NOAA/NESDIS/STAR/SOCD
Sea Ice Activities
(Altimetry and SAR Ocean Products System)
plus Update on PolarWatch

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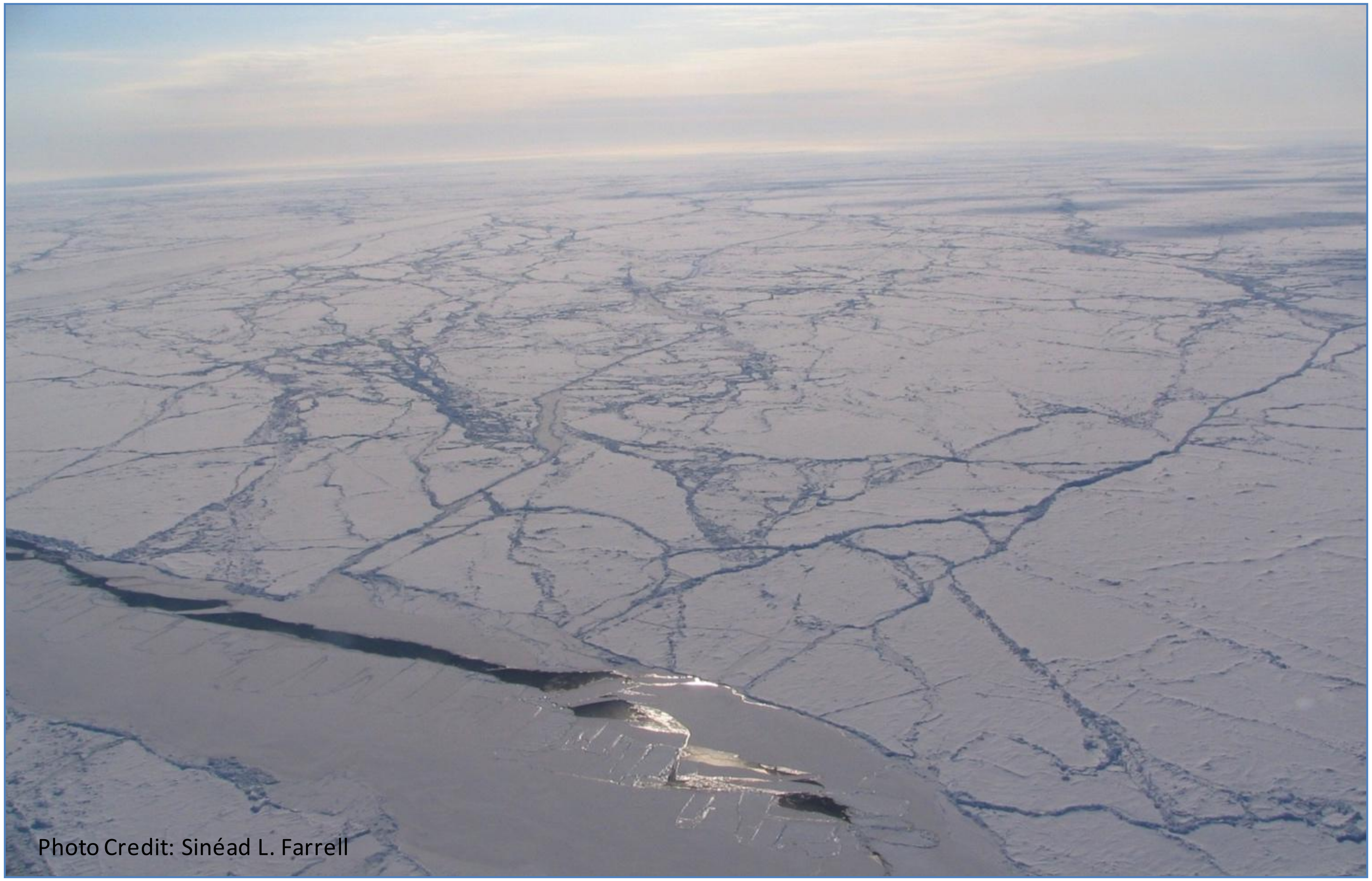
Sea Ice in the Climate System

Arctic Ocean

Southern Ocean

Global coverage ~ 18 – 27 x 10^6 km^2



- Arctic is warming twice as fast as other parts of the planet
- Sustained losses: 2.7% per decade (March – winter max.)
  13.3% per decade (Sept. – summer min.), relative to 1981-2010 avg.
- As the ice thins, and the fraction of open water, leads and polynyas increases, sea ice may no longer efficiently insulate the ocean from the atmosphere.

Implications of the Changing Arctic Ice Cover

- Loss of sea ice linked to:
  - Increase in temperatures of polar oceans/sub-polar seas
  - Increase in vegetation at high latitudes (tundra greening)
  - Increase in primary productivity
  - Decline of polar bear population and other species

  Source: "Arctic Report Card", Richter-Menge, Overland & Mathis (Eds.), NOAA

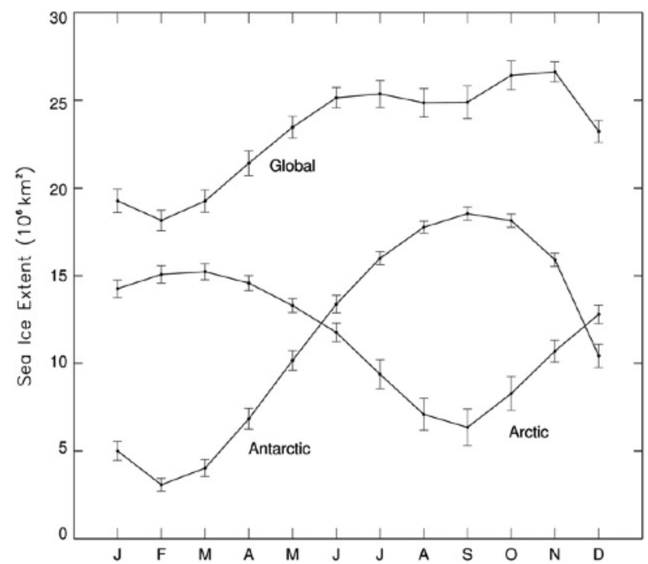
- Implications for regional and global climate, environment, ecology, biodiversity, global security, commerce and trade, …

- Sustained, long-term observations are needed to enable timely decisions by citizens, policy-makers, Arctic stake-holders, industry

- **NOAA's Arctic Action Plan includes: (i) improving our capability to forecast sea ice, and (ii) strengthening science to understand and detect Arctic climate and ecosystem change**

- Sea ice observational activities at SOCD include: **sea ice thickness observations, snow depth on sea ice, tracking multi-year ice extent, SAR analyses of sea ice edge and ice-type masking.**

Annual average sea ice extent (1979-2013)



Global coverage ranges from ~ 18 – 27 x 10^6 km^2 !!

Source: Parkinson (2014), J. Climate

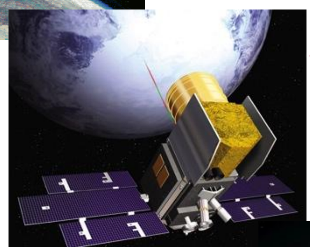
Photo Credit: Jennifer Hutchings, OSU

Time Series of Polar Altimetry

ERS-1 and -2: 1991- 2000, 1995 – 2003 RA-2 Radar Altimeter

81.5 ºN

Envisat: 2002 – 2012 RA-2 Radar Altimeter



ICESat: 2003 – 2009 GLAS Laser Altimeter

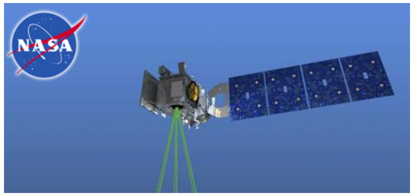
86 ºN

CryoSat-2: 2010 – present
SIRAL Radar Altimeter

88 ºN

Operation IceBridge:
2009 - present

90 ºN



ICESat-2
Due for launch: 2018

88 ºN

***plus* SARAL/AltiKa**
***and* SRAL on Sentinel-3!**

Sea Ice Thickness Processing
- at the Laboratory for Satellite Altimetry

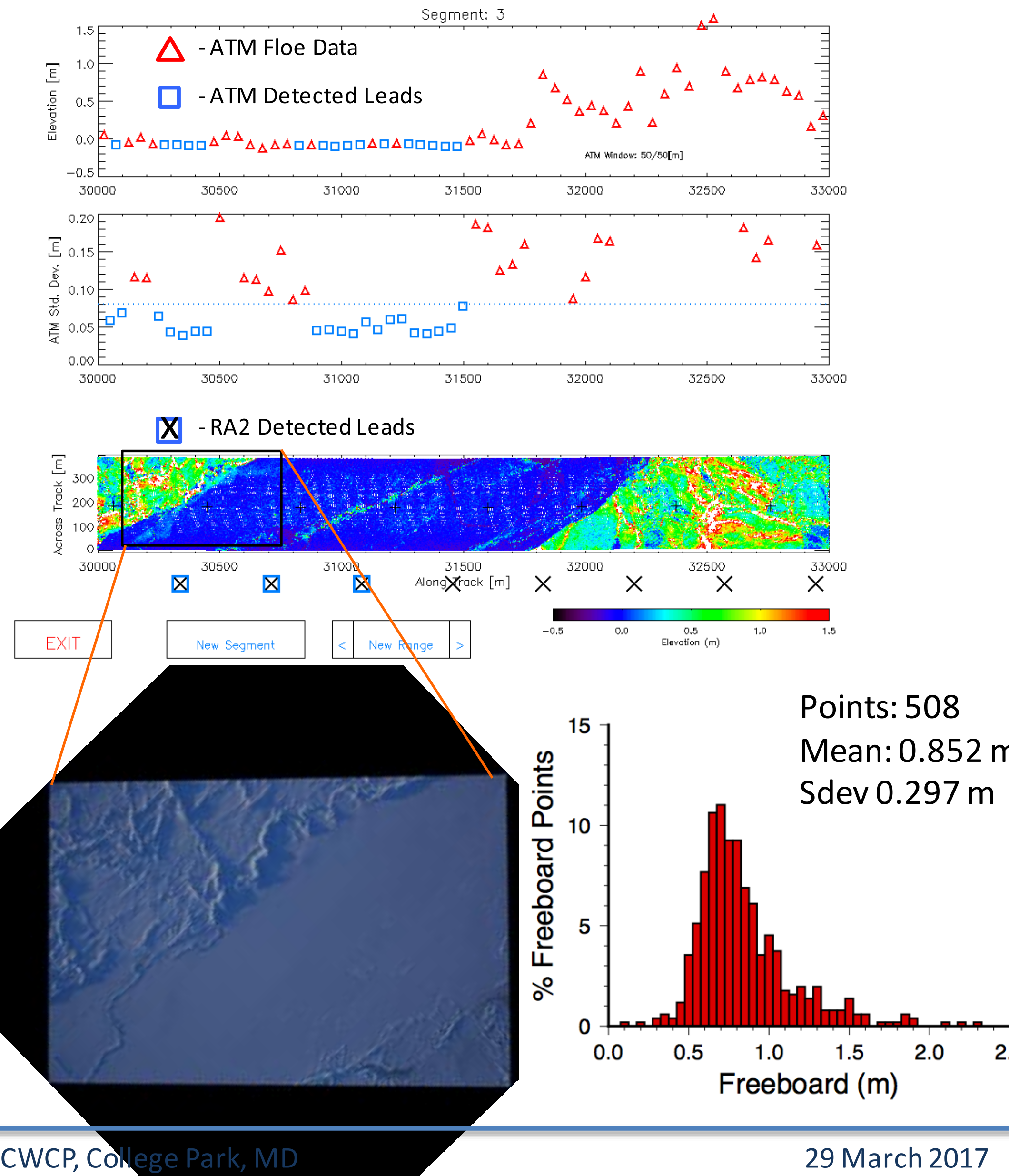
Goal: Develop robust sea ice freeboard algorithm for laser altimeter data

Coverage:
IceBridge Arctic Surveys: 2009-2016
72+ useable flight-lines across Canada Basin and Central Arctic
CryoSat-2: 2010 – present: basin scale cover

Snow Depth:
IceBridge Snow Radar to derive snow depth (tracking air/snow – snow/ice interfaces)

Freeboard:
IceBridge ATM laser provides ice/snow surface elevation.
Lead detection algorithm → SSH profiles
Difference to generate freeboard

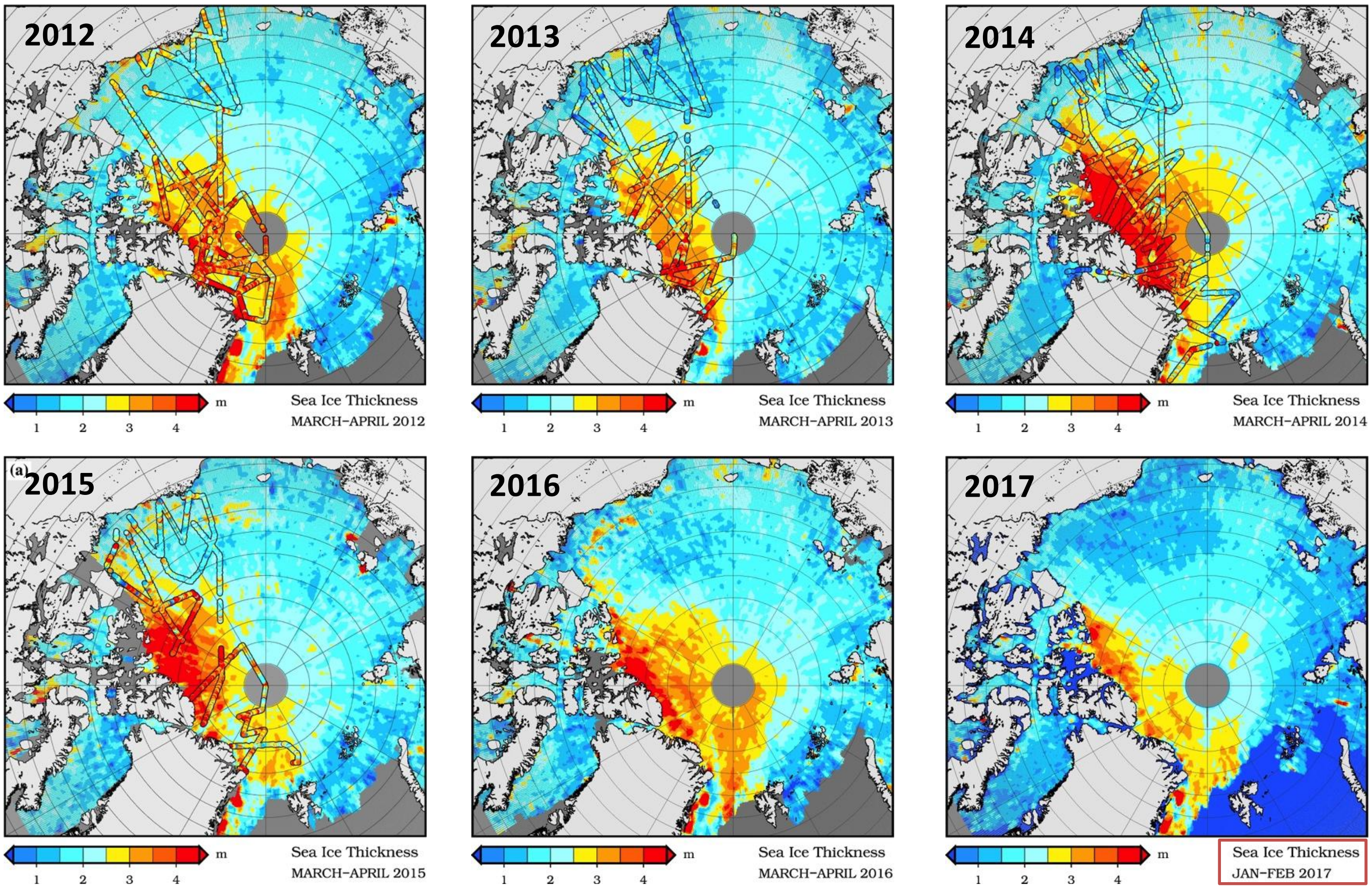
Sea Ice Thickness:
Combine freeboard, snow depth and ice type to derive sea ice thickness distributi
for first-year and multi-year sea ice.



Slide courtesy of Larry Connor (NOAA LSA)

Interannual Variability in Sea Ice Thickness

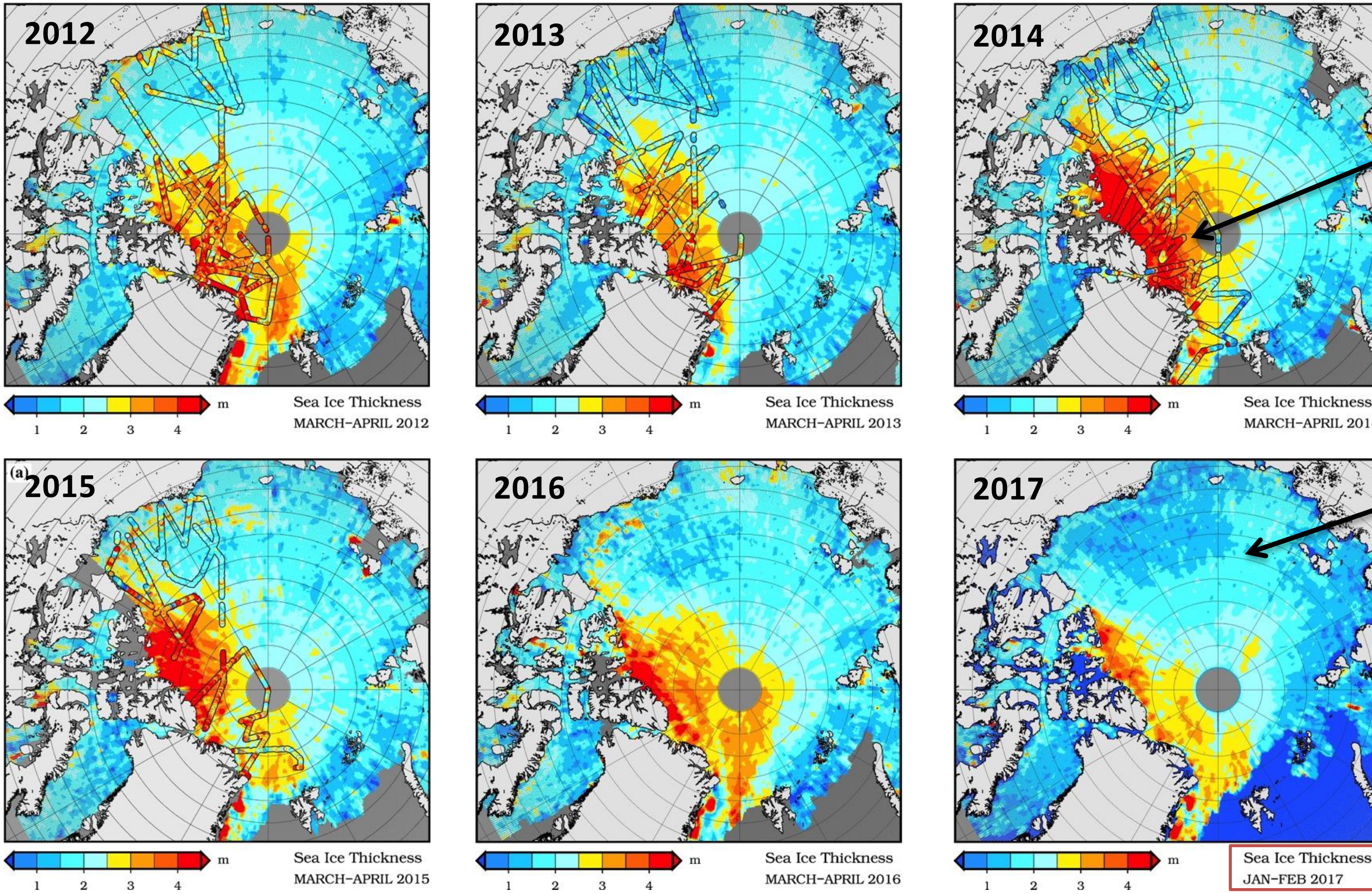
- at the end of winter



- **ESA CryoSat-2 Sea Ice Thickness Product**: Center for Polar Obs. & Modeling (CPOM) CryoSat Operational Polar Monitoring Web-Portal
  http://www.cpom.ucl.ac.uk/csopr/seaice.html
- **NASA IceBridge Sea Ice Thickness "QuickLook" Product**: National Snow and Ice Data Center (NSIDC)
  https://nsidc.org/data/docs/daac/icebridge/evaluation_products/sea-ice-freeboard-snowdepth-thickness-quicklook-index.html

Interannual Variability in Sea Ice Thickness

- at the end of winter



Oldest ice, north of Greenland and CAA ≥ 3 m

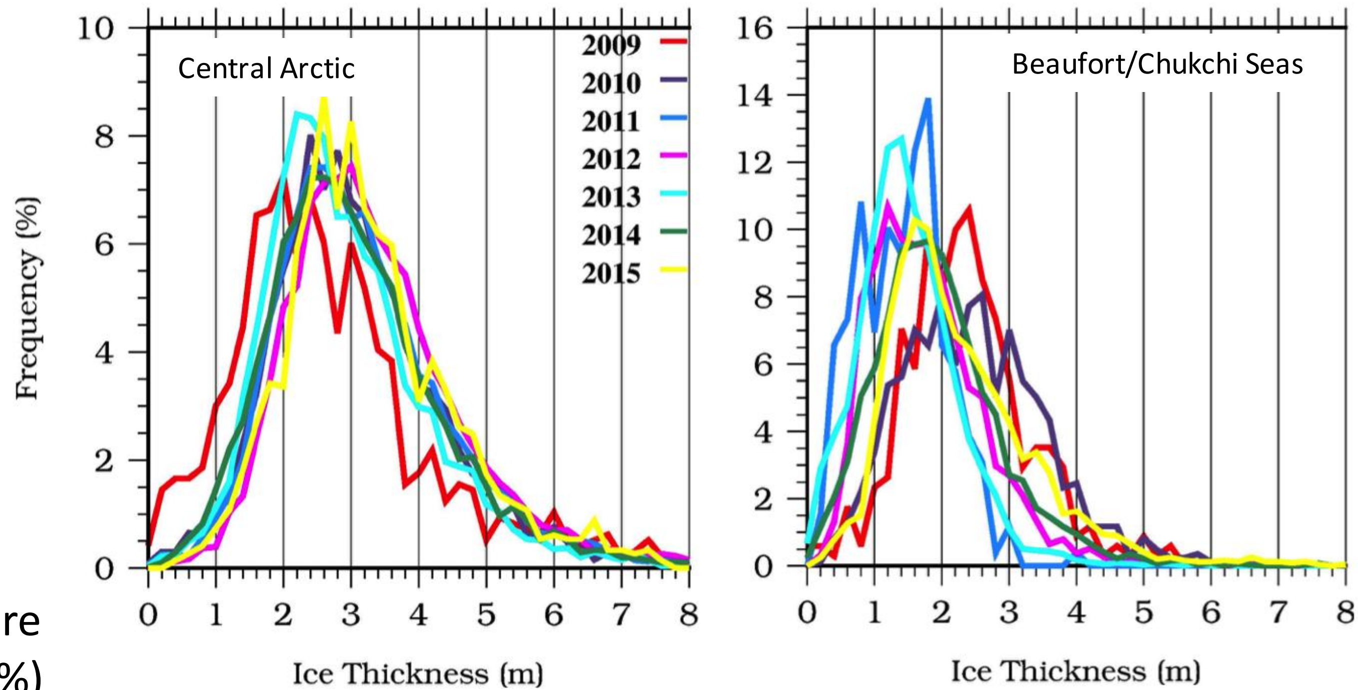
Strong gradient to thinner, seasonal ice in the Canada Basin and the eastern Arctic Ocean. Sea ice is 1 – 2.5 m thick.

Good consistency between independent estimates of sea ice thickness from IceBridge and CryoSat-2

Sea Ice Thickness Distribution

- March/April 2009 - 2015

IceBridge Data



Central Arctic:

- Predominantly multi-year ice
- Stable mean and modal ice thickness
- Mean: 3.2 m
  Mode: 2.5 m

Beaufort/Chukchi Seas:

- More seasonal in nature
- Mix of multiyear (~25 %) and first-year ice (~75 %)
- Year to year ice thickness distribution more variable
- Mean: 2.1 m. Mode: 1.8 m
- Inter-annual variability primarily related to the presence and location of a band of multi-year sea ice in the southern Beaufort Sea

Source: Richter-Menge and Farrell (2013) GRL, updated

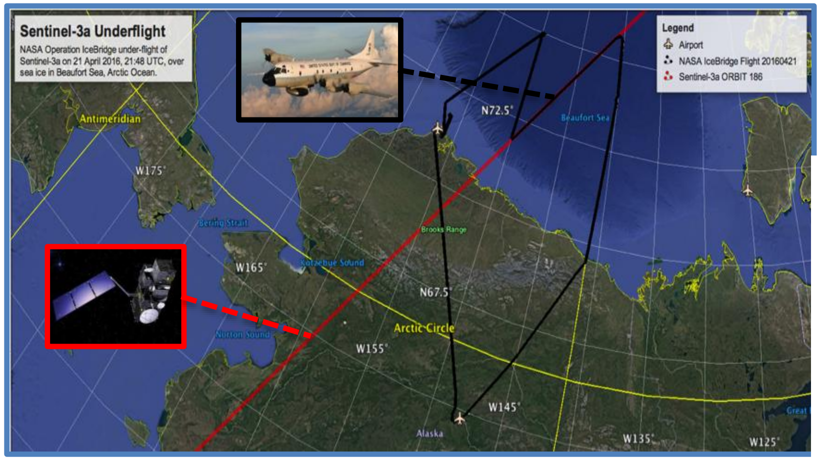
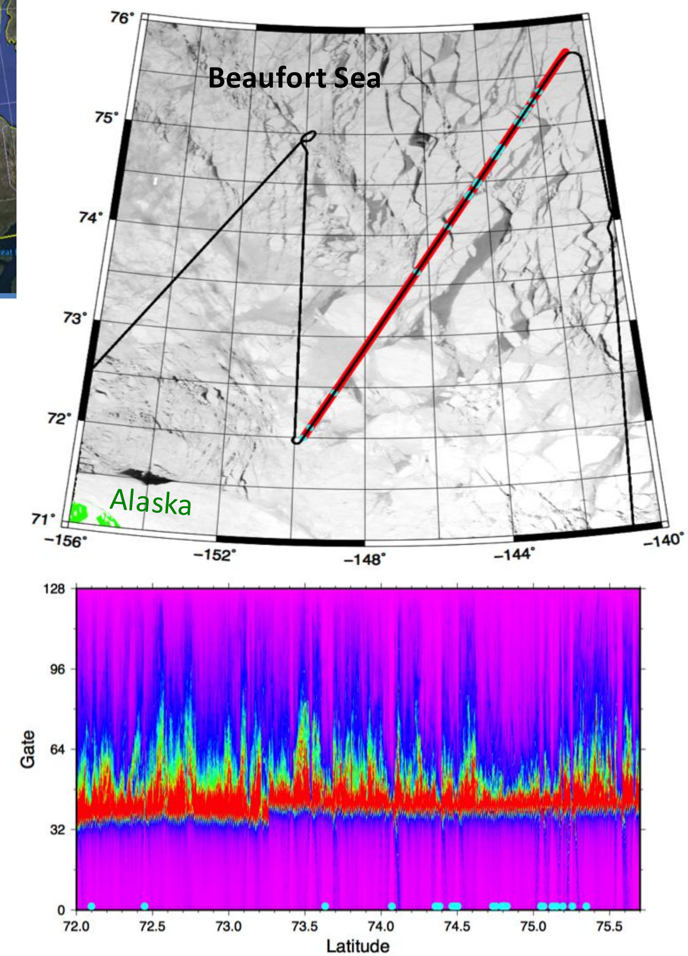


Figure 1: Spatially and temporally coincident data were collected by both IceBridge and Sentinel-3A in the eastern Beaufort Sea, north of Alaska, on 21 April 2016.

- IceBridge quicklook data and MODIS visible imagery provide details about sea ice conditions along the Sentinel-3A orbit.
- DMS images were used for verification of sea ice lead and floe delineations in the Sentinel-3A waveforms.
- An initial assessment shows that lead locations agree with specular returns evident in the Sentinel-3 A waveform stack.



Sentinel-3A Orbit
Cycle 3 Orbit 186
2016-04-21/21:49:28 UTC

OIB Flight #3
SIZRS Zig Zag
2016-04-21

Digital Mapping System
Lead Locations

MODIS image
2016-04-21/20:50 UTC
Δtime = 58 mins.

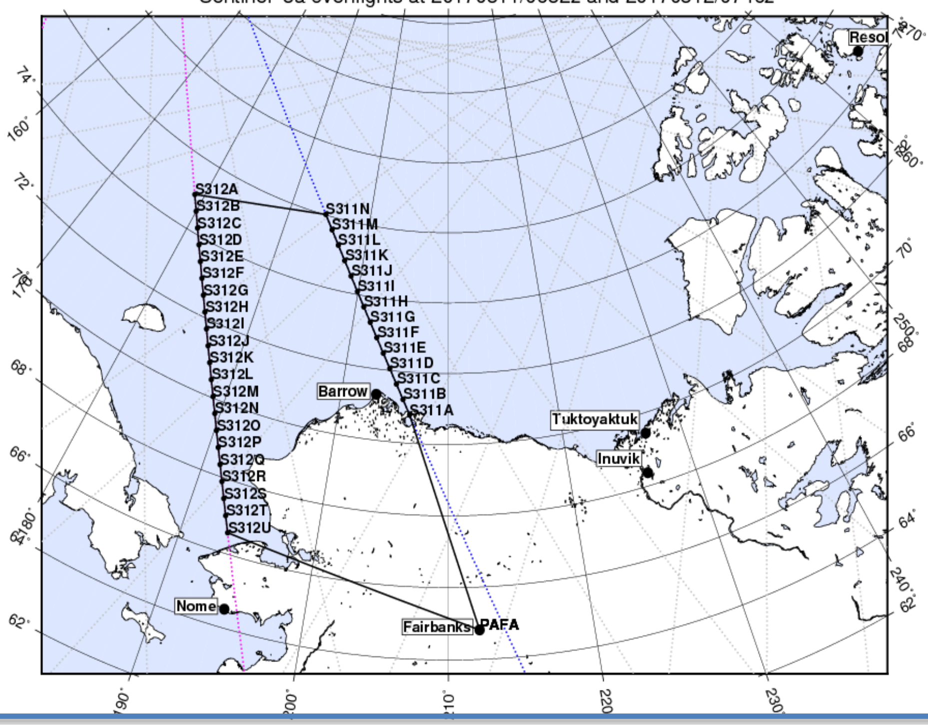
Figure 2: (Top left) Study-area comprised large sea ice floes interspersed with numerous leads. Lead locations (cyan dots) were derived using OIB Digital Mapping System (DMS) imagery. **(Bottom left)** Lead locations were delineated in Sentinel-3A waveform stack.

Operation IceBridge Under-flights of Sentinel 3A

- NOAA/LSA requested the OIB 2017 Arctic Campaign underfly > 300 km of S3A over sea ice
- 11 March 2017: Two long tracks in Chukchi West loop. Underflights > 12 hours from overpasses
- 12 March 2017: One short underflight in North Beaufort Loop. < 2 hours from overpass; fog conditions limit cameras; snow radar, ATM OK

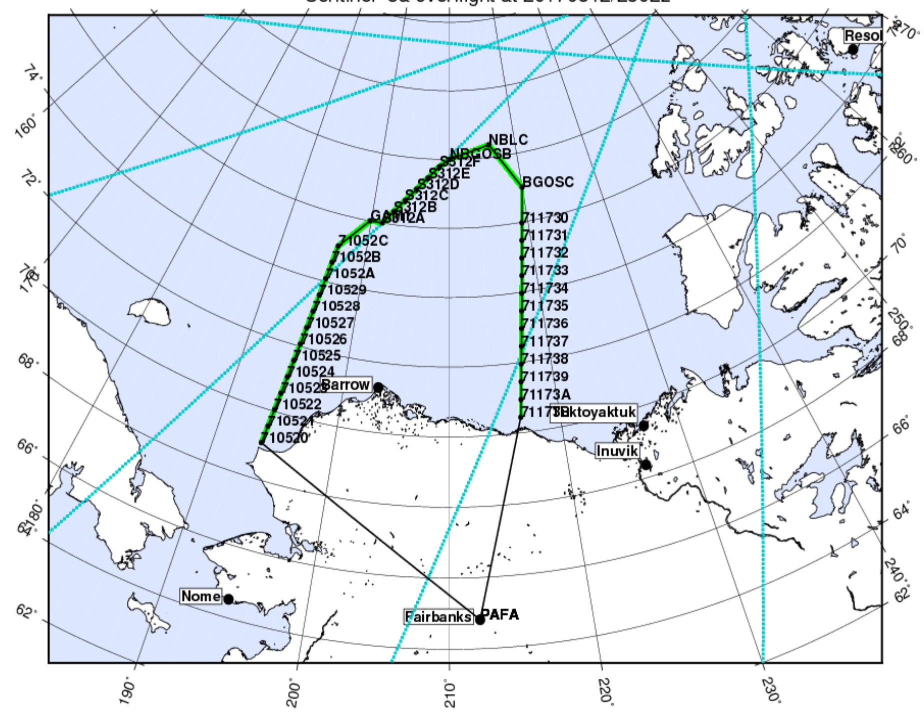
Sea Ice – Chukchi West

8.0 hours at 230 knots survey / 300 knots transit
Sentinel–3a overflights at 20170311/0632z and 20170312/0746z



Sea Ice – North Beaufort Loop

8.1 hours at 230 knots survey / 300 knots transit
Sentinel–3a overflight at 20170312/2302z



- Preparing for ICESat-2
- Launch: Sept. 2018
- Multi-beam Photon Counting Altimetry Over Sea Ice

Sea Ice Requirement:
ICESat-2 shall provide **monthly** surface elevation **products** to enable, when sea surface height references (leads) are available and under clear sky conditions, the determination of **sea-ice freeboard to an uncertainty of less than or equal to 3 cm along 25 km** segments for the **Arctic** and **Southern Oceans**; the track spacing should be less than or equal to 35 km at 70 degrees latitude on a monthly basis.

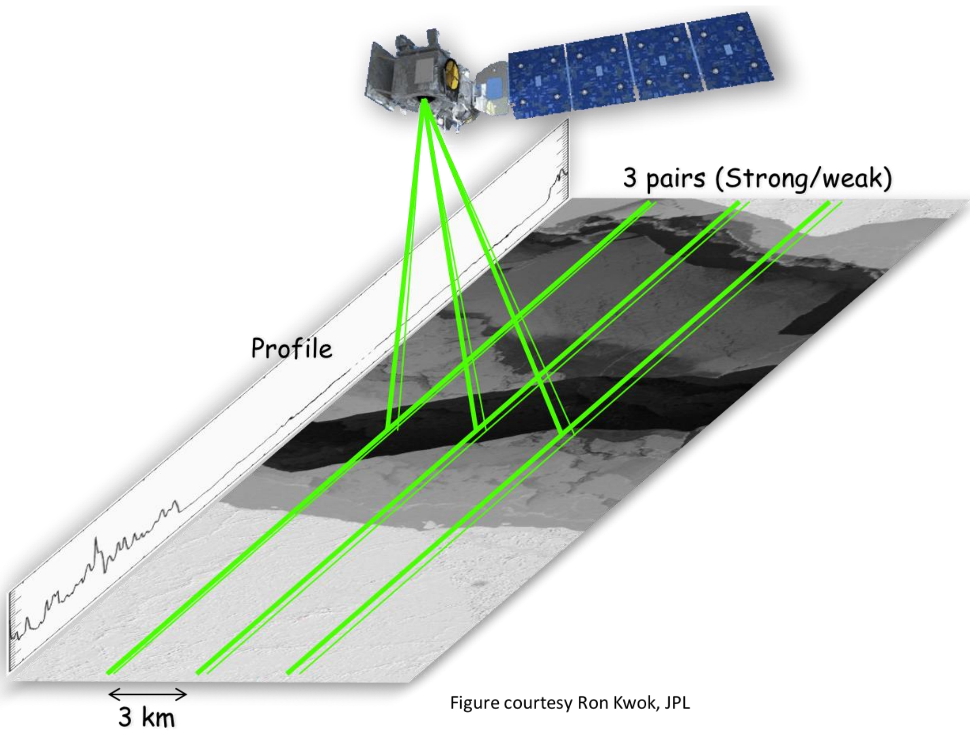


Figure courtesy Ron Kwok, JPL

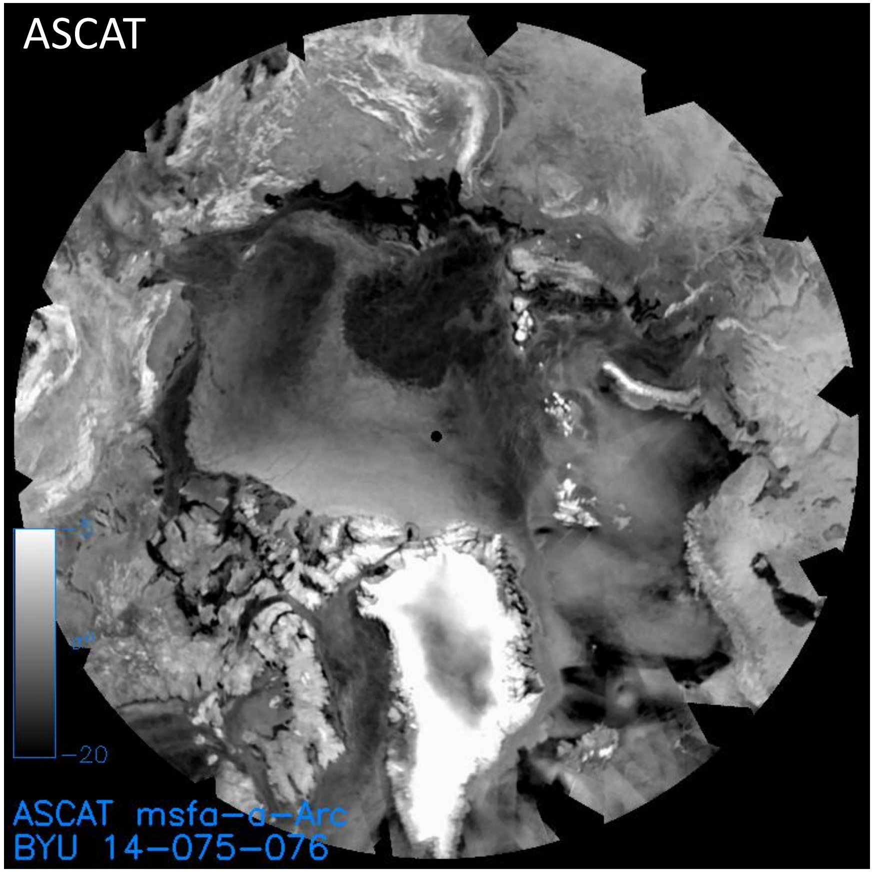
ICESat-2 SEA ICE PRODUCTS
Routine Products:
- along-track sea ice height (ATL07, Level 3A)
- along-track sea surface height (ATL07, Level 3A)
- along-track sea ice freeboard (ATL10, Level 3A)

Gridded Products:
- monthly sea ice freeboard (ATL20/L3B)
- monthly sea surface height (ATL21/L3B)

Research Products:
- Along-track sea ice thickness
- Gridded monthly sea ice thickness

Sea Ice Type/Age

- tracking multi-year ice (MYI) extent



- High-resolution data set (4.45 km) → consistent with resolution of altimetry observations
- Small pole hole → MYI mask area extends to 89.5 °N

Ice-type masks are derived from radar backscatter(σ_0) acquired by SeaWinds on QuikScat (1999 – 2009) and the Advanced Scatterometer (ASCAT) on METOP-A (2009 – present)

QuikScat :moderate resolution Ku-band
ASCAT: moderate resolution C-band

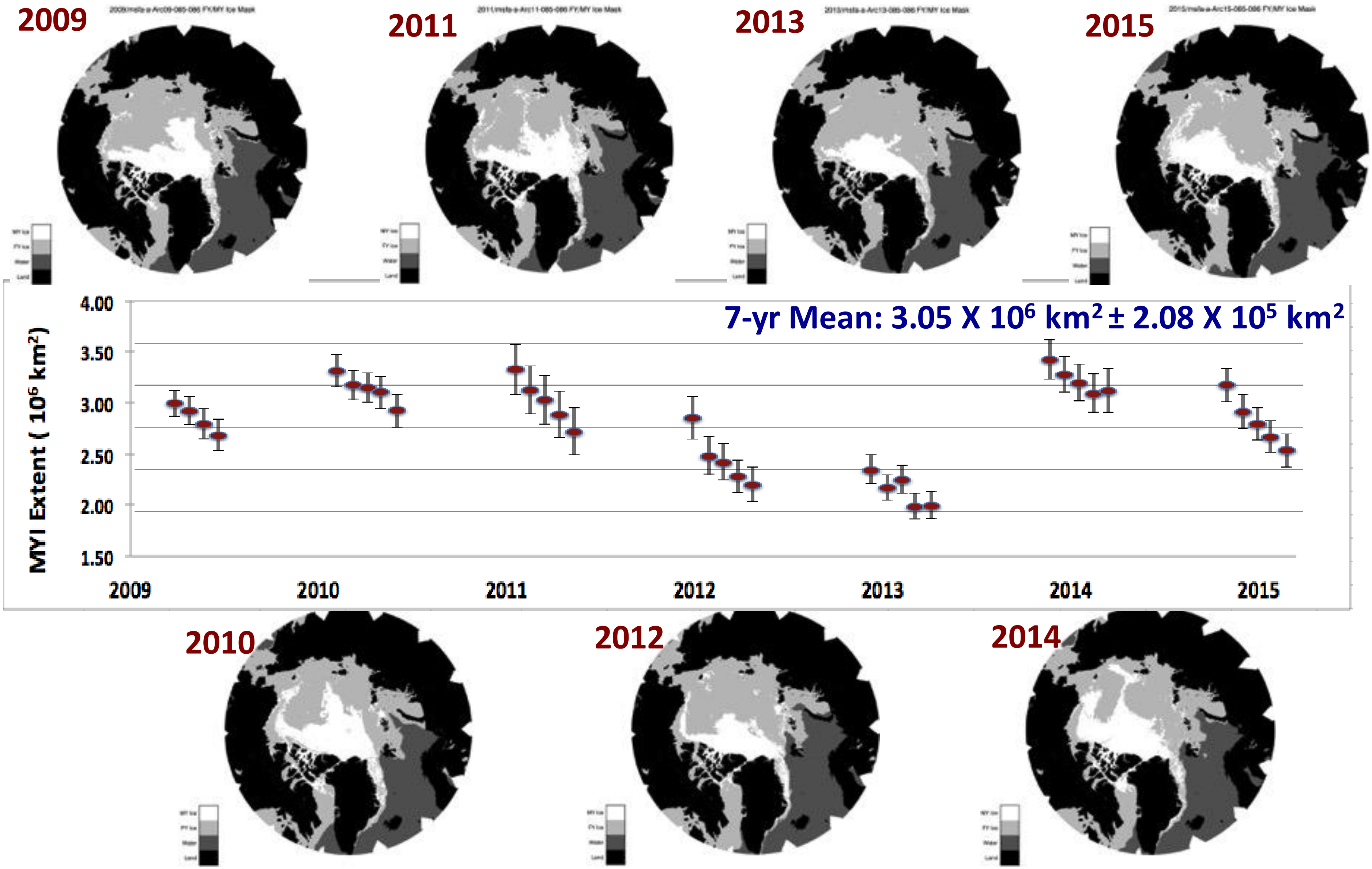
Data and sea ice type available at the Scatterometer Climate Record Pathfinder website at Brigham Young University (David Long, et al.)

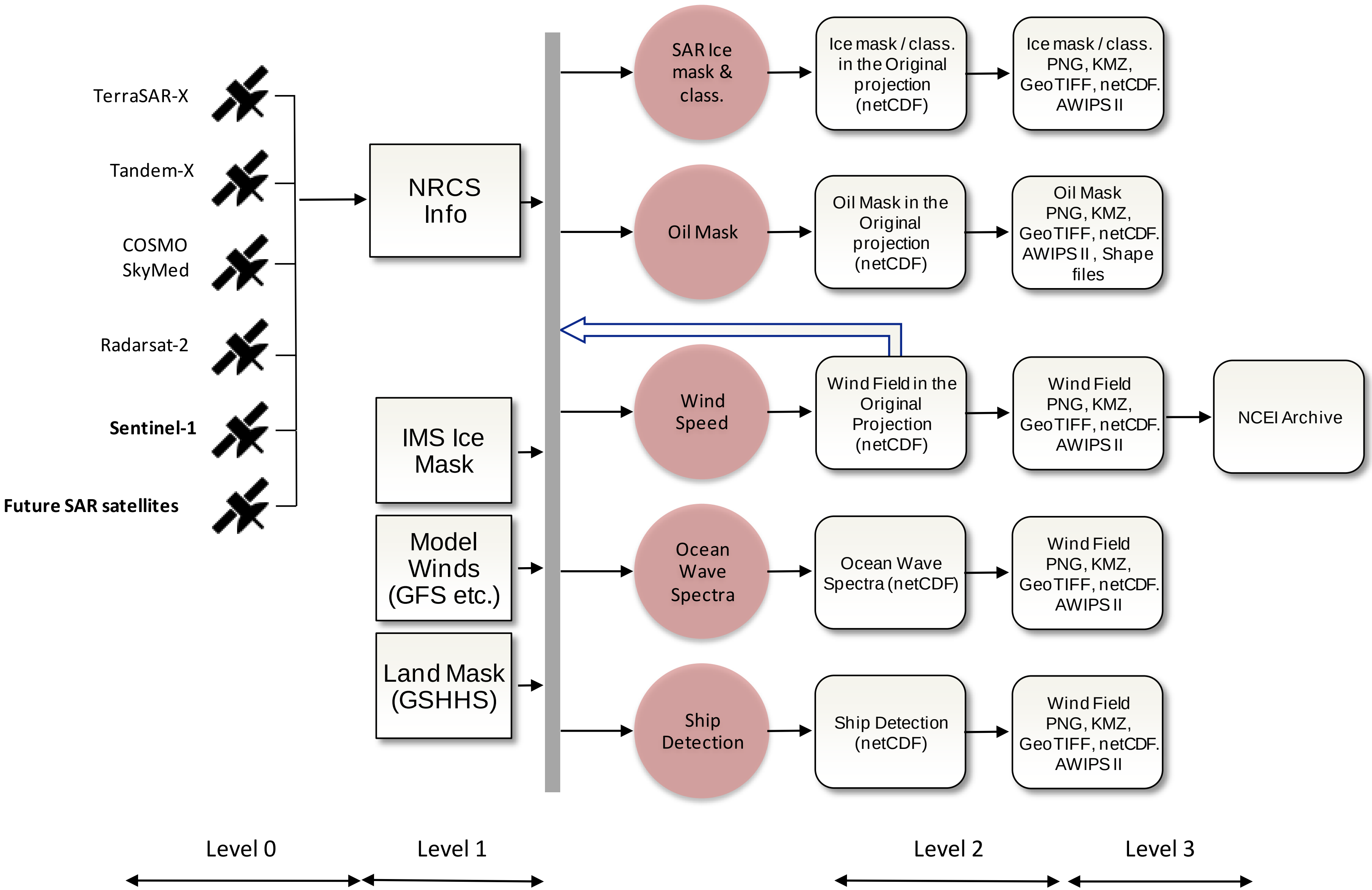
Daily normalized radar cross-sections & thresholding can be used to define the perennial (multi-year) sea ice zone

A correction is applied to account for high σ_0 due to motion of Marginal Ice Zone[MIZ]

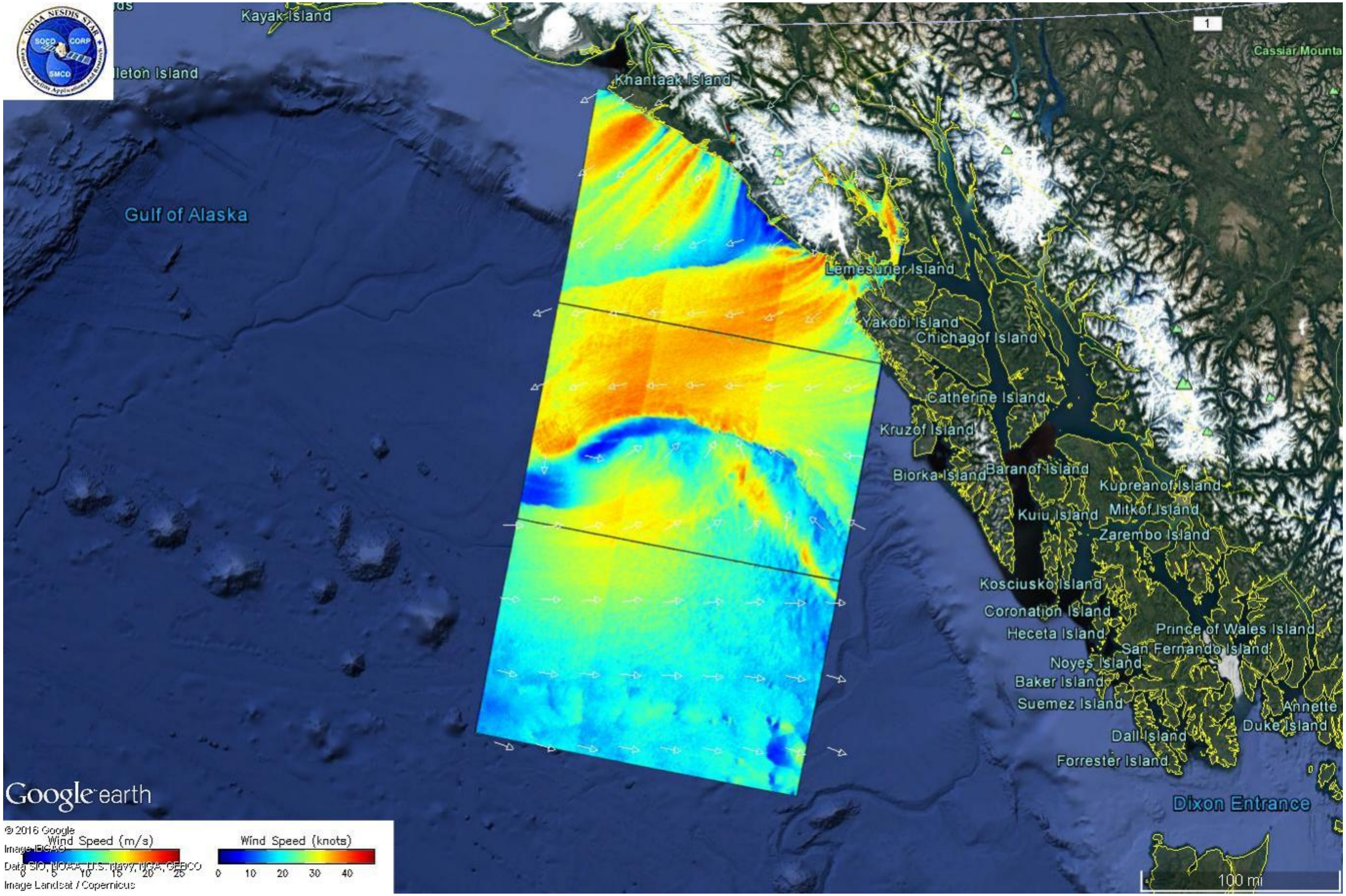
Inter-annual Variability in MYI Extent

- March 2009 - 2015

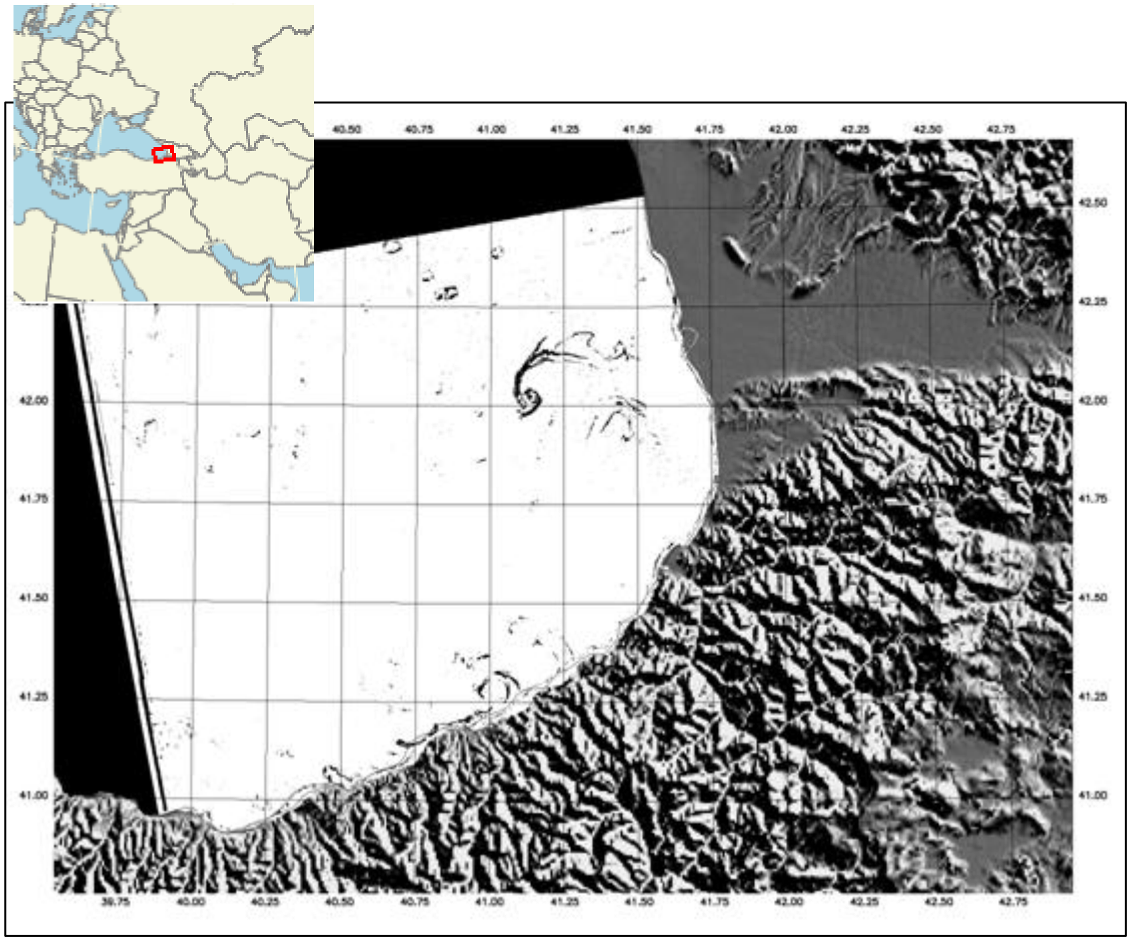



TerraSAR-X
Tandem-X
COSMO SkyMed
Radarsat-2
Sentinel-1
Future SAR satellites
NRCS Info
IMS Ice Mask
Model Winds (GFS etc.)
Land Mask (GSHHS)
SAR Ice mask & class.
Oil Mask
Wind Speed
Ocean Wave Spectra
Ship Detection
Ice mask / class. in the Original projection (netCDF)
Oil Mask in the Original projection (netCDF)
Wind Field in the Original Projection (netCDF)
Ocean Wave Spectra (netCDF)
Ship Detection (netCDF)
Ice mask / class. PNG, KMZ, GeoTIFF, netCDF. AWIPS II
Oil Mask PNG, KMZ, GeoTIFF, netCDF. AWIPS II , Shape files
Wind Field PNG, KMZ, GeoTIFF, netCDF. AWIPS II
Wind Field PNG, KMZ, GeoTIFF, netCDF. AWIPS II
Wind Field PNG, KMZ, GeoTIFF, netCDF. AWIPS II
NCEI Archive
Level 0
Level 1
Level 2
Level 3

Derived Wind Speed Image
- at 500 m Resolution



Automated Oil Spill Masking
- Using a Neural Network Approach



Sentinel-1A SAR Oil Mask (Interferometric Wide Mode)
15 October 2014 15:10 UTC Black Sea

Example PNG Output

SAR Oil Mapping Product
Basic output is NetCDF4 with layers:

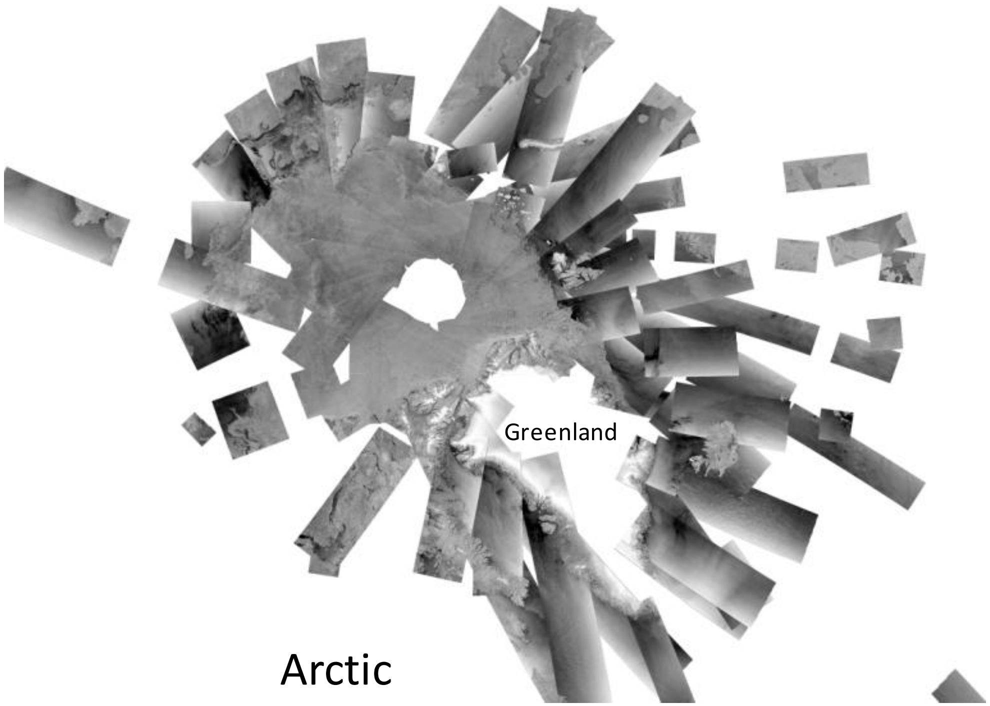
1. Oil Likelihood
2. Oil Mask
3. Latitude
4. Longitude
5. SAR Wind Speed
6. Model wind speed
7. Model wind direction
8. Land mask
9. Ice/snow mask
10. NRCS (sigma naught)

Derivative Products:

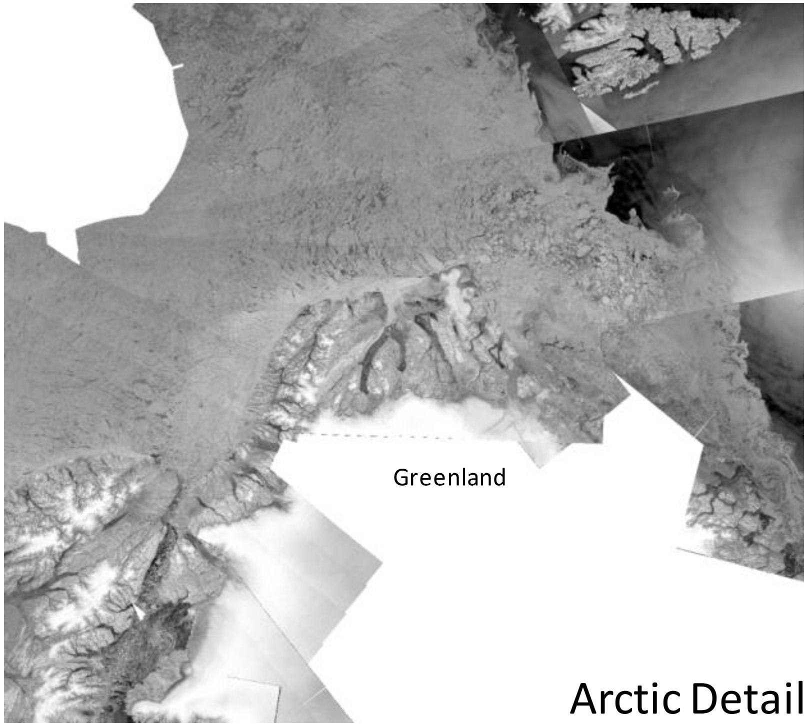
- Likelihood / Mask PNG
- Likelihood / Mask Geotiff
- Likelihood / Mask KMZ
- Shapefiles

Composite Sentinel-1 SAR Mosaic of Arctic Sea Ice

- used at the US National Ice Center



Arctic



Arctic Detail

The US National Ice Center uses daily 250-m resolution composites of Sentinel-1A/B radar cross imagery to aid analysts in sea-ice masking and ice type classification.

Contains modified Copernicus Sentinel data

PolarWatch

polarwatch.noaa.gov

PolarWatch is a new joint venture between the Center for Satellite Applications and Research (STAR) within NESDIS and the West Coast Regional Node (WCRN) of CoastWatch which is based out of the SouthWest Fisheries Science Center of NMFS.

PolarWatch started in the Fall of 2016 and will provide a user-driven information portal for accessing multi-sensor physical and biological ocean remote sensing data in support of a broad suite of applications and research in the Arctic and Antarctic.

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Timeline

polarwatch.noaa.gov

Version	Release	Functionality
Website	Mar 2017	About, FAQs
Beta 1.0	Apr 2017	- Data Catalog - Data subsetting. static projected preview - Data download, non-projected ERDDAP output - Demo datasets: Sea Ice Concentration SST – MUR Chlorophyll – NOAA VIIRS SSH – AVISO
Beta 2.0	Aug 2017	- Adds interactive data preview - Selection of map projection for preview and download - Expanded catalog of available datasets

Targeted Users

polarwatch.noaa.gov

Two NMFS science centers have been identified as primary users for PolarWatch:

1) **Alaska Fisheries Science Center (AFSC)**
Since 2006 the WCRN has hosted an Alaskan Satellite Data Browser in response to needs of the AFSC.

2) **AERD (Antarctic Ecosystem Research Division)**
NOAA Fisheries' Antarctic research is mandated by the U.S. Antarctic Marine Living Resources (AMLR) Convention Act of 1984, and the work undertaken and managed by the AERD is widely known as the U.S. AMLR Program. The AERD is part of the SWFSC, which is where the WCRN is located.

PolarWatch will also work with OAR, NOS and the NWS, as well as with managers and researchers outside of NOAA to identify and serve their needs.

Backup Slides

PolarWatch Players

polarwatch.noaa.gov

WestCoast/PolarWatch Regional Node of CoastWatch

Jennifer Patterson Sevadjian, Cara Wilson, Dale Robinson

NESDIS | STAR | SOCD | CoastWatch/OceanWatch

Paul DiGiacomo, Michael Soracco, Heng Gu & Veronica Lance

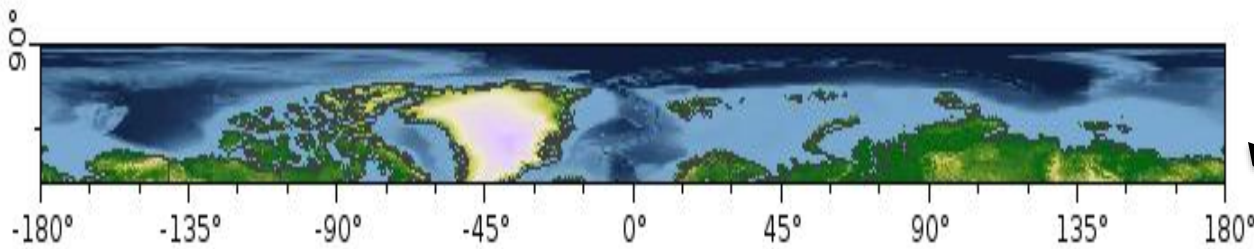
NESDIS | STAR | Laboratory for Satellite Altimetry

Sinead Farrell, Eric Leuliette & Laurence Connor

National Ice Center

Projections

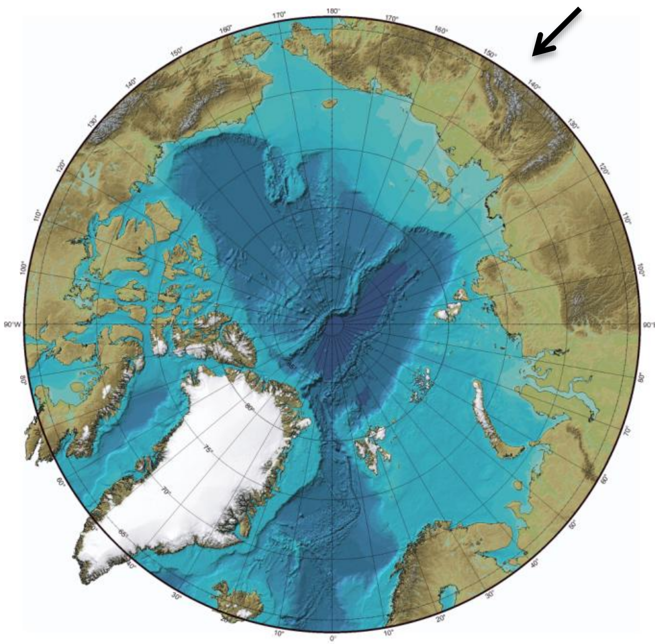
polarwatch.noaa.gov



Standard Rectilinear coordinates
versus
Polar coordinates

Nowhere on earth do mapping projections become as critical an issue as when working with data from polar regions.

PW data products will all be served in a projection(s) appropriate for high latitudes, such as a form of the polar stereographic map projection.



Sea Ice Thickness from the Vantage Point of Space

- Measurement Concept

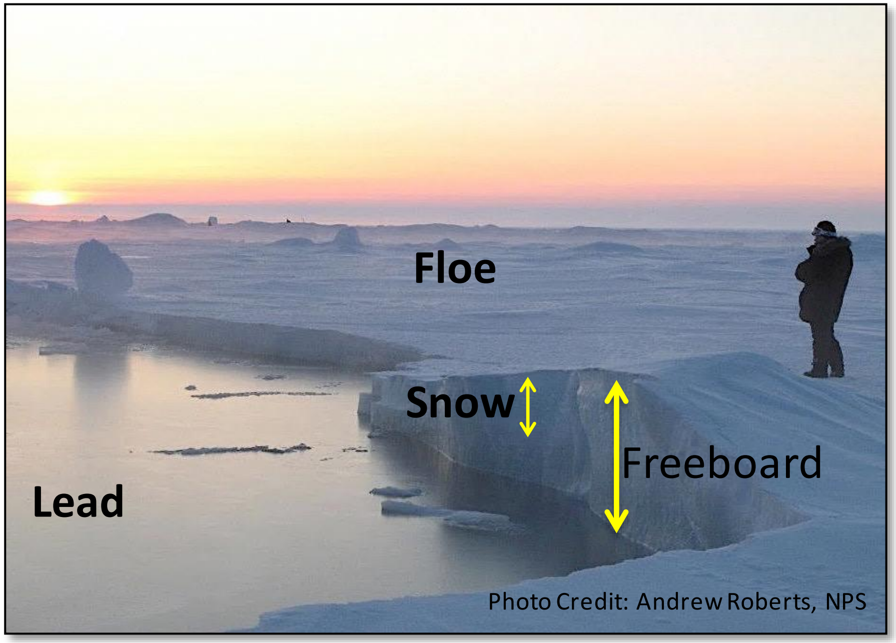


Photo Credit: Andrew Roberts, NPS

Sea Ice Thickness, h_i, from a laser altimeter:

$$h_{\mathrm{i}} = \frac{f_{\mathrm{s}}\rho_{\mathrm{w}}}{(\rho_{\mathrm{w}} - \rho_{\mathrm{i}})} + \frac{h_{\mathrm{s}}(\rho_{\mathrm{s}} - \rho_{\mathrm{w}})}{(\rho_{\mathrm{w}} - \rho_{\mathrm{i}})}$$

Where,

f_s = laser-measured freeboard

h_s = snow thickness

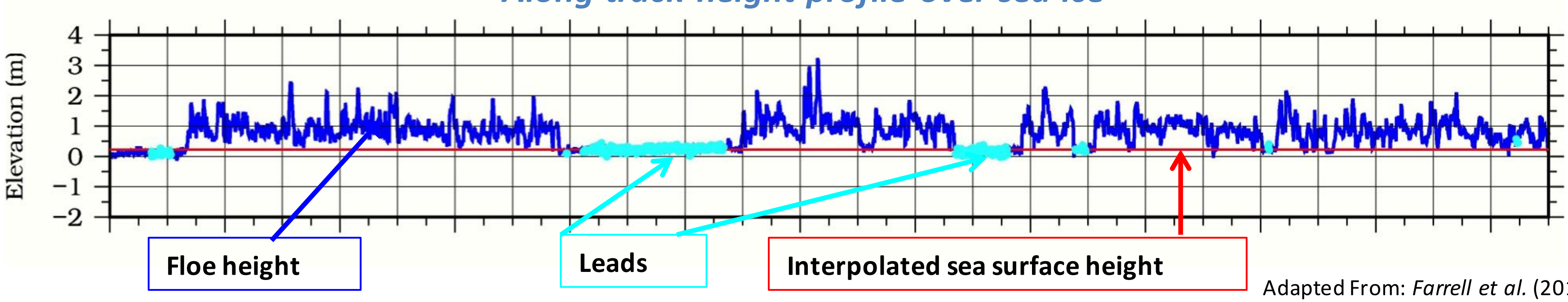
ρ_i = ice density

ρ_s = snow density

ρ_w = sea water density

$\left.\right\}$ Auxiliary inputs

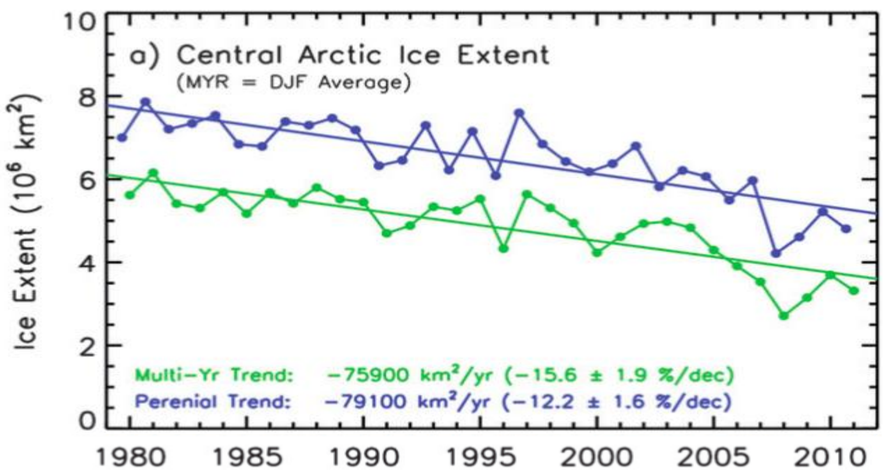
Along-track height profile over sea ice



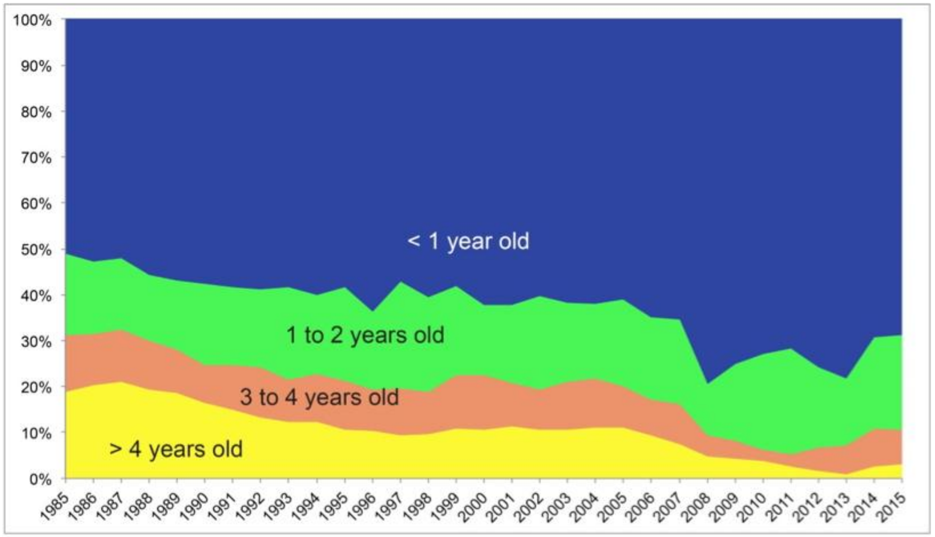
Adapted From: *Farrell et al.* (2014)

- Observations over last 3 decades show largest losses in the Arctic Ocean are to multi-year ice (MYI) cover

- *Comiso* [2012] measured a decline of ~ 15% in the extent of MYI cover from 1979-2011



Comiso [2012]



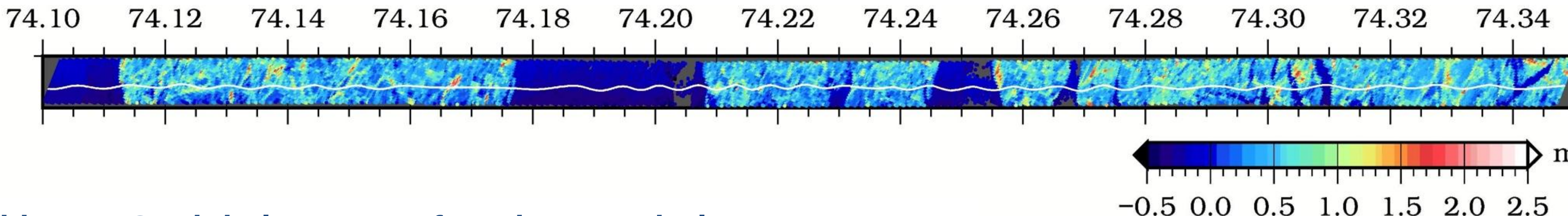
Tschudi et al., CU-Boulder, Arctic Report Card [2014]

A declining MYI cover will precondition the pack for further loss: altering the mass and energy budgets of the Arctic Ocean

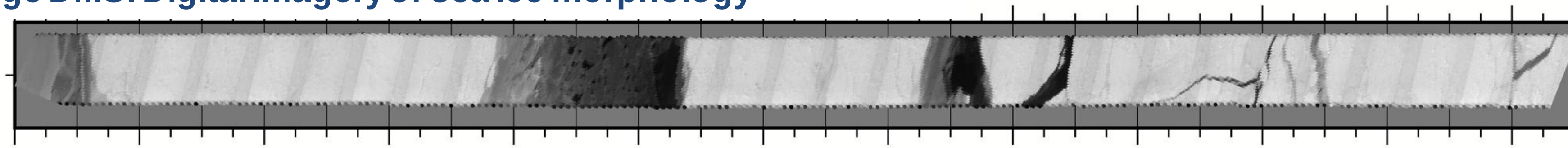
Photon Counting Technique over Sea Ice

- Demonstration of ICESat-2 emulator over Sea Ice: Coordinated Arctic Aircraft Experiment, March 2012
- NASA IceBridge: Multi-instrumented Airborne Survey
- MABEL Airborne simulator for ICESat-2

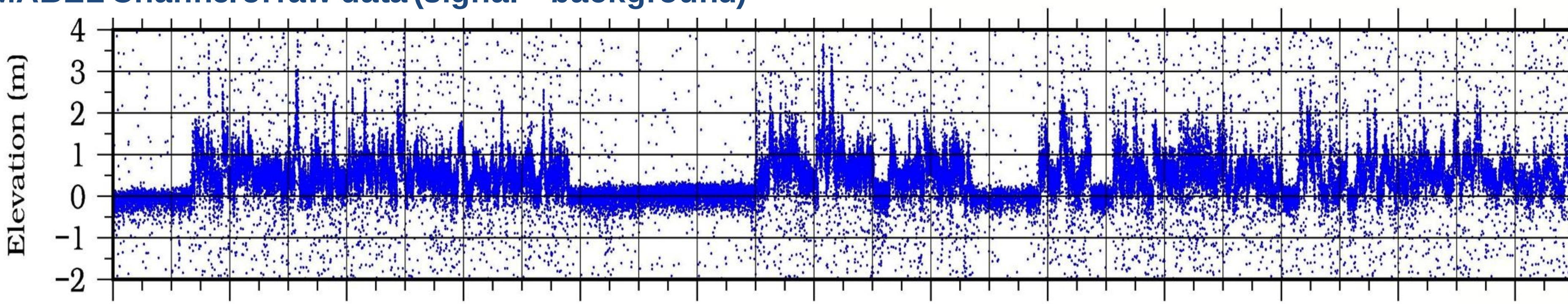
IceBridge ATM: Sea Ice Surface elevation above Geoid



IceBridge DMS: Digital Imagery of sea ice morphology

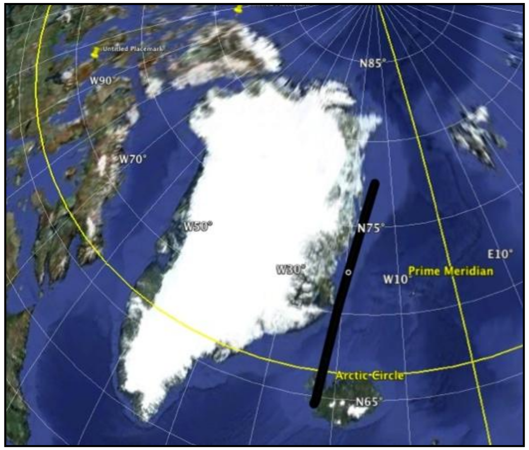


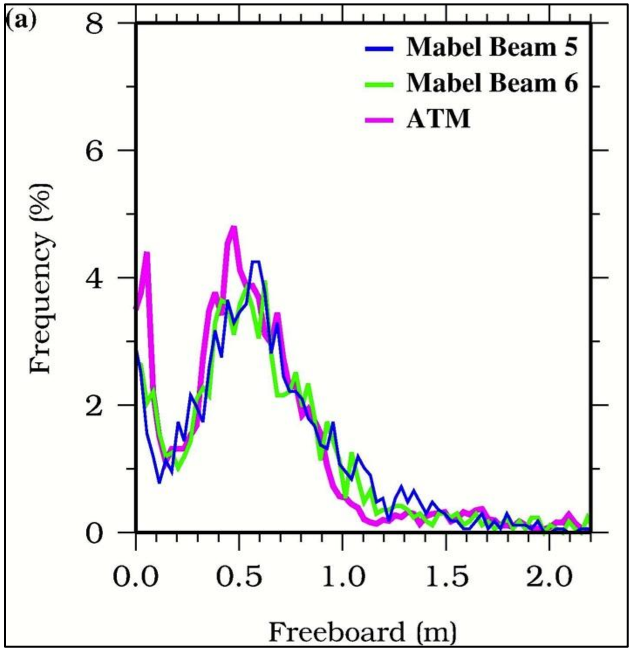
MABEL Channel 5: raw data (signal + background)



***Source:** Farrell et al.*, 2015

MABEL Sea Ice Freeboard Validation





Sea Ice Freeboard Distribution: Greenland Sea, April 2012

Sea-ice conditions		Ice floes with pressure ridges and narrow refrozen leads
Atmospheric conditions		Clear
Mean sea-ice freeboard* (m)	ATM	0.55
	MABEL beam 6	0.57
	MABEL beam 5	0.6
	OIB product	0.53
Modal sea-ice freeboard* (m)	ATM	0.475 ± 0.015
	MABEL beam 6	0.625 ± 0.015
	MABEL beam 5	0.575 ± 0.015
Mean snow thickness (m)	OIB product	0.24
Mean sea-ice thickness (uncertainty) (m)	ATM	3.60 (0.60)
	MABEL beam 6	3.79 (0.53)
	MABEL beam 5	4.07 (0.53)
	OIB product	3.97 (0.61)

Source: *Farrell et al.*, 2015

ICESat-2 Data Latency