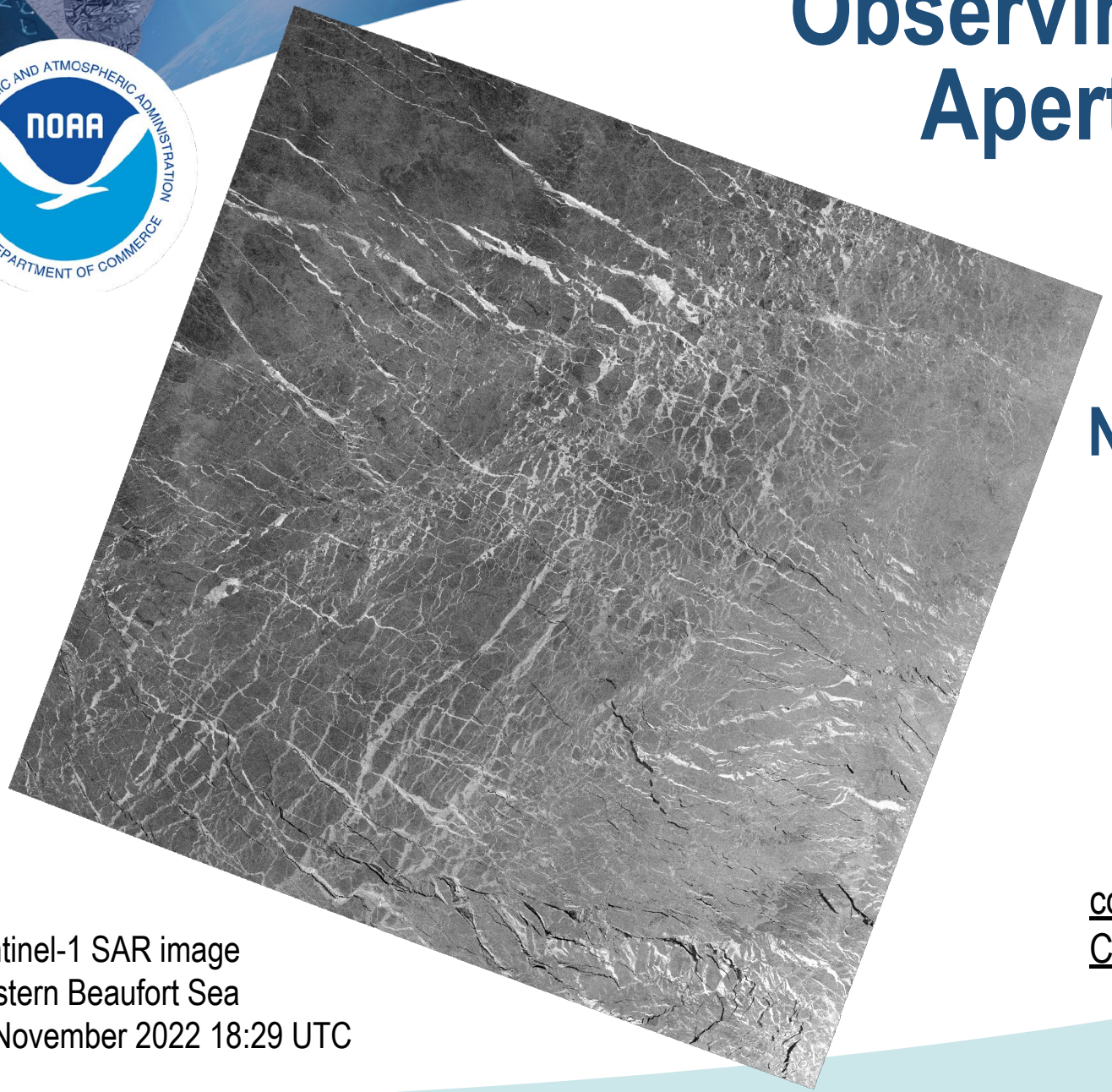
Observing Sea Ice in Synthetic Aperture Radar Imagery



Sentinel-1 SAR image
Western Beaufort Sea
28 November 2022 18:29 UTC

NOAA PolarWatch Sea Ice Training Course

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Last Updated: 10/20/2024

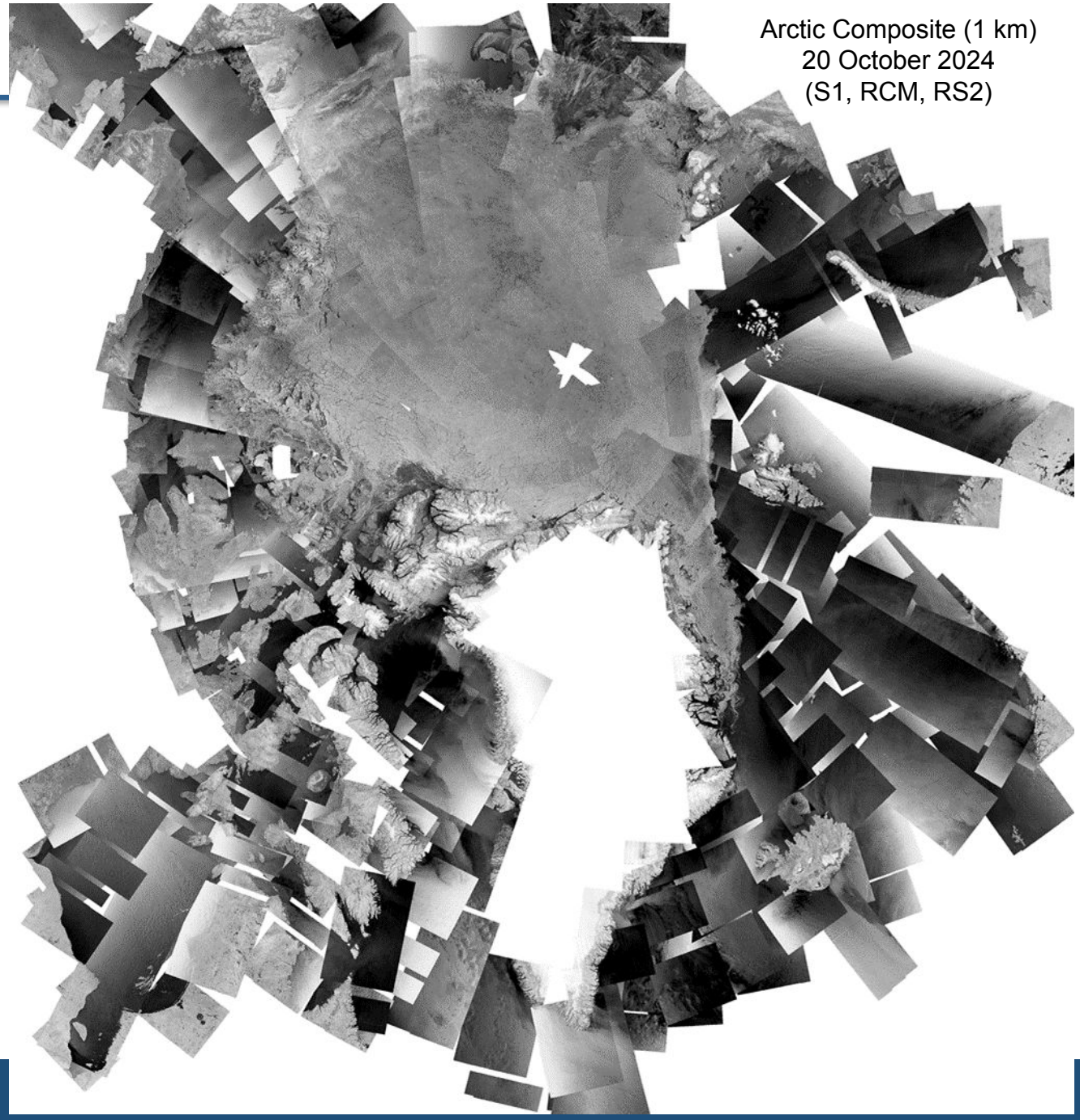
Overview

- Synthetic Aperture Radar Background
- Sea Ice Types / Features
- Effects Frequency / Polarization
- Lake Ice

Focus on the Northern Hemisphere
This short briefing is just a quick introduction to SAR sea ice observations

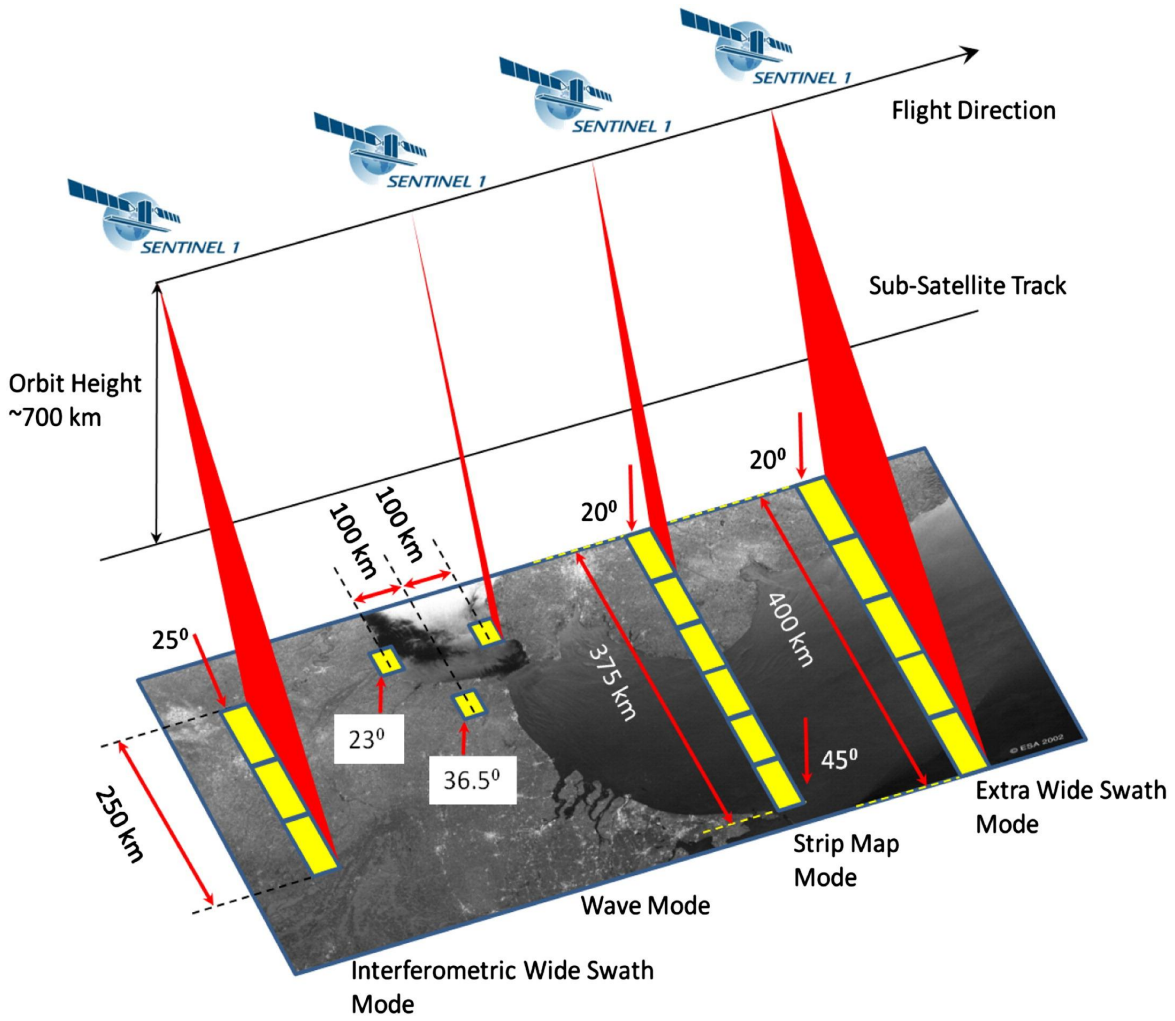
- Sentinel-1 (2014) ushered in a new era for SAR data coverage and access
- There is more SAR data available “today” then at any previous time (almost of it available free and in near real time)

- NOAA STAR currently processes imagery from the Radarsat-2, Sentinel-1A and RCM-1,2,3 SAR satellites into a variety of products.



Arctic Composite (1 km)
20 October 2024
(S1, RCM, RS2)

SAR Overview



- Synthetic aperture radar (SAR) works by transmitting radar pulses and recording both the amplitude and phase of the reflected return signals.
- These return pulses are then coherently combined over a specific time interval (the synthetic aperture) to produce a 2D image of radar backscatter.
  - For S1 this is ~0.5 sec (3.5 km)
- The latest generation of SAR have very sophisticated capabilities offering a wide variety of data collection modes
- For a SAR on a polar-orbiting satellite, this imagery can have fine spatial resolution of <3 to >100 meters over a swath that can be as wide as 500 kilometers
  - Tradeoffs between coverage area and resolution

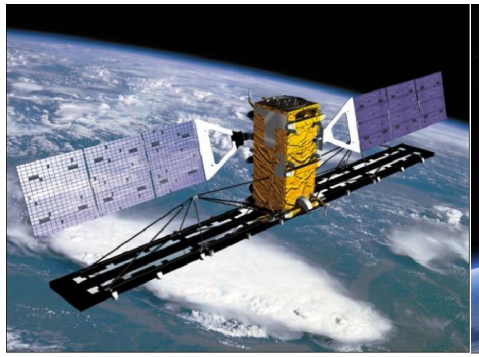
SAR Background

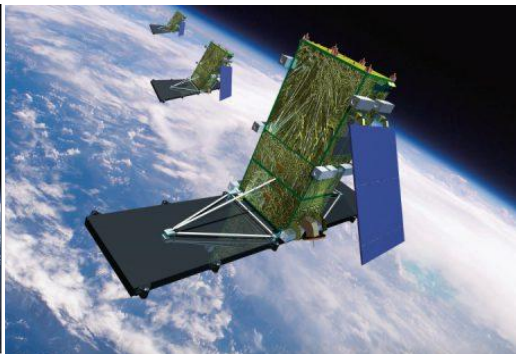
- Backscatter comes from surface roughness components that are on the scale of the radar wavelength.
- Normalized Radar Cross Section (NRCS) is the measure of radar backscattered power (linear / dB scaling) (Rough = Bright)
- Sea Ice: Surface texture and dielectric constant dictate the amount of backscatter.
  - These are influenced by formation conditions, age, and ice interactions.
- The appearance of sea ice features in SAR is influenced by radar frequency and polarization (L/C/X – VV/HH, VH/HV)
- Sea Ice is a very complicated material (wide variety of forms, changes over many time scales (hours to years), Stages of Freezing, Stages of Melting, Movement, Deformation (splits apart/pushes together)
  - WMO Sea-Ice Nomenclature WMO-No. 259 (2014) https://library.wmo.int/records/item/41953-wmo-sea-ice-nomenclature

SAR Satellites Background

There are many other satellite SAR systems

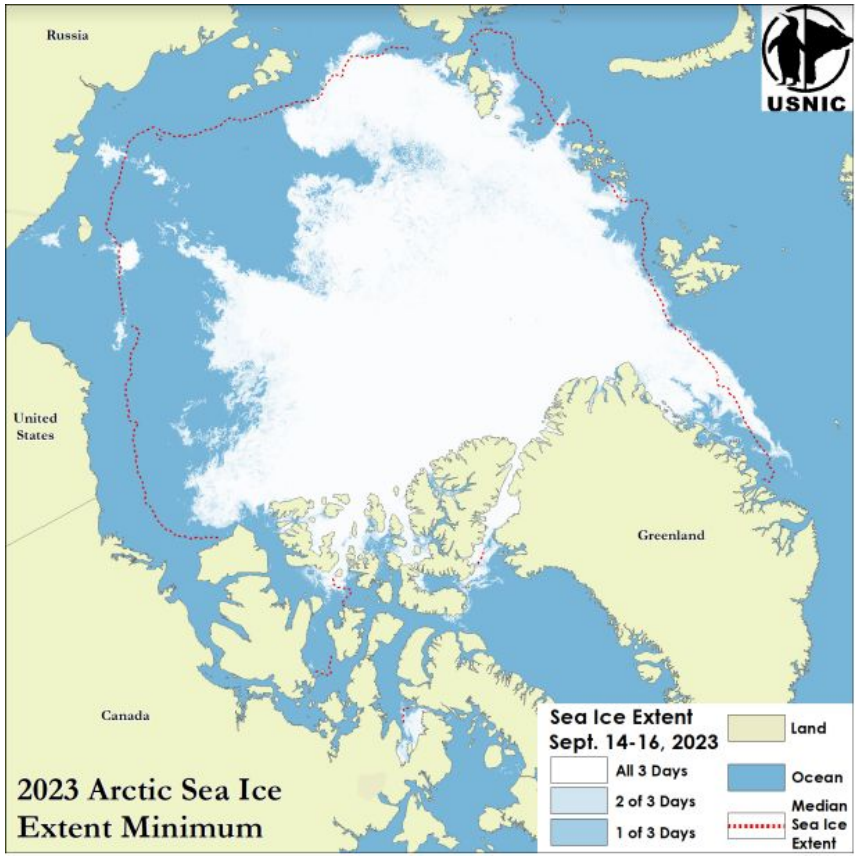
- **TerraSAR-X, CosmoSkyMED (X)**
- **ALOS-2, SAOCOM (L)**
- **Iceye, Capella (X)**





	Radarsat-2	Sentinel-1	RCM
Launch	2007	2014 (A) /2016 (B)	2019 (1,2,3)
Altitude	798 km	693 km	593 km
Repeat	24 Day	12 Day	12 Day
LT Ascending Node	18:00	18:00	18:00
Center Frequency	C-Band 5.405 GHz	5.405 GHz	5.405 GHz
Polarization	HH,VV,HV, VH	VV,VH (HH,HV)	HH,VV,HV, VH, Compact
Swath Width	100,150,300,500	80,240,400	30,125,350,500
Resolution (Wideswath)	50/100 m	40/80 m	30/50/100 m

Arctic Ice Cover - Extent



Minimum sea ice occurred on 14-16 September 2023 an area of 4.13 million square kilometers as analyzed by USNIC's IMS.
https://usicecenter.gov/PressRelease/ArcticMinimum2023

Maximum sea ice extent occurred on 11 March - 13 March, 2024 with an area of 15.14 million square kilometers as analyzed by USNIC's IMS
https://usicecenter.gov/PressRelease/ArcticMaximum2024

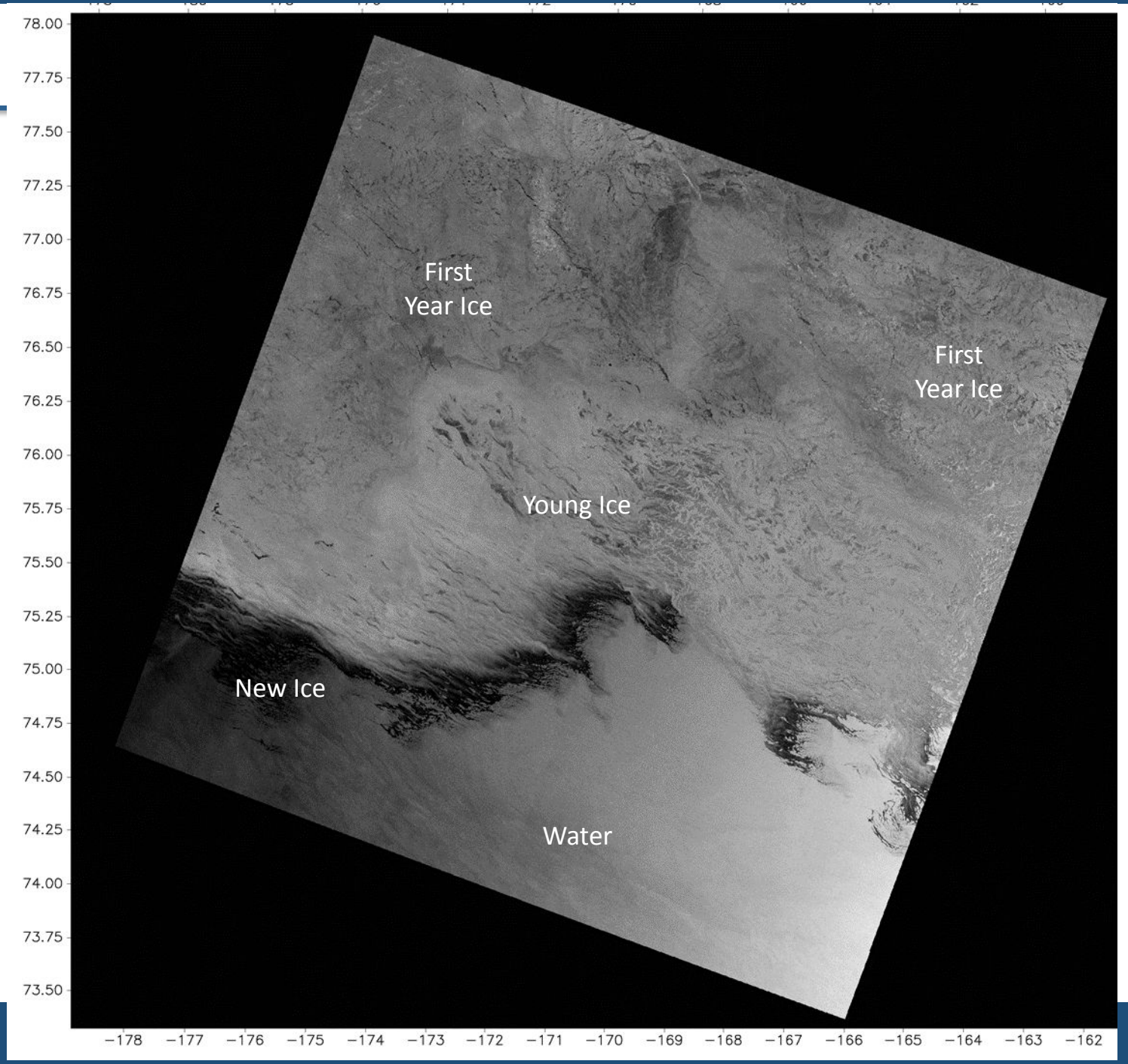
Sea Ice Development

Sentinel-1 SAR HH Co-Pol NRCS
23 October 2022 18:29 UTC

- This image shows a variety of ice types in the Western Beaufort Sea as the sea ice begins to form and expand in the weeks after sea ice minimum

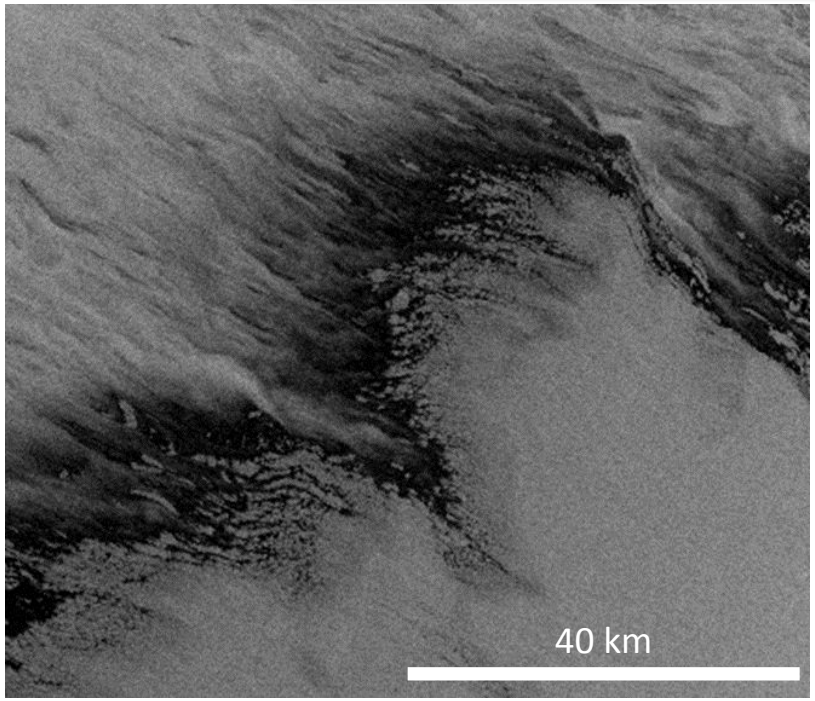
- New ice is smooth and appears black
- Young ice is influenced by the ocean currents
- First year ice is riddled with breaks and leads.
- This presentation will limit the ice classes to New, Young, First Year and Multiyear

https://www.star.nesdis.noaa.gov/socd/mecb/sar/AKDEMO_products/APL_winds/wind_images2/2022-10/S1A_ESA_2022_10_23_18_29_12_0719864952_169.95W_75.93N_HH_C_nrcs.png



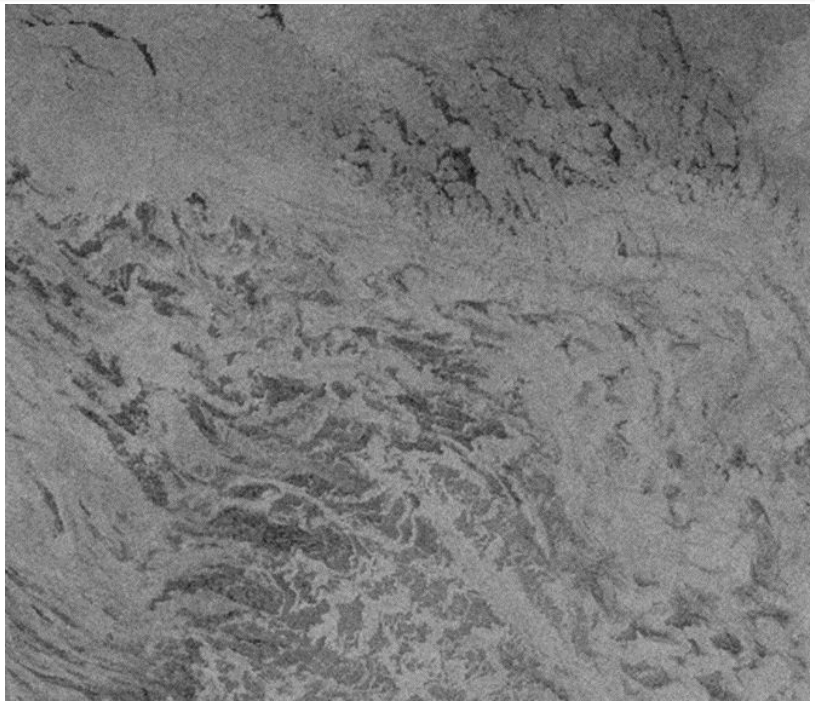
Sea Ice Types - Detail

Sentinel-1 SAR HH Co-Pol NRCS 23 October 2022 18:29 UTC



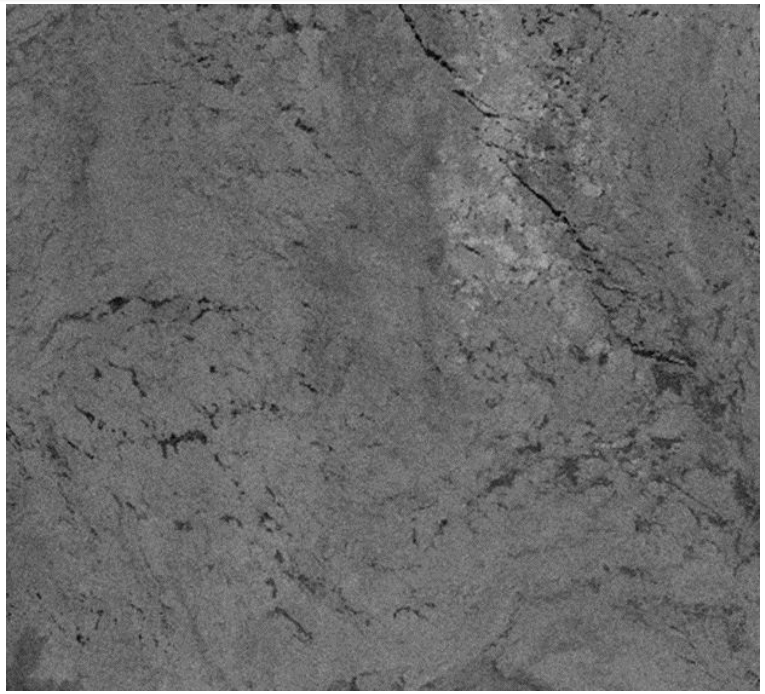
New Ice

Composed of ice crystals which are only weakly frozen together (if at all) and has a definite form only while afloat. In **Grease Ice** the crystals have coagulated to form a soupy layer on the surface. Grease ice is smooth resulting in low backscatter and appears black



Young ice

Ice in the transition stage between New Ice and First Year Ice and is between 10-30 cm in thickness. The ice is elastic, easily bending on swell waves and influenced by currents

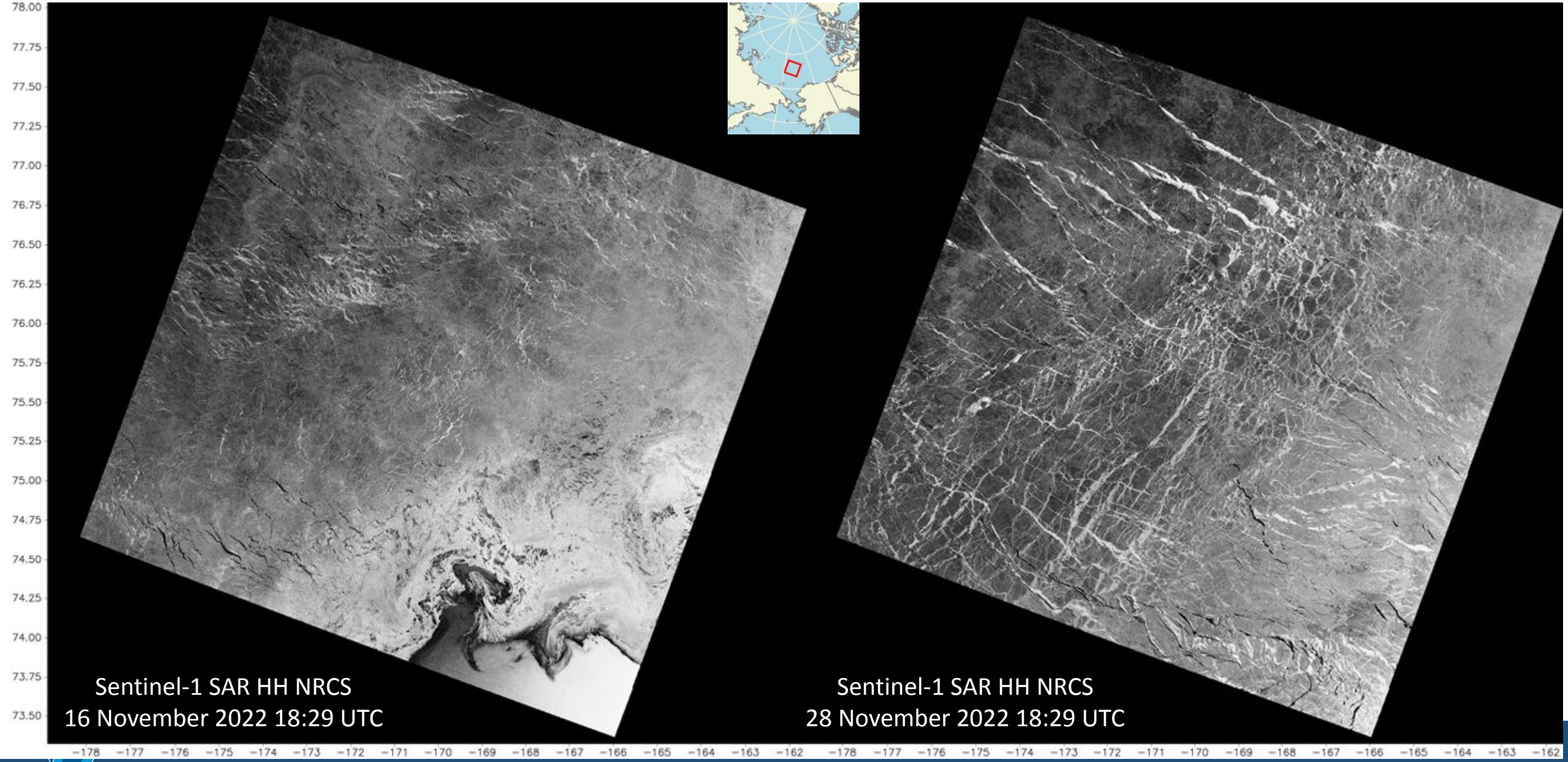


First-year

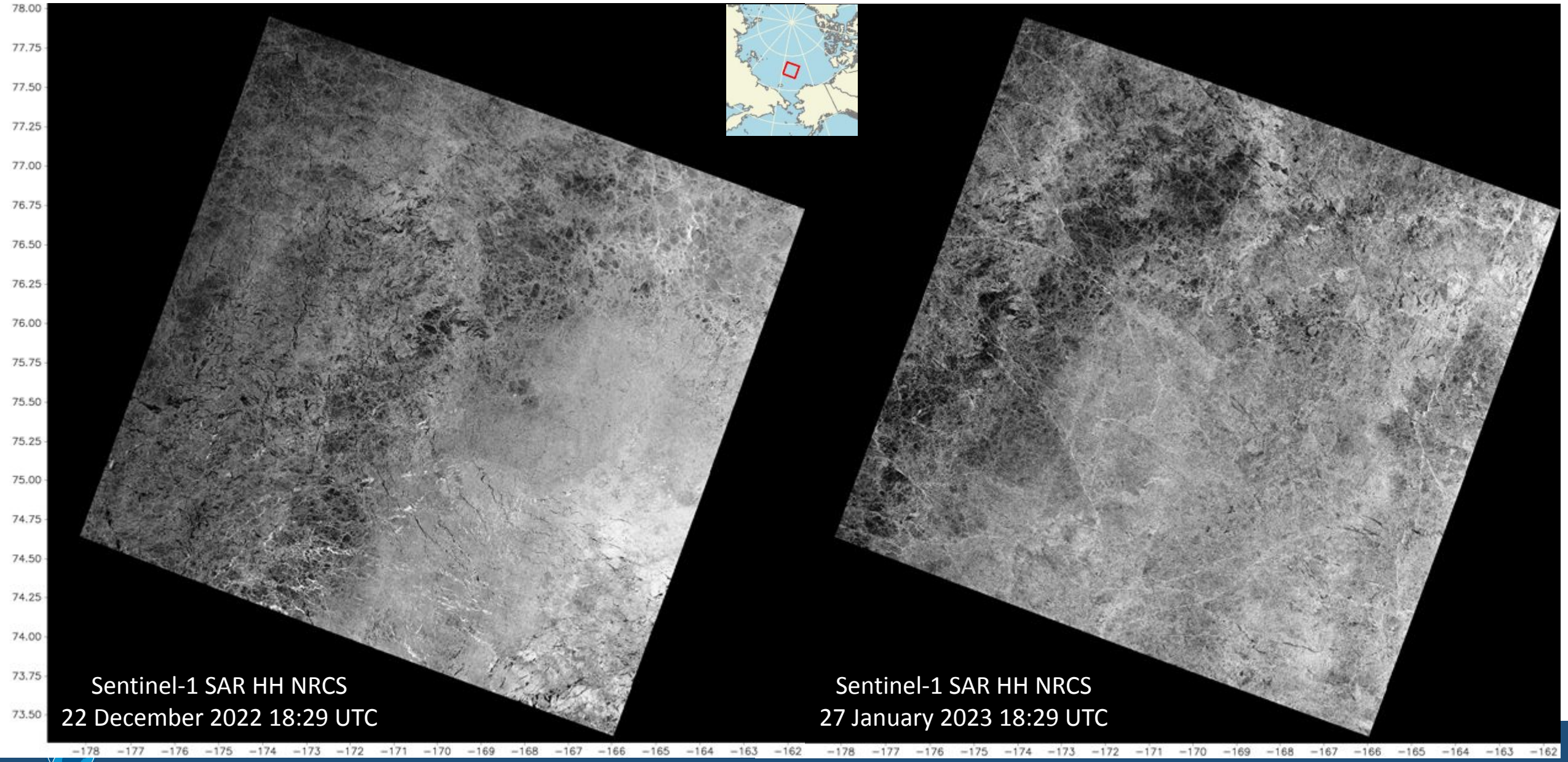
Sea ice of not more than one winter's growth, developing from young ice with a thickness between 30 cm - 2 m. First year ice is thick enough to be rigid and contain leads (breaks)

*Definitions adapted from WMO Sea-Ice Nomenclature WMO-No. 259 (2014)

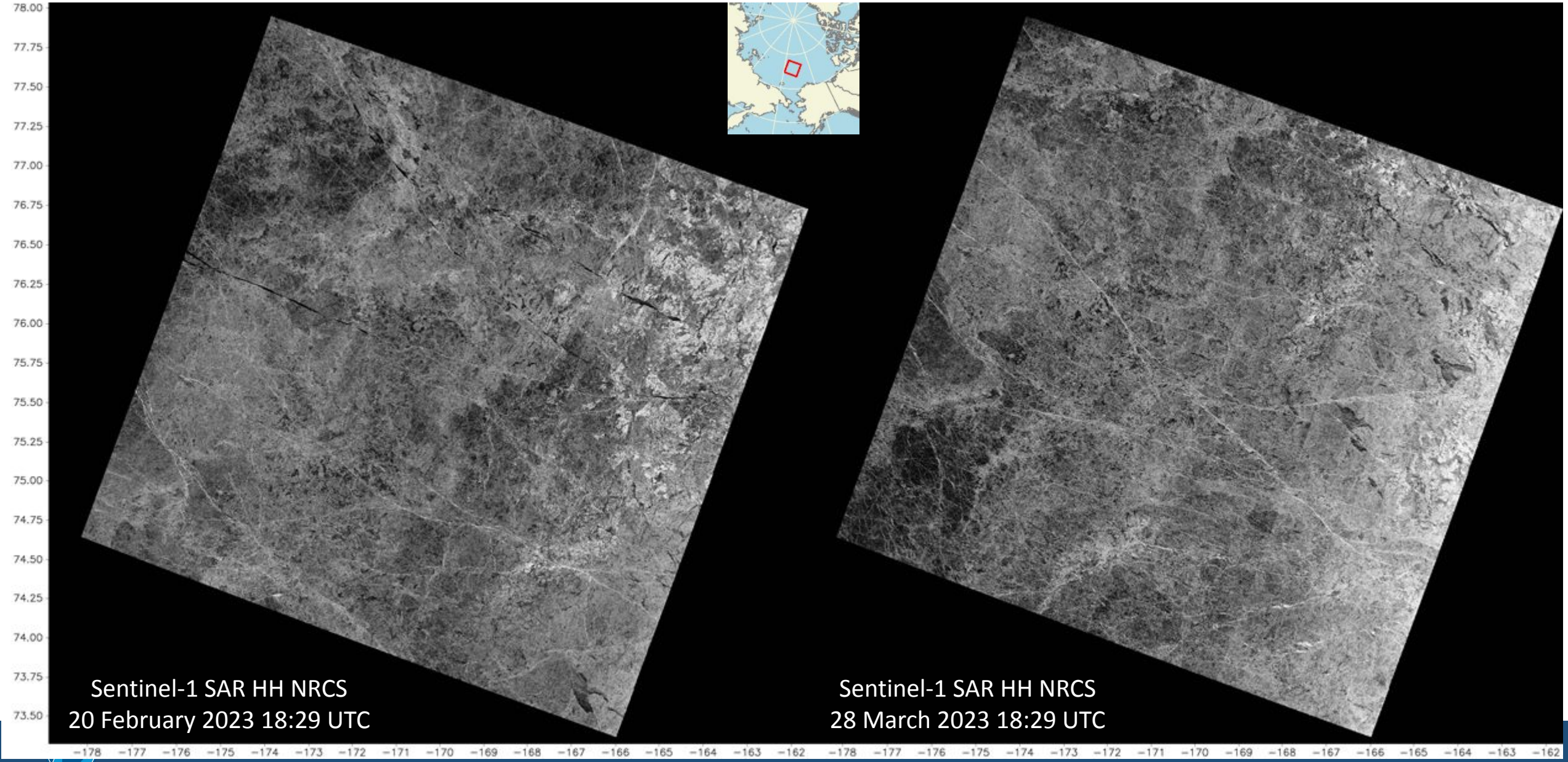
Beaufort Sea – November 2022



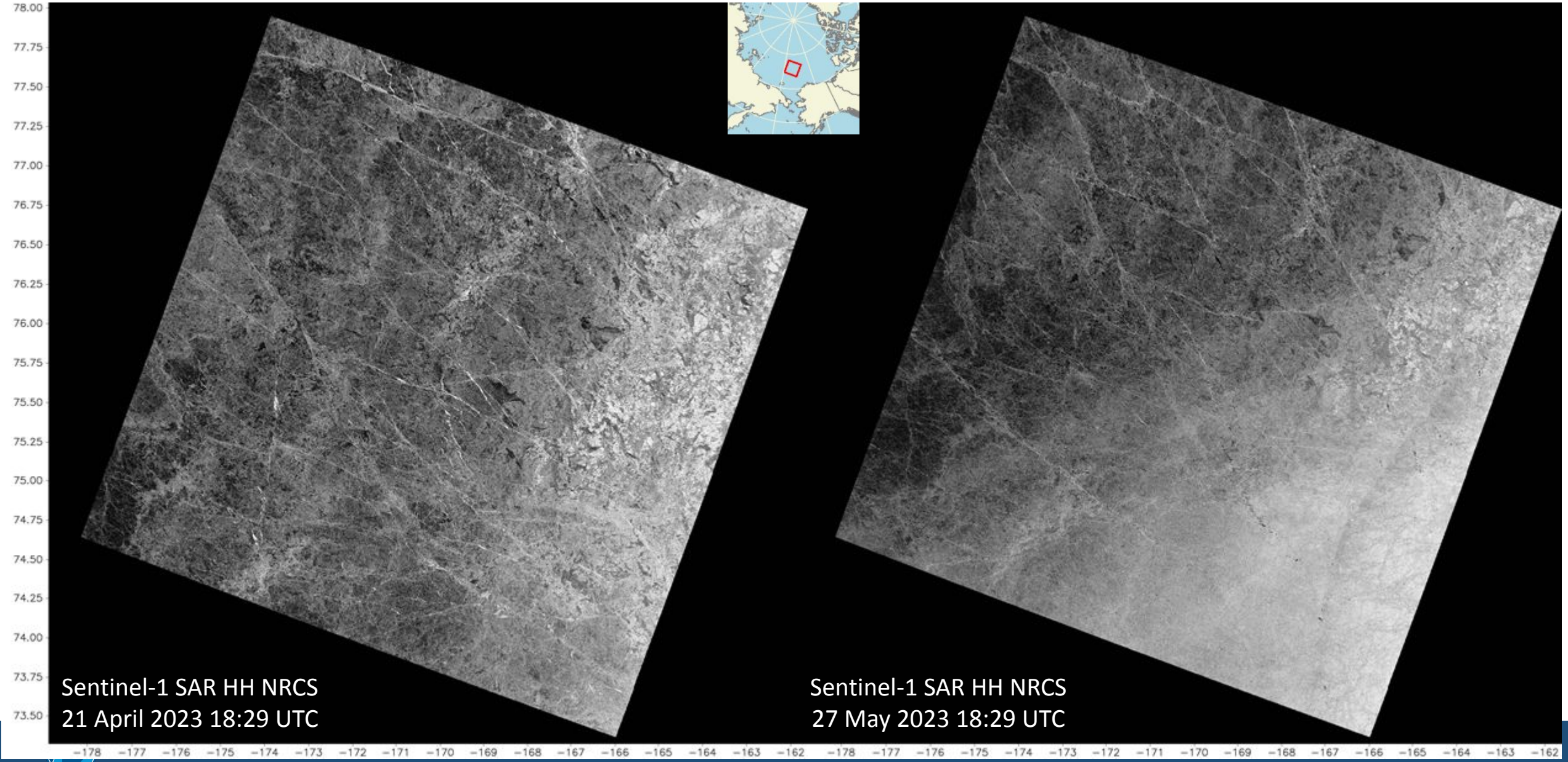
Beaufort Sea – December 2022 – January 2023



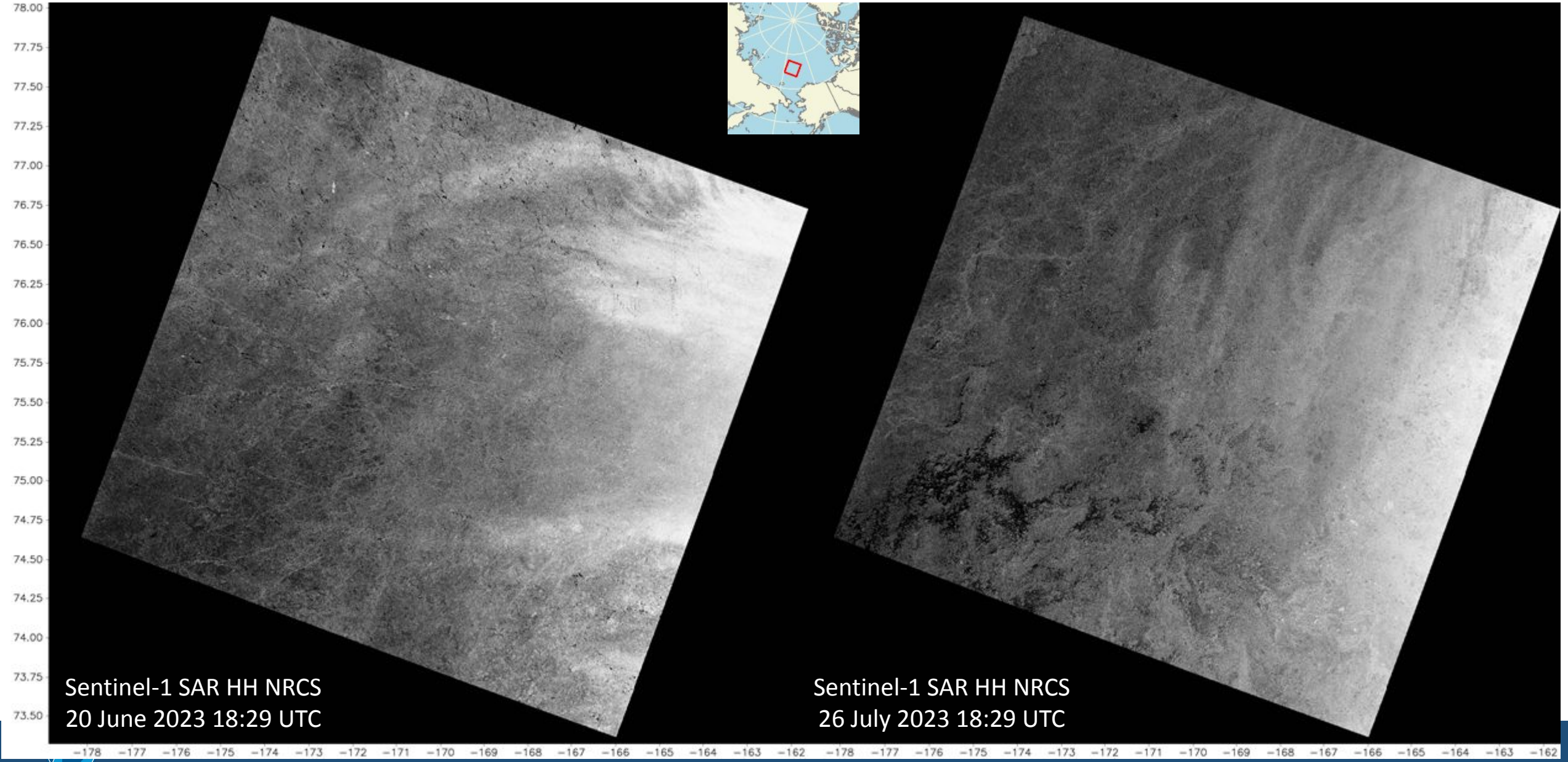
Beaufort Sea – February – March 2023



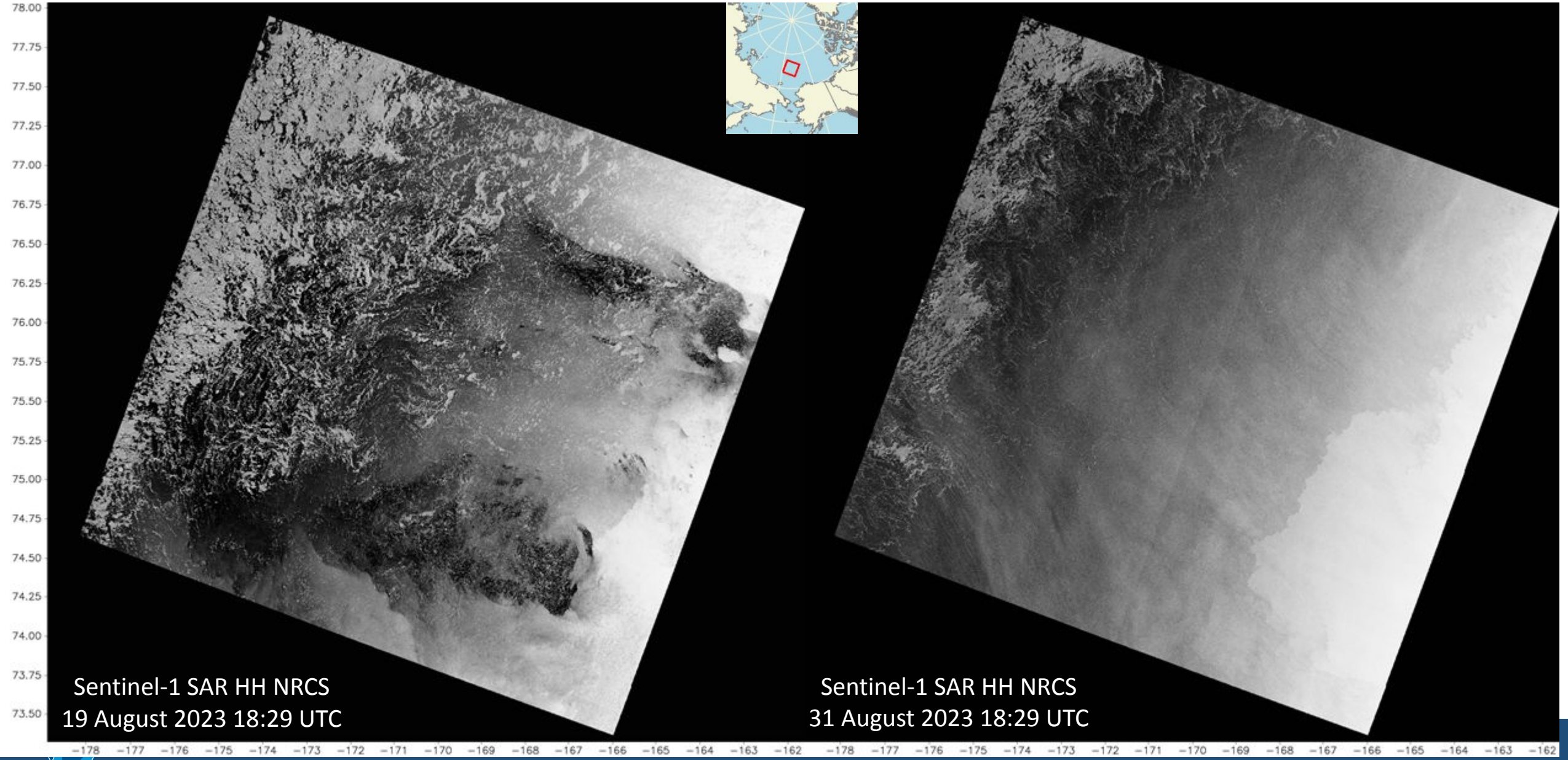
Beaufort Sea – April – May 2023



Beaufort Sea – June – July 2023

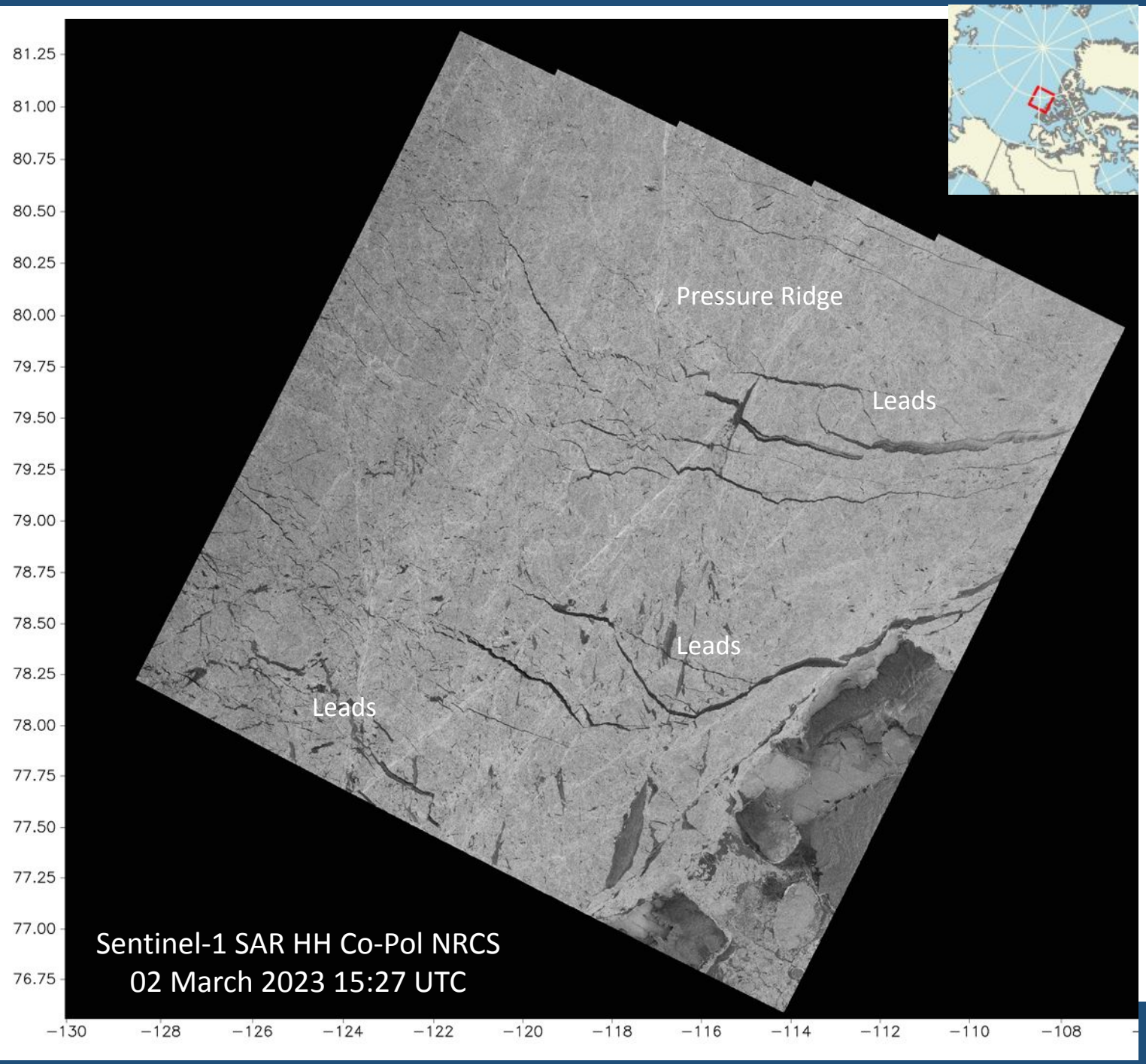


Beaufort Sea – August 2023



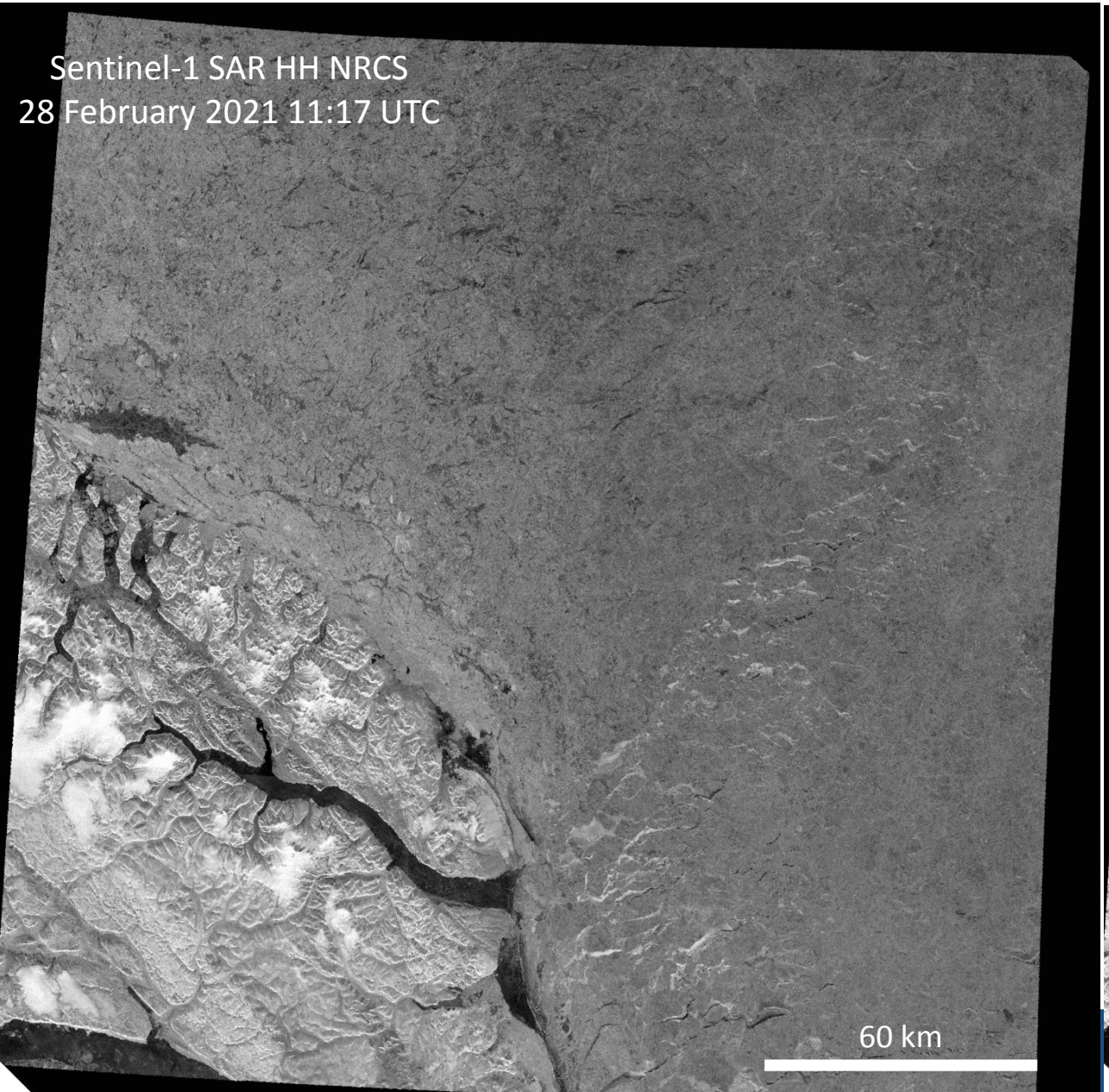
Sea Ice – Old / Multiyear Ice

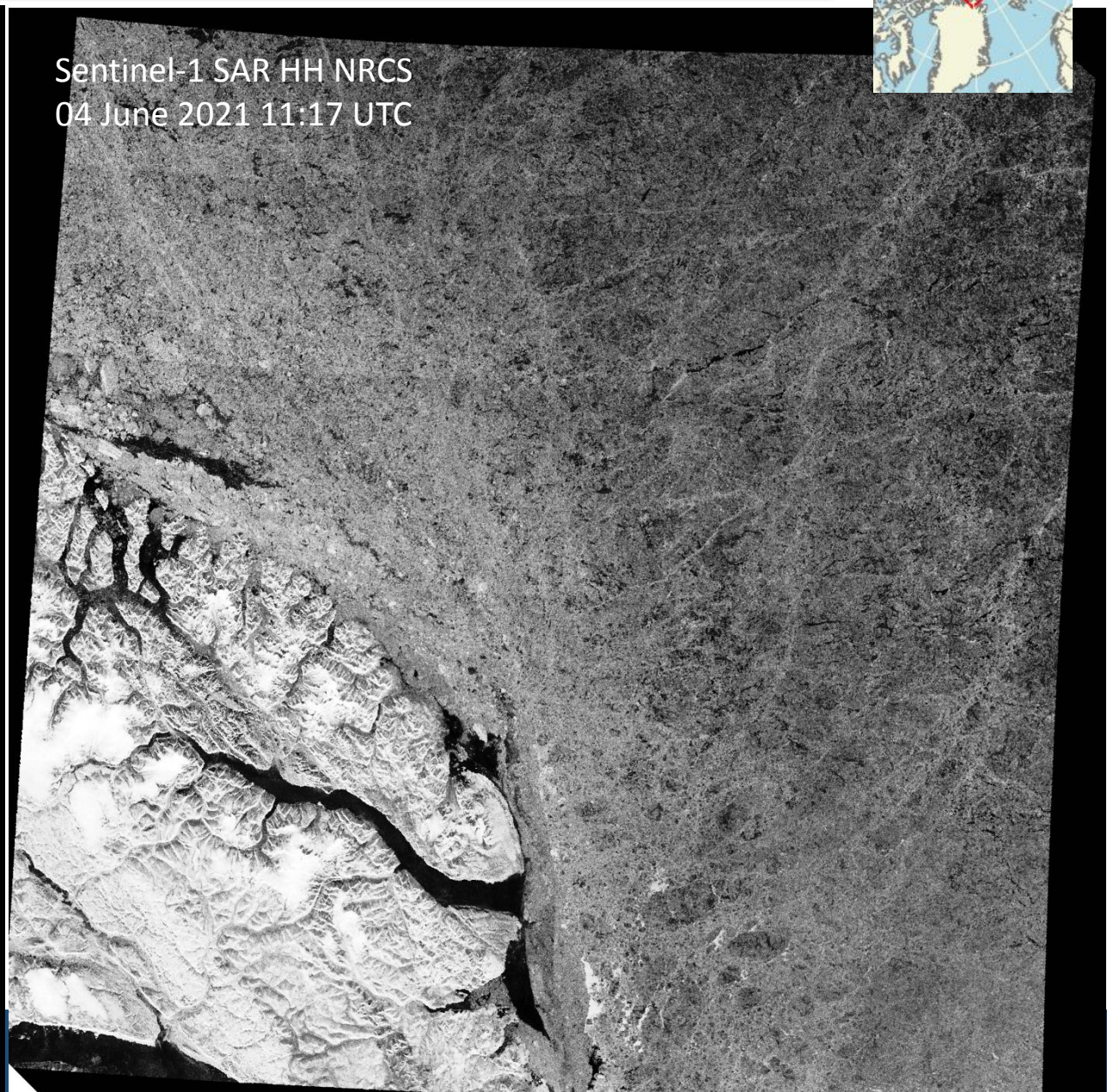
- Old (multi-year) ice has survived at least one summer's melt; typical thickness up to 3m or more. Most topographic features are smoother than on first-year ice
- Multi-year ice pack ice off the Canadian Archipelago contains leads (breaks in the ice that expose water) and pressure ridges (areas of sea ice compression).
- Old ice also contains less salt and may have a more uniform appearance compared to First Year Ice



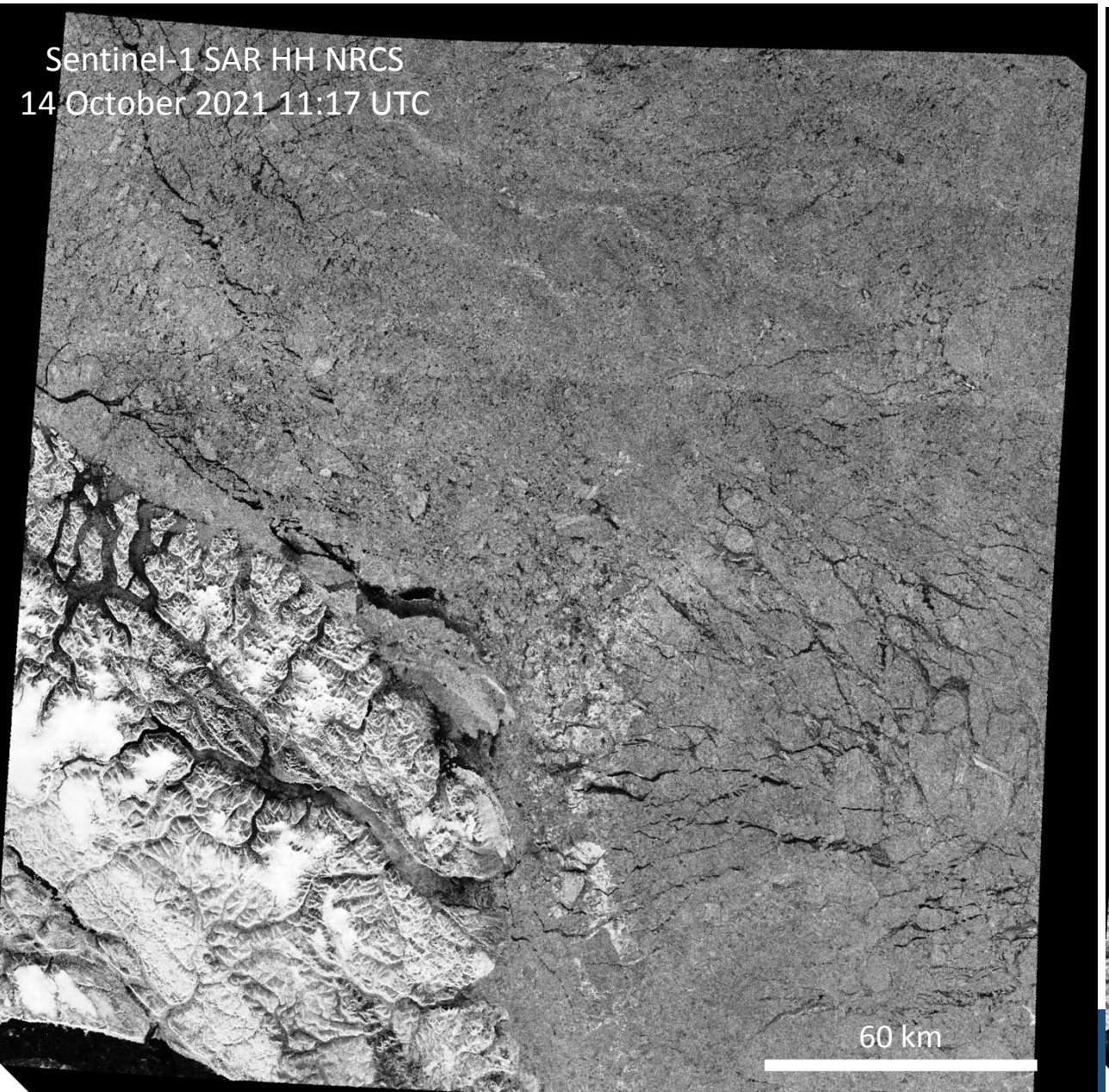
https://www.star.nesdis.noaa.gov/socd/mecb/sar/AKDEMO_products/APL_winds/wind_images2/2023-03/S1A_ESA_2023_03_02_15_27_02_0731086022_117.75W_79.51N_HH_C_nrcs.png

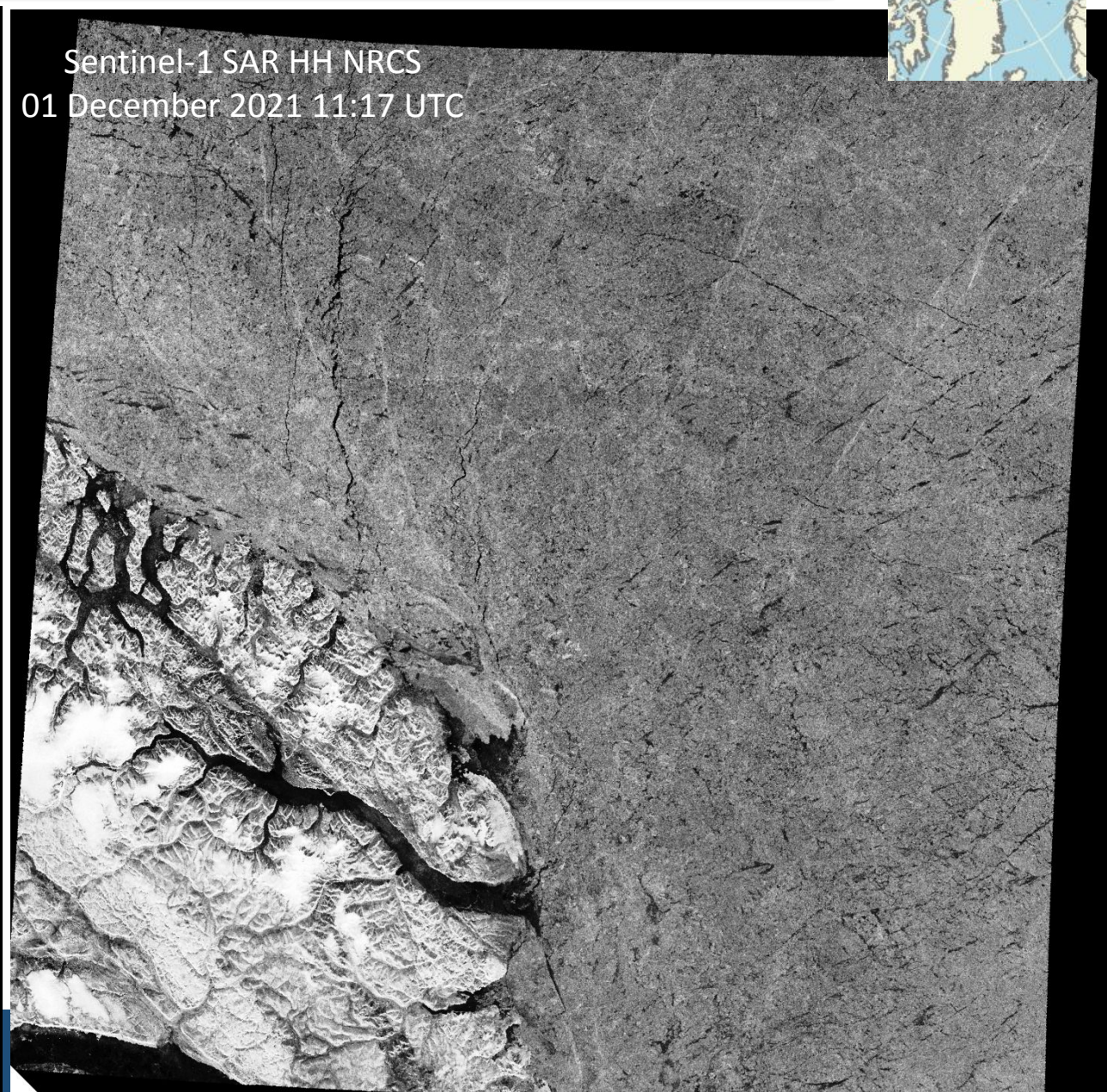
Old Ice – North of Greenland February and June 2021





Old Ice – North of Greenland October and December 2021

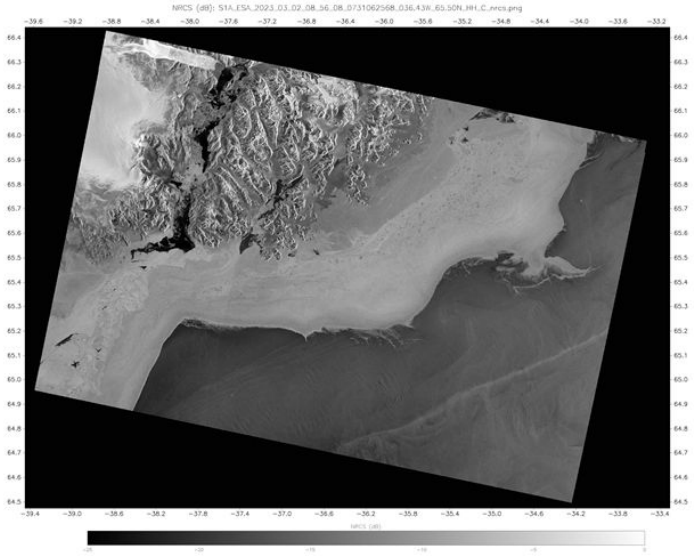




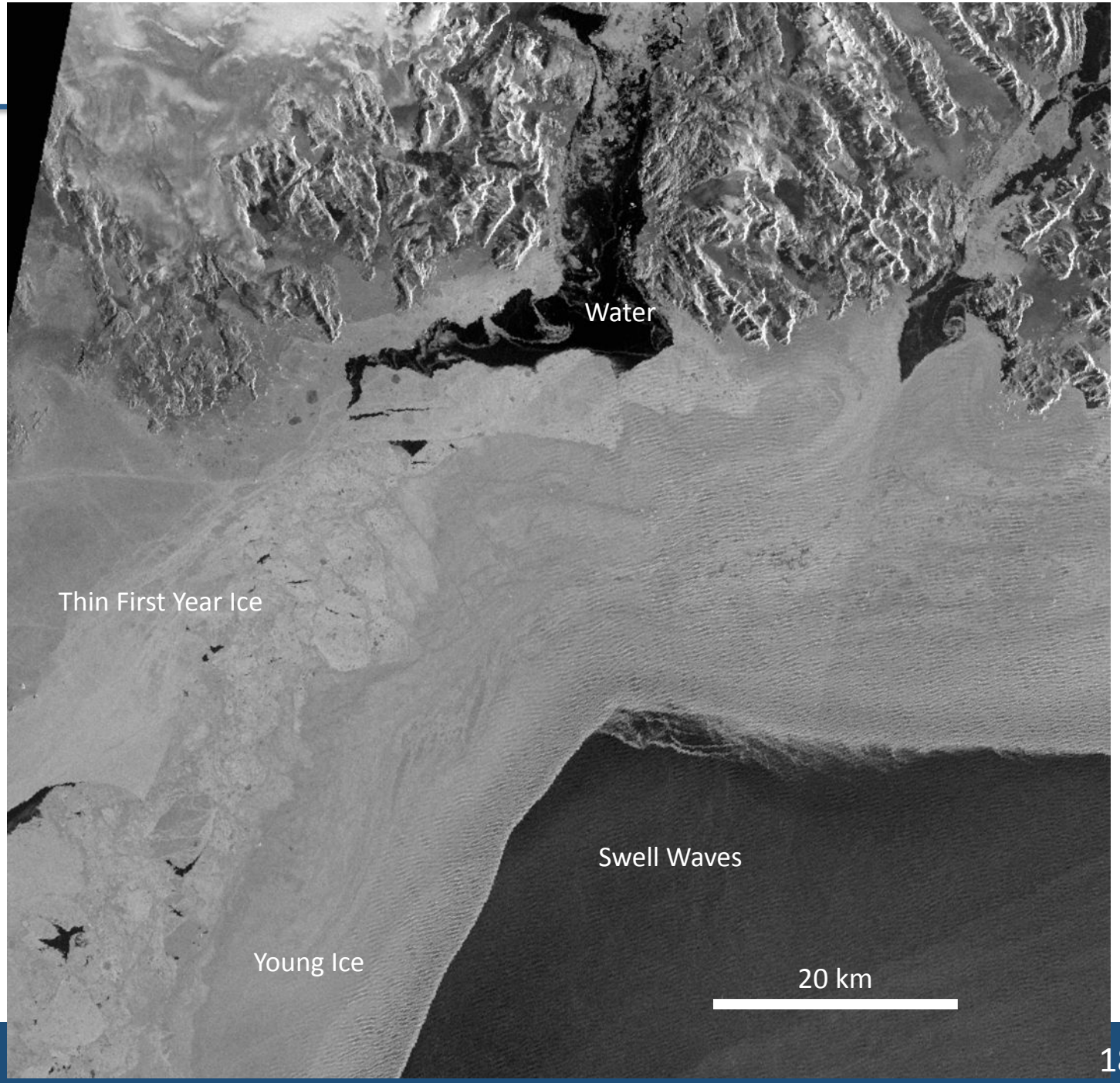
Marginal Ice Zone - Waves in Ice

Sentinel-1 SAR HH Co-Pol NRCS
02 April 2023 22:50 UTC

Marginal Ice Zone: The region of an ice cover which is affected by waves and swell penetrating into the ice from the open ocean.

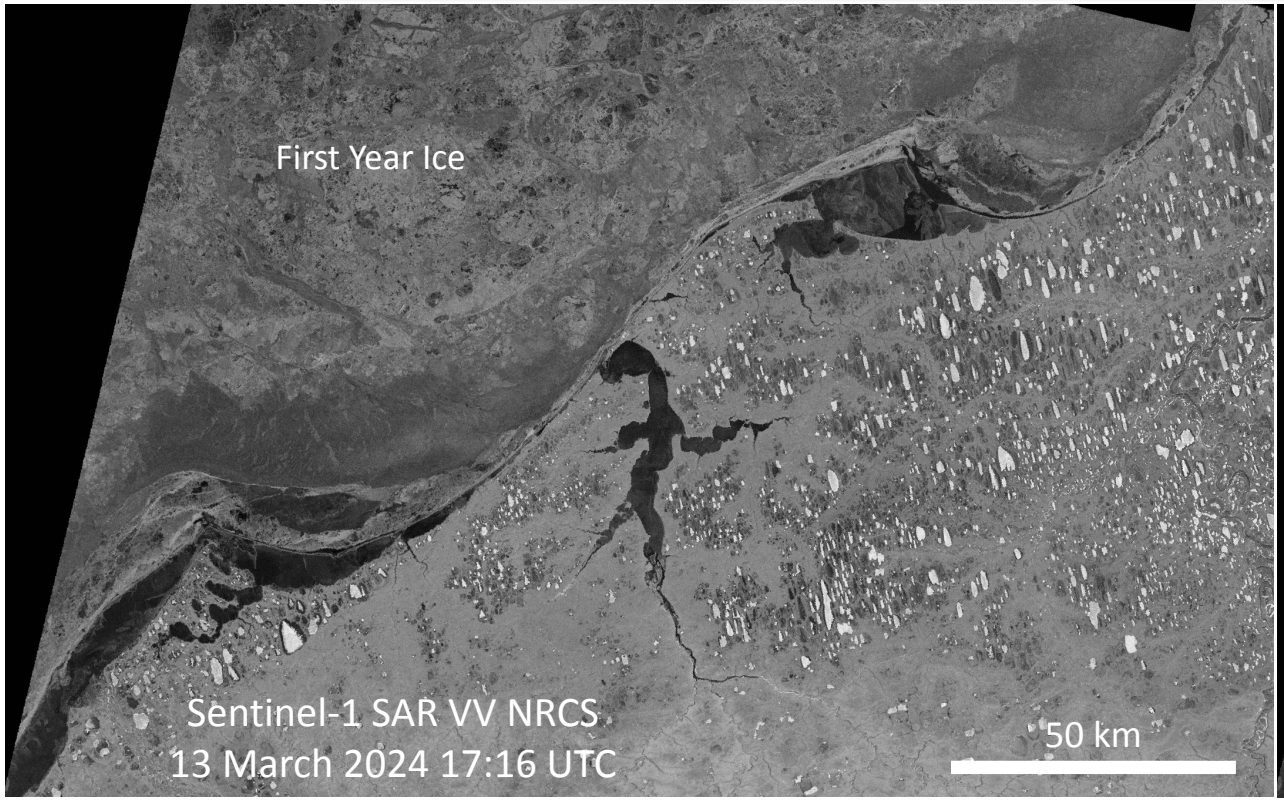


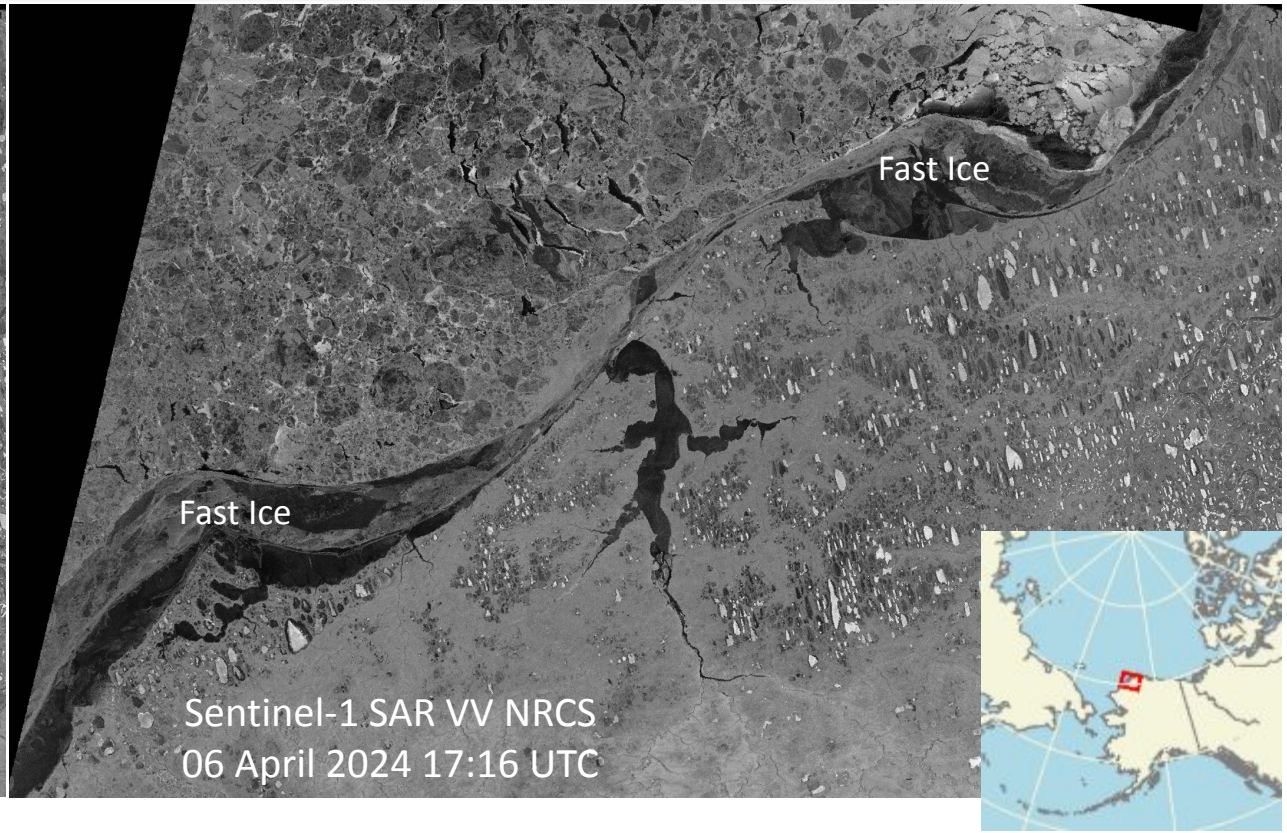
*Very few SAR images of the ice edge contain a swell wave pattern



https://www.star.nesdis.noaa.gov/socd/mecb/sar/AKDEMO_products/APL_winds/wind_images2/2023-03/S1A_ESA_2023_03_02_08_56_08_0731062568_036.43W_65.50N_HH_C_nrcs.png

Fast Ice – North Coast of Alaska

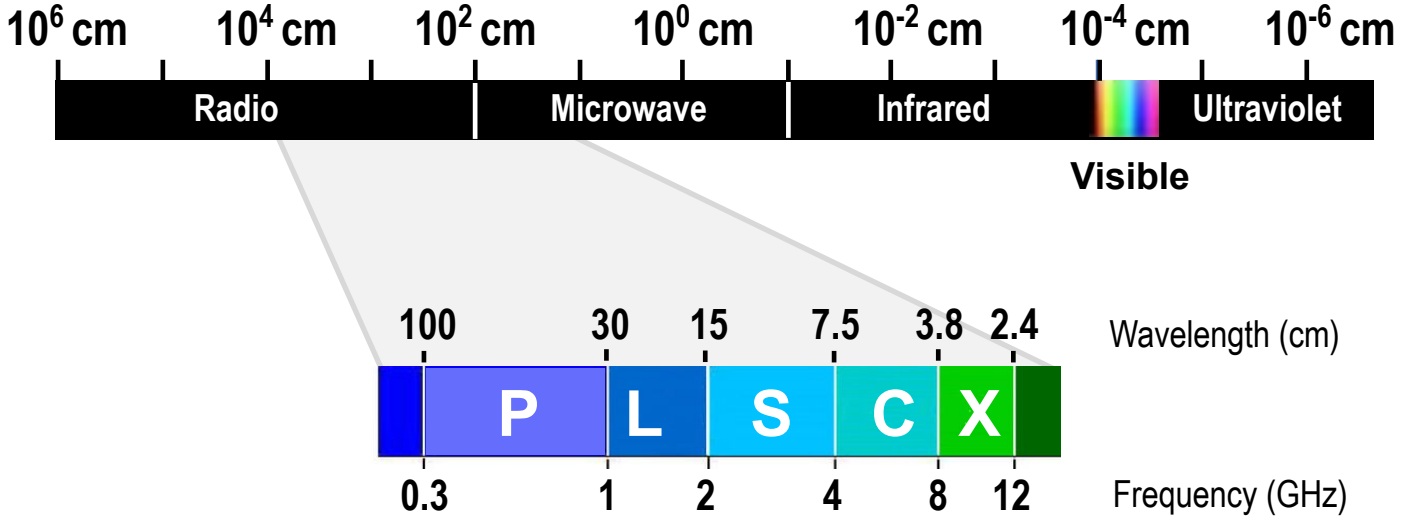


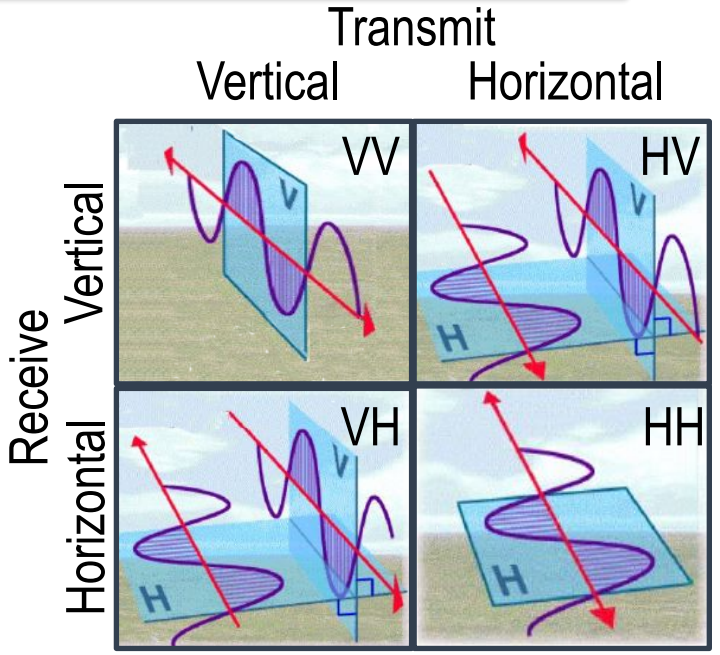


Fast Ice forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. Vertical fluctuations may be observed during changes of sea-level. Fast ice may extend a few meters or several hundred kilometers from the coast. Fast ice may be more than one year old. If it is thicker than about 2 m above sea-level it is called an ice shelf

The Fast Ice signature is nearly identical between dates while significant changes are visible in the FY ice

SAR Frequency and Polarization





Band	Frequency (GHz)	Wavelength (cm)
X	8-12	2.4-3.8
C	4-8	3.8-7.5
S	2-4	7.5-15
L	1-2	15-30
P	0.3-1	30-100

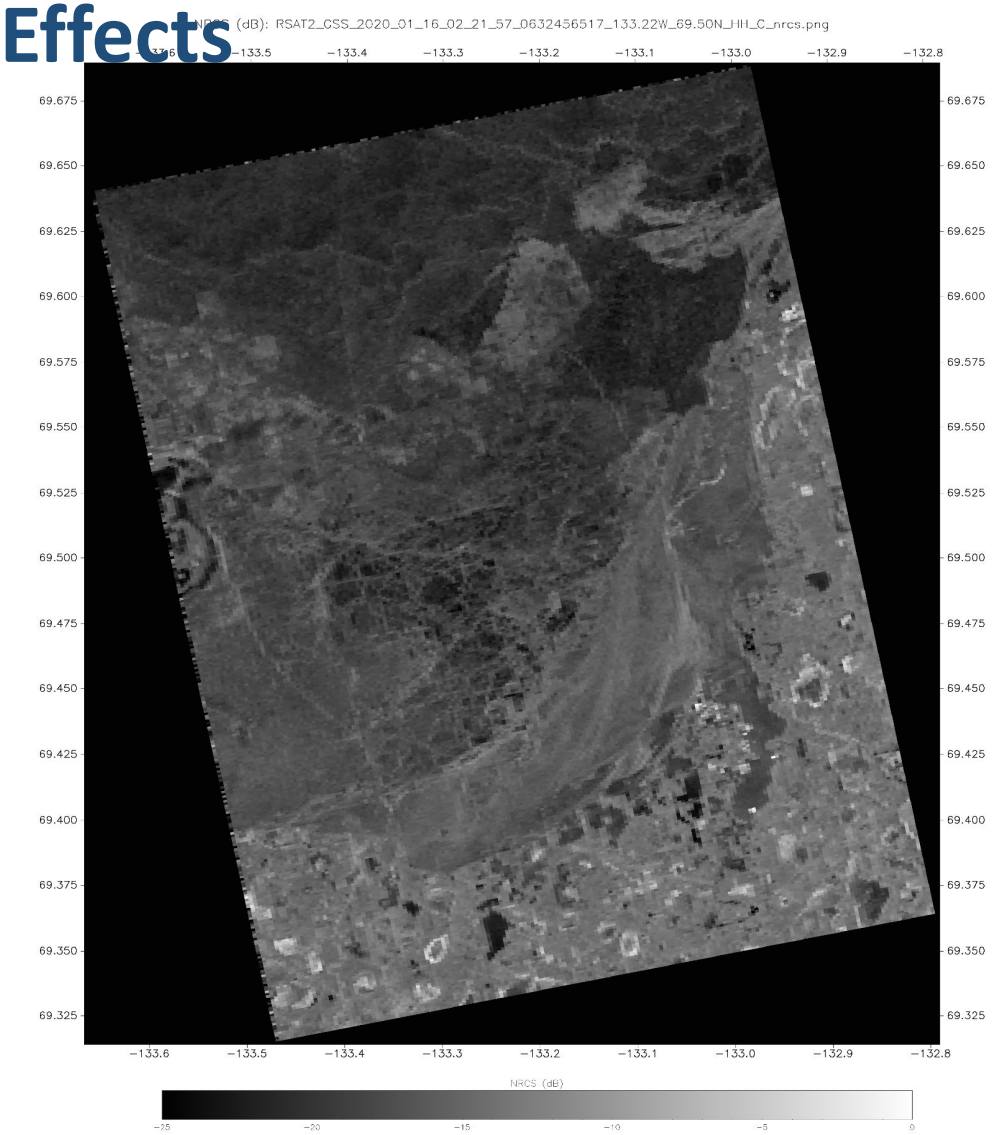
- SAR systems can operate at a variety of frequencies which are selected based on the application
- Polarization refers to the orientation of the plane in which the transmitted electromagnetic wave oscillates.
- Physical properties of the target will interact differently to different frequencies and polarizations

Polarization Effects

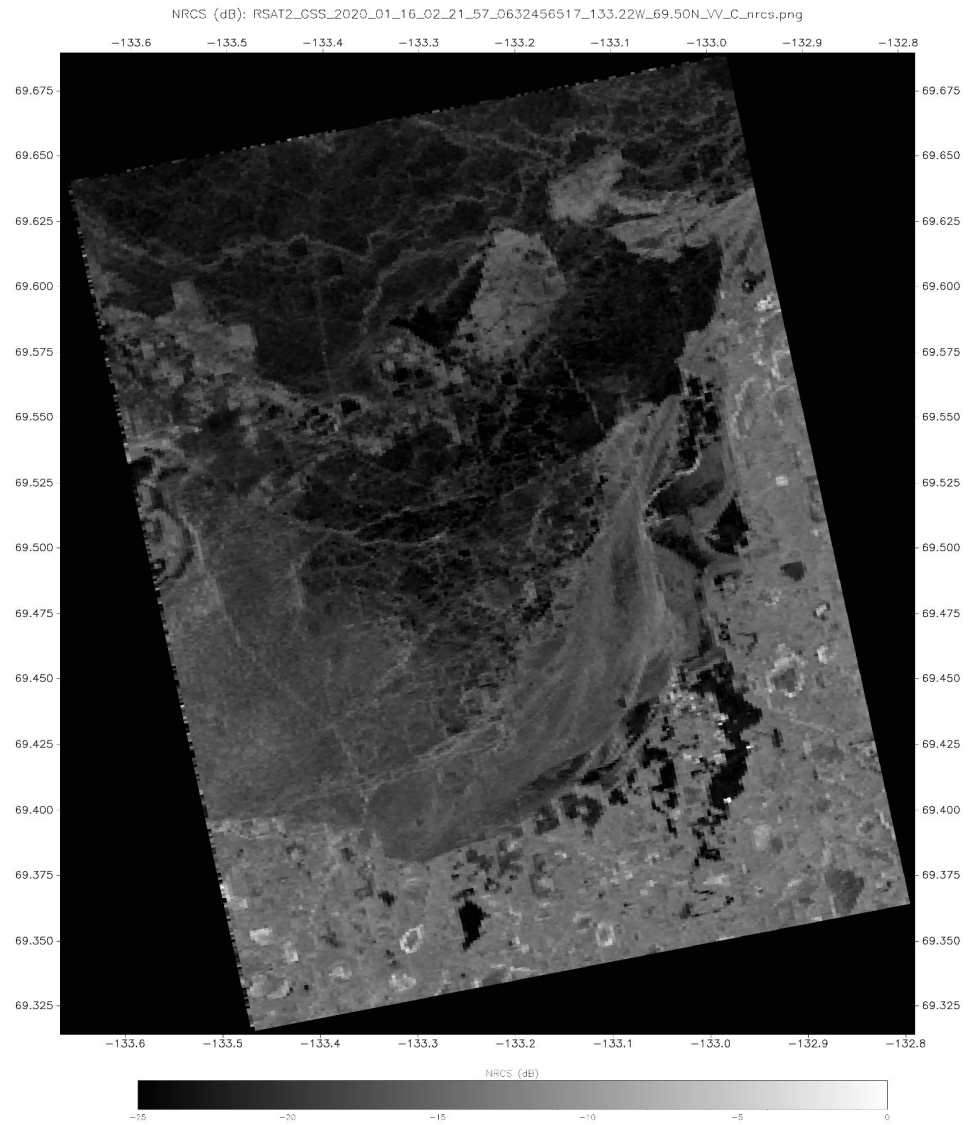
Radarsat-2
16 January 2020
02:22 UTC
Quad-Pol Collect

Sea Ice and
Coastal Canada

HH Polarization



VV Polarization

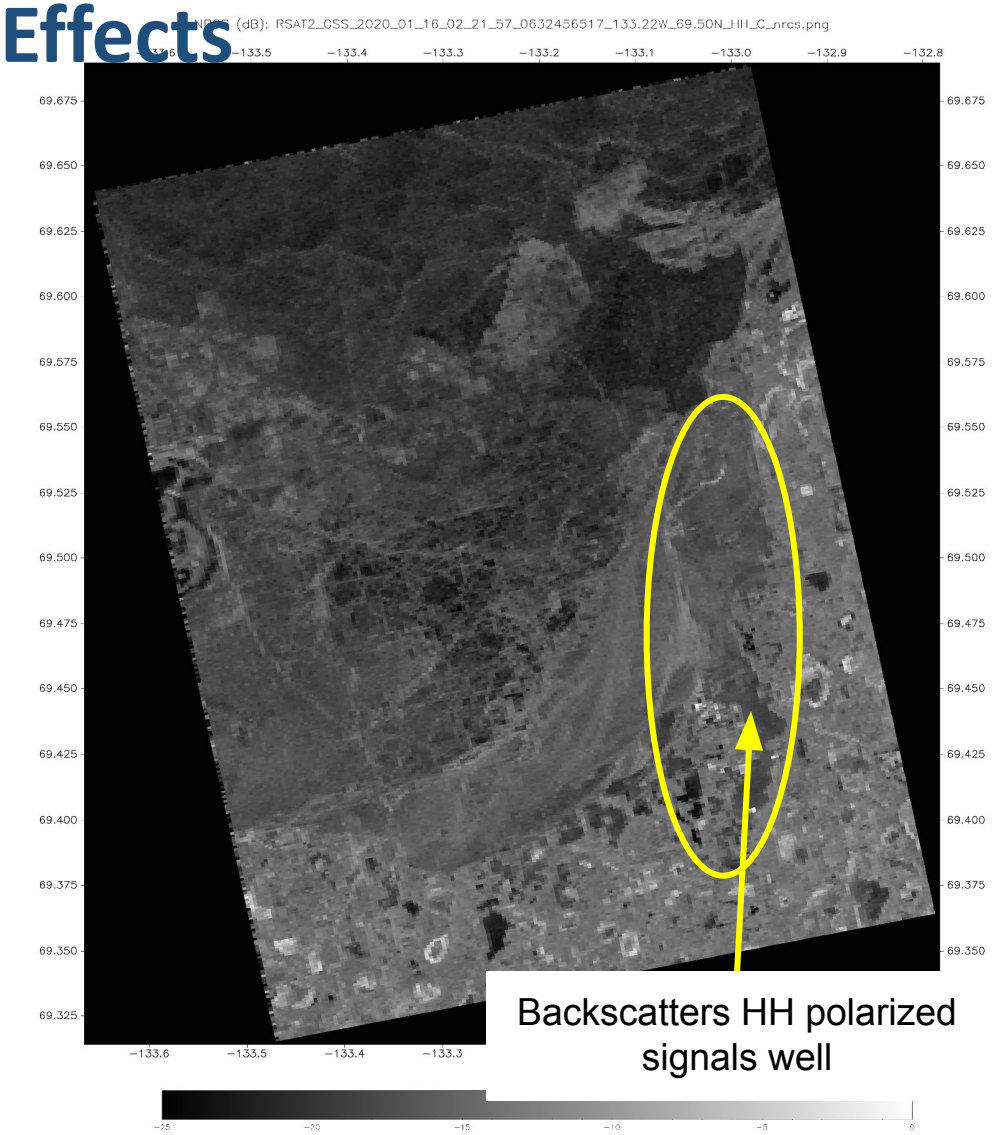


Polarization Effects

Radarsat-2
16 January 2020
02:22 UTC

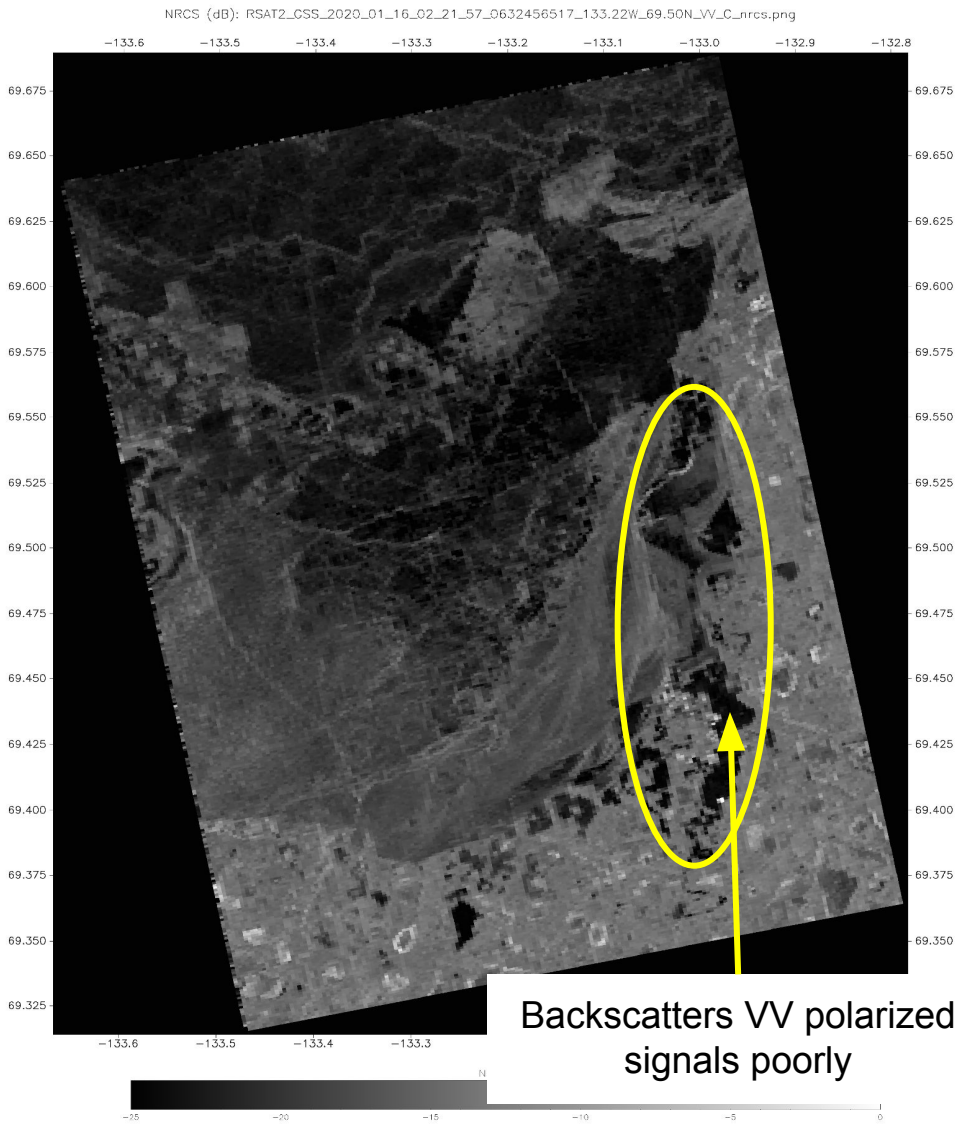
Sea Ice and
Coastal Canada

HH Polarization



Backscatters HH polarized signals well

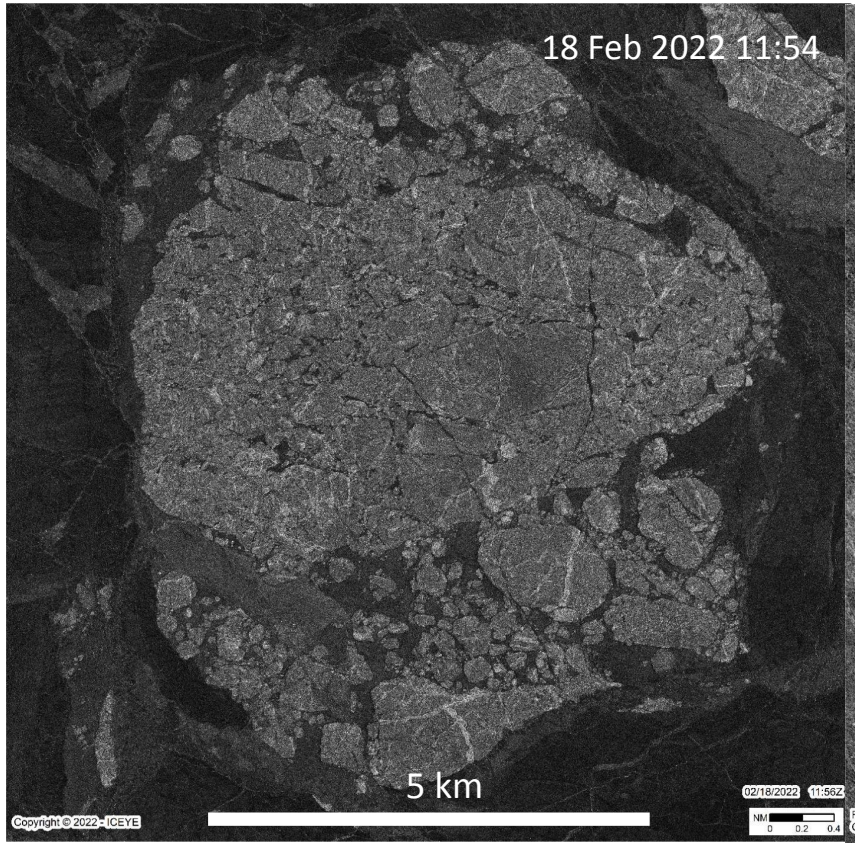
VV Polarization

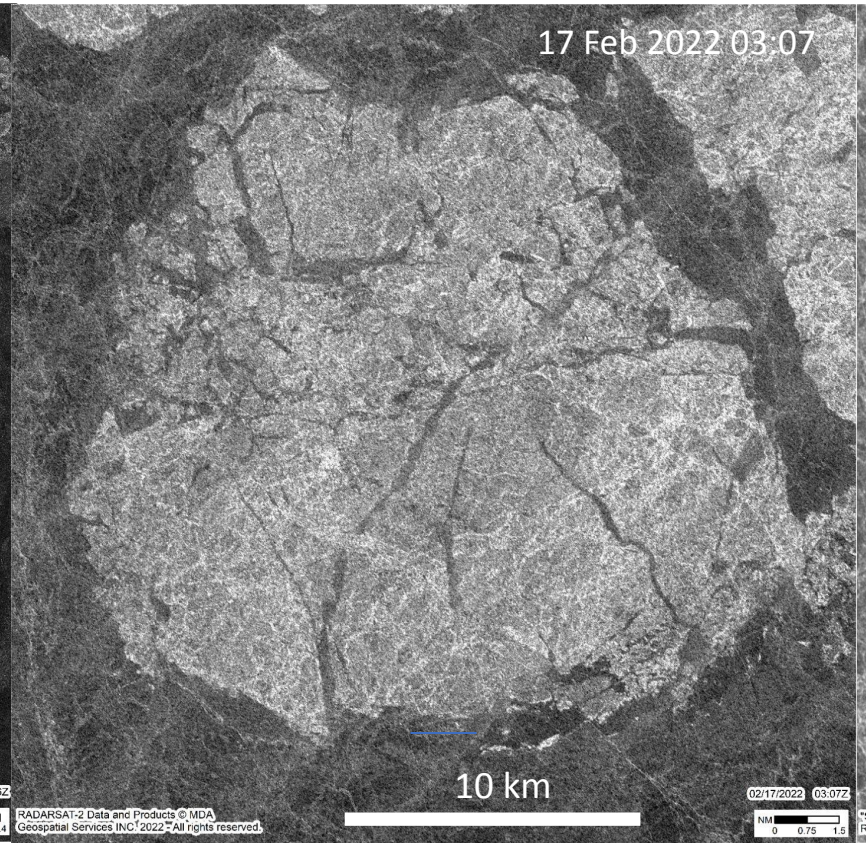


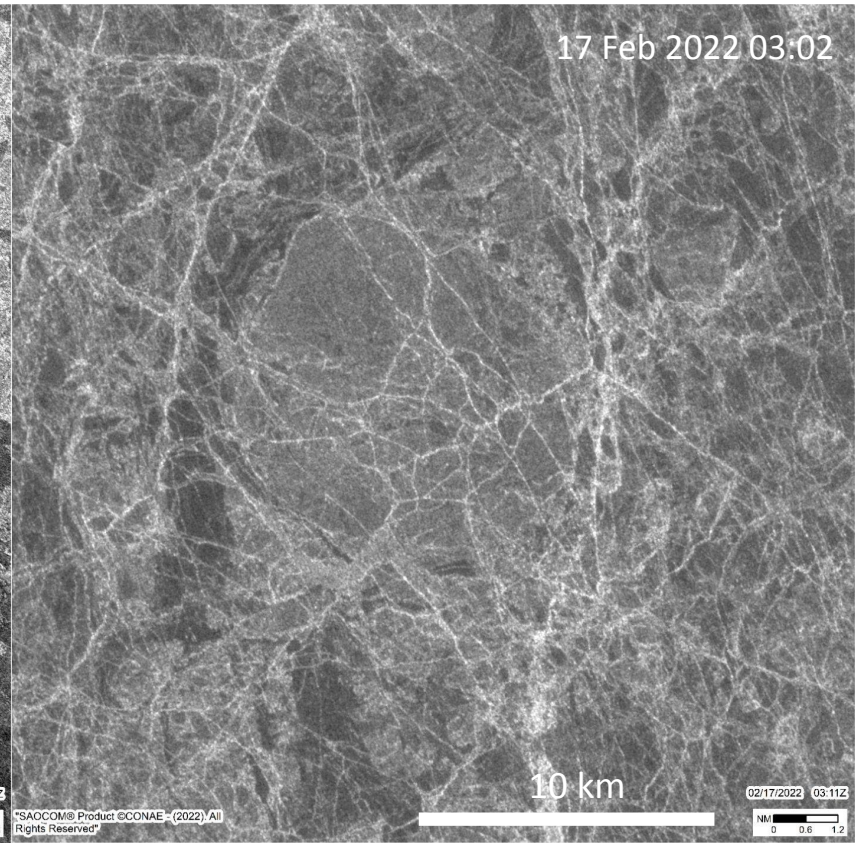
Backscatters VV polarized signals poorly

Frequency Effects*

X-Band – Iceye VV Pol – 3 m resolution	C-Band - Radarsat-2 HH Pol - 20 m resolution	L-Band SAOCOM ?? Pol – 50 m resolution







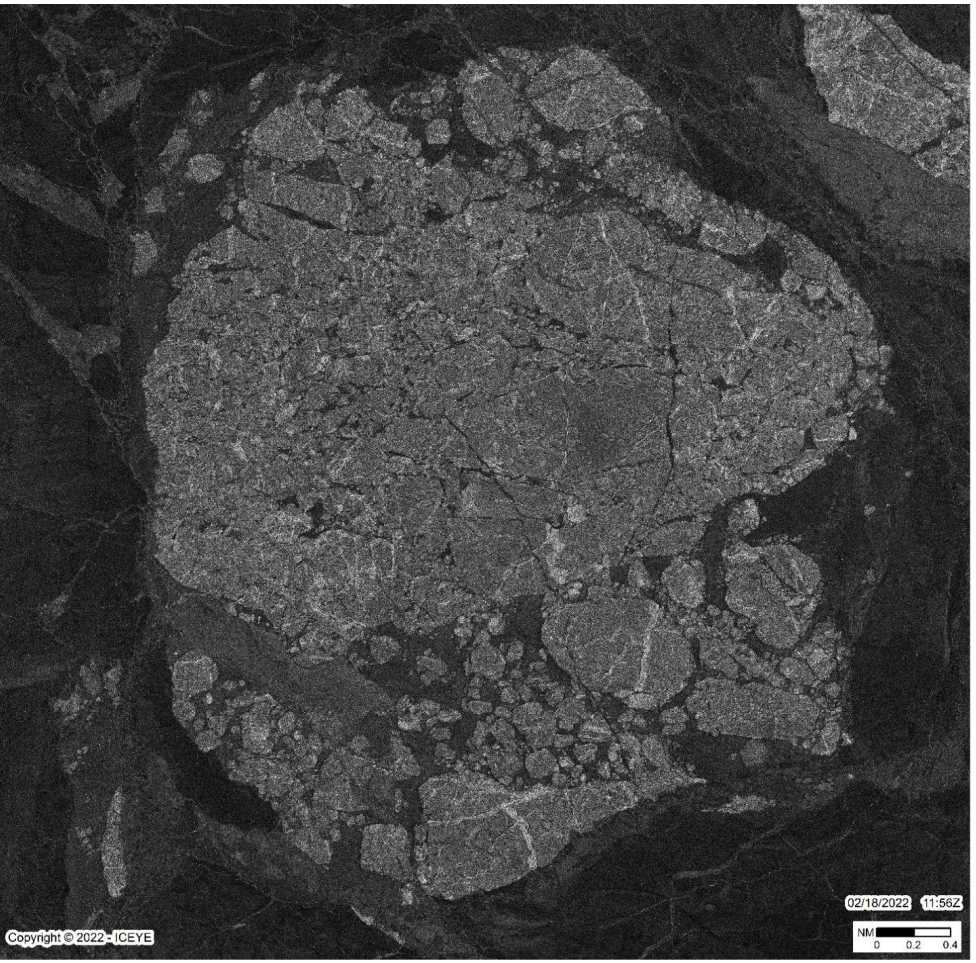
X-Band: Detects features precisely, including very small leads and the boundaries of tiny floes Comparable to C band on a regions scale; high resolution makes it superior on the local scale

C-Band: Distinguishes First year and Multi year ice, and reliable at detecting ridging and leads The primary operational SAR currently utilized; merit of other bands compared to it

L-Band: Superior ability to detect ridges, fractures, floe boundary. Does not confuse ridges for thicker ice, distinguishing stage of development.

*U.S. NIC Comparison of C, L, and X-Band SAR to Identify Arctic Ice Floe Features: ICEX Case Study 103rd AMS Annual 12 January 2023

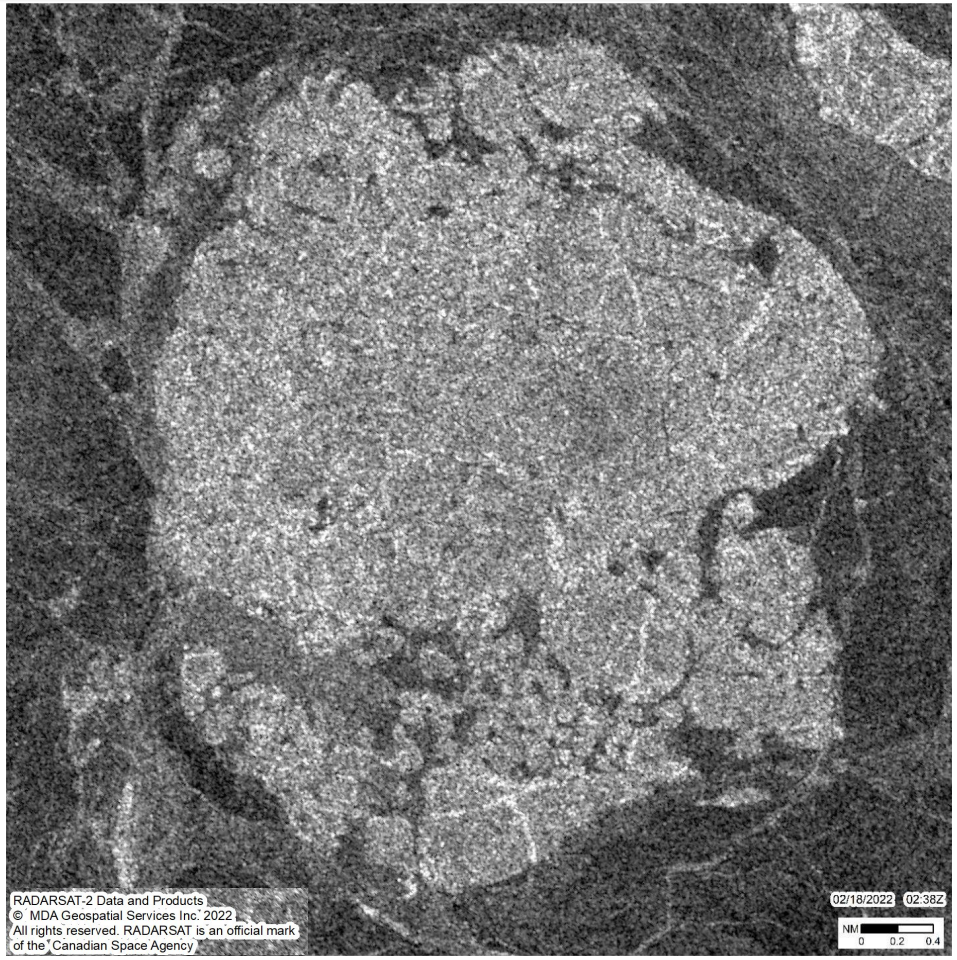
Comparing X-Band and C -Band: 18 February 2022



X band's higher spatial resolution and short wavelength allow it to detect smaller features more precisely than C band. This includes important features such as leads, ridges, and small brash floes.

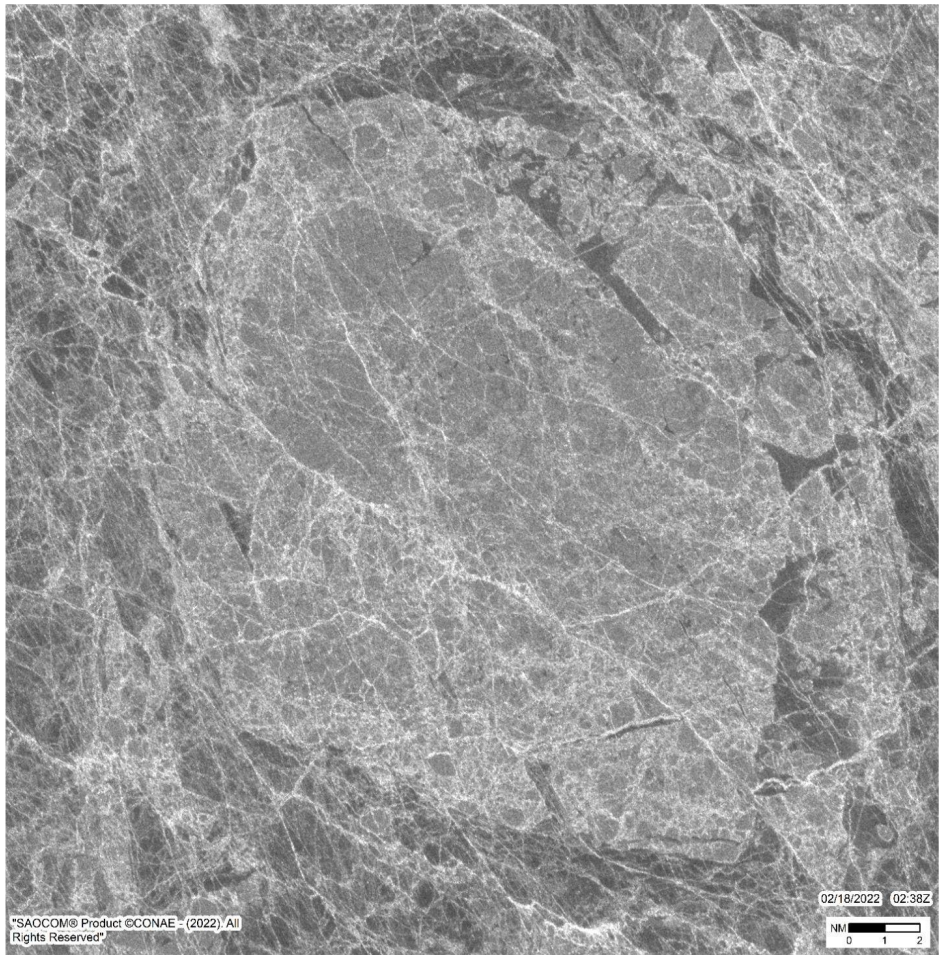
While C band makes the largest floe look relatively intact, X band allows for the interpretation that the floe is clearly actively continuing to fracture.

Both bands allow differentiation between multi-year and first-year ice.

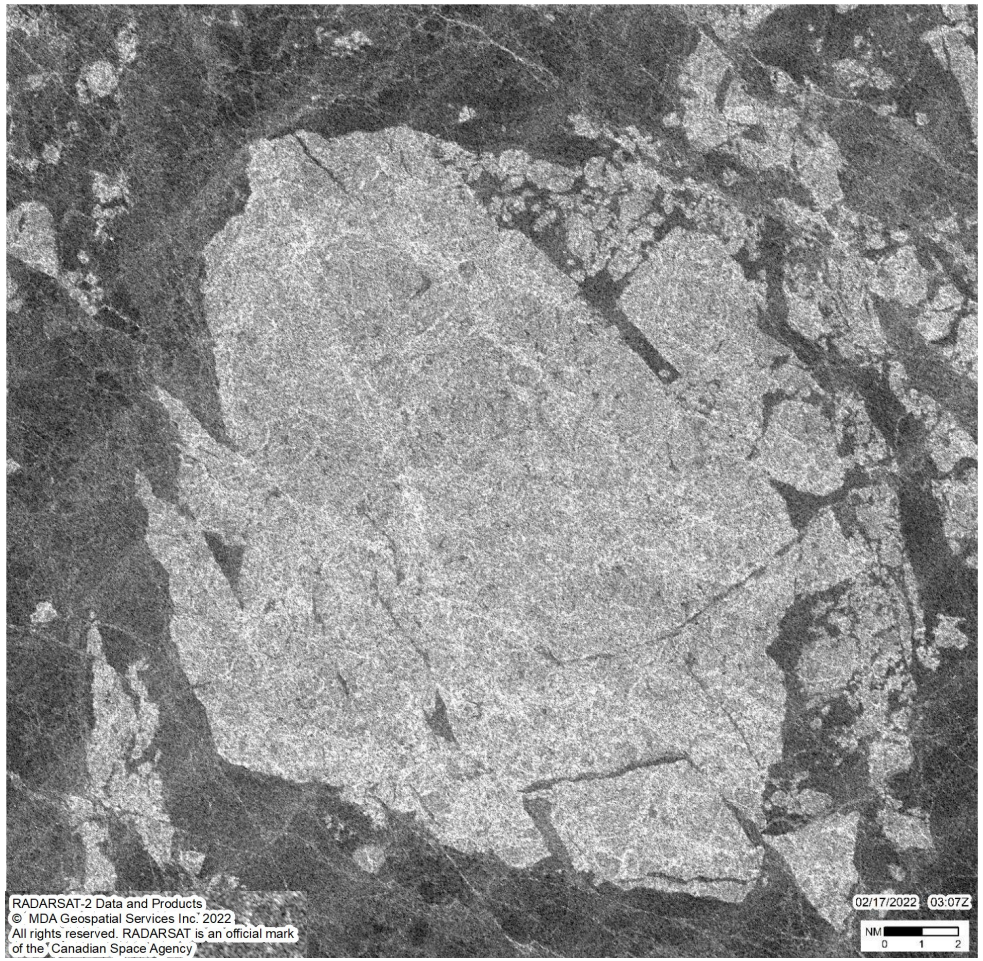


- The X-Band image shows distinct floes and the leads in a addition to rough and smooth surface features. It shows that the fractures and ridges are clearly the boundaries of distinguishable conglomerate ice floes within the larger floe. It can be a challenge to detect young ice and ridging within less developed ice types
- The C band image excels at detecting ridging in less developed ice and detecting young ice.

Comparing L-Band and C –Band: 17-18 February 2022

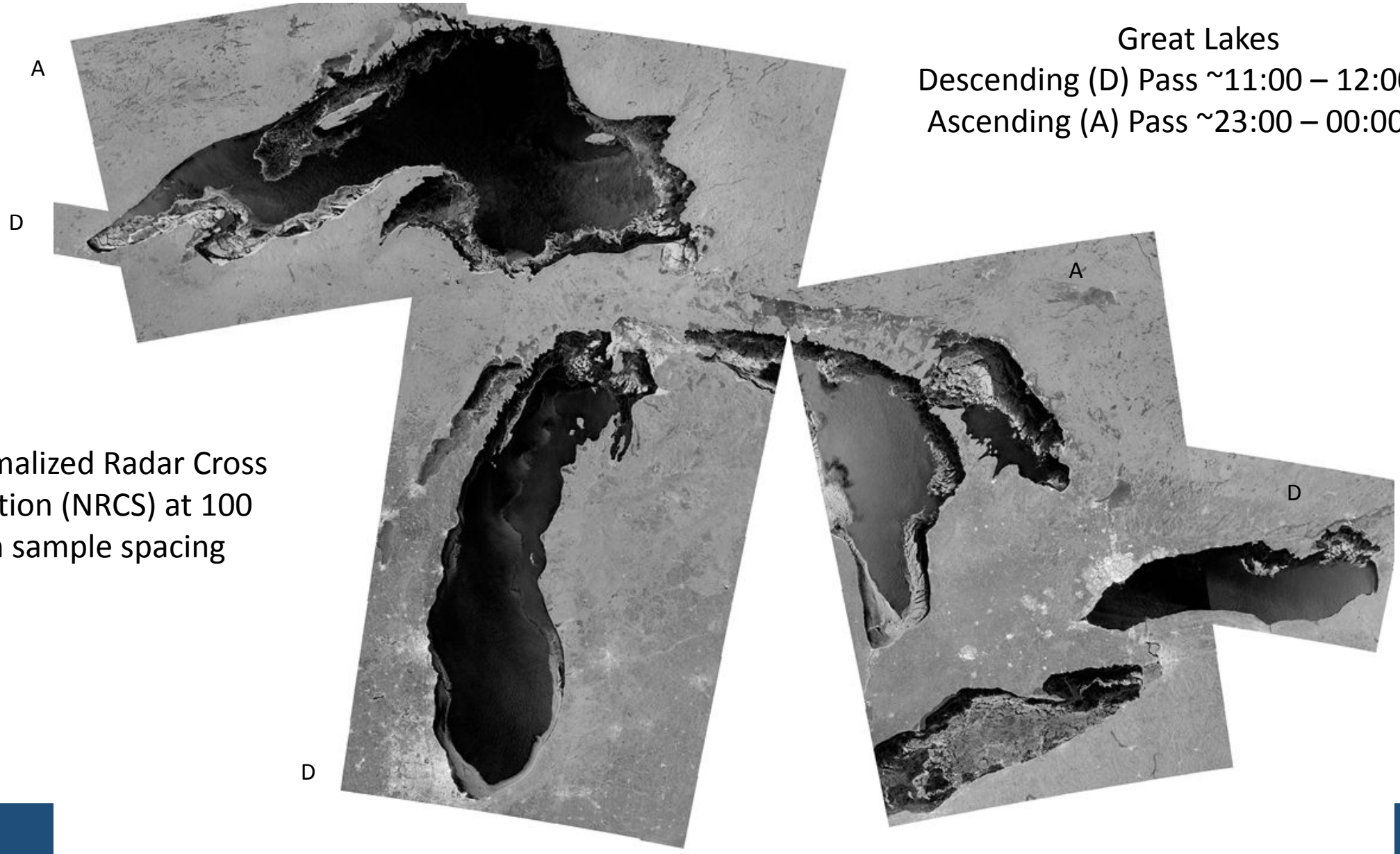


L-Band's longer wavelength and deeper penetration allows for the identification of internal features beyond the capabilities of C-Band. This includes internal floe boundaries, weaknesses, fractures, and roughness



- L-Band imagery demonstrates improved ability over C-Band to detect conglomerate floes within a larger floe. Additionally, it easily detects surface characteristics of the individual constituent floes, such as ridges, rubbles vs smooth surface.

Lake Ice - 14 February 2022 (Radarsat Constellation Mission Composite)

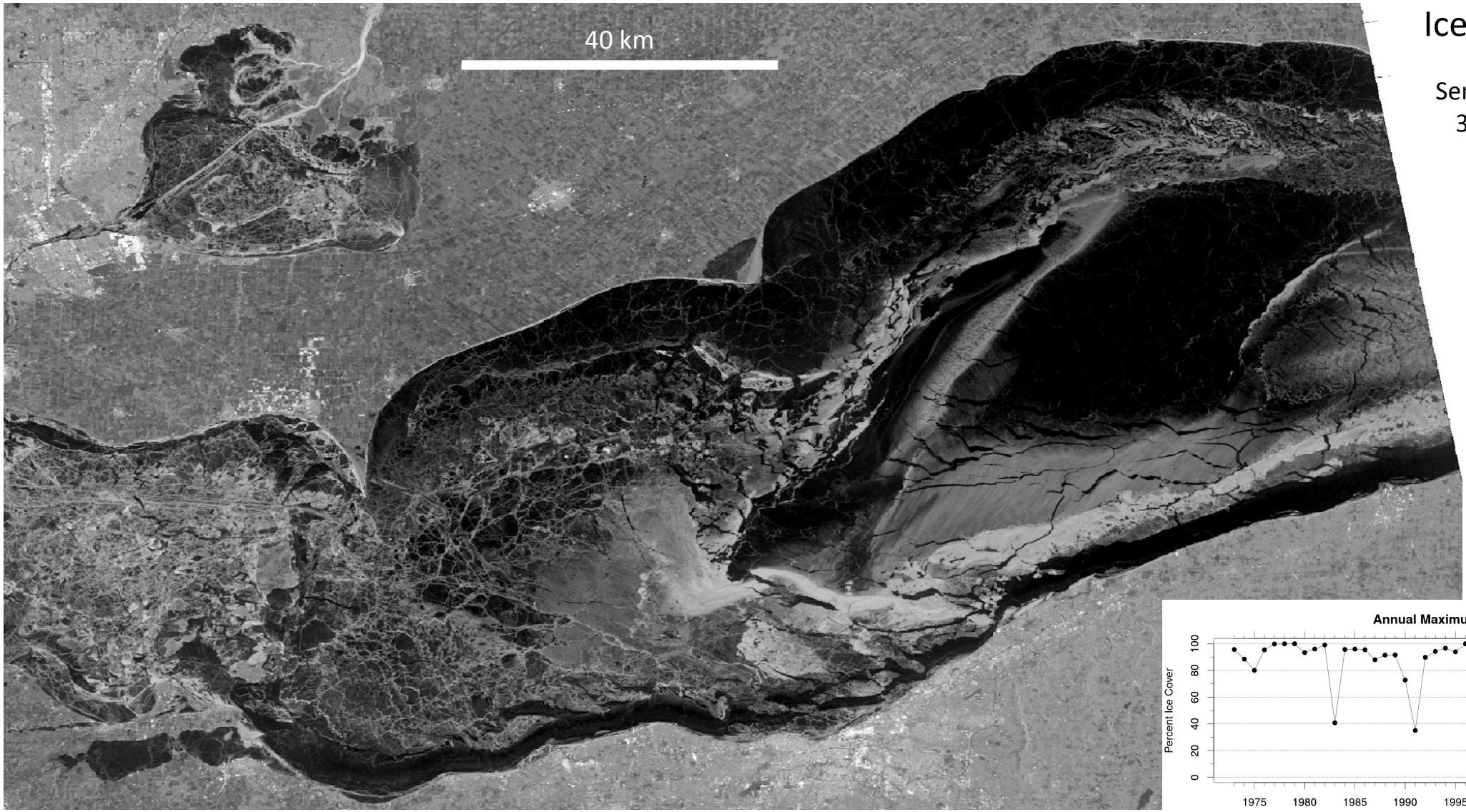


Great Lakes
Descending (D) Pass ~11:00 – 12:00 UTC
Ascending (A) Pass ~23:00 – 00:00 UTC

Normalized Radar Cross Section (NRCS) at 100 m sample spacing

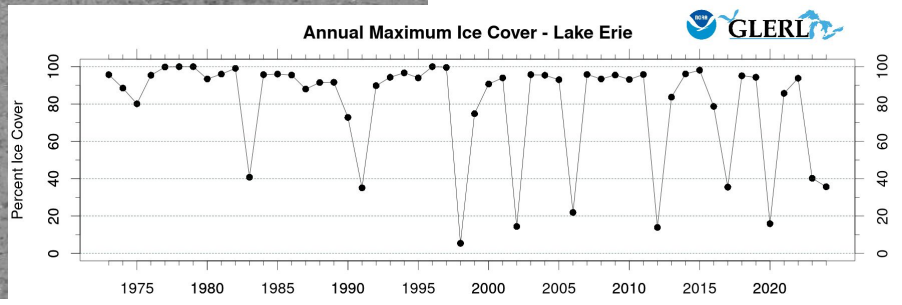
Lake Ice

See a True Color MODIS image from 31 Jan 2022
https://worldview.earthdata.nasa.gov/?v=-84.02631447225245,40.866,
-79.04768552774756,43.24900000000001&l=MODIS_Aqua_CorrectedReflectance_TrueColor&lg=true&t=2022-01-31-T22%3A37%3A51Z



Ice covering Lake Erie

Sentinel-1 SAR VV Co-Pol NRCS
30 January 2022 23:23 UTC

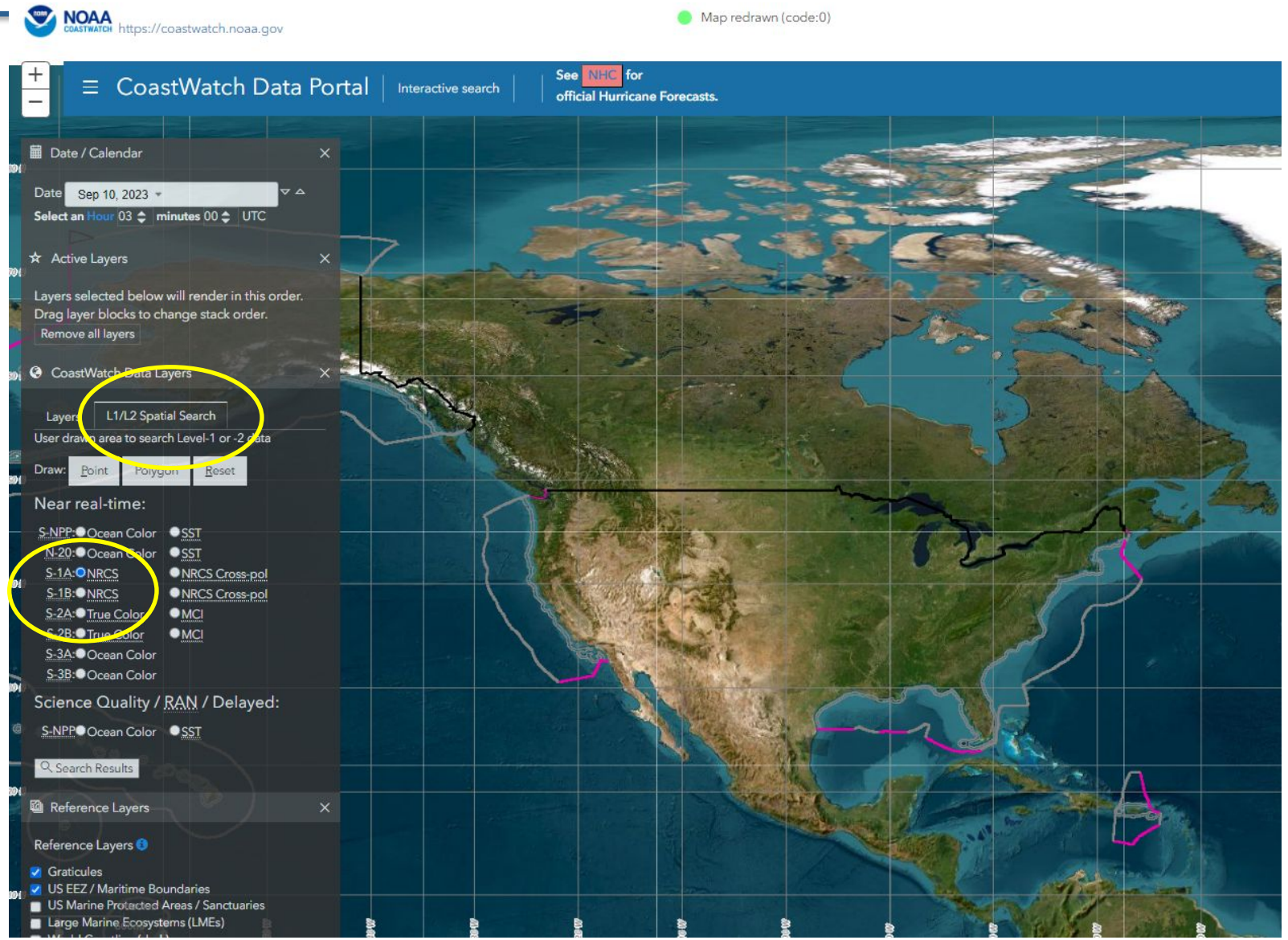


https://www.star.nesdis.noaa.gov/socd/mecb/sar/AKDEMO_products/APL_winds/wind_images2/2022-01/S1A_ESA_2022_01_30_23_24_38_0696900278_082.18W_41.77N_VV_C_nrcs.png

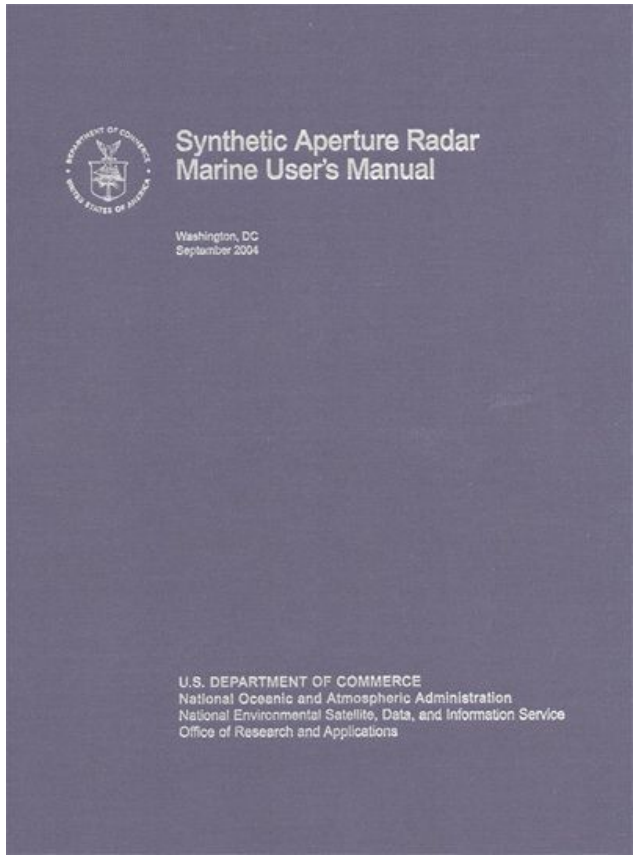
CoastWatch Data Portal

- Contains Sentinel-1 100m NRCS PNG/NetCDF files since October 2018. The data are principally over the US EEZ (including Alaska and Hawaii) but also extend over the Caribbean and North Atlantic
- Most of the imagery presented should be available.
- Search L1/L2->S1A NRCS or S1B NRCS

https://coastwatch.noaa.gov/cw_html/cwViewer.html



References and other online sites for imagery and information



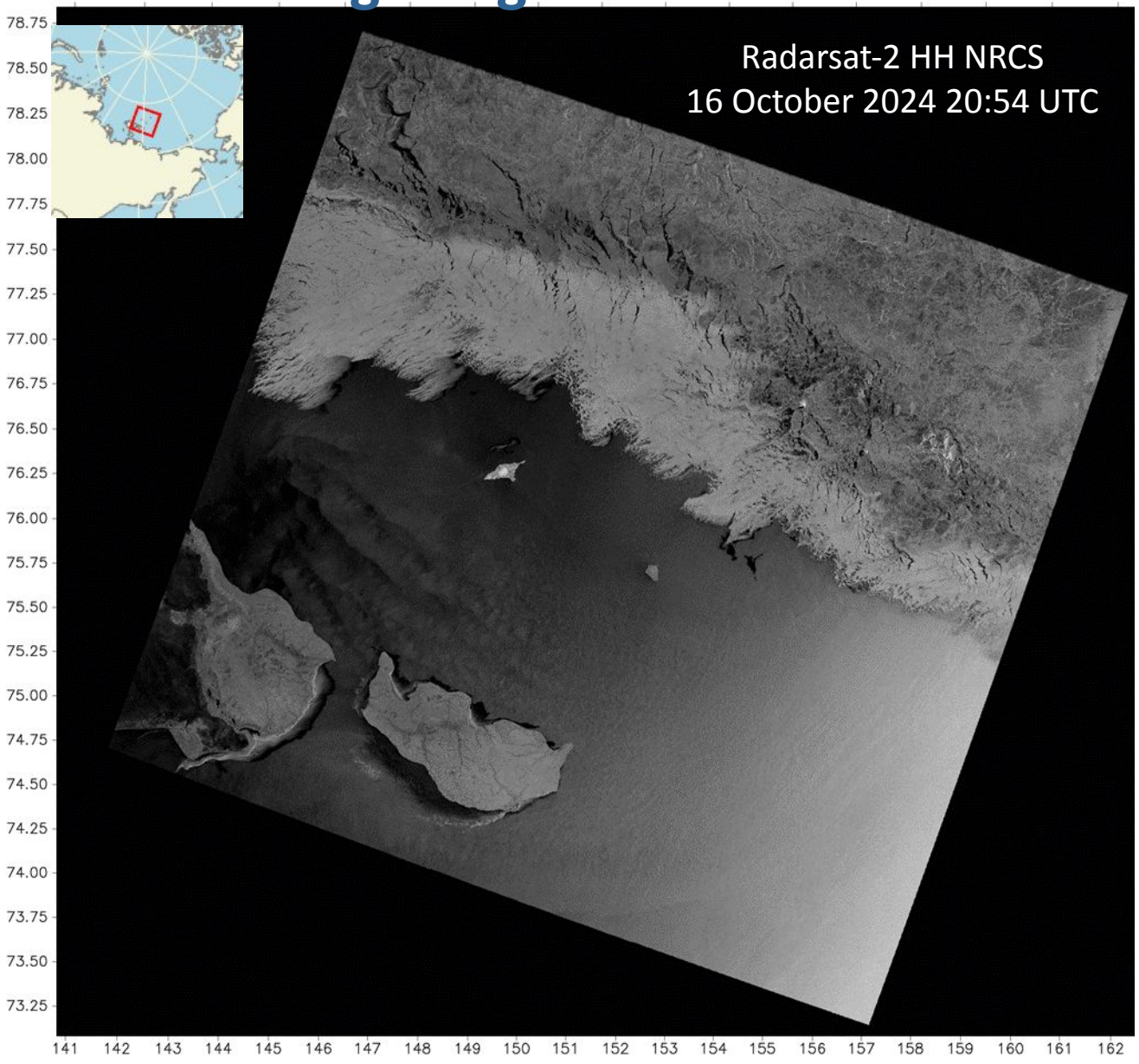
SAR Marine Users Manual (https://www.sarusersmanual.com)
Part I. Background
Part II. Oceanic Measurements
Part III. Atmospheric Boundary Layer Measurements
Part IV. Sea Ice Observations

NOAA STAR SAR Ocean Surface Winds
Sentinel-1:
https://www.star.nesdis.noaa.gov/socd/mecb/sar/sarwinds_s1.php
Radarsat-2 and Radarsat Constellation Mission (RCM):
https://www.star.nesdis.noaa.gov/socd/mecb/sar/sarwinds_rcm_rs2.php

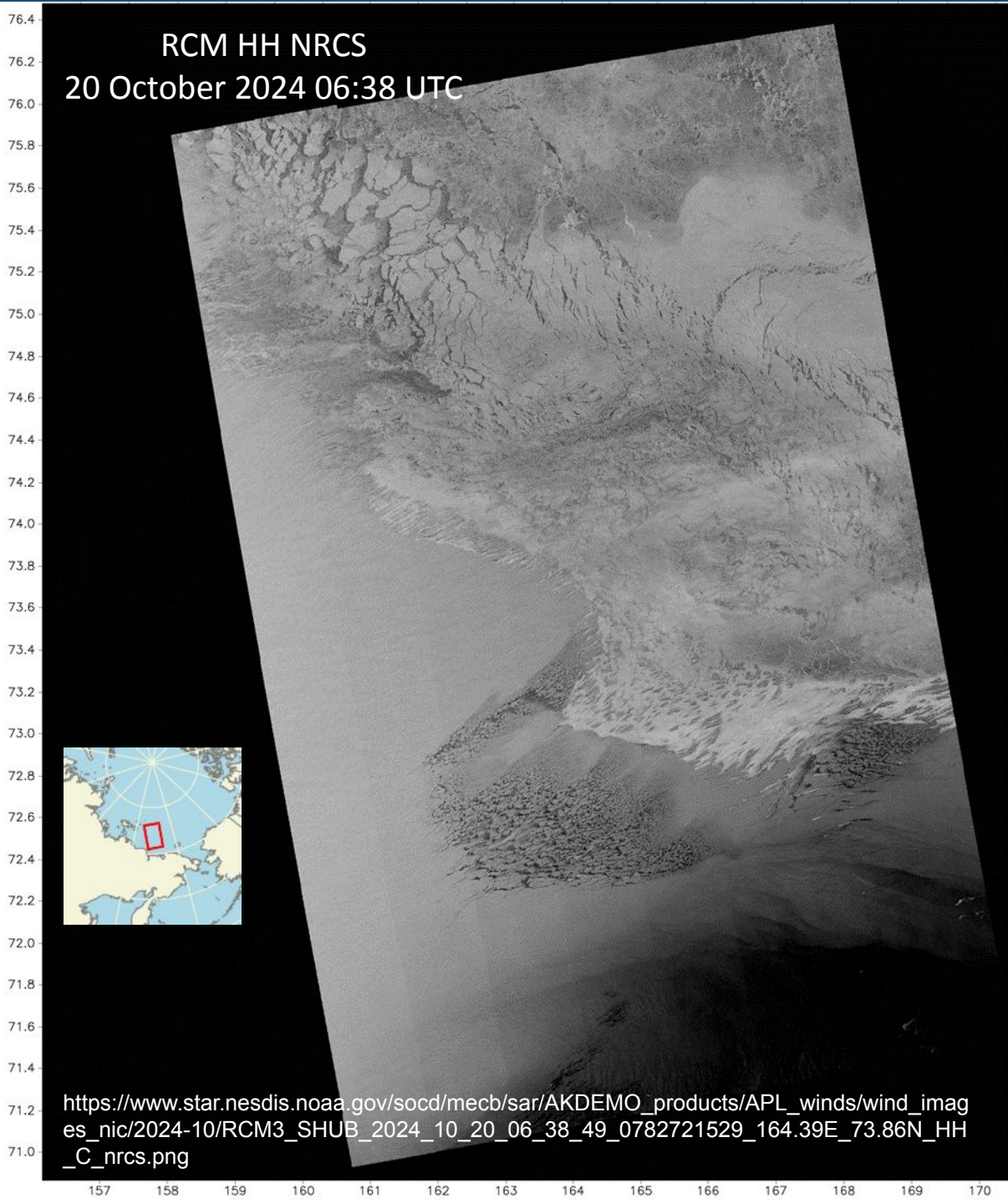
ASF Vertex: https://search.asf.alaska.edu/
EODMS:https://www.eodms-sgdot.nrcan-rncan.gc.ca/:

“Intro to SAR” CoastWatch SAR Presentation
https://umd.instructure.com/courses/1336575/modules#module_1699652

Interesting Images – Oct 2024



https://www.star.nesdis.noaa.gov/socd/mecb/sar/AKDEMO_products/APL_winds/wind_images_nic/2024-10/RSAT2_GSS_2024_10_16_20_54_29_0782427269_151.87E_76.41N_HH_C_nrcs.png



https://www.star.nesdis.noaa.gov/socd/mecb/sar/AKDEMO_products/APL_winds/wind_images_nic/2024-10/RCM3_SHUB_2024_10_20_06_38_49_0782721529_164.39E_73.86N_HH_C_nrcs.png