Climate Resources

Fact Sheets

These Fact Sheets are the Frequently Asked Questions from the report accepted by Working Group I of the Intergovernmental Panel on Climate Change. IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

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Frequently Asked Question 1.1

What Factors Determine Earth's Climate?

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. The atmospheric component of the climate system most obviously characterises climate; climate is often defined as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years). The climate system evolves in time under the influence of its own internal dynamics and due to changes in external factors that affect climate (called 'forcings'). External forcings include natural phenomena such as volcanic eruptions and solar variations, as well as human-induced changes in atmospheric composition. Solar radiation powers the climate system. There are three fundamental ways to change the radiation balance of the Earth: 1) by changing the incoming solar radiation (e.g., by changes in Earth's orbit or in the Sun itself); 2) by changing the fraction of solar radiation that is reflected (called 'albedo'; e.g., by changes in cloud cover, atmospheric particles or vegetation); and 3) by altering the longwave radiation from Earth back towards space (e.g., by changing greenhouse gas concentrations). Climate, in turn, responds directly to such changes, as well as indirectly, through a variety of feedback mechanisms.

The amount of energy reaching the top of Earth's atmosphere each second on a surface area of one square metre facing the Sun during daytime is about 1,370 Watts, and the amount of energy per square metre per second averaged over the entire planet is one-quarter of this (see Figure 1). About 30% of the sunlight that reaches the top of the atmosphere is reflected back to space. Roughly two-thirds of this reflectivity is due to clouds and small particles in the atmosphere known as 'aerosols'. Light-coloured areas of Earth's surface – mainly snow, ice and deserts – reflect the remaining one-third of the sunlight. The most dramatic change in aerosol-produced reflectivity comes when major volcanic eruptions eject material very high into the atmosphere. Rain typically

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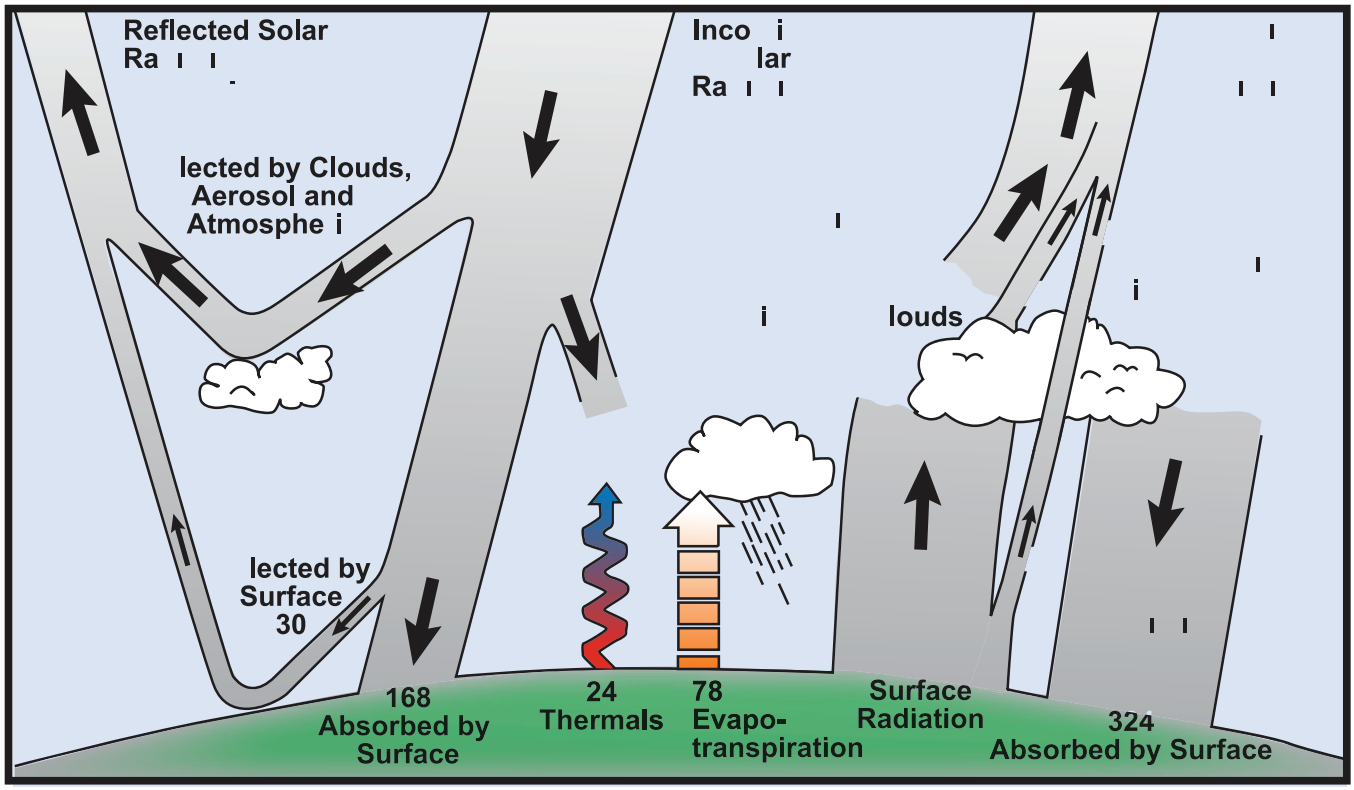

FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

clears aerosols out of the atmosphere in a week or two, but when material from a violent volcanic eruption is projected far above the highest cloud, these aerosols typically influence the climate for about a year or two before falling into the troposphere and being carried to the surface by precipitation. Major volcanic eruptions can thus cause a drop in mean global surface temperature of about half a degree celsius that can last for months or even years. Some man-made aerosols also significantly reflect sunlight.

The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere. This amount is approximately 240 Watts per square metre (W m^{-2}). To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. The Earth does this by emitting outgoing longwave radiation. Everything on Earth emits longwave radiation continuously. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates. To emit 240 W m^{-2}, a surface would have to have a temperature of around –19°C. This is much colder than the conditions that actually exist at the Earth's surface (the global mean surface temperature is about 14°C). Instead, the necessary –19°C is found at an altitude about 5 km above the surface.

The reason the Earth's surface is this warm is the presence of greenhouse gases, which act as a partial blanket for the longwave radiation coming from the surface. This blanketing is known as the natural greenhouse effect. The most important greenhouse gases are water vapour and carbon dioxide. The two most abundant constituents of the atmosphere – nitrogen and oxygen – have no such effect. Clouds, on the other hand, do exert a blanketing effect similar to that of the greenhouse gases; however, this effect is offset by their reflectivity, such that on average, clouds tend to have a cooling effect on climate (although locally one can feel the warming effect: cloudy nights tend to remain warmer than clear nights because the clouds radiate longwave energy back down to the surface). Human activities intensify the blanketing effect through the release of greenhouse gases. For instance, the amount of carbon dioxide in the atmosphere has increased by about 35% in the industrial era, and this increase is known to be due to human activities, primarily the combustion of fossil fuels and removal of forests. Thus, humankind has dramatically altered the chemical composition of the global atmosphere with substantial implications for climate.

Because the Earth is a sphere, more solar energy arrives for a given surface area in the tropics than at higher latitudes, where sunlight strikes the atmosphere at a lower angle. Energy is transported from the equatorial areas to higher latitudes via atmospheric and oceanic circulations, including storm systems. Energy is also required to evaporate water from the sea or land surface, and this energy, called latent heat, is released when water vapour condenses in clouds (see Figure 1). Atmospheric circulation is primarily driven by the release of this latent heat. Atmospheric circulation in turn drives much of the ocean circulation through the action of winds on the surface waters of the ocean, and through changes in the ocean's surface temperature and salinity through precipitation and evaporation.

Due to the rotation of the Earth, the atmospheric circulation patterns tend to be more east-west than north-south. Embedded in the mid-latitude westerly winds are large-scale weather systems that act to transport heat toward the poles. These weather systems are the familiar migrating low- and high-pressure systems and their associated cold and warm fronts. Because of land-ocean temperature contrasts and obstacles such as mountain ranges and ice sheets, the circulation system's planetary-scale atmospheric waves tend to be geographically anchored by continents and mountains although their amplitude can change with time. Because of the wave patterns, a particularly cold winter over North America may be associated with a particularly warm winter elsewhere in the hemisphere. Changes in various aspects of the climate system, such as the size of ice sheets, the type and distribution of vegetation or the temperature of the atmosphere or ocean will influence the large-scale circulation features of the atmosphere and oceans.

There are many feedback mechanisms in the climate system that can either amplify ('positive feedback') or diminish ('negative feedback') the effects of a change in climate forcing. For example, as rising concentrations of greenhouse gases warm Earth's climate, snow and ice begin to melt. This melting reveals darker land and water surfaces that were beneath the snow and ice, and these darker surfaces absorb more of the Sun's heat, causing more warming, which causes more melting, and so on, in a self-reinforcing cycle. This feedback loop, known as the 'ice-albedo feedback', amplifies the initial warming caused by rising levels of greenhouse gases. Detecting, understanding and accurately quantifying climate feedbacks have been the focus of a great deal of research by scientists unravelling the complexities of Earth's climate.

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Frequently Asked Question 1.2

What is the Relationship between Climate Change and Weather?

Climate is generally defined as average weather, and as such, climate change and weather are intertwined. Observations can show that there have been changes in weather, and it is the statistics of changes in weather over time that identify climate change. While weather and climate are closely related, there are important differences. A common confusion between weather and climate arises when scientists are asked how they can predict climate 50 years from now when they cannot predict the weather a few weeks from now. The chaotic nature of weather makes it unpredictable beyond a few days. Projecting changes in climate (i.e., long-term average weather) due to changes in atmospheric composition or other factors is a very different and much more manageable issue. As an analogy, while it is impossible to predict the age at which any particular man will die, we can say with high confidence that the average age of death for men in industrialised countries is about 75. Another common confusion of these issues is thinking that a cold winter or a cooling spot on the globe is evidence against global warming. There are always extremes of hot and cold, although their frequency and intensity change as climate changes. But when weather is averaged over space and time, the fact that the globe is warming emerges clearly from the data.

Meteorologists put a great deal of effort into observing, understanding and predicting the day-to-day evolution of weather systems. Using physics-based concepts that govern how the atmosphere moves, warms, cools, rains, snows, and evaporates water, meteorologists are typically able to predict the weather successfully several days into the future. A major limiting factor to the predictability of weather beyond several days is a fundamental dynamical property of the atmosphere. In the 1960s, meteorologist Edward Lorenz discovered that very slight differences in initial conditions can produce very different forecast results.

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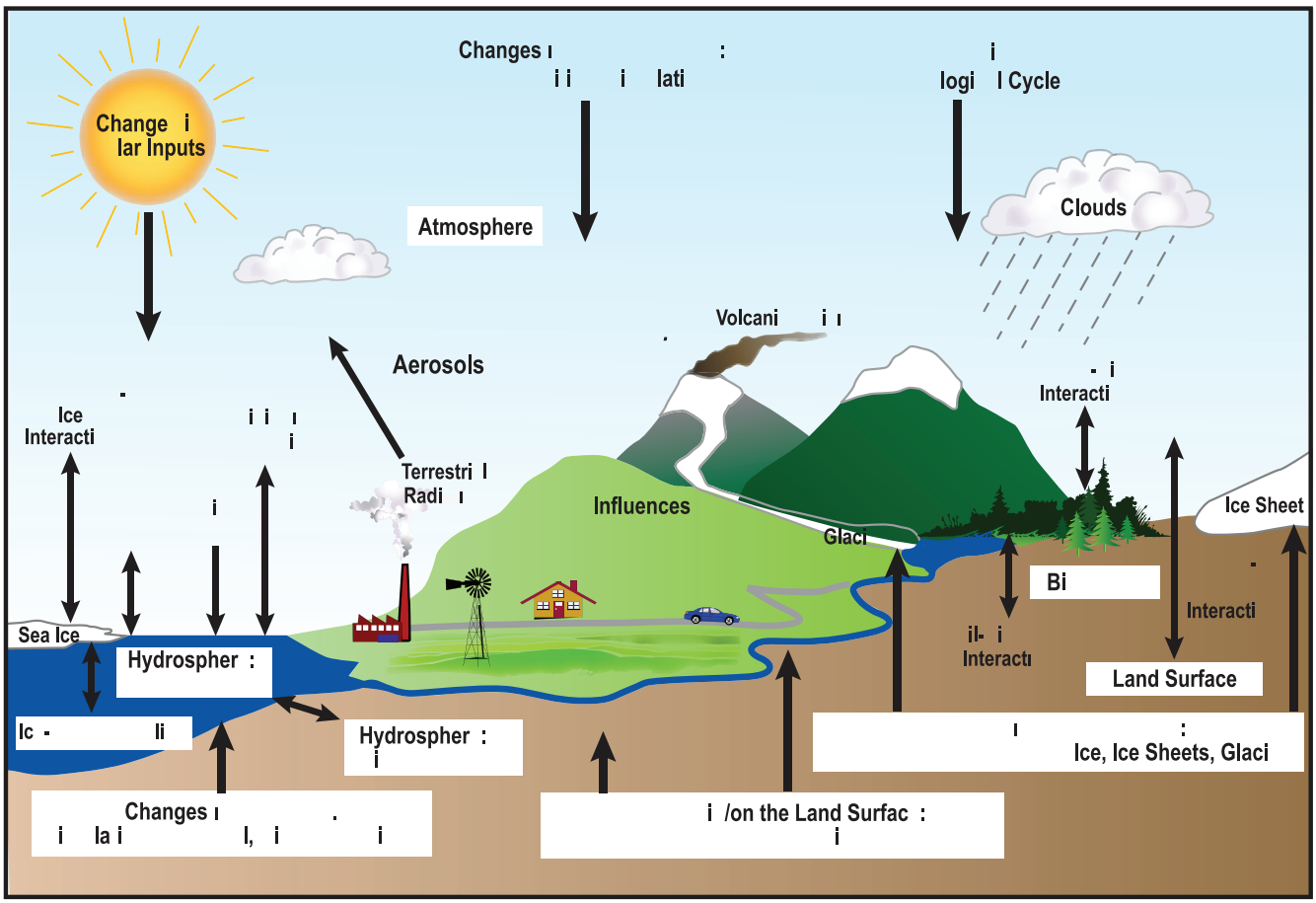

FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

This is the so-called butterfly effect: a butterfly flapping its wings (or some other small phenomenon) in one place can, in principle, alter the subsequent weather pattern in a distant place. At the core of this effect is chaos theory, which deals with how small changes in certain variables can cause apparent randomness in complex systems.

Nevertheless, chaos theory does not imply a total lack of order. For example, slightly different conditions early in its history might alter the day a storm system would arrive or the exact path it would take, but the average temperature and precipitation (that is, climate) would still be about the same for that region and that period of time. Because a significant problem facing weather forecasting is knowing all the conditions at the start of the forecast period, it can be useful to think of climate as dealing with the background conditions for weather. More precisely, climate can be viewed as concerning the status of the entire Earth system, including the atmosphere, land, oceans, snow, ice and living things (see Figure 1) that serve as the global background conditions that determine weather patterns. An example of this would be an El Niño affecting the weather in coastal Peru. The El Niño sets limits on the probable evolution of weather patterns that random effects can produce. A La Niña would set different limits.

Another example is found in the familiar contrast between summer and winter. The march of the seasons is due to changes in the geographical patterns of energy absorbed and radiated away by the Earth system. Likewise, projections of future climate are shaped by fundamental changes in heat energy in the Earth system, in particular the increasing intensity of the greenhouse effect that traps heat near Earth's surface, determined by the amount of carbon dioxide and other greenhouse gases in the atmosphere. Projecting changes in climate due to changes in greenhouse gases 50 years from now is a very different and much more easily solved problem than forecasting weather patterns just weeks from now. To put it another way, long-term variations brought about by changes in the composition of the atmosphere are much more predictable than individual weather events. As an example, while we cannot predict the outcome of a single coin toss or roll of the dice, we can predict the statistical behaviour of a large number of such trials.

While many factors continue to influence climate, scientists have determined that human activities have become a dominant force, and are responsible for most of the warming observed over the past 50 years. Human-caused climate change has resulted primarily from changes in the amounts of greenhouse gases in the atmosphere, but also from changes in small particles (aerosols), as well as from changes in land use, for example. As climate changes, the probabilities of certain types of weather events are affected. For example, as Earth's average temperature has increased, some weather phenomena have become more frequent and intense (e.g., heat waves and heavy downpours), while others have become less frequent and intense (e.g., extreme cold events).

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Frequently Asked Question 1.3
What is the Greenhouse Effect?

The Sun powers Earth's climate, radiating energy at very short wavelengths, predominately in the visible or near-visible (e.g., ultraviolet) part of the spectrum. Roughly one-third of the solar energy that reaches the top of Earth's atmosphere is reflected directly back to space. The remaining two-thirds is absorbed by the surface and, to a lesser extent, by the atmosphere. To balance the absorbed incoming energy, the Earth must, on average, radiate the same amount of energy back to space. Because the Earth is much colder than the Sun, it radiates at much longer wavelengths, primarily in the infrared part of the spectrum (see Figure 1). Much of this thermal radiation emitted by the land and ocean is absorbed by the atmosphere, including clouds, and reradiated back to Earth. This is called the greenhouse effect. The glass walls in a greenhouse reduce airflow and increase the temperature of the air inside. Analogously, but through a different physical process, the Earth's greenhouse effect warms the surface of the planet. Without the natural greenhouse effect, the average temperature at Earth's surface would be below the freezing point of water. Thus, Earth's natural greenhouse effect makes life as we know it possible. However, human activities, primarily the burning of fossil fuels and clearing of forests, have greatly intensified the natural greenhouse effect, causing global warming.

The two most abundant gases in the atmosphere, nitrogen (comprising 78% of the dry atmosphere) and oxygen (comprising 21%), exert almost no greenhouse effect. Instead, the greenhouse effect comes from molecules that are more complex and much less common. Water vapour is the most important greenhouse gas, and carbon dioxide (CO_2) is the second-most important one. Methane, nitrous oxide, ozone and several other gases present in the atmosphere in small amounts also contribute to the greenhouse effect. In the humid equatorial regions, where there is so much water vapour in the air that the greenhouse effect is very large, adding a small additional amount of CO_2 or water vapour has only a small direct impact on downward infrared radiation. However, in the cold, dry polar regions, the effect of a small increase in CO_2 or

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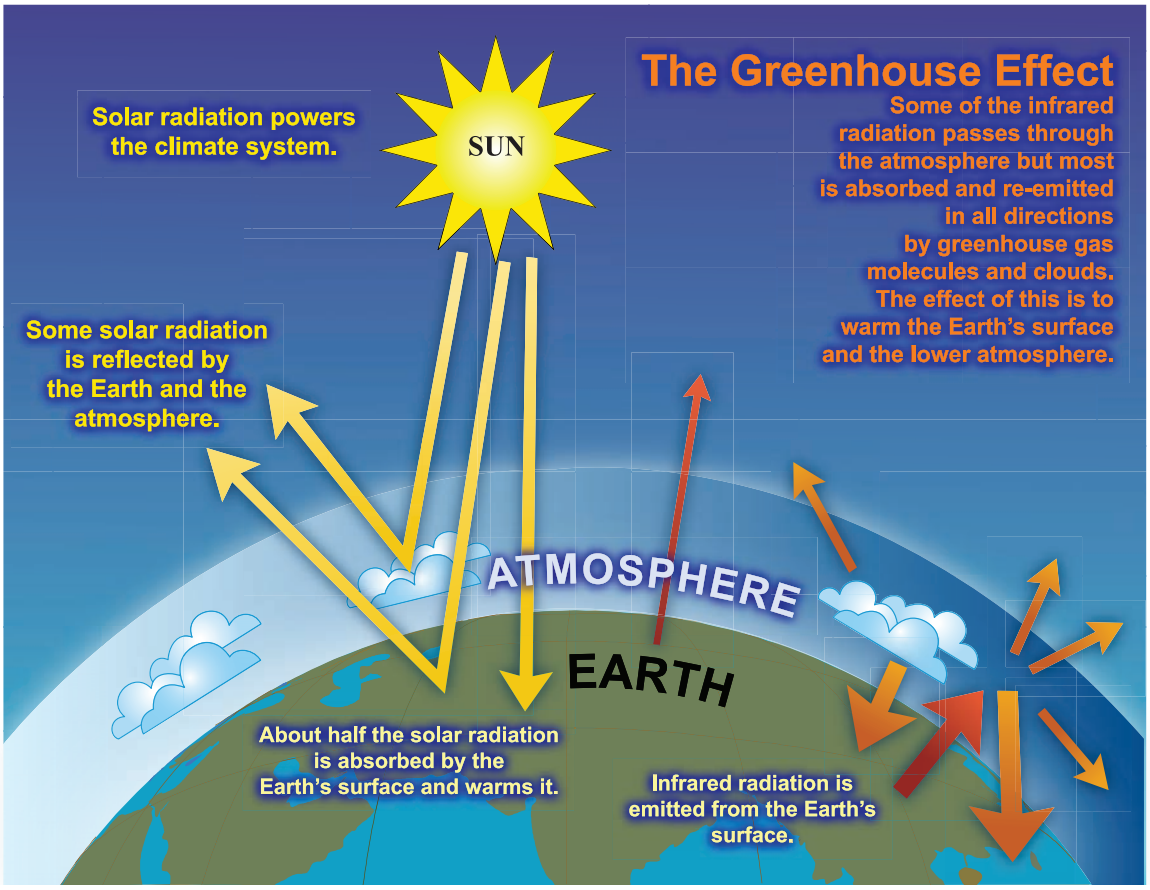

FAQ 1.3, Figure 1. *An idealised model of the natural greenhouse effect. See text for explanation.*

water vapour is much greater. The same is true for the cold, dry upper atmosphere where a small increase in water vapour has a greater influence on the greenhouse effect than the same change in water vapour would have near the surface.

Several components of the climate system, notably the oceans and living things, affect atmospheric concentrations of greenhouse gases. A prime example of this is plants taking CO_2 out of the atmosphere and converting it (and water) into carbohydrates via photosynthesis. In the industrial era, human activities have added greenhouse gases to the atmosphere, primarily through the burning of fossil fuels and clearing of forests.

Adding more of a greenhouse gas, such as CO_2, to the atmosphere intensifies the greenhouse effect, thus warming Earth's climate. The amount of warming depends on various feedback mechanisms. For example, as the atmosphere warms due to rising levels of greenhouse gases, its concentration of water vapour increases, further intensifying the greenhouse effect. This in turn causes more warming, which causes an additional increase in water vapour, in a self-reinforcing cycle. This water vapour feedback may be strong enough to approximately double the increase in the greenhouse effect due to the added CO_2 alone.

Additional important feedback mechanisms involve clouds. Clouds are effective at absorbing infrared radiation and therefore exert a large greenhouse effect, thus warming the Earth. Clouds are also effective at reflecting away incoming solar radiation, thus cooling the Earth. A change in almost any aspect of clouds, such as their type, location, water content, cloud altitude, particle size and shape, or lifetimes, affects the degree to which clouds warm or cool the Earth. Some changes amplify warming while others diminish it. Much research is in progress to better understand how clouds change in response to climate warming, and how these changes affect climate through various feedback mechanisms.

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Frequently Asked Question 2.1

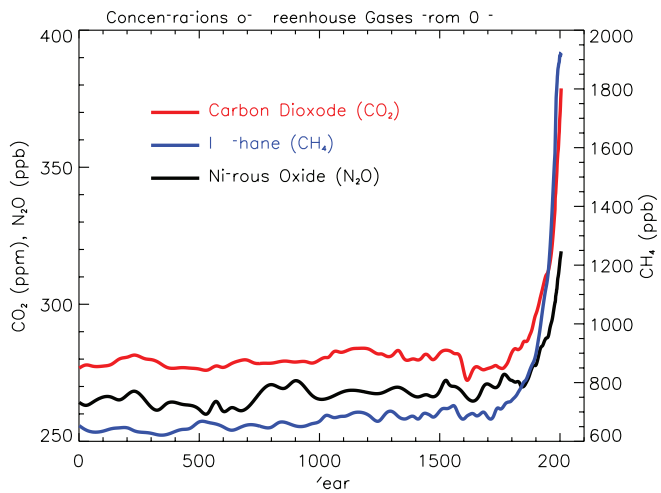
How do Human Activities Contribute to Climate Change and How do They Compare with Natural Influences?

Human activities contribute to climate change by causing changes in Earth's atmosphere in the amounts of greenhouse gases, aerosols (small particles), and cloudiness. The largest known contribution comes from the burning of fossil fuels, which releases carbon dioxide gas to the atmosphere. Greenhouse gases and aerosols affect climate by altering incoming solar radiation and outgoing infrared (thermal) radiation that are part of Earth's energy balance. Changing the atmospheric abundance or properties of these gases and particles can lead to a warming or cooling of the climate system. Since the start of the industrial era (about 1750), the overall effect of human activities on climate has been a warming influence. The human impact on climate during this era greatly exceeds that due to known changes in natural processes, such as solar changes and volcanic eruptions.

Greenhouse Gases

Human activities result in emissions of four principal greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the halocarbons (a group of gases containing fluorine, chlorine and bromine). These gases accumulate in the atmosphere, causing concentrations to increase with time. Significant increases in all of these gases have occurred in the industrial era (see Figure 1). All of these increases are attributable to human activities.

- Carbon dioxide has increased from fossil fuel use in transportation, building heating and cooling and the manufacture of cement and other goods. Deforestation releases CO_2 and reduces its uptake by plants. Carbon dioxide is also released in natural processes such as the decay of plant matter.
- Methane has increased as a result of human activities related to agriculture, natural gas distribution and landfills. Methane is also released from natural processes that occur, for example, in wetlands. Methane concentrations are not currently increasing in the atmosphere because growth rates decreased over the last two decades.
- Nitrous oxide is also emitted by human activities such as fertilizer use and fossil fuel burning. Natural processes in soils and the oceans also release N_2O.
- Halocarbon gas concentrations have increased primarily due to human activities. Natural processes are also a small source. Principal halocarbons include the chlorofluorocarbons (e.g., CFC-11 and CFC-12), which were used extensively as refrigeration agents and in other industrial processes before their presence in the atmosphere was found to cause stratospheric ozone depletion. The abundance of chlorofluorocarbon gases is decreasing as a result of international regulations designed to protect the ozone layer.



FAQ 2.1, Figure 1. *Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample. (Data combined and simplified from Chapters 6 and 2 of this report.)*

- Ozone is a greenhouse gas that is continually produced and destroyed in the atmosphere by chemical reactions. In the troposphere, human activities have increased ozone through the release of gases such as carbon monoxide, hydrocarbons and nitrogen oxide, which chemically react to produce ozone. As mentioned above, halocarbons released by human activities destroy ozone in the stratosphere and have caused the ozone hole over Antarctica.
- Water vapour is the most abundant and important greenhouse gas in the atmosphere. However, human activities have only a small direct influence on the amount of atmospheric water vapour. Indirectly, humans have the potential to affect water vapour substantially by changing climate. For example, a warmer atmosphere contains more water vapour. Human activities also influence water vapour through CH_4 emissions, because CH_4 undergoes chemical destruction in the stratosphere, producing a small amount of water vapour.
- Aerosols are small particles present in the atmosphere with widely varying size, concentration and chemical composition. Some aerosols are emitted directly into the atmosphere while others are formed from emitted compounds. Aerosols contain both naturally occurring compounds and those emitted as a result of human activities. Fossil fuel and biomass burning have increased aerosols containing sulphur compounds, organic compounds and black carbon (soot). Human activities such as

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surface mining and industrial processes have increased dust in the atmosphere. Natural aerosols include mineral dust released from the surface, sea salt aerosols, biogenic emissions from the land and oceans and sulphate and dust aerosols produced by volcanic eruptions.

Radiative Forcing of Factors Affected by Human Activities

The contributions to radiative forcing from some of the factors influenced by human activities are shown in Figure 2. The values reflect the total forcing relative to the start of the industrial era (about 1750). The forcings for all greenhouse gas increases, which are the best understood of those due to human activities, are positive because each gas absorbs outgoing infrared radiation in the atmosphere. Among the greenhouse gases, CO_2 increases have caused the largest forcing over this period. Tropospheric ozone increases have also contributed to warming, while stratospheric ozone decreases have contributed to cooling.

Aerosol particles influence radiative forcing directly through reflection and absorption of solar and infrared radiation in the atmosphere. Some aerosols cause a positive forcing while others cause a negative forcing. The direct radiative forcing summed over all aerosol types is negative. Aerosols also cause a negative radiative forcing indirectly through the changes they cause in cloud properties.

Human activities since the industrial era have altered the nature of land cover over the globe, principally through changes in

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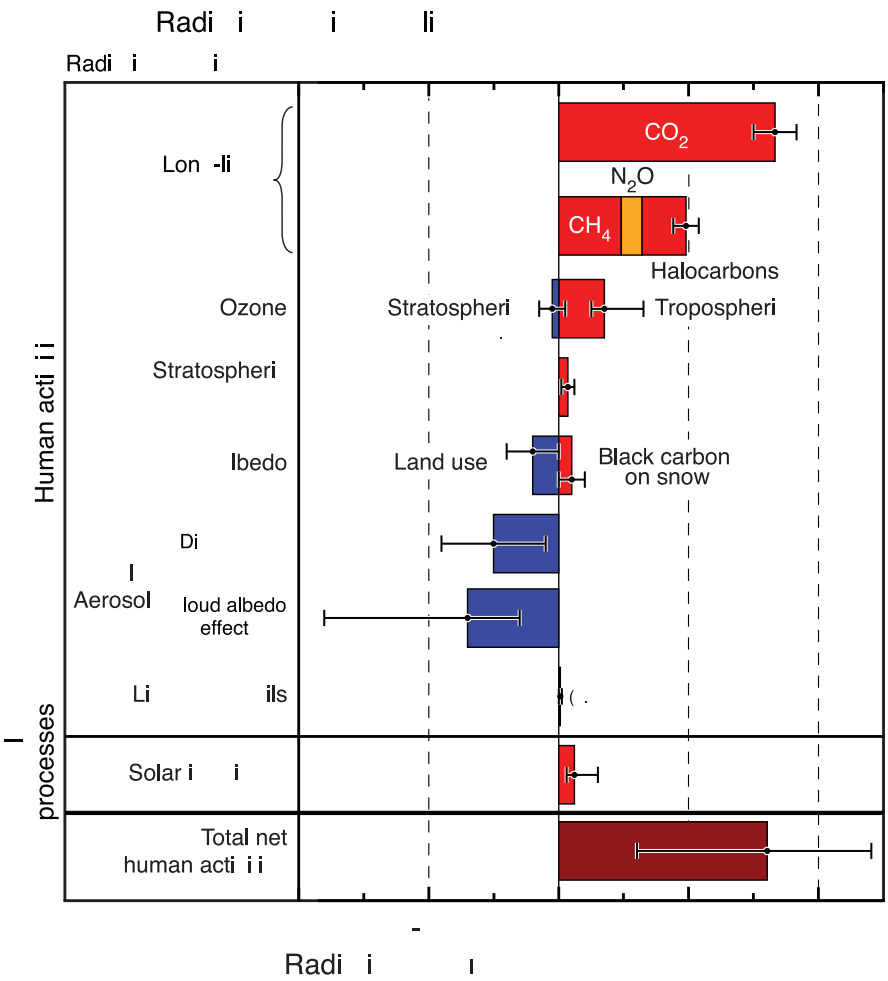

FAQ 2.1, Figure 2. *Summary of the principal components of the radiative forcing of climate change. All these radiative forcings result from one or more factors that affect climate and are associated with human activities or natural processes as discussed in the text. The values represent the forcings in 2005 relative to the start of the industrial era (about 1750). Human activities cause significant changes in long-lived gases, ozone, water vapour, surface albedo, aerosols and contrails. The only increase in natural forcing of any significance between 1750 and 2005 occurred in solar irradiance. Positive forcings lead to warming of climate and negative forcings lead to a cooling. The thin black line attached to each coloured bar represents the range of uncertainty for the respective value. (Figure adapted from Figure 2.20 of this report.)*

FAQ 2.1, Box 1: What is Radiative Forcing?

What is radiative forcing? The influence of a factor that can cause climate change, such as a greenhouse gas, is often evaluated in terms of its radiative forcing. Radiative forcing is a measure of how the energy balance of the Earth-atmosphere system is influenced when factors that affect climate are altered. The word radiative arises because these factors change the balance between incoming solar radiation and outgoing infrared radiation within the Earth's atmosphere. This radiative balance controls the Earth's surface temperature. The term forcing is used to indicate that Earth's radiative balance is being pushed away from its normal state.

Radiative forcing is usually quantified as the 'rate of energy change per unit area of the globe as measured at the top of the atmosphere', and is expressed in units of 'Watts per square metre' (see Figure 2). When radiative forcing from a factor or group of factors is evaluated as positive, the energy of the Earth-atmosphere system will ultimately increase, leading to a warming of the system. In contrast, for a negative radiative forcing, the energy will ultimately decrease, leading to a cooling of the system. Important challenges for climate scientists are to identify all the factors that affect climate and the mechanisms by which they exert a forcing, to quantify the radiative forcing of each factor and to evaluate the total radiative forcing from the group of factors.

croplands, pastures and forests. They have also modified the reflective properties of ice and snow. Overall, it is likely that more solar radiation is now being reflected from Earth's surface as a result of human activities. This change results in a negative forcing.

Aircraft produce persistent linear trails of condensation ('contrails') in regions that have suitably low temperatures and high humidity. Contrails are a form of cirrus cloud that reflect solar radiation and absorb infrared radiation. Linear contrails from global aircraft operations have increased Earth's cloudiness and are estimated to cause a small positive radiative forcing.

Radiative Forcing from Natural Changes

Natural forcings arise due to solar changes and explosive volcanic eruptions. Solar output has increased gradually in the industrial era, causing a small positive radiative forcing (see Figure 2). This is in addition to the cyclic changes in solar radiation that follow an 11-year cycle. Solar energy directly heats the climate system and can also affect the atmospheric abundance of some greenhouse gases, such as stratospheric ozone. Explosive volcanic eruptions can create a short-lived (2 to 3 years) negative forcing through the temporary increases that occur in sulphate aerosol in the stratosphere. The stratosphere is currently free of volcanic aerosol, since the last major eruption was in 1991 (Mt. Pinatubo).

The differences in radiative forcing estimates between the present day and the start of the industrial era for solar irradiance changes and volcanoes are both very small compared to the differences in radiative forcing estimated to have resulted from human activities. As a result, in today's atmosphere, the radiative forcing from human activities is much more important for current and future climate change than the estimated radiative forcing from changes in natural processes.

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Frequently Asked Question 3.1
How are Temperatures on Earth Changing?

Instrumental observations over the past 157 years show that temperatures at the surface have risen globally, with important regional variations. For the global average, warming in the last century has occurred in two phases, from the 1910s to the 1940s (0.35°C), and more strongly from the 1970s to the present (0.55°C). An increasing rate of warming has taken place over the last 25 years, and 11 of the 12 warmest years on record have occurred in the past 12 years. Above the surface, global observations since the late 1950s show that the troposphere (up to about 10 km) has warmed at a slightly greater rate than the surface, while the stratosphere (about 10–30 km) has cooled markedly since 1979. This is in accord with physical expectations and most model results. Confirmation of global warming comes from warming of the oceans, rising sea levels, glaciers melting, sea ice retreating in the Arctic and diminished snow cover in the Northern Hemisphere.

There is no single thermometer measuring the global temperature. Instead, individual thermometer measurements taken every day at several thousand stations over the land areas of the world are combined with thousands more measurements of sea surface temperature taken from ships moving over the oceans to produce an estimate of global average temperature every month. To obtain consistent changes over time, the main analysis is actually of anomalies (departures from the climatological mean at each site) as these are more robust to changes in data availability. It is now possible to use these measurements from 1850 to the present, although coverage is much less than global in the second half of the 19th century, is much better after 1957 when measurements began in Antarctica, and best after about 1980, when satellite measurements began.

Expressed as a global average, surface temperatures have increased by about 0.74°C over the past hundred years (between 1906 and 2005; see Figure 1). However, the warming has been neither steady nor the same in different seasons or in different locations. There was not much overall change from 1850 to about 1915, aside from ups and downs associated with natural variability but which may have also partly arisen from poor sampling. An increase (0.35°C) occurred in the global average temperature from the 1910s to the 1940s, followed by a slight cooling (0.1°C), and then a rapid warming (0.55°C) up to the end of 2006 (Figure 1). The warmest years of the series are 1998 and 2005 (which are statistically indistinguishable), and 11 of the 12 warmest years have occurred in the last 12 years (1995 to 2006). Warming, particularly since the 1970s, has generally been greater over land than over the oceans. Seasonally, warming has been slightly greater in the winter hemisphere. Additional warming occurs in cities and urban areas (often referred to as the urban heat island effect), but is confined in spatial extent, and its effects are allowed for both by excluding as many of the affected sites as possible from the global temperature data and by increasing the error range (the light grey band in the figure).

A few areas have cooled since 1901, most notably the northern North Atlantic near southern Greenland. Warming during this time has been strongest over the continental interiors of Asia and northern North America. However, as these are areas with large year-to-year variability, the most evident warming signal has occurred in parts of the middle and lower latitudes, particularly the tropical oceans. In the lower left panel of Figure 1, which shows temperature trends since 1979, the pattern in the Pacific Ocean features warming and cooling regions related to El Niño.

Analysis of long-term changes in daily temperature extremes has recently become possible for many regions of the world (parts of North America and southern South America, Europe, northern and eastern Asia, southern Africa and Australasia). Especially since the 1950s, these records show a decrease in the number of very cold days and nights and an increase in the number of extremely hot days and warm nights (see FAQ 3.3). The length of the frost-free season has increased in most mid- and high-latitude regions of both hemispheres. In the Northern Hemisphere, this is mostly manifest as an earlier start to spring.

In addition to the surface data described above, measurements of temperature above the surface have been made with weather balloons, with reasonable coverage over land since 1958, and from satellite data since 1979. All data are adjusted for changes in instruments and observing practices where necessary. Microwave satellite data have been used to create a 'satellite temperature record' for thick layers of the atmosphere including the troposphere (from the surface up to about 10 km) and the lower stratosphere (about 10 to 30 km). Despite several new analyses with improved cross-calibration of the 13 instruments on different satellites used since 1979 and compensation for changes in observing time and satellite altitude, some uncertainties remain in trends.

For global observations since the late 1950s, the most recent versions of all available data sets show that the troposphere has warmed at a slightly greater rate than the surface, while the stratosphere has cooled markedly since 1979. This is in accord with physical expectations and most model results, which demonstrate the role of increasing greenhouse gases in tropospheric warming and stratospheric cooling; ozone depletion also contributes substantially to stratospheric cooling.

Consistent with observed increases in surface temperature, there have been decreases in the length of river and lake ice seasons. Further, there has been an almost worldwide reduction in glacial mass and extent in the 20th century; melting of the Greenland Ice Sheet has recently become apparent; snow cover has decreased in many Northern Hemisphere regions; sea ice thickness and extent have decreased in the Arctic in all seasons, most dramatically in spring and summer; the oceans are warming; and sea level is rising due to thermal expansion of the oceans and melting of land ice.

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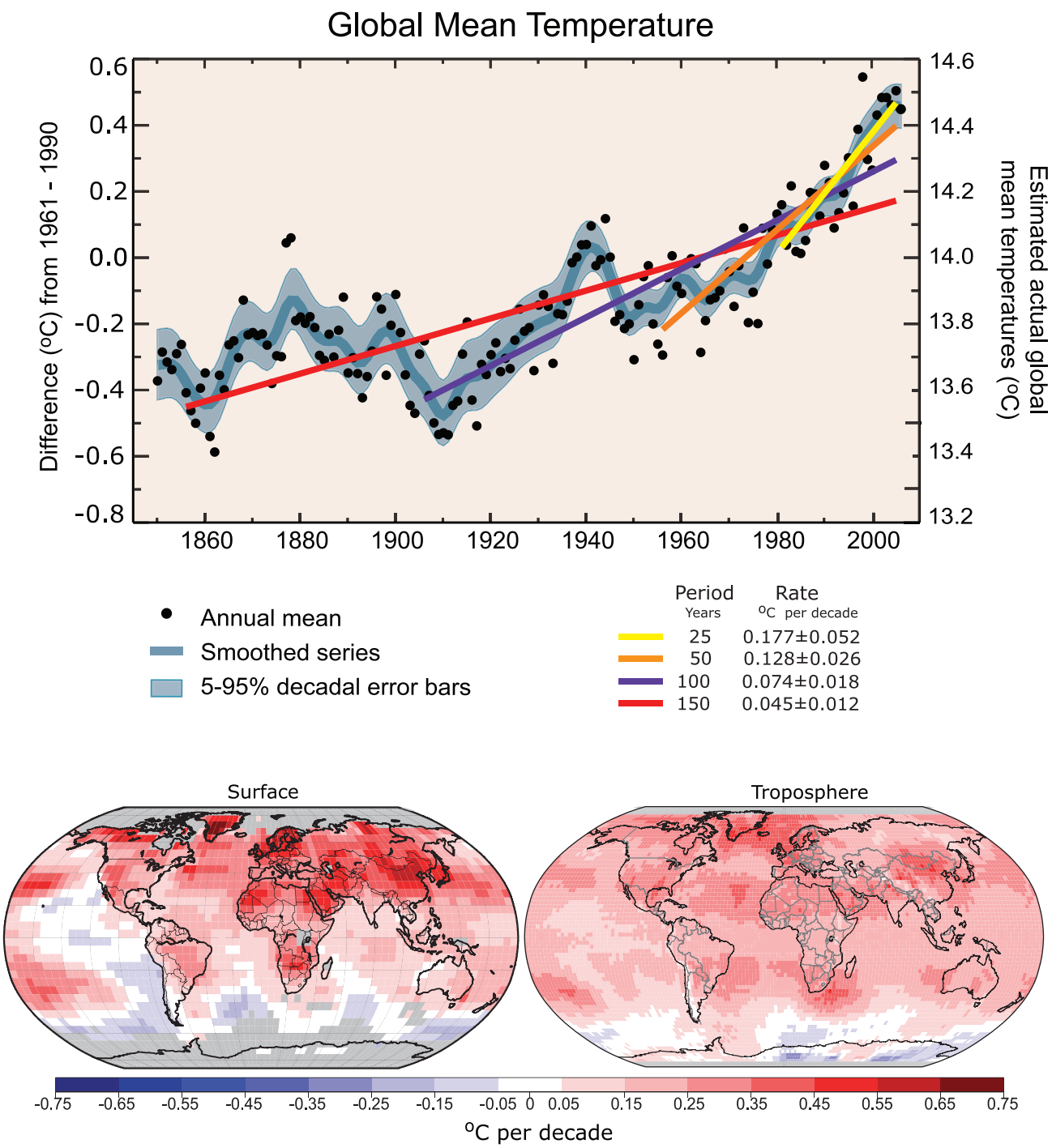

FAQ 3.1, Figure 1. *(Top) Annual global mean observed temperatures[1] (black dots) along with simple fits to the data. The left hand axis shows anomalies relative to the 1961 to 1990 average and the right hand axis shows the estimated actual temperature (°C). Linear trend fits to the last 25 (yellow), 50 (orange), 100 (purple) and 150 years (red) are shown, and correspond to 1981 to 2005, 1956 to 2005, 1906 to 2005, and 1856 to 2005, respectively. Note that for shorter recent periods, the slope is greater, indicating accelerated warming. The blue curve is a smoothed depiction to capture the decadal variations. To give an idea of whether the fluctuations are meaningful, decadal 5% to 95% (light grey) error ranges about that line are given (accordingly, annual values do exceed those limits). Results from climate models driven by estimated radiative forcings for the 20th century (Chapter 9) suggest that there was little change prior to about 1915, and that a substantial fraction of the early 20th-century change was contributed by naturally occurring influences including solar radiation changes, volcanism and natural variability. From about 1940 to 1970 the increasing industrialisation following World War II increased pollution in the Northern Hemisphere, contributing to cooling, and increases in carbon dioxide and other greenhouse gases dominate the observed warming after the mid-1970s. (Bottom) Patterns of linear global temperature trends from 1979 to 2005 estimated at the surface (left), and for the troposphere (right) from the surface to about 10 km altitude, from satellite records. Grey areas indicate incomplete data. Note the more spatially uniform warming in the satellite tropospheric record while the surface temperature changes more clearly relate to land and ocean.*

[1] *From the HadCRUT3 data set.*

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Frequently Asked Question 3.2
How is Precipitation Changing?

Observations show that changes are occurring in the amount, intensity, frequency and type of precipitation. These aspects of precipitation generally exhibit large natural variability, and El Niño and changes in atmospheric circulation patterns such as the North Atlantic Oscillation have a substantial influence. Pronounced long-term trends from 1900 to 2005 have been observed in precipitation amount in some places: significantly wetter in eastern North and South America, northern Europe and northern and central Asia, but drier in the Sahel, southern Africa, the Mediterranean and southern Asia. More precipitation now falls as rain rather than snow in northern regions. Widespread increases in heavy precipitation events have been observed, even in places where total amounts have decreased. These changes are associated with increased water vapour in the atmosphere arising from the warming of the world's oceans, especially at lower latitudes. There are also increases in some regions in the occurrences of both droughts and floods.

Precipitation is the general term for rainfall, snowfall and other forms of frozen or liquid water falling from clouds. Precipitation is intermittent, and the character of the precipitation when it occurs depends greatly on temperature and the weather situation. The latter determines the supply of moisture through winds and surface evaporation, and how it is gathered together in storms as clouds. Precipitation forms as water vapour condenses, usually in rising air that expands and hence cools. The upward motion comes from air rising over mountains, warm air riding over cooler air (warm front), colder air pushing under warmer air (cold front), convection from local heating of the surface, and other weather and cloud systems. Hence, changes in any of these aspects alter precipitation. As precipitation maps tend to be spotty, overall trends in precipitation are indicated by the Palmer Drought Severity Index (see Figure 1), which is a measure of soil moisture using precipitation and crude estimates of changes in evaporation.

A consequence of increased heating from the human-induced enhanced greenhouse effect is increased evaporation, provided that adequate surface moisture is available (as it always is over the oceans and other wet surfaces). Hence, surface moisture effectively acts as an 'air conditioner', as heat used for evaporation acts to moisten the air rather than warm it. An observed consequence of this is that summers often tend to be either warm and dry or cool and wet. In the areas of eastern North and South America where it has become wetter (Figure 1), temperatures have therefore increased less than elsewhere (see FAQ 3.3, Figure 1 for changes in warm days). Over northern continents in winter, however, more precipitation is associated with higher temperatures, as the water holding capacity of the atmosphere increases in the warmer conditions. However, in these regions, where precipitation has generally increased somewhat, increases in temperatures (FAQ 3.1) have increased drying, making the precipitation changes less evident in Figure 1.

As climate changes, several direct influences alter precipitation amount, intensity, frequency and type. Warming accelerates land surface drying and increases the potential incidence and severity of droughts, which has been observed in many places worldwide (Figure 1). However, a well-established physical law (the Clausius-Clapeyron relation) determines that the water-holding capacity of the atmosphere increases by about 7% for every 1°C rise in temperature. Observations of trends in relative humidity are uncertain but suggest that it has remained about the same overall, from the surface throughout the troposphere, and hence increased temperatures will have resulted in increased water vapour. Over the 20th century, based on changes in sea surface temperatures, it is estimated that atmospheric water vapour increased by about 5% in the atmosphere over the oceans. Because precipitation comes mainly from weather systems that feed on the water vapour stored in the atmosphere, this has generally increased precipitation intensity and the risk of heavy rain and snow events. Basic theory, climate model simulations and empirical evidence all confirm that warmer climates, owing to increased water vapour, lead to more intense precipitation events even when the total annual precipitation is reduced slightly, and with prospects for even stronger events when the overall precipitation amounts increase. The warmer climate therefore increases risks of both drought – where it is not raining – and floods – where it is – but at different times and/or places. For instance, the summer of 2002 in Europe brought widespread floods but was followed a year later in 2003 by record-breaking heat waves and drought. The distribution and timing of floods and droughts is most profoundly affected by the cycle of El Niño events, particularly in the tropics and over much of the mid-latitudes of Pacific-rim countries.

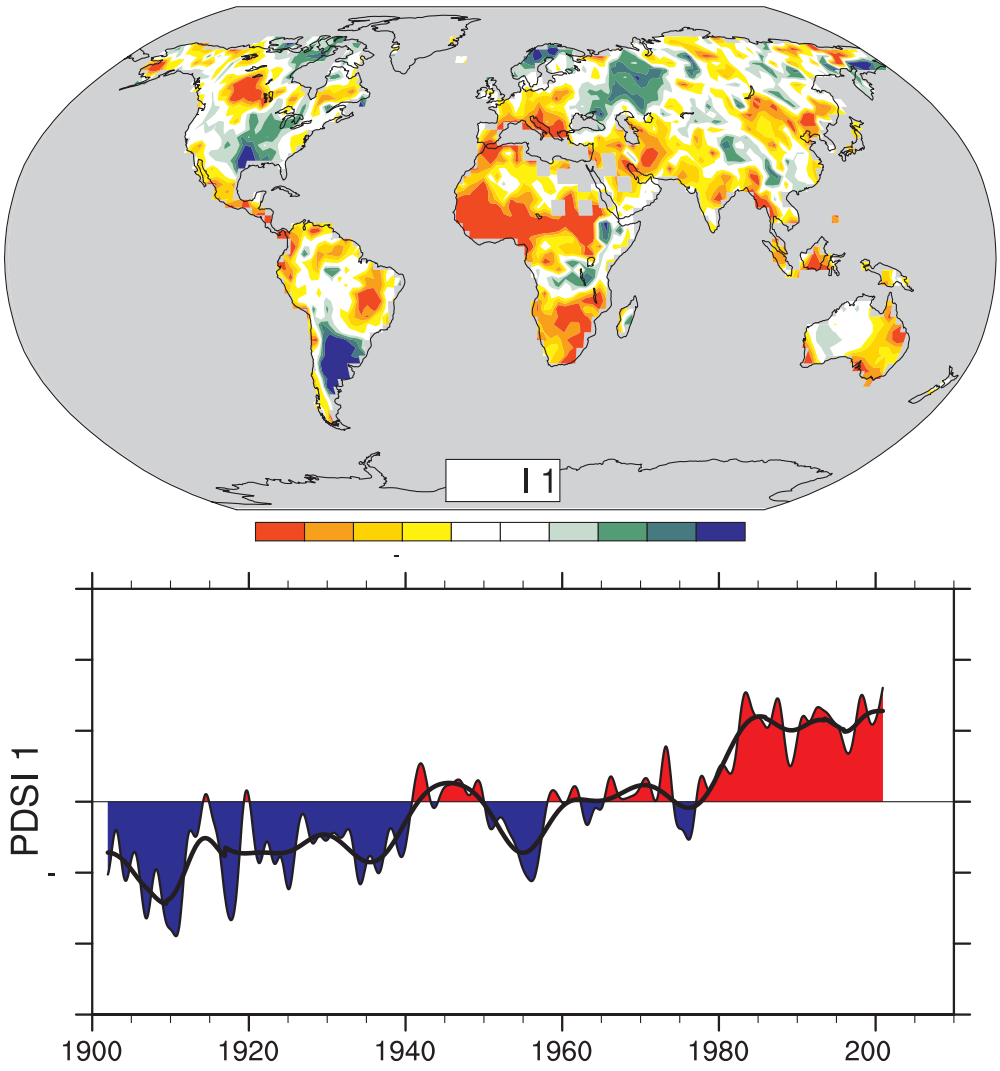
In areas where aerosol pollution masks the ground from direct sunlight, decreases in evaporation reduce the overall moisture supply to the atmosphere. Hence, even as the potential for heavier precipitation results from increased water vapour amounts, the duration and frequency of events may be curtailed, as it takes longer to recharge the atmosphere with water vapour.

Local and regional changes in the character of precipitation also depend a great deal on atmospheric circulation patterns determined by El Niño, the North Atlantic Oscillation (NAO; a measure of westerly wind strength over the North Atlantic in winter) and other patterns of variability. Some of these observed circulation changes are associated with climate change. An associated shift in the storm track makes some regions wetter and some – often nearby – drier, making for complex patterns of change. For instance, in the European sector a more positive NAO in the 1990s led to wetter conditions in northern Europe and drier conditions over the Mediterranean and northern African regions (Figure 1). The prolonged drought in the Sahel (see Figure 1), which was pronounced from the late 1960s to the late 1980s,

(continued)

continues although it is not quite as intense as it was; it has been linked, through changes in atmospheric circulation, to changes in tropical sea surface temperature patterns in the Pacific, Indian and Atlantic Basins. Drought has become widespread throughout much of Africa and more common in the tropics and subtropics.

As temperatures rise, the likelihood of precipitation falling as rain rather than snow increases, especially in autumn and spring at the beginning and end of the snow season, and in areas where temperatures are near freezing. Such changes are observed in many places, especially over land in middle and high latitudes of the Northern Hemisphere, leading to increased rains but reduced snowpacks, and consequently diminished water resources in summer, when they are most needed. Nevertheless, the often spotty and intermittent nature of precipitation means observed patterns of change are complex. The long-term record emphasizes that patterns of precipitation vary somewhat from year to year, and even prolonged multi-year droughts are usually punctuated by a year of heavy rains; for instance as El Niño influences are felt. An example may be the wet winter of 2004-2005 in the southwestern USA following a six-year drought and below-normal snowpack.



FAQ 3.2, Figure 1. *The most important spatial pattern (top) of the monthly Palmer Drought Severity Index (PDSI) for 1900 to 2002. The PDSI is a prominent index of drought and measures the cumulative deficit (relative to local mean conditions) in surface land moisture by incorporating previous precipitation and estimates of moisture drawn into the atmosphere (based on atmospheric temperatures) into a hydrological accounting system. The lower panel shows how the sign and strength of this pattern has changed since 1900. Red and orange areas are drier (wetter) than average and blue and green areas are wetter (drier) than average when the values shown in the lower plot are positive (negative). The smooth black curve shows decadal variations. The time series approximately corresponds to a trend, and this pattern and its variations account for 67% of the linear trend of PDSI from 1900 to 2002 over the global land area. It therefore features widespread increasing African drought, especially in the Sahel, for instance. Note also the wetter areas, especially in eastern North and South America and northern Eurasia. Adapted from Dai et al. (2004b).*

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Frequently Asked Question 3.3

Has there been a Change in Extreme Events like Heat Waves, Droughts, Floods and Hurricanes?

Since 1950, the number of heat waves has increased and widespread increases have occurred in the numbers of warm nights. The extent of regions affected by droughts has also increased as precipitation over land has marginally decreased while evaporation has increased due to warmer conditions. Generally, numbers of heavy daily precipitation events that lead to flooding have increased, but not everywhere. Tropical storm and hurricane frequencies vary considerably from year to year, but evidence suggests substantial increases in intensity and duration since the 1970s. In the extratropics, variations in tracks and intensity of storms reflect variations in major features of the atmospheric circulation, such as the North Atlantic Oscillation.

In several regions of the world, indications of changes in various types of extreme climate events have been found. The extremes are commonly considered to be the values exceeded 1, 5 and 10% of the time (at one extreme) or 90, 95 and 99% of the time (at the other extreme). The warm nights or hot days (discussed below) are those exceeding the 90th percentile of temperature, while cold nights or days are those falling below the 10th percentile. Heavy precipitation is defined as daily amounts greater than the 95th (or for 'very heavy', the 99th) percentile.

In the last 50 years for the land areas sampled, there has been a significant decrease in the annual occurrence of cold nights and a significant increase in the annual occurrence of warm nights (Figure 1). Decreases in the occurrence of cold days and increases in hot days, while widespread, are generally less marked. The distributions of minimum and maximum temperatures have not only shifted to higher values, consistent with overall warming, but the cold extremes have warmed more than the warm extremes over the last 50 years (Figure 1). More warm extremes imply an increased frequency of heat waves. Further supporting indications include the observed trend towards fewer frost days associated with the average warming in most mid-latitude regions.

A prominent indication of a change in extremes is the observed evidence of increases in heavy precipitation events over the mid-latitudes in the last 50 years, even in places where mean precipitation amounts are not increasing (see also FAQ 3.2). For very heavy precipitation events, increasing trends are reported as well, but results are available for few areas.

Drought is easier to measure because of its long duration. While there are numerous indices and metrics of drought, many studies use monthly precipitation totals and temperature averages combined into a measure called the Palmer Drought Severity Index (PDSI). The PDSI calculated from the middle of the 20th century shows a large drying trend over many Northern Hemisphere land areas since the mid-1950s, with widespread drying over much of southern Eurasia, northern Africa, Canada and Alaska (FAQ 3.2, Figure 1), and an opposite trend in eastern North and South America. In the Southern Hemisphere, land surfaces were wet in the 1970s and relatively dry in the 1960s and 1990s, and there was a drying trend from 1974 to 1998. Longer-duration records for Europe for the whole of the 20th century indicate few significant trends. Decreases in precipitation over land since the 1950s are the likely main cause for the drying trends, although large surface warming during the last two to three decades has also likely contributed to the drying. One study shows that very dry land areas across the globe (defined as areas with a PDSI of less than –3.0) have more than doubled in extent since the 1970s, associated with an initial precipitation decrease over land related to the El Niño-Southern Oscillation and with subsequent increases primarily due to surface warming.

Changes in tropical storm and hurricane frequency and intensity are masked by large natural variability. The El Niño-Southern Oscillation greatly affects the location and activity of tropical storms around the world. Globally, estimates of the potential destructiveness of hurricanes show a substantial upward trend since the mid-1970s, with a trend towards longer storm duration and greater storm intensity, and the activity is strongly correlated with tropical sea surface temperature. These relationships have been reinforced by findings of a large increase in numbers and proportion of strong hurricanes globally since 1970 even as total numbers of cyclones and cyclone days decreased slightly in most basins. Specifically, the number of category 4 and 5 hurricanes increased by about 75% since 1970. The largest increases were in the North Pacific, Indian and Southwest Pacific Oceans. However, numbers of hurricanes in the North Atlantic have also been above normal in 9 of the last 11 years, culminating in the record-breaking 2005 season.

Based on a variety of measures at the surface and in the upper troposphere, it is likely that there has been a poleward shift as well as an increase in Northern Hemisphere winter storm track activity over the second half of the 20th century. These changes are part of variations that have occurred related to the North Atlantic Oscillation. Observations from 1979 to the mid-1990s reveal a tendency towards a stronger December to February circumpolar westerly atmospheric circulation throughout the troposphere and lower stratosphere, together with poleward displacements of jet streams and increased storm track activity. Observational evidence for changes in small-scale severe weather phenomena (such as tornadoes, hail and thunderstorms) is mostly local and too scattered to draw general conclusions; increases in many areas arise because of increased public awareness and improved efforts to collect reports of these phenomena.

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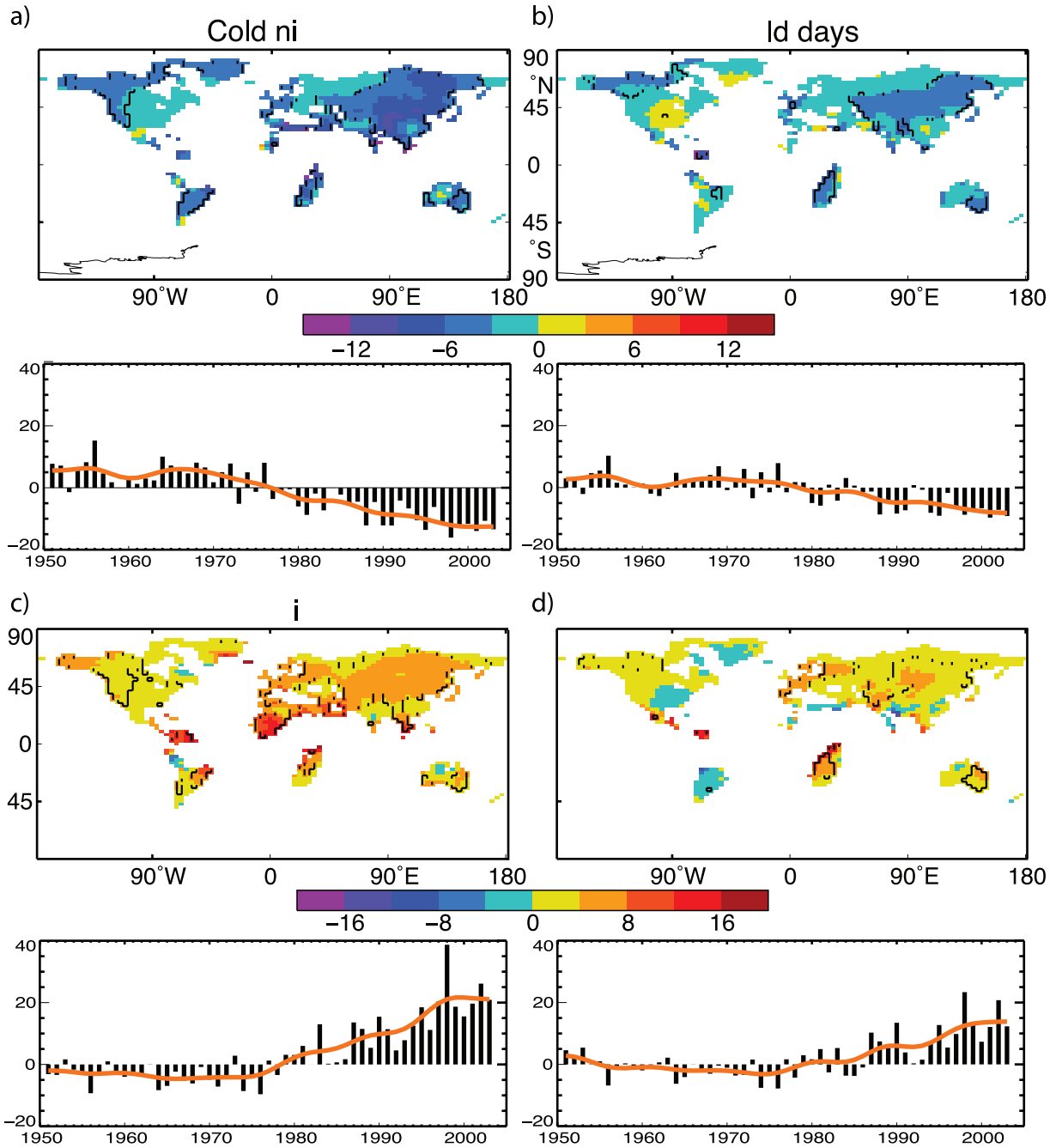

FAQ 3.3, Figure 1. *Observed trends (days per decade) for 1951 to 2003 in the frequency of extreme temperatures, defined based on 1961 to 1990 values, as maps for the 10th percentile: (a) cold nights and (b) cold days; and 90th percentile: (c) warm nights and (d) warm days. Trends were calculated only for grid boxes that had at least 40 years of data during this period and had data until at least 1999. Black lines enclose regions where trends are significant at the 5% level. Below each map are the global annual time series of anomalies (with respect to 1961 to 1990). The red line shows decadal variations. Trends are significant at the 5% level for all the global indices shown. Adapted from Alexander et al. (2006).*

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Frequently Asked Question 4.1

Is the Amount of Snow and Ice on the Earth Decreasing?

Yes. Observations show a global-scale decline of snow and ice over many years, especially since 1980 and increasing during the past decade, despite growth in some places and little change in others (Figure 1). Most mountain glaciers are getting smaller. Snow cover is retreating earlier in the spring. Sea ice in the Arctic is shrinking in all seasons, most dramatically in summer. Reductions are reported in permafrost, seasonally frozen ground and river and lake ice. Important coastal regions of the ice sheets on Greenland and West Antarctica, and the glaciers of the Antarctic Peninsula, are thinning and contributing to sea level rise. The total contribution of glacier, ice cap and ice sheet melt to sea level rise is estimated as 1.2 ± 0.4 mm yr^{-1} for the period 1993 to 2003.

Continuous satellite measurements capture most of the Earth's seasonal snow cover on land, and reveal that Northern Hemisphere spring snow cover has declined by about 2% per decade since 1966, although there is little change in autumn or early winter. In many places, the spring decrease has occurred despite increases in precipitation.

Satellite data do not yet allow similarly reliable measurement of ice conditions on lakes and rivers, or in seasonally or permanently frozen ground. However, numerous local and regional reports have been published, and generally seem to indicate warming of permafrost, an increase in thickness of the summer thawed layer over permafrost, a decrease in winter freeze depth in seasonally frozen areas, a decrease in areal extent of permafrost and a decrease in duration of seasonal river and lake ice.

Since 1978, satellite data have provided continuous coverage of sea ice extent in both polar regions. For the Arctic, average annual sea ice extent has decreased by 2.7 ± 0.6% per decade, while summer sea ice extent has decreased by 7.4 ± 2.4% per decade. The antarctic sea ice extent exhibits no significant trend. Thickness data, especially from submarines, are available but restricted to the central Arctic, where they indicate thinning of approximately 40% between the period 1958 to 1977 and the 1990s. This is likely an overestimate of the thinning over the entire arctic region however.

Most mountain glaciers and ice caps have been shrinking, with the retreat probably having started about 1850. Although many Northern Hemisphere glaciers had a few years of near-balance around 1970, this was followed by increased shrinkage. Melting of glaciers and ice caps contributed 0.77 ± 0.22 mm yr^{-1} to sea level rise between 1991 and 2004

Taken together, the ice sheets of Greenland and Antarctica are very likely shrinking, with Greenland contributing about 0.2 ± 0.1 mm yr^{-1} and Antarctica contributing 0.2 ± 0.35 mm yr^{-1} to sea level rise over the period 1993 to 2003. There is evidence of accelerated loss through 2005. Thickening of high-altitude, cold regions of Greenland and East Antarctica, perhaps from increased snowfall, has been more than offset by thinning in coastal regions of Greenland and West Antarctica in response to increased ice outflow and increased Greenland surface melting.

Ice interacts with the surrounding climate in complex ways, so the causes of specific changes are not always clear. Nonetheless, it is an unavoidable fact that ice melts when the local temperature is

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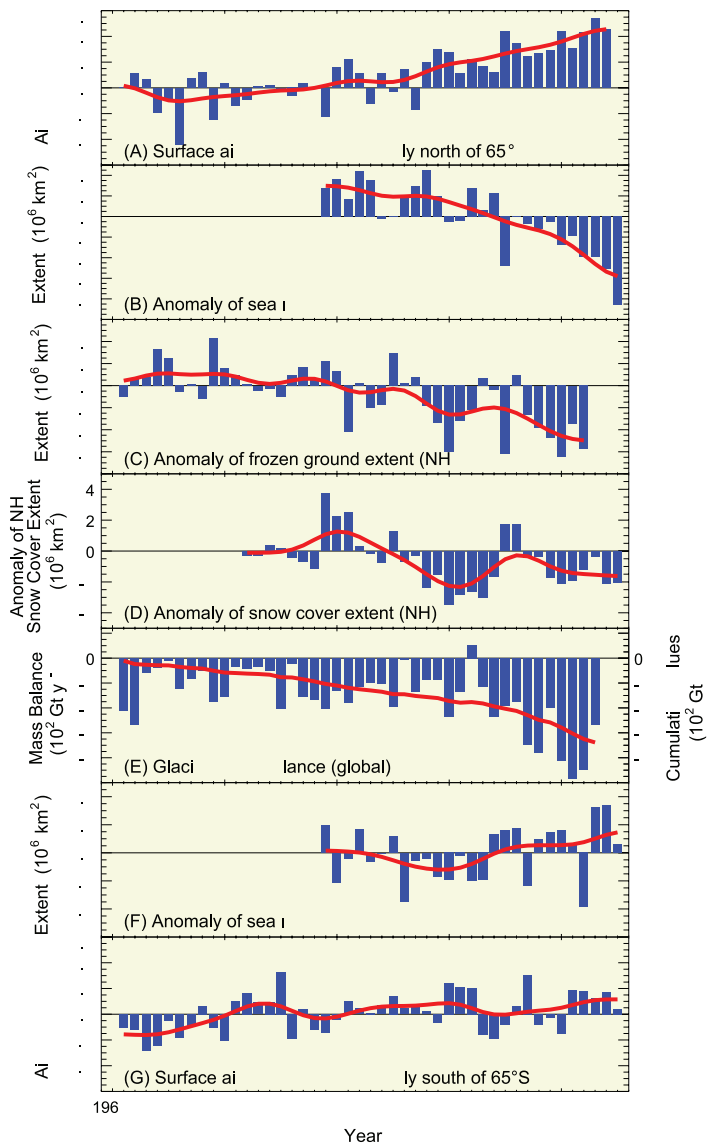

FAQ 4.1, Figure 1. *Anomaly time series (departure from the long-term mean) of polar surface air temperature (A, G), arctic and antarctic sea ice extent (B, F), Northern Hemisphere (NH) frozen ground extent (C), NH snow cover extent (D) and global glacier mass balance (E). The solid red line in E denotes the cumulative global glacier mass balance; in the other panels it shows decadal variations (see Appendix 3.A).*

above the freezing point. Reductions in snow cover and in mountain glaciers have occurred despite increased snowfall in many cases, implicating increased air temperatures. Similarly, although snow cover changes affect frozen ground and lake and river ice, this does not seem sufficient to explain the observed changes, suggesting that increased local air temperatures have been important. Observed arctic sea ice reductions can be simulated fairly well in models driven by historical circulation and temperature changes. The observed increases in snowfall on ice sheets in some cold central regions, surface melting in coastal regions and sub-ice-shelf melting along many coasts are all consistent with warming. The geographically widespread nature of these snow and ice changes suggests that widespread warming is the cause of the Earth's overall loss of ice.

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Frequently Asked Question 5.1
Is Sea Level Rising?

Yes, there is strong evidence that global sea level gradually rose in the 20th century and is currently rising at an increased rate, after a period of little change between AD 0 and AD 1900. Sea level is projected to rise at an even greater rate in this century. The two major causes of global sea level rise are thermal expansion of the oceans (water expands as it warms) and the loss of land-based ice due to increased melting.

Global sea level rose by about 120 m during the several millennia that followed the end of the last ice age (approximately 21,000 years ago), and stabilised between 3,000 and 2,000 years ago. Sea level indicators suggest that global sea level did not change significantly from then until the late 19th century. The instrumental record of modern sea level change shows evidence for onset of sea level rise during the 19th century. Estimates for the 20th century show that global average sea level rose at a rate of about 1.7 mm yr^{-1}.

Satellite observations available since the early 1990s provide more accurate sea level data with nearly global coverage. This decade-long satellite altimetry data set shows that since 1993, sea level has been rising at a rate of around 3 mm yr^{-1}, significantly higher than the average during the previous half century. Coastal tide gauge measurements confirm this observation, and indicate that similar rates have occurred in some earlier decades.

In agreement with climate models, satellite data and hydrographic observations show that sea level is not rising uniformly around the world. In some regions, rates are up to several times the global mean rise, while in other regions sea level is falling. Substantial spatial variation in rates of sea level change is also inferred from hydrographic observations. Spatial variability of the rates of sea level rise is mostly due to non-uniform changes in temperature and salinity and related to changes in the ocean circulation.

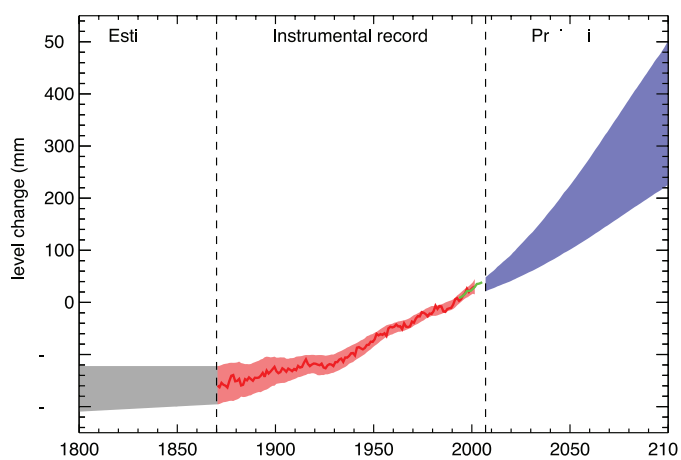
Near-global ocean temperature data sets made available in recent years allow a direct calculation of thermal expansion. It is believed that on average, over the period from 1961 to 2003, thermal expansion contributed about one-quarter of the observed sea level rise, while melting of land ice accounted for less than half. Thus, the full magnitude of the observed sea level rise during that period was not satisfactorily explained by those data sets, as reported in the IPCC Third Assessment Report.

During recent years (1993–2003), for which the observing system is much better, thermal expansion and melting of land ice each account for about half of the observed sea level rise, although there is some uncertainty in the estimates.

The reasonable agreement in recent years between the observed rate of sea level rise and the sum of thermal expansion and loss of land ice suggests an upper limit for the magnitude of change in land-based water storage, which is relatively poorly known. Model results suggest no net trend in the storage of water over land due to climate-driven changes but there are large interannual and decadal fluctuations. However, for the recent period 1993 to 2003, the small discrepancy between observed sea level rise and the sum of known contributions might be due to unquantified human-induced processes (e.g., groundwater extraction, impoundment in reservoirs, wetland drainage and deforestation).

Global sea level is projected to rise during the 21st century at a greater rate than during 1961 to 2003. Under the IPCC Special Report on Emission Scenarios (SRES) A1B scenario by the mid-2090s, for instance, global sea level reaches 0.22 to 0.44 m above 1990 levels, and is rising at about 4 mm yr^{-1}. As in the past, sea level change in the future will not be geographically uniform, with regional sea level change varying within about ±0.15 m of the mean in a typical model projection. Thermal expansion is projected to contribute more than half of the average rise, but land ice will lose mass increasingly rapidly as the century progresses. An important uncertainty relates to whether discharge of ice from the ice sheets will continue to increase as a consequence of accelerated ice flow, as has been observed in recent years. This would add to the amount of sea level rise, but quantitative projections of how much it would add cannot be made with confidence, owing to limited understanding of the relevant processes.

Figure 1 shows the evolution of global mean sea level in the past and as projected for the 21st century for the SRES A1B scenario.



FAQ 5.1, Figure 1. *Time series of global mean sea level (deviation from the 1980-1999 mean) in the past and as projected for the future. For the period before 1870, global measurements of sea level are not available. The grey shading shows the uncertainty in the estimated long-term rate of sea level change (Section 6.4.3). The red line is a reconstruction of global mean sea level from tide gauges (Section 5.5.2.1), and the red shading denotes the range of variations from a smooth curve. The green line shows global mean sea level observed from satellite altimetry. The blue shading represents the range of model projections for the SRES A1B scenario for the 21st century, relative to the 1980 to 1999 mean, and has been calculated independently from the observations. Beyond 2100, the projections are increasingly dependent on the emissions scenario (see Chapter 10 for a discussion of sea level rise projections for other scenarios considered in this report). Over many centuries or millennia, sea level could rise by several metres (Section 10.7.4).*

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Frequently Asked Question 6.1

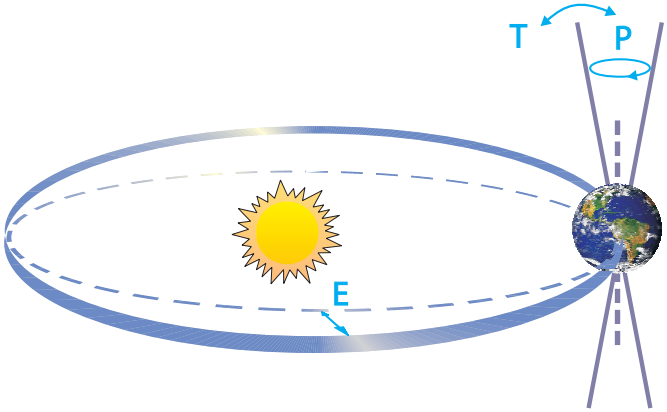
What Caused the Ice Ages and Other Important Climate Changes Before the Industrial Era?

Climate on Earth has changed on all time scales, including long before human activity could have played a role. Great progress has been made in understanding the causes and mechanisms of these climate changes. Changes in Earth's radiation balance were the principal driver of past climate changes, but the causes of such changes are varied. For each case – be it the Ice Ages, the warmth at the time of the dinosaurs or the fluctuations of the past millennium – the specific causes must be established individually. In many cases, this can now be done with good confidence, and many past climate changes can be reproduced with quantitative models.

Global climate is determined by the radiation balance of the planet (see FAQ 1.1). There are three fundamental ways the Earth's radiation balance can change, thereby causing a climate change: (1) changing the incoming solar radiation (e.g., by changes in the Earth's orbit or in the Sun itself), (2) changing the fraction of solar radiation that is reflected (this fraction is called the albedo – it can be changed, for example, by changes in cloud cover, small particles called aerosols or land cover), and (3) altering the long-wave energy radiated back to space (e.g., by changes in greenhouse gas concentrations). In addition, local climate also depends on how heat is distributed by winds and ocean currents. All of these factors have played a role in past climate changes.

Starting with the ice ages that have come and gone in regular cycles for the past nearly three million years, there is strong evidence that these are linked to regular variations in the Earth's orbit around the Sun, the so-called Milankovitch cycles (Figure 1). These cycles change the amount of solar radiation received at each latitude in each season (but hardly affect the global annual mean), and they can be calculated with astronomical precision. There is still some discussion about how exactly this starts and ends ice ages, but many studies suggest that the amount of summer sunshine on northern continents is crucial: if it drops below a critical value, snow from the past winter does not melt away in summer and an ice sheet starts to grow as more and more snow accumulates. Climate model simulations confirm that an Ice Age can indeed be started in this way, while simple conceptual models have been used to successfully 'hindcast' the onset of past glaciations based on the orbital changes. The next large reduction in northern summer insolation, similar to those that started past Ice Ages, is due to begin in 30,000 years.

Although it is not their primary cause, atmospheric carbon dioxide (CO_2) also plays an important role in the ice ages. Antarctic ice core data show that CO_2 concentration is low in the cold glacial times (~190 ppm), and high in the warm interglacials (~280 ppm); atmospheric CO_2 follows temperature changes in Antarctica with a lag of some hundreds of years. Because the climate changes at the beginning and end of ice ages take several thousand years,



FAQ 6.1, Figure 1. *Schematic of the Earth's orbital changes (Milankovitch cycles) that drive the ice age cycles. 'T' denotes changes in the tilt (or obliquity) of the Earth's axis, 'E' denotes changes in the eccentricity of the orbit (due to variations in the minor axis of the ellipse), and 'P' denotes precession, that is, changes in the direction of the axis tilt at a given point of the orbit. Source: Rahmstorf and Schellnhuber (2006).*

most of these changes are affected by a positive CO_2 feedback; that is, a small initial cooling due to the Milankovitch cycles is subsequently amplified as the CO_2 concentration falls. Model simulations of ice age climate (see discussion in Section 6.4.1) yield realistic results only if the role of CO_2 is accounted for.

During the last ice age, over 20 abrupt and dramatic climate shifts occurred that are particularly prominent in records around the northern Atlantic (see Section 6.4). These differ from the glacial-interglacial cycles in that they probably do not involve large changes in global mean temperature: changes are not synchronous in Greenland and Antarctica, and they are in the opposite direction in the South and North Atlantic. This means that a major change in global radiation balance would not have been needed to cause these shifts; a redistribution of heat within the climate system would have sufficed. There is indeed strong evidence that changes in ocean circulation and heat transport can explain many features of these abrupt events; sediment data and model simulations show that some of these changes could have been triggered by instabilities in the ice sheets surrounding the Atlantic at the time, and the associated freshwater release into the ocean.

Much warmer times have also occurred in climate history – during most of the past 500 million years, Earth was probably completely free of ice sheets (geologists can tell from the marks ice leaves on rock), unlike today, when Greenland and Antarctica are ice-covered. Data on greenhouse gas abundances going back beyond a million years, that is, beyond the reach of antarctic ice cores, are still rather uncertain, but analysis of geological

(continued)

samples suggests that the warm ice-free periods coincide with high atmospheric CO_2 levels. On million-year time scales, CO_2 levels change due to tectonic activity, which affects the rates of CO_2 exchange of ocean and atmosphere with the solid Earth. See Box 6.1 for more about these ancient climates.

Another likely cause of past climatic changes is variations in the energy output of the Sun. Measurements over recent decades show that the solar output varies slightly (by close to 0.1%) in an 11-year cycle. Sunspot observations (going back to the 17th century), as well as data from isotopes generated by cosmic radiation, provide evidence for longer-term changes in solar activity. Data correlation and model simulations indicate that solar variability and volcanic activity are likely to be leading reasons for climate variations during the past millennium, before the start of the industrial era.

These examples illustrate that different climate changes in the past had different causes. The fact that natural factors caused climate changes in the past does not mean that the current climate change is natural. By analogy, the fact that forest fires have long been caused naturally by lightning strikes does not mean that fires cannot also be caused by a careless camper. FAQ 2.1 addresses the question of how human influences compare with natural ones in their contributions to recent climate change.

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Frequently Asked Question 6.2

Is the Current Climate Change Unusual Compared to Earlier Changes in Earth's History?

Climate has changed on all time scales throughout Earth's history. Some aspects of the current climate change are not unusual, but others are. The concentration of CO_2 in the atmosphere has reached a record high relative to more than the past half-million years, and has done so at an exceptionally fast rate. Current global temperatures are warmer than they have ever been during at least the past five centuries, probably even for more than a millennium. If warming continues unabated, the resulting climate change within this century would be extremely unusual in geological terms. Another unusual aspect of recent climate change is its cause: past climate changes were natural in origin (see FAQ 6.1), whereas most of the warming of the past 50 years is attributable to human activities.

When comparing the current climate change to earlier, natural ones, three distinctions must be made. First, it must be clear which variable is being compared: is it greenhouse gas concentration or temperature (or some other climate parameter), and is it their absolute value or their rate of change? Second, local changes must not be confused with global changes. Local climate changes are often much larger than global ones, since local factors (e.g., changes in oceanic or atmospheric circulation) can shift the delivery of heat or moisture from one place to another and local feedbacks operate (e.g., sea ice feedback). Large changes in global mean temperature, in contrast, require some global forcing (such as a change in greenhouse gas concentration or solar activity). Third, it is necessary to distinguish between time scales. Climate changes over millions of years can be much larger and have different causes (e.g., continental drift) compared to climate changes on a centennial time scale.

The main reason for the current concern about climate change is the rise in atmospheric carbon dioxide (CO_2) concentration (and some other greenhouse gases), which is very unusual for the Quaternary (about the last two million years). The concentration of CO_2 is now known accurately for the past 650,000 years from antarctic ice cores. During this time, CO_2 concentration varied between a low of 180 ppm during cold glacial times and a high of 300 ppm during warm interglacials. Over the past century, it rapidly increased well out of this range, and is now 379 ppm (see Chapter 2). For comparison, the approximately 80-ppm rise in CO_2 concentration at the end of the past ice ages generally took over 5,000 years. Higher values than at present have only occurred many millions of years ago (see FAQ 6.1).

Temperature is a more difficult variable to reconstruct than CO_2 (a globally well-mixed gas), as it does not have the same value all over the globe, so that a single record (e.g., an ice core) is only of limited value. Local temperature fluctuations, even those over just a few decades, can be several degrees celsius, which is larger than the global warming signal of the past century of about 0.7°C.

More meaningful for global changes is an analysis of large-scale (global or hemispheric) averages, where much of the local variation averages out and variability is smaller. Sufficient coverage of instrumental records goes back only about 150 years. Further back in time, compilations of proxy data from tree rings, ice cores, etc., go back more than a thousand years with decreasing spatial coverage for earlier periods (see Section 6.5). While there are differences among those reconstructions and significant uncertainties remain, all published reconstructions find that temperatures were warm during medieval times, cooled to low values in the 17th, 18th and 19th centuries, and warmed rapidly after that. The medieval level of warmth is uncertain, but may have been reached again in the mid-20th century, only to have likely been exceeded since then. These conclusions are supported by climate modelling as well. Before 2,000 years ago, temperature variations have not been systematically compiled into large-scale averages, but they do not provide evidence for warmer-than-present global annual mean temperatures going back through the Holocene (the last 11,600 years; see Section 6.4). There are strong indications that a warmer climate, with greatly reduced global ice cover and higher sea level, prevailed until around 3 million years ago. Hence, current warmth appears unusual in the context of the past millennia, but not unusual on longer time scales for which changes in tectonic activity (which can drive natural, slow variations in greenhouse gas concentration) become relevant (see Box 6.1).

A different matter is the current rate of warming. Are more rapid global climate changes recorded in proxy data? The largest temperature changes of the past million years are the glacial cycles, during which the global mean temperature changed by 4°C to 7°C between ice ages and warm interglacial periods (local changes were much larger, for example near the continental ice sheets). However, the data indicate that the global warming at the end of an ice age was a gradual process taking about 5,000 years (see Section 6.3). It is thus clear that the current rate of global climate change is much more rapid and very unusual in the context of past changes. The much-discussed abrupt climate shifts during glacial times (see Section 6.3) are not counter-examples, since they were probably due to changes in ocean heat transport, which would be unlikely to affect the global mean temperature.

Further back in time, beyond ice core data, the time resolution of sediment cores and other archives does not resolve changes as rapid as the present warming. Hence, although large climate changes have occurred in the past, there is no evidence that these took place at a faster rate than present warming. If projections of approximately 5°C warming in this century (the upper end of the range) are realised, then the Earth will have experienced about the same amount of global mean warming as it did at the end of the last ice age; there is no evidence that this rate of possible future global change was matched by any comparable global temperature increase of the last 50 million years.

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Frequently Asked Question 7.1

Are the Increases in Atmospheric Carbon Dioxide and Other Greenhouse Gases During the Industrial Era Caused by Human Activities?

Yes, the increases in atmospheric carbon dioxide (CO_2) and other greenhouse gases during the industrial era are caused by human activities. In fact, the observed increase in atmospheric CO_2 concentrations does not reveal the full extent of human emissions in that it accounts for only 55% of the CO_2 released by human activity since 1959. The rest has been taken up by plants on land and by the oceans. In all cases, atmospheric concentrations of greenhouse gases, and their increases, are determined by the balance between sources (emissions of the gas from human activities and natural systems) and sinks (the removal of the gas from the atmosphere by conversion to a different chemical compound). Fossil fuel combustion (plus a smaller contribution from cement manufacture) is responsible for more than 75% of human-caused CO_2 emissions. Land use change (primarily deforestation) is responsible for the remainder. For methane, another important greenhouse gas, emissions generated by human activities exceeded natural emissions over the last 25 years. For nitrous oxide, emissions generated by human activities are equal to natural emissions to the atmosphere. Most of the long-lived halogen-containing gases (such as chlorofluorcarbons) are manufactured by humans, and were not present in the atmosphere before the industrial era. On average, present-day tropospheric ozone has increased 38% since pre-industrial times, and the increase results from atmospheric reactions of short-lived pollutants emitted by human activity. The concentration of CO_2 is now 379 parts per million (ppm) and methane is greater than 1,774 parts per billion (ppb), both very likely much higher than any time in at least 650 kyr (during which CO_2 remained between 180 and 300 ppm and methane between 320 and 790 ppb). The recent rate of change is dramatic and unprecedented; increases in CO_2 never exceeded 30 ppm in 1 kyr – yet now CO_2 has risen by 30 ppm in just the last 17 years.

Carbon Dioxide

Emissions of CO_2 (Figure 1a) from fossil fuel combustion, with contributions from cement manufacture, are responsible for more than 75% of the increase in atmospheric CO_2 concentration since pre-industrial times. The remainder of the increase comes from land use changes dominated by deforestation (and associated biomass burning) with contributions from changing agricultural practices. All these increases are caused by human activity. The natural carbon cycle cannot explain the observed atmospheric increase of 3.2 to 4.1 GtC yr^{-1} in the form of CO_2 over the last 25 years. (One GtC equals 10^{15} grams of carbon, i.e., one billion tonnes.)

Natural processes such as photosynthesis, respiration, decay and sea surface gas exchange lead to massive exchanges, sources and sinks of CO_2 between the land and atmosphere (estimated at ~120 GtC yr^{-1}) and the ocean and atmosphere (estimated at ~90 GtC yr^{-1}; see figure 7.3). The natural sinks of carbon produce a small net uptake of CO_2 of approximately 3.3 GtC yr^{-1} over the last 15 years, partially offsetting the human-caused emissions. Were it not for the natural sinks taking up nearly half the human-produced CO_2 over the past 15 years, atmospheric concentrations would have grown even more dramatically.

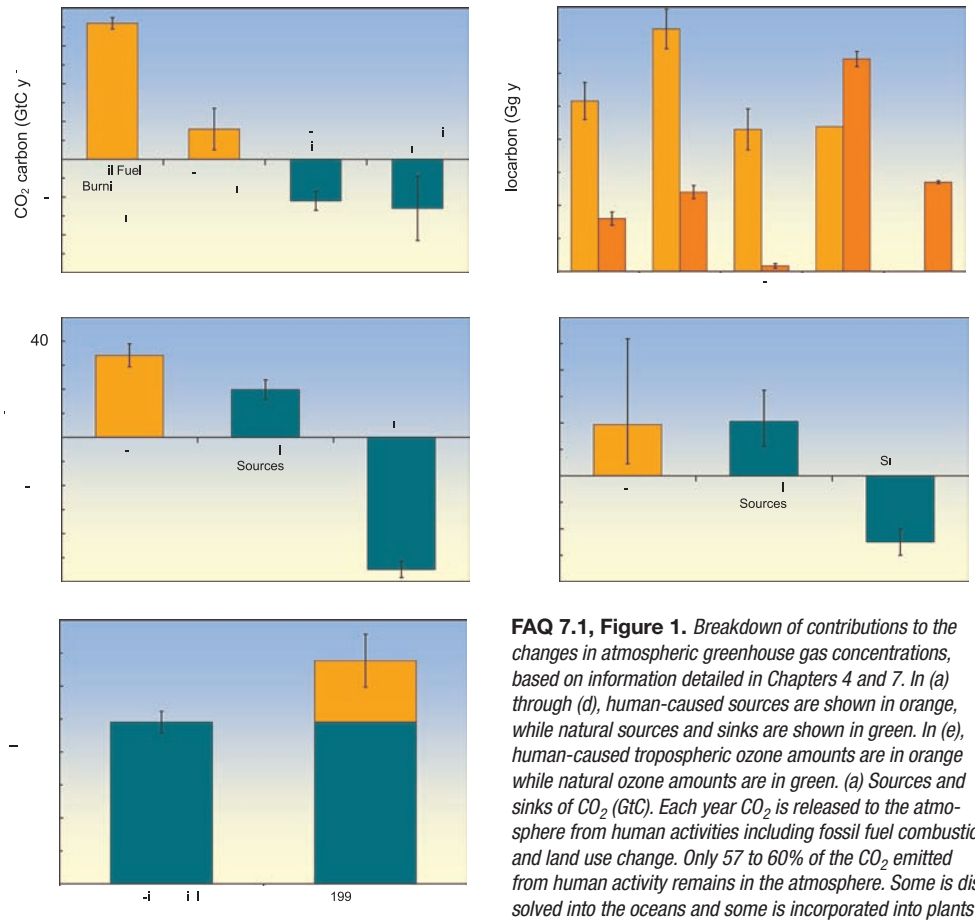
The increase in atmospheric CO_2 concentration is known to be caused by human activities because the character of CO_2 in the atmosphere, in particular the ratio of its heavy to light carbon atoms, has changed in a way that can be attributed to addition of fossil fuel carbon. In addition, the ratio of oxygen to nitrogen in the atmosphere has declined as CO_2 has increased; this is as expected because oxygen is depleted when fossil fuels are burned. A heavy form of carbon, the carbon-13 isotope, is less abundant in vegetation and in fossil fuels that were formed from past vegetation, and is more abundant in carbon in the oceans and in volcanic or geothermal emissions. The relative amount of the carbon-13 isotope in the atmosphere has been declining, showing that the added carbon comes from fossil fuels and vegetation. Carbon also has a rare radioactive isotope, carbon-14, which is present in atmospheric CO_2 but absent in fossil fuels. Prior to atmospheric testing of nuclear weapons, decreases in the relative amount of carbon-14 showed that fossil fuel carbon was being added to the atmosphere.

Halogen-Containing Gases

Human activities are responsible for the bulk of long-lived atmospheric halogen-containing gas concentrations. Before industrialisation, there were only a few naturally occurring halogen-containing gases, for example, methyl bromide and methyl chloride. The development of new techniques for chemical synthesis resulted in a proliferation of chemically manufactured halogen-containing gases during the last 50 years of the 20th century. Emissions of key halogen-containing gases produced by humans are shown in Figure 1b. Atmospheric lifetimes range from 45 to 100 years for the chlorofluorocarbons (CFCs) plotted here, from 1 to 18 years for the hydrochlorofluorocarbons (HCFCs), and from 1 to 270 years for the hydrofluorocarbons (HFCs). The perfluorocarbons (PFCs, not plotted) persist in the atmosphere for thousands of years. Concentrations of several important halogen-containing gases, including CFCs, are now stabilising or decreasing at the Earth's surface as a result of the Montreal Protocol on Substances that Deplete the Ozone Layer and its Amendments. Concentrations of HCFCs, production of which is to be phased out by 2030, and of the Kyoto Protocol gases HFCs and PFCs, are currently increasing. *(continued)*

Methane

Methane (CH_4) sources to the atmosphere generated by human activities exceed CH_4 sources from natural systems (Figure 1c). Between 1960 and 1999, CH_4 concentrations grew an average of at least six times faster than over any 40-year period of the two millennia before 1800, despite a near-zero growth rate since 1980. The main natural source of CH_4 to the atmosphere is wetlands. Additional natural sources include termites, oceans, vegetation and CH_4 hydrates. The human activities that produce CH_4 include energy production from coal and natural gas, waste disposal in landfills, raising ruminant animals (e.g., cattle and sheep), rice agriculture and biomass burning. Once emitted, CH_4 remains in the atmosphere for approximately 8.4 years before removal, mainly by chemical oxidation in the troposphere. Minor sinks for CH_4 include uptake by soils and eventual destruction in the stratosphere.



FAQ 7.1, Figure 1. *Breakdown of contributions to the changes in atmospheric greenhouse gas concentrations, based on information detailed in Chapters 4 and 7. In (a) through (d), human-caused sources are shown in orange, while natural sources and sinks are shown in green. In (e), human-caused tropospheric ozone amounts are in orange while natural ozone amounts are in green. (a) Sources and sinks of CO_2 (GtC). Each year CO_2 is released to the atmosphere from human activities including fossil fuel combustion and land use change. Only 57 to 60% of the CO_2 emitted from human activity remains in the atmosphere. Some is dissolved into the oceans and some is incorporated into plants as they grow. Land-related fluxes are for the 1990s; fossil fuel and cement fluxes and net ocean uptake are for the period 2000 to 2005. All values and uncertainty ranges are from Table 7.1. (b) Global emissions of CFCs and other halogen-containing compounds for 1990 (light orange) and 2002 (dark orange). These chemicals are exclusively human-produced. Here, 'HCFCs' comprise HCFC-22, -141b and -142b, while 'HFCs' comprise HFC-23, -125, -134a and -152a. One Gg = 10^9 g (1,000 tonnes). Most data are from reports listed in Chapter 2. (c) Sources and sinks of CH_4 for the period 1983 to 2004. Human-caused sources of CH_4 include energy production, landfills, ruminant animals (e.g., cattle and sheep), rice agriculture and biomass burning. One Tg = 10^{12} g (1 million tonnes). Values and uncertainties are the means and standard deviations for CH_4 of the corresponding aggregate values from Table 7.6. (d) Sources and sinks of N_2O. Human-caused sources of N_2O include the transformation of fertilizer nitrogen into N_2O and its subsequent emission from agricultural soils, biomass burning, cattle and some industrial activities including nylon manufacture. Source values and uncertainties are the midpoints and range limits from Table 7.7. N_2O losses are from Chapter 7.4. (e) Tropospheric ozone in the 19th and early 20th centuries and the 1990 to 2000 period. The increase in tropospheric ozone formation is human-induced, resulting from atmospheric chemical reactions of pollutants emitted by burning of fossil fuels or biofuels. The pre-industrial value and uncertainty range are from Table 4.9 of the IPCC Third Assessment Report (TAR), estimated from reconstructed observations. The present-day total and its uncertainty range are the average and standard deviation of model results quoted in Table 7.9 of this report, excluding those from the TAR.*

Nitrous Oxide

Nitrous oxide (N_2O) sources to the atmosphere from human activities are approximately equal to N_2O sources from natural systems (Figure 1d). Between 1960 and 1999, N_2O concentrations grew an average of at least two times faster than over any 40-year period of the two millennia before 1800. Natural sources of N_2O include oceans, chemical oxidation of ammonia in the atmosphere, and soils. Tropical soils are a particularly important source of N_2O to the atmosphere. Human activities that emit N_2O include transformation of fertilizer nitrogen into N_2O and its subsequent emission from agricultural soils, biomass burning, raising cattle and some industrial activities, including nylon manufacture. Once emitted, N_2O remains in the atmosphere for approximately 114 years before removal, mainly by destruction in the stratosphere.

Tropospheric Ozone

Tropospheric ozone is produced by photochemical reactions in the atmosphere involving forerunner chemicals such as carbon monoxide, CH_4, volatile organic compounds and nitrogen oxides. These chemicals are emitted by natural biological processes and by human activities including land use change and fuel combustion. Because tropospheric ozone is relatively short-lived, lasting for a few days to weeks in the atmosphere, its distributions are highly variable and tied to the abundance of its forerunner compounds, water vapour and sunlight. Tropospheric ozone concentrations are significantly higher in urban air, downwind of urban areas and in regions of biomass burning. The increase of 38% (20–50%) in tropospheric ozone since the pre-industrial era (Figure 1e) is human-caused.

It is very likely that the increase in the combined radiative forcing from CO_2, CH_4 and N_2O was at least six times faster between 1960 and 1999 than over any 40-year period during the two millennia prior to the year 1800.

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Frequently Asked Question 8.1

How Reliable Are the Models Used to Make Projections of Future Climate Change?

There is considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above. This confidence comes from the foundation of the models in accepted physical principles and from their ability to reproduce observed features of current climate and past climate changes. Confidence in model estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation). Over several decades of development, models have consistently provided a robust and unambiguous picture of significant climate warming in response to increasing greenhouse gases.

Climate models are mathematical representations of the climate system, expressed as computer codes and run on powerful computers. One source of confidence in models comes from the fact that model fundamentals are based on established physical laws, such as conservation of mass, energy and momentum, along with a wealth of observations.

A second source of confidence comes from the ability of models to simulate important aspects of the current climate. Models are routinely and extensively assessed by comparing their simulations with observations of the atmosphere, ocean, cryosphere and land surface. Unprecedented levels of evaluation have taken place over the last decade in the form of organised multi-model 'intercomparisons'. Models show significant and increasing skill in representing many important mean climate features, such as the large-scale distributions of atmospheric temperature, precipitation, radiation and wind, and of oceanic temperatures, currents and sea ice cover. Models can also simulate essential aspects of many of the patterns of climate variability observed across a range of time scales. Examples include the advance and retreat of the major monsoon systems, the seasonal shifts of temperatures, storm tracks and rain belts, and the hemispheric-scale seesawing of extratropical surface pressures (the Northern and Southern 'annular modes'). Some climate models, or closely related variants, have also been tested by using them to predict weather and make seasonal forecasts. These models demonstrate skill in such forecasts, showing they can represent important features of the general circulation across shorter time scales, as well as aspects of seasonal and interannual variability. Models' ability to represent these and other important climate features increases our confidence that they represent the essential physical processes important for the simulation of future climate change. (Note that the limitations in climate models' ability to forecast weather beyond a few days do not limit their ability to predict long-term climate changes, as these are very different types of prediction – see FAQ 1.2.)

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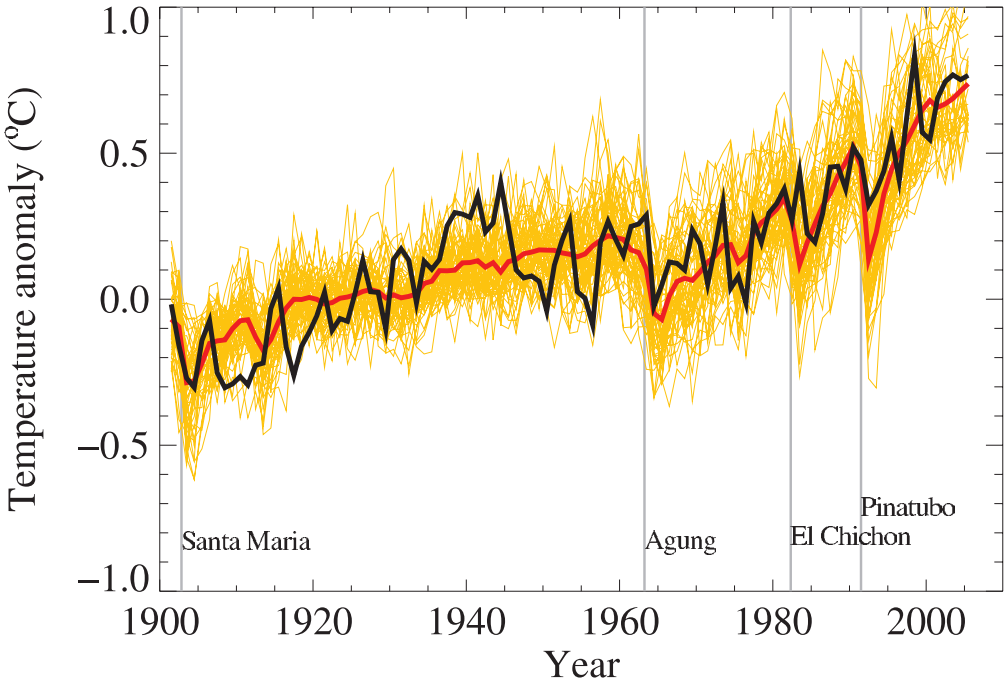

FAQ 8.1, Figure 1. *Global mean near-surface temperatures over the 20th century from observations (black) and as obtained from 58 simulations produced by 14 different climate models driven by both natural and human-caused factors that influence climate (yellow). The mean of all these runs is also shown (thick red line). Temperature anomalies are shown relative to the 1901 to 1950 mean. Vertical grey lines indicate the timing of major volcanic eruptions. (Figure adapted from Chapter 9, Figure 9.5. Refer to corresponding caption for further details.)*

A third source of confidence comes from the ability of models to reproduce features of past climates and climate changes. Models have been used to simulate ancient climates, such as the warm mid-Holocene of 6,000 years ago or the last glacial maximum of 21,000 years ago (see Chapter 6). They can reproduce many features (allowing for uncertainties in reconstructing past climates) such as the magnitude and broad-scale pattern of oceanic cooling during the last ice age. Models can also simulate many observed aspects of climate change over the instrumental record. One example is that the global temperature trend over the past century (shown in Figure 1) can be modelled with high skill when both human and natural factors that influence climate are included. Models also reproduce other observed changes, such as the faster increase in nighttime than in daytime temperatures, the larger degree of warming in the Arctic and the small, short-term global cooling (and subsequent recovery) which has followed major volcanic eruptions, such as that of Mt. Pinatubo in 1991 (see FAQ 8.1, Figure 1). Model global temperature projections made over the last two decades have also been in overall agreement with subsequent observations over that period (Chapter 1).

Nevertheless, models still show significant errors. Although these are generally greater at smaller scales, important large-scale problems also remain. For example, deficiencies remain in the simulation of tropical precipitation, the El Niño-Southern Oscillation and the Madden-Julian Oscillation (an observed variation in tropical winds and rainfall with a time scale of 30 to 90 days). The ultimate source of most such errors is that many important small-scale processes cannot be represented explicitly in models, and so must be included in approximate form as they interact with larger-scale features. This is partly due to limitations in computing power, but also results from limitations in scientific understanding or in the availability of detailed observations of some physical processes. Significant uncertainties, in particular, are associated with the representation of clouds, and in the resulting cloud responses to climate change. Consequently, models continue to display a substantial range of global temperature change in response to specified greenhouse gas forcing (see Chapter 10). Despite such uncertainties, however, models are unanimous in their prediction of substantial climate warming under greenhouse gas increases, and this warming is of a magnitude consistent with independent estimates derived from other sources, such as from observed climate changes and past climate reconstructions.

Since confidence in the changes projected by global models decreases at smaller scales, other techniques, such as the use of regional climate models, or downscaling methods, have been specifically developed for the study of regional- and local-scale climate change (see FAQ 11.1). However, as global models continue to develop, and their resolution continues to improve, they are becoming increasingly useful for investigating important smaller-scale features, such as changes in extreme weather events, and further improvements in regional-scale representation are expected with increased computing power. Models are also becoming more comprehensive in their treatment of the climate system, thus explicitly representing more physical and biophysical processes and interactions considered potentially important for climate change, particularly at longer time scales. Examples are the recent inclusion of plant responses, ocean biological and chemical interactions, and ice sheet dynamics in some global climate models.

In summary, confidence in models comes from their physical basis, and their skill in representing observed climate and past climate changes. Models have proven to be extremely important tools for simulating and understanding climate, and there is considerable confidence that they are able to provide credible quantitative estimates of future climate change, particularly at larger scales. Models continue to have significant limitations, such as in their representation of clouds, which lead to uncertainties in the magnitude and timing, as well as regional details, of predicted climate change. Nevertheless, over several decades of model development, they have consistently provided a robust and unambiguous picture of significant climate warming in response to increasing greenhouse gases.

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Frequently Asked Question 9.1

Can Individual Extreme Events be Explained by Greenhouse Warming?

Changes in climate extremes are expected as the climate warms in response to increasing atmospheric greenhouse gases resulting from human activities, such as the use of fossil fuels. However, determining whether a specific, single extreme event is due to a specific cause, such as increasing greenhouse gases, is difficult, if not impossible, for two reasons: 1) extreme events are usually caused by a combination of factors and 2) a wide range of extreme events is a normal occurrence even in an unchanging climate. Nevertheless, analysis of the warming observed over the past century suggests that the likelihood of some extreme events, such as heat waves, has increased due to greenhouse warming, and that the likelihood of others, such as frost or extremely cold nights, has decreased. For example, a recent study estimates that human influences have more than doubled the risk of a very hot European summer like that of 2003.

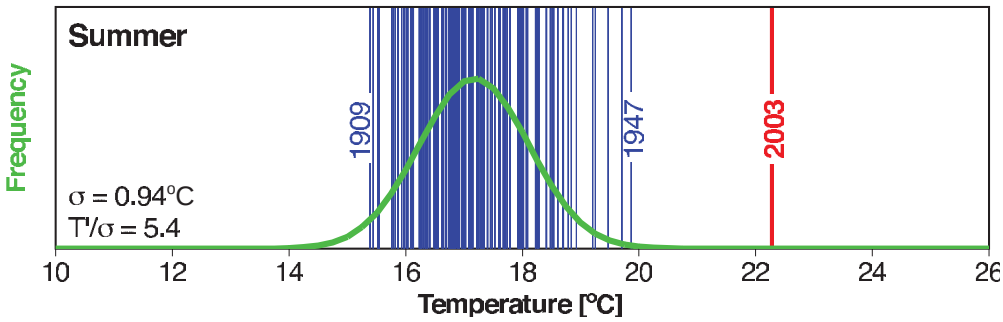
People affected by an extreme weather event often ask whether human influences on the climate could be held to some extent responsible. Recent years have seen many extreme events that some commentators have linked to increasing greenhouse gases. These include the prolonged drought in Australia, the extremely hot summer in Europe in 2003 (see Figure 1), the intense North Atlantic hurricane seasons of 2004 and 2005 and the extreme rainfall events in Mumbai, India in July 2005. Could a human influence such as increased concentrations of greenhouse gases in the atmosphere have 'caused' any of these events?

Extreme events usually result from a combination of factors. For example, several factors contributed to the extremely hot European summer of 2003, including a persistent high-pressure system that was associated with very clear skies and dry soil, which left more solar energy available to heat the land because less energy was consumed to evaporate moisture from the soil. Similarly, the formation of a hurricane requires warm sea surface temperatures and specific atmospheric circulation conditions. Because some factors may be strongly affected by human activities, such as sea surface temperatures, but others may not, it is not simple to detect a human influence on a single, specific extreme event.

Nevertheless, it may be possible to use climate models to determine whether human influences have changed the likelihood of certain types of extreme events. For example, in the case of the 2003 European heat wave, a climate model was run including only historical changes in natural factors that affect the climate, such as volcanic activity and changes in solar output. Next, the model was run again including both human and natural factors, which produced a simulation of the evolution of the European climate that was much closer to that which had actually occurred. Based on these experiments, it was estimated that over the 20th century, human influences more than doubled the risk of having a summer in Europe as hot as that of 2003, and that in the absence of human influences, the risk would probably have been one in many hundred years. More detailed modelling work will be required to estimate the change in risk for specific high-impact events, such as the occurrence of a series of very warm nights in an urban area such as Paris.

The value of such a probability-based approach – 'Does human influence change the likelihood of an event?' – is that it can be used to estimate the influence of external factors, such as increases in greenhouse gases, on the frequency of specific types of events, such as heat waves or frost. Nevertheless, careful statistical analyses are required, since the likelihood of individual extremes, such as a late-spring frost, could change due to changes in climate variability as well as changes in average climate conditions. Such analyses rely on climate-model based estimates of climate variability, and thus the climate models used should adequately represent that variability.

The same likelihood-based approach can be used to examine changes in the frequency of heavy rainfall or floods. Climate models predict that human influences will cause an increase in many types of extreme events, including extreme rainfall. There is already evidence that, in recent decades, extreme rainfall has increased in some regions, leading to an increase in flooding.



FAQ 9.1, Figure 1. *Summer temperatures in Switzerland from 1864 to 2003 are, on average, about 17°C, as shown by the green curve. During the extremely hot summer of 2003, average temperatures exceeded 22°C, as indicated by the red bar (a vertical line is shown for each year in the 137-year record). The fitted Gaussian distribution is indicated in green. The years 1909, 1947 and 2003 are labelled because they represent extreme years in the record. The values in the lower left corner indicate the standard deviation (σ) and the 2003 anomaly normalised by the 1864 to 2000 standard deviation (T'/σ). From Schär et al. (2004).*

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Frequently Asked Question 9.2

Can the Warming of the 20th Century be Explained by Natural Variability?

It is very unlikely that the 20th-century warming can be explained by natural causes. The late 20th century has been unusually warm. Palaeoclimatic reconstructions show that the second half of the 20th century was likely the warmest 50-year period in the Northern Hemisphere in the last 1300 years. This rapid warming is consistent with the scientific understanding of how the climate should respond to a rapid increase in greenhouse gases like that which has occurred over the past century, and the warming is inconsistent with the scientific understanding of how the climate should respond to natural external factors such as variability in solar output and volcanic activity. Climate models provide a suitable tool to study the various influences on the Earth's climate. When the effects of increasing levels of greenhouse gases are included in the models, as well as natural external factors, the models produce good simulations of the warming that has occurred over the past century. The models fail to reproduce the observed warming when run using only natural factors. When human factors are included, the models also simulate a geographic pattern of temperature change around the globe similar to that which has occurred in recent decades. This spatial pattern, which has features such as a greater warming at high northern latitudes, differs from the most important patterns of natural climate variability that are associated with internal climate processes, such as El Niño.

Variations in the Earth's climate over time are caused by natural internal processes, such as El Niño, as well as changes in external influences. These external influences can be natural in origin, such as volcanic activity and variations in solar output, or caused by human activity, such as greenhouse gas emissions, human-sourced aerosols, ozone depletion and land use change. The role of natural internal processes can be estimated by studying observed variations in climate and by running climate models without changing any of the external factors that affect climate. The effect of external influences can be estimated with models by changing these factors, and by using physical understanding of the processes involved. The combined effects of natural internal variability and natural external factors can also be estimated from climate information recorded in tree rings, ice cores and other types of natural 'thermometers' prior to the industrial age.

The natural external factors that affect climate include volcanic activity and variations in solar output. Explosive volcanic eruptions occasionally eject large amounts of dust and sulphate aerosol high into the atmosphere, temporarily shielding the Earth and reflecting sunlight back to space. Solar output has an 11-year cycle and may also have longer-term variations. Human activities over the last 100 years, particularly the burning of fossil fuels, have caused a rapid increase in carbon dioxide and other greenhouse gases in the atmosphere. Before the industrial age, these gases had remained at near stable concentrations for thousands of years. Human activities have also caused increased concentrations of fine reflective particles, or 'aerosols', in the atmosphere, particularly during the 1950s and 1960s.

Although natural internal climate processes, such as El Niño, can cause variations in global mean temperature for relatively short periods, analysis indicates that a large portion is due to external factors. Brief periods of global cooling have followed major volcanic eruptions, such as Mt. Pinatubo in 1991. In the early part of the 20th century, global average temperature rose, during which time greenhouse gas concentrations started to rise, solar output was probably increasing and there was little volcanic activity. During the 1950s and 1960s, average global temperatures levelled off, as increases in aerosols from fossil fuels and other sources cooled the planet. The eruption of Mt. Agung in 1963 also put large quantities of reflective dust into the upper atmosphere. The rapid warming observed since the 1970s has occurred in a period when the increase in greenhouse gases has dominated over all other factors.

Numerous experiments have been conducted using climate models to determine the likely causes of the 20th-century climate change. These experiments indicate that models cannot reproduce the rapid warming observed in recent decades when they only take into account variations in solar output and volcanic activity. However, as shown in Figure 1, models are able to simulate the observed 20th-century changes in temperature when they include all of the most important external factors, including human influences from sources such as greenhouse gases and natural external factors. The model-estimated responses to these external factors are detectable in the 20th-century climate globally and in each individual continent except Antarctica, where there are insufficient observations. The human influence on climate very likely dominates over all other causes of change in global average surface temperature during the past half century.

An important source of uncertainty arises from the incomplete knowledge of some external factors, such as human-sourced aerosols. In addition, the climate models themselves are imperfect. Nevertheless, all models simulate a pattern of response to greenhouse gas increases from human activities that is similar to the observed pattern of change. This pattern includes more warming over land than over the oceans. This pattern of change, which differs from the principal patterns of temperature change associated with natural internal variability, such as El Niño, helps to distinguish the response to greenhouse gases from that of natural external factors. Models and observations also both show warming in the lower part of

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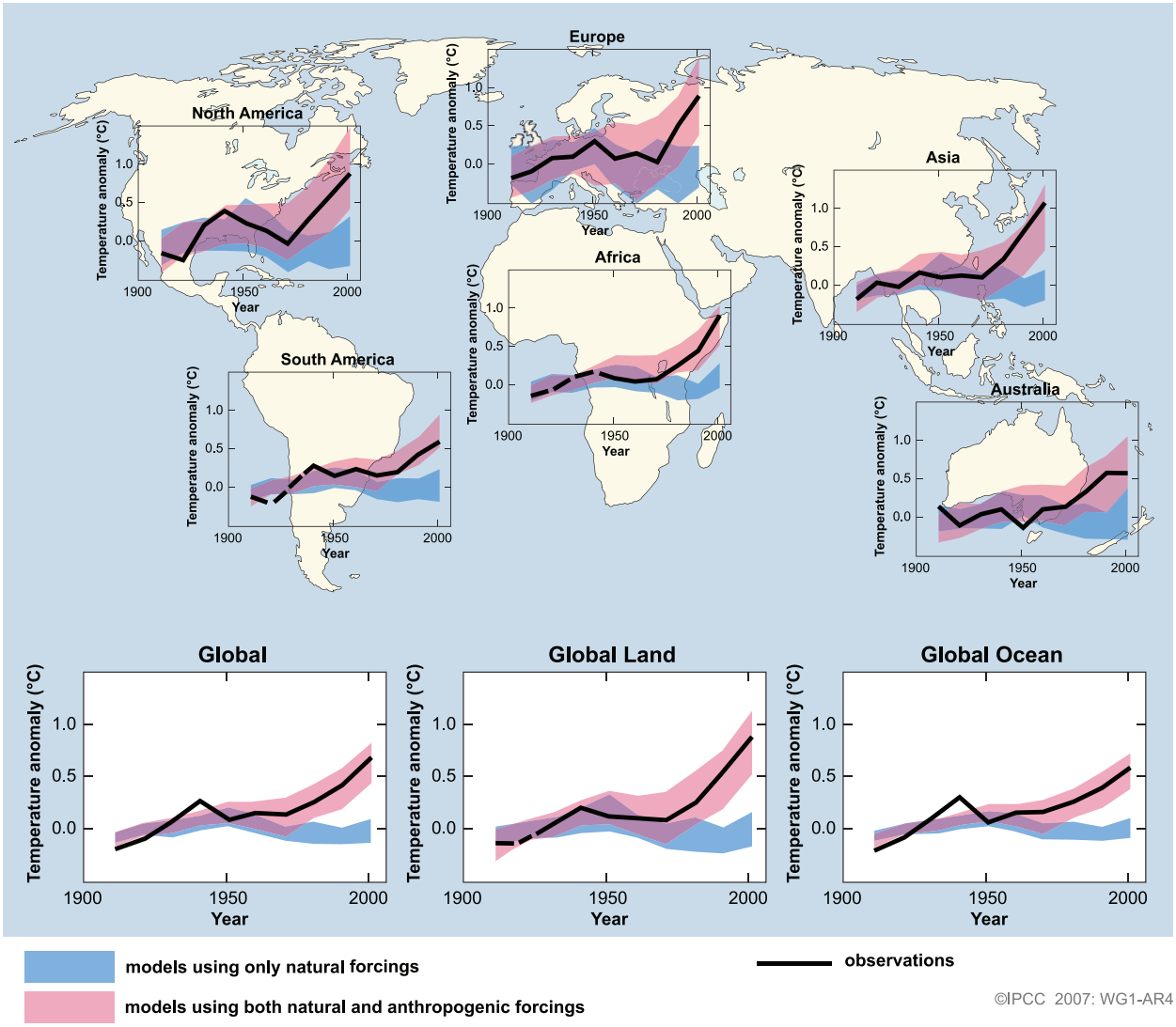

FAQ 9.2, Figure 1. *Temperature changes relative to the corresponding average for 1901-1950 (°C) from decade to decade from 1906 to 2005 over the Earth's continents, as well as the entire globe, global land area and the global ocean (lower graphs). The black line indicates observed temperature change, while the coloured bands show the combined range covered by 90% of recent model simulations. Red indicates simulations that include natural and human factors, while blue indicates simulations that include only natural factors. Dashed black lines indicate decades and continental regions for which there are substantially fewer observations. Detailed descriptions of this figure and the methodology used in its production are given in the Supplementary Material, Appendix 9.C.*

the atmosphere (the troposphere) and cooling higher up in the stratosphere. This is another 'fingerprint' of change that reveals the effect of human influence on the climate. If, for example, an increase in solar output had been responsible for the recent climate warming, both the troposphere and the stratosphere would have warmed. In addition, differences in the timing of the human and natural external influences help to distinguish the climate responses to these factors. Such considerations increase confidence that human rather than natural factors were the dominant cause of the global warming observed over the last 50 years.

Estimates of Northern Hemisphere temperatures over the last one to two millennia, based on natural 'thermometers' such as tree rings that vary in width or density as temperatures change, and historical weather records, provide additional evidence that the 20th-century warming cannot be explained by only natural internal variability and natural external forcing factors. Confidence in these estimates is increased because prior to the industrial era, much of the variation they show in Northern Hemisphere average temperatures can be explained by episodic cooling caused by large volcanic eruptions and by changes in the Sun's output. The remaining variation is generally consistent with the variability simulated by climate models in the absence of natural and human-induced external factors. While there is uncertainty in the estimates of past temperatures, they show that it is likely that the second half of the 20th century was the warmest 50-year period in the last 1300 years. The estimated climate variability caused by natural factors is small compared to the strong 20th-century warming.

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Frequently Asked Question 10.1

Are Extreme Events, Like Heat Waves, Droughts or Floods, Expected to Change as the Earth's Climate Changes?

Yes; the type, frequency and intensity of extreme events are expected to change as Earth's climate changes, and these changes could occur even with relatively small mean climate changes. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events (see FAQ 3.3).

In a warmer future climate, there will be an increased risk of more intense, more frequent and longer-lasting heat waves. The European heat wave of 2003 is an example of the type of extreme heat event lasting from several days to over a week that is likely to become more common in a warmer future climate. A related aspect of temperature extremes is that there is likely to be a decrease in the daily (diurnal) temperature range in most regions. It is also likely that a warmer future climate would have fewer frost days (i.e., nights where the temperature dips below freezing). Growing season length is related to number of frost days, and has been projected to increase as climate warms. There is likely to be a decline in the frequency of cold air outbreaks (i.e., periods of extreme cold lasting from several days to over a week) in NH winter in most areas. Exceptions could occur in areas with the smallest reductions of extreme cold in western North America, the North Atlantic and southern Europe and Asia due to atmospheric circulation changes.

In a warmer future climate, most Atmosphere-Ocean General Circulation Models project increased summer dryness and winter wetness in most parts of the northern middle and high latitudes. Summer dryness indicates a greater risk of drought. Along with the risk of drying, there is an increased chance of intense precipitation and flooding due to the greater water-holding capacity of a warmer atmosphere. This has already been observed and is projected to continue because in a warmer world, precipitation tends to be concentrated into more intense events, with longer periods of little precipitation in between. Therefore, intense and heavy downpours would be interspersed with longer relatively dry periods. Another aspect of these projected changes is that wet extremes are projected to become more severe in many areas where mean precipitation is expected to increase, and dry extremes are projected to become more severe in areas where mean precipitation is projected to decrease.

In concert with the results for increased extremes of intense precipitation, even if the wind strength of storms in a future climate did not change, there would be an increase in extreme rainfall intensity. In particular, over NH land, an increase in the likelihood of very wet winters is projected over much of central and northern Europe due to the increase in intense precipitation during storm events, suggesting an increased chance of flooding over Europe and other mid-latitude regions due to more intense rainfall and snowfall events producing more runoff. Similar results apply for summer precipitation, with implications for more flooding in the Asian monsoon region and other tropical areas. The increased risk of floods in a number of major river basins in a future warmer climate has been related to an increase in river discharge with an increased risk of future intense storm-related precipitation events and flooding. Some of these changes would be extensions of trends already underway.

There is evidence from modelling studies that future tropical cyclones could become more severe, with greater wind speeds and more intense precipitation. Studies suggest that such changes may already be underway; there are indications that the average number of Category 4 and 5 hurricanes per year has increased over the past 30 years. Some modelling studies have projected a decrease in the number of tropical cyclones globally due to the increased stability of the tropical troposphere in a warmer climate, characterised by fewer weak storms and greater numbers of intense storms. A number of modelling studies have also projected a general tendency for more intense but fewer storms outside the tropics, with a tendency towards more extreme wind events and higher ocean waves in several regions in association with those deepened cyclones. Models also project a poleward shift of storm tracks in both hemispheres by several degrees of latitude.

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Frequently Asked Question 10.2

How Likely are Major or Abrupt Climate Changes, such as Loss of Ice Sheets or Changes in Global Ocean Circulation?

Abrupt climate changes, such as the collapse of the West Antarctic Ice Sheet, the rapid loss of the Greenland Ice Sheet or large-scale changes of ocean circulation systems, are not considered likely to occur in the 21st century, based on currently available model results. However, the occurrence of such changes becomes increasingly more likely as the perturbation of the climate system progresses.

Physical, chemical and biological analyses from Greenland ice cores, marine sediments from the North Atlantic and elsewhere and many other archives of past climate have demonstrated that local temperatures, wind regimes and water cycles can change rapidly within just a few years. The comparison of results from records in different locations of the world shows that in the past major changes of hemispheric to global extent occurred. This has led to the notion of an unstable past climate that underwent phases of abrupt change. Therefore, an important concern is that the continued growth of greenhouse gas concentrations in the atmosphere may constitute a perturbation sufficiently strong to trigger abrupt changes in the climate system. Such interference with the climate system could be considered dangerous, because it would have major global consequences.

Before discussing a few examples of such changes, it is useful to define the terms 'abrupt' and 'major'. 'Abrupt' conveys the meaning that the changes occur much faster than the perturbation inducing the change; in other words, the response is nonlinear. A 'major' climate change is one that involves changes that exceed the range of current natural variability and have a spatial extent ranging from several thousand kilometres to global. At local to regional scales, abrupt changes are a common characteristic of natural climate variability. Here, isolated, short-lived events that are more appropriately referred to as 'extreme events' are not considered, but rather large-scale changes that evolve rapidly and persist for several years to decades. For instance, the mid-1970s shift in sea surface temperatures in the Eastern Pacific, or the salinity reduction in the upper 1,000 m of the Labrador Sea since the mid-1980s, are examples of abrupt events with local to regional consequences, as opposed to the larger-scale, longer-term events that are the focus here.

One example is the potential collapse, or shut-down of the Gulf Stream, which has received broad public attention. The Gulf Stream is a primarily horizontal current in the north-western Atlantic Ocean driven by winds. Although a stable feature of the general circulation of the ocean, its northern extension, which feeds deep-water formation in the Greenland-Norwegian-Iceland Seas and thereby delivers substantial amounts of heat to these seas and nearby land areas, is influenced strongly by changes in the density of the surface waters in these areas. This current constitutes the northern end of a basin-scale meridional overturning circulation (MOC) that is established along the western boundary of the Atlantic basin. A consistent result from climate model simulations is that if the density of the surface waters in the North Atlantic decreases due to warming or a reduction in salinity, the strength of the MOC is decreased, and with it, the delivery of heat into these areas. Strong sustained reductions in salinity could induce even more substantial reduction, or complete shut-down of the MOC in all climate model projections. Such changes have indeed happened in the distant past.

The issue now is whether the increasing human influence on the atmosphere constitutes a strong enough perturbation to the MOC that such a change might be induced. The increase in greenhouse gases in the atmosphere leads to warming and an intensification of the hydrological cycle, with the latter making the surface waters in the North Atlantic less salty as increased rain leads to more freshwater runoff to the ocean from the region's rivers. Warming also causes land ice to melt, adding more freshwater and further reducing the salinity of ocean surface waters. Both effects would reduce the density of the surface waters (which must be dense and heavy enough to sink in order to drive the MOC), leading to a reduction in the MOC in the 21st century. This reduction is predicted to proceed in lockstep with the warming: none of the current models simulates an abrupt (nonlinear) reduction or a complete shut-down in this century. There is still a large spread among the models' simulated reduction in the MOC, ranging from virtually no response to a reduction of over 50% by the end of the 21st century. This cross-model variation is due to differences in the strengths of atmosphere and ocean feedbacks simulated in these models.

Uncertainty also exists about the long-term fate of the MOC. Many models show a recovery of the MOC once climate is stabilised. But some models have thresholds for the MOC, and they are passed when the forcing is strong enough and lasts long enough. Such simulations then show a gradual reduction of the MOC that continues even after climate is stabilised. A quantification of the likelihood of this occurring is not possible at this stage. Nevertheless, even if this were to occur, Europe would still experience warming, since the radiative forcing caused by increasing greenhouse gases would overwhelm the cooling associated with the MOC reduction. Catastrophic scenarios suggesting the beginning of an ice age triggered by a shutdown of the MOC are thus mere speculations, and no climate model has produced such an outcome. In fact, the processes leading to an ice age are sufficiently well understood and so completely different from those discussed here, that we can confidently exclude this scenario.

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Irrespective of the long-term evolution of the MOC, model simulations agree that the warming and resulting decline in salinity will significantly reduce deep and intermediate water formation in the Labrador Sea during the next few decades. This will alter the characteristics of the intermediate water masses in the North Atlantic and eventually affect the deep ocean. The long-term effects of such a change are unknown.

Other widely discussed examples of abrupt climate changes are the rapid disintegration of the Greenland Ice Sheet, or the sudden collapse of the West Antarctic Ice Sheet. Model simulations and observations indicate that warming in the high latitudes of the Northern Hemisphere is accelerating the melting of the Greenland Ice Sheet, and that increased snowfall due to the intensified hydrological cycle is unable to compensate for this melting. As a consequence, the Greenland Ice Sheet may shrink substantially in the coming centuries. Moreover, results suggest that there is a critical temperature threshold beyond which the Greenland Ice Sheet would be committed to disappearing completely, and that threshold could be crossed in this century. However, the total melting of the Greenland Ice Sheet, which would raise global sea level by about seven metres, is a slow process that would take many hundreds of years to complete.

Recent satellite and *in situ* observations of ice streams behind disintegrating ice shelves highlight some rapid reactions of ice sheet systems. This raises new concern about the overall stability of the West Antarctic Ice Sheet, the collapse of which would trigger another five to six metres of sea level rise. While these streams appear buttressed by the shelves in front of them, it is currently unknown whether a reduction or failure of this buttressing of relatively limited areas of the ice sheet could actually trigger a widespread discharge of many ice streams and hence a destabilisation of the entire West Antarctic Ice Sheet. Ice sheet models are only beginning to capture such small-scale dynamical processes that involve complicated interactions with the glacier bed and the ocean at the perimeter of the ice sheet. Therefore, no quantitative information is available from the current generation of ice sheet models as to the likelihood or timing of such an event.

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Frequently Asked Question 10.3

If Emissions of Greenhouse Gases are Reduced, How Quickly do Their Concentrations in the Atmosphere Decrease?

The adjustment of greenhouse gas concentrations in the atmosphere to reductions in emissions depends on the chemical and physical processes that remove each gas from the atmosphere. Concentrations of some greenhouse gases decrease almost immediately in response to emission reduction, while others can actually continue to increase for centuries even with reduced emissions.

The concentration of a greenhouse gas in the atmosphere depends on the competition between the rates of emission of the gas into the atmosphere and the rates of processes that remove it from the atmosphere. For example, carbon dioxide (CO_2) is exchanged between the atmosphere, the ocean and the land through processes such as atmosphere-ocean gas transfer and chemical (e.g., weathering) and biological (e.g., photosynthesis) processes. While more than half of the CO_2 emitted is currently removed from the atmosphere within a century, some fraction (about 20%) of emitted CO_2 remains in the atmosphere for many millennia. Because of slow removal processes, atmospheric CO_2 will continue to increase in the long term even if its emission is substantially reduced from present levels. Methane (CH_4) is removed by chemical processes in the atmosphere, while nitrous oxide (N_2O) and some halocarbons are destroyed in the upper atmosphere by solar radiation. These processes each operate at different time scales ranging from years to millennia. A measure for this is the lifetime of a gas in the atmosphere, defined as the time it takes for a perturbation to be reduced to 37% of its initial amount. While for CH_4, N_2O, and other trace gases such as hydrochlorofluorocarbon-22 (HCFC-22), a refrigerant fluid, such lifetimes can be reasonably determined (for CH_4 it is about 12 yr, for N_2O about 110 yr and for HCFC-22 about 12 yr), a lifetime for CO_2 cannot be defined.

The change in concentration of any trace gas depends in part on how its emissions evolve over time. If emissions increase with time, the atmospheric concentration will also increase with time, regardless of the atmospheric lifetime of the gas. However, if actions are taken to reduce the emissions, the fate of the trace gas concentration will depend on the relative changes not only of emissions but also of its removal processes. Here we show how the lifetimes and removal processes of different gases dictate the evolution of concentrations when emissions are reduced.

As examples, Figure 1 shows test cases illustrating how the future concentration of three trace gases would respond to illustrative changes in emissions (represented here as a response to an imposed pulse change in emission). We consider CO_2, which has no specific lifetime, as well as a trace gas with a well-defined long lifetime on the order of a century (e.g., N_2O), and a trace gas with a well-defined short lifetime on the order of decade (such as CH_4, HCFC-22 or other halocarbons). For each gas, five illustrative cases of future emissions are presented: stabilisation of emissions at present-day levels, and immediate emission reduction by 10%, 30%, 50% and 100%.

The behaviour of CO_2 (Figure 1a) is completely different from the trace gases with well-defined lifetimes. Stabilisation of CO_2 emissions at current levels would result in a continuous increase of atmospheric CO_2 over the 21st century and beyond, whereas for a gas with a lifetime on the order of a century (Figure 1b) or a decade (Figure 1c), stabilisation of emissions at current levels would lead to a stabilisation of its concentration at a level higher than today within a couple of centuries, or decades, respectively. In fact, only in the case of essentially complete elimination of

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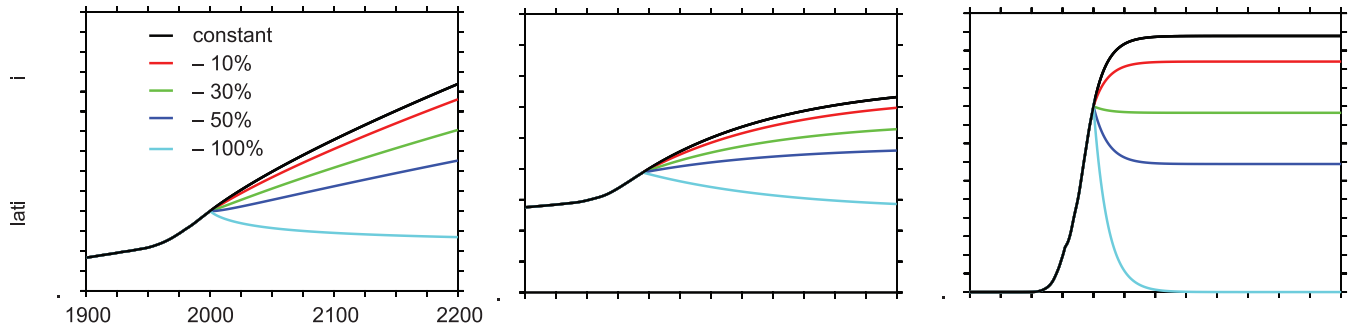

Figure 1. *(a) Simulated changes in atmospheric CO_2 concentration relative to the present-day for emissions stabilised at the current level (black), or at 10% (red), 30% (green), 50% (dark blue) and 100% (light blue) lower than the current level; (b) as in (a) for a trace gas with a lifetime of 120 years, driven by natural and anthropogenic fluxes; and (c) as in (a) for a trace gas with a lifetime of 12 years, driven by only anthropogenic fluxes.*

emissions can the atmospheric concentration of CO_2 ultimately be stabilised at a constant level. All other cases of moderate CO_2 emission reductions show increasing concentrations because of the characteristic exchange processes associated with the cycling of carbon in the climate system.

More specifically, the rate of emission of CO_2 currently greatly exceeds its rate of removal, and the slow and incomplete removal implies that small to moderate reductions in its emissions would not result in stabilisation of CO_2 concentrations, but rather would only reduce the rate of its growth in coming decades. A 10% reduction in CO_2 emissions would be expected to reduce the growth rate by 10%, while a 30% reduction in emissions would similarly reduce the growth rate of atmospheric CO_2 concentrations by 30%. A 50% reduction would stabilise atmospheric CO_2, but only for less than a decade. After that, atmospheric CO_2 would be expected to rise again as the land and ocean sinks decline owing to well-known chemical and biological adjustments. Complete elimination of CO_2 emissions is estimated to lead to a slow decrease in atmospheric CO_2 of about 40 ppm over the 21st century.

The situation is completely different for the trace gases with a well-defined lifetime. For the illustrative trace gas with a lifetime of the order of a century (e.g., N_2O), emission reduction of more than 50% is required to stabilise the concentrations close to present-day values (Figure 1b). Constant emission leads to a stabilisation of the concentration within a few centuries.

In the case of the illustrative gas with the short lifetime, the present-day loss is around 70% of the emissions. A reduction in emissions of less than 30% would still produce a short-term increase in concentration in this case, but, in contrast to CO_2, would lead to stabilisation of its concentration within a couple of decades (Figure 1c). The decrease in the level at which the concentration of such a gas would stabilise is directly proportional to the emission reduction. Thus, in this illustrative example, a reduction in emissions of this trace gas larger than 30% would be required to stabilise concentrations at levels significantly below those at present. A complete cut-off of the emissions would lead to a return to pre-industrial concentrations within less than a century for a trace gas with a lifetime of the order of a decade.

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Frequently Asked Question 11.1

Do Projected Changes in Climate Vary from Region to Region?

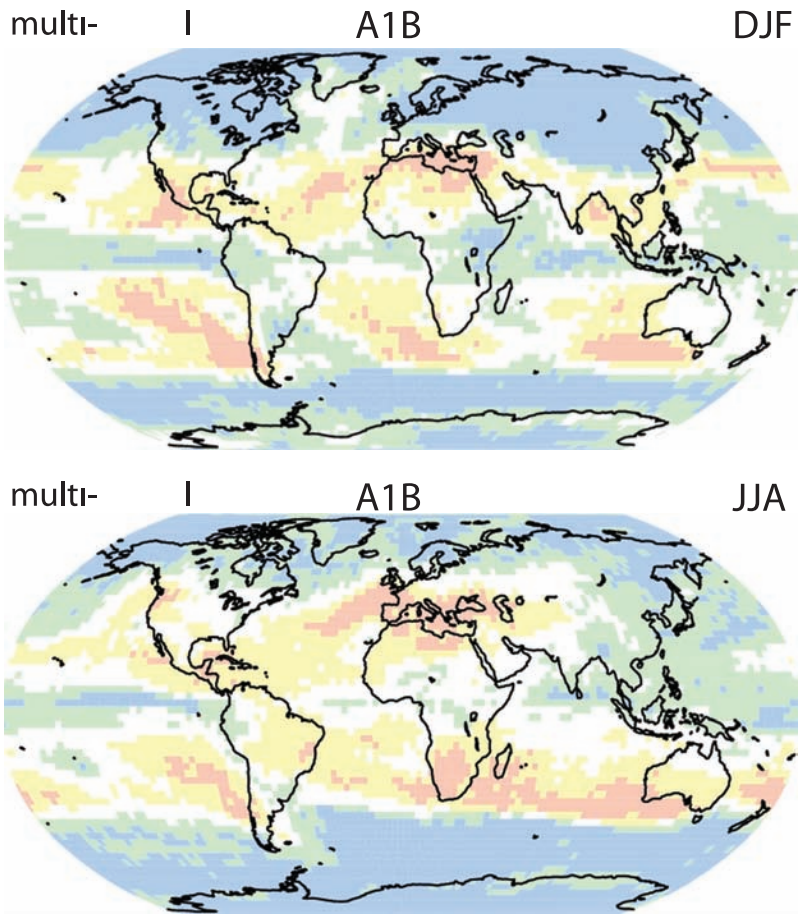
Climate varies from region to region. This variation is driven by the uneven distribution of solar heating, the individual responses of the atmosphere, oceans and land surface, the interactions between these, and the physical characteristics of the regions. The perturbations of the atmospheric constituents that lead to global changes affect certain aspects of these complex interactions. Some human-induced factors that affect climate ('forcings') are global in nature, while others differ from one region to another. For example, carbon dioxide, which causes warming, is distributed evenly around the globe, regardless of where the emissions originate, whereas sulphate aerosols (small particles) that offset some of the warming tend to be regional in their distribution. Furthermore, the response to forcings is partly governed by feedback processes that may operate in different regions from those in which the forcing is greatest. Thus, the projected changes in climate will also vary from region to region.

Latitude is a good starting point for considering how changes in climate will affect a region. For example, while warming is expected everywhere on Earth, the amount of projected warming generally increases from the tropics to the poles in the Northern Hemisphere. Precipitation is more complex, but also has some latitude-dependent features. At latitudes adjacent to the polar regions, precipitation is projected to increase, while decreases are projected in many regions adjacent to the tropics (see Figure 1). Increases in tropical precipitation are projected during rainy seasons (e.g., monsoons), and over the tropical Pacific in particular.

Location with respect to oceans and mountain ranges is also an important factor. Generally, the interiors of continents are projected to warm more than the coastal areas. Precipitation responses are especially sensitive not only to the continental geometry, but to the shape of nearby mountain ranges and wind flow direction. Monsoons, extratropical cyclones and hurricanes/typhoons are all influenced in different ways by these region-specific features.

Some of the most difficult aspects of understanding and projecting changes in regional climate relate to possible changes in the circulation of the atmosphere and oceans, and their patterns of variability. Although general statements covering a variety of regions with qualitatively similar climates can be made in some cases, nearly every region is idiosyncratic in some ways. This is true whether it is the coastal zones surrounding the subtropical Mediterranean Sea, the extreme weather in the North American interior that depends on moisture transport from the Gulf of Mexico, or the interactions between vegetation distribution, oceanic temperatures and atmospheric circulation that help control the southern limit of the Sahara Desert.

While developing an understanding of the correct balance of global and regional factors remains a challenge, the understanding of these factors is steadily growing, increasing our confidence in regional projections.



FAQ 11.1, Figure 1. *Blue and green areas on the map are by the end of the century projected to experience increases in precipitation, while areas in yellow and pink are projected to have decreases. The top panel shows projections for the period covering December, January and February, while the bottom panel shows projections for the period covering June, July and August.*

From the report accepted by Working Group I of the Intergovernmental Panel on Climate Change but not approved in detail

Frequently Asked Questions

FAQ Citation:

These Frequently Asked Questions have been taken directly from the chapters of the underlying report and are collected here. When referencing specific FAQs, please reference the corresponding chapter in the report from whence the FAQ originated.

When referencing the group of FAQs, please cite as:

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lesson Plan: Is It Getting Hot in Here?

Climate Change / Grades 9-12 / Earth Science

- Background Information
- Learning Procedure
- The Bridge Connection
- The "Me" Connection
- Extensions
- Resources
- National Science Education Standards
- Ocean Literacy Essential Principles and Fundamental Concepts

Focus Question

What are some causes and consequences of global climate change?

Learning Objectives

1. Students will define “forcing factor” and describe at least five forcing factors for climate change.
2. Students will describe at least five ways in which climate change could affect human communities.
3. Students will cite at least three lines of evidence that suggest the Earth’s climate may change in the 21st century.

Links to Overview Essays and Resources Needed for Student Research

http://oceanservice.noaa.gov/topics/coasts/ecoscience/

http://coastalscience.noaa.gov/stressors/climatechange

Materials

- Copies of “Climate Change Student Worksheet” found at the end of this lesson plan, one copy for each student or student group. Click here for a seperate printable worksheet.
- (optional) Computers with Internet access; if students do not have access to the Internet, download copies of materials cited under “Learning Procedure” and provide copies of these materials to each student or student group.

Audio/Visual Materials

None

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Groups of 2-3 students

Maximum Number of Students

21, if each group is to have a unique report topic

Key Words

Climate change
Forcing factor
Greenhouse gas
Paleo proxy

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Background Information

More than half of the U.S. population lives near a coast, and about one of every six jobs in the U.S. is related to coastal or marine resources. Ocean and coastal waters provide food, recreational opportunities, habitats for diverse plant and animal life, minerals, and transportation resources that support trade and commerce. These benefits cannot be taken for granted, because coastal environments are constantly subjected to forces that cause dramatic change. In addition to natural processes such as winds, storms, and rainfall, coastal environments are affected by forces resulting from human activities including pollution, invasive species, and climate change. Climate change associated with human activities increases natural climate variability and adds to natural stresses already present in coastal ecosystems. Processes that cause climate change are called “forcing factors,” and can be grouped into five categories:

1. **Ocean Temperature and Sea Ice** – In some part of the ocean, seawater temperatures rose during the last half of the 20th century, causing significant reductions in the extent of sea ice. By the end of the 21st century, seawater temperatures are expected to be much higher, and Arctic sea ice may be absent for most of the year. These changes will dramatically alter many marine ecosystems, and may result in deadly stress to organisms such as corals that live in habitats where temperatures are already near lethal levels. The disappearance of Arctic sea ice may result in extinction of polar bears and other species that depend upon this habitat.

2. **Sea Level Rise** – Globally, sea levels rose by 4-8 inches during the 20th century, continuing a trend that has been underway since the last ice age. But the rate of change is increasing, and the rise of global sea levels is expected to be several times larger during the 21st century. In areas where land is sinking (such as Louisiana and Texas), the relative change in sea level may be as much as 20-40 inches. Impacts of higher sea levels include increased coastal erosion,disappearance of many coastal habitats and their associated natural resources, and intrusion of saltwater into drinking water supplies and freshwater ecosystems.

3. **Ocean Currents** – Changes in global temperature could lead to changes in ocean circulation (such as El Niño in the Pacific Ocean). Such changes in the Atlantic Ocean could alter the flow of the Gulf Stream and cause major air temperature alterations in the North Atlantic, resulting in colder climates in western European countries that are presently warmed by the Gulf Stream.

4. **Coastal Storms** ñ Warmer temperatures can be expected to increase wind speed and rainfall in hurricanes, and the impacts of storm surges will be greater because of higher sea levels. Consequently, the damage to human communities normally associated with hurricanes will be more severe, coastal ecosystems will experience greater disturbance and stress, and supplies of fresh water may be jeopardized by saltwater intrusion.

5. **Freshwater Inflow** ñ Changing climates are likely to produce significant changes in runoff and river flows, which will affect the influx of chemicals and sediments to estuaries and coastal waters. Because these ecosystems are important nursery habitats for many species and help protect inland areas from erosion by coastal storms, alterations in freshwater flow are likely to be accompanied by stress to living organisms and human communities that depend upon these systems.

Earth’s climate has changed many times in its 4,500 million-year history. Regardless of their cause, the climate changes expected during the 21st century will profoundly alter coastal ecosystems as we

know them today. Because we depend on these ecosystems in many ways, it is vital to understand the causes of climate change, the resulting impacts to coastal environments, and how human communities should respond. The National Ocean Service's National Centers for Coastal Ocean Science are conducting research to understand the relationship of human-associated and natural climate change forces so that potential impacts on critical coastal ecosystems can be predicted and, where possible, mitigated. In this lesson students will investigate the history and causes of climate change, how these changes have affected natural systems and human communities, and what changes are forecast for the future.

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Learning Procedure

1. To prepare for this lesson, review questions on the ìClimate Change Student Worksheet.î Make copies of the worksheet, one copy for each student or student group

   If you do not plan to have students use the internet for research, download the following:

   - ìOverview of Climate Processesî (http://www.ngdc.noaa.gov/paleo/ctl/about4.html; the Overview includes four Web pages: The Big Picture, The Greenhouse Planet, Climate and the Water Balance, and Time Scales of Climate Change); and

   - ìClimate TimeLine Tutorialî (http://www.ngdc.noaa.gov/paleo/ctl/drought.html; the Tutorial includes three Web pages: Introduction, The Hydrograph Story, and Drought Data Inquiry)

   Make a copy of these pages for each student group. Most of these pages have links to other relevant topics, some of which you may also want to copy.

2. Lead a brief discussion of students' ideas about climate change, including whether they think Earth's climate really is changing, possible causes for such change, and the potential consequences of these changes to natural systems and human communities.

3. Have each student or student group complete the ìClimate Change Student Worksheet.î Lead a discussion of studentsí answers to the worksheet questions.

   Correct answers are:

   1. The primary force outside the Earth's internal system that drives the planet's weather and climate systems is the sun.

   2. Two factors outside Earth's environment and climate system that can cause the amount of energy reaching the surface of the Earth to vary are internal processes within the sun and changes in the Earth's orbit.

   3. About 30% of the radiation entering the Earth's atmosphere is reflected back to space, and about 70% is absorbed by the atmosphere and surface of the planet.

   4. About 25% of the radiation entering the Earth's atmosphere is absorbed by greenhouse gases.

   5. In recent years, concern has grown that human activities, especially the combustion of fossil fuels, are increasing carbon dioxide levels in the atmosphere to levels that haven't been seen in over 400,000 years.

   6. Venus receives about twice the radiation received by Earth and has an atmosphere rich in carbon dioxide.

   7. Residence time is the time it takes for a volume of water to cycle through the hydrologic system.

8. Tectonic scales are used to describe variation in Earth's climate over the past 300 million years.

9. Orbital scales are used to describe variation in Earth's climate over the past 3 million years.

10. Centennial scales are used to describe variation in Earth's climate over the past 1,000 years.

11. Temperature is the primary measure of climate and can be measured or reconstructed for the Earth's surface and sea surface.

12. Biomass and vegetation patterns may be discerned in a variety of ways and provide evidence of how ecosystems adapt to climate change.

13. Sea level is usually related to the degree of ice coverage in high latitudes and elevations.

14. Volcanic eruptions can alter climate due to aerosols emitted into the atmosphere.

15. Climate forcing refers to specific phenomena that directly influence changes in climate.

16. The hydrologic cycle has been described as Earth's thermostat.

17. Water vapor is the primary greenhouse gas in the atmosphere.

18. Milankovitch cycles are changes in Earth's orbit that occur in 100,000, 41,000, and 21,000 year periods.

19. Pacific Decadal Oscillation (PDO) is a cycle in the sea surface temperature pattern across the North Pacific Ocean that recurs approximately every ten years.

20. El Niño Southern Oscillation (ENSO) is an oscillation in sea surface temperature and surface pressure across the tropical Pacific Ocean, causing both local and global changes in weather and climate.

4. Tell students that their assignments are to use NOAA's Climate TimeLine Information Tool (http://www.ngdc.noaa.gov/paleo/ctl) to prepare reports on climate variation over various time scales. The Climate TimeLine provides information for time scales of 1 day, 1 year, 10 years, 100 years, 1,000 years, 10,000 years, and 100,000 years. Assign one of these time scales to each student group. Tell students that their reports should summarize information under the "Climate Science " heading for their assigned time scale, including forcing factors, relevant measurements, and how these measurements are made. To access this heading, students should move their cursor over the appropriate time scale on the left side of the page. A menu will pop up with "Summary, " "Climate Science," "Climate History," and "Resources" headings. They should select "Climate Science," and they're off. Students should also review information on adjacent time scales for additional data that may be relevant to their own.

5. Have each student group present their reports. Key points for each time scale are:

   1 day – Forcing Factors: Earth's rotation on its axis; rotation of moon around the Earth; volcanic aerosols may induce short-term variations; biological activity can produce short-term fluctuations in atmospheric carbon dioxide concentrations. Relevant Measurements: temperature, rainfall, surface water flows; measured with thermometers, satellites, rain gauges, and stream gauges.

   1 year – Forcing Factors: Earth's 23.5° tilt on its axis and revolution around the sun; biological carbon metabolism may affect annual atmospheric carbon dioxide concentrations; volcanic aerosols may induce short-term variations. Relevant Measurements: temperature, rainfall, surface water flows; measured with thermometers, satellites, rain gauges, and stream

gauges; paleo proxies such as tree rings and cores from corals, ice caps, and glaciers can provide historic information.

10 year – Forcing Factors: the El Niño Southern Oscillation (ENSO) is the largest single source of climate variability at this time scale; sunspots may have an influence as well, but this is not certain. Relevant Measurements: temperature, rainfall, surface water flows; measured with thermometers, satellites, rain gauges, and stream gauges; paleo proxies such as tree rings and cores from corals, ice caps, and glaciers can provide historic information.

100 year – Forcing Factors: oscillations in ocean temperatures such as the North Atlantic Oscillation (NAO) and possibly the Pacific Decadal Oscillation (PDO). Relevant Measurements: temperature; paleo proxies such as tree rings and cores from corals, ice caps, and glaciers provide the most useful information.

1,000 year – Forcing Factors: variations in solar irradiance, volcanism, carbon cycles (uptake of carbon dioxide, particularly by living organisms in the oceans, can alter carbon dioxide concentrations in the atmosphere which are involved in the greenhouse effect), and thermohaline circulation (variations in the circulation of deep ocean water). Relevant Measurements: temperature, precipitation, chemical composition of air and water, volcanic activity, and vegetation types; all estimated through various paleo proxies including tree rings; cores from corals, ice caps, and glaciers; pollen analysis; packrat middens; and sediments.

10,000 year – Forcing Factors: variations in Earth's orbit; oscillations in the atmosphere-ocean-ice system (Dansgaard-Oeschger cycles); possibly variations in solar output; abrupt climate change may have been caused by sudden release of glacial water from large lakes. Relevant Measurements: temperature, estimated from variations in the ratio of oxygen isotopes in ice cores.

100,000 year – Forcing Factors: variations in Earth's orbit (Milankovitch cycles). Relevant Measurements: timing of ice ages and orbital fluctuations, estimated with paleo proxies and astronomical observations.

6. Lead a discussion on the possibility of climate change in the 21st century. Ask students what factors might result in climate change. Based on information cited above, students should identify ENSO, NAO, PDO, variations in solar irradiance, volcanism, carbon cycles, and thermohaline circulation as possible forcing factors.

While we don't know for certain how and why climate may change in the 21st century or what the impacts of such change will be, we do know that:

- Concentration of carbon dioxide in the atmosphere is at the highest level in 400,000 years, and the rate of increase coincides with the burning of fossil fuels.

- Recent estimates by NASA indicate that Arctic sea ice is melting at a rate of 9% per decade. Data show that the Arctic warmed significantly during the 1990s, and has continued to do so (see http://www.arctic.noaa.gov/detect/ for more information).

- Most of Earth's 160,000 glaciers have been melting during the last century, but the rate of melting has accelerated dramatically since the mid-1990s. Experts predict that by the middle of the 21st century, the Rocky Mountains, Cascades, and Glacier National Park will have lost almost all their ice (see http://news.nationalgeographic.com/news/2002/08/0821_020821_wireglaciers.html for more information).

- Melting glaciers and polar ice are known to coincide with sea level rise.

There are natural forcing factors that cause these changes, but human activities are increasing the impact of these natural factors. Students should be aware that climate changes have happened repeatedly in Earthís history and natural systems have adapted to these changes. But be sure students also understand that there is no guarantee that any species (including our own) will not be adversely affected by climate change. You may want to point out that 99% of all species of living organisms that have ever lived on Earth are extinct, and climate change is believed to have been

responsible for several mass extinctions. Students should also understand that climate change does not always happen gradually over a long period of time; major changes in precipitation and temperature have occurred in less than a decade. Tell students that some scientists have pointed out that increased atmospheric concentration of greenhouse gases such as carbon dioxide and methane could result in temperature changes that would alter the Gulf Stream. If that happens, the result could be an abrupt cooling in parts of Europe and North America. You may want to review the Climate TimeLine section on Future Forecasts (http://www.ngdc.noaa.gov/paleo/ctl/future.html) for additional discussion.

Students should understand that human activity can affect the capacity of some systems to adapt. Coastal marshes, for example, can survive rising sea levels as long as they are able to accumulate and build soil at least as fast as the water level is rising. But human activities such as roads, canals, and dams can reduce the input of sediments to marshes and can also block their onshore migration. Ask students how human activity might mitigate climate change or its impacts. Using energy sources other than fossil fuels is an obvious strategy. But what about the carbon dioxide that has already entered the atmosphere? One interesting (and expensive) idea being studied is to transfer atmospheric carbon dioxide to another part of the carbon cycle by pumping liquefied carbon dioxide into the deep ocean. See http://www.lbl.gov/Science-Articles/Archive/sea-carb-bish.html/ for more information. Another idea is to fertilize portions of the tropical ocean to stimulate the growth of phytoplankton that theoretically could move carbon from the atmosphere to the deep ocean. See http://www.realclimate.org/index.php/archives/category/climate-science/geoengineering/ for discussion of this idea.

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The Bridge Connection

http://www.vims.edu/bridge/ – In the “Site Navigation” menu on the left, click on “Ocean Science Topics,” then “Atmosphere,” in the menu bar at the top of the page for links to resources about climate change.

The "Me" Connection

Have students write a brief essay describing what climate changes might be anticipated in their own community, using data from the State Climate Change Impacts information sheets at http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ImpactsStateImpacts.html.

Extensions

Have students analyze climate variation for a specific location chosen by the students or assigned by the teacher. Refer to directions at http://www.ngdc.noaa.gov/paleo/ctl/activity.html.

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Resources

http://www.ngdc.noaa.gov/paleo/ctl – NOAA’s Climate TimeLine Information Tool

http://oceanservice.noaa.gov/outreach/pdfs/nccos_climate_change.pdf – Coastal Areas and Marine Resources: The Potential Consequences of Climate Variability and Change

http://www.arctic.noaa.gov/ – NOAA Arctic Theme Page

http://www.oar.noaa.gov/k12/html/atmosphere2.html – Three lesson plans at: Science with NOAA Research: Atmosphere

http://www.realclimate.org/ – RealClimate is a commentary site on which working climate scientists comment on developing stories for the interested public and journalists. In addition, the site also provides context for many subjects that may be missing in mainstream news features.

http://news.nationalgeographic.com/news/2002/08/0821_020821_wireglaciers.html – " Glaciers Melting Worldwide, Study Finds"

http://www.lbl.gov/Science-Articles/Archive/sea-carb-bish.html – "Climate Change Scenarios Compel Studies of Ocean Carbon Storage"

http://www.epa.gov/climatechange/index.html – EPA climate change Web site

http://topex-www.jpl.nasa.gov/education/education.html – "Ocean Surface Topography from Space" Web site education page with links to educational resources and information about the TOPEX/Poseidon and JASON projects

http://www.ucsusa.org/publication.cfm?publicationID=331 – Curriculum guide with 10 classroom activities that explore global warming and climate change and their effects on the Gulf of Mexico region

http://www.ngdc.noaa.gov/paleo/education.html – NOAA Paleoclimatology Program Educational Outreach - Definition of what paleoclimatology is plus slide sets, data sets, and other educational materials

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Motions and forces
- Interactions of energy and matter

Content Standard D: Earth and Space Science

- Energy in the earth system
- Understandings about scientific inquiry
- Origin and evolution of the Earth system

Content Standard E: Science as Inquiry

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal and community health
- Population growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science

- Nature of scientific knowledge

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Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1. The Earth has one big ocean with many features

- Fundamental Concept c. Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of the Earth's rotation (Coriolis effect), the Sun, and water

density differences. The shape of ocean basins and adjacent land masses influence the path of circulation.

- Fundamental Concept f. The ocean is an integral part of the water cycle and is connected to all of the earth's water reservoirs via evaporation and precipitation processes.

- Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 2. The ocean and life in the ocean shape the features of the Earth

- Fundamental Concept b. Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.
- Fundamental Concept e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

Essential Principle 3. The ocean is a major influence on weather and climate

- Fundamental Concept a. The ocean controls weather and climate by dominating the Earth' s energy, water and carbon systems.

- Fundamental Concept b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.

- Fundamental Concept c. The El Niño Southern Oscillation causes important changes in global weather patterns because it changes the way heat is released to the atmosphere in the Pacific.

- Fundamental Concept d. Most rain that falls on land originally evaporated from the tropical ocean.

- Fundamental Concept e. The ocean dominates the Earth's carbon cycle. Half the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere.

- Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

- Fundamental Concept g. Changes in the ocean's circulation have produced large, abrupt changes in climate during the last 50,000 years.

Essential Principle 6. The ocean and humans are inextricably interconnected

- Fundamental Concept a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.

- Fundamental Concept f. Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).

- Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7. The ocean is largely unexplored

- Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Is It Getting Hot in Here?

Student Worksheet

Refer to “Climate TimeLine Tutorial” and “Overview of Climate Processes” that begin at http://www.ngdc.noaa.gov/paleo/ctl/drought.html and http://www.ngdc.noaa.gov/paleo/ctl/about4.html respectively.

1. The primary force outside the Earth’s internal system that drives the planet’s weather and climate systems is _____.

2. Two factors outside Earth’s environment and climate system that can cause the amount of energy reaching the surface of the Earth to vary are _____ and _____.

3. About _____ % of the radiation entering the Earth’s atmosphere is reflected back to space, and about _____ % is absorbed by the atmosphere and surface of the planet.

4. About _____% of the radiation entering the Earth’s atmosphere is absorbed by greenhouse gases.

5. In recent years, concern has grown that human activities, most particularly _____, are increasing carbon dioxide levels in the atmosphere to levels that haven’t been seen in over 400,000 years.

6. Venus receives about _____ the radiation received by Earth, and has an atmosphere rich in _____.

7. _____ is the time it takes for a volume of water to cycle through the hydrologic system.

8. _____ scales are used to describe variation in Earth’s climate over the past 300 million years.

9. _____ scales are used to describe variation in Earth’s climate over the past 3 million years.

10. _____ scales are used to describe variation in Earth’s climate over the past1000 years.

11. _____ is the primary measure of climate and can be measured or reconstructed for the Earth’s surface and sea surface.

12. _____ may be discerned in a variety of ways and provide evidence of how ecosystems change to adapt to climate change.

13. Sea Level is usually related to the degree of _____ in high latitudes and elevations.

14. _____ can alter climate due to aerosols emitted into the atmosphere.

15. _____ refers to specific phenomena that directly influence changes in climactic dynamics.

16. The _____ has been described as Earth’s thermostat.

17. _____ is the primary greenhouse gas in the atmosphere.

18. _____ are changes in Earth’s orbit that occur in 100,000, 41,000, and 21,000 year periods.

19. _____ is an oscillation in the sea surface temperature pattern across the North

Pacific Ocean.

20. _____ is an oscillation in sea surface temperature and surface pressure across the tropical Pacific Ocean, causing both local and far away changes in weather and climate.

(top)

Is It Getting Hot In Here?

Student Worksheet

Refer to "Climate TimeLine Tutorial" and "Overview of Climate Processes" that begin at http://www.ngdc.noaa.gov/paleo/ctl/drought.html and http://www.ngdc.noaa.gov/paleo/ctl/about4.html respectively.

1. The primary force outside the Earth's internal system that drives the planet's weather and climate systems is _____.

2. Two factors outside Earth's environment and climate system that can cause the amount of energy reaching the surface of the Earth to vary are _____ and _____.

3. About _____ % of the radiation entering the Earth's atmosphere is reflected back to space, and about _____ % is absorbed by the atmosphere and surface of the planet.

4. About _____% of the radiation entering the Earth's atmosphere is absorbed by greenhouse gases.

5. In recent years, concern has grown that human activities, most particularly _____, are increasing carbon dioxide levels in the atmosphere to levels that haven't been seen in over 400,000 years.

6. Venus receives about _____ the radiation received by Earth, and has an atmosphere rich in _____.

7. _____ is the time it takes for a volume of water to cycle through the hydrologic system.

8. _____ scales are used to describe variation in Earth's climate over the past 300 million years.

9. _____ scales are used to describe variation in Earth's climate over the past 3 million years.

10. _____ scales are used to describe variation in Earth's climate over the past1000 years.

11. _____ is the primary measure of climate and can be measured or reconstructed for the Earth's surface and sea surface.

12. _____ may be discerned in a variety of ways and provide evidence of how ecosystems change to adapt to climate change.

13. Sea Level is usually related to the degree of _____ in high latitudes and elevations.

14. _____ can alter climate due to aerosols emitted into the atmosphere.

15. _____ refers to specific phenomena that directly influence changes in climactic dynamics.

16. The _____ has been described as Earth's thermostat.

17. _____ is the primary greenhouse gas in the atmosphere.

18. _____ are changes in Earth's orbit that occur in 100,000, 41,000, and 21,000 year periods.

19. _____ is an oscillation in the sea surface temperature pattern across the North Pacific Ocean.

20. _____ is an oscillation in sea surface temperature and surface pressure across the tropical Pacific Ocean, causing both local and far away changes in weather and climate.

Lesson Plan: Are You Getting Thirsty?

Drought / Grades 9-12 / Earth Science

- Background Information
- Learning Procedure
- The Bridge Connection
- The "Me" Connection
- Extensions
- Resources
- National Science Education Standards
- Ocean Literacy Essential Principles and Fundamental Concepts

Focus Question

What causes droughts, and how do they affect coastal ecosystems and human communities?

Learning Objectives

1. Students will define “drought” and explain how drought conditions may affect coastal ecosystems.
2. Students will discuss how drought conditions correlate with water temperature changes in the tropical Pacific Ocean.
3. Students will use various data sources to investigate stream-flow and drought conditions in selected locations.

Links to Overview Essays and Resources Needed for Student Research

http://oceanservice.noaa.gov/topics/coasts/ecoscience/
http://www.ngdc.noaa.gov/paleo/drought/drght_what.html

Materials

- Copies of “Introduction to Drought as an Ecosystem Stressor” Student Worksheet, found at the end of this lesson plan, one copy for each student or student group. (Click here for a separate printable worksheet)
- (optional) Computers with Internet access; if students do not have access to the Internet, download copies of materials cited under “Learning Procedure” and “ Worksheets” and provide copies of these materials to each student or student group

Audio/Visual Materials

None

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Classroom style or groups of 2-3 students

Maximum Number of Students

Key Words

Drought
Palmer Drought Severity Index (PDSI)
El Niño Southern Oscillation (ENSO)
Hydrograph

(top)

Background Information

Coastal ecosystems provide many benefits to human communities, including food, ports, recreational opportunities, habitats for diverse plant and animal life, and minerals. But these systems are vulnerable to stress from natural processes and human activity. The National Ocean Service's (NOS) National Centers for Coastal Ocean Science (NCCOS) study five categories of ecosystem stress:

- Climate change, which may result in changes in sea level and ocean temperature;
- Extreme natural events, such as hurricanes, droughts, and harmful algal blooms;
- Pollution, such as fertilizers from agricultural and urban runoff;
- Invasive species, such as lionfish and zebra mussels; and
- Destructive uses of land and coastal resources, such as over-fishing.

Drought is defined as a period of abnormally dry weather that persists long enough to produce a serious hydrologic imbalance (as indicated by crop damage, water shortage, etc.). To quantify drought, scientists consider precipitation, temperature, and soil moisture data over a period of several months.

The Palmer Drought Severity Index (PDSI) is a commonly used indicator of drought conditions that combines these factors. The value of the PDSI reflects how soil moisture compares with normal conditions, so a PDSI value represents recent conditions as well as current conditions. For an in-depth discussion of the PDSI and other drought indices; see http://www.drought.unl.edu/whatis/indices.htm.

Although they are less spectacular than earthquakes or hurricanes, droughts affect more people in North America than any other natural hazard, and cost $6-8 billion in losses every year in the United States alone. The two major droughts of the 20th century occurred in the 1930s and 1950s. The 1930s drought combined with decades of poor land management to create the "Dust Bowl" that made ships 300 miles from shore in the Atlantic Ocean dusty with topsoil from the Great Plains. Midwestern settlers had plowed up grasslands in the late 1800s and early 1900s, then planted the land with cotton, wheat, and corn that depleted the soil of moisture and nutrients. When reduced precipitation made it impossible to grow these crops, there was nothing to prevent the soil from blowing away. In the 1950s drought, soil erosion was less severe thanks to improved agricultural practices such as crop rotation to avoid nutrient depletion and planting ground cover to stabilize soils. But despite these improvements, seven years of unusually high temperatures and unusually low precipitation devastated agriculture in the Midwest: 244 of the 254 counties in Texas were declared federal drought disaster areas. Although the 1987-89 drought covered only 36% of the U.S., compared to the 70% covered during the Dust Bowl drought, the 1980s drought was accompanied by extensive wildfires and caused $39 billion in damage. This was the most costly natural disaster in U.S. history and was a strong indication that many parts of the country are more vulnerable to drought than ever before.

With this increased vulnerability, drought is becoming a more serious issue for coastal ecosystems. Historically, the devastating impacts of prolonged drought in the U.S. have been documented most often in the Midwest. But while we don't often think of water shortage as a problem of coastal habitats, drought has a marked effect on coastal ecosystems. Droughts can alter the natural flow of streams and rivers that bring freshwater, nutrients and other materials into these systems. Estuaries and marshes, which provide important nursery areas and protect inland areas from erosion, are particularly susceptible to drought because they depend upon regular freshwater input. Droughts also increase the risk of fires and soil erosion, which can result in additional stress to coastal ecosystems

from high levels of sediment influx. When droughts reduce river flow and the influx of freshwater to coastal ecosystems, seawater can intrude into marshes and estuaries causing massive mortalities of species that cannot tolerate high salinity levels. In the summer of 2000, these conditions severely damaged oyster resources in Louisiana. The same drought was responsible for widespread destruction of marsh grass and increased coastal erosion in places normally stabilized by the grasses. Reduced freshwater flows also allowed seawater to enter aquifers, contaminating wells used for irrigation and killing crops.

Climate studies at NASA's Earth Observatory suggest that drought problems are also extending to the Pacific Northwest, an area usually thought of as rather wet. These studies show that coastal mountain ranges on the Pacific coast have lost 60 percent of their normal winter snowpack over the last 50 years, and that the amount of water stored as snow in these mountains may diminish by as much as 70 percent by the middle of the 21st century. Reduction in Western mountain snow cover will lead to increased fall and winter flooding accompanied by severe spring and summer droughts that will have serious impacts on West Coast fisheries, as well as agriculture and hydropower industries.

The causes of drought are not completely understood. Temperature variations in the tropical Pacific Ocean, however, have been found to correlate with drought conditions in North America. These events are popularly known as El Niño (unusually warm water temperatures in the eastern Pacific Ocean) and La Niña (unusually cool water temperatures in the eastern Pacific); oceanographers refer to the two events as the El Niño Southern Oscillation (ENSO). Normally, Pacific trade winds cause surface waters in the eastern Pacific Ocean to move toward the west, resulting in the upwelling of cold bottom water along the eastern margin of the Pacific. During El Niño events, the trade winds are weaker than usual, so there is less upwelling and sea surface temperatures in the eastern Pacific are higher than normal. These abnormalities affect atmospheric circulation in the mid-latitudes (between 30 ° and 60° latitude), causing wetter-than-normal winters from California to the southeastern United States, and higher-than-normal temperatures from Alaska south through southwestern Canada and east to the Great Lakes. In contrast, during La Niña events, cooler-than-normal sea surface temperatures in the eastern Pacific make drought conditions likely across the southwestern and southeastern U.S., wetter-than-normal winters in the northwestern U.S., and lower-than-normal temperatures from Alaska to southwestern Canada and across the northern border of the U.S. A La Niña-like event is believed to have been at least partially responsible for the 1930s "Dust Bowl" drought. NCCOS studies the effects of drought on U.S. coral reefs, the nation's estuaries, 13 national marine sanctuaries, 26 national estuarine research reserves, and ocean ecosystems. The purpose of this lesson is to introduce students to drought as an ecosystem stressor and to sources of data on current and historical drought conditions.

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Learning Procedure

1. Briefly review the concept of drought and its significance as a natural hazard. You may want to begin by asking students to identify the most expensive natural disaster in U.S. history, and perhaps include some images from the 1930s "Dust Bowl" drought. Ask students how drought might affect coastal ecosystems. Introduce the PDSI as an indicator of drought conditions.

2. Have students complete the "Introduction to Drought as an Ecosystem Stressor" worksheet, either individually or in groups of 2-3 students.

3. Discuss students' responses to questions on the worksheet. Key points include:

    - A hydrograph is a graph that represents stream flow or average flow rates of a stream over a period of time.

    - The most destructive climate-related event during the 20th century was the Yangtze River Flood of 1931 that impacted more than 51 million people and caused the deaths of 3.7 million people due to disease, starvation, or drowning. Note that this flood was preceded by a three-year drought.

    - A drought in China during the early 1940s resulted in widespread starvation that caused

the deaths of 3 million people.

- Possible reasons for the abandonment of Ancient Pueblo communities include drought, invasion by other tribes, volcanic activity that shortened growing seasons, or disease such as hanta virus.

- Oxygen isotope evidence from lake cores indicates a series of droughts that coincide with collapse of the classic Mayan culture.

- Prolonged periods of severe drought lasting three to six years coincided with the disappearance of the Roanoke Colonists.

- PDSI values reconstructed from tree-ring data indicate less severe drought conditions than PDSI values based on instrument measurements. This may reflect the ability of trees to withstand a certain amount of drought before these conditions have a significant effect on growth.

- La Niña events are typically accompanied by droughts in the southern U.S. and floods in the Pacific Northwest.

- Droughts in the western U.S. during the 1950s motivated intense dam-building for water storage and delivery.

- Map 1 corresponds to the 1954-1956 interval; Map 2 to the 1985-1995 interval; Map 3 to the 1934-1939 interval.

- The Channel Islands National Marine Sanctuary was subjected to extreme drought conditions in 1777, 1782, 1794, and 1795.

- According to instrument measurements, the area adjacent to the Channel Islands National Marine Sanctuary was exposed to extremely wet conditions in 1905, 1906, and 1941.

- According to instrument measurements, the coast adjacent to Gray's Reef National Marine Sanctuary was exposed to lower-than-normal precipitation in six years of the " dust bowl" decade; 1930, 1931, 1933, 1934, 1935, and 1936.

- Based on tree-ring data, students should infer that the Tijuana River estuary would probably have been quite dry in 1990, since the Tijuana River is described as "an intermittent stream," and the surrounding area had been exposed to a drought that began in 1985.

- The maximum monthly mean stream-flow recorded for the Pascagoula River was 56,210 cubic feet per second in January 1998. The minimum monthly mean stream-flow was 1,104 cubic feet per second in October 2000. In general, stream-flows are at their maximum in January, February, March and April.

- "Surface water: Peak stream-flow" will display the peak flow for each year; using this display, students should see that the longest interval in which peak flow did not reach 100,000 cubic feet per second was between 1957 and 1975.

Point out that droughts can result from human activity as well as natural causes. In the southwestern U.S., for example, water from the Colorado River has been diverted to support rapid economic development and increased agricultural production. This has caused periodic water shortages in Mexico, which also depends upon the Colorado to support some of its most productive agricultural areas. In 1944, the United States entered into a treaty that guarantees Mexico an minimum annual quantity of water from the Colorado, Tijuana Rivers and, Rio Grande Rivers. By the 1960s, human activity in the region had increased to the point that the quality of water reaching Mexico was severely degraded. In 1974, an additional agreement was reached guaranteeing that Mexico would receive water of the same quality as that being used in the United States. Since then, new development has placed additional demands upon water from the Colorado, increasing the

likelihood of future water shortages in the U.S. as well as Mexico.

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The Bridge Connection

http://www.vims.edu/bridge/ – In the “Site Navigation” menu on the left, click on “Ocean Science Topics,” then “Atmosphere,” then “Global Climate Change ” in the menu bar at the top of the page for links to resources about climate change.

The "Me" Connection

Have students write a brief essay in the form of diary notes describing changes in their community resulting from a drought during which the PDSI was below -5.0 for five consecutive years.

Extensions

Have students explore additional sources of data linked to the Climate TimeLine Data Access page (http://www.ngdc.noaa.gov/paleo/ctl/data.html).

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Resources

http://nerrs.noaa.gov/ – National Estuarine Research Reserve System website

http://www.ngdc.noaa.gov/paleo/ctl/drought.html – Climate TimeLine Drought Tutorial

http://www.ngdc.noaa.gov/paleo/drought/animation/pdsi_animation.html – “North American Drought Variability Table”; an animated map of PDSI values for the contiguous U.S. beginning in 1700

http://waterdata.usgs.gov/nwis – U.S. Geological Survey National Water Information System website

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard D: Earth and Space Science

- Energy in the Earth system
- Geochemical cycles

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal and community health
- Population growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

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Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1. The Earth has one big ocean with many features.

- Fundamental Concept f. The ocean is an integral part of the water cycle and is connected to all of the earth's water reservoirs via evaporation and precipitation processes.
- Fundamental Concept g. The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to estuaries and to the ocean.

Essential Principle 3. The ocean is a major influence on weather and climate.

- Fundamental Concept a. The ocean controls weather and climate by dominating the Earth's energy, water and carbon systems.
- Fundamental Concept b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.
- Fundamental Concept c. The El Niño Southern Oscillation causes important changes in global weather patterns because it changes the way heat is released to the atmosphere in the Pacific.
- Fundamental Concept d. Most rain that falls on land originally evaporated from the tropical ocean.
- Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.
- Fundamental Concept g. Changes in the ocean's circulation have produced large, abrupt changes in climate during the last 50,000 years.

Are You Getting Thirsty?

Student Worksheet - An Introduction to Drought as an Ecosystem Stressor

Refer to the following Web pages for answers to the questions below:

http://www.ngdc.noaa.gov/paleo/ctl/drought.html – Climate TimeLine Drought Tutorial

http://www.ngdc.noaa.gov/paleo/ctl/clisci10.html – Climate Science, 10 year time scale

http://www.ngdc.noaa.gov/paleo/ctl/100.html – Climate Summary, 100 year time scale

http://www.ngdc.noaa.gov/paleo/ctl/cliihis1000.html – Climate History, 1000 year time scale

http://www.ngdc.noaa.gov/paleo/drought/animation/pdsi_animation.html – North American Drought Variability Table

1. What is a hydrograph?
2. What was the most destructive climate-related event during the 20th century?
3. What happened during the early 1940s that caused the deaths of 3 million people in China?
4. What were four possible reasons for the Ancient Pueblo ("Anasazi") people of Mesa Verde to abandon their homes in Colorado and migrate south to New Mexico and Arizona?
5. What evidence is there for a relation between climate and the collapse of the classic Mayan culture?

6. What climatic events coincided with the disappearance of the Roanoke Colonists?

7. How do estimates of PDSI based on tree-rings compare with PDSI values calculated from actual measurements with scientific instruments?

8. What effects in the southern U.S. and Pacific Northwest would be expected during a La Niña event?

9. Droughts in mid-1950s in the western U.S. were the motivation for what human activity?

10. Refer to Maps 1, 2, and 3 on the "CTL and Drought - Part 3" page (http://www.ngdc.noaa.gov/paleo/ctl/drought3.html). Here's how you can use NOAA's "Climate Diagnostic Center's Monthly Mean Compositing Page" (http://www.cdc.noaa.gov/USclimate/USclimdivs.html) to decide which of these maps corresponds to the periods 1934-1939, 1954-1956, and 1985-1995:

    On the Climate Diagnostics Center page:

    - select "Palmer Drought Severity Index" from the pull down menu next to "Variable?";
    - select "Dec" from the pull down menu next to "Ending month";enter "1934" and "1939" in the boxes next to "Enter a range of years"; and
    - Click "Create Plot".

    Compare the resulting map to Maps 1, 2, and 3 to decide which map corresponds to the 1934 – 1939 period. Repeat these steps for the other time periods.

11. Refer to the "North American Drought Variability" Table (http://www.ngdc.noaa.gov/paleo/drought/animation/pdsi_animation.html). Click on the animation graphic to display the "Reconstruction of Past Drought Using Instrumental and Tree-ring Data" window, and use the playback tools to find answers to the following questions:

    a. In which years between 1770 and 1800 was the coast adjacent to the area that is now the Channel Islands National Marine Sanctuary subjected to an extreme drought (PDSI = -4.0 or less)? See the map of National Marine Sanctuary sites at http://sanctuaries.noaa.gov/ or http://channelislands.noaa.gov/focus/about.html to locate the Channel Island NMS.

    b. According to instrument measurements, in what years during the first half of the 20th century was the area adjacent to the Channel Islands National Marine Sanctuary exposed to extremely wet conditions (PDSI = 5 or more)?

    c. According to instrument measurements, in how many years during the "Dust Bowl" drought (1930 - 1939) was the coast adjacent to Gray's Reef National Marine Sanctuary exposed to lower-than-normal precipitation (PDSI less than 0)?

    d. Read the introductory page about the Tijuana River National Estuarine Research Reserve at http://nerrs.noaa.gov/TijuanaRiver/welcome.html. What do you think this estuary would have been like in 1990?

12. Here's how you can obtain a hydrograph that will give you an idea about freshwater inflows to the Grand Bay National Estuarine Research Reserve (Jackson County, Mississippi).

    - Refer to the Climate TimeLine Data Access page (http://www.ngdc.noaa.gov/paleo/ctl/data.html).
    - Click on "Find Your Place from NGDC."
    - Click on "U.S. Counties."
    - Choose "U.S. Stream Gauges" from the "Select" pull down menu on the left of the page.

- Type “Mississippi” and “Jackson” into the “State Name” and “County Name” boxes. Click “Select Data.”
- The program should return two Stream Gauge Stations that match the search criteria. Click on “Pascagoula River At Graham Ferry, Ms”.
- Select “Surface Water in the “Data Category” pull down menu at the top of the page.
- Select “Time Series: Monthly statistics” in the “Available data for this site” pulldown menu.
- A new window should appear; click the box next to “Discharge, cubic feet per second,” and set the date range to “From: 1994-01” “To: 2006-12,” then click “Submit”
- You should see a table of monthly streamflow beginning in 1994.

    a. What was the maximum monthly mean streamflow recorded?
    b. What was the minimum monthly mean streamflow recorded?
    c. In general, at what time of the year are streamflows at their maximum?

13. The Padilla Bay National Estuarine Research Reserve is located in the Salish Sea near Mount Vernon, Washington. The Salish Sea is a large estuary fed by many fresh water sources including the Fraser and Skagit Rivers. What was the longest period of time since 1950 that the peak flow from the Skagit River did not reach 100,000 cubic feet per second?

    Hints:

    a. If you don’t enter a county in the fourth step (above) the program will return a list of all stream stations in the specified state.

    b. Consider selecting one of the other options under the “Available data for this site” pulldown menu instead of “Surface-water: Daily streamflow.”

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    Hints:

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b. Consider selecting one of the other options under the "Available data for this site" pulldown menu instead of "Surface-water: Daily streamflow."

Lesson Plan: The Earth's Energy Budget

This lesson plan was developed by NSTA master teacher Jerry D. Roth through NSTA's partnership with NOAA.

Grade Level: 9–12

Subject Area:
Primarily Geoscience, but the lesson can also be used for General Science that has an Earth Science component.

Standards Alignment-National Science Education Standards:

- Earth Science
  - Structure of the Earth system
    - Temperature differences in the atmosphere are a result of the way solar energy is absorbed as it moves through the atmosphere.

- Earth Science
  - Structure of the Earth system
    - Heat energy is transferred through the atmosphere by conduction and convection.

Time Required:
One class period will be needed to demonstrate the three types of heat transfer and the processes that light as radiation can undergo: reflection, absorption, and refraction. The actual tutorial will take two periods.

Overall Lesson Goal:
The student should come away from this lesson with an understanding of the Earth's energy budget; the flow of energy from the sun to the Earth, and the outward flow from the Earth.

Individual Learning Objectives:
Understand that energy flows from the sun to the Earth as radiation.
About 30% of the solar radiation that strikes the atmosphere is reflected or scattered.
Roughly 20% of the solar radiation is absorbed by the atmosphere.
The remaining radiation, approximately 50% is absorbed by the surface of the Earth.

Prerequisite Knowledge; Misconceptions/Preconceptions:
The total amount of radiation striking the Earth is equal to the total amount being radiated back into space. If more incoming radiation was absorbed, the Earth would get hotter. If more radiation was radiated back into space, the Earth would get cooler.

Ultimately, the sun is the source of all of our weather as it provides energy to drive other systems. Students understand that the sun makes them hot in the summer even though they may not understand the mechanism completely. Few really understand solar radiation or the lack of it is also what makes them cold in the winter.

The Earth rotates. This rotation puts one half of the Earth's surface in line for sunlight to strike it. The other half of the Earth is radiating radiation back into space.

The three ways to move heat are radiation, which can take place through a vacuum; conduction, which requires the direct contact of materials; and convection, which causes a heated material to flow as it is being replaced by a cooler material. Three preparatory activities addressing heat transfer, radiation, conduction, and convection, can be found at the University Corporation for Atmospheric Research's Web site Introduction to the Atmosphere. The activities are lower than recommended grade level and you may find they are too low for your students, but I've never had a

group of students keep quiet when I pour carbon dioxide gas over a candle and extinguish it.

Once the students are comfortable with the types of heat transfer, they should move on to what may happen with radiation. Radiation can be reflected, refracted, or have its speed changed, or absorbed. All three of these happen in the atmosphere. Reflection occurs when radiation strikes an object and it bounces off. This happens in the atmosphere and on the surface of the Earth. Refraction, the changing of the speed of radiation as it energizes a substance it has entered is classically observed in rainbows, so we know it occurs in water molecules. Absorption is when the energy in the incoming radiation is passed from the electrons in the substance along to the nucleus of the atoms where it may be radiated back at a different wavelength, usually a lower frequency, longer wavelength wave. Reflection, refraction, and absorption are well explained at How Light Works.

We've got heat energy, electromagnetic radiation and the spinning Earth working together to produce weather and climate. What happens to solar radiation when it comes to the Earth's atmosphere is covered by the Solar Radiation Learning Module from the College of Alameda's Physical Geography Department. Access the learning module with your students and allow them to follow along as you lead them. Demonstrate how to navigate the site then allow them to go on their own. This module helps students understand the interaction of all of the factors above.

Procedures/Instructional Strategy:
All of the aspects of heat transfer and light processes can be demonstrated quickly and easily in one period. You need to set up everything in advance and turn on the heat sources as the students walk into class.

Step 1

(a): Place a 1000mL beaker filled with 800 mL water on a hot plate and turn the hot plate on hot to heat the liquid. Place another beaker with the 800 mL of water on another hot plate but do not turn this hot plate on.

(b): I would set up and turn on a heat lamp of 250 watts. Be sure to warn students that the lamp can get very hot!

(c): Point the heat lamp at a table about 2 ft away. Place two pieces of fabric, one black (I prefer heavy landscape fabric) and the other white, (a cotton t-shirt works well) flat on the table. Underneath each of the two pieces of fabric, place the bulb of a thermometer, and as much of a thermometer (range 0º to 100º C) as you can. As you turn the heat lamp on, have a student read both thermometers to get an initial temperature. Allow the lamp to heat the fabric for at least 10 minutes.

Step 2

(a): The demonstration! Take a thermometer and hold it in the air above the black fabric and give the class an initial temperature reading. Allow five minutes in the path of the heat lamp and take the temperature reading again. Has the temperature changed? Why? Heat has traveled through the air to warm the thermometer. This is radiation.

(b): Compare the temperature readings in the two beakers. Why has the beaker in contact with a working heat source gotten hotter? Why hasn't the beaker over the hot plate that is not turned on gotten hotter? There is no added heat from the plate that is not turned on. The other beaker is getting warmer because it is in direct contact with the heat source. This is conduction-transfer by direct contact.

(c): As the water over the hot plate gets hot squeeze a drop of food coloring into it along one side. Watch as the drop settles and then begins to diffuse upward. This is convection: heat transfer by movement!

Step 3

(a): Hold up a mirror and have the students describe what they see. The image is

reversed along the vertical plane. Reflection from a plane mirror!

(b): Take a temperature reading from the thermometers under the fabric. The black fabric has a higher reading because it has absorbed radiant energy from the light. The white fabric has reflected most of the energy. Absorption and reflection!

(c): Turn off all heat sources!

(d): Refraction can be demonstrated by using either a prism or a laser shown through a block of Lucite or clear gelatin. In a very dark room, light the laser and let the students note where the light enters the block at an angle that is not 90º. Note that the light appears to bend towards the center line (90º) as the light exits the block; it appears to bend away from the 90º line at the exit. This is textbook refraction. I have had success with this demonstration by holding the block on my whiteboard and having a student assist me by marking the entry and exit lines with an erasable marker.

On the second day, lead the students to the website from Alameda College's Solar Radiation Learning Module and have the students work through the very good tutorial found there. The module has three parts. If the students are thorough in their approach, they should complete the module's three parts in two days. What is particularly good about this module is that after demonstrating the methods of heat transfer and light processes, the students see firsthand how they impact the Earth's energy budget.

Outcome / Assessment:
When the three sections have been completed by the students, have them complete the Study Guide provided online at by writing the definitions of all of the key terms and writing answers to all of the questions listed in the objectives. There is a 10 question Online Quiz for the student that is reasonably well thought out. You may, of course, use the questions provided in your own test, but I have found the online quiz quite well done and use the results for a quiz grade.

Extensions:
Consider how your students might build on this lesson; offer suggestions for sharing what they have learned with their families and making it part of their world.

Internet Resources:
Keywords include: Energy In the Atmosphere. The specific URLs are:

- Earth's Energy Budget
- Introduction to the Atmosphere
- How Light Works
- Solar Radiation Learning Module
- Study Guide
- Online Quiz

Classroom Resources:
This lesson, really a tutorial, needs a classroom set of computers with Internet access, an LCD projector.

- 1 heat lamp
- White fabric and black fabric (about 1 square foot of each)
- 3 thermometers (range 0º to 100ºC)
- 2 hot plates
- 2 1000 mL beaker with 800 mL of water
- 1 bottle of red food coloring
- 1 pen-style laser
- 1 block of Lucite or gelatin

Alternately, to complete the heat transfer activities, go to the UCAR activities 5, 6, and 7 for materials and time (roughly three periods) The radiation experiment can double as the absorption demonstration.

(top)

Caution: Do Not Bleach!

Coral Reef Bleaching / Grades 9-12 / Life Science

- Background Information
- Learning Procedure
- The Bridge Connection
- The "Me" Connection
- Extensions
- Resources
- National Science Education Standards
- Ocean Literacy Essential Principles and Fundamental Concepts

Focus Question

Why are coral reefs important, and what are possible explanations for the phenomenon known as "coral bleaching?"

Learning Objectives

- Students will be able to identify and explain five ways that coral reefs benefit human beings.
- Students will be able to identify and explain three major threats to coral reefs.
- Students will be able to describe major components of the Coral Reef Early Warning System.
- Students will be able to identify and discuss actions that can be undertaken to reduce or eliminate threats to coral reefs.
- Students will be able to discuss at least one hypothesis that explains why corals under stress may expel their zooxanthellae.

Links to Overview Essays and Resources Useful for Student Research

http://oceanservice.noaa.gov/topics/oceans/coralreefs/welcome.html
http://www.coris.noaa.gov/about/biology
http://www.coris.noaa.gov/about/hazards/
http://oceanservice.noaa.gov/education/kits/corals/coral01_intro.html
http://oceanservice.noaa.gov/education/kits/corals/coral08_naturalthreats.html

Materials

- Copies of either "Coral Reef Subject Review" *(fill-in-the-blank version, with or without word bank)* or "Coral Reef Subject Review Crossword Puzzle," one copy for each student or student group (from the Corals Tutorial at *http://oceanservice.noaa.gov/education/kits/corals*)
- Computers (optional) with Internet access; if students do not have access to the Internet, you can download copies of materials cited under "Learning Procedure," and provide copies of these materials to each student or student group

Audio/Visual Materials

None, unless students require A-V equipment for their public education programs

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Classroom style or groups of 4-6 students

Maximum Number of Students

30

Key Words

Coral reefs
Aquarium
Symbiosis
Zooxanthellae
Broadcast spawning

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Background Information

Coral reefs are one of the most biologically productive ecosystems on Earth. Most people have seen images of brightly colored fishes and other reef-dwelling organisms, yet many do not understand why these systems are personally important. Programs and articles about coral reefs typically point out benefits that include protecting shorelines from erosion and storm damage, supplying foods that are important to many coastal communities, and providing recreational and economic opportunities. These benefits are obviously important to people who live near reefs, but there is another aspect of coral reefs that can benefit everyone: the highly diverse biological communities are new sources of powerful antibiotic, anti-cancer and anti-inflammatory drugs.

The idea of coral reefs as a source of important new drugs is new to many people; but in fact, most drugs in use today come from nature. Aspirin, for example, was first isolated from the willow tree. Morphine is extracted from the opium poppy. Penicillin was discovered from common bread mold. Although almost all of the drugs derived from natural sources come from terrestrial organisms, recent systematic searches for new drugs have shown that marine invertebrates produce more antibiotic, anti-cancer, and anti-inflammatory substances than any group of terrestrial organisms. Particularly promising invertebrate groups include sponges, tunicates, ascidians, bryozoans, octocorals, and some molluscs, annelids, and echinoderms. For more information on drugs from the sea, visit *http://oceanexplorer.noaa.gov/explorations/03bio/background/medicines/medicines.html*.

Despite their numerous benefits to humans, many coral reefs are threatened by human activities. Sewage and chemical pollution can cause overgrowth of algae, oxygen depletion, and poisoning. Fishing with heavy trawls and explosives damages the physical structure of reefs as well as the coral animals that build them. Careless tourists and boat anchors also cause mechanical damage. Thermal pollution from power plants and global warming cause physiological stress that kills coral animals and leaves the reef structure vulnerable to erosion. Many of these impacts are the result of ignorance; people simply aren't aware of the importance of coral reefs or the consequences of their actions, but the damage and threats to reefs continues to increase on a global scale.

Some of the most severe damage appears to be caused by thermal stress. Shallow-water reef-building corals live primarily in tropical latitudes (less than 30° north or south of the equator). These corals live near the upper limit of their thermal tolerance. Abnormally high temperatures result in thermal stress, and many corals respond by expelling the symbiotic algae (zooxanthellae) that live in the corals' tissues. Since the zooxanthellae are responsible for most of the corals' color, corals that have expelled their algal symbionts appear to be bleached. Because zooxanthellae provide a significant portion of the corals' food and are involved with growth processes, expelling these symbionts can have significant impacts on the corals' health. In some cases, corals are able to survive a "bleaching" event and eventually recover. When the level of environmental stress is high and sustained, however, the corals may die.

Prior to the 1980s, coral bleaching events were isolated and appeared to be the result of short-term events such as major storms, severe tidal exposures, sedimentation, pollution, or thermal shock. Over the past twenty years, though, these events have become more widespread, and many laboratory studies have shown a direct relationship between bleaching and water temperature stress. In general, coral bleaching often occur in areas where the sea surface temperature 1°C or more above the normal maximum temperature.

In 1998, the President of the United States established the Coral Reef Task Force (CRTF) to protect and conserve coral reefs. Activities of the CRTF include mapping and monitoring coral reefs in U.S. waters, funding research on coral reef degradation, and working with governments, scientific and environmental organizations, and business to reduce coral reef destruction and restore damaged coral reefs.

As co-chair of the CRTF, and as directed by the Coral Reef Conservation Act of 2000, NOAA has the responsibility to conserve coral reef ecosystems. NOAA's coral reef conservation efforts are carried out primarily through its Coral Reef Conservation Program (CRCP). Under this program, NOAA works with scientific, private, government, and nongovernmental organizations at the local, federal, and international levels to address conservation actions. Among other actions, the CRCP undertakes a variety of mapping and monitoring activities to understand:

- locations of coral reef ecosystems;
- how they function;
- how human activities impact reef processes; and
- how managers and the public can reduce or eliminate these impacts.

The first part of this lesson is intended to:

- introduce students to coral reefs and improve their understanding of why these systems are important, how they are threatened, and what can be done to protect and restore these unique and valuable ecosystems; and to

- introduce students to hypotheses that explain why corals under stress may expel their zooxanthellae.

In the second part of this lesson, students design and prepare educational programs to improve public awareness of the importance of coral reefs and what needs to be done to reduce or eliminate harmful impacts from human activities. This activity offers many opportunities for cross-curricular activities, and may be extended over several weeks or months. If time is limited, you may choose to use the first part alone.

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Learning Procedure

Part 1

1. Direct students to the Corals Tutorial at: http://oceanservice.noaa.gov/education/kits/corals. You may want to assign different tutorial sections to each student group. Have each student or student group complete one version of the Subject Review (downloadable), and lead a discussion to review the answers. Be sure that students understand the relationship between coral animals and their symbiotic algae (zooxanthellae), and that under thermal stress many corals will expel their zooxanthellae.

   Briefly explain the purpose and activities of the U. S. Coral Reef Task Force (CRTF) and the NOAA Coral Reef Conservation Program (CRCP), and highlight the monitoring functions that are intended to identify reef areas threatened by thermal stress or algal blooms (visit *http://www.coralreef.gov* for more information on the CRTF and *http://coralreef.noaa.gov* for more information on the CRCP).

2. Tell students that their assignment is to investigate possible explanations for zooxanthellae expulsion by corals under stress, and prepare a written report outlining at least one hypothesis that explains this behavior. The report should explain:

- the symbiotic relationship between corals and their zooxanthellae;
- how corals obtain their zooxanthellae; and
- how environmental stress may alter the symbiosis.

If you want to provide a starting point for this research, the following resources will be useful:

http://www.coralreefwatch.noaa.gov/ (NOAA Coral Reef Watch Program and Satellite Monitoring of Coral Bleaching)

http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html (Roadmap to Resources: Corals)

http://www.oneocean.org/overseas/200009/coral_bleaching_the_hows_and_whys_and_whats_next.html (article: Coral Bleaching: the Whys, the Hows and What Next?)

http://ioc.unesco.org/coralbleaching/Hughes%20et%20al.pdf (article: Climate Change, Human Impacts, and the Resilience of Coral Reefs)

http://www.crc.uri.edu/download/COR_0011.PDF (article: Coral Bleaching: Causes, Consequences and Response)

3. Lead a discussion of students' research results. Written reports should include some of the following points:

- Zooxanthellae are single-celled motile algae (dinoflagellates).
- Many marine invertebrates in addition to corals have symbiotic algae.
- Photosynthesis by zooxanthellae provides a significant source of nutrition for many host symbionts; as much as 90% of the total energy requirement in some coral and giant clam species.
- Zooxanthellae are also involved in calcium carbonate deposition (skeletal growth) in some corals.
- Some zooxanthellae produce an ultraviolet-absorbing pigment that may act as a sort of "sunscreen" for host corals.
- The mechanism by which corals obtain zooxanthellae (or, from a slightly different perspective, become infected with zooxanthellae) is not known, but sea anemone larvae have been reported to indiscriminantly ingest zooxanthellae along with other particulate materials. The algal cells become incorporated into the larvae's endodermal cells, while other particulate materials are either digested or expelled.
- "Bleaching" has been observed in most marine organisms that host zooxanthellae.
- It is not known whether bleaching happens because the algae leave their host animal or because the host expels the algae.
- Bleaching can also occur when algae expel their pigments.
- Bleaching appears to be the result of various types of environmental stress, including high temperature, exposure to excessive irradiance, lowered salinity, and pollution.
- Combinations of different stresses may result in bleaching, even though corals might be tolerant of the individual conditions (for example, if corals are near their upper thermal limit, even small increase in irradiance can result in bleaching)
- Elevated temperatures reduce the photosynthetic ability of zooxanthellae.
- Increased atmospheric carbon dioxide may lead to increased dissolved carbon dioxide in seawater, which will increase the solubility of calcium and reduce calcification.

- While there is no absolute proof that bleaching events are the result of climate change, most scientists consider the link to be incontrovertible.

- Different species of corals have different tolerance levels for various environmental factors. Similarly, different strains of zooxanthellae have different tolerance levels.

- Different strains of zooxanthellae are found within and among coral species.

- Coral genera with fast growth rates and high metabolic rates are most susceptible to bleaching.

- The "adaptive bleaching hypothesis" proposes that corals expel their zooxanthellae under stress so that they can be replaced with other strains that are better suited to the stress conditions. There is no evidence, however, that corals can simply take up more tolerant strains of algae. In addition, high mortality, reduced growth rates, and decreased fecundity in bleached corals do not suggest an effective adaptation to stress conditions.

- If the stress conditions that cause bleaching persist for more than about six weeks, corals may die. The duration of the stress conditions and the intensity of high temperatures determine the severity of bleaching and the ability of corals to survive.

- Some scientists have predicted that persistent temperature increases coupled with other stresses will lead to widespread loss of coral reefs, which may require 500 years or more to recover.

- Marine protected areas are currently the most effective management tool for protecting coral reefs and other marine resources, but they cannot stop temperature increases or other adverse climate changes.

Ask students to discuss why coral reefs are at risk, and what they think can or should be done to reduce or eliminate the negative impacts of human activity on coral reefs. There is a strong possibility that a significant part of the current risk to coral reef systems is the result of human activity, particularly as it relates to climate change. Meaningful actions to address this type of issue depend upon widespread understanding of the problem and commitment to workable solutions. Public education is an important step toward building this sort of understanding and commitment. Have students brainstorm what "key messages" might form part of a public education program about coral reefs, what audiences should be targeted to receive these messages, and how these messages might be most effectively delivered to these audiences.

Part 2

Have students or student groups prepare one or more public education programs about coral reefs, based on the results of their brainstorming sessions in Step 3. Encourage students to consider various media, including publications, visual presentations, drama, music, etc. You may want to have an entire class work on a single program, or have smaller groups work on multiple programs using the medium (or media) or their choice. There are many possibilities, depending upon the target audiences. These presentations also offer cross-curricular opportunities, particularly with social studies, English language arts, and fine arts. Whatever media students choose to work with, their final presentation should be accompanied by a list of sources for the information they present. A good starting point for this activity is the Roadmap to Resources: Corals (*http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html*), which provides links to many other sources of coral reef data and information.

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The Bridge Connection

The Bridge is a growing collection online marine education resources. It provides educators with a convenient source of useful information on global, national, and regional marine science topics. Educators and scientists review sites selected for the Bridge to insure that they are accurate and

current.

http://www.vims.edu/bridge/reef.html

The "Me" Connection

Have students write a short essay on why coral reefs are personally important, what personal actions may contribute to human-caused threats to coral reefs, and what they could do to reduce these threats.

Extensions

1. The symbiotic relationship between zooxanthellae and coral polyps can be a springboard for discussing other types of cellular symbionts. Many biology students tend to overlook microbial associations in natural communities, but there is mounting evidence that eukaryotic organisms were (and are) the result of symbiotic associations between prokaryotic organisms. At some point in these associations, one (or more) species (called endosymbionts) entered the cells of another species, and performed useful functions. Each species had its own DNA, and when these organisms reproduced, both were replicated. Eventually, the individual identities of the species disappeared, resulting in a new type of organism. This sort of transformation has actually been seen in the laboratory, and is described in Margulis and Sagan (1986). For more information and a lesson plan devoted to this topic, visit *http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/Meds_CellMates.pdf*

2. Have students or student groups prepare a report on a specific aspect of coral biology, ecology, or management. Some possible topics include:

   - coral diseases
   - natural and anthropogenic hazards
   - oil spills on coral reefs
   - coral reef restoration
   - species diversity on coral reefs
   - benthic habitats associated with coral reefs
   - relationships between coral reefs and seagrass or mangrove ecosystems

   See Roadmap to Resources: Corals (*http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html*) for links to information on these and other relevant topics.

3. For more lesson plans and activities related to coral reefs, visit the education web pages for NOAA's Ocean Explorer Cayman Islands Twilight Zone 2007 Expedition at http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/edu.html.

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Resources

http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html – The National Ocean Service education Web site's Roadmap to Resources about corals, with links to many other sources of coral reef data, background information, and reports

http://www.oneocean.org/overseas/200009/coral_bleaching_the_hows_and_whys_and_whats_next.html

Diamante-Fabunan, D. 2000. Coral Bleaching: the Whys, the Hows and What Next? OverSeas, The Online Magazine for Sustainable Seas.

http://www.crc.uri.edu/download/COR_0011.PDF – "Coral Bleaching: Causes, consequences and response;" a collection of papers from the ninth international coral reef symposium.

http://www.nmfs.noaa.gov/habitat/habitatconservation/publications/Separate%20Chapters

/Cover%20and%20Table%20of%20Contents.pdf – "The State of Deep Coral Ecosystems of the United States," 2007 report from NOAA providing new insight into the complex and biologically rich habitats found in deeper waters off the U.S. and elsewhere around the world.

http://www.latimes.com/news/local/oceans/la-oceans-series,0,7842752.special – "Altered Oceans," five-part series from the Los Angeles Times on the condition of Earth's ocean; published July 30 – August 3, 2006

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- The cell
- Interdependence of organisms
- Behavior of organisms

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

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Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1. The Earth has one big ocean with many features.

- Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 5. The ocean supports a great diversity of life and ecosystems.

- Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

Essential Principle 6. The ocean and humans are inextricably interconnected.

- Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

- Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

- Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7. The ocean is largely unexplored.

- Fundamental Concept c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

- Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

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Corals Subject Review

1. _____ organisms are composed of hundreds to hundreds of thousands of individual animals.

2. Individual coral animals are called _____.

3. The mouth of individual coral animals is surrounded by a circle of _____.

4. After food is consumed by corals, waste products are expelled through the _____.

5. Time of day when most corals feed: _____

6. To capture their food, corals use stinging cells called _____.

7. Nematocysts are capable of delivering powerful, often lethal, _____.

WORD BANK

algae
anthropogenic
asexual
atoll
barrier
basal plate
below
bleaching
branching
broadcast
buttress
calcium carbonate
calyx
clear
cm
colonial
crest
CREWS
digitate
El Niño
elkhorn
encrusting
erosion
euphotic
feed
fishing
flat
foliase
food
fringing
habitats
larvae
lunar
massive
medicines
metamorphose
millions
mortality
mouth
mucous
mushroom
mutualistic
nematocysts
night
photosynthesis
phototaxis
physical stress
plants
planulae
pollution
polyps
poor
predation
productive
recycling
saline
seaward slope
sessile
species
stresses
sunset
synchronized
table
temperatures
tentacles
theca
tidal emersions
tourism
toxins
weather
zooplankton
zooxanthellae

8. A coral's prey ranges in size from nearly microscopic animals called _____ to small fish.

9. Many corals collect fine organic particles in films and strands of _____.

10. Most reef-building corals contain photosynthetic algae called _____ which live in their tissues.

11. Corals and algae have a _____ relationship.

12. Symbiotic algae supply corals with glucose, glycerol, and amino acids, which are the products of _____.

13. Tropical ocean waters are generally [rich or poor] _____ in nutrients.

14. The relationship between the algae and coral polyp facilitates a tight _____ of nutrients, which is the driving force behind the growth and productivity of coral reefs.

15. The unique and beautiful colors of many stony corals are caused by _____.

16. _____ can cause coral polyps to expel their algal cells.

17. Coral _____ occurs when coral polyps expel their algal cells, causing the colony to take on a stark white appearance.

18. Because of their intimate relationship with symbiotic algae, reef-building corals respond to the environment like _____.

19. Because their algal cells need light for photosynthesis, reef corals require _____ water.

20. Although coral reefs require nutrient-poor water, they are among the most _____ and diverse marine environments.

21. Reefs form when polyps secrete skeletons of _____.

22. As they grow, coral reefs provide structural _____ for hundreds to thousands of different vertebrate and invertebrate species.

23. The skeletons of stony corals are secreted by the lower portion of the polyp. This process produces a cup, or _____, in which the polyp sits.

24. The walls surrounding the corals' skeletal cup are called the _____.

25. The floor of the corals' skeletal cup is called the _____.

26. _____ is a system of specially designed buoys that measure conditions that may cause bleaching on coral reefs.

27. When polyps are physically stressed, they contract into their calyx so that virtually no part is exposed above their skeleton. At other times, polyps extend out of the calyx. Most polyps extend the farthest when they _____.

28. _____ corals have primary and secondary branches.

29. _____ corals look like fingers or clumps of cigars and have no secondary branches.

30. _____ corals form table-like structures and often have fused branches.

31. _____ coral has large, flattened branches.

32. _____ corals have broad plate-like portions rising in whorl-like patterns.

33. _____ corals grow as a thin layer against a substrate.

34. _____ corals are ball-shaped or boulder-like and may be small as an egg or as large as a house.

35. _____ corals resemble the attached or unattached tops of mushrooms.

36. Coral reefs begin to form when free-swimming _____ attach to submerged rocks or other hard surfaces along the edges of islands or continents.

37. _____ reefs project seaward directly from the shore, forming borders along the shoreline and surrounding islands.

38. _____ reefs border shorelines, but are separated from their adjacent land mass by a lagoon of open, often deep water.

39. An _____ is formed when a reef has developed around a volcanic island that subsides completely below sea level while the coral continues to grow upward.

40. Massive corals have growth rates of 0.3 to 2 _____ per year

41. Bottom topography, depth, wave and current strength, light, temperature, and suspended sediments act on coral reefs to create horizontal and vertical zones of living species. The reef _____ is usually the zone closest to shore, followed by the reef _____ or algal ridge, then the _____ zone, and finally the _____.

42. Reef-building corals cannot tolerate water temperatures [above or below] _____ 18° Celsius (C).

43. Most reef-building corals require very _____ water.

44. Reef-building corals' requirement for high light explains why most reef-building species are restricted to the _____ ____ zone, the region in the ocean where light penetrates to a depth of approximately 70 meters.

45. As adults, almost all corals are _____, which means that they remain on the same spot on the sea floor for their entire lives.

46. In _____ reproduction, new polyps bud off from parent polyps to expand or begin new colonies.

47. In sexual reproduction, coral eggs and sperm join to form free-floating, or planktonic, larvae called _____.

48. Species that release massive numbers of eggs and sperm into the water to distribute their offspring over a broad geographic area are called _____ spawners.

49. The time between planulae formation and settlement is a period of exceptionally high _____ among corals.

50. Along many reefs, spawning occurs as a _____ event, when all the coral species in an area release their eggs and sperm at about the same time.

51. The long-term control of spawning may be related to temperature, day length and/or rate of temperature change (either increasing or decreasing). The short-term (getting ready to spawn) control is usually based on _____ cues.

52. The final release of gametes during spawning is usually based on the time of _____.

53. Planulae exhibit positive _____.

54. Once planulae settle on the bottom, they _____ into polyps and form colonies that increase in size.

55. Coral reefs support more _____ per unit area than any other marine environment.

56. Scientists estimate that there may be _____ of undiscovered species of organisms living in and around reefs. [how many?]

57. Coral reef biodiversity is considered key to finding new _____ for the 21st century.

58. Healthy reefs contribute to local economies through _____.

59. In developing countries, coral reefs provide critical _____ resources for tens of millions of people.

60. Coral reefs buffer adjacent shorelines from wave action and prevent _____, property damage and loss of life.

61. Natural damage to coral reefs frequently occurs because of _____.

62. Slow-growing corals that are damaged by storms may be overgrown by _____ before they can recover.

63. Reefs also are threatened by _____ that can cause shallow water coral heads to overheat and dry out.

64. Increased sea surface temperatures, decreased sea level and increased salinity from altered rainfall can all result from weather patterns such as _____.

65. Corals are vulnerable to _____ by fishes, marine worms, barnacles, crabs, snails and sea stars.

66. Human-caused, or _____ activities are major threats to coral reefs.

67. One of the most significant human-caused threats to reefs is _____.

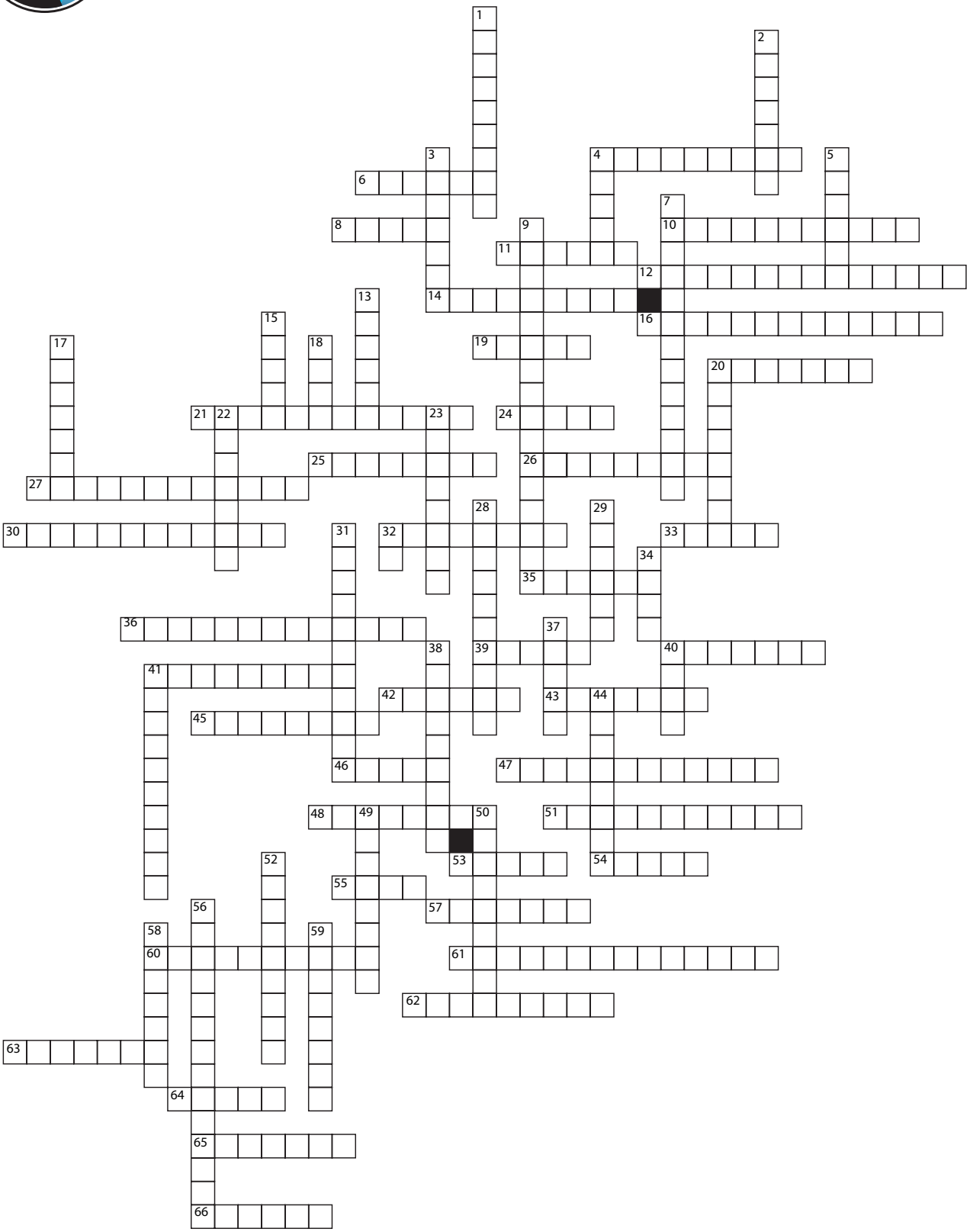
68. When some contaminants enter the water, nutrient levels can increase, promoting the rapid growth of _____ and other organisms that can smother corals.

69. In many areas, coral reefs are destroyed when cyanide or dynamite are used for _____ activities.

70. Coral diseases generally occur in response to biological _____, such as bacteria, fungi and viruses, and non-biological stresses, such as increased sea surface temperatures, ultraviolet radiation and pollutants.

71. Many scientists believe that the increased frequency of coral diseases over the last 10 years is related to deteriorating water quality and increased _____ that may allow for the proliferation and colonization of microbes.

Corals Crossword Puzzle



Across

4. The mouth of individual coral animals is surrounded by a circle of ____.
6. Many corals collect fine organic particles in films and strands of _____.
8. The long-term control of spawning may be related to temperature, day length and/or rate of temperature change (either increasing or decreasing). The short-term (getting ready to spawn) control is usually based on _____ cues.
10. To capture their food, corals use stinging cells called _____ _____.
11. Coral reefs begin to form when free-swimming _____ attach to submerged rocks or other hard surfaces along the edges of islands or continents.
12. _____ can cause coral polyps to expel their algal cells.
14. Coral reef biodiversity is considered key to finding new _____ for the 21st century.
16. Most reef-building corals contain photosynthetic algae called _____which live in their tissues.
19. After the food is consumed by corals, waste products are expelled through the _____.
20. _____ corals have broad plate-like portions rising in whorl-like patterns.
21. The _____ is usually the zone farthest from shore.
24. The skeletons of stony corals are secreted by the lower portion of the polyp. This process produces a cip or _____ in which the coral sits.
25. As they grow, coral reefs provide structural _____ for hundreds to thousands of different vertebrate and invertebrate species.
26. Coral _____ occurs when coral polyps to expel their algal cells, causing the colony to take on a stark white appearance.
27. Once planulae settle on the bottom, they _____ into polyps and form colonies that increase in size.
30. Many scientists believe that the increased frequency of coral diseases over the last 10 years is related to deteriorating water quality and increased _____ that may allow for the proliferation and colonization of microbes.
32. _____ organisms are composed of hundreds to hundreds of thousands of individual animals.

33. Slow-growing corals that are damaged by storms may be overgrown by _____ before they can recover.
35. Increased sea surface temperatures, decreased sea level and increased salinity from altered rainfall can all result from weather patterns such as _____.
36. The unique and beautiful colors of many stony corals are caused by _____.
39. _____ corals form table-like structures and often have fused branches.
40. In many areas, coral reefs are destroyed when cyanide or dynamite are used for _____ activities.
41. Corals are vulnerable to _____ by fishes, marine worms, barnacles, crabs, snails and sea stars.
42. Most reef-building corals require very _____ water.
43. In _____ reproduction, new polyps bud off from parent polyps to expand or begin new colonies.
45. _____ corals look like fingers or clumps of cigars and have no secondary branches.
46. Time of day when most corals feed [_____]
47. Along many reefs, spawning occurs as a _____ event, when all the coral species in an area release their eggs and sperm at about the same time.
48. _____ corals resemble the attached or unattached tops of mushrooms.
51. Corals and algae have a _____ relationship.
53. _____ is a system of specially designed buoys that measure conditions that may cause bleaching on coral reefs.
54. The skeletons of stony corals are secreted by the lower portion of the polyp. This process produces a cup, or _____, in which the polyp sits.
55. When polyps are physically stressed, they contract into their calyx so that virtually no part is exposed above their skeleton. At other times, polyps extend out of the calyx. Most polyps extend the farthest when they _____.
57. Natural damage to coral reefs frequently occurs because of _____.
60. Although coral reefs require nutrient-poor water, they are among the most _____ and diverse marine environments.
61. Reefs also are threatened by _____ that can cause shallow water coral heads to overheat and dry out.

62. The relationship between the algae and coral polyp facilitates a tight _____ of nutrients, which is the driving force behind the growth and productivity of coral reefs.
63. As adults, almost all corals are _____, which means that they remain on the same spot on the sea floor for their entire lives.
64. An _____ is formed when a reef has developed around a volcanic island that subsides completely below sea level while the coral continues to grow upward.
65. Coral reefs buffer adjacent shorelines from wave action and prevent _____, property damage and loss of life.
66. The final release of gametes during spawning is usually based on the time of _____.

Down

1. Species that release massive numbers of eggs and sperm into the water to distribute their offspring over a broad geographic area are called _____ spawners.
2. _____ reefs border shorelines, but are separated from their adjacent land mass by a lagoon of open, often deep water.
3. Healthy reefs contribute to local economies through _____.
4. The walls surrounding the corals' skeletal cup are called the _____
5. Individual coral animals are called _____
7. Human-caused, or _____ activities are major threats to coral reefs.
9. Reefs form when polyps secrete skeletons of _____
13. Because of their intimate relationship with symbiotic algae, reef-building corals respond to the environment like _____.
15. Reef-building corals cannot tolerate water temperatures [above or below] 18° Celsius (C).
17. _____ corals are ball-shaped or boulder-like and may be small as an egg or as large as a house.
18. Tropical ocean waters are generally _____ [rich or poor] in nutrients.
20. _____ reefs project seaward directly from the shore, forming borders along the shoreline and surrounding islands.
22. _____ coral has large, flattened branches.

23. In sexual reproduction, coral eggs and sperm join to form free-floating, or planktonic, larvae called _____.
28. _____ corals grow as a thin layer against a substrate.
29. Nematocysts are capable of delivering powerful, often lethal, _____
31. A coral's prey ranges in size from nearly microscopic animals called _____ to small fish.
32. Massive corals have growth rates of 0.3 to 2 _____ per year.
34. In developing countries, coral reefs provide critical _____ resources for tens of millions of people.
37. Because their algal cells need light for photosynthesis, reef corals require _____ water.
38. One of the most significant human-caused threats to reefs is _____.
40. The reef _____ is usually the zone closest to shore.
41. Planulae exhibit positive _____
44. Reef-building corals' requirement for high light explains why most reef-building species are restricted to the _____ zone, the region in the ocean where light penetrates to a depth of approximately 70 meters.
49. Coral diseases generally occur in response to biological _____, such as bacteria, fungi and viruses, and non-biological stresses, such as increased sea surface temperatures, ultraviolet radiation and pollutants.
50. The time between planulae formation and settlement is a period of exceptionally high _____ among corals.
52. _____ corals have primary and secondary branches.
56. Symbiotic algae supply corals with glucose, glycerol, and amino acids, which are the products of _____.
58. Coral reefs support more _____ per unit area than any other marine environment.
59. Scientists estimate that there may be _____ of undiscovered species of organisms living in and around reefs.

Who Has the Data?

Monitoring Coral Reefs / Grades 9-12 / Life Science, Earth Science

- Background Information
- Learning Procedure
- The Bridge Connection
- The "Me" Connection
- Extensions
- Resources
- National Science Education Standards
- Ocean Literacy Essential Principles and Fundamental Concepts

Focus Question

What types of data do scientists collect to monitor coral reefs, and how are these data used?

Learning Objectives

- Students will be able to access data on selected coral reefs and manipulate these data to characterize these reefs.
- Students will be able to explain the need for baseline data in coral reef monitoring programs.
- Students will be able to identify and explain five ways that coral reefs benefit human beings.
- Students will be able to identify and explain three major threats to coral reefs.

Links to Overview Essays and Resources Useful for Student Research

http://oceanservice.noaa.gov/topics/oceans/coralreefs
http://www.sanctuaries.noaa.gov/about/ecosystems/coralwelcome.html
http://www.coris.noaa.gov/activities/assessment.html#monitor
See specific citations on "Coral Monitoring Data Worksheet" of this Lesson Plan.

Materials

- "Coral Monitoring Data Worksheet," one copy per student group (Click here for separate printable worksheet)
- Grid (approximately 2 mm square) photocopied onto transparencies; one for each student group
- (optional) Computers with internet access; if students do not have access to the internet, you can download copies of the reef habitat images cited under "Learning Procedure;" you can also download copies of other materials cited under "Learning Procedure" and on the worksheet, and provide copies of these materials to each student or student group

Audio/Visual Materials

None

Teaching Time

Two 45-minute class periods, plus time for student research

Seating Arrangement

Groups of 3-4 students

Maximum Number of Students

32

Key Words

Coral reefs
Zooxanthellae
Monitoring
Benthic habitat
Fish census
Bleaching

(top)

Background Information

Coral reefs are some of the most biologically productive and economically valuable ecosystems on Earth. Benefits provided by coral reefs include protecting shorelines from erosion and storm damage, supplying foods that are important to many coastal communities, and providing recreational and economic opportunities. In addition, the highly diverse biological communities associated with coral reefs are new sources of powerful antibiotic, anti-cancer and anti-inflammatory drugs that have the potential to benefit the entire human race.

Despite these benefits, many coral reefs are threatened by human activities as well as natural processes. Sewage and chemical pollution can cause overgrowth of algae, oxygen depletion, and poisoning. Poor land management and deforestation can lead to excessive runoff and sedimentation that can smother living reefs and reduce light needed by many shallow-water corals. Fishing with heavy trawls, poisons, and explosives damages the physical structure of reefs as well as the coral animals that build them. Careless tourists, boat anchors, and collection for the aquarium trade also cause mechanical damage. Thermal pollution from power plants and unusually hot weather cause physiological stress that kills coral animals and leaves the reef structure vulnerable to erosion. Oil spills, fuel discharges, and anti-fouling chemicals from boats add additional stress. Many of these impacts are the result of ignorance; people simply aren't aware of the importance of coral reefs or the consequences of their actions. But the damage and threats to reefs continue to increase on a global scale.

In addition to stress from human activities, coral reefs are also subject to natural threats. Hurricanes and cyclones can break corals loose and scatter them into areas where they cannot survive. Severe storms also cause impacts on coastal areas that increase sedimentation and runoff. Unusually low tides can leave corals exposed to high temperatures, solar radiation, and the risk of drying out. Heavy rains can lower salinity to dangerous levels.

High temperatures associated with phenomena such as El Nino cause severe damage through thermal stress. Shallow-water reef-building corals are found primarily in tropical latitudes (less than 30° north or south of the equator) and live near the upper limit of their thermal tolerance, so temperatures one or two degrees above normal can result in thermal stress. One of the most striking responses to thermal stress is known as "bleaching." Most reef-building corals have single-cell algae (zooxanthellae) living within their tissues. These algae play an important role in the corals' nutrition and growth. Pigments in the algae are also responsible for most of the corals' color. Under thermal stress, some corals may expel these algae, causing the corals to appear bleached. Some corals may recover and acquire replacement algae, but others may die. Corals are also subject to predation and disease. Rates of disease outbreaks in corals appear to be increasing, and many researchers believe that at least part of the reason is that the corals have been weakened by other stress factors.

In response to growing concern for the future of coral reefs, the President of the United States established the Coral Reef Task Force (CRTF) in 1998 to protect and conserve coral reefs. The CRTF has prepared a plan to reduce human threats to coral reefs and to improve our understanding of coral reef ecosystems. Strategies for reducing human threats include:

- Expanding and strengthening coral reef marine protected areas (MPAs);
- Reducing damage caused by extractive uses such as overfishing;

- Reducing habitat destruction and pollution;
- Restoring damaged reefs; and
- Creating an informed public.

Strategies to improve our understanding of coral reef ecosystems include:

- Comprehensive mapping, inventory and monitoring of U.S. reefs; and
- Research on coral reef ecology, bleaching, diseases, and best management practices for successful coral reef conservation.

As co-chair of the CRTF, and as directed by the Coral Reef Conservation Act of 2000, NOAA has the responsibility to conserve coral reef ecosystems. NOAA's coral reef conservation efforts are carried out primarily through its Coral Reef Conservation Program (CRCP). Under this program, NOAA works with scientific, private, government, and nongovernmental organizations at the local, federal, and international levels to address conservation actions.

Among other actions, the CRCP undertakes a variety of mapping and monitoring activities to understand locations of coral reef ecosystems, how they function, how human activities impact reef processes, and how managers and the public can reduce or eliminate these impacts.

Mapping and monitoring are an essential part of coral reef conservation. The purpose of this activity is to acquaint students with sources of information and data on coral reef monitoring, and to provide hands-on experience with manipulating and interpreting some of these data.

(top)

Learning Procedure

1. Photocopy a grid (approximately 2mm squares) onto transparencies, and have students use the transparencies to count the number of grid squares contained in each of the habitat regions shown on the habitat maps. The total number of squares for each habitat type can be used to quantify the relative area occupied by each habitat.

2. Direct students to the Corals Tutorial at: *http://oceanservice.noaa.gov/education/kits/corals*. You may want to assign different tutorial sections to each student group. Have each student or student group complete one version of the Subject Review (downloadable), and lead a discussion to review the answers.

Briefly review the purpose and activities of the U. S. Coral Reef Task Force (CRTF) and the NOAA Coral Reef Conservation Program (CRCP), and highlight the monitoring functions that are intended to identify threatened reef areas and to improve understanding of reef ecosystems (visit *http://www.coralreef.gov* for more information on the CRTF and *http://coralreef.noaa.gov* for more information on the CRCP).

3. Tell students that their assignment is to use online data to investigate selected coral reefs. Assign one of the following marine protected areas in the Florida Keys to each student group:

- Carysfort/South Carysfort Reef
- French Reef
- Molasses Reef
- Conch Reef
- Hen and Chickens
- Davis Reef
- Alligator Reef
- Sombrero Key
- Looe Key
- Western Sambos/Eastern Sambos
- Sand Key

Provide each student group with a “Coral Monitoring Data Worksheet.” Have each student group complete the tasks described, and prepare a written report containing answers to the questions on the worksheet.

4. Lead a discussion of students’ results. Students should realize that a primary purpose of habitat and fish census data is to establish baselines that can be compared with subsequent surveys to detect changes in coral reef systems. Discuss the variability of habitats in marine protected areas of the Florida Keys. Students should recognize that there is often considerable variability among habitats, even though the habitats are in the same geographic area. An important part of developing a comprehensive understanding of coral reef ecosystems is knowing how reefs change over time in response to various types of environmental change. Students’ examination of sea surface temperature data should reveal that during the period January 1, 2001 – December 31, 2004, Sombrero Key (the monitoring station located in the Florida Keys) was:

- Exposed to “HotSpot” > 1 conditions during August and September 2001, August 2002, July and August 2003, and July and August 2004;
- There was likely to have been some bleaching as a result of thermal stress (Alert Level 1) in August 2003 and August 2004
- Not exposed to conditions defined as Alert Level 2
- Conditions defined as Alert Level 2 were measured during August 2005 and August and September 2007

Students should recognize that fish census data from St. Croix, USVI, are typical of many healthy coral reef systems in that while there are a large number of different species present, only a few of these are present in large numbers, and there are many more small fishes than large ones. The two most abundant species were *Halichoeres bivittatus* and *Thalassoma bifasciatum*, and the two species with the greatest number of large (> 30 cm) individuals were *Caranx chrysos* and *Sparisoma viride*.

(top)

The Bridge Connection

The Bridge is a growing collection online marine education resources. It provides educators with a convenient source of useful information on global, national, and regional marine science topics. Educators and scientists review sites selected for the Bridge to insure that they are accurate and current.

http://www.vims.edu/bridge/reef.html

The “Me” Connection

Have students write a short essay on why coral reefs are per¨sonally important and what specific actions individuals might take to reduce threats to coral reefs.

Extensions

1. Online data introduced in this activity can be used for a wide variety of additional activities related to coral reefs and coral reef management. Many of these data can be accessed through “Discover NOAA’s Data” at the CoRIS home page (*http://coris.noaa.gov/*) and the “Corals Roadmap to Resources” (*http://oceanservice.noaa.gov/education/kits/corals/supp_coral_roadmap.html*)

2. For more lesson plans and activities related to coral reefs, visit the education web pages for NOAA’s Ocean Explorer Cayman Islands Twilight Zone 2007 Expedition at http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/edu.html.

Resources

http://response.restoration.noaa.gov/audience_subtopic_entry.php?RECORD_KEY%28entry_subtopic

audience%29=entry_id,subtopic_id,audience_id&entry_id(entry_subtopic_audience)=5&subtopic_id(entry_subtopic_audience)=27&audience_id(entry_subtopic_audience)=2 –" Coral Reefs and Oil Spills: A Guided Tour" presented by the National Ocean Service, Office of Response and Restoration; includes a basic overview of coral ecology, types of things which can harm coral, and shows how resource managers go about response and restoration efforts

http://www.oneocean.org/overseas/200009/coral_bleaching_the_hows_and_whys_and_whats_next.html Diamante-Fabunan, D. 2000. Coral Bleaching: the Whys, the Hows and What Next? OverSeas, The Online Magazine for Sustainable Seas.

http://www.crc.uri.edu/download/COR_0011.PDF – "Coral Bleaching: Causes, consequences and response;" a collection of papers from the ninth international coral reef symposium.

http://www.nmfs.noaa.gov/habitat/habitatconservation/publications/Separate%20Chapters/Cover%20and%20Table%20of%20Contents.pdf – "The State of Deep Coral Ecosystems of the United States," 2007 report from NOAA providing new insight into the complex and biologically rich habitats found in deeper waters off the U.S. and elsewhere around the world.

http://www.latimes.com/news/local/oceans/la-oceans-series,0,7842752.special – "Altered Oceans," five-part series from the Los Angeles Times on the condition of Earth's ocean; published July 30 – August 3, 2006

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- Interdependence of organisms

Content Standard D: Earth and Space Science

- Geochemical cycles

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

(top)

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1. The Earth has one big ocean with many features.

- Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 5. The ocean supports a great diversity of life and ecosystems.

- Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Essential Principle 6. The ocean and humans are inextricably interconnected.

- Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws,

regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

- Fundamental Concept f. Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).
- Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7. The ocean is largely unexplored.

- Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
- Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

(top)

Who Has The Data?

Student Worksheet

1. Obtain a map of benthic habitats for your assigned area:

   a. Point your web browser to *http://coris.noaa.gov/*. This is the home page for NOAA's Coral Reef Information System (CoRIS), which is designed to be a single point of access to NOAA coral reef information and data products.

   b. Click on "Discover NOAA's Data," then "Browse," then "Browse Data Descriptions."

   c. Select "Place Keywords - Multiple Pages." Click on the letter "F," then scroll down to "Florida" and find the entry for "florida_keys_benthic_habitat_1992." Click on "FAQ" then 5.How can I download or order the data?."

   d. Select the link to "*http://flkeysbenthicmaps.noaa.gov*" then click on the link to "Maps" on the right side of the page.

   e. Click on "Protected Areas," then click on the name of the reef area that has been assigned to your group. A window will open with a benthic habitat map for the selected area.

   f. Scroll down to the bottom of the page and click on "Legend" and print a copy of the map legend.

2. Return to the previous page (with the benthic habitat map) and copy the map image into an image processing program such as Adobe Photoshop. Save the image as a TIFF or JPEG file. Print a color copy of the file onto an 8.5 in x 11 in page, and calculate the area of each habitat by placing a transparent grid over the image and counting the number of grid squares contained in each habitat.

3. When the area of all habitats has been calculated, add the area measurements for each habitat type and prepare a table showing these areas.

4. Add all the measurements together, then divide this number into the total area for each habitat type to calculate the relative area (percent of total) for each habitat.

5. Construct a pie chart showing the relative areas for each type of habitat.

6. Coral bleaching events often occur in areas where the sea surface temperature is 1°C or more above the normal maximum temperature. Find out whether coral reefs in the Florida Keys have been exposed to water temperatures that could cause "bleaching." From the entries under "Florida" in step 1c, find the entry for "avhrr_cur_sst_timeseries_sombrero_reef." Click on "FAQ," then "1.How should this data set be cited?" and select the link to *http://coralreefwatch.noaa.gov/satellite/current/sst_series_24reefs.html*, to open the "SST/DHW Time Series and Satellite Bleaching Alerts" page.

This page contains links to sea surface temperature (SST) data for 24 selected coral reef locations beginning in the year 2000. These data are obtained from the Advanced Very High Resolution Radiometer (AVHRR), which provides information on sea surface temperature (SST) for the entire Earth on a daily basis. The AVHRR is carried on NOAA's Polar Orbiting Environmental Satellite (POES).

"Coral bleaching HotSpots" are defined as sea surface temperatures that are greater than the normal maximum temperature. Some coral bleaching events have been noted in areas where the HotSpots are greater than 1° C. More often, coral bleaching results from thermal stress that accumulates over several days or weeks. "Degree Heating Weeks" (DHWs) indicate the accumulation of thermal stress that coral reefs have experienced over the past 12 weeks. One DHW is equivalent to one week of sea surface temperatures one stat Celsius greater than the expected summertime maximum. Two DHWs are equivalent to two weeks at one degree above the expected summertime maximum OR one week of two degrees above the expected summertime maximum.

HotSpots and DHWs are used to define a series of "alert levels" that are issued from NOAA Coral Reef Watch's Satellite Bleaching Alert System for 24 selected reef sites around the globe. Definitions of alert levels are:
No Stress = No thermal stress (no HotSpots)
Watch = Low-level thermal stress (0 < HotSpot < 1)
Warning = Thermal stress is accumulating (HotSpot >= 1 and 0 < DHW < 4)
Alert Level 1 = Bleaching expected (HotSpot >= 1 and 4 <= DHW < 8)
Alert Level 2: Significant bleaching expected (HotSpot >= 1 and DHW >= 8)

Click on the "Data" link for the location that is in or near the Florida Keys.
During the period January 1, 2001 – December 31, 2004:

- Were corals at this location ever exposed to HotSpot > 1 conditions? When?
- In what years was there likely to have been some bleaching as a result of thermal stress?
- In what years was there likely to have been significant bleaching?
- Have conditions defined as Alert Level 2 ever been measured at this site?

7. Point your web browser to *http://biogeo.nos.noaa.gov/*. This is the home page for NOAA's Biogeography Program that is responsible for developing knowledge and products on living marine resource distributions and ecology throughout the Nation's estuarine, coastal and marine environments, and to provide managers and scientists with an improved ecosystem basis for making decisions.

a. a. In the pull-down menus near the top of the page, click on "Ecosystems," then on "Coral Reefs." In the menu on the left side of the new page, click "Caribbean Coral Reef Ecosystem Monitoring." Now, click on the "Quick Link to Reef Fish Database" button.

b. Click on "Fish Queries" in the pull-down menus near the top of the page.

c. Set Query Parameters as follows:
Region = "Virgin Islands St. Croix
Year = All
Month = All
Structure = All
Permanent/Random = All

Management = All
Trophic Level = All
Family = All
Species = All
Under "Query Selection," click the button next to "Full Data Download." Click "Save as Text" to download a data file containing results of fish surveys in the vicinity of St. Croix, USVI. These data are much easier to analyze if you open the file with a spreadsheet program such as Microsoft Excel®.

d. Identify:

- Which two species had the largest number of individuals?
- Which two species had the largest number of individuals whose length was greater than 30 cm?

(top)

Who Has The Data?

Student Worksheet

1. Obtain a map of benthic habitats for your assigned area:

   a. Point your web browser to http://coris.noaa.gov/. This is the home page for NOAA's Coral Reef Information System (CoRIS), which is designed to be a single point of access to NOAA coral reef information and data products.

   b. Click on "Discover NOAA's Data," then "Browse," then "Browse Data Descriptions."

   c. Select "Place Keywords - Multiple Pages." Click on the letter "F," then scroll down to "Florida" and find the entry for "florida_keys_benthic_habitat_1992." Click on "FAQ" then 5.How can I download or order the data?."

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than the normal maximum temperature. Some coral bleaching events have been noted in areas where the HotSpots are greater than 1° C. More often, coral bleaching results from thermal stress that accumulates over several days or weeks. “Degree Heating Weeks” (DHWs) indicate the accumulation of thermal stress that coral reefs have experienced over the past 12 weeks. One DHW is equivalent to one week of sea surface temperatures one stat Celsius greater than the expected summertime maximum. Two DHWs are equivalent to two weeks at one degree above the expected summertime maximum OR one week of two degrees above the expected summertime maximum.

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Click on the “Data” link for the location that is in or near the Florida Keys.
During the period January 1, 2001 – December 31, 2004:

- Were corals at this location ever exposed to HotSpot > 1 conditions? When?
- In what years was there likely to have been some bleaching as a result of thermal stress?
- In what years was there likely to have been significant bleaching?
- Have conditions defined as Alert Level 2 ever been measured at this site?

7. Point your web browser to *http://biogeo.nos.noaa.gov/*. This is the home page for NOAA’s Biogeography Program that is responsible for developing knowledge and products on living marine resource distributions and ecology throughout the Nation’s estuarine, coastal and marine environments, and to provide managers and scientists with an improved ecosystem basis for making decisions.

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b. Click on “Fish Queries” in the pull-down menus near the top of the page.

c. Set Query Parameters as follows:
Region = “Virgin Islands St. Croix
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Permanent/Random = All
Management = All
Trophic Level = All
Family = All
Species = All
Under “Query Selection,” click the button next to “Full Data Download.” Click “Save as Text” to download a data file containing results of fish surveys in the vicinity of St. Croix, USVI. These data are much easier to analyze if you open the file with a spreadsheet program such as Microsoft Excel®.

d. Identify:

    - Which two species had the largest number of individuals?
    - Which two species had the largest number of individuals whose length was greater than 30 cm?

(top)

Lesson Plan: The Stinging Sea

Predicting sea nettles in the Chesapeake Bay / Grades 9-12 / Earth Science

- Background Information
- Learning Procedure
- The Bridge Connection
- The "Me" Connection
- Extensions
- Resources
- National Science Education Standards
- Ocean Literacy Essential Principles and Fundamental Concepts

Focus Question

How can the impacts of changes in coastal ecosystems be predicted to help prepare for potential impacts on natural resources and human communities?

Learning Objectives

- Students will define ecological forecasting, and be able to describe three examples of this process.
- Students will explain how the life cycle and ecological preferences of sea nettles help make them unusually abundant in the Chesapeake Bay.
- Students will describe the economic and ecological impacts associated with large numbers of sea nettles in the Chesapeake Bay, and how ecological forecasting may help reduce these impacts.
- Students will define “limiting factors,” explain how physical factors can be used to forecast sea nettle “outbreaks,” and describe the limitations of these forecasts.

Links to Overview Essays and Resources Needed for Student Research

http://oceanservice.noaa.gov/topics/coasts/ecoforecasting/

http://coastwatch.noaa.gov/seanettles/

Materials

- (optional) Computers with Internet access; if students do not have access to the Internet, make copies copies of descriptions of ecological forecasting projects found at: *http://oceanservice.noaa.gov/topics/coasts/ecoforecasting/*
- Copies of the "Student Worksheet - Ecological Forecasting of Sea Nettle Abumndance" and Appendix A (“Jellyfish in Chesapeake Bay and Nearby Waters” by Dr. Jennifer E. Purcell) found at the end of this lesson plan. Click here for a printable copy of the student worksheet. Click here for a printable copy of Appendix A.

Audio/Visual Materials

None

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Classroom style or groups of 3 – 4 students

Maximum Number of Students

30

Key Words

Sea nettle
Chrysaora quinquecirrha
Cnidaria
Medusa
Polyp
Jellyfish
Ecological forecasting
Limiting factors
Chesapeake Bay
Nematocyst

(top)

Background Information

Coastal ecosystems are constantly changing environments. Some changes are barely detectable (such as a gradual build-up of sediment over a period of twenty years), while others can have major impacts on natural resources and human communities (such as hurricanes or chemical spills). NOAA's National Ocean Service (NOS) has developed a series of ecological forecasting projects to predict these impacts and help prepare for them. The goals of ecological forecasting are to:

- Provide information needed to make effective decisions about how best to maintain benefits from coastal ecosystems (such as whether or not to prohibit harvest of certain species during reproductive seasons or limiting the number of certain species that can be harvested by humans);
- Reduce the negative impacts from extreme natural events and human activities (for example, by protecting wetlands from development to maintain the ability of these systems to buffer the effects of severe storms or floods);
- Apply scientific knowledge and technical capabilities to improve the use of coastal resources; and
- Identify ways that scientific research and monitoring can contribute to more accurate ecological forecasts.

Ecological forecasts vary in time and spatial scales that range from hours to decades and local to global. Current ecological forecasting projects include:

- Predicting the presence of sea nettles in the Chesapeake Bay (short-term, local scale);
- Predicting the movement and behavior of spilled oil or chemicals and evaluating the risk to resources (short-term, local scale);
- Predicting the abundance of pink shrimp in North Carolina in the spring and summer(short-term, local scale);
- Predicting the development, persistence, movement and landfall of harmful algal blooms off coastal Florida and in the Gulf of Maine (short-term, regional scale);

- Predicting the effectiveness of seagrass restoration efforts in North Carolina coastal waters(long-term, local scale);
- Predicting oyster abundance in Florida's Apalachicola Bay based on variable freshwater inflow scenarios (long-term, regional scale);
- Predicting changes in the size of the Gulf of Mexico Dead Zone (long-term, national scale);
- Predicting the potential population of cod and haddock on Georges Bank based on predator/prey relationships and environmental variability (long-term, regional scale); and
- Predicting shellfish bed closures based on freshwater input and large coastal storms (long-term, regional scale).

Ecological forecasting of sea nettle abundance in Chesapeake Bay is a good example of how physical and chemical environmental factors can be used to make predictions about biological organisms. Sea nettles in Chesapeake Bay belong to the species *Chrysaora quinquecirrha*, and are members of the phylum Cnidaria which also includes hydroids, anemones, corals, and other jellyfish. Like all jellyfish, sea nettles have an umbrella shaped body called a bell. Several dozen yellow tentacles and four long, frilly, white feeding arms hang down from the bell. The tentacles are equipped with rows of stinging cells called nematocysts. These cells are used to capture and immobilize prey, which can be almost any small creature that blunders into the tentacles. Small fish, microscopic crustaceans, larvae of many species, and comb jellies (another Cnidarian) are typical food. Studies in Chesapeake Bay tributaries have shown that in one day sea nettles are able to consume as much as 40% of bay anchovy eggs and 94% of the copepods present, demonstrating that sea nettles can have a significant impact on individual species and possibly on other organisms that use these species for food. While they are generally regarded as a nuisance or worse, sea nettles may actually benefit the oyster industry since they consume large quantities of comb jellies which are a major predator on oyster larvae. Nematocysts can also deliver a painful sting to humans, and in large numbers can pose a serious danger to people in the water. Knowing where and when to expect sea nettle "outbreaks" can help swimmers and fishermen avoid this risk.

Large numbers of sea nettles are associated with a specific range of salinity and temperature. This association is the basis for an ecological forecasting project that uses information on salinity and temperature in the Chesapeake Bay to create maps that describe the probable distribution patterns of sea nettle populations. A mathematical model of the Chesapeake Bay (the Chesapeake 3-D Physical Oceanographic Model, or C3PO) as well as satellite imagery are used to predict salinity and temperature conditions in the Bay. Every Friday, maps of probable sea nettle presence are created based on locations where current environmental conditions are favorable to sea nettles. In addition, the sea nettle forecasting project uses volunteer observers (such as high school and college students, boaters, fishermen, mariners, and individuals from organizations that use the Bay) to confirm or reject these predictions by reporting the presence or absence of sea nettles in all regions of the Bay.

The mathematical model to predict the probability of encountering sea nettles from estimations of sea-surface temperature and salinity was developed from data on *Chrysaora quinquecirrha* abundance collected between 1987-2000. Temperature, salinity, and depth were also measured at the sites where abundance data were collected, and a statistically significant correlation was found between these factors and *Chrysaora quinquecirrha* abundance. In this lesson, students will seek a correlation between abundance and physical factors, and make inferences about conditions that are most likely to be associated with large populations of sea nettles. In addition to acquainting students with the basis for ecological forecasting of sea nettle outbreaks, this lesson also provides an introduction to some of the data sources that can be useful for this type of project.

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Learning Procedure

1. To prepare for this lesson:
    - Review introductory information at

- *http://oceanservice.noaa.gov/topics/coasts/ecoforecasting/* and *http://coastwatch.noaa.gov/seanettles/*;

- Make copies of descriptions of ecological forecasting projects, unless you plan to have students review these online; and

- Copy Appendix A ("Jellyfish in Chesapeake Bay and Nearby Waters" by Dr. Jennifer E. Purcell), one copy for each student or student group.

2. Introduce the concept of ecological forecasting, describe some examples of ecological forecasting projects, and discuss the kinds of benefits that result from the ability to make accurate ecological forecasts. Briefly review the biology of cnidarians and jellyfish in particular. Be sure students understand the distinction between medusoid and polypoid forms, and that many cnidarians resemble both forms at some stage in their life cycle. Discuss the hazards posed by cnidarians, and introduce the problems associated with sea nettles in the Chesapeake Bay.

3. Provide each student or student group with a copy of "Jellyfish in Chesapeake Bay and Nearby Waters," or direct students to this material online. After students have reviewed this article, provide each student or student group with a copy of "Ecological Forecasting of Sea Nettle Abundance Worksheet." Direct students to answer questions in Part I, and complete the assignment described in Part II. Depending upon your students' research skills, you may want to:

    - Complete Part II as a class exercise; or
    - Walk through the steps before students begin this part of the lesson; or
    - Allow students to work through these steps on their own.

4. Lead a discussion of students' answers to questions on the worksheet. The following points

   should emerge:

Part I

1. The greatest numbers of sea nettles are found in the Chesapeake Bay, particularly the Middle Bay area.

2. The sting of the moon jelly, *Aurelia aurita*, is much less severe to humans than that of the sea nettle.

3. Sea nettle stings can be prevented by wearing lightweight protective clothing, or by spreading a layer of petroleum jelly (Vaseline™) on exposed skin. Jellyfish stings should be treated by liberally sprinkling meat tenderizer or baking soda on the area of affected skin. Vinegar, lemon juice or other dilute acids can also be effective in treating stings from the Portuguese Man-of-War (*Physalia physalis*).

4. During the summer, male and female sea nettles release eggs and sperm into the water. Fertilized eggs form larvae which attach to hard surfaces and grow into tiny polyps. These polyps are dormant during the winter. From May through August, the polyps bud off tiny medusae (jellyfish) that grow rapidly into visible sea nettles.

5. Sea nettles eat a variety of zooplankton, including juvenile fishes, fish eggs, worms, mosquito larvae, and comb jellies. Their primary food is copepods.

6. Sea nettles capture their food with tentacles that trail behind the swimming bell. Microscopic stinging cells stun or kill prey animals, which are transported by central tentacles to gastric pouches in the swimming bell where digestion occurs.

7. Sea nettles can feed at night, since they do not have eyes and consequently are not dependent upon light for feeding.

8. Sea nettles require very little food for rapid growth because only about 0.2% of their live weight consists of organic materials.

9. Sea nettles are said to be “geared for high reproduction” because:

    - They begin producing eggs when the swimming bell is only about 1 1/2 inches in diameter;

    - They produce large numbers of eggs (a nettle 4 inches in diameter produces about 40,000 eggs per day);

    - The polyps that grow from fertilized eggs can bud to produce more polyps; and

    - Each polyp can produce up to 45 jellyfish each summer.

10. Sea nettles’ preference for low salinity water is unusual among jellyfishes.

11. Sea Nettles’ preference for low salinity waters eliminates competition from most other jellyfishes that require salinities closer to that of normal seawater. In addition, sea nettles eat comb jellies which are their most abundant potential competitors. Lower salinities also exclude many potential predators such as fishes and sea turtles.

12. While there is no direct evidence that human activities have increased the numbers of sea nettles in the Chesapeake Bay, there is ample evidence that the Bay has been enriched by organic materials (such as wastewater) and fertilizers from surrounding human communities. This kind of enrichment can enhance the growth of microscopic plants (phytoplankton), which are food for microscopic grazing animals such as copepods. If enrichment led to an increase in phytoplankton, which in turn led to an increase in copepods, this series of events could provide food for larger populations of animals that feed on copepods – such as sea nettles. It has also been suggested that depletion of oysters in the Bay by commercial fishing could also increase phytoplankton which would otherwise have been consumed by the oysters.

Part II

Students have several options for calculating average January-June river discharge from monthly stream flow data. The easiest is to import the relevant data into a spreadsheet and perform the calculations with a simple sum function divided by 6. Alternatively, the appropriate data could be added using a calculator, or even paper and pencil.

Students should realize that years having the greatest abundance were also years with the highest sea surface temperatures (27°C-29°C), and years in which January-June discharge from the Susquehanna River averaged 1,594-3,637 ft^3/sec. Students should note that the abundance of was zero in 2000, even though the discharge rate was also in this range, and should infer that the sea surface temperature of 24.5°C (the lowest recorded during the study) was sufficiently low to outweigh potentially favorable salinity conditions. Following discussion of students’ results and inferences, you may want to tell them that the technical journal article on which this activity is based reports that the majority of *Chrysaora quinquecirrha* are observed in shallow (< 15 m) surface waters with temperatures ranging from 26 to 30°C and salinities ranging from 10 to 16 parts per thousand.

Discuss the concept of “limiting factors.” Be sure students understand that the habitat of a species is defined by many physical and biological parameters, and that one or more of these limits the size that populations can attain. Point out that while salinity and temperature are important physical factors that influence the presence of sea nettles, other factors (such as food availability) become limiting even when salinity and temperature are optimal.

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The Bridge Connection

http://www.vims.edu/bridge/chesapeake.html – Link to the Bridge Chesapeake Bay Resource Page

The Me Connection

Have students write a brief essay describing how the concept of ecological forecasting might be applied to human populations, and what limiting factors might be used as the basis for a forecasting model. You may also want to ask them to speculate on what might happen when one or more of these limiting factors are removed.

Extensions

Visit *http://jellieszone.com/* for more information about jellyfishes, including the deadly cubomedusae of Australia, as well as how jellyfish can be kept in aquaria (with a lot of work!).

Resources

http://www.intercom.net/local/shore_journal/jp010716.html – "Jellyfish in Chesapeake Bay and Nearby Waters" by Dr. Jennifer E. Purcell

http://www.mdsg.umd.edu/MarineNotes/Jul-Aug94/side1/ – "Neither Jelly nor Fish" University of Maryland Sea Grant Maryland Marine Notes, vol 12, number 5, July-August 1994

J.E. Purcell and M.B. Decker. 2002. Effects of climate on relative predation by scyphomedusae and ctenophores on copepods in Chesapeake Bay during 1987-2000. Limnology and Oceanography 50(1):376-387 – The technical article on which this lesson is based; available online at *http://aslo.org/lo/toc/vol_50/issue_1/0376.pdf*

http://www.nodc.noaa.gov/dsdt/index.html – Interactive Data Access and Retrieval System Web site, including access to real-time and archival AVHRR data

http://nwis.waterdata.usgs.gov/nwis – U.S. Geological Survey National Water Information System Web site

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- Interdependence of organisms
- Behavior of organisms

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal and community health
- Population growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

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Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1. The Earth has one big ocean with many features.

- Fundamental Concept g. The ocean is connected to major lakes, watersheds and waterways because all major watersheds on Earth drain to the ocean. Rivers and streams transport nutrients, salts, sediments and pollutants from watersheds to estuaries and to the ocean.

- Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 5. The ocean supports a great diversity of life and ecosystems.

- Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

- Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is “patchy”. Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Essential Principle 6. The ocean and humans are inextricably interconnected.

- Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

- Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7. The ocean is largely unexplored.

- Fundamental Concept e. Use of mathematical models is now an essential part of ocean sciences. Models help us understand the complexity of the ocean and of its interaction with Earth’s climate. They process observations and help describe the interactions among systems.

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The Stinging Sea

Student Worksheet - Ecological Forecasting of Sea Nettle Abundance

Part I – Subject Review

Answer the following questions after reading “Jellyfish in Chesapeake Bay and Nearby Waters” by Dr. Jennifer E. Purcell:

1. Where are the greatest numbers of sea nettles found?

2. The moon jelly, *Aurelia aurita*, is also common in the Chesapeake Bay during the summer. Does this species poses a stinging threat to humans similar to that of the sea nettle?

3. How can sea nettle stings be prevented? How should they be treated?

4. Where do sea nettles go during the winter?

5. What do sea nettles eat?

6. How do sea nettles capture their food?

7. Can sea nettles feed at night?

8. Sea nettles can grow rapidly with very little food. Why?

9. What are three aspects of sea nettles' life history that makes this species "geared for high reproduction"?

10. What ecological preference of sea nettles is unusual when compared to most other jellyfishes?

11. How do sea nettles deal with competition and predation from other species?

12. How may human activities have increased the numbers of sea nettles in the Chesapeake Bay?

13. Review examples of ecological forecasting projects at *http://oceanservice.noaa.gov/topics/coasts/ecoforecasting*, and describe three of these projects.

Part II – The Foundation for Ecological Forecasts of Sea Nettle Abundance

The mathematical model that is used to make ecological forecasts of sea nettle abundance in Chesapeake Bay was developed from data collected during 1987-2000 on *Chrysaora quinquecirrha* abundance, temperature, salinity, and depth. Forecasters use satellite data to obtain real-time estimates of sea surface temperature. Another mathematical model that describes water circulation in the Chesapeake Bay is used to estimate salinity distribution in various parts of the Bay. Because salinity is strongly influenced by freshwater input from major rivers, variations in the discharge rates of these rivers correlate closely with salinity changes in the Bay. In this exercise, you will use online databases to obtain information on sea surface temperature and river discharge for comparison with data on abundance in samples collected during summer months from 1987-2000.

Abundance data were obtained by towing plankton nets (1 m diameter, 1.6 mm mesh) equipped with a flowmeter. The volume of water filtered by the nets ranged from 60 m^3 to 160 m^3. Captured jellyfish were separated and counted by hand. Table 1 summarizes Chrysaora quinquecirrha abundances determined by this method.

Table 1. Chrysaora quinquecirrha Abundance in Chesapeake Bay 1987 – 2000

Date	*Chrysaora quinquecirrha* Abundance (Individuals/m^3)	Average Temperature for Sample Month (?C)	Susquehanna River Average Monthly (ft^3/sec)
7 Jul,1987	0.10	27	_____
28 Jul, 1988	0.05	27	_____
28ÝJun,Ý1989	0.04	26.5	_____
15ÝAug, 1990	0.13	27	_____
27ÝJul,Ý1995	0.045	29.0	_____
20ÝJul,Ý1996	0.005	25.6	_____
11-13 Jul,Ý1997	0.02	25.8	_____
11ÝAug,Ý1998	0.01	26.6	_____
29ÝJun,Ý1999	0.007	24.8	_____
28ÝJul,Ý2000	0.000	24.4	_____

Sea surface temperature (SST) is measured by satellites carrying the Advanced Very High Resolution Radiometer (AVHRR), which measures infrared radiation from Earth's surface in six spectral ranges. AVHRR data have been provided in Table 1.

The U.S. Geological Survey provides access to water data from approximately 1.5 million sites throughout the United States through the National Water Information System (NWIS). To obtain water discharge data for the Susquehanna River:

1. Point your internet browser to NWIS Web page at *http://nwis.waterdata.usgs.gov/nwis* to open the "NWISWeb Data for the Nation" page. Click on the "Surface water" button under "Data

Category" to open the "Surface-Water Data for the Nation" page.

2. Under "Statistics," click on "Monthly" which will open the Monthly Stream-flow Statistics page. There are many ways to specify sites for which data are to be retrieved, but in this case it is simplest to use the number of the USGS monitoring station on the Susquehanna River at Conowingo, MD. Under "Site Selection Criteria," locate the "Site Identifier: column and click on the box next to "Site Number." Click "Submit." This will open the "Surface-Water Monthly Statistics for the Nation" page.

3. Enter "01578310" in the box under "Site Number," then scroll down to the bottom of the page and click "Submit." Click on "01578310" in the table. A new page will open listing data that are available for USGS Station 01578310, Susquehanna River at Conowingo, MD. Click on the station number and another page will open. Click the box next to "Discharge, cubic feet per second," then scroll down to the bottom of the page and click "Submit." A new page will open with a table listing the mean monthly discharge in cubic feet per second beginning in October, 1967.

Compute the average monthly discharges from January through June for each of the sample years (1987-1990 and 1995-2000). Use these data to fill in the stream-flow discharge column in Table 1. Plot the data in Table 1. You will have to use three different scales for the y-axis since values for abundance, temperature, and river discharge differ by several orders of magnitude. What conditions appear to correlate with higher abundance of *Chrysaora quinquecirrha*?

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APPENDIX A

Jellyfish in Chesapeake Bay and Nearby Waters

by Dr. Jennifer E. Purcell, PhD
Resident Scientist
Shannon Point Marine Center, Western Washington University

What types of jellyfish occur here?

In the summertime in ocean waters, for example, off Ocean City, two types of large jellyfish often occur. The Moon Jelly (*Aurelia aurita*) is a clear, flattened disk, with numerous small tentacles around the edge, and a pink four-leaf clover design in the middle. This species has a very mild sting and poses no threat to swimmers. The Lion's Mane jellyfish (*Cyanea capillata*) is brown in color, and has longer tentacles hanging from the edge of its swimming disk and from the middle. This species has a potent sting, and while it is not dangerous to swimmers, it is very unpleasant to encounter. Some other jellyfish are seen less often in the coastal waters. In the autumn, the Mushroom Cap Jellyfish (*Rhopilema verrilli*) may enter the Bay. It has a deep swimming bell without tentacles, and is creamy white with darker markings on the sturdy central tentacle structures. The Cabbage Head or Cannonball Jellyfish (*Stomolophus meleaqris*) is like a white softball, or larger, and has a short, hard tentacle structure in the middle. Neither of these jellyfish sting swimmers. The Portuguese man of war (*Physalia physalis*) very seldom is seen off beaches north of Cape Hatteras. It is a relative of jellyfish that floats at the water's surface by means of a gas-filled blue float. Beneath the float are extremely long tentacles which have a powerful sting. They should be avoided by swimmers, because a serious sting would cause extreme pain, and could result in hospitalization. The Moon Jelly also occurs in southern Chesapeake Bay during the summer. The Lion's Mane, or Winter Jellyfish, is found in Chesapeake Bay during the winter (January-April). The jellyfish for which Chesapeake Bay is widely known in the summer is the Sea Nettle (*Chrysaora quinquecirrha*). It occurs from Cape Cod south along the U.S. East Coast, Caribbean and Gulf of Mexico, yet it abounds in Chesapeake Bay in numbers unequaled elsewhere. It occurs most abundantly in the tributaries of the middle Bay (salinities 10-20 ppt), where it is white in color. In the southern Bay, it often has red/maroon markings on the long central tentacles and on the swimming bell. It has an annoying sting, but is not dangerous to swimmers.

Jellyfish stings: How to prevent them and how to treat them

Lightweight protective clothing, like a lycra “swim skin” or panty hose, or a layer of petroleum jelly spread on unprotected skin, will protect a swimmers against stings. If you are stung by a jellyfish, liberally sprinkling a meat tenderizer or baking soda (or vinegar for *Physalia*) on the sting may reduce the irritation. Severe allergic reactions (anaphylaxis) are uncommon to jellyfish in U.S. waters, but emergency treatment is essential in such cases.

Where do the sea nettles come from each year?

The swimming jellyfish are either male or female. They produce eggs or sperm, which are shed daily into the water during the summer. Fertilized eggs form larvae that attach to hard surfaces, like oyster shells, and grow into tiny polyps. The bottom-dwelling polyps live through the winter in a dormant state. During May through August, the polyps bud off tiny sea nettles about 1/25 of an inch in diameter, that grow rapidly into the visible jellyfish.

How do sea nettles feed and what do they eat?

Sea nettles capture prey that contact the tentacles trailing behind the swimming bell. These tentacles have millions of microscopic stinging cells that inject toxins to stun or kill tiny animals, and which are responsible for the stings swimmers feel. The prey are transported up the central tentacles to the heart-shaped gastric pouches in the swimming bell where digestion occurs. Jellyfish are prodigious predators because they swim and feed continuously. They do not have eyes, and so do not need light to feed. They feed without interruption because the many tentacles function independently of the others. The tentacles provide a very large surface area for prey capture. Sea nettles feed mostly on microscopic crustaceans called copepods that are very abundant in Bay waters. They also eat young minnows, bay anchovy eggs, worms, mosquito larvae, and comb jellies, so they would seldom be without something to eat.

Why are there so many sea nettles in Chesapeake Bay?

Sea nettles are made up mostly of water and salts, with organic materials totaling only about 0.2kg of their entire live weight. For this reason, very little food can provide enough organic materials to result in a lot of growth. The jellyfish can get bigger very rapidly, and the amount of food they catch increases directly with their increasing size. Sea nettles are geared for high reproduction. They begin producing eggs when the swimming bell is only about 1 1/2 inches in diameter. The number of eggs increases tremendously as they grow, with a nettle about 4 inches in diameter shedding about 40,000 eggs into the water daily. The polyps can bud to produce more polyps. Each polyp produces up to 45 jellyfish each summer. The Sea Nettle is unusual in its ability to live in water of low salinity (salt content). Most jellyfish species live at ocean water salinity, about 35 ppt (35 parts salt to 965 parts water). The Sea Nettle prefers waters having as little as 12 ppt salinity, and may have estuaries like Chesapeake Bay, to itself without serious competition from most other jellyfish. In fact, sea nettles eat their most abundant competitors in the Bay, the comb jellies. Populations of plants and animals often are controlled by other organisms that feed on them. However, adult sea nettles may have few natural predators in the middle reaches of Chesapeake Bay. Sea turtles, which are known to eat Portuguese men-of-war and some other jellyfish, rarely come far into the Bay. And fish species (harvestfish, butterfish) observed feeding on sea nettles prefer waters of higher salinity.

Are there more sea nettles now than in earlier years?

It is possible that the changes in Chesapeake Bay caused by human activities have led to larger populations of the Sea Nettle in recent times. The waters of the Bay have been enriched with organic materials and nutrients from waste products and fertilizers due to heavy human settlement around the Bay. This kind of enrichment can change the species of microscopic plants suspended in the waters from large to small types. The small plants are more suitable as food for small grazers (copepods), which in turn are more suitable for predators like jellyfish, and less suitable for visual predators like fishes. Dr. Roger Newell proposed that removal of most of the oysters that were once so abundant in the Bay also may leave much uneaten plant material suspended in the water to be consumed by copepods, which in turn could be used by jellyfish and increase their populations. Unfortunately, no early records document the abundance of the Sea Nettle before Man began to seriously change Chesapeake Bay, so there is little with which to compare the present abundance. Mr. David Cargo kept daily records of the numbers of sea nettles at the Chesapeake Biological Laboratory in Solomons, MD for nearly 30 years. He found great annual variation in jellyfish numbers: more occurred in dry years than in rainy years, but no overall increase in abundance was

apparent. Such records would need to go back more than 100 years to reveal if human-caused changes in the Bay have affected the abundance of sea nettles.

Is it possible to reduce the numbers of jellyfish?

A lot of effort was spent on jellyfish control in the 1960s, but no method has been very successful. Nets and bubble screens were used to keep them away from swimming areas. The jellyfish tended to clog the nets and to break into pieces that continued to sting. The bottom-living polyp stage also was targeted. Chemicals that killed the polyps also killed many other organisms, and so were unsuitable. A small species of sea slug was found that ate the polyps, but culture methods to produce large numbers of the sea slugs were unsuccessful, and they did not live well at the low salinities favored by the polyps. So far, the greatest reduction of the jellyfish populations occurred after Hurricane Agnes in 1972, but this method of control cannot be recommended.

Can anything good be said about sea nettles?

Research in my laboratory has shown that sea nettles may help oysters. Oysters have a larval stage that spends about two weeks swimming in the Bay before they settle to grow into large oysters. During this swimming stage, they are vulnerable to predators such as sea nettles and comb jellies. Although sea nettles can catch the larval oysters, they spit them out undigested and unharmed. In contrast, comb jellies catch and digest the larvae readily. Comb jellies are a favorite food of sea nettles, and they reduce comb jelly populations to zero in the tributaries during the summer when oyster larvae are most abundant. Therefore, sea nettles appear to protect oyster larvae from a major predator.

What recent research is there on Sea Nettles?

In my laboratory, we have been working to determine the importance of sea nettles as predators of copepods. This is of interest because if sea nettles reduce copepod populations, then less food would be available for planktivorous fish, for example bay anchovy and menhaden, which then are food for piscivorous fish like striped bass and bluefish. We have found that sea nettles eat at most 5% of the copepods daily in mid Chesapeake Bay, which is small compared with the growth rate of the copepod population. In the tributaries, however, Sea Nettles can consume 50-90% of the copepods daily, and copepod abundances seem to decline over the summer, possibly due to this predation. Sea Nettles consume up to 50% daily of the bay anchovy eggs and larvae during the peak spawning in July. This research was in collaboration with Dr. Ed Houde of the Chesapeake Biological Laboratory. We also are studying which environmental factors have the greatest effects on the population size of sea nettles. We have done experiments to measure the numbers of sea nettles produced by polyps, and the survival and growth of the baby jellyfish at various combinations of salinity, temperature, and food concentrations. Few sea nettles are produced at low salinities (< 7 ppt) or at high salinities (> 25 ppt). I am beginning a large-scale project to map the distributions of jellies throughout Chesapeake Bay in April, July, and October. In collaboration with several other scientists, I will examine environmental and biological (e.g. food) factors that may determine the distribution and abundance of jellies in the Bay.

(top)

The Stinging Sea

Student Worksheet - Ecological Forecasting of Sea Nettle Abundance Worksheet

Part I – Subject Review

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1. Where are the greatest numbers of sea nettles found?
2. The moon jelly, *Aurelia aurita*, is also common in the Chesapeake Bay during the summer. Does this species poses a stinging threat to humans similar to that of the sea nettle?
3. How can sea nettle stings be prevented? How should they be treated?
4. Where do sea nettles go during the winter?
5. What do sea nettles eat?
6. How do sea nettles capture their food?
7. Can sea nettles feed at night?
8. Sea nettles can grow rapidly with very little food. Why?
9. What are three aspects of sea nettles' life history that makes this species "geared for high reproduction"?
10. What ecological preference of sea nettles is unusual when compared to most other jellyfishes?
11. How do sea nettles deal with competition and predation from other species?
12. How may human activities have increased the numbers of sea nettles in the Chesapeake Bay?
13. Review examples of ecological forecasting projects at *http://oceanservice.noaa.gov/topics/coasts/ecoforecasting*, and describe three of these projects.

Part II – The Foundation for Ecological Forecasts of Sea Nettle Abundance

The mathematical model that is used to make ecological forecasts of sea nettle abundance in Chesapeake Bay was developed from data collected during 1987-2000 on *Chrysaora quinquecirrha* abundance, temperature, salinity, and depth. Forecasters use satellite data to obtain real-time estimates of sea surface temperature. Another mathematical model that describes water circulation in the Chesapeake Bay is used to estimate salinity distribution in various parts of the Bay. Because salinity is strongly influenced by freshwater input from major rivers, variations in the discharge rates of these rivers correlate closely with salinity changes in the Bay. In this exercise, you will use online databases to obtain information on sea surface temperature and river discharge for comparison with data on abundance in samples collected during summer months from 1987-2000.

Abundance data were obtained by towing plankton nets (1 m diameter, 1.6 mm mesh) equipped with a flowmeter. The volume of water filtered by the nets ranged from 60 m^3 to 160 m^3. Captured jellyfish were separated and counted by hand. Table 1 summarizes Chrysaora quinquecirrha abundances determined by this method.

Table 1. Chrysaora quinquecirrha Abundance in Chesapeake Bay 1987 – 2000

Date	*Chrysaora quinquecirrha* Abundance (Individuals/m^3)	Average Temperature for Sample Month (°C)	Susquehanna River Average Monthly ($ft3^3$/sec)
7 Jul,1987	0.10	27	_____
28 Jul, 1988	0.05	27	_____
28 Jun, 1989	0.04	26.5	_____
15 Aug, 1990	0.13	27	_____
27 Jul, 1995	0.045	29.0	_____
20 Jul, 1996	0.005	25.6	_____
11-13 Jul, 1997	0.02	25.8	_____
11 Aug, 1998	0.01	26.6	_____
29 Jun, 1999	0.007	24.8	_____
28 Jul, 2000	0.000	24.4	_____

Sea surface temperature (SST) is measured by satellites carrying the Advanced Very High Resolution Radiometer (AVHRR), which measures infrared radiation from Earth's surface in six spectral ranges. AVHRR data have been provided in Table 1.

The U.S. Geological Survey provides access to water data from approximately 1.5 million sites throughout the United States through the National Water Information System (NWIS). To obtain water discharge data for the Susquehanna River:

1. Point your internet browser to NWIS Web page at *http://nwis.waterdata.usgs.gov/nwis* to open the "NWISWeb Data for the Nation" page. Click on the "Surface water" button under "Data Category" to open the "Surface-Water Data for the Nation" page.

2. Under "Statistics," click on "Monthly" which will open the Monthly Stream-flow Statistics page. There are many ways to specify sites for which data are to be retrieved, but in this case it is simplest to use the number of the USGS monitoring station on the Susquehanna River at Conowingo, MD. Under "Site Selection Criteria," locate the "Site Identifier: column and click on the box next to "Site Number." Click "Submit." This will open the "Surface-Water Monthly Statistics for the Nation" page.

3. Enter "01578310" in the box under "Site Number," then scroll down to the bottom of the page and click "Submit." Click on "01578310" in the table. A new page will open listing data that are available for USGS Station 01578310, Susquehanna River at Conowingo, MD. Click on the station number and another page will open. Click the box next to "Discharge, cubic feet per second," then scroll down to the bottom of the page and click "Submit." A new page will open with a table listing the mean monthly discharge in cubic feet per second beginning in October, 1967.

Compute the average monthly discharges from January through June for each of the sample years (1987-1990 and 1995-2000). Use these data to fill in the stream-flow discharge column in Table 1. Plot the data in Table 1. You will have to use three different scales for the y-axis since values for abundance, temperature, and river discharge differ by several orders of magnitude. What conditions appear to correlate with higher abundance of *Chrysaora quinquecirrha*?

APPENDIX A

Jellyfish in Chesapeake Bay and Nearby Waters

by Dr. Jennifer E. Purcell, PhD
Resident Scientist
Shannon Point Marine Center, Western Washington University

What types of jellyfish occur here?

In the summertime in ocean waters, for example, off Ocean City, two types of large jellyfish often occur. The Moon Jelly (Aurelia aurita) is a clear, flattened disk, with numerous small tentacles around the edge, and a pink four-leaf clover design in the middle. This species has a very mild sting and poses no threat to swimmers. The Lion's Mane jellyfish (Cyanea capillata) is brown in color, and has longer tentacles hanging from the edge of its swimming disk and from the middle. This species has a potent sting, and while it is not dangerous to swimmers, it is very unpleasant to encounter. Some other jellyfish are seen less often in the coastal waters. In the autumn, the Mushroom Cap Jellyfish (Rhopilema verrilli) may enter the Bay. It has a deep swimming bell without tentacles, and is creamy white with darker markings on the sturdy central tentacle structures. The Cabbage Head or Cannonball Jellyfish (Stomolophus meleaqris) is like a white softball, or larger, and has a short, hard tentacle structure in the middle. Neither of these jellyfish sting swimmers. The Portuguese man of war (Physalia physalis) very seldom is seen off beaches north of Cape Hatteras. It is a relative of jellyfish that floats at the water's surface by means of a gas-filled blue float. Beneath the float are extremely long tentacles which have a powerful sting. They should be avoided by swimmers, because a serious sting would cause extreme pain, and could result in hospitalization. The Moon Jelly also occurs in southern Chesapeake Bay during the summer. The Lion's Mane, or Winter Jellyfish, is found in Chesapeake Bay during the winter (January-April). The jellyfish for which Chesapeake Bay is widely known in the summer is the Sea Nettle (Chrysaora quinquecirrha). It occurs from Cape Cod south along the U.S. East Coast, Caribbean and Gulf of Mexico, yet it abounds in Chesapeake Bay in numbers unequaled elsewhere. It occurs most abundantly in the tributaries of the middle Bay (salinities 10-20 ppt), where it is white in color. In the southern Bay, it often has red/maroon markings on the long central tentacles and on the swimming bell. It has an annoying sting, but is not dangerous to swimmers.
Jellyfish stings: How to prevent them and how to treat them

Lightweight protective clothing, like a lycra "swim skin" or panty hose, or a layer of petroleum jelly spread on unprotected skin, will protect a swimmers against stings. If you are stung by a jellyfish, liberally sprinkling a meat tenderizer or baking soda (or vinegar for Physalia) on the sting may reduce the irritation. Severe allergic reactions (anaphylaxis) are uncommon to jellyfish in U.S. waters, but emergency treatment is essential in such cases.

Where do the sea nettles come from each year?

The swimming jellyfish are either male or female. They produce eggs or sperm, which are shed daily into the water during the summer. Fertilized eggs form larvae that attach to hard surfaces, like oyster shells, and grow into tiny polyps. The bottom-dwelling polyps live through the winter in a dormant state. During May through August, the polyps bud off tiny sea nettles about 1/25 of an inch in diameter, that grow rapidly into the visible jellyfish.

How do sea nettles feed and what do they eat?

Sea nettles capture prey that contact the tentacles trailing behind the swimming bell. These tentacles have millions of microscopic stinging cells that inject toxins to stun or kill tiny animals, and which are responsible for the stings swimmers feel. The prey are transported up the central tentacles to the heart-shaped gastric pouches in the swimming bell where digestion occurs. Jellyfish are prodigious predators because they swim and feed continuously. They do not have eyes, and so

do not need light to feed. They feed without interruption because the many tentacles function independently of the others. The tentacles provide a very large surface area for prey capture. Sea nettles feed mostly on microscopic crustaceans called copepods that are very abundant in Bay waters. They also eat young minnows, bay anchovy eggs, worms, mosquito larvae, and comb jellies, so they would seldom be without something to eat.
Why are there so many sea nettles in Chesapeake Bay?

Sea nettles are made up mostly of water and salts, with organic materials totaling only about 0.2kg of their entire live weight. For this reason, very little food can provide enough organic materials to result in a lot of growth. The jellyfish can get bigger very rapidly, and the amount of food they catch increases directly with their increasing size. Sea nettles are geared for high reproduction. They begin producing eggs when the swimming bell is only about 1 1/2 inches in diameter. The number of eggs increases tremendously as they grow, with a nettle about 4 inches in diameter shedding about 40,000 eggs into the water daily. The polyps can bud to produce more polyps. Each polyp produces up to 45 jellyfish each summer. The Sea Nettle is unusual in its ability to live in water of low salinity (salt content). Most jellyfish species live at ocean water salinity, about 35 ppt (35 parts salt to 965 parts water). The Sea Nettle prefers waters having as little as 12 ppt salinity, and may have estuaries like Chesapeake Bay, to itself without serious competition from most other jellyfish. In fact, sea nettles eat their most abundant competitors in the Bay, the comb jellies. Populations of plants and animals often are controlled by other organisms that feed on them. However, adult sea nettles may have few natural predators in the middle reaches of Chesapeake Bay. Sea turtles, which are known to eat Portuguese men-of-war and some other jellyfish, rarely come far into the Bay. And fish species (harvestfish, butterfish) observed feeding on sea nettles prefer waters of higher salinity.
Are there more sea nettles now than in earlier years?

It is possible that the changes in Chesapeake Bay caused by human activities have led to larger populations of the Sea Nettle in recent times. The waters of the Bay have been enriched with organic materials and nutrients from waste products and fertilizers due to heavy human settlement around the Bay. This kind of enrichment can change the species of microscopic plants suspended in the waters from large to small types. The small plants are more suitable as food for small grazers (copepods), which in turn are more suitable for predators like jellyfish, and less suitable for visual predators like fishes. Dr. Roger Newell proposed that removal of most of the oysters that were once so abundant in the Bay also may leave much uneaten plant material suspended in the water to be consumed by copepods, which in turn could be used by jellyfish and increase their populations. Unfortunately, no early records document the abundance of the Sea Nettle before Man began to seriously change Chesapeake Bay, so there is little with which to compare the present abundance. Mr. David Cargo kept daily records of the numbers of sea nettles at the Chesapeake Biological Laboratory in Solomons, MD for nearly 30 years. He found great annual variation in jellyfish numbers: more occurred in dry years than in rainy years, but no overall increase in abundance was apparent. Such records would need to go back more than 100 years to reveal if human-caused changes in the Bay have affected the abundance of sea nettles.

Is it possible to reduce the numbers of jellyfish?

A lot of effort was spent on jellyfish control in the 1960s, but no method has been very successful. Nets and bubble screens were used to keep them away from swimming areas. The jellyfish tended to clog the nets and to break into pieces that continued to sting. The bottom-living polyp stage also was targeted. Chemicals that killed the polyps also killed many other organisms, and so were unsuitable. A small species of sea slug was found that ate the polyps, but culture methods to produce large numbers of the sea slugs were unsuccessful, and they did not live well at the low salinities favored by the polyps. So far, the greatest reduction of the jellyfish populations occurred after Hurricane Agnes in 1972, but this method of control cannot be recommended.

Can anything good be said about sea nettles?

Research in my laboratory has shown that sea nettles may help oysters. Oysters have a larval stage that spends about two weeks swimming in the Bay before they settle to grow into large oysters. During this swimming stage, they are vulnerable to predators such as sea nettles and comb jellies. Although sea nettles can catch the larval oysters, they spit them out undigested and unharmed. In contrast, comb jellies catch and digest the larvae readily. Comb jellies are a favorite food of sea nettles, and they reduce comb jelly populations to zero in the tributaries during the summer when

oyster larvae are most abundant. Therefore, sea nettles appear to protect oyster larvae from a major predator.

What recent research is there on Sea Nettles?

In my laboratory, we have been working to determine the importance of sea nettles as predators of copepods. This is of interest because if sea nettles reduce copepod populations, then less food would be available for planktivorous fish, for example bay anchovy and menhaden, which then are food for piscivorous fish like striped bass and bluefish. We have found that sea nettles eat at most 5% of the copepods daily in mid Chesapeake Bay, which is small compared with the growth rate of the copepod population. In the tributaries, however, Sea Nettles can consume 50-90% of the copepods daily, and copepod abundances seem to decline over the summer, possibly due to this predation. Sea Nettles consume up to 50% daily of the bay anchovy eggs and larvae during the peak spawning in July. This research was in collaboration with Dr. Ed Houde of the Chesapeake Biological Laboratory. We also are studying which environmental factors have the greatest effects on the population size of sea nettles. We have done experiments to measure the numbers of sea nettles produced by polyps, and the survival and growth of the baby jellyfish at various combinations of salinity, temperature, and food concentrations. Few sea nettles are produced at low salinities (< 7 ppt) or at high salinities (> 25 ppt). I am beginning a large-scale project to map the distributions of jellies throughout Chesapeake Bay in April, July, and October. In collaboration with several other scientists, I will examine environmental and biological (e.g. food) factors that may determine the distribution and abundance of jellies in the Bay.

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Do You Want to Risk It?

Hurricanes / Grades 9-12 / Earth Science, Physical Science

- Background Information
- Learning Procedure
- The Bridge Connection
- The "Me" Connection
- Extensions
- Resources
- National Science Education Standards
- Ocean Literacy Essential Principles and Fundamental Concepts

Focus Question

How can coastal residents plan for the potential effects of natural hazards?

Learning Objectives

1. Students will define, compare and contrast the terms “risk” and “vulnerability.”
2. Students will determine the history of natural disaster events for a given county.
3. Students will discuss the relative risk from natural hazard events for selected counties based on the history of such events.
4. Students will discuss the impact of population increase on risk from natural hazards.
5. Students will use a geographic information system to investigate storm-related risks to specific facilities in a given community

Links to Overview Essays and Resources Useful for Student Research

http://oceanservice.noaa.gov/topics/coasts/assessment/
http://www.csc.noaa.gov/rvat/hazid.html

Materials

- Copies of “ Student Worksheet: Coastal Hazards Vulnerability Assessment,” found at the bottom of this lesson plan, one copy for each student group. Click here for a printable copy of the worksheet.
- Copies of "Table 1: Numeric Scales Used to Describe Risk from Storm-Related Hazards," found at the bottom of this lesson plan, one copy for each student group. Click here for a printable copy of Table 1.
- (optional) Computers with Internet access; if students do not have access to the Internet, download copies of materials cited under “Learning Procedure” and provide copies of these materials to each student group

Audio/Visual Materials

None

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Groups of 4-6 students

Maximum Number of Students

30

Key Words

Natural hazard
Hurricane
Risk
Vulnerability

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Background Information

Almost half of the people living in the United States live near the coast and the numbers are increasing. As the coastal population continues to grow, more people and property are exposed to hazards caused by hurricanes, tsunamis, shoreline erosion and other natural hazards. Homes and businesses are often built in low-lying areas and on barrier islands that are particularly vulnerable to these hazards. The potentially disastrous consequences of this trend became obvious during the summer of 2004 when residents of Florida were battered by four major hurricanes within six weeks, resulting in billions of dollars' worth of damage. Similar consequences made global headlines in August of 2005 when Hurricane Katrina wrought havoc on Gulf Coast communities in Alabama, Louisiana, and Mississippi. Much of the cost of these events is eventually borne by American taxpayers through federal government funds for for disaster relief and reconstruction.

These disasters emphasize the importance finding more effective ways to reduce the negative environmental, social, and economic impacts of natural hazards on coastal communities. To assist these efforts, NOAA's National Ocean Service provides essential information on natural hazards to government agencies and members of the general public concerned with lowering the risks associated with natural hazards. This information includes training, methods for assessing vulnerability to natural hazards, and tools that can be used to forecast threats such as floods and harmful algal blooms.

In the wake of catastrophic storms in 2004 and 2005, NOAA is spearheading a nationwide effort to lessen the impacts of such storms on coastal communities. This Coastal Storms Initiative (CSI) includes nine pilot projects to develop new ways to forecast coastal storms and new strategies to reduce their impacts. While the efforts are focused on specific regions of the country, the results are helping all coastal communities improve their ability to prepare for the inevitable coastal storm. The Risk and Vulnerability Assessment Tool (RVAT) is a CSI project that involves the development of an online tool for identifying risks and vulnerabilities to coastal storms in Brevard and Volusia Counties, Florida. This information can help communities in these counties create effective ways to reduce storm-related hazards and impacts, and provides the basis for developing similar tools for other communities.

In this lesson, students will use some of NOAA's online resources to make gather information about the vulnerability of coastal communities to storm hazards.

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Learning Procedure

1. To prepare for this lesson:

- Review information on the NOS Natural Hazards Assessment program (*http://oceanservice.noaa.gov/topics/coasts/assessment/*), as well as the process described on

the “Student Worksheet: Coastal Hazards Vulnerability Assessment Worksheet” found at the end of this lesson plan.

- Make copies of the “Student Worksheet: Coastal Hazards Vulnerability Assessment Worksheet.”
- Make copies of "Table 1: Numeric Scales Used to Describe Risk from Storm-Related Hazards."
- If students do not have Internet access, download information for the selected coastal communities as described on the Worksheet.

2. Briefly review the issue of coastal hazards. You may want to show some headlines from the 2004 and 2005 hurricanes in Florida and the U.S. Gulf Coast (your school or community library probably has back issues of weekly news magazines that could be used for this). Discuss the types of natural hazards that may pose a risk to coastal communities. The list should include hurricanes, floods, tsunamis, and earthquakes. Be sure students understand that increasing population in coastal communities means that an increasing number of people and their property are potentially threatened by these hazards.

   Some of sources may refer to the “100-year flood plain.” Storms are sometimes characterized by how often a storm having a specific severity is expected to occur. A “100-year storm” would be a storm having a severity that is expected to occur only once every 100 years (in other words, an extremely severe storm). So, a “100-year flood plain” represents the area that would be flooded by a storm having this severity.

   Discuss the concepts of “risk” and “vulnerability.” “Risk” is generally used as a measure of the likelihood of being exposed to a particular hazard. “Risk areas” are geographic regions that have a certain probability of being exposed to a given hazard. People and resources located within risk areas are considered to be “at risk” from this hazard. “Vulnerability” is a measure of the likelihood that people and/or resources will be negatively impacted by a given hazard. So, people living in a coastal community might all be at risk of being exposed to a hurricane, but their vulnerability to negative impacts could vary significantly depending upon the extent to which they were prepared to cope with this risk.

3. Tell students that their assignment is to obtain information about natural hazards that may pose a risk to a specific coastal community, and to make inferences about the relative risk of that community compared to other communities. Distribute copies of the “Coastal Hazards Vulnerability Assessment Worksheet” to each student group. Assign each group one of the following pairs of counties (the search address is to be used in Part 2 of the Student Worksheet):

- Harrison County, MS and Brevard County, FL (search address: 5000 N. West Ave., zip: 32927)
- Charleston County, SC and Volusia County, FL (search address: 367 Plaza Blvd, zip: 32188)
- Mobile County AL and Brevard County, FL (search address: 1450 Minutemen Causeway, zip: 32931)
- Plaquemines Parish, LA and Volusia County, FL (search address: 300 Mission Drive, zip: 32168)
- Bay County, FL and Brevard County, FL (search address: 500 First St, zip: 32949)
- New Hanover County, NC and Volusia County, FL (search address: 20 Seabridge Drive, zip: 32176)

4. Have each group present an oral summary of their results. When all groups have presented results for their assigned communities, each student or student group should prepare a written statement about the relative risk of their assigned counties. Lead a discussion of students’ data and inferences. The following points should be included:

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Harrison County, MS:

- Hurricanes category 3 or stronger since 1970: category 3 1979; category 3 1985; category 3 2004
- Trend in frequency of hazard events: major hurricane every 6-9 years since 1970
- Population trend since 1970: increasing; about 135,000 to 188,000 during this period

Charleston County, SC

- Hurricanes category 3 or stronger since 1970: Hurricane Hugo, category 4 1989
- Trend in frequency of hazard events: none evident
- Population trend since 1970: increasing; about 245,000 to 310,000 during this period

Mobile County, AL

- Hurricanes category 3 or stronger since 1970: category 3 1979; category 3 1985; category 3 1995; category 3 2004
- Trend in frequency of hazard events: major hurricane every 6-10 years since 1970
- Population trend since 1970: increasing; about 315,000 to 395,000 during this period

Plaquemines Parish, LA

- Hurricanes category 3 or stronger since 1970: category 3 1992; category 3 2005
- Trend in frequency of hazard events: none evident
- Population trend since 1970: slowly increasing, about 25,000 to 26,500 during this period

Bay County, FL

- Hurricanes category 3 or stronger since 1970: category 3 1975; category 3 1995
- Trend in frequency of hazard events: none evident
- Population trend since 1970: increasing, about 74,000 to 147,000 during this period

New Hanover County, NC

- Hurricanes category 3 or stronger since 1970: category 3 1996
- Trend in frequency of hazard events: none evident
- Population trend since 1970: increasing, about 80,000 to 160,000 during this period

Brevard County, FL

- Hurricanes category 3 or stronger since 1970: category 3 1998; category 3 2004
- Trend in frequency of hazard events: two major hurricanes since 1998
- Population trend since 1970: increasing, more than 200,000 (about double) during this period

Volusia County, FL

- Hurricanes category 3 or stronger since 1970: none
- Trend in frequency of hazard events: none evident
- Population trend since 1970: increasing, about 270,000 (more than double) during this period

Ask students which of these counties faces the greatest risk from the natural hazards listed on the worksheet. Harrison, and Mobile Counties have experienced three major hurricanes since 1970. Mobile County has a much larger population, which might suggest that of the six communities investigated, Mobile is at greatest risk from the natural hazards considered. It is worth noting, however, that the populations of New Hanover, Bay, Brevard, and Volusia Counties doubled since 1970; a trend that means increasing numbers of people are at risk from natural hazards.

It is also worth noting that Plaquemines Parish (which includes New Orleans) had the smallest population of the six communities investigated as well as the smallest rate of population increase (only about 6% since 1970). The experience of Hurricane Katrina shows that a scarcity of hurricanes over a 35-year period does not necessarily serve as a reliable indicator of future events. In this case, “it only takes one.”

From the exercises using the Risk and Vulnerability Assessment Tool, students should realize that risk and vulnerability can be defined at a much finer scale than county-wide, but this also involves

managing very large volumes of information. A geographic information system (which is the basis for the RVAT) can be an effective way to accomplish this task and can make it relatively easy for non-experts to retrieve and interpret relevant information.

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Answers to questions related to specific search addresses should include:

5000 N. West Ave., Brevard County, FL 32927

- Critical facilities within 0.5 mile radius: Lil Champ Store Sewage Plant; FPL Cape Canaveral Sewage Plant; Tower
- Facility within 0.5 mile with highest Composite Risk: FPL Cape Canaveral Sewage Plant
- Numeric storm-related risks for this facility: Flood: 6.8 Wind: 8 Surge: 4 Erosion: 0 Combined: 18.8
- Natural Hazard Summary Risk on land immediately adjacent to this facility: Moderately-High
- Land uses or land cover are found within a 0.5 mile radius of this facility: Urban, Range Land

367 Plaza Blvd, Volusia County, FL 32188

- Critical facilities within 0.5 mile radius: Seabreeze High School; Bel-Aire House; Two Aviation Towers
- Facility within 0.5 mile with highest Composite Risk: Aviation Tower
- Numeric storm-related risks for this facility: Flood: 5.1 Wind: 8 Surge: 2 Erosion: 3.3 Combined: 18.4
- Natural Hazard Summary Risk on land immediately adjacent to this facility: Moderate & Moderately-Low
- Land uses or land cover are found within a 0.5 mile radius of this facility: Urban

1450 Minutemen Causeway, Brevard County, FL 32931

- Critical facilities within 0.5 mile radius: Theodore Roosevelt K-8; Cocoa Beach High School; City of Cocoa Beach Water Reclamation Facility; Cocoa Beach Sewage Plant; Cocoa Beach Municipal Pool
- Facility within 0.5 mile with highest Composite Risk: Theodore Roosevelt K-8
- Numeric storm-related risks for this facility: Flood: 6.8 Wind: 8 Surge: 4 Erosion: 0 Combined: 18.8
- Natural Hazard Summary Risk on land immediately adjacent to this facility: Moderate and Moderately-High
- Land uses or land cover are found within a 0.5 mile radius of this facility: Urban, Wetland

300 Mission Drive, Volusia County, FL 32168

- Critical facilities within 0.5 mile radius: Eagle's Wings Roy's Ranch; New Smyrna Retirement Center; Sugarlake Retirement Home; Sugar Mill Ruins Travel Park
- Facility within 0.5 mile with highest Composite Risk: Sugar Mill Ruins Travel Park
- Numeric storm-related risks for this facility: Flood: 6.8 Wind: 8 Surge: 4 Erosion: 0 Combined: 18.8
- Natural Hazard Summary Risk on land immediately adjacent to this facility:
- Land uses or land cover are found within a 0.5 mile radius of this facility:

500 First St, Brevard County, FL 32949

- Critical facilities within 0.5 mile radius: Shellfish Inc. Sewage Plant; Hudgins Fish Farm Sewage Plant; Brevard County Fire Station; Tower
- Facility within 0.5 mile with highest Composite Risk: Shellfish Inc. Sewage Plant and Hudgins Fish Farm Sewage Plant
- Numeric storm-related risks for this facility: Flood: 6.8 Wind: 8 Surge: 4 Erosion: 0 Combined: 18.8
- Natural Hazard Summary Risk on land immediately adjacent to this facility: Moderate and Moderately-High
- Land uses or land cover are found within a 0.5 mile radius of this facility: Range Land, Forest, Urban, Wetland

20 Seabridge Drive, Volusia County, FL 32176

- Critical facilities within 0.5 mile radius: Kingston Shores Condos; Kingston Shores Condos Sewage Plant; North Peninsula Utilities; Bethesda Manor; Seabridge Waste Treatment Plant
- Facility within 0.5 mile with highest Composite Risk: Bethesda Manor
- Numeric storm-related risks for this facility: Flood: 6.8 Wind: 8 Surge: 4 Erosion: 0 Combined: 18.8
- Natural Hazard Summary Risk on land immediately adjacent to this facility: Moderately-High
- Land uses or land cover are found within a 0.5 mile radius of this facility: Urban, Forest, Wetland, Barren Land

Ask students to discuss what measures could be taken to reduce vulnerability to natural hazards. You may want to have students research appropriate preparation and response for selected hazards, particularly if students' own communities are at risk from one or more of these hazards.

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The Bridge Connection

The Bridge is a growing collection online marine education resources. It provides educators with a convenient source of useful information on global, national, and regional marine science topics. Educators and scientists review sites selected for the Bridge to insure that they are accurate and current.

http://www.vims.edu/bridge/ - In the "Site Navigation" menu on the left, click on "Ocean Science Topics," then "Atmosphere," for links to information and activities related to a variety of coastal hazards including flooding, erosion, hurricanes, and tsunamis.

The "Me" Connection

Have students write a brief essay describing the extent to which potential risk from natural hazards might influence their choice of a community in which to live, and which natural hazards they consider to be most dangerous to residents.

Extensions

1. Use information on risk and vulnerability assessments (RVAs) at *http://www.csc.noaa.gov/rvat/hazid.html* to develop a detailed RVA for a selected community.

2. Have students research what might be done to reduce vulnerability to selected natural hazards.

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Resources

http://www.educationworld.com/a_lesson/lesson/lesson015.shtml – Education World article with ideas and Web links for hurricane-related classroom activities.

http://www.miamisci.org/hurricane/index.html — Miami Museum of Science Web page, "Hurricane: Storm Science," including how storms happen, how storms are tracked, and how to make a weather station.

http://www.cln.org/themes/hurricanes.html – The Community Learning Network's Hurricanes Theme Page with links to curricular resources and instructional materials (lesson plans) on the topic of hurricanes.

http://hurricane.csc.noaa.gov/hurricanes/pop.jsp — NOAA's Coastal Services Center Coastal Population Tool

National Science Education Standards

Content Standard B: Physical Science

- Motion and Forces

Content Standard D: Earth and Space Science

- Energy in the Earth system

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal and community health
- Population Growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

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Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 3. The ocean is a major influence on weather and climate.

- Fundamental Concept a. The ocean controls weather and climate by dominating the Earth's energy, water and carbon systems.

- Fundamental Concept b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.

- Fundamental Concept c. The El Niño Southern Oscillation causes important changes in global weather patterns because it changes the way heat is released to the atmosphere in the Pacific.

Essential Principle 6. The ocean and humans are inextricably interconnected.

- Fundamental Concept a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.

- Fundamental Concept d. Much of the world's population lives in coastal areas. Fundamental Concept f. Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).

Essential Principle 7. The ocean is largely unexplored.

- Fundamental Concept e. Use of mathematical models is now an essential part of ocean sciences. Models help us understand the complexity of the ocean and of its interaction with Earth's climate. They process observations and help describe the interactions among systems

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Do You Want To Risk It?

Student Worksheet: Coastal Hazards Vulnerability Assessment

In this exercise, you will use online tools to gather information about the vulnerability of coastal communities to storm hazards.

Use the following tools to obtain information about your assigned community:

- National Ocean Service Coastal Population Tool (*http://hurricane.csc.noaa.gov/hurricanes/pop.jsp*)
- NOAA's Coastal Services Center's Risk and Vulnerability Assessment Tool (RVAT) (http://www.csc.noaa.gov/rvat/)

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    County: Volusia
    Street: 5400 Landis Avenue
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    Click the "Locate Address" button. Shortly, the page should reload with a map showing the location of this address, which turns out to be in Harbor Oaks, FL. On the left side of the page is a box titled "Potential Risk Level" that describes the risk from storm-related floods, wind, surge, and erosion. If you aren't sure what these terms mean, click the "About Hazards" button below the risk level box.

    At the top of the map are tool buttons for zooming in and out (magnifying glass with a plus or minus symbol), panning the map (hand symbol), and getting information about a particular feature (the "i" symbol, which stands for "Identify"). The tool on the far left (two overlapping rectangles) shows or hides the small map in the upper left corner that shows the location of the address within Volusia and Brevard Counties.

    Above the risk level box are tab buttons labeled "Legend," "Find," "Results," "Print," "Help," and "Info." Click on "Help" for more information about these tabs. The "Legend" tab is particularly important. RVAT maps are based on a Geographic Information System (GIS), which is a computer-based system that can be used to organize and analyze information about specific geographic locations. Data about these locations are stored in "layers," with each layer containing a specific type of data. A GIS allows researchers to manipulate and analyze these layers one-by-one or in combination with other layers. One of the most powerful features of a GIS is the ability to display information graphically - especially on maps - which often makes it much easier to understand relationships between locations.

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the small square button to the left of “Bridge,” and you will see that bridges on the map are indicated by a yellow line.

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The round buttons control which layer is “active;” only one layer can be active at a time. To see what this means, let’s load the map with a different set of layers that contain data about critical facilities (“critical facilities” are locations that may be important during an emergency, such as shelters, fire stations, hospitals, etc.). On the right side of the RVAT page is a list of available datasets (“Observations and Forecasts,” “Hazards,” “Critical Facilities,” etc.). Click on “Critical Facilities.” In a few moments the map will re-draw and a new layer list will appear on the left side of the page. Notice that the data layers are arranged in several folders. To see which layers are in a particular folder, click on the file folder symbol. The “CriticalFacilityLayers” folder should be open, showing the names of the 17 layers in that folder. The large square box next to “Composite Critical Facility Risk” should be checked, indicating that this data layer is visible. Click on the small square box next to “Composite Critical Facility Risk” to show the symbols used. Each of the colored circles on the map corresponds to the location of a specific “critical facility.” The color of the circle indicates the combined risk from storm-related floods, wind, surge, and erosion. The risk from each of these hazards is estimated on a numeric scale, and then the individual risk values are added together to find the “Composite Critical Facility Risk” (Table 1 below).

The map shows about ten yellow circles, which indicate critical facilities that have a “moderate” composite risk. To find out more about these facilities, click on the round button next to “Composite Critical Facility Risk” to make that layer active, then click the “Identify” (“i” symbol) button on top of the map. When you move your cursor over the map, and cross-hair symbol will appear. Put the cross-hair over the yellow circle near Landis Avenue and click once. The layer list to the left of the map should be replaced by a horizontal table containing information about the facility corresponding to the dot near Landis Avenue, including the name of the facility, address, latitude and longitude, and emergency functions performed at the facility. Near the right side of the table you will find the individual risk values for floods, wind, surge, and erosion.

Other types of information are contained in other datasets. Clicking on the link to the “Hazards” dataset will produce a map that is shaded to show the “Natural Hazard Summary Risks” which are the combined risks from storm-related floods, wind, surge, and erosion (similar to the Composite Critical Facility Risk, except for the entire land area of the map instead of specific facilities). The “Societal” dataset contains information on areas with various social needs. The “Economic” dataset includes information on various types of businesses and land use. The “Environmental” dataset has information about areas with high ecological value or that may pose environmental threats during a storm (such as facilities that store oil or hazardous chemicals). The “Mitigation Opportunities” dataset has information on areas that have experienced high losses in previous storms, or that are particularly susceptible to such losses (such as mobile homes).

3. Now that you a somewhat familiar with the RVAT, use this tool to answer the following questions about your assigned location in Volusia County or Brevard County:

    a. What critical facilities are within a 0.5 mile radius of the assigned search address?

b. Which facility has the highest Composite Risk?

c. What are the numeric risks from storm-related floods, wind, surge, and erosion for this facility? What is the numeric value of the combined risk?

d. What is the Natural Hazard Summary Risk on land immediately adjacent to this facility?

e. What land uses or land cover are found within a 0.5 mile radius of this facility?

(top)

Do You Want To Risk It?

Table 1: Numeric Scales Used to Describe Risk from Storm-Related Hazards

Flood Risk

8.5 = High (areas in the “Velocity” zone)
6.8 = Moderately-High (areas in the 100-year floodplain)
5.1 = Moderate (areas in the 500-year floodplain)
3.4 = Moderately-Low (flood-prone soils outside above areas)
1.7 = Low (other areas)

Wind Risk

8 (areas likely to experience winds of 120 mph or higher)
6.4 (areas likely to experience winds of 110 – 119 mph)
4.8 (areas likely to experience winds of 100 – 109 mph)

Surge Risk

4 (Storm surge category 1 and 2)
3 (Storm surge category 3)
2 (Storm surge category 4 and 5)
1 (Storm surge buffer (0.25 mile from entire surge coverage)
0 (outside surge area)

Erosion Risk

3.3 (Seaward of the CCCL*)
2.2 (CCCL to 30-year average erosion line)
1.1 (30-year average to 50-year average erosion line)
0 (other areas)
99 = No data available

Composite Risk

High = Combined flood, wind, surge, and erosion values of 19.7 - 23.8
Moderately-high = Combined flood, wind, surge, and erosion values of 16.3 - 19.7
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Low = Combined flood, wind, surge, and erosion values of 4.8 - 11.0

** - The Coastal Construction Control Line (CCCL) defines the zone along the coastline that is susceptible to flooding, erosion, and other impacts during a 100-year storm. Properties located seaward of the CCCL are subject to State-enforced elevation and construction requirements.*

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Do You Want To Risk It?

Student Worksheet: Coastal Hazards Vulnerability Assessment

In this exercise, you will use online tools to gather information about the vulnerability of coastal communities to storm hazards.

Use the following tools to obtain information about your assigned community:

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Images of Katrina

Hurricane Damage Assessment / Grades 9-12 / Earth Science

- Background Information
- Learning Procedure
- The Bridge Connection
- The "Me" Connection
- Extensions
- Resources
- National Science Education Standards
- Ocean Literacy Essential Principles and Fundamental Concepts

Focus Question

How can aerial photographs be used to quickly assess damage from a major natural disaster such as Hurricane Katrina?

Learning Objectives

1. Students will use maps and online data resources to locate the specific geographic areas included in aerial photographs.
2. Students will use aerial photographic imagery to assess some impacts of Hurricane Katrina.

Links to Overview Essays and Resources Useful for Student Research

http://oceanservice.noaa.gov/topics/navops/mapping/

Materials

- (optional) Computers with Internet access; if students do not have access to the Internet, download copies of materials cited under "Learning Procedure" and provide copies of these materials to each student or student group.
- Copies of "Student Worksheet: Aerial Surveillance of Impacts from Hurricane Katrina," found at the end of this lesson plan, one copy for each student group. Click here for a printable copy of the Student Worksheet

Audio/Visual Materials

None

Teaching Time

One 45-minute class period, plus time for student research.

Seating Arrangement

Groups of 4-6 students.

Maximum Number of Students

30

Key Words

Hurricane Katrina
Aerial photography
Damage assessment

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Background Information

The coastal zone is a region of constant change. Some changes occur relatively slowly over decades, while other dramatic changes can happen overnight. These changes may be the result of natural events such as erosion and severe storms, or may be caused by coastal development and other human activities. Whatever the cause, the ability to recognize and quantify these changes is vital to many coastal resource uses, including commercial shipping, fishing, recreation, tourism, as well as to the people who make their homes in these areas. High resolution aerial photographs are the primary source of information about coastal change. Obtaining these photographs for the 95,000 mile U.S. shoreline is the responsibility of the National Geodetic Survey, part of NOAA's National Ocean Service (NOS). Data from these photographs are used to produce nautical charts, define jurisdictional boundaries, such as boundaries between property owners, federal, state, and local jurisdictions, boundaries of territorial seas, and the Exclusive Economic Zone. Aerial photographs are publically available for any area in the United States and its territories through the NOS Data Explorer Web site (*http://oceanservice.noaa.gov/dataexplorer/*)

In some cases, the need for this information is extremely urgent and may literally be a matter of life and death. Such was the case when Hurricane Katrina made landfall in Plaquenines Parish on August 29, 2005. This extremely powerful storm caused widespread destruction in heavily populated areas of the U.S. Gulf of Mexico coast. In the days immediately following the storm, there were many urgent questions, including:

- Which major roads and bridges can be used by rescuers and relief agencies?
- Where is flooding taking place?
- Is there evidence of oil spills or other contamination from industrial facilities?

In addition, thousands of evacuees simply wanted to know whether their homes and businesses were still standing after the storm.

Because hundreds of miles of coastline were simultaneously affected, aerial photography provided the quickest and most effective means of answering many of these questions. On August 30, the day after the hurricane, NOAA's National Geodetic Survey began a series of missions to obtain high resolution aerial photographs of the affected coastal areas in Alabama, Louisiana, and Mississippi. In this lesson, students will acquire hands-on experience with some of the ways aerial photography can be used to answer practical questions about coastal resources.

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Learning Procedure

1. To prepare for this lesson:

    - Read the introductory essay on Aerial Photographic and Shoreline Mapping (*http://oceanservice.noaa.gov/topics/navops/mapping/*); and

    - Work through the "Student Worksheet: Aerial Surveillance of Impacts from Hurricane Katrina."

2. Lead a brief discussion of why aerial images are needed of the nation's shorelines, and how this information might be useful following natural disasters such as Hurricane Katrina. Provide each student group with a copy of the "Student Worksheet: Aerial Surveillance of Impacts from Hurricane Katrina" (and copies of relevant images if students do not have access to the Internet). If time is short, you may want to assign a smaller number of images for each group to analyze. All groups should complete Steps 1 through 5. The remaining steps may be divided among several groups if desired.

3. Lead a discussion of students' answers to problems on the worksheet. The following points should be included:

    - A large vessel, possibly a barge, appears to be aground on the beach along the portion of the Biloxi shoreline examined in the image titled "24333378.jpg".

    - This same image shows extensive roof damage to the motel at 1865 Beach Boulevard; several vehicles appear to be piled into one corner of the parking lot next to the building and piles of debris are scattered over the site.

    - Image 24333287 shows that the portion of US 90 that crosses Biloxi Bay between Biloxi and Ocean Springs, MS is completely destroyed; only concrete supports remain above the water.

    - Images 24333390 and 24333396 show two structures, apparently intact, between Beauvoir Road and Brady Drive. There is a large pile of debris between these structures. Reports posted on the Friends of Beauvoir website indicate that the main building at Beauvoir survived better than many more modern structures, but did sustain considerable damage. Other buildings, including the one in which Davis penned his post-war memoirs, were destroyed.

    - Images 24334575, 24334580, and 24841142 show that bridges connecting Bay St. Louis, MS to Biloxi along US 90 are destroyed.

    - The on-off ramp at the intersection of Interstate Highway 10 and Orleans Avenue in New Orleans was not useable because it was underwater.

    - Sheening is evident on the portion Mississippi to the south of the two storage tanks visible near the center of image 24727673. The aerial image shows many trees lying on the ground in the surrounding area. Note that the total size of this spill was estimated at 3.78 million gallons.

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The Bridge Connection

The Bridge is a growing collection online marine education resources. It provides educators with a convenient source of useful information on global, national, and regional marine science topics. Educators and scientists review sites selected for the Bridge to insure that they are accurate and current.

http://www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click on "Ocean Science Topics," then "Atmosphere" for links to activities and information concerning extreme weather events.

The "Me" Connection

Have students write a brief essay describing how they might personally use aerial photography following an event similar to Hurricane Katrina.

Extensions

1. Have students research a specific individual, business, or community that was affected by Hurricane Katrina, and locate aerial images of the area involved.

2. Another use of aerial photography and shorelines mapping is the creation of "Environmental Sensitivity Index (ESI) Maps." These maps are intended to provide information on the location of critical coastal resources so that responders to oil and chemical spills can quickly determine the most vulnerable areas that should be protected. Visit

http://oceanservice.noaa.gov/news/features/supp_jun03.html for more information, and http://response.restoration.noaa.gov/esi/exercise/maps.html for an exercise using ESI maps.

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Resources

http://oceanservice.noaa.gov/dataexplorer/ – NOS's Data Explorer web site providing access to coastal maps, shoreline surveys, coastal aerial photography, environmental sensitivity index maps, geodetic control points, maritime boundaries, estuarine bathymetry, and water level stations

http://www.geodesy.noaa.gov/RSD/coastal/cscap.shtml – Web site for the National Geodetic Survey's Coast and Shoreline Change Analysis Program, which analyzes shoreline changes by comparing recent high-resolution satellite imagery or high-altitude reconnaissance aerial photography with existing NOAA nautical charts

http://alt.ngs.noaa.gov/katrina – Web site for Hurricane Katrina aerial photographic images from NOAA's National Geodetic Survey

National Science Education Standards

Content Standard B: Physical Science

- Motions and forces

Content Standard D: Earth and Space Science

- Energy in the earth system

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

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Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 3. The ocean is a major influence on weather and climate.

- Fundamental Concept a. The ocean controls weather and climate by dominating the Earth's energy, water and carbon systems.

- Fundamental Concept b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain. Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.

Essential Principle 6. The ocean and humans are inextricably interconnected.

- Fundamental Concept a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.

- Fundamental Concept d. Much of the world's population lives in coastal areas.

- Fundamental Concept f. Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).

Essential Principle 7. The ocean is largely unexplored.

- Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

(top)

Images of Katrina

Student Worksheet: Aerial Surveillance of Impacts from Hurricane Katrina

Features on the aerial images are not labeled, so unless you are familiar with the area included in the image, it may be difficult to find specific locations. In addition, the geographic orientation of aerial images varies from image to image (that is, the top of the image may correspond to any direction; north, south, east, west, etc.). To overcome this problem, you can use an online mapping engine to locate street names and other features for the areas you want to examine. Matching conspicuous features on aerial images (such as shorelines, major highways, lakes, etc) with labeled images from online maps will help identify specific areas on aerial photographs. The following directions use the Google™ mapping engine to help locate specific features in the vicinity of Biloxi, MS.

1. Open the mapping Web site (*http://maps.google.com/*), and enter "biloxi" in the "Search" box at the top of the page and click on the "Search" button. A map of the greater Biloxi area will appear. Click on the "Satelite" button in the upper right corner of the map to display a satellite image of the area. Be sure that the "Show labels" box is checked so that major streets are outlined and labeled. Locate the "+" button in the upper left corner of the map, and click this button to zoom in. Locate the President Broadwater Golf Club, and zoom in until Beach Boulevard (U.S. highway 90, south of the golf club), Veterans Avenue (east of the golf club), Popps Ferry Road (west of the golf club), and Pass Road (north of the golf club) are visible.

2. Move the window containing the hybrid map to one side of your desktop. Open a second window,

3. In the second window, open the Katrina base map index at *http://ngs.woc.noaa.gov/katrina/KATRINA0000.HTM*. Click on the square overlying the location of Biloxi, Mississippi. A new index map should appear titled "Biloxi, Mississippi Image Index Map." The green lines on the map indicate major roadways. The series of open squares represent individual photographic images. When you place your cursor over a square, your browser should display the Web address of the corresponding image. Locate the square whose address is *http://ngs.woc.noaa.gov/storms/katrina/24333378.jpg*, and click on this square. This should open an image titled "24333378.jpg." If a different image opens, try again until the correct number appears.

4. You now have an aerial photographic image of a portion of the Biloxi shoreline. The left side of the image corresponds to south, the top of the image is west, the right side corresponds to north, and the bottom of the image is east. Position your cursor over the image. The cursor will change to a magnifying glass containing a "+" sign. Click once to zoom in. Use the scroll buttons to move the window until the shoreline comes into view. Scroll down to scan the shoreline. Do you notice anything unusual along this portion of the beach?

5. Locate Veterans Avenue near the bottom right corner of the image. Follow Veterans Avenue south (toward the left of the image) until the intersection of Veterans Avenue and Beach Boulevard is visible. Describe the apparent condition of the motel at 1865 Beach Boulevard (the northwest corner of the intersection).

6. Use your satellite map and the Biloxi index map to locate a photographic image that includes the portion of US 90 that crosses a bridge over Biloxi Bay between Biloxi and Ocean Springs, MS. Describe the condition of the bridge near the Biloxi side of the Bay.

7. Beauvoir, the retirement estate of Confederate President Jefferson Davis, was among many irreplaceable historic sites in Katrina's path. Beauvoir is located at 2244 Beach Boulevard in Biloxi (number 2244 is about halfway between Beauvoir Road and Brady Drive; use the lakes on the President Broadwater Golf Club, the large storage tank to the west of Beauvoir Road, and the marina east of Brady Drive to help locate this area on the aerial photograph). What can you determine from aerial imagery about the estate's condition following the hurricane?

8. Use the Katrina base map index to open an index map for Bay St. Louis, MS (see Step 3), and locate an aerial photographic image that includes bridges to the east of the city connecting to Biloxi along US 90. What is the condition of these bridges?

9. Use the Katrina base map index to open an index map for New Orleans, LA (see Step 3), and create a satellite map to locate the intersection of Interstate Highway 10 and Orleans Avenue. Use the satellite map as a guide to locate an aerial photographic image that includes this intersection (Orleans Avenue is between Esplanade and Canal Street; use the bends in the Mississippi River to help match the satellite image to locations on the index map). Was the on-off ramp at this intersection useable when the image was acquired?

10. The Mississippi River is the major waterbody in the dominant watershed in North America, and drains 41% of the United States. The lower Mississippi River supports a variety of wetland, open-water and floodplain habitats, but has been extensively modified for commercial shipping and other human activities. Because Louisiana is a major oil producing state with abundant crude oil reserves, extensive facilities have been developed to refine, store, and distribute petroleum products and other chemicals. Louisiana has the second highest petroleum refining capacity in the U.S. (after Texas). Many of these facilities are located on the lower Mississippi River or near the coast, and consequently are vulnerable to damage by severe storms. As of September 20, 2005, the National Ocean Service had detected visible sheening (the rainbow colored appearance of oil floating on water) in aerial images of approximately 80 spill sites. One such spill was reported from a refinery located near Cox Bay. Use an online mapping engine to locate Cox Bay. The aerial image that includes this area is located at *http://ngs.woc.noaa.gov/storms/katrina/24727673.jpg*. Do you see any evidence of sheening in this image? Where? (Note: sheening in these images looks sort of like confetti on the water surface). If you look at a satellite image of this area, you will see extensive tree cover along the Mississippi River shoreline. What do the aerial images show about the post-Katrina condition of these trees?

(top)

Images of Katrina

Student Worksheet: Aerial Surveillance of Impacts from Hurricane Katrina

Features on the aerial images are not labeled, so unless you are familiar with the area included in the image, it may be difficult to find specific locations. In addition, the geographic orientation of aerial images varies from image to image (that is, the top of the image may correspond to any direction; north, south, east, west, etc.). To overcome this problem, you can use an online mapping engine to locate street names and other features for the areas you want to examine. Matching conspicuous features on aerial images (such as shorelines, major highways, lakes, etc) with labeled images from online maps will help identify specific areas on aerial photographs. The following directions use the Google™ mapping engine to help locate specific features in the vicinity of Biloxi, MS.

1. Open the mapping Web site (*http://maps.google.com/*), and enter "biloxi" in the "Search" box at the top of the page and click on the "Search" button. A map of the greater Biloxi area will appear. Click on the "Satelite" button in the upper right corner of the map to display a satellite image of the area. Be sure that the "Show labels" box is checked so that major streets are outlined and labeled. Locate the "+" button in the upper left corner of the map, and click this button to zoom in. Locate the President Broadwater Golf Club, and zoom in until Beach Boulevard (U.S. highway 90, south of the golf club), Veterans Avenue (east of the golf club), Popps Ferry Road (west of the golf club), and Pass Road (north of the golf club) are visible.

2. Move the window containing the hybrid map to one side of your desktop. Open a second window, and adjust the size and position of the windows so that both are visible.

3. In the second window, open the Katrina base map index at *http://ngs.woc.noaa.gov/katrina/KATRINA0000.HTM*. Click on the square overlying the location of Biloxi, Mississippi. A new index map should appear titled "Biloxi, Mississippi Image Index Map." The green lines on the map indicate major roadways. The series of open squares represent individual photographic images. When you place your cursor over a square, your browser should display the Web address of the corresponding image. Locate the square whose address is *http://ngs.woc.noaa.gov/storms/katrina/24333378.jpg*, and click on this square. This should open an image titled "24333378.jpg." If a different image opens, try again until the correct number appears.

4. You now have an aerial photographic image of a portion of the Biloxi shoreline. The left side of the image corresponds to south, the top of the image is west, the right side corresponds to north, and the bottom of the image is east. Position your cursor over the image. The cursor will change to a magnifying glass containing a "+" sign. Click once to zoom in. Use the scroll buttons to move the window until the shoreline comes into view. Scroll down to scan the shoreline. Do you notice anything unusual along this portion of the beach?

5. Locate Veterans Avenue near the bottom right corner of the image. Follow Veterans Avenue south (toward the left of the image) until the intersection of Veterans Avenue and Beach Boulevard is visible. Describe the apparent condition of the motel at 1865 Beach Boulevard (the northwest corner of the intersection).

6. Use your satellite map and the Biloxi index map to locate a photographic image that includes the portion of US 90 that crosses a bridge over Biloxi Bay between Biloxi and Ocean Springs,

MS. Describe the condition of the bridge near the Biloxi side of the Bay.

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