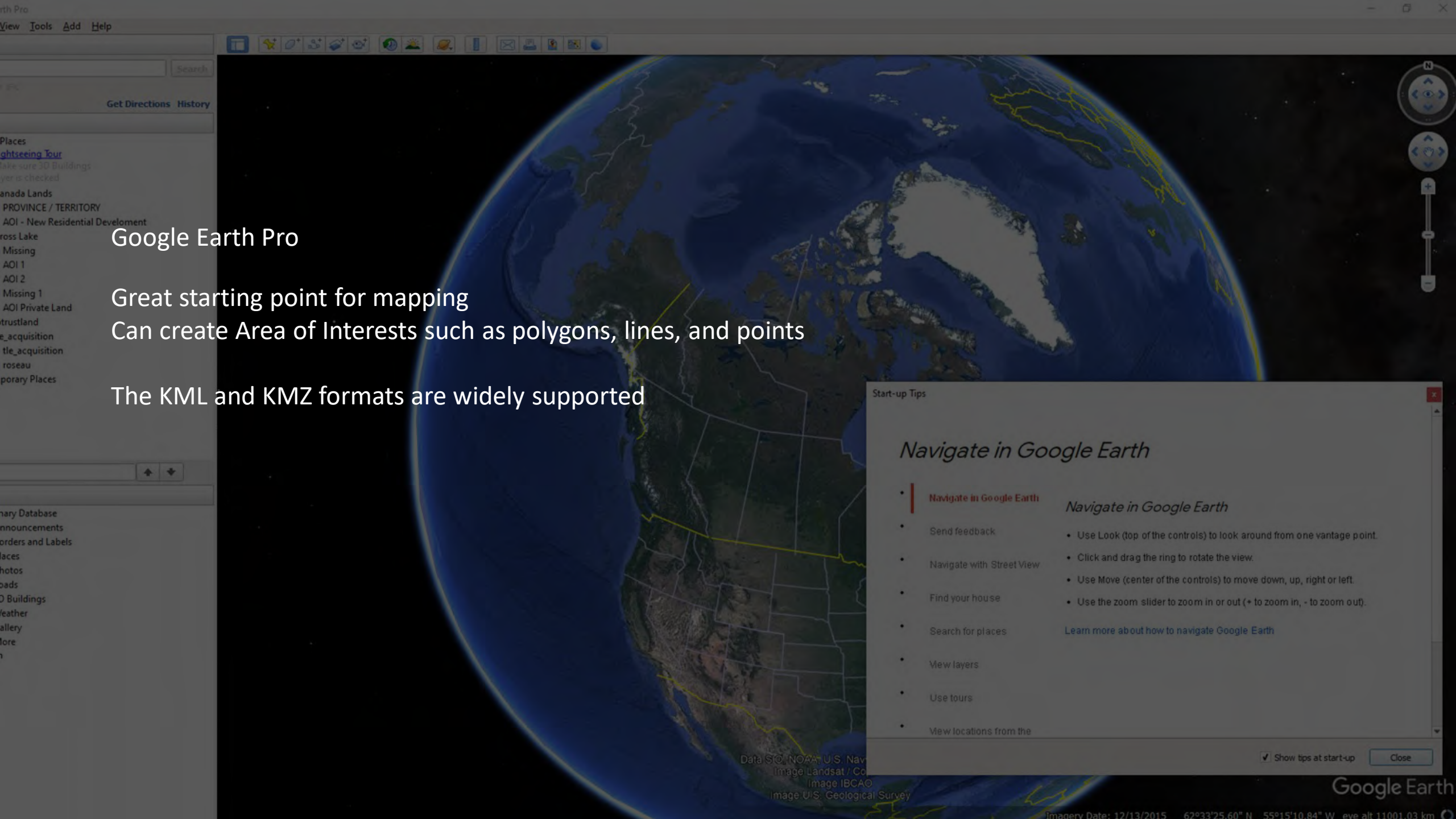
Image IBCAO
Image U.S. Geological Survey
Google Earth


Google Earth Pro
Great starting point for mapping
Can create Area of Interests such as polygons, lines, and points
The KML and KMZ formats are widely supported
Start-up Tips
Navigate in Google Earth
Navigate in Google Earth
Send feedback
Navigate with Street View
Find your house
Search for places
View layers
Use tours
View locations from the
Navigate in Google Earth
Use Look (top of the controls) to look around from one vantage point.
Click and drag the ring to rotate the view.
Use Move (center of the controls) to move down, up, right or left.
Use the zoom slider to zoom in or out (+ to zoom in, - to zoom out).
Learn more about how to navigate Google Earth
Show tips at start-up
Close
Google Earth

R-Studio

RStudio

File Edit Code View Plots Session Build Debug Profile Tools Help

Go to file/function · Addins

sl_quarry.Rmd | 20230212 Population Statistics by Treat... | statistics example.R | Population Statistics by Treaty.Rmd

Knit on Save · Knit · Run

Source Visual · Outline

Package cowplot required but is not installed. Install Don't Show Again

```
1  ---
2  title: "Treaty Population Stats"
3  author: "Ralph"
4  date: "2023-02-12"
5  output: html_document
6  ---
7
8
9
10 This script is meant to compare the First Nation populations by Treaty to non-aboriginal populations.
11
12 ```{r}
13 library(sf)
14 library(sp)
15 library(ggplot2)
16 library(dplyr)
17 library(cancensus)
18 library(cowplot)
19 options(scipen = 999)
20 #options(cancensus.cache_path = "CensusMapper_8725e1e58aed3f776a4c9860cf3cd09a"))
21 #options(cancensus.cache_path = "C:/Users/Ralph/OneDrive - Manitoba USKE/Documents - Manitoba
   USKE/Geomatics/demographic/cache") # home computer
22 #options(cancensus.cache_path = "C:/Users/user/OneDrive - Manitoba USKE/Documents - Manitoba
   USKE/Geomatics/demographic/cache") # work computer
23
24 ```
25
26 ```{r}
27 #rm(list = ls())
28 #setwd("C:/Users/Ralph/OneDrive - Manitoba USKE/Documents - Manitoba USKE/Geomatics/demographic") # home computer
29
30 #setwd("C:/Users/user/OneDrive - Manitoba USKE/Documents - Manitoba USKE/Geomatics/demographic")
31
32 ```
33
34 ```{r}
35 census.data.csd.sf <- get_census(dataset='CA21', regions=list(PR="46"),
36                          vectors=c("v_CA21_4210"), level='CSD', geo_format = "sf")
37 ```
38
39
40 ## Select columns
41
```

1:1 · Treaty Population Stats · R Markdown

Console Terminal Background Jobs

R 4.2.3 · ~/

```
R version 4.2.3 (2023-03-15 ucrt) -- "Shortstop Beagle"
Copyright (C) 2023 The R Foundation for Statistical Computing
Platform: x86_64-w64-mingw32/x64 (64-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
```

Environment History Connections Tutorial

Import Dataset · 144 MiB

R · Global Environment

Environment is empty

Files Plots Packages Help Viewer Presentation

whitebox Tool Metadata · Find in Topic

whitebox Tool Metadata

whitebox Tool Metadata

This vignette provides an introduction to the data sets included in the `whitebox` package. These data sets contain names, arguments and other metadata for tools available in WhiteboxTools.

What version of WhiteboxTools are these data sets generated from?

- Current version: **2.3.0**

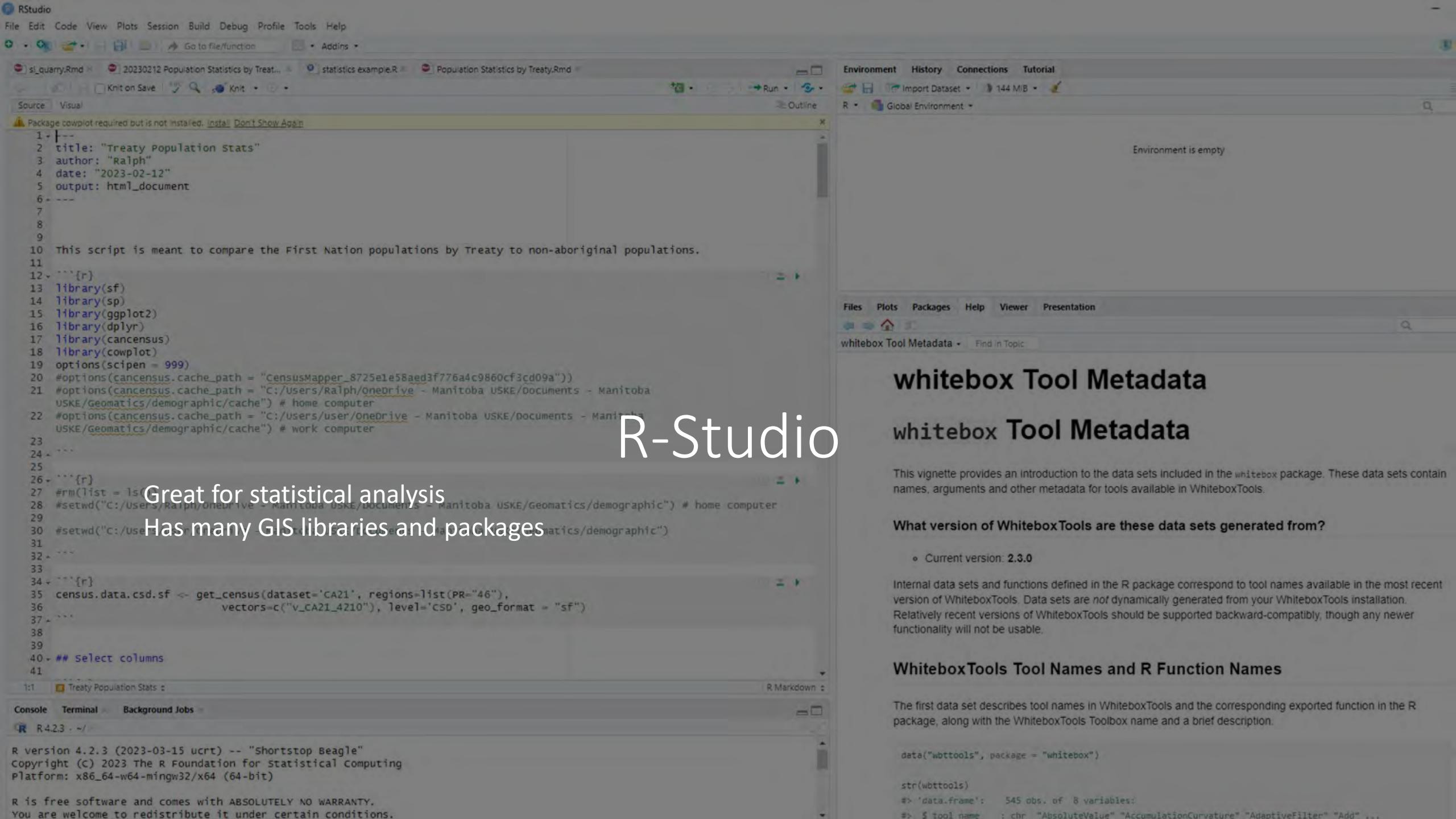
Internal data sets and functions defined in the R package correspond to tool names available in the most recent version of WhiteboxTools. Data sets are *not* dynamically generated from your WhiteboxTools installation. Relatively recent versions of WhiteboxTools should be supported backward-compatibly, though any newer functionality will not be usable.

WhiteboxTools Tool Names and R Function Names

The first data set describes tool names in WhiteboxTools and the corresponding exported function in the R package, along with the WhiteboxTools Toolbox name and a brief description.

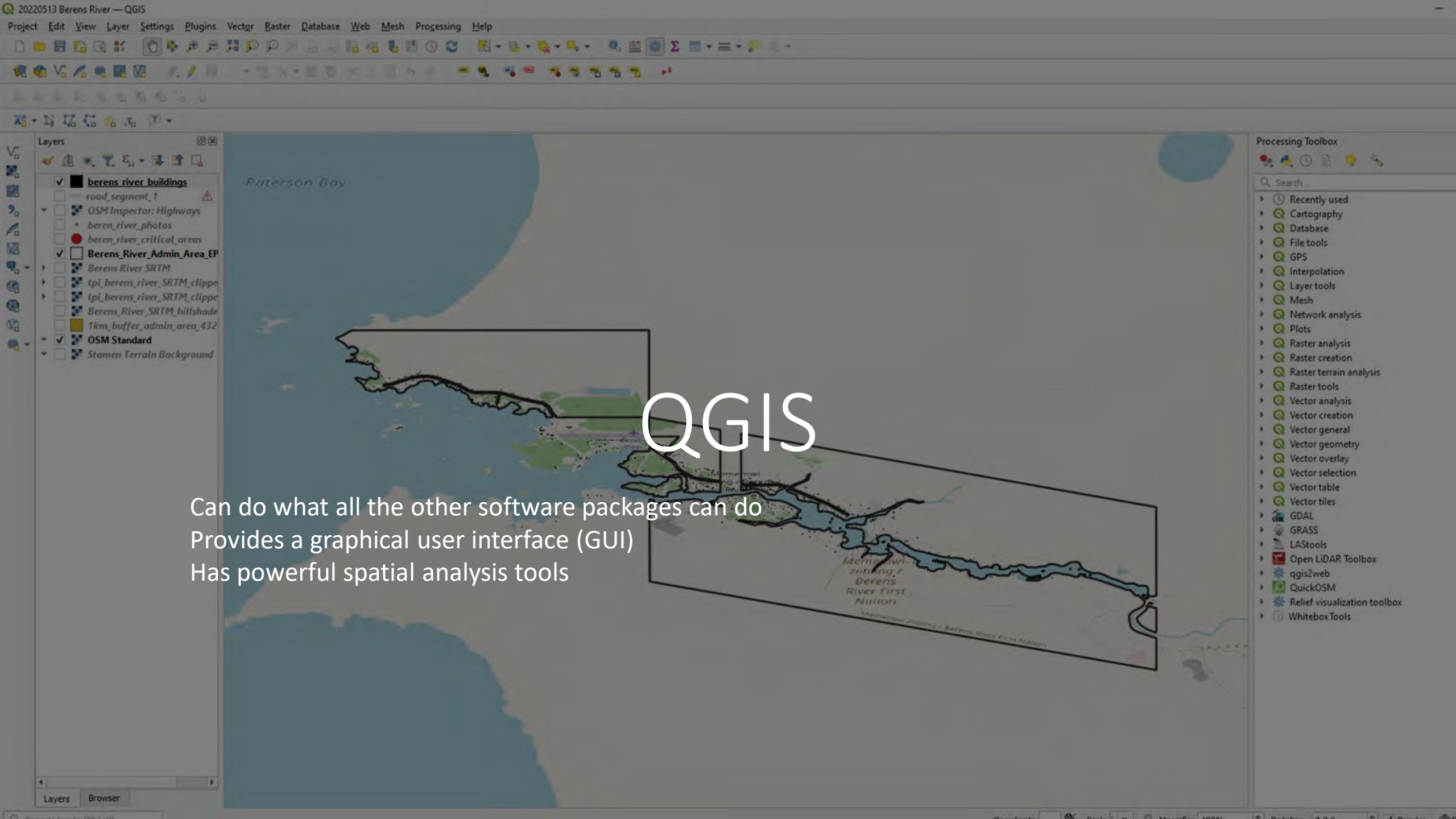
```
data("wbttools", package = "whitebox")

str(wbttools)
#> 'data.frame':    545 obs. of  8 variables:
#>  $ tool_name    : chr  "AbsoluteValue" "AccumulationCurvature" "AdaptiveFilter" "Add" ...
```



R-Studio

Great for statistical analysis
Has many GIS libraries and packages



QGIS

Can do what all the other software packages can do
Provides a graphical user interface (GUI)
Has powerful spatial analysis tools

Computer Hardware Considerations

Minimum Requirements

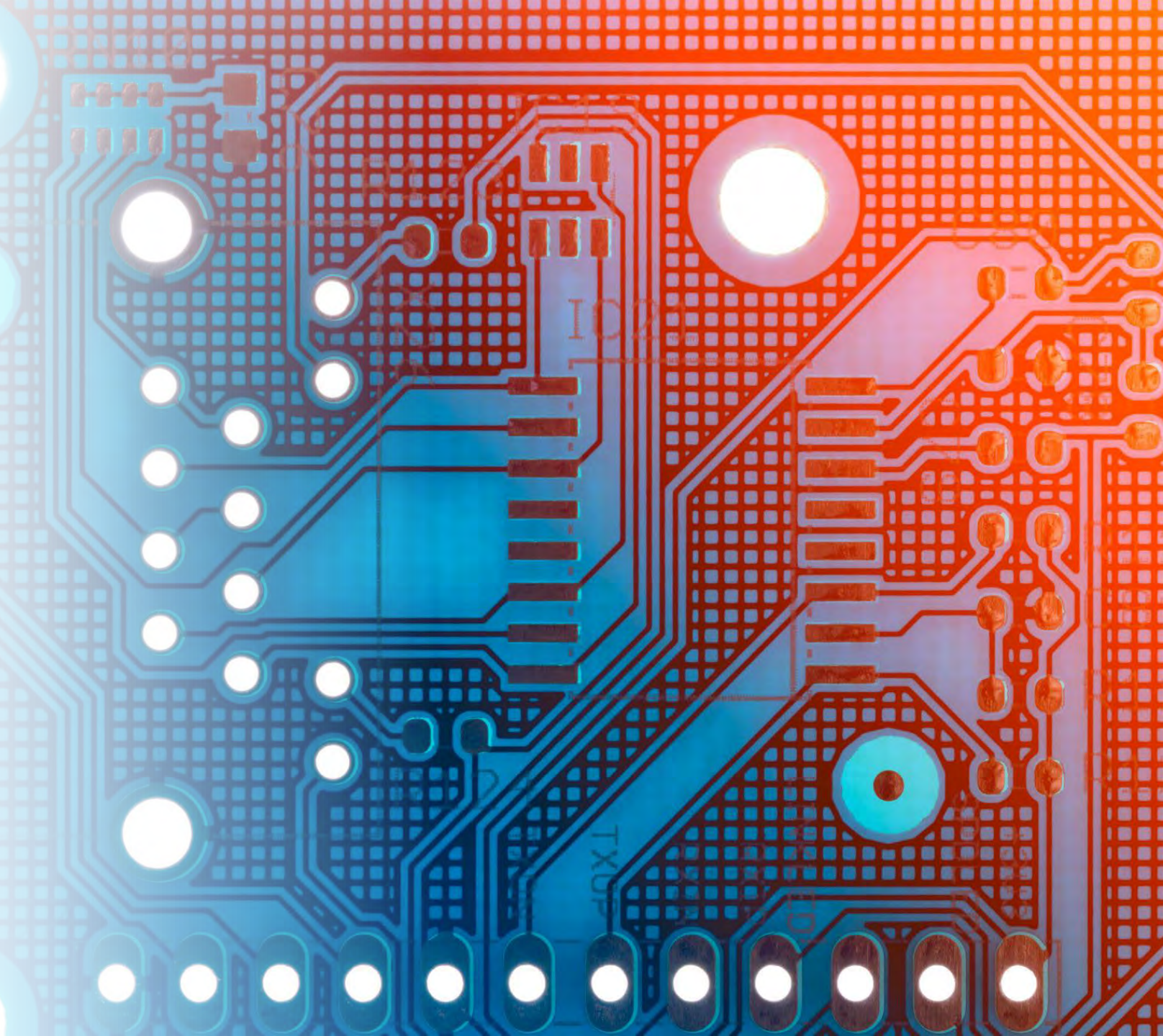
Fast and easy recommendation

Best gaming computer you can afford

- i7 (or equivalent) or better
- 16 GB RAM (32 GB for point clouds)
- 500 GB SSD
- 1 TB HDD

Creating Orthomosaics

- nVidia Graphics Card (RTX)



Questions?

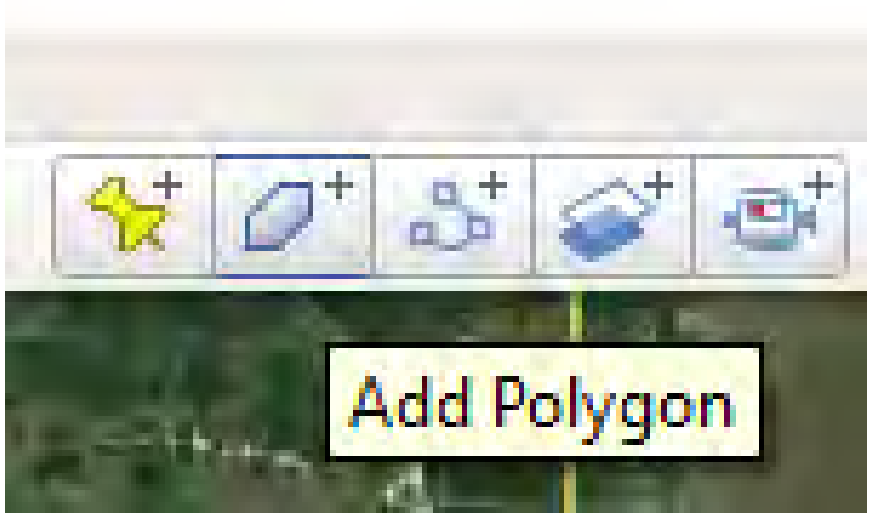
Geomatics

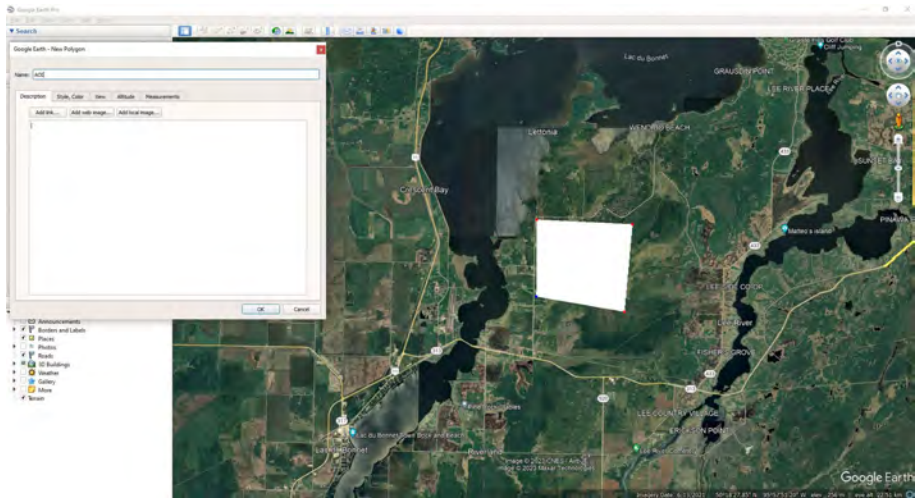
Google Earth Pro

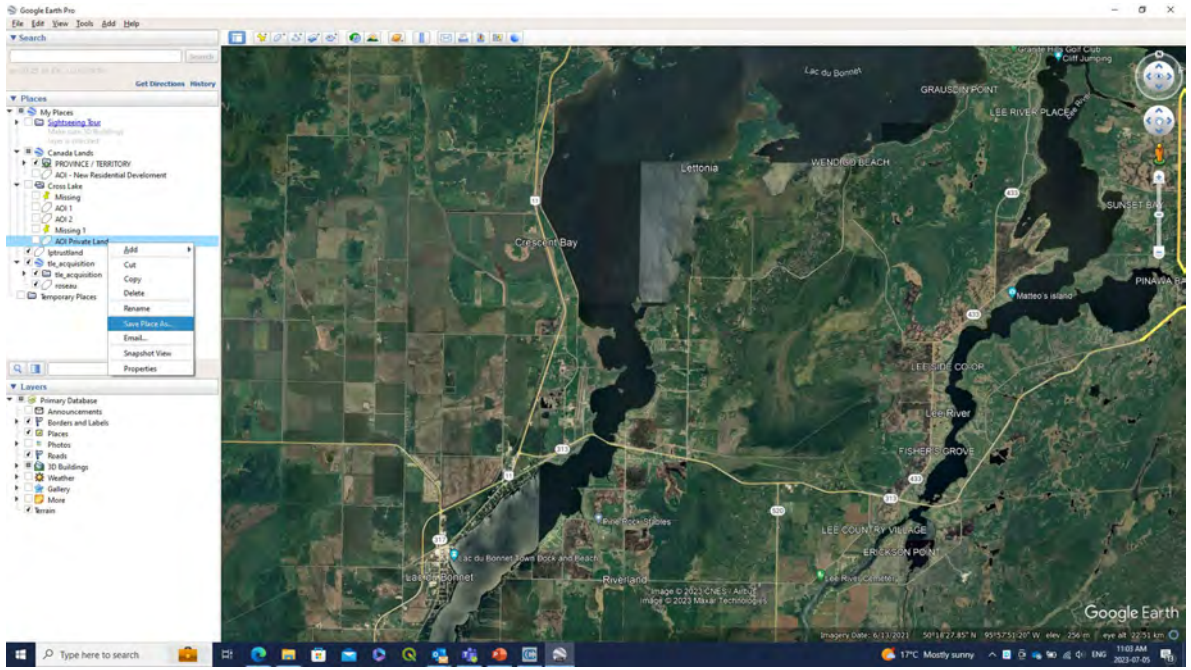
Google Earth Pro

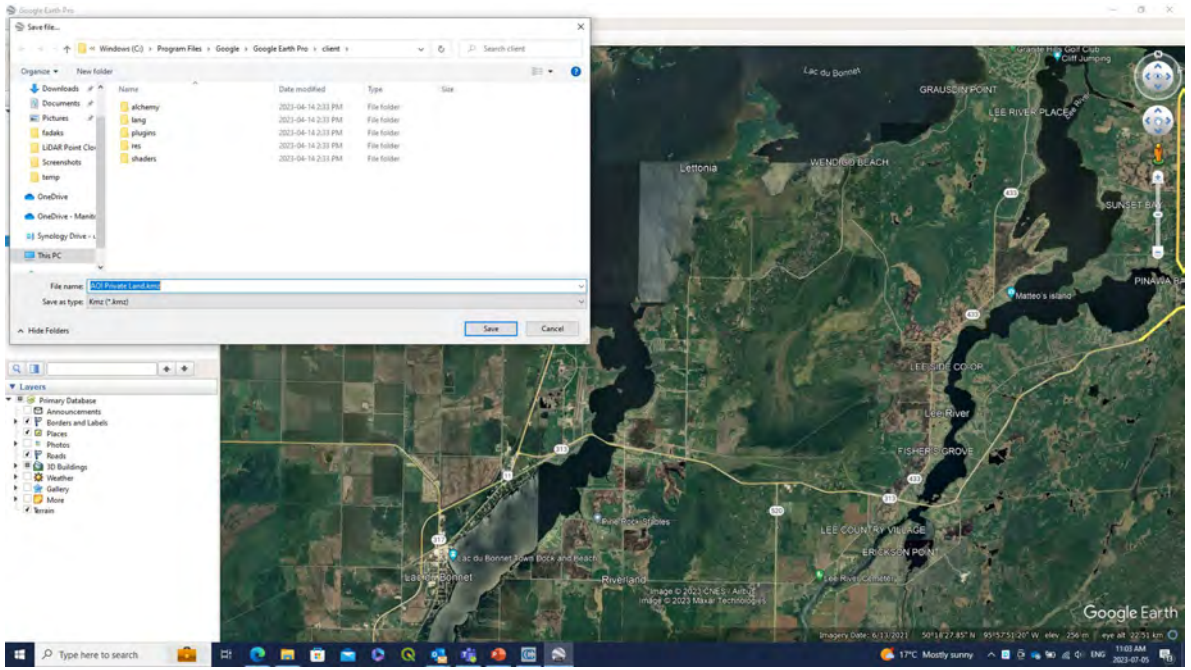
https://www.google.com/earth/versions/#download-pro

Creating Polygons using Google Earth









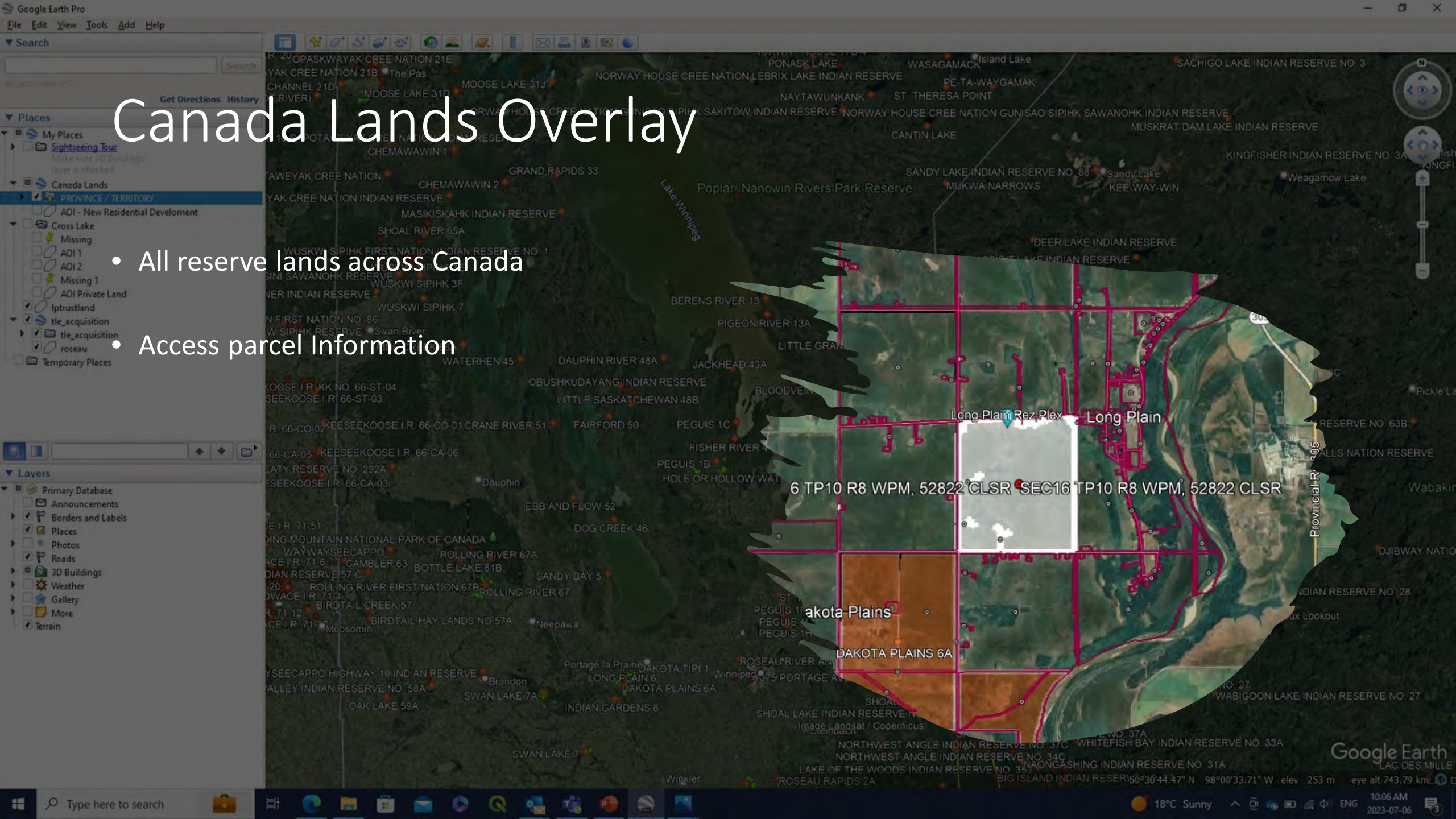
Exporting kml/kmz

Google Earth Pro – Canada Lands Overlay

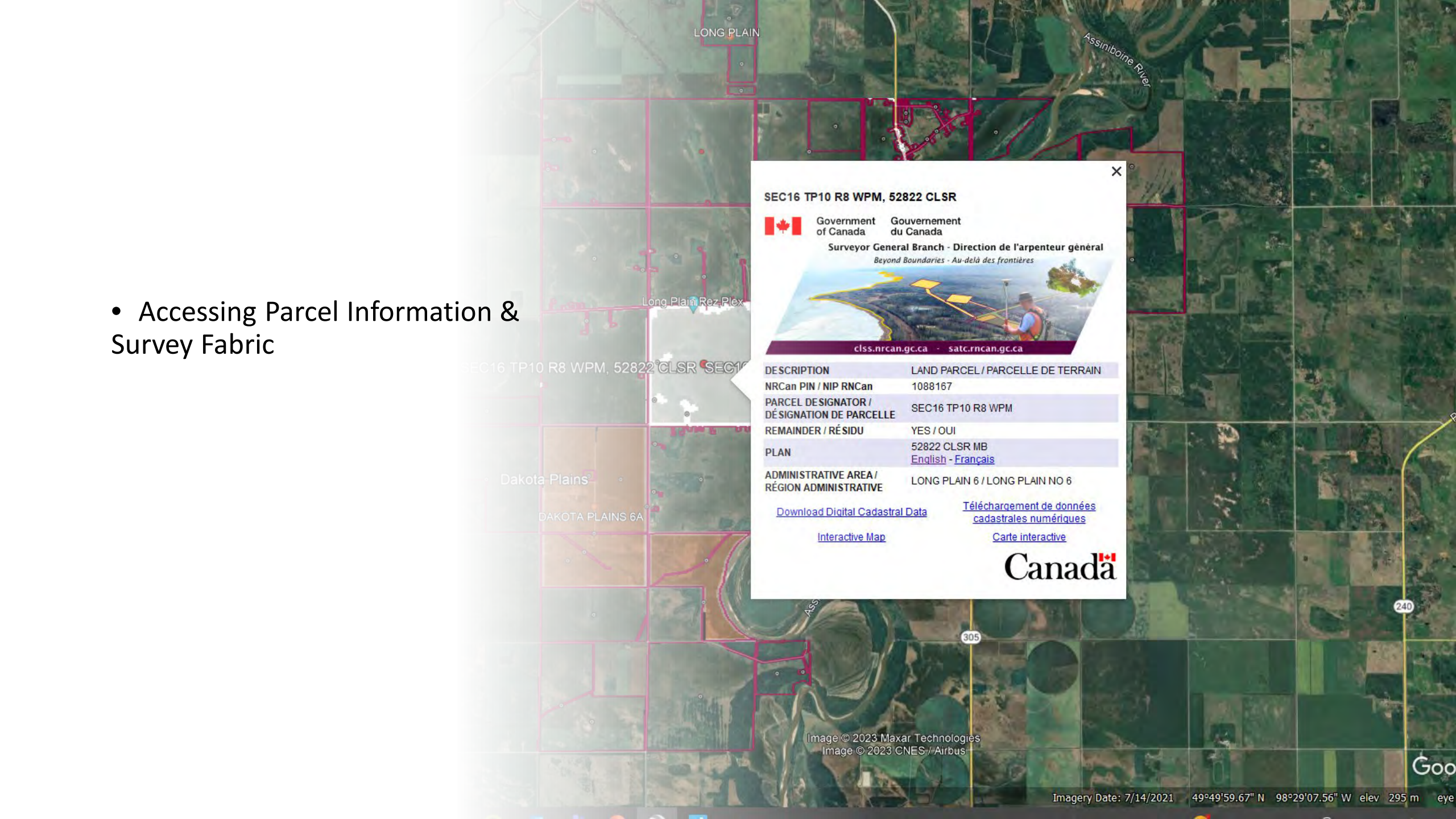
https://natural-resources.canada.ca/maps-tools-and-publications/maps/canada-lands-surveys/tools-applications-canada-lands-surveys/11094

Canada Lands Overlay

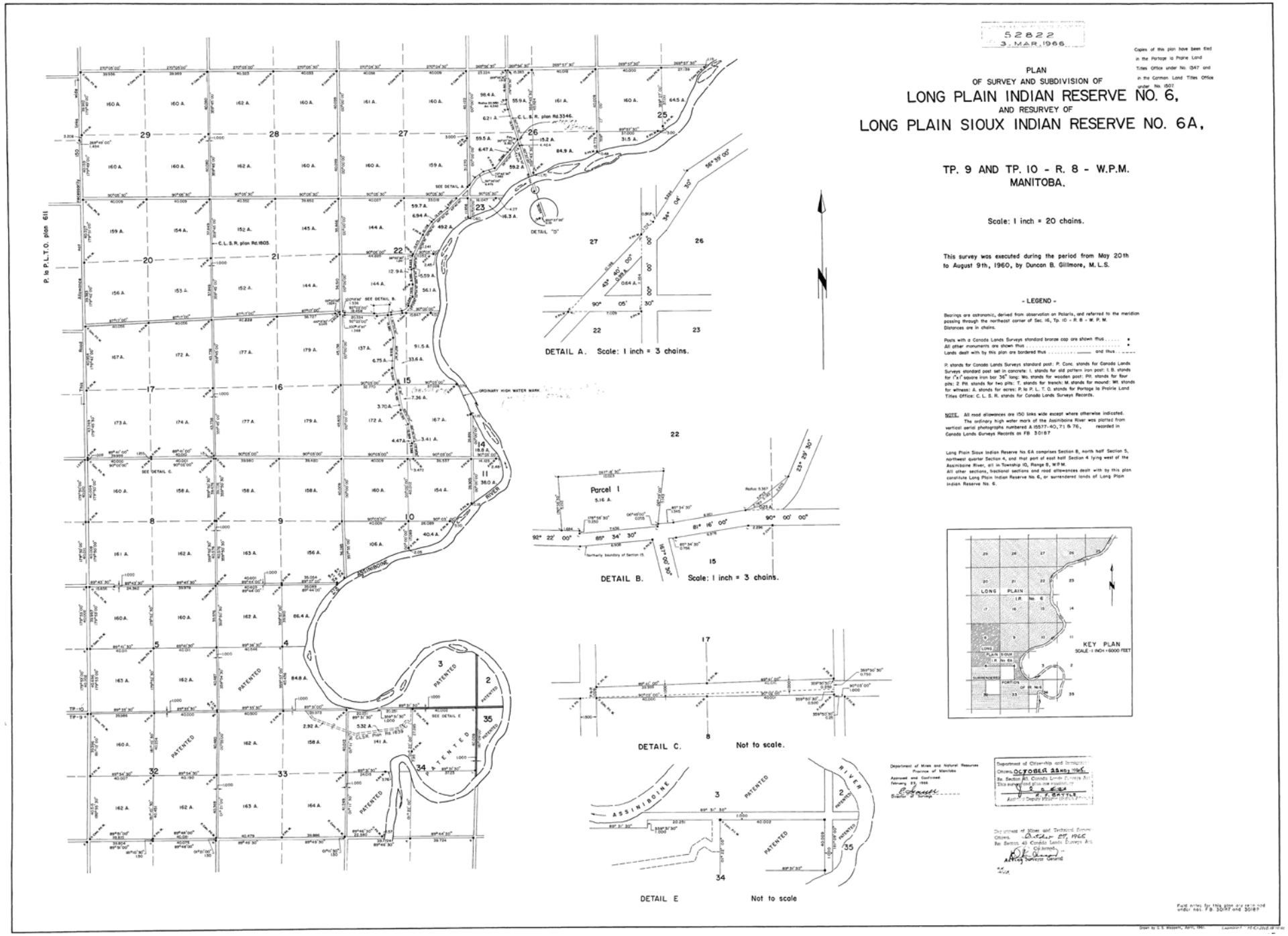
- All reserve lands across Canada
- Access parcel Information



- Accessing Parcel Information & Survey Fabric



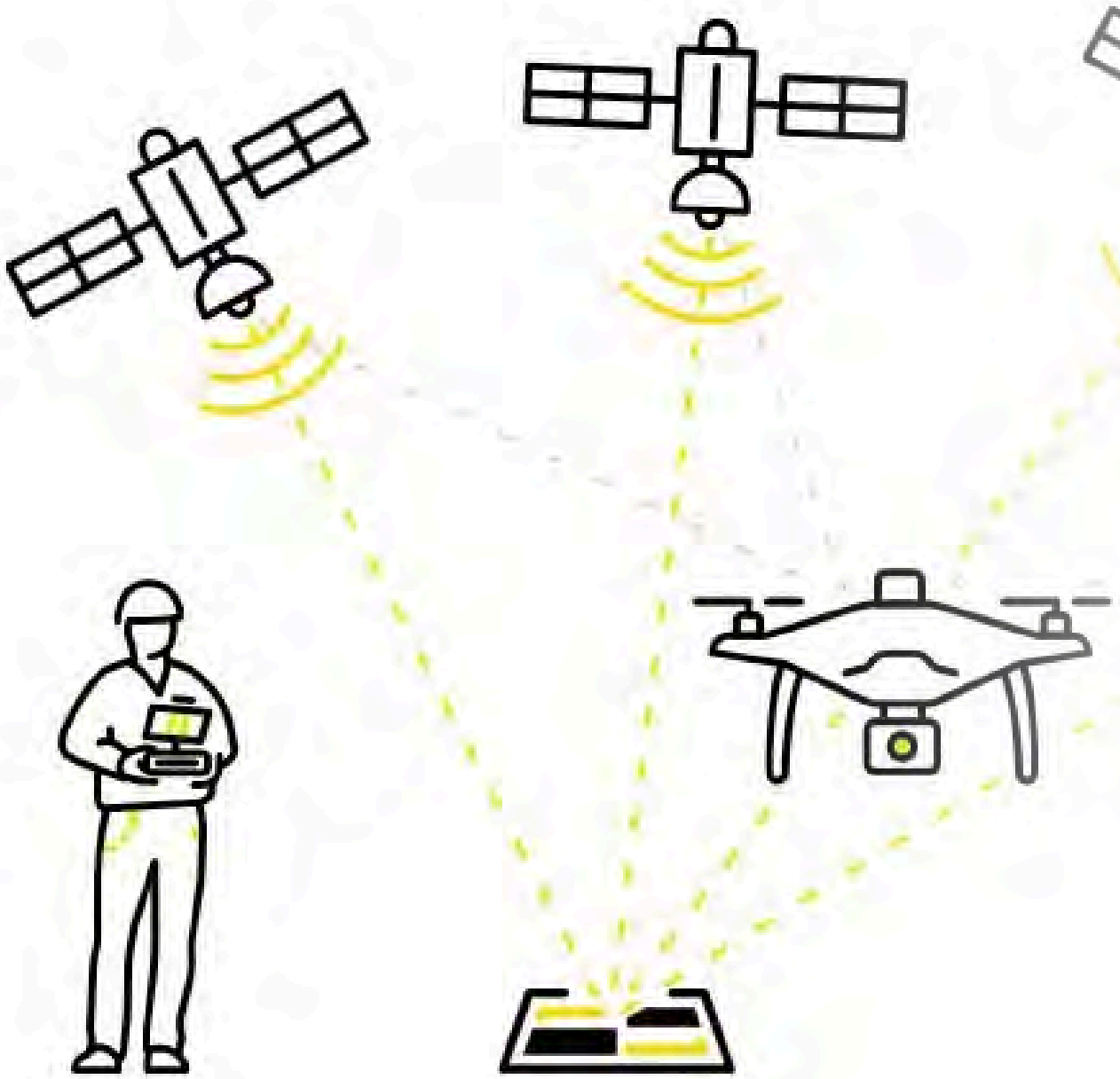
Survey Fabric



Questions?

Geomatics

GPS



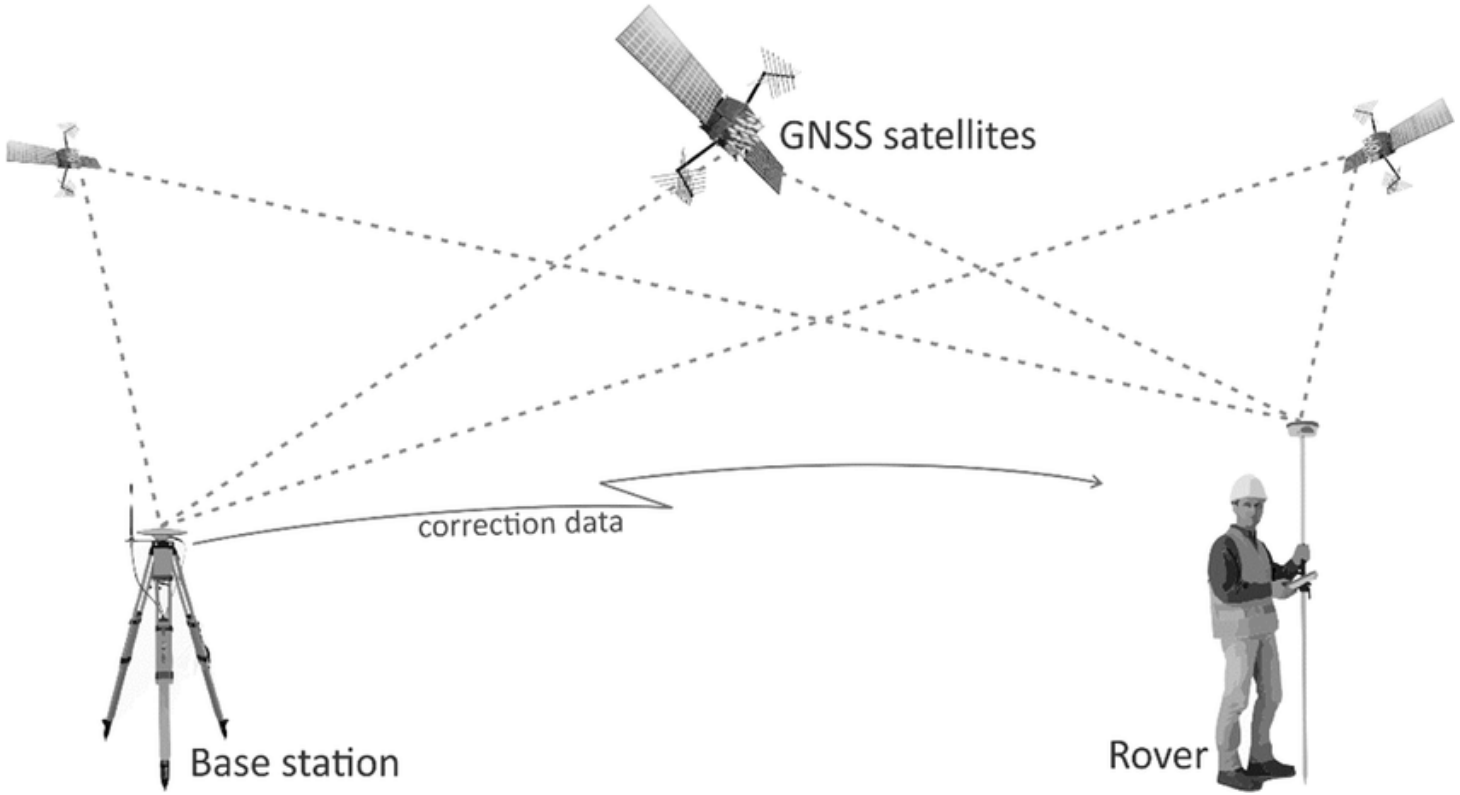
PPK vs RTK

GPS correction technologies

- Difference is when the positional correction takes place
- RTK = **Real Time** Kinematics (correction takes place during data acquisition)
- PPK = **Post Processing** Kinematics (correction takes place after data acquisition)

The correction of errors in current satellite navigation (GNSS) systems.

- Set up over a known point
  - If no point is available, set up equipment and leave for +12 hours
  - Send RINEX file to NRCan for post processing and corrections



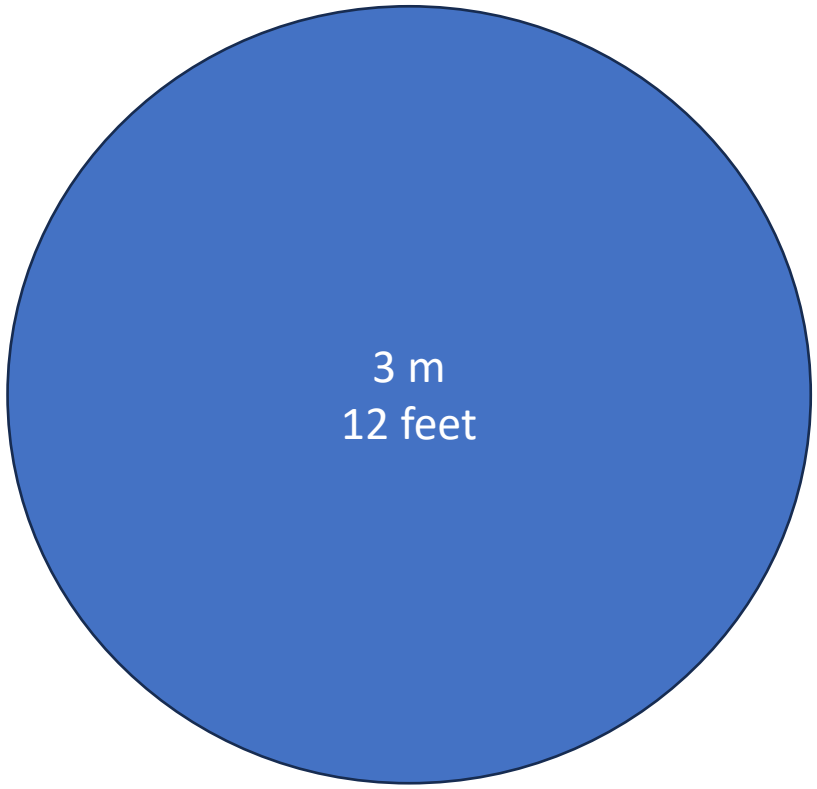
High Accuracy

Low Precision

“Accuracy is how close a given set of measurements (observations or readings) are to their true value, while precision is how close the measurements are to each other…”

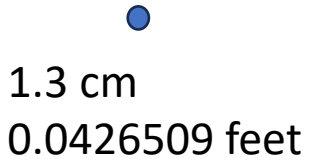
https://en.wikipedia.org/wiki/Accuracy_and_precision

Precision



Drone GPS
(ex. Phantom)

Assisted GPS
(ex. Mavic)



RTK and PPK

* Not to scale

CSRS-PPP 3.50.0 (2021-03-10)

sflog001.yyo
SEPT

Data Start	Data End	Duration of Observations
2021-08-18 15:10:00.00	2021-08-18 16:02:00.00	0:52:00
Processing Time		**Product Type**
18:37:04 UTC 2021/08/18		NRCan Ultra-rapid
Observations	**Frequency**	**Mode**
Phase and Code	Double	Static

Elevation Cut-Off	Rejected Epochs	Fixed Ambiguities	Estimation Steps
7.5 degrees	0.00 %	89.76 %	30.00 sec

Antenna Model	APC to ARP	ARP to Marker
SEPALTUS_NR3 NONE	L1 = 0.068 m L2 = 0.062 m	H:0.000m / E:0.000m / N:0.000m

(APC = antenna phase center; ARP = antenna reference point)

Estimated Position for sflog001.yyo

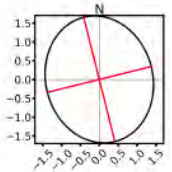
	Latitude (+n)	Longitude (+e)	Ell. Height
ITRF14 (2021.6)	50° 3' 48.94658"	-97° 57' 34.24126"	222.642 m
Sigmas(95%)	0.013 m	0.011 m	0.056 m
A priori*	50° 3' 48.94585"	-97° 57' 34.26083"	220.743 m
Estimated – A priori	0.023 m	0.389 m	1.900 m

Orthometric Height
CGVD2013
(CGG2013a)

249.417 m

(click for height reference information)

95% Error Ellipse (cm)
semi-major: 1.7 cm
semi-minor: 1.4 cm
semi-major azimuth: -14° 57' 41.04"

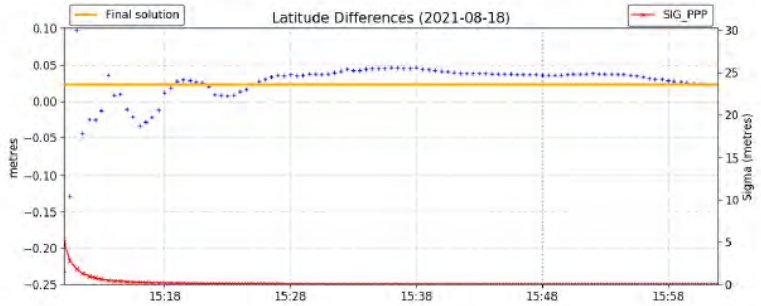


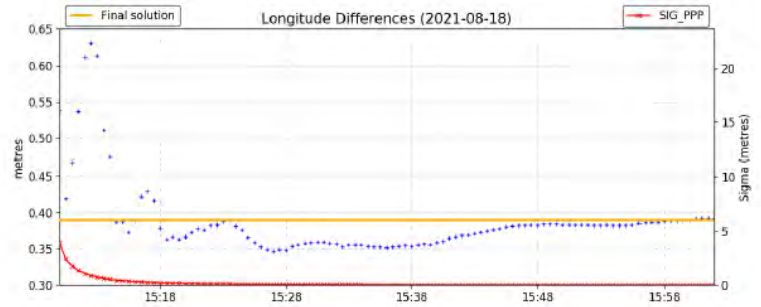
UTM (North)
Zone 14

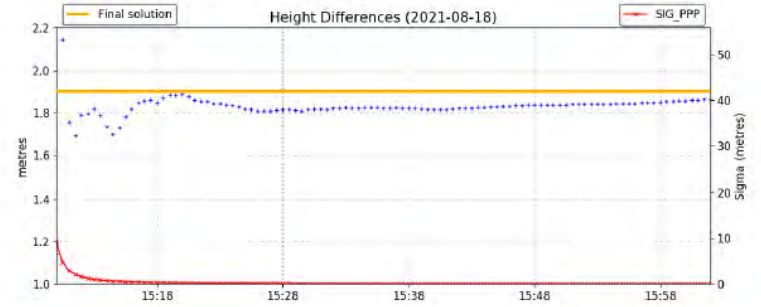
5546220.160 m (N)
574469.643 m (E)

Scale Factors
0.99966811 (point)
0.99963324 (combined)

*(Coordinates from RINEX header used as a priori position)







Questions?

DRONE SAFTY PLANNING

KNOW YOUR DRONE!

MATRICE 300 RTK SPECIFICATIONS

ITEM	Specification
Dimensions	Unfolded, propellers excluded: 810×670×430 mm (L×W×H) Folded, propellers included: 430×420×430 mm (L×W×H)
Diagonal Wheelbase	895 mm
Weight (with single downward gimbal)	Approx. 3.6 kg (without batteries) Approx. 6.3 kg (with two TB60 batteries)
Max Payload	2.7 kg
Max Takeoff Weight	9 kg
Operating Frequency	2.4000-2.4835 GHz 5.725-5.850 GHz
EIRP	2.4000-2.4835 GHz: 29.5 dBm (FCC); 18.5dBm (CE) 18.5 dBm (SRRC); 18.5dBm (MIC) 5.725-5.850 GHz: 28.5 dBm (FCC); 12.5dBm (CE) 28.5 dBm (SRRC)
Hovering Accuracy (P-mode with GPS)	Vertical: ±0.1 m (Vision System enabled) ±0.5 m (GPS enabled) ±0.1 m (RTK enabled) Horizontal: ±0.3 m (Vision System enabled) ±1.5 m (GPS enabled) ±0.1 m (RTK enabled)
RTK Positioning Accuracy	When RTK enabled and fixed: 1 cm+1 ppm (Horizontal) 1.5 cm + 1 ppm (Vertical)
Max Angular Velocity	Pitch: 300°/s, Yaw: 100°/s
Max Pitch Angle	30° (P-mode. Forward Vision System enabled: 25°)
Max Ascent Speed	S mode: 6 m/s P mode: 5 m/s
Max Descent Speed (vertical)	S mode: 5 m/s P mode: 3 m/s
Max Descent Speed (tilt)	S Mode: 7 m/s
Max Speed	S mode: 23 m/s P mode: 17 m/s
Service Ceiling Above Sea Level	5000 m (with 2110 propellers, takeoff weight ≤ 7 kg) / 7000 m (with 2195 propellers, takeoff weight ≤ 7 kg)
Max Wind Resistance	15 m/s

- Specifications
- Limitations

- Flight Time
- Wind Resistance
- Temperature
- Weight
- Max Take-Off Weight
- Operating Frequency
- Distance (Effective & Theorical)

DRONE SAFTY

- Purpose of Flight
  - Mapping
  - Aerial Photography
- Site Survey
  - Trees
  - Buildings
  - Hydro lines
- Equipment & Drone
  - Airworthy
    - Propellers
    - Any damage
    - Batteries
  - Equipment
  - Firmware update
- Weather

Source: https://trackimo.com/wp-content/uploads/2016/07/TRACKIMO-FI-Drone-Safety-Concerns-Increasing.jpg

COMMON SENSE

Manitoba

Drone blocks water bomber from fighting wildfire in Manitoba's Whiteshell Provincial Park

Source: https://www.cbc.ca/news/canada/manitoba/drone-intercepts-fire-1.6108946

". . .The water bomber was flying over the south shore of West Hawk Lake when a drone got in the way of its flight path.

The water bomber had to turn back, leaving the firefighters on the ground in jeopardy."

Questions?

DRONE MISSION PLANNING MAPPING

Drone Aerial Imagery

Drone Aerial Mapping

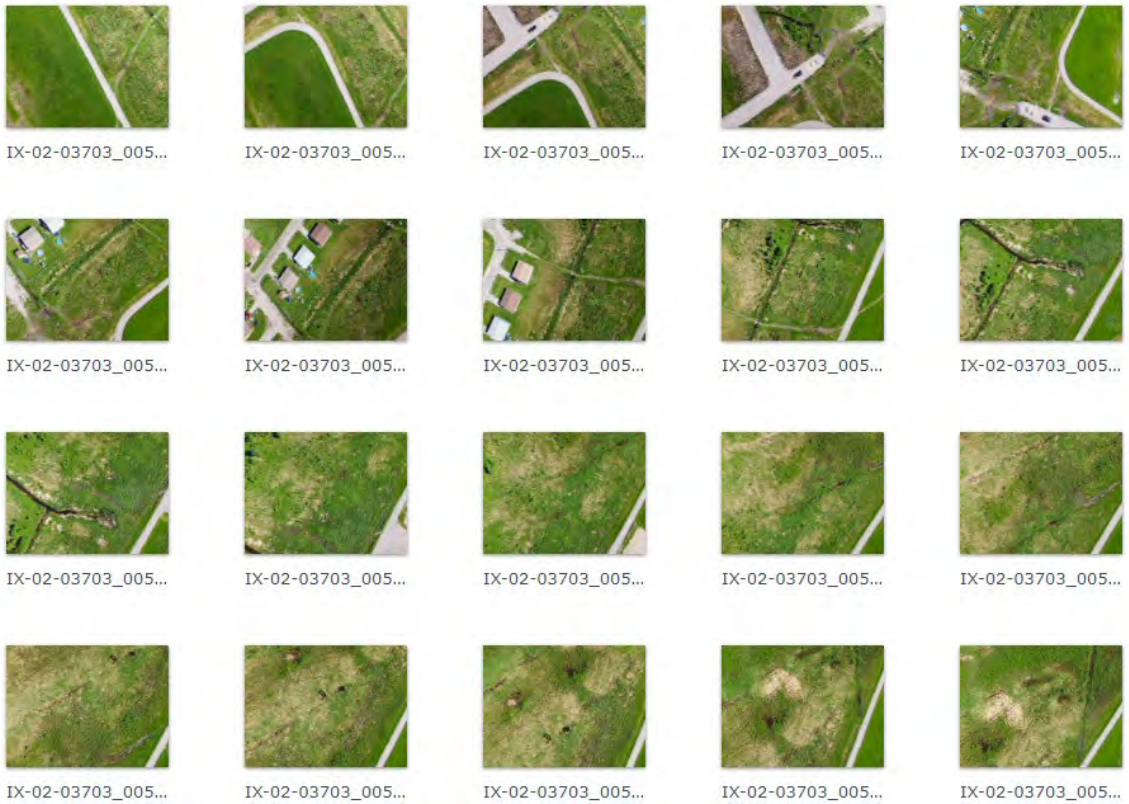
What it is not

≠

Drone Aerial Mapping

=

Drone Aerial Mapping

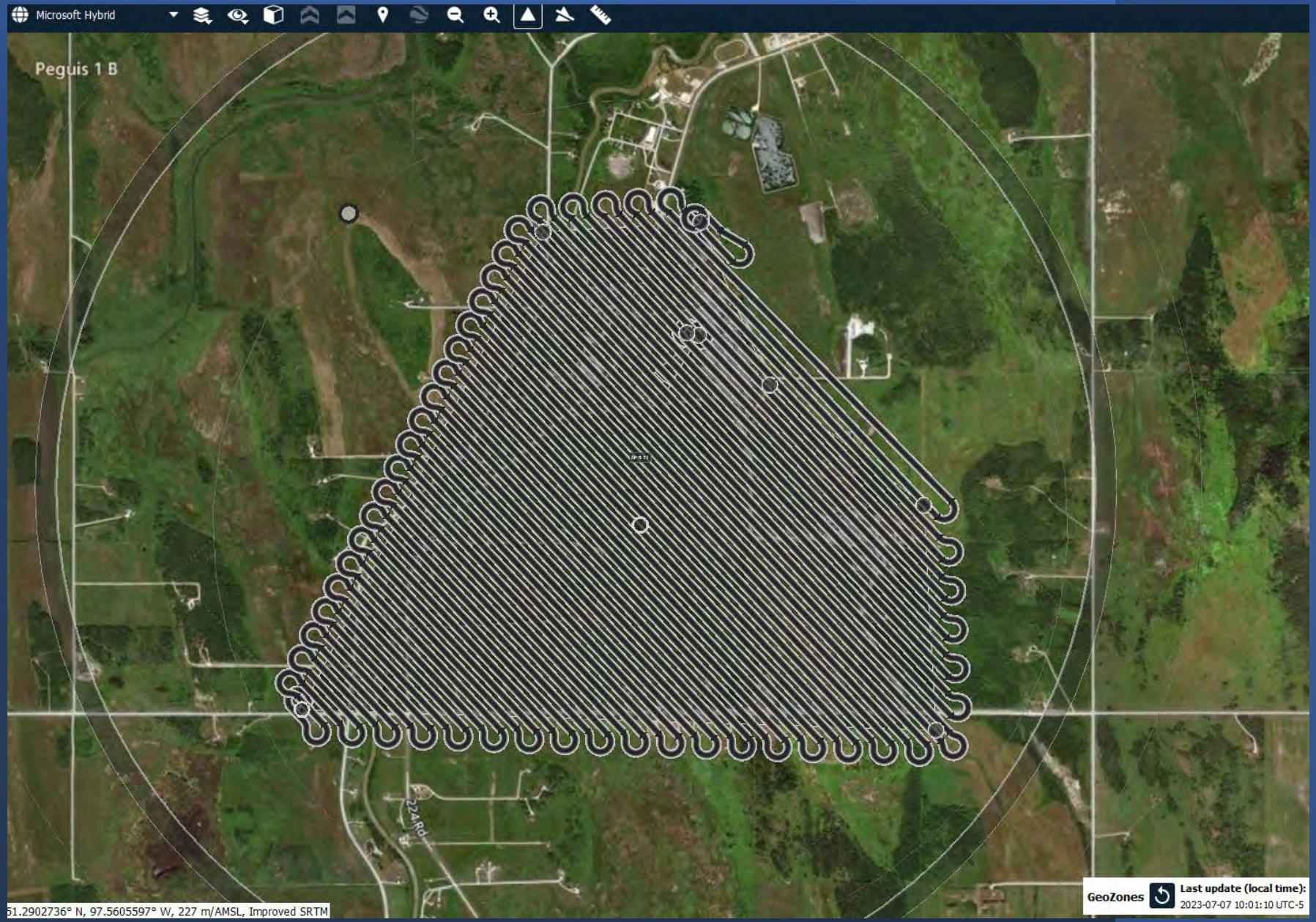


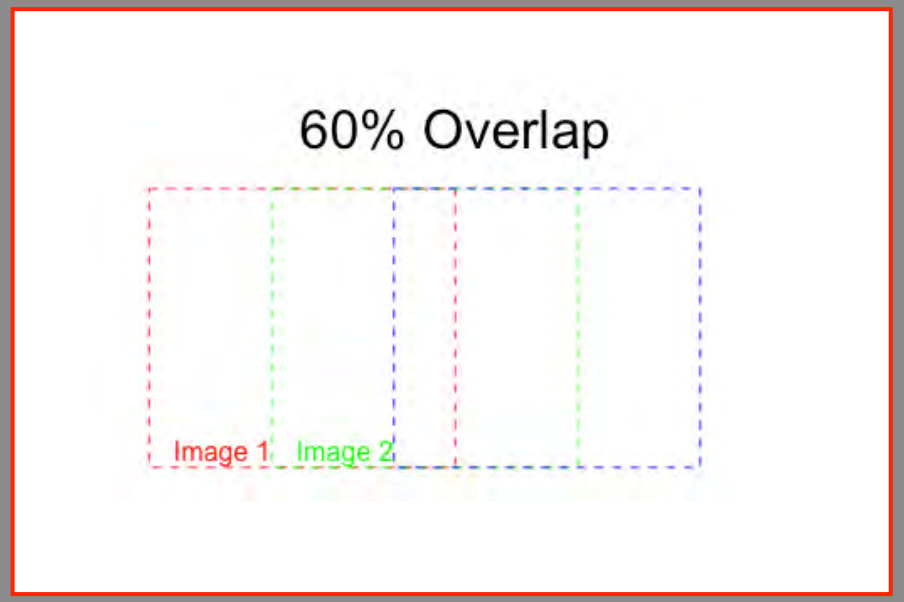
=

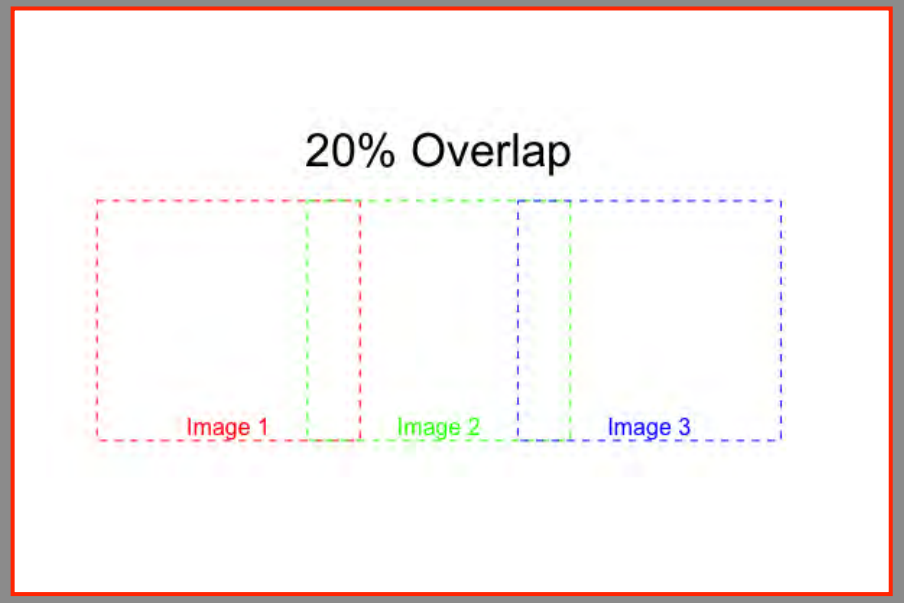
Mission Planning Software

- Drone Deploy (iPhone, Android)
- Pix4D Capture (iPhone, Android)
- eMotion (eBee specific, Windows)
- DJI Pilot (Specialized software for DJI Remotes)

- Software is similiar
- Allows creating an Area of Interest (polygon)
- Set mission height and drone speed
- Calculates flight time
- Calculates ground sampling distance (resolution)

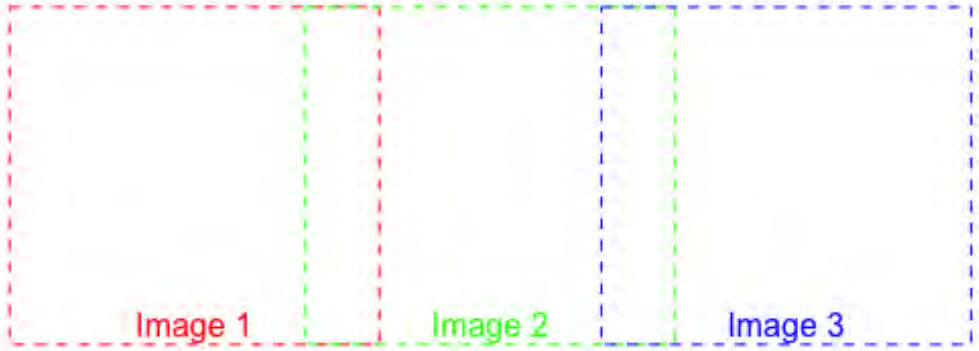

Microsoft Hybrid
Peguis 1 B
224 Rd
GeoZones
Last update (local time):
2023-07-07 10:01:10 UTC-5
51.2902736° N, 97.5605597° W, 227 m/AMSL, Improved SRTM


60% Overlap
Image 1
Image 2


20% Overlap
Image 1
Image 2
Image 3

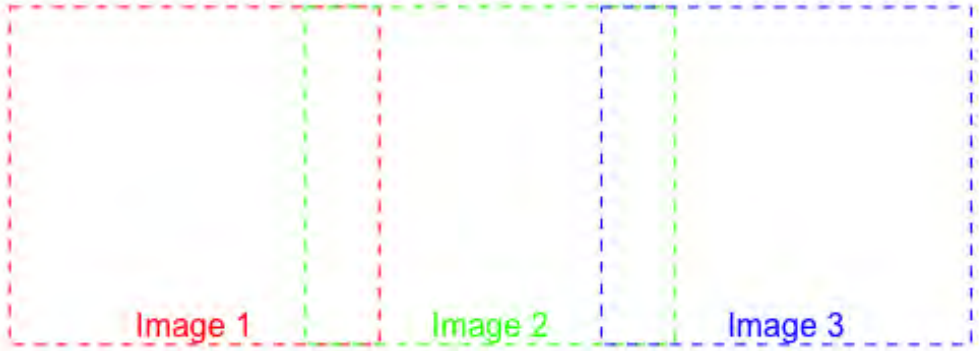

Blocks
Block #1
Horizontal Mapping
2.5 cm/px
149:24
480.7 ha
Name:
Block #1
Camera:
Aeria X
Plan above:
Elevation data - AED
Resolution:
2.50 cm/px
Lat. overlap:
60 %
Long. overlap:
60 %
Reverse flight
Perpendicular lines
Interlaced flight lines
Area:
480.7 ha, 4.81 km²
Flight altitude:
118.3 m/AED
Photos:
2267
Between photos:
40 m
Image coverage:
150x100 m
Est. flight time:
02:29:24
Est. flight distance:
106170 m
Flight line spacing:
60 m
Waypoints:
129
Reset progress
Show waypoints
Save as default

20% Overlap



60% Overlap

20% Overlap



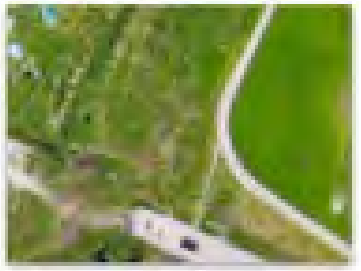
60% Overlap


IX-02-03703_005...


IX-02-03703_005...


IX-02-03703_005...


IX-02-03703_005...


IX-02-03703_005...

Quality Report

Generated with Pix4Dmapper version 4.5.6

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	2022_08_03_peguis_ppk_nrs_p1
Processed	2022-08-04 18:06:09
Camera Model Name(s)	senseFlyeXelaX_18.5_6000x4000 (RGB)
Average Ground Sampling Distance (GSD)	2.60 cm / 1.02 in
Area Covered	0.655 km^2 / 65.4853 ha / 0.25 sq. mi. / 161.9015 acres
Time for Initial Processing (without report)	13m:20s

Quality Check

Images	median of 5154 keypoints per image	✓
Dataset	734 out of 734 images calibrated (100%), all images enabled	✓
Camera Optimization	0.1% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 907.877 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

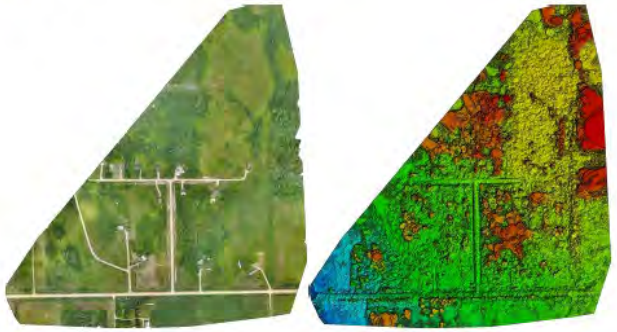
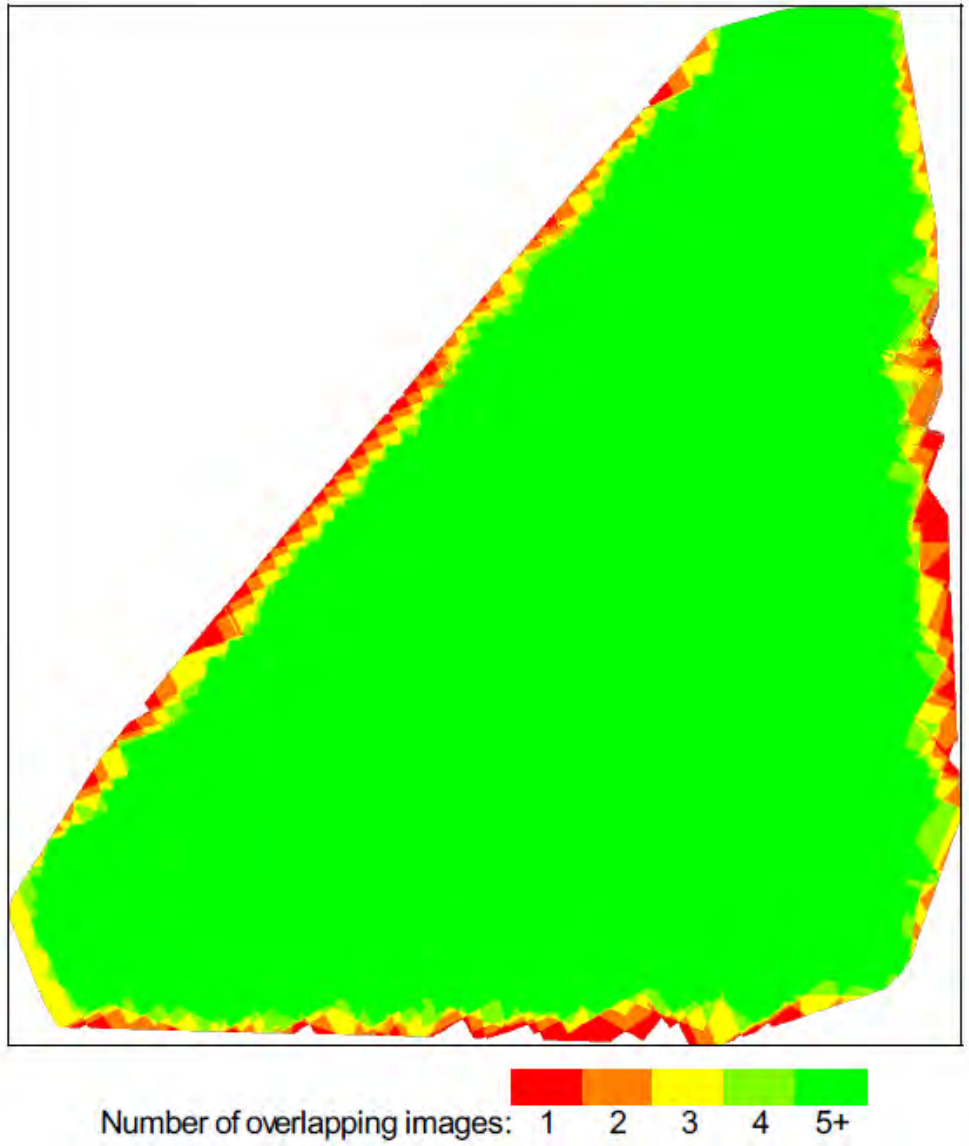


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.



Aerial Imagery Processing Software

- Drone Deploy
- Pix4D
- DJI Terra
- OpenDroneMapping (OSM)

- All software is the same
- Creates orthomosaics
- Creates digital surface models
- Some create point clouds
- Resource intensive

Questions?

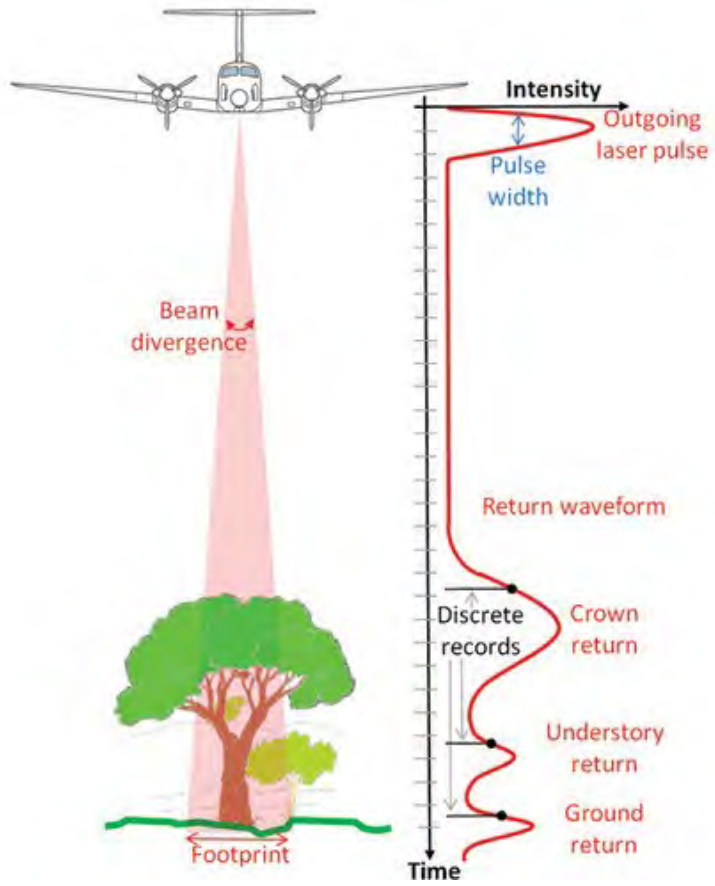
Geomatics

Basics of LiDAR

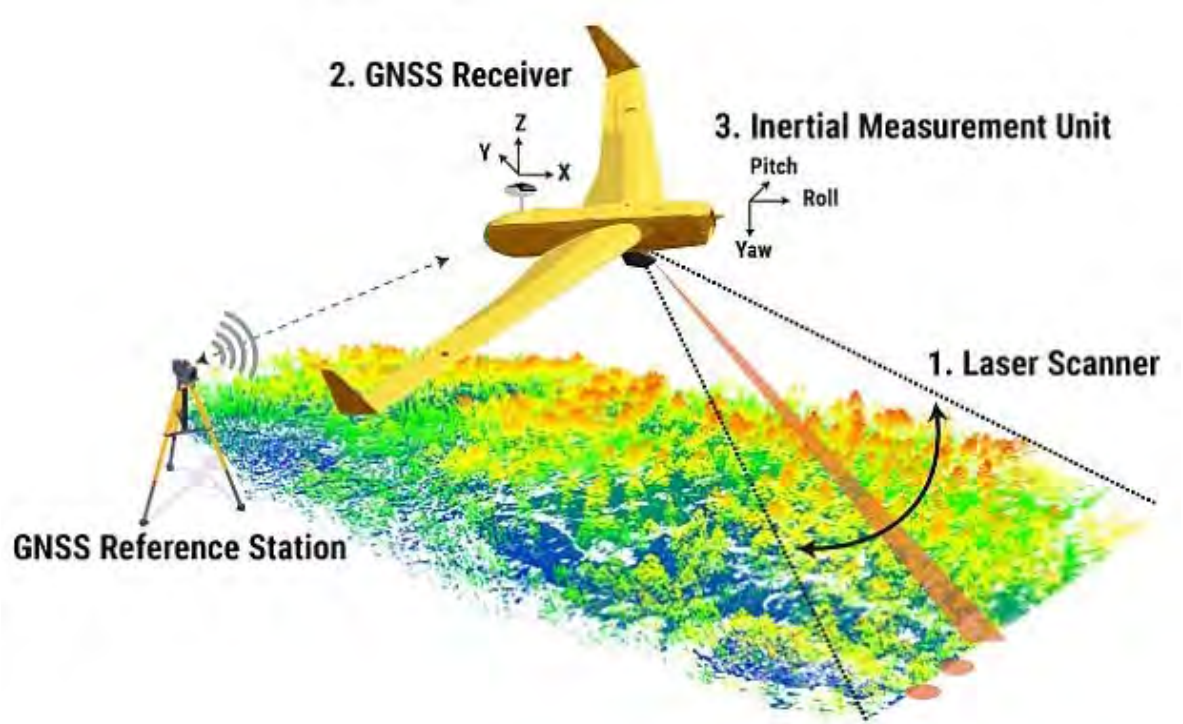
LiDAR Basics

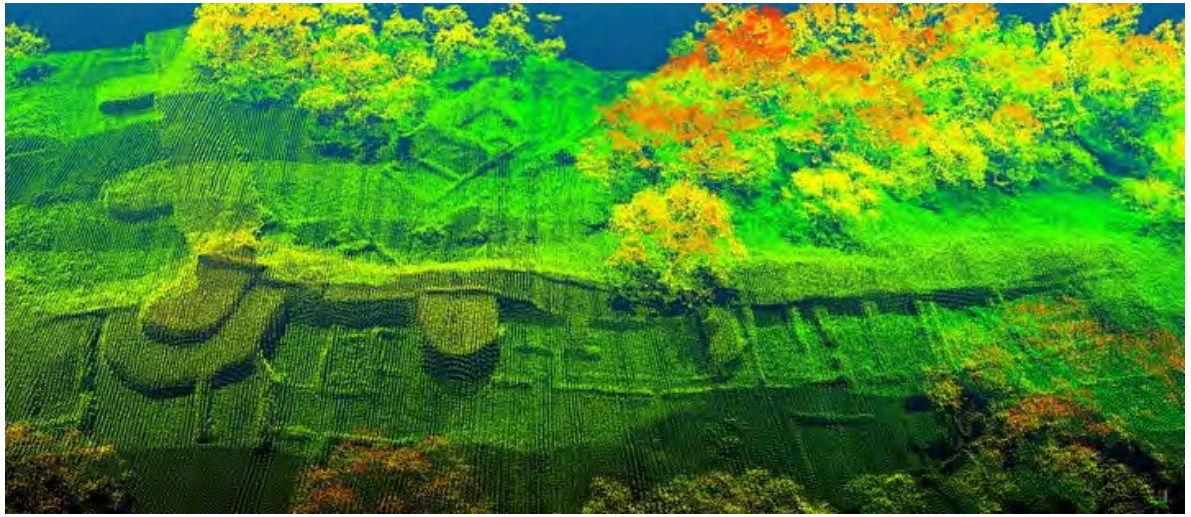
- A method for determining ranges by targeting an object or a surface with a laser and measuring the time for the reflected light to return to the receiver.

- Lidar returns are discrete observations* recorded when a laser pulse is intercepted and reflected by targets. Multiple returns derive from one laser pulse intercepting multiple targets (e.g. a top of a tree, its branches, and the ground).
- - Source [remote sensing - What are LiDAR returns? - Geographic Information Systems Stack Exchange]



LiDAR Capabilities





https://medium.com/supplyframe-hardware/lidar-looking-through-a-jungle-canopy-e19fc40e0f88

Point Cloud

Point cloud

- A **point cloud** is a discrete set of data points in space. The points may represent a 3D shape or object. Each point position has its set of Cartesian coordinates (X, Y, Z)

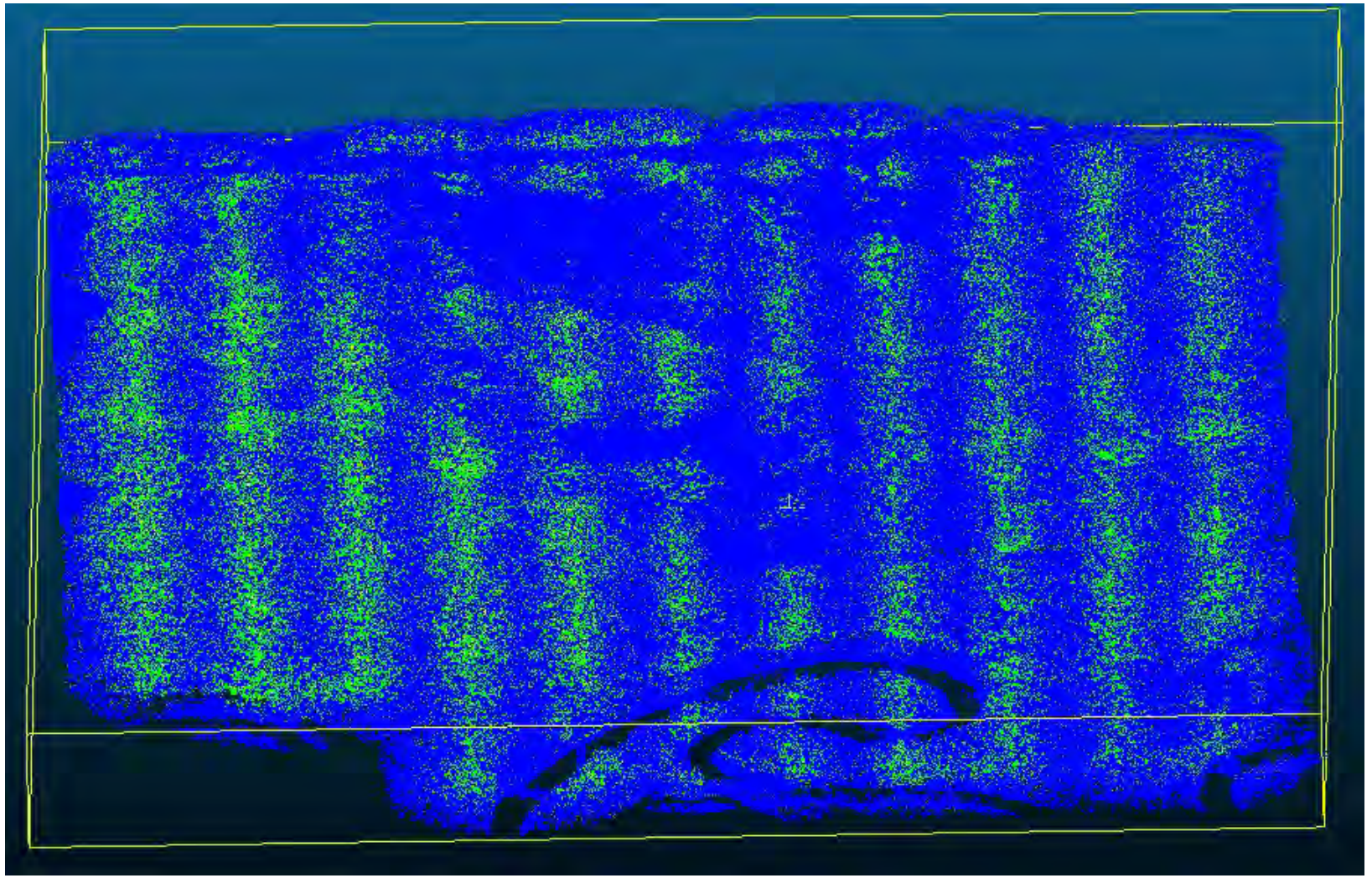
- source: https://en.wikipedia.org/wiki/Point_cloud

Point Cloud Generation

Relatively fast compared to orthomosaics

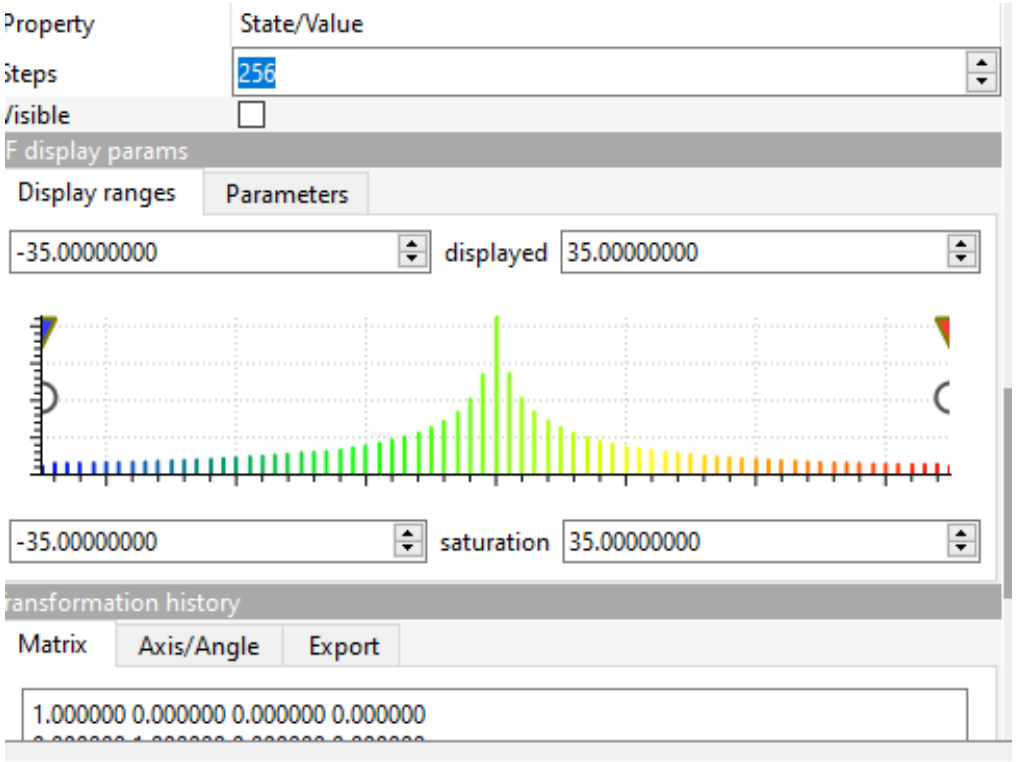
Classification and Derivatives can take a long time

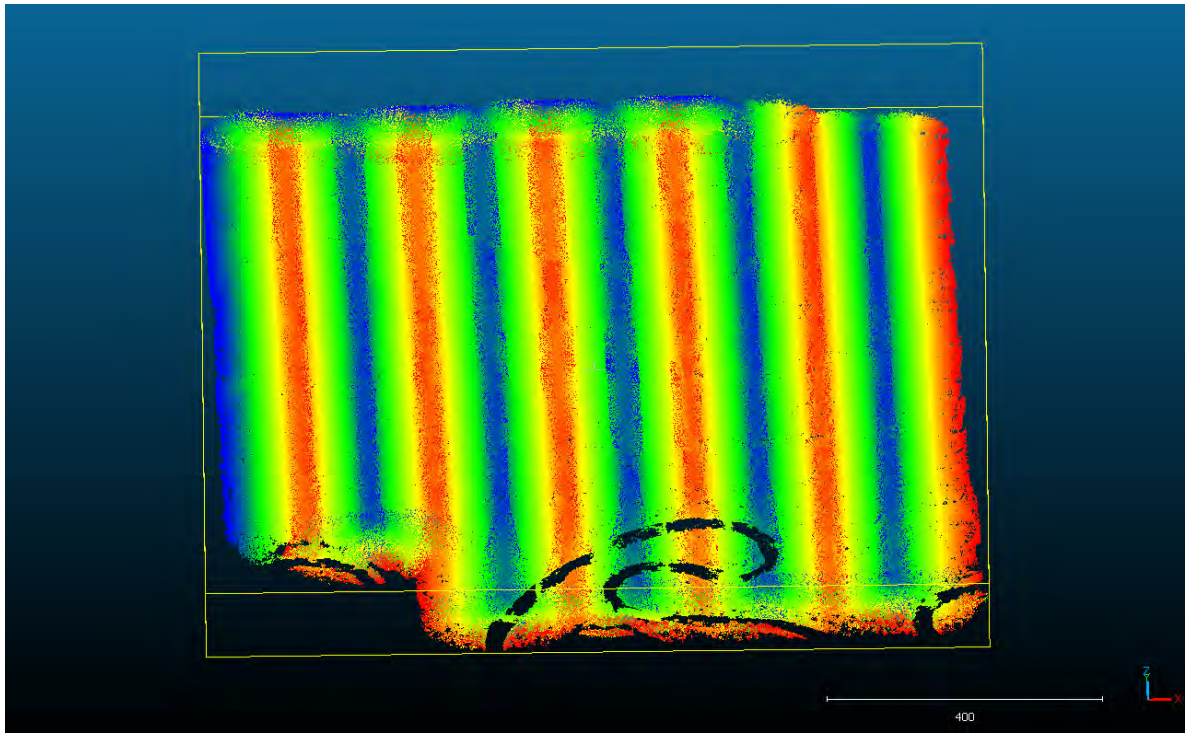
Roseau River Point Cloud – Number of Returns



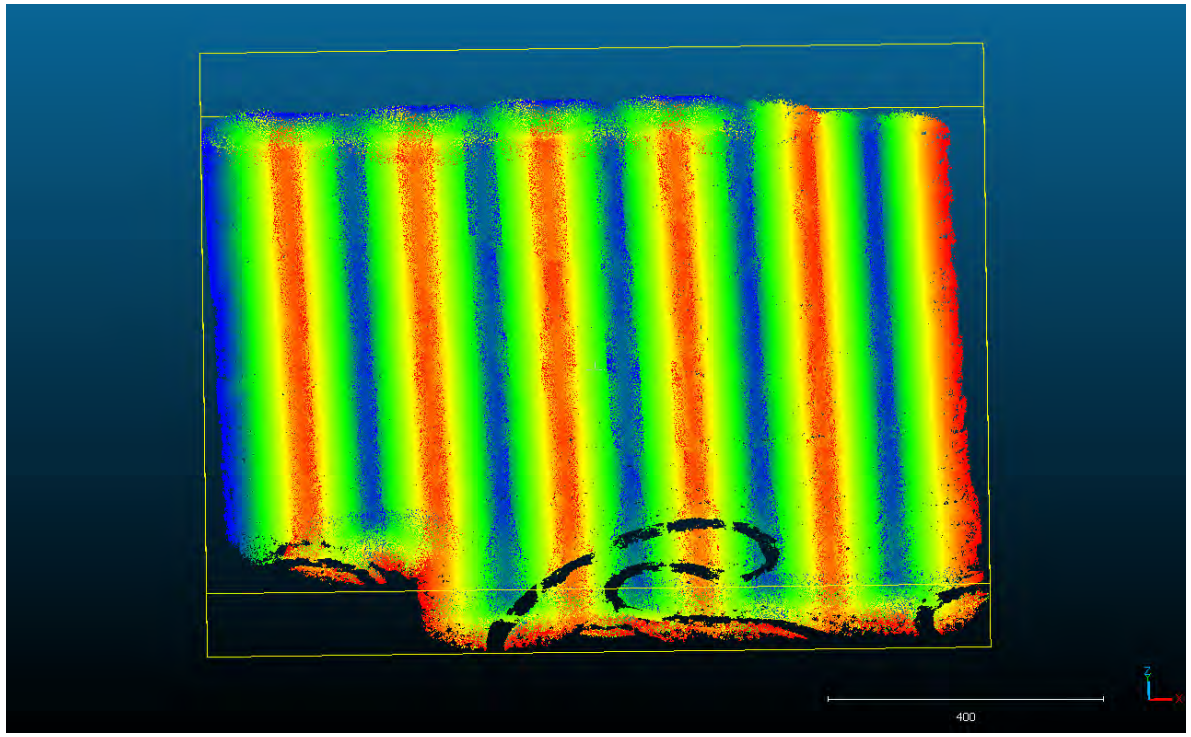
1 Return - Blue
2 Returns - Yellow
3 Returns - Red

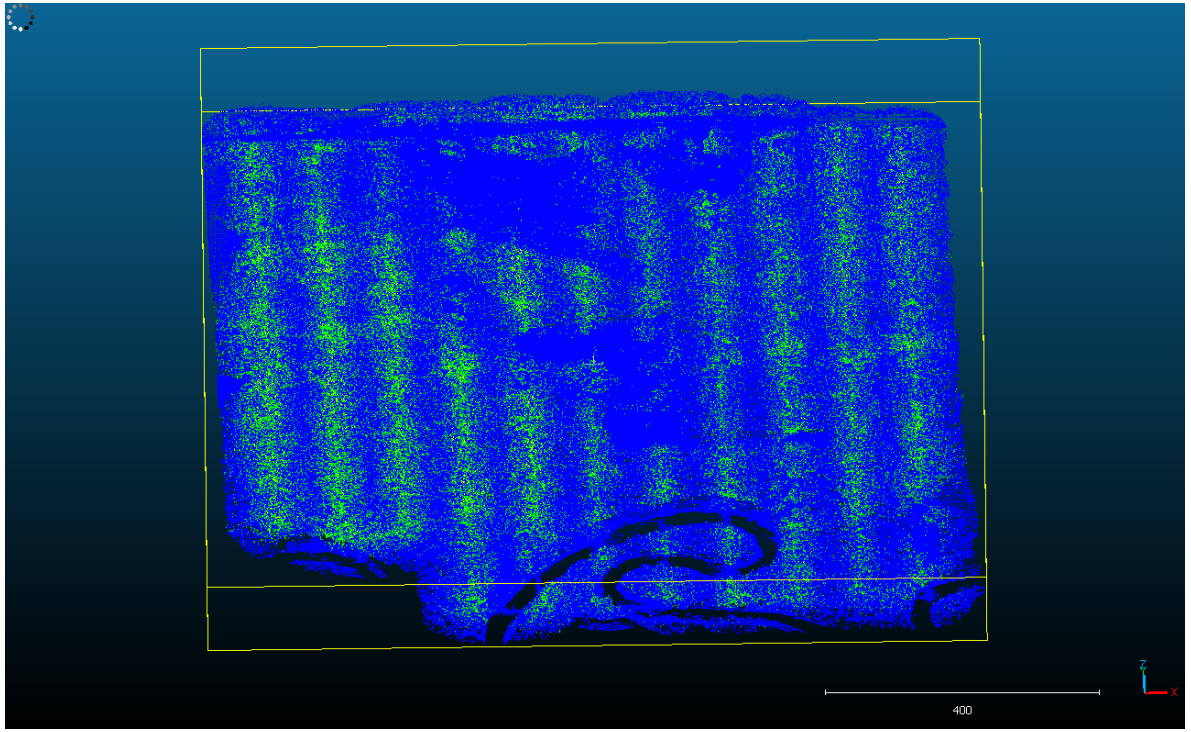
Roseau River Point Cloud – Scan Angle





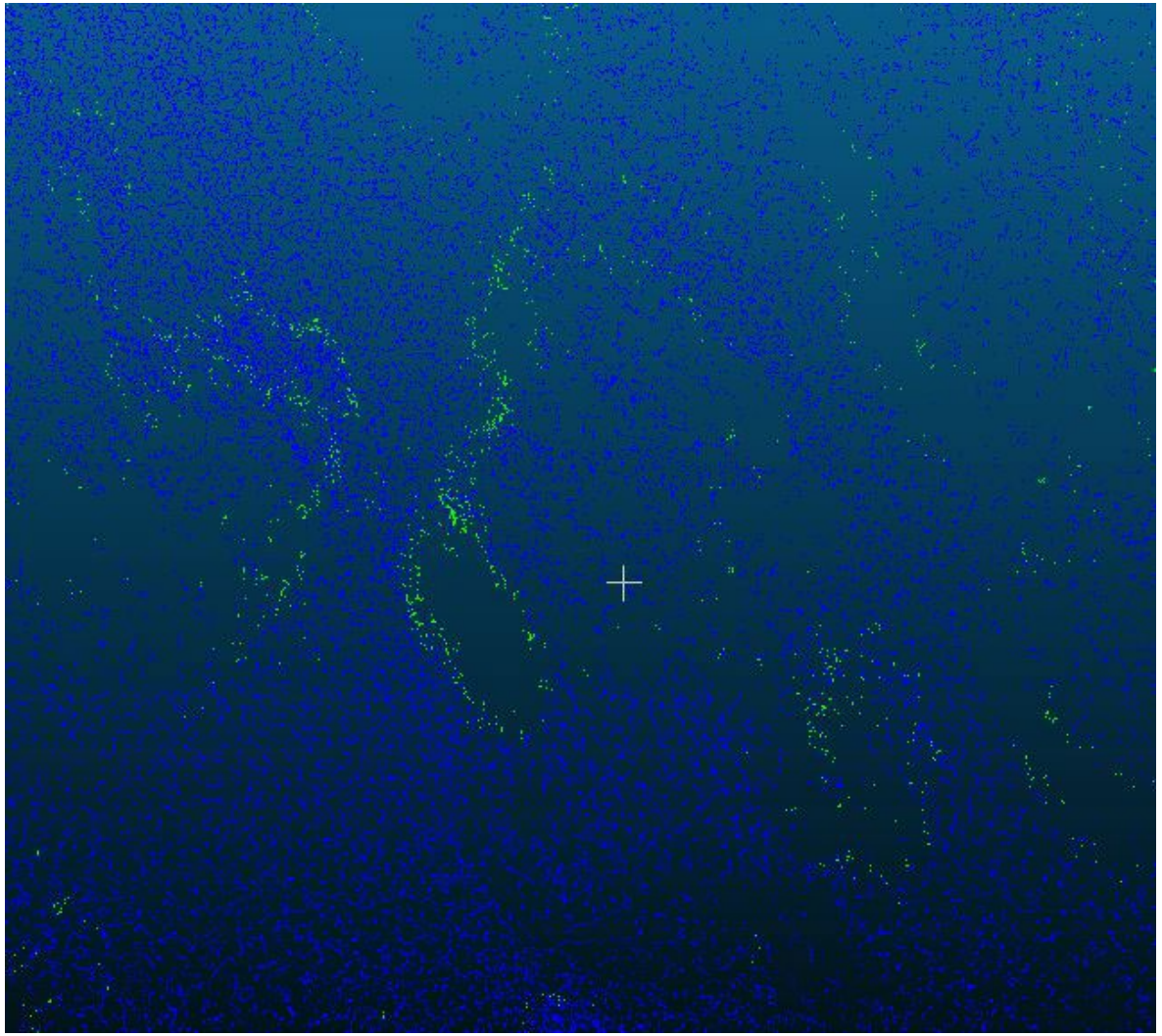
Scan Angle vs Number of Returns





Individual Points

Graphical Point Cloud



CSV Point Cloud

```
651280.08270264 5451866.06159973 240.20419891 159 179 114 -2.000000 1.000000 1.000000 371918984.754501 60.000000
651280.08740234 5451866.14279938 240.22440155 157 184 109 -1.000000 1.000000 1.000000 371918990.514877 47.000000
651280.11419678 5451866.21959686 240.24490173 158 183 108 -3.000000 1.000000 1.000000 371918979.661239 54.000000
651280.06430054 5451865.93689728 240.20160110 159 204 111 -2.000000 1.000000 1.000000 371918984.069930 67.000000
651280.17949677 5451865.93969727 240.24759872 171 211 121 -2.000000 1.000000 1.000000 371918986.036361 62.000000
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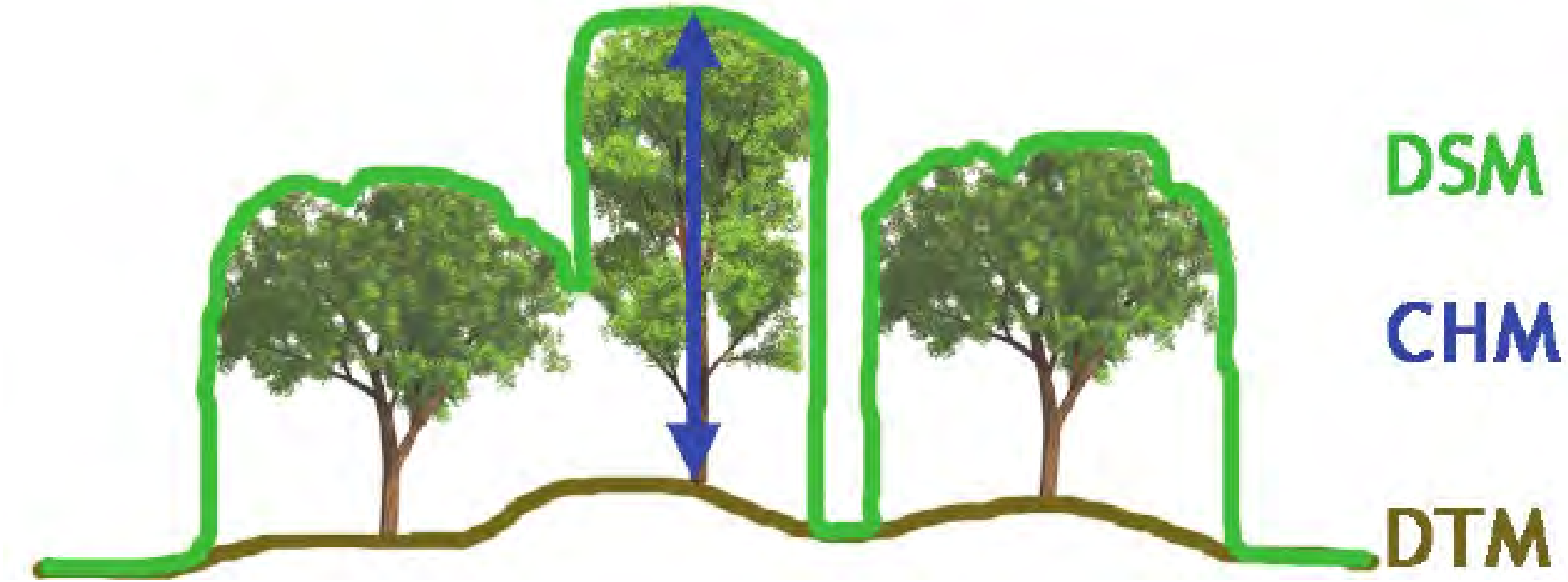
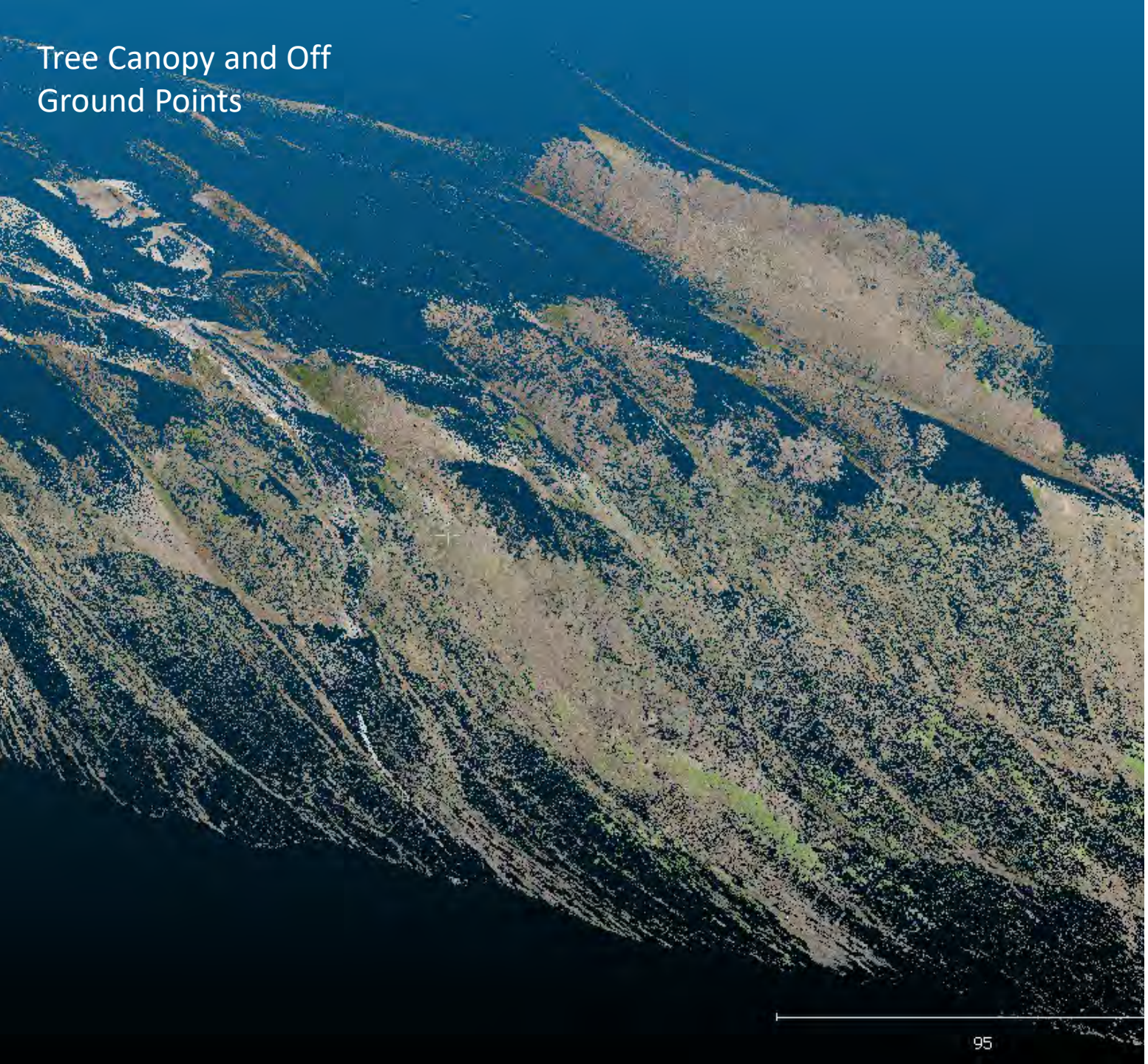
LiDAR Derived Products

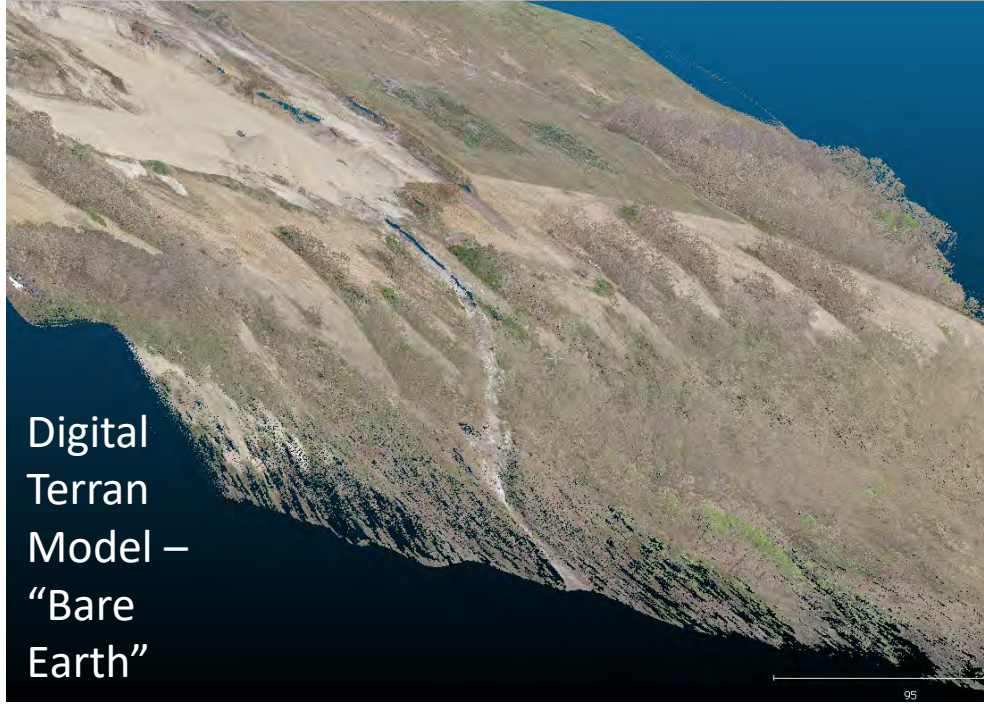
- Digital Surface Model
- Digital Terran Model or “Bare-Earth” Model
- Canopy Height Model
- Digital Elevation Model

DSM
CHM
DTM

- Digital Surface Model
- Canopy Height Model
- Digital Terran Model




Tree Canopy and Off Ground Points
95


Digital Terran Model – “Bare Earth”
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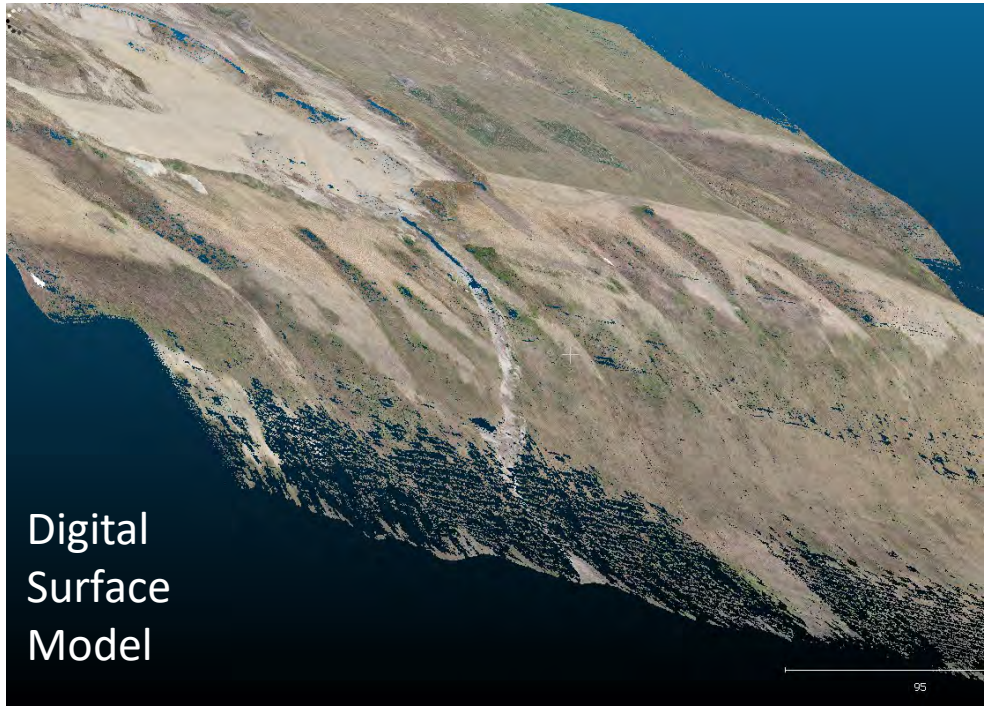
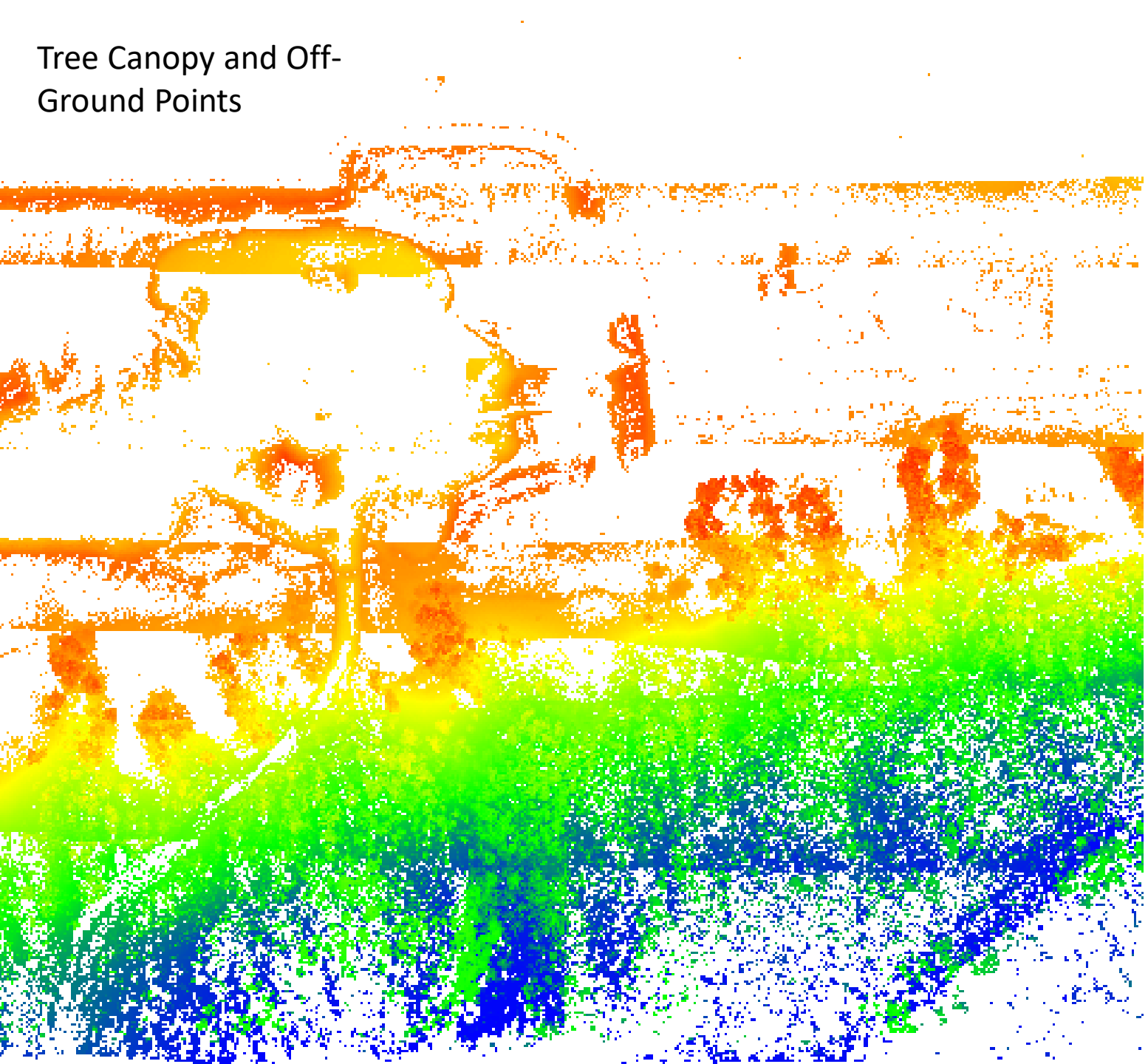

Digital Surface Model
95

Tree Canopy and Off-Ground Points



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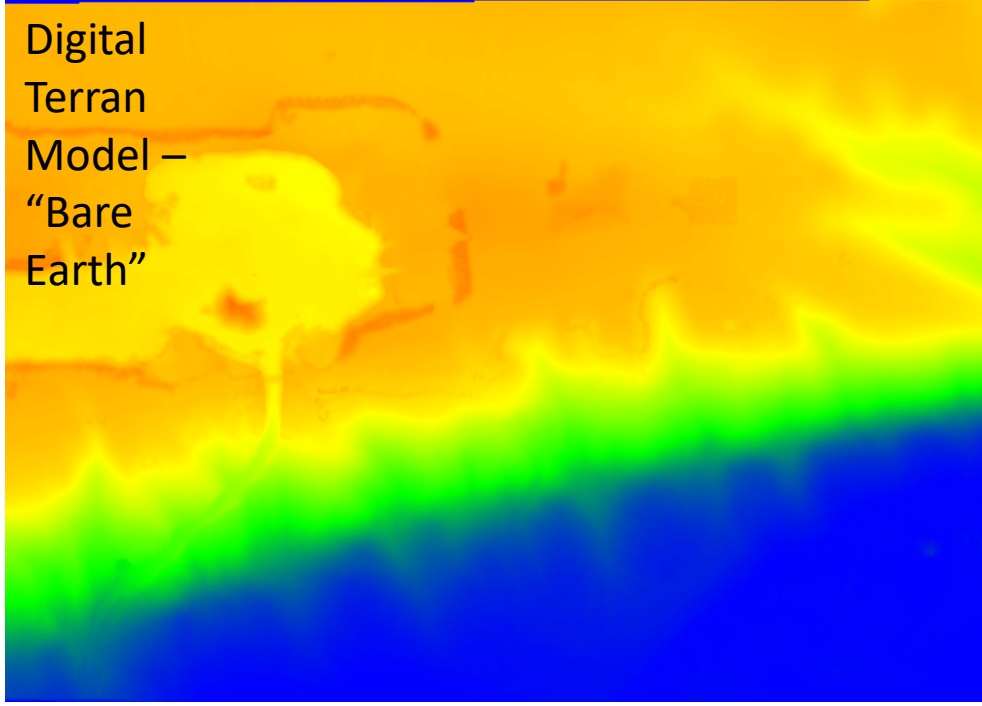
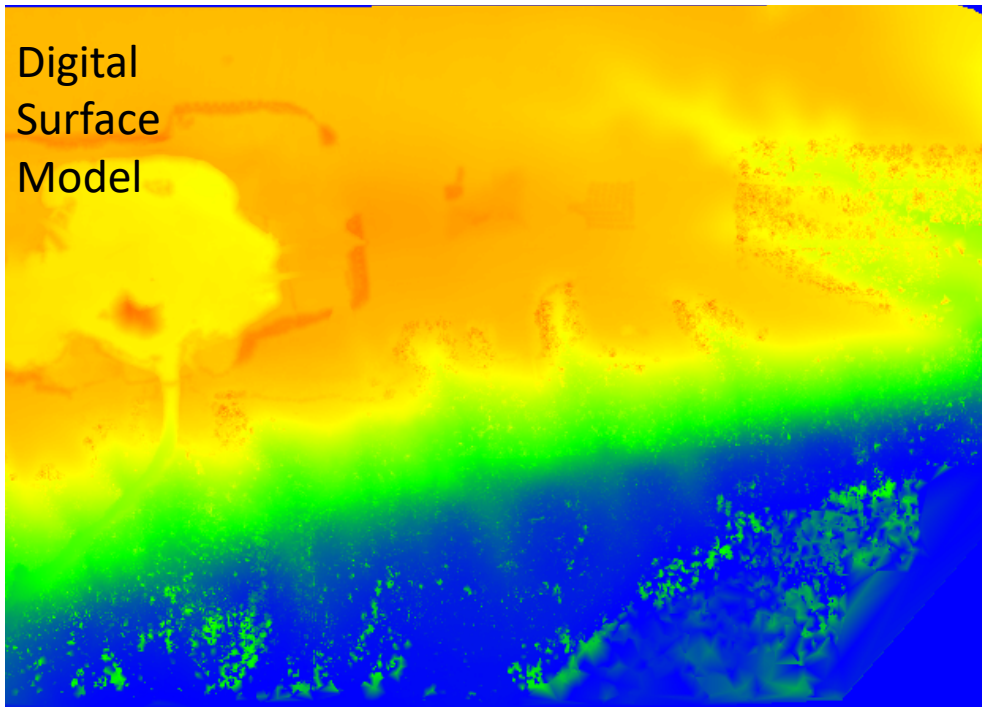
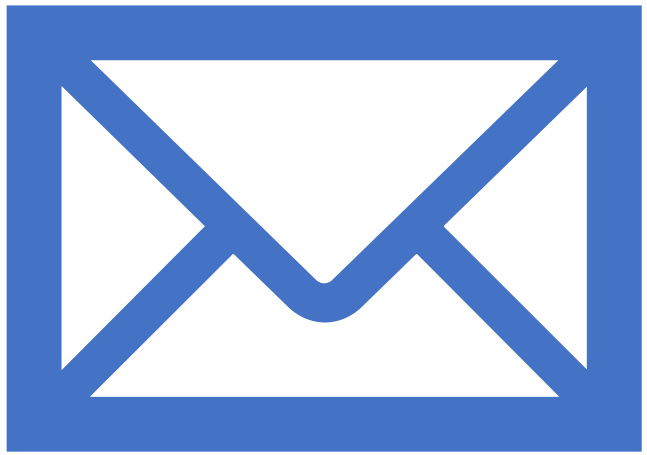


Digital Surface Model





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