Introduction

The main goal of this project is to fulfill various prompts and provide graphs using GNUPlot in order to view these data sets statistically. This project uses C programming language and GNUPlot softwares in order to generate codes and graphs which highlight land and ocean temperatures collected from the years 1750 to 2015. By using various weather monitoring systems around the world, the data collected for this group project corresponds to the real life data in which calculations and conclusions will be made with the code.

This project is intended for environmental and research scientists due to the fact that their studies require observing these behavioral patterns on lands and oceans. Another group of individuals which the work done in this project may be intended for, are data analyst scientists who process this kind of information. By the usage of the C programming language, it allows for the calculations required to be completed in an organized and structured manner. By doing so, observations can be further explained and expanded upon based on the results calculated.

The provided dataset includes the information required in order to complete the calculations. The information includes the dates of every month from the year 1750 to 2015, their land average, minimum, and maximum temperatures. The dataset also includes ocean temperature averages, starting from the year 1850.

Procedure

A base code was created to take all the data from the source file (GlobalTemperatures.csv) and place each column into an array - set values were defined for this to ensure that the memory isn't read over its limit. A struct was made so that each array can be easily accessed through a single point. The data was transferred into the arrays by using tokens in conjunction with switch statements to ensure that each column is properly placed in its specific array. After having a structured code, it was used in the questions to get the values required and allowed for computation to be followed easily.

Data

Question 1 output:

```
QUESTION 1
--
YEARLY AVERAGE LAND TEMPERATURE

1760: 7.19°C
1761: 8.77°C
1762: 8.61°C
1763: 7.50°C
1764: 8.40°C
1765: 8.25°C
1766: 8.41°C
1767: 8.22°C
1768: 6.78°C
1769: 7.69°C
1770: 7.69°C
1771: 7.85°C
1772: 8.19°C
1773: 8.22°C
1774: 8.77°C
1775: 9.18°C
1776: 8.30°C
1777: 8.26°C
1778: 8.54°C
1779: 8.98°C
1780: 9.43°C
1781: 8.10°C
1782: 7.90°C
1783: 7.68°C
1784: 7.86°C
1785: 7.36°C
1786: 8.26°C
1787: 8.03°C
1788: 8.45°C
1789: 8.33°C
1790: 7.98°C
1791: 8.23°C
1792: 8.09°C
1793: 8.23°C
1794: 8.53°C
1795: 8.35°C
```

```
1796: 8.27°C
1797: 8.51°C
1798: 8.67°C
1799: 8.51°C
1800: 8.48°C
1801: 8.59°C
1802: 8.58°C
1803: 8.50°C
1804: 8.84°C
1805: 8.56°C
1806: 8.43°C
1807: 8.28°C
1808: 7.63°C
1809: 7.08°C
1810: 6.92°C
1811: 6.86°C
1812: 7.05°C
1813: 7.74°C
1814: 7.59°C
1815: 7.24°C
1816: 6.94°C
1817: 6.98°C
1818: 7.83°C
1819: 7.37°C
1820: 7.62°C
1821: 8.09°C
1822: 8.19°C
1823: 7.72°C
1824: 8.55°C
1825: 8.39°C
1826: 8.36°C
1827: 8.81°C
1828: 8.17°C
1829: 7.94°C
1830: 8.52°C
1831: 7.64°C
1832: 7.45°C
1833: 8.01°C
1834: 8.15°C
1835: 7.39°C
1836: 7.70°C
1837: 7.38°C
1838: 7.51°C
1839: 7.63°C
1840: 7.80°C
1841: 7.69°C
1842: 8.02°C
1843: 8.17°C
1844: 7.65°C
1845: 7.85°C
1846: 8.55°C
1847: 8.09°C
1848: 7.98°C
1849: 7.98°C
1850: 7.90°C
1851: 8.18°C
1852: 8.10°C
1853: 8.04°C
1854: 8.21°C
1855: 8.11°C
1856: 8.00°C
1857: 7.76°C
1858: 8.10°C
1859: 8.25°C
1860: 7.96°C
1861: 7.85°C
1862: 7.56°C
1863: 8.11°C
1864: 7.98°C
1865: 8.18°C
1866: 8.29°C
1867: 8.44°C
1868: 8.25°C
1869: 8.43°C
1870: 8.20°C
```

```
1871: 8.12°C
1872: 8.19°C
1873: 8.35°C
1874: 8.43°C
1875: 7.86°C
1876: 8.08°C
1877: 8.54°C
1878: 8.83°C
1879: 8.17°C
1880: 8.12°C
1881: 8.27°C
1882: 8.13°C
1883: 7.98°C
1884: 7.77°C
1885: 7.92°C
1886: 7.95°C
1887: 7.91°C
1888: 8.09°C
1889: 8.32°C
1890: 7.97°C
1891: 8.02°C
1892: 8.07°C
1893: 8.06°C
1894: 8.16°C
1895: 8.15°C
1896: 8.21°C
1897: 8.29°C
1898: 8.18°C
1899: 8.40°C
1900: 8.50°C
1901: 8.54°C
1902: 8.30°C
1903: 8.22°C
1904: 8.09°C
1905: 8.23°C
1906: 8.38°C
1907: 7.95°C
1908: 8.19°C
1909: 8.18°C
1910: 8.22°C
1911: 8.18°C
1912: 8.17°C
1913: 8.30°C
1914: 8.59°C
1915: 8.59°C
1916: 8.23°C
1917: 8.02°C
1918: 8.13°C
1919: 8.38°C
1920: 8.36°C
1921: 8.57°C
1922: 8.41°C
1923: 8.42°C
1924: 8.51°C
1925: 8.53°C
1926: 8.73°C
1927: 8.52°C
1928: 8.63°C
1929: 8.24°C
1930: 8.63°C
1931: 8.72°C
1932: 8.71°C
1933: 8.34°C
1934: 8.63°C
1935: 8.52°C
1936: 8.55°C
1937: 8.70°C
1938: 8.86°C
1939: 8.76°C
1940: 8.76°C
1941: 8.77°C
1942: 8.73°C
1943: 8.76°C
1944: 8.85°C
1945: 8.58°C
1946: 8.68°C
```

```
1946: 8.68°C
1947: 8.80°C
1948: 8.75°C
1949: 8.59°C
1950: 8.37°C
1951: 8.63°C
1952: 8.64°C
1953: 8.87°C
1954: 8.56°C
1955: 8.63°C
1956: 8.28°C
1957: 8.73°C
1958: 8.77°C
1959: 8.73°C
1960: 8.58°C
1961: 8.80°C
1962: 8.75°C
1963: 8.86°C
1964: 8.41°C
1965: 8.53°C
1966: 8.60°C
1967: 8.70°C
1968: 8.52°C
1969: 8.60°C
1970: 8.70°C
1971: 8.60°C
1972: 8.50°C
1973: 8.95°C
1974: 8.47°C
1975: 8.74°C
1976: 8.35°C
1977: 8.85°C
1978: 8.69°C
1979: 8.73°C
1980: 8.98°C
1981: 9.17°C
1982: 8.64°C
1983: 9.03°C
1984: 8.69°C
1985: 8.66°C
1986: 8.83°C
1987: 8.99°C
1988: 9.20°C
1989: 8.92°C
1990: 9.23°C
1991: 9.18°C
1992: 8.84°C
1993: 8.87°C
1994: 9.04°C
1995: 9.35°C
1996: 9.04°C
1997: 9.20°C
1998: 9.52°C
1999: 9.29°C
2000: 9.20°C
2001: 9.41°C
2002: 9.57°C
2003: 9.53°C
2004: 9.32°C
2005: 9.70°C
2006: 9.53°C
2007: 9.73°C
2008: 9.43°C
2009: 9.51°C
2010: 9.70°C
2011: 9.52°C
2012: 9.51°C
2013: 9.61°C
2014: 9.57°C
2015: 9.83°C
--------
```

The code was formed using a variable to keep track of the month, year, a year counter and how many years were going to be counted. This was done to ensure that the following questions, 5 and 6, have enough information to be chained onto this question and answered. Using the code base, the rows for the required land average temperature and dates were scanned and copied into an average temperature and date array. The average for each year was taken by dividing by 12 each time the month counter reached it. It was then printed using a loop restricted by the year counter.

Question 2 output:

```
QUESTION 2
--
CENTURY AVERAGES FOR LAND TEMPERATURE

18th Century: 8.21°C
19th Century: 8.01°C
20th Century: 8.64°C
21st Century: 9.54°C
--------
```

A helper method was used to add up all the land average temperatures in a loop and return a single value for the century. This helper method took in the base data and the first and last row to be scanned for each century. The land average temperature was added to an average variable in the method and was divided by a year variable in the return statement, which would increment for each loop iteration. The helper method was called 4 times for each century. The output was finally printed inside the question 2 method itself.

Question 3 output:

```
--------
QUESTION 3
--
MONTHLY AVERAGES FOR AVERAGE LAND TEMPERATURES (1900-2015)

January: 2.82°C
February: 3.33°C
March: 5.40°C
April: 8.54°C
May: 11.39°C
June: 13.54°C
July: 14.45°C
August: 13.96°C
September: 12.17°C
October: 9.53°C
November: 6.22°C
December: 3.81°C
--------
```

An array to hold the average for each month and an array to count the number of times a month appears was initialized with a size of 12; the arrays were zeroed in the event that their memory cells still contained values that might be added onto. A month variable was then used in a switch case to indicate which month needed to be added onto, the variable incremented each iteration of the loop. When the final month was reached for the year, the month variable was zero'd to start the cycle over again. The loop was set to last for the number of rows between the required years. Finally, a month array containing the names of each month was used in conjunction with the average temperature array to print the values of the question.

Question 4 output:

```
--------
QUESTION 4

Coldest Month: January of 1768 (1768/01); T = -2.08°C
Hottest Month: July of 1761 (1761/07); T = 19.02°C
--------
```

A string array for the coldest and hottest month was created alongside a min and max temperature variable set to the first element of the land average temperature data provided by the base. The min and max variables were then compared with every element and swapped if it failed to be the lowest or, for hottest, the highest temperature; the string date for the element was copied into the string month arrays. After the loop finished comparing every element, tokens were used to split up the string containing the dates to extract the months. This month was then converted to an int and sent to a helper array to find the string representation of the month. Finally, the string and integer representation of the month, integer for the year, and double value of the temperature was displayed with one print statement.

Question 5 output:

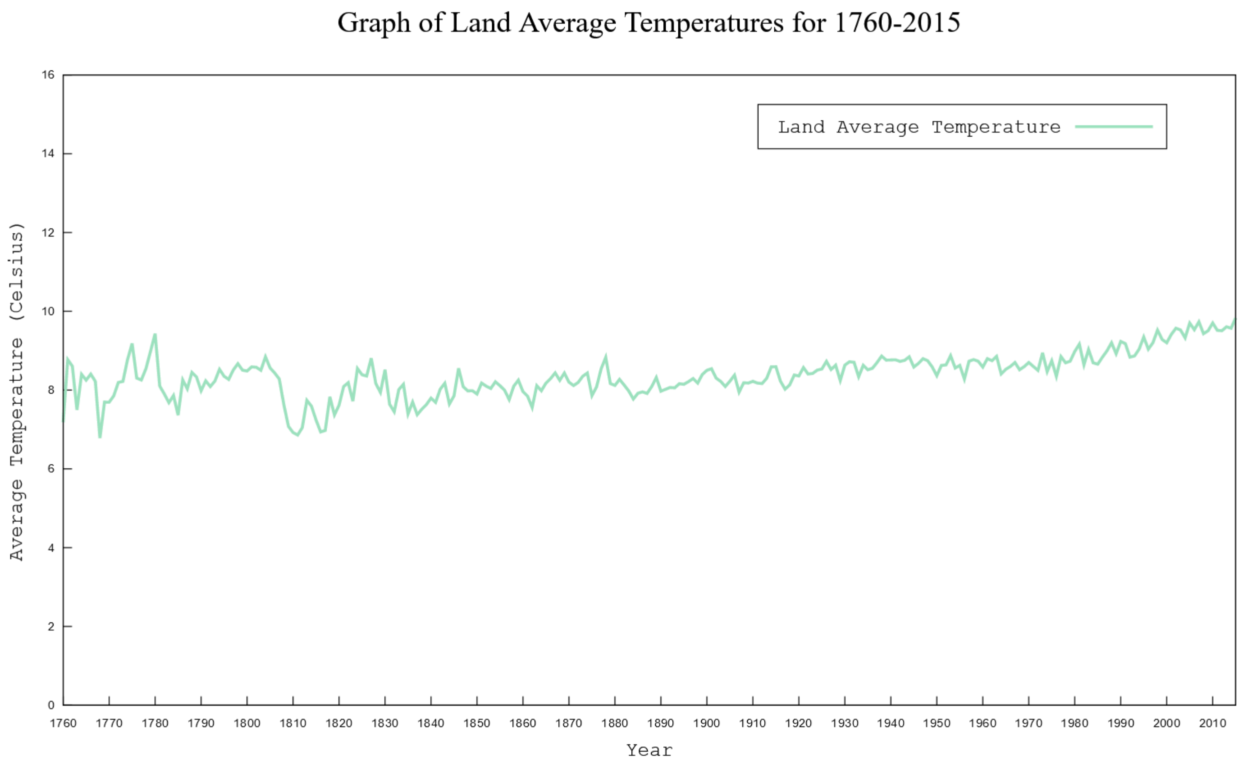
```
--------
QUESTION 5

Coldest Year: 1768, T = 6.78°C
Hottest Year: 2015, T = 9.83°C
--------
```

This question extended question 1, using values already found in question 1 to achieve its goal. The yearly averages, dates and year counter from question 1 were used to compare the min and max values for each element in the same way as question 4 - setting min/max to the first element of the data, then comparing with the rest of the elements to find the coldest/hottest temperature and it's string date. Once the maximum and minimum temperature was found, tokens were once again used to extract the year from the string to convert into an integer. The year was then displayed alongside the temperatures found.

Question 6 output:

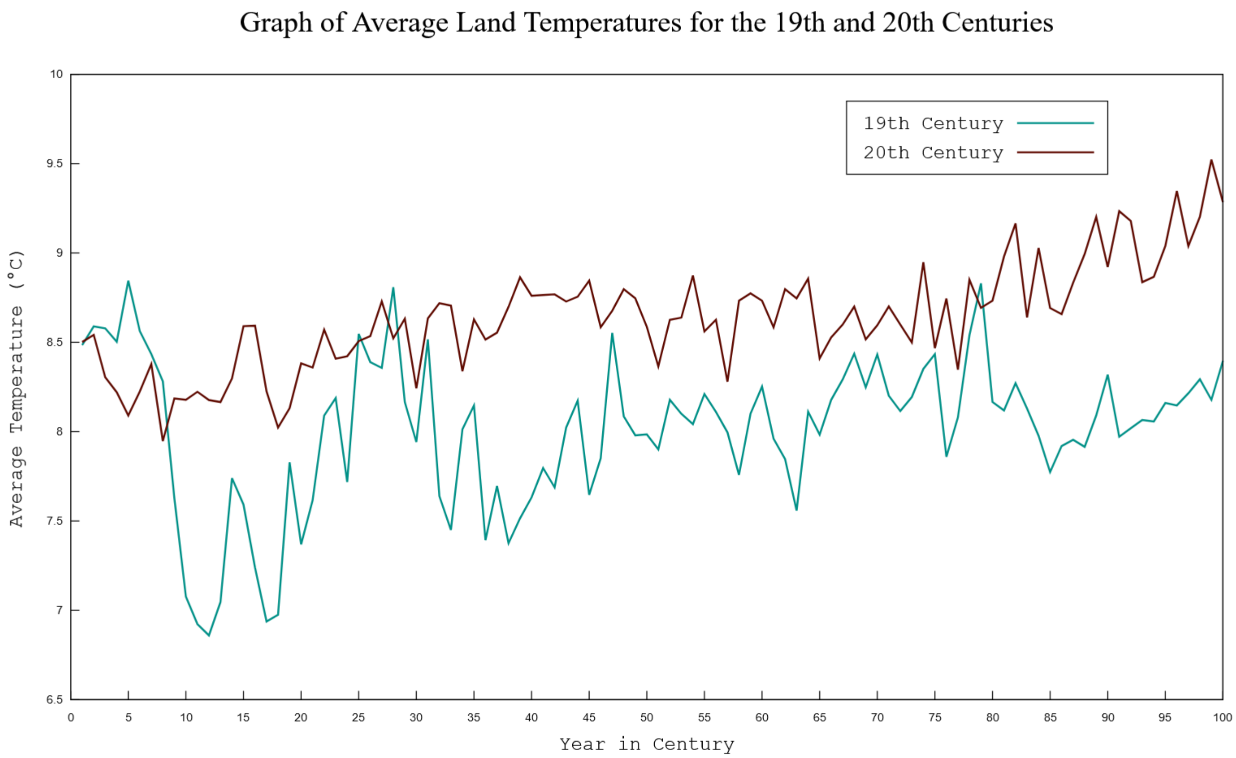
Figure 1: Land Average Temperature 1760-2015



Extending from question 1, the data extracted from the base struct for the yearly land temperature averages was passed to the question 6 method. A file was then created and written with all the data provided by question 1 into a .csv file which can be read, by columns, with GNUPlot. GNUPlot was then used to graph the data and make it more visually pleasing.

Question 7 output:

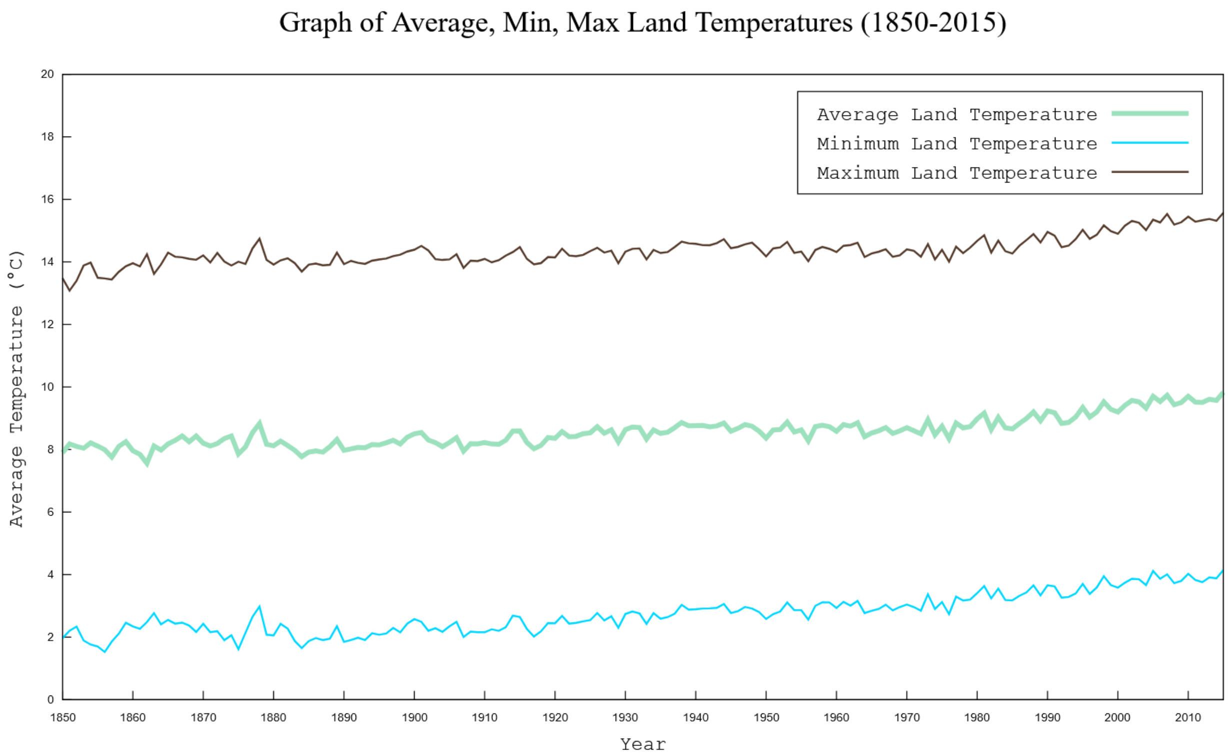
Figure 2: Average Land Temperatures 19th - 20th Century



Using a similar method used in question 2, a helper method was used to calculate the averages for each century using the data provided by the base struct and the rows numbers. A file created to write all the data to - a year variable was used with a for loop to write the data into a .csv file in a way such that GNUPlot reads the same years for each century on a column. The data was then plotted using GNUPlot and the scaling for the data was changed to make the temperature fluctuations between the two centuries more coherent.

Question 8 output:

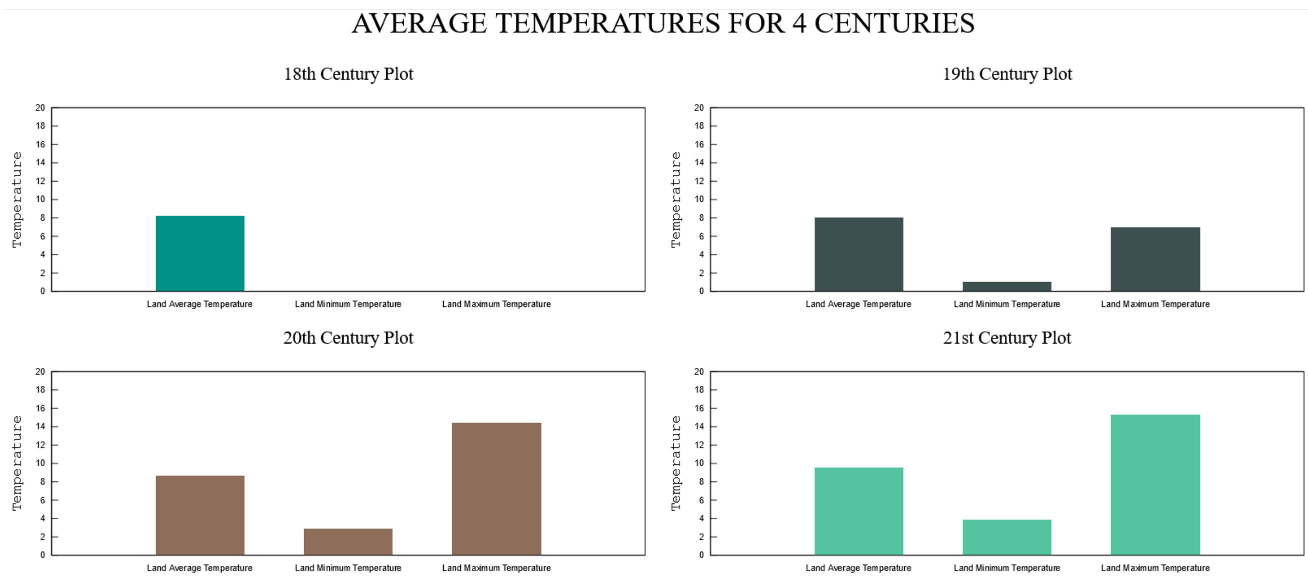
Figure 3: Max, Min, and Average Land Temperature (1850-2015)



An average, min, and max temperature array which can hold up to 200 elements was created, array size was buffed to 200 to ensure there was enough space. Temporary variables which would hold the temperature values were created. The rows for the years required were then taken and put into a for loop which would continuously add on to the temporary values. Using a month variable to determine when 12 months was reached, the temporary variables were divided by 12 and zeroed, a year variable was then incremented in this step; this cycle continued until the final year. Once the final year was reached, the data was written into a .csv to be read in GNUPlot. The three datasets were plotted on a single graph and the linewidth for the Average Land Temperature was manipulated to stand out more than the other two lines.

Question 9 output:

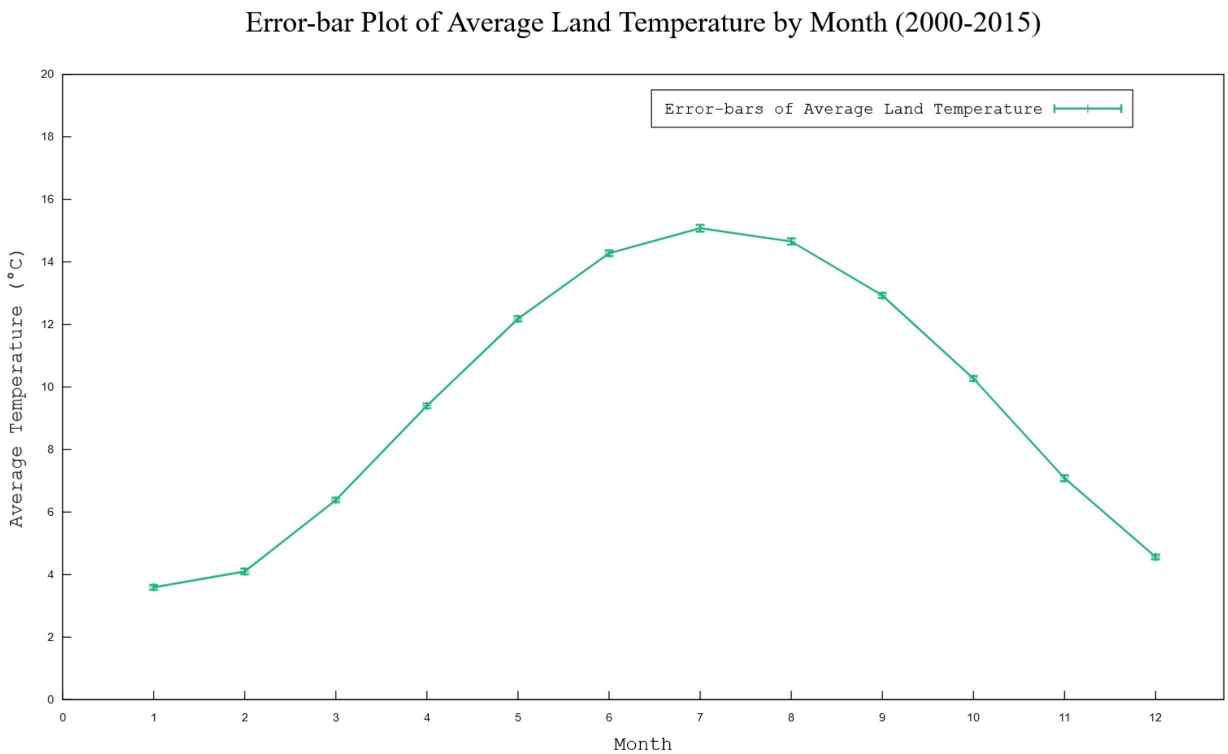
Figure 4: Average Temperatures For Each Century



The same methods used in question 2 and 7 were once again used to find the average temperatures but this time, for each century. The helper method mentioned in question 2 and 7 was changed to fit this requirement. Once the data was extracted, a file was created and it was written in a format such that the rows represent each temperature type; Land Average Temperature has its own row. A multiplot was then made using GNUPlot and the first column was used as the x-axis labels.

Question 10 output:

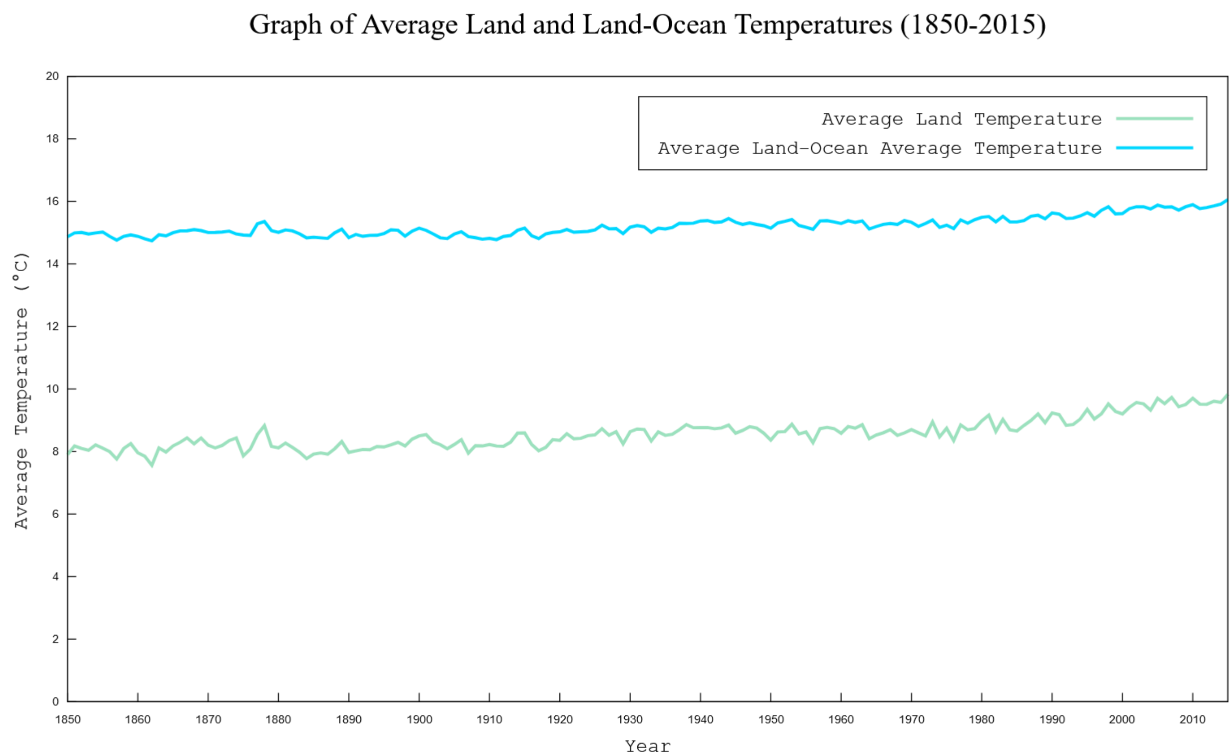
Figure 5: Error-Bar Plot (2000-2015)



Similar to question 3, a month double and month count array was created to keep track of the amount of times a month appears in the given time period; since uncertainty was required, another array was created for it. The same switch case algorithm in question 3 was used again, tracking the month using a month variable which increments and adding on to the index linked to that month. All the data was then written into a .csv file with each one having its own column. It was then plotted with GNUPlot and the y-axis error bars function was used to show the uncertainty. A special function for error bars was used to show lines connected to each point of uncertainty.

Question 11 output:

Figure 6: Average Land and Ocean Temperatures (1850-2015)



In similar fashion to question 8, arrays were initialized to hold values for the land and land-ocean averages taken from the base struct. A for loop running for the required amount of years was then used such that the temporary variables would be added onto; the average was then taken after 12 months and the cycle would repeat till the final year in the same way as question 8. The data was written into a .csv file and formatted into columns. GNUPlot was then used to plot the data, appropriate colors to represent the theme of the data sets were used.

Discussion & Conclusion

By observing the graphs above, it is evident that as the years progressed, the land's average temperature constantly increased. This pattern is due to the fact of an immense buildup of greenhouse gases trapped within the Earth's atmosphere. As the gases build up in the atmosphere, they create a layer which keeps the heat trapped inside, allowing for the Earth, or land to become warmer, as seen in *Figure 1*.

Also within *Figure 1*, a drastic change in temperature can be seen occurring between the years 1800-1815. This change in temperature could have been caused by extreme volcanic activity and eruptions which occurred during the years 1815, the Tambora eruption, and 1809 another volcanic eruption. Due to the extreme debris the volcanoes have let out, it caused the Earth's atmosphere to be covered in the ash, smoke, and debris which blocked out the amount of sunlight passing through the Earth's atmosphere. With less sunlight passing through, there is less heat for the land to absorb, allowing for this explanation to be the conclusion to why the temperature patterns behaved this way. However, this is also statistically proven, showing that the 19th century has the lowest average temperature with a value of 8.01°C, due to these unfortunate events.

In *Figures 1,3,4*, it can be seen how the temperature has been increasing, showing how the land has been getting warmer as time goes on. Even the minimum average temperature has been increasing to a warmer scale. This can be explained by the fact that there was an industrial revolution in which a lot of carbon emissions were emitted into the atmosphere, causing the land to become warmer.

With a new era coming into place which launched between 1760 to 1840, the rise in temperature is clear, besides the few incidents which caused the land to cool down. However, even after 1840, there were a lot of factories and manufacturing happening, also the increase of the human population which contributed greatly to the carbon emissions in the atmosphere. This data is proven mathematically with the hottest century being the 21st century with an average temperature of 9.54°C. All of these are examples and factors which cause global warming to occur, as well as increase the land's temperature in one way or another.

Figure 6 highlights and compares the average temperature on land versus in the ocean. As viewed in the figure, ocean temperatures are much greater than the land temperatures. This is due to the fact that oceans are able to absorb heat better, and for longer periods of time due to how dark in color the oceans are. They also hold a larger surface area on Earth than land does, allowing for more heat to be absorbed. Additionally, oceans, or water, has a higher heat capacity than land, which absorbs and stores the heat more efficiently, as well as with current, moves it around, changing the climate of different regions.

In conclusion, as this project was completed, the experience consisted of many struggles and successes, where the codes and graphs did not work at times but it was a rewarding experience which encouraged the enhancement of individual C programming and Plotting skills. As a collective, it was an incredible experience to work alongside others in a group and come up with solutions to these prompts. For future projects, something that can be done differently is to have more active feedback as a group, and additional meetings to ensure that solutions can be found as a collective. However, the experience overall was a success and an important lesson on overcoming tough circumstances.