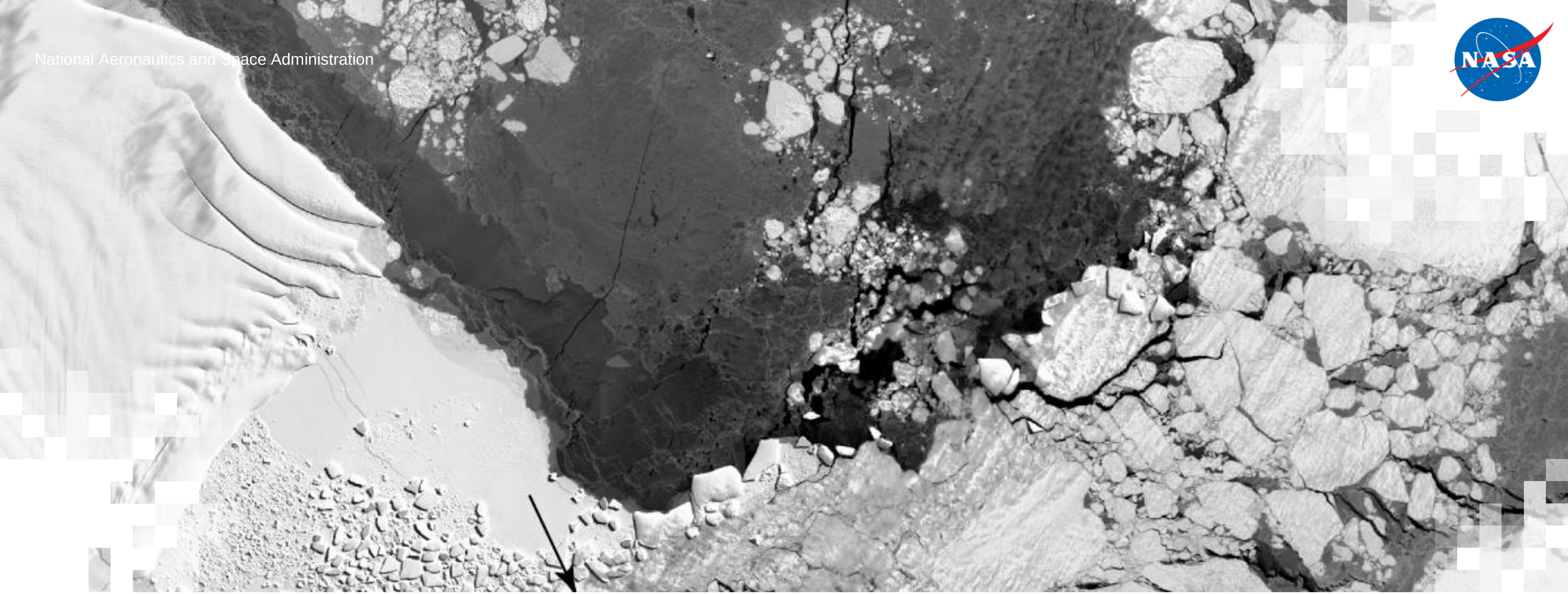
National Aeronautics and Space Administration

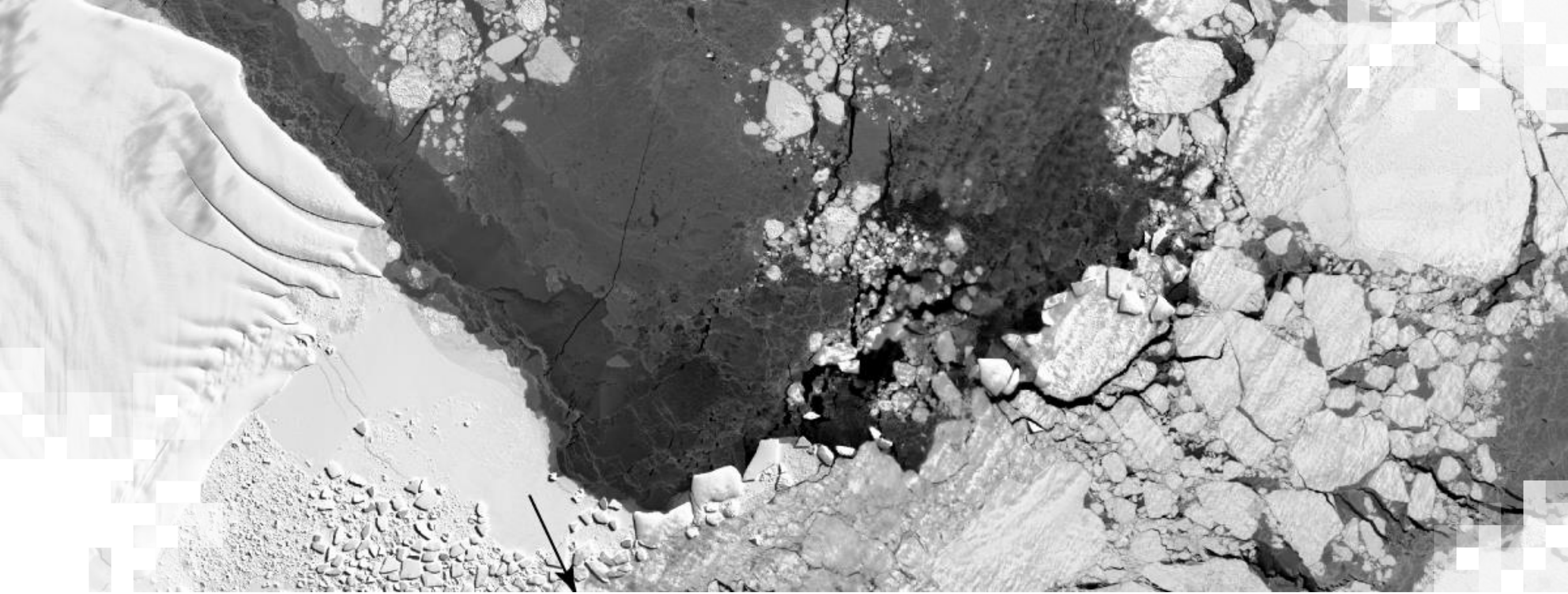


SAR for Detecting and Monitoring Floods, Sea Ice, and Subsidence from Groundwater Extraction

Session 1: Detecting and Monitoring Sea Ice with SAR

Malin Johansson, UiT The Arctic University of Norway

October 24, 2023



About ARSET

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

CLIMATE & RESILIENCE

DISASTERS

ECOLOGICAL CONSERVATION

HEALTH & AIR QUALITY

WATER RESOURCES

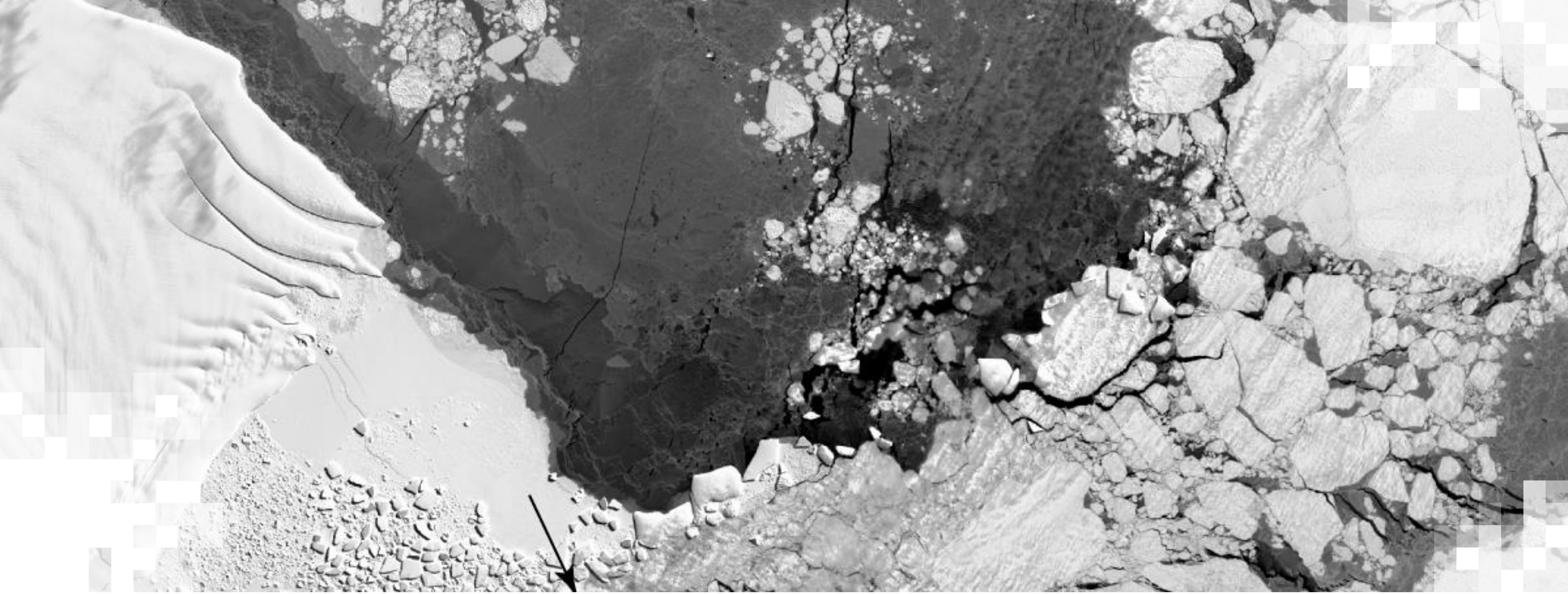
EARTH SCIENCE
APPLIED SCIENCES

CAPACITY BUILDING

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.



SAR for Detecting and Monitoring Floods, Sea Ice, and Subsidence from Groundwater Extraction

Overview

Sea Ice, Floods and Groundwater Extraction can be Seen from Space

- The objective of this training is for participants to learn how to use SAR to detect and address potential disasters related to sea ice, floods and groundwater extraction.
- These sort of events can have a large impact on human lives, infrastructure and the economy.
- SAR can be critical in informing on-the-ground efforts on disaster mitigation efforts and resilience.

Training Learning Objectives

By the end of this training, participants will be able to:

- Generate subsidence maps due to groundwater extraction to inform risk and resource management.
- Detect and monitor sea ice to identify potential risks to shipping and coastal erosion.
- Detect and monitor floods in order to more closely monitor increase/decrease of flood waters and better inform disaster response and management.

Prerequisites

- Fundamentals of Remote Sensing
- Introduction to Synthetic Aperture Radar (first and fourth sessions)
- Radar Remote Sensing for Land, Water, & Disaster Applications (second session)

Training Outline

Session 1

Detecting and Monitoring Sea Ice with SAR

Tue. Oct. 24, 2023

11:00-13:00 EDT (UTC-4)

Session 2

Measuring Surface Subsidence due to Groundwater Extraction with InSAR

Tue. Oct. 31, 2023

11:00-13:00 EDT (UTC-4)

Session 3

Detecting and Monitoring Floods with SAR

Wed. Nov. 1, 2023

11:00-13:00 EDT (UTC-4)

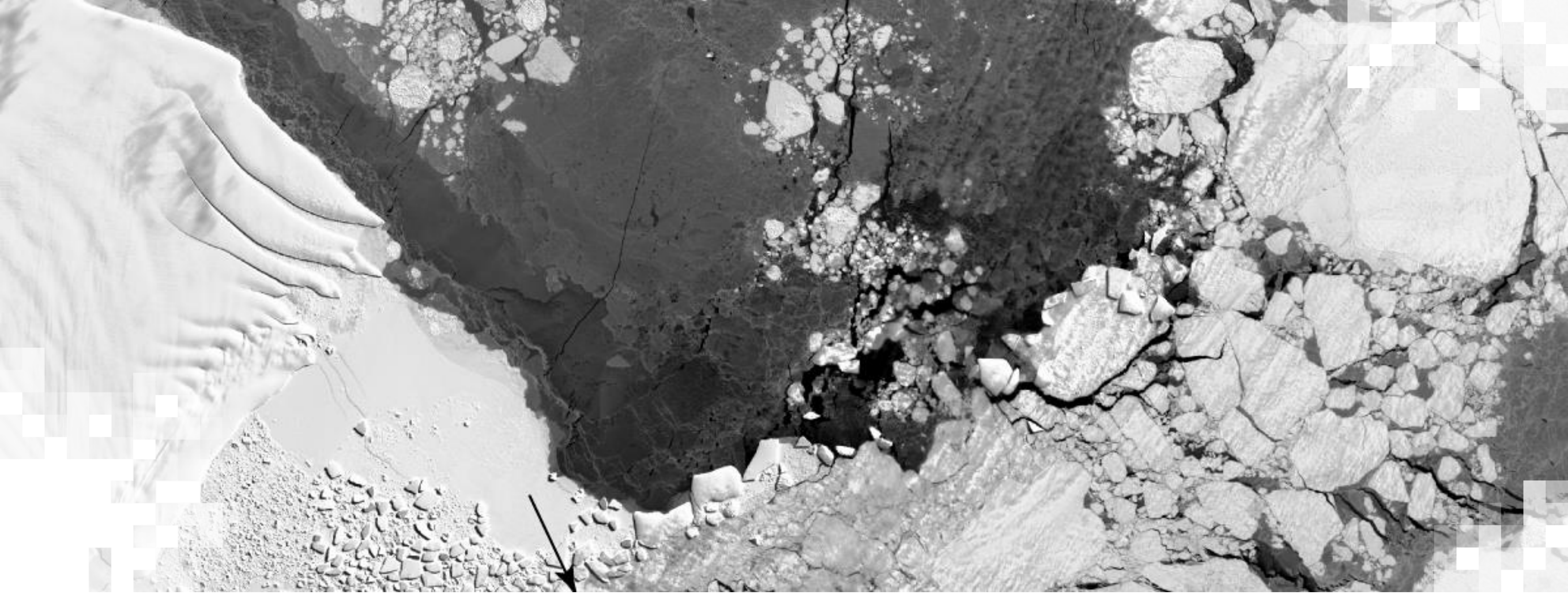
Homework

Opens Nov. 1– Due Nov. 17 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.



Session 1: Detecting and Monitoring Sea Ice with SAR

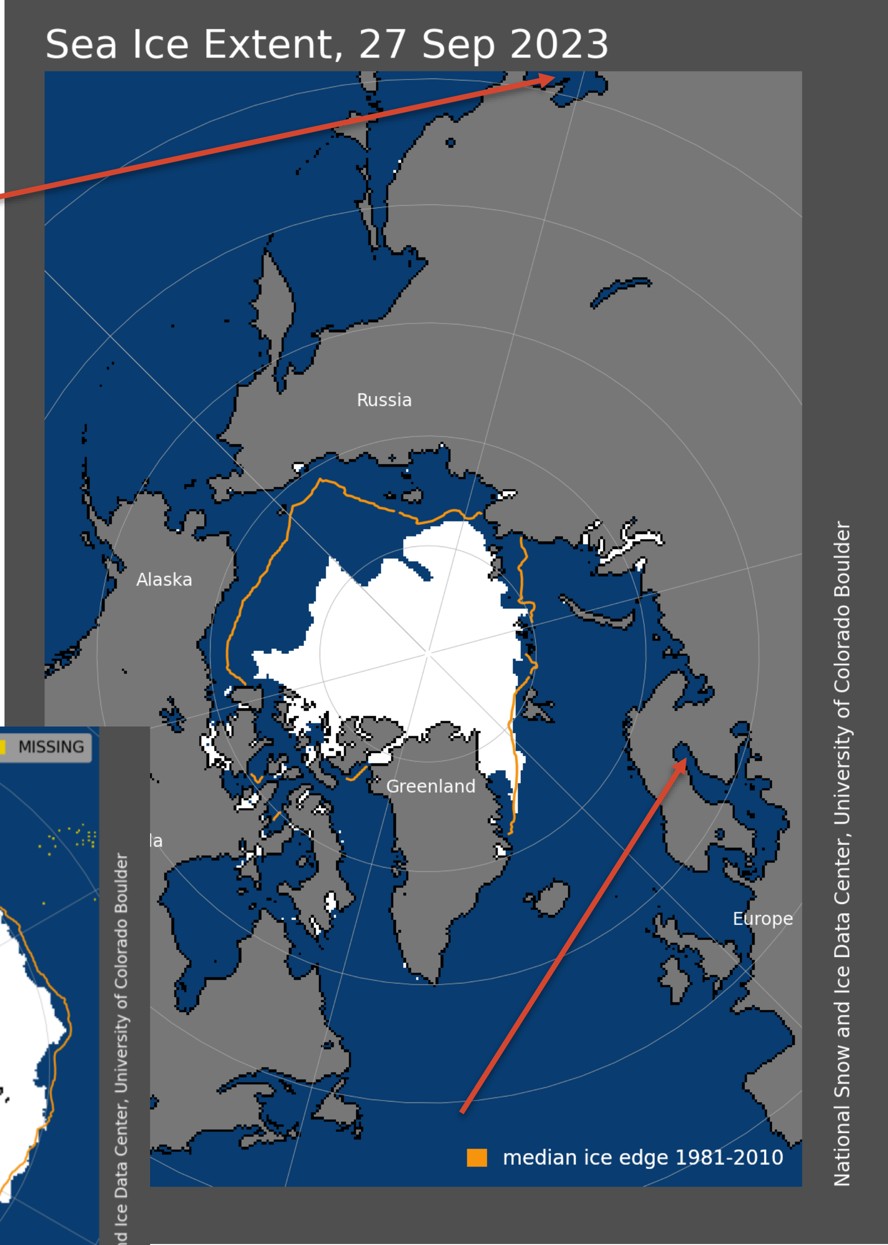
Session 1 Objectives

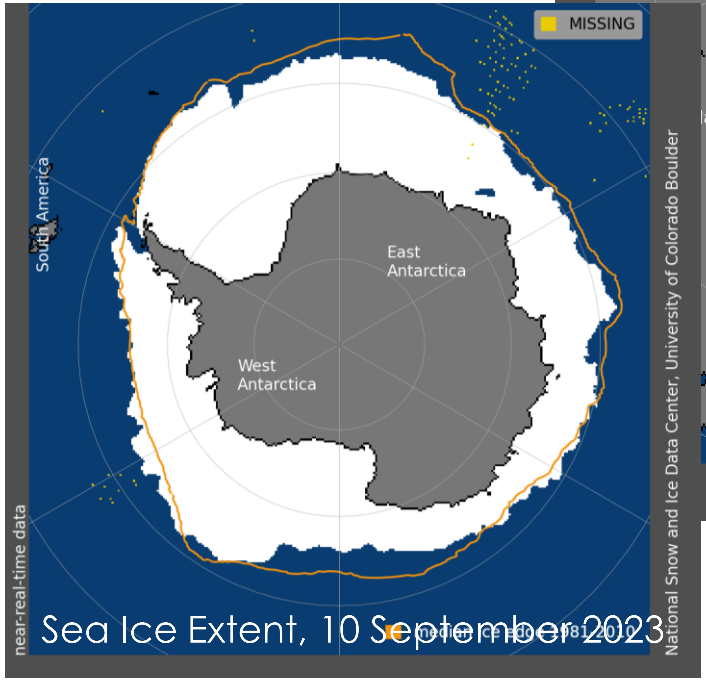
By the end of Session 1, participants will be able to:

- Understand the mechanism behind our ability to monitor sea ice
- Understand the challenges with sea ice monitoring
- Understand how sea ice characteristics can be derived using single- and dual-polarization SAR images
- See how satellite (SAR) images can fit into the larger-scale picture when it comes to safe shipping and climate models

What is sea ice?

- Ice that forms from freezing of sea water
  - Salty
- Covers the Arctic Ocean
- Surrounds Antarctica
- Occurs seasonally in sub-polar seas





What does sea ice look like?

Sheets of Nilas Ice

Pancake Ice

Lead

Thin First-Year Ice

Rough First Year Ice

Multi-First Year Ice

Photos: W. Guo, W. Copeland

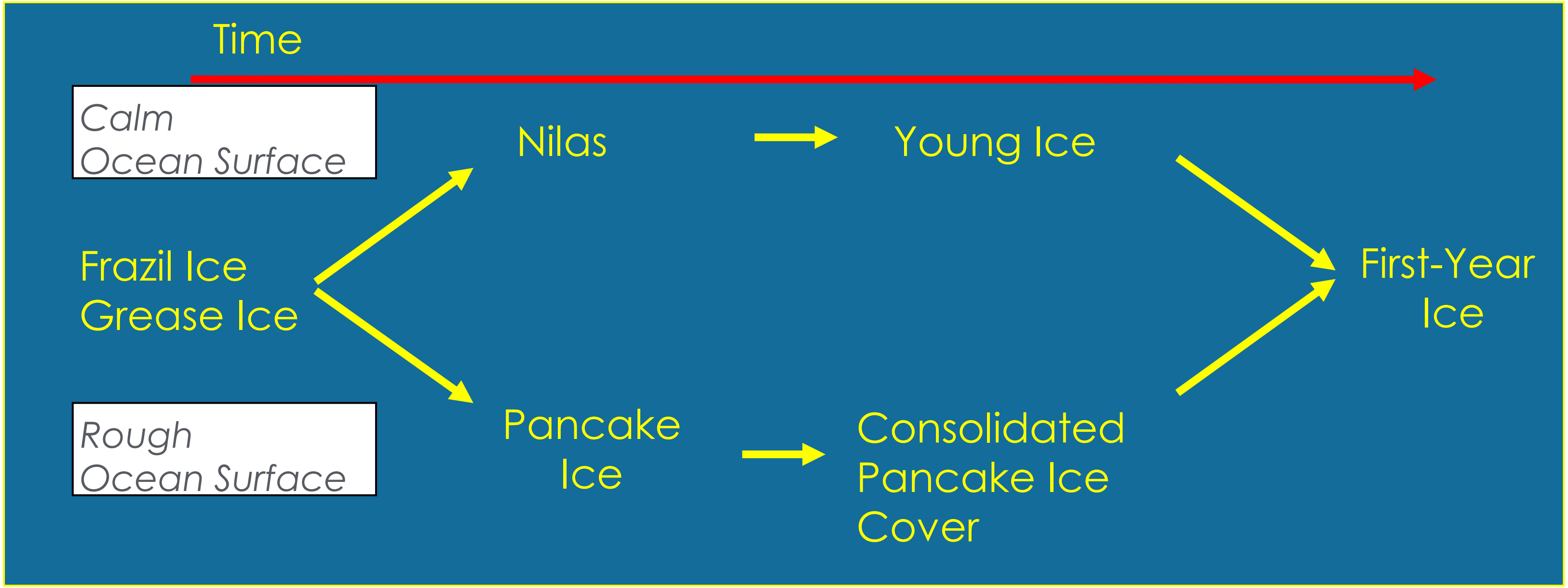
Basic Classes and Mechanisms of Ice Formation

Class	Description	Thickness
New Ice	Ice which began to grow a few hours or days ago	0 – 10 cm
Young Ice	Transition between new and first-year ice	10 - 30 cm
First-Year Ice	Ice of no more than one winter's growth	30 – 200 cm
Old Ice	Ice that has survived at least one summer's melt; most topographic features are smoother than on first-year ice	> 200 cm

Salinity

High

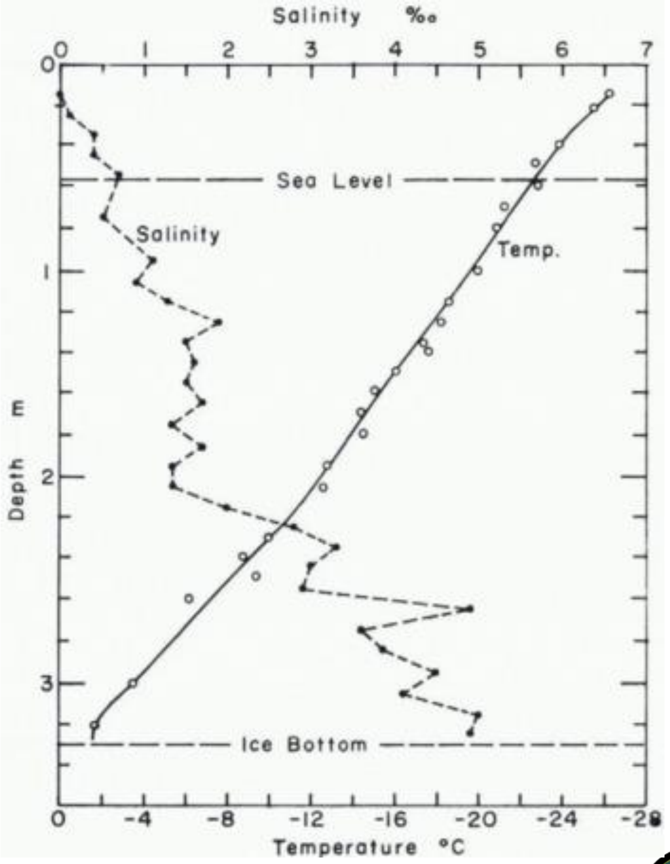
Low



What does sea ice look like?

- Sea ice includes brine pockets and air bubbles.
- As the ice ages and deforms, the salinity, density, surface roughness, and topography will change.

Photos: J. Landy



Cox and Weeks, 1974

What does sea ice look like?

- Sea ice core seen close up

Granular

Columnar

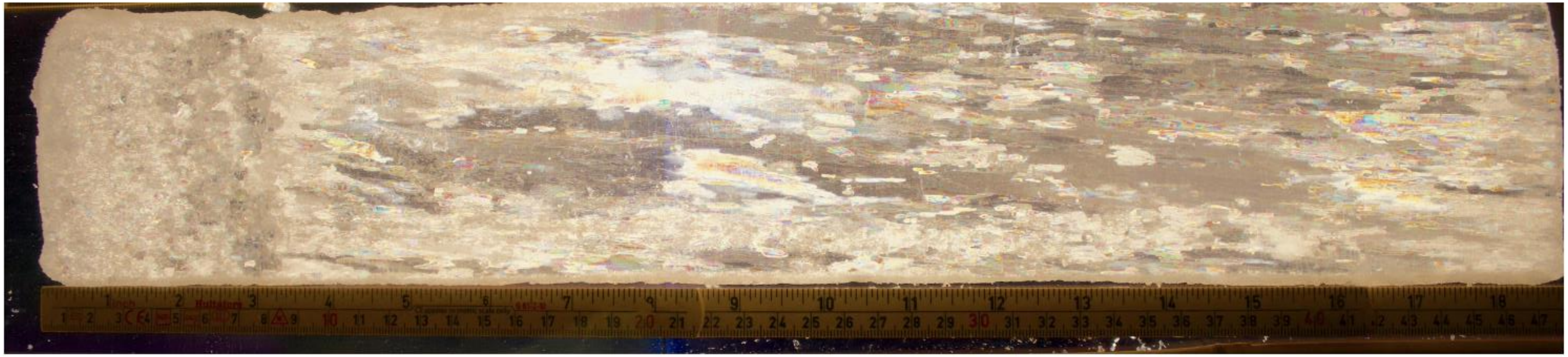


Photo: J. Osanen

How does it disintegrate?

- In the summer it melts
  - First the snow melts
  - Melt pond starts forming

Photo: T. Karlsen

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  - Due to interaction with the ocean, it breaks into smaller fragments

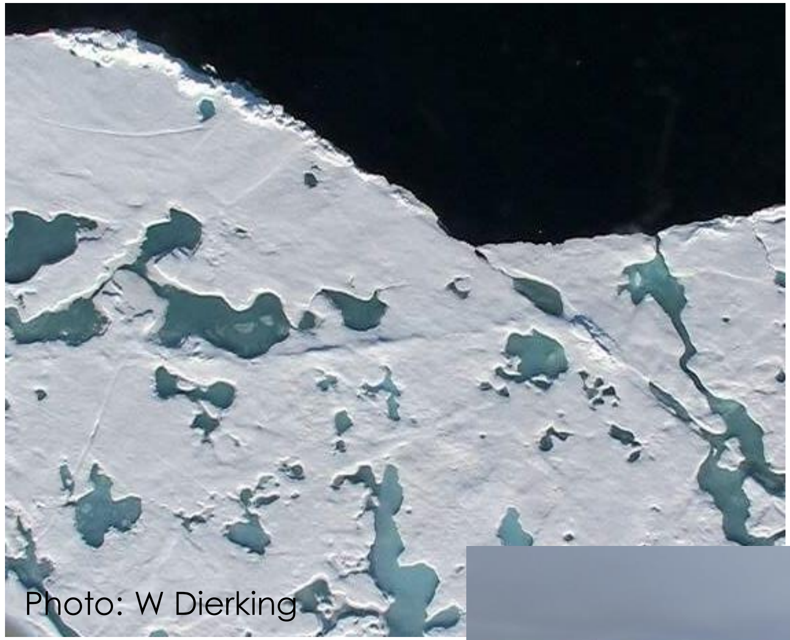

Photo: W Dierking

Photo: M. Johansson

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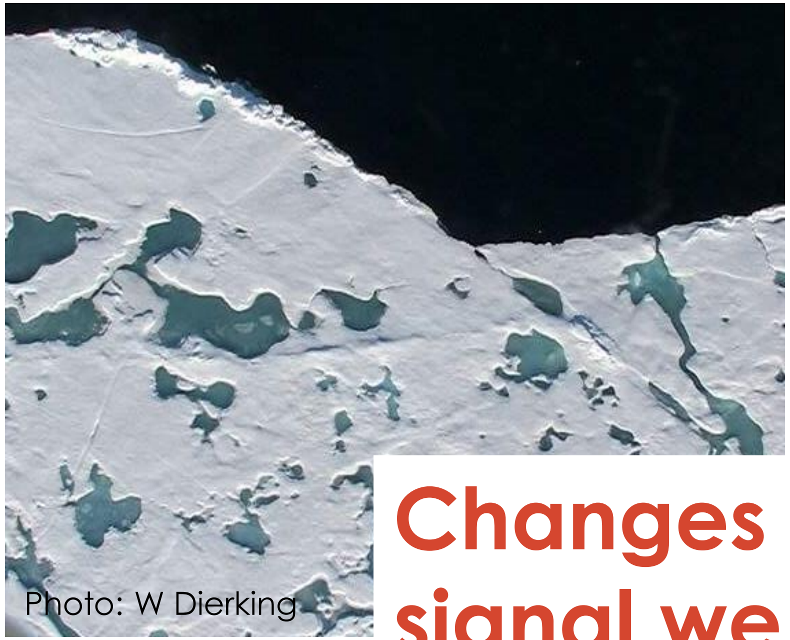
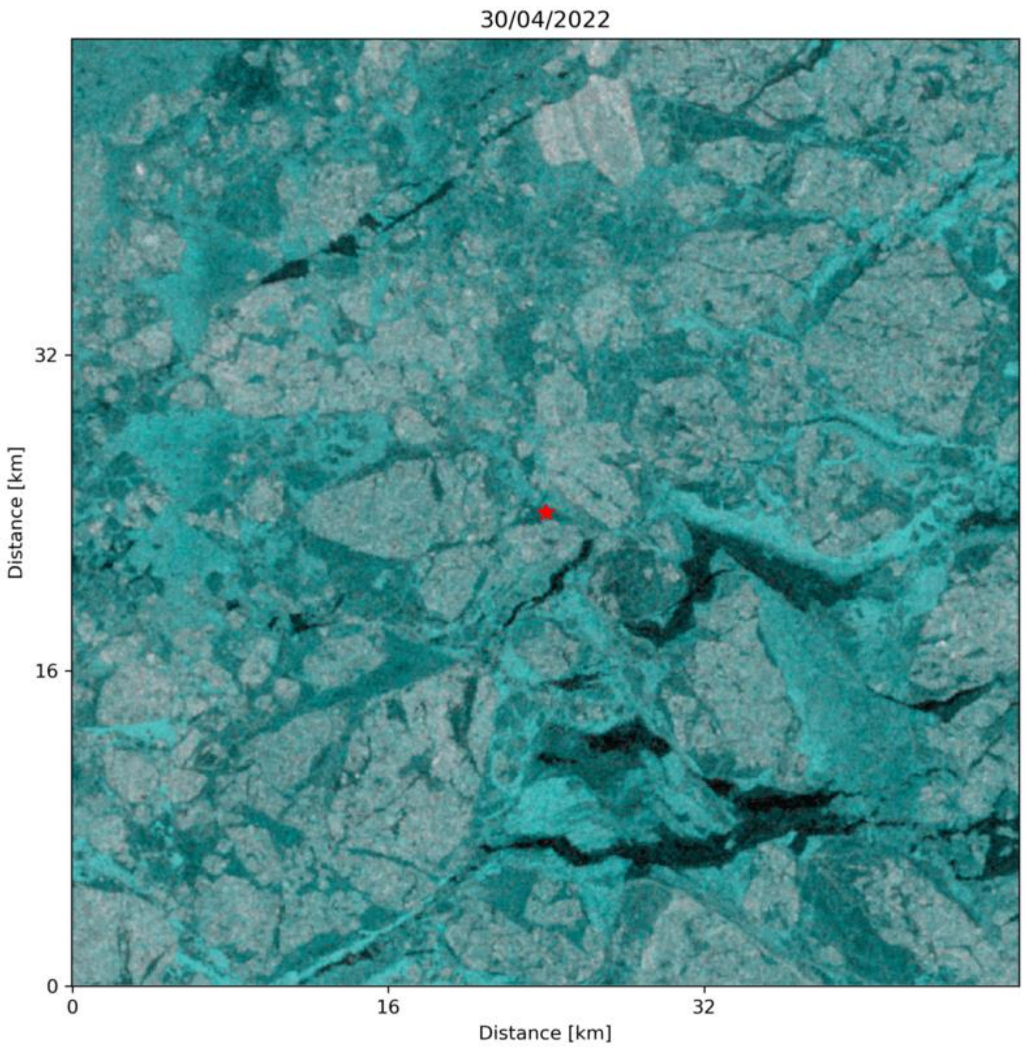


Photo: W Dierking

Changes the signal we can observe with SAR!

Photo: M. Johansson

How does sea ice look like in SAR images?



C. Taelmann et al, 2023

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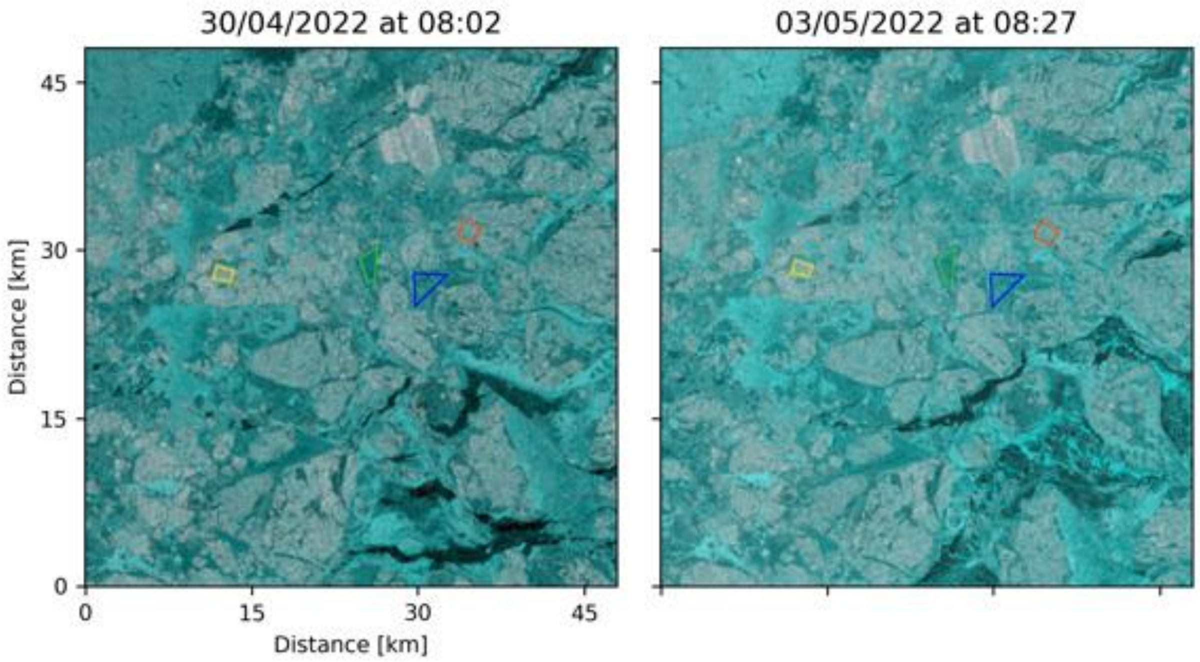
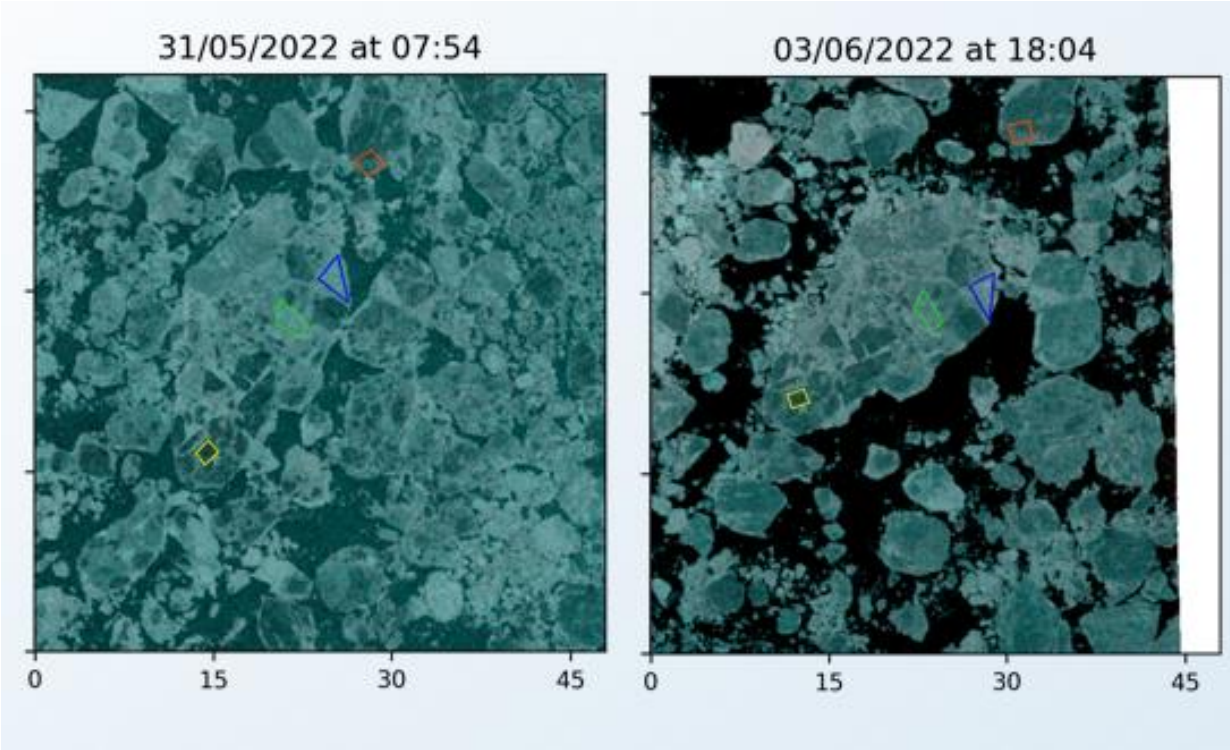


Freezing

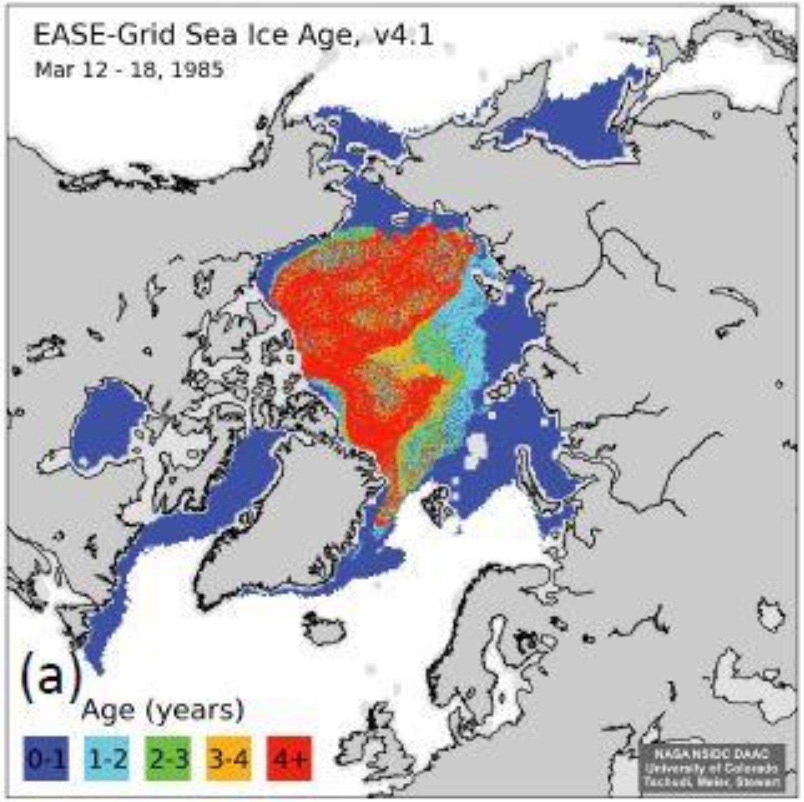
Melting

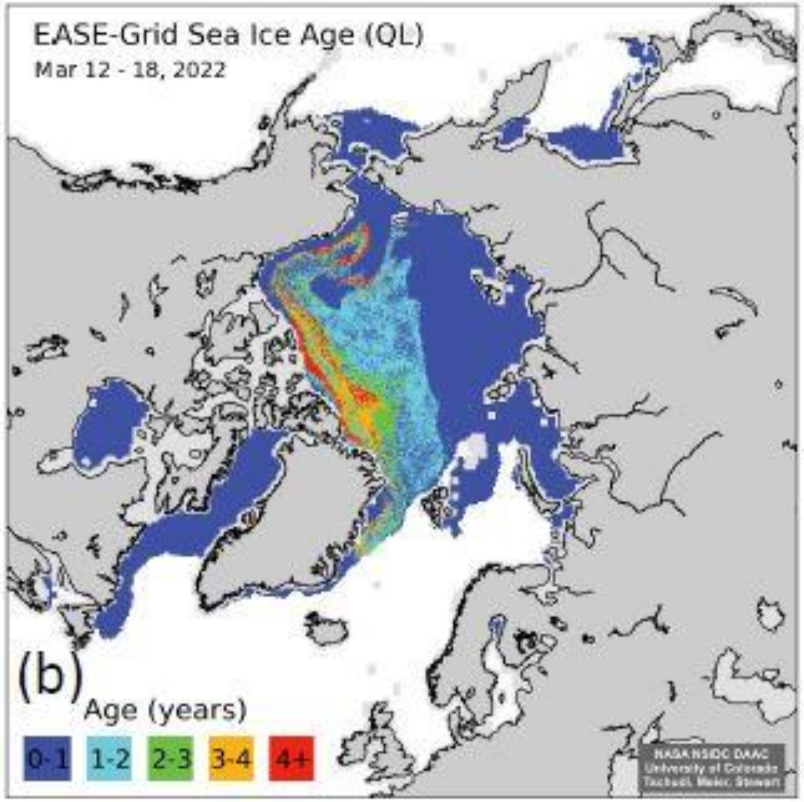


C. Taelmann et al, 2023

Changes to the Sea Ice in the Arctic Ocean

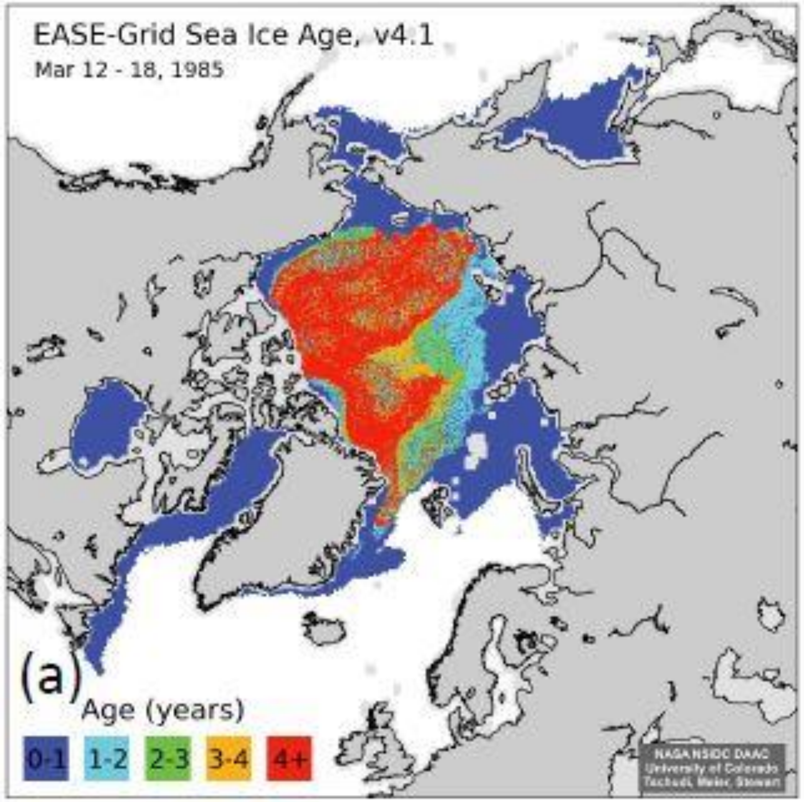
- The thicker ice is dissapearing.

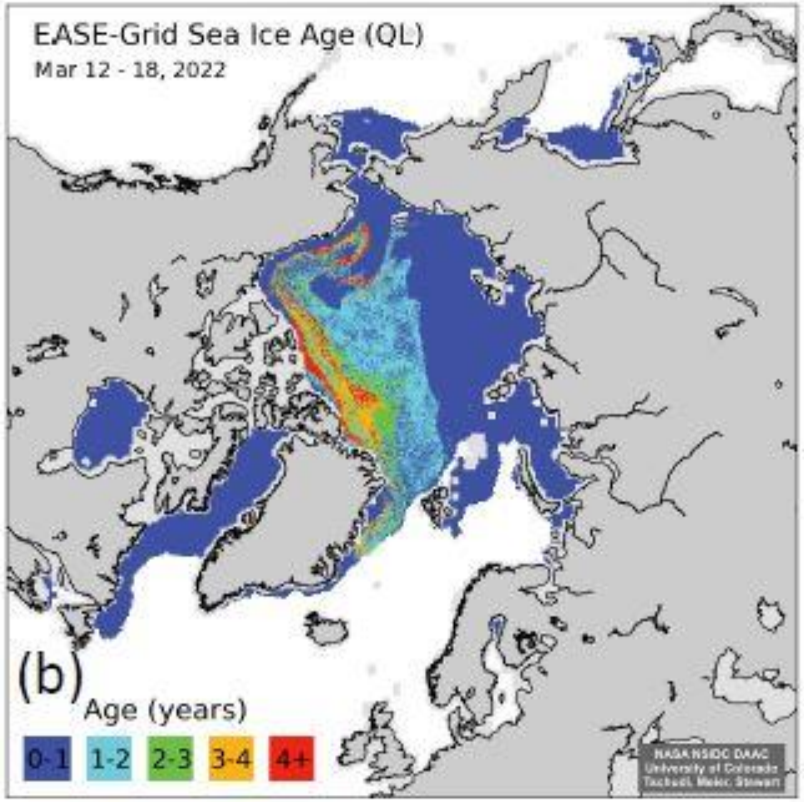




Changes to the Sea Ice in the Arctic Ocean

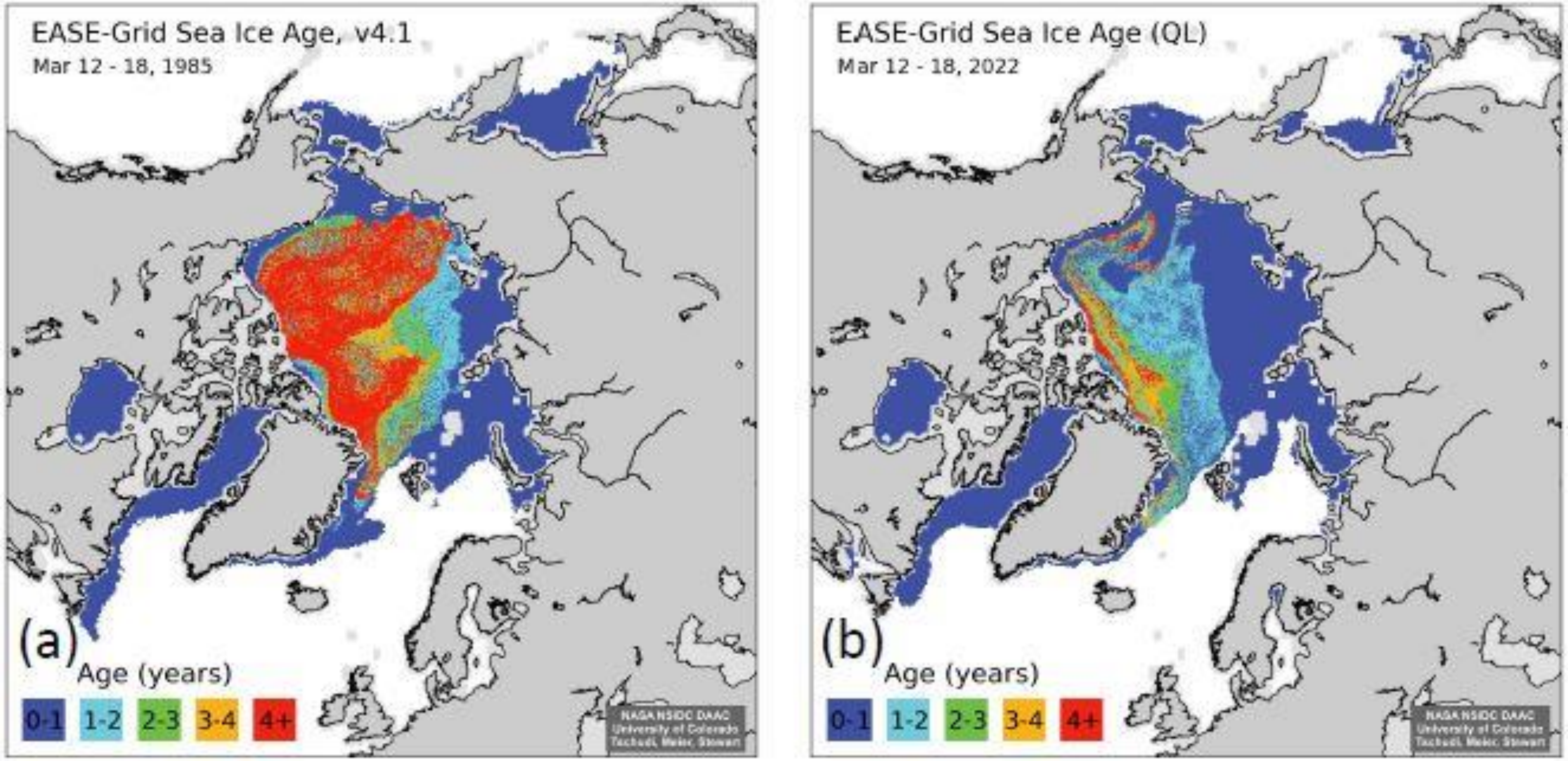
- The thicker ice is dissapearing.
- Today the larger fraction of Arctic sea ice is less than one year old.





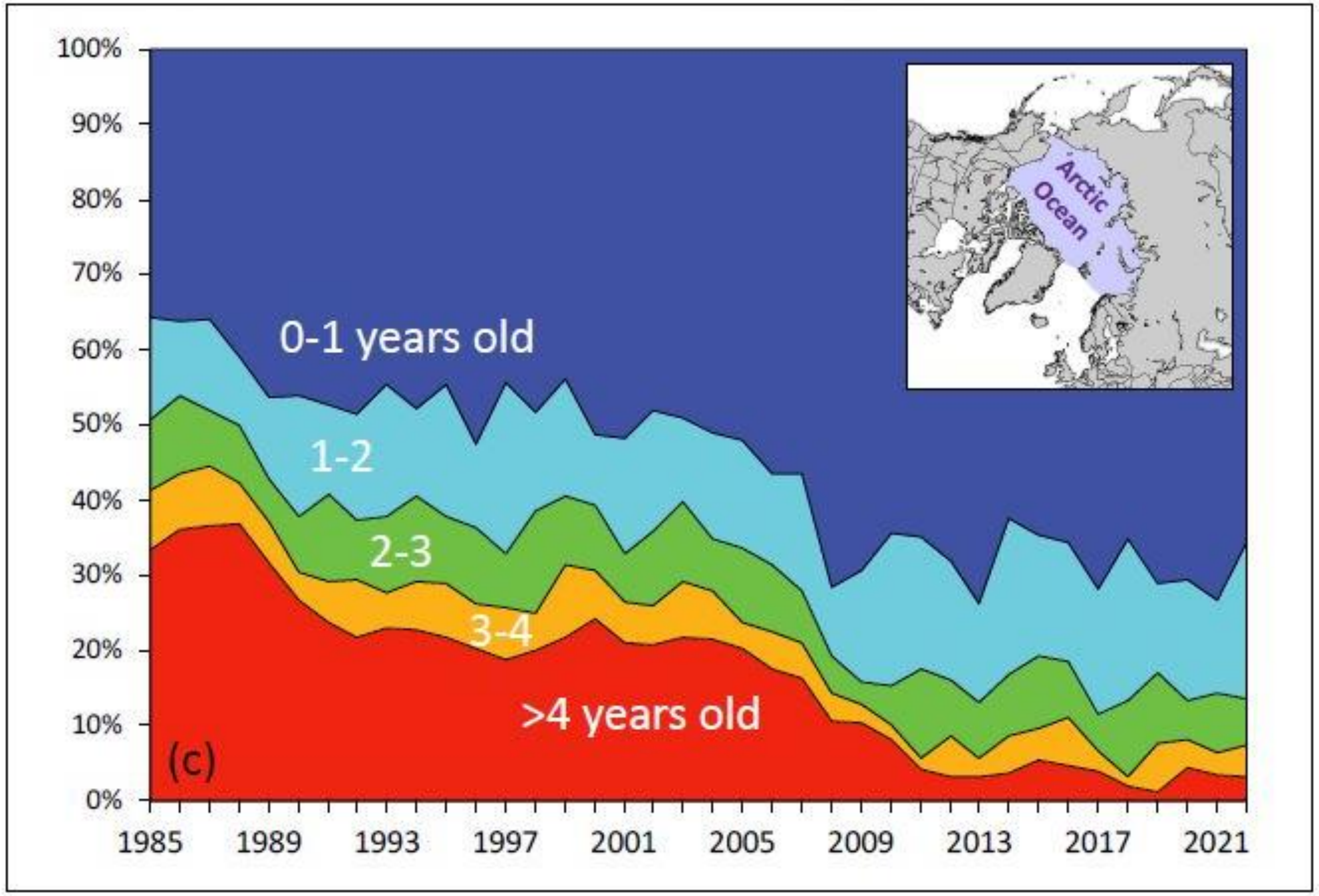
Changes to the Sea Ice in the Arctic Ocean

- The thicker ice is dissapearing.
- Today the larger fraction of Arctic sea ice is less than one year old.
  - Oldest (and thickest) in the West
  - Younger (and thinnest) in the East



Sea Ice Age

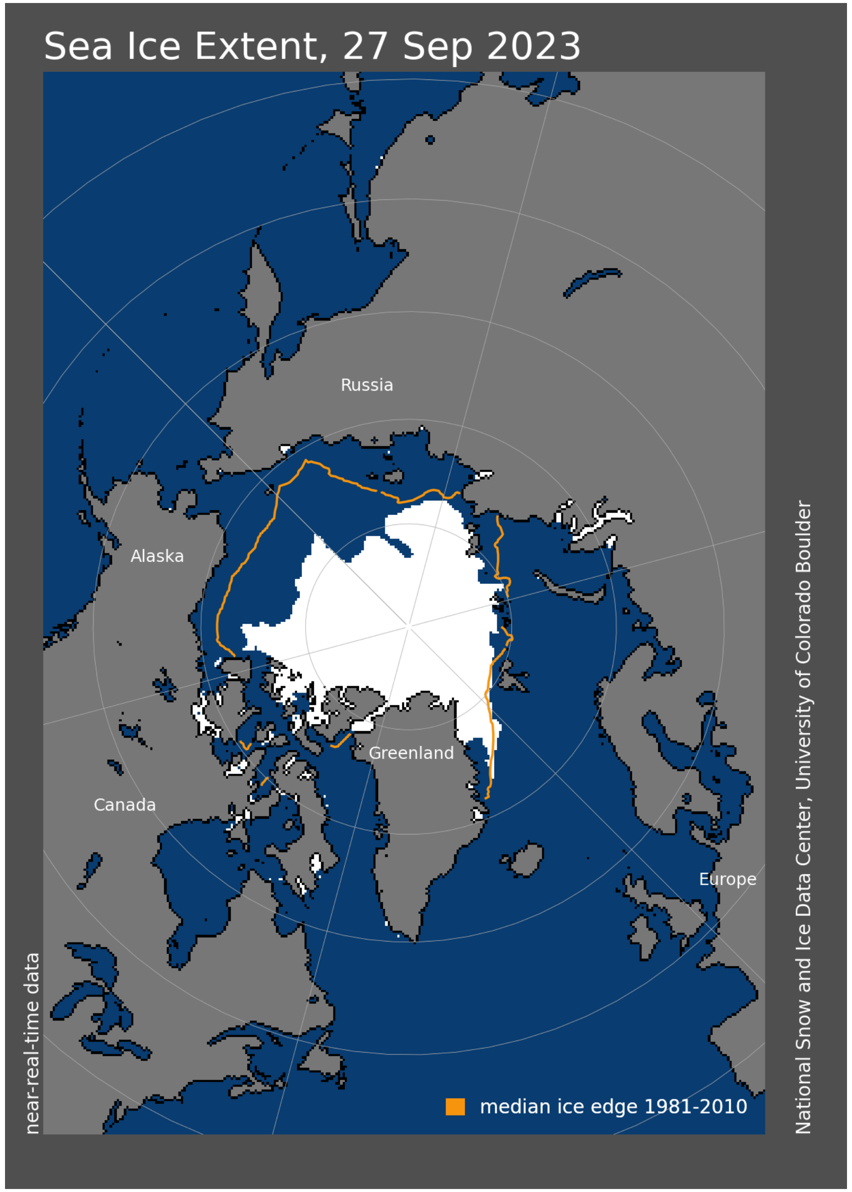
- How is the age of sea ice determined?
  - Count it from 1st September
  - Freeze-up season



© NSIDC

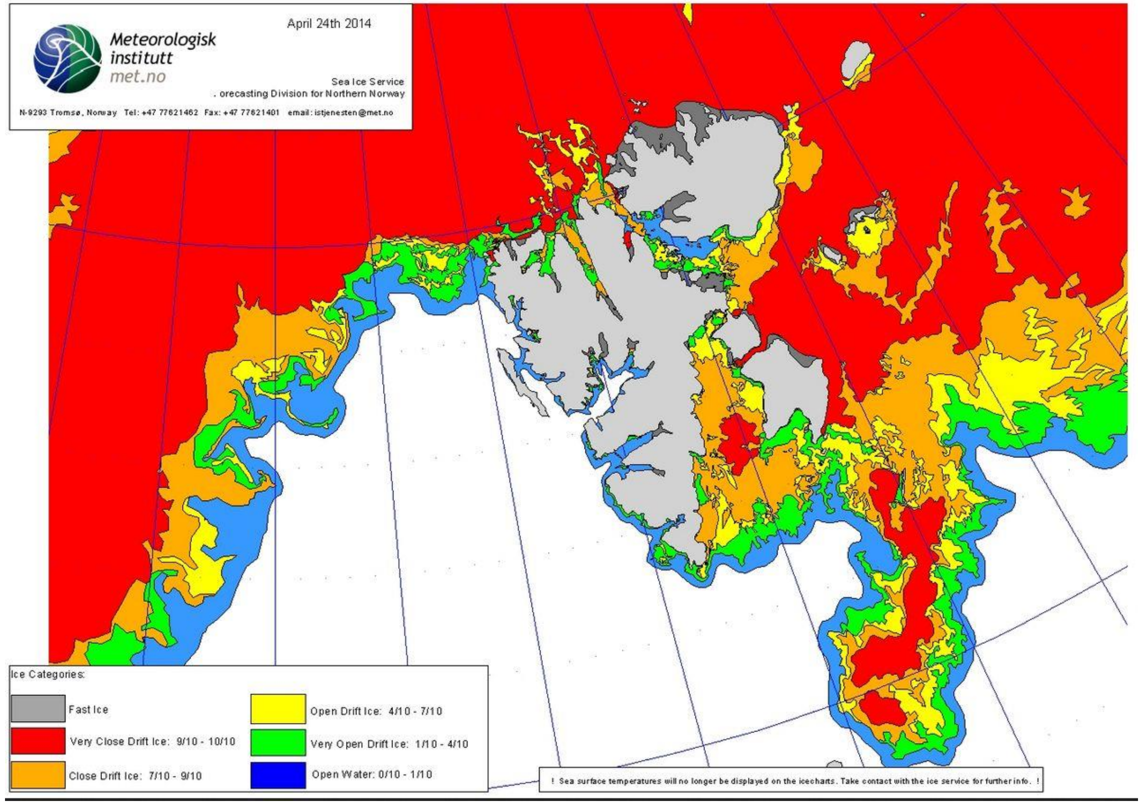
What do we monitor?

- Which parameters are used to describe the characteristics of the Arctic and Antarctic sea ice cover?
  - Sea ice extent



What do we monitor?

- Which parameters are used to describe the characteristics of the Arctic and Antarctic sea ice cover?
  - Sea ice extent
  - Sea ice concentration
  - Sea ice types



What do we monitor?

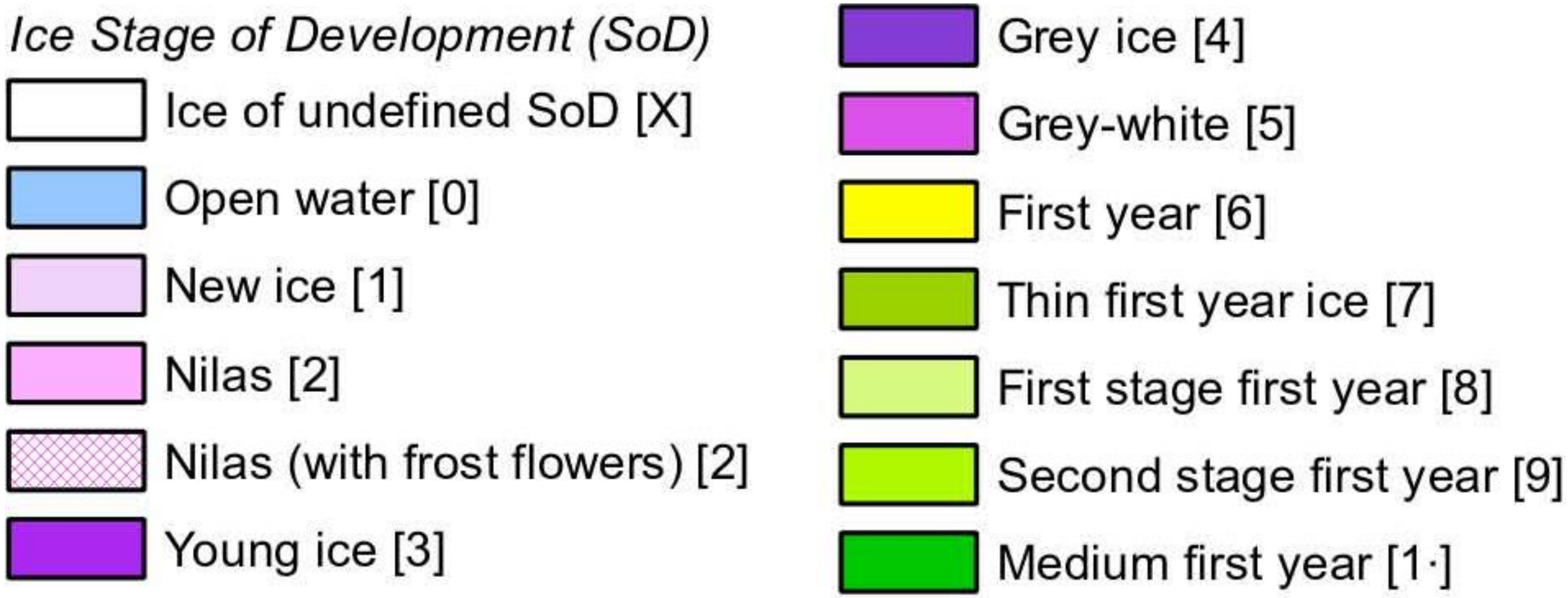
- Which parameters are used to describe the characteristics of the Arctic and Antarctic sea ice cover?
  - Sea ice extent
  - Sea ice concentration
  - Sea ice types
  - Sea ice stage of development

Sea Ice Monitoring and Detection

- WMO Nomenclature
  - Not directly compatible with SAR images
- SAR does not see ice thickness.

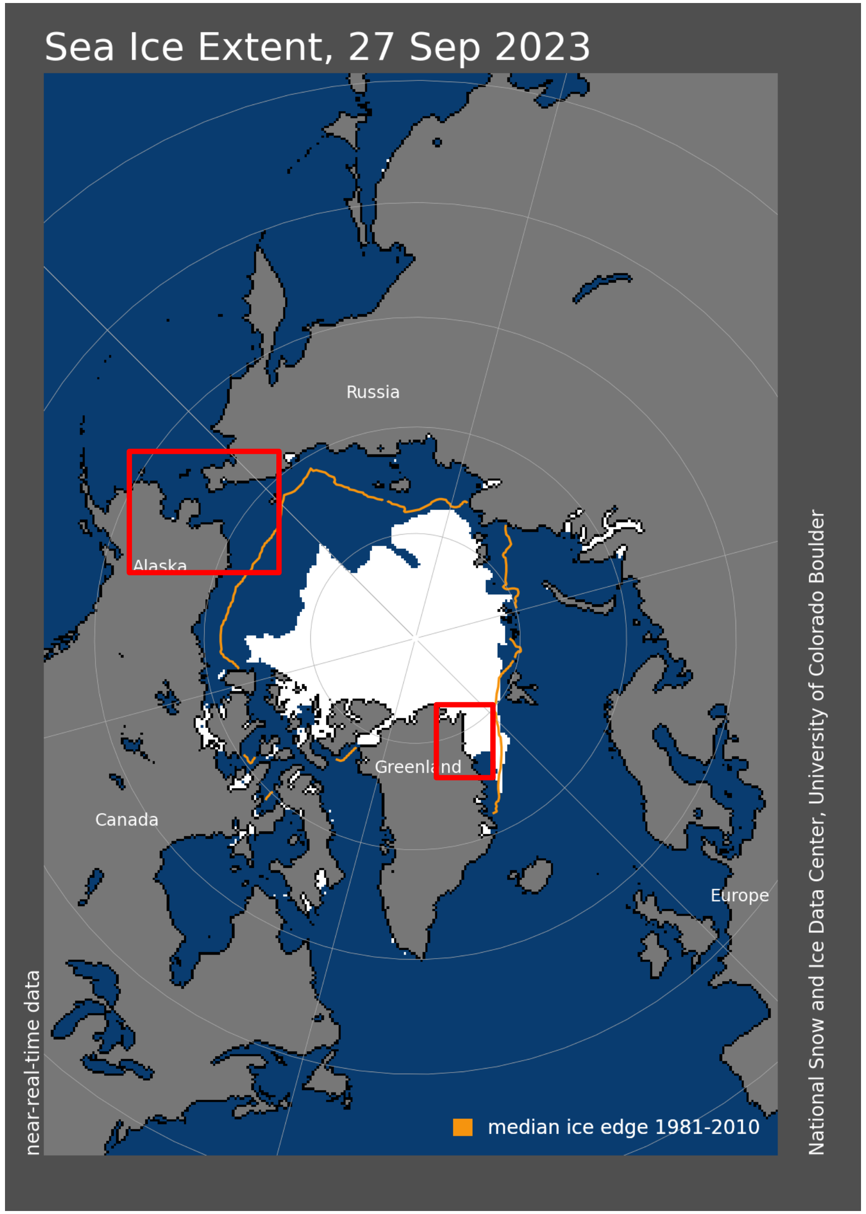
Sea Ice Monitoring and Detection

- WMO Nomenclature
  - Not directly compatible with SAR images
- SAR does not see ice thickness.
- SAR “sees“ surface roughness (mm to dm range) and volume inhomogeneities (air inclusions, brine pockets, large snow grains, etc.)



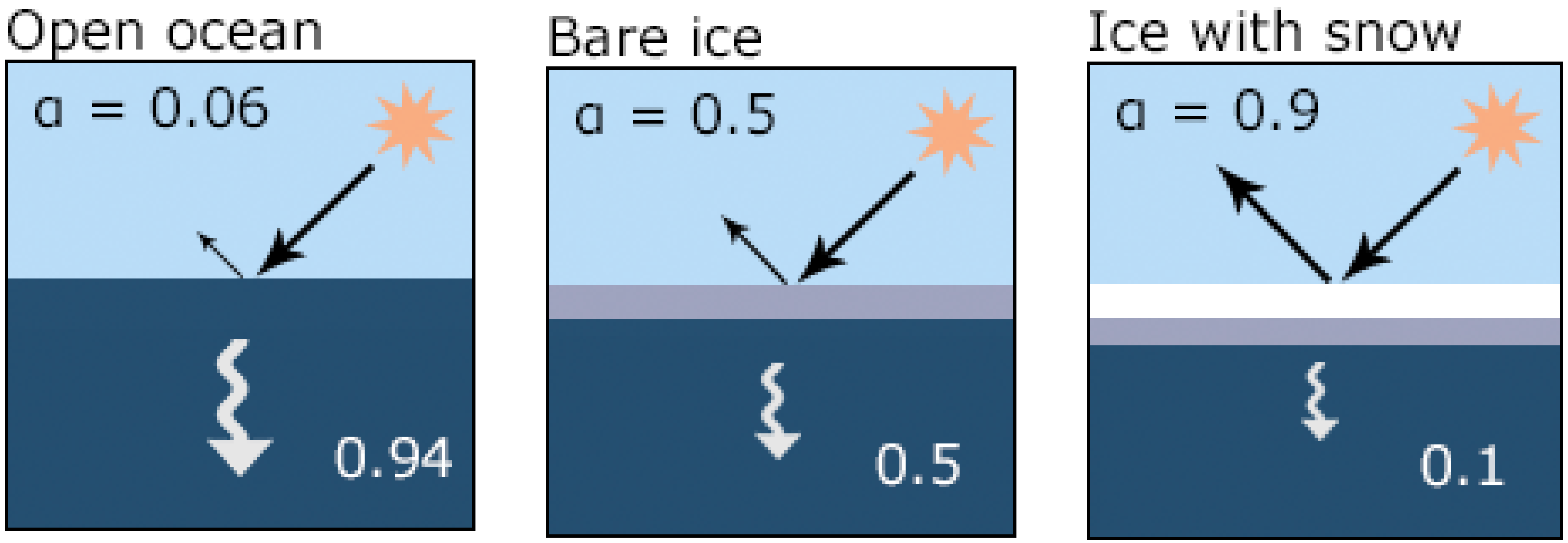
How does the sea ice extent vary?

- Seasonal Cycle
- Sea Ice Drift
  - Arctic Gateways
    - Bering Strait – Connects to the Pacific Ocean
    - Fram Strait – Connects to the Atlantic Ocean
- Fram Strait is located between Greenland and Svalbard
  - Fastest flowing sea ice drift



Why do we monitor sea ice?

- Albedo:
  - If there is no sea ice, the ocean absorbs the heat.
  - Presence of sea ice => higher albedo => the sea ice reflects more incoming solar radiation => ocean temperature increases less
  - Sea ice + snow => even higher albedo



Why do we monitor sea ice?

- Albedo
- Transportation
  - Hazard for shipping
  - Planning ship routing

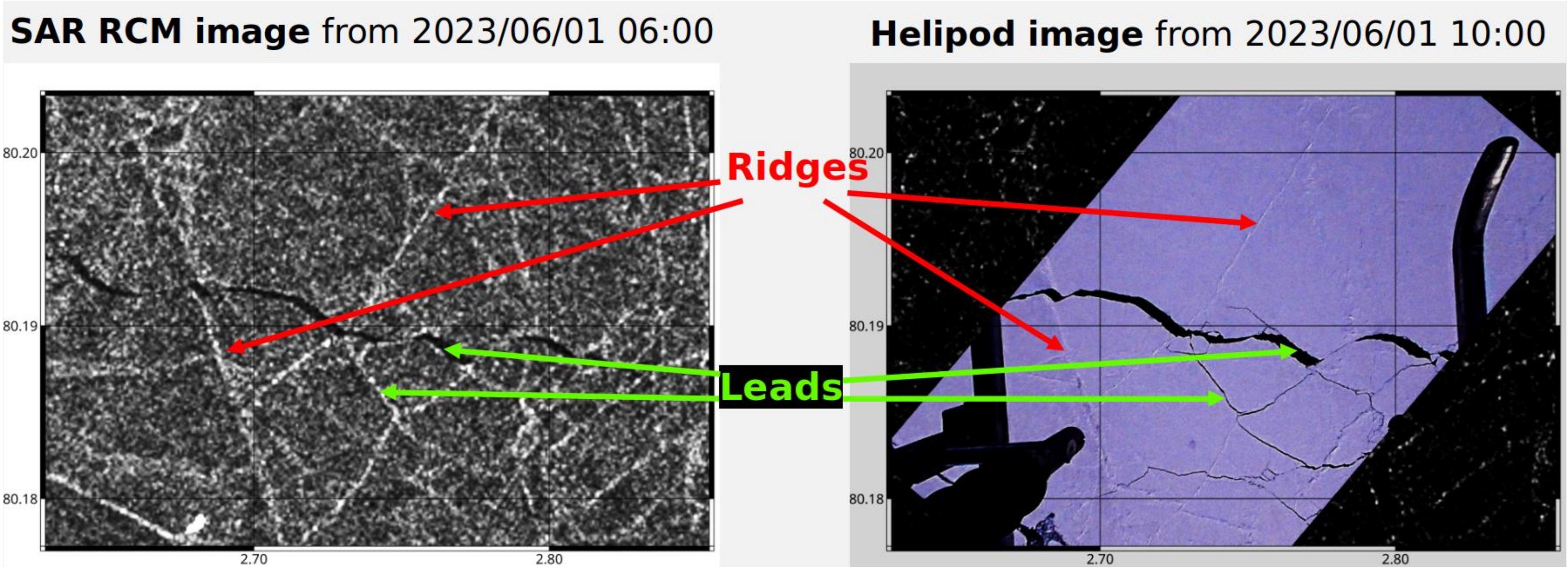
Photo: NORCE

Photo: T. Karlsen

Photo: C. Zoelly

Operational Sea Ice Mapping

- Need of SAR imaging for optimising icebreaker route



D. Demchev et al, 2023

Sea Ice Drift

- Sea ice moves -> leads and ridges

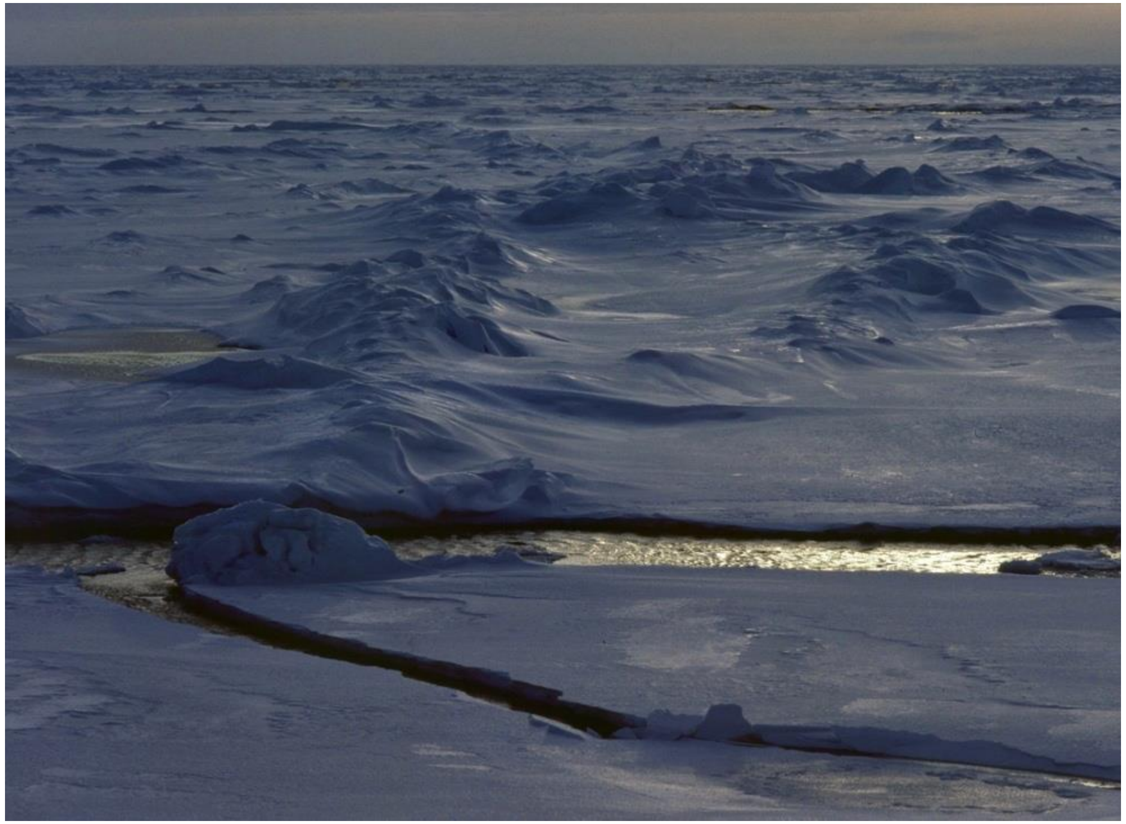
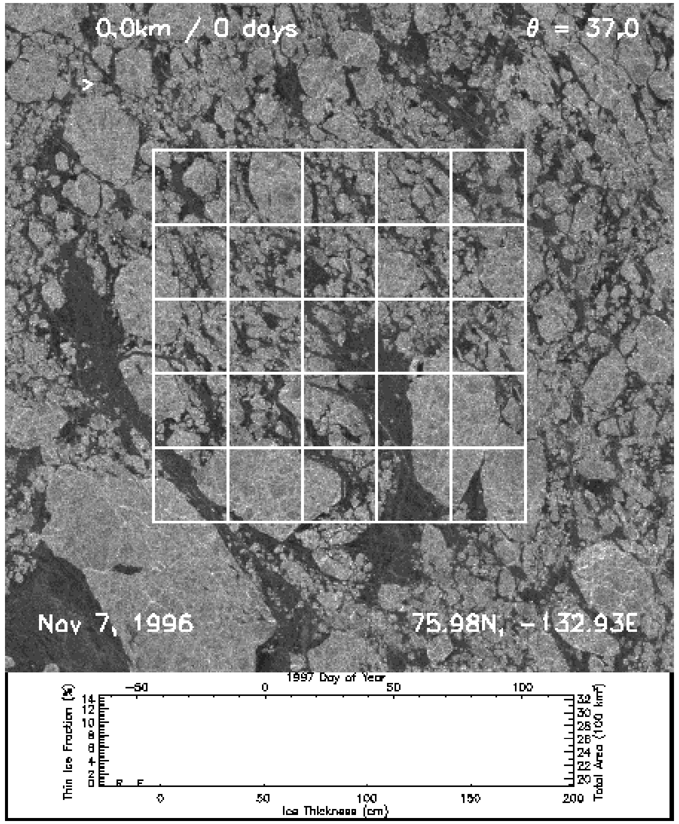


Photo: W. Dierking, 1991



Courtesy of R. Kwok

Why do we monitor sea ice?

- Albedo
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  - Used as road

Photo: W. Copeland

Why do we monitor sea ice?

- Albedo
- Transportation
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  - Used as road
- Coastal Erosion

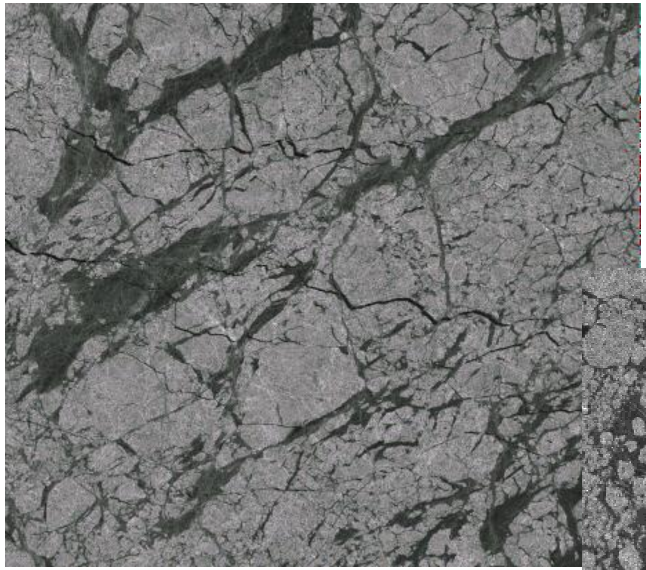

Photo: IGPAS


Photo: IGPAS

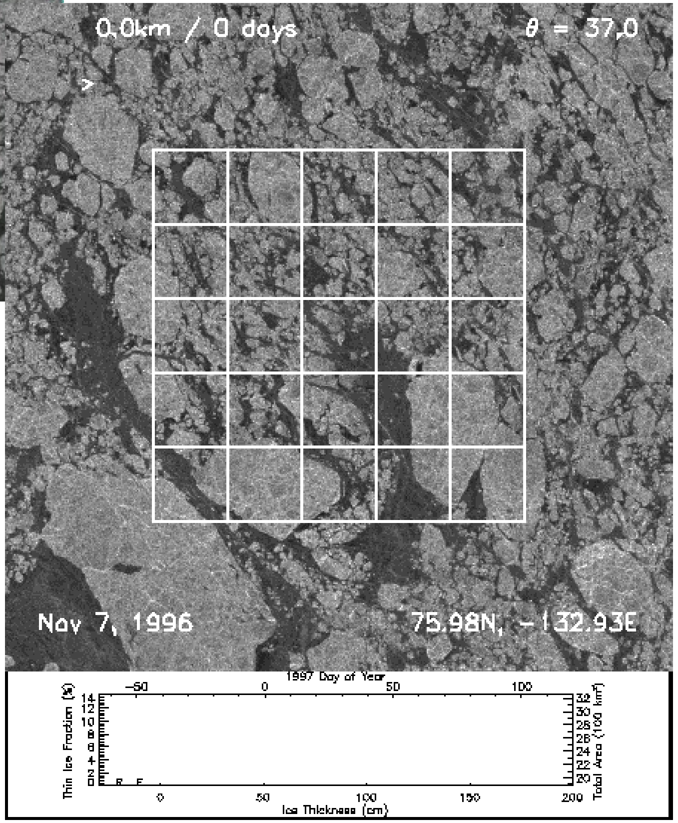

Photo: Z. Swirad

Why do we monitor sea ice?

- Albedo
- Transportation
  - Hazard for shipping
  - Planning ship routing
  - Used as road
- Coastal Erosion
- Climate System
  - Heat and gas exchanges
  - Heat flux sea surface: 100 -1000 W/m^2
  - Sea Ice >1m Thick: 5-20 W/m^2
  - Frequency and size of leads and polynyas influences regional heat flux.



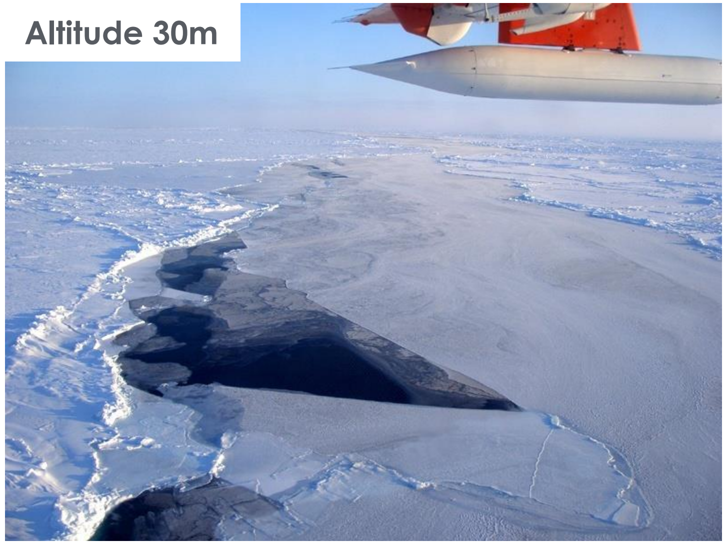
SAR Image, 100x100 km



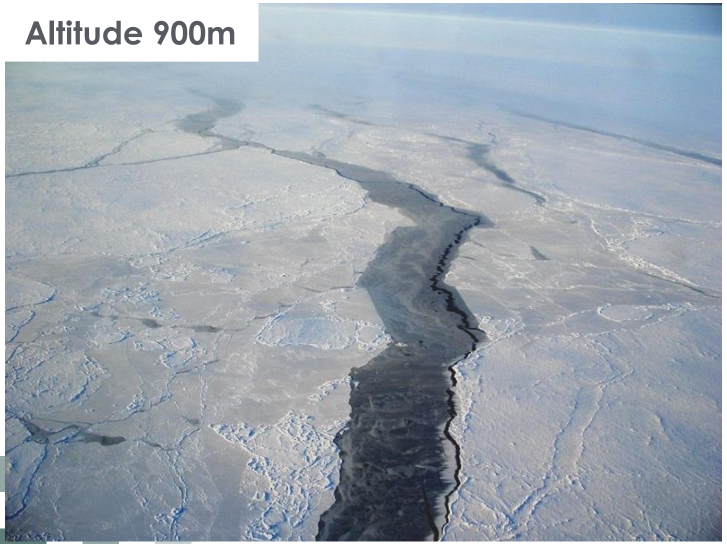
Courtesy of R. Kwok

How do we monitor sea ice?

Altitude 30m



Altitude 900m



Photos: W. Dierking

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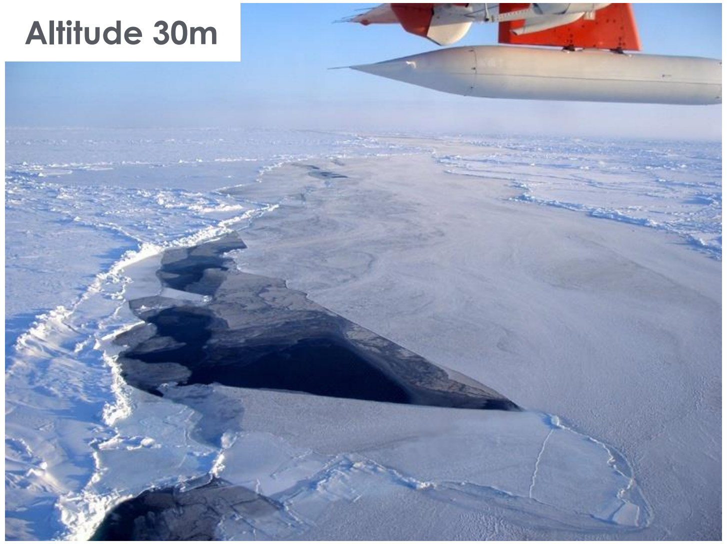
Altitude 30m



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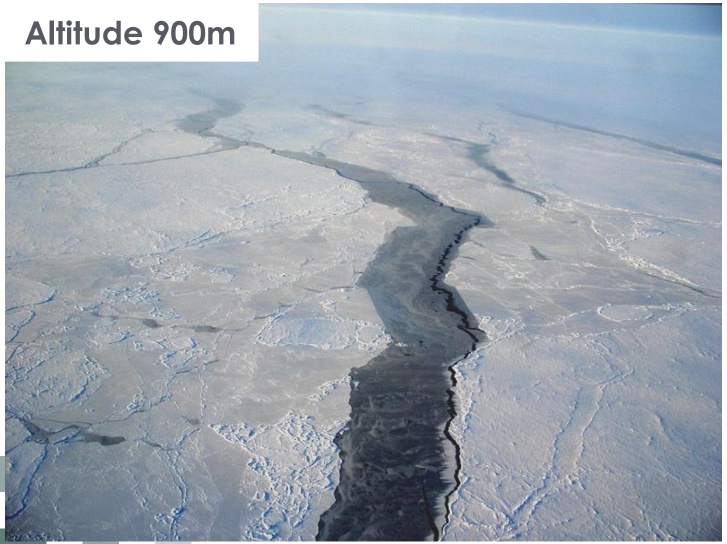

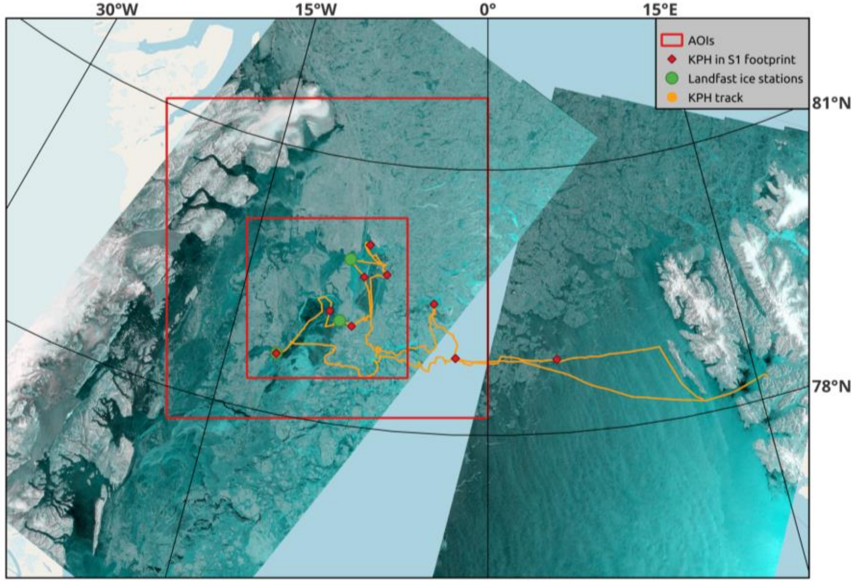

Photos: W. Dierking

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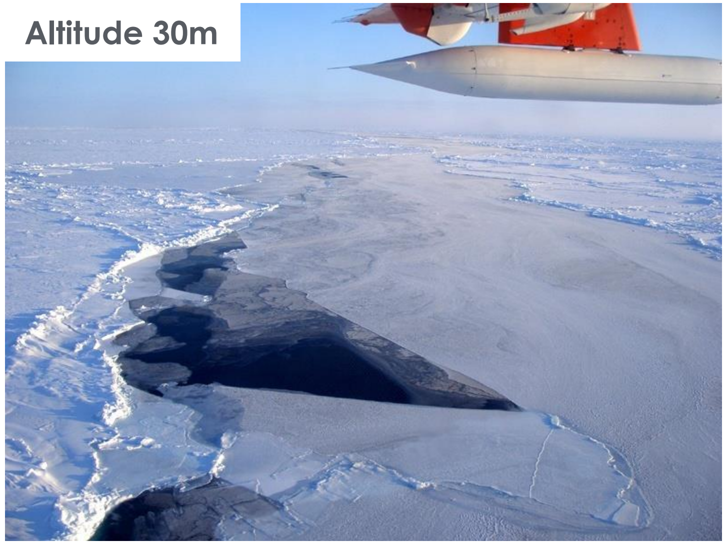

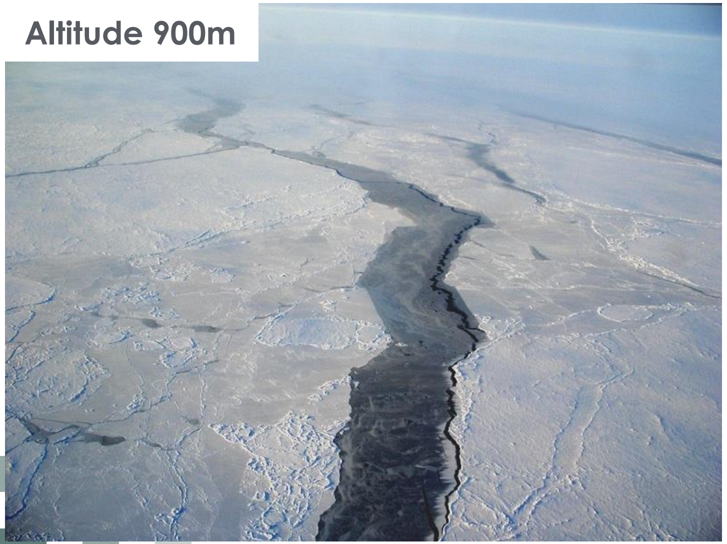

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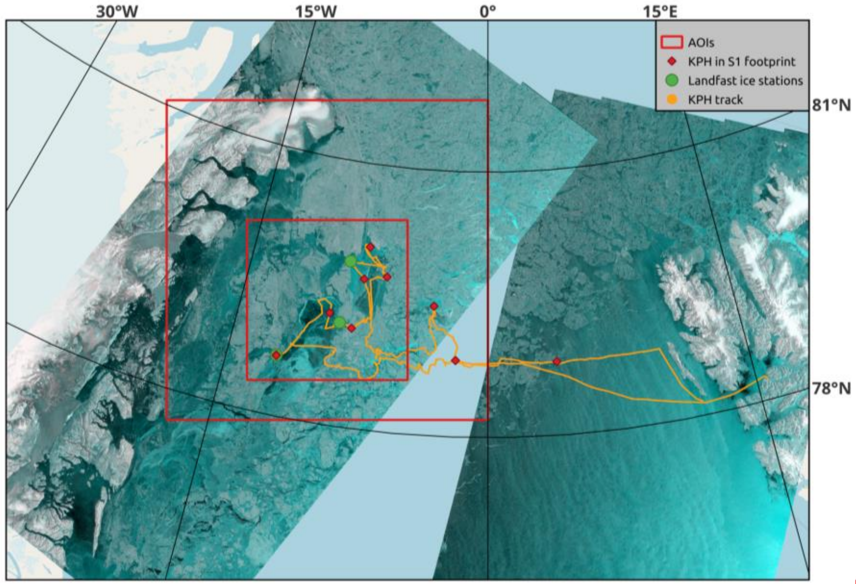
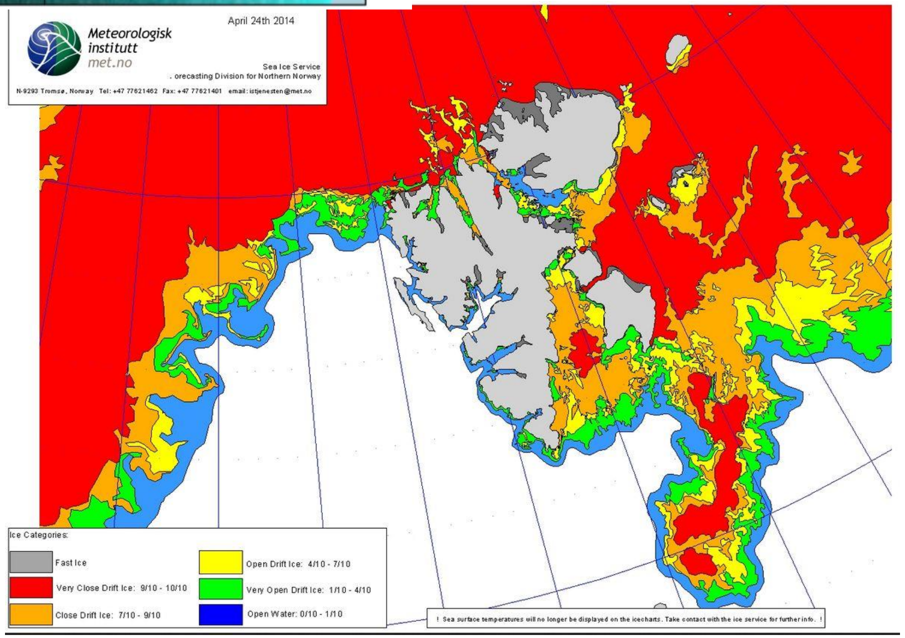




Sea Ice Maps

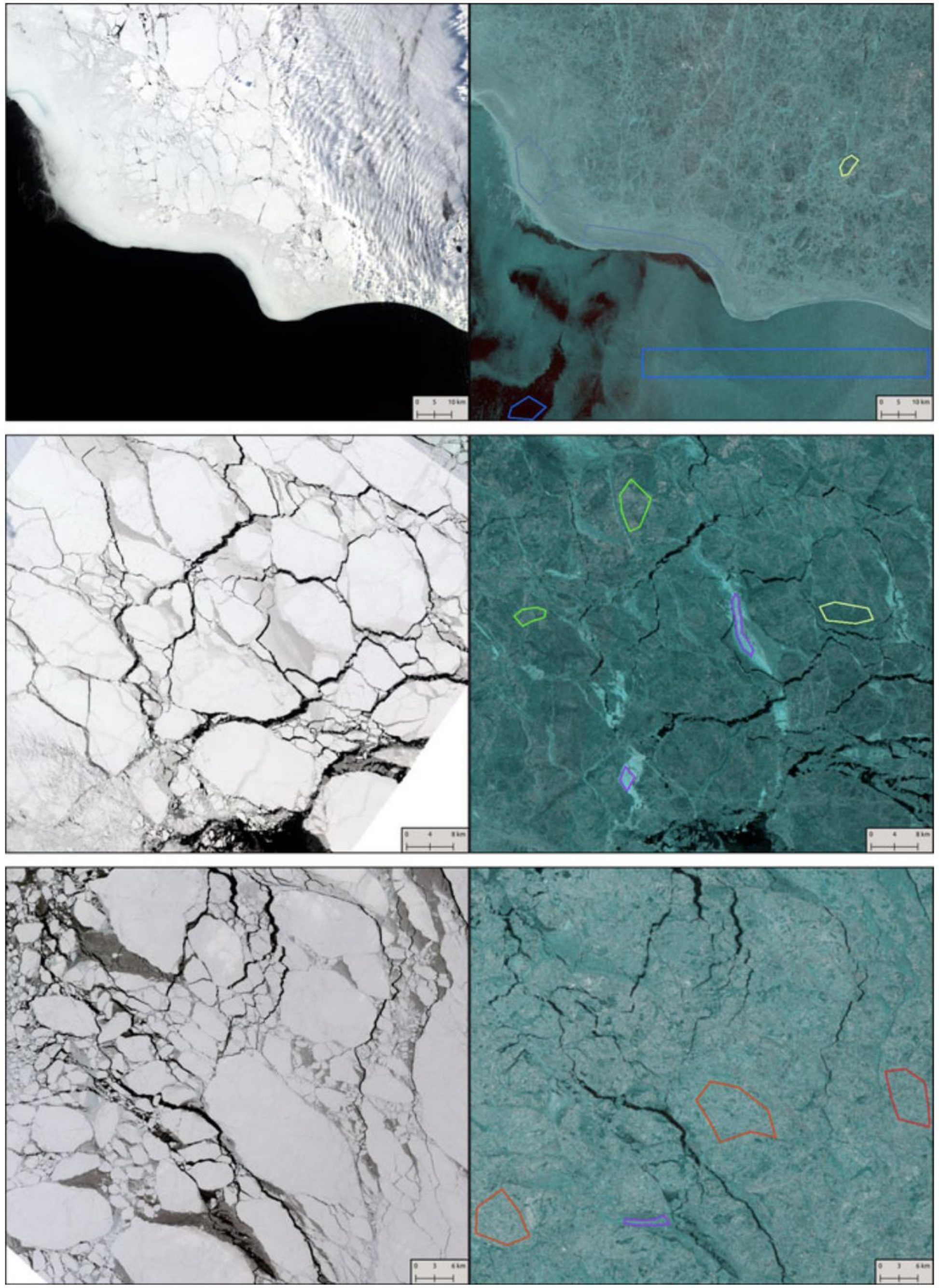
- Drawn by Hand
  - Expert knowledge
  - History from sequence of SAR images
  - Yesterday's images (from the past [hours to a day])
  - Information from ships
  - Other satellite sensors
  - Weather forecasts

- Remaining Challenges:
  - AI may be helpful in improving ice charts (under investigation)
  - Very important to avoid misclassifications regarding hazardous ice conditions

SAR vs. Optical

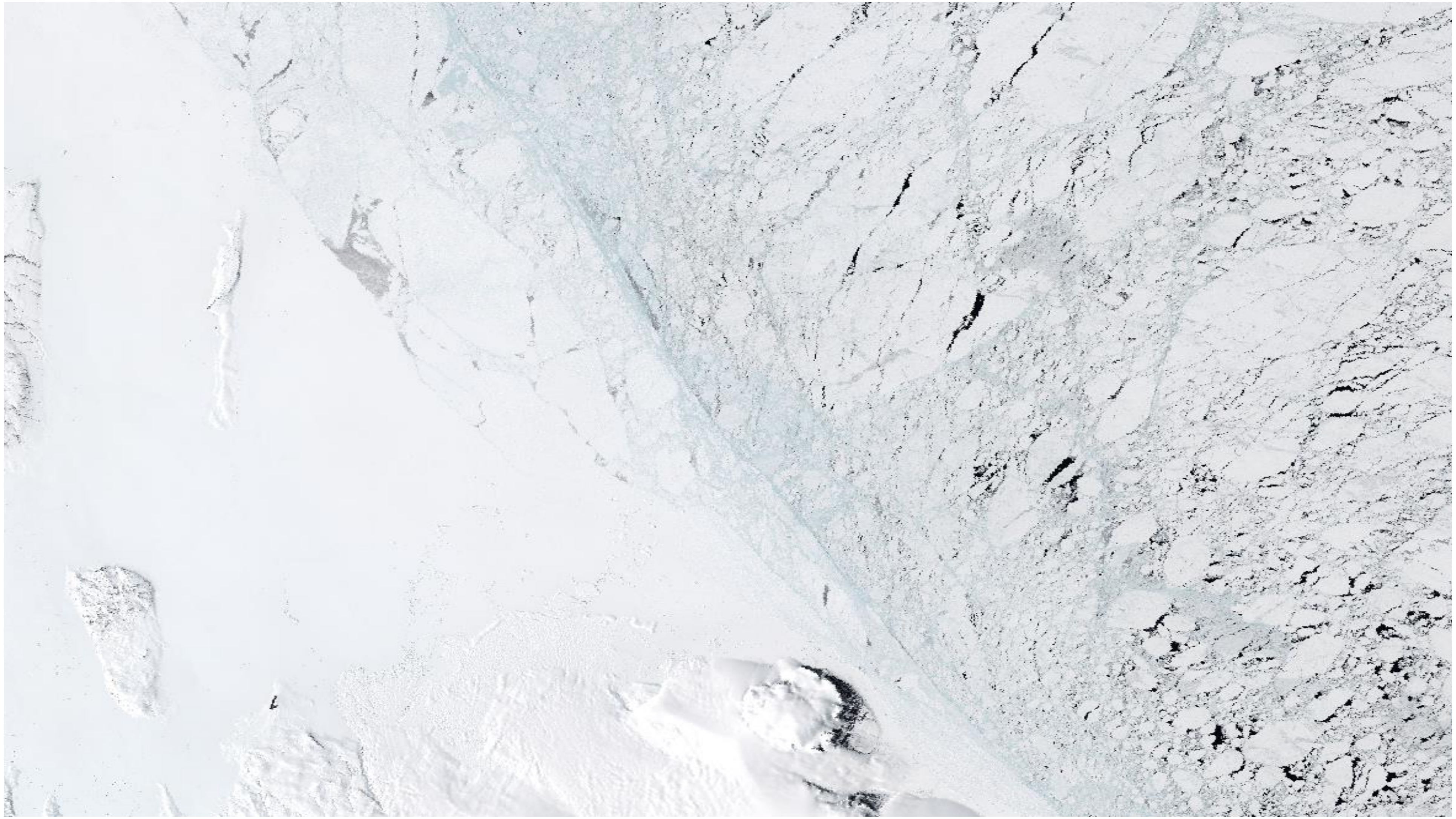
- SAR images can penetrate the clouds and work during polar night
  - Not as intuitive to interpret
  - Need to understand the radar signal's interaction with the ground

- Sentinel-2 on the left
- Sentinel-1 on the right
  - R = HV
  - G = HH
  - B = HH
- False color composite/image



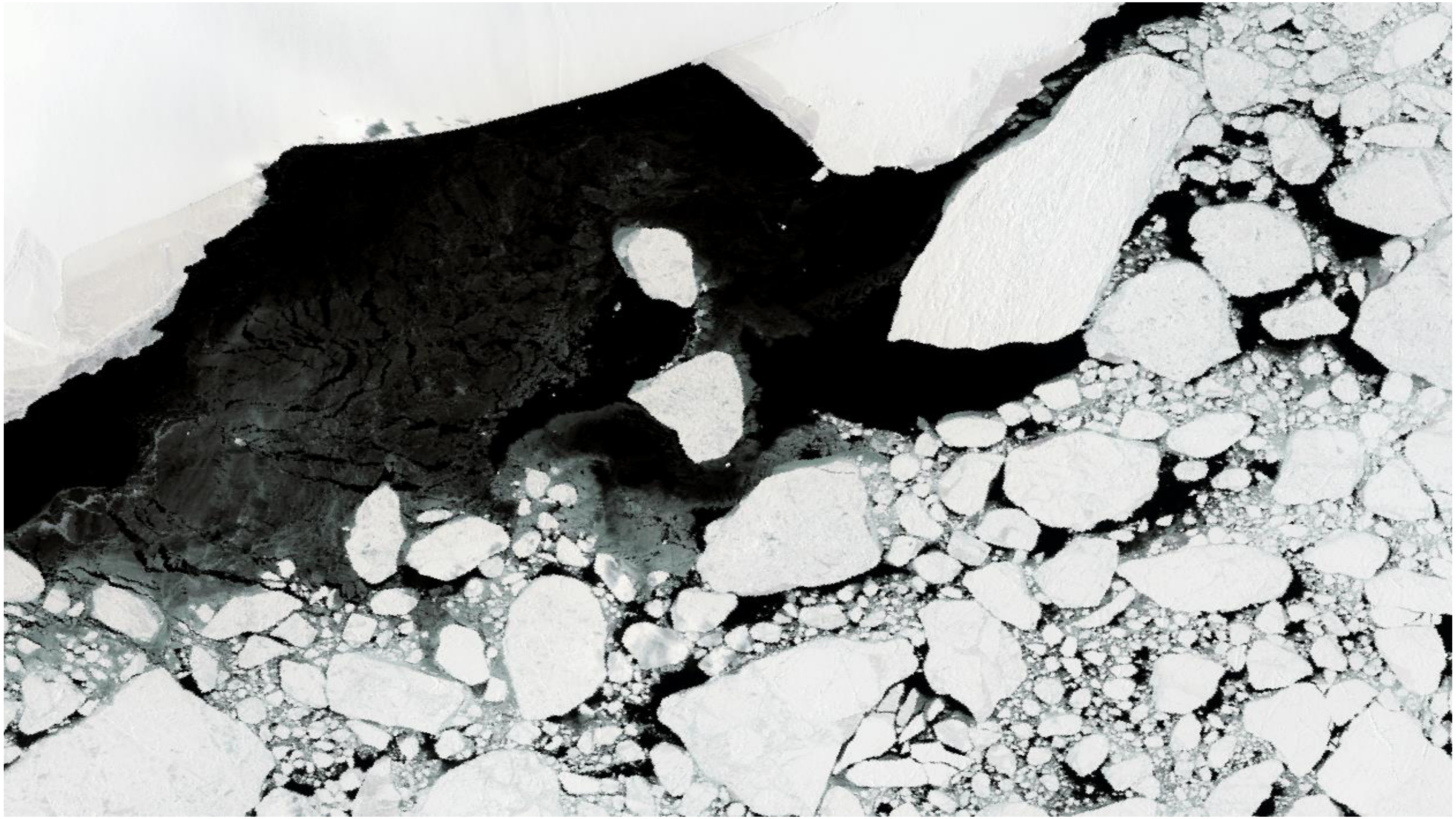
Lohse et al, 2020

Sentinel-1 & Sentinel-2



J. Lohse

Sentinel-1 & Sentinel-2



J. Lohse

Using SAR to Monitor and Detect Sea Ice

Positives

- Works at night
- Can see through the clouds
- Sea ice areas with rough topography can be recognized in SAR images
  - Used for detection of deformed sea ice areas

Using SAR to Monitor and Detect Sea Ice

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- Works at night
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Very useful for safe shipping

Using SAR to Monitor and Detect Sea Ice

Challenges

- Challenging to interpret
  - Multiple scales are involved, from micro to km scales

Using SAR to Monitor and Detect Sea Ice

Challenges

- Challenging to interpret
  - Multiple scales are involved, from micro to km scales
- Multiple scattering mechanisms involved
  - Young thin ice can be bright due to frost flowers, and looks similar to old, thick ice (multi-year ice)

Photo: W. Guo

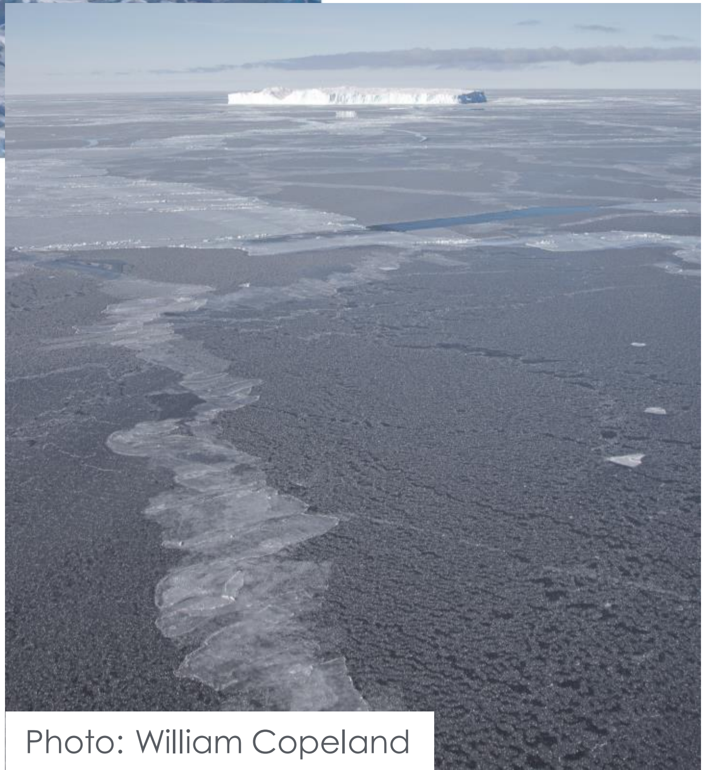
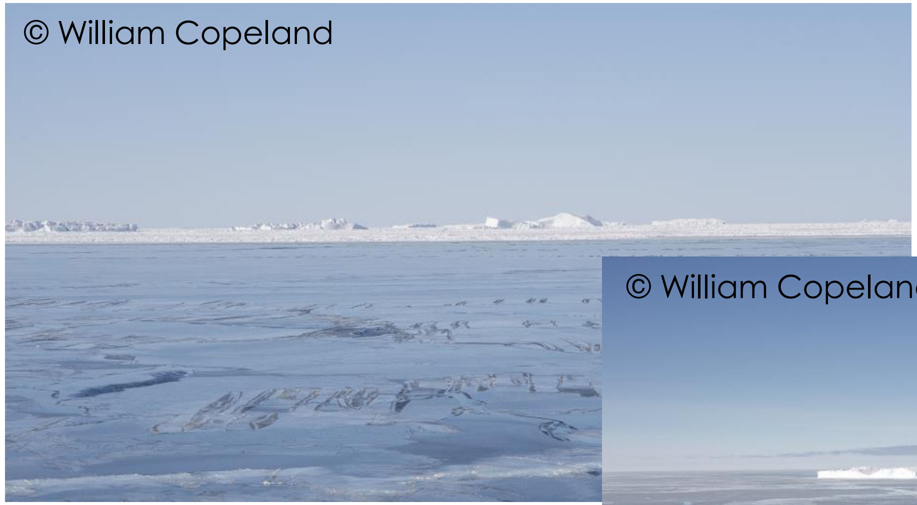


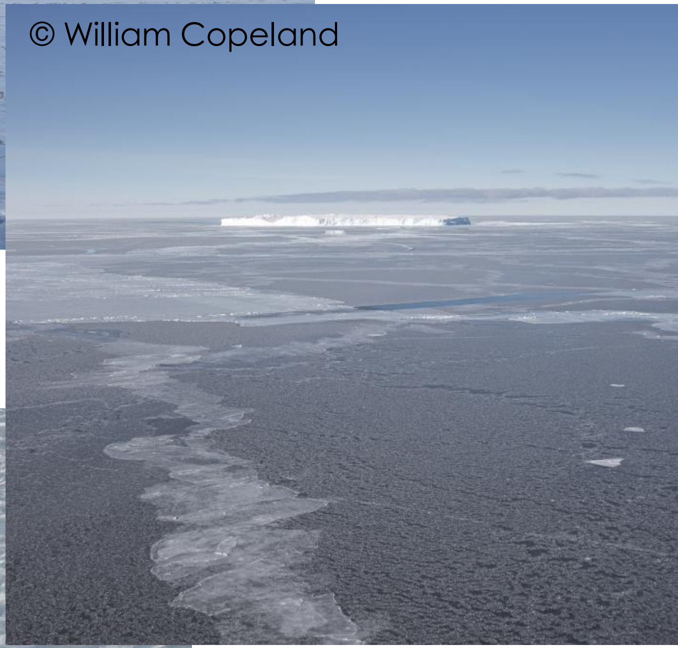
Photo: William Copeland

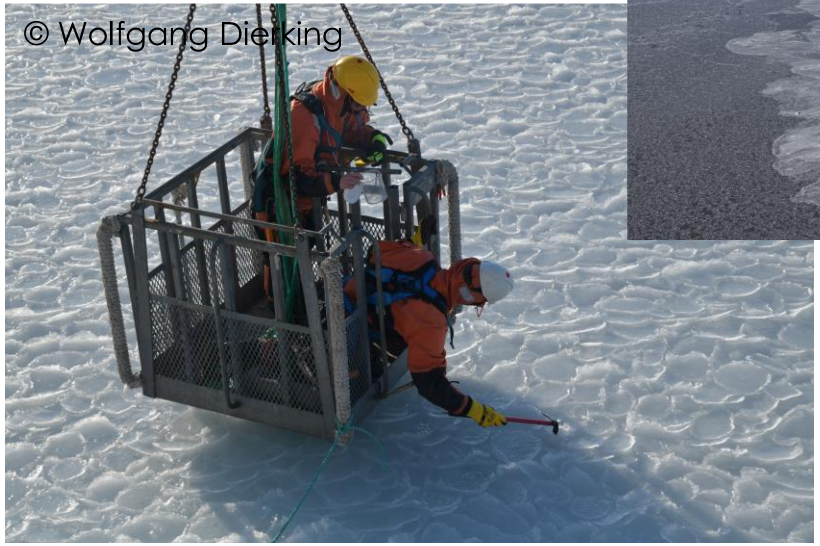
Using SAR to Monitor and Detect Sea Ice

Challenges

- Challenging to interpret
  - Multiple scales are involved, from micro to km scales
- Multiple scattering mechanisms involved
  - Young thin ice can be bright, due to frost flowers, and looks similar to old thick ice (multi-year ice)
- Young ice has a large range of SAR signatures

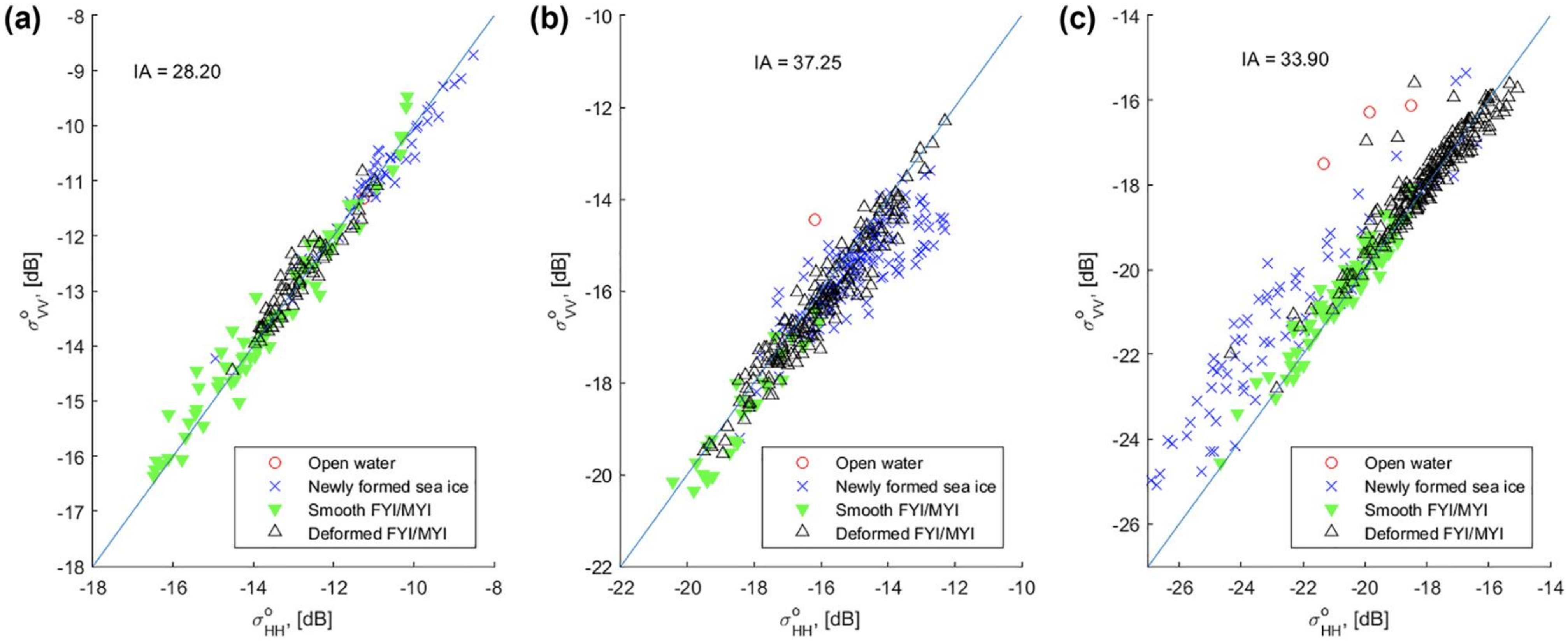






Using SAR to Monitor and Detect Sea Ice

- Evolution for young, smooth, and deformed sea ice
  - Variability is largest for the young ice type



Johansson et al, 2017

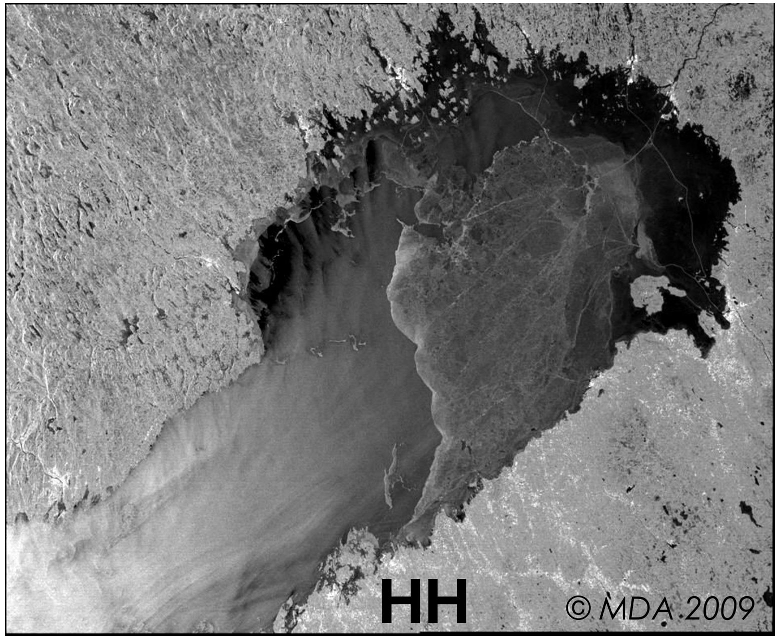
Using SAR to Monitor and Detect Sea Ice

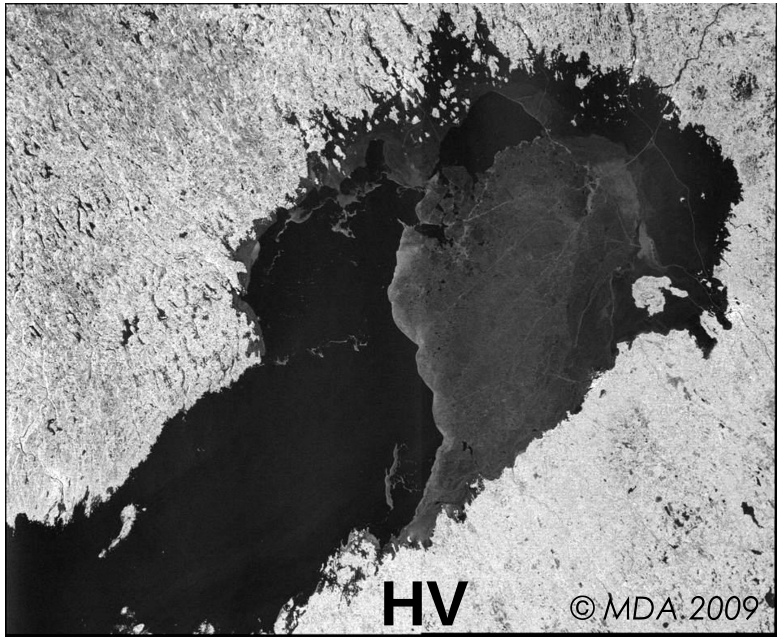
Challenges

- Separation between open ocean and sea ice -> wind speed dependent
- Propagation and scattering of radar waves in snow and ice layers cause complex interaction processes.
- Melt season changes everything!
  – Separation between wet sea ice, melt ponds on sea ice, and open ocean

What type of SAR data do we use?

- ScanSAR images primarily
  - Coverage
  - These days HH+HV
    - Good backscatter signatures



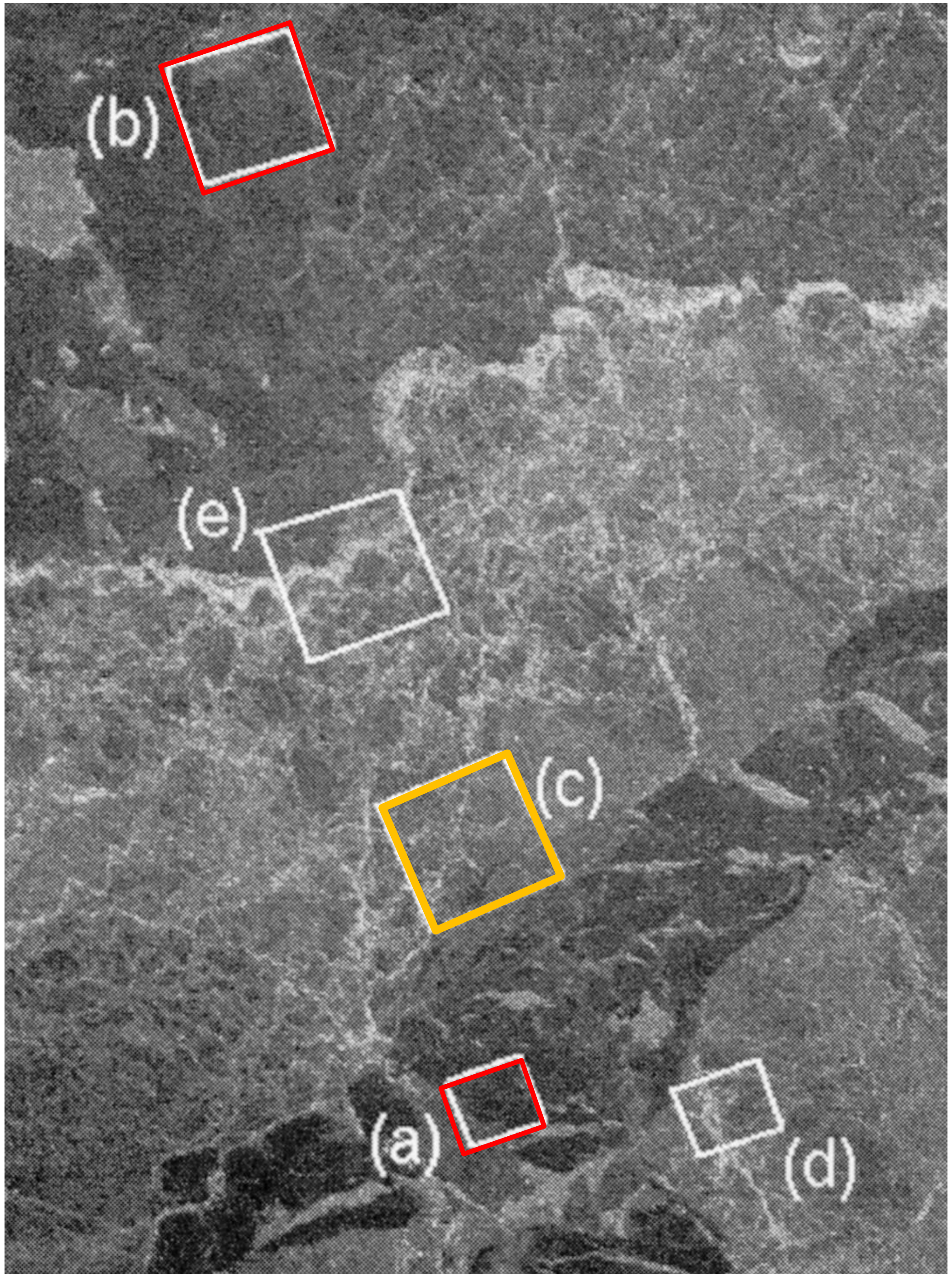


Satellite:
Radarsat-2
ScanSAR
Date: 2009-04-24

SAR Signatures

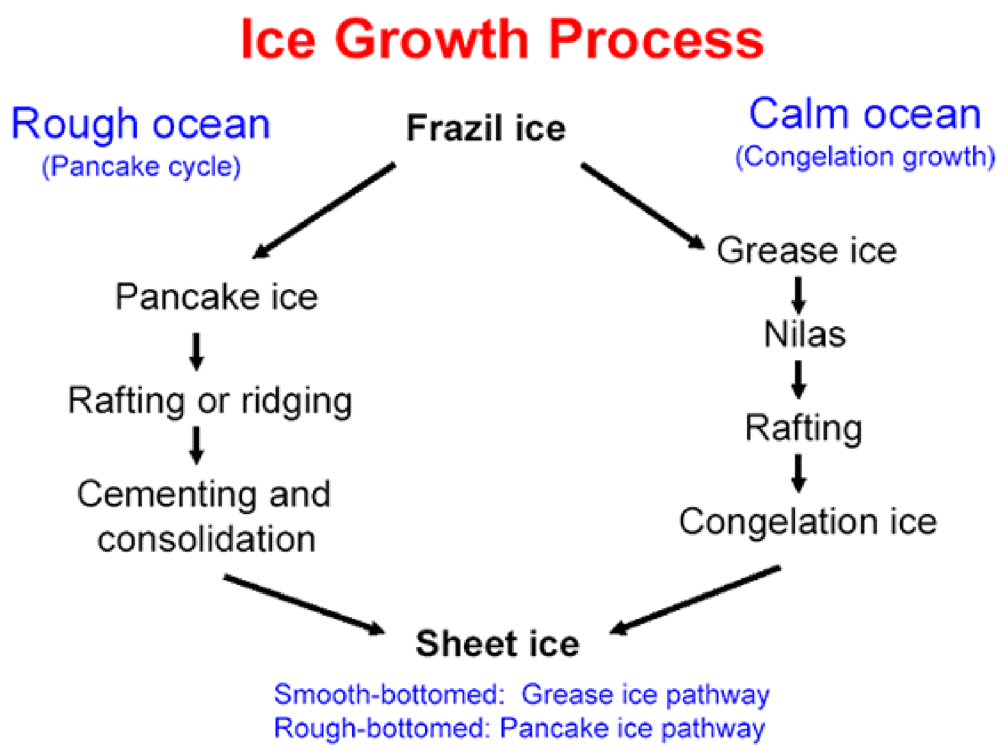
ERS-1 SAR image from 1992-03-17 showing different ice types in boxes:

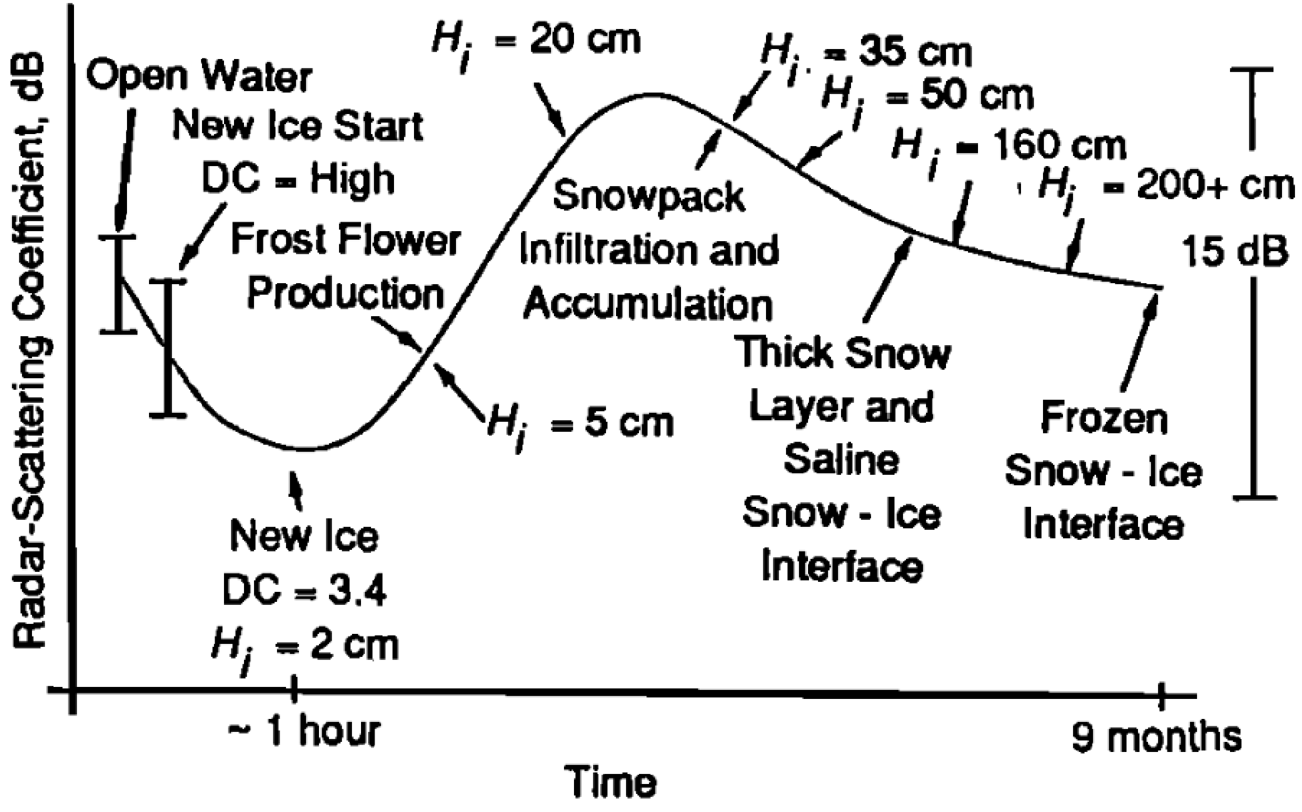
a) Smooth Level Ice
b) Rough Level Ice
c) Ridged Ice
d) Hummocked Ice
e) Rubble Fields
f) Jammed Brash Barrier



Courtesy of P. Dammert et al

Sea Ice Backscatter Signatures



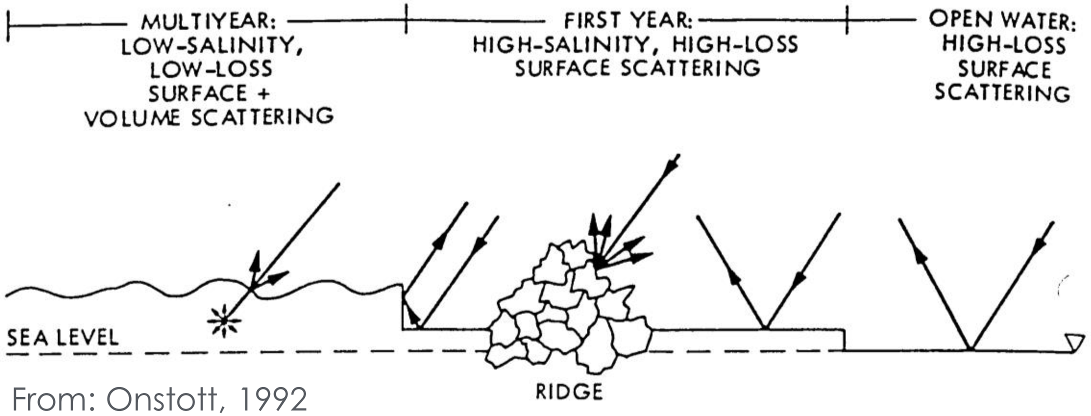


From: Onstott, 1992

Many factors affect SAR imaging.

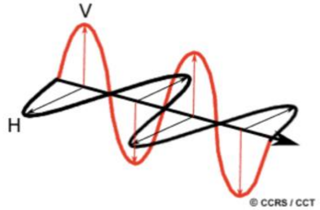
Sea Ice

- Difference in Salinity (dielectric constant, penetration depth)
- Porosity and Inclusions - Scattering
- Surface Roughness and Topography
- Layers
  - Snow/Sea Ice
  - Sea Ice/Water
- Snow Cover (density, grain size, moisture)

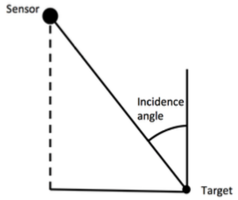


From: Onstott, 1992

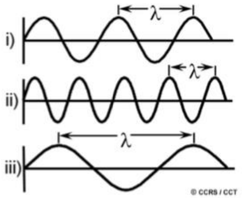
- **Sensor parameters**
  - Polarization



  - Incidence angle θ



  - Resolution, sensor noise, …
  - Frequency



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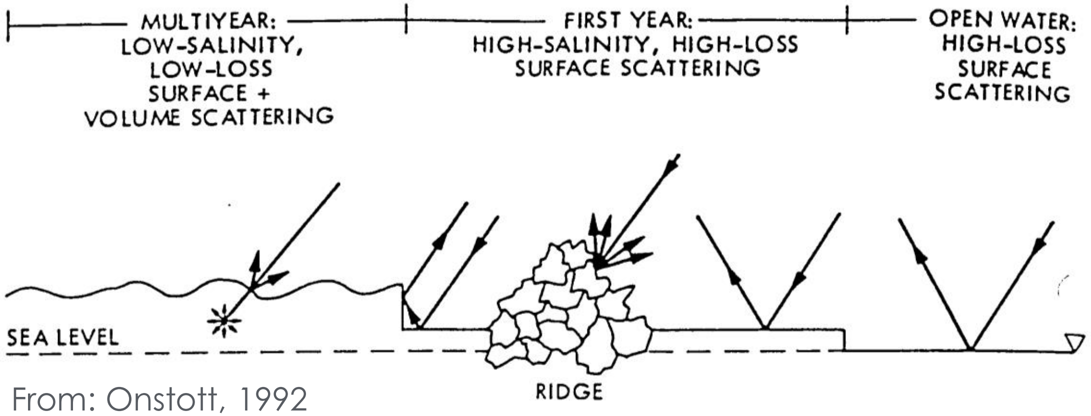

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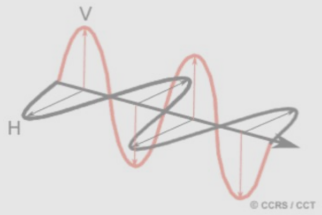

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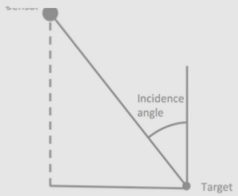

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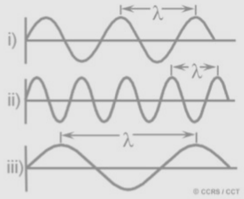

Many factors affect SAR imaging

Sea Ice

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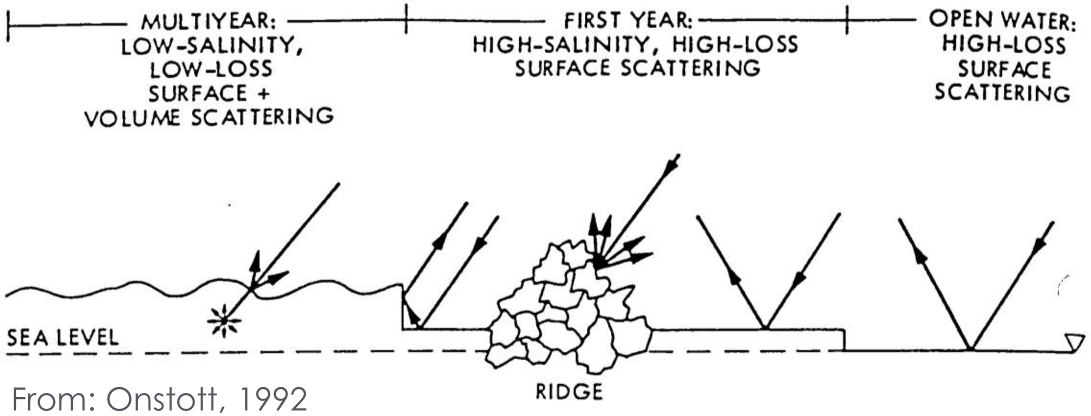
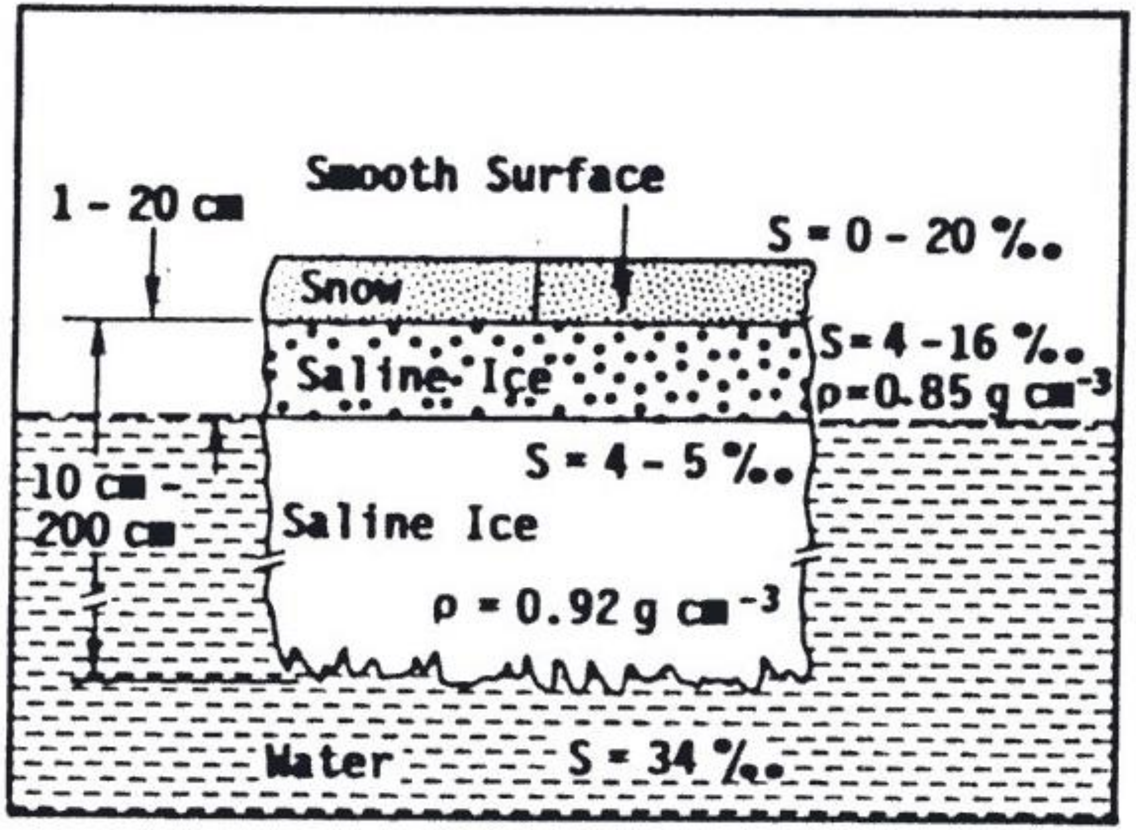


From: Onstott, 1992

Sea Ice Salinity



(b) First-Year Ice

Photo: J. Landy

Many factors affect SAR imaging.

Sea Ice

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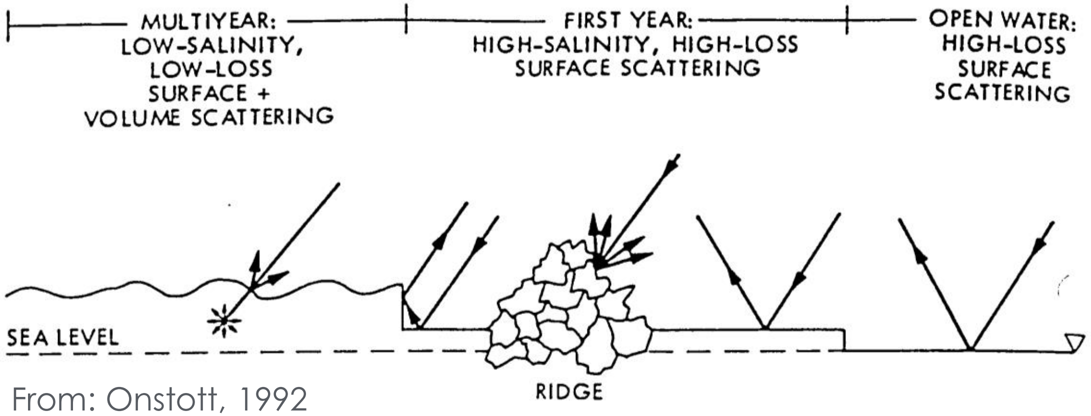
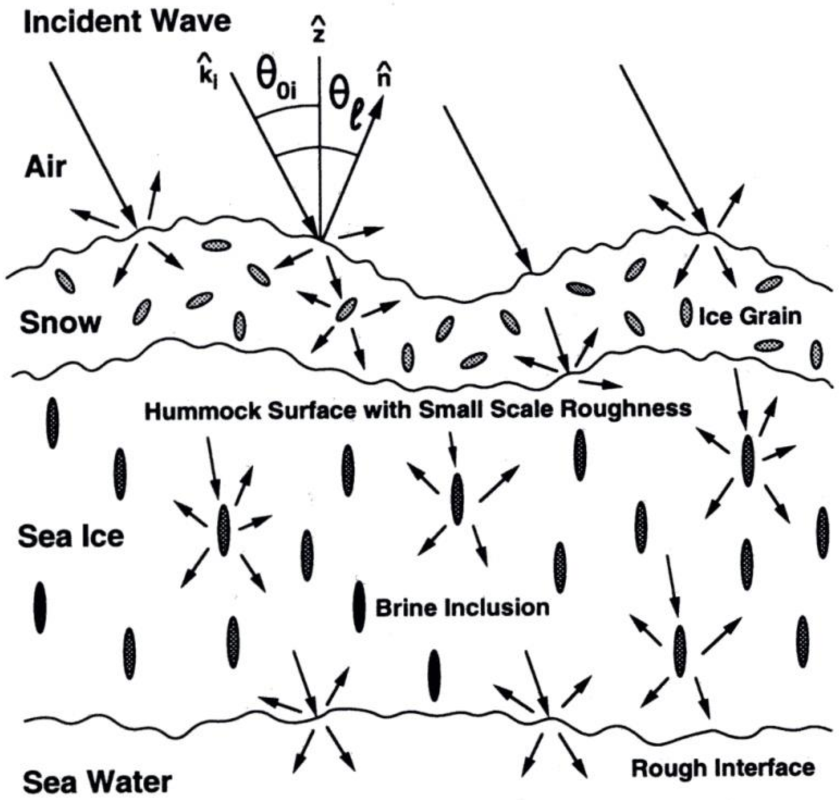


From: Onstott, 1992

Sea Ice Scattering



Wave scattering from sea ice (from Nghiem et al., [1995]).

Many factors affect SAR imaging.

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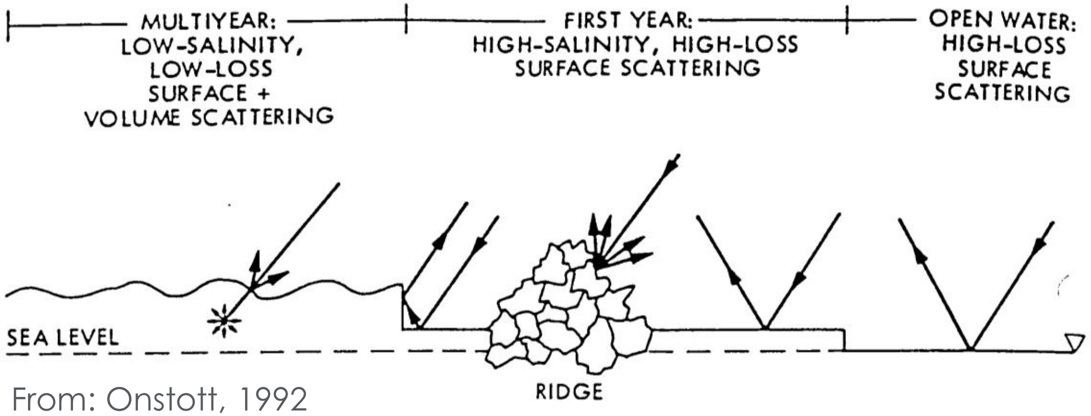
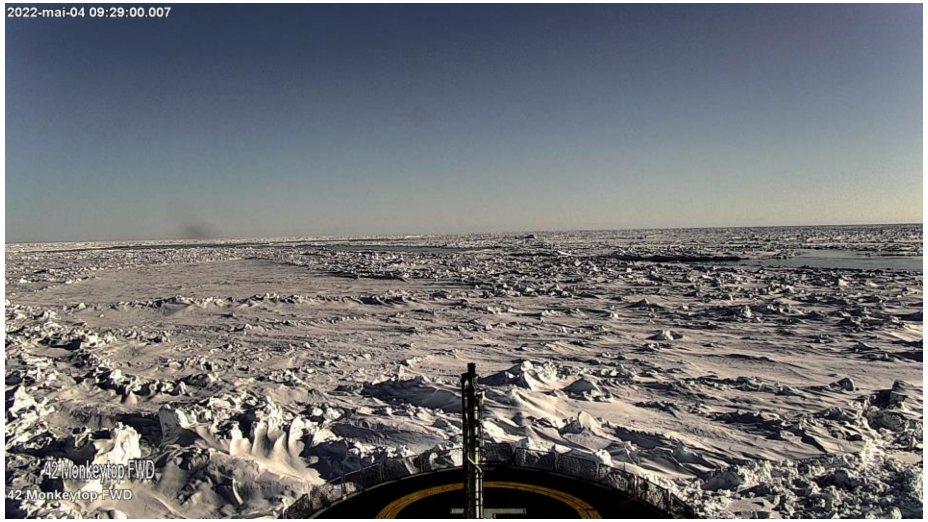


From: Onstott, 1992

Sea Ice Deformation and Roughness

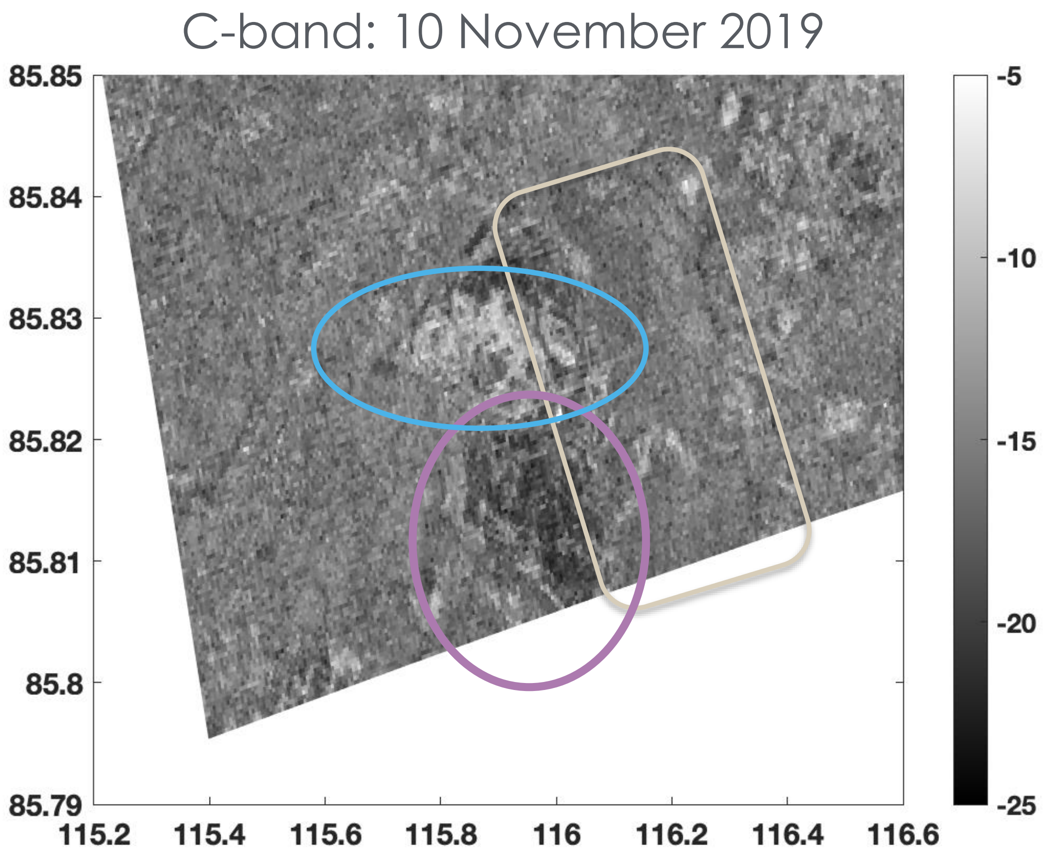


Young Ice

Ridges

Refrozen melt ponds

Thickness: < 1m
Snow: 10 cm



MOSAIC Expedition

Many factors affect SAR imaging.

Sea Ice

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  - **- Snow/Sea Ice**
  - **- Sea Ice/Water**
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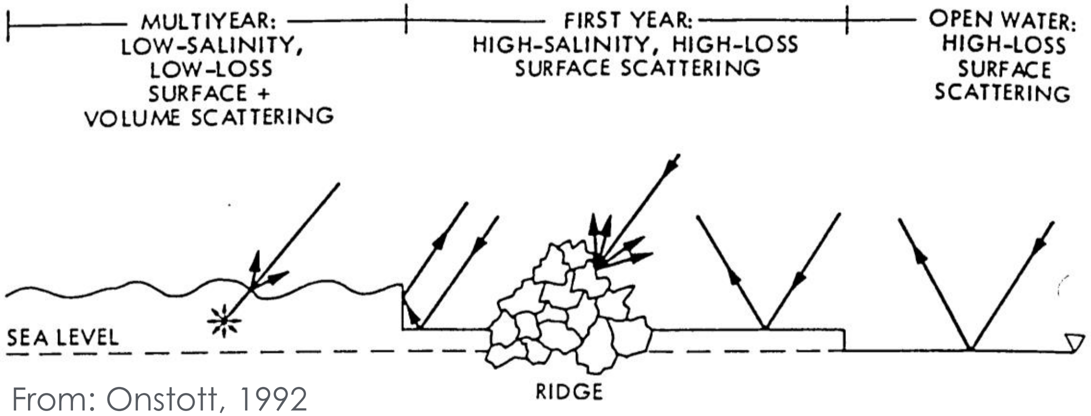
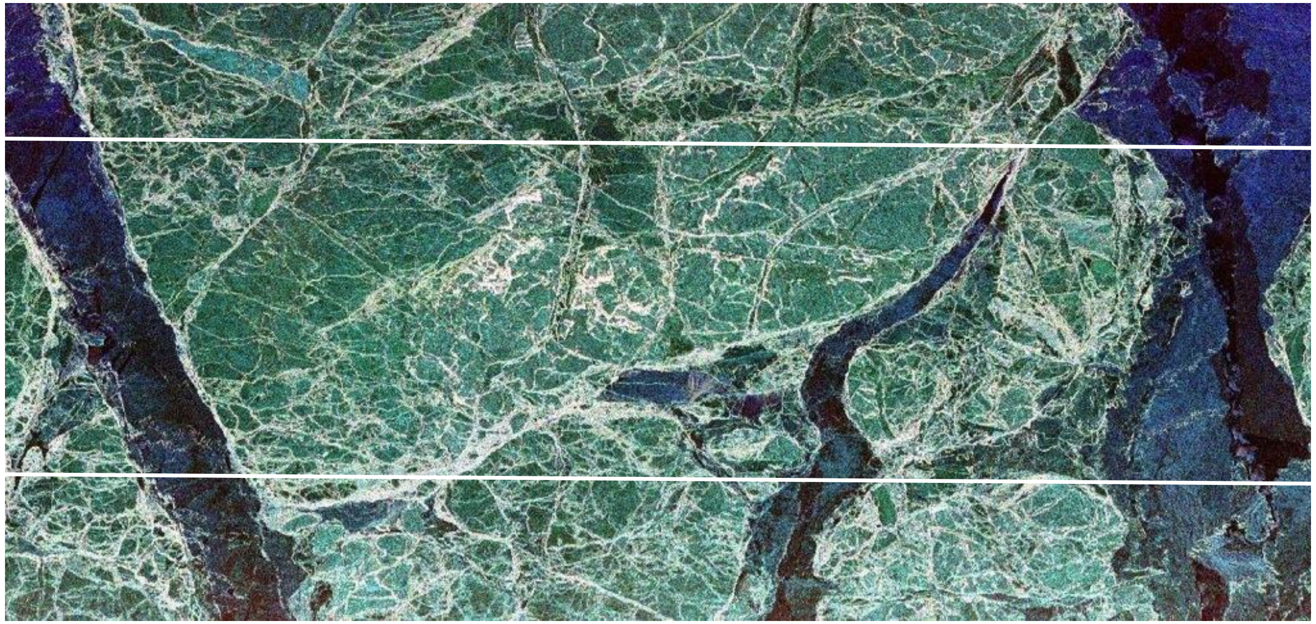


From: Onstott, 1992

Radars look through dry snow.

AWI/Optimare
Airborne
Color Line-Scanner

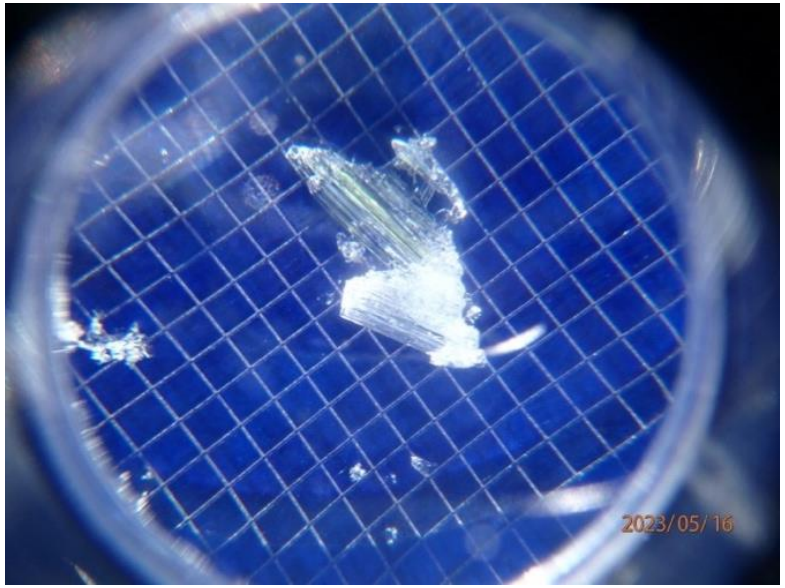


3 km

DLR ESAR:
L-Band
R: X-Pol.
G: H-Pol.
B: V-Pol.

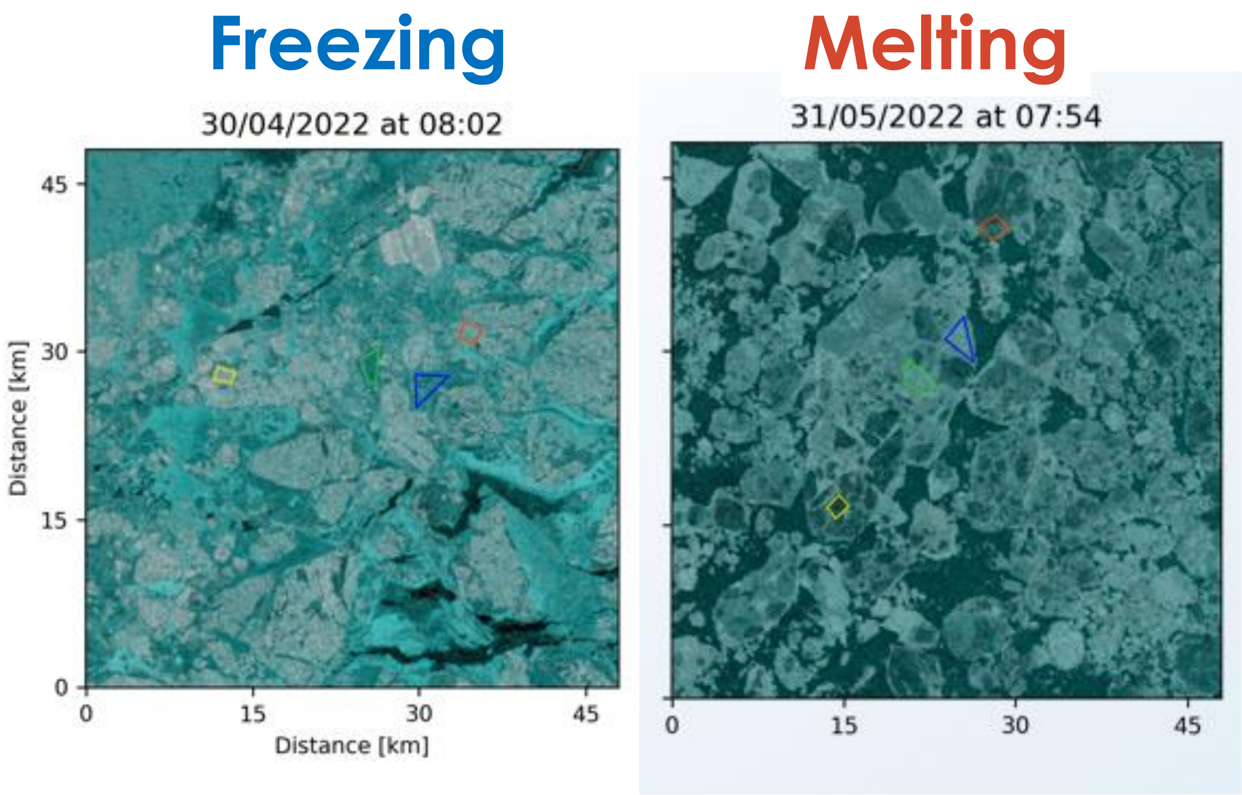
Sea Ice Dynamics – Influence of Snow

- ARTofMELT (Atmospheric rivers and the onset of sea ice melt)
- May 7th to June 15th
- 28 snow pits

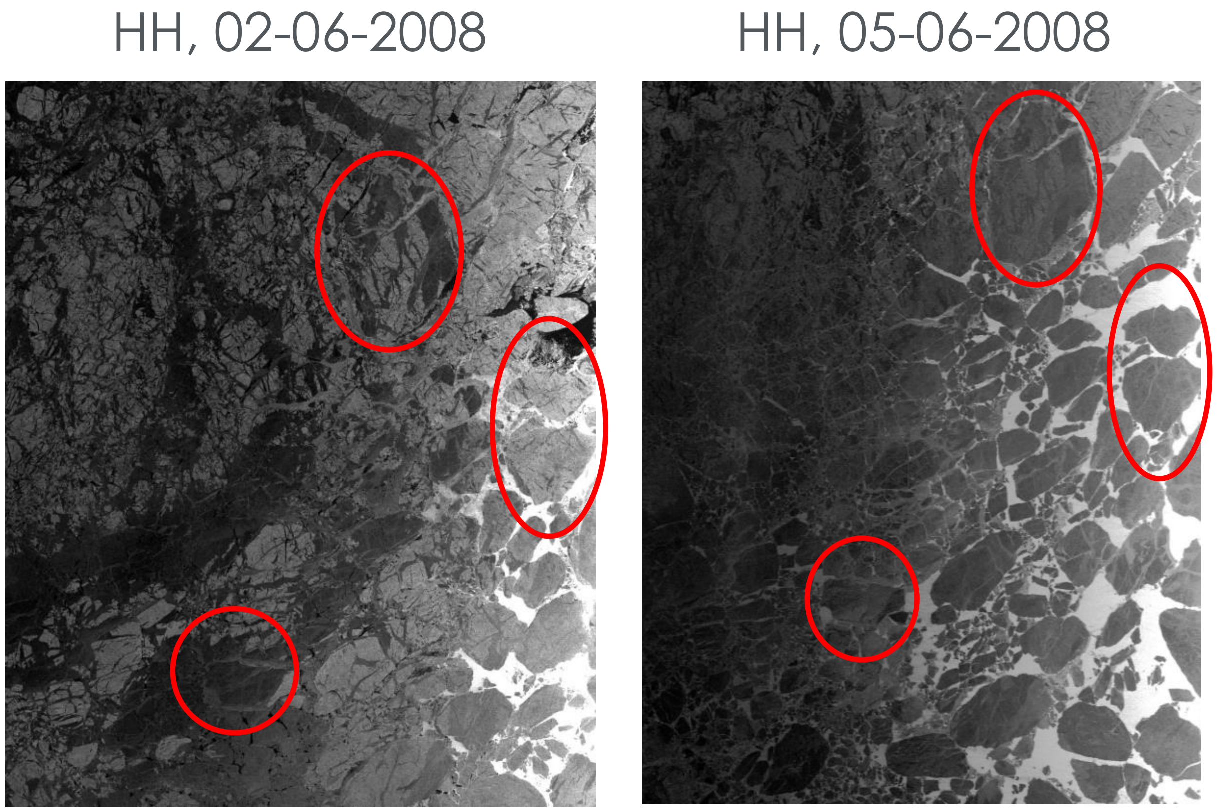


Photos: T. Karlsen

Influence of Snow



C. Taelmann et al, 2023



© ASAR Images

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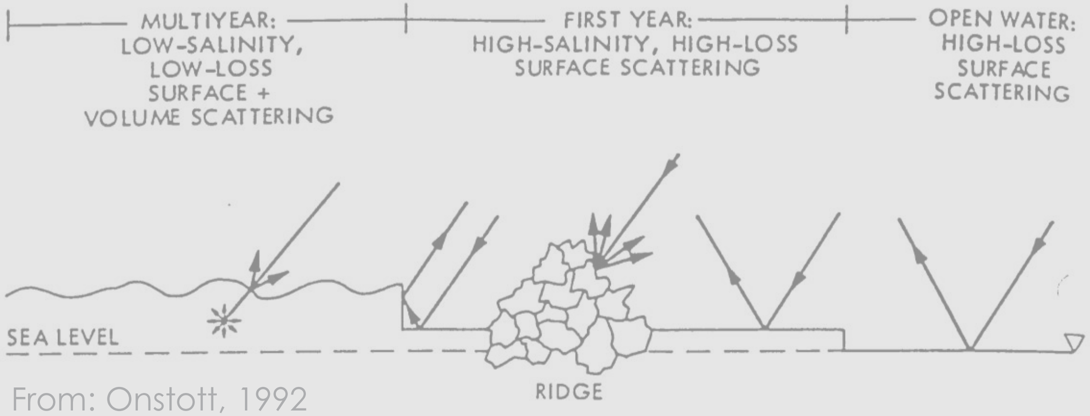
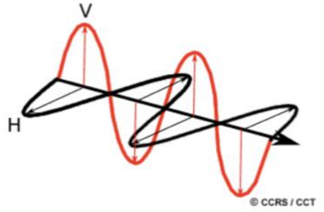
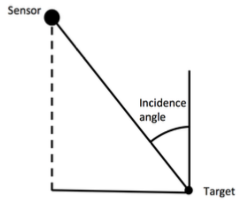


From: Onstott, 1992

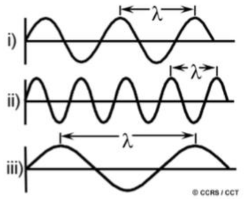
- **Sensor parameters**
  - Polarization



  - Incidence angle θ

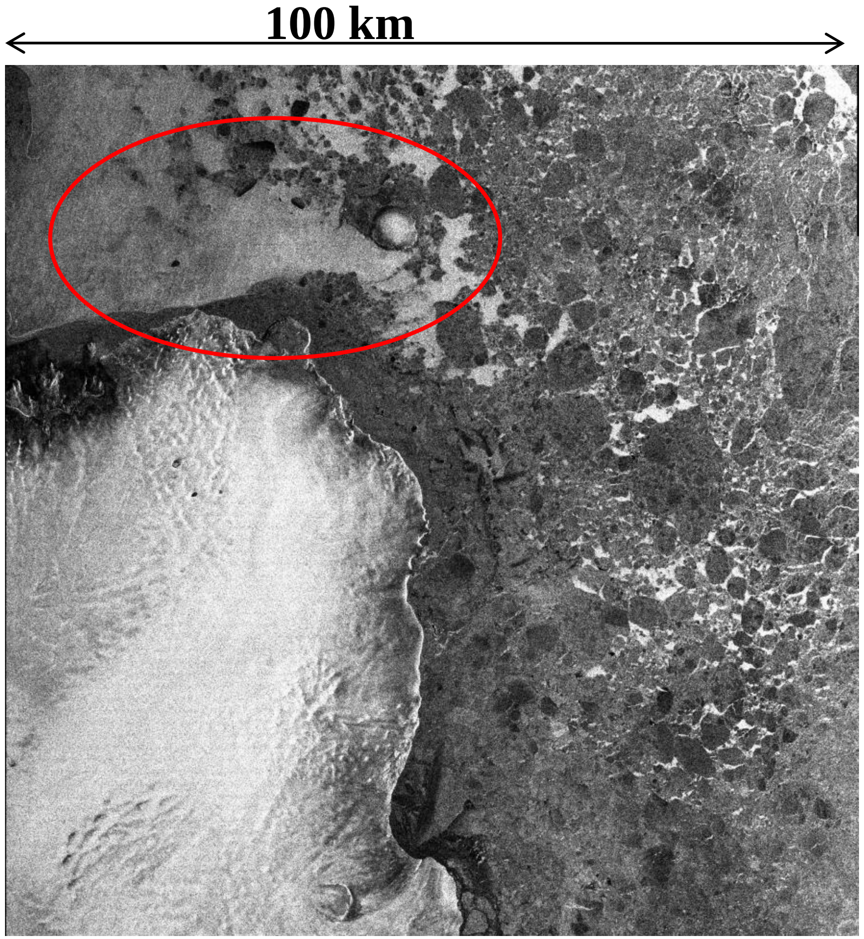


  - Resolution, sensor noise, …
  - Frequency

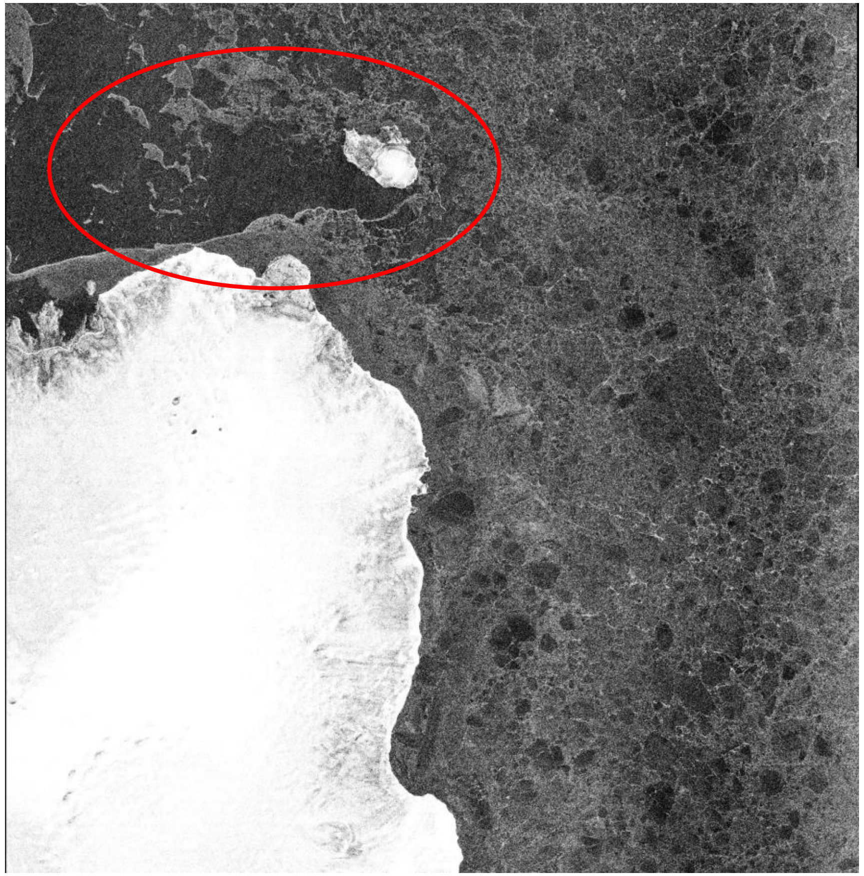


Sea Ice Backscatter Signatures

ASAR, March 17, 2007
(ICESAR-Campaign)



HH-Polarization

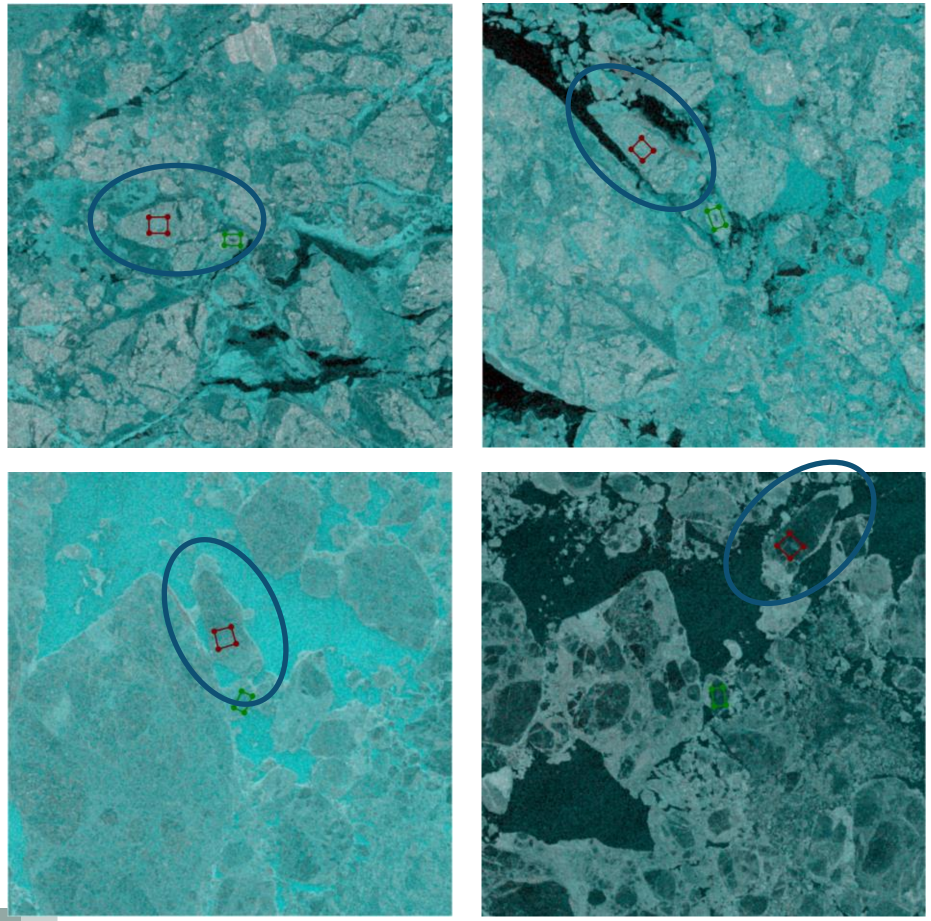


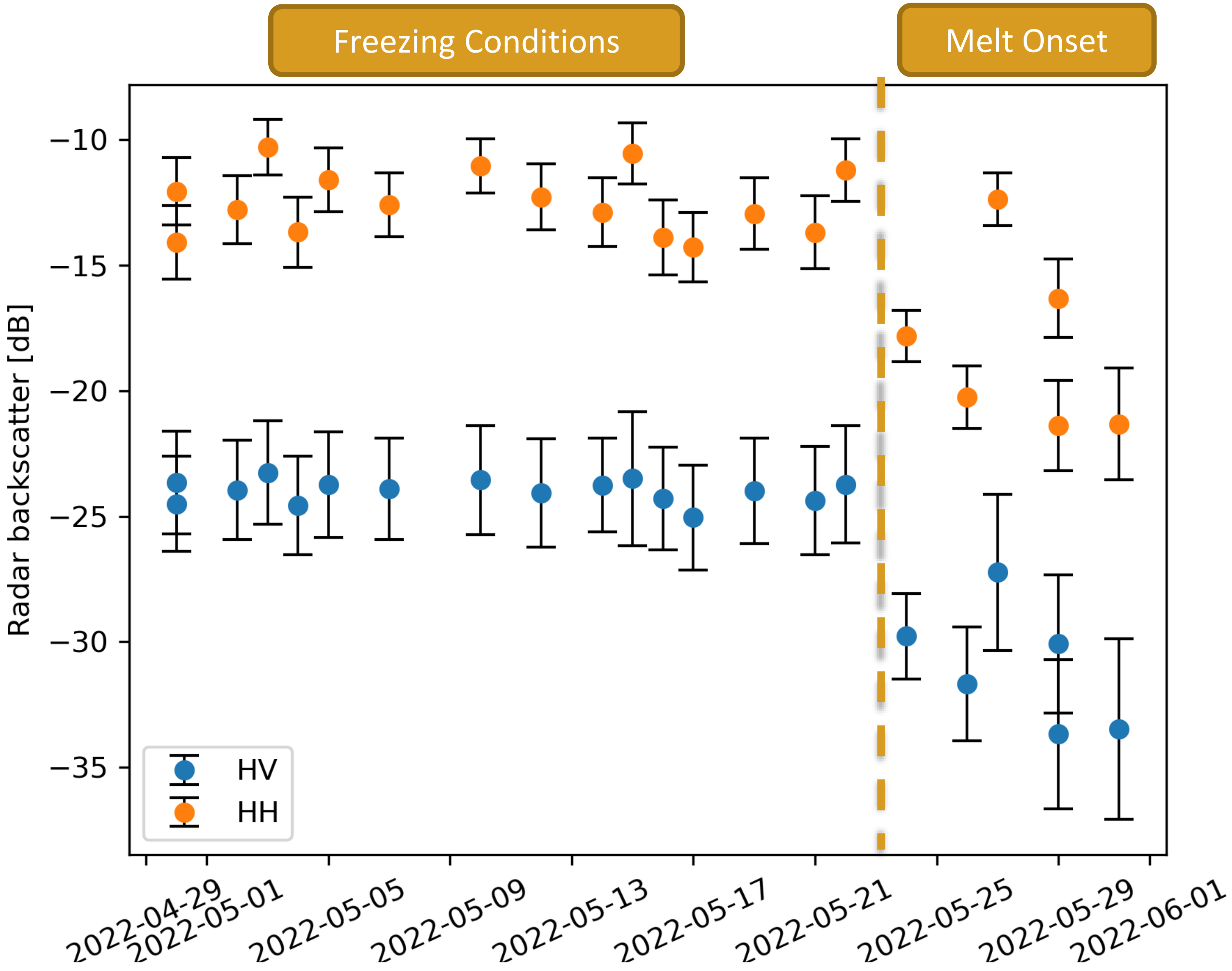
HV-Polarization

© W. Dierking

Sea Ice Backscatter Signatures

- Track the same ice over time
  - Multi-year ice floe





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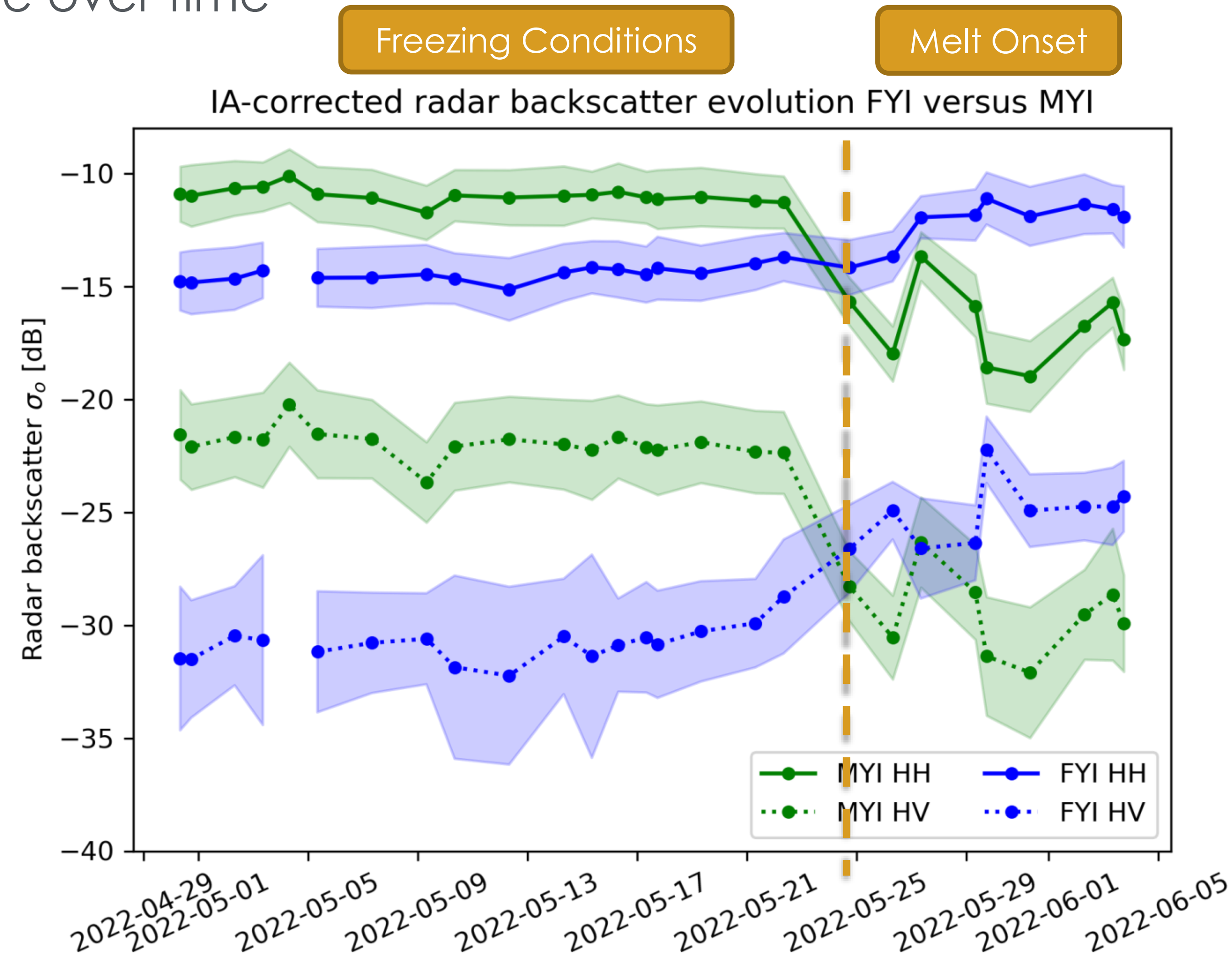

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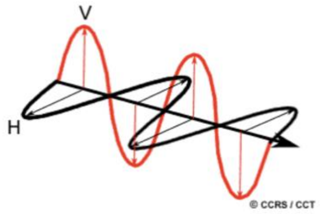
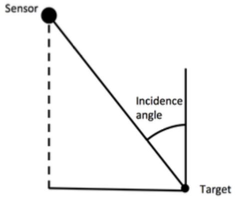
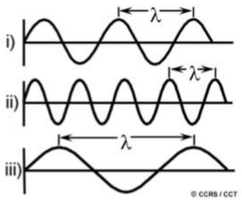
- **Sensor parameters**
  - Polarization



  - Incidence angle θ

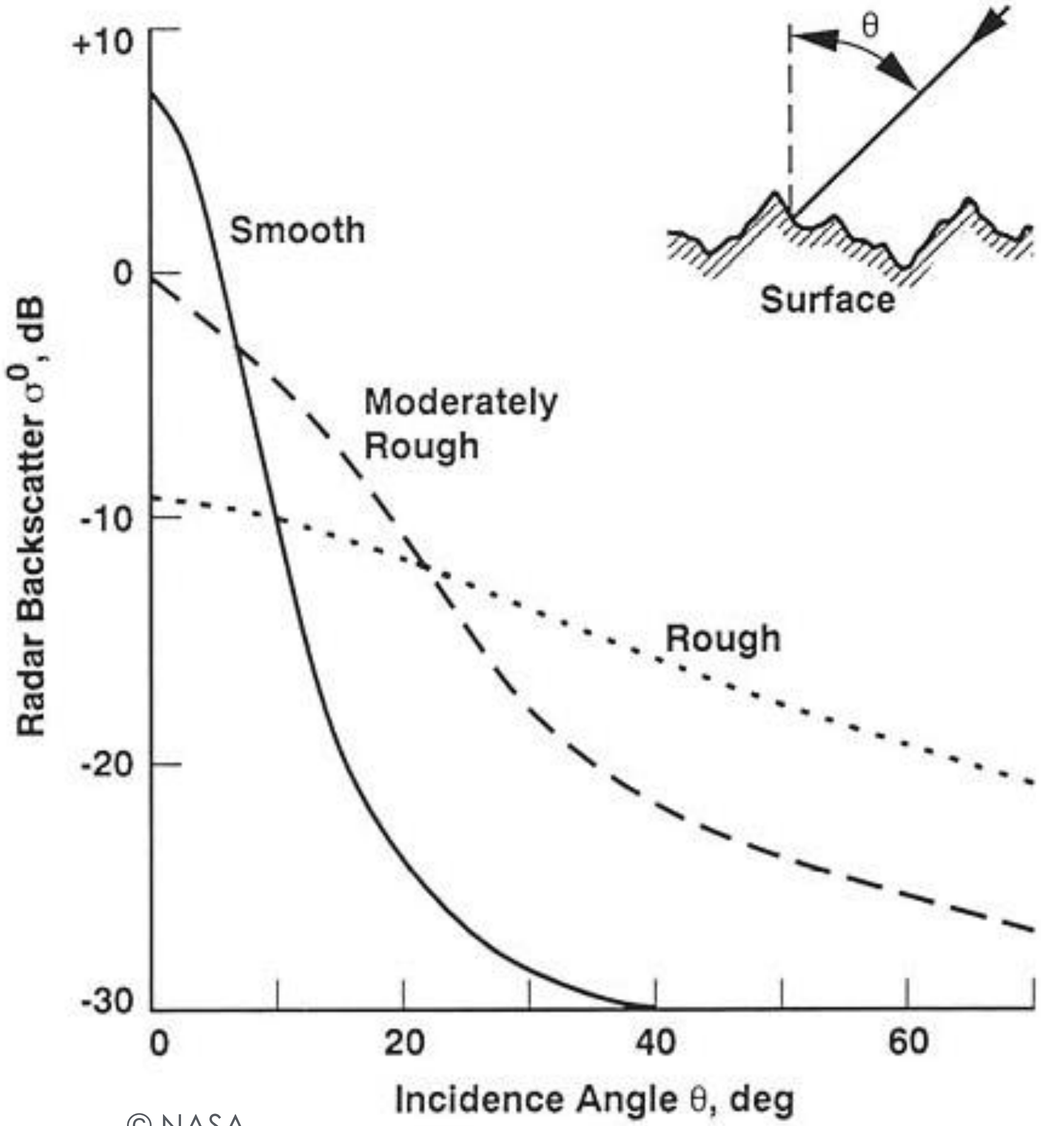


  - Resolution, sensor noise, …
  - Frequency



Incidence Angle

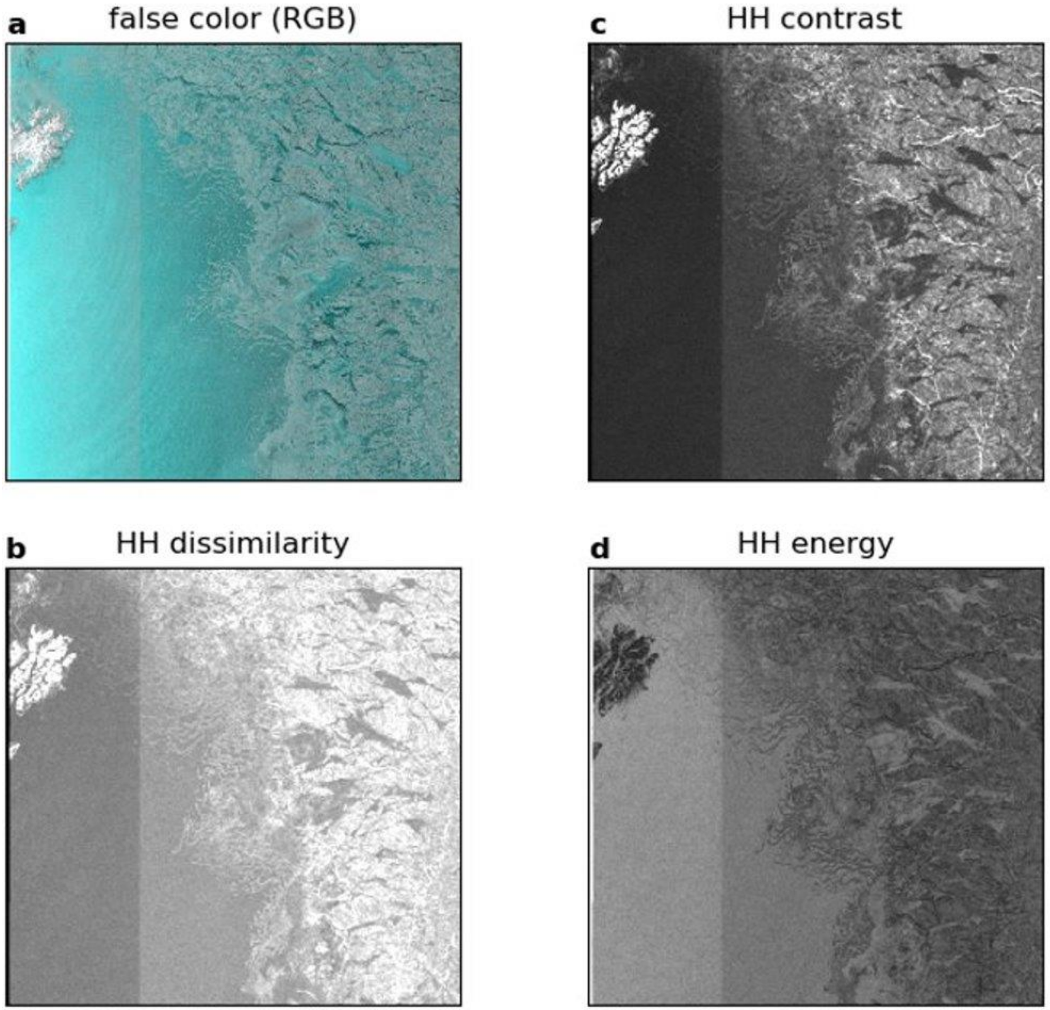
- Radar backscatter is reduced with increased incidence angle.



© NASA

Incidence Angle

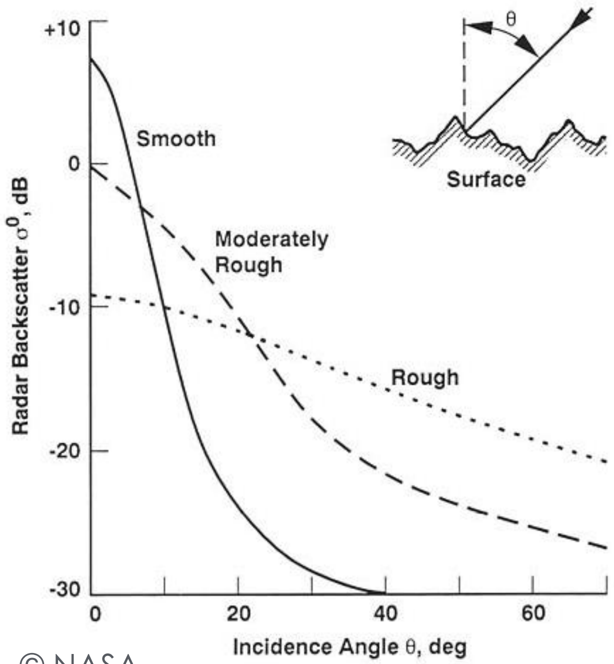
- We can either correct for the effect across the entire image
  - 0.22 dB/deg for C-band (Mahmud et al, 2018)
- Overall ice types, hence, not a perfect correction
- Or one correction for each ice type



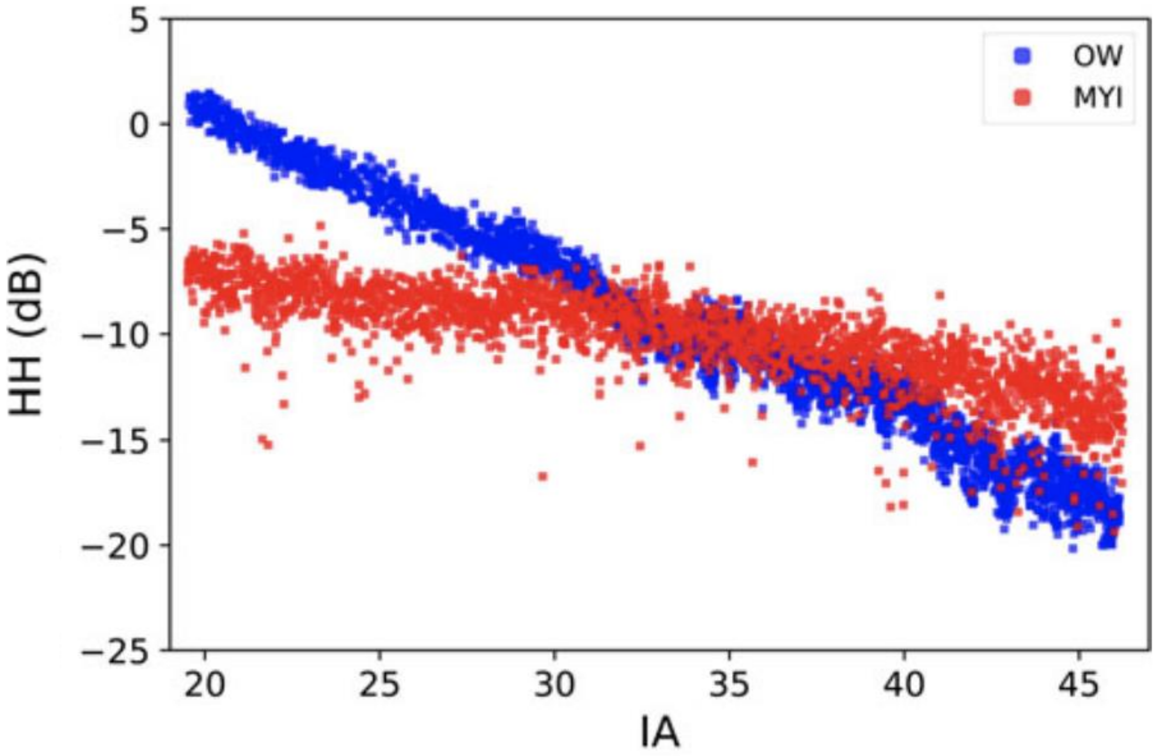
Lohse et al, 2021

Incidence Angle

- Radar backscatter is reduced with increased incidence angle.
- The change across the scene is dependent on the material on the ground.

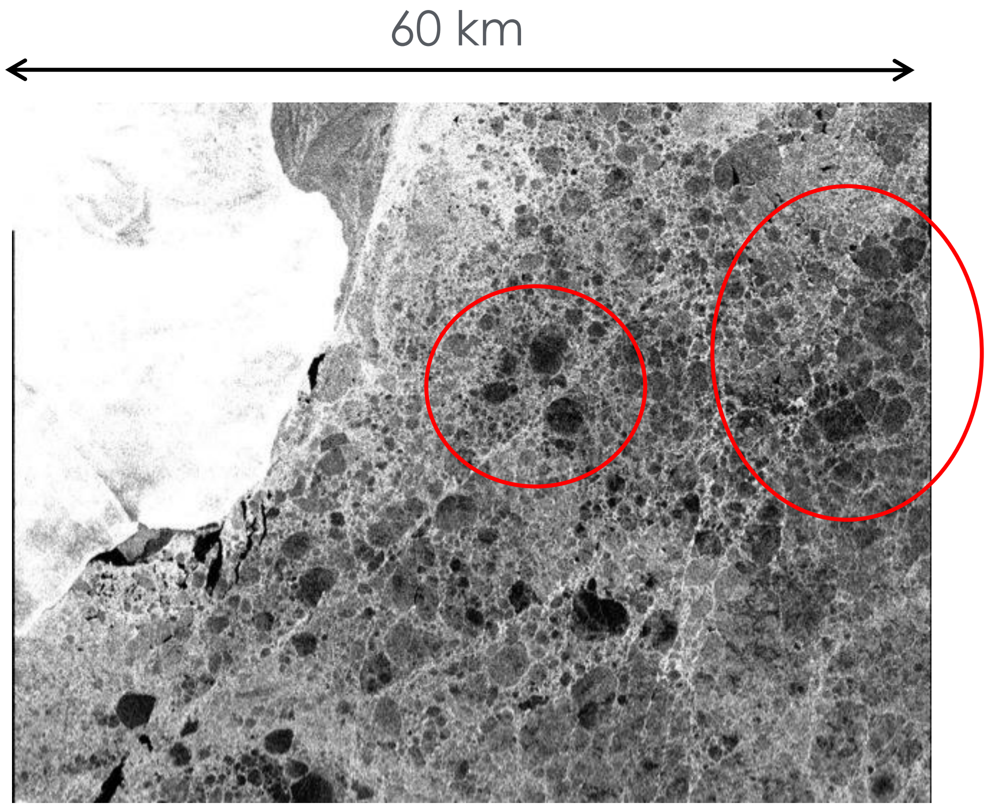


© NASA

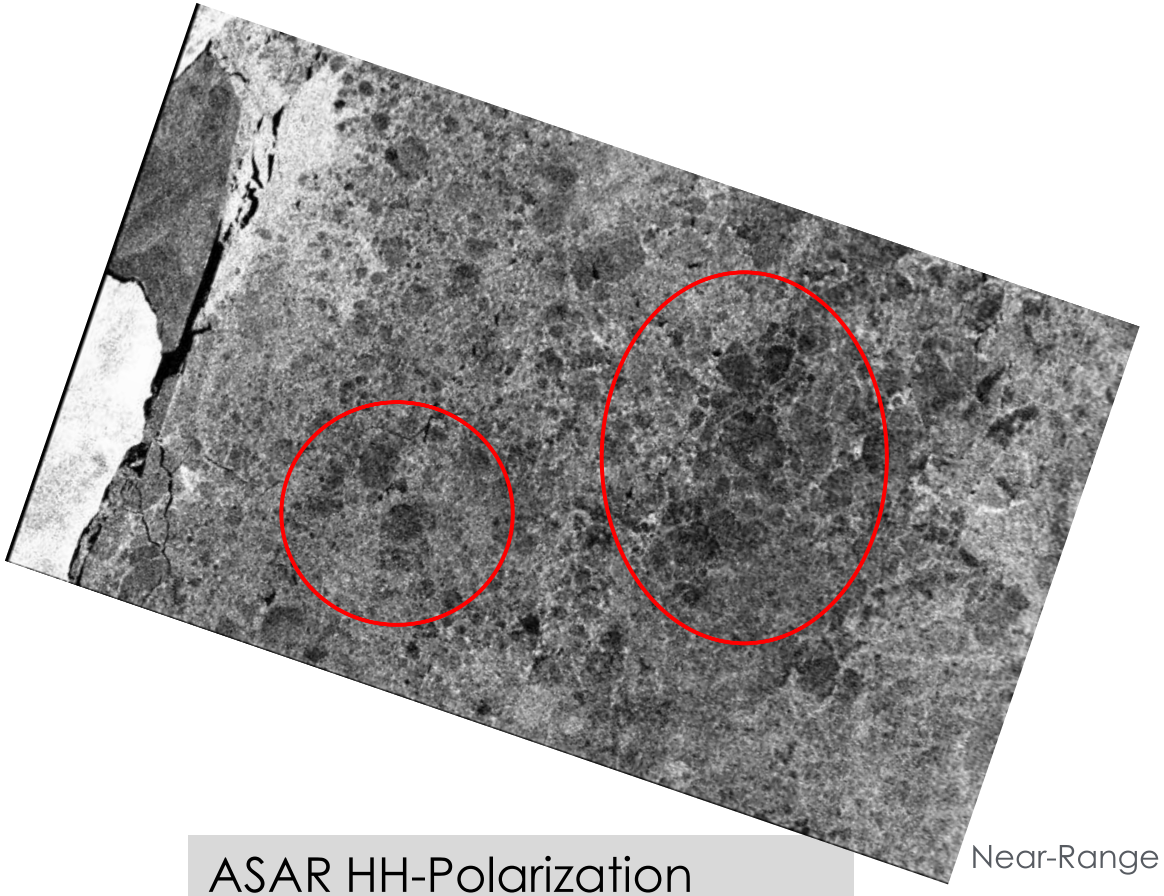


Lohse et al, 2020

Incidence Angle



ASAR HH-Polarization
20. March 2007, 9:11 UTC
Incidence Angle: 42 – 45°

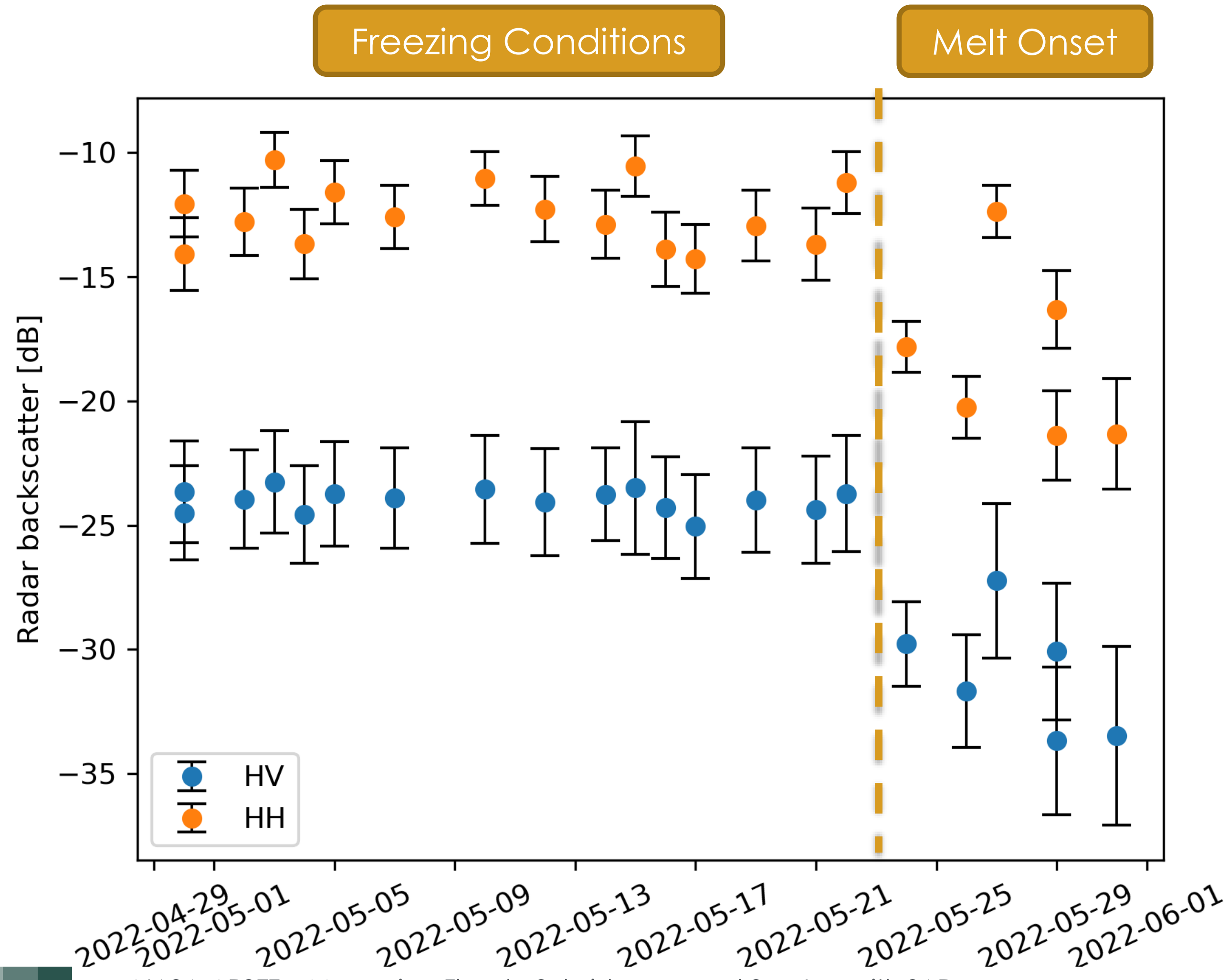


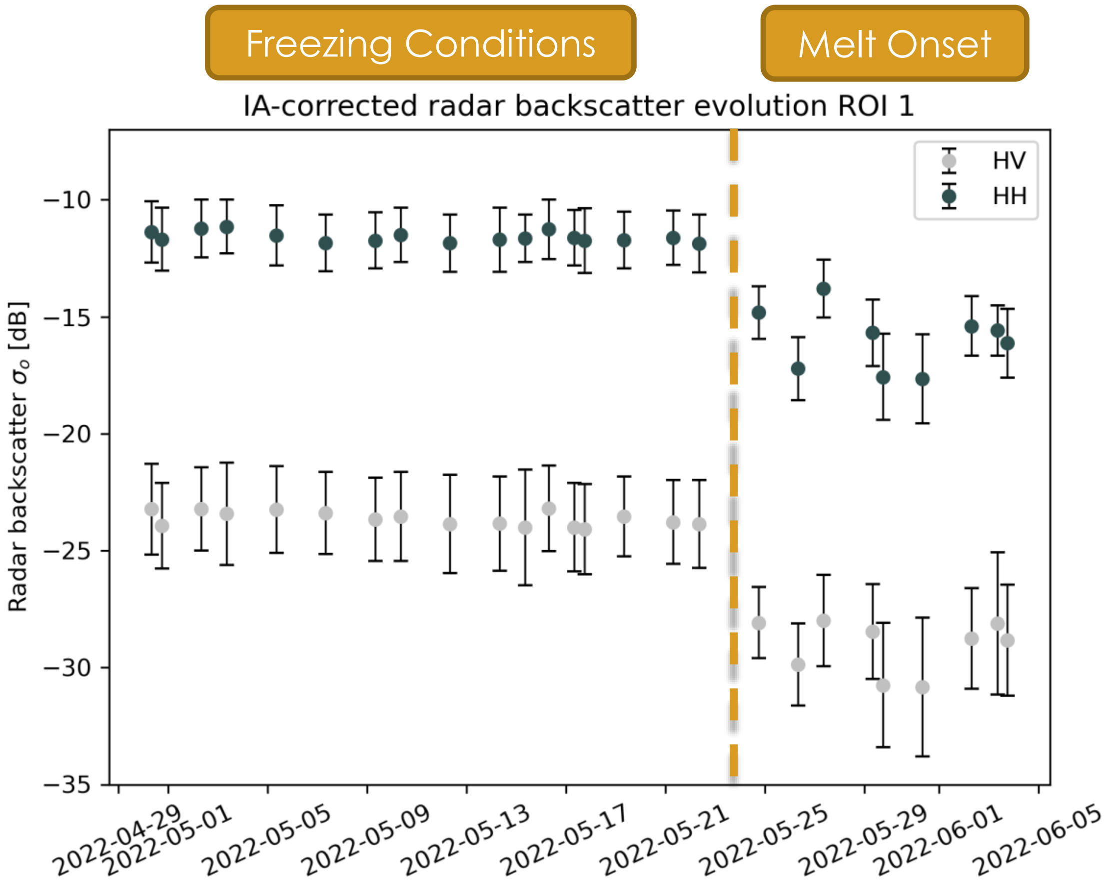
ASAR HH-Polarization
21. March 2007, 10:20 UTC
Incidence Angle: 19 – 22°

…hampers (automatic) segmentation/classification

Sea Ice Backscatter Signatures – Incidence Angle

- Track the same ice over time





© C. Taelman et al, 2023

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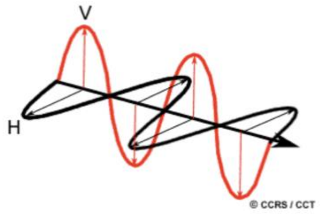
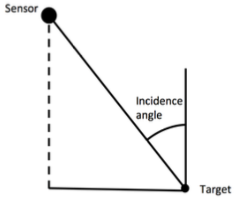
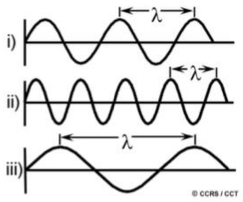
- **Sensor parameters**
  - Polarization



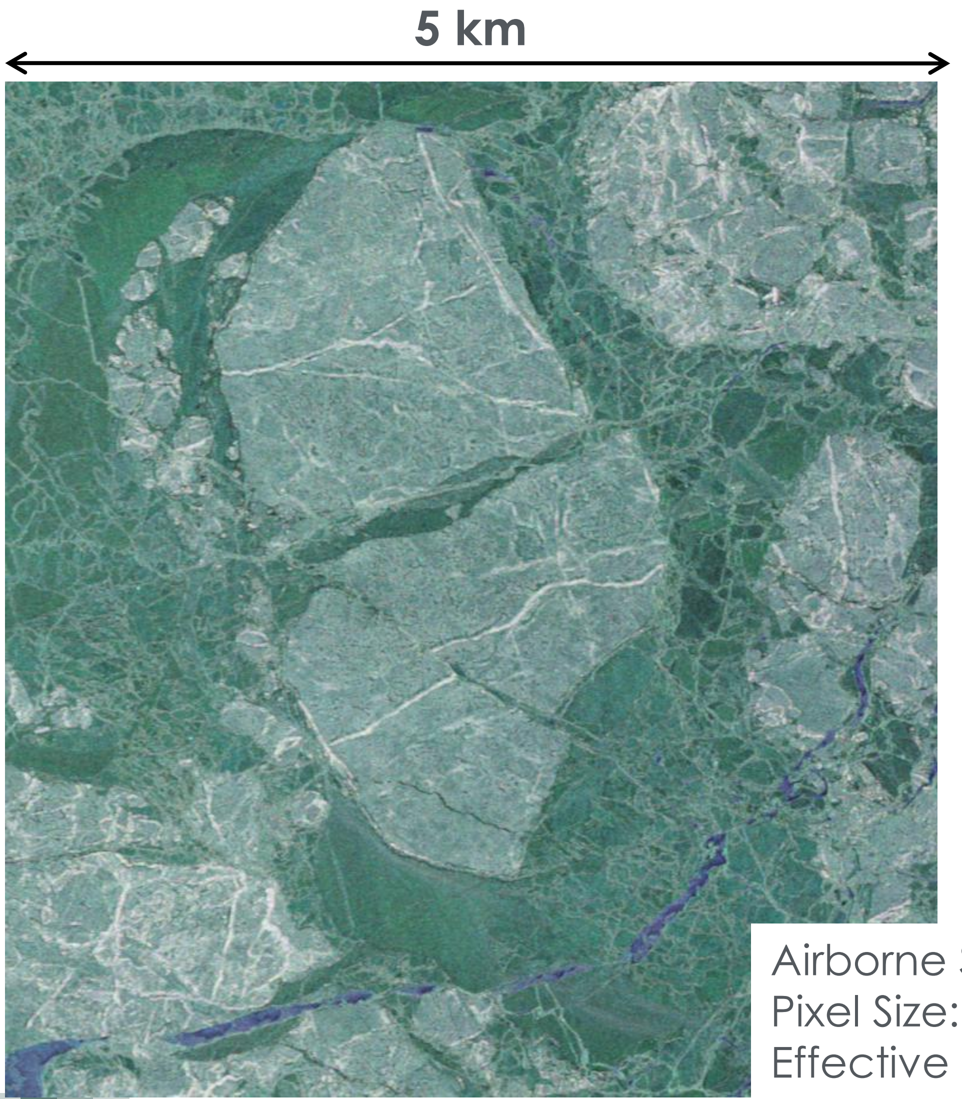
  - Incidence angle θ



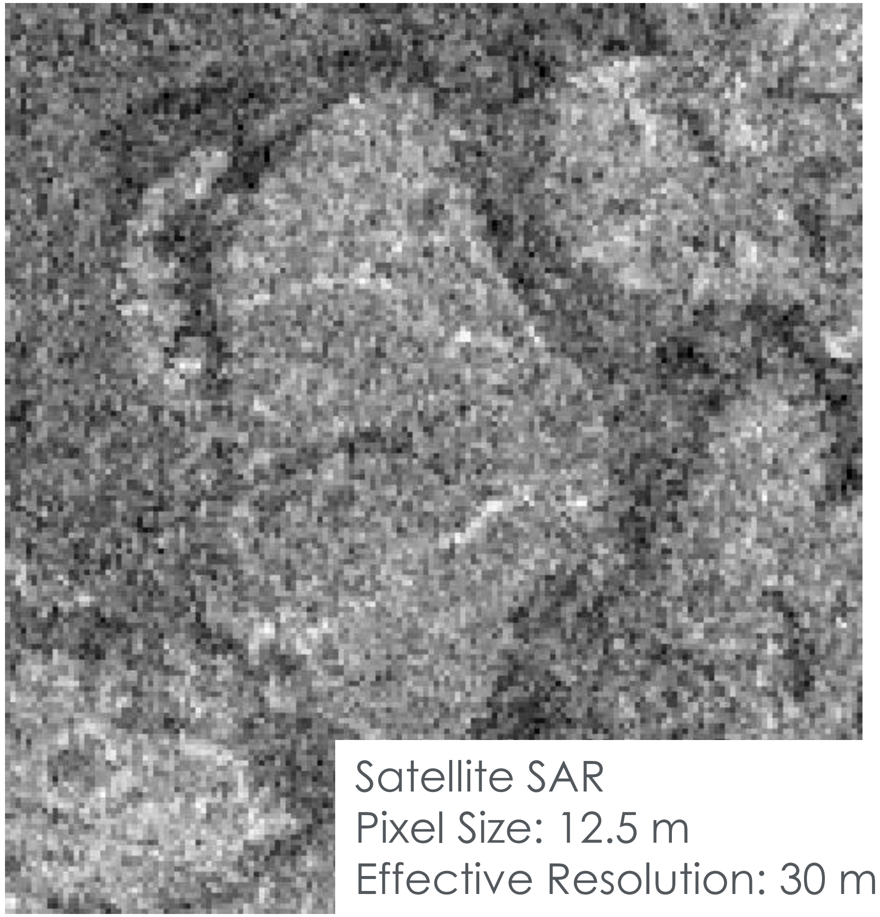
  - Resolution, sensor noise, …
  - Frequency



Effect of Spatial Resolution

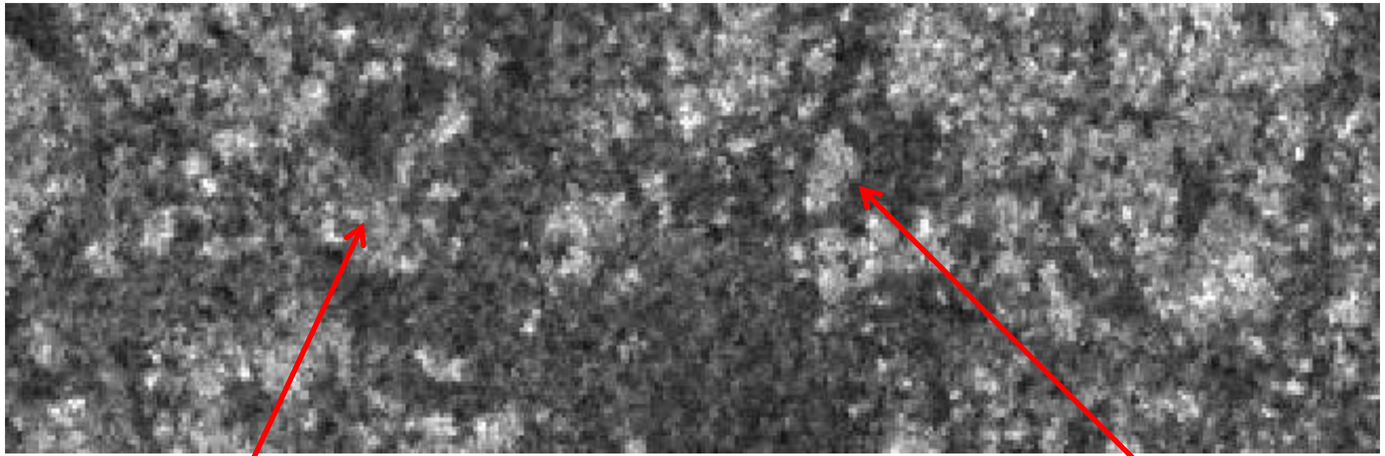


Airborne SAR
Pixel Size: 5 m,
Effective Resolution: 8 m



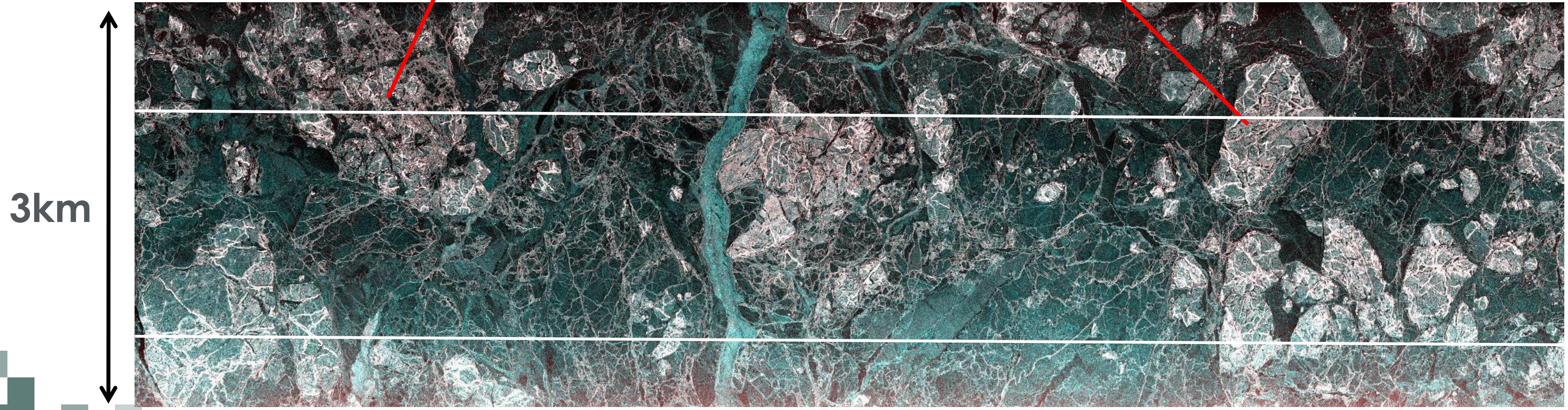
Satellite SAR
Pixel Size: 12.5 m
Effective Resolution: 30 m

Comparision Envisat ASAR – ESAR, Fram Strait, March 19, 2007



Envisat ASAR WSM image
HH – polarization
Incidence angel 26°
Resolution 150 m

@ 11:22 UTC



ESAR image
(R-VH, G-VV, B-VV)
Resolution 2m

@ 12:26 UTC.

Many factors affect SAR imaging.

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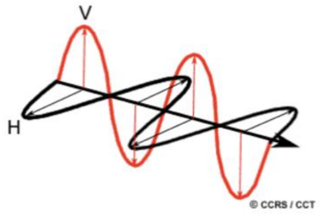
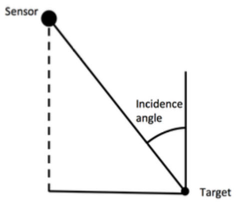
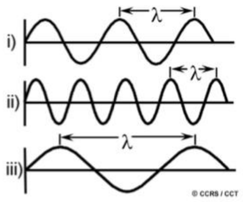


  - Incidence angle θ



  - Resolution, sensor noise, …
  - Frequency



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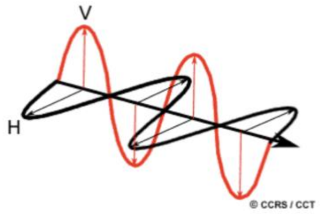

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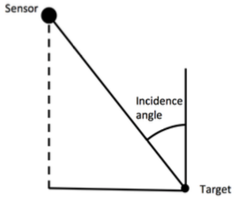

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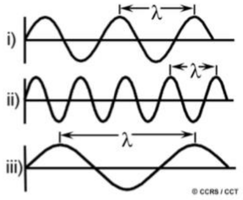


Exciting aspect with upcoming NISAR (2024), ALOS-4 (2024), ROSE-L (2028)

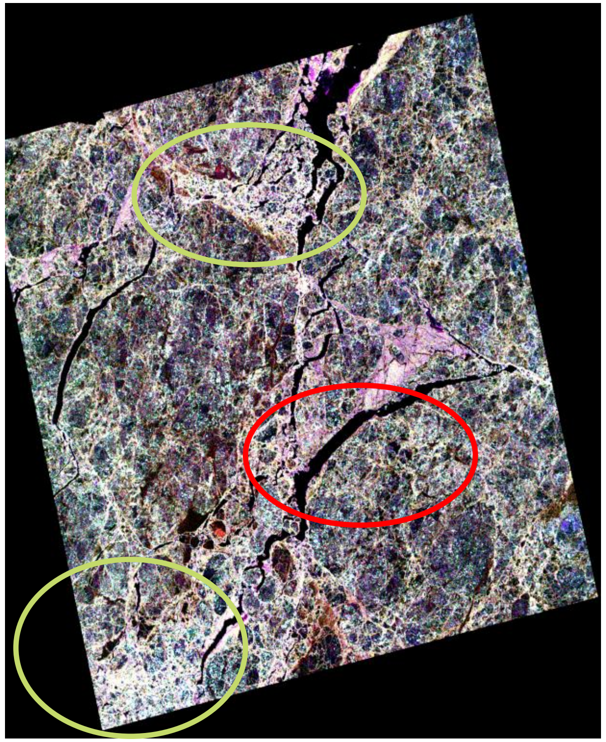
Existing missions ALOS-2 and SAOCOM

Frequency

Different frequencies have **different penetration depths**.

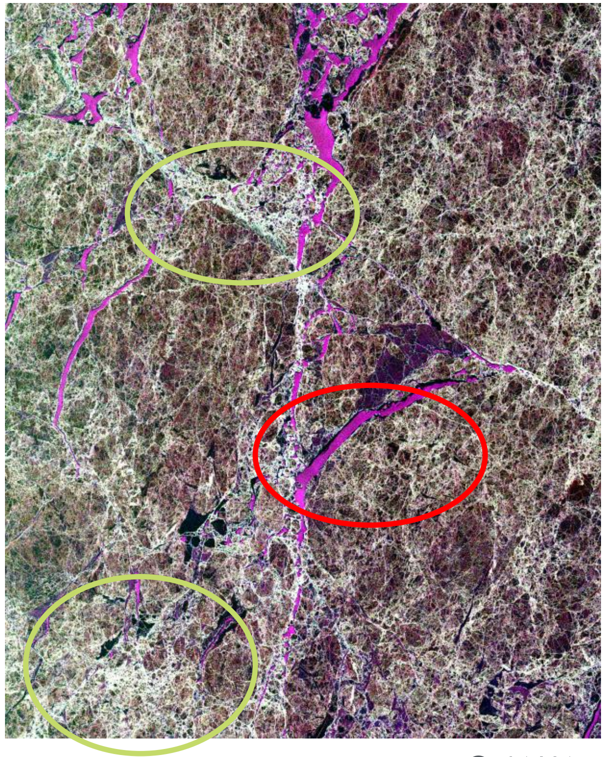
- An X-band radar, wavelength approx. 3 cm -> small penetration depth
- An L-band signal, wavelength approx. 23 cm -> greater penetration depth

C-Band



© MDA

L-Band



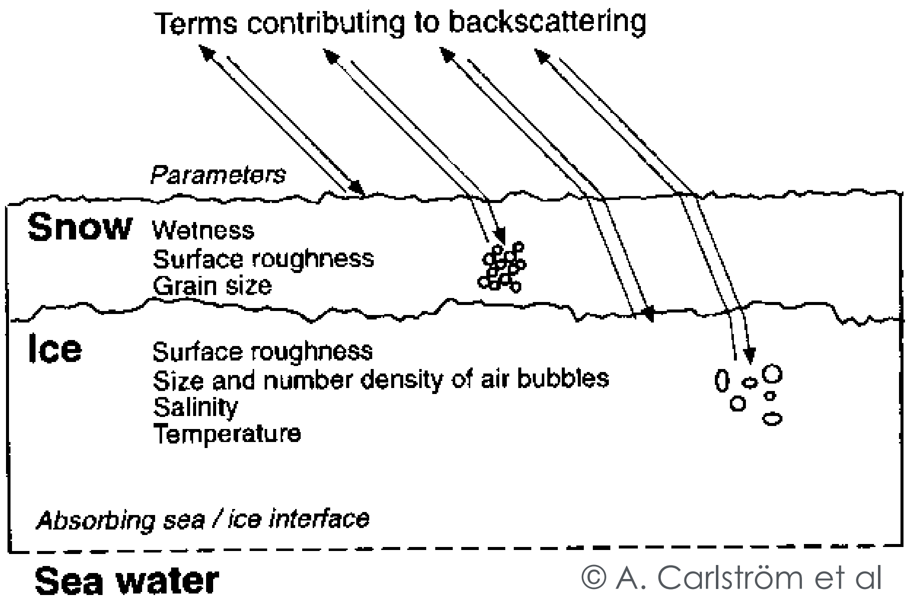
© JAXA

Frequency

- An X-band radar, wavelength approx. 3 cm -> small penetration depth
- An L-band signal, wavelength approx. 23 cm -> greater penetration depth

- Scattering and attenuation from:
  - Snow
  - Snow/Ice Surface
  - Ice Volume
  - Ice/Water Interface

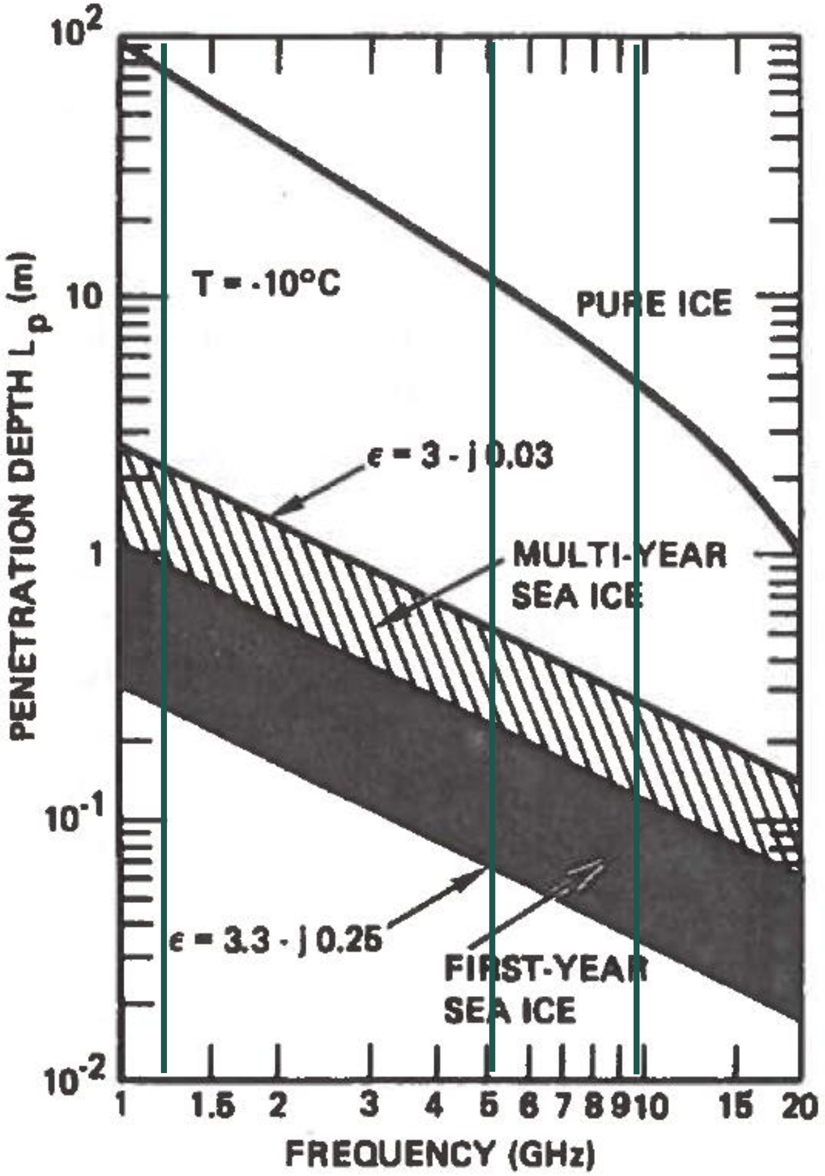
- X- and C-band from surface
- S-band partly from surface partly from ice volume
- L-band from ice volume



© A. Carlström et al

Frequency

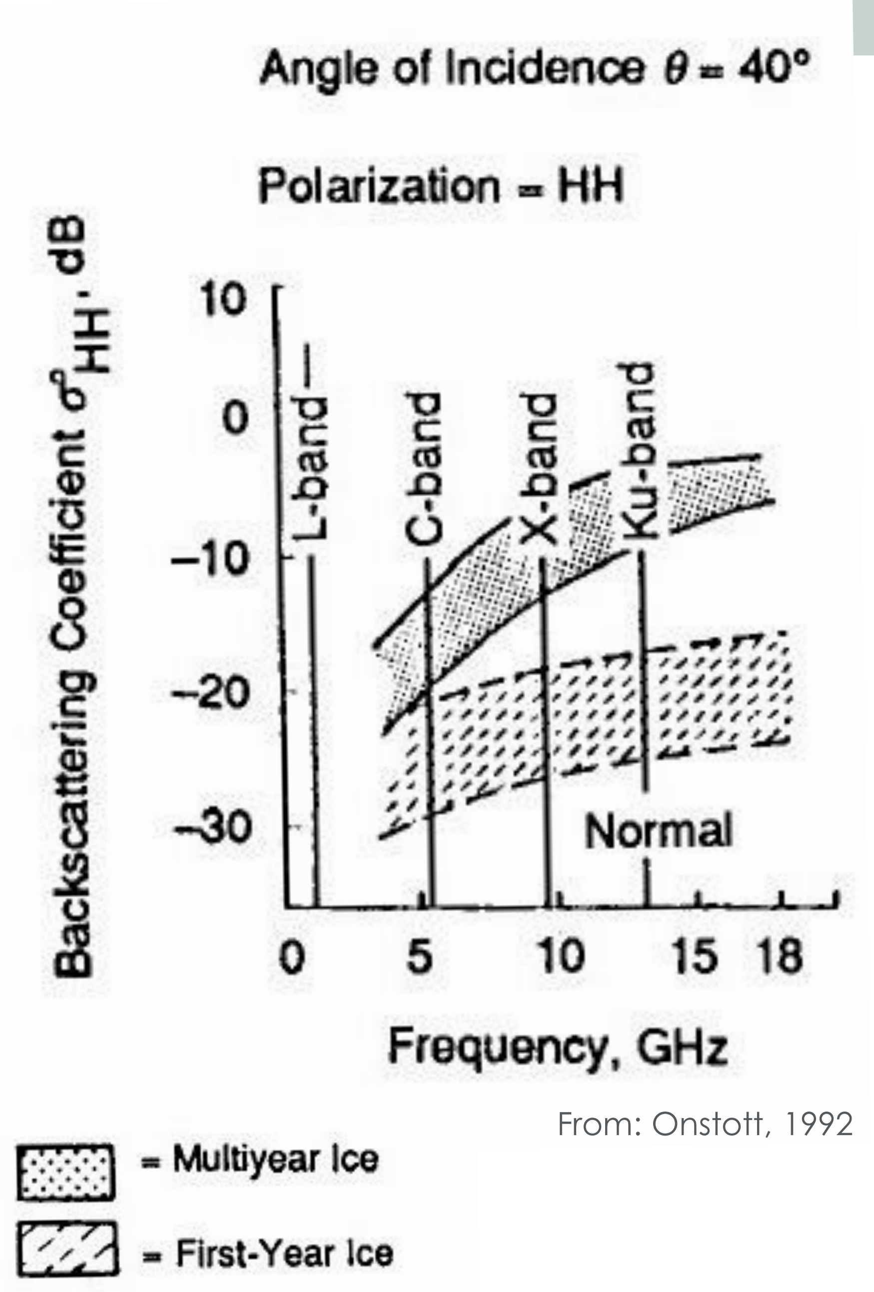
- Penetratation depth for different sea ice types
- The change in salinity affects the dielectric constant.



From: Ulaby et al. 1982

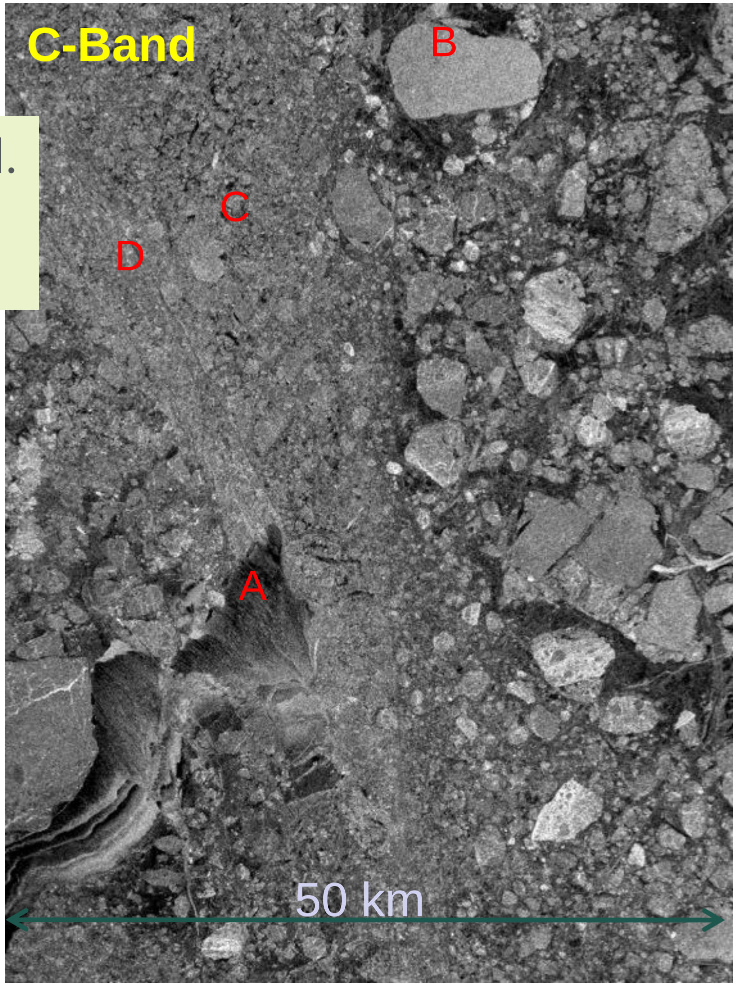
Frequency

- X-band data reveal largest intensity contrast between first-year and multi-year ice
- Larger sensitivity to snow on ice, and to surface and subsurface (a few centimeters depth) characteristics
- Larger sensitivity to the onset of melt

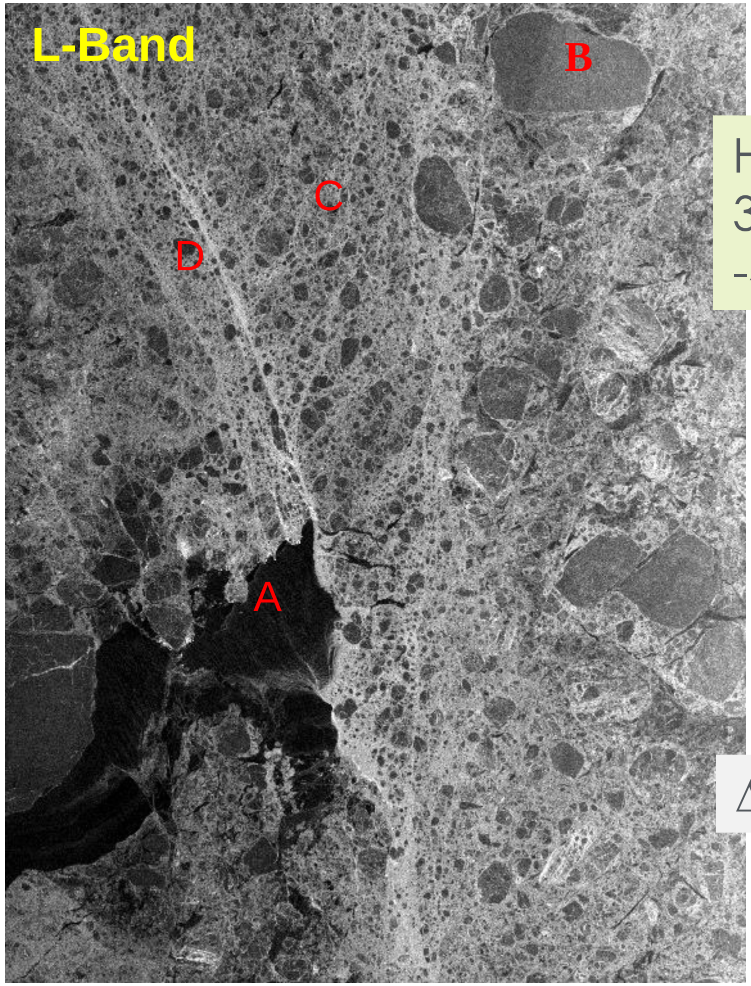


From: Onstott, 1992

Potential of Multi-Frequency



VV-Pol.
19.4°
-26.4°



HH-Pol.
35.6°
-41.7°

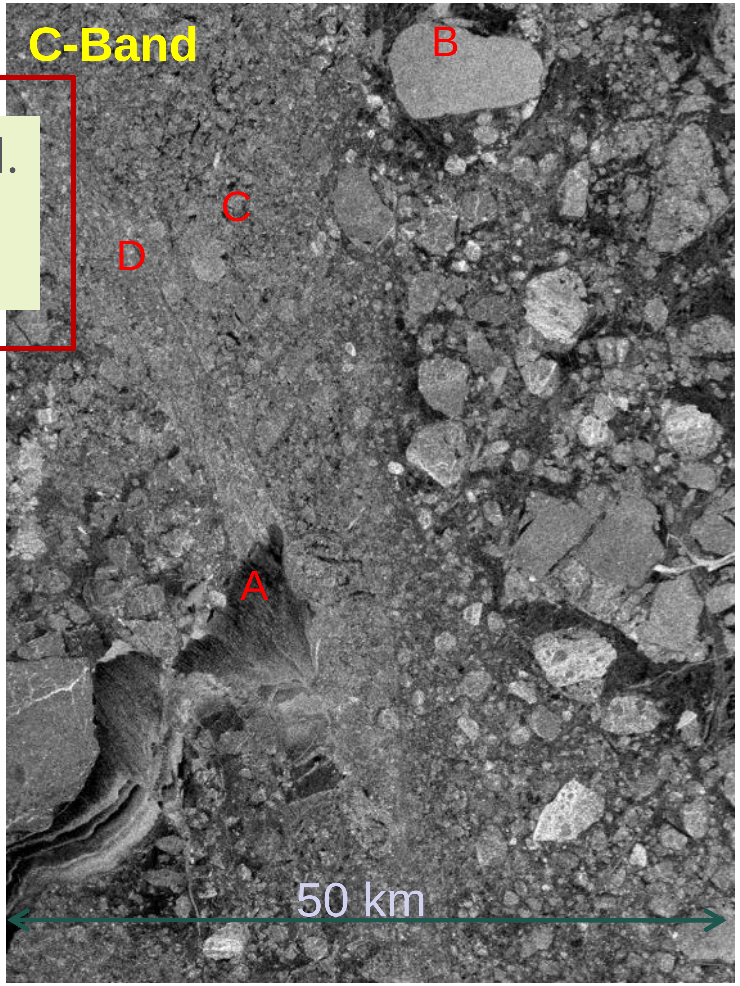
ΔT = 25 min

ERS-1

JERS-1

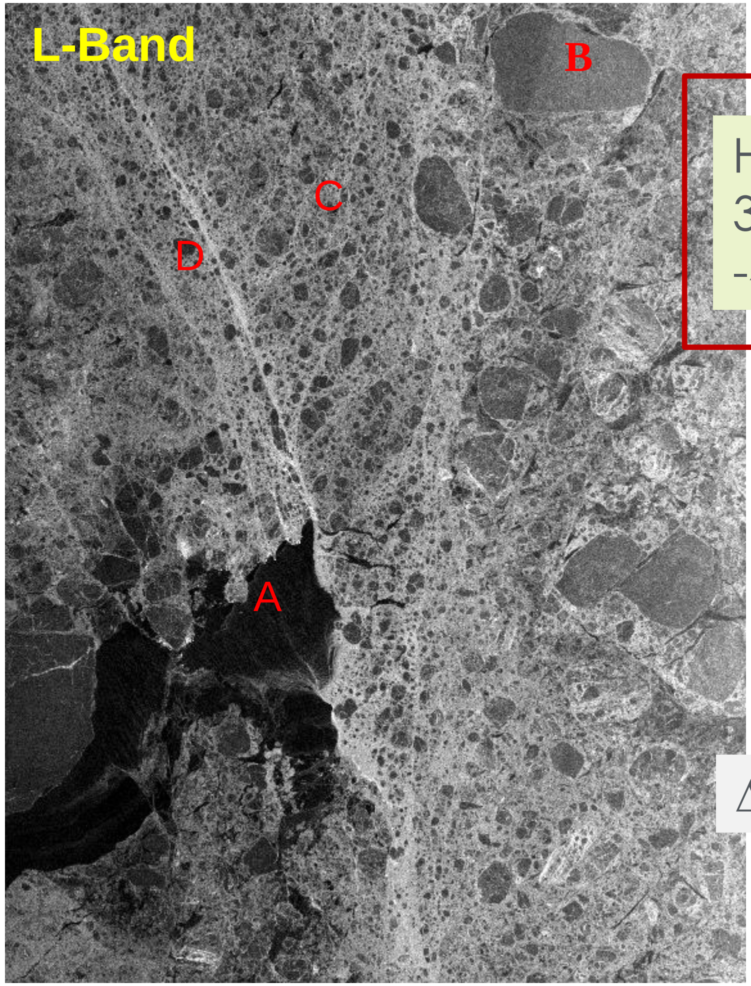
Coast of East Greenland

Potential of Multi-Frequency



VV-Pol.
19.4°
-26.4°

ERS-1



HH-Pol.
35.6°
-41.7°

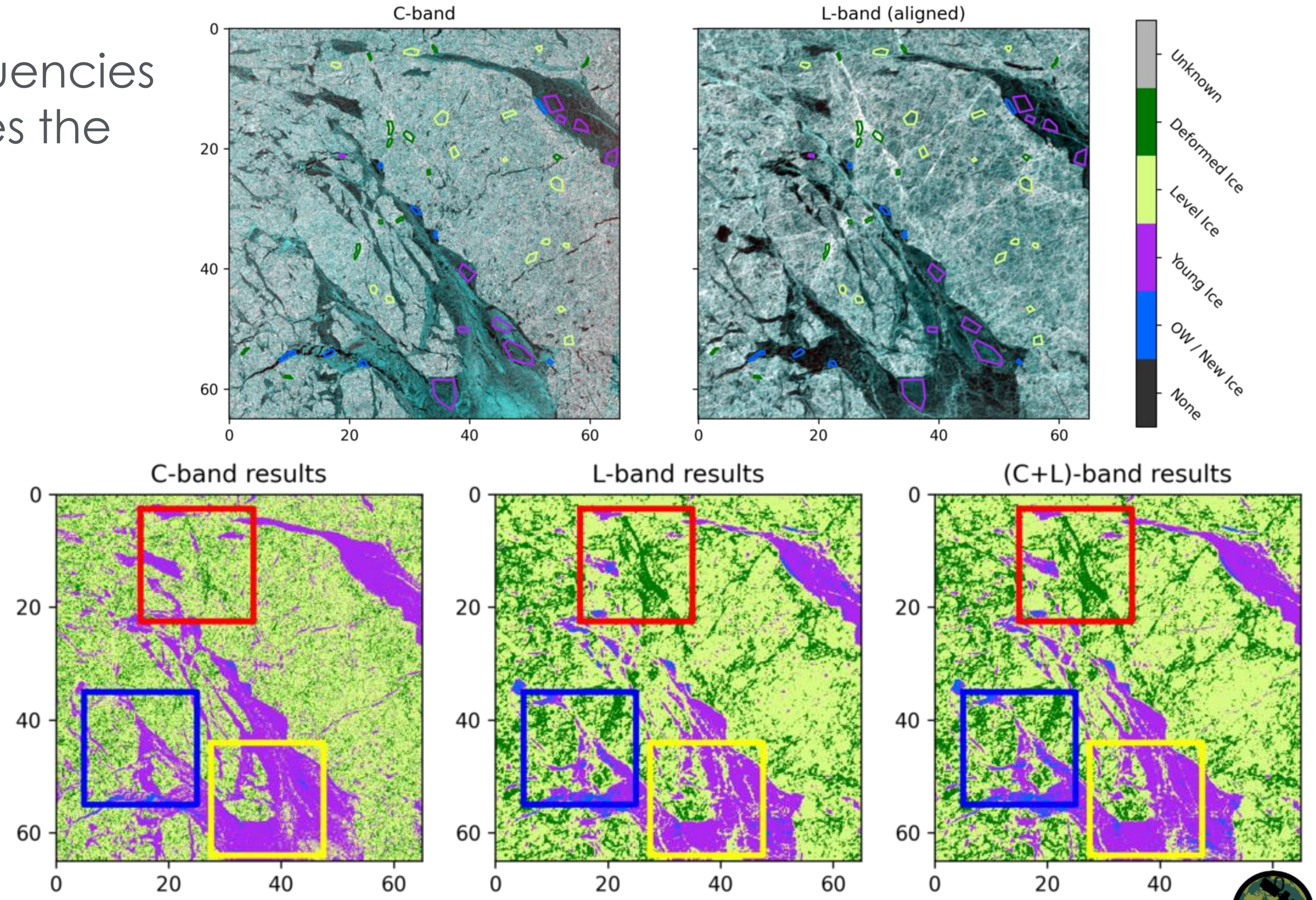
ΔT = 25 min

JERS-1

Coast of East Greenland

Potential of Multi-Frequency

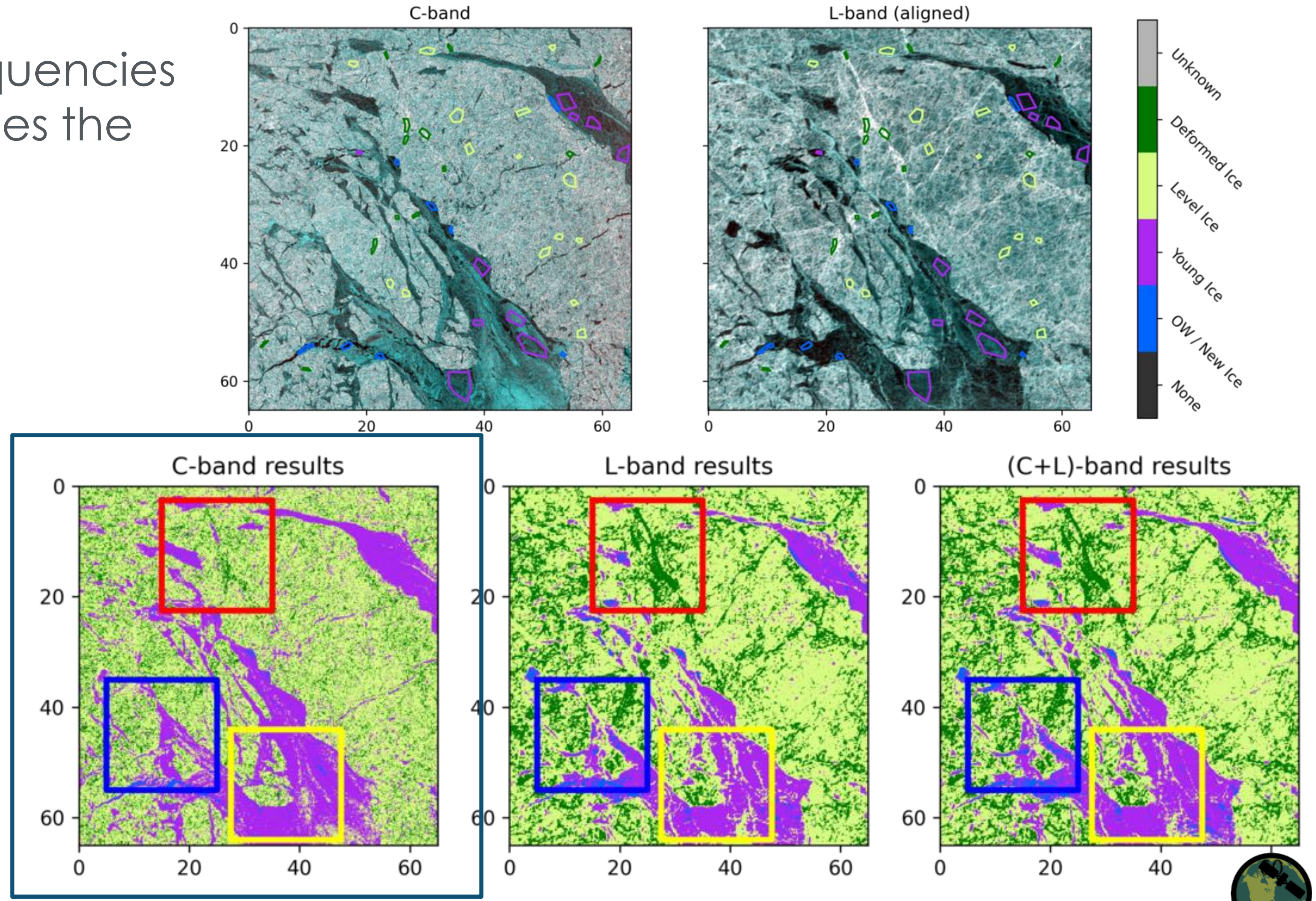
- Combining the two frequencies (L- and C-band) improves the classification accuracy.



Lohse et al, 2023

Potential of Multi-Frequency

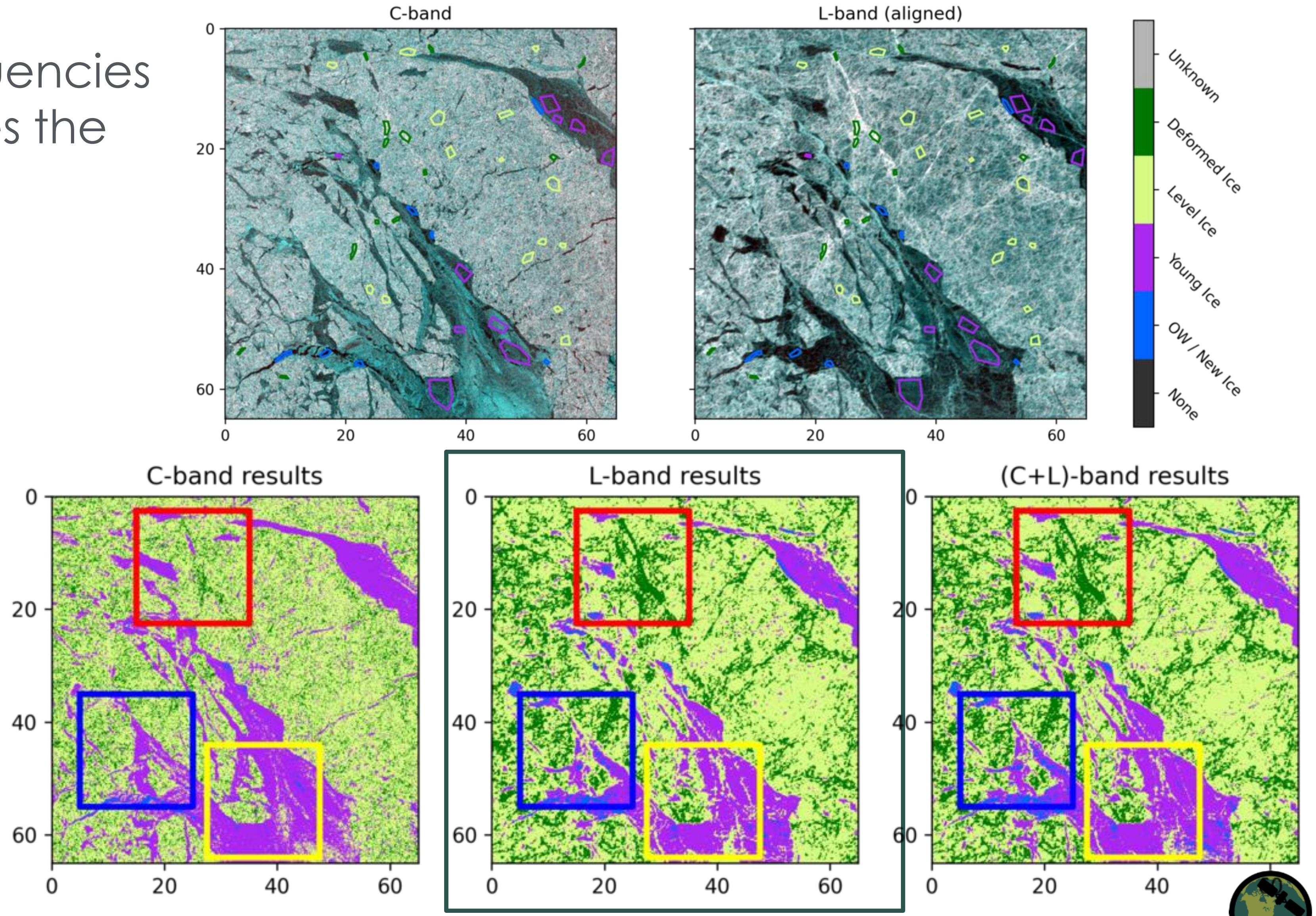
- Combining the two frequencies (L- and C-band) improves the classification accuracy.



Lohse et al, 2023

Potential of Multi-Frequency

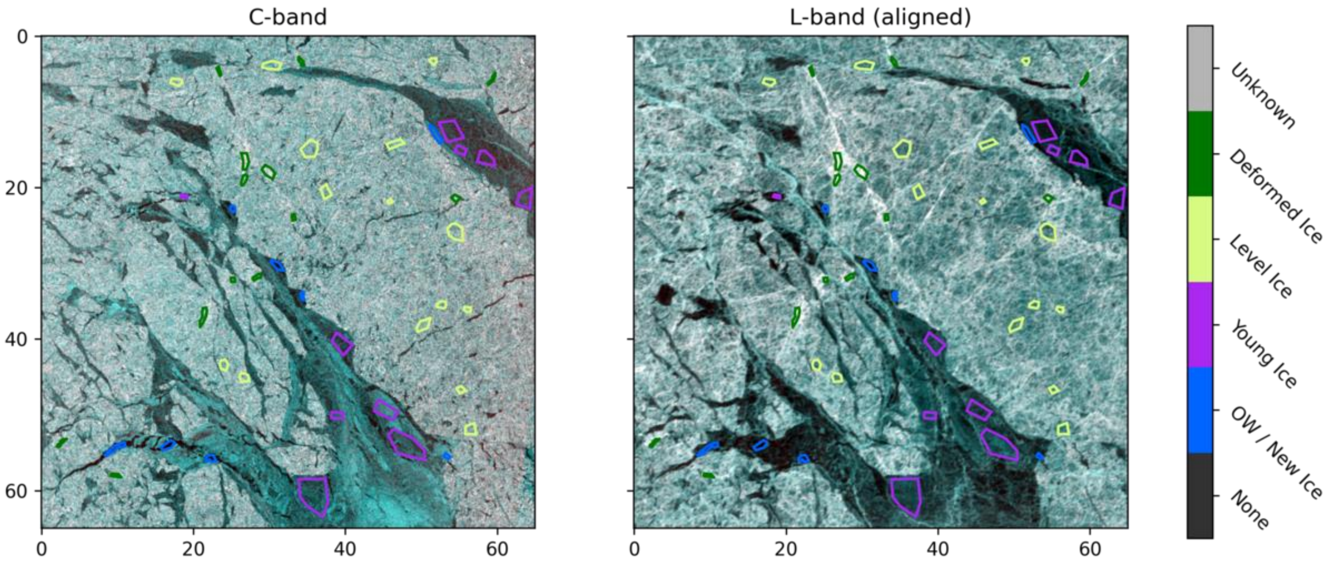
- Combining the two frequencies (L- and C-band) improves the classification accuracy.

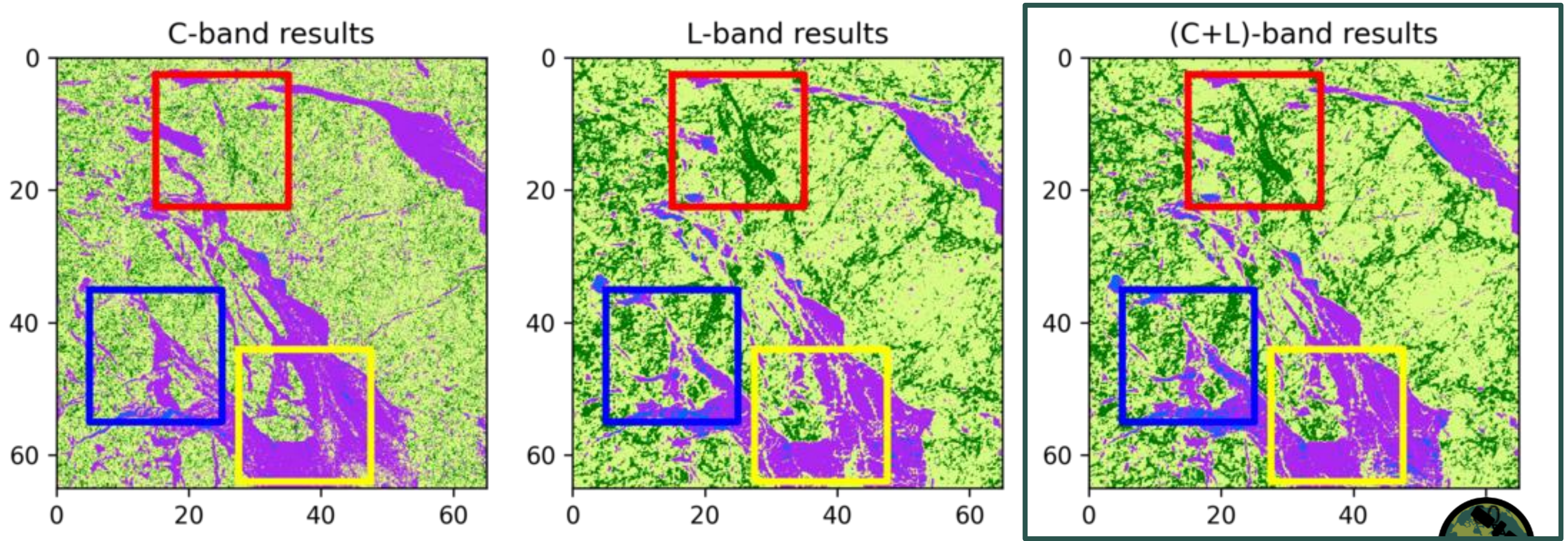


Lohse et al, 2023

Potential of Multi-Frequency

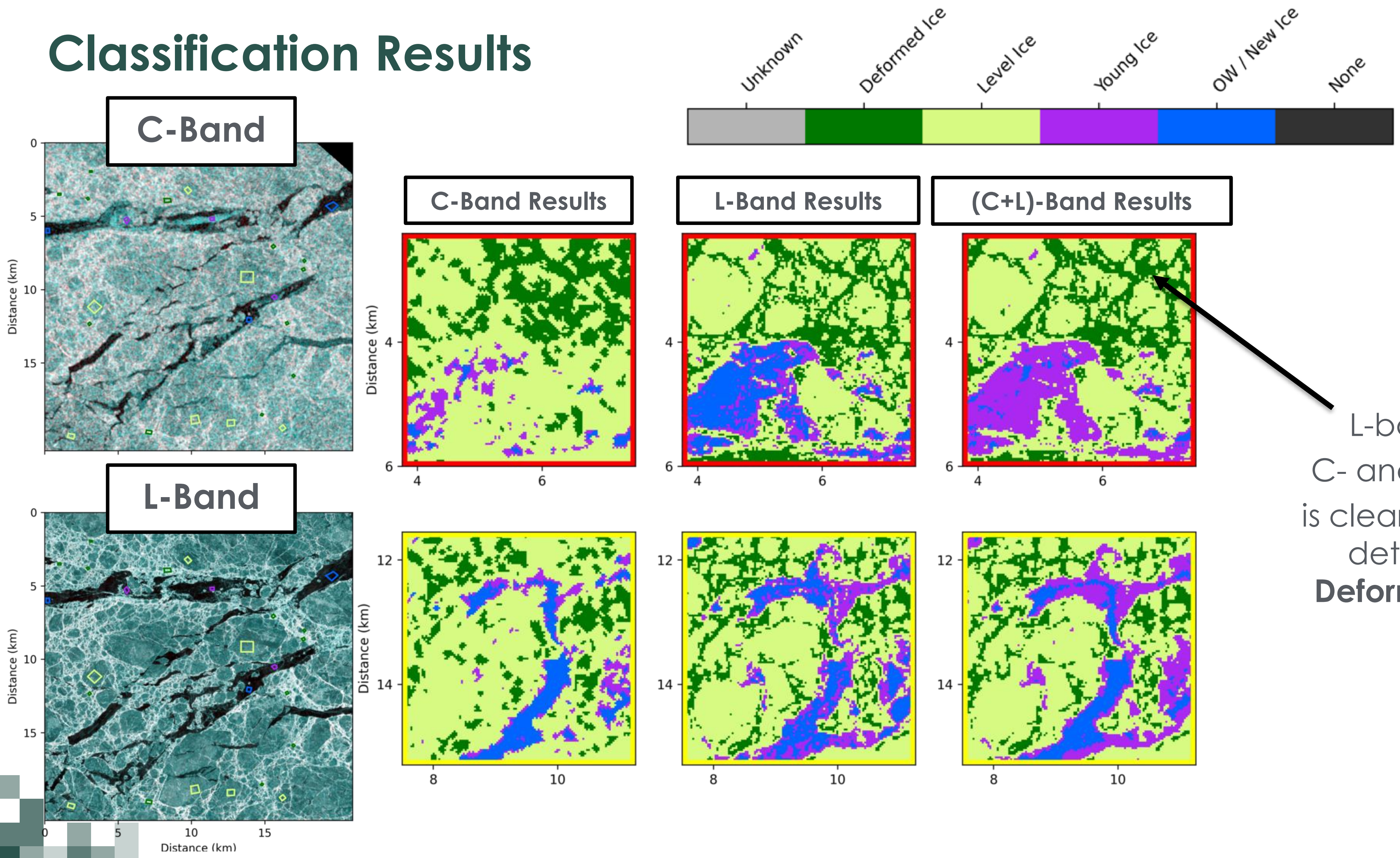
- Combining the two frequencies (L- and C-band) improves the classification accuracy.





Lohse et al, 2023

Classification Results



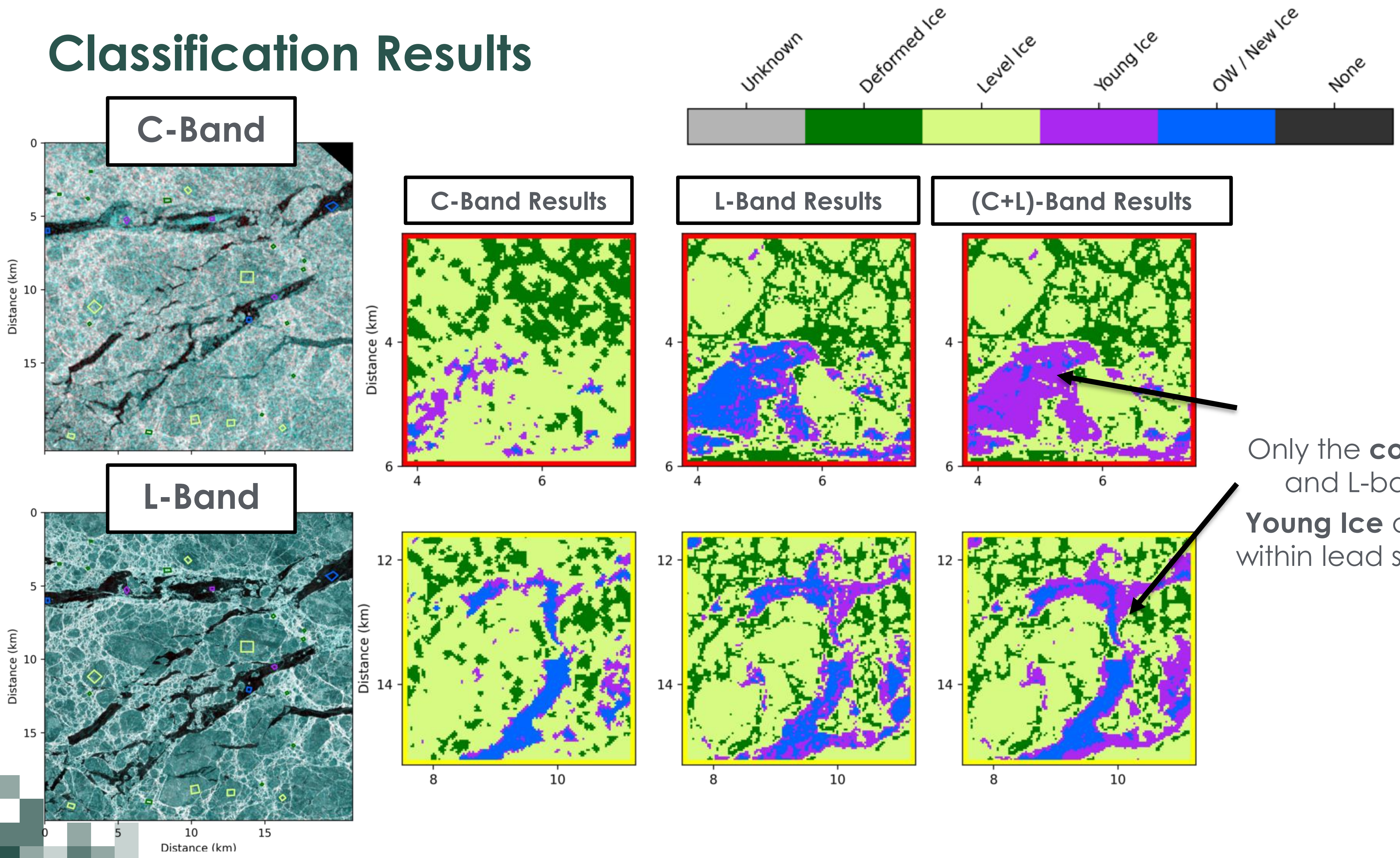
L-band or

C- and L-band

is clearly best at detecting **Deformed Ice**.

Lohse et al, 2023

Classification Results

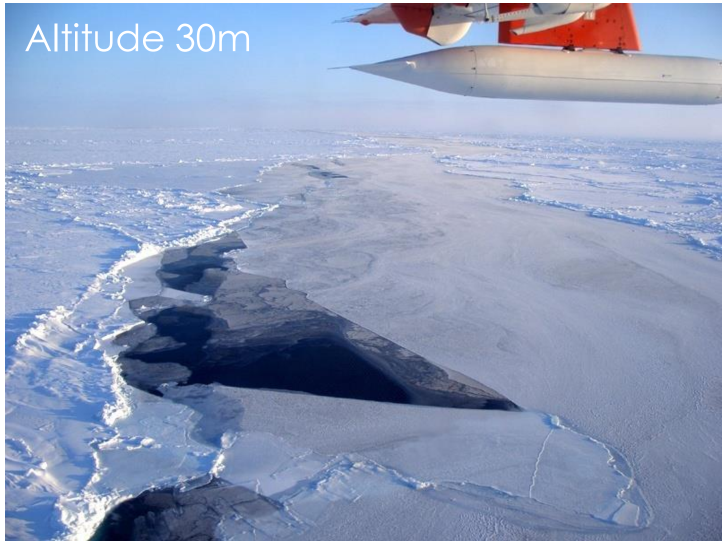


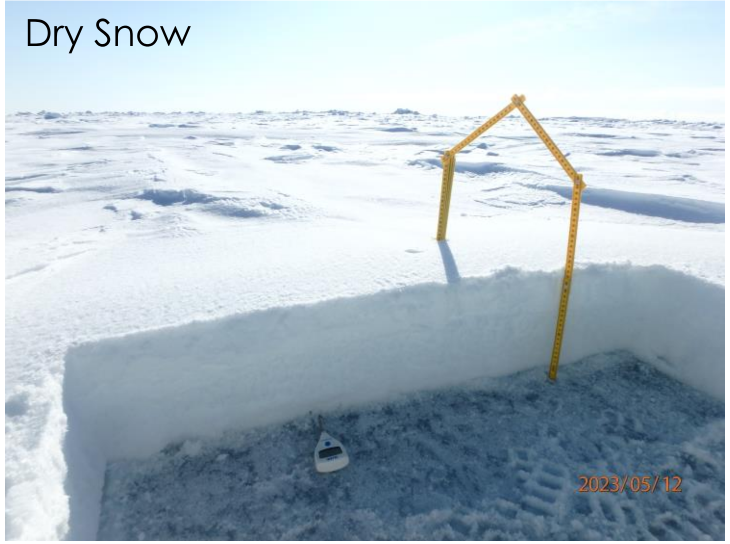
Only the **combination** of C- and L-band captures:

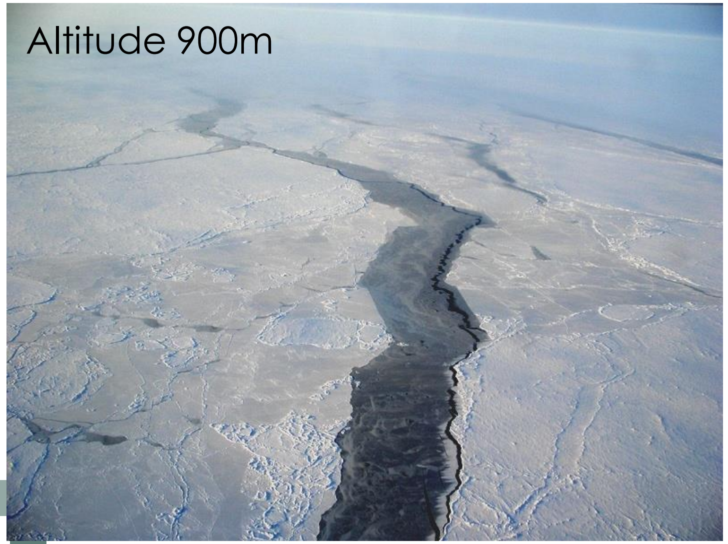
Young Ice and **Open Water** within lead systems correctly.

Lohse et al, 2023

How do we monitor sea ice?

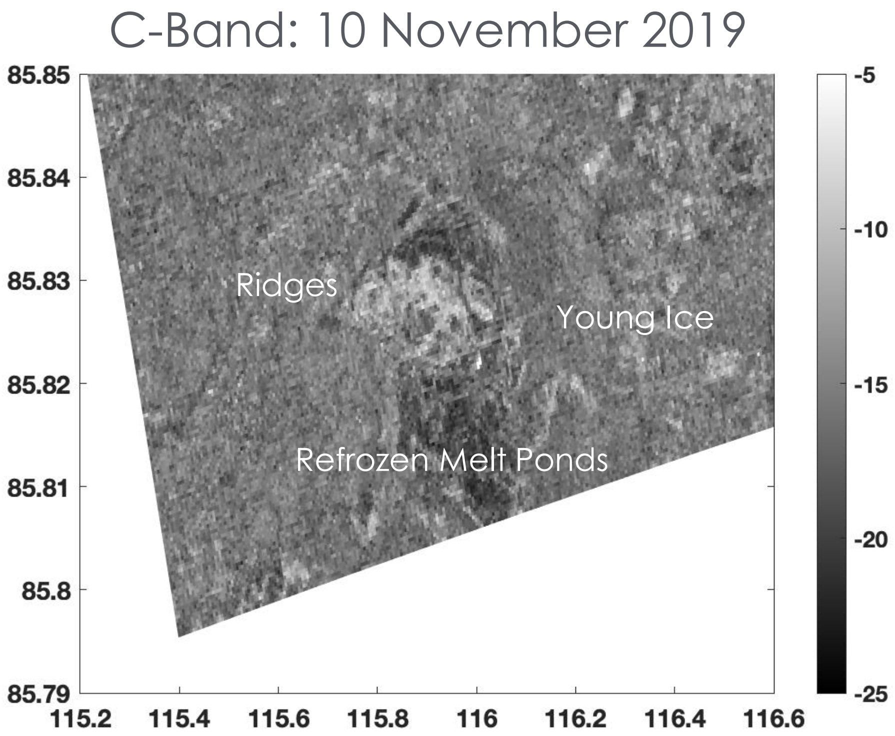






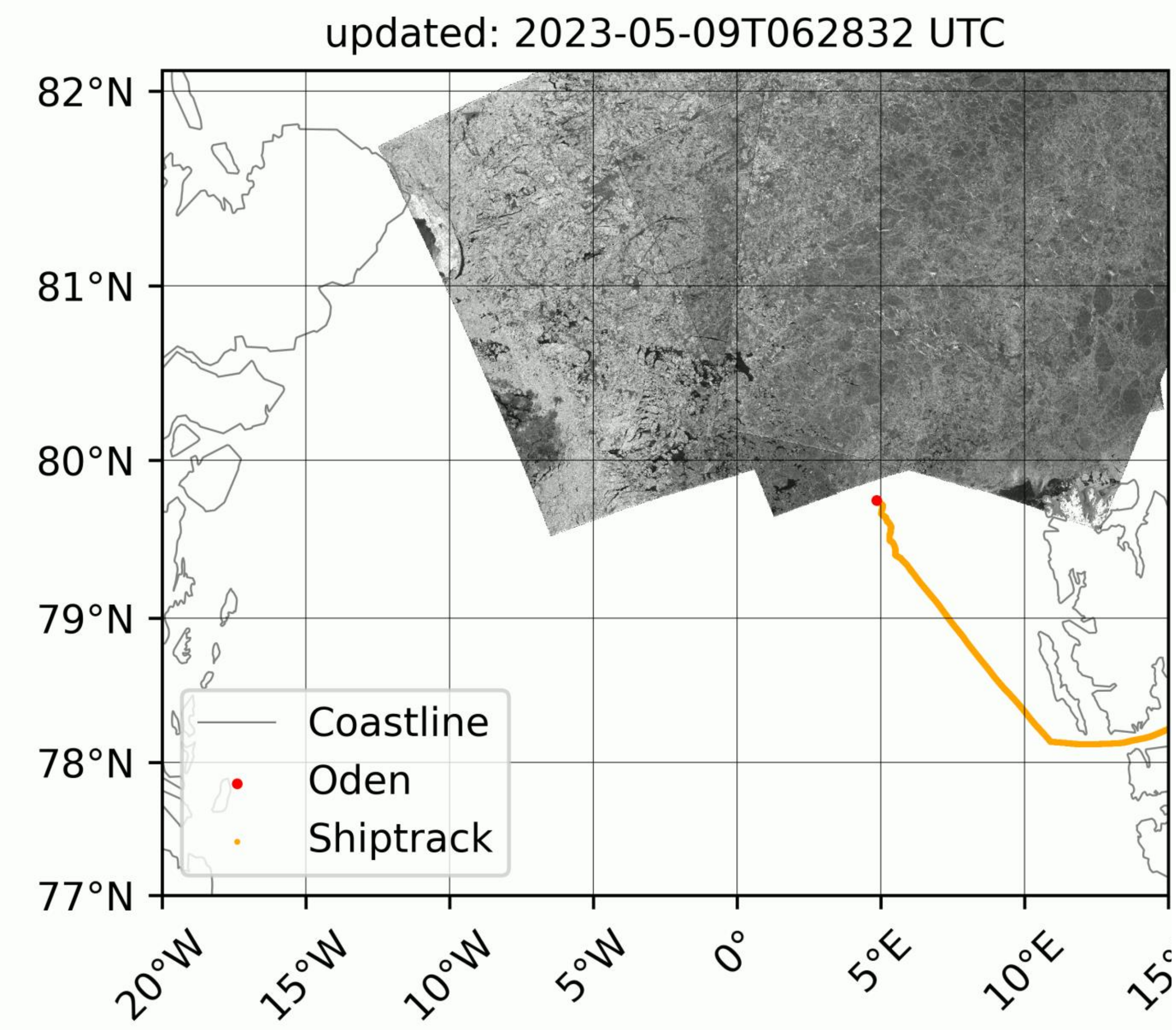
Photos: W. Dierking

Photos: T. Karlsen

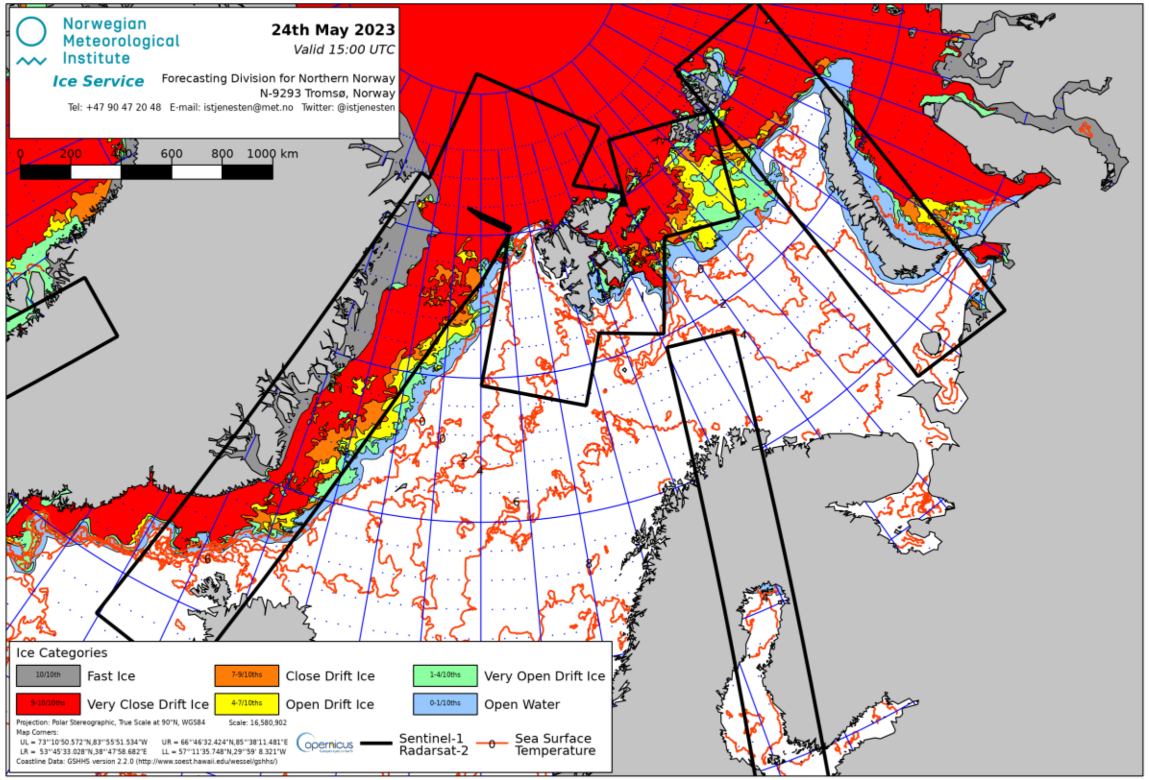


RADARSAT-2 © MDA

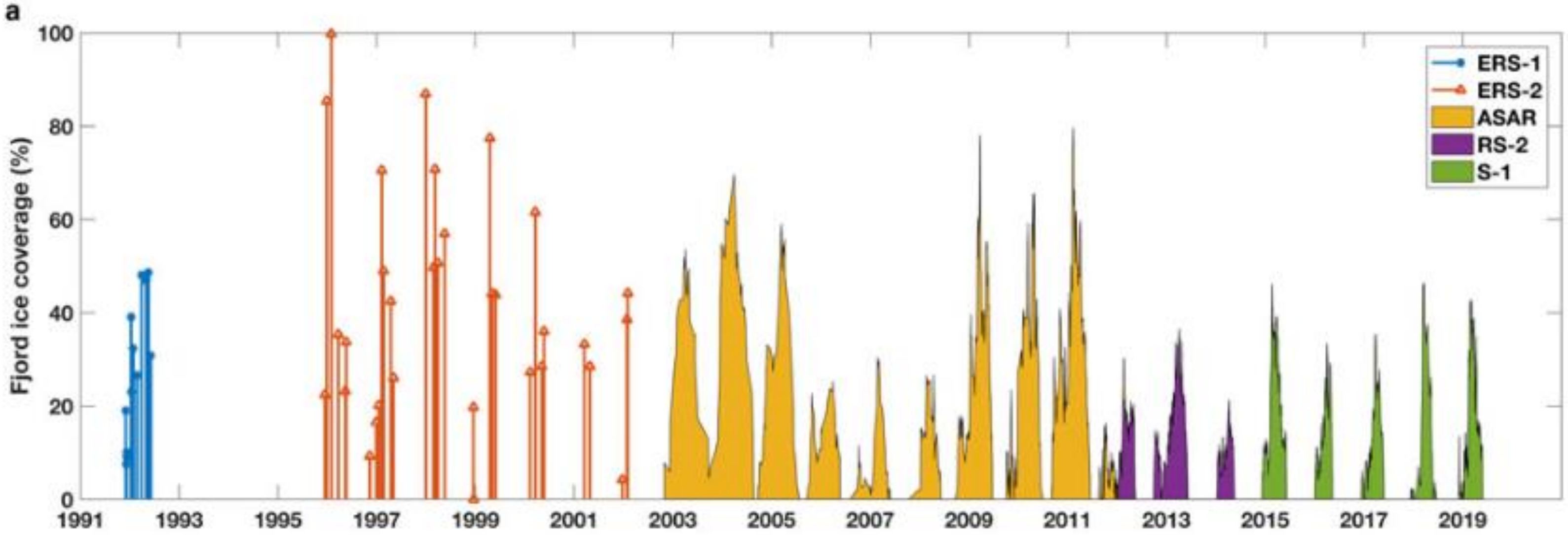
* Use all of the freely available images to generate sea ice maps.

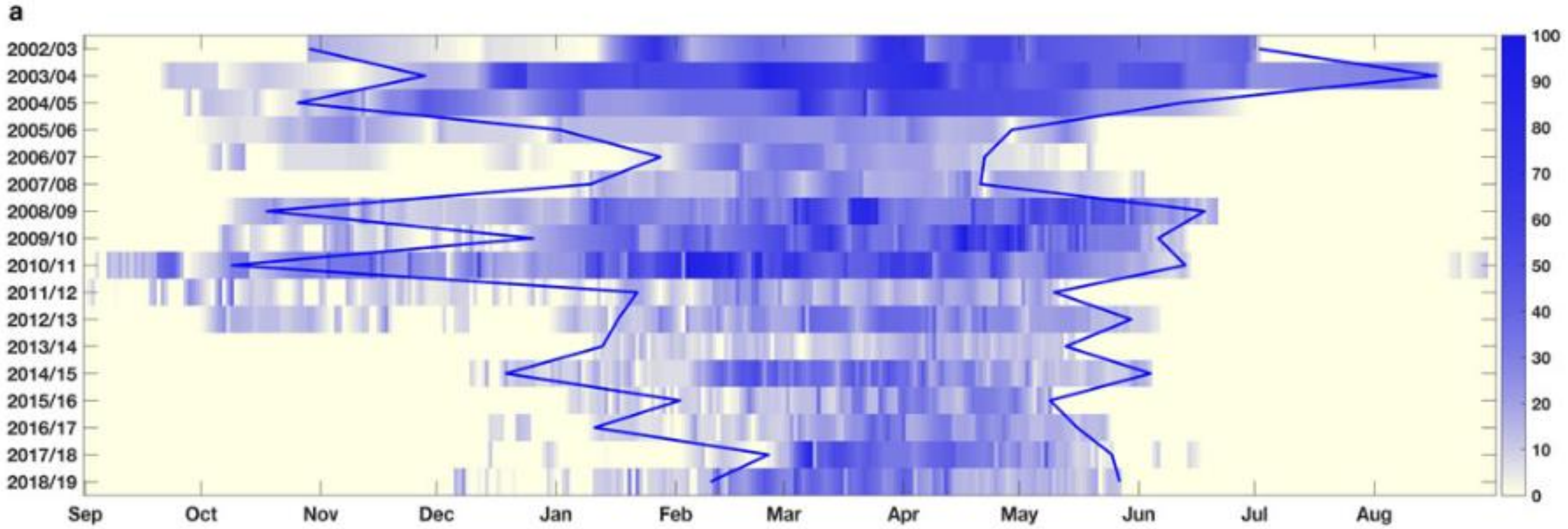


T. Karlsen, 2023



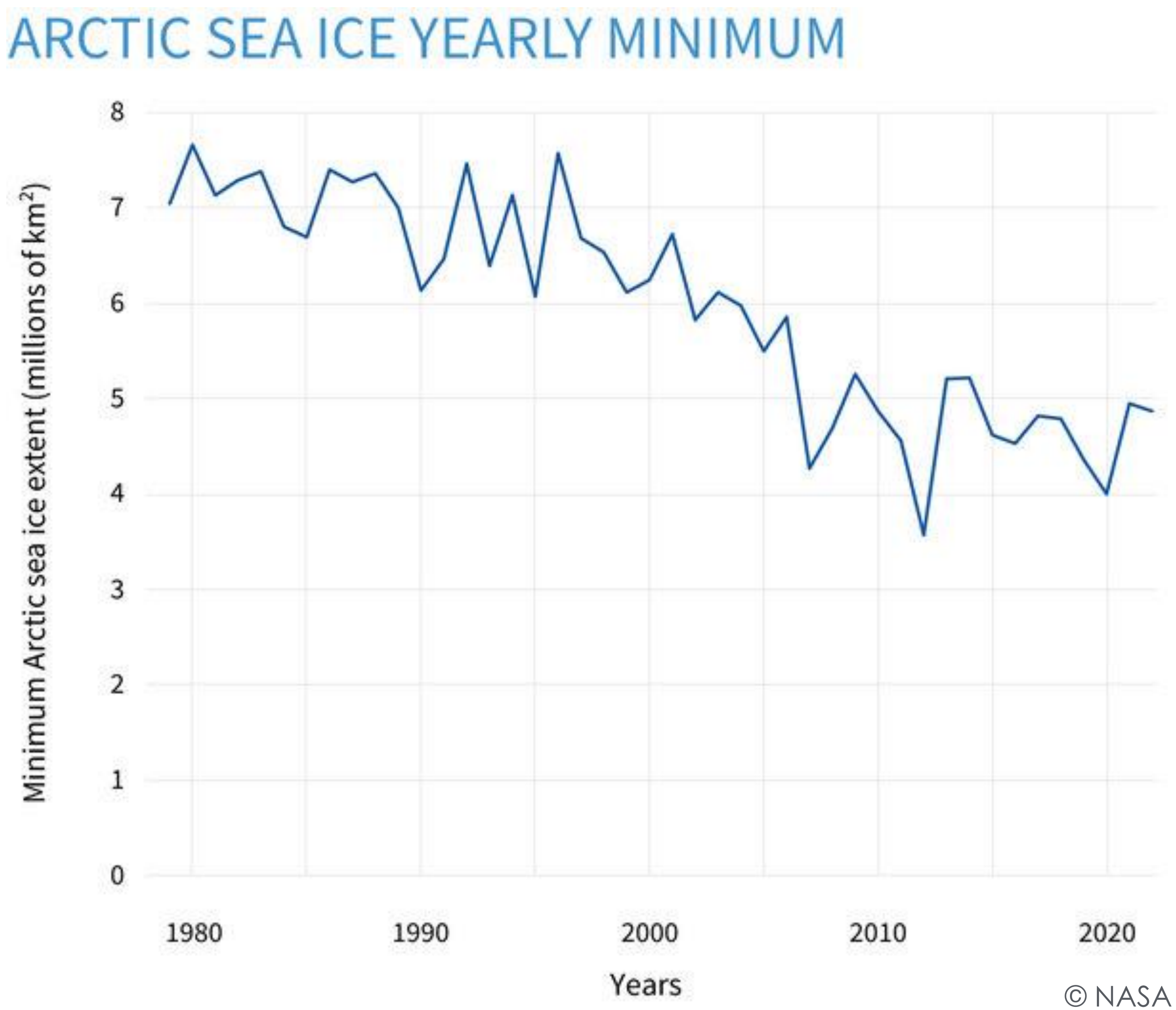
Monitor and Detect Regional Changes





Johansson et al, 2020

Monitor and Detect Global Changes



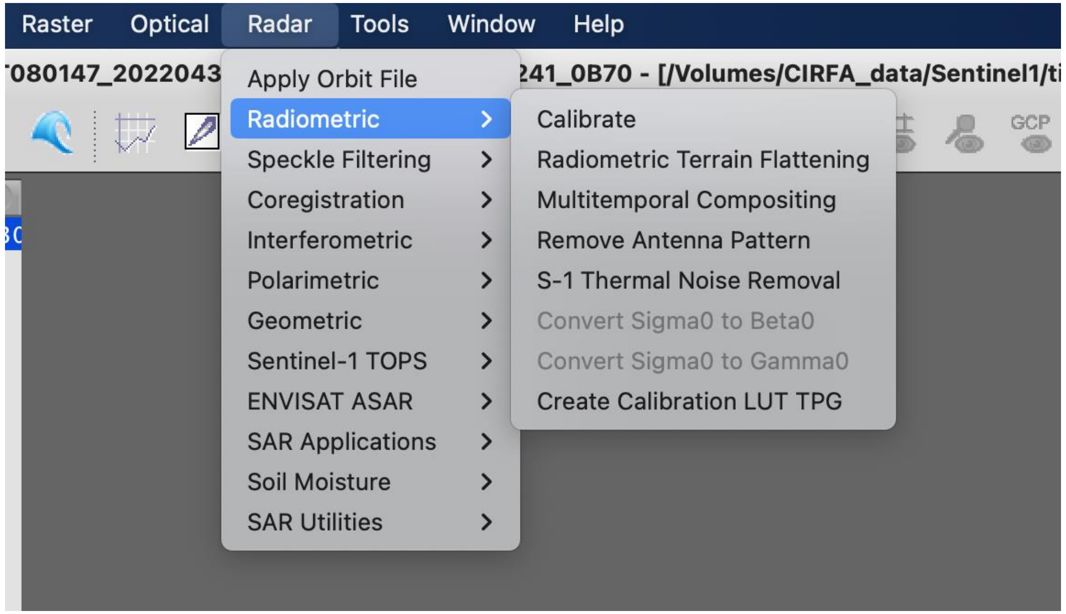
© NASA

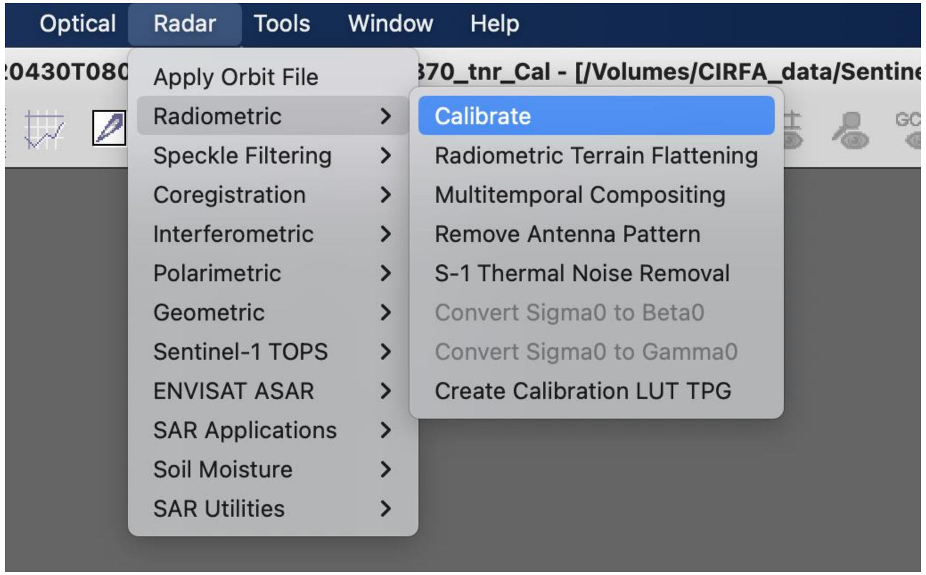
Summary

- We observe surface roughness with SAR, and in sea ice this takes many forms.
- Sensor specifics, such as incidence angle and frequency, affect detection and monitoring capabilities.
- SAR can be used to detect and monitor sea ice.
  - More than one channel is preferable, as the HV channel provides better separation between open water and sea ice.
  - We for the most part cannot derive sea ice thickness using SAR – making WMO classes challenging.
  - But we can identify areas with different deformation.
  - Young and thin ice is our most challenging ice type - > can look both like smooth, open water and as deformed MYI.
  - Time series can be used in climate models.

Perform Your Own Sea Ice Classification

- Classify deformed, level, young ice and open water within this image:
  - S1A_EW_GRDM_1SDH_20220430T080147_20220430T080251_043000_052241_0B70.SAFE
- Open the file in SNAP.
- Pre-Processing:
  - Thermal noise removal -> Radar -> Radiomeric -> S-1 Thermal Noise Removal
  - Calibration -> Radar -> Radiometric -> Calibrate



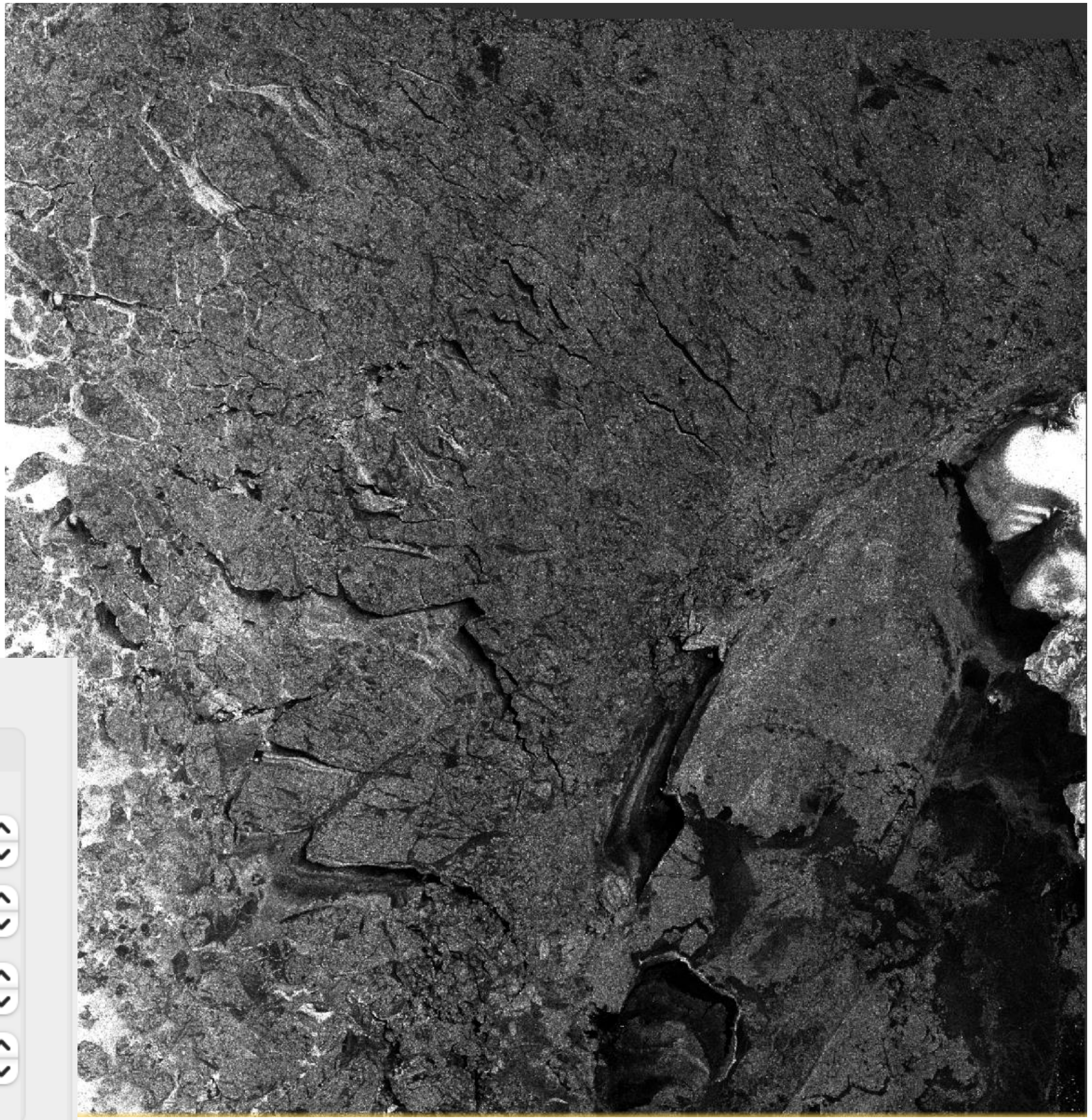


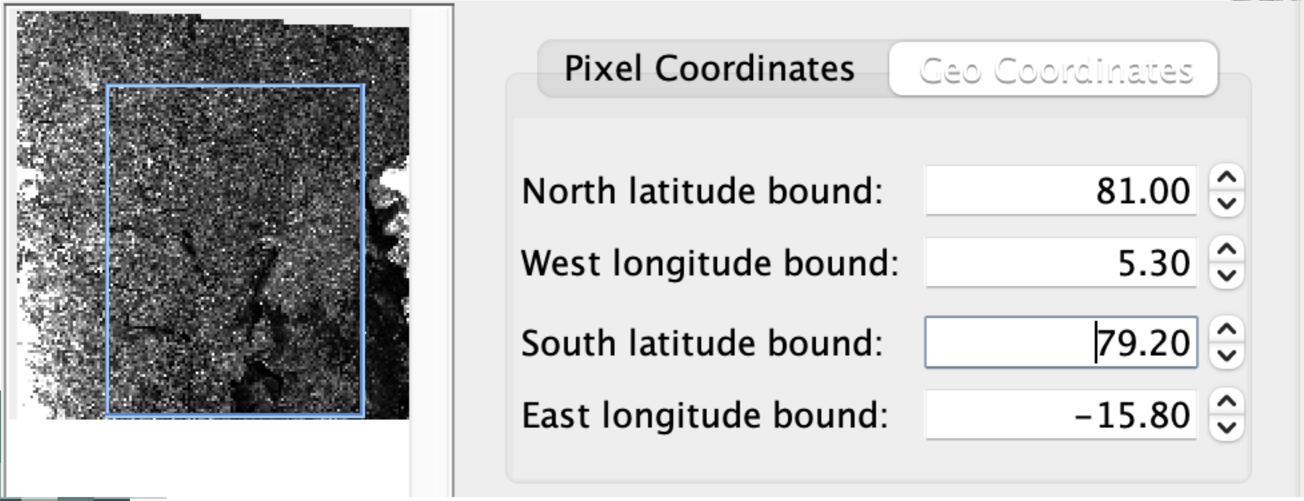
Perform Your Own Sea Ice Classification

- The image should then look something like this.

- The next step is to do a sub-setting, primarily to speed up the process.

- The area should be cut out as:

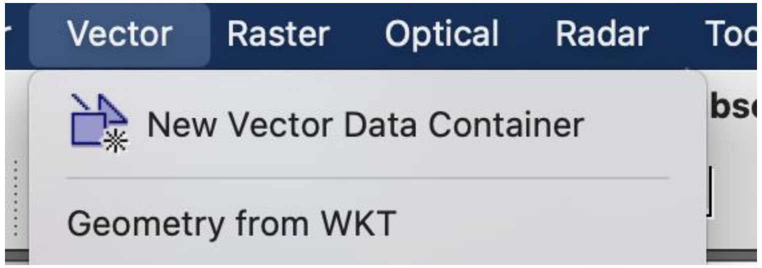




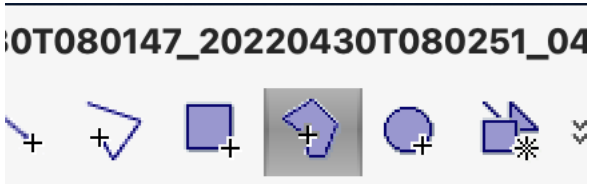
Perform Your Own Sea Ice Classification

- The image is now ready to be classified.
- Today we will do a random forest classification.
- For this we need some training data!
  - Deformed Ice
  - Level Ice
  - Young Ice
  - Open Water

- Training data is generated by identifying polygons containing the different ice types.

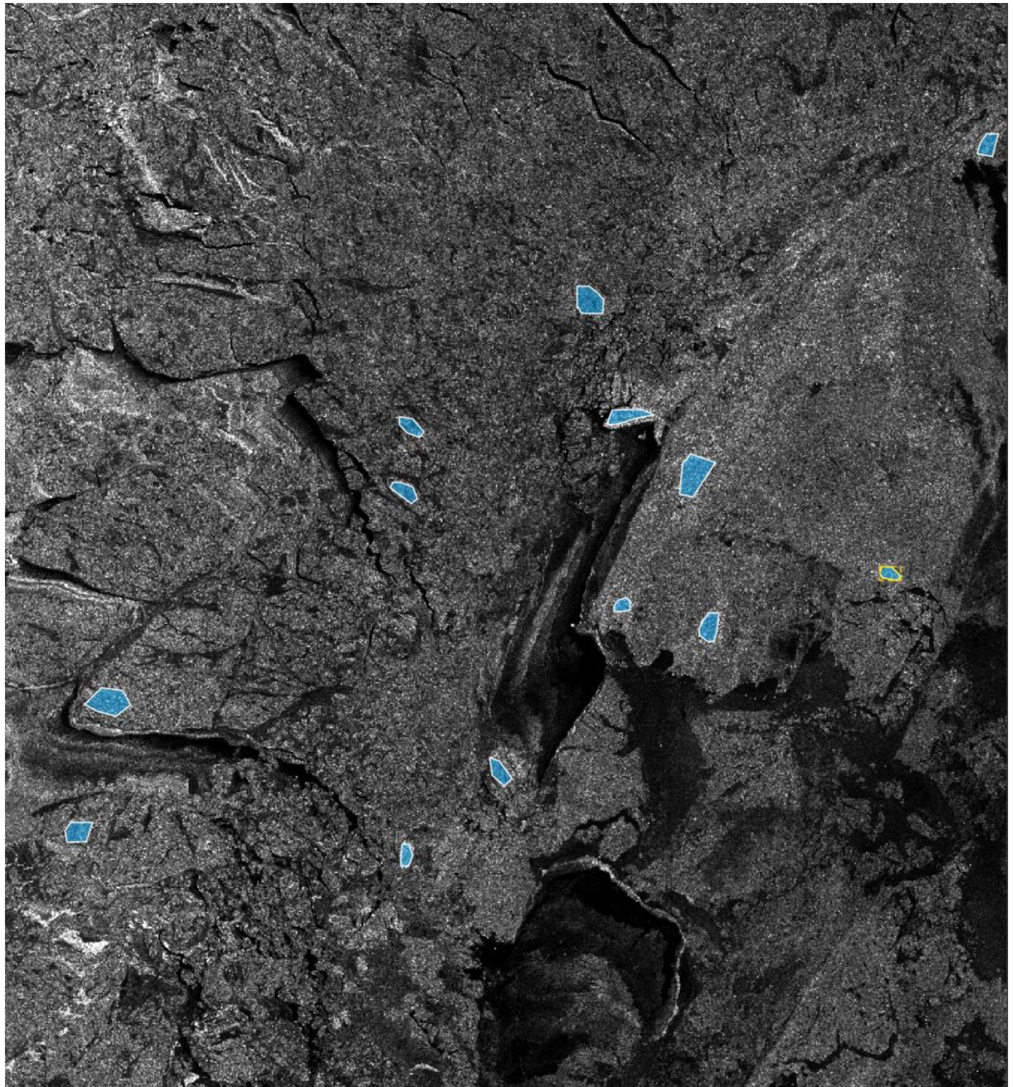


- And start creating polygons using this:

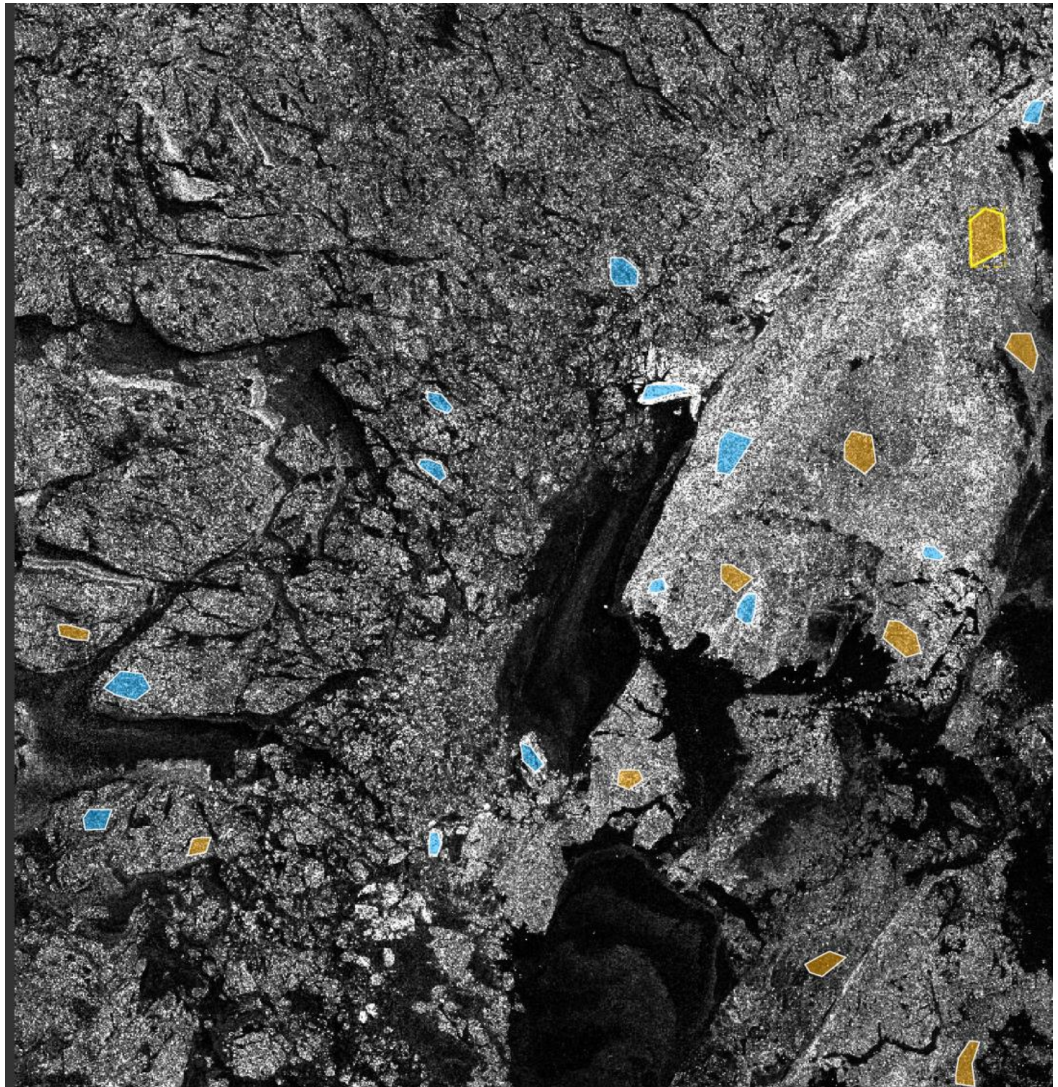


Deformed (Blue) and Level (Yellow) Sea Ice Polygons

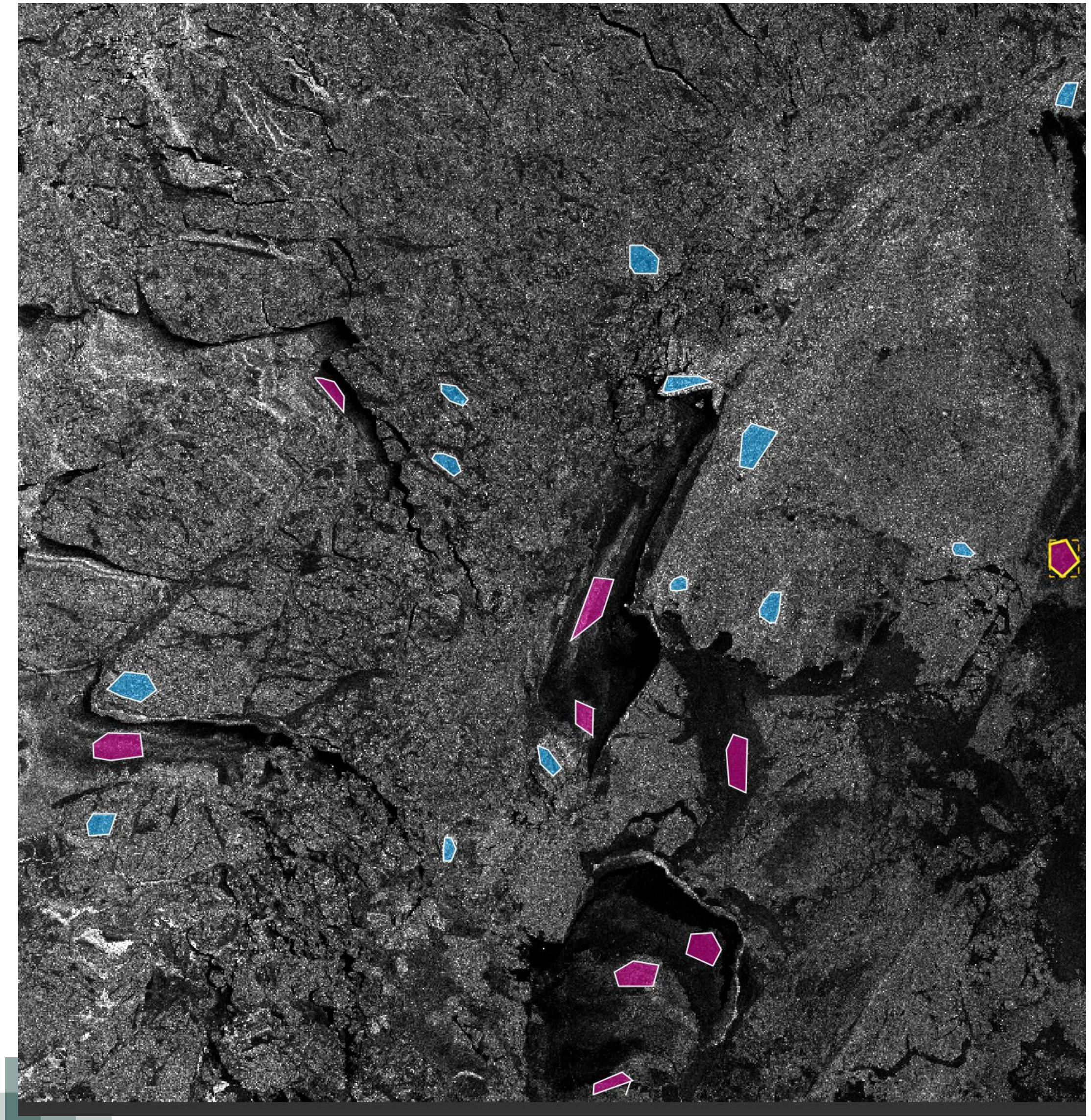
- HH-Channel

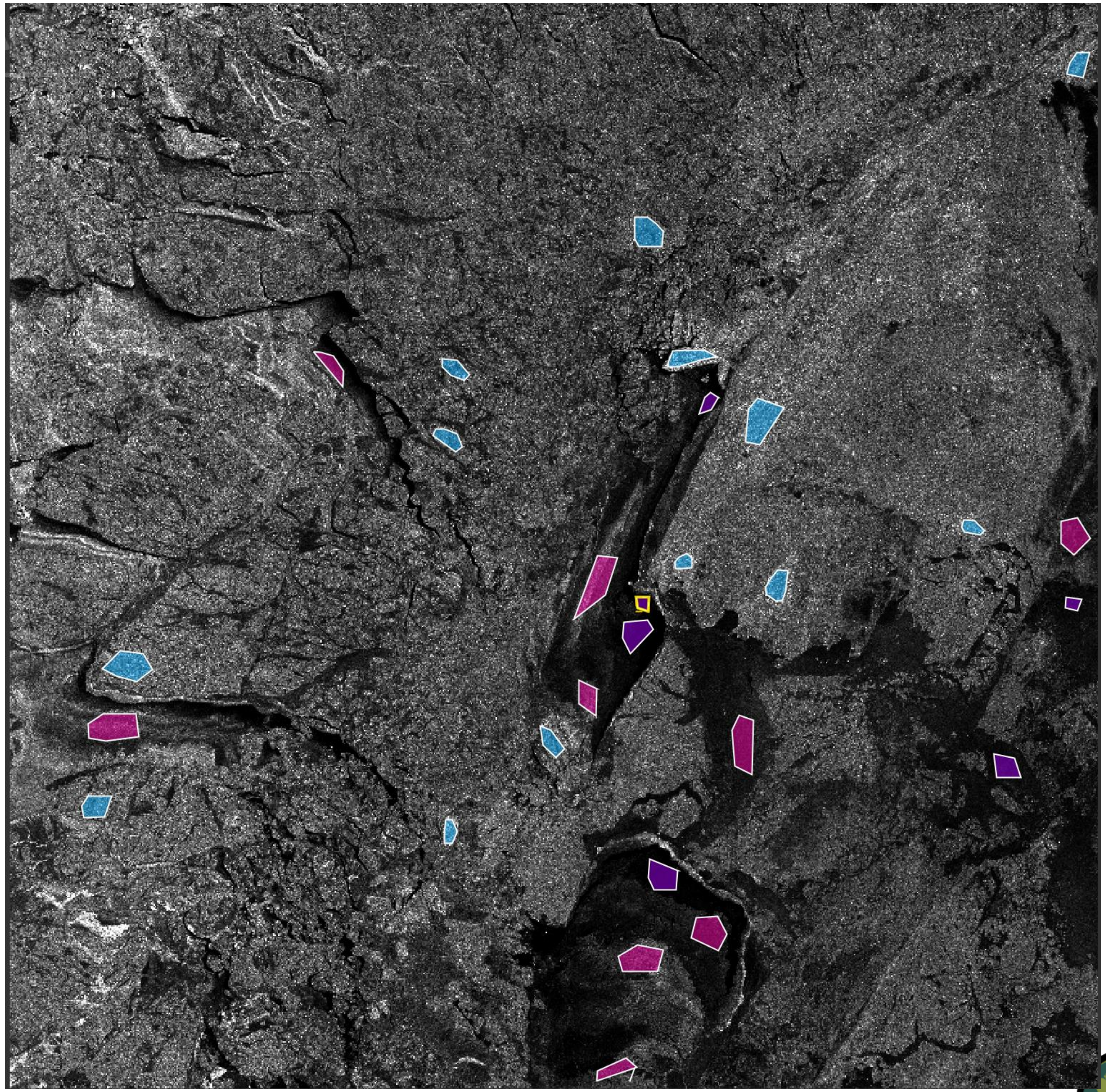


- HV-Channel



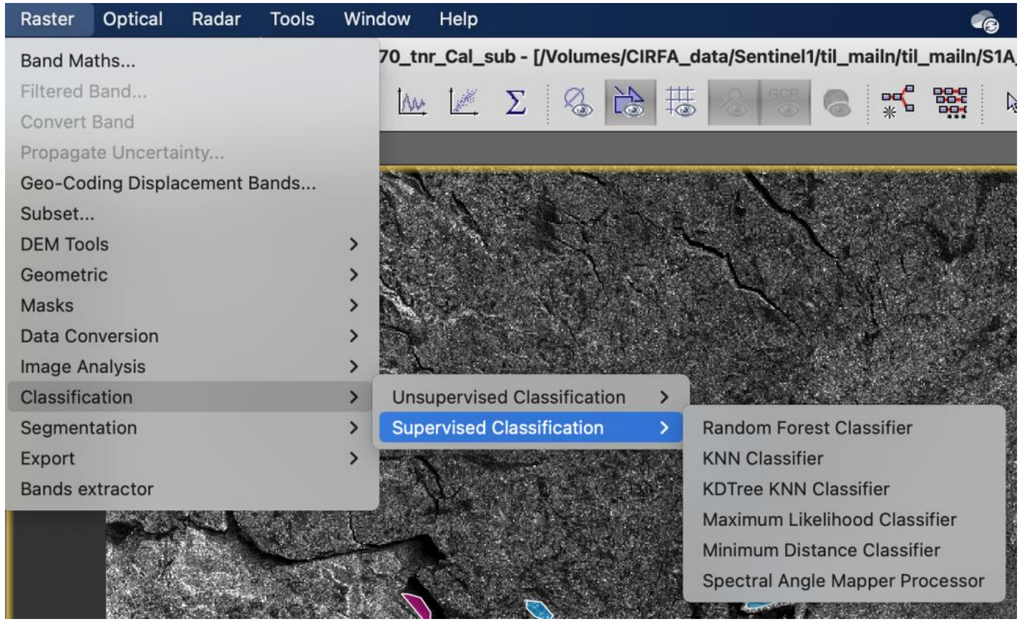
Young Ice (Pink) and Open Water (Purple)



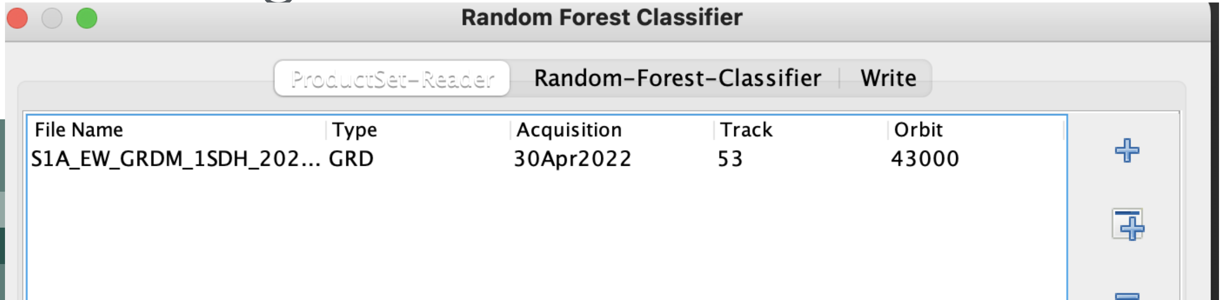


Perform the Random Forest Classification

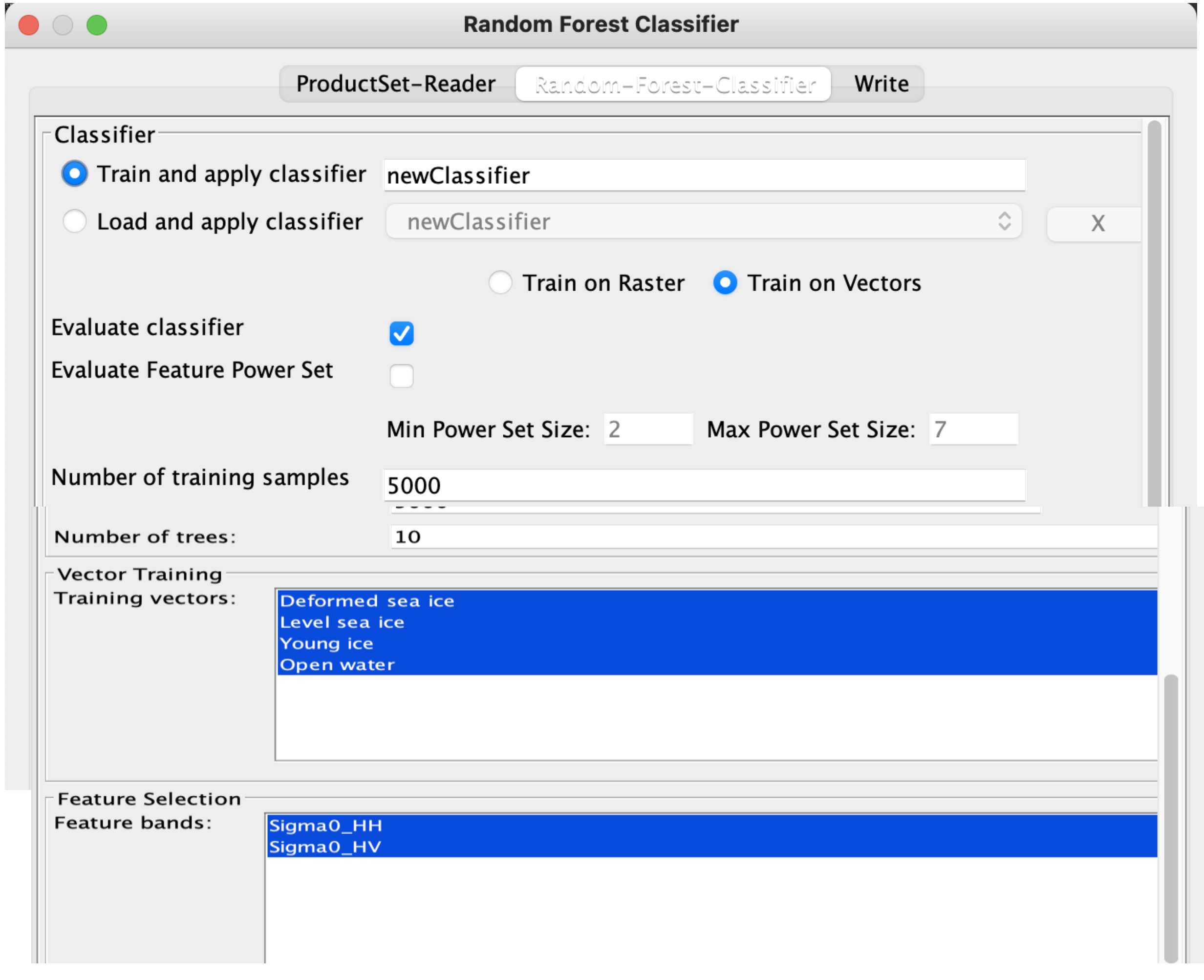
- Set up the random forest.



- Find the folder/image with your training data.



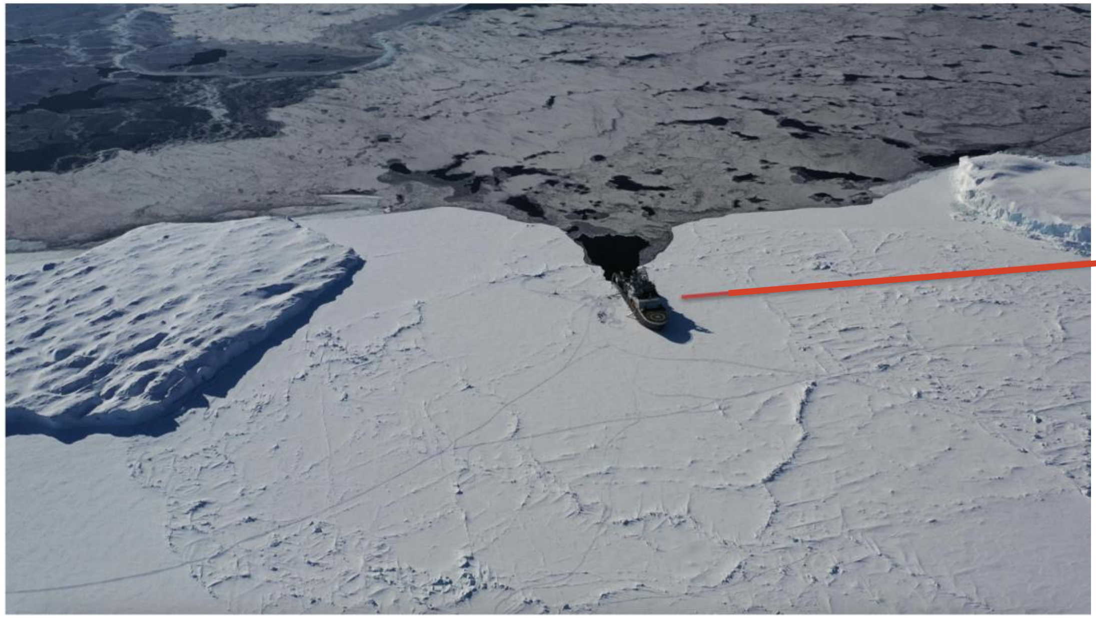
- Select the classes that you'd like to include.



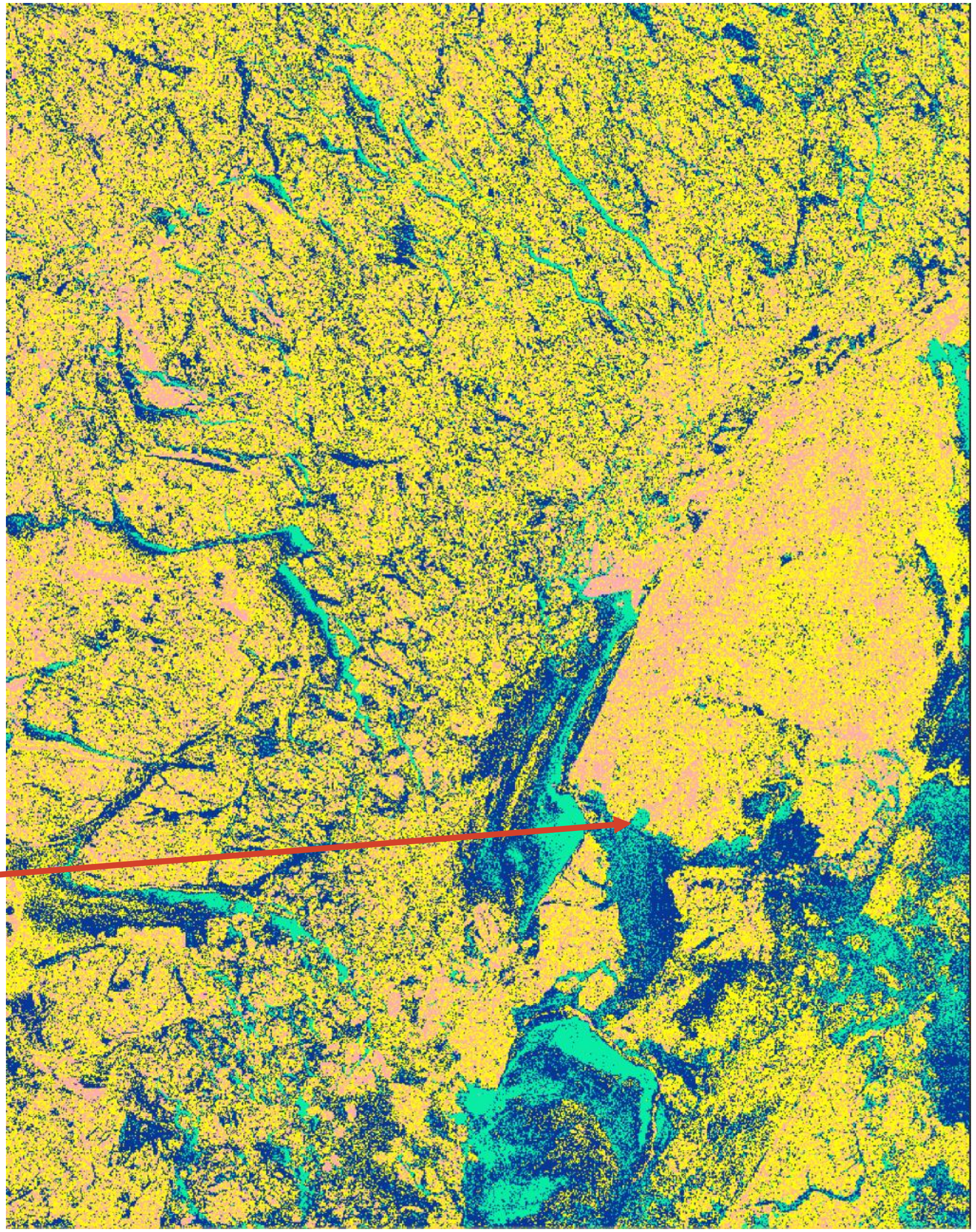
Perform the Random Forest Classification

- For the image and classes that I selected, my results turned out like this:

Label	Colour	Value
no data		-1
Deformed...		0
Level sea i...		1
Young ice		2
Open water		3



Picture courtesy: Morten Einarsve (Maritime Robotics)



Acknowledgements

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Wolfgang Dierking, Johannes Lohse, Catherine Taelman, Denis Demchev, Truls Karlsen, and Torbjørn Eltoft for slides, input and helpful feedback.

Janine Osanen for the sea ice stratigraphy image.

All those who have target ordered satellite data to overlap with the in-situ data for countless sea ice campaigns. Without you the temporal and spatial overlaps wouldn't have happened.

All those who have participated in fieldwork collecting in-situ data.

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- ARSET Website
- Follow us on Twitter!
  - @NASAARSET
- ARSET YouTube

Visit our Sister Programs:

- DEVELOP
- SERVIR

Resources

For the latest about the Arctic and Antarctic sea ice:

- https://nsidc.org/arcticseaicenews/
- https://nsidc.org/data/seaice_index/
- https://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph/
- https://earth.gsfc.nasa.gov/cryo/data/current-state-sea-ice-cover

WMO Sea Ice Nomenclature:

- https://library.wmo.int/viewer/41953?medianame=259-2015_multilingual_#page=1&viewer=picture&o=&n=0&q=

- Extreme Earth Dataset: https://earthanalytics.eu/datasets.html, https://zenodo.org/record/4683174#.YLTRA5MzZdA
- More information about our cruise: https://zenodo.org/record/7314066#.Y3I418fMJPZ

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Thank You!