Project Three – Arctic Ice Visualization and Carbon Dioxide Analysis

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Introduction

There are so many unknowns associated with climate changes such as causation, what current global and local changes are actually occurring, and what long term effects this will have on society that it behooves scientists to utilize a system capable of aggregating current data and visualizing it in meaningful ways to allow researchers to detect connections they might not have otherwise seen. This report documents our experience analyzing changing ice patterns in the arctic as well as carbon dioxide emissions. The goal of this project is to experience the procedure of visual analysis, starting with the collection and manipulation of climate data from independent sources and ending with visualizations that tell a vivid story about the changing environment.

Background

Typically climate is defined as the normal weather patterns and characteristics for a particular place over time [1]. However, climate is much more than that. What is considered climate is actually a complex interaction between solar energy, the earth's orbit, atmospheric conditions, ocean currents, topography, volcanic activity, and mankind [1], [2].

When the sun's rays enter the earth's atmosphere they warm the atmosphere and oceans causing air and water currents. The sun's heat also causes some of the oceans' water to evaporate and be circulated through the atmospheric currents as water vapor. Once the atmosphere reaches its maximum concentration of water vapor the vapor precipitates into its solid or liquid form and eventually falls back down to the earth. How much water actually evaporates and how much water vapor the atmosphere is capable of holding is dependent on how warm the region is [1]. Temperature is dependent on how much of the sun's solar energy the planet retains versus how much is released back into space. As previously mentioned, some of the energy is absorbed by the Earth's atmosphere. This energy is the source of wind and ocean currents. The remaining amount of energy is either absorbed by land or reflected off into the atmosphere. Local topography can affect how much heat is absorbed versus reflected back into the atmosphere. For example, in northern snowy environments, deforestation actually causes the local topography to reflect more of the sun's energy back into space. This may lead to an overall cooling effect on that area [1]. Some of the reflected energy is given off into space as heat but some of it is trapped by a diverse group of gasses like water vapor, carbon dioxide, methane, ozone and nitrous oxide, collectively coined the greenhouse gasses for their warming effect [1].

A system as complex as this would not be expected to remain static indefinitely, and indeed, there have been fluctuations in the past that have led to drastic climate changes. By examining fossil records, isotopic substances buried in arctic ice, and human records, scientists have estimated what climate trends for certain regions may have been like in the distant past. Researchers believe that for about the last half a million years the planet has undergone a 100,000 year period of severe cooling followed by a 4-10^{o} C warming period. Scientists believe that all forces being equal the earth should naturally be in the early stages of a cooling period, yet current real world data show the average global temperature for the last thirty years has increased by 0.15^{o}C per decade [1].

Changing activity in the planet's diverse ecosystems seems to support the notion that the Earth's temperature is rising. Winter temperatures around the world are recording higher temperatures than in the last century and significant amounts of ice sheets at both poles appear to be shrinking. In the animal kingdom, many species of animals have begun their springtime behaviors an average of 2-5 days earlier per decade [1].

After reviewing previous causes of climate changes like fluctuating incoming solar energy and volcanic activity, scientists have concluded these do not sufficiently explain the dramatic warming effects in the past century [2]. In lieu of naturally occurring phenomenon, scientists now believe that mankind may be responsible for the recent climate changes. Researchers argue that in past centuries human exerted only a local influence on the climate via deforestation. However, since the dawn of the Industrial Era mankind has exerted a more dramatic influence through carbon dioxide emissions. In the last century atmospheric carbon dioxide levels from fossil fuel consumption has skyrocketed, resulting in a 33% increase of carbon dioxide levels [1], [2].

In the past, the homeostasis of the planet's climate system shattered due to certain thresholds being exceeded, resulting in long term climate changes. What these thresholds actually are, scientists are unsure of, but they predict that if current conditions remain constant, by the year 2100 the overall surface temperature will increase by 1.7-4.9^{o}C [1]. Uncertainty still clouds how this temperature increase will affect mankind. Scientists think most possible changes will be gradual and allow for some form of adaptation. Agriculture may suffer as more soil erosion would be likely and what soil remains will probably have lower moisture content due to increased evaporation [1], [2]. Insects would likely have longer mating seasons and lifecycles with increased temperature and as a result, they (the insects) could potentially become more burdensome to crops [3]. Furthermore, the frequency of precipitation may decrease while the average severity of these occurrence increases. However, some scientists acknowledge the possibility of sudden drastic changes not allowing much time, if any, for adaptation. For example, in one scenario it is possible that ocean currents cease and that Western Europe will no longer have an influx of warm water causing it to cool by at least 10^{o}C and altering global atmospheric currents in the process. Another sudden change would be if the Arctic permafrost melts at such a pace that the significant amounts of methane it contains escaped into the atmosphere and accelerated the warming trend drastically faster than most scientists already predict [1].

Research Methodology

Most geographic visualizations systems tend to fall under Shneiderman's two dimensional category in his Task by Data Type Taxonomy [4]. Given the limited scope of this prototypical project this is the category we predominantly worked with using Google Earth with CO_2 and ice concentration data. In the case or arctic ice concentrations (to be discussed in more detail below) we used an image overlay technique to display fluctuations in ice concentrations in the arctic over 27 years in a geographic display. For the carbon dioxide levels tear shaped markers which when clicked on display an area's carbon dioxide levels were loaded into Google Earth.

Arctic Ice Visualization Analysis

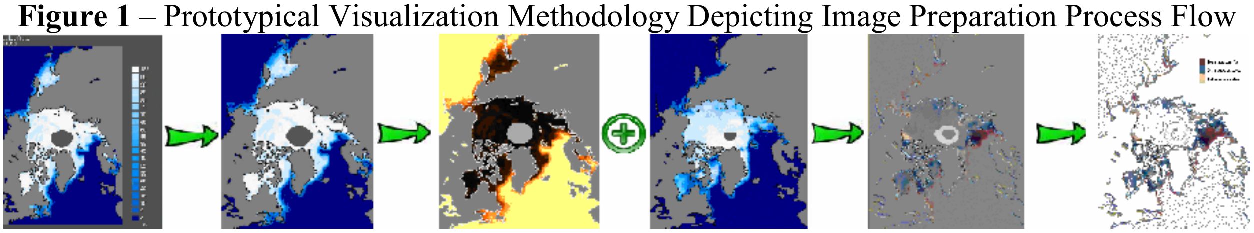
Arctic ice concentrations have been in flux for the last 27 years. The expected impact of the visualizations and this analysis is to demonstrate these fluctuations exist. The following prototypical visualization methodology explores these fluctuations and depicts a viable approach to monitoring these trends. The approach enlisted throughout this analysis involved sifting through artic ice concentration images over a 27 year period. The analysis broke the 27 year period into three nine year stages of comparison. The month of January was selected as a delta that we assumed would produce a consistent seasonal view of the arctic over the 27 year period. Another assumption made is that shades of darkness not identified in the legend are inferred to indicate lower concentrations of ice. Further, the lighter the color not identified in specific keys indicated higher concentrations of ice. This applies to all overlay visualizations depicted within this document.

Figure 1 depicts the image preparation process flow used in this analysis. This process is a simple and viable approach to monitoring these trends. The process consists of four steps which generally involve preparing the images, inverting them, overlaying them and removing constant colors.

Based on the simplicity of this process and the easily identifiable changes in ice concentration, the value of your visualization is extremely high. The results are clear and conclusively depict fluctuations with a tendency toward less ice concentration overall. However, the global impact of this trend remains unclear.

Figure 2 compares the change in arctic ice concentrations during the first nine year period used in this analysis. This period ranged from 1979 to 1988. Examining these two images side by side requires a detail review of all visible shorelines to gage the change. A side by side comparison of images was therefore deemed unreasonable for analysis purposes.

Figure 1 – Prototypical Visualization Methodology Depicting Image Preparation Process Flow



Step One	**Step Two**	**Step Three**	**Step Four**
Crop the images to be compared	Invert the base image	Overlay the second image	Manually remove gray

Figure 2 – Comparison of Change in Arctic Ice from January 1979 to January 1988

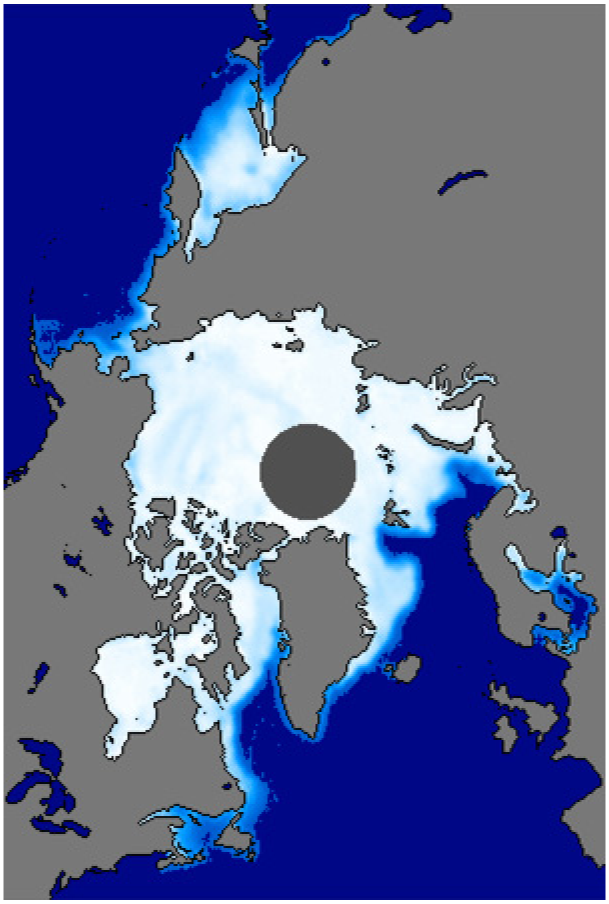
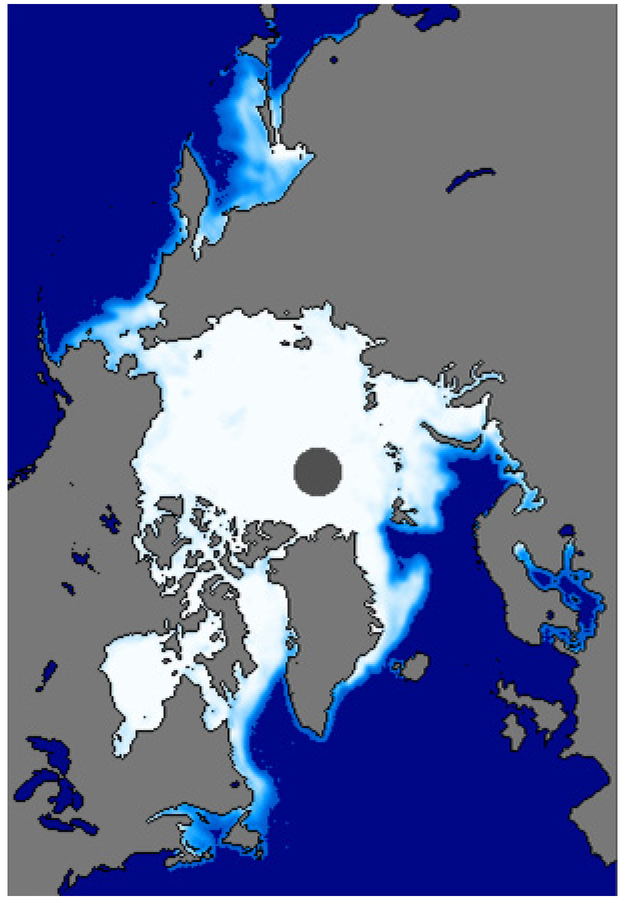
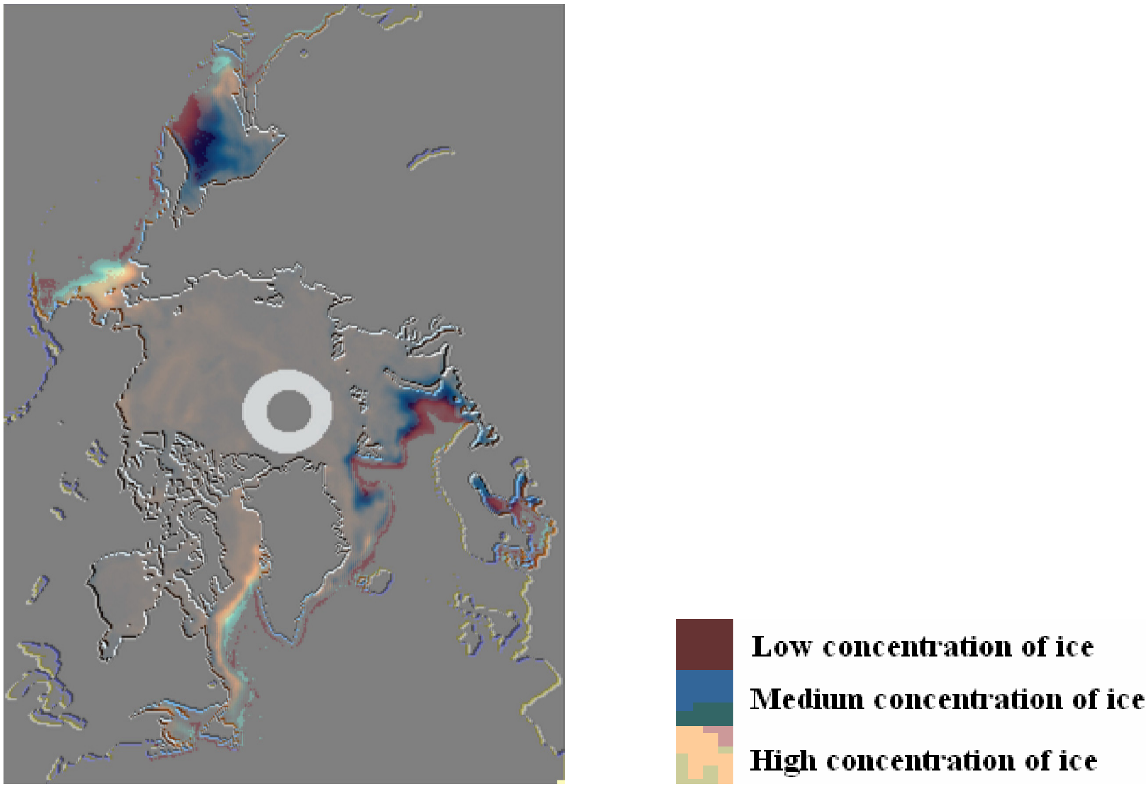
Sea Ice Concentration - January 1979	Sea Ice Concentration - January 1988
	

Figure 3 is the product of overlaying the two images above. As the legend indicates, there is a considerable amount of fluctuation in ice concentrations over this nine year period.

Figure 3 - Overlay of January 1979 and January 1988 Arctic Ice Concentration Images



As demonstrated in Figure 4, the south west corner of the region incurred higher ice concentrations in areas previously dominated by lower ice concentrations. Ice essentially replaced the ocean water. The opposite occurred in the north east corner of the region. The degree of change seemed visually higher in the northeast quadrant.

Figure 4 - Overlay Depicting Change between January 1979 and January 1988 Arctic Ice Concentration Images

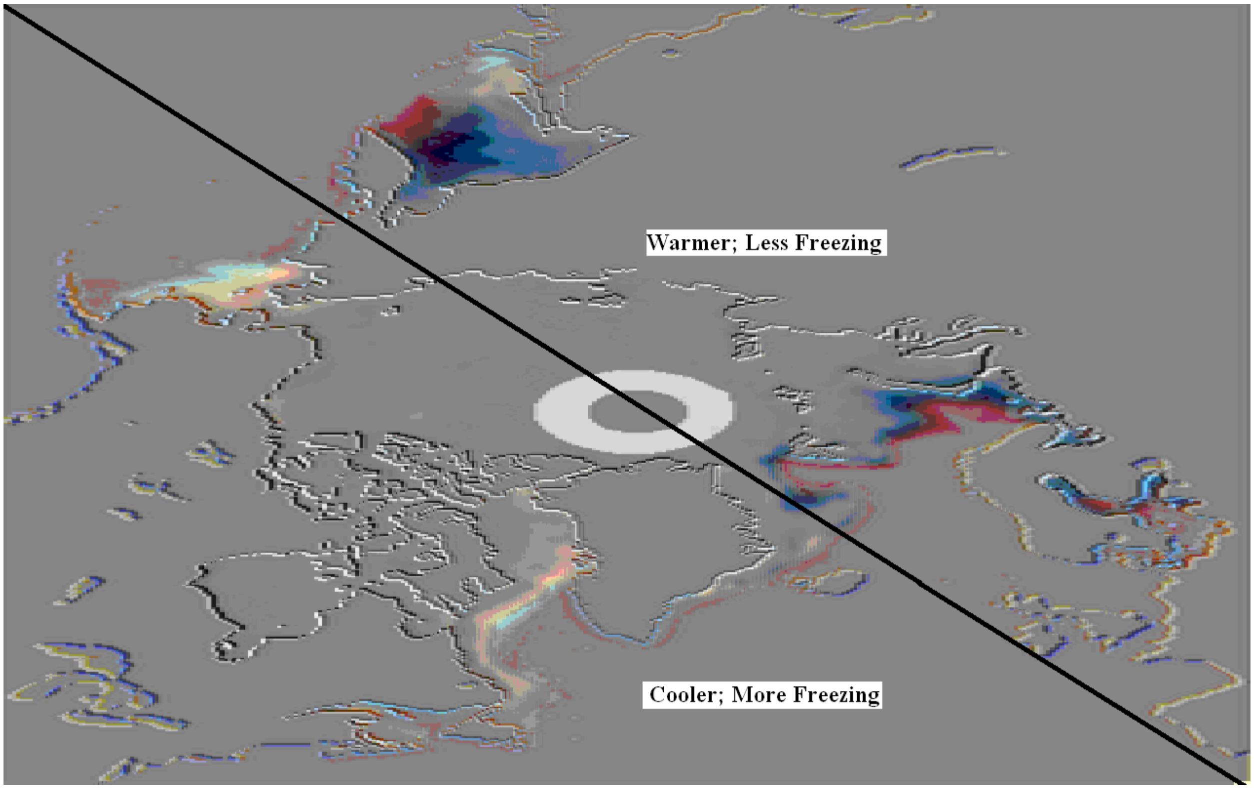


Figure 5 is the product of another image overlay. As the legend indicates, there is a considerable amount of fluctuation in ice concentrations over this nine year period. The most startling observation about this overlay is the decrease in concentration and simultaneous expansion of ice around the shorelines. Unlike the first overlay compared in Figure 3 above, ice concentrations are decreasing across the entire region. Moreover, the central land mass in Figure 5 has changed from a light pink to a light blue. Following our general assumption, darker colors indicate declines in ice concentration. This central body ice concentration may explain the expanded ice concentrations along the shorelines. That is, ice is melting and running off into the sea creating the impression that the ice is expanding when it really is not.

Figure 5 - Overlay of January 1988 and January 1997 Arctic Ice Concentration Images

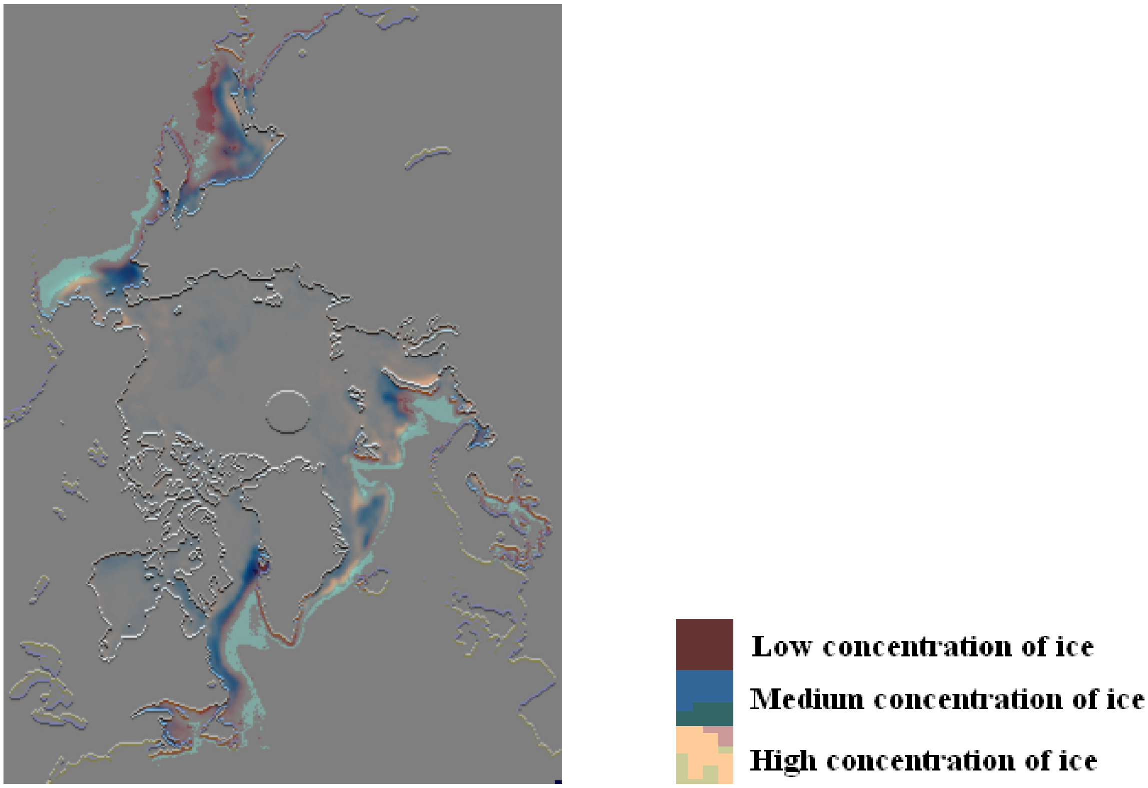
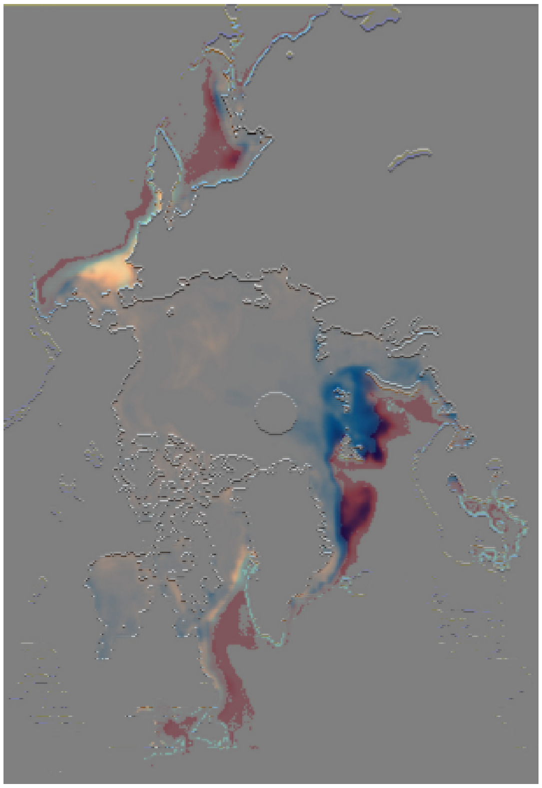


Figure 6 also indicates, there is a considerable amount of fluctuation in ice concentrations over this nine year period. The most startling observation about this overlay is the sheer decrease in concentration along the shorelines especially in the southeast and northwest regions. The central land mass in figure eight has changed back to light pink. Following our general assumption, lighter colors indicate increases in ice concentration. This central body ice concentration may have increased as a result of less volume of freezable material that occurred when the runoff began in the last nine year stage. There is no simultaneous expansion of ice around the shorelines because there is no more runoff from melting ice.

Figure 6 - Overlay of January 1997 and January 2006 Arctic Ice Concentration Images



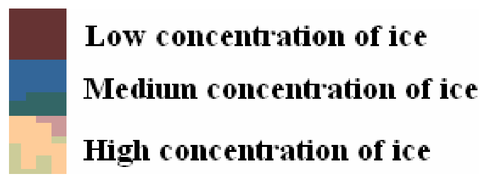


Figure 7 compares the overall change in arctic ice concentrations during the 27 year period used in this analysis. This period ranged from 1979 to 2006. June was selected as a new delta for this overall visualization. As the legend indicates, there is a considerable amount of fluctuation in ice concentrations over this 27 year period. The most startling observation about this overlay is the decrease in concentration and simultaneous expansion of ice around the shorelines. Following our general assumption, lighter colors indicate declines in ice concentration. This central body ice concentration has decreased. Shorelines in the southwest region seem to be experience pockets of higher ice concentrations. This is assumed to be the result of ice water runoff from the main land mass.

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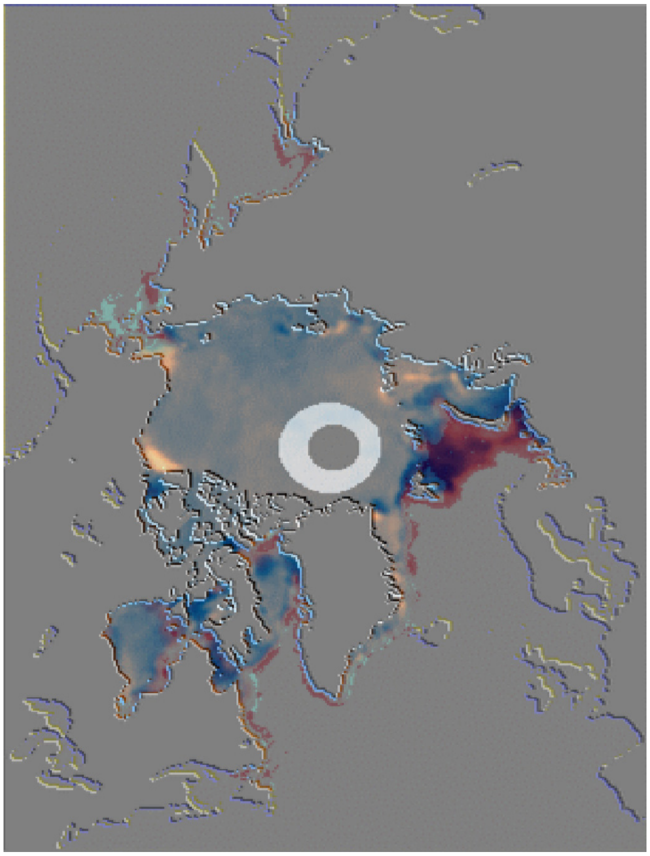
Figure 7 - Overlay Depicting Change between June 1979 and June 2006 Arctic Ice Concentration Images



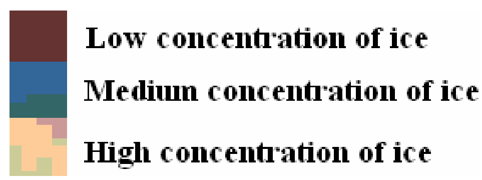


Figure 8 provides an enhanced view of the overall change in the arctic ice concentrations. From this image, the disproportion between freezing and melting can readily be observed.

Figure 8 - Overlay Transparency Depicting Change between June 1979 and June 2006 Arctic Ice Concentration Images – Alternative View

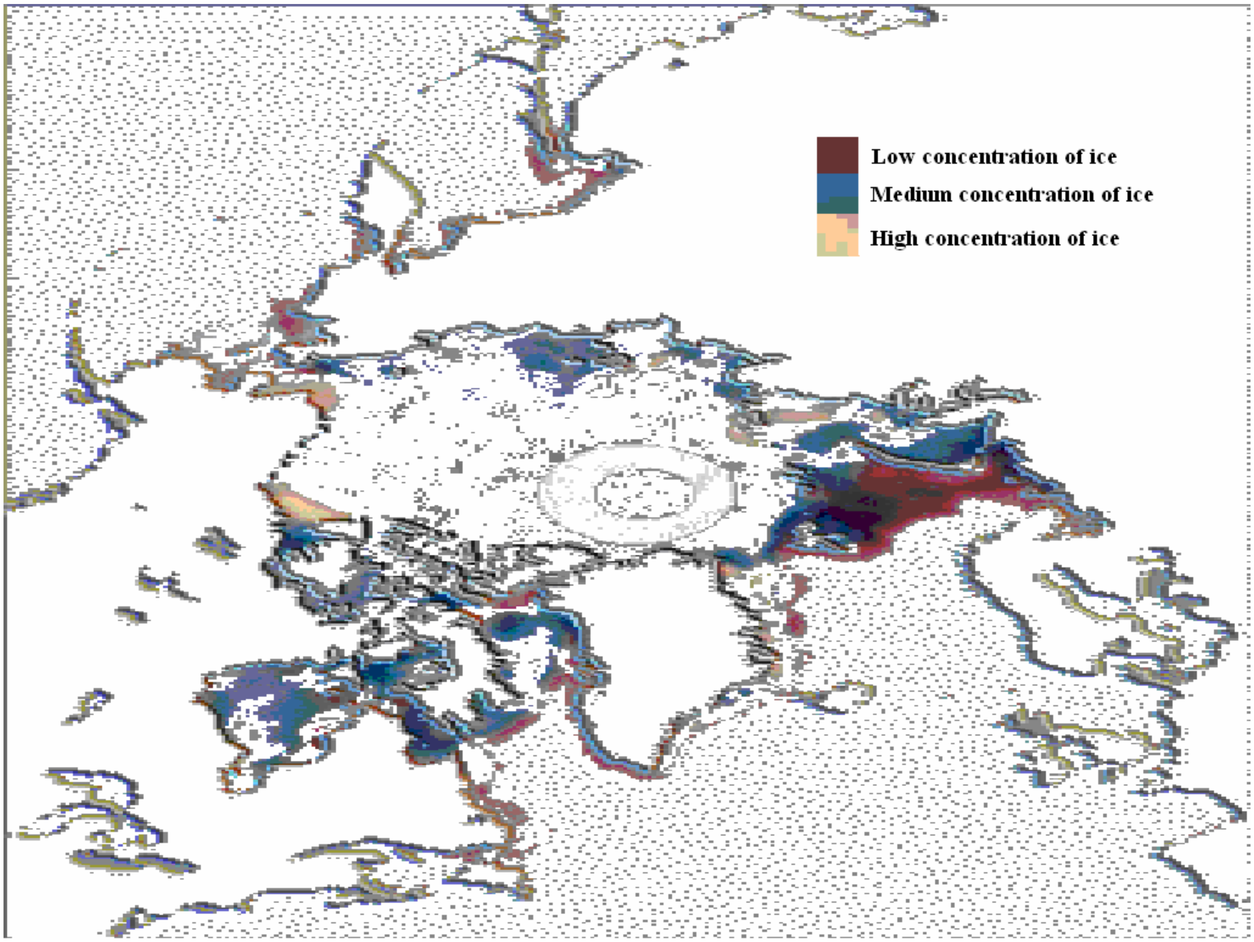


Figure 9 depicts an overall comparison of the base images used in this analysis. This visualization is useful, but requires careful study and does not show enough detail about ice concentration changes, especially on the shoreline.

Figure 9 – Progressive Comparison of January 1979, 1988, 1997 and 2006 Arctic Ice Concentration Images

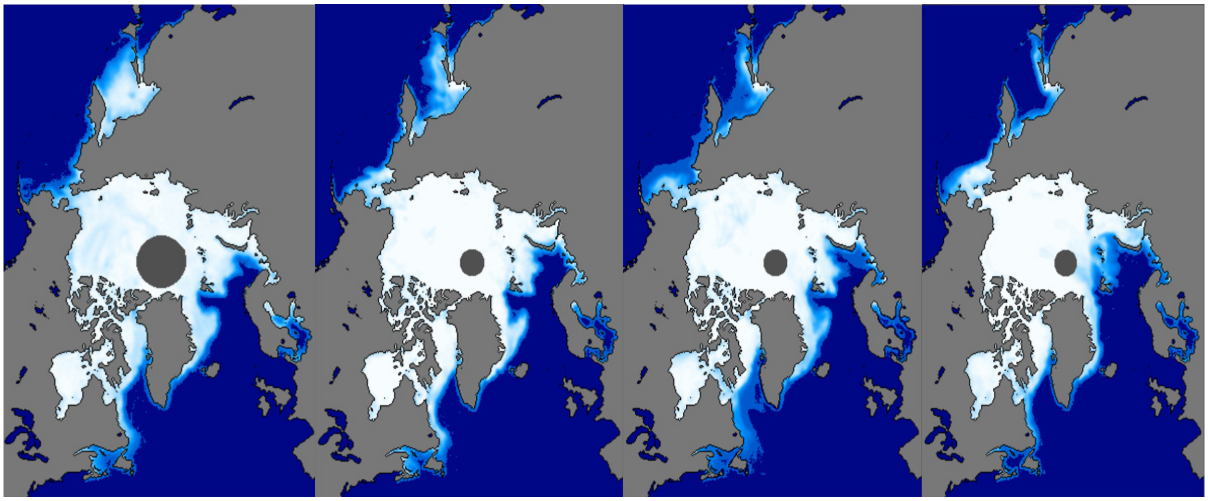


Figure 10 – Progressive Comparison of January 1979, 1988, 1997 and 2006 Arctic Ice Concentration Overlay Images

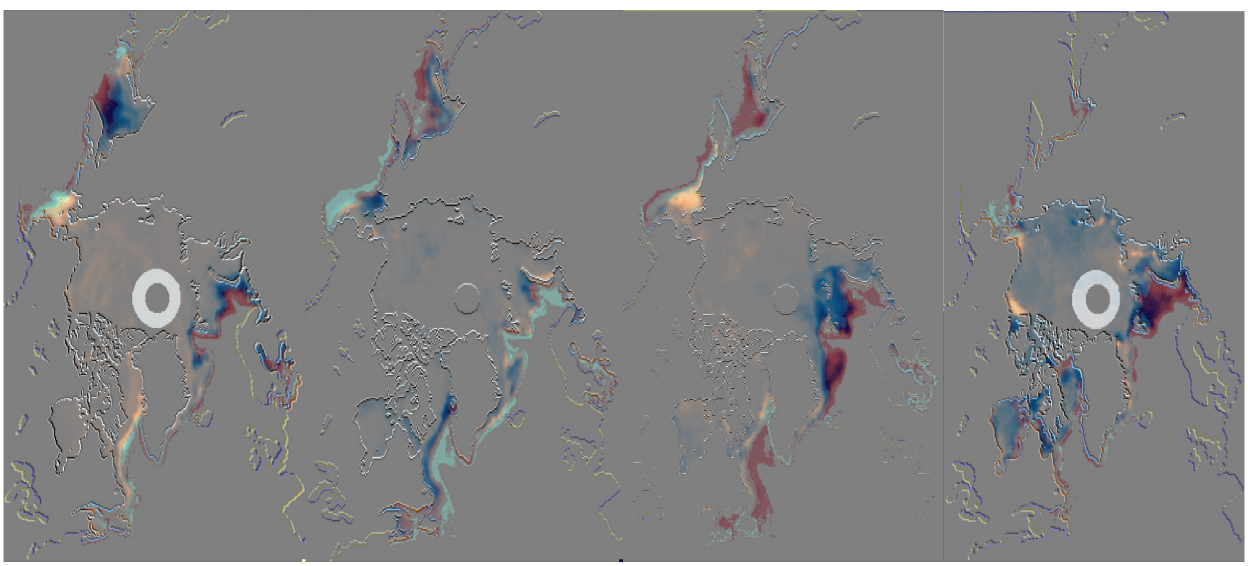


Figure 10 depicts an overall comparison of the overlay images used in this analysis. This visualization is very useful, as it does not require careful study and does show adequate detail about ice concentration changes, especially on the shoreline. This figure shows the extent of the climate fluctuations acting on the ice concentrations.

Carbon Dioxide Emission Visualization

Below are graphs showing the levels of CO_2 emissions in million metric tons (mmt) from 1980 to 2005. The graphs are for CO_2 emissions for the following regions: North America,

Figure 11 – CO_2 Emissions for North America

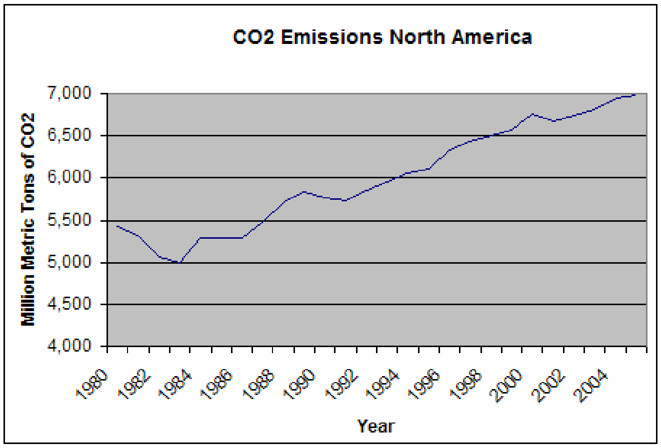
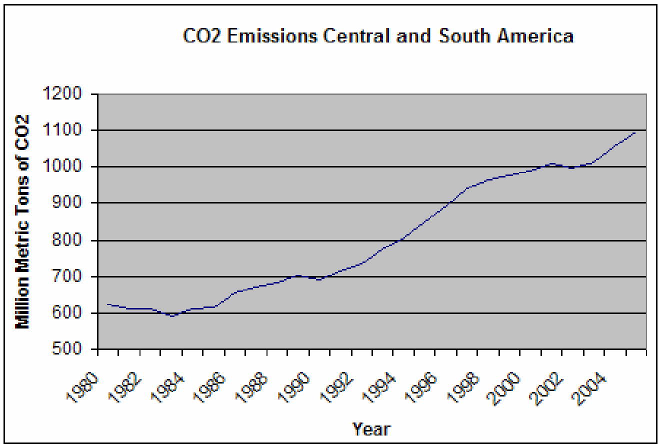


Figure 12 – CO_2 Emissions for Central & South America



Central & South America, Europe, Eurasia, Middle East, Africa, and Asia & Oceania. The final graph is a World graph, which looks at CO_2 emissions for the entire world.

Figure 11 indicates that between 1980 and 1983, there was a decrease in the levels of CO_2 emissions. Then between 1984 and 1986, the levels were constant with little to no change in levels of emissions. Although, between 1990 and 1992, there was a slight decrease, it was around this time that the level of CO_2 emissions began to increase exponentially. The total level of CO_2 emissions in North America from 1980 to 2005 was 155,917.47 million metric tons (mmt) while the average level of CO_2 emissions for the same period was 5,996.83 mmt. The North America region has the highest level of CO_2 emissions among all the regions. This level of increase could be due the increase of consumption by humans or possibly due to the increase in the population.

Figure 12 shows the levels of CO_2 emissions for Central and South America were significantly less than all the other regions except Africa. (For more information on the CO_2 emissions for Africa please see below). The levels of CO_2 emissions decreased very slightly from 1980 to 1983. However, from 1984 onwards, the levels of CO_2 emissions grew

Figure 13 – CO_2 Emissions for Europe

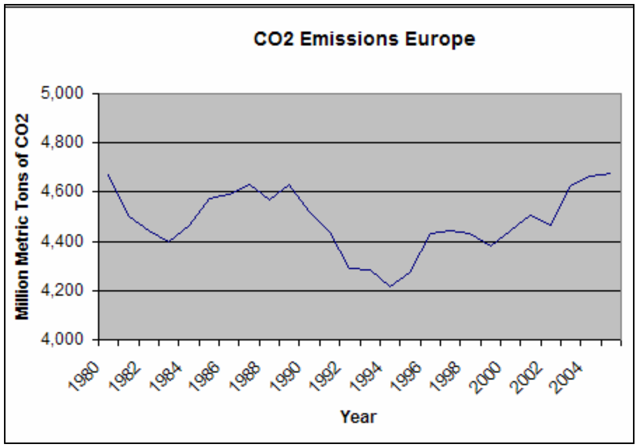
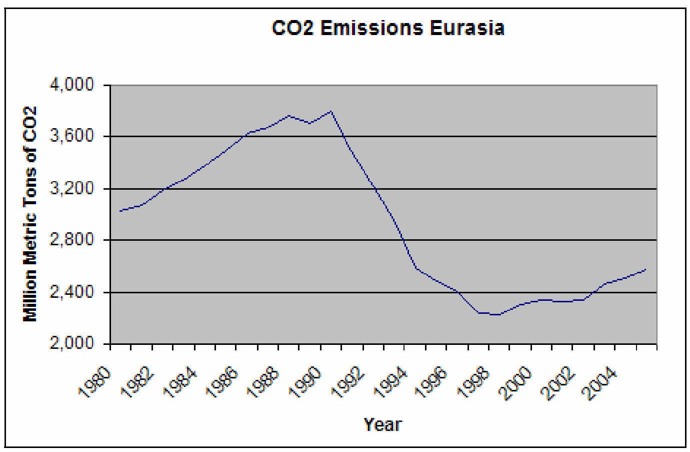


Figure 14 – CO_2 Emissions for Eurasia



exponentially. The total level of CO2 emissions in Central and South America from 1980 to 2005 was 20,886.22 while the average level of CO_2 emissions for the same period was 803.32 mmt. The increase is mainly due to the development of countries in the Central and South American region. It appears that as countries develop and the population increases, so too will the levels of CO_2 emissions.

Figure 13 demonstrates the levels of CO_2 emissions for Europe are not as linear as other regions' levels of emissions and follow a pattern of increasing/decreasing about every four years. First, there was a decrease and then an increase followed. The levels of CO_2 emissions follow a pattern of a bell curve somewhat with high peaks and low lows. The total level of CO_2 emissions in Europe from 1980 to 2005 was 116,553.70 mmt while the average level of CO_2 emissions for the same period was 4,482.83 mmt. At this time the causes of these fluctuations are unknown.

In Figure 14 the levels of CO_2 emissions for Eurasia follow a somewhat similar pattern of Europe. The levels of CO_2 emissions follow a pattern of a bell curve with extremely high peaks

Figure 15 – CO_2 Emissions for the Middle East

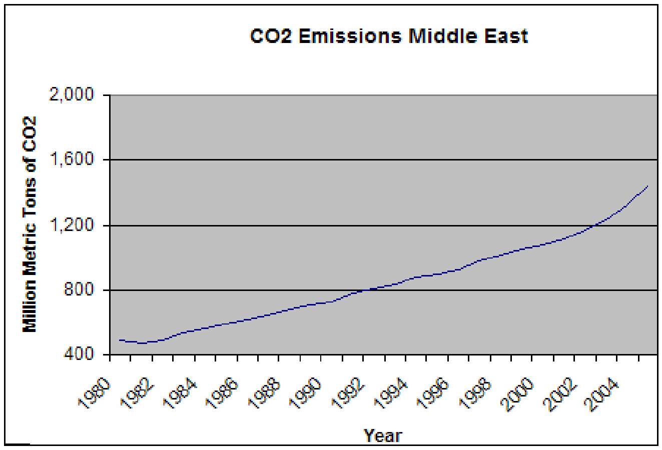
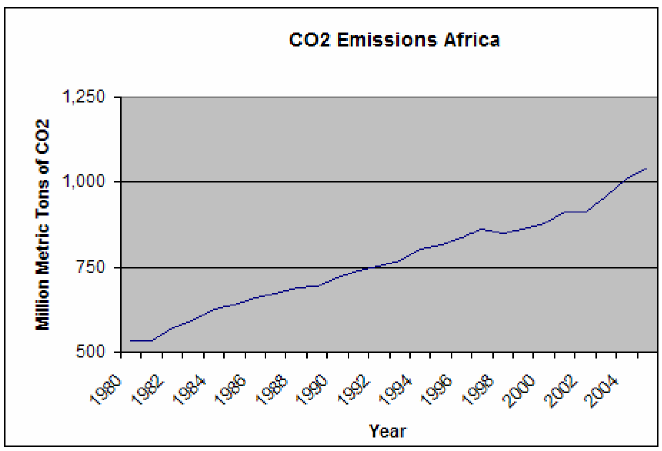


Figure 16 – CO_2 Emissions for Africa



and extremely low lows. The difference with the Eurasia emissions are they increase from 1980 to 1990 and again increase from 1999 to 2005. From 1991 to 1998 the levels decrease. The total level of CO_2 emissions in Eurasia from 1980 to 2005 was 76,465.63 mmt while the average level of CO_2 emissions for the same period was 2,940.99 mmt. It is assumed that as the populations for European countries increases so will the levels of CO_2 emissions and the pattern will stay relatively the same.

Figure 15 shows the levels of CO_2 emissions for the Middle East follows a linear pattern. In 1980, the level of CO_2 emissions was 491.82 mmt. By 1990, the level had risen to 726.07 mmt, an increase of 234.25 mmt. By 2000, the level had risen to 1,081.19 mmt and by 2005, the level had increased by 369.62 mmt to 1,450.81 mmt. The level of CO_2 emissions are increasing at a rapid rate. The total level of CO_2 emissions in the Middle East from 1980 to 2005 was 22,065.05 mmt while the average level of CO_2 emissions for the same period was 848.66 mmt. From the graph, it is expected that the level of CO_2 emissions will continue to increase for a time before finally leveling off.

Once again in Figure 16 the levels of CO_2 emissions for Africa also follows a linear pattern. In 1980, the level of CO_2 emissions was 534.47 mmt. By 1990, the level had risen to 718.13

Figure 17 – CO_2 Emissions for Asia and Oceania

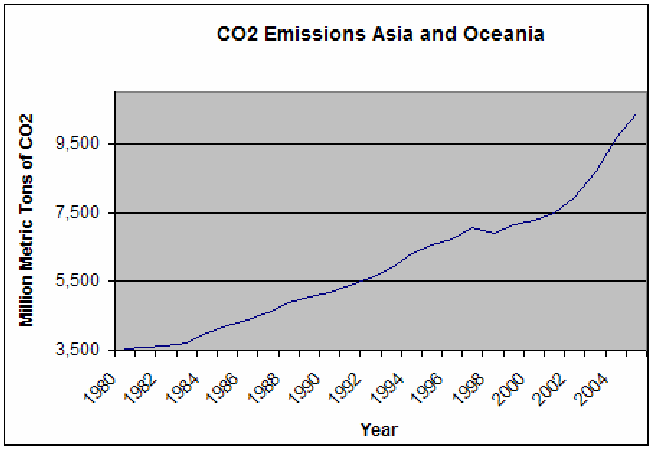
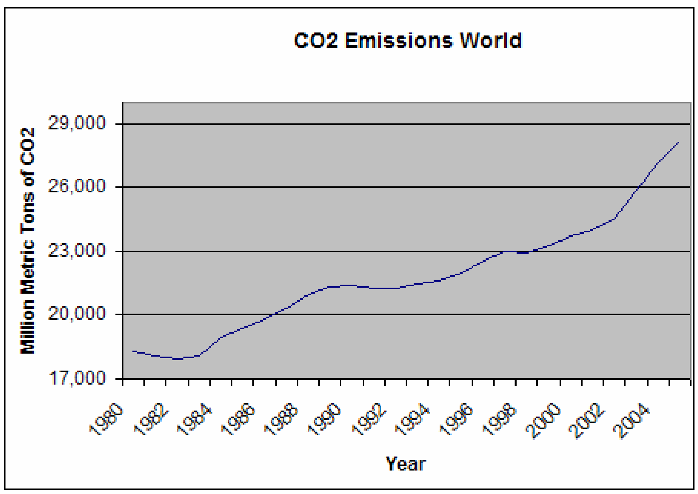


Figure 18 – CO_2 Emissions for the World



mmt, an increase of 183.66 mmt. By 2000, the level had risen to 881.24 mmt and by 2005, the level had increased by 161.68 mmt to 1,042.92 mmt. The level of CO_2 emissions are increasing at a slow steady rate. The total level of CO_2 emissions in Africa from 1980 to 2005 was 19,951.82 mmt while the average level of CO_2 emissions for the same period was 767.38 mmt. The African region has the lowest levels of CO_2 emissions among all the regions. From the graph, it is expected that the level of CO_2 emissions will continue to increase at a steady rate and will likely level off after a while.

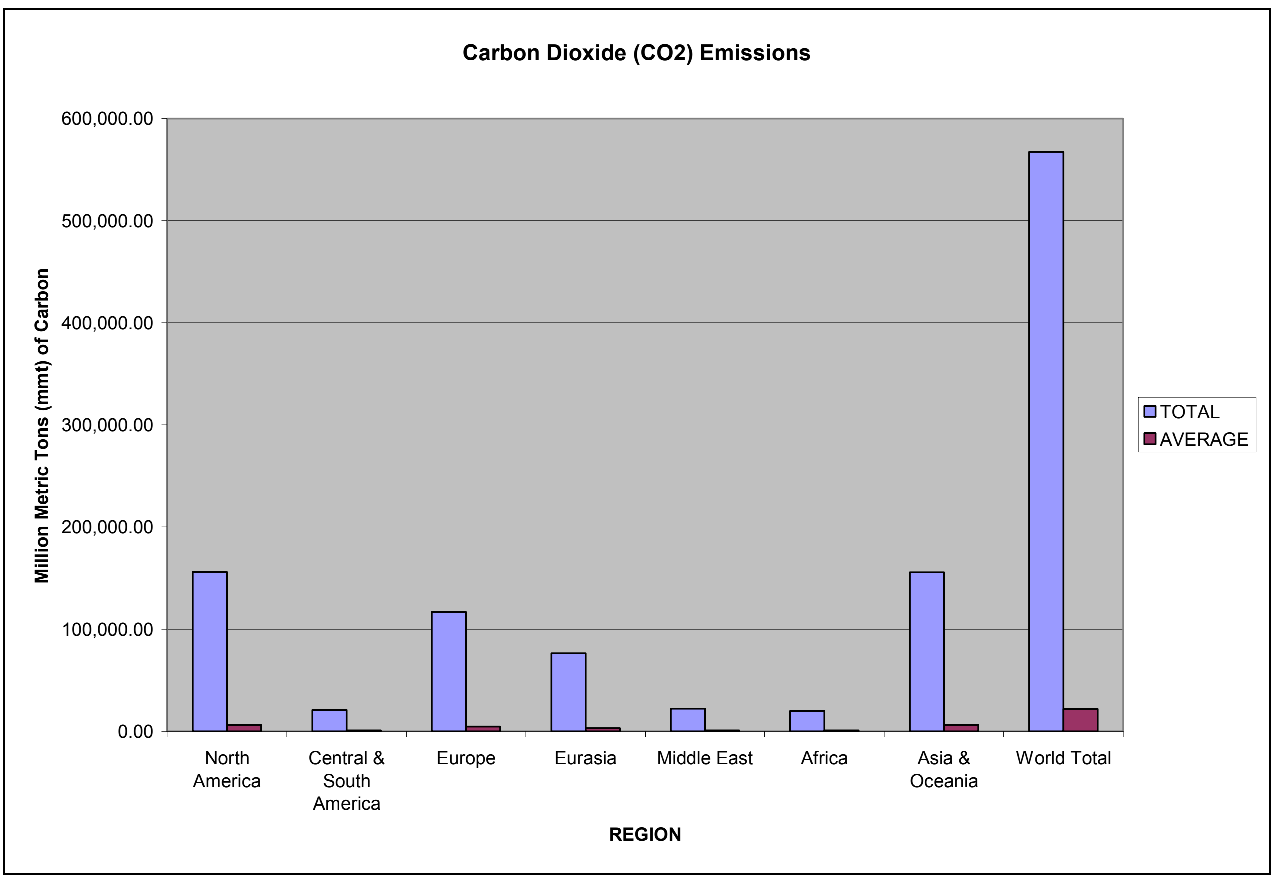
The levels of CO_2 emissions in Figure 17 for Asia and Oceania also follows a linear pattern. The CO_2 emission levels increased from 1980 to 1997. The only period when levels decreased was from 1197 to 1998, when the levels went from 7,068.18 mmt to 6,909.76 mmt, a decrease of 158.42 mmt. The greatest level of emission occurred in 2005, with an amount of 10,362.49 mmt. The level of CO_2 emissions are increasing at a rapid rate. The total level of CO_2 emissions in the Asia and Oceania region from 1980 to 2005 was 155,639.73 mmt while the average level of CO_2 emissions for the same period was 5,986.14 mmt. The Asia and Oceania region has the second highest levels of CO_2 emissions among all the regions. From the graph, it is expected that the level of CO_2 emissions will continue to increase at a steady rate.

According to Figure 18, the levels of CO_2 emissions for the entire World follows a linear pattern. The CO_2 emission levels increased yearly except for the 1981 to 1982 period as well as the 1991 to 1992 period. The greatest level of emission occurred in 2005, with an amount of 28,192.74 mmt. The level of CO_2 emissions are increasing at a rapid rate. The total level of CO_2 emissions for the world from 1980 to 2005 was 567,479.62 mmt while the average level of CO_2 emissions for the same period was 21,826.14 mmt. From the graph, it is expected that the level of CO_2 emissions will continue to increase at a steady rate.

Below Figure 19 illustrates the total and mean emissions for all regions as well as the world total and mean level of emissions. As can be identified from the graph, North America has the highest levels of carbon dioxide emissions with Asia and Oceania following close behind. The lowest areas with CO_2 emissions are Africa, Central & South America and the Middle East respectively.

From the individual graphs above for each region as well as the total and average chart above, the assumption can be made that the levels of carbon dioxide (CO_2) emissions will continue to increase at a steady rate. As to how these high levels of CO_2 emissions will affect the atmosphere and the climate, is still not known.

Figure 19– CO_2 Total and Mean Emissions for Regions and World



Conclusion

Given the dynamic and complex nature of climate change an ideal tool for scientists to use to detect patterns would be a multidimensional type, capable of aggregating multiple factors at once and displaying them over the same geographic display [4]. The current project was limited to viewing two of the most salient factors in climate change in two different displays. For scientists to truly be able to detect patterns future versions of this tool should incorporate both of these factors together as well as other raw data that may influence the more salient factors such as the number of new drivers' licenses issued, the number of cars manufactured/imported, and the increase of population. Examining data related to Eurasia and Europe's fluctuating CO_2 levels such as population changes, car manufacturing changes, or legal/regulations changes could be particularly helpful for scientists to try to pinpoint possible solutions to the drastic increase of CO_2 levels in other parts of the world.

If time and technological limitations were not an issue several improvements to these visualizations could be made. Being display the change in arctic ice patterns overtime and at specific moments of time in Google Earth would be helpful in analyzing patterns. This project has developed a way to visualize the raw data, which could be useful to researchers not limited to using Google Earth. Another improvement that could be made is in displaying CO_2 levels. As it stands now one must click on a marker icon to pull up a graph of emissions overtime. This makes a visual inspection more difficult. Ideally through some automated process the colors of the markers could change in relation to the amount of emissions at a point in time and the shape of the marker could change in relation to the rate of emissions at a current point in time. Thus a simple visual inspection of the markers would allow researchers to see how different regions related to each other in terms of emission amount and rate emitted.

Future students could help develop this tool by adding more salient factors to the visualization. Other promising factors for visualization not covered by this project are regional temperatures, annual precipitation levels, ocean currents, and volcanic activity. Precipitation levels and regional temperatures would be particularly useful in examining what changes are currently underway in order to make predictions about climate change that allow for reasonable adaptation.

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