University of Southern California:
Spatial Sciences Institute

Arctic Sea Ice Visualization Modeling and Climate Data Analysis

Geographic Information System Programming and Customization

Submission by: John Hemmer

Date of submission: 6 April 2023

Introduction:

Climate change is one of the defining problems of this century. Increased concentrations of greenhouse gases such as carbon dioxide and methane have led to an average global increase in temperatures (Manabe). This has led to weather pattern changes throughout the world, sea level rise (Mimura), intensification (Mousavi) and increased likelihood of extreme weather events among many other factors. Due to polar amplification, which is the increased global warming effect in the high latitude regions (Holland). The Arctic regions are very important to study regarding climate change because the ice melting causes global sea levels to rise. This endangers buildings, properties, even entire nations. Additionally, the influx of freshwater into salt water can change the balance of the oceans leading to changes in global ocean currents (Rahmstorf). This can potentially bring large scale shifts to climate all around the world. The arctic regions are primarily ice and snow covered surfaces providing high albedo (reflectivity), with it melting the global albedo level will decrease. This destabilizing feedback will only strengthen the effects of climate change.

The purpose of this workflow is to visualize changes in Arctic sea ice around the north pole through arcgis pro by utilizing remote sensed imagery and map algebra. Through web scraping and API authentication, daily carbon concentrations and temperature changes from NOAA weather stations were collected. Using jupyter lab, changes in atmospheric composition from the CO2 data can show how temperature and specifically ice latitude could potentially change.

Study Area:

The study area for the GIS part is the Arctic Sea Ice around the North Pole. Using the extent of the ice extent raster layer, I created a rectangle that will be our study area. As the Arctic region is not strictly defined, I will use the satellite data to define it. For the web scraping and API calling, there was not a specific location as data around the globe was used.

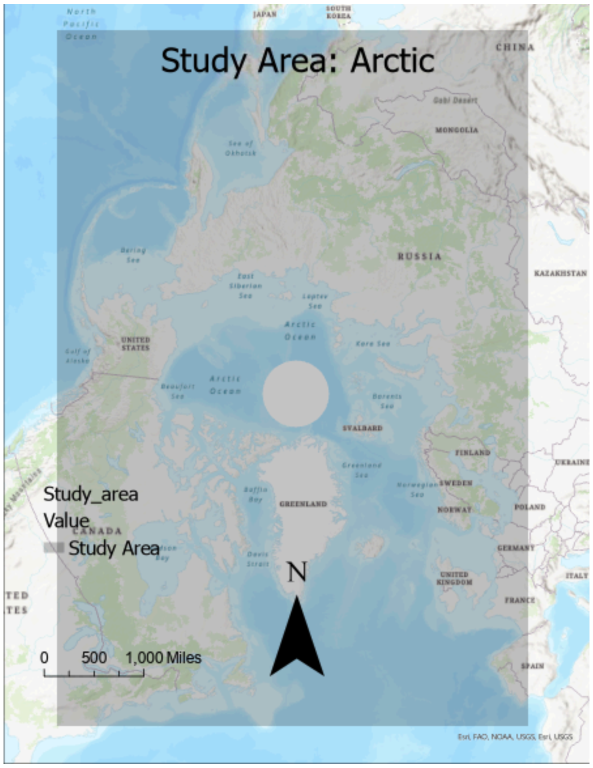


Figure 1: Study Area - Arctic

Data and Data Processing:

Table 1: Input data

Name	Description	Source
N_199012_concentration_v3.0.tif	A geotiff file of the ice concentration around the North Pole in 1990 (Stereographic North Pole)	https://nsidc.org/data/data-access-tool/NSIDC-0051/versions/2
N_199012_extent_v3.0.tif	A geotiff file of the ice extent around the North Pole in 1990 (Stereographic North Pole)	https://nsidc.org/data/data-access-tool/NSIDC-0051/versions/2
N_202212_concentration_v3.0.tif	A geotiff file of the ice concentration around the North Pole in 2022 (Stereographic North Pole)	https://nsidc.org/data/data-access-tool/NSIDC-0051/versions/2
N_202212_extent_v3.0.tif	A geotiff file of the ice e around the North Pole in	https://nsidc.org/data/data-access-tool/NSIDC-0051/version

	2022 (Stereographic North Pole)	s/2
NSIDC0051_SEAICE_PS_N25km_19901222_v2.0.nc	Net cdf file of sea ice elevation in 1990 (Stereographic North Pole)	https://nsidc.org/data/atl14/versions/2#anchor-1
NSIDC0051_SEAICE_PS_N25km_20221221_v2.0.nc	Net cdf file of Sea ice elevation in 2022 (Stereographic North Pole)	https://nsidc.org/data/atl14/versions/2#anchor-1

Table 2: Output Data

Name	Description
Sea ice elevation difference	Difference between sea ice elevation between 1990 and 2022(Stereographic North Pole)
Sea ice extent difference	Difference between sea ice extent between 1990 and 2022(Stereographic North Pole)
Sea ice concentration difference	Difference between sea ice concentration between 1990 and 2022 (Stereographic North Pole)
Daily CO2 concentrations	Line graph of daily CO2 concentrations
Daily Average Temperature	Line graph of average temperatures averaged across 10,000 NOAA weather observation stations.

Methods:
Visualizing the sea ice in arcgis pro methods:

The first step was to download the data in net cdf format by using a python script (1990_download.py and 2020_ice_download.py). The script asks for a username and password, which must be setup in order to download the data. Two separate scripts were used, one for the 12/20/1990 data and the other for 12/20/2022. The dates stayed the same to prevent changes in seasonal differences, as the change I wanted to visualize was over an extended period of time not seasonal. Next, under add data, use the multidimensional raster layer option and select the .nc files and rename them to Sea_ice_1990 and Sea_ice_2022 respectively. Next, export each raster layer and rename them "Sea_ice_2022.tif" and "Sea_ice_1990.tif". Using the raster calculator, input "Sea_ice_2022.tif" - "Sea_ice_1990.tif" and run the tool. This part (raster calculator) has model builder code, and can be run (called ice.py). The symbology was changed to stretch with a multipart color scheme (blue to red continuous), with a standard deviation stretch type and 2 standard deviations.

On another map, add the N_199012_concentration_v3.0.tif, N_199012_extent_v3.0.tif, N_202212_concentration_v3.0.tif, and N_202212_extent_v3.0.tif files. Next run 2 raster calculators. One will be "N_202212_concentration_v3.0.tif - N_199012_concentration_v3.0.tif" and the other will be the same thing except for extent. The output files can be any name, mine were "extent_diff" and "concentration_difference." For the sea ice extent, change the symbology to unique values. There should be 3 values: -1, 0 and 1. For -1 change the label to decrease, 0 no change and 1 increase. Change the color for -1 red, 0 black and 1 green. For the sea ice concentration, change the symbology to stretch, standard deviation with 3 standard deviations and change the color scheme to red-blue continuous. Then modify the color scheme to look similar to the one in figure 2. Another way of visualizing it is to change the color scheme to unique values and use red-blue continuous and change the value of 0 to the color black as well. However, this does not work well on the legend on the final layout as there are over 2000 different colors/values on the legend. The two final layers for this map are the difference between the sea ice extent and concentration. The purpose of having the black for that one value is due to most of the map having no change between 1990 and 2022. This is because a lot of the map is water or land with no change in ice, so it will have a value of 0 and we want that to be easily viewable. Unfortunately, there are also areas of sea ice that will not have changes, so that must be taken into account as well.

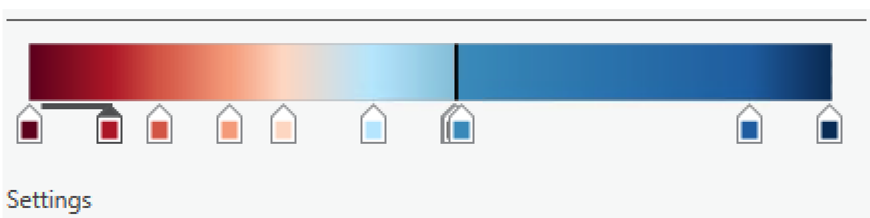


Figure 2: custom color scheme to visualize sea ice concentration

Building a simple climate model with jupyter lab:

Start by running "pip install climlab" in commandline to get the package. Next, open jupyter lab or notebook. The code is all provided in project_5.ipynb and should not require any changes/modifications for pathways.

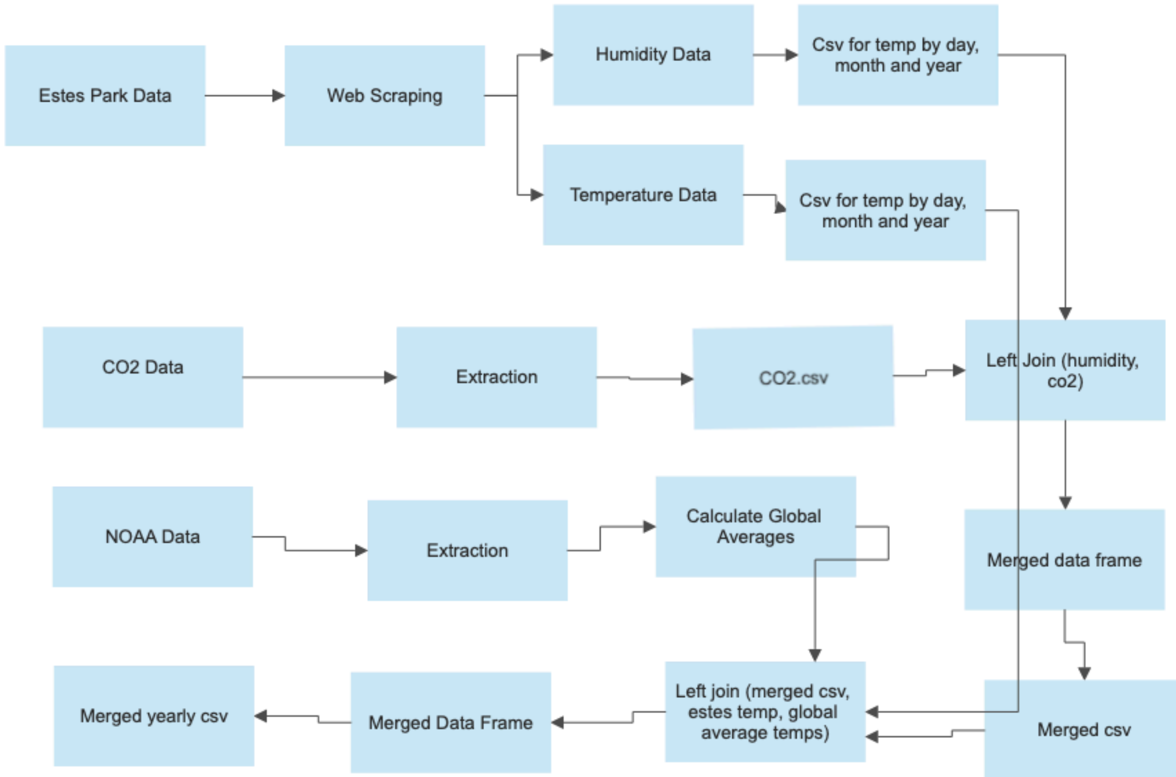
Collecting CO2 and temperature data in a jupyter notebook:

This notebook uses matplotlib.pyplot, pandas and requests, which must be imported. The main step in order to carry out this notebook is to request an api token from NOAA, which can be accessed here.

Using web scraping and API extraction, data points were grabbed from the internet. These were put into dictionaries and then turned into various csv files. Daily data was taken, also monthly and yearly averages were calculated and exported to different csv files. Each dataset was visualized by creating pandas objects and matplotlib to create line graphs with date as the x-axis and the variable of interest as the y-axis. Using the pd.read_csv function, the csv files were read in and turned into pandas objects. Using the pd.merge function the different datasets were combined together to create a merged dataset, one that was monthly averages, and the other was yearly averages. The yearly merged dataset was used to create scatterplots and correlation analysis was run through python with Spearman, and Pearson (default method) methods.

When accessing the NOAA API to get the weather station data, it took about 40 minutes to run everything. To fix this, I limited the number of weather stations to 1000, and then I used csv writer instead of the csv.write function. This cut down the running time to about 20 minutes. Unfortunately, I had to fix a few things in that cell, so I kept having to run the 20 minute block. I then took the csv.write into a different cell, and saved all of the values I needed in various dictionaries. This brought the run time down to just a few minutes.

An issue relating to the analysis was the seasonality issue versus the linearity of the CO2 line. To fix this, I added code that added a list of tuples with the date (datetime object with year and january first) and the yearly average. I was able to then put these data points into the merged panda dataframe and put it into a combined csv. From there I was able to create a scatterplot and run a more meaningful correlation analysis. Although simple, taking the average got rid of the sinusoidal nature of the temperature and humidity data



Workflow Diagram for Data Collection

Results:

For the climate model in the jupyter lab, the code is creating an Energy Balance Model with a variable snow/ice line. The model takes in some initial parameters that are provided and after integrating over a few years can provide some temperatures and different short and longwave radiation values over latitude as well as an ice line latitude. Although the model does not understand atmospheric composition, it can be artificially changed by making changes to the A parameter in the outgoing longwave radiation ($OLR=A+B\times T$). In the code, I tweak the delta A parameter and try to align with the co2 data collected later in web scraping. The initial CO2 level in 2013 from the web scraping is 394 and about 418 in 2022. To create a more dramatic difference I used the 1990 levels of CO2 as this is the year where the satellite imagery is from. The calculated deltaA value is then -.157 and the model was run again.

For the web scraping notebook the link, https://global-warming.org/api/co2-api is used to collect CO2 data from the year 2013 to 2022 (that is all that was available). The request came back in JSON format, so the year, month, day and CO2 levels were taken using a for loop. Using matplotlib.pyplot the data was visualized as a line graph with time on the x-axis and CO2 concentrations in parts per million (ppm) on the y-axis.

Using ncei.noaa.govs api and an api token I was also able to axis various NOAA weather stations to collect temperature data. Using a nested for loop I took data from the first of each month for 10 years across 10,000 different weather stations. I was able to calculate a daily average by averaging all of the weather stations temperatures for that day. Using a panda dataframe and matplot again, the data was visualized on a line graph with time on the x-axis and temperature in Celsius on the y-axis.

Looking at figure 3, the blue indicates an increase in ice elevation from 1990 to 2022 and red indicates a decrease in ice elevation from 1990 to 2022. Although there are some regions of increase, the majority are regions of decreasing ice elevation. There is a large area of decreasing elevation around Greenland, Alaska and North of central Russia. Less Arctic sea ice checks out with the consensus of climate scientists as well as a simple google search, but it is interesting to see the decrease in elevation specifically.

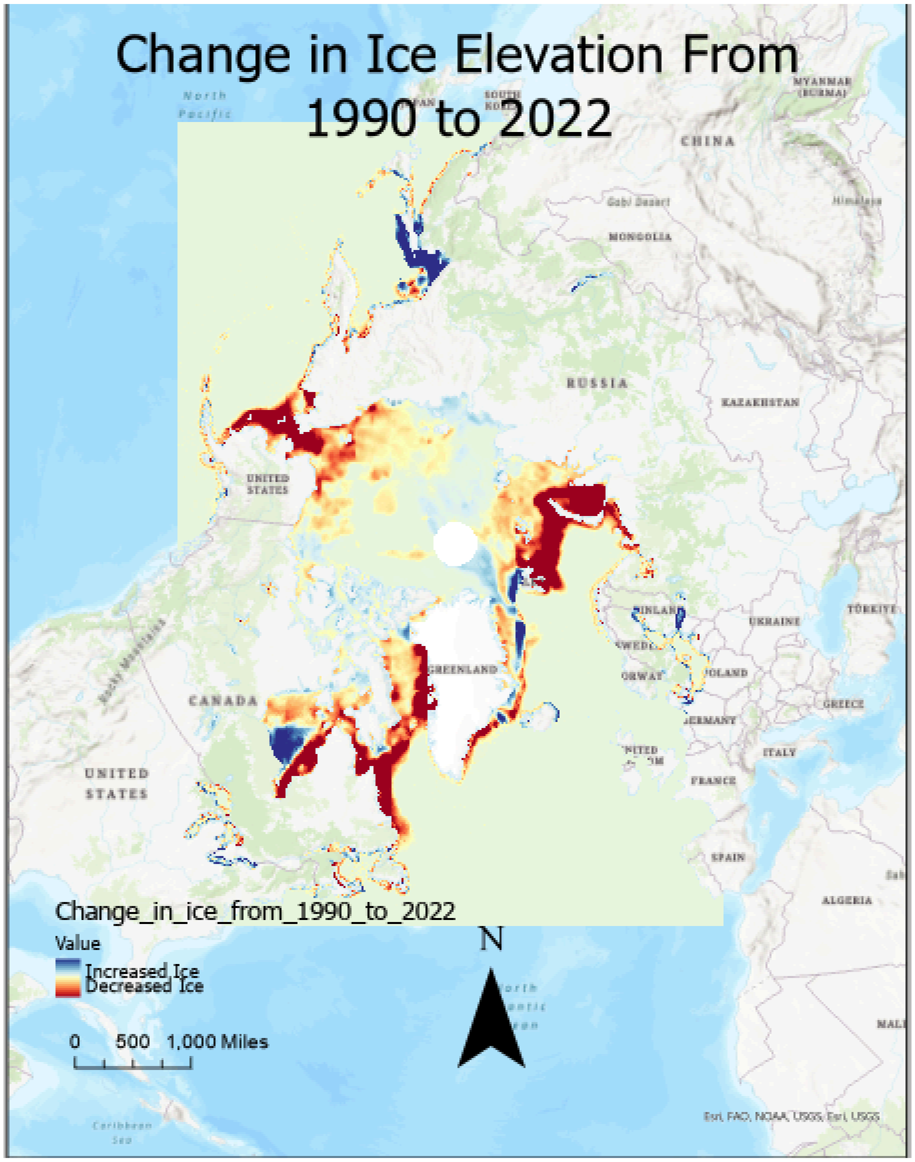


Figure 3: Change in ice elevation from 1990 to 2022. Blue colors indicate an increase in elevation and red colors indicate a decrease in elevation.

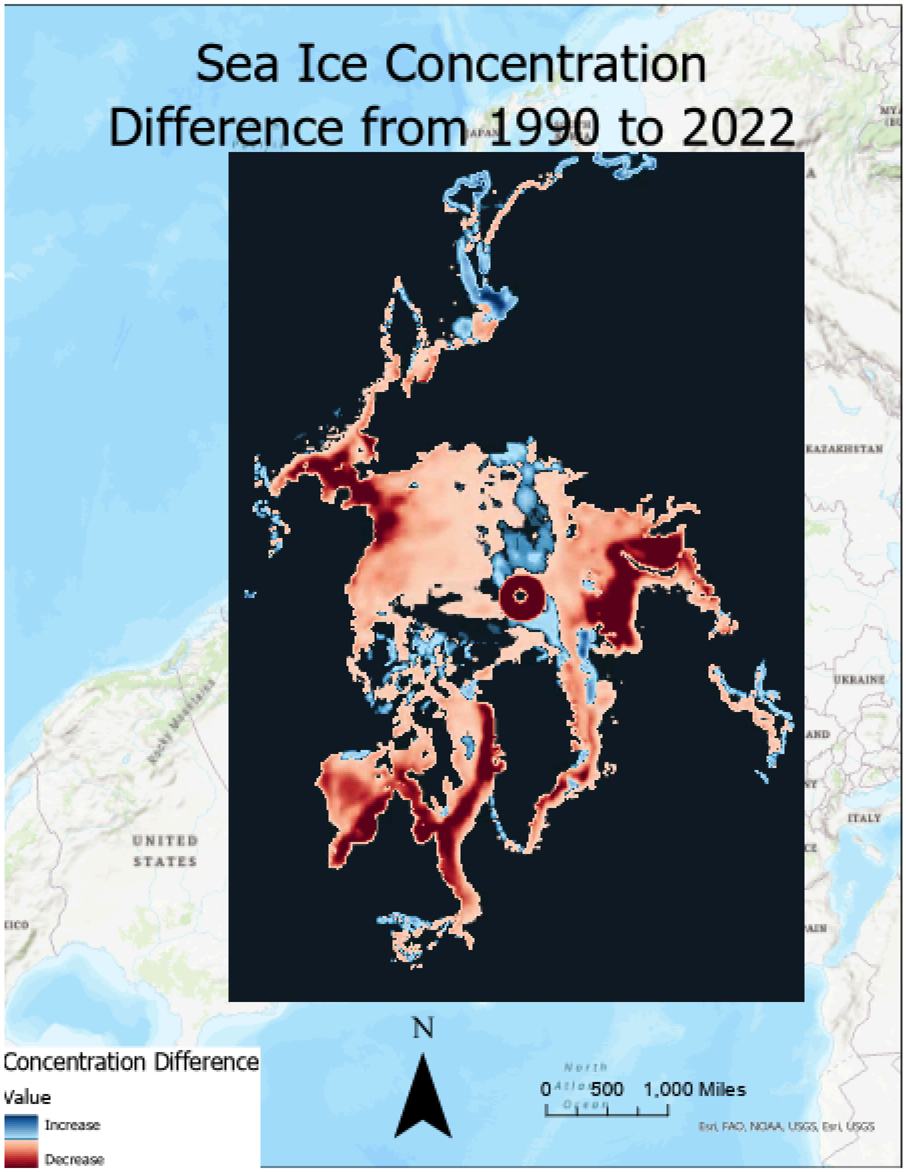


Figure 4: Sea ice concentration difference from 1990 to 2022.

In figure 4, we see the changes in sea ice concentrations. The dark blue shows an increase in ice whereas the red shows decreases in ice concentrations. Throughout most of the Arctic we see decreases in ice concentrations. Whereas the ice elevation decrease was mainly around the edges of the ice, the concentration is throughout the entirety of the Arctic. Although there are some increases, they are definitely overshadowed by the decreasing ice concentrations. Additionally, the places with strong decreases in ice concentration coincide with the decreases in ice elevation.

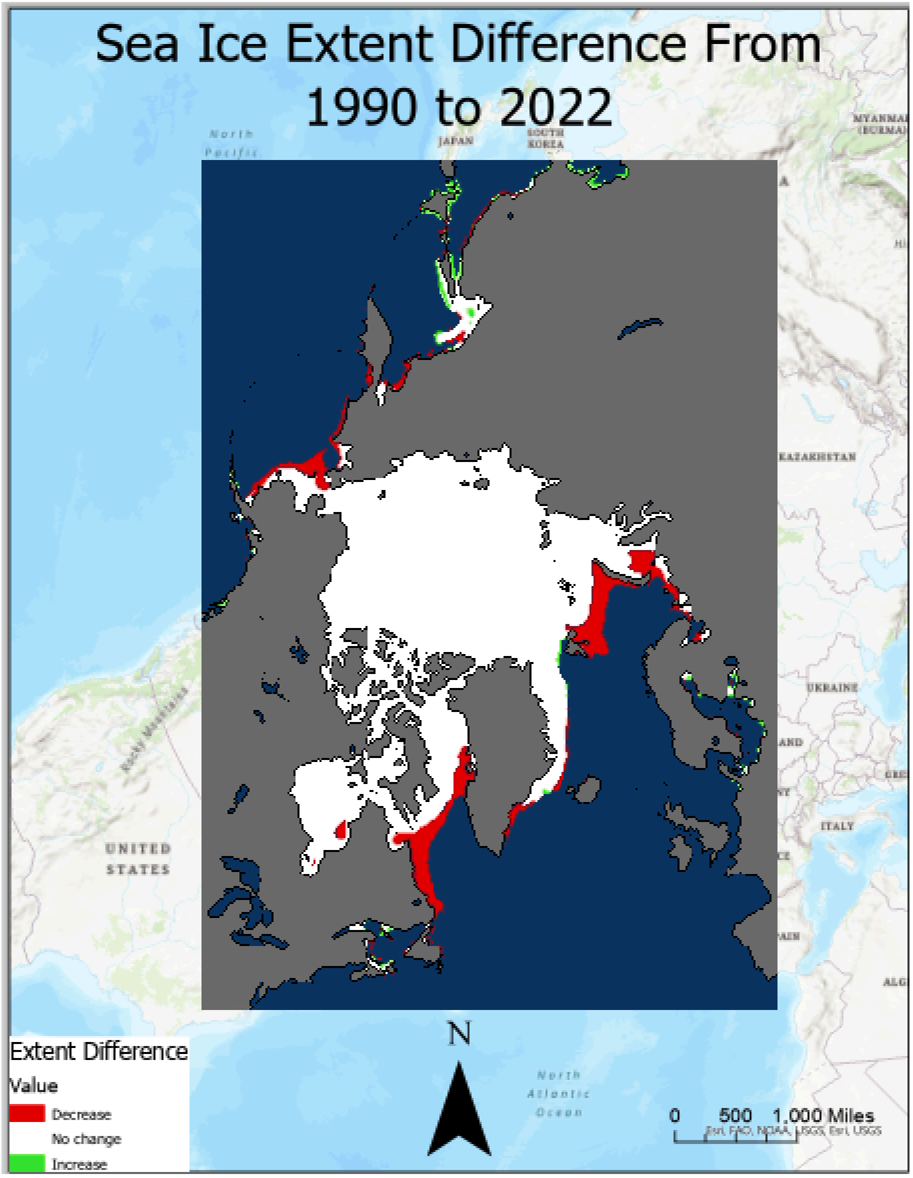


Figure 5: Sea ice extent difference from 1990 to 2022

The sea ice extent shows the 2022 ice levels in white, and then shows decrease from 1990 with red and increase with green. There are very few increases in the extent, and lots of areas with decreases in extent. The decreases in extent again coincide with the decreases in concentration and elevation. This logically makes sense, as a decrease in the extent means there is no longer any sea ice in that location, so there will obviously be an increase in the ice concentration and elevation.

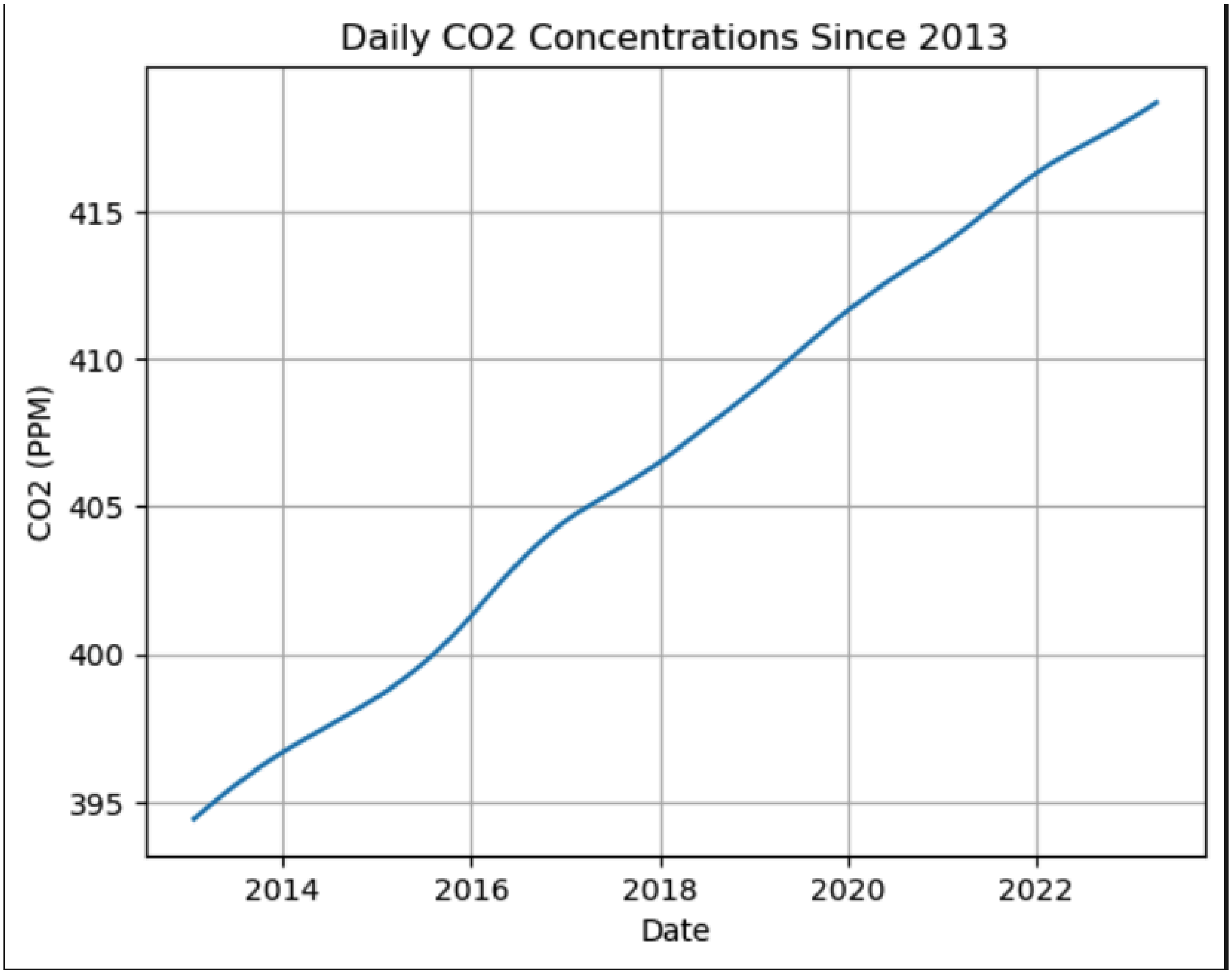


Figure 6: Daily CO2 Concentrations since 2013

Unfortunately, the data was only available from 2013 onwards, so we cannot see the CO2 back in 1990. The CO2 concentrations have been increasing in a steady linear fashion with a little bit of noise or oscillation. This is due to seasonality. Plants and other photosynthetic organisms such as phytoplankton will be more active during the spring and summer season. Since the Northern Hemisphere has far more land mass than the southern hemisphere, there will be slightly less CO2 in the atmosphere during the North American summer (NASA).

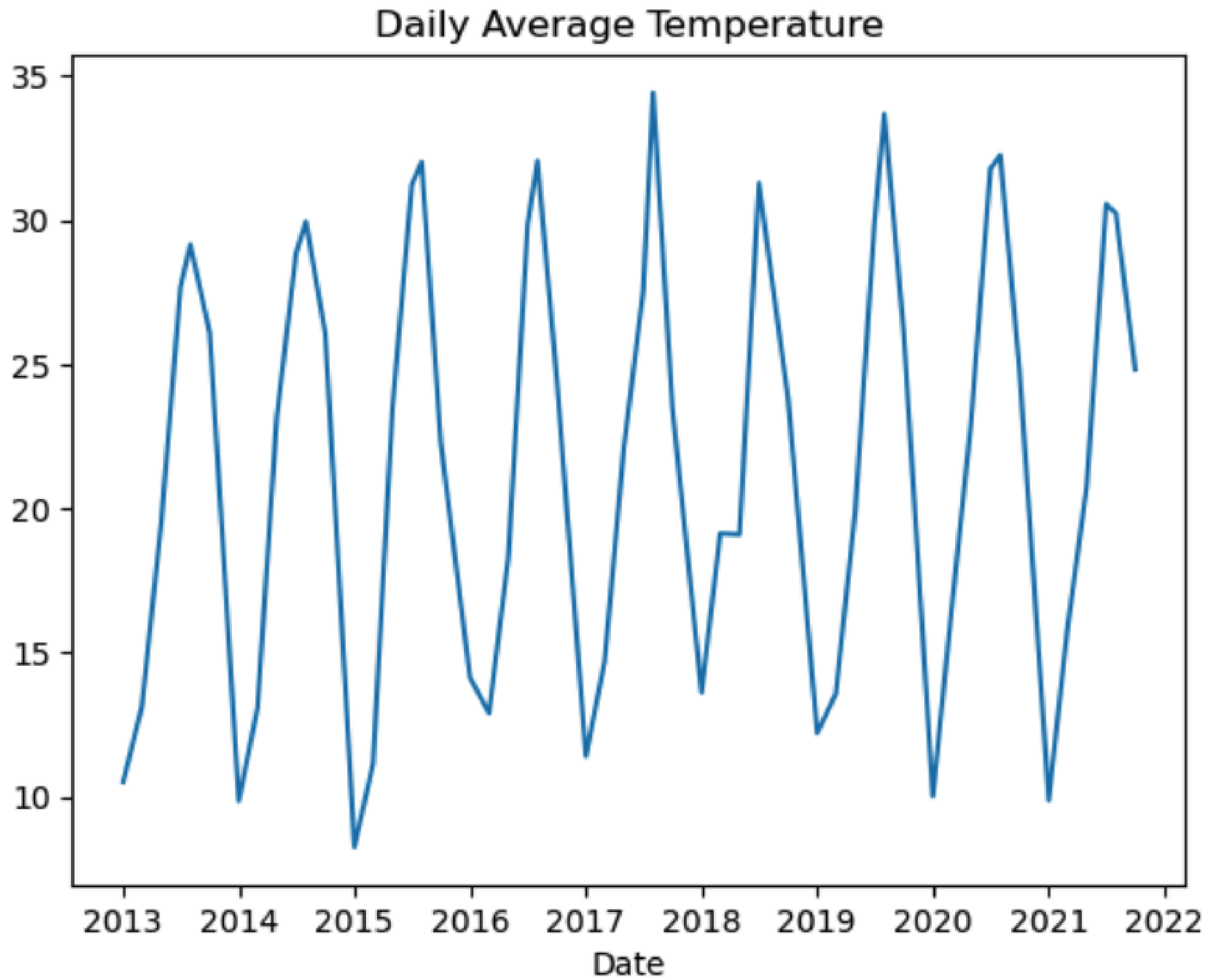


Figure 7: Daily average temperature from 10,000 NOAA weather stations

As seen in figure 7, there is high seasonality. Unfortunately, this is not quite the reality of global temperatures as it should stay quite consistent throughout the year. This large spike is due to the nonuniformity of the weather stations' locations. It is unfortunately not possible to view the temperature trends with much accuracy here as the calculated average was 20ºC which is 5º above the average. This could possibly indicate that more weather stations are closer to the equator.

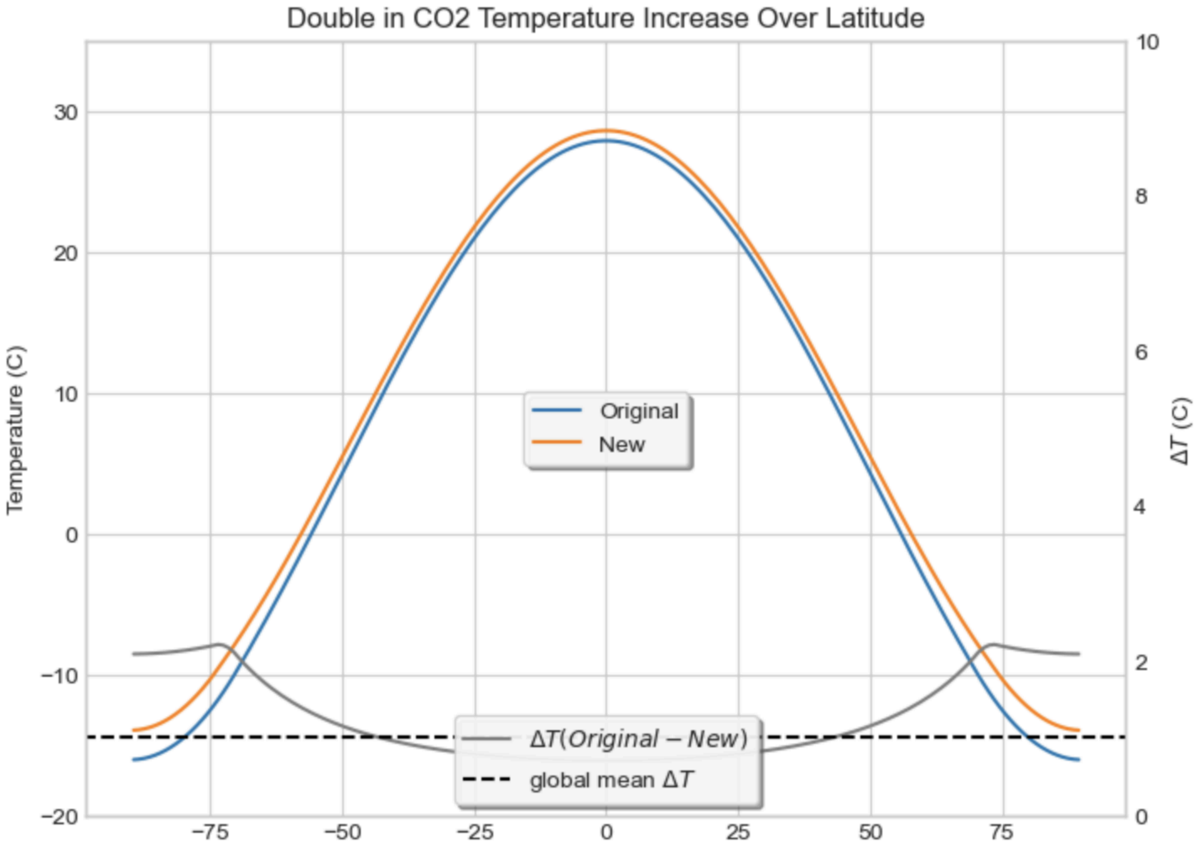


Figure 8: Climlab model when “doubling” CO2

```
[40]: model2.integrate_years(10)
      model2.icelat

      Integrating for 900 steps, 3652.4220000000005 days, or 10 years.
      Total elapsed time is 24.99999999999979 years.

[40]: array([-74.,  74.])
```

Figure 9: Climlab ice latitude when “doubling” CO2 from current levels

Since the climlab model does not know what atmospheric composition is, the longwave radiation is changed. When doing the equivalent of doubling the CO2, the ice latitude went from 70º all the way back to 74º.

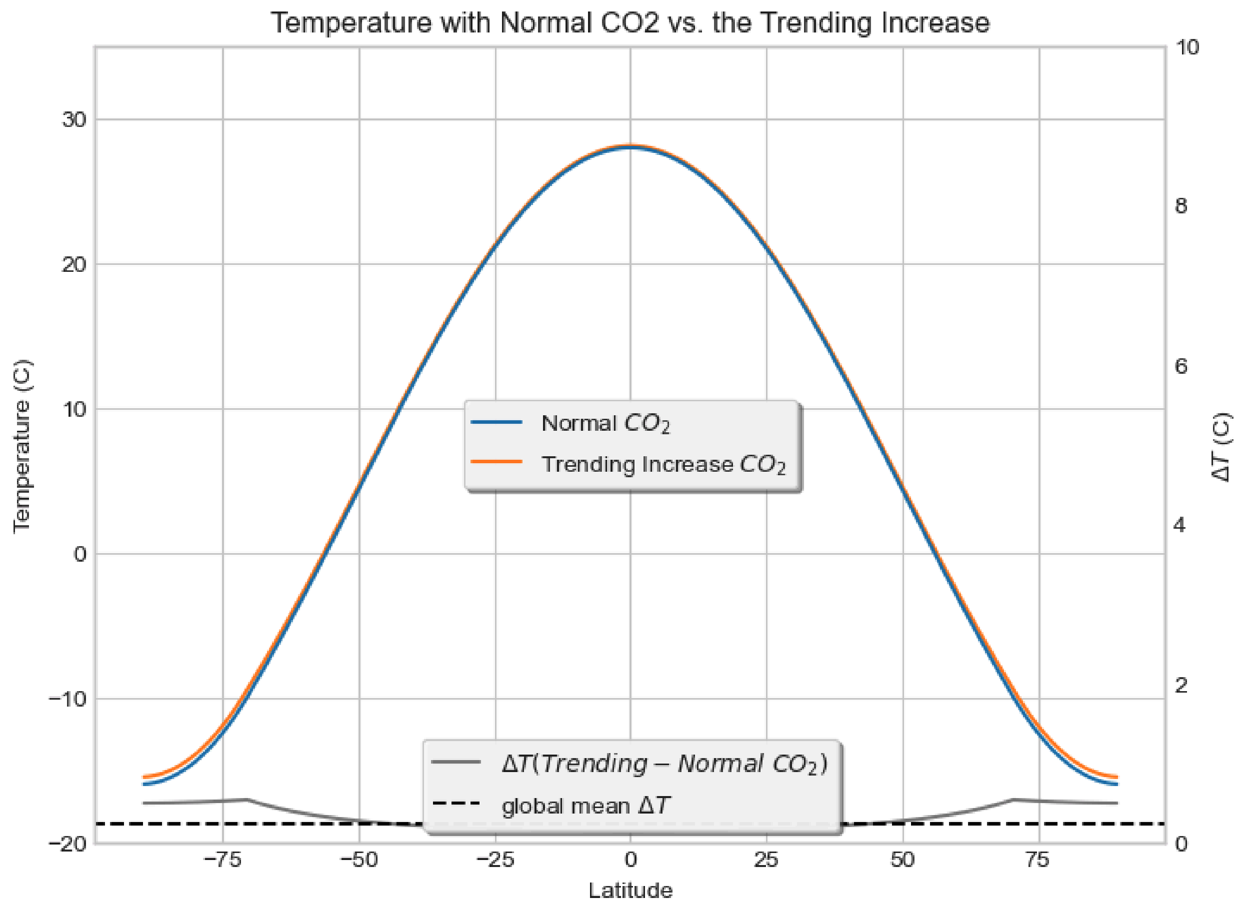


Figure 10: Increase in Temperature from Increase in CO2 from 2012 to 2022

In figure 10, we see that there is very little change between 2012 and 2022. This model is mainly meant for much larger changes, it also does not incorporate many of the destabilizing feedbacks that are present in the actual atmosphere. This model run had a delta A value of 0.157 and led to a 1 degree change in the ice latitude. The delta A was calculated by taking the max CO2 and minimum CO2 level from the 2012-2023 CO2. Although the model could have had a slightly larger or smaller increase in the ice latitude, it has to be an entire integer step, as the decimals are not calculated even if asked to display more decimals with np.set_printoptions(formatter={'float': '{:,.1f}'.format}) (which would set the output to 1 decimal or more).

Discussion:

Coding Issues:

When working with the .nc files I could not run the raster calculator at first because it failed, giving an error 000539. This is usually due to differences in cell size, projection or extent and looking through properties I could not see any differences. I solved the issue by exporting the layers and then running the raster calculator.

Working with climlab proved to be very difficult. I tried to add a CO2 diagnostic by using the add_diagnostic() function, but was not able to make any changes in the model. I then used an adjusted outgoing longwave radiation to account for changes in CO2, which worked pretty well. Unfortunately, small changes in CO2 did not do much to change the ice latitude. That being said, a 1° change in ice latitude is quite large and would most likely require a large increase in CO2 or over a long period of time.

The CO2 data collection was quite straightforward, but the temperature data proved to be incredibly difficult. At first the outputs were outrageous numbers such as -300 or 200, which are above and below the record recorded temperatures on Earth's surface, in fact -300 is below absolute zero. In the API request link, I had to add a units = metric and it started returning correct temperatures. The next issue was that without limiting the number of queries it gave a very small amount of data, so I limited it to 1000. However, I queried by year and it only gave data for the first of each year, but from 1000 different stations. I then queried by each month within each year and took the average temp from those 1000 different stations. The last issue that I still have is the nonuniformity of the weather stations which led to an inaccurate measurement of the global average temperature.

The results from the satellite imagery show decreasing ice elevation, concentration as well as extent throughout most of the Arctic region. Although this does not come as a surprise, it is still a bit of a shock to see the majority of the Arctic including around the pole see a decrease in ice concentration. This is concerning because ice levels decreasing can lead to destabilization of icebergs leading to quicker loss in ice than anticipated. Another concern is that the largest red areas (decrease in ice) were around the Northern Atlantic Ocean. As mentioned earlier, the influx of freshwater into a saltwater ocean causes decreased density and lower levels of ocean turnover, potentially slowing down the gulf current.

Although the results of the web scraping and API authentication were nothing new as visualization of this data is available with a quick google search. However, collecting this data and storing it is a very important first step for lots of climate and statistical analysis.

The climlab results were very interesting to see. The hypothetical what if the CO2 were to be doubled was interesting to see even if it was not totally accurate. The global climate system is impossible to fully accurately model, as even just the addition of a few variables could possibly exponentiate the resources needed to calculate. Additionally, as found in climate and weather modeling the butterfly effect or small changes to initial conditions can lead to huge differences later on. Simple models can show us a glimpse of possible behavior with a fraction of the computing power. However, it is important to understand that they are not the full picture.

Worked Cited

"NASA Scientific Visualization Studio - Seasonal Changes in Carbon Dioxide." NASA. NASA, May 4, 2017. https://svs.gsfc.nasa.gov/4565.

"Welcome to the CLIMLAB Documentation!¶." Welcome to the climlab documentation! - climlab 0.8.2.dev0 documentation. Accessed April 17, 2023. https://climlab.readthedocs.io/en/latest/.

Holland, Marika M., and Cecilia M. Bitz. "Polar amplification of climate change in coupled models." *Climate dynamics* 21, no. 3-4 (2003): 221-232.

Manabe, Syukuro. "Role of greenhouse gas in climate change." *Tellus A: Dynamic Meteorology and Oceanography* 71, no. 1 (2019): 1620078.

Mimura, Nobuo. "Sea-level rise caused by climate change and its implications for society." *Proceedings of the Japan Academy, Series B* 89, no. 7 (2013): 281-301.

Mousavi, Mir Emad, Jennifer L. Irish, Ashley E. Frey, Francisco Olivera, and Billy L. Edge. "Global warming and hurricanes: the potential impact of hurricane intensification and sea level rise on coastal flooding." *Climatic Change* 104 (2011): 575-597.

Rahmstorf, Stefan, Jason E. Box, Georg Feulner, Michael E. Mann, Alexander Robinson, Scott Rutherford, and Erik J. Schaffernicht. "Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation." *Nature climate change* 5, no. 5 (2015): 475-480.