Arctic Change Workshop

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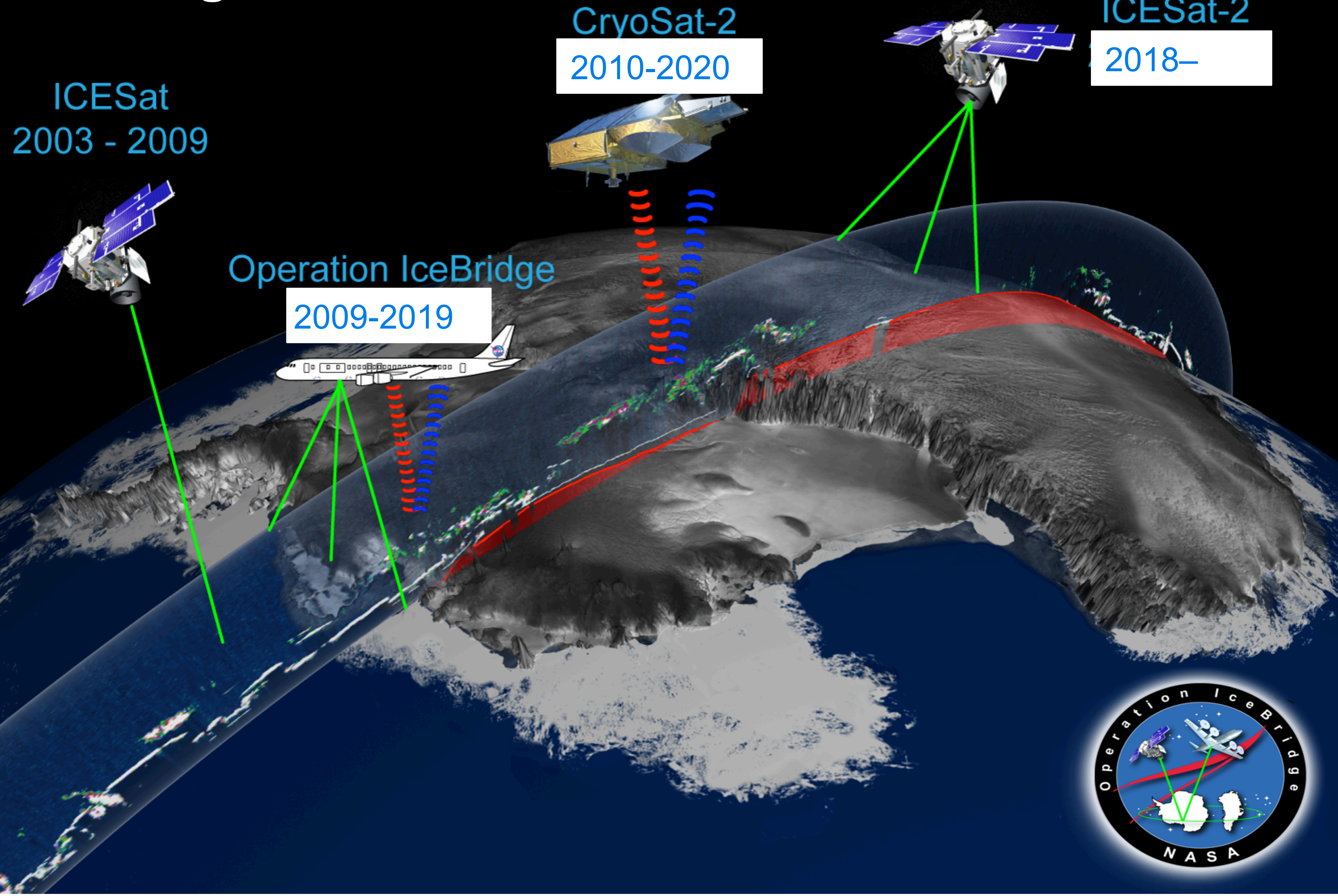
Photo: M. Studinger

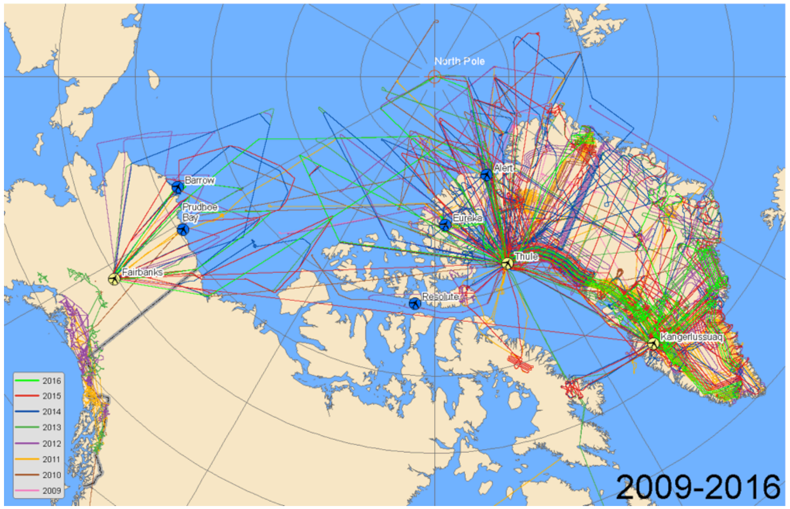
IceBridge mission motivation

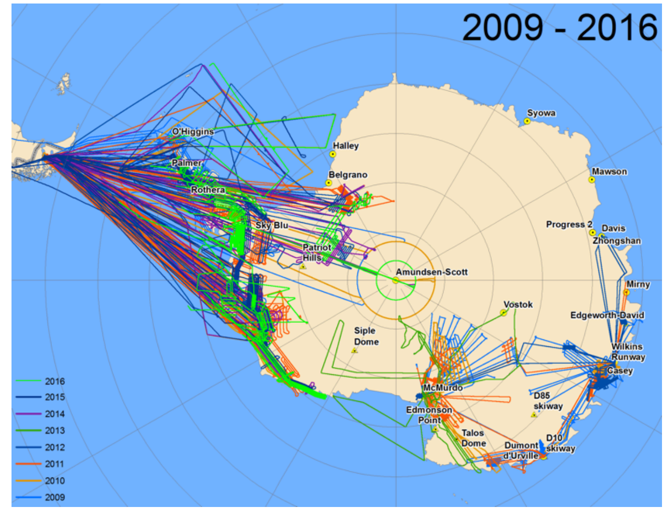


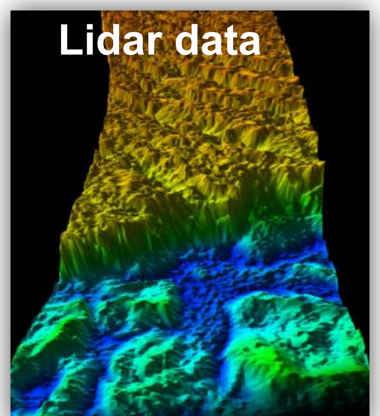
Mission Goals

- use airborne altimetry measurements over the ice sheets and sea ice to bridge the gap between ICESat and ICESat-2
- link the measurements made by ICESat, ICESat-2, and CryoSat-2 to allow accurate comparison and production of a long-term, ice altimetry record
- use airborne altimetry to monitor key, rapidly changing areas of ice in the Arctic and Antarctic to maintain a long term observation record
- collect other remotely sensed data to improve predictive models of sea level rise and sea ice cover: ice thickness, etc.

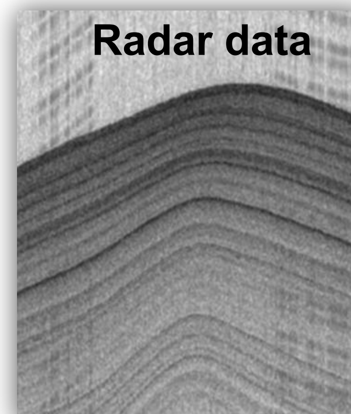
Operation IceBridge overview





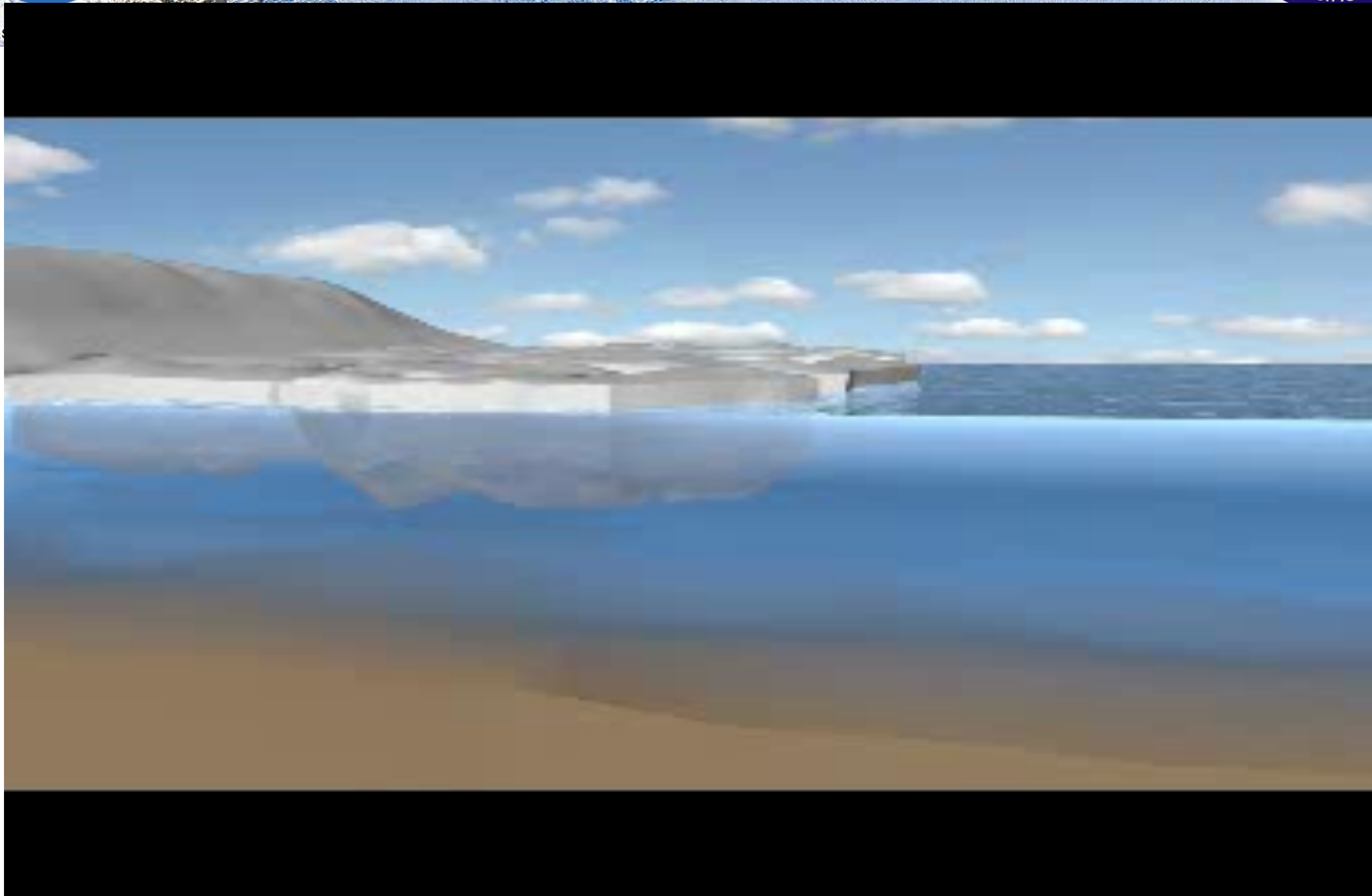


- **Ice surface elevation data** over ice sheets, glaciers, and sea ice to bridge the gap between **ICESat** and **ICESat-2** missions
- **New measurements critical to ice-sheet models**: bed topography, grounding line position, ice and snow thickness
- Science flights with **multiple platforms** (P-3B, DC-8, B200, HU-25, Basler BT-67, Single Otter, GV, C-130); **20** instruments and counting…



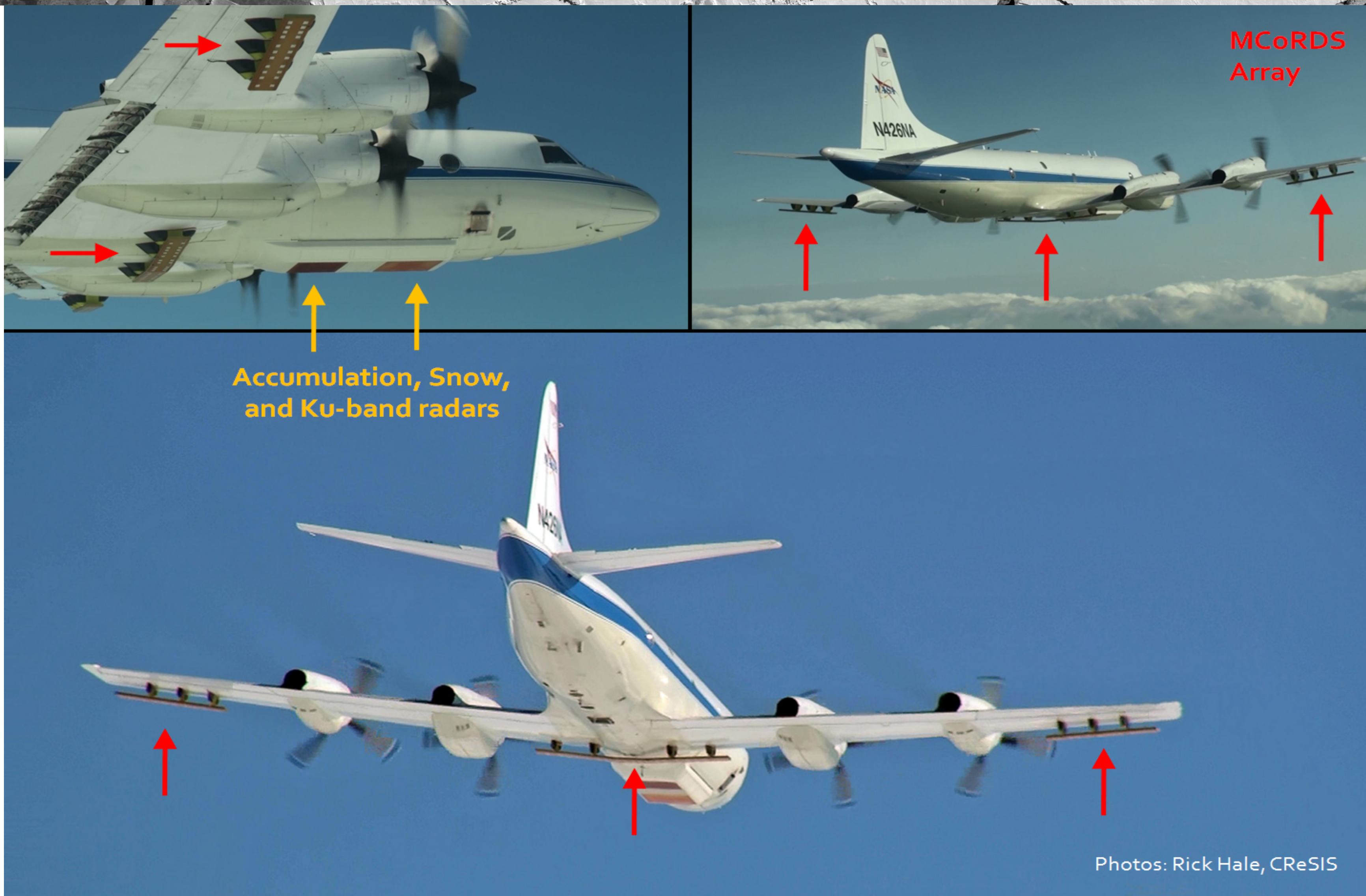
Operation IceBridge

Design: M.



IceBridge instruments

Photo: DMS



Photos: Rick Hale, CReSIS

IceBridge instruments

Photo: M. Studinger


Photo: M. Studinger


Photo: M. Studinger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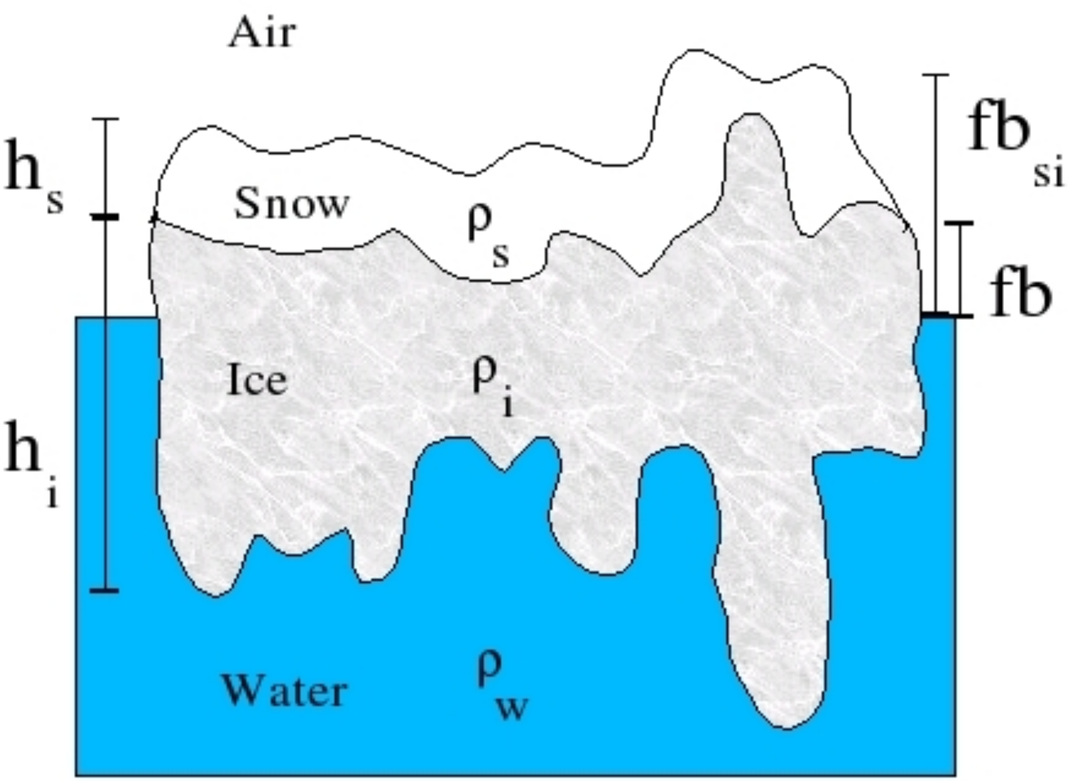
IceBridge instruments

Instrument	Operator	Purpose
ATM	NASA – WFF	laser altimeter 1,500 ft AGL (ice surface elevation)
DMS	NASA – ARC	digital photogrammetry (DEM generation)
MCoRDS	KU CReSIS	radar (ice thickness of ice sheets and outlet glaciers)
Snow radar	KU CReSIS	snow thickness over sea ice and near surface layers
Accumulation	KU CReSIS	near surface layers in ice sheets, snow accumulation
Gravimeter	LDEO	water depth beneath floating ice tongues, geoid
FLIR	NASA-WFF	IR camera (surface temperature)

Sea ice thickness retrieval concept

Photo: M. Studinger



Laser and radar altimetry are used to find the freeboard

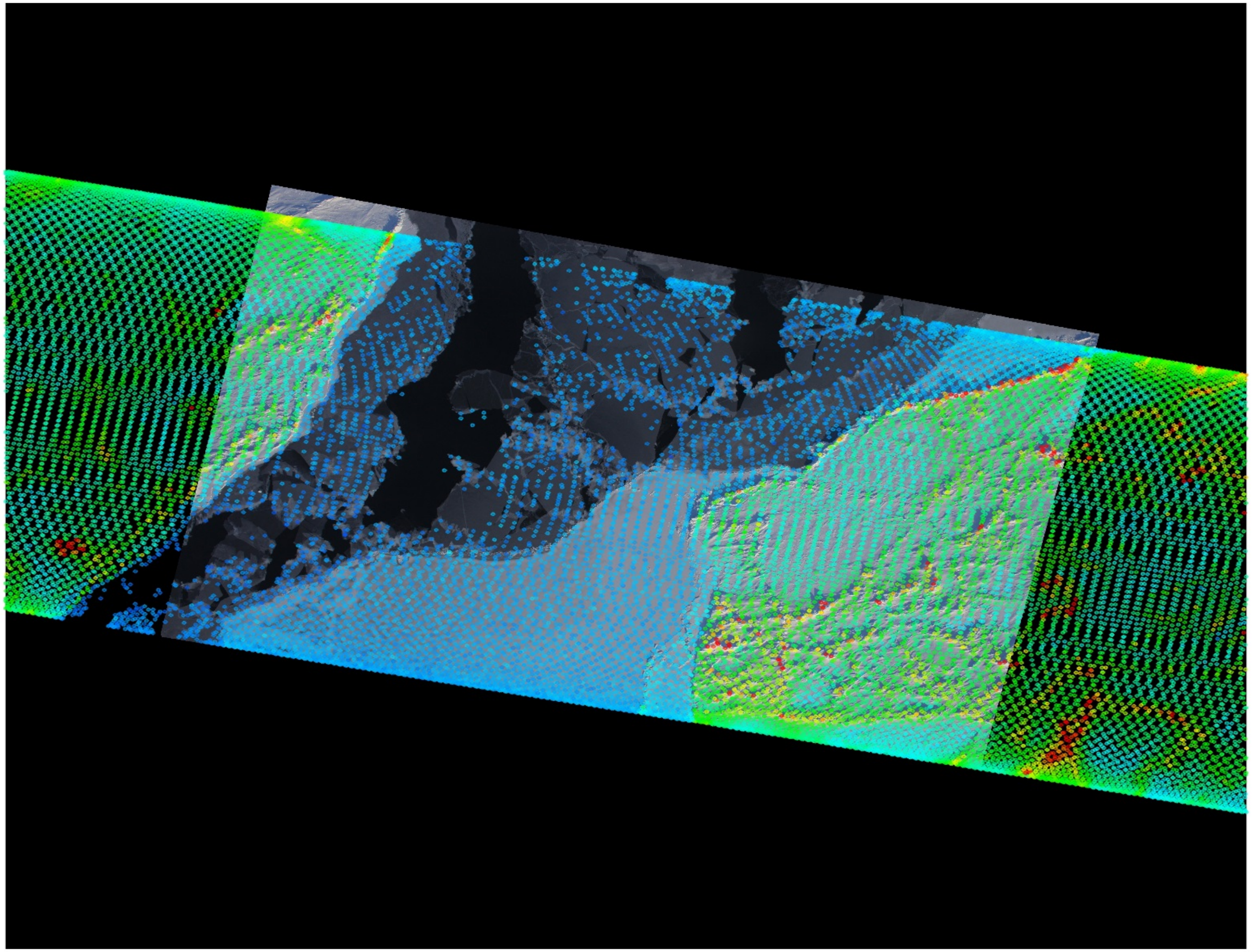
Archimedes principle: assuming hydrostatic balance the buoyant force from the displaced water equals the weight of the snow and ice column

$$\rho_s h_s + \rho_i h_i = \rho_w h_i - \rho_w fb$$

Rearranging gives ice thickness:

$$h_i = \frac{\rho_s - \rho_w}{\rho_w - \rho_i} h_s + \frac{\rho_w}{\rho_w - \rho_i} fb_{si}$$

Airborne laser altimetry mapping of sea ice



ATM Upgrades

Spring 2017 Deployment to the Arctic

- **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.
- ATM T6 single wavelength was onboard for Fall 2016 Antarctic deployment
- **New** ATM data collection system with 4 GHz digitization rate at 10,000 Hz laser PRF
- Improvements in range precision (ground test data)

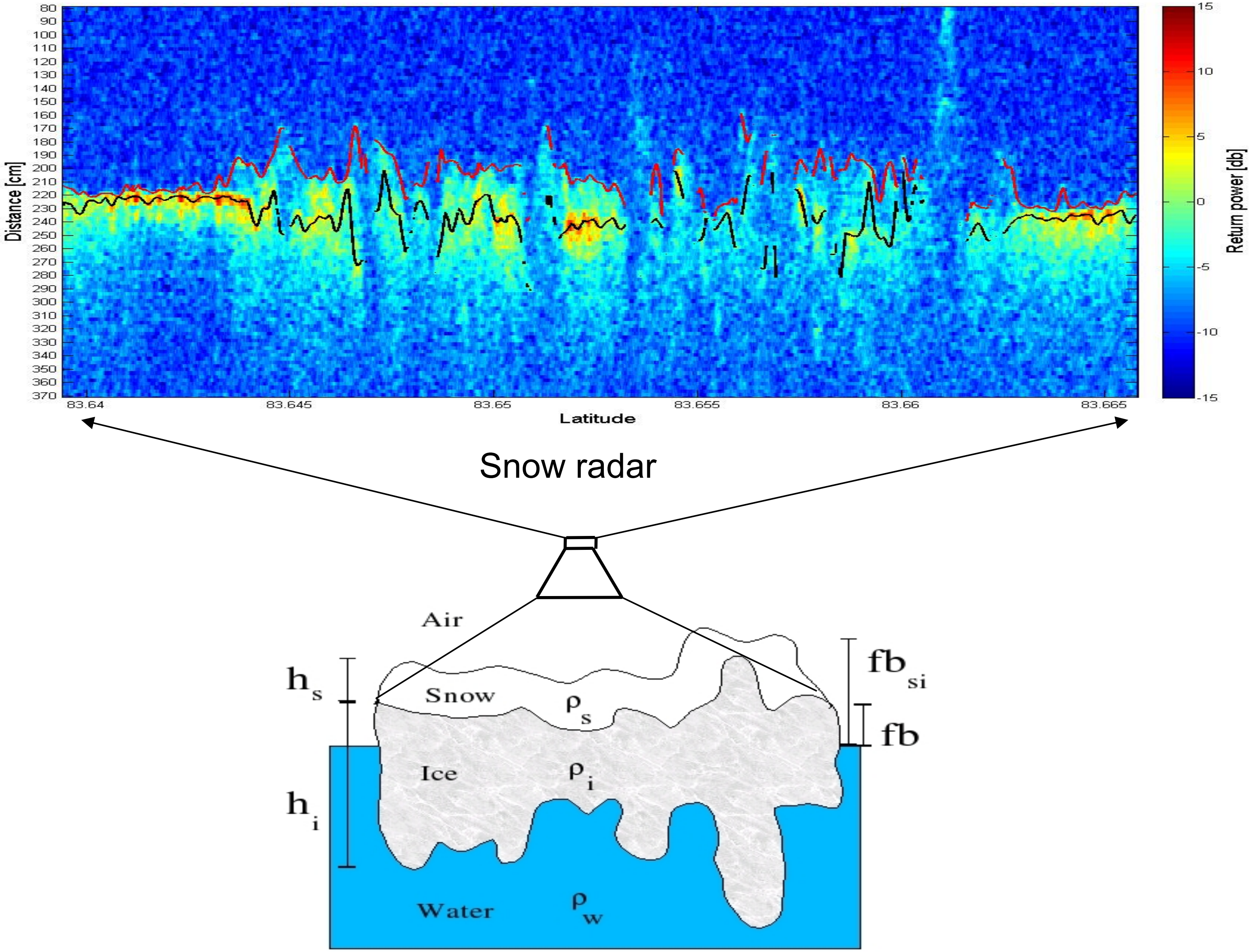
Baseline system for ICESat-2 cal/val

- Delivery of a 10,000 Hz/1.3 ns Hybrid Fiber Laser with dual-wavelength capability (532 & 1064 nm) in October/November 2016
- Experimental deployment planned on P-3 in Spring 2017
- 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

- Starting with the summer 2016 campaign, waveform data will be provided new HDF5 data products

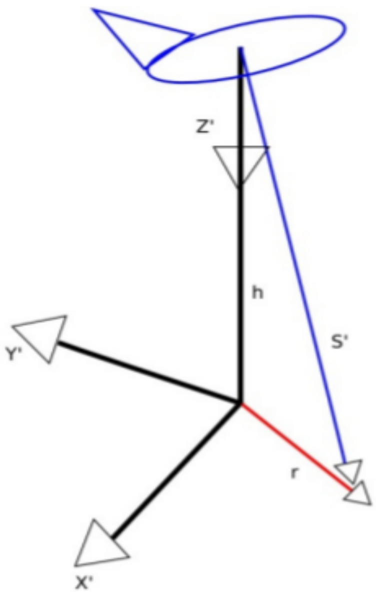
New FMCW snow radar

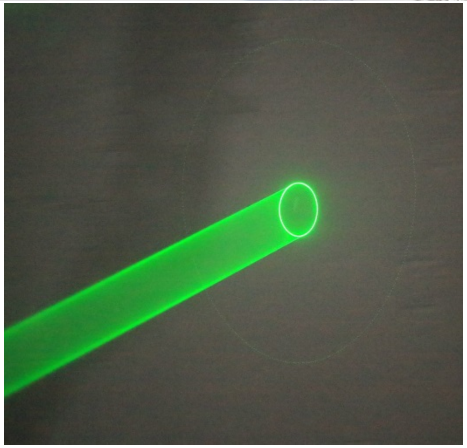


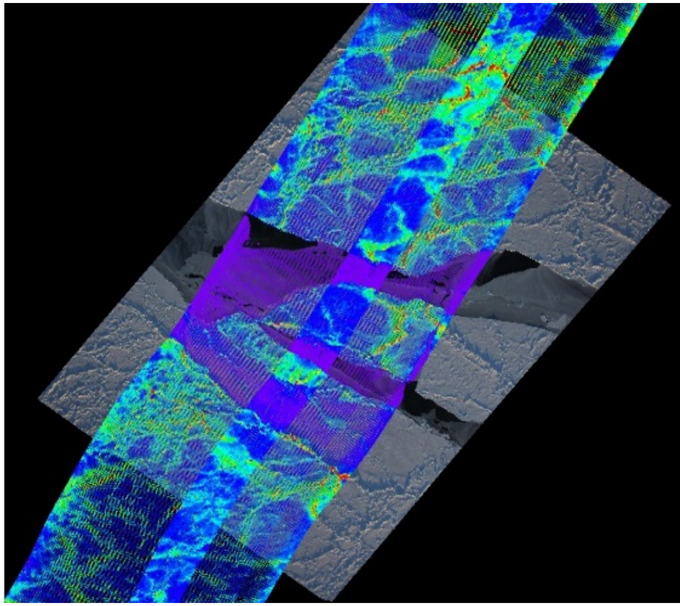
Laser altimeter concept

Photo: DMS

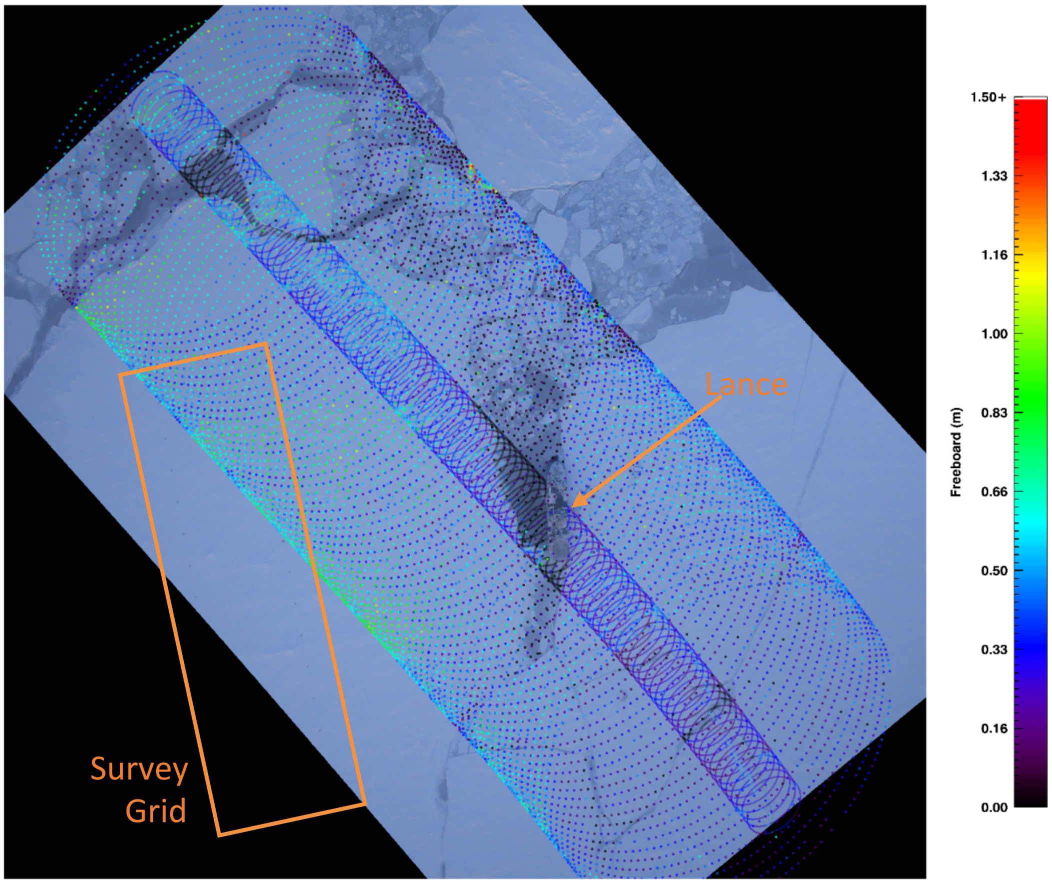
- The time difference between the transmitted and received laser pulses are used to find the range to the surface, this is combined with knowledge of the aircraft position and attitude to determine surface
- Elevation accuracy of better than 10 cm, precision of 3 cm







Operation IceBridge overflight of R/V Lance – March 19th, 2015



- Subset of DMS image: DMS_1543905_06097_20150319_15284917

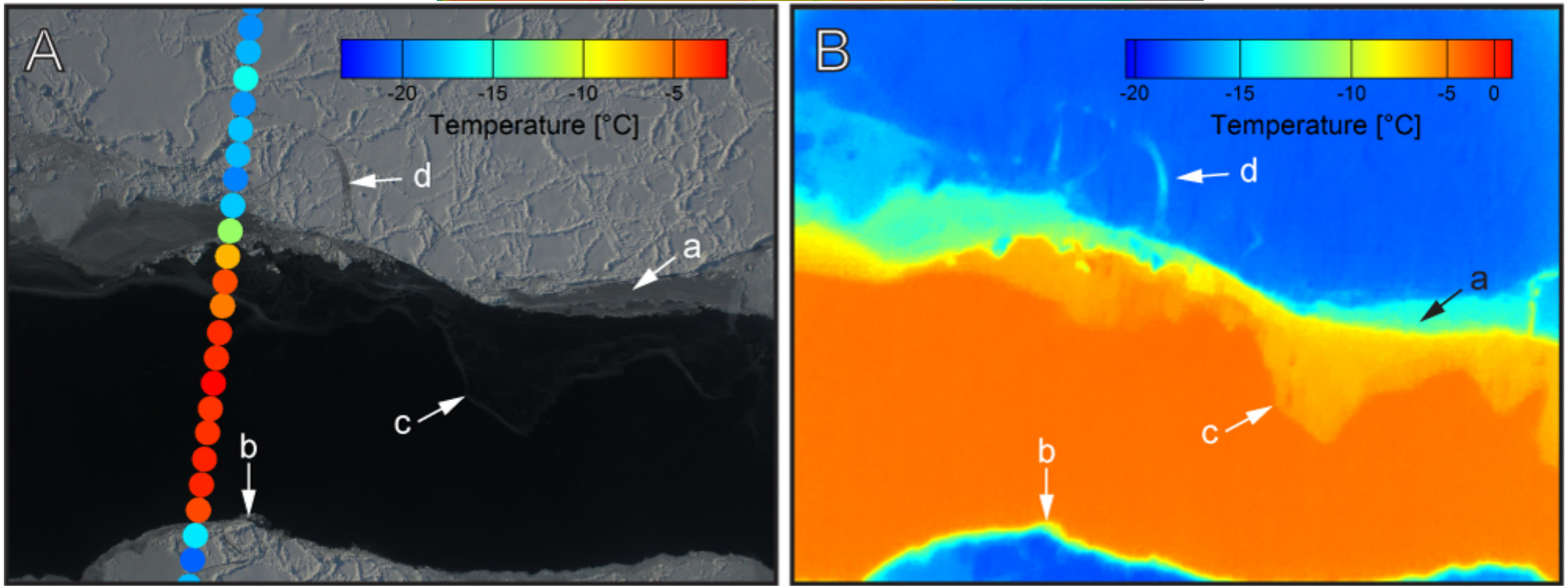
- Image shows first aircraft pass, where the crew oriented themselves with the ship and survey grid. The two subsequent passes were flown over the grid itself.

- ATM quicklook wide and narrow-scan data is overlaid on image, with ship-coincident data points filtered out.

- Narrow-scan freeboard statistics from this pass:
  - Freeboard mean: 0.34 m
  - Freeboard Standard deviation: 0.11 m
  - Mean Freeboard error: 0.037 m

- Due the nature of quicklook data, where mounting bias errors between lasers has not been fully resolved, wide-scan data was not included in the quicklook product for this portion of the overflight. It is included in this graphic for coverage visulization only, with elevations shown adjusted to an approximate local sea-surface height.

IR and visible cameras



New IR camera: path length and atmospheric correction

Photo: DMS

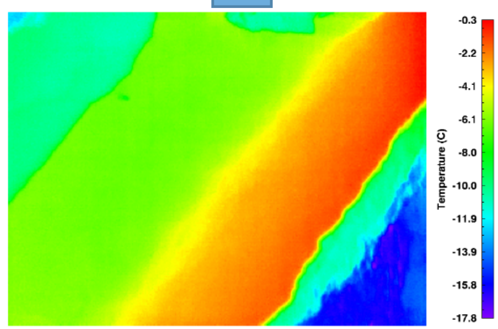
Determine path length and geolocation for each pixel

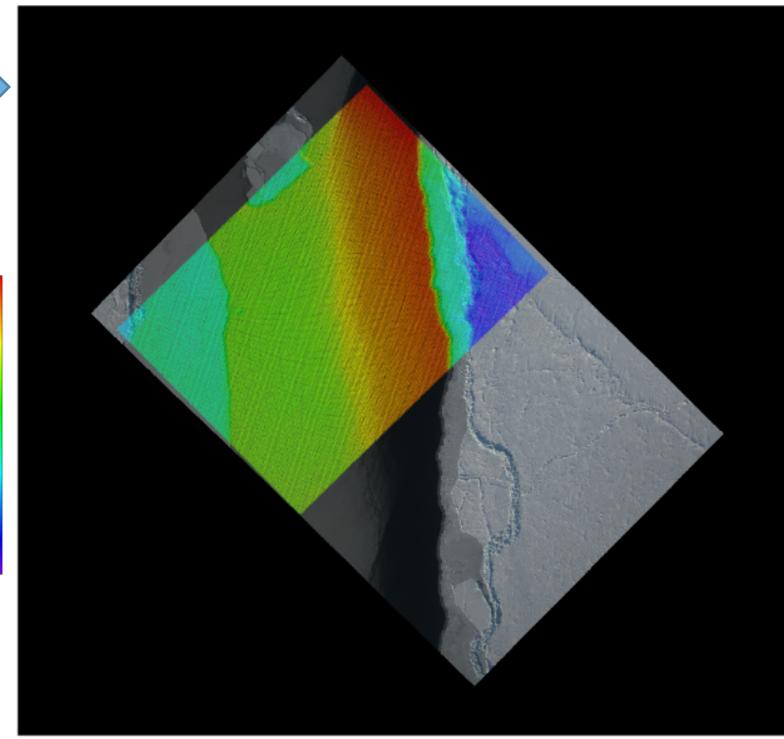
↓

Use kCARTA radiative transfer model to determine reflected atmospheric radiation and extinction coefficient

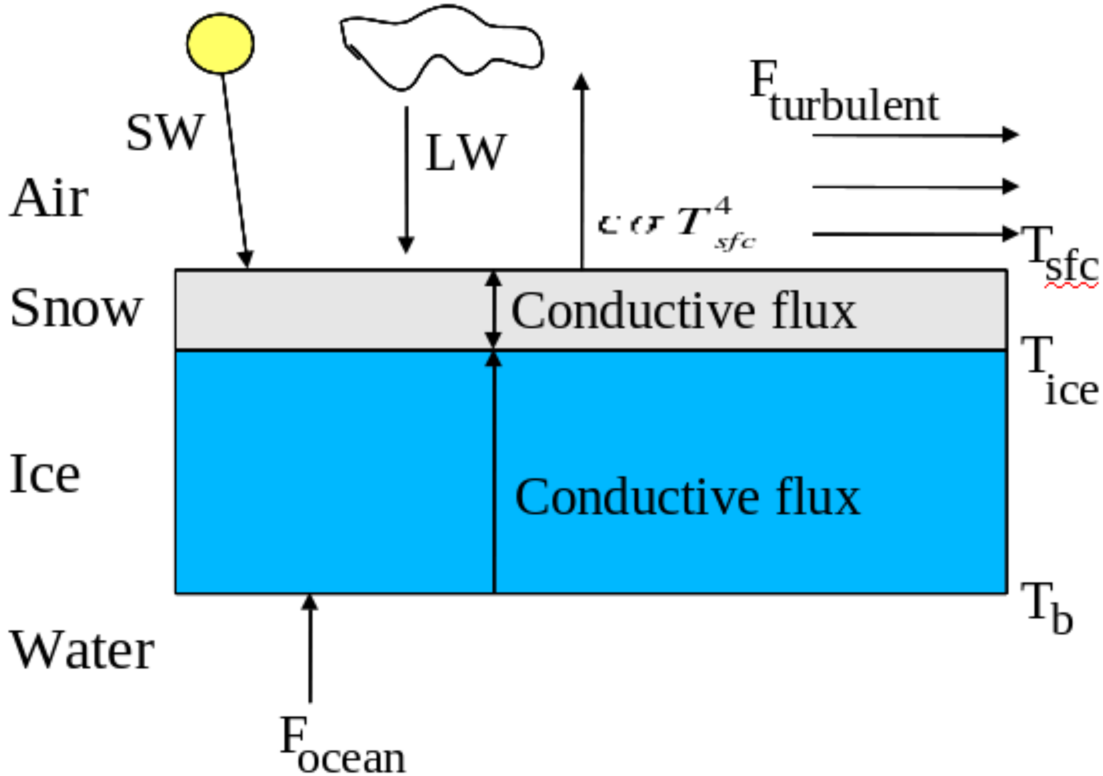
↓

Remove atmospheric effects and use Planck's Law to retrieve surface temperature





New IR camera: lead detection and thin ice thickness retrieval

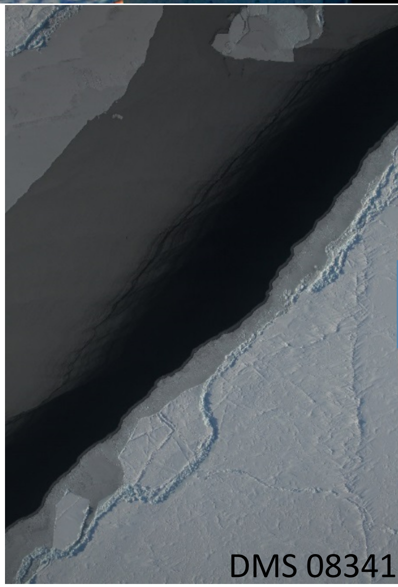


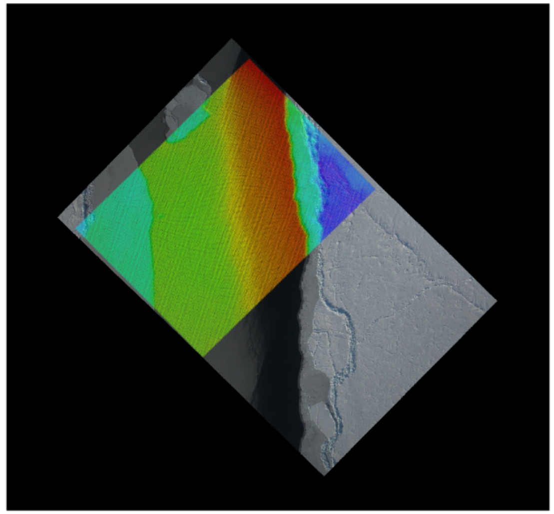
Assume thin ice is in thermodynamic equilibrium with atmosphere and ocean and use radiation balance equation

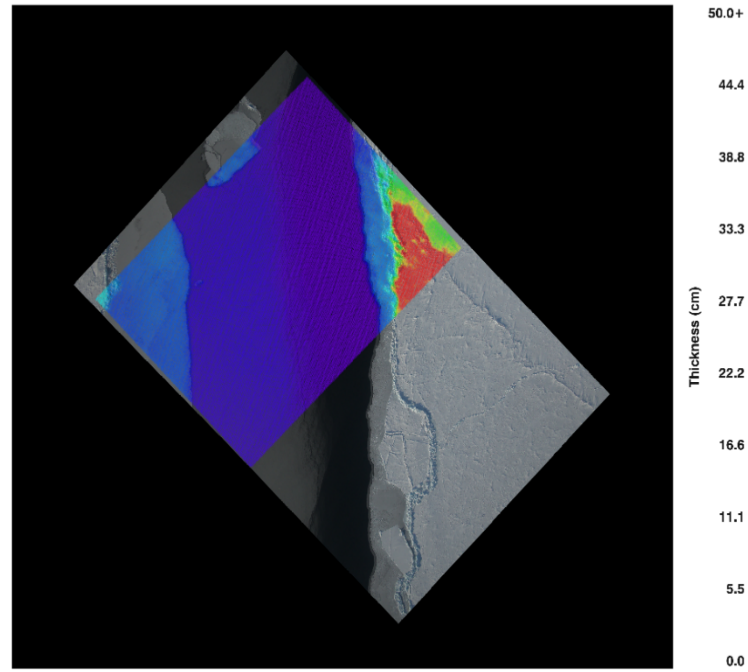
Solve to match surface temperature with ice thickness

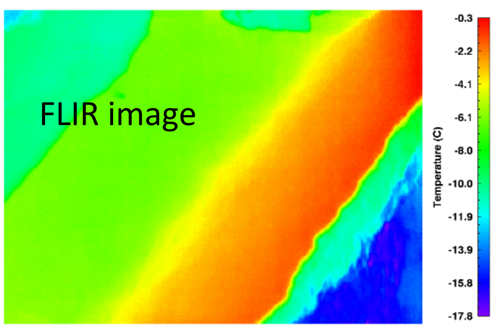
$$\alpha)F_r + \epsilon\sigma T_{sfc}^4 - F_{lw} + k_i (T_b - T_{sfc})/h_i + \rho c_p C_s u(T_a - T_{sfc}) + \rho L C_e u(q_a -$$

Determining thin sea ice thickness from temperature data









Thin ice thickness more accurate than altimetry alone
Allows easy detection of leads and in darkness
Allows determination of ice thickness bias in use of ice-covered leads as SSH reference

New ATM “HeadWall” Imaging Spectrometer Camera

- Commercial instrument (Headwall Photonics Inc) designed for short term drone flights

- Modified by ATM team for extended aircraft operation

- “Push-broom” configuration-640 element array spatial sampling driven by aircraft forward motion
- Initial missions on NASA P3 aircraft Spring 2017

- Complements DMS, ATM FLIR and CAMBOT image data

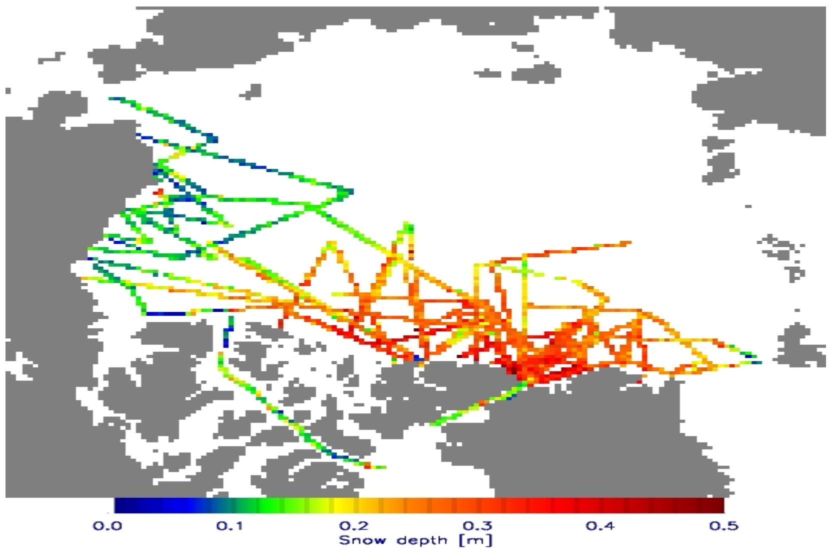
- Comparison of ATM waveform melt pond bathymetry and melt pond spectral response could improve knowledge of melt pond depth in extremely shallow/deep regions

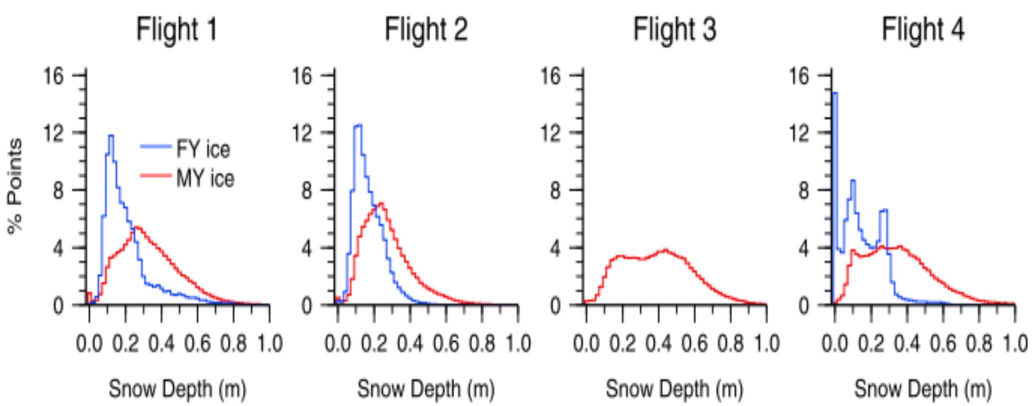
- Possible acquisition of spectral data related to snow grain size useful for light penetration models

- Wavelength range: 400–1000 nm
- 640 spatial bands, ~40 cm horizontal resolution
- 270 Spectral bands 270
- Dispersion/Pixel: 2.2 nm pixel^{-1}
- FWHM Slit Image: 6 nm
- FOV of 8 mm FL lens is 33°

Snow radar over sea ice

Photo: DMS

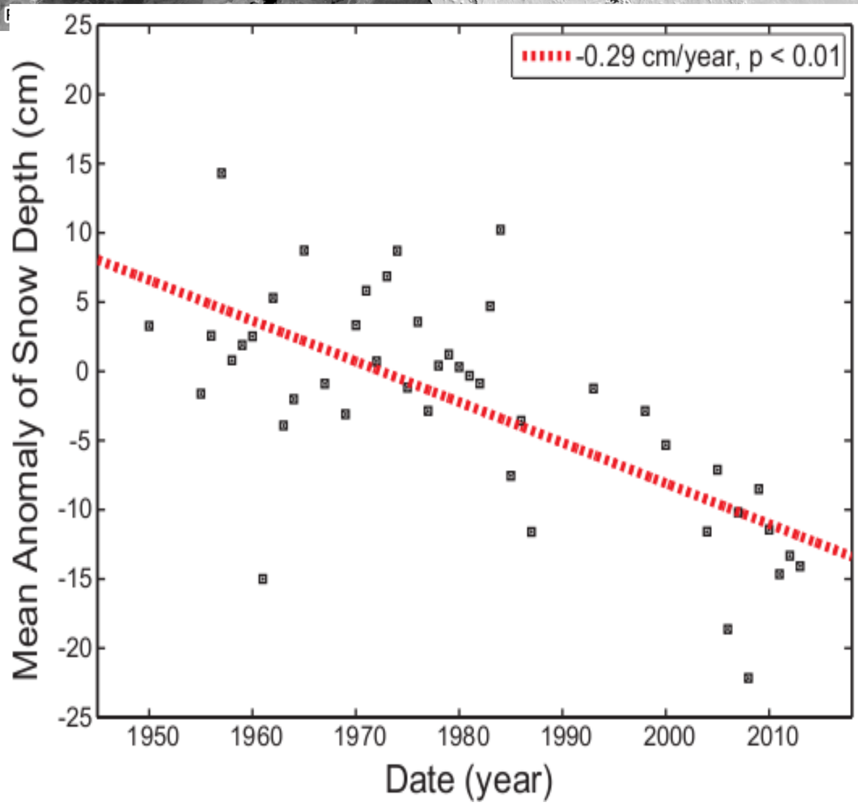


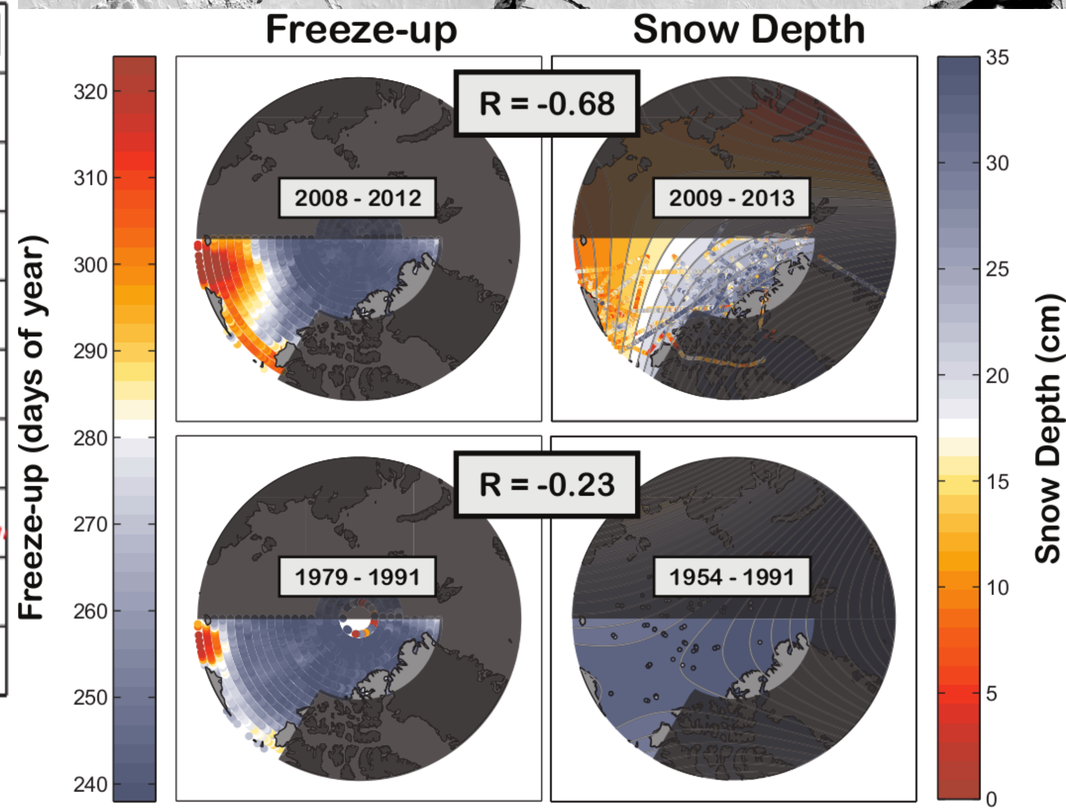


Kurtz and Farrell, 2011

- OIB snow radar provided the first basin-scale maps of snow depth on Arctic sea ice on first year and multi-year ice in a single season
- Provided first insight to the changing snow regime brought on by the decrease of multi-year ice
- Also important for the retrieval of sea ice thickness from laser and radar altimetry data

Interdecadal changes in snow on sea ice



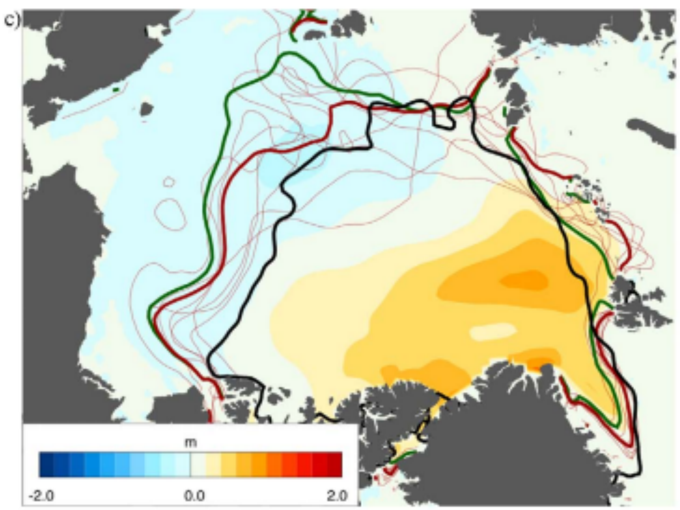


Webster et al., 2014

Large changes in snow depth on Arctic sea ice in the Western Arctic. Decadal-scale data from Soviet drifting stations (1950-1987), ice mass balance buoys (1993-2013), IceBridge snow radar (2009-2013). Changes are correlated to later freeze-up dates because most snow falls in September and October when sea ice may no longer be present

Seasonal sea ice forecasting

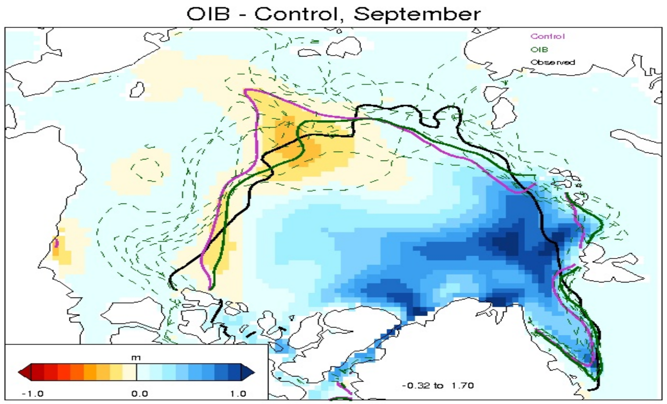
Design: M. Studinger



Observed ice extent

Model predicted ice extent, no assimilation

Model predicted ice extent, with assimilation



Lindsay et al., 2012

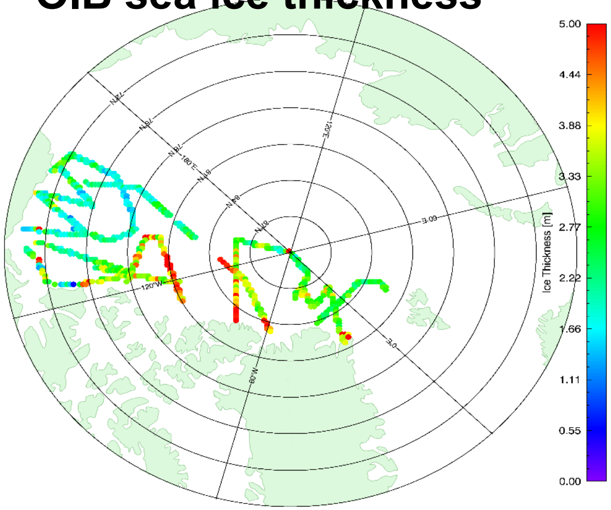
IceBridge quick look data and PIOMAS model simulations used for forecasting of the sea ice minimum using data assimilation

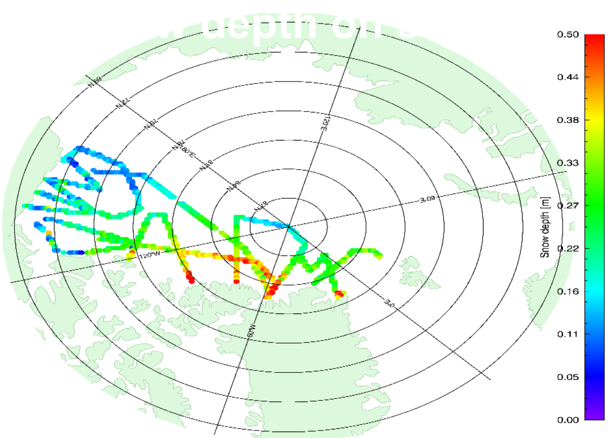
Incorporation of IceBridge thickness data slightly improved seasonal ice minimum prediction, but also demonstrated importance of weather and need for improved assimilation methods, and need to further improve model physics

Sea ice thickness: IceBridge and CryoSat-2

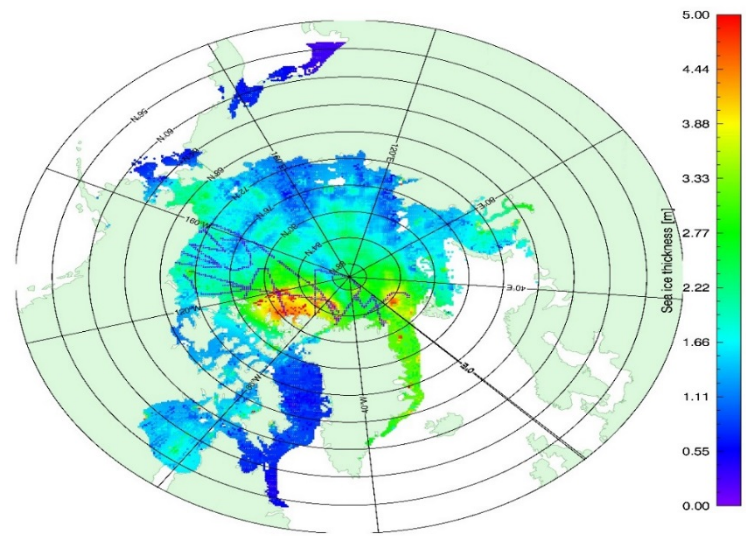
Photo: M. Studinger

OIB sea ice thickness





March 2015 blended CryoSat-2 and IceBridge sea ice thickness

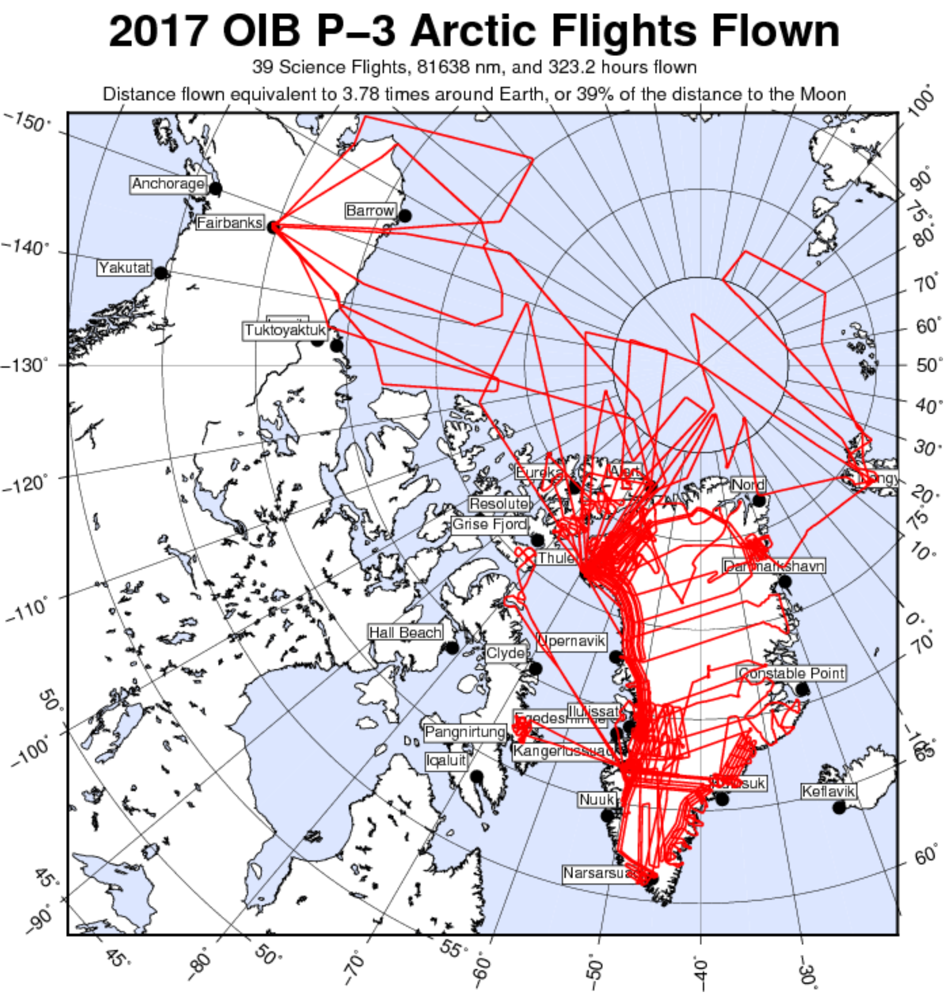


Quick look data provided approximately 1 month after completion of IceBridge Arctic campaign.

Archival data products as well: http://nsidc.org/data/docs/daac/icebridge/idcsi4/

https://nsidc.org/data/docs/daac/icebridge/evaluation_products/sea-ice-freeboard-snowdepth-thickness-quicklook-index.html

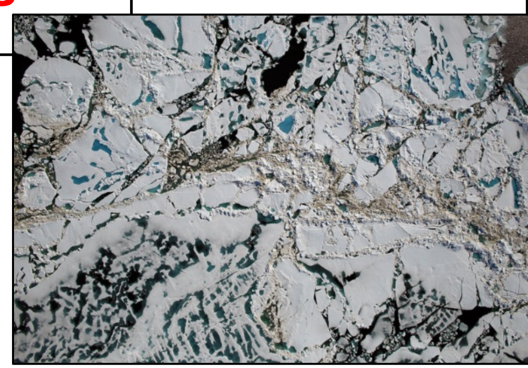
• 2017 Arctic spring



- **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
- Data collection with new and improved instrument suites: 2–18 GHz snow radar, high rate/narrow pulse ATM, new hybrid gravimeter

2017 Arctic Summer

Target	Instruments	Aircraft	Location	Dates	Hours / flights
Sea ice	ATM T6,FLIR, hyperspectral imager, DMS	**LaRC HU-25 Falcon**	Thule AB	July 13-28	24 hrs ~6 flights
Land ice	LVIS, nadir camera	**Dynamic B-200T King Air**	Thule AB & Kangerlussuaq	Late August / September 4 weeks	85 hrs ~10 flights



IceBridge master schedule

Last updated: 14 June 2017

Campaign	2015	2016	2017	2018	2019
Arctic spring ~March-May	NASA C-130	NOAA 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	
Arctic summer July-September	NASA Falcon AK / Greenland	NASA Falcon AK / Greenland	LaRC Falcon & Dynamic King Air		
Antarctic spring ~October- November	NCAR G-V Punta Arenas	NASA DC-8 Punta Arenas	NASA P-3 (Ushuaia)	NASA DC-8 or G-V Punta Arenas	

Current ICESat-2 launch window

Project Science Office