PhoREAL v3.22

Geospatial Analysis Toolbox for ICESat-2 Data

User Manual

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PhoREAL v3.22

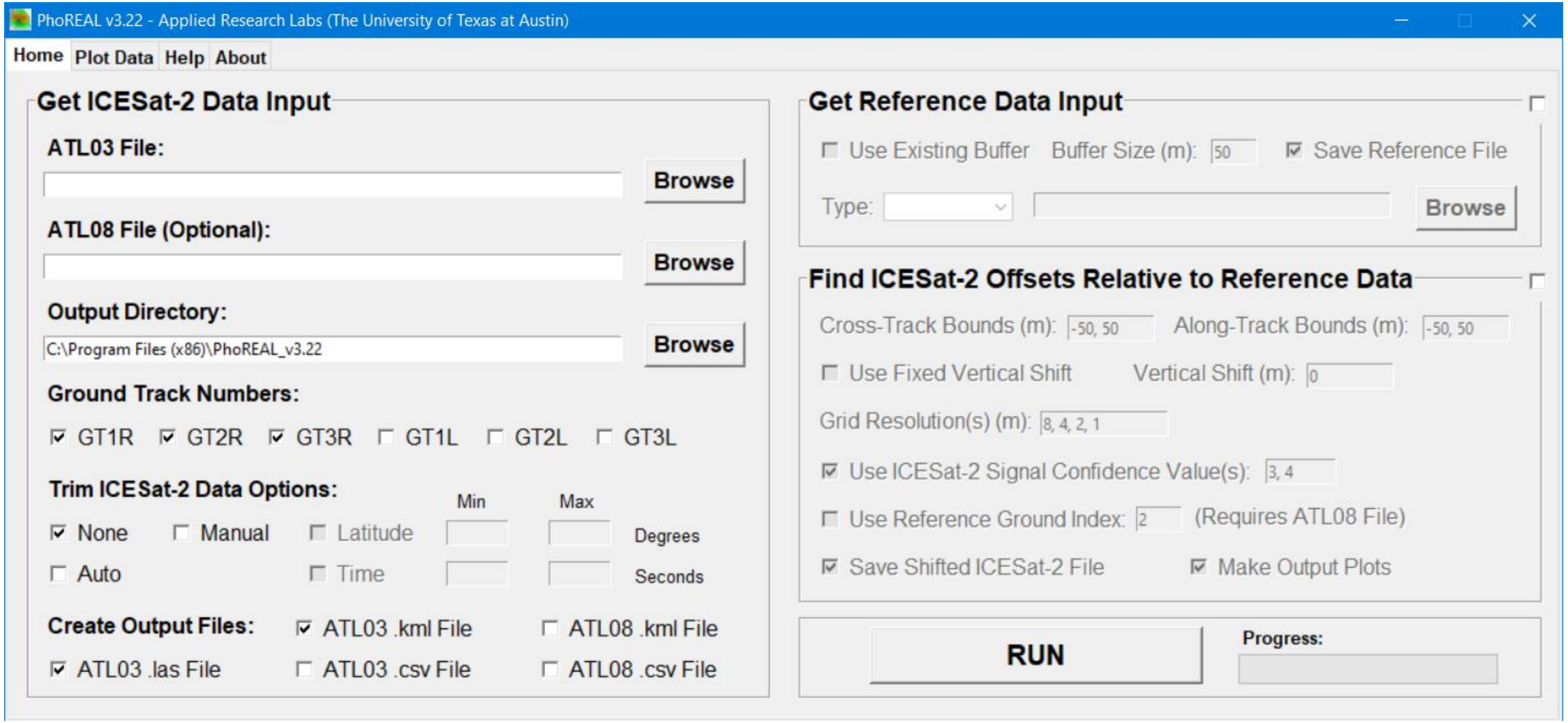
- PhoREAL (Photon Research and Engineering Analysis Library) is a geospatial analysis toolbox that allows users to read, process, analyze, and output ICESat-2 ATL03 and ATL08 data.

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

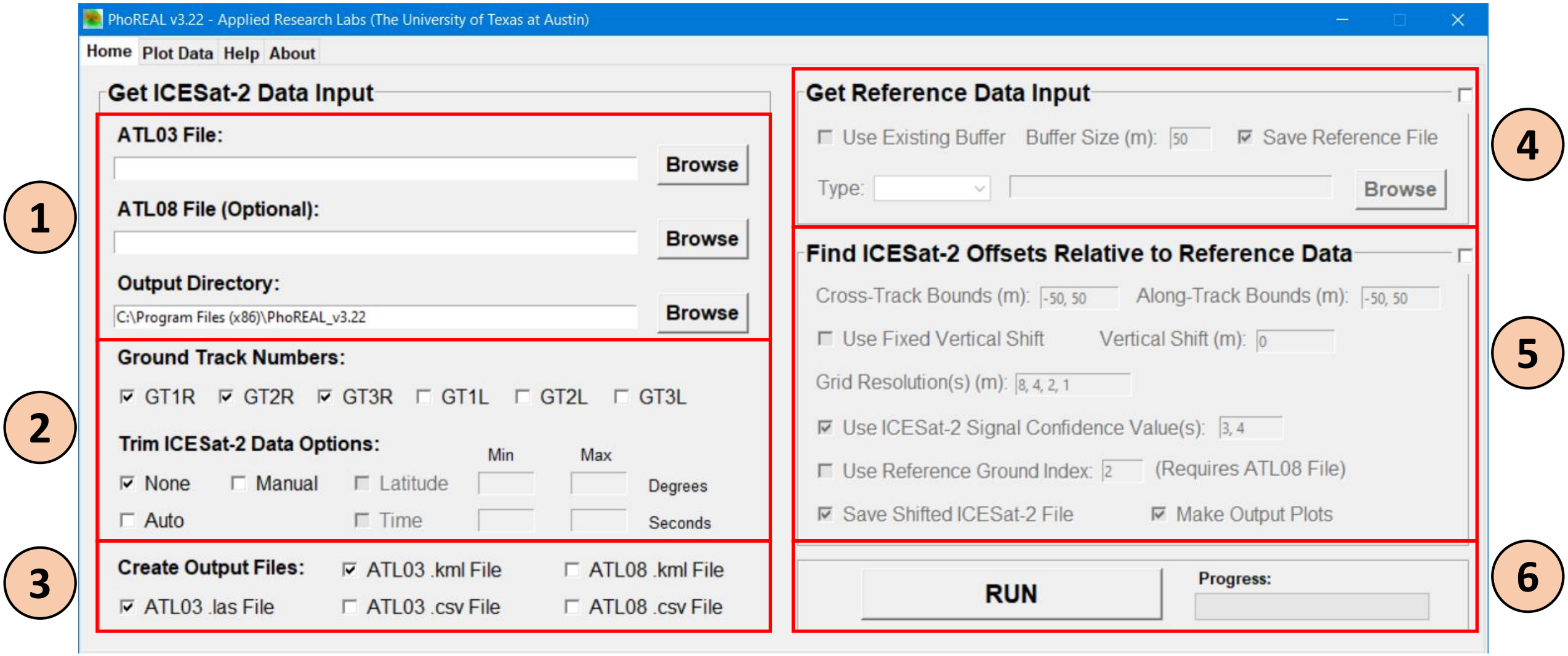
- On Linux systems, the PhoREAL toolbox can be run as a Python GUI or as a series of Python function commands via the Linux command line (Python v3.0+).

- Some highlights of PhoREAL v3.22 functionality:
  - Load and plot data from ICESat-2 ATL03 .h5 files
  - Classify ATL03 photons from a corresponding ATL08 .h5 file
  - Export ATL03/ALT08 data to .las, .kml, and .csv file formats
  - Load in reference data (single .las/.tif file, multiple .las/.tif files, or a directory of .las/.tif files)
  - Create reference swath data around ICESat-2 ATL03 track with specified buffer and store as .las file
  - Determine ICESat-2 ATL03 XYZ offsets relative to reference data
  - Plot ATL03 and ATL08 data (filter by ATL03 signal confidence or ATL08 classification)
  - Plot reference data
  - Compute stats for ATL03 data (and export to .csv file format)
  - View figures in HTML format

PhoREAL (Home Tab)

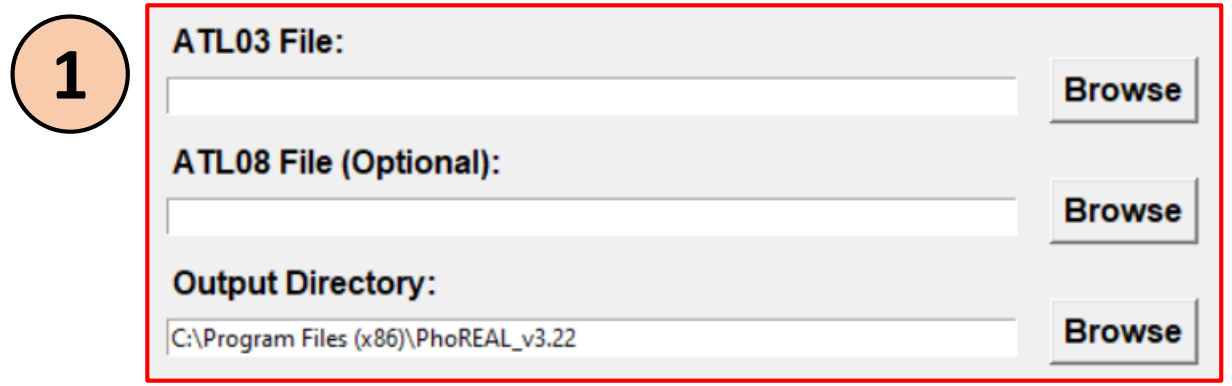


PhoREAL (Home Tab)



PhoREAL (Home Tab – File Inputs)

ATL03 File:
- ICESat-2 ATL03 .h5 file input
- The Browse button filters by .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):
- ICESat-2 ATL08 .h5 file input (optional input)
- The Browse button filters by .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

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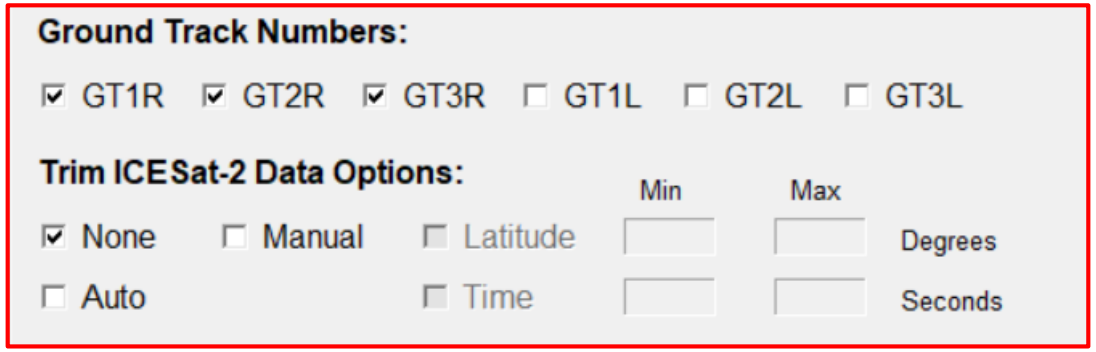


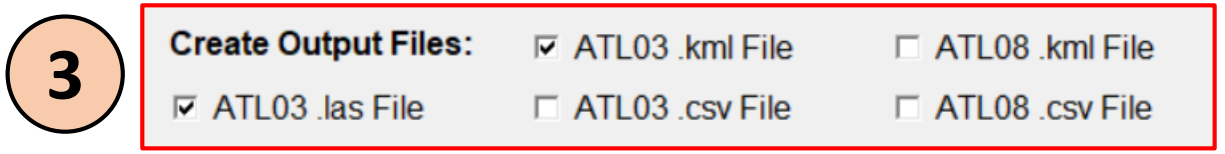
Trim ICESat-2 Data Options:

- This allows the user to trim the ATL03 ground tracks
- **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
- 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



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)

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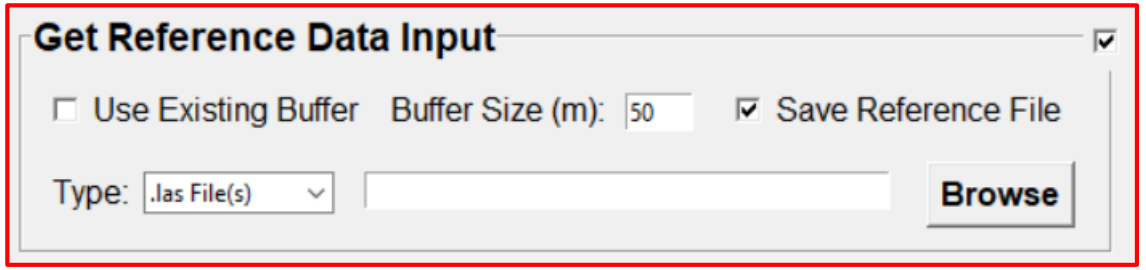


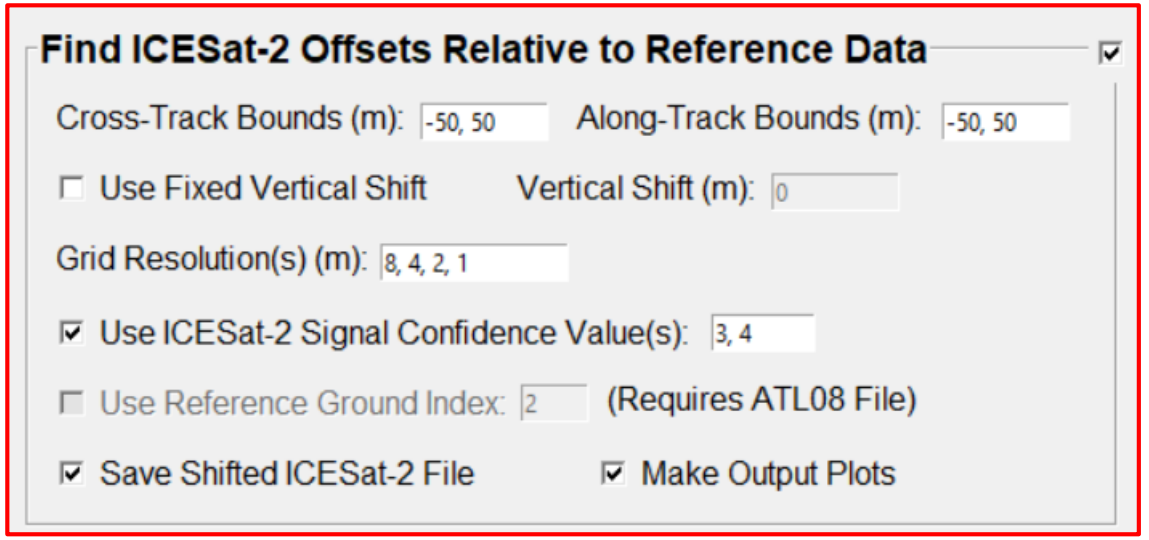
**Grayed out by default, check the box to activate*

- **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 (text cannot be copied here)
- 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.

PhoREAL (Home Tab – Finding ICESat-2 Offsets)

Find ICESat-2 Offsets Relative to Reference Data:

5



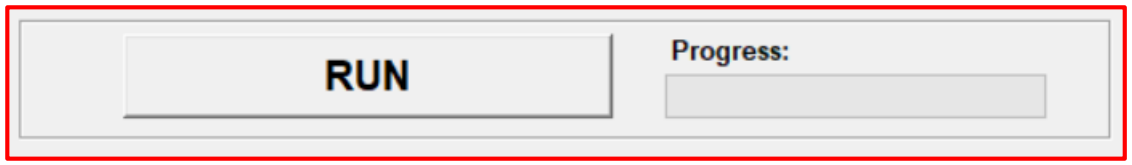
**Grayed out by default, check the box to activate*

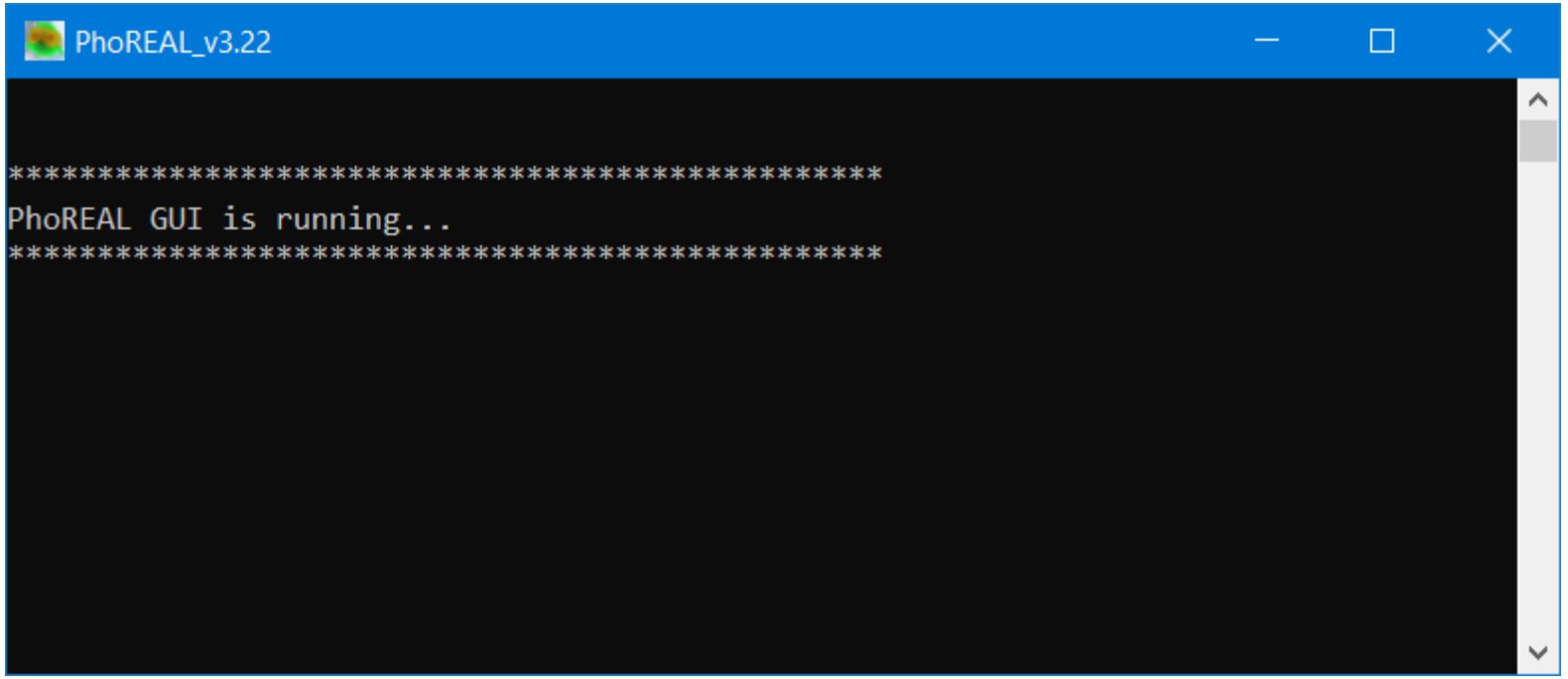
- This section creates raster data from the ICESat-2 and reference data and finds the ICESat-2 XYZ offsets that minimize the Z errors relative to the reference data
- The offset finding algorithm does an exhaustive search over the specified cross-track and along-track bounds to find the XYZ offset the minimizes the Z errors
- **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** – allows users to force a particular vertical shift
- **Vertical Shift** – allows users to set the vertical shift if this option is selected
- **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 Signal Confidence Value(s)** – This option compares the specified ICESat-2 signal confidence photons to the reference data and minimize 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)

PhoREAL (Home Tab – Run Button)

Run Button:

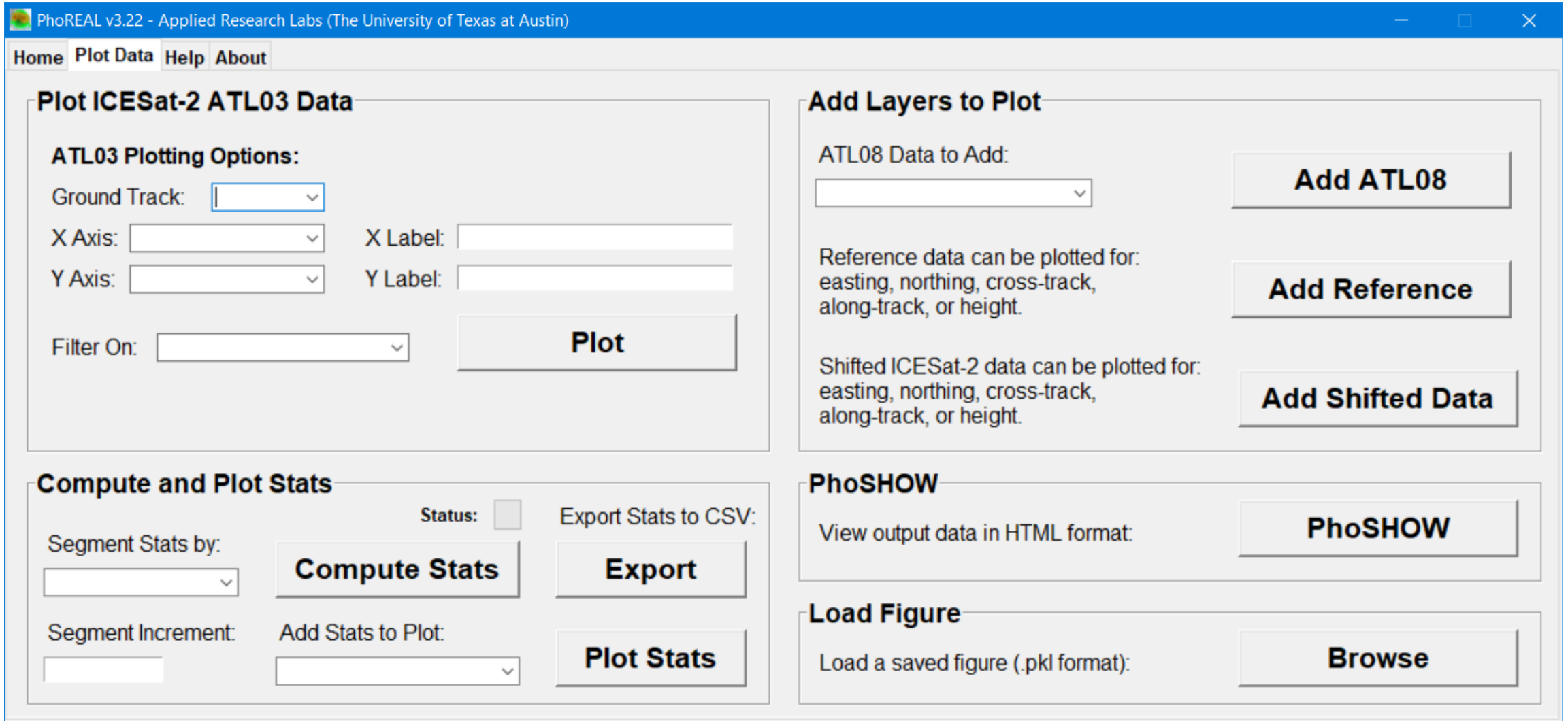
- This button runs PhoREAL
- This button grays out while PhoREAL is executing
- The progress bar show the current progress
- All verbose output is printed to the Windows terminal that opens up with PhoREAL. Do not delete the Windows terminal as it will close PhoREAL as well.



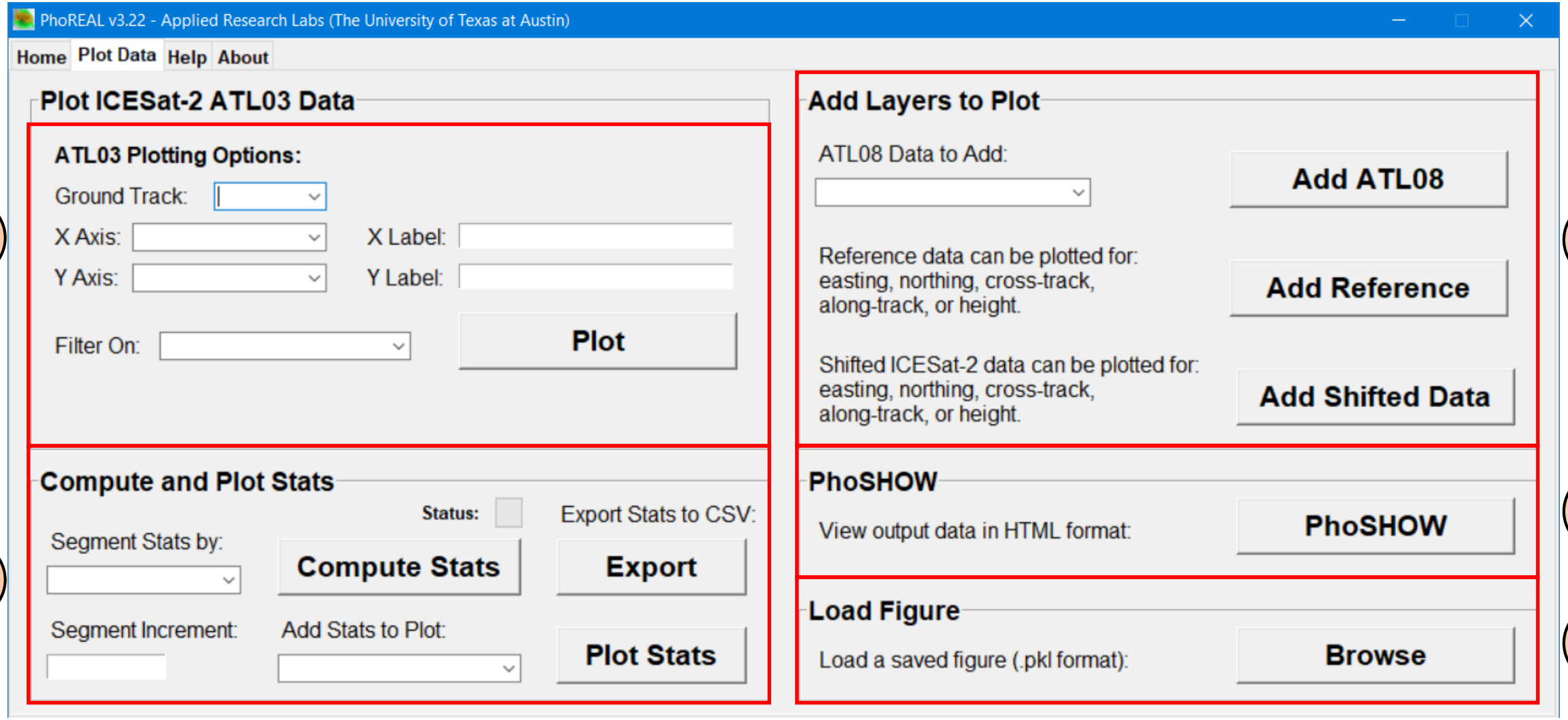


PhoREAL Windows Terminal

PhoREAL (Plot Data Tab)



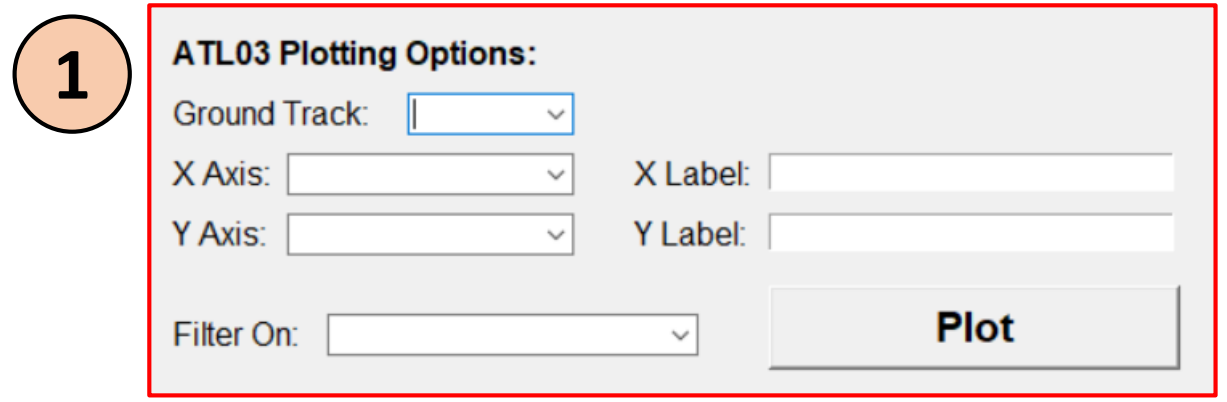
PhoREAL (Plot Data Tab)



PhoREAL (Plot Data Tab – Plotting Options)

ATL03 Plotting Options:

- This section will load after a successful execution of PhoREAL
- **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



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.

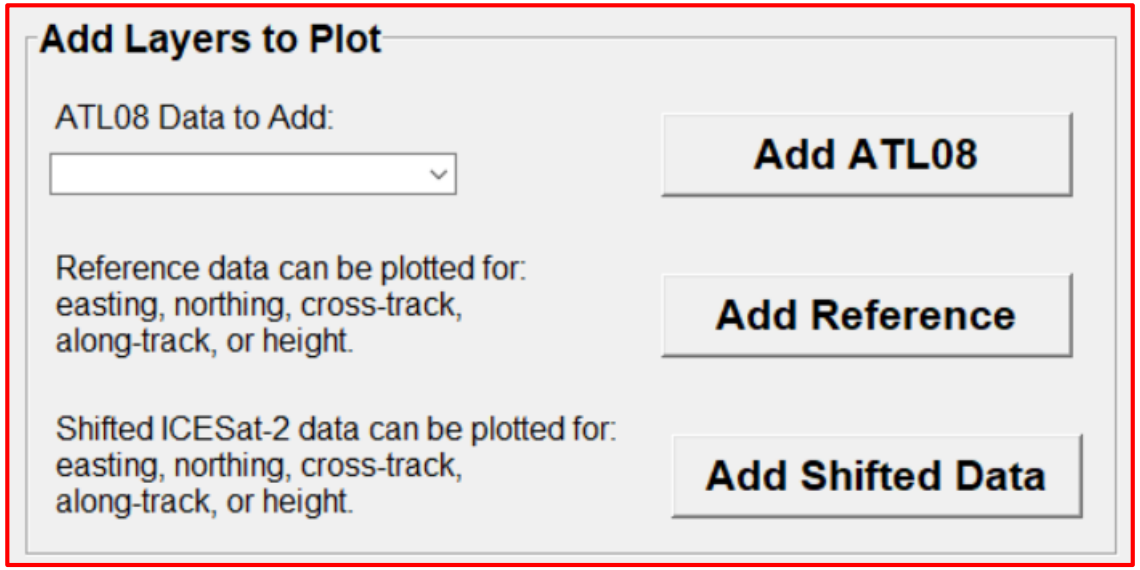
- **Add Stats to Plot** – this option populates after successful computation of stats. The stats can be added to a plot or exported to a .csv file (Stats Options: Ground Min, Ground Max, Ground Median, Ground Mean, Ground Mean + 3*Std, Ground Mean - 3*Std, All Canopy Min, All Canopy Max, All Canopy Median, 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

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, Terrain Median). This requires ATL08 data.
- **Add Reference** – this adds reference data to the most recent plot. This requires reference data. This data can only be plotted for UTM easting/northing, cross/along-track, or height (ellipsoidal).
- **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. This data can only be plotted for UTM easting/northing, cross/along-track, or height (ellipsoidal).

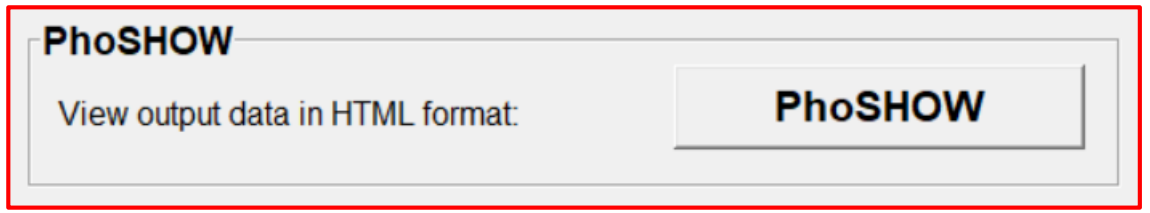
3



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.

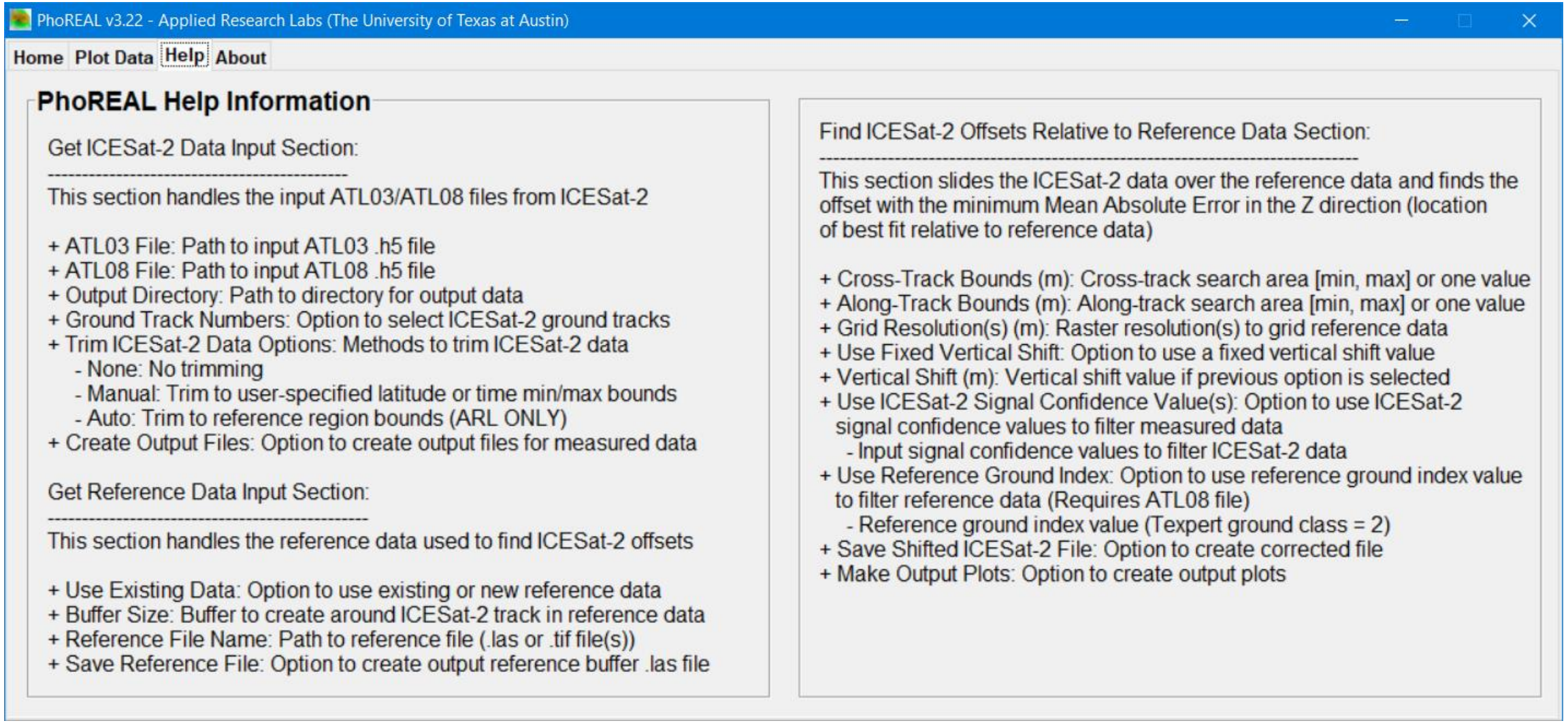


PhoREAL (Plot Data Tab – Load Figures)

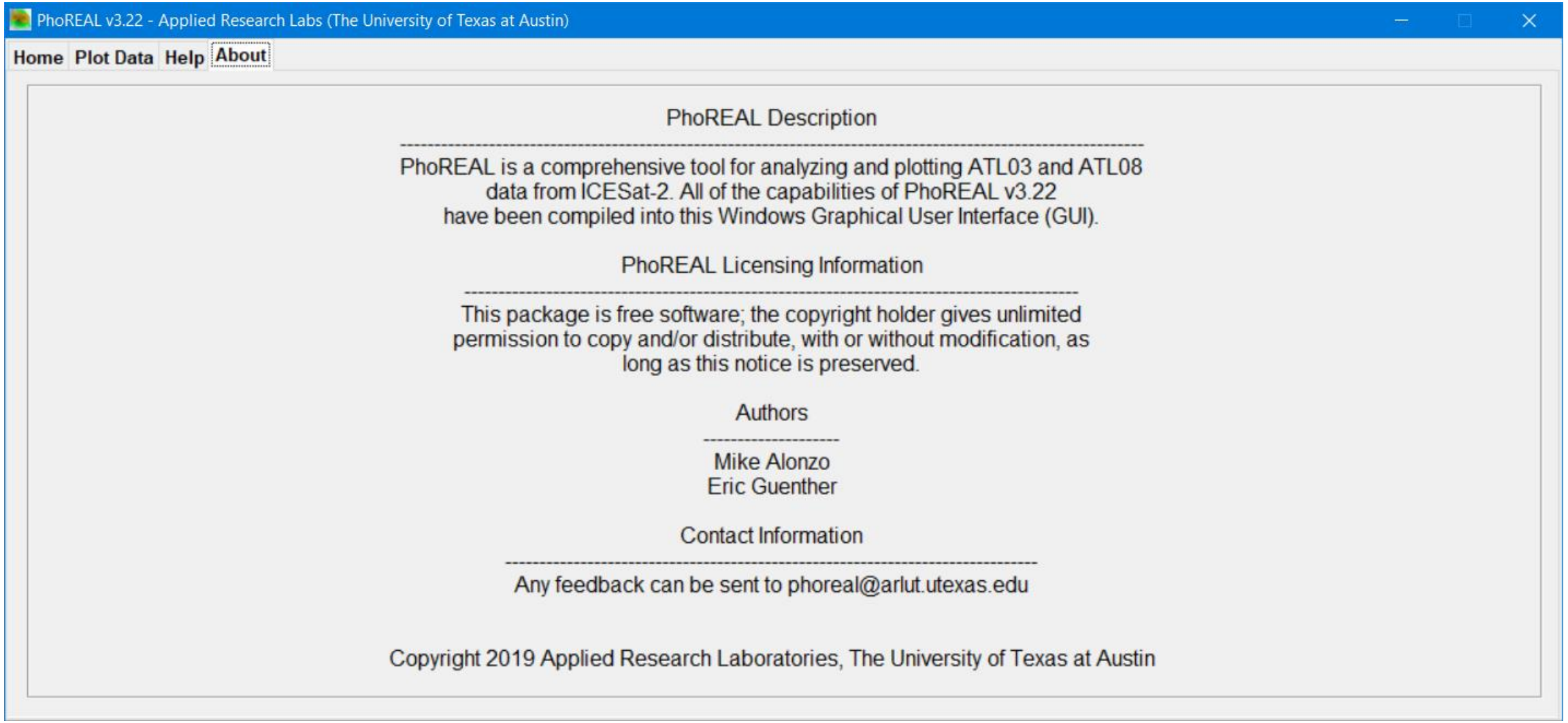
Load Figure:

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

PhoREAL (Help Tab)



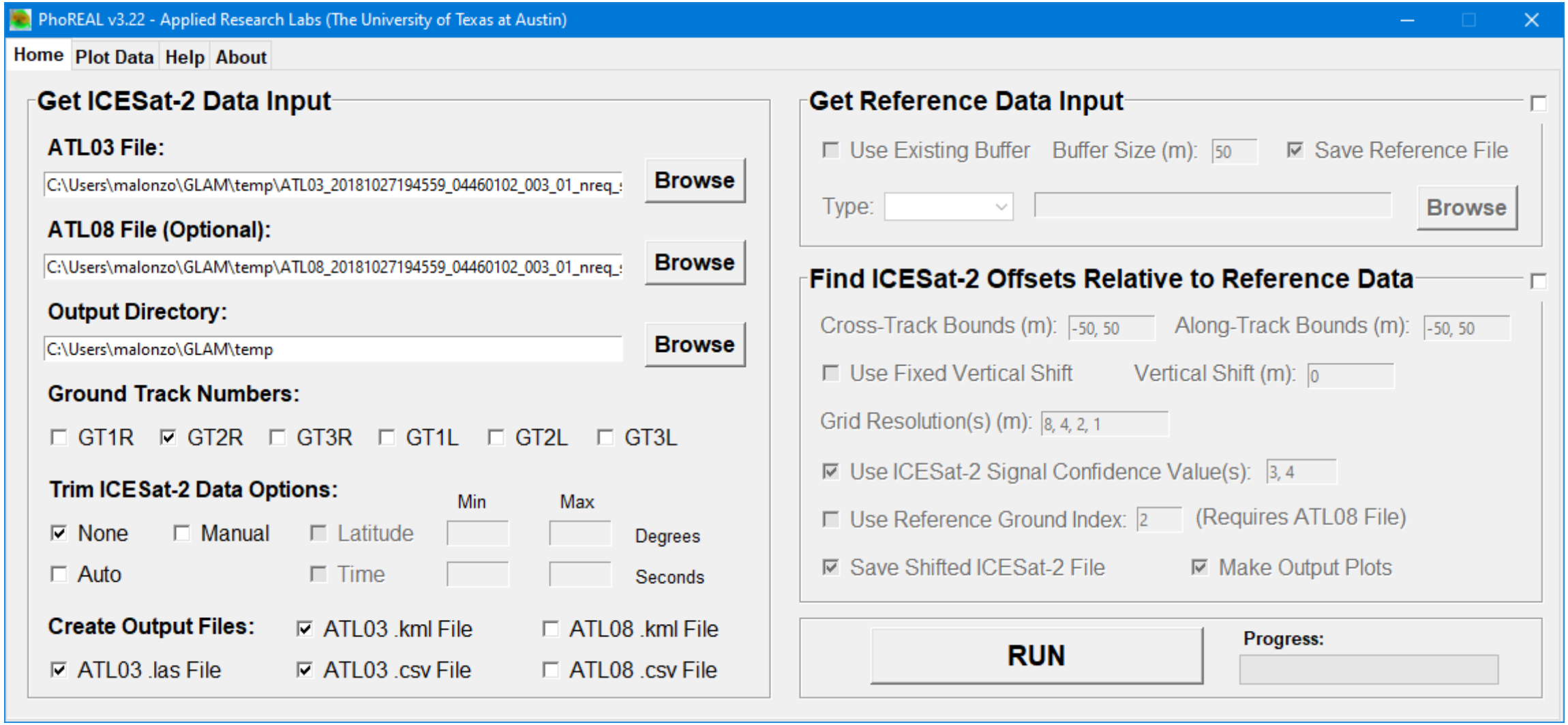
PhoREAL (About Tab)



PhoREAL v3.22

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

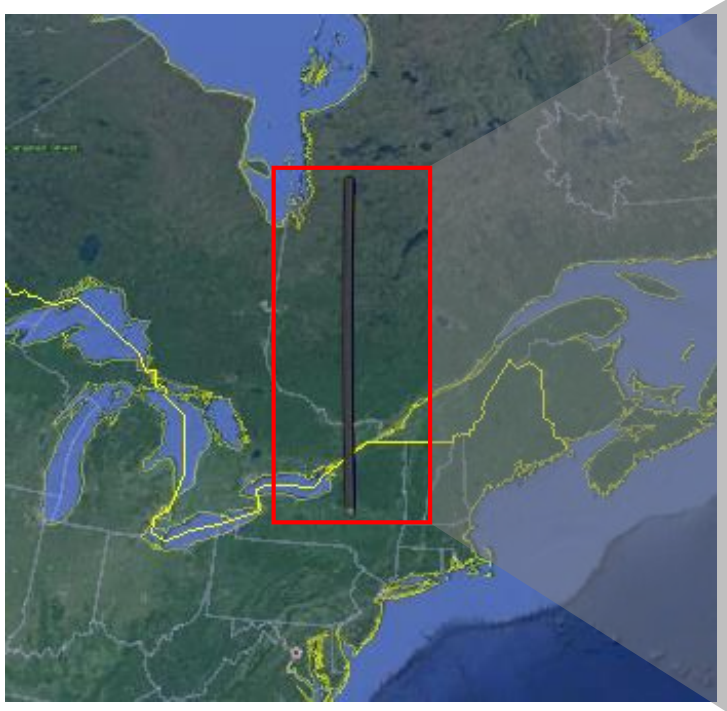
PhoREAL (User Example 1: GUI)



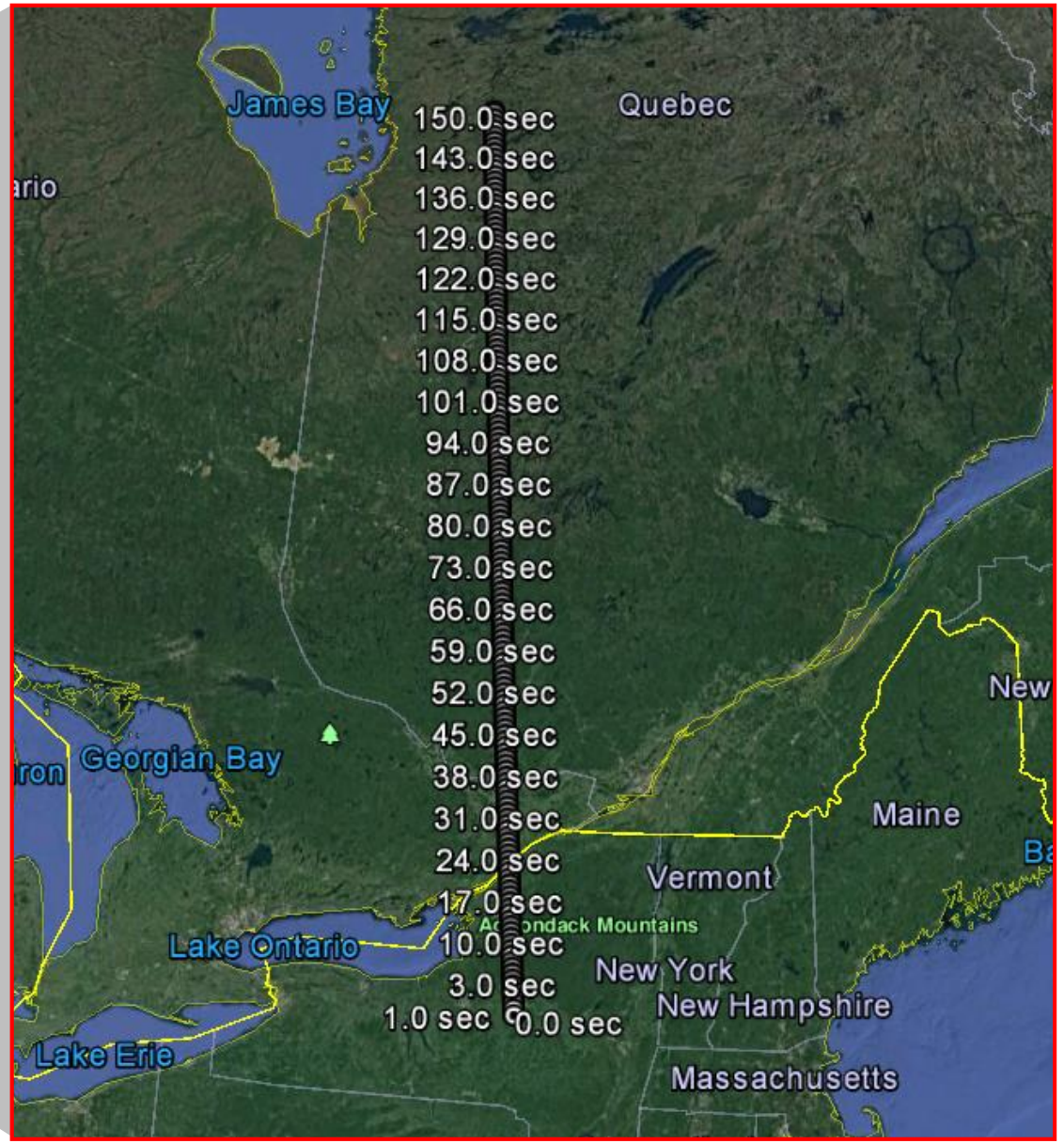
PhoREAL (User Example 1: Inputs)

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 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

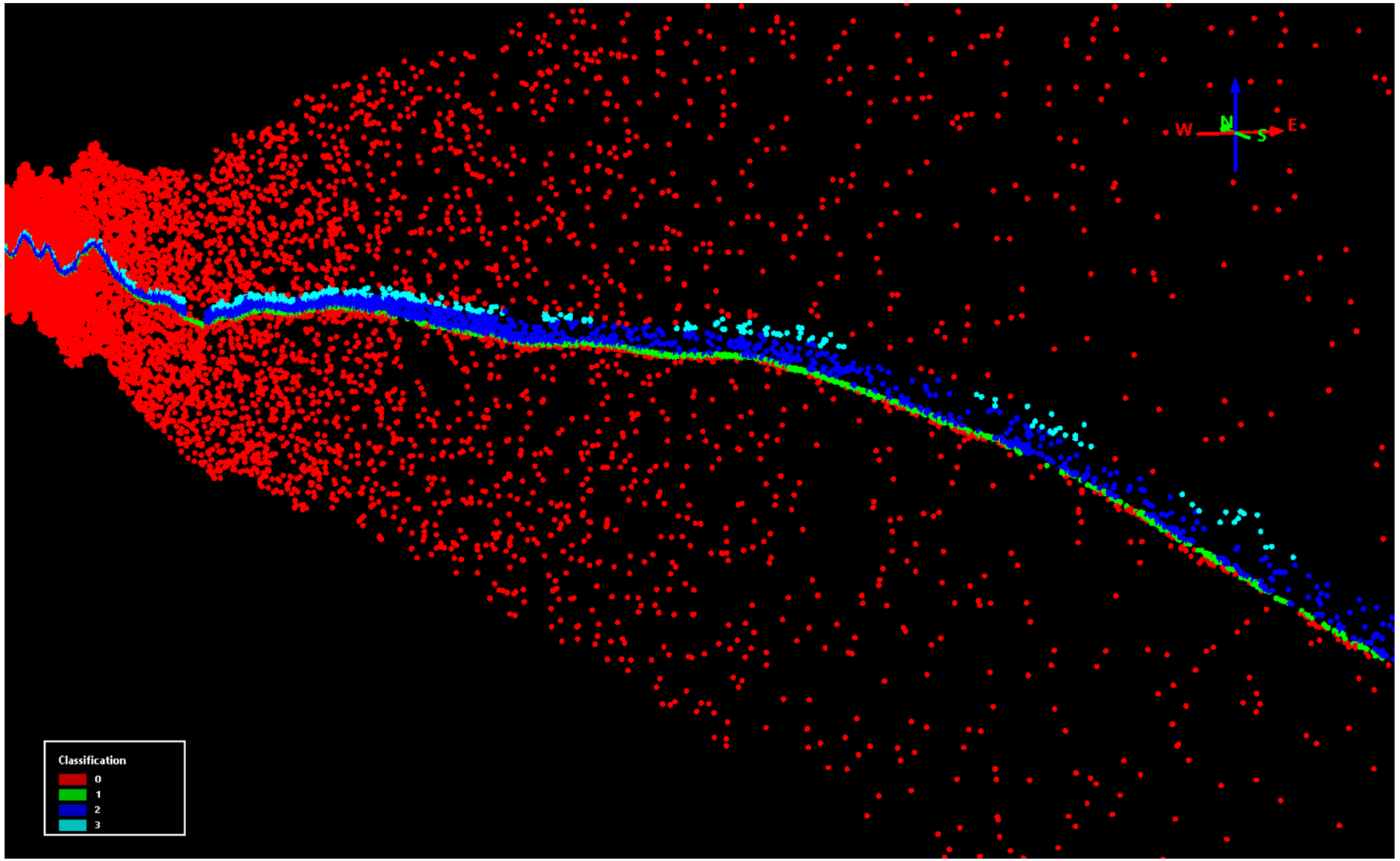


Output .kml File in Google Earth

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)

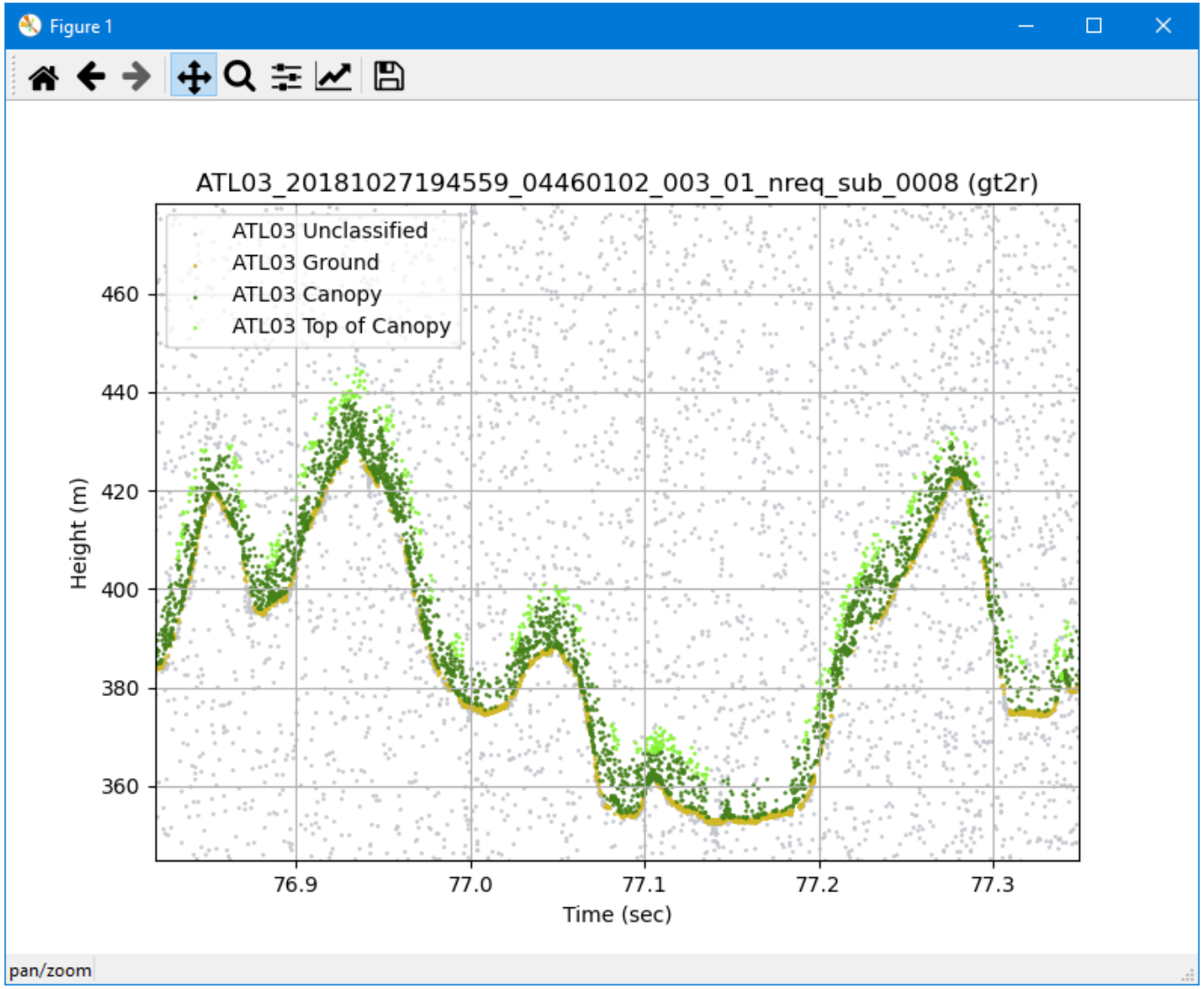
	A	B	C	D	E	F	G	H	I	J	K
1	Time (sec)	Delta Time (sec)	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)	Cross-Track (m)	Along-Track (m)	Height (m)	Classification	Signal Confidence
2	0	25905010.58	43.0022014	-75.37972241	469050.5412	4761129.205	0	0	841.6308594	0	-1
3	0	25905010.58	43.00220154	-75.3797226	469050.526	4761129.221	-0.013872161	0.017488829	844.3967896	0	-1
4	0	25905010.58	43.00220077	-75.3797216	469050.6066	4761129.135	0.05938581	-0.074920673	829.7900391	0	-1
5	0	25905010.58	43.00220027	-75.37972096	469050.6585	4761129.08	0.106586207	-0.134489347	820.3789063	0	-1
6	0	25905010.58	43.00219648	-75.37971609	469051.0542	4761128.657	0.466225988	-0.588282102	748.6723022	0	-1
7	0	25905010.58	43.00219294	-75.37971153	469051.4236	4761128.262	0.801988637	-1.01193969	681.7278442	0	-1
8	0	25905010.58	43.00219318	-75.37971184	469051.3987	4761128.289	0.779420604	-0.983462936	686.227417	0	-1
9	0.000100002	25905010.58	43.00220774	-75.37972317	469050.4822	4761129.91	-0.0009869	0.70742372	840.4920044	0	-1
10	0.000100002	25905010.58	43.00220575	-75.3797206	469050.6906	4761129.687	0.188501026	0.468336398	802.7105713	0	-1
11	0.000100002	25905010.58	43.00220408	-75.37971846	469050.8646	4761129.501	0.346610811	0.268830139	771.1859131	0	-1
12	0.000100002	25905010.58	43.00220433	-75.37971878	469050.8383	4761129.529	0.322726093	0.298974885	775.9481201	0	-1
13	0.000100002	25905010.58	43.00220258	-75.37971653	469051.0212	4761129.334	0.488938161	0.08923269	742.8082886	0	-1
14	0.000100002	25905010.58	43.00220045	-75.37971378	469051.2438	4761129.096	0.691281716	-0.166055655	702.4648438	0	-1
15	0.000100002	25905010.58	43.00220095	-75.37971443	469051.1914	4761129.152	0.643618882	-0.105929519	711.9678955	0	-1
16	0.000100002	25905010.58	43.0022003	-75.37971359	469051.2594	4761129.079	0.705465466	-0.183967498	699.6369629	0	-1
17	0.000100002	25905010.58	43.00219779	-75.37971037	469051.5209	4761128.8	0.94313665	-0.48384024	652.2505493	0	-1
18	0.000200011	25905010.58	43.00221452	-75.37972449	469050.3785	4761130.662	-0.042505138	1.466073237	847.4360352	0	-1
19	0.000200011	25905010.58	43.00221495	-75.37972504	469050.3333	4761130.711	-0.083583121	1.517885715	855.6265259	0	-1
20	0.000200011	25905010.58	43.00220949	-75.37971802	469050.9034	4761130.102	0.434563353	0.864113387	752.3154297	0	-1
21	0.000200011	25905010.58	43.00220472	-75.37971188	469051.4014	4761129.57	0.887186965	0.293007889	662.0714111	0	-1
22	0.000300013	25905010.58	43.00222111	-75.37972556	469050.294	4761131.395	-0.066625372	2.202739157	850.9126587	0	-1
23	0.000300013	25905010.58	43.00221525	-75.37971803	469050.9052	4761130.742	0.488887552	1.50180041	740.1514893	0	-1
24	0.000300013	25905010.58	43.002216	-75.37971899	469050.8272	4761130.825	0.417975532	1.591265985	754.2901611	0	-1
25	0.000300013	25905010.58	43.00221229	-75.37971422	469051.2142	4761130.412	0.769723152	1.147444449	684.1584473	0	-1
26	0.000300013	25905010.58	43.00220991	-75.37971115	469051.4631	4761130.146	0.996030621	0.861883358	639.0379639	0	-1
27	0.00040001	25905010.58	43.00222748	-75.37972636	469050.2321	4761132.103	-0.070192299	2.913450268	850.2927856	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



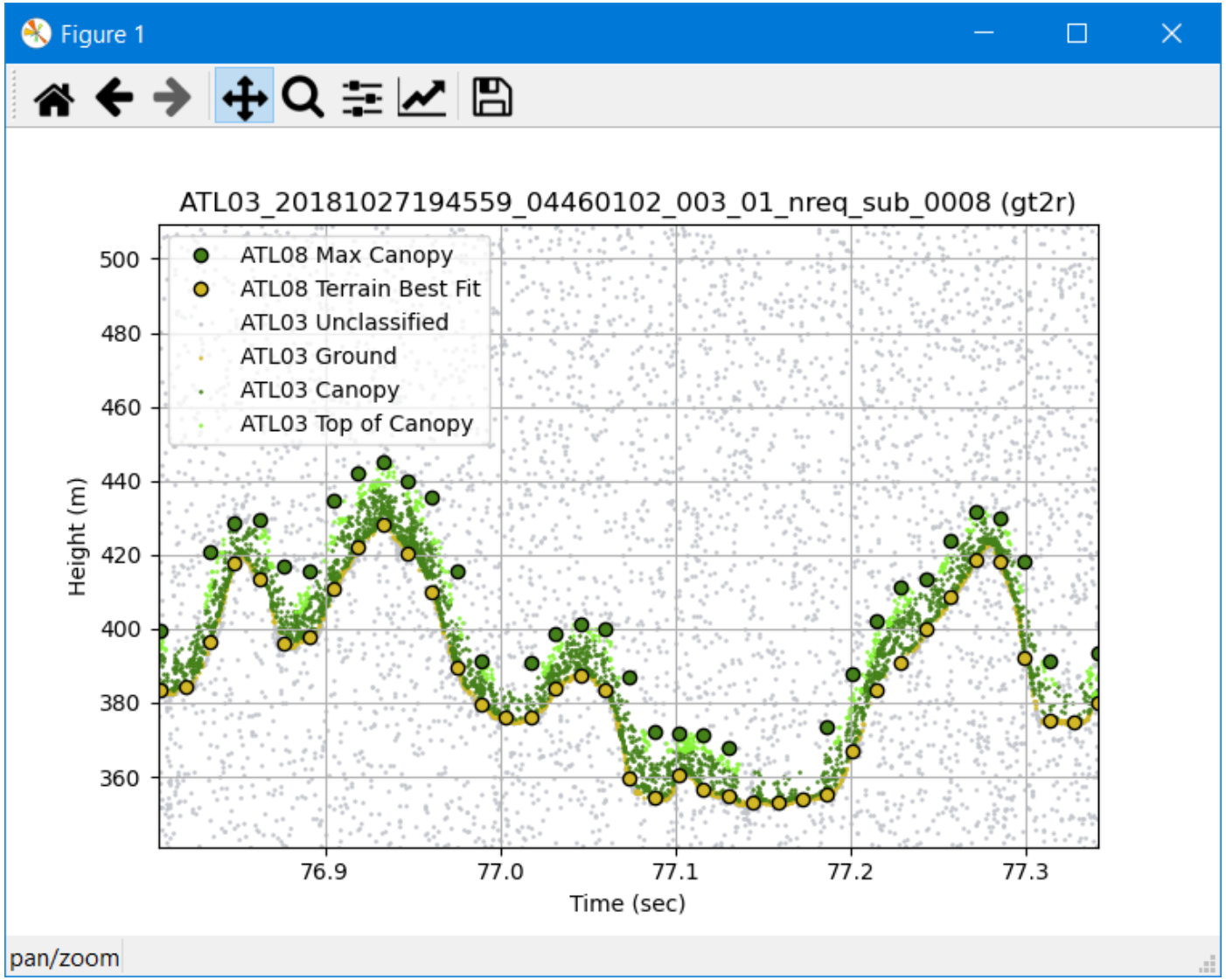
Output Figure in PhoREAL

PhoREAL (User Example 1: Output Figure in PhoREAL)

Adding ATL08 Layers

Classifications:

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



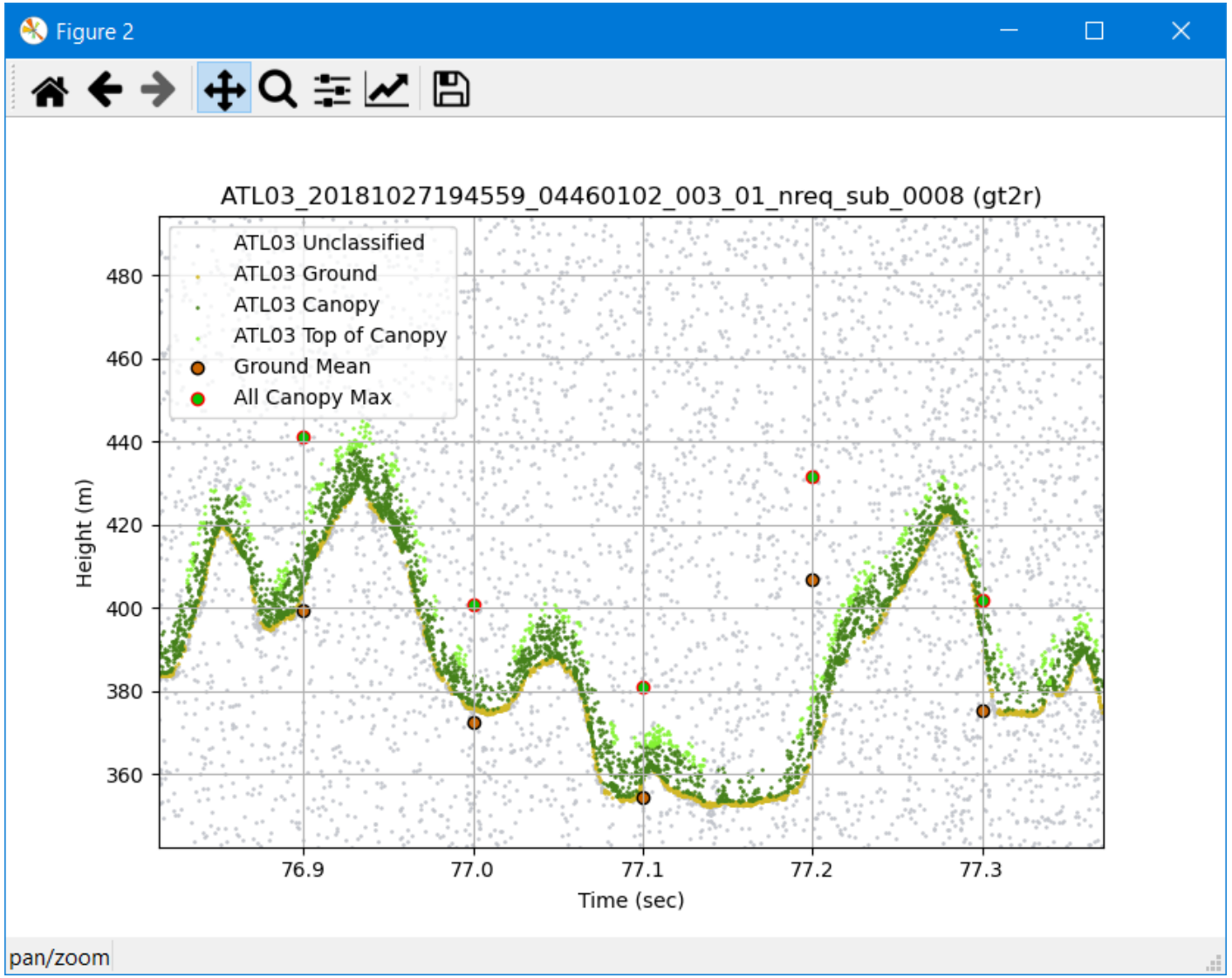
Output Figure in PhoREAL

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 Mean
- All Canopy Max

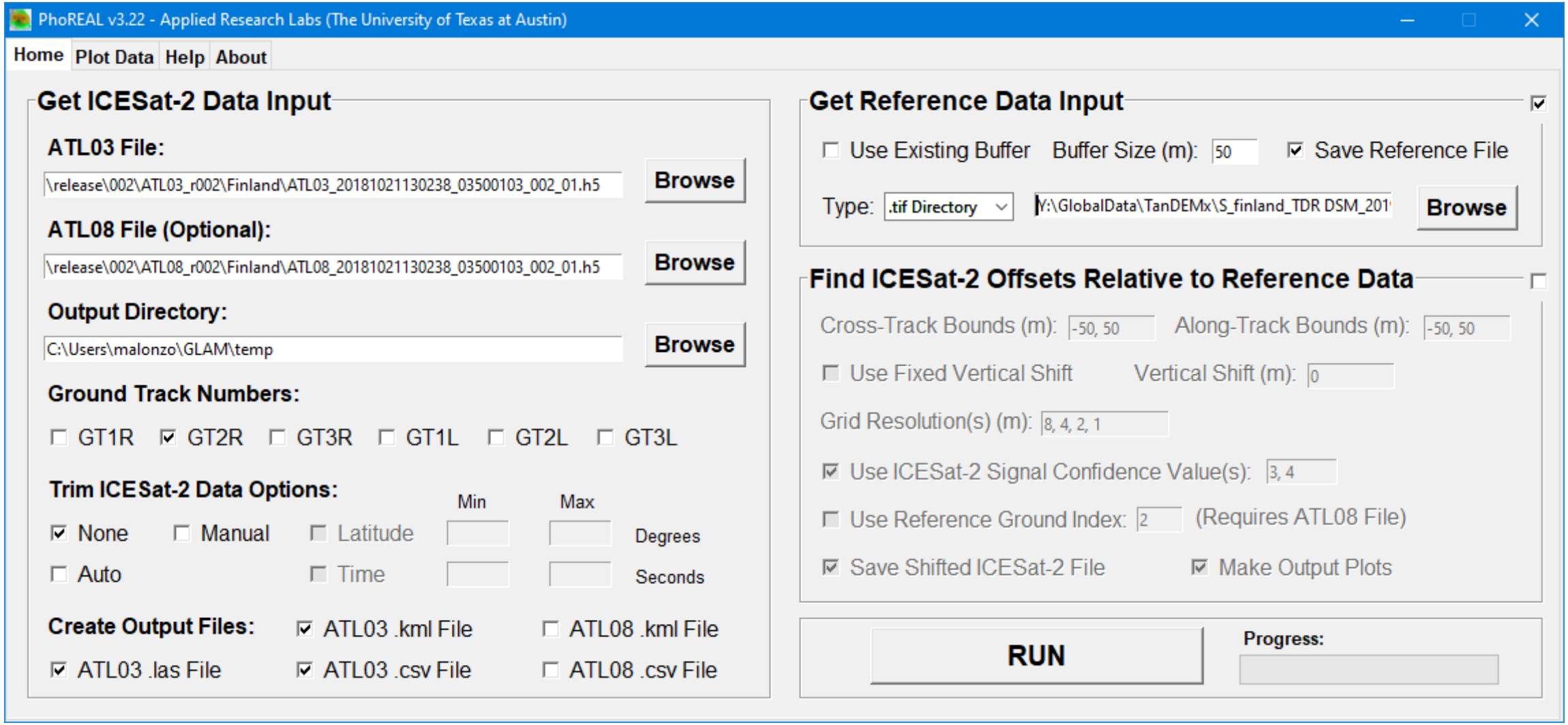


Output Figure in PhoREAL

PhoREAL v3.22

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

PhoREAL (User Example 2: GUI)

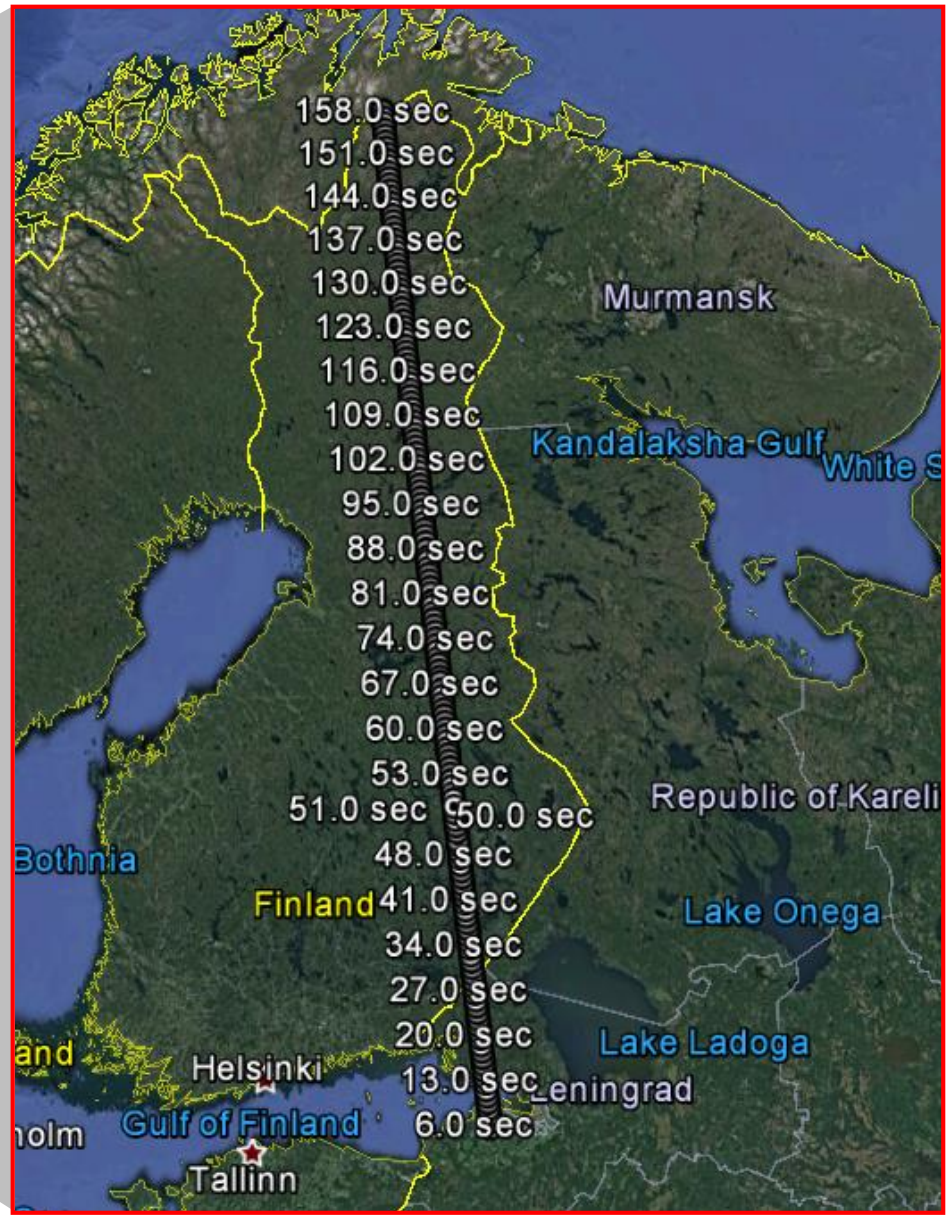


PhoREAL (User Example 2: Inputs)

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 Reference Ground Index:	N/A
	Save Shifted ICESat-2 File:	N/A
	Make Output Plots:	N/A

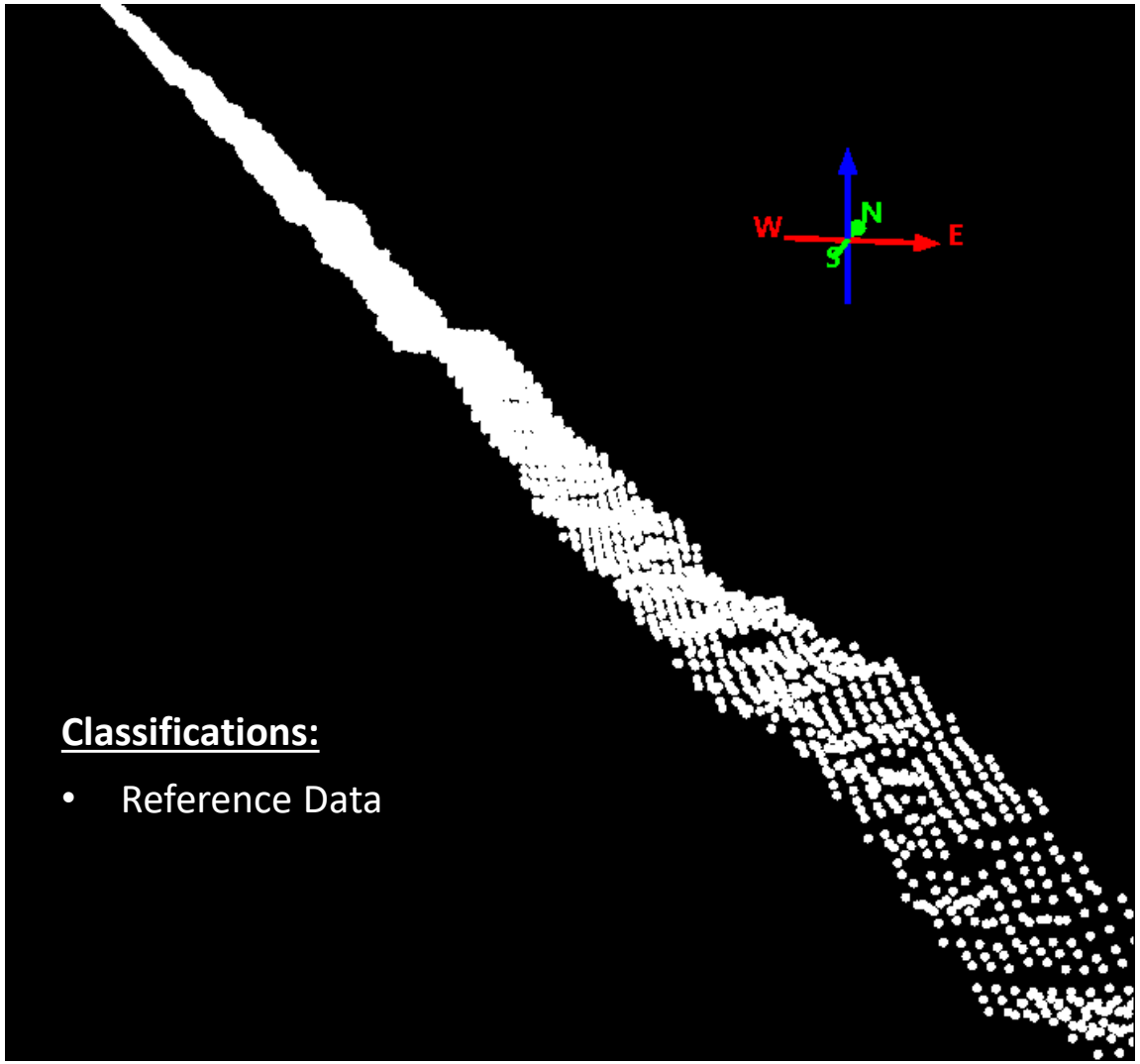
PhoREAL (User Example 2: Output .kml File)

ICESat-2 Track Over Finland

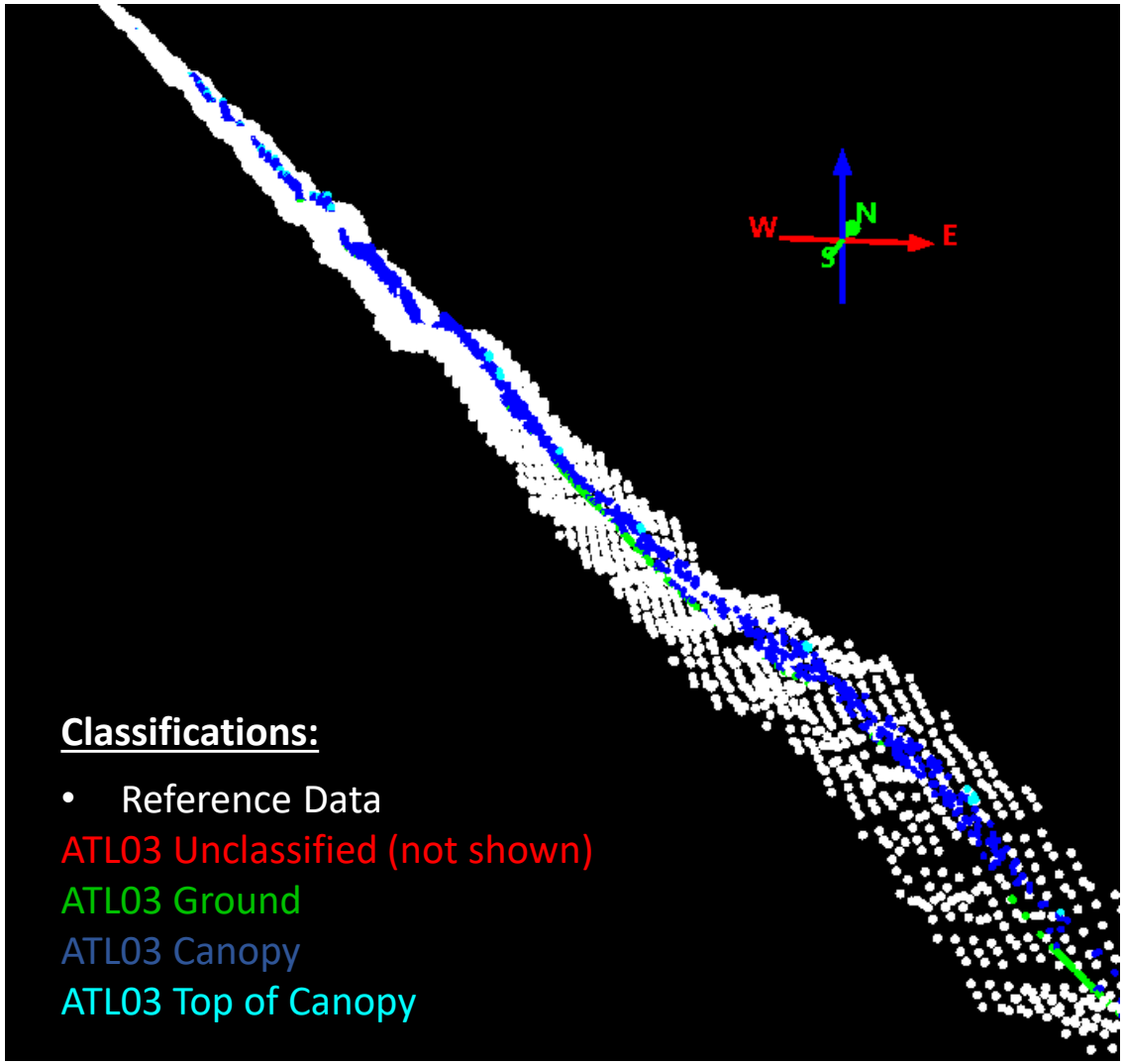


Output .kml File in Google Earth

PhoREAL (User Example 2: Output .las File)



Output .las File in QT Modeler



Output .las File in QT Modeler

PhoREAL (User Example 2: Output .csv File)

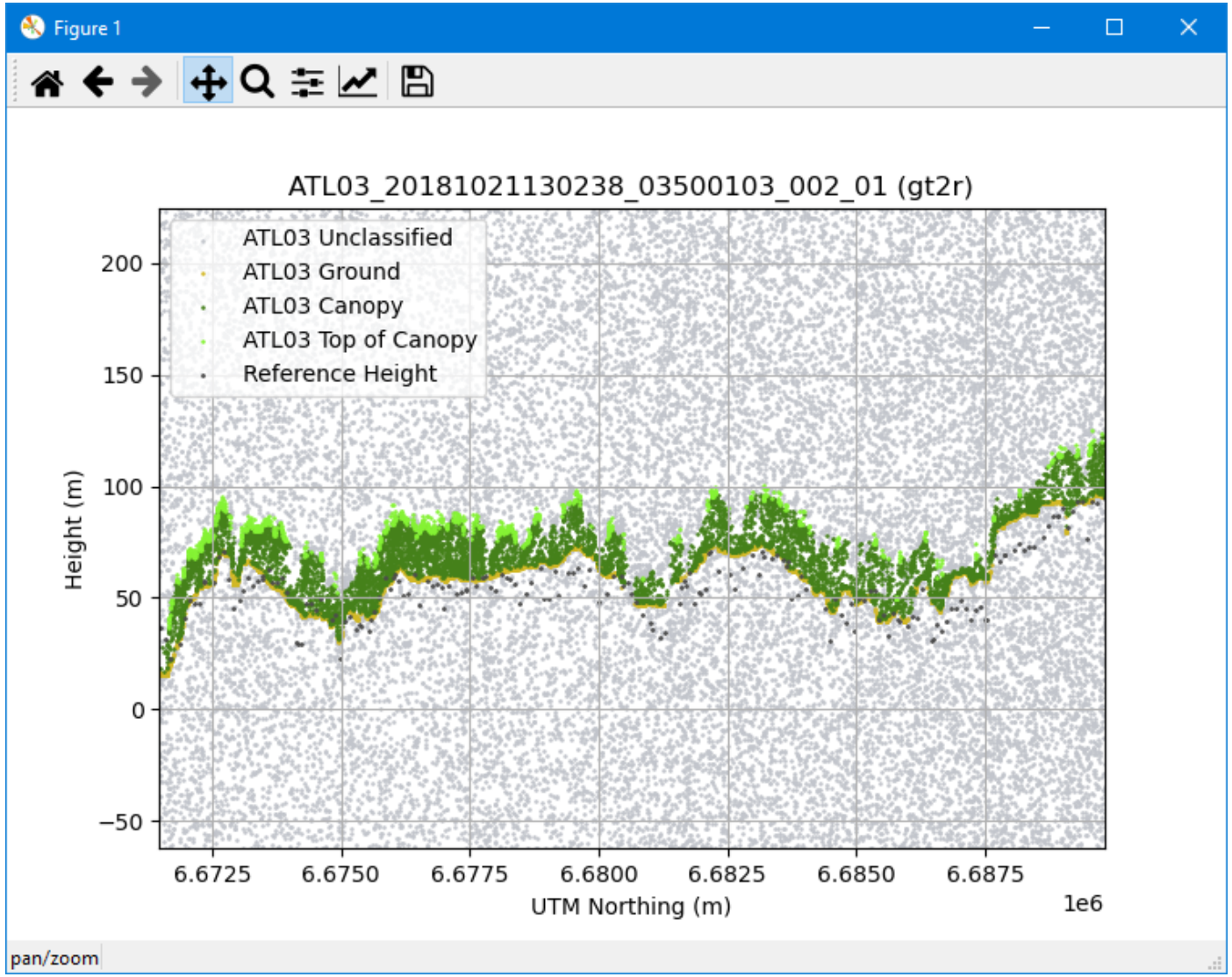
	A	B	C	D	E	F	G	H	I	J	K
1	Time (sec)	Delta Time (sec)	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)	Cross-Track (m)	Along-Track (m)	Height (m)	Classification	Signal Confidence
2	0	25362163.58	59.76168043	29.42821039	636392.7633	6627368.068	0	0	138.505188	0	0
3	0	25362163.58	59.76167952	29.42821201	636392.858	6627367.97	0.081130887	-0.110014085	120.5898056	2	0
4	0	25362163.58	59.76167812	29.42821447	636393.002	6627367.819	0.204605483	-0.277456445	93.32426453	1	2
5	0	25362163.58	59.76167477	29.42822039	636393.3483	6627367.459	0.501453401	-0.679971463	27.77549553	0	0
6	0.000200003	25362163.58	59.76169079	29.42821195	636392.8089	6627369.224	0.194353807	1.140496639	93.22445679	1	2
7	0.000200003	25362163.58	59.76168844	29.4282161	636393.0518	6627368.971	0.402596724	0.858115843	47.24100876	0	0
8	0.000300001	25362163.58	59.76169817	29.42820883	636392.6038	6627370.04	0.096211051	1.975526101	113.7114258	2	0
9	0.000300001	25362163.58	59.76169816	29.42820885	636392.6049	6627370.038	0.097196433	1.974184431	113.4938431	2	0
10	0.000400003	25362163.58	59.76170359	29.42820918	636392.6012	6627370.644	0.17163676	2.575173329	95.86914825	2	2
11	0.000500001	25362163.58	59.76170655	29.4282139	636392.8539	6627370.982	0.465876973	2.878034056	29.70742989	0	0
12	0.000700001	25362163.58	59.76172343	29.42820391	636392.2243	6627372.841	0.081468362	4.802895021	112.2069168	2	0
13	0.000800002	25362163.58	59.76172473	29.42821154	636392.6475	6627373.002	0.521903479	4.907417752	13.75674057	0	0
14	0.0009	25362163.58	59.76173631	29.428201	636392.0084	6627374.269	0.051717014	6.246697106	116.3837128	2	0
15	0.001000013	25362163.58	59.76174172	29.42820137	636392.0073	6627374.872	0.128381892	6.844479703	98.25485229	2	1
16	0.001100011	25362163.58	59.76174817	29.4281999	636391.898	6627375.587	0.112275524	7.567921151	100.6095047	2	1
17	0.001300011	25362163.59	59.76176042	29.4281981	636391.7475	6627376.947	0.138506977	8.935433538	92.40649414	0	2
18	0.00150001	25362163.59	59.7617755	29.42819131	636391.3042	6627378.611	-0.086278343	10.64316476	139.6233521	0	0
19	0.001600012	25362163.59	59.76177967	29.42819386	636391.4307	6627379.081	0.099746786	11.09232429	97.33203125	2	2
20	0.00170001	25362163.59	59.76178503	29.42819431	636391.4342	6627379.678	0.180351758	11.6843577	78.31732178	0	0
21	0.001800012	25362163.59	59.76179697	29.42818312	636390.7571	6627380.985	-0.322476393	13.06748616	188.133316	0	0
22	0.001800012	25362163.59	59.76179224	29.42819148	636391.2459	6627380.475	0.096513145	12.49934325	95.6120224	2	2
23	0.002000023	25362163.59	59.7618048	29.42818914	636391.0631	6627381.868	0.09498761	13.90396335	93.50499725	1	3
24	0.002100021	25362163.59	59.76180976	29.42819028	636391.1072	6627382.423	0.210292966	14.448767	66.8182373	0	0
25	0.002200022	25362163.59	59.76181746	29.42818661	636390.8692	6627383.272	0.08391045	15.32127284	93.49739838	1	3
26	0.00230002	25362163.59	59.76182472	29.42818368	636390.6754	6627384.075	-0.004675755	16.14247032	111.8281784	2	0
27	0.00230002	25362163.59	59.76182472	29.42818369	636390.676	6627384.074	-0.004184476	16.14180141	111.719696	2	0

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

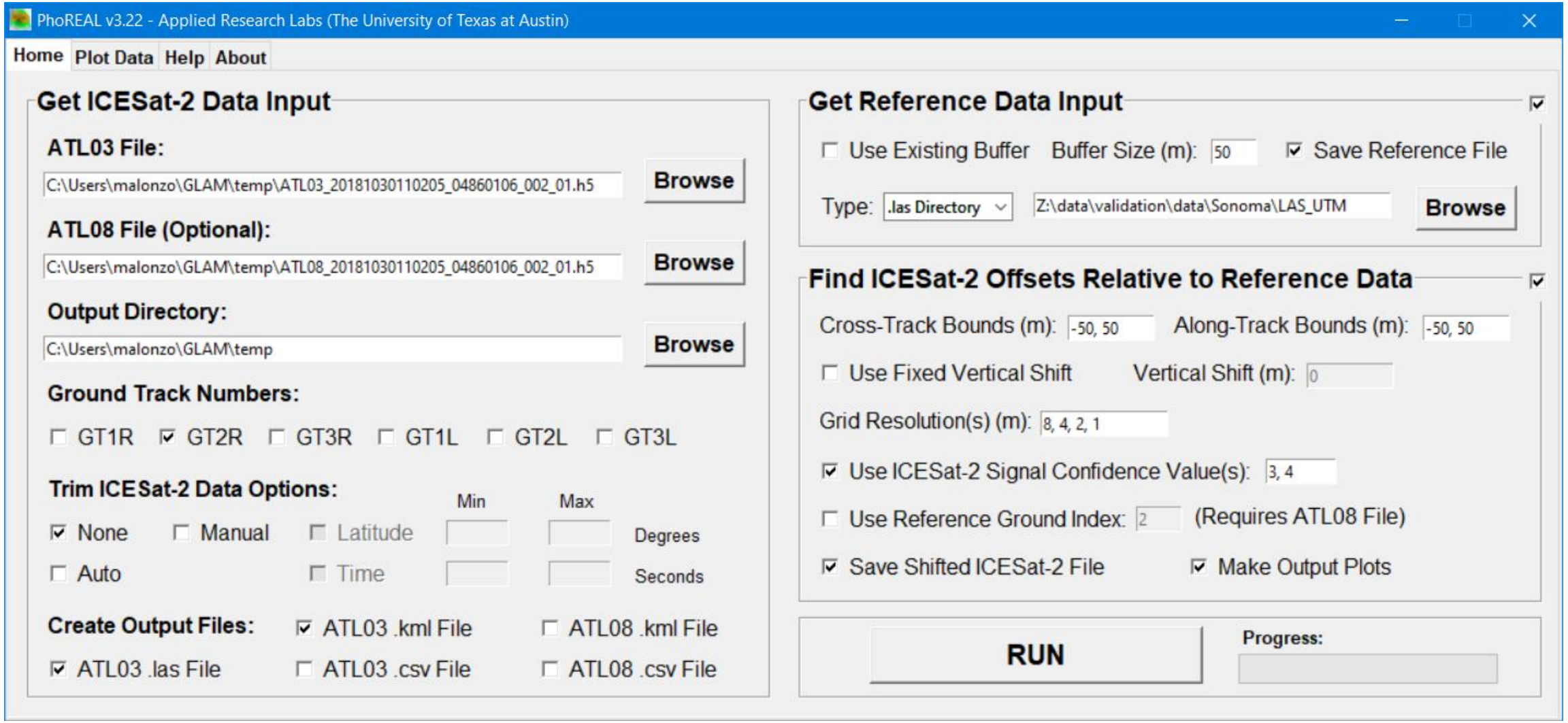


Output Figure in PhoREAL

PhoREAL v3.22

User Example 3
Comparing ICESat-2 to Reference .las Files
North Carolina

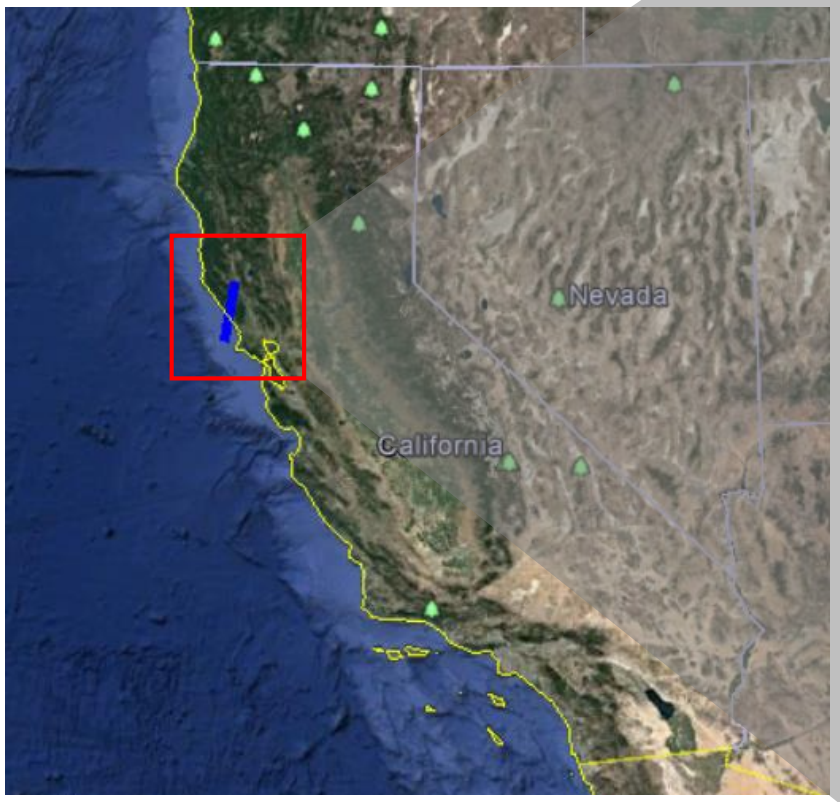
PhoREAL (User Example)



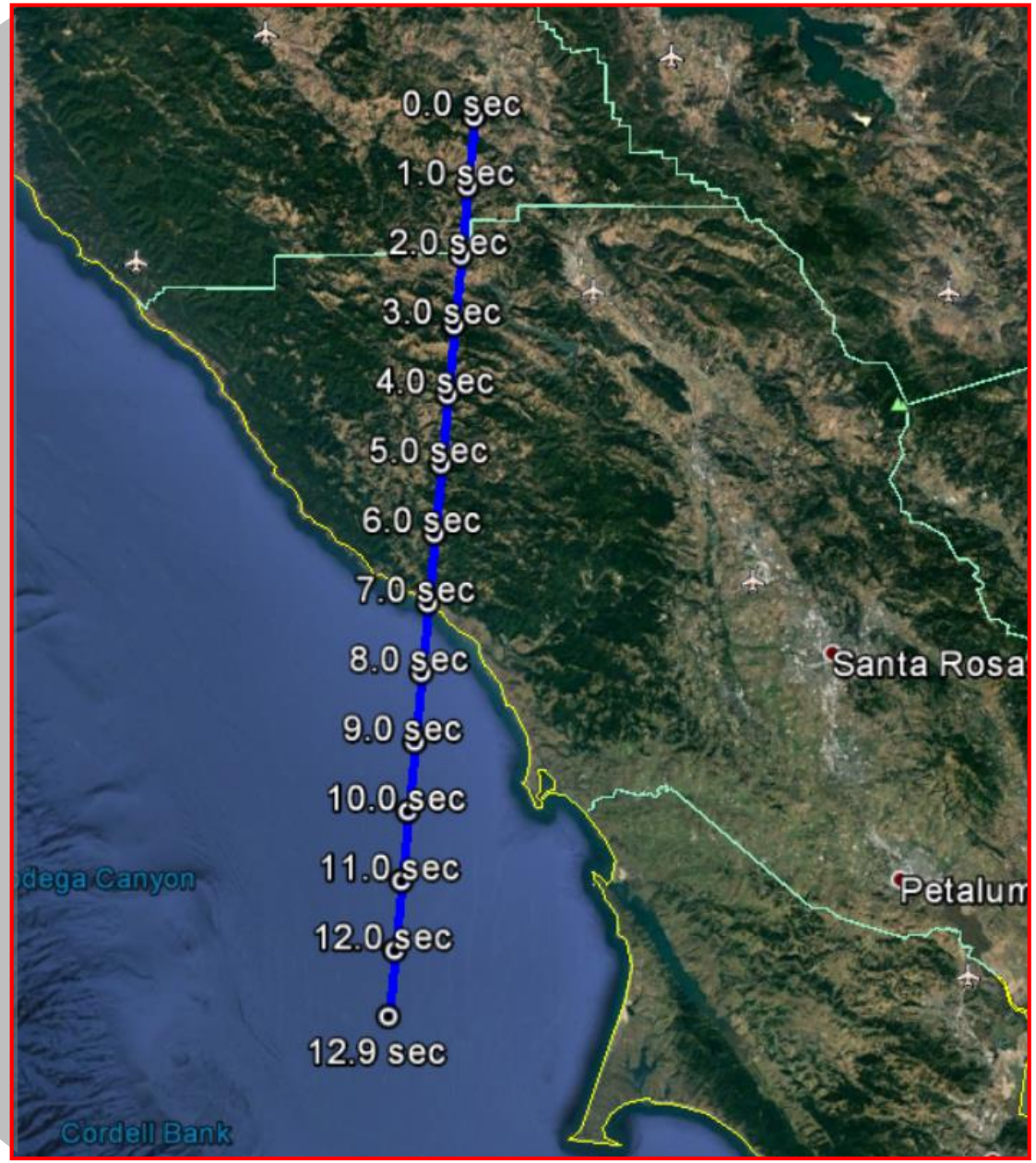
PhoREAL (User Example)

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 Reference Ground Index:	2
	Save Shifted ICESat-2 File:	Yes
	Make Output Plots:	Yes

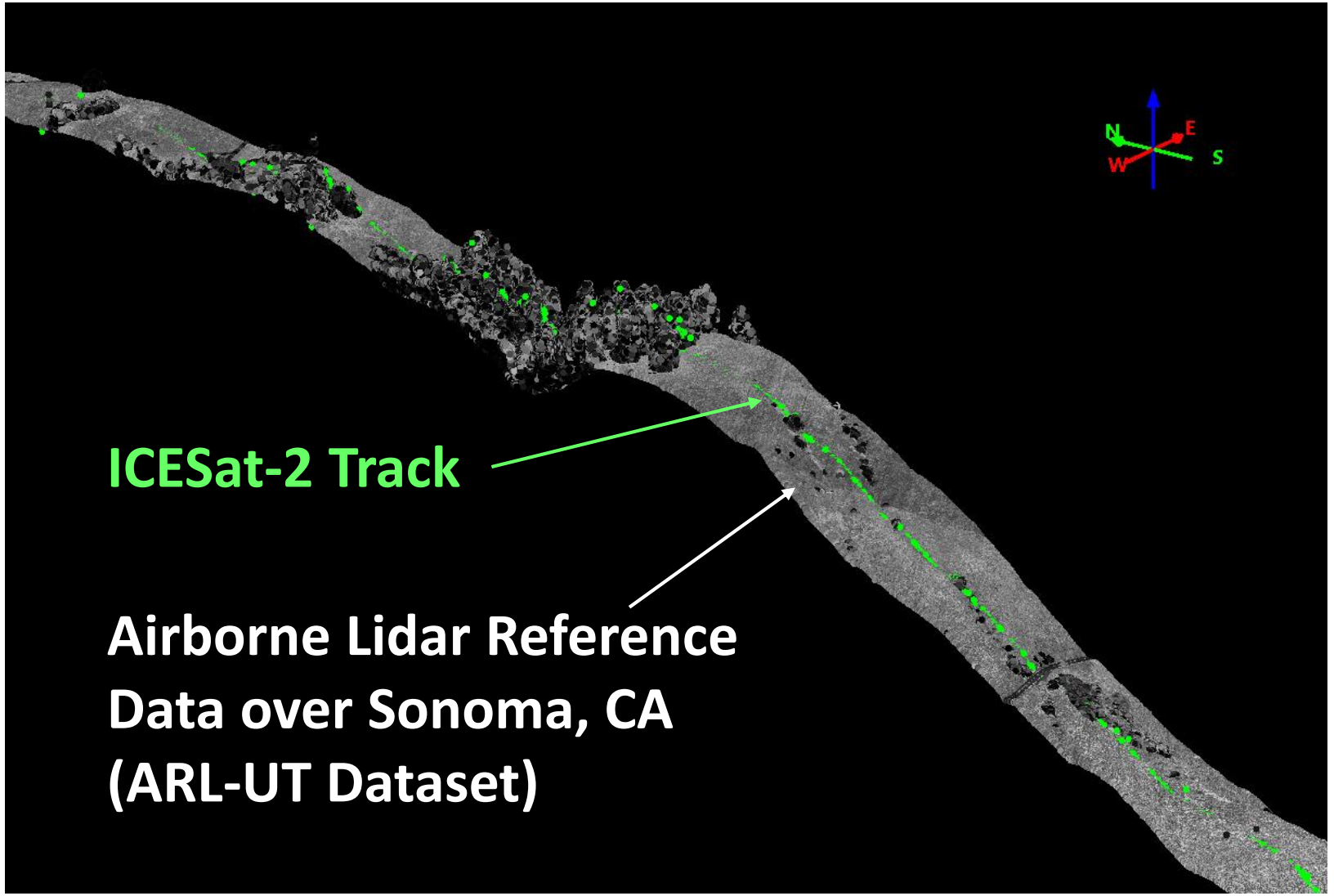
PhoREAL (Output .kml File)



ICESat-2 Track Over Sonoma, CA



PhoREAL (Output .las Files)

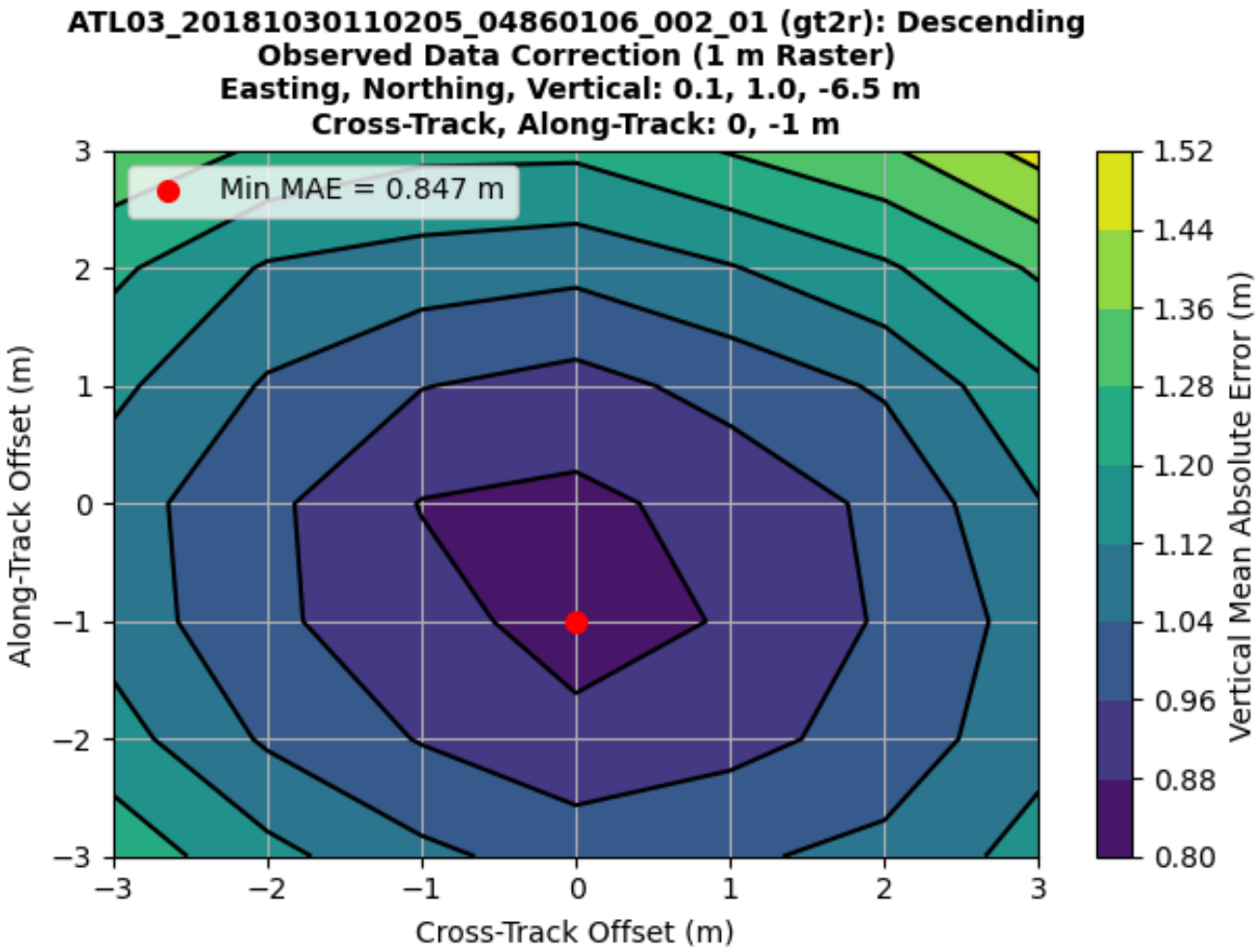


PhoREAL (Output .csv File)

	A	B	C	D	E	F	G	H	I	J	K
1	Time (sec)	Delta Time (sec)	Latitude (deg)	Longitude (deg)	Easting (m)	Northing (m)	Cross-Track (m)	Along-Track (m)	Height (m)	Classification	Signal Confidence
2	0	26132850.19	38.9354939	-123.1310807	488639.1911	4309626.479	0	0	563.015625	3	4
3	0	26132850.19	38.93549407	-123.1310805	488639.2105	4309626.497	-0.017602912	-0.019898601	559.947937	2	4
4	1.00E-04	26132850.19	38.93548771	-123.1310812	488639.1505	4309625.791	-0.026646042	0.688342408	559.0372925	2	4
5	0.000300009	26132850.19	38.93547495	-123.1310826	488639.0265	4309624.376	-0.041333659	2.108839092	557.812561	1	4
6	0.000300009	26132850.19	38.93547501	-123.1310825	488639.0336	4309624.383	-0.04769975	2.10165074	556.703186	0	4
7	0.00040001	26132850.19	38.93546848	-123.1310834	488638.9529	4309623.658	-0.038118096	2.83102886	559.0424194	2	4
8	0.000500008	26132850.19	38.93546197	-123.1310843	488638.8758	4309622.936	-0.031804899	3.55670097	560.8133545	2	4
9	0.000500008	26132850.19	38.9354621	-123.1310841	488638.8907	4309622.95	-0.045231472	3.541565759	558.4735107	2	4
10	0.000500008	26132850.19	38.93546212	-123.1310841	488638.8928	4309622.952	-0.047158665	3.539380994	558.1376953	1	4
11	0.00060001	26132850.19	38.93545559	-123.131085	488638.8135	4309622.228	-0.038807455	4.267415764	560.2650757	2	4
12	0.00060001	26132850.19	38.93545565	-123.1310849	488638.8205	4309622.235	-0.045128378	4.260278671	559.1635742	2	4
13	0.00060001	26132850.19	38.93545554	-123.1310851	488638.8066	4309622.222	-0.032578364	4.274448752	561.3505859	3	4
14	0.000700008	26132850.19	38.9354492	-123.1310857	488638.7502	4309621.519	-0.044930669	4.97909696	559.8712769	2	4
15	0.000700008	26132850.19	38.93544927	-123.1310856	488638.758	4309621.527	-0.052002295	4.971108857	558.638916	2	4
16	0.00080001	26132850.19	38.93544288	-123.1310863	488638.6945	4309620.817	-0.057936125	5.683084472	558.2794189	2	4
17	0.000900008	26132850.19	38.93543662	-123.1310869	488638.647	4309620.123	-0.078375927	6.378641077	555.3931274	1	4
18	0.001000009	26132850.19	38.93543003	-123.1310879	488638.5592	4309619.391	-0.062353077	7.115439964	558.8622437	2	4
19	0.001100011	26132850.19	38.93542381	-123.1310883	488638.5172	4309618.702	-0.087795875	7.805454637	555.1064453	1	4
20	0.001100011	26132850.19	38.93542361	-123.1310886	488638.4929	4309618.68	-0.065817203	7.830255951	558.9365845	2	4
21	0.001200009	26132850.19	38.9354174	-123.1310891	488638.4512	4309617.991	-0.091509005	8.519983479	555.1384277	1	4
22	0.001200009	26132850.19	38.93541742	-123.1310891	488638.4532	4309617.993	-0.093336741	8.517911502	554.8199463	1	4
23	0.001300011	26132850.19	38.93541088	-123.13109	488638.3718	4309617.267	-0.083059855	9.2482906	557.2909546	2	4
24	0.00140002	26132850.19	38.93539612	-123.1311022	488637.3098	4309615.63	0.814264975	10.98034604	714.3483887	0	0
25	0.00140002	26132850.19	38.93540457	-123.1310906	488638.318	4309616.567	-0.097811824	9.950456302	555.4014282	1	4
26	0.00140002	26132850.19	38.9354046	-123.1310906	488638.3224	4309616.571	-0.10184548	9.945912262	554.6984863	1	4
27	0.001500018	26132850.19	38.93539697	-123.131093	488638.1108	4309615.724	0.02620508	10.80927227	577.6953735	0	3

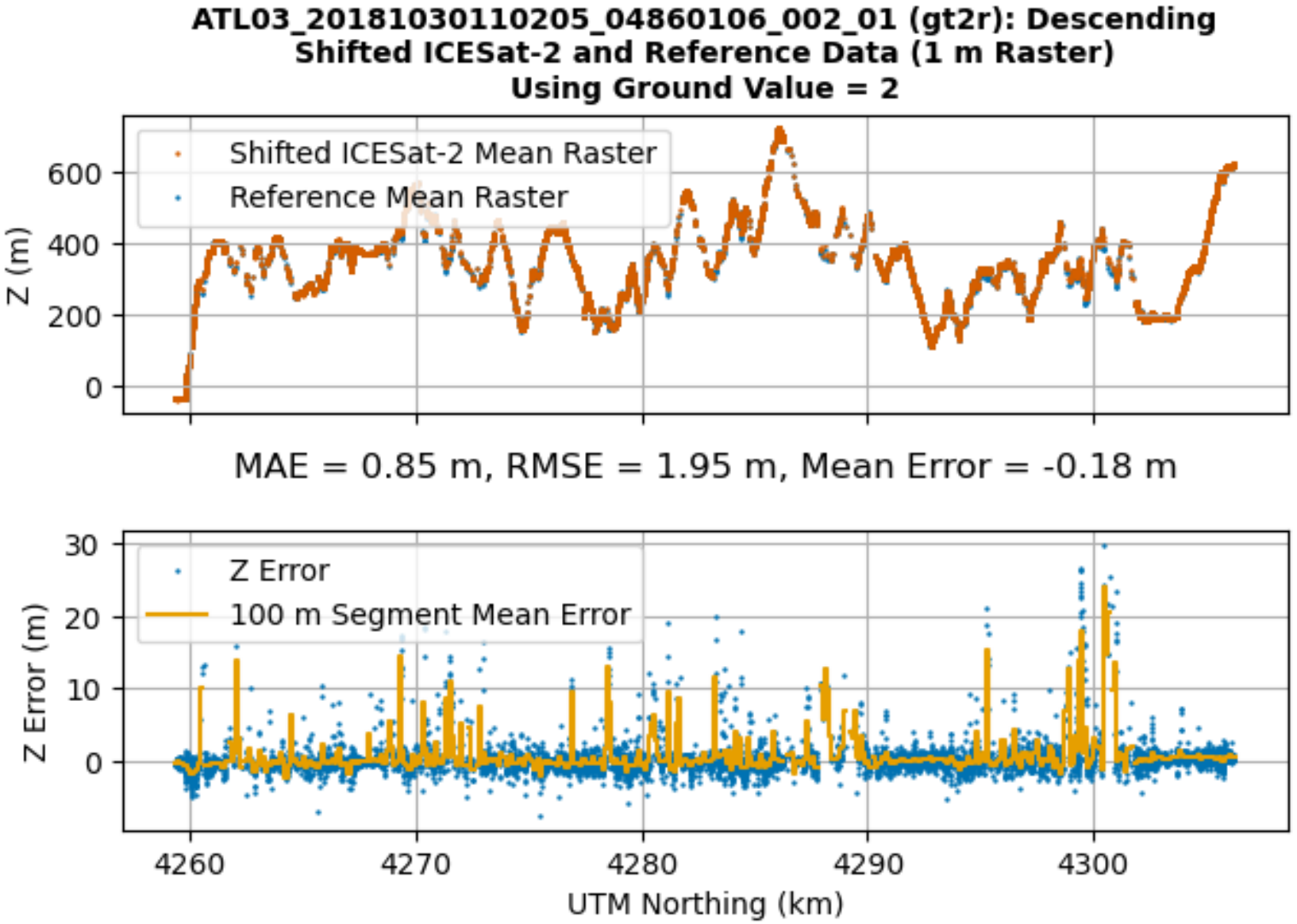
Output .csv File in Excel

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

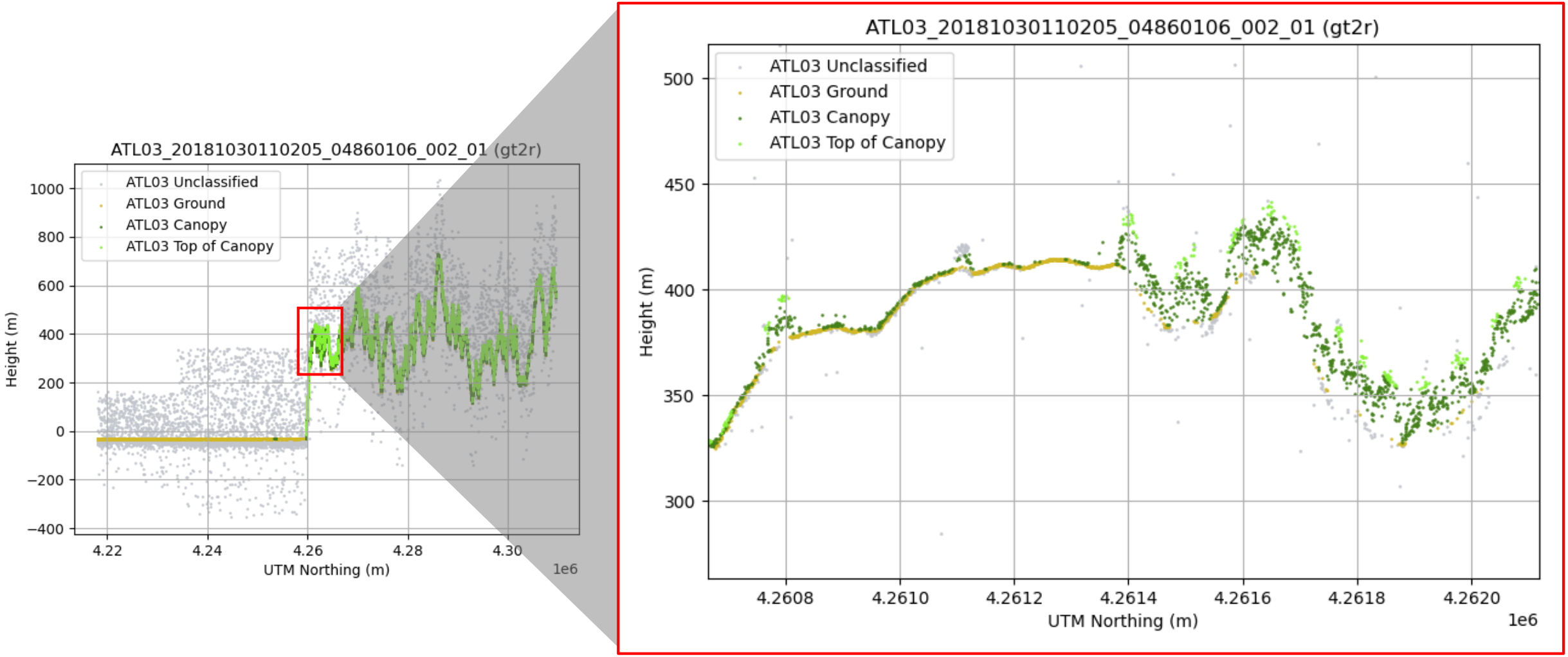


- Relative to the Sonoma reference data, PhoREAL computed that this particular ICESat-2 track is offset by 0.1 m in UTM Easting, 1.0 m in UTM Northing, and -6.5 m in vertical distance (this is equal to 0 m in cross-track distance and -1 m in the along-track distance of ICESat-2)
- The colors in the contour figure show the Vertical Mean Absolute Error at other discrete offsets locations, confirming that the minimum vertical error (0.847 m) is at 0 m in cross-track and -1 m in along-track (red dot)
- The reason for the high vertical offset (-6.5 m) is due to the reference dataset being in orthometric heights while ICESat-2 data is in ellipsoidal heights. An approximate geoidal height conversion is used which carries some level of error.
- A future release of PhoREAL will use ICESat-2 orthometric heights.

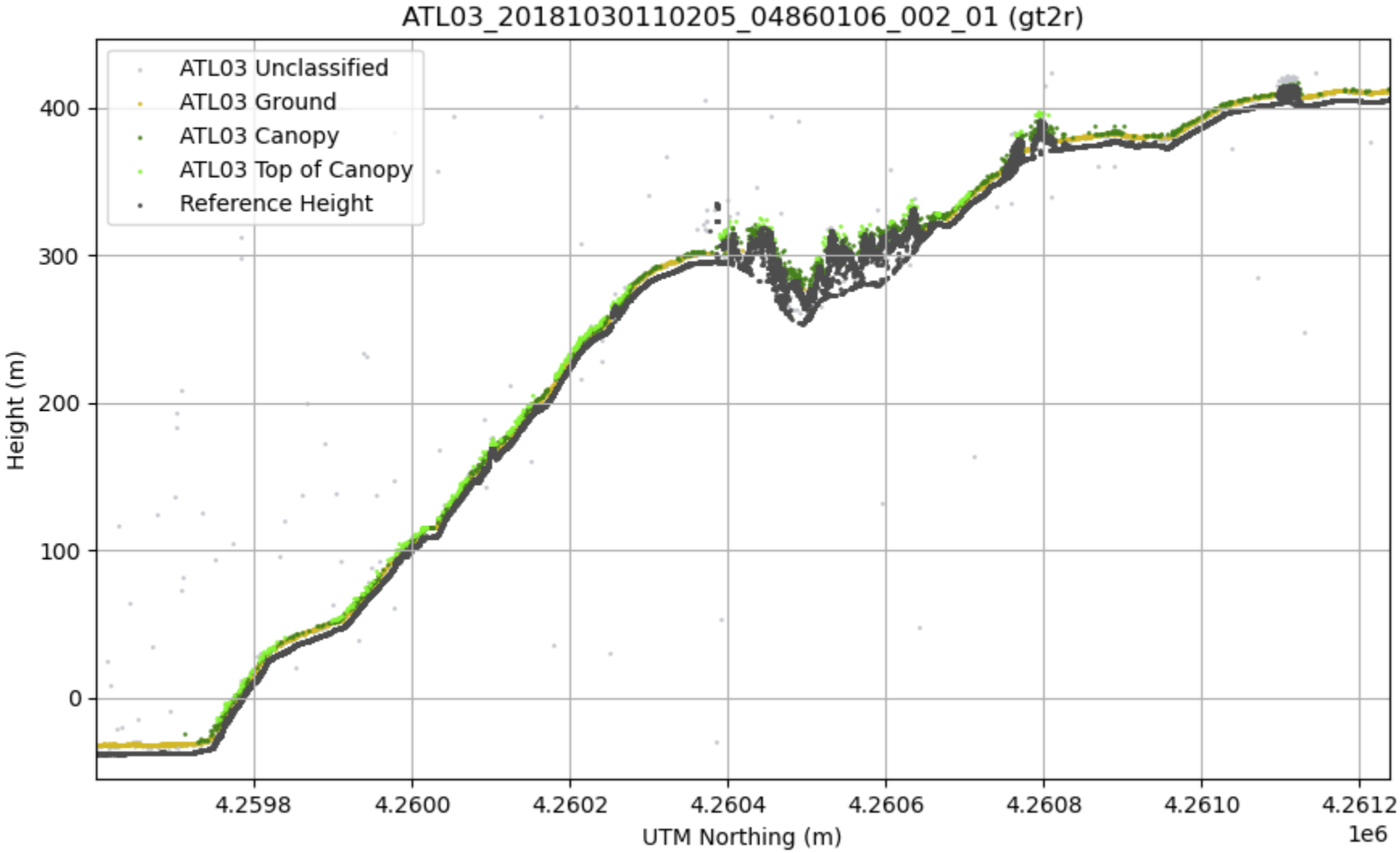
PhoREAL (Shifted ICESat-2 and Reference Data Comparison)



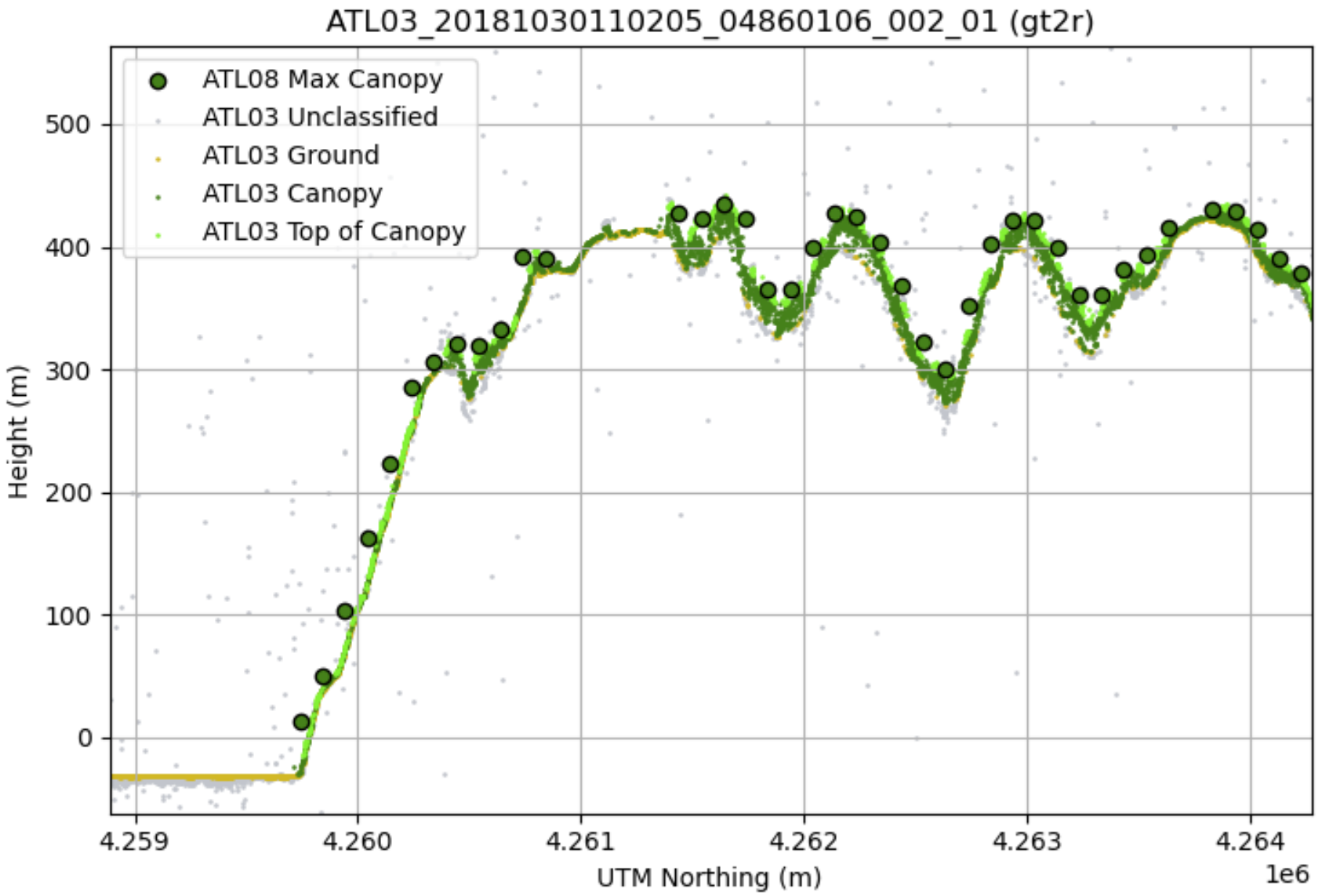
PhoREAL (Output Plot with Classifications)



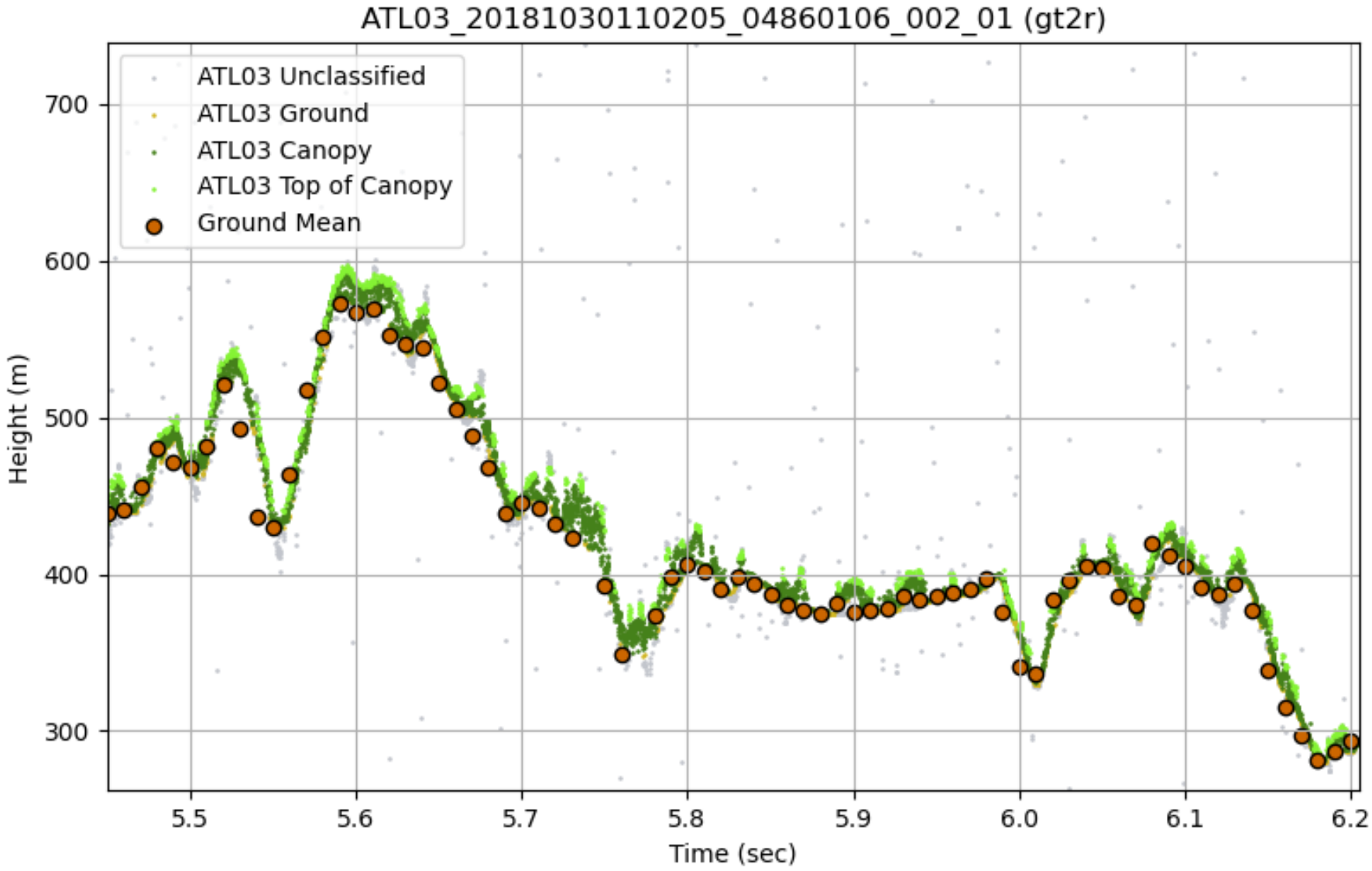
PhoREAL (Output Plot with Airborne Lidar Reference Data)



PhoREAL (Output Plot with ATL08 Max Canopy)



PhoREAL (Output Plot with Ground Mean Stats at 0.01 sec Intervals)



PhoREAL (Output HTML from PhoSHOW)