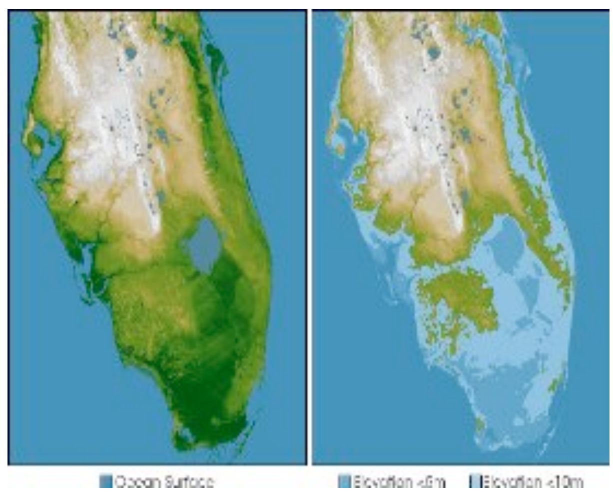
Global Climate Change:

The Science Needed to Understand the Issue



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Global climate change has become an important planetary issue, and given that K-12 students have numerous alternative conceptions or lack of prior knowledge, it is critical that teachers have an understanding of the fundamental science underlying climate change. The purpose of this study guide is to help understand the natural and human-induced factors affecting climate, and the potential consequences, and ways to mitigate and adapt to climate change.

Students and even the public often confuse weather and climate. According to the American Meteorological Society (AMS), weather is defined as the state of the atmosphere at some place and time, usually expressed in terms of temperature, humidity, cloudiness, precipitation, and wind speed and direction. Climate is defined in terms of mean and variability of temperature, precipitation, and wind over a period of time ranging from months to millions of years. It can also describe the state of the climate system with the classical period of time defined by the World Meteorological Organization as 30 years. Climate change refers to a significant change from one climatic condition to another, and global warming refers to a type of climate change whereby Earth's average temperature is increasing. At the present time, energy absorption and emission are not in balance, and globally, the Earth is experiencing a warming trend.

To understand the complexity of climate change, you will begin your study by learning about the atmosphere and the factors that influence climate across our planet.

The Atmosphere

The Composition of the Atmosphere

We live on a relatively small planet, the third from the sun. Earth is mostly rock, with 71% of its surface covered by a relatively thin layer of water (some of it frozen). It is the only planet in the solar system that appears able to support life. The other planets have compositions and conditions very different from Earth's. Venus has an average temperature of 450°C due to its thick atmosphere consisting mostly of carbon dioxide. Mars has a thin atmosphere with a very small percentage of carbon dioxide, making it much colder than Earth.

Earth also is surrounded by a relatively thin atmosphere; consisting of a mixture of gases. Nitrogen makes up 78% of these gases; oxygen, 21%; and the remaining 1% is carbon dioxide, hydrogen, and several rare and inactive gases (i.e. helium, neon, argon, krypton, and xenon). Carbon dioxide and water vapor make up less than 1% of the gases in the atmosphere, but they are very important because they trap heat more than other gases do.

The Ancient Atmosphere

In Earth's early history, the atmosphere was much different from today, and Earth did not have liquid water. Scientists think that Earth was bombarded by a lot of debris from space, which caused the outer layer of Earth to melt. After the bombardment stopped, Earth began to cool. As the molten surface became solid, gases were released into the atmosphere. These gases included water, carbon dioxide, nitrogen, and other trace gases. As Earth continued to cool, the water vapor condensed to form clouds, and great rains began. The oceans formed. The amount of water vapor and carbon dioxide in the atmosphere decreased as the rain continued to fill the ocean basins. This left Earth with a nitrogen-rich atmosphere with no oxygen. Eventually, ancient organisms evolved to use carbon dioxide, water, and sunlight to make their food energy and release oxygen. The oxygen content of the atmosphere slowly increased and other forms of life were able to evolve.

Ozone and The Ozone Hole

We breathe a form of oxygen, which has two atoms per molecule. Another form of oxygen, ozone, with three atoms per molecule, is found in the layer of the atmosphere, known as the stratosphere. Ozone absorbs most of the ultraviolet (UV) radiation coming from the sun, preventing this radiation from reaching Earth's surface. UV radiation is harmful to living things because it damages and destroys cells. UV radiation is linked to an increased incidence of skin cancers and immune system suppression. About 30 years ago, scientists discovered that the ozone layer was breaking down, so much that a large hole formed over Antarctica. Chlorofluorocarbons (CFCs) were discovered to be the cause of the decrease in ozone. CFCs were used as coolants in air conditioners and refrigerators and in aerosol spray cans. Most countries have stopped using CFCs and many scientists think that the ozone layer is recovering.

Factors that Affect Climate

Latitude and Climate

Like the other planets, the Earth rotates on its axis as it revolves around the sun. At the same time the Earth is rotating on its axis, it is also revolving around the sun. Earth is tilted on its axis 23.5°. The direction and angle of tilt do ***not*** change as the Earth moves around the sun. Therefore, as Earth revolves around the sun, the axis is tilted toward the sun part of the year and away from the sun for part of the year. When the Northern Hemisphere is tilted toward the sun, that half of the Earth has summer. At the same time, the Southern Hemisphere is titled away from the sun and has winter.

Summer and winter are not caused by the Earth's changing distance from the sun. Earth's orbit is slightly elliptical and is actually farthest away from the sun when the Northern Hemisphere is having summer. The hemisphere of the Earth that is tilted toward the sun receives more direct rays of sunlight and also has longer days than the hemisphere that is tilted away from the sun. The combination of more direct sunlight and longer days causes the hemisphere tilted toward the sun to receive more heat and have the summer season. Summer begins in the Northern Hemisphere on June 20 or 21 when the North Pole is tilted a full 23.5° degrees toward the sun. On this day, the Northern Hemisphere has the longest amount of daylight, while the Southern Hemisphere has the shortest amount of daylight. The angle of the sun above the Earth's Northern Hemisphere is greatest on this day, because of the tilt toward the sun. The North Pole has 24 hours of daylight on this day while the South Pole has 24 hours of darkness.

The Earth continues on its trip around the sun. Fall or autumn in the Northern Hemisphere begins on September 22 or 23 when the Earth is not tilted either toward or away from the sun, which means the length of day and night are equal (12 hours) all over the Earth. This day is known as the equinox, which means "equal night" in Latin. In the Southern Hemisphere, spring begins on this day.

Winter in the Northern Hemisphere begins December 21 or 22, when the North Pole is tilted a full 23.5° away from the sun. On this day, the angle of the sun is the lowest and there is the shortest amount of daylight in the Northern Hemisphere. In the Southern Hemisphere, this is the day with the longest amount of daylight and the beginning of the summer season. The North Pole has 24 hours of darkness on this day while the South Pole has 24 hours of daylight.

Spring season in the Northern Hemisphere begins March 20 or 21 when the Earth is again not tilted toward the sun. There are 12 hours of daylight and 12 hours of darkness this day. The Southern Hemisphere begins fall on this day.

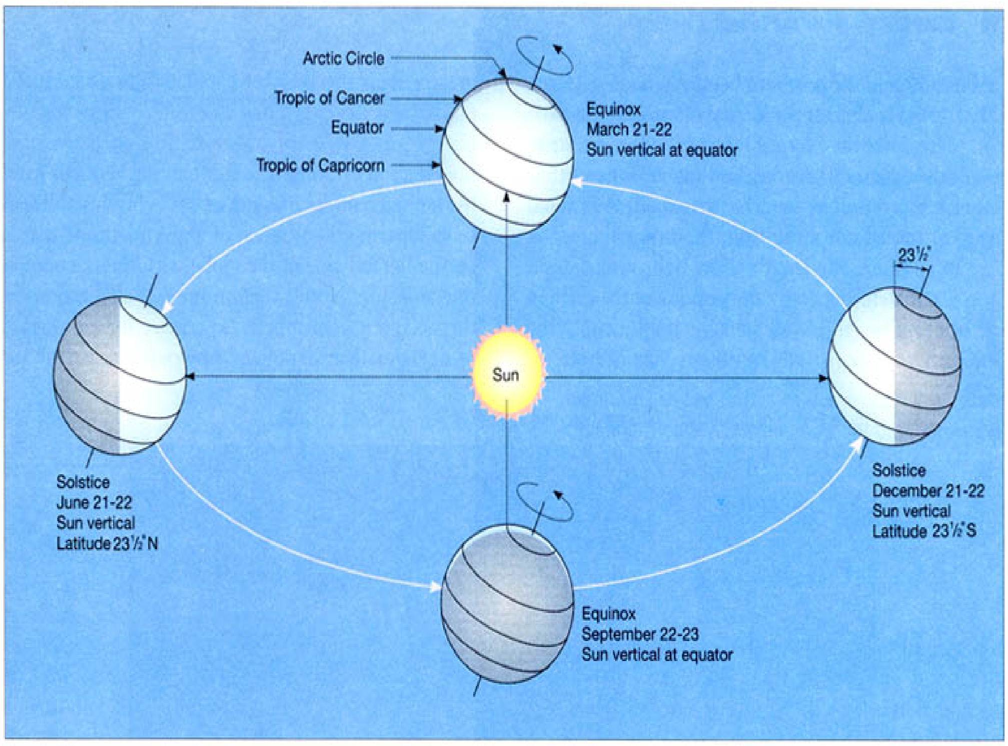


Figure 2•3 Earth–sun relationships.

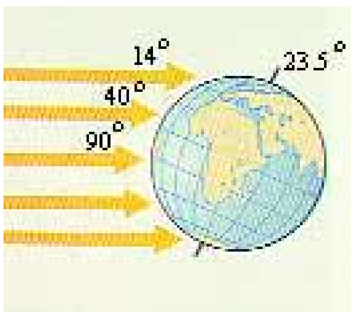
When sun's rays strike Earth's surface nearer the equator, the incoming solar radiation is spread over a smaller area than at higher latitudes. The sun's rays are more perpendicular near the equatorial region, causing the area to be warmer than areas at higher latitudes. Therefore, the higher the latitude of an area, the smaller the angle at which the sun's rays hit Earth and the smaller the amount of solar energy received by the area. At the equator (0° latitude), the sun's rays reach at a 90° angle. Temperatures near the equator are high. At higher latitudes, the angle of the sun's rays hitting Earth's surfaces is much smaller and concentrated or spread over a larger area. Areas are progressively colder as the latitude increases.

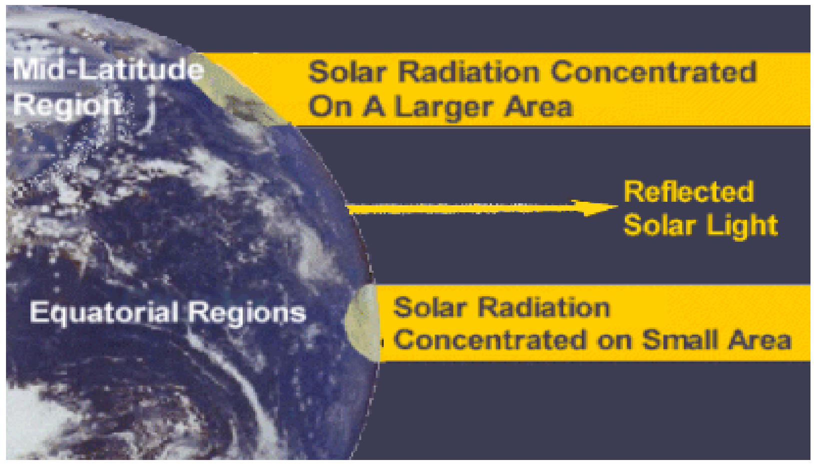
Earth-Sun Relations - Animation

http://esminfo.prenhall.com/science/geoanimations/animations/01_EarthSun_E2.html

University of Nebraska

http://astro.unl.edu/classaction/animations/coordsmotion/eclipticsimulator.html





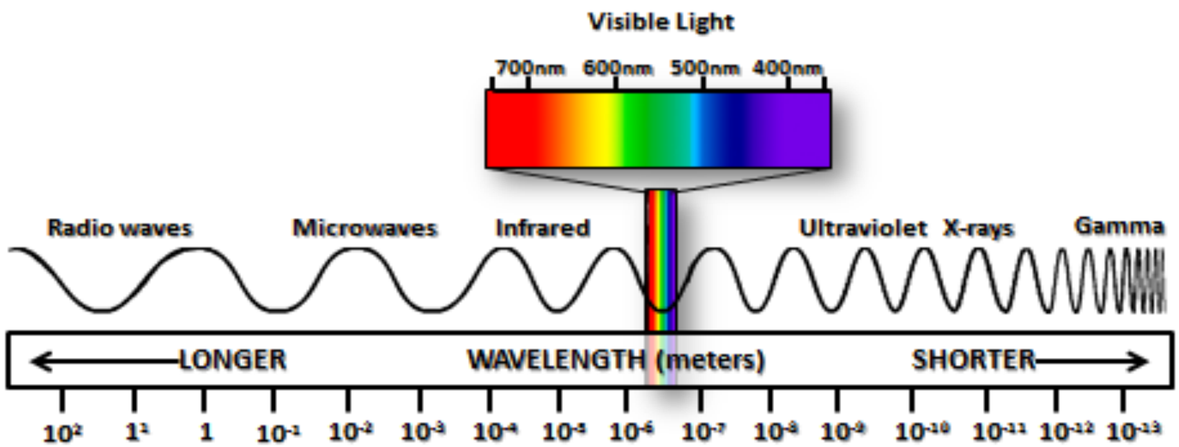
http://astro.unl.edu/classaction/animations/coordsmotion/daylightsimulator.html

University of Nebraska angle of sun animation
http://astro.unl.edu/classaction/animations/coordsmotion/transitmovie.html

Heat Transfer

Almost all of the energy available at Earth's surface comes from the sun. This energy reaches the Earth by radiation (known as solar radiation). **Radiation** is the transfer of energy by waves, such as light, through empty space. When this **radiant energy** from the sun is absorbed by the Earth, it is changed into heat.

The sun gets its energy from nuclear fusion within its inner regions. This energy eventually makes it way to the outer regions of the sun and is radiated out in the form of electromagnetic radiation. This radiation arrives mostly in the form of visible.



The Electromagnetic Spectrum

Earth's energy balance depends on the balance between the energy from the sun and the energy that is emitted from Earth back into space. Most of the solar radiation reaches Earth as visible and infrared wavelengths. As this shorter-wave solar radiation reaches the earth, a small percentage of it is absorbed, heating the surface. The remaining percentage is reflected back into space as longer- wave infrared radiation.

Heat energy is spread throughout the Earth's atmosphere in two other basic ways. **Conduction** is the direct spread of heat from one substance to another. This is why the area near the Earth's surface can be so warm on a summer day. **Convection** is the spread of heat in a gas or liquid. A **convection current** can form in the atmosphere or in bodies of water. These currents form when there is unequal heating of the atmosphere or water. Warm air or water becomes less dense and rises, while cooler air or water becomes denser and sinks.

Heat Properties of Water

The hydrogen bond, present between the molecules of water, causes water to need extra energy to break the bond and water to have an anomalously high freezing and boiling point. If there were no hydrogen bond, water would freeze at -90°C and boil at about -70°C and all of Earth would be gaseous.

Three other heat-properties of water are anomalously high because of the hydrogen bond: the heat capacity, the latent heat of fusion, and the latent heat of vaporization.

Heat Capacity is the amount of heat it takes to raise or lower the temperature of 1 g of a substance 1°C. The same amount of heat is released as water is cooled. The heat capacity of liquid water is 1 cal per gram per 1°C (1 cal/g/°C). The high specific heat of water keeps its temperature within a relatively narrow range.

Soil, rock, and metals have heat capacities of about 0.2 cal/g/°C compared to water, which has a heat capacity of 1 cal/g/°C. The difference is important ecologically. When the sun shines, the rocks, soil, and buildings on land warm faster that the ocean and other bodies of water do.

Water has 3 phases: solid, liquid, and gas. Water's **latent heat of fusion** and **latent heat of vaporization** are the amounts of heat that must be added to ice at the freezing point and to water at the boiling point to overcome the hydrogen bond attraction and change the phase from ice to water and water to water vapor.

The Water Cycle

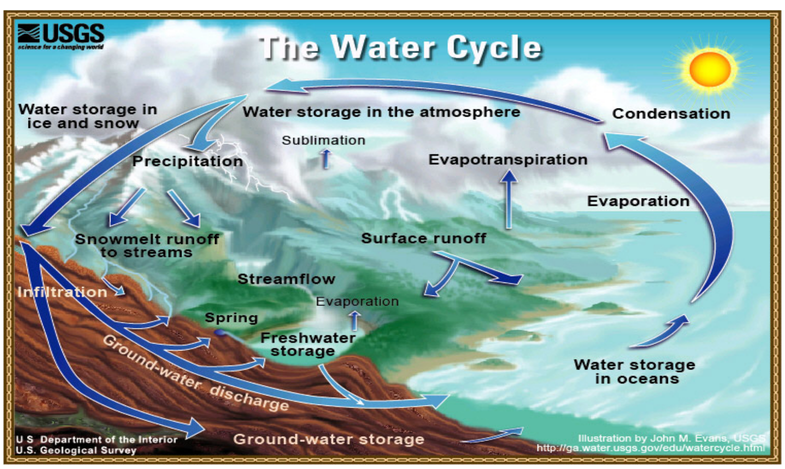
The water or **hydrologic cycle** is the constant exchange of water in its various forms of liquid, solid (ice and snow), and gas (water vapor) between the earth, the oceans, and the atmosphere. The hydrologic cycle constantly renews Earth's supply of fresh water.

The sun provides energy to drive the system as it heats the earth, causing evaporation of liquid water. Evaporation takes place from the surface of all the bodies of water on the earth as well from soil and living organisms. As plants transport water from their roots, much of the water evaporates through the leaves into the atmosphere. This is called **transpiration.**

Water vapor rises with warm air. As it moves farther away from the Earth's surface, the warm air cools. Cool air cannot hold as much water vapor as warm air. In cooler air, most of the water vapor condenses into droplets of water that form clouds. The temperature at which water vapor condenses is called the **dew point**. Clouds form as water vapor condenses on small particles (cloud condensation nuclei) in the atmosphere.

Precipitation forms when the water droplet that form in clouds become to numerous and heavy to stay in the air. The water falls as rain, snow, or ice and fall back to Earth's surface.

When precipitation reaches the Earth, it is evaporated, or flows over the surface (known as **runoff**) where it may accumulate in ponds or lakes or eventually reach streams, rivers, and the ocean. Plants require water and absorb it. Water may also be absorbed into the ground and become **groundwater** or frozen in snow or ice.



Air Pressure and Winds

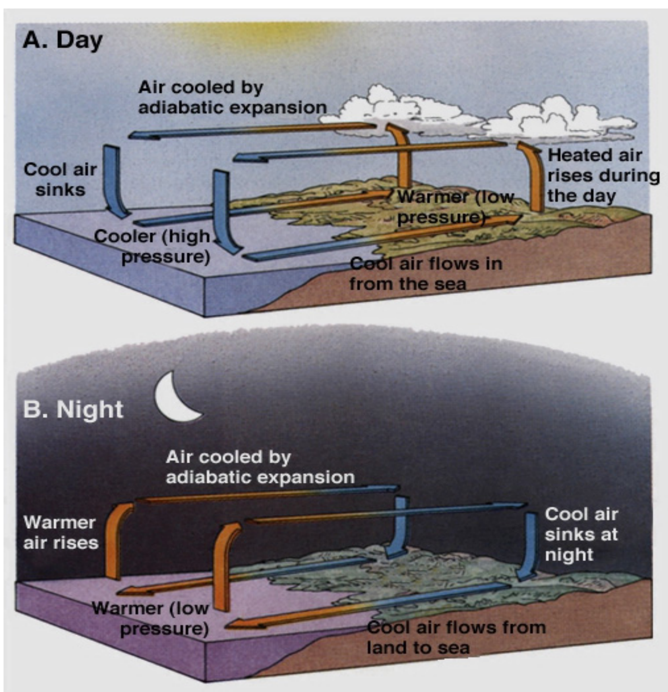
Air pressure at any point on Earth depends on the density of the air. Factors affecting density are temperature, water vapor, and elevation. The density of a fluid (gas or liquid) decreases when the fluid is heated. Less dense air exerts less pressure. Air with a large amount of water vapor is less dense than dry air because the water molecule has lass mass than either a nitrogen or an oxygen molecule. As elevation or altitude increases, the air becomes less dense.

Wind is the movement of air from an area of high pressure to an area of low pressure. There are two general types of winds – **Local** and **Global**. Both local and global winds are caused by differences in air pressure due to unequal heating of the atmosphere.

Local Winds

During the day, the air over a land area is often warmer than the air over a nearby lake or sea. The air is warmer because the land heats up faster than the water. As warm air over land rises, an area of low pressure is created. Cooler sinking air creates an area of high pressure over the sea. Air moves from an area of high pressure to an area of low pressure. This called a **sea breeze**. Winds are named for the direction from which the wind is blowing.

During the night, the land cools off faster than the water. The air over the sea is now warmer than the air over the land. The warm air over the sea rises and the cooler air over the land moves to replace the rising warm air. This is called a **land breeze**.



A **monsoon** is a major land and sea breeze that occurs seasonally in Asia. During the winter, when the sun's altitude is lower, air pressure builds over the Asian continent and causes air to flow southward into Southeast Asia and India. In the summer, when the sun's altitude is higher, air pressure is lower over the Asian continent, and the wind blows from the ocean to the land, bringing warm temperatures and huge amounts of rain.

Global Wind Patterns

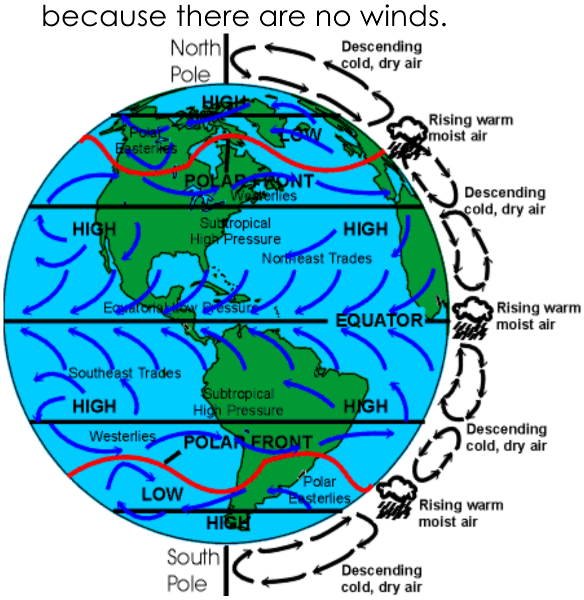
Large global wind systems are created by the uneven heating of the Earth's surface. These global wind systems, in turn, drive the oceans' surface currents. To understand how global winds form and drive the major ocean currents, students should know that wind is the basically the movement of air from an area of high pressure to an area of low pressure. Pressure is force per unit area, and **air pressure** is simply the weight (force) of the column of air above a particular location, per unit area. Air pressure therefore depends on elevation or altitude (higher up means less air above), the average temperature of the air above the particular location (hot air is lighter than cold air), and what the air's composition is. For example, air with a large amount of water vapor is less dense than dry air because the water molecule has less mass than either a nitrogen or an oxygen molecule. As elevation or altitude increases, the air becomes less dense.

Global Wind Patterns

Unequal heating of the Earth's surface also forms large global wind systems. In area near the equator, the sun is almost directly overhead for most of the year. Warm air rises at the equator and moves toward the poles. At the poles, the cooler air sinks and moves back toward the equator.

Global winds do not move directly from north to south or south to north because the Earth rotates. All winds in the Northern Hemisphere, therefore appear to curve to right as they move. In the southern hemisphere, winds curve to the left. This is known as the **Coriolis effect**, which is the apparent shift in the path of any fluid or object moving about the surface of the Earth due to the rotation of the Earth. **Global Winds include the following.**

Doldrums – at the equator, surface winds are calm and called the doldrums. A belt of air around the equator receives much of the sun's radiant energy. The warm, rising air produces a low-pressure area extending many kilometers north and south of the equator. Cooler, high-pressure air would normally flow into an area with low pressure, but the cooler air is warmed so rapidly near the equator that the winds that form cannot move into the low pressure area. The area is known as the doldrums because there are no winds.



Trade Winds – About 30° north and south of the equator, the warm air rising from the equator cools and begins to sink. Here the sky is clear. There are few clouds and little rainfall. Winds are calm. These are called the horse latitudes, because when food ran out, sailors had to throw horses overboard. At the horse latitudes some of the sinking air travels back toward the equator. The air moving back toward the equator forms warm, steady winds, known as the **trade winds**.

Prevailing Westerlies – Some of the cool, sinking air continues to move toward the North and South. These winds are called the westerlies and are located between 40° to 60° latitude in both hemispheres.

Polar Easterlies – In both hemispheres, the westerlies start rising and cooling between 50° and 60° latitude as they approach the poles. They meet extremely cold air flowing toward the equator from the poles and form the **polar easterlies**.

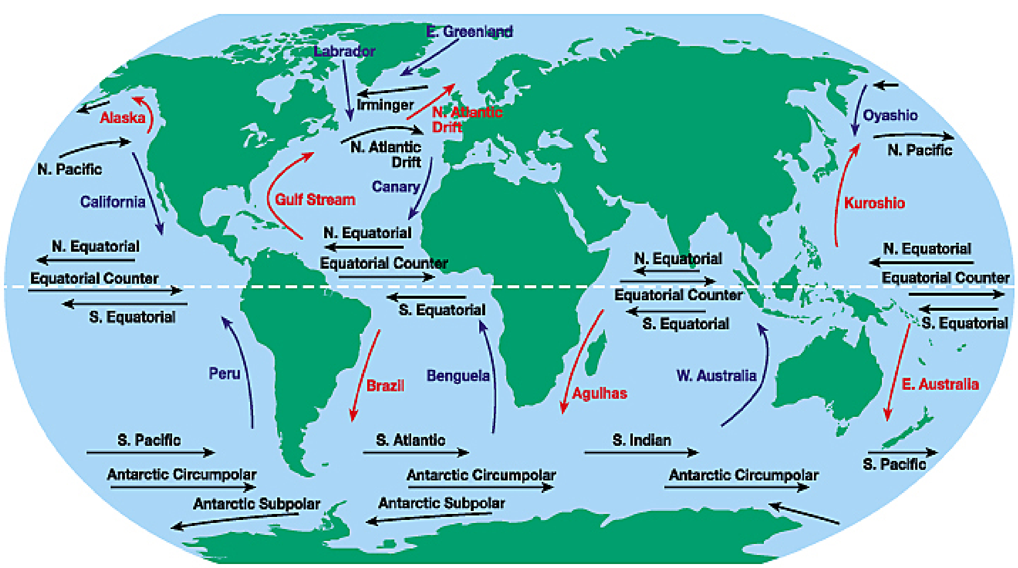
Ocean Currents

The ocean helps regulate Earth's climate because currents move heat that is absorbed from the sun's rays. Ocean currents may form near the surface due to the global wind patterns you just learned about or they may form deep in the oceans and move along the ocean floor.

Surface Currents

Surface waters of the Earth's ocean are moved primarily by winds. The sun's energy drives the major wind systems of the atmosphere. Because of Earth's spherical shape, the surface is heated unequally. The result is global wind patterns, which cause winds to blow across the oceans. Where winds blow in the same direction for long periods of time, currents develop and transport large masses of water over long distances.

As these currents flow along the edges of continents they affect the land's climate. On the East Coast, the Gulf Stream, which comes from the equatorial region, carries warm water and keeps the eastern coast of the U.S. relatively warm. The California Current comes from the polar region and carries cold water along the West Coast. This is why it is too cold for most people to swim at northern California beaches.



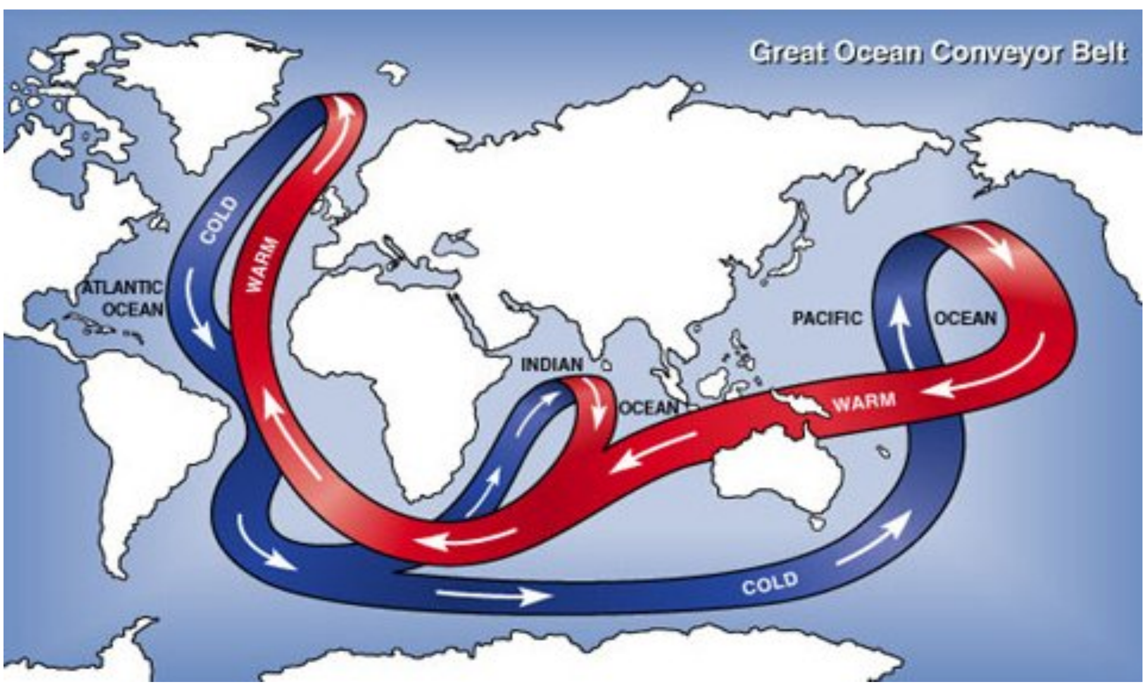
Deep Density-Driven (Thermohaline) Currents

Deep ocean currents are caused by density differences in water. Warmer, less saline water masses rise and colder, more saline water masses sink. Warmer water masses are found near equatorial regions and colder water masses are found near polar regions. More saline water masses are found in areas where there is a lot of evaporation or in polar areas where ice is formed. Less saline water is found where there is more precipitation or river input.

Together, the surface and deep currents of the oceans distribute heat. The ocean regulates global climate by absorbing and releasing heat as the water is transported around the Earth. Over the past few million years, ocean currents have flowed in the same general patterns. Some small changes have occurred as Earth's climate has slowly varied between ice ages and warmer periods. Today, however, we are facing a situation unlike any in the past. Due to an increased amount of greenhouse gases in Earth's atmosphere, the Earth's temperature could rise by as much as 10°C over the next 100 years. Warmer ocean temperatures will have a great effect on currents, sea level, and the climate of the Earth.

The surface ocean currents have a strong effect on Earth's climate. Areas near the equator receive more heat than areas near the poles. However, these areas are not constantly getting warmer and warmer. This is because the oceans and winds transport heat around the Earth from lower latitudes near the equator to higher latitudes near the pole.

The deep (density) ocean currents also have a strong effect on Earth's climate. Water in the North Atlantic Ocean is cold and salty. This colder, salty water sinks because of its greater density. It then flows southward deep in the ocean. This deep current flows throughout the Earth's oceans and eventually mixes with the surface currents and helps return surface water to the North Atlantic. This "conveyer belt" circulation of water moves heat around the Earth. One drop of ocean water in the North Atlantic Ocean takes about 1000 years to return to the same spot.



Scientists do not completely understand this flow of water, but they do believe that if Earth's atmosphere continues to warm, water will not sink as much in the North Atlantic Ocean. This may cause the global flow of ocean water to slow, drastically changing Earth's climate. Scientists think that if the conveyor slows or stops, the warmer surface water would not be propelled back toward the north Atlantic through the Gulf Stream. This could cause Europe to be frozen.

El Niño-Southern Oscillation

The El Niño-Southern Oscillation (ENSO) is a cycle of changing wind and ocean current patterns in the Pacific Ocean. Every 3 to 10 years, El Niño, which is the warm water condition of the ENSO, occurs causing the water temperature off of South America to be warmer. Warm water is transported westward in the Pacific by the trade winds until it accumulates near Indonesia and flows back to the east along the equator. During an El Niño, the southeastern trade winds decrease and warm water flows toward Peru, preventing the upwelling of nutrient-rich water. This can have devastating effects on marine life and can change global weather patterns. During an El Niño, typhoons, cyclones, and floods may occur in the Pacific Ocean and southeastern US. Droughts may occur in other areas of the world. La Nina is a cool-water phase.

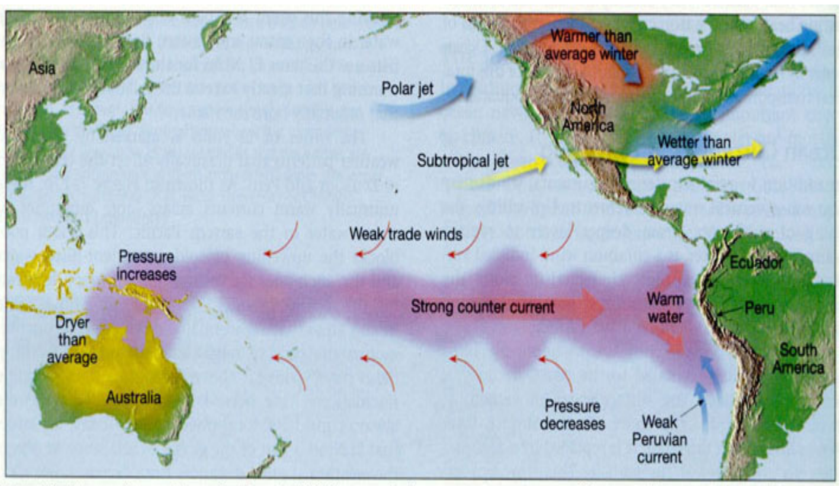


Fig.14 Upon the advent of an ENSO event, the pressure over the eastern and western Pacific flip-flops. This causes the trade winds to diminish, leading to an eastward movement of warm water along the equator. As a result, the surface waters of the central and eastern Pacific warm, with far-reaching consequences to weather patterns.

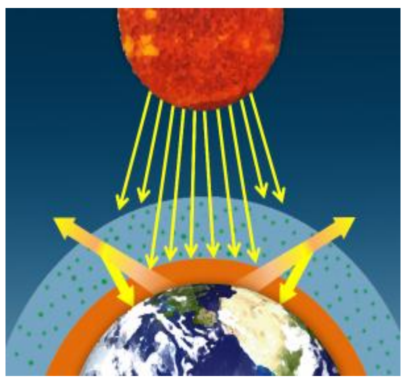
Global Climate Change

Climate change means that a significant change from one climatic condition to another is occurring, and **global warming** refers to a type of climate change whereby Earth's average temperature is increasing. Now that you understand some factors that affect climate, you are ready to learn more about climate change and global warming.

The Greenhouse Effect and Climate on Earth

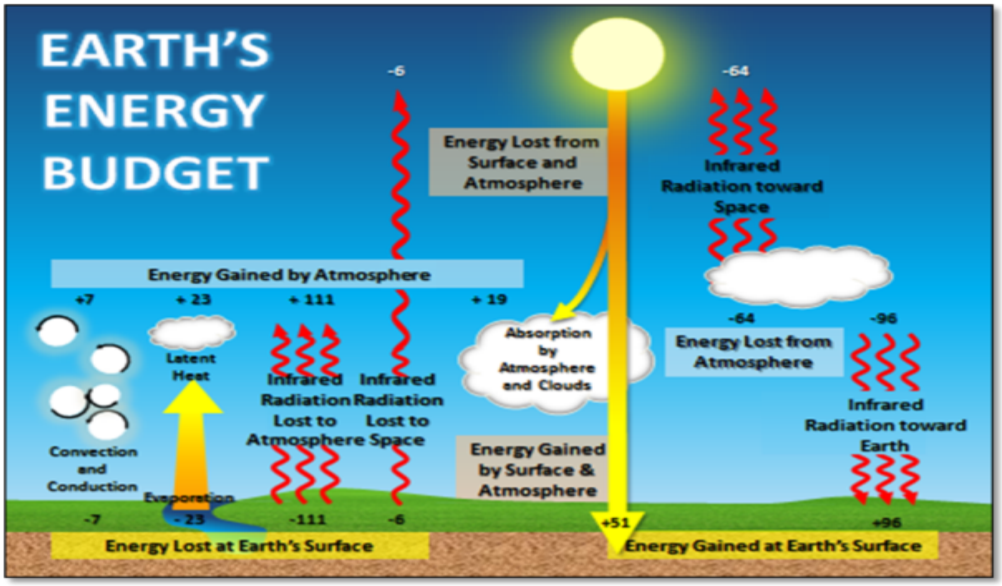
Sunlight passes easily through the atmosphere and reaches the Earth. This sunlight is absorbed mostly at Earth's surface by land, water, and vegetation. However, some of this energy is reflected or radiated back from the Earth's surface and by clouds to the atmosphere in the form of infrared rays or heat. In addition, some of the solar energy is converted to heat, which is radiated back from earth and the atmosphere to space in the form of infrared radiation. Much of this infrared radiation cannot pass back out into space through the atmosphere, because some of this radiation is absorbed by greenhouse gases. The greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. The process is known as the **greenhouse effect (Figure 2)** because these gases absorb infrared radiation and re-emit the infrared radiation to Earth's surface. Water vapor, carbon dioxide, and methane absorb the longer-wave infrared radiation, which cause Earth to be warmer than a planet without a greenhouse effect. This keeps Earth's average surface temperature at about 15°C (57°F).

A Simplified Diagram of the Greenhouse Effect



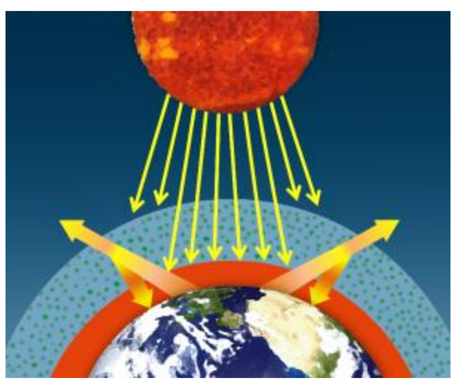
When averaged over a long period of time, the amount of energy received from the sun (solar radiation) and the amount emitted from Earth (terrestrial radiation) have been approximately in balance – known as radiative balance. At the present time, however, the energy inputs and outputs are not in balance and the Earth's surface is heating up.

Earth's Radiative Energy Budget



The burning of fossil fuels releases a significant amount of greenhouse gases into the atmosphere. As the concentration of these gases increases in the atmosphere, more infrared radiation is absorbed and emitted back toward Earth, causing an enhanced or intensified greenhouse effect and an increase in temperature.

A Simplified Diagram of an Intensified (Enhanced) Greenhouse Effect



To assess our understanding of climate change, the United Nations convenes a group of scientists about every five years. This group, known as the Intergovernmental Panel on Climate Change (IPCC), represents over 150 nations. The panel identifies options for societies to lessen (mitigate) the rate of change and adapt to the regional results of climate change. The IPCC's fourth report was produced in 2007 and states that global warming is unequivocal and primarily human-induced. Since 1906 and 2005, the Intergovernmental Panel on Climate Change (IPCC) (2007) estimated that the average temperature has increased by 0.74°C.

Methods for Studying Climate Change

Scientists study the past climate by several methods. First humans have kept records for of temperature and rainfall for over 100 years. Tree rings and coral reefs indicate past growth rates. Trees grow faster in warm and moist years, while coral reefs grow faster in warmer waters. Ice cores from polar regions can be used to measure the relative snowfall amounts over time. The air trapped in the ice when it froze provides a historical record of the gases in the atmosphere, which correlate to temperature.

The oxygen isotope ratio is another way to determine past temperatures. Isotopes are atoms of the same element that have a different number of neutrons. All isotopes of an element have the same number of protons and electrons, but a different number of neutrons. Because isotopes have a different number of neutrons, they have different mass numbers. Oxygen's most common isotope has a mass of 16 and is written ^{16}O. Marine shells contain both isotopes ^{16}O and ^{18}O. Because it is lighter in mass, ^{16}O will evaporate more easily than ^{18}O. When the ocean is cold, it takes more energy to evaporate the heavier isotope, ^{18}O, than it does to evaporate the lighter isotope, ^{16}O. Hence, the ratio of ^{18}O to ^{16}O is of seawater is higher in cooler climates.

Methods of Studying Past Climates

Method	Measurement	Indicator	Time Span
Thermometers	Temperature	Temperature at specific locations	Past 150 years
Tree rings	Ring width	Thin rings indicate cool weather and less precipitation.	Hundreds to thousands of years.
Ice cores	Concentration of gases in ice and meltwater	Amount of CO_2 in atmosphere (High levels indicate warmer climates.)	Hundreds of thousands of years
Ocean sediments	Concentration of oxygen isotope (^{18}O) in shells of microorganisms	Higher ^{18}O levels indicate colder climate.	Hundreds of thousands of years.
Fossils	Pollen types, leaf shapes, and animal body adaptations	Flower pollens and broad leaves indicate warm climates; evergreen pollens and small, waxy leaves indicate cool climates. Animal fossils show adaptations to climate changes.	Millions of years

Because many factors influence climate, studying climate is complicated. Scientists use computers to generate models to help them understand climate change. Computer models are complex because they model interactions between variables (e.g. oceans, wind, land, clouds, vegetation, etc.) that influence climate. These models simulate the many factors that influence climate, including precipitation, temperature, wind patterns, and sea level changes.

Causes of Climate Change

For the past 8,000 years, the Vostok ice core of Antarctica and Greenland records indicate that Earth's climate has been in an unusually stable. During this time, human civilization has developed and populated the world to over 7 billion today. If you want to know what number you were, go to: http://populationaction.org/Articles/Whats_Your_Number/Summary.php.

As you just learned, the average annual amount of energy coming in to Earth has been balanced by the energy being sent back to space. Any factor that causes a change to this balance is known as a **radiative forcing** or a **forcing**. A **positive forcing**, such as that produced by increasing concentrations of greenhouse gases, tends to warm the Earth's surface. A **negative forcing**, such as that produced by airborne particulates that reflect solar energy, tends to cool the Earth's surface. Forcings may also be either natural- or human-caused (also known as anthropogenic).

Natural Causes of Climate Change

Earth's climate has changed throughout geologic history, and most all of the changes have occurred due to natural factors. Some of these factors include volcanic eruptions, solar activity, plate tectonics, and Earth's orbital changes. *Volcanic eruptions* emit carbon dioxide and also dust particles, which may block sunlight, causing a cooling effect. The total amount of *solar radiation* varies by very small amounts. About 300 years ago, there was a period of reduced solar activity. This was called the Little Ice Age. The sun emits slightly more radiation during active periods of sunspots, which appear in approximately 11-year cycles. When *tectonic plates move*, landmasses are in different positions and latitudes. These changes affect global circulation patterns of air and ocean water and the climate of the continents. One form of evidence for plate tectonics and an example of how plate tectonics affects climate is the location of coal mines. Coal mines were formed over millions of years ago in tropical areas, yet are found at higher latitudes today.

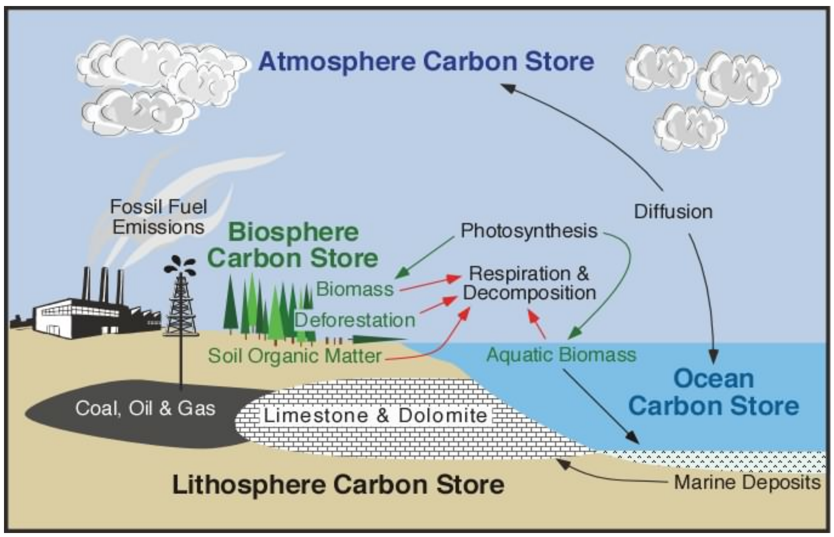
An ice age (glacial period) is a long period of climatic cooling, during which continents have repeated glaciations. A decrease in average global temperature of 5 degrees Celsius may be enough start an ice age. The Milankovitch Theory is the theory that cyclical changes in Earth's orbit and tilt occur over thousands of years and is the most accepted theory for explaining glacial and interglacial periods. Earth's orbit can be nearly circular, as it is presently, or more elliptical. This change, known as eccentricity, occurs every 100,000 years. The tilt of Earth's axis varies between 22.2 and 24.5 degrees every 41,000 years. Earth's axis also makes a complete circle every 25,700 years. During an ice age, sea level is lower because more water is in the form of ice. Sea level rises in the interglacial periods. Therefore, sea level has been rising since the last Ice Age peaked about 20,000 – 18,000 years ago.

The Carbon Cycle and Natural Cycles of Carbon Dioxide Exchange

Pure carbon is very rare. It is found in nature as the minerals, graphite and diamond. Most carbon is bonded to other elements to form compounds. Carbon, is especially of interest, because in the form of carbon dioxide, it is the major greenhouse gas. Calcite ($CaCo_3$) is a mineral found in sedimentary and metamorphic rocks. Hydrocarbons (such as coal, oil, and natural gas) are compounds made of hydrogen and carbon.

Carbon also combines with hydrogen and oxygen to form the basic compounds that make up living things. Carbon is the building block of life. We (as well as all of the other plants and animals on earth) are made of carbon (50% of our dry weight). It is the element that all organic substances contain from fossil fuels to DNA. Carbon cycles through the all four of Earth's spheres – the atmosphere, hydrosphere, geosphere, and biosphere. The cycle is known as the carbon cycle.

Carbon dioxide constantly moves into and out of the atmosphere through four major processes: photosynthesis, respiration, organic decomposition or decay, and combustion or burning of organic material. Carbon is found on Earth in three large reservoirs – as carbon dioxide in the atmosphere, as dissolved carbon dioxide in the oceans, and as coal, oil, natural gas, and calcium carbonate rock underground.



Natural Processes that Remove Carbon Dioxide

Carbon dioxide may be removed from the atmosphere when it is: 1) used by plants and algae for photosynthesis, 2) dissolved in water, or 3) buried in the sediments.

Photosynthesis. Green plants use water from the soil and carbon dioxide from the atmosphere to make glucose and oxygen in the process of **photosynthesis**. In the ocean, algae carry on the same process. During photosynthesis, light energy is converted into chemical energy. Plants and algae make more glucose in photosynthesis than they consume in respiration. The excess glucose produced by these photosynthetic organisms becomes the food consumed by animals.

$$6CO_2 + 6H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

carbon dioxide + water + energy glucose + oxygen

During photosynthesis, plants convert the radiant energy of the sun into chemical energy to make the carbohydrates (glucose) and produce oxygen as a byproduct. The oxygen is used by the animals and plants to oxidize food. When animals consume plants or animals that eat plants, the animals use these carbohydrates as a source of energy.

Carbon Dioxide Dissolves in Water. When carbon dioxide combines with water, it forms carbonic acid. Carbonic acid reacts with rock through chemical weathering to form bicarbonate ions that are carried by groundwater and streams to the ocean. Here marine organisms use bicarbonate to make shells, skeletons, and spines of calcite.

Deposition as Sediments. When the marine organisms die, the hard shells, skeletons, or spines settle to the ocean floor and become limestone, a type of sedimentary rock. A coral reef is huge colony of organisms that use calcium carbonate to build a hard outer skeleton.

Some carbon from decomposed or decaying organic matter is deposited as sediment. This carbon rich sediment eventually is buried and can be changed into fossil fuels (coal, oil, or natural gas) over very long periods of time.

Natural Sources of Carbon Dioxide

Carbon dioxide is added to the atmosphere naturally when 1) organisms respire, 2) organisms decompose (or decay), 3) forest fires occur, 4) rocks or skeletons are weathered, and 5) volcanoes erupt.

Respiration. During respiration, all plants and animals return both carbon dioxide and water vapor to the atmosphere. The process of respiration produces energy for organisms by combining glucose with oxygen from the air. During cellular respiration, glucose and oxygen are changed into energy and carbon dioxide. Every cell needs to respire to produce the energy it needs and this is known as cellular respiration. Therefore, carbon dioxide is released into the atmosphere during the process of cellular respiration.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + H_2O + \text{energy}$$

glucose + oxygen carbon dioxide + water + energy

Another definition of respiration is the exchange of oxygen and carbon dioxide between the blood of an animal and the environment. Carbon dioxide is also released when organisms breathe.

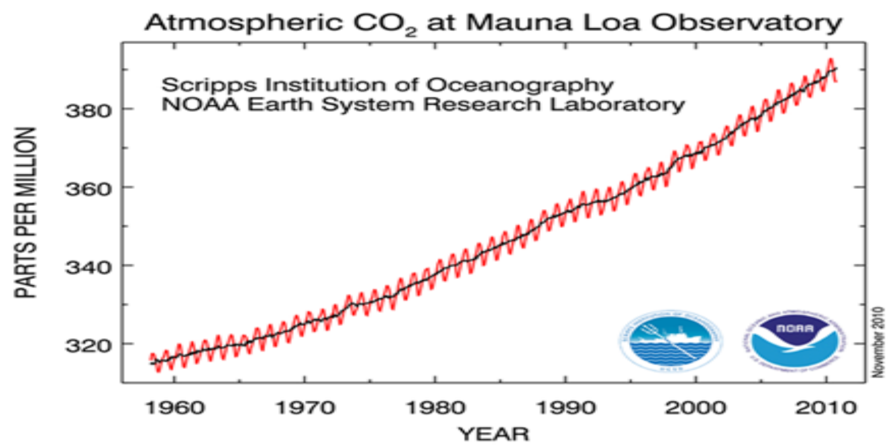
Decomposition. When organisms die and are decomposed by bacteria both on land and in the ocean, carbon dioxide is released into the atmosphere or water.

Other Sources of Carbon Dioxide. Carbon dioxide also enters the atmosphere as terrestrial plants are burned, carbonate rocks are weathered, and as carbonate rocks are vaporized inside volcanoes.

Human Activities and Climate Change

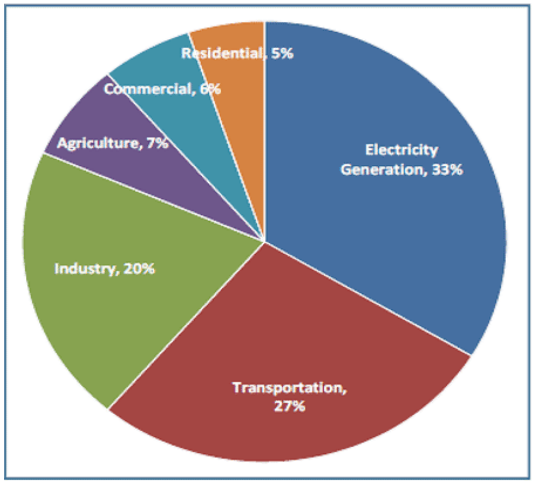
The concentration of carbon dioxide has been increasing steadily since the 1950s due mostly to the burning of fossil fuels. As the amount of carbon dioxide increases in the atmosphere, the greenhouse effect is enhanced, causing warmer temperatures.

Many scientists think that too much of the major greenhouse gas, carbon dioxide, is being added to the atmosphere. The concentration of CO_2 in the atmosphere has already increased by about 30% since the start of the industrial revolution sometime around the middle of the 19th century. The graph below shows the well-known "Keeling" the CO_2 atmospheric concentration collected atop Hawaii's Mauna Loa Observatory since 1958. Presently the level of CO_2 is 392 parts per million (ppm). (See http://www.350.org/ for the latest CO_2 concentration.)



Carbon dioxide is added to the atmosphere by human activities. When hydrocarbon fuels (i.e. wood, coal, natural gas, gasoline, and oil) are burned, carbon dioxide is released. These natural fuels come from once-living things and are made from carbon and hydrogen, which release carbon dioxide and water when they burn. Fossil fuels formed hundreds of millions of years ago as the remains of dead plants and animals were buried and changed into coal, oil, and natural gas. We are basically tapping energy that was originally stored in vegetation through photosynthesis hundreds of millions of years ago. During combustion or burning, carbon from the fossil fuels combines with oxygen in the air to form carbon dioxide and water vapor.

Fossil fuels are used to run power plants, cars and other types of transportation and to produce electricity for our homes and businesses. Coal is a type of fossil fuel (actually a sedimentary rock) that used by many power plants to generate electricity. Two-thirds of all coal reserves are in the U.S., Russia, China, and India. The U.S. uses 91% of its coal for electric power generation. Worldwide, it is estimated that coal burning accounts for 25% of the energy supply and approximately 40% of all carbon emissions to the atmosphere.

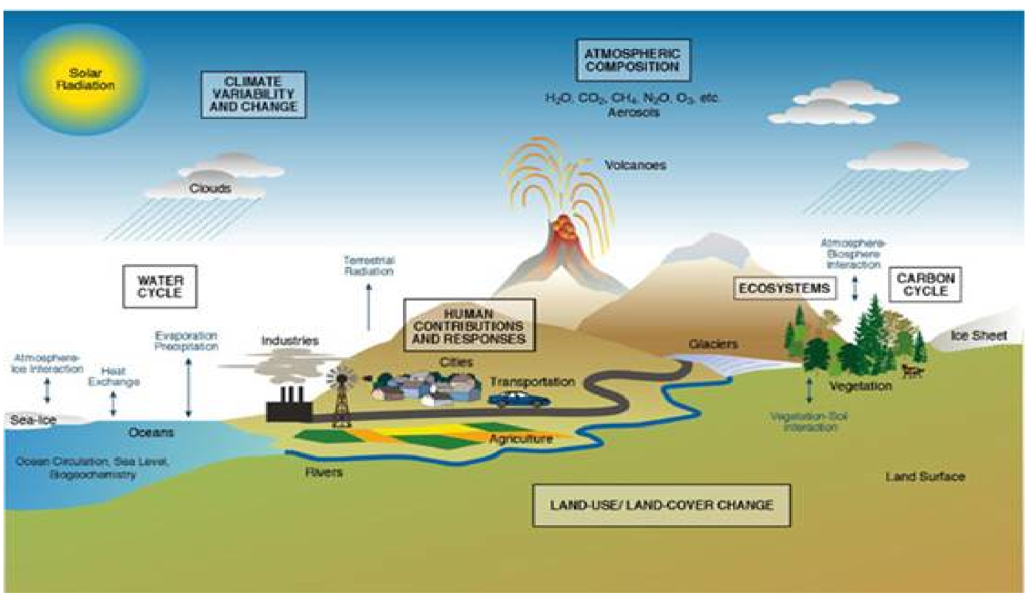


The burning of forests also releases carbon dioxide, but deforestation also affects the level of carbon dioxide. Trees reduce the amount of carbon dioxide from the atmosphere during the process of photosynthesis, so fewer trees means more carbon dioxide left in the atmosphere.

Landfills, rice farming and cattle farming release another minor greenhouse gas, called methane into Earth's atmosphere. Methane is emitted during the decomposition of organic wastes and the raising of livestock. Methane is produced as bacteria decompose organic plant and animal matter in such places as landfills, marshes, mudflats, flooded rice fields, sewage treatment plants, and the guts of cattle and termites.

Nitrogen oxides are released in the atmosphere as nitrogen-based fertilizers run-off the land and as a by-product from burning hydrocarbons. Ozone (O_3), a gas normally found in trace amounts in the atmosphere but also produced in industrial processes. Chlorofluorocarbons (CFCs), synthetic gases that were used in cleaning solvents, refrigerants, and plastic foam.

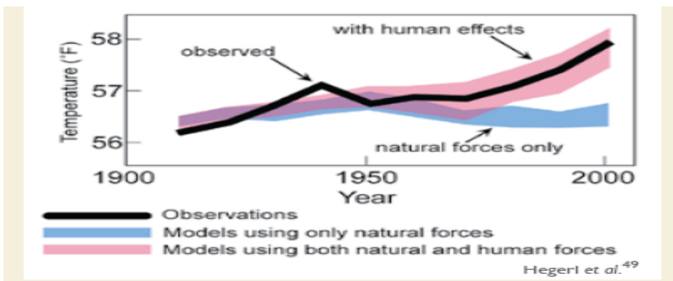
Overview of the Many Processes Involved in Climate Change



Impacts of Global Climate Change

The issue of human-induced, or anthropogenic, climate change has quickly become a major environmental issue worldwide due to its global scale and wide-range of harmful implications. As a result, the issue has become an important topic in international policy and political debates. Much of the science, particularly the result of instrument-aided observation, is relatively undisputed.

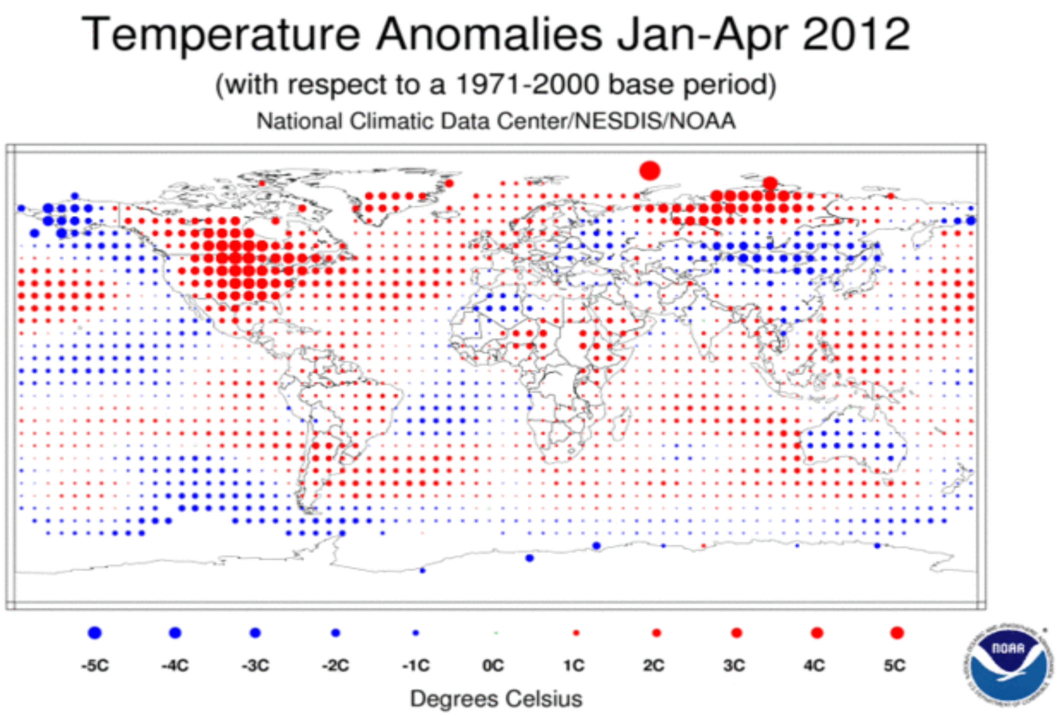
Scientists use computer models to predict climate change, and many recent climatic changes appear to be outside normal historical variability, especially over the past century. The following describes a few of the potential impacts of climate change as reported by the latest 2007 IPCC and the 2009 U.S. Global Change Research Program. **Figure 1** shows a comparison of models with natural forces and models with human effects. Actual observations correspond to the models with human effects.



The blue band shows how global average temperatures would have changed due to natural forces only, as simulated by climate models. The red band shows model projections of the effects of human and natural forces combined. The black line shows actual observed global average temperatures. As the blue band indicates, without human influences, temperature over the past century would actually have first warmed and then cooled slightly over recent decades.[58]

Rising Temperatures

Global average temperatures have increased approximately 0.7°C (1.3°F) over the last 100 years, but have increased substantially since 1970. This change in global average temperature is based on measurements from thousands of weather stations, ships, buoys, and satellites, which are independently compiled and analyzed. Models predict that if CO_2, doubles by the mid to late 21st century, temperature could rise 3°C (5.4°F) (IPCC, 2007). **Figure 4** shows the global temperature anomalies from January – April, 2012.



Source: http://www.ncdc.noaa.gov/sotc/

Changes in Precipitation Patterns

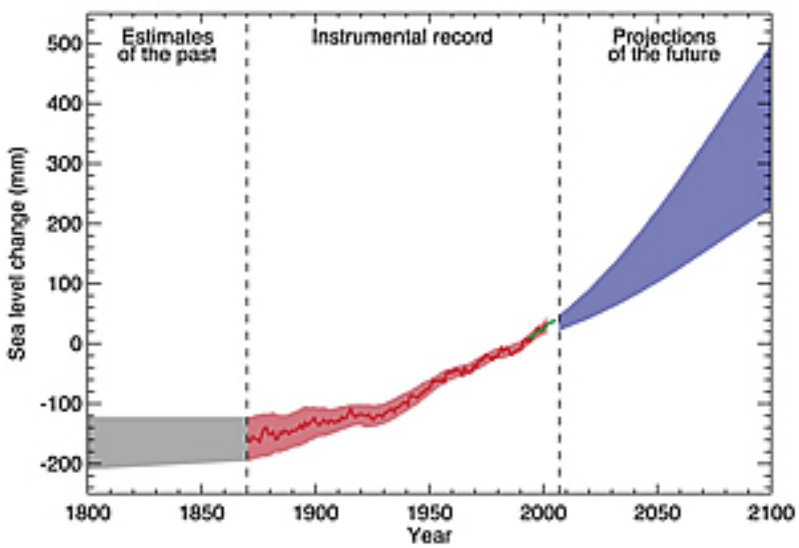
Precipitation is not distributed evenly over the planet with patterns being generally determined by atmospheric circulation, the amount of moisture, and surface topography. Warmer temperatures will cause more evaporation of water, which will eventually lead to an increased amount of precipitation, often occurring in heavy episodes. Hence, in some regions, droughts will increase; while in others, flooding will increase. With drought, forest fires also become more common.

Sea Level Rise

There are two main ways that sea levels rise due to global warming. Ocean water expands as it warms and glaciers and ice sheets melt. A glacier is a thick mass of ice originating on land as snow that remains long enough to transform into ice. Glaciers flow like a very slow river. Ice sheets are large masses of glacial ice, found only in Antarctica and Greenland. The Greenland Ice Sheet is experiencing record surface melting with a record rate of loss in the past decade. If Greenland melted, sea levels could rise by about 20 feet. If the West Antarctica Ice Sheet melted, ocean levels could rise by about 16 to 20 feet, but if the East Antarctica Ice Sheet melted, sea level could rise by about 200 feet.

The Arctic Sea ice is about one half as thick at it was in 1950 (IPCC, 2007). Even though this ice is melting, it does not contribute to sea level rise because the ice is floating on the Arctic Ocean. As floating ice melts, it does not contribute to sea level rise because of the unique properties of water. Water in the solid form (ice) is less dense than water. When ice melts, the volume of the water that was displaced is taken up by the melted ice – this is Archimedes Principle. The change in volume exactly counterbalances the extra bit of the ice that was up above the water's surface. When the Arctic Sea ice melts, ice and snow reflects more sunlight than water due to a higher albedo. With less ice, the water would absorb more heat, causing the Arctic Ocean to heat up even more.

After over 2000 years of little change, sea level rose about 8 inches during the past century due to melting of glaciers and to the expansion of water due to increased heat. Computer models predict a rise of 7 inches to as much as 23 inches (or ~18 to ~59 cm) in sea level during this century (IPCC, 2007); however, models do not include uncertainties in the climate-carbon cycle feedback nor the full dynamic processes of ice flow. **Figure 5** shows the past and the projected sea level changes.



igure 5. Sea level change (mm) from 1800 to 2100
ource:
ittp://planetearth.nerc.ac.uk/features/story.aspx?id=93

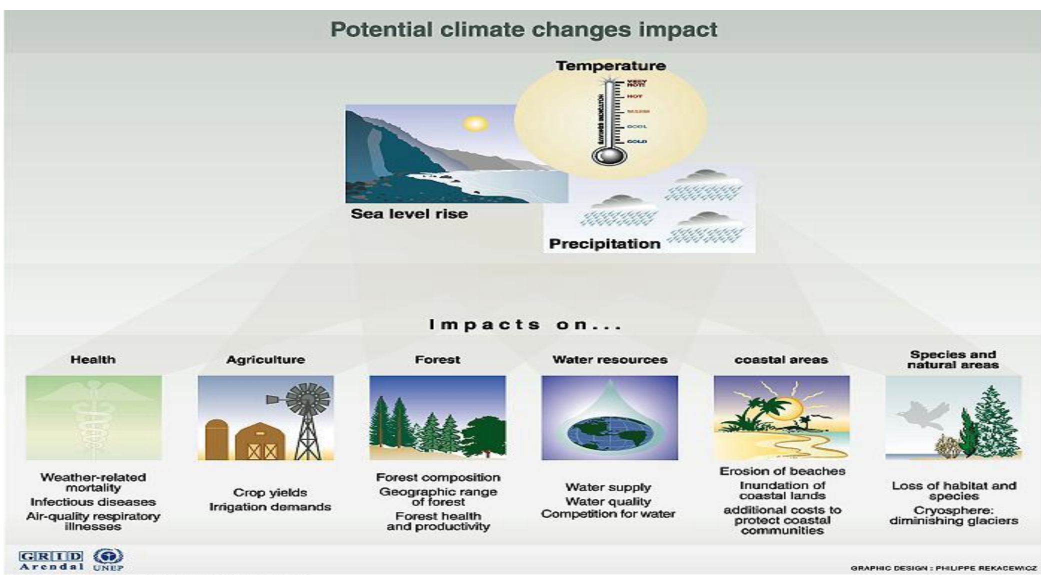
Implications of Climate Change for Life on Earth

There are many consequences of global warming for humans and ecosystems. Human health may be affected by the increase in cases of heat stress, insect-borne diseases, and shortages of water. If the temperature of the oceans warm, more intense hurricanes could occur. If the ice sheets continue to melt, sea level will rise and many coastal areas will be flooded. Changes in ecosystems will occur because organisms have different temperature requirements for living.

Ecosystems will respond to climate change in many ways. Animals may migrate to new locations more like their current climate. Plants and organisms may change to adapt to the climate, or decrease, or even become extinct. The earth has always adapted to changes in climate. However, human adaptations to these changes will be the challenge.

Warmer oceans would have an impact on many marine ecosystems. Coral bleaching occurs when corals release the symbiotic algae in their tissues. This phenomenon is linked to warmer ocean temperatures. Already approximately one-fourth of planet's coral reefs have died in the last few decades.

Ocean acidification is very alarming problem for Earth's oceans, and ultimately, life on Earth. As more carbon dioxide gas is absorbed in the ocean, the pH of the ocean becomes more acidic, therefore lowering the availability of the carbonate ions needed by organisms that build shells. This impact on organisms that build skeletons and shells out of calcium carbonate will profoundly affect ocean ecosystem and food webs. See the National Research Defense Council's film *Acid Test: The Global Challenge of Ocean Acidification Movie (22 minutes) at*: http://www.nrdc.org/oceans/acidification/aboutthefilm.asp.
For an overview of impacts of climate change, you may view this 20-minute presentation of Michael MacCracken, Chief Scientist for Climate Change Programs at The Climate Institute. He discusses global climate change impacts in the United States. The briefing was given to the US House of Representatives in Washington, DC in January 2010. http://www.ametsoc.org/atmospolicy/climatebriefing/maccracken.html.



Source: United States environmental protection agency (EPA).

Consequences for Southern Florida

Although effects of climate change, especially at regional levels, are not completely understood, it is important for decision makers to consider the potential impacts to the state of Florida. The South Florida Water Management District (District) is currently considering the threats of climate change to water supply, flood control, coastal ecosystems, and regional water management infrastructure. In 2009, the District published a report on climate change and water management to provide a foundation for future discussions on the effects of global climate on water management planning and operations. More importantly, their intent is to focus the global concepts of climate change at the regional level by providing an overview of how it may affect southern Florida's resources.

There are many significant uncertainties associated with forecasting future climate change and variability. However, southern Florida is considered to be among the world's more vulnerable areas, due to its low elevation, long coastline with 1197 miles and 663 miles of beaches, and a porous limestone base. Sea levels have been rising at a more rapid pace (1 foot during the past century, according to the tide gauge at Key West, Florida) in comparison to the last 2,000 years. During the next fifty years, southern Florida may experience seas that are in the range of 5 to 20 inches higher than current levels.

The results of sea level rise can be flooding of property and infrastructure, greater vulnerability to storm surges and erosion, and the destruction of coastal habitats. Furthermore, sea level rise would accelerate saltwater intrusion of the coastal aquifers that are currently used to provide water for much of the region

Source: www2.ucar.edu

So What Can We Do?

Even if we could stop releasing greenhouse gases, Earth would continue to warm another 0.5°C (0.9°F). ***Mitigation*** refers to taking actions that would decrease the amount of greenhouse gases emitted in order to reduce the potential effects of a warmer climate. ***Adaptation*** refers to taking actions to tolerate or adapt to a warmer climate.

Until we develop new technologies and make considerable changes to our lifestyles, we will not be able to decrease greenhouse emissions below our current levels. Another problem is that the effects of climate change are not expected to be linear. This is because positive feedback processes tend to amplify a change. For example, if global temperatures increases 2°C(3.6°F), the Greenland ice sheet will begin melting uncontrollably.

So what can we do? Personally, we can reduce our carbon footprint. (Use the websites below to calculate your footprint.) Then adopt changes that will reduce your home and transportation energy use, shop wisely, and eat less beef. In a 2006 study by the United Nations Food and Agriculture Organization found that emissions associated with livestock, from deforestation to fertilizer and cow flatulence, amount to 18% of the current human impact on climate! Finally become politically active and support research and development of new clean energy technology and most importantly teach science well and encourage your students to pursue careers in science!

Global Climate Change Website Resources

Current News

Climate Central
http://www.climatecentral.org/
Real Climate
http://www.realclimate.org/

Reports

Intergovernmental Panel on Climate Change
http://www.ipcc.ch/
Global Climate Change Impact in the United States
http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts
http://nca2009.globalchange.gov/
Pew Center on Global Climate Change
http://www.pewclimate.org/
Florida's Resilient Coasts
http://www.ces.fau.edu/files/projects/climate_change/Fl_ResilientCoast.pdf
Climate Change and Sea Level Rise in Florida: An Update of the Effects of Climate Change on Florida's Ocean & Coastal Resources
http://www.floridaoceanscouncil.org/
Human Health Perspective on Climate Change
http://www.niehs.nih.gov/climatereport

General

Global Climate Change: NASA's Eyes on the Earth
http://climate.nasa.gov/
NOAA Climate Services
http://www.climate.gov/#climateWatch

Windows to the Universe
http://www.windows2universe.org/earth/climate/climate.html
NCSE-NASA Curriculum for Interdisciplinary Climate Change Education (NNICCE)
http://www.eoearth.org/article/NCSE-NASA_Interdisciplinary_Climate_Change_Education
Student's Guide to Global Climate Change
http://epa.gov/climatechange/kids
National Wildlife Federation
http://www.nwf.org/Global-Warming.aspx
Climate, Adaptation, Mitigation, and e-Learning
http://www.camelclimatechange.org/
Journey North – Global Study of Wildlife Migration and Seasonal Change
http://www.learner.org/jnorth/
Climate Connections: A Global Journey
http://www.npr.org/templates/story/story.php?storyId=112073582
James Hansen's Website
http://www.columbia.edu/~jeh1/
Cake – Climate Adaptation Knowledge Exchange
http://www.cakex.org/
Global Climate Change Wildlife and Wetlands: A Toolkit for Formal and Informal Educators
http://www.globalchange.gov/resources/educators/toolkit
Energy Story
http://www.energyquest.ca.gov/story/index.html

Videos

NSF – video series "To What Degree?"
http://www.nsf.gov/news/special_reports/degree/
Climate Change Careers and Cartoon Videos
http://www.uen.org/climate/careers.shtml
National Geographic Videos
http://video.nationalgeographic.com/video/player/environment/global-warming-environment/way-forward-climate.html

Teaching Resources/Lesson Plans

Climate Literacy and Energy Awareness Network
http://cleanet.org/
Project Look Sharp
http://www.ithaca.edu/looksharp/?action=medialithandouts
Climate Classroom – An Inconvenient Truth Curriculum
http://www.climateclassroom.org/
Facing the Future – Lessons and Resources for Teaching About Global Issues – Climate Change Unit
http://www.facingthefuture.org/default.aspx

Guidelines for Teaching About Global Climate Change

Principles for Climate Literacy
http://www.cleanet.org/cln/climateliteracy.html
***Guidelines for K12 Global Climate Change Education* (National Wildlife Federation and the North American Association for Environmental Education)**
http://online.nwf.org/site/PageNavigator/ClimateClassroom/cc_naaee_guidelines
***Florida Sunshine State Standards* (See 6 page handout for list)**
http://www.floridastandards.org/homepage/index.aspx
AAAS Global Climate Change Resources

http://www.aaas.org/news/press_room/climate_change/
National Science Digital Library Weather and Climate Strand Map
http://strandmaps.nsdl.org/?id=SMS-MAP-1698
National Center for Science Education: Defending the Teaching of Evolution and Climate Science
http://ncse.com/climate

Climate Skeptic Resources

Skeptical Science
http://www.skepticalscience.com/
How to Talk to a Climate Skeptic
http://www.grist.org/article/series/skeptics/
Climate Skepticism: The Top 10
http://news.bbc.co.uk/2/hi/in_depth/629/629/7074601.stm
Debunking Climate Skeptics: Chuck Kutscher, Ph.D.," – very effective presentation of how to address skeptics' claims. http://www.skepticalscience.com/Video-Chuck-Kutscher-debunking-climate-skeptic-arguments.html
Climate Denial Crock of the Week
http://climatecrocks.com/overview/

Recommended Books
Textbook-Type Books

Archer and Rahmstorf (2010) – Climate Crisis
Cook and Washington (2011) – Climate Change Denial
Houghton (2009) – Global Warming: The Complete Briefing
Mann (2008) – Dire Predictions
Mathez (2009) - Climate Change: The Science of Global Warming and Our Energy Future"
Moran (2010) (American Meteorological Society) – Climate Studies: Introduction Science

Other Content-Focused Books

Archer (2009) – The Long Thaw
Blockstein (2010) – Climate Solutions Consensus
Crave (2009) - What's the Worst that Could Happen? A Rationale Response to the Climate Change Debate
Faris(2009) - Forecast: The Consequences of Climate Change from the Amazon to the Arctic, from Darfur to Napa Valley
Flannery, T. 2005 - The Weather Makers: How Man is Changing The Climate and What it Means It Means For Life on Earth.
Friedman (2008) - Hot, flat, and Crowded
Gore(2006) - An Inconvenient Truth
Gore (2009) - Our Choice
Hansen (2009) – Storms of My Grandchildren
Henson (2011) – Rough Guide to Climate Change
Hoggan (2009) – Climate Cover-Up
Klare (2008) Rising Powers Shrinking Planet: The New Geopolitics of Energy.
Lynas (2008) - Six Degrees: Our Future on a Hotter Planet
Monbiot (2007) – Heat: How to Stop the Planet from Burning
Pilkey & Young (2009) – The Rising Sea
UNEP (2009) – Climate in Peril (also online, great diagrams)

Volk (2008) – CO2 Rising: The World's Greatest Environmental Challenge
Weart (2008) – The Discovery of Global Warming

Climate Change Books that are more Interdisciplinary

Bradley (2011) – Global Warming and Political Intimidation: How Politicians Cracked Down on Scientists as the Earth Heated Up
Boykoff (2011) – Who Speaks for the Climate?
Brown (2011) – World on the Edge
Flannery (2009) – Now or Never
Gore (1992) – Earth in Balance, An Inconvenient Truth, and Our Choice
Gilding (2011) - The Great Disruption: Why the Climate Crisis will Bring on the End of Shopping and the Birth of a New World
Hayhoe (2009) – A Climate for Change: Global Warming Facts for Faith-Based Decisions
Hulme (2009) – Why We Disagree About Climate Change
Malone (2009) – Debating Climate Change
Oreskes (2011) – Merchants of Doubt: How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming
Parenti (2011) – Tropic of Chaos: Climate Change the New Geography of Violence
Powell (2011) – The Inquisition of Climate Science
Schneider (2009) – Science as a Contact Sport