

Satellite remote sensing of sea ice – a brief overview

Observations & Information Products

L. Brucker, L. Connor, S. Helfrich, C. Jackson, Y. Liu et al.

NOAA NESDIS Center for Satellite Applications & Research (STAR)

How can we monitor changes over the cryosphere?

Weather Stations, Buoys, Field measurements

Regional and Climate Models

Remote Sensing

Complementary approaches



How can we monitor changes over the cryosphere?

Complementary approaches

Weather Stations, Buoys, Field measurements

- ✱ Direct in situ measurements of geophysical variables
- ✱ Local measurements
- ✱ Requires maintenance / on site presence

Regional and Climate Models

- ✱ Full spatial coverage and good temporal resolution
- ✱ Provide high number of variables
- ✱ Depend on the parameterizations...

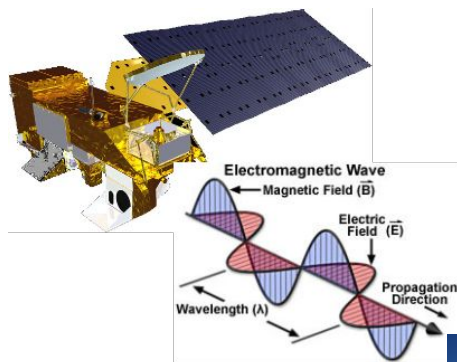
Remote Sensing

- ✱ Spatial coverage
- ✱ Offers measurements...
- ✱ ... an electromagnetic measurement

Observation vs Information



Developing algorithms to monitor cryospheric properties

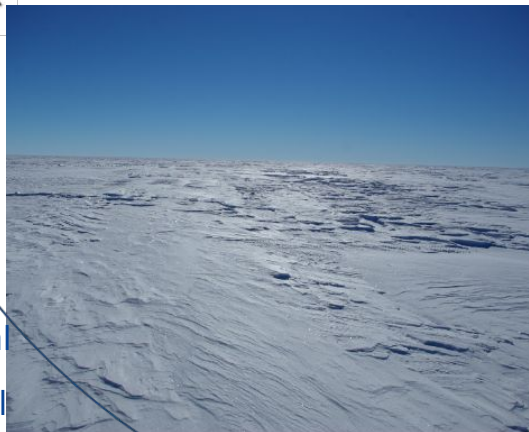


Observation = f (radiative transfer interactions)

Use of models to relate snow and radiation properties

Models & algorithms can be:

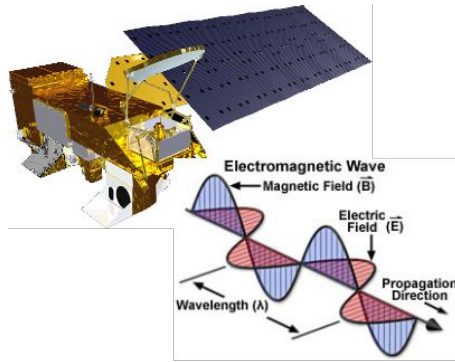
- * Theoretical
- * Semi empirical
- * Empirical



Ice sheet



Developing algorithms to monitor cryospheric properties



Observation = f (radiative transfer interactions)

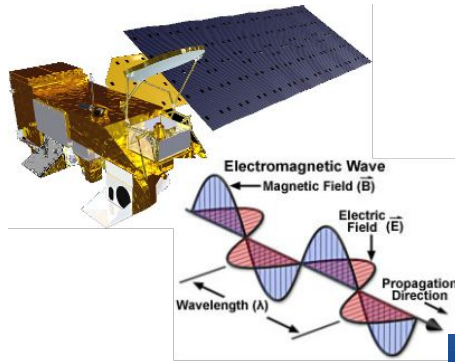
Use of models to relate snow and radiation properties

Models & algorithms can be:

- * Theoretical
- * Semi empirical
- * Empirical



Developing algorithms to monitor cryospheric properties



Observation = f (radiative transfer interactions)

Use of models to relate snow and radiation properties

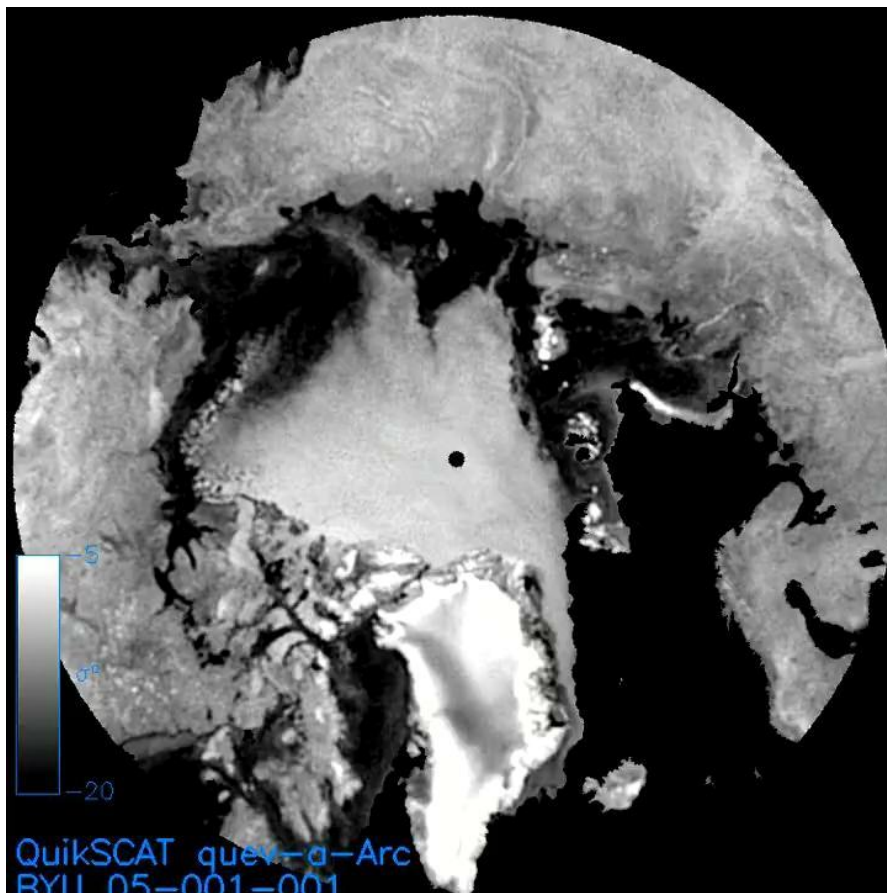
- Models & algorithms can be:
- * Theoretical
 - * Semi empirical
 - * Empirical



Sea ice



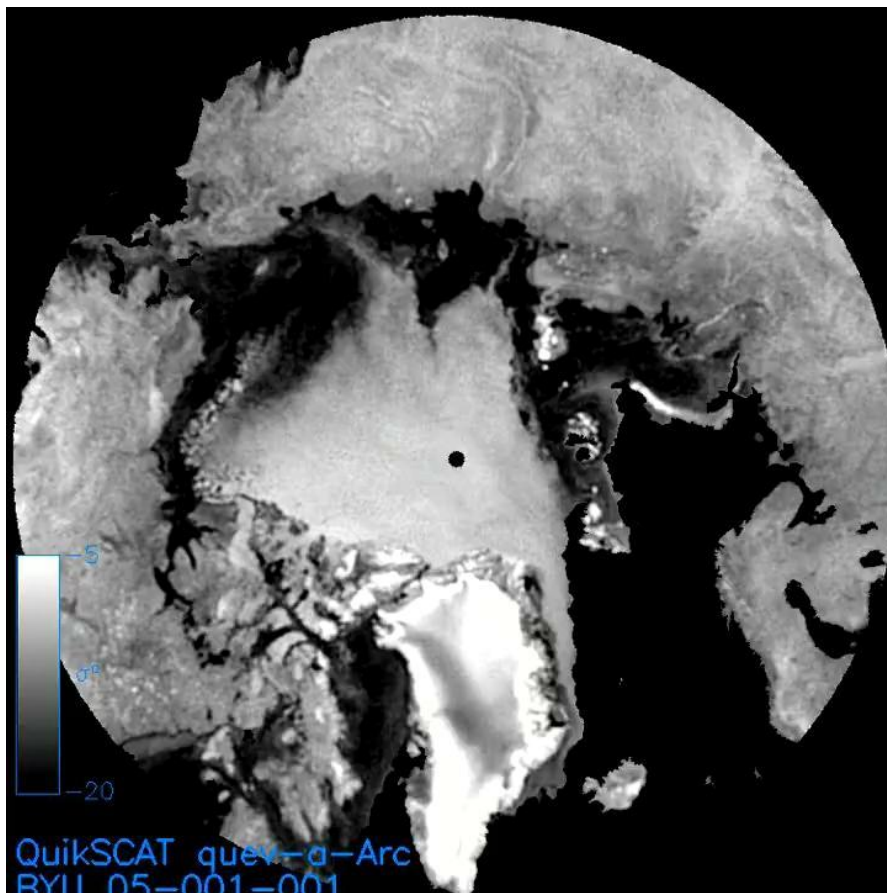
From Observations to Sea Ice Information



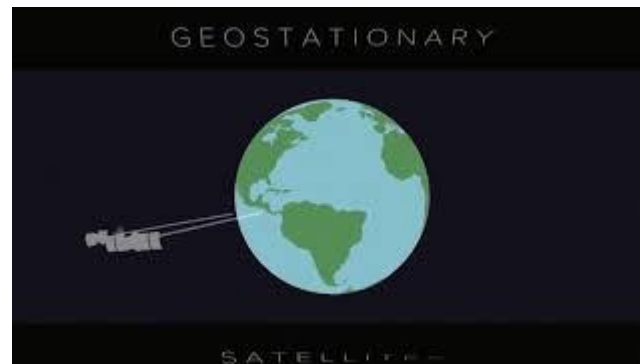
[QuikSCAT \(byu.edu\)](http://QuikSCAT(byu.edu))



From Observations to Sea Ice Information

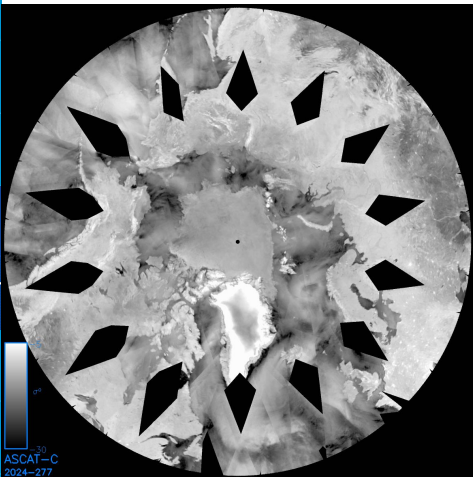


[QuikSCAT \(byu.edu\)](http://QuikSCAT(byu.edu))



Sensor on a polar orbiting satellite observes the polar regions ~ 14 x/day

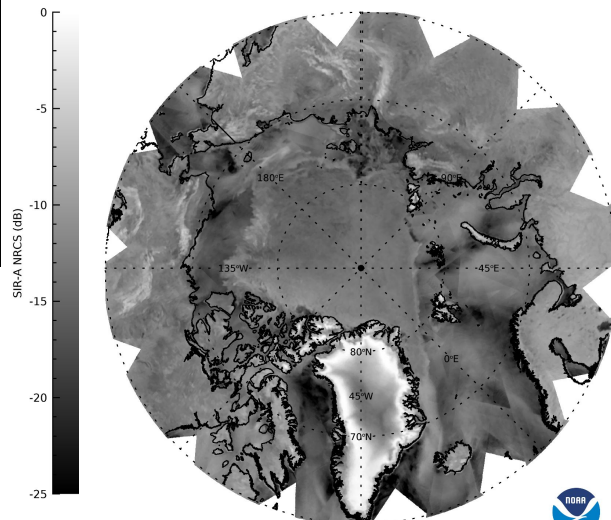
From Observations to Sea Ice Information



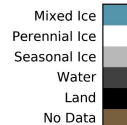
ASCAT-C
2024-277

[Advanced Scatterometer \(ASCAT\) Products \(noaa.gov\)](https://noaa.gov)

ASCAT (Metop-C) SIR-A Normalized Radar Cross Section
19-Oct-2024 (Day 293)



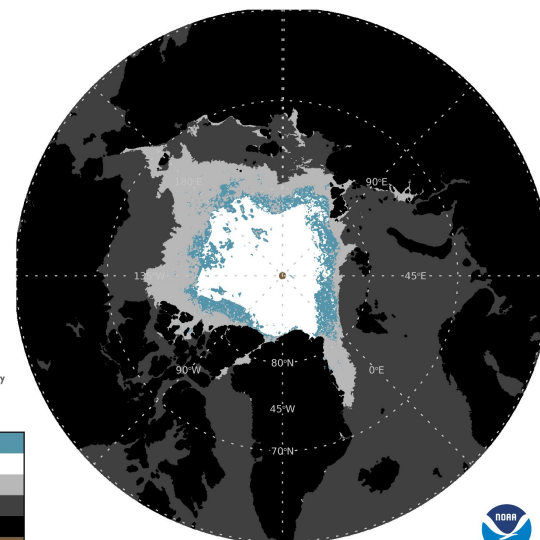
Produced at NOAA/NESDIS/STAR: 20 Oct 2024 06:42 UTC



[Ice Classification, Metop-C ASCAT, Arctic, PolarWatch](https://noaa.gov)

[USA Sea Ice Data Products - Sea Ice \(noaa.gov\)](https://noaa.gov)

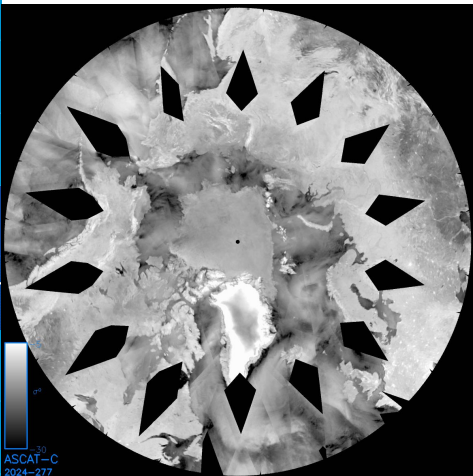
ASCAT (Metop-C) NOAA Ice Mode Mask
19-Oct-2024 (Day 293) (Preliminary)



Processed at NOAA/NESDIS/STAR: 20 Oct 2024 06:44Z



From Observations to Sea Ice Information



ASCAT-C
2024-277

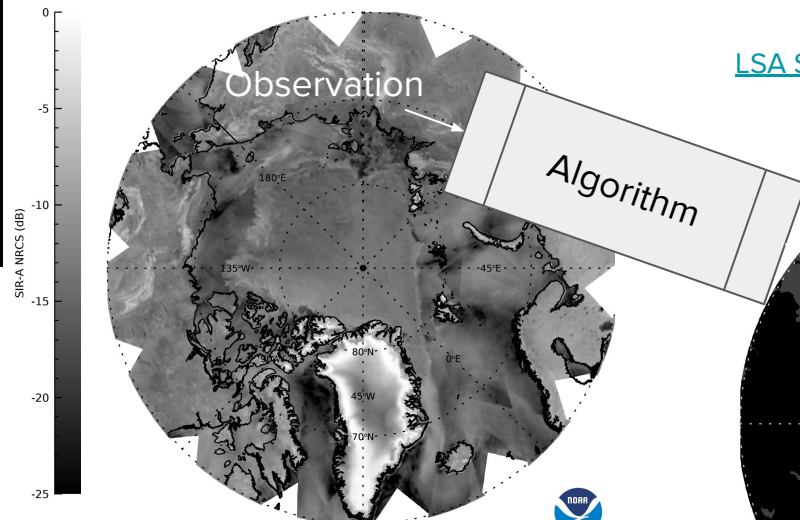
[Advanced Scatterometer \(ASCAT\) Products \(noaa.gov\)](https://noaa.gov)

Provides: ice type classification
multiyear, first-year ice

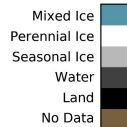
Satellites, e.g.
Scatterometer: ASCAT
passive microwave: AMSR2
vis/IR: JPSS VIIRS, GOES ABI

ludovic.brucker@noaa.gov

ASCAT (Metop-C) SIR-A Normalized Radar Cross Section
19-Oct-2024 (Day 293)



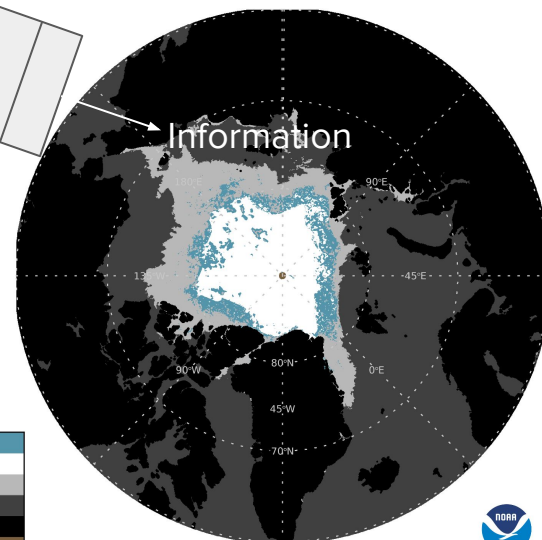
Produced at NOAA/NESDIS/STAR: 20 Oct 2024 06:42 UTC



[Ice Classification, Metop-C ASCAT, Arctic, PolarWatch](#)

[LSA Sea Ice Data Products - Sea Ice \(noaa.gov\)](https://noaa.gov)

ASCAT (Metop-C) NOAA Ice Mode Mask
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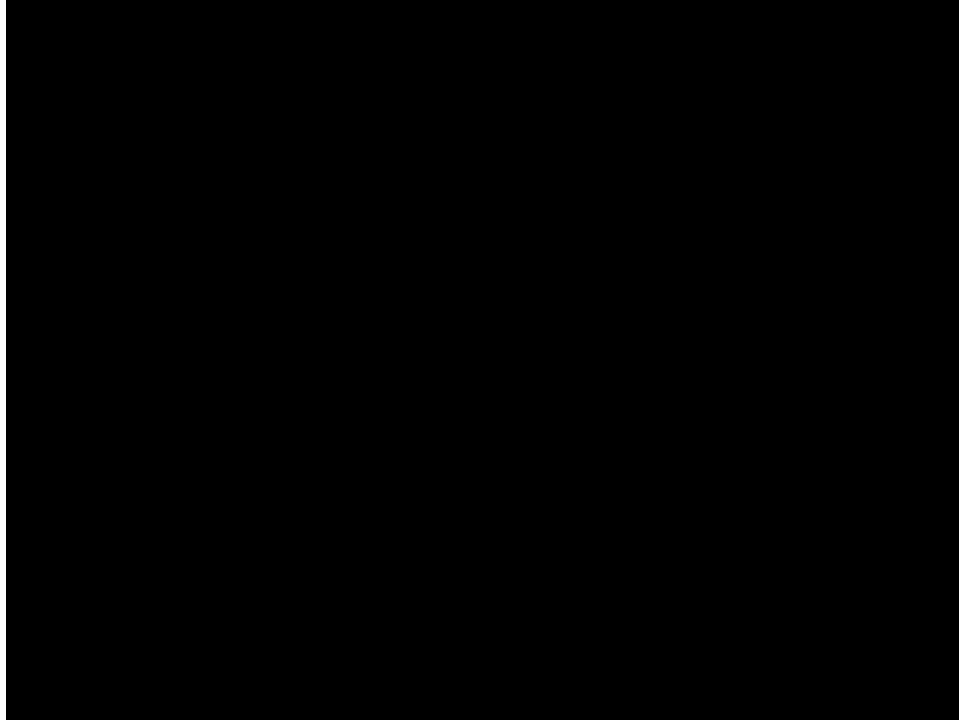


Processed at NOAA/NESDIS/STAR: 20 Oct 2024 06:44Z



Polar Orbiting

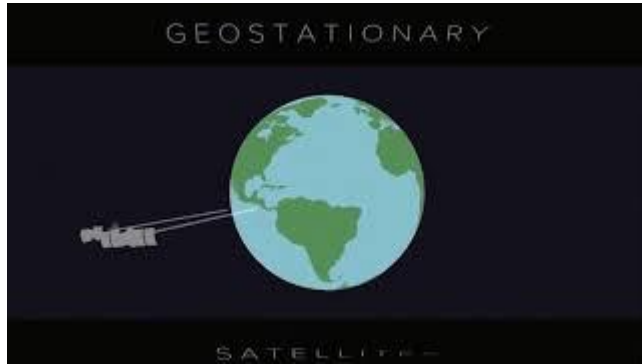
NOAA JPSS (VIIRS)



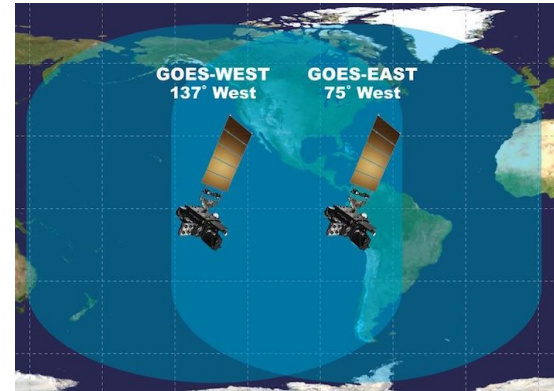
observes the polar regions 14x/day



Polar Orbiting vs Geostationary



Some spatial coverage of high latitudes



Observations every 30 s to 10 min

[GOES Overview \(noaa.gov\)](https://www.noaa.gov/goes-overview)

NOAA GOES East satellite observations

GOES: Geostationary Operational Environmental Satellites



[Ice Eddies in the Labrador Sea](#)

GOES-East true color RGB, April 18, 2020



[Ice on the Move in Lake Superior](#)

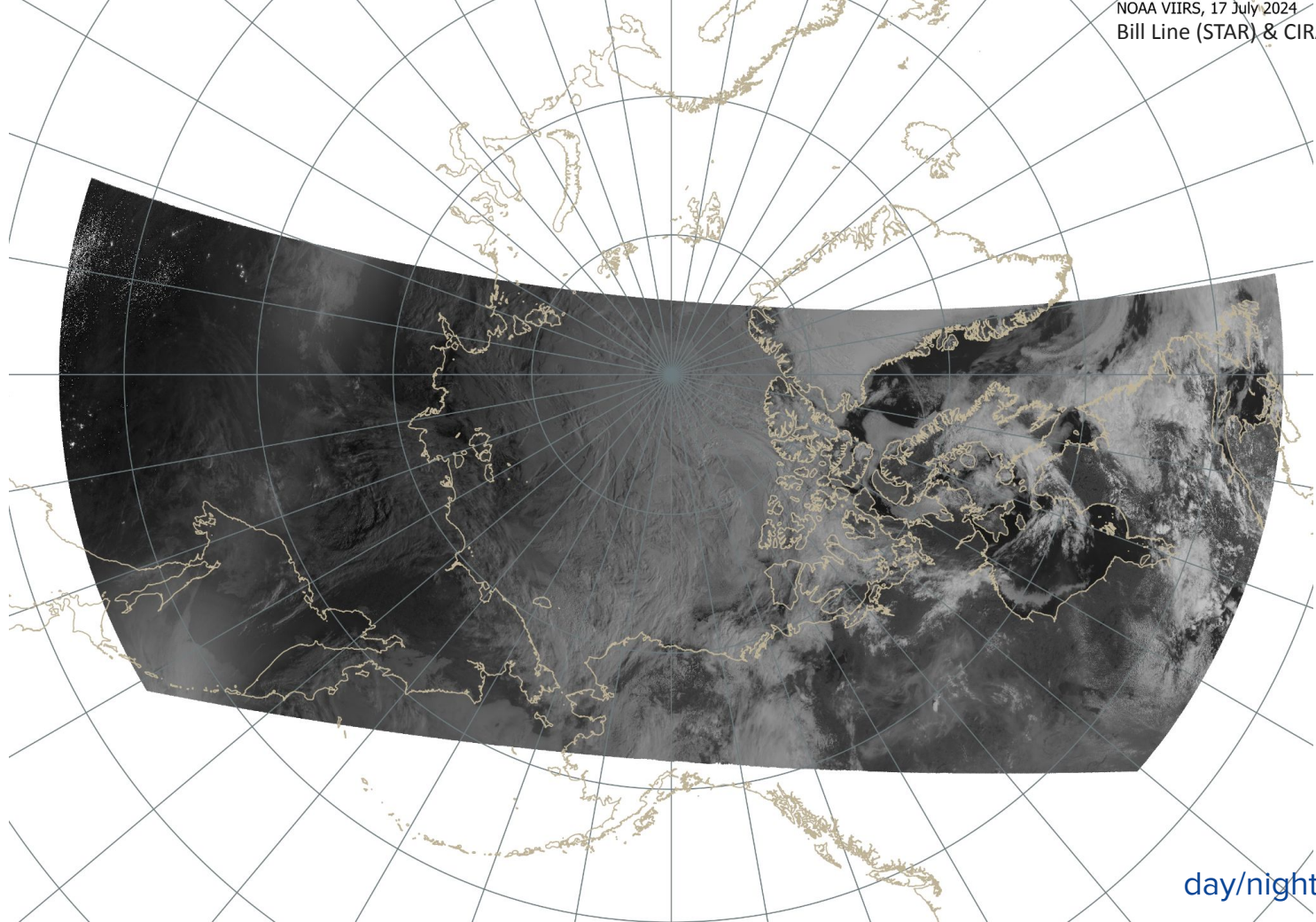
February 19, 2019, GOES East



[Ice Flows around Newfoundland and Labrador](#)

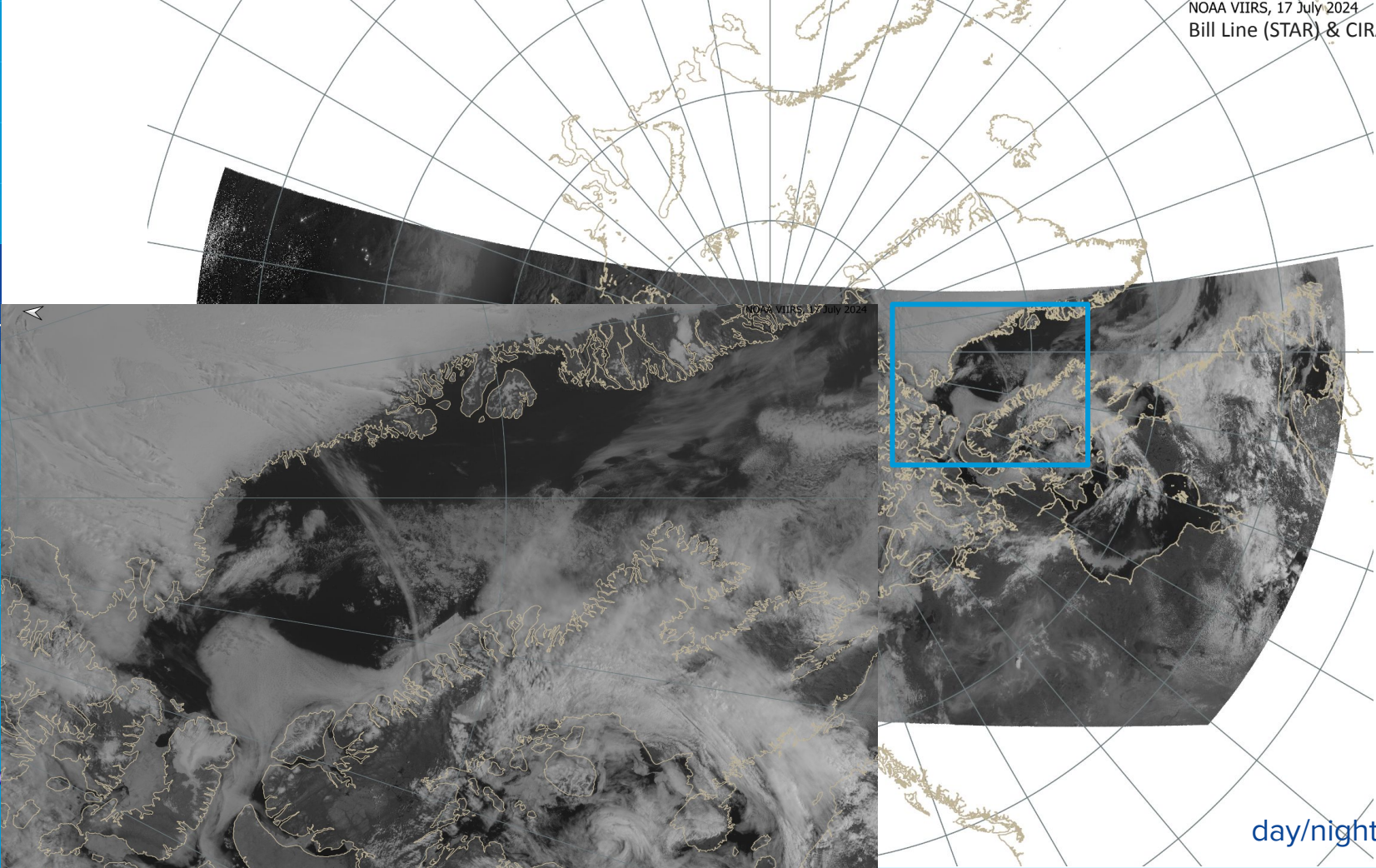
GOES East March 27, 2019

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nesdis.noaa.gov and [4 more links](#)
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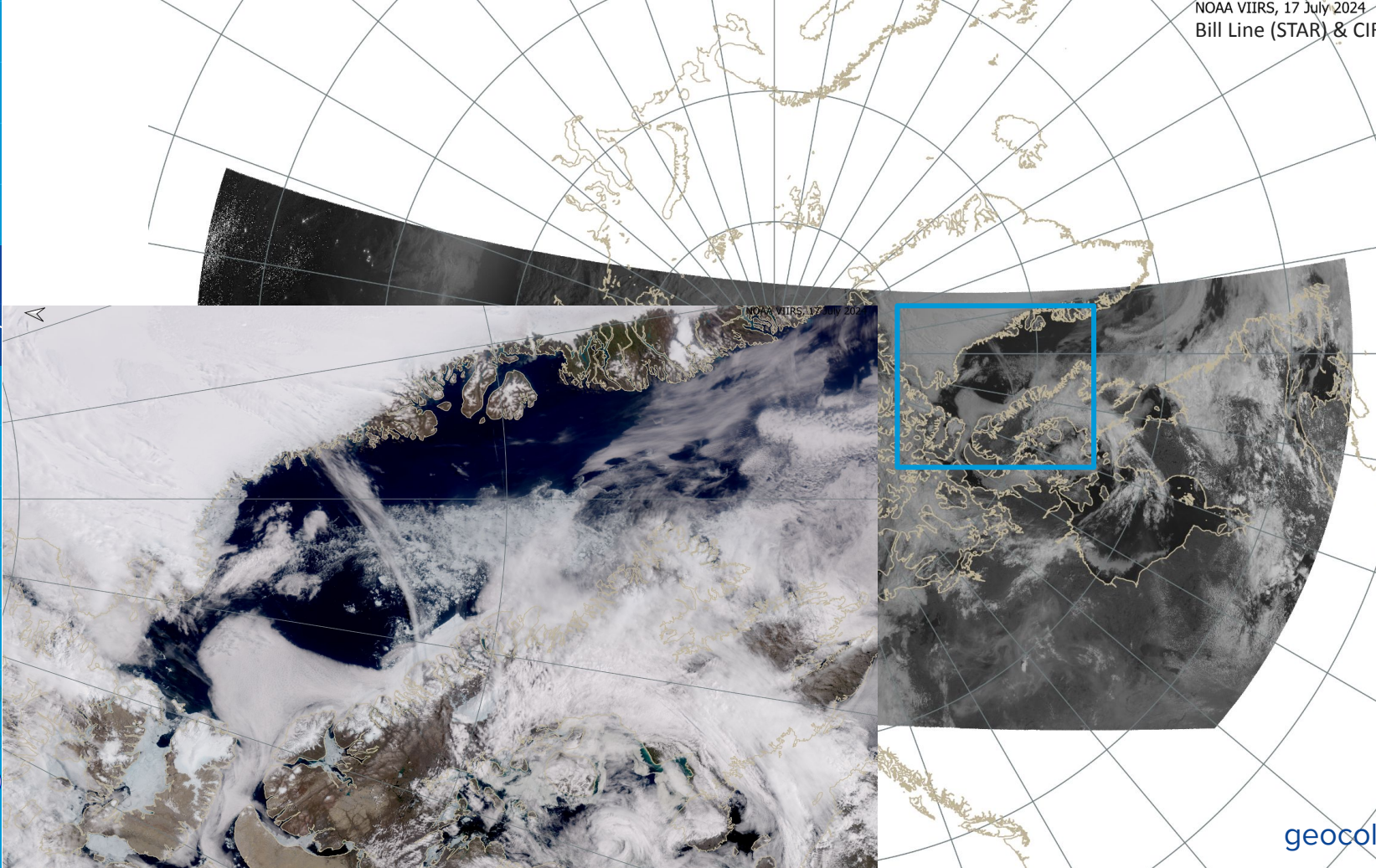
day/night band, 0.7 μ m



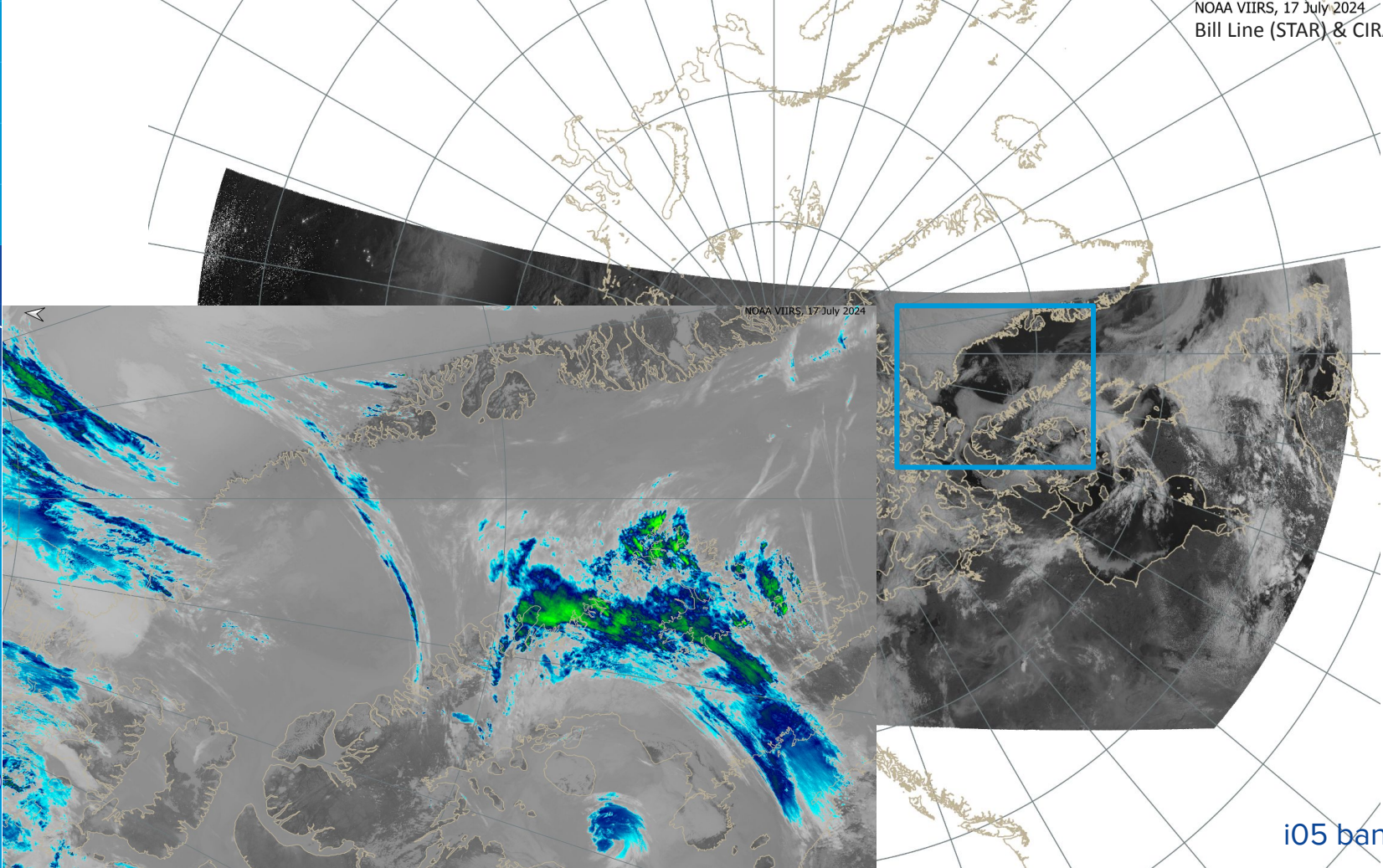


NOAA VIIRS, 17 July 2024

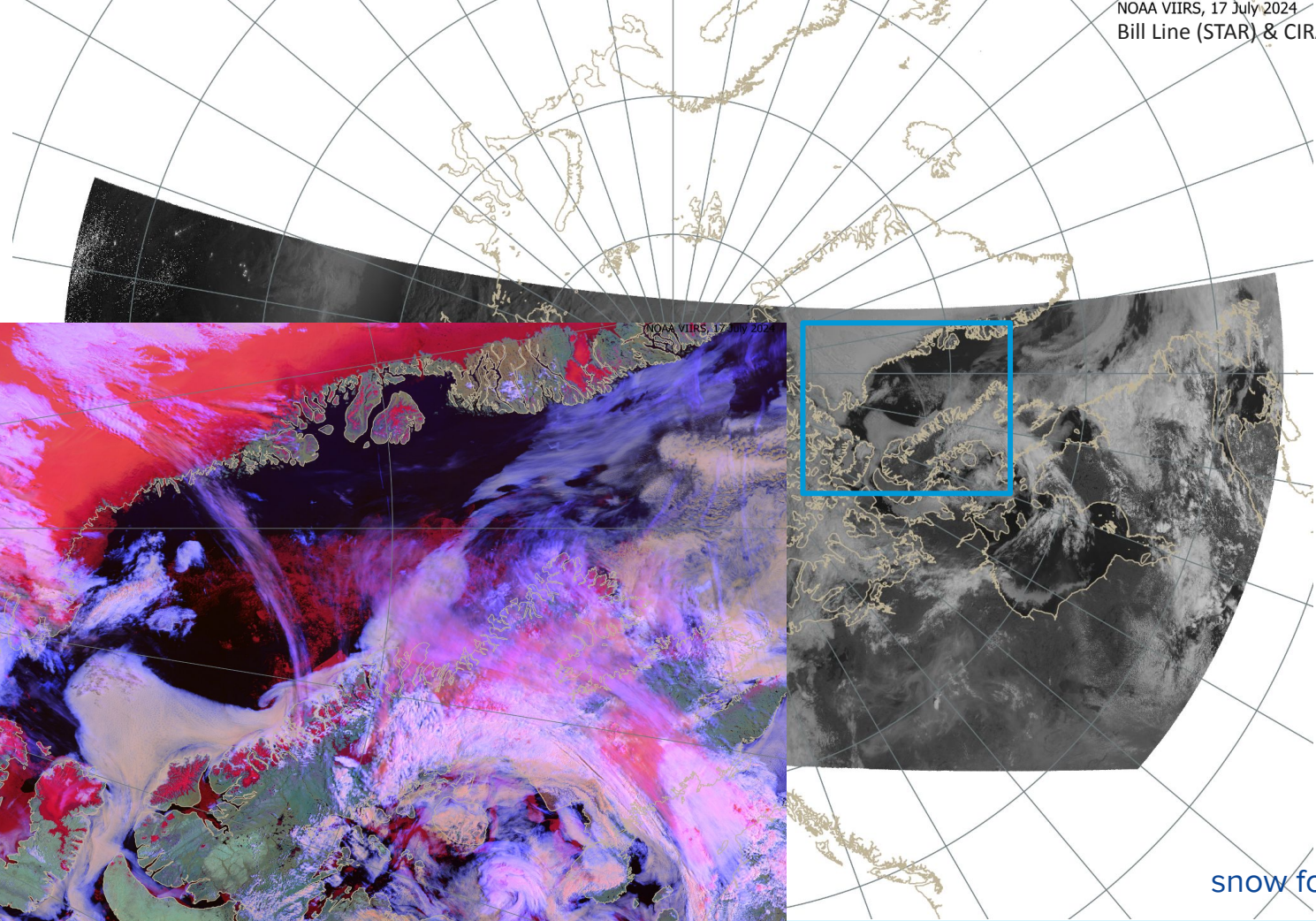
day/night band, 0.7 μ m



geocolor



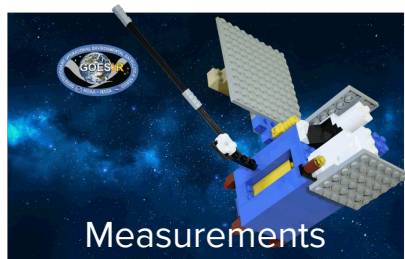
i05 band, 11.45μm



NOAA VIIRS, 17 JULY 2024

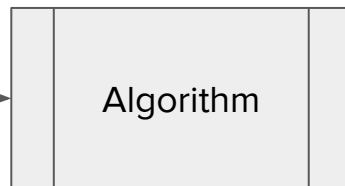
snow fog

From Observations to Information

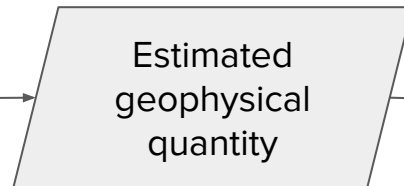


Measurements
(a.k.a. observations)

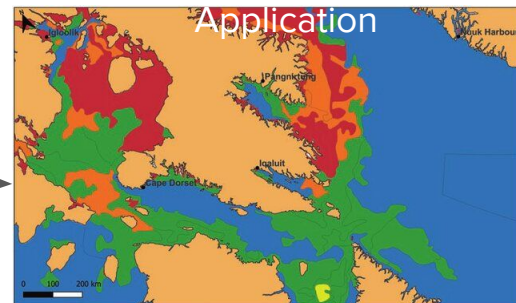
[LEGO Model](#) | [GOES-R Series](#)



Empirical
Semi-empirical
Theoretical



e.g. concentration
thickness
type
motion



Risk Index Outcome (RIO)

Blue: RIO ≥ 30 : Open Water Operations	Light Green: RIO between -10 and 0: Elevated Operational Risk
Green: RIO between 0 and 30: Normal Ice Operations	Orange: RIO between -10 and -20: High Risk Operations
Red: RIO < -20 : Extreme Risk Operations	

Ship Type : Polar Class 1A
Ice Analysis Source : US National Ice Centre
Ice Analysis Date : July 7th, 2020

[Stoddard et al. 2024](#)

The output quality depends on:

- . the quality of the observations
- . the performance of the algorithm
- . the completeness of the metadata

Metadata

- Projection
- Spatial (grid) resolution
- Temporal resolution

...

13:00 - 13:30 Presentation 8: ERDDAP Demo

Cara Wilson

13:30 - 13:45 Presentation 9: PolarWatch Portal Demo

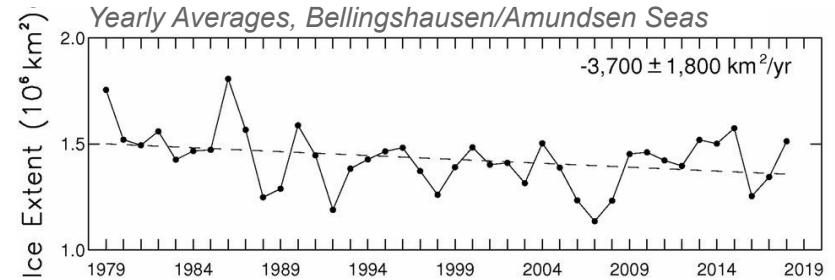
Sunny Hospital

Need for sea ice concentration?

Near real time, high resolution for a ship campaign



Long term data for studying teleconnection patterns



[Parkinson, 2019](#)

[NOAA Alaska Fisheries Science Center's Ice Seal](#)
[Research in the Eastern Bering Sea](#)
[Aboard the NOAA Ship Oscar Dyson](#)

[NOAA Climate.gov | Arctic Oscillation](#)

Need for sea ice concentration?

Near real time, high resolution for a ship campaign

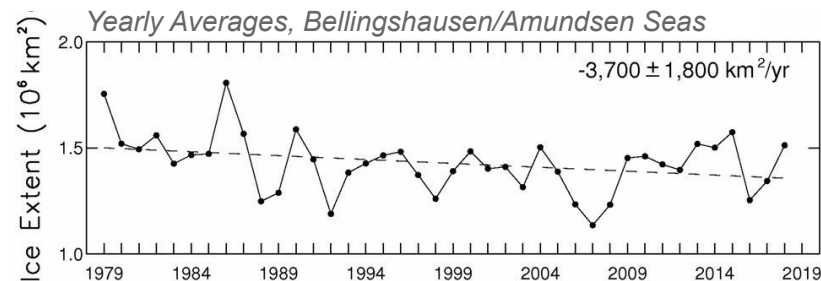


Ice concentration product characteristics:

- . 100 m resolution, or better
- . snapshot
- . available 3h after acquisition, or less
- . specific area of interest

[NOAA Alaska Fisheries Science Center's Ice Seal](#)
[Research in the Eastern Bering Sea Aboard the NOAA Ship Oscar Dyson](#)

Long term data for studying teleconnection patterns



[Parkinson, 2019](#)

Ice concentration product characteristics:

- . 25 km x 25 km grid cell
- . monthly averages
- . annual product release
- . hemispheric coverage

[NOAA Climate.gov | Arctic Oscillation](#)



Remote sensing: often a need for compromise

- . spatial resolution vs coverage
- . long term time series (legacy sensors) vs latest sensor
- . tolerance to atmospheric contributions (cloud, water vapor)
- . tolerance to the penetration of the radiation into the snow and ice media

Different satellite orbits

Low Earth Orbit (LEO) polar sun synchronous orbit vs Geostationary (GEO)

Different remote sensing techniques

Passive vs active

Scatterometry

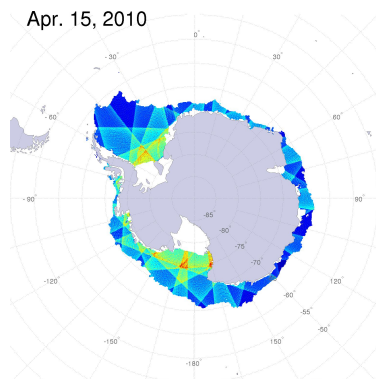
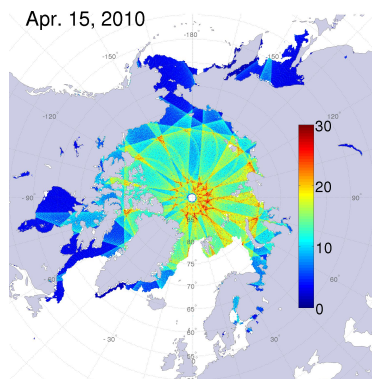
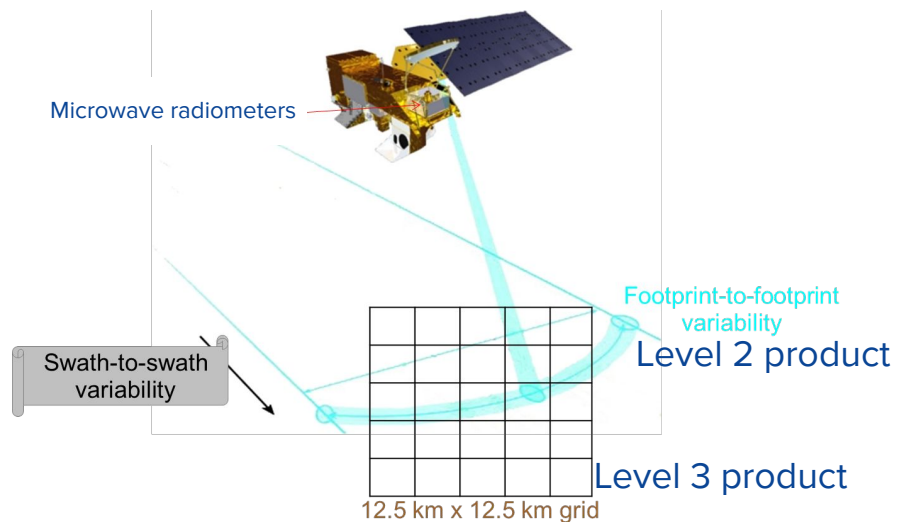
Altimetry

... interferometry, reflectometry

Different science groups,
i.e. different jargons

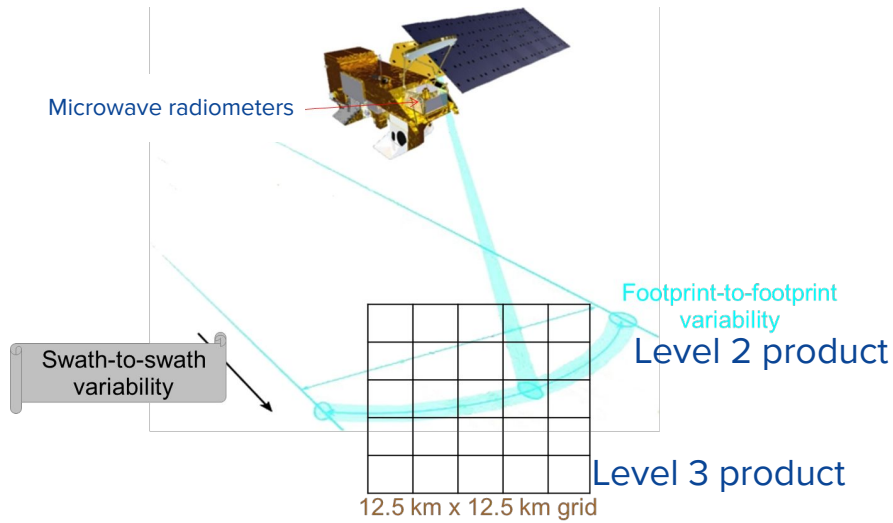
The use of a given satellite product is driven by your application need, your scope of research

Swath vs daily gridded products

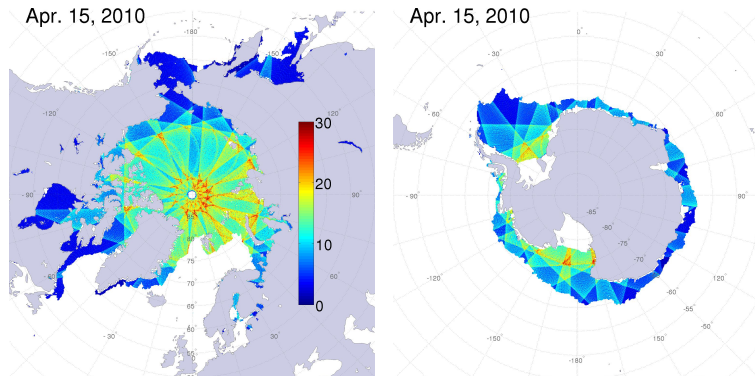
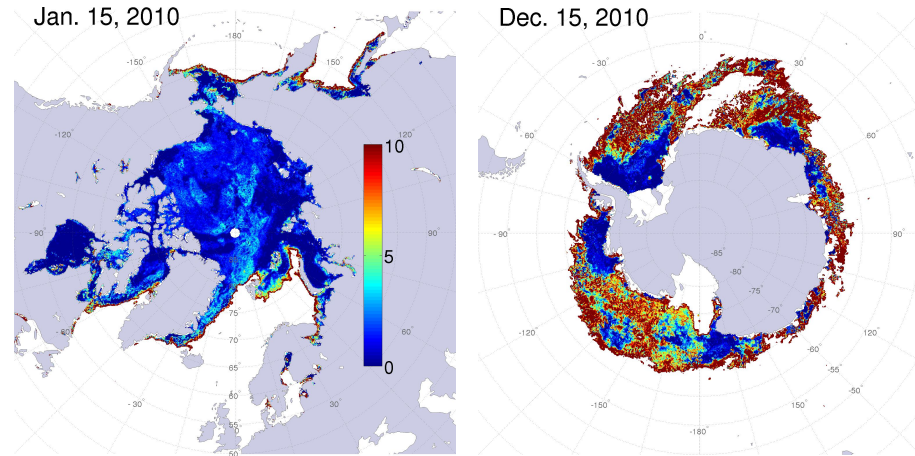


Number of observations per grid cell
where sea ice is present

Swath vs daily gridded products

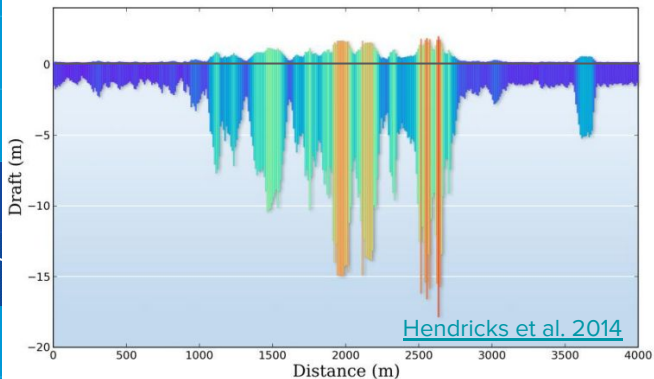


Sea ice concentration variability



Number of observations per grid cell
where sea ice is present

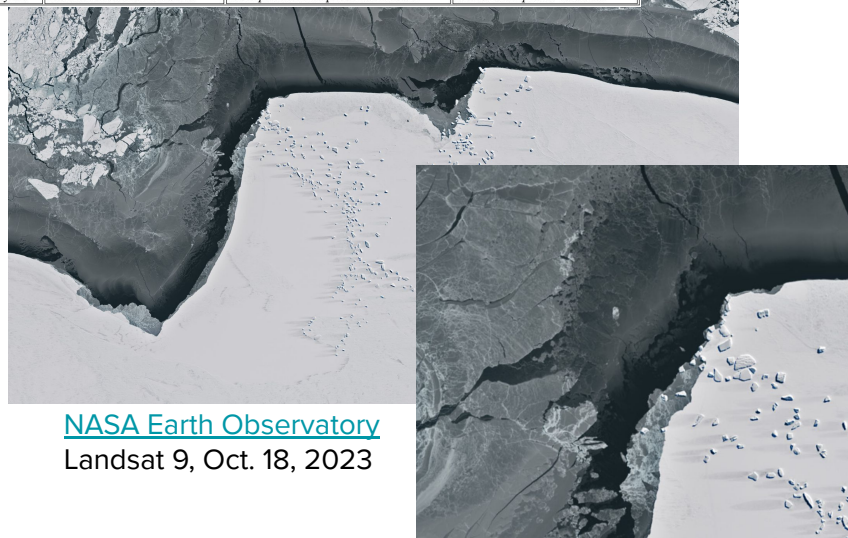
What sea ice looks like



WMO SEA-ICE NOMENCLATURE				
TERMINOLOGY - VOLUME I				
WMO/OMM/BMO - No.259 • Edition 1970 - 2017				
Linguistic equivalents				
Item No.	English	French	Russian	Spanish
I	Floating ice: Any form of ice found floating in water. The principal kinds of floating ice are <i>lake ice</i> , <i>river ice</i> , and <i>sea ice</i> which form by the freezing of water at the surface, and <i>glacier ice (ice of land origin)</i> formed on land or in an <i>ice shelf</i> . The concept includes ice that is stranded or grounded.	Glace flottante: Toute glace flottant dans l'eau. Les principales sortes de <i>glace flottante</i> sont la <i>glace de lac</i> , la <i>glace de rivière</i> , la <i>glace de mer</i> qui se forme par congélation de l'eau de mer en surface, et la <i>glace de glacier (glace d'origine terrestre)</i> formée sur la terre ferme ou provenant d'un <i>plateau de glace</i> . Ce concept comprend aussi la <i>glace jetée en côte</i> ou <i>échouée</i> .	Плавающий лёд: Любая форма льда, плавающего в воде. Основными видами <i>плавающего льда</i> являются: <i>озёрный лёд</i> , <i>речной лёд</i> , <i>морской лёд</i> , которые образуются вследствие замёрзания воды у поверхности, и <i>ледничерный лёд (лед материкового происхождения)</i> , образующийся на суше или на ледяном шельфе. Это понятие включает и лёд, свешив на мель.	Hielo Flotante: Cualquier forma de hielo que se encuentra flotando en el agua. Las principales clases de hielo flotante son el <i>hielo lacustre</i> , el <i>hielo fluvial</i> y el <i>hielo marino</i> , que se forman por la congelación del agua en superficie; y el <i>hielo de glacier (hielo de origen terrestre)</i> formado sobre tierra o en una <i>meseta de hielo</i> . El concepto incluye hielo encallado o varado.
I.1	Sea ice: Any form of ice found at sea which has originated from the freezing of sea water.	Glace de mer: Toute forme de glace trouvée en mer qui résulte du gel de l'eau de mer.	Морской лёд: Любая форма льда, встречающегося в море и образовавшегося в результате замёрзания морской воды.	Hielo marino: Cualquier forma de hielo en el mar originado por la congelación de sus aguas.
I.1.1	Fast ice: Cf. 3.1 - <i>Sea ice</i> which forms and remains fast along the coast, where it is attached to the shore, to an <i>ice wall</i> , to an <i>ice front</i> , between shoals or grounded icebergs. Vertical fluctuations may be	Banquise côtière: Voir 3.1 - <i>Glace de mer</i> qui se forme et reste fixe le long de la côte, où elle est attachée soit au rivage, soit à un <i>mur de glace</i> , soit encore à une <i>falaise de glacier</i> , entre des hauts-fonds ou des	Припай: См.3.1 - <i>Морской лёд</i> , который образуется и остается неподвижным вдоль побережья, где он прикреплен к берегу, к <i>ледной стене</i> , к <i>ледяному барьеру</i> , между отмелями или свешивши на отмели <i>айсбергами</i> . Во время изменения	Hielo fijo: Véase 3.1 - <i>Hielo marino</i> que se forma y permanece fijo a lo largo de la costa, quedando unido a la orilla, a un <i>frente</i> o <i>pared de hielo</i> , al frente de barrera, entre bajos fondos o <i>tiempos</i> varados.



[NASA Earth Observatory](#)
July 12, 2011



[NASA Earth Observatory](#)
Landsat 9, Oct. 18, 2023



Sea Ice Presence

Provides: ice/no ice information
binary

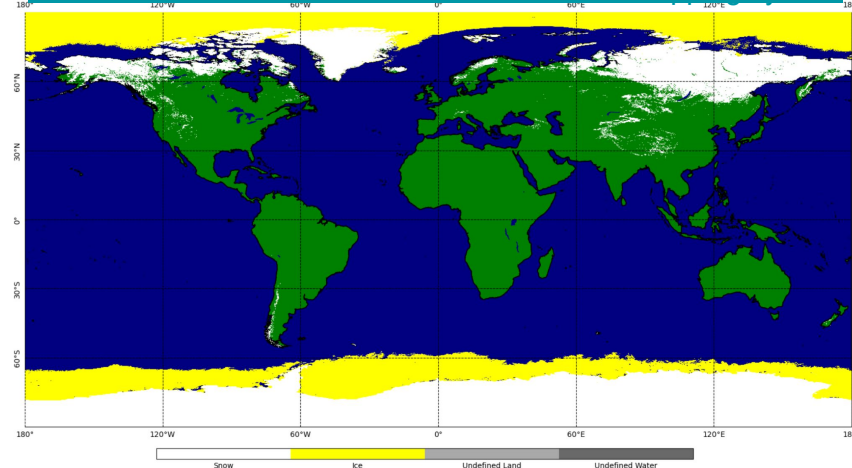
Satellites, e.g.

vis/IR: JPSS VIIRS, GOES ABI

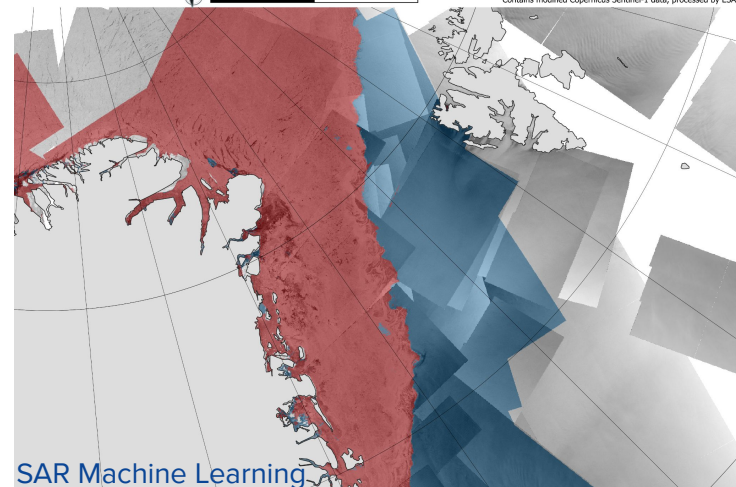
SAR: Sentinel-1, RCM

Derivatives: ice edge
ice extent

Global Multisensor Automated Snow and Ice mapping system



SAR 2024-10-19
0 250 500 km
RadarSat-2 © MDA Geospatial Services Inc.
RadarSat Constellation Mission © Government of Canada
Contains modified Copernicus Sentinel-1 data, processed by ESA





Sea Ice Concentration

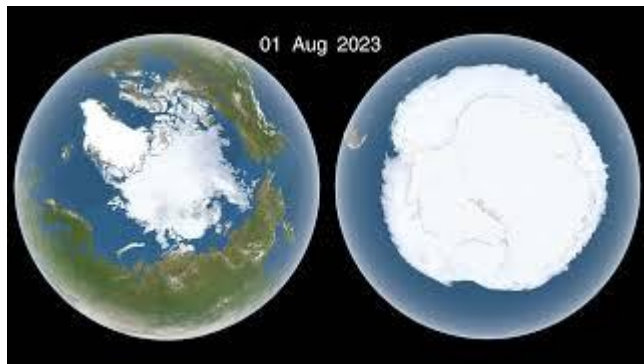
Provides: fraction of ice in each grid cell range (0 – 100%)

Satellites, e.g.

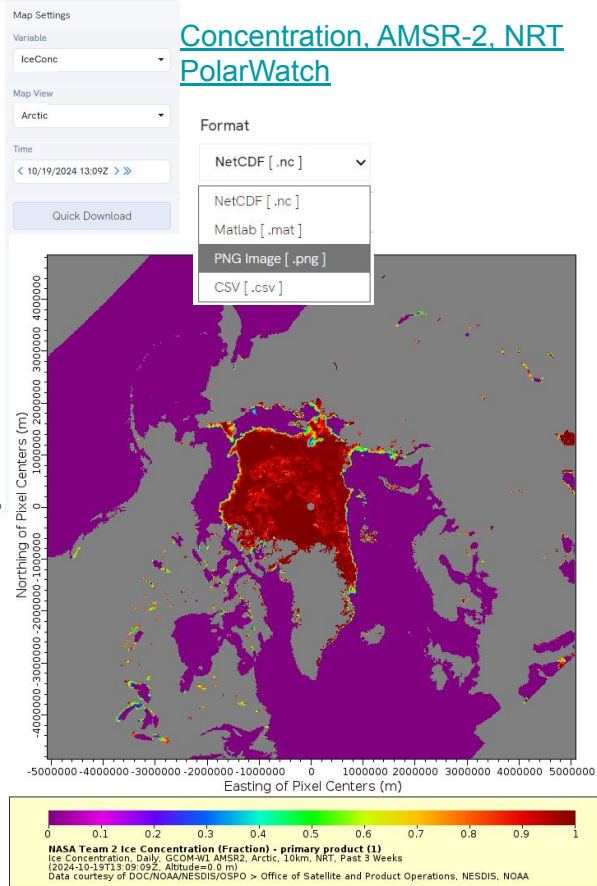
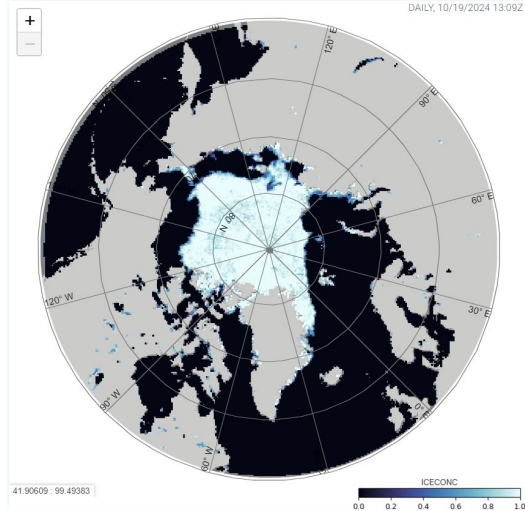
vis/IR: JPSS VIIRS, GOES ABI

passive microwave: AMSR2

Derivatives: ice extent & area



Daily Polar Sea Ice. Two Year History (NASA SVS)



Concentration, AMSR-2, NRT PolarWatch

Sea Ice Concentration, NOAA-20 VIIRS NRT PolarWatch

Temperature

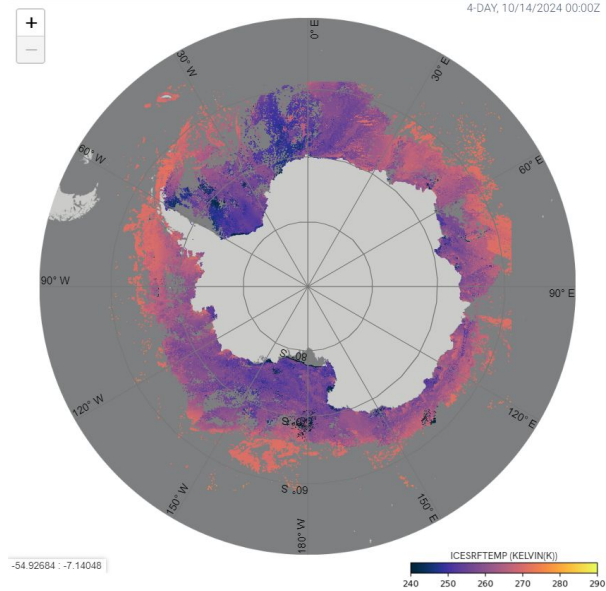
Provides: surface (skin) temperature
internal temperature

Satellites, e.g.

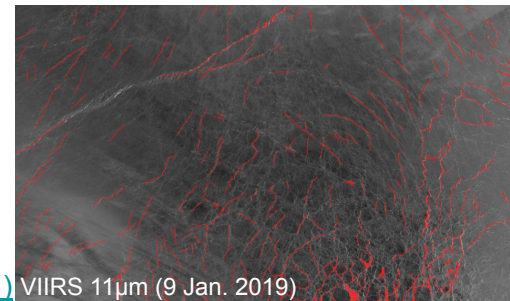
vis/IR: JPSS VIIRS, GOES ABI

passive microwave: AMSR2

Derivatives: melt onset dates lead presence



[Sea Ice Surface temperature, VIIRS NRT, PolarWatch](#)



[Hoffman et al. \(2021\)](#) VIIRS 11 μ m (9 Jan. 2019)



Sea Ice Thickness

Provides: information about the vertical dimension

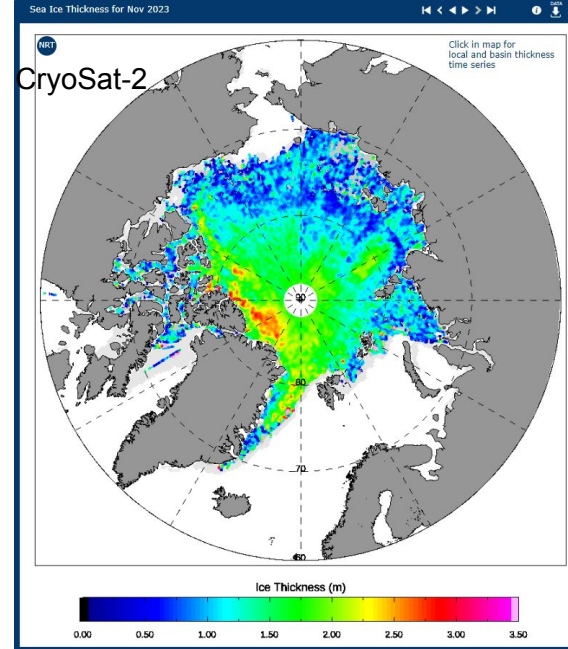
Satellites, e.g.

altimeters: CryoSat-2, ICESat-2

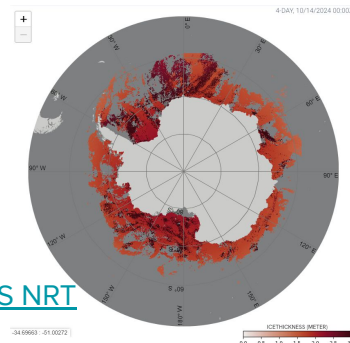
vis/IR: JPSS VIIRS

passive microwave: SMOS, SMAP

Derivatives: sea ice volume



[CryoSat Operational Monitoring \(ucl.ac.uk\)](http://ucl.ac.uk)



[Ice Thickness, VIIRS NRT PolarWatch](#)

Sea Ice Motion

Provides: speed, direction

Satellites, e.g.

SAR: Sentinel-1, RCM

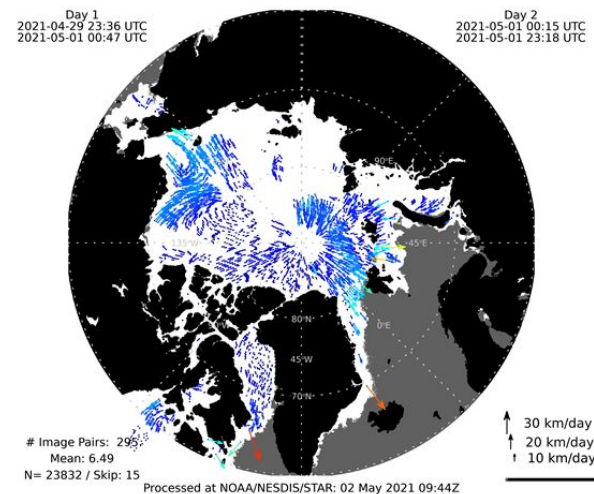
vis/IR: JPSS VIIRS, GOES ABI

passive microwave: AMSR2

Derivatives: Divergence Convergence



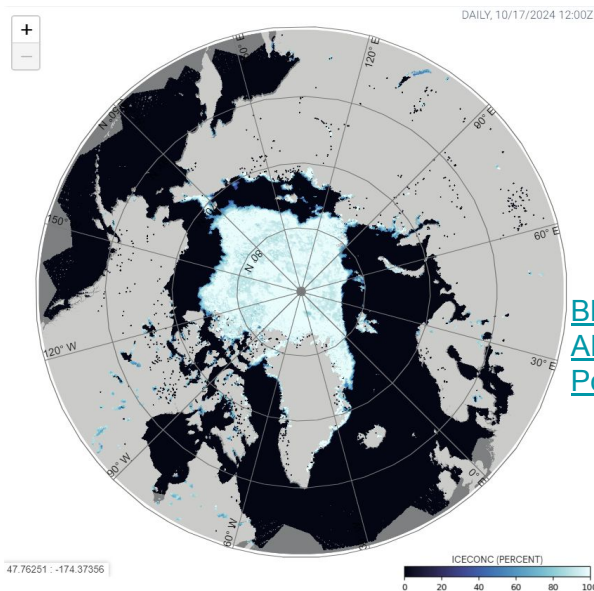
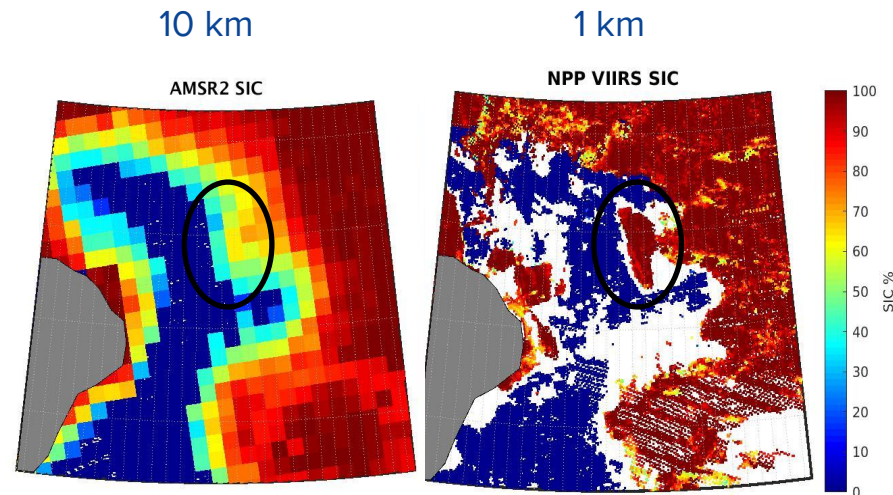
Old Arctic sea ice going down the drain



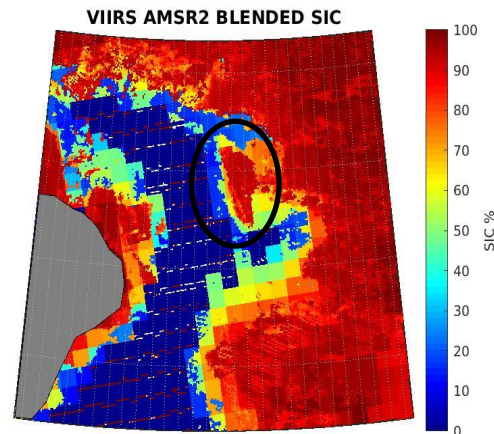
Blended Sea Ice Concentration

What it provides: fraction of ice in each grid cell

Taking advantage of the most useful observation and algorithm



[Blended Sea Ice Concentration from AMSR2/VIIRS Daily 1km, PolarWatch](#)

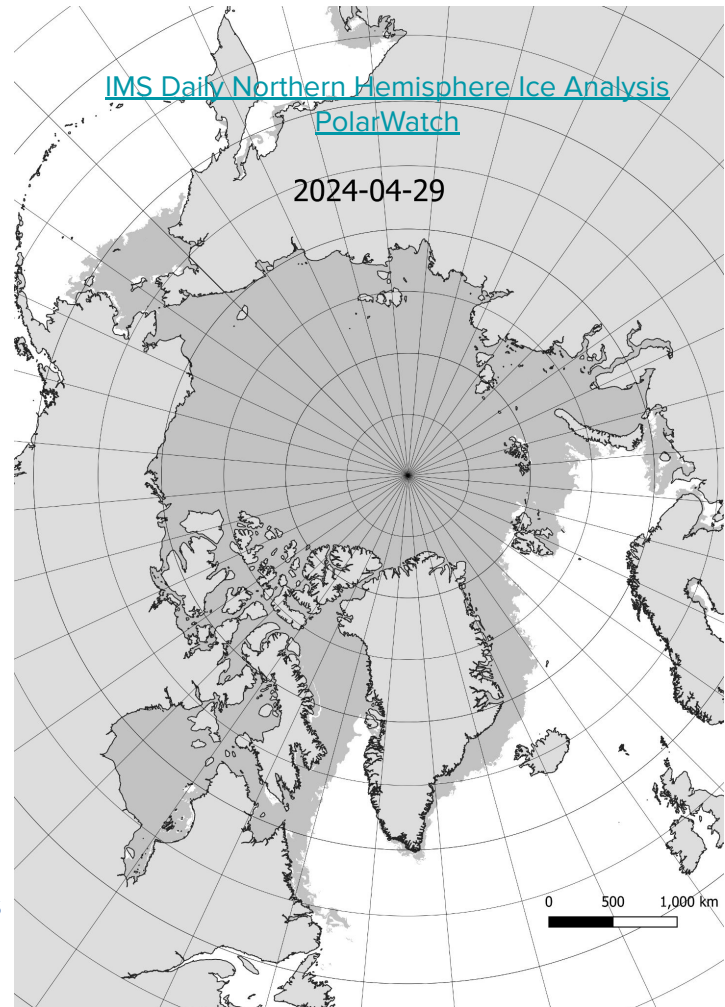


Satellite analysis of sea ice

Expert ice analysis based on satellite observations, and information products.

Data sources:

1. SAR (C band)
2. Visible/Infrared
3. Scatterometry
4. microwave radiometry
5. ice information products



Interactive Multisensor Snow and Ice Mapping System (IMS) [IMS Products \(usicecenter.gov\)](https://usicecenter.gov)

An initial list of things to keep in mind

The use of a given satellite product is driven by your application need, your scope of research

Area of interest, duration of the time series

- . Latency: Near real time (hours), delayed mode (days to weeks), annual re-processed long-term time series
- . Time coverage: Only today, no interest in past? a specified time in the past? a time series?
- . Diurnal warming: Is there a need to capture the diurnal variation?
- . Spatial resolution: Some grid size choices: 2 km, 5 km, 25 km, etc.
- . Data gaps: gap-filled with interpolation or are some missing values due to e.g. clouds acceptable?
- . Data quality: potential limitations that would be detrimental to the research

[NOAA PolarWatch](http://polarwatch.noaa.gov) : polarwatch.noaa.gov

[NOAA OneStop](http://data.noaa.gov/onestop): data.noaa.gov/onestop

[NOAA NCEI](http://www.ncei.noaa.gov): www.ncei.noaa.gov