

Preliminary results of Sea Ice Classification using combined Sentinel-1 and Sentinel-3 data

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Abstract—A sea ice classification is trained using a combination of Synthetic Aperture Radar (SAR) from Sentinel-1 and an existing sea ice classification using optical-thermal data from Sentinel-3. Compared to a SAR-only classification, preliminary results show improved classification reliability especially in open water areas.

Sea ice is constantly changing: wind and ocean currents can push together large ice masses and close leads; the pack ice formed by these processes is often not navigable even by icebreakers. Combining radar measurements of Sentinel-1 and results of a sea ice classification using the optical/thermal measurements of the SLSTR instrument onboard Sentinel-3 offers the possibility to improve the sea ice situation awareness. In radar data, different ice classes can mostly be distinguished by different radar backscatter, but some ice classes exhibit a similar backscatter, limiting the applicability of radar-based classification. Sentinel-3 data contain optical/thermal information of water, ice, and snow, allowing a refined ice class separation after classification, but the observations are in lower resolution and clouds may obstruct the view. The fused classification is based on a Convolutional Neural Network (CNN) classifier and discriminates 6 surface types. Its input data are the HH and HV polarization channels of the Sentinel-1 image plus pre-classified Sentinel-3 images with continuous RGB labels. Improved sea ice classification allows planning of safer routes and better awareness for possible dangerous situations for polar ships.

Index Terms—Synthetic Aperture Radar, SLSTR, Sea Ice Classification, Sentinel-1, Sentinel-3, Sensor Fusion

I. INTRODUCTION

Navigation through ice-infested waters is a challenge even for icebreakers. With the ongoing decline of polar sea ice cover, more shipping is expected in polar waters, especially commercial shipping along North-East- and North-West-Passage. Knowledge of the presence and type of sea ice is crucial for vessel safety. While sea ice charts are provided on a regular basis by several national sea ice services, their usability in changing sea-ice conditions is limited by their coarse resolution and low update frequency. An automated processing chain making high-resolution sea ice information generated from satellite data available directly to ship navigators will increase maritime safety in ice-infested waters. Such a processing chain is currently being developed using two sources of satellite data: Sentinel-1 (S-1) Synthetic Aperture Radar (SAR) data and Sentinel-3 (S-3) optical/thermal data from the Sea and Land Surface Temperature Radiometer (SLSTR).

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SAR detection is based on surface backscatter, in case of sea ice the SAR backscatter depends on the ice surface roughness and is used to discriminate between different ice ages and types. The SLSTR data contains optical and thermal information, the sea ice classification is based on the surface (and sub-surface) reflectivity in different bands. Both sensors, hence, use different phenomena for sea ice observations and a fused classification is expected to have a higher quality than individual classifications using only one type of data. This submission covers the methods and workflow of the fused classification and preliminary results.

II. METHOD

This section covers the generation of the SLSTR classification, data preparation for machine learning, and a description of the applied CNN classification.

A. SLSTR sea ice classification

The sea ice classification from SLSTR data was presented in [1] and more details are provided therein. The classification uses the 9 bands of the SLSTR instrument for optical and thermal discrimination of ice classes and was extensively validated using official ice charts, comparisons to higher resolution satellite imagery, and webcam recordings. Its output is a continuous, three channel (RGB) sea ice classification with 19 surface types, of which 8 classes include open water and sea ice with up to approximately 50 cm thickness. Clouds are masked out using information from three of the SLSTR channels. The current processor was further improved compared to the version presented in [1], for example with refined cloud masking and better operational useability.

B. Data preparation

Two sources of satellite data are merged in this process: Sentinel-1 L1B scenes and the Sentinel-3 L2 classified images. The S-1 data is acquired in Extended Wide Swath mode (EW) with a swath width of 410 km and consists of two channels, one for each polarizations (HH, HV). The data are delivered in GeoTiff format with a pixel spacing of 40 m. The images are oriented in satellite flight direction and not projected in a Coordinate Reference System (CRS); georeferencing is supplied by Ground Control Points (GCPs). The S-3 data are ingested as pre-classified 3-channel RGB GeoTiffs, projected in a polar-stereographic CRS, with a swath width of 1420 km and a pixel spacing of 500 m.

For further processing, both images have to be aligned, i.e. they need to have the same coverage, projection, and pixel

spacing. Therefore, first the S-1 data is warped to the CRS of the S-3 data. An intersection polygon of both scenes is then made and both scenes are cut to the extensions of this polygon. Since the S-1 image has lower coverage than the corresponding S-3 image, it is only cut in case of partial overlaps. The S-3 scene is then upsampled to the higher resolution of the S-1 scene, which finishes the alignment.

A binary validity mask in the same alignment is then created, marking areas where both scenes have valid data. Invalid data areas are clouds in the S-3 classification and black boundaries from reprojecting in both S-1 and S-3 data. Only pixels with valid data are later used in the training and classification.

The full stack of files for training consists of four files and seven channels:

- S-1 σ_0 -calibrated image (HH, HV channels)
- S-3 classification (R, G, B channels)
- binary validity mask
- S-1 preview image of HH channel

The latter S-1 preview of the HH channel is saturation-adapted for better useability during the data labeling process, allowing the separation of ice classes by visual inspection. This channel is only used for training and not for inference. One stack of files is generated for each S-1/S-3 scene pair.

C. CNN classification

The classification is conducted using a Convolutional Neural Network (CNN) using the previously described 6 channels (3 channels optical, 2 channels SAR, mask layer) as input data. A similar setup and method of classification was introduced before for SAR-only sea ice classification [2], more details on the classification algorithm are presented therein. The outcome is an image classified into six sea ice classes

- Open leads / water (smooth)
- Open leads / water (rough)
- New ice
- First Year ice
- Multi-Year ice
- Rough ice

plus an additional no-data entry used for areas with clouds (S-3 image) or geometrically not covered by both sensors.

III. PRELIMINARY RESULTS

The results presented in this section are derived from an early, limited training data sample of 12 data stacks as described in Section II-B. Figure 1 shows an exemplary set of input data (SAR, SLSTR) and a comparison of the classification results. The SAR scene in panel (a) is shown almost in full, only a small corner was removed during cutting. It is located at the boundary of the SLSTR scene and, hence, does not overlap fully. Panel (b) shows the SLSTR classification, here variations of red colors show sea ice with different ages of snow cover (darker: older, brighter: younger), while the green and green-brown tones show open water with different surface temperature (green: warmer, green-brown: colder, ready to freeze). Clouds are shown in different shades of grey, seen

here at the right side of the panel. For a full description of the SLSTR classification and its colors, the reader is referred to [1]. Only a small part of the SLSTR scene is used since it was cut to the extends of the SAR scene. A SAR-only classification is shown in panel (c), using only the SAR data for training and inference but otherwise identical to the fused classification. This does not correctly classify the bright open water sections in the lower right of the image. In comparison, the fused classification shown in panel (d) classifies most of these areas correctly as open water. Note that for this comparison, the validity mask derived from SAR and SLSTR (panels (a) and (b)) was applied to both classifications shown (panels (c) and (d)), visible by black borders and the cloud cutouts on the right side. In operational use, the SAR-only classification would not need to such a mask, it would only be applied to the fused classification.

IV. CONCLUSIONS AND OUTLOOK

The presented preliminary results show that the fused sea ice classification from SAR and optical images can improve the results especially in the task of open water and lead detection. The inclusion of more training data samples and an extended comparison of results will allow more detailed findings in the future.

Automated satellite-based sea ice information services can benefit from using and combining both sources of data. It was demonstrated here already with the preliminary results that fused information can provide a better accuracy of sea ice class determination and thereby improve the safety of ships sailing through ice-infested waters.

The presented classification is to become part of a near-real time sea ice information generation and delivery chain. The high coverage and acquisition frequency of the SLSTR scenes results in regularly possible fused classifications, as long as there is no cloud cover blocking the acquisitions. Nevertheless, also the individual classifications from SAR and SLSTR are made available to the end users due to their much higher availability, as the fused classification is only available where both sensors have acquired spatially overlapping data within a time interval of several hours.

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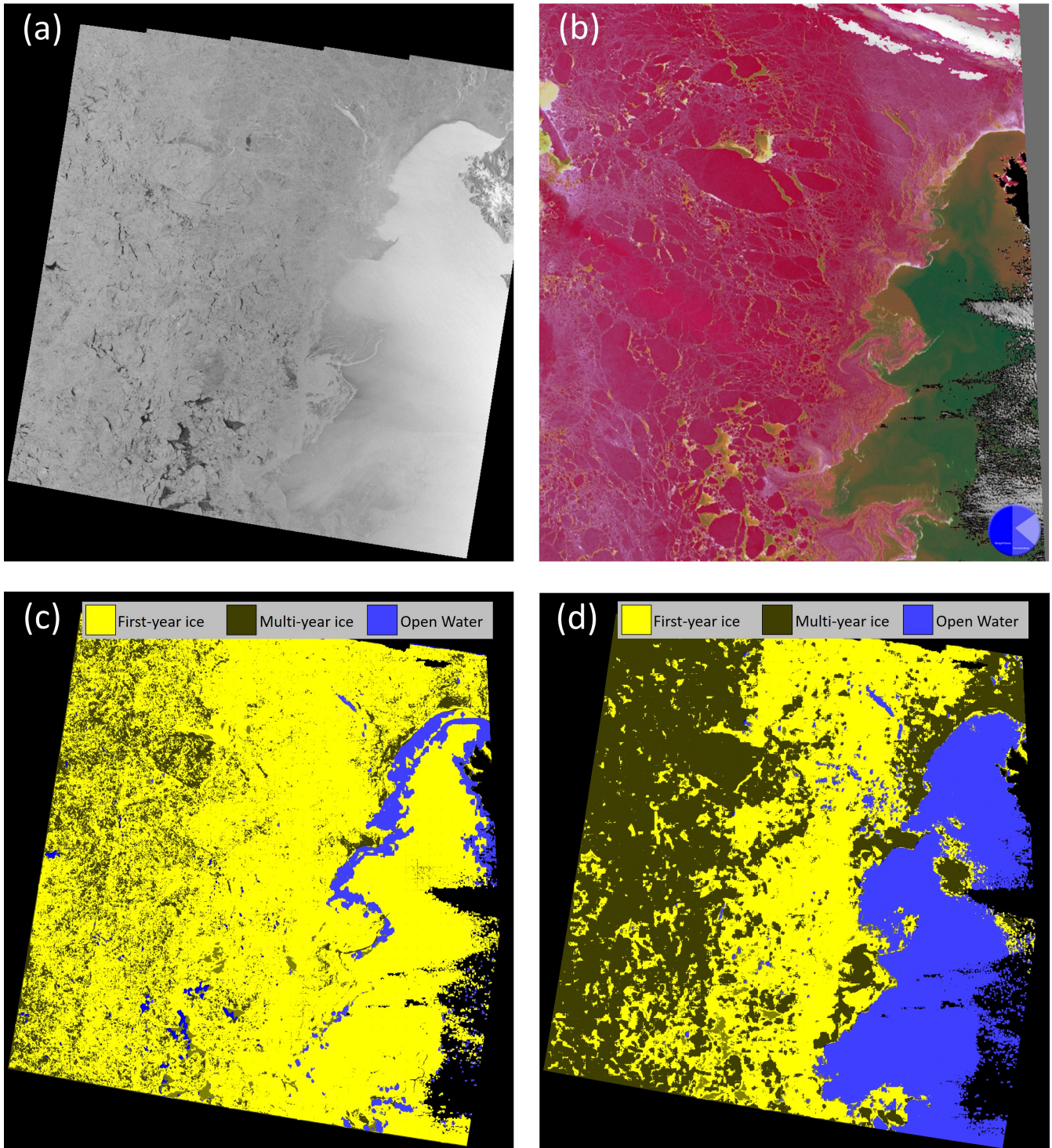


Fig. 1. Example data stack and classification results. (a) Sentinel-1 acquisition (HH, HV), (b) SLSTR classification (RGB); contains modified Copernicus Sentinel data (2020) (c) SAR classification using only Sentinel-1 data, (d) fused classification using SAR data and SLSTR classification. The open water areas in the lower right part of the figure are identified more correctly by the fused classification.