Visualizing Climate Change

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1 Introduction

Data visualization is an important tool for communicating large amounts of data and more general ideas. It can be impactful for the general public when done well as it does not require as much technical background and can better show general trends. Visualizations are great at telling a story to the intended viewer as they contain another dimension, making the data more memorable.

1.1 Background

In the field of climate change, it is essential that the public is involved as the effort to make global changes cannot be done by scientists, politicians, or individuals alone. As follows, there are already a few interesting data visualizations as depicted in Figures 1-4. Figure 1 is originally a video and it shows the temperature anomalies by country from the years 1880-2017 [1]. It is an interesting take on the normal temperature progression map because by separating the countries by name, it can add a size component to the temperature difference in addition to the emphasis placed by the color. From Figure 2, we can see that the speed with which a city is growing inversely correlates with its vulnerability to climate change [2]. Shown in the graph, these cities are mainly in Africa and Asia, and the trend could be caused by growth occurring without proper urban planning or environmental infrastructure. The map in Figure 3 demonstrates that not all ramifications of climate change will be in one direction [3]. Climate change projections predict both areas of greater and decreased wheat growth. That means that for some people, climate change could actually make their land better for crop cultivation. Finally, with the "Warming Stripes" shown in Figure 4, Ed Hawkins takes a more minimalistic approach and shows a general trend upwards without even giving numerical values [4].

One of the conclusions that I drew from these visualizations and kept in mind as I made my project is that a visualization does not have to include all data. There probably is not one visualization that will speak to everyone and convince them of the severity and existence of climate change. Therefore, it is important to have many graphings; some people may realize the extent of the change through the warming stripes that show trends but lack numbers while others may be more swayed by the change in crops. Each one of these visualizations contains the integral story that the globe is changing and it's within the time frame of our lives.

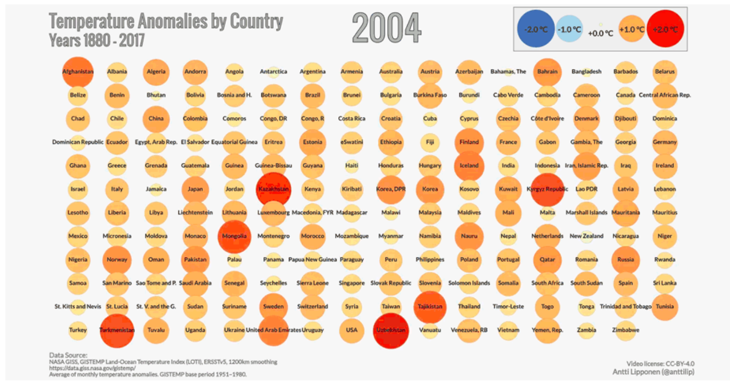


Figure 1: A video based on the NASA GISS GISTEMP data that shows the annual temperature anomalies by country

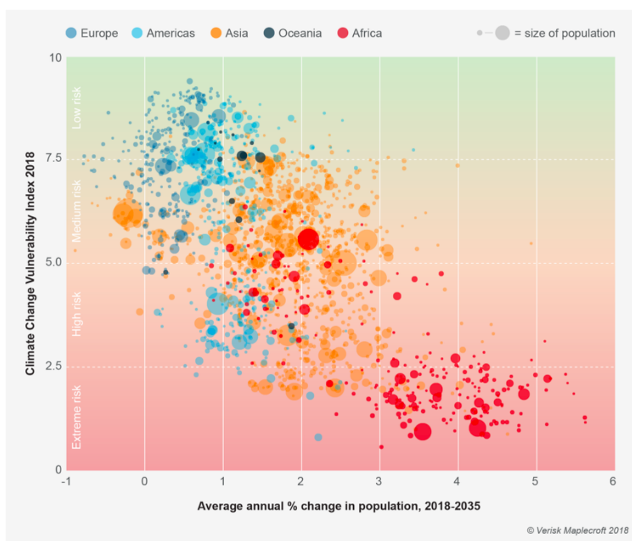


Figure 2: The rate of growth of a country's population verses their climate change vulnerability

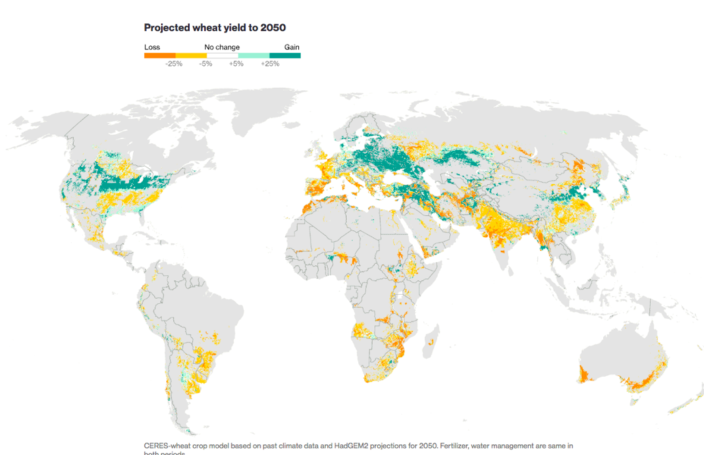


Figure 3: The forecasted change in wheat production by 2050 based on the CERES-wheat crop model and HadGEM2 projects for 2050

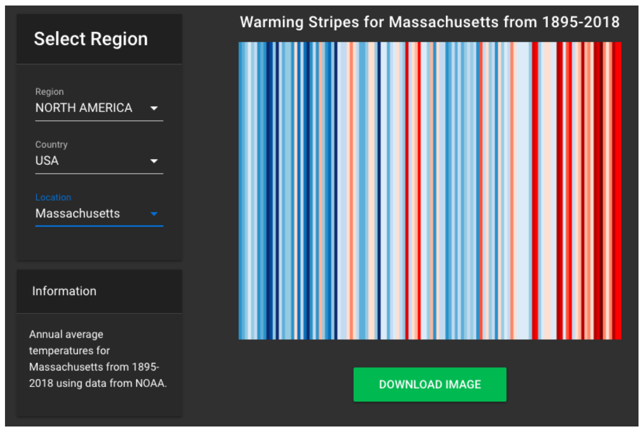


Figure 4:

2 Methods

When going about creating my own visualization, the two main decisions involved were where I got the data and what I used to plot it.

2.1 Data

The data I used came from the Climate Data Store, which is run by Copernicus, the Europeans Union's Earth observation program. The main reason that I chose this source of climate data was because it has an API, which made it straightforward to get data, and because there were a lot of variables for which it had data, which gave me greater choice when plotting. From the API, there were two main datasets that I used: ERA5 monthly averaged data on single levels from 1979 to present and Agroclimatic indicators from 1951 to 2099 derived from climate projects [5]. The first one offered historical data, which had been collected from satellite observations and other ground-based, airborne, and seaborne measurement tools. In addition to the historical measurements offered by the second database, it had data of projected values up until the year 2099. These values were obtained through the Inter-Sectoral Impact Model Intercomparison Project, which is a modelling initiative to provide quantitative data on the impact of climate change. This data, which had been bias corrected, was put into CMIP5 GCMs to calculate the period from 1950-2099. For forecasted calculations, there were four scenarios: RCP (representative concentration pathways) 2.6, 4.5, 6, and 8.5, which represent emission scenarios from least to most severe. RCP 2.6 represents a best-case scenario where there is a major turnaround in climate policies for both developing and developed countries. CO2 emissions peak by 2020 and decline to zero by 2080, the global population peaks mid-century at 9 billion, and while oil is still used, it declines and is offset by carbon capture. In the RCP 4.5 scenario, emissions will peak around 2050 and stable over the next 30 years to half the current levels. Compared to RCP 2.6, there will be greater population and economic growth, but higher energy usage and oil consumption will remain constant. The development predicted by RCP 6 is that emissions will double by 2060 and then fall dramatically, but still stay above current levels.

The population will peak at around 10 billion and energy consumption will increase until 2060, when it decline. Finally, RCP 8.5 is the worst-case scenario where emission continue to increase and stabilize at 30 gigatonnes of carbon per year in 2100 compared to the 8 gigatonnes per year in 200. The population continues to grow, reaching 12 billion by the end of the century and energy consumption also continues to grow, reaching 3 times over our current levels. For my project, I chose values produced by RCP 4.5 and 8.5 because I wanted to show the results of a more realistic scenario and an extreme one.

2.2 Tools

After selecting the datasets, the two main steps of the project were: plotting the data from the CDS API and displaying those plots on an HTML website. For the first part, I used python as that was an easier language for manipulating the data. The data came as nc files, so I used the netCF4 package to extract each value and the corresponding latitude and longitude and convert it to a form that could be plotted. I used the plotly package to then display that new object. I selected plotly because it handles location data, allowing users to hover over points to see the values and to zoom in and out of the map. Plotly outputs the graphs as html files, so I went into the files for the graphs and found the part where they displayed them. I could then add these HTML portions to a website and deploy the website.

3 Results

I selected six plots to show on the website, as displayed in Figures 5-7. These figures represent data of growing season length, vegetation cover, and soil moisture. The website with the interactive plots can be found at: `https://visualization-6s898.herokuapp.com`. The front page of the website is shown in Figure 8. Figure 5 depicts the progression of the growing season length, which is measured in days, ranging from 0-365. The three plots show the average value measured from 1981-2010, predicted under the RCP 4.5 scenario for 2011-2040, and predicted under the RCP 8.5 scenario for 2011-2040. Comparing the historical data with RCP 4.5, the trend is a little mixed. In some places, such as the Northwestern US, the growing season length seems to be increasing, however in others, like the Eastern US, the growing season length decreases. When comparing the historical data to the RCP8.5 scenario, the trend is a little more ubiquitous with the GSL increasing in most places (this comparison is easier to see when mousing over the graphs showing the values). A second relationship is shown in Figure 7 with the soil moisture. The two plots show the measured soil moisture in 1979 and 2017, where soil moisture is the ratio between the volume of water and the volume of soil and darker green indicated greater soil moisture. From the plots, the general trend seems to be that the soil has been getting less moist.

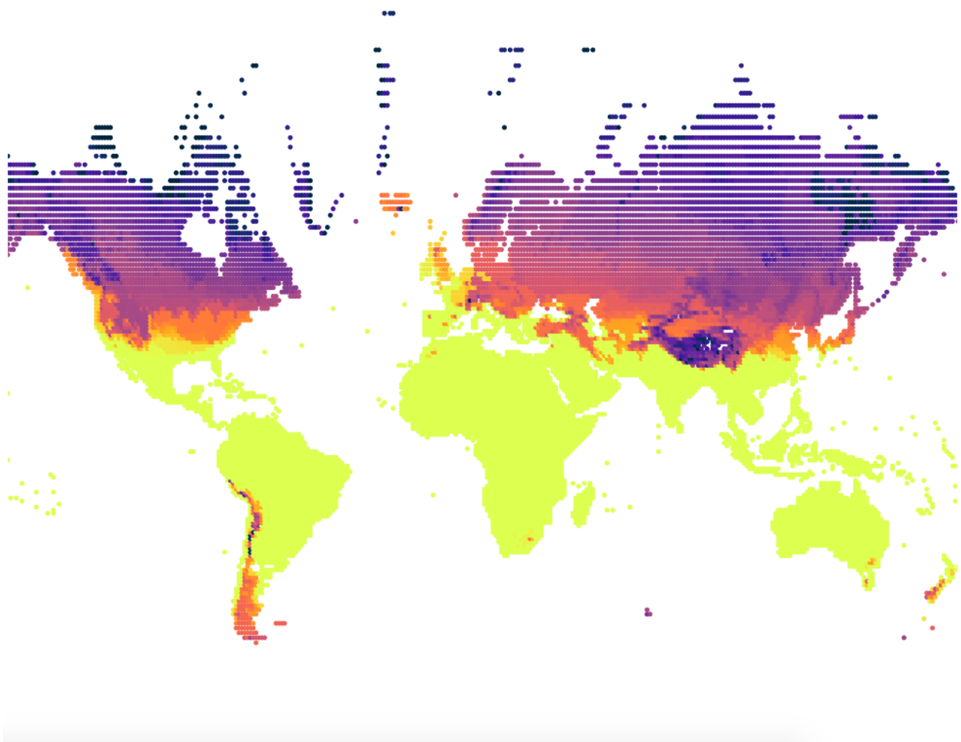
I chose these three variables to display because not only did I find the graphs interesting themselves, displaying global trends of which I was not aware, but I think that they supplement each other. Returning to the idea that visualizations tell a story, I wanted to tell a story about how the world will change. Small factors like growing season and soil moisture are not usually mentioned when talking about climate change. The trends they show is a little counter-intuitive to the usual message that climate change is going to make everything worse. In some areas, the GSL will increase, which would improve crop yield. The growing season is calculated from the average number of days between the last front in the spring and the first severe frost in autumn. Therefore, it makes sense that RCP 8.5 would predict overall increases in growing season if the global temperature increases. To this narrative, I wanted to add information about where agriculture can be cultivated. In most of Africa, the growing season length was 365 days, but Figure 5 adds the information that there's a large part of Africa, namely the Sahara Dessert, where vegetation does not grow. Therefore, while Africa may have the temperatures to grow food all year round, other conditions prevent someone from doing so. Finally, I wanted to show one of the ways in which climate change has impacted agriculture for the worse. Soil moisture is a key factor in farm productivity. Too little moisture can result in yield loss and plant death and as depicted in Figure 6, soil moisture has decreased between 1979 and 2017. One of the benefits of visualizations is that they allow for more varied interpretations, so people may have a different conclusion than I do, which is that climate change is not straightforward. Even if we could model the exact changes to the Earth from climate change, we still could not say how that will affect humanity, which is dangerous. Going into this project, I wanted to explore and thought that it was interesting to see the change in soil moisture and growing season, which not as commonly publicized. I think that this goal influenced my takeaways from the figures, which are that climate change is unpredictable.

4 User Testing

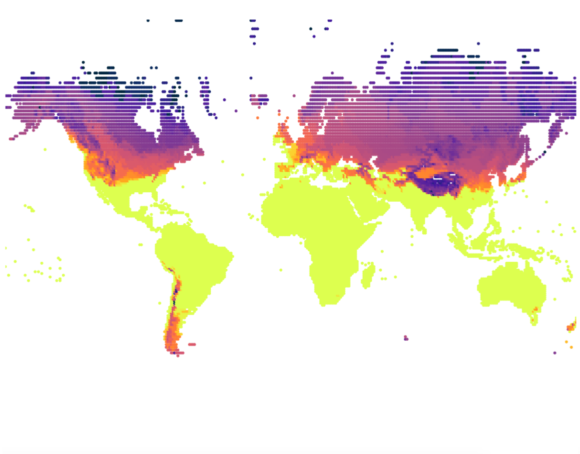
As this website is meant for the general public, my next step was to get feedback in the form of user testing. Usually, user testing is done in person as it allows for the collection of more data than a survey, and in total, I tested four people.

4.1 Procedure

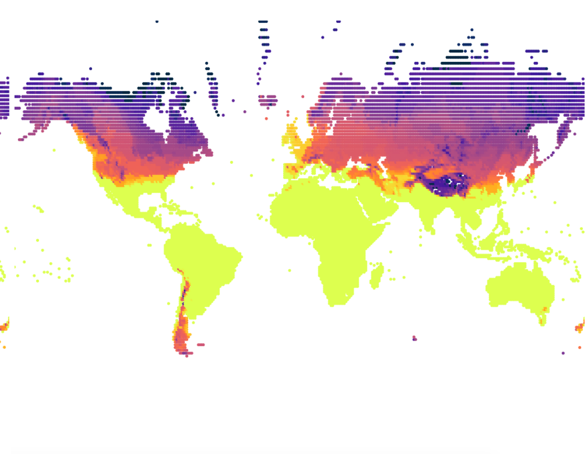
At the start of the test, I told the user to simply go through the website, explore the graphs, and look for patterns. When someone else goes to the website, they will not get the benefit of having me next to them, explaining my thought process and how I interpret the graph. Therefore, the I wanted a better idea about how the average user interacts with the site. After they had finished looking through it, I asked them four questions: Was anything surprising? Do you have any observations about the graphs or see any patterns? Do you feel like you have a new perspective on climate change? Do you have any suggestions for the website?



(a) Annual Average Growing Season Length from 1981-2010 (days)



(b) RCP 4.5 Predicted Growing Season Length from 2011-2040



(c) RCP 8.5 Predicted Growing Season Length from 2011-2040

Figure 5: The growing season length in days with yellow meaning 365 days and dark purple 0 days in the growing season. The top graph shows the average values from 1981-2010, the left on is the forecasted data between 2011-2040 using the RCP 4.5 scenario, and on the right is the forecasted dated between 2011-2040 using the RCP 8.5 scenario

Figure 6: The vegetation cover of the globe in 2017 with dark green indicating areas of greater coverage.

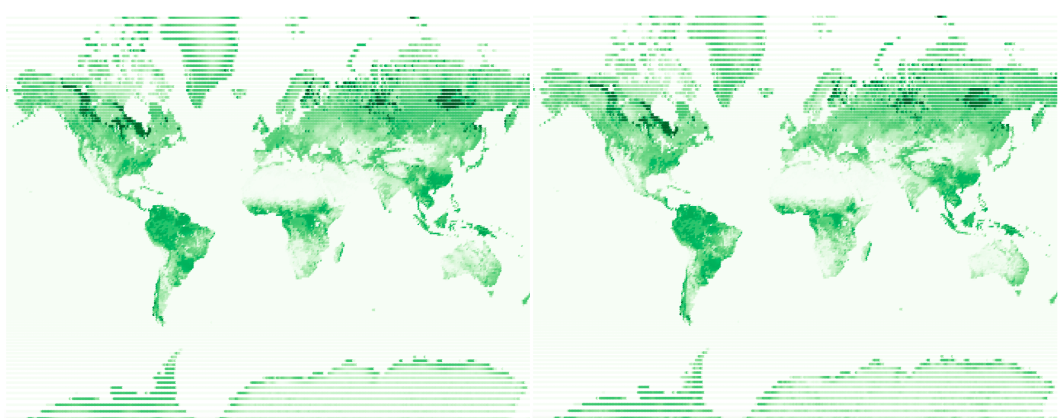


Figure 7: The average soil moisture measured from 1979 (top) and 2017 (bottom). The white indicates low soil moisture and dark green high soil moisture, where soil moisture is the ratio of volume of water over volume of soil. From these plots, it seems that overall, during the 40-year period, soil moisture decreased, which is most visible in Africa.

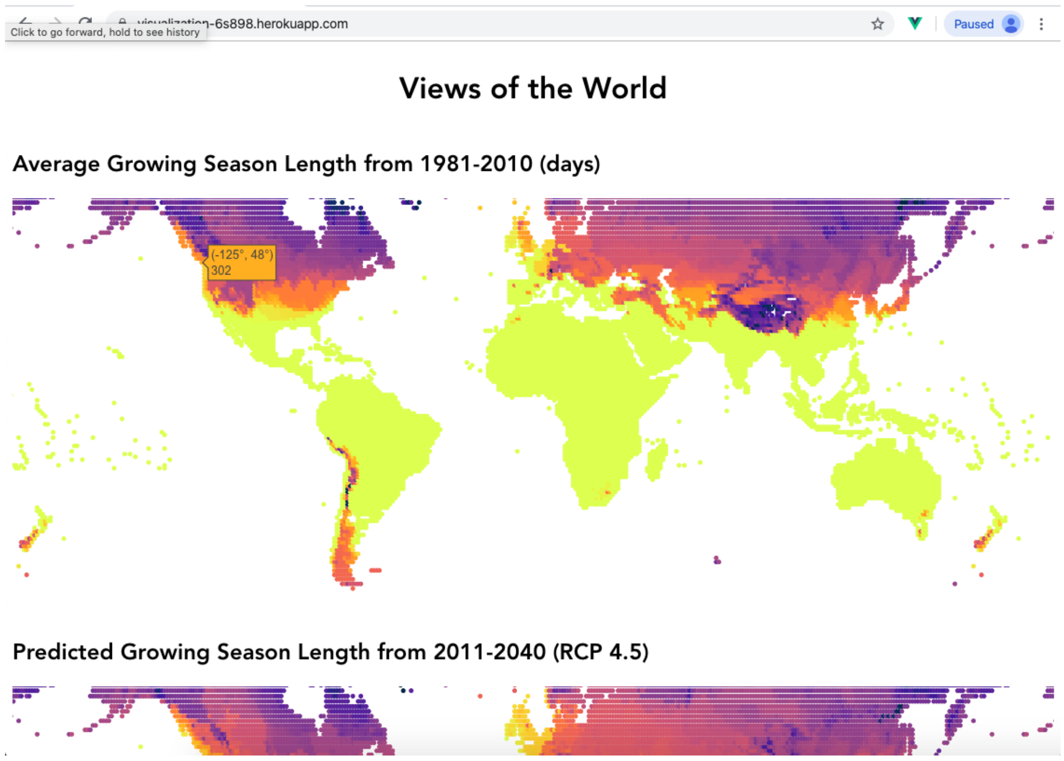


Figure 8: A screen capture of the resulting webpage

4.2 Observations

Seeing users interact with the website gave very useful feedback as there are many aspects that I inherently know as the person who made the site but were not clearly conveyed through the design. For example, in looking at the graphs, not everyone figured out straight away that there was mouse interaction, allowing them to see the value of particular points and zoom in and out. Even if they did end up seeing the feature by mistake, for some people, it still took some time to figure out what motion causes it. I already had found that for anyone using a two-finger scroll, it was harder to get between the graphs because the two-finger scroll would zoom in and out of the graph, and while user testing did confirm that people had difficulties navigating, they found various work-arounds.

4.3 Question Response

In people's answers to the questions, I also learned valuable insights.

4.3.1 What did you find surprising?

I was pleased to find that people did notice patterns, finding that growing season length got longer and the soil moisture decreased. However, the change was not always clear. Some people would notice one and not the other. I also took into account that because these people were in a user test, they were putting more consideration into the plots than someone who had clicked on the link and did not feel obligated to stay on the site.

4.3.2 Do you have any observations about the graphs or see any patterns?

These responses were mostly similar to those from the questions above. One person talked about how heading northward, the growing season got shorter, but that was not true to the same extent as you traveled southward.

4.3.3 Do you feel like you have a new perspective on climate change?

I was glad to find that people did come away having made a few conclusions. One person found it interesting to think about climate change in terms of different factors, like growing season length because she had not thought about how aspects such as that one would be affected by climate change. In a similar vein, another person commented that growing season is not something that we usually talk about. Even though agriculture is essential and the growing season plays a key part, it can get overlooked because there are many other avenues on which one can focus. One insight one of the users had that I had not thought about was that she found a greater difference between the historical growing season chart and either forecasted growing season charts than between the two forecasted charts, and her conclusion from this was that we should make changes now because either scenario will be bad. I like her action-focused viewpoint because the alternative is to conclude that there is not anything that we can do because the scenarios seem to have similar results.

4.3.4 Do you have any suggestions for the website?

I greatly appreciated the suggestions for the website as they came from people who had fresh eyes and therefore could more easily see the confusing aspects.

One of the main comments on the graphs was to make it easier to see the trends. For the graph showing the growing season length, I agree that the color scale of purple to yellow was not the most straightforward. Another suggestion was to add a color scale to the graph to make that relationship more clear. Additionally, the color scale for the vegetation color and the soil moisture was the same, so at first glance, they didn't seem like they were plotting different values. To show the changes in the graphs, one suggestion was to put the graphs side-by-side and another was to plot a difference graph. Originally, I tried to put them side-by-side, but found it to be difficult because the graphs had come from plotly, but plotting the difference graph would be feasible. The trend between graphs could be shown by plotting graphs on top of each other. For example, adding the graph of the vegetation cover of the globe on top of that of the growing season length, showing where there is both a long growing season and at least existing vegetation there even if it is not cultivated land.

Another issue that users brought up was in scrolling through the page. I got some creative suggestions, such as using three fingers to zoom into the graph. It's a nice idea, however from my research into plotly, it does not seem like the zoom can be changed. The three-finger scroll could instead be used for the page scroll, but scroll is a feature of the operating system, not the webpage, so it does not seem feasible to implement. It would also contradict the standard, thus making the website harder to use. A different suggestion for the same problem was to show more clearly where the graphs begin and end as then people could start scrolling when their cursor was outside of the graph. I like the design of having the plots blend into the page, but I see how changing the background color could help the user.

An alternative solution for both of these problems would be to use more words on the page. As I was watching people use the page, I realized that I never used the word climate change, which is the purpose of the site, so it should be more clearly stated. To clear up some of the scrolling issues, I got the feedback that I should explain how to interact with the graphs (i.e. that a two-finger scroll will zoom in and out of the graph and that you can click and graph to move the graph). I had connections in mind when I selected the graph, and after talking to a user about why I made the selections, she proposed adding more explanation to the graphs. I feel mixed about that suggestion because while I think that it could clarify some of the relationships that I see, it also biases the user towards my opinion. I would like for people to be able to

4.4 Design Modifications

Based on the user feedback, I made some modifications to the design of the website. First, I decreased the size of the plots and added margins, which makes scrolling much easier. Additionally, I changed the colors of the growing season length and soil moisture graphs. For the GSL graph, I changed the color scale to go from dark brown to blue, which to me, makes sense as the areas that are colored brown are not able to grow crops for as long during the year. The scale is not perfect as the plot is not informing viewers about the moisture or fertility of the ground, but I think that it is more intuitive than the previous color scheme. I changed the soil moisture graphs to shades of blue to both set them apart from the vegetation cover map and as blue makes sense for a map displaying the amount of soil in water. Finally, I added more description to the graphs. At the top, I explained how to interact with the plots, and as either subtitles or captions, I added information for the viewer to notice as they look at the graphs. in this way, I feel like I have reached more a balance in terms of giving users more guidance but still allowing them to make their own conclusions. I have included screen captures of some of these changes in Figures 9 and 10.

5 Next Steps

After addressing some of the suggestions brought up in the user testing, there is still more of their feedback that I can implement and a few ideas of my own.

5.1 Performance

The website is slow to load as the data is currently stored on the front end. One possible solution would be to add a database to the website. With the data in the database, plots

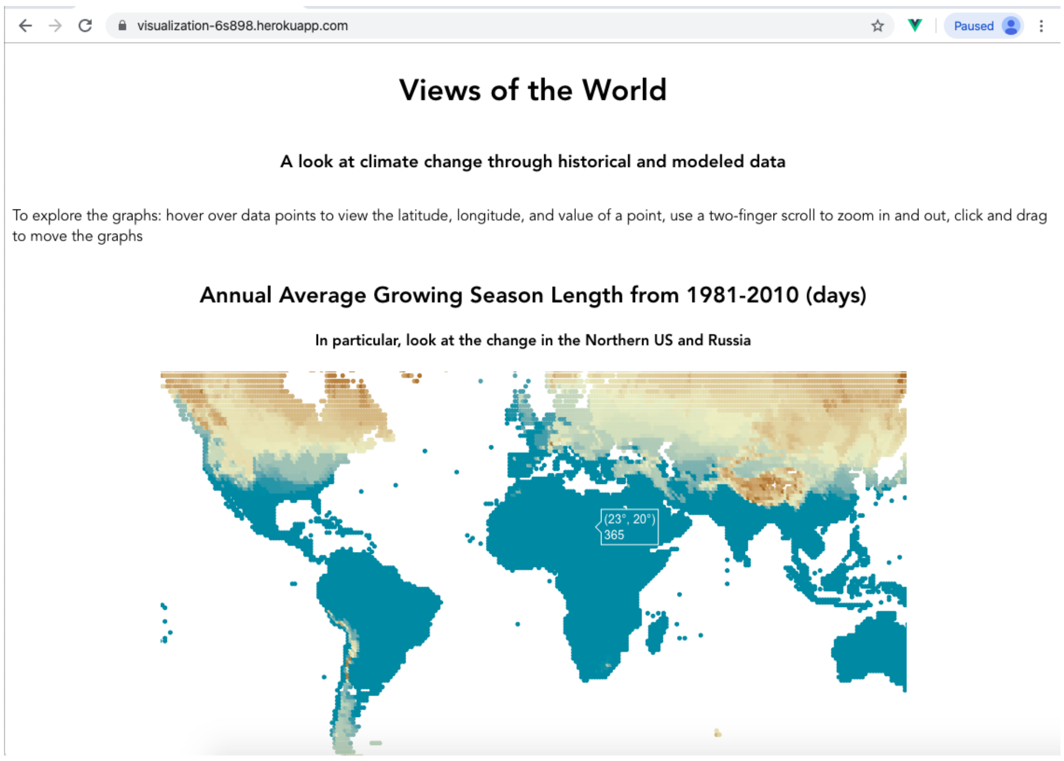


Figure 9: A screen capture of the modified webpage

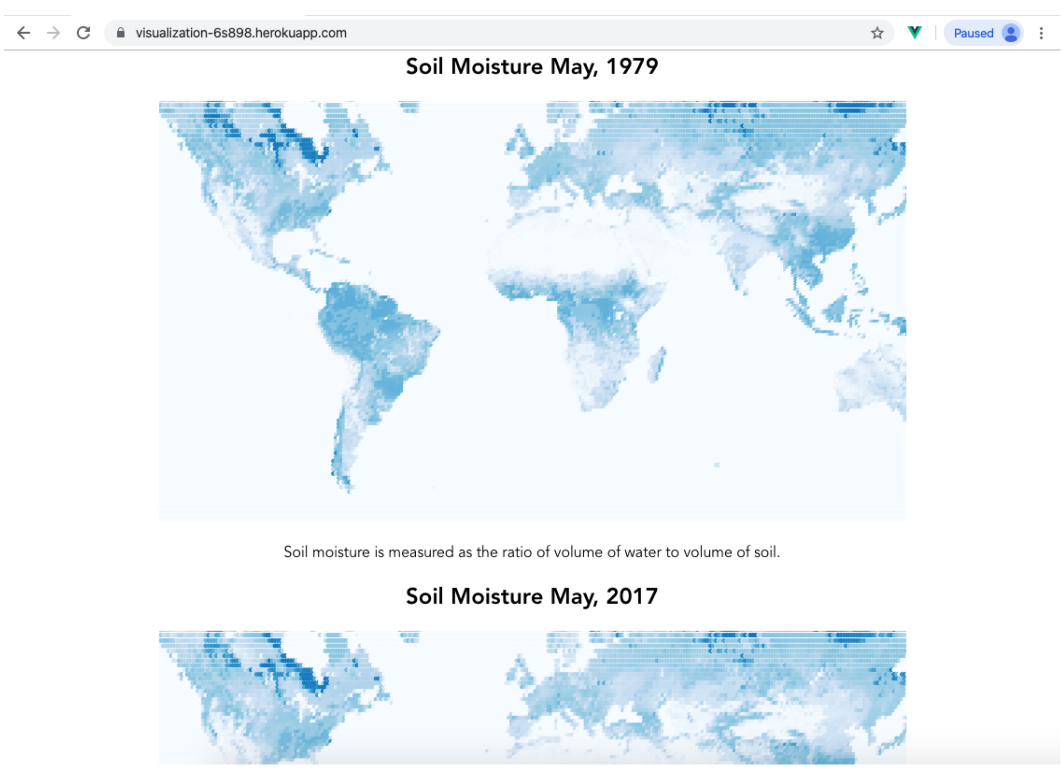


Figure 10: A screen capture of the modified webpage

could be generated dynamically and performance would be improved further if plots were separated onto different pages as then they do not all have to be generated at once.

5.2 Giving Users the Ability to Select Variables

In this project, I selected variables that I thought were interesting to view, but other people may differ in that opinion and find it more interesting to see other variables. The CDS API offers many datasets and many more variables even in the ones that I chose. An extension of the project pre-computer the plots based on more variables, then allow the user to select the ones that he or she wants to view. Another obstacle that I would have to overcome is that some of the datasets are very large. The ones that I used were around 1MB in size. A few variables that I wanted to explore include: heat waves and cold spells in Europe, biologically effective degree days (which determine the crop development stages/rates), and precipitation sum. However, these datasets ranged in size from 80-250MB, which is too large for me to transform into an object that I can plot.

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