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Atmospheric Modeling of Carbon Dioxide

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ATMOSPHERIC MODELING OF CARBON DIOXIDE

An Interactive Qualifying Project Report

submitted to the Faculty

of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

Kristen Ostermann

Date: 12 October 2007

Professor Mayer Humi, Advisor

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2 Abstract

The project considered the energy balance of the earth and the impact of trace gases on this balance. This issue was investigated through the use of a seven reservoir model of the earth's ecosystem. Simulations based on actual carbon dioxide data were used to predict the concentration of this gas in the lower atmosphere and its impact on Human society. Various strategies to increase the intake of this gas by plants and other "sinks" were considered.

3 Executive Summary

This project provides an analysis of the impact of higher concentrations of carbon dioxide on global climate change and its impact on the earth's ecosystem. To understand these effects and predict their evolution I used a model in MATLAB and changed the model parameters to study how the system can be affected. This model had seven sinks for carbon dioxide and produced graphs of the change in concentration by time. By using this program I found that models of atmospheric concentrations of carbon dioxide are very sensitive to any changes made to parameters such as equations, scales, and variables. Paying close attention to this input in the program was critical. To ensure a better understating of the results of these simulations, only one change was made at a time in order to better track the results of these changes.

By using data collected from the mid 1950's concerning the concentration of carbon dioxide in the atmosphere, I was able to formulate new equations for the input rate of carbon dioxide into the atmosphere by humans. These equations resulted in what appeared to be much more accurate results than the equations that were given in the original program. The graphs created by these new parameters all had similar shape, steadily increasing, with similar scales. Some of the graphs created from the original equations were not increasing and had wildly varying scales. Graphs with

increasing concentrations of carbon dioxide in each sink made logical sense since humans are constantly burning fossil fuels and putting more of this gas into the lower atmosphere.

No matter what model is used, it is clear that the concentration of carbon dioxide in the lower atmosphere is increasing and will more than likely continue to do so for the foreseeable future. This change in atmospheric concentration will almost certainly have a profound effect on the ecosystem of the earth. By using actual data of the increase of carbon dioxide in the atmosphere, which is, almost without question, due to human activity, the model is directly linked to the effect humans are having. These graphs are useful in encouraging the public to be more aware and conscientious of their environment.

4 Introduction

In recent years there has been significant coverage in the media about global warming but there has always been conflicting view points and interpretations of the data. My interest in this project stems from the fact that I would like to increase my understanding of global warming. I would like to understand the effect that humans have on global warming by deforestation, burning of fossil fuels, and other human activities. Therefore the effect that concentrations of trace gasses in the atmosphere have on global climate change is an integral part to this understanding. Since I am not interested in this subject for purely academic purposes, but also out of genuine concern for the effect climate change will have on life, I would also like to learn more about research that is being done on ways to mitigate the effects humans are having on the climate.

This project and my course of study are related by the fact that both deal with the impact humans have on the environment. My backgrounds in biology and chemistry are applicable to how climate change could affect life on Earth, as well as how the trace gasses in the atmosphere interact. Although this project will focus more on the effect

that human activity has on the atmosphere and my major of Environmental Engineering focuses more on the effect on groundwater and other systems on the ground. One aspect of environmental and civil engineering that is directly related to this project is the concept of green design in urban planning. Communities are being designed so there is less dependence on cars and therefore reducing the amount of carbon dioxide released into the atmosphere by human activities.

This project relates to my career goals of attempting to help reduce humans' impact on the environment. To help reduce the impact that humans have on the environment one must first understand how the environment is being impacted. This project is a crucial step to obtaining that understanding, since global warming and the impact of excess trace gasses released by the burning of fossil fuel has been a topic of heated debate in recent years.

This project may be designated as an Interactive Qualifying Project not only because it utilizes science and technology in a way to help the environment but also because it has technical depth and informational breadth. Society will be helped by this project because it is only through knowledge of the impact modern civilization has had on the Earth that we can understand how to reduce our impact and possibly have a more positive effect on the world in which we live. This project will benefit me since I am part of society as well as helping me to realize the best way in which I am best suited to help our species achieve a more sustainable way of life.

5 Research

5.1 Atmosphere

The Earth is a grey body, which is between a black body and a mirror. A black body would absorb all the radiation from the sun, while a mirror would reflect without absorbing any of the radiation. The Earth reflects some of the radiation due to characteristics of the atmosphere, such as clouds, and also due to the land cover. The

amount reflected by the Earth is dependent on the reflectivity of the current land cover, also known as the albedo of the Earth.

The radiation from the sun to the earth is concentrated in the short wave, high frequency, high energy radiation. The Earth is protected from some of the radiation from the sun and other sources by ozone and Van Allen Magnetic Belts. The short wave (visible light) radiation that reaches the earth is reflected or absorbed. The radiation that is absorbed results in heating the earth, therefore the Earth emits radiation as well. The radiation emitted by the earth is long wave, low frequency radiation. This radiation is at the exact frequencies necessary to cause carbon dioxide and methane to move to a higher energy state. The frequency of the emitted radiation does not match any of the energy levels of oxygen or nitrogen to move them to a higher energy state, so it is not absorbed. All molecules have discrete energy levels; they cannot exist at frequencies between those levels. Eventually the energy absorbed by the methane and carbon dioxide molecules is released because the increased energy state caused by the absorbed radiation is unstable. This released radiation can go in any direction, some out to space and some back to earth. In this way the atmosphere acts like a blanket, raising the average temperature of the Earth by trapping some of the radiation emitted by the earth.

Radiation is only one of the three ways that heat can propagate; heat can also be transmitted through conduction and convection. Conduction is the transfer of heat to a region of lower temperature from a region of higher temperature through matter. An example of this is when a person jumps into a body of cold water, quite quickly the person's body heat will be transferred to the colder water by conduction. Convection is the movement of heat due to the physical changes in a substance caused by the change in temperature. In the lower atmosphere, air is heated by the earth (which was heated by absorbing the sun's radiation), and as a result, the air becomes less dense and rises. As this air parcel rises further from the Earth's surface it cools, becoming more dense and sinking. In the atmosphere this process is the cause of weather patterns, while in the ocean it is the driving force between ocean currents. (Humi)

The Atmospheric Environment: Effects of Human Activity

Chapters 1 through 5

Michael B. McElroy

The first few chapters of this book provide a solid background for what is to come in the later chapters of the book. The second chapter is a quick review of some basic concepts that will be helpful in understanding the equations supporting the conclusions reached by the author. The concepts of length, time, and mass are introduced and how they are applied to create the quantities of speed, velocity, and acceleration. Throughout the chapter a general understanding is created with the presentation of increasingly complex ideas such as force, gravity, vectors, work, energy, and temperature.

The third chapter continues to provide background information with a broad coverage of chemistry. The manner in which atoms and molecules store energy, either through rotational or vibrational motion, is covered. This information appeared to be the most directly applicable information to atmospheric energy balance. The chemistry of acids, bases, and the different bonds that can form, also helps to create an important general understanding.

Chapters four and five begin to get more directly into the science of the atmosphere. Water is the first of three focuses, due to the important role it plays in our atmospheric interactions. Not only does it cover 70% of the surface of the earth but it is also the third most abundant molecule in the atmosphere. Water has some unique chemical characteristics that life on Earth is dependent upon. When water freezes to a solid it is less dense than its liquid form, which allows ice to float and therefore allowing organisms that live in the deeper water to survive throughout the winter. This chapter also emphasizes the importance of the phase diagrams of water and carbon dioxide and the importance these gases play in the composition of the atmosphere of the Earth as well as other planets. The phase diagram illustrates the triple point of substances, the point at which the temperature and pressure allow the molecule to exist in all three

phases; gas, liquid, and solid at the same time. The Earth overall is relatively near this triple point since all three phases of water are present over much of the surface of the earth.

An interesting history of the Earth is provided in chapter five, starting with the formation of this planet from the spinning mass of gas and dust that was our solar system. The elements with higher melting points, such as iron, were the first to condense and form the beginning of the inner planets. Molecules that condense at much lower temperatures precipitated out later creating the basis for the outer planets. After the Earth was mostly formed, it heated up and released elements like hydrogen, carbon, and nitrogen to the surface while iron stayed in the core. Nitrogen is a major component of the current atmosphere, accounting for 78%, while oxygen composes 21% of the atmosphere. When life first began on Earth there was very little oxygen, but eventually it accumulated in the atmosphere as a result of it being an end product of chemical reactions crucial to life on earth. Carbon dioxide on the other hand, which currently receives quite a bit of attention due to the amount created by human activity, only accounts for $350 \times 10^{-6} \%$. The relative abundance of molecules in the atmosphere is clearly not as important as their chemical properties. The different roles molecules play in the energy balance of the atmosphere depends on their different properties.

The Atmospheric Environment: Effects of Human Activity

Chapter 7: Vertical Structure of the Atmosphere

Michael B. McElroy

The atmosphere is composed of layers, which vary in pressure and temperature. The further one goes away from the surface of the earth, the lower the pressure. A simple way of understanding this change in pressure is imagining a box full of air. The force on the bottom of the box in the positive z direction is the pressure at that value of z times the area, or $p(z)A$. The force due to the air inside in the box is equal to $\rho gA(\Delta z)$, where ρ is mass density, g is gravitational acceleration, A is area, and Δz is the change in z . The force in the negative z direction on the top of the box is $p(z + \Delta z)A$, again A is

area multiplied by the pressure at the height found by adding the initial height and change in z . From this information the equation

$$p(z + \Delta z) = p(z) - \rho g \Delta z$$

can be derived. With this basic understanding of pressure and the perfect gas law, the equation for determining the pressure in small intervals, where the temperature is fairly constant can be calculated as:

$$p(z) = p(z_0) \exp[-(z - z_0)/H]$$

H has dimensions of length and is the atmospheric scale of height. It provides a measure of the effect of thickness of the atmosphere.

The temperature of the atmosphere is variable as one travels vertically through the atmosphere. The temperature decreases at an average rate of 7 K km^{-1} as one moves away from the surface of the earth until about 11 km where a minimum temperature of 216 K is reached; this region is the troposphere. The troposphere is unstable since it overturns and convects due to the decrease in temperature as altitude increases. As a result, the troposphere is also where most of the Earth's weather occurs. In the next layer, the stratosphere, which has a range from 20 km to 50 km, temperature increases with height, almost to the same temperature as on the surface, 270 K. Vertical motion is severely restricted because air attempting to rise above this layer becomes increasingly denser than the surrounding air and is forced back down. After this the temperature decreases again to reach another minimum of 180K at about 85 km from the surface; this is the mesosphere. Above this height the effects of the sun are more apparent, as the temperature varies between 750 K and 2000 K depending on the activity phase of the sun. The short wavelengths cycle every 11 years. This area of increasing temperature is the mesopause, after which comes the thermosphere, where the density is low enough for satellites to orbit for long periods of time. Within the thermosphere is the ionosphere, which is formed by free electrons created by the absorption of short wave length solar radiation. Although more is understood than ever before about the atmosphere, our knowledge is far from complete, which makes accurate modeling near impossible.

5.2 Energy Budget

The Atmospheric Environment: Effects of Human Activity

Chapter 6: Energy Budget of the Atmosphere

Michael B. McElroy

The sun emits energy in the form of photons, most of which are detectable with the naked eye. For equilibrium the energy that the Earth absorbs from the sun must be almost exactly equal to the amount of energy emitted by the Earth. This is necessary for the temperature stability of the Earth. The wavelengths of the radiation emitted by the Earth and the Sun differ due to the different types of energy emitted. The sun emits radiation with a much higher temperature; therefore it has a shorter wavelength and higher frequency, as described by the energy equations:

$$E_f = hf \text{ and } E_f = (hc)/\lambda$$

Where h is equal to Planck's constant, which is 6.62×10^{-27} erg sec, c is the speed of light, 3×10^{10} cm sec⁻¹, λ is the wavelength, and f is the frequency of the wave. Energy with waves of higher frequencies and shorter wavelengths tend to have higher energies than waves with longer wavelengths and lower frequencies. Therefore the lower energy radiation emitted by the Earth necessarily has a longer wavelength and a lower frequency than that emitted by the sun.

The visible radiation emitted by the sun is emitted from a 330 km thick layer of the sun called the photosphere. This layer ranges from 4000 to 6000 K. This temperature range contains the radiation emitted by a black body that is within the visible spectrum, 5800 K. The radiation of shorter wavelengths comes from high altitude layers of the sun's atmosphere where the temperature can be as high as 10^6 K. These high temperatures are fueled by energy released from solar reactions within the core in the form of waves that take about 11 years to travel to the outer layers of the solar atmosphere. The energy created by these reactions fluctuates over time resulting in noticeable changes in the Earth's magnetosphere resulting in changes of strength and

direction of Earth's magnetic field. The radiation emitted by the earth also has range, due to the fact the some of the radiation is just solar radiation being reflected back. In the atmosphere the gases H₂O, CO₂, O₃, CH₄, and N₂O absorb radiation in the range of wavelengths from 0.1 to 100 μm with a significant gap around blue in the visible spectrum. The other radiation is lower energy and is emitted by the surface of the earth in the infrared range.

There is an energy balance between what is absorbed and emitted by the Earth and its atmosphere. About 20% of solar radiation is reflected back by clouds, 4% by the surface, and another 6% is reflected back by the air. About 16% is absorbed by the atmosphere, 4% by the clouds, and 50% is absorbed by the surface of the Earth. This balance of energy is changing slightly due to the change in the composition of the atmosphere as a result of human activity. The amount reflected back by the surface has changed due to deforestation and the clearing of land for houses and cities. The burning of fossil fuels has resulted in a noticeable increase in the concentration of carbon dioxide in the atmosphere, while other emissions have resulted in changed cloud cover. These conclusions are reached from the information presented thus far by McElroy, but McElroy does not make these conclusions. A general description of the atmosphere of the Earth has been provided, which enable the reader to come to these conclusions. McElroy backs away from making any connections though, and presents the information so that the reader may come to his or her own conclusions.

5.3 Modeling Research

Modeling the Exchanges of Energy, Water, an Carbon Between Continents and
the Atmosphere

P. J. Sellers, R. E. Dickinson, D. A. Randall, A. K. Betts, F. G. Hall, J. A. Berry, G. J. Collatz, A. S. Denning, H. A. Mooney, C. A. Nobre, N. Sato, C. B. Field, A. Henderson-Sellers

Three increasingly complex and accurate models are discussed in this article. The first model, the simplest of the three, uses global atmospheric circulation models (ASCM). These models incorporate fluid mechanics equations, forces of gravity, Earth's rotation, pressure, temperature gradients, and friction to define the atmosphere's motion. In this model the surface of the Earth is generalized, with an average of the surface properties being used to represent the surface as a whole. The energy transfer processes considered are: radiative cooling and heating; convection; condensation; evaporation; transfer of energy; water; and momentum across the lower boundary of the atmosphere. The amount of radiant energy absorbed by land is equal to the solar energy plus energy absorbed from long wave radiation emitted by the overlying atmosphere minus the long wave radiation emitted by the surface;

$$R_n = S(1 - \alpha) + L_w - \varepsilon\sigma T_s^4$$

S is the isolation, which is calculated using latitude, longitude, cloud cover, and time of day. The surface, albedo, is represented by α , the first term for the amount of solar absorbed by the Earth because the albedo is taken into account. The second term L_w is the long wave radiation that is reflected back to the Earth by atmospheric gasses like carbon dioxide. T_s is surface temperature, the Stefan-Boltzmann constant, and ε is the surface emissivity. By combining these three terms, one finds the long-wave radiation emitted by the surface of the Earth. Two types of heat released that are considered in this model are local, sensible heat release, which raises the temperature of overlying air column, and non-local latent heat release, which has atmospheric impact.

The second model is more complex and accurate because it takes into account the effects of vegetation on atmospheric models. In this biophysical model, vegetation and soil interaction with the atmosphere were considered. The interactions studied were: Radiation absorption (vegetation is very absorbent at wavelengths from 0.4 to 0.72 μm); Momentum transfer (vegetation is a rough porous surface that enhances turbulence); Biophysical control of evapotranspiration (stomata control amount of

water vapor released); Precipitation interception (precipitation that lands on leaves is evaporated); Soil moisture availability (depth and density of roots determine water available for evapotranspiration), and Insulation (soil is insulated by the canopy). This model was found to be more accurate than the first; it was used to study the impact of large scale deforestation in the Amazon, which resulted in a surface temperature increase of 3 to 5 K.

The third model takes into account the carbon cycle and uses photosynthesis and plant water relations to provide a more accurate description of energy exchange. The efficiency with which a plant is able to capture photosynthetically active radiation and utilize the resulting products is considered in this model. The stomata contribute to a plant's efficiency by opening for carbon dioxide assimilation and closing during arid conditions so the plant does not lose copious amounts of water through the opening. This last model incorporates the other two as well as going a step further, resulting in the most accurate model.

This article seems to be a fairly straight forward presentation of the progressing accuracy and complexity of atmospheric models. It was stated the models have become more accurate but maybe this is only in certain areas, such as ones covered in dense vegetation. Maybe these models were not found to be as accurate in areas without vegetation, or at least the accuracy may not have increased from model to model in those areas. There also seemed to be a lack of discussion of types of coverage other than vegetation, such as bare rock or snow, and the differences between those. Again maybe these models may not be as accurate in these areas. Another short coming of this paper was the authors only focusing on possible contributions of climate change within the atmosphere, not accounting for contributions from elsewhere in the solar system. The sun has been shown to go through an eleven year cycle in the amount and type of radiation emitted. This study was quite thorough on vegetative effects, as the title implies, but it did not mention that fluctuations in solar radiation can also have an effect on climate change.

5.4 Climate Change

Part I: Climate Change – Our Approach

1 The Science of Climate Change: Scale of the Environmental Challenge

Global warming is presented as a fact, backed up by a comprehensive survey of different studies supporting different types of evidence of global climate change. The global average temperature has undeniably risen, most notably in the past 50 years, but the projected rise in temperature greatly depends on emissions. If the current concentrations of greenhouse gases are doubled then the resulting rise in temperature is between 2-5°C or if the rates of emission continue, the expected increase will be 3-10 °C. But these temperatures are modest; one reason is, they do not take into account 1-2 °C additional projected increase due to feedback. One form of feedback is the permafrost and wetlands, which contain more carbon dioxide than everything released by human activity so far. As the Earth warms, permafrost will melt releasing stored up carbon dioxide. This process is already happening in Siberia and currently accounts for about 15% of all emissions. The released carbon dioxide will contribute to atmospheric concentrations, reflecting back more of the Earth's released infrared energy, resulting in more global warming, which in turn would melt more permafrost.

The evidence of global climate change that is currently apparent to researchers provides a good indication of how more drastic climate change will affect the Earth. Biota has been affected by the increase in global temperature, which is indicated by the 6 km average each decade that animals have been traveling towards the poles. The impact on some plants and birds is evident by the fact that they have been flowering and laying eggs 2 to 3 days earlier each decade in recent history. The effects of global climate change have varying impacts throughout the world, not only due to the different ecosystems, but also due to the fact that the change in temperature is not distributed evenly. If the global temperature increases by 3 °C, the increase in temperature will be greater at the pole; 5-8 °C increase. The different impacts global climate change will have is compounded by the way ocean currents, rainfall, and weather patterns will be effected. Some areas, like the Mediterranean and Caribbean,

are expected to receive much less rainfall, while others, like northern North American and northern Asia, are expected to receive more. The North Atlantic Thermohaline Circulation may collapse and it is speculated that this current that keeps Europe and the North American coast warm has already experienced a 30% decrease. These results of global warming may have a cooling effect, but not so much as to offset the rising temperatures of the Northern Hemisphere due to the greenhouse effect. Since climate change is projected to have a more noticeable effect on temperature further from the equator, such as Europe and densely populated areas of North America, the effect on human civilization, especially 1st world countries, may be quite drastic.

Although this document was quite thorough with evidentiary support of global warming, there was a motivation behind it: to present evidence that not only is global warming occurring but that it is at least in part due to human activity. This report states that the concentration of carbon dioxide in the atmosphere has been increasing since 1750, mostly due to emissions of human activity. What is not mentioned is that the levels of carbon dioxide naturally increase as the temperature gets warmer due to the fact that carbon dioxide is less readily dissolved in the ocean at higher temperatures. Since there was a minor ice age in the 1700s, it is logical that the levels of carbon dioxide would increase. Although this explanation does not account for the rather large increase in the concentration of this gas, from 280 to 380 ppm, this fact still should have been mentioned.

6 Modeling

In order to better understand the modeling that has been done to predict what consequences will be experienced in the future due to the carbon dioxide that is currently being released into the atmosphere, an atmospheric modeling program was used. This Global carbon dioxide Model was used in MATLAB to generate the different levels of carbon dioxide currently found and the predicted levels for the seven different sinks on earth. The seven sinks are: upper atmosphere, lower atmosphere, long-lived

biota, short-lived biota, mixed ocean layer, deep sea, and marine biosphere. The lower atmosphere is the sink that has the most connections to other sinks. The carbon dioxide concentration can be modeled by the differential equation:

$$\frac{dC_i}{dt} = \sum k_{ij}C_j + F_i, \quad i = 1, \dots, 7$$

where C_i denotes the concentration of carbon dioxide in reservoir i . These concentrations can change in the lower atmosphere as it can exchange carbon dioxide with the upper atmosphere, long-lived biota, short-lived biota, and the ocean mixing layer. With these four sinks the lower atmosphere either receives or gives carbon dioxide by diffusion, flowing from high concentration to low concentration. The lower atmosphere also receives carbon dioxide from man-made effects and volcanic eruptions. Because of this extra input, carbon dioxide logically should be diffusing from the lower atmosphere into the other sinks.

To model the exchange of carbon dioxide this program utilizes differential equations to simulate the change in the concentration over time. The carbon concentration for a reservoir i is given by

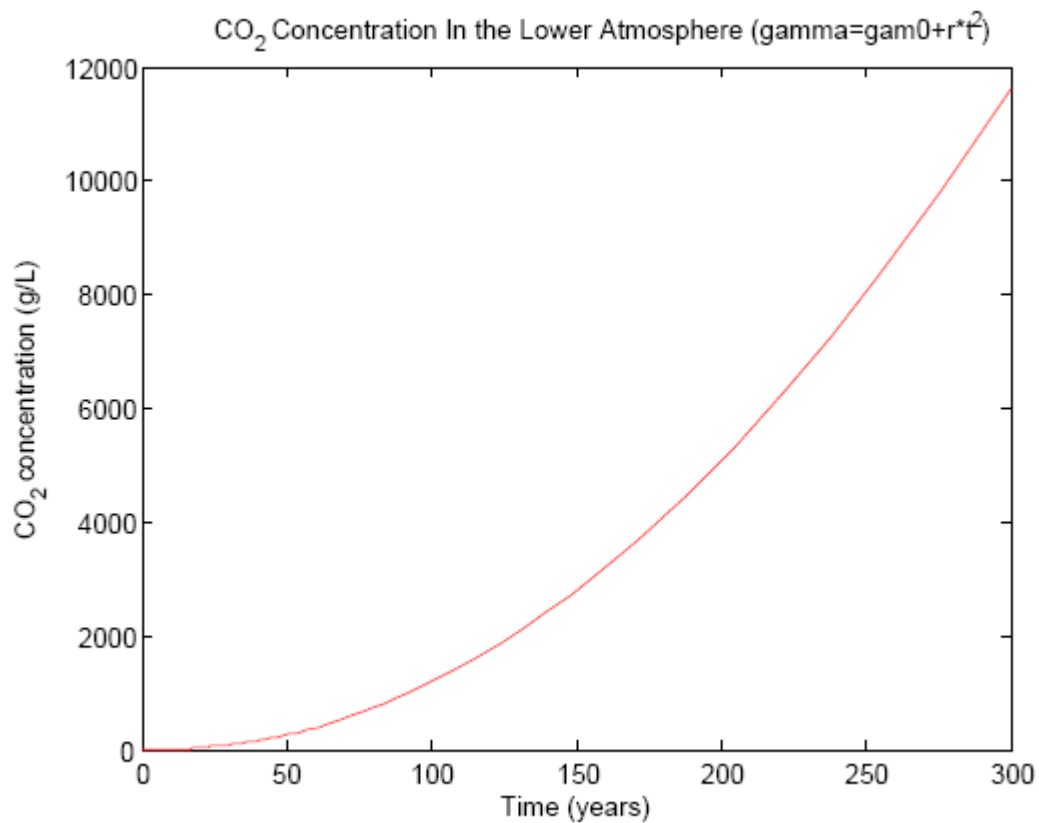
$$C_{ir}(t) = \frac{C_i(t) - C_i(1700)}{C_{ta}(1700)}$$

Where

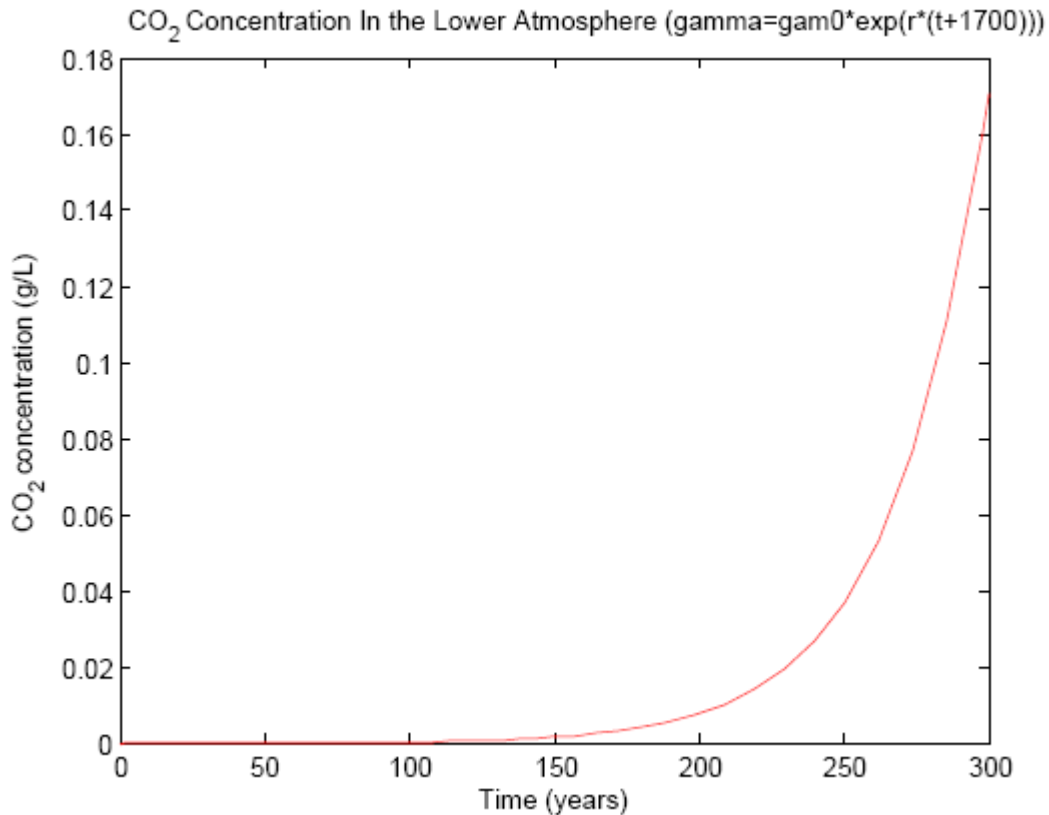
- $C_{ir}(t)$ Relative concentration of carbon in the i th reservoir at time t (dimensionless)
- $C_i(t)$ carbon in the i th reservoir at time t (grams)
- $C_i(1700)$ carbon in the i th reservoir at time $t = 1700$ (grams)
- $C_{ta}(1700)$ carbon in the total atmosphere at time $t = 1700$ (grams)

This model starts at year 1700 and goes forward three hundred years to year 2000; therefore this model derives equations from existing data. In order to focus this study more for the purposes of this project, the resulting graph for the lower atmosphere was

focused on. The lower atmosphere was chosen since it has the most connections with other sinks. And also because changes in the carbon dioxide concentrations in this sink will have the most impact on global climate patterns. In order to see how the predicted concentrations in each sink could change, different variables were changed to see how the model would be affected. For the initial model two different equations were used to model the fossil fuel combustion rate (1/year), which was denoted by $\gamma(t)$ or gamma. The graphs of the concentration of carbon dioxide in the lower atmosphere given by these two equations were:

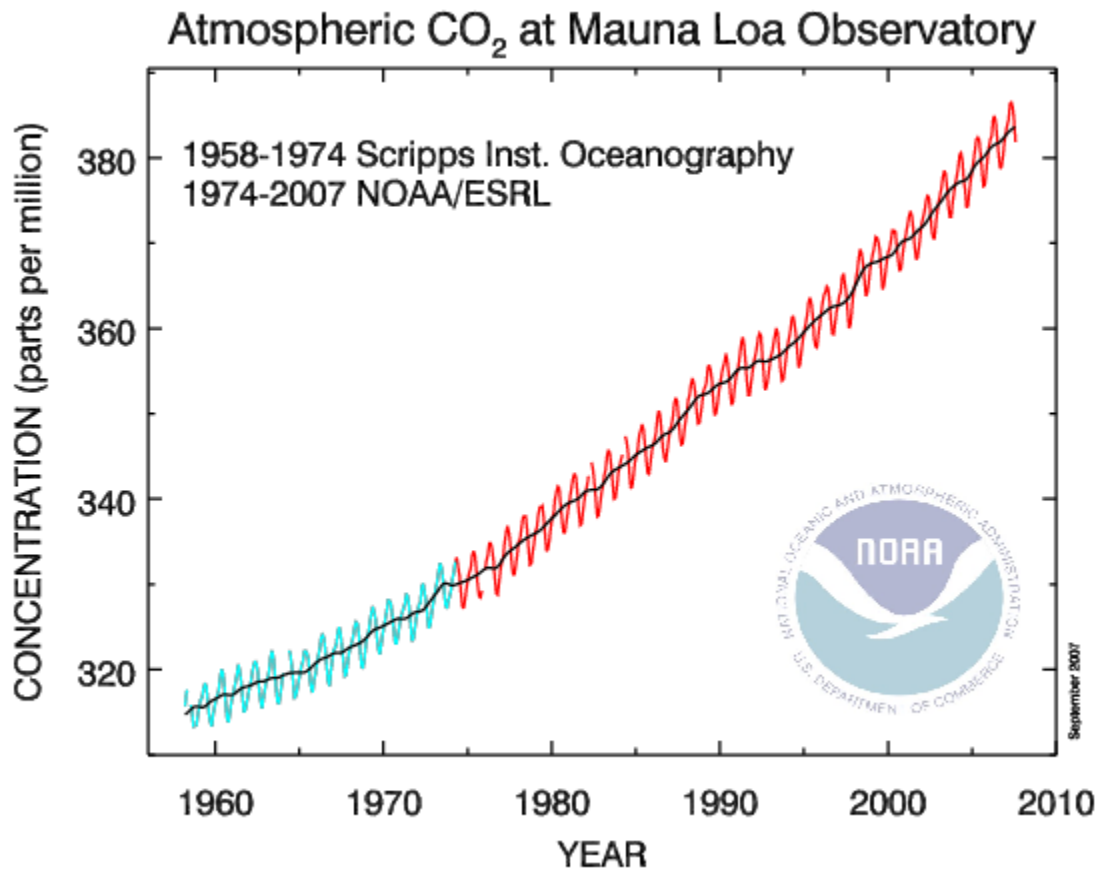


For this graph $\gamma = \gamma_0 + r \cdot t^2$, where $\gamma_0 = 2.3937 \cdot 10^{-29}$ 1/year, $r = 0.03077$ 1/year, both of which are given values.



For this graph $\gamma = \gamma_0 \cdot \exp(r \cdot (t + 1700))$. The difference between an exponential input and a second order equation is evident in the shape as well as the scale of these two graphs.

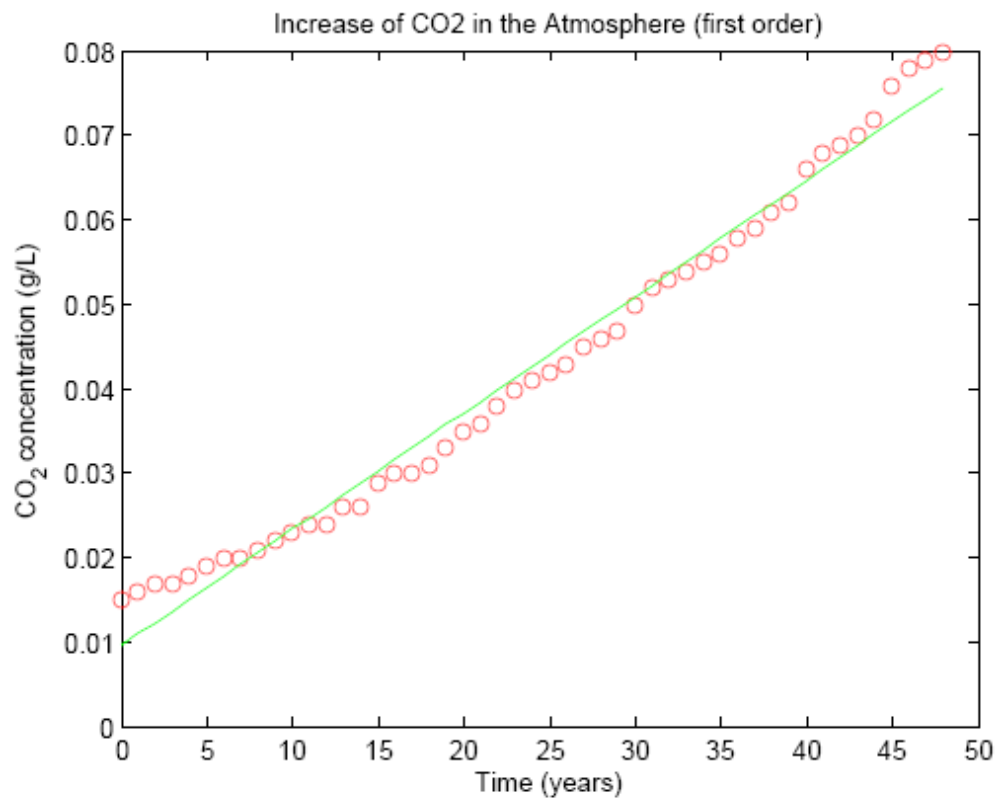
The accuracy with which these given values of gamma represent the fossil fuel combustion rate is questionable because there is such disparity in the scale. To get predictions that could be more accurate, data was taken from the oldest site continuously monitored for carbon dioxide, the Mauna Loa Observatory in Hawaii. This is a graph of carbon dioxide data that has been collected there at 4000 meters from the earth's surface for about the last fifty years.

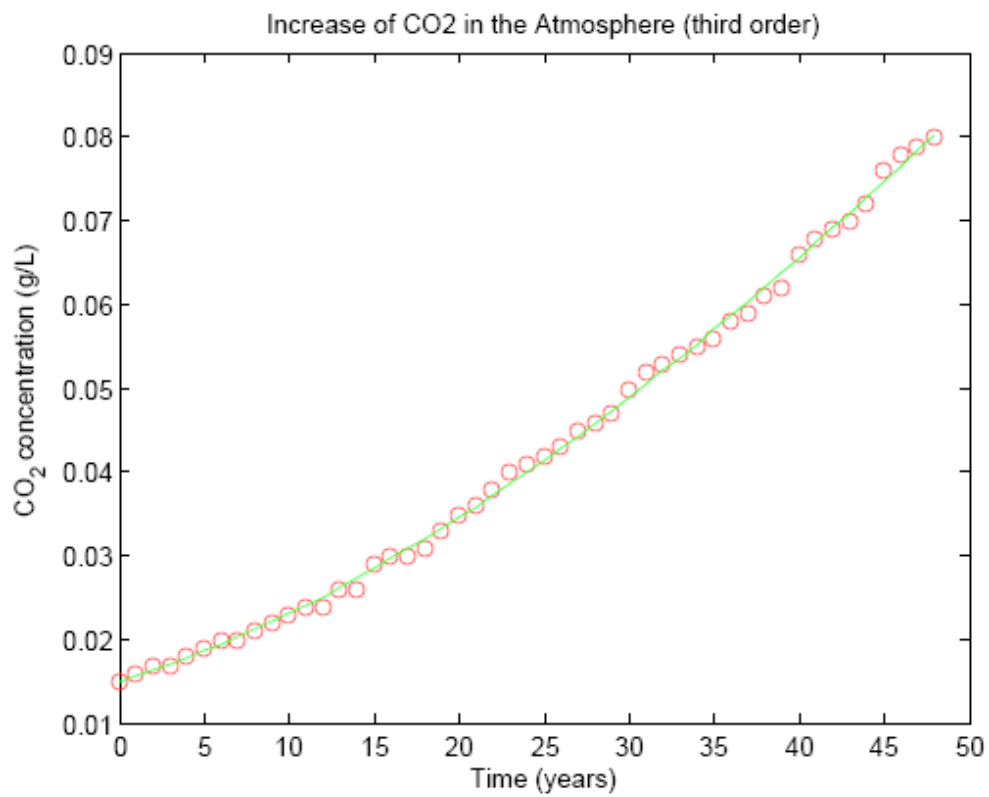
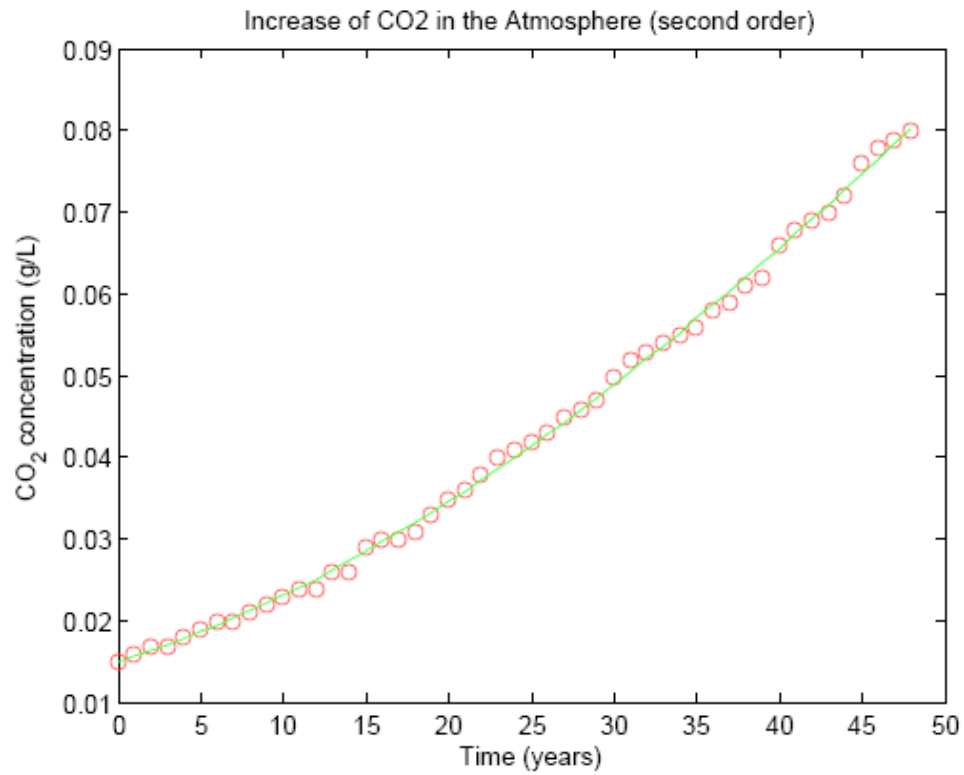


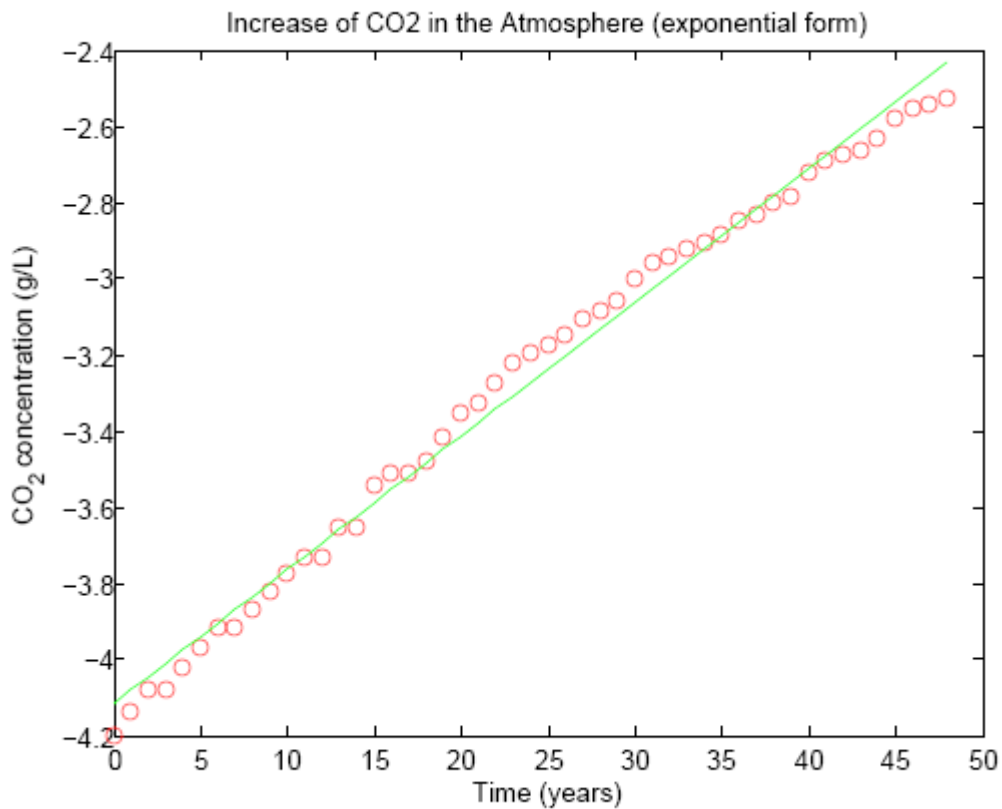
From this graph (NOAA: ESRL) a line of best fit was derived using MATLAB in order to best predict how the concentration will continue to rise in the coming years due to human activity. The data derived from this graph can be found in Appendix 11.1. To account only for the concentration of carbon dioxide added by humans, it was assumed that the initial concentration was 318 ppm, therefore 318 ppm was subtracted from each concentration. Essentially this causes the resulting data to start at a concentration of 0, allowing the derived equation to only represent the addition by human activity. Since the program is written for concentration in grams per liter the concentration in parts per million of this graph had to be converted to those units. An equation was found by inputting the year and the concentration found for each year into an excel sheet and using the Least Squares method in MATLAB to find equations for first, second, and third order equations (program can be found in Appendix 11.2). By taking the

natural log of the concentration, one is able to find an exponential equation, which appears most appropriate by looking at the curve of the graph created by NOAA.

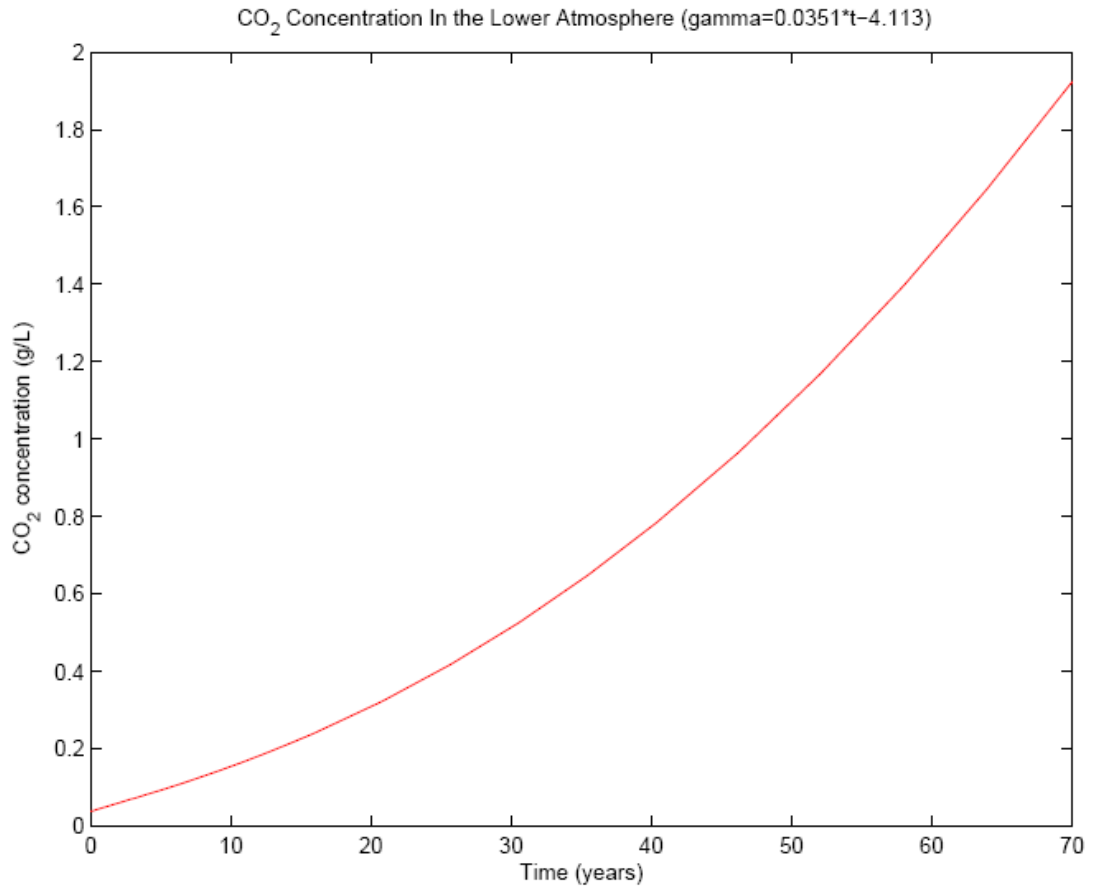
The following four graphs were created from the data from the NOAA graph. The first has a line of best fit that is first order, the second is second order, the third is third order, and the last is first order but with the natural log taken of the concentration in order to create an exponential equation.

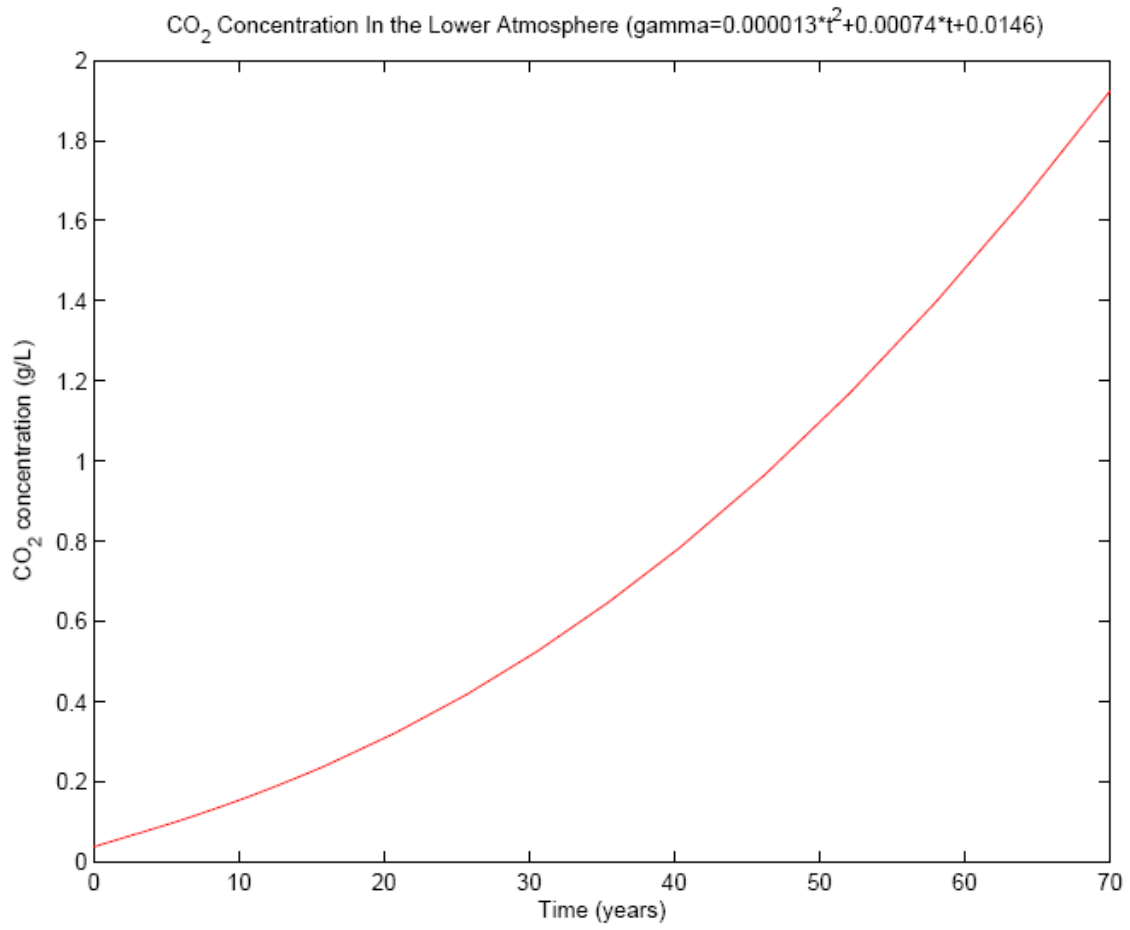


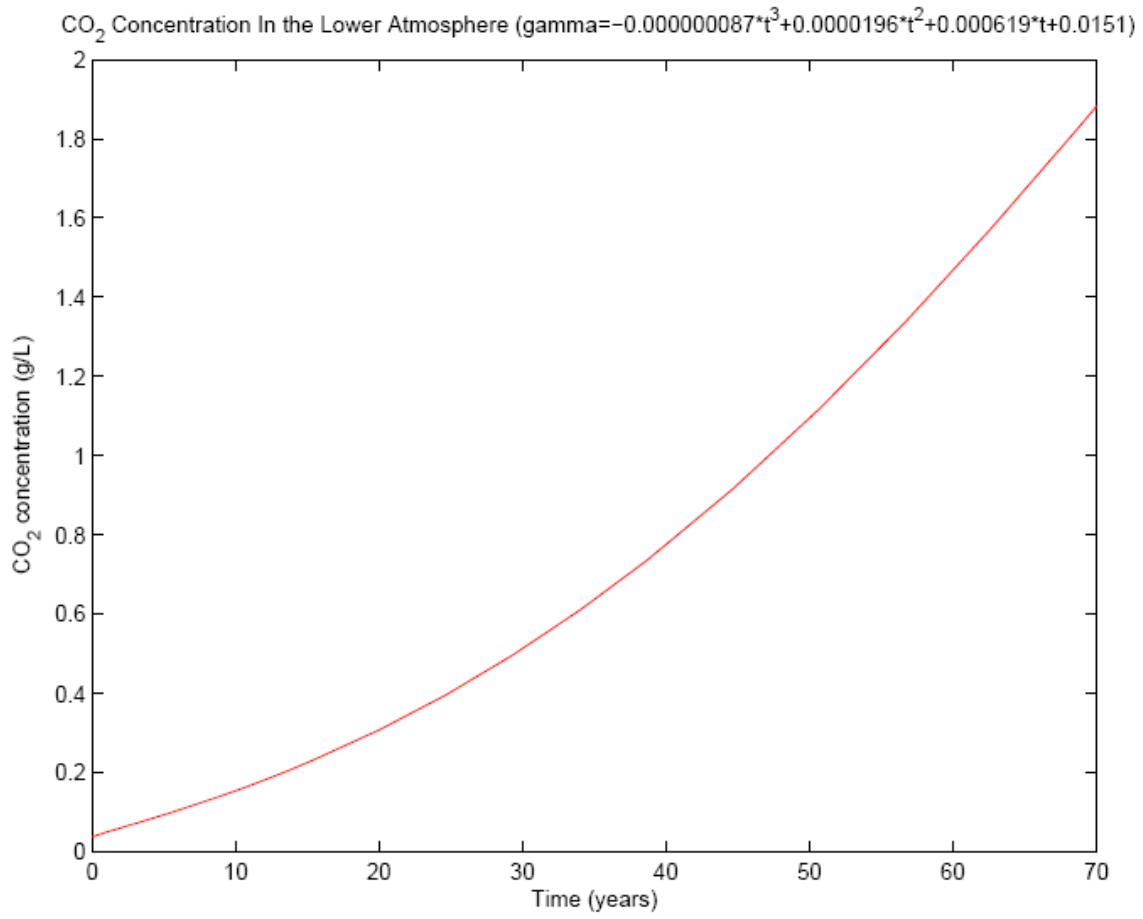


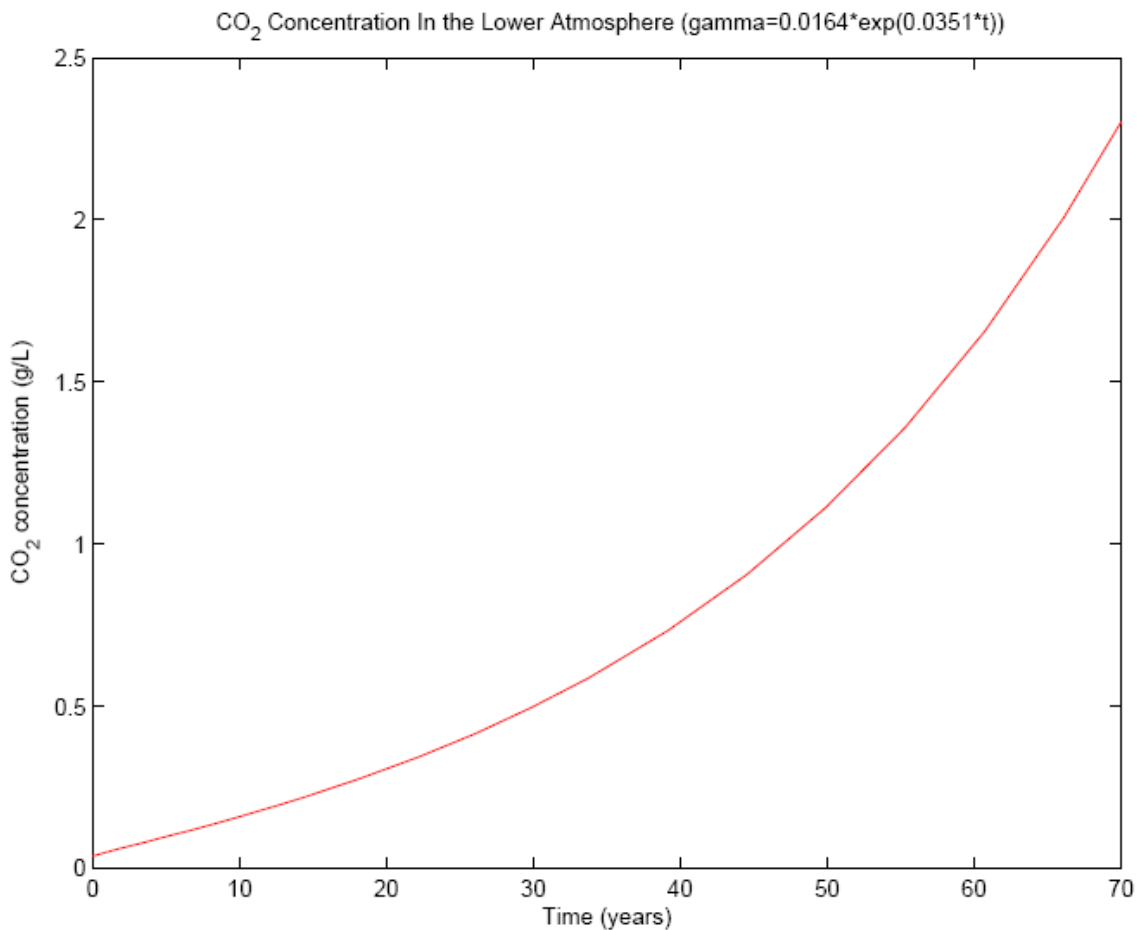


The equations for each line of best fit were inputted into the atmospheric modeling program in MATLAB for new equations for gamma. The two programs used in MATLAB to create these graphs can be found in Appendix 11.3 and 11.4. The resulting graphs for the lower atmosphere for the first, second, third order and exponential form of gamma are:









These graphs are very similar, which is not too surprising since the only difference between the four is the form of the equation used to fit the same data. The one noticeable difference is in the scale for the exponential, after 70 years it reaches a concentration of about 2.3 g/L, while the other models reach about 1.9 g/L. Although this is seemingly a minor difference between the graphs, it could result in major differences in climate. The graphs for the other sinks for these values of gamma can be found in the Appendix.

The process to create these graphs involved some missteps that resulted in graphs that were not realistic projections. Small changes in the model, such as having the incorrect scale or not accounting for the years correctly resulted in drastically different graphs. Some graphs had unrealistically high concentrations of carbon dioxide while others had the concentration of carbon dioxide decreasing, or increasing then

decreasing, instead of the expected increase in the concentration in all seven sinks. The drastic changes in the results of the graphs could make one question the validity of any modeling system, for any small change in initial conditions could completely change the predicted outcome.

7 Suggested Methods to Help Reduce Emissions

7.1 Plants

Genetically Modified Organisms 25 Years On
Mae-Wan Ho and Joe Cummins

In this article genetically modifying organisms is presented as being an unstable, unpredictable process, which appears to be more guess work than a precise science. The authors assert that genetically modified organisms (GMOs) are very inconsistent, perform poorly, and are overall a failure. The unreliability of GMOs is due to how the genomes are constructed out of genetic material from different sources in a way that would not happen naturally. The unintended effects of gene insertion include inactivating or over-expressing genes or scrambling and destabilizing the host genome. These effects are due to the random, haphazard manner in which foreign genes are inserted into the host genome. Due to this it has not been possible to produce stable transgenic lines of animals or plants for commercial use. Technology of genetic modification has improved little to none since its inception, partially due to the fact that new knowledge about genomes and splicing has not been incorporated.

Due to the trial and error guesswork nature of genetic modification, the effect that consumption of these organisms has on humans is largely unknown. The effects are becoming more apparent as more tests are being conducted and also as their widespread use results in greater consumption and in a sense resulting in human testing. Toxins from *Bacillus thuringiensis*, which have been widely used for their usefulness against

insects in the Order Coleoptera, have been shown to be harmful to mice, butterflies, and lacewings. The spores bt-toxins caused allergic reactions for farm workers, yet these toxins have been approved and widely used in GM food crops. The effects that inserting foreign genes into a host genome are widely unknown, resulting adverse effects like reduced immune response and possibly cancer among others. One result of gene insertion that is well understood is the resulting transgenic instability, which is structurally unstable DNA that easily comes apart, sometimes resulting in horizontal gene transfer. This is when the genes of GMOs are incorporated into another organism, humans or other plants that come in contact with the modified organism.

Part of the reason that GMOs have continued to have poor, unstable performance is that the newer understanding of how genes are translated has not been applied. When research with GMOs began, genes were thought to each be responsible for one trait meaning each gene had its own specific use. It is now understood that depending on how genes are spliced, one gene can result in a number of different traits. The same section of gene can result in the production of many different proteins depending on how the exons in introns are spliced in different cells at different times. Not only can genes be spliced for different results but by shifting the reading frame entirely different proteins can also be created.

Ho and Cummins presented one side of the argument over GMOs convincingly, although in a seemingly biased manner. The positive effects of GMOs, even if it was purely by chance that the genetic engineers found a genetic insertion that worked beautifully, were not mentioned. Some food has been genetically modified that has greatly benefited humans, such as rice with enhanced nutrients, seedless grapes, corn, and tomatoes. Other crops have been beneficial to the environment as well as humans because they reduced the need for and use of pesticides. Admittedly GMOs have some serious dangers and a lot still needs to be understood about them, but there also must be some positives to the research and application or it would have been stopped. It was mentioned that pesticide and insect resistant crops have been created but only in the context of the bad, unintentional effects that those modified crops also incurred. If

some of the benefits of GMOs had been presented, this article would garner more respect as a scientific article, resulting in a more beneficial experience for readers.

Practical Photosynthetic Carbon Dioxide Mitigation

G. Kremer, M. Vis, M. Prudich, D. Bayless

Plants are natural sinks of carbon dioxide, and cyanobacteria are especially efficient at utilizing carbon monoxide. Photosynthetic organisms absorb carbon dioxide, water, and sunlight to create complex sugars. The use of these organisms that naturally sequester carbon dioxide in an engineered photosynthetic system would be economical, reduce human's impact on the environment and have little associated risk.

Cyanobacteria, like other photosynthetic organisms, absorbs carbon dioxide from the air where it is only in concentrations of 350 parts per million. In flue gas, which is produced at coal-fired power plants, the concentration is 14%. High concentrations result in cyanobacteria being able to produce more biomass more quickly, for they have shorter life cycles making them readily adaptable to an increased concentration.

This engineered photosynthetic system would have some aspects of design that would need to be modified for each situation. Since a minimal pressure drop is required, the plates that the bacteria are on will be vertical, therefore the bacteria will have to be able to cling, while at the same time not being too difficult to harvest when they have stopped growing. Also the bacteria absorb the most carbon dioxide while growing, so they will have to be modified for those with the longest growing cycle. The temperature of the flue gas will help to determine which cyanobacteria will be most suitable in that environment, for the one that grows most optimally at that temperature will be chosen. Another design consideration is the distribution of sunlight to the bacteria, for the bacteria derive their energy passively from the sunlight. This system capitalizes on natural processes, instead of relying on genetically modified organisms. By ensuring the bacteria receive sunlight, it will be able to sequester carbon dioxide through the process of photosynthesis, which has been well studied and is fairly well

understood. Genetic modification, even after years of work done by hundreds of scientists, still yields unpredictable results.

The end products of this process are reduced emissions of carbon dioxide into the atmosphere as well as usable biomass. The biomass created by the cyanobacteria could be used as fuel, fertilizer or feedstock. The effect of the cyanobacteria on the surrounding flora and fauna should also be considered since it is a fast-growing organism, which can be a competitive advantage. The effects the bacteria could possibly have are small due to the fact the bacteria chosen grows optimally at the higher temperatures of the flue gas (50-75 °C) and is unlikely to do well at the ambient temperature of the surrounding area. One other byproduct of this process is oxygen, which is good product for us oxygen-requiring life forms.

A natural experiment on plant acclimation: Lifetime stomatal frequency response of an individual tree to annual atmospheric CO₂ increase

Friederike Wagner, Raimond Below, Pim De Klerk, David L. Dilcher, Hans Joosten, Wolfram M. Kürschner, and Henk Visscher

This article discusses the effects that increased levels of carbon dioxide in the atmosphere have on biota as made apparent by stomatal densities. Data was collected on a single birch (*Betula pendula*) tree, which had stomatal data going back for the entire life of the tree, about 47 ± 1 years. The stomatal data was recovered from leaf litter surrounding the tree, which had been well preserved within peat moss (*Sphagnum*), for three consecutive growing seasons. The leaf litter surrounding the tree was assumed to be created solely by this one tree since it stands alone and has done so for its entire lifespan, as determined by aerial photographs. In this region, the monoculture shifted from rye (*Secale cereale*) and corn (*Zea mays*) in 1973. In 1961, the amount of sand brought into the area by the wind significantly decreased due to surrounding arable fields being converted into grassland.

In the past fifty years, as atmospheric levels of carbon dioxide concentrations have been increasing, there has been a decrease in the stomatal frequency of the aforementioned birch tree. The stomatal frequency is measured in two ways, by stomatal density and stomatal index, both of which were found to have declined. The stomatal index is equal to $[\text{stomatal density}/(\text{stomatal density} + \text{epidermal cell density})] \times 100$. This change is not contributed to a rise in temperature since the temperature and other growth conditions have remained relatively stable. There has been ground water monitoring and local weather data collected for the past few decades, which show no significant trends. The size of the stomatal pores was also measured to determine if the decrease in density was also related to a decrease in size of the pores. The authors of this paper were surprised to find instead, that the pores increased in size as their frequency decreased, therefore partially negating the effect of fewer pores. The change in stomatal frequency over the lifetime of this tree provides evidence of a phenotypic acclimation instead of natural selection resulting in genotypic adaptation, answering a fundamental question to stomatal frequency and carbon dioxide concentration.

Although the results from this study do appear to be statistically significant all the data came from one tree. Any small change that was not accounted for could have also been the driving force between stomatal frequencies. Even though local weather records do not show any significant trends in mean seasonal temperature, it is well known that global warming has occurred, albeit not evenly throughout the globe, therefore some data from these records would be useful in backing up the authors' argument. It was stated that the stomatal frequency within a species was shown to be not statistically significant between saplings and older trees, which is an extremely important assumption to base their study on. This study did point out that since the stomatal density declined in a linear fashion for this tree in past half a century it is unlikely, as it has been assumed, that trees have plateaued and can not adapt any further to increased concentrations of carbon dioxide through stomatal response. Although it is understandable that it is difficult to find trees that stand alone in a good

substrate for preserving leaves, more data with a greater variety of trees needs to be collected to support these findings.

8 Effect on Humans

At this point the fact that humans impact the global climate is thought to be undeniable, by most educated people. The effect of these changes is starting to be noticed, little by little, as the more sensitive species, such as frogs, start dying off. Other animal and plant species also provide evidence as each year species migrate further from the equator in search of temperatures to which they are more closely adapted. There is no doubt that there is currently a huge decline in species diversity, so large that it has been called “The Sixth Extinction” since species are disappearing a faster rate than ever before (Leaky). There is no doubt a correlation between the climate change, which is likely caused by human activities such as deforestation and burning of fossil fuel, and the drop in species diversity. The impact on humans is a more complex measurement because mortality is not the only measure that is important to human civilization.

Human activities are changing our environment, the composition of our atmosphere, and in turn these changes will affect life on earth, including human civilization. Many of the changes that will be noticeable to humans are climatic changes. Slight changes in the average world temperature, which is a poor representation of the greater temperature changes experienced in some areas, can result in major differences in weather patterns. A major driving force of global winds is the differential heating due to the different rates at which sunlight energy is absorbed between the equator and poles. On a more local scale winds are also caused by differential heating between the land and a body of water, as well as winds created by mountains.

There are many different factors that influence the weather, not all of which are understood, which results in it being described as a chaotic system. Even still, a slight change in temperature is believed to be able to have a significant impact on the system, possibly due to the important role temperature plays in wind patterns and the large role of wind in weather. As humans continue to put greenhouse gasses into the atmosphere more severe weather events are theorized to become more frequent and have a greater impact. This can be evidenced by the European heat wave in the summer of 2003 and the tsunami that devastated India.

Fairly common climatic events such as floods and droughts are also expected to become more frequent and greater in scale. The increase in average global temperature, as mentioned, is an average of areas that experience a large increase in temperature, with regions that experience no increase or possibly a decrease. The places that experience the most climate change will be subject to more chaotic weather patterns. Increased droughts may cause human death, due to lack of access to water, as well as crop loss. Increased temperature can also result in crop loss due to plants accustomed to colder climates not performing as well. Floods can not only kill and destroy property, but also wash away vital nutrients for growing from the soil.

As the temperature rises flora and fauna will move further from the equator, in search of their more suitable habitats. The movement of species northward has already been documented, but tropical diseases are also expected to travel. These tropical diseases could have devastating impacts on the cities of first world countries which are located just close enough to be impacted. (De Leo)

The way in which the climate change will impact agriculture in Europe varies greatly by region. River runoff was used as an indicator of the agricultural impacts of climate changes for this model. In some areas climate change will not be detectable by 2050, for it will not create variation that is greater than annual or seasonal changes. Northern and southern Europe are expected to experience noticeable changes in mean runoff, which will be statistically significant over natural variability. Central and western

Europe are not expected to experience noticeable changes by this model. It is however emphasized that these are only the results from one model and by slightly changing a few variables the predicted results would be completely different. This reinforces the idea that atmospheric modeling of the future is more of an educated guess of what may happen in the future of a chaotic system. (Hulme)

Another result of global warming, which is more popular in the media, is the melting of polar ice caps and the resulting rise in sea level. The melting of polar ice caps is one result of the current energy imbalance of the Earth. The energy imbalance is due to the Earth not emitting as much energy in thermal radiation as it is absorbing from the Sun from solar radiation. The carbon dioxide and methane contribute to this effect by not allowing some thermal radiation to leave Earth's atmosphere and cause it to come back to Earth to be absorbed, sometimes in the form of melting polar ice. Models of sea level rise vary from rapid rises to a 9 to 88cm rise in 110 years, which are dependent on the levels of carbon dioxide in the atmosphere and the corresponding change in temperature. Extreme models are not necessary to greatly impact humans, a two meter rise in sea level would result in large tracts of land, such as much of Bangladesh, Florida, and many islands, to be underwater. This feasible rise in sea level would result in the forced migration of tens to hundreds of millions of people. A mass migration would not only affect those who were displaced but also other citizens and nations who experience the increased strain on resources. (Hansen)

9 Recommendations for Future Research

An idea for future research that could stem from this Interactive Qualifying Project is modeling and research on algal utilization of carbon dioxide. This may be more suited for a Major Qualifying Project for a biotechnology or biomechanical engineering major. Research for this project could involve actually doing laboratory tests of algae growth

with different concentrations of carbon dioxide under different environmental conditions, such as elevated temperature.

Another interesting topic related to this project is the history of human perception of the atmosphere, climate, and environment. This could stem from this project because this project is not only written at a time when a major shift in humans' perception of the environment is changing but also is about the topic which is causing this major shift. So an interesting project would be to research when the perception changed and what caused the change. If this were done as an Interactive Qualifying Project, the manner which this would relate technology and the environment is clear. This future project would also hopefully reveal whether it was increased knowledge of the environment or superstition and popular opinion that had a larger impact on people's perception and their resulting actions. The knowledge gained from this could possibly be used to have a greater influence on the public's opinion and encourage a more proactive approach to conserving the Earth's environment.

A third research idea is to do more modeling of the environment or at least an evaluation of some current models, considering the difficulty in creating an accurate model. Many different researchers have come out with different models and predictions of the future climate and thorough research of these models could result in clearer picture of what the most likely future climate will be based on current knowledge. This project could also involve doing some modeling by the students themselves but of the effects of methane on future climate. A model which is dependent on methane concentrations and the resulting atmospheric change could be combined with a model based on carbon dioxide to see the possible combined effects of the increased concentrations of these two gasses.

10 Conclusion

The atmosphere is clearly a very complex system which, even with current knowledge and tools, is difficult to model accurately. The atmosphere is a problem of organized

complexity where there are a number of different factors which are “all varying simultaneously and in subtly interconnected ways” (Jacobs). The albedo is one factor that is constantly changing depending on cloud cover, snow cover, and land cover. This affects the energy absorbed by the earth and the resulting temperature of the earth which can impact the weather and thereby influence cloud cover. The magnetic bands that surround the earth and the trace gases in the atmosphere also have a significant impact on the amount and type of energy absorbed. A change in the energy absorbed would possibly result in a change in the concentrations of the molecules in the atmosphere and this would continually act as a feedback mechanism. The atmosphere cannot be divided into parts to be analyzed but must be looked at as a whole, which is difficult since not all factors are known or understood. Due to this, the impact humans are having on the global climate by changing the composition of the atmosphere is still not well understood, although, through research it is becoming more clear.

Modeling, although difficult, is important in order to enable humans to better understand what impact they may be having on the global climate. When using a program to model the atmosphere the complexity, as well as how easy it was to make a mistake when creating equations to use in the model, was striking. At first the equations derived from the data extrapolated from the NOAA graph concerning the increased concentrations of carbon dioxide in the atmosphere resulted in unrealistic graphs. By analyzing the data and program it was found that two different types of units and incorrect time scale were being used for the derived equations. After incorporating these changes the results of the simulations appeared to be more accurate, or at least agreed with current knowledge of the projected concentrations of carbon dioxide. By making these mistakes it became clear how easy it is to change a variable or an equation in a model that is assumed to be accurate and create completely different results. Also by studying the literature that accompanied the model it appeared that many assumptions were made. Although these are no doubt assumptions with educated thought behind them, the slight inaccuracies in these assumptions could result in completely different predictions of atmospheric conditions.

The inherent inaccuracies of current models of future atmospheric carbon dioxide concentrations do not mean these models should not be created. In fact it yields insights into the possible future of the earth's ecosystem under current policy. However it should be realized that atmospheric carbon dioxide modeling is not an exact science, yet many people, especially in politics, find it useful to have scientific studies to back up their claims. Often to get public support there needs to be a legitimate reason and science can provide this reason. In this way atmospheric models can help convince the general populace that humans are having an impact on the environment that may negatively influence future civilization. Only by convincing the public of these negative impacts that may be felt in the near future can the society as a whole begin to plan for a more sustainable future. People are more easily convinced of the importance of recycling and conserving energy if they are aware that they are contributing negatively to the future by not doing so. Encouraging people to be more environmentally conscientious by making everyone aware that the earth is finite and all the waste we produce is starting to have an effect is important to future human life on earth. So although the atmosphere may be incredibly complex and almost impossible to accurately model, it is still important to create these models to make the public aware of the negative effects they are having on the earth and encourage them to be better custodians of their home.

11 Appendix

11.1 Table of Values of Carbon Dioxide Concentration

Year	ppm
1958	315
1959	316
1960	317
1961	317
1962	318
1963	319
1964	320
1965	320
1966	321
1967	322
1968	323
1969	324
1970	324
1971	326
1972	326
1973	329
1974	330
1975	330
1976	331
1977	333
1978	335
1979	336
1980	338
1981	340
1982	341
1983	342
1984	343
1985	345
1986	346
1987	347

Year	ppm
1988	350
1989	352
1990	353
1991	354
1992	355
1993	356
1994	358
1995	359
1996	361
1997	362
1998	366
1999	368
2000	369
2001	370
2002	372
2003	376
2004	378
2005	379
2006	380

11.2 Line of Best Fit Program Used in MATLAB

```
% Line of best fit for CO2 output of world

% get into correct directory
cd R:\IQP;

% read co2 excel file into MATLAB
co2table=xlsread('co2_last_50_years.2003.xls');

% make one variable for years and one for co2 values
year=co2table(:,1);
co2=co2table(:,2);

% calculate line of best fit and evaluate it
p = polyfit(year,co2,2);
f = polyval(p,year);

% plot line of best fit and data
figure();
plot(year,co2,'ro',year,f,'g')

% using data from this line find the equation  $y=1.3777x + 308.2309$ 
```


11.3 CO₂sys Program to Model Carbon Dioxide Concentrations

(Authored by Mayer Humi)

```
%file co2sys.m
```

```
function dx =co2sys(t,x)
```

```
global Na0 Tam Tul Tdm betta Flb0 Fsb0 Fmb0 Cmt Corg ...
```

```
eps P1 P2 P3 P4 P5 Ws Wm gam0 r
```

```
Cua=x(1);
```

```
Clb=x(2);
```

```
Csb=x(3);
```

```
Cla=x(4);
```

```
Cml=x(5);
```

```
Cmb=x(6);
```

```
Cds=x(7);
```

```
%Dlu=-Kul*Cua+Kul*(Nua/Nla)*Cla;
```

```
Dlu=1/Tul*(P1/(1-P1)*Cla-Cua);
```

```
%Dlb=beta*(Flb0/Nla)*Cla;
```

```
Dlb=beta*(Flb0/Na0)*Cla;
```

```
%Dsb=-(Fsb0/Nsb)*Csb+(Fsb0/Nlb)*Clb+beta*(Fsb0/Nla)*CLa;
```

```
Dsb=1/Na0*Fsb0*(beta*Cla+Clb/P2-Csb/P3);
```

```
%Dml=-Kam*(Na0/Nla)*Cla +Kam*Na0/(Cmt*Wm)*eps*Cml;
```

```
Dml=1/Tam*((1+Corg/Cmt)/P4*eps*Cml-1/(1-P1)*Cla);
```

```
%Dmb=beta*(Fmb0/Na0)*(1+Cmb*Na0/Nmb)*Cml*Na0/Nml;
```

```
Dmb=Fmb0/Na0*(1+Cmb/P5)*beta*Cml/P4;
```

```
%Dmd= -Kdm*Cds+((Ws-Wm)/Wm)*kdm*Cml
```

```
Dmd=1/Tdm*((Ws/Wm-1)*Cml-Cds);
```

```
%gam= -0.00000008741916*t^3+0.00001961312384*t^2+0.00061883887192
```

```
*t+0.01508927878844;
```

```
%gam= 0.00001331894460*t^2 + 0.00073844576128*t + 0.01463567827131;
```

```
%gam= 0.00137775510204*t + 0.00962775510204;
```

```
%gam= 0.016361499481*exp(0.035091034949294*t);
```

```
%gam= .0014*t +.0096;
```

```
%gam=
```

```
0.00119496855*16.361499480707831*0.035091034949294*exp(0.035091034949294*
```

```
t);
```

```

%gam = .0000164637402;
%gam = 309.5510001445042*exp(0.004003456*(t));
%gam= 0.0133189446*(t+1700)^2-51.41854128903*(t+1700)+49930.44919993667;
%gam= 1.377755*(t+1700)-308.25;
gam= gam0*exp(r*(t+1700));
%gam= gam0+r*(t)^2;
Tpy=gam*Na0/(2000*453.6);
dx=[Dlu;Dlb;Dsb;-Dlu-Dsb-Dlb+Dml+gam;-Dml-Dmd-Dmb;Dmb;Dmd];
%-----

```

11.4 CO2sim Program to Model Carbon Dioxide Concentrations

(Authored by Mayer Humi)

```
% help command prints help on the command

% define some global constants that will be valid
% when you call a function or a subroutine.
% cof is the coefficient matrix for the interaction between the reservoirs
global Na0 Tam Tul Tdm betta Flb0 Fsb0 Fmb0 Cmt Corg ...
eps P1 P2 P3 P4 P5 Ws Wm gam0 r

%request high accuracy
format long

% give values to the global constants
Na0=6.156d17;
Tam=5.8;
Tul=2.;
Tdm=1500.;
betta=0.6;
Flb0=2.6d16;
Fsb0=3.d16;
Fmb0=2.d16;
Cmt=(12.011)*0.002057;
Corg=0.001;
eps=12.5;
P1=0.15;
P2=2.534;
P3=0.122;
P4=2.;
P5=0.1;
Ws=1.370d21;
Wm=(P4*Na0)/(Cmt+Corg);
gam0=2.3937d-29;
r=0.03077;

% set error tolerance and method for the numerical
%integrator of the differential equations.
odeset('maxstep',1.,'reitol',1.e-3,'bdf','on')

%perform the integration 'lorsys' is a file that defines the system
%[0,300] time interval for the integration
%[5,5,5] define the initial conditions
%[t,x]=ode15s('co2sys',[0,70],[0.0065;0.03;0.004;0.038;0.006;0.002;0.004]);
```

```

[t,x]=ode15s('co2sys',[0,300],[0.;0.;0.;0.;0.;0.]);

%plot x=x(:,1) vs. time(t0=1700) in red
figure();
plot(t,x(:,1),'r')

%title for the plot
title('CO_2 Concentration In the Upper Atmosphere (gamma=-
0.000000087*t^3+0.0000196*t^2+0.000619*t+0.0151)')
xlabel('Time (years)')
ylabel('CO_2 concentration (g/L)')

%save the plot to a postscript file
%print -dpsc2 -r600 CO2simEgoodgammathird.ps
%print -dpdf -r600 CO2sim.pdf

%plot x=x(:,4) vs. time(t0=1700) in red
figure();
plot(t,x(:,4),'r')

%title for the plot
title('CO_2 Concentration In the Lower Atmosphere (gamma=gam0*exp(r*(t+1700)))')
xlabel('Time (years)')
ylabel('CO_2 concentration (g/L)')

%save the plot to a postscript file
%print -dpsc2 -r600 -append CO2simEgoodgammathird.ps
%print -dpdf -r600 -append CO2sim.pdf

%plot x=x(:,2) vs. time(t0=1700) in red
figure();
plot(t,x(:,2),'r')

%title for the plot
title('CO_2 Concentration In the Long-lived Biota (gamma=-
0.000000087*t^3+0.0000196*t^2+0.000619*t+0.0151)')
xlabel('Time (years)')
ylabel('CO_2 concentration (g/L)')

%save the plot to a postscript file
%print -dpsc2 -r600 -append CO2simEgoodgammathird.ps
%print -dpdf -r600 -append CO2sim.pdf

%plot x=x(:,3) vs. time(t0=1700) in red

```

```

figure();
plot(t,x(:,3),'r')

%title for the plot
title('CO_2 Concentration In the Short-lived Biota (gamma=-
0.000000087*t^3+0.0000196*t^2+0.000619*t+0.0151)')
xlabel('Time (years)')
ylabel('CO_2 concentration (g/L)')

%save the plot to a postscript file
%print -dpsc2 -r600 -append CO2simEgoodgammathird.ps
%print -dpdf -r600 -append CO2sim.pdf

%plot x=x(:,5) vs. time(t0=1700) in red
figure();
plot(t,x(:,5),'r')

%title for the plot
title('CO_2 Concentration the Ocean Mixed Layer (gamma=-
0.000000087*t^3+0.0000196*t^2+0.000619*t+0.0151)')
xlabel('Time (years)')
ylabel('CO_2 concentration (g/L)')

%save the plot to a postscript file
%print -dpsc2 -r600 -append CO2simEgoodgammathird.ps
%print -dpdf -r600 -append CO2sim.pdf

%plot x=x(:,6) vs. time(t0=1700) in red
figure();
plot(t,x(:,6),'r')

%title for the plot
title('CO_2 Concentration In the Marine Biosphere (gamma=-
0.000000087*t^3+0.0000196*t^2+0.000619*t+0.0151)')
xlabel('Time (years)')
ylabel('CO_2 concentration (g/L)')

%save the plot to a postscript file
%print -dpsc2 -r600 -append CO2simEgoodgammathird.ps
%print -dpdf -r600 -append CO2sim.pdf

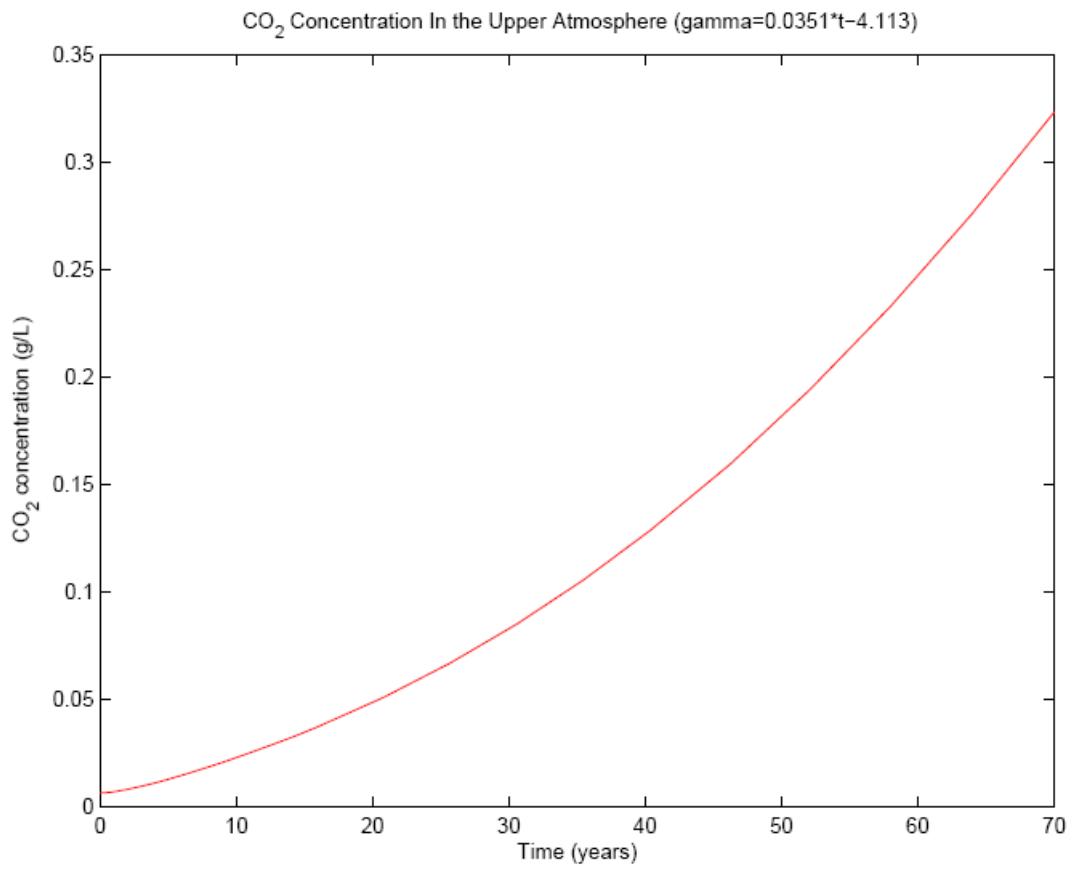
%plot x=x(:,7) vs. time(t0=1700) in red
figure();
plot(t,x(:,7),'r')

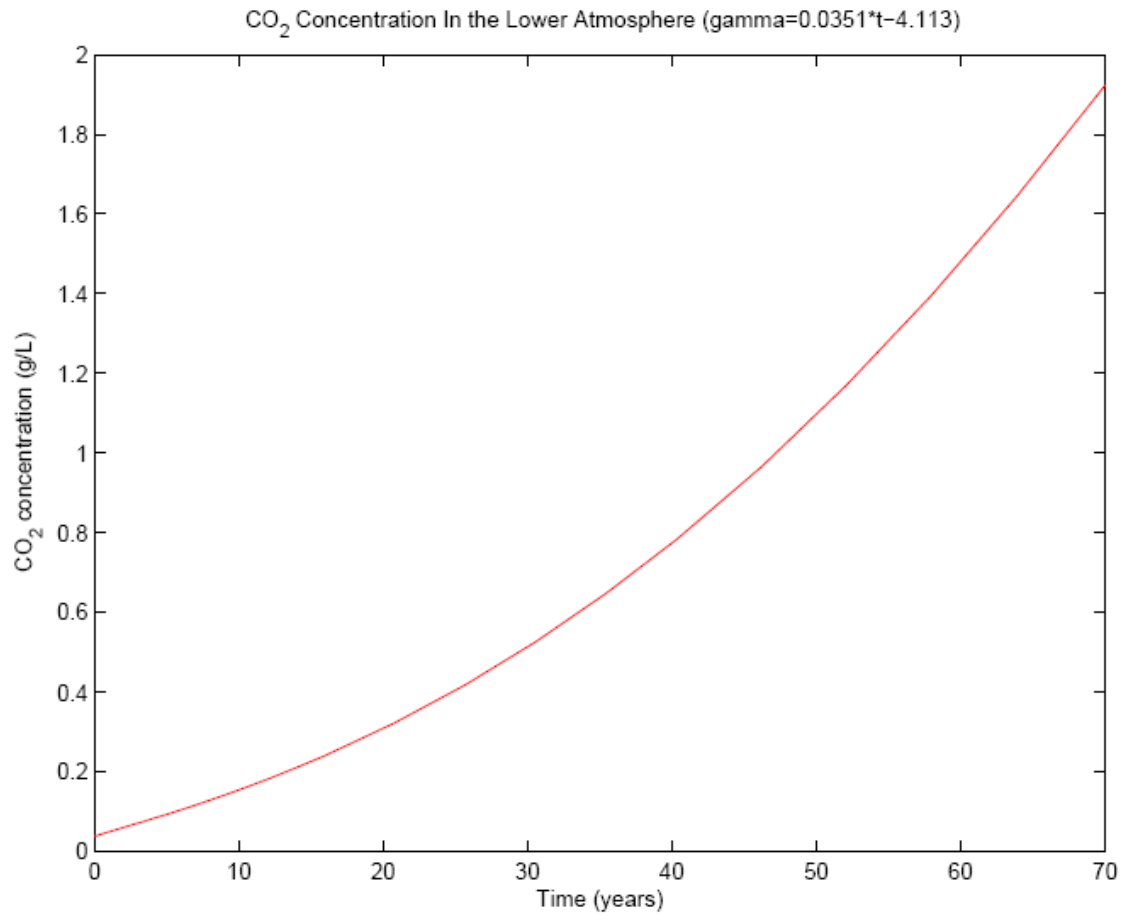
```

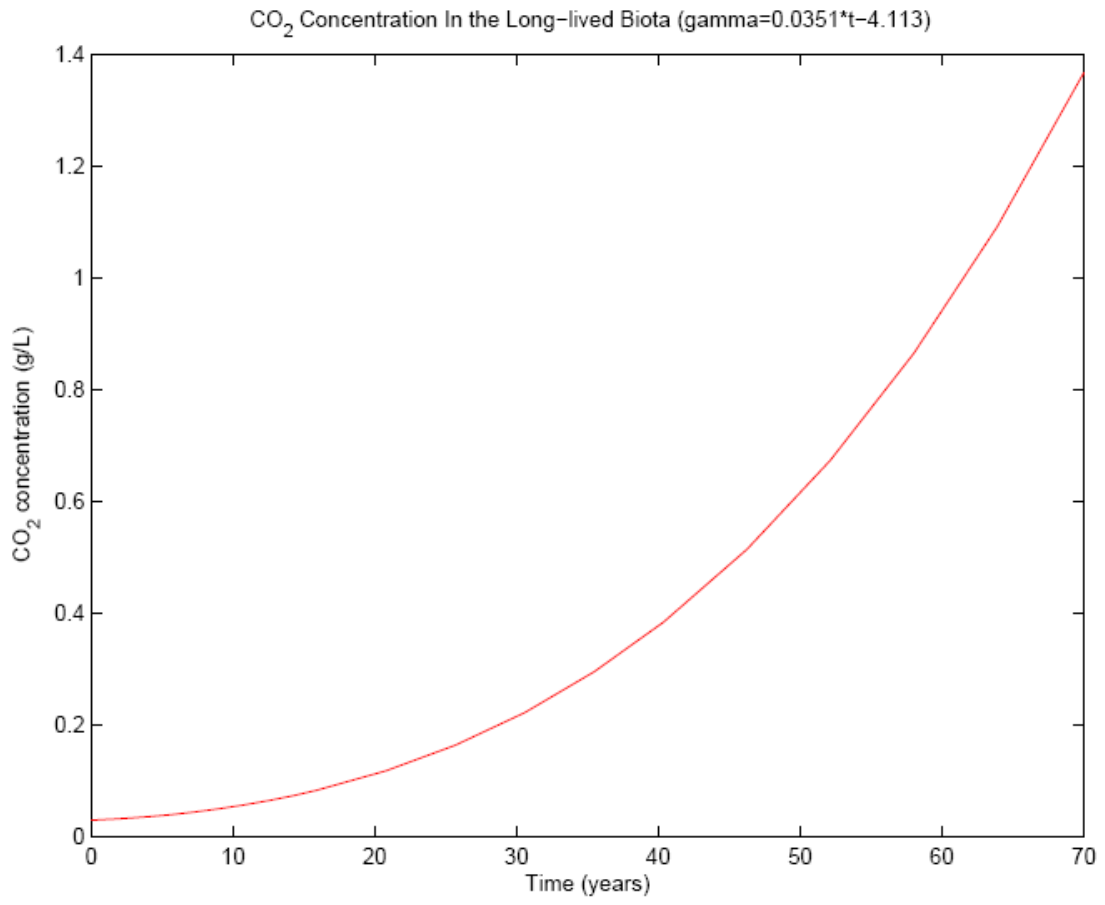
```
%title for the plot
title('CO_2 Concentration In the Deep Sea (gamma=-
0.000000087*t^3+0.0000196*t^2+0.000619*t+0.0151)')
xlabel('Time (years)')
ylabel('CO_2 concentration (g/L)')

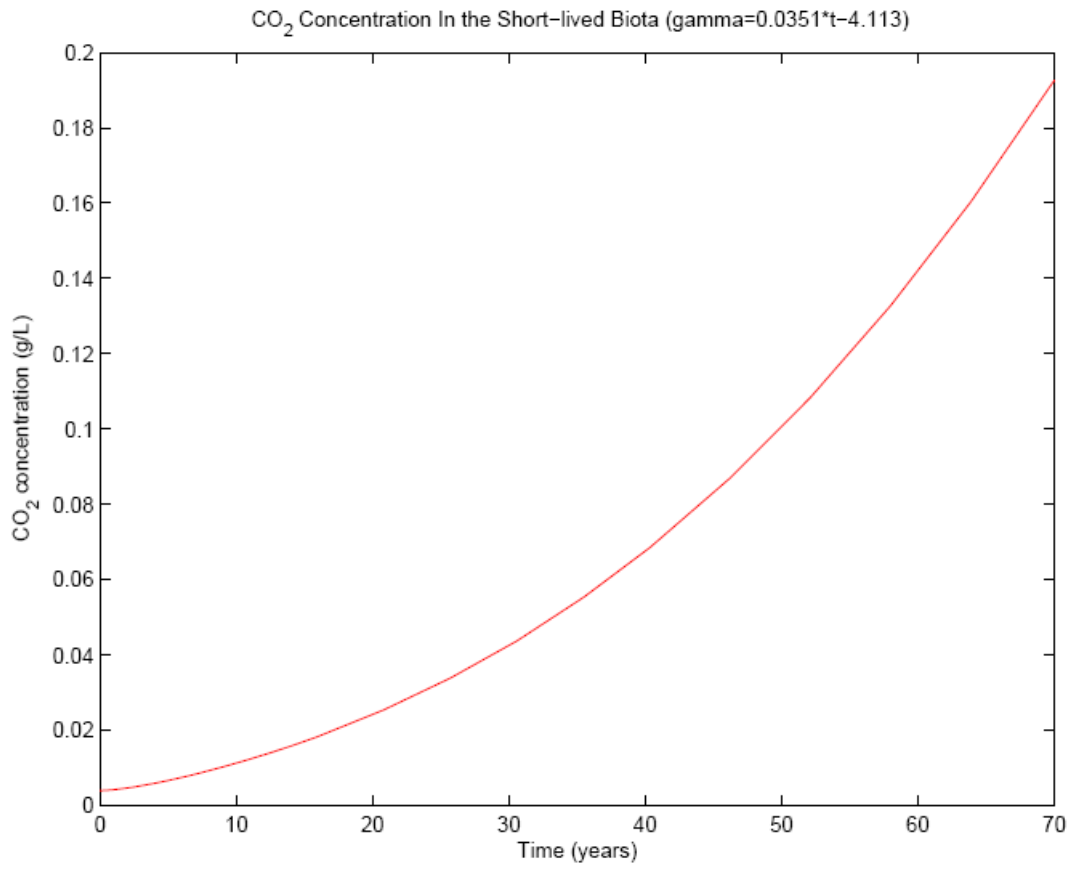
%save the plot to a postscript file
%print -dpsc2 -r600 -append CO2simEgoodgammathird.ps
%print -dpdf -r600 -append CO2sim.pdf
%to get out of matlab type 'quit' and return.
%-----
```

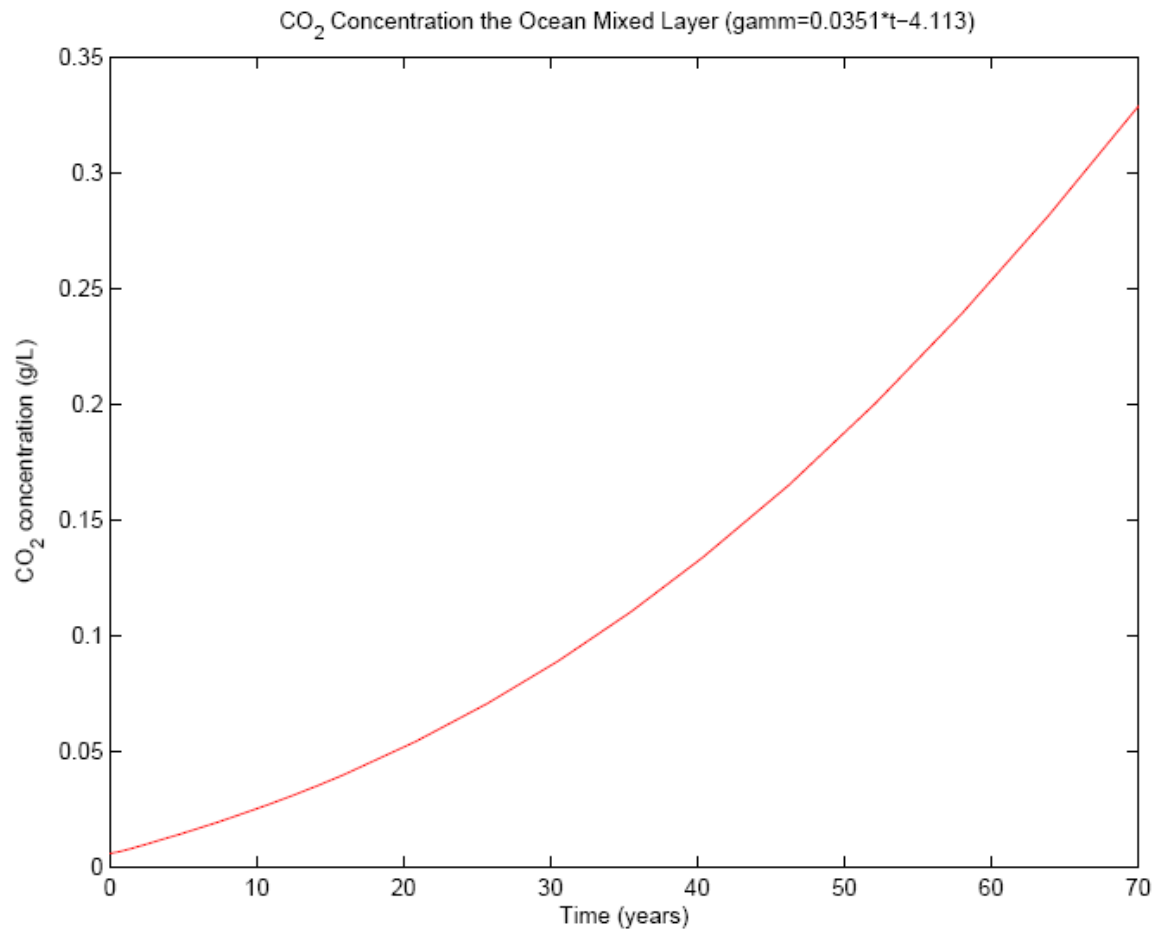
11.5 Graphs for First Order Gamma

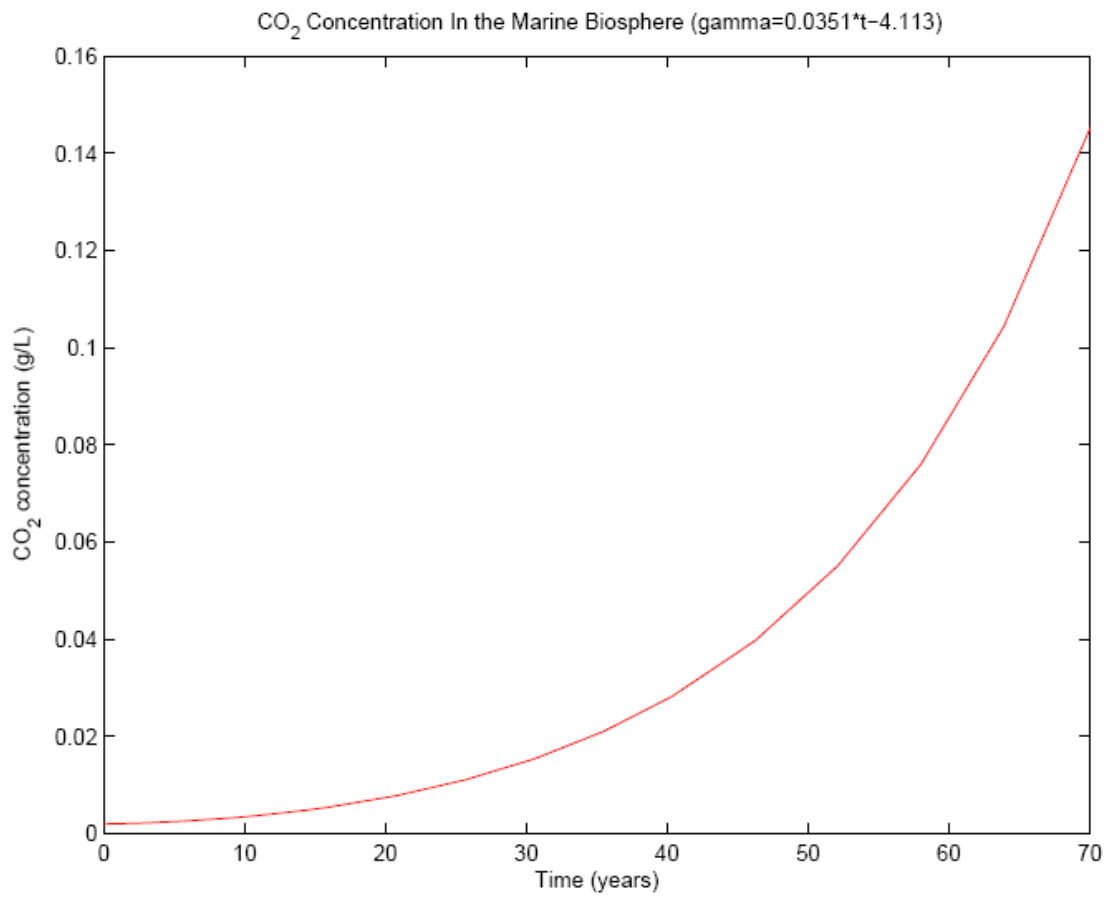


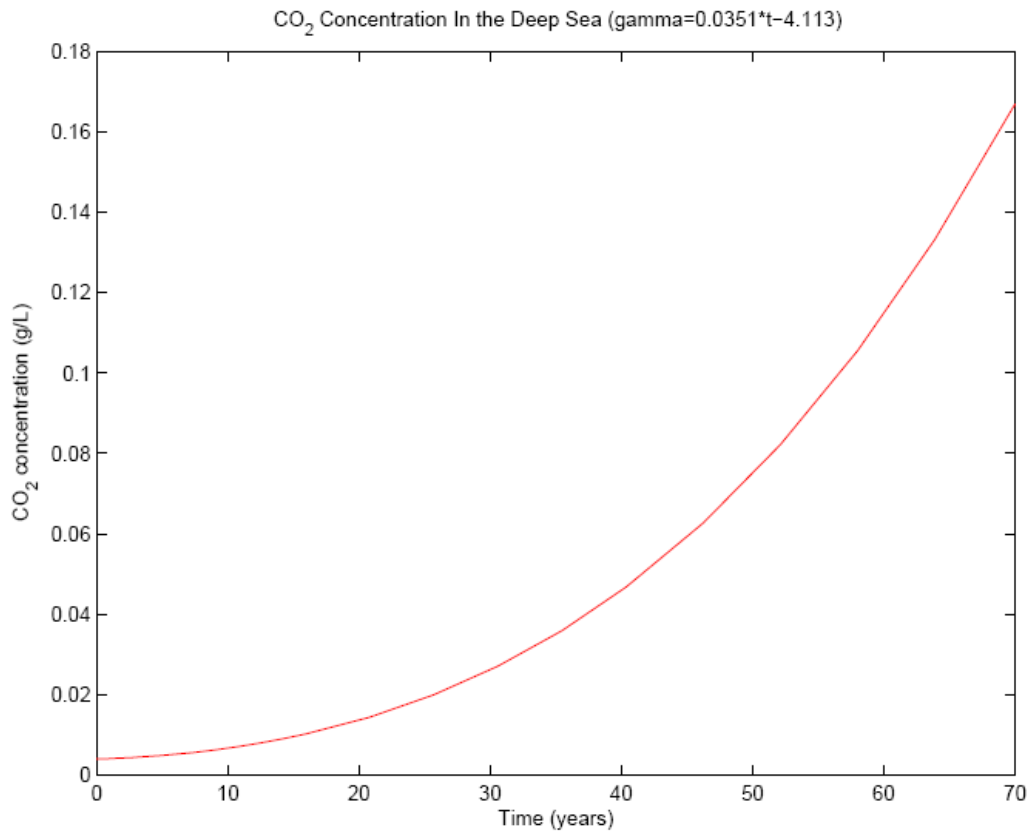




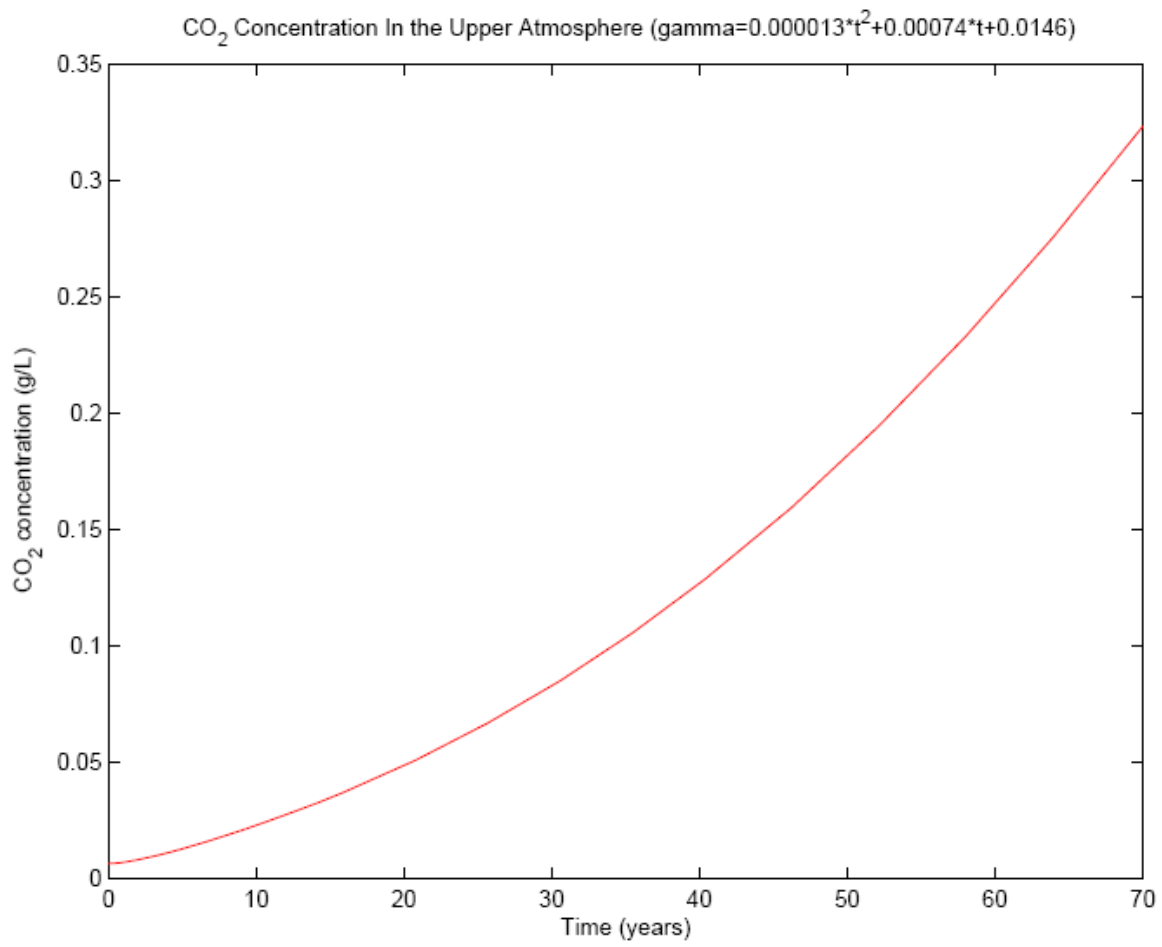


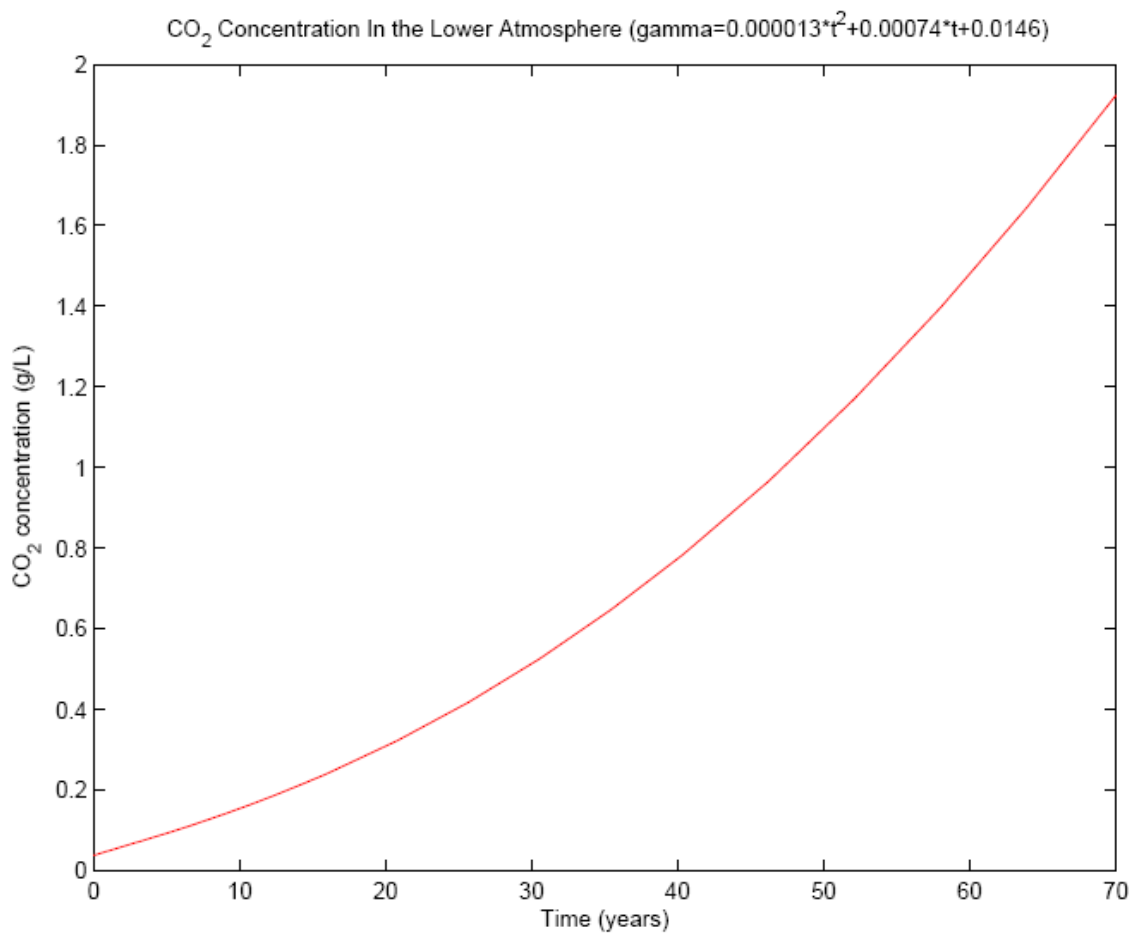


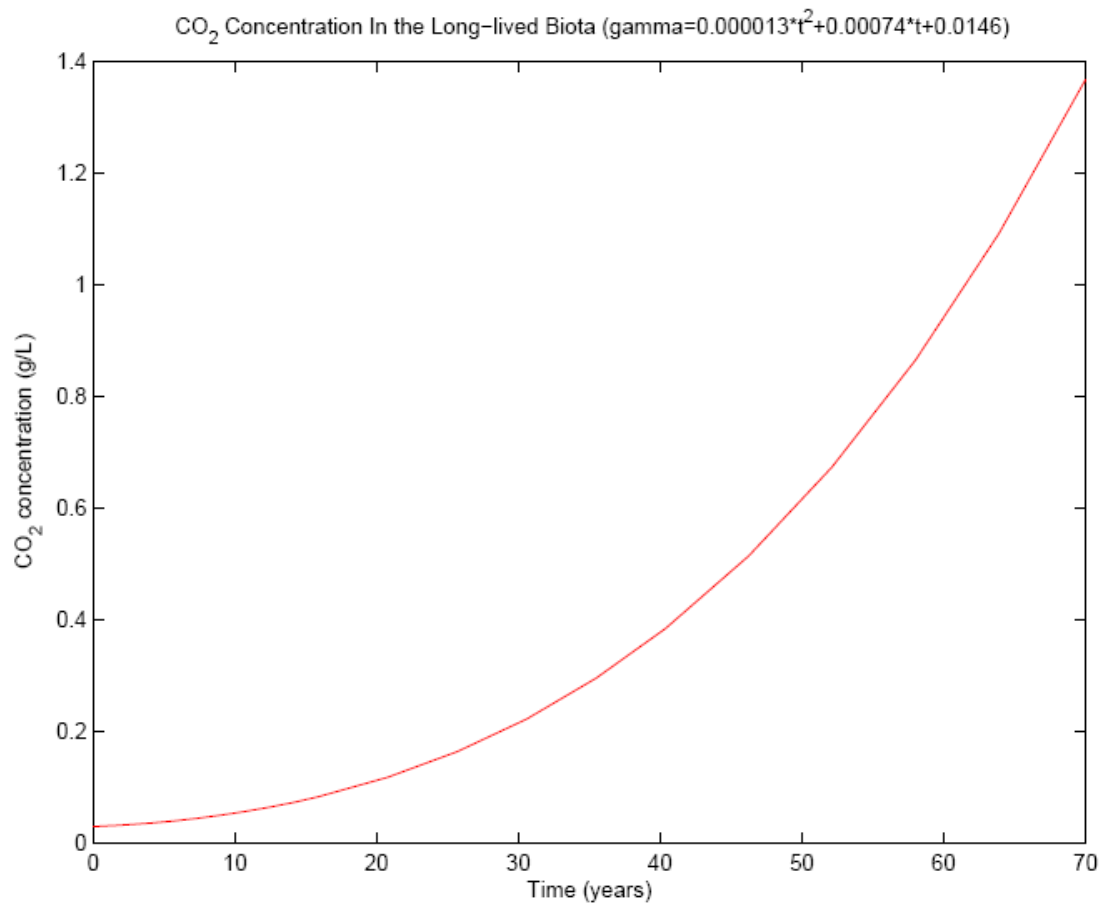


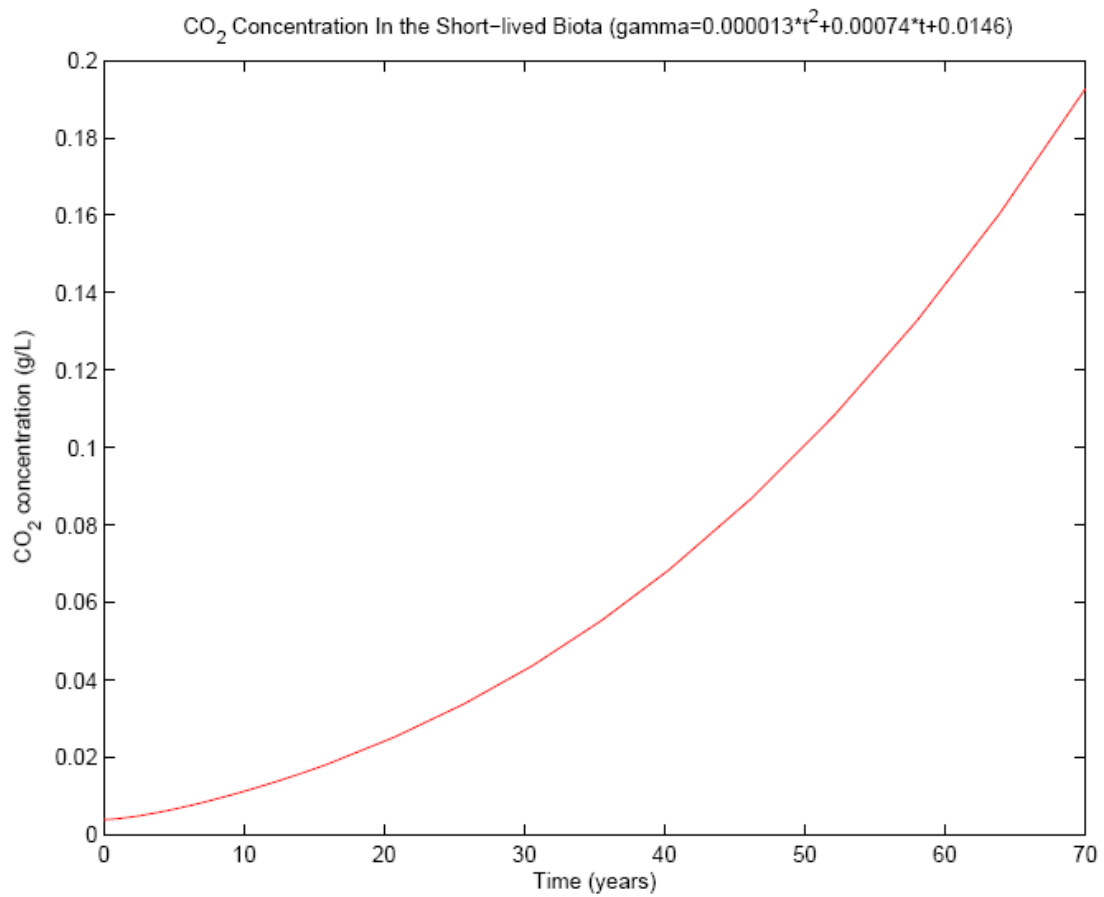


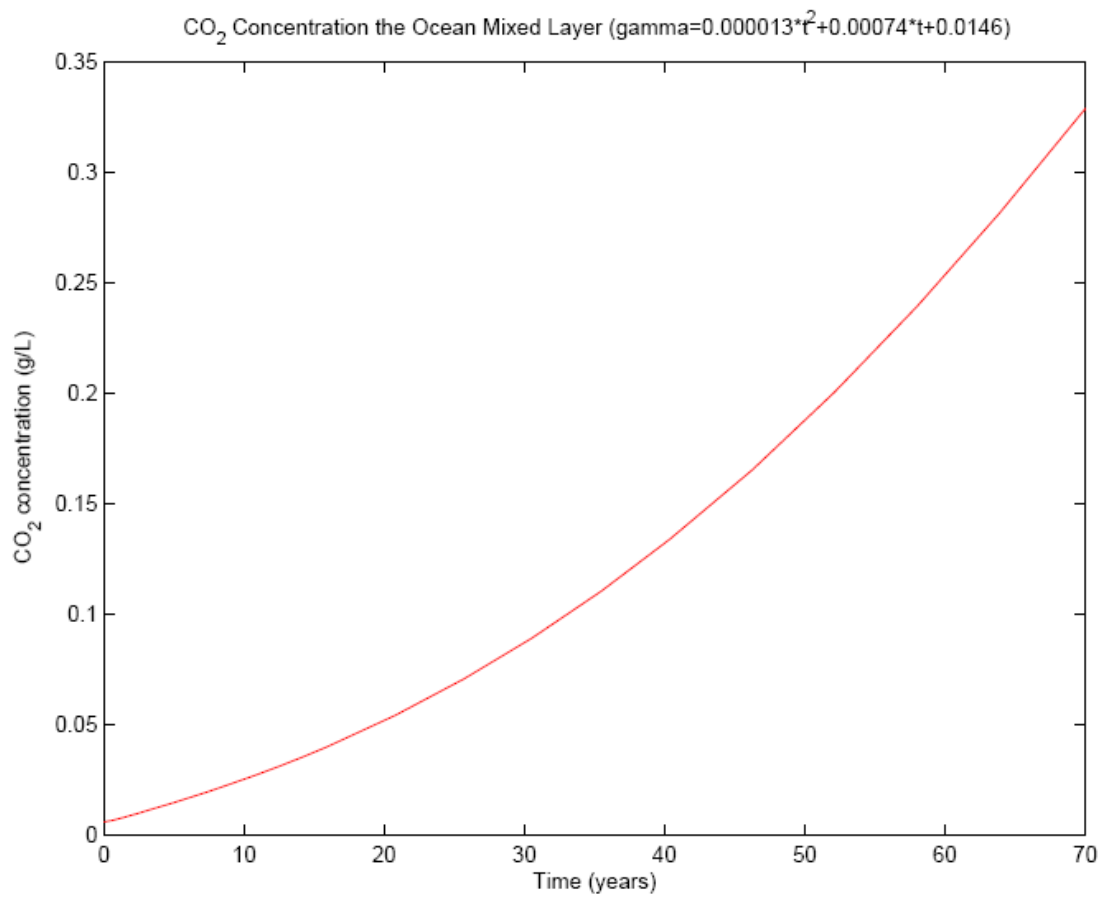
11.6 Graphs for Second Order Gamma

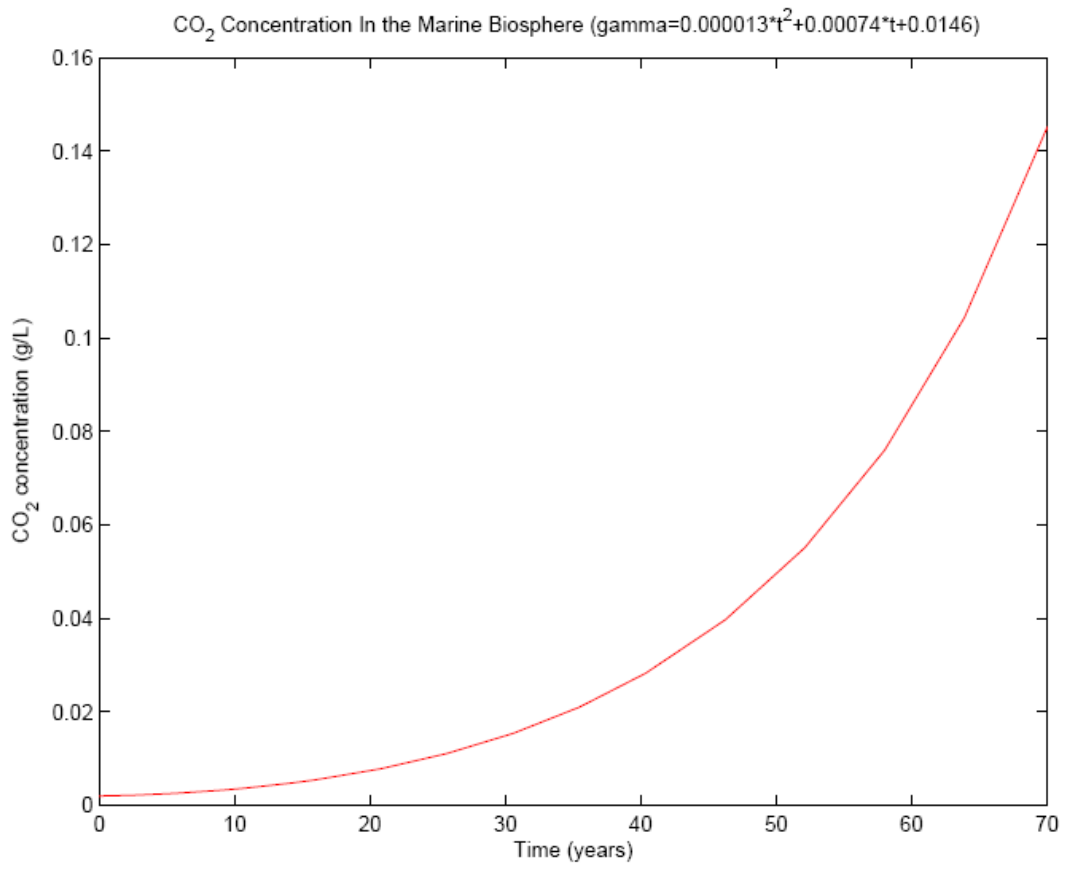


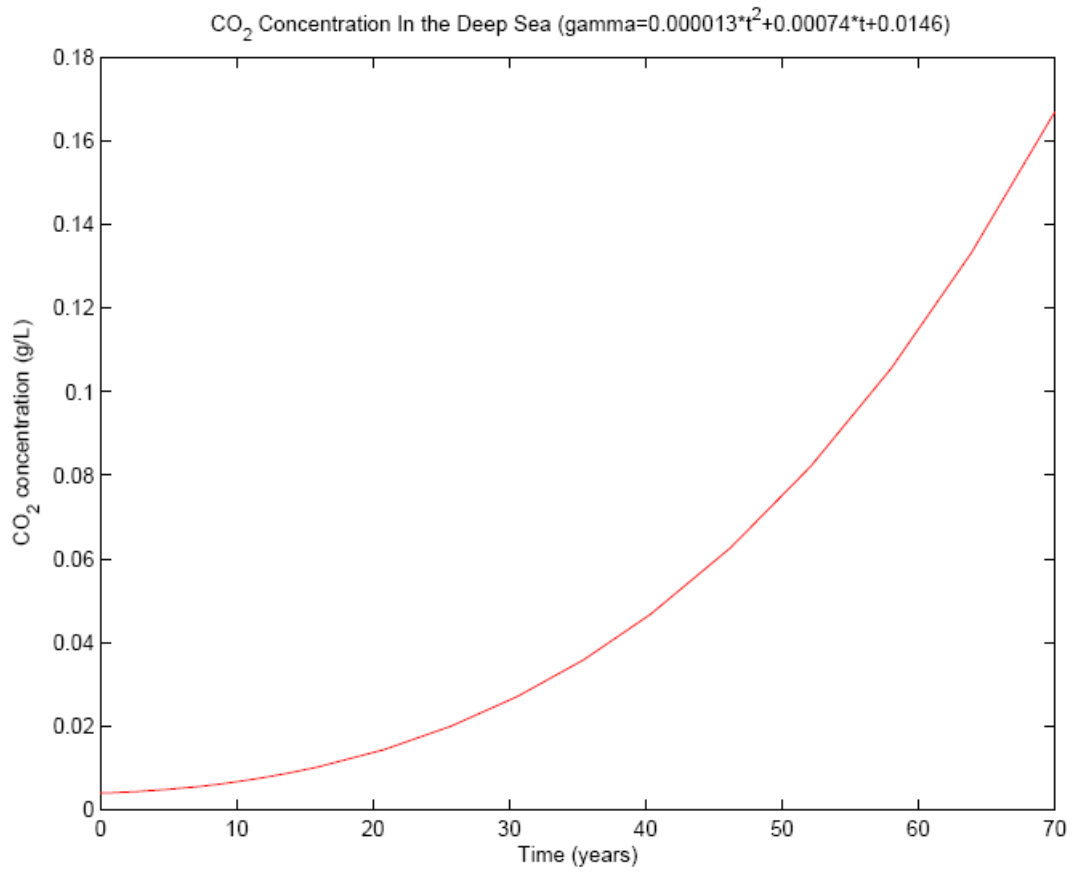




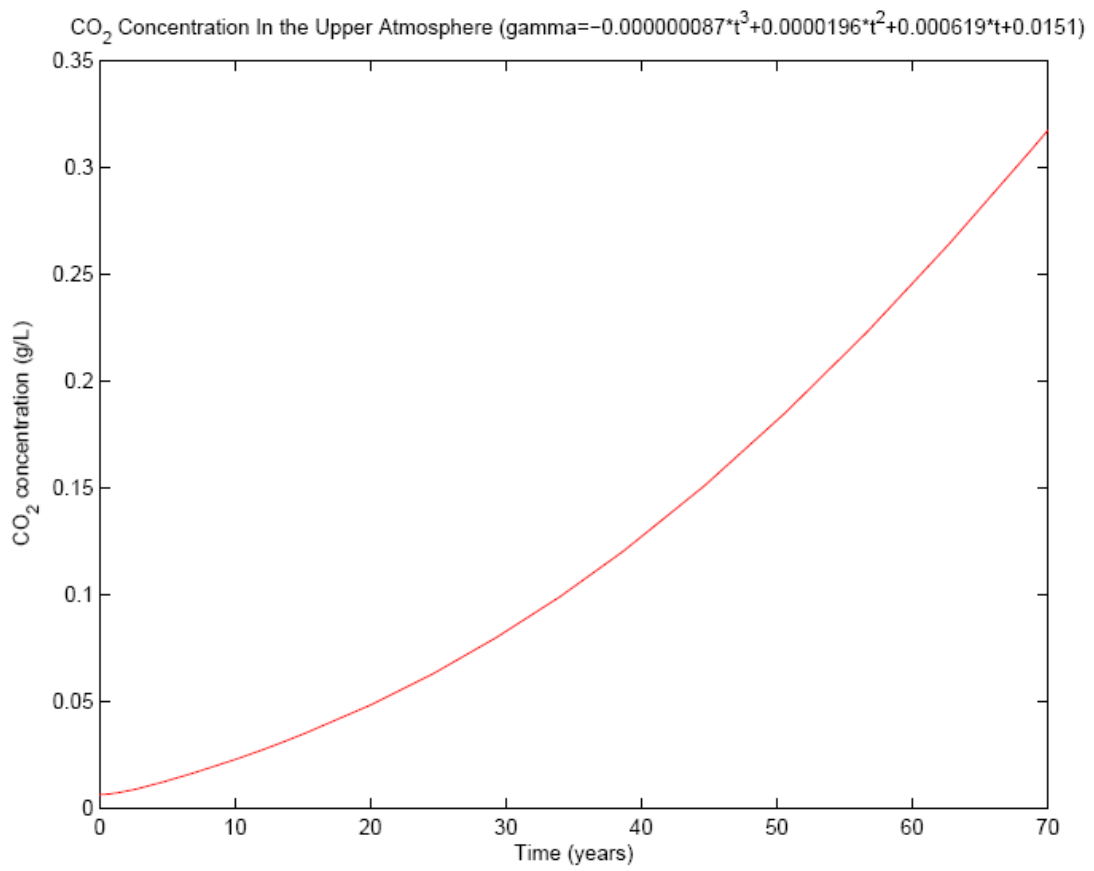


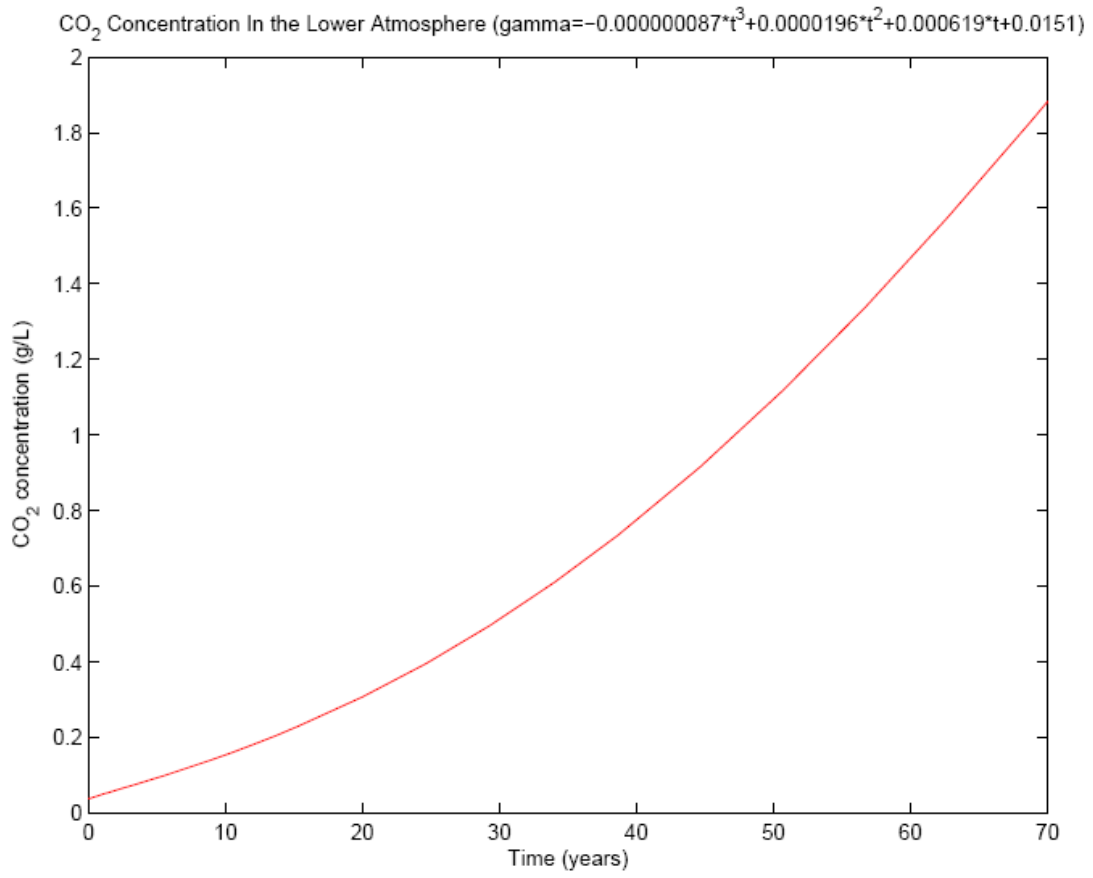


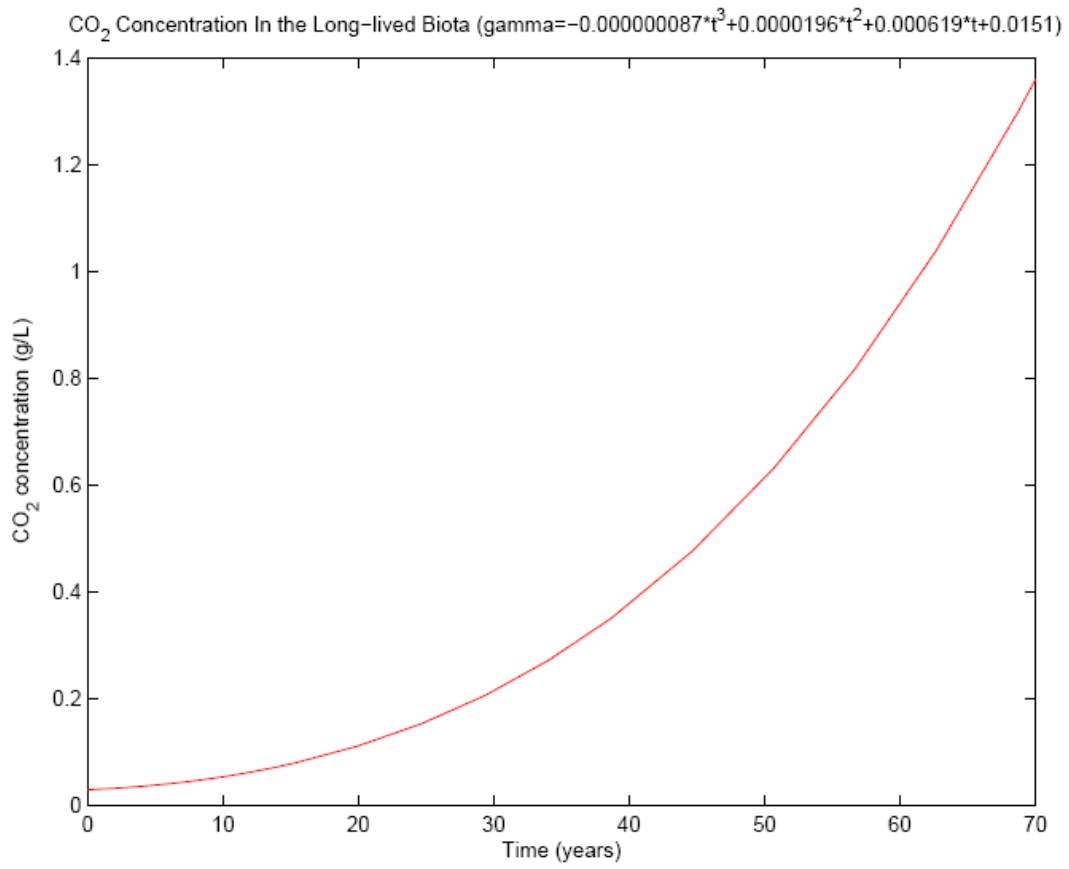


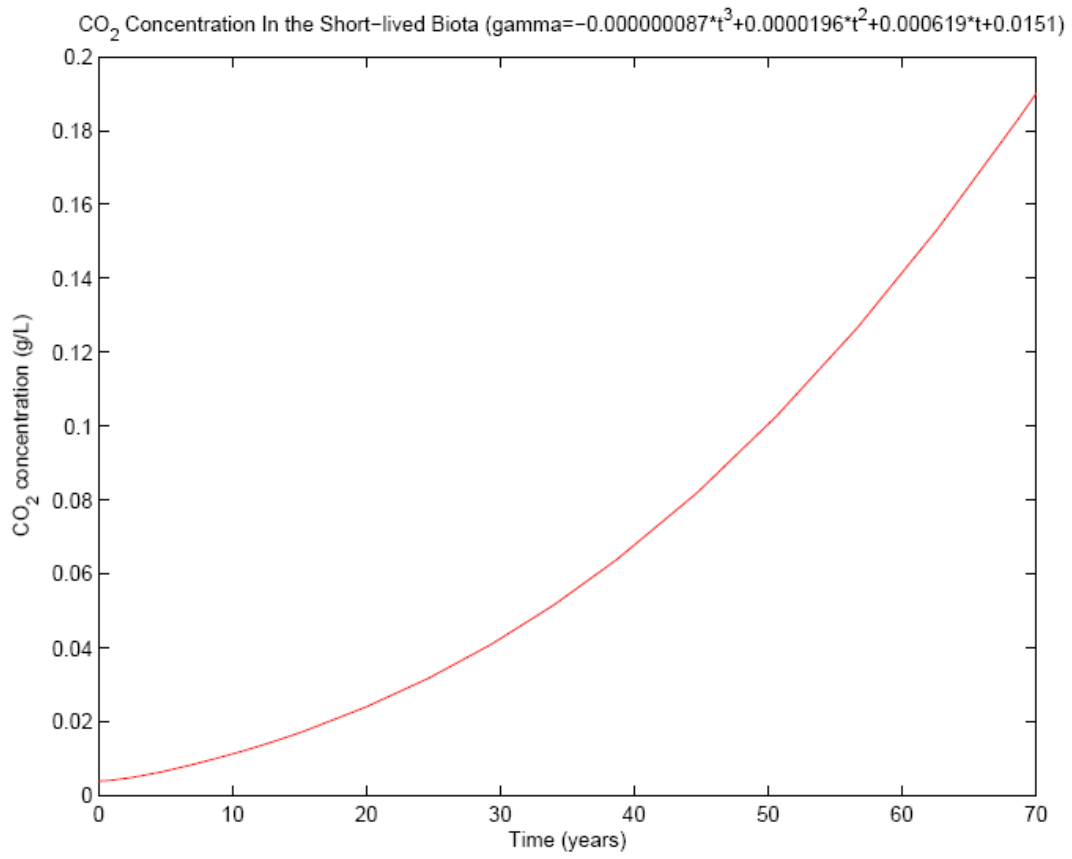


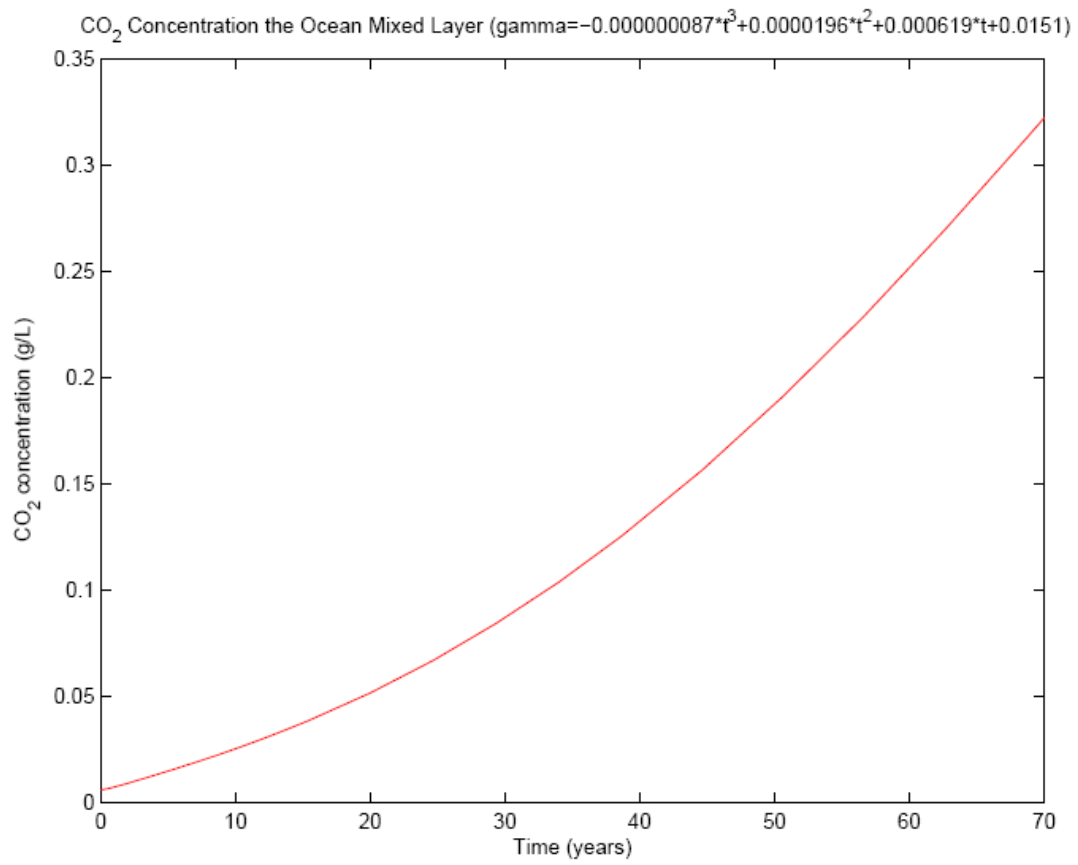
11.7 Graphs for Third Order Gamma

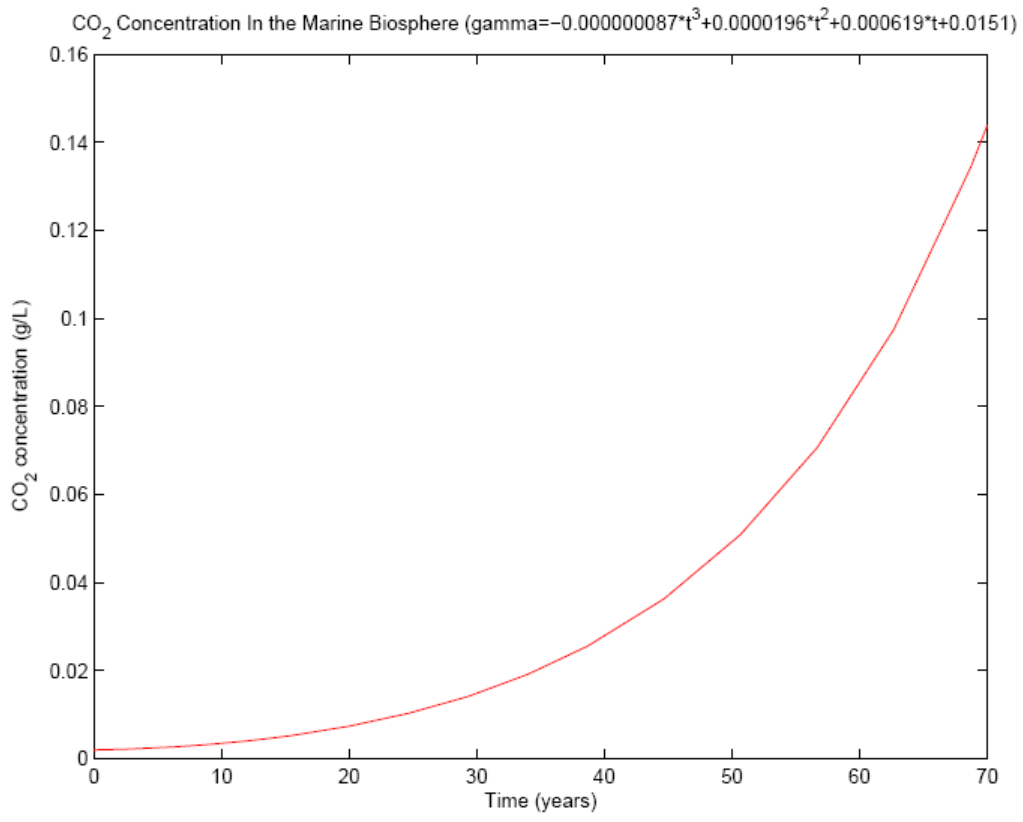


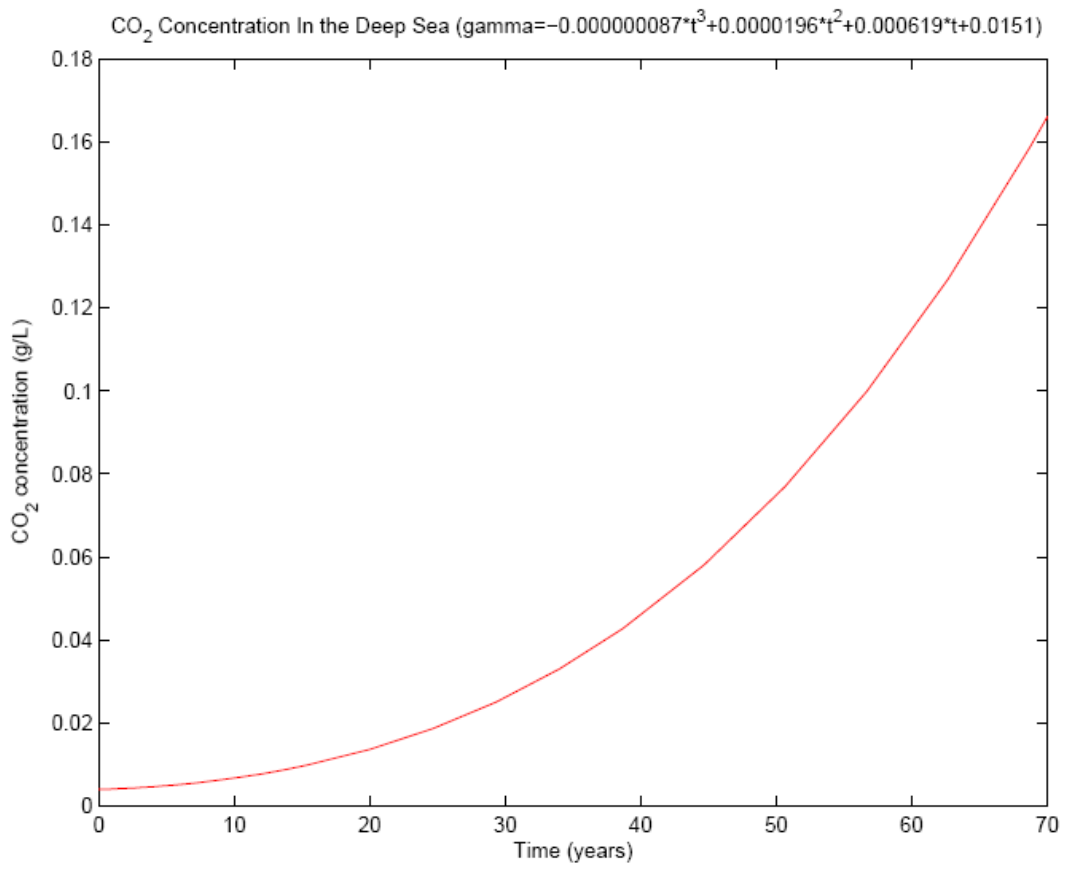




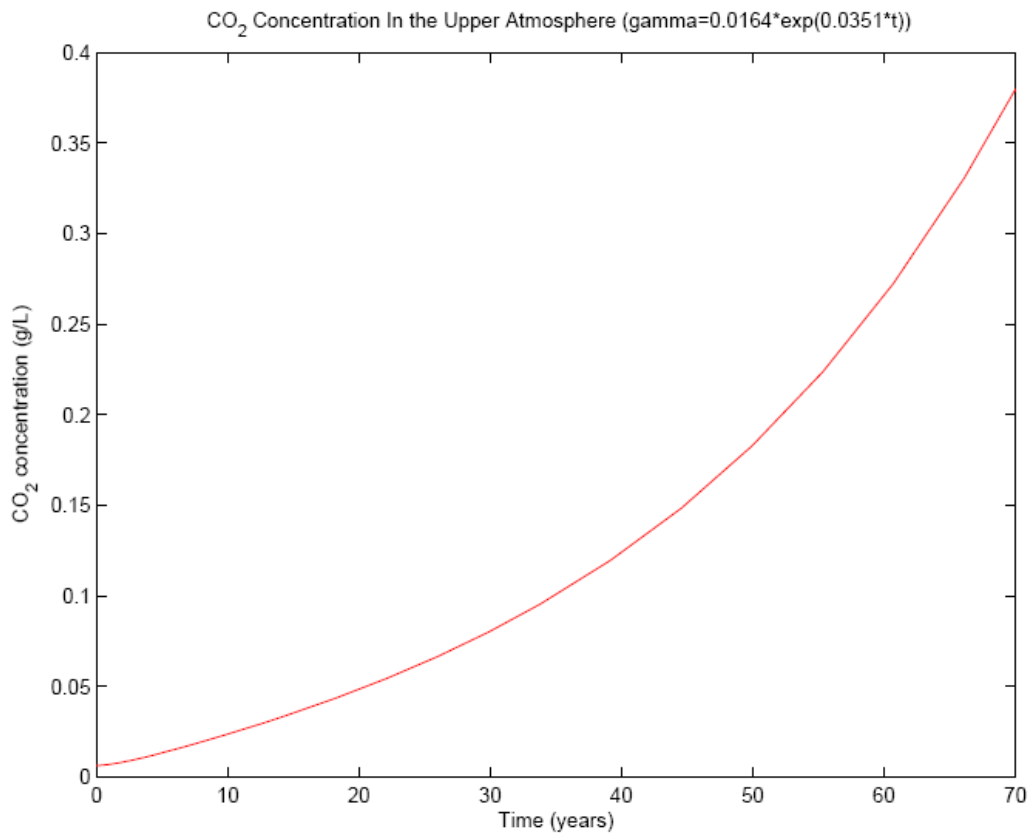


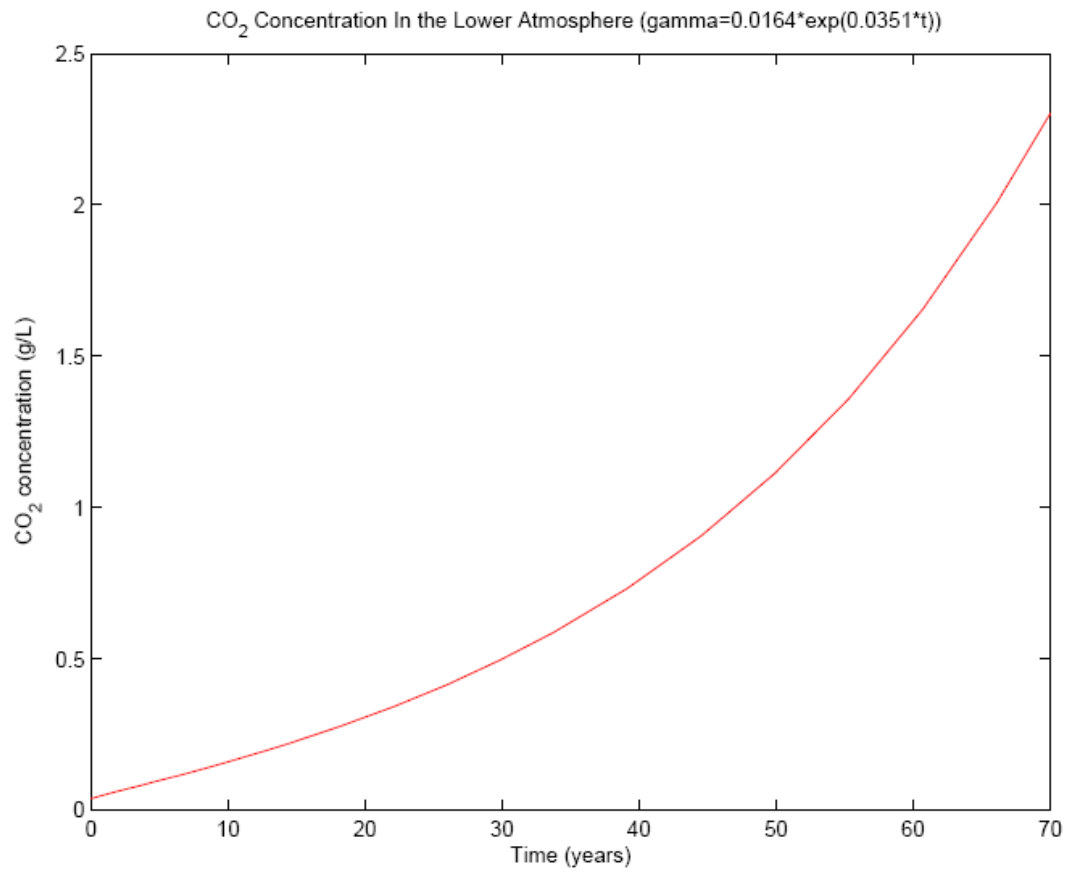


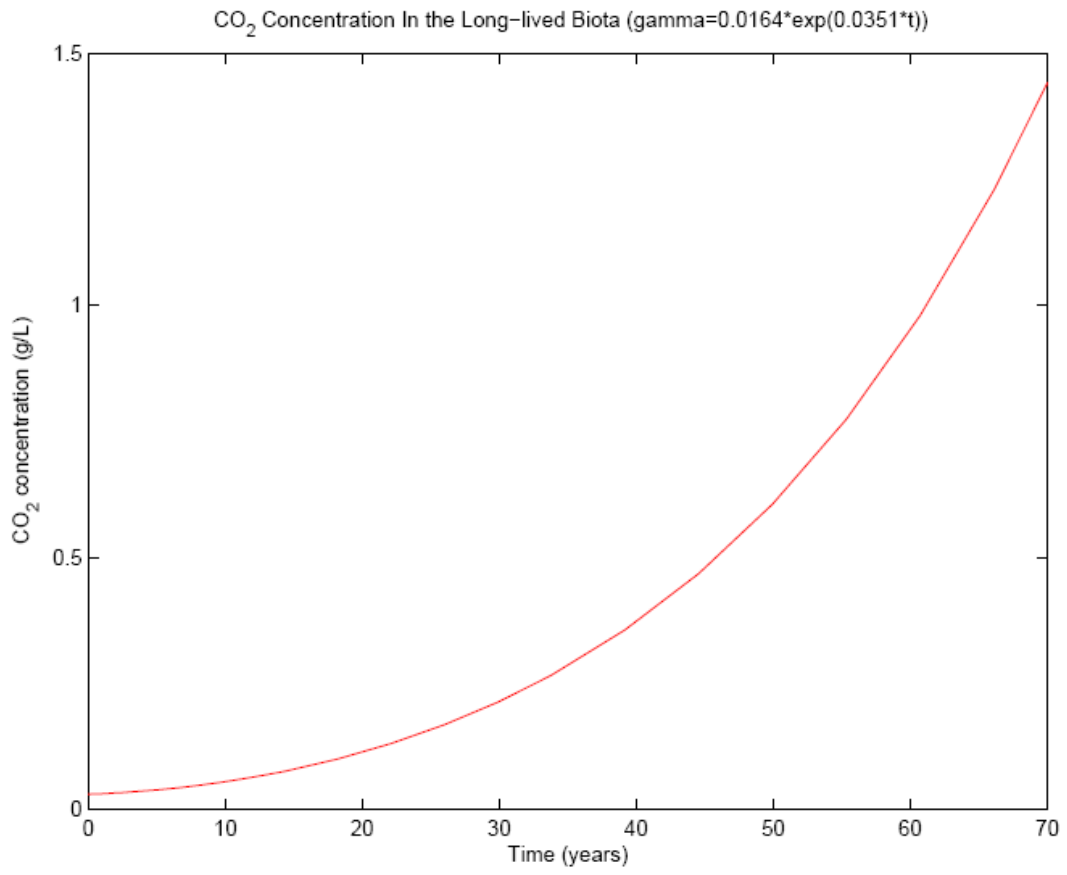


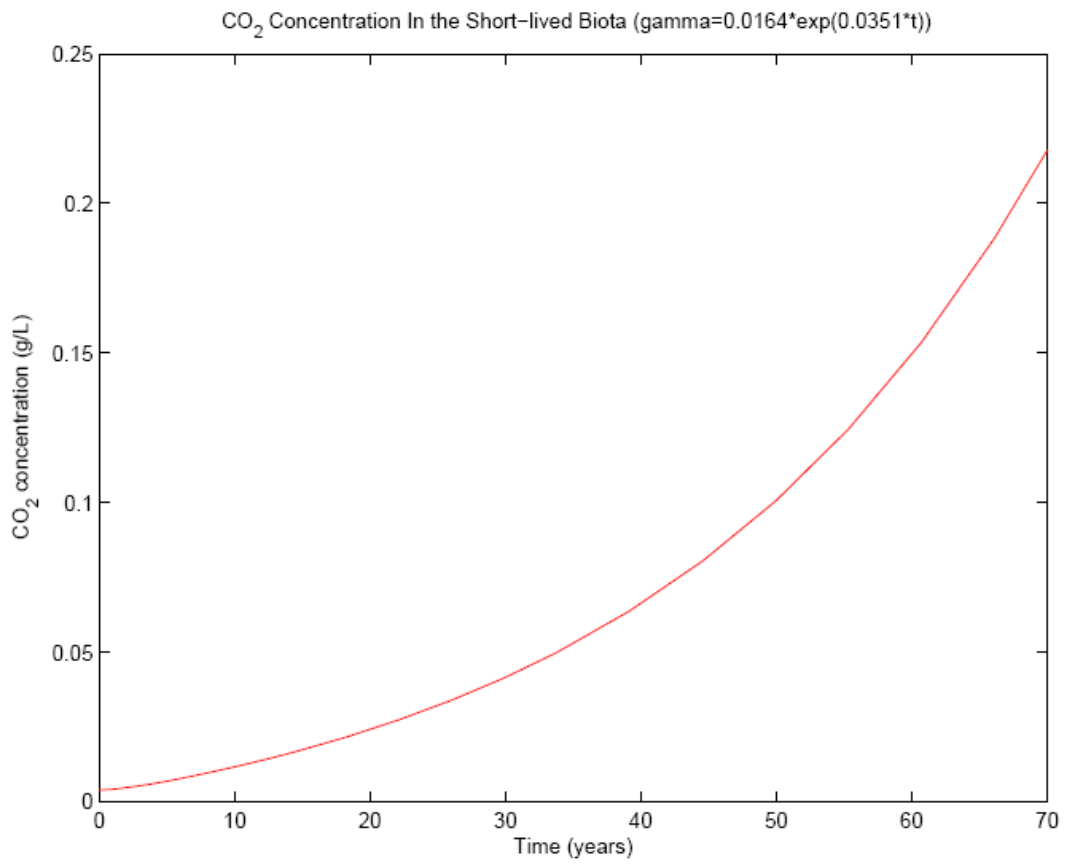


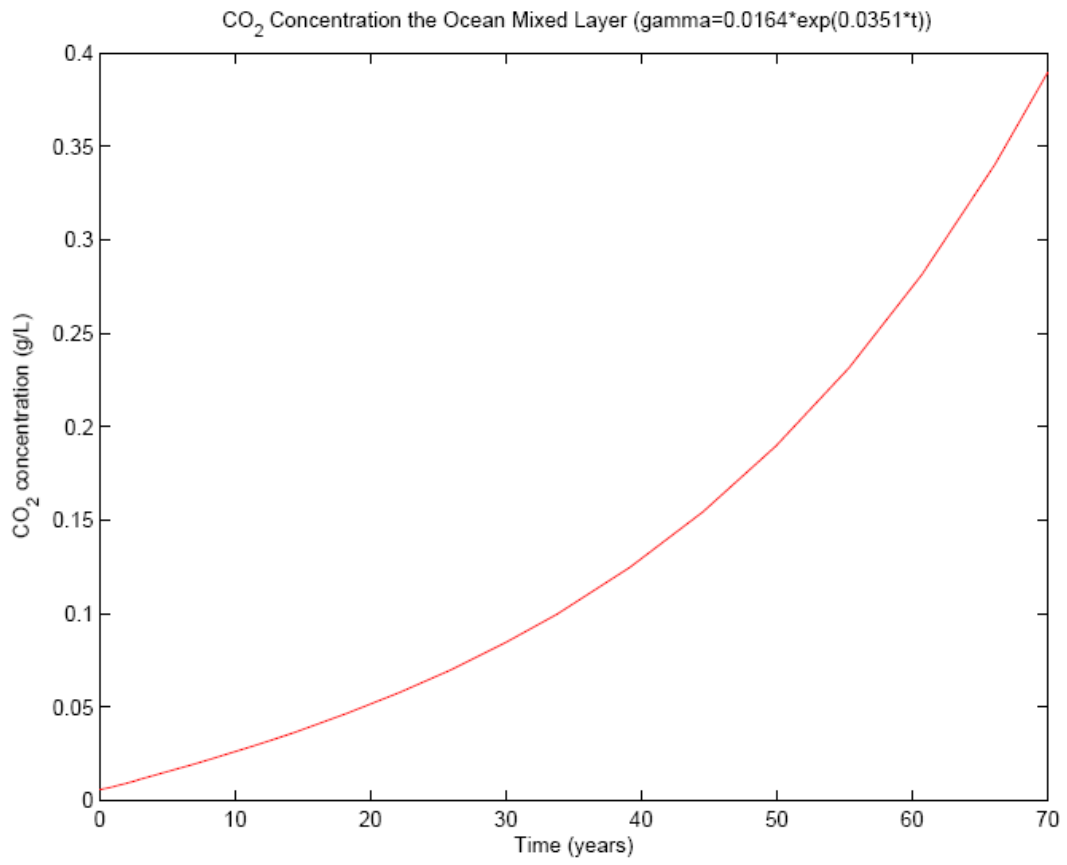
11.4 Graphs for Exponential form of Gamma

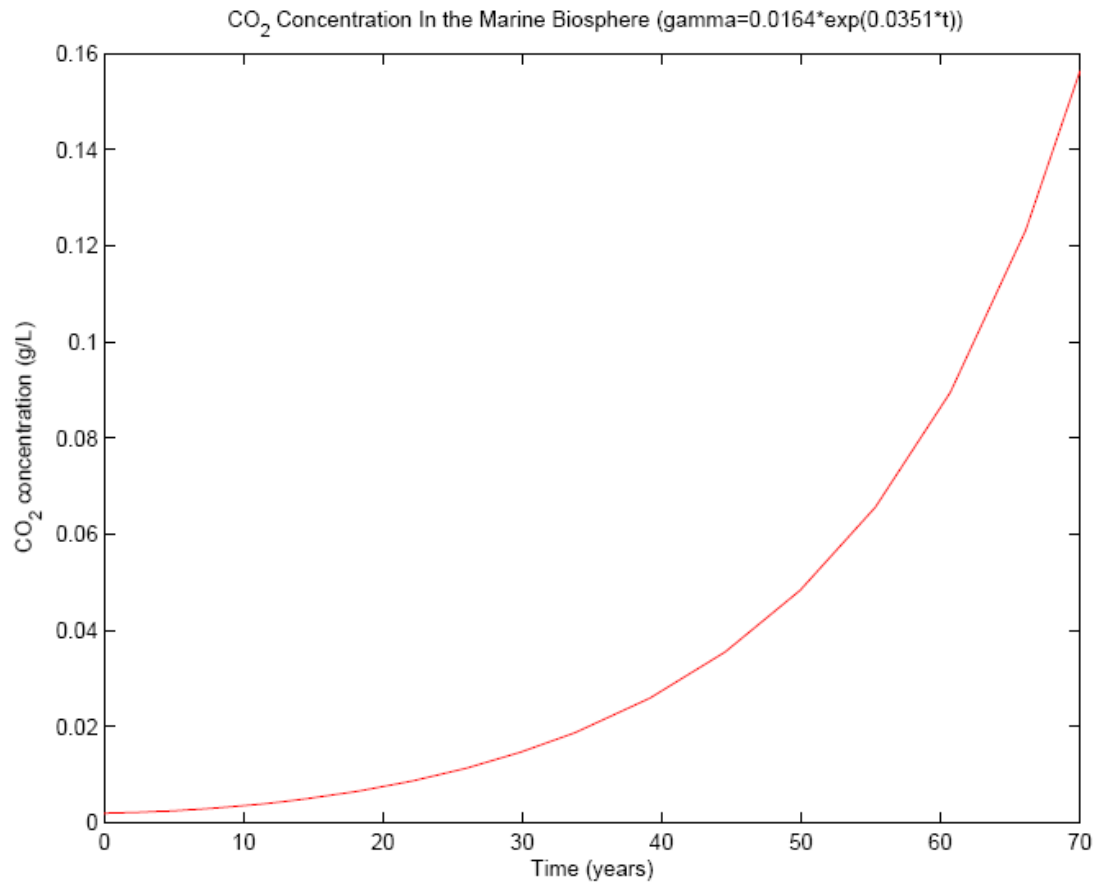


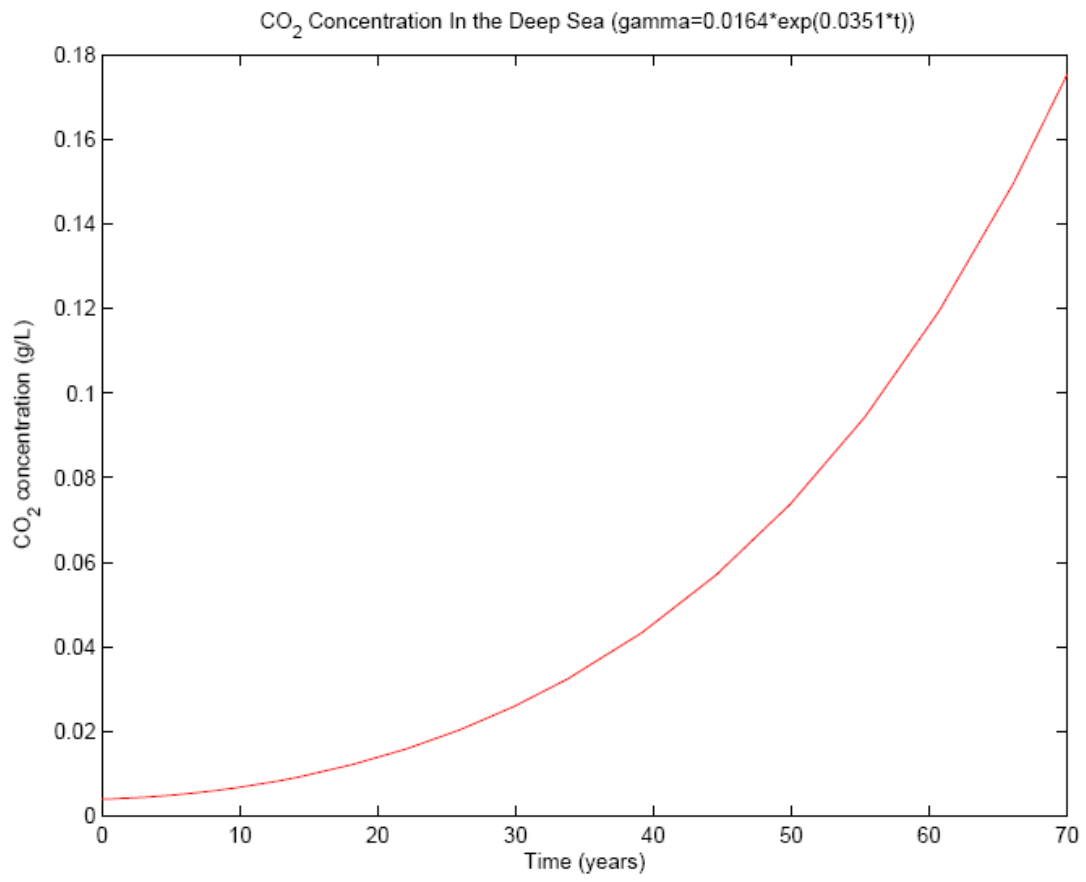












12 References

- De Leo, G. A., M. Gatto, A. Caizzi, and F. Cellina. "The ecological and economic consequences of Global Climate Change." Recent Research development in Biotechnology and Bioengineering. 22 September 2007
<http://www.arpalombardia.it/new/live/download/articoli/4cd/prom_sviluppo/Impact%20Projections%20Ver17%20FC%20original.pdf>
- Fabara, C. and B. Hoeneisen. "Global Warming: some back-of-the-envelope calculations." Universidad San Francisco de Quito. 11 March 2005.
- Hansen, James E. "A Slippery Slope: How Much Global Warming Constitutes "Dangerous Anthropogenic Interference?"" Climatic Change. 2005.
- Ho, Mae-Wan and Joe Cummins. "Genetically Modified Organisms." Institute of Science in Society.
- Hulme, Mike, Elaine M. Barrow, Nigel W. Arnell, Paula A. Harrison, Timothy C. Johns, and Thomas E. Downing. "Relative impacts of human-induced climate change and natural climate variability." Nature. 25 February 1999.
- Humi, Mayer. "Modeling Geophysical Flow." Department of Mathematical Sciences, Worcester Polytechnic Institute.
- IPCC. "Part I: Climate Change – Our Approach." STERN REVIEW: The Economics of Climate Change.
- Kremer, G. M. Vis, M. Prudich, D. Bayless. "Practical Photosynthetic Carbon Dioxide Mitigation." Ohio Coal Research Center. July 2007.
<www.ent.ohiou.edu/~ohiocoal>
- Leakey, Richard and Roger Lewin. The Sixth Extinction. New York: Knopf Publishing, 1995.
- McElroy, Michael B. The Atmospheric Environment: Effects of Human Activity. Princeton: Princeton University Press, 2002.
- McHugh, A. J. and S. Perusich. "Global CO₂ Model (GCM)." Department of Chemical Engineering, Lehigh University and Department of Chemical Engineering, Auburn University.
- Sellers, P. J., R. E. Dickinson, D. A. Randall, A. K. Betts, F. G. Hall, J. A. Berry, G. J. Collatz, A. S. Denning, H. A. Mooney, C. A. Nobre, N. Sato, C. B. Field, A. Henderson-

Sellers. "Modeling the Exchanges of Energy, Water, and Carbon Between Continents and the Atmosphere." Science. 24 January 1997.

"Trends in Carbon Dioxide." NOAA: Earth System Research Laboratory. 10 September 2007 < http://www.esrl.noaa.gov/gmd/ccgg/trends/co2_data_mlo.html>.

Wagner, Friederike, Raimond Below, Pim De Klerk, David L. Dilcher, Hans Joosten, Wolfram M. Kürschner, and Henk Visscher. "A natural experiment on plant acclimation: Lifetime stomatal frequency response of an individual tree to annual atmospheric CO₂ increase." Ecology. 29 July 1996.