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Topic 1 – An Introduction to the Climate System and Climate Change

Weather vs. Climate

Weather is what we experience on a day-to-day or season-to-season basis. Today's high temperature, or the amount of snowfall this winter, are examples of weather. *Climate* is the long-term average of weather, as well as the extremes. For a given location, the average high temperature for a given date, the average annual rainfall, or the largest snowfall ever recorded in January, are examples of climate. Scientists usually average twenty or more years of weather data before drawing conclusions about climate.

As one person put it, "Climate is what we expect, weather is what we get."

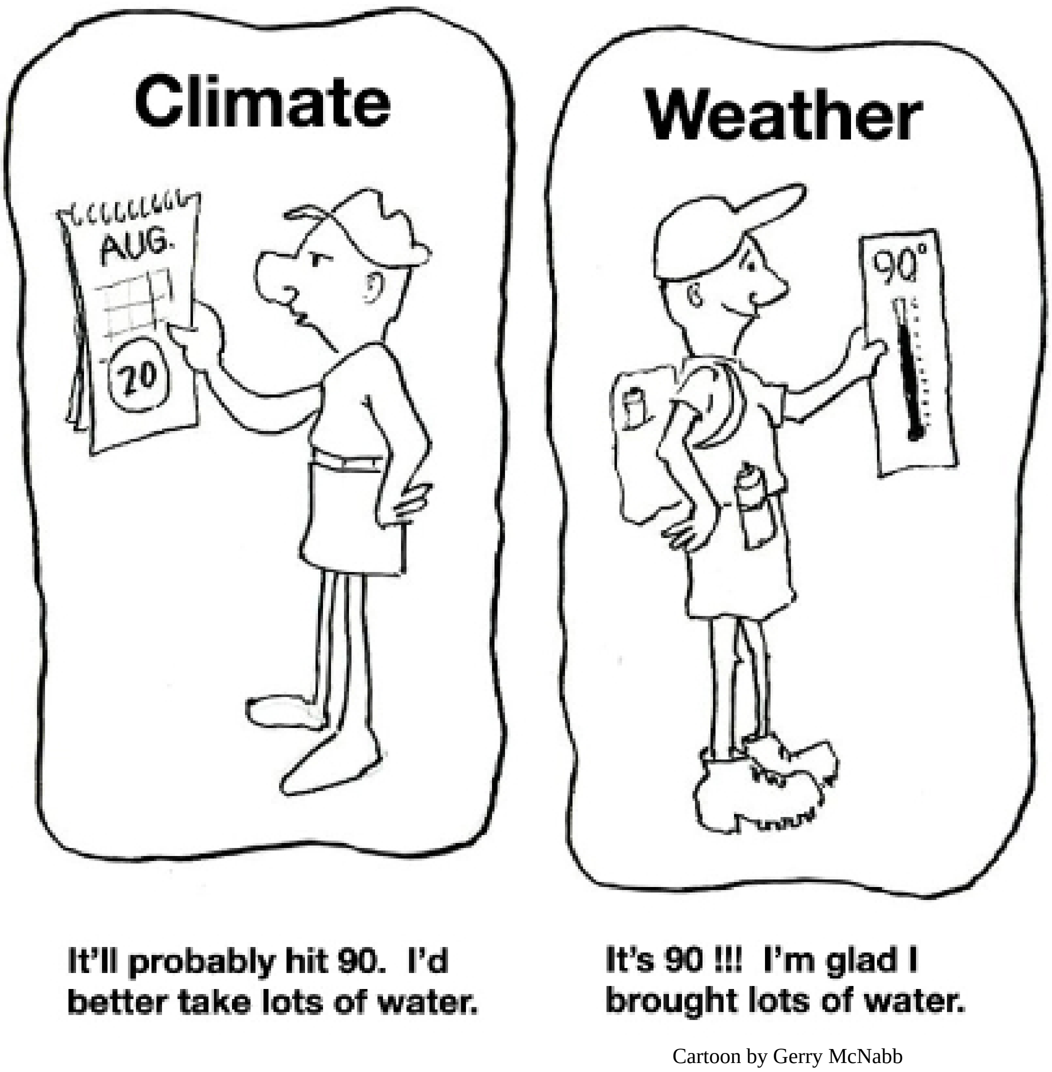
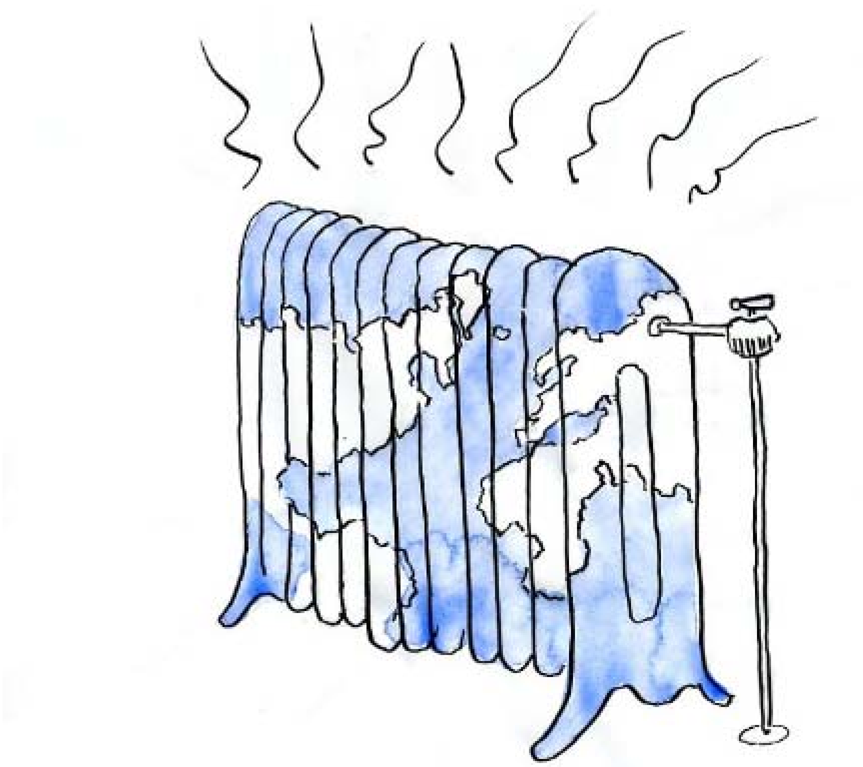


Figure 1 – The Difference between Climate and Weather

The Climate System Simplified

The Sun warms the Earth, but the process by which this happens is fairly complicated. On average, over the 24 hours of the day and the four seasons of the year, 343 watts/square meter (about 285 watts/square yard) of solar energy shine down on the top of the Earth's atmosphere. About a third of this energy never reaches the Earth's surface; it is reflected by clouds and particles in the atmosphere. Another sixth is reflected by the Earth's surface. The remaining half is absorbed by the Earth.

The Earth has to get rid of the energy it absorbs from the sun. If not, it would heat up and melt. The Earth gets rid of energy by radiating it back to space. It is a basic principle of physics that if a body is warmer than its surroundings it will radiate energy to those surroundings. Space is very cold, so the Earth is continually radiating energy to it.



Cartoon by Gerry McNabb

Figure 2 – The Earth Radiates Energy to Space

Greenhouse gases complicate this simple picture. They absorb some of the energy that the Earth radiates. When a molecule of greenhouse gas absorbs energy, it warms up. Because it is now warmer than its surroundings, it radiates energy, some of which goes back down to the Earth. This makes the Earth warmer than it would have been.

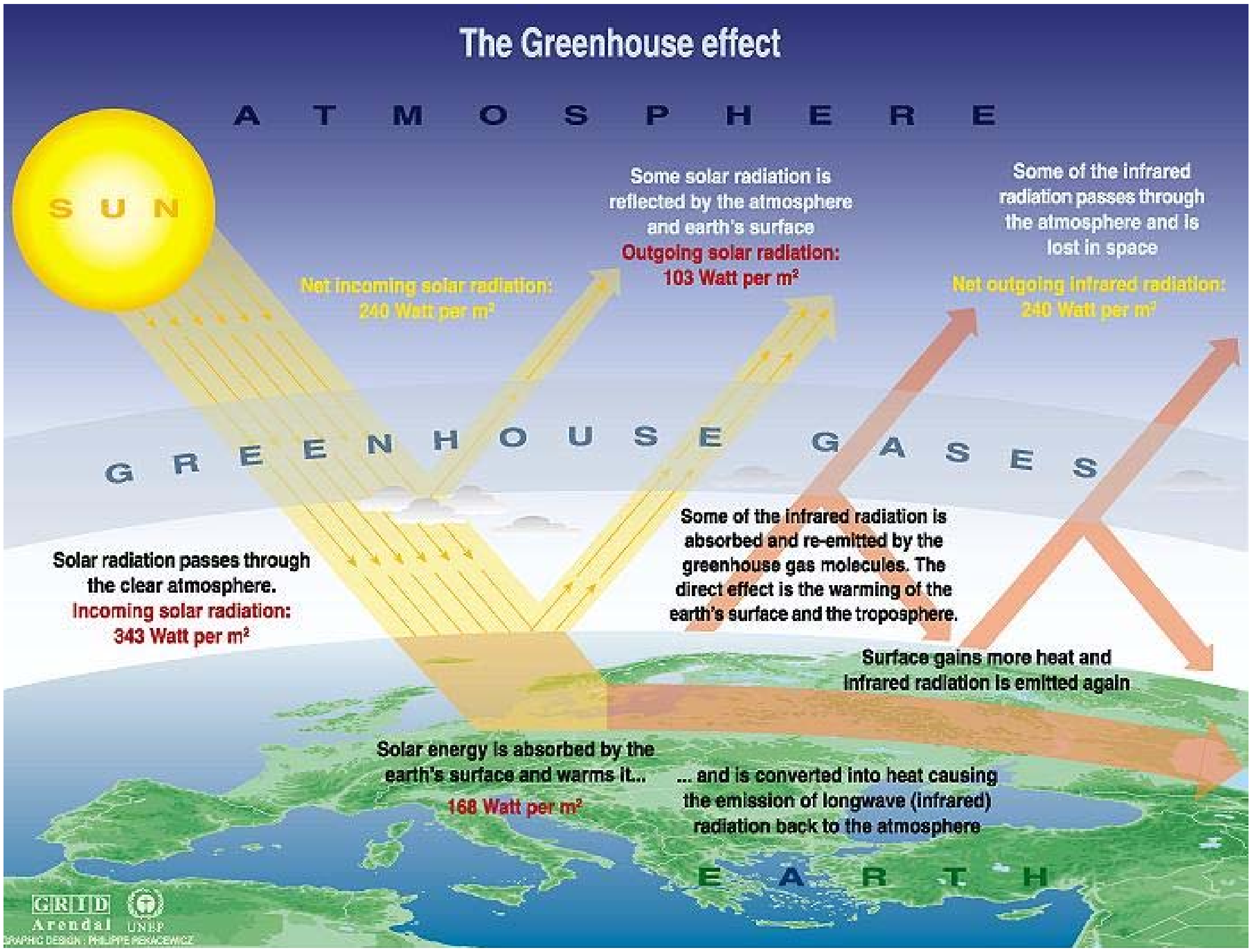
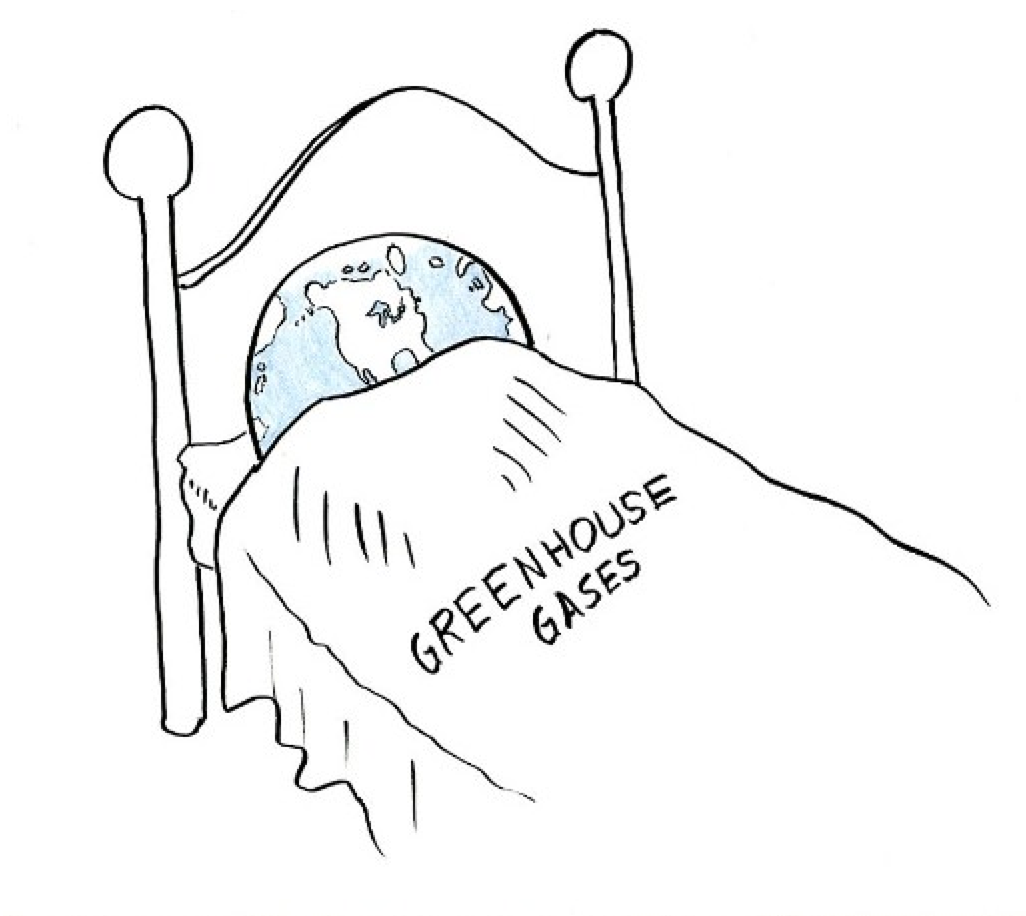


Figure 3 – The Greenhouse Effect
Source: UNEP, Vital Climate Change Graphics Update,
http://maps.grida.no/go/collection/vital-climate-change-graphics-update

A simple analogy to the effect of greenhouse gases is covering yourself with a blanket on a cold winter night. The blanket traps your body heat and keeps you warm. Greenhouse gases trap the Earth's heat and keep it warm. It is fortunate that our Earth's atmosphere has naturally occurring greenhouse gases, such as water vapor and carbon dioxide. They keep our planet at a comfortable temperature. The Earth's temperature (averaged over its whole surface and through the year) is about 58^{o}F. Without greenhouse gases, the Earth's average temperature would be about 0^{o}F.



Cartoon by Gerry McNabb

Figure 4 – Greenhouse Gases Warm the Earth

Figures 3 and 4 are oversimplified in one respect. They indicate that the atmosphere has a greenhouse gas layer, much like the ozone layer in the lower stratosphere. This is incorrect. Greenhouse gases are spread throughout the whole atmosphere, although they tend to concentrate in the lower atmosphere.

The actual climate system is much more complicated than this simple picture. Some of these complexities will be discussed below. However, even this simplified view of the climate system indicates three ways in which humans can affect climate.

1. We can increase the amount of greenhouse gas in the atmosphere, which will lead to warming.
2. We can increase the amount of particulate (dust, soot, sulfate particles, etc.) in the atmosphere, which will generally lead to cooling.

3. We can change the Earth's surface, for example, by clearing forests to plant crops, which will change the amount of the Sun's energy that the Earth reflects, and could lead to either warming or cooling.

Complexities in the Climate System

Climate Cycles

Many natural climate cycles, which temporarily warm or cool the Earth, have been identified. These cycles complicate identification of the warming effect of greenhouse gases. During a cycle's cool phase, short-term cooling due to the cycle can be larger than the warming due to greenhouse gases over the same period, leading to a temporary dip in temperature. However, as shown in Figure 5, when the cycle moves into its warm phase, the combined effect of the warming due to the cycle and the warming due to greenhouse gases will lead to even higher temperatures.

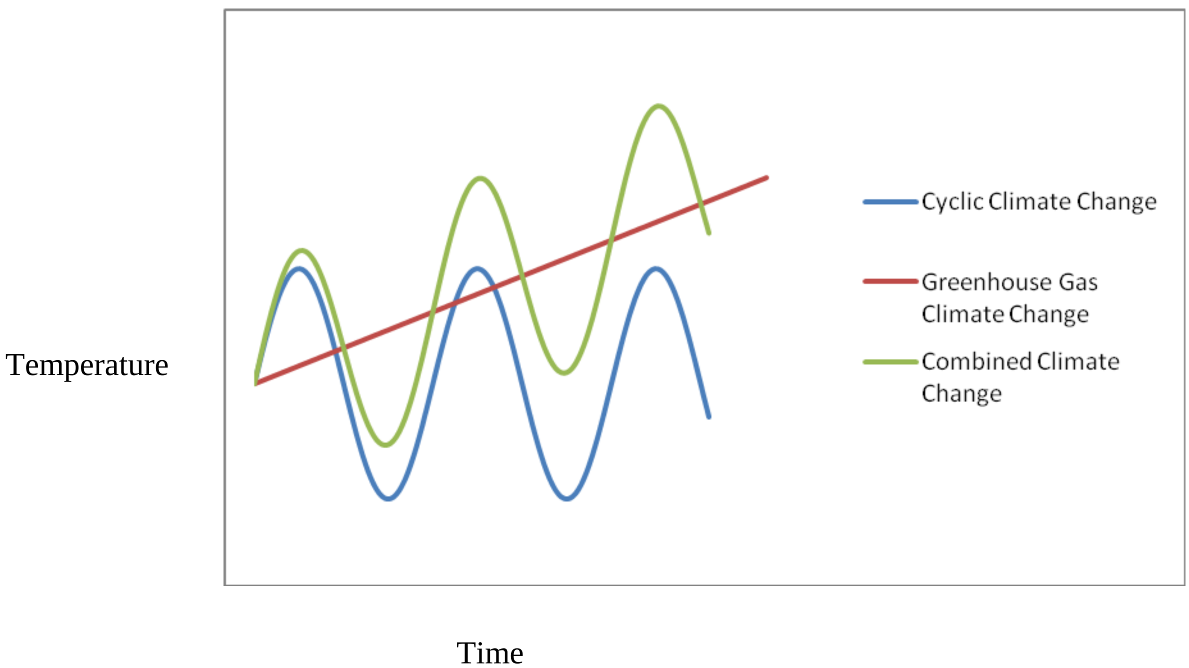


Figure 5 – Effects of Cyclic and Greenhouse Gas Climate Change

The climate cycle that receives the most attention is the 3-7 year El Niño-La Niña cycle, also known as the ENSO (El Niño – Southern Oscillation) cycle. During its warm, El Niño, phase, this cycle increases global average temperature. During its cool, La Niña, phase, it decreases global average temperature. 1998, the warmest year on record to date, was characterized by one of the strongest El Niños in recorded history.

Scientists have also documented a 50-70 year climate cycle in the North Atlantic Ocean and its surrounding land masses. Differences in temperature and salinity in the Atlantic Ocean are believed to cause warm water from the sub-tropical Atlantic to flow north and east, warming northwestern Europe. This phenomenon is known as the Atlantic meridional overturning circulation, or the Atlantic thermohaline circulation. Cyclic variations in this circulation can lead to significant amounts of warming and cooling in North America, Greenland and Europe. Ice core data indicates that this 50-70 year variability in the Atlantic has likely occurred for at least the past 1,000 years.

Cyclic behavior has its biggest impact on areas close to the source of the cycle. ENSO impacts the countries in or adjacent to the Pacific Ocean, from Australia to Peru. However, through a phenomenon known as tele-connections, the impact of climate cycles is also felt further way. ENSO also affects California and East Africa, locations far from the tropical Pacific. Impacts of the North Atlantic cycle are felt as far away as Siberia.

Feedbacks

Feedbacks are secondary changes that occur in the climate system as a result of warming. Positive feedbacks are changes that increase the warming, while negative feedbacks are changes that decrease the warming.

The most important positive feedback is the increase in water vapor with warming. If the Earth warms, more water will be evaporated, and the amount of water vapor in the atmosphere will increase. Since water vapor is a greenhouse gas, it will increase the amount of warming. This positive feedback leads to roughly a doubling of the warming caused by carbon dioxide alone. Warming will also cause more sea ice to melt. Sea ice reflects most of the solar energy that falls on it. The ocean water that is exposed when sea ice melts is much darker than the sea ice it replaces and will absorb most of the solar energy that falls on it. This change from reflection of most solar energy to absorption of most solar energy will lead to more warming, and is another positive feedback.

More water vapor in the atmosphere can mean more low level clouds. Low level clouds reflect the Sun’s energy and result in cooling. This is an example of a negative feedback.

Most climate scientists agree that positive feedbacks are stronger than negative feedback, but there is uncertainty about how much extra warming will occur. If there were no feedbacks, doubling the atmospheric concentration of carbon dioxide, the greenhouse gas of most concern, would lead to about 1^{o}C (1.8^{o}F) warming. However, estimates of the warming that would occur if carbon dioxide concentration doubled range from 2^{o}C to 4.5^{o}C (3.6-8.1^{o}F), with a best estimate of 3^{o}C (5.4^{o}F).

What Causes Climate Change

The Sun

Since the Sun is the source of energy for the climate system, any change in the intensity of solar energy will affect the climate. NASA satellites have been making direct measurements of solar energy hitting the Earth for the last 30 years. These measurements show that the intensity of solar energy reaching the Earth changes over the 11-year sunspot cycle, but by less than a tenth of a percent, not enough to account for the warming that has occurred over that period. However, indirect measurements of solar activity indicate that solar energy has increased slightly since 1750 and contributed a small part to the warming over that period.

The media have reported on a theory proposed by a few scientists that there are positive feedbacks on solar radiation that could magnify the small observed changes and explain the climate change of the last few decades. To date there has been no verification of this theory.

Volcanoes

Some volcanic eruptions throw large amounts of particulate matter into the lower stratosphere, where they can form dense clouds of sulfuric acid droplets. These droplets reflect solar energy and therefore have a cooling effect. Mt. Pinatubo, which erupted in 1991, caused a drop of $0.5^{o}C$ ($0.9^{o}F$) in global average temperature in 1992. However, by 1995, the climate effect of the eruption had largely disappeared because the sulfuric acid droplets settled into the troposphere, where they were washed out by rain and snow.

Man-Made Greenhouse Gas Emissions

Greenhouse gases are a natural part of the climate system. Water vapor is the most important natural greenhouse gas. Its concentration depends on temperature and relative humidity, and can be as high as 6% in tropical conditions. Burning of fossil fuels and other human activities emit water vapor, but in such small quantities compared with the naturally occurring water vapor that these emissions are usually ignored. Water vapor feedbacks are very important in the climate system, but these feedbacks result in changes in the amount of natural water vapor in the atmosphere.

Carbon dioxide (CO_2) is the most important man-made greenhouse gas. About 74% of man-made CO_2 emissions are caused by burning of fossil fuels (coal, oil and natural gas); 23% is caused by deforestation and other changes in land use, and 3% is caused by cement manufacture and other industrial processes. Ice core data indicates that for the thousand years before 1850, the atmospheric concentration of CO_2 was nearly constant at about 280 parts per million. Since 1850, human activities have increased the atmospheric concentration of CO_2 to 385 parts per million, an increase of nearly 40%.

Climate skeptics point to the fact that human emissions of CO_2 are small compared to the huge amount of CO_2 circulating through the atmosphere, oceans, and living plants as part of the carbon cycle. This is true, as shown in Figure 6, but these natural flows of CO_2 are nearly in equilibrium. About as much CO_2 is absorbed by growing plants and the oceans as released by decaying plants and other natural sources. Absorption and release of CO_2 from the ocean is about equal over the year. Scientists can show that about half of man-made CO_2 emissions are absorbed by additional plant growth and in the oceans. The remainder accumulates in the atmosphere leading to the increase in CO_2 concentration. It is human emissions that are unbalancing the system.

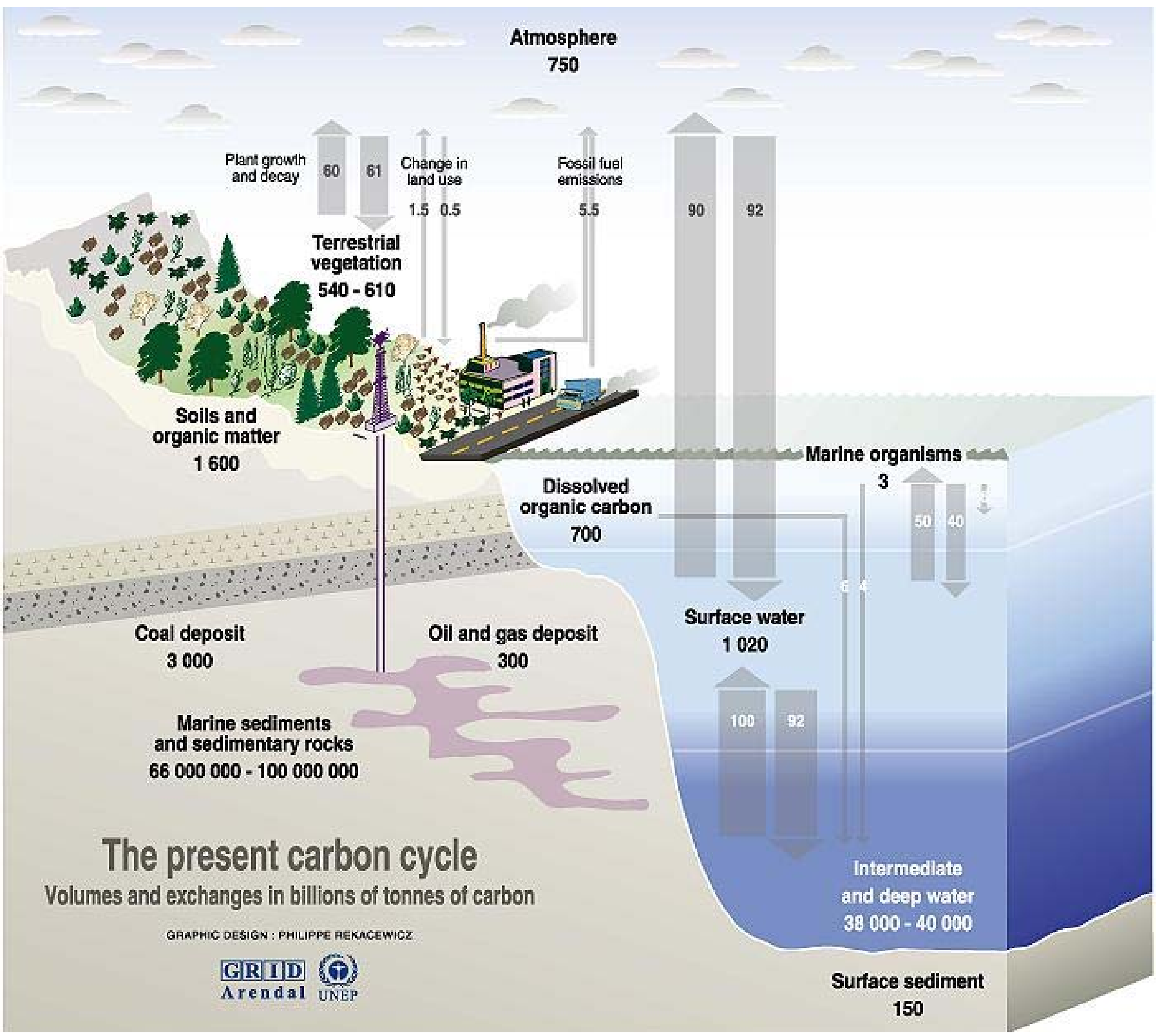


Figure 6 – The Carbon Cycle
Source: UNEP, Vital Climate Graphics, www.grida.no/publications/vg/climate/page/3066.aspx

Methane (CH_4) is the next most important man-made greenhouse gas. Most CH_4 emissions come from agriculture, including rice patties, manure piles and the digestive systems of cows and other grazing animals. Other sources of CH_4 include landfills, coal mines and natural gas leaks. Atmospheric concentrations of CH_4 have risen by about 150% since 1750.

Nitrous oxide (N_2O) is the third most important man-made greenhouse gas. Most man-made N_2O emissions come from the oxidation of nitrogen-containing fertilizer, but it is also emitted by sewerage treatment plants and a few chemical processes. Atmospheric concentrations of N_2O have risen by 15-20% since 1750.

The last important category of man-made greenhouse gas is the fluorinated gases (F-gases) used for refrigerants and for a variety of industrial processes. Many of these gases also contribute to stratospheric ozone depletion, and either have been banned, or are being phased out, by the Montreal Protocol, an international agreement on the protection of the ozone layer. However, some of the fluorine-containing refrigerants introduced to replace the banned gases are strong greenhouse gases with long lifetimes in the atmosphere.

The various man-made greenhouse gases have different impacts on the climate because they are more or less effective at trapping heat, and because they stay in the atmosphere for different amounts of time. To compare them, climate scientists multiply the pounds of emissions of each greenhouse gas by the ratio of the climate impact of one pound of the gas to the climate impact of one pound of CO_2. The resulting number is known as the carbon dioxide equivalent, abbreviated $CO_{2\text{-eq}}$. Global emissions of man-made greenhouse gases total 54 billion ton of $CO_{2\text{-eq}}$. in 2004, up from 32 billion ton in 1970. Figure 7 shows the relative importance of different sources of man-made greenhouse gases on a $CO_{2\text{-eq}}$. basis.

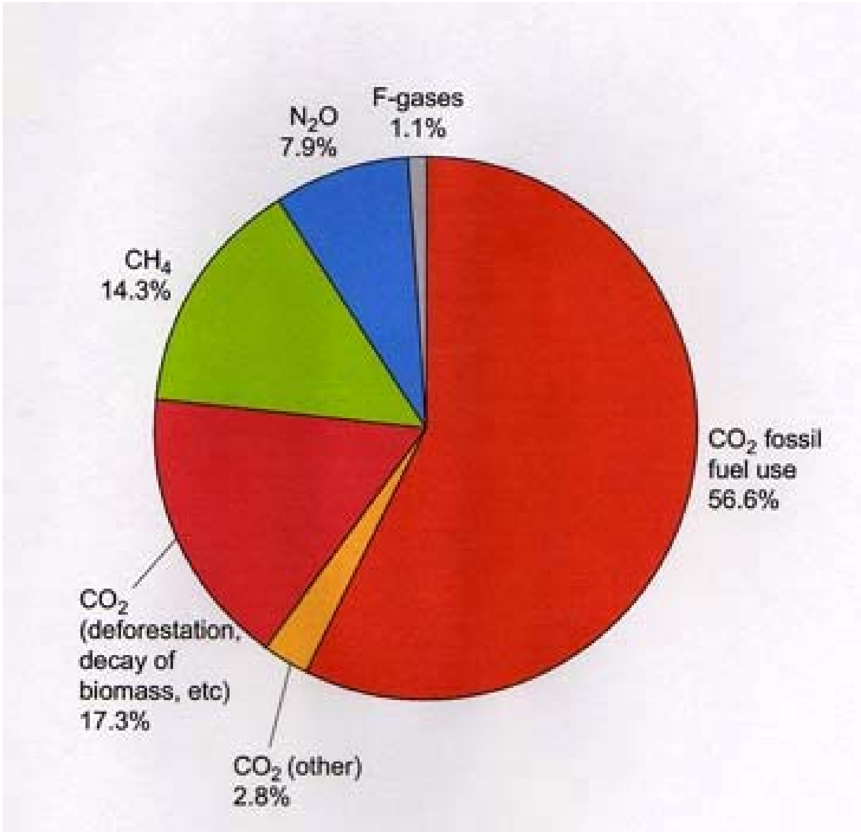


Figure 7 – Man-made Greenhouse Gas Emissions in 2004 (Source: Intergovernmental Panel on Climate Change Fourth Assessment Report, www.ipcc.ch)

Man-made Particulate Emissions

Man-made particulate emissions can result from either the direct emission of particles, such as those present in diesel exhaust, or from the emission of gases, such as sulfur oxides, which react in the atmosphere to form particles. Both the amount of man-made particulate emissions and their impact on the climate system are less well understood than the amount and impact of greenhouse gas emissions. Most man-made particulate emissions reflect solar energy and have a cooling effect, but some particulate emissions, such as the black carbon emitted by diesel engines, absorb solar energy and have a warming effect. Scientists have shown that black carbon deposited on snow and ice in the Arctic reduces the amount of solar energy it reflects, leading to increased melting and further reduction in snow and ice cover.

A further complication is that particles in the atmosphere, whether natural or man-made, are critical to cloud formation. Low altitude clouds tend to have a cooling effect, while high altitude clouds tend to have a warming effect. If there are more particles in the atmosphere because of human activities, there will be more clouds, but their impact on climate will depend on which type of cloud is formed.

Land Cover Changes

Currently about a sixth of incoming solar energy is reflected by the Earth’s surface. Since different surface covers reflect different amounts of solar energy, large scale changes in the Earth’s surface cover, for example, massive deforestation, could affect the climate system.

Adding it All Up

With so many factors affecting the climate system, scientists need a tool that adds the different components to give an overall impact. This tool is called radiative forcing (RF), and it is the effect that the change has on the amount of energy the Earth radiates back to space. Positive radiative forcing has a warming effect; negative radiative forcing has a cooling effect. Figure 8 shows the current best estimates of radiative forcing. The other human impacts summed in the figure include changes in the reflectivity of the Earth’s surface and several small impacts on the climate system, for example, aircraft contrails, which act like artificial clouds.

The total effect of all of these changes is warming, and, as shown at the bottom of Figure 8, the total man-made contribution to warming of the climate system is about ten times as large as the natural contribution from solar variability.

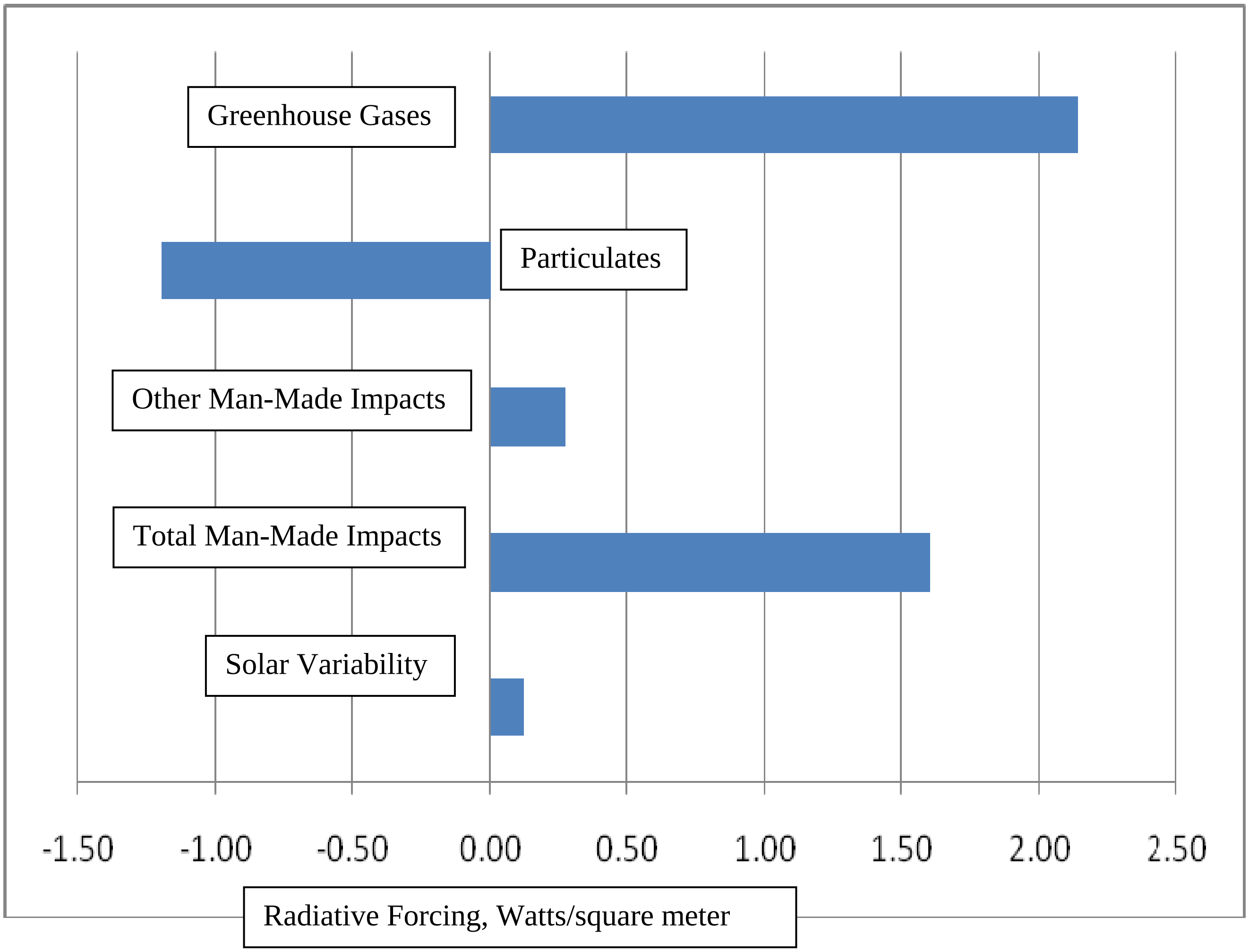


Figure 8 – Impacts on the Climate System
(Source: Intergovernmental Panel on Climate Change Fourth Assessment Report, www.ipcc.ch)

Topic 2 – Has Climate Changed Over the Last 50 Years?

The answer to this question is an unequivocal yes. Figure 9 shows global average temperature since 1850. The dots are temperature for individual years, the black line, the ten-year running average of temperature, and the blue band, the uncertainty around that average. Temperature change is the difference between the observed temperature and the average temperature for 1961-1990.

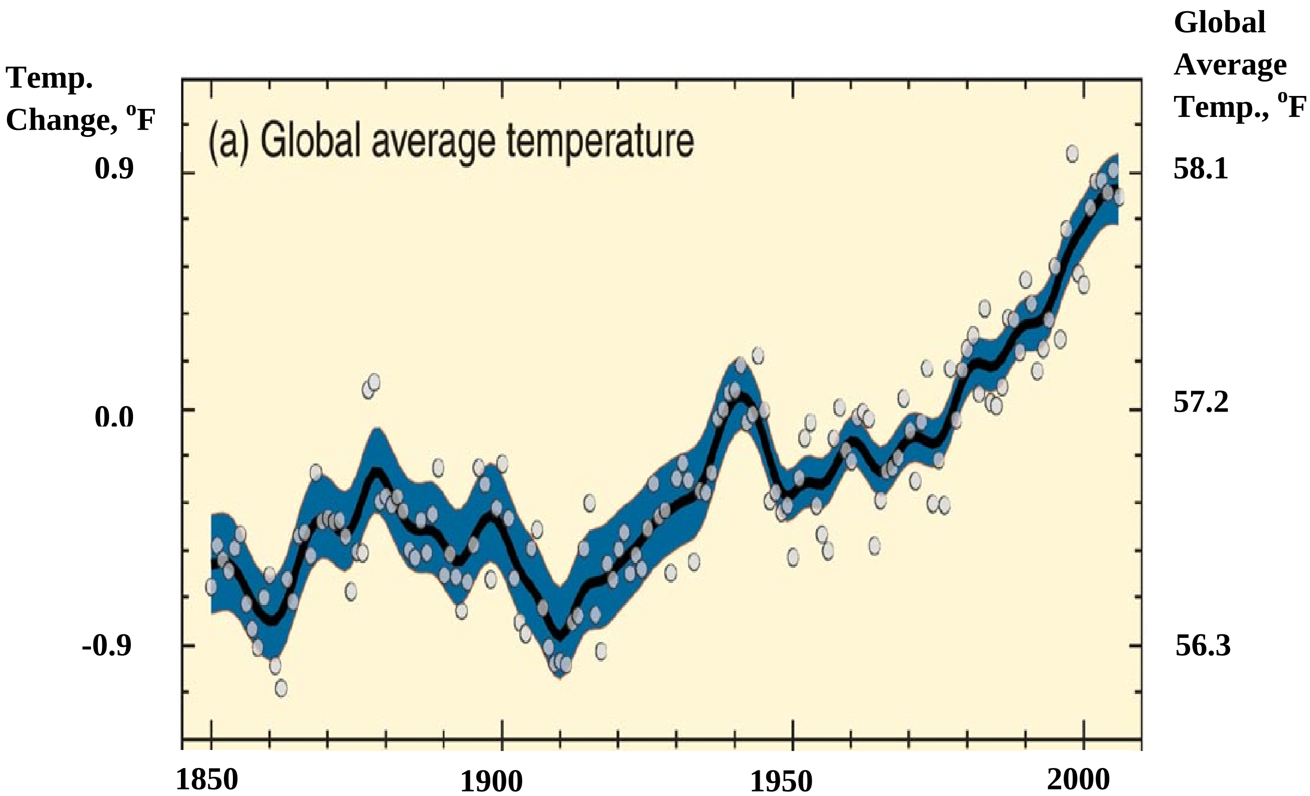


Figure 9 – Global Average Temperature, 1850 – 2005
(Temperature change compared to 1961-1990 average)
Source: *Intergovernmental Panel on Climate Change Fourth Assessment Report*, www.ipcc.ch

Figure 9 clearly shows that global average temperature has risen since 1960, and that the rise has been continuous since about 1975. This does not mean that temperature has risen at every point on the globe, nor does it prove that human activities are the cause of the temperature rise. Whether humans have caused the observed change in climate is discussed in the next section.

Many questions have been raised about the calculation of global average temperature, and no doubt there are uncertainties in this calculation. However, studies of physical phenomena, such as the date of break-up of ice on lakes and rivers in the spring, and biological phenomena, such as the date of first flowering of plants, all show a pattern consistent with warming of the Earth for at least the last 50 years.

Topic 3 – Have Humans Caused the Climate Change of the Last 50 Years?

The climate system is too complex to allow a simple correlation between temperature and greenhouse gas concentrations. Other factors, some natural, like changes in the intensity of solar radiation, and others man-made, like particulate emissions, also affect climate. The only practical way to study the climate impact of human activities is with a climate model.

Scientists and engineers use models for a wide variety of applications. Some of them are so accurate that we don't even think of them as models. For example, we can send space probes to rendezvous with the moons of Saturn because we have a highly accurate and highly sophisticated model of the gravitational interactions in the solar system. We can design bridges because we have an accurate model of the stresses that will be created by cars and trucks crossing the bridge, water flow under the bridge, and wind hitting the bridge structure.

Even though climate models are so large and complex that they require weeks of supercomputer time to complete a full simulation of past or future climate, they are not as accurate as the models used to guide space probes or design bridges. However, most climate scientists believe they are accurate enough to yield meaningful results.

One of the studies carried out with climate models was an attempt to simulate 20th century temperature changes using only natural causes of climate change (variations in solar intensity and the effects of volcanic eruptions), then using both natural and man-made causes of climate change. The results for global average temperature are shown in Figure 10.

The black line is the change in observed global average temperature for each decade from 1900 to 2000 relative to the 1901-1950 average temperature. The blue band shows the results of model simulations using only natural causes of climate change; and the pink band, the results of model simulations using both natural and man-made causes of climate change. While it is possible to get a reasonable simulation of observed temperatures increases to 1950 using only natural causes of climate change, it is not possible to simulate observed temperatures increases after 1950 without including man-made causes of climate change. Similar results were obtained for just the Earth's land areas, for just the oceans, and for each of the continents, except Antarctica. Too few temperature measurements were made in Antarctica before 1950 to allow such a comparison to be made.

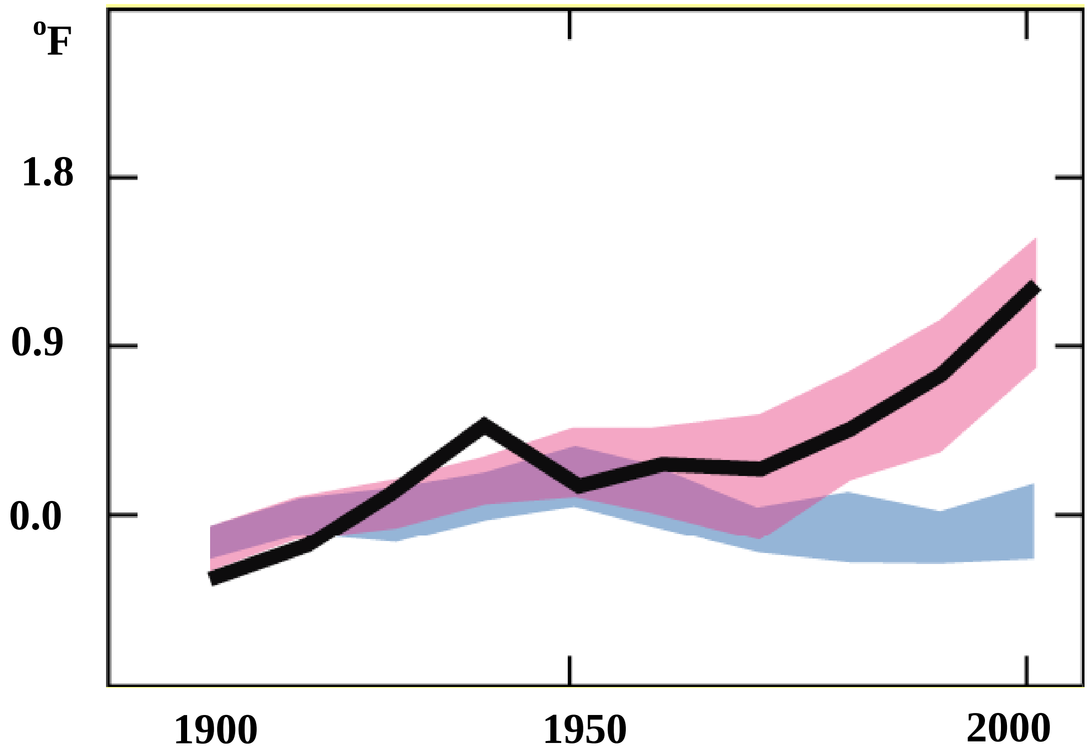


Figure 10 – Global Average Temperature Change Compared to 1901-1950 Average

Black line is observed 10-year average temperature. Blue band is climate model simulations using only natural causes of climate change. Pink band is climate model simulations using both natural and man-made causes of climate change.
Source: *Intergovernmental Panel on Climate Change Fourth Assessment Report*, www.ipcc.ch

Topic 4 – How Might Climate Change in the Future?

The same factors, both natural and man-made, which have affected the climate of the last 50 years, will continue to affect the climate of the next century. We can assume that volcanic eruptions will occur randomly over that period, but that they will not have a long-term impact on average climate. We can also assume that there will not be large changes in the amount of solar energy the Earth receives. If these assumptions are correct, then natural causes of climate change would result in global average temperature varying over a range of about 1°F, as it did from 1850 to 1950 (See Figure 9).

However, unless global efforts are made to control them, man-made greenhouse gas emissions, especially carbon dioxide emissions, are expected to increase dramatically over the next century, resulting in significant warming. The amount by which carbon dioxide emissions increase will depend on population, level of economic development, the energy technology used, and the degree to which CO_2 emissions are controlled. These factors are unknowable a century into the future.

To deal with an uncertain future, climate modelers use a scenario approach. These scenarios are not predictions of the future; they are a set of plausible ways in the world might develop over the course of the next century. They cover a wide range of possible outcomes, and therefore a wide range of possible emission levels.

Climate modelers refer to their results as projections, not forecasts or estimates. A projection is the result of a calculation using a specific model and a specific set of input conditions. Change the model or change the input conditions, and you'll get a different projection.

In 2000 the UN's Intergovernmental Panel on Climate Change published a set of six scenarios referred to as the SRES scenarios. The SRES scenarios assume that no action is taken to control greenhouse gas emissions, but total carbon dioxide emissions in the six scenarios vary by a factor of eight between 1990 and 2100 because of different assumptions about population, technology development, and the degree to which the world embraces sustainable development. They are the scenarios most widely used by climate modelers, and the basis for projections that between 1990 and 2100 global average temperature might rise by 2 to 11.5^{o}F. The wide range of projections of temperature rise to 2100 is the result of both the wide range in projections of future emissions and the differences between climate models. These two factors contribute about equally to the difference in projections.

Since most man-made greenhouse gases stay in the atmosphere for very long times, it is necessary to control their emissions to near zero to stop the increase in their atmospheric concentration, and the increase in greenhouse warming. Moderate reductions in greenhouse gas emissions will slow, but not prevent, further warming.

While projections of temperature rise are typically given for some time during the 21st century, even if emissions were to drop to very low levels by 2100, temperature would continue to rise slowly for the next few centuries. This is because it takes a long time for the oceans to warm up and come into equilibrium with the atmosphere.

Topic 5 – What are the Impacts of Past and Projected Future Climate Change?

From 1906 to 2005, global average temperature rose 1.3^{o}F, resulting in measurable effects. The temperature rise projected for the next century would have many effects, some of which are fairly certain, others of which are the subject of scientific debate.

- The most certain effect of rising temperature is rising sea level. Sea level rises because warmer temperatures will melt glaciers and ice sheets adding water to the oceans, and also because as the oceans warm, the water in them will expand. Glaciers around the world have been retreating because they lose more ice to melting in the summer than they gain from snowfall in the winter. There is evidence of large losses of ice from Greenland, but not from Antarctica, which is much colder. Globally sea level rose 7 inches in the last 100 years. Estimates of sea level rise to 2100 range from 7 to 23 inches, assuming that the polar ice sheets do not melt faster than they have been melting over the past few decades. Some scientists argue that further warming will dramatically increase the rate at which polar ice will melt. In his movie, *An Inconvenient Truth,* Al Gore highlighted faster melting of the polar ice sheets as one of the risks of climate change. Locally sea level can rise by more or less than the global average because the land under coast lines is rising or falling because of tectonic shifts.

  As with temperature, sea level will continue to rise for many centuries after greenhouse gas emissions are reduced to very low levels. If temperatures are high enough, the Greenland ice sheet could melt completely over the course of many centuries. This would raise sea level by up to 20 feet. Complete melting of the Antarctic ice sheet is very unlikely, but some parts of the Antarctic ice sheet could melt, creating additional sea level rise. Even a few feet of sea level rise would inundate parts of Florida's Everglades, southern Louisiana and the Texas coast.

- A highly certain result of warming is more hot spells and fewer cold spells. The definition of a hot spell is local and typically involves exceed a maximum daily temperature for a number of days. Maximum daily temperatures of 90^{o}F or more for a week would be a hot spell in New England, but typical summer weather in the desert southwest. As average temperature increases, the chance of experiencing hot spells increases. Conversely, the chance of experiencing cold spells in the winter decreases.

- Another highly certain effect of rising temperatures is changes in the amount, location, timing and intensity of rain and snowfall. Warmer temperatures will decrease the amount of precipitation falling as snow and increase the amount falling as rain. They also mean that more water is evaporated and held in the atmosphere as humidity. This in turn, means when it does rain, the rain is more likely to be intense and tropical in nature than gentle. Studies of rainfall records in the U.S. showed an increase in intense rainfall, two or more inches of rain in 24 hours, over the course of the 20th century. Increases in intense rainfall can lead to flooding.

  Warming can change weather patterns. While rainfall is likely to increase globally, some areas will get more rainfall, while others will get less. The warming of the 20th century brought more rainfall to the eastern U.S., but less to the Mediterranean area. Future warming is likely to exacerbate these trends. Generally, wet areas of the world will get more rainfall while dry areas of the world get less.

Even areas which receive more rainfall will have increased chance of drought. Since more of the rain is likely to fall as intense rain, it will run off more quickly, possibly as a flood. Also, higher temperature means more evaporation, leaving the land drier.

- Warming temperatures and changing precipitation patterns will lead to changes in habitats which will cause some species to disappear from certain areas and others to appear. Some of the species that lose their habitat will become extinct, though how quickly and extensively this will happen is uncertain. Some studies indicate that the climate change projected for the next century could put 40-70 percent of species at greater risk of extinction. Concern is greatest for species whose habitats disappear completely, who cannot migrate, or whose migration paths are blocked by human development. Ecosystem interactions are also important; a species might be able to migrate, but still face the threat of extinction if its food source cannot migrate along with it.

- Hurricanes draw their energy from warm ocean water, and warmer ocean water could lead to more intense hurricanes. However, other factors also affect hurricane intensity. Whether the warming since 1970 has led to more intense hurricanes in the North Atlantic is currently a subject of scientific debate.

- Climate change could have a large impact on human society. Humans are unique in their ability to adapt to different climates. Clothing, houses, food storage, and heating and air conditioning are just a few of the ways in which humans have adapted to climate. We will adapt to future climate. The questions are how smoothly and at what cost. Climate change will change the distribution of insect-borne diseases such as malaria and dengue. It will require farmers to plant different crops, and could require abandoning some areas of coastline. It may also create water shortages, change recreational (no snow for skiing) and tourism opportunities, and have a host of other predictable and unpredictable consequences.

Topic 6 – Does Everyone Agree with the Projections for Climate Change?

Not every scientist agrees with the consensus view of the causes and risks of climate change that can be found in Al Gore's *An Inconvenient Truth* or the reports developed by the UN's Intergovernmental Panel on Climate Change. Some feel that the projected impacts under-estimate the threat, while others question the certainty with which projected impacts of climate change are presented. This is not surprising. Scientific knowledge advances when scientists debate and challenge the findings of other scientists. There is rarely a scientific finding that is so obviously true that it is immediately agreed upon by all experts in the field. What is different is that climate change is an important political issue, and normal scientific debate is headline news. Advocates for and against control of greenhouse gas emissions seize on each new scientific finding to support their political positions.

A few of the more common questions about climate science are discussed below.

- Is climate science “settled?”

  Some environmental advocates, as part of their argument for control of greenhouse gas emissions, have stated that climate science is settled. No science is ever “settled.” Every new finding opens up new areas for research. However, the basis for concern about human impacts on the climate system is well-established. Human activities are driving an increase in atmospheric concentrations of greenhouse gases, and this increase will lead to warming. Warming will lead to a wide range of impacts that will, in general, have significant, negative impacts on human society.

  The question we should be asking is whether we know enough to act. With its climate change resolution, the ATC Board of Directors stated that it knows enough to take action to reduce ATC’s own greenhouse gas emissions and to support appropriate federal and state policies to reduce these emissions.

- Is the connection between carbon dioxide emissions and climate proven?

  Carbon dioxide affects climate through the Greenhouse Effect. The Greenhouse Effect is real. It can be demonstrated in the laboratory. Shining simulated sunlight on a flask of carbon dioxide will cause its temperature to rise. It can also be demonstrated in nature by comparing the temperature of the four inner planets of the Solar System (Mercury, Venus, Earth and Mars) as shown in Figure 11. Even though Venus is further from the sun, it is much hotter than Mercury. Venus’ atmosphere is 96% carbon dioxide, whereas Mercury has no atmosphere and therefore no carbon dioxide. Earth is about 60^{o}F warmer than it would be if it did not have water vapor, carbon dioxide and other greenhouse gases in its atmosphere. Any phenomenon that traps heat in the atmosphere will affect climate.

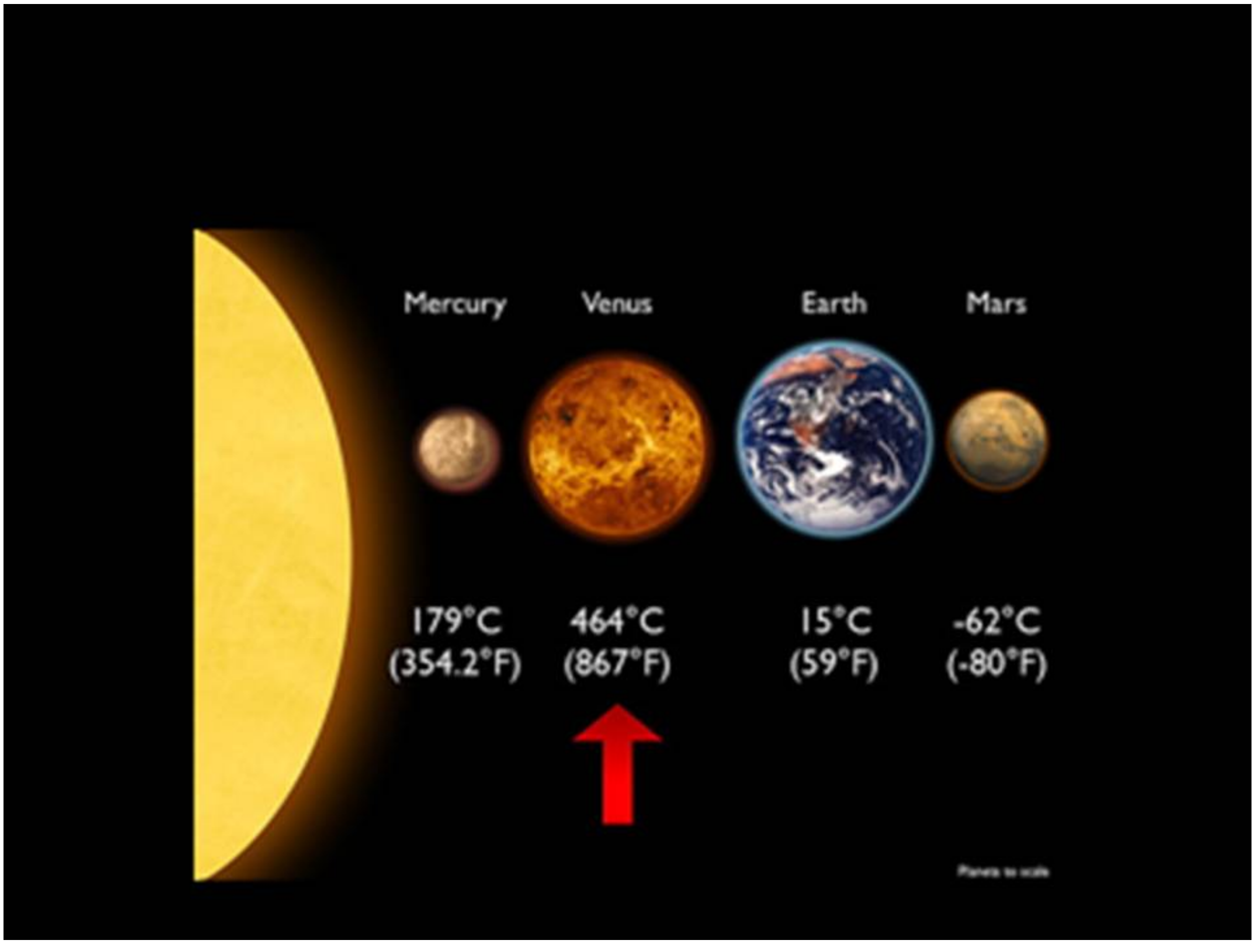


Figure 11 – Surface Temperature of the Four Inner Planets
Source: Hawk Metheny to supply

- Is a new Ice Age imminent and do we need carbon dioxide to avoid it?

  The best scientific evidence indicates that Ice Ages are the result of changes in the Earth's orbit which change its orientation to and distance from the sun. These occur on three cycles, the longest of which is 100,000 years. Astronomical measurements indicate that the Earth is at least 30,000 years away from entering another Ice Age. Ice core data indicate that during the last Ice Age, global average temperature was 7 to 13^{o}F lower than it is today. Higher concentrations of carbon dioxide and other greenhouse gases would counteract the temperature changes due to changes in the Earth's orbit, but purposely raising global average temperature by 7 to 13^{o}F during the 21st century in anticipation of an Ice Age that is not expected to occur for at least 30,000 years seems fool-hardy.

- Do we need higher levels of carbon dioxide to increase crop growth and feed the world's growing population?

In photosynthesis, carbon dioxide and water are combined to make plant matter. Put another way, carbon dioxide is plant food. Experiments have shown that if additional water and other plant nutrients are provided, increasing carbon dioxide increases plant growth. However, plants cannot use unlimited amounts of carbon dioxide. Many important food crops see only small benefits from increased carbon dioxide. The question is whether the benefits for plant growth from increased carbon dioxide in the atmosphere are worth the negative climate impacts that would occur.

- Can the climate change experienced to date be explained by climate cycles?

  Climate cycles are an important part of the climate system, and can lead to either temporary warming or cooling. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide, the three most important man-made greenhouse gases, are now significantly higher than they have been for more than 650,000 years, and all are projected to increase over the next few decades. The warming due to these higher levels of greenhouse gases has to be added to the warming or cooling due to climate cycles. (See Figure 5.) As shown in Figure 10, natural climate changes would have led to a slight cooling over the past 50 years. But even if the warming of the last century was due to climate cycles, increasing greenhouse gas concentrations will soon lead to warming that is outside the range of known climate cycles.