CIRFA
CENTRE FOR
INTEGRATED REMOTE SensING
AND FORECASTING FOR ARCTIC OPERATIONS

UNIVERSITY OF TROMSØ

sfi = Senter for forskningsdrevet innovasjon

Polarimetric Signatures for the Analysis of Fast Sea Ice in the Belgica Bank Area

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Objectives

Collecting data for testing and validating *information and forecast products* derived from satellite data by the SFI CIRFA:

- Observations of sea ice and icebergs from the **ship** and from **drones**
- **In-situ** sea ice measurements of snow and ice properties
- Snow-depth measurements with a **drone-borne UWF radar**
- Deployment of **drifters** on sea ice and icebergs to measure dynamics
- Deployment of sea ice **mass balance buoys**
- Tomographic radar measurements to study **radar scattering** from sea ice

Satellite acquisitions:

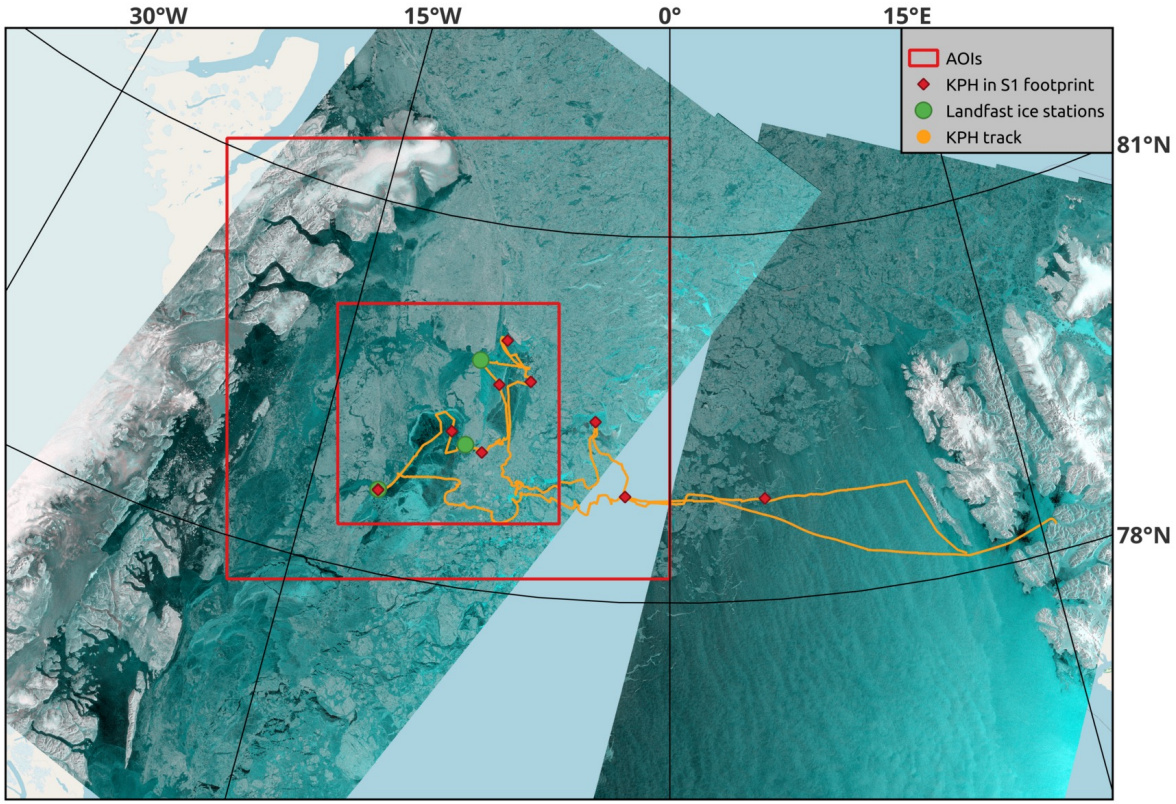
Co-located multi-polarization, multi-frequency SAR and optical satellite images, altimeter profiles: S-1, S-2, S-3, RS-2, ALOS-2, COSMO, TSX, ICEE-YE

CIRFA-22 cruise

RV Kronprins Haakon (KPH)

April 22nd - May 9th

Background: Sentinel-1 from May 3rd 2022



"...to perform measurements and make observations which allow for validation of information and forecast products resulting from CIRFA´s work."

ALOS-images from Belgica Bank

May 3 (78.882N -12.351W)

May 4 (79.075N -13.573W)

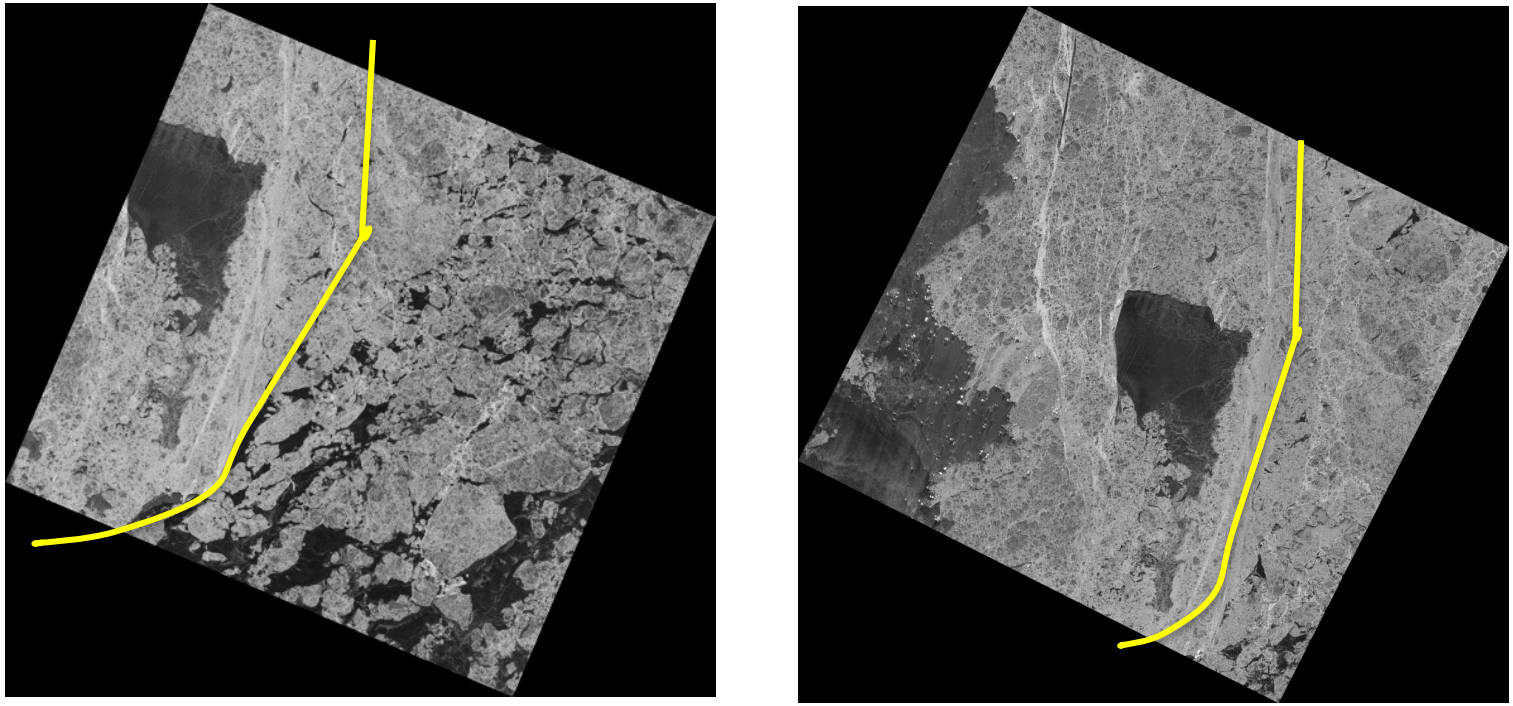
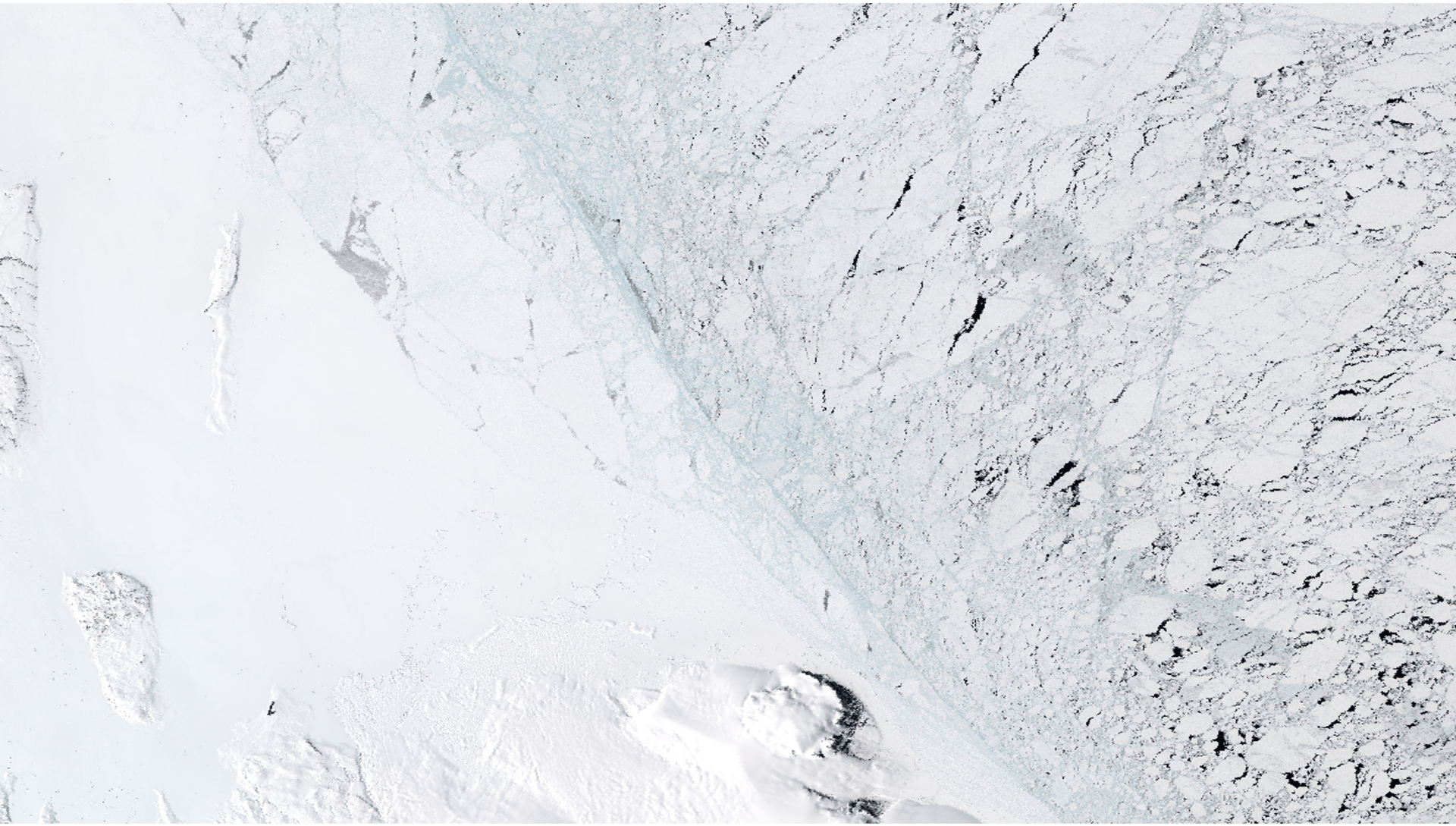


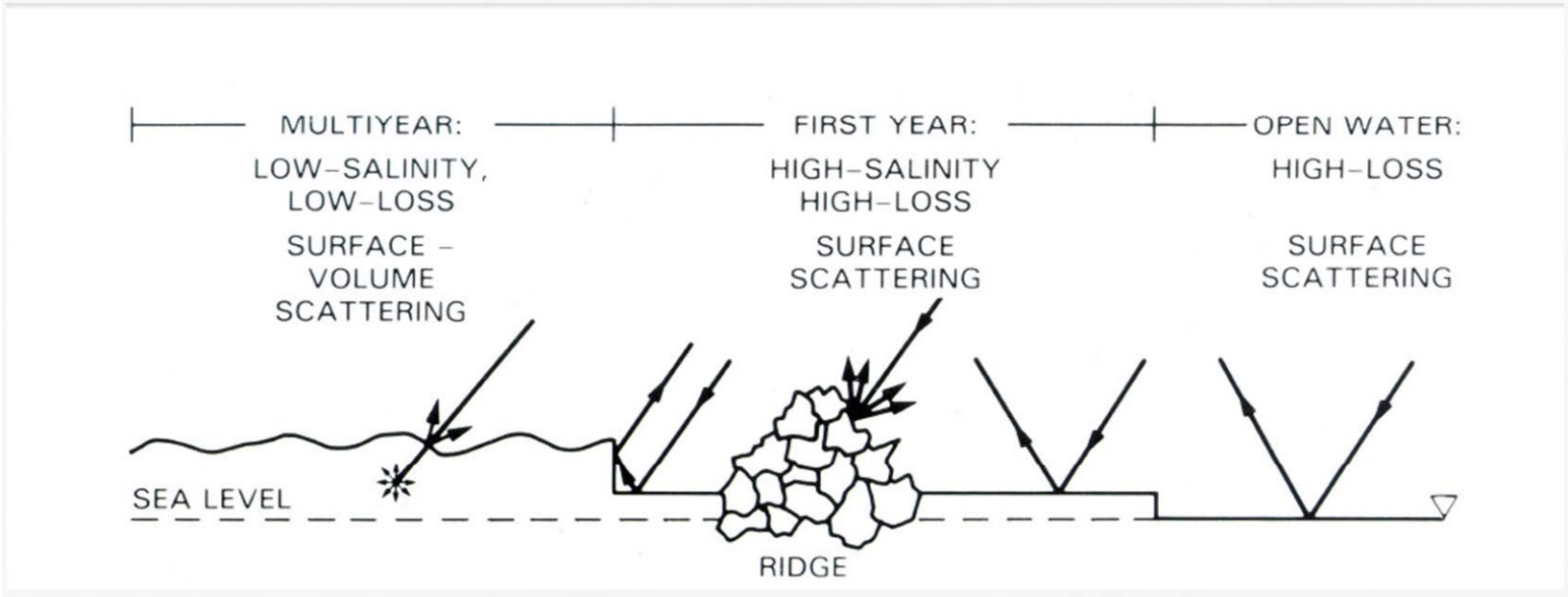
Fig. PALSAR-2 FB HH-polarization. The fast ice has not changed on May 3 / May 4, the drift ice zone reveals variable floe sizes and variable local ice concentrations. Courtesy JAXA

SAR (S1) - Optical (S2)

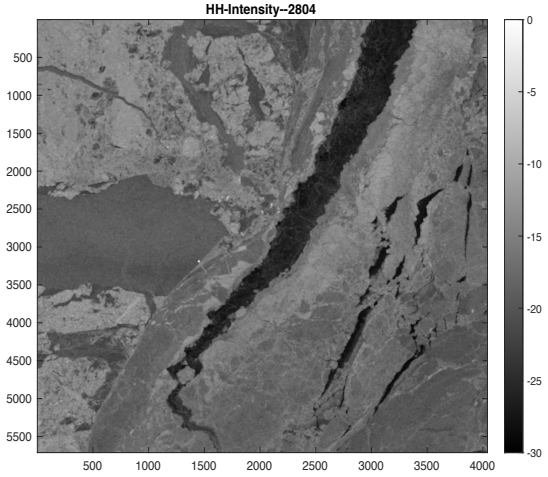


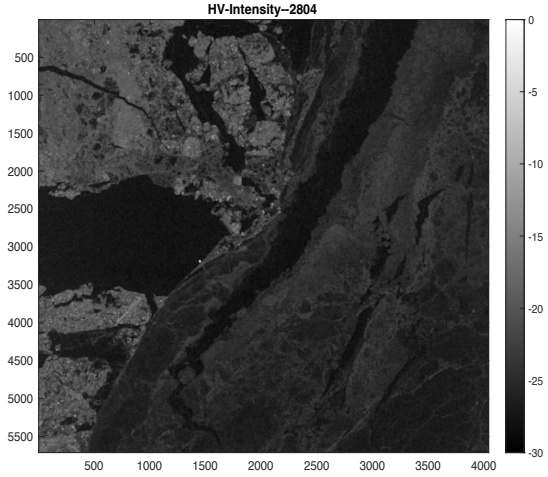
Courtesy: Thomas Kræmer, UiT

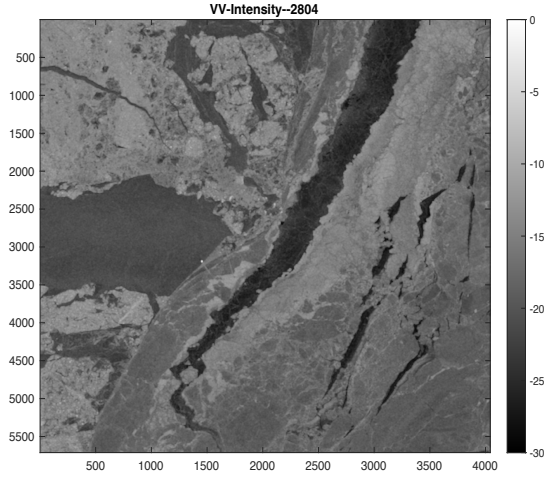
Some Sea Ice Preliminaries

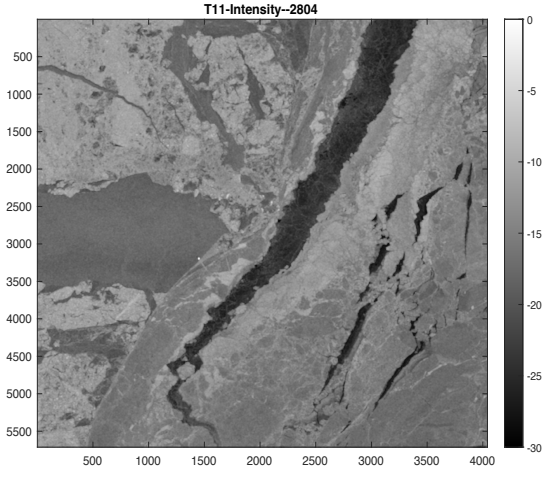


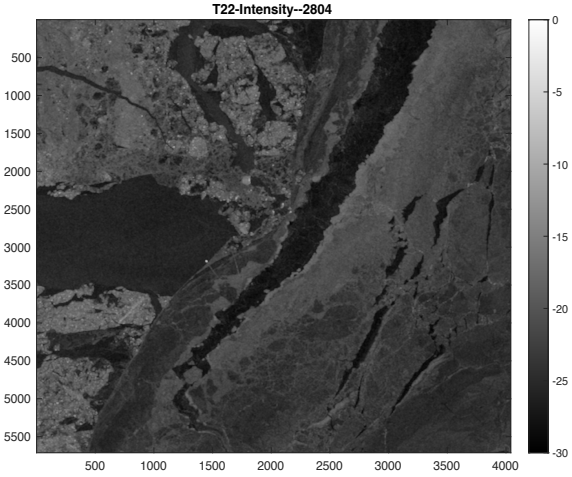
RS-2 intensity images April-28.04

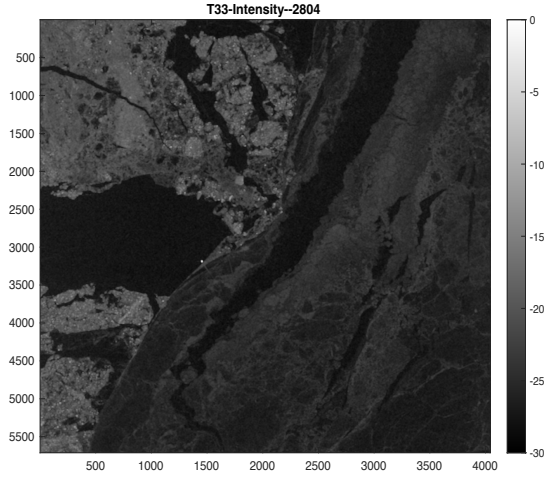




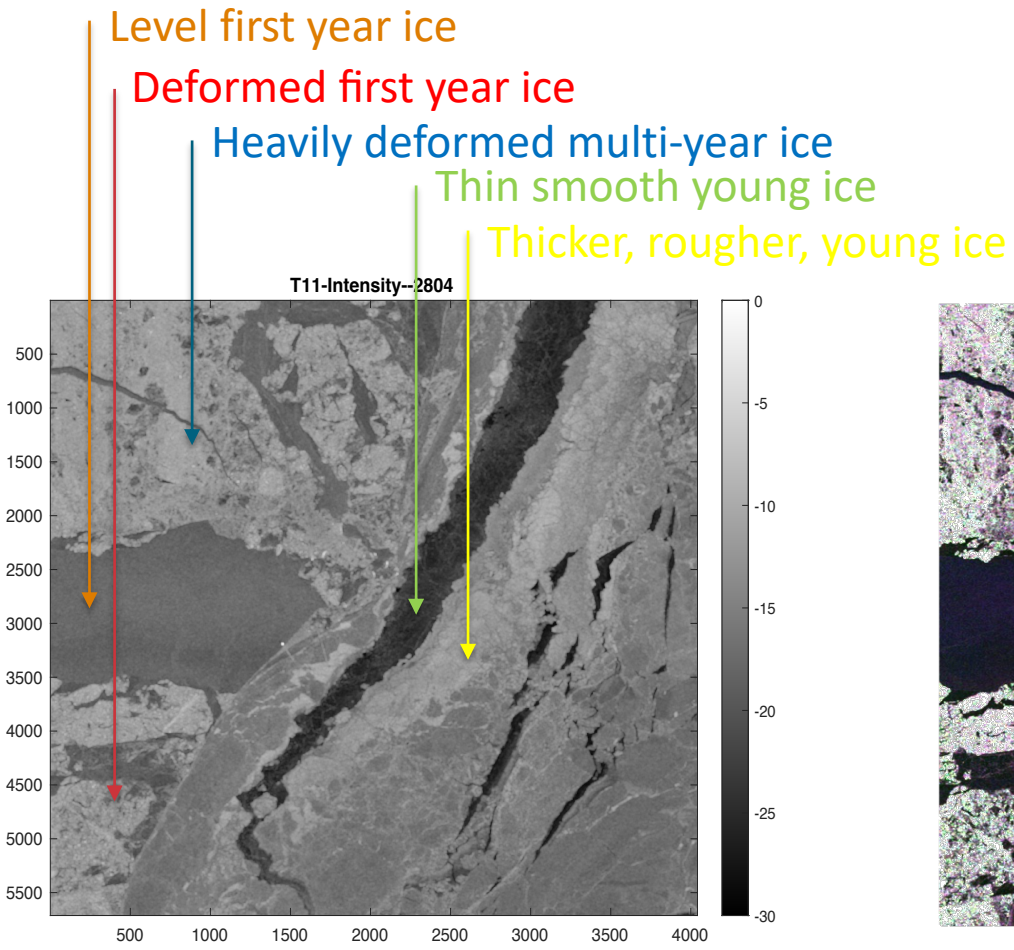




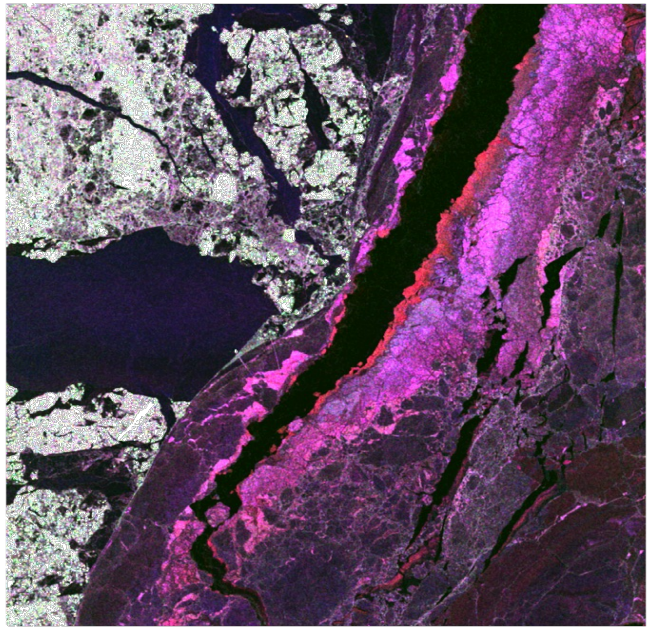




What do we see?

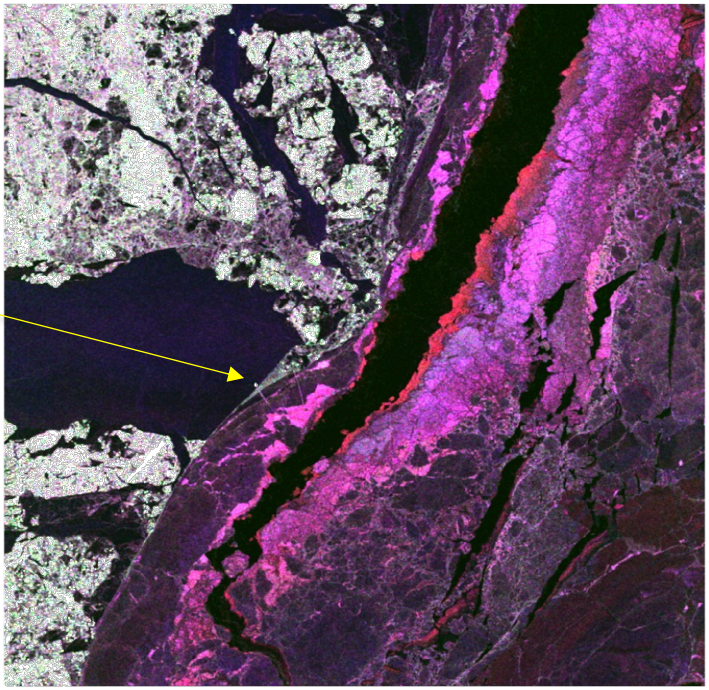


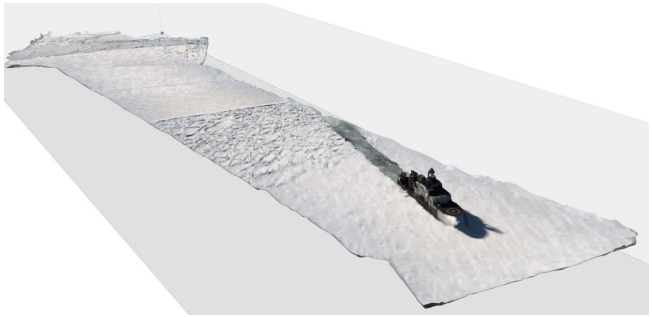
Corresponding Pauli image



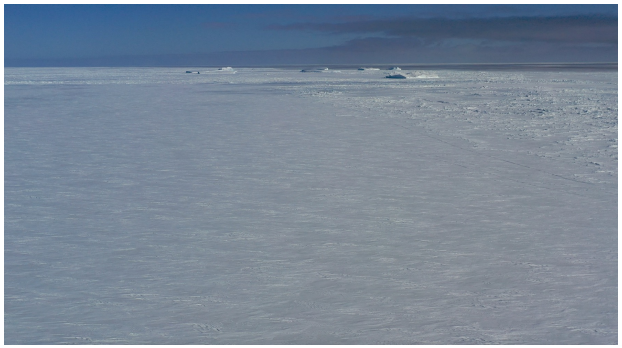
Visual

ship





Mosaic made by Maritime Robotics



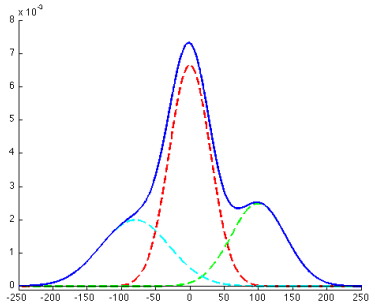
QUAD - polarimetric SAR-image segmentation

$$\begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \frac{\exp(jkr)}{r} \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} E_h^i \\ E_v^i, \end{bmatrix}$$

$$p(\mathbf{x};\mathbf{q}) = \sum_{i=1}^{K} \mu_i p_i(\mathbf{x};\mathbf{q}_i)$$

$$\mathbf{s} = [S_{HH}, \sqrt{2}S_{HV}, S_{VV}]$$

$$\mathbf{C} = < \mathbf{s}\,\mathbf{s}^* > \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix}$$



Feartures:

Relative kurtosis is a measure of non-Gaussianity: $RK = \frac{1}{Ld(d+1)} \sum_{i=1}^{L} \left[\mathbf{s}_i^{\dagger} \mathbf{C}^{-1} \mathbf{s}_i\right]^2$

Geometric brightness represents the total intensity $B = \sqrt[d]{det(\mathbf{C})}$

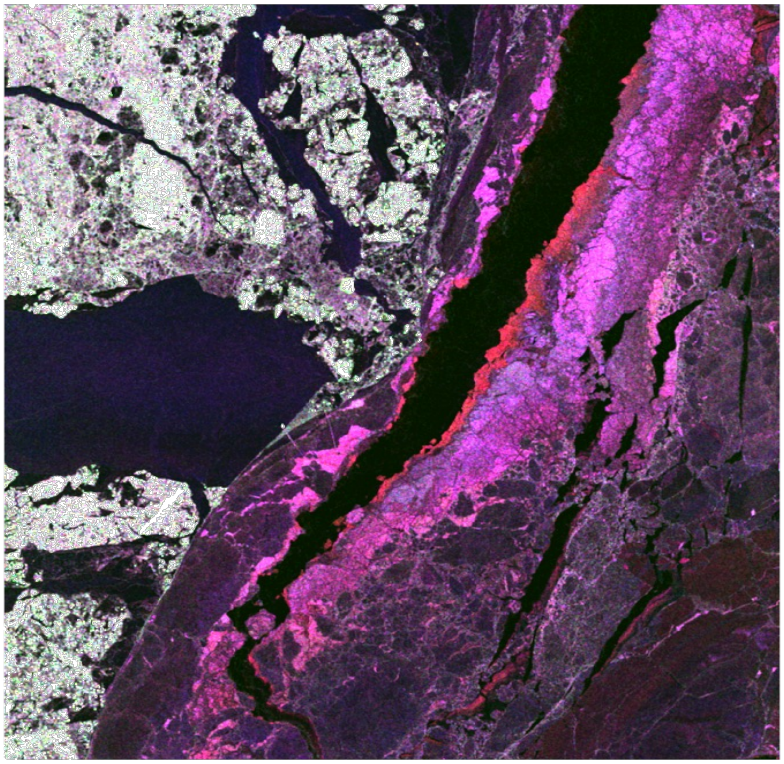
Co-polarization ratio: $R_{HH/VV} = \frac{\langle S_{HH} S_{HH}^* \rangle}{\langle S_{VV} S_{VV}^* \rangle}$

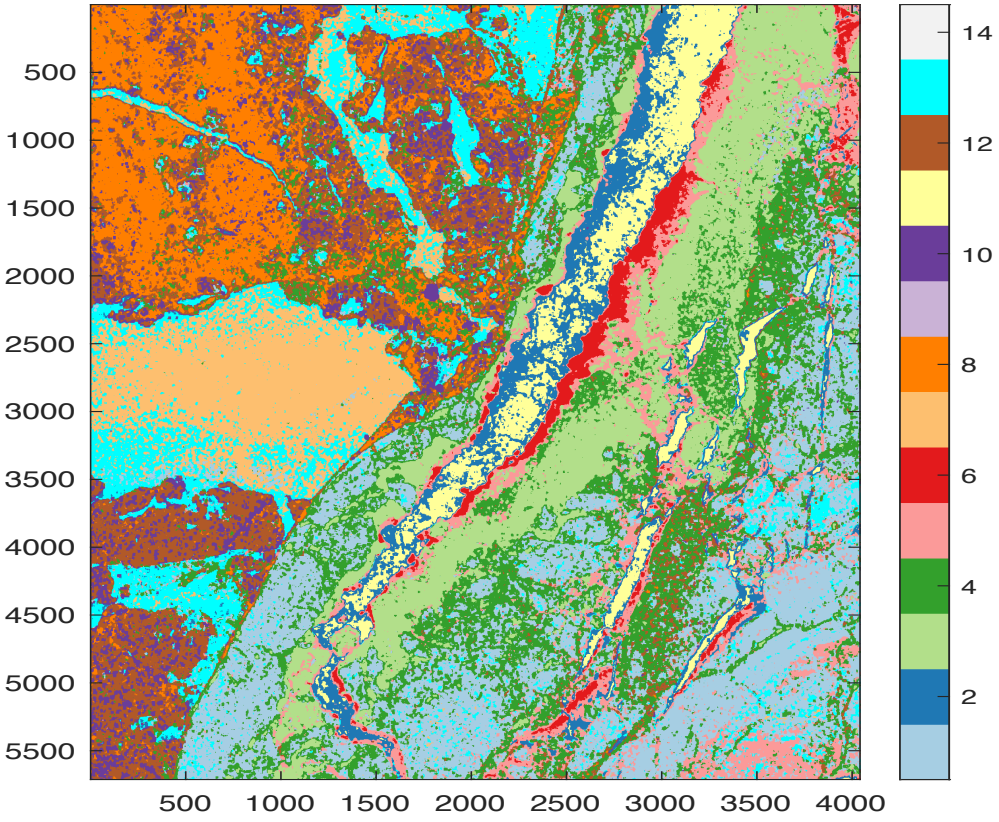
Cross-polarization ratio: $R_{HV/B} = \frac{\langle S_{HV} S_{HV}^* \rangle}{B}$

Real part of Co-polarization coherence: $Re\,|\rho| = Re \left| \frac{\langle S_{HH} S_{VV}^* \rangle}{\sqrt{\langle S_{HH} S_{HH}^* \rangle \langle S_{VV} S_{VV}^* \rangle}} \right|$

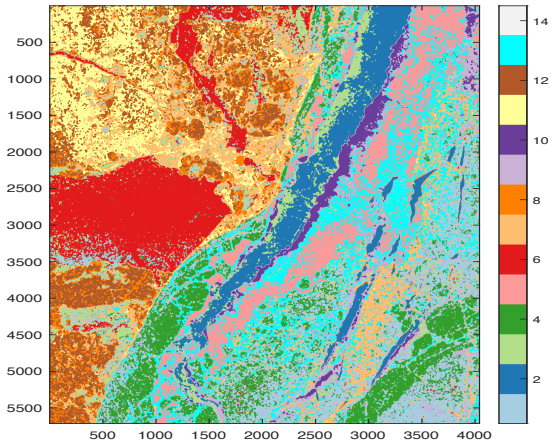
Imaginary part of Co-polarization coherence: $Im\,|\rho| = Im \left| \frac{\langle S_{HH} S_{VV}^* \rangle}{\sqrt{\langle S_{HH} S_{HH}^* \rangle \langle S_{VV} S_{VV}^* \rangle}} \right|$

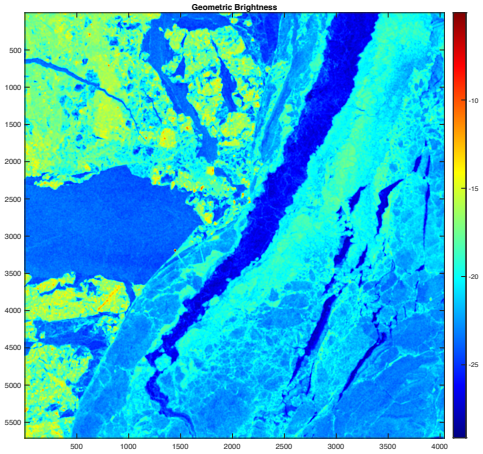
Segmentation of RS2-image: 28.04.2022

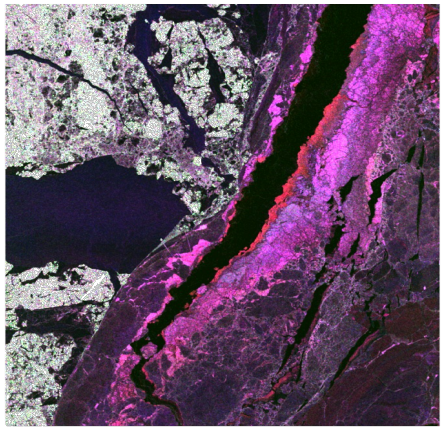


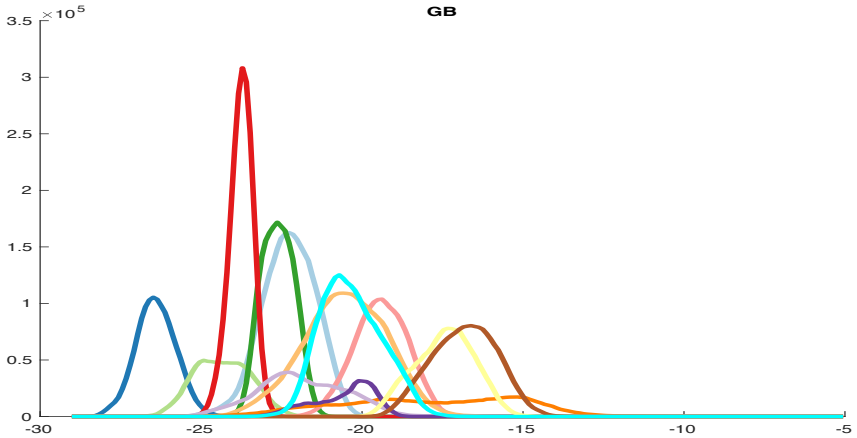


Geometric Brightness

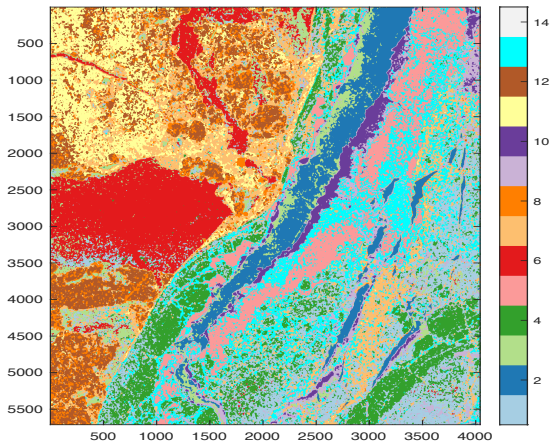








CoPol Ratio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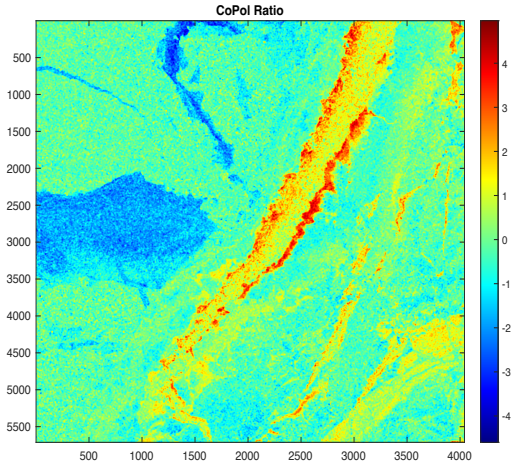
CoPol Ratio
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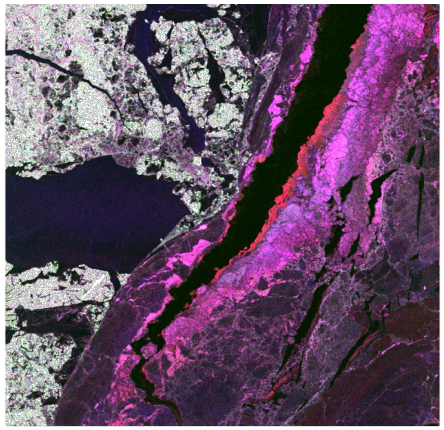
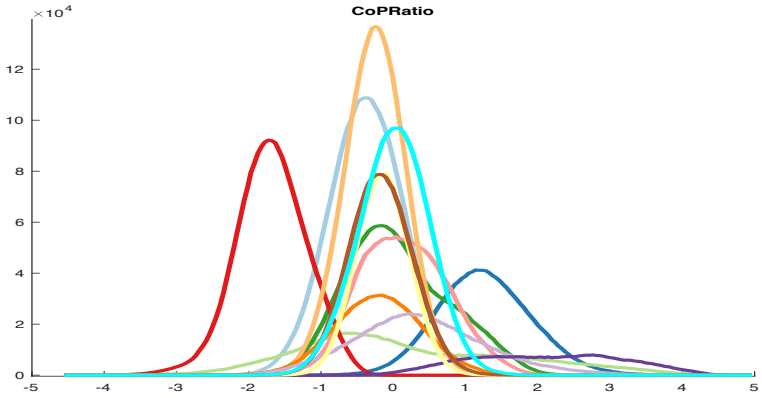
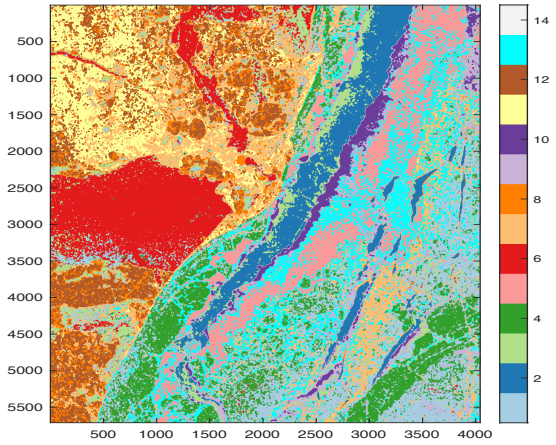
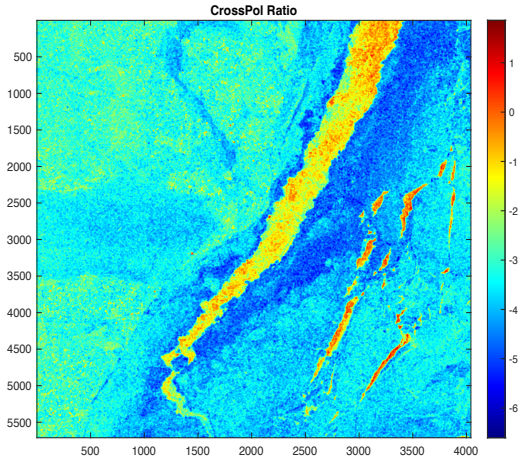
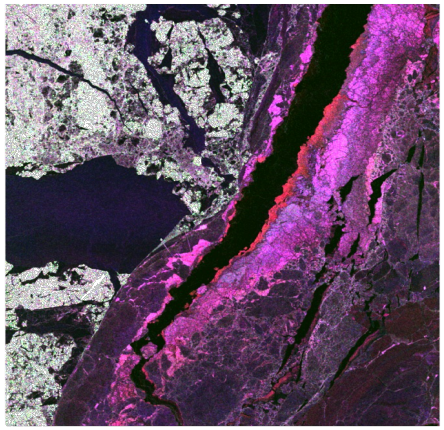


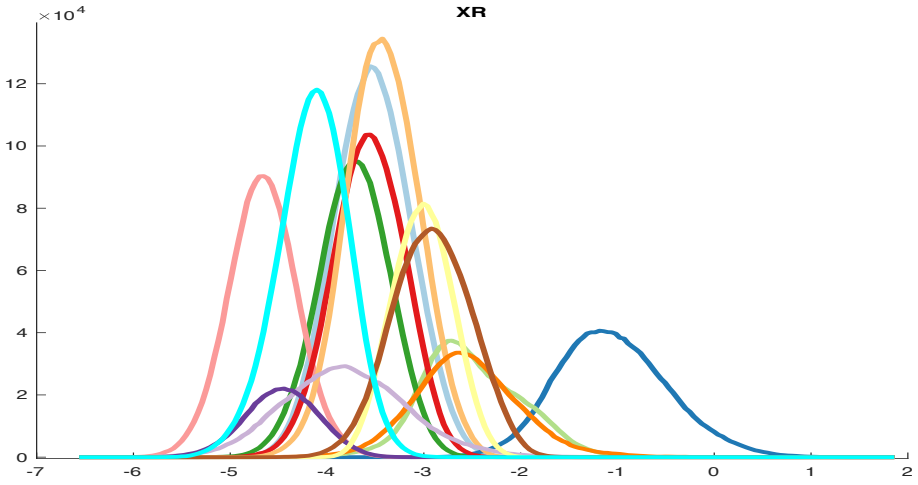

CoPRatio
×10^4
12
10
8
6
4
2
0
-5
-4
-3
-2
-1
0
1
2
3
4
5

CrossPol Ratio

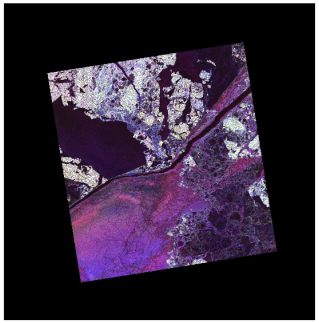




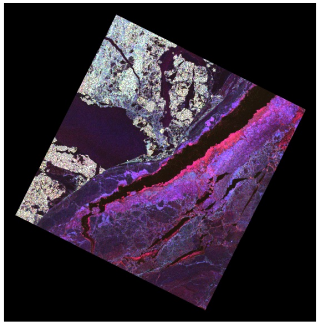




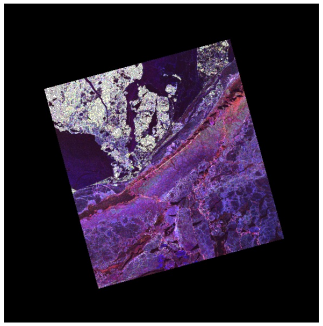
Pauli images of time series of RS-2 Quad-pol data



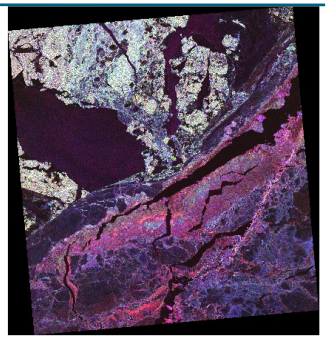
11.04



28.04



29.04



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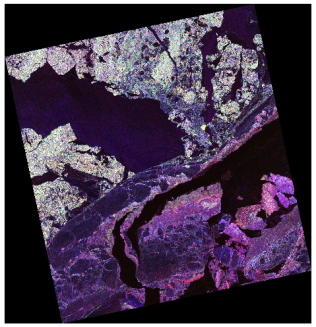
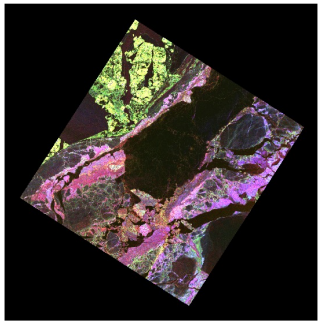
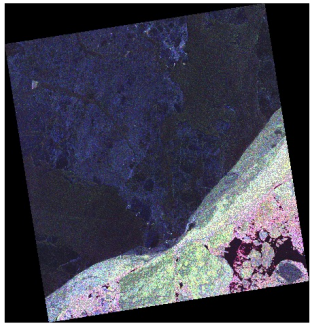


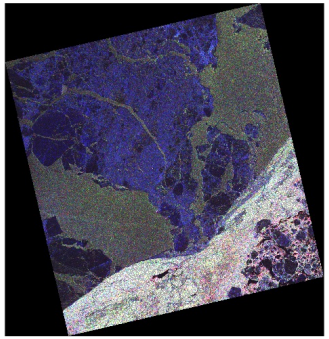
02.05



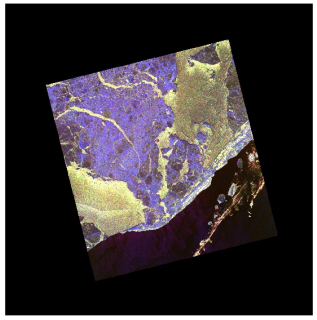
04.05



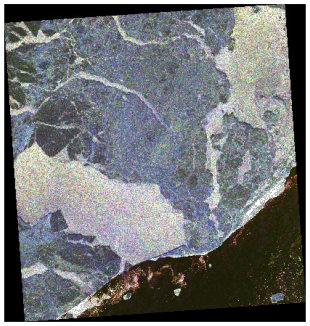
29.05



02.06



09.06



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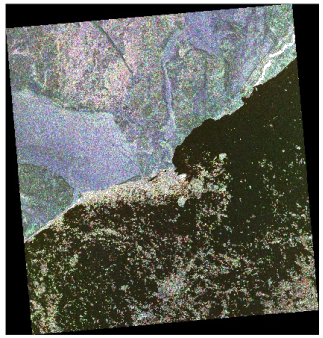


18.06

Dual - polarimetric SAR-image segmentation

$$\mathbf{s} = [S_{HH}, S_{HV}]$$

$$\begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \frac{\exp(jkr)}{r} \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} = \frac{\exp(jkr)}{r} \begin{bmatrix} S_{HH} \\ S_{VH} \end{bmatrix}$$

$$\mathbf{C} = < \mathbf{s}\,\mathbf{s}^* > \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix}$$

$$\begin{aligned} Q_1 &= < [|E_{HH}|^2 + |S_{VV}|^2] \\ Q_2 &= < [|E_{HH}|^2 - |S_{VV}|^2] \\ Q_3 &= 2 * Re < E_H E_V^* > \\ Q_4 &= 2 * Im < E_H E_V^* > \end{aligned}$$

$$m_l = \frac{\sqrt{Q_2^2 + Q_3^2}}{Q1}$$

Feartures:

Relative kurtosis is a measure of non-Gaussianity: $RK = \frac{1}{Ld(d+1)} \sum_{i=1}^{L} \left[\mathbf{s}_i^\dagger \mathbf{C}^{-1} \mathbf{s}_i \right]^2$

Geometric brightness represents the total intensity $B = \sqrt[d]{det(\mathbf{C})}$

Co-polarization intensity: C_{11}

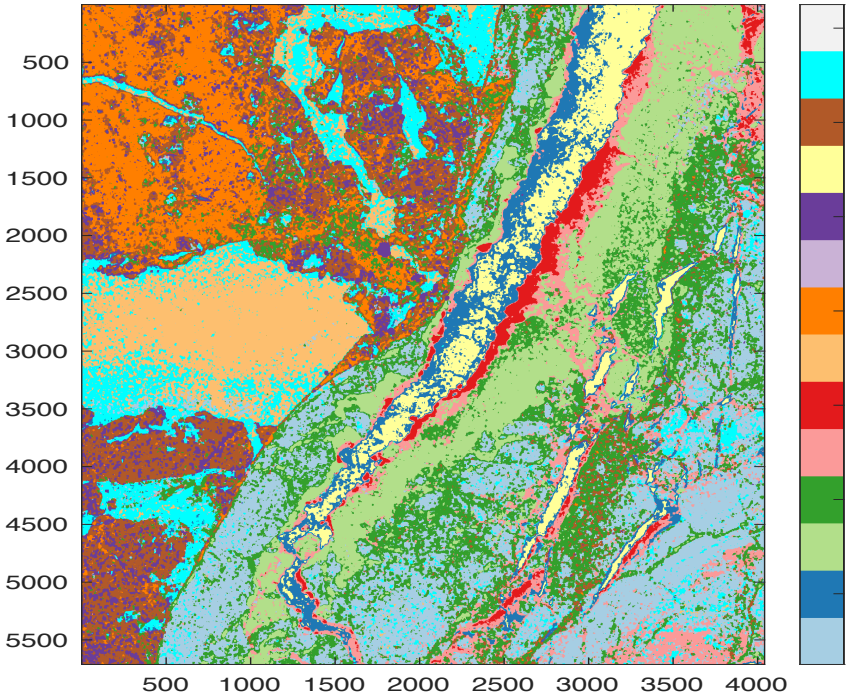
Cross-polarization intensity: C_{22}

Cross-polarization ratio: $R_{HV/B} = \frac{\langle S_{HV} S_{HV}^* \rangle}{B}$

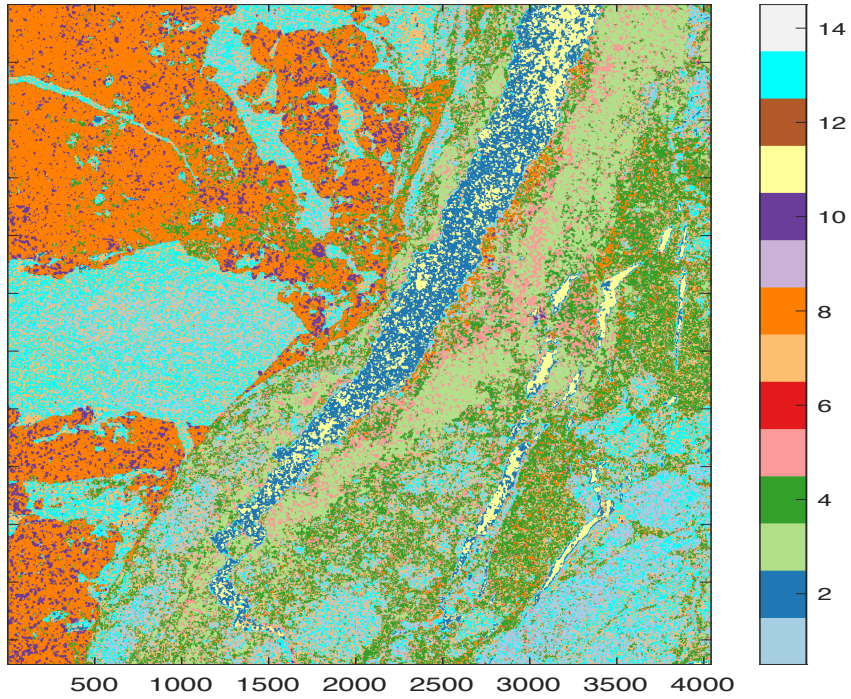
Degree of linear polarization: $m_l = \frac{\sqrt{Q_2^2 + Q_3^2}}{Q1}$

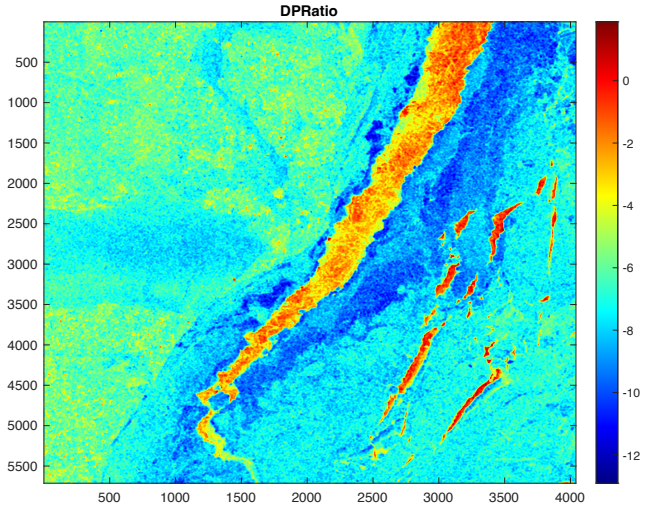
Segmentation of RS2-image: 28.04.2022

Quad-pol features



Dual-pol features




DPRatio
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-2
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-6
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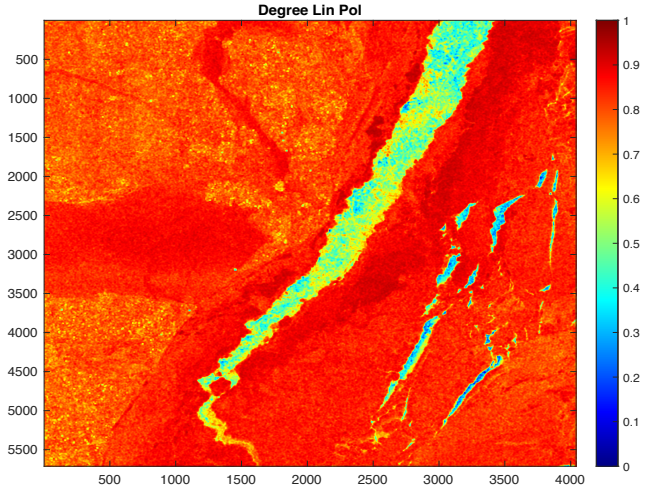
Degree Lin Pol
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5500
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0.8
0.7
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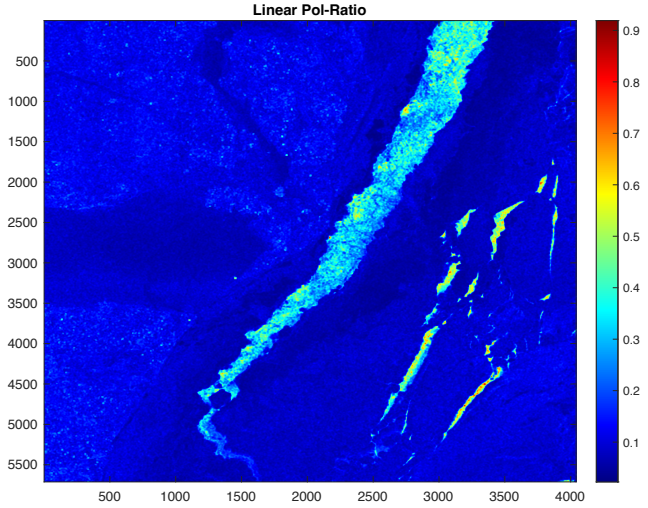
0.5
0.4
0.3
0.2
0.1
0


Linear Pol-Ratio
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0.9
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0.6
0.5
0.4
0.3
0.2
0.1

Some Sea Ice Preliminaries

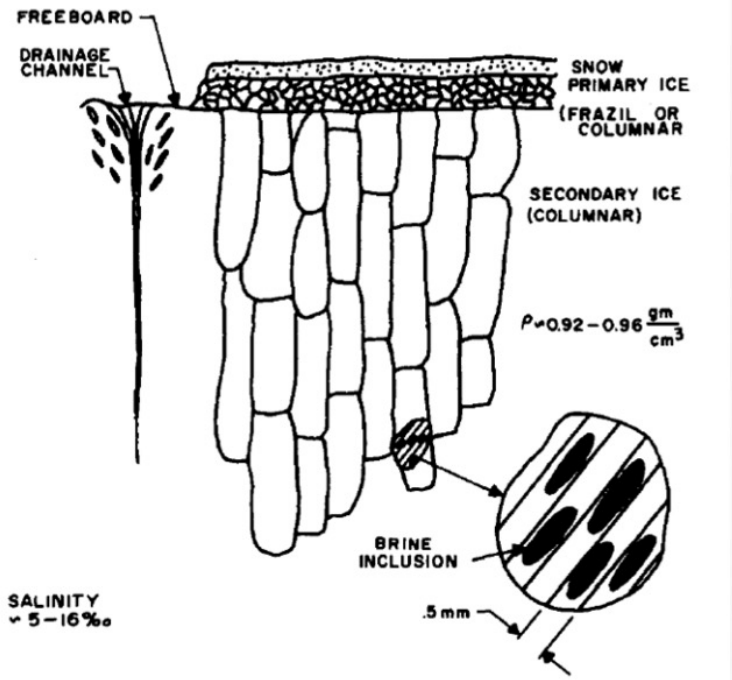


FIG. 1. Simplified geometry of first-year sea ice.

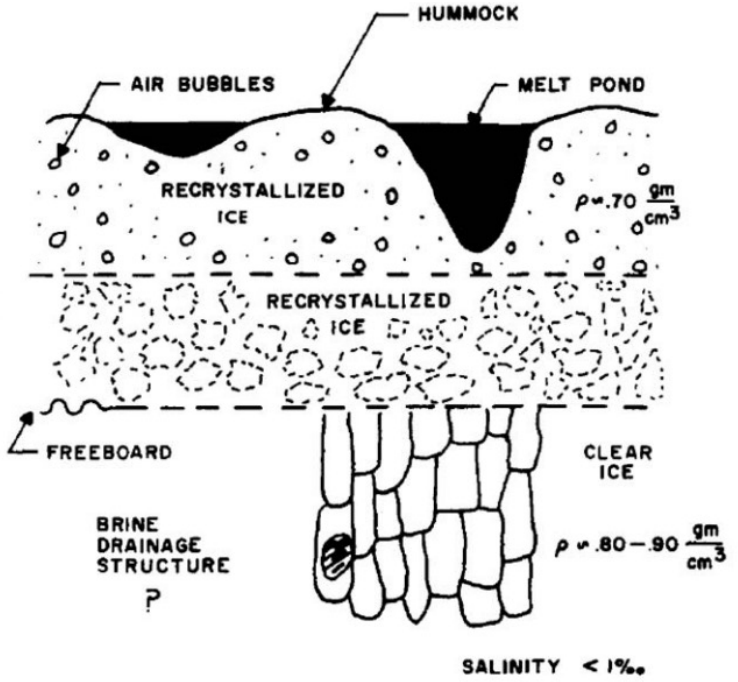
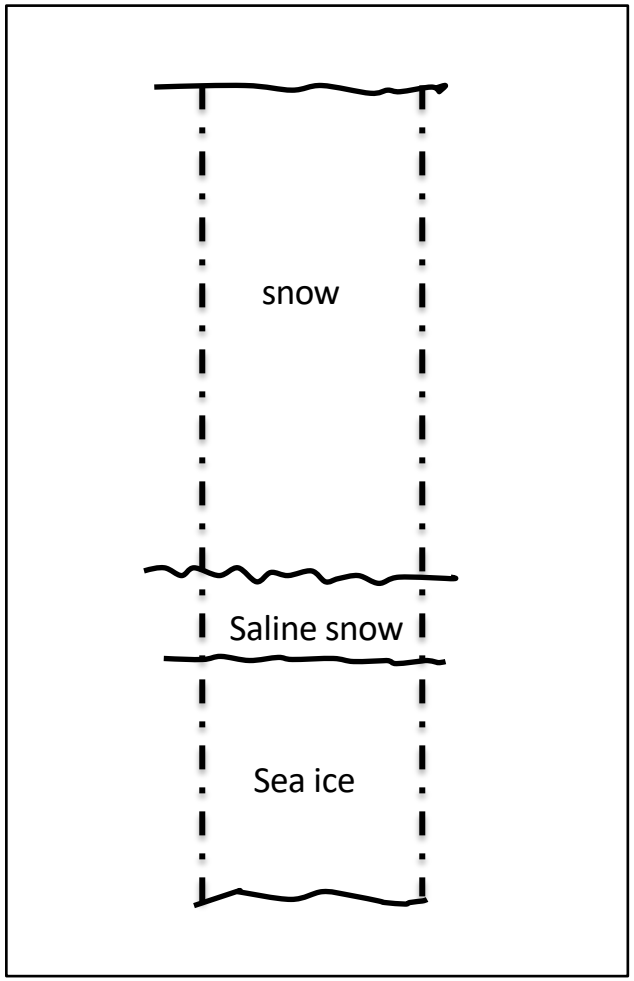
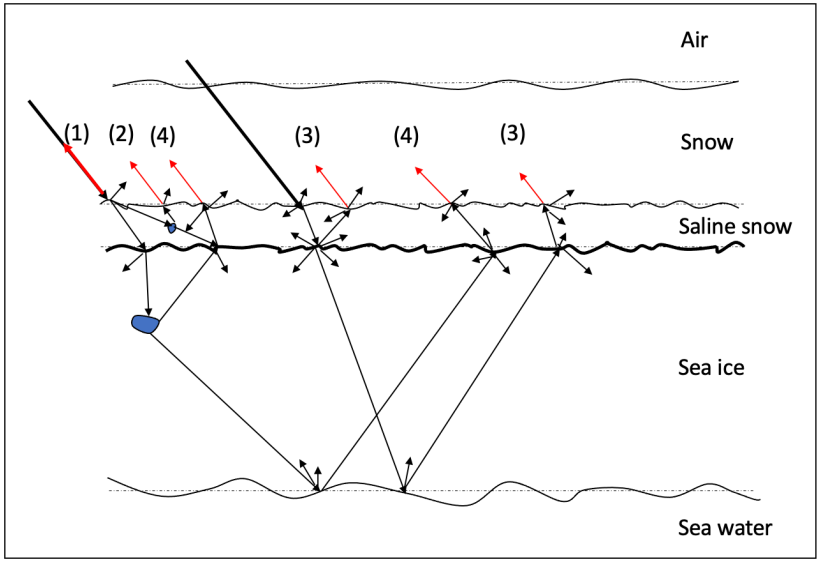


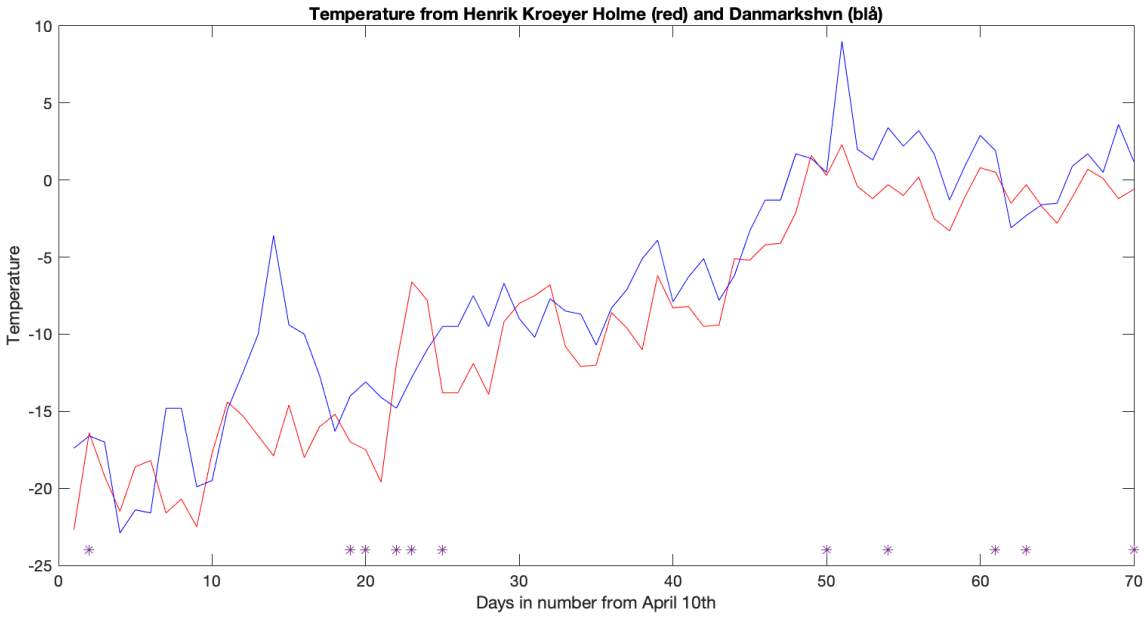
FIG. 2. Simplified geometry of multiyear sea ice.

Vant, Journal of AP, 1978

Some Sea Ice Preliminaries

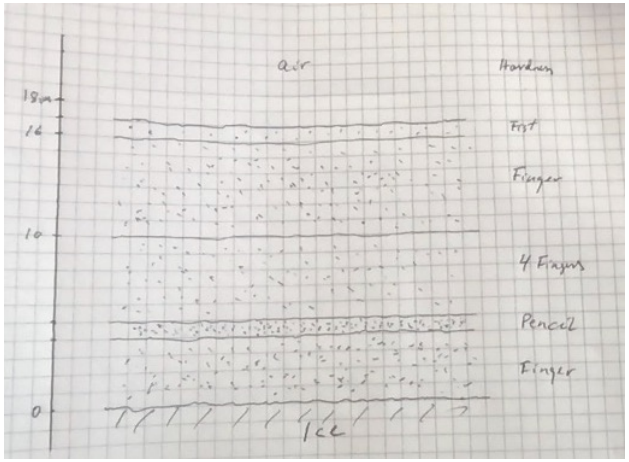




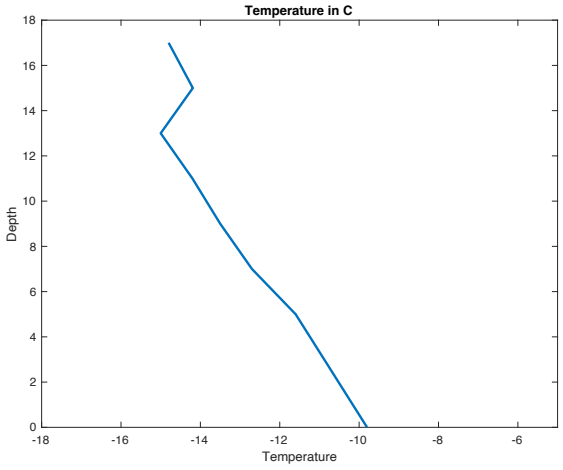

Temperature from Henrik Kroeyer Holme (red) and Danmarkshvn (blå)
Temperature
Days in number from April 10th
10
5
0
-5
-10
-15
-20
-25
0
10
20
30
40
50
60
70

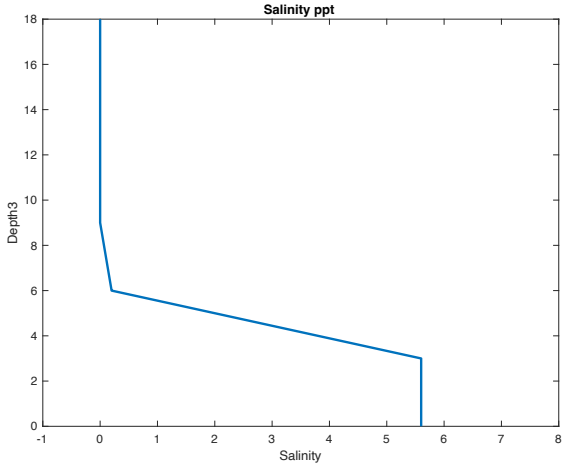

Henrik Krøyer Holme is located in Greer
Henrik
Krøyer
Holme
Danmarkshavn

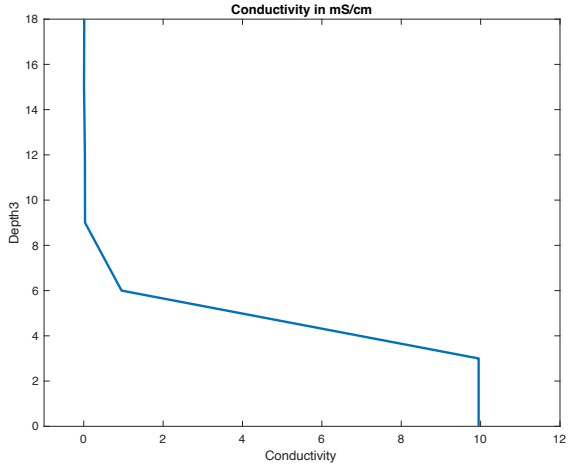
Snow pit 1

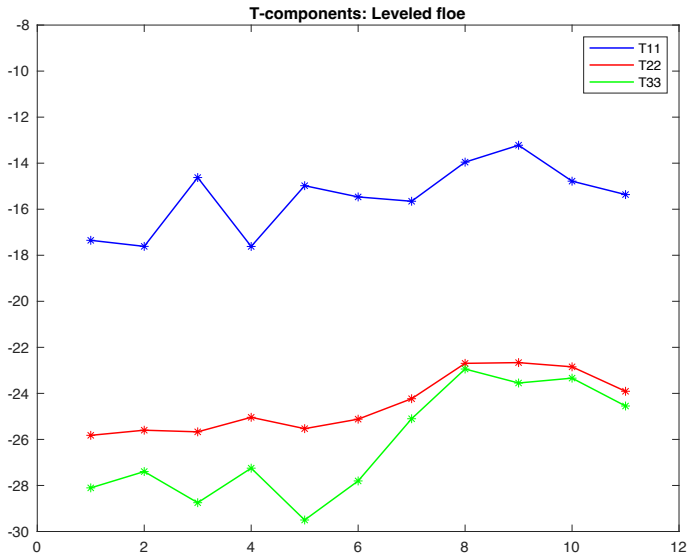


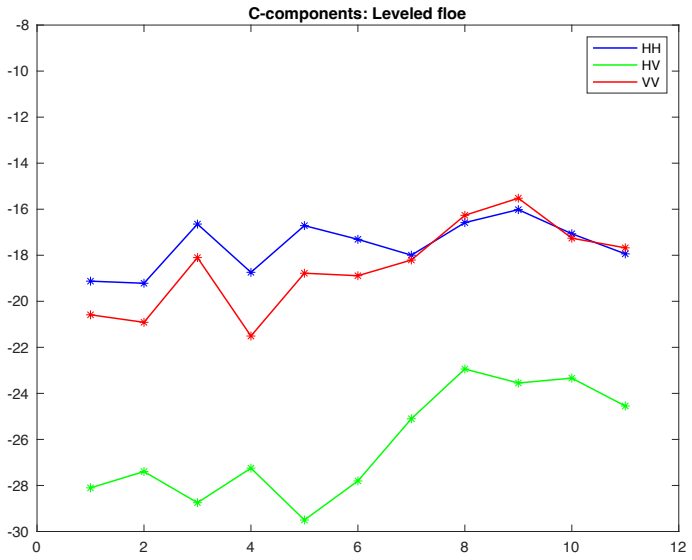
- Depth – 17 cm
- Variation in hardness
- Variation in density
- Increased conductivity at the bottom
- Rough bottom surface

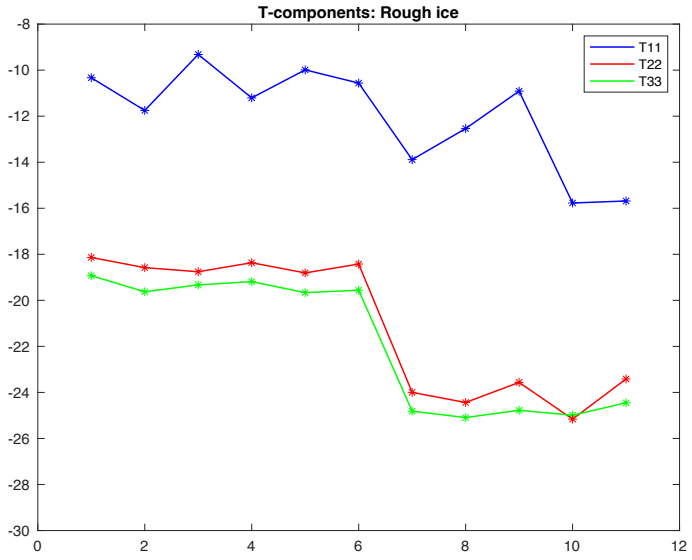


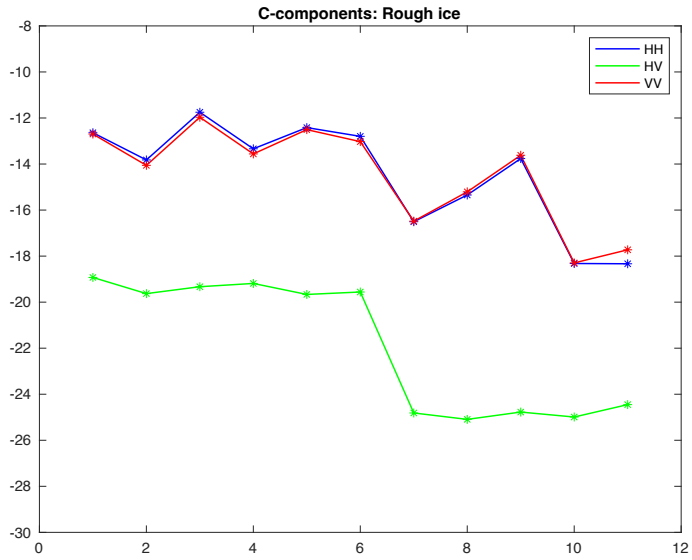


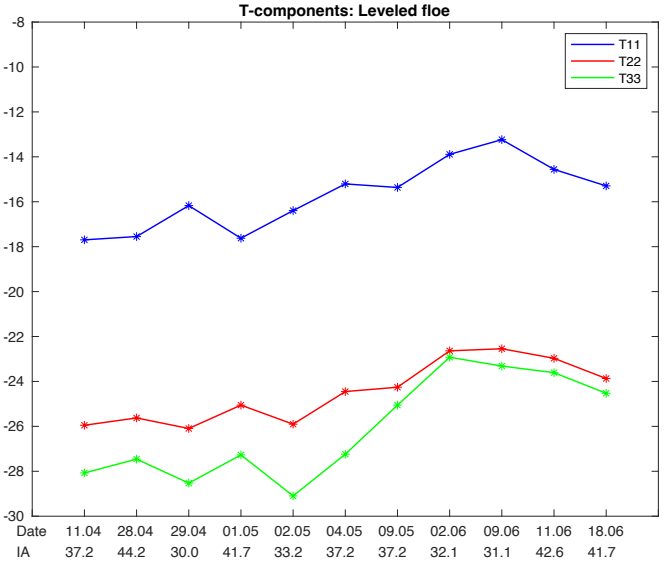


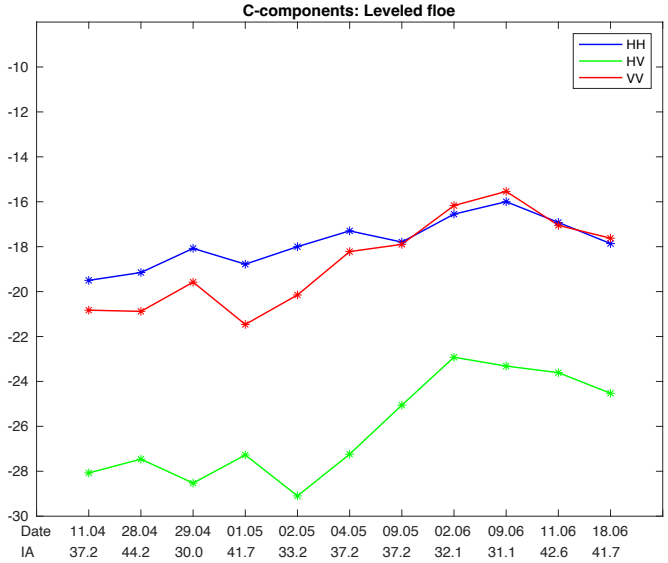

T-components: Leveled floe
T11
T22
T33
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
0
2
4
6
8
10
12


C-components: Leveled floe
HH
HV
VV
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
0
2
4
6
8
10
12


T-components: Rough ice
T11
T22
T33
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
0
2
4
6
8
10
12


C-components: Rough ice
HH
HV
VV
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
0
2
4
6
8
10
12


T-components: Leveled floe
T11
T22
T33
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
Date 11.04 28.04 29.04 01.05 02.05 04.05 09.05 02.06 09.06 11.06 18.06
IA 37.2 44.2 30.0 41.7 33.2 37.2 37.2 32.1 31.1 42.6 41.7


C-components: Leveled floe
HH
HV
VV
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
Date 11.04 28.04 29.04 01.05 02.05 04.05 09.05 02.06 09.06 11.06 18.06
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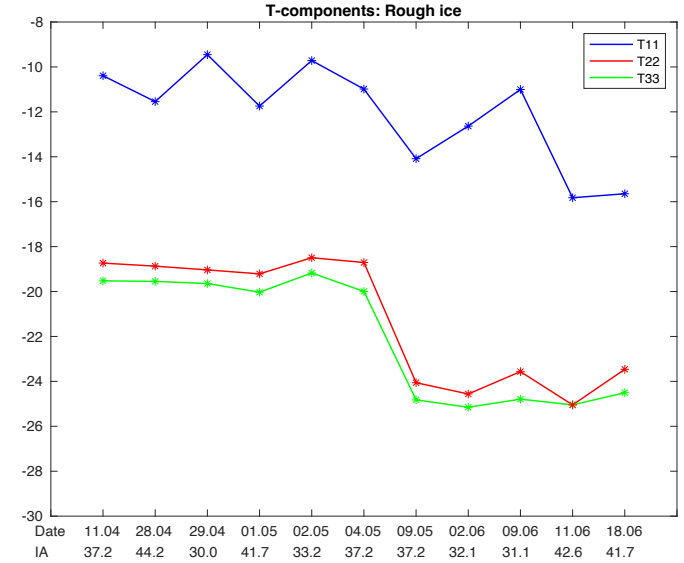
T-components: Rough ice
T11
T22
T33
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
Date 11.04 28.04 29.04 01.05 02.05 04.05 09.05 02.06 09.06 11.06 18.06
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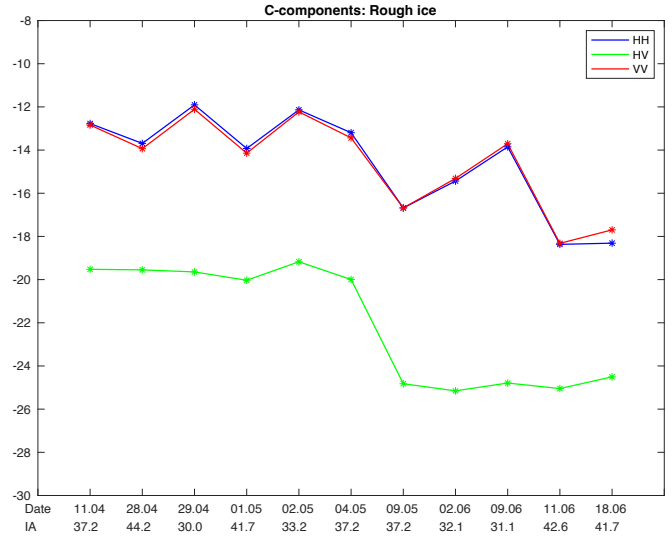
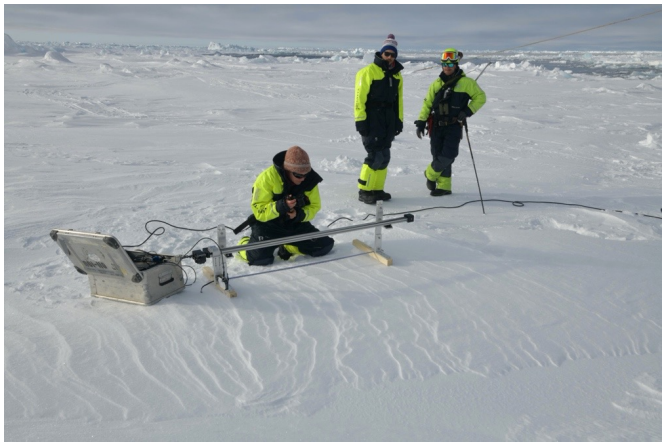
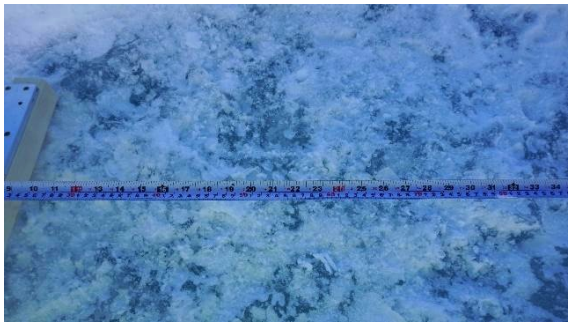

C-components: Rough ice
HH
HV
VV
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
Date 11.04 28.04 29.04 01.05 02.05 04.05 09.05 02.06 09.06 11.06 18.06
IA 37.2 44.2 30.0 41.7 33.2 37.2 37.2 32.1 31.1 42.6 41.7

In-situ ice measurements: Ice And Snow Roughness





- 25 sets of roughness profiles from 7 sites at sea ice stations
- acquisitions over upper snow surface and snow interfaces and from the snow-sea ice interface
- photographs of surface / interface characteristics

Ice Cores: In-situ sea ice measurements of dielectric properties and micro-structure

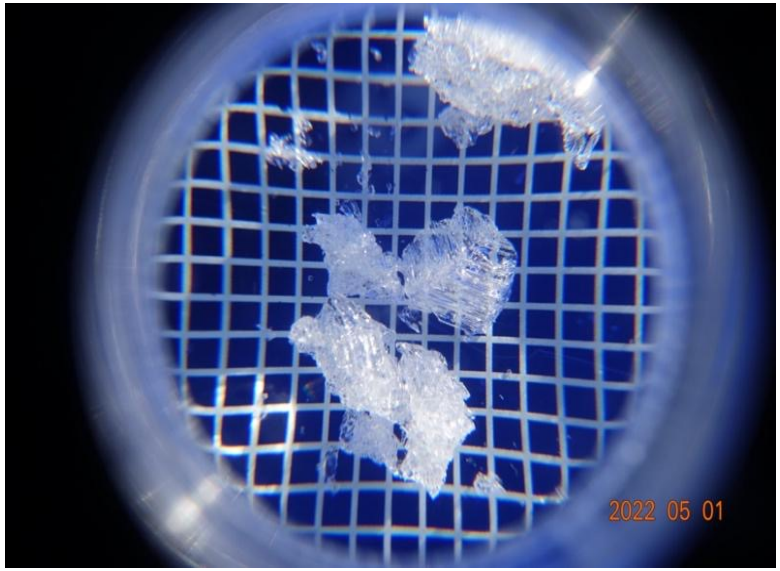
14 main ice core sites

- temperature profile (field)
- salinity profile (ship lab)
- oxygen istotopes: (NPI lab)
- density profile (NPI lab)
- chemistry core (NPI)
- archive core (NPI)

- Photographs for analysis of internal micro-structure (layers, air bubbles)
- Ice thickness

Snow pits: Layering and micro-structure

- snow depth
- number and thickness of snow layers
- snow grain types and sizes
- salinity
- density
- temperature
- snow water equivalent (SWE)
- wetness
- dielectric constant



Thank you

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https://cirfa.no/

Photos: S. Gerland