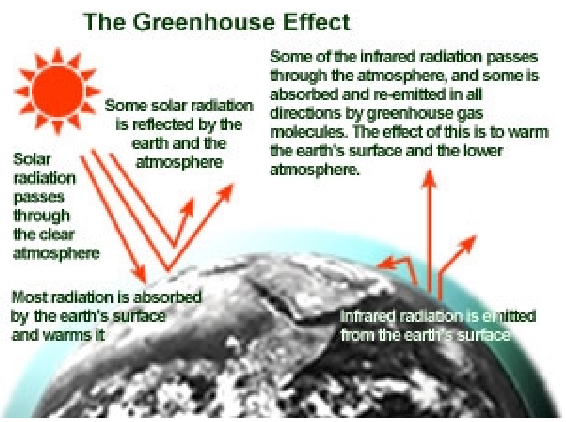
EPA – Global Warming

http://yosemite.epa.gov/oar/globalwarming.nsf/content/climate.html

Climate

An Introduction

According to the National Academy of Sciences, the Earth's surface temperature has risen by about 1 degree Fahrenheit in the past century, with accelerated warming during the past two decades. There is new and stronger evidence that most of the warming over the last 50 years is attributable to human activities. Human activities have altered the chemical composition of the atmosphere through the buildup of greenhouse gases – primarily carbon dioxide, methane, and nitrous oxide. The heat-trapping property of these gases is undisputed although uncertainties exist about exactly how earth's climate responds to them. Go to the Emissions section for much more on greenhouse gases.



Our Changing Atmosphere

Energy from the sun drives the earth's weather and climate, and heats the earth's surface; in turn, the earth radiates energy back into space. Atmospheric greenhouse gases (water vapor, carbon dioxide, and other gases) trap some of the outgoing energy, retaining heat somewhat like the glass panels of a greenhouse.

Without this natural "greenhouse effect," temperatures would be much lower than they are now, and life as known today would not be possible. Instead, thanks to greenhouse gases, the earth's average temperature is a more hospitable 60°F. However, problems may arise when the atmospheric concentration of greenhouse gases increases.

Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15%. These increases have enhanced the heat-trapping capability of the earth's atmosphere. Sulfate aerosols, a common air pollutant, cool the atmosphere by reflecting light back into space; however, sulfates are short-lived in the atmosphere and vary regionally.

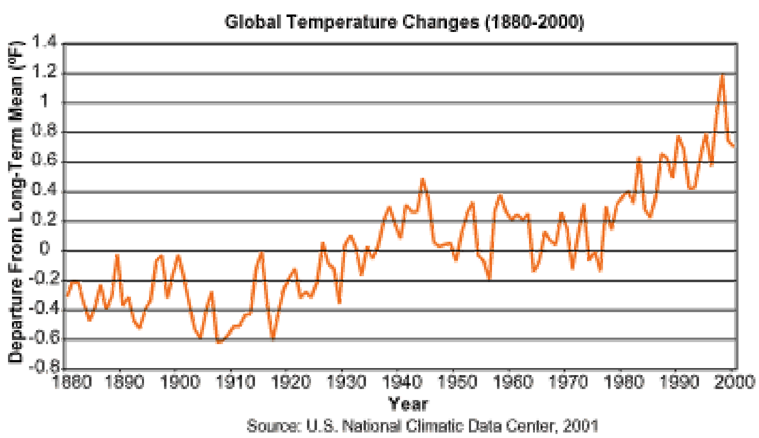
Why are greenhouse gas concentrations increasing? Scientists generally believe that the combustion of fossil fuels and other human activities are the primary reason for the increased concentration of carbon dioxide. Plant respiration and the decomposition of organic matter release more than 10 times the CO2 released by human activities; but these releases have generally been in balance during the centuries leading up to the industrial revolution with carbon dioxide absorbed by terrestrial vegetation and the oceans.

What has changed in the last few hundred years is the additional release of carbon dioxide by human activities. Fossil fuels burned to run cars and trucks, heat homes and businesses, and power factories are responsible for about 98% of U.S. carbon dioxide emissions, 24% of methane emissions, and 18% of nitrous oxide emissions. Increased agriculture, deforestation, landfills, industrial production, and mining also contribute a significant share of emissions. In 1997, the United States emitted about one-fifth of total global greenhouse gases.

Estimating future emissions is difficult, because it depends on demographic, economic, technological, policy, and institutional developments. Several emissions scenarios have been developed based on differing projections of these underlying factors. For example, by 2100, in the absence of emissions control policies, carbon dioxide concentrations are projected to be 30-150% higher than today's levels.

Changing Climate

Global mean surface temperatures have increased 0.5-1.0°F since the late 19th century. The 20th century's 10 warmest years all occurred in the last 15 years of the century. Of these, 1998 was the warmest year on record. The snow cover in the Northern Hemisphere and floating ice in the Arctic Ocean have decreased. Globally, sea level has risen 4-8 inches over the past century. Worldwide precipitation over land has increased by about one percent. The frequency of extreme rainfall events has increased throughout much of the United States.



Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change. Scientists expect that the average global surface temperature could rise 1-4.5°F (0.6-2.5°C) in the next fifty years, and 2.2-10°F (1.4-5.8°C) in the next century, with significant regional variation. Evaporation will increase as the climate warms, which will increase average global precipitation. Soil moisture is likely to decline in many regions, and intense rainstorms are likely to become more frequent. Sea level is likely to rise two feet along most of the U.S. coast.

Calculations of climate change for specific areas are much less reliable than global ones, and it is unclear whether regional climate will become more variable.

Trends

Data on a wide variety of environmental indicators are consistent with the consequences that scientists generally expect to result from increasing concentrations of greenhouse gases.

Temperature
Global temperatures are rising. Observations collected over the last century suggest that the average land surface temperature has risen 0.45-0.6°C (0.8-1.0°F) in the last century.

Precipitation
Precipitation has increased by about 1 percent over the world's continents in the last century. High latitude areas are tending to see more significant increases in rainfall, while precipitation has actually declined in many tropical areas.

Sea Level
Sea level has risen worldwide approximately 15-20 cm (6-8 inches) in the last century. Approximately 2-5 cm (1-2 inches) of the rise has resulted from the melting of mountain glaciers. Another 2-7 cm has resulted from the expansion of ocean water that resulted from warmer ocean temperatures

What Are Greenhouse Gases?

Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occuring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Certain human activities, however, add to the levels of most of these naturally occurring gases:

Carbon dioxide is released to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned.

Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from the decomposition of organic wastes in municipal solid waste landfills, and the raising of livestock.

Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of solid waste and fossil fuels.

Very powerful greenhouse gases that are not naturally occurring include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), which are generated in a variety of industrial processes.

Each greenhouse gas differs in its ability to absorb heat in the atmosphere. HFCs and PFCs are the most heat-absorbent. Methane traps over 21 times more heat per molecule than carbon dioxide, and nitrous oxide absorbs 270 times more heat per molecule than carbon dioxide. Often, estimates of greenhouse gas emissions are presented in units of millions of metric tons of carbon equivalents (MMTCE), which weights each gas by its GWP value, or Global Warming Potential.

For more on greenhouse gases and global warming potential, see:
Greenhouse Gases and Global Warming Potential Values, Excerpt from the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000 (82k pdf) U.S. Environmental Protection Agency, Office of Atmospheric Programs, April 2002.

This excerpt describes the characteristics of each of the various greenhouse gases and discusses the concept of Global Warming Potential (GWP) values. Both direct and indirect greenhouse gases are addressed. A detailed comparison of GWP values from the IPCC's Second Assessment Report (SAR) and Third Assessment Report (TAR) is also made, including the effect of a change in GWP values on U.S. greenhouse gas emission trends. Overall, revisions to GWP values do not have a significant effect on U.S. emission trends.

What Are Emissions Inventories?

An emission inventory is an accounting of the amount of air pollutants discharged into the atmosphere. It is generally
characterized by the following factors:

- the chemical or physical identity of the pollutants included,
- the geographic area covered,
- the institutional entities covered,
- the time period over which emissions are estimated, and
- the types of activities that cause emissions.

Emission inventories are developed for a variety of purposes. Inventories of natural and anthropogenic emissions are used by scientists as inputs to air quality models, by policy makers to develop strategies and policies or track progress of standards, and by facilities and regulatory agencies to establish compliance records with allowable emission rates. A well constructed inventory should include enough documentation and other data to allow readers to understand the underlying assumptions and to reconstruct the calculations for each of the estimates included. For an overview of the U.S. Greenhouse Gas Inventory, see the following brochure: In Brief -- The U.S. Greenhouse Gas Inventory (2.2 MB pdf)

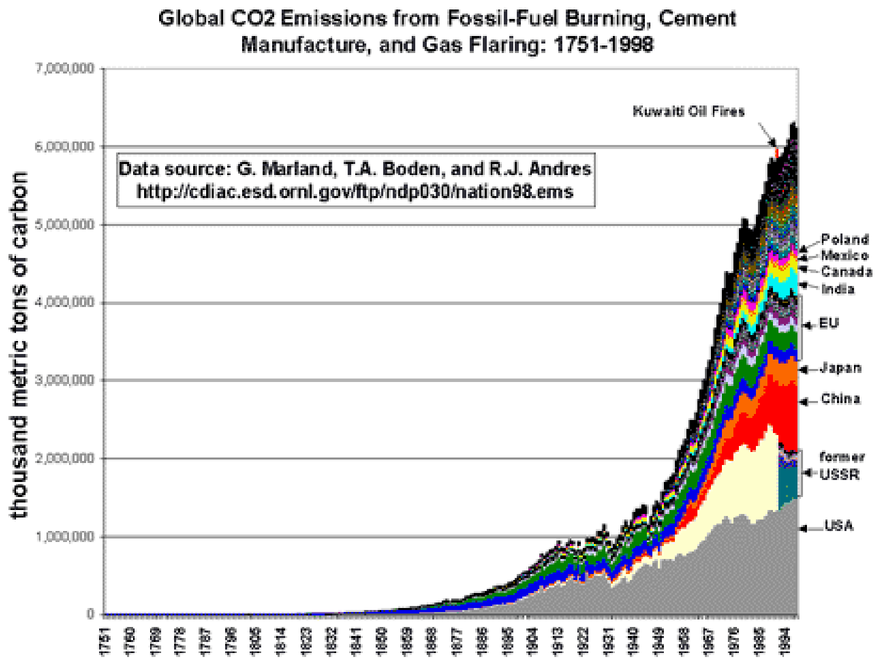
What Are Sinks?

A sink is a reservoir that uptakes a chemical element or compound from another part of its cycle. For example, soil and trees tend to act as natural sinks for carbon – each year hundreds of billions of tons of carbon in the form of CO2 are absorbed by oceans, soils, and trees.

International

Greenhouse gases are global in their effect upon the atmosphere. The primary greenhouse gases, unlike many local air pollutants like carbon monoxide, oxides of nitrogen, and volatile organic compounds, are considered stock pollutants. A stock air pollutant is one that has a long lifetime in the atmosphere, and therefore can accumulate over time. Stock air pollutants are also generally well mixed in the atmosphere. As a consequence of this mixing, the impact a greenhouse gas has on the atmosphere is mostly independent of where it was emitted. These characteristics of greenhouse gases imply that they should be addressed on a global (i.e., international) scale.

Anthropogenic emissions of greenhouse gases occur in every country of the world. These emissions result from many of the industrial, transportation, agricultural, and other activities that take place in each country. Countries that are signatories to the United Nations Framework Convention on Climate Change (UNFCCC) are committed to reporting their anthropogenic emissions of greenhouse gases to the Secretariat of the convention.



References for the International Emissions Section

UN Framework Convention on Climate Change, FCCC/CP/1998/INF.9 (1998), Table 1, Aggregate emissions of greenhouse gases (CO2 equivalent), 1990-1996, excluding land-use change and forestry.

Inventory of U.S.Greenhouse Gas Emissions and Sinks: 1990 – 1998 (April 2001) USEPA #236-R-01-001.

CO2 Emissions From Fuel Combustion, 1971-1998 (2000), International Energy Agency, OECD/IEA.

Recommended Links

Annual Energy Outlook EXIT disclaimer **The Annual Energy Outlook from the U.S. Department of Energy presents energy projections for the US through 2020 along with electricity, transportation, and carbon emissions projections.**

Carbon Dioxide Information Analysis Center (CDIAC) EXIT disclaimer **CDIAC provides the scientific and policy communities with greenhouse gas emission data for both regions and individual countries. CDIAC's emissions data have become standard reference materials.**

Center for International Earth Science Information Network (CIESIN) EXIT disclaimer **CIESIN provides data for the serious researcher in the scientific and policy fields related to global change studies. This site contains Greenhouse gas emissions projections up to**

the year 2100 using various economic models.

[International Energy Outlook] EXIT disclaimer **The U.S. Department of Energy's International Energy Outlook presents international energy projections through the year 2020, along with electricity, transportation, and carbon emission projections.**

[IPCC/OECD/IEA Programme on National Greenhouse Gas Inventories] EXIT disclaimer **Since 1991, the guidelines for developing national greenhouse gas emission inventories have been maintained by the Scientific Assessment Working Group (WGI) of the IPCC, in close collaboration with the OECD and the IEA under the IPCC/OECD/IEA Programme on National Greenhouse Gas Inventories. This site contains updates on current work, full downloadable versions of the GHG inventory guidelines, and other important information related to the internationally-agreed methodologies for calculation and reporting of national emissions of GHGs.**

[United National Framework Convention on Climate Change (UNFCCC)] EXIT disclaimer **The UNFCCC site provides greenhouse gas emissions data for countries that are a member to the convention and who have completed and reported these emissions to the Secretariat of the convention.**

Sun's Output Increasing in Possible Trend Fueling Global Warming

http://www.space.com/scienceastronomy/sun_output_030320.html

By Robert Roy Britt
Senior Science Writer
posted: 02:30 pm ET
20 March 2003

In what could be the simplest explanation for one component of global warming, a new study shows the Sun's radiation has increased by .05 percent per decade since the late 1970s.

The increase would only be significant to Earth's climate if it has been going on for a century or more, said study leader Richard Willson, a Columbia University researcher also affiliated with NASA's Goddard Institute for Space Studies.

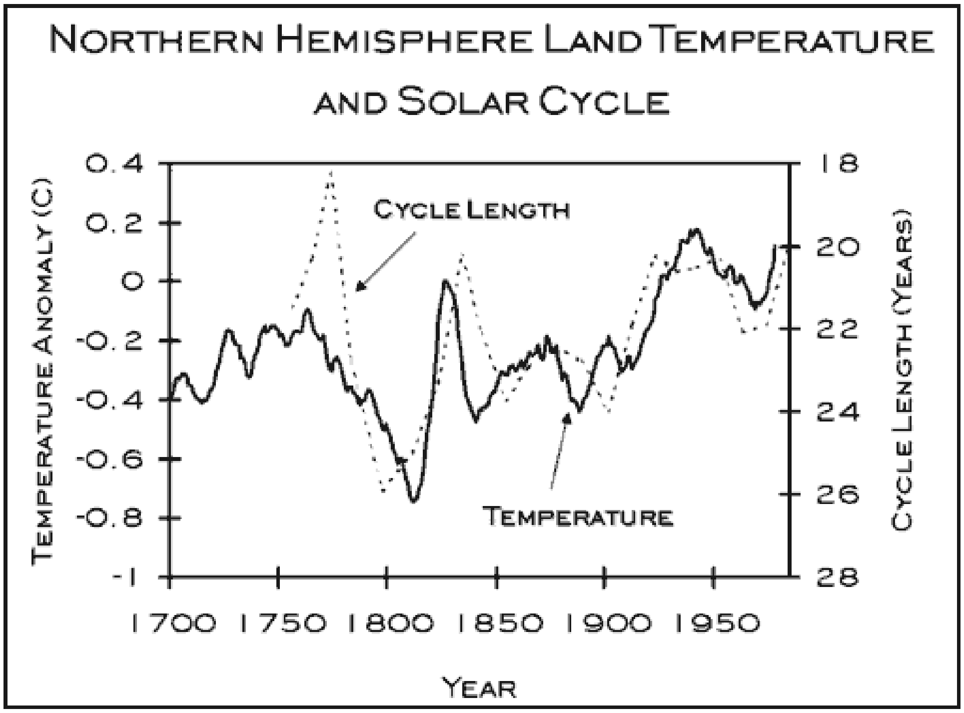
The Sun's increasing output has only been monitored with precision since satellite technology allowed necessary observations. Willson is not sure if the trend extends further back in time, but other studies suggest it does.

Changing Sun

In 1996, near the last solar minimum, the Sun is nearly featureless. By 1999, approaching maximum, it is dotted by sunspots and fiery hot gas trapped in magnetic loops.

SOURCE: ESA/NASA/SOHO/US Naval Research Laboratory

[Sun Cams: See the Sun Now]



SOURCE: S. Baliunas and W. Soon / Astrophysical Journal

The recent trend of a .05 percent per decade increase in Total Solar Irradiance (TSI) in watts per meter squared, or the amount of solar energy that falls upon a square meter outside the Earth's atmosphere. The trend was measured between successive solar minima that occur approximately every 11 years. At the bottom, the timeline of the many different datasets that contributed to this finding, from 1978 to present.

"This trend is important because, if sustained over many decades, it could cause significant climate change," Willson said.

In a NASA-funded study recently published in Geophysical Research Letters, Willson and his colleagues speculate on the possible history of the trend based on data collected in the pre-satellite era.

"Solar activity has apparently been going upward for a century or more," Willson told SPACE.com today.

Significant component

Further satellite observations may eventually show the trend to be short-term. But if the change has indeed persisted at the present rate through the 20th Century, "it would have provided a significant component of the global warming the Intergovernmental Panel on Climate Change reports to have occurred over the past 100 years," he said.

That does not mean industrial pollution has not been a significant factor, Willson cautioned.

Scientists, industry leaders and environmentalists have argued for years whether humans have contributed to global warming, and to what extent. The average surface temperature around the globe has risen by about 1 degree Fahrenheit since 1880. Some scientists say the increase could be part of natural climate cycles. Others argue that greenhouse gases produced by automobiles and industry are largely to blame.

Willson said the Sun's possible influence has been largely ignored because it is so difficult to quantify over long periods.

Confounding efforts to determine the Sun's role is the fact that its energy output waxes and wanes every 11 years. This solar cycle, as it is called, reached maximum in the middle of 2000 and achieved a second peak in 2002. It is now ramping down toward a solar minimum that will arrive in about three years.

Changes in the solar cycle -- and solar output -- are known to cause short-term climate change on Earth. At solar max, Earth's thin upper atmosphere can see a doubling of temperature. It swells, and denser air can puff up to the region of space where the International Space Station orbits, causing increased drag on the ship and forcing more frequent boosts from space shuttles.

Changing Sun
In 1996, near the last solar minimum, the Sun is nearly featureless. By 1999, approaching maximum, it is dotted by sunspots and fiery hot gas trapped in magnetic loops.
SOURCE: ESA/NASA/SOHO/US Naval Research Laboratory

Sun Cams: See the Sun Now

Long-term: A previous study showed that changes in the Sun's output appear to be related to temperatures on Earth, based on studies of tree rings, sunspots and other data. Solar max has also been tied to a 2 percent increase in clouds over much of the United States.

It might seem logical to assume tie climate to solar output, but firm connections are few. Other studies looking further back in time have suggested a connection between longer variations in solar activity and temperatures on Earth.

Examinations of ancient tree rings and other data show temperatures declined starting in the 13th Century, bottomed out at 2 degrees below the long-term average during the 17th Century, and did not climb back to previous levels until the late 19th Century. Separate records of sunspots, auroral activity (the Northern Lights) and terrestrial deposits of certain substances generated in atmospheric reactions triggered by solar output, suggest the Sun was persistently active prior to the onset of this Little Ice Age, as scientists call the event.

Solar activity was lowest during the 17th Century, when Earth was most frigid.

Large-scale ocean and climate variations on Earth can also mask long-term trends and can make it difficult to sort out what is normal, what is unusual, and which effects might or might not result from shifts in solar radiation.

To get above all this, scientists rely on measurements of total solar energy, at all wavelengths, outside Earth's atmosphere. The figure they derive is called Total Solar Irradiance (TSI).

Heating up

The new study shows that the TSI has increased by about 0.1 percent over 24 years. That is not enough to cause notable climate change, Willson and his colleagues say, unless the rate of change were maintained for a century or more.

On time scales as short as several days, the TSI can vary by 0.2 percent due to the number and size of sunspots crossing the face of the Sun. That shift, said to be insignificant to weather, is however equal to the total amount of energy used by humans, globally, for a year, the researchers estimate.

The study analyzed data from six satellites orbiting Earth at different times over the 24 years. Willson ferreted out errors in one of the datasets that had prevented previous studies from discovering the trend.

A separate recent study of Sun-induced magnetic activity near Earth, going back to 1868, provides compelling evidence that the Sun's current increase in output goes back more than a century, Willson said.

He said firm conclusions about whether the present changes involve a long-term trend or a relatively brief aberration should come with continued monitoring into the next solar minimum, expected around 2006.

- **New Photos of Sun are Most Detailed Ever**
- **Space Weather Forecast**
- **Mysteries of the Sun**
- **More Sun News**
- **Sun Cams**

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- Columbia Investigation Board: Even Without STS-107 Disaster, Shuttle Safety Issues a Concern
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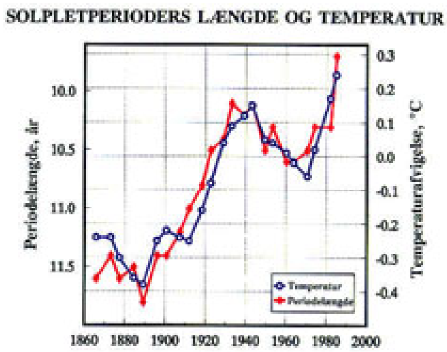
- Primeval Planet: Oldest Known World Conjures Prospect of Ancient Life

Global Warming
Does it Exist?
If so, is it Man- or Sun-made?

http://solar-center.stanford.edu/sun-on-earth/varsun.html

Graph of solar activity versus climate
From Friis-Christensen, E., and K. Lassen, "Length of the solar cycle: An indicator of solar activity closely associated with climate," Science, 254, 698-700, 1991.



Global warming -- the gradual increase in planet-wide temperatures -- seems to be accepted by many scientists and people now as fact. Generally, this warming is attributed to the increase of green-house gases in the Earth's upper atmosphere.

However, some solar scientists are considering whether the warming exists at all. And, if it does, might it be caused, wholely or in part, by a periodic but small increase in the Sun's energy output. An increase of just 0.2% in the solar output could have the same affect as doubling the carbon dioxide in the Earth's atmosphere.

What is the Problem?
What is the evidence for global warming? Certainly, there are considerably more green-house gases (e.g. carbon dioxide) in our atmosphere than in previous times. And there appears to be some evidence that global temperatures are rising. But, how accurate and correct are our global warming statistics? And, do we really know what role, if any, the Sun might play in any global warming patterns?
These issues are currently being debated, and may significantly affect you for the rest of your life. Would you like to do some research to find out more about global warming?

We suggest here some research topics and places to begin looking for information. But these are all controversial issues, and there are no definitive answers (yet). As an informed, and voting, citizen of the next millenium, you will need to keep listening, looking, and being alert to new research and evidence.

The following are key questions in your research on global warming:

What is global warming?
What is the evidence that global warming exists? How reliable and accurate is this evidence?
What are the projected effects of global warming?
What is the evidence that global warming might be caused by greenhouse gases?
What is the evidence that global climate change might be affected by solar variation?
What can or should be done about global warming, if it exists and is caused by pollutants and emissions? (Even if global warming does not exist, are there other reasons for lessening the emission of pollutants into our atmosphere?)
What can or should be done if there is global climate change being caused by solar variability?

Where Do I Start?

For information on global warming in general and student activities and research topics in particular, visit:

- **The NY Times -- Global Warming Issue, 1 December 1997** .
- **The NY Times -- Resources on Global Warming** . A collection of web sites and books related to global warming.
- **Douglas V. Hoyt (Sun-Earth Researcher)** . A collection of web sites related to global warming.
- **The Global Warming Project**. A good collection of student activities to research and examine global warming issues.
- **Issue Brief on Global Warming** An overview of global warming, prepared by the Natural Resources Defense Council.
- **Web-based student activities**. Designed to help students investigate global warming using web-based resources.

Now, to research whether or not global warming actually exists, and the affect the Sun may or may not be having on it, check out these:

- **Greenhouse Warming: Fact, Hypothesis, or Myth?**. Douglas Hoyt, a Senior Scientist with Hughes/STX, analyzes the various data on long-term global temperatures, as well as the proposed causes and effects of global warming, and concludes that "there is no evidence of a long-term warming of climate over the last 170 years". See also Hoyt's and Ken Schatten's 1997 book The Role of the Sun in Climate Change.

- A brief description of the Friis-Christensen/Lassen **graph** above.
- A BBC news report **"Scientists Blame Sun for Global Warming"**
- **University of Arizona Press Release** detailing a study which found that only 40% of global warming could possibily be attributed to solar variation.
  - **Dialogue about the Variable Sun**. A (non-scientific) discussion taken from a Usenet newsgroup about data suggesting that solar variability affects global climates. Are the arguments based on fact? Are the participants fully aware of current research?

For Teachers

Global Warming

http://www.ncpa.org/hotlines/global/pd020801g.html

Global Temperatures, Solar Activity And Cosmic Radiation Greenhouse gases are responsible for less than half the rise in global temperatures over the past century, a scientist with the European Space Agency says. Physicist Paal Brekke says natural processes involving changes in the Sun could have at least as powerful an effect on global temperature as increased emissions of carbon dioxide (CO_2).

Climate scientists have already looked at changes related to sunspot activity -- the 11-year cycle of flares on the Sun's surface -- and long-term changes in the Sun's brightness, which has a cycle that lasts for centuries. They have discounted the effect of both on the temperature increase over the last century because those cycles either happen over too short a timescale, or have too weak an effect.

But so far they have omitted to take two other factors into account:

Changes in the amount of ultraviolet radiation from the Sun do indeed affect the ozone layer.

The Sun's magnetic field and solar wind -- streams of electrons and protons from the Sun -- protects the entire Solar System by partially shielding it from cosmic rays (very energetic particles and radiation from outer space).

This shield does not stop all the cosmic rays, and its effectiveness varies with long-term changes in the Sun's activity, which can rise and fall on a timescale of centuries.

Satellite data show the amount of low clouds over the Earth closely follows the amount of cosmic rays reaching the Earth. The cloud cover, in turn, affects the amount of sunlight reaching the Earth's surface. Global warming due to this effect over the last century could be comparable to the amount of warming due to the greenhouse effect.

Source: Paal Brekke, "The Sun and Climate Change," BBC News Online: In Depth: Climate Change, November 16, 2000.

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For text http://news.bbc.co.uk/hi/english/in_depth/sci_tech/2000/climate_change/newsid_1026000/1026375.stm

For more on Global Warming http://www.ncpa.org/hotlines/global/gwhot.html

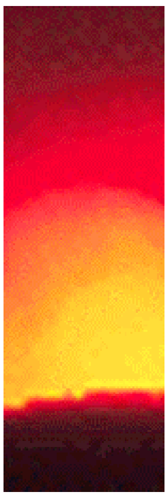
http://www.ictp.trieste.it/~pwc/index.html

NCDC / Climate Resources / Climate Research / Global Warming / Search / Help

National Oceanic and Atmospheric Administration

Global Warming

Frequently Asked Questions



- **Introduction**
- **What is the greenhouse effect, and is it affecting our climate?**
- **Are greenhouse gases increasing?**
- **Is the climate warming?**
- **Are El Niños related to Global Warming?**
- **Is the hydrological cycle (evaporation and precipitation) changing?**
- **Is the atmospheric/oceanic circulation changing?**
- **Is the climate becoming more variable or extreme?**
- **How important are these changes in a longer-term context?**
- **Is sea level rising?**
- **Can the observed changes be explained by natural variability?**
- **What about the future?**
- **Additional Information**

All figures linked from this page with the exception of global surface temperatures are from the IPCC 2001 report 'Climate Change 2001: The Scientific Basis'.

Introduction

This page is based on a brief synopsis of the 2001 report by the Intergovernmental Panel on Climate Change, and the National Research Council's 2001 report Climate Change Science: An Analysis of Some Key Questions, as well as NCDC's own data resources. It was prepared by David Easterling and Tom Karl, National Climatic Data Center, Asheville, N.C. 28801.

One of the most hotly debated topics on Earth is the issue of climate change, and the National Environmental Satellite, Data, and Information Service (NESDIS) data centers are central to answering some of the most pressing global change questions that remain unresolved. The National Climatic Data Center contains the instrumental records that can precisely define the nature of climatic fluctuations at time scales of a up to a century. Among the diverse kinds of data platforms whose data contribute to NCDC's armamentarium are: Ships, buoys, weather stations, balloons, satellites, and aircraft. The National Oceanographic Data Center contains the subsurface data which reveal the ways that heat is distributed and redistributed over the planet. Knowing how these systems are changing and how they have changed in the past is crucial to understanding how they will change in the future. And, for climate information that extends from hundreds to thousands of years, the paleoclimatology program, also at the National Climatic Data Center, helps to provide longer term perspectives.

Internationally, the Intergovernmental Panel on Climate Change (IPCC), under the auspices of the United Nations (UN), World Meteorological Organization (WMO), and the United Nations Environment Program (UNEP), is the most senior and authoritative body providing scientific advice to global policy makers. The IPCC met in full session in 1990, 1995 and in 2001. They address issues such as the buildup of greenhouse gases, evidence, attribution, and prediction of climate change, impacts of climate change, and policy options.

Listed below are a number of questions commonly addressed to climate scientists, and brief replies (based on IPCC reports and other research) in common, understandable language. This list will be periodically updated, as new scientific evidence comes to light.

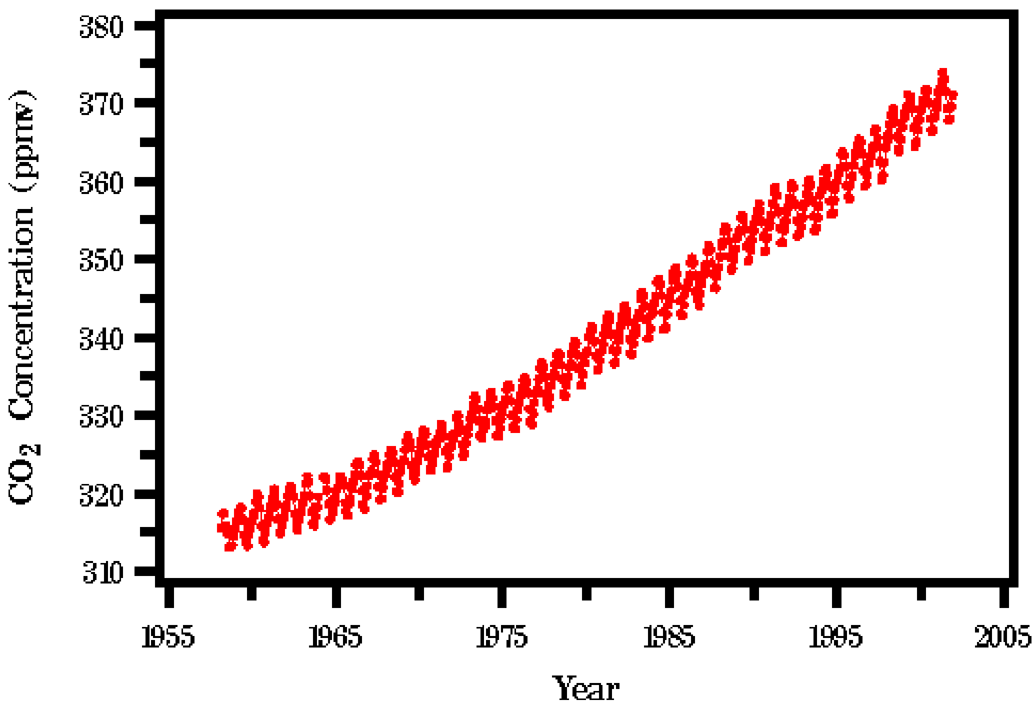
What is the greenhouse effect, and is it affecting our climate?

The greenhouse effect is unquestionably real and helps to regulate the temperature of our planet. It is essential for life on Earth and is one of Earth's natural processes. It is the result of heat absorption by certain gases in the atmosphere (called greenhouse gases because they effectively 'trap' heat in the lower atmosphere) and re-radiation downward of some of that heat. Water vapor is the most abundant greenhouse gas, followed by carbon dioxide and other trace gases. Without a natural greenhouse effect, the temperature of the Earth would be about zero degrees F (-18°C) instead of its present 57°F (14°C). So, the concern is not with the fact that we have a greenhouse effect, but whether human activities are leading to an *enhancement* of the greenhouse effect.

Are greenhouse gases increasing?

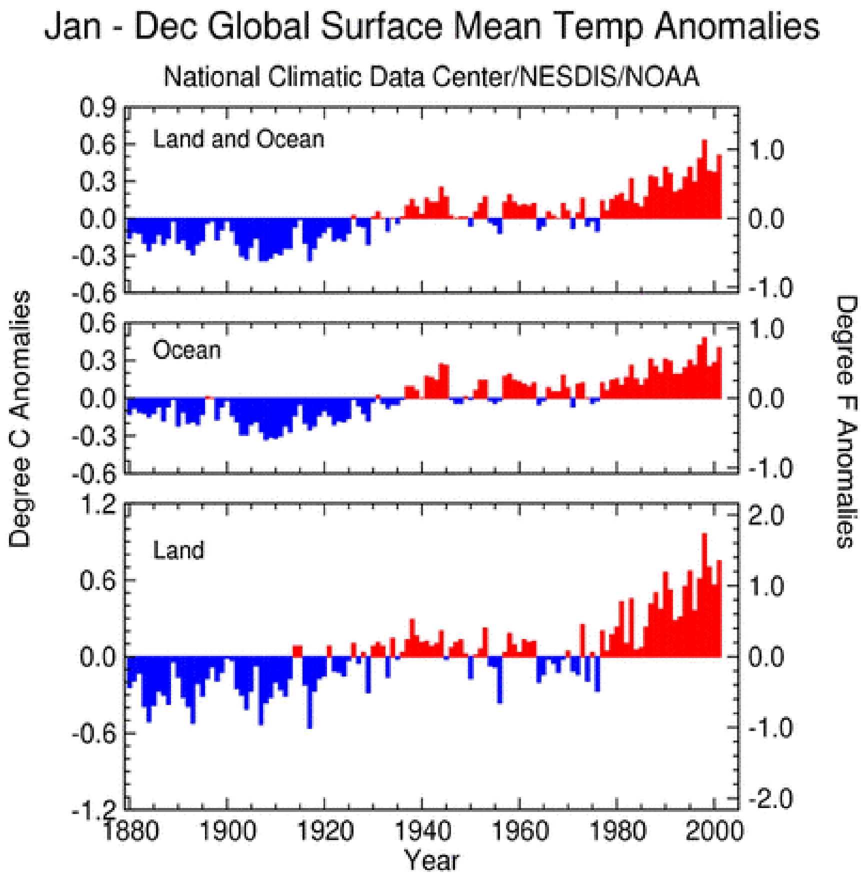
Human activity has been increasing the concentration of greenhouse gases in the atmosphere (mostly carbon dioxide from combustion of coal, oil, and gas; plus a few other trace gases). There is no scientific debate on this point. Pre-industrial levels of carbon dioxide (prior to the start of the Industrial Revolution) were about 280 parts per million by volume (ppmv), and current levels are about 370 ppmv. The concentration of CO_2 in our atmosphere today, has not been exceeded in the last 420,000 years, and likely not in the last 20 million years. According to the IPCC Special Report on Emission Scenarios (SRES), by the end of the 21st century, we could expect to see carbon dioxide concentrations of anywhere from 490 to 1260 ppm (75-350% above the pre-industrial concentration).

Carbon dioxide concentration as measured at Mauna Loa, Hawaii. These measurements represent the globally mixed concentration.



Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography)

Is the climate warming?



This graph shows annual mean global temperature anomalies over the period 1880-2001. The zero line represents the long term mean temperature from 1880-2001, and the red and blue bars are showing annual departures from that mean. As is evident in the graph, 2001 was second only to 1998 in terms of global temperature, and the trend has been toward increasing temperatures at least since the beginning of the 20th century. Land temperatures have greater anomalies than the ocean, which is to be expected since land heats up and cools down faster than water.

Yes. Global surface temperatures have increased about 0.6°C (plus or minus 0.2°C) since the late-19th century, and about 0.4°F (0.2 to 0.3°C) over the past 25 years (the period with the most credible data). The warming has not been globally uniform. Some areas (including parts of the southeastern U.S.) have, in fact, cooled over the last century. The recent warmth has been greatest over North America and Eurasia between 40 and 70°N. Warming, assisted by the record El Niño of 1997-1998, has continued right up to the present, with 2001 being the second warmest year on record after 1998.

Linear trends can vary greatly depending on the period over which they are computed. Temperature trends in the lower troposphere (between about 2,500 and 26,000 ft.) from 1979 to the present, the period for which Satellite Microwave Sounding Unit data exist, are small and may be unrepresentative of longer term trends and trends closer to the surface. Furthermore, there are small unresolved differences between radiosonde and satellite observations of tropospheric temperatures, though both data sources show slight warming trends. If one calculates trends beginning with the commencement of radiosonde data in the 1950s, there is a slight greater warming in the record due to increases in the 1970s. There are statistical and physical reasons (e.g., short record lengths, the transient differential effects of volcanic activity and El Niño, and boundary layer effects) for expecting differences between recent trends in surface and lower tropospheric temperatures, but the exact causes for the differences are still under investigation (see National Research Council report "Reconciling Observations of Global Temperature Change").

An enhanced greenhouse effect is expected to cause cooling in higher parts of the atmosphere because the increased "blanketing" effect in the lower atmosphere holds in more heat, allowing less to reach the upper atmosphere. Cooling of the lower stratosphere (about 49,000-79,500ft.) since 1979 is shown by both satellite Microwave Sounding Unit and radiosonde data, but is larger in the radiosonde data.

Relatively cool surface and tropospheric temperatures, and a relatively warmer lower stratosphere, were observed in 1992 and 1993, following the 1991 eruption of Mt. Pinatubo. The warming reappeared in 1994. A dramatic global warming, at least partly associated with the record El Niño, took place in 1998. This warming episode is reflected from the surface to the top of the troposphere.

There has been a general, but not global, tendency toward reduced diurnal temperature range (DTR), (the difference between high and low daily temperatures) over about 50% of the global land mass since the middle of the 20th century. Cloud cover has increased in many of the areas with reduced diurnal temperature range. The overall positive trend for maximum daily temperature over the period of study (1950-93) is 0.1°C/decade, whereas the trend for daily minimum temperatures is 0.2°C/decade. This results in a negative trend in the DTR of -0.1°C/decade

Indirect indicators of warming such as borehole temperatures, snow cover, and glacier recession data, are in substantial agreement with the more direct indicators of recent warmth. Evidence such as changes in glacier length is useful since it not only provides qualitative support for existing meteorological data, but glaciers often exist in places too remote to support meteorological stations, the records of glacial advance and retreat often extend back further than weather station records, and glaciers are usually at much higher alititudes that weather stations allowing us more insight into temperature changes higher in the atmosphere.

Large-scale measurements of sea-ice have only been possible since the satellite era, but through looking at a number of different satellite estimates, it has been determined that Arctic sea ice has decreased between 1973 and 1996 at a rate of -2.8 +/- 0.3%/decade. Although this seems to correspond to a general increase in temperature over the same period, there are lots of quasi-cyclic atmospheric dynamics (for example the Arctic Oscillation) which may also influence the extent and thickness of sea-ice in the Arctic. Sea-ice in the Antarctic has shown very little trend over the same period, or even a slight increase since 1979. Though extending the Antarctic sea-ice record back in time is more difficult due to the lack of direct observations in this part of the world.

Are El Niños related to Global Warming?

El Niños are not caused by global warming. Clear evidence exists from a variety of sources (including archaeological studies) that El Niños have been present for hundreds, and some indicators suggest maybe millions, of years. However, it has been hypothesized that warmer global sea surface temperatures can enhance the El Niño phenomenon, and it is also true that El Niños have been more frequent and intense in recent decades. Recent climate model results that simulate the 21st century with increased greenhouse gases suggest that El Niño-like sea surface temperature patterns in the tropical Pacific are likely to be more persistent.

Is the hydrological cycle (evaporation and precipitation) changing?

Overall, land precipitation for the globe has increased by ~2% since 1900, however, precipitation changes have been spatially variable over the last century. Instrumental records show that there has been a general increase in precipitation of about 0.5-1.0%/decade over land in northern mid-high latitudes, except in parts of eastern Russia. However, a decrease of about -0.3%/decade in precipitation has occurred during the 20th century over land in sub-tropical latitudes, though this trend has weakened in recent decades. Due to the difficulty in measuring precipitation, it has been important to constrain these observations by analyzing other related variables. The measured changes in precipitation are consistent with observed changes in streamflow, lake levels, and soil moisture (where data are available and have been analyzed).

Northern Hemisphere annual snow cover extent has consistently remained below average since 1987, and has decreased by about 10% since 1966. This is mostly due to a decrease in spring and summer snowfall over both the Eurasian and North American continents since the mid-1980s. However, winter and autumn snow cover extent has shown no significant trend for the northern hemisphere over the same period.

Improved satellite data shows that a general trend of increasing cloud amount over both land and ocean since the early 1980s, seems to have reversed in the early 1990s, and total cloud amount of land and ocean now appears to be decreasing. However, there are several studies that suggest regional cloudiness, perhaps especially in the thick precipitating clouds has increased over the 20th century.

Is the atmospheric/oceanic circulation changing?

A rather abrupt change in the El Niño - Southern Oscillation behavior occurred around 1976/77 and the new regime has persisted. There have been relatively more frequent and presistent El Niño episodes rather than the cool La Niñas. This behavior is highly unusual in the last 120 years (the period of instrumental record). Changes in precipitation over the tropical Pacific are related to this change in the El Niño - Southern Oscillation, which has also affected the pattern and magnitude of surface temperatures. However, it is unclear as to whether this apparent change in the ENSO cycle is caused by global warming.

Is the climate becoming more variable or extreme?

On a global scale there is little evidence of sustained trends in climate variability or extremes. This perhaps reflects inadequate data and a dearth of analyses. However, on regional scales, there is clear evidence of changes in variability or extremes.

In areas where a drought or excessive wetness usually accompanies an El Niño, these dry or wet spells have been more intense in recent years. Other than these areas, little evidence is available of changes in drought frequency or intensity.

In some areas where overall precipitation has increased (ie. the mid-high northern latitudes), there is evidence of increases in the heavy and extreme precipitation events. Even in areas such as eastern Asia, it has been found that extreme precipitation events have increased despite total precipitation remaining constant or even decreasing somewhat. This is related to a decrease in the frequency of precipitation in this region.

Many individual studies of various regions show that extra-tropical cyclone activity seems to have generally increased over the last half of the 20th century in the northern hemisphere, but decreased in the southern hemisphere. It is not clear whether these trends are multi-decadal fluctuations or part of a longer-term trend.

Where reliable data are available, tropical storm frequency and intensity show no significant long-term trend in any basin. There are apparent decadal-interdecadal fluctuations, but nothing which is conlusive in suggesting a longer-term component.

Global temperature extremes have been found to exhibit no significant trend in interannual variability, but several studies suggest a significant decrease in *intra*-annual variability. There has been a clear trend to fewer extremely low minimum temperatures in several widely-separated areas in recent decades. Widespread significant changes in extreme high temperature events have not been observed.

There is some indication of a decrease in day-to-day temperature variability in recent decades.

How important are these changes in a longer-term context?

Paleoclimatic data are critical for enabling us to extend our knowledge of climatic variability beyond what is measured by modern instruments. Many natural phenomena are climate dependent (such as the growth rate of a tree for example), and as such, provide natural 'archives' of climate information. Some useful paleoclimate data can be found in sources as diverse as tree rings, ice cores, corals, lake sediments (including fossil insects and pollen data), speleothems (stalactites etc), and ocean sediments. Some of these, including ice cores and tree rings provide us also with a chronology due the nature of how they are formed, and so high resolution climate reconstruction is possible in these cases. However, there is not a comprehensive 'network' of paleoclimate data as there is with instrumental coverage, so global climate reconstructions are often difficult to obtain. Nevertheless, combining different types of paleoclimate records enables us to gain a near-global picture of climate changes in the past.

For the Northern Hemisphere summer temperature, recent decades appear to be the warmest since at least about 1000AD, and the warming since the late 19th century is unprecedented over the last 1000 years. Older data are insufficient to provide reliable hemispheric temperature estimates. Ice core data suggest that the 20th century has been warm in many parts of the globe, but also that the significance of the warming varies geographically, when viewed in the context of climate variations of the last millennium.

Large and rapid climatic changes affecting the atmospheric and oceanic circulation and temperature, and the hydrological cycle, occurred during the last ice age and during the transition towards the present Holocene period (which began about 10,000 years ago). Based on the incomplete evidence available, the projected change of 3 to 7°F (1.5 - 4°C) over the next century would be unprecedented in comparison with the best available records from the last several thousand years.

Is sea level rising?

Global mean sea level has been rising at an average rate of 1 to 2 mm/year over the past 100 years, which is significantly larger than the rate averaged over the last several thousand years. Projected increase from 1990-2100 is anywhere from 0.09-0.88 meters, depending on which greenhouse gas scenario is used and many physical uncertainties in contributions to sea-level rise from a variety of frozen and unfrozen water sources.

Can the observed changes be explained by natural variability, including changes in solar output?

Since our entire climate system is fundamentally driven by energy from the sun, it stands to reason that if the sun's energy output were to change, then so would the climate. Since the advent of space-borne measurements in the late 1970s, solar output has indeed been shown to vary. There appears to be confirmation of earlier suggestions of an 11 (and 22) year cycle of irradiance. With only 20 years of reliable measurements however, it is difficult to deduce a trend. But, from the short record we have so far, the trend in solar irradiance is estimated at ~0.09 W/m^2 compared to 0.4 W/m^2 from well-mixed greenhouse gases. There are many indications that the sun also has a longer-term variation which has potentially contributed to the century-scale forcing to a greater degree. There is though, a great deal of uncertainty in estimates of solar irradiance beyond what can be measured by satellites, and still the contribution of direct solar irradiance forcing is small compared to the greenhouse gas component. However, our understanding of the indirect effects of changes in solar output and feedbacks in the climate system is minimal. There is much need to refine our understanding of key natural forcing mechanisms of the climate, including solar irradiance changes, in order to reduce uncertainty in our projections of future climate change.

In addition to changes in energy from the sun itself, the Earth's position and orientation relative to the sun (our orbit) also varies slightly, thereby bringing us closer and further away from the sun in predictable cycles (called Milankovitch cycles). Variations in these cycles are believed to be the cause of Earth's ice-ages (glacials). Particularly important for the development of glacials is the radiation receipt at high northern latitudes. Diminishing radiation at these latitudes during the summer months would have enabled winter snow and ice cover to persist throughout the year, eventually leading to a permanent snow- or icepack. While Milankovitch cycles have tremendous value as a theory to explain ice-ages and long-term changes in the climate, they are unlikely to have very much impact on the decade-century timescale. Over several centuries, it may be possible to observe the effect of these orbital parameters, however for the prediction of climate change in the 21st century, these changes will be far less important than radiative forcing from greenhouse gases.

What about the future?

Due to the enormous complexity of the atmosphere, the most useful tools for gauging future changes are 'climate models'. These are computer-based mathematical models which simulate, in three dimensions, the climate's behavior, its components and their interactions. Climate models are constantly improving based on both our understanding and the increase in computer power, though by definition, a computer model is a simplification and simulation of reality, meaning that it is an *approximation* of the climate system. The first step in any modeled projection of climate change is to first simulate the present climate and compare it to observations. If the model is considered to do a good job at representing modern climate, then certain parameters can be changed, such as the concentration of greenhouse gases, which helps us understand how the climate would change in response. Projections of future climate change therefore depend on how well the computer climate model simulates the climate and on our understanding of how forcing functions will change in the future.

The IPCC Special Report on Emission Scenarios determines the range of future possible greenhouse gas concentrations (and other forcings) based on considerations such as population growth, economic growth, energy efficiency and a host of other factors. This leads a wide range of possible forcing scenarios, and consequently a wide range of possible future climates.

According to the range of possible forcing scenarios, and taking into account uncertainty in climate model performance, the IPCC projects a global temperature increase of anywhere from 1.4 - 5.8°C from 1990-2100. However, this global average will integrate widely varying regional responses, such as the likelihood that land areas will warm much faster than ocean temperatures, particularly those land areas in northern high latitudes (and mostly in the cold season).

Precipitation is also expected to increase over the 21st century, particularly at northern mid-high latitudes, though the trends may be more variable in the tropics.

Snow extent and sea-ice are also projected to decrease further in the northern hemisphere, and glaciers and ice-caps are expected to continue to retreat.

Additional Information/links

Intergovernmental Panel on Climate Change
U.S. Environmental Protection Agency

World Data Center for Greenhouse Gases
A Paleoclimate perspective on global warming
EL Niño/La Niña
Climate of 2001, comprehensive (large pdf file)/ brief (html)
Climate of 2000comprehensive (large pdf file)/ brief (html)
Climate of 1999
Climate of 1998
U.S. Climate Returns to Heat of the 1930's as Global Warmth Continues

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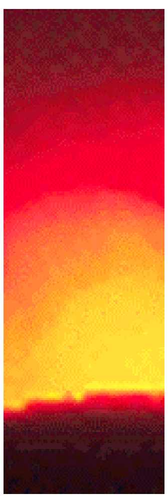
National Oceanic and Atmospheric Administration

Greenhouse Gases



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Introduction

What are greenhouse gases?

Many chemical compounds present in Earth's atmosphere behave as 'greenhouse gases'. These are gases which allow direct sunlight (relative shortwave energy) to reach the Earth's surface unimpeded. As the shortwave energy (that in the visible and ultraviolet portion of the spectra) heats the surface, longer-wave (infrared) energy (heat) is reradiated to the atmosphere. Greenhouse gases absorb this energy, thereby allowing less heat to escape back to space, and 'trapping' it in the lower atmosphere. Many greenhouse gases occur naturally in the atmosphere, such as carbon dioxide, methane, water vapor, and nitrous oxide, while others are synthetic. Those that are man-made include the chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs), as well as sulfur hexafluoride (SF_6). Atmospheric concentrations of both the natural and man-made gases have been rising over the last few centuries due to the industrial revolution. As the global population has increased and our reliance on fossil fuels (such as coal, oil and natural gas) has been firmly solidified, so emissions of these gases have risen. While gases such as carbon dioxide occur naturally in the atmosphere, through our interference with the carbon cycle (through burning forest lands, or mining and burning coal), we artificially move carbon from solid storage to its gaseous state, thereby increasing atmospheric concentrations.

Water Vapor

Water Vapor is the most abundant greenhouse gas in the atmosphere, which is why it is addressed here first. However, changes in its conentration is also considered to be a result of climate *feedbacks* related to the warming of the atmosphere rather than a direct result of industrialization. The feedback loop in which water is involved is critically important to projecting future climate change, but as yet is still fairly poorly measured and understood.

As the temperature of the atmosphere rises, more water is evaporated from ground storage (rivers, oceans, reservoirs, soil). Because the air is warmer, the relative humidity can be higher (in essence, the air is able to 'hold' more water when its warmer), leading to more water *vapor* in the atmosphere. As a greenhouse gas, the higher concentration of water vapor is then able to absorb more thermal IR energy radiated from the Earth, thus further warming the atmosphere. The warmer atmosphere can then hold more water vapor and so on and so on. This is referred to as a 'positive feedback loop'. However, huge scientific uncertainty exists in defining the extent and importance of this feedback loop. As water vapor increases in the atmosphere, more of it will eventually also condense into clouds, which are more able to reflect incoming solar radiation (thus allowing less energy to reach the Earth's surface and heat it up). The future monitoring of atmospheric processes involving water vapor will be critical to fully understand the feedbacks in the climate system leading to global climate change. As yet, though the basics of the hydrological cycle are fairly well understood, we have very little comprehension of the complexity of the feedback loops. Also, while we have good atmospheric measurements of other key greenhouse gases such as carbon dioxide and methane, we have poor measurements of global water vapor, so it is not certain by how much atmospheric concentrations have risen in recent decades or centuries, though satellite measurements, combined with balloon data and some in-situ ground measurements indicate generally positive trends in global water vapor.

Carbon Dioxide

The natural production and absorption of carbon dioxide (CO_2) is achieved through the terrestrial biosphere and the ocean. However, humankind has altered the natural carbon cycle by burning coal, oil, natural gas and wood and since the industrial revolution began in the mid 1700s, each of these actvities has increased in scale and distribution. Carbon dioxide was the first greenhouse gas demonstrated to be increasing in atmospheric concentration with the first conclusive measurements being made in the last half of the 20th century. Prior to the industrial revolution, concentrations were fairly stable at 280ppm. Today, they are around 370ppm, an increase of well over 30%. The atmospheric concentration has a marked seasonal oscillation that is mostly due to the greater extent of landmass in the northern hemisphere (NH) and its vegetation. A greater drawdown of CO_2 occurs in the NH spring and summer as plants convert CO_2 to plant material through photosynthesis. It is then released again in the fall and winter as the plants decompose.

Methane

Methane is an extrememly effective absorber of radiation, though its atmospheric concentration is less than CO_2 and its lifetime in the atmosphere is brief (10-12 years), compared to some other greenhouse gases (such as CO_2, N_2O, CFCs). Methane(CH_4) has both natural and anthropogenic sources. It is released as part of the biological processes in low oxygen environments, such as in swamplands or in rice production (at the roots of the plants). Over the last 50 years, human activities such as growing rice, raising cattle, using natural gas and mining coal have added to the atmospheric concentration of methane. Direct atmospheric measurement of atmospheric methane has been possible since the late 1970s and its conentration rose from 1.52 ppmv in 1978 by around 1%/year to 1990, since when there has been little sustained increase. The current atmospheric concentration is ~1.77 ppmv, and there is no scientific consensus on why methane has not risen much since around 1990.

Tropospheric Ozone

Ultraviolet radiation and oxygen interact to form ozone in the stratosphere. Existing in a broad band, commonly called the 'ozone layer', a small fraction of this ozone naturally descends to the surface of the Earth. However, during the 20th century, this tropospheric ozone has been supplemented by ozone created by human processes. The exhaust emissions from automobiles and pollution from factories (as well as burning vegetation) leads to greater concentrations of carbon and nitrogen molecules in the lower atmosphere which, when it they are acted on by sunlight, produce ozone. Consequently, ozone has higher concentrations in and around cities than in sparsely populated areas, though there is some transport of ozone downwind of major urban areas. Ozone is an important contributor to photochemical smog. Though the lifetime of ozone is short, and is therefore not well-mixed through the atmosphere, there is a general band of higher ozone concentration during NH spring and summer between 30°N and 50°N resulting from the higher urbanization and industrial activity in this band. Concentrations of ozone have risen by around 30% since the pre-industrial era, and is now considered by the IPCC to be the third most important greenhouse gas after carbon dioxide and methane. An additional complication of ozone is that it also interacts with and is modulated by concentrations of methane.

Nitrous Oxide

Concentrations of nitrous oxide also began to rise at the beginning of the industrial revolution and is understood to be produced by microbial processes in soil and water, including those reactions which occur in fertilizer containing nitrogen. Increasing use of these fertilizers has been made over the last century. Global concentration for N_2O in 1998 was 314 ppb, and in addition to agricultural sources for the gas, some industrial processes (fossil fuel-fired power plants, nylon production, nitric acid production and vehicle emissions) also contribute to its atmospheric load.

CFCs etc.

CFCs (chlorofluorocarbons) have no natural source, but were entirely synthesized for such diverse uses as refrigerants, aerosol propellants and cleaning solvents. Their creation was in 1928 and since then concentrations of CFCs in the atmosphere have been rising. Due to the discovery that they are able to destroy stratospheric ozone, a global effort to halt their production was undertaken and was extremely successful. So much so that levels of the major CFCs are now remaining level or declining. However, their long atmospheric lifetimes determine that some concentration of the CFCs will remain in the atmosphere for over 100 years. Since they are also greenhouse gas, along with such other long-lived synthesized gases as CF_4 (carbontatrafuoride), SF_6 (sulfurhexafluoride), they are of concern. Another set of synthesized compounds called HFCs (hydrofluorcarbons) are also greenhouse gases, though they are less stable in the atmosphere and therefore have a shorter lifetime and less of an impact as a greenhouse gas.

Carbon Monoxide and other reactive gases

Carbon monoxide (CO) is not considered a direct greenhouse gas, mostly because it does not absorb terrestrial thermal IR energy strongly enough. However, CO is able to modulate the production of methane and tropospheric ozone. The Northern Hemisphere contains about twice as much CO as the Southern Hemisphere because as much as half of the global burden of CO is derived from human activity, which is predominantly located in the NH. Due to the spatial variability of CO, it is difficult to ascertain global concentrations, however, it appears as though they were generally increasing until the late 1980s, and have since begun to decline somewhat. One possible explanation is the reduction in vehicle emissions of CO since greater use of catalytic converters has been made.

Volatile Organic Compounds (VOCs) also have a small direct impact as greenhouse gases, as well being involved in chemical processes which modulate ozone production. VOCs include non-methane hydrocarbons (NMHC), and oxygenated NMHCs (eg. alcohols and organic acids), and their largest source is natural emissions from vegetation. However, there are some anthropogenic sources such as vehicle emissions, fuel production and biomass burning. Though measurement of VOCs is extremely difficult, it is expected that most anthropogenic emissions of these compounds have increased in recent decades.

Additional Information

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