Though Earth’s climate system is complex and seeks equilibrium, it is subject to change when Earth’s energy budget is fundamentally altered. In the last unit, we learned how the different “spheres” (atmosphere, geosphere, hydrosphere, biosphere) interact with incoming solar radiation and shape our climate. Even small cyclical fluctuations to our climate have major consequences for life on Earth, perhaps especially for human civilization, which fares better with stability and predictability in our climate. For any large-scale, or long-term changes in Earth’s climate to take place, an event must drastically alter either the amount of incoming solar radiation or the properties of one or more of the “spheres.” Though scientists have many instruments to study climate and weather in real-time today, how do they know about Earth’s climate history when it predates human records, or even human existence? The answer is **paleoclimatology**. Paleoclimatology uses information from natural climate “proxies,” such as tree rings, ice cores, corals, and ocean and lake sediment cores to garner knowledge of Earth’s past climate variability.

The evidence from paleoclimatology points to two major **climate states** in Earth’s 4.6 billion year history: Icehouse and Hothouse. The **Hothouse** (or Greenhouse) state was marked by a total lack continental ice, desert or tropical conditions on nearly all the land surfaces, high concentrations of methane and carbon dioxide in the atmosphere, and sea temperatures ranging from 28°C at the equator to 0°C at the poles. The explosion of species during the Cambrian Period (540 million years ago) and the proliferation of dinosaurs during the Mesozoic Era took place in a Hothouse Earth state. By contrast, the **Icehouse** state is characterized by large continental ice sheets near the poles, mostly temperate to tundra conditions on land, reduced concentrations of greenhouse gases in the atmosphere, and fluctuations between **glacial and interglacial periods**. On one extreme of an Icehouse Earth is the Cryogenic Ice Age, over 635 million years ago, when glaciations reached the equator (known as “Snowball Earth”). On the opposite side is **right now**. Currently, the Earth is in an **Icehouse state** but an **interglacial period** (Holocene Epoch), demonstrated by the presence of both large sheets of ice at the poles and tropical conditions near the equator.

Fossil records and ocean sediment cores show that these climate states last for **millions of years**. They also point to **greenhouse gas** concentrations such as carbon dioxide and methane being the main forces for the heating and cooling—tectonic activity causing either up-swells in CO₂ release through increased volcanic activity or reductions in atmospheric carbon through sequestration in new soils formed when continental plates collide and form mountains.
Tectonic plate movement also affects ocean distribution. It is likely that this also has a large role in the changes between Icehouse and Hothouse periods. Continental rifts from diverging tectonic plates can cause new ocean pathways to form, while continental collisions from converging tectonic plates can close pathways. Scientists hypothesize that these major geologic shifts could either circulate warm ocean currents and melt reflective ice, or allow colder deep water to move around and aid in ice sheet formation. This causes a positive feedback loop.

The extent of ice cover on Earth changes its surface reflectivity. This is known as the **albedo effect**. Increased ice cover from cooler ocean conditions reflect more light from the sun back through the atmosphere, thus reducing heat gain. Alternatively, as ice melts from warmer conditions and is replaced by darker earth and ocean, more solar radiation is absorbed, instead of reflected, and the Earth warms more.

Finally, the biosphere, all the living things on Earth, has also been a large factor in Earth’s climate history—primarily due to its relationship to carbon dioxide, methane, and other greenhouse gases. Beginning approximately 3 billion years ago, cyanobacteria, or blue-green algae, began to **photosynthesize**. That is, they began using light energy from the sun (photons) to convert atmospheric carbon dioxide and liquid water into cellular energy (glucose)! They also released oxygen gas as a byproduct. Here is where all three “spheres” interconnect: geosphere changes weathered more rock, releasing minerals into the ocean; ocean currents distributed minerals around the world and fed the biosphere, including cyanobacteria; thriving cyanobacteria rapidly pulled CO₂ out of the atmosphere, allowing more heat to escape into outer-space, cooling the planet; dying cyanobacteria fell to the ocean floor, creating a lasting carbon sink.

As Earth’s biosphere became more complex, so did the **carbon cycle**. Previously driven by volcanic activity and weatherization, living things introduced organic carbon to the mix. The first heterotrophs (animals) emerged 620 million years ago, consuming algae and metabolizing it through oxidation, thereby releasing carbon dioxide. The evolution of land-based plants with vascular tissue 430 million years ago gave rise to trees (370 m.y.a.) that could sequester and store carbon in woody roots and trunks. By the late Carboniferous Period 300 million years ago, detrivores (invertebrates, fungi, and aerobic bacteria) had populated the globe, turning carbon over more rapidly from dead organisms back to the soil for new producers. In many ways, the added complexity of the carbon cycle may buffer the Earth from larger climate swings. For instance, as carbon dioxide in the atmosphere increases, so does the rate of tree growth and hence, carbon sequestration. Perhaps **biodiversity** today is what has contributed to a relatively stable climate period.
As stated before, the Earth is currently in an Icehouse State—and has been for the approximately the last 34 million years—but we are on the warmer end of the spectrum. A little more than 10,000 years ago, Earth emerged from the last glacial period, and is now in an interglacial period named the Holocene Epoch. Human civilization has developed in leaps and bounds during this milder, more stable climate period, beginning with the advent of agriculture. Farming replaced hunting and gathering as the primary method for food production, and allowed people to settle in larger groups, rather than roaming to follow herds as they migrated. Furthermore, by breeding storage crops and grains and domesticating livestock, settlements could thrive even through winter, and surpluses could be traded with neighboring settlements. Better safety and nutrition contributed to longer lifespans, allowing elders to share wisdom with their children and grandchildren. Without ice sheets covering much of the northern hemisphere, civilization could spread to all reaches of the planet. Human population started to increase exponentially.

Today, more than 8 million species of plant, fungus, animal, and bacteria share planet Earth with nearly 8 billion human beings. Life as it exists, in all of its forms, is best adapted for Earth’s current climate state. The cycling between glacial and interglacial periods has caused innumerable extinctions in the past few million years, and yet we are now experiencing an extinction event 100 to 1,000 times greater than the background rate (based on historical averages due to natural selection). Rapid global climate change is one powerful driver of mass extinctions. Clearly both human and nonhuman life has a lot at stake if the climate is changing. How do we know if the climate change we are experiencing today is normal or accelerated? And can natural forces alone explain these changes?

Unit II: Climate Change outlines the difference between natural and anthropogenic climate forcings, and explains how human activity is affecting the carbon cycle. Students will learn more about the Milankovitch cycles and how they affect solar insolation, or the amount of solar energy that reaches the Earth over time. The lessons will highlight the carbon cycle, identify carbon sources and carbon sinks, and explore the greenhouse effect. This unit will also allow students to explore paleoclimatology methods, by using simulated tree cores and ice cores. Finally, we will look at the current rate of change and how it compares to past warming or cooling periods.

Pre-requisite Next Generation Science Standards:

MS—PS1.A: Structure and Properties of Matter  
MS—PS3.A: Definitions of Energy  
MS—PS1.B: Chemical Reactions  
MS—PS3.B: Conservation of Energy and Energy Transfer  
MS—PS4.B: Electromagnetic Radiation  
II.A: Natural Forces—volcanoes, sunspots, & wobbles

Key Concepts and Web-app Resources:

Earth’s climate has hardly been consistent. Over the past 4.6 billion years, Earth has modulated between a Hothouse state (70% of the time), and an Icehouse state (30% of the time). Its current Icehouse state has lasted for several million years, but in-flux with cycling glacial and interglacial periods. What drives those ice age cycles?

In 1920, Serbian mathematician, astronomer, and climatologist Milutin Milanković published his astronomical theory of climate. This theory calculated a curve of solar insolation, the amount of heat energy a particular spot on Earth receives from the sun for any period of time, and correlated the oscillating pattern to the cycle of ice ages. Today, the term “Milankovitch Cycle” is used to describe the prevailing pattern of the last 800,000 years. Three cosmic factors play a role in this cycle: 1) the eccentricity of Earth’s orbit around the sun varies over a 100,000 year time period from nearly circular to mildly elliptical; 2) the angle of Earth’s axial tilt which affects the length of our seasons, cycles from 22.1° to 24.5° over the course of 41,000 years; and 3) Earth wobbles like a top as its axial precession changes with respect to the stars in a 25,700 year cycle.

Though paleoclimatological data supports the Milankovitch Cycle as a leading driver for long-term ice age cycles within the last 800,000 years, it does not account for the full extent of heating or cooling trends. Even shorter intervals, such as the 11-year change of solar activity as observed by a rise and fall in the number of sunspots, cannot explain the current changes in global temperatures. In fact, solar energy is on a downward trend while global temperatures are moving markedly upward. Though the sun is the primary source of energy on Earth, feedback mechanisms, like the albedo effect, greenhouse gas concentrations, and dust from volcanic activity have clearly factored as well.

In this chapter, students will interact with past and present climate data to discern how natural climate forcings, including volcanic activity, ice cover, and El Niño/La Niña events affect global temperature and precipitation patterns.

Unit IIA. Web-app Resources:

>Climate Science

>>Natural Forces: Volcanoes, Sunspots, and Meteors, Oh My!

>>>Natural Cycles: Evidence of Change

>>>Natural Climate Forces

>>>NASA Video Comparing Natural and Human Factors
Lesson: In what three ways does Earth’s orbit change? How do these cycles affect Earth’s solar heat gain, and thus climate?

*Adapted from NOAA reviewed resource that uses applet by Tom Whittaker - University of Wisconsin

**Subjects / grade levels:** 6th-12th grade, Earth Science, Physics.

**Materials:** Computer access, copies of student worksheet, and homework reference graph.

**NGSS Standards:**

**MS—ESS2-6: Weather and Climate**
- ESS2.D: Weather and Climate—Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric flow patterns.
- 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.

**MS—PS2-5: Motion and Stability: Forces and Interactions**
- Forces that act at a distance (electric, magnetic, and gravitational) can be explained by fields that extend through space and can be mapped by their effect on a test object.

**MS—PS3-3: Energy**
- PS3.A: Definitions of Energy—Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.

**MS—ESS1-1: Earth’s Place in the Universe**
- ESS1.A: The Universe and Its Stars—Patterns of the apparent motion of the sun, the moon, and stars in the sky can be observed, described, predicted, and explained with models.
- ESS1.B: Earth and the Solar System—This model of the solar system can explain eclipses of the sun and the moon. Earth’s spin axis is fixed in direction over the short-term but tilted relative to its orbit around the sun. The seasons are a result of that tilt and are caused by the differential intensity of sunlight on different areas of Earth across the year.

**HS—ESS1-1-4: Earth’s Place in the Universe**
- ESS1.B: Earth and the Solar System—Kepler’s laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.

**Lesson objective(s):** Students will gain a better understanding of how long-term changes is Earth’s orbit, known as Milankovitch Cycles, affect solar insolation and therefore Earth’s global temperature average. They will also begin to connect an 8°C temperature fluctuation with the difference between an ice age and a temperate climate.

**ENGAGEMENT (5 minutes)**
- Ask students: why does Earth experience different seasons? How do our seasons relate to the tilt of Earth’s axis and its orbit around the Sun? **A:** When Earth’s axis points away from the sun in orbit, we experience winter in the Northern Hemisphere and summer in the Southern Hemisphere. When it points towards the sun, the opposite is true.
- Is Earth’s tilt at a fixed angle? Is our orbit always the same shape? **A:** No, the Earth’s bulge at the equator makes it wobble on it’s axis. Gravitational forces from other planetary bodies also alter the shape of its orbit.
II.A: Milankovitch Cycle Lab—continued 2/4

EXPLORATION (20 minutes)

- Load the Vostok Core and Milankovic Cycles Climate Applet found here: http://itg1.meteor.wisc.edu/wxwise/climate/earthorbit.html. *This can be done on individual computers in a lab or alternatively on a shared computer and Smartboard.

- Orient students to the Vostok Ice Core temperature data on the right-hand side. It graphs lower atmosphere temperature anomalies from modern times (over Antarctica) for the past 400,000 years that range from approximately −9°C to 3°C.
  - Explain that this temperature variation also represents the difference between an ice age, where mile high ice sheets covered the New York Hudson Valley, and temperate conditions, like we experience today, where pervasive ice exists only on the poles and at high altitudes.

- Next, tell students to start the time slider along the temperature graph on the right at “Now” - found at the top. Later, students will view changes in Earth’s tilt and orbital eccentricity over time by sliding that timer down. For now, we want students just to learn about the current relationship between Earth’s tilt, its orbit and seasonal differences.
  - Have students toggle between the “Top View” and “Side View” button and the “Rotation,” “Orbit,” and “Faster Orbit” Checkboxes to see the differences.

- From the applet instructions at the bottom:
  - The view button toggles between showing a projection which is above the orbital plane and one which is more sideways.
  - The Label checkbox which toggles the seasonal labels on/off. The default is on.
  - The "rotation" checkbox which (when enabled) shows the Earth in its daily rotation about the axis.
  - The "orbit" checkbox which (when enabled) causes the orbital motion of the Earth to be in correct proportion to the rotation.
  - The "faster orbit" checkbox accelerates the orbital motion.

- After a few orbits (with seasonal labels on), students should be able to answer the first few questions about seasons on their worksheet.

- Next, students should explore each of the three main variations on the applet and define what each is in their own terms on the worksheet. To get clues on what each variation means, students will have to manipulate the Time Slider on the right. These variations are:
  - **Eccentricity**—sliding the time scale back and forth while on Top View shows that eccentricity refers to how elliptical Earth’s orbit is over time. Sometimes, it looks like almost perfectly circular, and sometimes it is a bit oblong. The eccentricity curve displayed is a combination of the 95 yr, 125 yr, and 140K yr cycles.
  - **Precession**—sliding the time scale back and forth while on Top View or Side View and toggling only precession on shows that Earth spins like a top, with its axis wobbling to point toward a different direction over time. The precession curve displayed is a combination of the 19 yr and 24K yr cycles.
  - **Tilt**—sliding the time scale back and forth while on Side View and toggling only tilt on shows that the degree of Earth’s axial tilt has changed with respect to the sun (how much it would point toward the sun during summer, or away from the sun during winter). The tilt curve displayed is the 41K yr cycle.
EXPLORATION continued

- Students can proceed to toggle each Checkbox to answer questions on their worksheet regarding the length of each type of cycle. How would variations in each affect the amount of direct sunlight the Earth receives in, let’s say, the Northern Hemisphere on the Summer Solstice?

- A: An increase in tilt would put more of the Northern Hemisphere in line with direct sunlight at the Summer Solstice, when it points towards the sun, increasing heat gain. Changes in precession would alter the timeline for our seasons over millennia—sometimes the Summer Solstice for the Northern Hemisphere would be in June, as it does now (because the Earth is tilted toward the sun); other times the Summer Solstice for the Northern Hemisphere would take place in September, in a hypothetical calendar year, as only then would the tilt point toward the sun. Now for the trickiest one: eccentricity. Changes in eccentricity would modulate the combined seasonal effects of tilt and precession. In other words, when eccentricity is minimized (a more circular orbit), the Summer Solstice in the Northern Hemisphere might feel relatively hotter than when eccentricity is greater. If the Northern Hemisphere’s Summer Solstice takes place on the “far end” of an elliptical orbit, as it does today, its increased distance from the sun would mitigate the increase in direct sunlight Earth receives.

- Finally, students should combine all three Checkboxes to see the resultant graph on solar insolation against temperature anomalies. Does the Milankovitch Cycle graphed (in magenta), illustrating the amount of sunlight Earth receives over time, correlate with temperature changes? Remember, the two graphs do not have to fit together perfectly—as they are different scales. Do the increases in direct sunlight generally match up with increases in temperature? A: Yes, but not always perfectly.

EXPLANATION (10 minutes)

- Now that we understand how the angle of tilt, the axial precession, and the eccentricity of Earth’s orbit contribute to glacial and interglacial climate cycles, what other natural forces may either exacerbate or modulate the Milankovitch cycle, or create briefer, less drastic climate cycles within each period?

- After giving students an opportunity to provide their own ideas, use the Web-based application to pull up the graphic on Natural Climate Factors:

>Climate Science>>Natural Forces: Volcanoes, Sunspots, & Wobbles, Oh My!>>Natural Climate Factors

- Use this Unit’s introduction to lead a discussion on how each of the terrestrial factors listed (ocean,
Now that students have charted Milankovitch Cycles, can they apply the same learned concepts of natural climate forcings to track the effects of volcanic activity, ocean-atmosphere interactions and sunspots on climate?

Break the class up into three team: volcanoes, ENSO, and sunspots.

- Powerful volcanoes, with a VEI of 5 or greater, expel large quantities of particulates into the upper atmosphere, which can reflect light. They also expel some CO$_2$ which is a heat-trapping gas.

- ENSO stands for El Niño Southern Oscillation, which is a repeating pattern of interaction between trade winds and seas, resulting in a predictable, though irregular fluctuation of sea surface temperatures (SST). El Niño means higher SST and La Niña means lower SST.

- Sunspots are used as a way of measuring solar activity. Generally, more sunspots mean an increase of solar output energy and fewer sunspots mean reduced solar output energy.

- Using the NOAA graph on the back of the worksheet, entitled Annual Global Temperature Anomaly (Combined Land and Ocean), students should use data related to their assigned team and plot years of high VEI, ENSO events, or peak sunspot activity onto the Temperature graph from 1880-2015.

- Significant Volcanic Eruption data can be found at NOAA’s National Center for Environmental Information database by plugging in the timeline (1880 to 2015) and VEI parameters (5 minimum to 8 maximum) here: https://www.ngdc.noaa.gov/nndc/servlet/ShowDatasets?dataset=102557&search_look=50&display_look=50

- ENSO events can be found at the bar on the right, here: https://www.esrl.noaa.gov/psd/enso/
  Students should track El Niño events in RED and La Niña Events in BLUE

- Sunspot data collected from the Zurich Observatory since 1849 and corroborated by NASA can be found here: https://solarscience.msfc.nasa.gov/images/Zurich_Color_Small.jpg
  Students should only track years of peak activity (the apex of the curve).

- Once the assignment is completed, ask students to report with their teams if their natural climate factor was usually a good predictor of changes in the climate from year to year and in what way (warmer or cooler?).

- Do any of these factors account for the warming trend of the last century, particularly over the last 2 decades?

- To recap—use the Web-based application to show the video on >Climate Science>>>Natural Forces: Volcanoes, Sunspots, & Wobbles, Oh My!>>>Natural Cycles: Evidence of Change, also found here: https://youtu.be/2_10jtPCjQw
Annual Global Temperature (Combined Land & Ocean)

1880-2014 Trend: +1.17°F per century
1998-2014 Trend: +1.04°F per century

Anomaly (°F) Relative to 20th Century Average

NCDC / NESDIS / NOAA
http://www.ncdc.noaa.gov/
This worksheet accompanies the Milankovitch Cycle applet found at [http://itg1.meteor.wisc.edu/wxwise/climate/earthorbit.html](http://itg1.meteor.wisc.edu/wxwise/climate/earthorbit.html). First, with the time slider set to “Now” allow the slow orbit and rotation to complete a cycle and answer the questions below. Switch between Top view and Side view to change the perspective.

1) What causes the temperature difference between the winter and summer solstices for the Northern Hemisphere?

_________________________________________________________________________________________________
_________________________________________________________________________________________________

2) What is the difference between the Perihelion Aphelion points in the Earth’s revolution around the sun?

_________________________________________________________________________________________________
_________________________________________________________________________________________________

3) Next, use the applet to learn more about variations to Earth’s tilt, axial precession, and elliptical orbit that affect climate cycles. After manipulating each variation alone, try to define them your own words.

Tilt:______________________________________________________________________________________________

Precession:_______________________________________________________________________________________
_________________________________________________________________________________________________

Eccentricity: ______________________________________________________________________________________
_________________________________________________________________________________________________

4) Using the applet, see how each variable graph (in magenta) compares to the Vostok Ice Core Temperature graph (in green). What is the full length of each cycle? Hint: you can drag the Time slider from one peak or valley to the next on the graphs and read the number of years on the Timer slider.

a) An axial tilt cycle takes approximately ________________ years.

b) An axial precession cycle takes approximately _________________________ years.

c) An orbital eccentricity cycle takes approximately ______________________________ years.

5) Consider how each cycle might affect the amount of direct sunlight the Earth receives in the Northern Hemisphere at the Summer Solstice. Record your thoughts here: _____________________________________________________
_________________________________________________________________________________________________
_________________________________________________________________________________________________
Finally, combine all three variations by making sure all the boxes are checked. This represents the true amount of insolation the Earth received over the last 400,000 years, accounting for these variations to tilt, precession, and eccentricity.

The graph below is the same Vostok Ice Core graph on the applet, showing temperature anomalies for the past 400,000 years, only presented horizontally and inverted for clarity. Peaks correspond to temperate climates, whereas valleys are ice ages. **Bonus: Try to recreate the total insolation graph by plotting it onto the Temperature graph below.**

![Temperature graph](image)


7) How well does the total insolation graph correlate to the temperature graph? Do the increases in direct sunlight generally match up with increases in temperature? Are there any glaring contradictions or lags?

_________________________________________________________________________________________________
_________________________________________________________________________________________________
_________________________________________________________________________________________________
_________________________________________________________________________________________________
_________________________________________________________________________________________________
II.B: Paleoclimatology: Clues in Trees & Ice

Key Concepts and Web-app Resources:

Direct climate measurements date back only to the 1880s, which provides very little perspective to compare current climate change to Earth’s long history. Scientists therefore use climate proxies, or preserved physical characteristics of the past environment, as substitutes for direct measurements. Climate proxies include ice cores, fossilized pollen grains, tree rings, ocean sediment cores, and layers of sedimentary rock. Scientists that gather climate proxy data and reconstruct it to learn about Earth’s past climate conditions are called paleoclimatologists.

Ice cores have been particularly helpful in extracting fairly precise information on the atmospheric conditions stretching back for hundreds of thousands of years. That is because, in the Earth’s current Icehouse state, some areas of polar ice have never melted. Year after year, precipitation (snow, hail, freezing rain) that accumulated formed annual rings through seasonal changes, much like a tree. Scientists drill into the ice-sheets and extract cores containing trapped gases in the layers. The further they drill down, the further back into history they can see. These ice cores are brought to frozen laboratories where the trapped gases can be extracted and assessed in a vacuum chamber to determine the amount of carbon dioxide present each year in parts per million (ppm). Oxygen isotopes in the frozen water can also be used to estimate relative annual temperatures at the surface. The Vostok Cores from Antarctica give paleoclimatologists workable data on Earth’s temperatures that stretch back to 400,000 years ago!

Tree cores and cookies also provide annual proxy data. Climate conditions affect the rate of tree growth—wider annual rings are indicative of favorable climate conditions, whereas more narrow rings mean poorer climate conditions for growth. Depending on the region and the species of tree, the relative size of the tree rings and cell size within each ring provide evidence of either warmer/cooler periods, or wetter/drier periods. Living trees can be cored with an increment borer and compared to cores, cookies, or even lumber from dead trees and the data can be cross-dated to construct a longer time-line. Given that some trees can live and grow for thousands of years, a lot can be learned by studying tree-rings. The study of tree-rings is called dendrochronology.

Unit IIB. Web-app Resources

> Climate Science
  >> Historical Climate Change: Clues in Trees and Ice
    >>> Dendrochronology: What tree cores tell about local climate history
    >>> Climate History in Ice Cores (NOVA Video Segment: Extreme Ice)
  >> The Greenhouse Effect and Anthropogenic Warming
    >>> CO₂ and Temperature Correlation (past 800,000 years)
II.B: Dendrochronology Lab

*This lesson is intended to be used with the Lab-Aids Dendrochronology kit, available for purchase here: https://www.nature-watch.com/dendrochronology-tree-ring-dating-kit-p-1785.html

The kit contains two sets of 12 simulated tree cores—each representing a different sample, student worksheets, and a teacher’s manual.

Lesson: How do scientists read annual growth rings from tree cores and cookies to determine past climate history? How can cores from multiple samples be cross-dated to create extended timelines of paleoclimate data?

Subjects / grade levels: 4th-9th grade, Earth Science, Living Science

Materials: Several tree cookies for comparison (can be cut from local fallen branches, or purchased at local craft stores or Nature-Watch.com; Lab-Aids #52: Dendrochronology—Tree Ring Dating Kit (available for purchase through several online retailers); student worksheets, rulers, computer(s) to view Web-application video.

NGSS Standards:

5-PS3-1 Energy
5-LS1-1 From Molecules to Organisms: Structures and Processes
5-LS2-1 Ecosystems: Interactions, Energy, and Dynamics
5-ESS2-1 Earth’s Systems
MS-LS1-1 From Molecules to Organisms: Structures and Processes
MS-LS1-7 From Molecules to Organisms: Structures and Processes

ENGAGEMENT: (5-8 minutes)

• Ask students: How would you describe your regional climate? Was it always like that?

• How do scientists know about Earth’s climate history—such as temperature or amount of precipitation thousands of years ago? A: Climate proxies. Scientists measure trapped gases in ice cores, study fossilized pollen in sediment cores, and measure growth rings in tree cores because they can be dated and indicate relative markers about the climate at that time.

• Tell students that today, they will become Dendrochronologists! Can they figure out what that means?

• Using the web-application, show students the following video on Dendrochronology:
  >Climate Science>>>Historical Climate Change: Clues in Trees and Ice>>>Dendrochronology: Tree Ring Dating (also found here: https://youtu.be/-Vfg4GieRTc)

• Review:
  • What is the study of past climates using proxies called? A: Paleoclimatology.
  • How does paleoclimatology data help scientists predict future climate changes? A: Collected data allows scientists to test the accuracy of Climate Models (simulated by computers)
  • What kind of climate data can be attained by looking at tree rings? A: Cloud cover, precipitation, temperatures

EXPLORATION: (10 minutes)

• Pass out Dendrochronology worksheets and tree cookies to each student.

• Have students use the diagram on their worksheet to help them find the first annual growth ring. How about the last? Note, not the bark!
II.B: Dendrochronology Lab 2/2

EXPLORATION (continued)

- Students should continue using their tree cookie to answer questions on the worksheet.
- Ask students to sum up what they learned about their tree cookies and what it tells them about the climate their tree grew in.

EXPLANATION (25 minutes)

- Tell students that these tree cross-sections, or cookies, were made from felled trees. Can they think of any other places where tree rings can be found and counted? How about lumber/furniture?
- Ask students if they can guess the age of the oldest living tree? **A:** It is a bristlecone pine—over 5,200 years old. That’s a lot of climate data! These trees are hardly the biggest, but there are many narrow rings, as bristlecone pines grow in arid areas. The largest trees in the world, the coastal redwoods and giant sequoias, can live to be thousands of years old as well, and grow in temperate climates. But how do we get data from living trees without cutting them down? **A:** Dendrochronologists use an increment borer to drill to the center growth ring of the living tree and get a core.
- Follow the directions on the Lab-Aids 52: Tree Ring Dating to learn more about tree cores and cross-dating techniques that dendrochronologists use to get proxy data.

ELABORATION (10 minutes)

- While tree rings can tell us a lot about precipitation rates, temperature, or even about wildfires, the data at best stretches back about 13,000 years. What other climate proxies can scientists use that might provide information about Earth’s climate hundreds of thousands of years in the past?
- Using the web-application, show students the following video on Ice Cores:
  >Climate Science>>>Historical Climate Change: Clues in Trees and Ice>>>Climate History in Ice Cores (NOVA Video Segment: Extreme Ice)
  (also found here: https://ny.pbslearningmedia.org/resource/nvei.sci.earth.climate/ice-core-record-of-climate/)
- If there is time, discuss what new information is gained from ice core data.
Dendrochronologists study tree rings, to determine the growth rate and age of trees. This provides insight into past climate in the region where the tree grew, such as annual precipitation and relative temperatures. Tree cores from living trees can be used to contrast and compare with tree slices, or “cookies” from preserved, dead trees. Every band represents a year of growth.

1) Look at your tree cookie sample and count the rings to determine how old it is.
A: __________________________________________

2) Use the chart to the right to identify the first and last annual growth rings. If the tree came down this year, in what year did it begin growing?
A: ____________________________________________

3) What year did the tree grow the fastest? How do you know?
A: ____________________________________________
_________________________________________________________________________________________________

4) What does rapid growth probably mean for the weather conditions that year? _____________________________
_________________________________________________________________________________________________

5) Record any other notable observations from your tree cookie that may provide climate proxy data (ie: fire scar, all the rings are narrow, all the rings are wide, a knot in the wood, etc.)
_________________________________________________________________________________________________
_________________________________________________________________________________________________
_________________________________________________________________________________________________

6) How does your tree cookie compare to your neighbor’s? To the class? Do you think they all grew in the same climate?
_________________________________________________________________________________________________
_________________________________________________________________________________________________

Source: NASA - Climate Kids
II.C: Our Atmosphere and the Greenhouse Effect

Key Concepts and Web-app Resources:

Earth’s atmosphere consists of a mixture of gases separated into layers by their density, and bound to Earth by gravity. Though incredibly thin, the atmosphere has a potent affect on Earth’s climate system. In fact, it is our atmosphere that allows Earth to sustain life at all. It contains the air that we breathe, and gases that protect us from harmful cosmic rays, and gases that trap heat and keep Earth full of liquid water—a key component of life. According to NOAA, the chemical composition of our atmosphere is: Nitrogen — 78.09%; Oxygen — 20.95%; Argon — 0.93%; Water vapor — .39%; Carbon dioxide — 0.04%; trace amounts of neon, helium, methane, krypton, hydrogen, nitrous oxide, sulfur hexafluoride, and ozone.

The composition, temperature, and pressure of this mixture of gases forms five distinct layers in our atmosphere: the troposphere—which hugs Earth’s surface and contains the air we breathe, the stratosphere—where you can find commercial aircrafts flying, the mesosphere—which despite it being frigidly cold is where meteors burn up upon entry, the thermosphere—which reflects and absorbs the most harmful incoming radiation, and the exosphere—which fades into outer space where satellites can orbit Earth.

Although Nitrogen, Oxygen, and Argon make up over 99.5% of the Atmosphere, they absorb almost no incoming solar radiation nor outgoing infrared radiation. Instead, the other .5% of the atmosphere which contains water vapor, carbon dioxide, nitrous oxide, and methane are responsible for trapping most of the Earth’s outgoing infrared radiation and heating the planet. Because of this thermal ability, we refer to them as greenhouse gases. The process by which incoming high-frequency light waves from the sun—absorbed at Earth’s surface and reradiated as low-frequency infrared waves—are then absorbed by greenhouse gases and turned into heat energy, is called the greenhouse effect. These trace gases act just as the glass on a greenhouse ceiling do. The greenhouse effect is natural and quite beneficial to life on Earth. Without it, we’d be a frigid planet! According to NOAA, “the global average temperature is 14°C (57°F), which is approximately 33°C (59°F) warmer than temperatures would be without an atmosphere and GHGs.”

Though methane and sulfur hexafluoride are the most potent greenhouse gases, carbon dioxide molecules are much more abundant, and they stay in the atmosphere for far longer. The feedback effect of carbon dioxide in the atmosphere on global temperatures is well documented in both the paleoclimate record and in real-time climate data.
II.C: Our Atmosphere and the Greenhouse Effect—Rate of Change Activity

Lesson: How do global temperature averages and atmospheric carbon dioxide concentrations correlate in the past 130+ years?

Subject / grade level: 6th-12th grade, Earth Science

Materials: Copies of the student worksheets and NOAA graph charting Global Temperature and Carbon Dioxide from 1880-2010; Earth Science reference book; rulers; calculators; Web-based application.

NGSS Standards:
SS2.D: Weather and Climate
• Weather and climate are influenced by interactions involving sunlight, the ocean, the atmosphere, ice, landforms, and living things. These interactions vary with latitude, altitude, and local and regional geography, all of which can affect oceanic and atmospheric

Lesson objective(s): Students will calculate rate of change to determine if the 20th century temperature increase is significant. They will also determine the relationship between the two graphs.

ENGAGEMENT (5 minutes)
• Ask students to define global warming in their own terms? If we are in an interglacial period, some degree of warming would be expected. Ask: how do you think current “global warming” compares to past warming?

EXPLORATION (15-20 minutes)
• Pass out worksheets and NOAA graphs to each student (or group of students). If you would like to display the graph on a smart board, you can find it on the web-based application by going to: >Climate Science>>The Greenhouse Effect and Anthropogenic Warming>>>Post-Industrial CO2 and Temperature (1880—2010)
• Orient students to the Y axis on the left*. This charts Global Temperature in degrees Fahrenheit (°F). Blue bars represent temperatures that are colder than the 20th century average; red bars are warmer than the 20th century average. (The horizontal “line” that runs between the blue and red bars represents the 20th century average).
• Students should use rulers to match up the year 1900 on the graph to the corresponding blue bar. To get the global temperature for blue bar years, such as 1900, they need to use their rulers to then line up the bottom of that bar with the scale on the Y axis at left. To measure the temperature for red bar years, they need to trace the top of those bars to the Y axis on the left. *Some students may have trouble estimating points between the given marked temperature intervals. It may be preferable to mark more intervals on that axis, such as .25°F or even .125°F.
• Next orient students to the Y axis on the right. This charts CO₂ Concentration in parts per million (ppm). This means there are X many molecules of carbon dioxide for every million other gas molecules in the atmosphere. The bold black line graphed represents the measured CO₂.
II.C: Our Atmosphere and the Greenhouse Effect—Rate of Change Activity

EXPLORATION (continued)

- Have students work independently or in groups with their Earth Science Reference books (or provide them the formula for rate of change). They should be able to answer questions 1-4.

EXPLANATION (10 minutes)

- Ask them to share their answers for questions 2 & 4. **A:** Temperature and carbon dioxide concentrations have a direct relationship. In other words, as one goes up, so does the other. The rate of change for 1950-2010 is about 10 times greater than the rate of change for 1900-1950. Earth is warming more rapidly and CO2 increases are accelerating.

- Before they answer Part B on their worksheets, discuss the meaning of a 1-2 degree Fahrenheit increase in global temperatures. It does NOT mean that a New York summer day may be one degree warmer. Instead, these values are the land and water temperatures averaged out for the whole globe over the entire year.

  - Earth’s average temperature is much like our internal temperature—a 1-2°F increase in 100 years or less is significant. For a human, it would mean getting a fever. When a human gets sick with a fever, they may get a headache, start sweating, get lethargic, or break out in a rash. When Earth’s temperature increases rapidly, we notice deadly heat waves, more powerful storms, and rapid ice melt.

- Using the web-based application, watch the NASA Visualization Studio video on Global Temperature Timelapse:
  >Climate Science>>The Greenhouse Effect and Anthropogenic Warming>>>Global Temperature Time-lapse 1884-2012 (NASA Scientific Visualization Studio) (can also be found here: [https://svs.gsfc.nasa.gov/4609](https://svs.gsfc.nasa.gov/4609))

  - Tell students that this will show how the annual temperature averages look when mapped out over the globe. **White** would represent average temperatures over land or ocean. **Deep blue** are −4°F from the average whereas **deep red** are +4°F from the average temperatures.

- Students should now answer part B on their worksheets.

ELABORATION (5 minutes)

- Use your Teacher Answer Sheet to discuss their answers.

- What do they think may be the consequence of an accelerated rate of change for both CO2 and Temperature on our climate system? What sort of effects do they expect to see around the world from introducing a quick change of entropy? **A:** Unpredictability in ice cover, atmospheric conditions, ocean currents, etc.
PART A: Use the graph provided, Global Temperature and Carbon Dioxide, to answer the following questions.

1) Look at the graph. Record the Temperature and CO$_2$ below for the following years. Be sure to include the right unit of measurement! The average temperature in this timeline is ____________________

A: 1900— Temp:_________________________ CO$_2$:________________________

A: 1950— Temp:_________________________ CO$_2$:________________________

A: 2010— Temp:_________________________ CO$_2$:________________________

2) What is the relationship between the graphed data? (direct or inverse?) ______________________________

3) Use your Reference Book to look up the formula for Rate of Change. Next, calculate the rate of change for temperature and carbon dioxide over the following time intervals.

...from 1900-1950? # of years: ________ Temp:_________________________ CO$_2$:________________________

...from 1950-2010? # of years: ________ Temp:_________________________ CO$_2$:________________________

4) To what degree do they differ? Temp:_________________________ CO$_2$:________________________

PART B: Watch the NASA Visualization on Global Temperature Time-lapse 1884-2012 before answering the following questions.

5) Why do you think the Northern Hemisphere seems to heat up much faster than the Southern Hemisphere? *Hint: Think about ice cover and albedo effect; also look up the specific heat values in your Reference book.*

_____________________________________________________________________________________________
_____________________________________________________________________________________________

6) Describe in your words what this average global temperature increase looks like when mapped out over the globe.

A: _________________________________________________________________________________________
___________________________________________________________________________________________
II.C: Climate and Rate of Change Teacher Answer Sheet

Use the graph provided, Global Temperature and Carbon Dioxide, to answer the following questions.

1) Look at the graph. Record the Temperature and CO₂ below for the following years. Be sure to include the right unit of measurement! The average temperature in this timeline is ___57.6°F__________

   a: 1900 — Temp: ~57.6°F ____________________ CO₂: ~295ppm
   b: 1950 — Temp: ~57.3°F ____________________ CO₂: ~310ppm
   c: 2010 — Temp: ~58.6°F ____________________ CO₂: ~390ppm

2) What is the relationship between the graphed data? (direct or inverse?) Direct

3) Use your Reference Book to look up the formula for Rate of Change. Next, calculate the rate of change for temperature and carbon dioxide over the following time intervals.

   A) ...from 1900-1950? # of years: 50 Temp: -.006°F/year CO₂: .3ppm/year
   B) ...from 1950-2010? # of years: 60 Temp: .022°F/year CO₂: 1.33ppm/year

4) To what degree do they differ? Temp: B is 35.7 times faster than A CO₂: B is 3.4 times faster than A

Watch the NASA Visualization on Global Temperature Time-lapse 1884-2012 before answering the following questions.

5) Why do you think the Northern Hemisphere seems to heat up much faster than the Southern Hemisphere? Hint: Think about ice cover and albedo effect; also look up the specific heat values in your Reference book.

   There is more land mass in the northern hemisphere. Land heats up faster than water because water has a high specific heat value. As ice melts in the north pole and Greenland, less solar reflection creates a positive feedback to further increase warming.

6) Describe in your words what this average global temperature increase looks like when mapped out over the globe.

   A: It looks like pockets of extreme warming on land some years, and slow warming of our entire oceans. The planet on the whole seems to have changed significantly in just the past 130 years.
II.D: Anthropogenic Warming

Key Concepts and Web-app Resources:

Humans have long-altered our planet’s resources, often to the detriment of other species, but could we really fundamentally change our global climate system? Throughout this unit, we have learned about the ways in which the atmosphere, geosphere, hydrosphere, and biosphere interact with Earth’s energy budget. We have also learned about the unique role that carbon dioxide, as a heat trapping gas in the atmosphere, has had in past changes to our climate. Anthropogenic warming refers to the change in global temperatures that cannot be accounted for by natural processes alone. Human influence, particularly on the atmosphere and biosphere, is the primary driver to climate change today.

When humans began repopulating the globe after the last ice age, a stable climate allowed for settlements to form and agriculture to become the predominant method of food production. To clear forests and grow crops, trees and brush were slashed and burned, releasing their stored carbon. The ground was plowed, turning up roots and mixing in oxygen. The disturbance to the soil increased decomposition rates and released more carbon dioxide and methane into the atmosphere as well. This uptick in CO$_2$ was remediated by other forests, still in abundance, and the oceans, still cold and able to dissolve more gases. However, by the 1800’s, the Industrial Revolution was in full swing, and manufacturing plants brought coal-fires for steel production, fuel-driven steam engines, and clear-cutting of forests to make room for roads, trains, farms, mining, and more factories. In the late 1800’s the invention of the steam-powered generator to produce electricity was introduced. More fuel was needed to meet increased consumption. Fuel is burned to boil water, which creates steam, which expands and pushes pistons in a generator, which spin powerful electromagnets, which provide a current of electricity. To meet demand, humans turned to new fuel sources and new methods of extraction. Coal, oil, and natural gas soon became our fuels of choice, as they seemed almost unlimited in their quantity deep in the Earth’s crust.

In the last lesson (II.C), we learned how greenhouse gases work to trap solar gain and convert it to heat energy. Scientists know from paleoclimate data in ice cores, field experiments, and computer models, that increases in the greenhouse gas, carbon dioxide, have been the greatest predictor of increases in global temperatures. Today, the amount of carbon dioxide in the atmosphere is over 400 parts per million—a level not seen in the last 400,000 years. Predictably, global temperatures are also on a marked increase. Human activity is the main climate forcing today.

Unit IID. Web-app Resources:
>Climate Science
>>The Greenhouse Effect and Anthropogenic Warming
>>>Separating Natural and Human Factors
>>>Post Industrial CO2 and Temperature (1850-2015)
>>Natural Forces: Volcanoes, Sunspots, and Meteors, Oh My!
>>>NASA Video Comparing Natural and Human Factors
II.D: Anthropogenic Warming—Carbon Cycle Activity

*This activity was adapted from the Nitrogen Cycle Game, developed for the National Earth Science Teachers Association by Lisa Gardiner of the UCAR Center. It was modified by Groundwork to teach about the Carbon Cycle in 2016 after partnering with NOAA. Tokens were introduced to replace dice as a way of showing forces of change.

Lesson: What are the natural and anthropogenic sources of carbon? Where are the biggest carbon sinks? How is human activity “loading the dice” for atmospheric and oceanic carbon dioxide concentrations?

Subjects / grade levels: 5th-9th grade, Earth Science, Living Science

Materials: 7 Envelopes; Carbon Cycle Game printouts (Student Passports for each student, 7 Stations: Sources and Sinks, and Tokens), available for download here: Tokens should be cut out ahead of time and placed in corresponding 6 Station envelopes. (Laminating tokens and station sheets makes them more durable). Be sure that each station has at least one of the tokens listed.

NGSS Standards:
MS—PS1-1: Matter and Its Interactions
PS1.A: Structure and Properties of Matter—Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
PS1.B: Chemical Reactions—Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.
MS—ESS3-3: Earth and Human Activity
ESS3.C: Human Impacts on Earth Systems—Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth’s environments can have different impacts (negative and positive) for different living things.
MS—ESS3-5: Earth and Human Activity
ESS3.D: Global Climate Change—Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth’s mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities.

ENGAGEMENT

• Ask students to name all of the carbon molecules they can think of. (ex: carbon dioxide, carbon monoxide, methane (CH₄), glucose (C₆H₁₂O₆), calcium carbonate (CaCO₃) found in seashells... ) Where can you find carbon in the atmosphere? A: As trace carbon dioxide and methane. The biosphere? A: Stored in plants and other trees, in living cells of animals (proteins, carbohydrates, lipids). The hydrosphere? A: Dissolved in the oceans and lakes. The geosphere? A: In the sunken remnants of dead marine organisms and buried deep in the Earth’s crust as coal, oil, or methane.

• Tell students that the same fixed amount of carbon, used as a building block of life, has been in cycle since Earth’s beginning over 4 billion years ago. How does this carbon get moved from one organism to the next, or even one sphere to the next?
  • The movement of carbon atoms from oceans, to atmosphere, to plants, to animals, to Earth’s crust is called the Carbon Cycle.
II.D: Anthropogenic Warming—Carbon Cycle Activity 2/3

ENGAGEMENT continued

- Photosynthesis, consumption, assimilation, and decomposition all transform and move organic carbon, while geologic forces (tectonic movement, weathering, volcanoes), and physical forces such as dissolving, diffusion, and burning, can transform and move inorganic carbon.

- Some of these processes happen in a geologic instant! For instance, plants convert atmospheric carbon dioxide to glucose in their leaves every day. Other processes take millions of years, such as the layering of ocean sediment containing carbon from dead marine organisms being heated and compressed by the weight of the crust and turned into “fossil fuels.”

- Can humans alter the carbon activity? If so, how? A: We disturb soil and rock through agriculture, mining, and construction—changing the rates of weathering. We have clear-cut forests through slash-and-burn techniques, releasing the carbon stored in trees. We burn trees and fossil fuels for heat and electricity production.

EXPLORATION (15-20 minutes)

- Set up the room to space out the 7 Carbon Cycle Stations—Atmosphere, Oceans, Soils, Living Animals, Living Plants, Dead Plants & Animals, Fossil Fuels. Make sure each station has its associated envelope containing its tokens. *For now, leave the fuel token out of the Fossil Fuel station envelope.*

- Pass out the Student Passports to students. Make sure everyone has a pencil.

- Ask students to position themselves at a station. **Start at least one student at the Fossil Fuel station.**

- Read over the directions at the top of the passport out loud with students and have them fill in the correct information for their starting station. Keeping track of their particular carbon molecule at each station is optional—but you can offer bonus points for doing so. Explain that the way they fill out remaining stations changes a bit.

- Also, it is important that students RETURN the token to its envelope after they record it on their passport. The tokens are station-specific. They should not take tokens with them to the next station.

- Explain that it is quite possible to draw the same token multiple times in a row. This represents longer stays at each station in geologic time. Students should record each draw as a new trip on their passports.

- Allow the students 10 minutes to move through the Carbon Cycle Stations and populate their passports. After the first few minutes, the student(s) at the Fossil Fuel station will begin to get frustrated. They are stuck—round after round, millennium after millennium. They represent the ultimate carbon sink… for now. After they have filled in at least 4 stations, announce to the class that you are going to introduce anthropogenic forces: FUELS.

- At least 2 Fuel tokens should be placed in the Fossil Fuel station envelope. The remaining can be divided between the Living Plants and the Dead Plants & Animals station envelopes. (After all, we do burn biomass other than coal, oil, and gas for fuel).

- Students should return to their seats after completing their passport.
II.D: Anthropogenic Warming—Carbon Cycle Activity 3/3

EXPLANATION

• Ask students to share what they learned from this activity. As a carbon atom, would their journey ever truly end? Was every person’s journey the same? Why not?
  • At which stations were they most likely to repeat consecutively? These are carbon sinks. Where were they least likely to repeat? These are carbon sources. Which carbon sink have humans converted to a carbon source? Where did carbon from burned fuels end up? A: The Atmosphere as carbon dioxide.

[Diagram of the carbon cycle]

ELABORATION

• Show students the above diagram of the carbon cycle to review. The sizes of the arrows are approximately proportional to the amount of flow of carbon atoms. (Also found here: https://scied.ucar.edu/carbon-cycle-diagram-doe)
• Ask students to create a diagram like this but documenting only their journey.
• Ask a few students to come to the front of the room to compare their diagrams. Be sure to include at least one person that started at the fossil fuel station.
  • How do the diagrams differ? How does human activity disrupt the natural balance of the carbon cycle?
• Connect this lesson back to what we know about the atmosphere and historical climate change. Why might disruptions to the carbon cycle (by humans) cause global warming?
• Using the web-application, show students the following NASA video comparing natural and anthropogenic forcings:
  >Climate Science>>>Natural Forces: Volcanoes, Sunspots, and Wobbles, Oh My!>>>NASA Video Comparing Natural and Human Factors
  (also found here: https://climate.nasa.gov/climate_resources/144/video-how-global-warming-stacks-up/)
• What must we conclude is the primary cause for our current warming trend?
CARBON CYCLE GAME: PASSPORT

1) Mark your starting station on your passport.
2) Pick a starting nitrogen molecule from the possibilities at that station (read token descriptions on Destination Sheet and look for the first boldface carbon molecules listed).
3) Select a token from the bag. Mark it on your passport under “Mode of Travel.”
4) Find the corresponding directions depending on your selected token and mark your next destination on your passport. Travel now to this destination. Congrats, you’ve just become part of the N cycle!

<table>
<thead>
<tr>
<th>Starting Station:</th>
<th>Mode of travel (token):</th>
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<tbody>
<tr>
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<table>
<thead>
<tr>
<th>Starting Carbon Molecule:</th>
<th>1st New Destination:</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

5) Repeat steps 3-4 for each new station, always marking your Mode of Travel (token), your new form (nitrogen molecule) and next destination on your Passport for 8 total trips.

6) Return to your seat to discuss how this conceptual experiment worked!

<table>
<thead>
<tr>
<th>Trip 1:</th>
<th>Trip 2:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of travel (Token):</td>
<td>Mode of travel (Token):</td>
</tr>
<tr>
<td>Next Destination:</td>
<td>Next Destination:</td>
</tr>
<tr>
<td>New Carbon Molecule form</td>
<td>New Carbon Molecule form</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Trip 3:</th>
<th>Trip 4:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of travel (Token):</td>
<td>Mode of travel (Token):</td>
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<td>Next Destination:</td>
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<tr>
<td>New Carbon Molecule form</td>
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<th>Trip 5:</th>
<th>Trip 6:</th>
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<td>Mode of travel (Token):</td>
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<td>Next Destination:</td>
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<tr>
<td>New Carbon Molecule form</td>
<td>New Carbon Molecule form</td>
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<th>Trip 7:</th>
<th>Trip 8:</th>
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<td>Next Destination:</td>
</tr>
<tr>
<td>New Carbon Molecule form</td>
<td>New Carbon Molecule form</td>
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</tbody>
</table>
Climate change has been readily observable around the planet for the past century. Global temperature averages have increased over 1.04°C (or 1.5°F), creating a chain reaction on the rest of our climate system. Polar ice melt and thermal expansion have caused sea levels to rise, warmer oceans have propelled more powerful storm events, hotter, drier conditions inland have caused wildfires to spread faster, and increased air temperatures have given rise to more issues with air pollution and health effects. Scientists forecast that the planet will continue to warm another 2.5—10°F by the year 2100. This rapid change could bring dire circumstances for vulnerable biological communities and coastal populations. Knowing what the impacts have been and what they will be in the future can aid ecologists, farmers, policy makers, industry, and urban planners in formulating adaptation strategies.

In **Unit III: Climate Change Impact**, we explore in detail the impacts of climate change on different sectors: ice cover, the water cycle and weather, oceans and coasts, agriculture, forest cover, wildlife, and human health. In 2014, a team of 300 expert scientists from NOAA’s Climatic Data Center, NASA, and other ocean and climate research institutes around the world put together the [Third National Climate Assessment](https://www.globalchange.gov/nca3).* This report documents twelve key findings of their research on our changing climate. This unit and the associated web-based application resources draw heavily from this National Climate Assessment. Additional scientific data comes from the National Snow and Ice Data Center, NASA, NOAA, USDA, and National Geographic.

* This report is updated periodically. The Fourth National Climate Assessment, released on November 23, 2018, can be found here: [https://www.globalchange.gov/nca4](https://www.globalchange.gov/nca4)