Arctic sea Ice observations from satellite SAR and PMW data using deep learning

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Anton Korosov, *Nansen Environmental Remote Sensing Center (NERSC), Bergen, Norway*

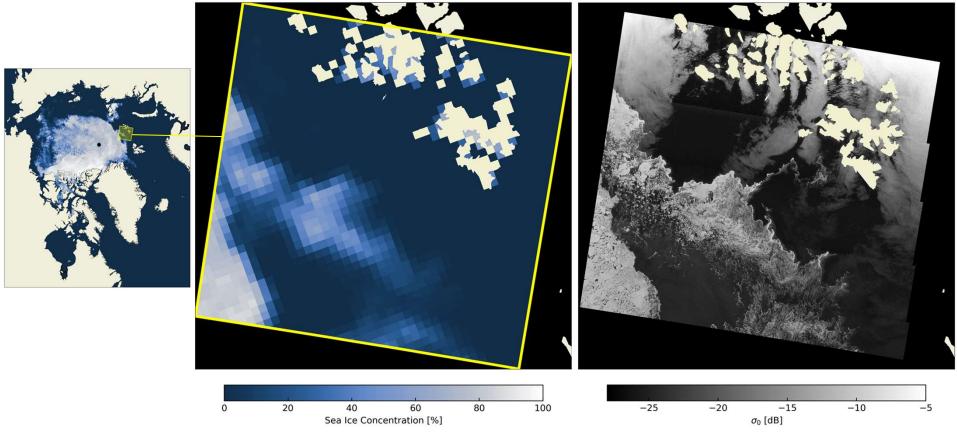Frode Dinessen and Cecilie Wettre, *Norwegian Meteorological Institute (MET), Oslo and Bergen, Norway*

Motivation for SAR-based sea ice retrievals

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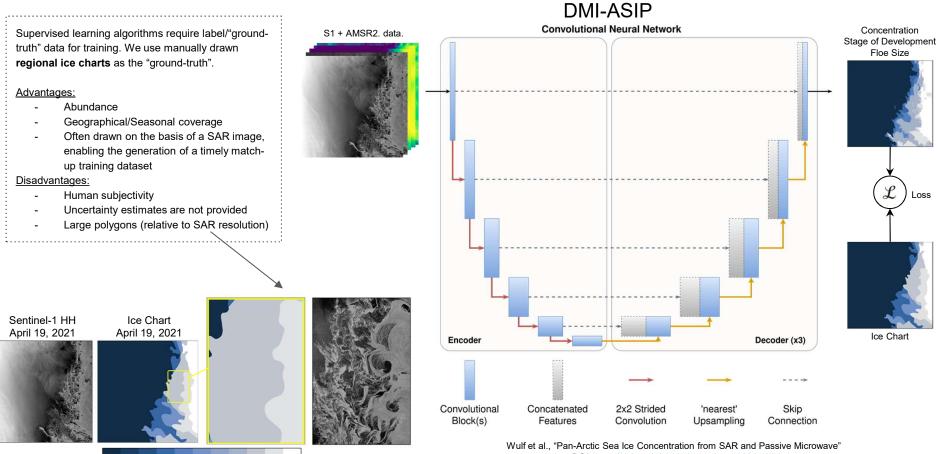Sea Ice Concentration (SIC)
Sep. 9th, 2021, 12:00 UTC

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

Sea Ice Concentration [%]

0   20   40   60   80   100

σ_0 [dB]

−25   −20   −15   −10   −5

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)

Sentinel-1 HH
April 19, 2021

Ice Chart
April 19, 2021

Ice Free 1/10 2/10 3/10 4/10 5/10 6/10 7/10 8/10 9/10 10/10
Sea Ice Concentration

S1 + AMSR2. data.

DMI-ASIP
Convolutional Neural Network

Encoder

Decoder (x3)

Convolutional Block(s)

Concatenated Features

2x2 Strided Convolution

'nearest' Upsampling

Skip Connection

Concentration
Stage of Development
Floe Size

$\mathcal{L}$ Loss

Ice Chart

Wulf et al., "Pan-Arctic Sea Ice Concentration from SAR and Passive Microwave"
DOI: https://doi.org/10.5194/egusphere-2024-178

Copernicus Marine Service

The Danish Meteorological Institute

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

Sentinel-1 HH

Ice chart polygon map

Ice chart look-up table

Sentinel-1 HV

AMSR-2 brightness temperatures

6.9 GHz, H-pol

18.7 GHz, H-pol

89.0 GHz, H-pol

Buus-Hinkler et al., "AI4Arctic Sea Ice Challenge Dataset", DOI: https://doi.org/10.11583/DTU.c.6244065.v2

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,

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

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

$$z = [z_1, z_2, \ldots, z_k].$$

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

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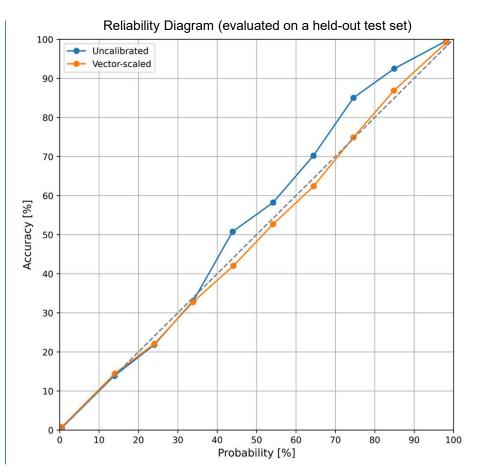
It is empirically known that modern neural networks tend to be poorly calibrated, i.e. $\hat{p}$ can not be directly interpreted as posterior probabilities, and thus does not reflect the predictive uncertainty of the trained model, hence the need for calibration,

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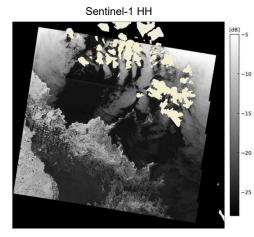
Parameters W and b are learned on a held-out validation dataset. Given a well-calibrated model output, the SIC and the associated uncertainty can be computed as a weighted average and a weighted standard deviation of the 11 increments I, respectively, with weights given by their respective class probabilities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

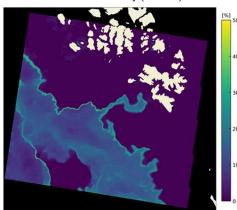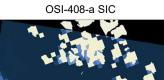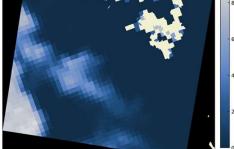$$SIC = \sum_i^k \hat{p}_i I_i \qquad STD_{SIC} = \sqrt{\sum_i^k \hat{p}_i (I_i - SIC)^2}$$

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

DMI-ASIP SIC Output Example

Sentinel-1 HH

OSI-408-a SIC
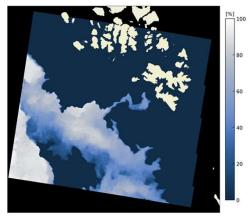
DMI-ASIP uncertainty (st. dev.)

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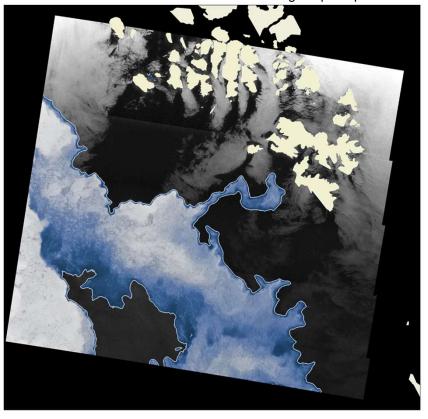
Sentinel-1 HH with DMI-ASIP SIC and ice edge superimposed

Sea Ice Concentration [%]
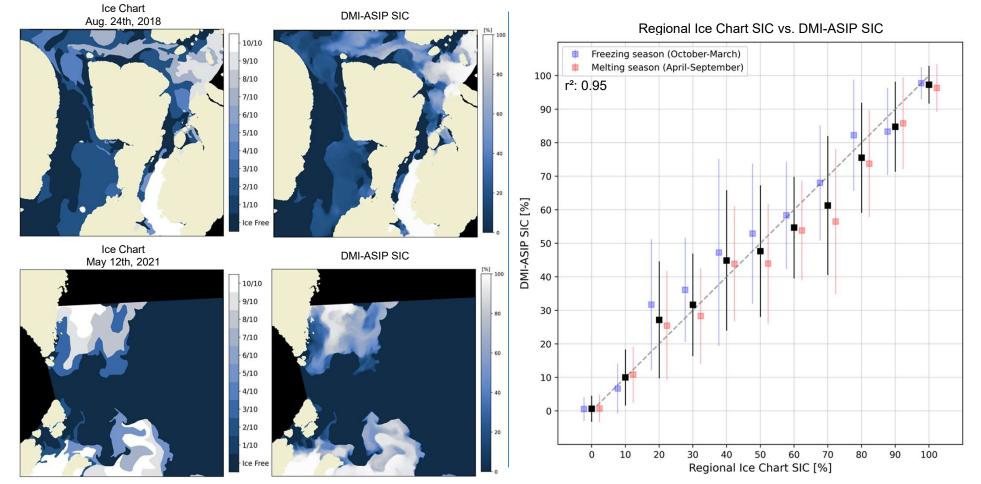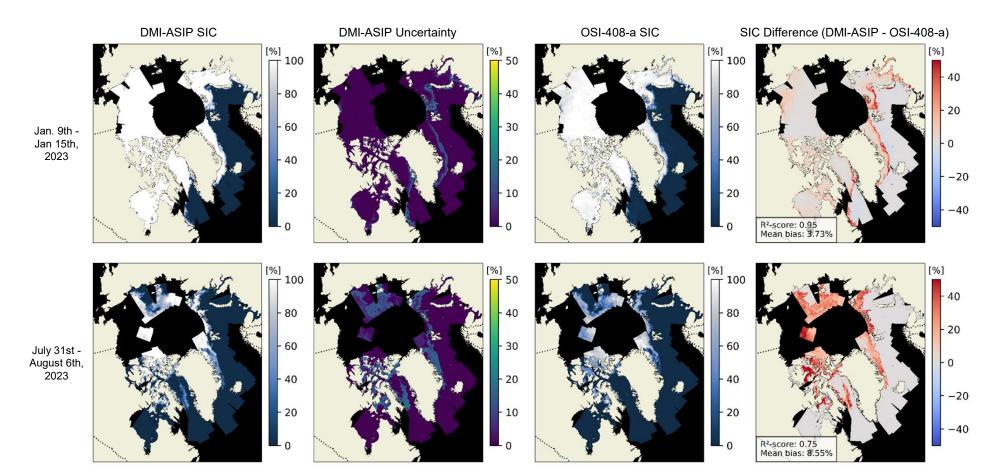
DMI-ASIP SIC evaluation against 50 regional ice charts

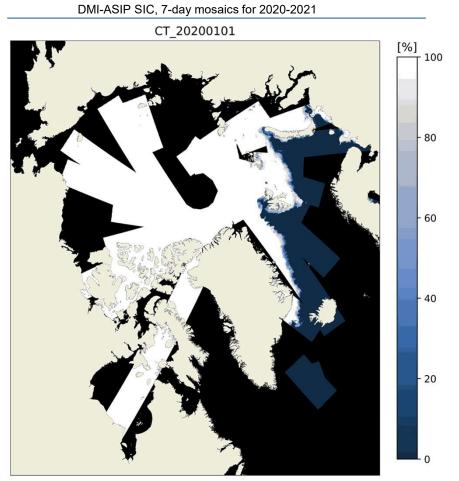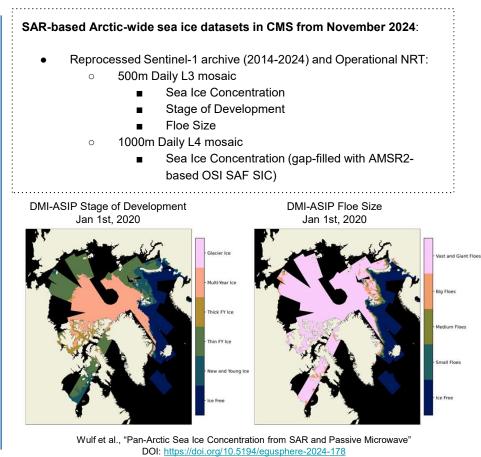# Pan-Arctic comparison with OSI-408-a

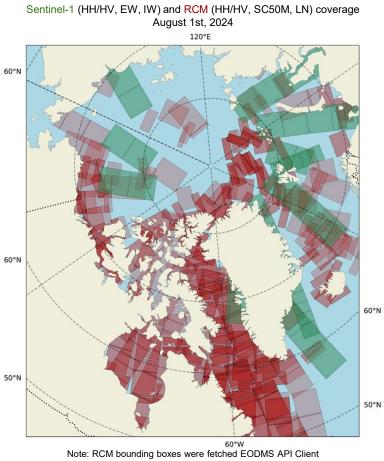# Operational NRT and reprocessed (2014-2024) datasets

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

Wulf et al., "Pan-Arctic Sea Ice Concentration from SAR and Passive Microwave"
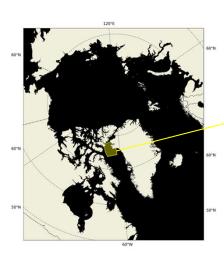DOI: https://doi.org/10.5194/egusphere-2024-178

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
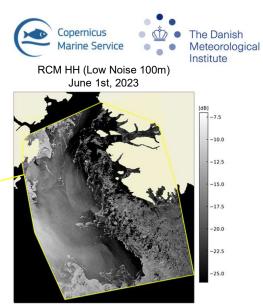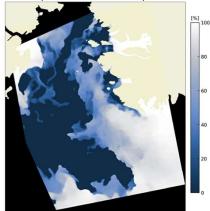
DMI Ice Chart
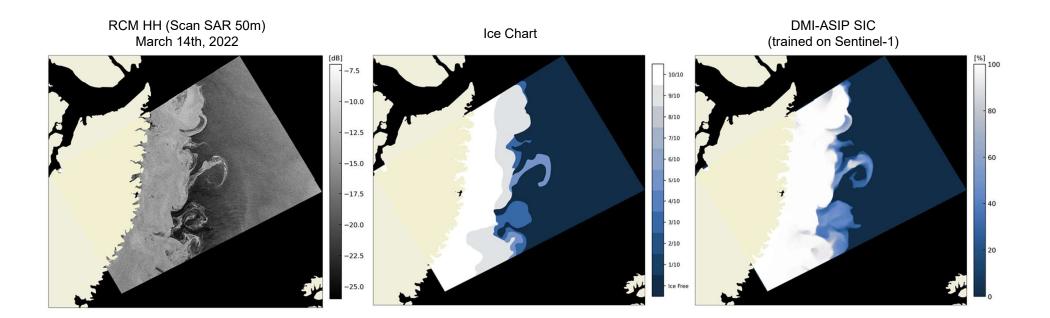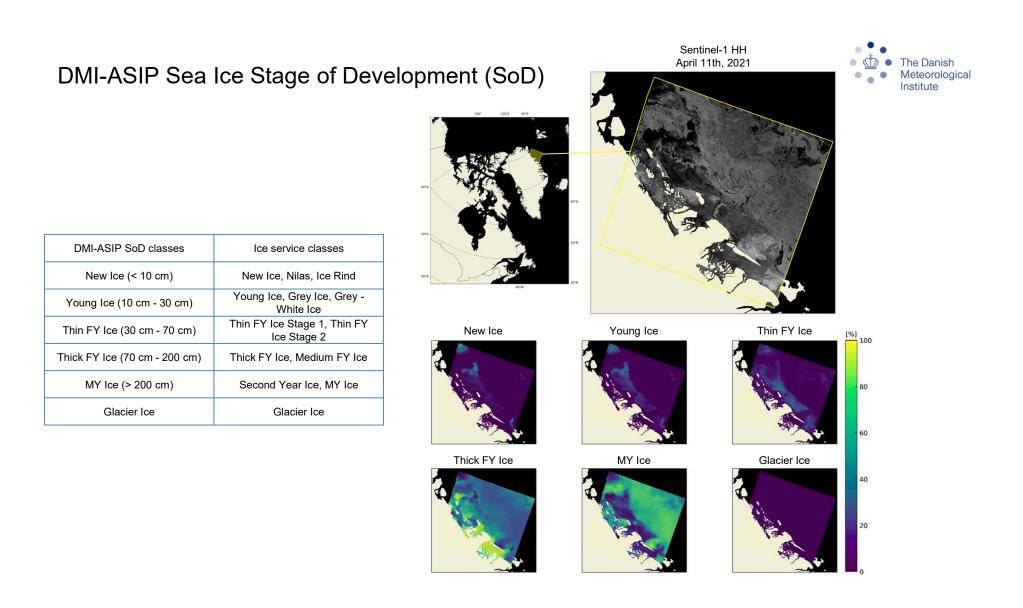
DMI-ASIP SIC
(trained on Sentinel-1)

DMI-ASIP integration of RCM data

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

Ice Chart

DMI-ASIP SIC
(trained on Sentinel-1)

DMI-ASIP Sea Ice Stage of Development (SoD)

DMI-ASIP SoD classes	Ice service classes
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

Sentinel-1 HH
April 11th, 2021

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
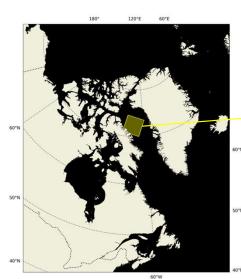
100% SIC	100% SIC
100% Thick FY Ice	80% Thick FY Ice
-	15% MY Ice
-	5% Thin FY Ice
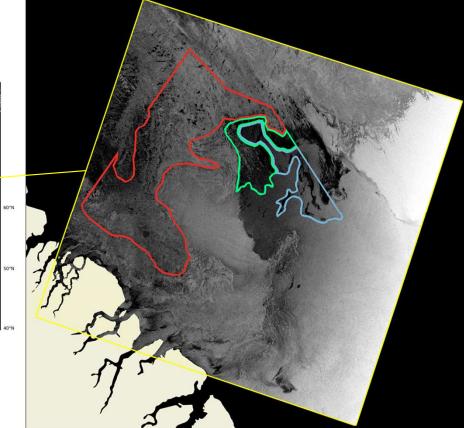
90% SIC	95% SIC
20% MY Ice	20% MY Ice
80% Thick FY Ice	35% Thick FY Ice
-	10% Thin FY Ice
-	20% Young Ice
-	15% New Ice

DMI-ASIP SoD comparison with ice charts

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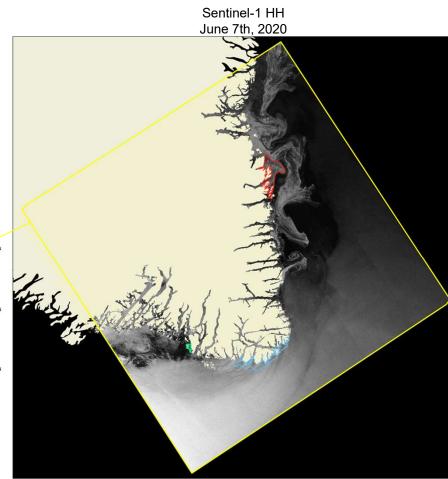
70% SIC	50% SIC
30% Young Ice	30% Young Ice
70% New Ice	70% New Ice

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

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

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

The Danish
Meteorological
Institute

Thanks for listening!

Dataset

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

Paper

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