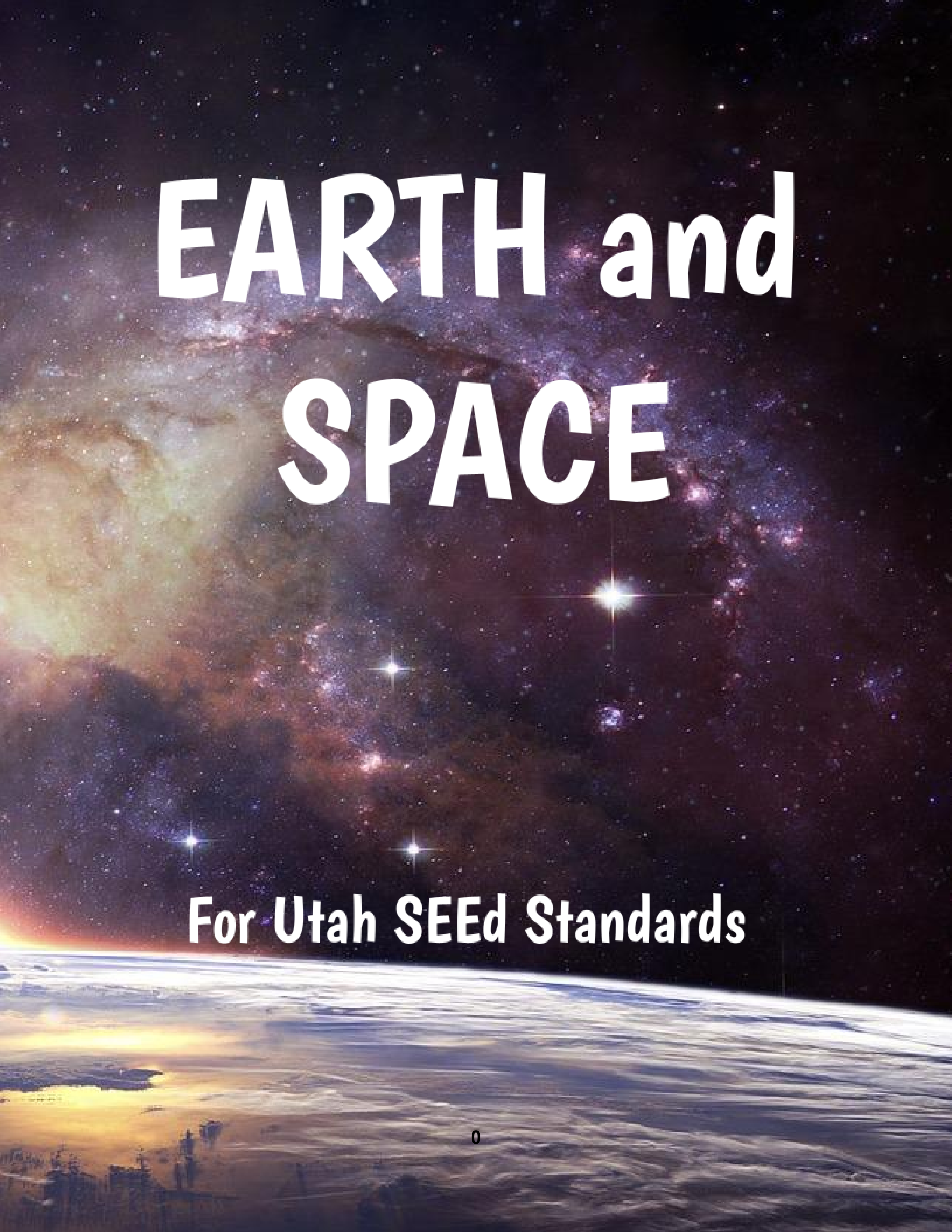

EARTH and SPACE

For Utah SEEd Standards

Earth and Space

for Utah SEEd Standards

Utah State Board of Education OER

Printed: May, 2023

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USBE OER

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We especially wish to thank the amazing Utah science teachers whose collaborative efforts made the book possible. Thank you for your commitment to science education and Utah students!

Students as Scientists

What does science look and feel like?

If you're reading this book, either as a student or a teacher, you're going to be digging into the "practice" of science. Probably, someone, somewhere, has made you think about this before, and so you've probably already had a chance to imagine the possibilities. Who do you picture doing science? What do they look like? What are they doing?

Often when we ask people to imagine this, they draw or describe people with lab coats, people with crazy hair, beakers and flasks of weird looking liquids that are bubbling and frothing. Maybe there's even an explosion. Let's be honest: Some scientists do look like this, or they look like other stereotypes: people readied with their pocket protectors and calculators, figuring out how to launch a rocket into orbit. Or maybe what comes to mind is a list of steps that you might have to check off for your science fair project to be judged; or, maybe a graph or data table with lots of numbers comes to mind.

So let's start over. When you imagine graphs and tables, lab coats and calculators, is that what you love? If this describes you, that's great. But if it doesn't, and that's probably true for many of us, then go ahead and dump that image of science. It's useless because it isn't you. Instead, picture yourself as a maker and doer of science. The fact is, we need scientists and citizens like you, whoever you are, because we need all of the ideas, perspectives, and creative thinkers. This includes you.

Scientists wander in the woods. They dig in the dirt and chip at rocks. They peer through microscopes. They read. They play with tubes and pipes in the aisles of a hardware store to see what kinds of sounds they can make with them. They daydream and imagine. They count and measure and predict. They stare at the rock faces in the mountains and imagine how those came to be. They dance. They draw and write and write and write some more.

Scientists — and this includes all of us who do, use, apply, or think about science — don't fit a certain stereotype. What really sets us apart as humans is not just that we know and do things, but that we wonder and make sense of our world. We do this in many ways, through painting, religion, music, culture, poetry, and, most especially, science. Science isn't just a method or a collection of things we know. It's a uniquely human practice of wondering about and creating explanations for the natural world around us. This ranges from the most fundamental building blocks of all matter to the widest expanse of space that contains it all. If you've ever wondered "When did time start?", or "What is the smallest thing?", or even just "What is color?", or so many other endless questions then you're already thinking with a scientific mind. Of course you are; you're human, after all.

But here is where we really have to be clear. Science isn't just questions and explanations. Science is about a sense of wondering and the sense-making itself. We have to wonder and then really dig into the details of our surroundings. We have to get our hands dirty. Here's a good example: two young scientists under the presence of the Courthouse Towers in Arches National Park. We can be sure that they spent some amount of time in awe of the giant sandstone walls, but here in this photo they're enthralled with the sand that's just been re-washed by recent rain. There's this giant formation of sandstone looming above these kids in the desert, and they're happily playing in the sand. This is ridiculous. Or is it?

How did that sand get there? Where did it come from? Did the sand come from the rock or does the rock come from sand? And how would you know? How do you tell this story?

Look. There's a puddle. How often is there a puddle in the desert? The sand is wet and fine; and it makes swirling, layered patterns on the solid stone. There are pits and pockets in the rock, like the one that these two scientists are sitting in, and the gritty sand and the cold water accumulate there. And then you might start to wonder: Does the sand fill in the hole to form more rock, or is the hole worn away because it became sand? And then you might wonder more about the giant formation in the background: It has the same colors as the sand, so has this been built up or is it being worn down? And if it's being built up by sand, how does it all get put together; and if it's being worn away then why does it make the patterns that we see in the rock? Why? How long? What next?

Just as there is science to be found in a puddle or a pit or a simple rock formation, there's science in a soap bubble, in a worm, in the spin of a dancer and in the structure of a bridge. But this thing we call "science" is only there if you're paying attention, asking questions, and imagining possibilities. You have to make the science by being the person who gathers information and evidence, who organizes and reasons with this, and who communicates it to others. Most of all, you get to wonder. Throughout all of the rest of this book and all of the rest of the science that you will ever do, wonder should be at the heart of it all. Whether you're a student or a teacher, this wonder is what will bring the sense-making of science to life and make it your own.

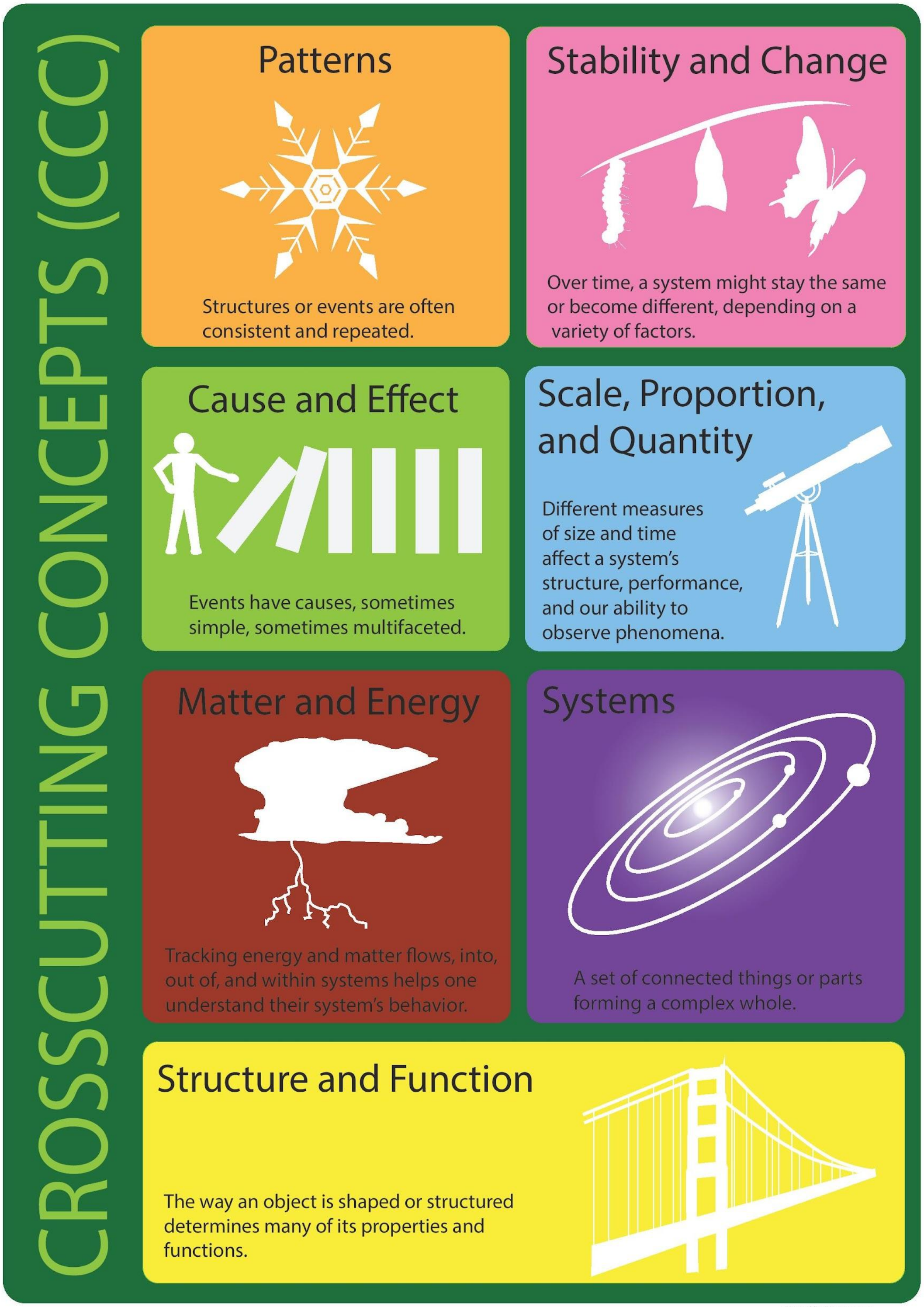
Adam Johnston
Weber State University

Science and Engineering Practices

Science and Engineering Practices are what scientists do to investigate and explore natural phenomena

Crosscutting Concepts

Crosscutting Concepts are the tools that scientists use to make sense of natural phenomena.



What is involved in Engineering Design?

Engineering is a creative process where each new version of a design is tested and then modified, based on what has been learned up to that point. This process includes a number of components:

1. Identifying the problem and defining criteria and constraints.
2. Generating ideas for how to solve the problem. Engineers use research, brainstorming, and collaboration with others to come up with ideas for solutions and designs.
3. Use criteria and constraints to evaluate possible design solutions to identify the one(s) that best address these parameters for the problem in context
4. Build and test the prototypes. Using data collected, the engineer analyzes how well prototypes meet the given criteria and constraints.
5. Suggest or make improvements to prototypes to optimize the design.

In the Science with Engineering Education (SEEd) Standards, specific engineering standards generally involve two types of tasks:

1. If the standard includes the idea of designing, then the design process will contain components of defining the problem (along with identifying the criteria and constraints), developing many possible solutions, and optimizing a solution (e.g., determining a best solution for the situation based on the criteria and constraints, testing the solution, refining the solution).
2. If the standard includes the idea of evaluating, then the design process will contain components of defining the problem (along with identifying the criteria and constraints) and optimizing a solution. The idea of developing many possible solutions is not included because various solutions will be provided. The idea of evaluating then means determining a best solution from the provided solutions for the situation based on meeting the criteria and constraints requirements.

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CHAPTER 1

Strand 1: Matter and Energy in Space

Chapter Outline

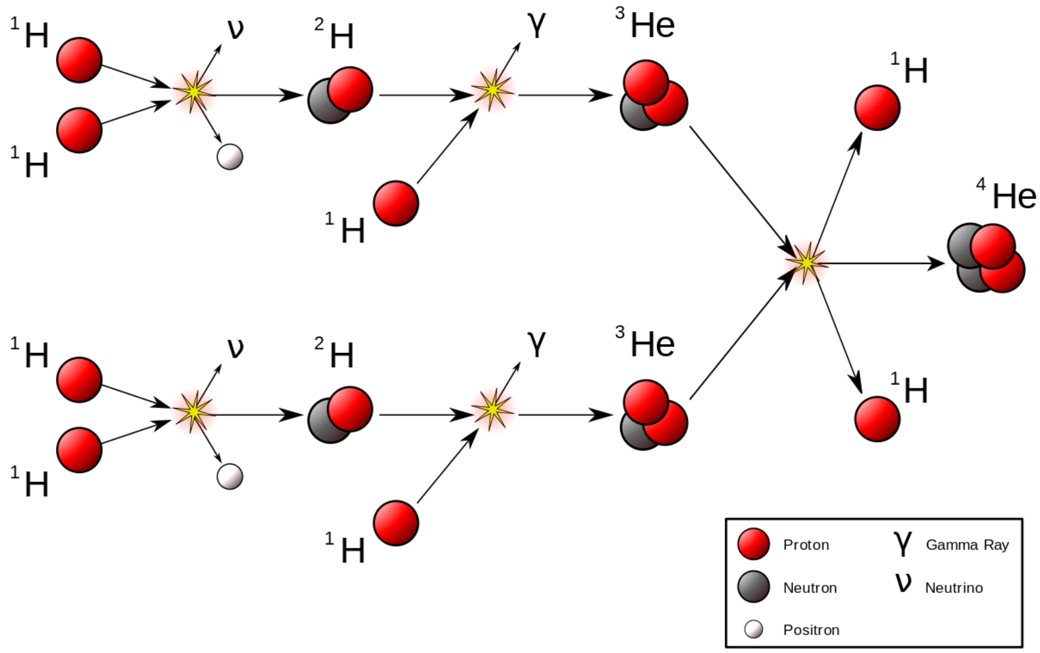
Magnificent CME Erupts on the Sun - August 31
https://images.nasa.gov/details-GSFC_20171208_Archive_e001662, by NASA, CC BY

The Sun releases energy that eventually reaches Earth in the form of electromagnetic radiation. The Big Bang theory is supported by observations of distant galaxies receding from our own as well as other evidence. The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth. Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, releasing electromagnetic energy. Heavier elements are produced when certain massive stars reach a supernova stage and explode. New technologies advance scientific knowledge including space exploration.

1.1 Where does the Sun's Energy Come from? (ESS.1.1)

Phenomenon

The diagram below shows a nuclear fusion reaction. These reactions take place in the Sun's core and produce energy, which is then transferred to Earth.



Proton-proton reaction chain.svg by Doctor C, https://commons.wikimedia.org/wiki/File:Proton-proton_reaction_chain.svg CC BY-SA

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions:

1. Is matter lost during the nuclear fusion reaction?

2. In what form is energy produced during the nuclear fusion reaction?

ESS.1.1 Where does the Sun's Energy Come From?

Develop a model based on evidence to illustrate the life span of the Sun and the role of nuclear fusion releasing energy in the Sun's core. Emphasize energy transfer mechanisms that allow energy from nuclear fusion to reach Earth. Examples of evidence for the model could include observations of the masses and lifetimes of other stars, or non-cyclic variations over centuries. (PS1.C, PS3.D, ESS1.A, ESS1.B)

In this section, look for examples of the conservation of matter and energy. Matter and energy cannot be destroyed, only converted, transformed, or moved from place to place.

Milky Way Bulge by NASA, https://hubblesite.org/contents/media/images/2018/01/4101-Image.html, CC BY

An Introduction to Stars

When you look at the sky on a clear night, you can see hundreds to thousands of stars. The image above is a Hubble space telescope image of a small part of our own Milky Way Galaxy.

A star is a massive object made of plasma that is held together by gravity. Stars have temperatures over a million degrees in their cores. A star's color is related to its temperature. Hot stars tend to appear blue and cool stars appear red. Stars produce incredible amounts of energy that they release into space, some of which is visible to humans as visible light, a form of electromagnetic radiation.

Our star, the sun, has a temperature of about 6,000° Kelvin (5,727°C) on its surface. Our star has a yellowish color compared to other stars. Many stars are like our Sun, but most are cooler and more red than our Sun. Except for our own Sun, all stars are so far away that they only look like single points in the night sky, even through a telescope.

Energy from Nuclear Fusion

Stars shine because of nuclear fusion. Stars are made mostly of the elements hydrogen and helium. Both are very lightweight gasses. A star contains so many of these elements that the weight of the gasses is enormous. The weight produces pressure at the center of a star that heats the plasma to extreme temperatures of millions of degrees. This combination of high temperature and pressure causes nuclear fusion reactions to occur.

In fusion, two or more small nuclei combine to form a single, larger nucleus. It takes place only at extremely high temperatures because a great deal of energy is needed to overcome the force of repulsion between two positively charged nuclei. A small amount of the mass of hydrogen is converted to energy in each reaction, but otherwise, matter is conserved. The total amount of protons and neutrons remains the same throughout the process. Since there are so many hydrogen atoms fusing in the Sun, it produces a huge amount of energy.

In the Sun's primary nuclear fusion reaction, nuclei of four hydrogen nuclei fuse together, forming a helium nucleus and energy. A portion of that reaction is shown below. In this example, nuclei of two types of hydrogen (tritium and deuterium) fuse to form a helium nucleus. A neutron and a tremendous amount of energy is also released.

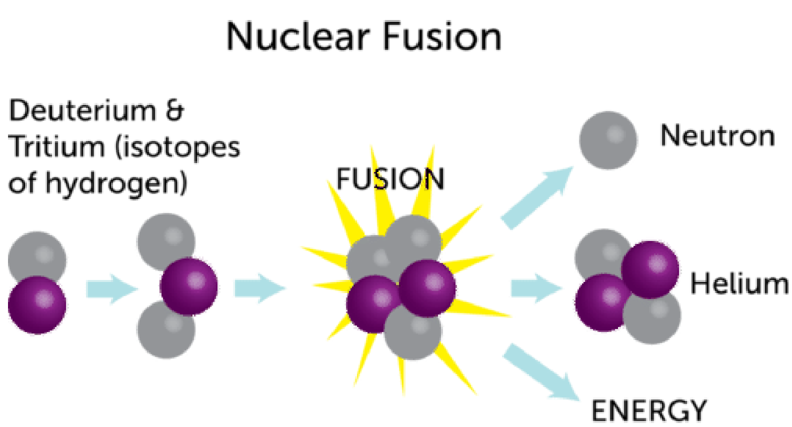


Image by Christopher Auyeung, CK-12 Foundation, CC BY-NC 3.0

Matter from Nuclear Fusion

This section "Matter from Nuclear Fusion" is adapted from NASA, The Imagine Team; https://imagine.gsfc.nasa.gov/science/objects/stars1.html CC BY

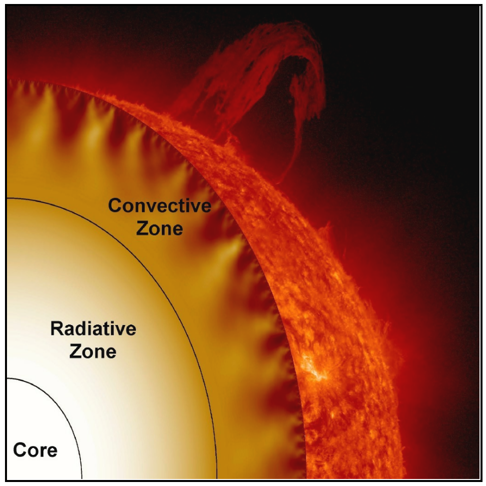
A star is born, lives, and dies, much like everything else in nature. Using observations of stars, astronomers have constructed a lifecycle that all stars appear to go through. The fate and life of a star depends primarily on the amount of hydrogen the star contains, which is used to fuel nuclear fusion. Near the end of its life cycle, a star will eventually run out of its hydrogen fuel. When that happens, the star begins to die.

When a medium sized star (up to about 7 times the mass of the Sun) nears the end of its life, the core will have enough heat and pressure to cause helium to fuse into carbon. Once the helium in the core is gone, nuclear fusion will stop, energy and light will no longer be produced, and the star dies. Our own Sun is considered a medium sized star. Medium sized stars contain enough hydrogen to fuel nuclear fusion for about 10 billion years.

A large star (with more than 7 times the mass of the Sun) will begin to die similarly to medium sized stars, where fusion of helium into carbon begins in the core. But when the supply of helium runs out, because the core has more mass, it will become hot and dense enough to fuse carbon into neon. In fact, when the supply of carbon is used up, other fusion reactions occur, until the core is filled with iron atoms. Fusing iron requires an input of energy, rather than producing energy. With a core full of iron, the star runs out of fuel for nuclear fusion. The core temperature rises to over 100 billion degrees as the iron atoms are crushed together. The repulsive force between the positively charged nuclei overcomes the force of gravity, and the core explodes in one of the most spectacular events in the universe; a supernova. The energy from the supernova is enough to fuse even larger atoms than iron, forming the heavy elements of the periodic table. These newly formed elements are scattered into space.

Energy Transfer in and from Stars

Like most stars, the Sun is made almost entirely of the elements hydrogen and helium, and most of those atoms exist as plasma. Plasma is superheated gas with an electrical charge. Because the Sun is made of these gasses, it does not have a defined outer boundary. It does, however, have a definite internal structure with identifiable layers. Since the layers are not solid, the boundaries are fuzzy and indistinct. From inward to outward, the layers are: the core, the radiative zone, and the convection zone.



The Solar Interior by NASA;
https://solarscience.msfc.nasa.gov/interior.shtml; CC BY

The core is the Sun's innermost layer, where nuclear fusion takes place at temperatures of around 15 million°C. In these reactions, energy is produced as hydrogen is fused into helium. The energy produced by these reactions moves toward the outer layers of the Sun. The layers of the Sun are named by the type of energy transfer that occurs there. Outside the core is the radiative zone, with a temperature of about 4 million°C. Here energy travels by radiation, in the form of energy waves. Energy takes more than 170,000 years to slowly move through the radiative zone. When energy leaves the radiative zone, it enters the convection zone, where energy continues to move outward as matter circulates in convection currents. Eventually, the energy created by those reactions in the core reaches the outer layers of the sun and is released into space as electromagnetic radiation. Once it leaves the Sun, this radiated energy takes approximately 8 minutes to reach Earth.

The Sun's Energy on Earth

This section "The Sun's Energy on Earth" is adapted from NOAA;
https://www.climate.gov/news-features/understanding-climate/climate-change-incoming-sunlight CC BY

The amount of sunlight energy that reaches Earth changes because the Sun's energy output changes. The most regular pattern is an 11-year cycle of high and low sunspot activity caused by reversal of the Sun's magnetic poles. During strong cycles, the Sun's total brightness at solar maximum is about 0.1 % higher than it is at solar minimum.

The amount of sunlight energy that reaches Earth through time also varies due to changes in our planet's orbit and position in space relative to the Sun. Called Milankovitch cycles, these predictable orbital patterns have repeat times of tens to hundreds of thousands of years. For the past million years at least, Milankovitch cycles have coincided with 100,000-year-long ice ages interrupted by short intervals of rapid warming.

The most significant changes in the amount of sunlight reaching Earth come from three variations in Earth's orbit:

- eccentricity (~100,000 years): how far Earth's orbit is from being a perfect circle;
- obliquity (~41,000 years): how tilted Earth's axis of rotation is;
- precession (~26,000 years): the slow rotation or "wobble" in the Earth's axis of rotation.

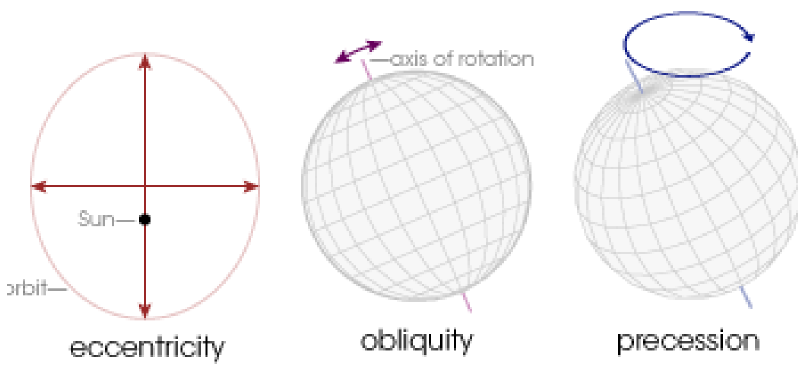
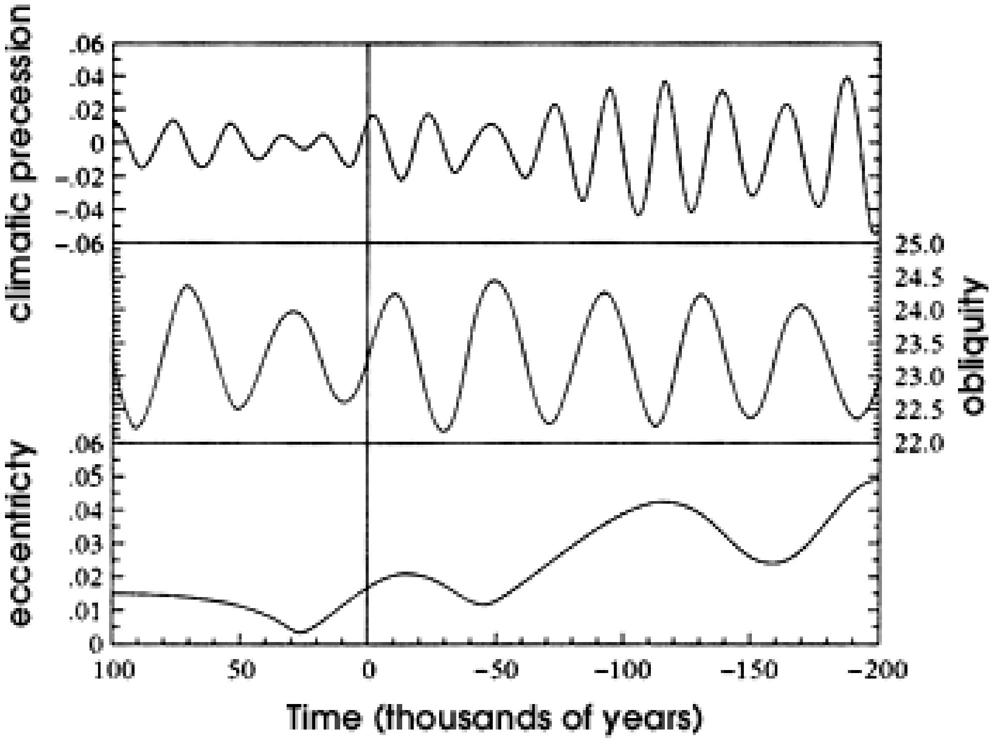


Image from NASA, Earth Observatory; https://earthobservatory.nasa.gov/features/Paleoclimatology_Evidence; CC BY

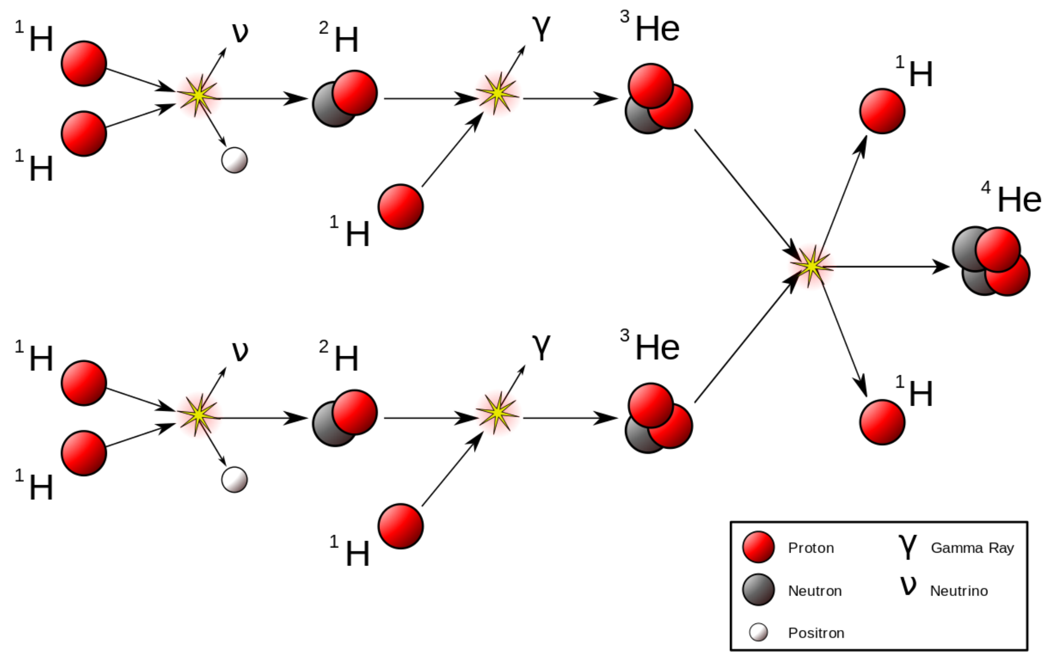
Because these cycles have different lengths, they overlap in complex rhythms that are detectable in geologic records. The graphs below show calculated values for 300,000 years of orbital variation. The line labeled "0" represents today, while "-200" indicates 200,000 years in the past and "100" indicates 100,000 years from now. Whenever the peaks of variation occur at the same time, the Earth receives significantly less sunlight than average, and conditions are right for reduced temperatures and a buildup of snow and ice common to an ice age.



Here on Earth, the energy from the Sun is detectable as visible light and heat, but electromagnetic radiation can also be converted to other forms. For example, it may be converted to chemical energy through photosynthesis, which is an essential process that supports all life on Earth. The very small amount of energy that reaches Earth is responsible for much of the dynamics of our planet.

Putting It Together

Nuclear fusion reactions in the Sun's core produce energy which is then transferred to Earth.



Proton-proton reaction chain.svg by Doctor C, https://commons.wikimedia.org/wiki/File:Proton-proton_reaction_chain.svg CC BY-SA

Focus Questions:

1. How is matter conserved during the nuclear fusion reaction?

2. How is energy transformed as it flows from the Sun's core to Earth?

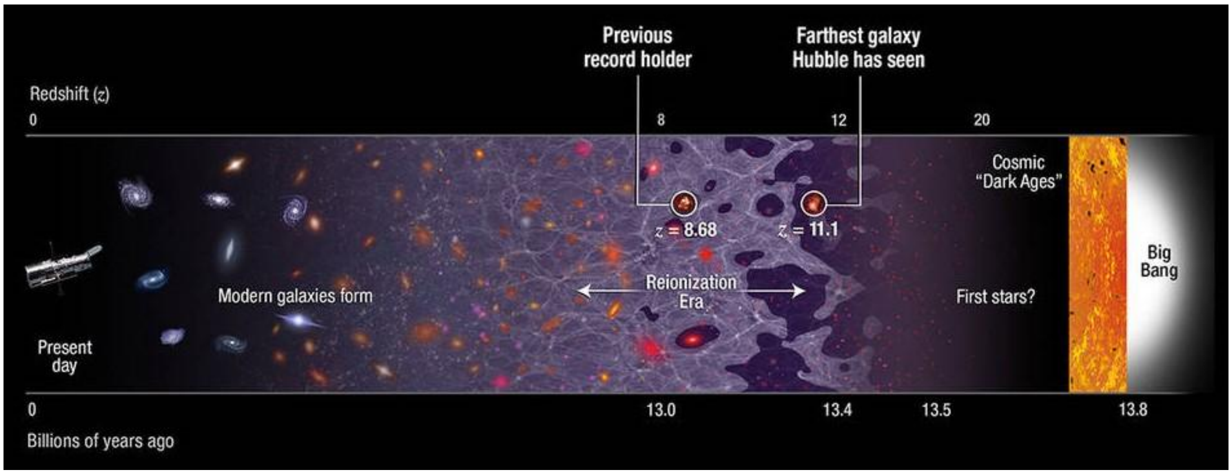
Final Task:

Draw and label a model showing where energy is produced in the Sun and how it reaches Earth.

1.2 Origins and History of the Universe (ESS.1.2)

Phenomenon

The diagram below shows a history of the universe and recent discoveries about the oldest galaxies we've ever discovered using the Hubble space telescope.



Hubble spectroscopically confirms farthest galaxy to date.
Credits: NASA, ESA, P. Oesch and B. Robertson (University of California, Santa Cruz), and A. Feild (STScI);
https://www.nasa.gov/feature/goddard/2016/hubble-team-breaks-cosmic-distance-record, CC BY

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

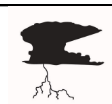
Focus Questions:

1. According to the diagram, how has the distribution of matter changed over time?

2. According to the diagram, what appears to be the relationship between the redshift (z) of a galaxy and its age?

ESS.1.2 Origins and History of the Universe

Construct an explanation of the Big Bang theory based on astronomical evidence of electromagnetic radiation, motion of distant galaxies, and composition of <u>matter</u> in the universe. Emphasize redshift of electromagnetic radiation, cosmic microwave background radiation, and the observed composition and distribution of matter in the universe. (PS4.B, ESS1.A)

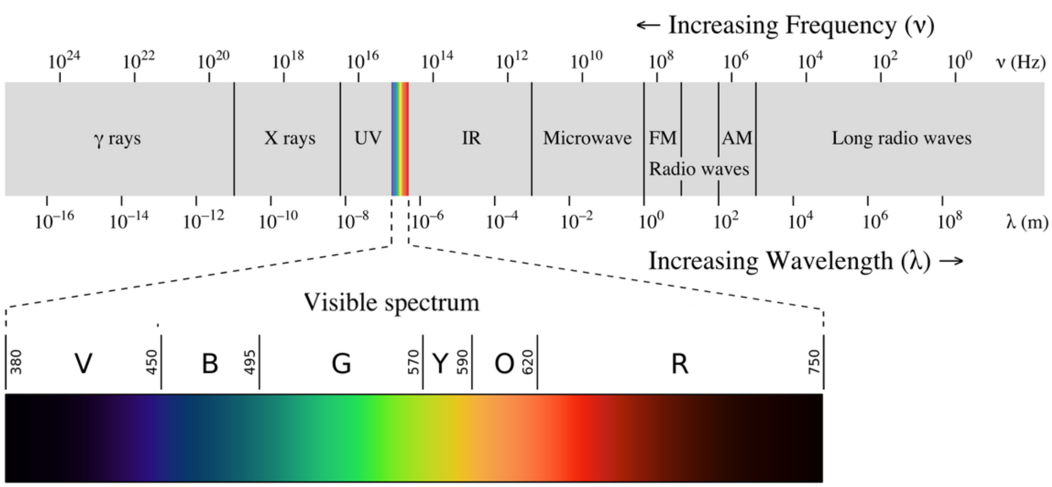


In this section, look for examples that show the distribution of energy and matter can be used to explain past, present, and future changes on Earth and throughout the universe.

A Changing Universe

In the early 1920's, an astronomer named Edwin Hubble discovered that the universe is much larger than we thought and that there are many galaxies outside of our own Milky Way Galaxy. After discovering that there are galaxies beyond the Milky Way, Edwin Hubble went on to measure the distances to other galaxies and discovered that they were all redshifted. His data would eventually show how the universe is changing, and would even yield clues as to how the universe was formed. To explain his discovery, you need to understand the properties of light and the concept of redshift.

Properties of Light



EM spectrum revised by Philip Ronan, Gringer; https://commons.wikimedia.org/wiki/File:EM_spectrumrevised.png, CC BY-SA

Light is electromagnetic energy. It travels in waves and spans a broad spectrum from very long radio waves to very short gamma rays, shown in the diagram above. The human eye can detect only a small part of this spectrum, called visible light. However, the rest of the spectrum, most of the light in the universe, is invisible to human eyes.

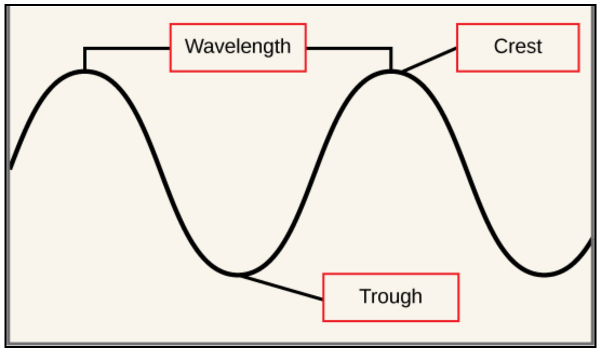


Figure 08 02 02 by CNX OpenStax;
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Light has several basic properties that describe it: frequency, wavelength, and energy. Frequency counts the number of waves that pass by a given point in one second. Wavelength is the distance from the peak of one wave to the peak of the next. These two properties are closely and inversely related: The larger the frequency, the smaller the wavelength — and vice versa. Energy is related to frequency in that the higher the frequency of the light wave, the more energy it carries.

Your eyes detect electromagnetic waves that are roughly the size of a virus. Your brain interprets the various wavelengths of visible light as different colors, ranging from red to violet. Red has the longest wavelength and violet the shortest.

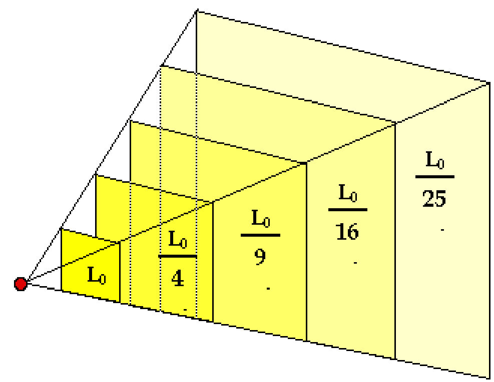
Electromagnetic waves differ from other waves in that they do not require any substance (gas, liquid, or solid) to travel through. This means that electromagnetic waves can travel through the vacuum of space. While the speed of light varies depending on the material it travels through, when traveling through a vacuum, light travels at a constant, finite speed of approximately 300,000 km/sec (186,000 mi/sec). A traveler, moving at the speed of light, would travel around the Earth approximately 7.5 times in one second. By comparison, a traveler in a jet aircraft would cross the continental U.S. once in 4 hours.

Our Sun, and other stars, produce energy across the full electromagnetic spectrum. The Sun’s electromagnetic radiation bombards our atmosphere constantly. However, the Earth's atmosphere protects us from exposure to a range of higher energy waves that can be harmful to life. Gamma rays, x-rays, and some ultraviolet waves are "ionizing," meaning these waves have such a high energy that they can knock electrons out of atoms. Exposure to these high-energy waves can alter atoms and molecules and cause damage to cells in organic matter. These changes to cells can sometimes be helpful, as when radiation is used to kill cancer cells, and other times not, as when we get sunburned.

Electromagnetic radiation is reflected or absorbed mainly by several gasses in the Earth's atmosphere, among the most important being water vapor, carbon dioxide, and ozone. Some radiation, such as visible light, largely passes (is transmitted) through the atmosphere.

Measuring the Distance and Motion of Stars

The light that reaches Earth from a star can tell us a lot about the star. The luminosity of a star describes how much light it emits, but the brightness of light we see from a star is dependent on its distance. This relationship can be illustrated by the diagram, which shows the apparent brightness of a source with luminosity L_0 at distances r, 2r, 3r, etc. Notice that as the distance increases, the light must spread out over a larger surface.

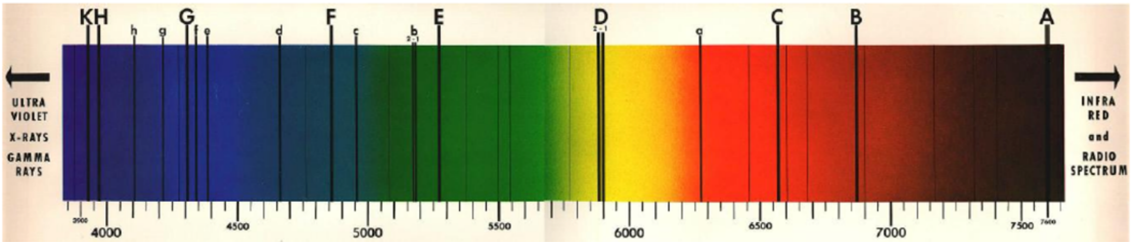


The brightness decreases in accordance with an inverse squared relationship and can be used to determine the distance between Earth and a star.

An example of the "one over r-squared" relationship for light by NASA, Imagine the Universe, https://imagine.gsfc.nasa.gov/features/yba/M31_velocity/lightcurve/more.html; CC BY

If you look at starlight through a tool called a spectroscope, you will see the full spectrum of visible light that the star is emitting as a rainbow of colors. The spectrum will have specific dark bands where elements in the star absorb light of certain wavelengths. By examining the arrangement of these dark absorption lines, astronomers can determine the composition of elements that make up a distant star. In fact, the element helium was first discovered in our Sun—not on Earth—by analyzing the absorption lines in the spectrum of the Sun. The original spectrum including absorption lines for our Sun is shown below.

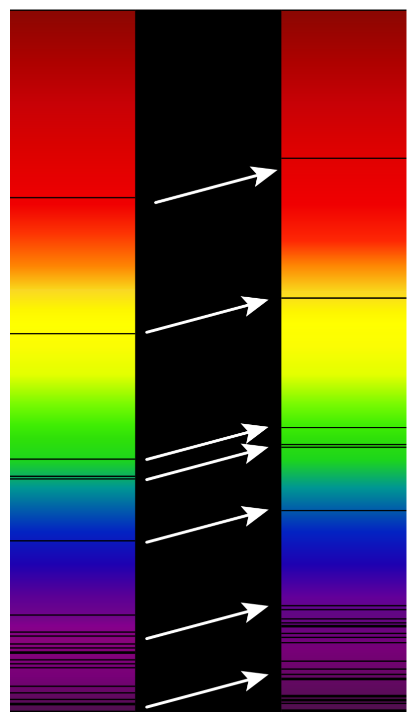
In 1814, Fraunhofer invented the spectroscope, and discovered 574 dark lines appearing in the solar spectrum. They are still called Fraunhofer lines. Kirchhoff and Bunsen showed in 1859 that they are atomic absorption features providing diagnostics-at-a-distance of the local conditions in the atmospheres of the Sun and other stars.



scale in Ångstrom; 1 Å = 0.1 nm

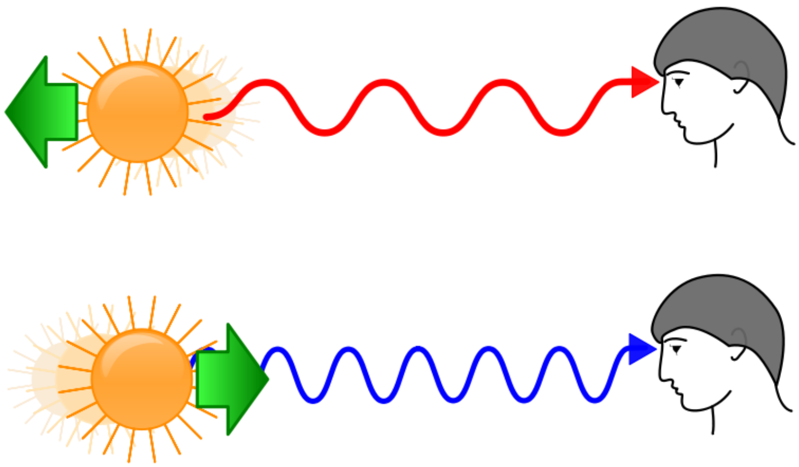
The Solar Spectrum by NASA; https://mark4sun.jpl.nasa.gov/report/UT_seminar_Solar_Spectrum_Toon.pdf; CC BY

While studying the spectrum of light from distant galaxies, astronomers noticed something strange. The dark lines in the spectrum were in the patterns they expected, but they were shifted toward the red end of the spectrum, as shown in the figure. This shift of absorption bands toward the red end of the spectrum is known as redshift.



This diagram to the right above shows the absorption lines in the visible spectrum of a distant galaxy (right), as compared to absorption lines in the visible spectrum of the Sun (left). Arrows indicate redshift.

The absorption lines are shifted because of the Doppler Effect. For example, when an object that produces sound approaches you, the sound waves are squished together, causing you to hear a higher pitch. As that sound-producing object moves away from you, its sound waves are stretched out producing a lower pitch. The change of the length of the wave changes the sound you hear. If you've ever watched a car race on TV or waited at a train crossing, you have heard this phenomenon. This is known as the Doppler effect.



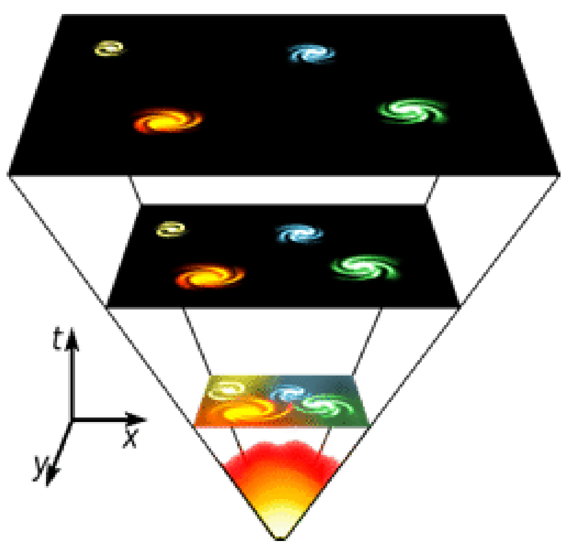
Redshift Blueshift by *by Aleš Tošovský*, *https://commons.wikimedia.org/wiki/File:Redshift_blueshift.svg, CC-BY-SA 3.0*

The Doppler effect does not just apply to sound waves, it can also occur with light waves. Redshifts occur when a light source is moving away from an observer and the light waves are stretched. It can also occur when the space between the observer and the source is stretched.

What does it mean that stars and galaxies are redshifted? When astronomers see redshift in the light from a galaxy, they know that the galaxy is moving away from Earth. Most observable galaxies in the universe are redshifted.

Expansion of the Universe

Edwin Hubble combined measurements of the distances to galaxies with measurements of redshift. From this data, he noticed a relationship, which is now called Hubble's Law: the farther away a galaxy is, the faster it is moving away from us. This relationship means that the universe is expanding. According to Hubble's Law, the farther away a galaxy is, the faster it's moving, and the farther its spectrum will be redshifted.



As we look at galaxies we see a vast majority of them are moving away from our point of view (our galaxy). The diagram is a simplified representation of the expansion of the universe. It shows that over time, the distance between galaxies gets bigger, although the size of each galaxy stays the same. Another way to picture this is to imagine a balloon covered with tiny dots to represent the galaxies. When you inflate the balloon, the dots slowly move away from each other because the rubber stretches in the space between them. If you were standing on one of the dots, you would see the other dots moving away from you. No matter which dot you stand on, all the other dots move away. Also, the dots farther away from you on the balloon would move away faster than dots nearby.

An inflating balloon is only a rough analogy to the expanding universe for several reasons. One important reason is that the surface of a balloon has only two dimensions, while space has three dimensions. But space itself is stretching out between galaxies like the rubber stretches when a balloon is inflated. This stretching of space, which increases the distance between galaxies, is what causes the expansion of the universe.

The Big Bang Theory

Before Hubble, most astronomers thought that the universe didn’t change. However, if the universe is expanding, it must have been smaller in the past. Go back even farther in time and the universe was contained in a single, tiny point. This is the basic idea behind the Big Bang Theory.

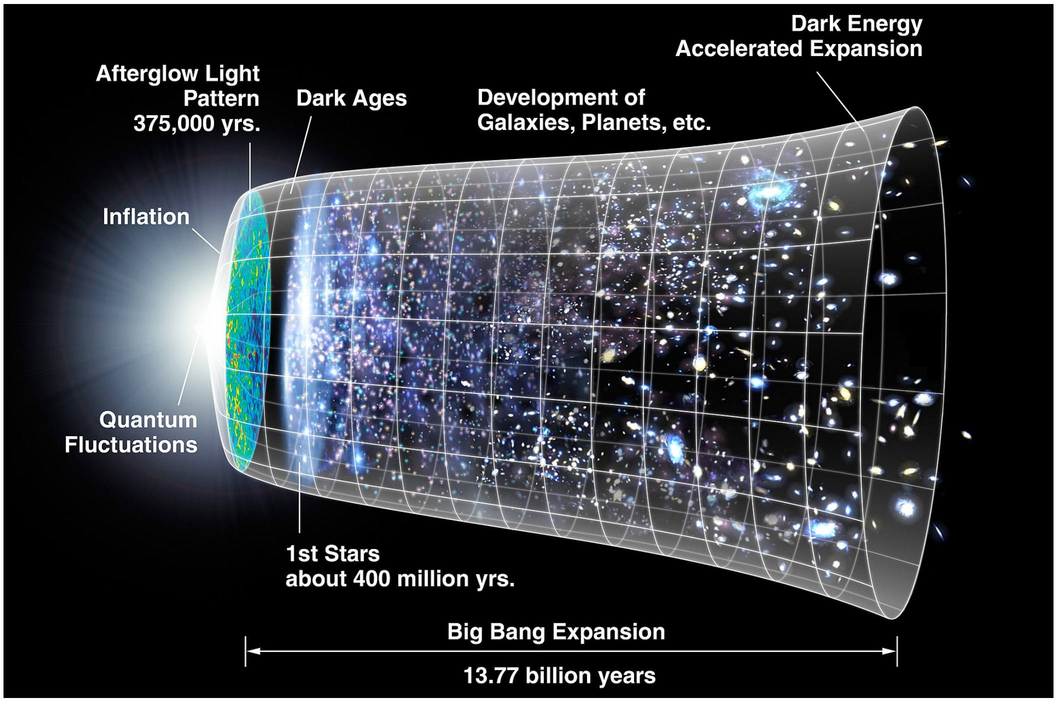
According to the Big Bang Theory, the universe began about 13.8 billion years ago. Everything that is now in the universe existed as a single, hot, chaotic mass that began to rapidly expand. All the matter and energy in the universe, and even space and time, resulted from this expansion.

After the Big Bang

In the first few moments after the Big Bang, the universe was unimaginably hot and dense. As the universe expanded, it became less dense and began to cool. After only a millionth of a second, protons (hydrogen nuclei) and neutrons could form. After a few minutes, some of these subatomic particles came together to create helium nuclei. Eventually electrons formed, combined with nuclei and we had the first neutral atoms (almost exclusively hydrogen and a little helium).

Because of the rapid inflation of the universe in its first moments, matter was smoothly distributed across space. We see light elements like hydrogen and helium scattered throughout the universe. However, some of the hydrogen and helium were drawn together by gravity into clumps. These clumps were the seeds that eventually became countless trillions of stars, billions of galaxies, and other structures that now form most of the visible mass of the universe.

These stars provide us with another piece of evidence that the universe is aging. The hydrogen in stars is being changed by fusion into helium and heavy elements. About 92% of the first elements formed after the Big Bang were hydrogen; the remaining 8% were helium and traces of lithium. Today we have about 74% hydrogen and 24% helium with the 90 other naturally occurring elements forming the remaining 2%. By modeling how much hydrogen the universe started with, and the rate that stars use it, we can determine when stars began fusing. We can also use this rate to estimate how much longer fusion will continue. Right now you live in the springtime of the universe's life - most of the universe is still hydrogen. Hundreds of billions of stars in hundreds of billions of galaxies are using up hydrogen and turning it into heavier elements as the universe continues to age.



Timeline of the history of the universe. The time on the left is the origin, on the right is today.
Image by NASA/WMAP,
https://en.wikipedia.org/wiki/Big_Bang#/media/File:CMB_Timeline300_no_WMAP.jpg, public domain

The Energy of the Big Bang

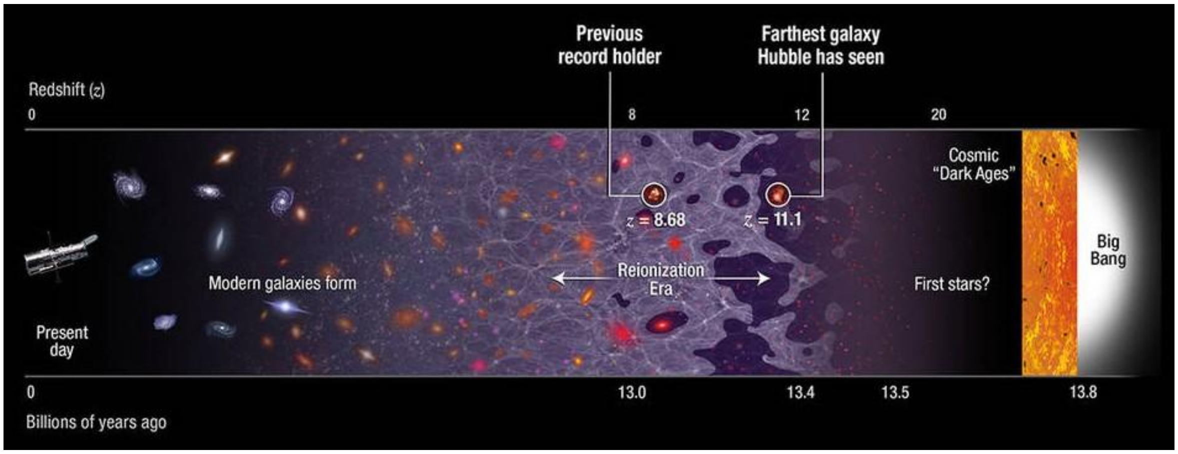
After the publication of the Big Bang hypothesis, many astronomers still thought the universe was static (or not changing). However, the Big Bang Theory made a prediction that was different from what was expected in a static universe. It predicted that there should be some heat energy left over from the Big Bang. With the continued expansion of the universe, the temperature should be very low today, only a few degrees K (Kelvin) above absolute zero. In 1964, two researchers at Bell Laboratories (Arno Penzias and Robert Wilson) were calibrating a radio telescope. They pointed it at empty space but discovered only static coming from space wherever they looked. The static was later found to be leftover heat from the Big Bang. This heat was at 4°K, just as Robert Dickie and his team had predicted. Using it, they discovered microwave radiation in all parts of the sky. This microwave radiation is the cooled, leftover energy from the Big Bang and serves as one of the most significant forms of evidence for this model of the universe.

Summary of the Evidence for the Big Bang Theory

There are several independent lines of evidence that support the Big Bang Theory. Together, they form the pillars of modern cosmology, the study of the universe.

1. **Redshift Data:** By studying the spectra produced by galaxies throughout the universe, we can identify that most objects are moving away from each other and that the universe is expanding. According to Hubble's Law, if you know how fast the universe is expanding (called Hubble's Constant), you can calculate roughly how long ago the universe began for it to reach its current size. This gives us a universe that is at least 12 billion years old.
2. **Composition of the Universe:** Another piece of evidence comes from the abundance of the elements we see in the universe. According to the Big Bang Theory, the simplest elements would have been the first to form and all heavier elements would have come from nuclear fusion inside stars. When astronomers look at the elements in the universe, we find that the identifiable matter in the universe is mostly hydrogen. This matches the predictions made by the Big Bang Theory. In fact, measurements show that the universe is 74% hydrogen and 24% helium. In order to create this much helium from nuclear fusion, the universe would have to be at least 12 billion years.
3. **Age of Stars:** The universe cannot be younger than the oldest stars. Stars form in different sizes, usually from the collapse of a nebula or cloud of dust and gas in space. The larger stars fuse hydrogen into helium at a tremendous rate, and die as supernova explosions after only a few million years. Smaller stars take longer to use up their hydrogen. Some stars, such as our Sun, have formed partly from the exploded remains of older stars. The oldest stars are among the smallest, and are called red dwarf stars. Estimates of the age of the oldest red dwarfs give an age for the universe of at least 13 billion years.
4. **Cosmic Background Radiation:** According to the Big Bang Theory, as the universe expanded, the energy of the early universe should have cooled. That cooled energy should still be found throughout the entire universe, with small fluctuations found throughout. We can detect this remaining energy, with predicted fluctuations, as the cosmic background radiation (CBR). By measuring the size of the irregularities in the CBR, you can calculate the age of the universe with great accuracy. This gives an age for the universe of 13.8 billion years.

Putting It Together



https://www.nasa.gov/feature/goddard/2016/hubble-team-breaks-cosmic-distance-record

Focus Questions:

1. Explain the present day distribution of matter compared to the distribution of matter 13.8 billion years ago.

2. Explain how the redshift of distant galaxies can help us understand the history of the universe.

Final Task:

Construct an explanation for the Big Bang based on evidence of the distribution of matter and energy in the universe.

1.3 Life Cycle of a Star (ESS.1.3)

Phenomenon

The table below displays data for three different stars.

	Betelgeuse	The Sun	Sirius A
Size	Supergiant	Dwarf/Medium	Medium
Color	Red	Yellow	White
Mass	20x mass of sun	1 Solar Mass	2x mass of sun
Surface Temperature	3226.85°C	5504.85°C	9666.85°C
Elements in the Core	Nitrogen, Carbon, neon, magnesium	Hydrogen, Helium	Hydrogen, Helium

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions:

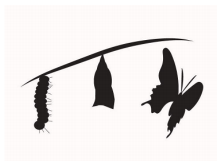
1. According to the table, what appears to be the relationship between the size and mass of a star and its color?

2. According to the table, what appears to be the relationship between the size and mass of a star and its surface temperature?

3. According to the table, what appears to be the relationship between the size and mass of a star and the elements in its core?

ESS.1.3 Life Cycle of a Star

Develop a model to illustrate the changes in matter occurring in a star's life cycle. Emphasize that the way different elements are created varies as a function of the mass of a star and the stage of its lifetime. (PS3.D, ESS1.A)



In this section, look for examples that show stability and change in systems can be measured and modeled, and that some changes may be irreversible.

Image by PublicDomainVectors.org, CC0

What changes do stars undergo in their lifetimes?

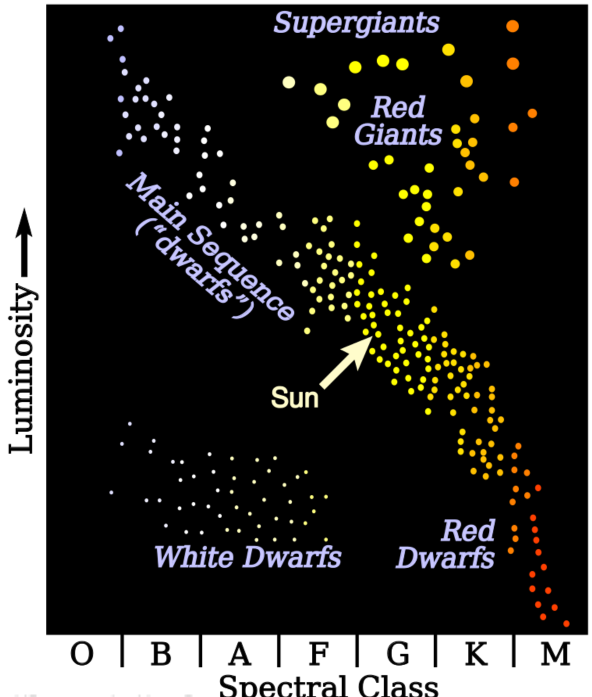
Stars have a life cycle, just like people: they are born, grow, change over time, and eventually grow old and die. Most stars change in size, color, and class at least once in their lifetime. What astronomers know about the life cycles of stars is because of data gathered from visual, radio, and X-ray telescopes.

Star Life Cycles: the HR Diagram

Astronomers now realize that everything which appears to distinguish one star from another - temperature, luminosity, size, life span, and the elements they produce through nuclear fusion - is determined almost entirely by one factor: the star's mass.

In 1910, two astronomers named Ejnar Hertzsprung and Henry Norris Russell independently discovered a relationship between the luminosity of a star and the star's temperature or color, called spectral class. They mapped these properties, and created a chart that is now known as the HR Diagram. They found that stars fell into certain well-defined areas of the diagram.

Depending on its initial mass, every star goes through a life cycle determined by its internal structure and how it produces energy. Each of these stages corresponds to a change in the temperature and luminosity of the star, which can be seen to move to different regions on the HR diagram as it evolves. This reveals the true power of the HR diagram – astronomers can know a star's internal structure and evolutionary stage simply by determining its position in the diagram. All of this can be measured and observed by the starlight that reaches us here on Earth.

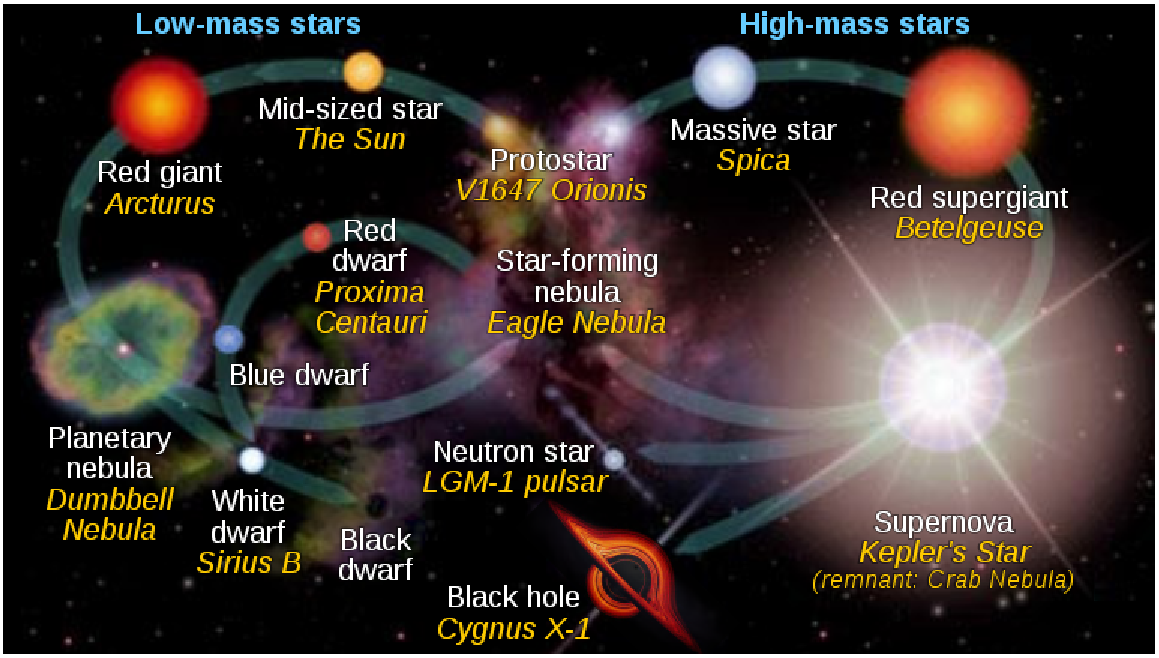


HR-sparse by User:Rursus, https://commons.wikimedia.org/wiki/File:HR-sparse.svg; CC BY-SA

Star Formation

Stars are born in clouds of gas and dust called nebulas. An example is the Orion Nebula, shown below. Our sun and solar system formed out of a nebula as well. For a star to form, gravity pulls gas and dust together. As more gas continues to accumulate, the material becomes denser and the pressure and the temperature increase. When the temperature at the center becomes hot enough, nuclear fusion begins and the ball of gas becomes a star.

https://nasaviz.gsfc.nasa.gov/12086, Image by NASA, public domain



Stellar evolution of low-mass (left cycle) and high-mass (right cycle) stars, with examples in italics. https://commons.wikimedia.org/wiki/File:Star_life_cycles_red_dwarf_en.svg

The Main Sequence

A star is a main sequence star for most of its life. Main sequence stars actively fuse hydrogen into helium and release energy. For stars on the main sequence, temperature is directly related to brightness. A star is on the main sequence as long as it is able to balance the inward force of gravity with the outward force produced by nuclear fusion in its core. The more massive a star, the more it must burn hydrogen fuel to prevent gravitational collapse. Because they burn more fuel, more massive stars have higher temperatures. Massive stars also run out of hydrogen sooner than smaller stars do.

Our Sun has been a main sequence star for about 5 billion years and will continue on the main sequence for about 5 billion more years. Very large stars may be on the main sequence for only 10 million years. Very small stars may last tens to hundreds of billions of years.

Red Giants and White Dwarfs

As a star begins to use up its hydrogen, it fuses helium atoms together into heavier atoms such as carbon. When the light elements are mostly used up, the star can no longer resist gravity and starts to collapse inward. The outer layers of the star grow outward and cool. The larger, cooler star turns red in color and so is called a red giant.

Eventually, a red giant burns up all of the helium in its core. What happens next depends on how massive the star is. A typical star, such as the Sun, stops fusion completely. Gravitational collapse shrinks the star's core to a white, glowing object about the size of Earth, called a white dwarf. A white dwarf will ultimately fade out.

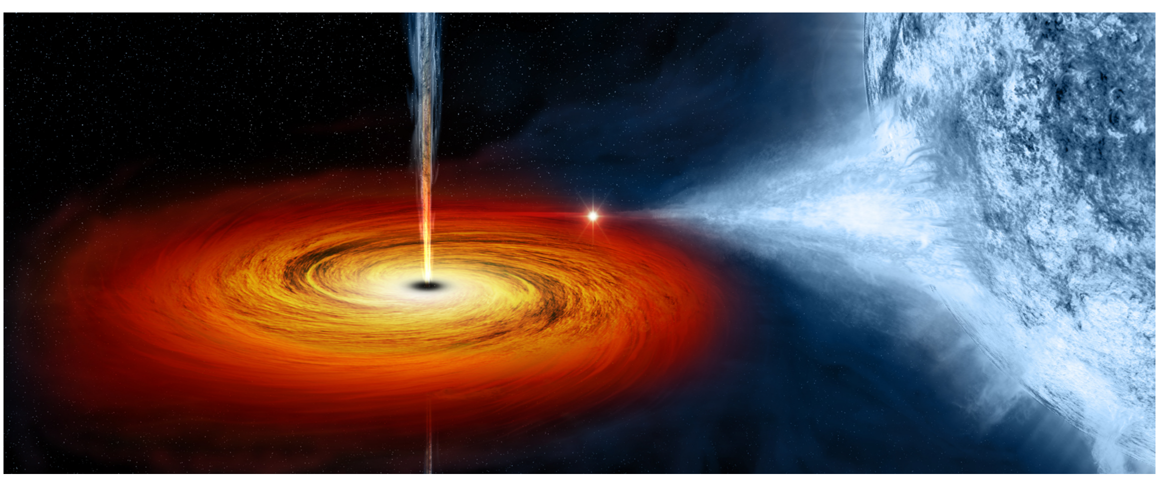
Supergiants and Supernovas

When very massive stars leave the main sequence, they become red supergiants. Unlike a red giant, when all the helium in a red supergiant is gone, fusion continues. Lighter atoms fuse into heavier atoms up to iron atoms. Creating elements heavier than iron through fusion uses more energy than it produces, so stars do not ordinarily form any heavier elements. When there are no more elements for the star to fuse, the core succumbs to gravity and collapses, creating a violent explosion called a supernova. A supernova explosion contains so much energy that atoms can fuse together to produce heavier elements such as gold, silver, and uranium. A supernova can shine as brightly as an entire galaxy for a short time.

Neutron Stars and Black Holes

After a supernova explosion, the leftover material in the core is extremely dense. If the core is less than about four times the mass of the Sun, the star becomes a neutron star. A neutron star is more massive than the Sun, but only a few kilometers in diameter. A neutron star is made almost entirely of neutrons, relatively large particles that have no electrical charge.

If the core remaining after a supernova is more than about five times the mass of the Sun, the core collapses into a black hole. Black holes are so dense that not even light can escape their gravity. With no light, a black hole cannot be observed directly. But a black hole can be identified by the effect that it has on objects around it and by radiation that leaks out around its edges.



An artist's drawing a black hole named Cygnus X-1 that pulls matter from a blue star beside it. https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-a-black-hole-k4.html

Putting It Together

	Betelgeuse	The Sun	Sirius A
Size	Supergiant	Dwarf/Medium	Medium
Color	Red	Yellow	White
Mass	20x mass of sun	1 Solar Mass	2x mass of sun
Surface Temperature	3226.85ºC	5504.85ºC	9666.85ºC
Elements in the Core	Nitrogen, Carbon, neon, magnesium	Hydrogen, Helium	Hydrogen, Helium

Focus Questions:

1. Using the stars from the table, explain how the characteristics of each star will change as they progress through their lifetime.

2. Explain the differences in the elements found in the cores of the three from the table.

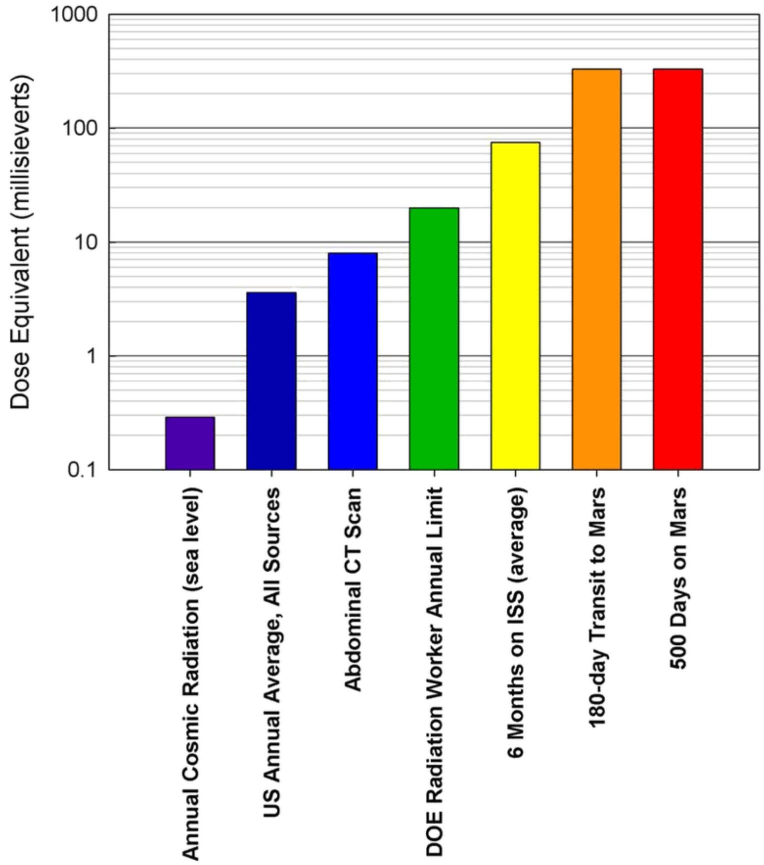
Final Task:

Draw and label a model showing the changes to energy and matter that occur in an average star throughout its lifetime.

1.4 Space Exploration (ESS.1.4)

Authentic Situation

The Sun emits a constant stream of radiation into space. Here on Earth we are protected from dangerous levels of radiation by the Earth's magnetic field. The graph below shows a comparison of radiation exposure for humans in different locations and scenarios.



PIA17601-Comparisons-RadiationExposure-MarsTrip-20131209 by NASA; https://commons.wikimedia.org/wiki/File:PIA17601-Comparisons-Radiation Exposure-MarsTrip-20131209.png, public domain

Observations and Wonderings:

What is the problem in this situation?

What are possible criteria (positive outcomes) to this situation?

What are constraints (limitations) with this situation?

Focus Questions:

1. According to the graph, how much more radiation are astronauts in space exposed to compared to humans on Earth?

2. Predict what might happen if humans are exposed to high levels of radiation.

3. What challenges does radiation pose for the future of space exploration?

ESS.1.4 Space Exploration

Design a solution to a space exploration challenge by *breaking it down into smaller, more manageable problems that can be solved through the* structure and function of *a device. Define the problem, identify criteria and constraints, develop possible solutions using models, analyze data to make improvements from iteratively testing solutions, and optimize a solution.* Examples of problems could include, cosmic radiation exposure, transportation on other planets or moons, or supplying energy to space travelers. (ESS1.A, ESS1.B, ETS1.A, ETS1.B, ETS1.C)

In this section, focus on the idea that the structure and functions of designed objects can be used as solutions to current problems.

Information and images in this section courtesy of NASA
Challenges to Human Space Exploration: https://www.nasa.gov/hrp/5-hazards-of-human-spaceflight, CC-BY

Exploring Space

When exploring space, whether using manned or unmanned missions, problems are abundant. Below is a list of some of the challenges, according to NASA, that arise for manned space exploration.

1. Radiation

The first hazard of human exploration of space is radiation. Radiation is a name for high energy electromagnetic radiation, invisible to the human eye, but very damaging. Radiation is considered one of the most menacing of the five hazards this text will cover.

Above Earth's natural protection, the atmosphere and magnetic field, radiation exposure increases risk of cancer, damages the central nervous system, can alter cognitive function, reduce motor function, and prompt behavioral changes.

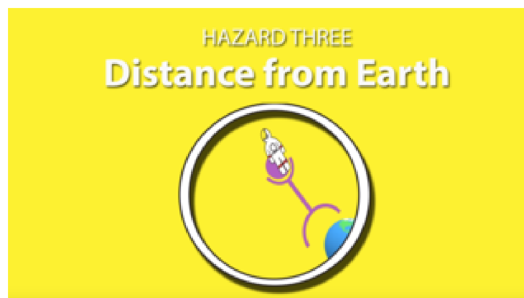
The space station sits just within Earth's protective magnetic field, so while our astronauts are exposed to ten-times higher radiation than on Earth, it's still a smaller dose than what deep space has in store.

2. Isolation and Confinement

Behavioral issues among groups of people crammed in a small space over a long period of time, no matter how well trained they are, are inevitable. The Crew will be carefully chosen, trained and supported to ensure they can work effectively as a team for months or years in space.

On Earth we have the luxury of picking up our cell phones and instantly being connected with nearly everything and everyone around us. In space, astronauts will be more isolated and confined than we can imagine. Sleep loss, a change in sleep cycle, and work overload compound this issue and may lead to a decrease in performance, adverse health outcomes, and compromised mission objectives.

3. Distance from Earth



The third and perhaps most apparent hazard is, quite simply, the distance traveled from Earth. For example a mission to Mars would propel humans, on average, 140 million miles from Earth. Rather than a three-day lunar trip, astronauts would be leaving our planet for roughly three years. While International Space Station expeditions serve as a rough foundation for the expected impact on planning logistics for such a trip, the data isn't always comparable. If a medical event or emergency happens on the space station, the crew can return home within hours. Additionally, cargo vehicles continually resupply the crews with fresh food, medical equipment, and other resources. Once you burn your engines for Mars, there is no turning back and no resupply.

Planning and self-sufficiency are essential keys to a successful space mission. Facing a communication delay and the possibility of equipment failures or a medical emergency, astronauts must be capable of confronting an array of situations without support from their fellow humans on Earth.

4. A Lack of Gravity

The variance of gravity that astronauts will encounter is the fourth hazard of a human mission. For example, on Mars, astronauts would need to live and work in three-eighths of Earth's gravitational pull for up to two years. Additionally, on the six-month round trip between the planets, explorers will experience total weightlessness.

Besides Mars and deep space there is a third gravity field that must be considered. When astronauts finally return home they will need to readapt many of the systems in their bodies to Earth's gravity. Bones, muscles, and the cardiovascular system have all been impacted by years without standard gravity. To further complicate the problem, when astronauts transition from one gravity field to another, it's usually quite an intense experience. Blasting off from the surface of a planet or a hurdling descent through the atmosphere is many times the force of gravity.

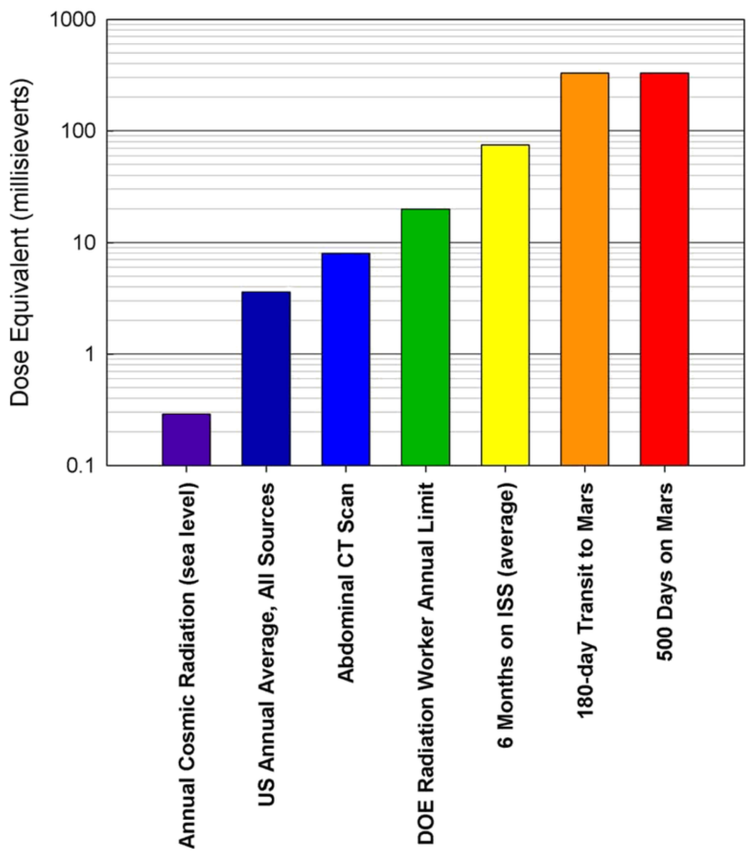
5. Hostile/closed environments

A spacecraft is not only a home, it's also a machine. The ecosystem inside a space-bound vehicle plays a big role in everyday astronaut life. Important habitability factors include temperature, pressure, lighting, noise, and quantity of space. It's essential that astronauts are getting the requisite food, sleep and exercise needed to stay healthy and happy.

Technology, as often is the case with space exploration, comes to the rescue in creating a habitable home in a harsh environment. Everything is monitored, from air quality to possible microbial inhabitants. Microorganisms that naturally live on your body are transferred more easily from one person to another in a closed environment. Astronauts help us understand the effects of space on the human body and can reveal valuable information about possible stressors. They are also asked to provide feedback about their living environment, including physical impressions and sensations so that the evolution of spacecraft can continue addressing the needs of humans in space. Extensive recycling of resources we take for granted is also imperative: oxygen, water, carbon dioxide, even human waste.

Putting It Together

The Sun emits a constant stream of radiation into space. Here on Earth we are protected from dangerous levels of radiation by the Earth's magnetic field. The graph below shows a comparison of radiation exposure for humans in different locations and scenarios.



https://commons.wikimedia.org/wiki/File:PIA17601-Comparisons-RadiationExposure-MarsTrip-20131209.png

Focus Questions:

1. What role could engineering play in addressing the challenges posed by radiation exposure in space?

2. How might the structure and function of space suits, space craft, or the international space station (ISS) prevent or limit radiation exposure?

Final Task:

Design and explain a device that will prevent or limit radiation exposure for astronauts traveling to Mars.

CHAPTER 2

Strand 2: Patterns in Earth's History and Processes

Chapter Outline

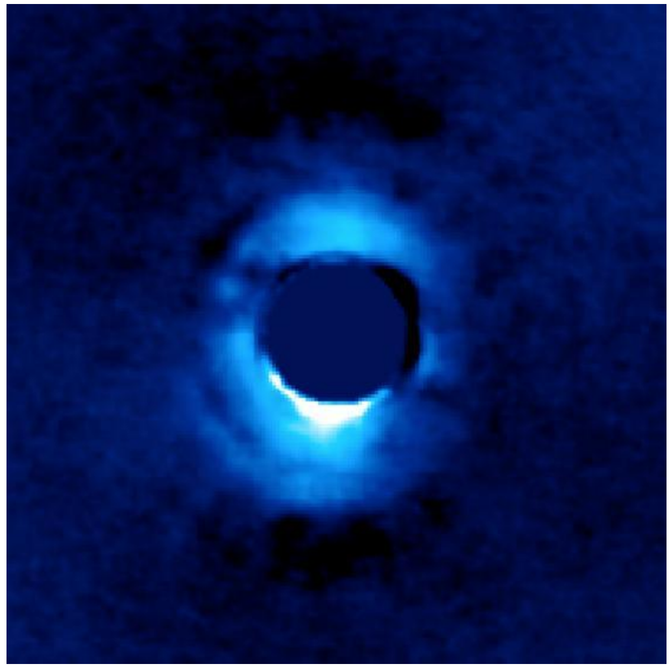
Image by Volcanic Hazards from USGS
https://www.usgs.gov/media/images/k-lauea-volcano-fissure-8-lava-fountain-0 ; public domain

Earth's geologic history can be pieced together based on discoveries of the solar system and Earth's interior. Deep inside the Earth, mantle material is convecting. Earth's internal heat, which drives this convection, is generated by energy produced during radioactive decay and left-over energy from Earth's formation. The constant cycling of warm and cool mantle material causes Earth's crust at the surface to also move creating volcanoes, earthquakes, and other surface features. The theory of Plate Tectonics describes why Earth's crust moves as well as past and current movements of Earth's crust. By piecing together the Earth's history of Plate Tectonics we can understand the geologic past and co-evolution of life on Earth.

2.1 History of Earth (ESS.2.1)

Phenomenon

This image shows the dusty disk of planetary material surrounding the young star HD 141569, located 380 light-years away from Earth. This image was captured by blocking the light from the star in the center (the dark circle) which revealed the ring of orbiting dusty material (brighter disk surrounding the dark circle). The disk around the star extends from 23 to 70 astronomical units (one astronomical unit is the distance between Earth and our sun).



PIA21090: Young Star HD 141569 by NASA/JPL-Caltech; https://photojournal.jpl.nasa.gov/catalog/PIA21090; public domain

Observations and Wonderings

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions

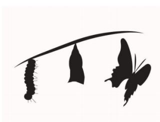
1. Why is HD 141569 surrounded by so much rock, dust, and gas?

2. Predict how the debris orbiting HD 141569 will change over time.

3. Is HD 141569 unique, or are there other stars with similar disks of orbiting dust?

ESS.2.1 History of Earth

Analyze and interpret data to construct an explanation for the changes in Earth's formation and 4.6 billion year history. Examples of data could include the absolute ages of ancient Earth materials, the size and composition of solar system objects like meteorites, or the impact cratering record of planetary surfaces. (ESS1.C)



In this section, focus on identifying the events and processes that caused early Earth's surface to form and change.

Earth's Formation and Age

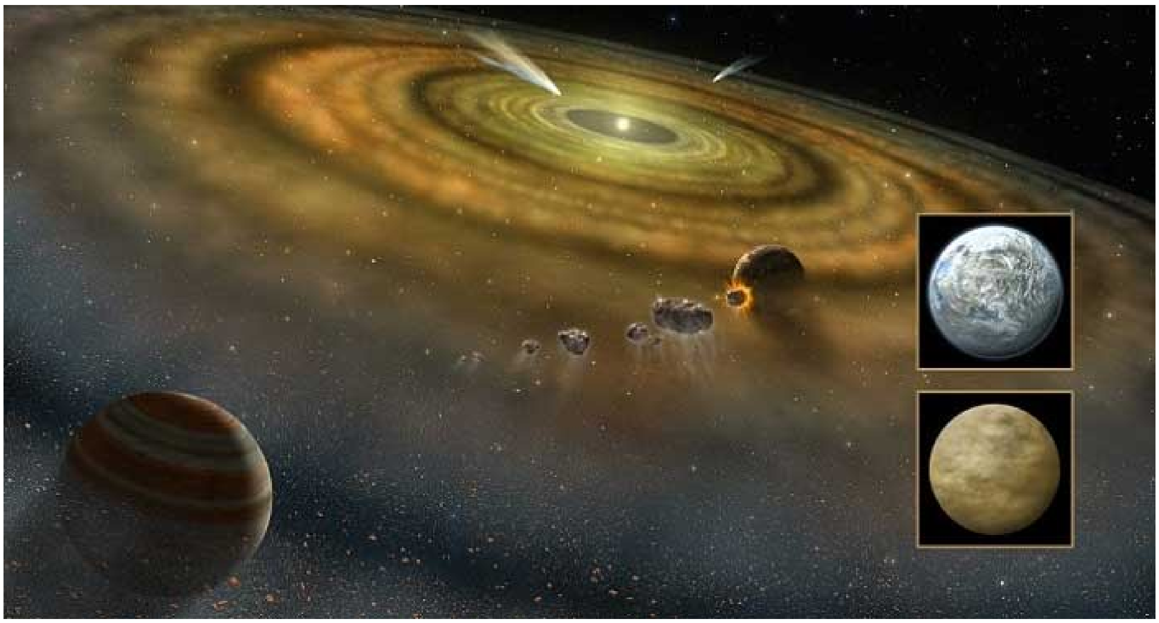
Image by NASA Goddard Space Flight Center, https://flic.kr/p/pPF3FW, CC BY

The image above is an artist's interpretation of what Earth may have looked like after it formed about 4.6 billion years ago. Instead of rivers of water, rivers of molten rock flowed over its surface. Life as we know it could not have survived in such a place. How did this fiery hot planet become today's Earth, covered with water and teeming with life?

Earth's Formation

Our universe was born from the Big Bang 13.8 billion years ago. The first stars were formed from the hydrogen and helium that was made during the Big Bang. Those first stars lived out their lives and eventually exploded, sending heavier elements out into the cosmos. That original stellar material was recycled as another generation of stars, and many of these, too, exploded at the end of their lives. Our Sun is thought to be a third-generation star and our entire solar system is made of the recycled star stuff of previous star generations.

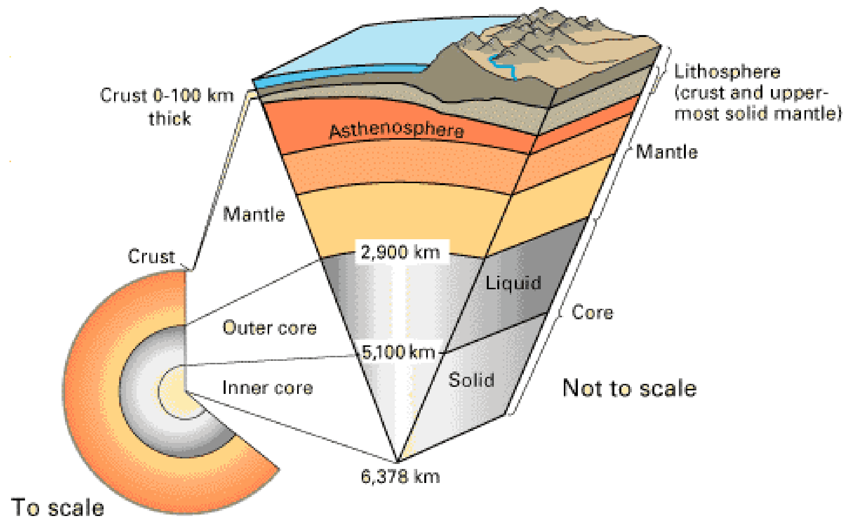
Our solar system began forming about 4.6 billion years ago within a concentration of dust and gas called a nebula. The cloud was probably disturbed by a nearby supernova, which made it collapse and swirl due to its own gravity and our proto-Sun formed in the hot dense center. The remainder of the cloud formed a rotating disk called the solar nebula.



https://mobile.arc.nasa.gov/public/iexplore/missions/pages/yss/november.html; Image by NASA; public domain

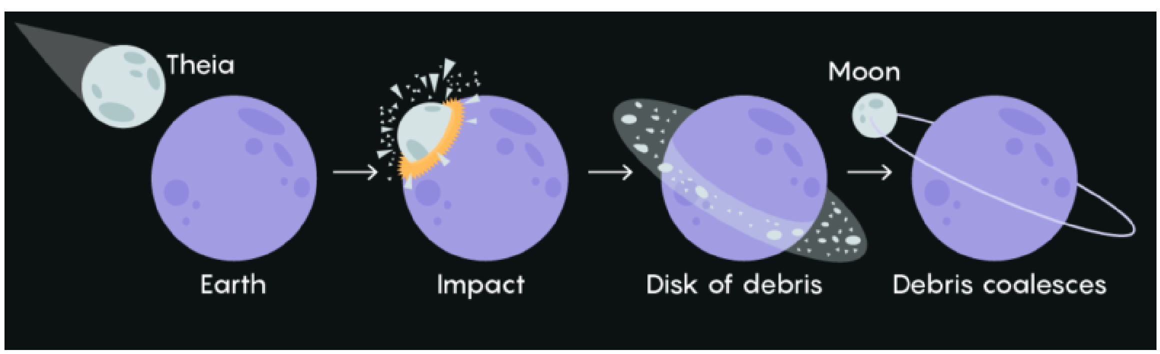
Within the solar nebula, scientists believe that dust and ice particles in the gas collided and clumped together. Through this process, called accretion, these microscopic particles formed larger bodies that eventually became planetesimals with sizes up to a few kilometers across. In the inner, hotter part of the solar nebula, planetesimals were composed mostly of rock and metals. In the outer, cooler portion of the nebula, water ice was the dominant material from which planets were made.

When the planets of the early Solar System grew from a few kilometers to a few hundred kilometers across, they became massive enough that their gravity influenced each other's motions. This increased the frequency of collisions, through which the largest bodies grew most rapidly. As Earth grew, the constant impacts of rocky materials heated it up. While in a molten state, the planet differentiated itself to form layers. The most dense materials were pulled by gravity to the center of the forming planet, while the least dense materials made their way to the surface.



https://upload.wikimedia.org/wikipedia/commons/f/f8/Earth_cutaway_schematic-en.png , CC0

Shortly after Earth formed, the Moon formed. A large object called Theia (about half as wide as Earth) collided with our planet. This collision disintegrated Theia, increased Earth's spin, remelted Earth's outer layers, and flung debris into orbit around Earth. This material formed a ring of gas, dust and molten rock around Earth. In less than a hundred years -- an incredibly short time for the formation of an entire world -- this debris clumped (accreted), growing larger and larger to form our Moon.



https://en.wikipedia.org/wiki/Giant-impact_hypothesis#/media/File:Moon_-_Giant_Impact_Hypothesis_-_Simple_model.png; Image *Simplistic Representation of the Giant -Impact Hypothesis* by Citronade; CC BY-SA 4.0

Determining the Age of Earth and the Solar System: Radiometric Dating

Rocks can be used to determine the Earth's age. However, scientists have not found a way to determine the exact age of the Earth directly from Earth rocks because Earth's oldest rocks have been recycled and destroyed by the rock cycle and the process of plate tectonics. If there are any of Earth's original rocks left, they have not yet been found. Nevertheless, scientists have been able to determine the probable age of the Solar System and to calculate an age for the

Earth by assuming that the Earth and the rest of the planets and rocks in the Solar System formed at the same time and are, therefore, of the same age.

The ages of Earth, Moon rocks, and meteorites are measured by radioactive decay. Radioactive decay is the breakdown of unstable elements into stable elements. To understand this process, recall that the atoms of all elements contain the particles protons, neutrons, and electrons.

An element is defined by the number of protons it contains. All atoms of a given element contain the same number of protons. The number of neutrons in an element may vary. Atoms of an element with different numbers of neutrons are called isotopes. Consider hydrogen as an example. Three isotopes of hydrogen are shown below. Compare their protons (P) and neutrons (n). Each contains one proton, but each contains a different number of neutrons.

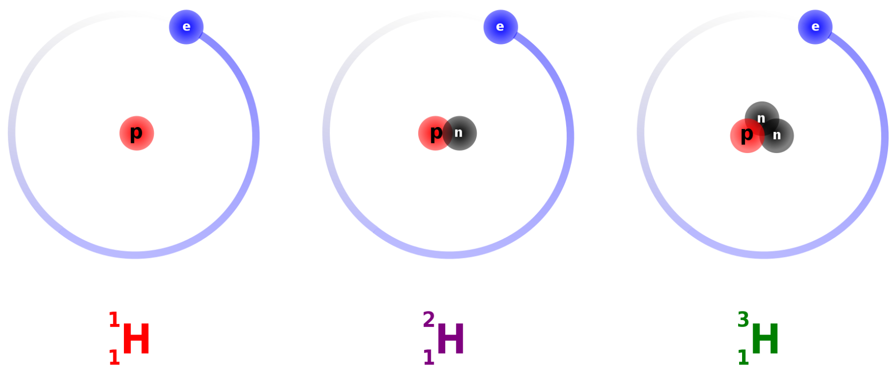


Image by Dirk Hünniger; Derivative work in english - Balajijagadesh - This file was derived from: Hydrogen Deuterium Tritium Nuclei Schmatic-de.svg
https://en.wikipedia.org/wiki/Isotopes_of_hydrogen#/media/File:Hydrogen_Deuterium_Tritium_Nuclei_Schmatic-en.svg; CC BY-SA 3.0

Hydrogen atoms with two neutrons are unstable. It is a radioactive isotope of hydrogen. The decay of an unstable isotope to a stable element occurs at a constant rate. This rate is different for each isotope. The decay rate is measured in a unit called the half-life. The half-life is the time it takes for half of a given amount of an isotope to decay. For example, the half-life of radioactive hydrogen is 12.3 years. The rate of decay of unstable isotopes can be used to estimate the absolute ages of fossils and rocks. This type of dating is called radiometric dating.

Unstable Isotope	Decays to	Half-Life (years)	Dates Rocks Aged (years old)
Potassium-40	Argon-40	1.3 billion	100 thousand – 1 billion
Uranium-235	Lead-207	700 million	1 million – 4.5 billion
Uranium-238	Lead-206	4.5 billion	1 million – 4.5 billion

The isotopes listed above are used to date igneous rocks. These isotopes have much longer half-lives than hydrogen. Because they decay more slowly, they can be used to date much older specimens.

Radiometric dating is a very useful tool, but it does have limits:

1. The material being dated must have measurable amounts of the original, radioactive material (parent isotopes) and/or the decayed material (daughter isotopes).
2. Radiometric dating can only be used with some types of rocks. It is not useful for determining the age of sedimentary rocks. For this, geologists date a nearby igneous rock. Then they use relative dating techniques to figure out the age of the sedimentary rock. They may not get it exactly, but there will be some ideas.

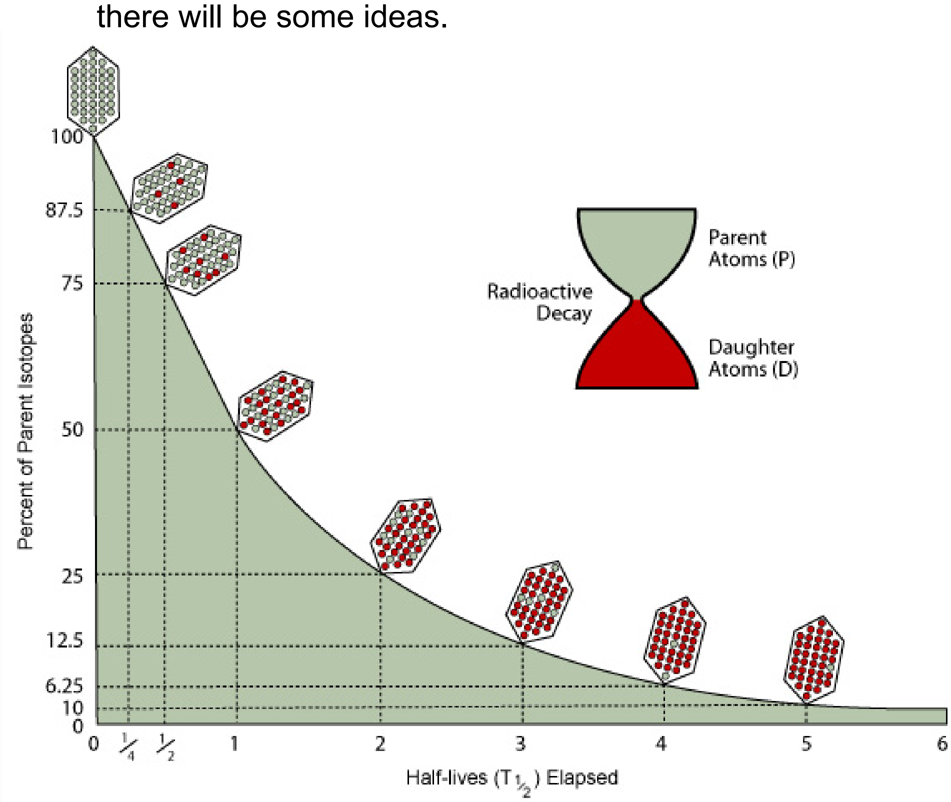


Image by NOAA;

https://oceanexplorer.noaa.gov/edu/learning/player/lesson15/l15_la1.html; public domain

The previous shows the decay of parent atoms to daughter atoms during radioactive decay in a crystal over time.

Using radiometric dating, the ages measured for Earth's oldest rocks and oldest crystals show them to be at least 4.3 to 4.4 billion years in age. Moon rocks have not been disturbed by the rock cycle, but only a small number of rocks were returned to Earth by the six Apollo and three Luna missions. The oldest dated moon rocks have ages between 4.4 and 4.5 billion years and provide a minimum age for the formation of our nearest planetary neighbor.

The best estimate of Earth's age is from iron meteorites, specifically the Canyon Diablo meteorite, a fragment of which is shown below. Thousands of meteorites, which are pieces of asteroids that fall to Earth, have been recovered. When meteorites fall to Earth's surface they can be analyzed to give scientists clues about planet formation and composition. We can assume that because our Earth formed in the same environment as meteorites, that their composition and age can teach us about the timeline of the solar system formation. There are more than 70 meteorites, of different types, whose ages have been measured using radiometric dating techniques. The results show that the meteorites, and therefore the Solar System, formed between 4.53 and 4.58 billion years ago. When averaged, this results in an age for the Earth and meteorites, and hence the Solar System, of 4.54 billion years with an uncertainty of less than 1 percent.

Image by Geoffrey Notkin, Aerolite Meteorites of Tucson; https://en.wikipedia.org/wiki/Canyon_Diablo_(meteorite); CC BY-SA 2.5

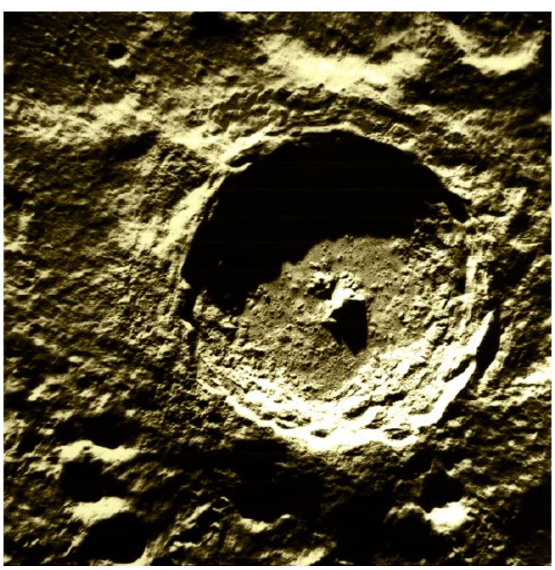
Determining the Age of Earth and the Solar System: Cratering

A crater is a nearly circular depression made on the surface of a planet by an impact event, when meteorites impact the surface. In the images below you can see impact craters on the surface of the Moon, Mercury, and Earth. Earth's surface has been cratered from past impact events, but we don't often see these craters because weathering, erosion, and plate tectonic activity erases them over time.

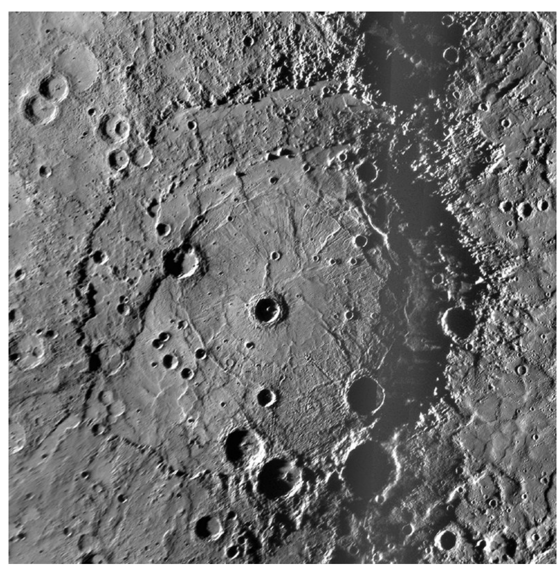
Scientists can study the number of impact craters on the surface of a planet or moon and determine its relative age. Generally, older surfaces will have more impact craters because they have been exposed for a longer period of time. Younger surfaces will have fewer craters. Because the rate at which impacts have occurred in the Solar System has been roughly constant for several billion years, scientists can estimate the age of a surface by counting the number of impact craters. When there are no forces to eliminate craters, the number of craters is simply proportional to the length of time the surface has been exposed. This technique has been applied successfully to many solid planets and moons throughout the Solar System.

Meteor Crater, Arizona

Image Meteor Crater Panorama near Winslow, Arizona, 2012 07 11 by Tsaiproject; https://en.wikipedia.org/wiki/Meteor_Crater#/media/File:Meteor_Crater_Panorama_near_Winslow,_Arizona,_2012_07_11.jpg; CC BY-SA 3.0



The prominent crater Tycho in the southern highlands of the Moon



Rembrandt Impact Basin, Mercury

https://en.wikipedia.org/wiki/Impact_crater#/media/File:Tycho_crater_on_the_Moon.jpg; CC0

Image by NASA;
https://en.wikipedia.org/wiki/Rembrandt_(crater)#/media/File:Rembrandt_crater_mosaic.jpg, public domain

Putting It Together

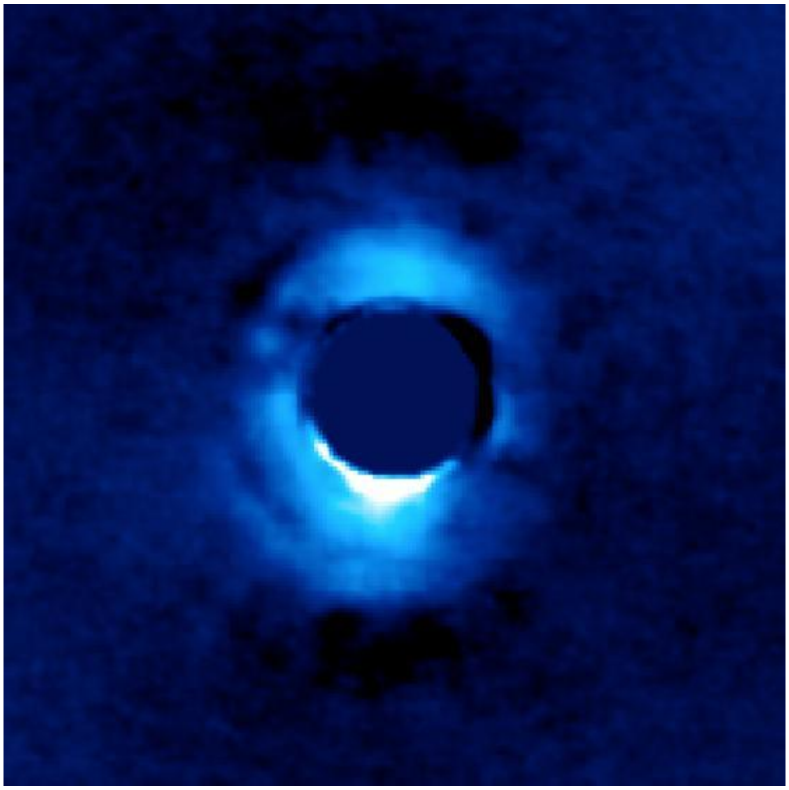


Image by NASA/JPL-Caltech https://photojournal.jpl.nasa.gov/catalog/PIA21090; public domain

This image shows the dusty disk of planetary material surrounding the young star HD 141569, located 380 light-years away from Earth.

Focus Questions

1. Why is there a disk of dusty material orbiting the young star HD 141569? Include in your explanation where the material came from.

2. What will the material in the orbiting disk or nebula of HD 141569 most likely turn into in several billion years?

3. How does this image of HD 141569 and its orbiting disk of dust relate to the history of our own Solar System?

Final Task

Construct an explanation for why the rocks and other materials in HD 141569’s orbiting nebula could be used to determine the age of HD 141569’s solar system?

2.2 Earth's Interior (ESS.2.2)

Phenomenon

This image is of a volcanic rock with visible green olivine crystals called peridotite (a mafic-rich rock). Olivine-rich rocks are rare on Earth's surface because they originate deep within the Earth's mantle. This rock was found in Peridot Mesa, Arizona in 2018.

Peridotite mantle xenoliths in phonotephrite by James St. John; https://flic.kr/p/2bFw7k1; CC BY

Observations and Wonderings

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions

1. Why did this rock originate inside Earth's mantle and not somewhere else?

2. What processes inside the Earth could have brought this olivine-rich rock up to the Earth's surface?

ESS.2.2 Earth's Interior

Develop and use a model based on evidence of Earth's interior and describe the cycling of matter by thermal convection. Emphasize the density of Earth's layers and mantle convection driven by radioactive decay and heat from Earth's early formation. Examples of evidence could include maps of Earth's three-dimensional structure obtained from seismic waves or records of the rate of change of Earth's magnetic field. (PS1.C, ESS2.A, ESS2.B)

In this section, focus on examples of how energy and matter are able to move within Earth's internal layers.

The processes that formed the Earth and the solar system 4.54 billion years ago also caused the early Earth to be very hot. In fact, it was hot enough for the planet to be entirely melted. This melting allowed the most dense materials to sink to the middle of the planet and the lightest, least dense elements to float outward. This resulted in a density stratified planet. The most dense materials make up the central layer, the core. It is surrounded by the mantle, and the layer that you spend your life on is known as the crust.

Earth's Inner Layers

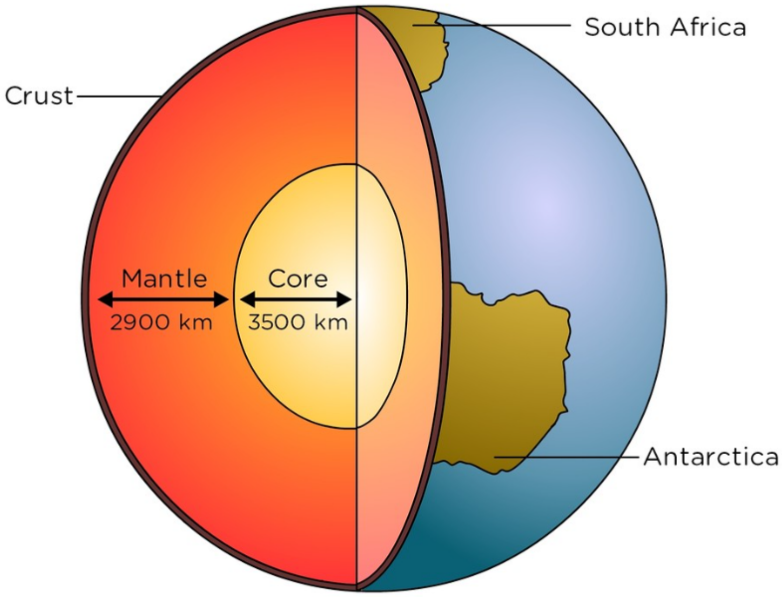


Image Layers of the Earth_simple by Siyavula Education; https://www.flickr.com/photos/121935927@N06/13581799543/; CC BY

Core

The core is dense and forms the center of the Earth. The core is distinguished from other layers of the Earth by its chemical composition. It is primarily composed of iron. The Core can be divided into two layers based on their physical characteristics. The inner core is solid, and the outer core is molten liquid. Here is some of the evidence we have used to understand the core.

Mantle

Outside of the core is the mantle. The mantle is made of hot, solid rock. Scientists know this because of seismic waves, meteorites, and the heat that comes from inside the planet. Mantle rock is mostly peridotite, which is rich in iron and magnesium. Peridotite is rare at Earth's surface.

Like the core, the mantle is separated into different layers based on physical characteristics. The lower part of the mantle is known as the mesosphere. It makes up most of the mantle and is solid and rigid. The next part of the mantle is known as the asthenosphere. This section is still made of the same material, but it is partially molten and less rigid than the mesosphere. This is where convection of mantle materials happens. The very top part of the mantle and the Earth's crust make up a rigid outer layer that is broken up into pieces known as Earth's tectonic plates.

Crust

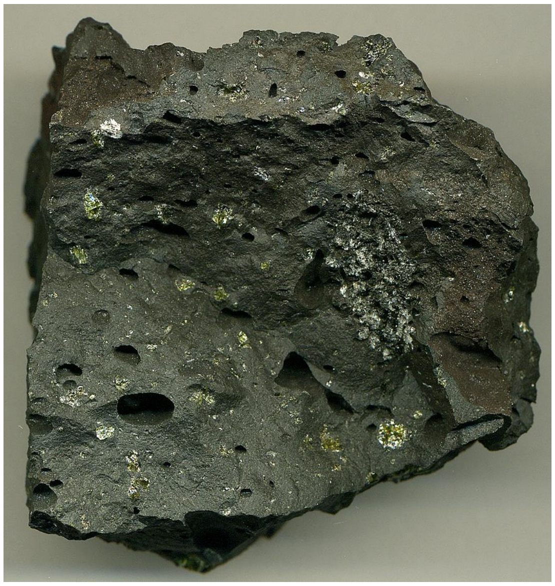
At the surface is the crust. Earth's crust is a thin, brittle outer shell. The crust is made of solid rock. This layer is thinner under the oceans and much thicker in the continents. There are two different types of crust on our planet.

Oceanic crust is made of basalt lavas that flow onto the seafloor. As the molten material cools, it becomes relatively thin and dense. The rocks of the oceanic crust are denser than the rocks that make up the continents. Thick layers of mud cover much of the ocean floor.

Continental crust is much thicker than oceanic crust but its exact thickness varies. Continental crust is made up of many different rocks. All three major rock types—igneous, metamorphic, and sedimentary—are found in the crust. On average, continental crust is much less dense than oceanic crust. Since it is less dense, it rises higher above the mantle than oceanic crust.

The core is mostly iron and nickel, similar to metallic meteorites.

Mantle rock is mostly peridotite (green crystals).



Oceanic crust is made of dense basalt.

Continental crust is made of less dense rocks, like granite.

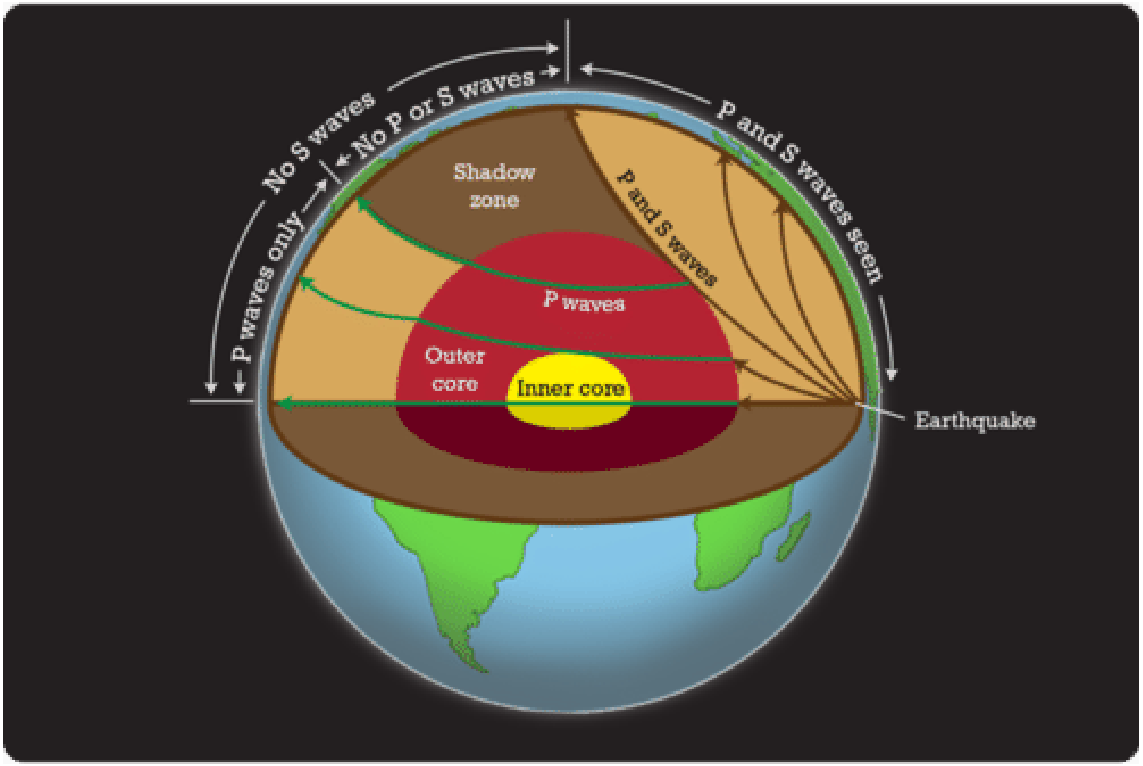
Evidence for Earth's Interior

Properties and Effects of the Core

There is a lot of evidence for what we know about the core. Scientists calculate Earth's density from the planet's rotation. To match the total density, the inner layers must be denser than the outer layers. They must be as dense as metal. This is supported by the idea that metallic meteorites are thought to be some of the material that helped form the earth and the same composition that is found at the core. Also, Earth has a magnetic field. For there to be a magnetic field, there must be liquid metal in the core. The metal must be convecting. If the core did not have convecting metal, there would be no magnetic field.

Seismic Waves

Geologists study earthquake waves to “see” Earth's interior. Waves of energy radiate out from an earthquake’s focus. These waves are called seismic waves (Figure below). Seismic waves react differently depending on the material through which they travel. They travel at different speeds, they change speed when they go from one type of material to another (causing them to bend toward the surface), and some seismic waves do not travel through liquids or gasses at all - they just stop. The patterns by which waves travel through the Earth, because of the structure of Earth's interior and the properties of its different layers, produce shadow zones at Earth’s surface. The seismic shadow zone is the area of the Earth's surface where seismographs cannot detect an earthquake after the waves have passed through Earth’s interior. Because of the different patterns that waves produce as they travel through Earth’s interior, scientists use information from seismic waves to understand the properties of Earth’s interior.



Seismic waves allow scientists to understand the properties of Earth's interior.
Image by Christopher Auyeung and Laura Guerin, CK-12 Foundation, CC BY-NC 3.0

Meteorites

Scientists study meteorites to learn about the composition of Earth's interior. Meteorites formed in the early Solar System and represent early solar system materials . Some meteorites are made of iron and nickel. They are thought to be very similar to Earth's core.

Magnetic Field

Earth has a magnetic field. In order to produce the magnetic field there must be metal within the planet. Iron and nickel are both magnetic. The metallic core must also be convecting. The Earth's outer core is liquid and in a state of turbulent convection. This convection is a result of heat produced by radioactive decay. The convecting liquid metal in the outer core is a bit like a naturally occurring electrical generator, where the convective kinetic energy is converted to electrical and magnetic energy. The motion of the electrically conducting iron in the presence of the Earth's magnetic field induces electric currents. Those electric currents generate their own magnetic field, and as the result of this internal feedback, the process is self-sustaining so long as there is an energy source sufficient to maintain convection. Earth's magnetic field extends several thousand kilometers into space where it shields us from harmful radiation from the Sun and protects our atmosphere from destruction by solar winds.

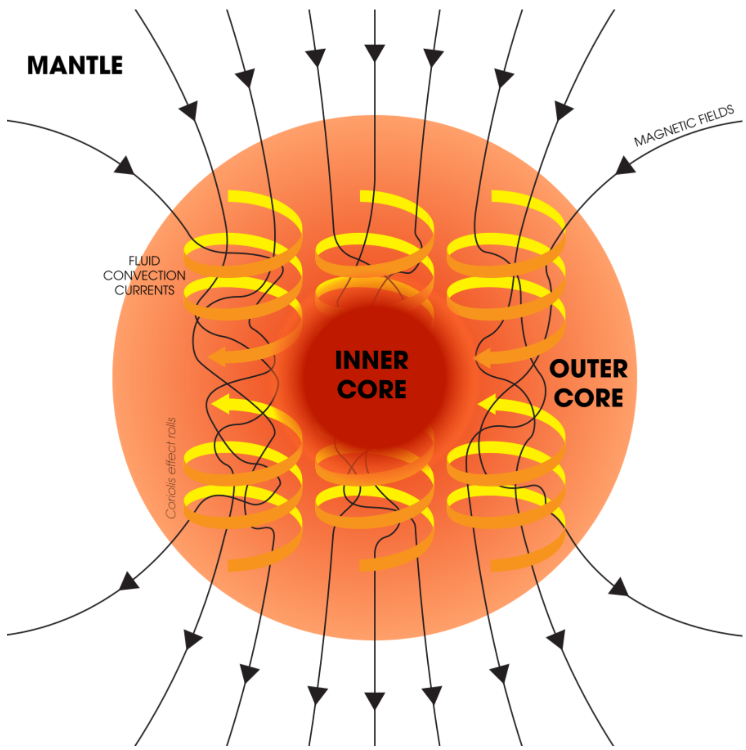


Image by Andrew Z. Colvin; https://commons.wikimedia.org/wiki/File:Dynamo_Theory_-_Outer_core_convection_and_magnetic_field_geenration.svg; CC BY-SA

Earth's Internal Heat

The flow of heat from Earth's interior to the surface comes from two main sources: the heat left over from the formation of Earth and the heat produced by the radioactive decay of isotopes in the Earth's interior.

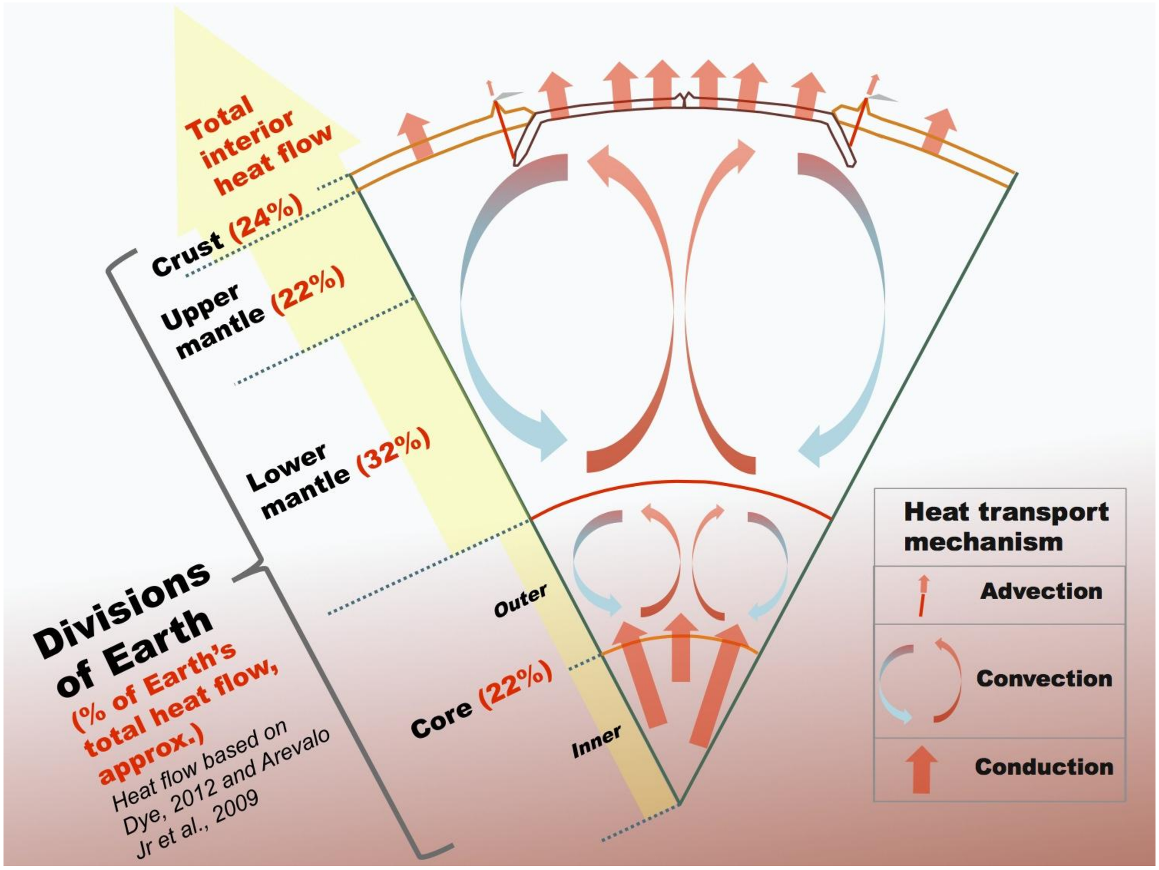
According to the nebular theory of the formation of our solar system there were many collisions that happened to create our present day planet. A lot of heat and energy were generated in that process. Many small particles collided and their kinetic energy was transferred to the newly formed Earth. This energy became heat and raised Earth's temperature. This process is called heat of formation or primordial heat. The early Earth must have been so hot it was a big ball of molten rock. As time progressed the Earth began to cool and rocks on the surface hardened.

However, Earth also makes its own heat. Another source of Earth's interior heat comes from radioactive decay. Radioactive decay occurs when an unstable element breaks down to form a different element. This process releases energy. Deep within Earth's core and mantle there are radioactive elements that are constantly breaking down. Many of these elements are the same elements that scientists use to determine the age of the Earth: potassium and uranium.

Mantle Convection

The heat in Earth's interior eventually works its way to the surface through the process of convection. Convection is the transfer of thermal energy by a moving fluid (either a gas or a liquid). Thermal energy is the total kinetic energy of moving particles of matter, and the transfer of thermal energy is called heat. Thermal energy is always transferred from matter with a higher temperature to matter with a lower temperature. Natural convection results from the tendency of most fluids to expand when heated. They become less dense and rise as a result of the increased buoyancy. Once energy is released, they contract, become dense, and sink to start the cycle over again.

Earth's core is the source of Earth's internal heat. As the heat from the core moves outwards, it warms surrounding material in the mantle. The material in the mantle gains heat and begins to become less dense. As the material in the mantle becomes less dense, it rises through the mantle carrying the heat with it. Eventually the mantle material can no longer rise due to the solid layers above it. When the hot material reaches this point, the heat it was carrying is passed on to the crust where it conducts upwards to the surface. Eventually the mantle loses all of its energy to the crust, cools, and becomes dense again, causing it to sink back towards the core. Once this material gets closer to the core it will warm up again and start the process of convection over. This process of mantle convection takes millions of years and is what allows heat from Earth's core to reach the surface and cause plate tectonics.



Energy transfer mechanisms and heat flow within Earth's interior and at the surface.

Putting It Together

Image by James St. John from Flickr https://www.flickr.com/photos/jsjgeology/45079478214/ ; CC BY

This image is of a volcanic rock with visible green olivine crystals called peridotite (a mafic-rich rock) originating from an ancient lava flow in Peridot Mesa, Arizona.

Focus Questions

1. Why does the composition of this rock tell you it came from the Earth's mantle?

2. How does mantle convection help create lava flows like the one that produced this mafic-rich rock?

3. Describe how density and temperature play a role in mantle convection.

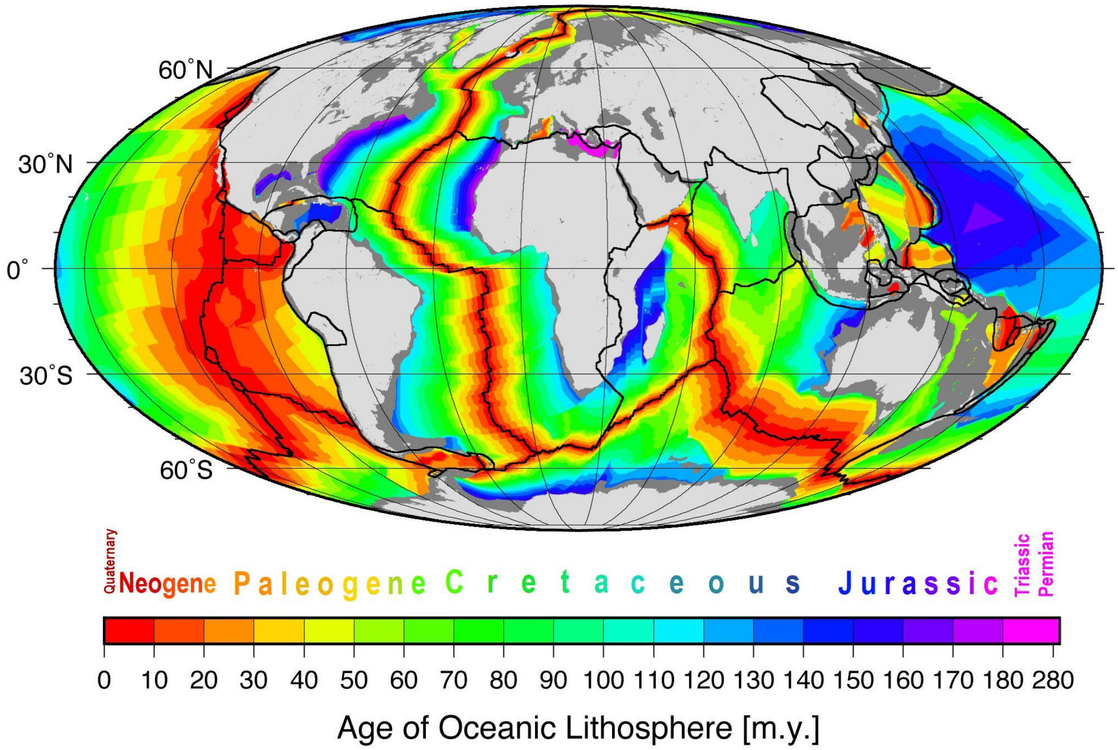
Final Task

Draw and label a model describing how heat from the Earth's core travels through the planet and is able to move mantle material to Earth's surface.

2.3 Plate Tectonics (ESS.2.3)

Phenomenon

This diagram shows the age of the ocean crust. The legend beneath the diagram is in millions of years. 0 m.y. is the present day.



Age of Oceanic Lithosphere by NOAA; Muller, R.D., M. Sdrolias, C. Gaina, and W.R. Roest (2008); https://commons.wikimedia.org/wiki/File:Age_of_oceanic_lithosphere.jpg; CC BY-SA 3.0

Observations and Wonderings

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions

1. Where is the youngest oceanic crust generally located?

2. Where is the oldest oceanic crust generally located?

3. The Earth is over 4 billion years old. Why is there no oceanic crust older than 280 million years?

ESS.2.3 Plate Tectonics

Construct an explanation for how plate tectonics results in patterns on Earth's surface. Emphasize past and current plate motions. Examples could include continental and ocean floor features such as mountain ranges and mid-ocean ridges, magnetic polarity preserved in seafloor rocks, or regional hot spots. (ESS2.B)

In this section, focus on identifying the patterns visible on Earth's surface that are created by the processes of plate tectonics.

Developing the Plate Tectonic Theory

The identification and investigation of patterns on Earth's surface lead to the development of the plate tectonic theory.

Plate tectonic theory had its beginnings in 1915 when Alfred Wegener proposed his "continental drift" hypothesis. Wegener proposed that the continents were once joined and have since moved apart. He had a lot of evidence for his ideas including the locations of fossils, significant rocks, and more. Wegener was one of the first to realize that there was evidence that Earth's surface has changed through time, and that continents that are separated now may have been joined together at one point in the past.

Wegener's ideas were very controversial because he didn't have an explanation for why the continents moved, just that there was observational evidence that they had. His idea was hotly debated off and on for decades before it was largely dismissed. However, beginning in the 1950s, new evidence emerged about patterns on the ocean floor to revive the debate about the movement of Earth's crust.

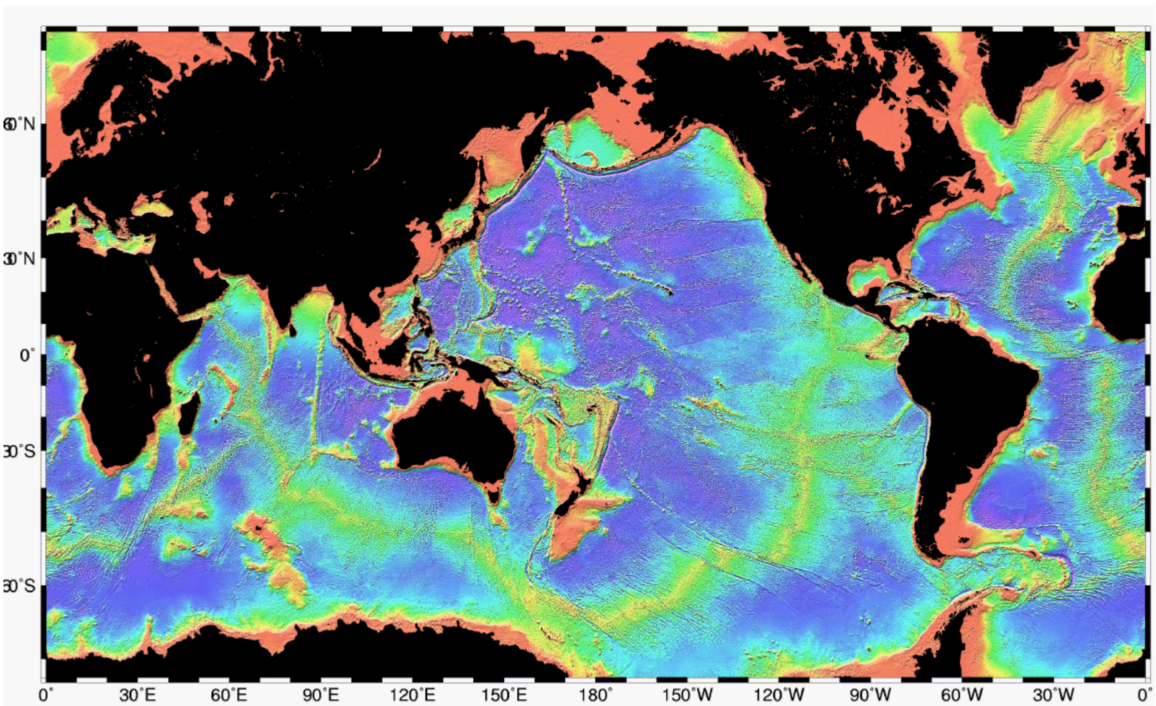
Patterns on the Ocean Floor

About two thirds of the Earth's surface lies beneath the oceans. Before modern tools allowed us to explore the ocean floor, most people thought that it was relatively flat and featureless. Modern oceanic exploration has greatly improved our knowledge of the ocean floor and we now know that it is rugged and complex, and most of the geologic processes occurring on land are linked, directly or indirectly, to the changes on the ocean floor.

In the 19th century deep-sea line soundings, where a weighted line with distances marked off at regular intervals is used to measure the depth of water under a boat, were routinely made in the Atlantic and Caribbean. From these measurements a chart was published that revealed the first evidence of underwater mountains in the central Atlantic. This was later confirmed by survey ships laying the trans-Atlantic telegraph cable. After World War I simple sonar devices began to measure ocean depth by recording the time it took for a sound signal from the ship to bounce off the ocean floor and return. Time graphs of the returned signals confirmed that the ocean floor was much more rugged than previously thought and mapped out the submarine mountain chain in the central Atlantic suggested by the earlier measurements.

In the 1950s, oceanic exploration greatly expanded. Data gathered by oceanographic surveys led to the discovery that a great mountain range on the ocean floor virtually encircled the Earth. Called the global mid-ocean ridge, this immense submarine mountain chain is more than 50,000 km (31,000 miles) long and, more than 800 km (500 miles) across, and rises an average of about 4.5 km (2.8 miles) above the sea floor. It zig-zags between the continents, winding its way around the globe like the seam on a baseball.

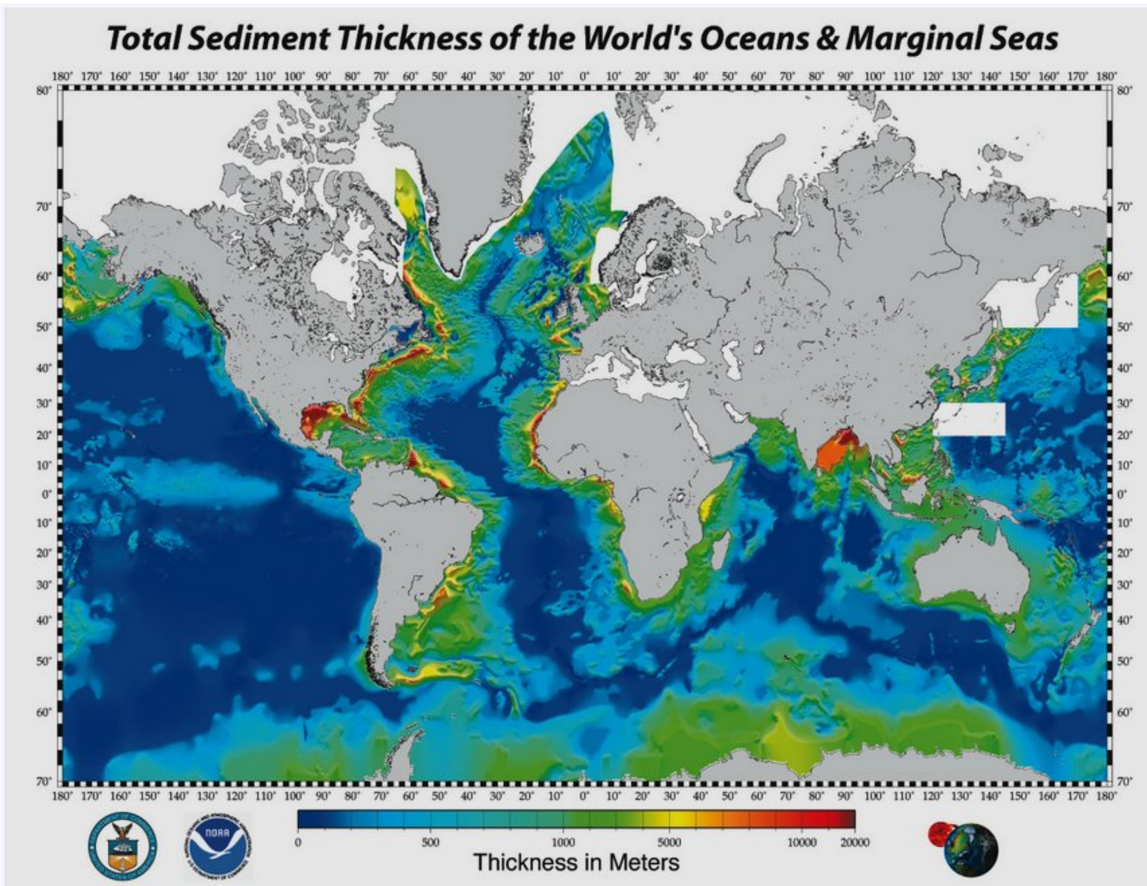
The image below shows depths of the ocean floor. Pink areas are continental shelves, the extension of the continental crust under water. The mid-ocean ridge system is shown as yellow-green areas.



Bathymetry of the ocean floor showing the continental shelves (red) and the mid-ocean ridges (yellow-green) by NOAA;
https://en.wikipedia.org/wiki/Bathymetry#/media/File:Mid-ocean_ridge_system.gif; public domain

In 1947, scientists found that the sediment layer on the floor of the Atlantic was much thinner than originally thought. Scientists had previously believed that the oceans have existed for at least 4 billion years, so therefore the sediment layer should have been very, very thick as material from the continents is weathered, eroded, and deposited on the ocean floor.

The image below shows the thickness of seafloor sediments. The sediments sit on top of the ocean crust, and are thick (green and yellow) along the continental shelves and down the continental slopes. They are at their thinnest (dark blue) near and along the mid-ocean ridge.



Total Sediment Thickness of the World's Oceans and Marginal Seas by NOAA; https://commons.wikimedia.org/wiki/File:Marine_sediment_thickness.jpg; public domain

In the 1950s, scientists identified odd magnetic variations across the ocean floor. Grains of the mineral magnetite in volcanic rock can align themselves with the orientation of the Earth's magnetic field. When magma cools to form solid volcanic rock, the alignment of the magnetite grains is "locked in," recording the Earth's magnetic orientation or polarity at the time of cooling. Scientists began to classify ocean crust rock into two groups according to their magnetic properties. One group has so-called *normal polarity*, where the magnetic minerals in the rock have the same polarity as that of the Earth's present magnetic field. In this case, the minerals of the rock would "point" to the magnetic north pole. The other group, however, has *reversed polarity*, where the minerals "point" south, opposite to that of the Earth's present magnetic field.

As more and more of the seafloor was mapped during the 1950s, it was discovered that the magnetic variations were not random, but instead revealed recognizable patterns. When these magnetic patterns were mapped over a large area, the ocean floor showed a zebra-stripe-like pattern. Alternating stripes of magnetically different rock were laid out in rows on either side of the mid-ocean ridge. The overall pattern, defined by these alternating bands of normally and reversely polarized rock, became known as magnetic striping.

The image below shows the pattern and orientation of normal and reversed polarity stripes surrounding a mid-ocean ridge at the center of the pattern.

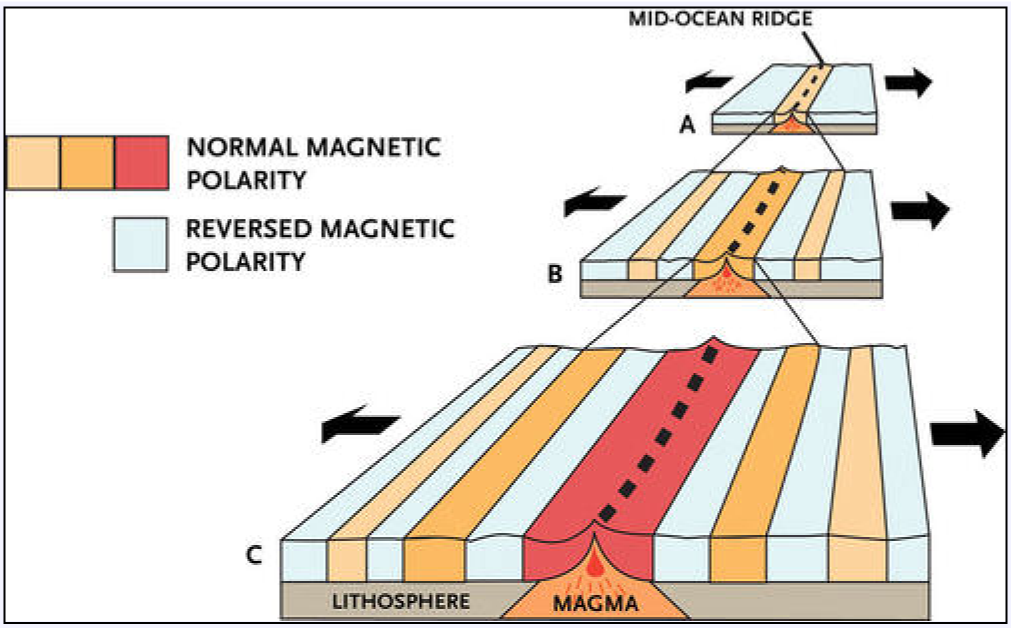


Image Courtesy of US Geological Survey, redrawn by CK-12 Foundation; https://flexbooks.ck12.org/cbook/ck-12-middle-school-earth-science-flexbook-2.0/section/5.5/primary/lesson/magnetic-evidence-for-seafloor-spreading-ms-es/; public domain

The Theory of Seafloor Spreading

Based on the patterns discovered on the seafloor, in 1961 scientists began to theorize that mid-ocean ridges mark areas where the ocean floor was being ripped in two. New magma from deep within the Earth rises easily through these weak, fractured zones and eventually erupts along the crest of the ridges to create new oceanic crust. This process, called seafloor spreading, operating over many millions of years, has built the 50,000 km (31,000 mile) long system of mid-ocean ridges. This hypothesis was supported by several lines of evidence. First, at or near the crest of the ridge, the rocks are very young, and they become progressively older the further away from the ridge crest one goes. Second, at the mid-ocean ridge sediments are very thin and get thicker farther away from the ridge. Third, the youngest rocks at the ridge crest always have present-day (normal) polarity and stripes of rock parallel to the ridge crest alternated in magnetic polarity, suggesting that the Earth's magnetic field has flip-flopped many times and has been recorded by the rocks as they form. The theory of seafloor spreading was confirmed when drill-core rock samples were analyzed and their ages supported the theory.

Scientists Robert Dietz and Harry Hess were among the small handful to understand the implications of sea floor spreading. If the Earth's crust was expanding along the oceanic ridges, Hess reasoned, it must be shrinking elsewhere. He suggested that new oceanic crust continuously spread away from the ridges in a conveyor belt-like motion. Many millions of years later, the oceanic crust eventually descends into oceanic trenches, which are very deep, narrow canyons along the rim of ocean basins. As old oceanic crust was consumed in the trenches, new magma rose and erupted along the spreading ridges to form new crust. In effect, the ocean basins were perpetually being "recycled," with the creation of new crust and the destruction of old oceanic crust occurring simultaneously. Hess' ideas neatly explained why the Earth does not get bigger with seafloor spreading, why there is so little sediment accumulation on the ocean floor, and why oceanic rocks are much younger than continental rocks.

Confirming Seafloor Spreading with Earthquake Data

During the 20th century, improvements in technology enabled scientists to learn that earthquakes tend to be concentrated along the oceanic trenches and spreading mid-ocean ridges. By the late 1920s, seismologists were beginning to identify several prominent earthquake zones parallel to the trenches and extended several hundred kilometers into the Earth. These zones later became known as Wadati-Benioff zones in honor of the seismologists who first recognized them, Kiyoo Wadati of Japan and Hugo Benioff of the United States. The study of global seismicity greatly advanced in the 1960s with the establishment of the Worldwide Standardized Seismograph Network (WWSSN) to monitor the compliance of the 1963 treaty banning above-ground testing of nuclear weapons. The improved data allowed seismologists to map precisely the zones of earthquake concentrations worldwide.

The connection between earthquakes, mid-ocean ridges, and ocean trenches helped confirm the seafloor-spreading hypothesis by pin-pointing the zones where Hess had predicted oceanic crust is being formed (along the ridges) and the zones where oceanic crust sinks back into the mantle to be destroyed (beneath the trenches). The following map shows all earthquakes, by magnitude, over the last century. Most earthquakes occur at the locations Hess identified.

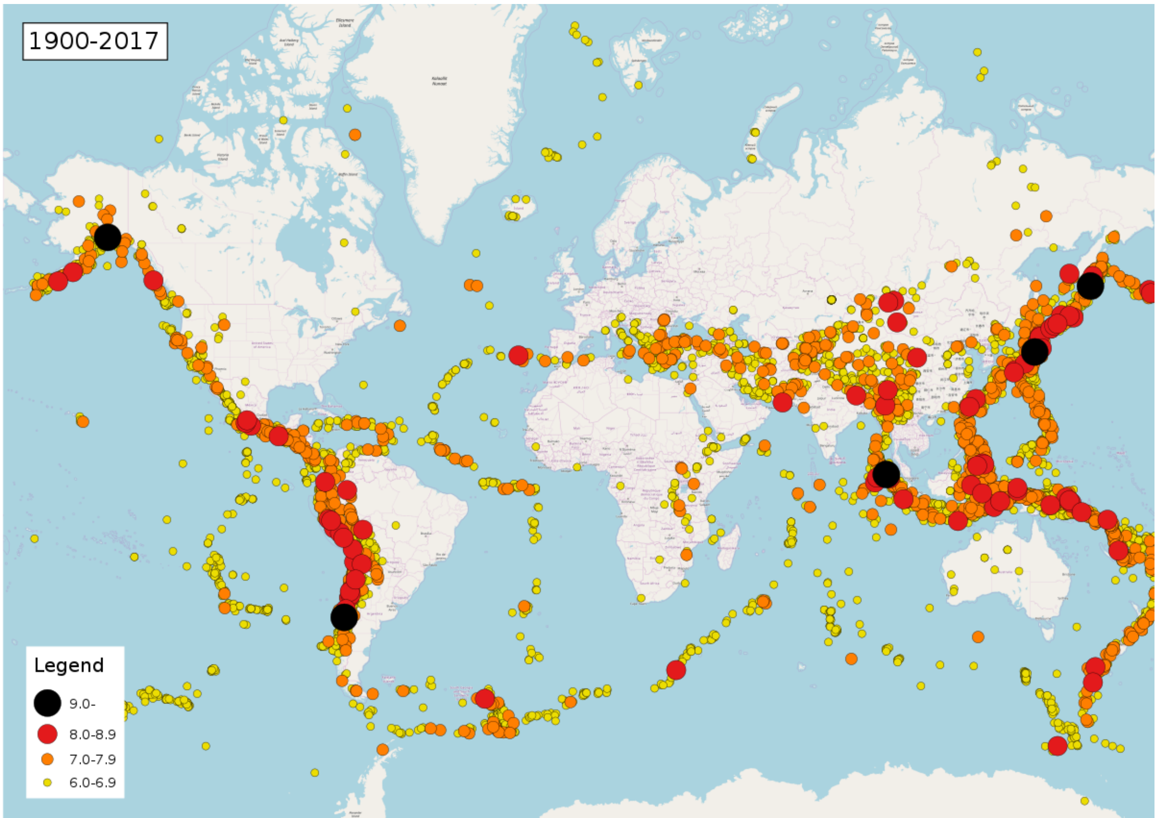


Image by Kml data with data obtained from Earthquake Archives, USGS (earthquake.usgs.gov) https://commons.wikimedia.org/wiki/File:Map_of_earthquakes_1900-.svg; CC BY-SA

The Theory of Plate Tectonics

The ideas of Wegener, the patterns observed on the seafloor, mantle convection, and the theory of seafloor spreading are brought together in our modern theory of plate tectonics. Scientists now have a fairly good understanding of how the plates move and how such movements relate to earthquake activity and the surface features that are a product of plate motions.

Earth’s crust is broken into pieces called plates. Plates are made of oceanic and/or continental crust. The plates are moved around on Earth's surface by seafloor spreading, at about the same rate as your fingernails grow. Convection in the mantle drives seafloor spreading. In fact, plate tectonics can be viewed as the surface expression of mantle convection. Mantle convection describes the movement of the mantle as it transfers heat from the white-hot core to the brittle lithosphere. Convection occurs when hot material rises due to reduced density, cools and increases density, then sinks. As the mantle moves, oceanic crust is created at mid-ocean ridges, the crust moves outward from the ridge over time, then the crust may eventually sink into the mantle to be destroyed. If a continent sits on a plate with a mid-ocean ridge, the continent will be pushed along by these tectonic forces.

The diagram below shows the relationship between mantle convection, spreading at a mid-ocean ridge and the movement of crust, and the destruction of crust as it is pulled back down into the mantle.

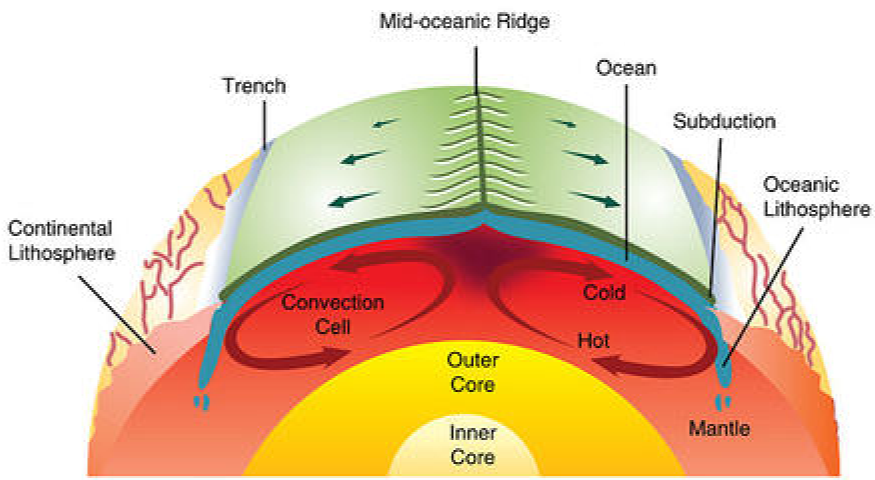


Image by CK12 Foundation;

Putting It Together

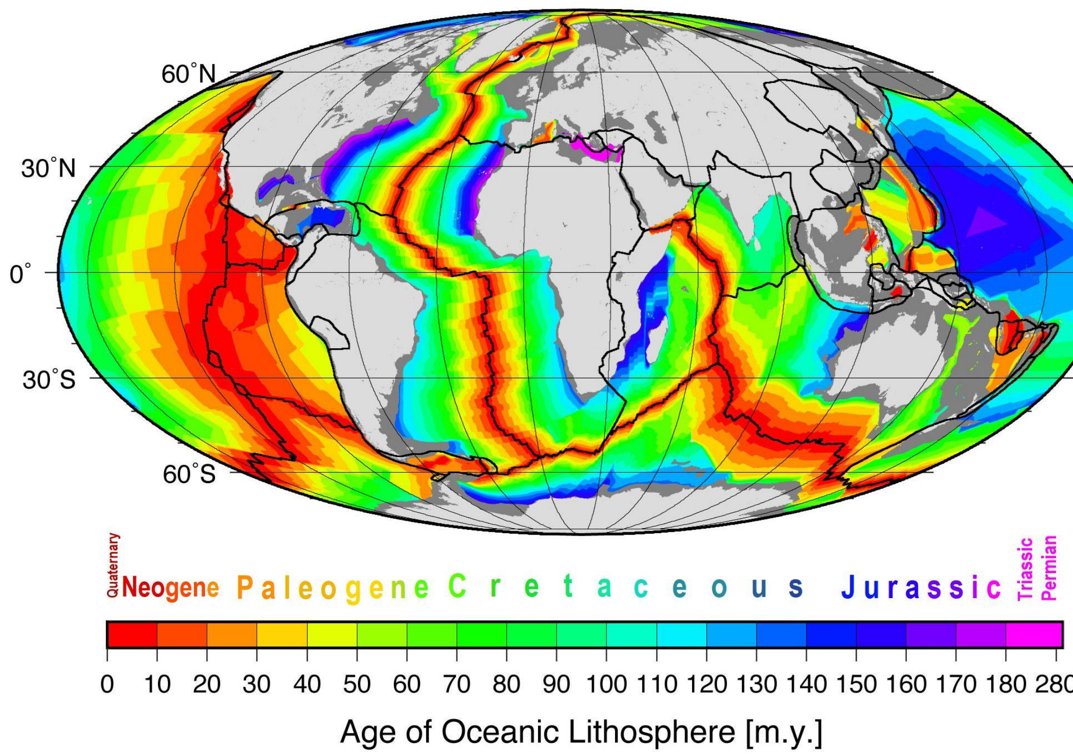


Image by Muller, R.D., M. Sdrolias, C. Gaina, and W.R. Roest (2008)
https://commons.wikimedia.org/wiki/File:Age_of_oceanic_lithosphere.jpg; CC BY-SA

Focus Questions

1. What is happening within the mantle where the youngest oceanic crust is located?

2. What surface features would you expect to find along the ocean floor where the youngest oceanic crust is located?

3. What is happening within the mantle where the oldest oceanic crust is located?

4. How is movement of the Earth's tectonic plates influenced by mantle convection?

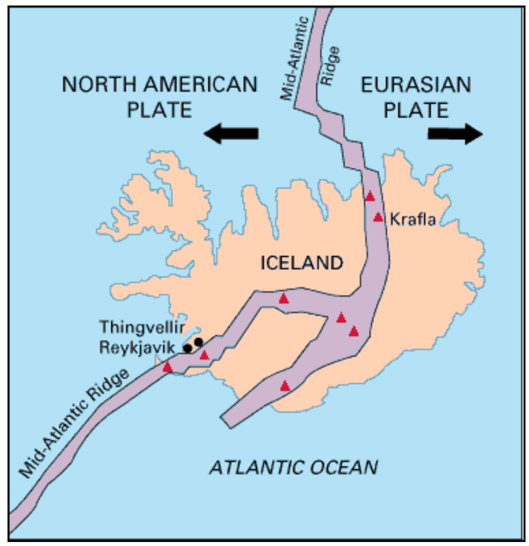
Final Task

The Earth is over 4 billion years old but there is no oceanic crust older than 280 million years. Explain how mantle convection deep beneath Earth's surface is responsible for the continual creation and recycling of oceanic crust.

2.4 Earth Processes (ESS.2.4)

Phenomenon

This image is of Silfra Canyon, Iceland. Silfra Canyon, located within Thingvellir National Park, is a popular scuba diving destination due to the stunning scenery and the chance to swim between two actively rifting tectonic plates! The diagram is a map of Iceland's plate boundary showing the Mid-Atlantic Ridge which separates the North American and Eurasian Plates. Reykjavik, the capital of Iceland, the Thingvellir area, and the locations of some of Iceland's active volcanoes (red triangles) are included.



Observations and Wonderings

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions

1. What type of plate boundary is causing Silfra Canyon in Iceland to slowly get wider every year?

2. Why are there active volcanoes located along the Mid-Atlantic Ridge part of the island?

ESS.2.4 Earth Processes

Develop and use a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal <u>scales</u>. Emphasize how the appearance of land and seafloor features are a result of both constructive forces and destructive mechanisms. Examples of constructive forces could include tectonic uplift or mountain building. Examples of destructive mechanisms could include weathering or mass wasting. (ESS2.B)

In this section, focus on how mantle convection, plate tectonics, and other surface processes take place at different spatial and temporal scales.

Earth is old. Very, very old. It's difficult for us to fully understand just how old our planet is. Some of the processes that have formed Earth have taken billions of years to complete. On the other hand, some events that help to form our earth happen quickly, taking minutes or seconds, and occur every day. Earth is also very big, so big that it appears to be flat to those walking around on its surface. We are too small, and it is too big, for us to easily see its rounded surface. But the Earth is also made up of smaller things that make an impact, like the 8 billion grains of blowing sand in a cubic meter of desert dune. Earth's internal and surface processes operate at different spatial (size or space) and temporal (time) scales and can be both constructive and destructive.

How has the Earth Changed Through Time?

Prior to 1830, scientists believed that the features seen on the Earth's surface, such as mountains and valleys, were formed by large, abrupt changes - catastrophic events. The idea was called catastrophism. The idea of catastrophism was eventually challenged based on observations of the slow, steady processes of mountain building, weathering, erosion, and sedimentation (depositing sediments). The idea that the Earth has formed by slow, steady changes is called uniformitarianism. In this way, "the present is the key to the past," because the slow, steady geologic processes we see happening now are the exact processes that formed the geologic features in the past, like the Himalayan Mountains, or the Grand Canyon. Modern scientists generally agree that Earth changes due to slow, gradual processes interrupted by occasional catastrophic events that violently affect Earth, its life, and its geology - a blend of the ideas of catastrophism and uniformitarianism.

Tectonic Processes Can Happen Over Long Periods on a Global Scale

Using modern technology we can measure how fast tectonic plates are moving. For example, Australia is one of the fastest moving continents on Earth. It travels about 7 cm (3 inches) a year in a northeasterly direction. This may not seem like very much, but 7 cm a year over thousands to millions of years will add up. It is these small, slow rates of movement that produce large changes such as the formation and destruction of the supercontinent Pangaea.

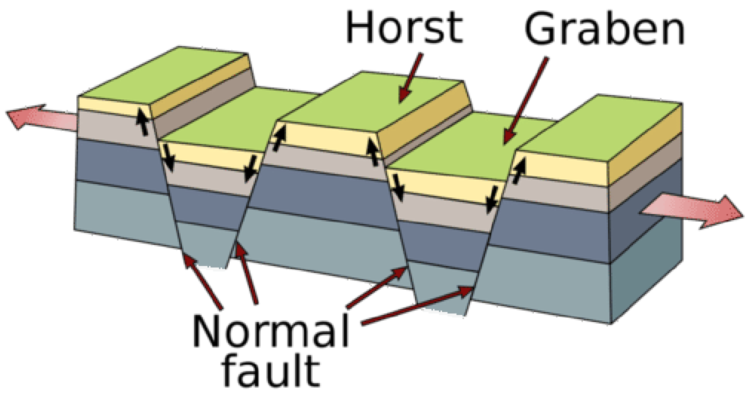
To calculate the movement of plates in the past, scientists can use the patterns of magnetic reversals. Because the ocean-floor magnetic striping records the alternating magnetic field, scientists, knowing about how long a reversal lasted, can calculate the average rate of plate movement during a given time span. These average rates of plate separations can range widely. The Arctic Ridge has the slowest rate (less than 2.5 cm/yr), and the East Pacific Rise has the fastest rate (more than 15 cm/yr (6 inches)). According to the measured age of ocean rocks, it has taken over 175 million years for slow seafloor spreading to form the central Atlantic Ocean, growing from the mid-Atlantic ridge.

Construction and Destruction at Tectonic Plate Boundaries

When two tectonic plates meet they form a plate boundary. There are three basic types of plate boundaries, since there are three ways that plates can meet. There are also many subtypes based on the type of crust interacting at the boundary. Continental crust is less dense than the mantle, so no matter how much force is used to push or pull it, it will never sink down into the mantle. Oceanic crust is similar to, or more dense than the mantle, so when given the chance, it will sink back down into the mantle to be destroyed.

Divergent Boundary

A divergent boundary occurs when two tectonic plates move away from each other and new crust is created. There are two types of divergent boundaries. One forms on continental crust, and the other forms on oceanic crust to produce two different sets of surface features and effects. When continental crust is pulled apart by tectonic forces, it breaks into blocks. These blocks of crust are separated by normal faults. This is known as block faulting. The blocks slide up or down. The result is alternating mountain ranges and valleys. This topography is known as basin-and-range and will include earthquakes as the blocks move and interact. The area near Death Valley, California is the center of a classic basin-and-range province that includes the western parts of Utah.



This diagram shows how a basin-and-range forms.
Image courtesy of the US Geological Survey, Gregors;Jodi So, http://commons.wikimedia.org/wiki/File:Fault-Horst-Graben.svg;Public Domain

Mid-ocean ridges occur along divergent plate boundaries in the ocean crust, where new ocean floor is created as the Earth's tectonic plates move apart. As the plates separate, molten rock rises to the seafloor and produces enormous volcanic eruptions of basalt. The speed of spreading affects the shape of a ridge. Slower spreading rates result in steep, irregular ridges and slopes while faster spreading rates produce much wider ridges and more gentle slopes.

The diagram below shows the features and mechanisms of both a continental and oceanic divergent plate boundary.

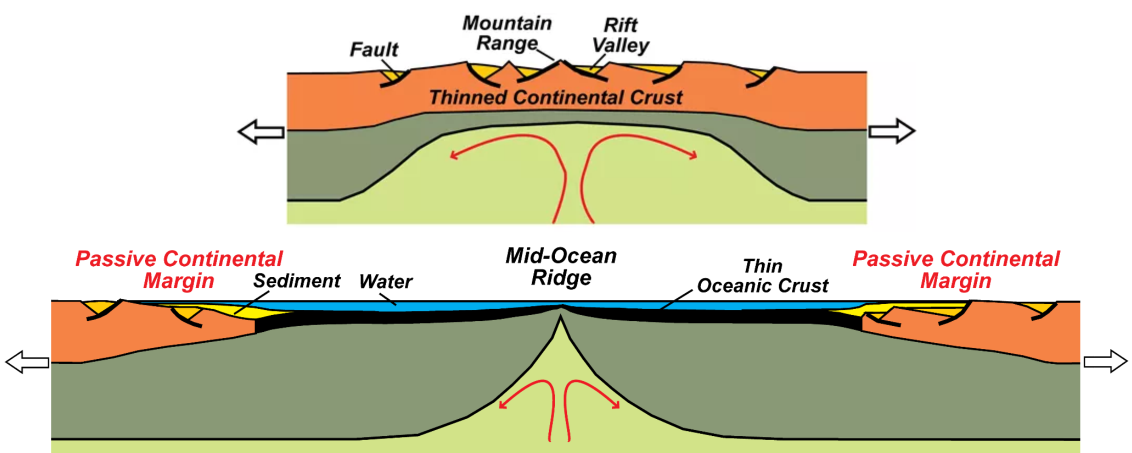


Image by NPS.gov; https://www.nps.gov/subjects/geology/plate-tectonics-divergent-plate-boundaries.htm; CC BY

Convergent Boundary

When two plates collide, it is known as a convergent boundary. There are different types of convergent boundaries dependent on the types and densities of the crust involved. When oceanic plates converge, the oceanic crust is more dense and a plate may bend down to form a subduction zone where crust is pushed into the mantle to be destroyed. A chain of volcanoes often forms parallel to this type of convergent plate boundaries and powerful earthquakes are common where the down-going plate comes in contact with overriding crust and forces its way into the mantle. When two low density continental plates collide, the edges of both plates break and buckle, folding into mountain ranges. Neither plate is dense enough to sink back into the mantle.

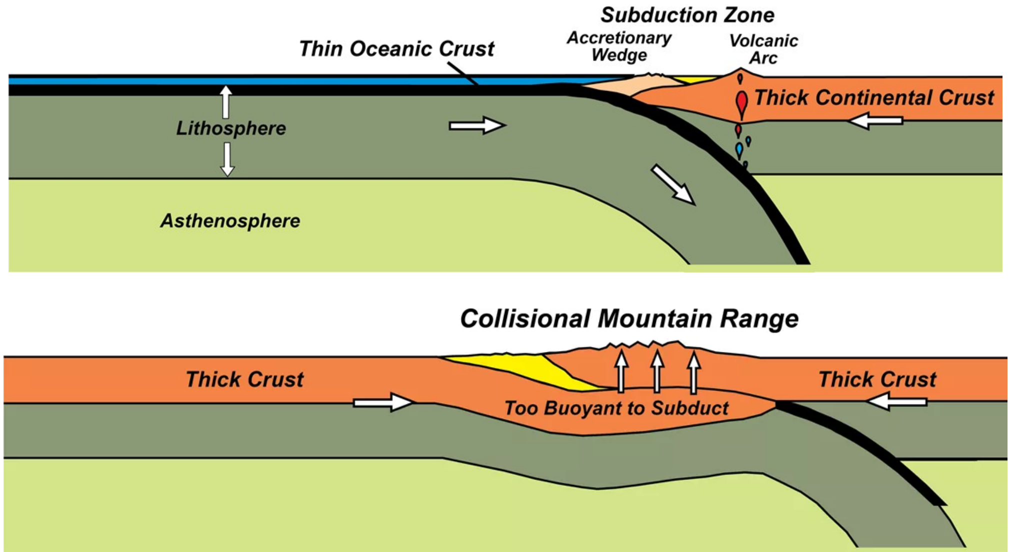


Image by NPS.gov
https://www.nps.gov/subjects/geology/plate-tectonics-collisional-mountain-ranges.htm; CC BY

At convergent boundaries, continental crust is uplifted and oceanic crust is destroyed. The previous diagram shows the two main types of convergent plate boundaries and their features.

Transform Boundary

Two plates sliding past each other form a transform plate boundary. Rocks that line the boundary are pulverized as the plates grind along, creating a linear fault valley or undersea canyon. The broad zone of shearing at a transform plate boundary includes masses of rock displaced tens to hundreds of miles, shallow earthquakes of high magnitude, and a landscape consisting of long ridges separated by narrow valleys. In contrast to convergent and divergent boundaries, crust is cracked and broken at transform margins, but is not created or destroyed.

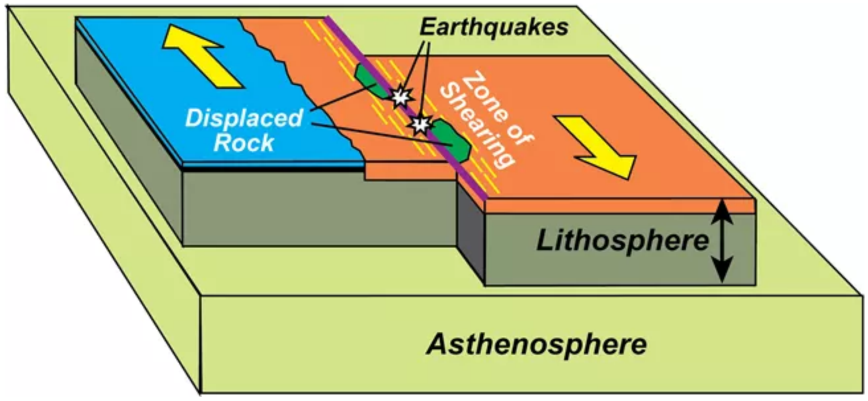


Image by NPS.gov
https://www.nps.gov/subjects/geology/plate-tectonics-transform-plate-boundaries.htm; CC BY

The Effects of Tectonic Processes Can Be Sudden, Local Events

Earthquakes

An earthquake is ground movement caused by the sudden release of energy stored in rocks. Earthquakes happen when so much stress builds up in the rocks that the rocks rupture. The energy is transmitted by seismic waves. Each year there are more than 150,000 earthquakes strong enough to be felt by people and 900,000 recorded by seismometers. About 80% of all earthquakes strike around the Pacific Ocean basin because it is lined with convergent and transform boundaries. About 15% take place in the Mediterranean-Asiatic Belt, where convergence is causing the Indian Plate to run into the Eurasian Plate.

Though they are frequent, strong ground shaking during a moderate to large earthquake typically lasts only an average of about 10 to 30 seconds. This short release of energy can be very destructive. For example, if an earthquake were to occur on a central part of the Wasatch fault in Utah, the damage to buildings could exceed $4.5 billion in Davis, Salt Lake, Utah, and Weber counties. This may only represent 20% of the total economic loss, however. Unreinforced masonry buildings (for example, brick homes built before 1960) are particularly vulnerable to ground shaking and are expected to account for 75% of the building losses. Surface faulting and ground failures due to shaking during a large earthquake would also cause major disruption of lifelines (utilities, water, sewer), transportation systems (highways, bridges, airports, railways), and communication systems.

When earthquakes occur underwater they can produce tsunamis. In March 2011 an enormous 9.0 earthquake struck off of Sendai in northeastern Japan. This quake, called the 2011 Tōhoku earthquake, was the most powerful ever to strike Japan and one of the top five known in the world. It shook the ground for six minutes. Damage from the earthquake was nearly overshadowed by the tsunami it generated, which wiped out coastal cities and towns. Two months after the earthquake, about 25,000 people were dead or missing, and 125,000 buildings had been damaged or destroyed. Aftershocks, some as large as major earthquakes, continued to rock the region after the initial earthquake.

Volcanic Eruptions

Volcanoes are common along convergent and divergent plate boundaries. Volcanoes erupt because crustal rock melts. At convergent plate boundaries, the subducting plate heats up as it sinks into the mantle. Also, water is mixed in with the sediments lying on top of the subducting plate. This water lowers the melting point of the crust, which increases melting. At divergent plate boundaries, hot mantle rock rises where the plates are moving apart. This releases pressure on the crust, which lowers its melting temperature. Lava erupts through long cracks in the ground called fissures.

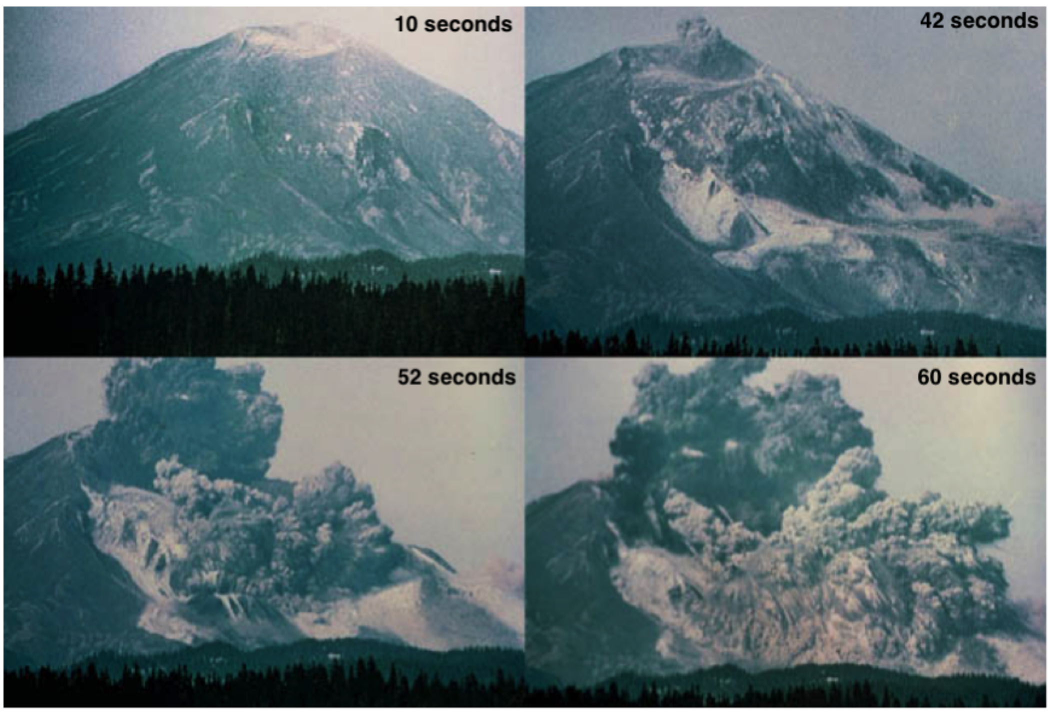


Image by USGS; https://volcanoes.usgs.gov/volcanic_ash/mount_st_helens_1980.html; public domain

An example of a volcanic eruption along a convergent plate boundary occurred in the United States in 1980, shown by the previous progression of images. After two months of earthquakes and small explosions, Mount St. Helens, in Washington State, cataclysmically erupted. A high-speed blast leveled millions of trees and ripped soil from bedrock. The eruption fed a towering plume of ash for more than nine hours, and winds carried the ash hundreds of miles away. Lahars (volcanic mudflows) and the largest landslide in US history, carried large boulders and logs, which destroyed forests, bridges, roads, and buildings. The eruption and following events led to 57 deaths and caused the worst volcanic disaster in the recorded history of the continental United States.

A large explosive volcanic eruption is even more devastating than the force of the atom bomb dropped on Nagasaki at the end of World War II in which more than 40,000 people died. These types of eruptions are 10,000 times as powerful. Trapped, hot, gas-rich magma churns within the chamber, building up pressure until the pressure is eventually released, sometimes by an earthquake or even a landslide (in the case of Mount St Helens). When this pressure is finally released, magma, rock, and ash burst upward in an enormous explosion. Scorching hot rock, ash, and gas may speed down the volcano's slopes at 700 km an hour (450 mph) as a pyroclastic flow. Pyroclastic flows knock down everything in their path. The temperature inside a pyroclastic flow may be as high as 1,000°C (1,800°F).

Generally, the duration of volcanic eruptions are also short compared to other tectonic processes. 9 percent of eruptions end in less than one day, 24 percent within one week, 43 percent within a month, and 83 percent within a year. There are exceptions, however. The Hawaiian volcano Kīlauea has been gently erupting for more than 16 years, which is an extraordinary long time for an eruption to last.

Other Examples of Constructive and Destructive Forces

Weathering and Erosion

Weathering and erosion act together on Earth's surface to destroy rocks and landforms. Weathering is the process that changes solid rock into smaller pieces through chemical or mechanical means. Weathering rates will vary depending on the process, but can also vary depending on the rock material that is being weathered. Differential weathering processes contribute to the unique formation of many landforms. Climate can also produce differential weathering for the same type of rock. For example, limestone weathers more quickly in wet climates than dry climates.

The following image shows the goblins, or "hoodoos" of Bryce Canyon National Park in Utah. They were formed through gradual differential erosion of sandstone. The spires of rock remain because they represent the material that was more resistant to weathering, while the rock that once surrounded the spire has weathered and eroded away.

Image Hoodoos in Bryce Canyon National Park, Utah by Luca Galuzzi; https://en.wikipedia.org/wiki/Hoodoo_(geology)#/media/File:USA_10654_Bryce_Canyon_Luca_Galuzzi_2007.jpg; CC BY-SA 2.5

Once rock is broken down into sediment, erosion is the process that moves the sediments. While plate tectonics forces work to build huge mountains and other landscapes, the forces of weathering and erosion gradually wear those rocks and landscapes away and carry the sediments to new locations. Because of these processes, tall mountains turn into hills and even plains. The Appalachian Mountains along the east coast of North America were once as tall as the Himalayas but are now significantly smaller.

Another example of the power of erosion is the formation of the Grand Canyon. Between 70 and 30 million years ago, tectonic forces uplifted the area producing the relatively flat Colorado Plateau. Then, beginning just 5-6 million years ago, the Colorado river began to carve its way downward, weathering and eroding the rock to produce the canyon. Still today these forces of nature are at work slowly deepening and widening the Grand Canyon. The canyon is now bigger than the state of Rhode Island. It is 1,857 meters (6,093 feet) deep, 446 km (277 miles) long, and up to 29 km (18 miles) wide.

The Grand Canyon is so large it can be seen from space. The following image of the Grand Canyon and its surrounding area was taken from the International Space Station on March 25th, 2014.

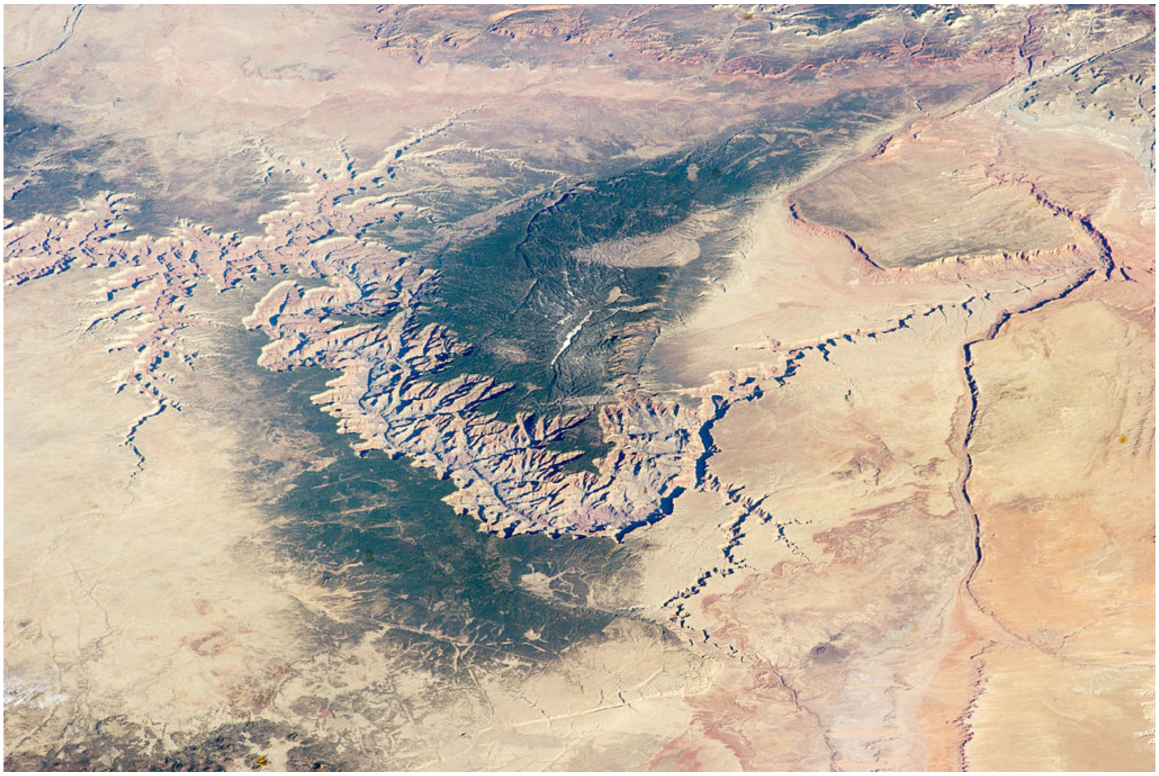


Image of the Grand Canyon and surrounding area taken from the International Space Station by NASA; https://en.wikipedia.org/wiki/Grand_Canyon#/media/File:GrandCanyon.NASA.2014.jpg; public domain

Though the erosional processes discussed so far have taken up to millions of years, erosion can also be rapid. Mass wasting, or landslides, is a rapid form of erosion that works primarily under the influence of gravity. It occurs very quickly and can result in either small or large scale changes to Earth's surface features.

In 1983, the most costly landslide in US history swept down on the tiny town of Thistle Utah, damming up the Spanish Fork River, and severing the rail line that connects Salt Lake City with Denver. Winter and spring had been extraordinarily wet along the Wasatch Front that year. Rain saturated the ground, and late snow melted quickly to destabilize mountain slopes. This allowed gravity to pull the loose sediments down slope. Once triggered, the slide reached a maximum speed of 3.5 feet per hour. Residents were ordered to evacuate, and within a few days the slide had completely closed off the river, causing water to build up behind the artificial dam and bury the town. The landslide ultimately reached 1,000 feet in width, nearly 200 feet in thickness, and over one mile in length.

The following image is an aerial photo of the Thistle area in spring 1983 showing the dam formed by the landslide, "Lake Thistle" over the submerged town, and the construction to re-route highway US-6, US-89, and the rail line around the landslide area. The Thistle landslide disaster cost the state of Utah and the Denver and Rio Grande Western Railroad around 200 million dollars.

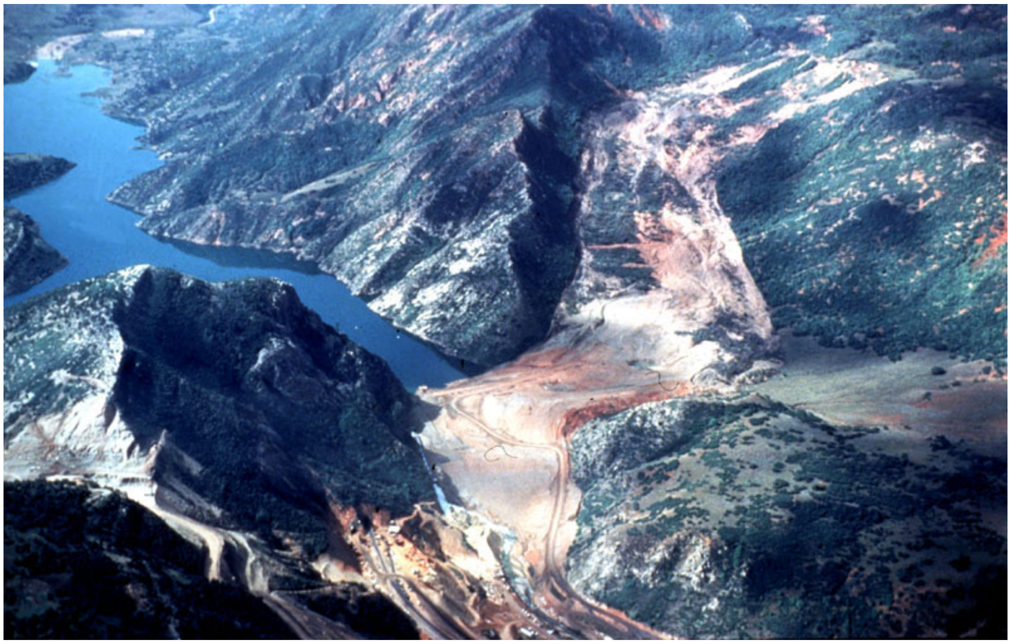


Image Aerial photo of the Thistle area in spring 1983 showing the dam formed by the landslide, "Lake Thistle" over the submerged town, and the construction to re-route US-6, US-89, and the D&RGW around the landslide area by USGS; https://en.wikipedia.org/wiki/Thistle,_Utah#/media/File:Thistlelandslideusgs.jpg; public domain

Sediment Deposition

Deposition is a constructive process that lays down or places weathered and eroded materials in a location that is separate from their source. Deposition is not specific to a single weathering, erosion, or mass wasting event. The accumulation of deposited materials alters the landscapes and builds various landform features. For example, floodplains are large depositional features built by the accumulation of river or stream deposits, and sand dunes are depositional landforms built by wind-related processes.

Speleothems are cave features, including stalactites and stalagmites, formed by the deposition of minerals. As rainwater flows through cracks in rock, it dissolves minerals. When this water that now holds the dissolved rock is exposed to the air in a cave minerals are deposited on cave walls, ceilings, and floors. Speleothems form at varying rates as mineral crystals build up. Several factors can determine the rate of growth. Two important factors are the temperature outside and the amount of rainfall. The shapes of speleothems are determined by how water enters the cave (by dripping, seeping, or splashing) and how the water stands or flows after entering the cave.

Shown in the first image below is Coral Pink Sand Dunes State Park in Utah. The dunes are formed from the erosion of pink-colored sandstone surrounding the park. High winds passing through local canons pick up loose sand particles and then drop them onto the dunes. The dunes are estimated to be between 10,000 and 15,000 years old and can move as much as 50 feet per year. The second image shows Timpanogos Cave formations from 340 million year old limestone deposits. The cave was formed initially by a series of faults running off of the Wasatch fault. Since that time the actions of water and uplift of the Wasatch Mountains has formed the modern cave system. The speleothems first started to form about 750,000 years ago as the rocks were slowly lifted away from and above the American Fork River, now at the base of the canyon.

Image Coral Pink Sand Dunes by Murray Foubister;
https://commons.wikimedia.org/wiki/File:Coral_Pink_Sand_Dunes_-_%2819924311289%29.jpg;
CC BY-SA

Image Timpanogos Cave National Monument by RuggyBearLA;
https://commons.wikimedia.org/wiki/File:Timpanogos_Cave_National_Monument_-_49392140198.jpg; CC BY

Putting It Together

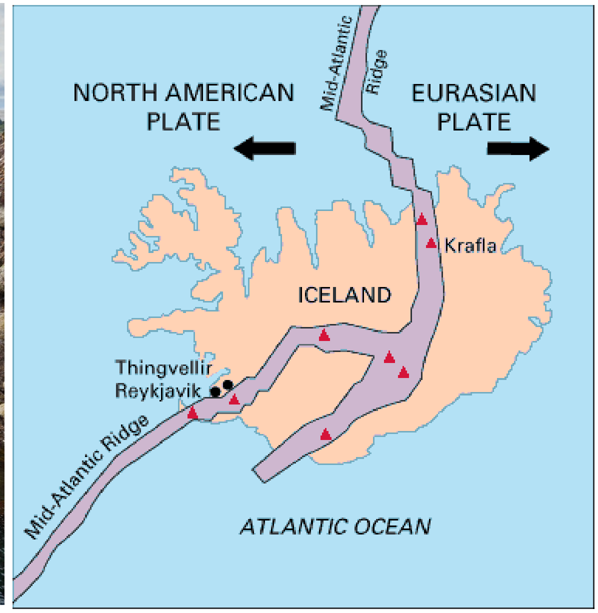


Image by Diego Delso, delso.photo License CC-BY-SA
https://commons.wikimedia.org/wiki/File:Ca%C3%B1%C3%B3n_Silfra,_Parque_Nacional_de_%C3%9Eingvellir,_Su%C3%B0urland,_Islandia,_2014-08-16,_DD_055.JPG
Diagram by USGS https://pubs.usgs.gov/gip/dynamic/understanding.html

Silfra Canyon, a popular diving location, is located on the island of Iceland within Thingvellir National Park which covers part of the area where the Mid-Atlantic ridge runs through the island.

Focus Questions

1. How is mantle convection influencing the volcanoes on Iceland?

2. How is mantle convection influencing the movement of the North American and Eurasian Plates at Iceland?

3. Silfra Canyon isn't the only area on Iceland that is widening because of the Mid-Atlantic Ridge plate boundary. Why do the deconstructive forces of weathering and erosion prevent us from seeing the bottom of the Mid-Atlantic Ridge on land?

Final Task

Draw and label a diagram showing the scale at which mantle convection is happening in the mantle compared to the surface features forming on Iceland (i.e. Silfra Canyon, volcanoes).

2.5 Earth's Geologic History (ESS.2.5)

Phenomenon

The first image is of a life-sized model of an ancient insect called meganisoptera. Meganisoptera are the ancestors of modern day dragonflies. Their wingspan was up to 3 ft wide (about the size of a modern day crow). The second image is of a meganisoptera fossil. Meganisoptera fossils, and other similarly large insects, are found in Permian aged rocks but soon after disappear from the fossil record. During the Permian, Earth's atmosphere had much higher oxygen levels than today allowing insects to reach these gargantuan sizes.


Image 1 by Werner Kraus from Wikimedia Commons *https://commons.wikimedia.org/wiki/File:Meganeuropsis_2_W._Kraus.jpg; CC BY-SA 4.0*
Image 2 by Didier Descouens from Wikimedia Commons *https://commons.wikimedia.org/wiki/File:Meganeura_monyi_au_Museum_de_Toulouse.jpg; CC BY-SA 4.0*

Observations and Wonderings

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions

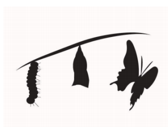
1. What allowed meganisoptera insects to grow so large?

2. Predict what other differences animals and plants might have had during the Permian period.

3. Predict what you think caused the meganisoptera and other large insects to go extinct.

ESS.2.5 Earth’s Geologic History

Engage in argument from evidence for how the simultaneous co- evolution of Earth’s systems and life on Earth led to periods of stability and change over geologic time. Examples could include how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants or how the evolution of corals created reefs that altered patterns of coastal erosion and deposition providing habitats for the evolution of new life forms. (LS4.D, ESS2.D, ESS2.E)



In this section, focus on how stability and change throughout Earth’s geologic history influenced the evolution of life.

The Geologic Time Scale

Humans subdivide time into usable units such as our calendar year, months, weeks, and days; geologists also subdivide time. They have created a tool for measuring geologic time, breaking it into usable, understandable segments. For geologists, the “calendar” is the geologic time scale, displayed in the chart below.

The planet Earth is approximately 4.5 billion years old. Scientists use the geological time scale to describe Earth’s history from its formation to the present day. The time span of 4.5 billion years is divided into smaller segments or units called eons, eras, periods, epochs, and ages (in order from longest to shortest segments of time).

The geologic time scale grew out of need: organizing the large amount of geologic time and geologic events on a worldwide scale. No one person or expert committee proposed the geologic time scale used today. It grew by trial and error through the efforts of numerous geologists working independently. Today the recognition of formal subdivisions of geologic time is determined by international committees. As geologists discover more evidence of Earth’s history, the geologic time scale will be updated and refined.

The geologic time scale distinguishes each segment of time by the occurrence of major geologic events and the appearance, or disappearance, of significant life-forms. It shows periods of stability and instances of change that are revealed by evidence from Earth’s rock and fossil records.

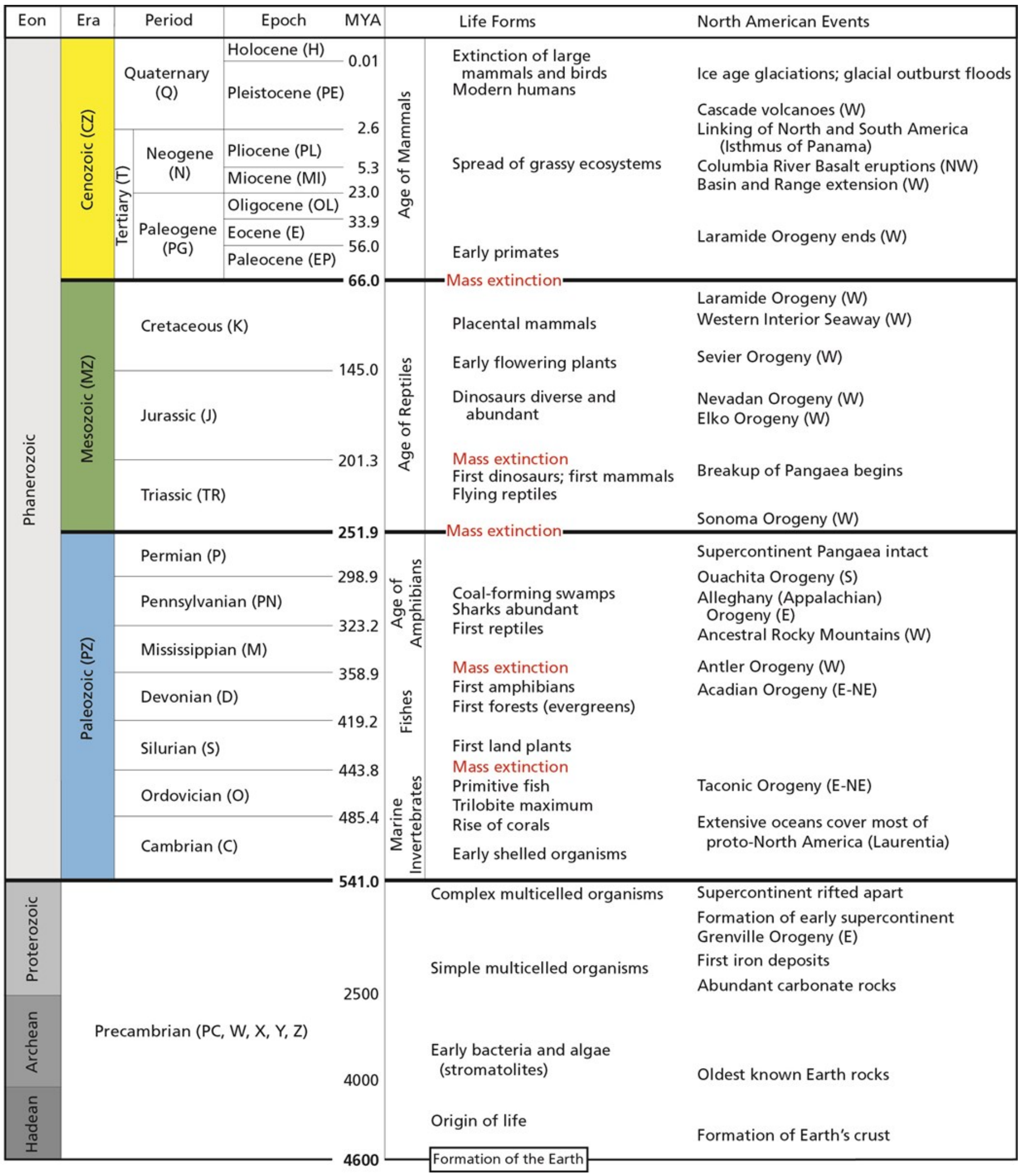


Image by NPS Geologic Resources Inventory, 2018; https://www.nps.gov/subjects/geology/time-scale.htm; public domain

Periods of Stability

Each section of the geologic time scale represents a segment of Earth's history that was relatively stable, where similar organisms lived under similar conditions. Below, we will discuss the three periods of the Mesozoic Era (middle life) that occurred 252 to 66 million years ago. We know a lot about these time periods because of the abundance of rocks and fossils that are available for geologists to study.

Triassic Life and Landscape; Image by Friends of Dinosaur Park and Arboretum mural by William Sillin; https://www.nps.gov/subjects/fossils/triassic-dinosaurs.htm; public domain

Triassic Period

The earliest period of the Mesozoic Era is the Triassic, which occurred from 252 to 201 million years ago. During this time the supercontinent Pangaea was the only landmass on Earth, and at the end of the period, it was beginning to break apart. The climate during much of the Triassic was warm with a dry continental interior and no evidence of ice at the poles. There is evidence of wet/dry and warm/cool seasons. Under these conditions reptiles became the dominant land animals. The first dinosaurs, marine reptiles, lizards, and tortoises appeared. Crocodiles were abundant and it was in this period that insects attained complete metamorphosis. The common plants of this period were simple conifers (cone-bearing trees), cycads (cone-bearing palm-like plants), and ferns.

Jurassic Period

The second period of the Mesozoic Era is the Jurassic, which occurred from 201 to 145 million years ago. During this time the supercontinent Pangaea continued to break apart. Shallow, inland seas covered much of what would become Western North America. Warm tropical greenhouse conditions occurred worldwide. Under these conditions dinosaurs flourished. Giant plant-eating dinosaurs and their carnivorous dinosaur predators roamed the Earth. The shallow inland seas contained abundant life from tiny plankton to huge, whale-sized marine reptiles. Flying reptiles and the first birds appeared. Cycads diversified and became very abundant, so much so that the Jurassic is sometimes called the “Age of Cycads.”

Cretaceous Period

The final period of the Mesozoic Era is the Cretaceous, which occurred from 145 to 66 million years ago. During this time the pieces of what was once Pangaea continued to separate and move apart. Much of each continent was covered with shallow continental oceans and inland seas. What would become North America, Europe, Asia, and Africa became a series of islands. Warm conditions continued and were enhanced as rising sea levels allowed shallow ocean currents to carry warm water farther toward the poles to create a mild global climate with ice free poles. Under these conditions dinosaurs and marine reptiles continued to flourish and many new species appeared, including diverse birds and groups of mammals that are still present on Earth today. One of the most significant developments during the Cretaceous was the appearance and rapid diversification of the first flowering plants which led to the appearance of many modern groups of insects.

Cretaceous age Quetzalcoatlus and T. rex; NPS image of mural by paleoartists Julius Csotonyi and Alexandra Lefort. https://www.nps.gov/subjects/fossils/cretaceous-dinosaurs.htm; public domain

The above descriptions of the conditions of the Triassic, Jurassic, and Cretaceaous are examples of periods of stability represented by the geologic time scale. But what truly distinguishes one stable segment of time from another is the instances of change that separate them and the effects those changes have. Earth’s history is broken down into spans of time marked by various events, such as the emergence of certain species, their evolution, and their extinction, that help distinguish one era from another.

Instances of Change

Scientists estimate that at least 99.9 percent of all species of plants and animals that ever lived are now extinct. However, mass extinctions—when at least half of all species die out in a relatively short time—have occurred only a handful of times over the course of our planet's history. Each of these events is associated with significant, rapid, large-scale environmental changes that mark the end of a stable period of Earth's history. The largest mass extinction event happened around 250 million years ago, when perhaps 95 percent of all species went extinct. Some mass extinction events are famously caused by random chance, like the asteroid that killed the dinosaurs and 50% of the species on the planet at the time, but other mass extinction events are the result of processes on Earth that affect the ability of its systems to remain stable.

The single biggest driver of mass extinctions appears to be major changes in Earth's carbon cycle. A change in the carbon cycle can be the result of large amounts of volcanic activity that cover hundreds of thousands of square miles with lava. These eruptions also eject massive amounts of heat-trapping gasses such as carbon dioxide into the atmosphere, enabling runaway global warming and related effects such as ocean acidification and a loss of dissolved oxygen in water. Another type of change in the carbon cycle can be the result of plate tectonics, where huge mountain ranges are raised, producing chemical weathering that uses carbon dioxide, removing it from the atmosphere and producing global cooling. A change in climate, either warming or cooling, will have a negative impact on life that is adapted to specific conditions.

Instances of change in Earth's history are not always associated with a dramatic mass extinction, but may be caused by a more moderate shift in conditions that leads to a new period of stability.

Coevolution of Life and Earth's Systems

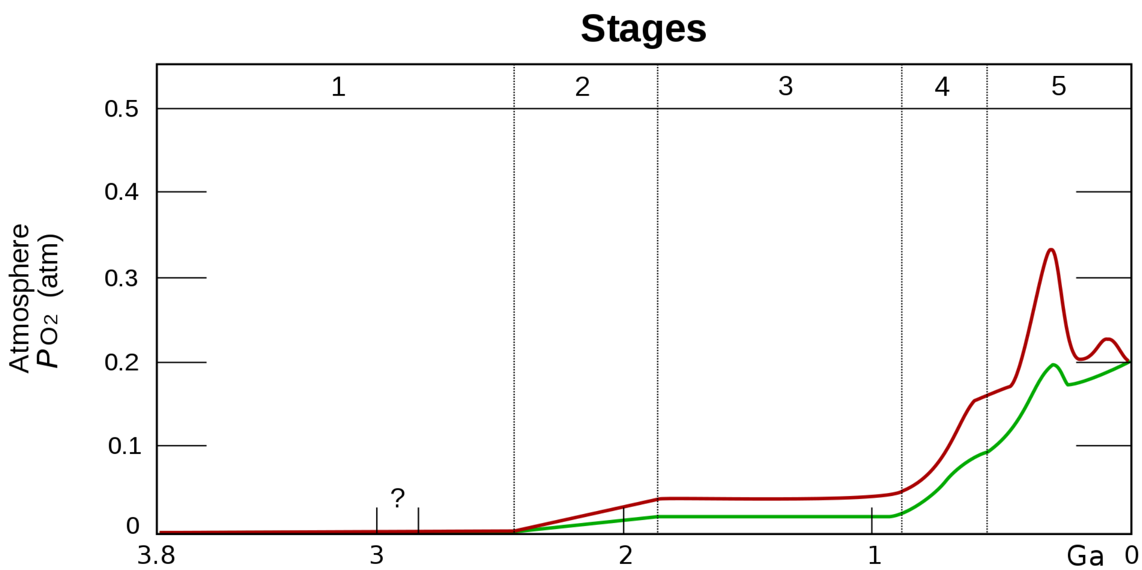
The simultaneous coevolution of life and Earth's systems drives both periods of stability and instances of change. Earth's systems have shaped biology by creating favorable conditions for life's emergence and evolution, but this also works in reverse: life has shaped our planet's atmosphere, oceans and landscapes in many ways. The following examples illustrate this relationship between life and Earth's systems.

The geological record shows that the Earth was very warm when it was young, much warmer than it is now, with no permanent ice anywhere on Earth. This is counter to our understanding that the Sun was dimmer and cooler, as are all young stars. In fact, the Earth should be about 30° warmer now than it was after it formed if we consider just the energy available from the Sun. The warm young

Earth can be explained by powerful warming caused by the presence of greenhouse gasses in the atmosphere that act to trap heat. But these greenhouse gasses can't have come from volcanoes, which produce the greenhouse gas carbon dioxide. Evidence of carbon dioxide would be found in rocks, and it isn't. Instead, the warming of the early Earth is likely the result of methane in the atmosphere.

This methane would have come from bacteria. Bacteria that produce methane are very common now, but they must have been much more common billions of years ago. The abundance of methane in the atmosphere warmed the planet and prevented it from being a cold, dead, and lifeless world. The actions of bacteria changed the atmosphere, which in turn changed the conditions of the planet and made it possible for other forms of life to evolve.

Photosynthetic microorganisms evolved about 2.3 billion years ago. They produce oxygen as a product of photosynthesis. Oxygen is poisonous to methane producing bacteria, and they were slowly replaced (though not completely) by the Sun-energy-loving photosynthesizers. Also, oxygen will react with methane to produce carbon dioxide, a greenhouse gas with less warming potential than methane. This reduced the ability of the atmosphere to trap and retain heat, dramatically reduced global temperatures, and plunged the Earth into its first ice age. This event is called the Great Oxygenation Event.



Oxygenation-atm.svg: Heinrich D. Holland derivative work; https://en.wikipedia.org/wiki/Great_Oxidation_Event#/media/File:Oxygenation-atm-2.svg;

The graph above shows the abundance of oxygen during and leading up to the Great Oxygenation Event. Red and green lines represent the range of the estimates of oxygen while time is measured in billions of years ago (Ga).

The production of an oxygen rich atmosphere is extremely important for the world as we know it. Animals, including humans, need oxygen to breathe. If photosynthesizers had not evolved, there would be no animals as we know them. Since that time, 2.3 billion years ago, Earth's systems have fluctuated chaotically between long ice ages and warmer intervals. The actions of photosynthesizers changed the atmosphere, which in turn changed the conditions of the planet and made it possible for other forms of life to evolve.

With oxygen in the atmosphere, another major part of today's atmosphere could develop. Oxygen is needed to make ozone. Ozone is a molecule made of three oxygen atoms. There is a region of the upper atmosphere that has higher than normal concentrations of ozone called the ozone layer. This ozone has the ability to absorb harmful incoming radiation from the sun. Since much of the Sun's harmful radiation was no longer able to reach the Earth's surface, more complex life was finally able to develop. As you can see, there are multiple reasons that without oxygen, life on Earth would have been very simple.

Life on Earth continues to affect oceans, the atmosphere, land, and human societies today. For example, coral reefs provide protection from erosion of nearby coasts. The coral reef structure buffers shorelines against waves, storms, and floods, helping to prevent loss of life, property damage, and erosion. When reefs are damaged or destroyed, the absence of this natural barrier can increase the damage to coastal communities from normal wave action and violent storms. Several million people live in U.S. coastal areas adjacent to or near coral reefs and are affected by their presence or absence. The impacts of coastal development (e.g., marina, dock, and bridge construction, dredging to replenish beaches) and polluted runoff from coastal areas can damage coral reefs over the long term. Therefore, the health of coral reefs depends on sustainable coastal development practices that protect sensitive coral ecosystems and the creatures that reside there

Humans are increasingly aware that they have shaped the planet to an unprecedented extent due to the emission of greenhouse gasses linked to the Industrial Revolution, 200 years ago, and to the advent of the Agricultural Revolution some 8,000 years ago. Our species is most likely the first to have the abilities to recognise and mitigate its impact on the environment on which it depends.

Earth's systems, including life, are interconnected.

Putting It Together

Image 1 by Werner Kraus from Wikimedia Commons
https://commons.wikimedia.org/wiki/File:Meganeuropsis_2_W._Kraus.jpg
Image 2 by Didier Descouens from Wikimedia Commons
https://commons.wikimedia.org/wiki/File:Meganeura_monyi_au_Museum_de_Toulouse.jpg

The Meganisoptera was one of several large flying insects that lived during the Permian period. These large insects went extinct when atmospheric oxygen levels dropped from 30% to 12% at the end of the Permian period.

Focus Questions

1. Why did a change in the atmospheric oxygen levels cause the meganisoptera to go extinct?

2. How do extinction events lead to the evolution of new kinds of life?

3. What do you predict happened to the size of insects when oxygen levels decreased after the Permian?

Final Task

Construct an explanation for how the stability of oxygen levels in the atmosphere allowed large insects like the meganisoptera to evolve during the Permian period.

2.6 Reducing the Effects of Natural Disasters (ESS.2.6)

Authentic Situation

This image is of a landslide in Riverdale, Utah in 2018. Over several months the landslide crept closer to the houses pictured here, eventually claiming the playset and a corner of the garage of the house in the background. Several houses along this street were eventually vacated and later torn down due to the danger of the landslide.

Image by Ben Erickson from UGS; https://geology.utah.gov/map-pub/survey-notes/the-curious-spring-creek-road-landslide/; public domain

Observations and Wonderings

What is the problem in this situation?

What are possible criteria (positive outcomes) to this situation?

What are constraints (limitations) with this situation?

Focus Questions

1. What could be causing this landslide in Riverdale?

2. How are the people who lived in these houses affected?

3. Can landslides like this one be predicted? Why or why not?

ESS.2.6 Reducing the Effects of Natural Disasters

Evaluate **design solutions** that reduce the effects of natural disasters on humans. *Define the problem, identify criteria and constraints, analyze available data on proposed solutions, and determine an optimal solution.* Examples of natural disasters could include earthquakes, tsunamis, hurricanes, drought, landslides, floods, or wildfires. (ESS3.B, ETS1.A, ETS1.B, ETS1.C)

In this section, focus on ways to reduce the effects of natural disasters on human populations.

Natural Hazards vs Natural Disasters

This section is adapted from Natural Hazards *by FEMA; https://hazards.fema.gov/nri/natural-hazards; public domain*

Natural hazards and natural disasters are related concepts but are not the same thing. A natural hazard is the threat of an event that will likely have a negative impact. A natural hazard can be defined as an environmental phenomenon that has the potential to impact societies and the human environment. There are 18 natural hazards included in the National Risk Index of Federal Emergency Management Agency (FEMA): avalanche, coastal flooding, cold wave, drought, earthquake, hail, heat wave, hurricane, ice storm, landslide, lightning, riverine flooding, strong wind, tornado, tsunami, volcanic activity, wildfire, and winter weather. A natural disaster is the actual negative impact that follows the occurrence of natural hazard. Not all natural hazards have a negative impact. For instance, a landslide in the middle of a forest that does not affect any human cities, buildings, people, or roads would only be considered a natural hazard but not a disaster. In contrast, Hurricane Katrina (2005) caused 1,800 fatalities and $125 billion in damages; this would be classified as both a hazard and disaster. If a natural event does not pose any risk to human property or lives, it is simply a natural hazard; hazards and disasters only occur in conjunction with human society.

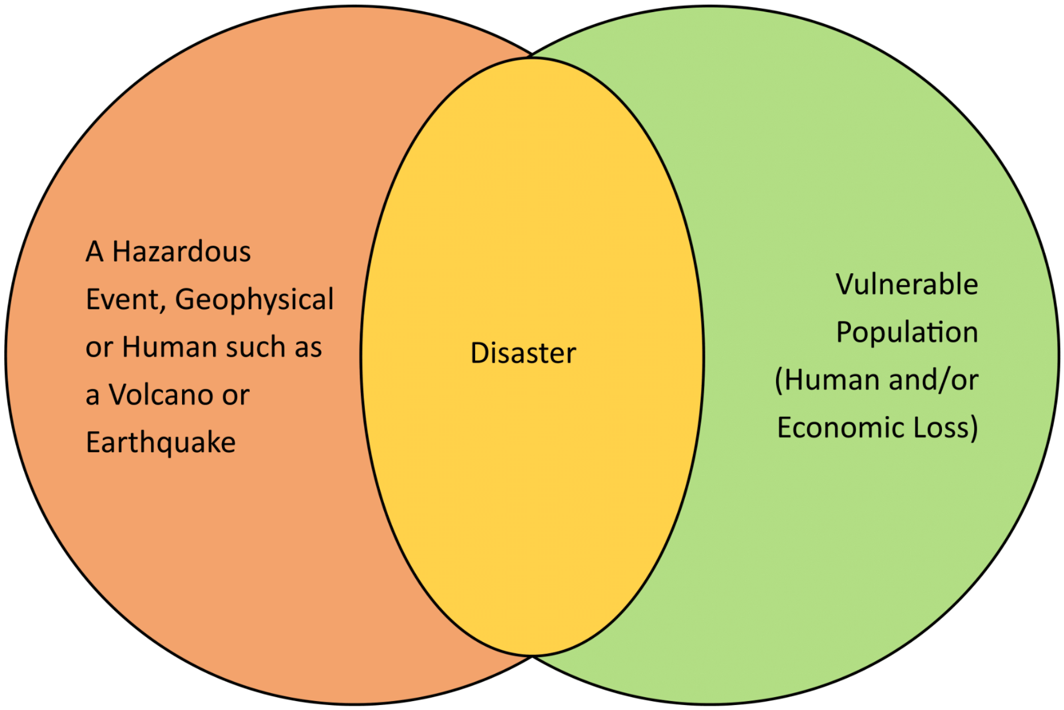


Image by Emeraldfrogs. https://commons.wikimedia.org/wiki/File:Degg%27s_Model.png; CC BY-SA

Common Hazards and Mitigation Techniques

This section is adapted from FEMA Mitigation Ideas (2013) https://www.fema.gov/sites/default/files/2020-06/fema-mitigation-ideas_02-13-2013.pdf and Hazard Mitigation Plannin https://www.fema.gov/emergency-managers/risk-management/hazard-mitigation-planning; CC BY

Across the world there are many different kinds of natural hazards. Different areas have different risks for hazards based on their unique conditions and geography. For instance, a mountainous region that is far inland will have a greater risk of landslides than hurricanes. Some of the most common hazards according to FEMA are the following: drought, earthquake, erosion, extreme temperatures, flood, hail, landslide, lightning, sea level rise, severe wind, severe winter weather, storm surge, subsidence, tornado, tsunami, and wildfire.

Mitigation is the process of reducing risk. Hazard mitigation planning reduces loss of life and property by minimizing the impact of disasters. It begins by identifying natural disaster risks and vulnerabilities that are common in an area. After identifying these risks, scientists and local leaders can develop long-term strategies for protecting people and property from similar events. Mitigation plans are key to breaking the cycle of disaster damage and reconstruction.

Drought

A drought is a period of unusually constant dry weather that persists long enough to cause shortages in water supply (surface or underground). Droughts are slow-onset hazards, but, over time, they can severely affect irrigation of crops, city water supplies, recreational resources, and wildlife. If drought conditions extend for many years, the direct and indirect economic impacts can be significant. High temperatures, high winds, and low humidity can worsen drought conditions and also make areas more susceptible to wildfire. In addition, human actions and demands for water resources can accelerate drought-related impacts. Common mitigation strategies to help lessen the effect of droughts are the following:

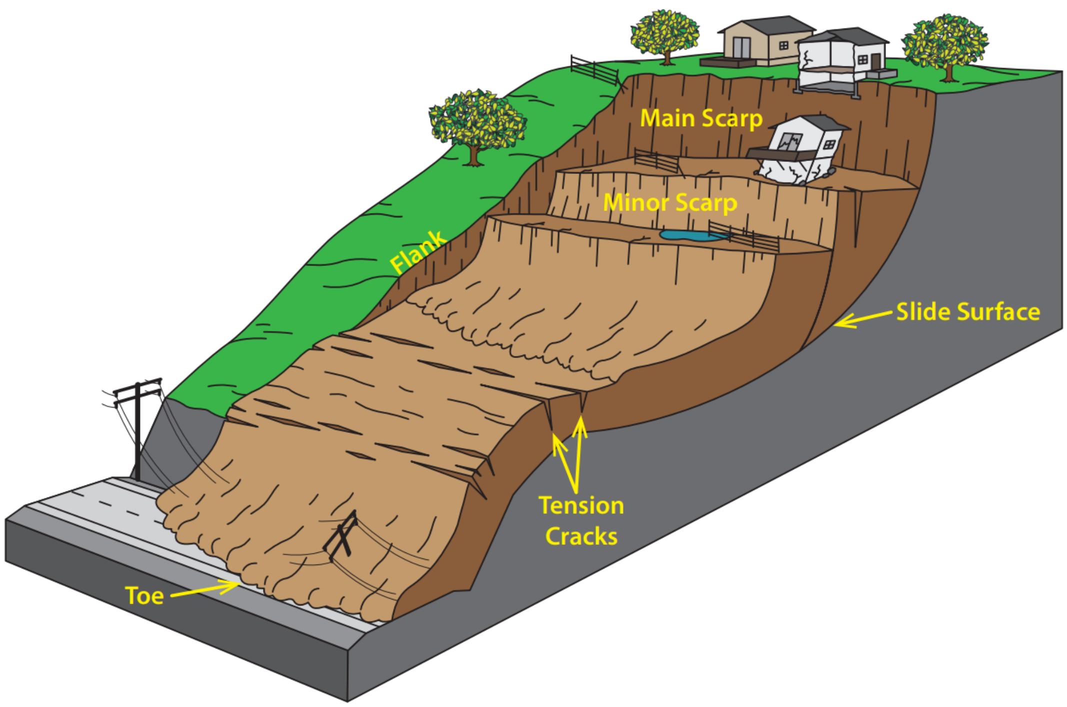
- Gathering and analyzing water and climate data to gain a better understanding of local climate and drought history
- Identifying local drought indicators, such as precipitation, temperature, surface water levels, soil moisture, snow pack, etc.
- Regularly checking for leaks to minimize water losses to maximize water supply.
- Turning water flow off while brushing teeth or during other cleaning activities to reduce waste.
- Incorporating drought tolerant or xeriscape practices into landscape to reduce dependence on irrigation.

Using natural vegetation in landscaping removes the need to water thus minimizing the local water needs and preserving water in the time of droughts.
Image by 伟 贾 from Pixabay. https://pixabay.com/photos/plant-succulent-plants-flower-960312/; CC0

- Practicing contour farming by farming along shallow slopes to slow water runoff during rainstorms and prevent soil erosion, allowing the water time to absorb into the soil.

Landslide

The movement of a mass of rock, debris, or earth down a slope by force of gravity is considered a landslide. Landslides occur when the slope or soil stability changes from stable to unstable, which may be caused by earthquakes, storms, volcanic eruptions, erosion, fire, or additional human-induced activities. Slopes greater than 10 degrees are more likely to slide, as are slopes where the height from the top of the slope to its bottom is greater than 40 feet. Slopes are also more likely to fail if vegetative cover is low and/or soil water content is high. Potential impacts include environmental disturbance, property and infrastructure damage, and injuries or fatalities.



Common mitigation strategies to help lessen the effect of landslides are the following:

- Using GIS to identify and map landslide hazard areas.
- Developing and maintaining a database to track community vulnerability to landslides.
- Installing catch-fall nets for rocks at steep slopes near roadways.

Rock falls along walking paths and roadways can cause damage to persons and property. Installing a rockfall screen is a great way to catch rock debris before it reaches the ground. Image by sandid from Pixabay. https://pixabay.com/photos/road-narrow-protection-netting-2819158/; CC0

- Assessing vegetation in wildfire-prone areas to prevent landslides after fires (e.g., encourage plants with strong root systems).
- Reduce lawn watering and irrigation during seasonal runoff times to prevent soil from becoming oversaturated.

Earthquake

An earthquake is a sudden release of energy that creates a movement in the earth's crust. Most earthquake-related property damage and deaths are caused by the failure and collapse of structures due to ground shaking. The level of damage depends upon the extent and duration of the shaking. Other damaging earthquake effects include landslides (the down-slope movement of soil and rock in mountain regions and along hillsides), and liquefaction (water saturated soil becomes a liquid). Common mitigation strategies to help lessen the effect of earthquakes are the following:

- Adopting and enforcing updated building code provisions to reduce earthquake damage risk.
- Incorporating structural and non-structural seismic strengthening actions into buildings.
- Collecting geologic information on seismic sources, soil conditions, and related potential hazards.

- Encourage citizens to secure furnishings, storage cabinets, and utilities to prevent injuries and damage.

Image by Earthquake Alliance; https://www.earthquakecountry.org/step1/; CC BY

- Examples include anchoring tall bookcases and file cabinets, installing latches on drawers and cabinet doors, restraining desktop computers and appliances, using flexible connections on gas and water lines, mounting framed pictures and mirrors securely, and anchoring and bracing propane tanks and gas cylinders.

Flood

A flood is the partial or complete inundation (covering) of normally dry land. The various types of flooding include riverbank flooding, coastal flooding, and shallow flooding. Common impacts of flooding include damage to personal property, buildings, and infrastructure; bridge and road closures; service disruptions; and injuries or even fatalities. Flooding can often cause other types of hazards such as excess erosion and landslides. Common mitigation strategies to help lessen the effect of floods are the following:

- Limit construction in floodplain areas or require by local law that floodplains be kept as open spaces.
- Prohibiting the building of basements in places where flooding is known to happen.
- Elevating roads and bridges above the base flood elevation to maintain dry access.
- Build grassy ditches along roadsides and retention ponds to catch flood waters.

Stormwater retention pond in Waukesha, Wisconsin. The pond was constructed in 2011. Nine single-family homes were purchased by the city, residents relocated, the homes demolished, and the pond constructed. The area was subject to repeated severe stormwater flooding.
Image by Aaron Volkening. https://www.flickr.com/photos/87297882@N03/13851531525 CC BY

- Encouraging the use of porous pavement, vegetative buffers, and islands in large parking areas.
- Shape the slope of pavement to the natural landscape to allow easier draining of storm water.
- Revising and updating regulatory floodplain maps.

Tsunami

A tsunami is a series of large waves that are created by undersea disturbances, such as earthquakes or volcanic eruptions. Unlike typical waves that crash at the shoreline, tsunamis bring a continuously flowing “wall of water” that has the potential to cause devastating damage in coastal areas immediately along the shore. Areas at greatest risk are less than 50 feet above sea level and within 1 mile of the shoreline. Most deaths that occur during a tsunami result from drowning. Associated risks include flooding, polluted water supplies, and damaged gas lines. Common mitigation strategies to help lessen the effect of tsunamis are the following:

- Limiting new development in areas where tsunamis are known to occur.
- Build structures along shorelines that slow water currents, steer water forces, and block water forces. Examples include floodwalls.

- Conducting tsunami drills so citizens are prepared incase of an emergency evacuation.

Tsunami hazard and evacuation signs can be found along coastal areas at danger of tsunamis. Following the evacuation signs is the quickest way to get to safety.
Image by NOAA; https://blog.response.restoration.noaa.gov/tsunamis-know-signs-hear-stories-and-get-prepared; public domain

- Clearly mark evacuation routes to make clearing the area as fast as possible.

Wildfire

A wildfire is any outdoor fire that is not controlled, supervised, or planned. The probability of a wildfire depends on local weather conditions; outdoor activities such as camping, debris burning, and construction; and the degree of public cooperation with fire prevention measures. Wildfires can result in widespread damage to property and loss of life. Common mitigation strategies to help lessen the effect of wildfires are the following:

- Build clear access to fire hydrants.
- Encouraging the use of non-combustible materials (i.e., stone, brick, and stucco) for new construction in wildfire hazard areas.
- Creating buffers around residential and non-residential structures by removing flammable vegetation, including clearing tree branches.

- Using controlled burning (a purposeful and supervised fire to burn up dry vegetation) to prevent an actual wildfire.

Controlled burns can be done in urban, rural, or wildland areas. Controlled burns is the process of burning away dead undergrowth in a controlled setting. This helps prevent wildfires from burning out of control because the natural fuel is already gone.
Image by David Mark from Pixabay. https://pixabay.com/photos/forest-trees-woods-spain-fire-line-82701/ ; CC0

- Informing the public about proper evacuation procedures.
- Removing dead or dry leaves, needles, twigs, and combustibles from roofs, decks, eaves, porches, and yards.
- Installing and maintaining smoke detectors and fire extinguishers on each floor of homes or other buildings.

Utah's Natural Disasters

This section is adapted from Natural Hazards Programs of the Utah Division of Emergency Management; https://dem.utah.gov/natural-hazards/

Here in Utah we have many different types of natural disasters. Scientists, engineers, and local emergency responders work to reduce the effects of our natural disasters. Earthquakes, flooding and wildfires are the most common natural disasters in Utah. As we have seen in recent years, landslides, windstorms, pandemics, droughts, and smoke also represent a risk to Utah residents.

Putting It Together

Image by Ben Erickson from UGS shorturl.at/ayAV1

This image is of a landslide in Riverdale, Utah in 2018 which eventually caused several families along this street to leave their houses as the landslide grew.

Focus Questions

1. Describe how the slope and water levels in the area influenced the growth of this landslide.

2. How can engineering practices help scientists monitor the Riverdale landslide and other landslides?

Final Task

Design and explain a solution to help prevent or lessen the effects of future landslides on the people living in the Riverdale, Utah area.

CHAPTER 3

Strand 3: System Interactions: Atmosphere, Hydrosphere, and Geospere

Chapter Outline

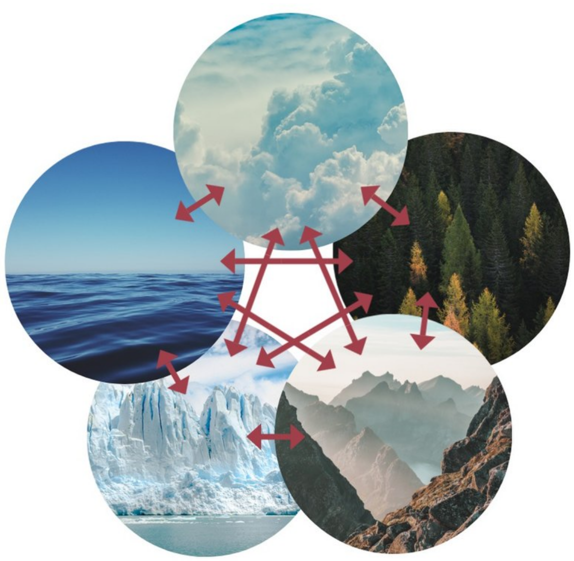


Image "The five components of the climate system all interact." by Femkemilene; https://en.wikipedia.org/wiki/Climate_system#/media/File:Climate-system.jpg; CC BY-SA 4.0

The abundance of liquid water on Earth's surface and its unique properties are central to Earth system interactions. The foundation for Earth's global weather and climate systems is electromagnetic radiation from the Sun. The ocean exerts a major influence on weather and climate by absorbing energy from the Sun, releasing it over time, and globally redistributing it through ocean currents. Changes in the atmosphere due to human activity increase carbon dioxide concentrations and thus affect climate. Current scientific models predict that future average global temperatures will continue to rise, although regional climate changes will be complex and varied.

3.1 Water and Earth's Materials and Processes (ESS.3.1)

Phenomenon

On January 29, 2016, a massive sinkhole opened up in the coastal town of Harbor, Oregon.

Harbor sinkhole by Oregon Department of Transportation; https://flic.kr/p/DBSvYX; CC BY

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions:

1. How can water produce changes to Earth’s surface?

2. What other parts of Earth systems can water change or affect?

ESS.3.1 Water and Earth's Materials and Processes

Plan and carry out an investigation of the properties of water and its effects on Earth materials and surface processes. Examples of properties could include water's capacity to expand upon freezing, dissolve and transport material, or absorb, store, and release energy. (ESS2.C)

In this section, look for examples that show that the properties of matter cause changes to Earth's systems.

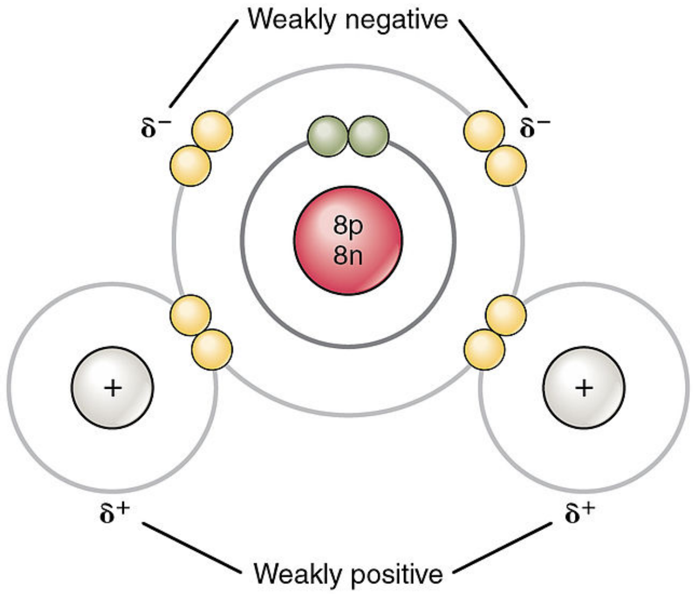
Introduction to Water

Water has many unique properties. For example, water is tasteless, odorless, and transparent. In small quantities, it is also colorless. The transparency of water is important for organisms that live in water. Because water is transparent, sunlight can pass through it. Sunlight is needed by water plants and other water organisms for photosynthesis. However, when a large amount of water is observed, as in a lake or the ocean, it is actually light blue in color. The blue hue of water is an intrinsic property and is caused by selective absorption and scattering of white light. These and other properties of water depend on its chemical structure.

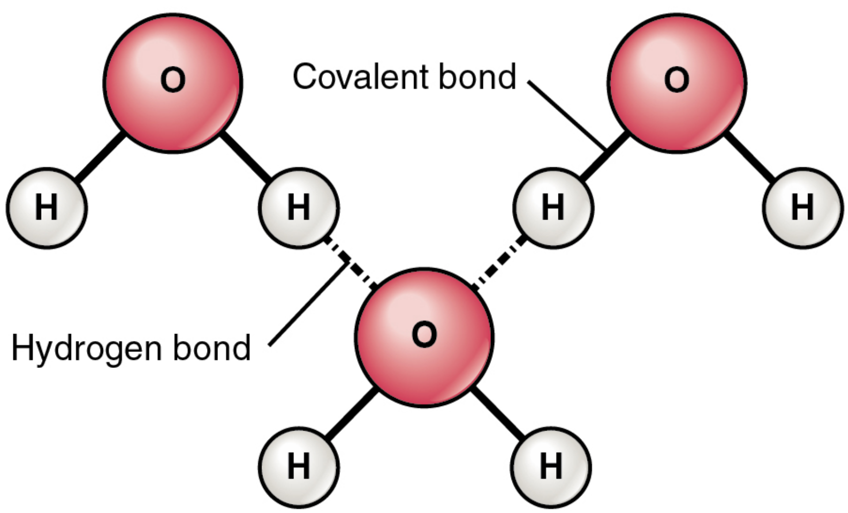
Chemical Structure of Water

Water's characteristics are caused by its chemical structure. Each molecule of water consists of one atom of oxygen and two atoms of hydrogen, H_2O. The arrangement of atoms in a water molecule explains many of water's chemical properties. In each water molecule, the nucleus of the oxygen atom has more protons and more strongly attracts electrons than do the hydrogen nuclei. This results in a negative electrical charge near the oxygen atom and a positive electrical charge near the hydrogen atoms, shown by the diagram below.

A difference in electrical charge between different parts of a molecule is called polarity. A polar molecule is a molecule in which part of the molecule is positively charged and part of the molecule is negatively charged. This also allows water to form hydrogen bonds where the positive part of one molecule is bonded to the negative part of another.



Polar Covalent Bonds in Water by OpenStax College;
https://commons.wikimedia.org/wiki/File:209_Polar_Covalent_Bonds_in_a_Water_Molecule.jpg; CC BY 3.0



Hydrogen Bonds Between Water Molecules by OpenStax College;
https://commons.wikimedia.org/wiki/File:210_Hydrogen_Bonds_Between_Water_Molecules-01.jpg; CC BY 3.0

Water's Properties Impact Earth's Surface

The polar nature of the water molecule and its ability to form hydrogen bonds gives it some unique properties. It makes it an excellent solvent, and water can dissolve many substances. When substances are dissolved, the water can then carry them from place to place. Water can also carry heat.

Water has a high specific heat because it takes a lot of energy to raise or lower the temperature of water. As a result, water plays a very important role in temperature regulation. Earth's water filled oceans regulate climate because they do not change temperature quickly even though they absorb a lot of energy. This is partially why coastal areas have significantly smaller temperature swings from summer to winter than locations found in the center of continents.

Another interesting feature of water is that when water freezes, it becomes less dense than liquid water. The melting/freezing point of water is 0°C. Below this temperature, water is a solid (ice). Water expands when it freezes. Water molecules line up less efficiently and more orderly in ice than in liquid water. As a result, water molecules are spaced farther apart in ice, giving ice a lower density than liquid water. A substance with lower density floats on a substance with higher density. This explains why ice floats on liquid water, whereas many other solids sink to the bottom of their liquid counterpart.

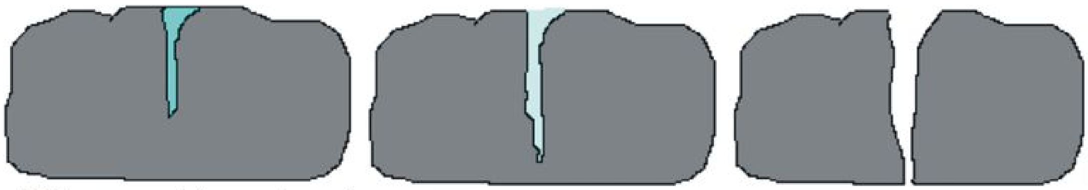
In a large body of water, such as a lake or the ocean, the water with the greatest density always sinks to the bottom. Water is most dense at about 4°C, which is above its freezing point. As a result, the water at the bottom of a lake or the ocean usually has a temperature of about 4°C. In climates with cold winters, this layer of 4°C water is warmer than the freezing temperatures at the surface. Lake organisms such as fish can survive the winter by staying in this cold, but unfrozen, water at the bottom of the lake.

Weathering by Water

Due to its properties, water can cause change. One of the primary ways that water has shaped the surface of the Earth is through weathering and erosion. There are two types of weathering. Chemical weathering changes the chemical makeup of a rock. Water's ability to dissolve so many substances means that when water carrying various materials comes in contact with rocks, chemical reactions can alter the chemical makeup of that rock. Mechanical weathering (also called physical weathering) breaks rocks into smaller pieces. These smaller pieces are identical to the bigger rock in all ways except size. That means the rock has changed physically without changing its composition. The smaller pieces have the same minerals, in just the same proportions as the original rock.

Because water expands when it freezes, it can lead to a type of mechanical weathering called ice wedging, shown in the diagram below. Ice wedging is the main form of mechanical weathering in any climate that regularly cycles above and below the freezing point, either by day and night, or through the seasons.

The process is common in Earth’s polar regions and mid latitudes, and also at higher elevations, such as in the mountains.



Ice wedging.
Image by Julie Sandeen; CK-12 Foundation, CC BY-NC 3.0

Rocks on a beach are worn down by abrasion as passing waves cause them to strike each other.
Image by Steven Depolo, https://flic.kr/p/6WTjDC, CC BY

Another form of mechanical weathering is abrasion. It occurs when one rock bumps against another rock. Moving water causes abrasion as particles in the water collide and bump against one another. Other forces can also cause abrasion. Gravity causes abrasion as a rock tumbles down a mountainside or cliff. Strong winds carrying pieces of sand can sandblast surfaces. Ice in glaciers carries many bits and pieces of rock. Rocks embedded at the bottom of the glacier scrape against the rocks below.

Abrasion makes rocks with sharp or jagged edges smooth and round. If you have ever collected smooth, rounded beach glass or cobbles from a stream, you have seen the product of abrasion.

Erosion by Water

Water that flows over Earth's surface includes runoff, streams, and rivers. After material is weathered into smaller pieces (by abrasion or ice wedging, for example), water flowing over the surface of the land can carry that material for up to thousands of miles. This process of moving sediment from one place to another is called erosion.

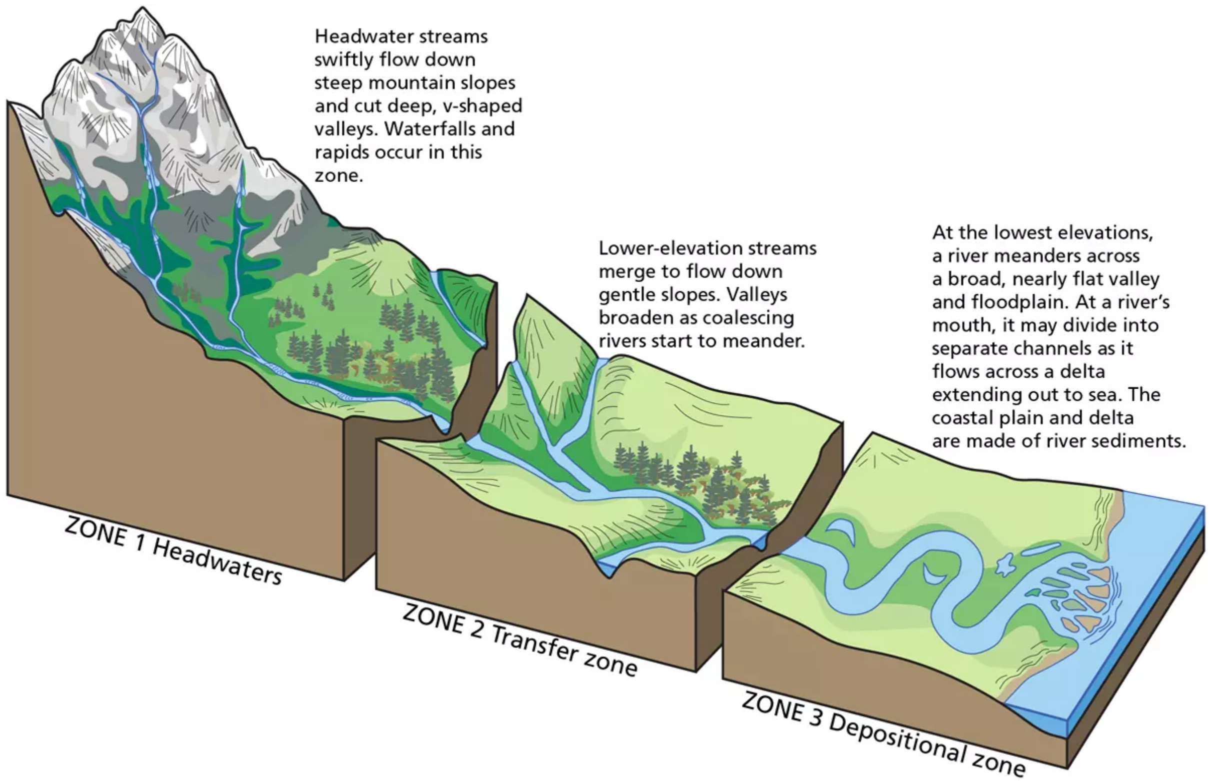
Erosion can occur when a lot of rain falls in a short period of time and much of the water is unable to soak into the ground. Instead, it runs over the land as runoff. Runoff is a major cause of erosion around the world because it occurs everywhere. Gravity causes the water to flow from higher to lower ground. As the runoff flows, it will pick up loose bits of soil and sand and move them.

Runoff causes more erosion if the land is bare. Plants help hold the soil in place. Much of the material eroded by runoff is carried into bodies of water, such as streams, rivers, ponds, lakes, or oceans.

Erosion by a stream depends on the velocity of the water. Quickly moving water erodes more material than slowly moving water. The eroded materials carried by water will eventually be deposited. As the velocity of water slows, larger particles are deposited first. As the water slows even more, smaller particles are deposited.

Streams often start in mountains, where the land is very steep. A mountain stream flows very quickly because of the steep slope. This causes a lot of erosion and very little deposition. The rapidly falling water carves a narrow, v-shaped channel.

Streams eventually run onto flatter ground. Rivers flowing over gentle slopes erode the sides of their channels more than the bottom. Large curves, called meanders, form because of erosion and deposition by the moving water. The curves are called meanders because they slowly "wander," or meander, over the land. As meanders erode from side to side, they create a floodplain. This is a broad, flat area on both sides of a river. Eventually, a meander may become cut off from the rest of the river. This forms an oxbow lake.



Fluvial Systems by Trista L. Thornberry, Colorado State University; https://www.nps.gov/subjects/geology/fluvial-landforms.htm; CC BY

Putting It Together

On January 29, 2016, a massive sinkhole opened up in the coastal town of Harbor, Oregon.

https://www.flickr.com/photos/oregondot/24691134235

Focus Questions:

1. How does water affect soil and rock?

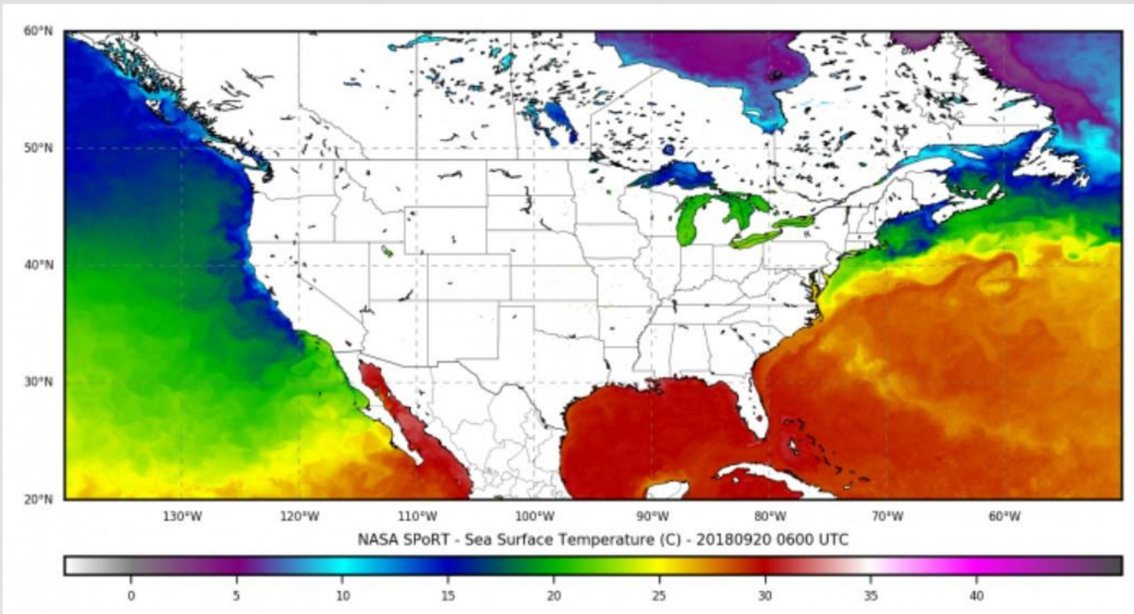
2. What properties of water have allowed it to erode the ground beneath this road in Harbor, Oregon?

Final Task:

The sink hole above is a product of weathering and erosion by water. Construct an explanation for how the formation of the Grand Canyon results from similar processes.

3.2 Oceanic Energy (ESS.3.2)

Phenomenon



SPoRT Sea Surface Temperatures (SST) composite image from 9/20/18.

Image by NASA Earth Science Disasters Program, https://disasters.nasa.gov/hurricane-florence-2018/hurricane-florence-resources-sport-sea-surface-temperatures, Public Domain

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions:

1. What temperature is the Pacific Ocean off the west coast of the United States?

2. What temperature is the Atlantic Ocean off the east coast of the United States?

3. Compare and contrast the patterns of sea surface temperature between the Atlantic and Pacific Oceans around the United States.

ESS.3.2 Oceanic Energy

Construct an explanation of how heat (energy) and water (matter) move throughout the oceans causing patterns in weather and climate. Emphasize the mechanisms for surface and deep ocean movement. Examples of mechanisms for surface movement could include wind, Sun's energy, or the Coriolis effect. Examples of mechanisms for deep ocean movement could include water density differences due to temperature or salinity. (ESS2.C, ESS2.D)

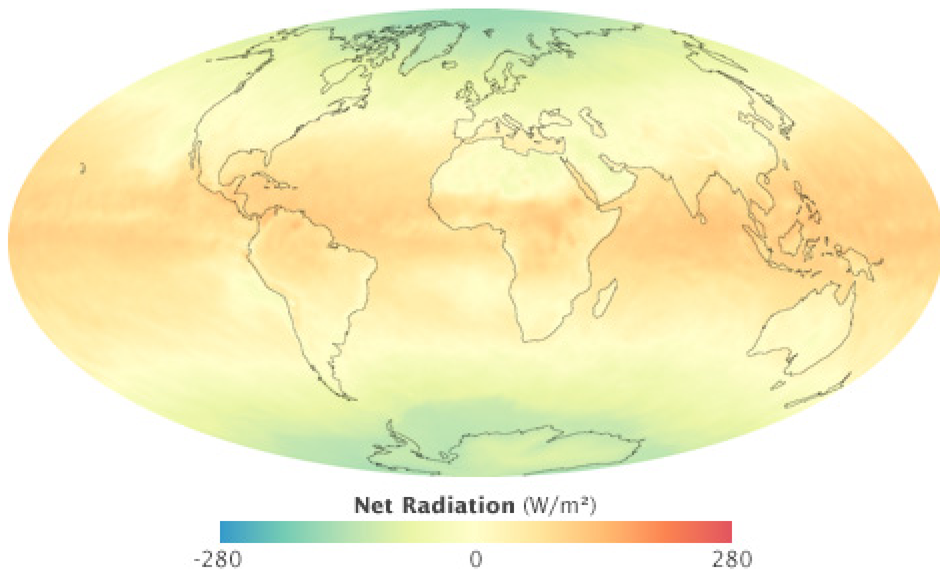
In this section, look for examples that show the movement of energy and matter will create patterns in Earth's systems.

Earth's Heat Engine

Globally, over the course of the year, the Earth system—land surfaces, oceans, and atmosphere—absorbs an average of about 240 watts of solar power per square meter. The absorbed sunlight drives photosynthesis, fuels evaporation, melts snow and ice, powers wind and ocean currents, and warms the Earth system.

But the Sun doesn't heat the Earth evenly. The map below is global average net radiation (incoming sunlight minus reflected light and outgoing heat). It shows global energy imbalances in September 2008, the month of an equinox. Areas around the equator absorbed more energy on average than they reflected or radiated (orange and red). Areas near the poles reflected and/or radiated more energy than they absorbed (green and blue). Mid-latitudes were roughly in balance. Because the Earth is a sphere, the Sun heats equatorial regions more than polar regions creating this imbalance of energy by latitude. This imbalance of energy is a major reason why air and water flows.

The atmosphere and ocean work non-stop to even out solar heating imbalances through evaporation of surface water, convection, rainfall, winds, and ocean circulation. This coupled atmosphere and ocean circulation is known as Earth's heat engine.



NASA map by Robert Simmon, based on CERES data; https://earthobservatory.nasa.gov/features/EnergyBalance/page3.php; public domain

Mechanisms that Drive Surface Ocean Currents

Solar Energy and Wind

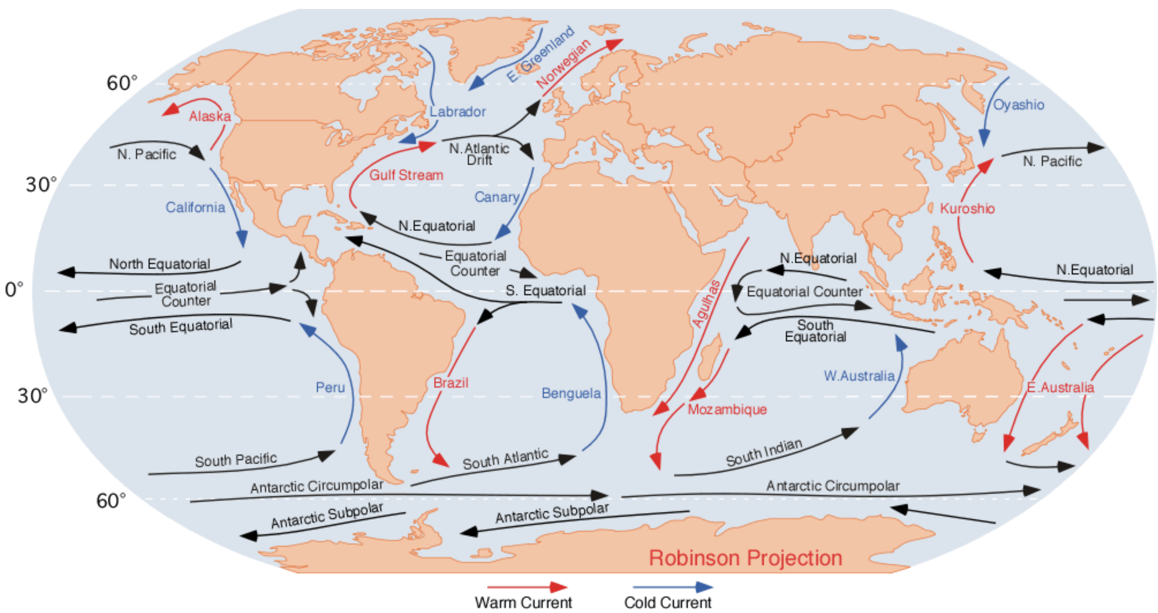
Ocean water moves in currents. A current is similar to a river of water that flows through the ocean. If winds blow constantly from the same direction on the ocean's surface for long periods of time, ocean surface currents can be produced. Earth's major wind belts, prevailing winds, are examples of prolonged winds that produce large-scale currents. They produce a constant input of wind energy that keeps water moving in the same direction.

Surface currents are only 50 to 100 meters deep and range in length from relatively small longshore currents near a beach to currents that span entire ocean basins. They are extremely important in determining the world's weather and climates, and in distributing the ocean's heat and nutrients.

Coriolis Effect

The Coriolis effect describes how Earth's rotation causes the path of freely moving objects to appear to curve. As wind or an ocean current moves, the Earth spins underneath it. As a result, wind or water that travels toward the poles from the Equator is deflected to the east, while wind or water that travels toward the Equator from the poles gets bent to the west. The Coriolis effect curves the direction of surface currents to the right in the Northern Hemisphere and left in the Southern Hemisphere.

The major surface currents are pictured below. They flow in a clockwise direction in the Northern Hemisphere. In the Southern Hemisphere, they flow in the counterclockwise direction. When ocean currents loop back on themselves, due to the Coriolis Effect and the blocking effect of the location of landmasses, they are called gyres.



Surface Ocean Currents

Image by Dr. Michael Pidwirny; https://en.wikipedia.org/wiki/Ocean_current#/media/File:Corrientes-oceanicas.png; public domain

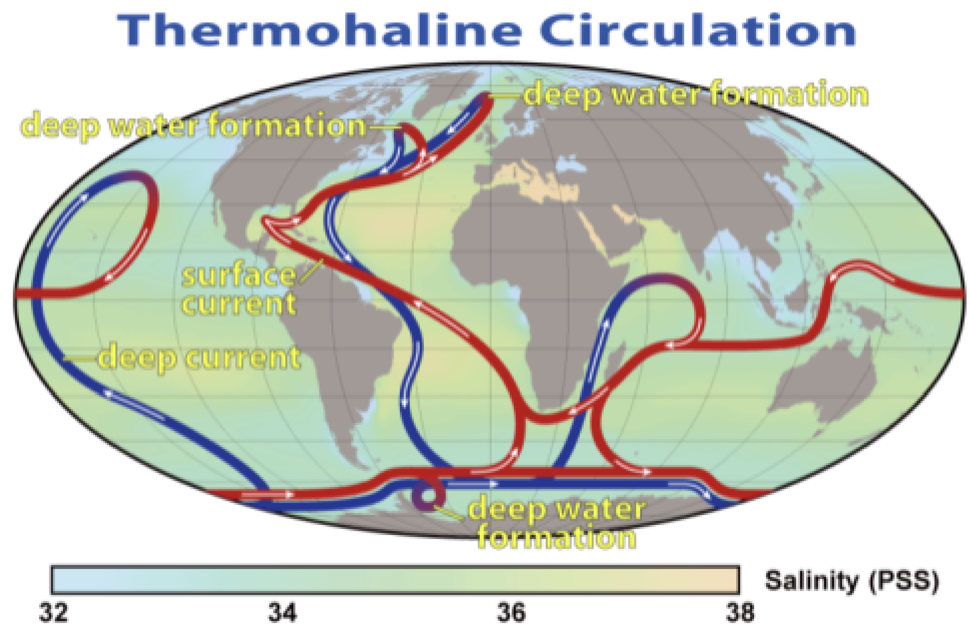
Mechanisms that Drive Deep Ocean Currents

Deep ocean circulation is primarily driven by density differences. It is called thermohaline circulation (thermo- means heat and -haline means salty or salinity), because density differences are due to temperature and salinity.

Lower temperature and higher salinity yield the densest water. When a volume of water is cooled, the molecules move less vigorously, so the same number of molecules takes up less space and the water is denser. If salt is added to a volume of water, there are more molecules in the same volume, so the water is even more dense.

Changes in temperature and salinity of seawater takes place at the surface. Water becomes dense near the poles. Cold polar air cools the water to less than 4°C. Water freezes out of seawater to become sea ice, leaving its salt behind and increasing the salinity of the remaining water. This very cold, very saline water is very dense and sinks. This sinking is called downwelling.

Sinking ocean water reaches the ocean floor and slowly flows in a current that spans the entire globe. It is only where upwelling occurs that this deep ocean water is returned to the surface. Upwelling occurs when winds blowing across the ocean surface push water away and water rises up from beneath the surface to replace it. Upwelling connects deepwater circulation to surface currents to complete a continuous loop.



Cold water (blue lines) sinks in the North Atlantic, flows along the bottom of the ocean and upwells in the Pacific or Indian. The water then travels in surface currents (red lines) back to the North Atlantic. Deep water also forms off of Antarctica.

Image courtesy of Robert Simmon, NASA, http://commons.wikimedia.org/wiki/File:Thermohaline_Circulation_2.png, public domain

Ocean Currents Affect Weather and Climate

Ocean currents are extremely important because they distribute heat around the planet. Water's exceptional capacity to absorb, store, transfer, and release large amounts of energy allow it to have a large effect on weather and climate. Currents act much like a conveyor belt, transporting warm water from the equator toward the poles and cold water from the poles back to the tropics.

Because of this flow of energy, currents regulate global climate. A cool current will decrease temperatures and reduce precipitation for nearby coastal communities. A warm current will increase temperatures and, because warm water evaporates, increase precipitation as well. Ocean currents also help to counteract the uneven distribution of solar radiation reaching Earth's surface through the transport of energy. Without currents, regional temperatures would be more extreme—hot at the equator and frigid toward the poles—and much less of Earth's land would be habitable.

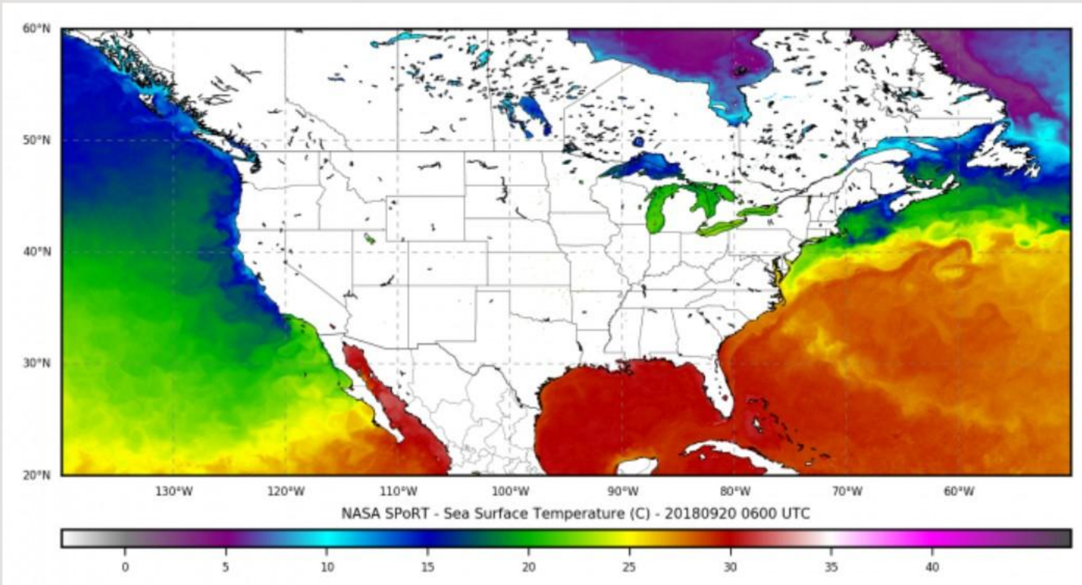
A famous example of how currents can impact weather and climate is the Gulf Stream Current. The Gulf Stream is a strong ocean current that brings warm water from the Gulf of Mexico into the Atlantic Ocean. It extends all the way up the eastern coast of the United States and Canada and then to Europe, shown in the figure below.

This strong current of warm water influences the climate of the east coast of Florida, keeping temperatures there warmer in the winter and cooler in the summer than the other southeastern states. Since the Gulf Stream also extends toward Europe, it warms western European countries as well.

England is about the same distance from the equator as cold regions of Canada, yet England enjoys a much warmer climate. If it weren't for the warm water of the Gulf Stream, England would have a much colder climate.

Image by NOAA; https://scijinks.gov/gulf-stream/; public domain

Putting It Together



SPoRT Sea Surface Temperatures (SST) composite image from 9/20/18.

Image by NASA Earth Science Disasters Program, https://disasters.nasa.gov/hurricane-florence-2018/hurricane-florence-resources-sport-sea-surface-temperatures, Public Domain

Focus Questions:

1. What is the source of warm water in the Atlantic Ocean and cool water in the Pacific Ocean?

2. What determines the direction of flow of warm water in the Atlantic Ocean and cool water in the Pacific Ocean?

Final Task:
Construct an explanation of how heat and water move throughout the oceans causing patterns in sea surface temperature to the east of the United States.

3.3 Energy and Atmospheric Processes (ESS.3.3)

Phenomenon

A NASA satellite captured this image of a plume of dust (artificially colored yellow and blue) flowing from the dry Sahara desert in Northern Africa, over the Atlantic Ocean, to be deposited in Central and South America.

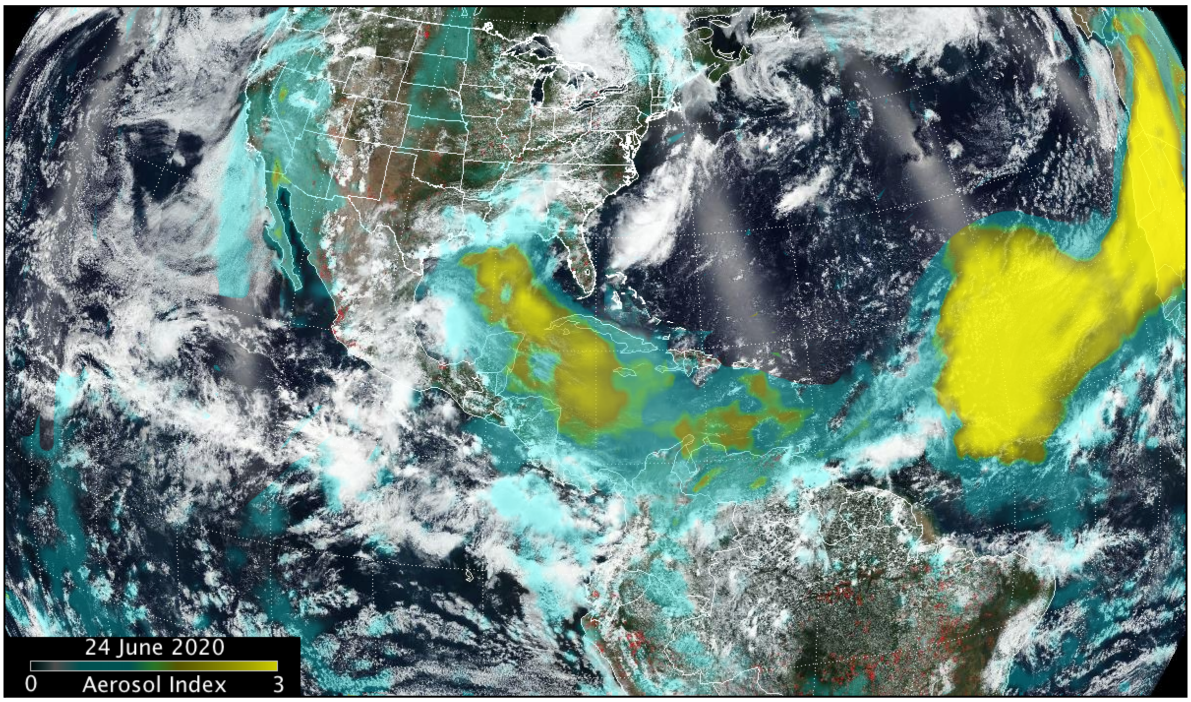


Image by NASA Global Climate Change; https://climate.nasa.gov/news/2999/nasa-noaa-satellite-analyzes-saharan-dust-plume/; public domain

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions:

1. How does dust from the Sahara end up on the opposite side of the Atlantic Ocean?

2. What patterns do you observe as the dust travels across the Atlantic Ocean?

ESS.3.3 Energy and Atmospheric Processes

Construct an explanation for how energy from the Sun drives atmospheric processes and how atmospheric currents transport matter and transfer energy. Emphasize how energy from the Sun is reflected, absorbed, or scattered; how the greenhouse effect contributes to atmospheric energy; and how uneven heating of Earth's atmosphere combined with the Coriolis effect creates an atmospheric circulation system. (PS3.A, ESS1.B, ESS2.A, ESS2.D)

In this section, look for examples that show processes on Earth are driven by interactions between energy and matter.

Atmospheric Circulation and Climate Zones

There is a consistent, prevailing pattern to how air moves around our planet's atmosphere. This pattern, called atmospheric circulation, is caused because the Sun heats the Earth more at the equator than at the poles. It's also affected by the spin of the Earth.

Near the equator, Earth is heated more than anywhere else. This heat warms the air and it rises. When it gets about 10-15 km (6-9 miles) above the Earth's surface it starts to flow away from the equator and towards the north or south poles. When the air cools, it drops back to the ground, flows back towards the Equator, and warms up again and the pattern repeats. This pattern of rising warm material and sinking cool material is known as convection.

However, air doesn't flow in a straight current from the equator to the poles. Because Earth is spinning, the air that moves north and south from the equator also turns with the spin of the Earth. Air going north turns to the right. Air traveling south turns to the left. The power of Earth's spin to turn flowing air is known as the Coriolis Effect. If the Earth didn't spin, there would be just one large convection cell between the equator and the North Pole and one large convection cell between the equator and the South Pole. But because the Earth does spin, convection is divided into three cells north of the equator and three south of the equator.

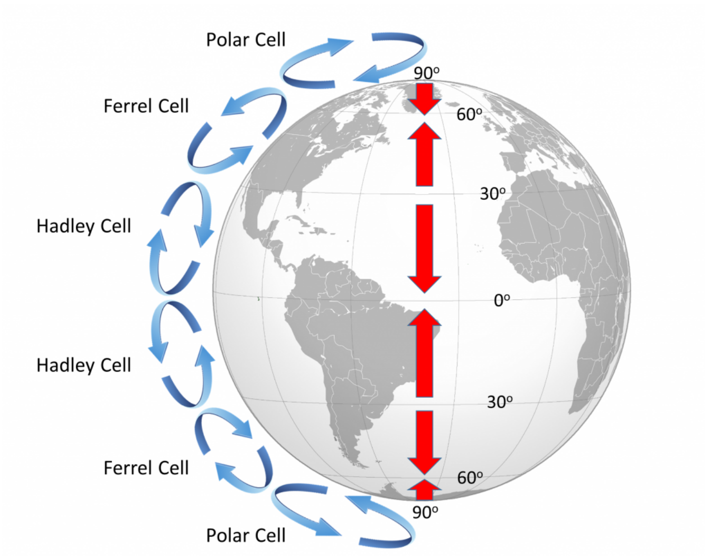


Image modified by Paul Webb from globe image by Location_of_Cape_Verde_in_the_globe.svg: Eddo derivative work: Luan fala! [CC BY-SA 3.0], via Wikimedia Commons
https://bio.libretexts.org/Courses/University_of_Pittsburgh/Environmental_Science_(Whittinghill)/08%3A_Atmosphere_and_Air_Pollution/8.03%3A_Atmospheric_and_Ocean_Circulation

Where convection cells interact with Earth's surface they produce global prevailing wind in belts that encircle the planet. Air blowing at the base of the circulation cells, from high pressure to low pressure, creates the global wind belts. These global wind belts are enormous and the winds are relatively steady and reliable. They were named for the direction from which they flow and their usefulness to sailors, such as the north east trade winds that facilitated commerce between people on opposite shores.

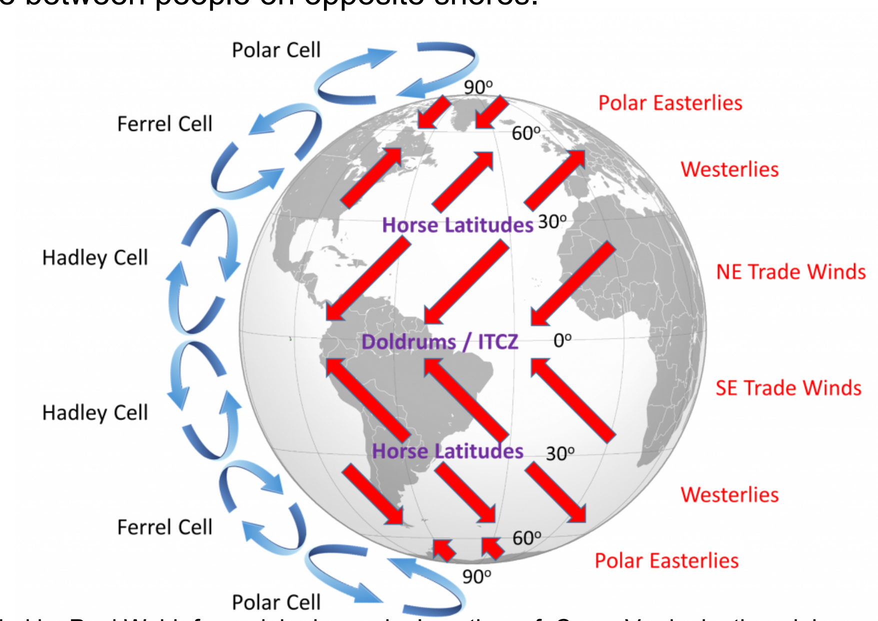


Image Modified by Paul Webb from globe image by Location_of_Cape_Verde_in_the_globe.svg: Eddo derivative work: Luan fala! [CC BY-SA 3.0], via Wikimedia Commons https://bio.libretexts.org/Courses/University_of_Pittsburgh/Environmental_Science_(Whittinghill)/08%3A_Atmosphere_and_Air_Pollution/8.03%3A_Atmospheric_and_Ocean_Circulation

The wind belts are also influenced by the Coriolis Effect and do not flow in a straight north-south pattern. Instead they are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. For instance, the wind produced at Earth's surface by the Ferrel cell should flow south-to-north, but they are deflected and instead flow from southwest to northeast. These are the Westerlies and represent the prevailing winds that influence the air flow over most of the United States.

The areas of high pressure (sinking air) and low pressure (rising air) created by the six atmospheric circulation cells also determine general climate patterns. Precipitation is common in low pressure regions due to warm, moist, rising air. Cool, dry, sinking in high pressure areas produced dry weather. The combination of precipitation and temperature by latitude produces belts of general climate zones around the globe.

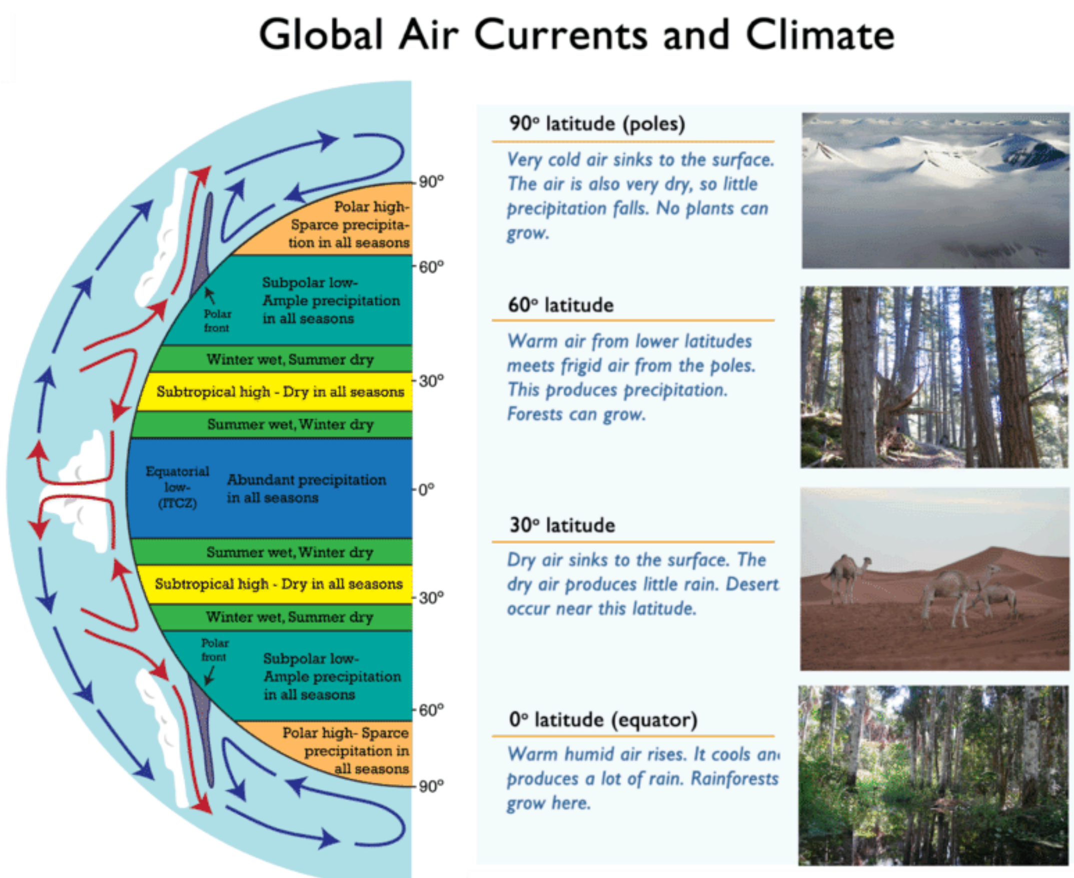
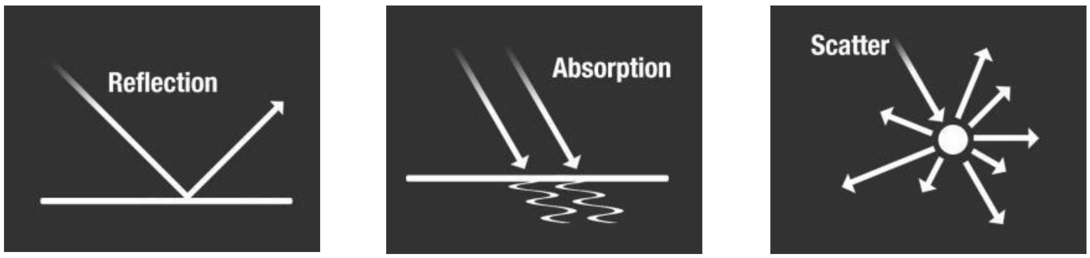


Image *Global Circulation Diagram* by CK-12 Foundation - Christopher AuYeung; Snow: Kitty Terwolbeck (http://www.flickr.com/photos/kittysfotos/7902668768/); Forest: Thomas Quine (Flickr:quinet) (http://www.flickr.com/photos/quinet/7406208974/); Desert: John Yavuz Can (http://www.flickr.com/photos/yavuzcan/8177337117/); Rainforest: Ivan Mlinaric;Gulf of Maine Research Institute (http://www.flickr.com/photos/eye1/3187012243/;http://www.gma.org/herring/biology/distribution/comparing_oceans.asp);

https://flexbooks.ck12.org/cbook/ck-12-middle-school-earth-science-flexbook-2.0/section/12.3/primary/lesson/effect-of-atmospheric-circulation-on-climate-ms-es/

Solar Energy and Earth's Atmosphere

Sunlight travels 150 million kilometers (93 million miles) to Earth. When this energy arrives on Earth, one of several things can happen. In order to understand these processes, we need to understand the behavior of waves.



Images by NASA; https://science.nasa.gov/ems/03_behaviors; public domain

Light waves across the electromagnetic spectrum behave in similar ways. When a light wave encounters an object, it is either transmitted, reflected, absorbed, refracted, polarized, diffracted, or scattered depending on the composition of the object and the wavelength of the light. The same can be said of any and all light entering our atmosphere and interacting with the Earth's surface.

Reflection is when incoming light hits an object and bounces off. Very smooth surfaces such as mirrors reflect almost all light. The color of an object is actually the wavelengths of the light reflected while all other wavelengths are absorbed. Dark colored surfaces, like ocean and forests, reflect very little of the solar energy that gets to them. Light colored parts of the planet surface, like snow and ice, reflect almost all of the solar energy that gets to them.

The amount of energy reflected by a surface is called albedo. Albedo is measured on a scale from zero to one, or as a percentage. Very dark colors have an albedo close to zero (or close to 0%). Very light colors have an albedo close to one (or close to 100%). Earth's planetary albedo is about 0.31. That means that about a third of the solar energy that gets to Earth is reflected out to space and about two thirds is absorbed.

Absorption occurs when photons from incident light hit atoms and molecules and cause them to vibrate. The light energy is absorbed to become kinetic energy. The more an object's molecules move and vibrate, the hotter it becomes. This heat is then emitted from the object as thermal energy, also called infrared radiation.

Some objects, such as darker colored objects, absorb more light energy than others. For example, black pavement absorbs visible and UV energy and reflects very little, while a light-colored concrete sidewalk reflects more energy than it absorbs. Thus, the black pavement is hotter than the sidewalk on a hot summer day. Thermal radiation from the energy-absorbing asphalt and roofs in a city can raise its surface temperature by as much as 10° Celsius.

Scattering occurs when light bounces off an object in a variety of directions. The amount of scattering that takes place depends on the wavelength of the light and the size and structure of the object.

The sky appears blue because of this scattering behavior. Light at shorter wavelengths—blue and violet—is scattered by nitrogen and oxygen as it passes through the atmosphere. Longer wavelengths of light—red and yellow—transmit through the atmosphere. This scattering of light at shorter wavelengths illuminates the skies with light from the blue and violet end of the visible spectrum. Even though violet is scattered more than blue, the sky looks blue to us because our eyes are more sensitive to blue light.

Earth's Energy Budget

The diagram below shows where sunlight energy goes once it reaches Earth. The average energy from sunlight coming to the top of Earth's atmosphere is approximately 340 W/m^2.

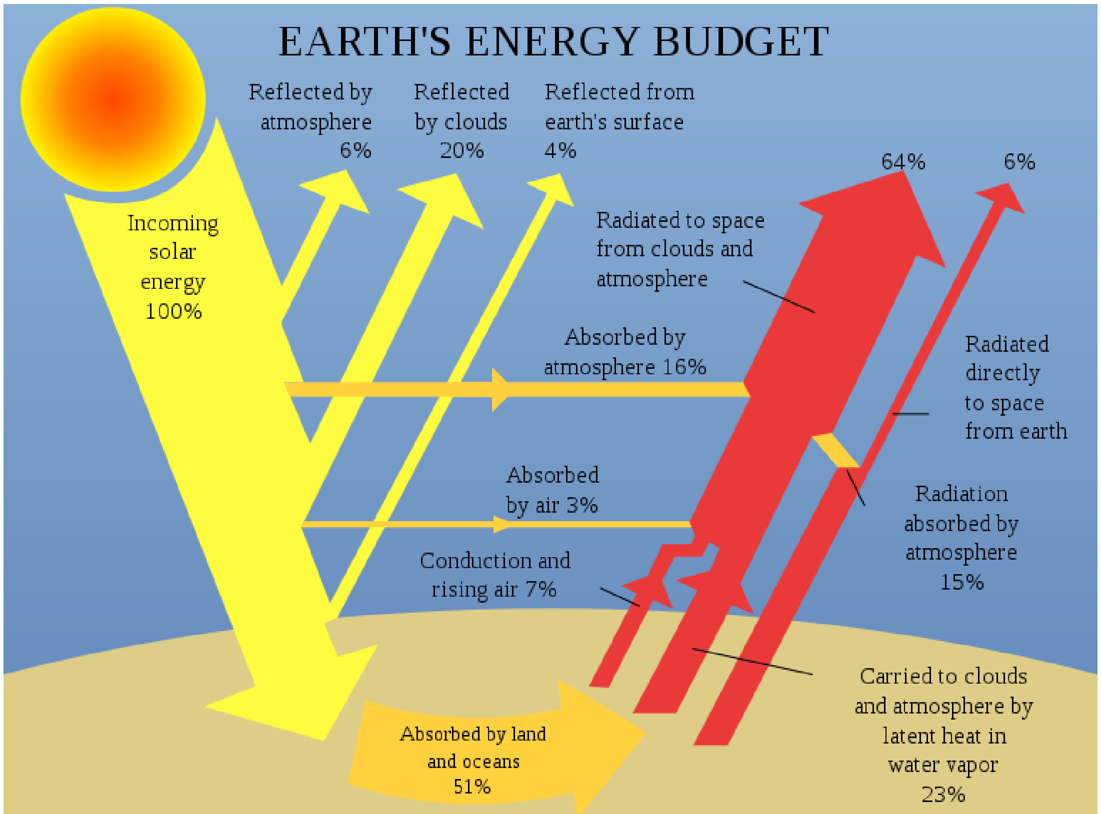


Image by Christoph S.; https://en.m.wikipedia.org/wiki/File:Earth_energy_budget.svg; public domain

Less than half of the incoming sunlight heats the ground. The rest is reflected away by bright white clouds or ice or gets absorbed by the atmosphere. The sunlight that makes it to the ground warms the Earth's surface. Once absorbed, the energy is transformed and emitted as thermal energy, or infrared radiation, which we feel as heat. That heat moves back up through the atmosphere. Most of it is trapped by greenhouse gasses, preventing the energy from leaving as fast as they arrived. After a while, the heat leaks back out into space.

For the most part, the energy coming to Earth as sunlight equals the energy leaving as heat. If it doesn't, Earth heats up or cools down. Recently the energy budget has not been balanced. As we add greenhouse gasses to the atmosphere, they trap more heat close to the planet and Earth warms.

The Greenhouse Effect

Greenhouse gasses warm the atmosphere by trapping heat. After the Earth has absorbed some of the energy from the Sun, it radiates energy back into space, typically as infrared energy. Greenhouse gasses in the atmosphere absorb some of that outgoing energy, sending some of it back toward the Earth, warming the Earth's surface. The greenhouse effect is a natural process that maintains a habitable temperature on Earth. Average temperatures on Earth would drop as low as –18˚C (–0.4˚F), without the greenhouse effect.

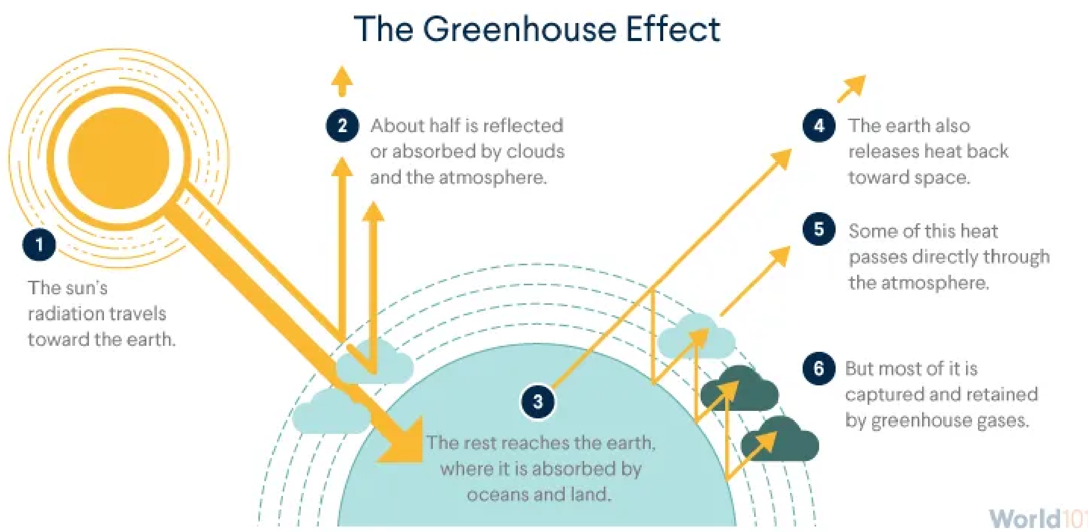


Image by Global Era Issues; https://world101.cfr.org/global-era-issues/climate-change/greenhouse-effect;

Like a blanket on a sleeping person, greenhouse gasses act as insulation for the planet. The warming of the atmosphere because of insulation by greenhouse gasses is called the greenhouse effect. Greenhouse gasses are components of the atmosphere that trap heat at Earth's surface.

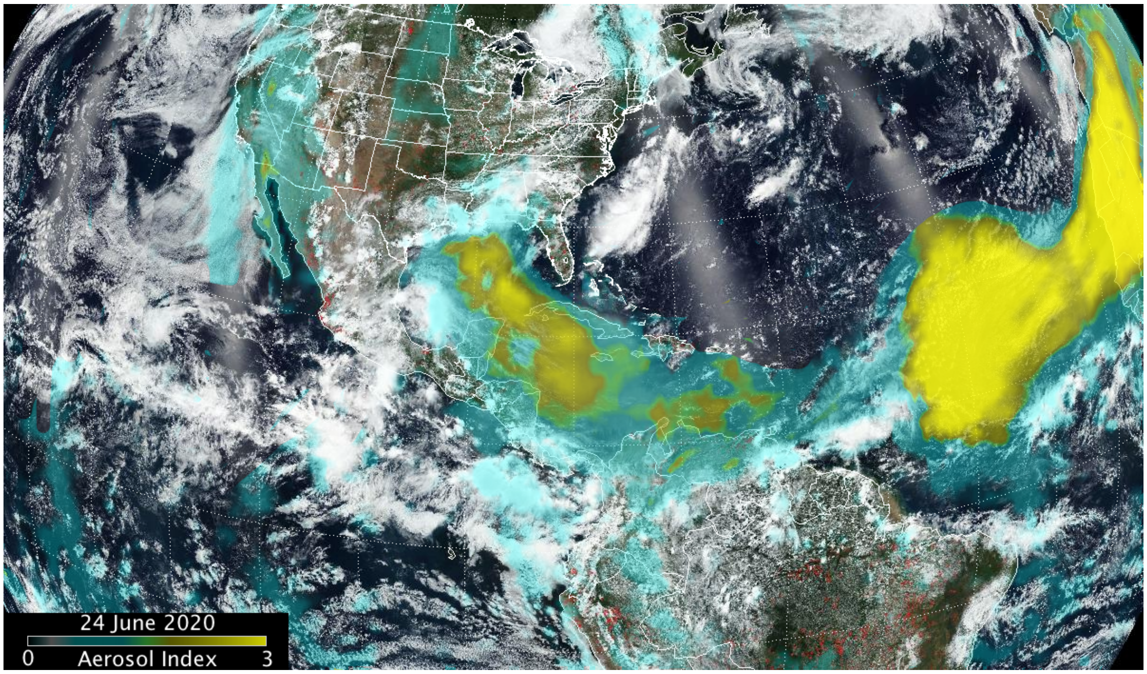
Greenhouse gasses include CO_2, H_2O, methane, O_3, nitrous oxides (NO and NO_2), and chlorofluorocarbons (CFCs). All are a normal part of the atmosphere except CFCs. Table below shows how each greenhouse gas naturally enters the atmosphere.

Greenhouse Gas	Where It Comes From
Carbon dioxide	Respiration, volcanic eruptions, decomposition of plant material; burning of fossil fuels
Methane	Decomposition of plant material under some conditions, biochemical reactions in stomachs
Nitrous oxide	Produced by bacteria
Ozone	Atmospheric processes
Chlorofluorocarbons	Not naturally occurring; made by humans

Different greenhouse gasses have different abilities to trap heat. For example, one methane molecule traps 23 times as much heat as one CO_2 molecule. One CFC-12 molecule (a type of CFC) traps 10,600 times as much heat as one CO_2. Still, CO_2 is a very important greenhouse gas because it is much more abundant in the atmosphere.

Human activity has significantly raised the levels of many greenhouse gasses in the atmosphere. Methane levels are about 250% higher as a result of human activity. Carbon dioxide has increased more than 35%. CFCs have only recently existed. As the concentration of greenhouse gasses in the atmosphere increases, the amount of energy they retain in the atmosphere increases, and temperatures increase.

Putting It Together



https://climate.nasa.gov/news/2999/nasa-noaa-satellite-analyzes-saharan-dust-plume/

Focus Questions:

1. How did energy from the Sun play a role in the movement of dust from the Sahara Desert, over the Atlantic Ocean, to be deposited in Central and South America?

2. The transport of dust from the Sahara to the Americas is a repeated, reliable phenomenon. Why is dust never transported eastward, toward Southern Asia?

Final Task:

Construct an explanation for the transport of dust from the Sahara to the Americas using evidence including patterns of the distribution of solar energy and atmospheric circulation.

3.4 Factors Controlling Climate and Weather (ESS.3.4)

Phenomenon

The image below is a satellite image of the Western United States on April 25, 2004.

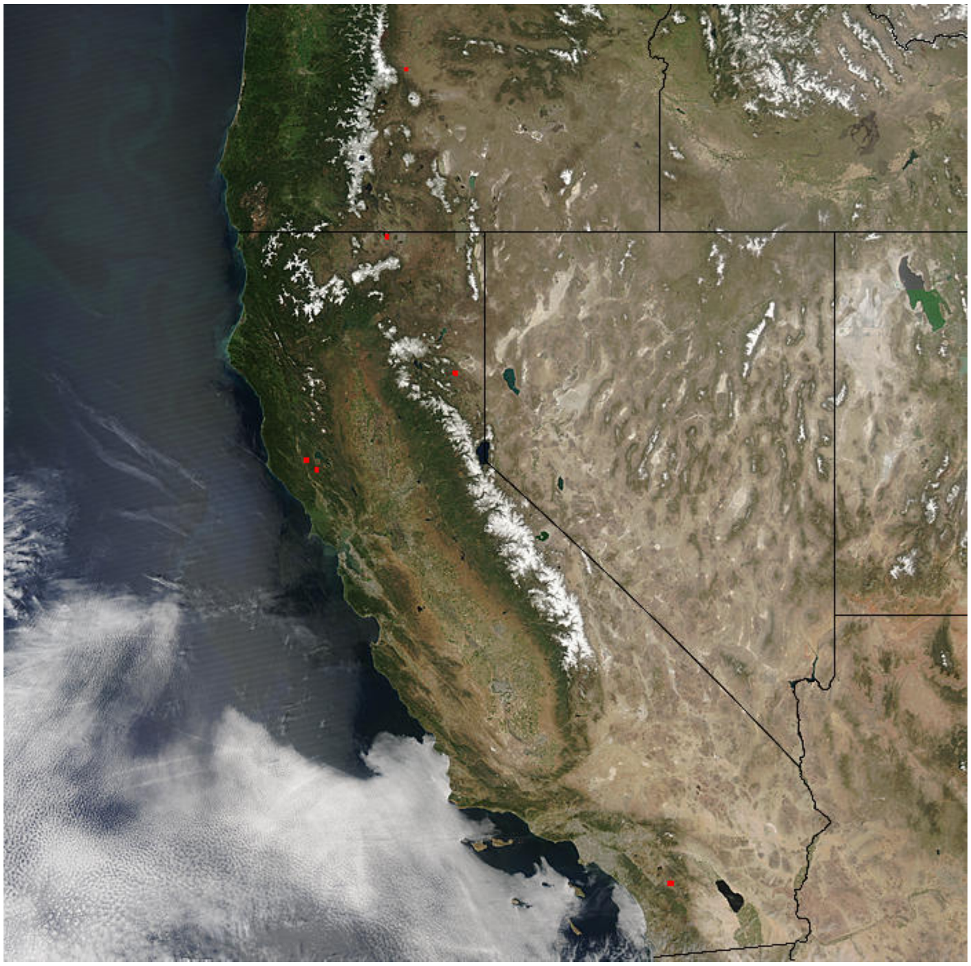


Image by Jeff Schmaltz, MODIS Rapid Response Team, NASA/GSFC; https://visibleearth.nasa.gov/images/70897/western-united-states; public domain

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions:

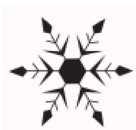
1. Describe the patterns of vegetation you see in the image.

2. Describe the patterns of snow you see in the image.

3. Compare the snow and vegetative patterns you see on the coast (California) versus inland (Nevada).

ESS.3.4 Factors Controlling Climate and Weather

Analyze and interpret patterns in **data** about the factors influencing weather of a given location. Emphasize the amount of solar energy received due to latitude, elevation, the proximity to mountains and/ or large bodies of water, air mass formation and movement, and air pressure gradients. (ESS2.D)



In this section, look for examples that show patterns may be observed when a system is studied and can provide evidence for cause and effect relationships.

Weather Versus Climate

Weather describes the conditions of the atmosphere at a specific time and place. A location's weather can depend on air temperature, air pressure, humidity, cloud cover, precipitation, and wind speed and direction.

Weather on Earth is caused by the energy of the Sun and its effects on the atmosphere and water. All weather occurs in the lower atmosphere where the Sun's energy warms the air, causing it to rise as it heats. The Sun's energy also evaporates water to increase humidity. Cool air rushes in to replace heated, rising air making wind. Water in the air forms clouds. Winds move clouds and moisture to new areas and produce precipitation.

Although the weather can often change from day-to-day, the climate is more predictable. Climate is the average weather in a location over a long period of time, measured for 30 years. A location's climate is most often described primarily by temperature ranges and amounts of precipitation. The climate for a particular place is steady and changes only very slowly.

The climate of any particular place is influenced by many interacting factors. These include latitude, elevation, ocean currents or nearby water, air mass formation and movement, position within a continent, topography, and more.

Distribution of Solar Energy by Latitude

One of the most important factors influencing the climate of an area is its distance from the equator, a measurement called latitude. This is because different latitudes receive different intensities of solar radiation. This happens for two reasons. At the poles, energy spreads over a larger surface area, lessening its intensity. Also at the poles, sunlight must travel a longer distance through the atmosphere, which absorbs, scatters and reflects the solar radiation. Locations near the equator receive solar radiation which is more concentrated and more intense producing higher temperatures.

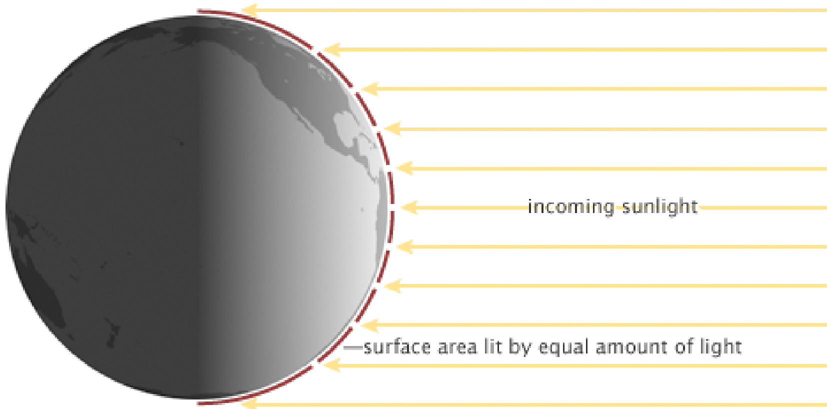


Image by NASA's Earth Observatory;
https://earthobservatory.nasa.gov/features/EnergyBalance/page1.php; public domain

The amount of daylight an area receives is also dependent on latitude. At the equator days are equally long year-round and the sun is just about directly overhead at midday. Polar regions receive the least solar radiation. The night lasts six months during the winter.

The image below shows the amount of energy that reaches the top of the atmosphere by latitude. Far more energy is received near the equator than farther north or south.

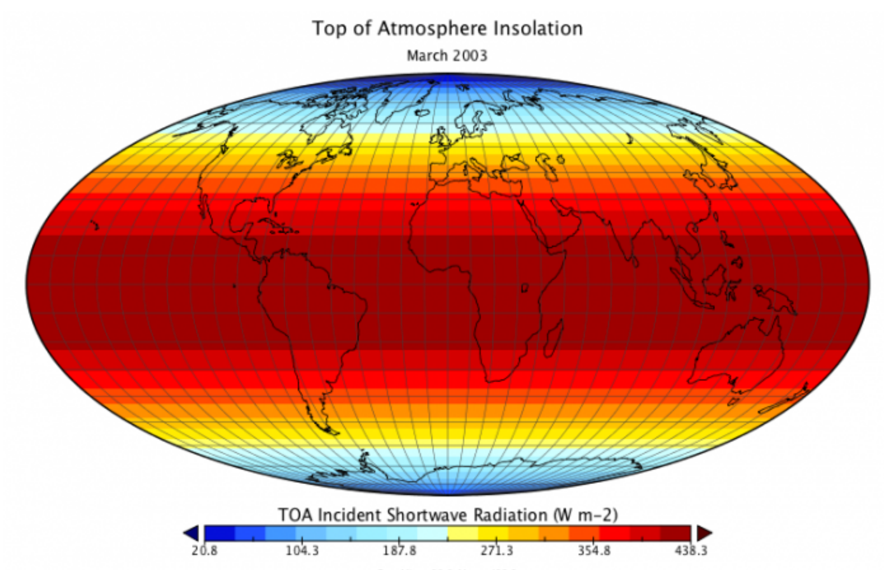


Image by David Bice; Penn State University;
https://www.e-education.psu.edu/earth103/node/1007; CC BY-NC-SA 4.0

Precipitation of an area is also influenced by the latitude due to the production of atmospheric circulation and belts of high and low pressure. This causes a band of precipitation at the equator. However, at 30° North or South of the equator, air is frequently sinking, causing dry areas. Some of the driest areas on Earth are found at 30° North and South of the equator.

Elevation and Mountains

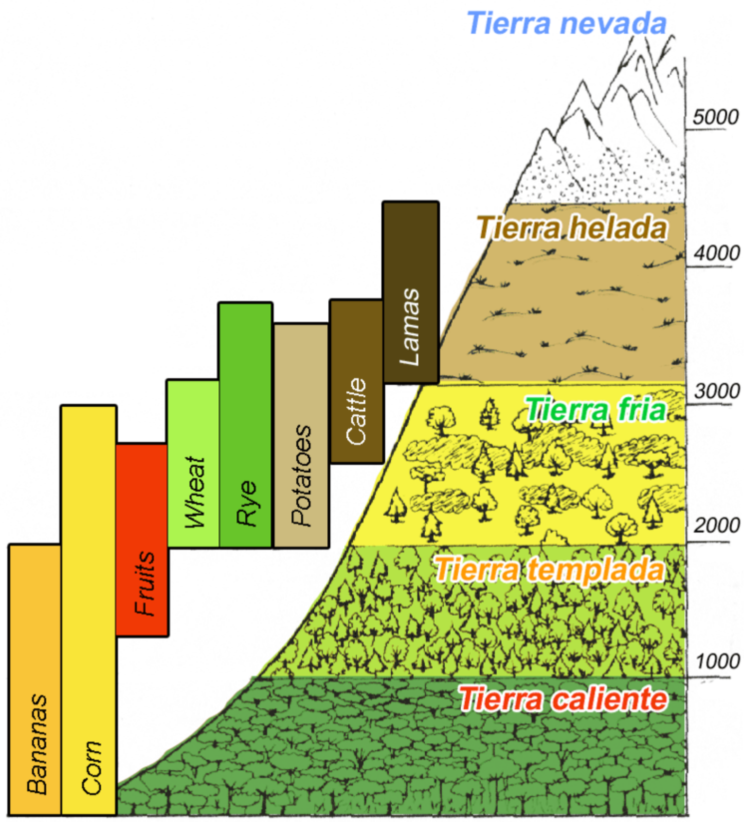


Image Altitudinal variation in the Andes by Chris.urs-o; Maksim; Anita Graser - Wikipedia de;
https://en.wikipedia.org/wiki/Life_zones_of_Peru#/media/File:Hoehenstufen_der_anden.en.PNG;
CC BY-SA 3.0

The image shows the changing temperatures and habitats of the Andes Mountains as elevation is increased and the corresponding communities of agriculture and livestock that can be raised in each area.

Altitude can change the temperature of an area. Air pressure and air temperature decreases with altitude. The more closely molecules are packed together, the more likely they are to collide. Collisions between molecules give off heat, which warms the air. At higher altitudes, the air is less dense and air molecules are more spread out and less likely to collide.

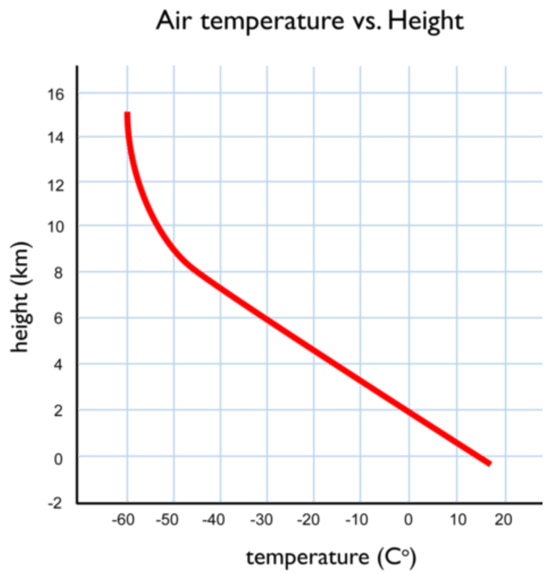
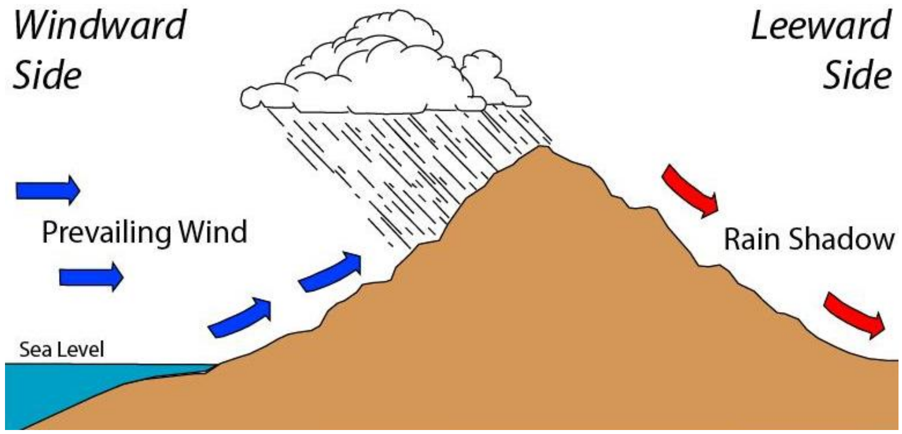


Image by Hana Zavadska; CK-12 Foundation; https://flexbooks.ck12.org/cbook/ck-12-middle-school-earth-science-flexbook-2.0/section/12.5/primary/lesson/effect-of-altitude-and-mountains-on-climate-ms-es/

A location in the mountains has lower average temperatures than one at the base of the mountains. In Colorado, for example, Lakewood's (5,640 feet) average annual temperature is 62°F (17ºC), while Climax Lake's (11,300 feet) is 42ºF (5.4ºC). Air temperature drops as you go higher. This relationship is shown by the graph to the right.

Mountains can also affect precipitation. Mountains and mountain ranges can cast a rain shadow. As winds rise up the windward side of a mountain range, the air cools, water condenses into clouds and precipitation falls. On the other side of the mountain range, the leeward side, the air is dry, sinks, and is warmed. So there is very little precipitation on the leeward side of a mountain range.



Effect of rain shadow by Meg Stewart;
https://www.flickr.com/photos/megstewart/8644087724/;

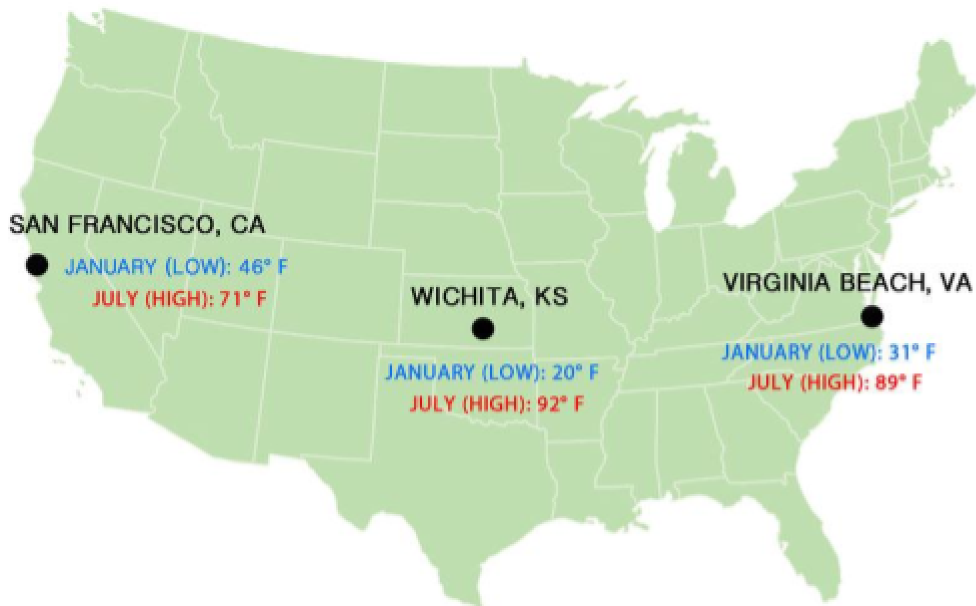
Water and Land

The majority of radiation from the Sun is absorbed by the ocean, particularly in tropical waters around the equator. But the ocean doesn't just store solar radiation, it also helps to distribute heat around the globe. Ocean water is constantly evaporating, increasing the temperature and humidity of the surrounding air to form rain and storms that are then carried by winds. In fact, almost all rain that falls on land starts off in the ocean. The tropics are particularly rainy because heat absorption, and thus ocean evaporation, is highest in this area.

Outside of Earth's equatorial areas, weather patterns are driven largely by ocean currents. Ocean currents act much like a conveyor belt, transporting warm water and precipitation from the equator toward the poles and cold water from the poles back to the tropics. Thus, ocean currents regulate global climate, helping to counteract the uneven distribution of solar radiation reaching Earth's surface. The temperature of the water offshore also influences the temperature of coastal locations on land, particularly if the winds come off the sea. For example, the cool waters of the California Current bring cooler temperatures to the California coastal region.

The influence of water and land on local climate and weather is a result of their different heat capacities. Heat capacity is a measure of the amount of energy it takes to warm a substance. Water absorbs a lot of energy before it changes temperature. Land surfaces absorb a much smaller amount of energy before they change temperature. This means that water will lessen extreme changes in temperature, and land will produce extremes in temperature. For coastal climates, temperatures vary a relatively small amount seasonally and daily as a result of the proximity of water. A continental climate is more extreme, with greater temperature differences between day and night and between summer and winter because it lacks the influence of large amounts of water.

The ocean's influence in moderating climate can be seen in the following temperature comparisons. Each of these cities is located at 37°N latitude, within the westerly winds (Figure below).

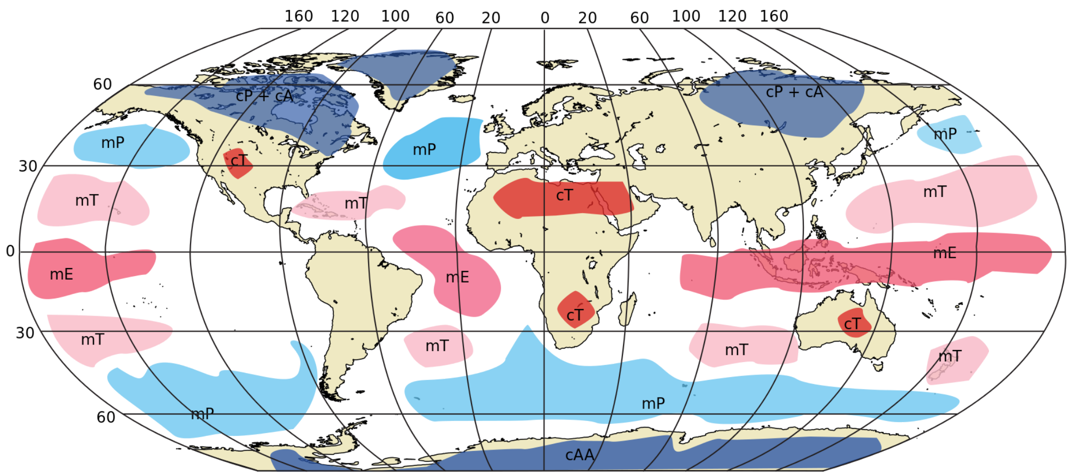


How does the ocean influence the climate of these three cities?
Image by Laura Guerin, CK-12 Foundation, CC BY-NC 3.0

The climate of San Francisco is influenced by the cool California current and offshore upwelling. Wichita has a more extreme continental climate. Virginia Beach, though, is near the Atlantic Ocean. Why is the climate there less influenced by the ocean than is the climate in San Francisco? The weather in San Francisco comes from over the Pacific Ocean while much of the weather in Virginia comes from the continent due to the direction of the westerly winds.

Air Mass Formation and Movement

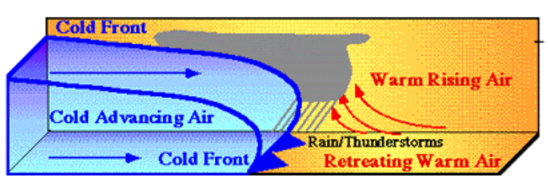
An air mass is a very large clump of air that has nearly the same temperature and humidity throughout. As the air mass sits over a region for several days or longer, it picks up the distinct temperature and humidity characteristics of that region. The characteristics of an air mass develop where they form, known as its source region. An air mass is named with a two letter abbreviation based on its source region. The first letter in the abbreviation tells you whether its source region is a continent (c) or an ocean (m, for maritime). The second letter tells you whether it formed in a cold, arctic area (A); cool, polar area (P); warm, tropical area (T); or near the equator (E). The air mass source regions and the two letter names for the air masses formed around the world are shown below.



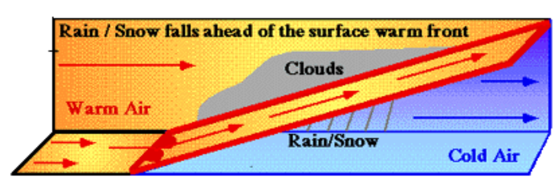
Air Masses; https://en.wikipedia.org/wiki/Air_mass#/media/File:Air_masses.svg; CC0

Air masses are slowly pushed along by high-level winds. When an air mass moves over a new region, it shares its temperature and humidity with that region. So the temperature and humidity of a particular location depends partly on the characteristics of the air mass that sits over it. When an air mass moves into an area that has different characteristics than the air mass, a storm forms. For example, when a colder air mass moves over warmer ground, the bottom layer of air is heated. That air rises, forming clouds, rain, and sometimes thunderstorms.

The boundary between two air masses is called a weather front. Weather fronts are where most weather occurs. The type of front, and the weather produced, is dependent on the characteristics and movements of the air masses involved. A cold and warm front are shown and described below.



A cold front (above) occurs when a cold air mass moves into a warm air mass.



A warm front (above) occurs when a warm air mass moves into a cold air mass.

Image by the National Weather Service and NOAA; https://www.weather.gov/lmk/basic-fronts; public domain

Pressure Gradient and Wind

The difference in temperature causes differences in air pressure between the two spots. An area of warm air will rise, creating low pressure. An area of cool air will sink, creating high pressure. This air pressure difference leads to the formation of winds as the atmosphere tries to equalize the air pressure. Generally, the larger the temperature difference, or the faster it changes, the stronger the resulting winds will be.

Winds around the globe are usually stronger in the winter, especially along fronts between highly contrasting air masses. There is a stronger temperature gradient between the poles and the equator during the winter months because the poles receive minimal sunlight at this time of year, while the tropics receive the same amount of solar energy year-round. This causes the winds to blow stronger in winter.

Temperature gradients between water and land can also cause local winds that affect weather and climate. During the day in summer when the land heats up more quickly than water, hot air rises over land, moves over the water, cools, then returns to land as a cooling "sea breeze". At night, the water is often warmer than the land and the reverse circulation, which includes a breeze from land to sea called a "land breeze", takes its place.

Severe Weather

Severe weather is any dangerous weather that can cause damage, serious social disruption, or loss of human life. The types of severe weather that occur in an area are dependent on many factors, including latitude, elevation, landscape or terrain, and general atmospheric conditions. The scale and scope of weather events can be unpredictable and can affect human life and property.

In Utah, common severe weather conditions include heat waves, drought, lightning strikes, and winter storms. These types of weather events can lead to secondary problems such as wildfires when lightning strikes dry vegetation, or flash floods and landslides after large thunderstorms with a lot of precipitation. In Utah severe weather has resulted in 225 deaths between 1950 and 2018.

Severe weather conditions can be created or worsened by changes to normal weather patterns. For example, El Niño events are triggered by a change in the prevailing winds that lead to changes in air pressure, precipitation, sea surface temperatures, ocean currents, etc. An El Niño year will change the normal weather patterns of the United States so that, in the winter, there are regional warmer conditions and droughts in the northern states and cooler, wetter than normal conditions in the southern states (see below).

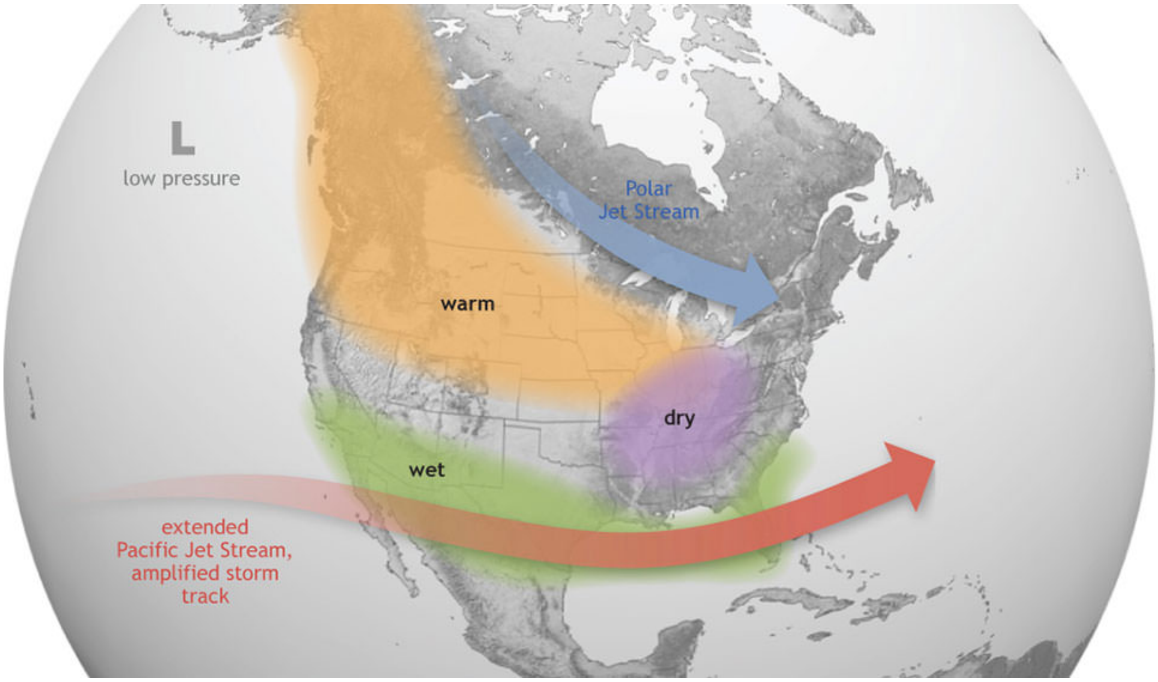
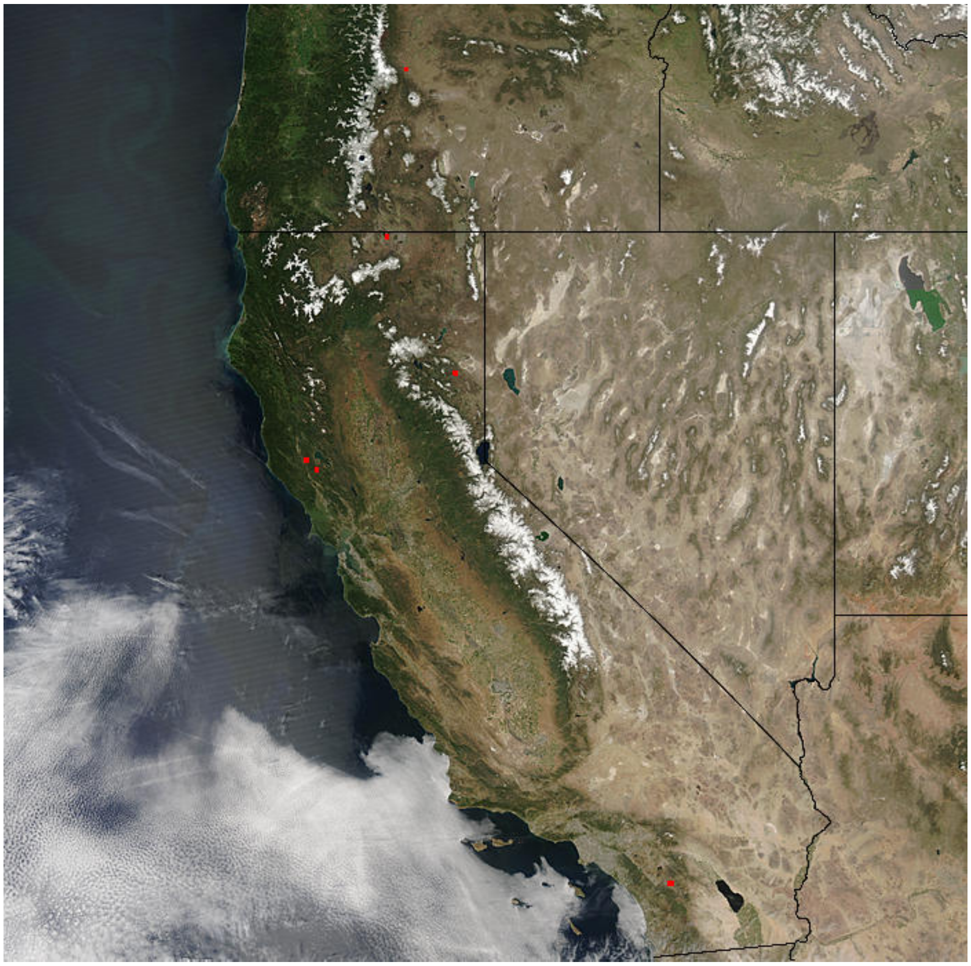


Image by NOAA; https://oceanservice.noaa.gov/facts/ninonina.html; public domain

Putting It Together



https://visibleearth.nasa.gov/images/70897/western-united-states

Focus Questions:

1. How do the presence of large bodies of water and the proximity of mountains affect the weather and climate of coastal California?

2. How do the presence of large bodies of water, and the proximity of mountains affect the weather and climate of Nevada?

Final Task:

Construct an explanation for the difference between the climate of coastal California and inland Nevada.

3.5 Carbon Cycle (ESS.3.5)

Phenomenon

The chart below shows Earth's carbon reservoirs, some of the ways that carbon moves between them, and the amount of carbon that is moved. PgC stands for petagrams (10^{15} g) of carbon.

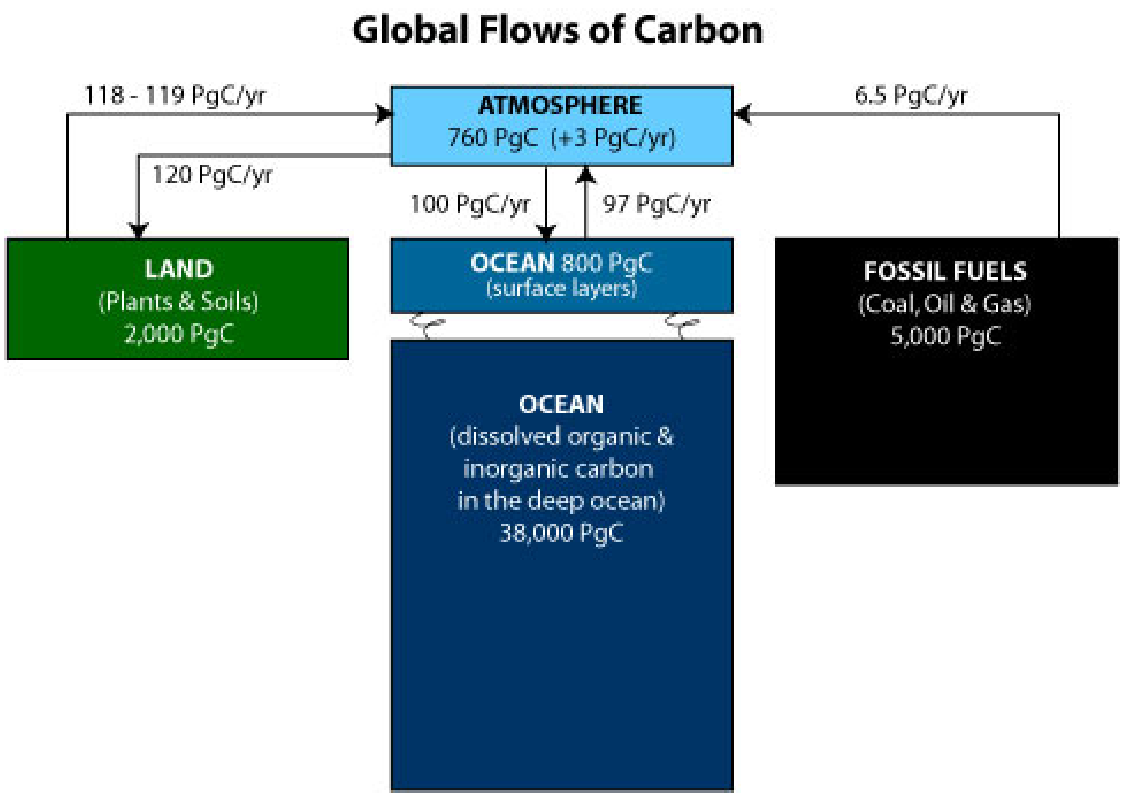


Image by NASA, https://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-carbon-cycle, public domain

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions:

1. Calculate the in and outflow of carbon in the surface layers of the ocean.

2. Calculate the in and outflow of carbon in the atmosphere.

3. Which reservoirs of carbon appear to be increasing according to the flows in the diagram?

ESS.3.5 Carbon Cycle

Develop and use a quantitative **model** to describe the cycling of carbon among Earth's systems. Emphasize each of Earth's systems (hydrosphere, atmosphere, geosphere, and biosphere) and how the movement of carbon from one system to another can result in changes to the system(s). Examples could include more carbon absorbed in the oceans leading to ocean acidification or more carbon present in the atmosphere leading to a stronger greenhouse effect. (LS2.B, ESS2.D, ESS3.D)

In this section, focus on the idea that Earth systems are composed of matter and energy, and their inputs and outputs can be analyzed and described using models.

The Carbon Cycle

This section is adapted from The Carbon Cycle *by NASA's Earth Observatory; https://earthobservatory.nasa.gov/features/CarbonCycle; public domain*

Carbon is the backbone of life on Earth. We are made of carbon, we eat carbon, and our civilizations—our economies, our homes, our means of transport—are built on carbon.

Formed in the cores of aging stars, carbon is the fourth most abundant element in the Universe. Most of Earth's carbon—about 65,500 billion metric tons—is stored in rocks. The rest is in the ocean, atmosphere, plants, soil, and fossil fuels.

Carbon flows between reservoirs (areas of storage) in an exchange called the carbon cycle. The carbon cycle is a combination of fast and slow processes that move carbon from one reservoir to another. Any change in the cycle that shifts carbon out of one reservoir puts more carbon in another reservoir. The amount of time that carbon stays, on average, in a reservoir is the residence time of carbon in that reservoir. Places that supply and remove carbon are carbon sources and carbon sinks, respectively. If more carbon is provided than stored, the place is a carbon source. If more carbon dioxide is absorbed than is emitted, the reservoir is a carbon sink. Though geologic evidence indicates that carbon reservoirs have fluctuated over time due to changes to Earth's systems, when the movement of carbon through the cycle is in balance, the Earth system remains in balance too.

In the diagram below, black numbers indicate how much carbon is stored in carbon reservoirs (areas of storage) in billions of tons (gigatons—GtC). The arrows show how carbon moves among Earth's spheres.

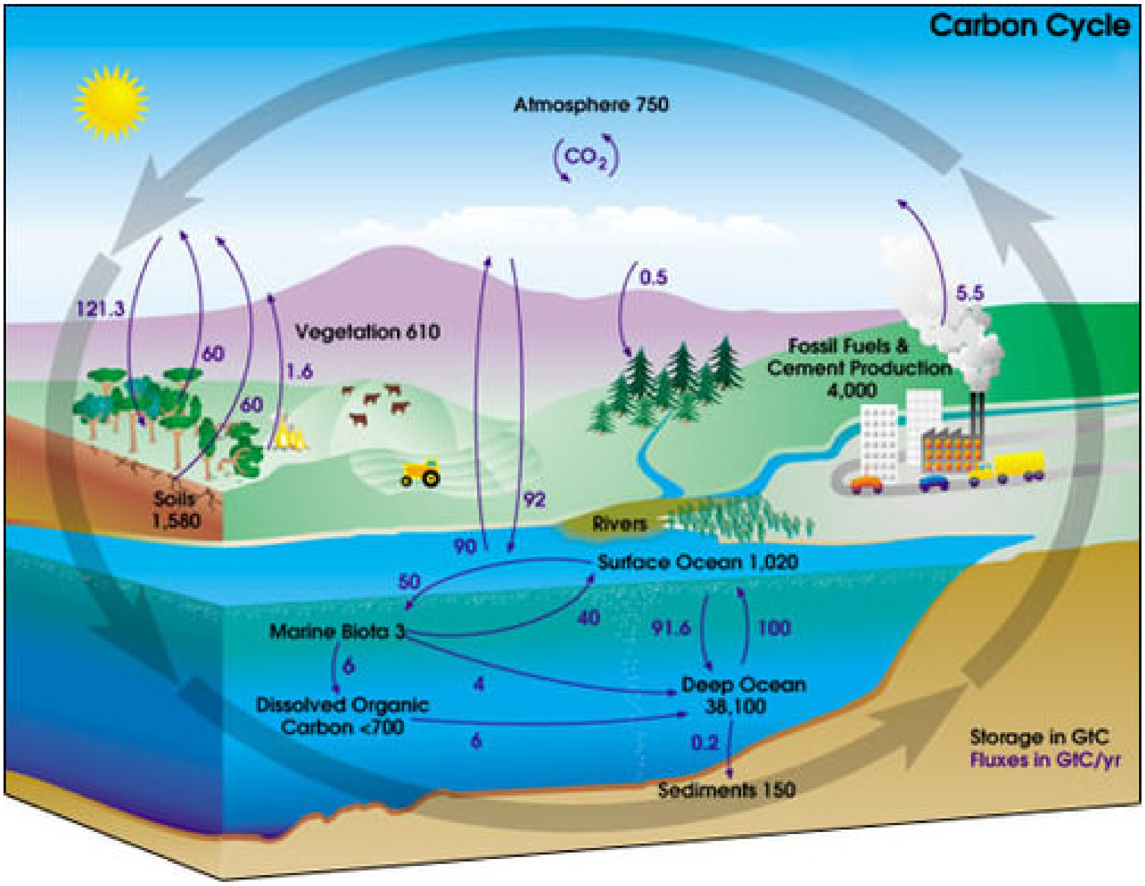


Image by NASA, https://commons.wikimedia.org/wiki/File:Carbon_cycle-cute_diagram.jpeg, public domain

Short Term Cycling of Carbon

The time it takes carbon to move through the fast part of the carbon cycle is measured in a lifespan. The fast carbon cycle is largely the movement of carbon through life forms on Earth, or the biosphere. Between 1,000 to 100,000 million metric tons of carbon move through the fast carbon cycle every year.

Carbon plays an essential role in biology because of its ability to form many bonds—up to four per atom—in a seemingly endless variety of complex organic molecules.

The main processes of the fast carbon cycle are photosynthesis and cellular respiration. Through photosynthesis, atmospheric carbon dioxide (CO_2) plus water and energy from sunlight is transformed into organic carbon (food) with oxygen given off as a waste product. Photosynthesis transforms the light energy of the Sun into a usable form of chemical energy.

The chemical equation for photosynthesis is:

$$6CO_2 + 6H_2O \xrightarrow{\text{Energy from Sunlight}} C_6H_{12}O_6 + 6O_2$$

Carbon Dioxide	Water		Glucose (sugar)	Oxygen

Plants and animals engage in the reverse of photosynthesis, which is cellular respiration. In cellular respiration, animals use oxygen to convert the organic carbon in sugar into energy they can use. Plants also go through cellular respiration and consume some of the sugars they produce.

The chemical reaction for cellular respiration is:

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

Oxygen	Glucose (sugar)	Water	Carbon Dioxide

Photosynthesis and respiration are a gas exchange process. In photosynthesis, CO_2 is converted to O_2; in cellular respiration, O_2 is converted to CO_2.

The fast carbon cycle is so tightly tied to plant life that the growing season can be seen by the way carbon dioxide fluctuates in the atmosphere. In the Northern Hemisphere winter, when few land plants are growing and many are decaying, atmospheric carbon dioxide concentrations climb. During the spring, when plants begin growing again, concentrations drop.

The relationship between seasons and the short term carbon cycle are shown by the diagrams below. The graph shows the average monthly change in atmospheric carbon dioxide, and the maps show the seasonal distribution of carbon dioxide around the globe.

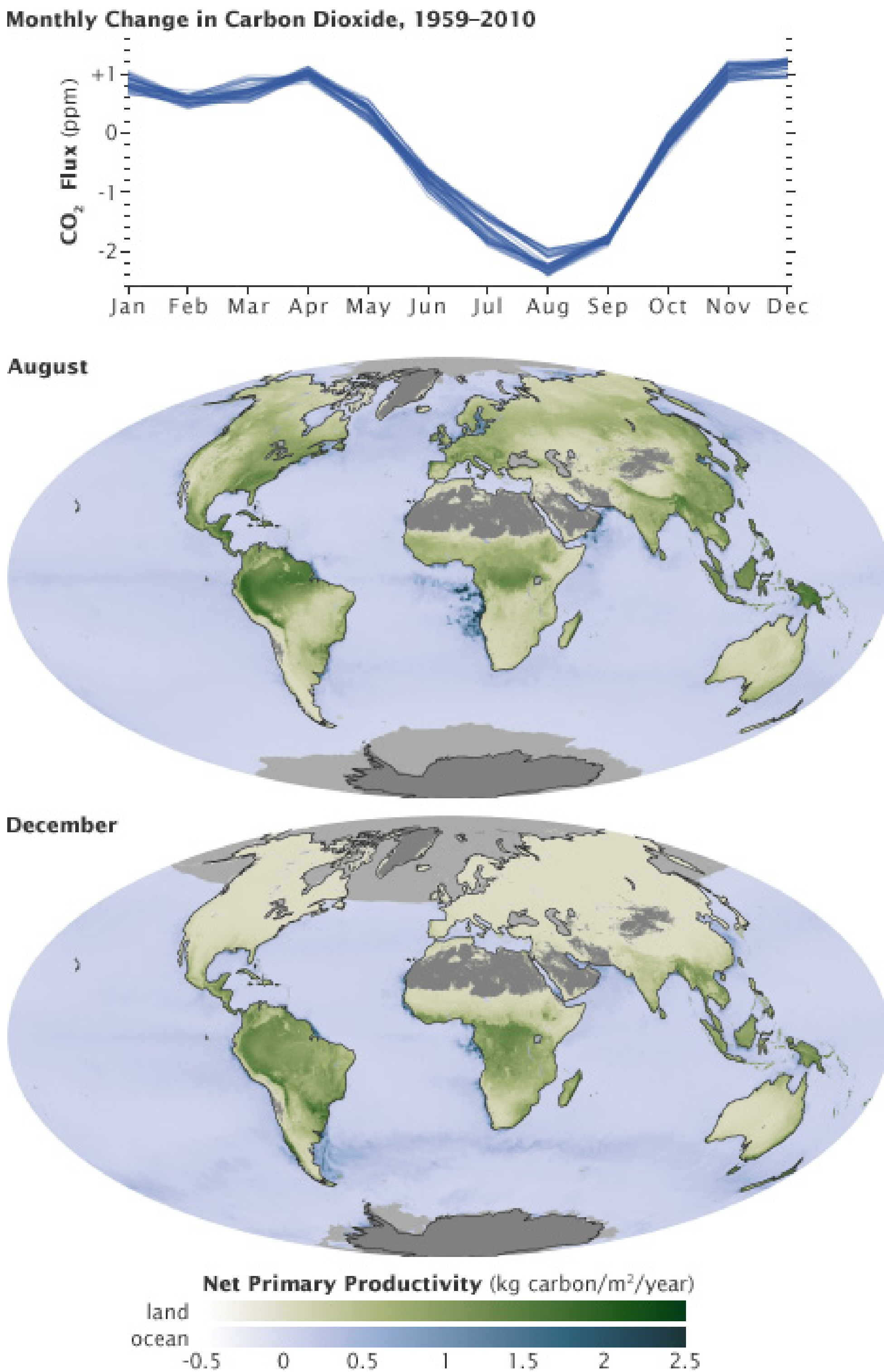


Image by Graph by Marit Jentoft-Nilsen and Robert Simmon, using data from the NOAA Earth System Research Laboratory. Maps by Robert Simmon and Reto Stöckli, using MODIS data; https://earthobservatory.nasa.gov/features/CarbonCycle; public domain

Long-Term Carbon Cycling

Through a series of chemical reactions and tectonic activity, carbon takes between 100-200 million years to move between rocks, soil, ocean, and atmosphere in the slow carbon cycle. On average, 10–100 million metric tons of carbon move through the slow carbon cycle every year. Much less than the fast carbon cycle.

The movement of carbon from the atmosphere to the lithosphere (rocks) begins with rain. Atmospheric carbon combines with water to form a weak acid that falls to the surface in rain. The acid dissolves rocks—a process called chemical weathering—and ions. Rivers carry the ions to the ocean.

Ions carried to the ocean combine with ions in the ocean water in complicated chemical processes that, over time, produce layers of carbon-based sedimentary rock, storing the carbon in the rock of the ocean floor.

The slow cycle returns carbon to the atmosphere through volcanoes. Earth's land and ocean surfaces sit on several moving crustal plates. When the plates collide, one sinks beneath the other, and the rock it carries melts under the extreme heat and pressure. The heated rock melts, releasing carbon dioxide in volcanic emission.

At present, volcanoes emit between 130 and 380 million metric tons of carbon dioxide per year. This is not a very large amount. For comparison, humans emit about 30 billion tons of carbon dioxide per year by burning fossil fuels.

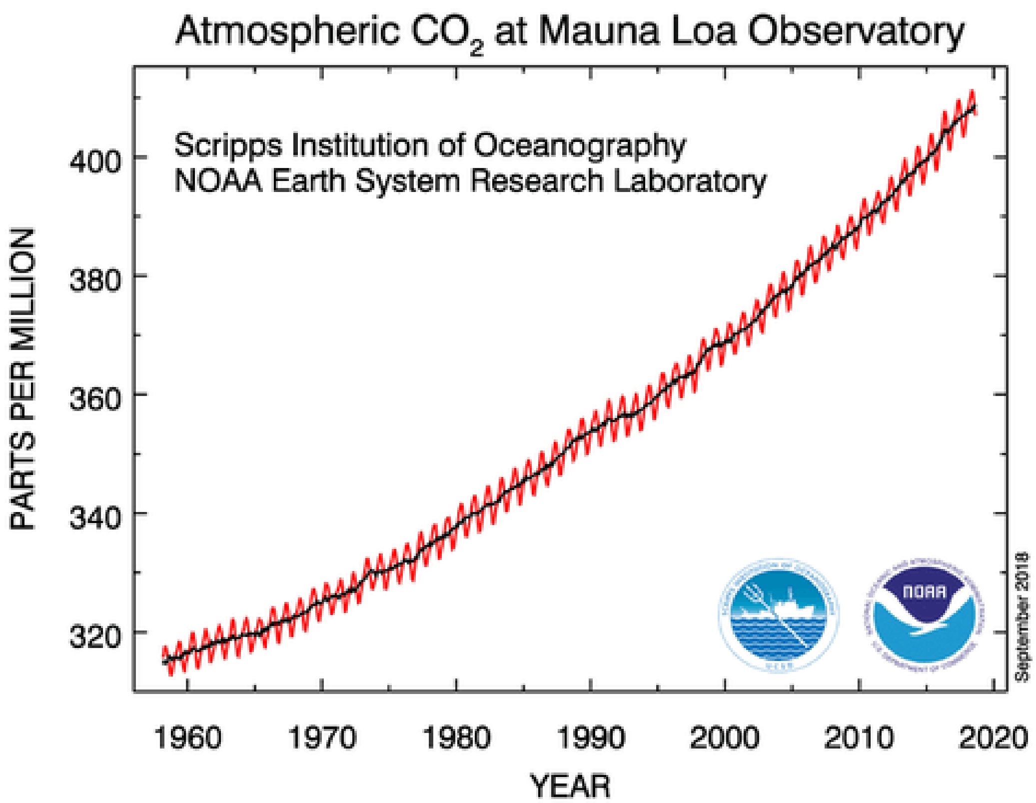
The Changing Carbon Cycle

Usually, the fast and slow carbon cycles maintain a relatively steady concentration of carbon in the atmosphere, land, plants, and ocean. But when anything changes the amount of carbon in one reservoir, the effect ripples through the others.

For example, the amount of CO_2 in the atmosphere is very low compared to other reservoirs that hold carbon. This means that a small increase or decrease in atmospheric CO_2 levels can have a large effect.

By measuring the composition of air bubbles trapped in glacial ice, scientists can learn the amount of atmospheric CO_2 at times in the past. Of particular interest is the time just before the Industrial Revolution when society began to use fossil fuels. That value is thought to be the natural content of CO_2 for this time period; that number according to ice core records was 280 parts per million (ppm).

By 1958, when scientists began to directly measure CO_2 content from the atmosphere at Mauna Loa volcano in the Pacific Ocean, the amount was 316 ppm (Figure below). In 2018, the atmospheric CO2 content reached 410 ppm.



The amount of CO_2 in the atmosphere has been measured at Mauna Loa Observatory since 1958. The black line shows yearly averaged CO_2. The red line shows seasonal variations in CO_2.
Image by NOAA, public domain

This is an increase in atmospheric CO_2 of 40% since before the Industrial Revolution. About 65% of that increase has occurred since the first CO_2 measurements were made on Mauna Loa Volcano, Hawaii, in 1958.

A change to the amount of carbon stored in the atmosphere will result in changes to the other reservoirs of the cycle and Earth's systems.

Human Actions Impact the Carbon Cycle

Today, changes in the carbon cycle are happening because of people. We alter the natural carbon cycle by burning fossil fuels and clearing land.Humans have changed the natural balance of the carbon cycle because we use coal, oil, and natural gas to supply our energy demands. Fossil fuels are a sink for CO_2 when they form, but they are a source for CO_2 when they are burned.

The equation for the combustion of propane, which is a simple hydrocarbon, looks like this:

$$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$$

Propane + Oxygen → Carbon Dioxide + Water

According to the equation, when propane burns it uses oxygen and produces carbon dioxide and water. So when a car burns a tank of gas (not propane, but a similar substance), the amount of CO_2 in the atmosphere increases just a little. Added over millions of tanks of gas and coal burned for electricity in power plants and all of the other sources of CO_2, the result is the increase in atmospheric CO_2 seen in the graph of Atmospheric CO_2 at the Mauna Loa Observatory above.

The second largest source of atmospheric CO_2 is deforestation. Trees naturally absorb CO_2 while they are alive. Trees that are cut down lose their ability to absorb CO_2 and may add CO_2 to the atmosphere if the tree is burned or decomposes. A forest can go from being a carbon sink to being a carbon source.

Effects of Changes to the Carbon Cycle

The slow carbon cycle contains a slightly faster component: the ocean. At the surface, where air meets water, carbon dioxide gas dissolves in and is released from the ocean in a steady exchange with the atmosphere. When carbon dioxide dissolves in ocean water, the water becomes more acidic.

Before the industrial age, the exchange of carbon dioxide between the ocean and the atmosphere was in balance. However, since carbon concentrations in the atmosphere have increased, the ocean now takes more carbon from the atmosphere than it releases. Over millennia, the ocean will absorb up to 85 percent of the extra carbon people have put into the atmosphere. It will become more and more acidic.

Ocean acidification is already impacting many ocean species, especially organisms like oysters and corals that make hard shells and skeletons. Acidic water prevents these organisms from building and maintaining such structures. If water continues to become more acidic, shells and skeletons can even begin to dissolve.

Ocean acidification can impact human populations, as well, if ocean organisms decline. Billions of people worldwide rely on food from the ocean as their primary source of protein. Many jobs and economies in the U.S. and around the world depend on the fish and shellfish that live in the ocean.

It is significant that so much carbon dioxide has been moved to the atmosphere because CO_2 is the most important gas for controlling Earth's temperature.

Carbon dioxide is a greenhouse gas. Greenhouse gasses trap heat energy that would otherwise radiate out into space. Greenhouse gasses insulate our planet and keep us warm. The carbon cycle naturally maintains small amounts of carbon dioxide in the atmosphere which helps to maintain life supporting warmth.

However, an increase in the amount of carbon dioxide in the atmosphere leads to an increase in the amount of energy that is insulated, increasing average temperature. Based on surface and atmospheric temperatures from thousands of locations, and from satellites worldwide, scientists have determined that the global mean temperature has risen 0.8 degrees C (1.4 degrees F) since 1880 (as of 2020). We know the carbon dioxide released from the fossil fuels that humans are burning is responsible for this change because its unique chemical signature matches that found in the carbon dioxide entering our atmosphere right now.

The image below compares the natural greenhouse effect (left) with the human enhanced greenhouse effect (right) as a result of increased carbon dioxide in the atmosphere.

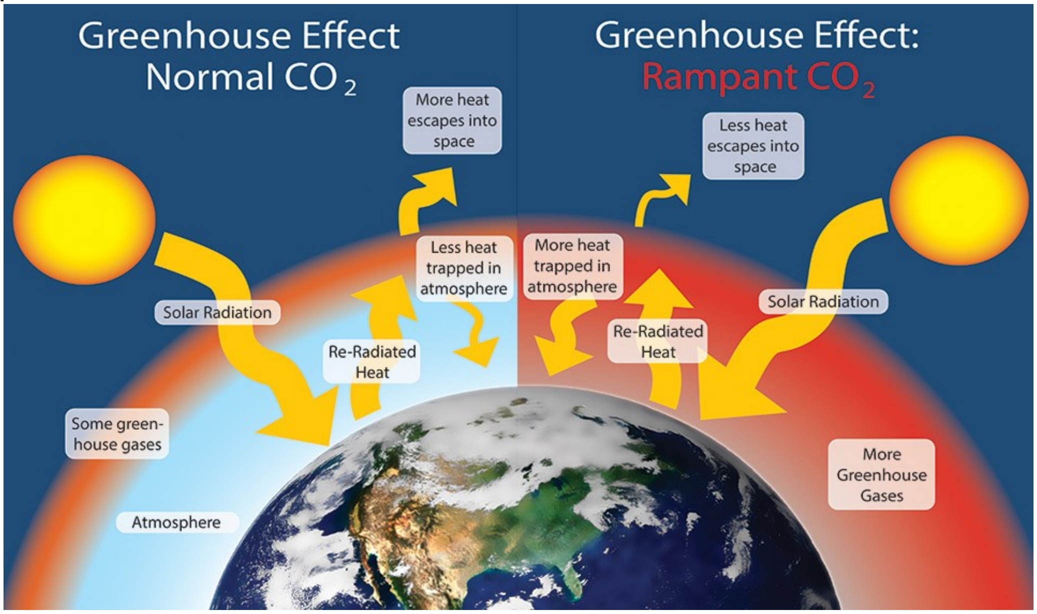


Image by Will Elder, NPS; https://www.nps.gov/goga/learn/nature/climate-change-causes.htm;; public domain

Putting It Together

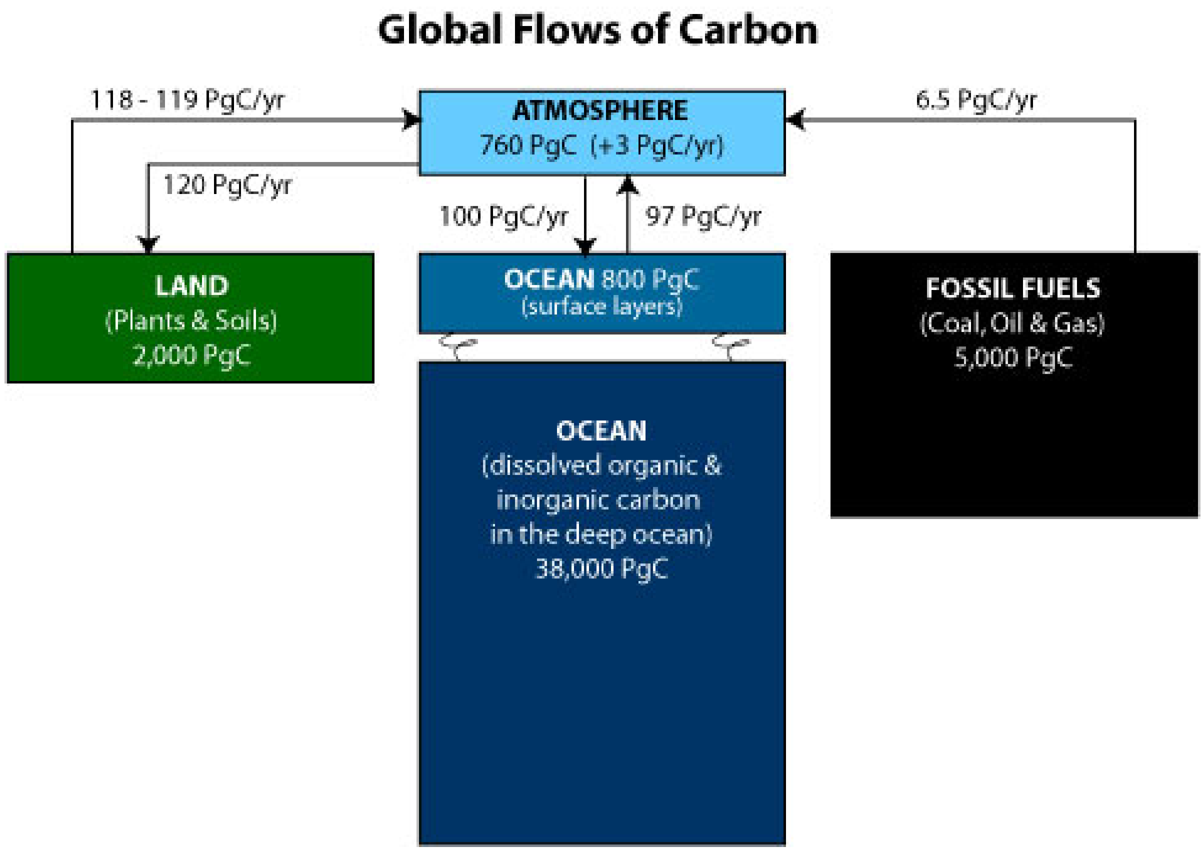


Image by NASA, https://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-carbon-cycle, public domain

Focus Questions:

1. Predict the effects of the changes to the amounts of carbon in the surface layers of the ocean, shown by the chart.

2. Predict the effects of the changes to the amounts of carbon in the atmosphere, shown by the chart.

3. According to the chart, what is the human influence on the movement of carbon through the different reservoirs of the carbon cycle?

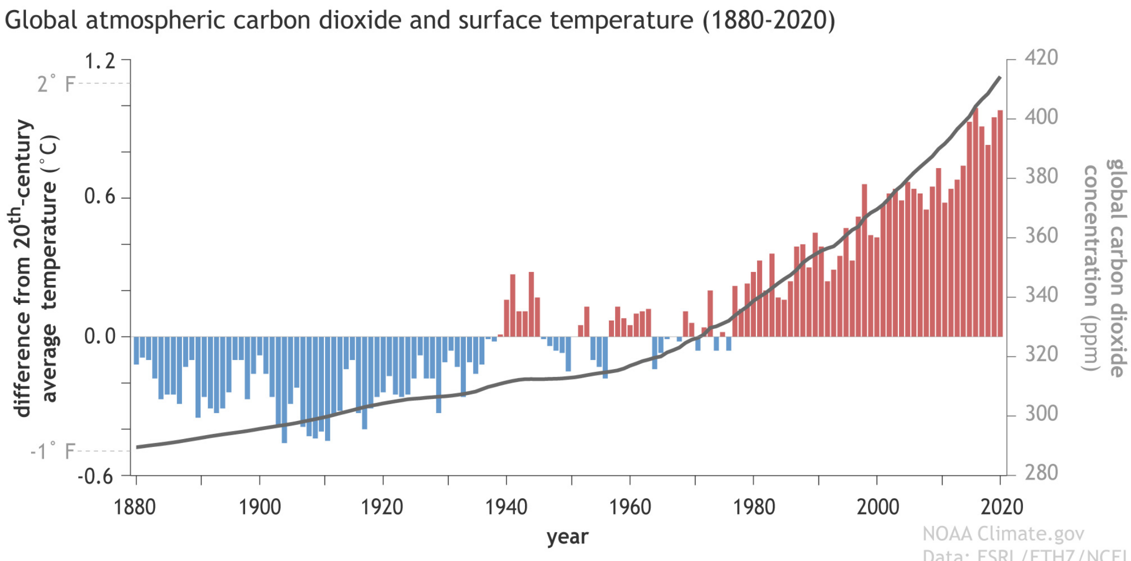
Final Task:

Using the chart above, predict how the amounts of carbon in the atmosphere will change if humans stop burning fossil fuels.

3.6 Global Climate History and Trends (ESS.3.6)

Phenomenon

The graph below shows yearly temperature (red and blue bars) compared to the twentieth-century average (0.0) from 1880–2019, and atmospheric carbon dioxide concentrations (gray line).



Graph by NOAA Climate.gov; https://www.climate.gov/media/13840; public domain

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions:

1. What is the modern trend in average temperature (bars)?

2. What is the modern trend in atmospheric CO_2 concentration (line)?

3. Predict how the trends might be related?

ESS.3.6 Global Climate History and Trends

Analyze and interpret data from global climate records to illustrate changes to Earth's systems throughout geologic time and make predictions about future variations using modern trends. Examples of data could include average sea surface temperature, average air temperature, composition of gasses in ice cores, or tree rings. (ESS2.D, ESS3.D)

In this section, focus on the idea that models can be used to infer and predict the behavior of Earth's past and future climate system.

Earth's Past Climate

The Earth's climate has changed throughout history. Just in the last 650,000 years there have been seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 7,000 years ago marking the beginning of the modern climate era — and of human civilization. Most of these climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives and natural changes to Earth's atmospheric composition .

Evidence of Past Climate

This section is adapted from What is proxy data? *by NOAA National Centers for Environmental Information;* https://www.ncei.noaa.gov/news/what-are-proxy-data; *public domain*

In paleoclimatology, or the study of past climates, scientists use what is known as proxy data to reconstruct past climate conditions. These proxy data are preserved physical characteristics of the environment that can substitute for direct measurements. Paleoclimatologists gather proxy data from natural recorders of climate variability such as corals, pollen, ice cores, tree rings, caves, pack rat middens, ocean and lake sediments, and historical data. By analyzing records taken from these and other proxy sources, scientists can extend our understanding of climate far beyond the instrumental record. The following paragraphs describe just a few examples of the environmental recorders scientists can use to learn about ancient climates.

Historical Data

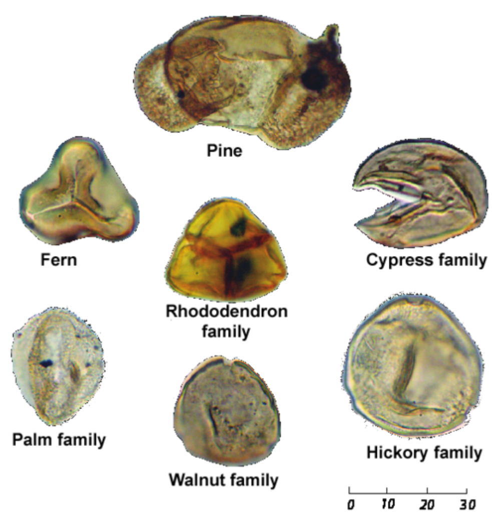
Historical documents, which are one type of proxy data, can contain a wealth of information about past climates. Observations of weather and climate conditions can be found in ship and farmers' logs, travelers' diaries, newspaper accounts, and other written records. When properly evaluated, historical documents can yield both qualitative and quantitative information about past climate. For example, scientists used historical grape harvest dates to reconstruct summer temperatures, between April and September, in Paris from 1370 to 1879.

Corals

Another type of proxy data, corals build their hard skeletons from calcium carbonate—a mineral extracted from seawater. The density of these calcium carbonate skeletons changes as the water temperature, light, and nutrient conditions change, giving coral skeletons formed in the summer a different density than those formed in the winter. The carbonate also contains isotopes of oxygen as well as trace metals that can be used to determine the temperature of the water in which the coral grew. Scientists can then use this information to reconstruct the climate when the coral lived.

Pollen Fossils

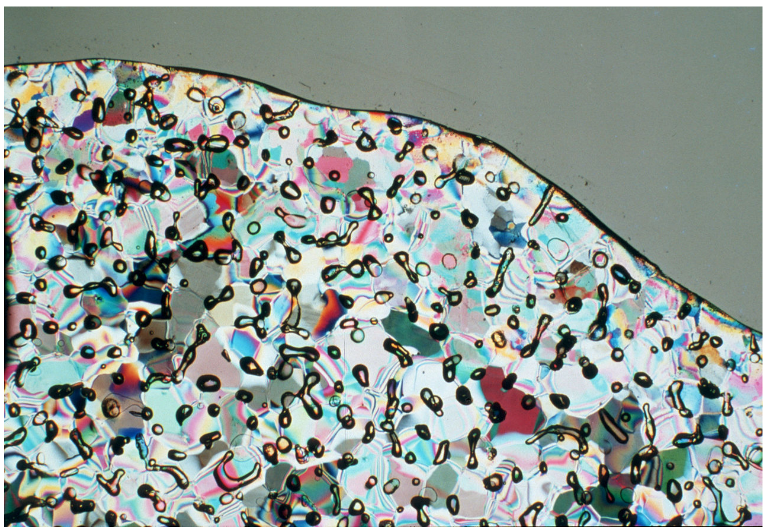
All flowering plants produce pollen grains, which are another type of proxy data. Scientists can use the distinctive shapes of pollen grains to identify the type of plant from which they came. Since pollen grains are well preserved in the sediment layers in the bottom of a pond, lake, or ocean, an analysis of the pollen grains in each layer tells scientists what kinds of plants were growing at the time the sediment was deposited. Scientists can then make inferences about the climate of the area based on the types of plants found in each layer since most plants will only grow under certain conditions.



Fossil pollen and spores preserved in sediments. *Image by USGS;* https://www.usgs.gov/programs/climate-research-and-development-program/science/paleoclimate-proxies; public domain

Ice Cores

Located high in the mountains and near the poles, ice—another type of proxy data—has accumulated from snowfall over many millennia. Scientists drill through the deep ice to collect ice cores, which often have distinct layers in them. These layers contain dust, air bubbles, or isotopes of oxygen, differing from year to year based on the surrounding environment, that can be used to interpret the past climate of an area. Ice cores can tell scientists about temperature, precipitation, atmospheric composition, volcanic activity, and even wind patterns.



Bubbles in an Antarctic ice sample illuminated with polarized light.

Image by CSIRO; https://en.wikipedia.org/wiki/Ice_core#/media/File:CSIRO_ScienceImage_518_Air_Bubbles_Trapped_in_Ice.jpg; CC BY 3.0

Tree Rings

Trees and their unique rings also serve as proxy data. Because climate conditions influence tree growth, patterns in tree-ring widths, density, and isotopic composition reflect variations in climate. In temperate regions where there is a distinct growing season, trees generally produce one ring a year, recording the climate conditions each year. If they depend heavily on warm temperatures or lots of moisture in the growing season, their rings will be wider when those conditions are present and narrower when they aren't. Trees can also grow to be hundreds to thousands of years old and can contain annual records of climate for centuries to millennia.

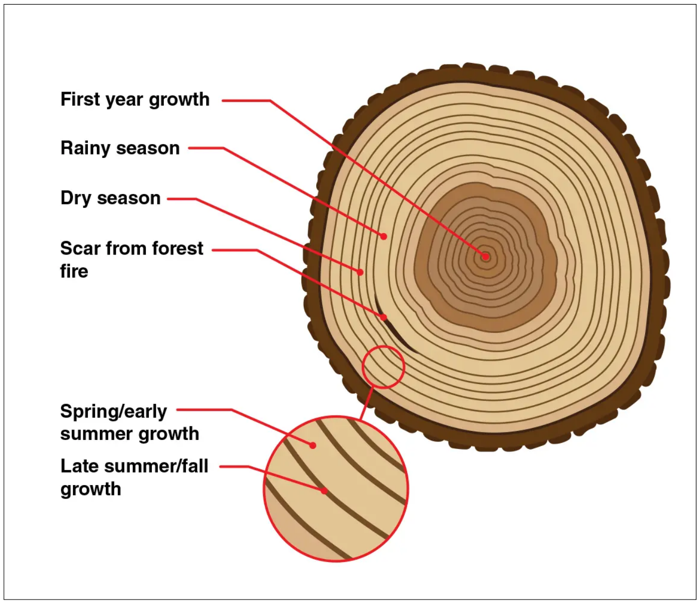


Image by NASA Global Climate Change; https://climate.nasa.gov/news/2540/tree-rings-provide-snapshots-of-earths-past-climate/; public domain

Cave Formations

Caves and the unique rock formations inside them also serve as proxy data. These underground chambers contain the secrets of Earth's climate in speleothems—also known as stalactites, stalagmites, and other formations. Speleothems grow over time as water drips down from a cave's ceiling or pools in its floor and mineral deposits build up in thin, shiny layers. Because the amount of water making its way into caves determines the amount speleothems grow, their layers can indicate times of both heavy precipitation and drought.

Sediment Samples

Another type of proxy data can be found on the floors of Earth's oceans and lakes. Billions of tons of sediment accumulate in ocean and lake basins each year, providing a vast amount of information about the environment. Scientists drill cores of the sediments from the basin floors and examine their contents, which include tiny fossils and chemicals, to interpret past climates.

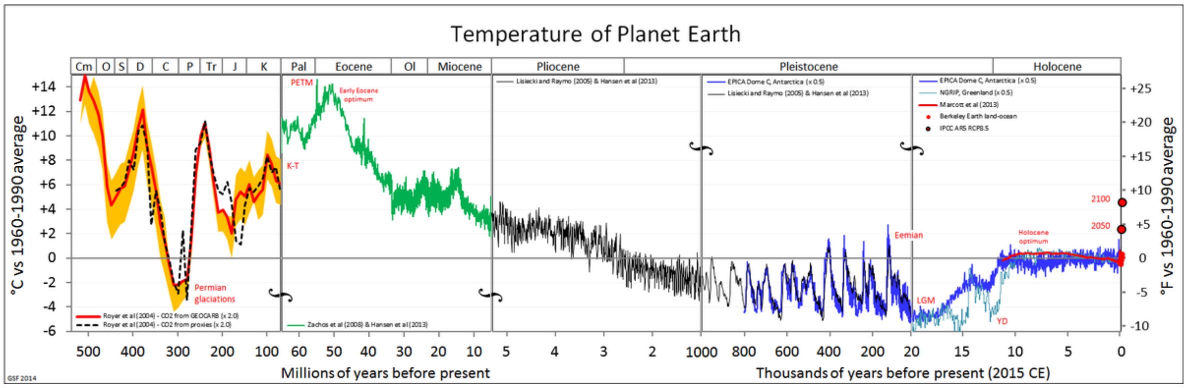


Image *Global average temperature estimates for the last 540 My* by Glen Fergus; https://commons.wikimedia.org/wiki/File:All_palaeotemps.png; CC BY-SA 3.0

The graph above shows estimates of global average surface air temperature over the ~540 million years. It was produced using proxy data. The temperature proxy measurements between 540 to 1 million years ago were produced by chemical measurements from the shells of microscopic marine organisms found in sediments. Measurements from 1 million to 20,000 years ago were taken from ice cores. Measurements from 20,000 years ago to the present were made by ice core analysis and other temperature proxies.

Natural Causes of Climate Change

Several natural processes have affected Earth's temperature throughout its history. The amount of energy the Sun radiates is variable. Sunspots are magnetic storms on the Sun's surface that increase and decrease over an 11-year cycle. When the number of sunspots is high, solar radiation is also relatively high. But the entire variation in solar radiation is tiny relative to the total amount of solar radiation that there is, and there is no known 11-year cycle in climate variability.

Plate tectonic movements can alter climate. Over millions of years as seas open and close, ocean currents may distribute heat differently. For example, when all the continents were joined into one supercontinent (such as Pangaea), nearly all locations experienced a continental climate. When the continents separate, heat is more evenly distributed. Plate tectonic movements may also help start an ice age. When continents are located near the poles, ice can accumulate, which may increase albedo and lower global temperature. Low enough temperatures may start a global ice age. Climate change caused by Plate Tectonics can take millions of years, much longer than the warming we are seeing today.

Plate motions trigger volcanic eruptions, which release dust and CO_2 into the atmosphere. Ordinary eruptions, even large ones, have only a short-term effect on weather. Massive eruptions of fluid lavas release much more gas and dust and can change climate for many years. This type of eruption is exceedingly rare and none has occurred since humans have lived on Earth.

Most significant changes in Earth's climate in the past are attributed by scientists to variation in the Earth's position relative to the Sun, known as Milankovitch cycles. The Earth goes through regular variations in its position relative to the Sun. When these three variations are charted out, a climate pattern of about 100,000 years emerges. Ice ages correspond closely with Milankovitch cycles. Since glaciers can form only over land, ice ages only occur when landmasses cover the polar regions. Therefore, Milankovitch cycles are also connected to plate tectonics.

Greenhouse gas levels have varied throughout Earth's history and can cause changes in climate. For example, CO_2 has been present at concentrations less than 200 parts per million (ppm) and more than 5,000 ppm. But for at least 650,000 years, CO_2 has never risen above 300 ppm, during either glacial or interglacial periods, shown below.

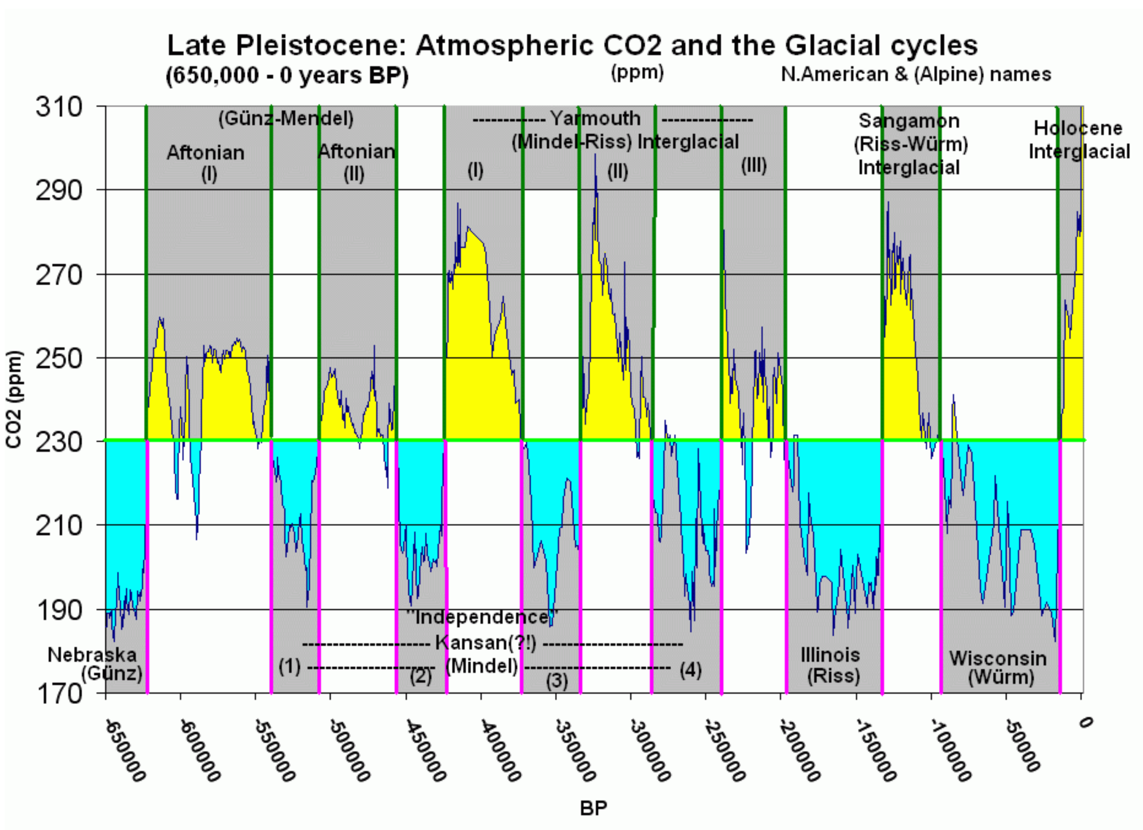
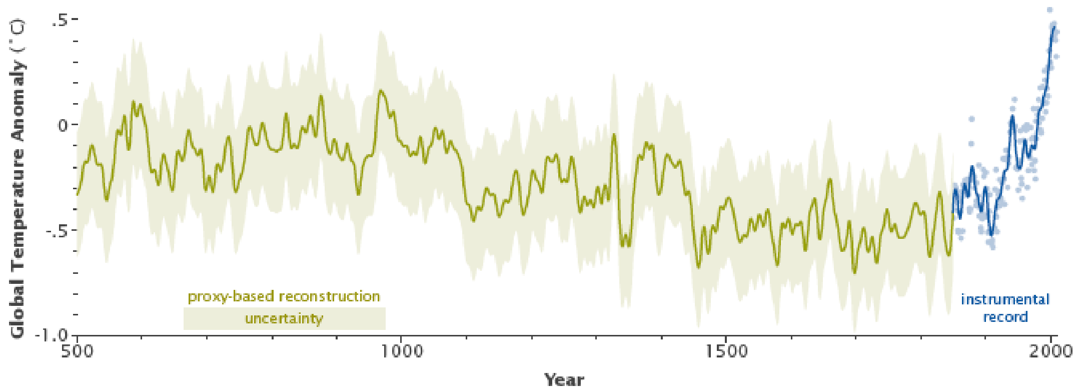


Image Atmospheric CO2 with glaciers cycles by Tom Ruen; https://commons.wikimedia.org/wiki/File:Atmospheric_CO2_with_glaciers_cycles.png; public domain

Current Climate Change

Paleoclimate records reveal that current warming of the climate is occurring much more rapidly than past warming events. In the past century alone, the temperature has risen roughly ten times faster than the average rate of ice-age-recovery warming. The predicted rate of warming for the next century is at least 20 times faster. This rate of change is extremely unusual and has never been seen before in Earth's history.



NASA graph by Robert Simmon, based on data from Jouzel et al., 2007; https://earthobservatory.nasa.gov/features/GlobalWarming/page3.php; public domain

The graph above shows Temperature histories from paleoclimate data (green line) compared to the history based on modern instruments (blue line). The data suggests that global temperature is warmer now than it has been in the past 1,000 years, and possibly longer.

Evidence for Current Climate Change

This section is adapted from Evidence: How do we know climate change is real by NASA Global Climate Change https://climate.nasa.gov/evidence/; public domain.

The current warming trend is different because it is clearly the result of human activities since the mid-1800s, and is proceeding at a rate not seen over the past millions of years. Human activities have produced an abundance of atmospheric greenhouse gasses that have trapped more of the Sun's energy in the Earth system. This extra energy has warmed the atmosphere, ocean, and land, and produced widespread and rapid changes in the atmosphere, ocean, ice cover, and biosphere.

The evidence for rapid climate change is compelling. First, global temperature is rising. The planet's average surface temperature has risen about 2 degrees Fahrenheit (1 degrees Celsius) since the late 19th century, a change driven largely by increased carbon dioxide emissions into the atmosphere and other human activities. Most of the warming occurred in the past 40 years. The years 2016 and 2020 are tied for the warmest year on record. The number of record high temperature events in the United States has been increasing, while the number of record low temperature events has been decreasing since 1950.

The ocean is getting warmer. The ocean has absorbed much of this increased heat, with the top 100 meters (about 328 feet) of ocean showing warming of more than 0.6 degrees Fahrenheit (0.33 degrees Celsius) since 1969. Earth stores 90% of the extra energy in the ocean. The graph below shows changes in heat content of the top 700 meters of the world's oceans between 1955 and 2020.

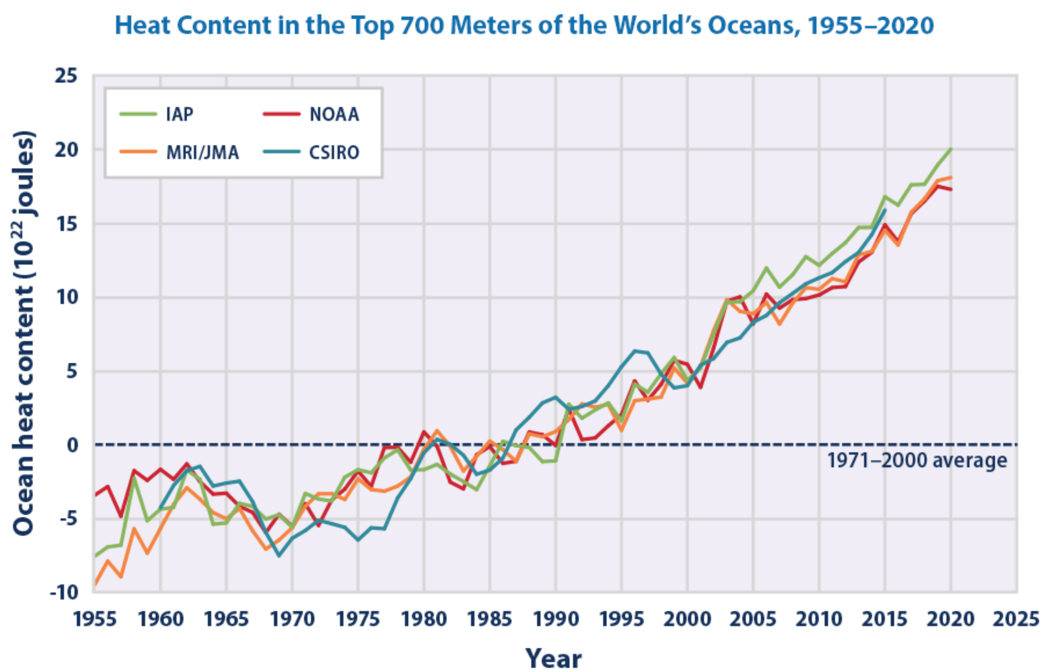


Image by EPA;
https://www.epa.gov/climate-indicators/climate-change-indicators-ocean-heat; public domain

Earth's ice, its cryosphere, is shrinking. The Greenland and Antarctic ice sheets have decreased in mass. Data shows Greenland lost an average of 279 billion tons of ice per year between 1993 and 2019, while Antarctica lost about 148 billion tons of ice per year. Glaciers are retreating almost everywhere around the world, including in the Alps, Himalayas, Andes, Rockies, and elsewhere. Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades. Satellite observations reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and the snow is melting earlier.

The first graph below shows the cumulative change in mass in the ice sheets of Greenland and Antarctica since 1992. The second graph below shows the cumulative mass of four U.S. reference glaciers since measurements began in the 1950s or 1960s. The third diagram below is a map of the western United States that shows trends in April snowpack, measured in terms of snow water equivalent. Blue circles represent an increased snowpack; red circles represent a decrease.

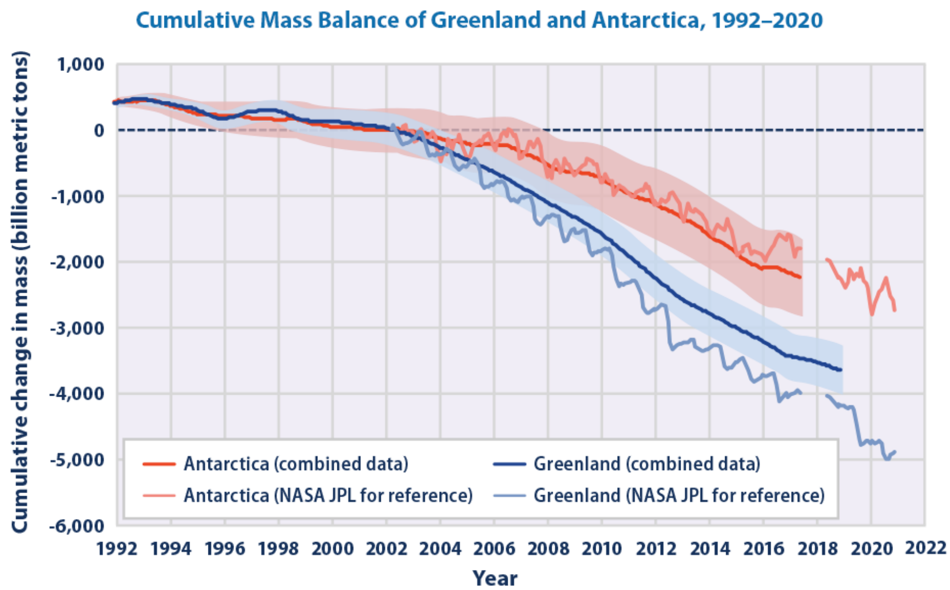


Image by EPA; https://www.epa.gov/climate-indicators/climate-change-indicators-ice-sheets; public domain

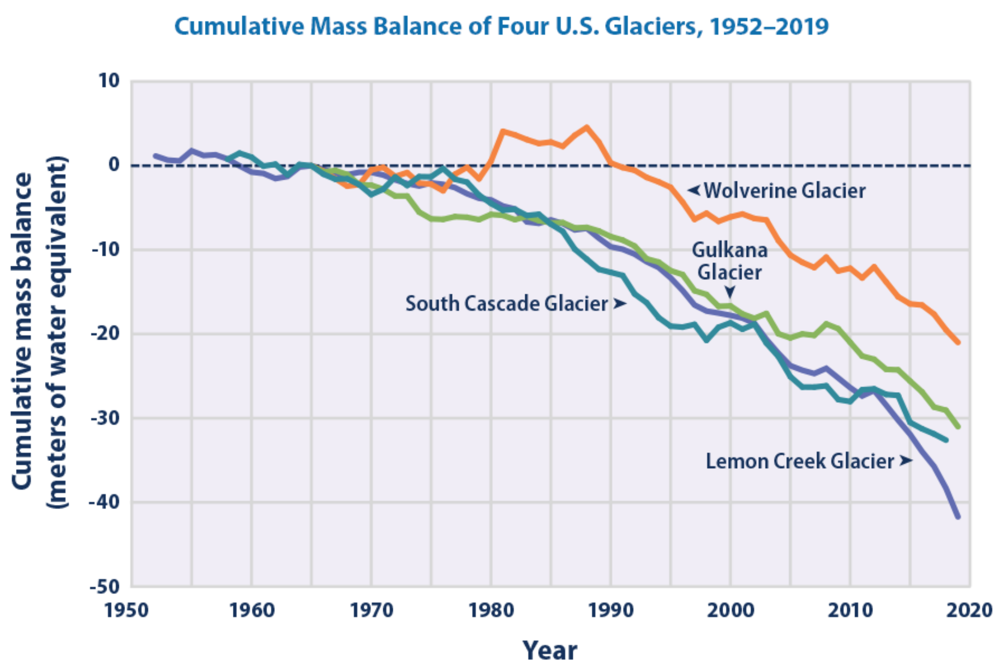


Image by EPA; https://www.epa.gov/climate-indicators/climate-change-indicators-glaciers; public domain

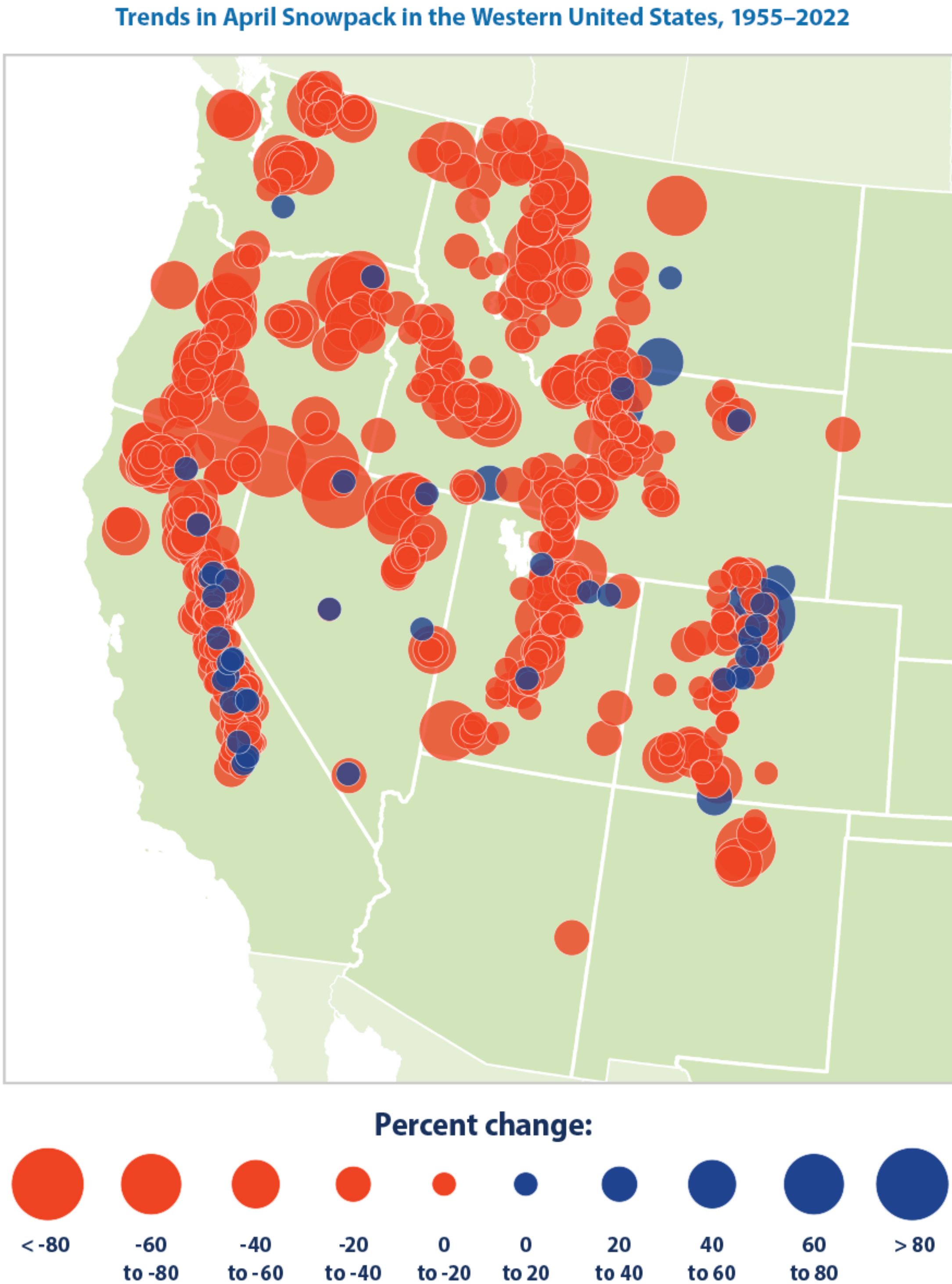


Image by EPA; https://www.epa.gov/climate-indicators/climate-change-indicators-snowpack; public domain

Ocean waters are changing in response to changes in climate. Global sea level rose about 8 inches (20 centimeters) in the last century. The rate in the last two decades, however, is nearly double that of the last century and accelerating slightly every year. Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30%. This increase is due to humans emitting more carbon dioxide into the atmosphere and therefore more being absorbed into the ocean. The ocean has absorbed between 20% and 30% of total human produced carbon dioxide emissions in recent decades (7.2 to 10.8 billion metric tons per year). The graph below shows cumulative changes in sea level for the world's oceans since 1880.

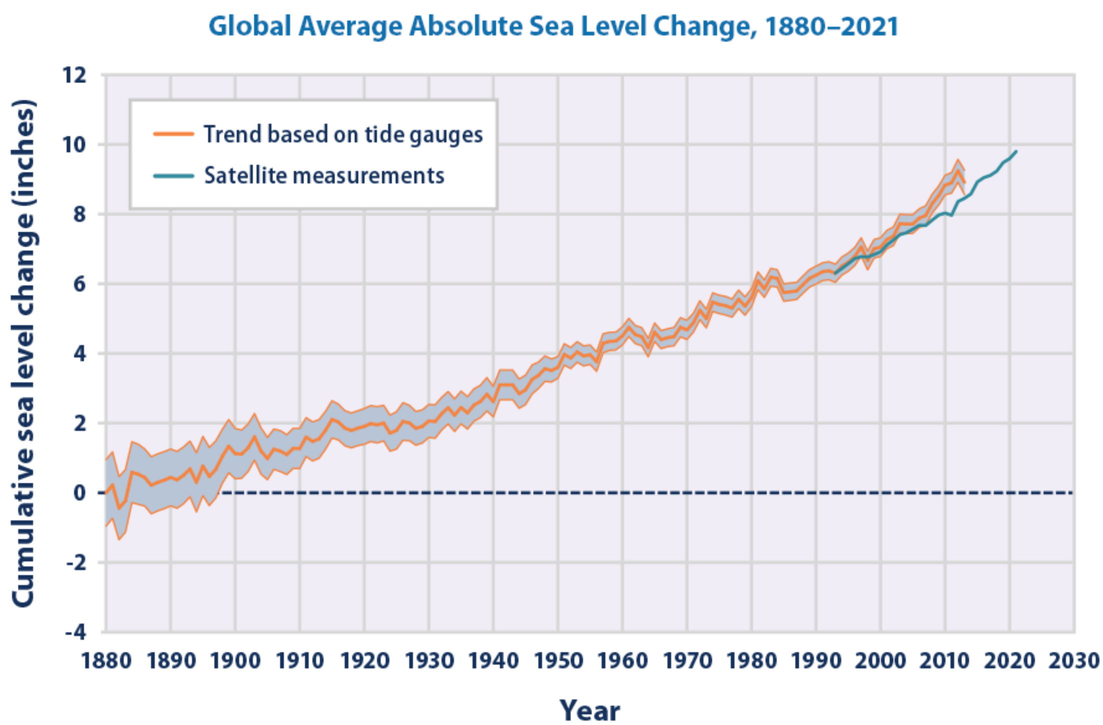


Image by EPA: https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level; public domain

There is much more evidence of current climate change than is described above. The Earth's climate is changing. Temperatures are rising, snow and rainfall patterns are shifting, and more extreme climate events – like heavy rainstorms and record high temperatures – are already happening. Many of these observed changes are linked to the rising levels of carbon dioxide and other greenhouse gasses in our atmosphere.

Future Climate

Future climate is predicted using climate models. Climate models are complex. They use mathematical equations to characterize how energy and matter interact in different parts of the ocean, atmosphere, land. Once a climate model is set up, it can be tested by running the model from the present time backwards into the past. The model results are then compared with observed climate and weather conditions to see how well they match. This testing allows scientists to check the accuracy of the models and, if needed, revise its equations. Once a climate model is tested and performs well, its results for simulating future climate are also assumed to be accurate.

To predict climate in the future, models are run using different conditions and variables to represent different scenarios. Scenarios are possible stories about how quickly the human population will grow, how land will be used, how economies will evolve and affect climate policies, and the atmospheric conditions that would result for each storyline.

Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. They also show that human decisions and behavior we choose today will determine how dramatically the climate will change in the future.

The graphs and images below show the different pathways that climate could take based on greenhouse gas emissions and concentrations. Each different scenario produced by climate models is called a Representative Concentration Pathway (RCP). The trend lines of an RCP is dependent on the concentration of greenhouse gasses. More greenhouse gas emissions will result in warmer temperatures and sea level rise. Reduced greenhouse gas emissions will produce less extremes.

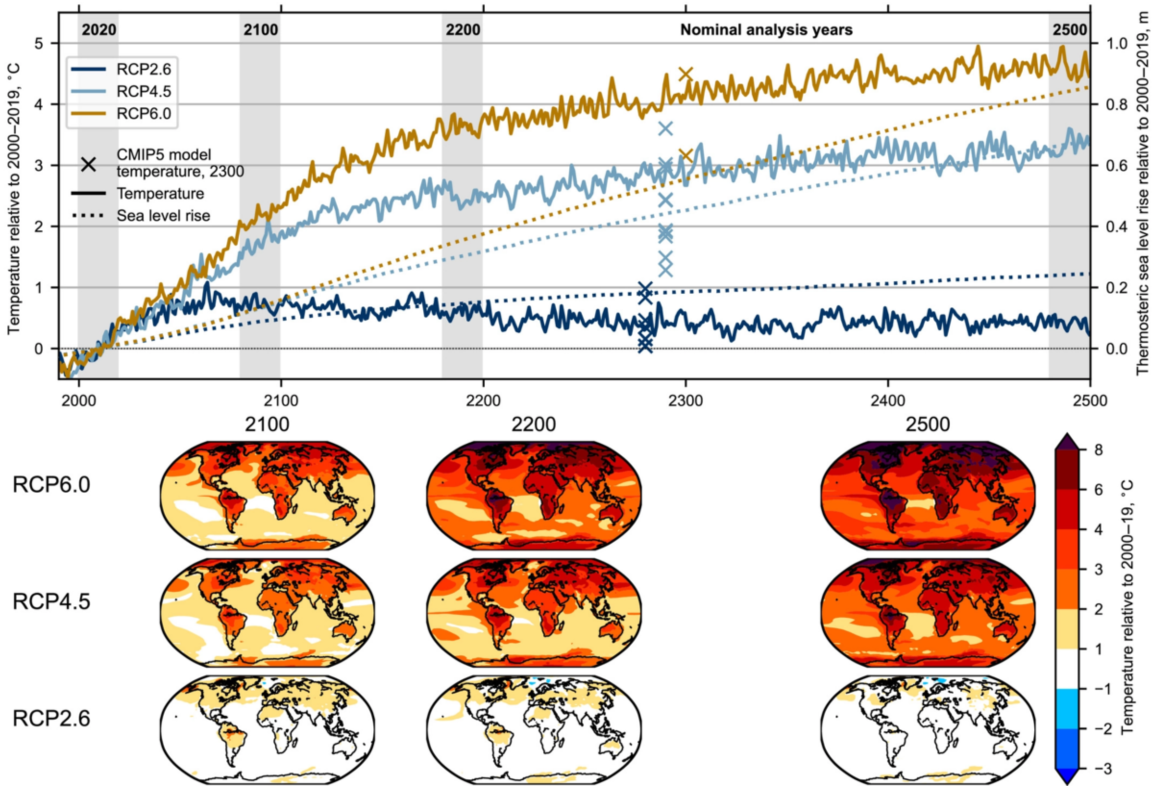
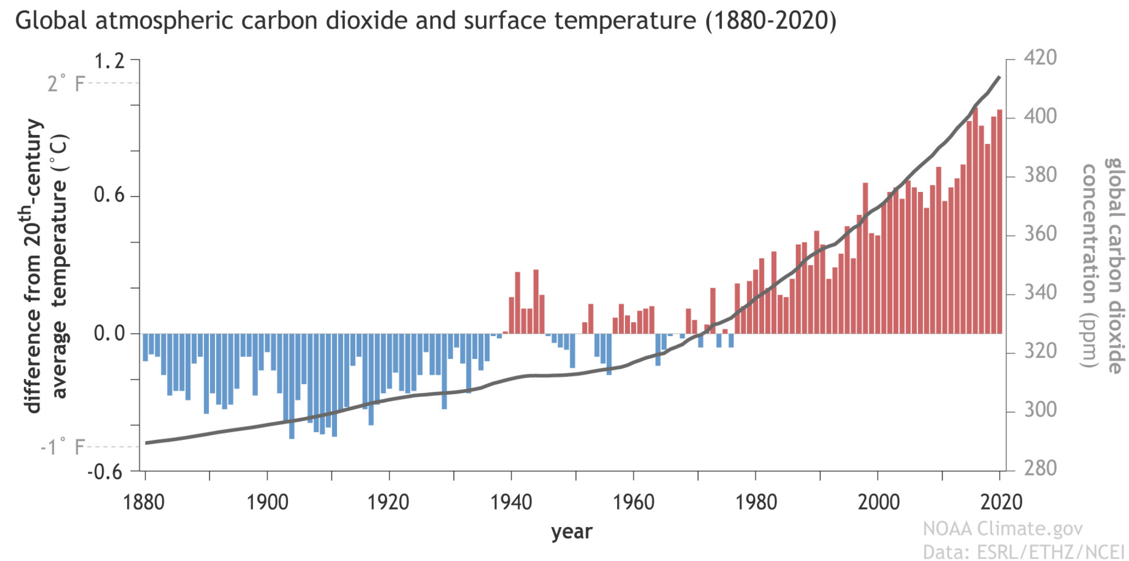


Image by Christopher Lyon, Erin E. Saupe, Christopher J. Smith, Daniel J. Hill, Andrew P. Beckerman, Lindsay C. Stringer, Robert Marchant, James McKay, Ariane Burke, Paul O'Higgins, Alexander M. Dunhill, Bethany J. Allen, Julien Riel-Salvatore, and Tracy Aze; https://en.wikipedia.org/wiki/File:Global_mean_near-surface_air_temperature_and_thermosteric_sea-level_rise_anomalies_relative_to_the_2000%E2%80%932019_mean_for_RCP_climate_change_scenarios.webp; CC BY 4.0

Putting It Together



https://www.climate.gov/media/13840

Focus Questions:

1. What impacts to the environment will occur if modern trends continue in the future?

2. What can be done to change current trends in atmospheric CO_2 and global temperatures?

Final Task:

Develop and explain a method for preventing or limiting future changes in climate due to carbon dioxide.

3.7 Feedback Loops (ESS.3.7)

Phenomenon

The east side of Mount Timpanogos used to host a large glacier that remained on the mountain year-round. This photo, taken in the summer of 1925, shows people enjoying a day sliding down the mountain. Today the glacier is gone, and snow does not remain on the mountain during the summer. The amount of annual sunlight reaching Mount Timpanogos has not changed since 1925.

Image by John Wakefield, https://contentdm.lib.byu.edu/digital/collection/BYUPhotos/id/248/rec/2, public domain

Observations and Wonderings:

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions:

1. Is energy absorbed or reflected by the glacier's surface?

2. Is energy absorbed or reflected by the rock and soil around the glacier?

3. What effect would the absorption and reflection of energy from the glacier and the rock and soil have on temperature?

ESS.3.7 Feedback Loops

Engage in argument from evidence to support the claim that one change to Earth's surface can create climate feedback loops that cause changes to other systems. Examples of climate feedbacks could include ice-albedo or warming oceans. (PS3.B, ESS2.A)

In this section, focus on the idea that negative feedback can stabilize a system, while positive feedback can destabilize a system.

The Study of Earth as an Integrated System

This section was primarily adapted from Climate Forcing *by NOAA Climate.gov; https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-forcing ; public domain*

Earth system science is the study of how scientific data from various fields of research, such as the atmosphere, oceans, land ice and others, fit together to form the current picture of our planet as a whole, including its changing climate.

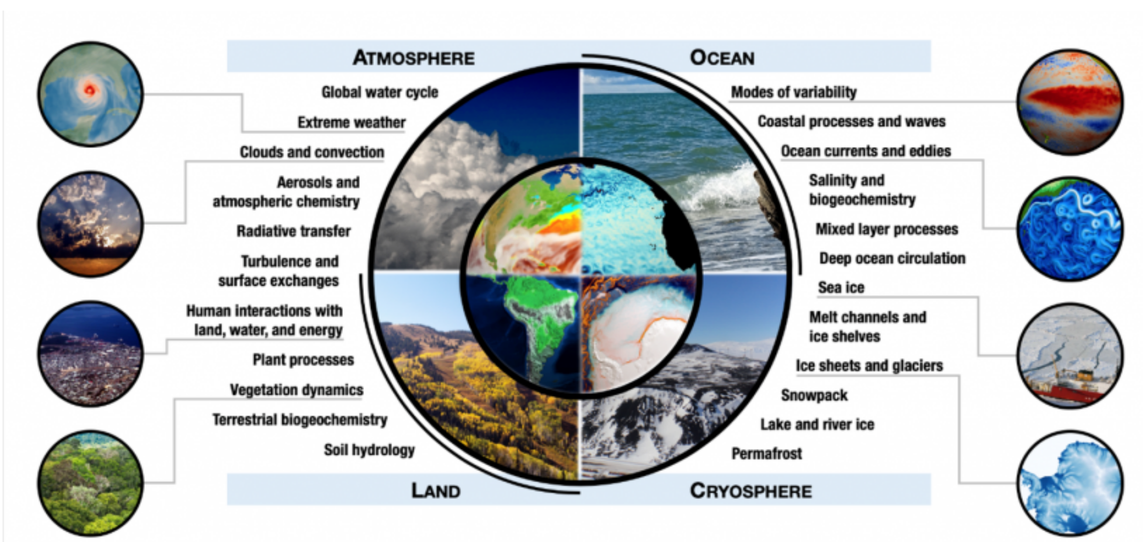


Image by Image courtesy of Paul Ullrich, University of California, Davis; https://www.energy.gov/science/doe-explainsearth-system-and-climate-models; CC BY

Earth is continually bathed in energy from the sun. Some of the energy that arrives at Earth is reflected back into space, some is absorbed directly by the atmosphere, and some moves through the atmosphere to the surface. Sunlight energy heats the land and water at the surface, and in turn, they emit heat. This heat provides further warming of the atmosphere. Greenhouse gasses in our atmosphere keeps some of the heat energy from escaping directly to space. The trapping of heat by atmospheric gasses is the naturally occurring greenhouse effect, keeping Earth warm enough to support life.

Climate scientists have three main ways to describe climate change and the factors that affect it: climate drivers, climate feedbacks, and climate thresholds.

Climate Drivers

A climate driver is something that affects the climate on Earth. Natural climate drivers include changes in the sun's energy output, regular changes in Earth's orbital cycle, and large volcanic eruptions that put light-reflecting particles into the upper atmosphere. Human-caused climate drivers include emissions of greenhouse gasses and changes in land use that affect albedo to make land reflect more or less sunlight energy. Since 1750, human-caused climate drivers have been increasing, and their effects have overshadowed natural climate drivers.

Earth's climate is all about energy balance. Climate drivers cause disruptions to this balance in two ways: by either trapping more heat in the system or letting more heat escape from the system. When climate drivers trap more heat than escapes from the system, the planet will warm. On the other hand, when more energy escapes than is captured, the planet will cool.

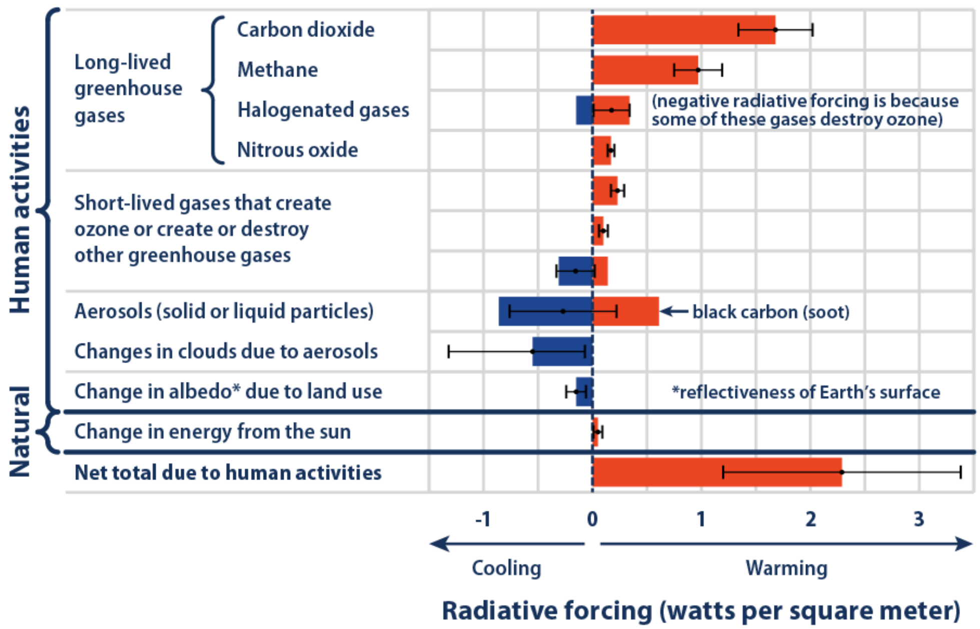


Image by EPA: https://www.epa.gov/climate-indicators/climate-change-indicators-climate-forcing; public domain

The image above shows the different types of human caused (since 1750) climate drivers that produce changes in atmospheric energy (radiative forcing). Red bars show a climate driver that is causing a warming effect by trapping energy in the atmosphere while the blue bars show a climate driver that is causing a cooling effect by allowing more energy to escape the atmosphere. The dotted black line in the middle represents a null influence or no change to the current global temperature or climate. The natural change in the energy received from the sun over this time period is provided for reference.

Climate Feedbacks

A feedback loop is a cause and effect system where the outputs of a system can be used as inputs, see the image below. Climate drivers can trigger climate feedback that intensifies or weakens the original condition of the climate.

A feedback that increases an initial warming of the climate is called "positive feedback." Positive feedback tends to destabilize the climate and produce change. A feedback that reduces an initial warming of the climate is a "negative feedback." Negative feedback tends to stabilize the climate. There are many examples of both positive and negative feedbacks in the climate system.

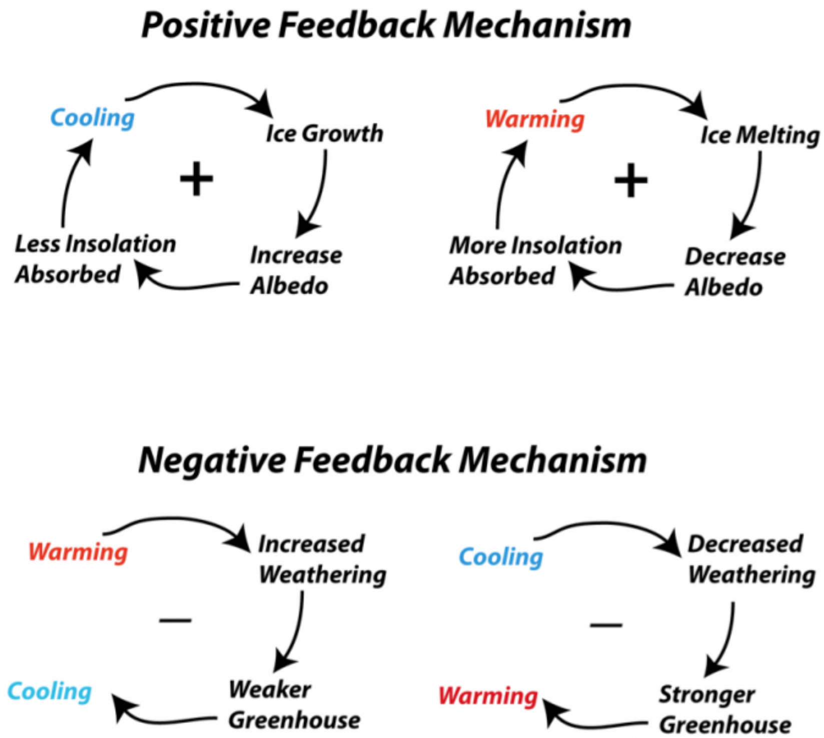


Image Feedback Mechanisms by Dr. David Bice, EARTH 103: Earth in the Future © Penn State University; https://www.e-education.psu.edu/geog430/node/519; CC BY-NC-SA 4.0

The ice-albedo feedback is a very strong positive feedback. Ice is white and very reflective in contrast to the ocean surface which is dark and absorbs heat faster. As the atmosphere warms and sea ice melts, the darker ocean absorbs more heat, causes more ice to melt, and makes the Earth warmer overall.

An example of the complexity of climate feedback is water in the atmosphere. Clouds have an enormous impact on Earth's climate, reflecting about one-third of the total amount of sunlight that hits the Earth's atmosphere back into space. Even small changes in cloud amount, location and type could have large consequences. A warmer climate could cause more water to be held in the atmosphere, leading to an increase in cloudiness and altering the amount of sunlight that reaches the surface of the Earth. Less heat would get absorbed, which could slow the increased warming.

Global climate models show that precipitation will generally increase due to the increased amount of water held in a warmer atmosphere, but not in all regions. Some regions will dry out instead. Changes in precipitation patterns, such as increased water availability, may cause an increase in plant growth, which in turn could potentially remove more carbon dioxide from the atmosphere.

The diagram below shows some of the positive and negative feedbacks that affect climate change.

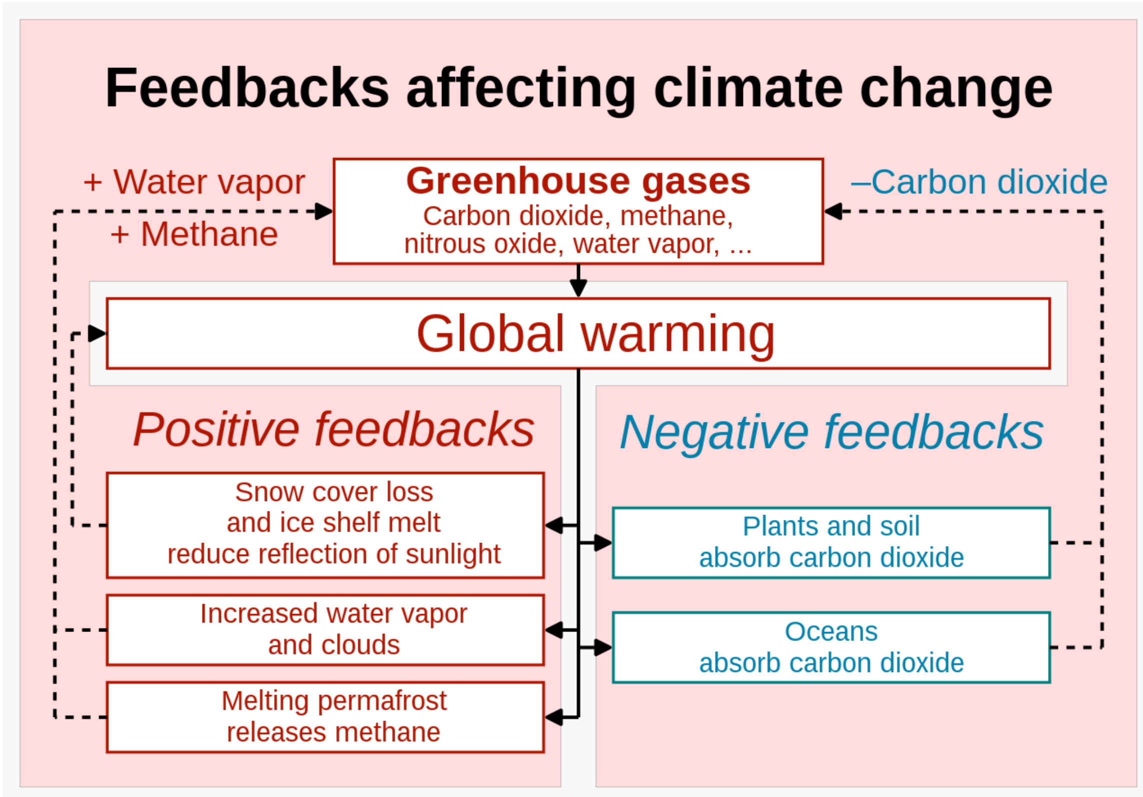


Image by RCraig09; https://en.wikipedia.org/wiki/Climate_change_feedback#/media/File:20220726_Feedbacks_affecting_global_warming_and_climate_change_-_block_diagram.svg; CC BY-SA 4.0

Climate Tipping Point

A positive feedback will destabilize the climate system until a tipping point is reached. A climate tipping point is the point at which small changes to the climate system build up to become significant enough to cause an abrupt, irreversible change. This means that the climate system responds to a climate driver by moving from one stable state to another; permanently. This is shown in the diagram below, where a system is forced over a tipping point and it moves from one steady state (regime A) to another steady state (regime B). Regime A and B are steady because the system is in equilibrium and will not move without a force being applied. Systems at a tipping point will always move toward more stable states. In the case of Earth, energy into the system will equal energy out of the system at equilibrium. As climate changes, and tipping points are reached and exceeded, the stable state of Earth's climate system will change to a new normal.

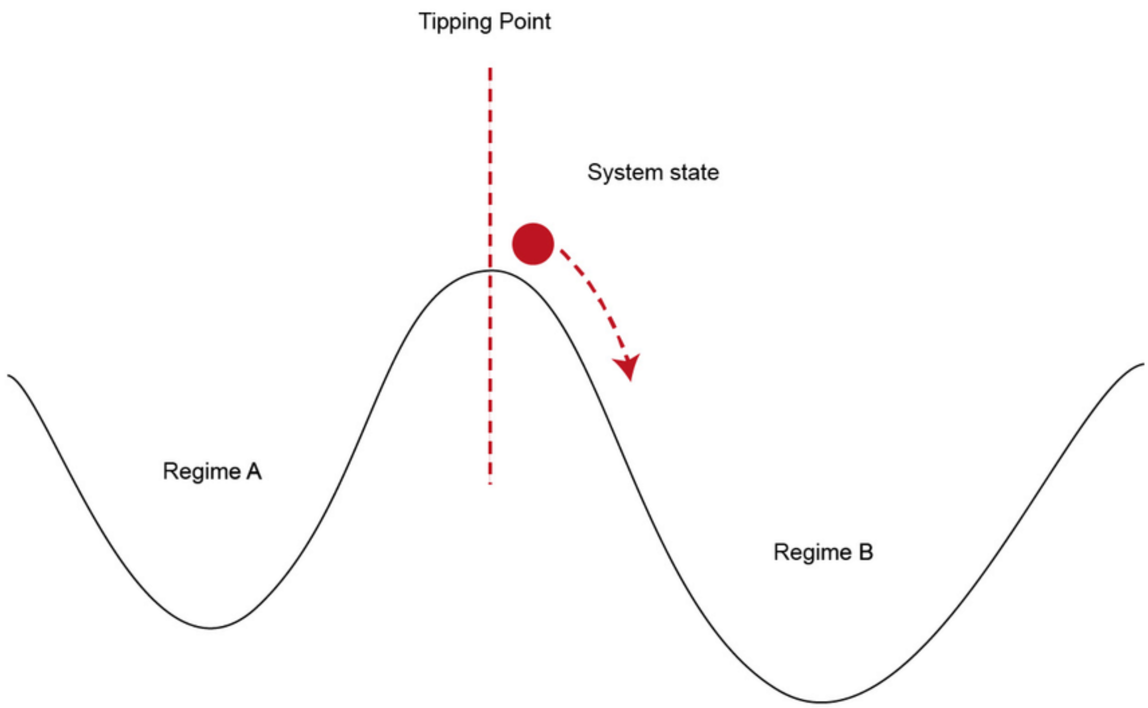


Image by Magdalena Burtscher-Rauter, Thomas Thaler, Marie-Sophie Attems, Sven Fuchs; https://www.researchgate.net/figure/A-tipping-point-is-reached-when-a-system-tips-over-from-regime-A-to-regime-B-adapted_fig1_336273061; CC BY

Three examples of tipping points for Earth's climate system are described below. If these scenarios occur, and a tipping point is reached, the climate system will adjust and establish a new equilibrium, a new normal, and the system will not return to its previous state.

1. As Arctic sea ice and the Greenland ice sheet melt, ocean circulation in the Atlantic may divert the Gulf Stream. This and/or other changes would significantly change regional weather patterns and temperature, perhaps permanently. A change in the Gulf Stream could lead to a significant cooling in Western Europe. This highlights the importance of ocean circulation in maintaining regional climates.

2. Due to the strong positive feedback of ice albedo, if enough ice melts, it will cause Earth's surface to absorb more and more heat, melting more ice. Shrinking ice sheets contribute to sea level rise. Higher sea levels and temperatures may be permanent, beyond a tipping point. Many hundreds

of millions of people live near a coast, so our ability to predict sea level rise over the next century has substantial human and economic ramifications.

3. Deposits of frozen methane, a potent greenhouse gas, and carbon dioxide lie beneath permafrost in Arctic regions. About a quarter of the Northern hemisphere is covered by permafrost. As the environment warms and the permafrost thaws these deposits can be released into the atmosphere and present a risk of enhanced warming, perhaps permanently increasing the temperature if we reach that threshold.

Putting It Together

Focus Questions:

Image by John Wakefield, https://contentdm.lib.byu.edu/digital/collection/BYUPhotos/id/248/rec/2, public domain

1. If a glacier begins melting and exposes more rock and soil around a glacier, how might it affect its melting rate?

2. What type of feedback is described above?

3. Is the situation from the previous questions stabilizing or destabilizing?

Final Task:

Construct an argument to support the claim that a change to surface albedo has caused the glacier to completely melt in the last 100 years.

CHAPTER 4

Strand 4: Stability and Change in Natural Resources

Chapter Outline

Image by Duernsteiner from Pixabay https://pixabay.com/photos/mountains-village-lake-town-7080595/; CC0

Humans coexist with the world. We are an essential part of Earth's systems. Our interactions have an impact on the natural world and the natural world has an impact on us. Human civilizations have always been built in places where resources (like air, water, minerals, and energy) are plentiful. Responsible management of human-used natural resources is essential to supporting human societies and the natural biodiversity in the world around us. The sustainability of natural resources can be achieved by building technologies that create less pollution, less waste, and have smaller impacts on natural ecosystems. Sustainability is also achieved by finding solutions to the local and global environmental problems that have naturally arisen as humans have interacted with the world around us.

4.1 Natural Resources (ESS.4.1)

Phenomenon

This image is of the population density of the globe in 2020. The size of each circle on the map represents the average number of people living within 1 sq kilometer in the region. Larger circles represent larger populations.

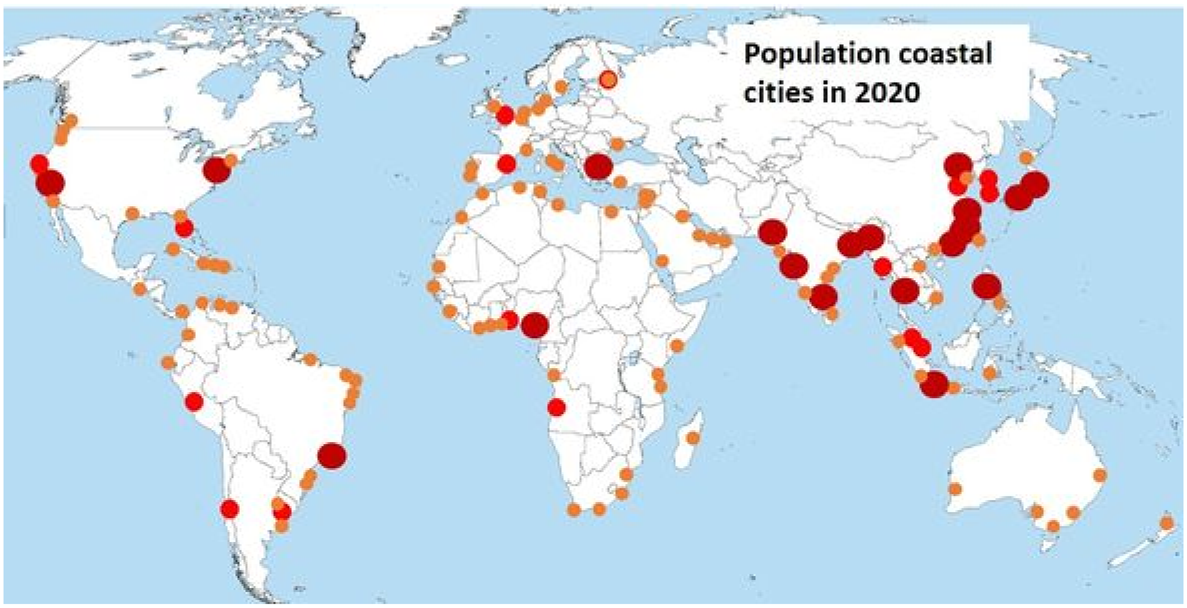


Image by Dronkers J from Coastal Wiki CC-BY
http://www.coastalwiki.org/wiki/File:PopulationCoastalCities.jpg#filelinks

Observations and Wonderings

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions

1. Predict why so many human civilizations are established along coastlines.

2. What could be the advantages of living so close to the ocean?

3. What could be the disadvantages of living so close to the ocean?

ESS.4.1 Natural Resources

Construct an explanation for how the availability of natural resources, the occurrence of natural hazards, and changes in climate affect human activity. Examples of natural resources could include access to fresh water, clean air, or regions of fertile soils. Examples of factors that affect human activity could include that rising sea levels cause humans to move farther from the coast or that humans build railroads to transport mineral resources from one location to another. (ESS3.A, ESS3.B)

In this section, focus on how the availability of natural resources, occurrence of natural disasters, and changes in climate affect human populations.

What’s a Natural Resource?

When you pick up your personal electronics device or your mobile phone do you ever think about what's in it? A tremendous variety of elements are needed to make a single electronic device. Some are rare, some are common. All must somehow come from Earth or its environment.

A natural resource is anything in nature that humans need. Metals and fossil fuels are natural resources. But so are water, sunlight, soil, and wind. Even living things are natural resources. We need natural resources for just about everything we do. We need them for food and clothing, for building materials, and energy.

What definition for natural resources shall we use? On the Department of Energy’s “Ask a Scientist” website, Bob Hartwell defines a natural resource as “something supplied by nature which supports life on this planet.”

Renewable vs Nonrenewable Resources

Applied to natural resources, renewable or non-renewable are relative terms, meaning they depend on the context of their use. Not surprisingly, we use human parameters to classify resources into these two categories.

A resource replenished by natural processes at a rate roughly equal to the rate at which humans consume it is a renewable resource. Sunlight and wind, for example, will never be used up. They will always be available.

Image 1 by Sebastian Ganso from Pixabay. https://pixabay.com/photos/photovoltaic-system-solar-2742302/; CC0
Image 2 by Ed White from Pixabay; https://pixabay.com/photos/wind-energy-wind-farm-wind-turbines-7342177/ ; CC0
Image 3 by Russ McElroy from Pixabay. https://pixabay.com/photos/dam-river-water-landscape-power-929406/; CC0

Hydropower is renewed by the Earth's hydrologic cycle. Until modern times, water has also been considered renewable, but overpumping of groundwater is depleting aquifers (underground stores of water), and pollution threatens the use of many water resources. This shows that the consequences of resource use are not always simple depletion. Soils are often considered renewable, but erosion and depletion of minerals proves otherwise. Living things (forests and fish, for example) are considered renewable because they can reproduce to replace individuals lost to human consumption. This is true only up to a point, however; overexploitation can lead to extinction, and overharvesting of trees can remove nutrients so that soil fertility does not allow forest renewal. Energy resources derived from living things, such as ethanol, plant oils, and methane, are considered renewable, although their costs to the environment are not always adequately considered. Renewable materials would include sustainably harvested wood, cork, and bamboo as well as sustainably harvested crops. Metals and other minerals are sometimes considered renewable because they are not destroyed when they are used, and can be recycled.

Image 1 by Ben Scherjon from Pixabay. https://pixabay.com/photos/coal-cabbage-burned-fuel-black-842468/
Image 2 by David Mark from Pixabay. https://pixabay.com/photos/russia-oil-platform-rig-boat-ship-112445/
Image 3 by Bruno /Germany from Pixabay. https://pixabay.com/photos/industry-power-plant-2663191/

A non-renewable resource is not regenerated or restored on a time scale comparable to its consumption. Non-renewable resources exist in fixed amounts (at least relative to our time frame), and can be used up. The classic examples are fossil fuels such as petroleum, coal, and natural gas. Fossil fuels have formed from remains of plants (for coal) and phyto- and zoo-plankton (for oil) over periods from 50 to 350 million years. Ecologist Jeff Dukes estimates that 20 metric tons of phytoplankton produce 1 liter of gasoline! We have been consuming fossil fuels for less than 200 years, yet even the most optimistic estimates suggest that remaining reserves can supply our needs for

- Oil: 45 years
- Gas: 72 years
- Coal: 252 years

Nuclear power is considered a nonrenewable resource because uranium fuel supplies are finite. Some estimates suggest that known uranium supplies could last 70 years at current rates of use - although known, and probably unknown reserves are much larger, and new technologies could make some reserves more useful.

Recall the Second Law of Thermodynamics which states that the entropy (or disorder) of a system will increase over time. This means that things that are in order, will become less orderly over time. Energy sources that are usable, once used, will become less usable. This reinforces our view of “renewable” and “non-renewable” resources: Energy flows downhill – gets used up, is transformed into heat; only materials that can be recycled are “renewable.” It is only our time scale which makes any form of energy renewable. Eventually, the sun will burn out, as well.

Resource Availability and Populations

Natural resources are not evenly distributed across the globe. Different resources are concentrated in different areas. For instance, water can be found in the ocean, lakes, rivers, and sometimes underground. Wood can be found in forests. Minerals such as iron, silver, and copper can be found near mountains. Coal and oil are found buried deep beneath the ground, often beneath the ocean floor. This uneven distribution of resources has directly affected human populations.

Think about water. Water is a vital natural resource. In 2017, fourteen of the world’s largest fifteen cities were located close to the ocean. The oceans have allowed for cost-effective transportation between populations as well as food in the form of fishing. Water is also necessary for agriculture, drinking, and washing. Therefore, human populations have always been concentrated along the coastlines of continents or major rivers for easy access to water.

Image by Yee Ki Wan from Pixabay. https://pixabay.com/photos/hongkong-harbour-city-building-3908078/; CC0

Other natural resources have also influenced where humans have built cities. Forests provide easy access to wood, mountains often have abundant mineral resources, grasslands can be turned into farmland, and the list continues. While living in areas with abundant natural resources have their benefits, as human populations increase so do the interactions humans have with the world around them. This can deplete resources and also increase the likelihood of natural disasters.

Natural Hazards and Humans

There are many things that influence whether natural hazards can or will happen. This can be anything from the layout of the surrounding landscape, the type of soil, proximity to water, etc. One impact that has increased the likelihood of natural disasters is the global increase of the human population. Today more people than ever live in areas where natural hazards are likely to occur simply because world populations are growing. Because more people are concentrated in these areas, the likelihood of a natural hazard becoming a disaster has increased.

Climate Change and Humans

This section is adapted from NOAA; https://www.noaa.gov/education/resource-collections/climate/climate-change-impacts *and* [*https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level*](https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level) *public domain*

Climate change has also impacted human populations. Global temperatures rose about 1.98°F (1.1°C) from 1901 to 2020, but climate change refers to more than an increase in temperature. It also includes sea level rise, changes in weather patterns like drought and flooding, and much more. Things that we depend upon and value — water, energy, transportation, wildlife, agriculture, ecosystems, and human health — are experiencing the effects of a changing climate. Climate change impacts are seen throughout every aspect of the world we live in. However, climate change impacts are uneven across the country and the world — even within a single community, climate change impacts can differ between neighborhoods or individuals. Drought can harm food production and human health. Flooding can lead to the spread of disease and can damage ecosystems and infrastructure. Human health issues can increase mortality, impact food availability, and limit worker productivity.

The image above shows a type of flooding called sunny day flooding in Miami, Florida. Here the sea level has become high enough that during king tide, even on sunny days when there are no storms, streets inland are flooded. https://en.wikipedia.org/wiki/File:October_17_2016_sunny_day_tidal_flooding_at_Brickell_Bay_Drive_and_12_Street_downtown_Miami,_4.34_MLLW_high_tide_am.jpg

One of the most obvious impacts of climate change is the rise of sea level. Global mean sea level has risen about 8–9 inches (21–24 centimeters) since 1880. The rising water level is mostly due to a combination of meltwater from glaciers and ice sheets and thermal expansion of seawater as it warms. By the end of the century, global mean sea level is likely to rise at least another foot (0.3 meters), even if greenhouse gas emissions are reduced in coming decades.

In the sections above, it was mentioned that fourteen out of the world largest fifteen cities are along ocean coastlines. As sea level continues to rise over the next several decades, these high-density population areas will be at greatest risk. Coastal cities will flood, erosion will increase, and populations will be displaced.

A Part of the Planet

Humans are just one part of the complex web of systems that connects us with the planet. Previously Bob Hartwell defined a natural resource as “something supplied by nature which supports life on this planet.” Humankind is a part of nature, one species in an interdependent web which includes the Earth and all life. Without question, we are a unique species: we have the power to change that interdependent web in ways no other species can, we have the ability to learn about and understand the patterns and processes which maintain the web, and we have the responsibility to use our natural resources, together with that understanding, in ways which sustain the web – for our ourselves and for all life.

Putting It Together

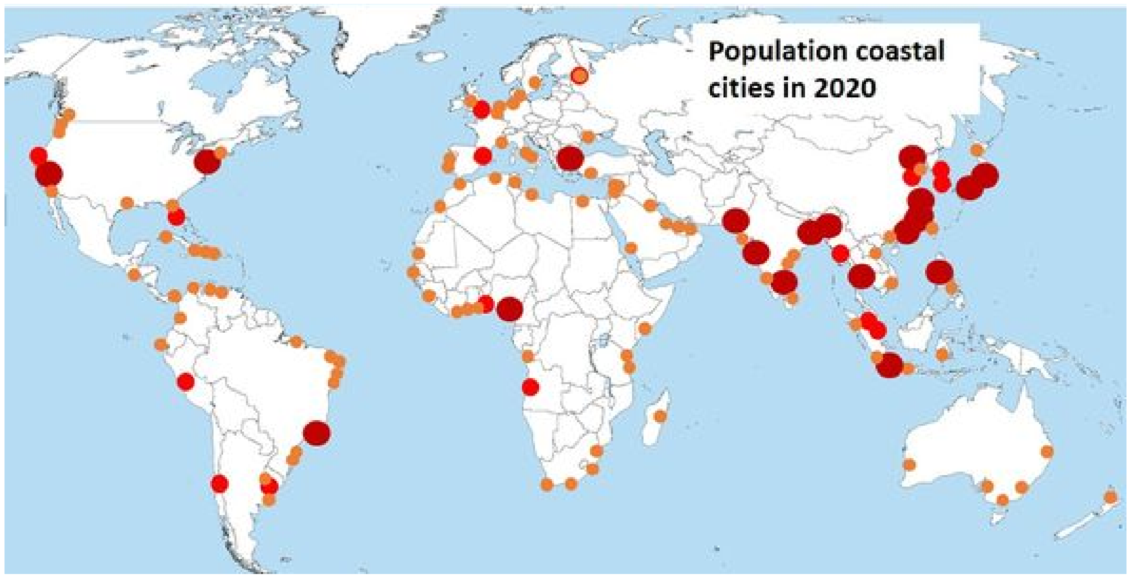


Image by Dronkers J from Coastal Wiki CC-BY
http://www.coastalwiki.org/wiki/File:PopulationCoastalCities.jpg#filelinks

This image is of the population density of the globe in 2020. The size of each circle on the map represents the average number of people living within 1 sq kilometer in the region. Larger circles represent larger populations.

Focus Questions

1. What types of natural resources are readily available when living by a large body of water?

2. What types of natural hazards would pose a risk for people living close to a large body of water?

Final Task

Increasing global temperature due to climate change is causing sea level to rise globally. Predict how the availability of natural resources and the occurrence of natural hazards will change for people living along coastlines with rising sea levels.

4.2 Sustainability (ESS.4.2)

Phenomenon

This image is of a logging site west of Tampere, Finland. Here the trees have been clear-cut, which means the trees in this area have all been completely cut down and harvested.

Image by Reijo Telaranta from Pixabay https://pixabay.com/photos/forestry-timber-logging-6596153/

Observations and Wonderings

What are you observing about this phenomenon?

What are you wondering about this phenomenon?

Focus Questions

1. What natural resources are humans using in the area?

2. What can humans use these natural resources for?

3. What did the natural environment look like before humans started logging here?

4.2 Sustainability (ESS.4.2)

Use computational thinking to explain the relationships between the sustainability of natural resources and biodiversity within Earth systems. Emphasize the importance of responsible stewardship of Earth's resources. Examples of factors related to sustainability could include costs of resource extraction, per-capita consumption, waste management, agricultural efficiency, or levels of conservation. Examples of natural resources could include minerals, water, or energy resources. (ESS3.A)

In this section, focus on the relationship of sustainability and natural biodiversity.

What is Biodiversity?

The term biodiversity (from "biological diversity") refers to the variety of life on Earth at every level: from the smallest bacteria, the deadliest protist, the most bizarre fungi, the prettiest plant, and the biggest mammal. Humans, one of many living creatures on the planets, are a part of Earth's biodiversity. The term "biocultural" describes the dynamic, continually evolving and interconnected nature of people and the place they live at. This concept recognizes that humans have an impact on the ecosystems they are a part of and that the ecosystem itself can have an impact on humans. This relationship makes all biodiversity, including the species, land and seascapes, and the cultural links to the places where we live—be right where we are or in distant lands—important to our wellbeing as they all play a role in maintaining a diverse and healthy planet.

Why Is Biodiversity Important?

The success of life everywhere (humans and other parts of ecosystems) benefit greatly from biodiversity. Biodiversity generally increases the productivity and stability of ecosystems. It helps ensure that at least some species will survive environmental change. For example:

- Plants and algae maintain the atmosphere. During photosynthesis, they add oxygen and remove carbon dioxide.
- Plants help prevent soil erosion. They also improve soil quality when they decompose.
- Microorganisms purify water in rivers and lakes. They also return nutrients to the soil.
- Bacteria fix nitrogen and make it available to plants. Other bacteria recycle the nitrogen from organic wastes and remains of dead organisms.

- Insects and birds pollinate flowering plants, including crop plants.
- Natural predators control insect pests. They reduce the need for expensive pesticides, which may harm people and other living things.

Biodiversity is also important for human development. Without healthy biodiversity many of the benefits humans receive from nature would not be possible. For example:

- Wild plants and animals maintain a valuable pool of genetic variation. This is important because domestic species are genetically uniform. This puts them at great risk of dying out due to disease.
- Other organisms provide humans with many different products. Timber, fibers, adhesives, dyes, and rubber are just a few.
- Certain species may warn us of toxins in the environment. When the peregrine falcon nearly went extinct, for example, it warned us of the dangers of DDT.
- More than half of the most important prescription drugs come from wild species. Only a fraction of species have yet been studied for their medical potential.

The rosy periwinkle is an invaluable source of two important cancer-fighting drugs.
Image by Shaarc from Pixabay. https://pixabay.com/photos/flower-madagascar-periwinkle-723814/

- Other living things provide inspiration for engineering and technology. For example, the invention of the velcro tape was inspired by the spiny seeds of the burdock plant.

The velcro tape used in the shoe strap (right) is a useful invention whose design was inspired by the spiny, sticky seeds of the burdock plant.
Image by Bruno /Germany from Pixabay
https://pixabay.com/photos/burdock-plant-nature-staple-2855249/
Image by Holger Langmaier from Pixabay
https://pixabay.com/photos/children-s-shoes-shoes-sandals-449691/

The examples above are only a fraction of the benefits biodiversity provides the planet. Every single ecosystem, big or small, remains healthy and resilient because of the balance between the many integral parts of biodiversity. Maintaining biodiversity is essential for a healthy planet and healthy human civilizations.

Human Impact on Biodiversity

As humans have come to dominate the planet, they have caused rapid ecosystem change and massive loss of biodiversity across the planet. The Earth has experienced change and extinctions in the past, but today these changes are occurring at a much faster rate than they have before. It takes time for an ecosystem to adapt to the changes being made. Without this time the changes being made are affecting the biodiversity and the benefits of diversity are being lost. Some of the largest human-caused threats to biodiversity include: habitat loss, unsustainable resource use, invasive species, pollution, and global climate change.

Habitat loss, such as deforestation, is one of the largest changes' humans have made to ecosystems. Deforestation refers to the process of clearing out forest lands for the use of timber, agriculture, and/or to build roads and cities.

> "Forests contain some of the richest concentrations of biodiversity on the planet. But between 1990 and 2020, around 420 million hectares of mainly tropical forest has been lost and a further 10 million hectares, an area the size of Scotland and Wales combined, is being lost each year. Without the shelter, food and water the forests supply, the many thousands of species that coexist within and beneath the canopy of trees also vanish."

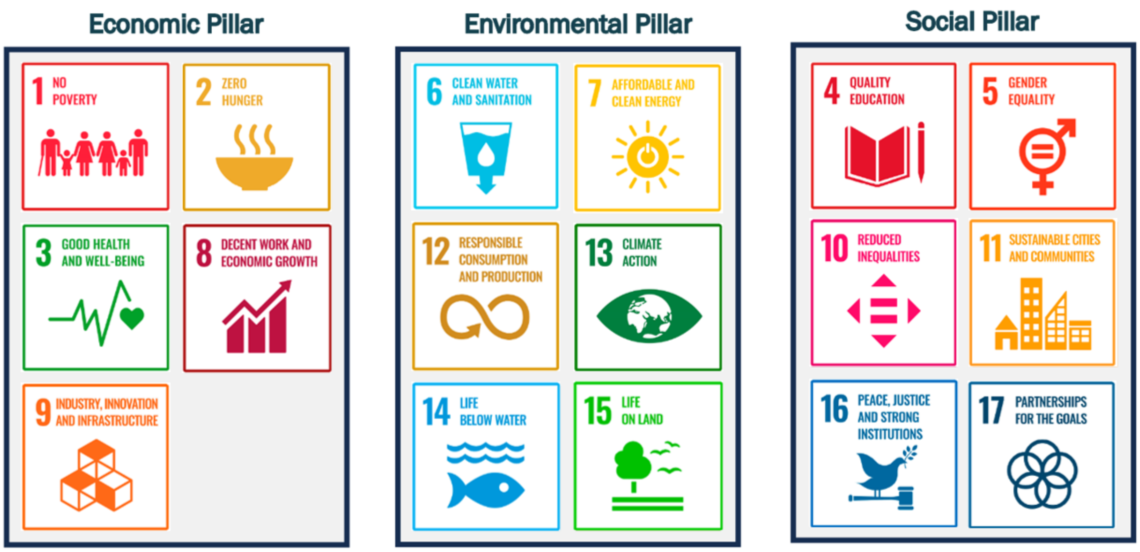
-*The Royal Society, How does deforestation affect biodiversity (2022);* *https://royalsociety.org/topics-policy/projects/biodiversity/deforestation-and-biodiversity/*


Image 1 by ivabalk from Pixabay. https://pixabay.com/photos/deforestation-calamity-bark-beetle-6913287/
Image 2 by Alex Rio Brazil. https://en.wikipedia.org/wiki/File:Hillside_deforestation_in_Rio_de_Janeiro.jpg

When a forest is cut down the plants and animals that live in the forest are also affected. They either migrate or die causing local biodiversity to decrease. The creatures that use the forest as shelter or for food lose resources preventing them from adapting to the changed environment. The soil erodes faster now that tree roots are no longer holding the ground in place. Sunlight is absorbed faster into the ground, increasing surface temperatures; The CO_2 that the trees were storing is released into the atmosphere causing atmospheric CO_2 levels to rise. The entire local, and even global, ecosystem has been disrupted and the benefits once given from biodiverse forests are lost.

Sustainability and Biodiversity

There are many things humans can do to help ensure the survival of species and the health and integrity of ecological systems simply by changing our actions. Conservation efforts help us understand the threats to biodiversity and the effects of decreasing biodiversity, allowing us to prepare to manage conservation challenges and protect biodiversity. When scientists understand how Earth's natural systems work, they can recognize how people are impacting them. Scientists can work to develop technologies that can be used to solve problems wisely. This is the goal of sustainable development. The United Nations defines sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Protecting biodiversity and the benefits we receive from the Earth is at the core of sustainable practices.



The United Nation Sustainable Development Goals separated into the three pillars of sustainable development: economy, environment, and social well-being.
https://www.mdpi.com/2071-1050/11/7/1961 and https://www.mdpi.com/2071-1050/13/5/2560

Many efforts have been made over the past decades that have had a significant difference in the state of biodiversity today. Today, over 100,000 protected areas - such as national parks, wildlife refuges, game reserves, and marine protected areas, managed both by governments and local communities - provide habitat for wildlife, and help keep deforestation in check. When protecting habitat is not enough, other types of sustainable actions are taken. Restoration of destroyed land, reintroduction of lost species, and the control of invasive species have all helped increase biodiversity in areas where it was once lost. These efforts have been bolstered by continuous efforts to improve environmental policies at local, regional, and global scales. Finally, the lifestyle choices of individuals and communities can have a large effect on their impacts on biodiversity and the environment. While we might not be able to prevent all negative human impacts on biodiversity, with knowledge we can work to change the direction and shape of our effects on the rest of life on Earth.

Putting It Together

Image by Reijo Telaranta from Pixabay https://pixabay.com/photos/forestry-timber-logging-6596153/

This image is of a logging site west of Tampere, Finland where the practice of clear-cutting has been used to harvest the trees to be used for lumber.

Focus Questions

1. How has the landscape of this area changed due to clear cutting?

2. What impacts has clear cutting had on the biodiversity of the area?

3. What practices can be implemented to reduce the effects of clear cutting?

Final Task

Construct an explanation for how this area's natural biodiversity and environment can be sustainably managed while still allowing logging practices to continue?

4.3 Managing Resources (ESS.4.3)

Authentic Situation

Both of these images are of Kennecott Copper Mine, the largest open-pit mine in the world and located in the Oquirrh Mountain Range (20 miles southwest of SLC). The mine is 0.75 miles deep and 2.5 miles wide. The main mineral resource extracted from the ground is copper, which is often used in electronics. The mine also produces gold, silver, and molybdenum. The first image offers a view inside the mine, SLC can be seen in the background. The second image is a view of the mine from SLC valley.

Images by arbyreed from Flickr
https://www.flickr.com/photos/19779889@N00/48009310262/in/album-72157627780868214/; CC BY-NC-SA

Observations and Wonderings

What is the problem in this situation?

What are possible criteria (positive outcomes) to this situation?

What are constraints (limitations) with this situation?

Focus Questions

1. How has the mountain been changed because of the man-made excavations?

2. What can the minerals be used for that are mined out of the ground here?

3. How can the impacts of this mine on the natural environment be lessened?

ESS.4.3 Managing Resources

Evaluate **design solutions** for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios on large and small scales. *Define the problem, identify criteria and constraints, analyze available data on proposed solutions, and determine an optimal solution.* Emphasize the conservation, recycling, and reuse of resources where possible and minimizing impact where it is not possible. Examples of large-scale solutions could include developing best practices for agricultural soil use or mining and production of conventional, unconventional, or renewable energy resources. Examples of small- scale solutions could include mulching lawn clippings or adding biomass to gardens. (ESS3.A, ETS1.A, ETS1.B, ETS1.C)

In this section, focus on ways to responsibly develop, manage, and utilize natural energy and mineral resources.

Responsible Stewardship

Responsible stewardship is essential for the success of natural biodiversity, the continued availability of natural resources, and the progression of human development. As the human population has increased, so has the rate of consumption. The concept of renewable vs. non-renewable resources, as mentioned previously, clearly depends on rates of human use. Of course, we could change our rates of consumption. Indeed, if we increase our rate of consumption, renewable resources may need to be reclassified as non-renewable. This is the foundation of the concept of sustainable use – use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs. In order to accomplish the goal of sustainability, humans must become responsible stewards of the world around us.

The first step towards responsible stewardship is to minimize the impact of current resource use. This is often referred to as the three “R”s: reduce, reuse, and recycle. Reducing resource use means just what it says—using fewer resources. Reusing resources means using items again instead of throwing them away. Recycling resources means materials are reused in new products. The practices of reducing, reusing, and recycling can be done on the local or global level and the larger the scale of the implementation the larger the improvement will be on the natural world.

Another practice that can help humans achieve responsible stewardship is the use of alternative energy resources. Alternate energy resources are any type of energy resource that does not emit greenhouse gasses (CO2) when used. Think of an alternate energy resource as an energy resource source that is used as an alternative to coal, oil, and natural gas. Because alternate energy resources do not emit greenhouse gasses their direct impact on the environment is usually extremely low. While similar, an alternate energy resource is not the same as a renewable energy resource. To be considered an alternative resource, the energy resource must simply not produce fossil fuels (or greenhouse gasses) when used. A renewable resource is a resource that can never be depleted. Examples of alternate energy resources that are also renewable resources are solar energy and wind energy. These energy resources can never be depleted and do not produce greenhouse gasses when used. An example of an alternate energy resource that is not a renewable resource is nuclear power. Nuclear power uses uranium and thorium (deposits of which will eventually be depleted) but when used it does not produce greenhouse gasses. Alternative resources have their benefits and drawbacks just like all types of energy resource uses do. The pros and cons of each type of energy resource should be considered throughout the entire process of energy resource planning, extraction, and use.

In the end, no matter what method is used, the goal of responsible stewardship is sustainability. This means that whatever management technique is used to extract natural resources for human benefit, the end result should be to decrease the human impact of the extraction and subsequent use of that resource and ensure that there are resources left for future generations to use. Management techniques can take a variety of forms from increased extraction efficiency, minimizing land impact, or using a completely different resource to avoid impact all together. See below for management technique examples for two common natural resources used by humans across the world.

Management Techniques

Timber Resources

This section is adapted from FAO; https://www.fao.org/state-of-forests/en/; CC BY-NC-SA 3.0 IGO and https://en.wikipedia.org/wiki/Bamboo, CC BY-SA (retrieved 1/22/2023).

Timber resources refers to the wood of trees that can or will be used for building material. This could be for construction, paper products, furniture, etc. While not all trees are cut for the same purpose the effect of deforestation on the local area is the same. In 2020, it was estimated that 10 million hectares of trees will be lost per year. This is roughly the size of the country or Portugal or Iceland. When forest land is cut down the biodiversity of the area is greatly diminished and the CO_2 stored in trees is released into the atmosphere. To help restore biodiversity and reduce the effects of deforestation new trees can be planted where old trees are cut. This is called reforestation. While reforestation does improve the forest ecosystem, it takes a significant amount of time for a forest to regrow to its original size. Currently, reforestation is not fast enough to positively offset the number of trees cut down each year globally.

Image by Downtowngal. https://commons.wikimedia.org/wiki/File:Reforestation_Southern_Oregon.jpg

Another management technique is to use alternate wood resources that regrow faster and take up less land. One such example of this is bamboo. Bamboo is a type of grass that has the same hardness strength as most woods do, making it a usable alternative to wood. A single bamboo grove can be regrown in 5 years versus the 20+ years it takes to regrow the average grove of trees. Bamboo is also able to accumulate carbon from the atmosphere in larger amounts than its tree counterparts. “One study estimates that a one-hectare plantation of bamboo and its products could store 306 tons of carbon over a 60-year period compared to the 178 tons stored in Chinese fir trees.” (*quoted from China Dialogue* *(https://chinadialogue.net/en/climate/fighting-climate-change-with-bamboo) CC BY-NC-ND)*

Bamboo's ability to store carbon while growing and after being harvested allows it to offset the high amount of CO_2 in the atmosphere faster than other types of wood resources do. As an alternative resource, bamboo not only has the same strength as wood, it can be regrown faster and has a higher offset for the global climate impact of CO_2 emission caused by cutting down trees.

Image by Pexels from Pixabay https://pixabay.com/photos/bamboo-trees-green-growth-1283976/

Mineral Resources

Adapted from Ck-12 resources and https://en.wikipedia.org/wiki/Mine_reclamation CC BY-SA (retrieved 1/22/2023).

Mining is the process of extracting mineral resources from Earth's crust to be used for various human needs. Most modern-day conveniences come from a mineral resource that has been mined from the ground. Although mining provides people with many needed resources, the environmental costs can be high. Surface mining clears the landscape of trees and soil, and nearby streams and lakes are inundated with sediment which completely destroys the ecosystems in which they are found there. Pollutants from the mined rock, such as heavy metals, enter the sediment and water system which affect the immediate area and may travel downstream or downwind to cause problems elsewhere. Acids flow from some mine sites, changing the composition of nearby waterways. U.S. law has changed in recent decades so that a mine region must be restored to its natural state, a process called reclamation. Reclamation is a resource management technique that aims to reduce the negative environmental impacts of mining on the land. The end goal of reclamation is to return the land back to a usable state, preferably its original state. A usable state is defined as anything from the restoration of a productive ecosystem, the creation of new agricultural land, or residential/commercial development.

Examples of reclamation projects include:

- Turning an open mine pit into a local recreation water reservoir.
- Creating a golf course, farm, or other beneficial place for the local community in the place of where the mine was.
- Cultivating a natural wildlife or wetland area at the location of the mine once mining has finished.

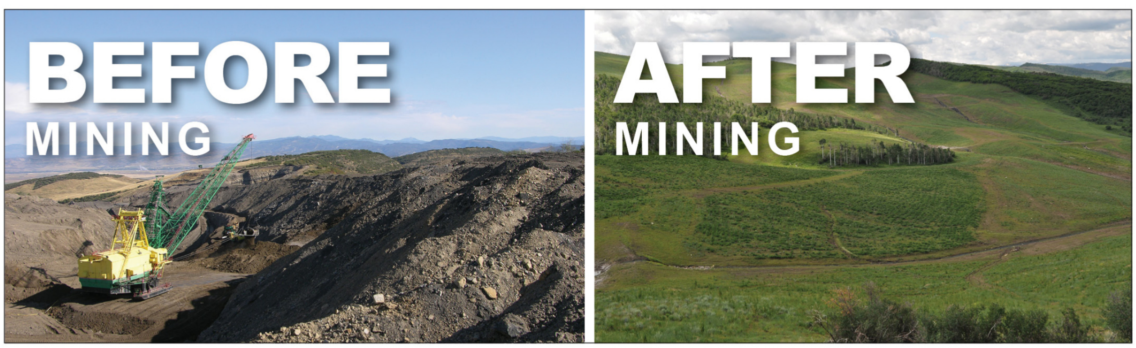


Image by Peabody Energy, Inc., https://commons.wikimedia.org/wiki/File:Coal_Mine_Land_Reclamation.png

Besides reclamation, another management technique to prolong mineral resources is through recycling. Many mineral resources can be reused which lessens the need to mine for new resources in the ground.

There are two types of recyclable materials: old scrap (from post-consumer products like cars, electronics, and cans) and new scrap (from the manufacturing process, such as excess material from shaping, cutting, and molding products that never made it into a product). Instead of being thrown out, old and new scrap metals can be reincorporated into new products. Currently, recycling provides 40-50% of the U.S. metal supply.

(Quoted from
https://www.americangeosciences.org/geoscience-currents/recycling-source-mineral-commodities; CC BY-ND-NC)

If the amount of recycled material increases, then the dependence on new mines will continue to decrease thus also decreasing the impact of mines on the environment.

Image by Alexa from Pixabay. https://pixabay.com/photos/copper-thrash-metal-scrap-metal-1504098/

Putting It Together

Images by arbyreed from Flickr
https://www.flickr.com/photos/19779889@N00/48009310262/in/album-72157627780868214/ and https://www.flickr.com/photos/19779889@N00/16373929793/in/album-72157627780868214/

Both of these images are of Kennecott Copper Mine, the largest open-pit mine in the world and located in the Oquirrh Mountain Range (20 miles southwest of SLC).

Focus Questions

1. How has the Kennecott Copper Mine impacted the mountain range?

2. How has the Kennecott Copper Mine impacted the biodiversity of the area?

3. What are the steps of sustainable mine production?

4. Will the Kennecott Copper Mine area ever go back to its natural state? Why or why not?

Final Task

When mining production ends the Kennecott Copper Mine will need to be reclaimed, or returned to its natural state. Design and explain a solution for reclaiming this mine.

4.4 Environmental Solutions (ESS.4.4)

Authentic Situation

This image is of New Delhi, India, one of the fastest growing cities in the world. The geographic region of New Delhi doubled in size from 1991 to 2010. By 2028, New Delhi is projected to become the most populous city in the world. As populations have increased the air quality in the area has dramatically decreased as seen by the thick layer of smog visible in the atmosphere here.

Image by Ville Miettinen from wikimedia commons
https://commons.wikimedia.org/wiki/File:Connaught_Place_sunset.jpg

Observations and Wonderings

What is the problem in this situation?

What are possible criteria (positive outcomes) to this situation?

What are constraints (limitations) with this situation?

Focus Questions

1. How can increasing population cause air quality to decrease in New Delhi?

2. Predict the effects of lower air quality on people living in New Delhi.

3. What are some possible solutions to air pollution in New Delhi?

ESS.4.4 Solutions

Evaluate **design solutions** for a major global or local environmental problem based on one of Earth's systems. *Define the problem, identify criteria and constraints, analyze available data on proposed solutions, and determine an optimal solution.* Examples of major global or local problems could include water pollution or availability, air pollution, deforestation, or energy production. (ESS3.C, ETS1.A, ETS1.B, ETS1.C)

In this section, focus on evaluating solutions to environmental problems that affect Earth's systems locally and globally.

Environmental Problems

The environment plays a crucial role in the sustainability of life as we know it here on Earth. All living things depend on the planet's resources to survive, humans included. As populations have increased over the last 100 years the number of local and global environmental problems have also increased. The United States is just one of the many countries being impacted by – and causing – environmental problems. From air pollution to the depletion of natural resources, the nation is beginning to recognize and address environmental issues within its borders.

Habitat Loss

On average, the United States population grows by more than 1 million people each year. With more people, we need more space to live. This has caused the rate of urbanization to increase which has led to rapid deforestation and habitat loss, but it is more than just housing that has impacted habitats. More people require more resources which means natural ecosystems are disrupted not only by housing but also by logging, mining, and even agriculture.

Development on the outskirts of towns can cause deforestation as land is cleared to make room for new buildings.
Image by Alexandr from Pixabay. https://pixabay.com/photos/deforested-construction-outskirts-574185/

Air Pollution

Major cities with large populations tend to struggle with air pollution. Consider the Salt Lake City urban corridor. In 2022, this area was #10 out of the 25 top most ozone polluted cities in the United States (American Lung Association, *Most Polluted Cities, 2022)* One of the most commonly recognized types of air pollution is smog which comes from cars and factories. Smog forms when nitrogen oxides combine with other organic compounds in the atmosphere. While ugly, smog can also cause and exasperate health issues for both humans and other species.

Winter air pollution in the Salt Lake and Utah Valley is visible due to the inversion caused by the cold air layered in the valley.
Image by Derrellwilliams. https://commons.wikimedia.org/wiki/File:Inversion_in_Salt_Lake_City.jpg

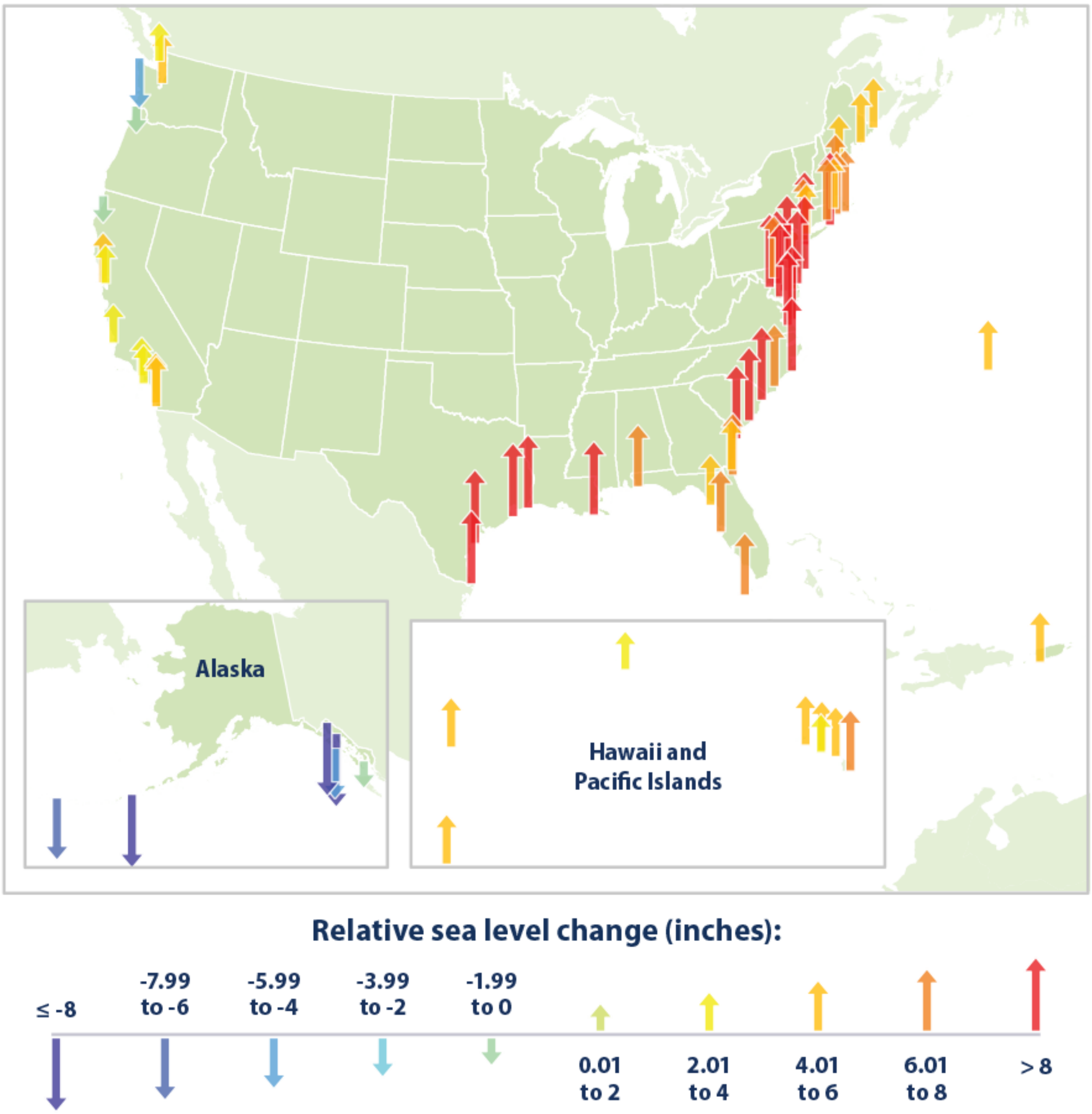
Modern Climate Change

This section is adapted from Effects: The effects of climate change *by NASA; public domain*

Changes in climate is a natural cycle that Earth's systems go through. The concern with modern climate change is not that it is happening but rather that it is happening too fast. Human influences have increased greenhouse gas emissions over the past 200 years at extreme rates causing global temperatures to also rise. In a report published by the United Nations in 2021 it was found that human emissions of heat-trapping gasses have already warmed the climate by nearly 2 degrees Fahrenheit (1.1 degrees Celsius) since pre-Industrial times (starting in 1750).1 The global average temperature is expected to reach or exceed 1.5 degrees C (about 3 degrees F) within the next few decades. These changes will affect all regions of Earth.

One of the most obvious examples of these effects is a rise in sea level. Global sea level has risen about 8 inches (0.2 meters) since reliable record-keeping began in 1880. By 2100, scientists project that it will rise at least another foot (0.3 meters), but possibly as high as 8 feet (2.4 meters), if we continue carbon emissions at our current rate. Sea level is rising because of added water from melting land ice and the expansion of seawater as it warms. Even small sea level changes can cause increased flooding, because storm surge and high tides combine with sea level rise and sinking of land along coastlines to amplify flooding in some regions. Sea level rise will continue past 2100 because the ocean takes a very long time to fully respond to warmer conditions at Earth's surface. As ocean waters continue to warm, sea level will continue to rise.

Relative Sea Level Change Along U.S. Coasts, 1960–2021



Data source: NOAA (National Oceanic and Atmospheric Administration). 2022 update to data originally published in: NOAA. 2009. Sea level variations of the United States 1854–2006. NOAA Technical Report NOS CO-OPS 053. www.tidesandcurrents.noaa.gov/publications/Tech_rpt_53.pdf.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

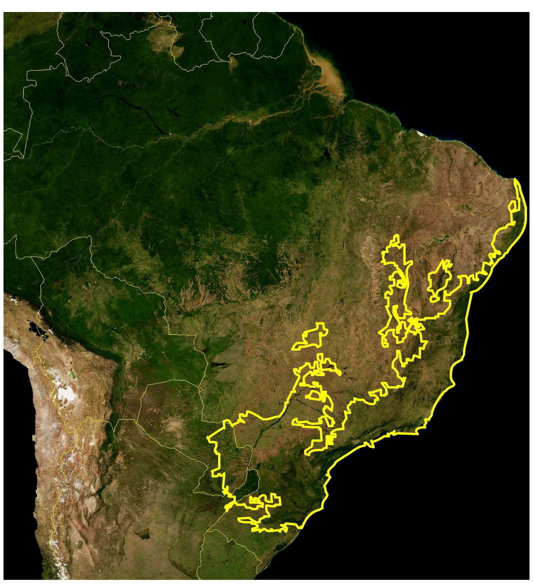
Image by EPA. https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level#ref6

Environmental Solutions

While human development has increased local and global environmental problems, humans also have the power and resources to fix current problems and minimize problems in the future. As scientific research increases so does the human ability to efficiently solve problems. There are already successful environmental solutions in place that help lead and shape how future problems can continue to be solved.

Reforestation Helps Combat Habitat Loss

The Amazon Rainforest in Brazil is a good example of what successful reforestation and habitat restoration can look like. As part of the international Paris Climate Agreement Brazil set a goal to reestablish 12 million hectares (29 million acres) of forests by 2030. Many landowners are helping biodiverse, carbon-rich forests grow back through the process of natural regeneration. Natural regeneration is a reforestation process where people prioritize the growth of naturally occurring species. This can be done by transplanting native plants to the area, preventing forest fires so plants can grow, or even leaving the land alone to let it recover on its own. Allowing native species to gain a stronghold in clear cut areas is especially beneficial to biodiversity and climate change. As the natural biodiversity of the Amazon Rainforest has increased through reforestation, endangered species are able to rebound and more carbon is sequestered into the newly growing trees helping the fight against climate change. More than 9.5 million hectares (23.4 million acres), an area larger than Portugal, has been regenerating in the Amazon alone since 2008.

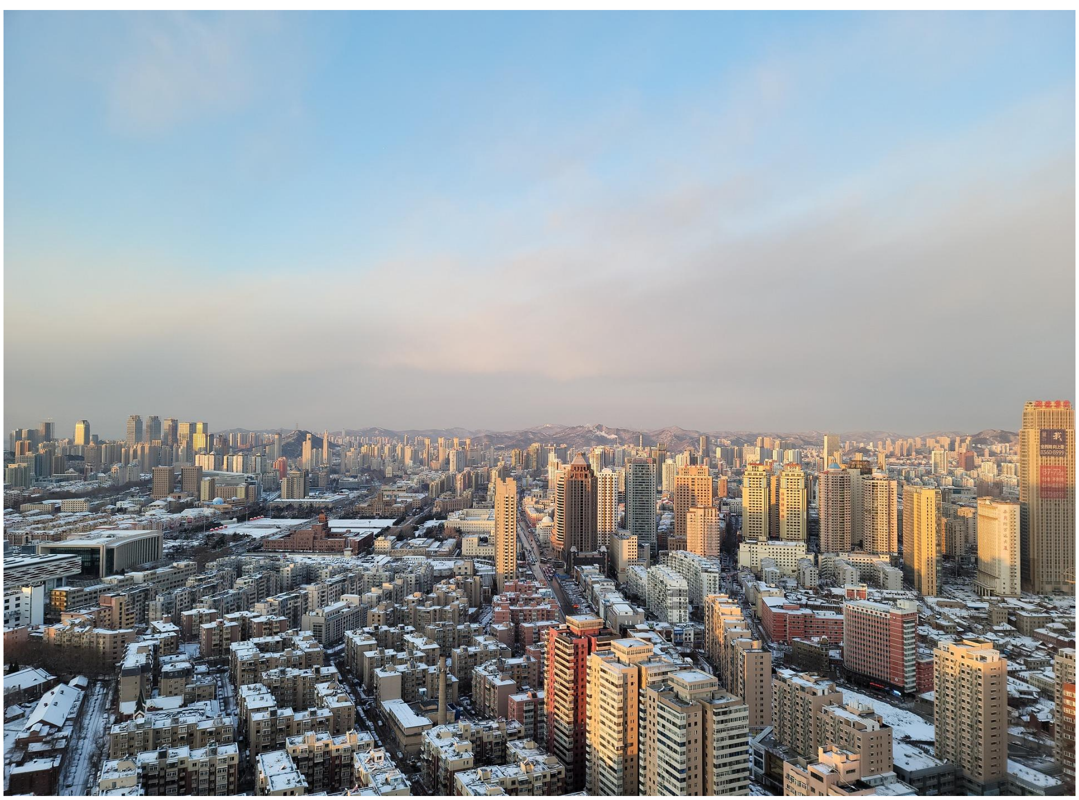


The Atlantic Rainforest located on the coast of Brazil is outlined in yellow. Reforestation efforts in the

rainforest are shown on the right.
Image 1 by NASA and Miguelrangeljr. https://en.wikipedia.org/wiki/File:Atlantic_Forest_WWF.jpg; public domain
Image 2 by James Anderson/WRI.
https://www.wri.org/insights/brazils-forests-are-being-restored-now-we-can-see-where; CC BY

Local Policies Help Reduce Air Pollution

Air pollution in China has dropped dramatically over the last decade due to action taken against unclean air. The Air Pollution Action Plan, released in 2013, became one of China’s most influential environmental policies. The motivation for creating this policy and others came after atmospheric particulate matter (PM2.5) reached record highs in the winter of 2012 – 2013. The Air Pollution Action Plan set goals to decrease PM2.5 levels by 25% by 2017, a goal which was achieved and exceeded. A Ministry of Ecology and Environment report shows that average PM2.5 levels nationwide have fallen from 72 micrograms (μg) per cubic meter in 2013 to 30 μg/m3 in 2021 – a 58% fall and a major improvement in air quality (https://chinadialogue.net, CC BY-NC-ND). While air pollution is still above the World Health Organization's recommended PM2.5 level of 10 μg/m3, China’s aggressive stance against air pollution has produced incredible improvements in air quality which are predicted to continue over the next decade. These successes are an encouraging example of how large-scale environmental problems can be solved through local policies.



Blue skies are visible in Dalian, China thanks to massive air quality improvements made over the last decade.
Image by LYUCHI from Pixabay. https://pixabay.com/photos/china-dalian-winter-snow-clean-air-5963806/

International Environmental Solutions

Some solutions to environmental problems take more than just a local, or nationwide, involvement level. Many environmental problems, like the ozone layer and global climate change, require global action.

Repairing the Ozone Layer

The ozone is a portion of the upper atmosphere that has shielded life from as much as 97 – 99% of the sun's lethal UV radiation for as long as 2 billion years. When referring to the "hole" in the ozone layer, scientists are referring to the depletion of ozone found in the stratosphere. The causes of ozone depletion are chlorine and bromine gasses which can be found in chlorofluorocarbons (CFCs), refrigerants (freon), cleaning solvents, and fire extinguishers. When these ozone-depleting substances (ODS) escape into the stratosphere they break down ozone. Scientists estimate that CFCs take 15 years to reach the stratosphere, and can actively break down ozone for 100 years. In 1987, the depletion of ozone in the upper atmosphere was large enough that it became a global concern. 43 nations agreed in the Montreal Protocol to freeze and gradually reduce production and use of CFCs. This global agreement was necessary to prevent the further decline of the ozone layers as it was too large of a problem for a single country to fix. In 1990, the protocol was strengthened to seek elimination of CFCs for all but a few essential uses.

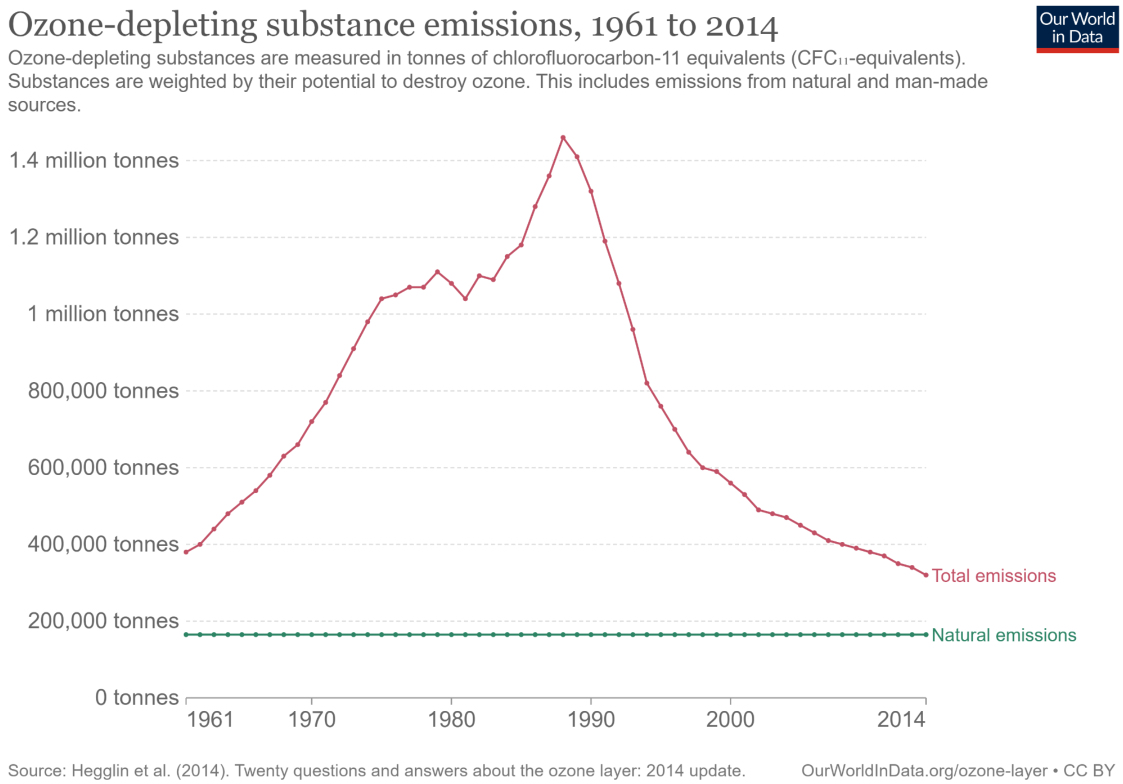
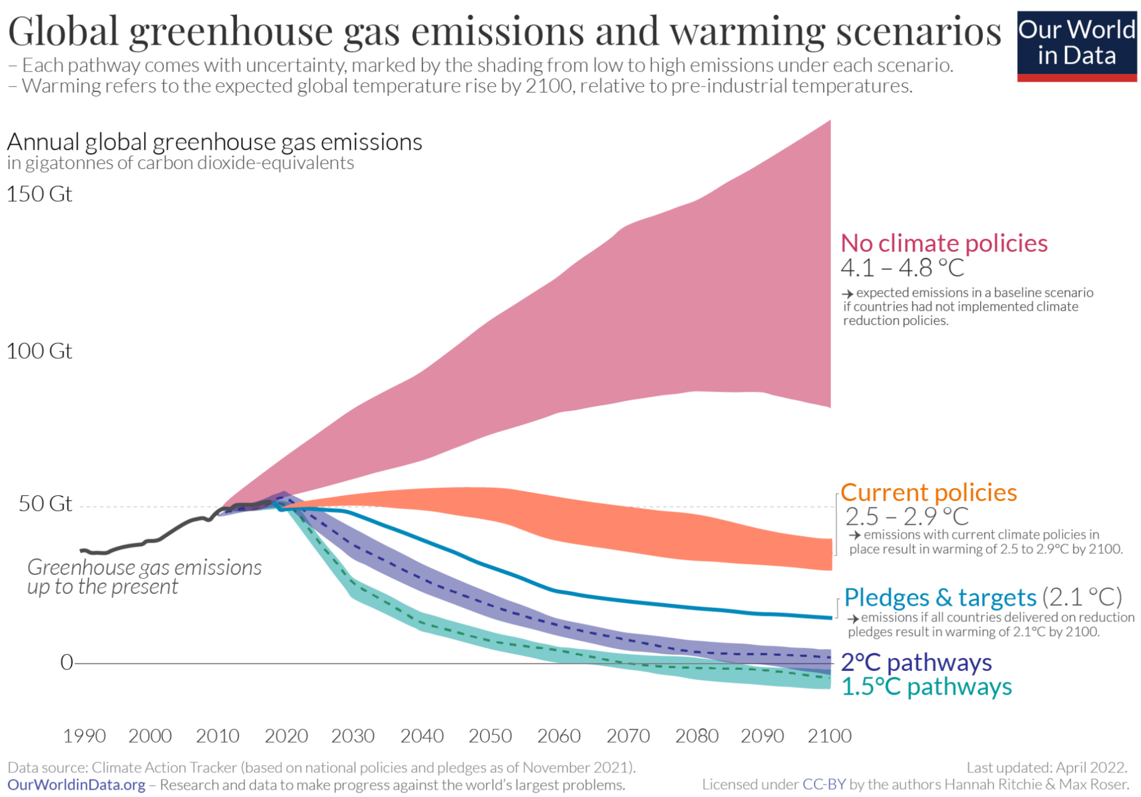


Image from Our World Data. https://ourworldindata.org/ozone-layer; CC BY

While the ozone layer in the stratosphere has not recovered completely, it is on its way to regaining its original ozone levels. Levels of CFCs in the atmosphere are beginning to decline, and ozone levels appear to be stabilizing. Scientists predict that ozone levels can recover by the second half of this century (after 2050); the delay is due to the long half-life of CFCs in the stratosphere. In order to ensure the ozone layer continues to recover it will be essential to continue to prohibit the use of CFCs globally and also work to curb the advancement of global climate change (changes in temperature of the upper atmosphere can aid the depletion of ozone).

Global Climate Change Action

The Kyoto Protocol, adopted in December 1997, was the first international treaty to commit participating countries to lower greenhouse gas emission. The Protocol's goal was to lower greenhouse gas concentrations in the atmosphere to "a level that would prevent dangerous [human-caused changes to the global] climate system." The protocol was based on the principle of common but differentiated responsibilities, meaning countries that had a larger output of greenhouse gasses had a larger responsibility to reduce their own emission levels. This international treaty had 36 participants, all of which complied with the Protocols mandates throughout the duration of the agreement. Unfortunately, despite the success of the countries involved, the Kyoto Protocol's ultimate goal of reducing global levels of greenhouse gasses in the atmosphere was not achieved. Greenhouse gas emissions have increased since 1997 instead of decreased. The failure of the protocol's goals has been credited to the lack of worldwide support. Large carbon emitting countries, such as China, India, and the United States never agreed to the mandate. Despite not reaching its goals, the Kyoto Protocol was a monumental step towards creating a global plan to slow greenhouse gas emissions.



This graph predicts future greenhouse gas emissions based on current trends. Each scenario shown will have a different effect on the global temperature increase. In order to achieve the Paris Agreements goal of a 2 degrees or lower increase, there will need to be a dramatic decrease in greenhouse gasses globally. Image by Our World Data. https://ourworldindata.org/future-emissions

In 2015, the Kyoto Protocol was replaced with The Paris Agreement. This agreement recognized the need for a stronger response to the danger of climate change and requires all countries involved to reduce their emissions. This international treaty was ratified by 194 parties. The United States originally withdrew from the agreement in 2020, but rejoined in 2021. Individual governments set goals for their countries keeping the collective goal in mind: preventing the world's average temperature from rising more than 2°C above pre-industrial levels. The global agreement of both the Kyoto Protocol and subsequent Paris Agreement are historic landmarks in the international fight against climate change and show that global action is possible. In order to achieve these ambitious goals, active progress must continue to be made and if more countries join the Paris Agreement then the likelihood of success will also increase.

Putting It Together

Image by Ville Miettinen from wikimedia commons
https://commons.wikimedia.org/wiki/File:Connaught_Place_sunset.jpg

This image is of New Delhi, India, one of the fastests growing cities in the world. A thick layer of smog, a type of air pollution, is visible in the atmosphere.

Focus Questions

1. What effects does air pollution have on the composition and quality of the atmosphere?

2. How does air pollution affect humans living in large cities like New Delhi?

3. What solutions have large cities across the world implemented to combat rising air pollution?

Final Task

Design and explain a solution for improving air quality in growing cities like New Delhi.