Interactive Visual Exploration of Arctic Sea Ice Extent 1978-2023

D. P. Pedersen [1], L. I. K. Hansen [1], E. B. Sørensen[1,2], G. Walsh[1], J. Kusnick[1] and S. Jänicke[1]

[1]Department of Mathematics and Computer Science, University of Southern Denmark, Odense, Denmark
[2]Department of Biology, University of Southern Denmark, Odense, Denmark

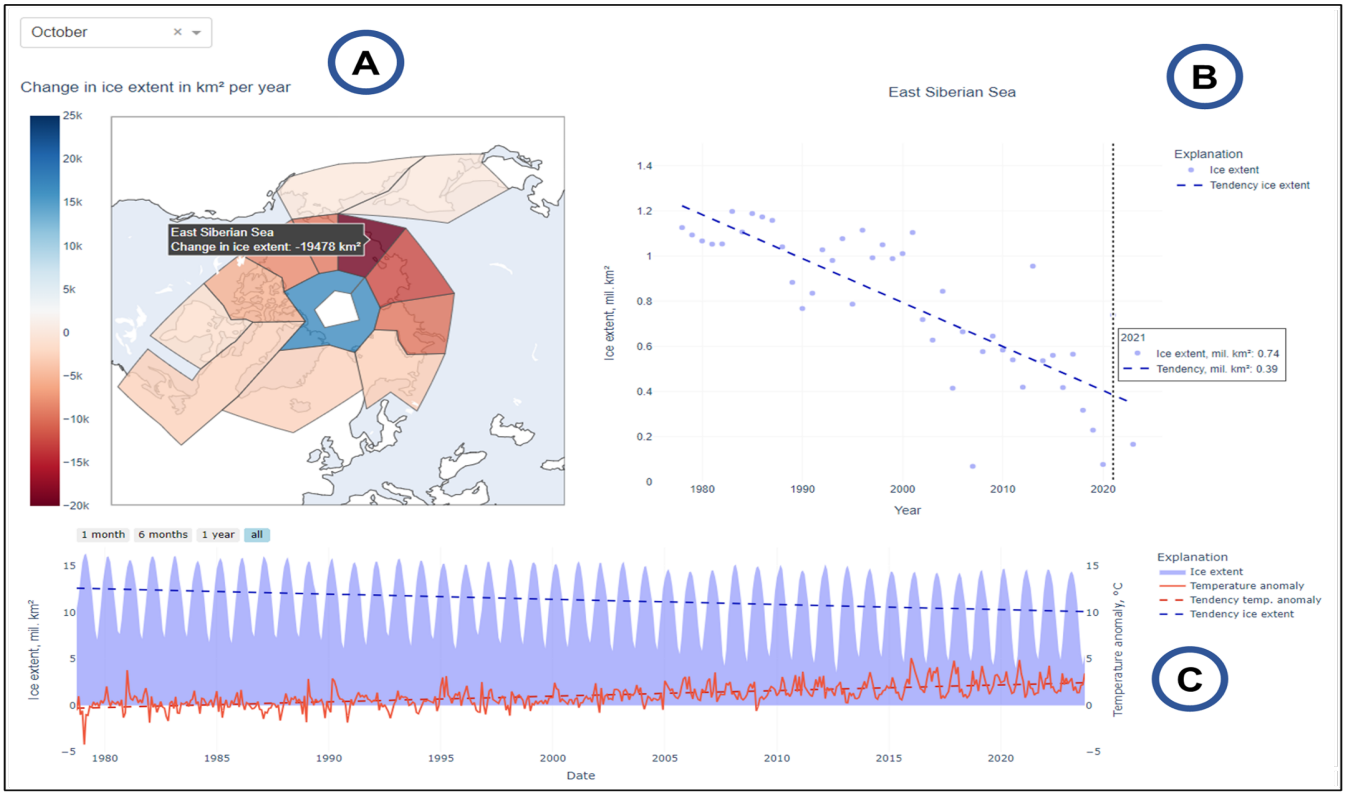

Figure 1: *Overview of the whole tool, including the geospatial map (**A**), displaying the tendency of sea ice extent development in each of the Arctic regions in a chosen month throughout the years. The coloring of the regions ranges from blue to red with respect to the regression slope, which conveys how much the sea ice extent has decreased or expanded over time. The scatter plot (B) shows the mean sea ice extent of a selected area for the chosen month throughout the years, including a regression line. The overall timeline (C) displays the development of the total Arctic ice extent and temperature anomalies as well as regression lines for both parameters.*

Abstract

The Arctic region and it ecosystem is undergoing rapid and significant environmental transformations by climate change. Traditional visualizations on this lack interactivity, hindering in-depth exploration by domain experts. This paper presents a participatory approach to developing a more interactive visualization tool for exploring the extent of Arctic sea ice. Leveraging data from the National Snow and Ice Data Center, our prototype offers insights into overall trends, seasonal variations, regional differences, and historical comparisons. By combining geospatial and temporal overviews, users can analyze changes comprehensively. Our visualization tool is a step towards interactively exploring the Arctic sea ice developments and thereby facilitating researchers to gain informed insights into the complex dynamics of a key aspect in the Arctic ecosystem.

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1. Introduction

Over the last decades, the Arctic region has seen drastic shifts to its ecosystem due to climate change [LCD*23]. This is manifested by temperatures three times higher than the global average, fast retrieving glaciers, increased indices of wildfires, and a fast declining sea ice extent [AA20]. So even completely ice-free summers are predicted to occur around the middle of this century [Nor]. Sea ice constitutes the foundation of the entire food web in the Arctic and the rapid changes have massive consequences for local wildlife and human communities but also the entire global ecosystem indirectly [PBB*13].

Several official institutions present visualizations to monitor the development of the Arctic sea ice and thereby enable interested researchers, policymakers, and the wider public to stay informed about changes in the region. What these platforms have in common is that their visualizations offer limited opportunities for interaction and are presented in separate products, usually scattered throughout the sub-pages of the websites [NAS]. One example is the National Snow and Ice Data Center (NSIDC). The visualizations only include the current sea ice extent compared with the last four years and thus do not communicate the temporal trend of the overall decreasing tendency [Nata]. Currently domain experts are lacking the ability to explore the sea ice extent data in further detail, which is consequently difficult to achieve with the lack interconnected visualizations. We believe that a participatory approach could benefit the development of an interactive visualization tool for exploring the temporal trend in Arctic sea ice extent [JKKS20]. This could contribute to an intuitive exploration of seasonal changes in the Arctic sea ice extent, correlations with important factors (e.g., temperature anomalies), and clearly have the ability to compare historical patterns seen in different regions of the Arctic.

2. Data

The NSIDC provides a continuous time series of daily values on the sea ice extent that spans from 1978 to the present [Natb]. The data originates from remote sensing with a spatial resolution of 25 x 25 km and covers both the Arctic and Antarctic regions [WAC23]. The data are aggregated into 14 Arctic sub-regions, which represent regional changes in sea ice extent measured in square kilometers. To allow for responsive interactions within the visualization, data abstraction methods were applied for a simplified representation of time series. We have reduced the temporal aspect from daily to monthly aggregated values for each of the 14 regions and obtained the total Arctic sea ice extent by merging the regions together [SAAF18]. Arctic temperature anomalies were included to allow further comparison and are calculated with respect to the 1910-2000 average [NOA].

3. Visual Design

The proposed visualization tool (see Figure 1) was developed in a participatory design process [JKKS20] to include insightful domain knowledge from an Arctic researcher. The implementation was done in the web-based Python library *Dash by Plotly* [Inc15] Thereby, we have worked out and processed the following major user tasks: **1)** Visualize the overall tendency of the pace at which the Arctic is either gaining or losing sea ice. **2)** Analyze this tendency on a finer level to show whether the regions are behaving differently. **3)** Highlight seasonal variations and dependencies of temperature and ice extent. The three interlinked views of our visualization tool to tackle these tasks are designed according to Shneiderman's *Visual Information Seeking Mantra* by starting with a geospatial and temporal (see Figure 1**A** & **B**) overview which is interconnected with the other visualization and allows the user to further zoom and filter for certain areas and time periods [Shn96]. The timeline (see Figure 1**C**) explores the data regarding the total sea ice extent for the entire Arctic. Whereas views A and B can also present information on regional level and give the opportunity to filter the data by specific time interval and areas. For the analysis, these filtering interactions are important since the ice masses behave differently due to, e.g., proximity to deep open water or larger areas with shallow shelves and throughout summer and winter months [AvDP08].

Use Case – The East Siberian Sea in October:
Figure 1 presents a use case where the focus lies on the month of October throughout all of the years to research periodicity and trends. The coloring of the spatial regions in Figure 1**A** gives the user a quick intuition of which regions have seen drastic changes. One of them is the East Siberian Sea, which is then selected by a click on the region of interest to discover the details further as seen in Figure 1**B**. There, it becomes apparent that the ice extent in this region has decreased by an average of 19,478 square kilometers per year in October from 1978 to 2023. The temporal overview within the timeline in Figure 1**C** reveals the fluctuation of the whole Arctic ice extent and the user can thereby relate it to the regional changes of the East Siberian Sea.

4. Conclusion

In this project, we have explored how interactive visualizations can contribute to an improved communication of changes in the Arctic sea ice extent and thereby address limitations of current visualizations. The result is a concise visualization tool that enables the user to explore development and tendencies for sea ice extent on multiple zoom levels with the option to compare years, seasons, months, and regions. Future work will include further inclusion of domain experts and making the current prototype available online.

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