NASA Facts

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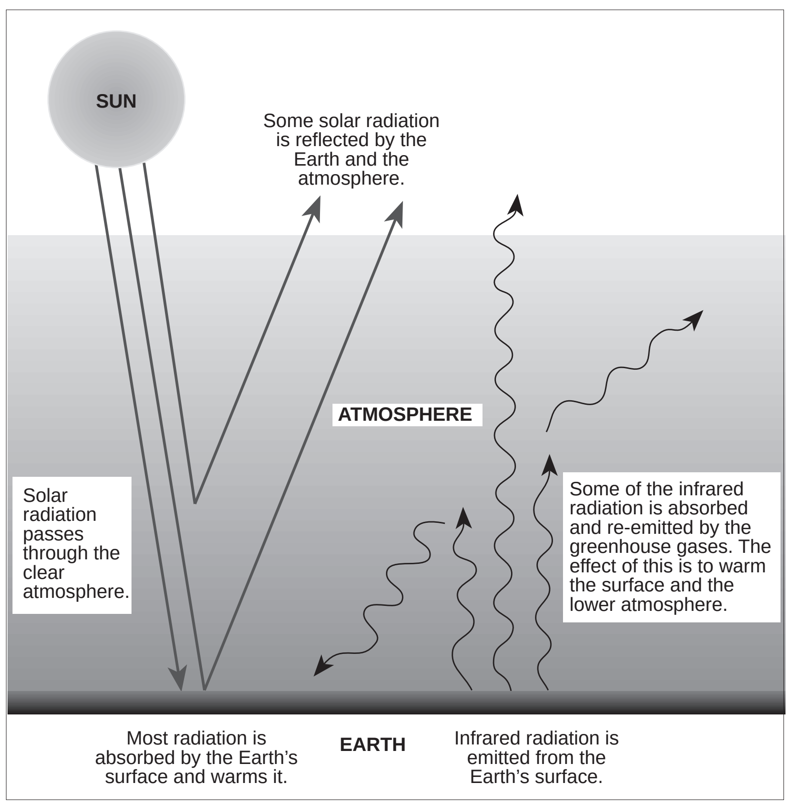
These articles consider Earth's many dynamic processes and their interactions.

Global Warming

Global Change /Climate Change

The prediction of climate change due to human activities began with a prediction made by the Swedish chemist, Svante Arrhenius, in 1896. Arrhenius took note of the industrial revolution then getting underway and realized that the amount of carbon dioxide being released into the atmosphere was increasing. Moreover, he believed carbon dioxide concentrations would continue to increase as the world's consumption of fossil fuels, particularly coal, increased ever more rapidly. His understanding of the role of carbon dioxide in heating Earth, even at that early date, led him to predict that if atmospheric carbon dioxide doubled, Earth would become several degrees warmer. However, little attention was paid to what must have been seen to be a rather far-out prediction that had no apparent consequence for people living at that time.

Arrhenius was referring to a potential modification of what we now call the greenhouse effect. A simplified explanation of this is as follows (see the diagram). Shortwave solar radiation can pass through the clear atmosphere relatively unimpeded, but longwave infrared radiation emitted by the warm surface of the Earth is absorbed partially and then re-emitted by a number of trace gases—particularly water vapor and carbon dioxide—in the cooler atmosphere above. Because, on average, the outgoing infrared radiation balances the incoming solar radiation, both the atmosphere and the surface will be warmer than they would be without the greenhouse gases. One should distinguish between the "natural" and a possible "enhanced" greenhouse effect. The *natural* greenhouse effect causes the mean temperature of the Earth's surface to be about 33°C warmer than it



A simplified diagram illustrating the greenhouse effect would be if natural greenhouse gases were not present. This is fortunate, for the natural greenhouse effect creates a climate in which life can thrive and humankind can live under relatively benign conditions. Otherwise, the Earth would be a very frigid and inhospitable place. On the other hand, an *enhanced* greenhouse effect refers to the possible raising of the mean temperature of the Earth's surface above that occurring due to the natural greenhouse effect because of an increase in the concentrations of greenhouse gases due to human activities. Such a global warming would probably bring other, sometimes deleterious, changes in climate; for example, changes in precipitation, storm patterns, and the level of the oceans. The word "enhanced" is usually omitted, but it should not be forgotten in discussions of the greenhouse effect.

Nearly 100 years after the Arrhenius prediction, we are now aware that carbon dioxide in the atmosphere is increasing, with the possibility that it will double by the middle of the next century from the levels at the time of Arrhenius. Post-World War II industrialization has caused a dramatic jump in the amount of carbon dioxide in the atmosphere. As the prospect of considerable change in the atmosphere becomes more real and threatening, new computer models are being applied to the problem. These models take into account the natural processes that must be part of the whole picture to understand what could happen to Earth's climate as carbon dioxide increases. An important aspect of the newer models is their treatment of the "amplifier" or feedback effect, in which further changes in the atmosphere occur in response to the warming initiated by the change in carbon dioxide.

In addition to moisture and cloud processes, the newer models are beginning to take into account the role of vegetation, forests, grasslands, and crops in controlling the amount of carbon dioxide that actually will be in the atmosphere. Along with their role as "sinks" for carbon dioxide, the various types of vegetation in the biosphere have further effects on climate. Plants heat or cool the air around them (through the reflection and absorption of solar radiation and the evaporation process), remove momentum from surface winds, and take up and release moisture into the air (thus contributing to alterations in the hydrologic cycle). In turn, changes in climate will affect the patterns of vegetation growth. For instance, forest stands that require relatively cool conditions may not be able to adjust to the relatively rapid warming that is being predicted for the interiors of continents. With slow warming, scientists expect that the northern edges of North American forests would creep slowly forward to more-favorable conditions, while the southern edges would give way to grasslands that are better suited to the warmer conditions. With overly rapid warming rates, however, the loss at the southern edge would be more extreme, and the migration at the northern edges would not be able to make up for the loss at the southern edge.

Other feedback effects at work also must be considered. In normal conditions, plant leaves take in carbon dioxide from the air and release moisture to the air as part of the photosynthesis process. The release of moisture through evapotranspiration causes the air to cool. With increasing atmospheric carbon dioxide, one can expect to see a change in plant carbon exchange rates and water relations. This may result in reduced evaporation rates, thus amplifying the summer continental warming. Without plants, the ground and air would become warmer, exacerbating the problem.

Greenhouse Gases

To predict climate change, one must model the climate. One test of the validity of predictions is the ability of the climate models to reproduce the climate as we see it today. Elements of the models such as the physics and chemistry of the processes that we know—or think we know—are essential to represent in the models. Therefore, the models have to embody the characteristics of the land and the oceans that serve as boundaries of the atmosphere represented in the models. Models also have to take into account the radiative characteristics of the gases that make up the atmosphere, including the key radiative gas, water vapor, that is so variable throughout the atmosphere.

Global records of surface temperature over the last 100 years show a rise in global temperatures (about 0.5° C overall), but the rise is marked by periods when the temperature has dropped as well. If the models cannot explain these marked variations from the trend, then we cannot be completely certain that we can believe in their predictions of changes to come. For example, in the early 1970's, because temperatures had been decreasing for about 25 to 30 years, people began predicting the approach of an ice age! For the last 15 to 20 years, we have been seeing a fairly steady rise in temperatures, giving some assurance that we are now in a global warming phase.

The major gases in the atmosphere, nitrogen and oxygen, are transparent to both the radiation incoming from the sun and the radiation outgoing from the Earth, so they have little or no effect on the greenhouse warming. The gases that are not transparent are water vapor, ozone, carbon dioxide, methane, nitrous oxide, and the chlorofluorocarbons (CFCs). These are the greenhouse gases.

There has been about a 25% increase in carbon dioxide in the atmosphere from 270 or 280 parts per million 250 years ago, to approximately 360 parts per million today (see Figure 1 in NASA Facts, **NF-223**, titled *Biosphere*). The record of carbon dioxide in the atmosphere shows a variation as seasons change. This variation is more pronounced in the northern hemisphere, with its greater land area, than in the southern hemisphere because of interactions in the atmosphere caused by vegetation. In the growing season, during daylight, vegetation takes in carbon dioxide; at night and in the senescent season, vegetation releases carbon dioxide (see Figures 2a & 2b in NASA Facts, **NF-223**, titled *Biosphere*). The effect is more pronounced in the northern hemisphere because most of the land on Earth is located there.

Modeling

To understand and predict climate change, the following types of models are needed:

- Socio-economic models that predict future fossil fuel consumption and utilization of alternative fuels. These models depend upon technology, e.g., industrial production methods, energy efficiency, new materials, etc.; public policy and social attitudes, e.g., concern for the environment; and economic development, standard of living and reliance on energy and chemical-based products.

- Chemical-physical-biophysical models of the Earth System that tell us what happens to gases released into the atmosphere, e.g., how much carbon dioxide is taken up by the oceans and the biosphere, and how industrial and agricultural uses of chemicals and natural processes on Earth's surface affect the release of methane, nitrogen oxides, and other greenhouse gases into the atmosphere.

- Coupled ocean-atmosphere models that tell us how the climate system, e.g., temperatures, humidity, clouds, and rainfall, responds to changes in the chemical composition of the atmosphere.

Getting reliable predictions from models is difficult because many of the secondary processes are not understood. For example, when temperatures start to warm because of the direct radiative effect of increasing carbon dioxide, will clouds increase or decrease? Will they let in less radiation from the sun, or more? These secondary processes are important.

The direct radiative effect of doubling carbon dioxide is relatively small, and there is not much disagreement on this point among models. Where models conflict is in regard to the secondary, or feedback effects. Models that predict a very large warming from carbon dioxide show cloud cover changes that greatly amplify the warming effects, while models that predict more-modest warming show that clouds have a small or even damping effect on the warming.

Can we match the observation of temperature trends with the model predictions? The temperature record of the past hundred years does show a warming trend, by approximately 0.5°C. However, the observed warming trend is not entirely consistent with the carbon dioxide change. Most of the temperature increase occurred before 1940, after which Earth started to cool until the early seventies, when warming resumed. Carbon dioxide, on the other hand, has been increasing steadily throughout the past century. Other factors that could have affected climate during this period include the possible change in the solar energy reaching Earth, the cooling effects of volcanic aerosols, and the possibility that sulfur dioxide and other pollutants might be affecting the amount of solar radiation that is reflected back to space. Some of these effects can cause a cooling that could counteract the warming due to carbon dioxide and other greenhouse gases. All of these effects would have to be taken into account and appropriately modeled in order to predict the changes that one might expect in the next century.

NASA Investigations of the Greenhouse Effect

Over the past 30 years, a number of satellite missions have been launched to obtain the data about Earth's radiation budget that are critical to understanding the greenhouse effect. Some of these missions are listed in the accompanying table.

Another very important aspect of greenhouse investigations has been the development of models. A number of climate models have been developed by NASA, and one of the most detailed is a General Circulation Model (GCM) developed by the Goddard Institute for Space Studies (GISS) in New York City. A GCM uses extremely high-speed computers to solve the basic equations governing atmospheric motions and processes by numerical techniques. The GISS group, using its model, predicted that the annual global temperature would reach a new record high sometime during the first three years of the 1990's. Indeed, that record was reached in 1990. However, in June 1991, the Mount Pinatubo volcano erupted and sent 25 to 30 million tons of sulfur dioxide into the stratosphere. There, the sulfur dioxide reacted with water vapor to produce a long-lasting haze of sulfuric acid droplets.

The GISS group then inserted the new information into the model, estimated how much sunlight the Pinatubo aerosol cloud would block, and predicted that the global temperature would drop about 0.3°C. Again, the predicted change actually occurred. These successful climate predictions have been encouraging, and scientists are continuing their research to further increase the credibility of their model predictions.

An important need in the further development and verification of climate models is the acquisition, assembly, and analysis of reliable climate data. The highly-accurate, self-consistent, and long-term data sets that will be acquired by the Earth Observing System (EOS), as part of NASA's Mission to Planet Earth, with a series of satellite launches beginning in 1998, are designed to fulfill that need.

Earth Science Enterprise

Selected Missions Leading to an Improved Understanding of the Greenhouse Effect

Mission	Launch	Scientific Objective
Explorer-7	1959	First satellite radiation budget experiment (spinning black and white hemispheres)
Nimbus-2, -3	1966, 1969	Global radiation budget measurements from the Medium Resolution Infrared Radiometer
Earth Radiation Budget Experiment (ERBE)/Earth Radiation Budget Satellite (ERBS) NOAA-9 NOAA-10	1984 1984 1986	Coordinated radiation budget measurements from the Earth Radiation Budget Experiment sensors in three different orbits
Tropical Rainfall Measuring Mission (TRMM)	1997	Radiation budget data from the Clouds and Earth's Radiant Energy System (CERES) experiments. This mission will complement CERES experiments on EOS satellites
Earth Observing System (EOS)	1998-	Radiation budget data from CERES to complement experiments on TRMM. A broad spectrum of physical and chemical measurements of atmosphere, ocean, and land characteristics from different EOS missions