Sea Ice Mapping from SAR:

An overview of methods and approaches developed during 8 years of CIRFA

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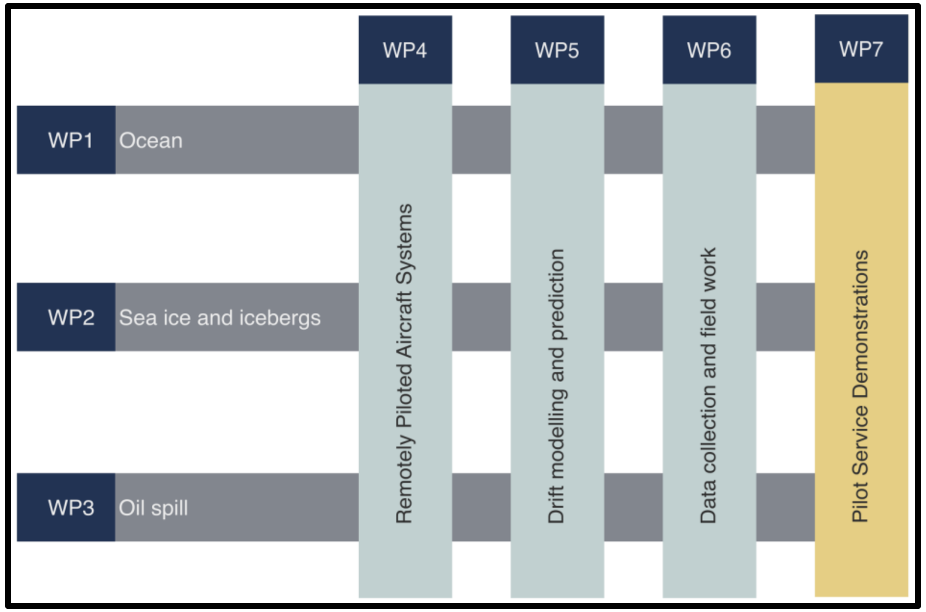
SuperIce Workshop 2024
Frascati

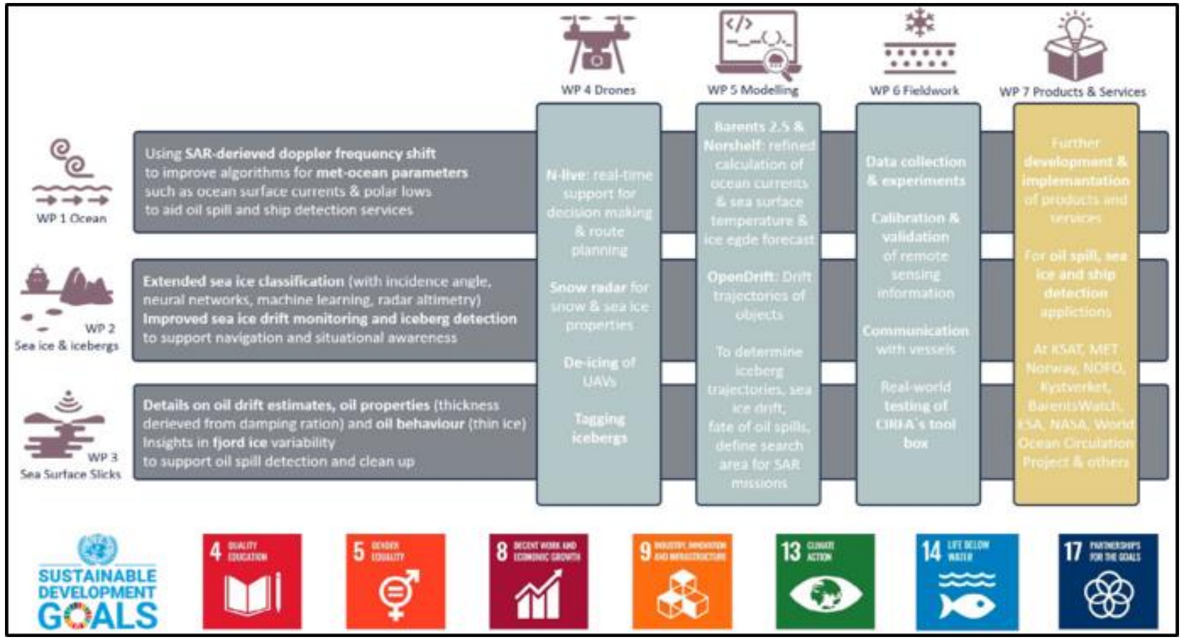
CIRFA overview

Center for Integrated Remote Sensing and Forecasting for Arctic Operations

- NFR and industry-funded center for **research-based innovation** (SFI)
- Conduct research and develop methods to **advance remote sensing monitoring capabilities and forecasting skills**, enabling safer operations, and reduced risk of human-induced environmental hazards
- Become a **knowledge hub for Arctic remote sensing**, specifically addressing challenges of maritime industrial operations in Arctic waters
- **Met-ocean, sea ice, and oil spill remote** sensing



CIRFA WP2: Sea ice and icebergs

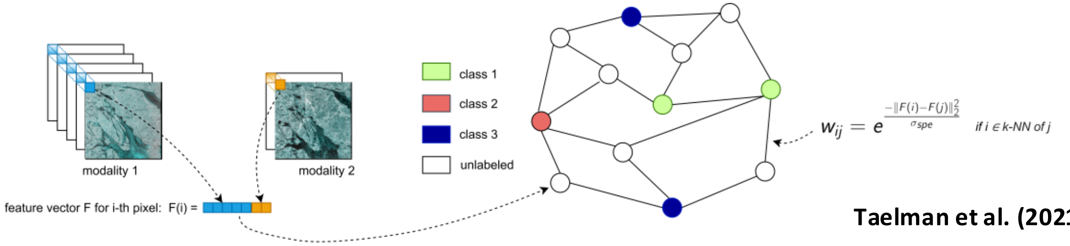


WP2:

- High-resolution **sea ice mapping** and iceberg detection
- Sea ice drift retrieval
- Focus on **SAR**, but combinations with multi-spectral instruments and PMR data
- Investigate radar scattering mechanisms from snow and sea ice
- Multi-frequency SAR

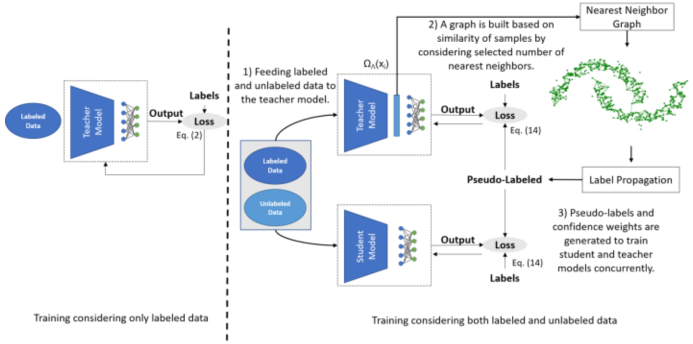
CIRFA WP2: Sea ice mapping approaches

Graph-based label propagation:



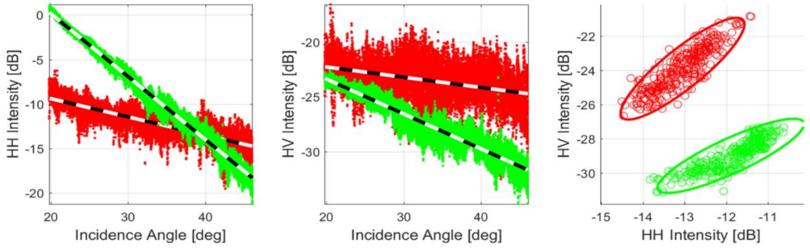
Taelman et al. (2021)

Deep Semi-Supervised Teacher-Student Model based on Label Propagation (TSLP-SSL):



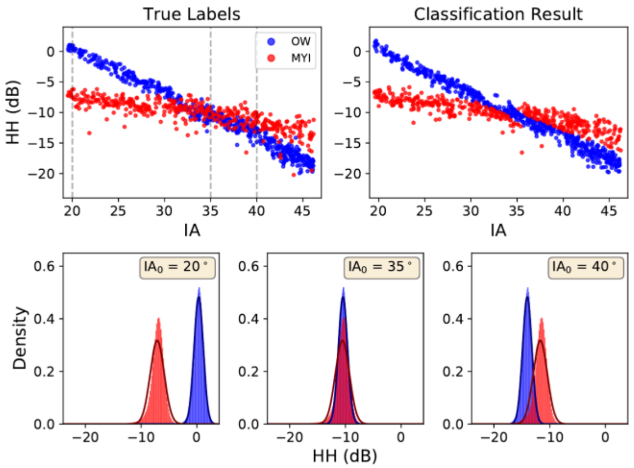
Khalegian et al. (2021)

Unsupervised statistical methods:



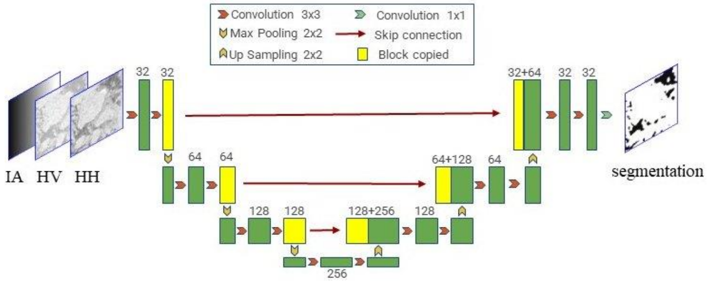
Cristea et al. (2020)

Supervised statistical methods:



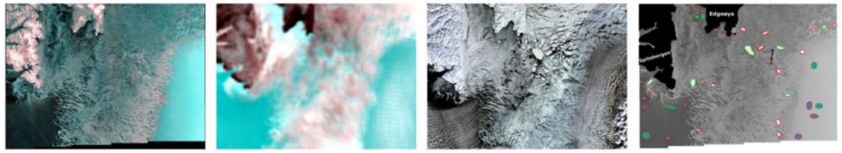
Lohse et al. (2020)

Reduced UNET architecture for pixel-wise classification:



Wang et al. (2023)

Graph-based information selection from multi-sensor data:



Khachatrian et al. (2022)

Outline

- Sea ice in SAR imagery
- **Statistical methods**
  - Demonstrated in operations for navigation support
  - Understand the SAR signal from sea ice
- **UNET for pixel-wise ice-water separation**
  - Advantages of machine learning for this task
  - Challenges when expanding it to other ice types
- Comparison of images and **ice charts**
  - Why train on ice charts?
  - Or why not?
- Thoughts/ideas/recommendations for **future work**

What controls the appearance of sea ice in SAR imagery?

Sea ice parameters:

- **Large-scale** features and **sea ice conditions**

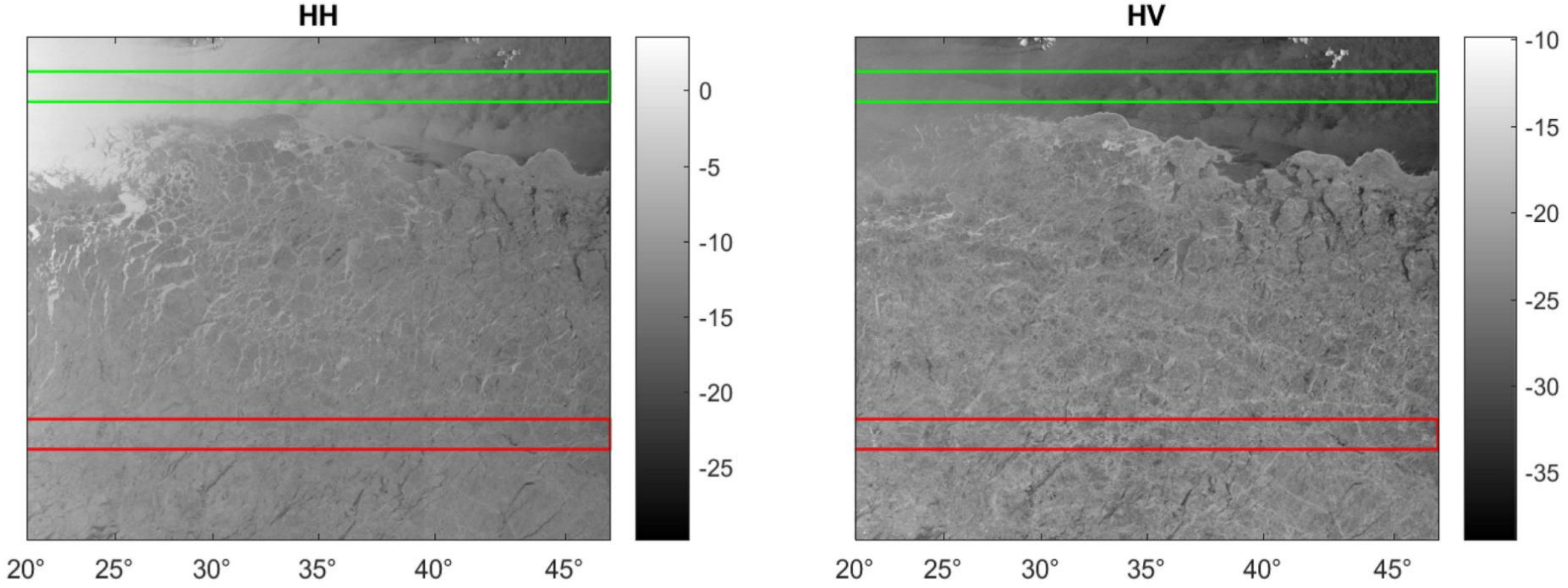
  (level ice, deformed ice, ridges, leads, young ice, ...)

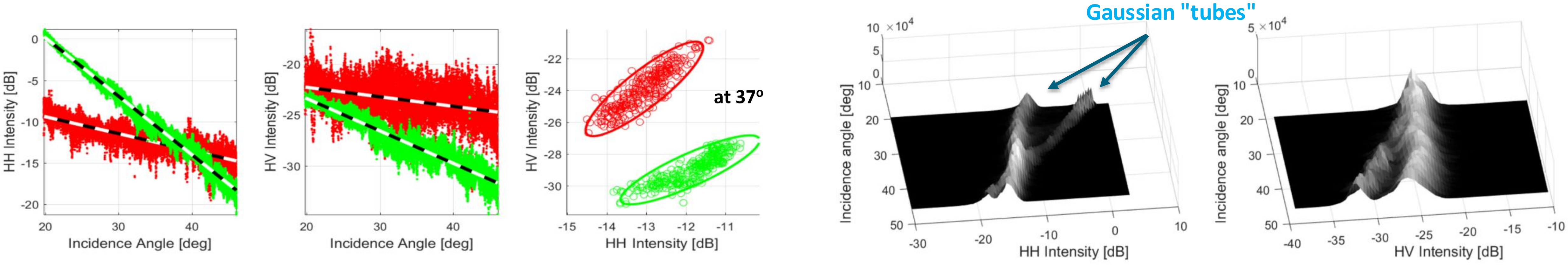
- **Small-scale** surface roughness (mm-dm)
- Sea ice **volume structure** (layers, brine inclusions, air bubbles)
- Sea ice **temperature** and **salinity**
- **Snow** cover (density, grain size, moisture content)

Radar parameters:

- Frequency, polarization, **incidence angle**
- Spatial resolution

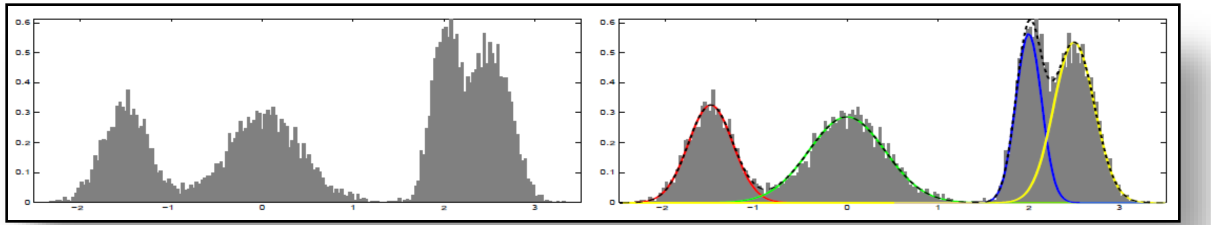
Incidence angle effect





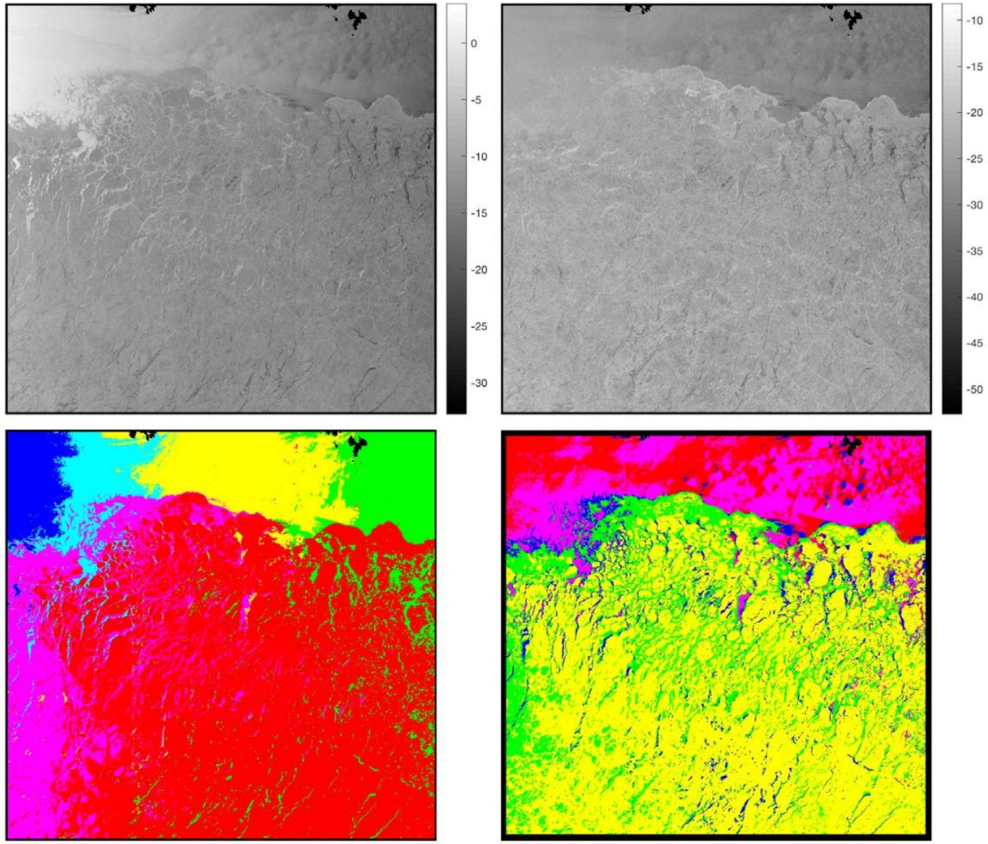
Gaussian mixture model with linearly variable mean

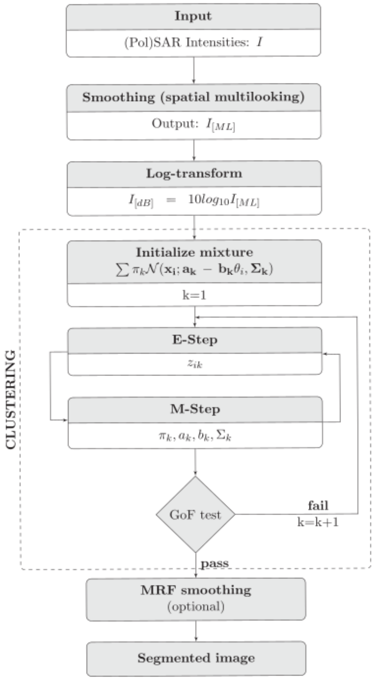
- Fit **multi-variate Gaussian** functions to the data until the image statistics are well represented
- Use statistics from entire image
- Incidence angle leads to banding in segmentation



For continuous segments in wide-swath SAR imagery:

- Assume a **linear variation of mean** vectors
- With **class-dependent slopes**
- Replace constant mean with linearly variable mean: $\bar{I}_{\mathrm{dB}}(\theta_i) = a - b\theta_i$





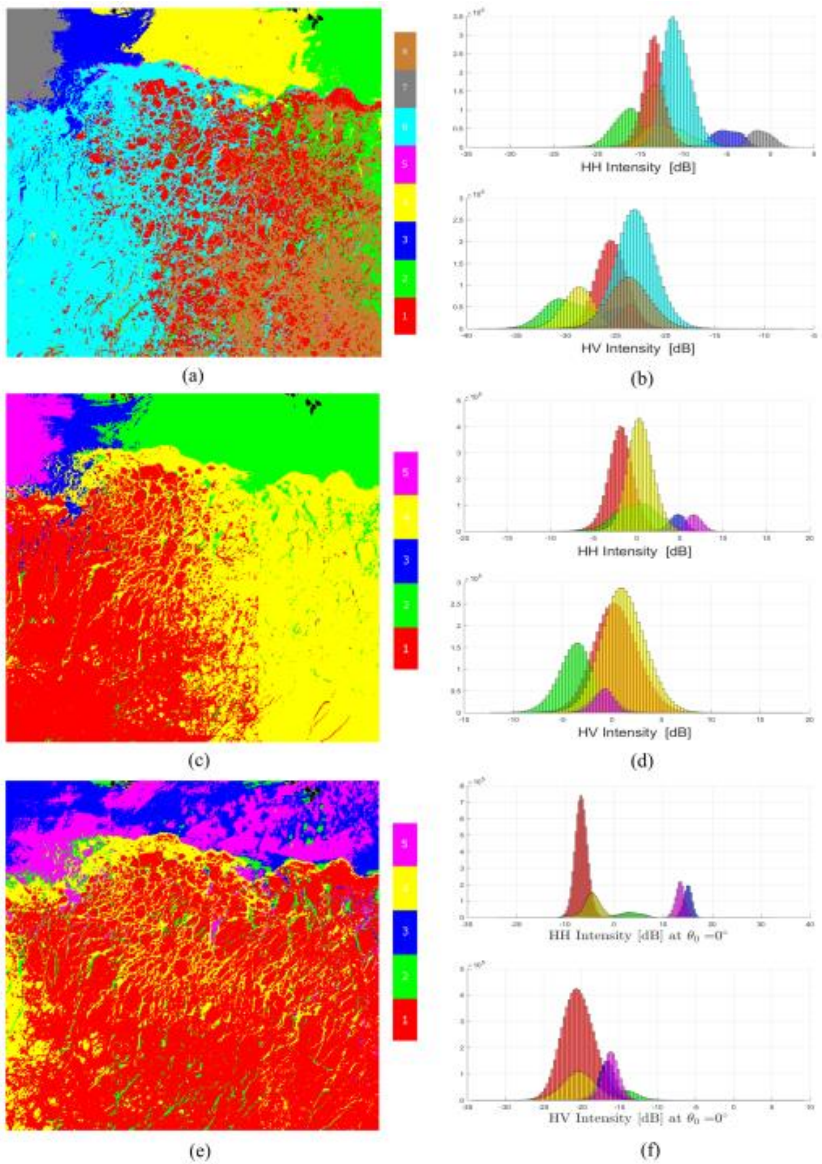
Gaussian mixture model with linearly variable mean

a) and b): Gaussian mixture model

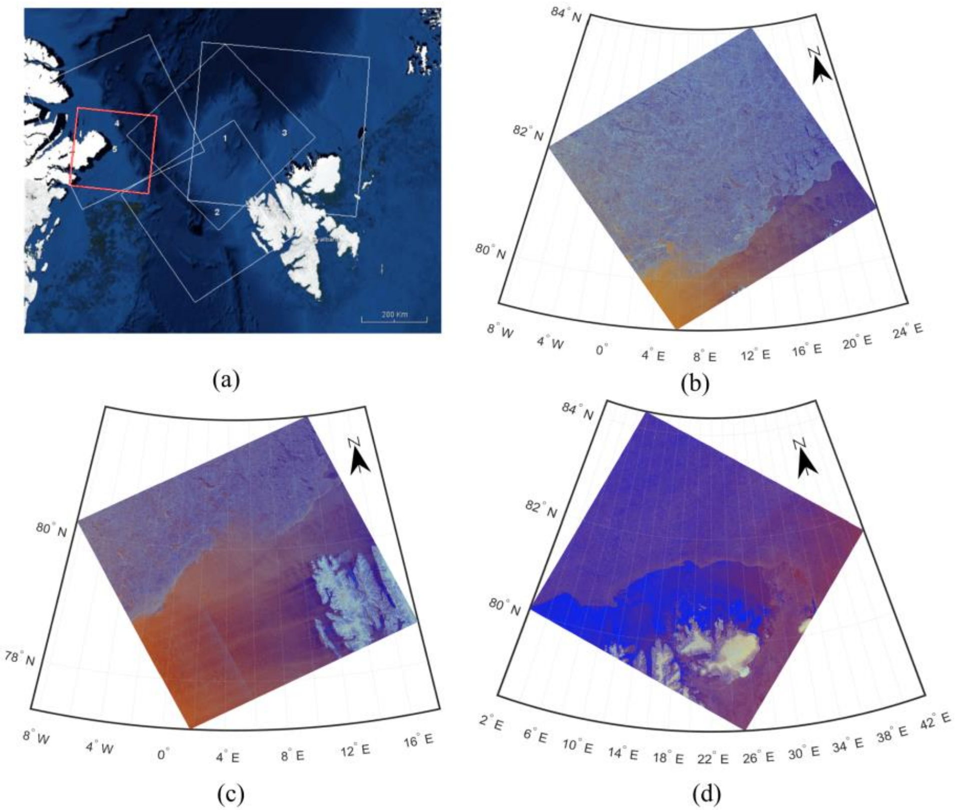
c) and d): Gaussian mixture model with global IA correction

e) and f): Non-stationary mixture model

Results from the three approaches show incremental **improvement of across-range segment connectivity and class distinction.**

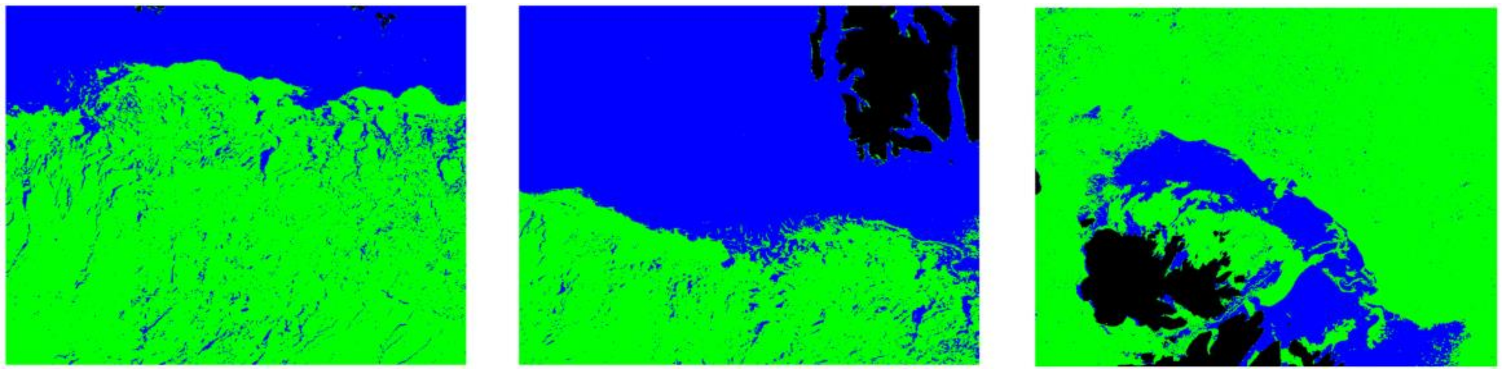


Unsupervised image segmentation: Ice-vs-Water?



Ice-water maps can be obtained by segmentation and thresholding of the slopes

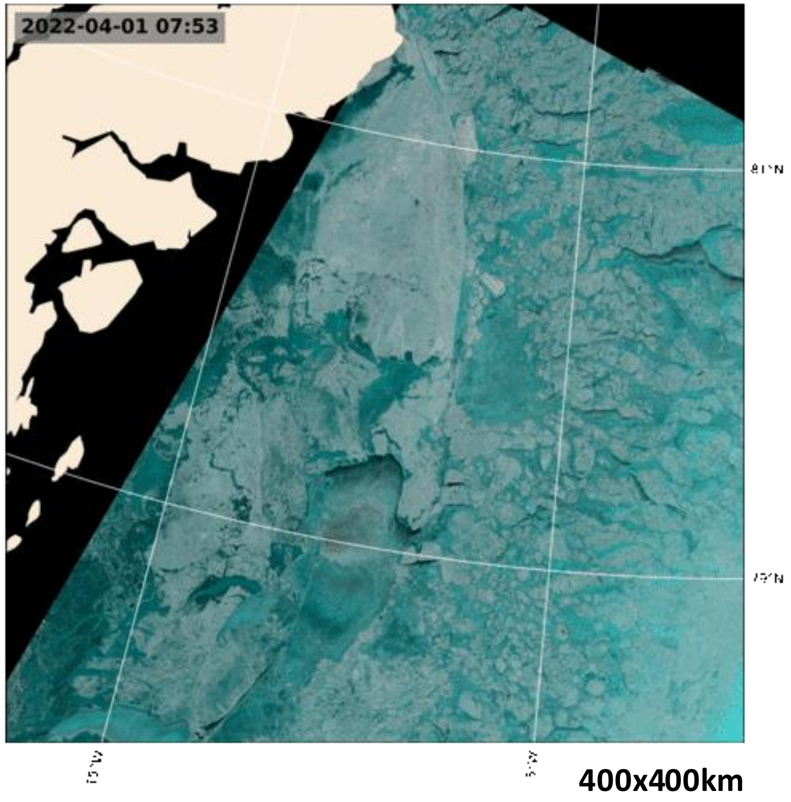
- Water usually has a steeper slope than ice
    - Mostly single-bounce surface scattering
- Some dark areas can me mis-labelled -> additional information needed

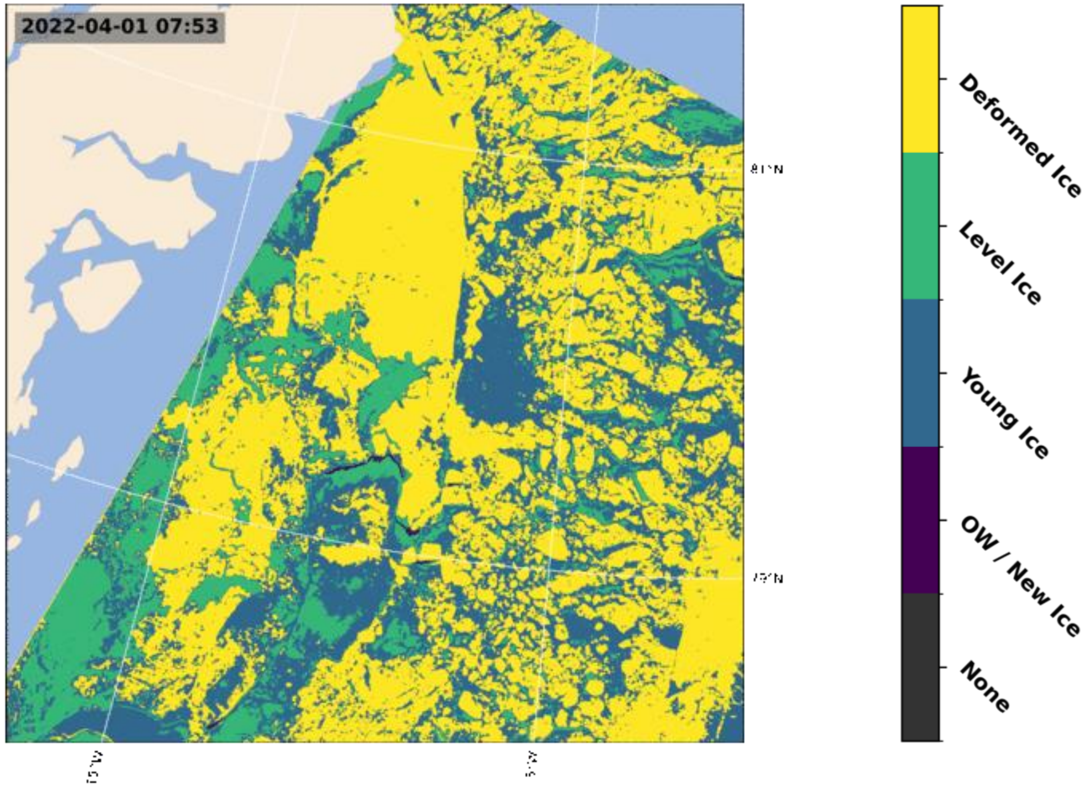


Supervised classification with per-class IA effect

We can apply the same concept in a **supervised** way:

Learn **slope, intercept, and covariance matrix** directly from training data.



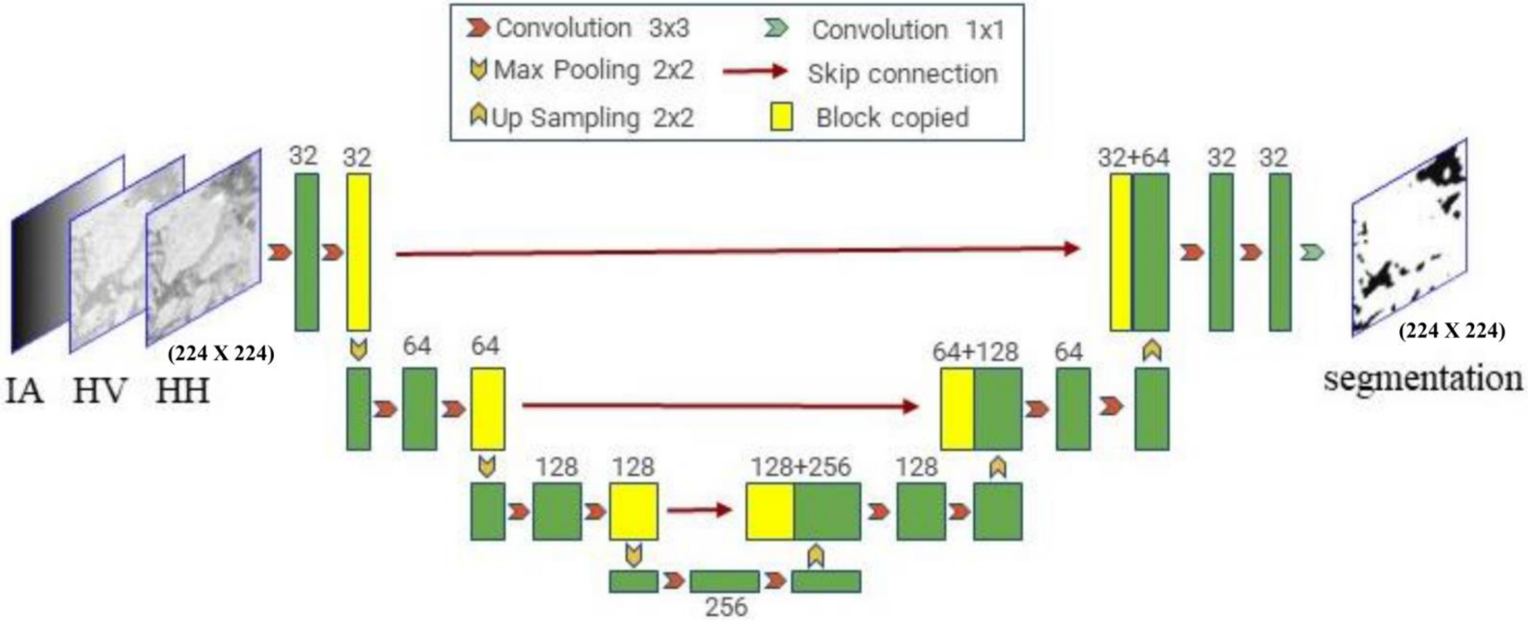


- Works well for most ice types
- Most challenging ice type: Young ice -> varying backscatter due to small-scale surface roughness
- Difficult for open water, when using only backscatter intensity

Ice-water mapping

- "Traditional" methods (e.g. statistical approaches) require **texture features for reliable ice-water separation**
    - e.g. GLCM texture
    - Long computation time for high resolution
    - Actual resolution reduced by large window sizes

- **CNNs perform much better** (and faster) at this task
- Most people seem to go for a UNET ...
    - How to train the network?
    - Ice charts?

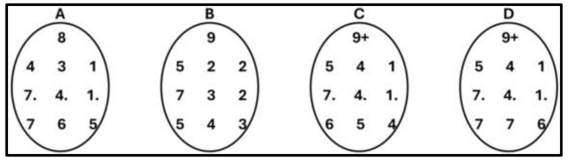


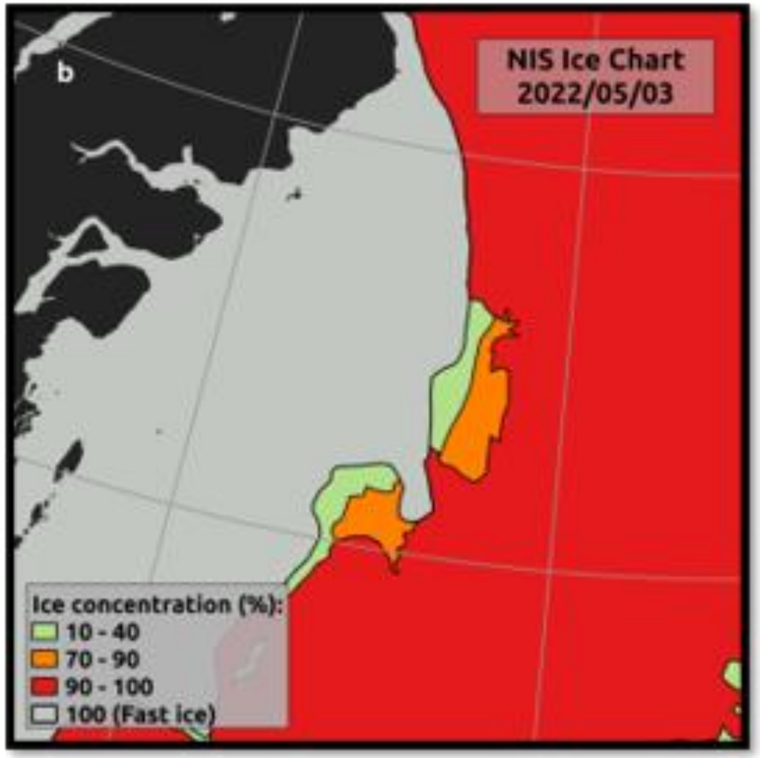
Train CNN for ice-water mapping

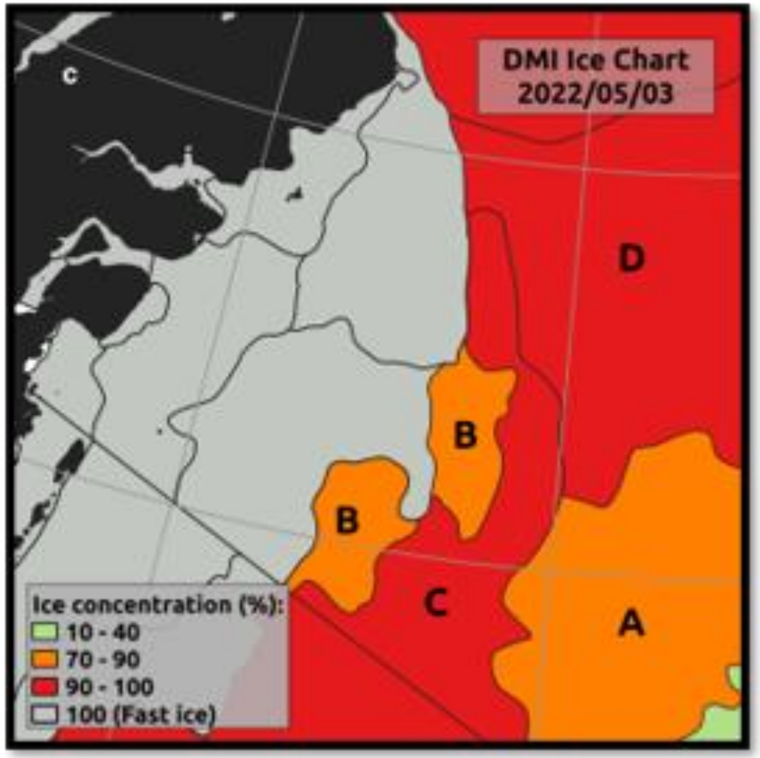
- Training the network from ice charts (AutoICE, DMI-ASIP, etc)
- Lots of training and good results

But:

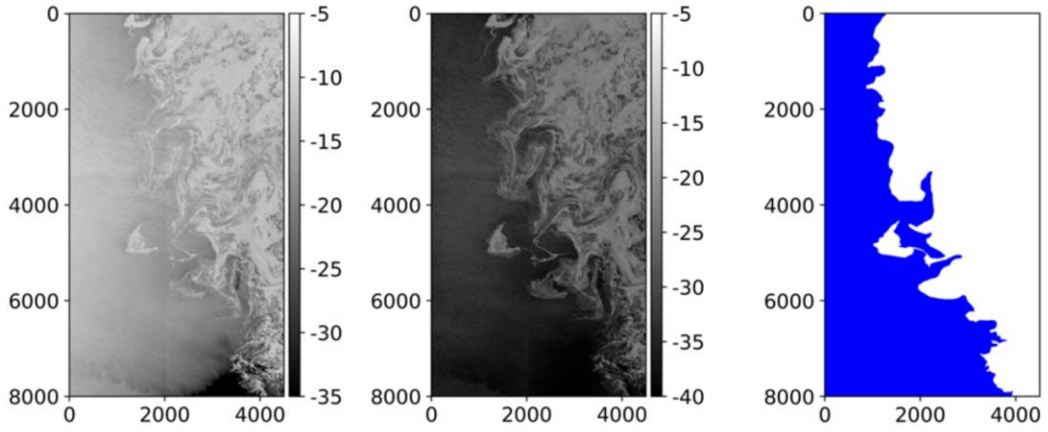
- Not directly transferable between all ice services
- Is there more information in the SAR data?







Train CNN for ice-water mapping

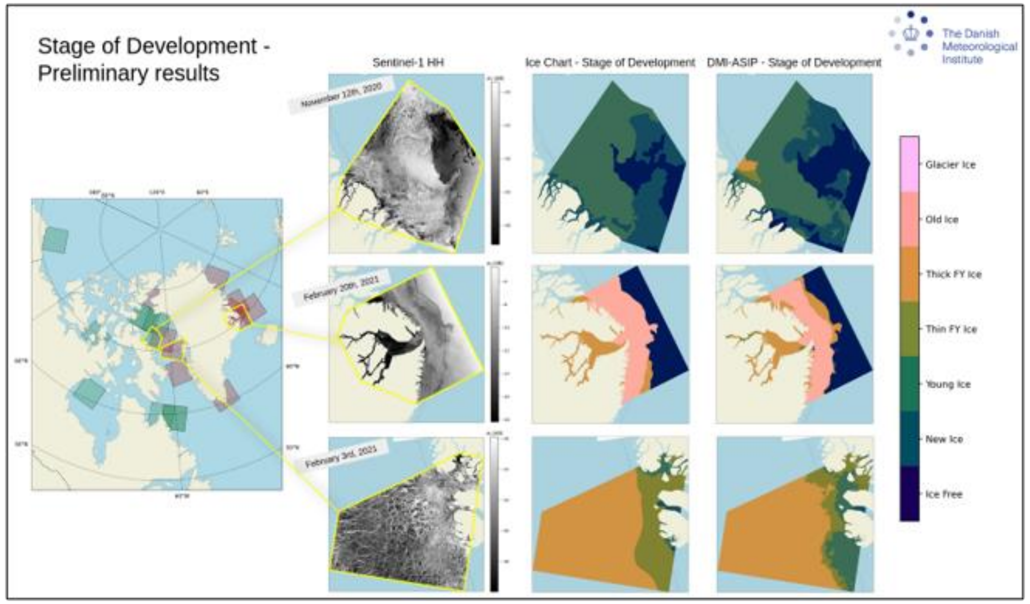


UiT and NIS training set from Extreme Earth:

- Good, but not at pixel level
- Limited amount of training data

Ice charts:

- Good, but not at pixel level
- Large amount of training data
- Preliminary results of automated SoD also good, but maybe lacking spatial detail?



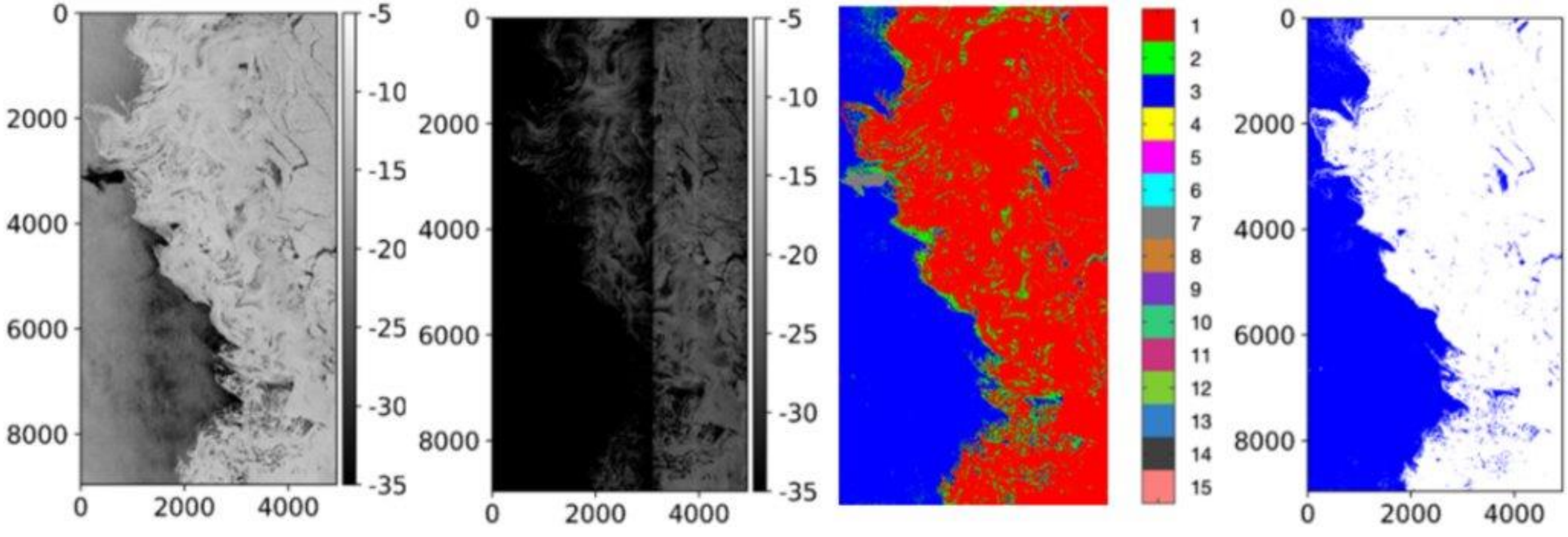
from Tore Wulf (IICWG-DA 2023 presentation)

Unsupervised segmentation for training

Different approach: Unsupervised pixel-level segmentation to generate training data

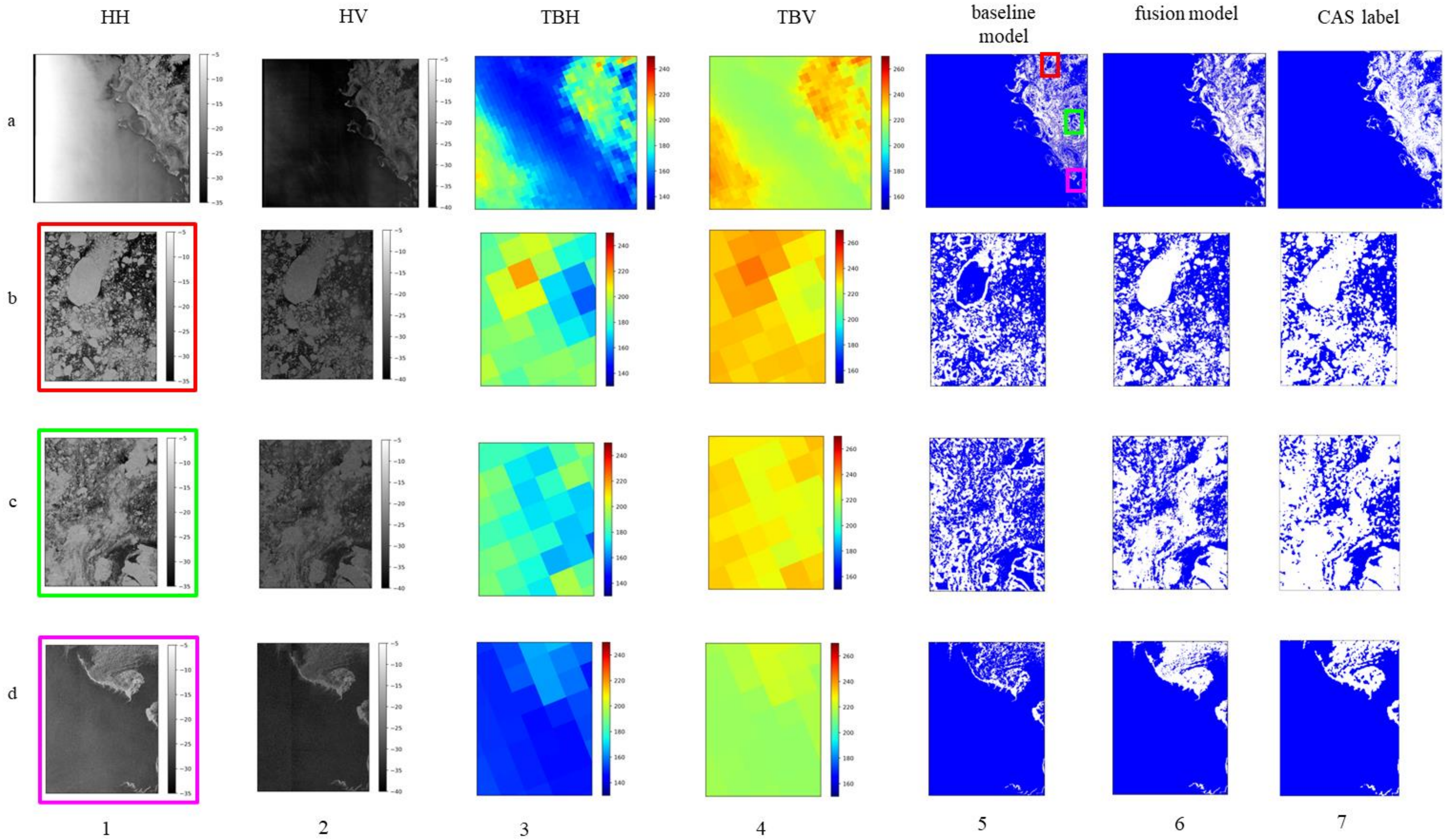
Segment the image and threshold the slopes to obtain **ice/water training on individual pixel level**

- Visual inspection and tuning of segmentation required
- Not necessary to use full images



How to treat lead areas with newly formed ice or young ice: Ice or water?

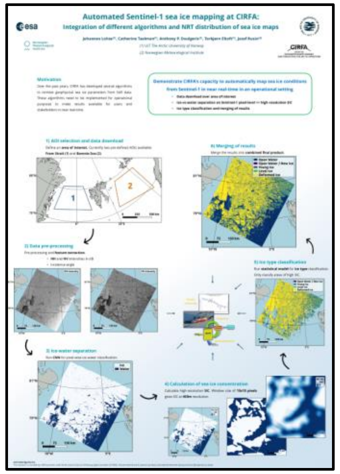
UNET for pixel-wise ice/water mapping

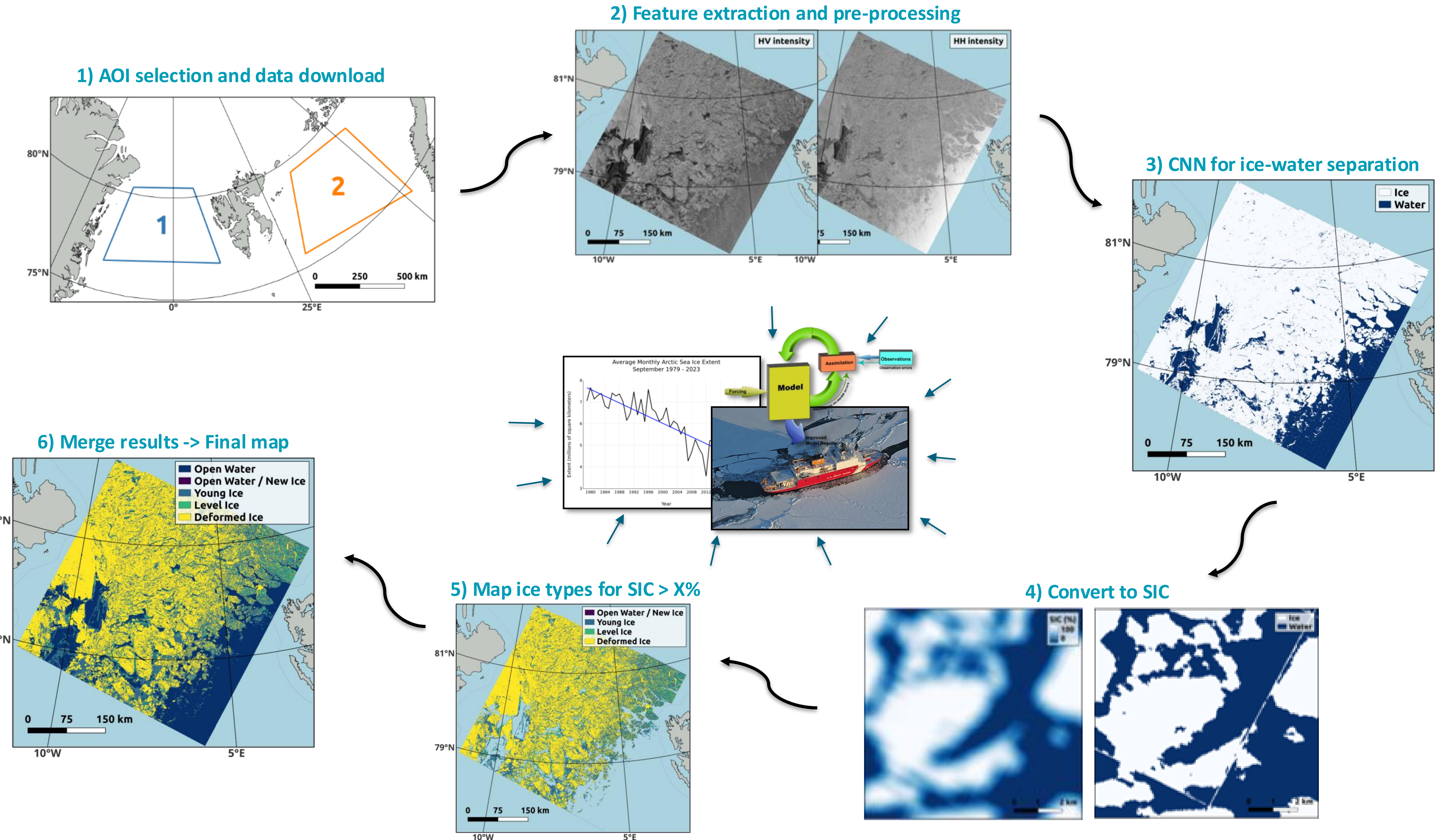


What now?

- Train on ice charts?
  - Possible to combine ice chart training from more ice services?
  - Can we add more detail about individual leads?
- Combine CNN ice/water map (any version) with pixel-wise ice type classification
  - e.g. pixel-wise ice types within ASIP polygons?
  - Or in areas of high SIC from UiT algorithm (Arctic Phi Lab)
- Prepare for L-band data (NISAR, ROSE-L, ALOS-2/4):
  - For better ice type separation (also in the melt season)
  - For ice/water mapping

SCAN ME





1) AOI selection and data download
80°N
75°N
0°
25°E
1
2
0 250 500 km
2) Feature extraction and pre-processing
HV intensity
HH intensity
81°N
79°N
0 75 150 km
10°W
5°E
3) CNN for ice-water separation
Ice
Water
81°N
79°N
0 75 150 km
10°W
5°E
4) Convert to SIC
5) Map ice types for SIC > X%
Open Water / New Ice
Young Ice
Level Ice
Deformed Ice
81°N
79°N
0 75 150 km
10°W
5°E
6) Merge results -> Final map
Open Water
Open Water / New Ice
Young Ice
Level Ice
Deformed Ice
81°N
79°N
0 75 150 km
10°W
5°E
Average Monthly Arctic Sea Ice Extent
September 1979 - 2023
Year
Model
Assimilation
Observations
Forcing

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Questions?

(maybe later)

Thank you