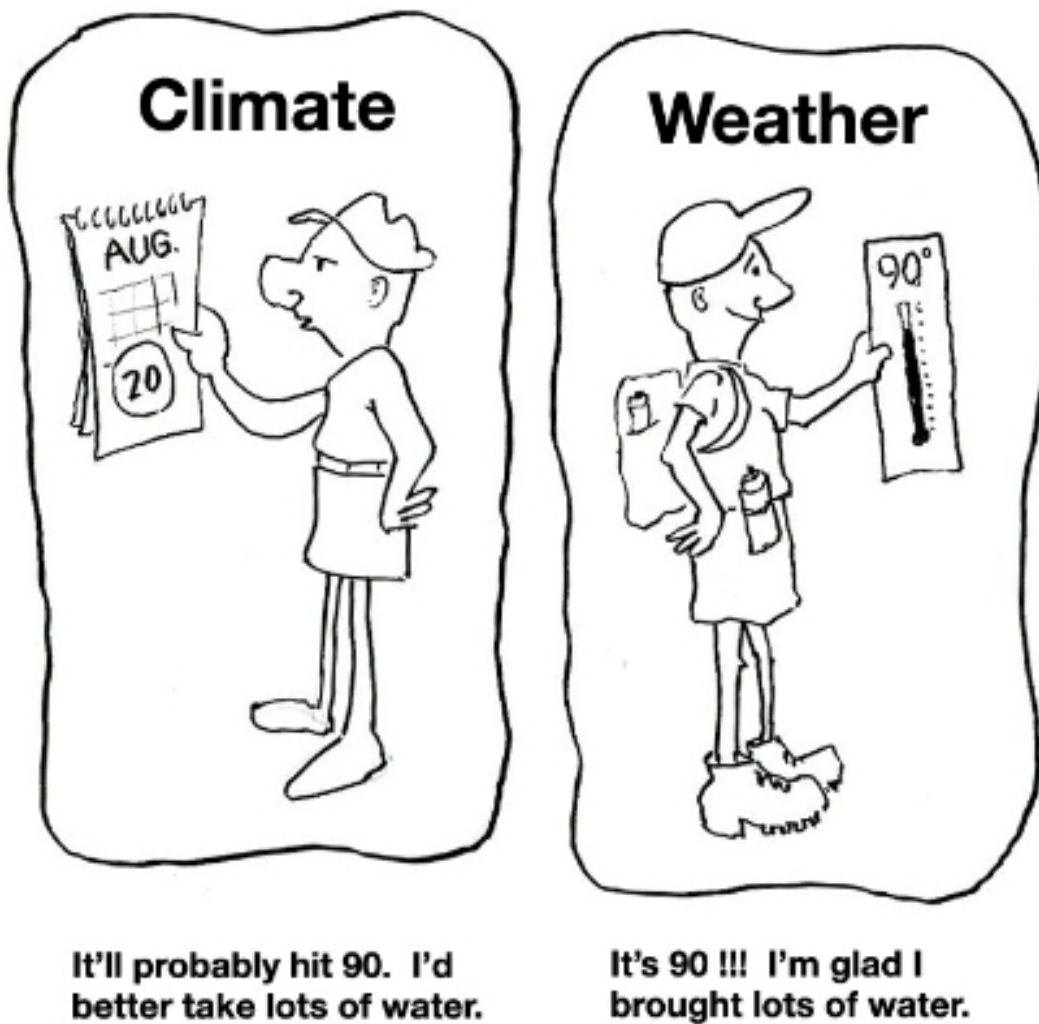


Topic 1 – An Introduction to the Climate System and Climate Change

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."



Cartoon by Gerry McNabb

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.

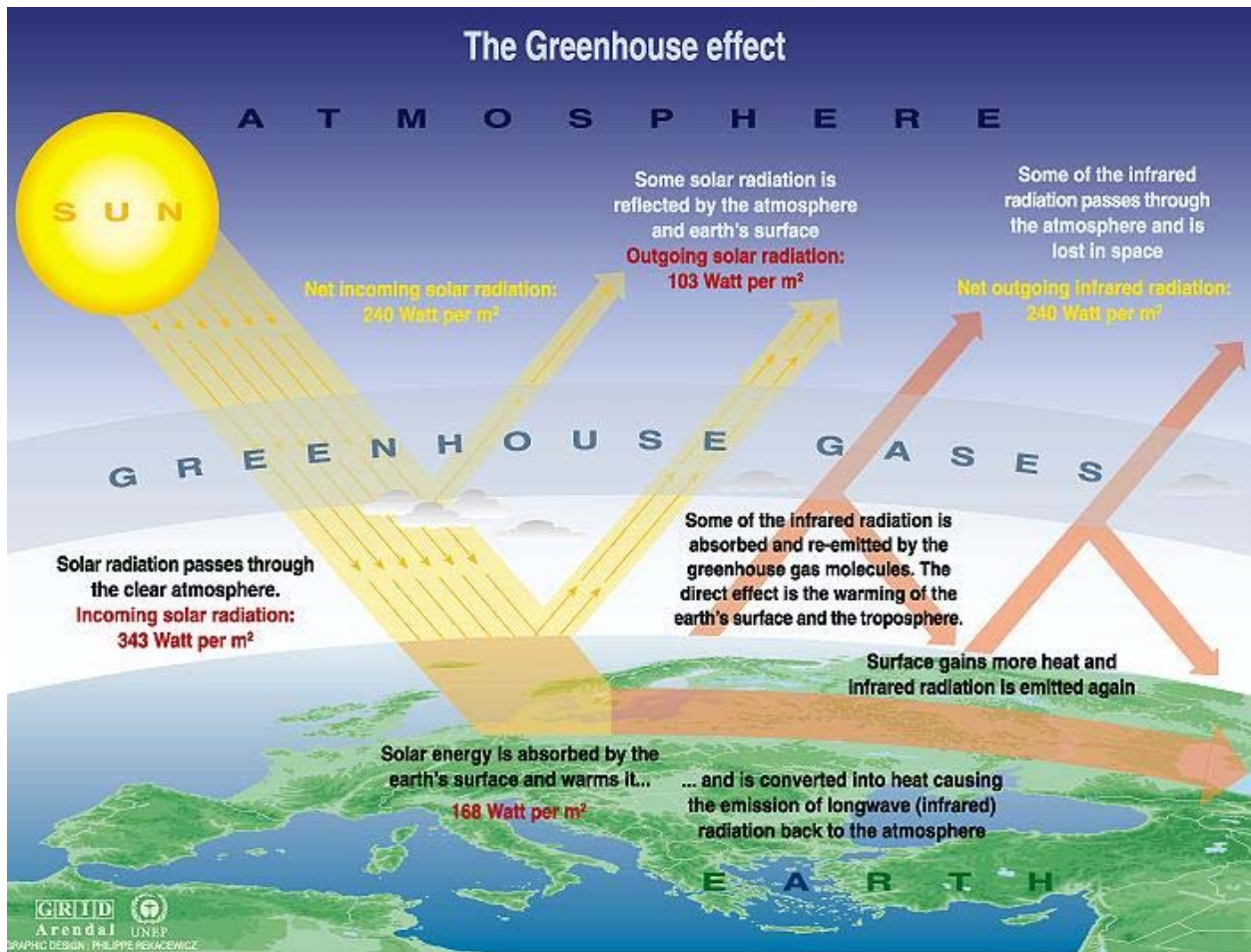


Figure 3 – The Greenhouse Effect

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°F. Without greenhouse gases, the Earth's average temperature would be about 0°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.

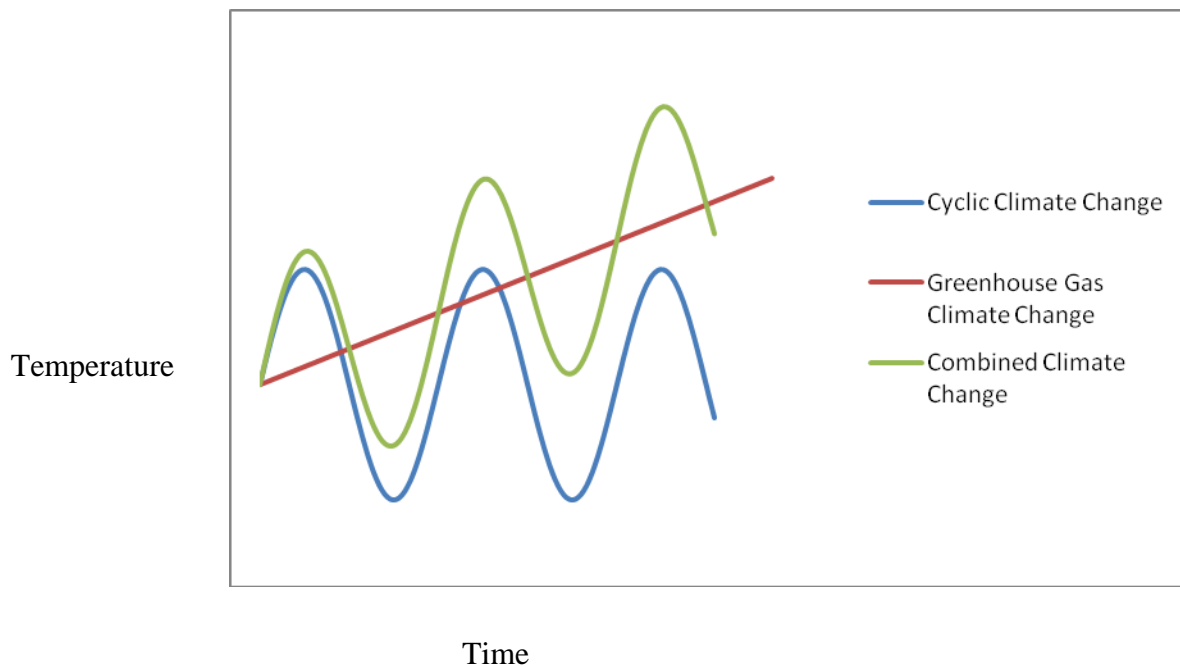


Figure 5 – Effects of Cyclic and Greenhouse Gas Climate Change

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°C (1.8°F) warming. However, estimates of the warming that would occur if carbon dioxide concentration doubled range from 2°C to 4.5°C (3.6-8.1°F), with a best estimate of 3°C (5.4°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°C (0.9°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 (CO₂) is the most important man-made greenhouse gas. About 74% of man-made CO₂ 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 CO₂ was nearly constant at about 280 parts per million. Since 1850, human activities have increased the atmospheric concentration of CO₂ to 385 parts per million, an increase of nearly 40%.

Climate skeptics point to the fact that human emissions of CO₂ are small compared to the huge amount of CO₂ 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 CO₂ are nearly in equilibrium. About as much CO₂ is absorbed by growing plants and the oceans as released by decaying plants and other natural sources. Absorption and release of CO₂ from the ocean is about equal over the year. Scientists can show that about half of man-made CO₂ emissions are absorbed by additional plant growth and in the oceans. The remainder accumulates in the atmosphere leading to the increase in CO₂ concentration. It is human emissions that are unbalancing the system.

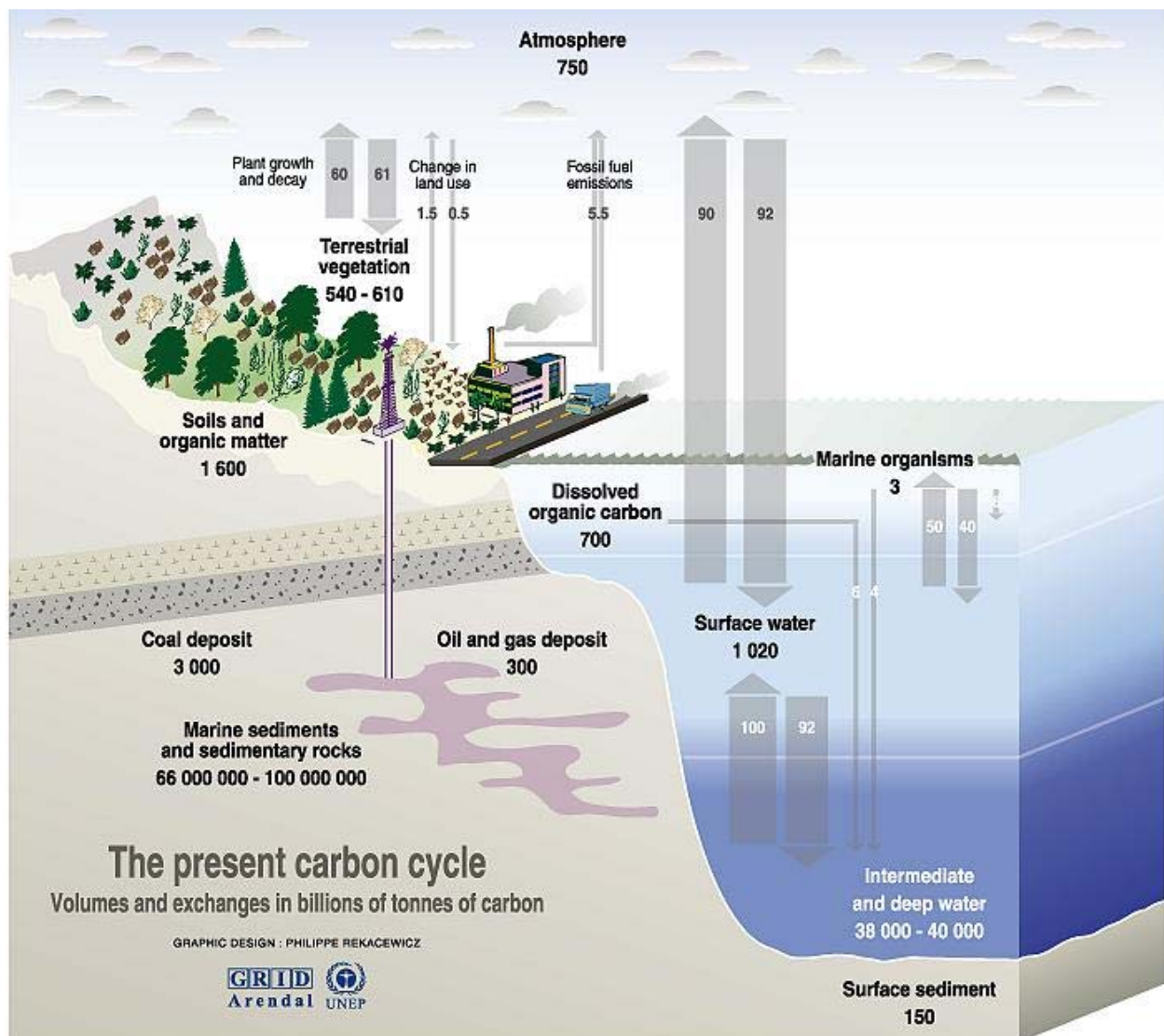


Figure 6 – The Carbon Cycle

Source: UNEP, Vital Climate Graphics, www.grida.no/publications/vg/climate/page/3066.aspx

Methane (CH₄) is the next most important man-made greenhouse gas. Most CH₄ emissions come from agriculture, including rice patties, manure piles and the digestive systems of cows and other grazing animals. Other sources of CH₄ include landfills, coal mines and natural gas leaks. Atmospheric concentrations of CH₄ have risen by about 150% since 1750.

Nitrous oxide (N₂O) is the third most important man-made greenhouse gas. Most man-made N₂O 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 N₂O 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 CO₂. The resulting number is known as the carbon dioxide equivalent, abbreviated CO₂-eq. Global emissions of man-made greenhouse gases total 54 billion ton of CO₂-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 CO₂-eq. basis.

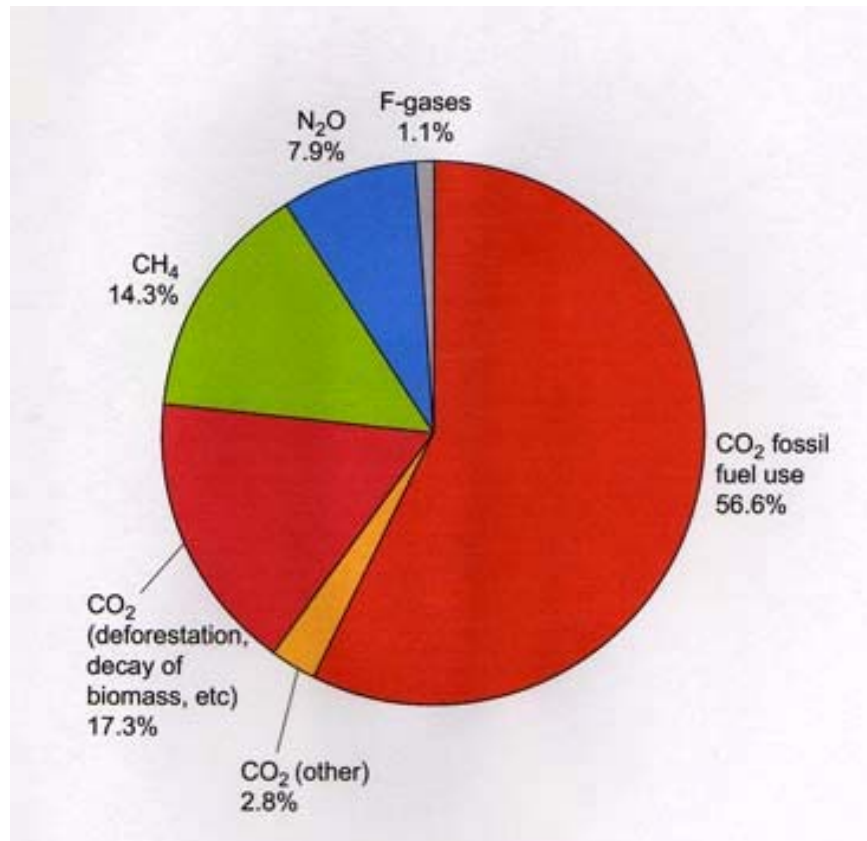


Figure 7 – Man-made Greenhouse Gas Emissions in 2004 (Source: Intergovernmental Panel on Climate Change Fourth Assessment Report, www.ipcc.ch)

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.

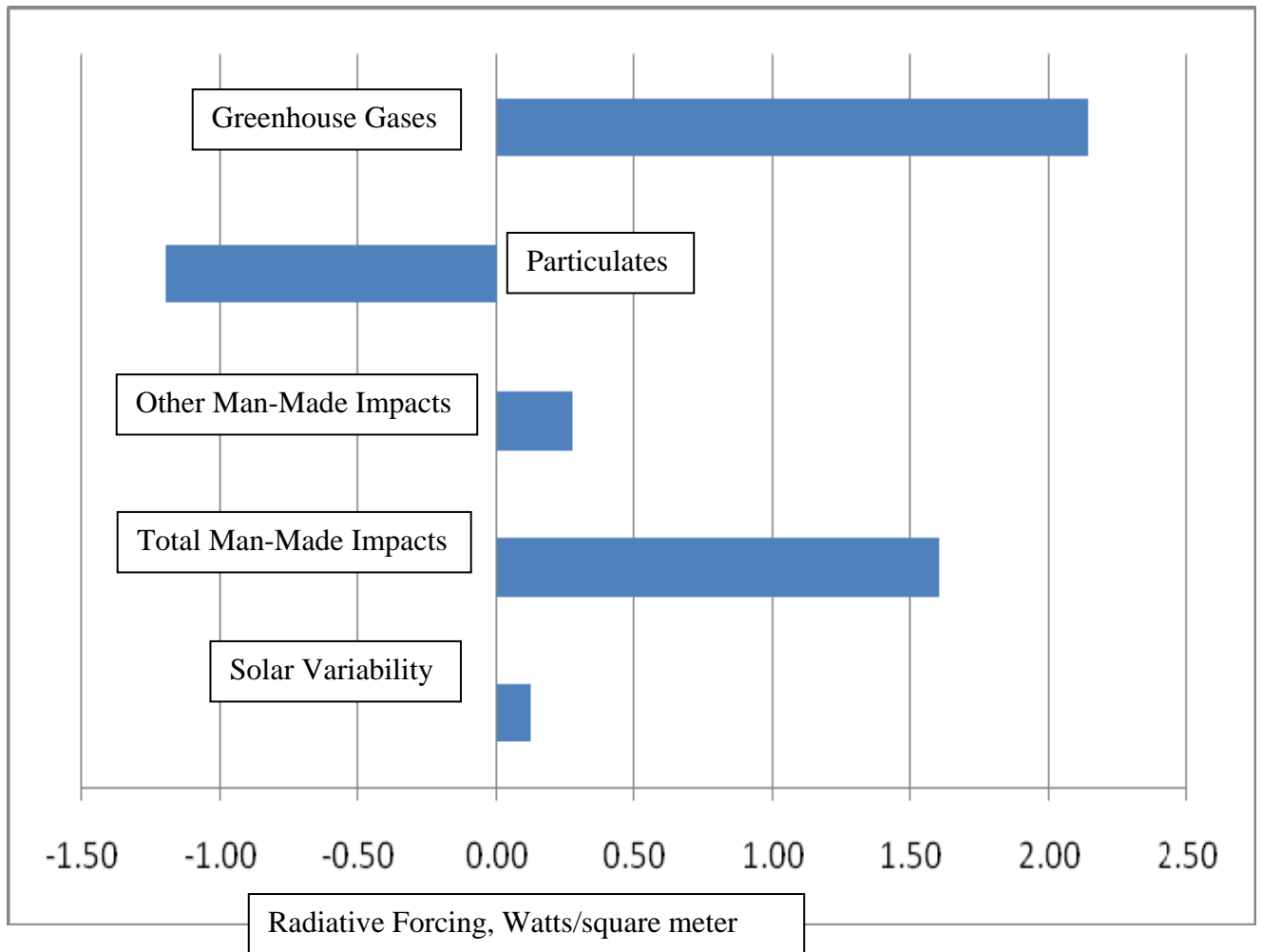


Figure 8 – Impacts on the Climate System
(Source: Intergovernmental Panel on Climate Change Fourth Assessment Report, www.ipcc.ch)