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

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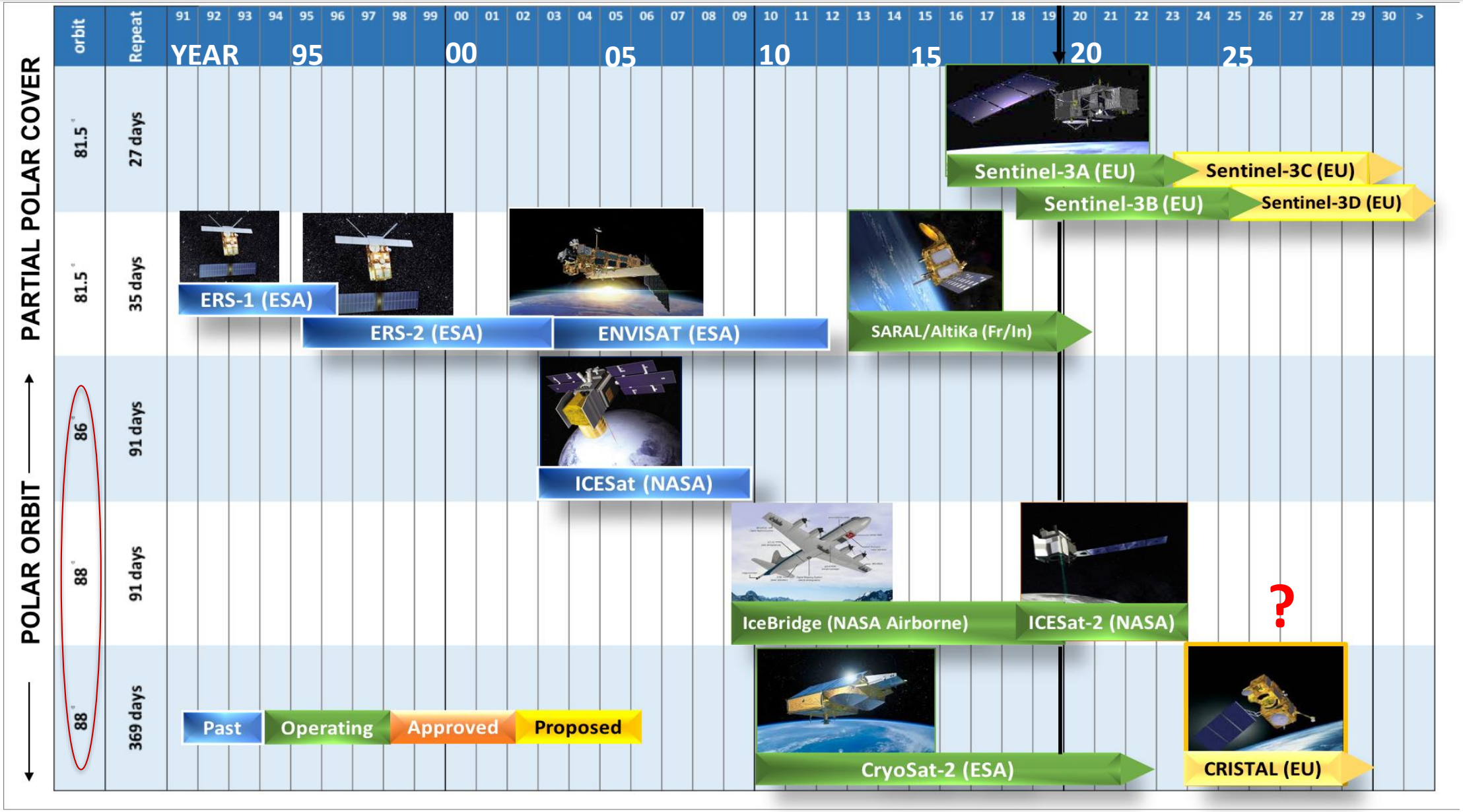
Ocean Surface Topography Science Team Meeting (OSTST)

21-25 October, 2019

Chicago, Illinois

Polar Altimeter Time Series



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

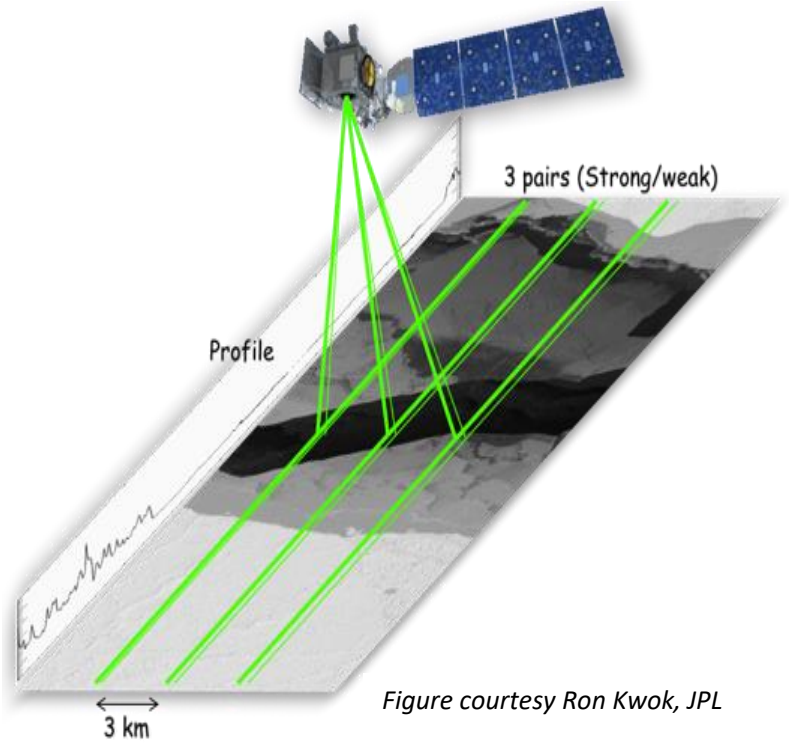


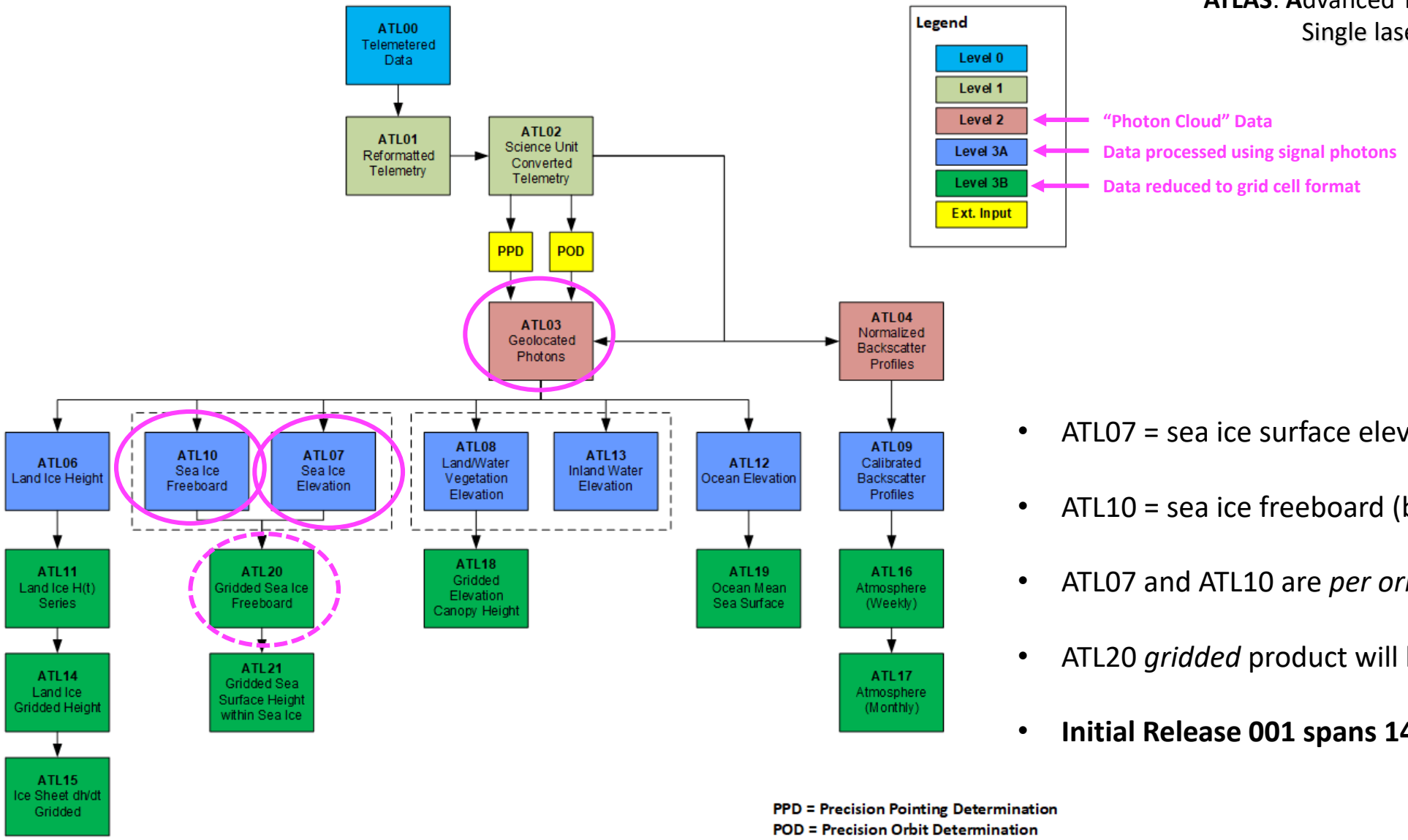
Figure courtesy Ron Kwok, JPL

- 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 ^{o}N to 88 ^{o}S
- Exact Repeat: 91 days; Sub-cycles: ~4 days; 29 days

More info. and orbits:
https://icesat-2.gsfc.nasa.gov/

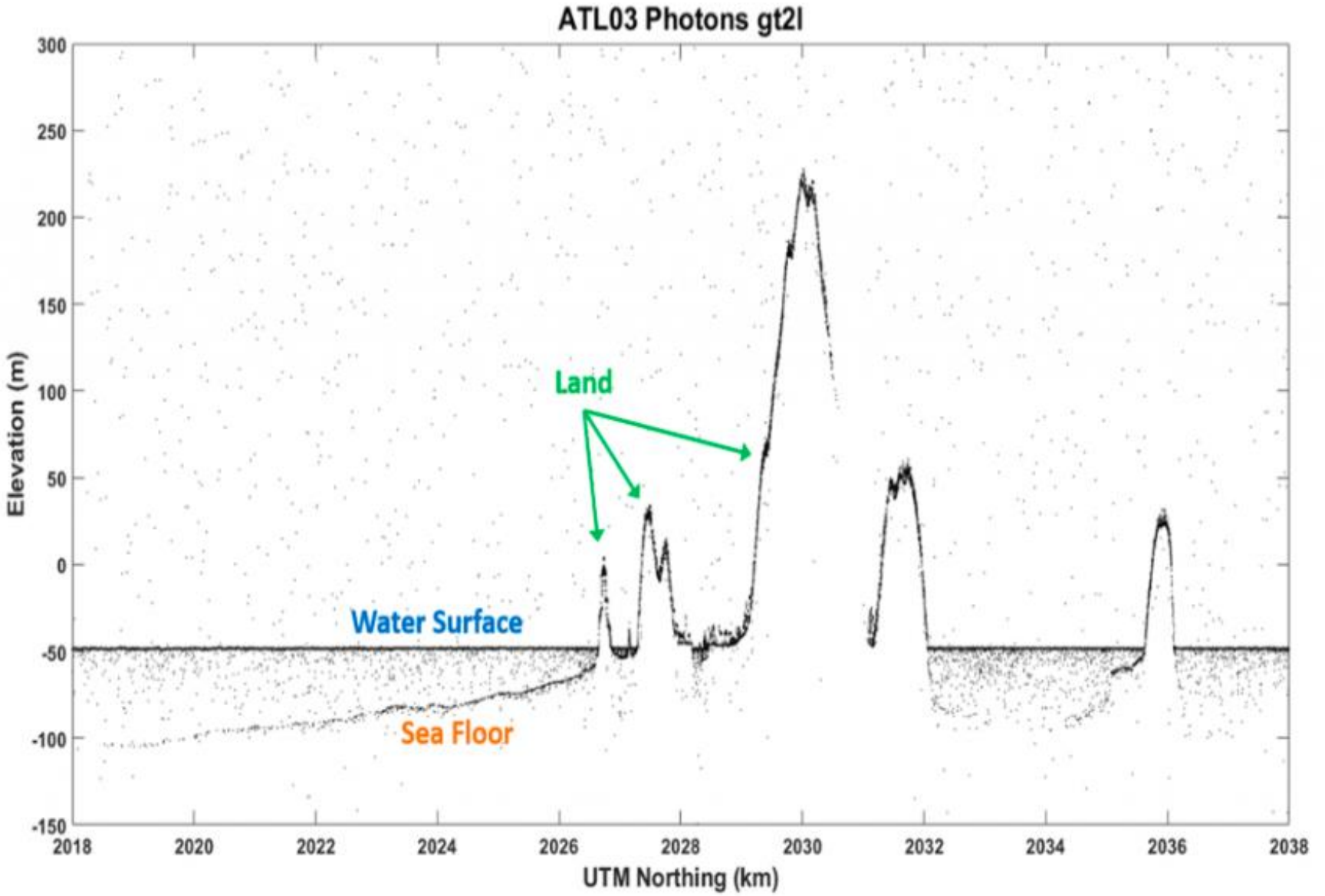
ICESat-2 Data Products

ATLAS: **A**dvanced **T**opographic **L**aser **A**ltimeter **S**ystem
Single laser pulse (532 nm) split into 6 beams
Photon counting detector



- 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**

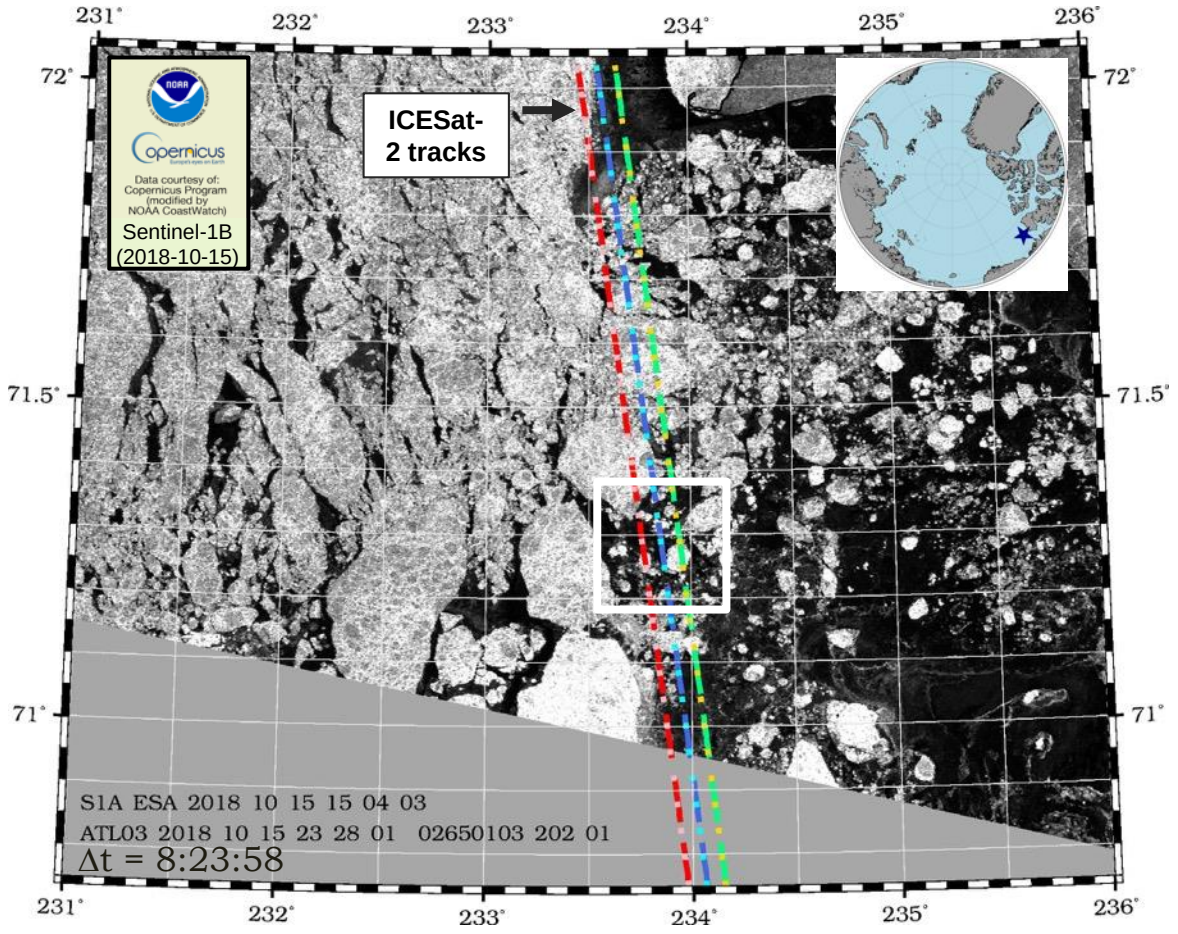
ICESat-2 Bathymetry

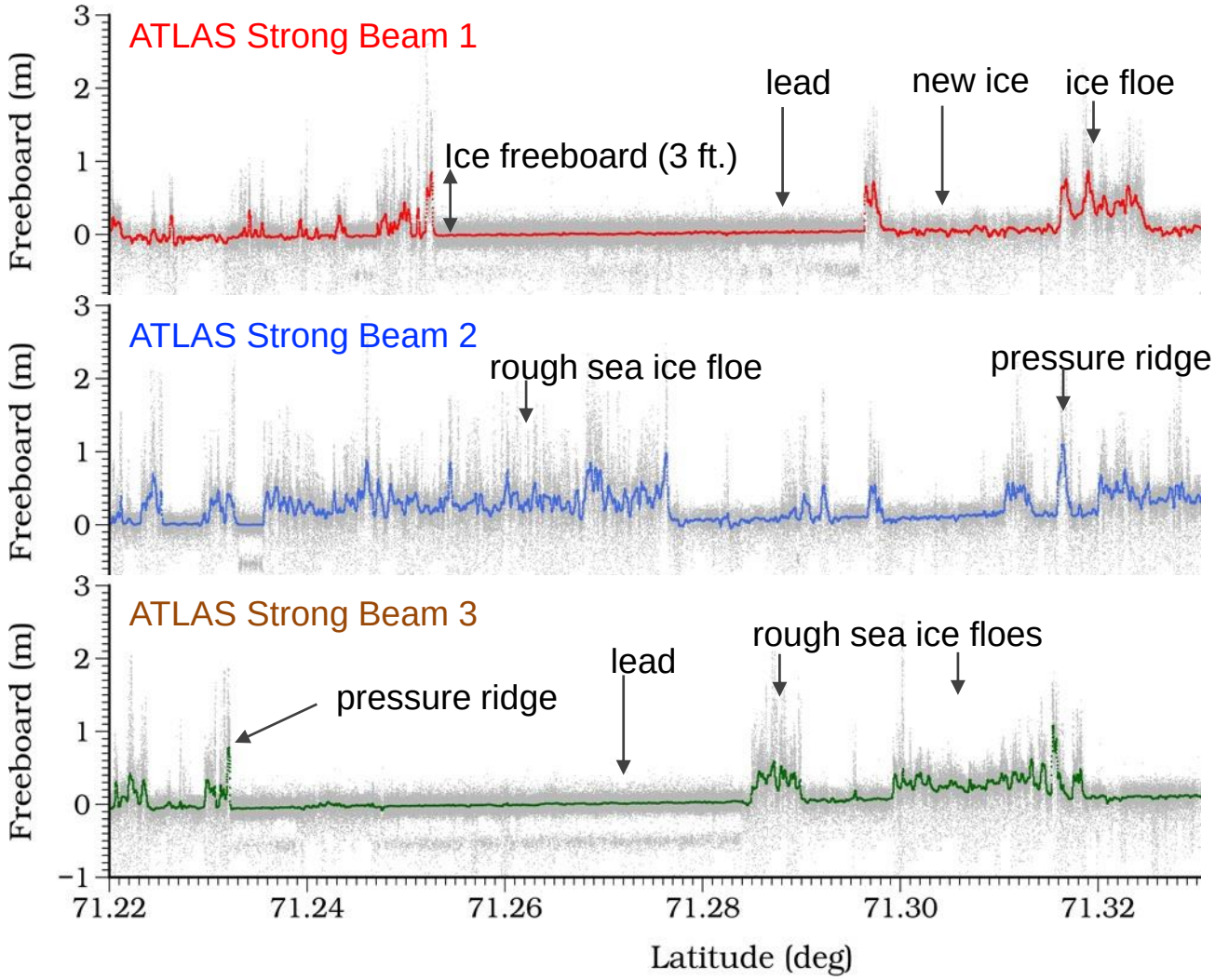


- ICESat-2 transect over Saint Thomas, U.S. Virgin Islands, shows measurements of land surfaces above and below the water surface
- Submerged topography eventually disappears as water depth increases

Credit: *Magruder et al., EOS, 2019*

ICESat-2 Profiles over the Arctic Sea Ice - October 2018

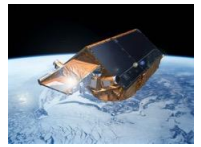




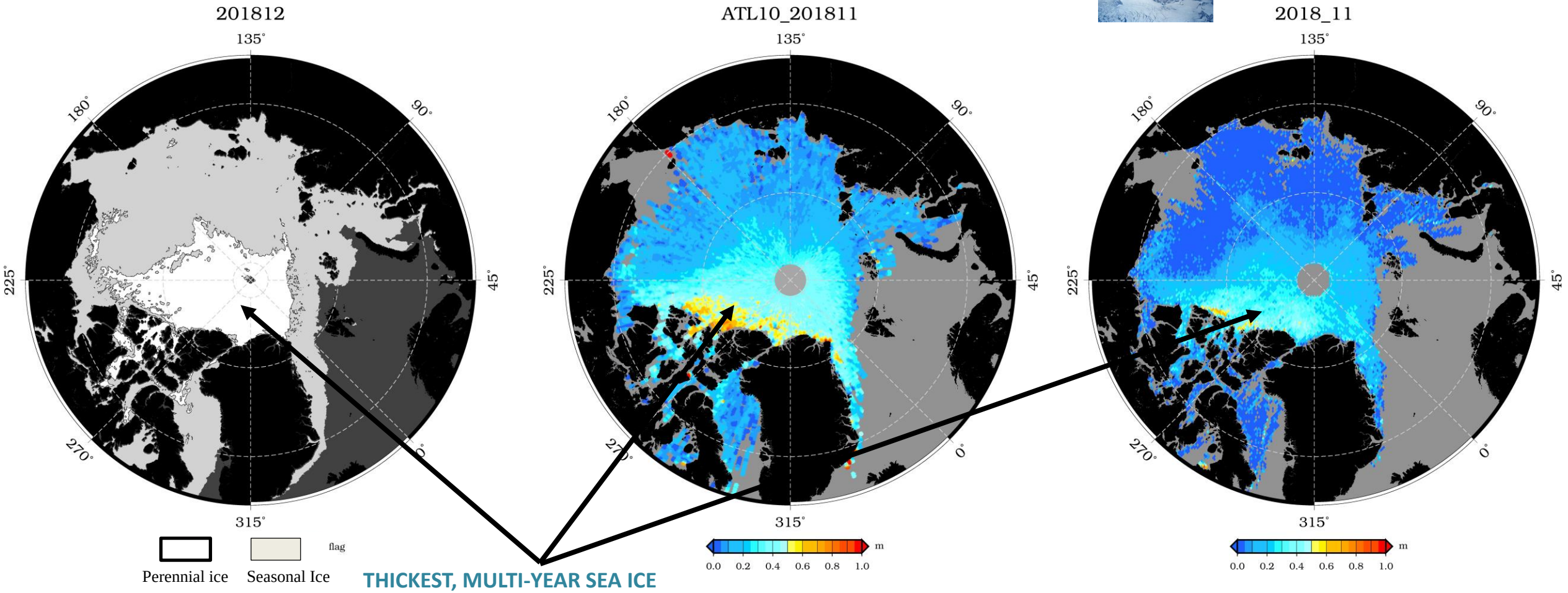
Arctic Sea Ice Conditions in Winter 2018

Multiyear Sea Ice Extent
ASCAT on Met-Op A/B/C

ICESat-2
snow depth + ice freeboard



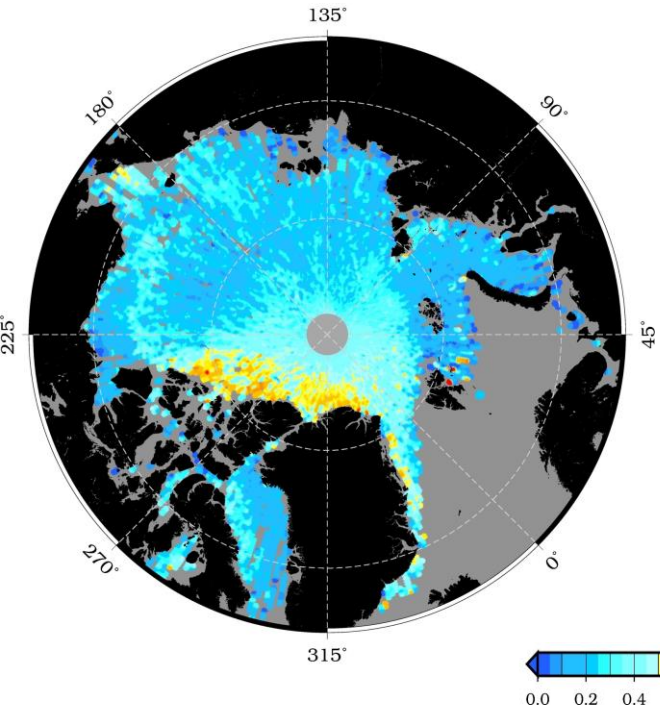
CryoSat-2
ice freeboard only



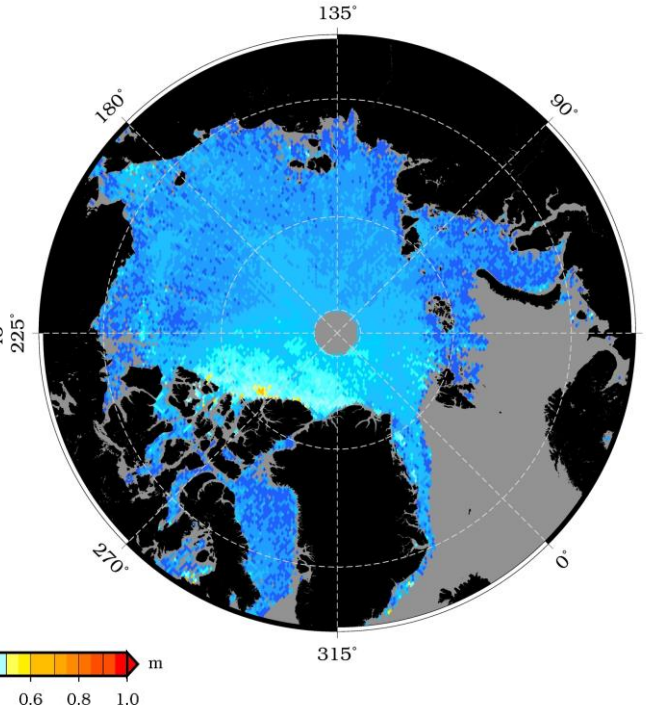
Independent, multi-sensor sea ice observations from ASCAT (left) and CryoSat-2 (right), show remarkable consistency with ICESat-2 (middle)

Laser-Radar Altimetry over Arctic Sea Ice

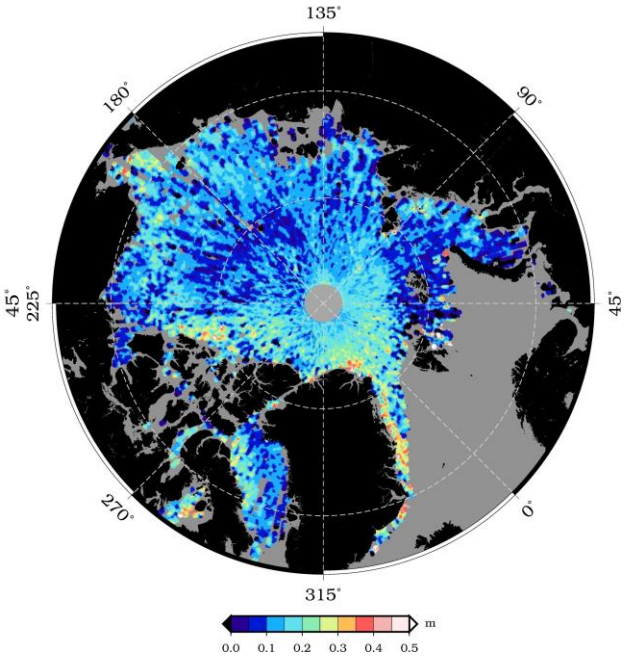
ICESat-2
Sea Ice Freeboard

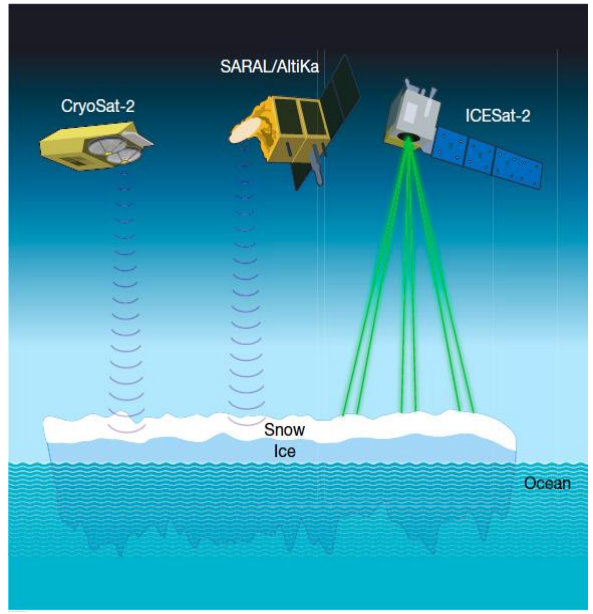


CryoSat-2
Sea Ice Freeboard



LARA* Freeboard
ICESat-2 *minus* CryoSat-2

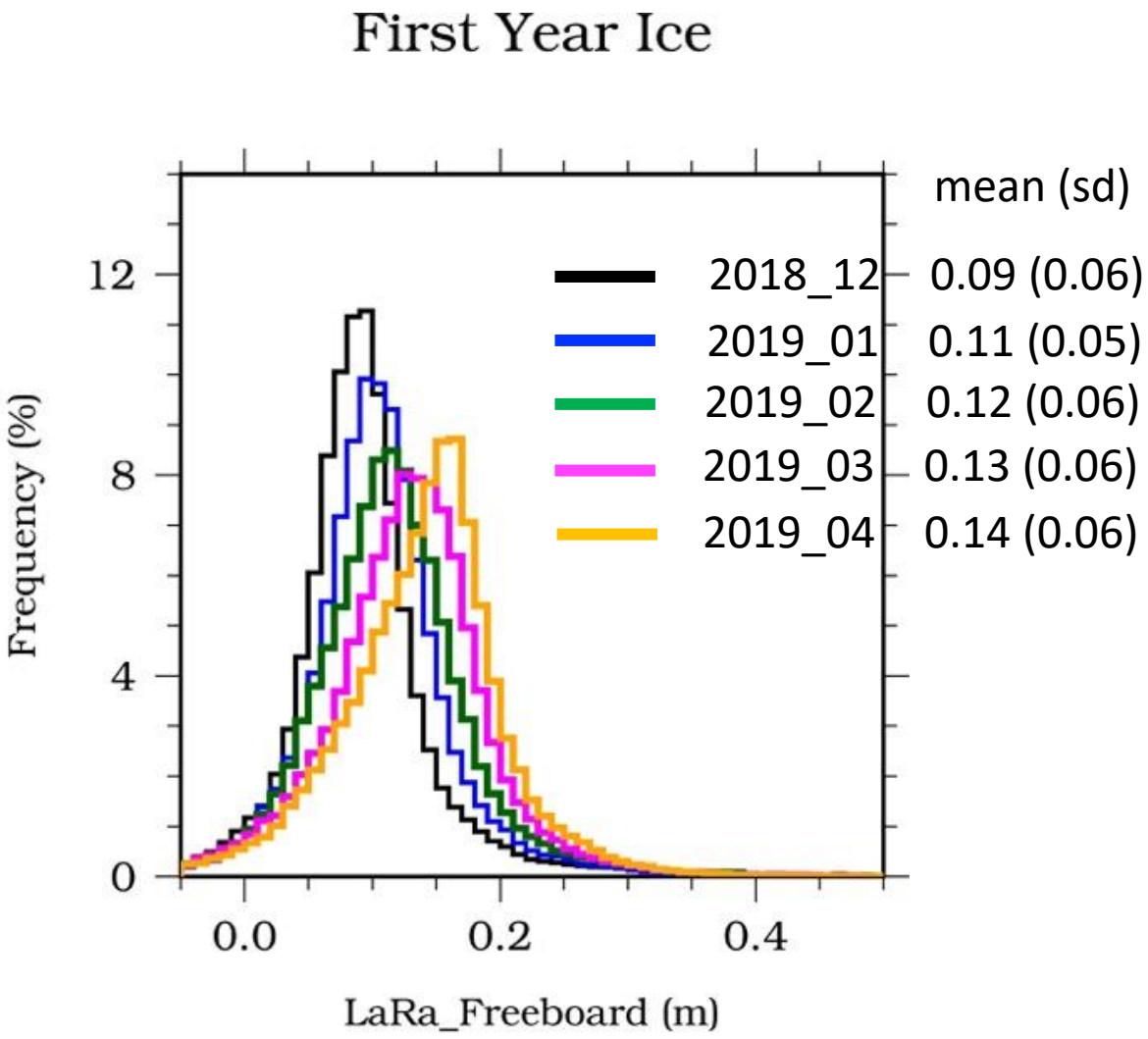


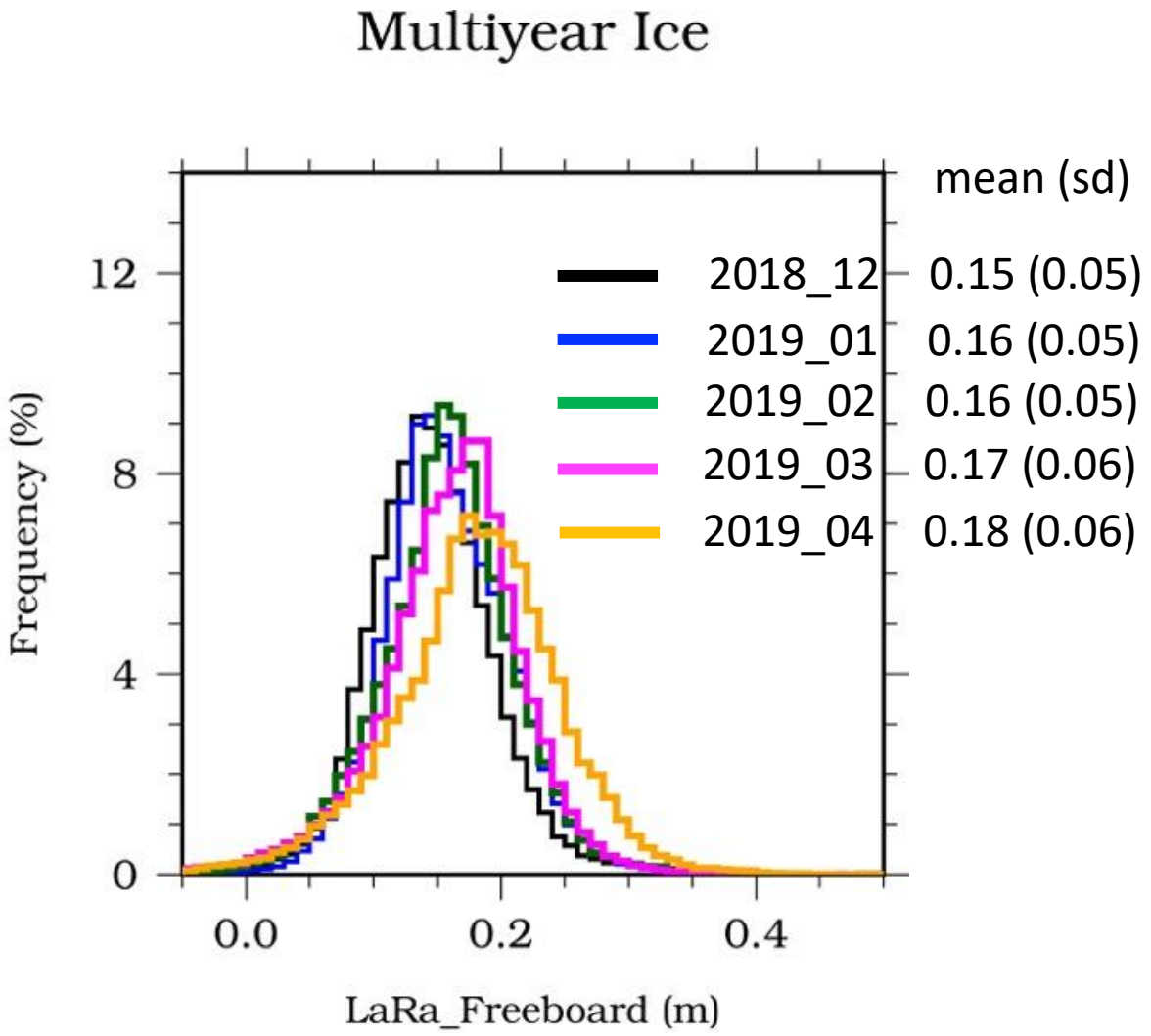


Difference in radar and laser penetration depth into snow on sea ice.
Credit: *Shepherd, Fricker, Farrell (2018)*

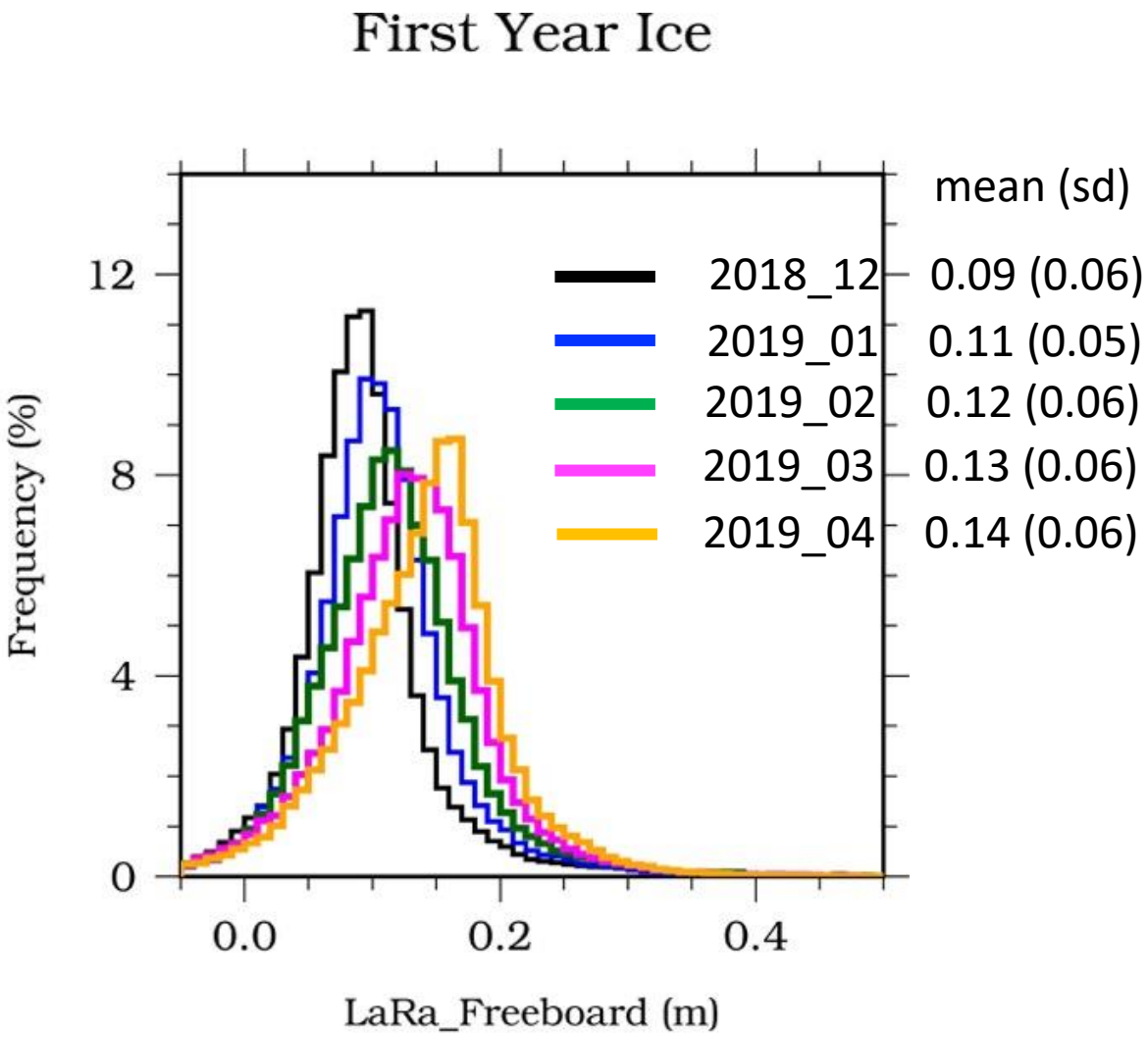
- First coincident *airborne* laser and radar altimetry data were collected over sea ice during the **joint NOAA/NASA/ESA Laser Radar Altimetry (LaRA) field campaign**, May 2002 (*Giles et al.*, 2007).

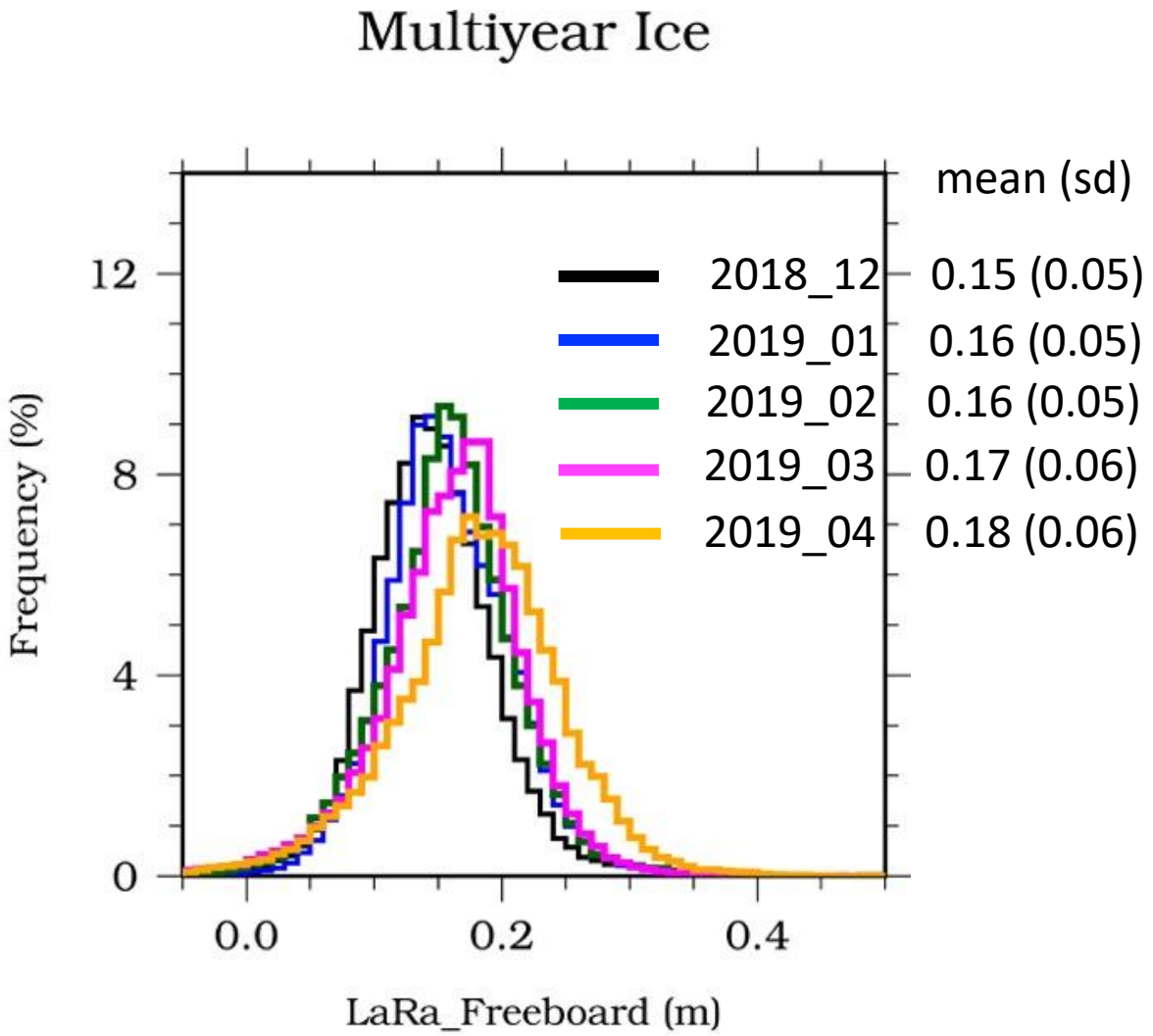
LaRa Freeboard: Dec 2018 – April 2019





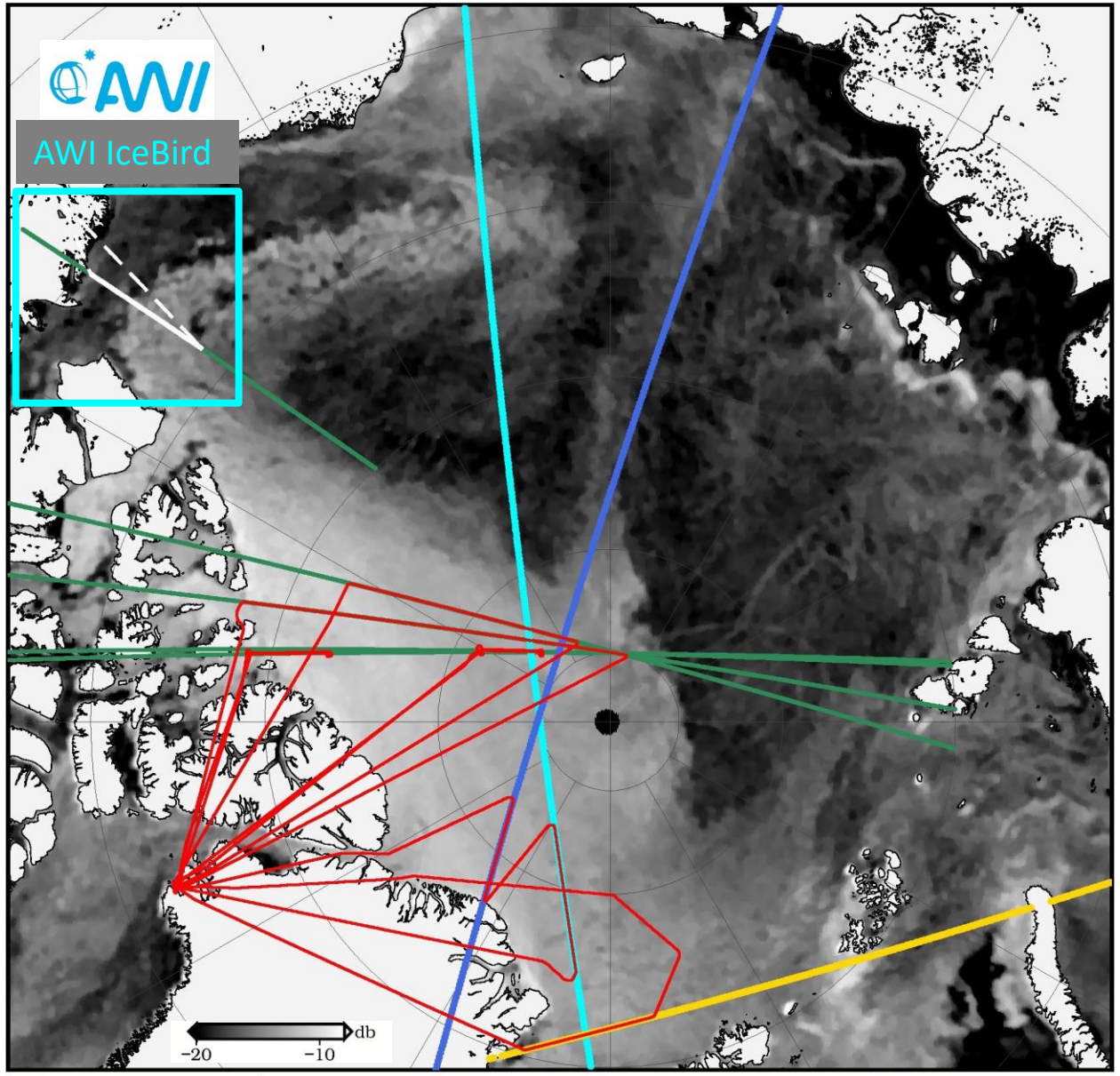
LaRa Freeboard: Dec 2018 – April 2019





- 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

Airborne Validation Experiments – April 2019



NASA IceBridge Validation Flights

AWI IceBird IS-2 Validation Flight

ICESat-2 Orbits:

2019-04-08 ΔT (OIB – satellite): 0 hrs. IC2 RGT157

2019-04-10 ΔT (OIB – satellite): 0 hrs IC2 RGT 189

2019-04-12 ΔT (OIB – satellite): 0 hrs. IC2 RGT 218

2019-04-19 ΔT (OIB – satellite): 0 hrs. IC2 RGT 325

2019-04-22 ΔT (OIB – sat.): +38 mins. IC2 RGT 371

CryoSat-2 Orbit:

2019-04-06 ΔT (OIB – satellite): +2.92 hrs

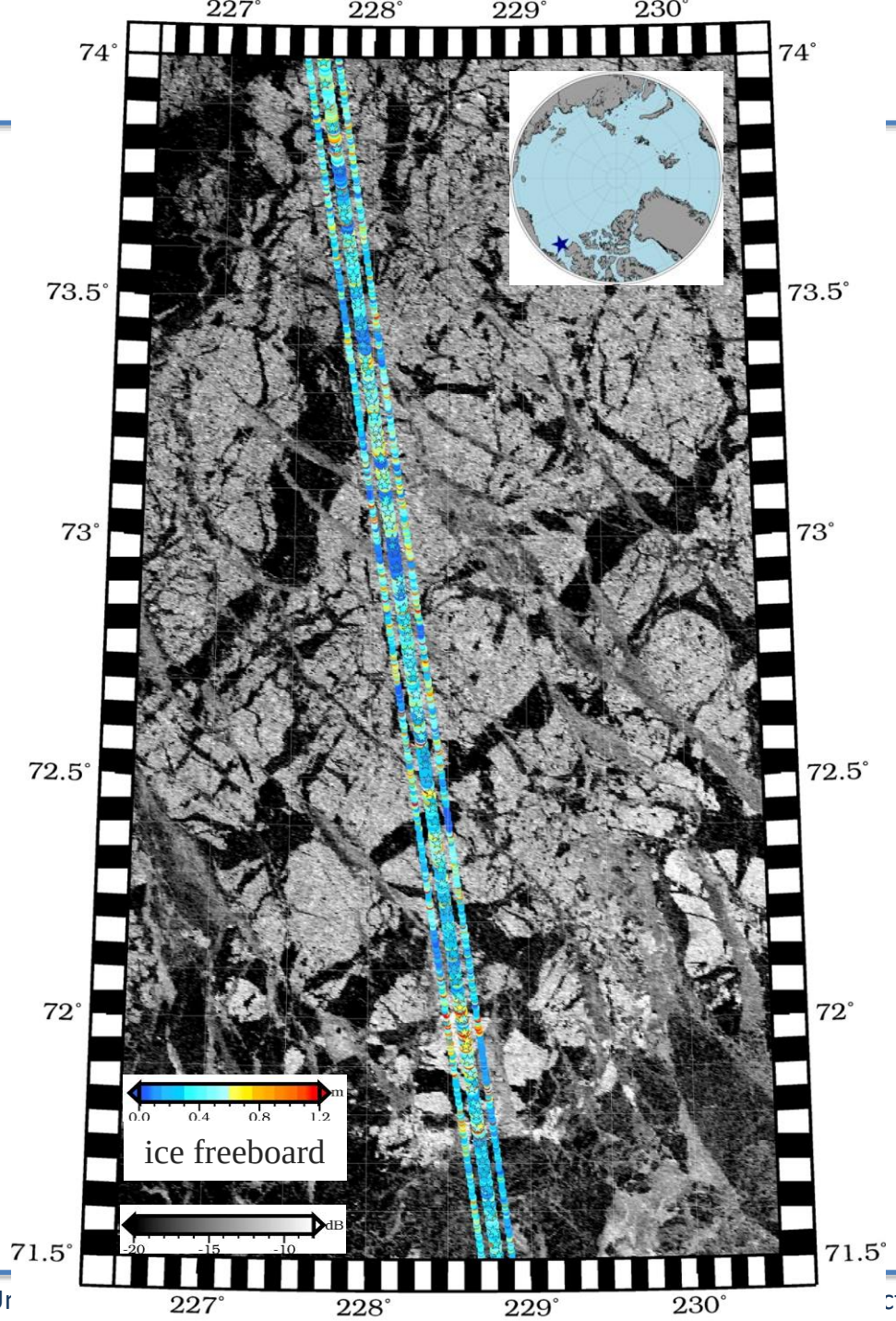
CryoSat-2 Orbit:

2019-04-06 ΔT (OIB – satellite): +2.73 hrs

Sentinel-3B Orbit

2019-04-20 ΔT (OIB – satellite): 0 hrs

ICESat-2 Evaluation - 10 April 2019



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

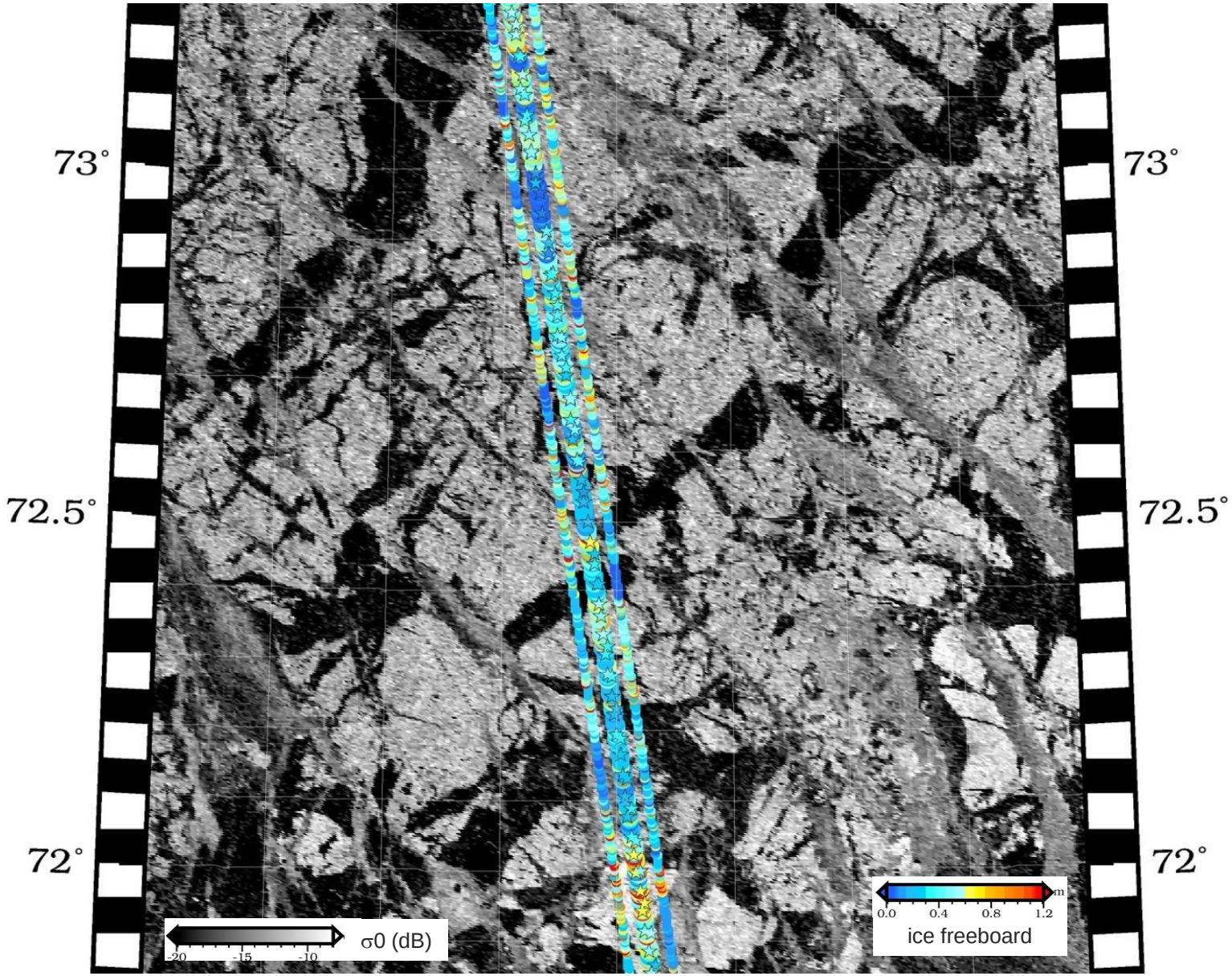
Observations:

- 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:

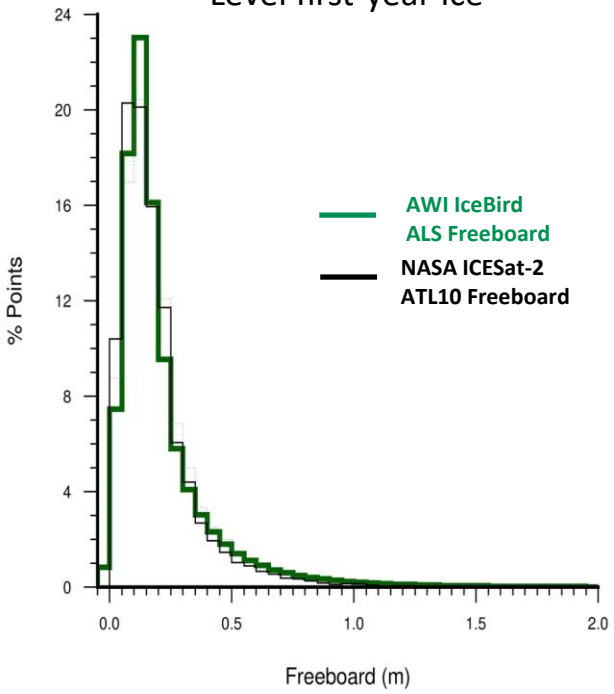
- ICESat-2, orbit 0189: 15:06:12 - 15:07:08
- AWI IceBird aircraft survey start: 15:06:55, end: 18:53:26
- Sentinel-1B SAR image acquisition: 15:27:54

ICESat-2 Evaluation - 10 April 2019



Evaluating ICESat-2 Sea Ice Freeboard

70.3 – 71.4° N
Level first-year ice

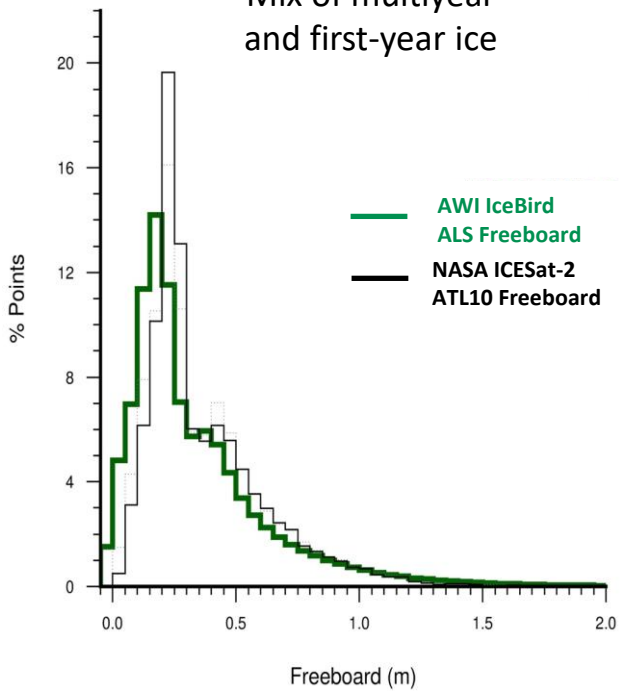


-- Airborne
Mean: 0.216 m
SDev: 0.219 m
Mode: 0.125 m
Median: 0.151 m
Min: -3.640 m
Max: 5.025 m

-- ICESat-2
Mean: 0.188 m
SDev: 0.160 m
Mode: 0.075 m
Median: 0.148 m
Min: 0.000 m
Max: 1.650 m

Mean Diff (IC2 – ALS) - 0.03 m
Median Diff (IC2 – ALS) + 0.00 m
Modal Diff (IC2 – ALS) - 0.05 m

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

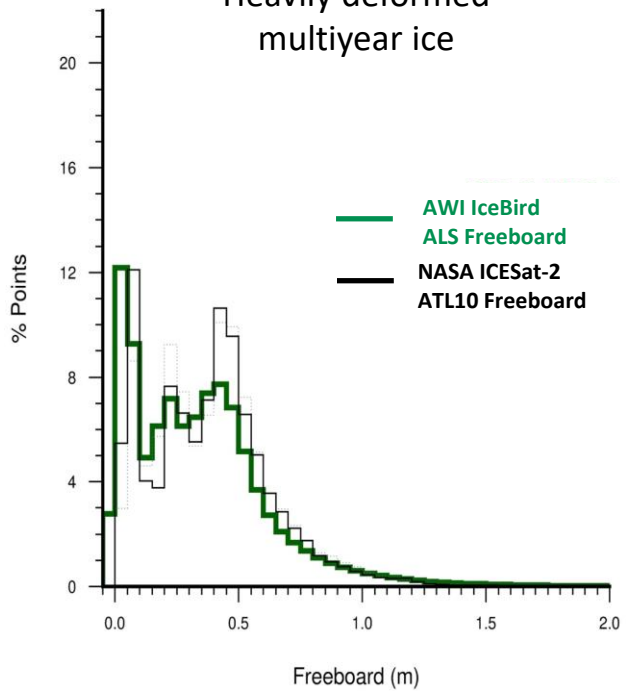


-- Airborne
Mean: 0.349 m
SDev: 0.312 m
Mode: 0.175 m
Median: 0.248 m
Min: -139.493 m
Max: 6.645 m

-- ICESat-2
Mean: 0.378 m
SDev: 0.243 m
Mode: 0.225 m
Median: 0.285 m
Min: 0.000 m
Max: 2.160 m

Mean Diff (IC2 – ALS) + 0.03 m
Median Diff (IC2 – ALS) + 0.04 m
Modal Diff (IC2 – ALS) + 0.05 m

72.6 – 74.0° N
Heavily deformed multiyear ice

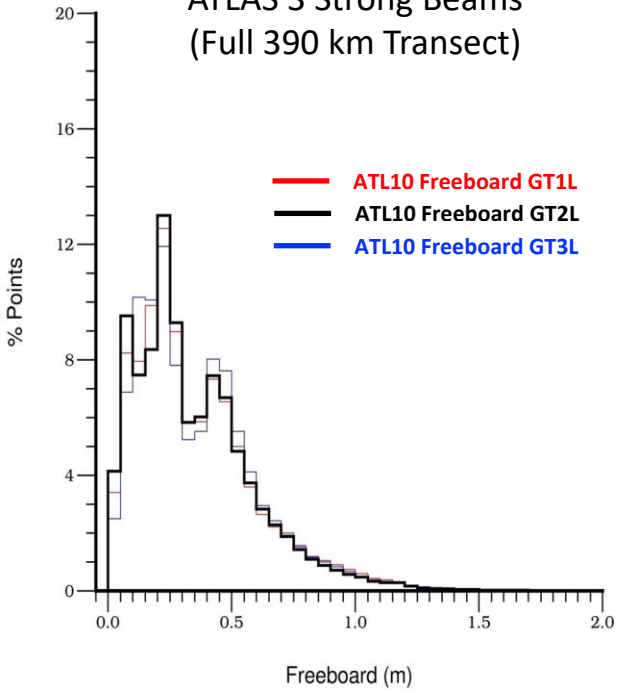


-- Airborne
Mean: 0.343 m
SDev: 0.289 m
Mode: 0.025 m
Median: 0.311 m
Min: -164.991 m
Max: 5.959 m

-- ICESat-2
Mean: 0.382 m
SDev: 0.249 m
Mode: 0.075 m
Median: 0.387 m
Min: 0.000 m
Max: 2.382 m

Mean Diff (IC2 – ALS) + 0.04 m
Median Diff (IC2 – ALS) + 0.08 m
Modal Diff (IC2 – ALS) + 0.05 m

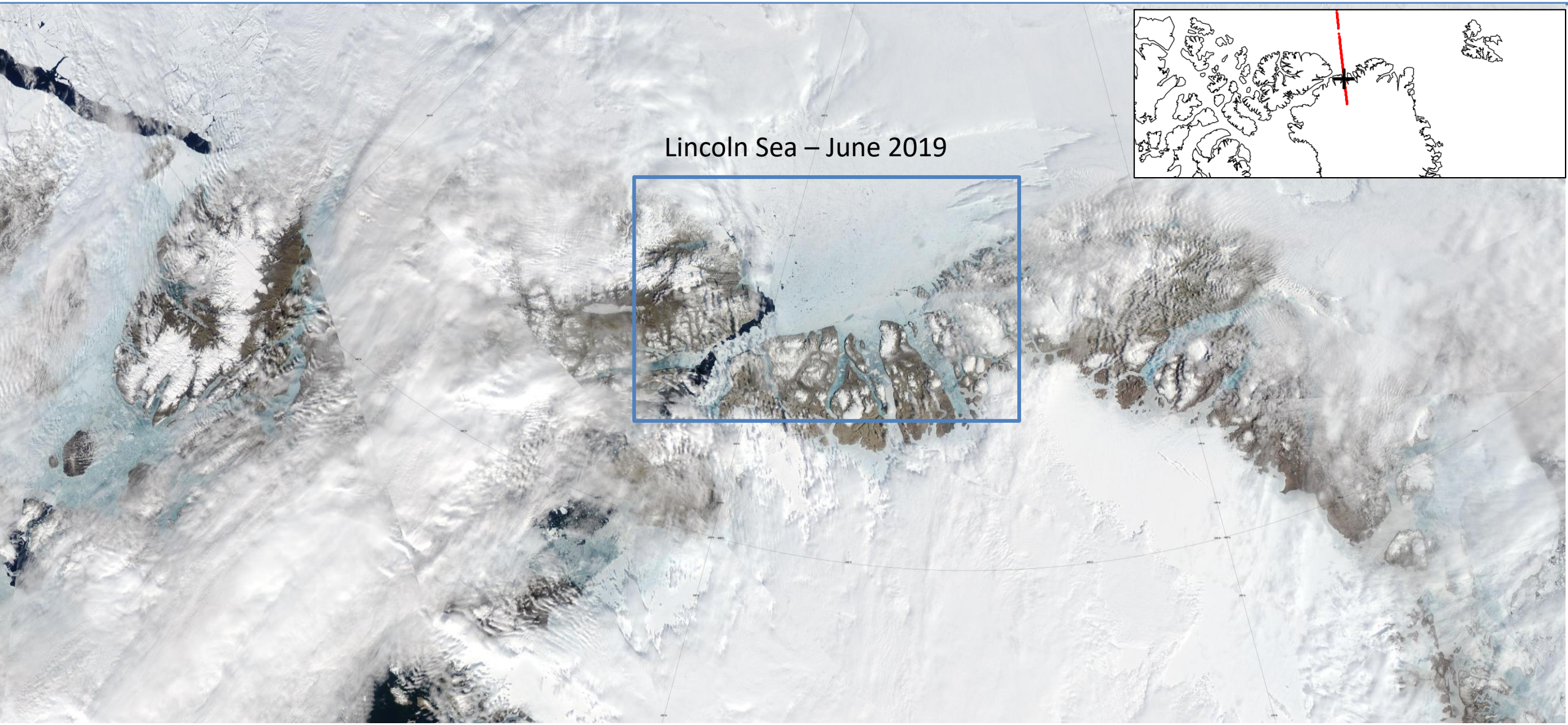
70.3 – 74.0° N
ATLAS 3 Strong Beams (Full 390 km Transect)



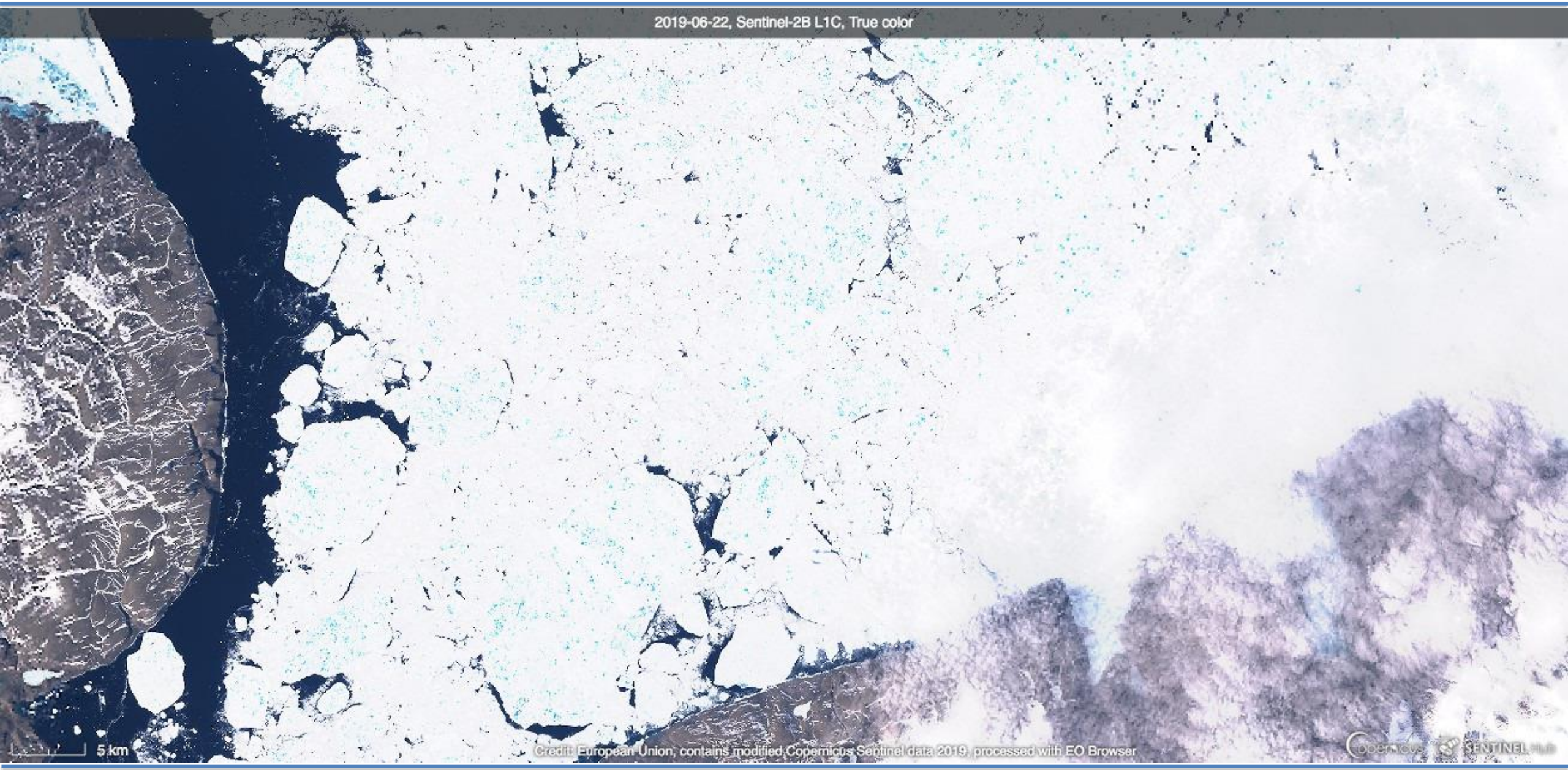
-- ICESat-2 (all)

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

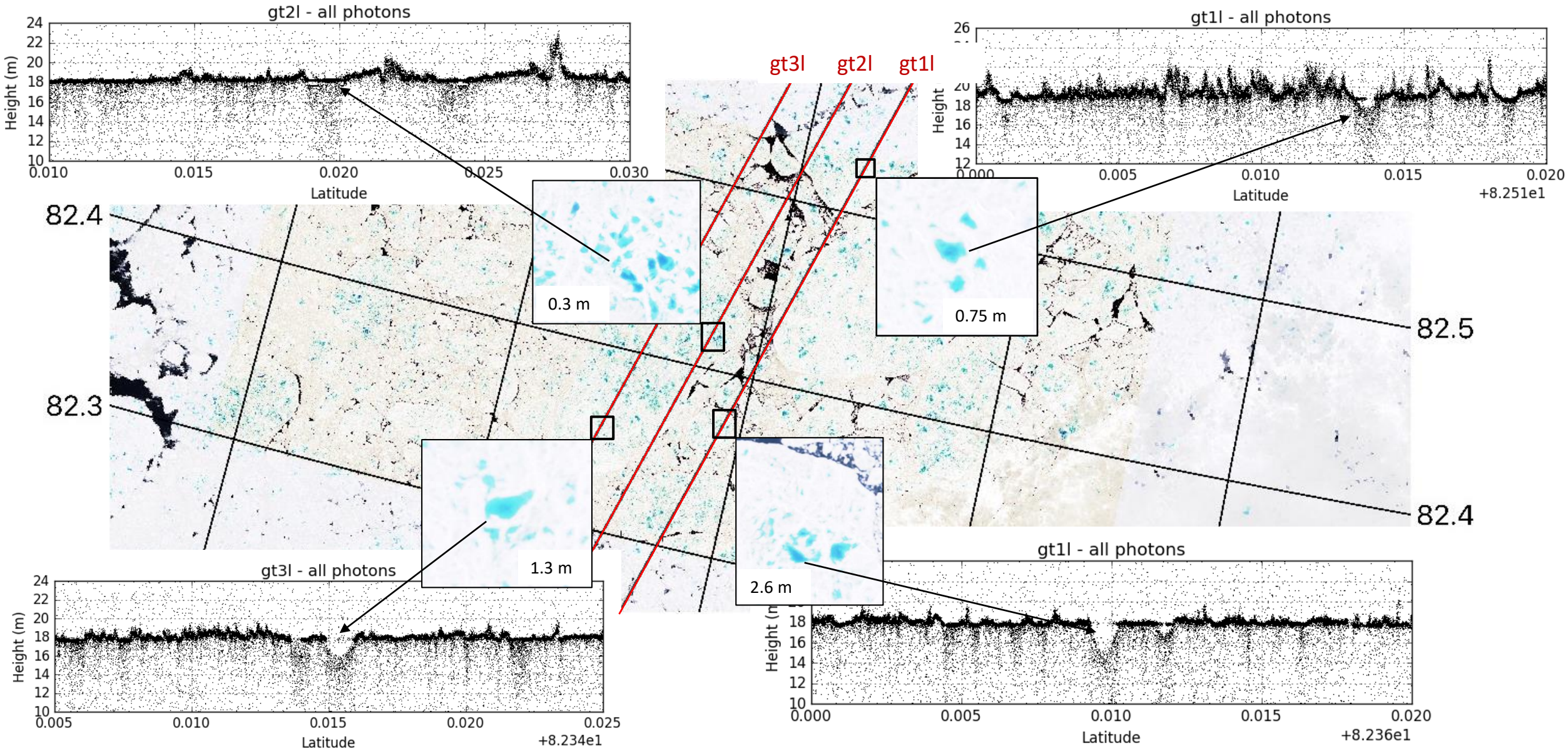
Arctic Summer Melt – June 2019



Sea Ice Undergoing Melt, Lincoln Sea, June 2019



First Spaceborne Altimeter Observations of Sea Ice Melt Ponds!!



Summary & Status Update

- ICESat-2 data **publicly** available at: **https://nsidc.org/data/icesat-2**

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

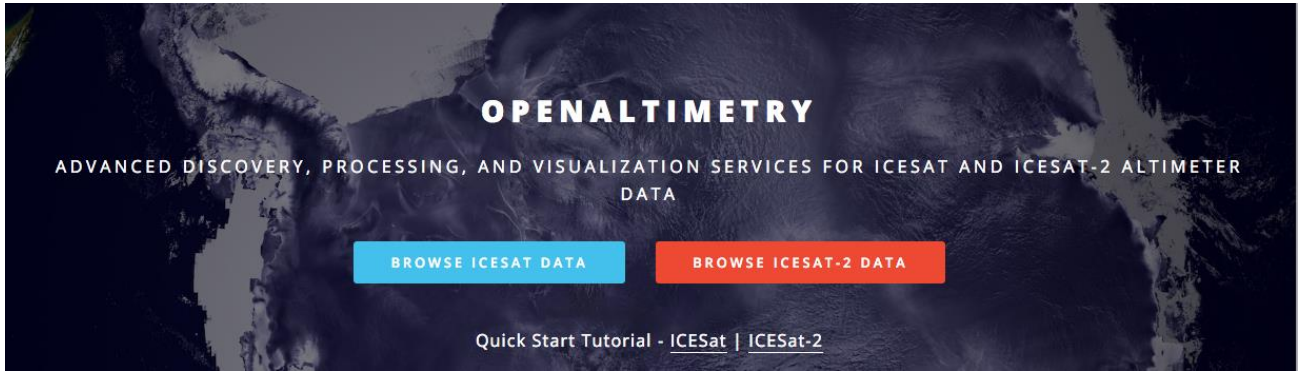
- Release 002 of ATLAS data being distributed at NSIDC - October 2019 (LIVE: 4:30 pm EDT today!)
  - Reprocessing of Release 001 - fixes to ATBDs (algorithms)

- Data spans: 14 Oct 2018 – 26 June 2019

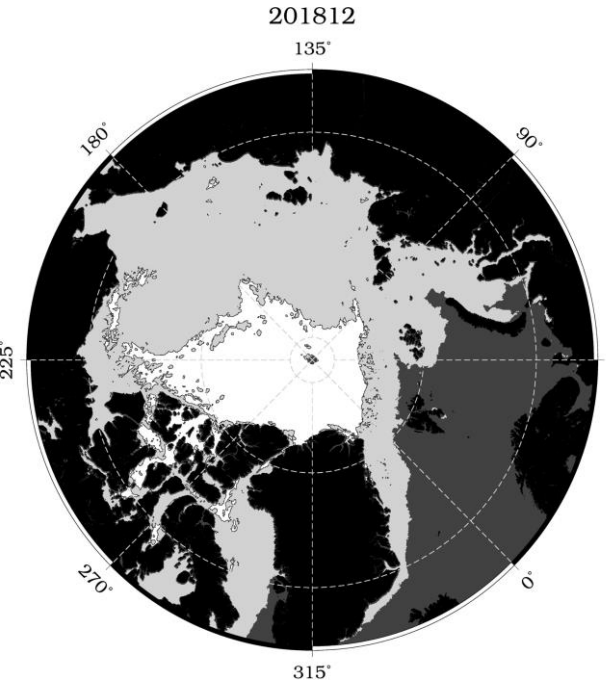
  - ATL03 data posted first;
  - ATL07/10, ATL06, ATL08 etc. online at NSIDC from end October through mid-November

- 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. ☺

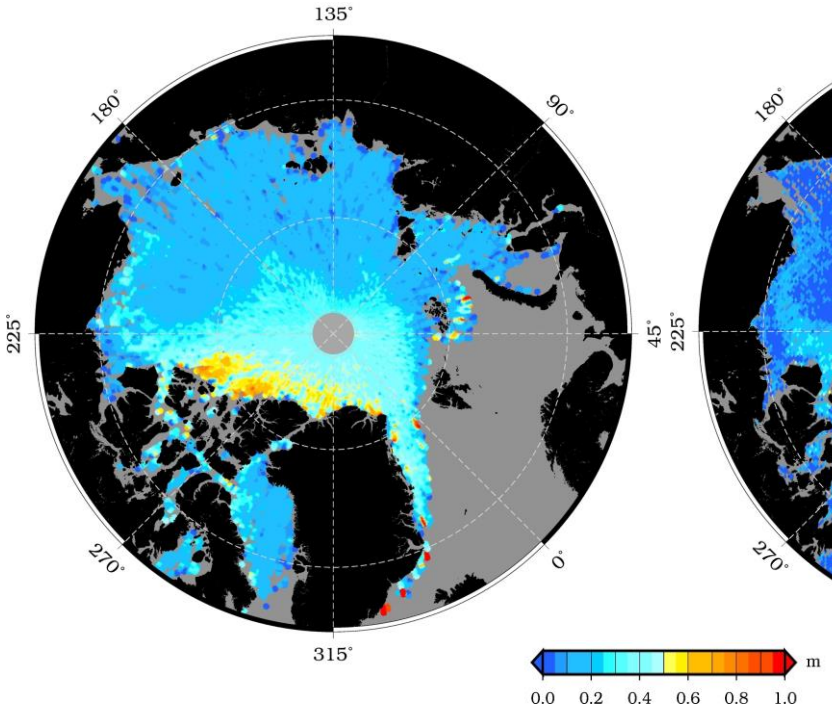
- Data also accessible though Open Altimetry
  https://openaltimetry.org/data/icesat2/



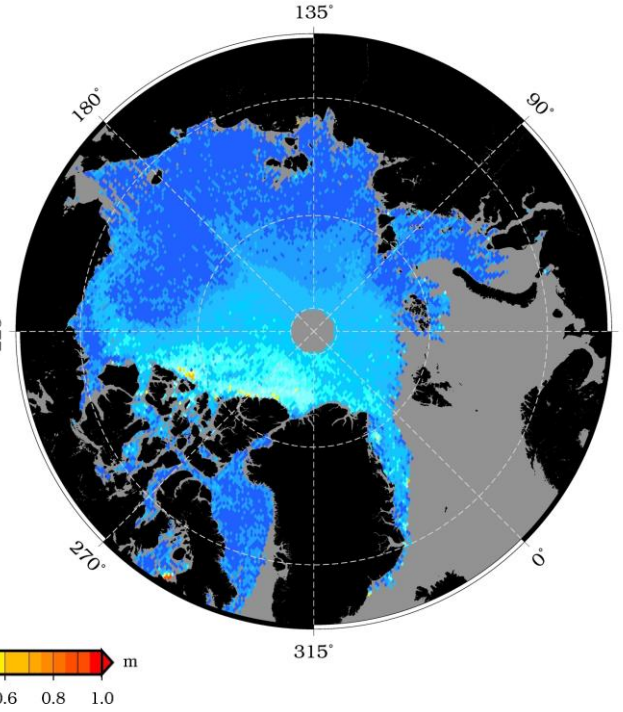
ASCAT
Multi-year Ice Extent



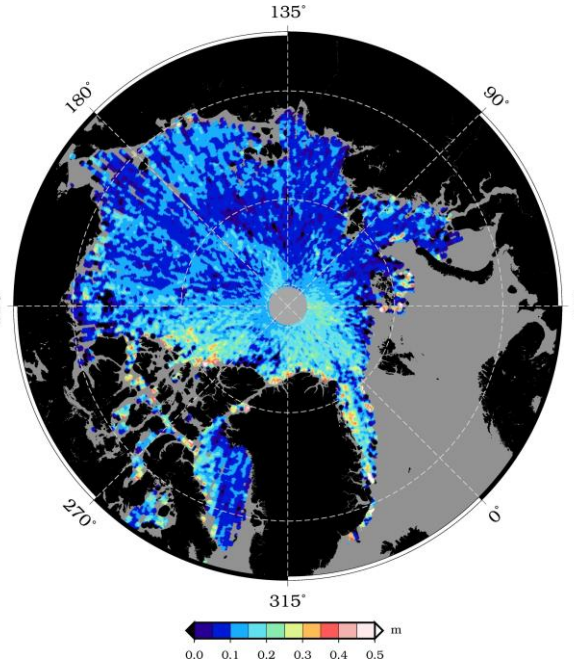
ICESat-2
Sea Ice Freeboard



CryoSat-2
Sea Ice Freeboard



LARA* Freeboard
ICESat-2 *minus* CryoSat-2



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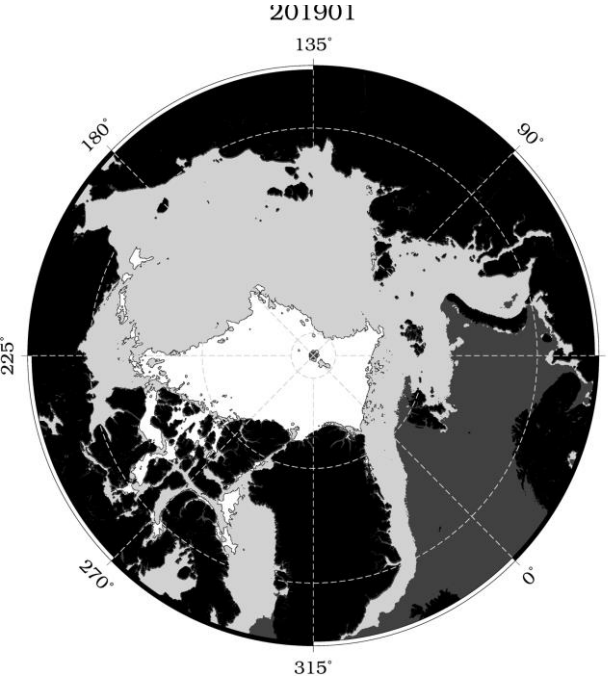
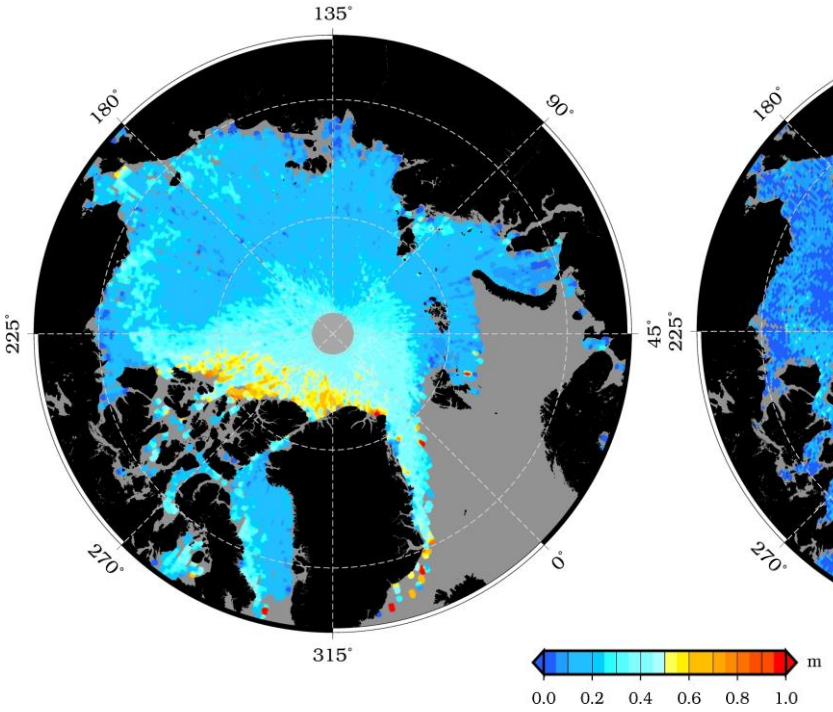
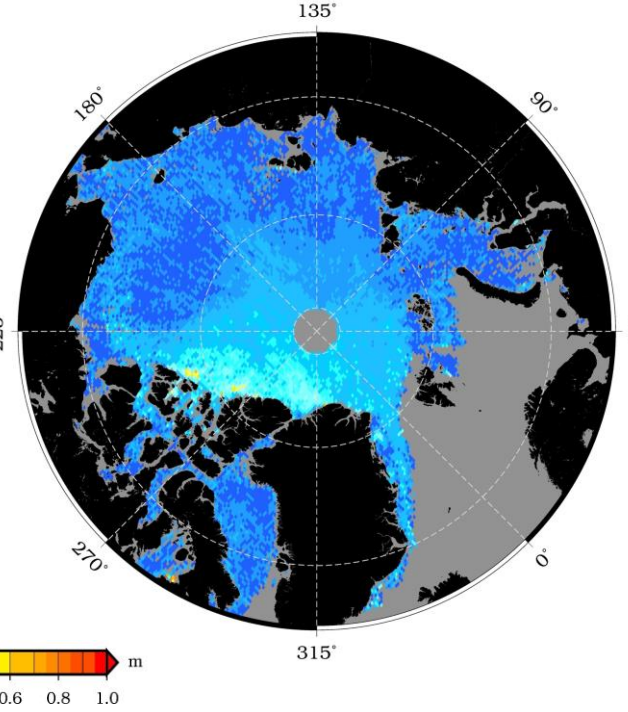


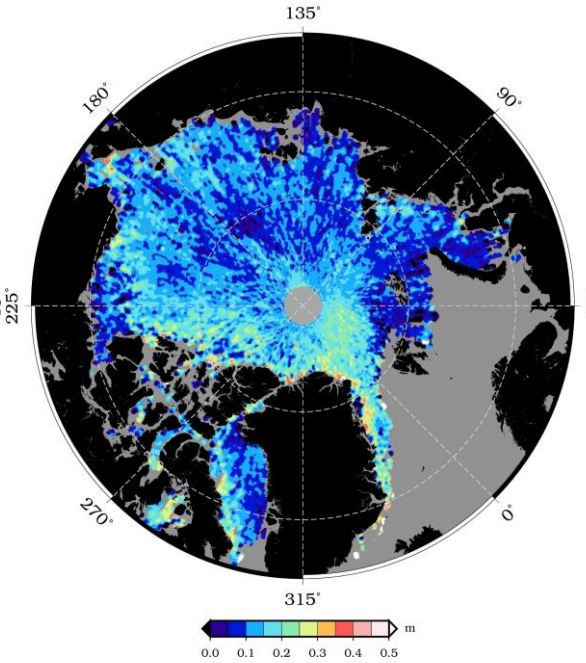
ICESat-2
Sea Ice Freeboard



CryoSat-2
Sea Ice Freeboard



LARA* Freeboard
ICESat-2 *minus* CryoSat-2



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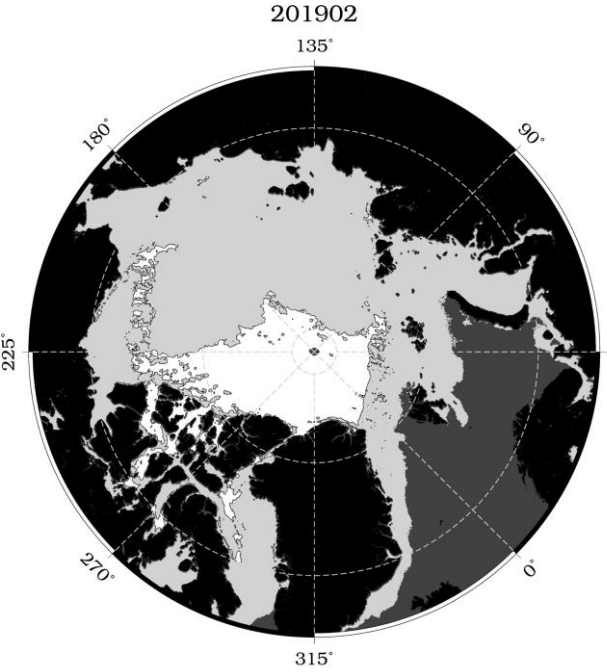

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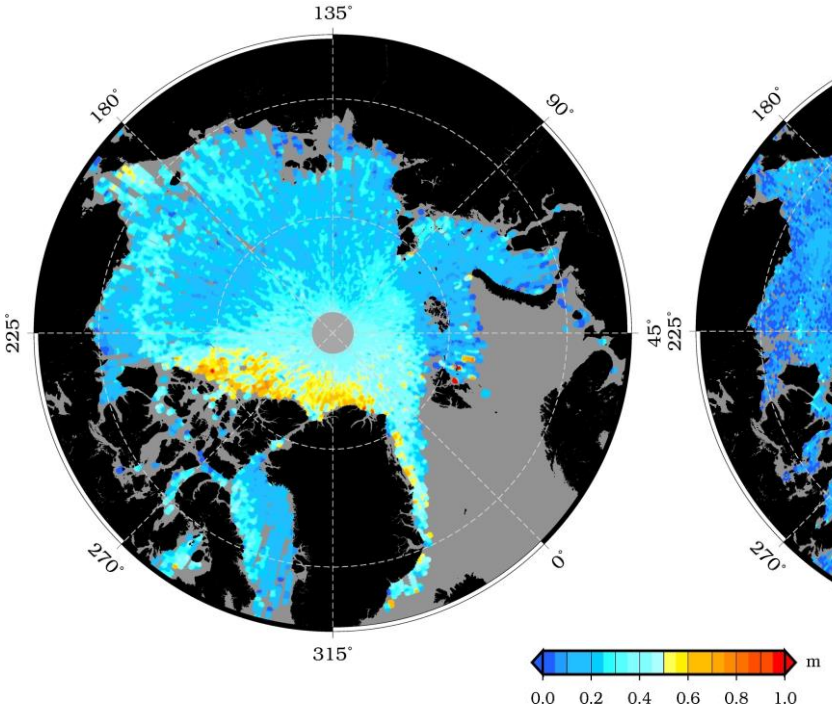
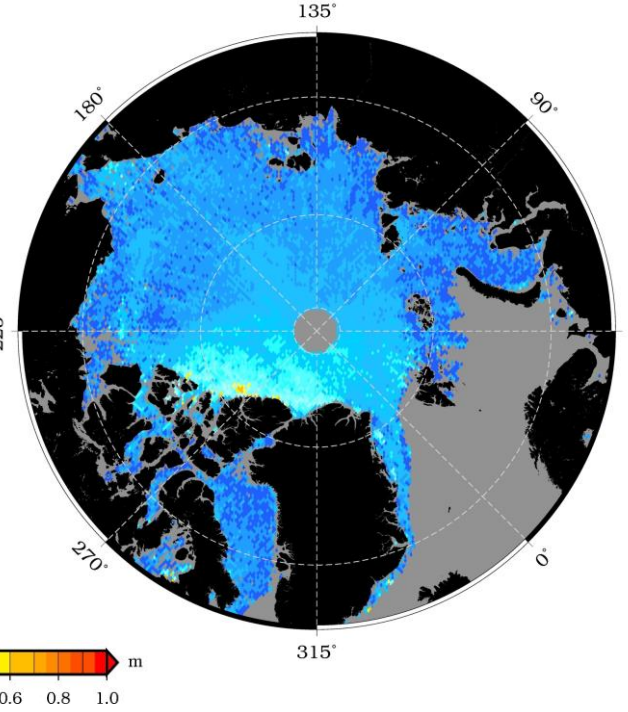
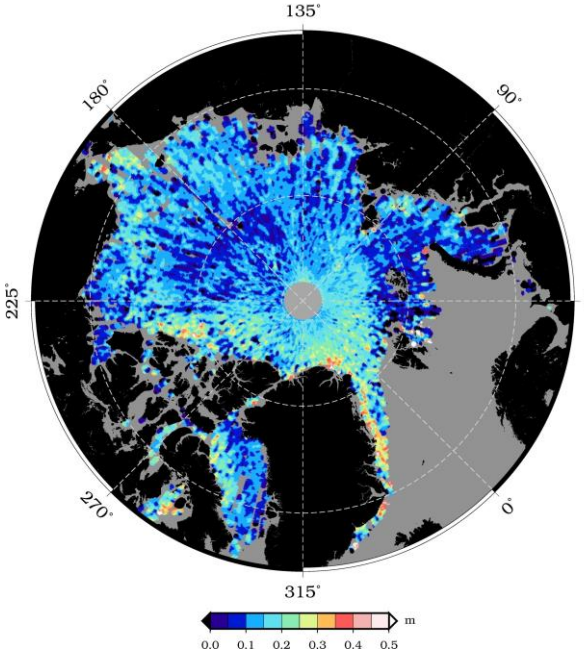


CryoSat-2
Sea Ice Freeboard



LARA* Freeboard
ICESat-2 *minus* CryoSat-2



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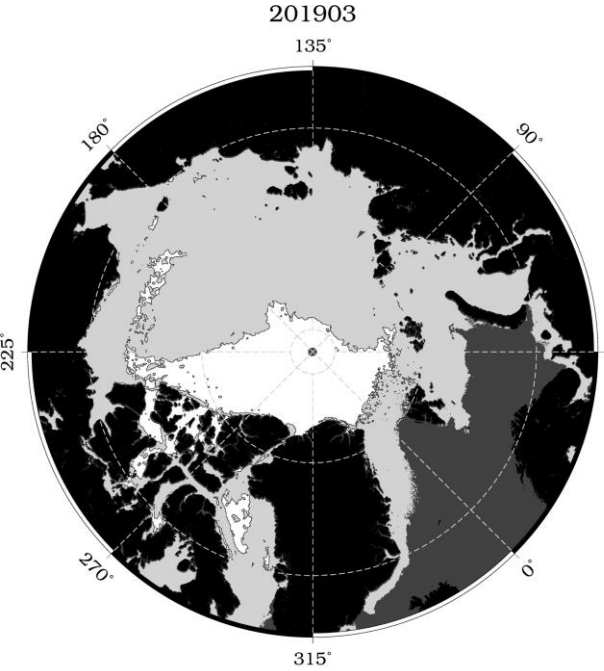

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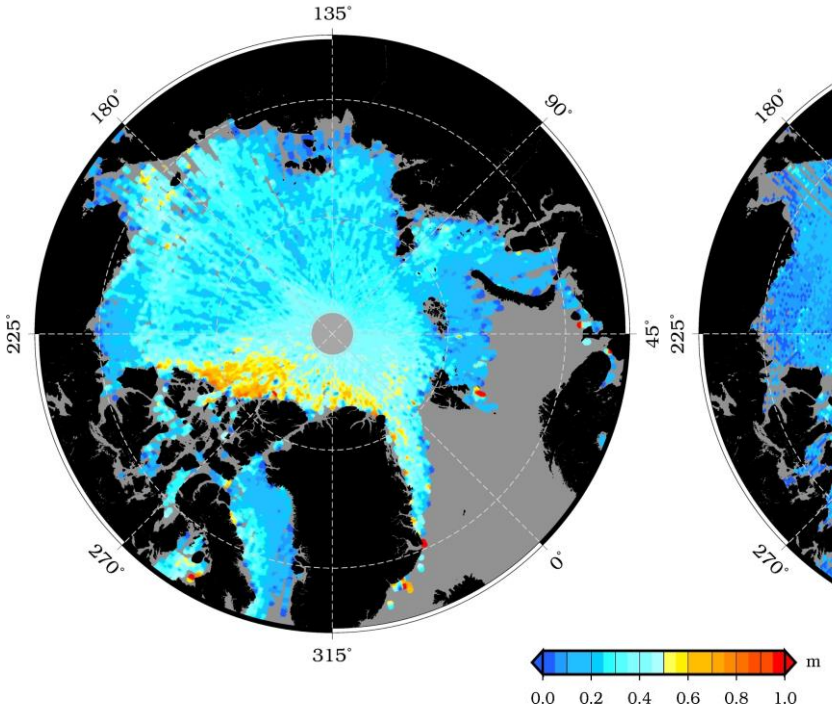
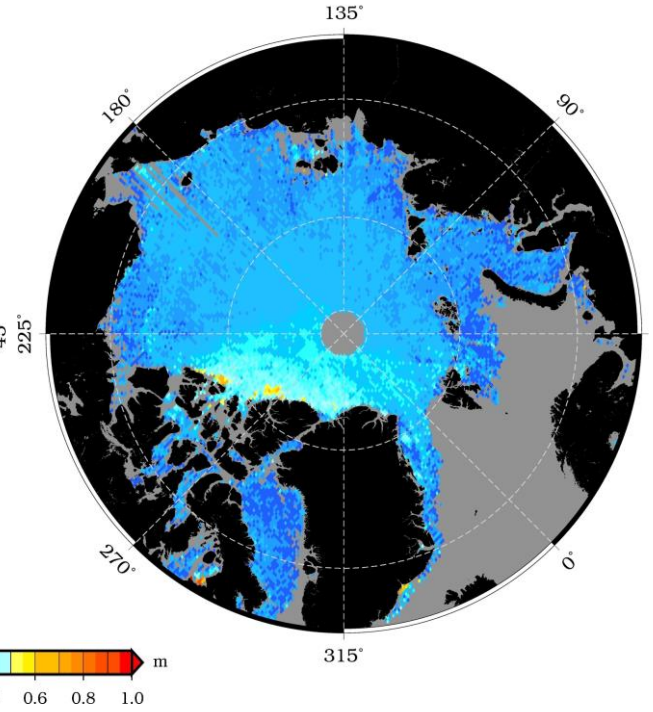
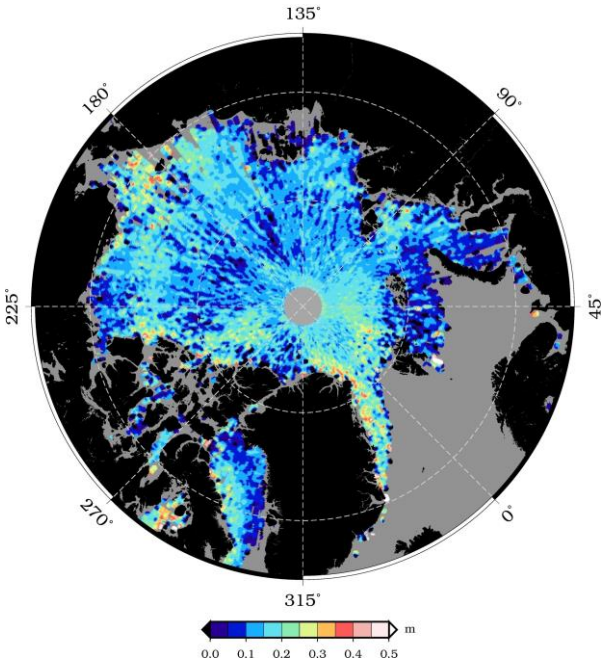


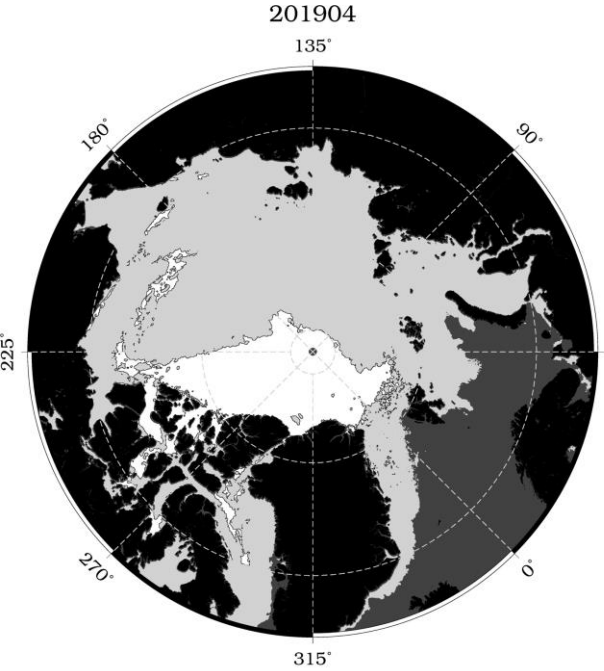
CryoSat-2
Sea Ice Freeboard



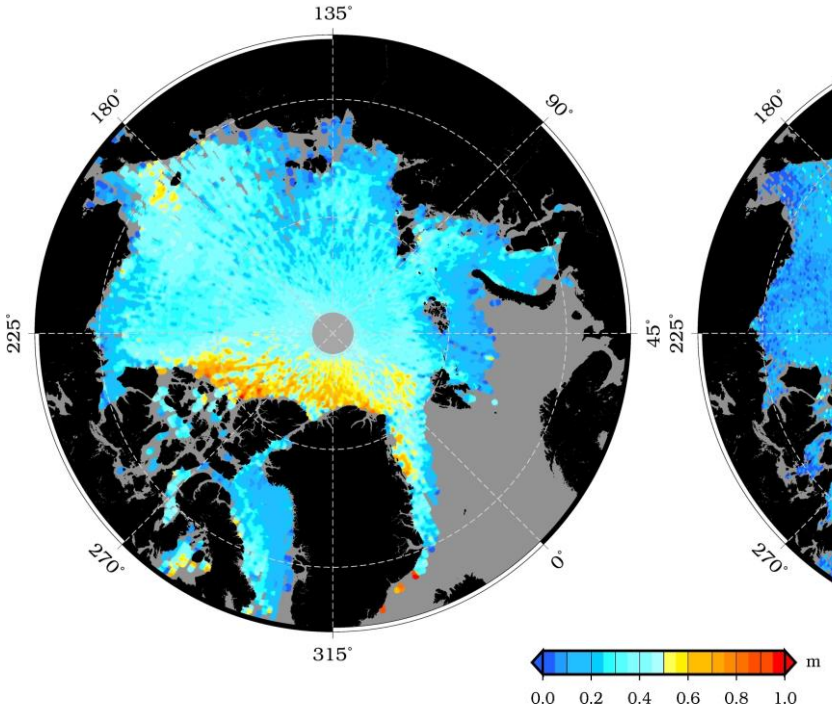
LARA* Freeboard
ICESat-2 *minus* CryoSat-2



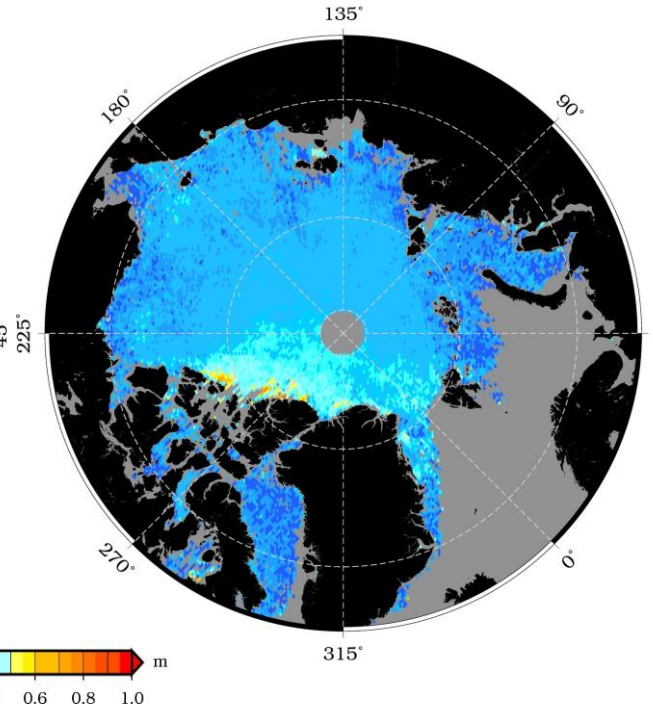
ASCAT
Multi-year Ice Extent



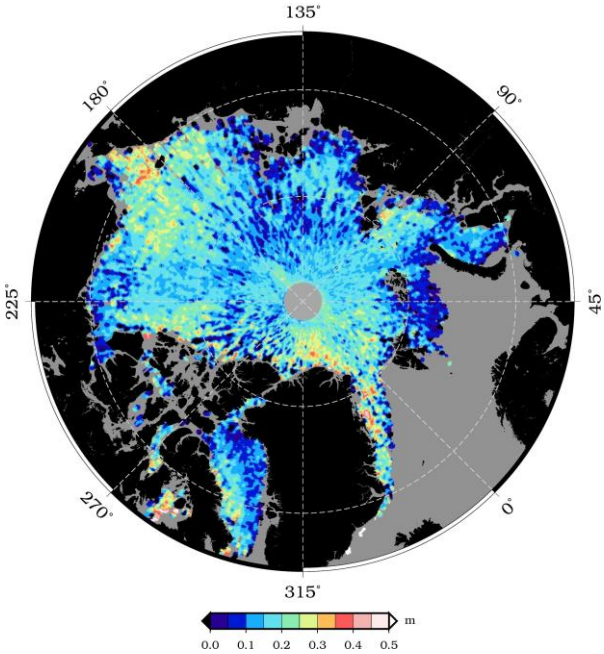
ICESat-2
Sea Ice Freeboard



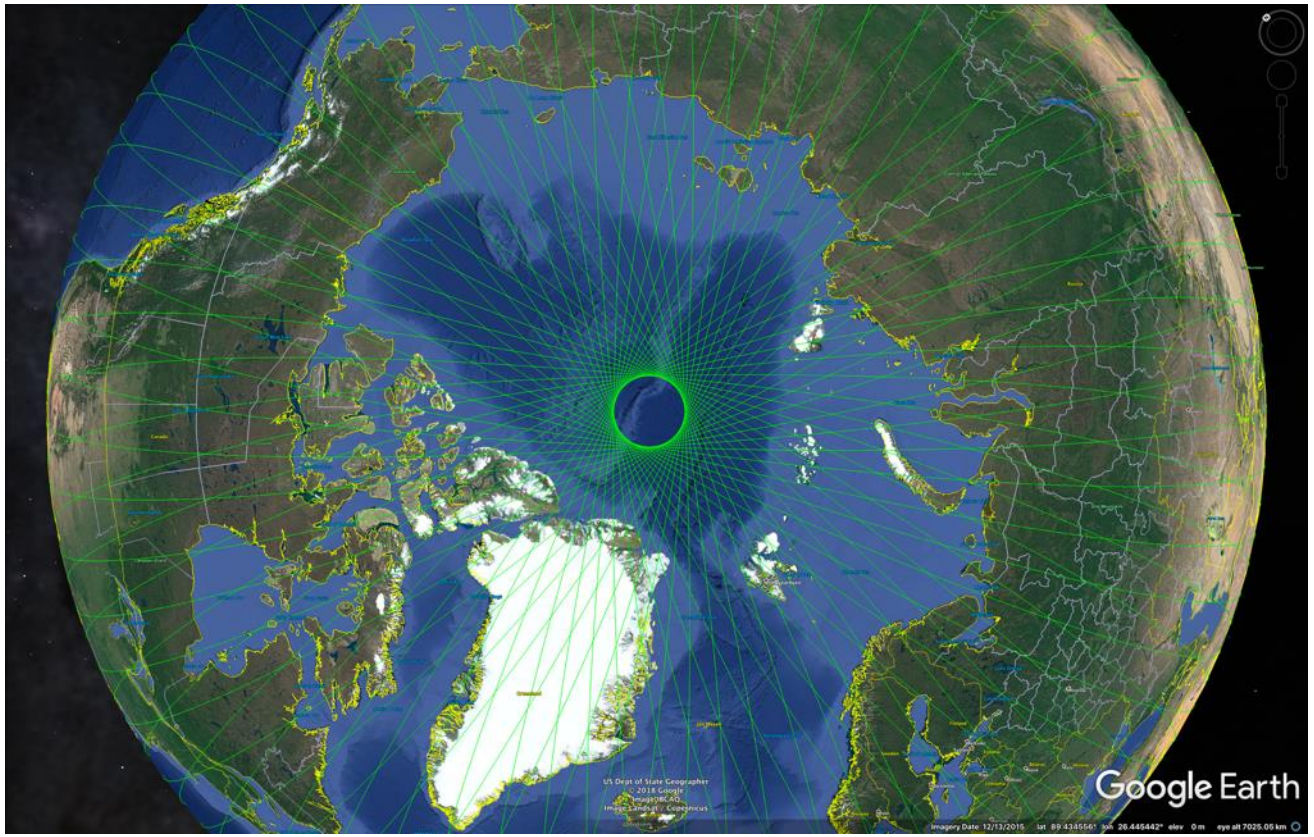
CryoSat-2
Sea Ice Freeboard



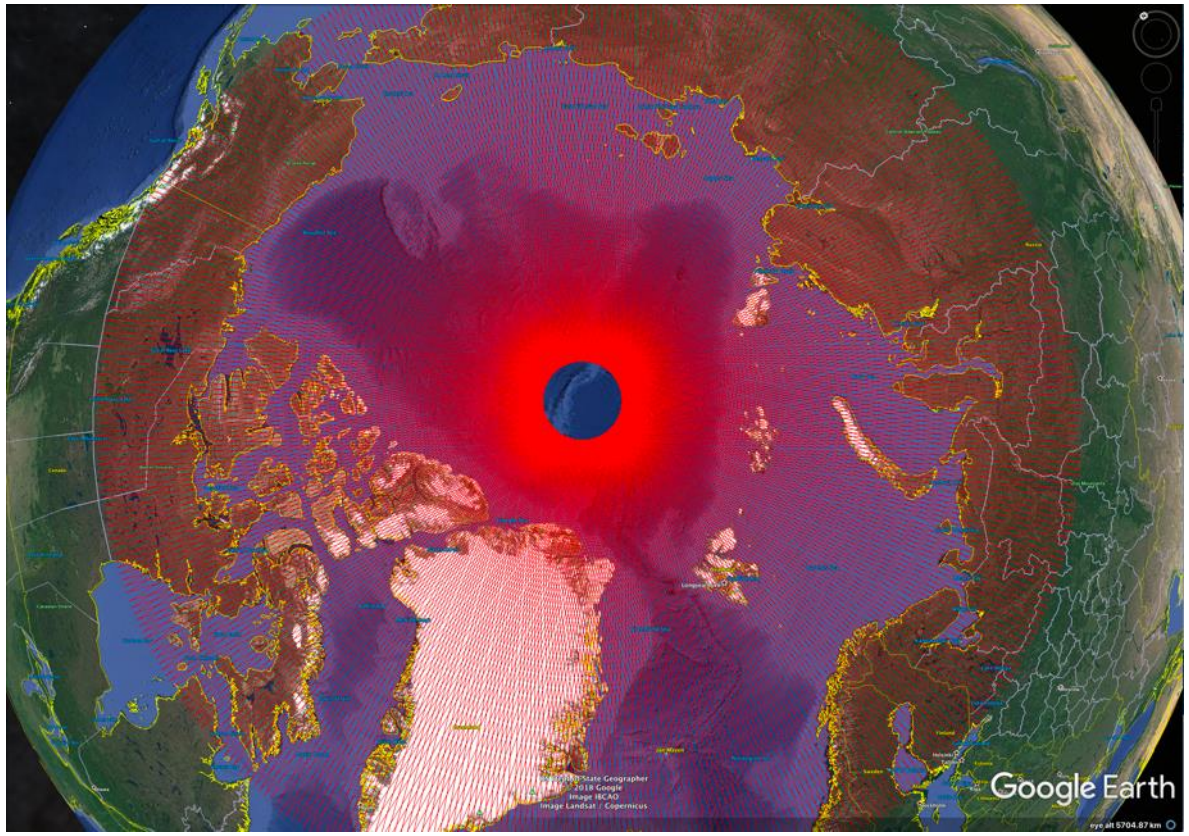
LARA* Freeboard
ICESat-2 *minus* CryoSat-2

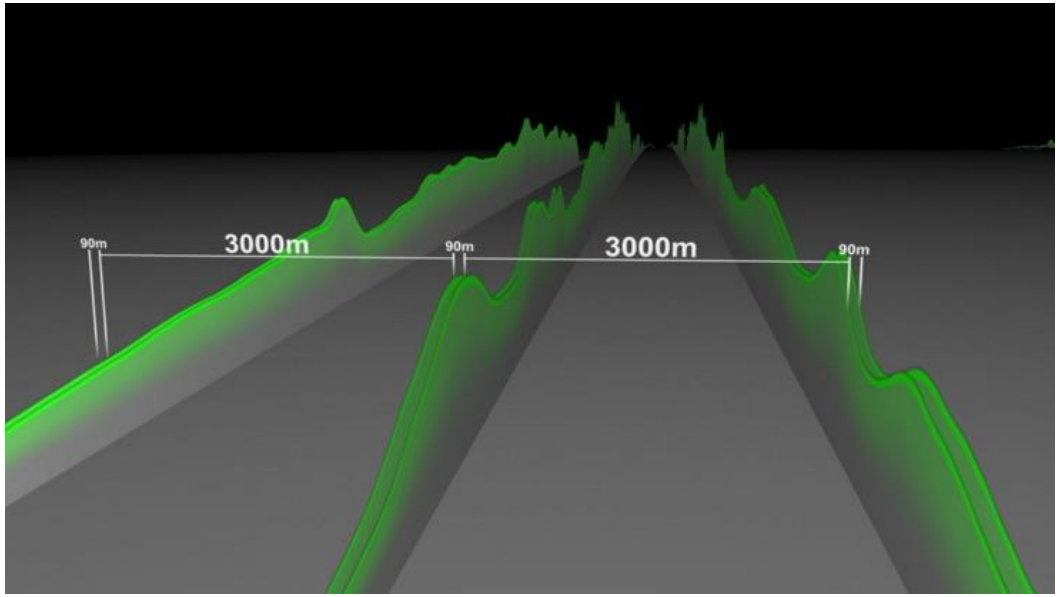


After 4 days (61 orbits)



After 29 days (442 orbits)





Launch – 28 Dec 2018

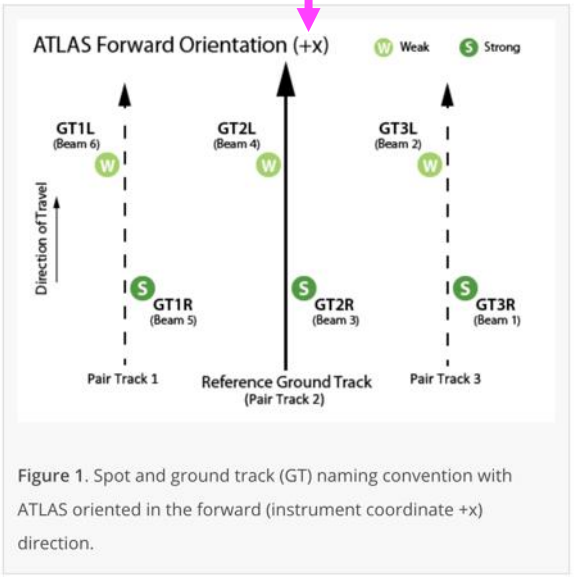


Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

28 Dec 2018 – present

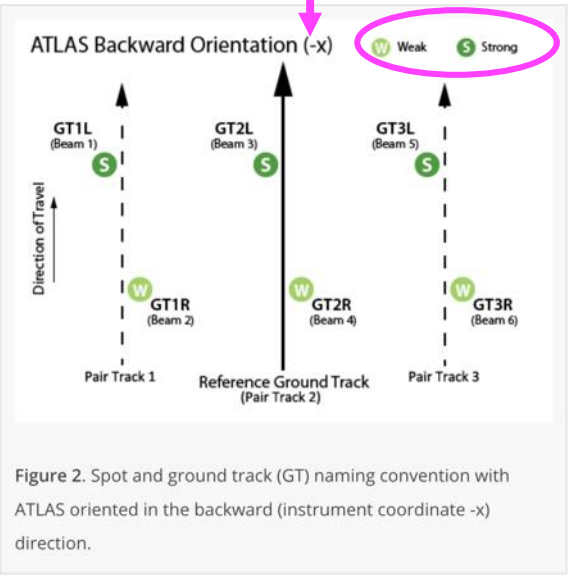


Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.