

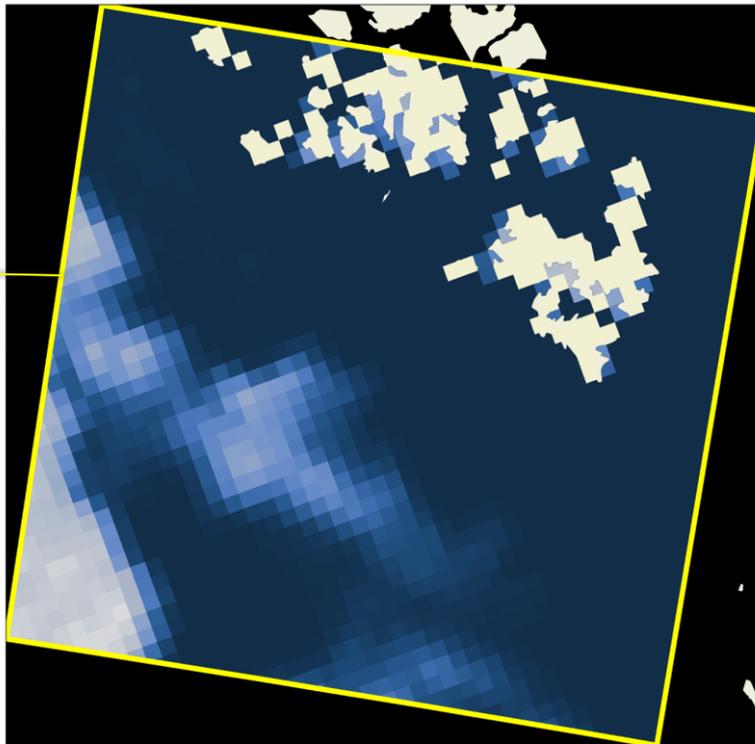
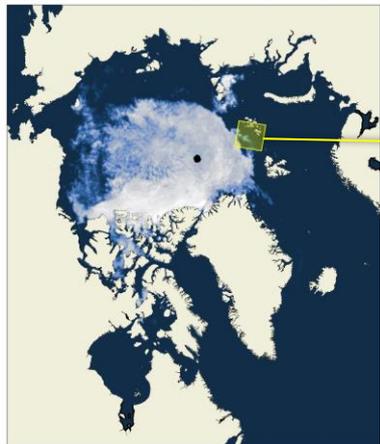
CNN-based retrieval of Arctic sea ice information from SAR and Passive Microwave

Tore Wulf, Jørgen Buus-Hinkler, Suman Singha, Hoyeon Shi, Ninna Juul Ligaard, Matilde Brandt Kreiner

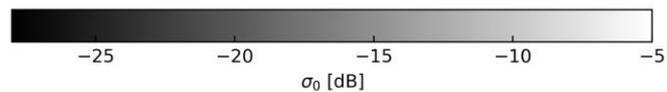
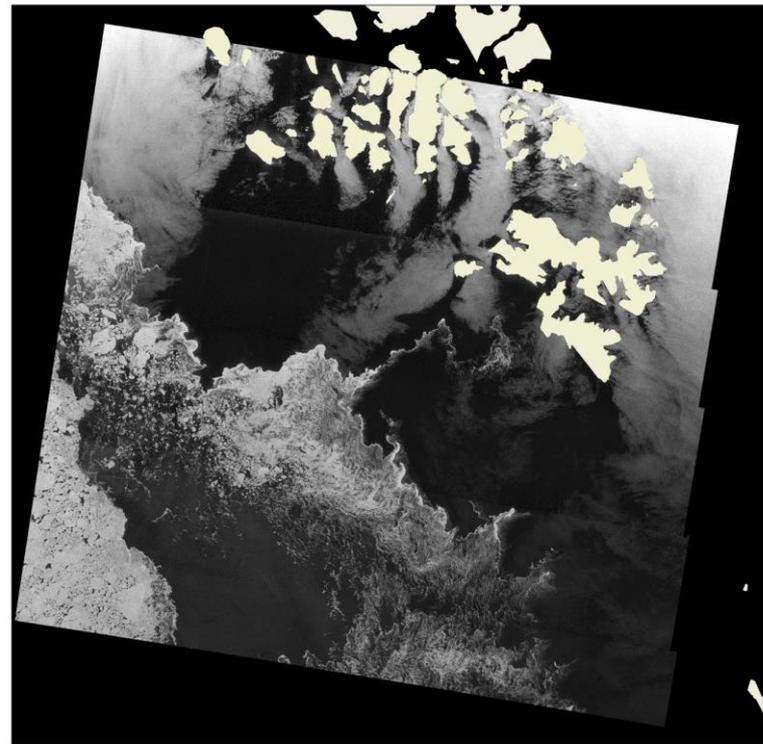


Motivation for SAR-based sea ice retrievals

OSI SAF (OSI-408-a)
Sea Ice Concentration (SIC)
Sep. 9th, 2021, 12:00 UTC



Sentinel-1 HH
Sep. 9th, 2021, 04:51 UTC



Supervised deep learning and ice charts as label data

Supervised learning algorithms require label/"ground-truth" data for training. We use manually drawn regional ice charts as the "ground-truth".

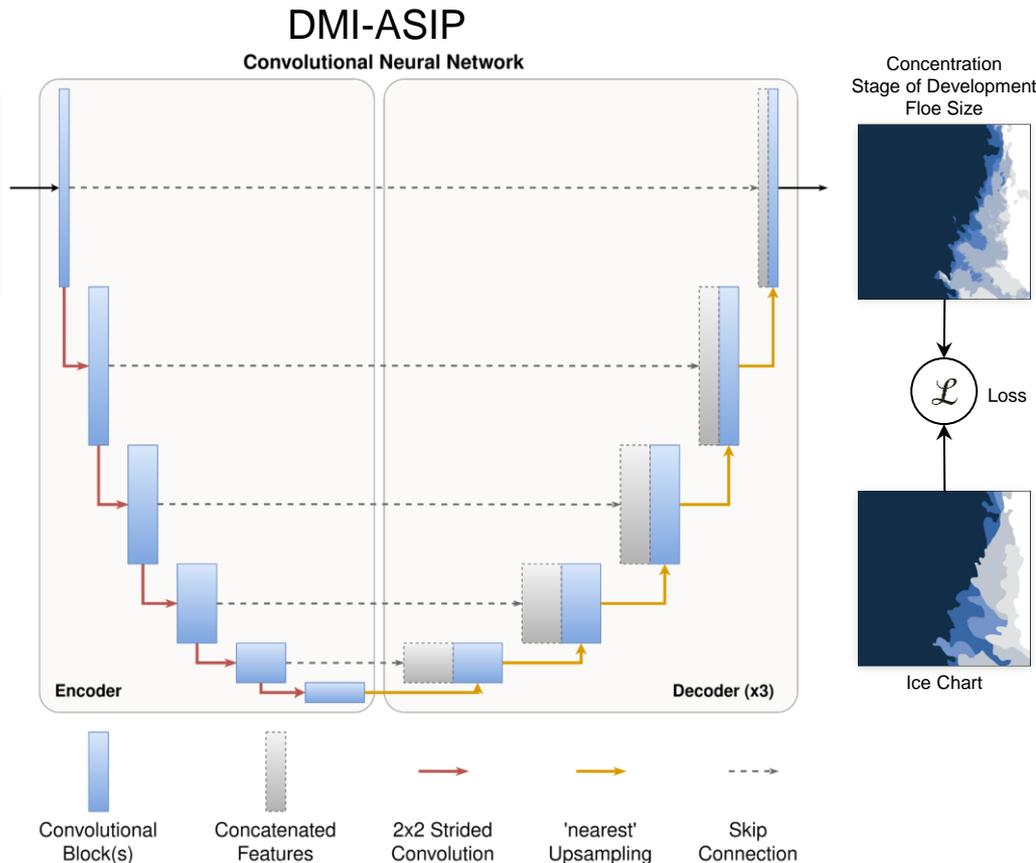
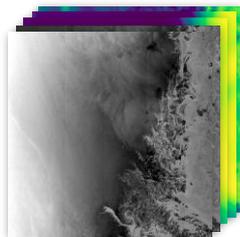
Advantages:

- Abundance
- Geographical/Seasonal coverage
- Often drawn on the basis of a SAR image, enabling the generation of a timely match-up training dataset

Disadvantages:

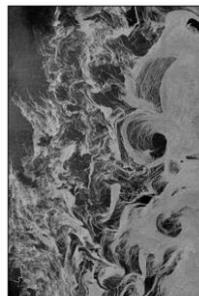
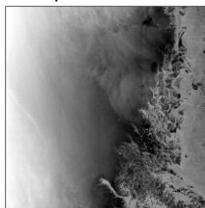
- Human subjectivity
- Uncertainty estimates are not provided
- Large polygons (relative to SAR resolution)

S1 + AMSR2. data.

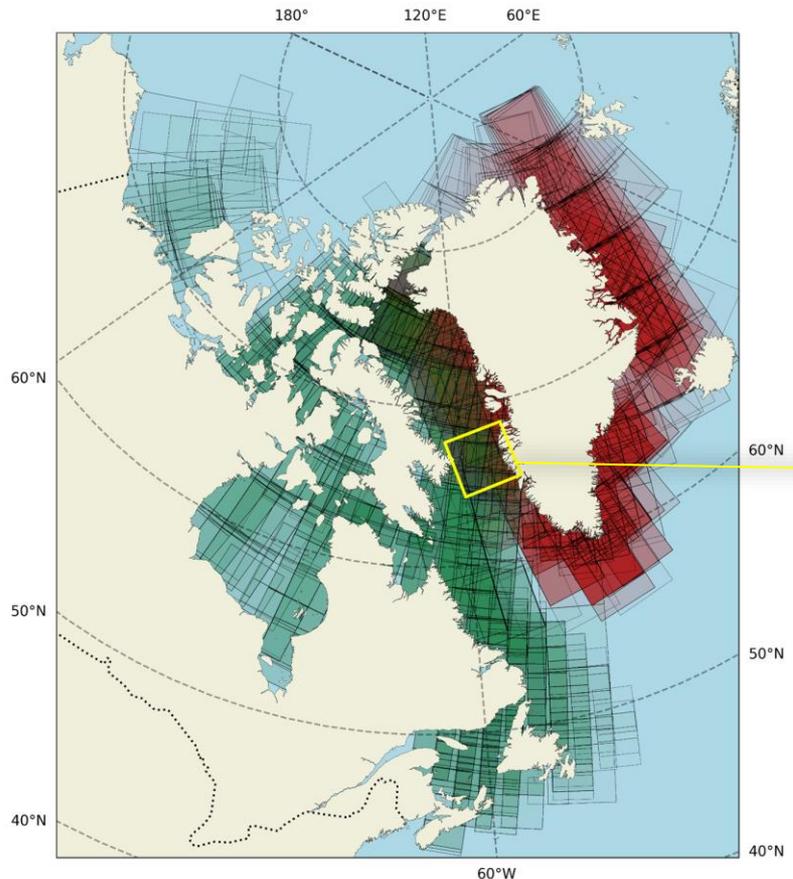


Sentinel-1 HH
April 19, 2021

Ice Chart
April 19, 2021



ASIP/AI4Arctic Sea Ice Dataset

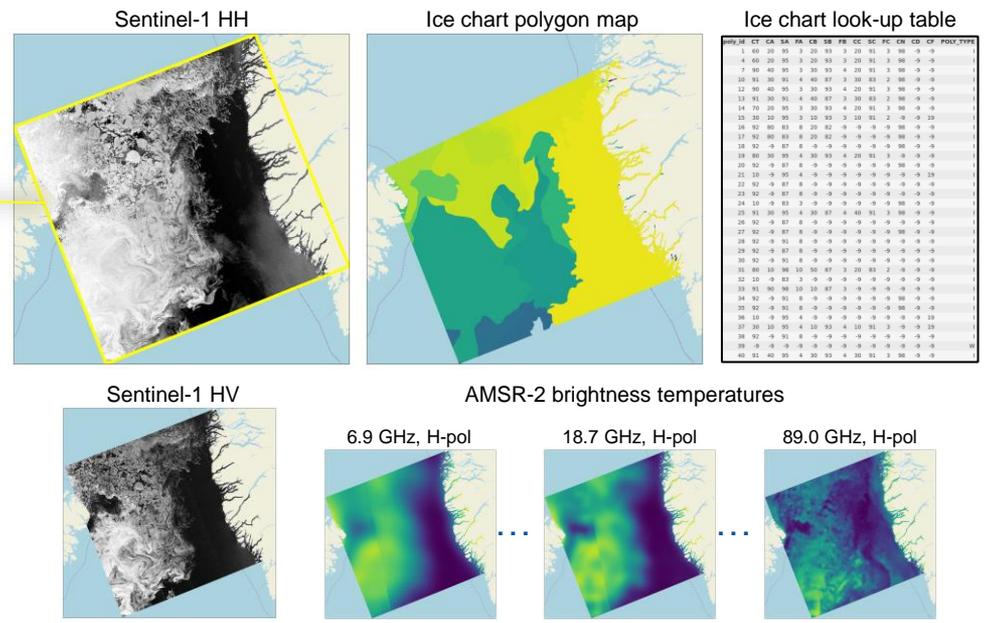


5382 unique matches of Sentinel-1 EW/IW imagery and manually produced ice charts from 2018 up to and including 2021, covering **Greenland waters (DMI ice charts)** and the **Canadian Arctic (CIS ice charts)**.

Auxiliary observations:

- AMSR-2 brightness temperatures for frequencies {6.9, 7.3, 10.7, 18.7, 23.8, 36.5, 89.0} GHz and polarisations {H, V}

Example scene, May 16th, 2021



Thanks a lot to the **Canadian Ice Service** and the **Greenland Ice Service** at DMI for providing the ice charts for this dataset!

DMI-ASIP SIC retrieval and uncertainty estimation

The sea ice concentration (SIC) parameter in the ice charts is given as discrete increments I from 0-100%, in steps of 10%, giving a total of $k=11$ SIC increments,

$$I \in \{0, 10, 20, \dots, 100\}.$$

Given an input \mathbf{x} , DMI-ASIP is trained to output a k -dimensional vector for each grid point with non-normalized scores for each increment class,

$$\mathbf{z} = [z_1, z_2, \dots, z_k].$$

The non-normalized scores \mathbf{z} are passed through the softmax function σ to obtain class "probabilities" $\hat{\mathbf{p}}$,

$$\hat{\mathbf{p}} = \sigma(\mathbf{z})$$

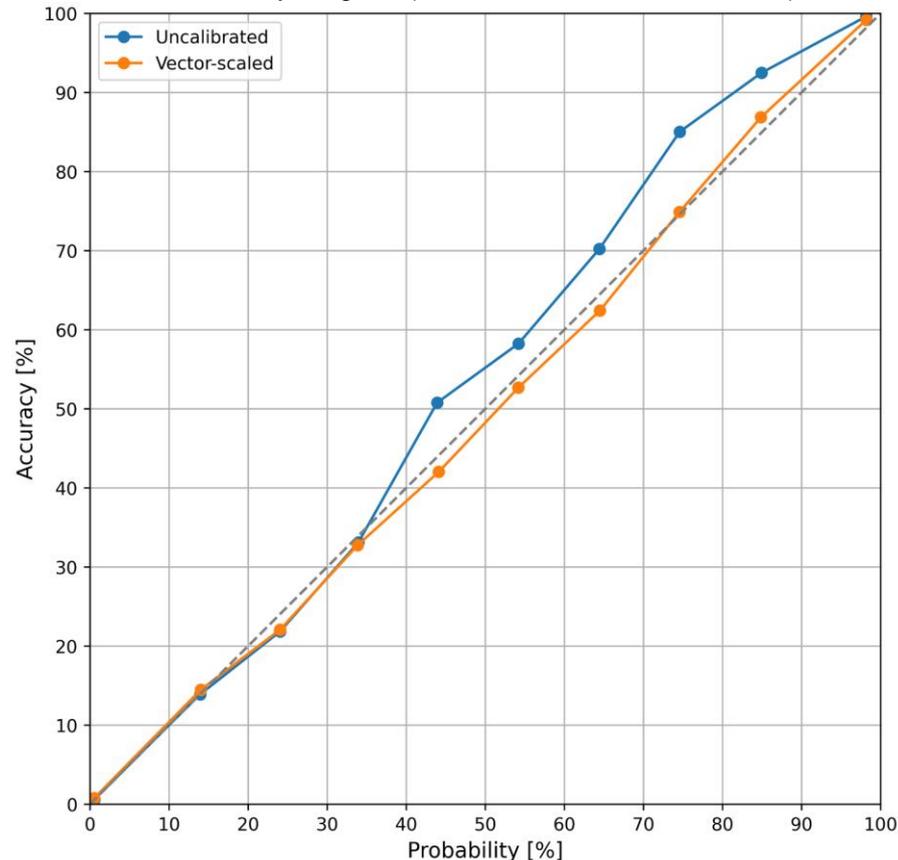
It is empirically known that modern neural networks tend to be poorly calibrated, i.e. $\hat{\mathbf{p}}$ can not be directly interpreted as posterior probabilities, and thus does not reflect the predictive uncertainty of the trained model, hence the need for calibration,

$$\hat{\mathbf{p}} = \sigma(\mathbf{W}\mathbf{z} + \mathbf{b})$$

Parameters \mathbf{W} and \mathbf{b} are learned on a held-out validation dataset. Given a well-calibrated model output, the SIC and the associated uncertainty can be computed as a weighted average and a weighted standard deviation of the 11 increments I , respectively, with weights given by their respective class probabilities $\hat{\mathbf{p}}$,

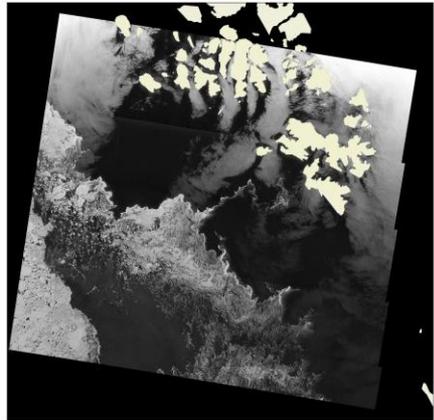
$$SIC = \sum_i^k \hat{p}_i I_i \quad STD_{SIC} = \sqrt{\sum_i^k \hat{p}_i (I_i - SIC)^2}$$

Reliability Diagram (evaluated on a held-out test set)

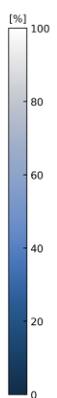
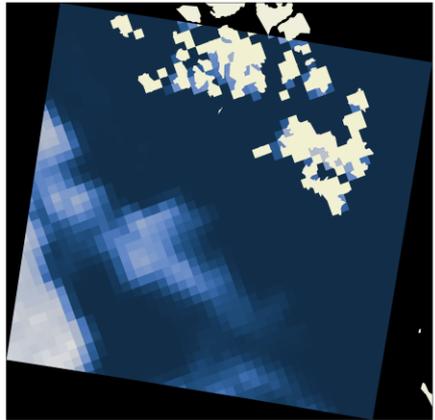


DMI-ASIP SIC Output Example

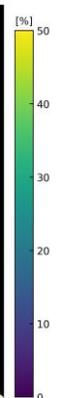
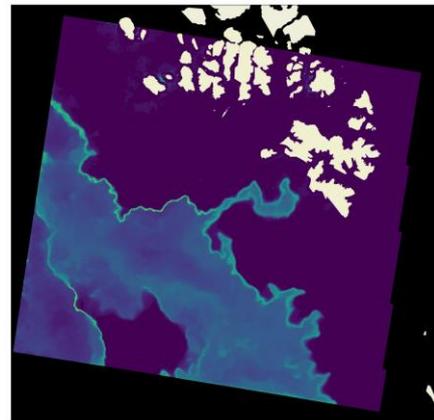
Sentinel-1 HH



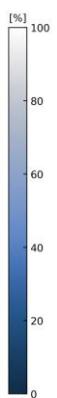
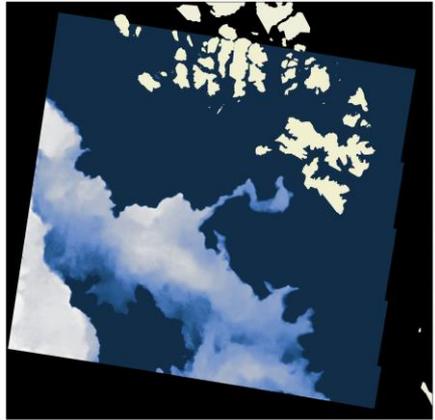
OSI-408-a SIC



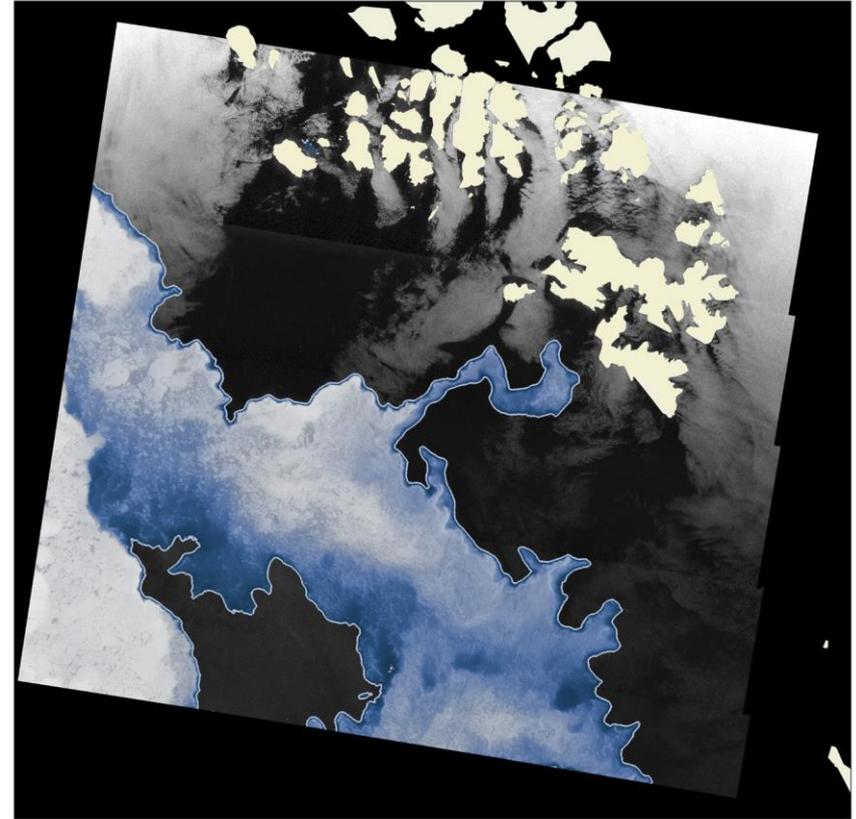
DMI-ASIP uncertainty (st. dev.)



DMI-ASIP SIC



Sentinel-1 HH with DMI-ASIP SIC and ice edge superimposed



Sea Ice Concentration [%]

Pan-Arctic comparison with OSI-408-a

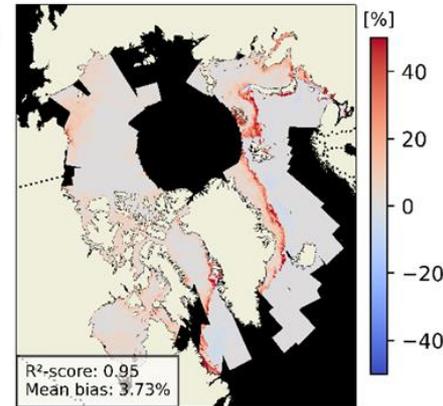
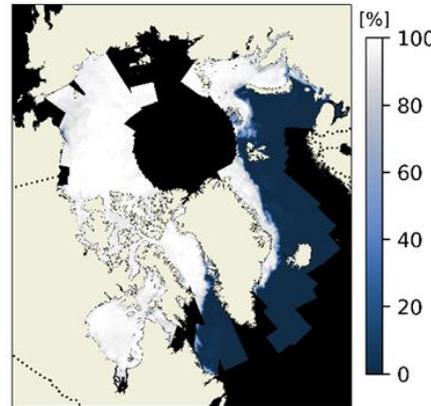
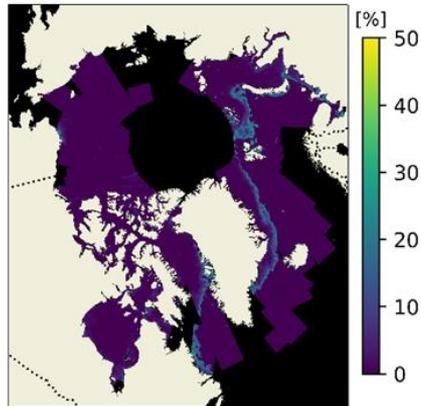
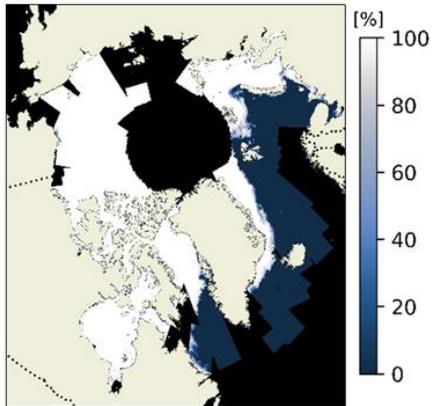
DMI-ASIP SIC

DMI-ASIP Uncertainty

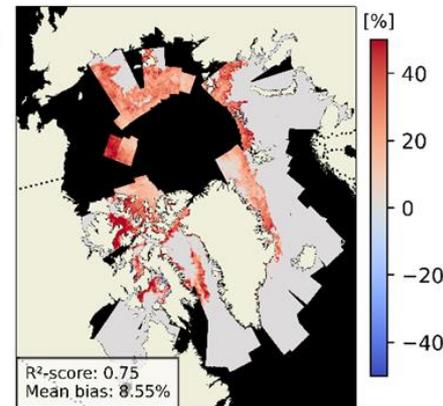
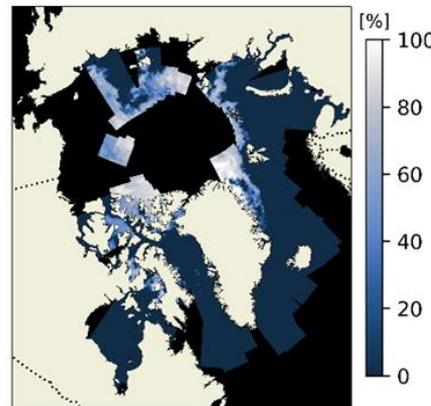
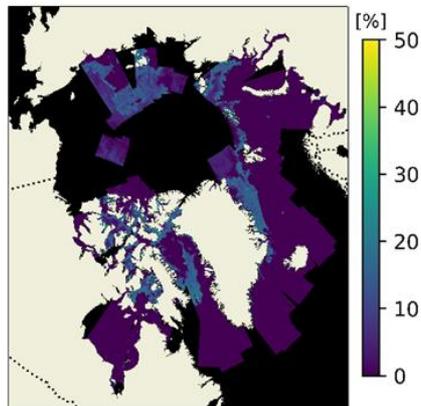
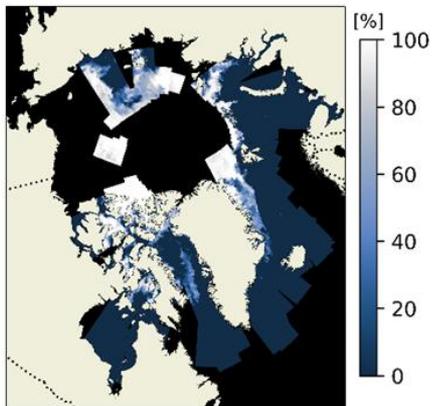
OSI-408-a SIC

SIC Difference (DMI-ASIP - OSI-408-a)

Jan. 9th -
Jan 15th,
2023



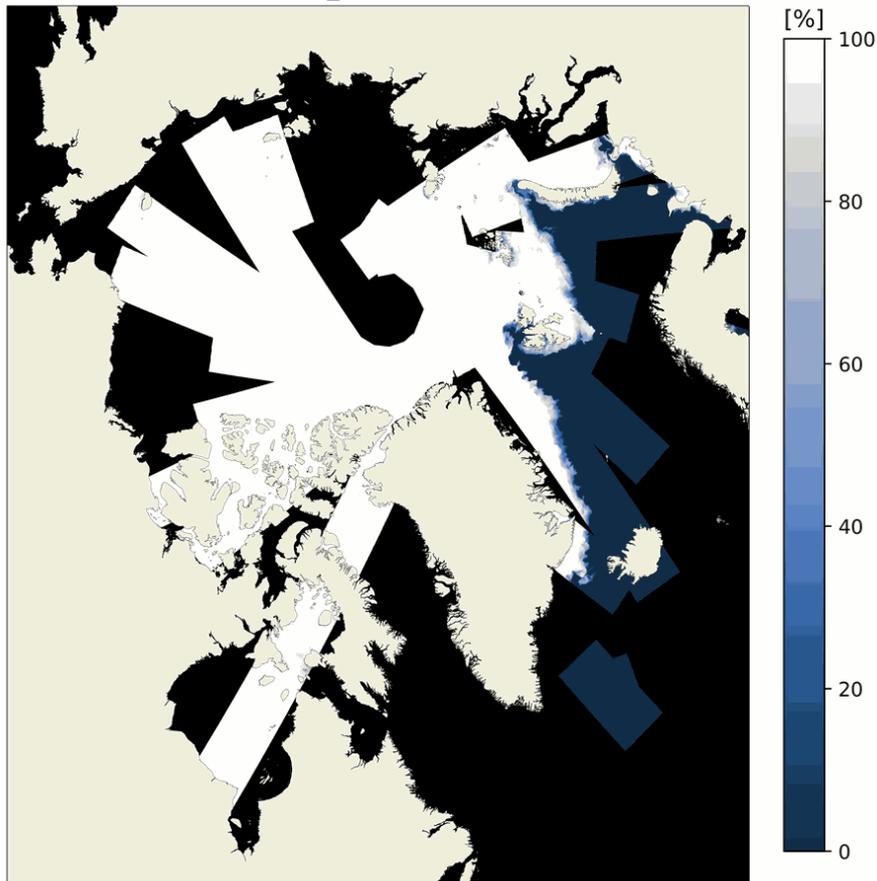
July 31st -
August 6th,
2023



Operational NRT and reprocessed (2014-2024) datasets

DMI-ASIP SIC, 7-day mosaics for 2020-2021

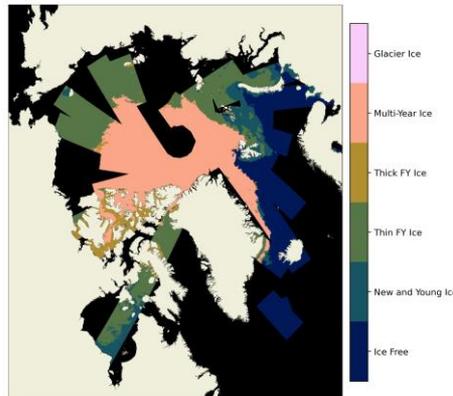
CT_20200101



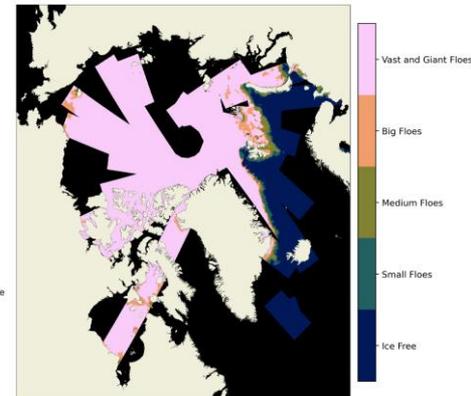
SAR-based Arctic-wide sea ice datasets in CMS from November 2024:

- Reprocessed Sentinel-1 archive (2014-2024) and Operational NRT:
 - 500m Daily L3 mosaic
 - Sea Ice Concentration
 - Stage of Development
 - Floe Size
 - 1000m Daily L4 mosaic
 - Sea Ice Concentration (gap-filled with AMSR2-based OSI SAF SIC)

DMI-ASIP Stage of Development
Jan 1st, 2020



DMI-ASIP Floe Size
Jan 1st, 2020

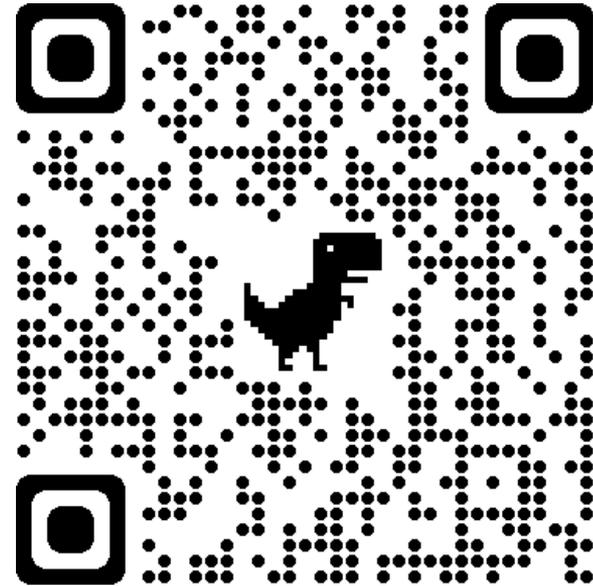


Thanks for listening!

Dataset



Paper

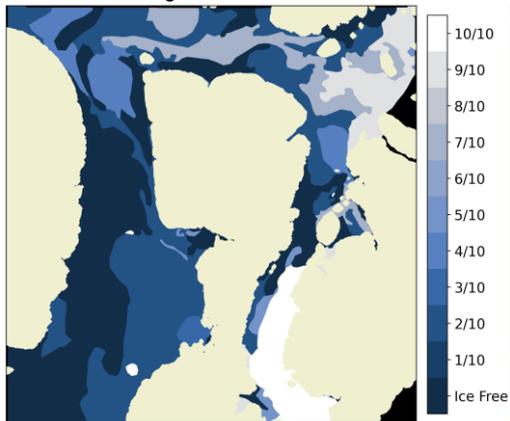


Buus-Hinkler, J., Wulf, T., Stokholm, A. R., Korosov, A., Saldo, R., Pedersen, L. T., Arthurs, D., Solberg, R., Longép , N., Kreiner, M. B.: **AI4Arctic Sea Ice Challenge Dataset**, <https://doi.org/10.11583/DTU.c.6244065.v2>, 2022.

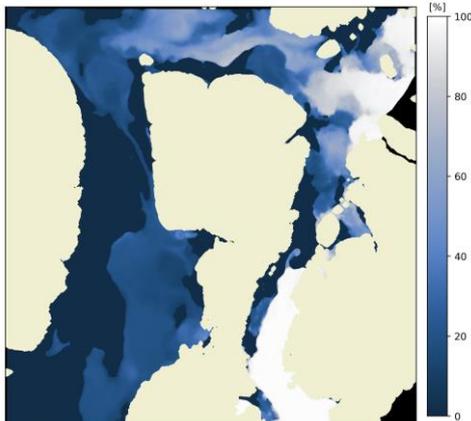
Wulf, T., Buus-Hinkler, J., Singha, S., Shi, H., and Kreiner, M. B.: **Pan-Arctic Sea Ice Concentration from SAR and Passive Microwave**, EGU sphere [preprint], <https://doi.org/10.5194/egusphere-2024-178>, 2024.

DMI-ASIP SIC evaluation against 50 regional ice charts

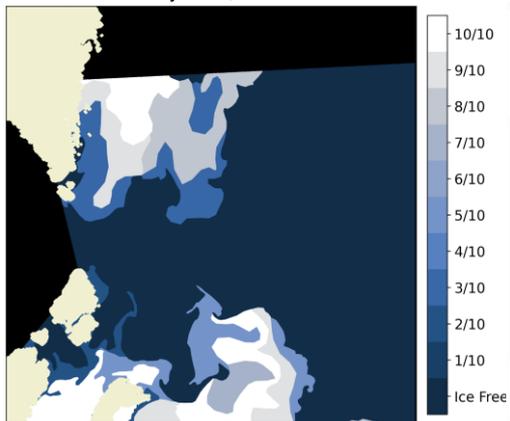
Ice Chart
Aug. 24th, 2018



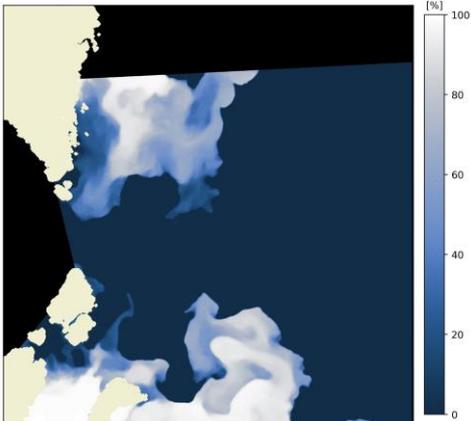
DMI-ASIP SIC



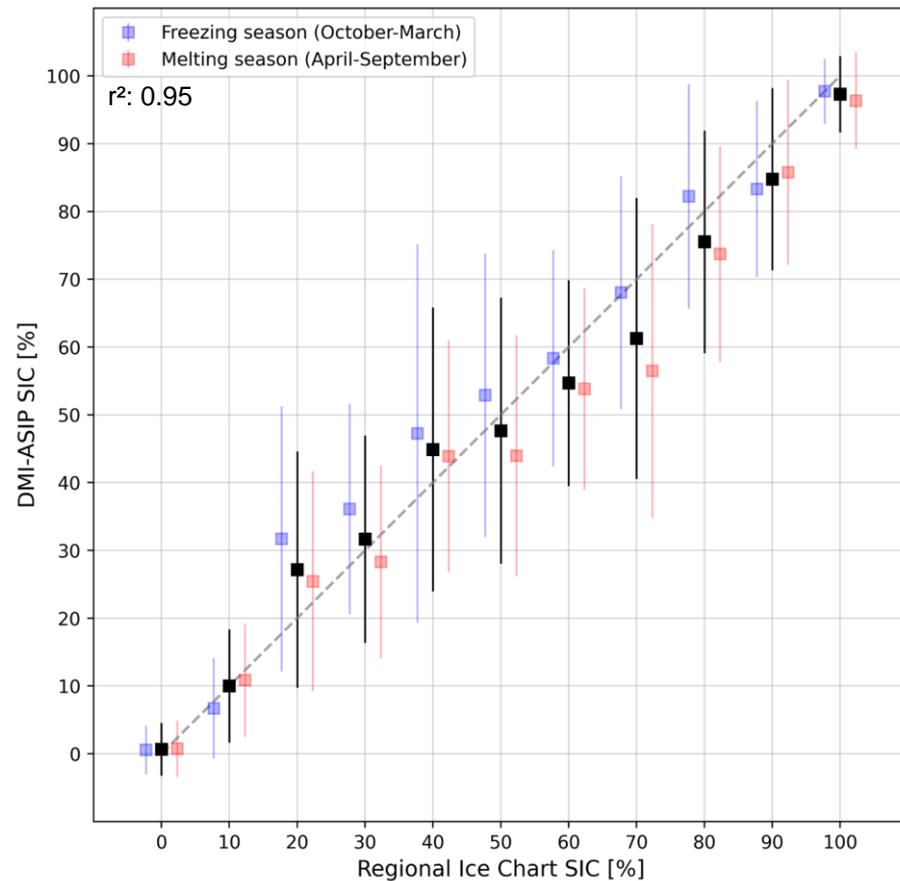
Ice Chart
May 12th, 2021



DMI-ASIP SIC

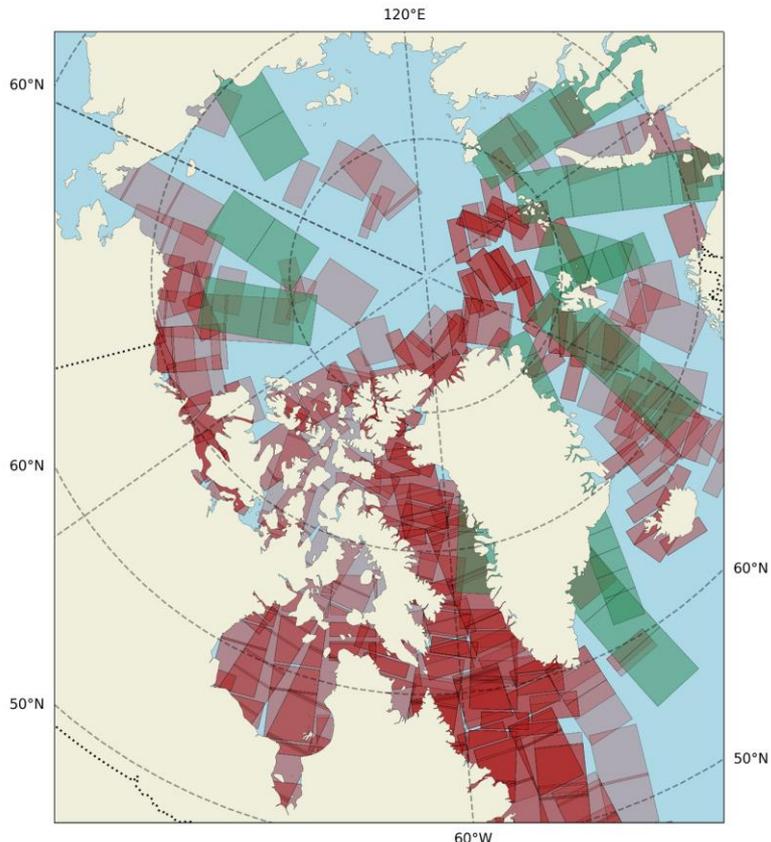


Regional Ice Chart SIC vs. DMI-ASIP SIC



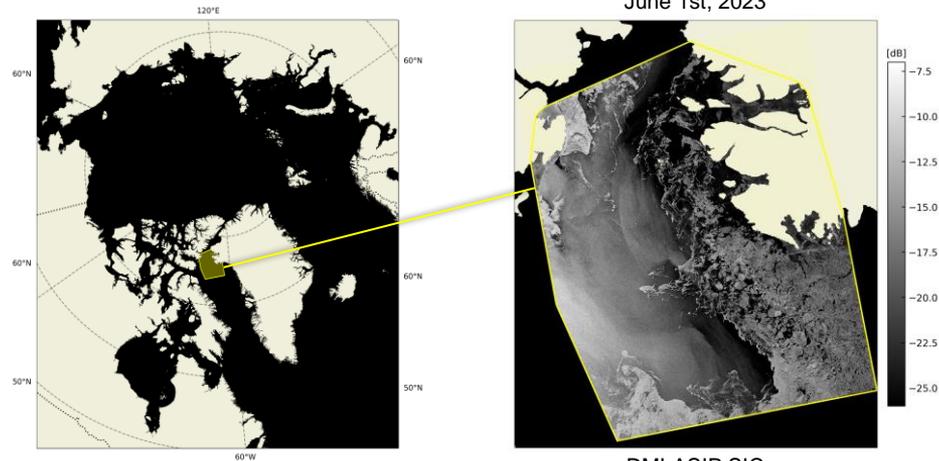
DMI-ASIP integration of Radarsat Constellation Mission obs.

Sentinel-1 (HH/HV, EW, IW) and RCM (HH/HV, SC50M, LN) coverage August 1st, 2024

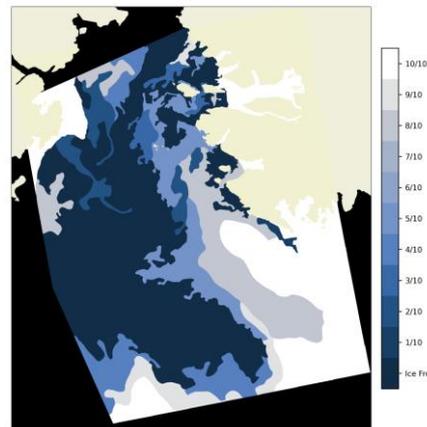


Note: RCM bounding boxes were fetched EODMS API Client (<https://github.com/m9brady/eodms-api-client>)

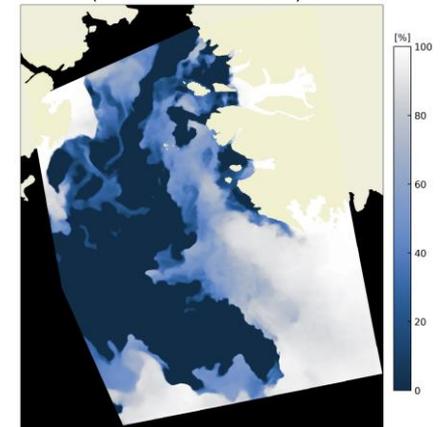
RCM HH (Low Noise 100m)
June 1st, 2023



DMI Ice Chart



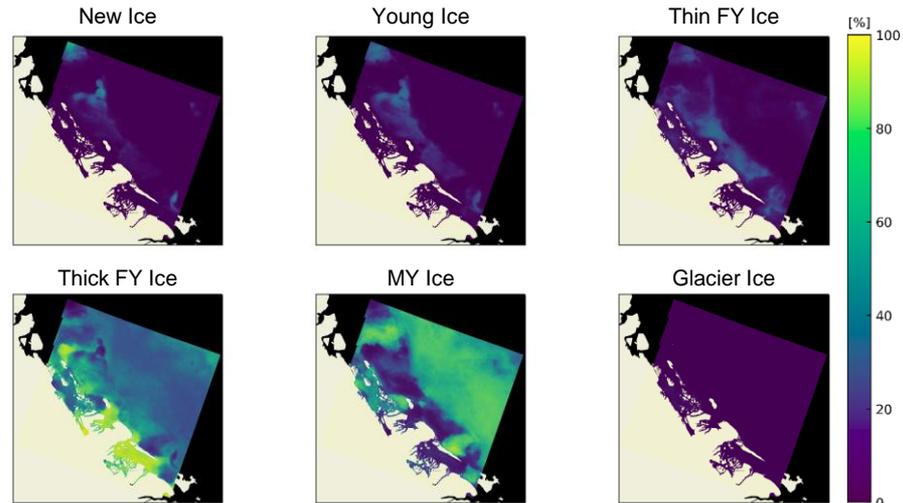
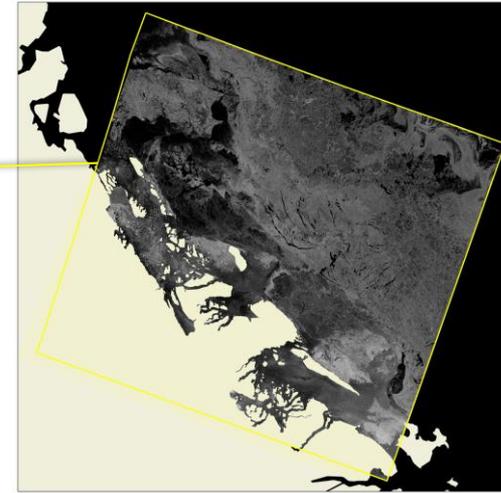
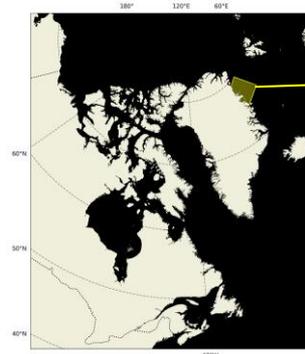
DMI-ASIP SIC
(trained on Sentinel-1)



DMI-ASIP Sea Ice Stage of Development (SoD)

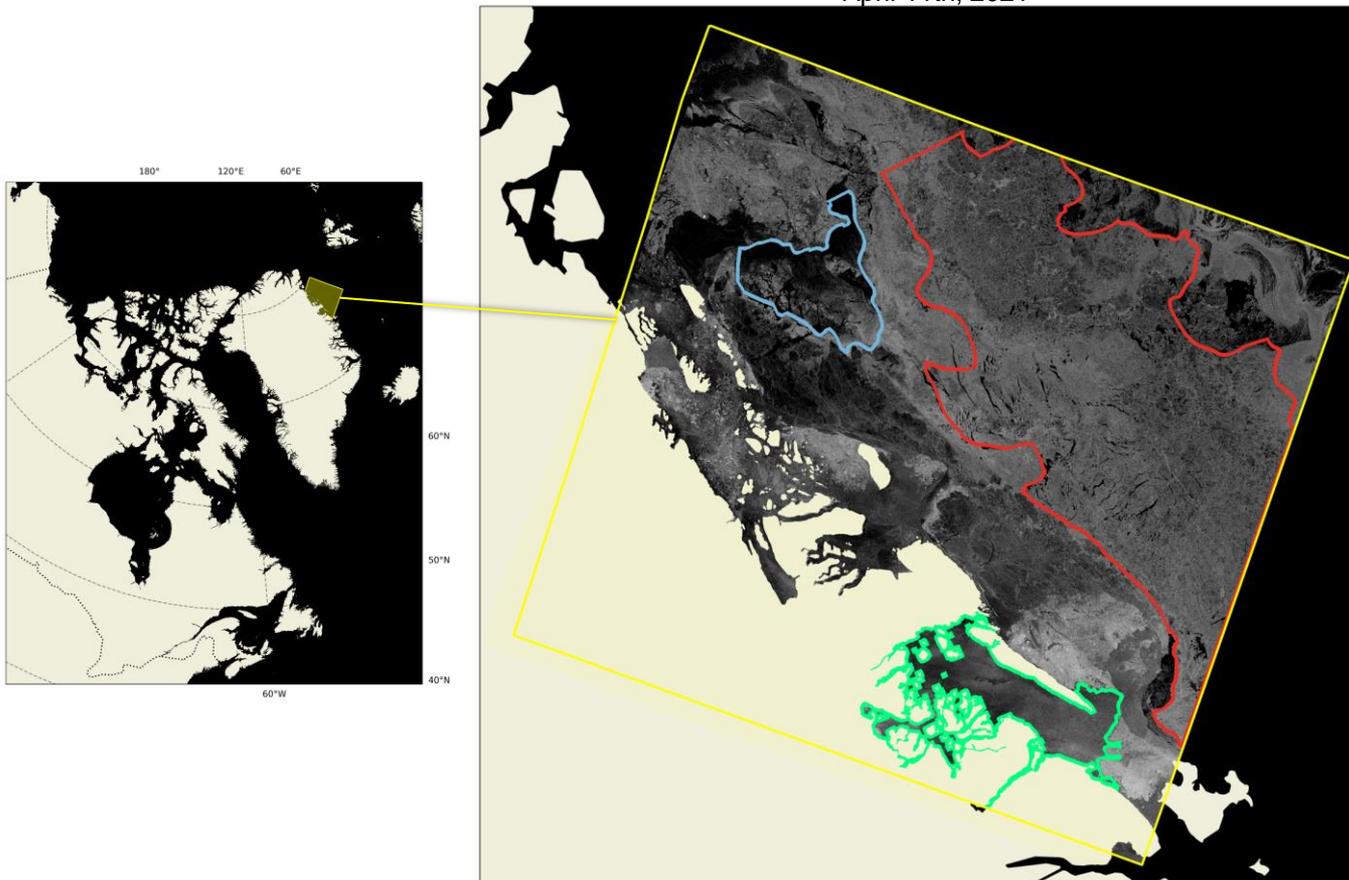
Sentinel-1 HH
April 11th, 2021

New Ice (< 10 cm)	New Ice, Nilas, Ice Rind
Young Ice (10 cm - 30 cm)	Young Ice, Grey Ice, Grey - White Ice
Thin FY Ice (30 cm - 70 cm)	Thin FY Ice Stage 1, Thin FY Ice Stage 2
Thick FY Ice (70 cm - 200 cm)	Thick FY Ice, Medium FY Ice
MY Ice (> 200 cm)	Second Year Ice, MY Ice
Glacier Ice	Glacier Ice



DMI-ASIP SoD comparison with ice charts

Sentinel-1 HH
April 11th, 2021



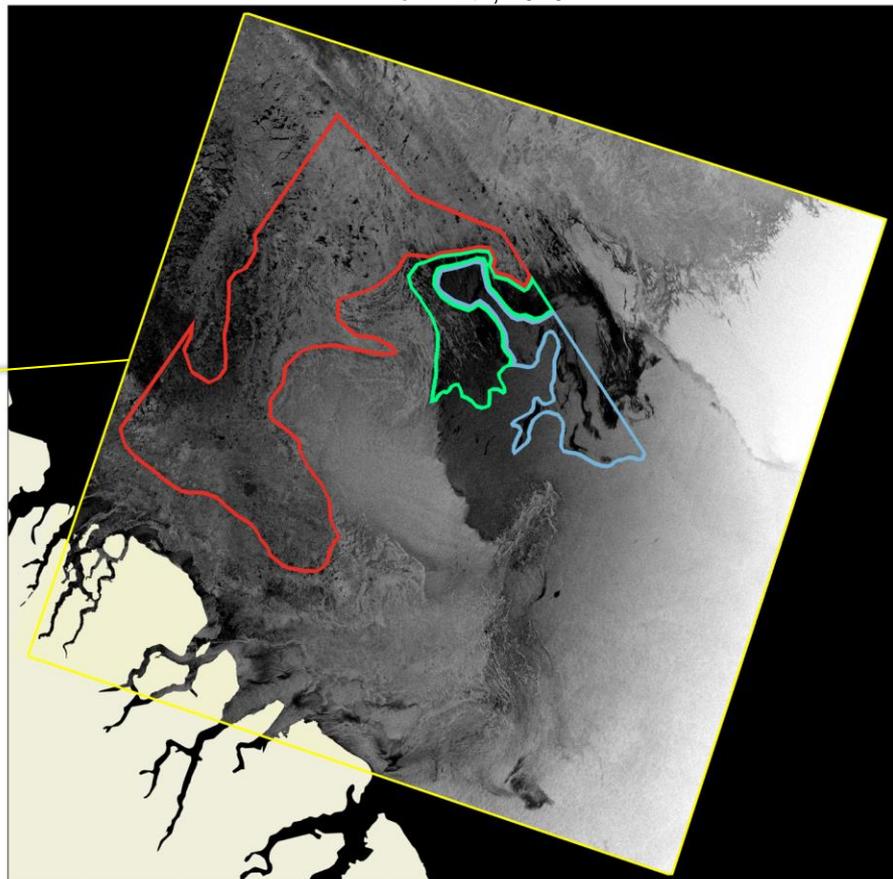
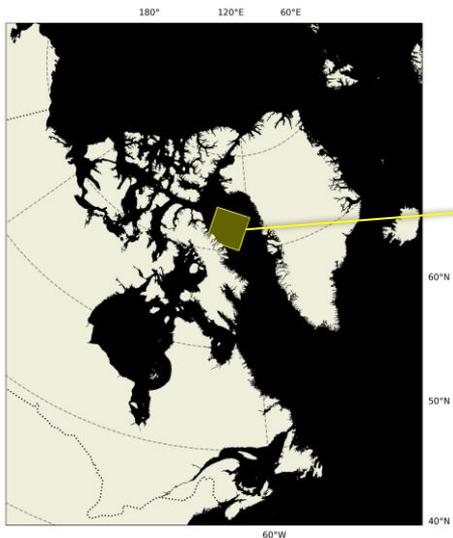
Ice Chart	DMI-ASIP
100% SIC	95% SIC
70% MY Ice	70% MY Ice
30% Thick FY Ice	30% Thick FY Ice

100% SIC	100% SIC
100% Thick FY Ice	80% Thick FY Ice
-	15% MY Ice
-	5% Thin FY Ice

90% SIC	95% SIC
20% MY Ice	20% MY Ice
80% Thick FY Ice	35% Thick FY Ice
-	10% Thin FY Ice
-	20% Young Ice
-	15% New Ice

DMI-ASIP SoD comparison with ice charts

Sentinel-1 HH
Nov. 12th, 2020



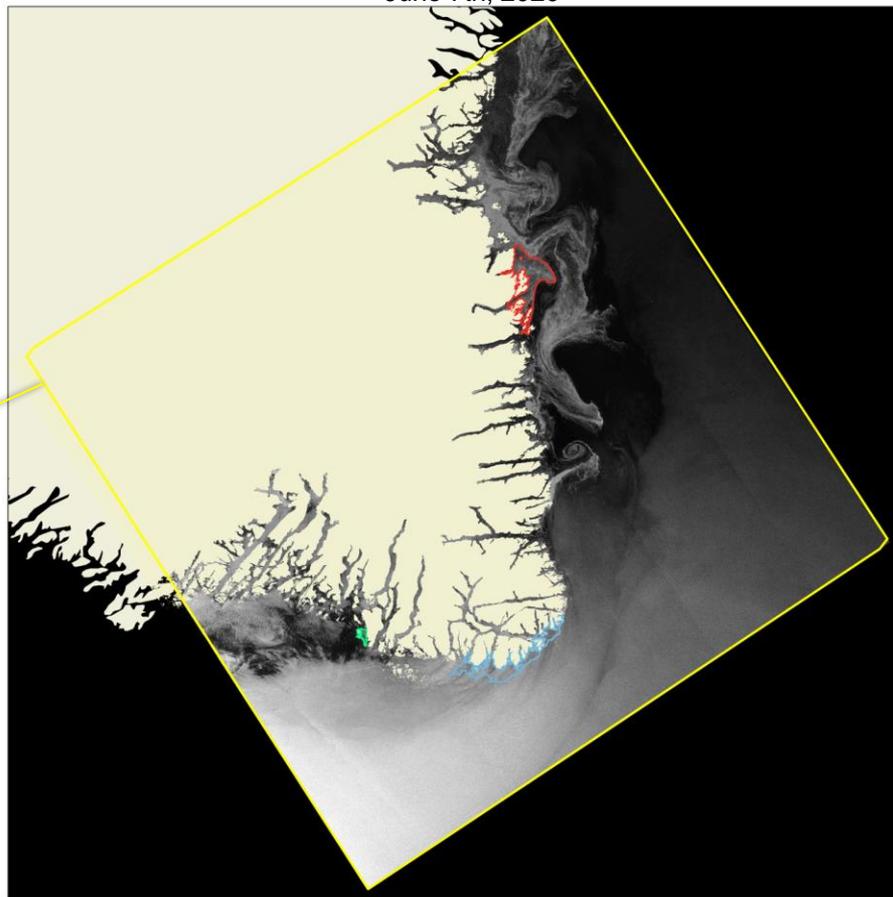
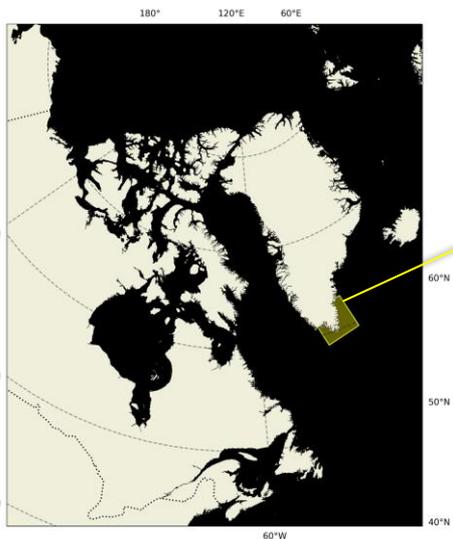
Ice Chart	DMI-ASIP
100% SIC	95% SIC
90% Young Ice	65% Young Ice
10% New Ice	35% New Ice

70% SIC	50% SIC
30% Young Ice	30% Young Ice
70% New Ice	70% New Ice

40% SIC	20% SIC
100% New Ice	80% New Ice
-	20% Young Ice

DMI-ASIP SoD comparison with ice charts

Sentinel-1 HH
June 7th, 2020



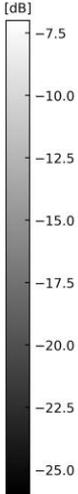
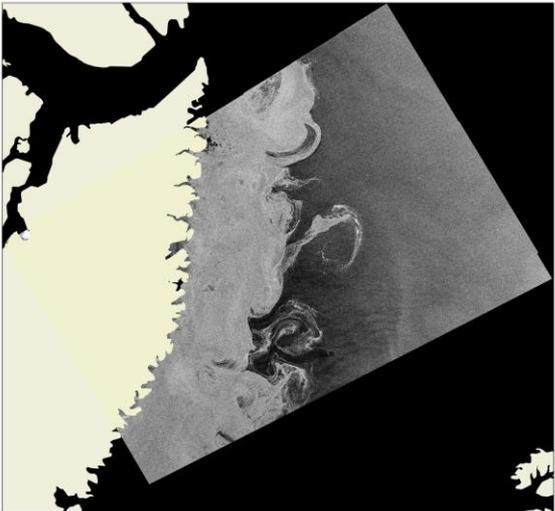
Ice Chart	DMI-ASIP
60% SIC	60% SIC
65% MY Ice	55% MY Ice
35% Thick FY Ice	45% Thick FY Ice

40% SIC	20% SIC
75% MY Ice	35% MY Ice
25% Thick FY Ice	10% Thick FY Ice
-	55% Glacier Ice

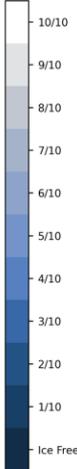
20% SIC	15% SIC
100% MY Ice	60% MY Ice
-	20% Thick FY Ice
-	20% Glacier Ice

DMI-ASIP integration of RCM data

RCM HH (Scan SAR 50m)
March 14th, 2022



Ice Chart



DMI-ASIP SIC
(trained on Sentinel-1)

