

Global Warming

Scientists started thinking about global warming due to CO₂ buildup in the atmosphere about 100 years ago. At that time, it was only a theoretical consideration. It could be easily shown CO₂ was a very good absorber of solar energy and it was apparent that more and more CO₂ was produced every year from the burning of coal but there was no way to measure it.

By the late 1950s a number of scientists had become concerned and the United States launched a long term research program to measure the CO₂ in the atmosphere. This research showed that the amount of CO₂ in the atmosphere was indeed increasing.

By the 1980s scientists were beginning to use computer based numerical models to determine the effects of doubling the CO₂ concentrations in the atmosphere. The results were startling. It appeared that doubling the CO₂ concentration in the atmosphere would have a significant influence on the planetary climate. It was also apparent from the atmospheric measurements that we were well on our way to doubling the CO₂ concentrations.

The solution seemed obvious. Cut back on the atmospheric CO₂ emissions. But, there was a problem. The world's economy depends upon carbon based energy and for many people, cutting back CO₂ emissions also meant reducing the world's economy. The issue very rapidly became political and heated.

During the 1990s, accusations were made on both sides. The news media latched onto this and found the political discussions much more interesting than the actual science. They dubbed it the "Great Global Warming Debate" and from a political point of view, they were correct. From a scientific point of view, there was no debate. Essentially all scientists, world wide agreed the world was becoming warmer and we were causing it by burning fossil fuels and releasing CO₂ produced by the combustion into the atmosphere.

Intergovernmental Panel on Climate Change

In 1988, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC). All three organizations are part of the United Nations.

The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. Review by experts and governments are an essential part of the IPCC process. The Panel does not conduct new research, monitor climate-related data or recommend policies. Membership in the IPCC is open to all member countries of the WMO and UNEP.

The IPCC does not do research or monitor climate change. It produces reports. Volunteer scientists, world wide prepare reports based upon the work of climate researchers. The last report, "The Fourth Assessment Report (Climate Change 2007) was produced by 600 authors from 40 countries and reviewed by over 620 experts and governments. Before being finally accepted, the summary report was reviewed line-by-line by representatives from 113 governments. All 113 governments had to approve the report before it was published. Differences in opinion were discussed, negotiated and reports changes were made until all parties agreed with every sentence in the report. You can download the IPCC reports from the website <http://www.ipcc.ch/>.

Much of the information in this paper comes from this Forth Assessment Report.

Have We Had an Impact?

We have undergone a very dramatic expansion in our numbers. The graph at the right shows the dramatic change in the human population over the last two thousand years.

Worldwide human population was under a billion people until about 1850. At that time, due to the beginnings of modern medicine and the industrial revolution, the population began to grow dramatically. In 2005, there were approximately 6.5 billion people on the Earth and conservative estimates say there will be 9 billion people by 2050.

We have created industries, power plants and transportation systems that put out billions of tons of carbon dioxide each year. Carbon dioxide is invisible but the other gases produced by these processes are clearly visible in every major city in the world.

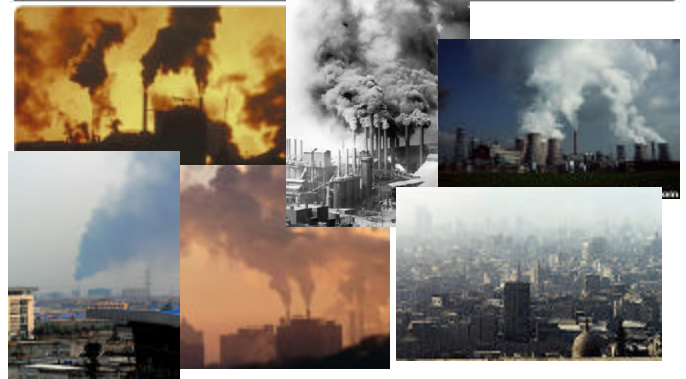
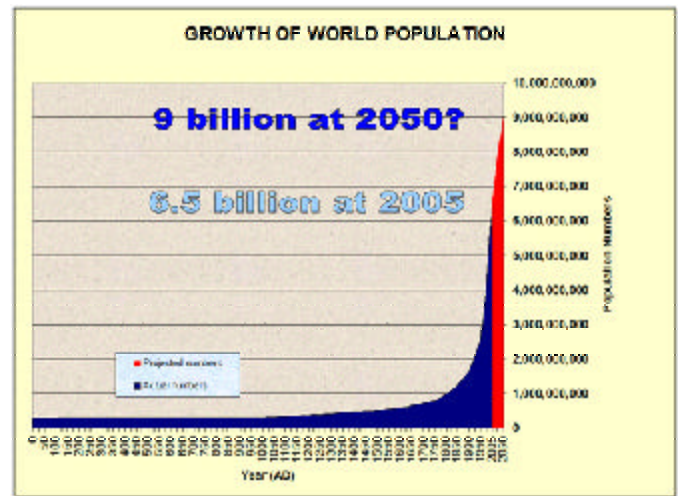
The NASA photo in the figure at the right show the lights from our cities at night. At night, much of the land surface of the Earth is lighted by electric lights. Most of the energy powering these lights comes from burning fossil fuels.

The carbon in these fuels combines with atmospheric oxygen to produce carbon dioxide. The process takes carbon that has been sequestered underground for millions of years and reintroduces it to the atmosphere.

The Earth is approximately 25,000 miles in circumference and because of its size you frequently hear people say "Humans could not have an effect on anything that large". If we were affecting the entire Earth, this statement might be true but our CO₂ emissions affect only the atmosphere.

The atmosphere is a very narrow band of gas that surrounds the planet. Seventy five percent of the atmosphere is below an altitude of 7 miles. The air above 7 miles is very thin and does not interact or mix very much with the lower part of the atmosphere.

Heating the Earth



Heat is transferred using three different methods. They are conduction, convection, and radiation. Conduction requires that two objects touch. When a hot object touches a cooler object, heat is transferred from the hotter object to the cooler one.

Convection occurs when heat is transferred using a gas or a liquid. This process can happen on a small or large scale. A breeze can cool you when you are hot or winds can move heat from the equator to higher latitudes.

Both convection and conduction require matter for heat transfer. Conduction requires a solid while convection requires a fluid. Radiation requires neither. Radiant heat is transferred with electromagnetic radiation and does not require matter. The radiation may be infrared, visible or ultraviolet light. Space is a vacuum containing no matter. The Earth can only be heated or cooled through radiant heat transfer.

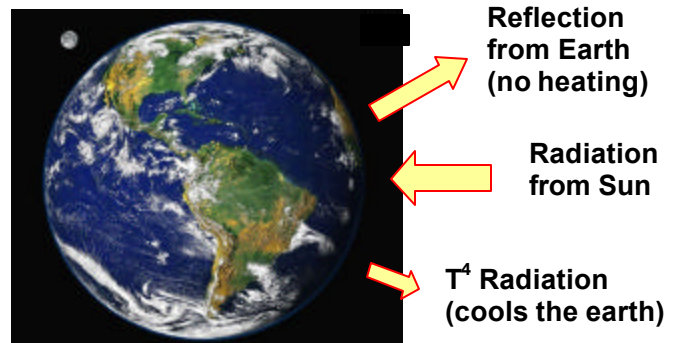
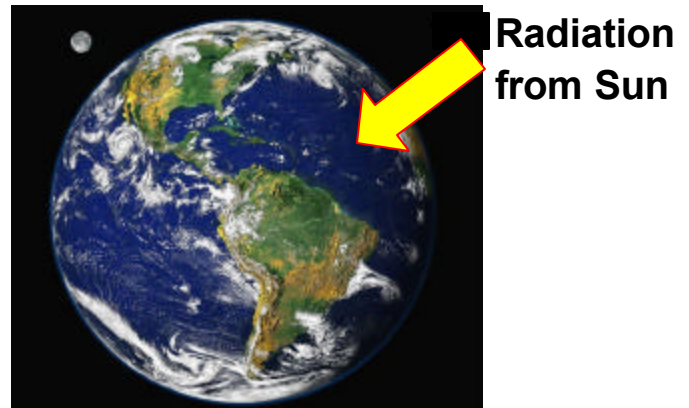
All objects emit electromagnetic radiation. The amount of radiation emitted is related to the temperature of the object raised to the fourth power. As the temperature, T of an object goes up, the amount of radiation increases by T^4 . A small change in the temperature changes the amount of emitted radiation by a large amount.

The Earth is warmed by the Sun. Radiant energy from the sun strikes the earth. Some of this energy is reflected back into space by particles in the air or by the surface of the earth. The rest of the radiant energy from the Sun is absorbed by the atmosphere or by the surface of the Earth. This absorbed energy is what heats the Earth.

Energy that is reflected back into space does not heat the Earth. It comes and goes without affecting the temperature of the Earth.

Energy that is absorbed heats the Earth or the atmosphere and is eventually emitted back into space as T^4 radiation. The amount of energy coming into the earth from the sun and leaving the earth due to reflection and T^4 radiation are in balance. There is just as much energy coming in from the Sun as there is leaving.

If the Earth were to become more reflective, the temperature of the Earth would decrease and less energy would be emitted by T^4 radiation. If the Earth were to become less reflective, the temperature would increase and more energy would be emitted by T^4 radiation.



The reflectivity of the Earth changes with the color or albedo of the Earth. The oceans are dark and reflect very little energy back into space. The oceans can absorb up to 90% of the solar energy striking them.



Oceans are dark and reflect little energy back to space – 90% absorption

Forested areas are lighter and reflect more energy back into space than do the oceans.



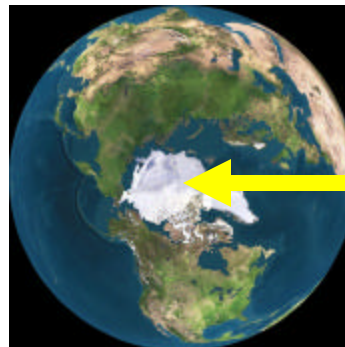
Forested areas are lighter and reflect more back to space

Desert areas are still lighter and reflect more energy back into space than do forested areas.



Desert areas reflect more light

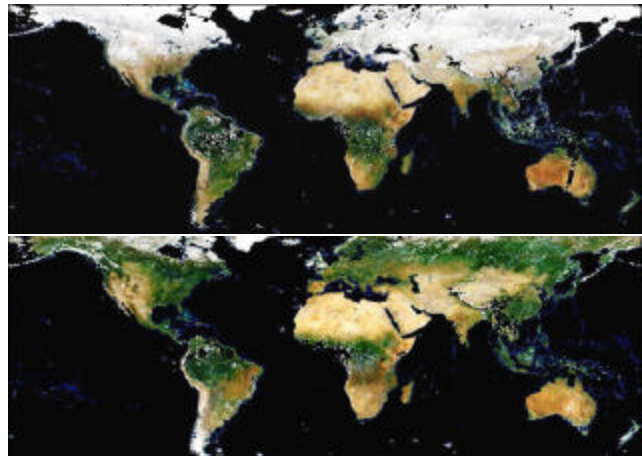
Ice and snow covered areas reflect up to 90% of the solar energy back into space. There is a big difference between the ice floating on an ocean and the ocean itself in terms of reflectivity.



Ice reflects the most amount of light back to space – 10% absorption

The albedo or color of the Earth changes with the seasons. The pictures to the right show the surface of the Earth during the northern hemisphere's winter and summer seasons. During the summer, the snow is replaced by green plants. The summer plants absorb much more solar radiation than does the winter snow.

December / January



Greenhouse Gases

The atmosphere contains several different types of gases and some of these gases are called greenhouse gases.

Greenhouse gases directly absorb radiant energy from the Sun. Non-greenhouse gases do not absorb energy from the Sun and are heated only by convection and conduction.

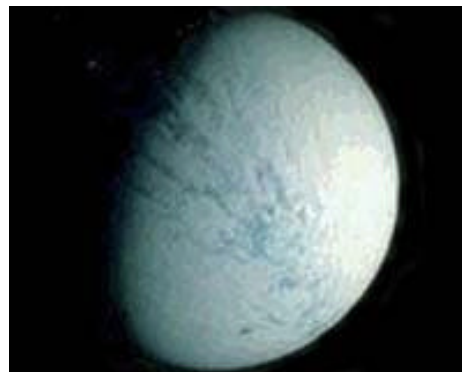
The major gases in the atmosphere are:

Oxygen	~21%	non-greenhouse
Nitrogen	~78%	non-greenhouse
Water	up to 4%	greenhouse
CO ₂	trace	greenhouse
Methane	trace	greenhouse

June / July

Nitrogen and oxygen are not greenhouse gases and do not absorb solar energy. Water vapor, CO₂, and methane are greenhouse gases and do absorb solar energy.

These greenhouse gases make up a very small part of the atmosphere but are very important in warming the Earth. Without greenhouse gases, the Earth would have an average temperature of -18 degrees centigrade. It would be a very cold ice ball. The greenhouse gases are very good at absorbing solar energy and very small amounts of these gases make a very large difference in the temperature of the Earth.



**Average
Temperature
-18
Centigrade**

Water vapor is naturally occurring in the atmosphere. The maximum amount of water vapor in the atmosphere is controlled by the temperature of the air. The warmer the air, the more water vapor it can hold.

Water vapor is not as strong a greenhouse gas as is carbon dioxide although it is much more common than carbon dioxide.

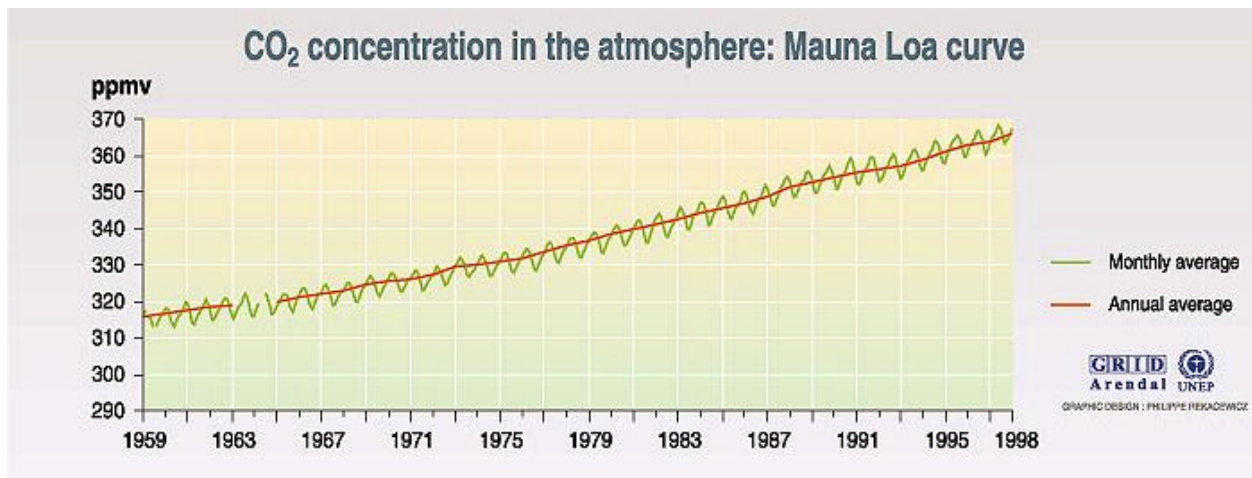
Methane is a much stronger greenhouse gas than is CO₂ but there is less common than CO₂ in the atmosphere so its contribution to solar warming is less than CO₂'s.

Carbon dioxide in the atmosphere is naturally created by the decay of plants and animals and is released by volcanoes. It is also the byproduct of burning coal and petrochemicals.

Coal is almost entirely made of carbon and produces the most amount of CO₂ per pound when burned. Petrochemicals are hydrocarbons and produce both water vapor and CO₂ when they are burned. They do not produce as much CO₂ per pound as coal.

Measuring Carbon Dioxide

In 1958, the United States sponsored a long term research program to measure the amount of CO₂ in the atmosphere. A researcher named Charles David Keeling set up a monitoring station on Mauna Loa a very high mountain in Hawaii. This location was selected because it was very far from industrial processes that were emitting CO₂. The results of this research are shown in the curve below.



Source : Scripps Institution of oceanography (SIO), University of California, 1998.

The saw tooth line indicates the actual measurements and the smooth line is the annual average. The saw tooth line goes up and down with the seasons. During the spring and summer in the northern hemisphere (most of the land mass of the earth is in the northern hemisphere) plants grow and absorb CO₂ and during the fall and winter, the leaves fall from the trees and they and other plants decay releasing CO₂.

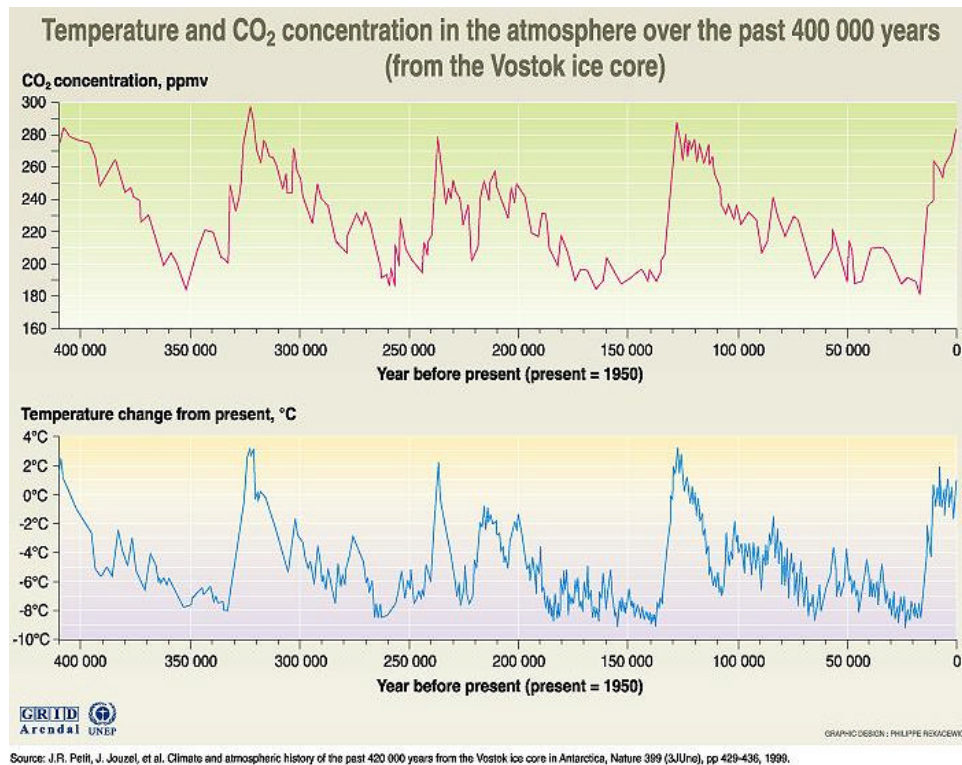
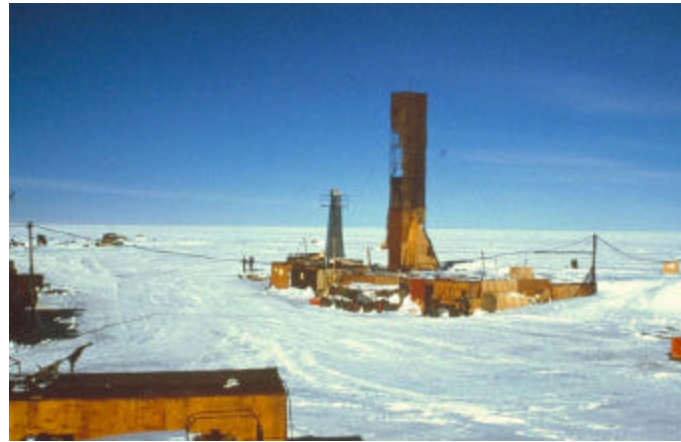
It is easy to see from the curve that the general trend of the curve is up. The amount of CO₂ in the atmosphere increases every year.

Obviously something was happening but what did it mean? There were no records prior to 1950 and to fully understand the impact of this increasing CO₂ concentration, much more data was needed.

A good solution was to measure the CO₂ concentration in gas bubbles trapped in glaciers. Glaciers are created by snow falling and accumulating year after year. There is a different layer for each year and the layers can be counted like rings on a tree. As the snow falls it traps air and this air forms small bubbles in the glacial ice.

Cores were taken from glaciers all over the world. Scientists used these cores to measure the CO₂ concentrations for many years into the past. These ice cores were consistent in showing the same rise and fall of CO₂ over large time spans.

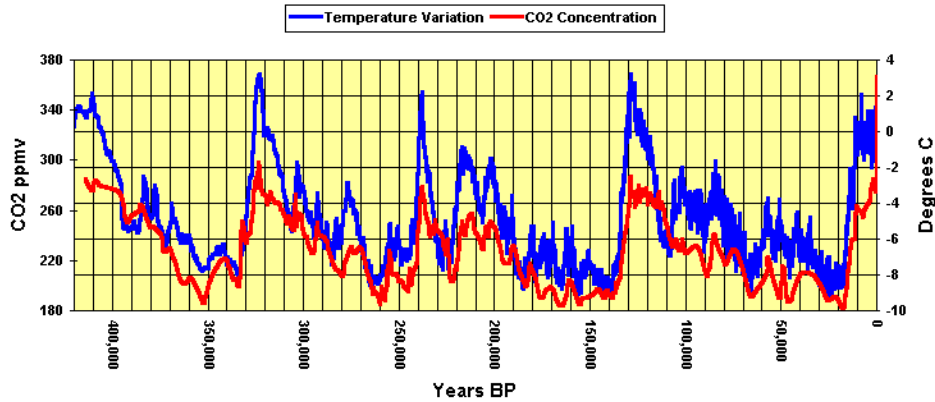
Vostok, Antarctica produced ice cores going back the farther in time than any other location. The air bubbles trapped in the lowest levels of these ice cores were more trapped more than 450,000 years ago. By counting the years and sampling bubbles along the way, scientists were able to construct the top graph shown below.



The bottom graph shows the average global temperature during this same time span. It was constructed by measuring the amount of O₁₈, an oxygen isotope in the air bubbles. There is a very good correlation between the O₁₈ concentrations and the global temperature.

Both graphs have peaks and valleys and they seem to match. When the CO₂ concentrations are high, the temperature is high and when the CO₂ concentrations are low, the temperatures are low. The next graph puts both curves together making the comparison a little easier to see.

Antarctic Ice Core Data 1



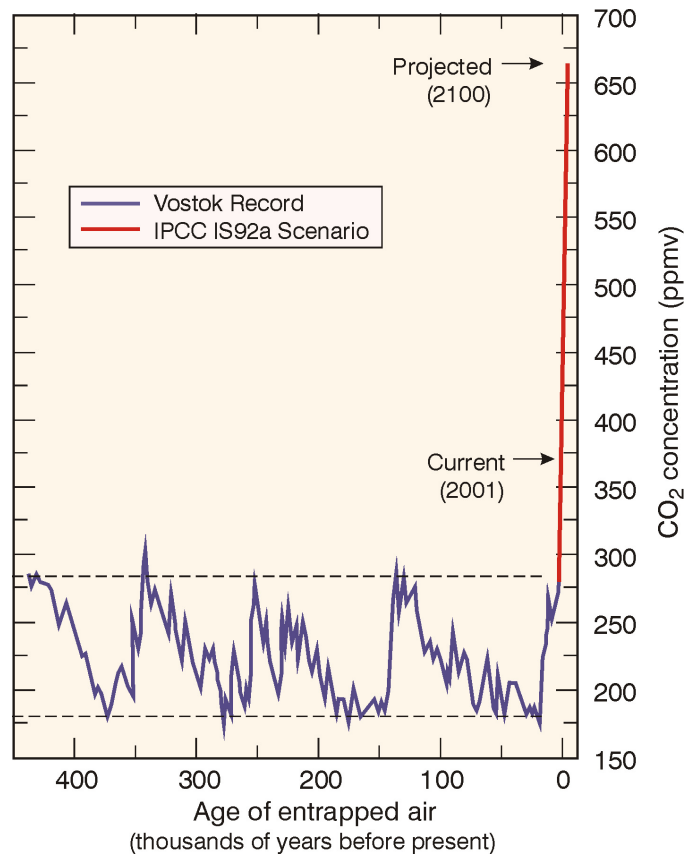
Zero degrees on the graph represents the average global temperature in the 1960 to 1980 time frame. You can see there is a natural variability in both the CO₂ levels and in the average temperature of the planet.

The maximum CO₂ levels in the last 450 thousand years is close to 280 parts per million (ppm). When the CO₂ levels are this high, the world was experiencing a mild climate like we have today. When the CO₂ level drops below 240 ppm, the earth enters an ice age. If you are living in New York, a difference of 40 ppm of CO₂ means the difference in a nice day and standing on more than a mile of ice. The climate is very sensitive to CO₂ concentrations.

The right hand side of the graph ends at 1950. No values are shown later than that date. From 1950 to the present, scientists have accurately measured the CO₂ concentrations in the atmosphere and the curve on the right shows what they have found.

This graph shows CO₂ concentrations starting 450,000 years ago and projects the concentration to the end of the century. Currently, there is 370 ppm of CO₂ in the atmosphere and it is rising quickly. It is now much higher than it has been for the last 450,000 years. If it continues to increase at the present rate, it is projected to be 670 ppm by the end of the century.

The question is, if a drop of 40 ppm means an ice age and a mile of ice under foot, what does an increase of 390 ppm mean?

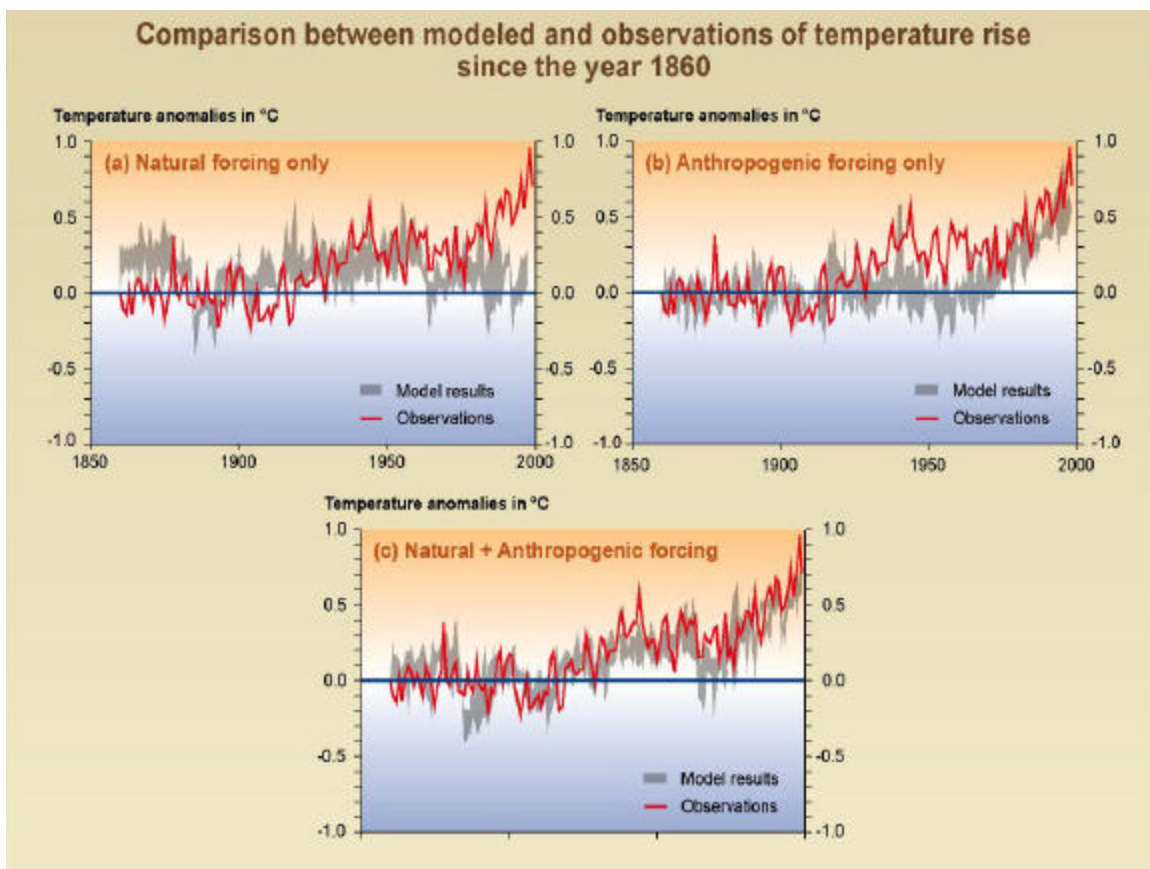


Forecasting the Future

It is relatively easy to measure the past but how do we measure the future? If the CO₂ concentrations were the same as they were in the past, then we could say the weather 100 years from now will be the same as it was 100 years ago. The problem is that we are now in uncharted territory. The current CO₂ concentration of 370 ppm is much higher than it has been for the last 450,000 years and it appears that it will go much higher.

Scientists have approached this problem by constructing computer programs that simulate the weather. These programs take in thousands of variables and compute what the weather will be in the future. They are not the same programs that are used to compute tomorrow's weather. They are designed to compute what is happening on a large scale not the details of tomorrow's weather.

The programs are tested by computing the weather in the past and comparing that with actual measurements. The graphs below show the measured average global temperature in red. The gray curve is the computed global average temperature.



The top left chart shows the computations with only natural changes but without the CO₂ and other greenhouse gases produced by humans. The top right chart shows the computations with the human caused greenhouse gases but without natural forcing. Both of these charts show a poor correlation between the computed temperature and the actual measured temperature.

The third chart at the bottom shows the combination of human and natural forcing on the global temperature. Here there is a good correlation between the computed temperature and the measured temperature. It is important to validate the accuracy of the computer models before using them for projections that cannot be checked.

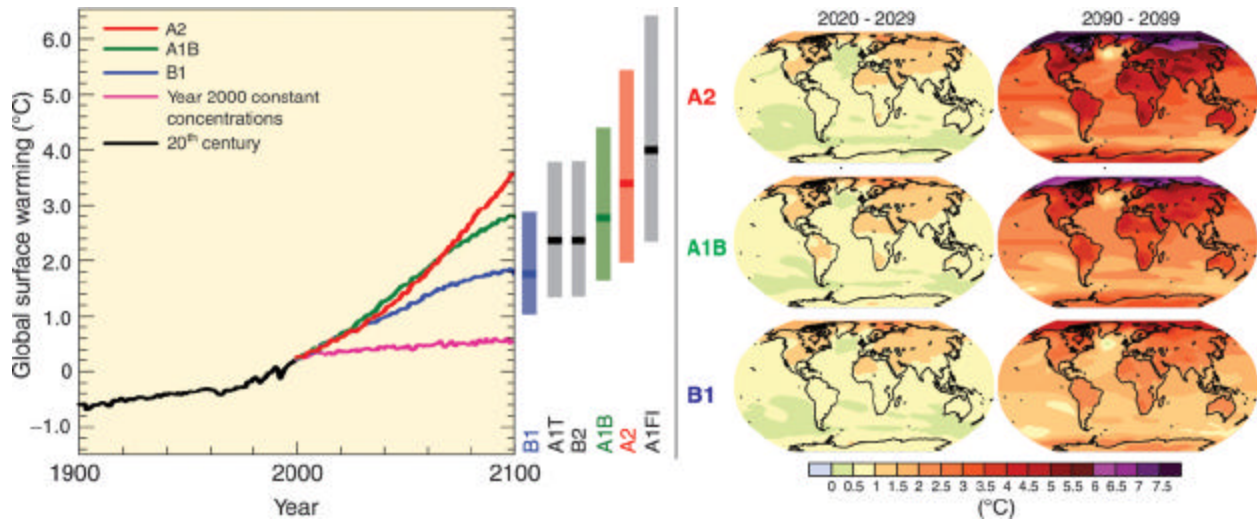
Our behavior in the future will affect the weather. If we quickly reduce the amount of CO₂ we are putting into the air the future will be different than it will be if we continue to supply most of our energy needs with carbon based fuels as we have done in the past. The computer programs need to know what we are going to do in order to make accurate computations.

Atmospheric scientists sidestep this issue by making several different assumptions and trying all of these in the computer models. Some of their assumptions have us quickly moving to a carbon free economy and others have us continuing as we have in the past. Several of the widely used assumptions are listed here.

IPPC IS92a	business as normal – 1% increase in CO ₂ per year
A1F1	the future is heavily dependent upon fossil fuels
A1T	most energy comes from non-fossil sources
A1B	a balanced approach with fossil and non fossil fuels
A2	world remains culturally divided and population in the underdeveloped countries continues to grow.
B1	World cultures converge and the population peaks at mid century.
B2	Emphasis on local solutions to problems – the population continues to grow but not as fast as A2.

Each of these assumes a different amount of CO₂ in the atmosphere and produces a different outcome. The results are shown in the graph below. Currently the global average temperature is about 0.7 °C above the 1960 – 1980 average. The graph shows temperature rise by the end of the century might be as little as 1.8 °C or as high as 6.0 °C.

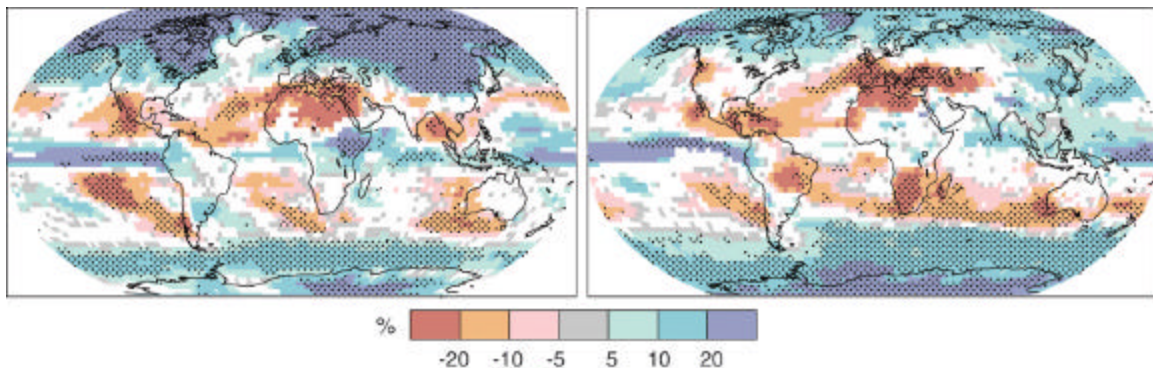
These temperature increases do not sound very high but they will have a dramatic influence on the future. The graphic below shows the amount of warming using several different scenarios. The chart on the left shows the average global temperature change with the colored bars showing the possible range of temperatures. The maps show the temperature distribution across the globe. The Polar Regions will increase in temperature more than the equatorial zones. The increase could be as large as 8 °C in some of the Polar Regions.



It should be noted that these are the temperature increases reported by the IPCC. The IPCC by its nature (all countries must agree) is a very conservative organization. Computer modeling done by some very credible researchers shows significantly higher global temperature increases.

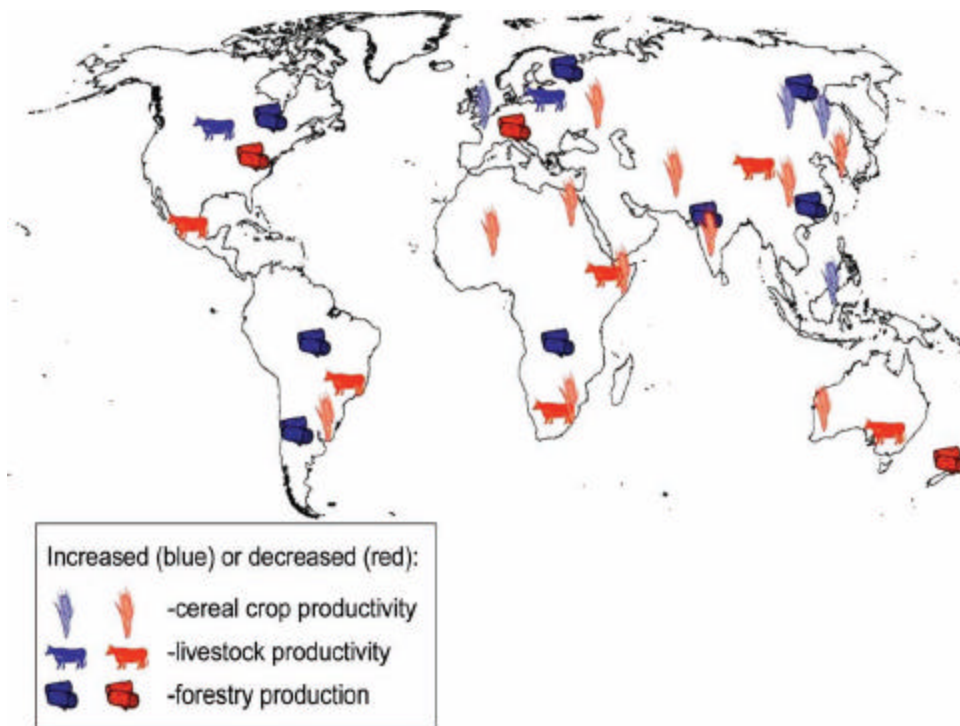
Effects of Global Warming

The question is what effects will this have on people in various regions of the Earth. In some areas, the warming may favorably change conditions and make life easier but in many, this is not the case. In general, all of civilization was built on conditions much like they are today. Everything has been built around these stable conditions and all changes are undesirable.



Increased Drought Due to Global Warming

The map above shows the change in precipitation under an average scenario. The map on the left represents December through February while the map on the right represents June to August. White indicates areas where the computer models did not agree close enough for a statement to be made. The map shows Polar Regions and equatorial zones will receive more precipitation but the mid latitudes where most agriculture takes place will receive less.



Decreased Food Production

Less precipitation usually means a decrease in food production. The change in food production is shown in the map above. Some areas will have an increase in production but most will not. Most of the increase will occur in more northern climates and southern climates. Typically these areas are not as heavily populated. Modern transportation systems allow food to be moved between prosperous countries but underdeveloped less prosperous countries usually cannot afford imported food. It is also apparent from the map that many of the areas of high poverty are also areas where food production will decline the most.

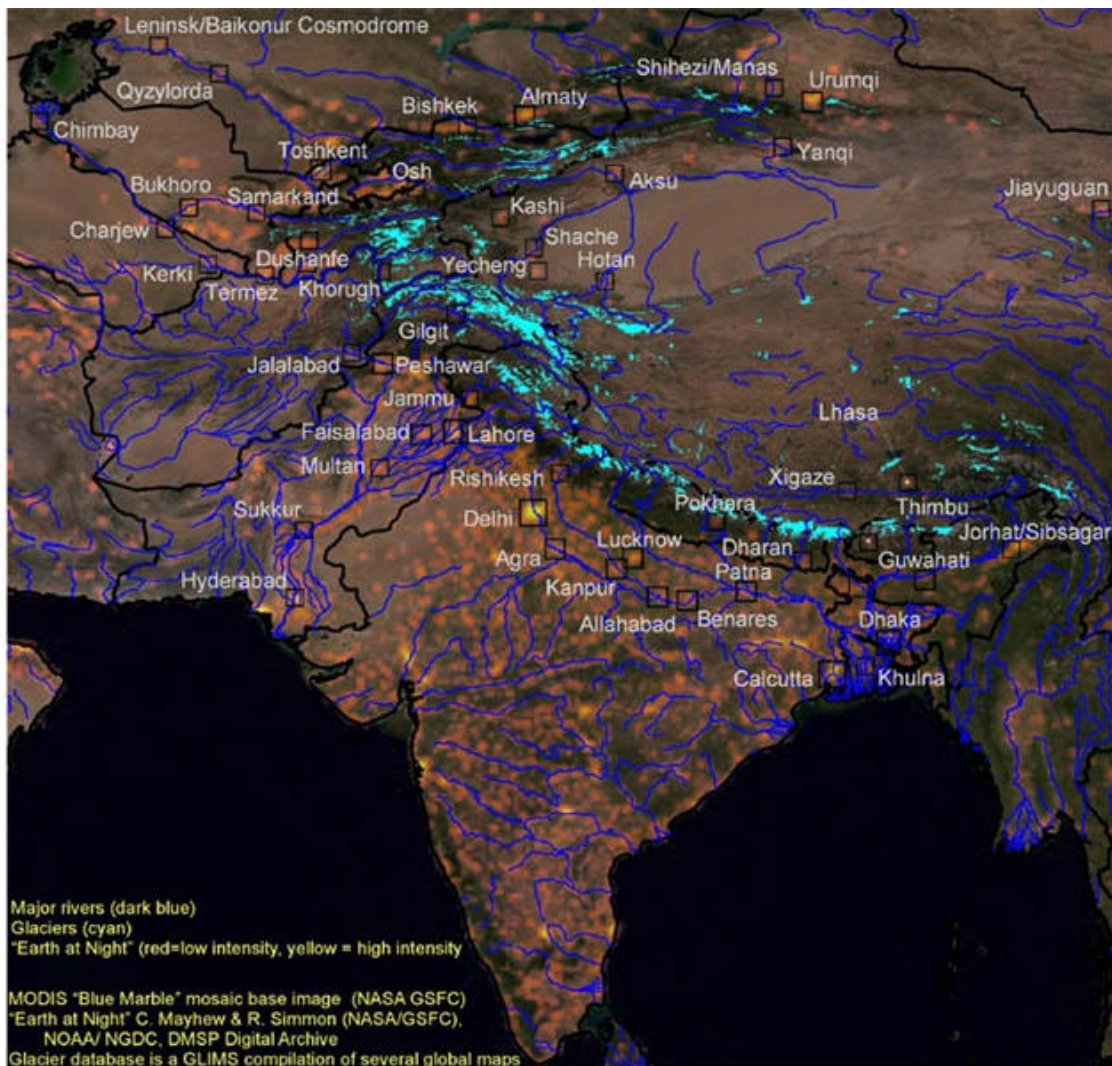
Glacial Melting – Water Shortages

The effects of global warming can already be seen in glacial melting. Below are two images of the same area in Glacier National Park. The picture on the left was taken in 1932 and the one on the right was taken in 1988.



Glaciers are melting all over the world and the melt rate is accelerating. This is important because the water from glaciers supplies the drinking water for many people throughout the world. For thousands of years, the glaciers would grow in the winter and melt in the summer and stay approximately the same size. During the summer when they are melting, they supply water to rivers and these rivers supply drinking water for billions of people. If the glaciers disappear or decrease substantially in size, they will produce much less water during the summer and the people that depend upon this water will do without.

This is especially true in Asia. Most of the glaciers in the Himalayas are shrinking and they supply the drinking water for over a billion people. This is shown in the satellite picture below. The glaciers are shown in cyan (blue green) and the rivers are shown in dark blue. It is estimated that one quarter of the glaciers that feed these rivers will disappear by 2050 and half will disappear by 2100.

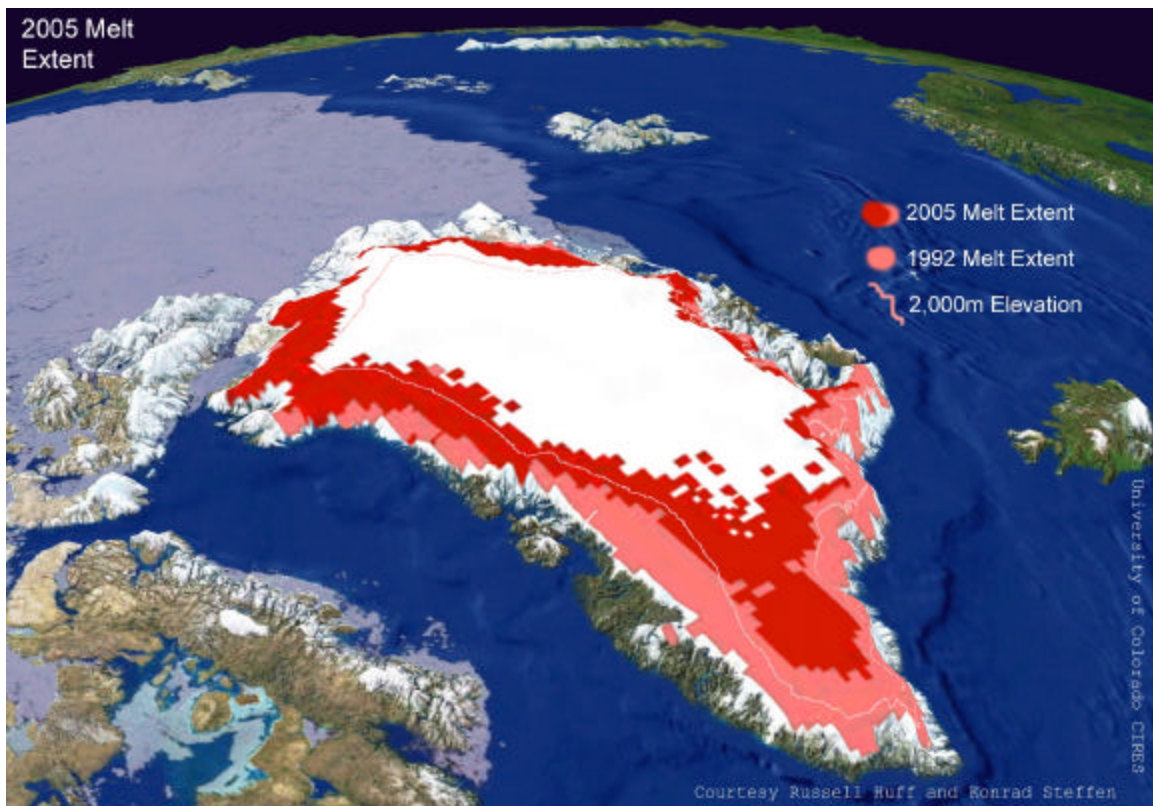


Sea Level Rise

Another problem is sea level rise. Many people live near the ocean¹ and even a small rise in sea level can affect them negatively. Their homes may still be above sea level but a slight rise in sea level can make them much more venerable to flooding during storms.

Sea level rise is due to the thermal expansion of the oceans due to warming and the increase of water coming from the melting of non-floating ice. The main bodies of non-floating ice are in Greenland and in Anta. Floating ice in ice shelves and in the North Polar Region will not add to the sea level if they were to melt because they are floating.

The sea level rise due to thermal expansion is much easier to compute than the rise due to ice melt in Greenland and Anta. Currently, models predict a sea level rise of 1 to 2 feet during the century but this assumes the contribution from melting stays constant at the 1993 to 2003 rate. This may not be a realistic prediction. The map below shows the extent of the ice melt in Greenland in 1992 (pink) and in 2005 (red). It appears that the amount of melt is increasing quickly and the constant rate assumption may be very conservative. As the world warms, one would expect the melt rate to increase.



The Forth IPCC report Summary states, “Partial loss of ice sheets on polar land could imply meters of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands. Such changes are projected to occur

¹ In the United States, 50% of the population lives within 50 miles of the coast.

over millennial time scales, but more rapid sea level rise on century time scales cannot be excluded”.

Positive Feedback Loops

There are several global feedback systems that could exaggerate global warming. One is the melting of the ice around the northern polar region. The ice is about 90% reflective. That means that 90% of the sunlight falling on the ice is reflected back into space and does not heat the Earth. With global warming, the amount of ice is decreasing. The ocean the ice is floating on absorbs about 90% of the sunlight so as the ice melts the reflectivity changes from 90% to 10%. Much more heat is absorbed which melts the ice more rapidly. The polar region is melting very rapidly and best estimates indicate the pole will be ice free in the summer within 15 years.

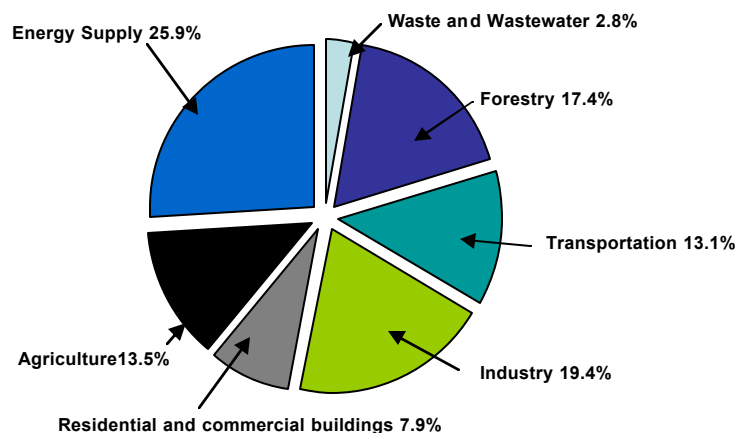
Another feedback loop can be found in the arctic. Much of the arctic consists of frozen tundra. During the summer, the top surface of the tundra melts and plants grow in this area. During the winter these plants freeze and die but never decay. This process has been occurring for thousands of years. The amount of frozen plant material is hundreds of feet deep in some areas. As the planet warms, the tundra thaws. When the tundra thaws, the organic materials decay releasing CO₂ and methane. Methane is a much stronger greenhouse gas than is CO₂ and this produces another positive feedback loop. The tundra thaws and decays producing methane and CO₂ which warms the planet which causes more tundra to thaw creating more methane and CO₂.

There are many such feedback loops that could potentially increase global warming but they are very hard to model with a computer. This doesn't mean they do not exist or that their influence is small. It only means that currently we do not have the technical skills or knowledge to develop computer models that accurately incorporate these feedback loops. For the most part, they have been ignored in the IPCC modeling.

What Can We Do?

The computer models show a likely global temperature rise of from 1.8 to 4.0 C° for the 21st century. The actual rise depends upon our actions. If the world unites and makes an all out effort to significantly reduce greenhouse gases the effects of global warming could be minimized. If we are slow to make changes, and the temperature rises to the 4.0 C° range, the planet will be substantially different from the one we have today. The changes brought about by this amount of global warming will in no way be desirable.

The chart below shows how different segments of our economy that contribute to greenhouse gas production.



It is easy to see that there is no one segment that can be “fixed” to eliminate the problem global warming. In fact, it appears that almost everything we do creates greenhouse gases. It will take a very large globally coordinated effort to significantly reduce the amount of greenhouse gases we produce. We will have to fundamentally change everything we do.

There are many ideas such as solar power, hydrogen cars, nuclear power plants, carbon sequestration, etc. but ideas do not reduce greenhouse gases. Only fully implemented plans can reduce greenhouse gases and there is a lot of engineering that must be done between the idea and the completed, fully functional implementation. Have fun!

Homework

Use the web to answer the following questions. Write a paragraph or two that summarizes the information you found. Your work must be typed. Handwritten work is not acceptable. **List your sources.**

1. How will an intelligent electrical grid work and what will be its benefits?
2. There is a lot of talk in the media about clean coal. Is clean coal a viable possibility for clean energy or is this just hype from the coal industry?
3. What effect has global warming had on the lodge pole pine forest in North America?
4. As the planet continues to warm, what is the climate outlook for the southwestern United States?