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Vision & Image Processing Group
Systems Design Engineering

Automated Classification of Operational SAR Sea Ice Images

Shuhrat Ochilov and David A. Clausi

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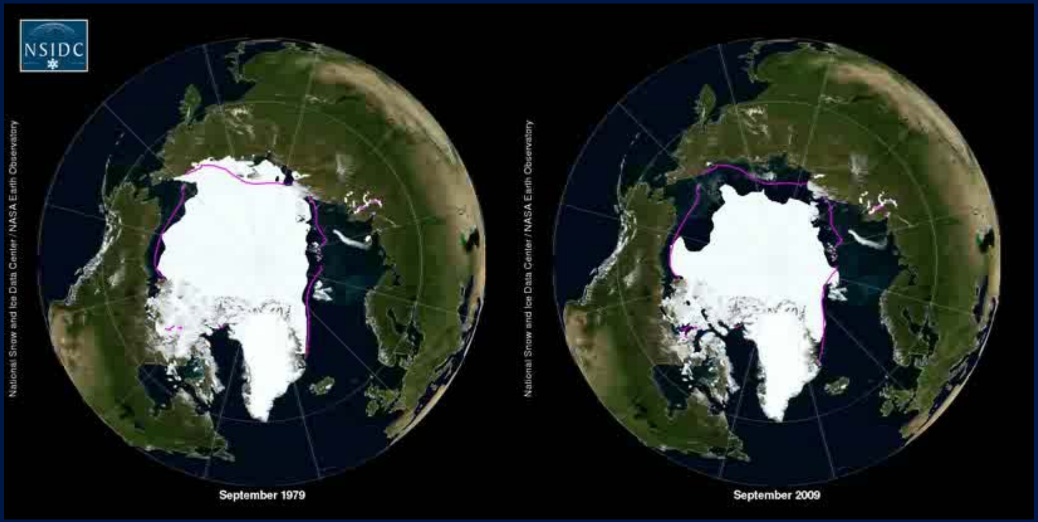
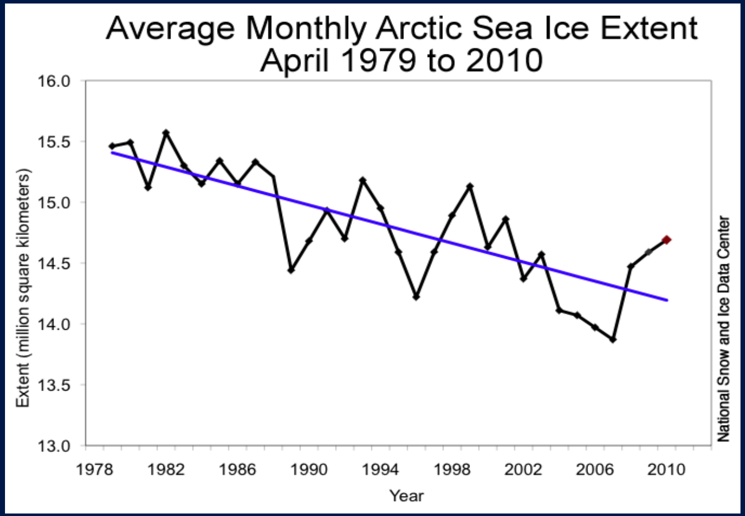
Why Processing Sea Ice Images

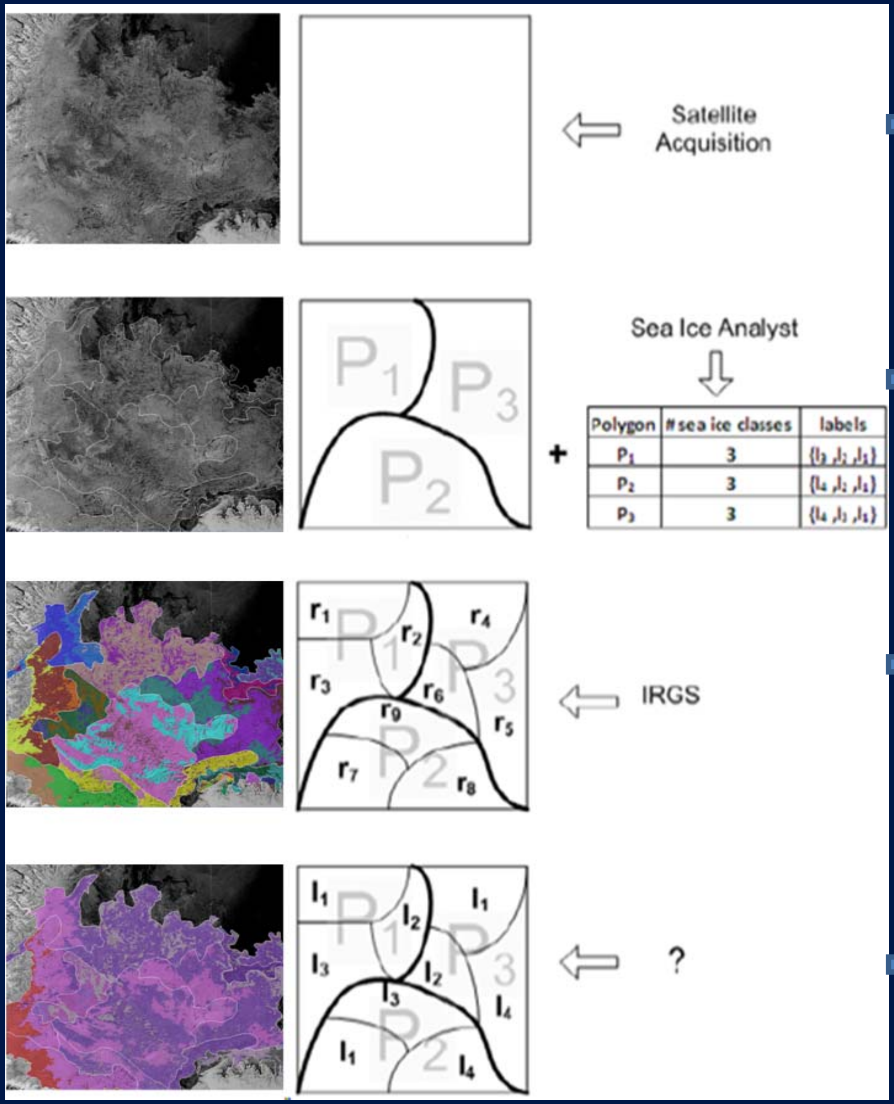
The ships are trapped in ice in the Baltic Sea of Sweden

- ***Ship Navigation***
  - *CIS manually processing approximately 4000, 10Kx10K SAR sea-ice images, annually*
- ***Climate Research***
  - *Importance of implications of climate change*





Problem Definition



- *Large synthetic aperture radar (SAR) scenes*
- *Trained ice analysts divide SAR images into "polygon" areas and then identify the number and type of ice classes per polygon*
- *Full scene clasification can be performed by first segmenting each polygon into distinct regions algorithmically.*
- *How to perform labeling if there is insufficient information to assign a sea ice label for each region within an individual polygon?*

Sea Ice Labeling Model

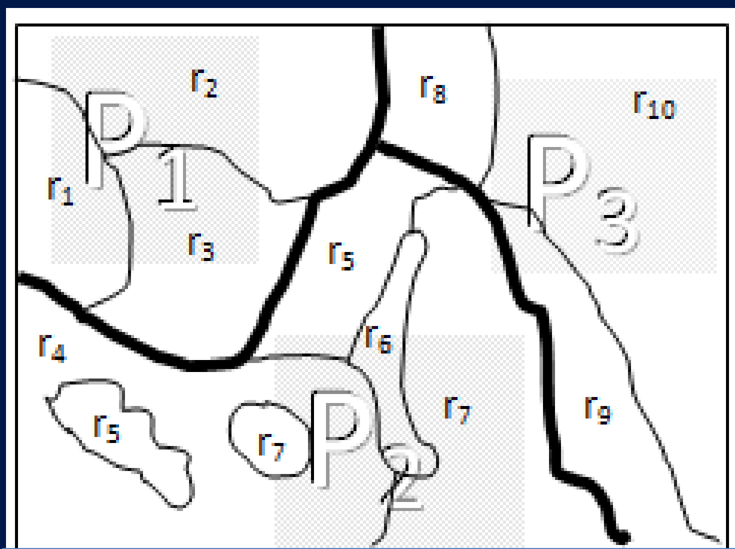
- ***Markov random field formulation using joint information to label each region in a full SAR scene has been developed to solve sea ice labelling problem***
- ***The model effectively defines the spatial and statistical relationship between the regions across the full SAR sea ice scene***

Implemented Method (highlights)

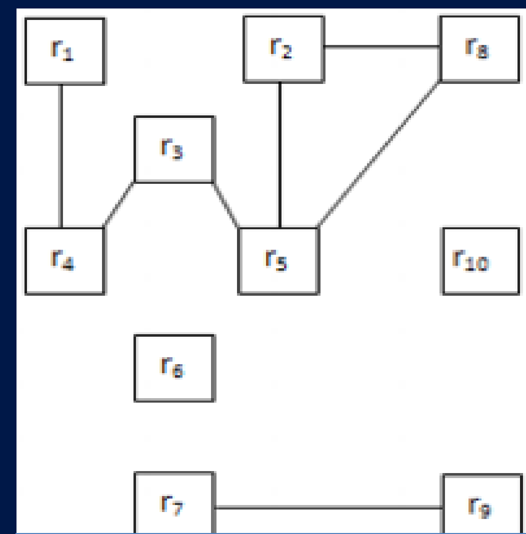
- ***MRF model for sea ice labeling***
  - *is compatible with any segmentation technique*
  - *utilize new neighbourhood for polygon interactions*
  - *utilize edge penalty as a spatial term*
  - *includes domain knowledge as a constraint*
  - *incorporates information from all polygons in the definition of energy*
  - *utilize simulated annealing and Metropolis sampling for global optimization*

Polygonal Neighbourhood

- ***Two regions are polygonal neighbours if the boundary exist between them and they do not belong to the same polygon***

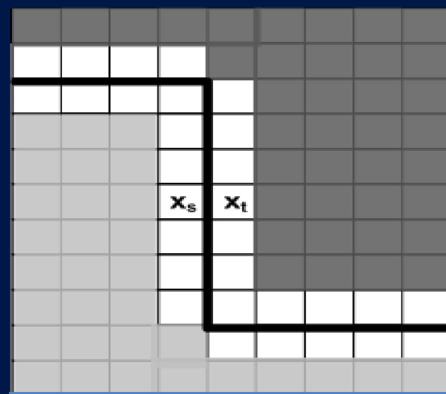


The example of segmentation result



Polygonal neighbourhood

Edge Strength



White are boundary sites

- *The boundary is the set of all sites connecting two regions based on first-order neighbourhood*

$$\partial r_{ij} = \{s, t | s \in r_i, t \in r_j, t \in N_s\}$$

- *Edge strength is the absolute difference between the boundary sites*

$$\nabla_{r_i r_j} = \sum_{s,t \in \partial r_{i,j}} |x_s - x_t|$$

- *Edge penalty is high if the edge strength is small*

$$g(\nabla_{r_i r_j}) = 1 - \nabla_{r_i r_j}$$

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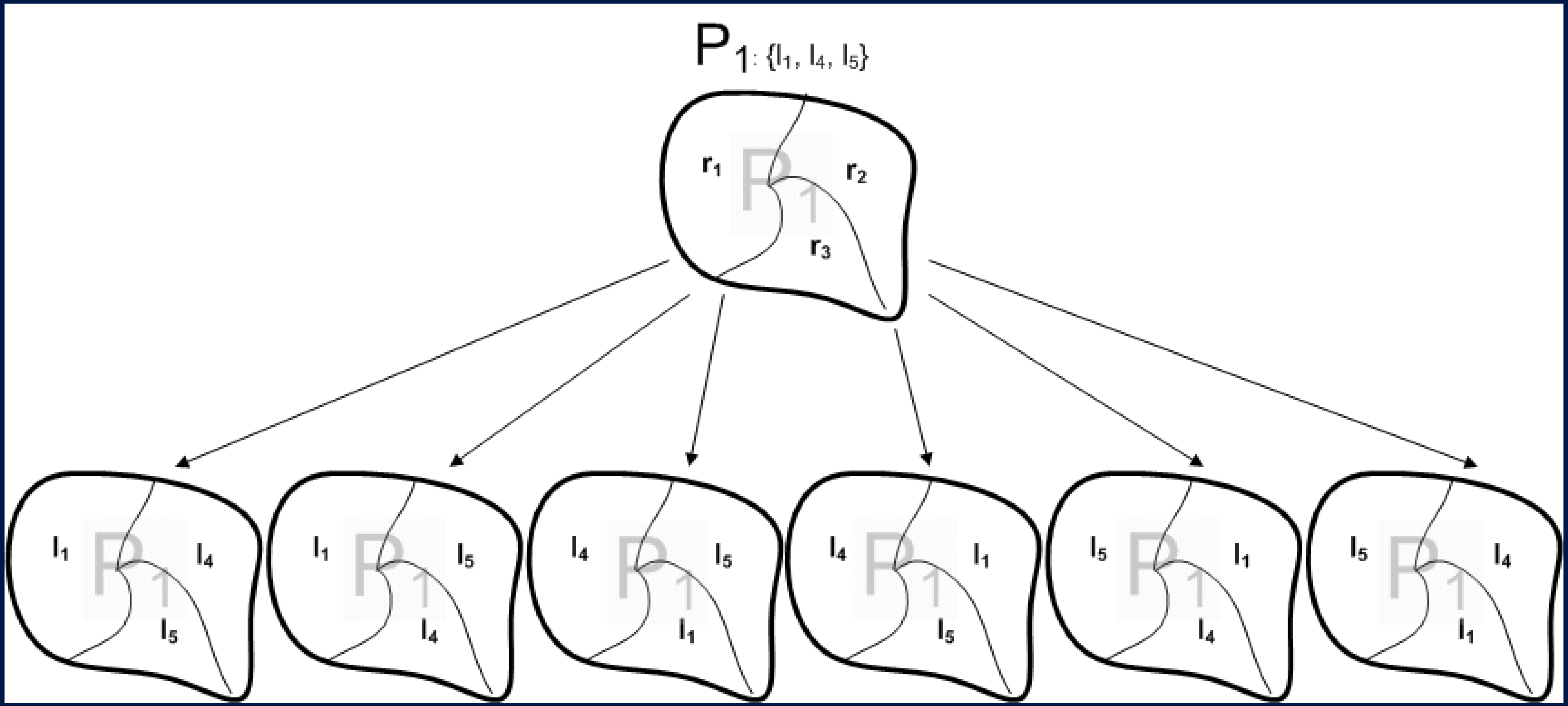
Incorporating Domain Knowledge

- *The labelling realization of regions in any polygon is constrained to permutation of sea-ice classes given for that polygon*



MAP estimation as Energy Minimization

Feature energy model Gaussian mixture

$$E(r_i) = \sum_{s \in r_i} \left\{ \frac{1}{2} \ln(2\pi)^K |\Sigma_{z_i}| + \frac{1}{2}(x_s - u_{z_i})^T \Sigma_{z_i}{}^{-1}(x_s - u_{z_i}) \right\}$$

Feature energy of a single region

$$E_f = \sum_{i=1}^{n_r} E(r_i)$$

MAP estimation

$$\arg \min_{\{z_s | s \in S\}} (\alpha E_f + \beta E_r)$$

Clique Energy Model

$$V_2(r_i, r_j)_{(r_i, r_j) \in N_r} = \begin{cases} \beta g(\nabla_{r_i, r_j}) & z_i \neq z_j \\ 0 & z_i = z_j \end{cases}$$

Pair wise clique potential

$$E_r = \sum_{r_i, r_j \in N_p} V_2(r_i, r_j)$$

Optimization

- ***The goal is optimizing objective function:***

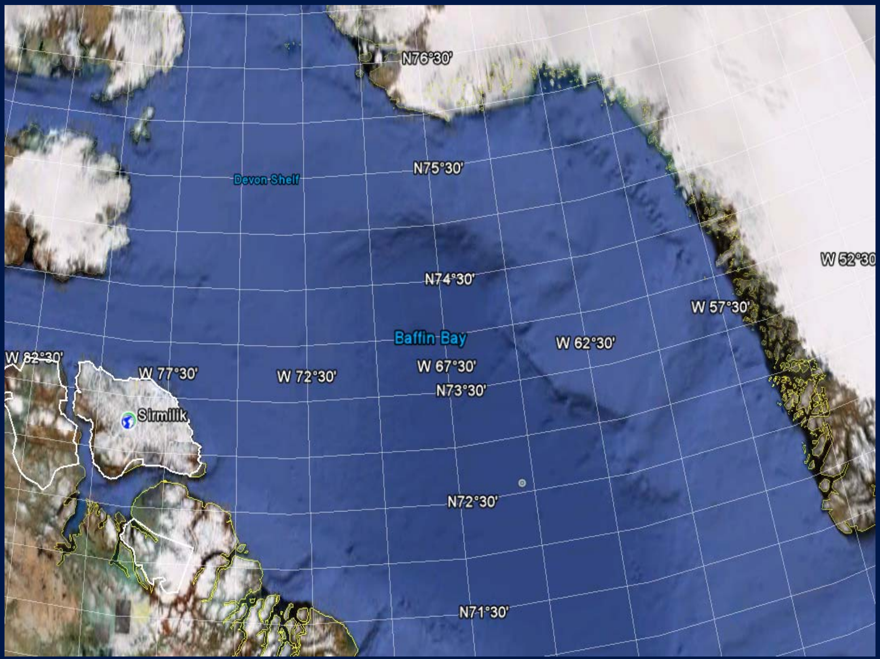
$$\arg\min_{\{z_s | s \in S\}} \alpha \sum_{i=1}^{n_r} \sum_{s \in r_i} \left\{ \frac{1}{2} \ln(2\pi)^K |\Sigma_{z_i}| + \frac{1}{2}(x_s - u_{z_i})^T \Sigma_{z_i}^{-1} (x_s - u_{z_i}) \right\}$$
$$+ \beta \sum_{r_i, r_j \in N_p} \left\{ [1 - \delta(z_i, z_j)] \left[1 - \sum_{s,t \in \partial r_{i,j}} |x_s - x_t| \right] \right\}$$

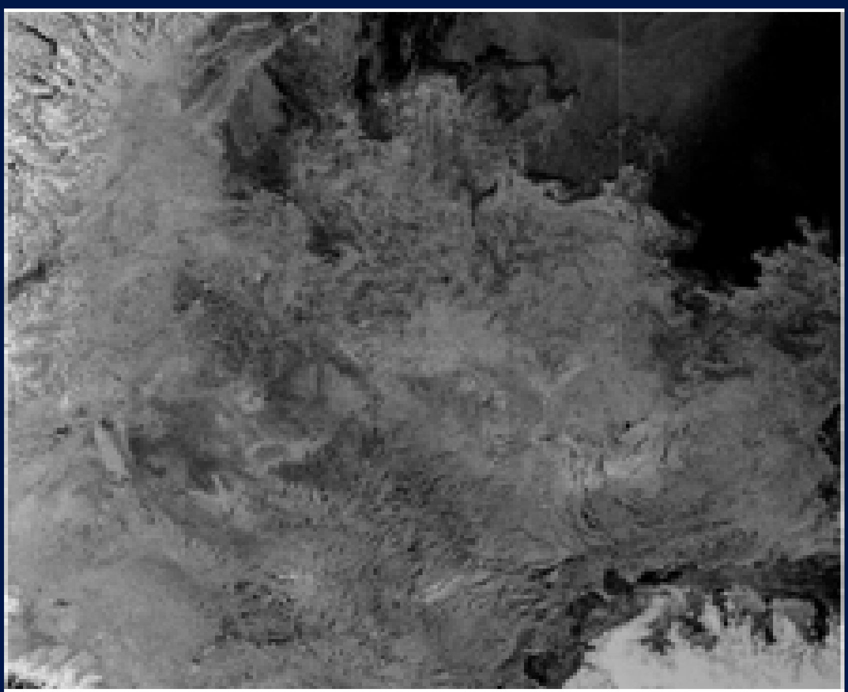
- ***Using***
  - ***Simulated annealing and Metropolis Sampling***

Iteration	region	polygon	size M	size N	time
100	55	22	5008	5387	79s

Operational SAR Sea Ice Image

- ***Operational SAR Sea Ice Image of Arctic region (Baffin Bay) {69.7270◦,76.9649◦} / {−80.5216◦,−66.0010◦}***





- ***Acquired by RADARSAT-1 satellite in Scan SAR Wide mode on October 30, 2005***

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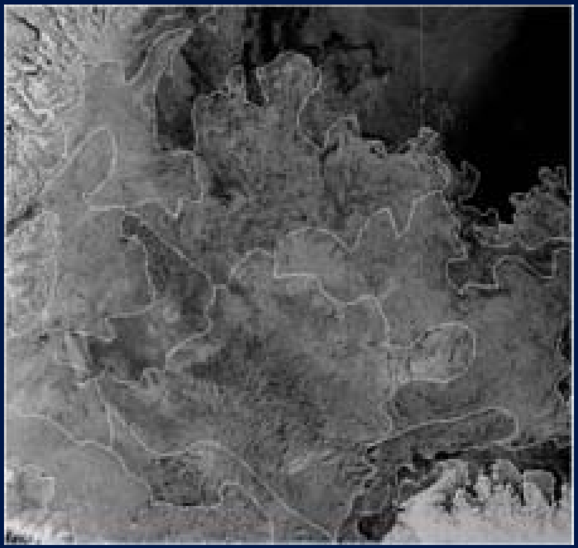
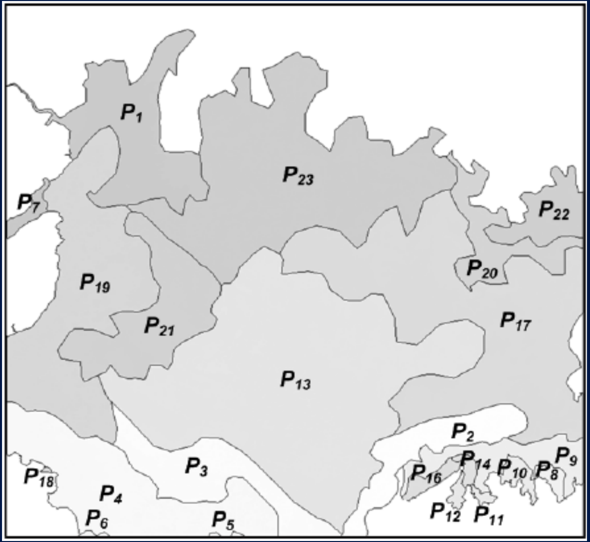
CIS Metadata





Polygon	$\#iceclasses$	labels
P_1	3	$\{5,4,1\}$
P_2	2	$\{4,1\}$
P_3	3	$\{5,4,1\}$
P_4	3	$\{9,5,4\}$
P_5	2	$\{4,1\}$
P_6	3	$\{9,5,4\}$
P_7	2	$\{4,1\}$
P_8	2	$\{L,5\}$
P_9	3	$\{L,4,1\}$
P_{10}	2	$\{L,5\}$
P_{11}	2	$\{L,5\}$
P_{12}	2	$\{L,5\}$
P_{13}	3	$\{5,4,1\}$
P_{14}	3	$\{L,5,4\}$
P_{15}	3	$\{L,5,4\}$
P_{16}	3	$\{5,4,1\}$
P_{17}	2	$\{4,1\}$
P_{18}	3	$\{9,5,4\}$
P_{19}	2	$\{4,1\}$
P_{20}	3	$\{5,4,1\}$
P_{21}	2	$\{4,1\}$
P_{22}	2	$\{4,1\}$

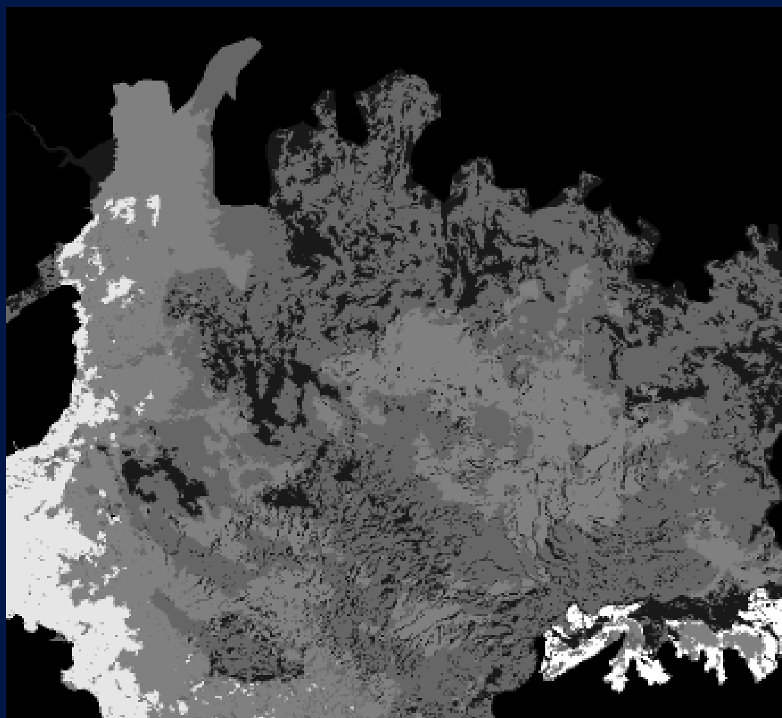
- ***2x2 block averaged to a pixel resolution 100m***
- ***Separated into closely located 22 polygons***
- ***World Meteorological Organization (WMO) standard, labels refer to new ice (1), grey ice (4), grey white ice (5), multiyear ice (9), and fast ice (L)***

Validation

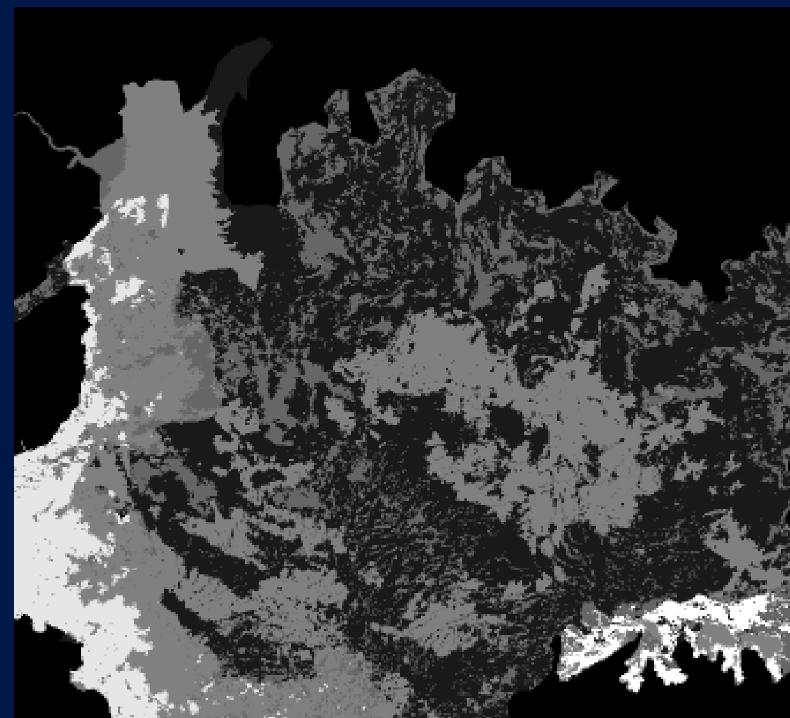
- ***Due to the logistical impossibility field ground truth for the operational SAR sea ice image is not available***

- ***The segmentation and labeling results presented here have been validated by a trained SAR sea ice expert at CIS***

Labeling Results



Proposed method ~80%+ accuracy



GMM ~40% accuracy

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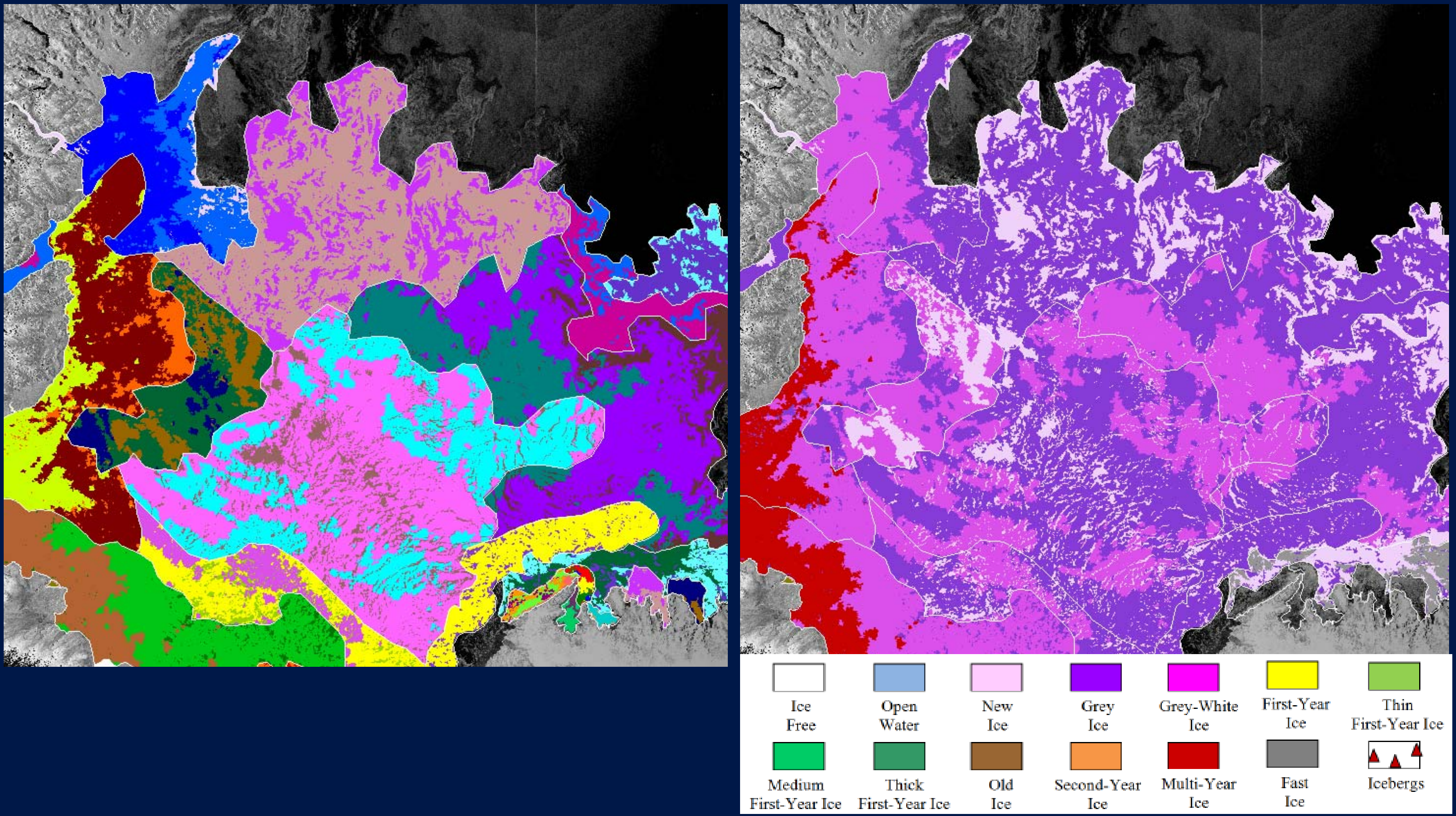
Labeling Result WMO Color Code



Limitations

- ***The number of classes provided might be determined incorrectly by the ice analyst***
- ***Ice analyst might be biased toward assigning thicker ice type in some polygons.***
- ***Polygons are drawn manually so the boundaries are often imprecise and accidentally include ice types not recorded for a particular polygon***
- ***The segmentation might fail over some complex scenarios resulting in incorrectly formed regions***

Conclusion

- ***If the operator provided information is accurate then the segmentation has a stronger accuracy and the labeling process produces a more accurate pixel classified map***
- ***This approach has been successfully applied to operational CIS data***
- ***Is the first known successful end-to-end process for automatically classifying operational SAR sea ice images***

T H A N K S !

Shuhrat Ochilov David.A.Clausi