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

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Arctic Ocean

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.

Global coverage ~ 18 – 27 x 10^6 km^2
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.


ICESat: 2003–2009 GLAS Laser Altimeter

CryoSat-2: 2010–present SIRAL Radar Altimeter

Operation IceBridge: 2009–present

plus SARAL/AltiKa and SRAL on Sentinel-3!

ICESat-2
Due for launch: 2018

81.5°N
86°N
88°N
90°N
88°N
**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 $\rightarrow$ SSH profiles
Difference to generate freeboard

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

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*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)

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29 March 2017
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

Sinéad L. Farrell
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29 March 2017
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
US – EU Partnerships in the Arctic
Sentinel-3A and NASA IceBridge observations

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.

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.
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
• 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.

**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

Figure courtesy Ron Kwok, JPL
Sea Ice Type/Age
- tracking multi-year ice (MYI) extent

Ice-type masks are derived from radar backscatter ($\sigma_0$) 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 $\sigma_0$ due to motion of Marginal Ice Zone [MIZ]

- High-resolution data set (4.45 km) → consistent with resolution of altimetry observations
- Small pole hole → MYI mask area extends to 89.5°N
Inter-annual Variability in MYI Extent
- March 2009 - 2015

2009 2011 2013 2015

7-yr Mean: $3.05 \times 10^6 \text{ km}^2 \pm 2.08 \times 10^5 \text{ km}^2$
SAR Ocean Products Systems (SAROPS): An Integrated Approach to SAR Products

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29 March 2017
Derived Wind Speed Image
- at 500 m Resolution

Frank Monaldo
NCWCP, College Park, MD
29 March 2017
Automated Oil Spill Masking
- Using a Neural Network Approach

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

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

Example PNG Output
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 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**

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

Sea Ice Thickness, $h_i$, from a laser altimeter:

$$h_i = \frac{f_s \rho_w}{(\rho_w - \rho_i)} + \frac{h_s (\rho_s - \rho_w)}{(\rho_w - \rho_i)}$$

Where,

- $f_s$ = laser-measured freeboard
- $h_s$ = snow thickness
- $\rho_i$ = ice density
- $\rho_s$ = snow density
- $\rho_w$ = sea water density

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

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

*Comiso* [2012]

Photons 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

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29 March 2017
MABEL Sea Ice Freeboard Validation

Sea Ice Freeboard Distribution: Greenland Sea, April 2012

Sea-ice conditions

<table>
<thead>
<tr>
<th>Ice floes with pressure ridges and narrow refrozen leads</th>
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<tbody>
<tr>
<td>ATM</td>
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<tr>
<td>MABEL beam 6</td>
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<tr>
<td>MABEL beam 5</td>
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<tr>
<td>OIB product</td>
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</tbody>
</table>

Atmospheric conditions

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<th>Mean sea-ice freeboard* (m)</th>
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Modal sea-ice freeboard* (m)

<table>
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*Note: Freeboard is the vertical distance between the surface of the ocean and the ice surface.

**Source:** Farrell et al., 2015
ICESat-2 Data Latency

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