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Earth and Space Science

Supporting Information for

ICESat-2/ATLAS Onboard Flight Science Receiver Algorithms: Purpose, Process, and Performance

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Introduction

This document includes figures that show how the Receiver Algorithms processed on-orbit data through various conditions (Figures S1 – S4), as well as additional material on building and testing the Receiver Algorithms (Table S1).

Table S1 lists a large selection of the tests performed during the various stages of Algorithms checkout from Simulator, through ATLAS Instrument, to Mission testing. Included in these tests were those that verified the performance during the various Design Cases.

The plots in Figures S1 through S4 are representative examples from our analysis of many hours of data that support our assessment of the Algorithms performance on-orbit and, combined with other analysis, lead to the conclusion that the Algorithms are meeting their requirements.

The data files used to produce Figure 6 and the Tables in the paper, as well as Figures S1 – S4 in this Supplemental Material, are available through the National Snow and Ice Data Center (https://nsidc.org/data/icesat-2, ATL02, ATL03 and ATL04 products) and the ICESat-2 website (https://icesat-2.gsfc.nsa.gov/calibration-data, Simplot text files).

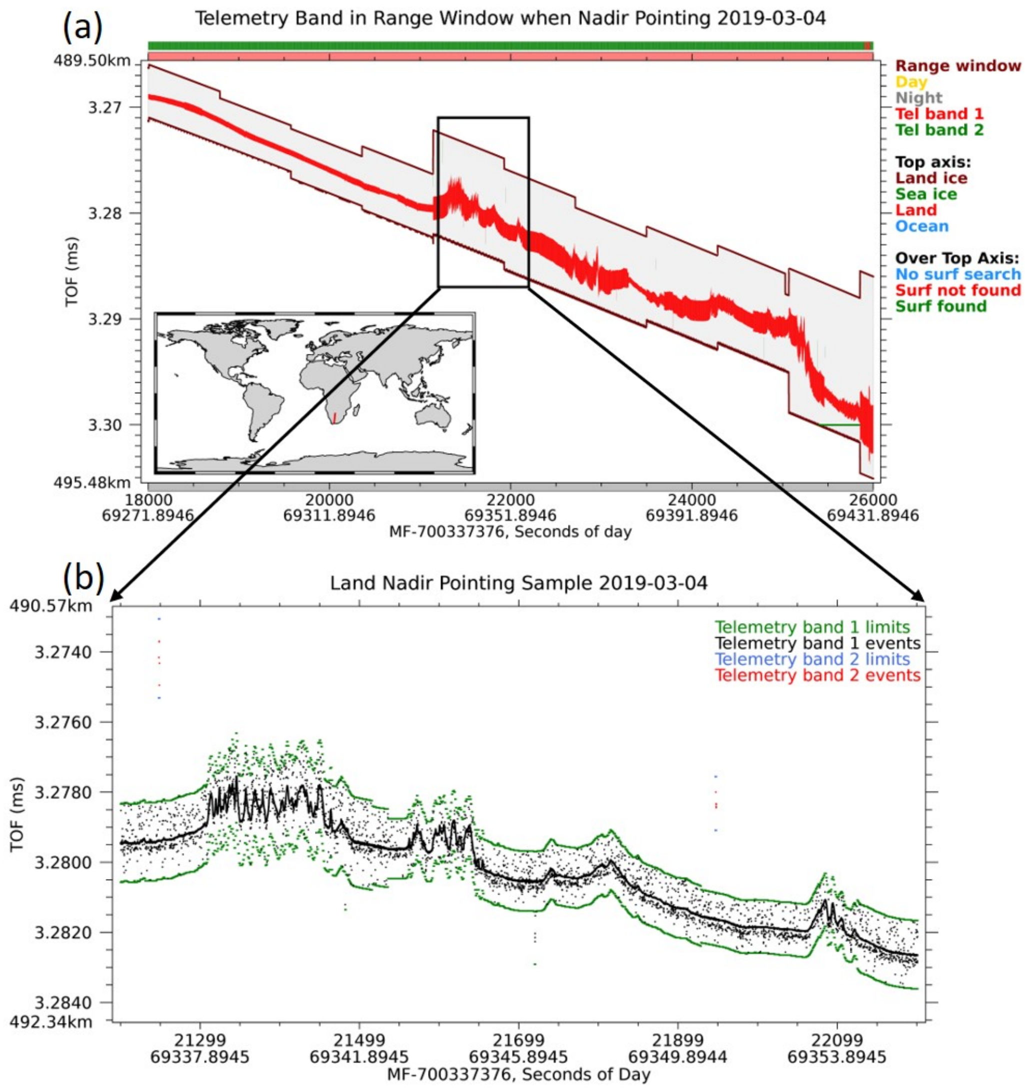

Figure S1. Position of telemetry bands in the spot 3 Range Window (RW) on 4 March 2019 while nadir pointing. The start of the RW (closest to the spacecraft) is at the top, while the end of the RW (closest to the surface) is at the bottom. Gray background in the range window of plot (a) indicates night-time observations as does the gray bar across the bottom. The red vertical lines in the RW in (a) are the primary telemetry bands and the green are the secondary. The green secondary telemetry bands in lower right part of the RW in plot (a) contain the Transmitter Echo Pulse (TEP). The bars across the top of plot (a) show: (1) the surface type (lower bar), and (2) results from the ATL04 cloud test (upper bar) indicating the likelihood of clouds being present. The lower plot (b) shows the time of flight events within the primary and secondary telemetry bands for a portion of the upper plot. There are only a few secondary bands and these appear to contain noise. The horizontal axis units are in relative Major Frames (MF) and seconds of day. The red line in the map inserted in plot (a) shows the global location of ICESat-2 during the data collection.

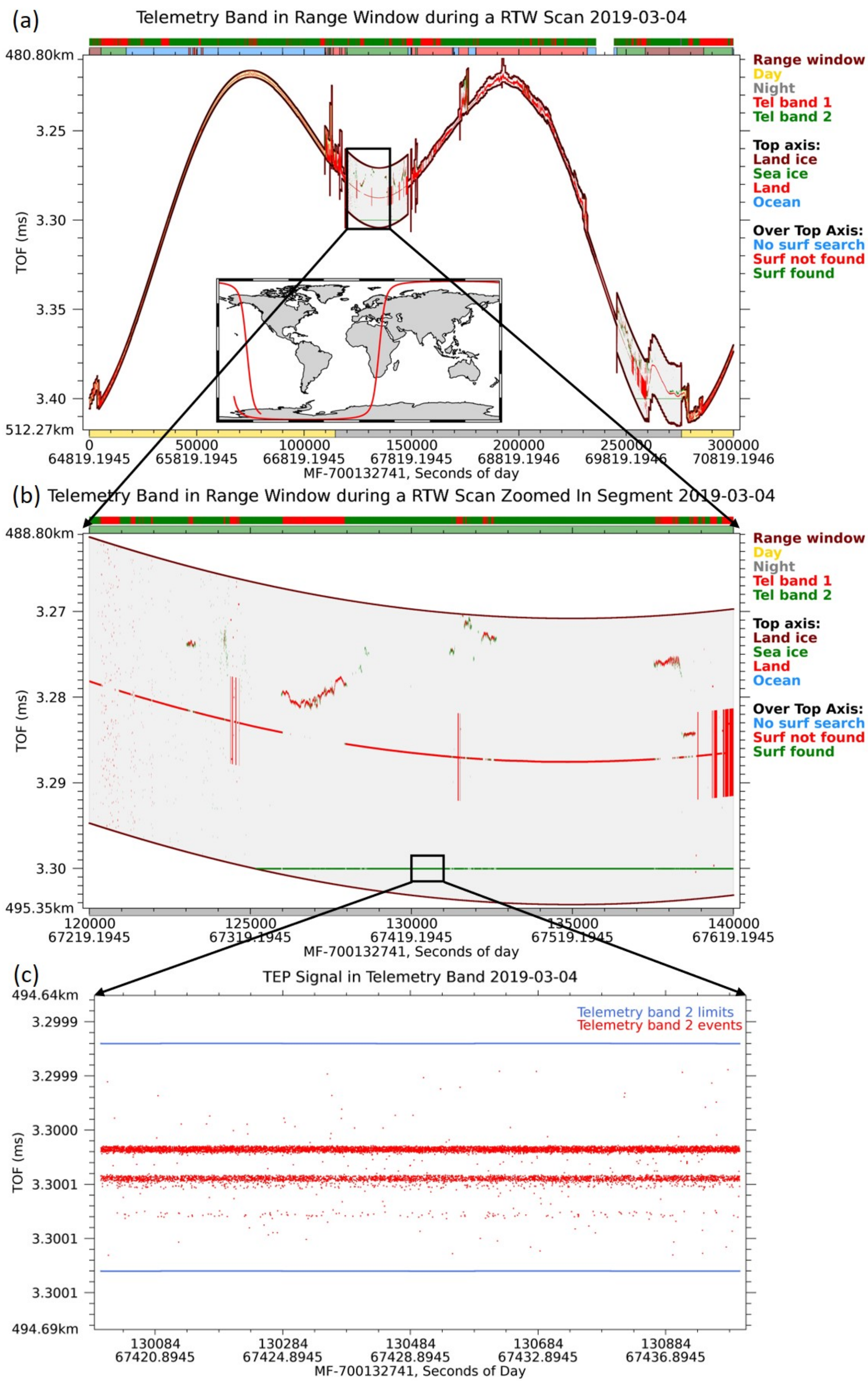
(a)
Telemetry Band in Range Window during a RTW Scan 2019-03-04
480.80km
512.27km
TOF (ms)
3.25
3.30
3.35
3.40
0
50000
100000
150000
200000
250000
300000
64819.1945
65819.1945
66819.1945
67819.1945
68819.1946
69819.1946
70819.1946
MF-700132741, Seconds of day
Range window
Day
Night
Tel band 1
Tel band 2
Top axis:
Land ice
Sea ice
Land
Ocean
Over Top Axis:
No surf search
Surf not found
Surf found
(b)
Telemetry Band in Range Window during a RTW Scan Zoomed In Segment 2019-03-04
488.80km
495.35km
TOF (ms)
3.27
3.28
3.29
3.30
120000
125000
130000
135000
140000
67219.1945
67319.1945
67419.1945
67519.1945
67619.1945
MF-700132741, Seconds of day
Range window
Day
Night
Tel band 1
Tel band 2
Top axis:
Land ice
Sea ice
Land
Ocean
Over Top Axis:
No surf search
Surf not found
Surf found
(c)
TEP Signal in Telemetry Band 2019-03-04
494.64km
494.69km
TOF (ms)
3.2999
3.2999
3.3000
3.3001
3.3001
3.3001
Telemetry band 2 limits
Telemetry band 2 events
130084
130284
130484
130684
130884
67420.8945
67424.8945
67428.8945
67432.8945
67436.8945
MF-700132741, Seconds of Day

Figure S2. Position of telemetry bands in the spot 3 Range Window (RW) during a Round The World (RTW) scan on 4 March 2019. The start of the RW (closest to the spacecraft) is at the top, while the end of the RW (closest to the surface) is at the bottom. Gray background in the range window of the (a) and (b) plots indicates night-time observations as does the gray section of the bar across the bottom. Yellow background in the range window of plot (a) indicates day-time observations as does the yellow section of the bar across the bottom. The red vertical lines in the RW in (a) and (b) are the primary telemetry bands and the green are the secondary. The bars across the top of plots (a) and (b) show: (1) the surface type (lower bar), and (2) results from the ATL04 cloud test (upper bar) indicating the likelihood of clouds being present. The middle plot is a zoom into the box shown in the top plot. The lower plot (c) shows the time of flight events within the secondary telemetry bands for a portion of the middle plot. The events captured in plot (c) are the Transmitter Echo Pulse (TEP) from internal reflections of the ATLAS laser. These internal reflections are collected for calibration purposes. This plot shows that the TEP is well centered within the telemetry band. The horizontal axis units are in relative Major Frames (MF) and seconds of day. The red line in the map inserted in plot (a) shows the global location of ICESat-2 during the data collection.

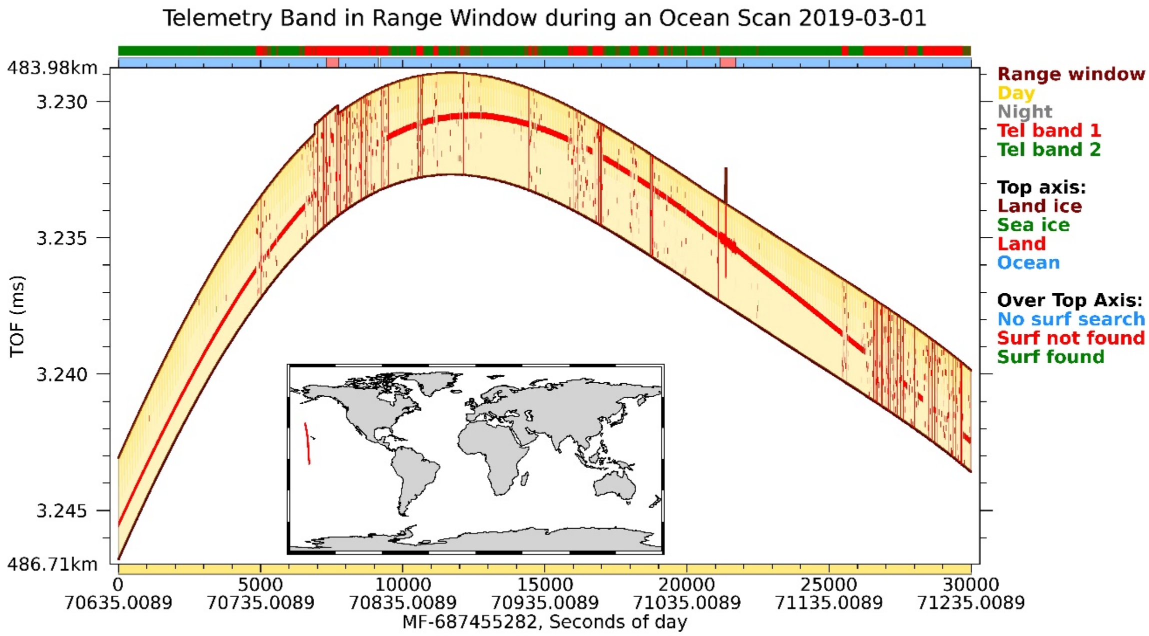

Figure S3. Position of telemetry band in the spot 5 Range Window (RW) during an Ocean Scan on 1 March 2019. The start of the RW (closest to the spacecraft) is at the top, while the end of the RW (closest to the surface) is at the bottom. Yellow background in the range window indicates day-time observations as does the yellow bar across the bottom. The red vertical lines in the RW are the primary telemetry bands and the green are the secondary. The bars across the top of the plot show: (1) the surface type (lower bar), and (2) results from the ATL04 cloud test (upper bar) indicating the likelihood of clouds being present. The horizontal axis units are in relative Major Frames (MF) and seconds of day. The red line in the map inserted in the plot shows the global location of ICESat-2 during the data collection.

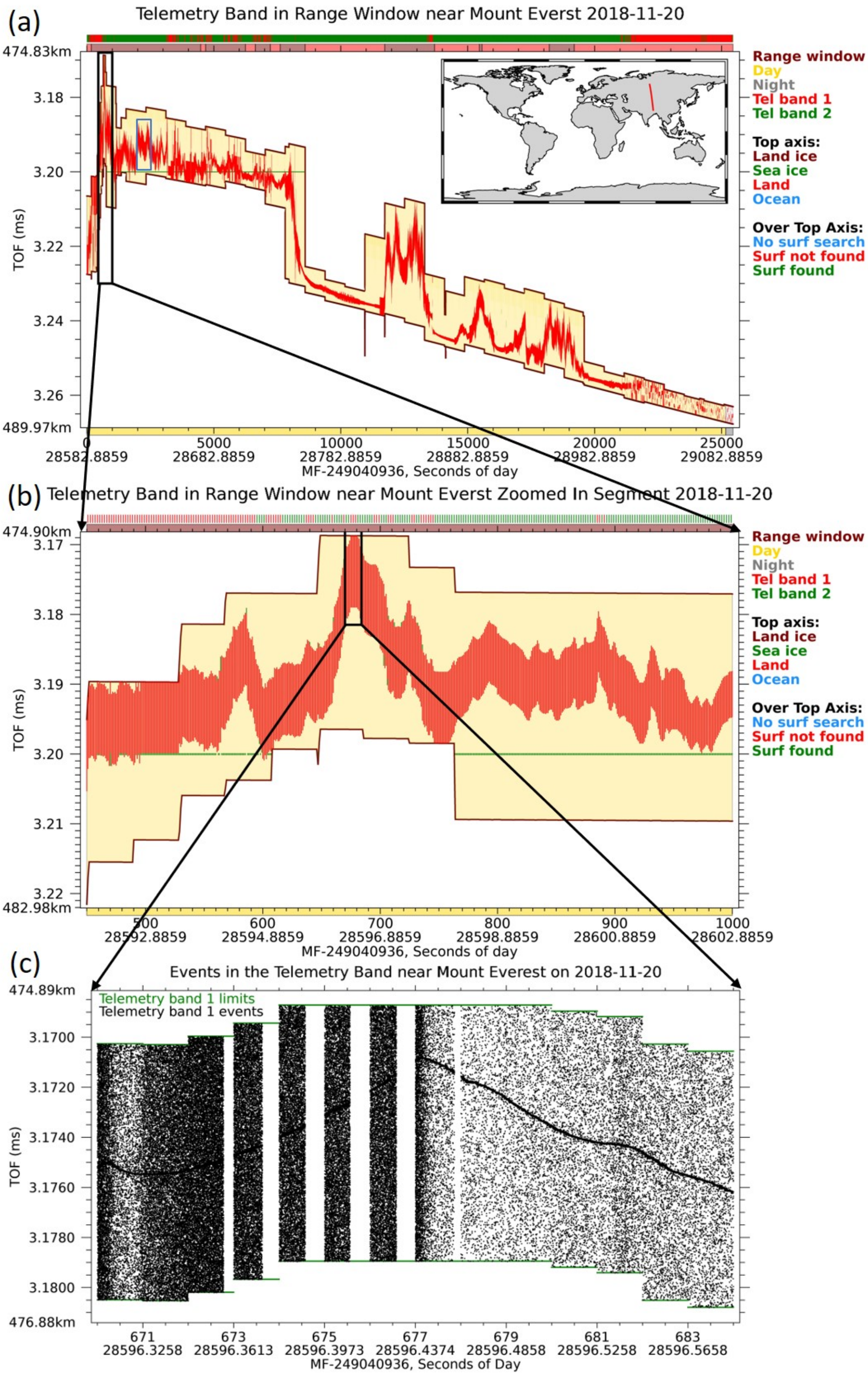
(a)
Telemetry Band in Range Window near Mount Everst 2018-11-20
474.83km
489.97km
TOF (ms)
MF-249040936, Seconds of day
Range window
Day
Night
Tel band 1
Tel band 2
Top axis:
Land ice
Sea ice
Land
Ocean
Over Top Axis:
No surf search
Surf not found
Surf found
(b)
Telemetry Band in Range Window near Mount Everst Zoomed In Segment 2018-11-20
474.90km
482.98km
TOF (ms)
MF-249040936, Seconds of day
(c)
Events in the Telemetry Band near Mount Everest on 2018-11-20
474.89km
476.88km
Telemetry band 1 limits
Telemetry band 1 events
TOF (ms)
MF-249040936, Seconds of Day

Figure S4. Position of telemetry bands in the spot 3 Range Window (RW) during a pass near Mount Everest on 20 Nov 2018. This is a nadir pointing pass. The start of the RW (closest to the spacecraft) is at the top, while the end of the RW (closest to the surface) is at the bottom. Yellow background in the range window of the (a) and (b) plots indicates day-time observations as does the yellow bar across the bottom. The red vertical lines in the RW in (a) and (b) are the primary telemetry bands and the green are the secondary. Almost all of the secondary telemetry bands shown in this plot are the Transmitter Echo Pulse (TEP). The bars across the top of plots (a) and (b) show: (1) the surface type (lower bar), and (2) results from the ATL04 cloud test (upper bar) indicating the likelihood of clouds being present. The middle plot (b) is a zoom into the box shown in the top plot. The lower plot (c) shows the time of flight events within the primary telemetry bands for a portion of the middle plot. The signal is lost over segments of this region due to clouds. The horizontal axis units are in relative Major Frames (MF) and seconds of day. The red line in the map inserted in plot (a) shows the global location of ICESat-2 during the data collection.

TEST ID	Test Title	Purpose	Test Length (minutes per spot)	Orbit File
1	Data Volume Tests (Preliminary)	Data volume before instrument data becomes available.	20	Nominal
2	Surface Type Tests	Designed to run systematically through all surface type Receiver Algorithms paths, test both strong and weak spots, and test the Receiver Algorithms through various conditions. Results of these tests are also used to check the Cloud (Palm) Algorithm.	8	Nominal
3	Probability of Acquisition Tests – Land Ice, Dynamic (T003)/ Static (T003s)	Probability of finding signal as a function of signal strength and background rate for land ice.	196	Nominal
4	Probability of Acquisition Tests – Sea Ice, Dynamic (T004)/ Static (T004s)	Probability of finding signal as a function of signal strength and background rate for sea ice.	147	Nominal
5	Probability of Acquisition Tests – Land, Dynamic (T005)/ Static (T005s)	Probability of finding signal as a function of signal strength and background rate for land.	245	Nominal
6	Probability of Acquisition Tests – Ocean, Dynamic (T006)/ Static (T006s)	Probability of finding signal as a function of signal strength and background rate for ocean.	147	Nominal
7	Multiple Signal Locations Tests (Secondary Signals)	Ensure that the Receiver Algorithms can handle more than one surface echo per frame, can handle surface echo movement within the frame and from frame to frame, and can correctly telemeter these signals.	2.5	Nominal
8	Multiple Signal Locations Tests (TEP)	Check the performance of the Receiver Algorithms in the presence of the Transmitter Echo Pulse (TEP), when there are two signals, and test the handling of the TEP.	10	Nominal
9	Cloud Tests	Check the Receiver Algorithms performance under various controlled cloud conditions and to ensure that the Cloud (Palm) Algorithm is being used when needed and is working correctly.	3	Nominal

TEST ID	Test Title	Purpose	Test Length (minutes per spot)	Orbit File
10	Full Orbit Test – Nominal Parameters	Full orbit test with nominal parameter settings. Replaced by test 25.	90	Nominal
11	Full Orbit Test – Increased Solar Irradiance	Full orbit with increased solar background as a comparison against nominal test.	90	Nominal
12	Full Orbit Test – Reduced Data Volume Parameters	Full orbit test with parameters set to decrease data volume. Replaced by test 26.	90	Nominal
13	Full Orbit Test – Increased Data Volume Parameters	Full orbit test with parameters set to increase data volume. Replaced by test 27.	90	Nominal
14	Full Orbit Test – DRM for Land SW Bin Size	Full orbit test using the DRM for land software bin size	90	Nominal
15	Orbital Maneuver Test – Ocean Scan	Check performance of Receiver Algorithms during Ocean Scans.	30	Maneuvers
16	Orbital Maneuver Test – Round the World Scan	Check performance of Receiver Algorithms during Round the World Scans.	90	Maneuvers
17	Orbital Maneuver Test – Targets of Opportunity	Check performance of Receiver Algorithms during Targets of Opportunity.	100	Maneuvers
18	Range Window and Signal Tests	Ensure Receiver Algorithms can handle the range window correctly, can follow surface echo jumps and rates as required, can handle no-signal situations, and can limit the range window as the hardware requires.	23.5	Nominal
19	No-Signal Tests	Ensure the Receiver Algorithms handle no-signal conditions correctly. Each surface type can be treated differently and there are many knobs that can affect the behavior of the Receiver Algorithms when there is no signal.	10	Nominal
20	Special Telemetry Tests	Test major telemetry situations and parameters such as nonzero telemetry band offset, increased relief padding, modified no-signal scaling, tertiary signal given priority over secondary signal, and 3 or 4 signals (primary, secondary, etc) in one MF.	2	Nominal
21	Diagnostic Tests and Uploading Commands	Test commands expected to be uploaded on orbit.	4.5	Nominal

TEST ID	Test Title	Purpose	Test Length (minutes per spot)	Orbit File
22	Miscellaneous	Miscellaneous tests: limiting weak/strong spot separation, early avionics testing support, future dates, probability of acquisition, software channel disables, TEP_not, maximized data volume, rapidly changing background rate, maximum nutation, and no-signal cases that do not occur elsewhere.	13	Max Nutation/ Nominal/ Future
23	Full Orbit Test – Computed Solar Zenith Angle	Full orbit test with computed solar zenith angle.	90	Nominal
24	Full Orbit Test – High Data Volume	Full orbit test entirely in daytime, with cloud algorithm not used.	90	Nominal
25	Full Orbit Test – Nominal Parameters (New Orbit)	Full orbit test with nominal parameter settings. New orbit that covers more land ice for a more representative data volume. Replaces test 10.	90	Nominal
26	Full Orbit Test- Reduced Data Volume Parameters (New Orbit)	Full orbit test with parameters set to decrease data volume. Replaces test 12.	90	Nominal
27	Full Orbit Test- Increased Data Volume Parameters (New Orbit)	Full orbit test with parameters set to increase data volume. Replaces test 13.	90	Nominal
28	Orbit in the Life (OITL) – Abbreviated	Abbreviated OITL test to check the performance of the Receiver Algorithms before running full OITL.	30	OITL
29	Orbit in the Life (OITL)	Full OITL to support Thermal Vacuum (TVAC) and Observatory testing.	>240 (>4 hours)	OITL
30	Full Orbit Test – Increased Transmission (New Orbit)	Full orbit test with increased receiver transmission to evaluate effects on data volume.	90	Nominal

TEST ID	Test Title	Purpose	Test Length (minutes per spot)	Orbit File
30a	Several Days in the Life (SDITL) - Abbreviated	To provide ATLAS data output during Mission Observatory testing, to provide a realistic data volume flow during the several days of testing. Designed for unlimited time. Actual runs at Observatory were > 24 hours. NOTE: SDITL did not involve an Embedded Simulator file for the Bench Checkout Equipment (BCE) – rather the BCE ran a constant background rate, return signal strength and range to surface.	>1440 (>24 hours)	Nominal
31	Day Rollover Test	Check that Simulator can handle a day change in the middle of a simulation.	10	Maneuvers

Table S1. Table of Receiver Algorithms Tests. The ATLAS Receiver Algorithms (RA) were tested through a large range of possible on-orbit conditions. The tests were designed to determine the performance of the Receiver Algorithms over a range of conditions that included all the Design Cases as well as conditions under which the Receiver Algorithms were not expected to be able to determine the location of the ground return. This series of tests was also used to test various Algorithm Parameter configurations and to finalize our best estimate of the optimal Algorithm Parameter settings. All tests were run with the RA Simulator and the majority were run during Integration and Testing (I&T). During Observatory Testing, the Comprehensive Performance Test (CPT), Orbit In The Life (OITL), and Several Days In The Life (SDITL) were run. The CPT included test 25 and test 30.

Orbital files containing the spacecraft position, velocity, and attitude information were provided by the ICESat-2 Precision Orbit Determination Team or were produced using data from the Spacecraft Team, and were used for the Receiver Algorithms testing. Each orbital file contained 24 hours of data with spacecraft position and attitude at 1 second intervals. Each test in the Table S1 used one of the orbital files and started at a specific offset in the file. The offset for each test was based on the purpose of that test and the type of Earth conditions required. The orbital files used in Receiver Algorithms testing were:

- Max Nutation (Orbit file v7) – This orbit file was generated during a period of time when the maximum expected nutation occurred.
- Nominal (Orbit file v8) – The nominal expected orbital file was used for most tests. This orbit assumed the spacecraft was nominally nadir pointing.

- Maneuvers (Orbit file v9G) – The expected maneuvers orbital file had periods of non-nadir pointing separated by nadir-pointing periods. Included in the non-nadir pointing events were Ocean Scans, Round the World Scans, and Targets of Opportunity.
- Future (Orbit file v9H) – This orbit had dates in the future. While most of the orbital data used during testing were from 2005, this file was dated in 2018, and was used during testing in 2016 and 2017.