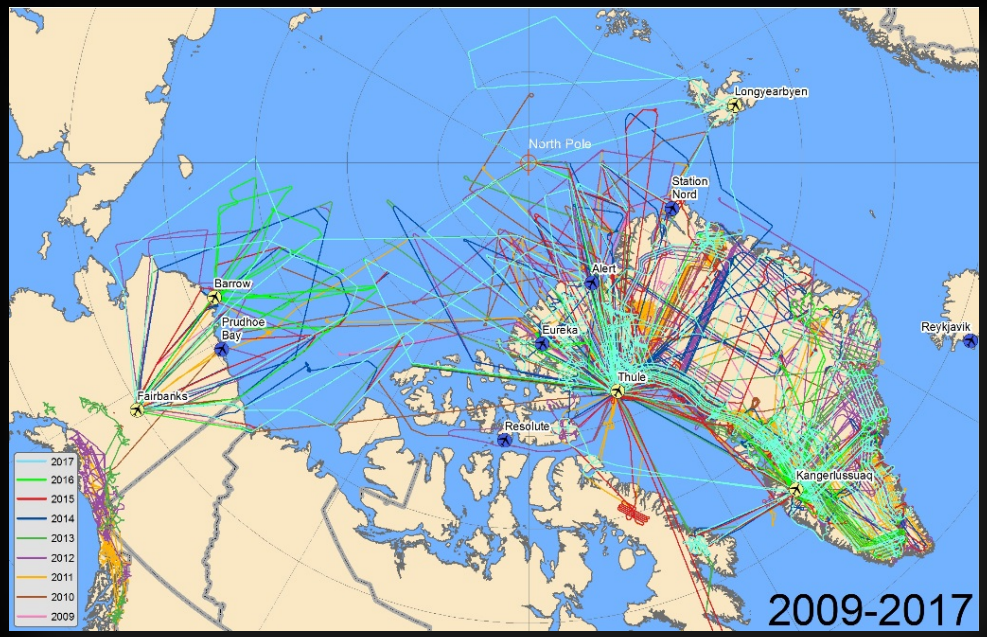
NASA Operation IceBridge 2018

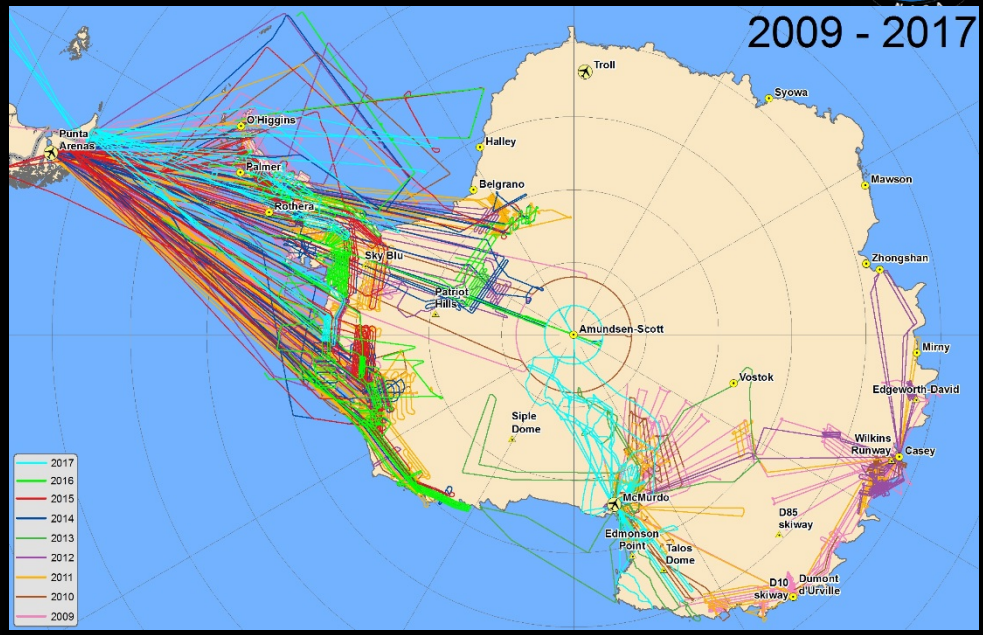
(personal communication)

Nathan Kurtz, NASA GSFC

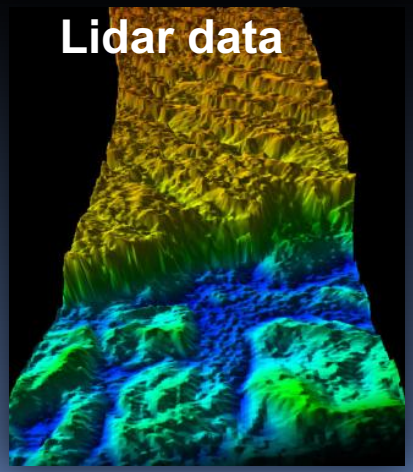
Photo: M. Studinger

Operation IceBridge Overview



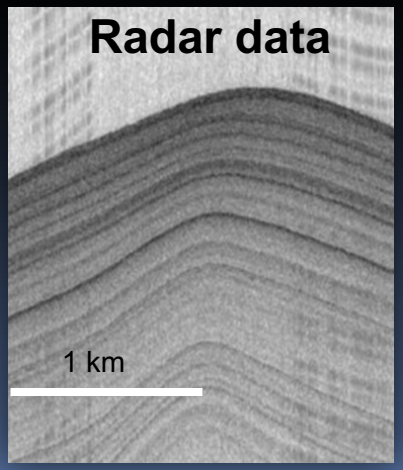


- Ice surface elevation data over ice sheets, glaciers, and sea ice to bridge the gap between ICESat and ICESat-2 missions
- New measurements critical to ice sheet models: bed topography, grounding line position, ice and snow thickness

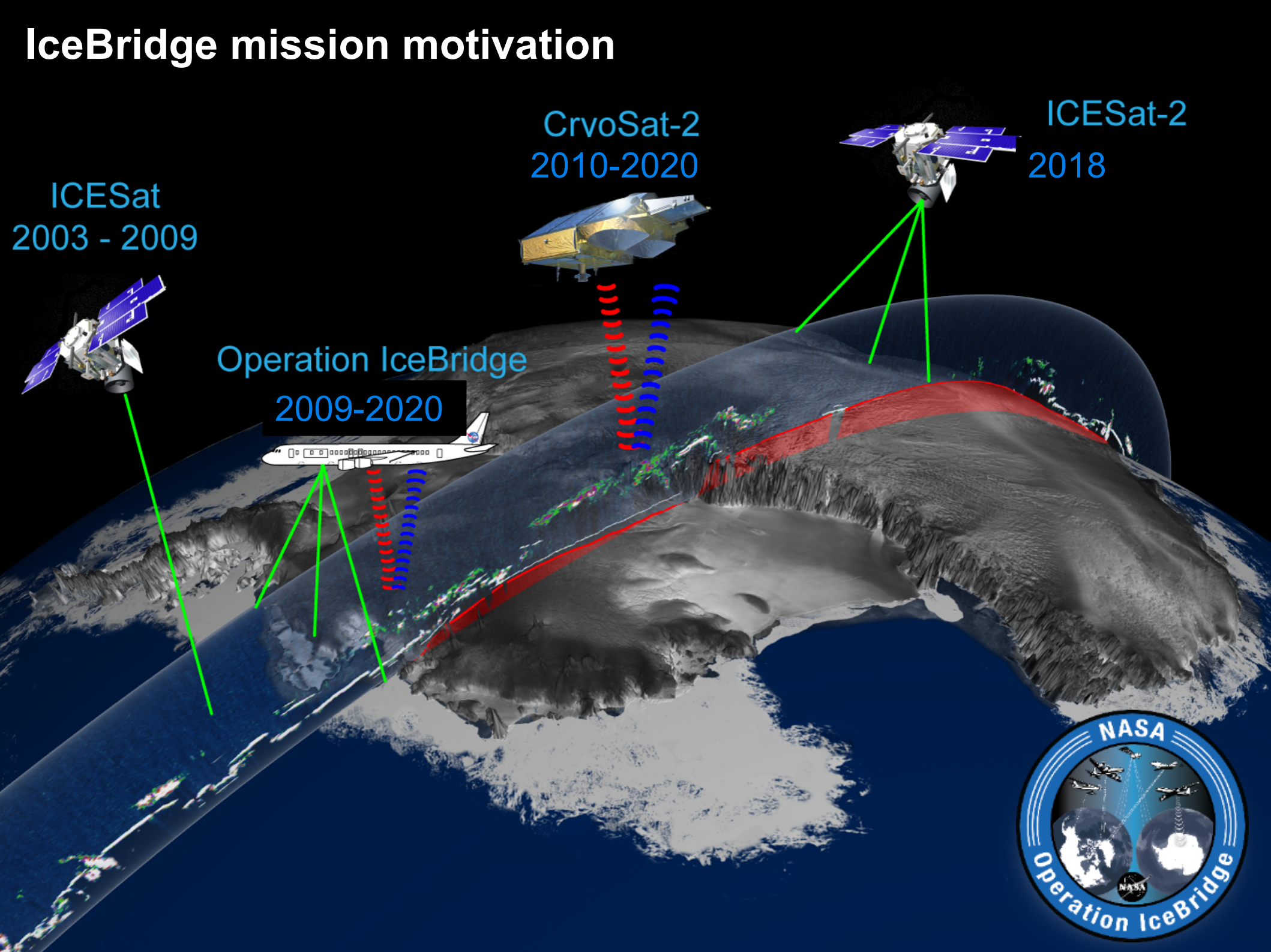


Major results from more than **450 publications**: First maps of snow thickness over Arctic sea ice; fundamental redraw of Antarctic bedmap; new insights into dynamic processes of the major ice sheets, discovery of mega-canyon in Greenland; discovery of widespread perennial aquifer in Greenland ice sheet; revelation of the destabilization of glaciers in Antarctica and Greenland; contribution of Alaskan glaciers to sea level rise

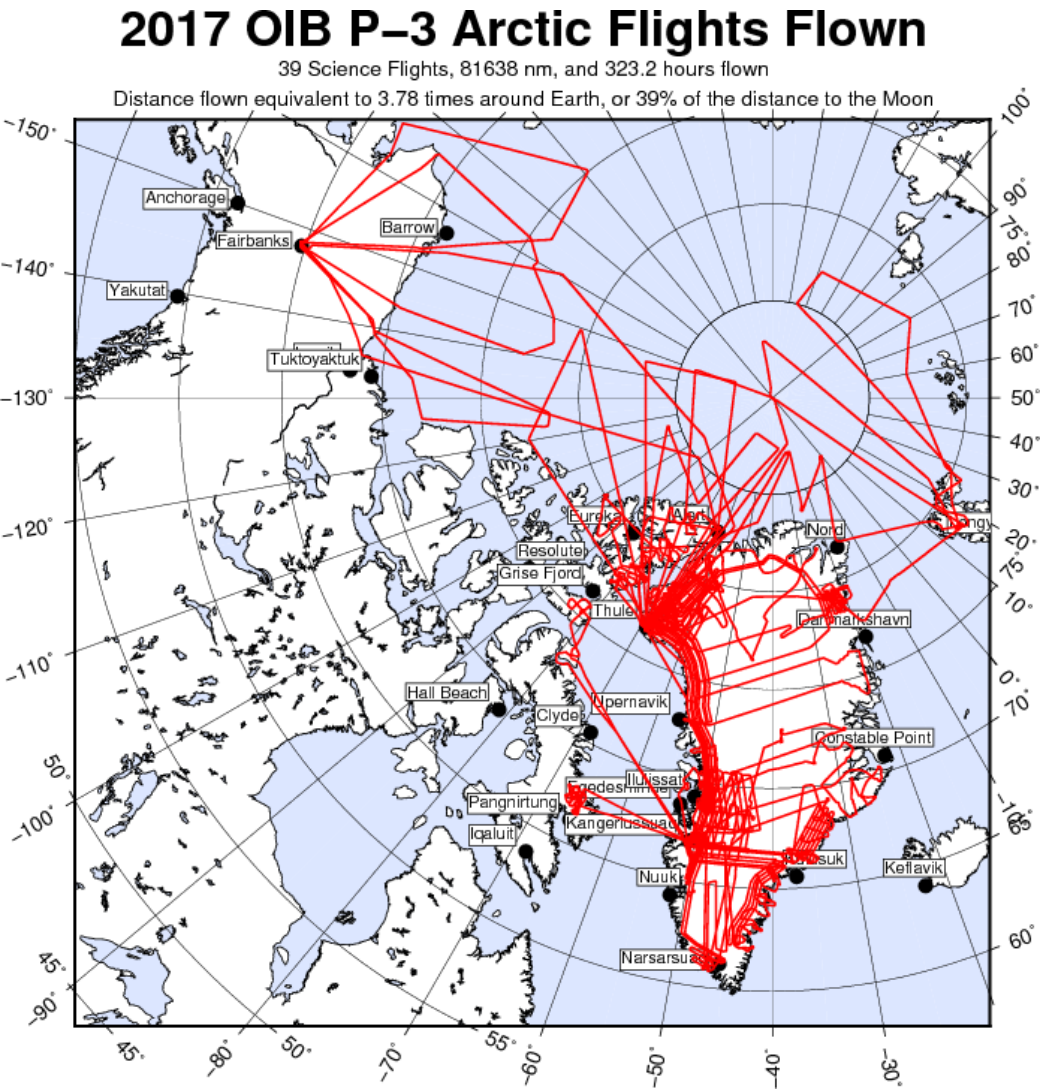
Science flights with multiple platforms (P-3B, DC-8, B200, HU-25, Basler BT-67, Single Otter, GV, C-130); more than 20 instruments



IceBridge mission motivation



2017 Arctic spring



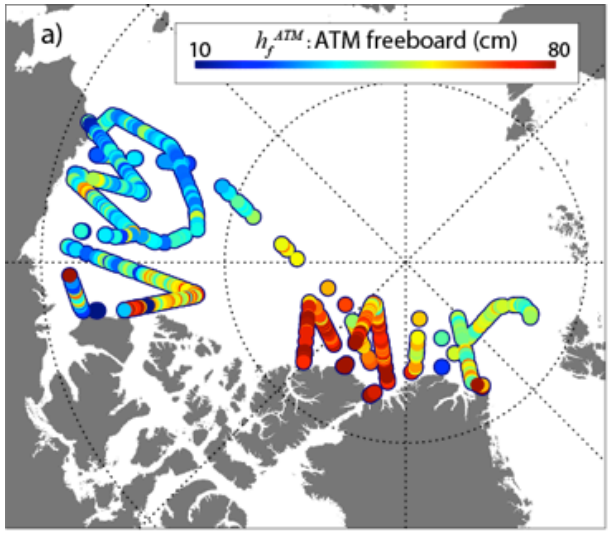
- **40 missions total: 14 sea ice, 26 land ice**
- Most geographically extensive Arctic campaign to date: coverage of new areas in the Eurasian half of the Arctic Basin with flights based out of Svalbard and into the western Chukchi Sea from Fairbanks
- **Extensive coordination with other operations**
  - **Airborne campaigns:** ESA CryoVex, NASA OMG/GLISTIN JSC-G3
  - **Satellite missions:** CryoSat-2, Sentinel-3A
  - **In-situ surveys:** ESA/CryoVEx snow measurements, 2Dgrees snow on sea ice surveys near the North Pole, USNA snow measurements near Thule, CRREL snow survey sites near Fairbanks, Summit ICESat 0412 cal/val site, GreenTrACS/FirnCover core sites, PROMICE sites, K-Transect line

Snow radar improvements

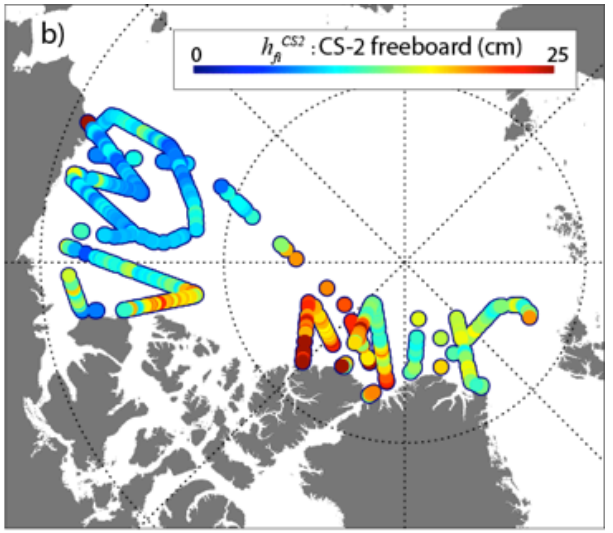
- Starting in Spring 2017 a new 2-18 GHz snow radar has been deployed on IceBridge campaigns
- Resolves thin snow cover with ~1 cm resolution
- Sub-band processing to continue heritage of previous systems: 2-8 GHz snow and 12-18 GHz Ku radars

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

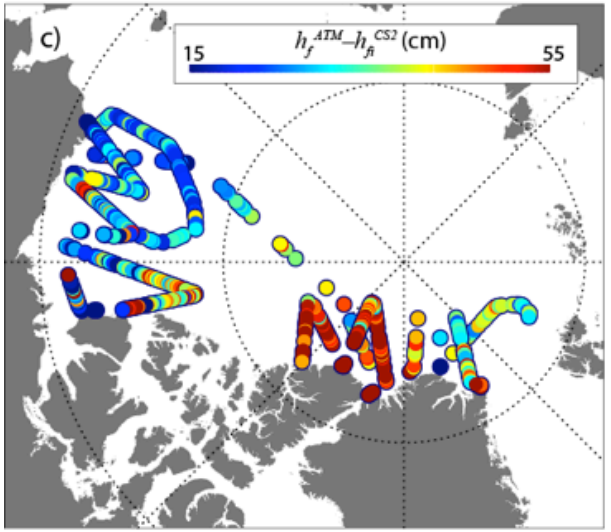
Potential basin-scale estimates of Arctic snow depth with sea ice freeboards from CryoSat-2 and ICESat-2: An exploratory analysis (Kwok and Markus)



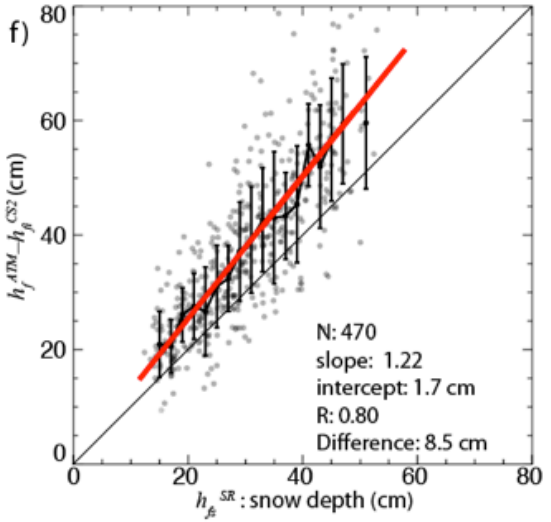
ATM Lidar freeboard (IS-2 proxy)
Reflections from top of air-snow interface



CS-2 freeboard
Scattering from snow-ice interface



Difference between the two freeboards
Gives snow depth



Regressions shows residual slope due to refractive index of snow

Background: there are no direct measurements of time-variable snow depth at the spatial scale needed for understanding surface heat flux and for derivation of sea ice thickness from altimeter freeboard.

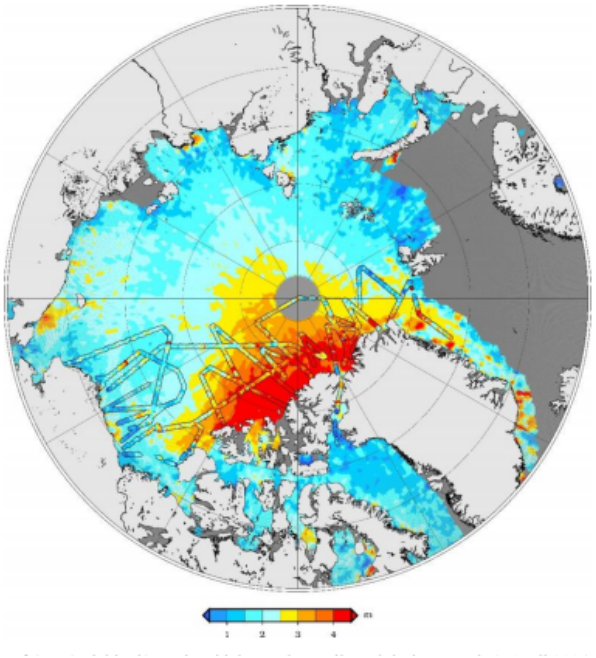
Findings: The potential of deriving snow depth estimates using differences in freeboard heights from CryoSat-2 (CS-2) and ICESat-2 (to be launched) is examined. Exploratory analysis (using OIB snow radar and ATM data) demonstrates feasibility of estimating snow depth using simulations with data from the Operation IceBridge lidar and CS-2 sea ice freeboard.

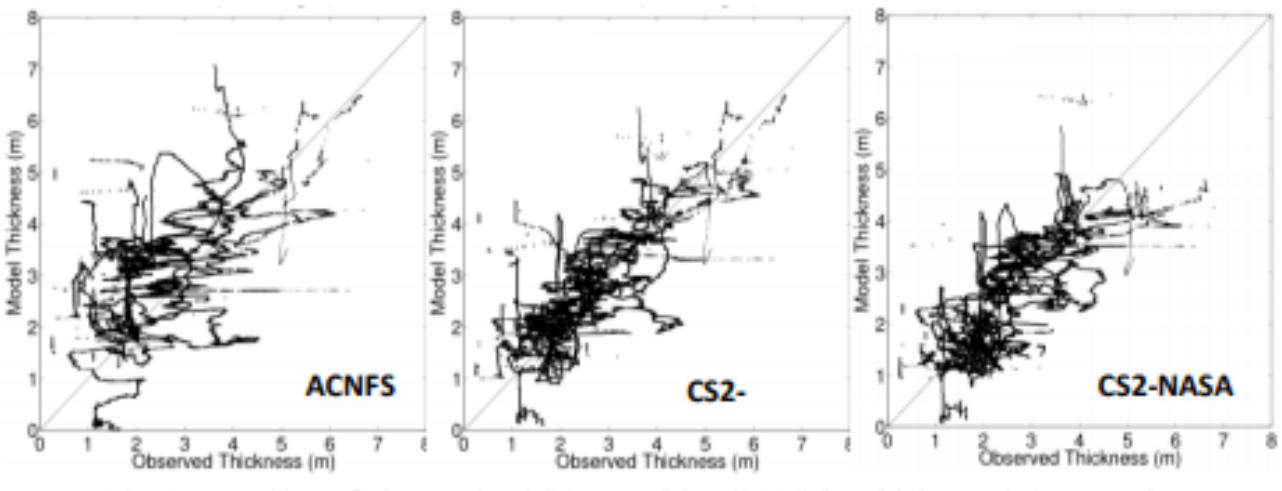
Implications: The adjustment of the orbit of CS-2 for providing more optimized overlaps between IS-2 and CS-2 is recommended.

Kwok, R. and T. Markus (2017), Potential basin-scale estimates of Arctic snow depth with sea ice freeboards from CryoSat-2 and ICESat-2: An exploratory analysis, Adv. Space. Res., in press.

OIB and CryoSat-2 data used for model initialization and cal/val

March-April 2014 CS-2 and OIB Thickness

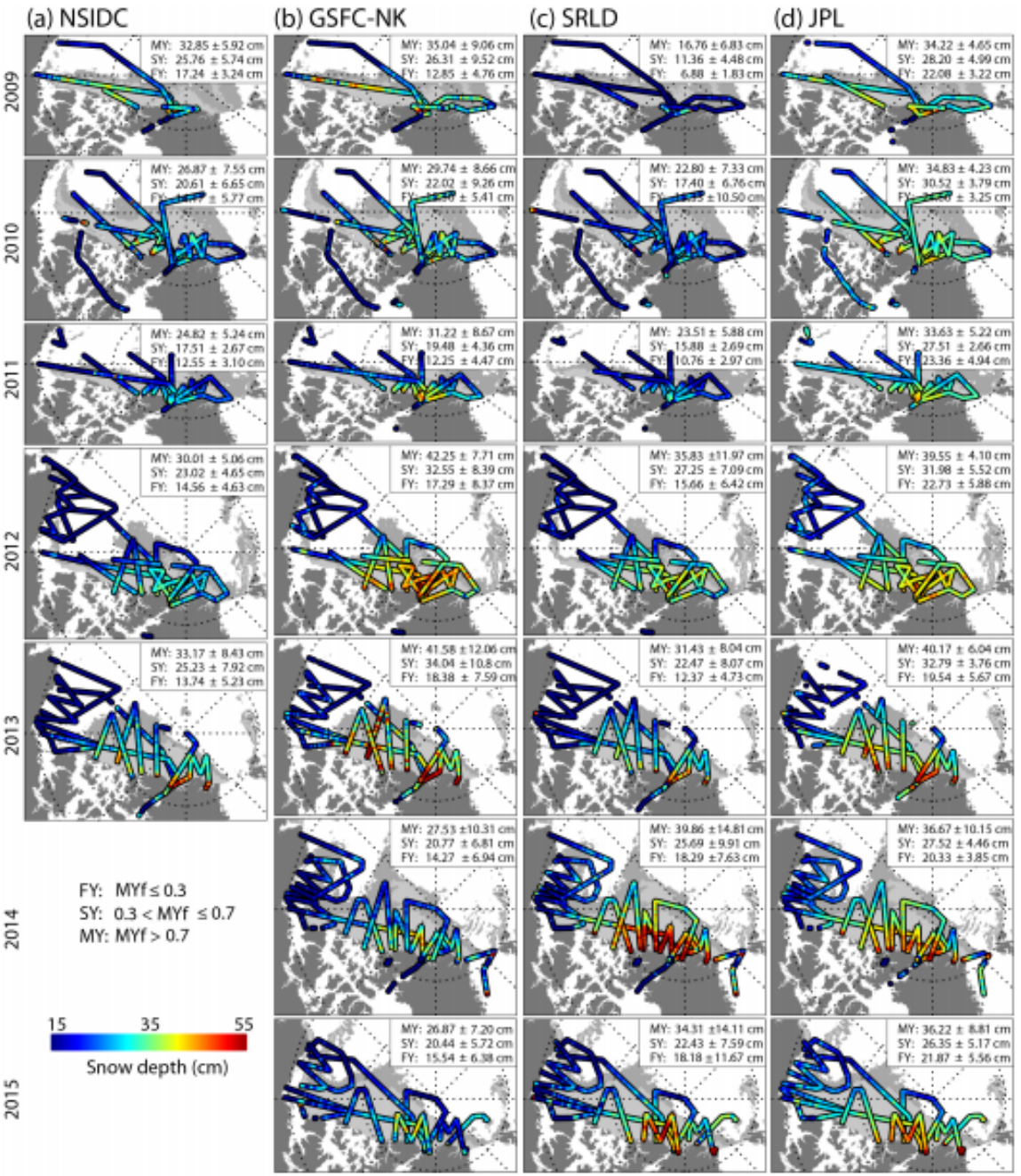




Allard et al.

- Arctic Cap Nowcast/Forecast System model initialized with sea ice thickness data
- Comparisons with independent data sets including OIB show greatly reduced biases in sea ice thickness with the initialized data
- Initialized model exhibits skill in predicting ice thickness for the initial period of up to 6 months

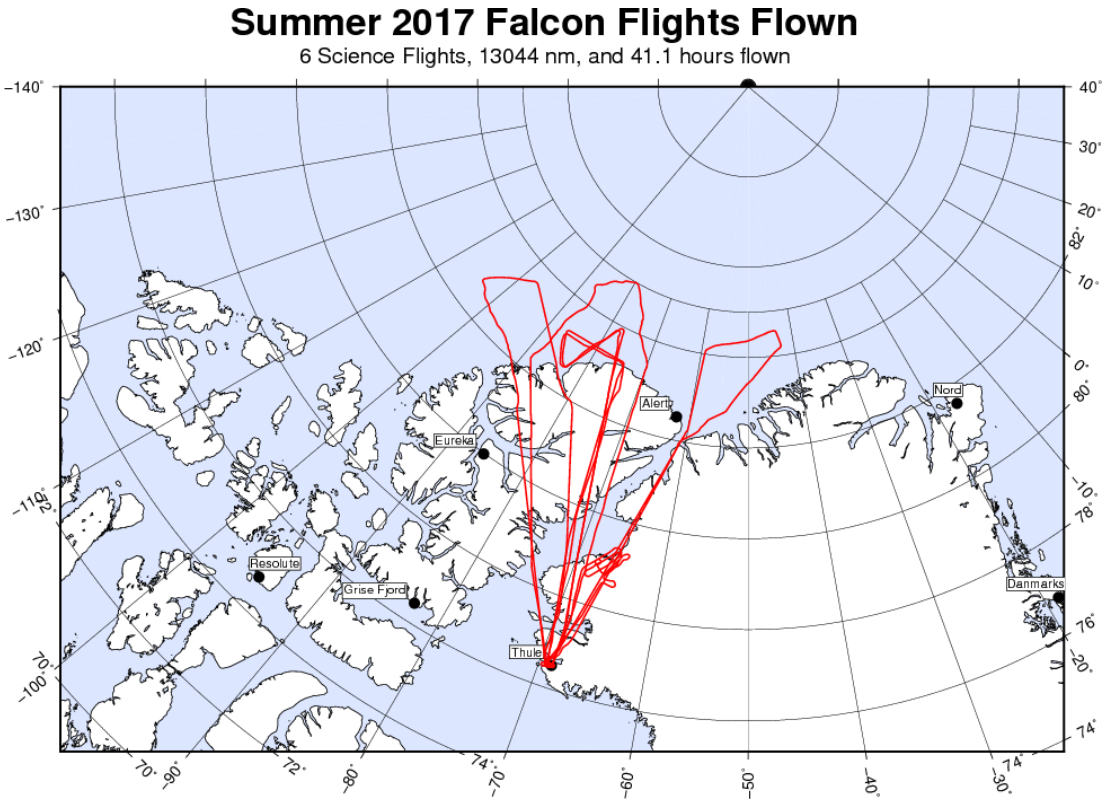
Snow depth algorithm inter-comparison project results

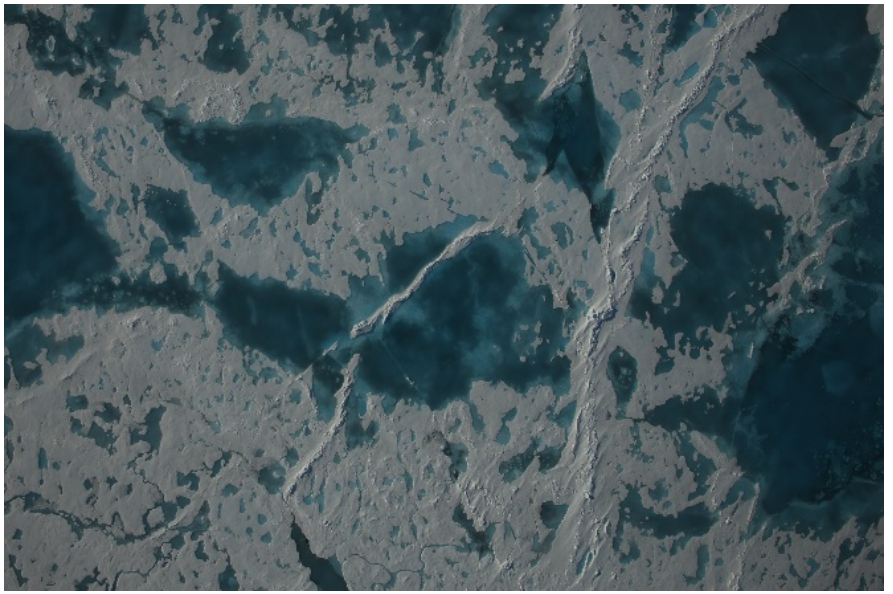


Kwok et al., 2017

- Broad inter-comparison of 5 different snow depth on sea ice retrieval algorithms to assess strengths and weaknesses of each algorithm to inform next-generation snow depth algorithm development
- Comparisons between algorithms, in-situ data, and reanalysis data
- Study highlights the need for multi-year assessments and ability of algorithms to adapt to changing radar parameters

Operation IceBridge
Arctic summer 2017, Falcon phase 1





- **6 total overflights** of sea ice surveyed from the OIB spring mission using ice-motion tracking data to assess thickness change over the melt season
- **Convergence experiment** north of Ellesmere Island to analyze the impact of ice dynamics on ice thickness change; Worldview satellite imagery collected north of Ellesmere Island
- **First summer data collection with improved high rep rate/narrow pulse ATM** for shallow sea ice melt pond depth measurements
- Greely North flight near Elesmere Island followed advected lines from coordinated flight line with CryoVEx

ATM Upgrades

Improved laser system

- **New** Northrop Grumman Hybrid Fiber Laser (replaces 3 kHz/6 ns laser)
- 10,000 Hz pulse repetition frequency and 1.3 ns pulse width at 200 µJ
  2.1 ns detected pulse width due to present PMT response
- **New** ATM T6 transceiver with increased scan-azimuth accuracy through increased mechanical rigidity and improved scan-angle measurements. Incorporates dichroic optics.
- **New** ATM data collection system with 4 GHz digitization rate at 10,000 Hz laser PRF
- Improvements in range precision (ground test data) to better than 1 cm

Baseline system for ICESat-2 cal/val

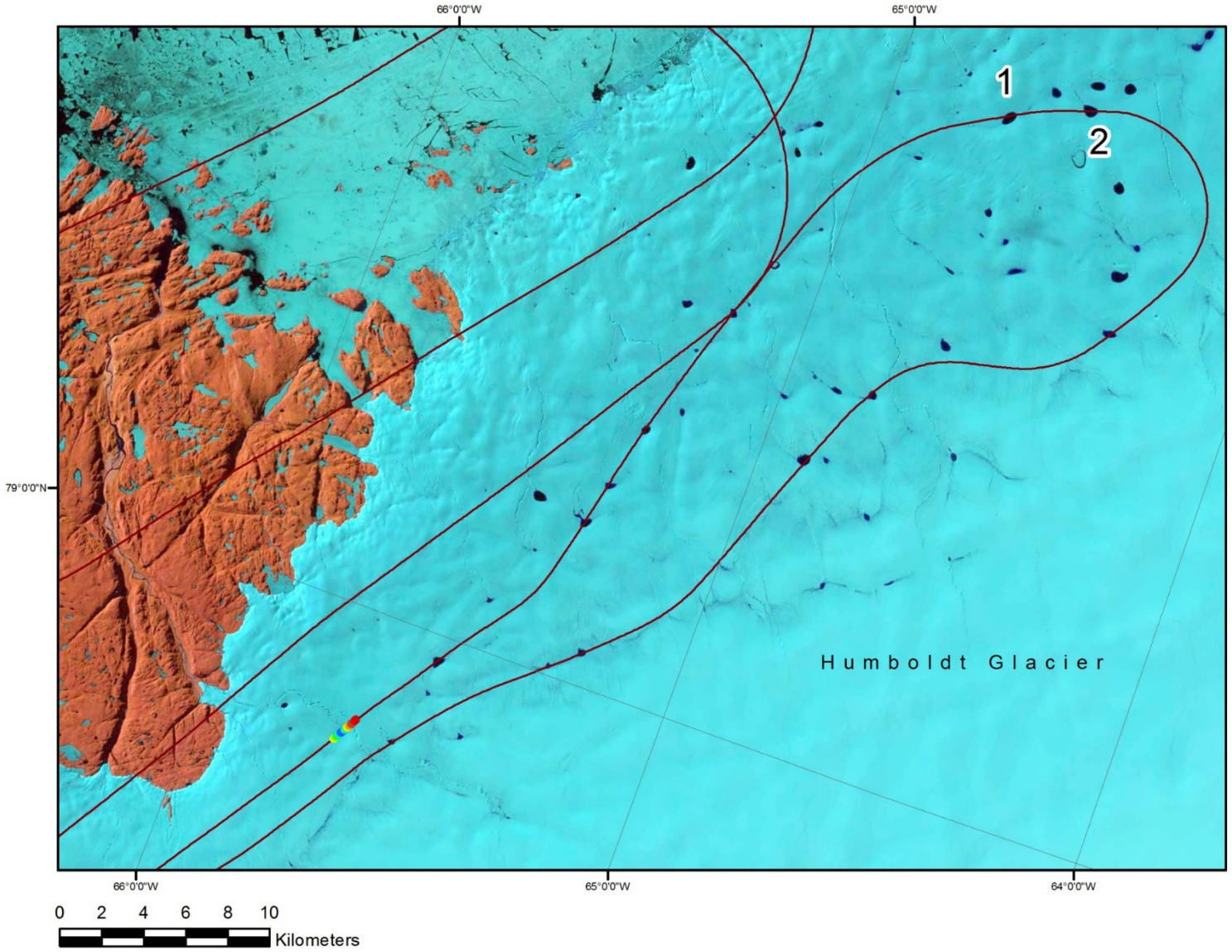
- Delivery of a 10,000 Hz/1.3 ns Hybrid Fiber Laser with dual-wavelength capability (532 & 1064 nm) in Fall 2017
- Experimental deployment on P-3 in Antarctic 2017 campaign
- Dual purpose:
  - Operational backup for current 3 kHz lasers for the remainder of IceBridge
  - Co-located green/near infrared capability to study differential penetration for potential ICESat-2 cal/val

Waveform data availability

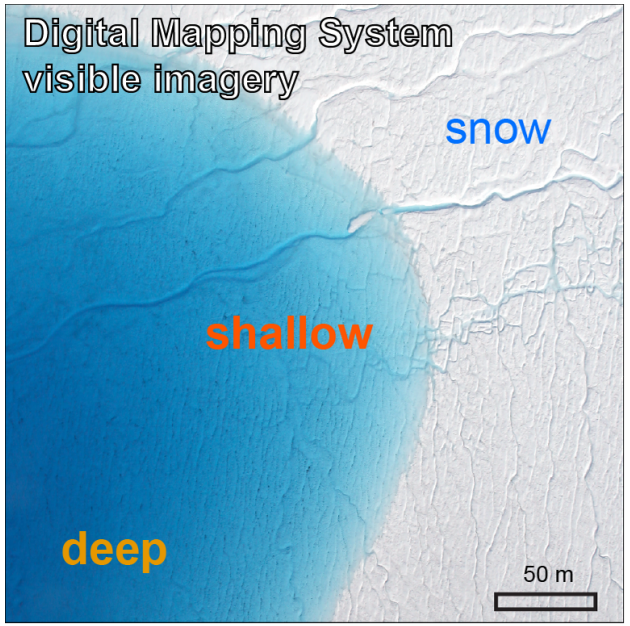
- New waveform data to be provided next year with new HDF5 data products

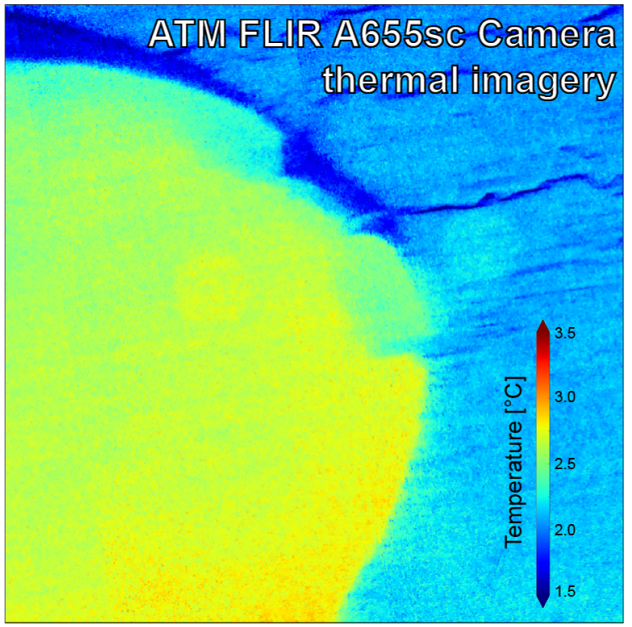
Estimating the depth of supraglacial lakes

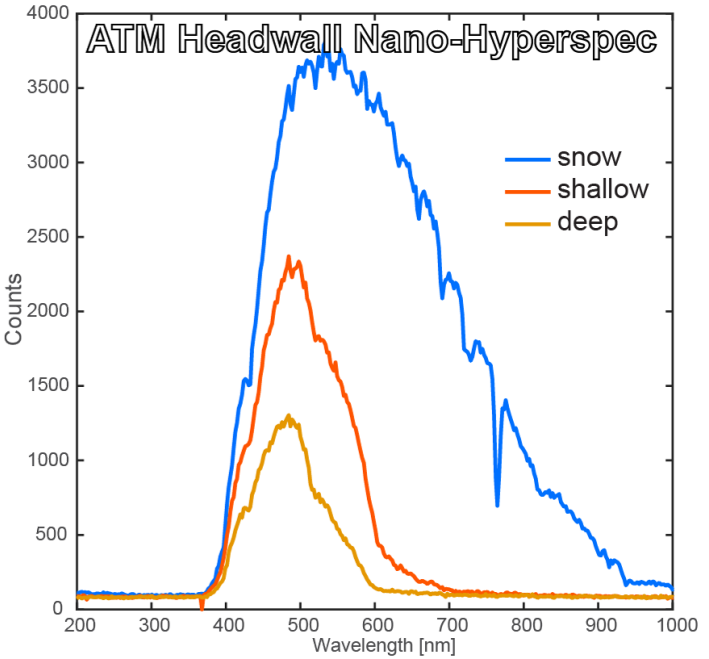
- Data from recent Arctic campaign - July 2017
- New 10 kHz/1.3 ns laser
- Background image: Landsat-8 OLI from day of flight



Multi-instrument observations of supraglacial lakes

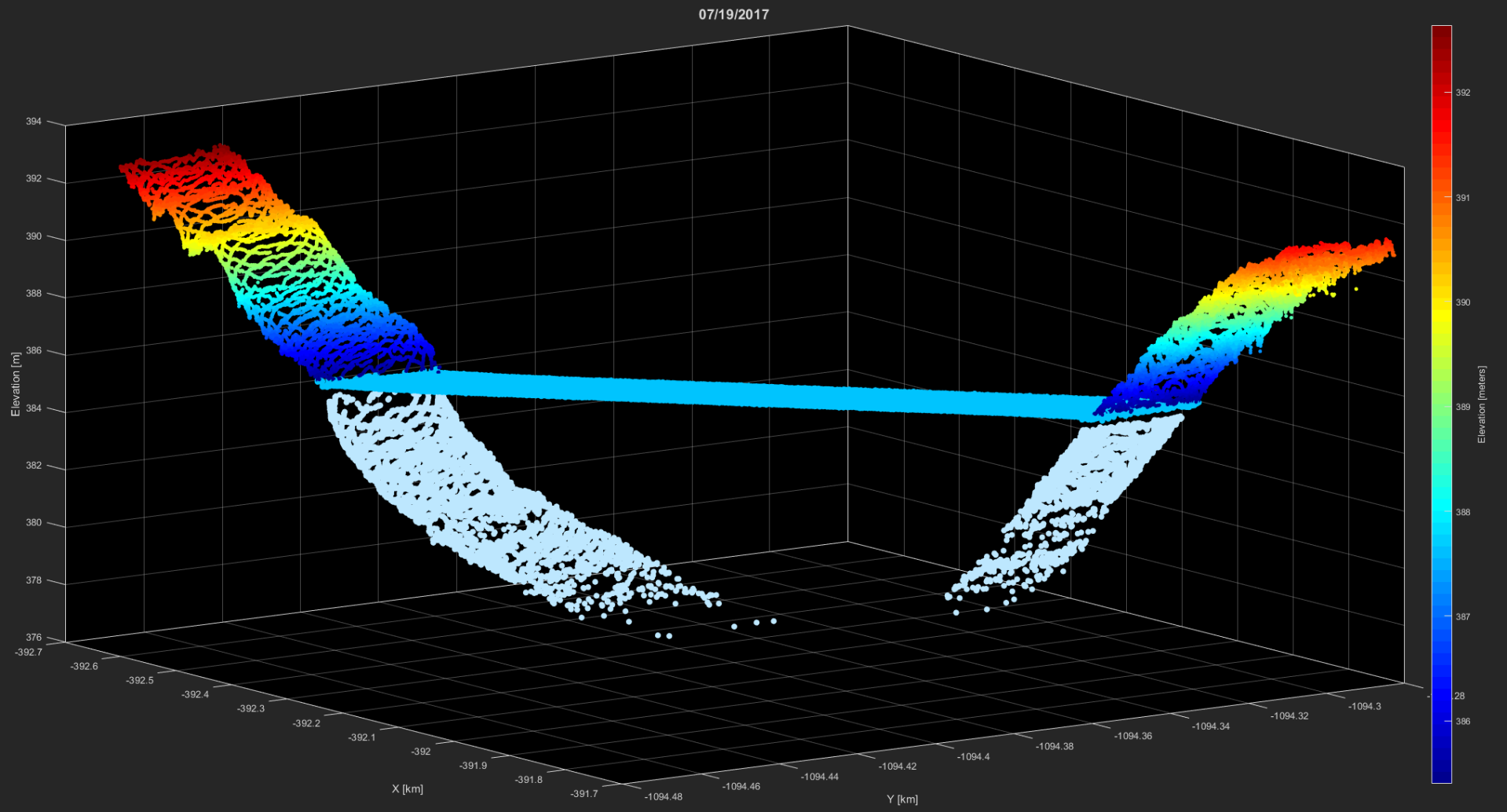






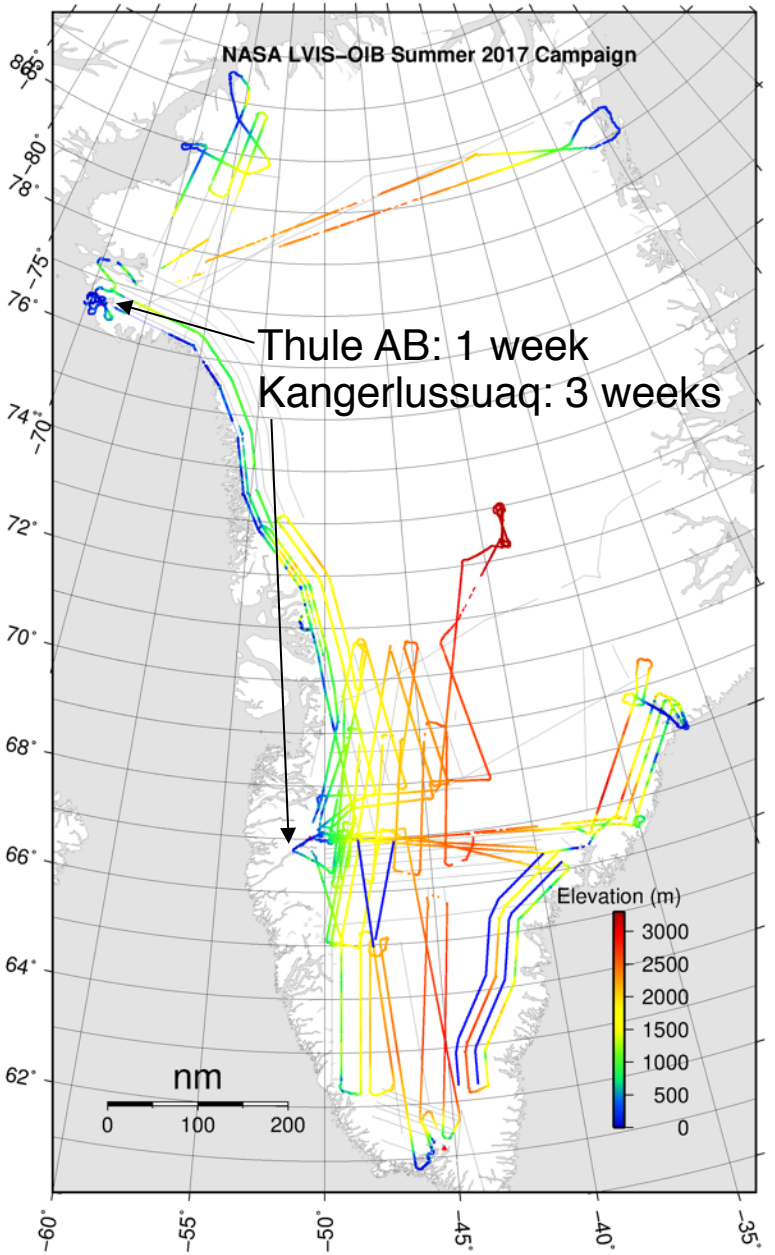
- **<u>FLIR A655sc Thermal Imaging Camera (middle panel)</u>**
  The camera records 16-bit 640 × 480 pixel images with over 300,000 accurate temperature measurements in every image. Pixel size at 1,500 ft AGL is 0.6 × 0.6 m. Data from the camera can become a new tool for studying physical processes at high spatial resolution over entire ocean basins/ice sheets.
- **Headwall hyperspectral imager (right panel)**
  The Headwall Nano-Hyperspec is an integrated hyperspectral sensor covering the VNIR (400–1000 nm) spectral range with 270 spectral bands at 2.2 nm resolution. The system is currently deployed for the first time in an experimental mode. Preliminary results show how spectra can be used to calibrate spaceborne depth measurements over supraglacial lakes.

ATM T6 green-light penetration of a supraglacial lake



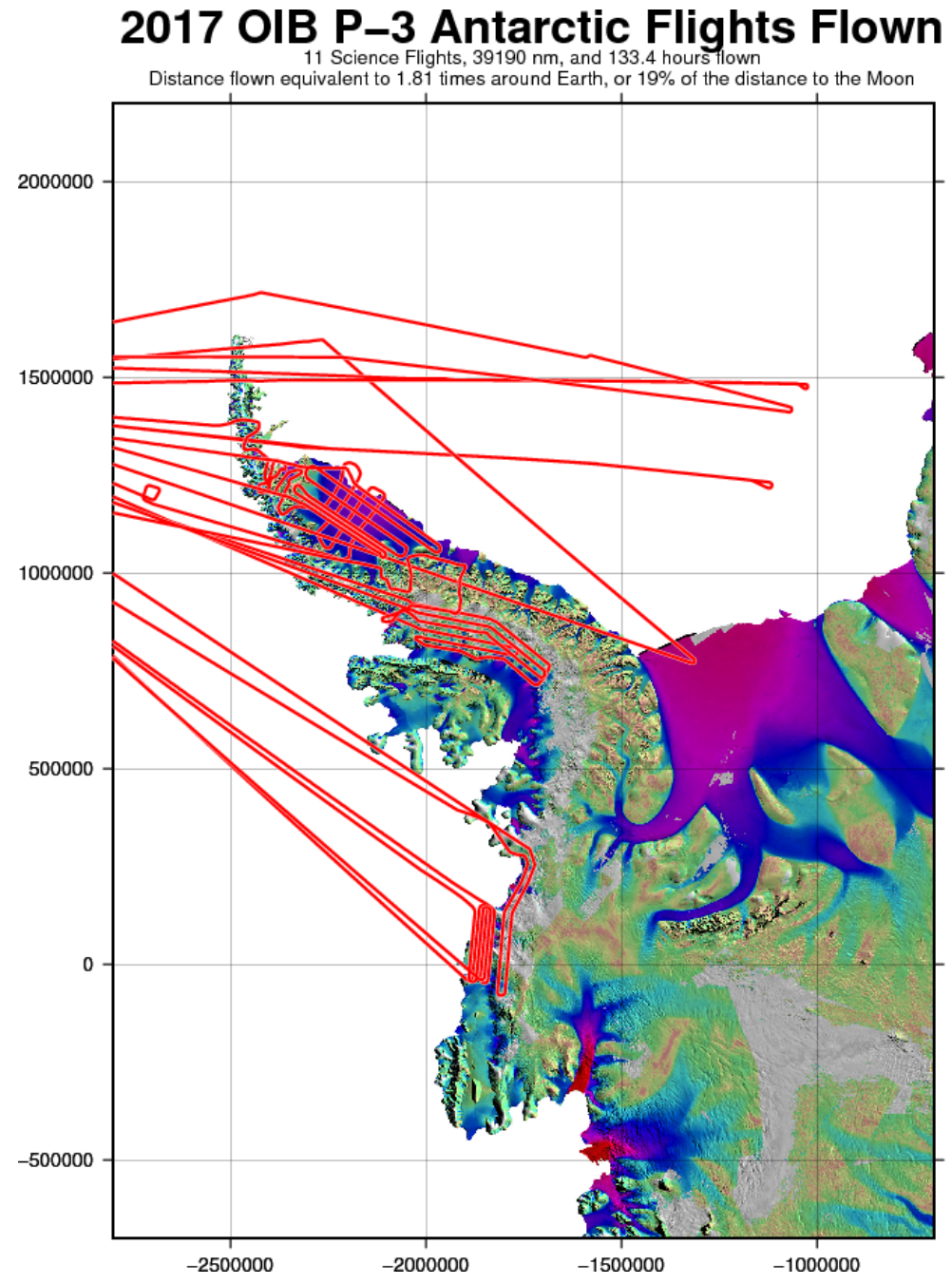
NASA Operation IceBridge
2017 Arctic summer #2: B-200T / LVIS

- **Objective:** Survey surface elevation of the Greenland Ice Sheet after the end of the summer melt season, to measure total ice melted after this year's spring campaign
- **Platform:** Dynamic Aviation B-200T King Air @ 28,000'; 3 maintenance down days
- **Instruments:** LVIS facility instrument (laser altimeter), nadir camera (imagery)
- **Flights:** 15 flights btwn. 08/25/17–09/20/17 (incl. calibration & Thule–Kanger. transit), exceeding baseline (13) and surveying 18/20 planned missions; 6 weather down days; 87.5 total science hours
- **Outcome:** Very broad survey of surface elevation across Greenland's ablation, percolation and dry snow zones; well-timed relative to end-of-summer freeze-up
- **Outreach:** Mid-campaign press release, one Image of the Day; daily social media



LVIS quick-look surface elevation across Greenland

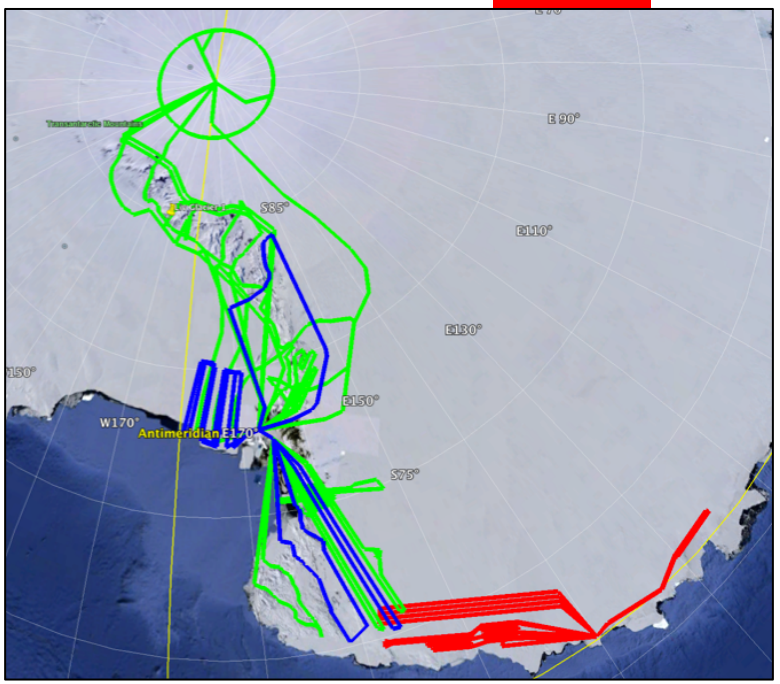
Operation IceBridge 2017 Antarctic spring P-3 campaign summary



- **11 total science flights** around the Antarctic Peninsula area and Weddell Sea
  - **7 land ice science flights**, all of which were baseline and high priority missions
  - **4 sea ice flights** with extensive coverage of the Weddell Sea
- Engineering test of new **ATM T7 dual-color** laser
- **New gravity surveys** of the Larsen C and Venable Ice Shelves
- **Two coordinated TanDEM-X underflights** spacecraft as part of the OTASC experiment in collaboration with the German Aerospace Center (DLR)
- Unable to attain CryoSat-2 underflights due to challenging weather in the Weddell Sea

OIB Antarctica 2017 Basler campaign

done | not done | Dumont d'Urville



done | not done

Priority	Name
Baseline	Hamilton Line 1
Baseline	Hamilton Line 2
High	TAM East
High	TAM Gate East Low
High	ITASE 67
High	TAM Grounding Line West
High	David A
High	Victoria D
High	George V Gap B
High	Cook A
Medium	TAM Central
Medium	Ross flowlines
Medium	TAM West
Medium	TAM West Flux
Medium	Cape Adare A
Medium	Victoria A
Medium	Matusevich A
Medium	Ninnis A
Medium	Dibble-Frost A
Low	TAM Gate East High
Low	Northwest Ross A
Low	Northwest Ross B
Low	TAM Gate West
Low	David B
Low	Victoria B
Low	Victoria C
Low	George V Gap A

Dumont d'Urville

- **McMurdo-based campaign** with UAF Riegl lidar and CReSIS UWB MCoRDS depth sounding radar (belly array only)
- Originally planned 1 week based at South Pole, which we nixed in favor of 2 longer days with refuels there; 2 Shackleton Glacier Camp refuels
- Missions were a mixture of new missions as well as lines flown previously in 2013
- Highest priority lines around the 88ºS pole hole and Transantarctic mountains
- **16 total science missions** for this campaign in 108 science flight hours, exceeding our original baseline goal
- **2/2 baseline missions**; **6/6** possible high-priority missions (not including DDU); **5/6** possible medium-priority missions); **3/6** low-priority missions

Validating long-duration satellite altimetry with OIB

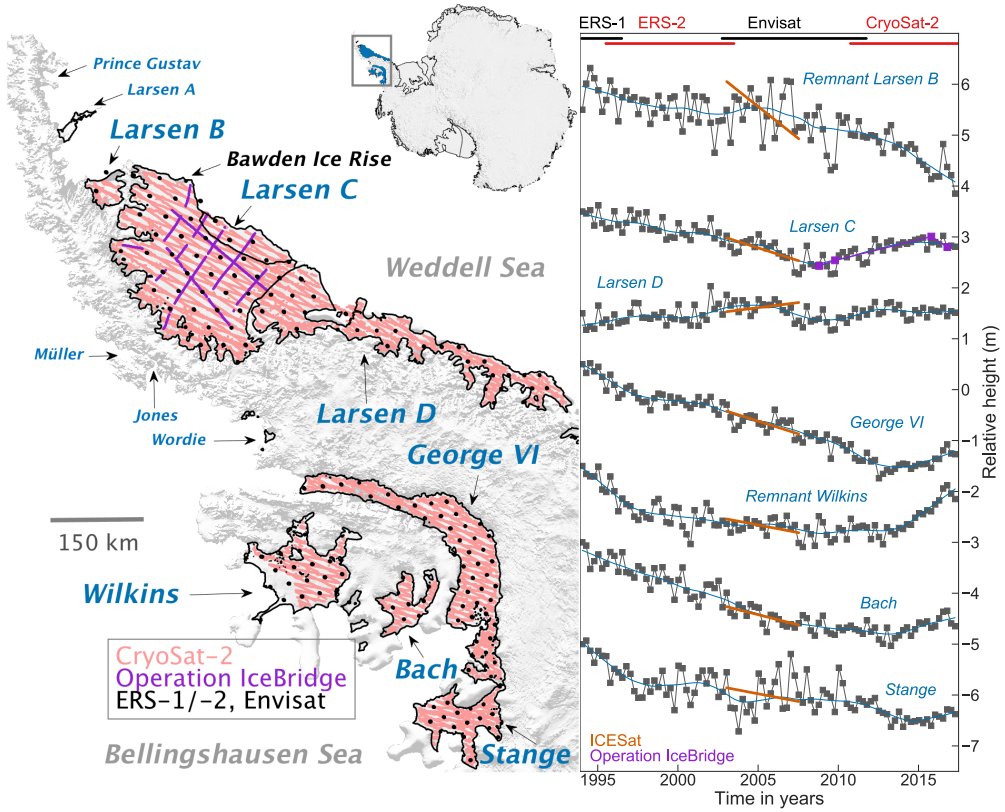


Figure 1: *Adusumilli et al.* (in review) used 2008, 2009, 2015, 2016 laser altimetry surveys (LVIS, ATM) over Larsen C Ice Shelf to confirm a multi-year thickening between 2008 and 2016 due to reduced basal melting and thickening of the firn column. The agreement between satellite radar and OIB laser altimetry provides confidence that the satellite observations capture true height-changes, not changes in radar reflecting horizon.

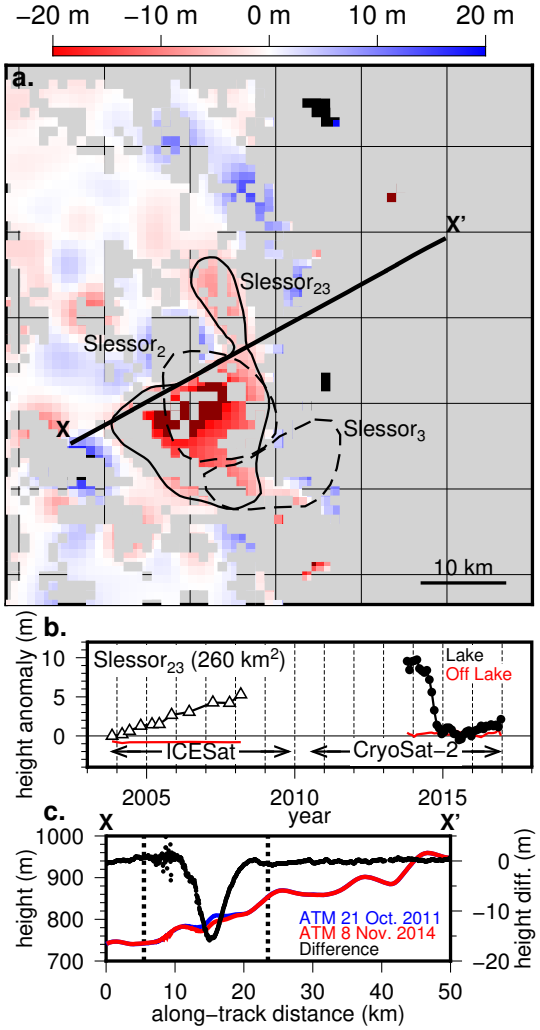
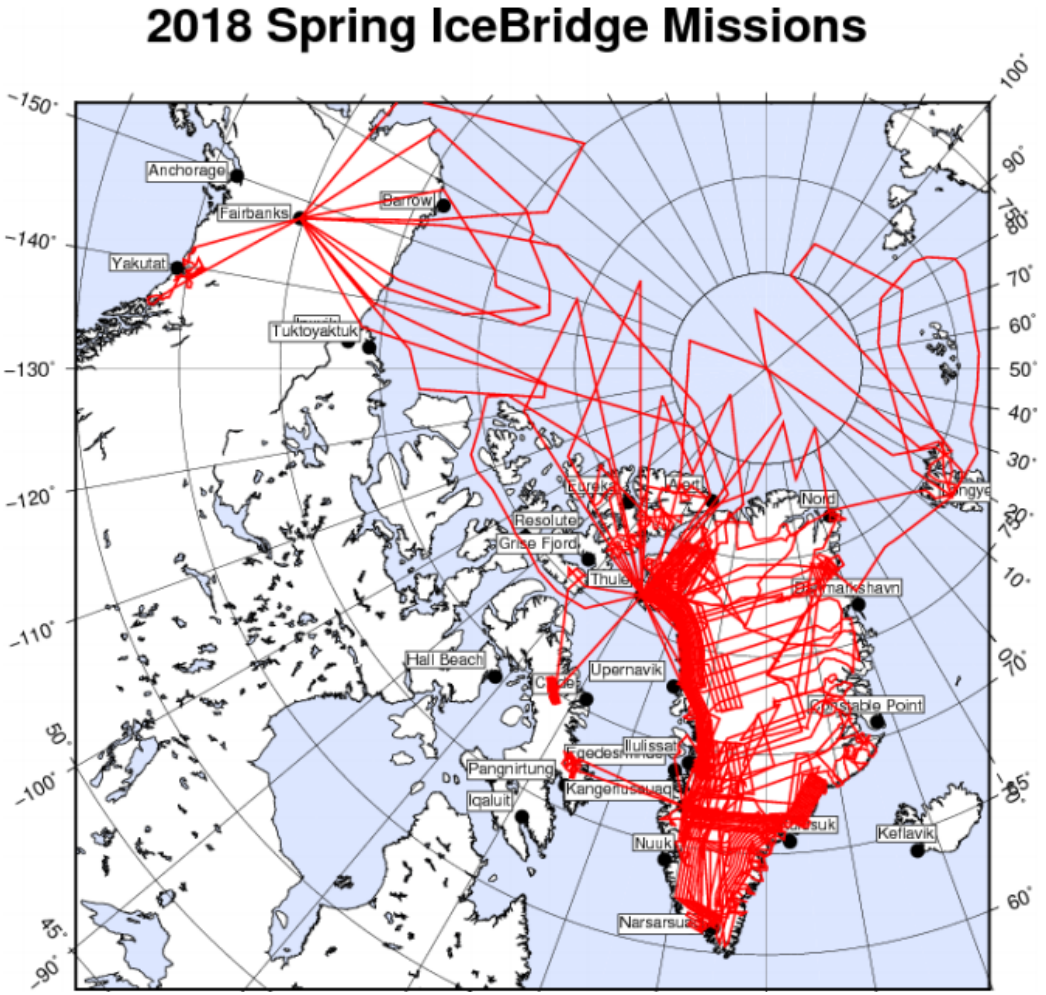


Figure 2: *Siegfried and Fricker* (in press) used ATM surveys of 2011 and 2014 over Slessor Glacier, East Antarctica to validate a combined ICESat-CryoSat-2 time series of a large subglacial lake drainage event. OIB laser altimetry showed a peak surface-height anomaly of > 15 m. The 2011 OIB survey occurred during a gap in satellite altimetry data (early 2009 to late 2014), revealing that the subglacial lake likely remained at high-stand for multiple years and demonstrating the ability of OIB data to "bridge" gaps between satellite missions over dynamic ice-sheet features.

NASA P-3 for Arctic 2018

- ~19 March – 27 April
- Mission start delays may prevent Svalbard flights
- Planned underflights of CryoSat-2 and Sentinel-3A
- Instrument suite:
  - ATM wide and narrow scan lidars (T6 and T7), dual color laser
  - 180–210 MHz MCoRDS
  - UHF accumulation radar
  - 2–18 GHz UWB snow/Ku radars
  - DMS (sea ice only)
  - CAMBOT (whole campaign)
  - FLIR
  - Hyperspectral imaging spectrometer



2018 Arctic spring

Date / window	Main event	Other events
5-19 March	Wallops–Thule	Currently unknown deployment date
9–16 March	Svalbard?	
18–28 March	Fairbanks time window	ICEX ends March 22
March 28 – 6 April	Thule	NBC TODAY visit, tentatively April 4–6
7–30 April	Kangerlussuaq	TBD but multiple possible guest video crews / writers

IceBridge master schedule

Last updated: 8 Dec. 2017

Campaign	2015	2016	2017	2018	2019	2020
Arctic spring ~March-May	NASA C-130	NOAA P-3	NASA P-3	NASA P-3	NASA P-3	NASA P-3
Alaska ~May & August	UAF DHC-3	UAF DHC-3	UAF DHC-3	UAF DHC-3	UAF DHC-3	
Arctic summer July-September	NASA Falcon AK / Greenland	NASA Falcon AK / Greenland	**LaRC Falcon** (ATM/DMS) **Dynamic B200** (LVIS)	TBD	TBD	
Antarctic spring ~October-November	NCAR G-V Punta Arenas	NASA DC-8 Punta Arenas	**NASA P-3** Ushuaia **US Basler** Antarctica	NASA DC-8 Punta Arenas	FY20 ½ Year	

Current ICESat-2 launch window

2018 Overview

- 6-7 week Arctic campaign from March to April with updated instrument suite
- No summer campaign scheduled as of yet
- DC-8 campaign out of Punta Arenas for Antarctic spring season, potential delayed deployment to better coordinate with ICESat-2 launch in September 2018