



A GLOBAL COMMONS Our atmosphere is a “global commons”—something held and shared by everyone on Earth. As manned balloon flights have shown, the air over one place can be halfway around the world a week later. The air over China is traveling over the United States a few days later and in five days is over Europe.

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The atmosphere is used by everyone as a dumping ground for all sorts of pollution. While most particulate pollutants fall out of the atmosphere relatively quickly, some gaseous pollutants can remain in the atmosphere for a long time. Eventually these can accumulate to the point where they begin to change the chemical composition of the atmosphere. It is this kind of pollution that is causing global warming.

The other global commons, the ocean, has the International Law of the Sea. It's not a particularly strong law, but it includes some regulations designed to stop pollution and protect the ocean from being used as a dumping ground. There is no such law for the atmosphere.

GLOBAL WARMING IS UNEQUIVOCAL

Based on the Keynote Presentation by Kevin Trenberth, Senior Scientist, National Center for Atmospheric Research, and Member of the Intergovernmental Panel on Climate Change

RISING CARBON DIOXIDE LEVELS Among the evidence that the composition of the atmosphere is changing is the record of carbon dioxide levels kept since 1958 at Mauna Loa, Hawaii. This record shows what could be called the breathing of our planet. The amount of carbon dioxide in the air normally decreases by about five parts per million in spring and summer when it is “inhaled” for photosynthesis by trees and other plants as they bloom and grow. Then it increases by a similar amount again in autumn and winter as it is “exhaled” by decaying plants and tree leaves. The Mauna Loa record shows a steady increase in the amount of carbon dioxide in the air to where it is now about 65 parts per million more than it was 50 years ago.

Carbon dioxide has a long atmospheric lifetime—more than 100 years—so it is the ever-increasing amount of carbon dioxide accumulating in the air from deforestation and the massive amounts of carbon-laden coal and petroleum we’ve burned over the past century that matters most in terms of what is causing the climate change we are seeing today.

From 1850 to 2004, the United States was the largest single source of fossil-fuel carbon dioxide emissions in the world—nearly as large as the combined total for all European nations—followed by Russia, China, India and rest of the world. While the United States is still largest single source today, by 2004 both China and India had more than doubled their shares of the total amount of carbon dioxide emitted from human sources. Within three or four years, China’s percentage of total emissions is estimated to surpass that of the United States.

Another way of looking at this is per-capita emissions. Again, Americans lead the world in the amount of carbon dioxide emitted per person, while the average European contributes less than half as much. Why is that? One reason is that gasoline in Europe costs eight or nine dollars a gallon, electricity costs a lot more, and so people use less of both. It’s been shown that if the cost of gasoline goes up 10 percent, amount consumed goes down three percent.

China’s per-capita emission rate is about a tenth of ours, but more of its people are using cars and electricity, so its total emissions are going up rapidly. Similarly, because of its massive population, emissions from India are growing despite a per-capita emission rate that’s one-twentieth that of the average American. To improve the standard of living for their citizens, China and India have been bringing one new coal-fired electrical power plant online every three days for the last five years.

THE GREENHOUSE EFFECT The so-called “greenhouse effect” is key to understanding the problem. Without heat-trapping gases in the atmosphere, Earth would be too cold to sustain life as we know it. The composition of this “gas greenhouse” is about 60 percent water vapor, 26 percent carbon dioxide, eight percent ozone, six percent nitrous oxide and methane, and less than one percent other trace gases.

As the sun’s radiation reaches Earth, some is deflected by the atmosphere or reflected back into space by clouds and snow, but most of it is absorbed by the ocean and continents, warming them. This warmth then radiates back out into space, but as it passes up through the atmosphere much of it gets detained by clouds and the greenhouse gases. This is what keeps Earth’s surface and the lower atmosphere warm.

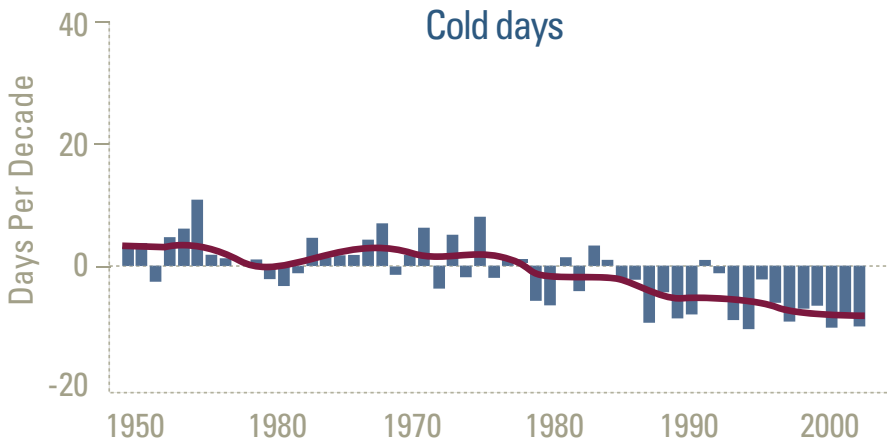
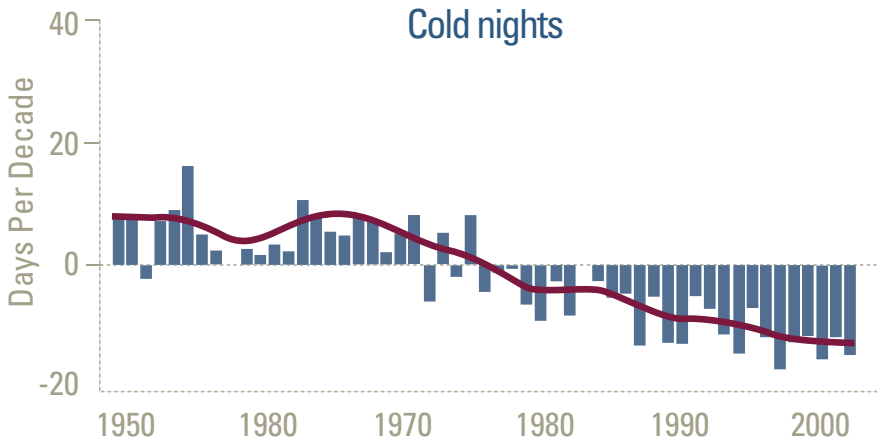
The amount of incoming energy from the sun amounts to about 175 petawatts, or 175 million billion watts, of which about 120 petawatts is absorbed by our planet. This is the equivalent of 120 million of the biggest, thousand-megawatt electrical power plants we have today. This tells us:

- Direct human influences are tiny compared to those of nature.
- The primary way human activities can affect climate is by interfering with the natural flow of energy, such as by changing the composition of the atmosphere.

And the rapid increase in the amount of carbon dioxide and other greenhouse gases from human activities is changing the composition of the atmosphere, and this is adding to the natural greenhouse effect.

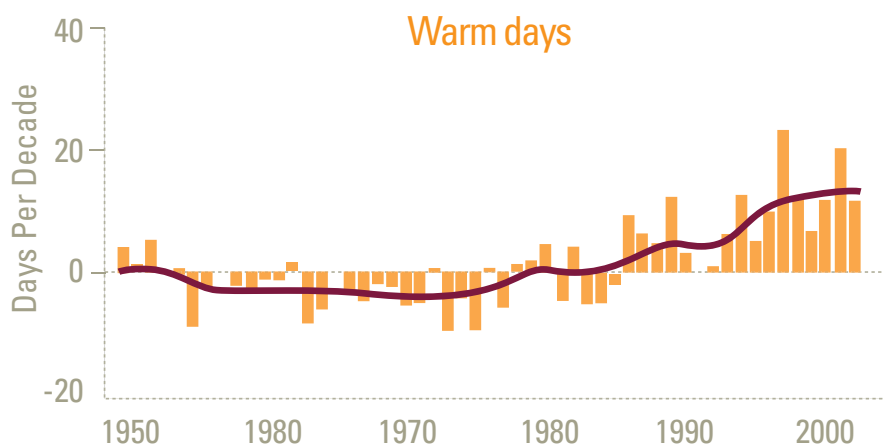
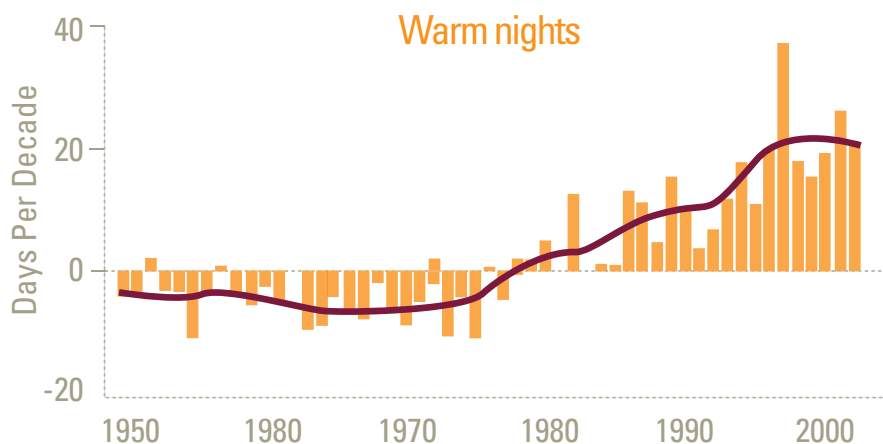
TEMPERATURES RISING Over the last 30 years, the effects of this change in atmospheric composition have really emerged from the background noise of natural variability. Since 1970, we have seen a worldwide rise in temperatures in the lower atmosphere, both over land and in the ocean. We have also seen a worldwide rise in ocean water levels, water vapor, precipitation north and south of the tropics, and rainfall intensity. Hurricane intensity, drought, extreme high temperatures and heat waves have also increased. At the same time, we have seen a decrease in cold temperatures, snow cover in the Northern Hemisphere, arctic sea ice and glaciers.

Global mean temperatures are rising faster with time. The mean rate of temperature rise for the last 150 years works out to about 0.08 degrees Fahrenheit per decade. Over the last 50 years, the rate increased to 0.23



degrees per decade, and the mean rate over the last 25 years has been 0.32 degrees per decade. As a result, we have seen a sharp rise over the last 30 years in both land and sea surface temperatures, with land surface warming faster than the ocean surface. This increasingly upward trend explains why the 12 warmest global mean temperatures on record have all occurred since 1990.

Ever notice that when the sun comes out after a rain shower, the puddles all dry up before the temperature increases? Just as the human body uses sweat to control heat, Earth uses water vapor. Warmer temperatures cause the air to retain more water vapor—about four percent more for each degree Fahrenheit rise in temperature. Since 1970, we have observed a one degree rise in surface and lower atmosphere temperatures over the ocean, and we measure four percent more water vapor in the air. Not only is this enhancing the greenhouse effect, it means more moisture in the air for precipitation.



MORE RAIN, MORE DROUGHT The annual amount of precipitation has been changing significantly over broad areas of land around the world since 1900. We see precipitation increasing in northern and eastern North America, northern and central Europe, Argentina, and northern Asia. Precipitation has decreased—notably within the last 50 years—in the Sahel Region of western Africa, northern and southern Africa, southern Europe and the Mediterranean Basin, and Southeast Asia. In general, it is becoming drier throughout Africa and the northern subtropics (20-35 degrees latitude), while it is getting wetter in higher latitudes (35-55 degrees latitude).

In the United States, total precipitation rose seven percent between 1900 and 2002 for all of the lower 48 states except in the Southwest. We have also observed a 14 percent increase in heavy precipitation and, more significantly, a 20 percent increase in very heavy (upper one percentile) precipitation, with an increasing frequency of both over the last 25 years or so. When it rains, it's raining harder now.



Hurricane Katrina:
Globally, the
number and
percentage of
intense hurricanes
is increasing
with the rise in
sea surface
temperatures.

Most other places around the world are also showing an increase in heavy rainfall, and this is related to the increase in water vapor in the atmosphere. Another significant change is the character of this precipitation: More is falling as rain than as snow, especially in the fall and spring, resulting in less winter snowpack in many mountain and continental areas where it is important to the water supply. Coupled with warmer temperatures, which are causing the snowmelt to occur faster and sooner in the spring, this results in less soil moisture when summer arrives, increasing the risks of drought and wildfires substantially.

One symptom of this can be seen in one of the largest manmade reservoirs in the United States, Lake Powell on the Colorado River along the Utah-Arizona border. A drought began in 1999 that has reduced Lake Powell's water level more than 100 feet below its high water mark. Its water levels declined steadily through November 2004, when an El Niño event brought rains that provided some short-term relief, but the hydrological drought has not gone away.


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It's much the same story at the nation's largest manmade reservoir, Lake Mead, also on the Colorado River about 30 miles southeast of Las Vegas, which gets most of its water from melting snowcaps on the Western Colorado Rockies. Since 2000, below-average snowfalls have caused a steady drop in Lake Mead's water level to where it is now down to half of full capacity.

The Palmer Drought Severity Index (PDSI) combines rainfall and temperature together as an indicator of the total supply of water and also the effects of evaporation and drying associated with higher temperatures. The PDSI indicates that climate change due to rising greenhouse gases is not only causing wet areas to become wetter, but dry areas to become more arid. Water management—dealing with how to save in times of excess for times of drought—will be a major challenge in these areas in the future.

MORE HOT SPOTS Temperature extremes have been changing across large parts of most continents. Recently, researchers looked at the very low temperatures and very high temperatures—those in the top and the bottom five percentile. They found that, since 1950, cold nights are becoming fewer everywhere, and cold days are becoming fewer in most places, except in the eastern United States. Warm nights are increasing and more common everywhere, and warm days are increasing most places, though not in southern Greenland, Argentina and the eastern United States.

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An aerial photograph of Lake Powell, a large man-made reservoir in the southwestern United States. The lake is surrounded by rugged, brownish-red desert rock formations. The water level is significantly lower than when the lake was first filled, leaving behind a prominent white, ring-like deposit of mineral-rich sediment around the shoreline, known as a 'bathtub ring'. The water in the lake is a deep blue color. The surrounding landscape is arid and rocky, with some sparse vegetation visible on the slopes.

Aerial photo of Lake Powell taken in May 2007. Note the prominent “bathtub ring” left by the dropping water level.

The increasing number of warm days is causing an increase in heat waves around the world, such as the extreme heat wave in the summer of 2003 in Europe that killed 70,000 people. Europe has had a generally upward trend in June-July-August temperature anomalies since 1980.

The reason the eastern half of the United States and Argentina have been an exception to the warming is because they have two things in common: both are east of mountain ranges (the Rockies and Andes, respectively), and both are east of the Pacific Ocean, downwind from where El Niño occurs. El Niño events in the mid-Pacific affect the flow of the high-altitude jet streams, which direct where storms go and rain falls. The reason average temperatures have not risen in these two regions is because of cloudy and wet conditions caused by El Niño.

TROUBLED WATERS Globally, the number and percentage of intense hurricanes is increasing with the rise in sea surface temperatures. The number of North Atlantic hurricanes and named storms has shown a marked increase since 1994 coinciding with the rise in sea surface temperatures.

The rate of sea level rise is also increasing with increasing seawater temperatures. The rate of sea level rise during 1993-2003 is nearly double the annual rate recorded over the entire 20th century. Since 1993, the global sea level has risen 1.6 inches, about 60 percent of which is due to the water expanding as it warms, the rest from melting glaciers.

The area of arctic sea ice has contracted at a rate of 2.7 percent per decade since the 1970s. Similarly, the area of the Northern Hemisphere still snow-covered in March and April declined five percent during the 1980s. The glacial melt zones in Greenland now reach much further inland and more than 6,500 feet above sea level.

PREDICTING THE FUTURE Scientific models of the climate system are designed to take into account all of the key factors and the many variables that affect Earth's climate. They are then tested against measurements and observations of past climate, refined and retested, and fine-tuned until they can simulate actual climate behavior in the past. Most of the climatic changes observed over the last 50 years are now closely simulated by our climate models, and this increases our confidence in these models to make future projections.

For example, a run of the climate model starting in 1890 and using only natural factors, like volcanic activity and changes in solar radiation, indicates a global average temperature that should have been much lower than

what we've seen since the 1970s. It is only when the model includes the measured increase in carbon dioxide and other changes in the composition of the atmosphere from human activities that it closely approximates the observed rise in the global average temperature over the last century—especially during the last 30 years of that century.

Run forward in time, climate and carbon cycle model simulations indicate temperatures over land areas will increase more rapidly than over the ocean, and the greatest degree of warming will occur in the polar areas and the high northern latitudes, where median temperatures could rise by more than 14 degrees over the next 300 years if fossil fuel use continues at present rates.

Projected patterns of precipitation change over the course of the 21st century show that the patterns observed in recent years are likely to continue into the 2090s, with precipitation increases of more than 20 percent very likely in the high northern latitudes, while most subtropical regions will likely experience similarly large decreases in rainfall.

WARNINGS FROM THE PAST Analysis of Antarctic ice cores has found remarkable parallels in the rise and fall in carbon dioxide and methane concentrations and ambient temperature during the last 420,000 years. The ice core record indicates that continental glaciers take tens of thousands of years to develop, yet it appears they melt very quickly with an abrupt climate change at the end of each ice age. The cause is still under investigation, but this may have very important ramifications for rapid melting of the Antarctic glaciers and the potential for a relatively fast and large rise in sea level.

Ice ages and the warm periods between them are both caused by subtle changes in the Earth's orbit around the sun—orbital roundness (eccentricity), the tilt of Earth's axis (inclination) and how close the poles are to the sun during winter and summer (precession).

Antarctic ice cores show that atmospheric concentrations of carbon dioxide and methane—a greenhouse gas 20 times more potent—are timed exquisitely with rising and falling Antarctic temperatures. This is because as the cold seawater warms, it gives off more carbon dioxide (like warm carbonated water), and warmth also increases biological activity, which generates more methane. Due to the greenhouse effect, rising levels of carbon dioxide and methane accelerate the warming, so the planet warms up relatively quickly. As it cools, the exact opposite happens, and cooling begets more cooling. These “positive feedback loops” are the crux of the science of global warming.

The ice cores tell us that atmospheric levels of carbon dioxide have varied from about 180 parts per million to around 280 parts per million over the last 420,000 years, and during that time Antarctic temperatures ranged from 50 below to 36 degrees above zero.

Today, atmospheric carbon dioxide levels have risen to 375 parts per million, and they are projected to reach a concentration of at least 550 and perhaps as high as 1,000 parts per million. Earth's climate system has not experienced such high levels of carbon dioxide in more than a million years, and this is why climate scientists are so concerned.

Members of the Intergovernmental Panel on Climate Change are not absolutely certain about exactly how our climate will change, but they are certain it is changing—and that the changes it brings could be very disruptive and extremely costly to people throughout the world.