Understanding Climate

Climate is more than just weather. It is also a long-term pattern of changing natural conditions, a collective grouping of all the earth sciences that involves 1) the interaction of the sun's radiation, 2) Earth's orbital mechanics, 3) the changing polar ice caps and glaciers, 4) the circulation and chemistry of Earth's atmosphere, 5) the deep ocean currents, volcanic activity and now, 6) with evidence of increasing concentrations of greenhouse gases, the impact of humans. The centuries during which we have cleared forests and burned coal, oil and gas, putting carbon dioxide and other heat-trapping gases into the atmosphere faster than plants and oceans can absorb them, have brought the atmospheric level of carbon dioxide higher than it has been for hundreds of thousands of years. Studies indicate that the increase in temperature in the 20th century is likely to have been the largest of any century during the past 1,000 years.

Climate change is neither new nor unnatural. Climate has been changing continually as the planet has evolved geologically over its 4.6 billion-year existence, with species coming and going as a result of changing habitats. Even during the blink of humanity's presence on Earth, settlements, cities and states have emerged and vanished in response to changes in the climate.

Climatologists say they have found patterns and cycles in climate. These patterns are important because they suggest that some aspects of climate change are understandable and even predictable. Here is a sampling of what they've discovered.

1

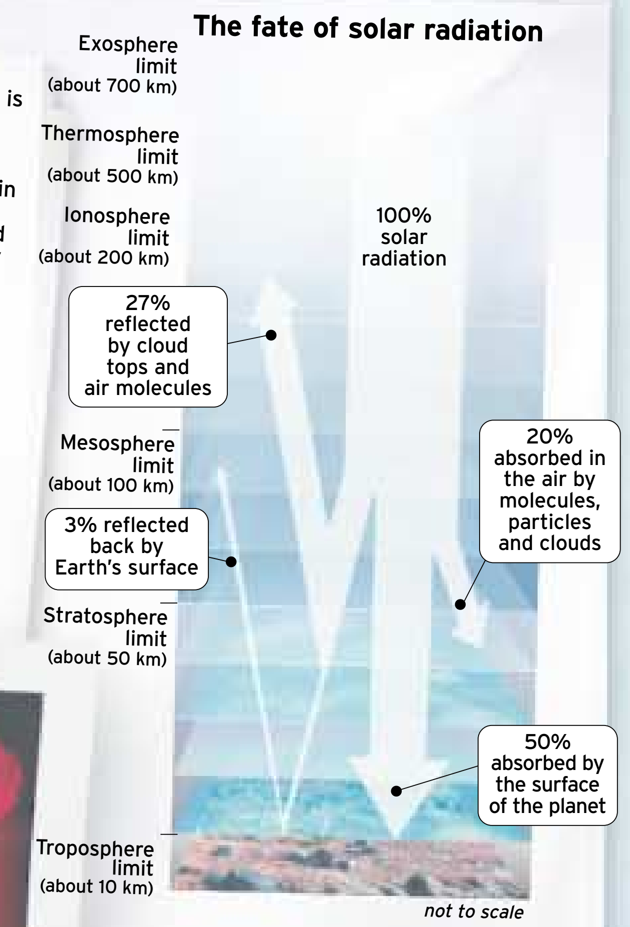
The sun's radiation

Global patterns of atmospheric temperature, pressure, resultant winds and precipitation ultimately are caused by uneven heating of Earth by the sun. Over a long span, incoming, shortwave radiation energy from the sun is balanced by outgoing, long-wave radiation from Earth back into space. At any given time and place, however, there are imbalances in the radiation.

Closer to the equator, the amount of incoming shortwave radiation from the sun is greater than outgoing long-wave radiation; this surplus results in warmer temperatures along the equator. Closer to the poles, outgoing radiation is greater than incoming; this deficit results in cold polar temperatures. As Earth circles the sun in its seasonal cycle, this belt of surplus radiation shifts from south of the equator in January (summer in the Southern Hemisphere) to north of the equator in July (summer in the Northern Hemisphere).

As all of this solar energy hits Earth's atmosphere, land surface and oceans, it heats them. This energy is absorbed both by oceans and continents, but since the oceans cover more than 70 percent of Earth's surface and are darker than the continents, they absorb more of the sun's energy, storing much of it in the form of heat with very little change in temperature. Scientists believe the way the oceans store and transport heat is related to climate. The heat energy stored in the water is picked up by winds that blow over the ocean surface. When the wind releases the water as precipitation, the heat energy of the water is released into the atmosphere, leading to an increase in temperature.

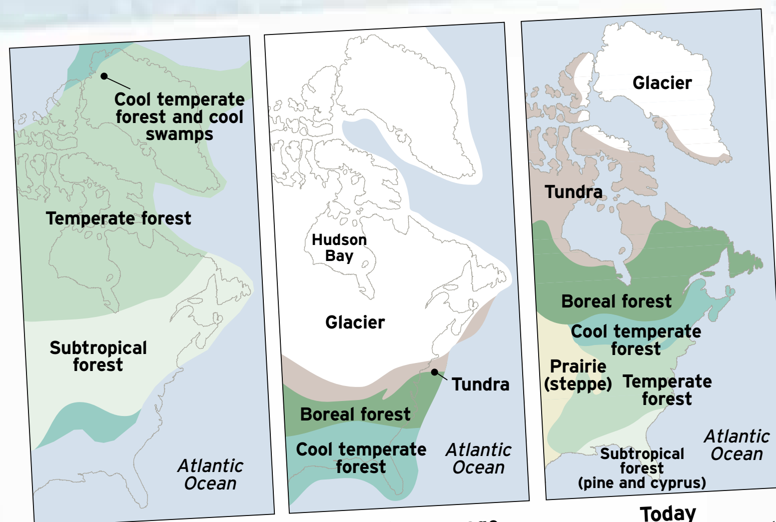
Scientists once believed the amount of solar energy leaving the sun and reaching Earth changed very little; now evidence suggests there are variations. An 11-year cycle of sunspot activity has been observed that corresponds with slight changes in solar output, while historical records of an absence of observed sunspots between 1645 and 1710 has been linked to what is believed to be a cooler period of climate from the 17th to 19th centuries, the latter half of a period that researchers now call the "Little Ice Age."



Layers of the atmosphere

The atmosphere is divided into layers according to temperature variation and height. In the troposphere, the closest to Earth, temperature decreases with height. In the lower troposphere, ozone, or smog, causes respiratory problems in people. In the stratosphere, (where most ozone resides, protecting life on Earth from excess ultraviolet radiation), the temperature increases with height. The mesosphere lies above the stratosphere and is a thin layer of gases where the temperature drops rapidly. Gases within the final three layers of the atmosphere – the ionosphere, thermosphere and exosphere – get progressively thinner.

Although the atmosphere is about 700 kilometers deep – approximately 435 miles – there is no real boundary; it simply fades away into space as the air becomes thinner and light gas molecules such as hydrogen and helium float away.



50-60 million years ago was the most recent globally warm period, when the Arctic was ice-free and subtropical forests extended northward to Greenland.

18,000 years ago was the height of the Pleistocene glaciation, before glaciers began retreating.

Today tundra, white pine and northern hardwood forests have all shifted north.

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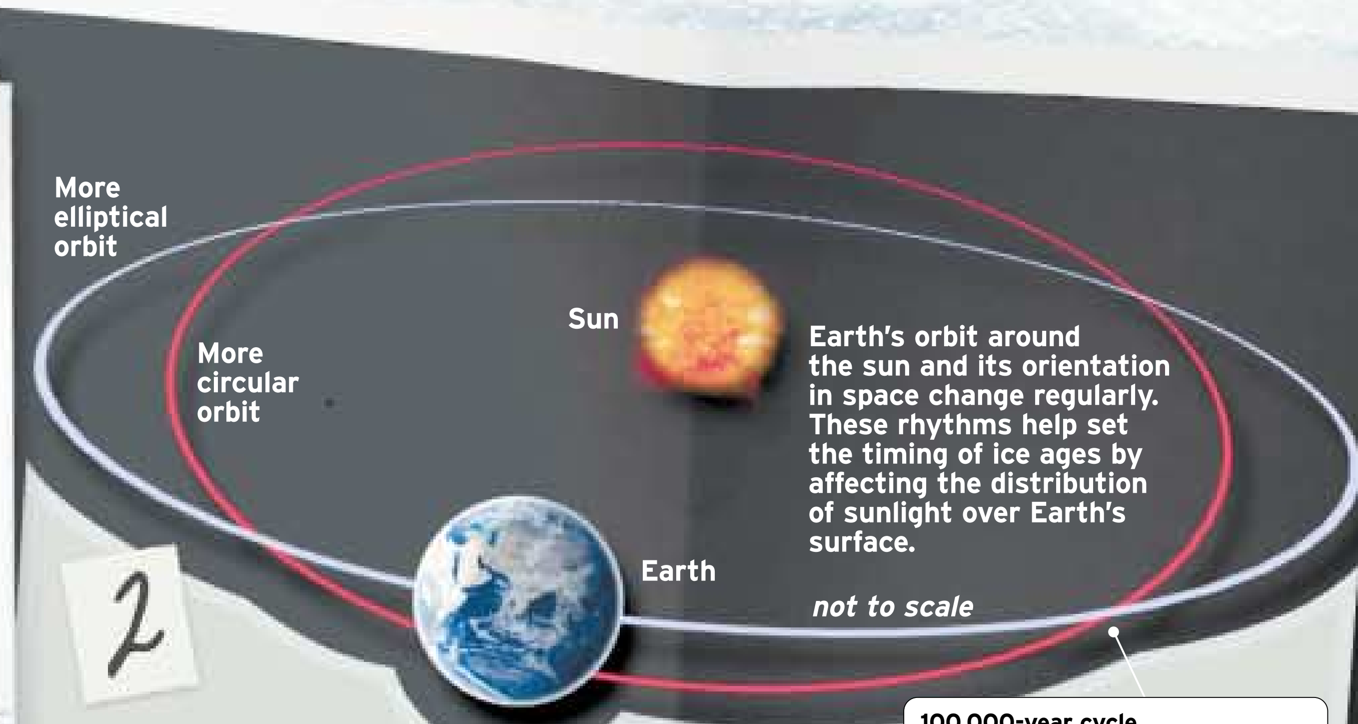


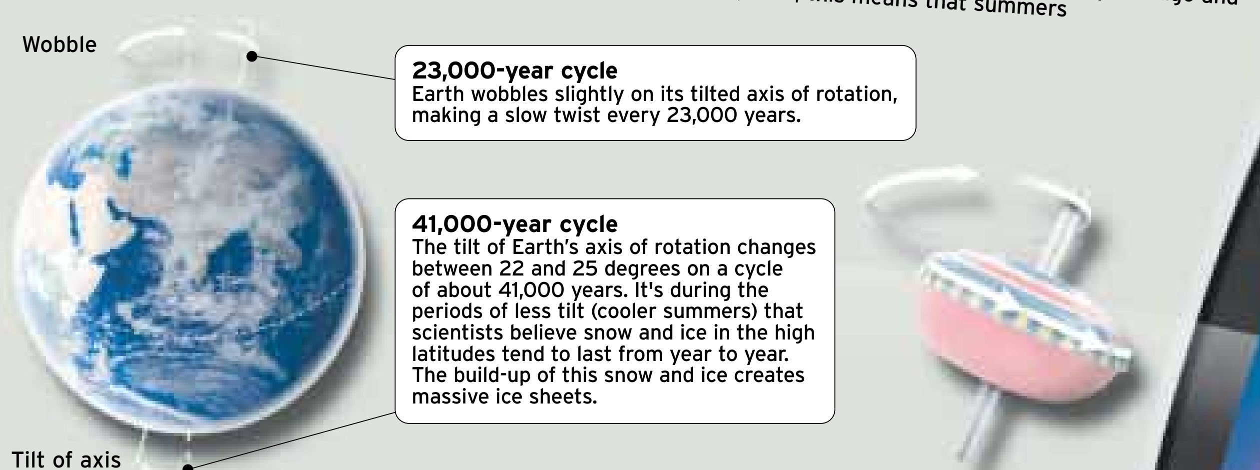
100,000-year cycle
Earth circles the sun in an eccentric orbit that expands and contracts, alternating between a path that is more circular to one that is more elliptical.

Earth's Orbital Mechanics

Certain astronomical rhythms – precession, obliquity and eccentricity – affect climate. For the past 2.5 million years, for instance, Earth has cycled through ice ages. During the past million years or so, these glacial cycles have occurred at fairly regular intervals of about 100,000 years as Earth's orbit stretches to become more elliptical, i.e. less round. Its axial tilt in relation to its plane of orbit also changes, in cycles of 41,000 years, while Earth's precession (the wobble of its spin, like that of a top slowing down) varies on a 23,000-year cycle. All of these cycles are involved in the "Milankovitch hypothesis," which suggests that these variations in Earth's orbit cause changes in how warm Earth is, especially in its Northern Hemisphere. It is when polar regions receive less sunlight that ice ages occur. Interglacial periods occur when the area receives more sunlight. These orbital variations are due to interactions between the sun, Earth, its moon, and the other planets. Scientists refer to this as astronomical forcing.

Earth's orbit

Because of the wobble of its axis of rotation, Earth is closest to the sun in an opposing hemisphere every 23,000 years, resulting in the precession of the equinoxes. Earth was closest to the sun during the June solstice 11,000 years ago and today is closest during the December solstice. For the Northern Hemisphere, this means that summers were warmer 11,000 years ago.



23,000-year cycle
Earth wobbles slightly on its tilted axis of rotation, making a slow twist every 23,000 years.

41,000-year cycle
The tilt of Earth's axis of rotation changes between 22 and 25 degrees on a cycle of about 41,000 years. It's during the periods of less tilt (cooler summers) that scientists believe snow and ice in the high latitudes tend to last from year to year. The build-up of this snow and ice creates massive ice sheets.

Seasonal shifts

The tilt of Earth's axis creates seasons. During the summer season in the Northern Hemisphere, the North Pole is tilted toward the sun. During the winter season in the Northern Hemisphere, the North Pole is tilted away from the sun. This is why Earth's Northern and Southern hemispheres experience seasons in reverse. While people in the Northern Hemisphere enjoy summer, those in the Southern Hemisphere are living in winter conditions.

3

Climate cycles: Glacial and interglacial periods

One of the most pronounced climate cycles is that of alternating ice ages and thaws, called glacial and interglacial periods. It is believed that these cycles are caused by a combination of up to three different factors. Probably responsible for much of the change is atmospheric composition (especially carbon dioxide and methane). Changes in Earth's orbit around the sun, known as Milankovitch cycles (and possibly the sun's own orbit around the galaxy), and the arrangements of the continents also have had significant impact.

We know from geological and other evidence that vast ice sheets (similar to the ones that now cover Greenland and Antarctica) once covered major parts of North America and Eurasia. During the last million years, roughly the time during which humans have existed as a species, Earth experienced about a dozen glaciations. During the greatest of them, the Laurentide Ice Sheet, centered over Hudson Bay, covered Chicago and points south in ice perhaps as much as a mile thick. So much water was bound up in ice that the level of the seas was about 400 feet lower than it is currently.

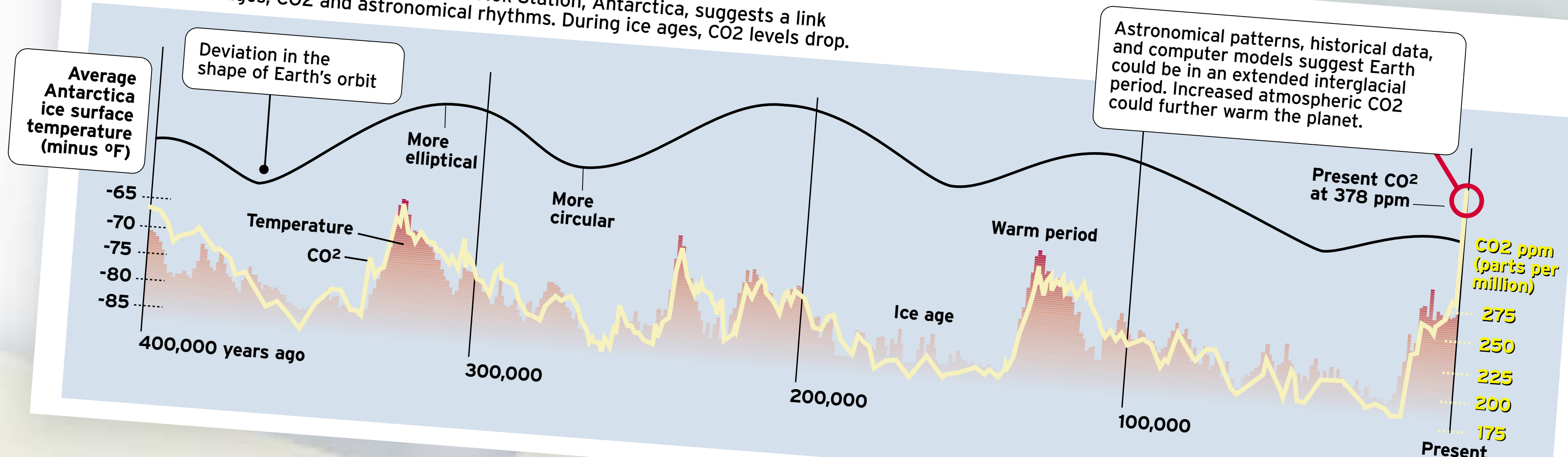
The last glacial period in human experience peaked about 20,000 years ago, with ice melting during the period 17,000-11,500 years ago. The glacial periods tended to last much longer than the interglacial periods. While humans carved out a living as hunter-gatherers before that time, much of what we call human civilization, including the practice of agriculture, emerged only during the most recent interglacial period.

The biosphere and climate

Earth's biosphere always has played a role in driving the climate system. For example, plankton in the ocean and plants on the land affect levels of carbon dioxide in the atmosphere, while methane levels are influenced, in part, by the ability of the Arctic's permafrost to store large volumes of it. Global warming could affect the natural processing of both gases, thus affecting Earth's temperature even more.

Ice ages, CO2 and astronomical cycles

A 400,000-year ice-core record from Vostok Station, Antarctica, suggests a link between ice ages, CO2 and astronomical rhythms. During ice ages, CO2 levels drop.



Astronomical patterns, historical data, and computer models suggest Earth could be in an extended interglacial period. Increased atmospheric CO2 could further warm the planet.

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Earth's greenhouse effect

Almost all (99 percent) of Earth's atmosphere consists of two main gases that play important roles in supporting life on Earth but little direct role in regulating climate: nitrogen and oxygen.

The remaining 1 percent or so of Earth's atmosphere is made up of small amounts of a number of "trace" gases that include water vapor, carbon dioxide, nitrous oxide, methane, chlorofluorocarbons, or CFCs, and ozone, all of which can be important in the regulation of climate. These trace gases are known as the greenhouse or "radiatively active" gases as they absorb or reflect infrared radiation.

Because the trace gases exist in the atmosphere in such small amounts, pollution and other forces resulting from human activities can alter their proportions in quite significant ways and thereby affect climate. A natural ingredient in the atmosphere, carbon dioxide, or CO2, is particularly important as a greenhouse gas because human activities generate so much of it. By burning coal, oil and natural gas, people take carbon dioxide out of Earth and put it into the atmosphere. Although the natural parts of the carbon cycle (the air-sea exchange and the biological processes) have long been in close balance, at least on the time scales of immediate relevance to humans it now seems that industrial activities, agriculture and land-use changes have significantly tipped the balance.

There is consensus among the international scientific community that most of the warming observed over the last 50 years is attributable to human activities. The portion of the warming believed to be caused by human activities is referred to as the "enhanced" greenhouse effect.

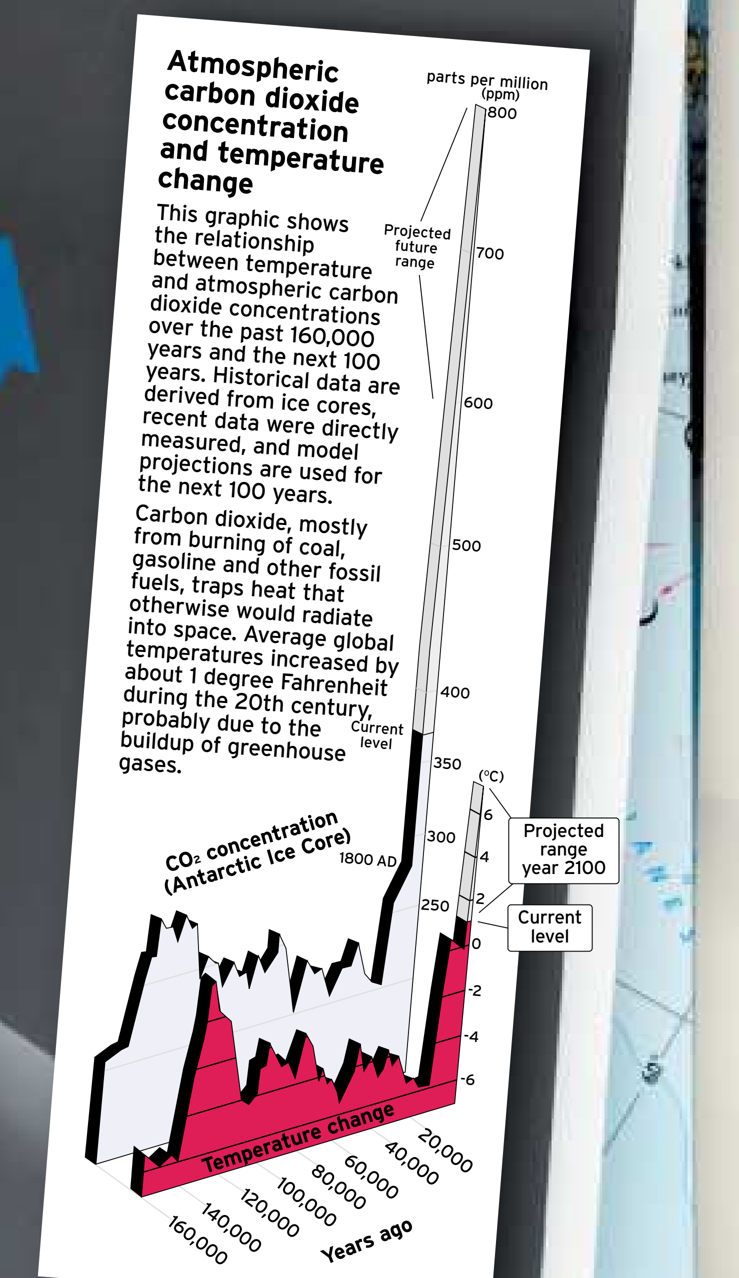
The greenhouse effect and global warming
Most of the heat energy emitted from Earth's surface is absorbed by greenhouse gases, which radiate some of it back down to warm the lower atmosphere and the surface. This "greenhouse effect" naturally warms Earth enough to sustain life. Increasing the concentrations of greenhouse gases increases the warming of the surface and slows the loss of heat energy to space. This century, carbon dioxide levels have risen due to increased burning of fossil fuels. This has led to near-surface global warming – the retention of extra heat by the lower atmosphere and a rise in Earth's average temperature.

Sea-level change
As a result of global climate change, scientific models predict the average sea level will rise by a minimum of 20 centimeters (about 8 inches) but will more likely rise by 0.6 to 1 meter, or about 2 to 3 feet, in the next 100 years.

Atmospheric carbon dioxide concentration and temperature change

This graphic shows the relationship between temperature and atmospheric carbon dioxide concentrations over the past 160,000 years and the next 100 years. Historical data are derived from ice cores, recent data were directly measured, and model projections are used for the next 100 years.

Carbon dioxide, mostly from burning of coal, gasoline and other fossil fuels, traps heat that otherwise would radiate into space. Average global temperatures increased by about 1 degree Fahrenheit during the 20th century, probably due to the buildup of greenhouse gases.



Predictions for the next century

About 80 percent of the world's energy is currently derived from burning fossil fuels, and carbon dioxide emissions from these sources are growing rapidly. Because excess carbon dioxide persists in the atmosphere for centuries, it will take at least a few decades for concentrations to peak and then begin to decline even if concerted efforts to reduce emissions are begun immediately. Altering the warming trend will thus be a long-term process, with excess carbon dioxide levels likely to have an impact on climate change for centuries to come.

The Intergovernmental Panel on Climate Change Predictions for the Next Century

- Globally averaged surface temperature is projected to increase by 1.4 to 5.8 degrees Celsius over the period 1990 to 2100.
- Warming will be greater than during the 20th century, and is very likely to be without precedent during the last 10,000 years.
- It is very likely that nearly all land areas will warm more rapidly than the global average. (Model results suggest warming in North America and central Asia may exceed the global average by more than 40 percent. Other regions will experience less than the average global increase.)
- Global average water-vapor concentration and precipitation are projected to increase in the 21st century.
- Higher minimum temperatures, as well as fewer cold days and frost days, are very likely over nearly all land areas.
- Glaciers and ice caps will continue to retreat.

Hurricane Katrina and climate change?
The number and intensity of hurricanes are known to vary naturally, with some years producing many violent storms and others hardly any. But both scientific theory and computer modeling predict that as human activities heat the world, warmer sea-surface temperatures will fuel hurricanes, increasing wind speeds and rainfall. Several new studies suggest that climate change has already made hurricanes grow stronger.

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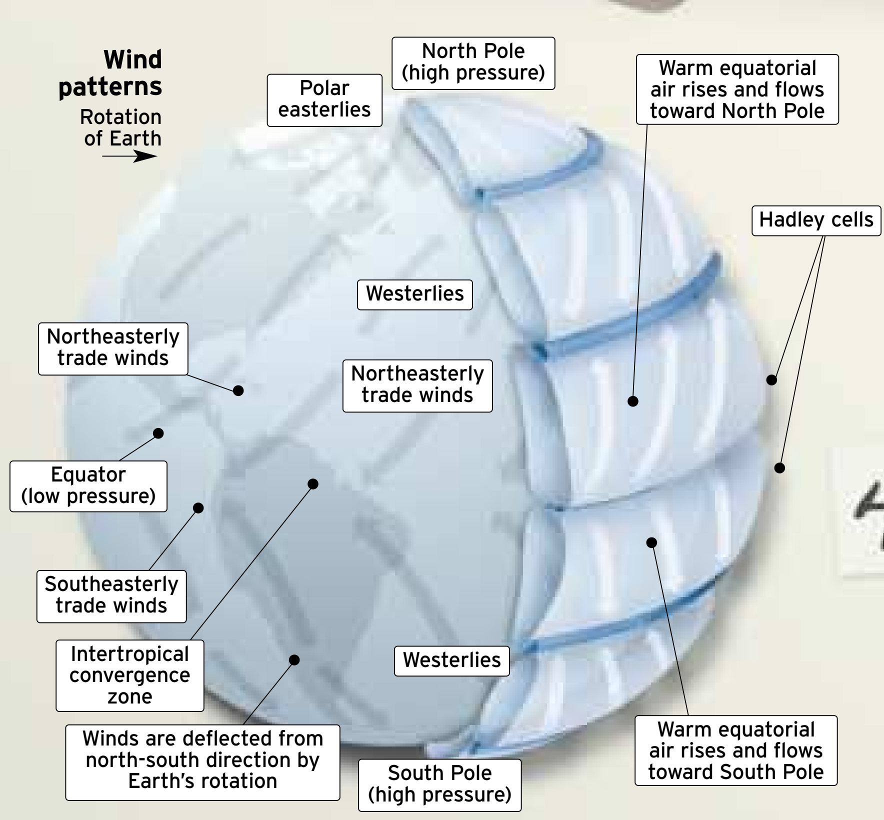

Earth's circulatory system: air and water

Incoming solar radiation warms the equator more than it does the poles. Because hot air rises at the equator and sinks as it cools approaching the poles, this unequal heating of the atmosphere on land and the oceans creates winds and circulation.

The atmosphere is split into three zones or "cells," each with its own wind pattern: dry, northeasterly and southeasterly trade winds in the tropics; warm, moist westerlies in the midlatitudes; and cold, polar easterlies in the polar regions. Winds also are affected by the distribution of oceans and continents and the rotation of Earth.

For equatorial regions not to get warmer and warmer and polar regions not to get correspondingly cooler and cooler, there must be a transport of heat from low to high latitudes. This heat transport is accomplished by both atmospheric and oceanic circulation. In the tropics, heat is moved poleward by large-scale meridional circulation cells, known as Hadley cells. Surface heating in the equatorial region results in rising, poleward-moving air aloft. As this air moves poleward in both hemispheres, it cools radiatively, and sinks near 30 degrees North and 30 degrees South latitude, where it then returns at low levels toward the equator. In the Northern and Southern hemispheres, corresponding northeasterly and southeasterly trade winds blow equatorward from the subtropical high at around 30 degrees North and 30 degrees South toward lower pressure near the equator. These wind fields converge near the equator in a region called the intertropical convergence zone.

On a smaller scale, heat transport also is accomplished by hurricanes that evaporate water in the tropics and later release the latent heat acquired when condensation occurs at higher latitudes. At mid- to high latitudes, heat is transported by frontal storms. These storms tend to track along the polar front (the boundary between cold polar air and warmer subtropical air).

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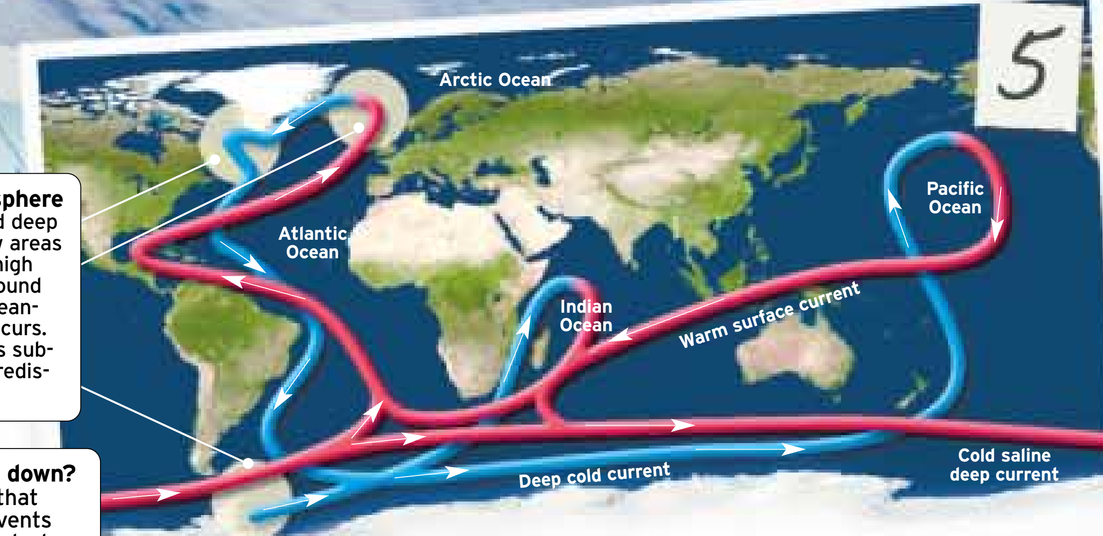

Heat released to the atmosphere
Warm surface currents and cold deep currents are connected in a few areas of deepwater formation in the high latitudes of the Atlantic and around Antarctica, where the major ocean-to-atmosphere heat transfer occurs. This current system contributes substantially to the transport and redistribution of heat.

What if the conveyor shuts down?
Ice core records have shown that major rapid climate change events have occurred throughout the last 110,000 years, and probably throughout Earth's climate history. Many of these events were associated with a shutdown of the world's "Great Ocean Conveyor Belt." Slowing thermohaline circulation, or oceanic mixing, would limit carbon dioxide absorption in the deep ocean and would allow more to build up in the atmosphere, leading to additional global warming. It also would slow the northward transport of heat by Atlantic Ocean currents, slowing the rate of warming in the North Atlantic.

Great Ocean Conveyor Belt: Thermohaline circulation

An ocean circulation pattern known as the "conveyor" moves heat around Earth through a globally interconnected movement of ocean waters primarily driven by differences in heat and salt content known as thermohaline circulation ("therm" for heat and "haline" for salt.) Warm, low-salinity water flows north along the surface of the Atlantic, becoming saltier (red path). Cooling of this saltier water in the North Atlantic produces high enough densities for the water to sink and flow southward in the deep ocean and into other ocean basins (blue path). If Arctic ice melts and the North Atlantic waters grow warmer and less salty, they will no longer sink. Some scientists speculate that the conveyor might suddenly shut down, slowing the Gulf Stream and dropping temperatures significantly across Europe and the Northeast United States.

The role of the North Atlantic

Ocean water sinks when it is dense. The colder and saltier the water, the denser it becomes. Because it fits this cold and salty profile, the water of the North Atlantic propels a "conveyor belt" of oceanic circulation that, as a consequence, drives heat from the tropics up along the East Coast of North America, and then to the higher latitudes. The surface warm water that moves toward Europe is the Gulf Stream and the atmospheric component of this system (the warm air over the Gulf Stream) is referred to as the "Nordic Heat Pump." This heat pump exerts great influence on climate throughout the entire Northern Hemisphere and determines whether Europe, in particular, will be cold or warm. Evidence suggests that a shutdown of the conveyor belt may have caused the turbulent European weather of the 1970s.

Ocean layers

Ocean water is structured in layers, which are important to circulation patterns. The uppermost layer, where heat is first absorbed, is mixed by wind and waves. Much of the heat absorbed by this layer goes to evaporate water, resulting in warm, humid air. This rising warmth can be a major force driving weather systems. Warm late-summer surface water from the tropical Atlantic, for example, fuels hurricanes.

Ocean and land "sinks"

Atmospheric carbon dioxide comes from many sources, most of them natural, but it is usually brought into balance by "sinks" that drain carbon out of the atmosphere. This carbon flow is called the carbon cycle.

One of the biggest "sources" is the exchange of gas between the atmosphere and the ocean surface. This exchange is actually a finely balanced two-way process, involving tremendous amounts of carbon dioxide.

Carbon dioxide in the atmosphere is constantly being dissolved in water on the surface of the oceans, while the sea surface is constantly releasing carbon dioxide back into the atmosphere. The sea surface is a sink for atmospheric carbon dioxide, i.e., it takes out more than it puts back. Similarly, the land acts as a sink; the carbon dioxide taken out of the atmosphere every year by plants is almost balanced by the total put back into the atmosphere each year by respiration and decay.

El Nino
El Nino is a good example of the strong coupling between the circulations of ocean and atmosphere. Wind on the ocean surface drives ocean circulation. while heat input to the atmosphere from the ocean, especially that arising from evaporation, influences atmospheric circulation.