EARTH OBSERVATION

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Ice Detection with SWOT data

Potential of SWOT measurements for the monitoring of lake ice cover

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Magellium operates the High Resolution Water, Snow and Ice (HR-WSI) production for the Copernicus Land Monitoring Service (CLMS), funded by the European Environment Agency. The HR-WSI portfolio provides detailed monitoring of snow, ice, and water cover across Europe. It includes products derived from Sentinel-1 and Sentinel-2 satellite data, offering high-resolution maps with pixel spacing ranging from 10 m to 60 m. The CLMS products are continuously being improved. In this context, the goal of this study is to evaluate whether SWOT high-resolution (HR) observations can also enable the **detection and the monitoring of ice over lakes**, with potential applications to sea ice.

Input data - KaRIn HR products

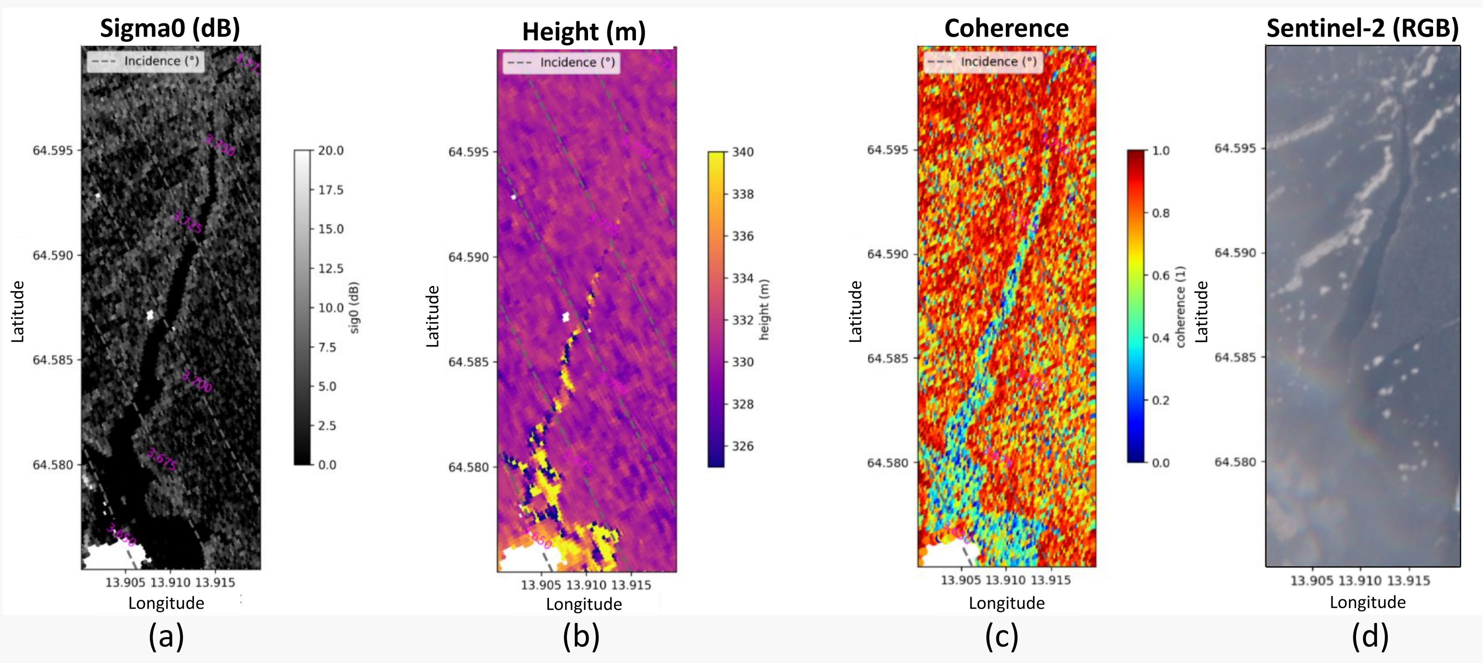


Fig. 1. Lead in Lake Kvarnbergsvattnet on May 15, 2023. Subfigures (a), (b) and (c) show the sigma0, height and coherence variables directly taken or computed from HR_PIXC (tile 014_039L) product. Subfigure (d) shows the RGB bands from Sentinel-2 over the same area and the same day.

Data from HR Pixel-cloud products (SWOT_L2_HR_PIXC **version C**):

- Sigma0 (dB)
- Coherence (computed from +y and -y channels)
- Height (m)

Geolocation is taken from L2_HR_PIXCVec products.

The **combined use** of sigma0, height and coherence data allows to discriminate between **open water** and **ice**. The open water signature depends on meteorological conditions:

- in low wind conditions ('dark water'): lower sigma0, lower coherence and noisier height estimates in open water. See Fig.1.
- in windy conditions: higher sigma0, higher coherence in open water

Algorithm implementation

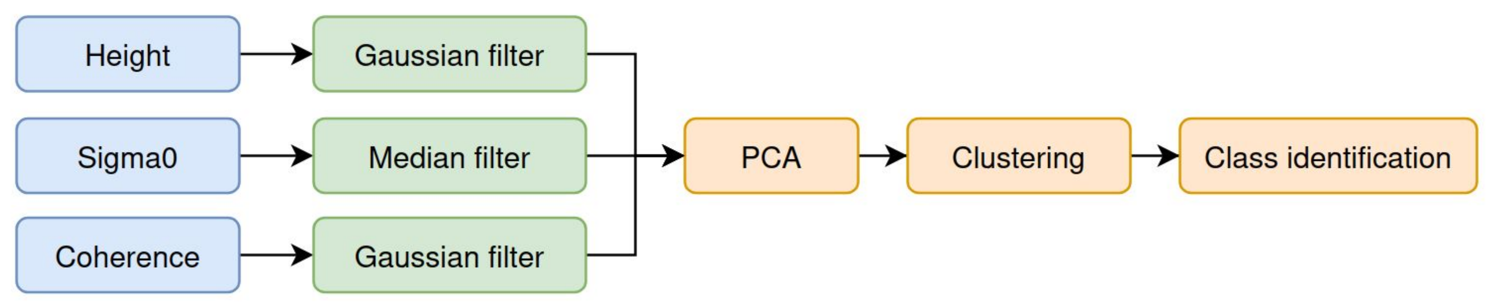


Fig. 2. Overview of the ice / open water classification algorithm on lakes based on SWOT HR products

An **unsupervised pixel-wise classification algorithm** has been implemented, following the structure described in Fig.2.:

- Different spatial filters are applied in order to reduce the noise in the input data.
- The Principal Component Analysis (PCA) step removes the coherence/sigma0 1st order relationship
- Clustering: several algorithms have been tested: K-means, Gaussian Mixture Models…
- The class identification is based on thresholds that have been manually defined based on the analysis of several lake scenes

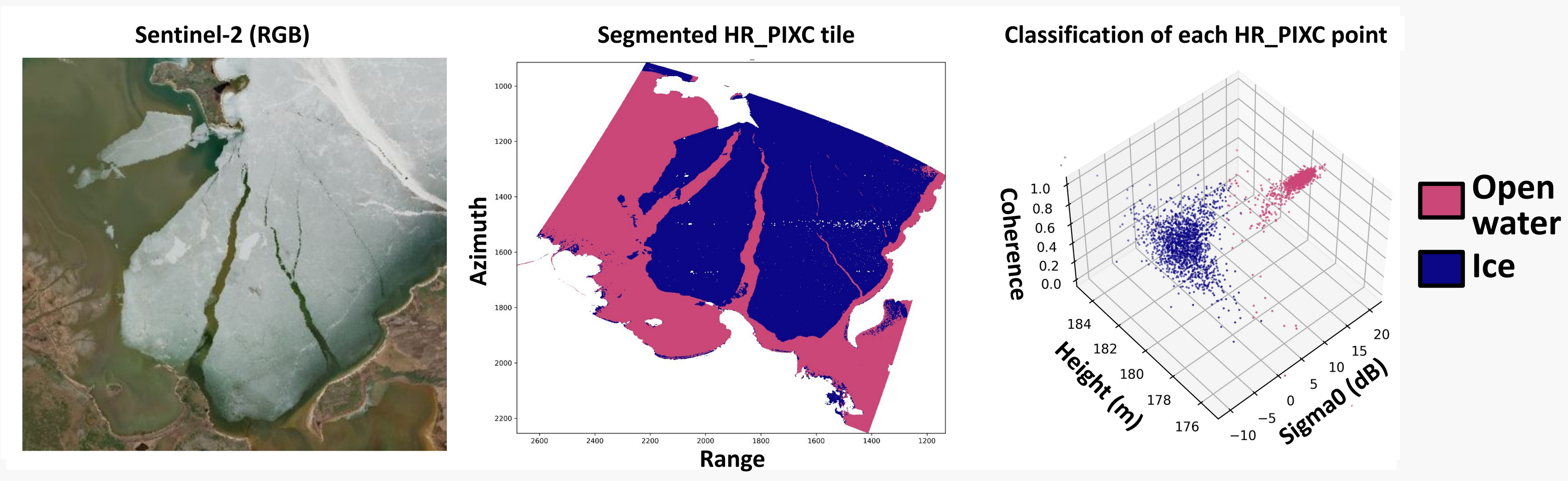


Fig. 3. Segmentation of an HR Pixel cloud scene over lake Athabasca on May 6, 2023. The KaRIn acquisition took place at 11:49 AM, and the Sentinel-2 true color image has been taken at 6:39 PM.

Validation

The performance of the developed segmentation algorithm has been tested on a small set of two hand labelled Sentinel-2 images over several lakes in Scandinavia.

- Validation scenes have to follow **specific requirements**:
  - No cloud cover
  - Diverse configurations: completely/partially frozen, high/low wind
  - Close acquisition dates between validation and SWOT data. Indeed, ice exhibits dynamic behavior: when the ice cover breaks up, ice sheets may derive due to winds.
- **Results**:
  - The algorithm version using K-means clustering was the most performant
  - Windy conditions increase the contrast between ice and open water, leading to a better segmentation
  - Small features can be detected, for example the lead in Fig.4. over Lake Kvarnbergsvattnet in May 2024.
  - Features on the ice cover are detected with KaRIn data, but cannot be characterized easily with optical data: presumably snow patches, varying ice rugosity …

Wind conditions	Precision	f1-score	
		Open water	Ice
Windy (~4 m/s)	0.89	0.80	0.93
Low wind (~1 m/s)	0.95	0.37	0.98

Tab.1. Classification scores over Lake Kvarnbergsvattnet in windy conditions (Fig. 4.) on May 9, 2024, and in low wind conditions on April 17, 2023. Wind speeds are taken from ERA5 reanalysis.

Mismatch possibly due to: mislabellisation, projection errors, ice cover dynamics between the SWOT and Sentinel-2 acquisition dates

Fig. 4c. Pixelwise comparison between KaRIn and Sentinel-2 data

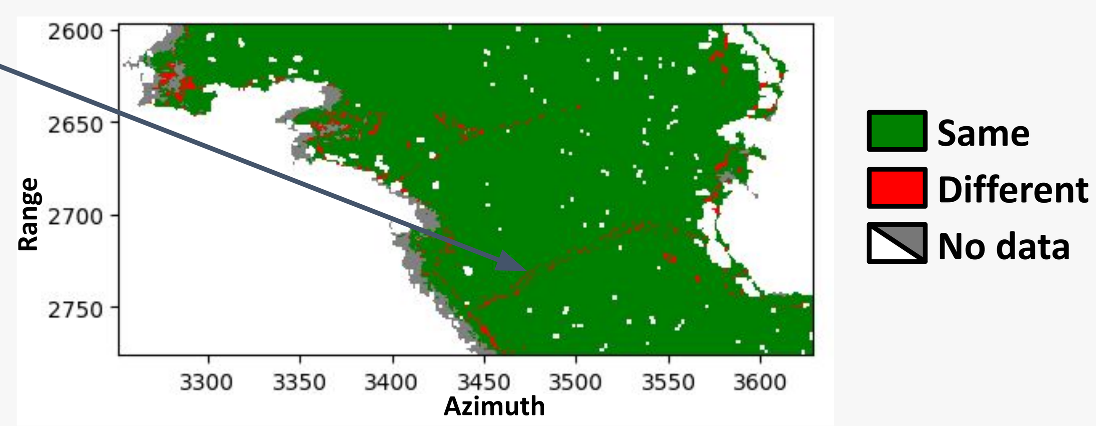
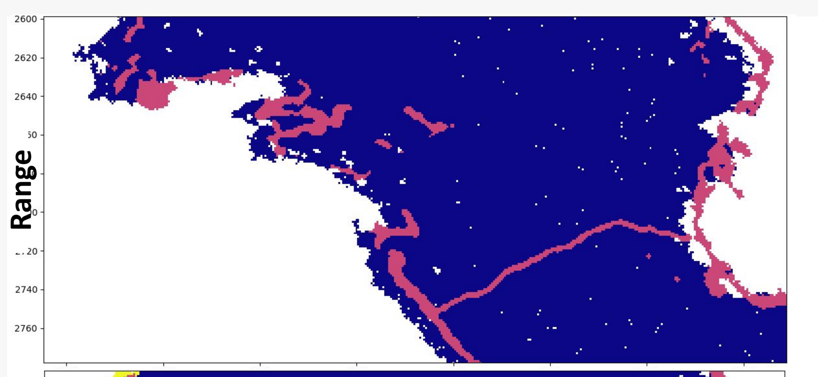


Fig. 4a. Classification from the segmentation algorithm based on L2_HR_PIXC on May 9, 2024



Open water
Ice
Other

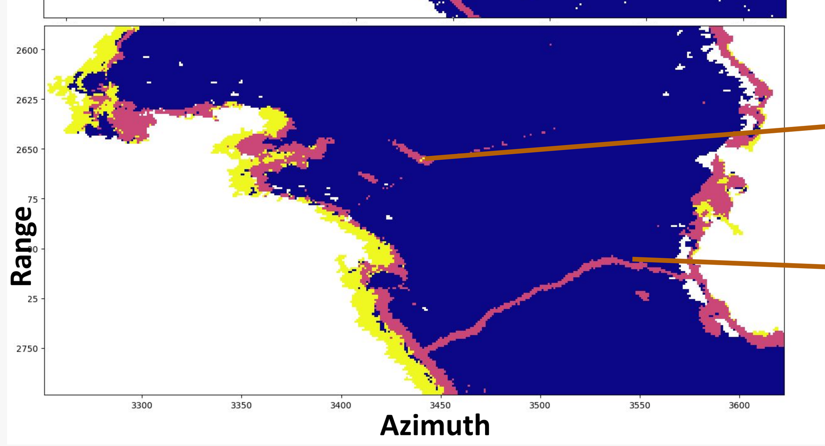


Fig. 4b. Hand labelled Sentinel-2 image on May 11, 2024. Note the deformation of the main lead due to the projection to the SWOT swath coordinates.

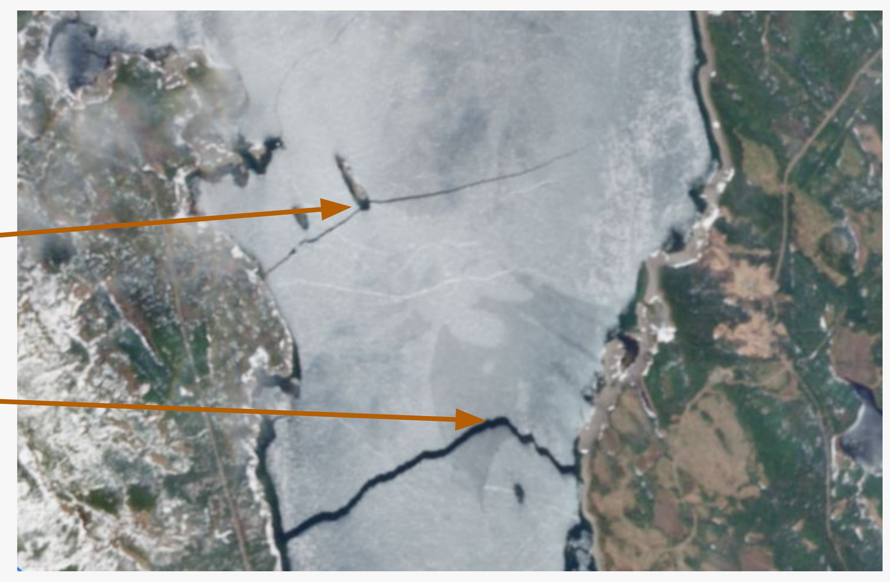


Fig. 5. Sentinel-2 true color image of Lake Kvarnbergsvattnet on May 11,2024.

Key messages

Main results:

- KaRIn HR data enables the detection of lake ice cover
- The implemented algorithm is able to detect small features. It has been assessed against a validation dataset, showing encouraging results.
- KaRIn data shows additional features in the ice cover, that are not observed by other sensors.

Next steps:

- Update the HR algorithm to the version D HR products
- Refine the HR algorithm beyond pixelwise classification (Markov random fields, CNN …)
- Expand the HR training dataset (Sentinel-1/2,RCM scenes)
- Combining S1, S2 and KaRIn-HR data could enable sea-ice detection.

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