Check for updates

RESEARCH ARTICLE

Leveraging Copernicus for Ice Block Detection: A Step Towards Safer Arctic Navigation

[version 1; peer review: 1 approved with reservations, 1 not approved]

Jesús Alonso, Tatiana Silva

Tree Technology, Oviedo, 33003, Spain

v1 **First published:** 30 Jul 2024, **4**:159
https://doi.org/10.12688/openreseurope.18090.1
Latest published: 30 Jul 2024, **4**:159
https://doi.org/10.12688/openreseurope.18090.1

Abstract

Background

The Arctic is becoming more accessible due to ice melting, posing challenges for navigation due to floating ice blocks. Detecting these ice blocks is crucial for ensuring the safety of vessels navigating these waters.

Methods

This study introduces a novel method for detecting ice blocks in the Arctic using Artificial Intelligence (AI) and Synthetic Aperture Radar (SAR) satellite images from the Sentinel-1 mission of the Copernicus program. Our approach combines state-of-the-art image segmentation and deep learning techniques. We utilize a Convolutional Neural Network (CNN) classifier to accurately locate ice blocks within the images and retrieve their geographic coordinates. The method's performance is validated using precision, recall, and F1-score metrics.

Results

Our CNN classifier demonstrates robust performance in detecting ice blocks, validated through precision, recall, and F1-score metrics. The practical application of our technology was showcased in the AI-ARC project's Arctic demo, receiving positive feedback from coast guards across various European countries. The system provides near-real-time alerts about detected ice blocks, allowing for timely route adjustments and reducing collision risks.

Open Peer Review

Approval Status ? ✗

	1	2
version 1 30 Jul 2024	? view	✗ view

1. **Lauren Hoffman**, University of California San Diego, San Diego, USA

2. **Karl Kortum**, German Aerospace Center (DLR), Cologne, Germany

Any reports and responses or comments on the article can be found at the end of the article.

Conclusions

The developed system significantly contributes to Arctic navigation safety by providing accurate and timely detection of ice blocks. This work underscores the transformative potential of AI in environmental monitoring and maritime safety. Future refinements will be based on user feedback and advancements in AI technology, enhancing the system's effectiveness and reliability.

Keywords
AI, Arctic, CNN, Copernicus, Geospatial, Ice block detection, Image segmentation, SAM, SAR, Satellite, Sentinel-1

H2020 This article is included in the Horizon 2020 gateway.

Corresponding author: Jesús Alonso (jesus.alonso@treelogic.com)

Author roles: Alonso J: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – Original Draft Preparation; **Silva T**: Funding Acquisition, Project Administration, Resources, Supervision, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: This project has received funding from the European Union's Horizon 2020 research and innovation Programme under grant agreement No : 101021271 (AI-ARC project)
The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Copyright: © 2024 Alonso J and Silva T. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

How to cite this article: Alonso J and Silva T. **Leveraging Copernicus for Ice Block Detection: A Step Towards Safer Arctic Navigation [version 1; peer review: 1 approved with reservations, 1 not approved]** Open Research Europe 2024, **4**:159 https://doi.org/10.12688/openreseurope.18090.1

First published: 30 Jul 2024, **4**:159 https://doi.org/10.12688/openreseurope.18090.1

Introduction

The Arctic, a region undergoing alarming and irreversible ice melting due to climate change, is becoming increasingly accessible. This presents both challenges and opportunities for human activities, particularly in the realm of Arctic navigation. With fewer ice sheets in the Arctic, there are now navigable waters providing the ability to extract natural resources, support commerce, and encourage tourism. However, the presence of floating ice blocks can pose significant risks to vessels navigating these waters. Therefore, the development of technology for the automatic accurate detection of ice blocks in near-real time in the Arctic Ocean is not only a response to the challenges posed by climate change but also a proactive measure to ensure the safety and efficiency of Arctic navigation in the face of these rapidly changing conditions.

In this letter, we are excited to introduce a groundbreaking method for detecting ice blocks in radar satellite images, powered by Artificial Intelligence (AI). Our method is rooted in the application of a combination of state-of-the-art image segmentation and deep learning techniques. These techniques are employed to accurately locate ice blocks within the images and then retrieve their precise geographic coordinates. The strength of our method lies in its performance. The models we have developed have shown promising results in accurately identifying and locating ice blocks. This has significant implications for improving the safety and efficiency of Arctic navigation, particularly in the context of the rapidly changing conditions in the region. Our work was presented as part of the AI-ARC project's[1] Arctic demo, where it was well-received by different end users, the ones from the project's consortium and as well as external ones. This validation from the user community underscores the potential of our method to make a meaningful contribution to addressing the challenges posed by climate change in the Arctic.

Data collection and processing

Our primary objective is to build a technology capable of detecting floating ice blocks at sea. To achieve this, we leverage the Copernicus program[2], the European Union's Earth observation program. Copernicus aims at achieving a global, continuous, autonomous, high-quality, wide-range Earth observation capacity. The Copernicus program includes several missions, each with its own unique capabilities:

- Sentinel-1[3] comprises a constellation of satellites performing C-band Synthetic Aperture Radar (SAR) imaging.
- Sentinel-2[4] provides high-resolution optical imagery for land services, including vegetation, soil and water cover, inland waterways, and coastal areas.
- Sentinel-3[5] offers high-accuracy optical, radar, and altimetry data for marine and land services.
- Sentinel-4[6] and Sentinel-5[7] are dedicated to atmospheric composition monitoring.
- Sentinel-5P[8] is a precursor mission to Sentinel-5, providing data continuity until the launch of Sentinel-5.
- Sentinel-6[9] provides high accuracy altimetry for measuring global sea-surface height.

Inside Copernicus, we specifically use Sentinel-1, which comprises a constellation of satellites performing C-band Synthetic Aperture Radar (SAR) imaging. SAR satellite sensors can see through clouds and in the dark, providing 24/7 unobscured views of Earth[10]. This makes SAR ideal for our purpose as it can penetrate cloud cover and "see through" darkness and weather, allowing a unique view of ice block distribution. This is particularly useful in the Arctic region where weather conditions can be extreme and unpredictable.

We download Sentinel products from the publicly available Copernicus API[11]. The Copernicus Data Space Ecosystem offers multiple Application Programming Interfaces (APIs) that provide a range of services including access to the catalogue, product download, visualization, and processing web services. After downloading the products, we perform sigma-0 calibration on them[12], and convert them to decibels, using geospatial libraries, obtaining as a result an image like the one shown in Figure 1. We use these calibrated products to build a dataset that is subsequently used to validate the technology we develop. In addition to this, we also have access to a labelled dataset of small, 75×75 pixel patches of sea from Sentinel-1 images. These patches contain either a vessel, an ice block (Figure 2), or neither of them, providing a diverse range of data for our model to learn from.

Methods

Our methodology begins with the receipt of a calibrated Sentinel-1 product. This product is then processed using a state-of-the-art image segmentation model, SAM[13]. The SAM

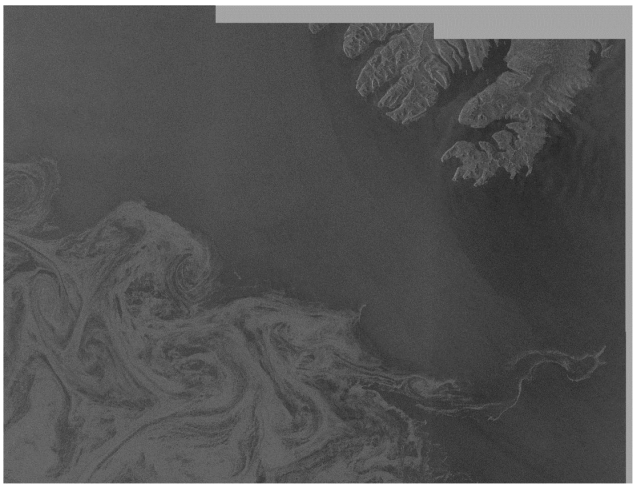


Figure 1. Example Sentinel-1 product after calibration and conversion to decibels.

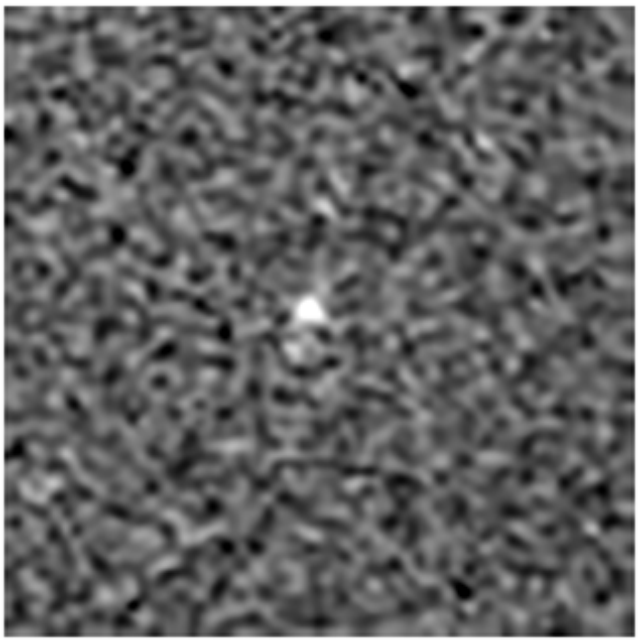


Figure 2. Example 75×75 pixel patch containing an ice block.

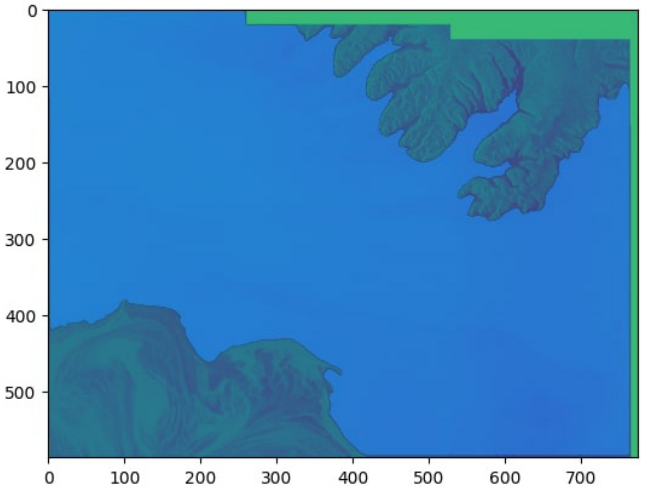


Figure 3. Example Sentinel-1 product after segmentation. The separation between land and sea is clearly seen, with the coastline accurately delimited.

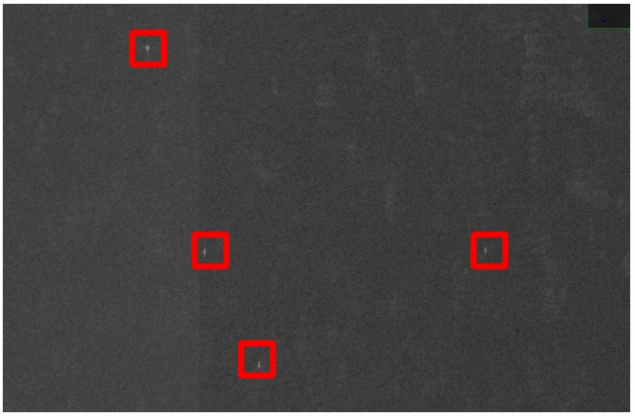


Figure 4. Detail of ice blocks detected on sea in a Sentinel-1 product. There is an ice block inside every red square.

model is specifically designed to distinguish between different elements in the image, such as the sea, land, and sea-ice sheets. An example of a segmented image can be seen in Figure 3.

Once the image is segmented, the sea area is scanned using a moving window approach. This process involves extracting patches of 75×75 pixels that cover the entire sea area. These patches are then processed using a Convolutional Neural Network (CNN)[14] multilabel classifier. The CNN is trained using the labelled dataset of patches, presented in the former section, which match the size of the extracted patches. This allows the CNN to detect the presence of a boat or an ice block within each patch. The performance of the CNN model is validated using standard metrics such as precision, recall, and F1-score.

Patches where ice blocks are detected are marked on the image, as can be seen in Figure 4. Following the detection process, the geographic coordinates of the patches containing ice blocks are retrieved. This is achieved by correlating the image coordinates of these patches with the geolocation information contained in the full Sentinel-1 product. This allows us to geographically locate the detected ice blocks and issue alerts accordingly.

The results of this process, including the geographic coordinates of detected ice blocks, are sent via Kafka[15], an open-source distributed event streaming platform, to a geospatial visualization and analysis software. In the demos of the project, we use the DigLT[16], developed by another project partner. This software displays the detected ice blocks on a map for users and provides the image of the 75×75 pixel patch containing the ice block, along with its metadata. Our system is also equipped to receive Sentinel-1 products in streaming. This feature enables it to alert about near-real time detections, providing timely and critical information for maritime navigation and safety. Free alternatives that perform equivalent functions to the DigLT include QGIS[17], OpenLayers[18], CelsiumJS[19], and Leaflet[20].

Results and demonstration

Our multilabel CNN classifier, which is designed to detect ice blocks and vessels in 75×75 pixel patches of sea, has been thoroughly evaluated using precision, recall, and F1-score metrics. The results of this evaluation are presented in Table 1, demonstrating the robust performance of our model. The unsupervised detections of ice blocks, as visualized in Figure 4, further substantiate the accuracy of our model.

Table 1. Results of the CNN detecting ice blocks and vessels in 75×75 pixel patches.

	precision	recall	f1-score	support
iceberg	0,92	0,82	0,86	66
vessel	0,88	0,91	0,89	86
micro avg	0,89	0,87	0,88	152
macro avg	0,9	0,86	0,88	152
weighted avg	0,89	0,87	0,88	152
samples avg	0,54	0,55	0,54	152

To showcase the practical application of our technology, we conducted a demonstration in Reykjavik as part of the AI-ARC project's Arctic demo. This event provided an excellent platform to exhibit the capabilities of our system in a real-world setting. For this demonstration, we curated a set of Sentinel-1 products located in the vicinity of Iceland. These products were specifically chosen for their proximity to the demo location and the presence of ice blocks within them.

During the demonstration, the detected ice blocks were displayed on the geospatial visualization and analysis software. We also conducted an alert simulacrum to illustrate how our system can provide timely alerts about detected ice blocks. This demonstration was conducted in front of an audience of end users, primarily consisting of coast guards from various European countries. The audience expressed satisfaction with the results of the exercise, validating the effectiveness of our system.

Conclusions

Our system significantly contributes to Arctic navigation safety by detecting ice blocks and providing near-real-time alerts to vessels. This allows for timely route adjustments, reducing the risk of collisions. This work represents a substantial advancement in the use of AI for environmental monitoring.

We anticipate further refining our method based on user feedback and advancements in AI technology. This underscores the transformative potential of AI in environmental monitoring and maritime safety. We are optimistic about the future of our system and its role in promoting safe navigation in the Arctic or other regions that may have ice blocks.

Ethics and consent

Ethical approval and consent were not required.

Data availability

- The dataset composed of Sentinel-1 images downloaded from the Copernicus API, and curated by us, is available from the repository *Set of Copernicus Sentinel-1 images around Iceland*: https://zenodo.org/doi/10.5281/zenodo.12653877[16].
- License: Creative Commons Attribution 4.0 International.
- Additionally, this study leverages the dataset for the Statoil/C-CORE Iceberg Classifier Challenge, available in: https://www.kaggle.com/competitions/statoil-iceberg-classifier-challenge/data, under a proprietary license.

Software availability

- The software developed by us to detect ice blocks in satellite images is archived and available from: https://zenodo.org/doi/10.5281/zenodo.12684755.
- License: Creative Commons Attribution 4.0 International.
- Additionally, for geospatial visualization and analysis, our project utilizes the DigLT[17], developed by another project partner. However, there are several open-source alternatives available that can perform equivalent functions, including QGIS[18], OpenLayers[19], CesiumJS[20], and Leaflet[21].

References

1. **AI-ARC project**. Reference Source
2. **Copernicus Programme**. Reference Source
3. **Sentinel-1**. Reference Source
4. **Sentinel-2**. Reference Source
5. **Sentinel-3**. Reference Source
6. **Sentinel-4**. Reference Source
7. **Sentinel-5**. Reference Source
8. **Sentinel-5P**. Reference Source
9. **Sentinel-6**. Reference Source
10. Zhao Q, Yu L, Du Z, *et al.*: **An overview of the applications of earth observation satellite data: impacts and future trends.** *Remote Sens-Basel.* 2022; **14**(8): 1863. Publisher Full Text
11. **https://dataspace.copernicus.eu/analyse/apis/sentinel-hub**
12. Laur H, Bally P, Meadows P, *et al.*: **Derivation of the backscattering**

coefficient σ0 in ESA ERS SAR PRI products. *Proc of the Second International Workshop on ERS Applications.* 2002; 139.

13. Kirillov A, Mintun E, Ravi N, *et al.*: **Segment Anything.** *Proceedings of the IEEE/CVF International Conference on Computer Vision.* 2023; 4015–4026.
Publisher Full Text

14. Schmidhuber J: **Deep learning in neural networks: an overview.** *Neural Netw.* 2015; **61**: 85–117.
PubMed Abstract | **Publisher Full Text**

15. Sax MJ: **Apache kafka.** In: Sakr, S., Zomaya, A. (eds) *Encyclopedia of Big Data Technologies.* Springer, Cham, 2018.
Publisher Full Text

16. Alonso J: **Set of Copernicus Sentinel-1 images around Iceland.** [Data set]. *Zenodo.* 2024.
http://www.doi.org/10.5281/zenodo.12653878

17. **The digital map table**.
Reference Source

18. QGIS: **A free and open source geographic information system**.
Reference Source

19. OpenLayers: **A high-performance, feature-packed library for all your mapping needs**.
Reference Source

20. CesiumJS: **3D geospatial visualization for the web**.
Reference Source

21. Leaflet: **A JavaScript library for interactive maps**.
Reference Source

Open Peer Review

Current Peer Review Status: ? ✗

Version 1

Reviewer Report 25 September 2024

https://doi.org/10.21956/openreseurope.19553.r43635

© **2024 Kortum K.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

✗

Karl Kortum
German Aerospace Center (DLR), Cologne, Germany

Your Report
General Comments:
The manuscript shortly presents a detection method for ice in the ocean. Unfortunately, the work is lacking some key elements necessary for scientific publication:

1. The work does not place itself in scientific context: There are almost no sources or mention of previous work done in this exact line of research. To qualify as a scientific publication these should be discussed and compared against. Any statement made about the state of the art or the environment should be backed up by research.
2. The work does not take up established scientific terms: Only use terms of 'ice blocks' and 'ice sheets' are used, which do not at all align with established notation of different ice types or ice bergs. Therefore, it is completely unclear what kind of ice is actually being talked about.
3. The work is not reproducible: The architecture and training set-up of the classifier is not described in enough detail (layer sizes, losses, hyperparameters, ...). The datasets used are referenced but should be described none-the-less.

Before these things are addressed, I believe publication is not warranted. The language and clarity of the text also needs improvement. The use of established scientific terms would aid in this.

Specific Comments:

1. If only Sentinel-1 is used, why are the other Copernicus Satellite missions described in the text?
2. Why is the image segmented at all, before being passed through the CNN patch-wise? If the aim is to separate land and water, an existing land mask would be a much better option. In Figure 3, some of the ocean surface in the bottom left, which has evidence of sea ice growth in it, is not labelled as ocean.
3. In 'Results and demonstration', you claim that the ice blocks (I assume you mean ice bergs – see general comment 2) are detected in an unsupervised manner, yet in the previous section it is mentioned that they are detected by a CNN, which is trained in a supervised manner as far as I understand the manuscript.
4. In Table 1. Why is there no detail given for an open water class? Also, please explain the

micro avg, macro avg, weighted avg and samples avg. If three classes exist, a confusion matrix might be helpful, as well as the number of occurrences in the dataset.

Is the work clearly and accurately presented and does it cite the current literature?
No

Is the study design appropriate and does the work have academic merit?
No

Are sufficient details of methods and analysis provided to allow replication by others?
No

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Sea ice remote sensing, artificial intelligence, computer vision

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 03 September 2024

https://doi.org/10.21956/openreseurope.19553.r43636

© 2024 Hoffman L. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

?

Lauren Hoffman
University of California San Diego, San Diego, California, USA

Major Comments

1. *General:* Throughout the paper the authors refer to “ice blocks”, “ice sheets”, “icebergs” (Table 1). Within the polar community there are specific definitions for different types of ice, which the authors should pay attention to. To that note, could you comment on this and clarify what you mean by ‘ice blocks’ (i.e. to what type of ice you are referring). Would this method also be useful for floes of sea ice? (related to Major comment #7)

1. https://nsidc.org/learn/parts-cryosphere/ice-sheets/ice-sheet-quick-facts

2. *Introduction:* Could you provide citations for the first paragraph about changes in the state of the Arctic?
3. *Introduction:* Could you provide a few examples of other similar work that has made data-driven or numerical predictions of sea ice using satellite products?
4. *Methods:* Could you include a figure that shows the processing / model steps? i.e. show the inputs, pre-processing, the model levels, CNN architecture, outputs, etc.?
5. *Methods:* Can you list all of the evaluation metrics here, show how they are calculated, and discuss what they mean, i.e. what does it mean to have a 0.92 precision? What is support? Recall? F1 score? Could you provide a bit more discussion of these performance metrics in the results section?
6. *Table 1:* Could you describe what you mean by "micro avg", "macro avg", etc.
7. *Results:* What data is used for the model evaluation? Is it different from the training data?
8. *Conclusion:* Could you provide suggestions as to what types of regions this model would be useful? For example, in regions with compact ice, the MIZ, open ocean with sparse 'ice blocks' ?

Minor Comments

1. *Introduction:* Remove "and irreversible", as this is speculative.
2. *Introduction:* In the second to last sentence of the introduction the phrasing "and as well as" is redundant. I suggest you remove either "and" or "as well as".
3. *Data:* In the second sentence of 'Data collection and processing': "Copernicus program, the European Union's Earth observation program" – the phrasing here is a bit confusing. Are these two separate programs? Is it the EU's Earth observation program by Copernicus?
4. *Data [beginning of the second paragraph]:* "Inside Copernicus" makes it sound like you're referring to work being done at Copernicus. Could you rephrase this and say "Among these Copernicus products…"
5. *Data:* The next two sentences are redundant – you could combine them as follows: "SAR is ideal for our use as the SAR satellite sensors can penetrate cloud cover and 'see through' darkness and weather, providing 24/7 unobscured views of Earth and allowing a unique view of ice distribution"
6. *Data [Last paragraph]:* you can remove the commas after "them" and "decibels" in the following sentence "After downloading the products, we perform sigma-0 calibration on them and convert them to decibels using geospatial libraries…"
7. *Data*: "We also have access to a labeled dataset" – where did the labels come from? i.e. who labeled the data? Citation?
8. *Methods*: Change "The performance of the CNN model is validated…" to "We validate the performance of the CNN model…"

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and does the work have academic merit?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Arctic sea ice, machine learning

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.