Trends in the Earth’s global temperature and natural cycles

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Abstract: We examine in this project recent trends in the Earth's global surface temperature. We attempt to filter out oscillations from both linear and quadratic trends. Physically these oscillations may be explained by natural cycles such as the El Nino/La Nina oscillation. This work supports the idea that the pace of global warming has not stalled in the last couple of years. We project observed trends into the future to obtain a measure of expected warming by 2050 and by 2100. Physically these projections rely on the assumption that man-made emissions of greenhouse gases will either continue at today's levels, or will continue to increase at today's rate. Finally we review what the expected impacts of average temperature change are on sea level rise, the precipitation cycle, and what adverse effects are feared regarding agriculture production.

Introduction

This paper's intended purpose is to examine how the Earth's environment is changing, and to look into whether or not this is due to human influence, and if we can accurately predict the upcoming average temperature. To do so, the reader will see graphs of the worldwide mean temperature from for the EPA (Environmental Protection Agency) and NASA (National Aeronautics and Space Administration) to determine both overarching as well as specific influences such as ENSO (El Nino Southern Oscillation).

1. 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 any drastic change in climate. Scientists also use the data that 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.

1.1 Global Temperatures

Starting in 1950, NASA began recording the earth's surface temperature by using measurements from multiple stations in which there is a digital thermometer that records the temperatures daily.[i] The stations are heavily ventilated so that the thermometers are not influenced by any heat that may be trapped inside and are inside such that variables such as rain, sunlight, and wind do not have an impact on the recorded temperature. NOAA records the temperatures in both hemispheres and takes the mean temperatures then records the data on graphs.[ii] Figure 7 shows the mean temperatures of both hemispheres recorded from 1950 to 2010 and analyzed from 1880 to 1949. The figures 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:

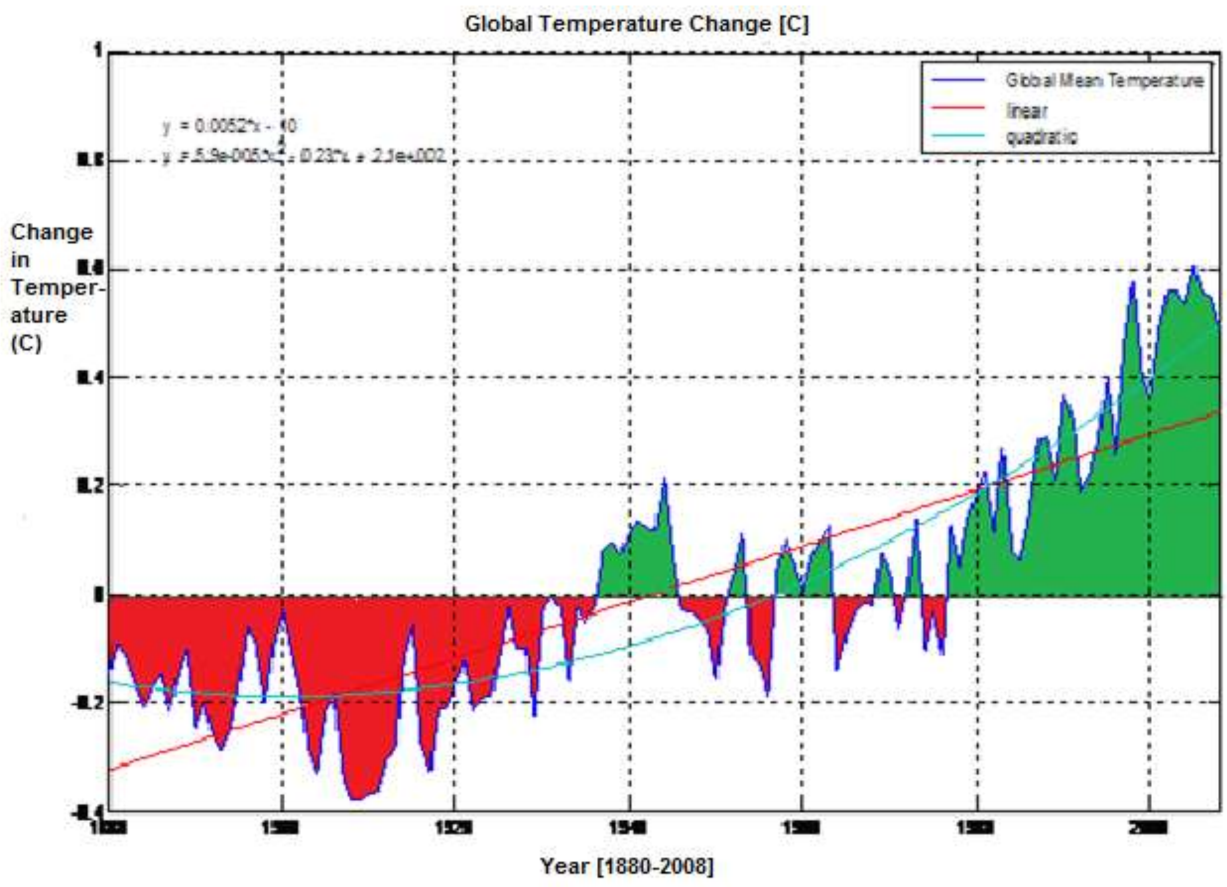


Figure 1 – Temperature Readings from the average of the Northern and Southern Hemispheres during the period 1880-2008. The zero mark along the y-axis is the zero mean of the entire data set.

All of these figures depict a trend of global temperatures in which these figures will only increase with the current tendency of natural and human-influenced global activity such as emissions. On top of the human activity induced signal, small variations beginning before the Industrial Era (pre-1880) such as changes in gulf streams or weather patterns. Some of these include volcanic activity that releases both aerosol and carbon dioxide into the atmosphere creating what we now call 'greenhouse gases', the Earth's orbit can cause the mean temperature to change based on its location and relative to the sun and changes in the sun's intensity.[iii] According to the Environmental Protection Agency, it is recorded that there was some cooling during the 15th through 18th century, causing global temperatures to be lower than the average 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).

1.2 Natural Influences Explaining Short Term Oscillations

Although recent studies have indicated that the primary reason for the global temperature trend is due to the amount of emissions that human beings issue, there are other sources including natural events that contribute to this trend by a year by year fluctuation. One of these events is called ENSO 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. They 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. 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 the irregular climate oscillation called ENSO (El Niño/Southern 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."[iv]. 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.

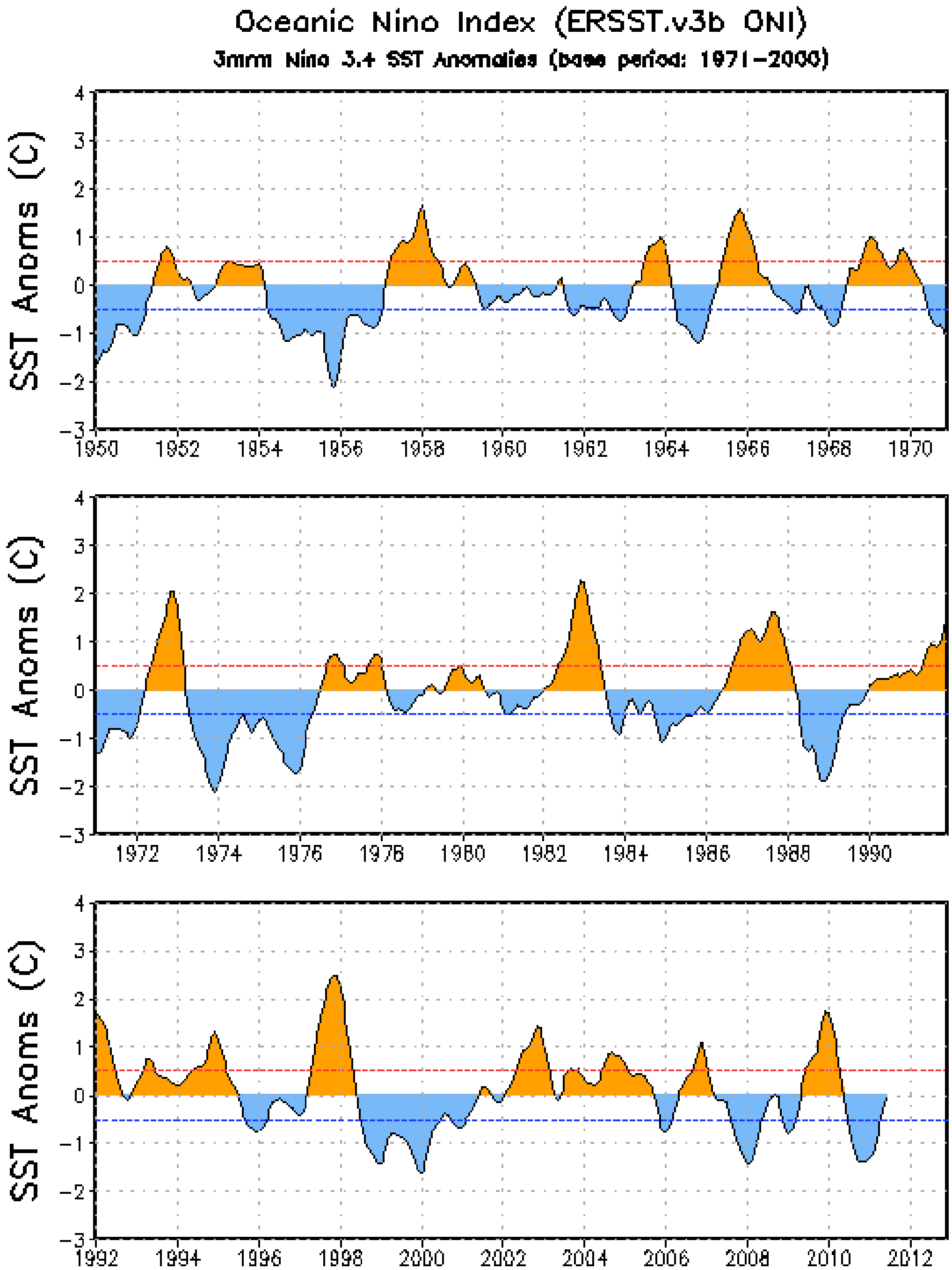


Figure 2 - Oceanic Nino Index – The red line indicates an El Niño cycle while the blue line represents a La Niña cycle[v]

The figure above shows information from NOAA that has the record of different months in which both El Niño and La Niña occur. 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:

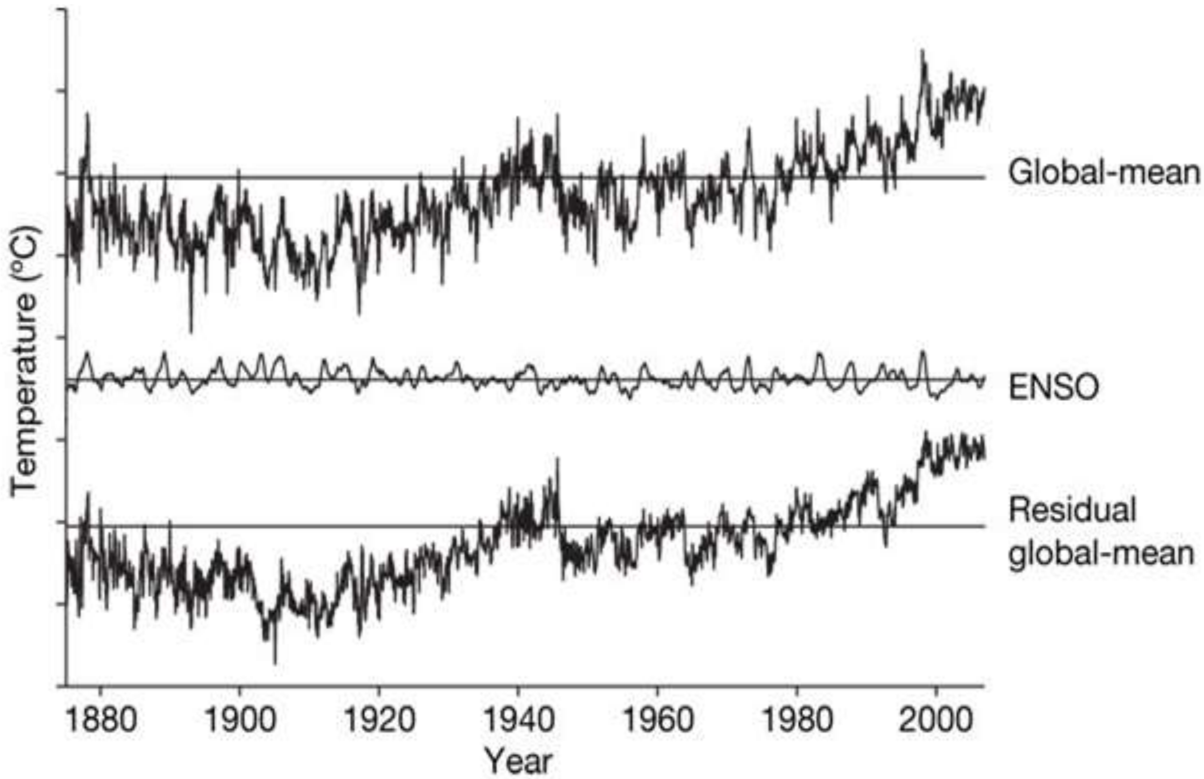


Figure 3 - Comparing Global Mean Temperatures from a figure taken from NOAA which compares natural patterns to the mean temperature readings discovered[vi]

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.[vii] 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.

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

After scientists discover data based on the various proxies and temperature readings, the scientists begin to analyze the physical cause of any increase or decreasing in climate temperature. Using their findings, a set of scientists belonging to the Intergovernmental Panel on Climate Change (or the IPCC) publish assessment reports to show to the public the results from the 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.

2.1 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."[viii] Some of these greenhouse gases are carbon dioxide (CO_2), methane gas (CH_4), and nitrous oxide (N_2O) which are released by burning fossil fuels to 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. There are so many greenhouse gases in the air, that the heat generated by the Sun's solar radiation is trapped in the Earth's atmosphere such that the Earth is beginning to heat up, just as if the Earth was a greenhouse.

2.2 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" in which they analyzed whether or not recent climate changes are human-influenced, natural or a compromise between the two. This goal has been modified with recent findings such that the IPCC is working hard to help determine solutions to combat the human influence that impacts the Earth's climate. Figure 12 is from a recent report that shows how the earth distributes the 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 due to the back radiation 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 4 – Energy balance model for Earth's climate[ix]

Over the past few decades, climatologists have conducted large amounts of research pertaining to global climates that have helped in understanding and modeling the Earth's climate systems. Due to this increase, more and more physical aspects have been incorporated into the more recent climate models which are displayed in Figure 11b. "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."[x] 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 more of the simple factors that affect climate change: CO_2 levels as well as acid rain. As more reports came from the IPCC, more and more factors began emerging from their research***.*** As depicted from Figure 14, the complexity of climate models has developed such that they have calculated various factors in 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 influences on the Earth's climate.[xi] The IPCC began looking at how natural events influenced the current climate and looked at volcanic activity. These 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.

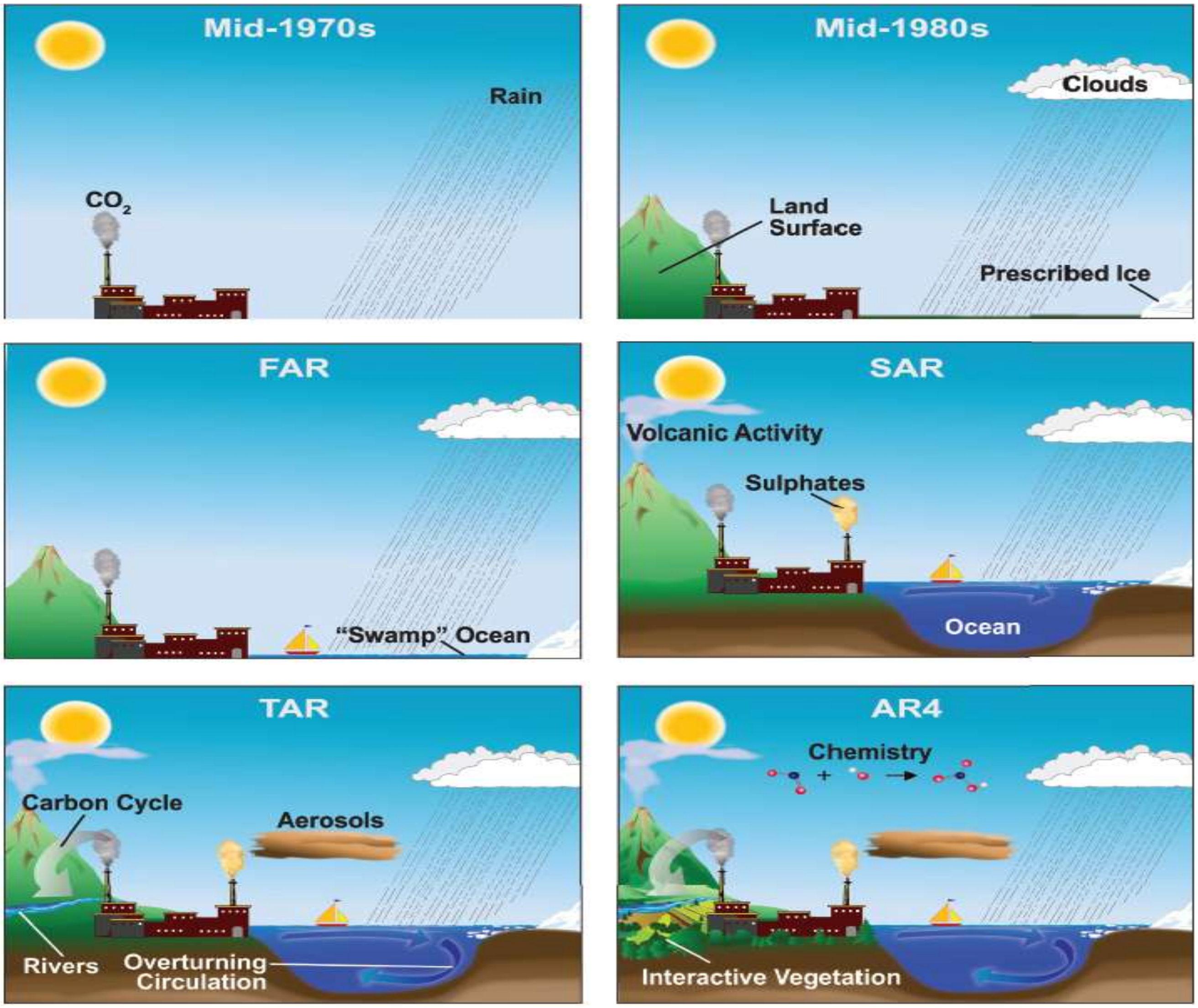


Figure 5 – A progression of the factors considered within the IPCC Global Assessment Report starting from the First (FAR) to the Fourth (AR4)[xii]

What does this mean for the future?

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:

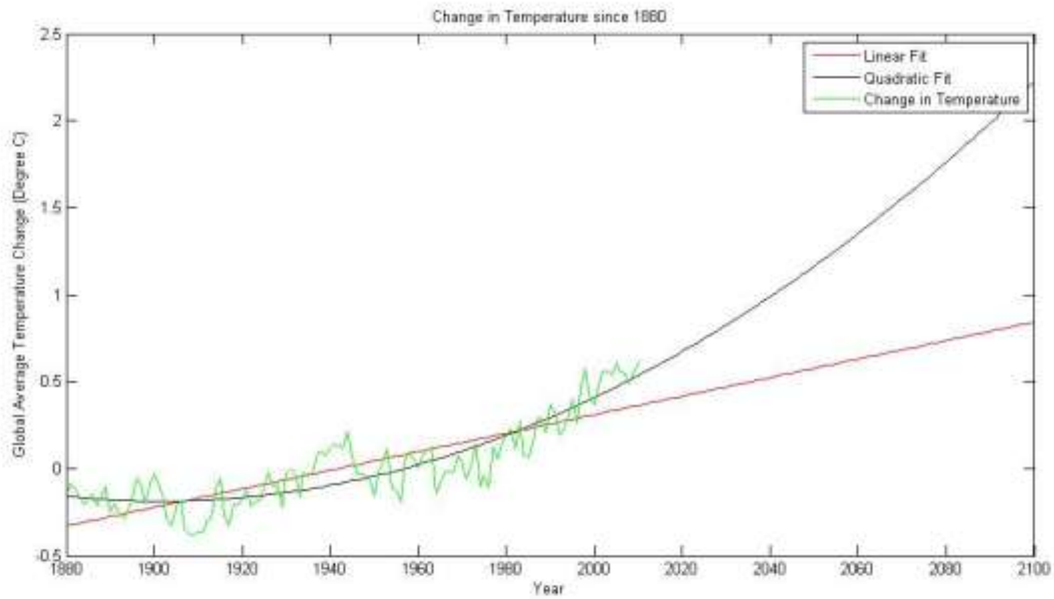


Figure 10a

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 temperature is at 2050 = 1.14, at 2100 = 2.17. This graph is the data received from 1880 until 2010 and then extrapolated until the year 2100.

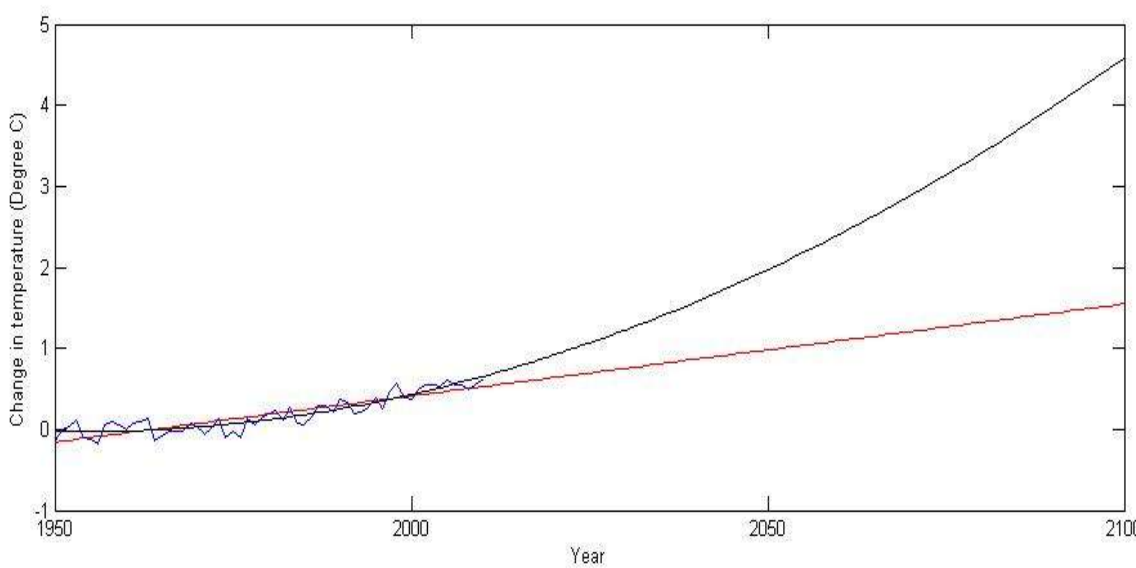


Figure 10b

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 received from 1950 until 2010 and then extrapolated until the year 2100.

As shown in the second graph, 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.

2.3 Modeling additional influences

In an attempt to gain additional accuracy, the next several graphs are the results of an attempt to include the ENSO oscillations in the model and from there determine whether or not more additional influences can be factored in. The proposed model to be used for the ENSO oscillations was a sin wave, with the variables being phase, frequency, and amplitude. When adding this on to the linear or quadratic graphs previously given, the intent was to find a more accurate model to predict temperatures in the coming years.

The following graph is a depiction of the error margin from the linear approximation (red) and the quadratic approximation (blue).

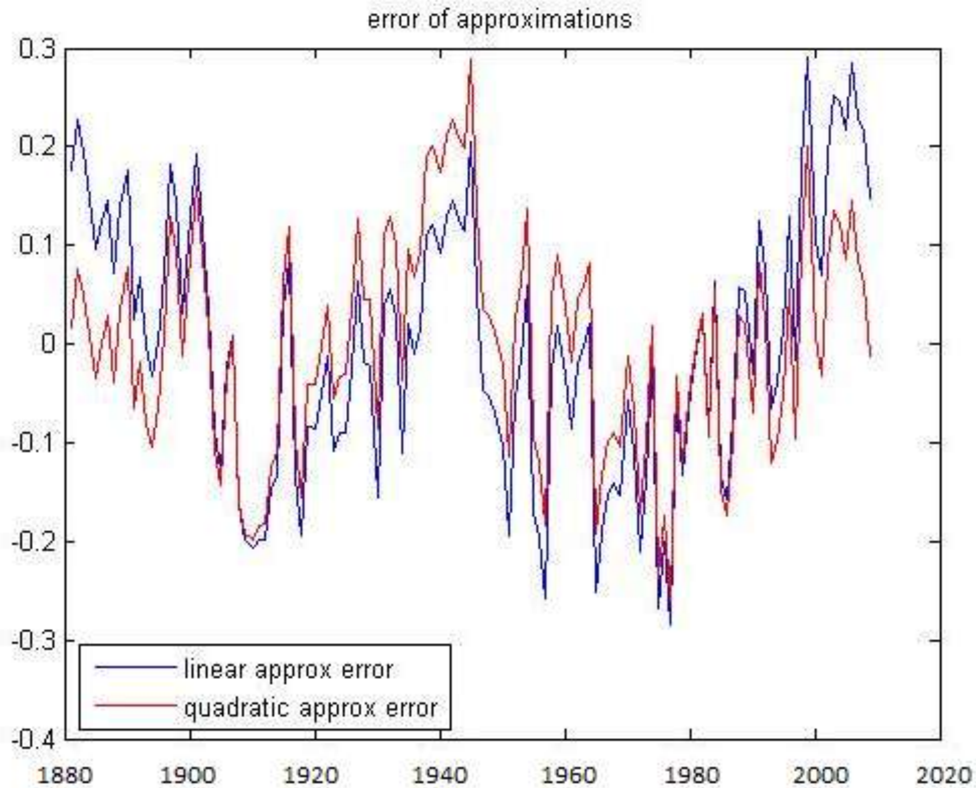


Figure 6: Error Approximations from the Linear and Quadratic Models

The attempted model for the ENSO oscillations was (A sin (B*x +C)). The figures on the next page display the error of the attempted sinusoidal fits for both the linear and quadratic formulae. As can be seen by the figures, the linear fit does not gain too much from the sinusoidal form, however a large amount of the greatest disparities between the quadratic fit and the actual data were smoothed over by the addition of the sinusoidal function.

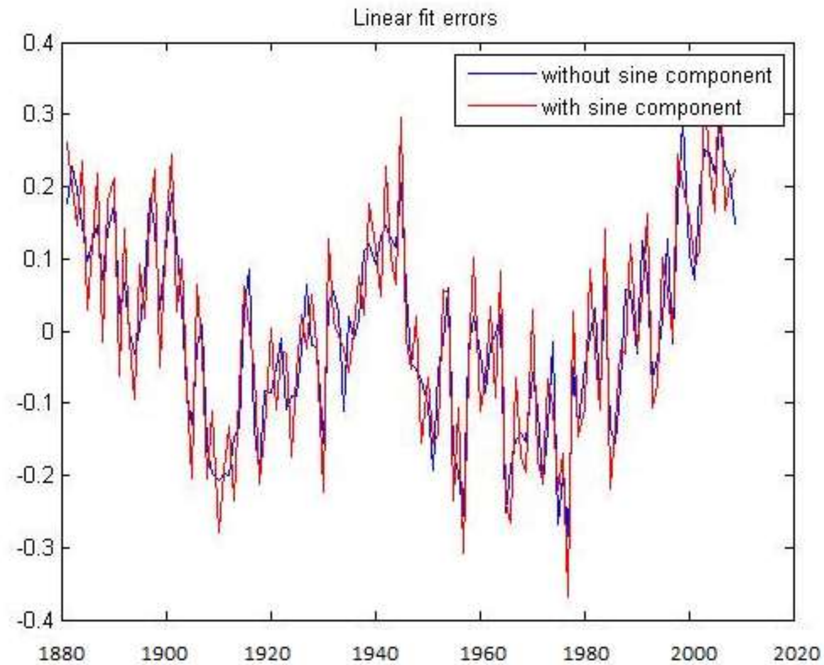


Figure 7.1 Linear Fit Errors with and without the Sine component, In years since 1880

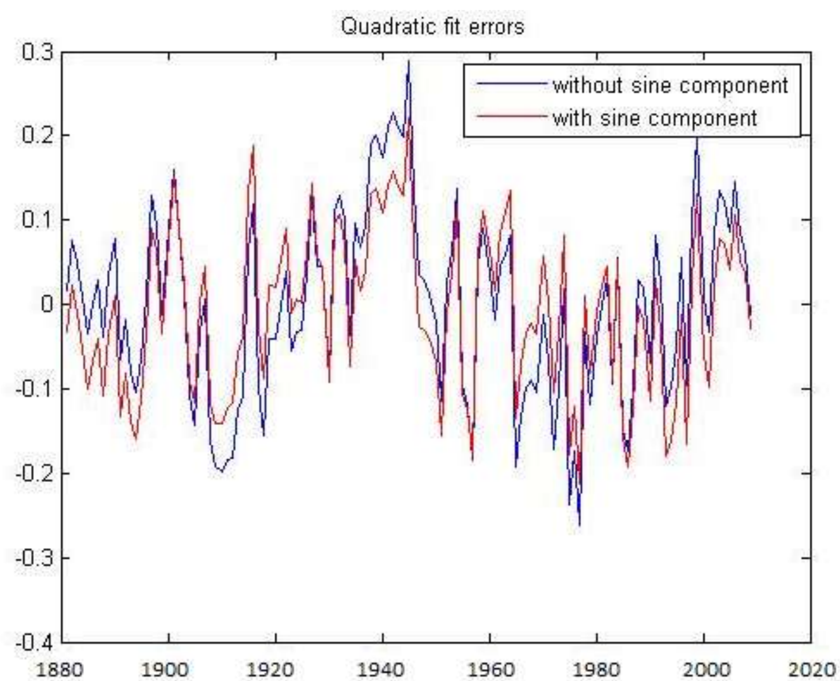


Figure 10.2 Quadratic Fit Errors with and without the Sine component, In years since 1880

Finally, the end results of this work, displaying the linear and quadratic fits with the sinusoidal component on top of the original data.

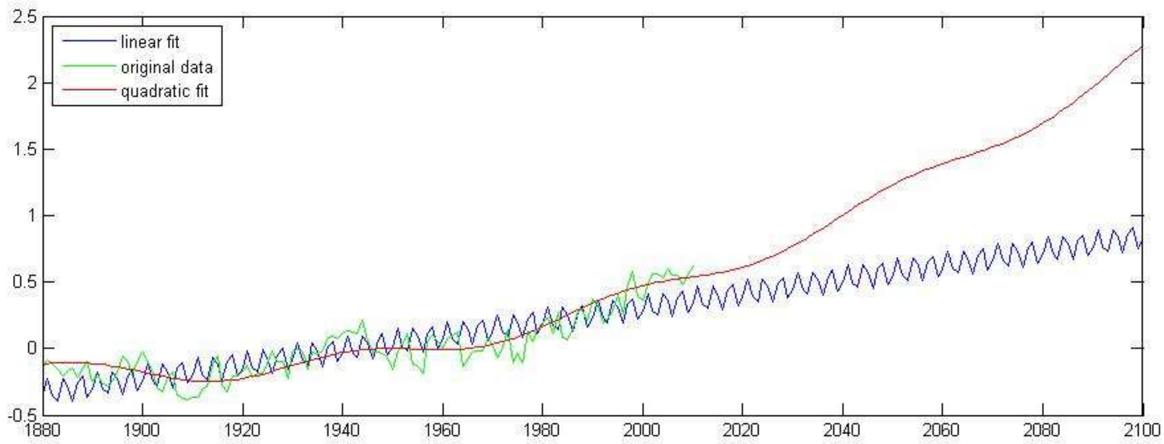
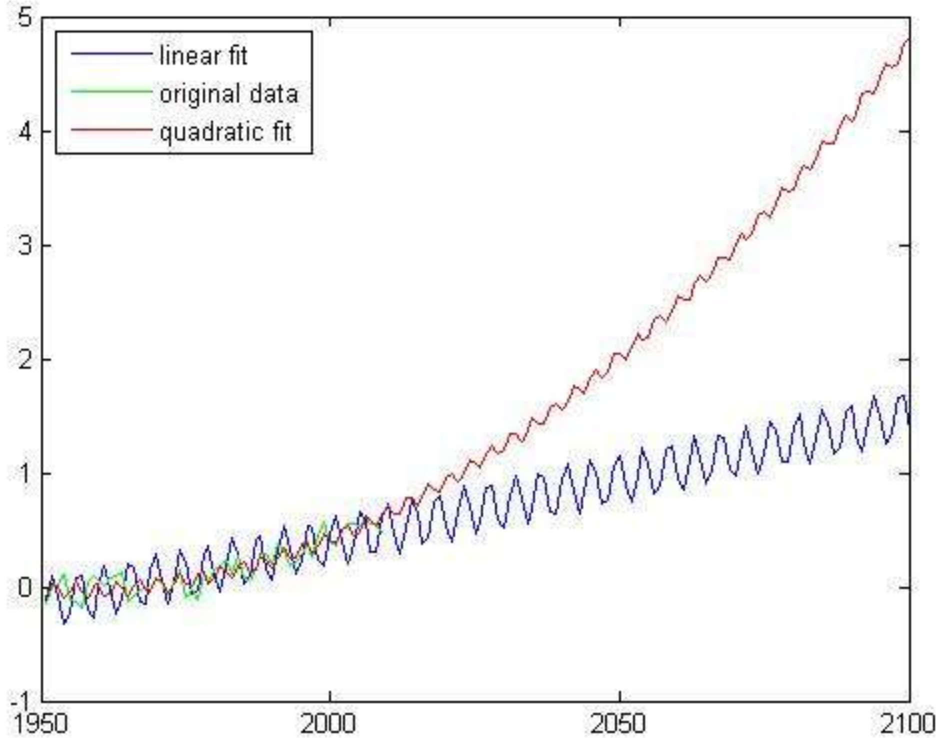


Figure 8 Projection of future temperatures, including sinusoidal components in Years Since 1880

With this, it appears that there is a fairly important periodic component. In the linear fit approximation, it attempted to approximate the yearly ENSO shifts, having a very short period. In the quadratic fit, however, it caught a larger recurring cycle, with a period of roughly fifty years. This was the most accurate fit, having an error margin of only 10.32 as opposed to the next most accurate graph’s margin of 14.05, decreasing the error by 17%.



This image was created when only the data points from 1950 onward were included in the data used to make the calculations. These data points are significantly more accurate than those taken before 1950, but show a much sharper upwards trend than the data from before 1950. Taken over the amount of data we have, the Error is not much smaller than it would have been otherwise, and the only really interesting thing that this graph shows is that in the shorter time span, a much larger gain is predicted. In addition, the longer-term sinusoidal component has disappeared for the quadratic approximation, overwhelmed by the short-term fluctuations.

2.4 Effects of Temperature Increase

Looking at the graphs, it appears likely that temperatures will continue to rise as we head further into the 21st century. With that in mind, some of the possible effects must be looked at so it can be seen if preparations should be made. In this paper, three possible effects are going to be covered: the effects of the rising temperature on the sea levels, agriculture and the precipitation/evaporation water cycle.

Sea Level Rise

The first and simplest effect to look at is the potential rise in sea levels should the warming continue. As it currently stands, the majority of the ice in the world resides in one of two places: Greenland and Antarctica. If the Earth's climate continues to warm, then the volume of ice locked in these ice sheets will continue to decrease. Greenland and the West Antarctic ice sheet are particularly vulnerable. The melting Greenland ice sheet has the potential to raise the current sea levels by almost seven meters, while the West Antarctic has the potential to reach another eight. If melting continues at its current rate, it can be expected that the combined sea level rise resulting from both ice sheets partially melting will be in the vicinity of seven meters over the next hundred years. Even this rise could have catastrophic results for anyone living on a coastline. Some large-population areas, such as the Nile River Delta and Bangladesh would be completely swamped, displacing millions of people. Even on our own Eastern Seaboard, we would lose many of our cities, including a large part of New York, and the bottom end of Florida. Many of the cities on the Gulf of Mexico are only slightly above sea level, and would also be severely impacted. The rise in ocean levels would be catastrophic, due to the number of displaced people and the effects on the infrastructure we have based in those cities.

Precipitation Cycle

In addition, there are the effects that global warming will have on the natural precipitation cycle. As the temperature increases, the trapped heat energy serves to accelerate the cycling of water (as water vapor) from the surface to the atmosphere, and enhances the transfer of the water vapor back to the surface as rain and snow (condensation and precipitation). The increased availability of water vapor in the atmosphere also leads to a significant increase in the energy available to drive storms and associated weather fronts, therefore affecting rainfall rates, precipitation amounts, storm intensity, and related runoff. In recent years, we have seen more storms with more intensity than in years before. To provide an updated assessment of the current state of knowledge of the impact of global warming on tropical systems, the World Meteorological Organization's hurricane researchers published a consensus statement. Their conclusions include (WMO, 2006):

> "Though there is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record to date, no firm conclusion can be made on this point."
>
> There is general agreement that no individual events in [2004 and 2005] can be attributed directly to the recent warming of the global oceans…[but] it is possible that global warming may have affected the 2004-2005 group of events as a whole."

Higher temperatures and heavier precipitation in winter imply more runoff and smaller mountain snowpacks in places such as the northwestern United States. In other words, both winter floods and summer water shortages are expected to become more frequent and intense. More surface reservoirs will be needed to handle both pressures, yet the building or even the maintenance of dams is facing increasing opposition, often from environmental groups. However, Northern Hemisphere snow cover extent has consistently remained below average since 1987, and has decreased by about 10% since 1966. This is mostly due to a decrease in spring and summer snow extent over both the Eurasian and North American continents since the mid-1980s. The final worrying thing about how global warming will affect the water cycle is the danger of a positive feedback loop. The trapped heat energy serves to accelerate the cycling of water (as water vapor) from the surface to the atmosphere, and enhances the transfer of the water vapor back to the surface as rain and snow (condensation and precipitation). The increased availability of water vapor in the atmosphere also leads to a significant increase in the energy available to drive storms and associated weather fronts, therefore affecting rainfall rates, precipitation amounts, storm intensity, and related runoff. With more water vapor in the air, more of the heat will be reflected back to the earth, evaporating more and more of the water. The positive water-vapor feedback loop has the potential to greatly increase the rate of global warming. This response is one of the major uncertainties in climate-change prediction.

Agriculture

Finally, there are the effects that the temperature rise would have on agriculture. Some of the signs are already beginning to show. The southwestern United States is already experiencing a lack of water—without water for irrigation, this area is too dry for large-scale agriculture—and serious desertification is expected to happen within the next few decades. Conditions similar to the Dust Bowl of the 1930s are expected to be the norm in the area by the 2030s. To continue, maple syrup production in the American northeast is suffering. The climate in which maple trees thrive is expected to move north to Canada. Maple syrup production is already down by about 10% because of warmer and shorter winters. Global-warming-related changes will affect the future of farming in myriad ways. The snow pack in California's Sierra Mountains has been gradually declining for the last 50 years, and the latest Intergovernmental Panel on Climate Change (IPCC) report says that it could ultimately be reduced by 60% to 90%. This will result in a very serious lack of water for Central Valley farmers during the summer months. Southern California will be particularly hard hit. Most importantly for the US economy and for the "mainstream" industrial food system, which is primarily "corn-fed," the latest climate models predict that it might become too hot and dry to grow corn in what is now called the Corn Belt. In the larger world, South Africa could lose upwards of 30% of its primary crop, maize, while southern Asia has the potential for losses of many regional staples, such as rice, millet and maize that could top 10%. Both of these would devastate their regions.

MatLab Coding

```
function [Epsilon Delta] = Willsthing2
A=table;
y = A(130:258);
x = [1:129];

plot(x,y);
b = polyfit(x,y,1)
c = polyfit(x,y,2)

d = y-(b(1)*x + b(2));
e = y-(c(1)*x.^2 + c(2)*x + c(3));

q=[0:.01:.29];
r=[0:1:99];
s=[0:.02*pi:2*pi-.02*pi];
x1 = [1:219];
for j=1:30
    for j1=1:100
        for j2 = 1:100
            res(j,j1,j2) = sum(abs(d-(q(j)*cos(r(j1)*(x+s(j2))*(2*pi)))));
        end
    end
end

M = min(min(min(abs(res))))
loc = find (res == M)
loc1 = floor(loc/3000) + 1
loc2 = floor((loc-floor(loc/3000)*3000)/30)+1
loc3 = loc -((loc1-1)*3000 + (loc2-1)*30)

res(loc3,loc2,loc1)
tau = (q(loc3)*cos(r(loc2)*(x1+s(loc1))*2*pi));
Delta = (b(1)*x1 + b(2))+(q(loc3)*cos(r(loc2)*(x1+s(loc1))));


for j=1:30
    for j1=1:100
        for j2 = 1:100
            res(j,j1,j2) = sum(abs(e-(q(j)*cos(r(j1)*(x+s(j2))))));
        end
    end
end

M = min(min(min(abs(res))))
loc = find (res == M)
loc1 = floor(loc/3000) + 1
loc2 = floor((loc-floor(loc/3000)*3000)/30)+1
loc3 = loc -((loc1-1)*3000 + (loc2-1)*30)

res(loc3,loc2,loc1)
gamma = (q(loc3)*cos(r(loc2)*(x1+s(loc1))));
Epsilon = ((c(1)*x1.^2 + c(2)*x1 + c(3)))+(q(loc3)*cos(r(loc2)*(x1+s(loc1))));


hold off
plot(x1,(b(1)*x1 + b(2)), 'r');
hold on
plot(x1,(c(1)*x1.^2 + c(2)*x1 + c(3)), 'k');
hold off
pause
plot (x,d);
hold on
plot (x,e,'r');
title('error of approximations')
legend('linear approx error', 'quadratic approx error', 'Location', 'SouthWest')
pause
hold off
%plot(x1, tau);
%hold on
%plot (x1, gamma);
%hold off
%pause
plot(x1,Delta);
hold on
plot(x,y, 'g');
plot(x1,Epsilon, 'r');
legend('linear fit', 'original data', 'quadratic fit','Location', 'NorthWest')
hold off
pause

%size(y)
%size(Delta)

plot (x,(y-Delta(1:129)));
hold on
plot (x,(y-Epsilon(1:129)), 'r')
pause

hold off
```

```
plot (x,d)
hold on
plot (x,(y-Delta(1:129)),'r');
title('Linear fit errors')
legend('without sine component', 'with sine component')
pause
hold off

plot (x,e);
hold on
plot (x,(y-Epsilon(1:129)), 'r');
title('Quadratic fit errors')
legend('without sine component', 'with sine component')


function A=table
A=[ 1880   -0.1467;

1881   -0.0896;

1882   -0.1182;
...
```

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[i] *NASA* – (National Aeronautics and Space Administration), Southern/Northern Hemisphere temperatures [4/9/2009], http://data.giss.nasa.gov/gistemp/tabledata/SH.Ts+dSST.txt

[ii] Kettlewell, Julianna. “Ice cores unlock climate secrets”. BCC. 4 April 2009<http://news.bbc.co.uk/2/hi/science/nature/3792209.stm>

[iii] *EPA* – (Environmental Protection Agency), ‘Past Climate Change’ [4/2/2009], http://www.epa.gov/climate/science/pastcc.html

[iv] ESR – ‘El Niño: definition’ [5/3/2009], http://www.esr.org/outreach/glossary/el_nino.html

[v] NOAA – ‘El Niño’ [5/3/2009], http://www.cpc.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf

[vi] Nature.com – ‘ENSO v GMT’ [4/22/2009], http://www.nature.com/nature/journal/v453/n7195/fig_tab/nature06982_F1.html

[xiv] Broccoli A. J., Lau N. –C., Nath M. J., Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, New Jersey, ETATS-UNIS. *The cold ocean-warm land pattern : Model simulation and relevance to climate change detection*. American Meteorological Society, Boston, MA, ETATS-UNIS.

[viii] *Encyclopedia of Earth* – ‘Greenhouse gas’ [4/15/2009], http://www.eoearth.org/article/Greenhouse_gas

[xv]Le Treut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson and M. Prather, 2007: Historical Overview of Climate Change. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. (Page 96, FAQ 1.1, Figure 1)

[xvi] *IBID* – (Page 98)

[xvii] IPCC Assessment Reports <http://www1.ipcc.ch/ipccreports/assessments-reports.htm> 11/16/2009

[xviii]Le Treut, H., R. Somerville, U. Cubasch, Y. Ding, C. Mauritzen, A. Mokssit, T. Peterson and M. Prather, 2007: Historical Overview of Climate Change. In: *Climate Change 2007: The Physical Science Basis. Contribution of*

Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. – (Page 99, Figure 2)