Trace Gases and Their Impact on Global Warming

An Interactive Qualifying Project Report

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Abstract

This report examines the impact of trace gases, such as carbon dioxide, on a global scale. To establish quantitative results, a seven-reservoir model was implemented to test proposed policies to reduce the emission rate of anthropogenic carbon. Research was conducted, examining various methods of carbon mitigation, sequestration, and reduction. A 450-ppm concentration of atmospheric carbon, likely to be reached by 2050, is seen as a significant value in terms of lasting negative environmental effects on a global scale.

Executive Summary

Atmospheric carbon dioxide levels have increased dramatically since the start of industrialization. At the start of the industrial revolution, the atmosphere's carbon level was approximately 280 parts per million (ppm). The atmospheric concentration of carbon dioxide is currently at 385 ppm, an increase of over 100 ppm. The increase of atmospheric carbon dioxide has been tied to a number of negative environmental, economical, and meteorological effects.

The buildup of Greenhouse gases, such as carbon dioxide, has been proposed as one of the underlying causes of global warming. The greenhouse effect involves the ability of certain atmospheric gases to absorb and reflect solar radiation from the sun back to earth. In terms of gases from anthropogenic sources, the most abundant greenhouse gas is carbon dioxide. Deforestation also plays a role in terms of reducing land biota, a major land sink for carbon. Lack of albedo from deforestation has also been proposed as a cause for increased global warming, but the conversion of forestland to cropland cancels out most of the albedo reduction due to deforestation. Lack of albedo has been seen as a major factor in icecap melting in regions such as Greenland.

Climate change in a number of forms has also been linked to global warming. Changes in regional temperature have been noted, as well as intensified weather patterns, increased flooding and drought, and rises in sea level. These climate anomalies effect human and animal migration, and in most cases have major economical effects.

A number of technologies and policies may be put into effect to reduce the atmospheric carbon concentration or the rate of global carbon emissions. Alternative energy options involving renewable sources is an area of interest that hold some promise. Emerging technologies involving the creation of artificial sinks to absorb atmospheric carbon have also been proposed recently. From a political standpoint, the cap-and-trade method has been a popular form of industrial emissions control.

The use of a seven-reservoir model was implemented, and used to test different policies and technologies effects on total carbon concentrations. Using bulk emissions and rate of emissions data from various sources, changes in rate were calculated and placed into the model code. The main parameter changed was the rate value found in the CO2_rate code page. This value represented the change in the rate of emissions annually. By changing the rate value for each scenario, the model was able to output a graph that showed the estimated increase in carbon concentration in ppm up to 2050 for that scenario. The results of the model can be used to roughly gauge the effectiveness of a particular policy and could aid in policy modification and implementation for mitigating and reducing atmospheric CO_2 levels.

Introduction

In recent decades, the apparent causes and possible effects of global warming have been a topic of much discussion and debate. The buildup of greenhouse gas is viewed as the most likely cause of global warming, through the greenhouse effect linked to increased emissions since the industrial era began. Recent observation and analysis has linked global warming to weather anomalies, such as intense weather conditions, flooding, drought, sea level rise, and most obviously a rise in global mean temperatures. The results of these anomalies are a loss of habitat, livelihood, and life for a large number of the human population.

Throughout this study, research was conducted on general knowledge pertaining to the underlying causes of global warming such as the greenhouse effect, as well as the severity of the various global effects the process has on the environment, specifically when humans are involved. Various methods for mitigation and prevention of both the causes and the effects of global warming were also researched.

The use of a seven reservoir model was implemented to test various methods for the reduction of atmospheric CO_2 release. Three major areas were studied, the reduction of overall emissions through all of industry, a conversion of the generation of energy to a renewable source that does not increase the level of atmospheric carbon, and finally an increase in the production of a researched artificial carbon sink system on a larger scale. Through the use of the model, a rough estimate of policy effectiveness could be obtained. These estimates are important as they allow for a clearer view of certain policies feasibility and will aide in the development process so that policy may be put into effect as soon as possible.

Background Research

Causes of Global Warming

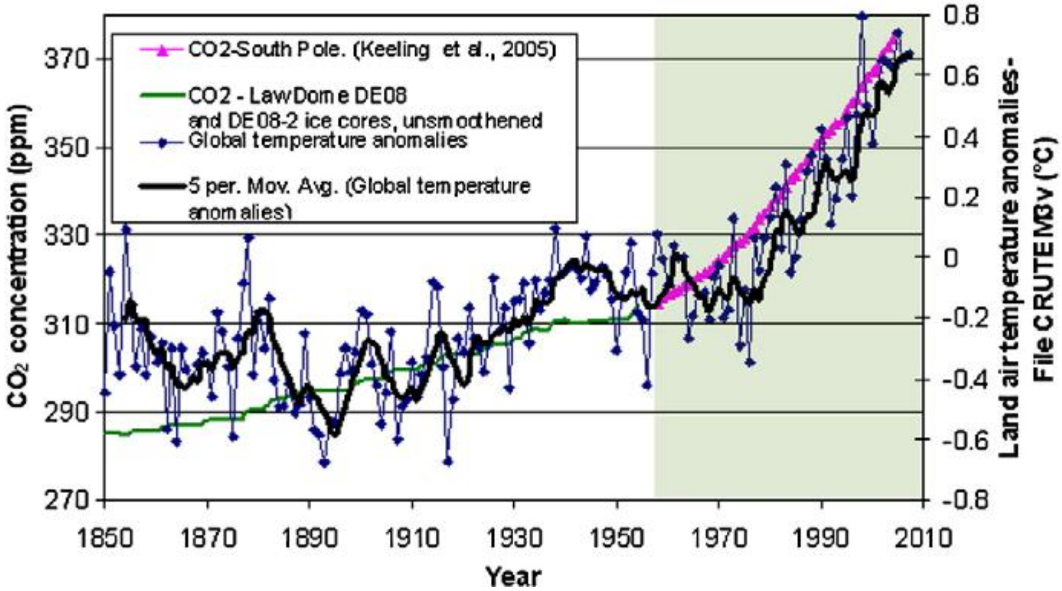
Effects of Gases

Carbon dioxide has been widely considered the main anthropogenic driving force of global climate change through the greenhouse effect. The greenhouse effect involves the ability of certain atmospheric gases to absorb and reflect solar radiation from the sun back to earth. In terms of gases from anthropogenic sources, the most abundant greenhouse gas is carbon dioxide. Overall, water vapor contributes a larger portion of the atmosphere; however, with water vapor, less than 1% of the atmospheric total originates from anthropogenic sources. Human sources have resulted mostly in an increase of carbon dioxide; this occurred simultaneously with increases in the mean global temperature due to the greenhouse effect.

Many studies have attempted to prove or disprove the correlation between human emission of carbon dioxide and the increase in global mean temperature in the past decades. They intend to derive whether greenhouse gases raise the global mean temperature through the greenhouse effect, or if the increasing temperatures result in the release of greenhouse gases from natural deposits. The process perpetuates its own growth due to the releasing of more greenhouse gases. This imbalance may prove to be an issue within the next century as temperature levels increase to thresholds that cause irreversible effects on the earth's climate, environment, and eventually all life.

Historical data reveals that carbon dioxide has increased dramatically since the start of industrialization. At the start of the industrial revolution, the atmosphere's carbon level peaked at 280 parts per million (ppm). This value is currently at approximately 385 ppm, an increase of over 100 ppm (1). Two major sources provide data used in the calculation of trends in the composition of carbon dioxide in the atmosphere: direct atmospheric measurement records for relatively recent data, and ice core measurements for older data. The result of this increase seems for the most part canceled out by the increase in carbon sink activity, such as biota and the oceans. A key threshold for the ocean sink seems to be at 450 ppm; at this point, the absorption of carbon by the ocean sinks will cause acidification of the ocean to intolerable levels for plankton species, severely affecting the oceanic ecosystem because plankton constitutes the most basic food source in the oceanic food chain.

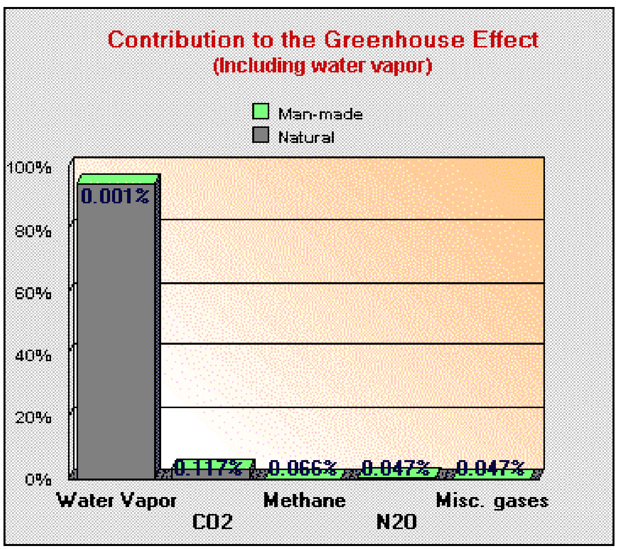
Figure 1 ***(1)***



Though there is debate on the actual effects, if any, of increased atmospheric carbon, the increase in carbon levels seems to correlate with a number of negative temperature and climate conditions, and may prove to have additional devastating effects that are still unknown. Even if the effects appear insignificant at the current time, they compound over time as the affect adds up. Plans should consider the affect of the atmospheric gases on the climate in order to minimize possible unforeseen imbalances that could cause serious damage to the planet in the future.

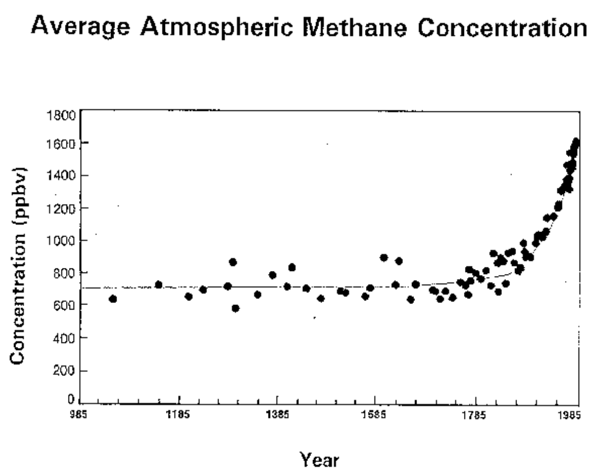
The greenhouse gas that increased the most from industrialization is carbon dioxide. Of the anthropogenic greenhouse gases, carbon dioxide has the greatest concentration and the most noticeable effect on the environment; however, water vapor, a naturally occurring gas, has a greater effect than carbon dioxide (2). Water vapor is 99.999% from natural sources and is the greenhouse gas that is in the greatest concentration in the atmosphere (2). Because water vapor is almost entirely natural, the biggest amplifier of global warming is independent of human input. Water contributes the greatest influence on global warming because it amplifies the effects of other gases (3). "Scientists calculated that 70 percent of the recent increase in temperatures in central Europe is due to water vapor, and 30 percent is due to other greenhouse gases" (4). Water vapor comes mainly from the evaporation of the ocean's surface. More water vapor releases into the atmosphere from the melting of the ice caps as well. As the surface of the ocean is heated, more water releases into the atmosphere; however, as seen in Figure 2, only 0.001% of water vapor in the atmosphere exists because of human production (2). Although water vapor amplifies global warming more than any other greenhouse gas, it is the one least affected by man. It amplifies the effects of other gases and makes them more noticeable.

Figure 2 (2)



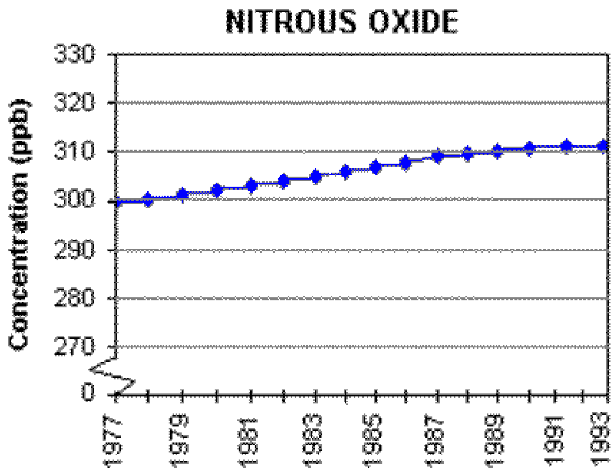
Though carbon dioxide and water vapor are the two most abundant greenhouse gases, other greenhouse gases play a role in global climate change. Some of the more notable gases are methane and nitrous oxide. From 1750 to 1994, carbon dioxide has increased from 280 ppm to 360 ppm, roughly a 29% increase (5). Over this same amount of time, nitrous oxide has risen from 280 ppb to 330 ppb, an increase of approximately 11%, and methane has risen from 0.7 ppm to 1.7 ppm, an increase of 143% (5). Although these other gases exist in lesser concentrations than carbon dioxide, their individual particles have a greater effect than that of carbon dioxide. One methane molecule is worth 25 carbon dioxide molecules in terms of its affect on global warming (5). This is due to the larger physical size of the methane molecule in comparison to a carbon dioxide molecule (6). Methane contributes to 19% of the greenhouse effect as shown in spite of its smaller atmospheric concentration, as seen in Figure 3. Methane is mostly a result of the burning of biomass, enteric fermentation, rice paddies, and bovine flatulence (6). These sources have seen an increase attributable to human influences such as domestification and planting large crops. Natural additions to this increase include oceanic methane, methane stored in wetlands, and methane produced by termites (6). The release of methane from natural deposits contributes to an increase in global temperature; such deposits remain currently trapped in stagnant bodies of water, frozen in oceanic deposits, and stored in permafrost (7). An increase in methane concentration causes further atmospheric warming, thus propagating the process. Natural sinks for this increase of methane include reactions with hydroxide and microorganisms absorbing it in the soil (6). Direct effects of methane include

Figure 3 (6)



absorption of infrared radiation, tropospheric ozone and hydroxide compositions, stratospheric ozone and water compositions, and carbon dioxide production (6). At its current rate of increase

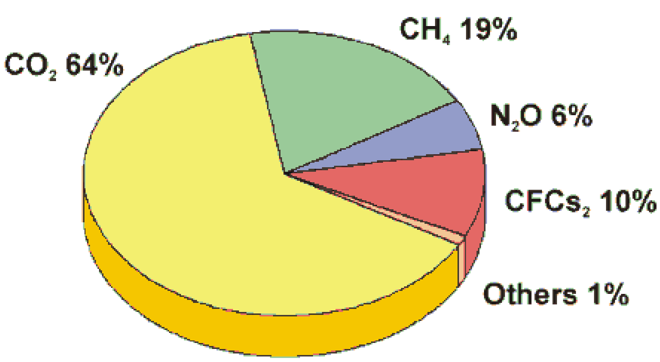
Figure 5 ***(5)***



of 10 ppb per year, methane will eventually become the dominant greenhouse gas in the atmosphere (5).

Nitrous oxide originates from multiple sources including the burning of biomass, the burning of fossil fuel, and the use of fertilizers (6). Natural sinks of nitrous oxide are stratospheric photolysis, reaction with ozone, and absorption into soil (6). Nitrous oxide absorbs infrared radiation, and it affects stratospheric ozone levels (6). The rate of increase of nitrous oxide has leveled off in recent years due to stricter pollution regulations on vehicles, as seen in Figure 5. This allows greater amounts solar radiation to enter the earth's atmosphere, heightening the affects of global warming. Nitrous oxide contributes about 6% of total infrared radiation absorption; see Figure 4. Although this specific greenhouse gas is leveling off, many others continue to increase at a constant rate.

Figure 4 ***(6)***



Vehicle emissions play a large role in the human input of carbon dioxide and trace gases; exhaust contains primarily carbon and nitrogen based compounds. Figure 6 shows the chemical composition of some of the trace gases found in petrol and diesel vapor emissions (8). Carbon based emissions are a primary contributor to global warming effect, and make up a large part of emissions. By comparing petrol to diesel vapor emissions, it becomes evident that petrol emissions contain, on average, ten times more carbon based molecules than in the emissions from diesel.

Figure 6 ***(8)***

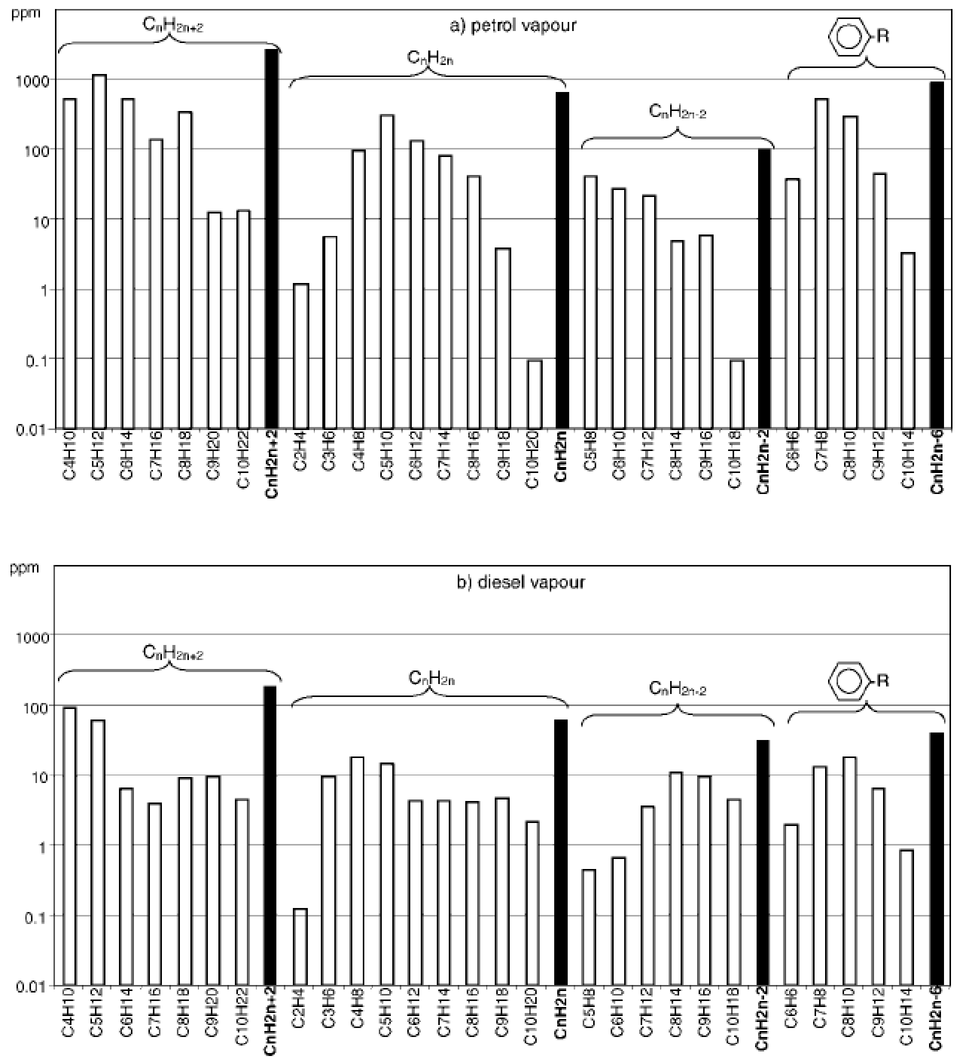


Figure 8 (8)

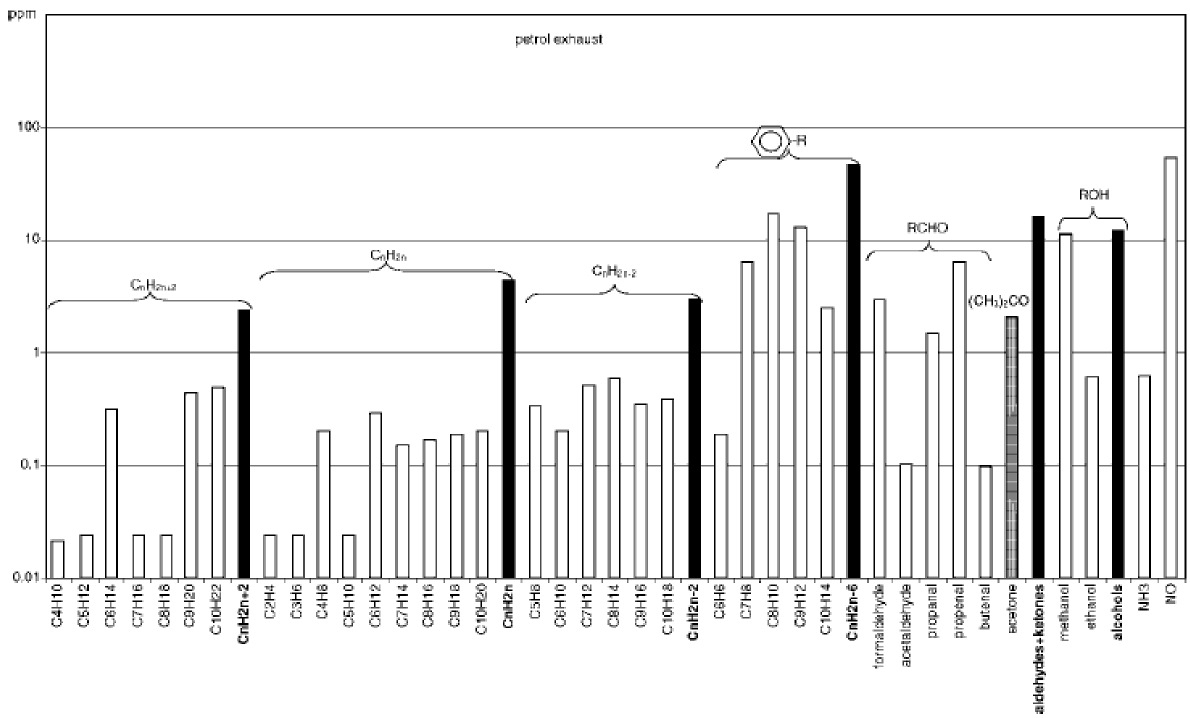
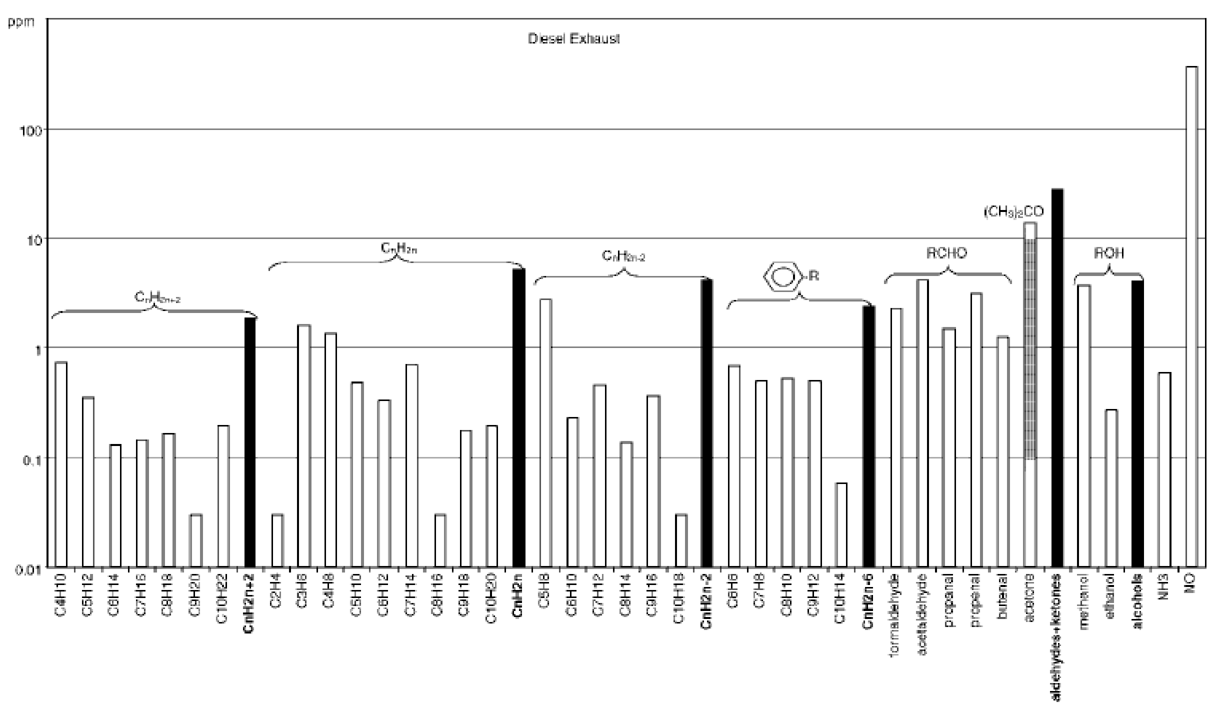


Figure 7 (8)



While diesel fuels release less carbon based molecules than petrol, they still release a

Figure 9 *(8)*

Vehicle/Control Technology	CO_2 (g/mi)
Gasoline Passenger Cars	
Low Emission Vehicles	451
Tier 1	459
Tier 0	480
Oxidation Catalyst	616
Non-Catalyst	855
Uncontrolled	814
Gasoline Light-Duty Trucks	
Low Emission Vehicles	637
Tier 1	637
Tier 0	801
Oxidation Catalyst	801
Non-Catalyst	967
Uncontrolled	932
Gasoline Heavy-Duty Vehicles	
Low Emission Vehicles	1,301
Tier 1	1,301
Tier 0	1,637
Oxidation Catalyst	1,667
Non-Catalyst Control	2,124
Uncontrolled	2,124
Diesel Passenger Cars	
Advanced	381
Moderate	399
Uncontrolled	513
Diesel Light Trucks	
Advanced	531
Moderate	533
Uncontrolled	668
Diesel Heavy-Duty Vehicles	
Advanced	1,588
Moderate	1,627
Uncontrolled	1,765
Motorcycles	
Non-Catalyst Control	352
Uncontrolled	428

substantial amount of carbon-based emissions into the atmosphere. The data from Figure 6 reveals the ppm of many of the carbon-based particles in both diesel and petrol fuels, while the data from Figure 8 and Figure 7 reveals even more about the chemical makeup of these two fuels (8). This second set of figures shows the composition of the exhaust of petrol and the exhaust of diesel fuel. Both sets of data have similar ppm values for many of the molecules, however, most notable are the two primary differences: petrol exhaust contains a higher concentration of alcohols and the most complex types of hydrocarbons whereas diesel fuel contains a higher concentration of acetone and nitrous oxide.

While trace gases found in specific fuel vapors and emissions are important, they only account for a small portion of the overall emissions of vehicles. Perhaps the most important emissions to look at are carbon dioxide, methane, and nitrous oxide. Figure 9 shows the carbon dioxide released by specific vehicle types in grams per mile (9). Considering that the carbon dioxide released into the atmosphere is as large as it is, ranging from roughly 500 to 2000 grams

Figure 10 (8)

Vehicle Type Control Technology	Nitrous Oxide				Methane			
	IPCC g/mi	FTP g/mi	Run g/mi	Start g/start	IPCC g/mi	FTP g/mi	Run g/mi	Start g/start
Gasoline Passenger Cars								
Low Emission Vehicles	0.028	**0.012**	**0.000**	**0.090**	0.040	**0.013**	**0.009**	**0.032**
Tier 1	0.046	**0.030**	**0.015**	**0.113**	0.048	**0.020**	**0.012**	**0.055**
Tier 0	0.082	**0.054**	**0.042**	**0.092**	0.064	**0.066**	**0.062**	**0.034**
Oxidation Catalyst	0.052	0.042	0.032	0.072	0.113	**0.133**	**0.132**	**0.009**
Non-Catalyst	0.017	0.017	0.013	0.028	0.193	**0.162**	**0.155**	**0.059**
Uncontrolled	0.017	0.017	0.013	0.028	0.217	0.171	0.162	0.062
Gasoline Light-Duty Trucks								
Low Emission Vehicles	0.035	**0.009**	**0.001**	**0.059**	0.048	**0.017**	**0.011**	**0.046**
Tier 1	0.058	**0.067**	**0.041**	**0.200**	0.056	**0.034**	**0.023**	**0.082**
Tier 0	0.102	0.090	0.069	0.153	0.113	**0.071**	**0.062**	**0.072**
Oxidation Catalyst	0.065	0.054	0.042	0.093	0.145	**0.143**	**0.130**	**0.099**
Non-Catalyst	0.021	0.019	0.015	0.032	0.225	0.184	0.175	0.067
Uncontrolled	0.021	0.019	0.015	0.032	0.217	0.195	0.186	0.071
Gasoline Heavy-Duty Vehicles								
Low Emission Vehicles	0.113	0.019	0.002	0.120	0.071	0.034	0.022	0.094
Tier 1	0.139	0.138	0.083	0.409	0.097	**0.047**	**0.024**	**0.163**
Tier 0	0.175	0.183	0.142	0.313	0.121	**0.218**	**0.194**	**0.183**
Oxidation Catalyst	0.111	0.113	0.088	0.194	0.145	**0.208**	**0.179**	**0.215**
Non-Catalyst Control	0.035	0.041	0.032	0.070	0.201	0.403	0.384	0.147
Uncontrolled	0.035	0.043	0.033	0.074	0.435	0.445	0.423	0.162
Diesel Passenger Cars								
Advanced	0.016	0.001	0.001	0.000	0.016	0.001	0.001	-0.003
Moderate	0.016	0.001	0.001	0.000	0.016	0.001	0.001	-0.003
Uncontrolled	0.016	0.001	0.002	-0.001	0.016	0.001	0.002	-0.003
Diesel Light Trucks								
Advanced	0.032	0.002	0.002	-0.001	0.016	0.001	0.002	-0.004
Moderate	0.032	0.002	0.002	-0.001	0.016	0.001	0.002	-0.004
Uncontrolled	0.032	0.002	0.002	-0.001	0.016	0.002	0.002	-0.004
Diesel Heavy-Duty Vehicles								
Advanced	0.048	**0.005**	**0.005**	**-0.002**	0.064	**0.004**	**0.006**	**-0.011**
Moderate	0.048	0.005	0.005	-0.002	0.081	0.004	0.006	-0.011
Uncontrolled	0.048	0.005	0.005	-0.002	0.097	0.004	0.006	-0.011
Motorcycles								
Non-Catalyst Control	0.007	0.007	0.005	0.012	0.209	0.067	0.064	0.024
Uncontrolled	0.007	0.009	0.007	0.015	0.418	0.090	0.085	0.033

per mile for the different vehicles listed, it is clear that carbon dioxide emissions from vehicles contribute largely to global warming. The public reliance on passenger vehicles, as well as transportation of goods, makes the amount of carbon dioxide released by these a major factor in global warming. Figure 10 displays the total miles traveled by residential vehicles in the United States in three separate years: 1988, 1991, and 1994 (10). The value for 1994 was almost 1800 miles traveled; even when using an ideal scenario of all of those miles being traveled using an advanced diesel passenger car, the amount of carbon dioxide released by residential vehicles alone would be nearly 700 kg. While this may not seem an extreme number, this is using the lowest carbon dioxide emitting passenger vehicle for only residential traffic in one country.

Figure 11 (9)

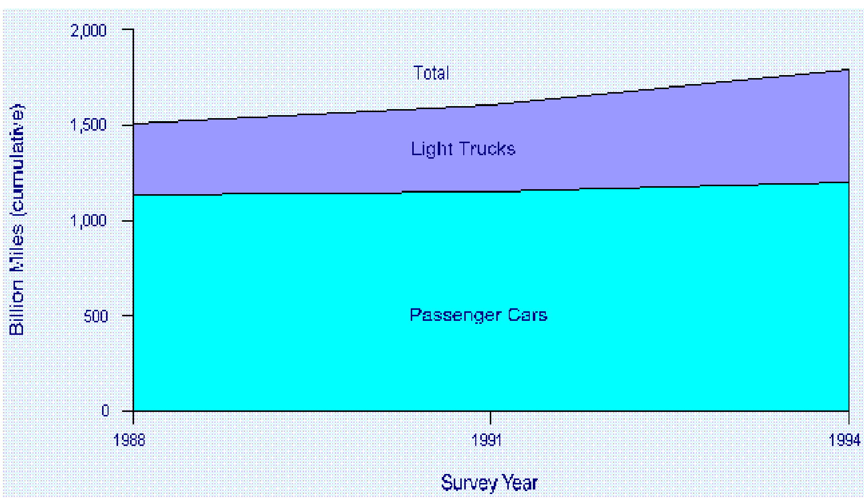


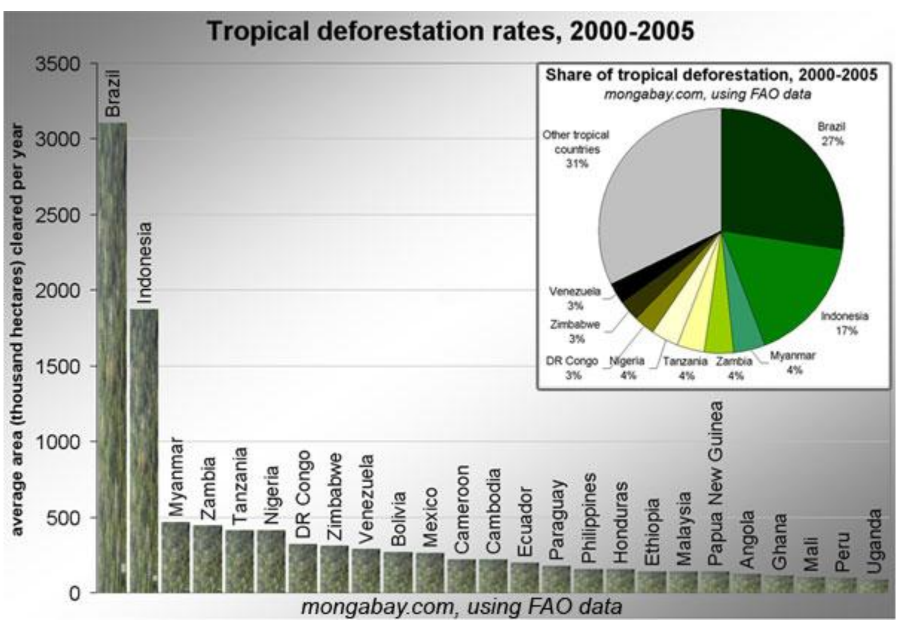
Figure 11 shows the methane and nitrous oxide emissions in grams per mile for varying vehicles and conditions (9). This chart shows the 1997 IPCC values, as well as a Federal Test Protocol performed in 2004, with calculations performed to determine emissions during the running of a car, and the starting of a car. While heavy-duty vehicles had massive carbon dioxide output, when it comes to nitrous oxide and methane output, gasoline passenger cars have significantly higher g/mi values in almost all scenarios (9). Given the significance of methane as a factor in global warming, this study suggests that light-duty passenger vehicles have a larger effect on global warming than their carbon dioxide emissions would suggest.

Deforestation

Significant human alteration of natural landscape has been occurring for hundreds of years. Changes in landscape by humans ease the procurement of resources and fuel, and allow other uses for the land. The ever-growing human population, along with the development of new technologies, increases demand for resources and space to expand. One of the most dramatic means of altering landscape has always been deforestation. Conducted studies thoroughly test its environmental implications, including climate change.

Deforestation involves removing forested areas for use as building material or fuel, to make room for croplands, structures, or for other land requirements. There are two major studied impacts of landscape alteration in terms of radiative interactions; the first of which is dry land cultivation that decreases albedo, a measure of reflectivity ranging from 0 to 1, resulting in the covering of more land with light-absorbing vegetation. The loss of albedo due to a higher land cover of crops mostly cancels the increase in albedo due to the removal of the absorbent forest canopies. The result is a balancing effect where light absorbent tree canopies are replaced with light absorbent crops, resulting in a minor change in

Figure 12 (48)



albedo and a minor change in terms of an increase in global mean temperature; especially if taken into account the lower percentage of land area to that of oceans.

Deforestation also reduces a major land carbon sink, plants. Plants absorb atmospheric carbon dioxide and convert it into oxygen, and act as a major natural sink for atmospheric carbon removal. Before agricultural times the land covered by forests has been estimated to have been 57 million km^2 and contained approximately 500 PgC of carbon. By 1990, an estimated 20-30% of original forest had been lost contributing to 45% of the atmospheric carbon gain since 1850. Carbon emissions from fossil fuel consumption surpassed deforestation in recent decades, however deforestation still accounts for approximately 25% of anthropogenic carbon. Deforestation most definitely has an impact on atmospheric carbon increases. It was reported that in 2002 tropical deforestation results in a release of 1.7 PgC per year into the atmosphere (11).

The accuracy of total carbon release reports due to deforestation is a subject of debate. A group of scientists challenged a report by Achard, assessed deforestation of humid tropical forests worldwide during 1990-1997, by stating that the analysis underestimated the true value due to the overlooking of key components that would contribute to net carbon release. The authors of the original study defended their findings, claiming their methods were sound and accurate. The group that challenged the original findings then released a study, to show evidence for their argument (12).

Fearnside assessed the issues presented by Achard when he released a report detailing specific problems with the accuracy of the original study. The study estimated that a 0.96 Gt release for all tropical forests, which was substantially lower than the 1.6 Gt estimation by the

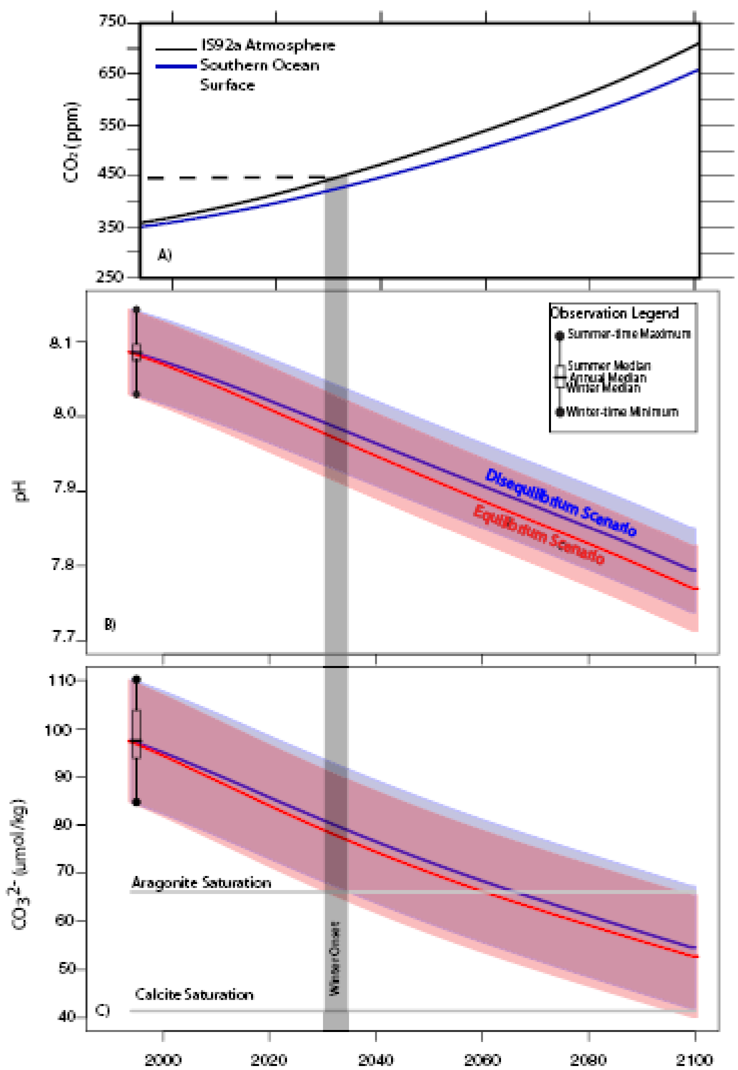
Intergovernmental Panel on Climate Change (IPCC) (12). The major issue the group found with Achard was the omission of key components in the total carbon release calculation such as, selective logging, surface fires, habitat fragmentation, edge effects, and other anthropogenic impacts (12). Their ignoring of forest degradation concerned the team, since the original study made comparisons to the IPCC estimate, which included all forms of land changes, like forest degradation. In total the group determined through their modification of the original calculations that the original study underestimated the actual impact by a factor of two (12). The inconsistency between these researches is just one example of the debate among researchers on the significance of an impact a particular cause of global warming has. This causes difficulty in deciding which cause to focus on, or which to implement first, causing the delays in the prevention of further global temperature increase.

Climate Change

Oceanic Acidification

There exists a need to establish a limit to the concentration of atmospheric CO2 levels in order to prevent major ecological destruction. The study of the oceans acidity is an area of interest, since an increase in ocean acidity is usually the result of increased carbon dioxide absorption. The ocean, more specifically the upper ocean, being one of the largest natural sinks is a major component in keeping the atmosphere equilibrated. Recently, it was observed and postulated, that an increase in the upper oceans acidity can cause damage to certain organisms, such as *Limacina helicina*, during their larval stages when they are most sensitive to increased acidity (13). The level of atmospheric CO2 concentration where acidity would cause major damage to the *Limacina helicina*, and in turn the ecosystem, has been estimated to be 450ppm (13). Devastating losses to an organism will in turn cause losses to other organisms that depend on the species as a food source, which could lead to disruption of an entire food chain.

Figure 13 (13)



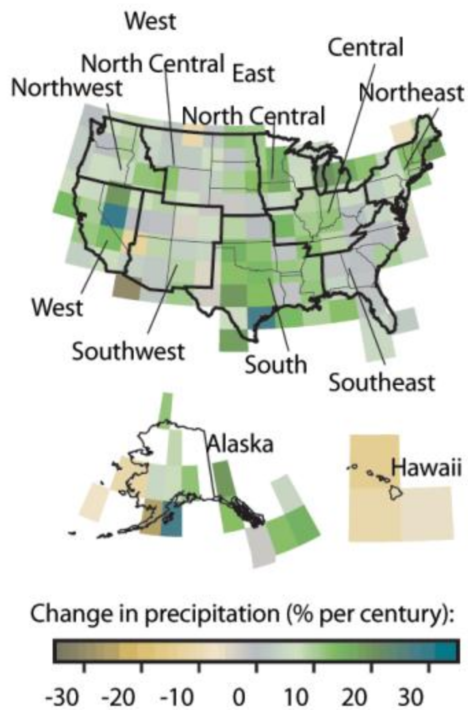
A study involving seasonal pH changes in southern oceans gave the estimate of 450ppm as the critical point for the reduction of *Limacina helicina* levels. The study, conducted by Ben I. McNeil and Richard J. Matear, uses empirical data up to the year 2000 normalized to account for interannual CO2 uptake to the common year of 1995. A multiple linear least-squares regression was performed on the data. This data was subject to error analysis and the results showed a pH uncertainty of ± 0.02. The study used independent carbon measurements obtained during winter months to verify the applicability of the empirical predictions.

CO2 disequilibrium exists because the upper ocean lags the increase in atmospheric CO2 (13). The delay in absorption occurs because of the limitations between air-water interaction and the slow interaction rate between upper and lower ocean. Disequilibrium levels and pH changes were determined from 1995 to the year 2100 Figure 13. A known was used scenario to estimate future reductions in *Limacina helicina* populations. The studies estimation points to substantial reductions likely to begin once atmospheric CO2 reaches 450 ppm, though this is dependent on future policy regarding emissions.

Precipitation

Global warming affects the climate of earth in ways that vary in different locations around the world. Global warming has altered precipitation in certain regions, and increased global mean temperatures. Although the average precipitation has changed in many different areas, no drastic changes have occurred in the global mean precipitation. Precipitation increases in some regions while it decreases in others, as a result, the average precipitation worldwide remains the same. There has been an increase in flooding since the 1900s and an increase in droughts in recent decades. The EPA states that "In the Northern Hemisphere's mid- and high latitudes, the precipitation trends are consistent with climate model simulations that predict an increase in precipitation due to human-induced warming" (14). Figure 14, found on the EPA website, provides a visual representation of the change in precipitation patterns in the United States. According to Figure 14, and the statement by the EPA, there has been an observed increase in precipitation in the northern hemisphere that directly relates to global warming. These increases vary from roughly 10-20% in most areas, but they may reach as much as 30% few (14).

Figure 14 (14)

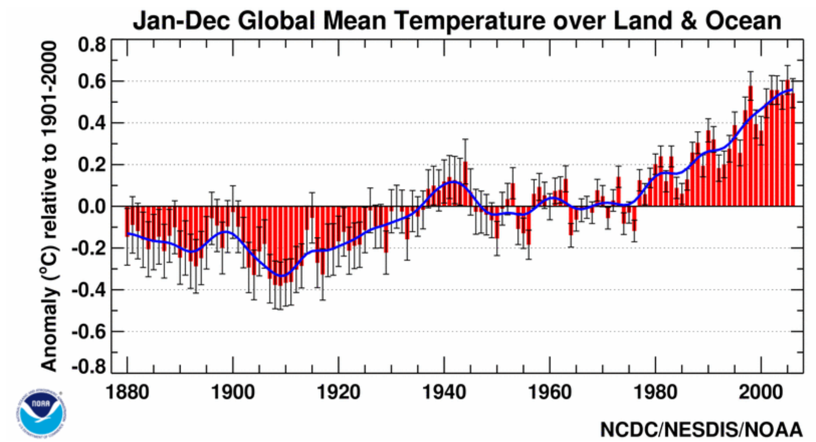


Another observed effect of global warming is an increase in global mean temperature in the past century, particularly drastic in the past few decades. Figure 15 from NOAA shows the more drastic increase in temperature over the past century. It is also clearly visible from Figure

15 that over the past few decades, primarily 1970 on, there has been an even greater increase than over the entire century.

The EPA states that, "The Earth's surface is currently warming at a rate of about 0.32ºF/decade or 3.2°F/century" and "Since the mid 1970s, the average surface temperature has warmed about 1°F" (14). This correlates with the general warming over the past century, and an increased effect since the 1970s.

Figure 15 ***(14)***



These two examples of recent climate change show the effects of global warming in the past century or so, however, when looking further into the past, a new perspective on the global climate change becomes noticeable. A global mean temperature increase of 1°F over a couple decades may not seem large increase; even when paired with data over the course of a century, the increase may still seem insignificant. If looking at a much larger scale, and a general trend that the temperature and climate are progressing toward, however, we can clearly see that this increase is much more significant that 1°F may initially seem. When looking at

Figure 16 ***(14)***

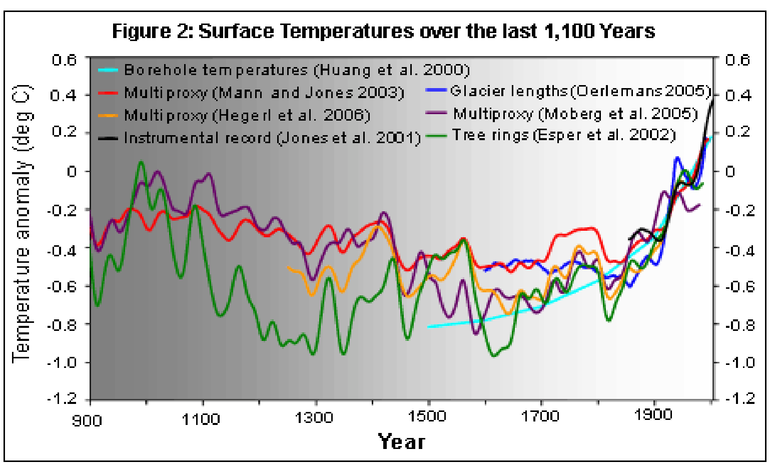
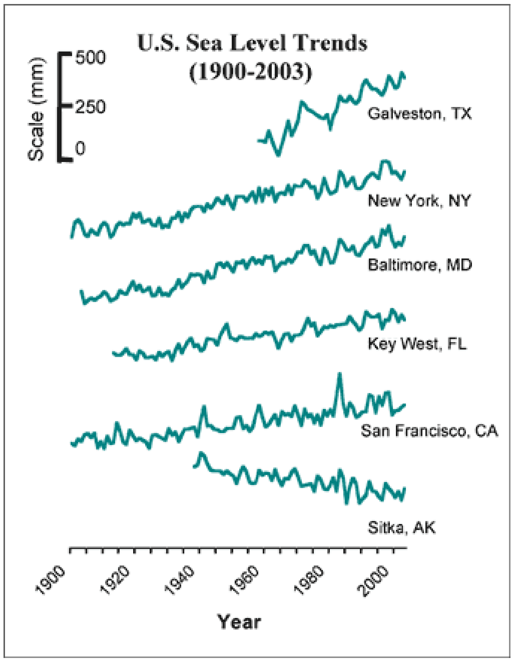


Figure 16 found in a report on the EPA website, one can see that since 1900, there has been roughly a 0.6-0.8°C increase in temperature (14). When looking as far back as 1000 AD, however, we can see that the last high peak in temperature was 0.2-0.4°C cooler than the current peak in temperature, which shows no signs of cooling.

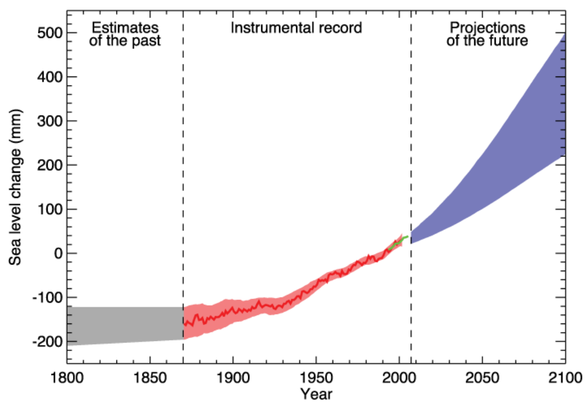
Figure 17 *(14)*



Another effect of global warming with respect to climate change is the recent change in sea levels. When looking specifically at the United States, as shown in Figure 17, we can see that the sea level is increasing in some areas, but decreasing in others. In Texas, for example, the sea level has risen roughly 500mm since the 1960s. New York, Maryland, Florida, and California all seem to show parallel trends of an increase in approximately 500mm since 1900. Alaska, however, has shown a decrease of 250mm since 1940 (14). The EPA attributes these values to the land sinking in the gulf and Atlantic coastlines, and land rising on the Alaskan coast. This specific look at sea levels shows that while most areas are experiencing a rise in sea level, some may be experiencing a fall in sea level (14). When looking at the global scale, however, it is clear that there is a general increase in sea levels, which has accelerated midway through the 1900s. According to this chart from the EPA, prior to 1900 there had been a slow increase, possible even no increase, in global sea levels. Since 1900, there has been a clear observed increase in sea level of about 200mm up until the present time. Projections of sea levels in the next century show an additional increase of anywhere from 200mm to 400m.

These changes in climate patterns have direct consequences on human society and economy. An increase in flooding and droughts can cause more frequent food shortages, particularly in tropical areas where crops grown near their maximum tolerable temperature. Decreased crop yields will result in malnutrition and starvation in areas that rely on subsistence farming. The increase of intensity and frequency of extreme weather, such as hurricanes, monsoons, floods, etc. creates substantially more property damage to human society. The insurance industry in the 1990s paid out roughly $100 billion for losses from weather related disasters. This was an increase of about four to five times over the amount paid out in the 1980s. Heat waves are a direct consequence of global warming; in France in 2003, a heat wave caused around 30,000 deaths. Although heat waves have occurred before, global warming has caused prolonged and more frequent heat waves. Additionally, as global temperature increases, diseases such as malaria and West Nile virus become more prevalent in areas where they had not previously been a threat. These diseases, combined with heat waves and drought, are some of the most devastating effects of global warming.

Figure 18 (14)



Drought

Average global temperature increase predicts droughts to be more widespread, persistent, and severe. Increased temperatures affect hydrologic processes (15). When the temperature increases, the vapor pressure of water is increased. When this happens, moisture evaporates out at a higher pace. This leads to drier ground and less moisture available for plant growth. Although drought-like conditions have expanded to larger areas, the moisture content of the air has increased (16). Because of this, the average global precipitation has increased as well. Certain areas are becoming drier while others are becoming wetter. The regions that are becoming wetter are most commonly mountainous regions. This gradual increase of global temperature, global warming, affects natural weather patterns.

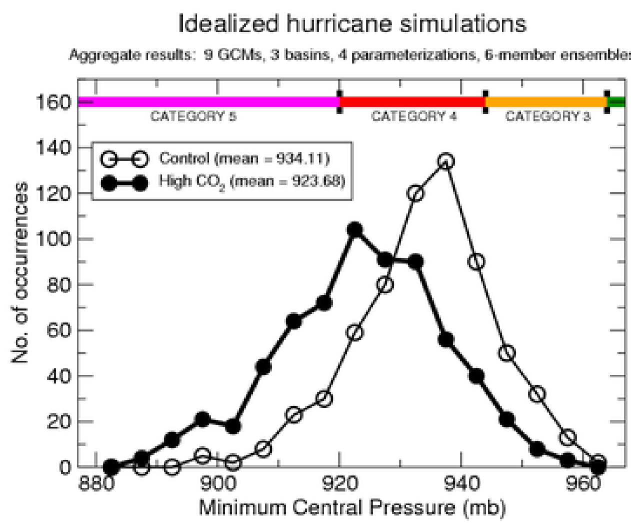
The Palmer Drought Sensitivity Index measures the dryness of the ground. In recent years, the fraction of land worldwide experiencing drought-like conditions, a Palmer Index of three, has increased greatly. In 1970, the percentage of land experiencing these conditions was at 10-15% (16). Thirty years later, this number increased to 30% (16). This is a very significant change for a short amount of time. However, these are just recent short-term changes. For moisture content in soil data for years before human recording, the rings in trees exist as a natural measurement tool (17). Scientists are able to use the thickness of tree rings in comparison to known hot periods in history to see how much or little trees grew in that time in comparison to other years (17). The centuries between 900 and 1300 were "the most persistently dry period on record in the last 1,200 years" (17). This coincides with the “Medieval Warm Period.” Tree rings from this time show considerably less growth (17). In addition to the thickness of the rings, scars from fires can be seen during these times indicate wild fires because of the drier flora (17). This data shows a direct correlation between global temperature and ground moisture.

These changes in water evaporation rates greatly change precipitation rates. Mountainous regions, like the Rocky Mountains, Argentina, and certain other areas, have experienced more rainfall (16). However, many more other areas: Caribbean Islands and large areas of Africa and Asia have received decreased rainfall and are suffering the effect (15). During the years of 1997 and 1998, "the strong El Niño was associated with extremely dry conditions and large forest fires in many areas of the world, including Indonesia, eastern Russia, Brazil, Central America, and Florida" (15). Although men caused many of the causes for these fires, global warming allowed the conditions that enabled these fires to be as devastating as they were (15). As rainfall moves to new areas, crop death, drought, and wild fires will become more frequent and serious. In addition to causing droughts, global warming also makes oceanic storms more intense.

Oceanic Storms

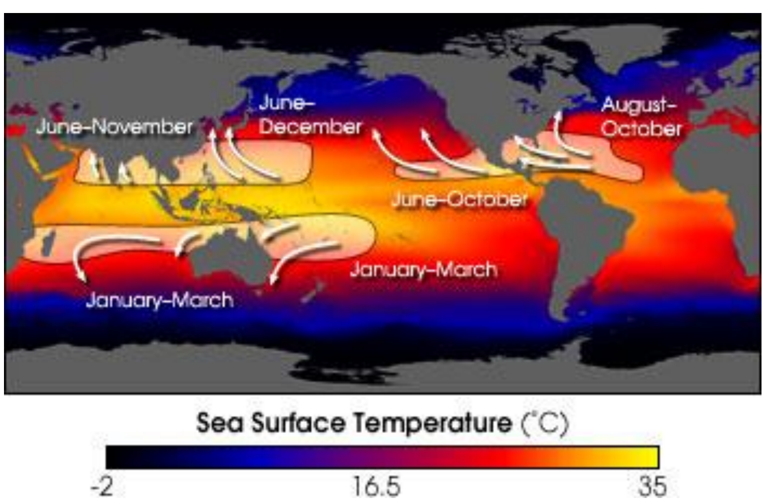
Global warming has had a massive effect on the climate patterns of earth. It has resulted in an abnormal increase in temperature, a general rise of sea levels, and a modification of global precipitation in localized areas. These are only some of the effects, however, as there has been an observed increase in storm intensity which can also be attributed to global warming. Each of these effects, though seemingly small, show that they are in fact a drastic change from the norm when put in perspective over the course of centuries, and these effects only show trends of continuing on the path they are now.

Figure 19 ***(20)***



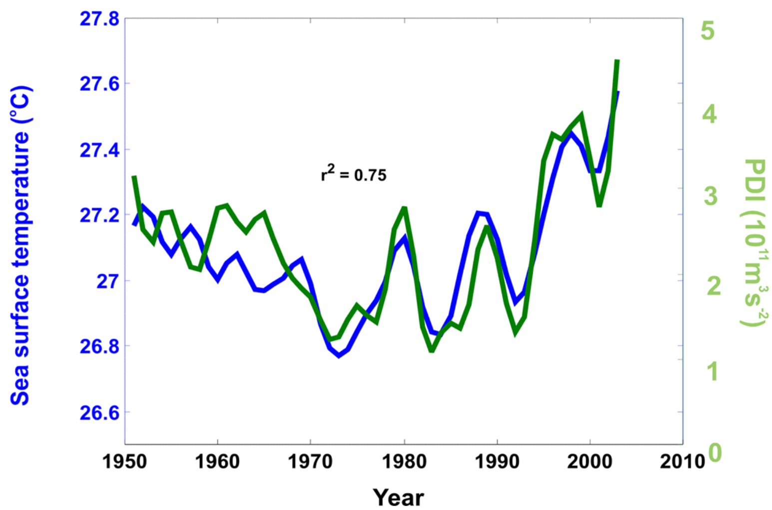
Global warming affects the environment in many ways; its influence on oceanic weather has been a cause of concern for many years. The intensities of hurricanes and typhoons show increases in recent years, notable examples being Hurricane Katrina and Hurricane Ivan in the Atlantic. Typhoons also show trends of increasing power. This suggests that increased oceanic temperatures foster the growth of more

Figure 20 ***(21)***



powerful hurricanes and typhoons.

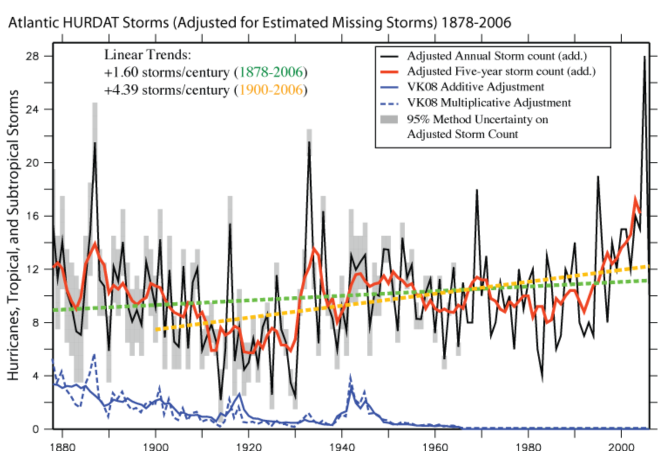
Figure 22 (20)



Natural phenomena's, El Nino and La Nina affect cyclonic activity as well. El Nino, which raises oceanic temperatures in the Pacific, has been occurring more often (18). This increase in frequency shows a possible link to global warming, and as the oceanic temperature rises, we can expect to see more severe cyclonic activity.

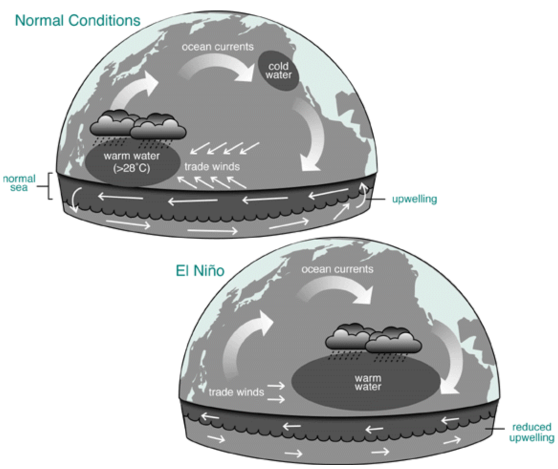
Cyclonic storms are some of the most destructive acts of nature. Hurricanes in the Atlantic Ocean and typhoons in the Pacific Ocean have always plagued coastal regions. Cyclones are large rotating storms with warm low-pressure centers. They form near the equator (between 8 to 20 degrees latitude), and generally go towards the west and angle away from the equator (19). The reason why they form near the equator is that they require warm water (typically 26.5 degrees Celsius [80 Fahrenheit] or greater) for their formation (20). These conditions exist mainly during the summer and fall when ocean temperatures are the warmest. A cyclone starts out as a grouping of thunderstorms over the

Figure 21 (20)



tropical regions known as tropical disturbance. When they collide, they cause an uprising of the air, and with the aid trade winds along the equator, a cyclone is formed (21). The warm moist air produced by the ocean powers a cyclone. As the water evaporates from the ocean's surface, it releases energy. If oceanic temperatures are greater, more water with more energy will be released (18). According to Rasmussen, "Atmospheric moisture around the globe has risen about 10% since the early 1970s." Because cyclone formation is dependent on the temperature of the water, this leads to the idea that global warming will influence the formation process.

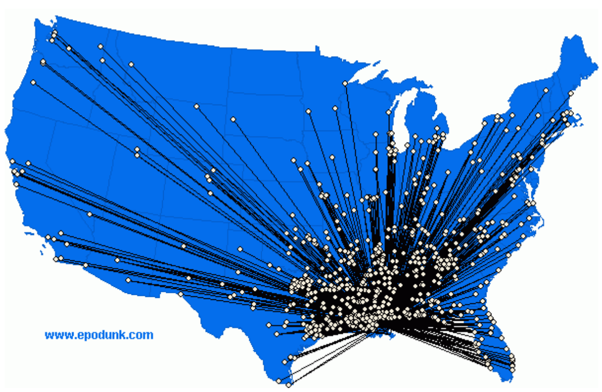
Figure 23 (23)



Global warming increases the surface temperature of the ocean. A small increase can greatly increase the area and time period over which cyclone formation is possible. A study of the sea surface temperature (SST) and the power dissipation index (PDI) of hurricanes in the Atlantic Ocean reveal a relation between the SST and PDI. When compared to one another, one can see that the peaks and valleys of the two plots line up almost perfectly. This increase in the SST is physical proof that the average global temperature directly affects cyclonic PDI (22). When greenhouse gases prevent the escape of excess energy in the form infrared energy, this energy has to go somewhere, so it heats the earth's surface and the surface of the ocean. Because the PDI is so sensitive to the temperature of the ocean's surface, an increase of even one degree could prove disastrous. According to Trenberth, Davis, and Fasullo, an increase of power output of 6-8% for every 10C increase of temperature on the surface of the ocean. Along with increasing in power, hurricanes are increasing in number (22). Over the last 100 years, the number of recorded hurricanes has increased. Although early records are not 100% accurate, slight trends become obvious over larger time increments. These increases, however, are of much less severity than the increase in the power of the storms. In addition, although there has been a slight increase in Atlantic hurricane frequency of about 1.6 storms per century since the late 1800's, there has been no noticeable increase on a global scale (22). These leads to the theory that global warming will lead to an increase of the severity of cyclones, but no significant change to their frequency.

Cyclones feed off warm air and warm oceanic surface temperatures. When they lose their supply, they dissipate. However, if they have a steady supply, they grow stronger. Global warming creates larger areas of warmer water. This means that cyclones have a greater area over which to become stronger. Cyclones have greater max wind speed due to the warming of the ocean's surface than they would without (19).

Figure 24 (25)



In addition, increased temperatures result increased water vapor released into the atmosphere. El Nino, a natural phenomenon used to release excess energy stored by the ocean, compounds this effect (23). The ocean releases this excess energy in the form of heat. This is what feeds cyclones. The heat produces more water vapors that in turn form stronger storms. El Nino increases typhoon activity in the Pacific Ocean, and it is occurring more frequently in recent years. As the atmosphere and the ocean trap and absorb more energy and heat from the sun, the ocean needs to release its excess energy more often in the form of El Nino (23). It has been occurring twice as often as usual in the last twenty years. This has lead to an increase in the intensity of typhoons.

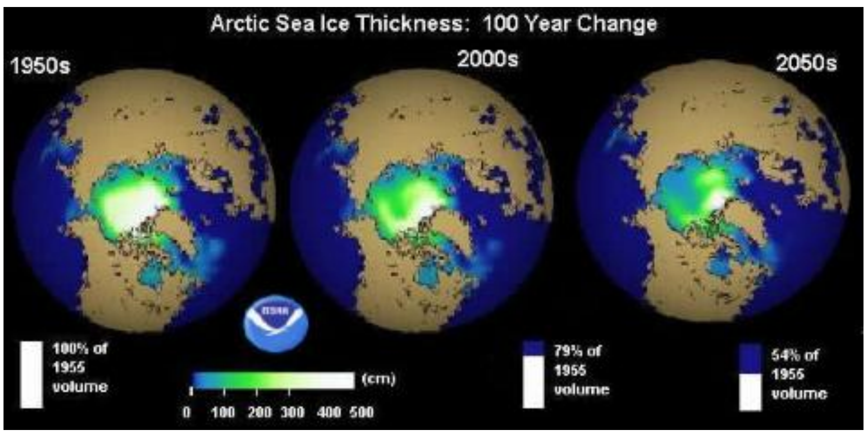
As hurricanes increase in power, there will be a greater impact on the economy. The stronger the hurricane is, the more destruction it will generate. This raises the costs of reconstruction. For Hurricane Katrina alone, insurance companies estimate a loss of $25 billon dollars in destroyed property alone (24). However, this does not account for loss of revenue. According to the "Financial Times," total revenue loss is closer to $100 billion dollars (24). The Gulf area is also responsible for about 30% of the United States oil production, so disruption of this leads to large losses of revenue. The power of a hurricane directly affects the cost of the damage that it inflicts. Due to the destruction of homes and businesses, cyclones force the inhabitants to move elsewhere (24). When Hurricane Katrina struck, nearly 1 million citizens evacuated to all regions of the United States (25). Many of these evacuees continue to reside elsewhere making this event one of the biggest mass migrations in United States history. The only event that may have had more evacuees that are permanent was the Civil War. When hurricanes destroy property, they displace many people, and this effect often becomes permanent.

Global warming has a significant impact on power of cyclones. Because the earth is unable to release all of the excess energy from the sun, there is an accumulation of energy on the surface of earth resulting in a temperature increase (20). This increased temperature on the ocean's surface results in increased water vapor and updraft. Combined, these provide the sustenance needed for larger cyclones. However, these effects do not greatly influence the number of storms. If temperatures continue to rise, global oceans will experience larger and fiercer cyclones. This can cause more damage than many of the other effects of global warming. This leads to money loss of increasing values and migration away from coastlines.

Albedo

Along with carbon dioxide, water vapor, and trace gases, the earth's albedo affects global warming. Albedo is the amount of energy reflected by the earth. The most prominent variable is the atmosphere; cloud cover is the most prevalent source of reflecting solar radiation the earth receives. Cloud cover is not constant from year to year, and typically runs in trends over decades. If cloud cover is lower than average, the earth reflects less sunlight and therefore accentuate the effect of global warming.

Figure 25 (28)



The albedo of the earth has a drastic effect on the net transfer of energy from the sun to the earth. On average, the sun radiates 341 watts per square meter on the earth (26). Earth's albedo, roughly 0.30, reflects around 30% of the energy from the sun (26). A small change in albedo, dropping by 0.01, would cause a 3.4-watt increase in net energy from the sun, and would have a much greater warming effect on the global climate than that of carbon dioxide (26). From February 2000 to February 2004, there was a net decrease in earth's albedo of about 0.0027, which translates to 0.9 watts of energy per square meter increase in solar energy (26). If the earth's albedo decreases, it will absorb more solar energy, and as a result, increase the effect of global warming.

Along with atmospheric clouds, the earth's surface also plays a role in its albedo. One primary factor in this is the ice caps. The polar ice caps are reflective compared to most natural surfaces on the earth (roughly a 0.30-0.40 reflectivity) (27), and thus have a beneficial effect on the earth's albedo. Since the 1950s, the northern ice cap has lost a significant volume, and expects a loss a 50% of the 1950 volume by 2050, as demonstrated by Figure 25 (28). Because of this, the reflective effects of the ice caps will drastically diminish as well, heightening the effect of global warming even more as previously mentioned.

Figure 26 (28)

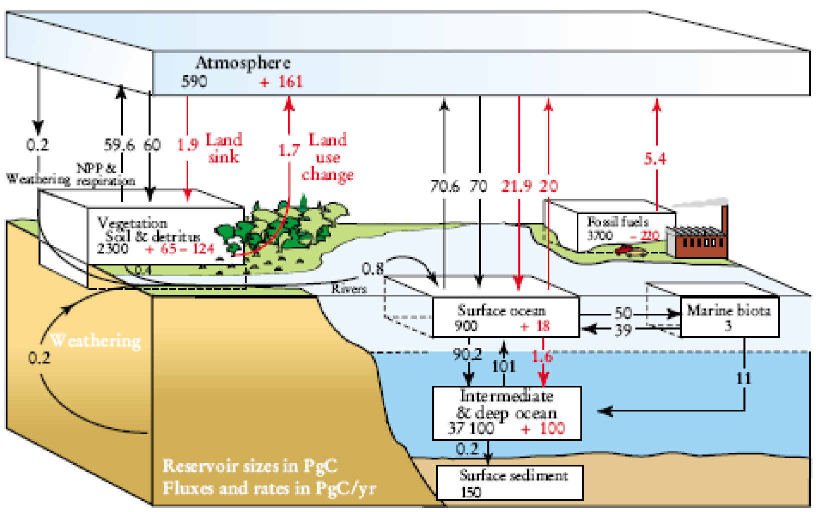


FIGURE 1. GLOBAL CARBON CYCLE. Arrows show the fluxes (in petagrams of carbon per year) between the atmosphere and its two primary sinks, the land and the ocean, averaged over the 1980s. Anthropogenic fluxes are in red; natural fluxes in black. The net flux between reservoirs is balanced for natural processes but not for the anthropogenic fluxes. Within the boxes, black numbers give the preindustrial sizes of the reservoirs and red numbers denote the changes resulting from human activities since preindustrial times. For the land sink, the first red number is an inferred terrestrial land sink whose origin is speculative; the second one is the decrease due to deforestation.[16] Numbers are slight modifications of those published by the Intergovernmental Panel on Climate Change.[3] NPP is net primary production.

Migration

Human migration

The effects of global warming create many adverse environmental events, such as more extreme weather conditions. Extreme weather events cause severe damage to the areas they are located, destroying homes and livelihoods. Even with the more subtle effects such as sea level rise and desertification, have huge impacts on the human population. People affected by these disasters have the desire or need to migrate to different locations. These migrations need monitoring by a manner of national or global policies, to prevent major economical or greater environmental hazards from forming.

Many individuals and organizations have developed policy guidelines that they feel would facilitate better policy making. Herman J. Ketel writes, “To address the field of environmentally induced population displacements more effectively, the following actions are needed (29). Appropriate policy development within governments and agencies (30). A move away from reactive interventions to proactive strategies and action plans (31). The development of a worldwide monitoring system would need to look closely at the relation between global warming and environmentally sensitive areas (32). The establishment of a platform for the exchange of information on important issues between governments and agencies would aid refugees from natural disasters (31). Ketel feels that these policies would help nations and global organizations create and implement effective policies regarding environmental refugees. Ketel's second point involves the implementation of proactive policy, as opposed to reactive strategies. A proactive strategy focuses on prevention to minimize loss of life and resources due to adverse weather anomalies. The proactive approach allows the avoidance of major losses instead of having those losses occur and having the need to implement policy to repair damages. Ketel's third point involves the development of a worldwide monitoring system to examine the correlation between major climate anomalies and global warming more closely. Establishing correlations allows for the implementation of more effective preventative measures or perhaps possible solutions to prevent major weather conditions from occurring.

A number of countries and global organizations have already adopted policy regarding migrations due to environmental reasons. The Indonesian government has implemented a population-resettling plan, that moved Javanese to low-density islands, preventing the uncontrolled displacement of a large group of people, and in effect, any problems that displacement may cause. There was a 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janiero, which came to a number of conclusions and recommendations regarding migration policy due to environmental effects. A number of participating countries signed on these policies, but they have waned over the years. Ketel writes, “Environmental policies, guidelines, checklists, and impact assessments are exactly the sort of tools agencies and governments should apply to their development and relief operations if environmentally induced population displacements are to be reduced. The principles of sustainability in development programs and other activities (emergency relief, rehabilitation, and even nature conservation programs) no longer need study, but should be put into practice” (31). Here he directly outlines the specifics of what the policies need to accomplish and that these programs no longer need to be studied extensively because there is a need for them to be implemented now.

There are a number of organizations, such as the Red Cross, dedicated to the study of these disaster trends in the environment and help in the relief effort. Global warming caused a record number of natural disasters across the world in 2007, up nearly 20 percent from a year earlier, stated the International Federation of the Red Cross (IFRC). The IFRC also stated that, “As of 10 October 2007, the Federation had already recorded 410 disasters, 56 percent of which were weather-related, which is consistent with the trend of rising numbers of climate change-related disasters” (32). Groups like the IFRC not only aid the victims of these global disasters but also observe and report the growing trends of the disasters, taking a step toward forming preventative policy to combat them.

Global warming has had a severe effect on one region in particular, Greenland. The average ocean temperature off Greenland’s west coast have risen in recent years — from 38.3 degrees Fahrenheit to 40.6 F, causing adverse effects to the population (33). The native Inuit, who constitute a large percentage of the country’s population, have had their livelihoods disrupted greatly by the melting ice. Viable periods for running sled dogs and fishing on the ice have notably shortened from six months to about two. This can be very detrimental because limited food and transport in these northern regions can destroy entire villages.

Climate changes due to global warming have had significant impacts on both human and animal migration and territory. Proper study of weather anomalies allows the implementation of preventative policies; this requires a global effort to be effective. Major weather disasters cause loss of life, homes, and livelihoods, and there is evidence to show that these disasters are an effect in some part due to global warming. It is important to study the exact links between global warming and climate anomalies to prevent major ecological, economical, and human loss.

Animal Migration

There is no question that humans have a profound impact on the planet; affecting every aspect of life on earth including the environment. Many studies have been conducted on the emission of greenhouse gases and their effect on global temperature, specifically global warming. Evidence suggests that the effects of global warming due to greenhouse gases have had a significant impact on the movement of animal habitats (29). The warmer global temperature may also have affected the migratory and winter patterns of certain bird species (30). Additionally, scientists conducted studies on a group of butterflies in an attempt to better understand and predict global climate changes (29). A number of case studies have been performed that give strong evidence that the change in global mean temperature is having an effect on the movement patters of certain animals and that there is a need to study these patterns to better understand the climate changes, and to help predict future ecological issues.

Among animals most sensitive to climate changes, the insect is a prime example. Insects are extremely sensitive to temperature, have rapid reproduction and short generations, as well as high mobility; these characteristics make insects the perfect subject to observe the effects of global temperature change on animal migration patterns. A case study involving the Sanchem Skipper Butterfly (*Atlopedes Campestris*) tracked the range of the butterflies' territory. Observations showed an approximately 700 kilometer northward addition to the species' territory within the last 35 years (29). The butterflies' migration seems to coincide with the increase in average temperature in the region over the years. However, two seemingly related events may not have any correlation with each other; establishing a relation between the two observations requires scientific testing. Lisa Crozier, author of a case study involving the species, was able to provide experimentation to try to establish a relationship between the increase in regional average temperature, and the northward shift of *A. Campestris* populations. In her study, she developed hypotheses on range-limiting factors that correlated with the range change and biology of the species, and attempted to identify the major physiological constrains that would allow climate changes to affect the species range. Experiments with field transplantation test these hypotheses and constraints. Crozier's purpose for the experiments was to attempt to establish a model for predicting the effect of climate changes on various species. Crozier hypothesized that the more rapidly rising minimum temperature in the region; especially during the winter months was having a profound effect on the species range. Using the field transplantation method, she was able to gain information on temperature changes and the relation to mortality rates in the species. Her testing seems to suggest that the recent warming trend in the Pacific Northwest regions is a major factor in the *A. Campestris'* range.

Lisa Crozier's findings reinforce the possible correlation between global warming and animal range extension. It is also important to reflect upon the possible environmental problems the extension of some species' ranges may cause to the indigenous species of the new area they inhabit. Increases in specie’s range may cause an overlap in niches, leading to competition for resources. Competition for food, nesting ground, and other resources may lead to problems between the indigenous species and those whose range has increased to the new area, which may even lead to the endangerment of the regions entire ecosystem. Studies such as Crozier's give us more insight into how exactly global warming causes serious environmental issues that not only affect climate but in turn also affect biological and ecological systems.

Another study highlighting winter bird assemblages in the Cape Cod region was also conducted that came to conclusions similar to those of Lisa Crozier. To eliminate census errors due to varying population sizes within different testing regions, the group decided to internalize their study by examining the ratio in regions between birds with a southern winter distribution

[S] and a northern winter distribution [N] (30). With this procedure, higher S/N ratios in more northern regions from year to year would establish a correlation between the rise in temperature and the migration of birds. Simply put, finding a higher ratio of southern winter distribution birds, which prefer warmer winters, to northern ones would indicate that the rise in regional/global temperature is causing a shift in the territory of these bird species northward. The data obtained by the researchers shows an increase in southern species, and a decrease in northern species populations correlating with the year-to-year increase in average temperature (30). The conclusions they came upon are that the change in global temperature seems to have a greater effect on shifting the range of the birds, even more of an effect than other environmental changes to the region over the years, and that this pattern may apply to wildlife other then the birds in their study.

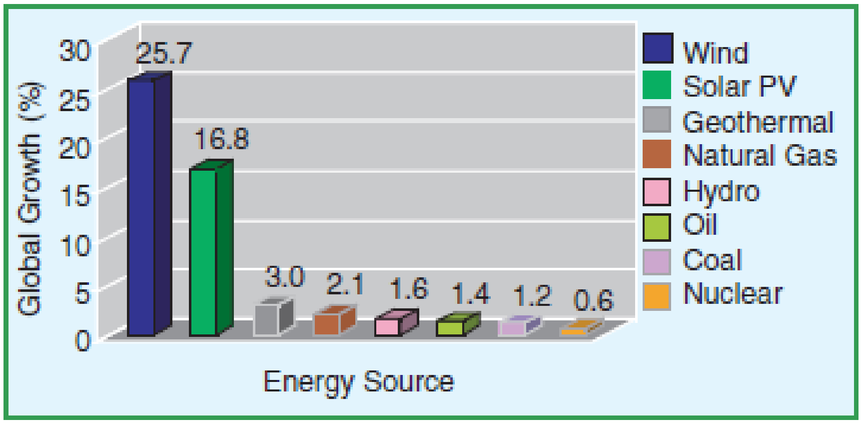
The researchers in the Cape Cod census were able to eliminate factors other than temperature by examining the ratios between two groups subject to the same regional conditions. The major difference between the two groups of birds was the temperature of the region at which they spend the winter months. This allowed the establishment of a direct relationship between the rising of the global temperature and the territorial changes in these birds. Much like the butterfly study, the bird study established the affect of climate changes, specifically global warming, on animal migration and population ranges.

Solutions

Alternative Energy

Using sources of energy that do not produce greenhouse gases reduce the acceleration of global warming. This will lead to a stabilization of the environment. Currently our use of fossil fuels has generated exorbitant amounts of carbon dioxide that directly relate to the increase of temperatures around the globe. Alternative energy sources produce little to no harmful emission. In addition, many of them are renewable making them more useful as we are currently running low on our supply of fossil fuels. Although it is not quite as cost effective now as it will be in the near future due to carbon taxes, switching to other sources of energy will help to reduce global warming.

Figure 27 (47)



Renewable energy is energy obtained from natural sources that replenish themselves over time, or do not diminish because of their use. This type of energy inflicts no harm to the environment. Renewable energy, sometimes called "Green Energy," take energy from natural processes that contain so much energy, the amount withdrawn by humans barely scratches the surface (34). Examples of energy sources that provide suitable amounts of energy are solar, wind, hydro, geothermal, and tidal. Instead of having the energy dissipate into the atmosphere, these methods harness the energy for a more constructive purpose. Power turbines and plants that take in this energy do not require fuel as nature provides it (34). These reasons are why renewable energy provides a good replacement to fossil fuel.

Figure 28 (34)

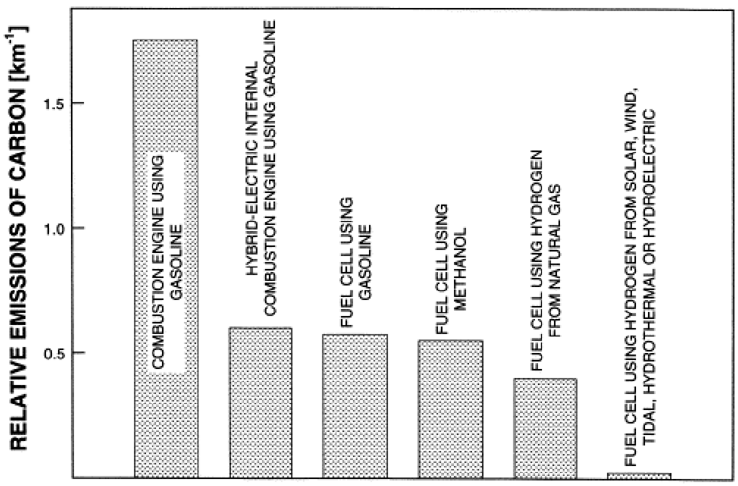
Resource	Generation Cost (¢/kWh)	External Cost of Generation* (¢/kWh)
Coal	3.11-3.41	1.94-14.6
Gas turbine	2.53-3.41	0.97-3.89
Nuclear	3.31-5.74	0.19-0.58
Good wind site	5.84	0.05-0.24
Optimal wind site	3.89	0.05-0.24

*The estimated costs to society and the environment due to their operation, not including nuclear waste and decommissioning costs.

The fastest growing source of alternative energy is wind energy. Previous uses of wind energy over the last few centuries include windmills; more recently, windmills have been adapted for electricity generation for roughly two decades. Current wind turbines use large fan blades to rotate wire coils within a magnetic field. Instead of using steam to turn the coils, like in a traditional power plant, wind provides the source of energy, so no manual input is required. This is one of the fastest growing energy sources because it has one of the lowest costs to society and the environment. In addition, almost anywhere allows the construction of wind power turbines, which is good for areas that are very developed and have little available land. In the year 2000, 70% of wind energy produced worldwide was in Europe (35). This is because wind turbines are able to be constructed almost anywhere and do not take up much space. This is good for Europe, because there is less land available for power plants, so wind turbines use this space with greater efficiency. It is also ideal for areas far from developed areas because it requires little maintenance compared to other energy sources. Some humane groups use wind turbines to provide energy to underdeveloped villages in places like Africa. Wind power provides a good source of energy at any location with no harmful effects to the environment.

The second fastest growing form of renewable energy is solar energy. Using photovoltaic cells, the photons in sunlight are absorbed and converted to electricity. This has no adverse effects on the environment because there are no emissions or pollutants created in this process. The placement of solar panels on buildings and vehicles show how versatile and useful they can be. The main concern with solar power is that solar power plants occupy large areas of land in order to supply power for cities (35). Solar panels are panes of silicon with different impurities on opposite sides. As photons strike one side and produce electrons through the photovoltaic effect, they are attracted to the other side due to the different impurities. This creates a voltage difference that performs similarly to a battery. Another way solar energy is collected is by using mirrors to collect light and heat up a substance like molten salts or water (34). This stored thermal energy proceeds in a manner similar to a traditional power plant by heating water to turn a turbine. Solar panels are relatively cheap, and they require no moving parts, this allows use in places that are otherwise impractical.

Figure 29 (34)



Many different processes have utilized hydro energy over the centuries. An example of a process that utilized hydro energy is water mills. By using a river to turn a large wheel, the rivers flow converts into mechanical energy. This has been grand scaled in the construction of dams. Dams reduce flooding by blocking and controlling the river flow. By doing this, it uses gravity and the water flow to turn its turbines. Today, hydropower contributes about 21% of electricity generation worldwide (34). Unfortunately, the production of new hydroelectric power plants is very limited because the number of possible sites for dams is limited. Dams can only exist along large rivers where water has an area to pool without flooding the nearby countryside. Additionally, many of these sites are unavailable for the construction of hydroelectric plants due to previous development (34). Remaining available sites are limited because construction there would have adverse affects on the environment and the indigenous people. Hydropower is a very effective source of energy, but due to the reduced construction possibilities, it has limited growth in the coming years (35).

Scientists predict hydrogen to be the most commonly used fuel in the future because it is the most ideal to replace gasoline. This is because it can be manufactured using a renewable energy source, and it has no harmful emissions. Not found naturally on earth's surface, hydrogen gas must be manufactured (36). This is the main problem with using hydrogen as a fuel. One of the more popular ways to obtain hydrogen is to use solar energy to split water into hydrogen and oxygen. This would make it so that fuel could be

Figure 30 (36)

Comparative Power Costs

CASE (Year 2002 $)	REAL LEVELIZED COST Cents/kWe-hr
Nuclear (LWR)	6.7
+ Reduce construction cost 25%	5.5
+ Reduce construction time 5 to 4 years	5.3
+ Further reduce O&M to 13 mills/kWe-hr	5.1
+ Reduce cost of capital to gas/coal	4.2
Pulverized Coal	4.2
CCGT[a] (low gas prices, $3.77/MCF)	3.8
CCGT (moderate gas prices, $4.42/MCF)	4.1
CCGT (high gas prices, $6.72/MCF)	5.6

a. Gas costs reflect real, levelized acquisition cost per thousand cubic feet (MCF) over the economic life of the project.

generated using only renewable resources. Because of this, there would be no need to fear running out of fuel. Hydrogen also has a high-energy content making it more viable than ethanol (36). Its lack of harmful emissions also makes it a viable replacement fuel.

Nuclear power is another source of energy that does not produce greenhouse gases. It works by using radioactive fuel rods to provide the energy to heat water in order to use the steam to turn a turbine. It draws in water from a nearby water source, and it releases steam into the atmosphere and warmed water back into the water source (37). Because it does not produce greenhouse gases, nuclear power provides a good replacement for the combustion of fossil fuels. However, a few things inhibit the widespread use of nuclear power plants. Of this list, the four leading problems are cost, safety, security, and waste resulting in the production of less nuclear power plants than possible. Nuclear power provides 20% of the energy in the United States and 17% of world energy (37). As the world develops, energy consumption will increase as well. In the next fifty years, energy use expects an increase of 75% whereas nuclear power expects an increase of only 5% (37). These results reflect both economic concerns and anti-nuclear sentiments in major countries.

Compared to fossil fuels, nuclear power has greater costs over its lifetime; however, this does not take into account carbon taxes and other costs implemented to reduce the use of fossil fuels. Nuclear power will succeed only if it costs less than other forms of energy. At current prices, it is not economically sound for the production of nuclear power plants over fossil fuel power plants because power plants that use fossil fuels cost less at the current time (37).

Nuclear power has generated many concerns by the public. The first of these is safety for the environment and the health of people nearby. Accidents that have occurred relating to nuclear power have greatly influenced public opinion on the subject. The public has always been concerned over the issues, but the infamous disasters of Three Mile Island in 1979 and Chernobyl in 1986 greatly increased negative thoughts on the subject (37). The public is also concerned over the costs and the technology because they believe the costs are too high and technology is not sufficient. To obtain more support for nuclear energy, the public needs to be informed the technology and safety precautions along with prices that can beat fossil fuels (37). Another concern is security because nuclear waste and nuclear fuel enable in the construction of powerful weapons. As nuclear power plants become more widespread, there are more possibilities that terrorists, or other people of sinister intent, can obtain said nuclear material and inflict serious harm unto the global community. Nuclear power is a form of energy that produces no greenhouse gases. Unfortunately, it can have other effects on the environment that have detrimental health effects in the result of an accident (37). Nuclear waste presents many different health risks to the populous. It is difficult to store, and it remains dangerous for a long period of time (37). Constructions of disposal facilities are in production, but if nuclear power usage substantially increases, this could lead to new problems. It is important to address these problems for the greater construction of nuclear power plants.

Coal is a very abundant fuel commonly used for power generation, currently used in roughly half of the power generation for the United States. Current common processes for converting coal into energy result in a high rate of emissions. The reliance on coal and its abundance call for a cleaner way of converting it to energy as an important step in the solution for global warming. According to the US Department of Energy (DOE), "'Clean coal technology' describes a new generation of energy processes that sharply reduce air emissions and other pollutants from coal-burning power plants." Current clean coal research focuses on reducing sulfur, nitrogen, and mercury pollutants from emissions, and reducing greenhouse gas emissions by increasing efficiency of coal's conversion to energy (38). Earlier efforts have been made towards cleaner coal; however, the primary concern of these had been with environmental concerns other than global climate change (38). The current cleanest coal plant is located in Florida; the coal is converted to a gas and then burned. While this process removes sulfur and nitrogen, eliminating acid rain, it has little effect on carbon emissions (39). The Department of Energy has created the Clean Coal Power Initiative (CCPI) in order to develop new processes to reduce environmentally harmful emissions resulting from coal; one of the primary concerns of this initiative is the use of carbon sequestration (38).

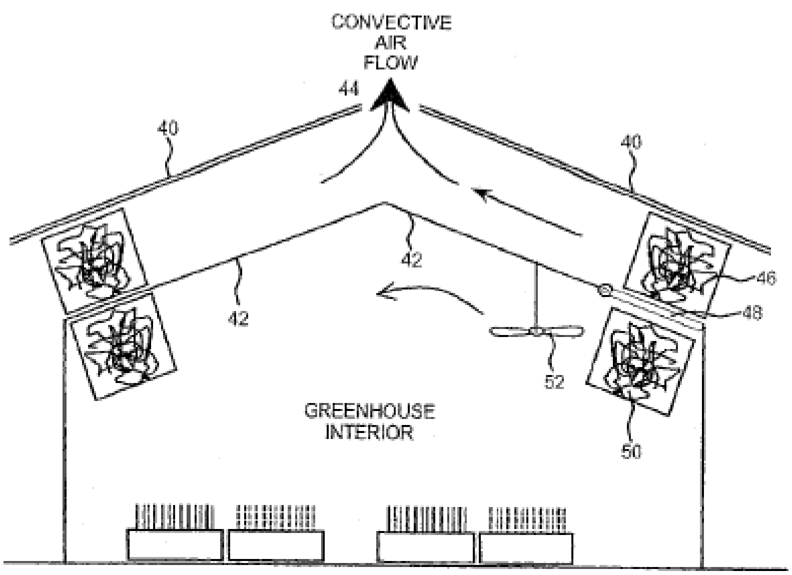
Coal gasification is currently the best form of clean coal technology available (40). Coal is exposed to steam and air or oxygen to convert it to a gaseous form, resulting in minimal Sulfur and Nitrogen emissions (40). When oxygen is used in place of air, carbon dioxide is emitted in a concentrated stream, allowing for easier carbon sequestration (40). The coal gasification process is more efficient than traditional coal plants (as much as 50% more efficient), making it even more environmentally and economically desirable (40).

Switching to alternative sources of energy reduces the human impact on global warming. With a reduced carbon dioxide output, we can decrease the amount of carbon dioxide in the atmosphere in the future. Because carbon dioxide shows a direct relation to global warming, this reduction would be very beneficial. The best-suited alternative is dependent on the region, but many of them can be adapted to fit in anywhere. Because of the decreasing supply of fossil fuels and their impact on global warming, it would be in the world’s best interest to research more alternative forms of energy and employ current forms in larger areas.

Carbon Sinks

Since the industrial revolution, fossil fuels have been one of the most common fuels since then. Fossil fuels, when burned, emit carbon dioxide, among other gases, which can be absorbed through a variety of natural systems present on earth. These natural "sinks" are part of the carbon cycle, a natural process that balances the atmospheric carbon dioxide concentration keeping many of earths others systems in equilibrium. The major issue involving carbon emissions is the high rate at which emissions are occurring; so high in fact, that the planet's natural systems are not able to absorb all the carbon produced. The lack of adequate absorption of carbon dioxide by natural means is creating a need for artificial solutions, such as a new device developed this year by Global Research Technologies, LLC (GRT), a technology research and development company, and Klaus Lackner from Columbia University.

Figure 31 (43)



Natural sinks exist both on land and in the oceans. Land carbon sinks consist of vegetation and soil, effects from weathering, as well as bodies of freshwater. The ocean itself is a major carbon sink, due to carbonate reactions with carbon dioxide at the surface, making sea water a good buffer, with carbon dioxide as the solute. Surface ocean contains carbon stores of about 900 Pg of carbon dioxide whereas intermediate and deep ocean stores have around

37100 Pg of carbon contained within them Figure 26 (28). Although it can store more carbon dioxide, intermediate and deep ocean does not play as crucial a role as carbon sinks because of the lack of contact with the surface; additionally, the transition of carbon from surface ocean to the deeper levels is also very slow. Estimates show the deepest parts of the ocean, located in the North Pacific, have been out of contact with the surface of the ocean for the past 1000 years (41). The result of the lack of absorption of carbon from the atmosphere is a steady rise in the planet's atmospheric carbon levels since industrialization began. The carbon level continues to rise and the intervention of artificial carbon sinks may be necessary to supplement the strained natural ones.

A new artificial carbon sink prototype has demonstrated the feasibility of carbon dioxide from atmosphere removal systems. The device from Global Research Technologies, LLC (GRT), and Klaus Lackner, removes carbon dioxide directly from the air to where it pumps into greenhouses and is absorbed by plants, consumed by an algae culture, or stored by other means. The devices opening plays a role in the quantity of carbon dioxide absorbed, “A device with an opening of one square meter can extract about 10 tons of carbon dioxide from the atmosphere each year. If a single device were to measure 10 meters by 10 meters it could extract 1,000 tons each year,” the new system is also more cost effective than converting existing technologies to produce fewer emissions (42). The system uses a carbonate/bicarbonate resin that is sensitive to humidity. A high humidity will cause the resin to absorb carbon dioxide, while a low humidity facilitates carbon dioxide absorption. The device is ideally adjacent to a greenhouse; this allows the movement of the device inside after absorbing the carbon dioxide from outside (43). The low humidity outside the greenhouse causes the resin to absorb the carbon dioxide in the atmosphere. The device then moves into a greenhouse where the higher humidity causes the resin to release the stored carbon dioxide into the greenhouse allowing for either plants or an algae culture to absorb and convert it into nutrients or precipitates (43). The only energy required in the system is the energy required to move the device from the outside to the greenhouse (42). This is an advantage over previous devices that create heat and pressure, as well as the devices own emissions, which reduces the net carbon dioxide absorption.

The major advantage of this carbon dioxide absorption device, other than cost effectiveness, is its relative size and its location. Ideally, the device's construction is small and adjacent to areas where the stored carbon dioxide use occurs, such as greenhouse or algae cultures. This allows the placement of the device anywhere, eliminating the need to put the source and the sink in the same area. The device shows great promise, and Global Research Technologies, LLC, is planning to expand the technology to a larger scale. Devices, such as the one developed by Klaus Lackner, could result in the reduction of atmospheric carbon noticeable in our lifetimes as well as possible preindustrial levels in the far future.

Crop Modification

Famine is a major global issue that can be caused by a number of environmental and economic factors, resulting in widespread malnutrition and death. The prevalence of flooding in south east Asia is having a devastating effect on crop yields, causing annual losses of over US$1 Billion (44). With rice (*Oryza sativa*) being the largest carbohydrate source in Asia, options for modification of the rice genome to make a more submergence resistant stain have been investigated. Submergence of plants, which occurs during flooding of cropland, inhibits aerobic respiration and photosynthesis, leading to the eventual death of the plant. A recent investigation into plant modification has led to the development of a new strain of rice that is resistant to submergence.

Oryza sativa ssp. indica cultivar FR13A, are highly tolerant and survive up to two weeks of complete submergence (44). The locus of this genetic trait has been designated Submergence 1 (Sub1). The Sub 1 locus is comprised of three regions: Sub1A, Sub1B, and Sub1C, of these Sub1B and Sub1C are traits found in all rice species. Sub1A is a variable region, where two alleles were identified: Sub1A-1 and Sub1A-2. Over expression of Sub1A-1 in a submergence-intolerant O. sativa ssp. japonica showed an enhanced tolerance towards submersion, giving evidence that Sub1A-1 is a primary determinant of submergence tolerance.

The study introgressed The FR13A Sub1 locus into a widely grown Asian rice cultivar using marker-assisted selection. By this process, the team was able to develop a strain of rice more tolerant to submergence. The introgressing method used allows specific genes to be passed down without any undesired genetic information to be passed down. Creating a cultivar with similar properties aside from submergence tolerance is important in a practical setting because it creates a new crop that behaves like previous strains in terms of management and taste, which are important factors in the new strains viability. A submergence tolerant cultivar allows for a much lower annual crop loss due to flooding of crop areas, since cultivars expressing the Sub1 region have over twice the survivability of cultivars that did not have the Sub1 genetic region.

The strain developed by the research team is being implemented in real world scenarios, is at an advanced stage for Laos, Bangladesh and India, and has already been reported in Thailand (44). The viability of the strain has been proven through the actual use of the strain in these regions and is a major step in the prevention of famine due to crop loss from flooding. With flooding closely linked to climate anomalies due to global warming it is imperative to develop climate resistant crops to prevent famine in addition to developing strategies for prevention.

Policies to Reduce Anthropogenic Carbon Dioxide

Major environmental issues such as Global Warming bring about the creation of a number of political and economic legislatures that attempt to eliminate or curtail the issue (Comparison of Legislatice Climate Change Targets). In the case of Global Warming, most policy involves the reduction of annual greenhouse gas emissions by imposing a cap-and-trade system where businesses are rationed emission credits that they are free to trade amongst themselves. Cap-and-trade policies limit the amount of annual industry carbon emissions, while allowing businesses to distribute the sources of emission through free trade of emission credits allowing for a lesser financial impact. Those companies that require a higher emission output to remain profitable will buy credits from those companies that require less than they are allotted, preserving the maximum level of annual carbon emissions while merely changing the source of the emission.

A 2007 bill proposal S.485, proposed by Senator John Kerry is a prime example of industry regulation through cap-and-trade policies, with the addition of methods to invest in renewable energy and limit emissions (Global Warming Reduction Act of 2007, S. 485, 110th Congress, 1st Session). One of the major goals of the plan is to create annual reductions from 2010 through 2020 that bring economy-wide emissions down to 1990 levels by 2020. The reduction to 1990 levels is followed by 2.5 percent annual reductions from 2021 through 2029 and 3.5 percent annual reductions from 2030 through 2050. The plan would result in a total reduction of emissions by 65 percent from year 2000 levels.

The Kerry plan defines two major goals, one for emission reduction and an additional goal involving economic stability, technological investment, and support for damages due to climate change. The first goal is to provide a means for which to achieve an average global atmospheric concentration of carbon dioxide that does not exceed 450 parts per million and to reverse emission increases by 2010, so that by the year 2050 the emission rate is 65% of year 2000 levels (Global Warming Reduction Act of 2007, S. 485, 110th Congress, 1st Session). The second goal of the plan is to continue economic growth, mitigate energy cost increases to consumers, to provide transitional assistance from high-carbon emitting energy sources, to encourage the development of technologies designed to sequester or reduce carbon emissions, encourage carbon sequestration through increased land biota, to reward early reductions in greenhouse gas emissions, and to aide in the prevention and mitigation of negative climate changes.

In terms of renewable energy, S.485 calls for an increase in the percentage of electric energy from renewable sources through the forty years that the plan covers. At year 2010 the amount of total electrical energy, whose source is from renewable means, from all retail suppliers should be 5%, 10% from 2011 to 2015, 15% from 2015 to 2020, and 20% at 2021 and onwards (Global Warming Reduction Act of 2007, S. 485, 110th Congress, 1st Session). A gradual increase in renewable electrical energy allows for a transition from the use of high-carbon emitting sources for the production of energy, and allows for reduced emissions from the industry sector pertaining to electrical energy generation. The addition of a renewable fuel program by amending the Clean Air Act (42 U.S.C. 7545(o) (2)) would call for 10 billion gallons of renewable fuel by 2010, 30 billion gallons by 2020, and 60 billion gallons by 2030 (Global Warming Reduction Act of 2007, S. 485, 110th Congress, 1st Session). The amendment of the Clean Air Act couples with an amendment to various acts involving tax incentives for advanced technology vehicles that use non-carbon emitting fuel sources. The amendments for tax incentives on advanced technology vehicles would effectively double the previous values. Building incentives for the purchase of advanced technology vehicles aids in a transition in the transportation sector to have a lower carbon emissions impact annually.

Changes in regulation and the formation of aide programs is an important aspect of the proposed plan. International regulation is of particular interest, with industry in countries like China and India growing rapidly (Raupach), the plan calls for the government to aide in establishing mitigation commitments by all countries seen as major contributor to the release of carbon into the atmosphere. The government would also establish flexible mechanisms to minimize the costs of participating countries. According to S.485, the specific international programs should be monitored through a bipartisan Senate observation group, designated by the Chairman and Ranking Member of the Committee on Foreign Relations of the Senate, and which should include the Chairman and Ranking *Member of the Committee on Environment and Public Works of the Senate.*

The *Global Warming Reduction Act of 2007 (S.485)* introduced in senate by Senator Kerry, forms a comprehensive plan to combat the increase in carbon emissions. The plan details strategies to regulate sources of carbon due to electrical energy generation and transportation in an effort to make those sectors output a lower net carbon release annually. Funding for new technologies to mitigate, sequester, or eliminate carbon from the atmosphere is also a major component of S.485, along with stricter monitoring and authoritative policies that would allow for a more stringent regulatory system. Overall, the *Global Warming Reduction Act of 2007* hopes to uses cap-and-trade methods on various industry sectors to achieve, by 2050, a carbon emission rate that is 65% of what it was in the year 2000. A reduction at the magnitude proposed by the plan would allow for an atmospheric carbon concentration of 450ppm, which some studies show is a tipping point for major ecological effects (McNeil).

Model Calculations

Equations

The model created by Griffiths, McHugh, and Schiesser utilized a system of ordinary differential equations (ODEs) in order to better predict the growth of carbon dioxide concentrations in the atmosphere. The integration of ODEs allows an easier and more accurate prediction of concentration levels. Commonly used for mass transfer problems, ODEs generate an equation for a characteristic, like temperature or concentration, of a material with respect to time. An integration of an equation solving for the rate of change with respect to the condition itself produces the equation of the condition with respect to time. In order to do this, an initial condition is necessary. The model by Griffiths uses ODEs of the change in concentration over time with respect to the concentration itself. The information required for the model to function is the rate constants and the initial concentrations. Because the initial concentrates originated from real data and were accurate, we modified the constants that dealt with the rate that carbon dioxide entered the atmosphere.

In order to calculate the global carbon dioxide system, the model uses seven different layers in the earth's ecosystem. These seven layers are the upper atmosphere, the lower atmosphere, the short-lived biota, the long-lived biota, the upper ocean layer, the deep ocean layer, and the marine biosphere. Due to their important effect on global carbon dioxide dynamics, these reservoirs were the ideal layers to use to calculate carbon dioxide rates and concentrations (45). In order to simply calculations, the model assumed perfect mixing in the layers, neglecting any variations over the large areas in which the layers encompass. By neglecting these spatial variations, calculations became possible using average transfer rates and compositions (45). This limited the only independent variable to time rather than time and position. Integration of the ODEs used starting concentrations of data based off concentrations of carbon dioxide in the year 1850 (45). Calculations of the concentration in the reservoirs depend on the anthropogenic emission of carbon dioxide in the lower atmosphere, known as the emission rate.

For use in calculations, dimensionless units allowed relations between the compositions of the different layers. These dimensionless units used the following labels (45):

Table 1 ***(45)***

Concentration	Reservoir
$c_{ua}(t)$	Upper atmosphere
$c_{la}(t)$	Lower atmosphere
$c_{sb}(t)$	Short lived biota
$c_{lb}(t)$	Long lived biota
$c_{ul}(t)$	Ocean upper layer
$c_{dl}(t)$	Ocean deep layer
$c_{mb}(t)$	Marine biosphere
T	Time (calendar year)

The values obtained for Table 1 used the following equation:

Equation 1 ***(45)***

$$c(t) = \frac{c_{dim}(t) - c_{dim}(t = 1850)}{c_{dim}(t = 1850)}$$

The variable, c(t), is the respective dimensionless value for each specific layer, and the variable, $c_{dim}(t)$, is the dimensional value of the concentration for that layer. This equation predicts the displacement of the selected concentrations from the initial time, the year 1850. At this time, Equation 1 predicts c(t = 1850) = 0 due to the fact that t = 1850 is the baseline (45). Because these numbers are dimensionless, the concentrations in the different layers exist on a common scale, allowing equations that relate multiple layers to each other. The model used the following equations in order to obtain the equations for concentrations expressed in Table 1 (45).

Equation 2 (45)

$$\frac{dc_{ua}}{dt} = \frac{1}{\theta_{ua-la}}(c_{la} - c_{ua}), \mathrm{c_{ua}}(1850) = 0$$

Equation 3 (45)

$$\frac{dc_{sb}}{dt} = \frac{1}{\theta_{sb-la}}(c_{la} - c_{sb}), \mathrm{c_{sb}}(1850) = 0$$

Equation 4 (45)

$$\frac{dc_{lb}}{dt} = \frac{1}{\theta_{lb-la}}(c_{la} - c_{lb}), \mathrm{c_{lb}}(1850) = 0$$

Equation 5 (45)

$$\frac{dc_{dl}}{dt} = \frac{1}{\theta_{dl-la}}(c_{la} - c_{dl}), \mathrm{c_{dl}}(1850) = 0$$

Equation 6 (45)

$$\frac{dc_{mb}}{dt} = \frac{1}{\theta_{mb-la}}(c_{la} - c_{mb}), \mathrm{c_{mb}}(1850) = 0$$

These equations generate the equations for the concentrations of carbon dioxide in the indicated atmosphere as a function of time. The constant $\theta_{ua\text{-}la}$, in Equation 2, is the mean residence time, or mixing time, of carbon dioxide that enters the upper atmosphere from the lower atmosphere (45). The difference between the concentrations in the lower atmosphere and the upper atmosphere power this function, and when they match, the function is at steady state, and becomes equal to zero. When c_{la} is greater than c_{ua}, the net transfer from the lower atmosphere to the upper atmosphere $\frac{dc_{ua}}{dt}$ is positive (45). The net transfer is negative when c_{la} is less than c_{ua}. These dimensionless equations covert back to a dimensional form; this enables their interpretation as a basic mass balance.

Equation 7 (45)

$$\frac{dc_{ul}}{dt} = \frac{1}{\theta_{ul-la}}(c_{la} - c_{ul}) + \frac{1}{\theta_{ul-dl}}(c_{dl} - c_{ul}) + \frac{1}{\theta_{ul-mb}}(c_{mb} - c_{ul}), c_{ul}(1850) = 0$$

Equation 7 behaves similarly to Equation 2 through Equation 6 in that it is dependent on the mean residence time and the relationship between the different layer concentrations. This equation has multiple θ and c values because the ocean upper layer equation needs to take into consideration the carbon dioxide that flows out of the ocean upper layer into other related layers (45). The ocean deep layer and the marine biota layer obtain their carbon dioxide from the ocean upper layer. This is necessary to consider in this equation because it would not follow the Law of Conservation of Mass otherwise.

Equation 8 (45)

$$\frac{dc_{la}}{dt} = \frac{1}{\theta_{la-ua}}(c_{ua} - c_{la}) +$$

$$\frac{1}{\theta_{la-sb}}(c_{sb} - c_{la}) +$$

$$\frac{1}{\theta_{la-lb}}(c_{lb} - c_{la}) +$$

$$\frac{1}{\theta_{la-ul}}(c_{ul} - c_{la}) +$$

$$Q_c(t), \mathrm{c_{la}}(1850) = 0$$

Equation 8 behaves similarly to Equation 7 because it is affected by the mean residence times and concentrations of multiple layers. This equation also introduces a new term, $Q_c(t)$ the anthropogenic output of carbon dioxide into the atmosphere. The concentrations of the whole system depend on this due to their relationship to the concentration in the lower atmosphere. This term constitutes the source of all the carbon dioxide in the model; the following equation defines Q_c (45).

Equation 9 (45)

$$Q_c(t) = c_1 e^{r_1 t}$$

In the model, c_1 and r_1 were adapted to match real life carbon dioxide concentrations. The constant c_1 was set at 4.4×10^{-3} because this value allowed the calculated concentration in the lower answer to match the actual concentration in the year 2007 (45). The value of r_1 varies as a function of time; it represents the rate at which emissions increase. Before the year 2010, r_1 is set to 0.01 based on historical data. In 2010, the model allows r_1 to change based on various predictions. It does this by introducing a new term, r_{1c}, and the following equation:

Equation 10   (45)

$$r_1 = r_{1b} + r_{1c}\frac{(t-2010)}{(2100-2010)}$$

Equation 10 estimates that by the year 2100, the world will have switched to some other form of energy, making fossil fuels obsolete (45). This does not mean, however, that carbon dioxide emissions go to zero, but that they remain at a constant rate. By increasing or decreasing r_{ic}, the model predicts future concentrations due to different approaches to reduce emissions. A positive value represents an increase in the emissions production rate, and a negative value represents a decrease in the rate. By influencing this value, we generated multiple plots that predicted different plans.

The mean residence time values use predictions and estimates to obtain their values. Because there is no quantitative number for these values, deductive reasoning was required to estimate their values. For example, θ_{sb-la} for carbon dioxide from the lower atmosphere to the short lived biota is treated as 1 year because short lived biota largely consists of agricultural crops that grow and are harvested in one year (45). For long-lived biota, 100 years represents the residence time due to the longevity of trees (45). In addition, $\theta_{dl-ul} = 1000$ reflects the consensus that the transfer of carbon dioxide from the upper layer to the deep layer takes 1000 years (45). Table 2 reveals the rest of the θ values.

Table 2 (45)

θ	Value (years)
θ_{la-ua}	5
θ_{la-sb}	1
θ_{la-lb}	100
θ_{la-ul}	30
θ_{ua-la}	5
θ_{sb-la}	1
θ_{lb-la}	100
θ_{ul-la}	30
θ_{ul-dl}	100
θ_{ul-mb}	10
θ_{dl-ul}	1000
θ_{mb-ul}	10

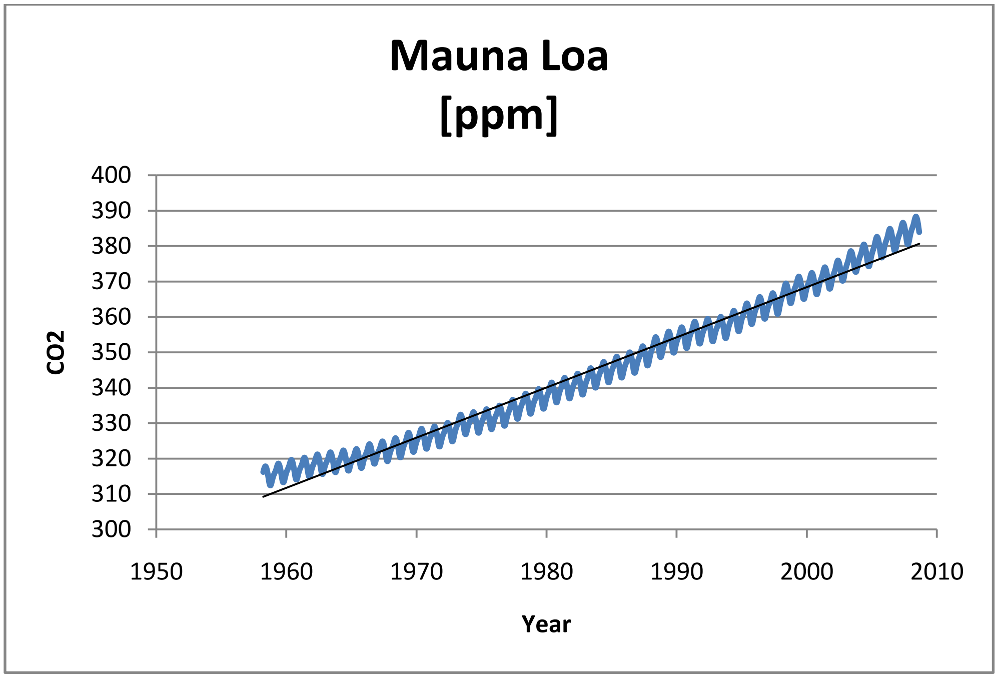
By using ordinary differential equations, this model can reasonably predict future carbon dioxide predictions. By change the rate at which carbon dioxide production increase with respect to time, it can also compare different policies on the subject with one another. By collecting data from different sources, we were able to determine many different possible rates for comparing.

Climate Models and Results

For the model, we calculated the effect of different rates on the concentration of carbon dioxide in the atmosphere. First, we fixed the rate of change for the emissions to match actual data from Mauna Loa. Then we adjusted this rate to match plans proposed to reduce emissions to see their effect on the concentration of carbon dioxide in the lower atmosphere in the year 2050. With these percent reductions of emissions, we replaced the r_{c1} values obtained new concentration lines.

In order to obtain a concentration line that better fit real life values, we derived the rate of change from the Mauna Loa data. Over the course of time, the rate of carbon dioxide added to the atmosphere increases very slightly each year. Over the course of a year, the concentration fluctuates in a sinusoidal fashion due to the seasons as seen in Figure 32 (1). In order to find the average change in the rate it increased by, we calculated the difference between each point and the previous point. These values were the change in the concentration with respect to time, and they fluctuated between positive and negative changes due to the sinusoidal nature of the line. Do to the upward trend, however, the average tended to be positive. When we took the average of these values, we obtained a value for the percent increase, 1.259%. Consequently, we replaced the base rate of increase at the 2010 mark with this rate, $c_{r1} = 0.00259$.

Figure 32 (1)



Using the base rate increase set by the Mauna Loa calculations, we modified the rate of increase using different plans. A plan presented by Senator John Kerry to Congress proposed a reduction of emissions in the United States by 35% by the year 2050. We assumed best-case scenario and treated it as if these changes occurred immediately in the year 2010. Because the United States constitutes approximately 22.2% of global emissions, this constituted a change in global emissions by about 5.5%. In order to see this effect on a larger scale, we applied this reduction to China as well. China produces a greater percentage of carbon dioxide than the United States, 24.4%, and together they generate nearly half of the carbon dioxide produced worldwide. When we applied this change to both China and the United States, the total reduction in global emissions was 14.6 %, significantly less than when we applied it to the United States alone. The final plan we applied was the Kyoto Protocol. This plan calls for a reduction to 5.2% less than the 1990 concentrations, 29% less than today's rate. By applying this to the Mauna Loa data, we received the greatest decrease global concentration. A worldwide application of this policy is highly unlikely by 2010, however, if the United States and China were to adopt the Kerry plan or a similar policy such as the Kyoto Protocol, it would not only reduce CO_2 concentrations by about half of what a global policy change would accomplish, but it would set an example that many countries would potentially follow. While the implementation of these policies only reduces the global concentration of CO_2 by 10-17ppm in 2050, they have the potential of bringing concentrations below the 450-ppm level, minimizing drastic environmental effects.

For comparisons sake, we calculated what would happen if global emissions stopped increasing. If this were to occur, the carbon dioxide in the atmosphere would eventually level off and remain constant. By looking at the chart, this trend becomes noticeable. This would require no production of new processes that emit greenhouse gases, and may cause severe disadvantages to developing nations. In the following table is a list of r_{1c} values and the resulting compositions in the year 2050.

Using values from the EDGAR dataset for CO_2 emissions, we were able to isolate power generation from the two largest CO_2 emitting countries, USA and China. Creating multiple Scenarios where these countries convert percentages of their power generation from CO_2 emitting sources to wind or solar power, we modified the rate of CO_2 increase to determine the effect on global CO_2 concentrations (46). Because the USA and China are so close in emissions, three of the scenarios returned nearly identical results. Due to the small difference in percentage change of the rate, The model revealed that a full switch to wind and solar of the USA or China or a half switch of both to wind/solar power would result in about the same concentration of CO_2 (455.3ppm). The most successful policy of these is clearly the full switch for both countries to wind and solar power, resulting in 450.9ppm by 2050 (46). While these values are not drastic changes from the current progression, combining a power generation policy change for the USA and China, and instituting one of the policies from the previous graph is not a very drastic policy change, yet it could decrease the concentration of CO2 to below the 450 ppm threshold, a significant environmental level of CO2 concentrations (46).

The artificial carbon sink discussed earlier claimed that 1 square meter had the potential to extract 1000 tons of carbon dioxide per year. Annual CO2 emissions are slightly more than 27 billion metric tons per year. The amount of CO2 per year a square kilometer of this artificial carbon sink would remove turns out to be roughly 907 thousand metric tons. By this same logic, 10 square kilometers would remove 10 times this, and 100 square kilometers would remove 100 times this. Removal of these amounts of CO2 divided by the total human CO2 input should then reveal the percentage decrease effect of each examples of these artificial carbon sinks. When these values are applied to the model, there are drastic results. The 1 square kilometer had a decrease of 2 ppm CO2 by 2050, the 10 square kilometer had a nearly 20-ppm decrease, and the 100 square kilometer had an 80-ppm decrease. These values show the potential effect the artificial carbon sink could have on global CO2 concentrations. While these results seem promising, there are possible flaws with the mathematics involved with the carbon sink's effectiveness. The first potential flaw could be the artificial sink's effectiveness as carbon concentrations decrease; while it may remove as much as 1000 tons per year, at a lower CO2 ppm it may not be as effective. The second issue with this system is the use of algae and relies on an external component being moved from outside to inside a greenhouse; depending on how the movement is performed, a large scale realization of this artificial sink may prove to be impractical, as it requires some form of external energy. Another potential issue with the system is the effectiveness of large quantities of the sink in the same area; 1 square kilometer may be severely less effective than 1 square meter, meaning the system would need to be spread out to be most effective. While these concerns are valid, and the effectiveness of the artificial carbon sink at a large scale may be less than its effectiveness on the small scale, should the results of a large scale realization of this artificial sink be even nearly as effective as the small scale, it would prove to be an incredibly effective system as a possible solution to global warming.

Figure 33 *(45)*

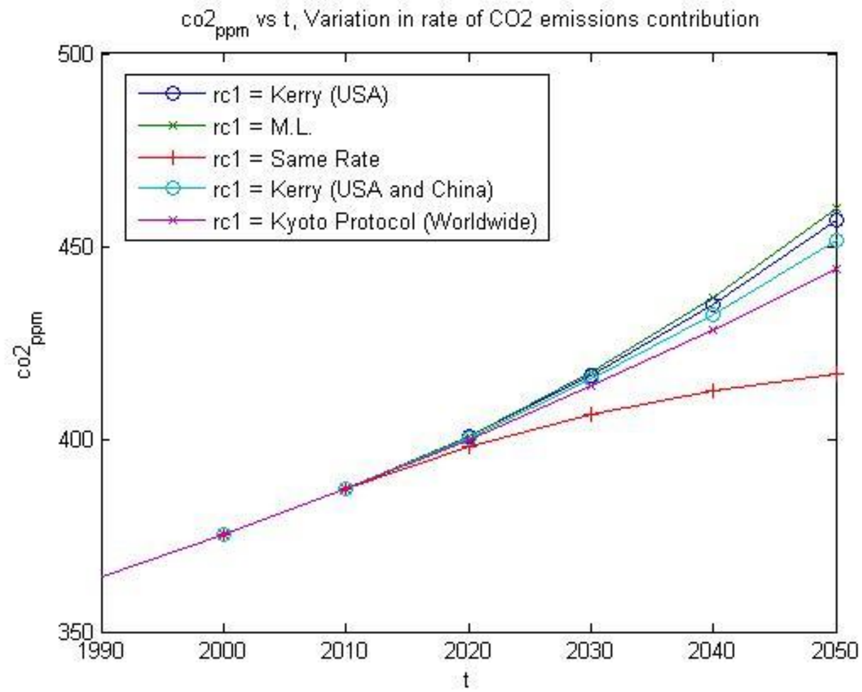


Table 3 *(45)*

Name of Rate	r_{1c}	**ppm of CO_2 in the year 2050**
Mauna Loa	0.00259	460
Stagnant	-0.0100	417
Kerry Plan (USA)	0.001902	456.7
Kerry Plan (USA + China)	0.000768234	451.5
Kyoto Protocol (Worldwide)	-0.0010611	443.9

Figure 34 *(45)*

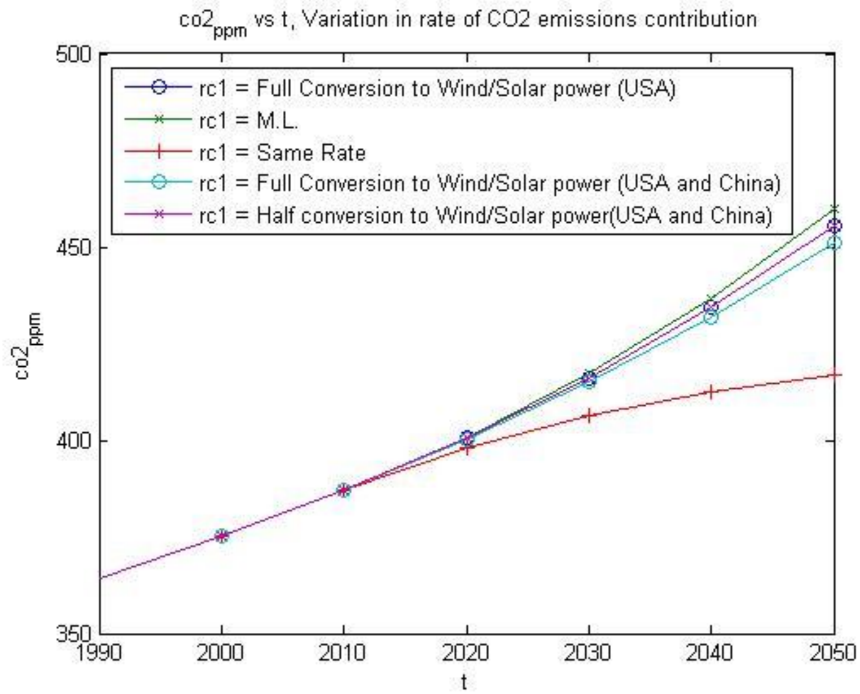


Table 4 *(45)*

Name of Rate	r_{1c}	**ppm of CO_2 in the year 2050**
Mauna Loa	0.00259	460
Stagnant	-0.0100	417
Wind/Solar Conversion (USA)	0.001613	455.3
Wind/Solar Conversion (USA + China)	0.000627219	450.9
50% Wind/Solar Conversion (USA + China)	0.001609239	455.3

Figure 35 ***(45)***

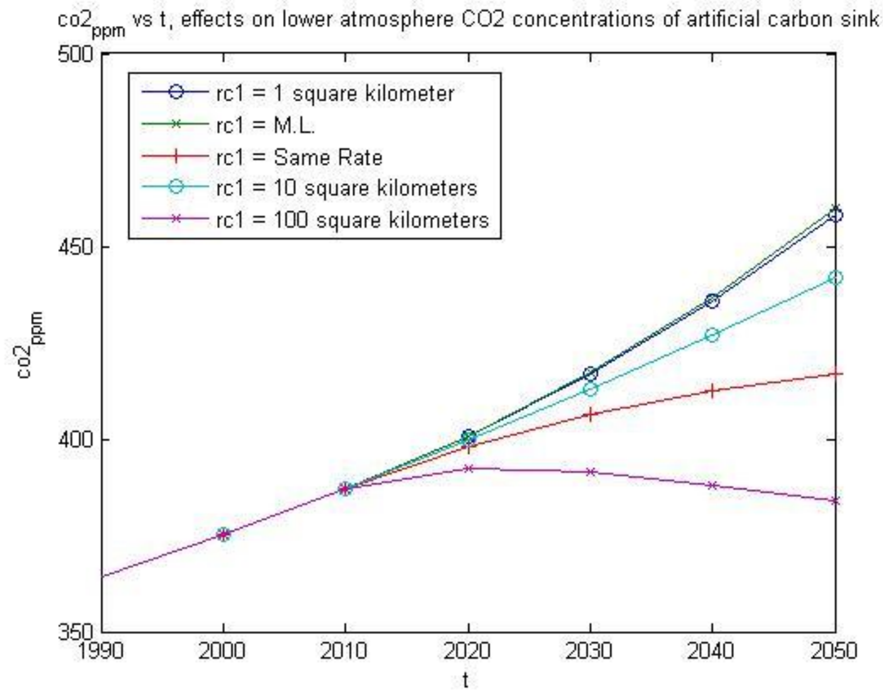


Table 5 ***(45)***

Name of Rate	$\mathbf{r_{1c}}$	**ppm of CO_2 in the year 2050**
Mauna Loa	0.00259	460
Stagnant	-0.0100	417
1 square kilometer	0.00217	458
10 square kilometers	-0.0016	441.8
100 square kilometers	-0.03933	384

Recommendations for Future Projects

Throughout our research a number of possible methods for carbon emission and atmospheric carbon concentration reduction were found, as well information involving increase of the earth's reflectivity, or albedo. Investigating solutions for Global Warming should be the primary course of study, as the atmosphere's carbon dioxide concentration continues to rise.

The development of an outline for a cost effective cap-and-trade policy would be an area in need of study, with cap-and-trade policy being the main regulator policy proposed by legislative officials. An economically sound method for regulating the global industry's emission of Greenhouse Gases such as carbon dioxide would be a crucial step in the prevention of an annual increase in the rate of carbon emissions globally.

Research pertaining to new technologies for carbon mitigation, sequestration, and conversion should also be taken into an account. One proposed method studied in this report has the ability to remove approximately one thousand tons of carbon from the atmosphere annual, taking up the space of one square meter. This technology, on a much larger scale, was modeled and showed significant reduction in carbon levels by the year 2050. Further research in artificial carbon sink technologies is recommended.

Conclusion

It is undeniable that the carbon dioxide currently in the atmosphere today is much greater than that before the dawn of the Industrial Revolution. Additionally, there is evidence to support an increase of global temperature over this period. This data, and data from other sources, demonstrate that there is a direct relationship to the concentration of greenhouse gases in the atmosphere, and the average mean temperature of the earth. Because the human race produces more and more greenhouse gases each year, we may do irreparable damage to the earth's ecosystem unless we control our output.

Our research allowed us to understand the affect of global warming on earth's environment and ecosystem. According to data we obtained, the composition of carbon dioxide will reach a critical point by the year 2050. At this time, carbon dioxide will be at 450 ppm, and the oceans will start to become too acidic to support algae. This will disrupt the entire oceanic ecosystem, which could prove disastrous. By using a model, we tested different scenarios that could reduce the carbon dioxide in the atmosphere.

Using data obtained from Mauna Loa observations of carbon dioxide concentrations in the lower atmosphere, we calculated a rate at which the carbon dioxide in the atmosphere is increasing. By altering the rate in the model, we adjusted it to match what we believed best fit the carbon dioxide level in the atmosphere in the future. Using this rate as a baseline, we calculated different effects of carbon dioxide reduction plans.

The analysis of the Kerry Plan, the Kyoto Protocol, and the implementation of alternative fuels show promising yet not necessarily drastic changes in global CO2 concentration. The model representation of the artificial carbon sink revealed a much more drastic change in global CO2 concentrations, meaning it has a higher potential than political policies or alternative fuels.

While alternative fuels and policy changes should be considered an integral part of the solution to global warming, the artificial carbon sink shows promising results if it can reliably be implemented on a large scale. The graphical representations of the implementation of each of these areas of possible solutions reveal how effective each would likely be. When taking into consideration significant environmental consequences to CO_2 concentrations of 450 and 650ppm, it becomes apparent that action should be taken soon in order to avoid or diminish the effects of reaching these levels. The model provides a small window for analyzing the effect of these specific policies, and how effective they could be at delaying or preventing these dangerous CO_2 levels.

Works Cited

1. *Exchanges of Atmospheric CO2 and 13CO2 With the Terrestrial Biosphere and Oceans from 1978 to 2000.* **Keeling, C. D., et al.** 2008, Scripps Institution of Oceanography, p. 88.

2. **Hieb, Monte.** Water Vapor Rules the Greenhouse System. *Geocraft.* [Online] January 2003. http://www.geocraft.com/.

3. **Koerner, Brendan I.** Is Global Warming Caused by Water Vapor? *Slate.* [Online] The Green Lantern, January 2008. http://www.slate.com/.

4. **Appel, Arianne.** Global Warming Supercharged by Water Vapor? *National Geographic News.* [Online] National Geographic, November 2005. http://news.nationalgeographic.com/.

5. **Bothun, Dr. Greg.** Greenhouse Effect. *The Electronic Universe: an educational outreach server.* [Online] 1998. http://zebu.uoregon.edu/.

6. —. All About Methane. *The Electronic Universe: an educational outreach server.* [Online] 2004. http://zebu.uoregon.edu/.

7. **Hasslberger, Sepp.** Global Warming: Methane Could Be Far Worse Than Carbon Dioxide. *Networking For A Better Future.* [Online] September 2008. http://www.newmediaexplorer.org/.

8. **Smith, David, Cheng, Ping and Spanel, Partik.** Analysis of petrol and diesel vapour and vehicle engine exhaust gases using selected ion flow tube mass spectrometry. *Wiley Interscience.* [Online] June 15, 2002. [Cited: February 1, 2009.] http://www3.interscience.wiley.com/.

9. **United States Environmental Protection Agency, Office of Transportation and Air Quality.** *Update of Methane and Nitrous Oxide Emission Factors for On-Highway Vehicles.* 2004. EPA420-P-04-016.

10. Chapter 3. Vehicle Miles Traveled. *eia Transportation.* [Online] February 1, 2002. [Cited: February 5, 2009.] http://www.eia.doe.gov/emeu/rtecs/chapter3.html.

11. *Forests, Carbon and Global Climate.* **Malhi, Yadvinder and al., et.** 2002, Philisophical Transactions: Mathematical, Physical and Engineering Sciences, pp. 1567-1591.

12. *Tropical Deforestation and Greenhouse-Gas Emissions.* **Fearnside, Philip M. and al, et.** 2004, Ecological Applications, pp. 982-986.

13. *Southern Ocean Acidification: A tipping point at 450-ppm Atmospheric CO2.* **McNeil, B.** 2008, PNAS. 105, pp. 18860-18864.

14. **EPA.** *Environmental Protection Agency.* [Online] 2007. http://www.epa.gov/.

15. **UCS.** Early Warning Signs of Global Warming: Droughts and Fires. *Union of Concerned Scientist: Citizens and Scientists for Environmental Solutions.* [Online] UCS, November 2003. http://www.ucsusa.org/.

16. **Boulder.** Drought's Growing Reach: NCAR Study Points to Global Warming as Key Factor. *The University Corporation for Atmospheric Research.* [Online] UCAR, January 2005. http://www.ucar.edu/.

17. **Boxall, Bettina.** Global Warming: Epic Droughts Possible, Study Says. *CommonDreams.org.* [Online] October 2004. http://www.commondreams.org/.

18. **R. A. Pielke, Jr., et al.** Hurricanes and Global Warming. *Bulletin of the American Meteorological Society, 86:1571-1575.* [Online] http://sciencepolicy.colorado.edu/.

19. Hurricanes, Typhoons, Cyclones - In Depth. *The University Corporation for Atmospheric Research.* [Online] September 2008. http://www.ucar.edu/.

20. **Knutson, Thomas R.** Global Warming and Hurricanes. *Geophysical Fluid Dynamics Laboratory.* [Online] September 2008. http://www.gfdl.noaa.gov/.

21. **Graham, Holli Riebeek and Steve.** Hurricanes: The Greatest Storms on Earth. *Earth Observatory.* [Online] November 2006. http://earthobservatory.nasa.gov/.

22. **Trenberth, Kevin E., Davis, Christopher A. and Fasullo, John.** Water and Energy Budgets od Hurricanes: Cases Studies of Ivan and Katrina. *Journal of Geophysical Research. Vol. 112, D23106.* [Online] December 2007. http://www.cgd.ucar.edu/.

23. **Rasmussen, Carol.** El Niño and global warming: What's the connection? *The University Corporation for Atmospheric Research.* [Online] April 2000. http://www.ucar.edu/.

24. **McMahon, Tim.** Are Hurricanes Inflationary or Deflationary? *Hurricane Katrina: The Economics of Disaster.* [Online] http://inflationadata.com/.

25. **Edmondson, Brad.** American Diaspora. *ePodunk.* [Online] 2007. http://www.epodunk.com/.

26. **NASA Earth Observatory.** Earth's Albedo in Decline: Image of the Day. [Online] February 2009. http://earthobservatory.nasa.gov/IOTD/.

27. Albedo. *Encyclopedia of Earth.* [Online] 2008. http://www.eoearth.org/article/Albedo/.

28. Earth Warms; Arctic Ice Cap Thins. *Ecology Global Network.* [Online] November 2001. http://ecology.com/featuresarchive/earthwarms/.

29. *Wildlife Responses to Climate Change: North American Cas Studies.* **Crozier, Lisa and Schneider, S. H.** [ed.] T. L. Root. s.l. : Island Press, 2001.

30. *Shifts in Winter Distrubution in Birds: Effects of Global Warming and Local Habitat Change.* **Valiela, Ivan and Bowen, Jennifer L.** 2003, Ambio, pp. 476-480.

31. **Ketel, Hermen J.** Global Warming and Human Migration, Climate Change, Human Systems and Policy. *Encyclopedia of Life Support Systems (EOLSS).* [Online] 2004. http://www.eolss.net/.

32. [Online] http://afp.google.com/article/ALeqM5jbrzPnyd1kod-jMJpGPWYhWmuHoA.

33. [Online] http://www.msnbc.msn.com/id/9255431/.

34. **Rahmun, Saifur.** Green Power: What Is It and Where Can We Find It? *Power and Energy Magazine, IEEE. Volume: 1, Issue: 1.* [Online] January/February 2003. http://ieeexplore.ieee.org/.

35. —. Green Power: What Is It and WHere Can We Find It? *Power and Energy Magazine, IEEE. Volume: 1, Issue: 1.* [Online] January/February 2003. http://ieeexplore.ieee.org/.

36. **Bak, T., et al.** Photo-electrochemical hydrogen generation from water using solar energy. [Online] March 2002. http://www.sciencedirect.com/.

37. **Beckjord, Eric S.** The Future of Nuclear Power. [Online] 2003. http://web.mit.edu/nuclearpower/.

38. **Fossil Energy Office of Communications.** Clean Coal Technology. [Online] February 2009. http://www.fossil.energy.gov/programs/powersystems/cleancoal/.

39. **Andrews, Wyatt.** Clean Coal - Pipe Dream or Next Big Thing? [Online] June 2008. http://www.cbsnews.com/stories/2008/06/20/eveningnews/main4199506.shtml.

40. **Fossil Energy Office of Communications.** Gasification Technology R&D. [Online] December 2008. http://www.fossil.energy.gov/programs/powersystems/gasification/index.html.

41. *Sinks For Anthropogenic Carbon.* **Gruber, Nicolas and Sarmiento, Jorge L.** August 2002, Physics Today, pp. 30-36.

42. **Wright, Allan B. and Lackner, Klaus S.** Method And Apparatus For Extracting Carbon Dioxide From Air. *Global Research Technologies, LLC, assignee. Patent WO 2008/042919 A2.* 2008.

43. First Successful Demonstration of Carbon Dioxide Air Capture Technology Achieved. [Online] http://www.physorg.org/news96732819.html.

44. **Xu, Kenong et al.** Sub1 A is an ethylene-response-factor-like gene that confers submergence tolerance to rice. *Nature.* 2006, pp. 442, 705-708.

45. *An Introductory Global CO2 Model.* **Griffiths, G. W., McHugh, A. J. and Schiesser, W. E.** 2008, p. 43.

46. **Berdowki, Van Aardenne et al. (2001) adjusted to Olivier and.** The EDGAR Database. [Online] 2001. http://www.mnp.nl/edgar/model/.

47. **Rahmun, Saifur.** Green Power: What Is It and Where Can We Find It? *Power and Energy Magazine, IEEE. Volume: 1, Issue: 1.* [Online] January/February 2003. http://ieeexplore.ieee.org/.

48. **Howden, Daniel.** Deforestation: The Leading Cause of CO2 Emissions. [Online] May 2007. http://www.appinsys.com/GlobalWarming/Deforestation.htm.

Appendix

Table of Figures

Provided Coded For Model taken from Griffiths et al.

Code for CO_2 Rate for Table 3 and Figure 33 (45)

File: CO2_Rate.m

```
  function [c1,r1]=CO2_rate(t)
%
% Function CO2_rate returns the constants c1, r1 in the CO2 % source term %
%   CO2_rate = c1*exp(r1*(t-1850))
%
% for the case ncase.
%
  global ncase
%
% c1 sets the CO2 ppm at 2007
  c1=4.4e-03;
%
% Base CO2 rate
  r1b=0.0100;
  r1=r1b;
%
% Change the base rate for t > 2010
  if(t>2010)
    if(ncase==1)r1c= 0.001902; end
    if(ncase==2)r1c= 0.00259; end
    if(ncase==3)r1c= -0.0100; end
    if(ncase==4)r1c= 0.000768234; end
    if(ncase==5)r1c= -0.0010611; end
    if(ncase==6)r1c=-0.001061; end
    if(ncase==7)r1c=-0.0029; end
%
%   Linear interpolation in t between 2010 and 2100
    r1=(r1b+r1c*(t-2010)/(2100-2010));
  end
```

File: Model.m

```
%
% Clear previous files
  clear all
  clc
%
% Parameters shared with other routines
  global ncall ncase
%
% Spline coefficient arrays
  global epss hions Tcs pHs
%
% Equilibrium constants
```

```
  global k0 k1 k2 kb kw
%
% Select case
%
% for ncase=1:1 - case 1 (nend=1)
% for ncase=2:2 - case 2 (nend=1)
% for ncase=3:3 - case 3 (nend=1)
% for ncase=4:4 - case 4 (nend=1)
% for ncase=1:4 - all four cases (nend=4)
  for ncase=1:5
  nend=5;
%
% Initial condition
  n=7;
  y0=zeros(1,n);
%
% Independent variable for ODE integration
  t0=1850;
  tf=2100;
  tout=[t0:10:tf]';
  nout=26;
  ncall=0;
%
% Set up spline interpolation
  nouts=2;
  [epss,hions,Tcs,pHs]=splines(nouts);
%
% ODE itegration
  reltol=1.0e-06; abstol=1.0e-06;
  options=odeset('RelTol',reltol,'AbsTol',abstol);
  mf=2;
  if(mf==1) % explicit integration
    [t,y]=ode45 (@model_1,tout,y0,options); end
  if(mf==2) % implicit integration
    [t,y]=ode15s(@model_1,tout,y0,options); end % % Display selected output
  fprintf('\n mf = %2d   abstol = %8.1e   reltol = %8.1e\n\n',...
        mf,abstol,reltol);
  fprintf('\n     t       cla       cul       pm       eps       pH       r1\n')
  for it=1:nout
%
%   CO2 emissions rate (in lower atmosphere)
    [c1,r1]=CO2_rate(t(it));
%
%   CO2 ppm (in lower atmosphere)
    pm(it)=280*(1+y(it,1));
%
%   Evasion factor
    eps(it)=ppval(epss,pm(it));
%
%   pH
    pH(it)=ppval(pHs,pm(it));
%
%   Total carbon
```

```
    Tc(it)=ppval(Tcs,pm(it));
%
%   Hydrogen ion
    hion(it)=ppval(hions,pm(it));
%
%   CO2 (CO2 + H2CO3 in upper layer)
    co2(it)=k0*pm(it);
%
%   Bicarbonate
    hco3(it)=k0*k1*pm(it)/hion(it);
%
%   Carbonate
    co3(it)=k0*k1*k2*pm(it)/hion(it)^2;
%
%   Boron
    B=0.409;
    boh4(it)=B/(1+hion(it)/kb);
%
%   Selected output
    fprintf(' %5.0f%10.4f%10.4f%10.1f%10.3f%10.3f%10.4f\n',...
            t(it),y(it,1),y(it,5),pm(it),eps(it),pH(it),r1);
  end
%
% ppm at 2007 (linear interpolation between 2000 and 2010)
  p2007=pm(16)+(pm(17)-pm(16))*(2007-2000)/(2010-2000);
  fprintf('\n ncase = %2d, ppm(2007) = %6.1f\n',ncase,p2007);
  fprintf('\n ncall = %4d\n',ncall);
%
% Plot numerical solution
%
% vs t
  figure(1);
  plot(t,y(:,1),'o-',t,y(:,5),'+-',t,y(:,6),'x-')
  title('c(frac) vs t'); xlabel('t'); ylabel('c(frac)')
  legend('lower atmosphere','upper layer','deep layer','Location','NorthWest')
  figure(2);
  plot(t,pm,'-')
  title('c_{la}(ppm) vs t'); xlabel('t'); ylabel('c_{la}(ppm)')
  figure(3);
  plot(t,eps,'-')
  title('eps vs t'); xlabel('t'); ylabel('eps')
  figure(4);
  plot(t,pH,'-')
  title('pH vs t'); xlabel('t'); ylabel('pH') % % vs pH
  figure(5);
  plot(pm,co2,'-')
  axis tight
  title('CO_2 + H_2CO_3 (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('CO_2 + H_2CO_3')
  figure(6);
  plot(pm,hco3,'-')
  axis tight
  title('HCO_3^- - bicarbonate (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('HCO_3^-')
  figure(7);
```

```
  plot(pm,co3,'-')
  axis tight
  title('CO_3^{-2} - carbonate (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('CO_3^{-2}')
  figure(8);
  plot(pm,boh4,'-')
  axis tight
  title('B(OH)^-_4 (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('B(OH)^-_4')
  figure(9);
  plot(pm,co2/co2(1),'o-',pm,hco3/hco3(1),'+-',pm,co3/co3(1),'x-')
  axis tight
  title('c(frac) vs ppm'); xlabel('ppm'); ylabel('c(frac)')
  legend('CO_2+H_2CO_3','HCO_3','CO_3','Location','NorthWest')
%
% Array for parametric plot
  for it=1:nout
    ppm(it,ncase)=pm(it);
  end
%
% Next case
  end
%
% Parametric plot
  if(nend==5)
    figure(10)
    plot(t,ppm(:,1),'o-',t,ppm(:,2),'x-',t,ppm(:,3),'+-',t,ppm(:,4),'O-',t,ppm(:,5),'X-')
    axis([1990 2050 350 500]);
    legend('rc1 = Kerry (USA)','rc1 = M.L.','rc1 = Same Rate','rc1 = Kerry (USA and China)', 'rc1 = Kyoto
Protocol (Worldwide)')
    title(' co2_{ppm} vs t, Variation in rate of CO2 emissions contribution');
    xlabel('t'); ylabel('co2_{ppm}');
  end
```

Code for CO_2 Rate for Table 4 and Figure 34 (45)

File: CO2_Rate.m

```
  function [c1,r1]=CO2_rate(t)
%
% Function CO2_rate returns the constants c1, r1 in the CO2 % source term %
%   CO2_rate = c1*exp(r1*(t-1850))
%
% for the case ncase.
%
  global ncase
%
% c1 sets the CO2 ppm at 2007
  c1=4.4e-03;
%
% Base CO2 rate
  r1b=0.0100;
  r1=r1b;
%
% Change the base rate for t > 2010
  if(t>2010)
    if(ncase==1)r1c= 0.001613; end
    if(ncase==2)r1c= 0.00259; end
    if(ncase==3)r1c= -0.0100; end
    if(ncase==4)r1c= 0.000627219; end
    if(ncase==5)r1c= 0.001609239; end
    if(ncase==6)r1c=-0.001061; end
    if(ncase==7)r1c=-0.0029; end
%
%   Linear interpolation in t between 2010 and 2100
    r1=(r1b+r1c*(t-2010)/(2100-2010));
  end
```

File: Model.m

```
%
% Clear previous files
  clear all
  clc
%
% Parameters shared with other routines
  global ncall ncase
%
% Spline coefficient arrays
  global epss hions Tcs pHs
%
% Equilibrium constants
  global k0 k1 k2 kb kw
%
% Select case
```

```
%
% for ncase=1:1 - case 1 (nend=1)
% for ncase=2:2 - case 2 (nend=1)
% for ncase=3:3 - case 3 (nend=1)
% for ncase=4:4 - case 4 (nend=1)
% for ncase=1:4 - all four cases (nend=4)
  for ncase=1:5
  nend=5;
%
% Initial condition
  n=7;
  y0=zeros(1,n);
%
% Independent variable for ODE integration
  t0=1850;
  tf=2100;
  tout=[t0:10:tf]';
  nout=26;
  ncall=0;
%
% Set up spline interpolation
  nouts=2;
  [epss,hions,Tcs,pHs]=splines(nouts);
%
% ODE itegration
  reltol=1.0e-06; abstol=1.0e-06;
  options=odeset('RelTol',reltol,'AbsTol',abstol);
  mf=2;
  if(mf==1) % explicit integration
    [t,y]=ode45 (@model_1,tout,y0,options); end
  if(mf==2) % implicit integration
    [t,y]=ode15s(@model_1,tout,y0,options); end % % Display selected output
  fprintf('\n mf = %2d   abstol = %8.1e   reltol = %8.1e\n\n',...
          mf,abstol,reltol);
  fprintf('\n     t       cla       cul        pm       eps        pH        r1\n')
  for it=1:nout
%
%   CO2 emissions rate (in lower atmosphere)
    [c1,r1]=CO2_rate(t(it));
%
%   CO2 ppm (in lower atmosphere)
    pm(it)=280*(1+y(it,1));
%
%   Evasion factor
    eps(it)=ppval(epss,pm(it));
%
%   pH
    pH(it)=ppval(pHs,pm(it));
%
%   Total carbon
    Tc(it)=ppval(Tcs,pm(it));
%
%   Hydrogen ion
```

```
    hion(it)=ppval(hions,pm(it));
%
%   CO2 (CO2 + H2CO3 in upper layer)
    co2(it)=k0*pm(it);
%
%   Bicarbonate
    hco3(it)=k0*k1*pm(it)/hion(it);
%
%   Carbonate
    co3(it)=k0*k1*k2*pm(it)/hion(it)^2;
%
%   Boron
    B=0.409;
    boh4(it)=B/(1+hion(it)/kb);
%
%   Selected output
    fprintf(' %5.0f%10.4f%10.4f%10.1f%10.3f%10.3f%10.4f\n',...
            t(it),y(it,1),y(it,5),pm(it),eps(it),pH(it),r1);
  end
%
% ppm at 2007 (linear interpolation between 2000 and 2010)
  p2007=pm(16)+(pm(17)-pm(16))*(2007-2000)/(2010-2000);
  fprintf('\n ncase = %2d, ppm(2007) = %6.1f\n',ncase,p2007);
  fprintf('\n ncall = %4d\n',ncall);
%
% Plot numerical solution
%
% vs t
  figure(1);
  plot(t,y(:,1),'o-',t,y(:,5),'+-',t,y(:,6),'x-')
  title('c(frac) vs t'); xlabel('t'); ylabel('c(frac)')
  legend('lower atmosphere','upper layer','deep layer','Location','NorthWest')
  figure(2);
  plot(t,pm,'-')
  title('c_{la}(ppm) vs t'); xlabel('t'); ylabel('c_{la}(ppm)')
  figure(3);
  plot(t,eps,'-')
  title('eps vs t'); xlabel('t'); ylabel('eps')
  figure(4);
  plot(t,pH,'-')
  title('pH vs t'); xlabel('t'); ylabel('pH') % % vs pH
  figure(5);
  plot(pm,co2,'-')
  axis tight
  title('CO_2 + H_2CO_3 (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('CO_2 + H_2CO_3')
  figure(6);
  plot(pm,hco3,'-')
  axis tight
  title('HCO_3^- - bicarbonate (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('HCO_3^-')
  figure(7);
  plot(pm,co3,'-')
  axis tight
  title('CO_3^{-2} - carbonate (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('CO_3^{-2}')
```

```
  figure(8);
  plot(pm,boh4,'-')
  axis tight
  title('B(OH)^-_4 (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('B(OH)^-_4')
  figure(9);
  plot(pm,co2/co2(1),'o-',pm,hco3/hco3(1),'+-',pm,co3/co3(1),'x-')
  axis tight
  title('c(frac) vs ppm'); xlabel('ppm'); ylabel('c(frac)')
  legend('CO_2+H_2CO_3','HCO_3','CO_3','Location','NorthWest')
%
% Array for parametric plot
  for it=1:nout
    ppm(it,ncase)=pm(it);
  end
%
% Next case
  end
%
% Parametric plot
  if(nend==5)
    figure(10)
    plot(t,ppm(:,1),'o-',t,ppm(:,2),'x-',t,ppm(:,3),'+-',t,ppm(:,4),'O-',t,ppm(:,5),'X-')
    axis([1990 2050 350 500]);
    legend('rc1 = Full Conversion to Wind/Solar Power (USA)','rc1 = M.L.','rc1 = Same Rate','rc1 =  Full
Conversion to Wind/Solar Power (USA and China)', 'rc1 =  Half Conversion to Wind/Solar Power (USA and
China)')
    title(' co2_{ppm} vs t, Variation in rate of CO2 emissions contribution');
    xlabel('t'); ylabel('co2_{ppm}');
  end
```

Code for CO_2 Rate for Table 5 and Figure 35 (45)

File: CO2_Rate.m

```
  function [c1,r1]=CO2_rate(t)
%
% Function CO2_rate returns the constants c1, r1 in the CO2 % source term %
%   CO2_rate = c1*exp(r1*(t-1850))
%
% for the case ncase.
%
 global ncase
%
% c1 sets the CO2 ppm at 2007
 c1=4.4e-03;
%
% Base CO2 rate
 r1b=0.0100;
 r1=r1b;
%
% Change the base rate for t > 2010
 if(t>2010)
   if(ncase==1)r1c= 0.00217; end
   if(ncase==2)r1c= 0.00259; end
   if(ncase==3)r1c= -0.0100; end
   if(ncase==4)r1c= -0.0016; end
   if(ncase==5)r1c= -0.03933; end
   if(ncase==6)r1c=-0.001061; end
   if(ncase==7)r1c=-0.0029; end
%
%   Linear interpolation in t between 2010 and 2100
   r1=(r1b+r1c*(t-2010)/(2100-2010));
 end
```

File: Model.m

```
%
% Clear previous files
 clear all
 clc
%
% Parameters shared with other routines
 global ncall ncase
%
% Spline coefficient arrays
 global epss hions Tcs pHs
%
% Equilibrium constants
 global k0 k1 k2 kb kw
%
% Select case
%
```

```
% for ncase=1:1 - case 1 (nend=1)
% for ncase=2:2 - case 2 (nend=1)
% for ncase=3:3 - case 3 (nend=1)
% for ncase=4:4 - case 4 (nend=1)
% for ncase=1:4 - all four cases (nend=4)
  for ncase=1:5
  nend=5;
%
% Initial condition
  n=7;
  y0=zeros(1,n);
%
% Independent variable for ODE integration
  t0=1850;
  tf=2100;
  tout=[t0:10:tf]';
  nout=26;
  ncall=0;
%
% Set up spline interpolation
  nouts=2;
  [epss,hions,Tcs,pHs]=splines(nouts);
%
% ODE itegration
  reltol=1.0e-06; abstol=1.0e-06;
  options=odeset('RelTol',reltol,'AbsTol',abstol);
  mf=2;
  if(mf==1) % explicit integration
    [t,y]=ode45 (@model_1,tout,y0,options); end
  if(mf==2) % implicit integration
    [t,y]=ode15s(@model_1,tout,y0,options); end % % Display selected output
  fprintf('\n mf = %2d   abstol = %8.1e   reltol = %8.1e\n\n',...
        mf,abstol,reltol);
  fprintf('\n     t       cla       cul       pm       eps       pH       r1\n')
  for it=1:nout
%
%   CO2 emissions rate (in lower atmosphere)
    [c1,r1]=CO2_rate(t(it));
%
%   CO2 ppm (in lower atmosphere)
    pm(it)=280*(1+y(it,1));
%
%   Evasion factor
    eps(it)=ppval(epss,pm(it));
%
%   pH
    pH(it)=ppval(pHs,pm(it));
%
%   Total carbon
    Tc(it)=ppval(Tcs,pm(it));
%
%   Hydrogen ion
    hion(it)=ppval(hions,pm(it));
```

```
%
%   CO2 (CO2 + H2CO3 in upper layer)
    co2(it)=k0*pm(it);
%
%   Bicarbonate
    hco3(it)=k0*k1*pm(it)/hion(it);
%
%   Carbonate
    co3(it)=k0*k1*k2*pm(it)/hion(it)^2;
%
%   Boron
    B=0.409;
    boh4(it)=B/(1+hion(it)/kb);
%
%   Selected output
    fprintf(' %5.0f%10.4f%10.4f%10.1f%10.3f%10.3f%10.4f\n',...
            t(it),y(it,1),y(it,5),pm(it),eps(it),pH(it),r1);
  end
%
% ppm at 2007 (linear interpolation between 2000 and 2010)
  p2007=pm(16)+(pm(17)-pm(16))*(2007-2000)/(2010-2000);
  fprintf('\n ncase = %2d, ppm(2007) = %6.1f\n',ncase,p2007);
  fprintf('\n ncall = %4d\n',ncall);
%
% Plot numerical solution
%
% vs t
  figure(1);
  plot(t,y(:,1),'o-',t,y(:,5),'+-',t,y(:,6),'x-')
  title('c(frac) vs t'); xlabel('t'); ylabel('c(frac)')
  legend('lower atmosphere','upper layer','deep layer','Location','NorthWest')
  figure(2);
  plot(t,pm,'-')
  title('c_{la}(ppm) vs t'); xlabel('t'); ylabel('c_{la}(ppm)')
  figure(3);
  plot(t,eps,'-')
  title('eps vs t'); xlabel('t'); ylabel('eps')
  figure(4);
  plot(t,pH,'-')
  title('pH vs t'); xlabel('t'); ylabel('pH') % % vs pH
  figure(5);
  plot(pm,co2,'-')
  axis tight
  title('CO_2 + H_2CO_3 (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('CO_2 + H_2CO_3')
  figure(6);
  plot(pm,hco3,'-')
  axis tight
  title('HCO_3^- - bicarbonate (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('HCO_3^-')
  figure(7);
  plot(pm,co3,'-')
  axis tight
  title('CO_3^{-2} - carbonate (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('CO_3^{-2}')
  figure(8);
```

```
  plot(pm,boh4,'-')
  axis tight
  title('B(OH)^-_4 (millimols/liter) vs pm (ppm)'); xlabel('pm (ppm)'); ylabel('B(OH)^-_4')
  figure(9);
  plot(pm,co2/co2(1),'o-',pm,hco3/hco3(1),'+-',pm,co3/co3(1),'x-')
  axis tight
  title('c(frac) vs ppm'); xlabel('ppm'); ylabel('c(frac)')
  legend('CO_2+H_2CO_3','HCO_3','CO_3','Location','NorthWest')
%
% Array for parametric plot
  for it=1:nout
    ppm(it,ncase)=pm(it);
  end
%
% Next case
  end
%
% Parametric plot
  if(nend==5)
    figure(10)
    plot(t,ppm(:,1),'o-',t,ppm(:,2),'x-',t,ppm(:,3),'+-',t,ppm(:,4),'O-',t,ppm(:,5),'X-')
    axis([1990 2050 350 500]);
    legend('rc1 = 1 square kilometer','rc1 = M.L.','rc1 = Same Rate','rc1 = 10 square kilometers', 'rc1 = 100
square kilometers')
    title(' co2_{ppm} vs t, effects on lower atmosphere CO2 concentrations of artificial carbon sink');
    xlabel('t'); ylabel('co2_{ppm}');
  end
```