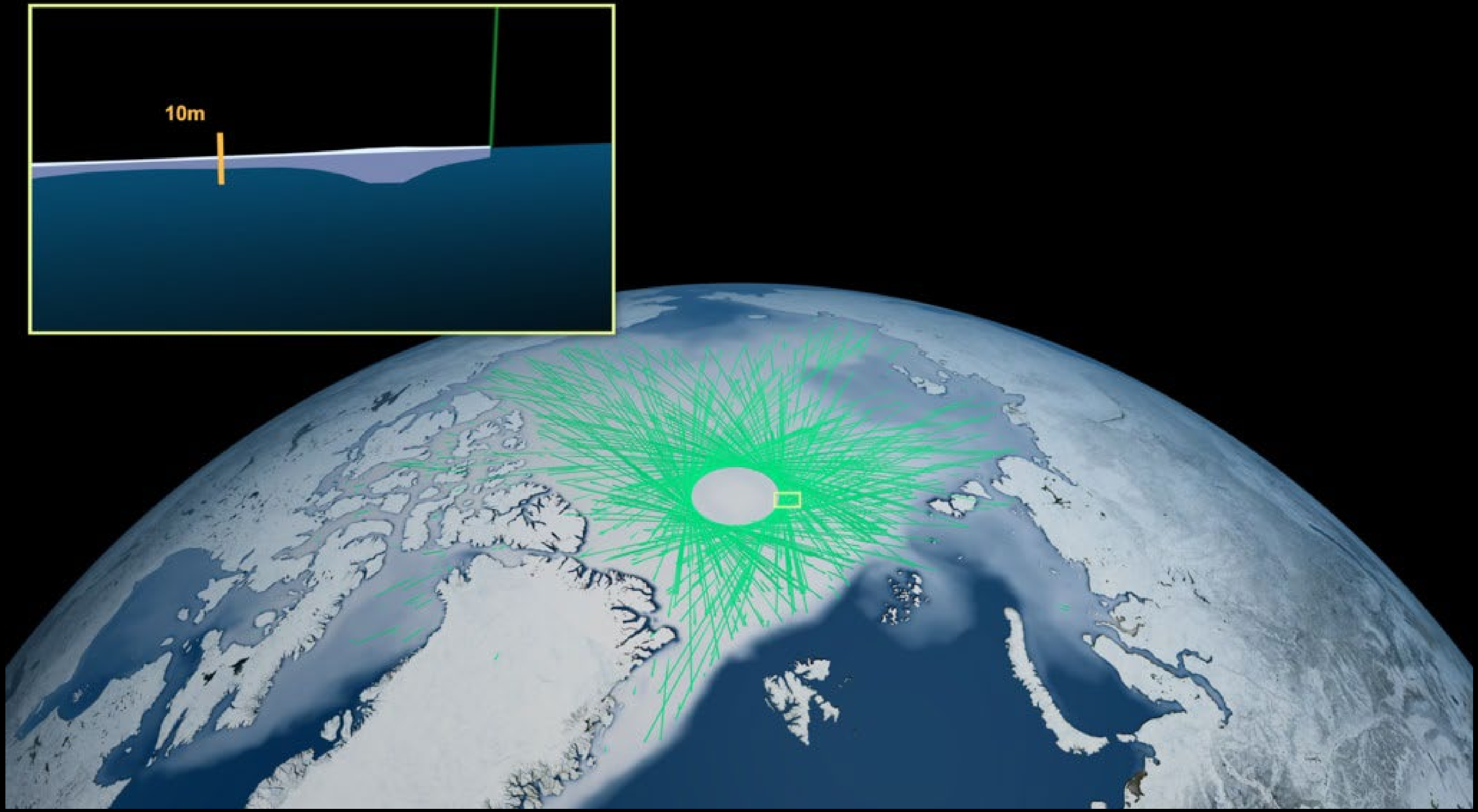
Winter Arctic sea ice profiling from NASA's ICESat-2: 2018-2022

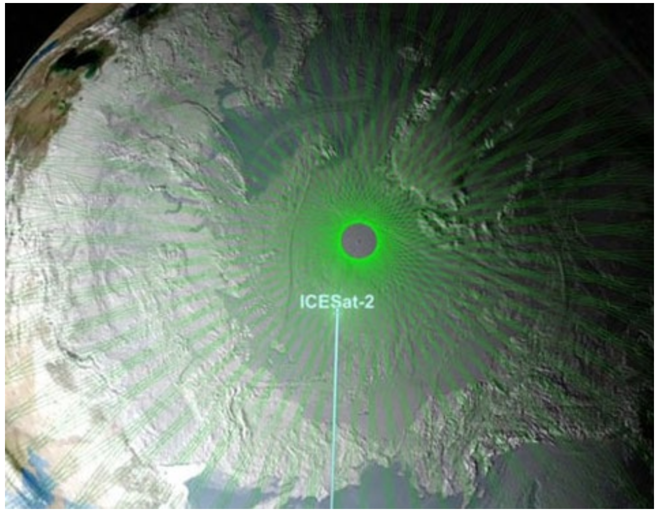
Alek Petty*,
Marco Bagnardi (presenting),

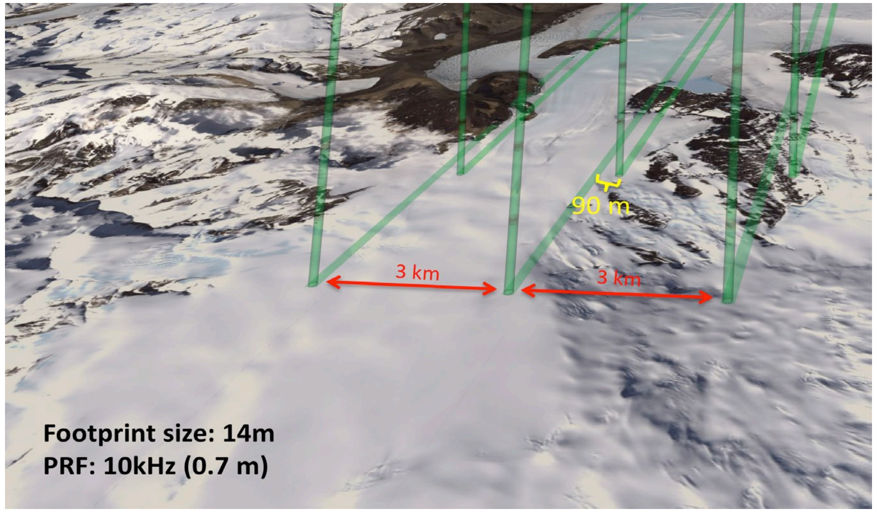
Nathan Kurtz, Rachel Tilling,
Steven Fons, Nicole Keeney,
Alex Cabaj, Paul Kushner,

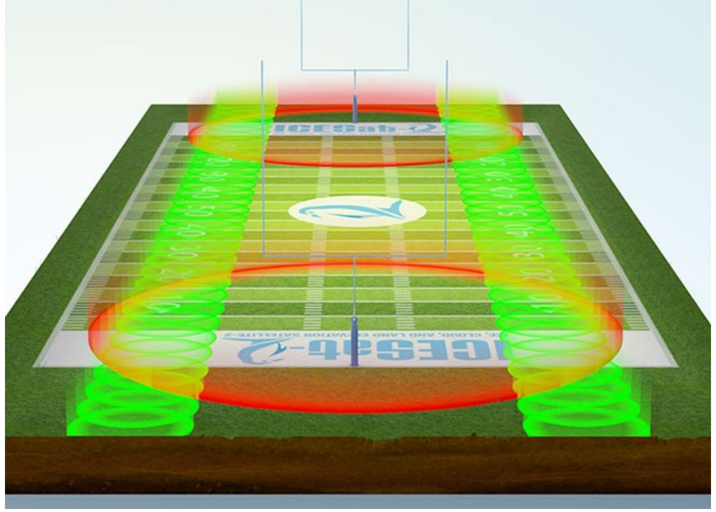


NASA’s ICESat-2 mission

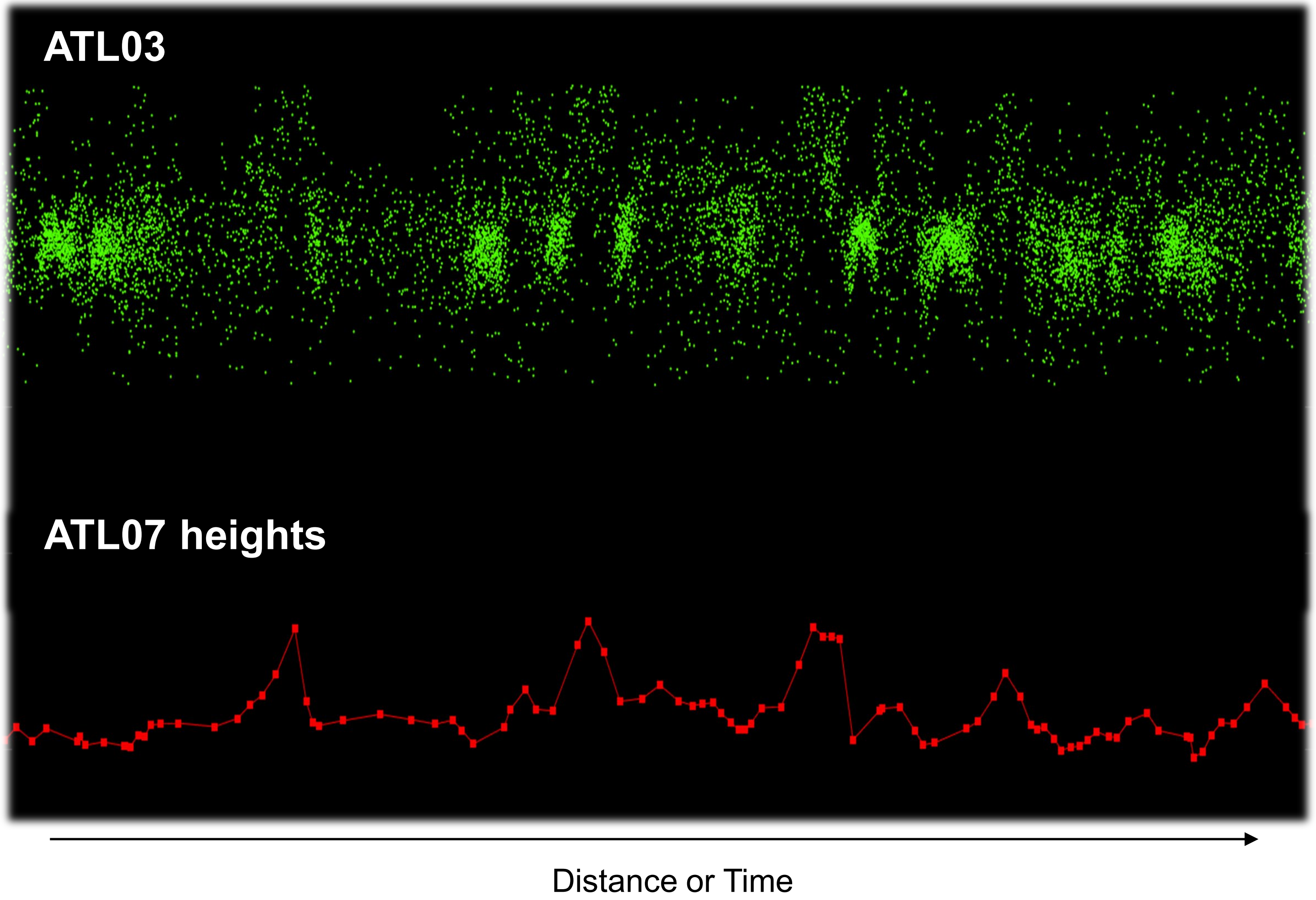
- Photon counting laser altimeter (ATLAS).
- A strong and weak beam (strong beam with 4x the energy pulse strength of the weak beam) 90 m apart but 2.5 km along-track.
- Much better resolution, sampling rate and precision than ICESat.
- Very consistent science quality data since October 2018.





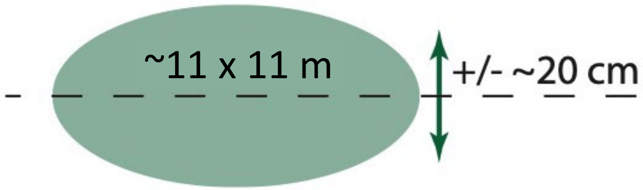


ATL03 photons to ATL07 segment heights



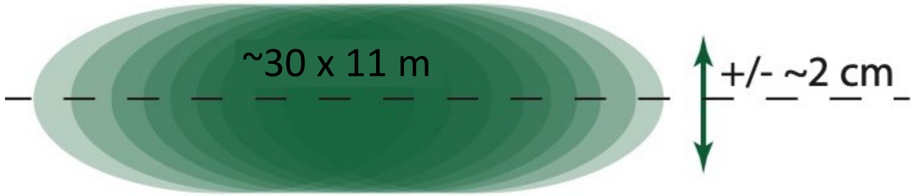
ATL03

- Individual photon heights
- Vertical uncertainty of ~20 cm
- Footprint diameter of ~11 m

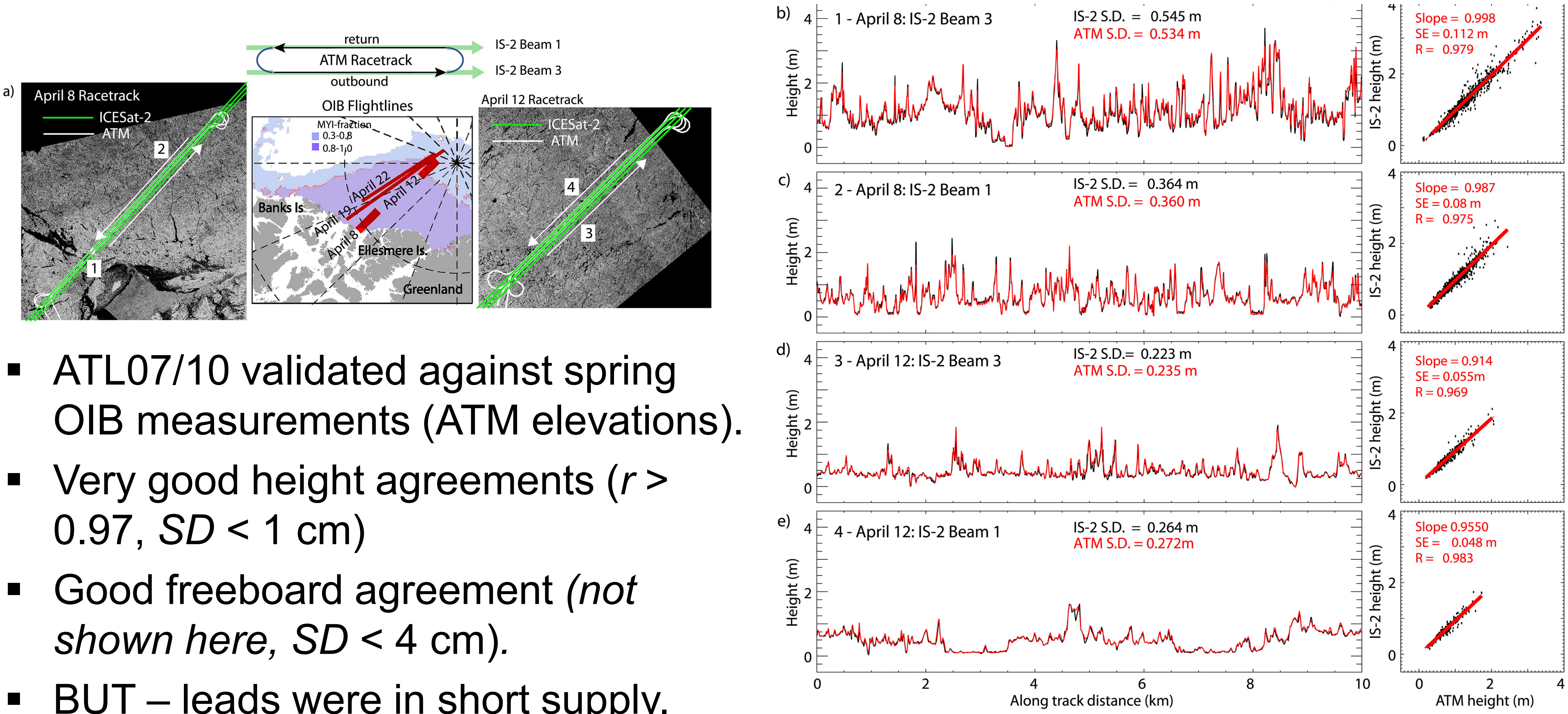


ATL07 (surface heights)
ATL10 (freeboard)

- Aggregate of 150 along-beam photons
- Coarse/fine windowing filters.
- Lowers vertical precision to ~2 cm
- Mean along-track resolution of ~30 m



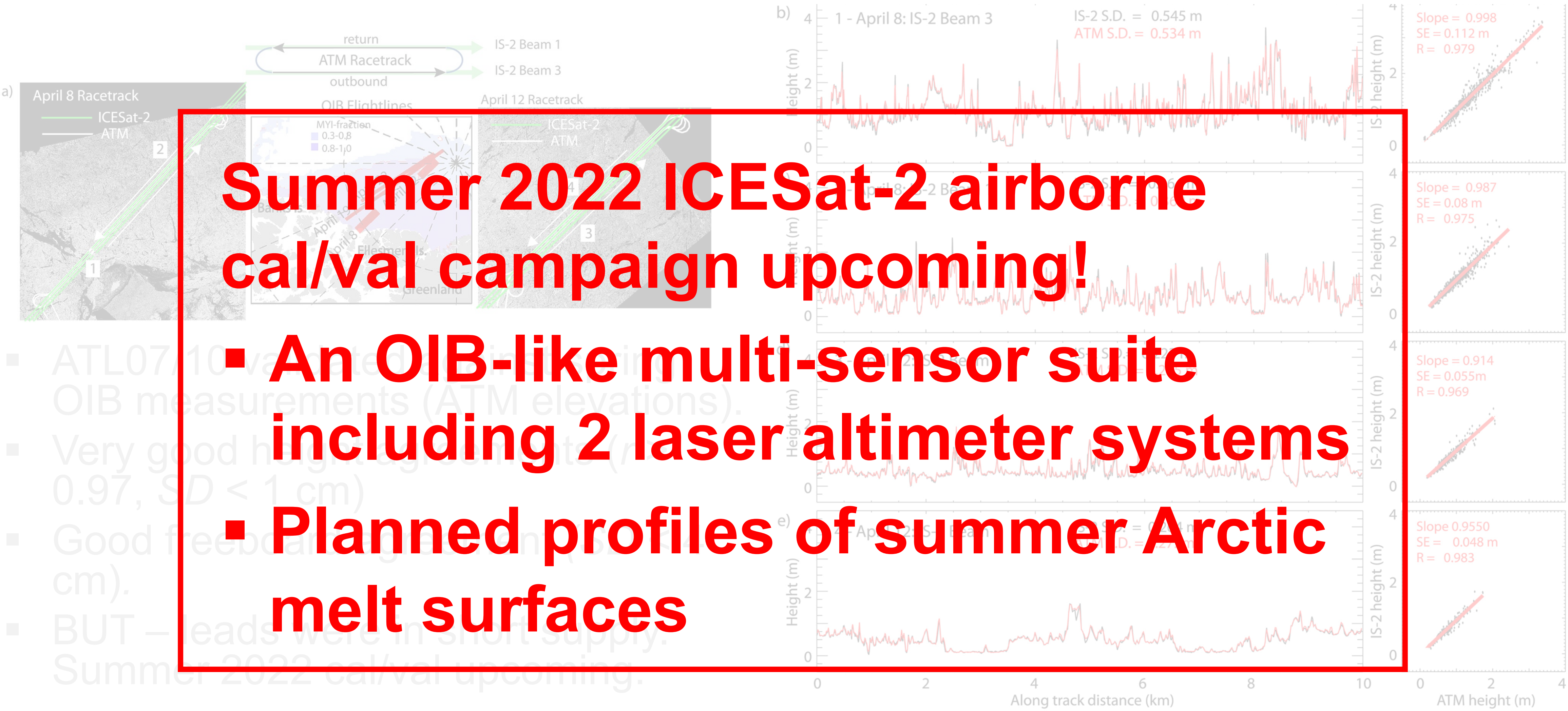
Validation of ATL07/ATL10 with spring 2019 OIB/ATM



- ATL07/10 validated against spring OIB measurements (ATM elevations).
- Very good height agreements (*r* > 0.97, *SD* < 1 cm)
- Good freeboard agreement *(not shown here, SD < 4 cm).*
- BUT – leads were in short supply.

See Kwok et al., 2019 for more info.

Validation of ATL07/ATL10 with spring 2019 OIB/ATM



Summer 2022 ICESat-2 airborne cal/val campaign upcoming!

- **An OIB-like multi-sensor suite including 2 laser altimeter systems**
- **Planned profiles of summer Arctic melt surfaces**

See Kwok et al., 2019 for more info.

Surface type classification (needed for freeboard)

***__Radiometric classification:__* Decision tree for estimating surface type**

1. Photon Rate (proxy for surface reflectance)

2. Gaussian fit (proxy for surface roughness)

3. Normalized background rate (proxy for surface albedo)

Specular lead *(high photon rate, low roughness and low background if solar elevation high)*

Dark lead *(low photon rate, low-medium roughness, low background if solar elev high)*

Sea ice: *everything else**

__Sea surface classification:__ *additional height filter for increased reliability*

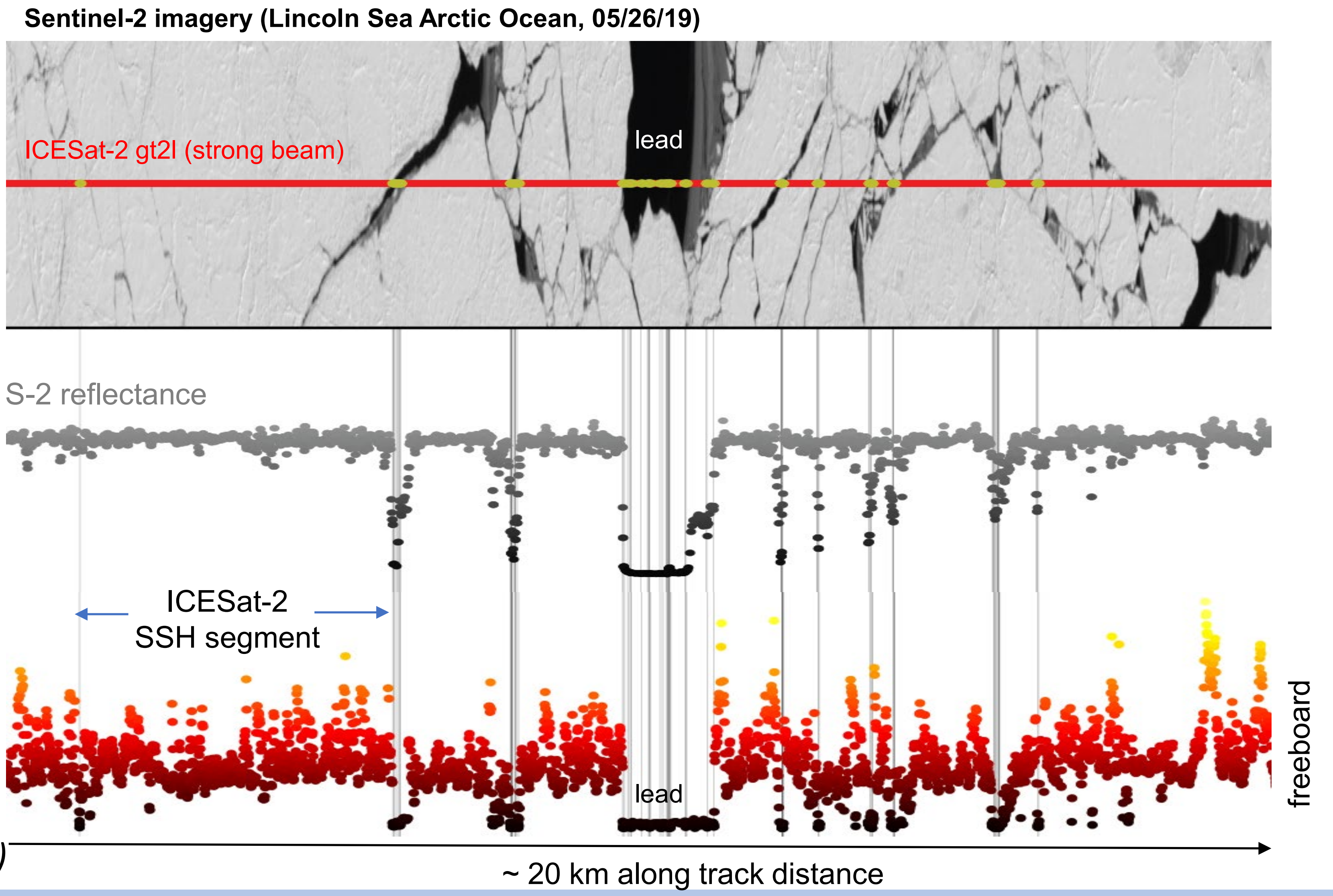
4. Relative height

Candidate sea surface segment *(low height compared to local distribution)*

**In summer everything could also be a melt pond! Also cloud flag but that is very rare/unused.*

Comparisons of ATL07 surface classification with Sentinel-2

- Coincident Sentinel-2 imagery (<1.5 hours in this case, near exact spatial overlap).
- Multiple examples show strong agreement in the specular ATL07 leads and S-2 imagery.
- ATL07 dark (rough) leads show more mixed response due to cloud contamination.



Petty et al., 2021 (Earth and Space Science)

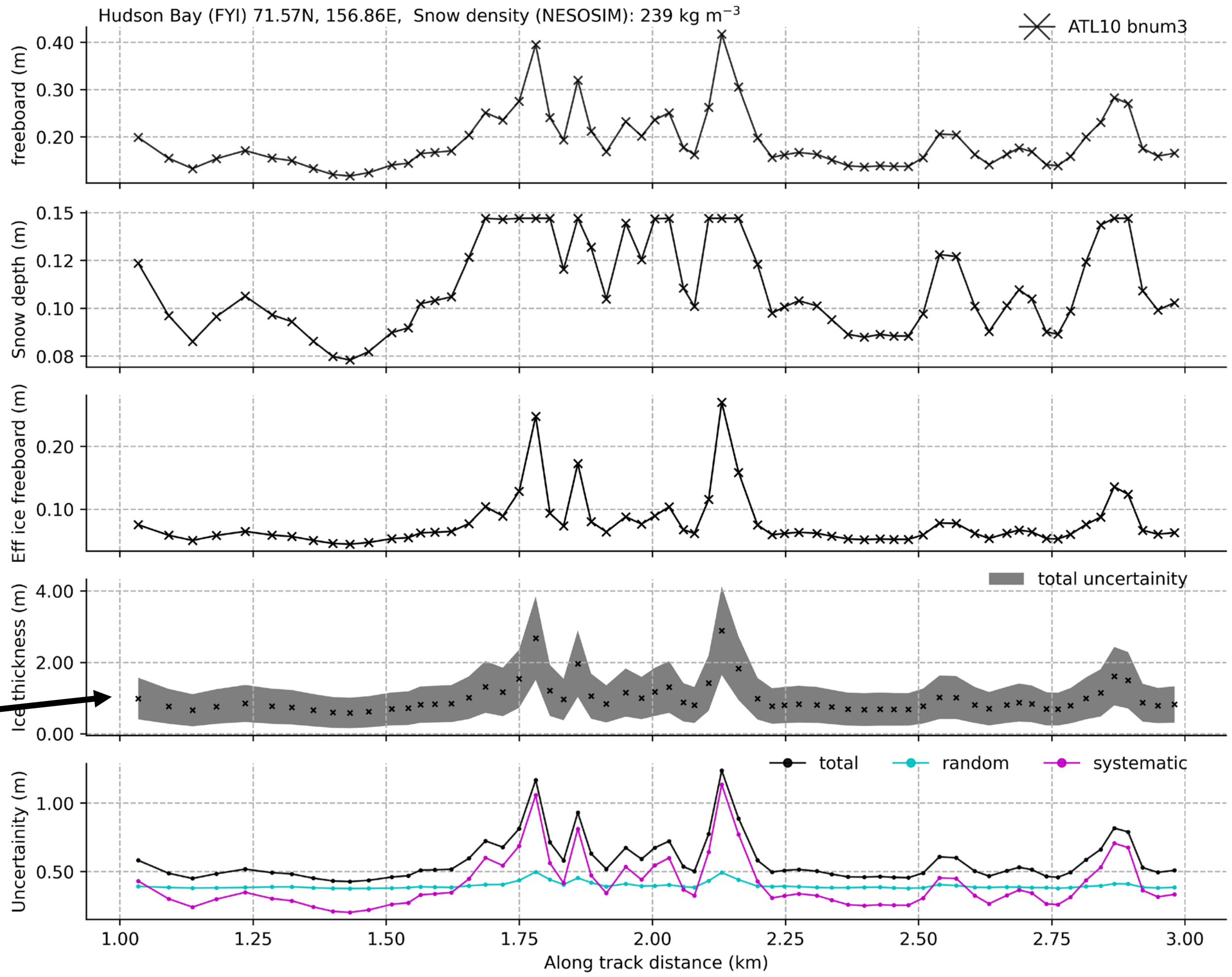
The official ICESat-2 sea ice products (ATL07/ATL10/ATL20/ATL21) only go as far freeboard/sea surface height, but we can *hopefully* do more…

- Sea ice thickness **this talk!**
- Dynamic Ocean Topography **earlier talk!**
- Surface roughness/pressure ridge distributions
- Lead/pond fraction and ice concentration **upcoming poster**
- Chord length/floe size **upcoming poster**

See also "Combining High-Resolution ESA and NASA Satellite Altimetry to Advance Understanding of Arctic Sea Ice Topography", Date: 27.05.2022, poster session for A9.06 Sea Ice Remote Sensing

Along-track winter Arctic sea ice thickness (IS2SITDAT4)

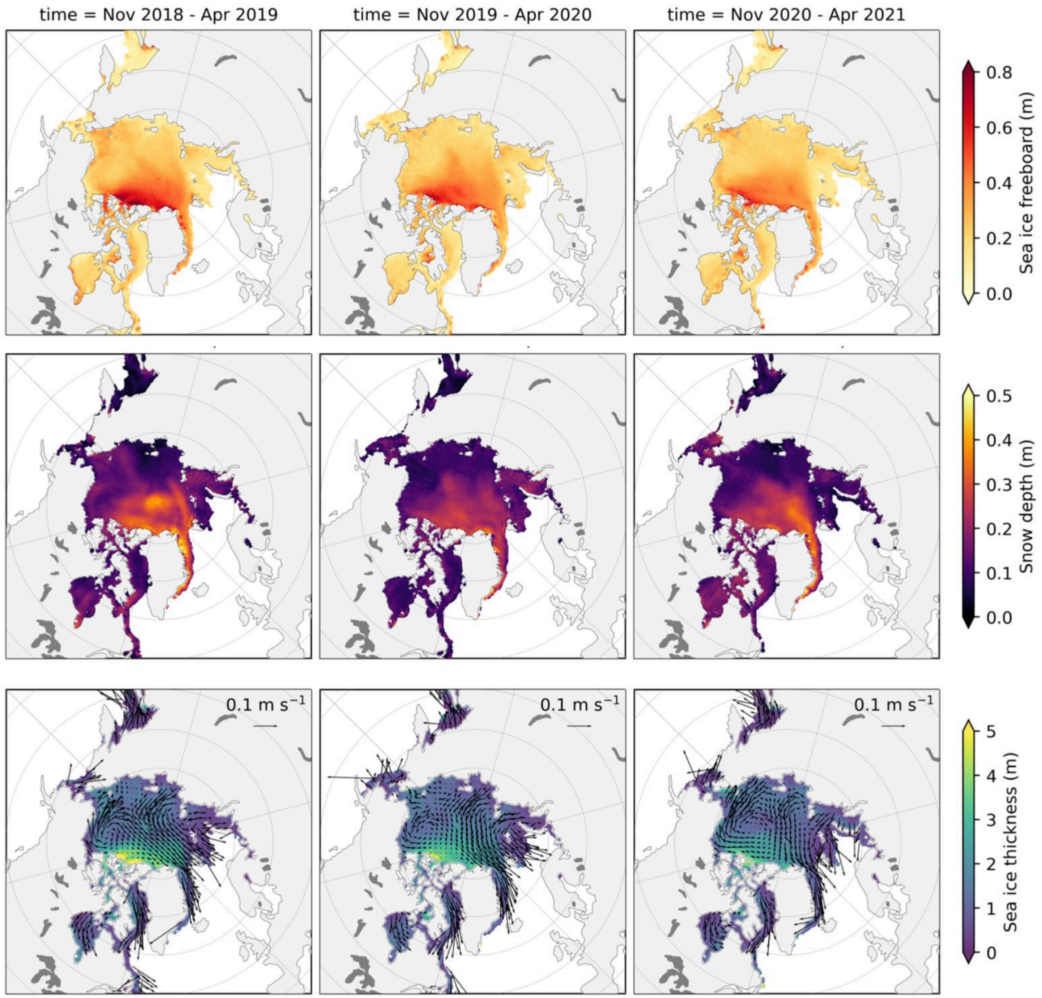
- Use hydrostatic equilibrium to convert freeboard to thickness
- Apply daily gridded (100 km) snow loading estimates from NESOSIM v1.1 redistributed to ATL10 (~20 m) using OIB regression analysis.
- Use spread in input assumptions for uncertainty quantification.
- IS2SITDAT4 V1 thickness data (full-res and 10 km means) now posted at the NSIDC.



updated IS2SITDAT4 example from Petty et al., 2020 (JGR Oceans).

Monthly gridded winter Arctic sea ice thickness (IS2SITMOG4)

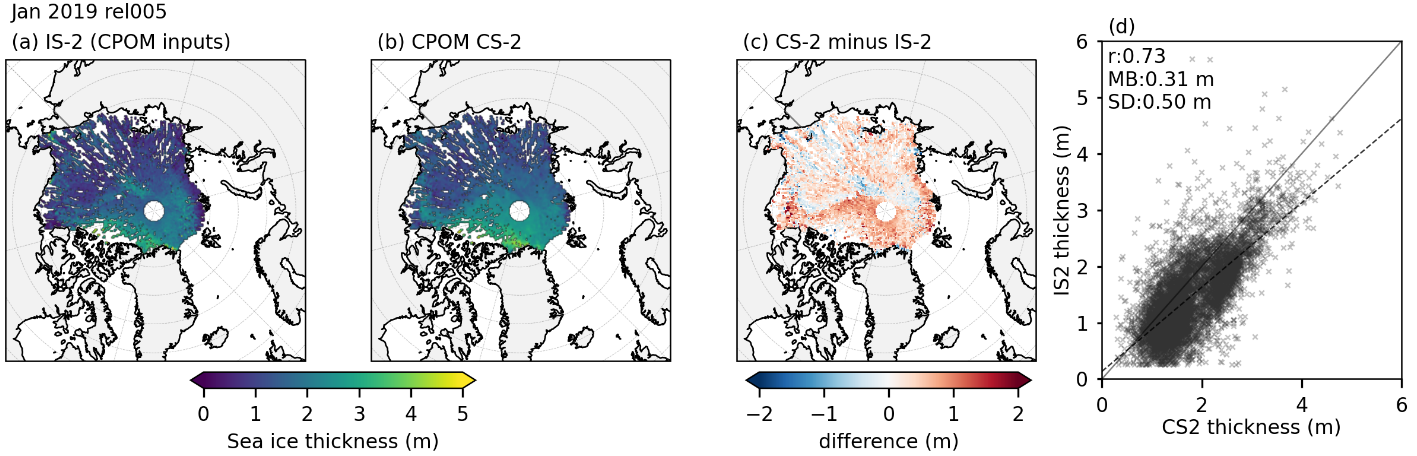
- Produce monthly gridded data by binning along-track data onto a 25 km North Polar stereographic grid.
- Easier means of visualizing and analyzing large-scale winter sea ice conditions from ICESat-2
- Includes ancillary data of ice type (OSI SAF) and concentration (CDR)
- IS2SITMOG4 V2 now at the NSIDC.



Version 1 presented in Petty et al., 2020 (JGR Oceans).
Version 2 in Petty et al., 2022 (The Cryosphere Discuss).
Interactive analysis presented in a novel online JupyterBook: nicolekeeney.com/icesat2-book

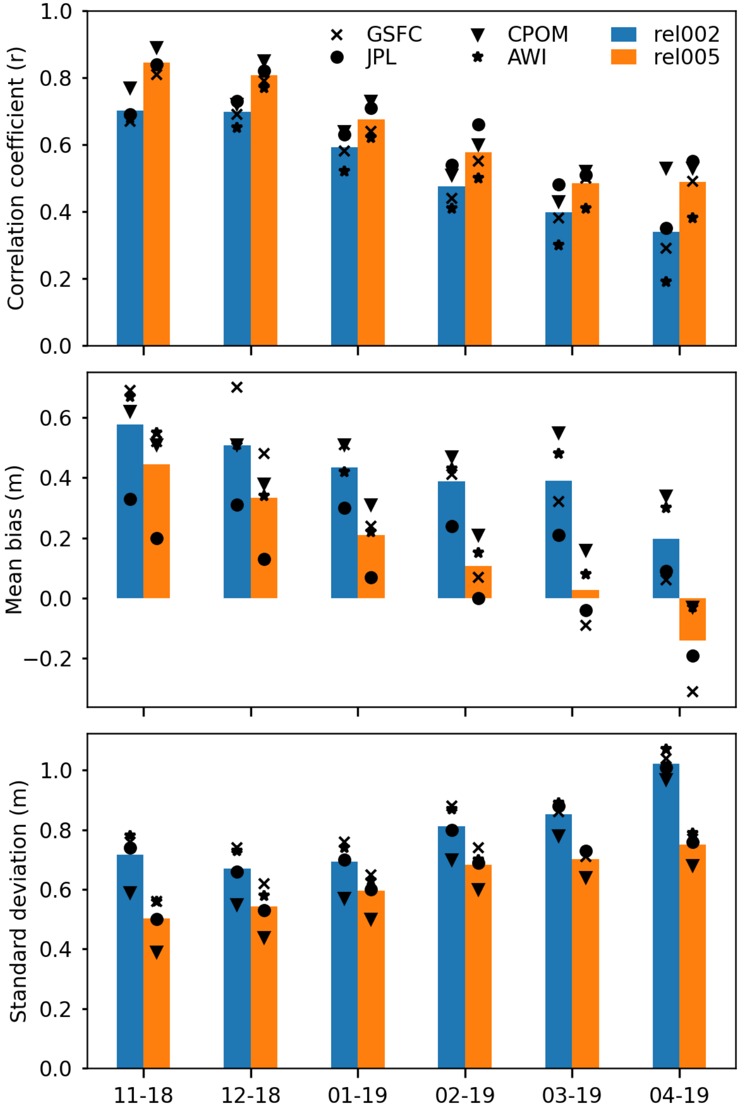
Comparisons with CryoSat-2 products

Example monthly gridded comparison (IS-2 vs CPOM)

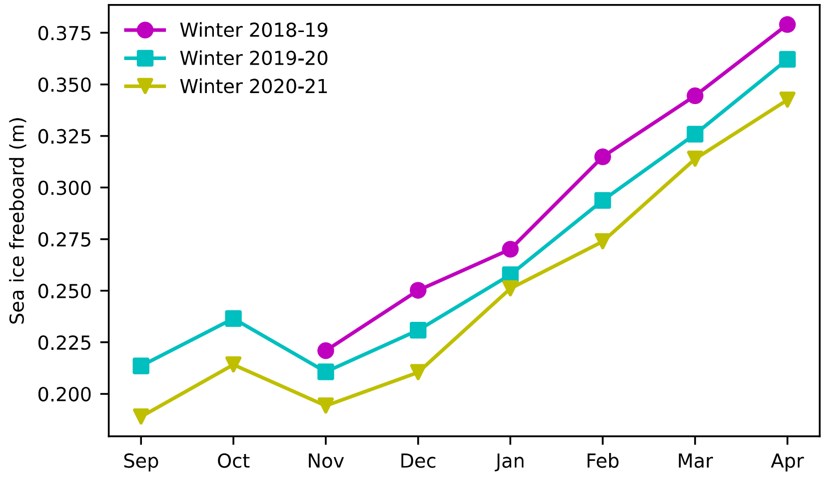


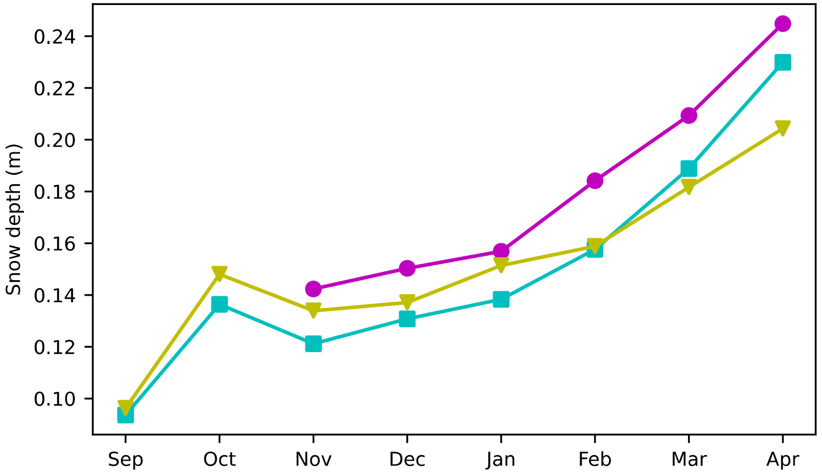
- Better agreement with CryoSat-2 thickness products in rel003-rel005 compared to rel002 (rel002 comparisons presented in Petty et al., 2020).
- Improvement related to removal of dark leads/increases in freeboard in rel003 onwards.
- Next step is CRYO2ICE along-track thickness comparisons, ideally with the Europeans!

Summary stats (2018 Nov to 2019 Apr)

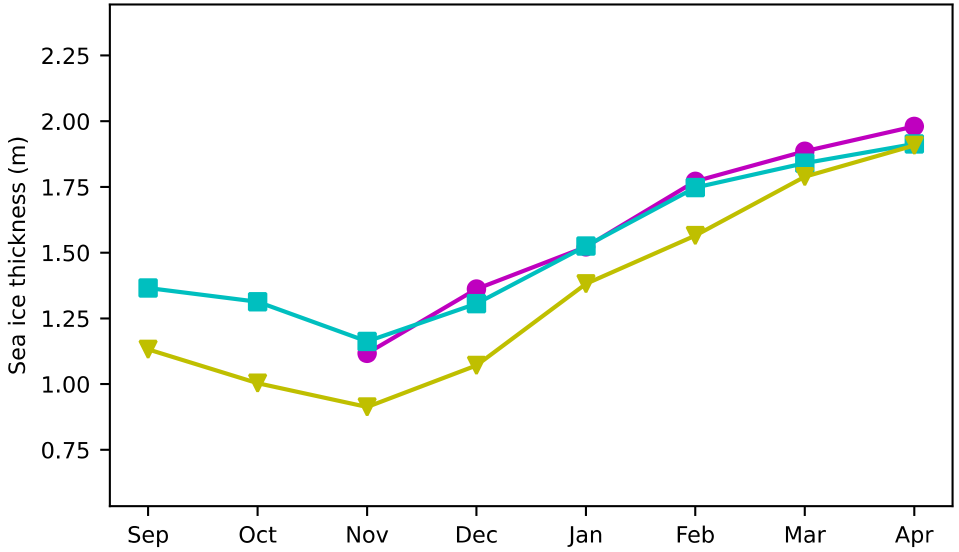


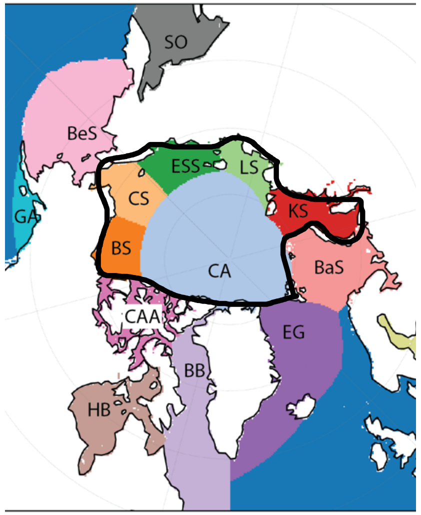
ICESat-2 winter Inner Arctic Ocean – All ice





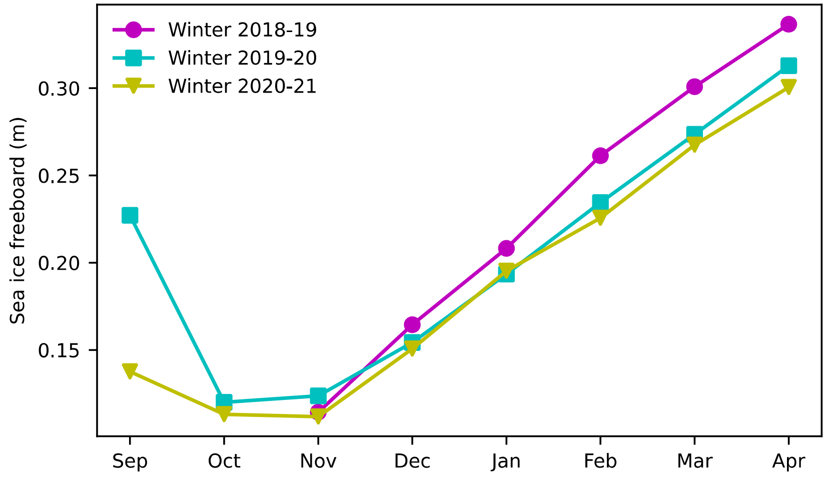
- Freeboard declines of 2-3 cm/yr.
- NESOSIM snow depth interannual rankings different to freeboard rankings.
- Thinner 2020-2021 sea ice compared to previous 2 winters, especially in Nov/Dec 2020.

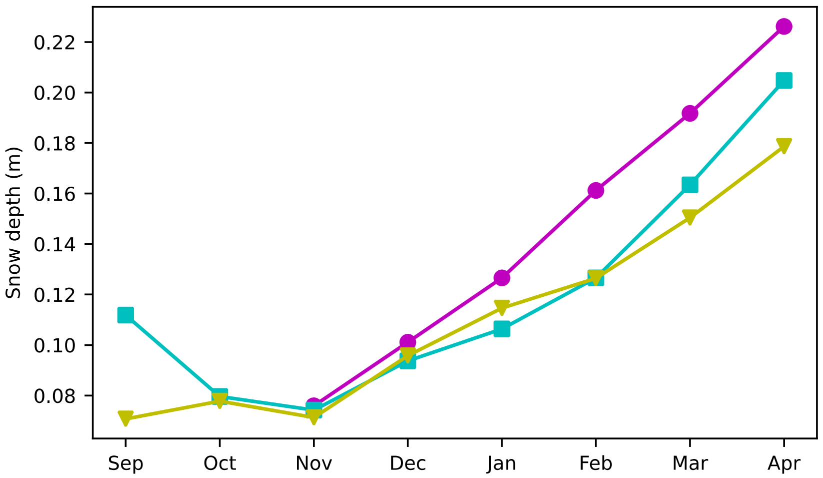


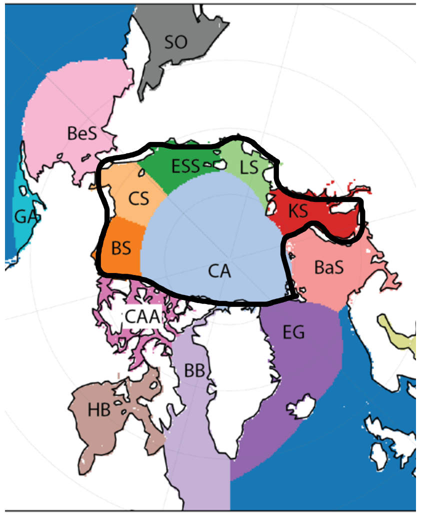


Inner Arctic Ocean (black contour)

ICESat-2 winter Inner Arctic Ocean – First-year ice only

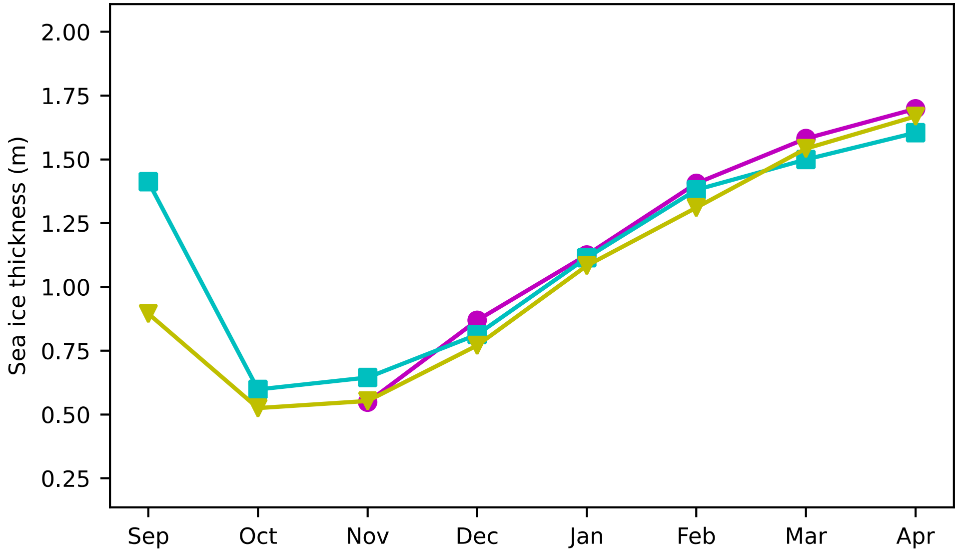




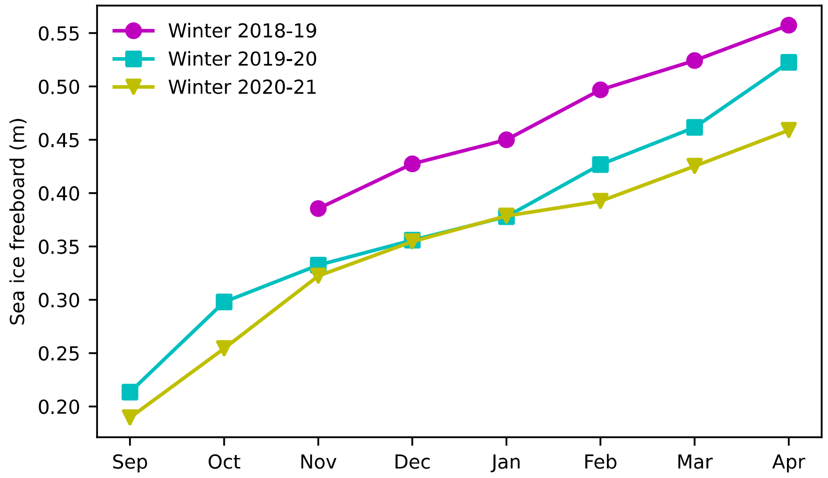


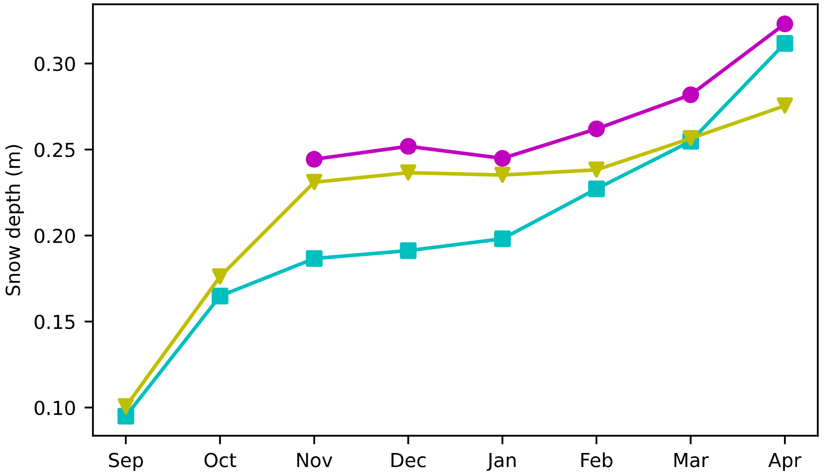
Inner Arctic Ocean (black contour)

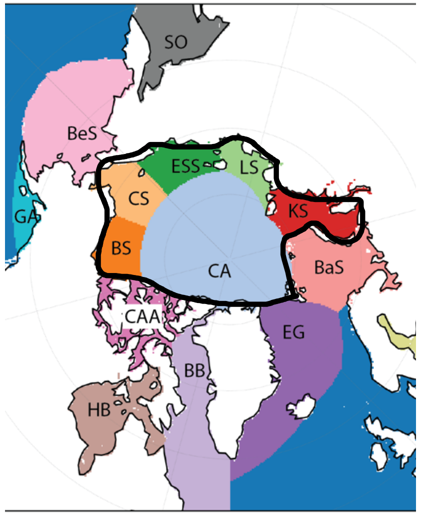
- Thinner FYI freeboards in past 2 winters.
- First-year ice interannual freeboard differences largely explained by changes in NESOSIM snow depths.
- Result is very consistent thicknesses across the 3 winters.



ICESat-2 winter Inner Arctic Ocean – Multi-year ice only

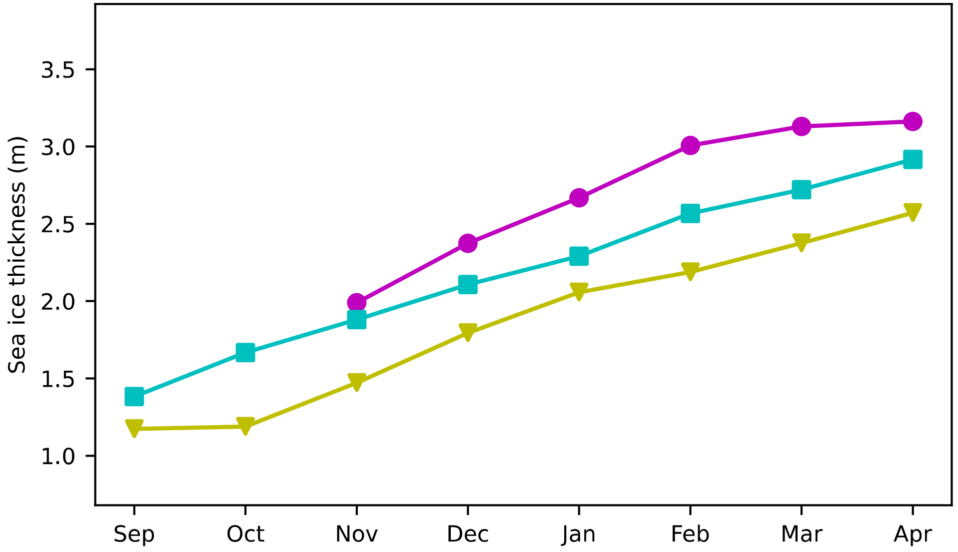






Inner Arctic Ocean (black contour)

- Much thinner freeboards in past 2 winters, partly offset by snow depth differences.
- 10-50 cm declines in MYI thickness, lowest in the most recent 2020-2021 winter.
- Good agreement with Kwok and Kacimi (2022) CryoSat-2/ICESat-2 results, e.g. 50 cm MYI decline.



ICESat-2 sea ice summary

- Very happy with how ICESat-2 is performing over sea ice.
- Still actively engaged with cal/val activities to improve data quality and uncertainty quantification, while also producing higher-level sea ice data.
- Keen to work with our European colleagues on CRYO2ICE comparisons

	ATL03 (photon heights)	ATL07/10 (segment heights)	ATL20/21 (daily/monthly gridded)	IS2SITMOGR4 (monthly gridded)	IS2SITDAT4 (segment thickness)	Chord length (along-track and gridded)
Time period	Year-round, Entire mission	Year-round, entire mission	Year-round, entire mission	Winter only, up to Apr 2021	Winter only, up to Apr 2021	Winter only, up to Apr 2019
Hemisphere	Both	Both	Both	Arctic only	Arctic only	Both
Quick-look also?	No	Yes	Not yet	No	No	No
Latest version	rel005	rel005	rel003/rel002	Version 2	Version 1	Version 1
Latency	~60 days	~60 days/~2-3 days (QL)	~60 days	~60-210 days (June/July)	~60-210 days (June/July)	TBD

Thank you! (alek.a.petty@nasa.gov)

References

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- Analysis available at nicolekeeney.com/icesat2-book

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