Analysis and Prediction of Northern Hemisphere Sea Ice Extent

University of Minnesota - Twin Cities
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Daniel Binsfeld
Chris Park
Nate Stearley

Background:

The US National Snow and Ice Data Center (NSIDC) collects and manages research and data on worldwide solid precipitation (snow, sea ice, lake ice, icebergs, glaciers). The NSDIC works to analyze and understand how the Earth's system of solid precipitation (aka the cryosphere) changes over time and how we can best predict the future state of the Earth's cryosphere using historical data. For this study, we obtained a large dataset (approximately 5,500 days/data points) of Arctic Ice Measurements from Regions of the Northern Hemisphere through the NSIDC. Our data contains daily Multisensor Analyzed Sea Ice Extent (MASIE) measurements from January 1, 2006, to January 14, 2021, which we analyze using a **Correlation Matrix** and individual **Linear Least Squares Regression Models** for specific locations within our data set. Additionally, using the LLS Regression, we make ice measurement predictions for the entirety of the **Northern Hemisphere** and for three individual regions: the **Canadian Archipelago**, **Hudson Bay**, and the **Bering Sea**.

Data and Data Measurement:

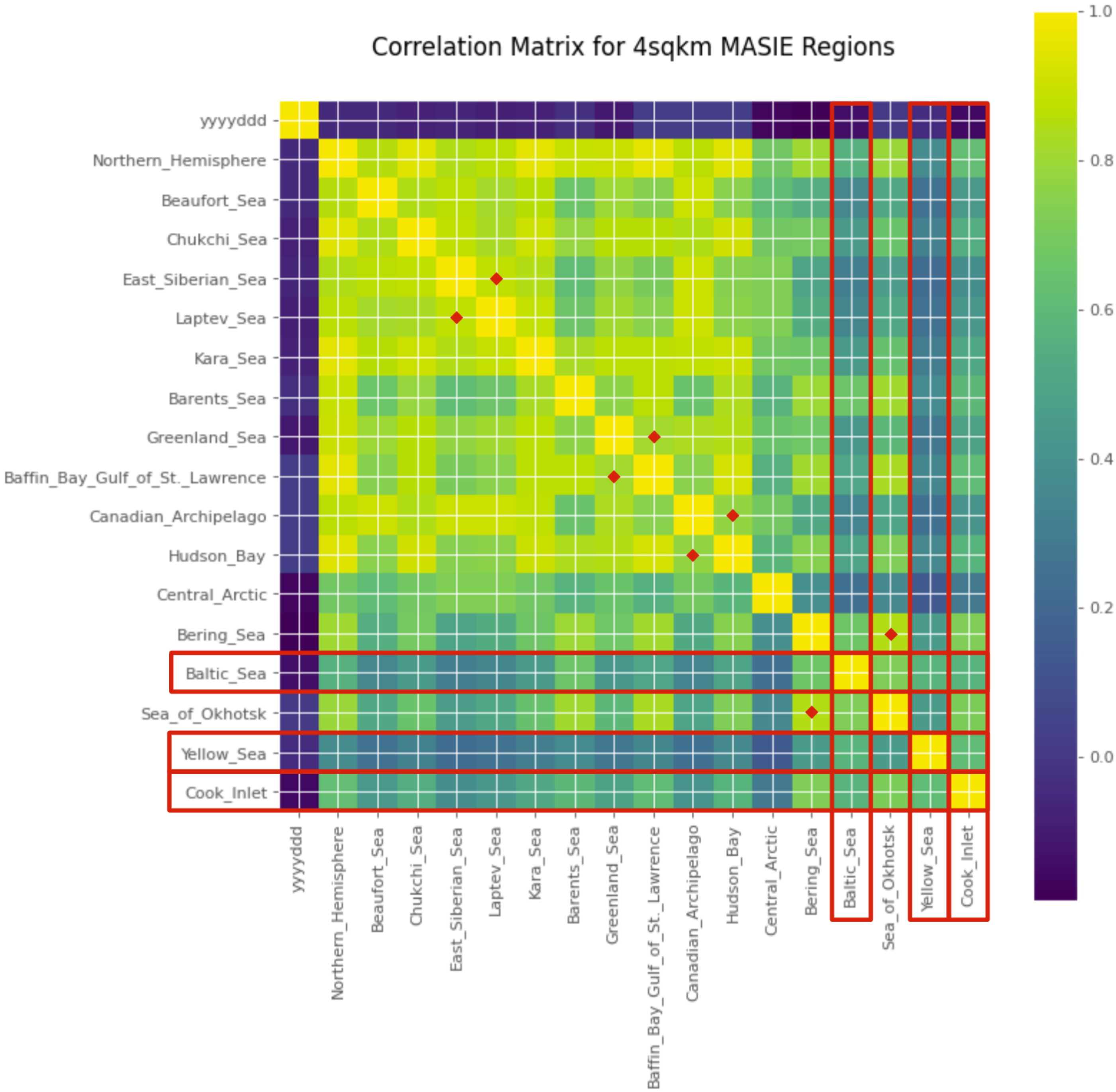
There are two common methods of recording sea ice data: the Sea Ice Index and MASIE. While Sea Ice Index data is based on passive microwave data, which produces a larger amount of irregularities and inaccuracies in collected data, satellite imagery is the main method of data collection for MASIE. This gives MASIE a greater degree of data accuracy when making ice extent observations. As previously mentioned, our data was obtained through the NSIDC website and contains approximately 5,500 days of MASIE data from January 1, 2006, to January 14, 2021. Our data is based on 18 different locations with 4 km^2 areas, with each exact location summarizing the ice extent data and patterns of its general location in the below figure. Also worth noting is a potential flaw in the MASIE data: it tops out at 0 when an area is fully covered in ice and at a maximum value (varies per location) when a region is completely covered in ice. This means that the data for a given location may reach a hard upper or lower limit depending on the sea ice extent measurements of the area. Although the data is still accurate, it is worth keeping this in mind as a potential area in which to improve this study in the future.

<u>Number - Location Name</u>	
1 - Beaufort Sea 2 - Chukchi Sea 3 - East Siberian Sea 4 - Laptev Sea 5 - Kara Sea 6 - Barents Sea 7 - Greenland Sea 8 - Baffin Bay/Gulf of St. Lawrence 9 - Canadian Archipelago 10 - Hudson Bay 11 - Central Arctic 12 - Bering Sea 13 - Baltic Sea 14 - Sea Okhotsk 15 - Yellow Sea 16 - Cook Inlet 17 - Northern Hemisphere (All Entries)	

Locational Data Correlation:

The first step in our data analysis was to compare MASIE locational data from each of our 18 listed locations in order to determine the correlation of ice extent between them. As expected with a correlation matrix, each location correlates perfectly (1.0) with itself, and has varying degrees of correlation with other locations. We expected to see at least a slight correlation between location data from geographically close areas, which was confirmed with a comparison of several location pairs from our data set. The correlation of these pairs is listed in the below table and marked by a red diamond on the “Correlation Matrix for 4sqkm MASIE Regions”. Additionally, there were three regions - the Baltic Sea (13), the Yellow Sea (15), and the Cook Inlet (16) that had very low correlation with data from the other regions in our data set, with most correlation entries ranging between 0.2 and 0.5. These three regions are highlighted in red on the “Correlation Matrix for 4sqkm MASIE Regions”.

Location 1	**Location 2**	**Correlation (approximate)**
3 - East Siberian Sea	4 - Laptev Sea	0.9
7 - Greenland Sea	8 - Baffin Bay/ Gulf of St. Lawrence	0.8
9 - Canadian Archipelago	10 - Hudson Bay	0.8
12 - Bering Sea	14 - Sea Okhotsk	0.8



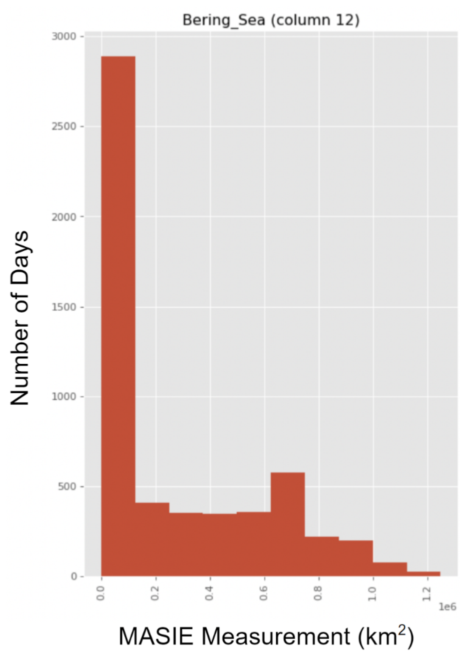
Correlation Matrix for 4sqkm MASIE Regions
yyyyddd
Northern_Hemisphere
Beaufort_Sea
Chukchi_Sea
East_Siberian_Sea
Laptev_Sea
Kara_Sea
Barents_Sea
Greenland_Sea
Baffin_Bay_Gulf_of_St._Lawrence
Canadian_Archipelago
Hudson_Bay
Central_Arctic
Bering_Sea
Baltic_Sea
Sea_of_Okhotsk
Yellow_Sea
Cook_Inlet
1.0
0.8
0.6
0.4
0.2
0.0

Locational Data Analyses and LLS:

For the final portion of this study, we selected three distinct locations - the Canadian Archipelago, the Hudson Bay, the Bering Sea, and the Northern Hemisphere as a whole - and used a LLS Regression Model for each location to make predictions about future MASIE data. We selected these three specific locations so we would have one example each for decreasing, increasing, and stagnant ice extent levels. This allowed us to test our predictions for three different types of ice extent changes to ensure that our LLS Regression Models were consistently accurate, regardless of the ice extent growth loss/gain trend pattern. Although the annual fluctuations of sea ice extent create a sinusoidal data set for each location as well as the Northern Hemisphere as a whole, we are able to flatten out our data through our use of LLS. In addition, we chose to focus on the month of January for our prediction models. This offers a more-specific scope for our regression analysis and proves its efficacy on a smaller scale of monthly trends as compared to the yearly trends represented by analysis of the dataset as a whole.

A1 - Bering Sea (Net Decrease)

Our first observed location for analysis and prediction was the Bering Sea. Located off the coast of Alaska, the Bering Sea is located further away from the Central Arctic than many other observed locations for this study. The lower left figure shows a graphical representation of the accumulated data for the region, with a clear graphical maximum on days with little-to-no snow (0.0 - 0.2e6 km^2) that suggests a potential decrease in sea ice extent over the past 15 years. Our LLS model (pictured below on the right) verifies a consistent decrease in maximum sea ice extent within the Bering Sea over the timespan of our data set.




```
Bering_Sea linear least squares regression
A matrix - [[0.000e+00 1.000e+00]
 [1.000e+00 1.000e+00]
 [2.000e+00 1.000e+00]
 ...
 [5.447e+03 1.000e+00]
 [5.448e+03 1.000e+00]
 [5.449e+03 1.000e+00]]

Slope of line:  -44.78241097816808
Y-intercept:  389085.8288035969
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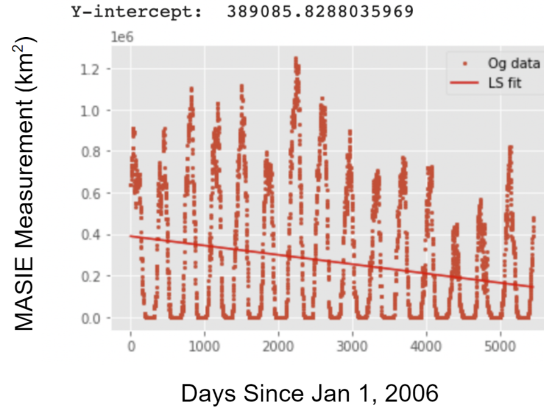
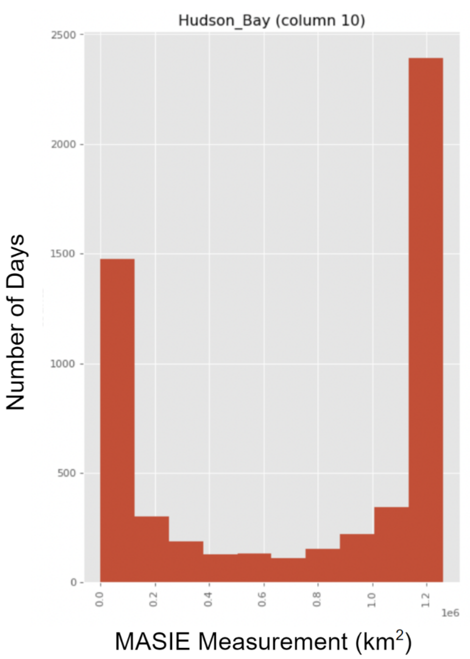
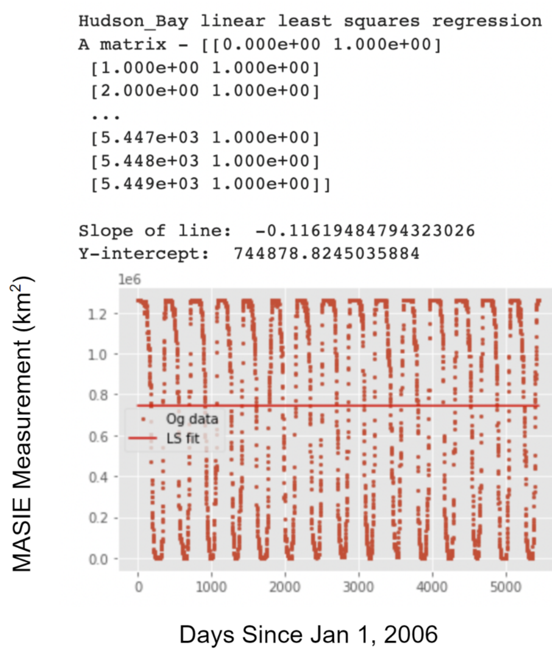


B1 - Hudson Bay (Stagnant)

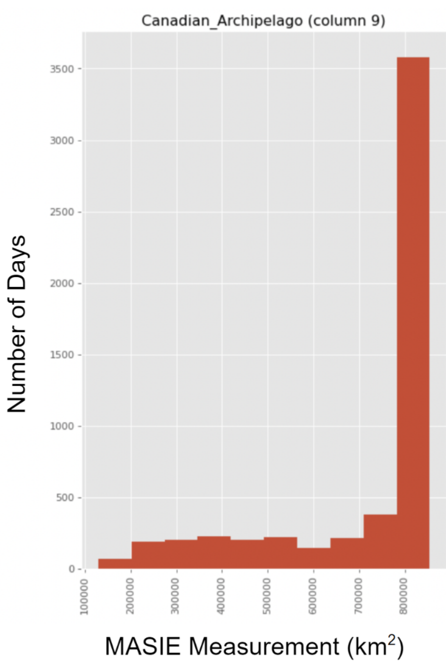
The second of our observed locations for analysis and prediction was the Hudson Bay, located in north-central Canada. With the Hudson Bay being nearly landlocked, we expected to see a greatly reduced variation in sea ice extent than other locations, with less influence from ocean currents and seasonal oceanic weather. The lower left figure shows a graphical representation of the accumulated data for the region, with clear graphical maximums in both the minimum (0.0 - 0.2e6 km^2) and the maximum (1.2e6 km^2) sea ice extent values suggesting a healthy variation of ice throughout the year. Our LLS model (pictured on the right) confirmed this healthy variation through a virtually stagnant rate of change for the region's sea ice extent measurements over the past 15 years.





C1 - Canadian Archipelago (Net Increase)

Selected as our final location for individual analysis, the Canadian Archipelago is located slightly north of the Hudson Bay inside of the Arctic Circle. In contrast to the Bering Sea, this location has a large grouping of sea ice extent measurements in the maximum value of 800,000 km^2 on the lower left graphical data representation. As such we expected our LLS model to show a net increase in sea ice extent over the timespan of our data. Congruent with our initial assumptions, our LLS model showed a gradual increase in sea ice extent over the data collection timespan. It is worth noting that this increase is very slight when contrasted with the sharp decrease in sea ice extent seen in the Bering Sea LLS model.




```
Canadian_Archipelago linear least squares regression
A matrix - [[0.000e+00 1.000e+00]
 [1.000e+00 1.000e+00]
 [2.000e+00 1.000e+00]
 ...
 [5.447e+03 1.000e+00]
 [5.448e+03 1.000e+00]
 [5.449e+03 1.000e+00]]

Slope of line:  1.89819204774033
Y-intercept:  721503.3482319866
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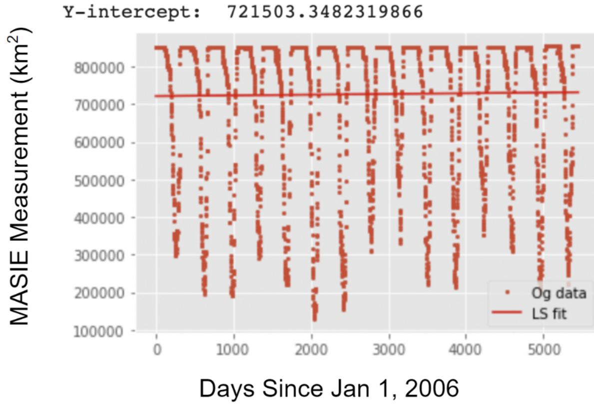
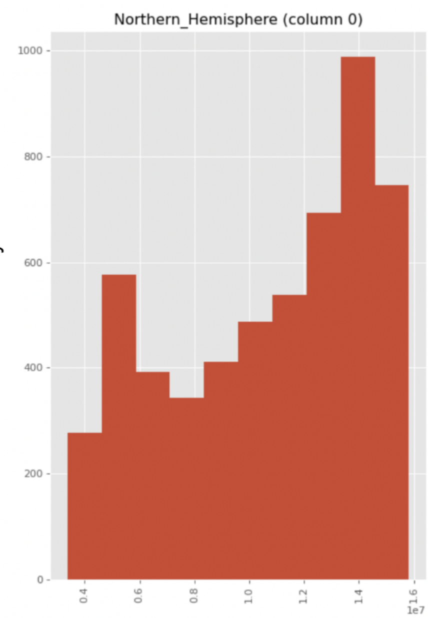


D1 - Northern Hemisphere (Net Decrease)

Finally, we analyze the Northern Hemisphere in its entirety. Supported by the modern political and scientific movement centered around the climate crisis, there has been an observable decrease in the overall sea ice level of the Northern Hemisphere since January of 2006. While seasonal variations have continued, the maximum sea ice extent measurements have been decreasing at a notable rate, with collected data growing closer and closer to bottoming out with no sea ice at all for specific days of the year.

Number of Days

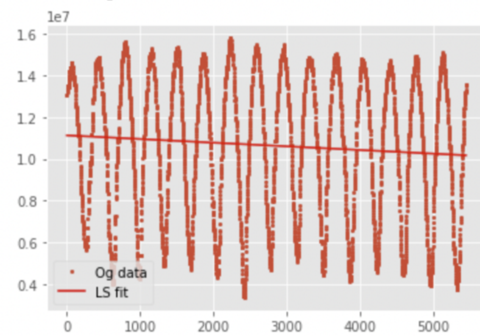


MASIE Measurement (km^2)

```
Northern_Hemisphere linear least squares regression
A matrix - [[0.000e+00 1.000e+00]
 [1.000e+00 1.000e+00]
 [2.000e+00 1.000e+00]
 ...
 [5.447e+03 1.000e+00]
 [5.448e+03 1.000e+00]
 [5.449e+03 1.000e+00]]

Slope of line:  -175.3199801108963
Y-intercept:  11130734.690333232
```

MASIE Measurement (km^2)

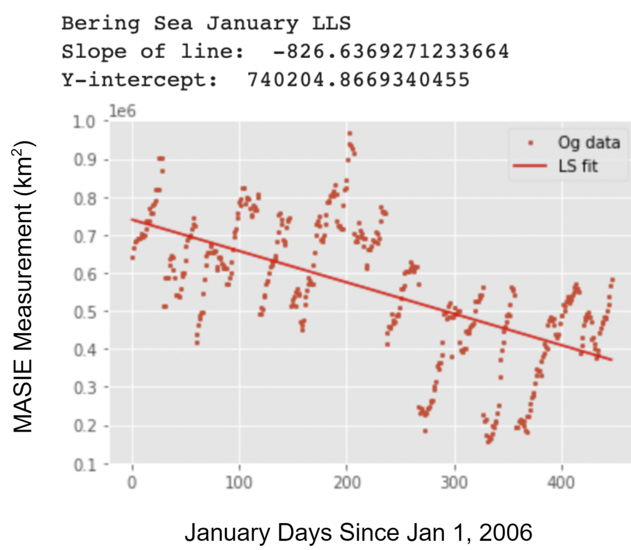


Days Since Jan 1, 2006

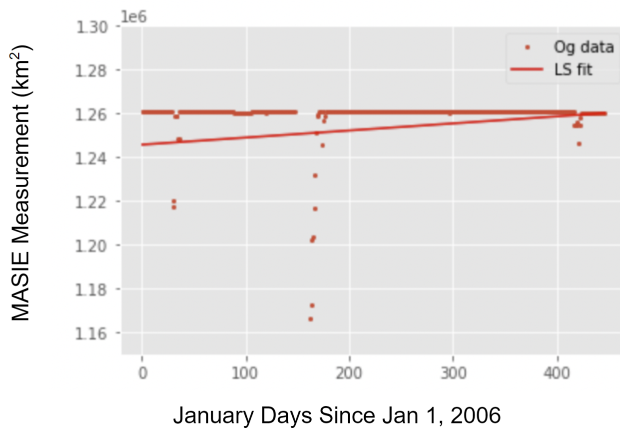
Locational Data Predictions for January, 2021

For all of the following predictions, we began by calculating the individual predictions for each of 31 days in January, 2021 using our LLS models. We then averaged all 31 of those data points because our model holds true when analyzing the month of January as a whole, but will produce inaccurate predictions when used on individual days. This required specificity in our data and predictions is due to the large ice extent fluctuations that can be seen throughout January for the above models (specifically for the Bering Sea and the Northern Hemisphere as a whole). Worth noting is the apparent differences in the percent change of the Canadian Archipelago when compared to the overall trends of the region. Apparent differences such as this are justified when considered in the context of the prediction. We are solely predicting the month of January, which means that our isolated predictions may not conform to the general ice extent trends of a given region.

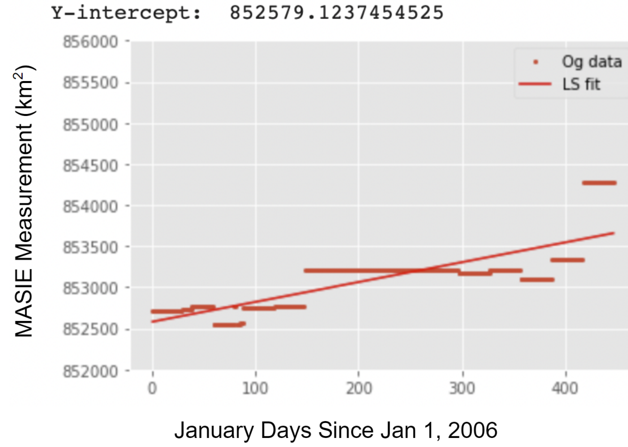
A2 - Bering Sea Prediction

January, 2021 MASIE Prediction:	361823.98 km^2	
Percent Change from Jan 2020 to Jan 2021:	-22.78%	

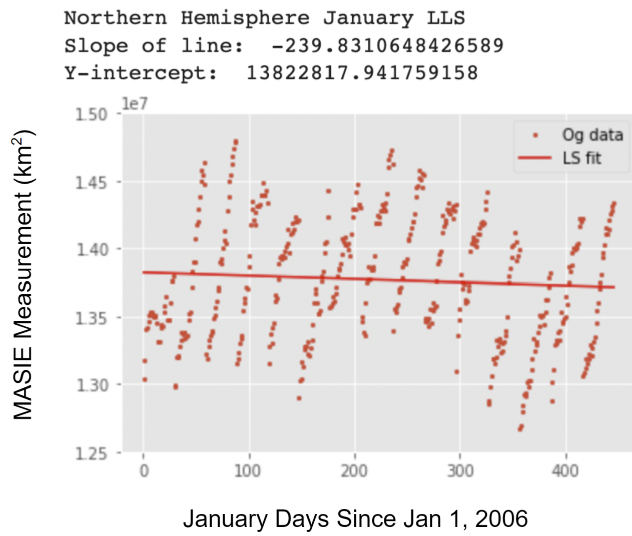
B2 - Hudson Bay Prediction

<table>
<tr><td>January, 2021 MASIE Prediction:</td><td>1260788.30 km^2</td><td rowspan="2">Hudson Bay January LLS
Slope of line: 32.31723835191575
Y-intercept: 1245759.4931700511

</td></tr>
<tr><td>Percent Change from Jan 2020 to Jan 2021:</td><td>0.16%</td></tr>
</table>

C2 - Canadian Archipelago Prediction

<table>
<tr><td>January, 2021 MASIE Prediction:</td><td>853697.40 km^2</td><td rowspan="2">Canadian Archipelago January LLS
Slope of line: 2.417796064728981
Y-intercept: 852579.1237454525

</td></tr>
<tr><td>Percent Change from Jan 2020 to Jan 2021:</td><td>-0.06%</td></tr>
</table>

D2 - Northern Hemisphere Prediction

<table>
<tr><td>January, 2021 MASIE Prediction:</td><td>13732220.77 km^2</td><td rowspan="2">
</td></tr>
<tr><td>Percent Change from Jan 2020 - Jan 2021:</td><td>0.26%</td></tr>
</table>

Works Cited:

“Masie-NH Daily Image Viewer.” *National Snow and Ice Data Center*, https://nsidc.org/data/masie.