Assessment of ICESat-2 Performance over the Arctic Ocean During its First Year in Orbit

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$^1$University of Maryland $^2$NOAA Laboratory for Satellite Altimetry
<table>
<thead>
<tr>
<th>YEAR</th>
<th>00</th>
<th>05</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLANETARY COVER</td>
<td>81.5°</td>
<td>81.5°</td>
<td>86°</td>
<td>88°</td>
<td>88°</td>
<td>369 days</td>
</tr>
<tr>
<td>Orbits</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Repeat</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>91</td>
</tr>
</tbody>
</table>

**Partial Polar Cover**:
- ERS-1 (ESA) - 81.5°, 35 days
- ERS-2 (ESA) - 81.5°, 35 days
- ENVISAT (ESA) - 86°, 91 days
- ICESat (NASA) - 88°, 91 days
- IceBridge (NASA Airborne) - 88°, 369 days
- ICESat-2 (NASA) - 88°, 369 days
- CryoSat-2 (ESA) - 88°, 369 days
- Sentinel-3A (EU) - 81.5°, 27 days
- Sentinel-3B (EU) - 81.5°, 27 days
- Sentinel-3C (EU) - 81.5°, 27 days
- Sentinel-3D (EU) - 81.5°, 27 days

**Polar Orbit**:
- Past
- Operating
- Approved
- Proposed

**Spacecraft Timeline**:
- Sinéad L. Farrell, University of Maryland
- 24 October 2019
- OSTST 2019, Chicago, USA
NASA successfully launched ICESat-2 from Vandenberg Air Force Base, California, on 15th Sept. 2018, at 13:02 UTC!

**ATLAS**: Advanced Topographic Laser Altimeter System  
Single laser pulse (532 nm) split into 6 beams; photon counting  
Redundant laser and detector

- **Surface Elevation**: over ice-covered ocean (ATL07), provides height measurements of level sea ice floes, ridged/deformed sea ice floes, lead/sea surface height (SSH)
- **Sea Ice Freeboard (ATL10)**: routine measurements of sea ice freeboard in both Arctic and Southern Oceans, available along-track

- Beams arranged in pairs (strong/weak beam combination)  
- Pair spacing: ~ 90 m, for slope determination  
- Spacing between pairs: ~ 3 km, for spatial coverage  
- Footprint spot size: ~ 14 m  
- PRF: 10 kHz (0.7 m sampling along-track)  
- Coverage: 88 °N to 88 °S  
- Exact Repeat: 91 days; Sub-cycles: ~4 days; 29 days

More info. and orbits:  
ATL07 = sea ice surface elevation
ATL10 = sea ice freeboard (both hemispheres)
ATL07 and ATL10 are *per orbit* sea ice products
ATL20 *gridded* product will be available later in Fall 2019
Initial Release 001 spans 14 Oct 2018 to 2 May 2019

**ATLAS:** Advanced Topographic Laser Altimeter System
Single laser pulse (532 nm) split into 6 beams
Photon counting detector
• ICESat-2 transect over Saint Thomas, U.S. Virgin Islands, shows measurements of land surfaces above and below the water surface
• Submerged topography eventually disappears as water depth increases

Credit: Magruder et al., EOS, 2019
ICESat-2 Profiles over the Arctic Sea Ice - October 2018

ATLAS Strong Beam 1

Ice freeboard (3 ft.)

ATLAS Strong Beam 2

rough sea ice floe

ATLAS Strong Beam 3

pressure ridge

Ice freeboard (3 ft.)

rough sea ice floe

lead

new ice

ice floe

lead

pressure ridge

rough sea ice floes
Independent, multi-sensor sea ice observations from ASCAT (left) and CryoSat-2 (right), show remarkable consistency with ICESat-2 (middle)
First coincident *airborne* laser and radar altimetry data were collected over sea ice during the joint NOAA/NASA/ESA Laser Radar Altimetry (LaRA) field campaign, May 2002 (Giles *et al*., 2007).
LaRa Freeboard: Dec 2018 – April 2019

First Year Ice

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>2018_12</td>
<td>0.09</td>
<td>0.06</td>
</tr>
<tr>
<td>2019_01</td>
<td>0.11</td>
<td>0.05</td>
</tr>
<tr>
<td>2019_02</td>
<td>0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>2019_03</td>
<td>0.13</td>
<td>0.06</td>
</tr>
<tr>
<td>2019_04</td>
<td>0.14</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Multiyear Ice

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean</th>
<th>SD</th>
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<tbody>
<tr>
<td>2018_12</td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>2019_01</td>
<td>0.16</td>
<td>0.05</td>
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<tr>
<td>2019_02</td>
<td>0.16</td>
<td>0.05</td>
</tr>
<tr>
<td>2019_03</td>
<td>0.17</td>
<td>0.06</td>
</tr>
<tr>
<td>2019_04</td>
<td>0.18</td>
<td>0.06</td>
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Insights from early LaRa Freeboard comparisons indicate potential for satellite-derived snow depth.

LaRa freeboard is ~ 55-60% snow depth (April). Distributions mirror snow distributions on FYI/MYI.
**NASA IceBridge Validation Flights**

**ICESat-2 Orbits:**
- 2019-04-08
- 2019-04-10
- 2019-04-12
- 2019-04-19
- 2019-04-22

**ΔT (OIB – satellite):**
- 0 hrs. IC2 RGT 157
- 0 hrs IC2 RGT 189
- 0 hrs IC2 RGT 218
- 0 hrs IC2 RGT 325
- +38 mins. IC2 RGT 371

**CryoSat-2 Orbits:**
- 2019-04-06
- 2019-04-06

**ΔT (OIB – satellite):**
- +2.73 hrs
- +2.92 hrs

**Sentinel-3B Orbit**
- 2019-04-20

**ΔT (OIB – satellite):**
- 0 hrs

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**Airborne Validation Experiments – April 2019**

Sinéad L. Farrell, University of Maryland

24 October 2019

OSTST 2019, Chicago, USA
Sea Ice Conditions on 10 April 2019:

- Validation flight conducted in southeastern Beaufort Sea
- A mix of older multi-year sea ice floes in a matrix of seasonal ice
- Approximately 390 km of sea ice was surveyed

Observations:

- ICESat-2 ATLAS
  - Assessment of freeboard on 3 strong ATLAS beams
- AWI IceBird Airborne Laser Scanner (ALS)
  - High-resolution sea ice topography
- AWI IceBird – EM Bird
  - Sea ice thickness
- Sentinel-1 A/B, SAR: cross and co-pol

Temporal Coincidence:

- ICESat-2, orbit 0189: 15:06:12 - 15:07:08
- AWI IceBird aircraft survey start: 15:06:55, end: 18:53:26
- Sentinel-1B SAR image acquisition: 15:27:54
ice freeboard

σ0 (dB)

72° - 73°

72.5° - 73°
Evaluating ICESat-2 Sea Ice Freeboard

70.3 – 71.4° N
Level first-year ice

71.4 – 72.6° N
Mix of multiyear and first-year ice

72.6 – 74.0° N
Heavily deformed multiyear ice

70.3 – 74.0° N
ATLAS 3 Strong Beams (Full 390 km Transect)

--- Airborne --- ICESat-2

<table>
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<tr>
<th>Mean Diff (IC2 – ALS)</th>
<th>+0.03 m</th>
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<td>Median Diff (IC2 – ALS)</td>
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<tr>
<td>Modal Diff (IC2 – ALS)</td>
<td>-0.05 m</td>
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- AWI IceBird ALS Freeboard
- NASA ICESat-2 ATL10 Freeboard

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--- ICESat-2 (all) ---

| Mean | 0.35 m |
| Sdev | 0.24 m |
| Mode | 0.23 m |
| Median | 0.29 m |
| Min | 0.00 m |
| Max | 2.38 m |

- ATL10 Freeboard GT1L
- ATL10 Freeboard GT2L
- ATL10 Freeboard GT3L
Lincoln Sea – June 2019
Sea Ice Undergoing Melt, Lincoln Sea, June 2019
First Spaceborne Altimeter Observations of Sea Ice Melt Ponds!!
• ICESat-2 data **publicly** available at:  [https://nsidc.org/data/icesat-2](https://nsidc.org/data/icesat-2)

• 14 Oct 2018 to 02 May 2019 currently available at NSIDC, Release 001

• Release 002 of ATLAS data being distributed at NSIDC - October 2019 (LIVE: 4:30 pm EDT today!)
  • Reprocessing of Release 001 - fixes to ATBDs (algorithms)

• Data spans: 14 Oct 2018 – 26 June 2019
  • ATL03 data posted first;  
  • ATL07/10, ATL06, ATL08 etc. online at NSIDC from end October through mid-November

• Observatory was in safe-hold mode: 27 June 2019 – 9 July 2019: no data collected
• A timing error occurred: 9 July 2019 to 25 July 2019: data potentially recoverable
• Nominal operations: 26 July 2019 to date. 😊

• Data also accessible though Open Altimetry
  [https://openaltimetry.org/data/icesat2/](https://openaltimetry.org/data/icesat2/)
ASCAT Multi-year Ice Extent
ICESat-2 Sea Ice Freeboard
CryoSat-2 Sea Ice Freeboard
LARA* Freeboard ICESat-2 minus CryoSat-2
ASCAT
Multi-year Ice Extent

ICESat-2
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January 2019
ASCAT Multi-year Ice Extent
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Multi-year Ice Extent

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ASCAT
Multi-year Ice Extent

ICESat-2
Sea Ice Freeboard

CryoSat-2
Sea Ice Freeboard

LARA* Freeboard
ICESat-2 minus CryoSat-2
ICESat-2 Coverage in the Arctic

After 4 days (61 orbits)

After 29 days (442 orbits)
Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.