Visualizing Sunlight Radiation in the Arctic Ocean

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Abstract

The Arctic is experiencing dramatic environmental transformation due to rising temperatures and melting ice, which are affecting its environment, wildlife, and human communities. Remote sensing technologies (e.g. satellites) are increasingly being used to understand environmental change in the remote and understudied Arctic Ocean across broad spatial and temporal scales, generating vast data sets that require interactive visualization to be dynamically explored. We present a prototype visualization that uses aggregation means on different zoom levels to allow exploring a 200GB data set on sunlight in the Arctic Ocean, which consists of monthly time series of coastal pixels, photosynthetically available radiation (PAR), light attenuation coefficient (KPAR), and PAR estimated at the seafloor (PARBOTTOM) from 1998 to 2018. Our main example—the analysis of trends in sunlight radiation levels along the west coast of Greenland—exemplifies our tool's value for marine biologists to getting a concise and interactive overview of sunlight radiation levels, which allows studying potential impacts on the Arctic ecosystem.

1. Introduction

The Arctic Ocean is a unique and fragile ecosystem that is particularly vulnerable to the effects of climate change. As temperatures rise and ice melts, the region is undergoing significant changes that are having far-reaching impacts on its environment, wildlife, and human communities [MA20]. The changes are happening rapidly, with large changes in temperature and ice cover being registered over the last decades [AMA21]. The diminishing Arctic ice pack has made the Arctic Ocean more exposed to sunlight, potentially stimulating photosynthesis at the base of the Arctic Ocean food chain. Understanding the availability of sunlight radiation in the ocean is therefore a key research frontier [MA20]. Of particular interest is Photosynthetically Available Radiation (PAR), which consists of the spectral range of solar radiation between 400-700nm. PAR is utilized by primary producers during photosynthesis, a process that transforms light energy to chemical energy and is central to ecosystems [K.J81]. Satellites are increasingly being used to understand ecosystem change in remote and understudied regions such as the Arctic. However, exploring the complex and large data sets being generated by satellites can be challenging, and static plots are often used to communicate the data, making it impossible to dynamically explore the data across time and space. The National Snow & Ice Data Center supports the world with daily updates on the Arctic climate and how it is changing [Cen22]. Although the plot gives researchers a good overview of the latest changes, it does not allow for interactive exploration of temporal developments or geospatial patterns. To the best of our knowledge, interactive visualizations of sunlight radiation in the Arctic do not yet exist. The purpose of this study was thus to develop a dynamic visualization of remotely sensed sunlight data for the Arctic Ocean as a solution to this knowledge gap. We present the current stage of our development, which includes two visual design iterations.

2. Data

A significant challenge of this project was developing strategies for effectively managing the vast amount of PAR data available. The data for the project was produced by GGAD20 from ocean colour remote sensing data collected by the GlobColour Project [Glo22]. It consists of a monthly time series of Coastalpixels, PAR, PAR attenuation coefficient (KPAR), and PAR at the bottom (PARBOTTOM). The time series extends from 1998 to 2018, with each monthly file being stored as a NetCDF file. NetCDF is a file format commonly used in natural sciences which stores data in 3-dimensional space. Each file in the coastal light time series ranges in size from 8 to 900MB, resulting in a total of approximately 200GB for the entire data set. Temporal data is collected per month, and the geospatial resolution of the data set is 4.6 km (bathymetric resolution is 0.46km) measured at Equator and has coverage for coastal waters up to a depth of 200m on the entire globe. The available months for the Arctic region (60-90°N) is from June to October because of lack of available light in the rest of the year [GGAD20]. We thereby have 105 available months covering the span of the 21 year long time series.

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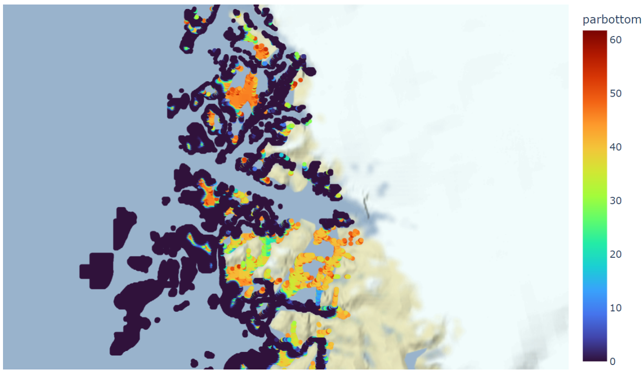

Figure 1: *The first prototype shows the West Coast of Greenland, each pixel is colored using the (contentious) rainbow color scale, which intended to allow detecting minor attribute changes.*

3. Visual Design

The visualization tool has been developed in close collaboration with the oceanographers co-authoring this paper. It has been evaluated and revised in each iteration to suit their needs and to accommodate a participatory visual design process [JKKS20], which is based on Munzner's Nested Model [Mun09]. Of particular importance for the researchers was the ability to get an overview of different features of coastal light radiation, and to zoom and filter different regions of interests. This paper presents two iterations of our visual design, implementing the information seeking capacity [Shn96].

First Prototype. The first prototype (Figure 1) focused on a small area on the west coast of Greenland. The main goal of this visualization was to gain knowledge of how to handle the large amount of data and to learn on the limitations associated with it. We utilized all available pixels and values in the predetermined area. This allows for a detailed visualization of the variations in the selected value and the user has the possibility to browse through the whole time series. However, it became apparent that it was computationally too heavy and that it did not allow for useful interactions for the domain expert. It lacked an overall view of the changes for all regions in the Arctic.

Second Prototype. To address the problems of the first prototype, the second iteration was inspired by the framework by Teanby [Tea06]. He proposes a 4-step process utilizing a binning approach to aggregate large amounts of geospatial data. Therefore, we make use of the MASIE-regions [FFCC10, DCYG18], similar to a related visualization that allows to observe ice extent in the Arctic [Cen22]. Clicking a region filters the data and zooms to the respective geographical area. Depending on the zoom level, we aggregate the corresponding data points in hexagons of different size. The three different resolution layers allowed our domain expert to interact with the data and dynamically zoom and compare different areas of interest. Users can choose among the three data attributes PAR, KPAR and PARBOTTOM, select a month (of the year), and hexagons are colored according to the correlation with time, i.e., a "coastal light" trend is shown for each hexagon. This highlights areas with similar impacts of coastal light radiation, which can be analyzed in detail in a scatterplot that shows the temporal development of the chosen coastal light attribute (see Figures 2 and 3).

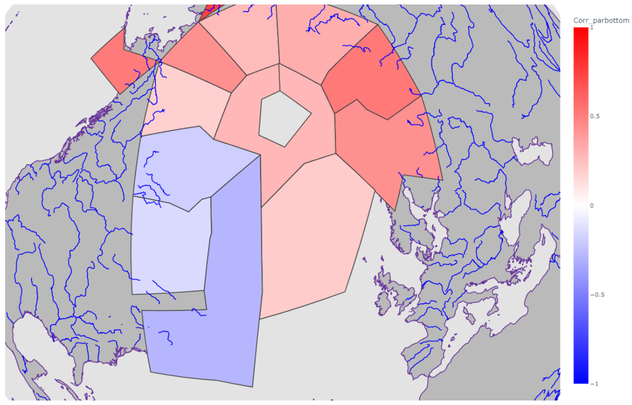

Figure 2: *The first zoom level shows the MASIE regions. The color scale shows correlations of the chosen variable and time using blue for negative and red for positive correlations. For a clicked region, a more detailed hexagonal binning of the data is shown.*

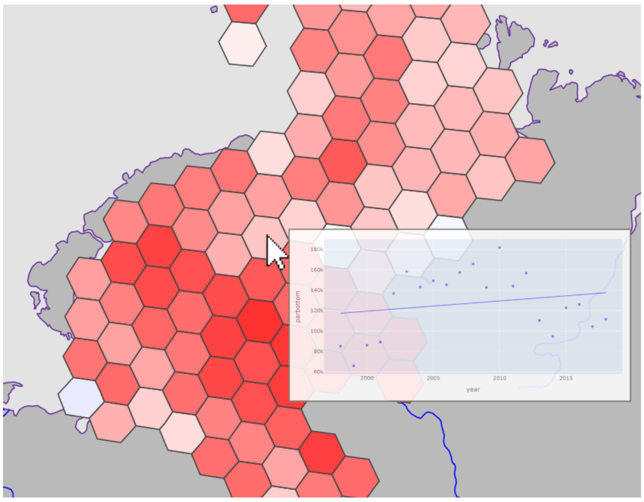

Figure 3: *On the second zoom level, the Kara Sea region for the month of July and the variable PARBOTTOM shows mainly positive correlations. The hexagons are clickable which shows a finer, more detailed hexagon grid and a scatter plot for detailed analysis.*

4. Conclusion

Our main objective is giving oceanographers a brief and concise overview of the light levels from 1998-2018 and creating an interactive visualization experience. The first two prototype visualizations show the capabilities of using big data visualization strategies to manage the very large data set. With the current version, researchers now have an opportunity to zoom in on certain areas of interest instead of only possessing static plots. Future extensions will include small multiple views for more detailed analysis opportunities of coastal light features.

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