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Past, Present and Future Mean Temperatures for Earth's Global Climate

A Study of Global Temperatures and their Trends

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2. Introduction

Global Warming has been interpreted in different contexts from scientific to political. The dictionary defines Global Warming as “an increase in the Earth’s atmospheric and oceanic temperatures”[i]. One of the primary concerns that scientists have regarding Global Warming is whether or not the effects of Global Warming are caused by a natural temperature cycle or if the effects are caused by human-influenced actions. To help determine whether Global Warming is naturally or unnaturally caused, scientists look back thousands of years as well as observe present-day temperature readings to predict the root cause of any increase in global temperature. To help gauge past climates, scientists use proxies to analyze what the Earth’s climate was like before humans had a chance to impact the Earth. For present day climates, scientists look at temperature readings from various stations around the world and compare the readings to natural events, such as El Niño, to figure out if humans are causing a spike in global mean temperatures. In this paper the reader will be introduced to various methods used by scientists to help resolve doubts about Global Warming and observe the different types of research numerous groups have been conducting in response to the concern for Global Warming. This report will help the reader gain insight into one of the concerns that impact today’s environmental decisions.

3. Reconstruction of Past Climates

Even though there are records of measured temperatures from the past, the records themselves are no more than a few hundred years old. In order to go further back into the past, climate scientists, or often called *climatologists*, use proxies in order to make accurate estimations of past temperature as well as what the climate was like in particular regions. The study of climate using these proxies is called *Paleoclimatology* and some examples of these proxies are tree rings, coral rings, ice cores and sedimentary contents. Although there are many types of proxies, some of them provide finer details than others. These proxies are mostly dependent on the geography of the region to determine which sample is needed for the particular proxy. For example, in the ocean bed, the most suitable method would be to look at the coral rings since its growth is similar to tree ring. Figure 2 is an example of an ice core proxy and how scientists use this proxy to look into the past.

3.1 Tree and Coral Rings

One of the before mentioned proxies is called *Dendrochronology,* or the study of annual tree rings in determining the dates and the chronological order of past events. Using this method, scientists are able to determine when key climate events occurred by observing the thickness of each ring within the tree. Below is a figure taken from a young coniferous tree that indicates the different sections that scientists observe in using this proxy to determine whether or not the tree experienced a key event (i.e. forest fire, flood, drought).

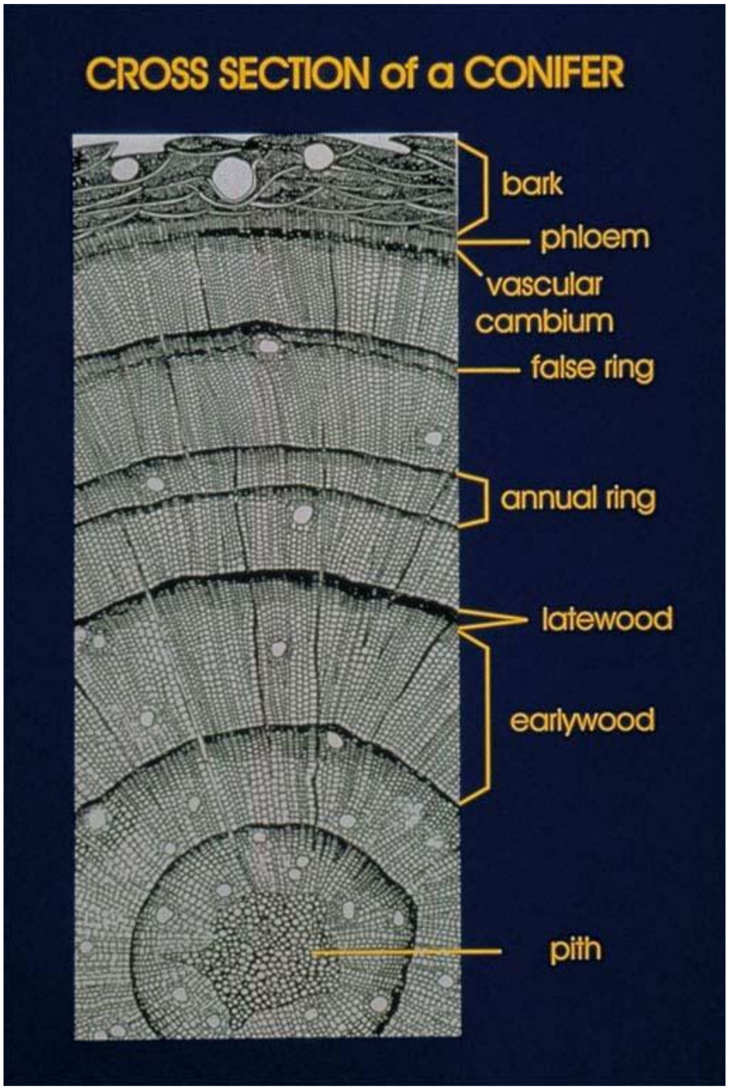

Figure 1 – Diagram of rings in a young conifer. Scientists pay close attention to the annual ring and can judge, based on the thickness, whether or not the climate was favorable or unfavorable to this particular tree.[xxii]

Discovered by Professor A.E. Douglass from the University of Arizona, Dendrochronology does not specifically tell scientists what the temperature was during a given time period, but it does tell scientists any influx in weather patterns that occur. For instance, if there was regular rainfall for several years in a row, the tree rings would be consistent as opposed to an instance where a tree experiences an unexpected drought for a year. Dendrochronology can be used to help solve irrigation problems, but in relevance to global climate issues, tree bark from certain trees date back 9000 years which provides scientists with lots of data.[iii]

3.2 Ice Core Techniques

The scientific definition of an ice core is "A cylindrical section of ice removed from a glacier or an ice sheet in order to study climate patterns of the past. By performing chemical analyses on the air trapped in the ice, scientists can estimate the percentage of carbon dioxide and other trace gases in the atmosphere from a given time period."[iv] Since ever year air get trapped within these sheets of snow and ice, scientists pull ice cores out to analyze the air composition. Scientists prefer high mountain regions like Antarctica and Greenland to obtain accurate readings from past climates. With these readings scientists are able to calculate the chemical compositions which help display what the climate and temperature were like in particular time periods.

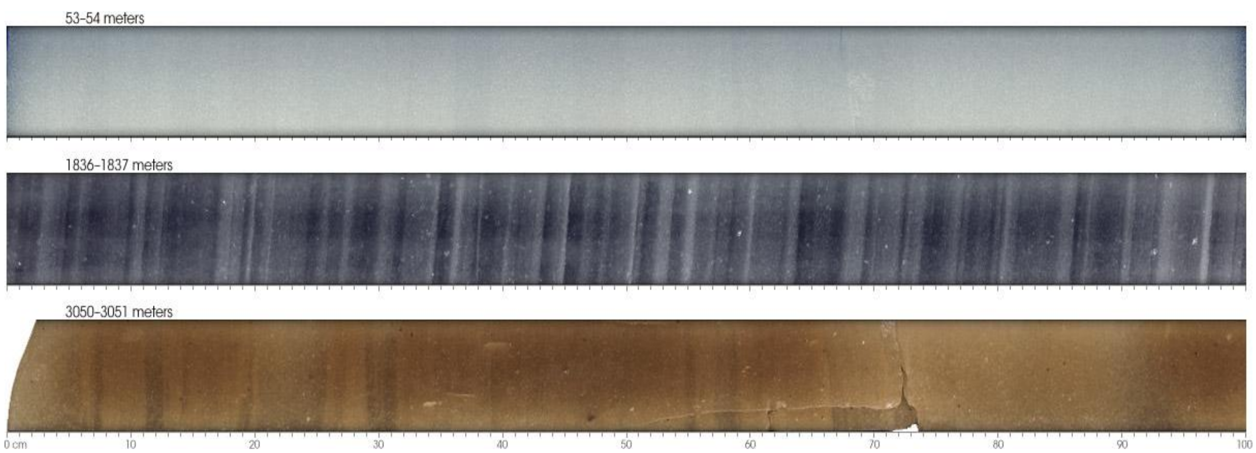

Figure 2-An ice core layer [v]

Figure 2 shows different layers of an ice core as if observing from different depths. The top layer is the new snow that accumulates from hardened ice and from regular snowfall, the middle layer consists of older and more compact layers of ice and the bottom layers of an ice core are mainly rock and sand from the Earth's crust [iv].

What climatologists generally look for in ice core data is the composition of the air molecules trapped within the ice that contain CO_2 and various isotopes (atoms of elements which have the same number of protons but different number of neutrons) such as hydrogen and oxygen. One example of what scientists look for is the amount of deuterium (^2H instead of the common ^1H) found within these ice cores which helps determine how warm the temperature was for that particular time period [xiii]. In general, scientists are more concerned with the composition of ^{16}O and ^{18}O, or also known as light and heavy oxygen.

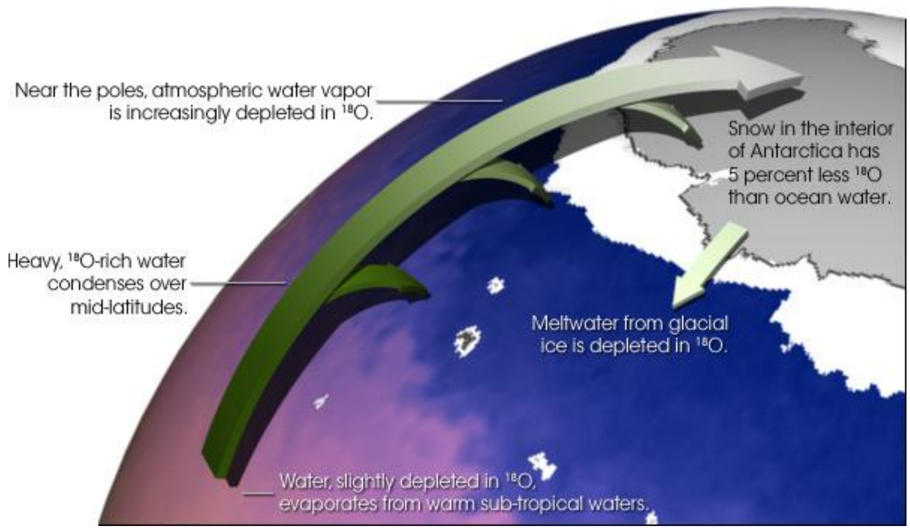

Figure 3-Heavy and Light Oxygen Balance [vi]

As the temperature decreases, ^{18}O water vapor precipitates at lower latitudes while the ^{16}O water vapor condenses as it moves toward the North and South Poles which then becomes trapped within ice sheets. The result is a higher concentration of ^{18}O in the ocean compared to the worldwide average as well as a higher concentration of ^{16}O in the polar ice sheets. Therefore, high concentrations of ^{18}O in the ocean means that ^{16}O was trapped in the ice sheets and the exact oxygen ratios can show how much ice covered the Earth in the past. On the other hand, when the temperature increases, the ice melts and the ^{16}O, which was trapped within the ice, returns to the ocean while ^{18}O water vapor becomes precipitated and, as the result, there is a higher concentration of ^{16}O in the ocean than ^{18}O's [ii].

Depending on the region in which an ice core temperature was obtained, scientists receive different estimations of past temperatures. Scientists calculate these temperatures using the modern spatial isotope/surface temperature relationship ($\delta = aT_s + b$), where δ can be the ratio of either [δD] (Deuterium) or [$\delta^{18}O$] (Heavy Oxygen) in the ice core and T_s is the mean surface temperature of the area where the ice core was obtained.[vii] [$\delta^{18}O$] can be calculated using the equation $\delta^{18}O = \left[\frac{R_{sample} - R_{VSMOW}}{R_{VSMOW}}\right] * 1000$, where R_{sample} is the isotopic ratio of [^{18}O /^{16}O] of the sample and R_{VSMOW} is the ratio taken from the Vienna Standard Mean Ocean Water[viii]. The Vienna Standard Mean Ocean Water (or VSMOW) is the water standard developed in 1968 by the International Atomic Energy Agency.

Figure 4 shows the change in temperature and the heavy oxygen concentration from the past 6000 years. From this figure this supports the notion that as the $\delta^{18}O$ value increases, the climate temperature increases. [ix] The other two figures, 5 and 6, show temperature patterns from different locations that show the similar impact of the heavy oxygen ratio from different locations.

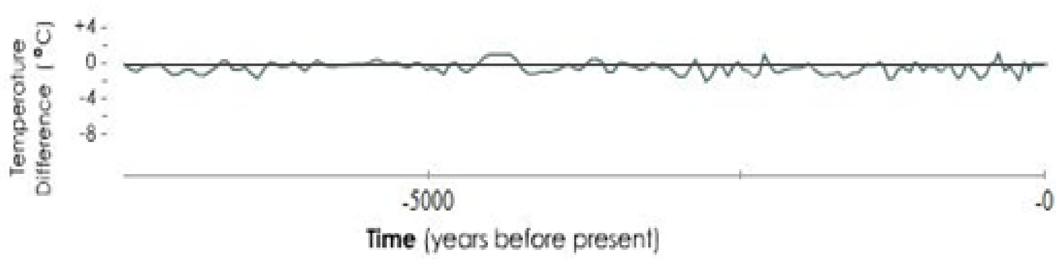

Figure 4- An ice core reading taken from Vostok, Antarctica[viii]

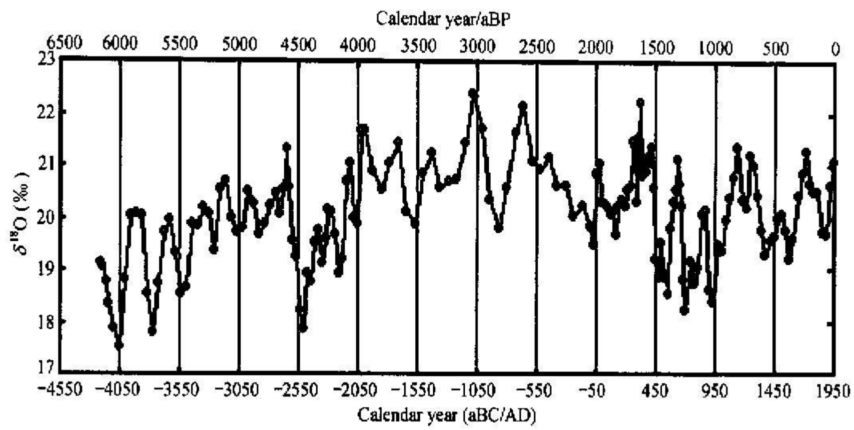

Figure 5- The δ[18]O concentration of Hongyuan, China for the past 6000 years which has been proven to be an effective proxy in determining temperatures from the past [ix]

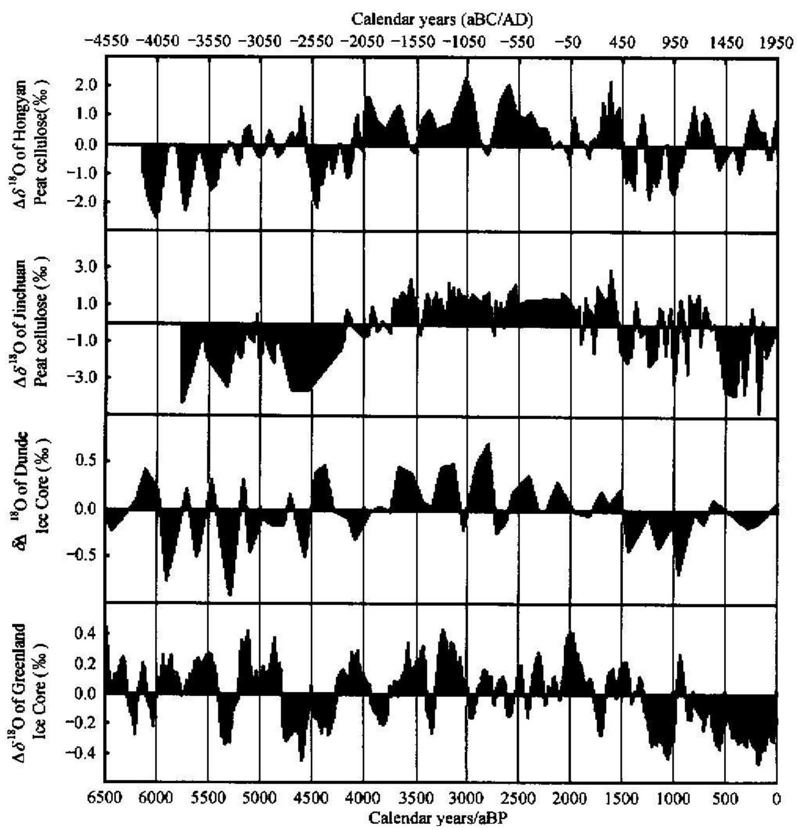

Figure 6- A comparison of ice core readings from different locations. The different locations used for Figure 6 are (from top to bottom): Hongyuan, Jinchuan and Dunde in China with Greenland being the last of the four graphs. [x]

4. Recent Temperature Trends and Projections for the Future

Using the information gathered from the various proxies, scientists are able to analyze and compare data from the distant past to present day to help determine if any unnatural changes occur in present-day climates. Scientists also use the data they collect to help predict what the Earth's climate will be like in years to come. In order to create these predictions, scientists must have accurate data of the most recent years in order to determine if any climate change is natural or human-influenced.

4.1 Global Temperatures

Starting back in 1950, NASA began recording the earth's surface temperature by using measurements from multiple stations in which a digital thermometer records the daily temperatures.[xi] The stations are heavily ventilated so that the thermometers are not influenced by any heat that may be trapped inside. These stations are inside so that variables such as rain, sunlight, and wind do not have an impact on the recorded temperature. NOAA records the temperatures across both hemispheres and takes the mean temperatures. NOAA then records into a computerized system which helps calculate trends and produces various graphs. [xii] Figure 7 shows the mean temperatures of both hemispheres recorded from 1950 to 2008 and are approximated from previous recording methods from 1880 to 1949. Some of the figures below also show both linear and quadratic best fit lines that indicate an increasing rate of changes in temperature. The changes in temperature are measured in degrees Celsius and range from (-0.4 to 0.8) degrees Celsius. For Figures 7, 10, 11 and 12, the zero mark represents the average based on the entire data set (1880-2008).

To help predict the future temperature changes, the following figures depict the global mean temperatures from 1880 to 2008 respectively:

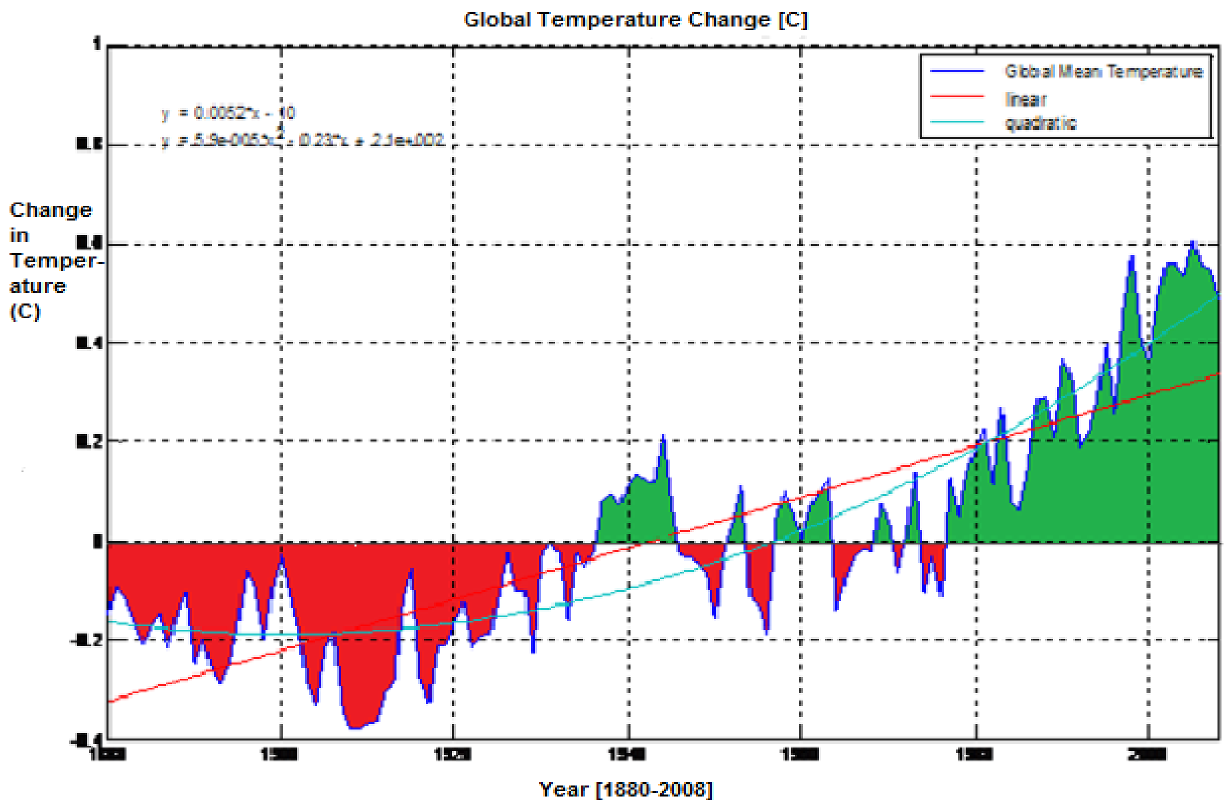

Figure 7 – Temperature Readings from the average of the Northern and Southern Hemispheres during the period 1880-2008. The zero mark along the y-axis is the zero mean of the entire data set.

All of these figures depict a global temperature trend that shows a consistent increase, possibly due to the current tendency of natural and human-influenced global activity such as emissions. Along with this discovered trend, scientists discovered small variations that began before the Industrial Era (pre-1880) in gulf streams and weather patterns. Some of these variations include volcanic activity that release both aerosol and carbon dioxide into the atmosphere. The Earth's orbit can also cause the mean temperature to change based on its location and relative to the sun and changes in the sun's intensity.[xiii] According to the Environmental Protection Agency, it has been recorded that there was some cooling between the 15th through 18th century, which caused global temperatures to be lower than the average.

Scientists discovered this cooling based on the results found in ice cores. [xi] Although this issue is highly disputed, there have been reports based on information gathered from places such as Greenland as well as the North Atlantic Basin (please see the information presented in the Ice Core section).

4.2 Natural Influences Explaining Short Term Oscillations

Although recent studies have indicated that the primary reason for global warming is due to the amount of emissions that human beings issue, there are other sources including natural events that contribute to this event year by year. One of these events is called ENSO [El Niño Southern Oscillation] or El Niño, in which "El Niño events are large climate disturbances which are rooted in the tropical Pacific Ocean, and occur every 3 to 7 years. These events have a strong impact on the continents around the tropical Pacific, and some climatic influence on half of the planet. The developed phase of El Niño is characterized by elevated temperatures of the ocean surface (of at least 0.5° Celsius) from a section of the Equatorial Pacific.[xii] The trigger for an El Niño is not about how long it lasts, but rather the temperature readings recorded. It is traditional that a La Niña period will follow an El Niño period since the Earth will try to create equilibrium. A consequence of such warming is the long-term perturbation of the weather systems over the lands around, notably heavy rains in usually dry areas, drought in normally wet regions. El Niño is also seen as the warm phase of irregular climate oscillation which is caused by unstable interactions of the ocean and atmosphere. Conversely to El Niño, the cold phase, La Niña, occurs with some cooling of the surface waters in the equatorial Pacific Ocean. A La Niña event may follow an El Niño, but not always."[xiv]. This event causes warmer air to be distributed among the Earth at a normal time in which the Earth would be cooled off. Its counterpart, La Niña, occurs when there are cooler temperatures over the summer. Scientists from NOAA, the National Oceanic and Aerospace Administration, have been trying to determine when they should expect an El Niño year and when the temperatures recorded for that year are influenced by a different source.

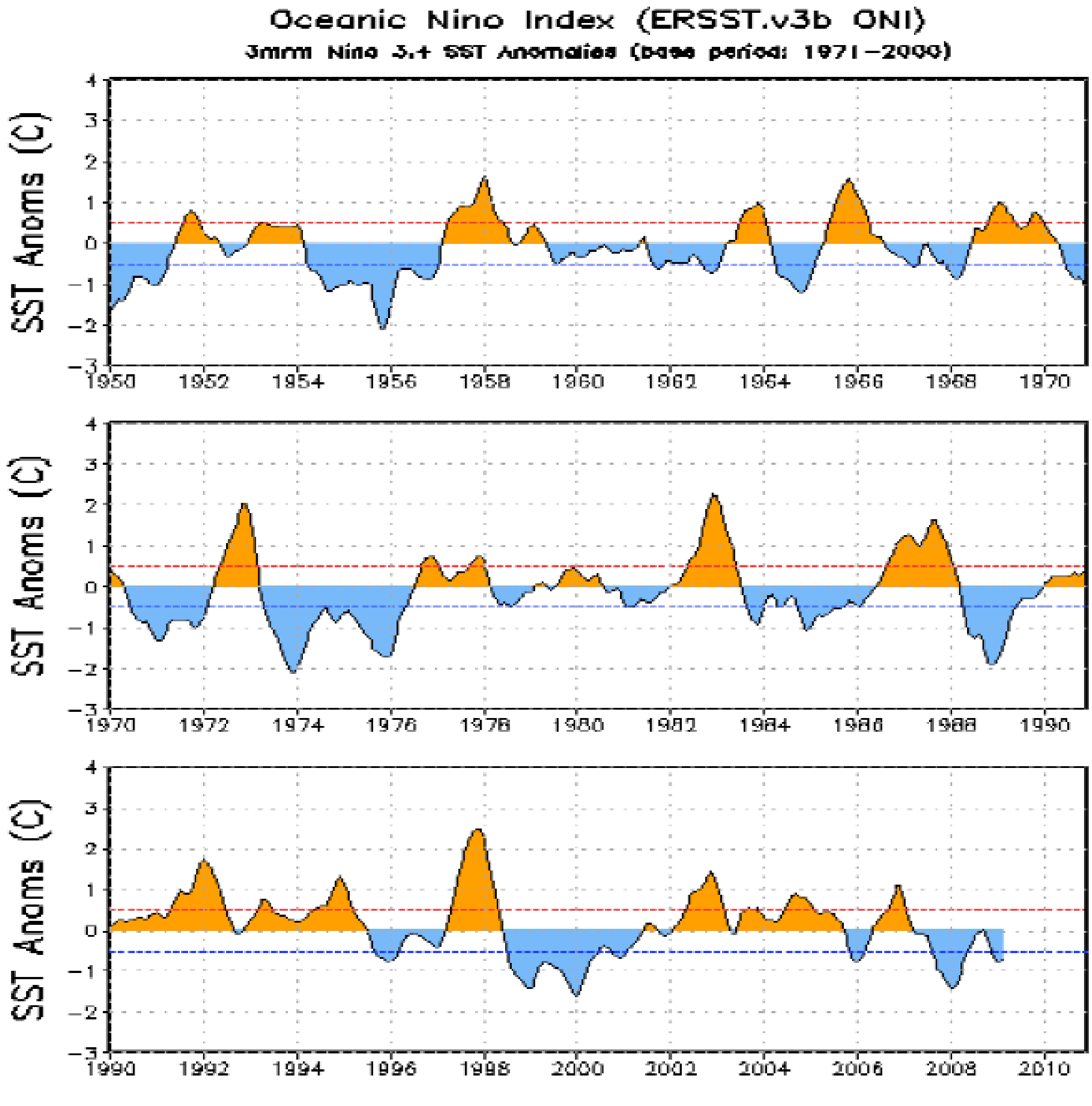

Figure 8 - Oceanic Nino Index – The red line indicates an El Niño cycle while the blue line represents a La Niña cycle[xv]

The figure above shows information from NOAA that has the record of different months in which both El Niño and La Niña occur. The graph indicates an El Niño period when the graph exceeds the Red line and indicates a La Niña period when the graph dips below the dotted blue line. By looking at when El Niño occurs and by using the following graph which indicates the impact that ENSO has on the global mean temperature the actual global mean temperature change is shown:

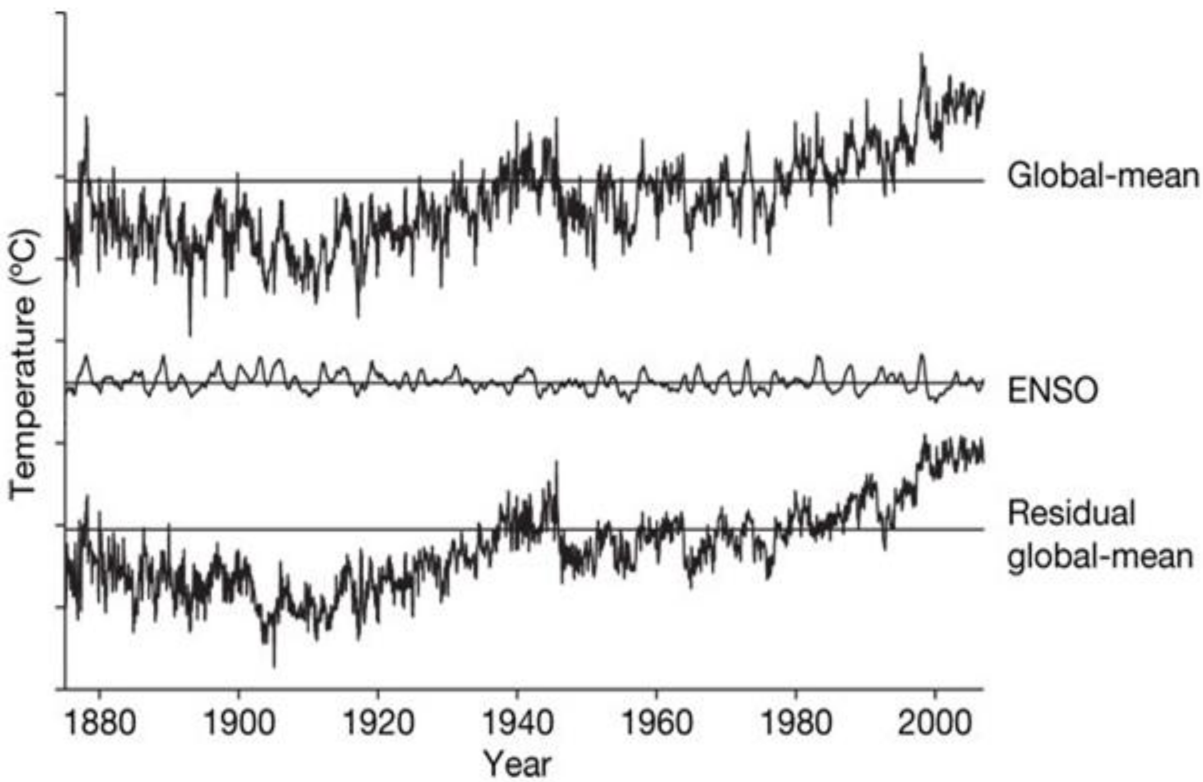

Figure 9 - Comparing Global Mean Temperatures from a figure taken from NOAA which compares natural patterns to the mean temperature readings discovered[xvi]

The graph indicates several spikes in ENSO influence especially during 1998 and 1983, but overall the graph still indicates an increasing slope from factors other than natural occurrences such as ENSO. The residual global-mean graph was determined when scientists took the global-mean temperatures and took out the ENSO pattern. In their findings they discovered that in some regions, there was a temperature clash of cold air coming from the ocean and warmer air coming from the land.[xvii] This concept can be coupled with that of the Gulf Stream which is why specific areas, such as the United Kingdom, may have latitude closer to the Arctic Circle, but the mean temperatures are warmer than that of other nearby countries. With those natural influences set aside, scientists are able to understand more of the human influence that impact present-day climates.

4.3 Projections for Future Mean Temperatures

When looking at issues such as global warming, it is a scary thought to think that the problem will only get worse, but by looking at the following graphs which project a further increase in global mean temperature the problem is projected to worsen. The following graphs indicate what the global mean temperature will be like with the various trends until the year 2100:

Figure 10 (1880-2100)

Temperature readings at 2050 = 0.561, at 2100 = 0.821 (degrees Celsius warmer than the 20th century mean) for the linear trend and for the quadratic trend the mean temperature change is recorded at 2050 = 1.14, at 2100 = 2.17. This graph is the data received from 1880 until 2008 and then extrapolated until the year 2100.

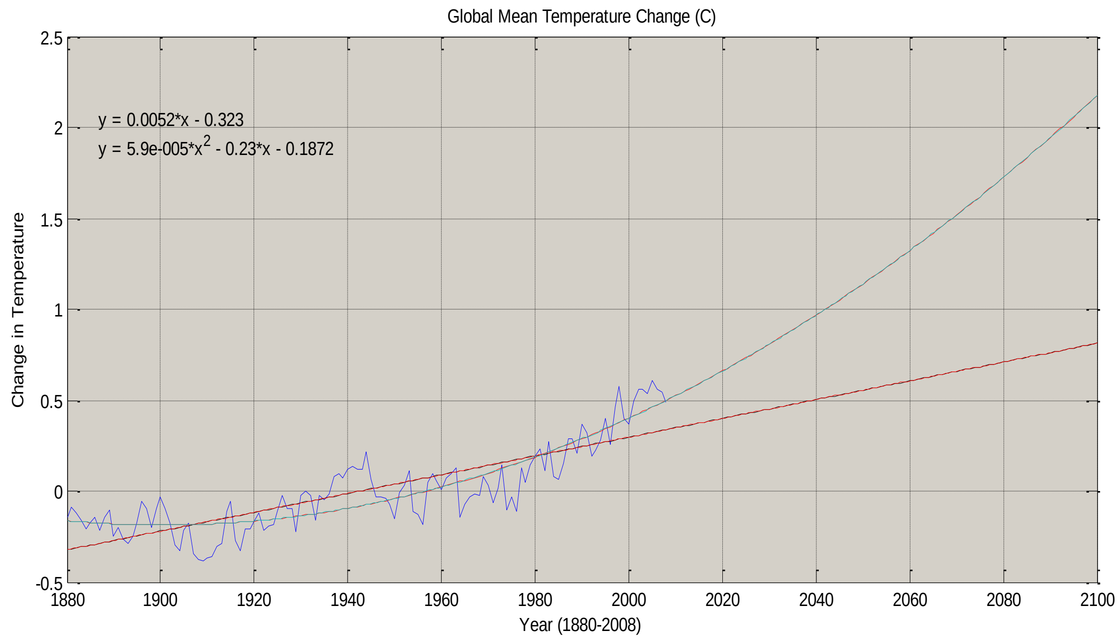

Figure 10 – Graph of temperature records for the period between 1880-2008. Figures 10-12 show the data (dark blue), the linear fit (red) and the quadratic fit (light blue). The Y-axis is centered on '0' to represent the mean of the entire data set recorded by NASA. The data set is a combination of temperature readings from both the Northern and Southern Hemispheres.

Figure 11 (1950-2100)

The temperature readings were found to be at 2050 = 0.961 and 2100 = 1.52 (degrees Celsius warmer than the 20th century mean) for the linear curve and were found to be at 2050 = 2.06, 2100 = 4.85 for the quadratic curves (all in degrees Celsius). This graph was created from the data recorded from 1950 until 2008 and then extrapolated until the year 2100.

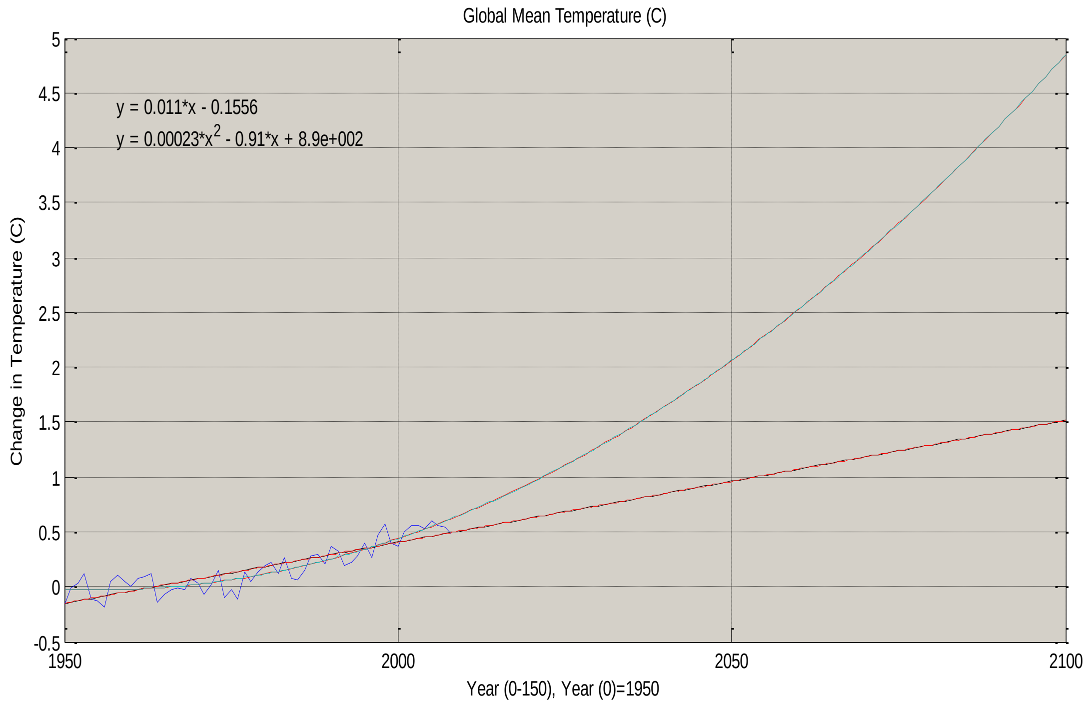

Figure 11 - Graph of temperature records for the period between 1950-2100.

Figure 12 (1980-2100)

The temperature readings found were at 2050 = 1.29 and 2100 = 2.12 (degrees Celsius, linear) and were found at 2050 = 1.82 and 2100 = 4.08 (degrees Celsius, quadratic). This graph was created from the data recorded from 1980 until 2008 and then extrapolated until the year 2100.

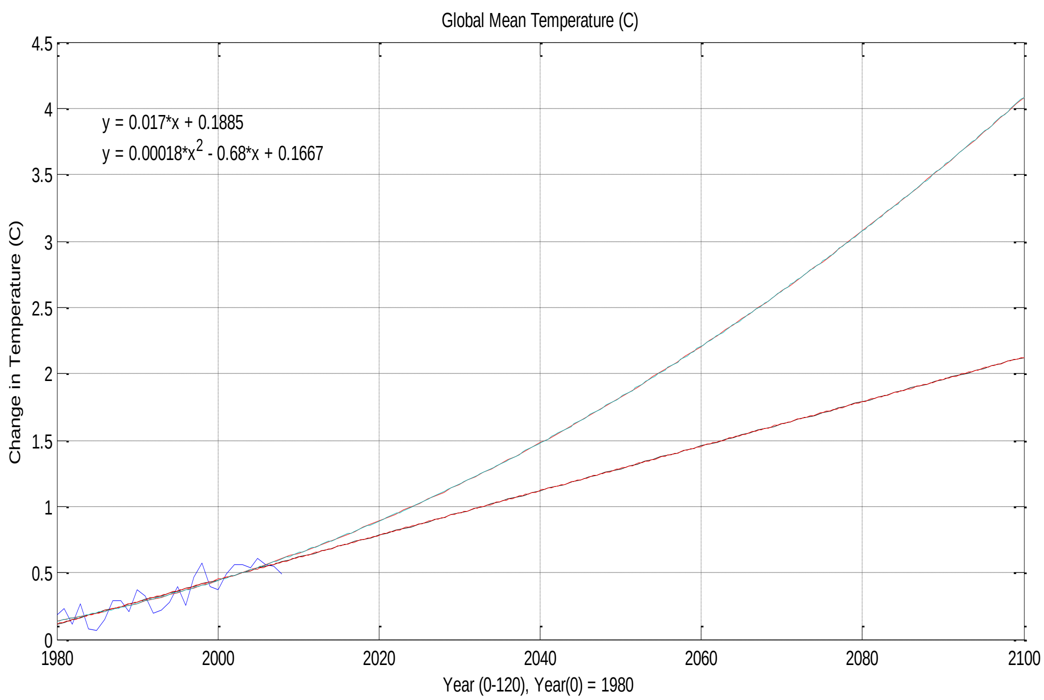

Figure 12 - Graph of temperature records for the period between 1980-2100.

As shown in the later graphs, the trend of increasing temperatures seems to have more of an impact in more recent years rather than during the early 20th century. Reasons as to the cause of this trend can be indicated by various factors such as population growths, technological advances, emissions output, and greenhouse gases. For all of these graphs, the equations have been given for the readers to establish any particular year they may be interested in. As indicated in the various graphs the linear trends have been increasing (.0055 in Figure 9, .011 in

Figure 10 and .017 in Figure 11) which shows that in more recent years there has been a significant temperature change.

5. Physics of the Earth's Climate System and its Modeling by Climatologists

After scientists discovered data regarding the earth's climate based on the various proxies and temperature readings, these scientists began to analyze the physical cause of any increase or decreasing in climate temperature. Using these findings, a set of scientists, the Intergovernmental Panel on Climate Change (or the IPCC), publish assessment reports to show the public the results from these scientists' research. There are currently four assessment reports that have been published with the fifth report being scheduled to be finalized during the year 2014. In these reports, scientists have claimed that an increase of Greenhouse gases is a factor in the earth's climate.

5.1 Greenhouse Gases

The definition of a greenhouse gas is "a chemical compound that contributes to the greenhouse effect. When in the atmosphere, a greenhouse gas allows sunlight (solar radiation) to enter the atmosphere where it warms the Earth's surface and is reradiated back into the atmosphere as longer-wave energy (heat). Greenhouse gases absorb this heat and 'trap' it in the lower atmosphere."[xviii] Some of these greenhouse gases are carbon dioxide (CO_2), methane gas (CH_4), and nitrous oxide (N_2O) which are introduced into the atmosphere by methods like burning fossil fuels and human beings exhaling. It is because of the most recent growth in technology and in population that the earth is suffering from the Greenhouse Effect to a larger extent. There are many greenhouse gases in the air, such that the heat generated by the Sun's solar radiation is trapped in the Earth's atmosphere. This effect causes the Earth to heat up, just as if the Earth was a greenhouse.

5.2 Climate Impacts from the IPCC

The IPCC's (Intergovernmental Panel on Climate Change) goal is to "asses the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change." These scientists analyze whether or not recent climate changes are human-influenced, natural or a compromise between the two. This goal has been modified with recent findings and the IPCC is working hard to help determine solutions to combat any human influence that may impact the Earth's climate. Figure 13 is from a recent report that shows how the earth distributes solar radiation (energy from the sun). Notice how, in the figure, some of the radiation is reflected off of the Earth's surface while most of the radiation is absorbed into the surface of the Earth. Some of the radiation escapes as evapo-transpiration (similar to evaporation, but from vegetation instead of coming just through water), but then most of it gets reflected back to the Earth's surface. This is the Greenhouse effect. Although the figure shows energy balance, if the amount of Greenhouse gases increases, the amount of Back Radiation increases as well. This causes the atmosphere to radiate more energy which is then converted into heat. Eventually the radiation is returned back into space from whence it came, but not before some of that radiation gets reflected which causes the Earth to absorb more energy. As time has passed, humans have introduced more Greenhouse gases which lead to more solar radiation and cause more energy to be released into the atmosphere.

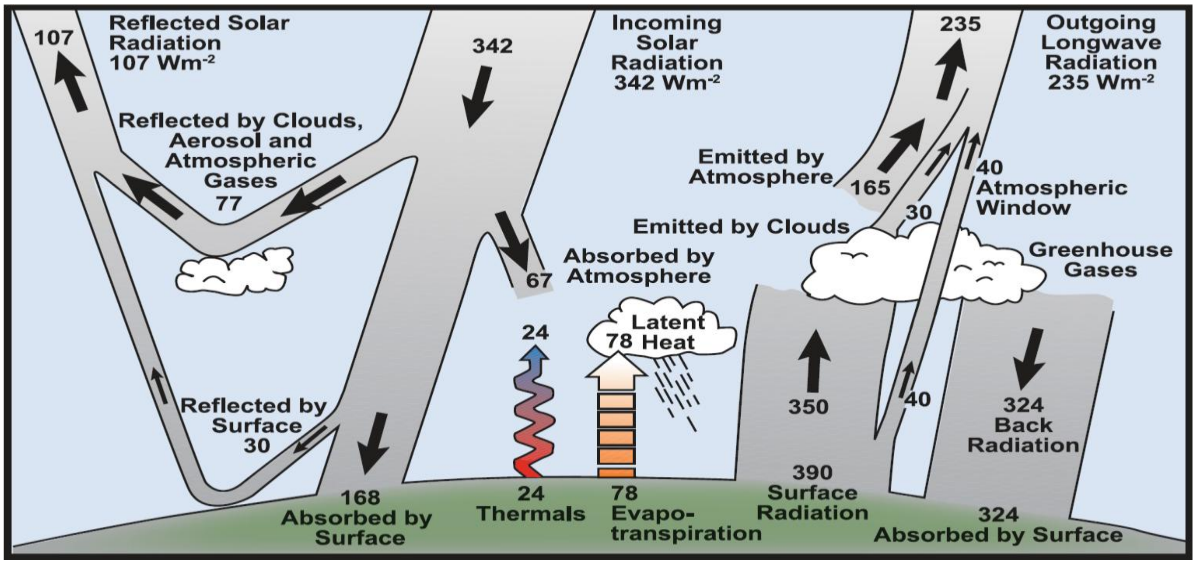

Figure 13 – Energy balance model for Earth's climate[xix]

Over the past few decades, climatologists have conducted research pertaining to global climates which helped in understanding and modeling the Earth's climate systems. Due to this research, more and more physical aspects have been incorporated into more recent climate models which are displayed in Figure 14. "95% of all the climate change science literature since 1834 was published after 1951. Because science is cumulative, this represents considerable growth in the knowledge of climate processes and in the complexity of climate research."[xx] As time has passed, from the mid-1970's, climatologists have incorporated factors such as CO_2 concentrations to solar radiation and have progressed to incorporate carbon cycles and the chemistry in the air. Based on Figure 14, the IPCC began exploring factors that they believed affected climate change: CO_2 levels as well as acid rain. As more research and more reports were created, more factors began emerging from their research. As depicted from Figure 14, the complexity of current climate models has developed such that they have calculated various factors that impact today's climate. For example, in the Second Assessment Report, SAR issued in 1995, the report focuses primarily on ocean currents, volcanic activity and sulphate levels on the Earth.[xxi] Another aspect that this report shows is that natural events were depicted primarily as the impact that El Niño and La Niña have on present-day climates. The IPCC's Global Assessment Report continues on to discuss factors such as aerosols being released into the air and to express more in detail the chemistry of the air within the atmosphere and how it contributes to the Greenhouse effect as well as back radiation.

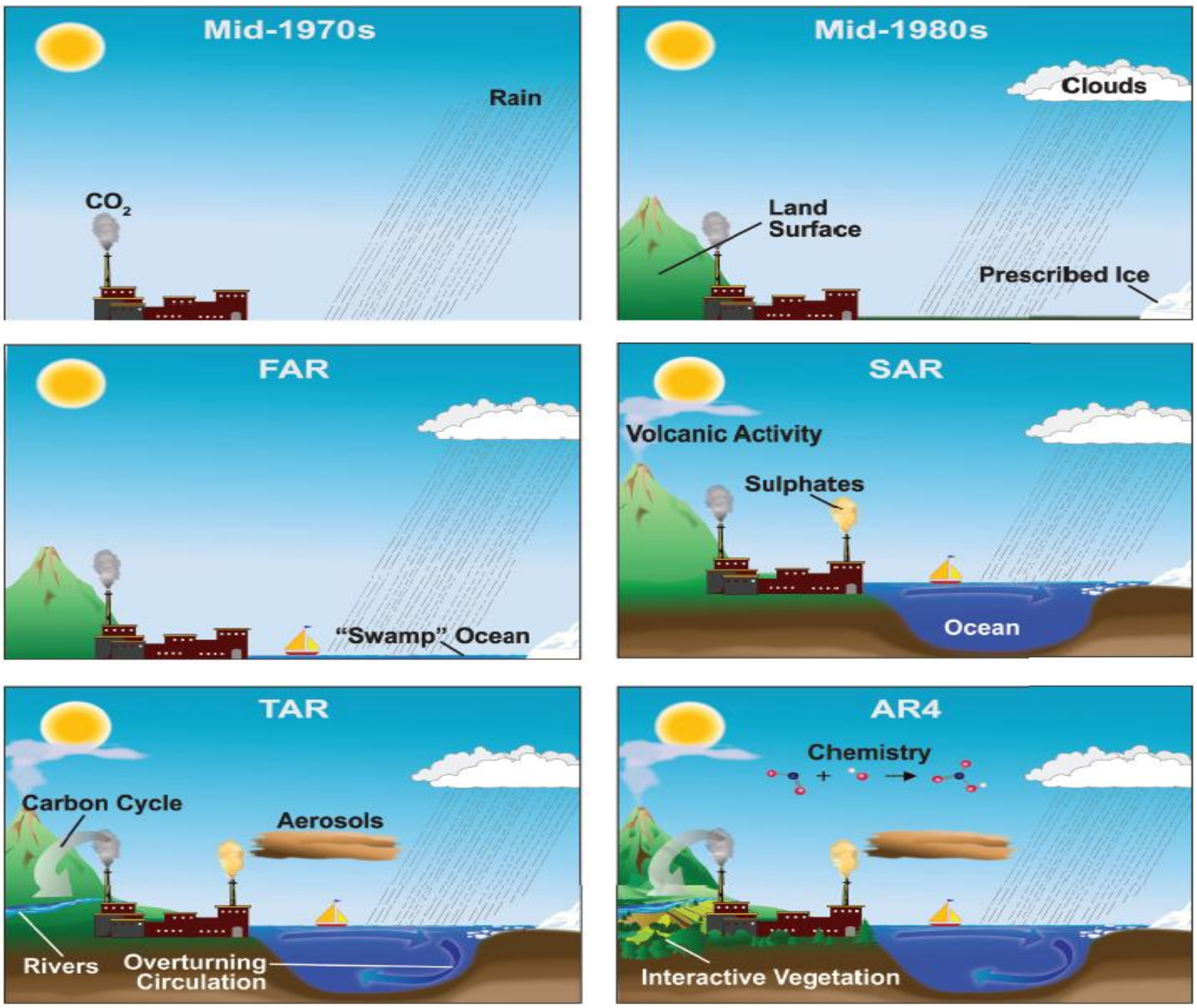

Figure 14 – A progression of the factors considered within the IPCC Global Assessment Report starting from the First (FAR) to the Fourth (AR4)[xxii]

6. Conclusion

From ice core technology to worldwide stations, scientists are working hard to answer questions presented by the appearance of Global Warming. Based on the information presented by the scientists of the IPCC, there is an increase in global temperatures; however, it is still unclear as to whether or not these trends are entirely human-influenced or are caused by natural events or a combination of both. Regardless of who or what causes these events, it is important for people to be aware of how everyday actions, such as pollution, impact today's climate. Scientists are still analyzing lots of data to help fully understand Global Warming and how to prevent its effects, but it is important for every person to be conscientious of the world around them. Panels and special groups, like the IPCC, are hard at work presenting new facts and figures by introducing new factors that involve the Earth's climate and how humans could impact global climates. In short, scientists have only begun exploring the key factors that impact Earth's global climate and will continue to explore all temperature trends to help solve the growing problem that is Global Warming.

7. Appendix – MatLab Code

The following is the MatLab code used in forming Figures 10-12 in this paper:

```
function [p1 p2]=mean_temp_finals
%Welcome, the following Matlab code can be executed by issuing the command
%'run mean_temp_finals'.  We begin by establishing our first of three
%tables to represent the 1880 graph.
A=table;
s=size (A);
s=s(1);

for j=1:s

    x(j)=A(j,1);

    y(j)=A(j,2);

end
```

```
plot(x,y)
%p1 and p2 in this case are the linear 'p1' and the quadratic 'p2' fits
%that will go into the graph.  Matlab reads the equation as polyfit(1st
%variable, 2nd variable, degree of computation).
p1 = polyfit(x,y,1);
p2 = polyfit(x,y,2);
hold on
%For 'x', we want to establish the boundaries of our data.
x=1880:2100;
inter=p1(1)*x+p1(2);
%This will display in Matlab what the equations are that it uses for the
%best linear and quadratic fits.
display(sprintf('%g*x^2 + %g*x + %g', p2(1),p2(2),p2(3)));
display(sprintf('%g*x + %g', p1(1), p1(2)));
%Using the equations we now plot some key points and indicating them with
%an 'X' for the linear fit and a Cross for the quadratic fit.
plot(x,inter,'k');
plot (2050, 0.561, 'kx')
plot (2100, 0.821, 'kx')
plot (2050, 1.14, 'r+')
plot (2100, 2.17, 'r+')
inter=p2(1)*x.^2+p2(2)*x+p2(3);
plot(x,inter,'r');
%We define a span of values for the y-axis by using the following code:
axis([1880 2100 -0.5 2.5]);
pause
clear all
hold off

%Just as explained before, the following set of code is used for the 1950
%graph where the code is practically identical, but altered slightly so that
%the variables do not confuse Matlab and still produce the desired graph with
%the desired key points.
B=table2;
s2=size (B);
s2=s2(1);

for j=1:s2

    x2(j)=B(j,1);

    y2(j)=B(j,2);

end

plot(x2,y2)

p3 = polyfit(x2,y2,1);
p4 = polyfit(x2,y2,2);
hold on
x2=1950:2100;
inter2=p3(1)*x2+p3(2);
display(sprintf('%g*x^2 + %g*x + %g', p4(1),p4(2),p4(3)));
display(sprintf('%g*x + %g', p3(1), p3(2)));

plot(x2,inter2,'k');
```

```
plot (2050, 0.961, 'kx')
plot (2100, 1.52, 'kx')
plot (2050, 2.06, 'r+')
plot (2100, 4.85, 'r+')

inter3=p4(1)*x2.^2+p4(2)*x2+p4(3);
plot(x2,inter3,'r');
axis([1950 2100 -0.5 5]);
pause
hold off
clear all


%This set of data is for the 1980 graph:
C=table3;
s3=size (C);
s3=s3(1);

for j=1:s3

    x3(j)=C(j,1);

    y3(j)=C(j,2);

end

plot(x3,y3)

p5 = polyfit(x3,y3,1);
p6 = polyfit(x3,y3,2);
hold on
x3=1980:2100;
inter5=p5(1)*x3+p5(2);
display(sprintf('%g*x^2 + %g*x + %g', p6(1),p6(2),p6(3)));
display(sprintf('%g*x + %g', p5(1), p5(2)));

plot(x3,inter5,'k');
plot (2050, 1.29, 'kx')
plot (2100, 2.12, 'kx')
plot (2050, 1.82, 'r+')
plot (2100, 4.08, 'r+')

inter6=p6(1)*x3.^2+p6(2)*x3+p6(3);
plot(x3,inter6,'r');
pause
hold off

function A=table

A=[1880   -0.1467;

1881   -0.0896;

...

2007    0.5480;
```

```
2008    0.4859];

function B=table2
B=[1950   -0.1556;
1951   -0.0119;
...
2007    0.5480;
2008    0.4859];
s=size (B);s=s(1);
for j=1:s
    x2(j)=B(j,1);
    y2(j)=B(j,2);
end
plot(x2,y2)
function C=table3
C=[1980    0.1885;
1981    0.2292;
...
2007    0.5480;
2008    0.4859];
s=size (C);s=s(1);
for j=1:s
    x3(j)=C(j,1);
    y3(j)=C(j,2);
end
plot(x3,y3)
```

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