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System dynamics applied to the effect of carbon dioxide emissions on global warming modelling

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Abstract: *Future predictions of carbon dioxide emissions and its effects on global temperatures do not look too promising. Since the advent of the industrial evolution that has seen an increase in burning of fossil fuels and other sources for energy, carbon dioxide emissions from these have skyrocketed. Comparing the increase in global temperature anomalies and the increase in carbon dioxide emissions, it seems there is a correlation between the global temperature anomalies and the increase in carbon dioxide emissions. This paper uses systems dynamics to model the increase in carbon dioxide emissions using several parameters and variables that are changed to see how much each affects carbon dioxide levels and in effect global temperature anomalies. In doing so, this paper provides a simplified model of global warming.*

1. Background Information

In the 21st century, the term greenhouse effect has a negative connotation. Common terms often associated with it are: global warming, climate change, burning of fossil fuels, etc. and none of them are mentioned in a positive light. However, global warming and the greenhouse effect are not inherently detrimental to life on earth and have not always been destructive and disadvantageous. In their paper, *The Science of Climate Change*, Oppenheimer and Anttila-Hughes state that, "the greenhouse effect is a prerequisite for life as we know it because without it, Earth would be colder (by about $32°C$ or $57.6°F$ and drier: a frozen desert." [2]. In the 18th century, most scientists saw warming as beneficial rather than problematic, due to the temperature anomalies at that time (seen in Figure 1).

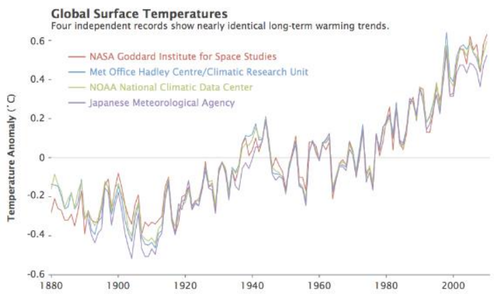

Figure 1: Temperature anomalies from 1800 to 2016 [1]

By the end of the 20th century, after the advent of the industrial revolution, the temperature anomalies had risen too high to be ignored as seen in Figure 1.

2. Problem Statement

"The greenhouse effect is a natural process that warms the Earth's surface" [3]. When the sun's rays reach the earth, some bounce back into space, the rest is absorbed by greenhouse gases. These greenhouse gases re-radiate the heat trapped which keeps the Earth warm enough to sustain life [3]. Among these greenhouse gases are carbon dioxide, water vapor, carbon monoxide, methane, nitrous oxide, ozone and some artificial chemicals such as chlorofluorocarbons (CFCs). The main interest of this paper is the effect of carbon dioxide on global warming and what it means to the Earth decades, and even billions of years from now.

3. Justification of the problem statement for investigation

Carbon dioxide as well as other greenhouse gases have a lifetime of about few days to a few thousand years [4]. Due to their relatively long lifetimes, they stay long enough to be uniformly distributed in the atmosphere [2][4]. This means for as long as there is more than the recommended concentration of carbon dioxide in the atmosphere, climate change will continue to be a problem [5]. Furthermore, the effects of carbon dioxide emissions linger for several decades, meaning that future generations will have to battle a problem they had no hand in creating [2].

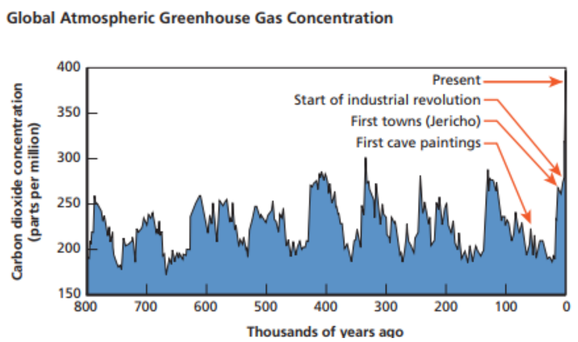

Figure 2: Increase in greenhouse gases, specifically carbon dioxide concentration over the course of human history, from the first cave paintings to present time (21st century [5])

This is made worse by the increasing carbon dioxide concentrations over time (seen in Figure 2).

All these make it clear that climate change because of carbon dioxide emissions is a problem that humanity must think about.

The aims and objectives of this research paper are to:

a. To model the concentration of carbon dioxide in the atmosphere
b. To identify parameters and variables that affect the concentration of carbon dioxide emissions and their effect when ignored or varied.
c. To investigate the effect of carbon dioxide on global temperature anomalies
d. To predict the concentration of carbon dioxide emissions over a period of 200 years
e. To make recommendations on how to tackle the issue of climate change

4. Materials and Methodology

4.1. Model formulation

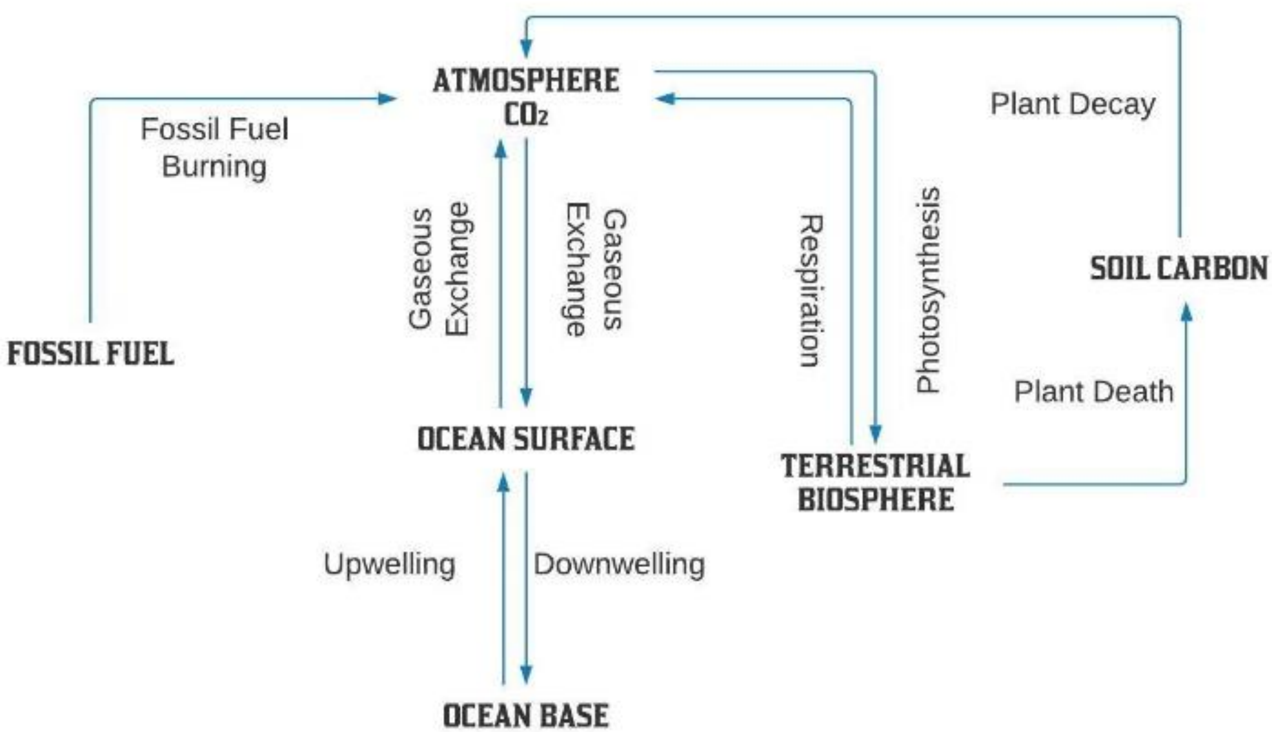

Figure 3: Flow Chart detailing the simplified carbon cycle model used in this paper

Many sources contribute to carbon dioxide emissions each year. Among these sources, those of interest for this paper are fossil fuel burning, plant death and decay and, respiration from living organisms. Carbon dioxide is also taken from the surroundings through a variety of means and the main one of interest is photosynthesis. A very simplified carbon dioxide cycle was used to estimate the concentration of carbon dioxide produced on an annual basis (as seen in Figure 3).

To achieve each of the aims and objectives of this paper, there were some assumptions that were made to further simplify the carbon dioxide cycle and obtain a block diagram.

4.2. Assumptions made

a. Global warming only affects the atmosphere
b. The only contributing factor to global warming is carbon dioxide
c. G_s and G_F were assumed to have constant values. The initial value for carbon dioxide present in the atmosphere (at $t = 0$) is assumed to be $36138285 * 10^3 tonnes$, which is the concentration of carbon dioxide emissions in the atmosphere as of 2014 [6].
d. For this paper, the system's boundary is the atmosphere; no other part of the earth is being considered.

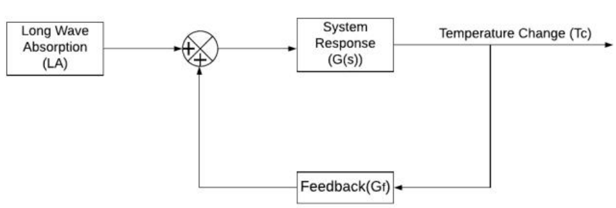

Figure 4: Block Diagram of System Considered

The resulting block diagram is as seen in Figure 4.

G_s is the system's response to the input, which is the long wave absorption of carbon dioxide, while G_F represents the effect temperature change will have on carbon dioxide concentration levels in the atmosphere. Given G_s and G_F, the temperature change in the atmosphere can be determined using the following equation: $T_C = \frac{G_s}{(1-G_sG_F)} L_A$

Where $L_A = 5.35 \ln\left(\frac{C_i}{C_o}\right)$

$$G_s = -1.59$$
$$G_F = 0.187 \text{ [7]}$$

.

C_i and C_o represent the final and initial concentrations of carbon dioxide, respectively.

e.

5. Results and Analysis

5.1. Analysis of Results (Without Changes made to the Parameters)

Using the model formulated for this paper, the graphs seen in Figure 5 were generated using the MATLAB code in Appendix A. It is observed that an increase in carbon dioxide emissions results in an increase in global temperatures [5].

N.B. These graphs were generated using the assumptions stated in Section 4.2. No changes have been made to any variables.

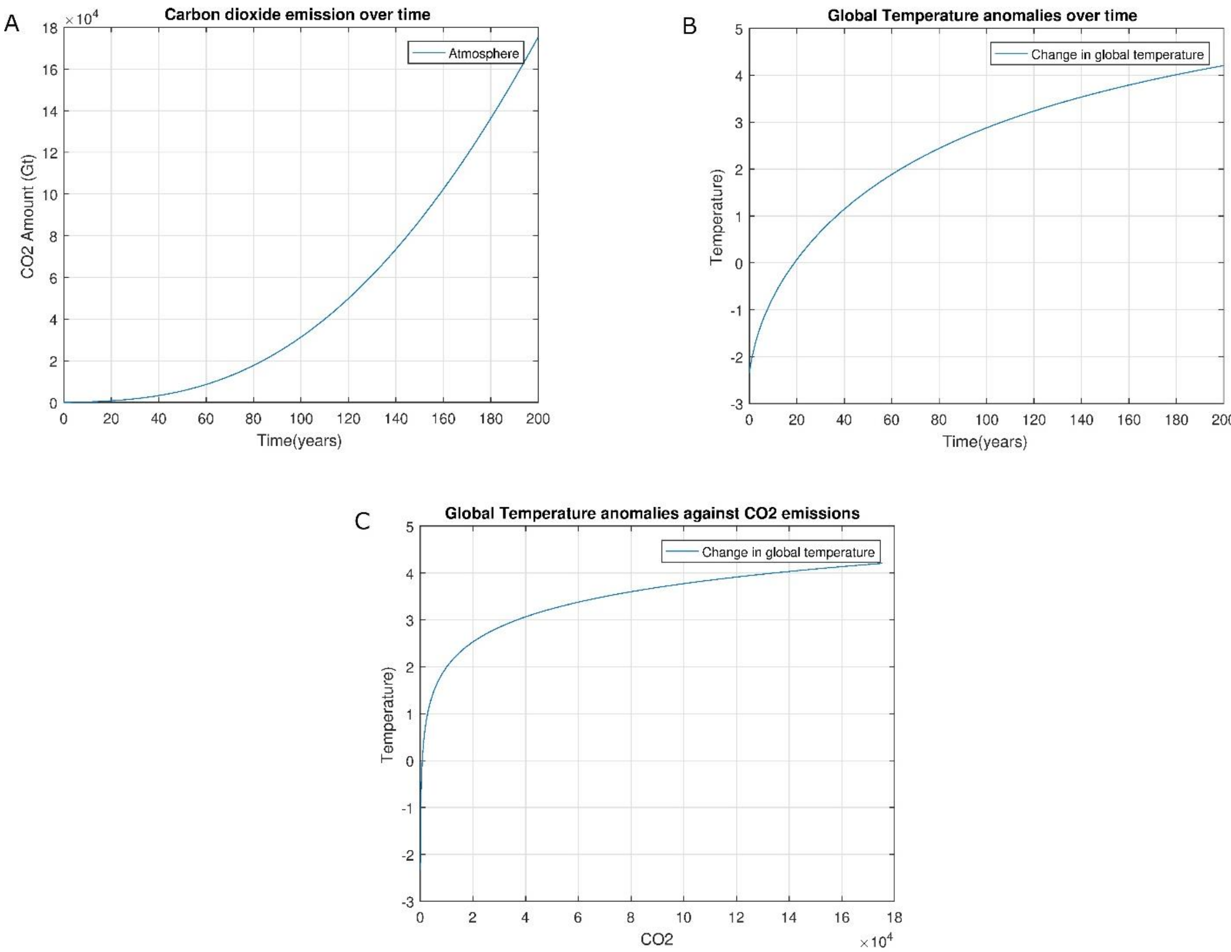

Figure 5: Graphs generated from system model. A shows the graph of carbon dioxide emissions over time. B shows the global temperature anomalies over time. C shows the global temperature anomalies against CO2 emission. It is observed that CO2 emissions are in some way related to the increase in global temperatures .

5.2. Changes because of changing parameters

To reduce the complexity of the model, the only parameters changed were:

- the initial carbon dioxide concentration and,
- the sign of G_F. G_F is assumed to be a damping factor due to a variety of reasons, meaning that it was a negative feedback. G_F is made a positive feedback to observe its effect on global temperatures.

N.B. The effect of each is considered individually, not as a lumped effect

The various values assigned to the parameters being varied (as described in Section 5.2 can be seen in Table 1.

	C_o
Case I: Very low C_o	$0.0036138\ Gt$
Case II: Very high C_o	$3613.8\ Gt$
Case III: Initial value of C_o with G_f as a positive feedback	$36.138\ Gt$

Table 1: Values assigned to parameters being varied

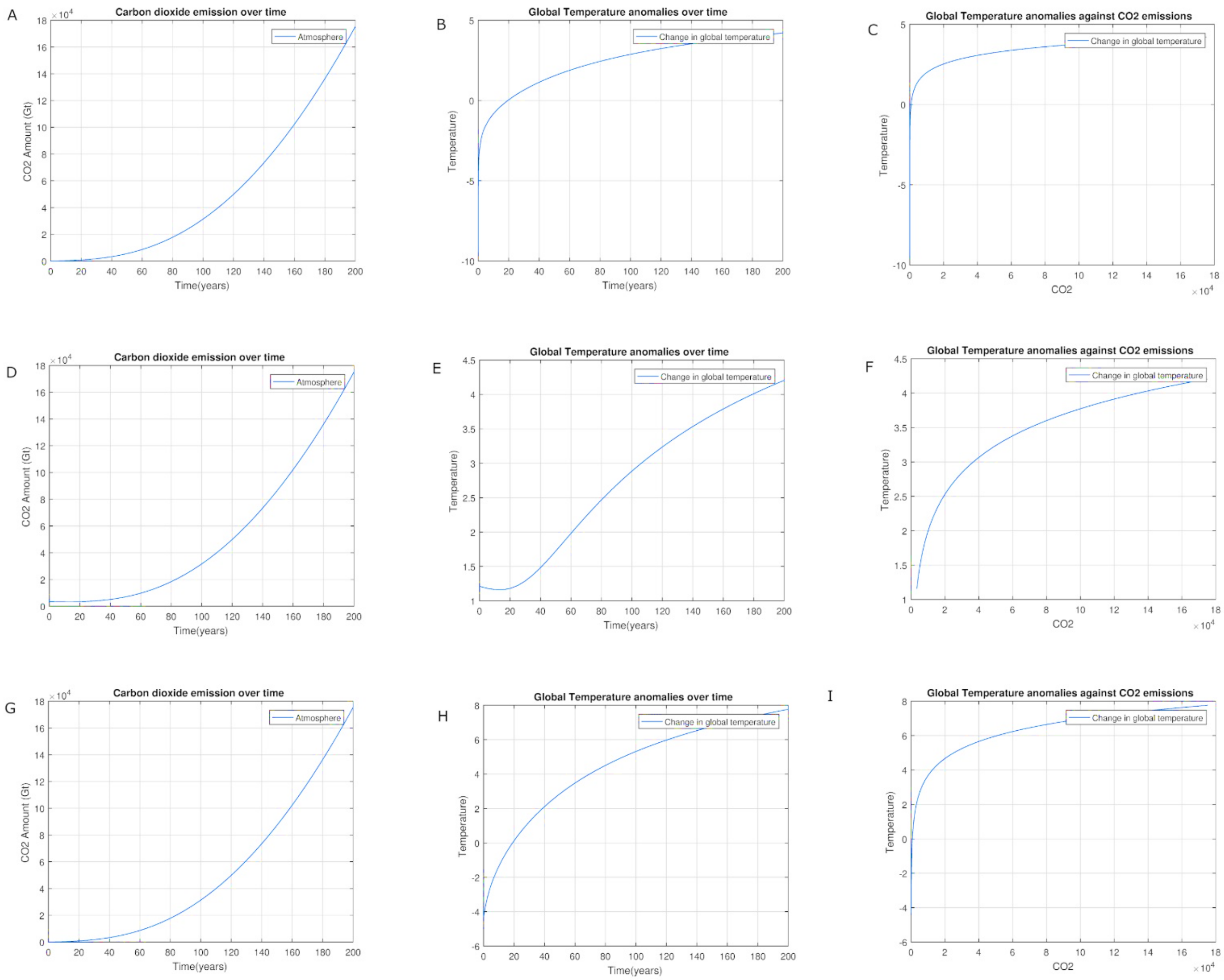

Figure 6: Simulation Results. (A - C) show Case I, the result of making the initial CO2 concentration very low. (D - F) show Case II, the resulf of making the initial CO2 concentration very high. (G - I) show Case III, the result of making Gf, a positive feedback value.

From each of the above cases, it is seen that, as the concentration of carbon dioxide increases, global temperatures increase. However, for the first two cases, it is observed that not much change occurs when the initial concentration of carbon dioxide is increased or decreased.

In Case III, it is obvious that changing G_F to a positive feedback did not affect the levels of carbon dioxide concentrations, but rather, had a pronounced effect on global temperatures, increasing it by as much as 2℃ as compared to B and C.

The model formulated can be used to model the effect of other greenhouse gases on global warming. It can also include them to estimate the lumped effect on global temperatures.

6. Discussion of results and analysis

From the system's model, it is expected that an increase in the concentration of carbon dioxide emissions in the atmosphere results in an increase of global temperature.

In all cases (Figures 6), it is observed that expectations were met.

Although all expectations were met, the model might be inaccurate because it does not consider other parameters and variables that influence global warming. In addition, there are other gases apart from carbon dioxide that contribute to global warming.

Furthermore, the model assumes the current state of the world will exist even 200 years from now, which is impossible; there will be inevitable changes, which this model cannot consider.

However, this model is a good start to predicting global temperatures for the future**.**

Several limitations to the project made the model inaccurate.

a. Since there was the lack of actual data, most of the research was secondary.
b. There was difficulty in isolating articles focused on the effect of carbon dioxide on global warming
c. There was the lack of current data for other initial conditions (fossil fuel burning, soil carbon, ocean surface, terrestrial biosphere, and deep ocean), which also influence the amount of carbon dioxide in the atmosphere.
d. The lifetime of carbon dioxide makes its effect extremely long lasting. With the other limitations, recommendation on the next steps will be hard to suggest with this model.

The following adjustments can be made to the model to make it a more accurate representation of the global warming system.

a. Expanding the system's boundaries, and modelling other contributing factors to carbon dioxide emissions, such as cement production.
b. Including other greenhouse gases in the model.

Global warming is a cause of panic to millions around the world because of its negative connotation. It is a problem – if not checked – that could lead to the apocalypse of the world. However, by predicting carbon dioxide levels over the next few years, a good step has been taken, one that will lead to many more in the right direction.

7. References

[1]"The Modern Temperature Trend", *History.aip.org*, 2017. [Online]. Available: https://history.aip.org/climate/20ctrend.htm[Accessed: 16- Dec- 2017].

[2]M. Oppenheimer and J. Antilla-Hughes, "The Science of Climate Change", *The Future of Children*, vol. 26, no. 1, pp. 11-30, 2016.

[3]"Department of the Environment and Energy", *Department of the Environment and Energy*. [Online]. Available: http://www.environment.gov.au/climate-change/climate-science-data/climate-science/greenhouse-effect[Accessed: 16- Dec- 2017].

[4]"Overview of Greenhouse Gases | US EPA", *US EPA*, 2017. [Online]. Available: https://www.epa.gov/ghgemissions/overview-greenhouse-gases[Accessed: 16- Dec- 2017].

[5]J. Dobbins, R. Solomon, M. Chase, R. Henry, F. Larrabee, R. Lempert, A. Liepman, J. Martini, D. Ochmanek and H. Shatz, *Choices for America in a turbulent world*. Santa Monica, Calif.: RAND, 2015, pp. 69-86.

[6]"Climate Change | Data", *Data.worldbank.org*. [Online]. Available: https://data.worldbank.org/topic/climate-

change?end=2014&start=1960. [Accessed: 16-Dec- 2017].

[7]M. de Rougemont, *Temperature Anomalies and Carbon Dioxide, a Correlation Attempt*. pp. 1-25.

Appendix A

```
function dy = climate(t,y)

%constants
gas_exchange = (y(2)-y(1))/75;
downwelling = y(2)* 0.03;
upwelling = y(4) * 0.0007048;
respiration = y(3) * 0.09565;
plant_death = y(3)* 0.09565;
plant_decay = y(5) * 0.0392857;
photosynthesis = y(3) *0.1913 -
y(6)*0.1;

%differential equations
%Fossil Fuel burning
dy(6) = 6 * (1 + (0.14*t));
%Atmosphere
dy(1) = gas_exchange + respiration +
plant_decay - photosynthesis + dy(6);
%Ocean Surface
dy(2) = gas_exchange + upwelling -
downwelling;
%Terrestial Biosphere
dy(3) = photosynthesis - respiration -
plant_death;
%Deep Ocean
dy(4) = downwelling-upwelling;
%Soil Carbon
dy(5) = plant_death - plant_decay;


dy = [dy(1); dy(2); dy(3); dy(4);
dy(5); dy(6)];

end

clear all
clc

atmosphere = 36.138;  %Gt C
ocean_surface = 750;  %Gt C
terrestial_biosphere = 575;  %Gt C
deep_ocean = 37600;  %Gt C
soil_carbon = 1400; %Gt_c
fossil_fuel_burning = 6; %Gt_c

y0 =
[atmosphere,ocean_surface,terrestial_bi
osphere,deep_ocean,soil_carbon,fossil_f
uel_burning];
[t,y] = ode45(@climate, [0 200], y0);
x = length(y(:,1));
r=y(:,1);
r(1)
for i = 1:x
    Fghg(i) = 5.35*(log(r(i)/750));
    dT(i) =
((0.187/(1+(0.187*1.59)))*Fghg(i));

end

%Plotting the differential equations
figure(1)
plot(t,y(:,1))
grid on
xlabel('Time(years)')
ylabel('CO2 Amount (Gt)')
title('Carbon dioxide emission over
time')
legend('Atmosphere')

%Plotting the temperature
figure(2)

plot(t,dT)
grid on
xlabel('Time(years)')
ylabel('Temperature)')
title('Global Temperature anomalies
over time')
legend('Change in global temperature')

figure(3)
plot(y(:,1),dT)
grid on
xlabel('CO2')
ylabel('Temperature)')
title('Global Temperature anomalies
against CO2 emissions')
legend('Change in global temperature')
```

MATLAB Code for global warming modelling