PhoREAL v3.27

Geospatial Analysis Toolbox
for ICESat-2 Data

User Manual

Applied Research Laboratories
The University of Texas at Austin

PhoREAL v3.27

- PhoREAL (<u>Ph</u>oton <u>R</u>esearch and <u>E</u>ngineering <u>A</u>nalysis <u>L</u>ibrary) is a geospatial analysis toolbox that allows users to read, process, analyze, and output ICESat-2 ATL03 and ATL08 data.

- On Windows systems, the PhoREAL toolbox can be downloaded as a Windows installer executable file and operated as a Graphical User Interface (GUI).

- On Linux systems, the PhoREAL toolbox can be run as a Python GUI or as a series of Python function commands via the Linux command line (Python v3.0+).

- Some highlights of PhoREAL v3.24 functionality:
    - Batch mode capability (can process single/multiple ATL03/ATL08 file(s) or a directory of ATL03/ATL08 files)
    - Incorporation of ICESat-2 Orthometric (Mean Sea Level) heights (computed using EGM2008 ellipsoid)
    - Addition of latitude/longitude, time, and delta time for reference data
    - Addition of latitude/longitude, time, delta time, classification, and signal confidence for shifted ICESat-2 data
    - Clearer plotting of stats onto figures
    - Ability to load in files previously executed by PhoREAL for quicker plotting and analysis
    - Additional ground track inputs including beam number and ground track strong/weak beam
    - Additional output columns to .csv file (solar elevation, UTM zone, UTM hemi, GT #, beam #, beam type)
    - New Stats tab to compute stats on ICESat-2 data
    - Option to write out .pkl file for saving output variables

PhoREAL (Home Tab)

PhoREAL (Home Tab)

PhoREAL (Home Tab – File Inputs)

ATL03 File:
- Select ".h5 File(s)" or ".h5 Directory" for input type
- Single/multi ICESat-2 ATL03 .h5 file input
- The Browse button filters by ATL03*.h5 file types
- File path names can be pasted into this entry box
- Do not change the .h5 file name as parts of this file name are used by PhoREAL

ATL08 File (Optional):
- Select ".h5 File(s)" or ".h5 Directory" for input type
- Single/multi ICESat-2 ATL08 .h5 file input (optional input)
- The Browse button filters by ATL08*.h5 file types with the same base name as the ATL03 file name
- File path names can be pasted into this entry box
- Do not change the .h5 file name as parts of this file name are used by PhoREAL
- Use of this file allows for classification of ATL03 photons from the ATL08 product

Output Directory:
- Output directory for all output files
- Directory path names can be pasted into this entry box
- The output directory defaults to the location where PhoREAL is stored on the user's machine, however, this directory may need admin privileges for writing files and it is advised that this directory be changed to another location with read/write privileges so that output data can be saved properly

PhoREAL (Home Tab – Filter Options)

Ground Track Numbers:
- Select the ICESat-2 ground tracks to analyze
- Options are: GT # Right/Left, GT # Strong/Weak, or Beam Number
- Based upon the user input, the ground track selections will change accordingly

(2)

Ground Track Numbers:	☑ GT1R	☑ GT2R	☑ GT3R
Select By: GT Right/Left ▼	☐ GT1L	☐ GT2L	☐ GT3L

Trim ICESat-2 Data Options: Min Max

☑ None   ☐ Manual   ☐ Latitude   [____]   [____]   Degrees

☐ Auto   ☐ Time   [____]   [____]   Seconds

Trim ICESat-2 Data Options:
- This allows the user to trim the ATL03 ground tracks if desired
- **None** – the default option which will not trim the ATL03 ground track
- **Manual** – this option allows the user to trim the ground track by latitude or time. This option is recommended when the ATL03 ground tracks are very long as PhoREAL could run into memory issues.
- **Auto** – this option will trim the ATL03 ground track by the latitude/longitude min/max values specified in the kmlBounds.txt file. This file is located in the directory where PhoREAL gets installed on the user's machine and can be freely edited by the user as desired. The current values of this file are meant to serve as a template and can be discarded.

PhoREAL (Home Tab – Export Options)

Create Output Files:
- This section allows the user to export ATL03/ATL08 data to .las, .kml, or .csv file formats
- Note that ATL08 files cannot be written to .las file format as this information is not as informative as the ATL03 .las file output
- Las files can be opened with QT Modeler or other free point cloud viewers such as Cloud Compare, Trimble, etc.
- Kml files can be opened with Google Earth or Google Earth Pro
- Note that the ATL03 data is down-sampled to a 1 second resolution to write to kml format due to kml file size limitations
- Note that writing to a csv file may take a long time for very large ATL03 ground tracks, trimming the data is recommended if this occurs
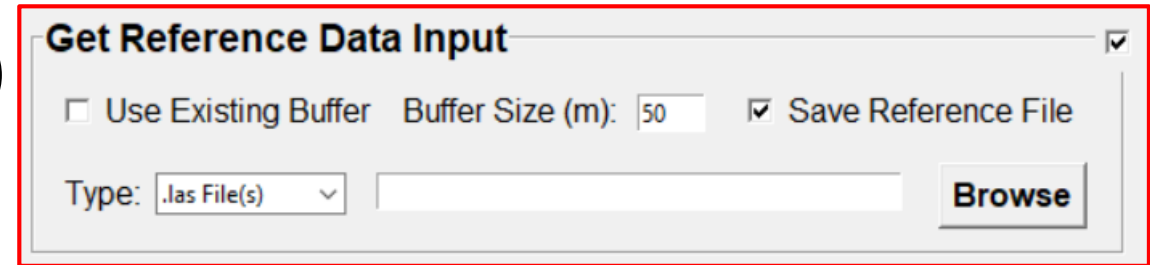
3

Create Output Files:	☑ ATL03 .kml File	☐ ATL08 .kml File
☑ ATL03 .las File	☐ ATL03 .csv File	☐ ATL08 .csv File

PhoREAL (Home Tab – Reference Data)

Get Reference Data Input:

- This section is grayed out by default, but it can be activated by clicking the checkbox in the upper right hand part of this section
- Note that PhoREAL does not come pre-loaded with reference data, all reference data must be provided by the user (reference data can be in .las/.tif file formats)
- **Use Existing Buffer** – this option allows users to read in reference buffer files previously created by PhoREAL
- If this option is selected, the Buffer Size option is grayed out and the Browse button filters by *buffer.las files
- **Buffer Size** – if not using an existing buffer file, the user can set the buffer size which will create a new reference buffer file that consists of all the reference data that falls within the buffer size from the ICESat-2 ATL03 ground track photons
- **Save Reference File** – this checkbox allows users to save the output reference buffer file
- **Type** – this pull-down menu allows users to inform PhoREAL about the type of reference files to read (options are .las files(s), .tif file(s), directory of .las files, or directory of .tif files)
- **Browse** – this button allows users to set the appropriate .las/.tif file(s) or directory
- When creating new reference buffer files, PhoREAL will read the header information for all selected .las/.tif file(s) to get the extents of each file and the associated EPSG code for the projection. PhoREAL will store this information in a file called phoReal_headers.csv located in the directory with the reference file(s). PhoREAL does this to save time for future use instead of having to read in all of the header information every time, which can be time consuming depending on the number of reference files. Note that write privileges need to be allowed in the reference directory to create this file.

(4)

Get Reference Data Input

☐ Use Existing Buffer   Buffer Size (m): 50   ☑ Save Reference File

Type: .las File(s) ▼   [   ]   **Browse**

Grayed out by default, check the box to activate

PhoREAL (Home Tab – Finding ICESat-2 Offsets)

Find ICESat-2 Offsets Relative to Reference Data:

- This section creates raster data from the ICESat-2 and reference data and finds the ICESat-2 XYZ offsets that minimize the Z errors relative to the reference data
- **Cross-Track Bounds** – sets the cross-track search bounds. Set this value to a single number to force that offset.
- **Along-Track Bounds** – sets the along-track search bounds. Set this value to a single number to force that offset.
- **Use Fixed Vertical Shift** – option to force a particular vertical shift
- **Vertical Shift** – the vertical shift value to use
- **Grid Resolutions** – The offset finding algorithm uses a multi-resolution approach to minimize the Z errors between ICESat-2 and the reference data. The algorithm converges better when moving from low to high resolutions (1 m limit)
- **Use ICESat-2 Heights** – option to compare ICESat-2 ellipsoidal (HAE) or orthometric (MSL) heights to reference data
- **Use ICESat-2 Signal Confidence Value(s)** – This option compares the specified ICESat-2 signal confidence photons to the reference data mean Z values and minimizes the Z error
- **Use Reference Ground Index** – This option specifies the classification number of the ground photons in the reference file to compare against the ATL03 ground classified photons (requires an ATL08 file)
- **Save Shifted ICESat-2 File** – Saves the shifted ICESat-2 ground track with XYZ offsets as a .las file
- **Make Output Plots** – Saves output figures from the offset finding algorithm (.png and .pkl file formats)

(5)

Find ICESat-2 Offsets Relative to Reference Data ☑

Cross-Track Bounds (m): -50, 50   Along-Track Bounds (m): -50, 50

☐ Use Fixed Vertical Shift   Vertical Shift (m): 0

Grid Resolution(s) (m): 8, 4, 2, 1   Use ICESat-2 Heights: Ellipsoidal (HAE) ▼

☑ Use ICESat-2 Signal Confidence Value(s): 3, 4

☐ Use Reference Ground Index: 2   (Requires ATL08 File)

☑ Save Shifted ICESat-2 File   ☑ Make Output Plots

Grayed out by default, check the box to activate

PhoREAL (Home Tab – Run Button)

Run Button:

- This button runs PhoREAL
- This button grays out while PhoREAL is executing
- The progress bar show the current progress
- All verbose output is printed to the Windows terminal that opens up with PhoREAL. Do not delete the Windows terminal as it will close PhoREAL as well.

6

RUN	Progress:

PhoREAL Windows Terminal

PhoREAL (Plot Data Tab)

PhoREAL (Plot Data Tab)

PhoREAL (Plot Data Tab – Plotting Options)

ATL03 Plotting Options:

- This section will populate with data after a successful execution of PhoREAL
- **File Name (Load)** – this button provides users with the option to load files previously executed using PhoREAL. After successful execution of PhoREAL, a *_data.pkl file gets created in the output directory which can be loaded for quick analysis.
- **Ground Track** – displays the available ground tracks for plotting (based on user selection and which ground tracks contained data)
- **X Axis** – displays the values that can be plotted on the X axis (Options: Time, Delta Time, Latitude, Longitude, UTM Easting, UTM Northing, Cross-Track, Along-Track, Height (Ellipsoidal), Classification)
- **X Label** – sets the X label for the plot, this can be edited
- **Y Axis** – displays the values that can be plotted on the Y axis (Options: Time, Delta Time, Latitude, Longitude, UTM Easting, UTM Northing, Cross-Track, Along-Track, Height (Ellipsoidal), Classification)
- **Y Label** – sets the Y label for the plot, this can be edited
- **Filter On** – allows the user to set how to filter the plot (Options: None, ATL08 Classification, or ATL03 Signal Confidence)
- If the Filter option is used, the Signal Confidence or Classification filter options populate below the Filter On box
- **Plot Button** – this button creates the plot as a new figure window

1

Plot ICESat-2 ATL03 Data

File Name: [_____] **Load**

Ground Track: [_____⌄]

X Axis: [_____⌄]   X Label: [_____]

Y Axis: [_____⌄]   Y Label: [_____]

Filter On: [_____⌄]   **Plot**

PhoREAL (Plot Data Tab – Stats Options)

Compute and Plot Stats:
- This section will load after a successful execution of PhoREAL (requires an ATL08 file)
- **Segment Stats By** – segment option to compute stats (Options: Time, Latitude, UTM Northing)
- **Segment Increment** – segment increment to compute stats
- **Compute Stats Button** – computes stats using the segment inputs. This button grays out during execution.
- **Add Stats to Plot** – this option populates after successful computation of stats. The stats can be added to a plot or exported to a .csv file (Stats Options: Ground Min, Ground Max, Ground Median, Ground Mean, Ground Mean + 3*Std, Ground Mean - 3*Std, All Canopy Min, All Canopy Max, All Canopy Median, All Canopy Mean, All Canopy Mean + 3*Std, All Canopy Mean - 3*Std, All Height Min, All Height Max, All Height Median, All Height Mean, All Height Mean + 3*Std, All Height Mean - 3*Std)
- **Export Button** – exports stats to a .csv file
- **Plot Stats Button** – adds stats to most recent plot

(2)

Compute and Plot Stats

Status: Export Stats to CSV:

Segment Stats by: **Compute Stats**   **Export**

Segment Increment: Add Stats to Plot: **Plot Stats**

PhoREAL (Plot Data Tab – Adding Layers)

Add Layers to Plot:
- This section will load after a successful execution of PhoREAL and allows users to add layers onto the most recent plot
- **ATL08 Data to Add** – this adds ATL08 data to the most recent plot (Options: Max Canopy, Terrain Best Fit, and Terrain Median for HAE and MSL heights). This requires ATL08 data.
- **Add Reference** – this adds reference data to the most recent plot. This requires reference data. This data cannot be plotted when the X/Y axis parameters are set to Classification or Signal Confidence. Note: in order to provide Time and Delta Time values for the reference data, these values had to be calculated via linear interpolation using the ICESat-2 times.
- **Add Shifted Data** – this adds the shifted ICESat-2 data to the most recent plot. This is the data that has been shifted in XYZ to minimize Z error relative to the reference data. The shifted data will be plotted for whichever parameters are set in the X/Y axis for the ICESat-2 plot.

3

Add Layers to Plot

ATL08 Data to Add:

Add ATL08

Reference data can be plotted for:
easting, northing, cross-track,
along-track, or height.

Add Reference

Shifted ICESat-2 data can be plotted for:
easting, northing, cross-track,
along-track, or height.

Add Shifted Data

PhoREAL (Plot Data Tab – HTML Option)

PhoSHOW:

- **PhoSHOW Button** – this button calls a function to arrange the output plot data into HTML format and renders it in a web browser for interactive viewing.
- If there is no internet connection, this function calls a local copy of d3 (JavaScript plotting package) to help render the data into a web browser.
- If there is an internet connection, then this data is rendered in a regular web browser and base maps can be used.

④

PhoSHOW

View output data in HTML format: **PhoSHOW**
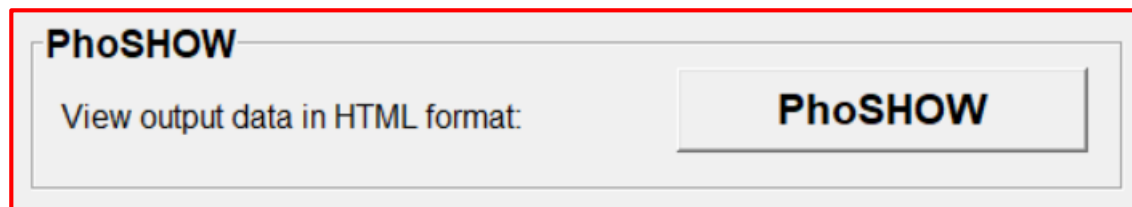
PhoREAL (Plot Data Tab – Load Figures)

Load Figure:

- **Browse Button** - this button loads figures created by PhoREAL that are stored in *fig*.pkl format.
- These figures are interactive and can be analyzed better than using figures in .png format.

PhoREAL (Help Tab)

PhoREAL v3.27 - Applied Research Labs (The University of Texas at Austin) — □ ✕

Home Stats Plot Help About

PhoREAL Help Information
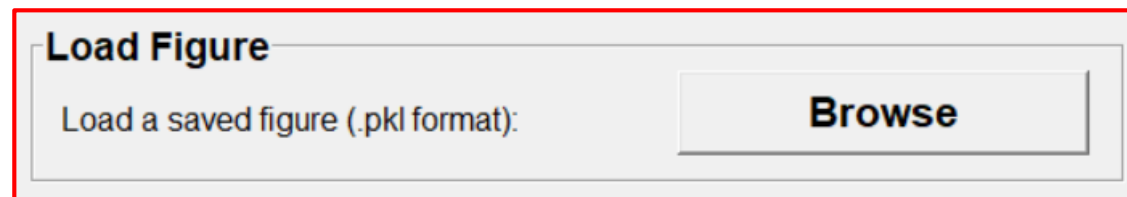
Get ICESat-2 Data Input Section:

This section handles the input ATL03/ATL08 files from ICESat-2

+ ATL03 File: Path to input ATL03 .h5 file(s) or directory
+ ATL08 File: Path to input ATL08 .h5 file(s) or directory
+ Output Directory: Path to directory for output data
+ Ground Track Numbers: Option to select ICESat-2 ground tracks
+ Trim ICESat-2 Data Options: Methods to trim ICESat-2 data
   - None: No trimming
   - Manual: Trim to user-specified latitude or time min/max bounds
   - Auto: Trim to reference region bounds (uses kmlBounds.txt file)
+ Create Output Files: Option to create output files for ICESat-2 data

Get Reference Data Input Section:

This section handles the reference data used to find ICESat-2 offsets

+ Use Existing Data: Option to use existing reference buffer data
+ Buffer Size: Buffer to create around ICESat-2 track in reference data
+ Save Reference File: Option to create output reference buffer .las file
+ Reference File(s): Path to reference file(s) or directory (.las or .tif)

Find ICESat-2 Offsets Relative to Reference Data Section:

This section slides the ICESat-2 data over the reference data and finds the offset with the minimum Mean Absolute Error in the Z direction (location of best fit relative to reference data)

+ Cross-Track Bounds (m): Cross-track search area [min, max] or one value
+ Along-Track Bounds (m): Along-track search area [min, max] or one value
+ Use Fixed Vertical Shift: Option to use a fixed vertical shift value
+ Vertical Shift (m): Vertical shift value if previous option is selected
+ Grid Resolution(s) (m): Raster resolution(s) to grid reference data
+ Use ICESat-2 Heights: Option to use Ellipsoidal (HAE) heights or Orthometric (MSL) heights when comparing to reference data
   Note: Geoidal heights have been calculated on the ATL03 data product using the EGM2008 ellipsoid
+ Use ICESat-2 Signal Confidence Value(s): Option to use ICESat-2 signal confidence values to filter measured data
   - Input signal confidence values to filter ICESat-2 data
+ Use Reference Ground Index: Option to use reference ground index value to filter reference data (Requires ATL08 file)
   - Reference ground index value (ASPRS ground class = 2)
+ Save Shifted ICESat-2 File: Option to save ICESat-2 shifted XYZ file
+ Make Output Plots: Option to create output plots

PhoREAL (About Tab)
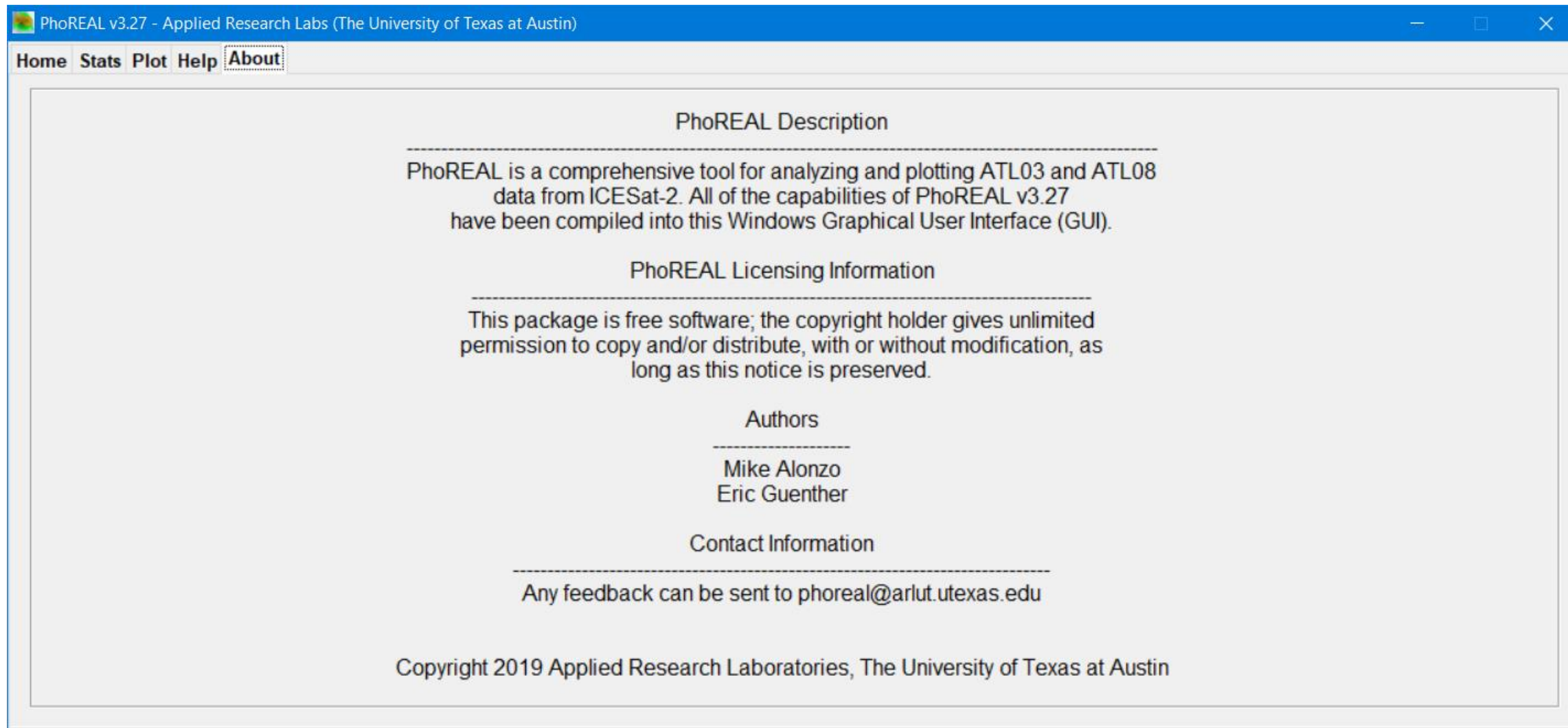
PhoREAL v3.24

User Example 1
ATL03 Classifications
ICESat-2 Ground Track over Quebec, Canada

PhoREAL (User Example 1: GUI)

PhoREAL (User Example 1: Inputs)

PhoREAL Section	Input Parameter	Value
ICESat-2 Inputs	**ATL03 File:**	ATL03_20181027194559_04460102_003_01.h5 (Quebec, Canada)
	ATL08 File:	ATL08_20181027194559_04460102_003_01.h5 (Quebec, Canada)
	Ground Track:	GT2R
	Trim Mode:	None
	Output Files:	ATL03 .las, .kml, .csv
Reference File Inputs	**Reference File:**	N/A
	Buffer Size:	N/A
	Save Reference File:	N/A
ICESat-2 Offset Inputs	**Cross-Track Bounds:**	N/A
	Along-Track Bounds:	N/A
	Use Vertical Shift:	N/A
	Grid Resolutions:	N/A
	Use ICESat-2 Heights:	N/A
	Use Reference Ground Index:	N/A
	Save Shifted ICESat-2 File:	N/A
	Make Output Plots:	N/A

PhoREAL (User Example 1: Output .kml File)
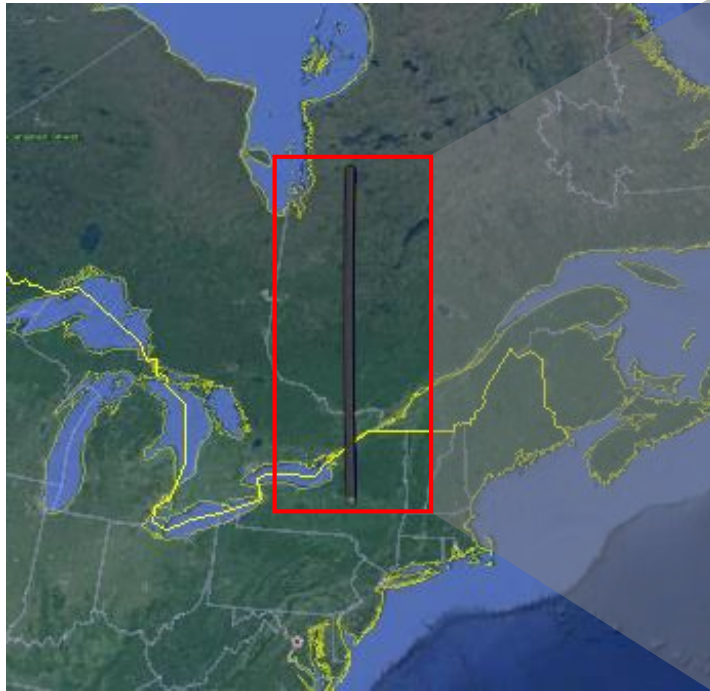
ICESat-2 Track Over Quebec
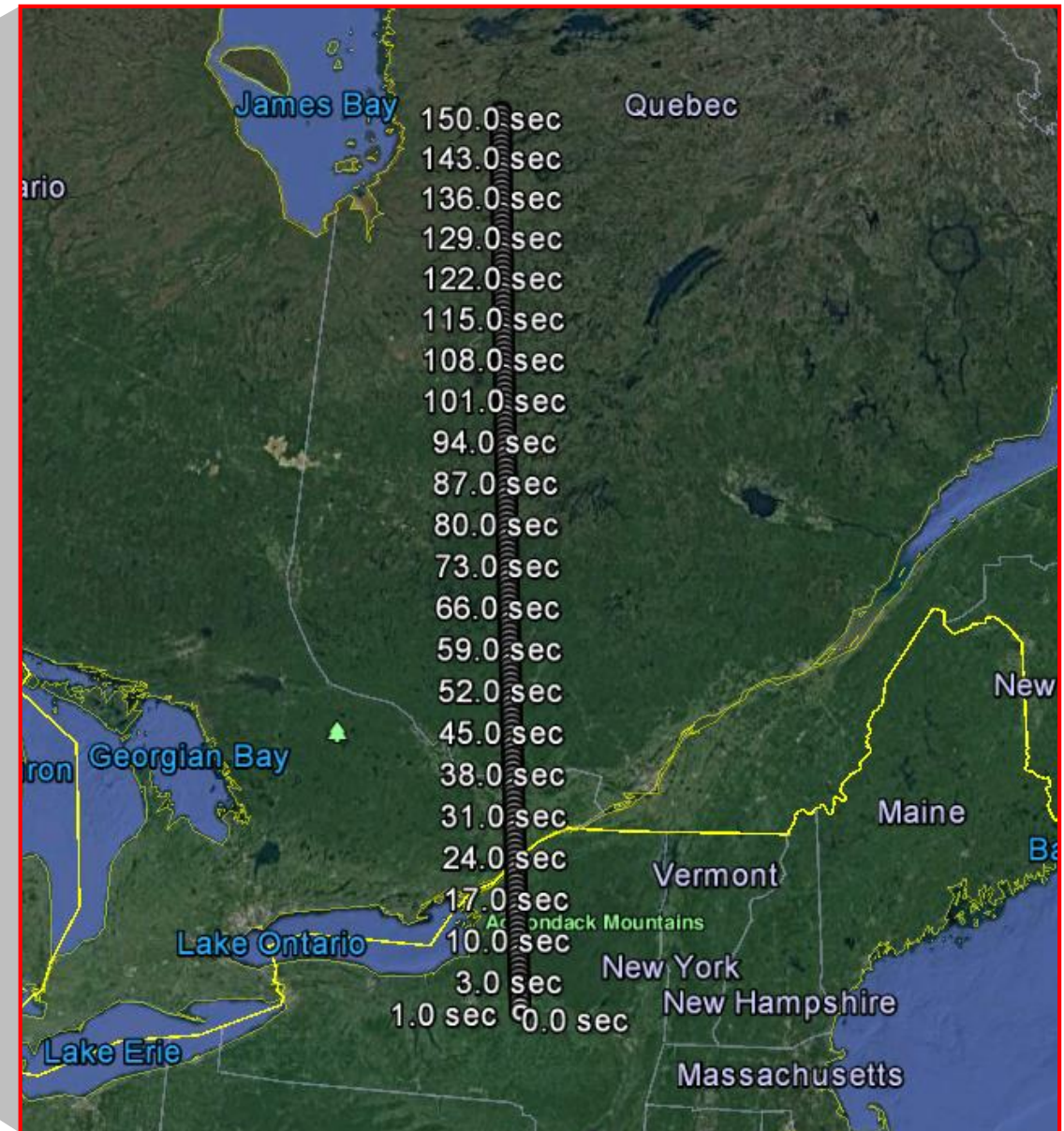
Output .kml File in Google Earth

PhoREAL (User Example 1: Output .las File)

Classifications:

- 0 = ATL03 Unclassified
- 1 = ATL03 Ground
- 2 = ATL03 Canopy
- 3 = ATL03 Top of Canopy

Output .las File in QT Modeler

PhoREAL (User Example 1: Output .csv File)

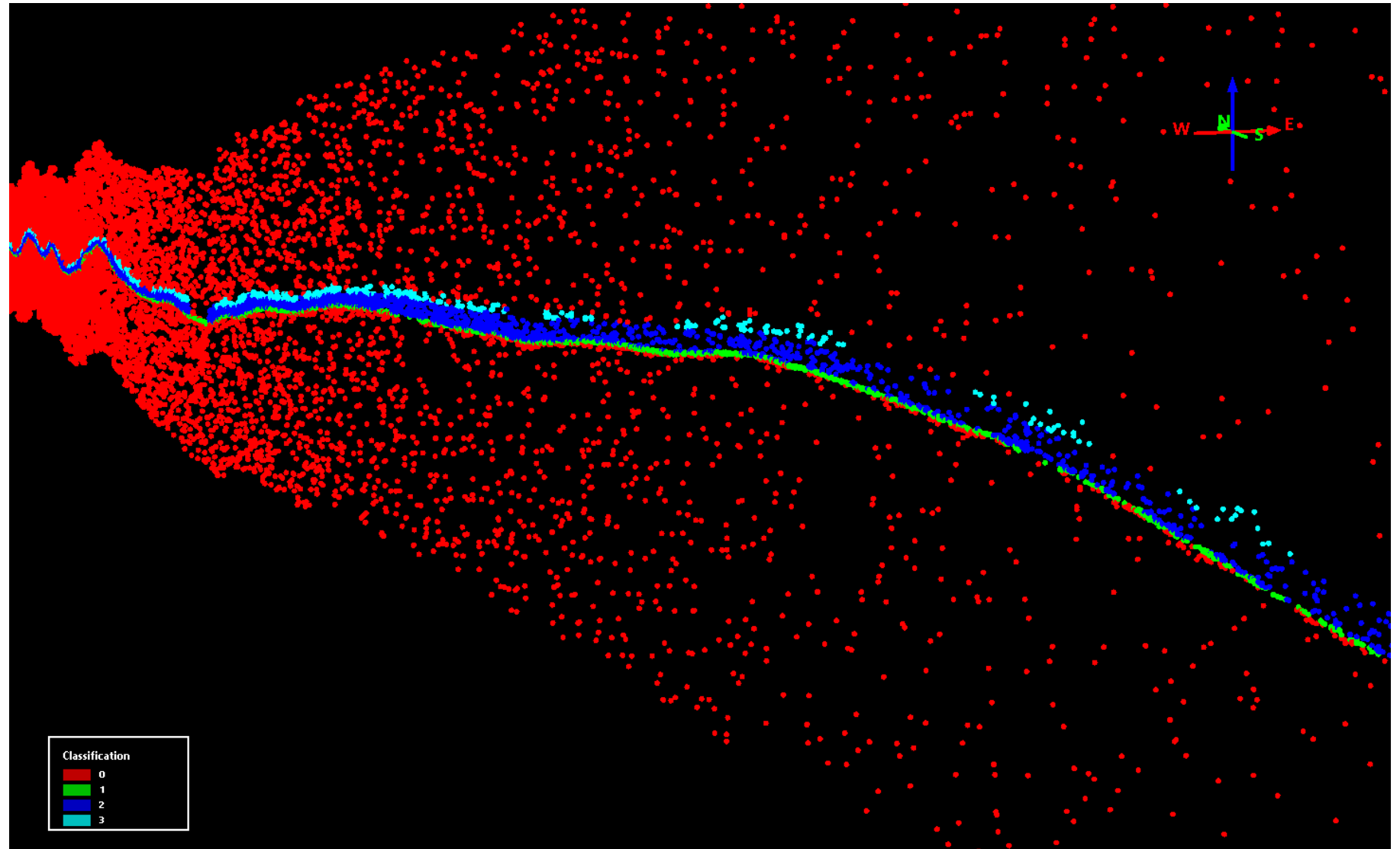|	A	B	C	D	E	F	G	H	I	J	K	L
1	Time (sec)	Delta Time (sec)	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)	Cross-Track (m)	Along-Track (m)	Height (m HAE)	Height (m MSL)	Classification	Signal Confidence
2	0	25905010.58	43.0022014	-75.37972241	469050.5412	4761129.205	0	0	841.6308594	874.562767	0	-1
3	0	25905010.58	43.00220154	-75.3797226	469050.526	4761129.221	-0.013872161	0.017488829	844.3967896	877.3286972	0	-1
4	0	25905010.58	43.00220077	-75.3797216	469050.6066	4761129.135	0.05938581	-0.074920673	829.7900391	862.7219467	0	-1
5	0	25905010.58	43.00220027	-75.37972096	469050.6585	4761129.08	0.106586207	-0.134489347	820.3789063	853.3108139	0	-1
6	0	25905010.58	43.00219648	-75.37971609	469051.0542	4761128.657	0.466225988	-0.588282102	748.6723022	781.6042099	0	-1
7	0	25905010.58	43.00219294	-75.37971153	469051.4236	4761128.262	0.801988637	-1.01193969	681.7278442	714.6597519	0	-1
8	0	25905010.58	43.00219318	-75.37971184	469051.3987	4761128.289	0.779420604	-0.983462936	686.227417	719.1593246	0	-1
9	0.000100002	25905010.58	43.00220774	-75.37972317	469050.4822	4761129.91	-0.0009869	0.70742372	840.4920044	873.4239302	0	-1
10	0.000100002	25905010.58	43.00220575	-75.3797206	469050.6906	4761129.687	0.188501026	0.468336398	802.7105713	835.6424971	0	-1
11	0.000100002	25905010.58	43.00220408	-75.37971846	469050.8646	4761129.501	0.346610811	0.268830139	771.1859131	804.1178389	0	-1
12	0.000100002	25905010.58	43.00220433	-75.37971878	469050.8383	4761129.529	0.322726093	0.298974885	775.9481201	808.8800459	0	-1
13	0.000100002	25905010.58	43.00220258	-75.37971653	469051.0212	4761129.334	0.488938161	0.08923269	742.8082886	775.7402144	0	-1
14	0.000100002	25905010.58	43.00220045	-75.37971378	469051.2438	4761129.096	0.691281716	-0.166055655	702.4648438	735.3967696	0	-1
15	0.000100002	25905010.58	43.00220095	-75.37971443	469051.1914	4761129.152	0.643618882	-0.105929519	711.9678955	744.8998213	0	-1
16	0.000100002	25905010.58	43.0022003	-75.37971359	469051.2594	4761129.079	0.705465466	-0.183967498	699.6369629	732.5688887	0	-1
17	0.000100002	25905010.58	43.00219779	-75.37971037	469051.5209	4761128.8	0.94313665	-0.48384024	652.2505493	685.1824751	0	-1
18	0.000200011	25905010.58	43.00221452	-75.37972449	469050.3785	4761130.662	-0.042505138	1.466073237	847.4360352	880.3679791	0	-1
19	0.000200011	25905010.58	43.00221495	-75.37972504	469050.3333	4761130.711	-0.083583121	1.517885715	855.6265259	888.5584698	0	-1
20	0.000200011	25905010.58	43.00220949	-75.37971802	469050.9034	4761130.102	0.434563353	0.864113387	752.3154297	785.2473736	0	-1
21	0.000200011	25905010.58	43.00220472	-75.37971188	469051.4014	4761129.57	0.887186965	0.293007889	662.0714111	695.0033551	0	-1
22	0.000300013	25905010.58	43.00222111	-75.37972556	469050.294	4761131.395	-0.066625372	2.202739157	850.9126587	883.8446208	0	-1
23	0.000300013	25905010.58	43.00221525	-75.37971803	469050.9052	4761130.742	0.488887552	1.50180041	740.1514893	773.0834514	0	-1
24	0.000300013	25905010.58	43.002216	-75.37971899	469050.8272	4761130.825	0.417975532	1.591265985	754.2901611	787.2221232	0	-1
25	0.000300013	25905010.58	43.00221229	-75.37971422	469051.2142	4761130.412	0.769723152	1.147444449	684.1584473	717.0904094	0	-1

Output .csv File in Excel

PhoREAL (User Example 1: Output Figure in PhoREAL)

Classifications:

- ATL03 Unclassified
- ATL03 Ground
- ATL03 Canopy
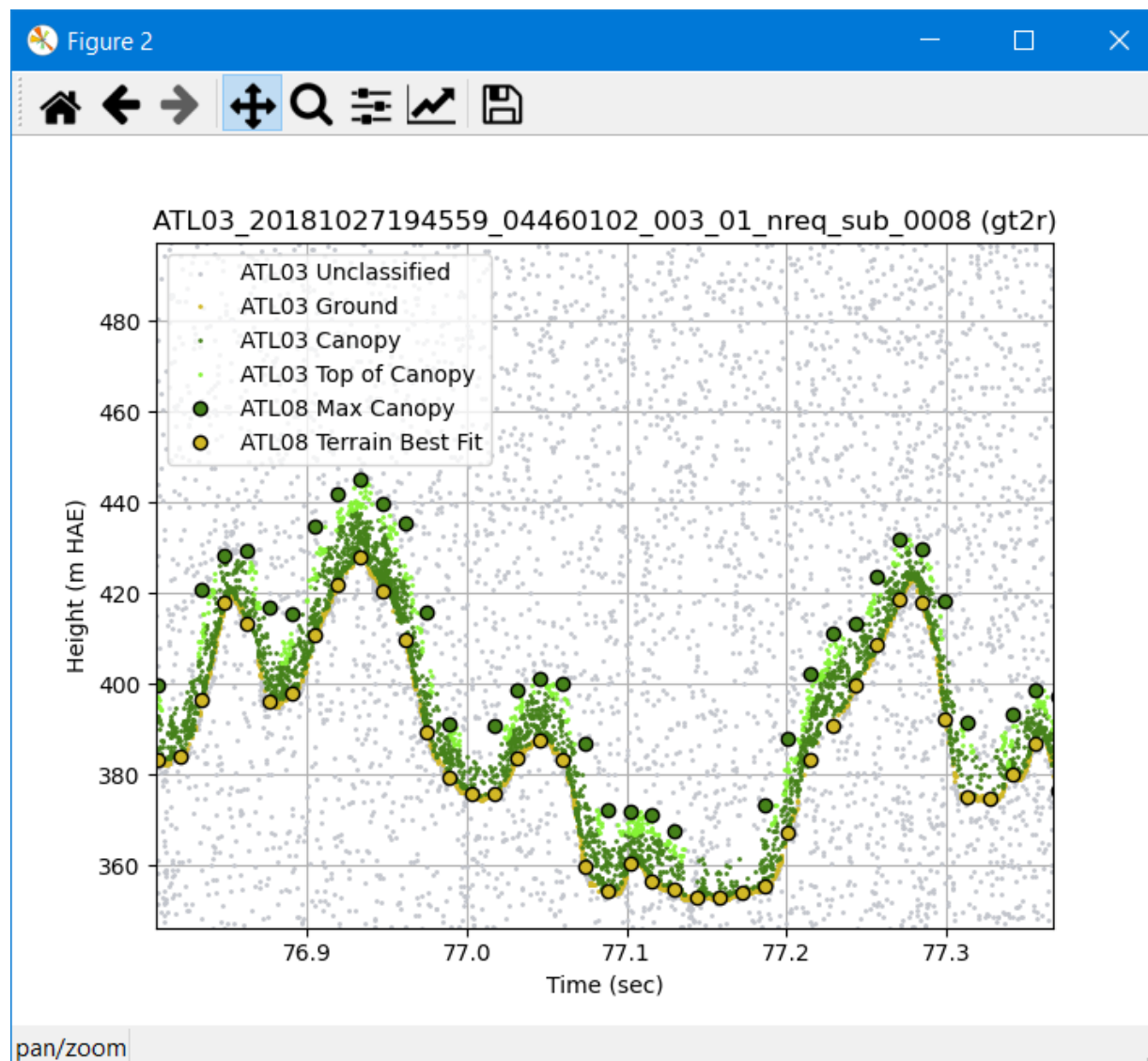- ATL03 Top of Canopy
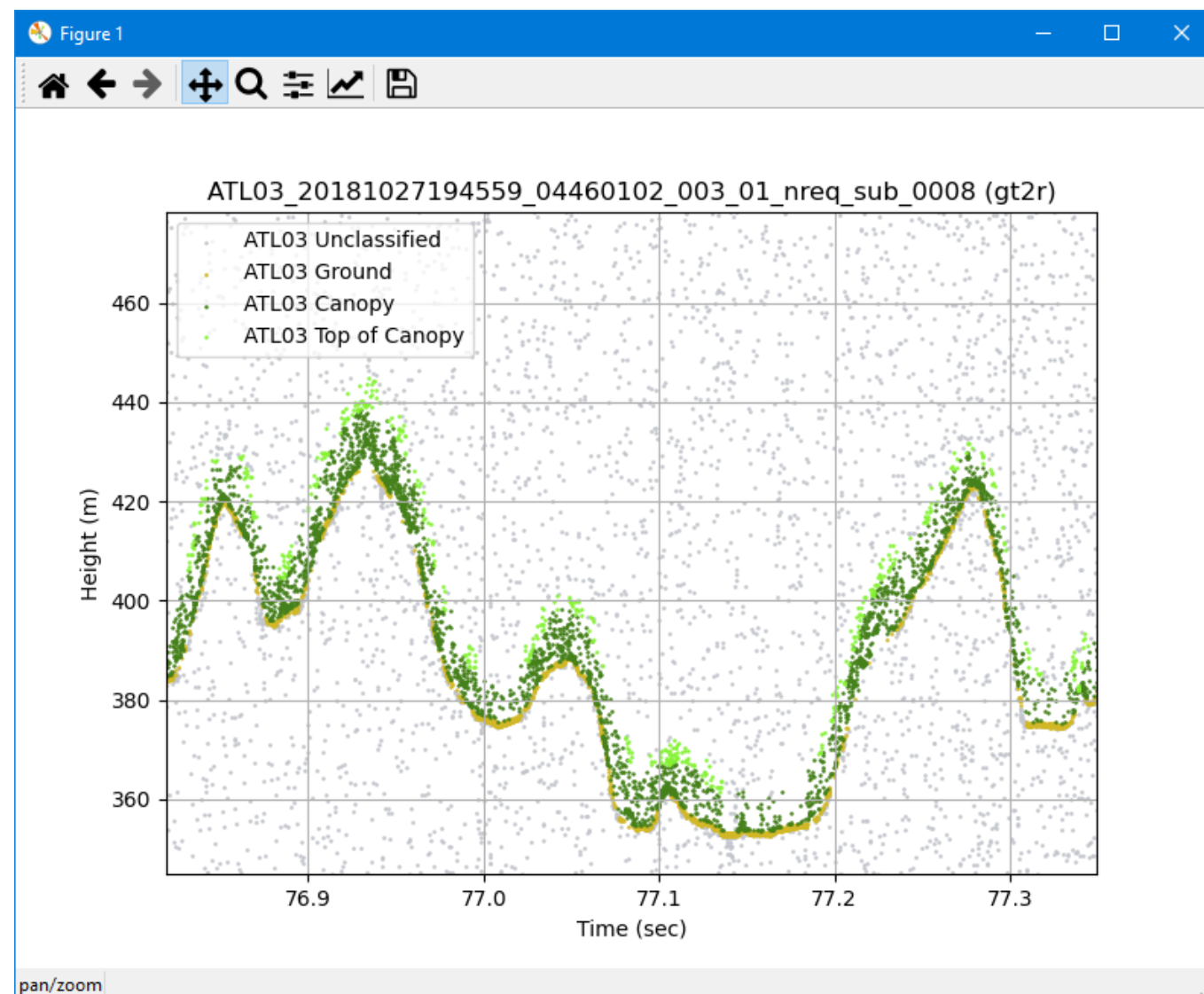
Output Figure in PhoREAL

PhoREAL (User Example 1: Output Figure in PhoREAL)

Adding ATL08 Layers

Classifications:

- ATL03 Unclassified
- ATL03 Ground
- ATL03 Canopy
- ATL03 Top of Canopy
- ● ATL08 Max Canopy
- ● ATL08 Terrain Best Fit

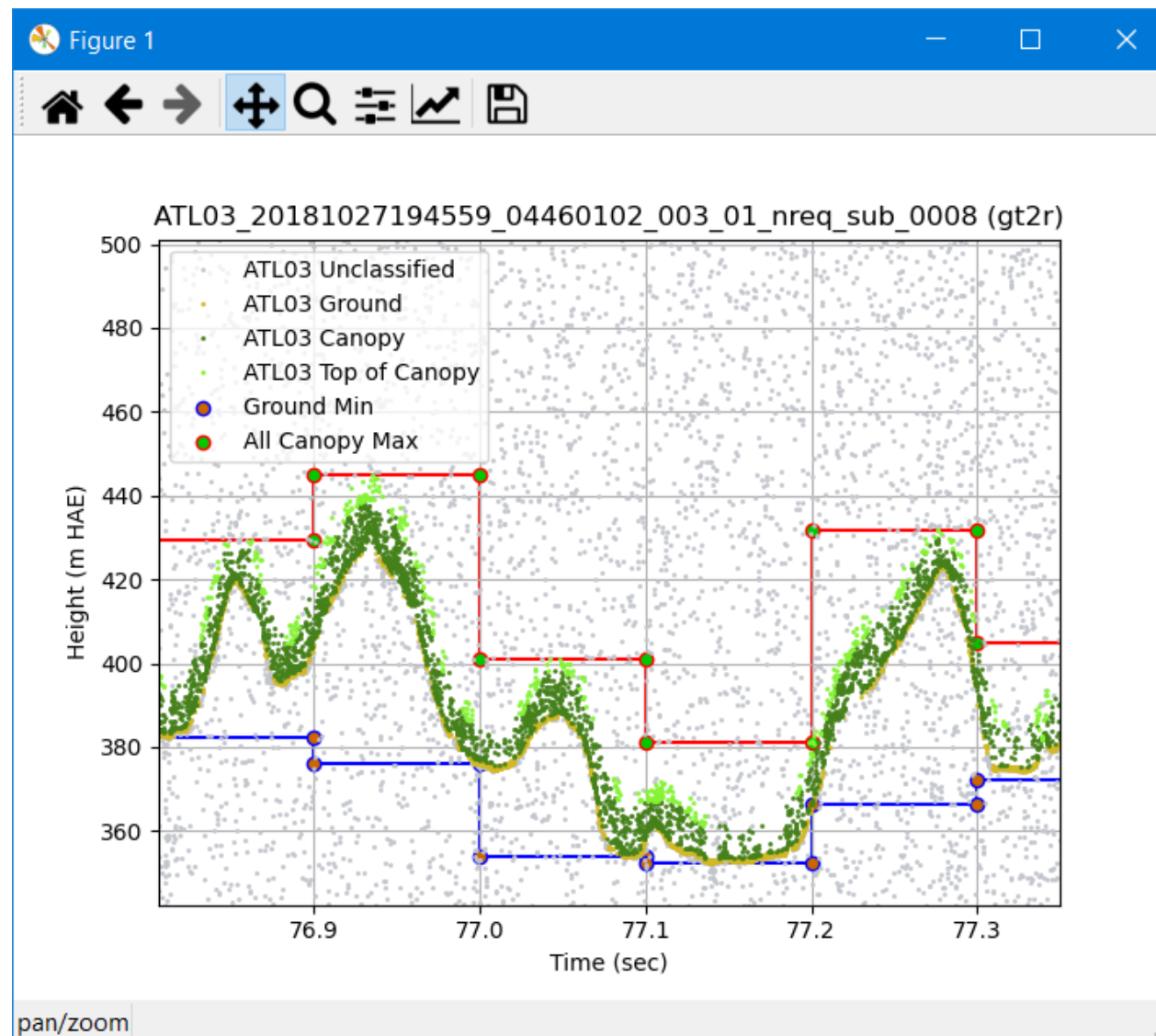*Output Figure in PhoREAL*

PhoREAL (User Example 1: Output Figure in PhoREAL)

Adding Stats Layers at
0.1 sec intervals

Classifications:

- ATL03 Unclassified
- ATL03 Ground
- ATL03 Canopy
- ATL03 Top of Canopy
- Ground Min
- All Canopy Max

Output Figure in PhoREAL

PhoREAL v3.24

User Example 2
Comparing ICESat-2 to Reference .tif Files
Finland

PhoREAL (User Example 2: GUI)

PhoREAL (User Example 2: Inputs)

PhoREAL Section	Input Parameter	Value
ICESat-2 Inputs	**ATL03 File:**	ATL03_20181021130238_03500103_002_01.h5 (Finland)
	ATL08 File:	ATL08_20181021130238_03500103_002_01.h5 (Finland)
	Ground Track:	GT2R
	Trim Mode:	None
	Output Files:	ATL03 .las, .kml, .csv
Reference File Inputs	**Reference File:**	Directory of TanDEM-X reference .tif files over Finland (ARL Dataset)
	Buffer Size:	50 m
	Save Reference File:	Yes
ICESat-2 Offset Inputs	**Cross-Track Bounds:**	N/A
	Along-Track Bounds:	N/A
	Use Vertical Shift:	N/A
	Grid Resolutions:	N/A
	Use ICESat-2 Heights:	N/A
	Use Reference Ground Index:	N/A
	Save Shifted ICESat-2 File:	N/A
	Make Output Plots:	N/A

PhoREAL (User Example 2: Output .kml File)
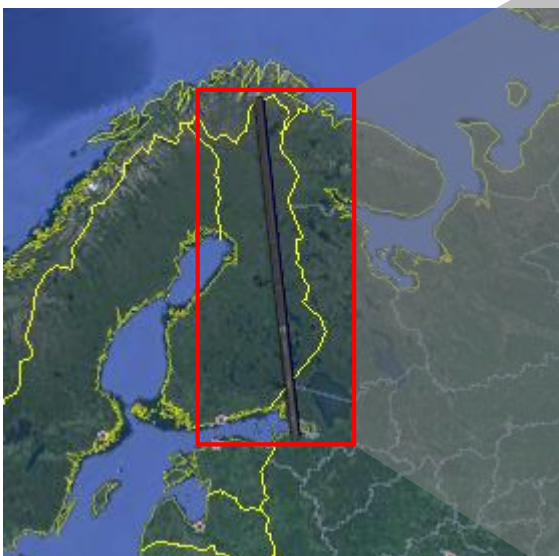
ICESat-2 Track Over Finland
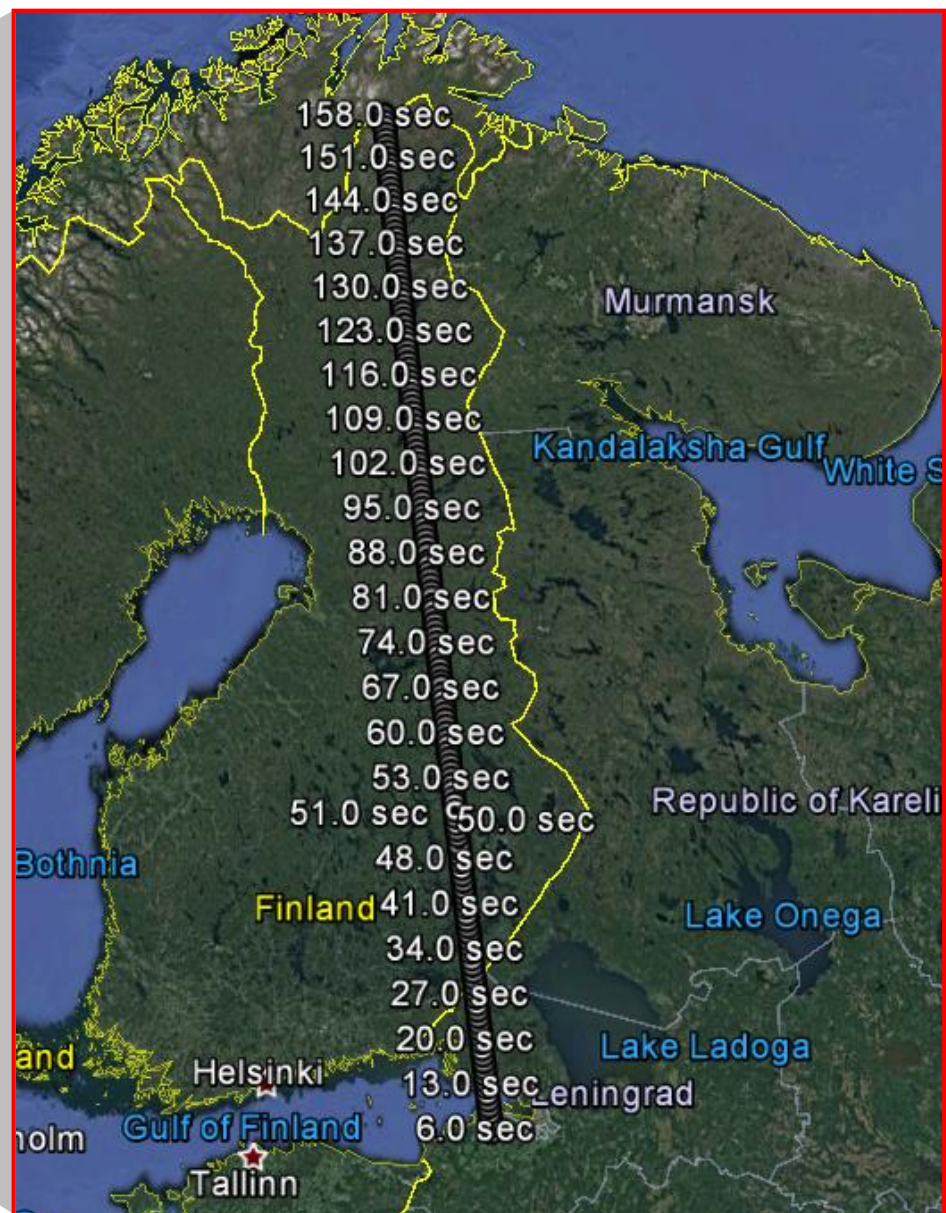
Output .kml File in Google Earth

PhoREAL (User Example 2: Output .las File)

Output .las File in QT Modeler

Classifications:

- Reference Data

Output .las File in QT Modeler

Classifications:

- Reference Data
- ATL03 Unclassified (not shown)
- ATL03 Ground
- ATL03 Canopy
- ATL03 Top of Canopy

PhoREAL (User Example 2: Output .csv File)

	A	B	C	D	E	F	G	H	I	J	K	L
1	Time (sec)	Delta Time (sec)	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)	Cross-Track (m)	Along-Track (m)	Height (m HAE)	Height (m MSL)	Classification	Signal Confidence
2	0	25362163.58	59.76168043	29.42821039	636392.7633	6627368.068	0	0	138.505188	122.6956013	0	0
3	0	25362163.58	59.76167952	29.42821201	636392.858	6627367.97	0.081130887	-0.110014085	120.5898056	104.7802189	2	0
4	0	25362163.58	59.76167812	29.42821447	636393.002	6627367.819	0.204605483	-0.277456445	93.32426453	77.5146778	1	2
5	0	25362163.58	59.76167477	29.42822039	636393.3483	6627367.459	0.501453401	-0.679971463	27.77549553	11.96590881	0	0
6	0.000200003	25362163.58	59.76169079	29.42821195	636392.8089	6627369.224	0.194353807	1.140496639	93.22445679	77.41489078	1	2
7	0.000200003	25362163.58	59.76168844	29.4282161	636393.0518	6627368.971	0.402596724	0.858115843	47.24100876	31.43144275	0	0
8	0.000300001	25362163.58	59.76169817	29.42820883	636392.6038	6627370.04	0.096211051	1.975526101	113.7114258	97.90187013	2	0
9	0.000300001	25362163.58	59.76169816	29.42820885	636392.6049	6627370.038	0.097196433	1.974184431	113.4938431	97.68428743	2	0
10	0.000400003	25362163.58	59.76170359	29.42820918	636392.6012	6627370.644	0.17163676	2.575173329	95.86914825	80.05960297	2	2
11	0.000500001	25362163.58	59.76170655	29.4282139	636392.8539	6627370.982	0.465876973	2.878034056	29.70742989	13.89789496	0	0
12	0.000700001	25362163.58	59.76172343	29.42820391	636392.2243	6627372.841	0.081468362	4.802895021	112.2069168	96.3974026	2	0
13	0.000800002	25362163.58	59.76172473	29.42821154	636392.6475	6627373.002	0.521903479	4.907417752	13.75674057	-2.052763282	0	0
14	0.0009	25362163.58	59.76173631	29.428201	636392.0084	6627374.269	0.051717014	6.246697106	116.3837128	100.5742193	2	0
15	0.001000013	25362163.58	59.76174172	29.42820137	636392.0073	6627374.872	0.128381892	6.844479703	98.25485229	82.44536916	2	1
16	0.001100011	25362163.58	59.76174817	29.4281999	636391.898	6627375.587	0.112275524	7.567921151	100.6095047	84.80003193	2	1
17	0.001300011	25362163.59	59.76176042	29.4281981	636391.7475	6627376.947	0.138506977	8.935433538	92.40649414	76.59704208	0	2
18	0.00150001	25362163.59	59.7617755	29.42819131	636391.3042	6627378.611	-0.086278343	10.64316476	139.6233521	123.8139208	0	0
19	0.001600012	25362163.59	59.76177967	29.42819386	636391.4307	6627379.081	0.099746786	11.09232429	97.33203125	81.52261037	2	2
20	0.00170001	25362163.59	59.76178503	29.42819431	636391.4342	6627379.678	0.180351758	11.6843577	78.31732178	62.50791129	0	0
21	0.001800012	25362163.59	59.76179697	29.42818312	636390.7571	6627380.985	-0.322476393	13.06748616	188.133316	172.3239159	0	0
22	0.001800012	25362163.59	59.76179224	29.42819148	636391.2459	6627380.475	0.096513145	12.49934325	95.6120224	79.8026223	2	2
23	0.002000023	25362163.59	59.7618048	29.42818914	636391.0631	6627381.868	0.09498761	13.90396335	93.50499725	77.69561794	1	3
24	0.002100021	25362163.59	59.76180976	29.42819028	636391.1072	6627382.423	0.210292966	14.448767	66.8182373	51.00886838	0	0
25	0.002200022	25362163.59	59.76181746	29.42818661	636390.8692	6627383.272	0.08391045	15.32127284	93.49739838	77.68803985	1	3

Output .csv File in Excel

PhoREAL (User Example 2: Output Figure in PhoREAL)

Classifications:

- ATL03 Unclassified
- ATL03 Ground
- ATL03 Canopy
- ATL03 Top of Canopy
- Finland Reference Data

Output Figure in PhoREAL

PhoREAL v3.24

User Example 3
Comparing ICESat-2 to Reference .las Files
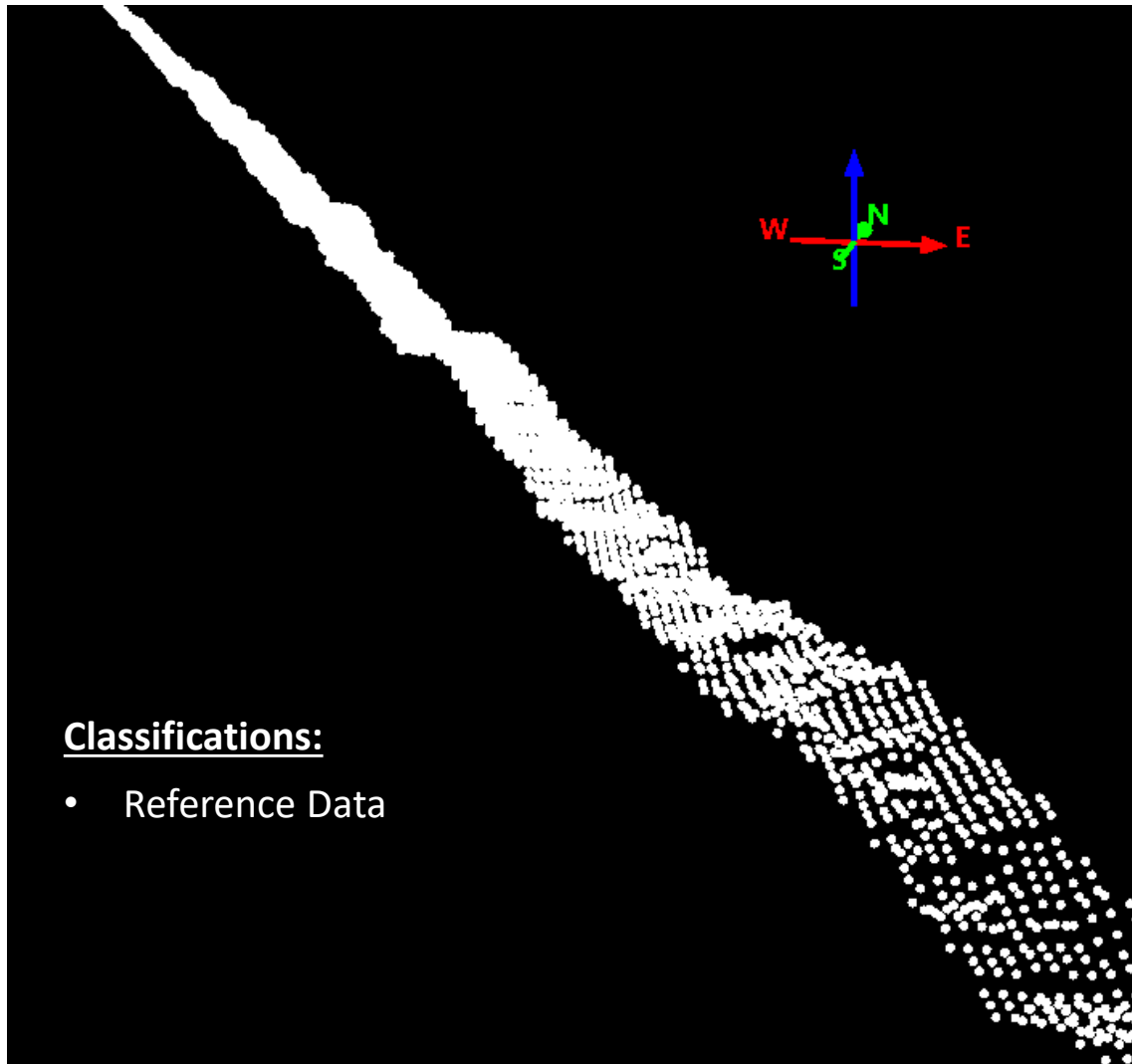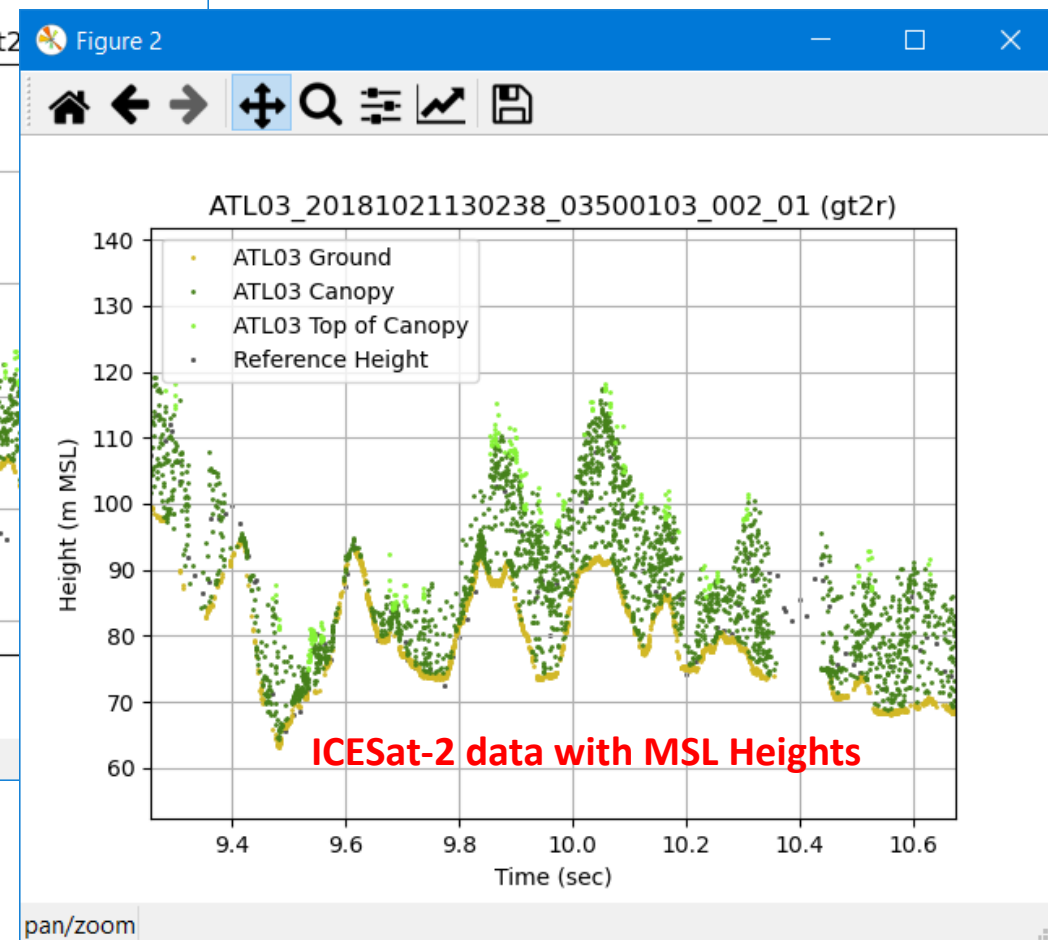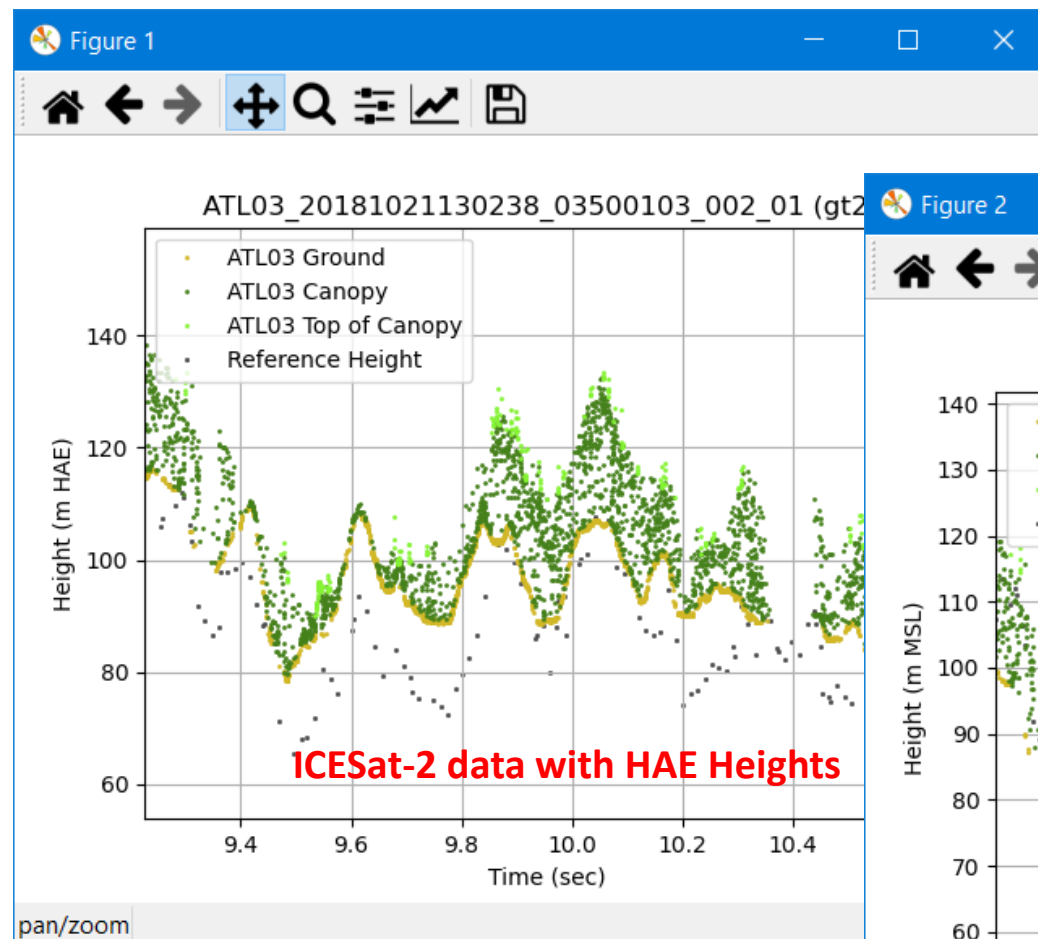## Sonoma, CA

PhoREAL (User Example)

PhoREAL (User Example)

PhoREAL Section	Input Parameter	Value
ICESat-2 Inputs	**ATL03 File:**	ATL03_20181030110205_04860106_002_01.h5 (Sonoma, CA)
	ATL08 File:	ATL08_20181030110205_04860106_002_01.h5 (Sonoma, CA)
	Ground Track:	GT2R
	Trim Mode:	None
	Output Files:	ATL03 .las, .kml, .csv
Reference File Inputs	**Reference File:**	A directory of airborne lidar reference .las files over Sonoma, CA (ARL-UT Dataset)
	Buffer Size:	50 m
ICESat-2 Offset Inputs	**Save Reference File:**	Yes
	Cross-Track Bounds:	-50, 50
	Along-Track Bounds:	-50, 50
	Use Vertical Shift:	No
	Grid Resolutions:	8, 4, 2, 1
	Use ICESat-2 Heights:	Orthometric (MSL)
	Use Reference Ground Index:	2
	Save Shifted ICESat-2 File:	Yes
	Make Output Plots:	Yes

PhoREAL (Output .kml File)
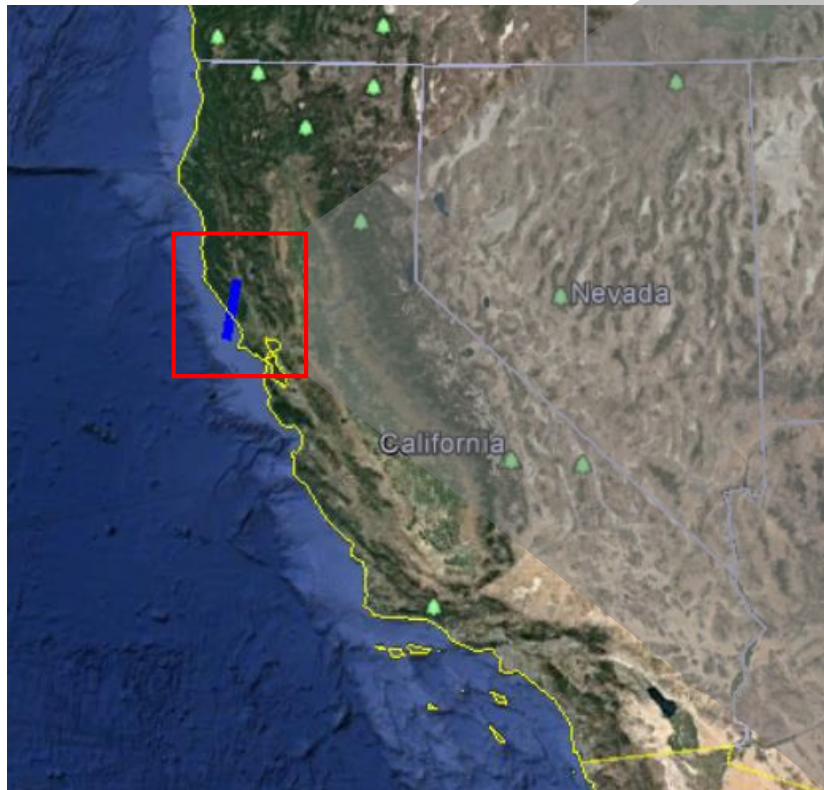
ICESat-2 Track Over Sonoma, CA
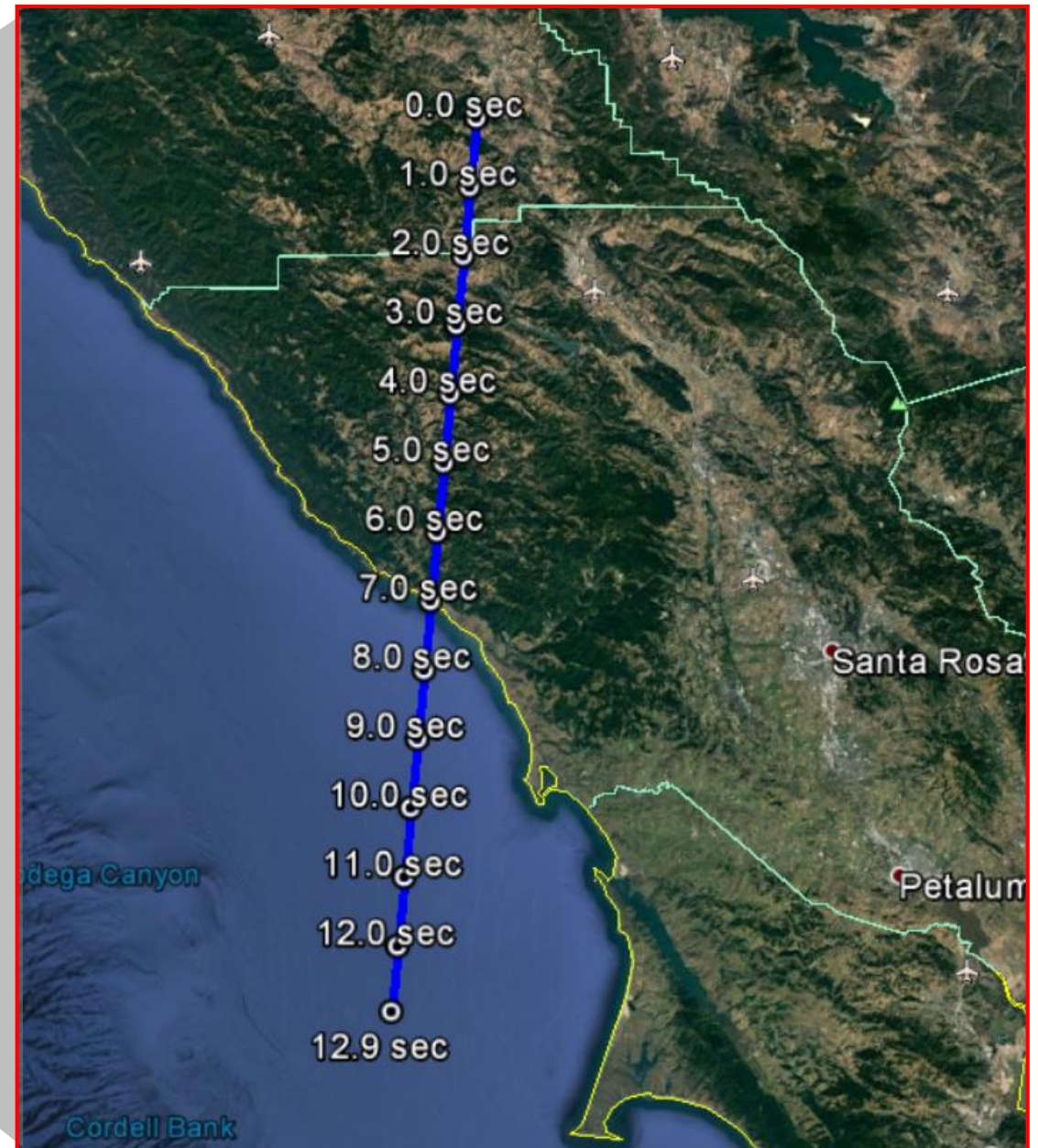
Output .kml File in Google Earth

PhoREAL (Output .las Files)

ICESat-2 Track

Airborne Lidar Reference
Data over Sonoma, CA
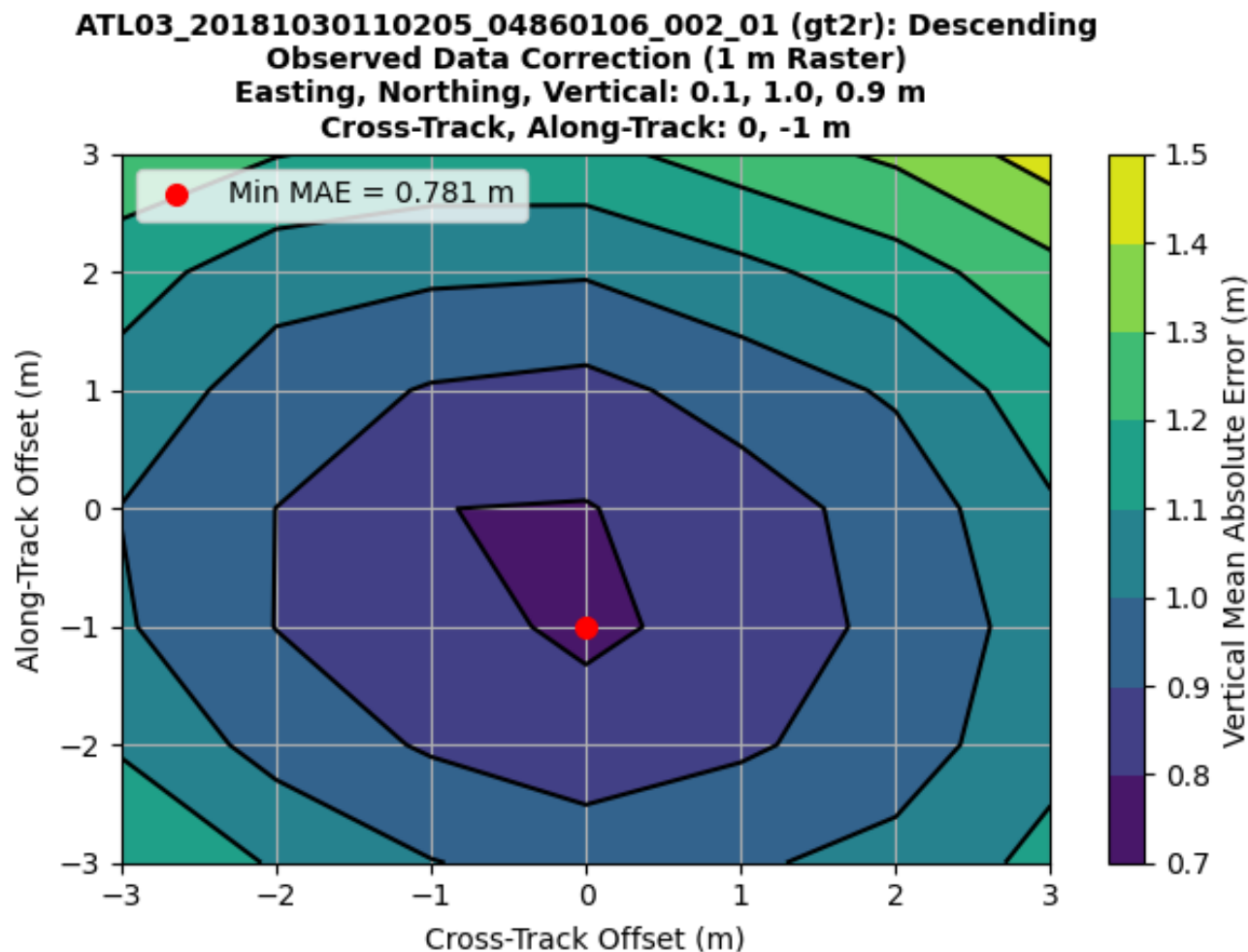(ARL-UT Dataset)
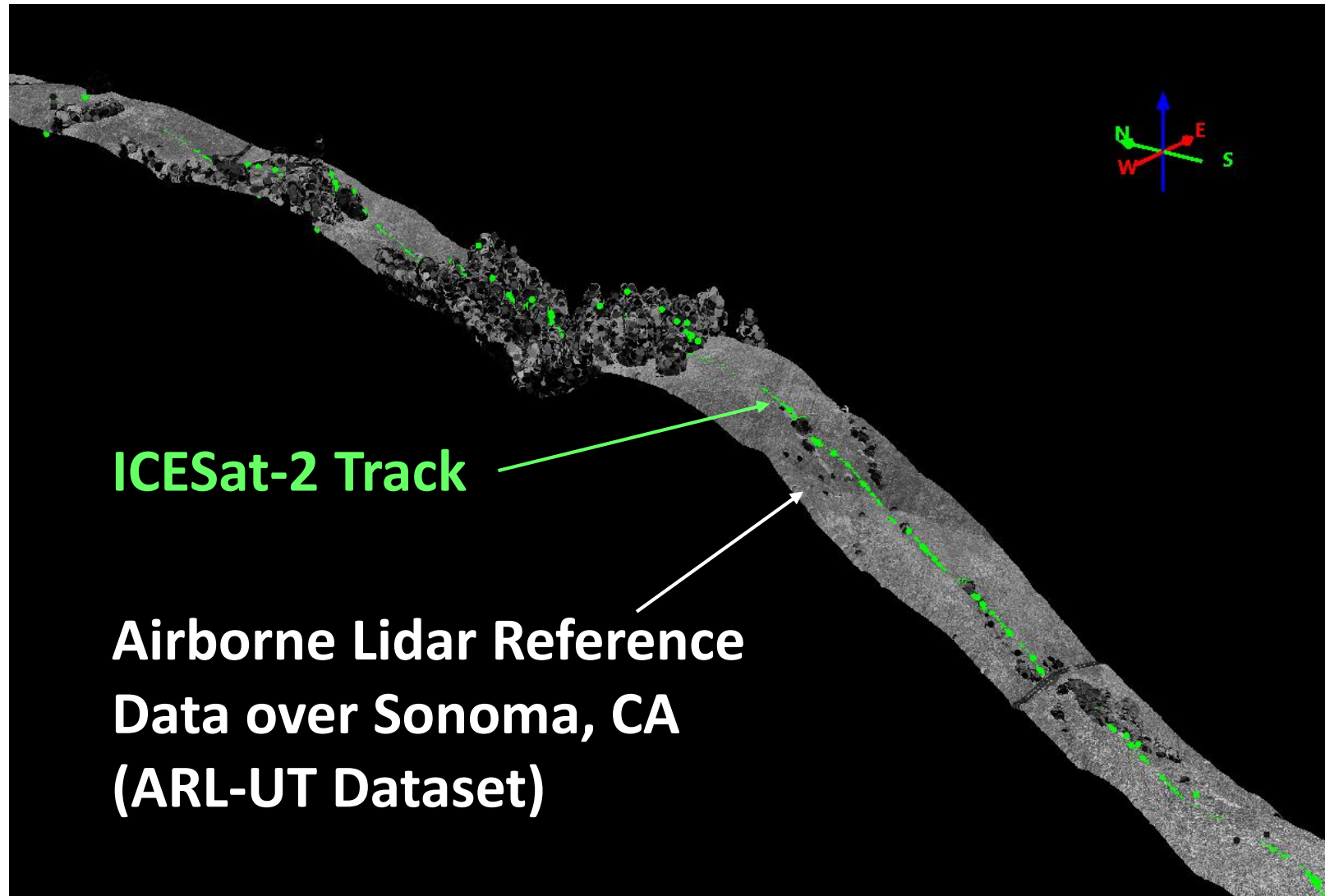
Output .las Files in QT Modeler

PhoREAL (Output .csv File)

|	A	B	C	D	E	F	G	H	I	J	K	L
1	Time (sec)	Delta Time (sec)	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)	Cross-Track (m)	Along-Track (m)	Height (m HAE)	Height (m MSL)	Classification	Signal Confidence
2	0	26132850.19	38.9354939	-123.1310807	488639.1911	4309626.479	0	0	563.015625	592.9954263	3	4
3	0	26132850.19	38.93549407	-123.1310805	488639.2105	4309626.497	-0.017602912	-0.019898601	559.947937	589.9277383	2	4
4	1.00E-04	26132850.19	38.93548771	-123.1310812	488639.1505	4309625.791	-0.026646042	0.688342408	559.0372925	589.0171131	2	4
5	0.000300009	26132850.19	38.93547495	-123.1310826	488639.0265	4309624.376	-0.041333659	2.108839092	557.812561	587.7924204	1	4
6	0.000300009	26132850.19	38.93547501	-123.1310825	488639.0336	4309624.383	-0.04769975	2.10165074	556.703186	586.6830454	0	4
7	0.00040001	26132850.19	38.93546848	-123.1310834	488638.9529	4309623.658	-0.038118096	2.83102886	559.0424194	589.0222981	2	4
8	0.000500008	26132850.19	38.93546197	-123.1310843	488638.8758	4309622.936	-0.031804899	3.55670097	560.8133545	590.7932525	2	4
9	0.000500008	26132850.19	38.9354621	-123.1310841	488638.8907	4309622.95	-0.045231472	3.541565759	558.4735107	588.4534087	2	4
10	0.000500008	26132850.19	38.93546212	-123.1310841	488638.8928	4309622.952	-0.047158665	3.539380994	558.1376953	588.1175933	1	4
11	0.00060001	26132850.19	38.93545559	-123.131085	488638.8135	4309622.228	-0.038807455	4.267415764	560.2650757	590.244993	2	4
12	0.00060001	26132850.19	38.93545565	-123.1310849	488638.8205	4309622.235	-0.045128378	4.260278671	559.1635742	589.1434915	2	4
13	0.00060001	26132850.19	38.93545554	-123.1310851	488638.8066	4309622.222	-0.032578364	4.274448752	561.3505859	591.3305033	3	4
14	0.000700008	26132850.19	38.9354492	-123.1310857	488638.7502	4309621.519	-0.044930669	4.97909696	559.8712769	589.8512135	2	4
15	0.000700008	26132850.19	38.93544927	-123.1310856	488638.758	4309621.527	-0.052002295	4.971108857	558.638916	588.6188527	2	4
16	0.00080001	26132850.19	38.93544288	-123.1310863	488638.6945	4309620.817	-0.057936125	5.683084472	558.2794189	588.2593749	2	4
17	0.000900008	26132850.19	38.93543662	-123.1310869	488638.647	4309620.123	-0.078375927	6.378641077	555.3931274	585.3731028	1	4
18	0.001000009	26132850.19	38.93543003	-123.1310879	488638.5592	4309619.391	-0.062353077	7.115439964	558.8622437	588.8422383	2	4
19	0.001100011	26132850.19	38.93542381	-123.1310883	488638.5172	4309618.702	-0.087795875	7.805454637	555.1064453	585.0864593	1	4
20	0.001100011	26132850.19	38.93542361	-123.1310886	488638.4929	4309618.68	-0.065817203	7.830255951	558.9365845	588.9165985	2	4
21	0.001200009	26132850.19	38.9354174	-123.1310891	488638.4512	4309617.991	-0.091509005	8.519983479	555.1384277	585.1184611	1	4
22	0.001200009	26132850.19	38.93541742	-123.1310891	488638.4532	4309617.993	-0.093336741	8.517911502	554.8199463	584.7999796	1	4
23	0.001300011	26132850.19	38.93541088	-123.13109	488638.3718	4309617.267	-0.083059855	9.2482906	557.2909546	587.2710073	2	4
24	0.00140002	26132850.19	38.93539612	-123.1311022	488637.3098	4309615.63	0.814264975	10.98034604	714.3483887	744.3284607	0	0
25	0.00140002	26132850.19	38.93540457	-123.1310906	488638.318	4309616.567	-0.097811824	9.950456302	555.4014282	585.3815002	1	4

Output .csv File in Excel

PhoREAL (Output ICESat-2 Offsets Relative to Reference Data)

ATL03_20181030110205_04860106_002_01 (gt2r): Descending
Observed Data Correction (1 m Raster)
Easting, Northing, Vertical: 0.1, 1.0, 0.9 m
Cross-Track, Along-Track: 0, -1 m

- Relative to the Sonoma reference data, PhoREAL computed that this particular ICESat-2 track is offset by 0.1 m in UTM Easting, 1.0 m in UTM Northing, and 0.9 m in vertical distance (this is equal to 0 m in cross-track distance and -1 m in the along-track distance of ICESat-2)
- The colors in the contour figure show the Vertical Mean Absolute Error at other discrete offsets locations, confirming that the minimum vertical error (0.781 m) is at 0 m in cross-track and -1 m in along-track (red dot)

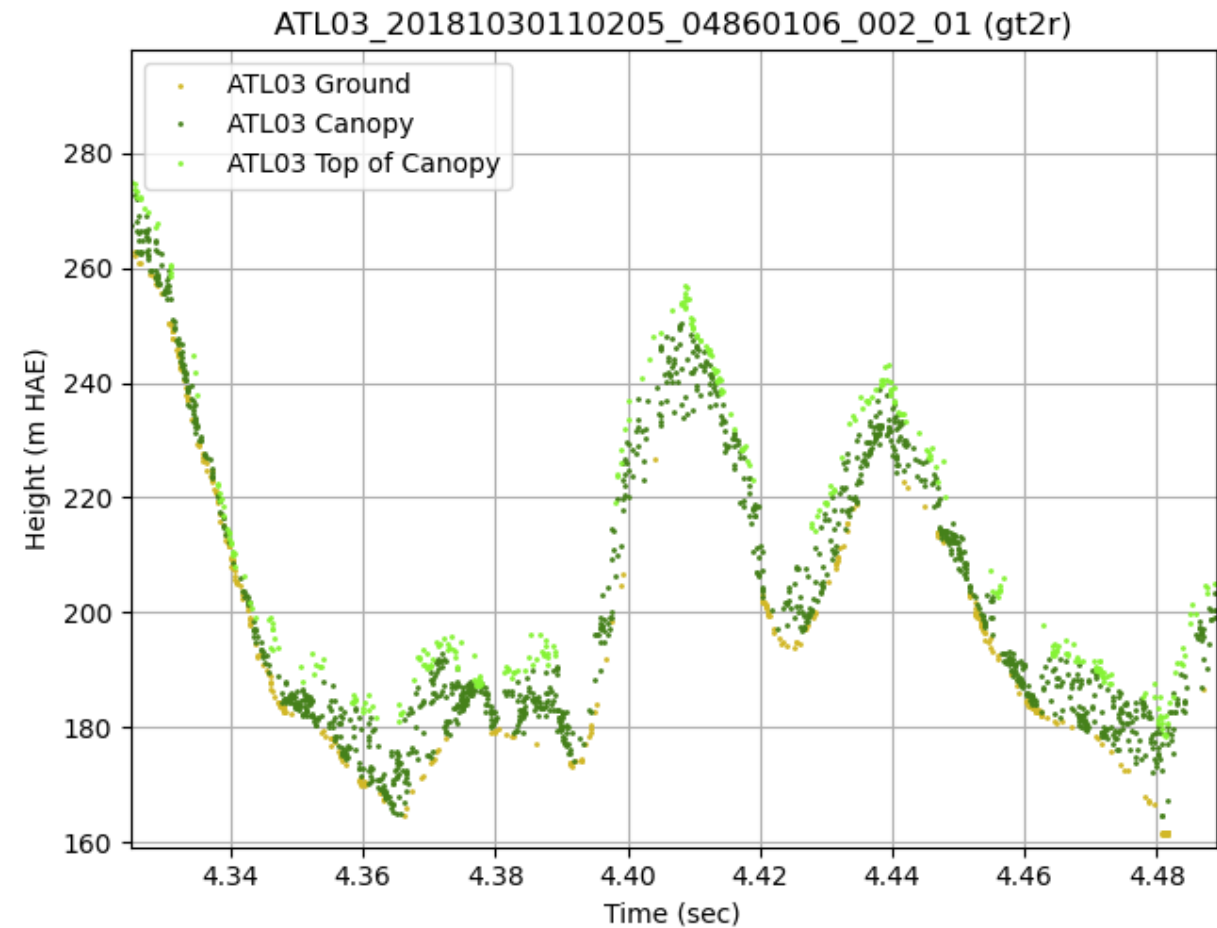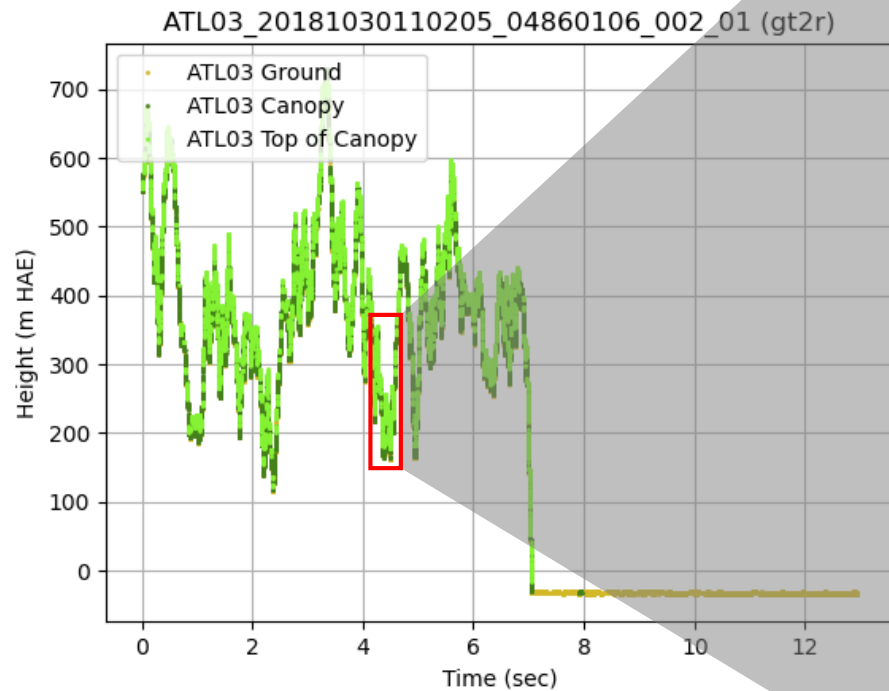# PhoREAL (Shifted ICESat-2 and Reference Data Comparison)

ATL03_20181030110205_04860106_002_01 (gt2r): Descending
Shifted ICESat-2 and Reference Data (1 m Raster)
Using Ground Value = 2
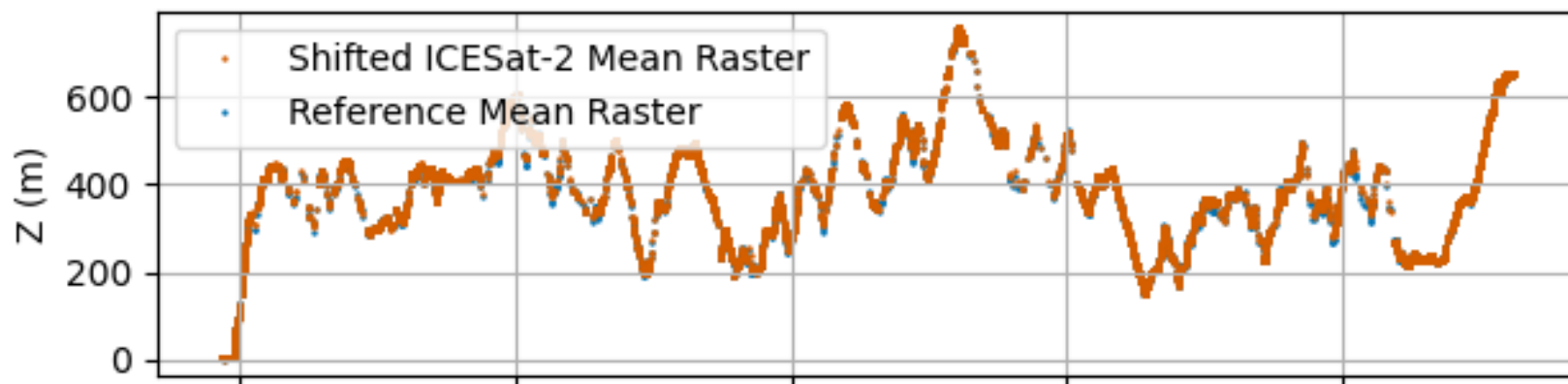
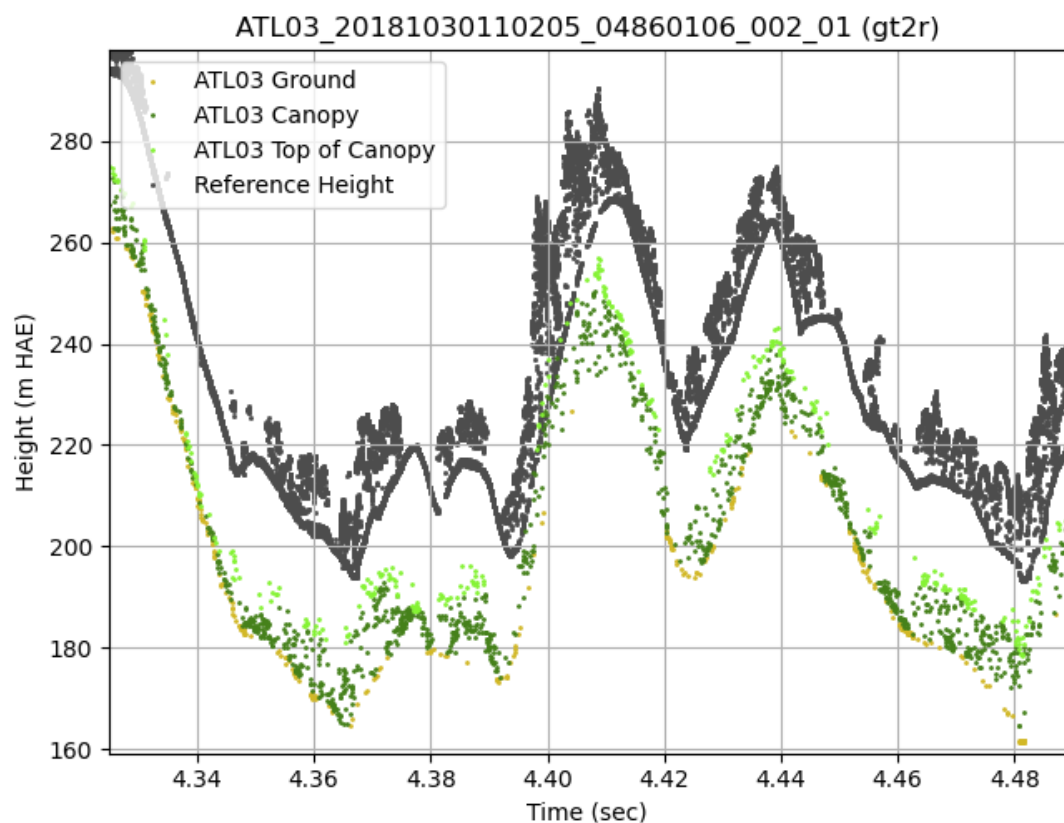MAE = 0.78 m, RMSE = 1.93 m, Mean Error = -0.13 m
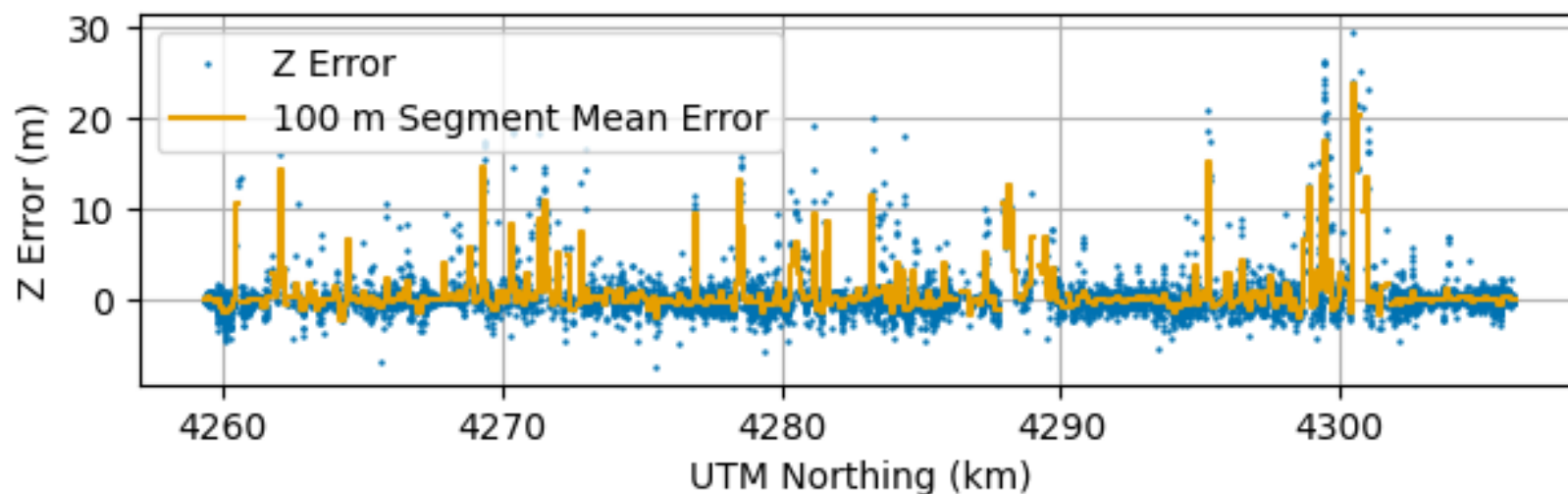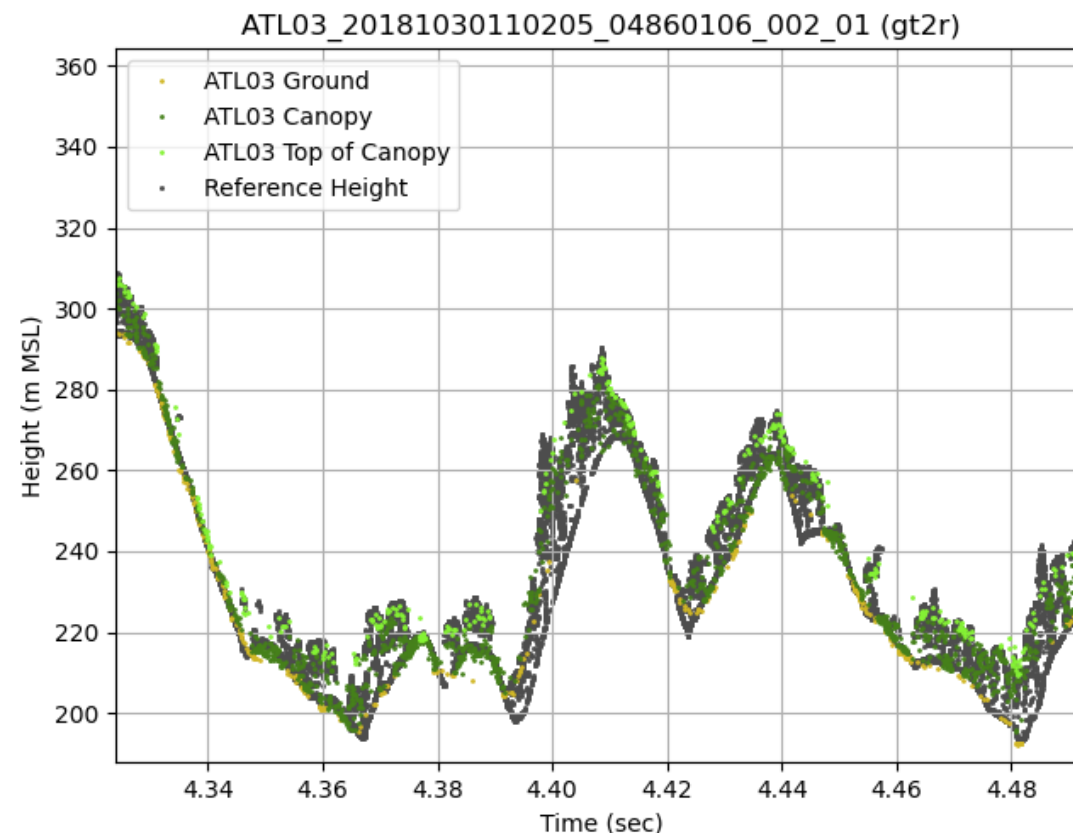
PhoREAL (Output Plot with Classifications)

Output Figure in PhoREAL

PhoREAL (Output Plot with Airborne Lidar Reference Data)


ICESat-2 data with HAE Heights

ICESat-2 data with MSL Heights

Note that the ARL Sonoma reference data set is in MSL heights, so ICESat-2 MSL heights should also be used for comparison

PhoREAL (Output Plot with ATL08 Max Canopy and ATL08 Terrain Best Fit)

Classifications:

- ATL03 Unclassified
- ATL03 Ground
- ATL03 Canopy
- ATL03 Top of Canopy
- ATL08 Max Canopy
- ATL08 Terrain Best Fit

ATL03_20181030110205_04860106_002_01 (gt2r)

Legend:
- ATL03 Ground
- ATL03 Canopy
- ATL03 Top of Canopy
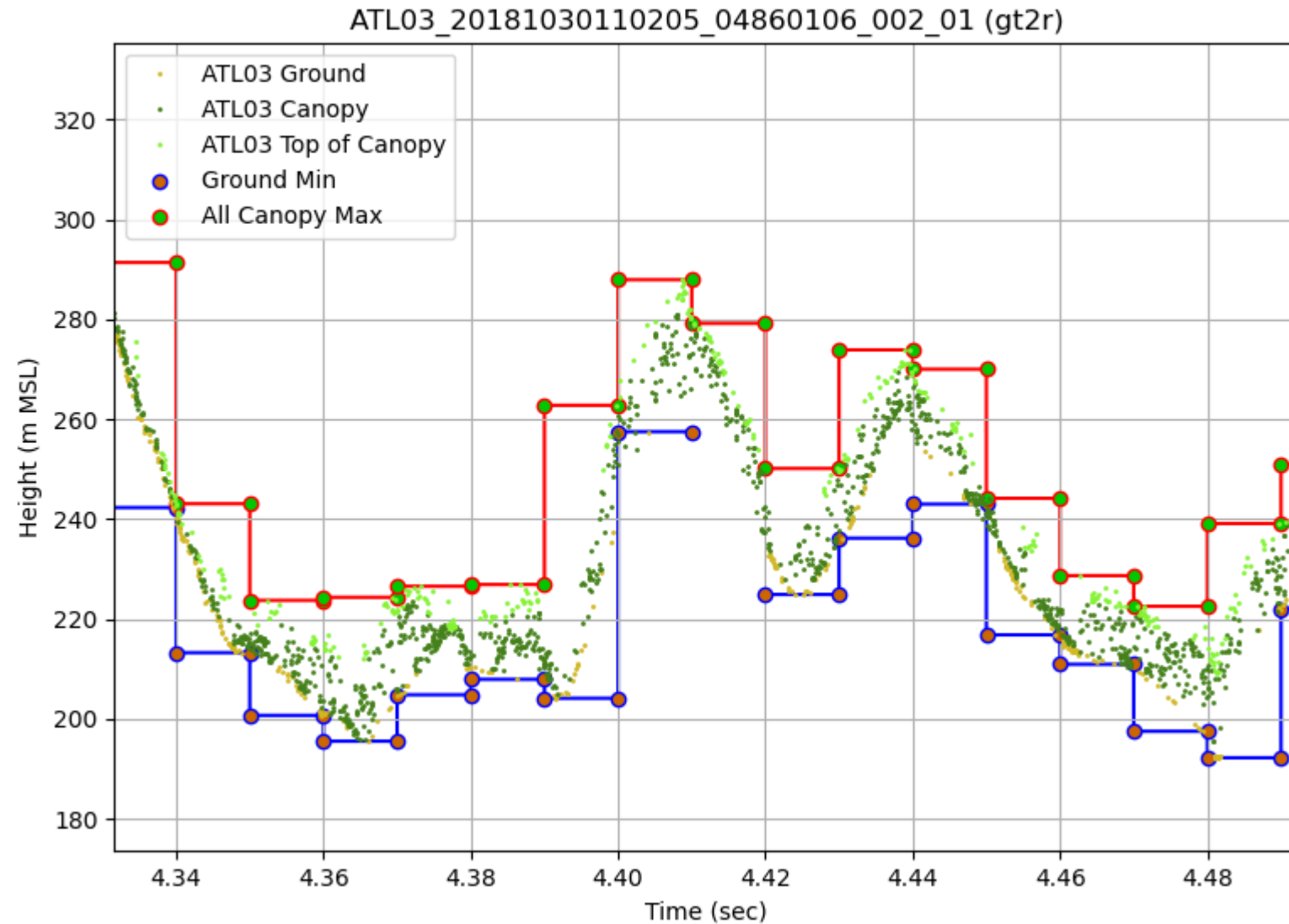- ATL08 Max Canopy
- ATL08 Terrain Best Fit
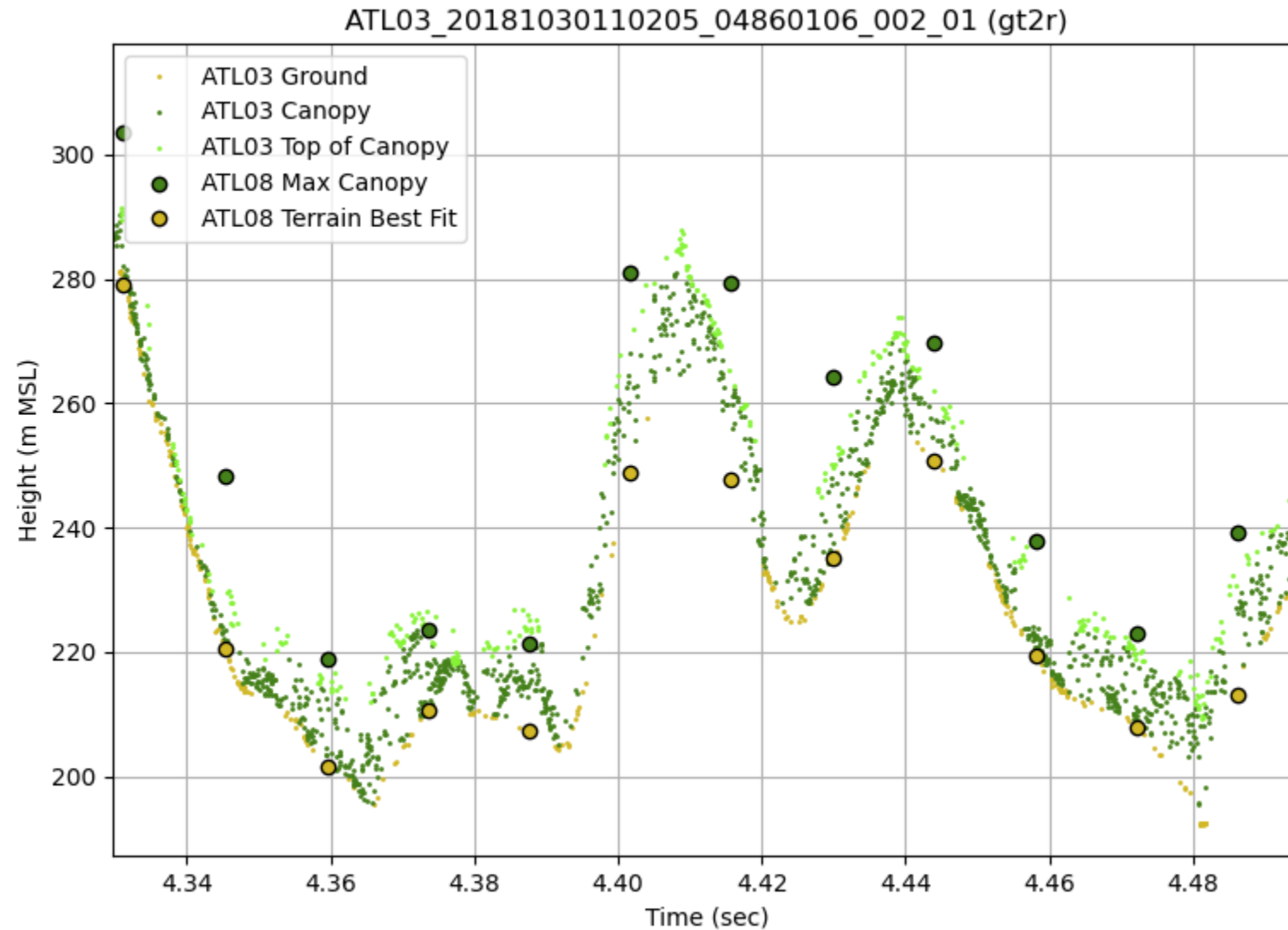
PhoREAL (Output Plot with Ground Mean Stats at 0.01 sec Intervals)

Adding Stats Layers at
0.01 sec intervals

Classifications:

- ATL03 Unclassified
- ATL03 Ground
- ATL03 Canopy
- ATL03 Top of Canopy
- Ground Min
- All Canopy Max

ATL03_20181030110205_04860106_002_01 (gt2r)

PhoREAL (Output HTML from PhoSHOW)