THE GREENHOUSE EFFECT

Overview

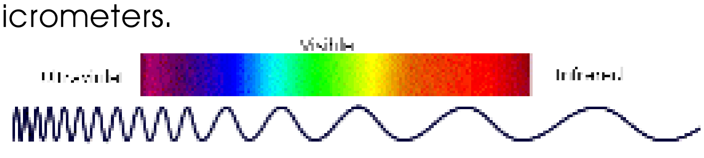
Planets are heated by light from the Sun. Planets cool off by giving off an invisible kind of light, *longwave infrared light.* The Greenhouse Effect is a process whereby certain gasses in the atmosphere, called *greenhouse gasses,* inhibit the surface from cooling off. The causes the surface temperature to be significantly hotter than it would be without an atmosphere.

Light energy

Heat is a form of energy. Light is also a form of energy. The Sun gets rid of the heat it generates by giving off light from its surface. This process is called *thermal radiation* or *thermal emission*.

Light from the Sun is transformed into heat when it is absorbed by a planet's surface. The planet's surface continually cools itself off by transforming heat into *infrared light*. This is also thermal radiation.

The difference between visible light and infrared light is the wavelength. The wavelength of light is measure in **micrometers.** A micrometer is a millionth of a meter. The wavelength of visible light varies from 0.7 micrometers (for red light) to 0.4 micrometers (for violet light). The Sun also gives off **shortwave infrared light** with a wavelength of 0.7 to 5 micrometers. The Earth gives off **longwave infrared light** with a wavelength of about 10 micrometers.



The temperature of a planet is determined by the balance between

1) solar energy (shortwave visible light and infrared light) absorbed by the daytime side of the planet, and
2) thermal energy (longwave infrared light) given off by all sides of the planet.

Rotation affects this balance. If the planet rotates rapidly (in a few hours), the temperature will not vary much between day and night and will always be close to the average. If the planet rotates slowly, then it is necessary to make separate calculations for the daytime and nighttime sides of the planet.

An atmosphere can also affect the temperature if it contains greenhouse gasses. Here we will assume a rapidly rotating planet with no atmosphere or a thin atmosphere without greenhouse gasses.

Thermal emission

The amount of energy per second per square meter given off by the surface of a planet or star is given by **Stefan's Law:**

$$\text{energy/sec/meter}^2 = \sigma T^4$$

where T is the average surface temperature on the Kelvin scale. The Greek letter σ (sigma) is the Stefan-Boltzmann constant. This law says that:

the hotter a planet or star, the more light energy it gives off

Solar energy

Solar energy (light) falls on the daytime side of the Earth at the rate of 1400 Watts/meter^2. This is called the **solar constant**.

The solar constant is the amount of energy falling on the sub-solar point (where the Sun is directly overhead). The energy averaged over the entire day-night cycle and the entire planet is 1/4 of this.

$$\text{average energy/sec/meter}^2 = (350\ \text{W/m}^2)$$

Some of this energy will be absorbed by the surface and some will be reflected back out into space. The fraction that is reflected is the **reflectivity** or **albedo** *(a)*. The fraction that is absorbed is then (1–*a*). The solar energy that is absorbed by the surface is thus:

$$\text{solar light absorbed/sec/meter}^2 = (1-a)\ (350\ \text{W/m}^2)$$

For other planets, this amount must be modified to account for the distance between the planet and the Sun.

Energy balance

When averaged over the day/night cycle, the solar energy falling on the planet must equal the thermal energy given off.

average solar light absorbed= planet's IR given off

The planet's temperature adjusts itself so that this balance is maintained. If the temperature gets too low, the Sun heats up the planet faster than the planet gives off infrared light, and the temperature goes up.

If the planet gets too hot, it gives off infrared light energy faster than the Sun can replace the energy, and the temperature goes down.

If the temperature is just right, a balance is achieved and the planet gets neither hotter nor colder on the average.

The Greenhouse Effect

The Greenhouse Effect occurs when the planet has an atmosphere. Air, as you know, is transparent — it lets light through nearly unimpeded. This is because air is largely made of nitrogen and oxygen, gasses which don't absorb visible light. They don't absorb infrared light, either, so they don't affect the temperature balance of a planet.

Some gasses, called **greenhouse gasses,** are transparent in visible light but block some of the longwave infrared light; that is to say, they are partially opaque in infrared light. Greenhouse gasses include water vapor, carbon dioxide, methane, and others. Water vapor is the most abundant greenhouse gas in the Earth's atmosphere.

The effect of a greenhouse gas is to partially block the longwave infrared light given off by a planet, making it harder for the planet to cool off. The temperature rises. As it rises, the amount of infrared light emitted increases, in accordance with Stefan's law. Soon, the amount of infrared light energy given off rises until it is again in balance with the amount of visible light coming in from the Sun. The balance is restored, but the surface is at a higher temperature.

Note that the Greenhouse Effect doesn't mean that the temperature is rising. The temperature is steady, but it's hotter than it would have been without the greenhouse gasses.

People sometimes confuse the Greenhouse Effect with the effect of the ozone layer. The ozone layer is about 50 miles above the surface. It is important because ozone absorbs shortwave ultraviolet light from the Sun. It is true that ozone is also a greenhouse gas, but the ozone layer doesn't contribute to increasing the surface temperature.

The Greenhouse Effect on Earth

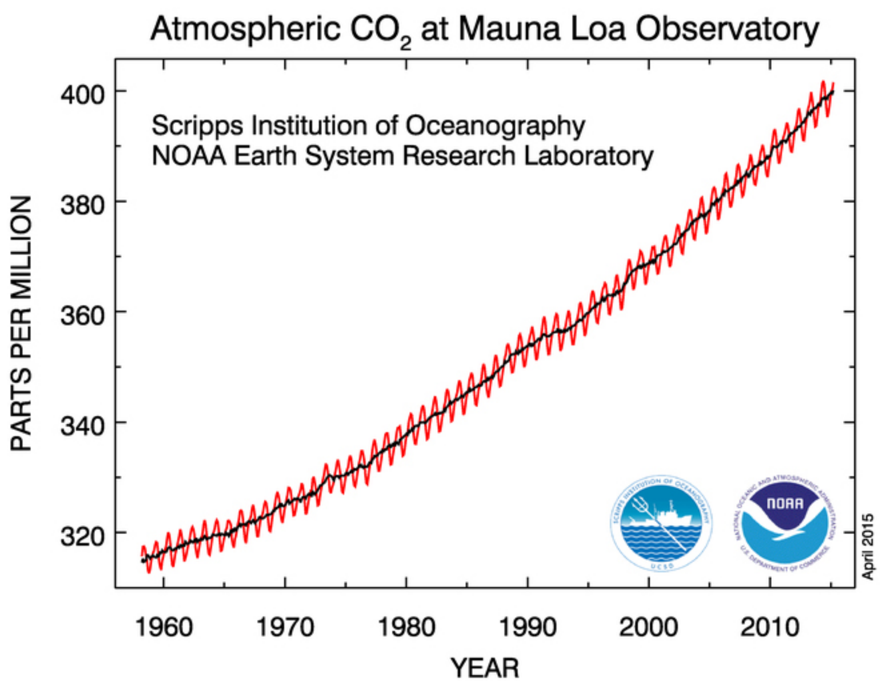
Most of the Greenhouse Effect on Earth is due to **water vapor**. Water vapor is a weak greenhouse gas, but it produces the greatest effect simply because there is so much of it in the atmosphere. Water vapor in the atmosphere raises the surface temperature about 20 K (1 K= 1C°). Without watervapor, the Earth's temperature would be below freezing and the oceans would freeze over.

In addition to water vapor, greenhouse gasses on Earth include **carbon dioxide**, **methane**, and **ozone**. Carbon dioxide is given off by volcanos. Animals it breathe out.CO_2 is also produced by the burning of dead trees or plants. Human civilization adds CO_2 to the atmosphere by burning **fossil fuels** such as coal, oil, and natural gas. Some methane is produced naturally by bacteria; cows give off methane as well. Ozone is a component of air pollution.

Man-made carbon dioxide

The Industrial Revolution, which started about 1800, greatly increased the amount of fossil fuels used by civilization. The inevitable result is a large increase in the amount of CO_2 in the air. Since CO_2 is a rather rare gas, its amount is measured in parts per million (ppm). In 1800, there was approximately 280 ppm of CO_2 in the atmosphere. By 2000 that figure had risen to 380 ppm, and exceeded 400 ppm in 2015. There is more CO_2 in the atmosphere today than there has been since before the ice ages.

Surprisingly, regular measurement of the amount of CO_2 in the air didn't begin until 1958, when Mauna Loa Observatory in Hawaii was established. The graph of the CO_2; measurement is called the Keeling Curve in honor of scientist Charles Keeling, of Scripps Institution of Oceanography, who measured it for over 30 years. The curve shows a small seasonal variation up and down, but every year since 1958 the annual average has increased.



Global climate change

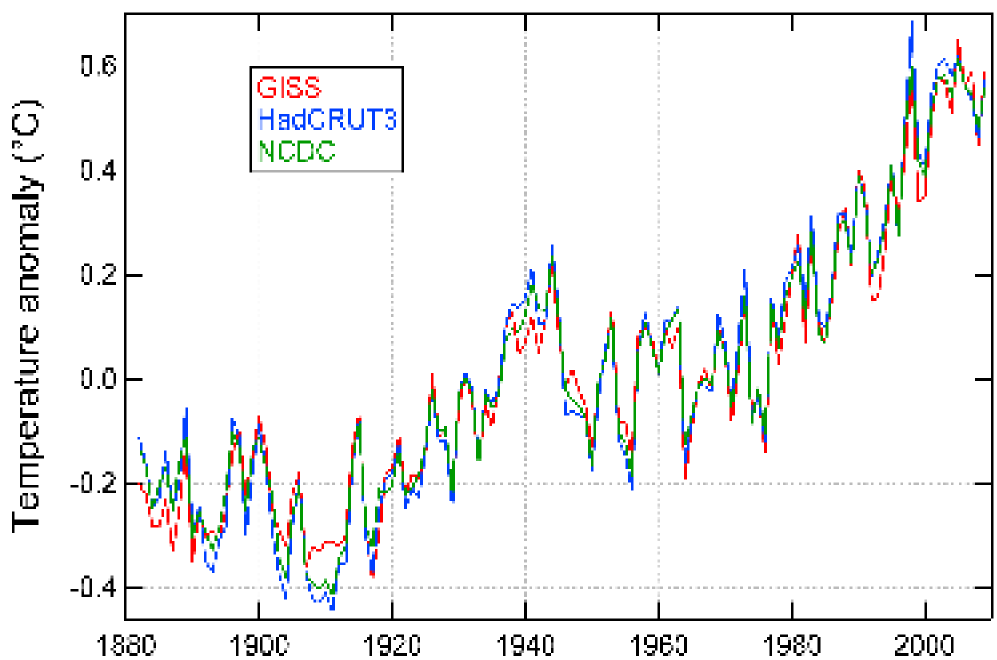
Sooner or later, the rising level of CO_2 is bound to have an effect on the Earth's climate. How much of an effect and how soon is not easy to say. The problem is that the Earth's climate is exceedingly complicated. It depends on many factors:

the incoming light from the Sun
the amount of greenhouse gasses in the air

the extent of cloud cover
the amount of haze particles (aerosols)
ocean currents
the rate of absorption of CO_2 by the ocean

In order the predict what will happen in the future, scientists must build a complicated mathematical model of the climate system and use a big computer to calculate its future response to rising CO_2 levels. The NASA Godard Institute of Space Studies (GISS) in New York, The Hadley Centre in England, the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey, and the National Center of Atmospheric Research (NCAR) in Boulder, Colorado are four places doing such calculations.

These models are checked by seeing how well they "predict" the Earth's temperature in the past. Accurate records of the global temperature mean extend back to about 1880. These data show that the world has warmed about 0.8 K (1.5 F°), consistent with the models.



These calculations predict that the Earth's mean temperature will rise 3–5 K (5 to 9 F°) by 2100 if current rates of fossil fuel burning continue. Such an increase may seem small, but it will have far-reaching consequences. For comparison, the Earth was about 5 K *colder* during the depths of the last ice age.

Consquences of global warming

Some predicted consequences of global warming include:

Shrinking of alpine glaciers and reduction in summer melt, threatening water supplies.
Rising sea level as Greenland ice melts, threatening low-lying countries such as Bangladesh.
Melting of the permafrost in the Arctic.
Retreating sea ice in the Arctic with impact on polar bears.
Eventually, collapse of the West Antarctic ice cap, resulting in a sea level rise of 10 feet.
Stronger hurricanes and other storms.
Shifting of desert belts away from the equator.
Increasing drought in some areas; more rainfall in others.
Acidification of the ocean and destruction of coral reefs.
Mass extinctions of wildlife unable to adapt to a changing climate.

None of these events means the end of the world. But the sheer number of them does mean that almost every part of the world will have to deal with the impact of climate change.

IPCC

The **IPCC (Intergovernmental Panel on Climate Change)** is an international collaboration of government bureaucrats and scientists who meet every few years to assess the state of the world's climate in order to advise national governments.

The Fifth Report was released in 2015. Among the conclusions:

The atmosphere and the ocean are unquestionably getting warmer.
It is *extremely likely* that human activity is part of the reason.
The most significant cause of warming is the rising amount of CO_2.
The temperature rise (over the year 1900) will probably exceed 1.5 K and probably 2.0 K by the year 2100 if current trends continue.
Sea level will rise at an increasing rate.