must therefore include some measures of this human impact and its relative contribution to the planet's overall carbon budget. Human activities are, as of 2014, adding about 10 gigatons of carbon per year to the atmosphere, primarily from burning of fossil fuels. This means that our anthrosphere is adding more net carbon to the atmosphere than any of the other Earth **systems [CCC-4]**. Humans annually emit roughly 135 times more carbon than volcanoes, which originally supplied Earth's early atmosphere with a rich concentration of CO_2 (Gerlach 2011). Students will build on this understanding of both the natural cycling of carbon and their own impact on the carbon cycle in the next instructional segment about global climate.

IS2 Earth and Space Sciences Instructional Segment 2: Climate

The topic of global climate change offers an excellent opportunity to explore the concept of planet Earth as a system (ESS2.A) and to apply science and engineering practices to a very important and highly visible societal issue. While the details of global climate change are complex and technical, the underlying science is fundamentally simple and has been known for a long time. The main ideas relate to

- the flows of energy into, within, and out of the Earth system;
- Earth's cycles of matter, especially the carbon cycle;
- the effects of human activities, especially the combustion of fossil fuels.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 2: CLIMATE

Guiding Questions

- What regulates weather and climate?
- What effects are humans having on the climate?

Performance Expectations

Students who demonstrate understanding can do the following:

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. [Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 2: CLIMATE

HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [*Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.*]

HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. [Clarification Statement: The carbon cycle is a property of the Earth system that arises from interactions among the hydrosphere, atmosphere, geosphere, and biosphere. Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.]

HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.* [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems. [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [*Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.*]

HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.* [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [*Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.*]

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 2: CLIMATE

The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

Highlighted Science and Engineering Practices	Highlighted Disciplinary Core Ideas	Highlighted Crosscutting Concepts
[SEP-1] Asking Questions and Defining Problems [SEP-2] Developing and Using Models [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-7] Engaging in Argument from Evidence	ESS1.B: Earth and the Solar System ESS2.A: Earth Materials and Systems ESS2.D: Weather and Climate ESS3.A: Natural Resources ESS3.D: Global Climate Change ETS1.A: Defining and Delimiting Engineering Problems ETS1.B: Developing Possible Solutions	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [CCC-7] Stability and Change Influence of Science, Engineering, and Technology on Society and the Natural World Connections to Nature of Science Science Addresses Questions About the Natural and Material World

Highlighted California Environmental Principles and Concepts:

Principle I The continuation and health of individual human lives and of human communities and societies depend on the health of the natural systems that provide essential goods and ecosystem services.

Principle II The long-term functioning and health of terrestrial, freshwater, coastal and marine ecosystems are influenced by their relationships with human societies.

Principle III Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

Principle IV The exchange of matter between natural systems and human societies affects the long-term functioning of both.

Principle V Decisions affecting resources and natural systems are based on a wide range of considerations and decision-making processes.

CA CCSS Math Connections: N-Q.1–3; MP.2, MP.4

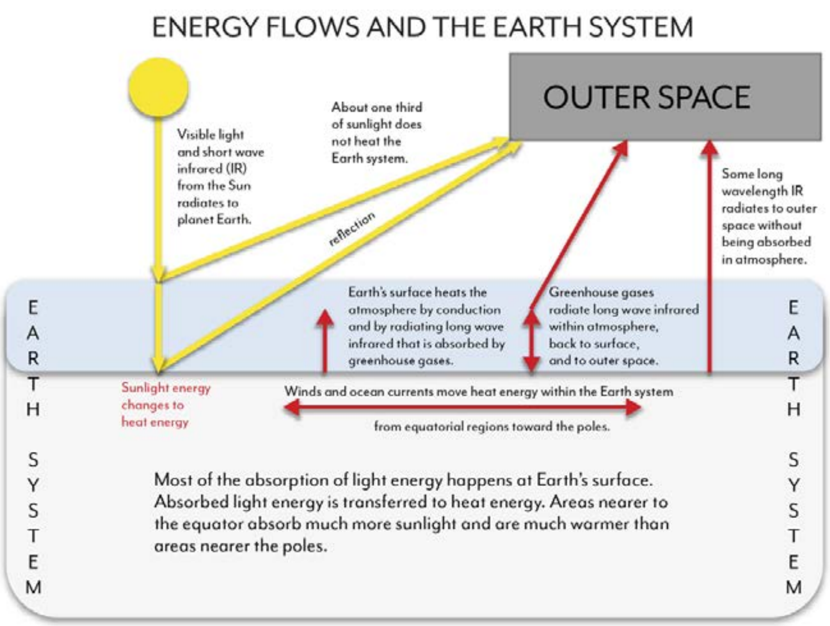
CA CCSS for ELA/Literacy Connections: SL.11–12.5; RST.11–12.1, 2, 7, 8

CA ELD Connections: ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

The performance expectations in this instructional segment build on significant work on DCIs related to weather and climate (ESS2.D) in the middle grades standards in which students learned that ocean and atmospheric currents are the equivalent of Earth's circulation system, transferring heat from the warm equator towards the cooler poles and bringing the planet closer to thermal balance (MS-ESS3-4). Students have also learned about the role that moving air masses play in determining short-term weather (MS-ESS2-5). They have been introduced to climate change and that global average temperatures have risen in the last century and have investigated possible causes (MS-ESS2-6). In this instructional segment they must delve into a more sophisticated understanding of Earth's **energy [CCC-5]** balance and its relationship to the global carbon **cycle [CCC-5]**.

The crosscutting concept of **systems [CCC-4]** is crucial to understanding Earth's climate. When scientists think about a system, they need to consider the **energy and matter [CCC-5]** that flow into or out of the system, as well as the inner workings of the system. In some systems, it is hard to decide where to draw the boundaries between what is considered inside the system and what is considered outside, but Earth's climate does not present such a challenge if we consider the entire planet as a system. Earth is somewhat isolated out in space, with relatively little matter entering or leaving the planet. **Energy [CCC-5]**, however, flows into and out of the Earth (figure 8.47).

Figure 8.47. Energy Flows in the Earth System



Energy flows in the Earth system, an illustration of a systems model. Diagram by Dr. Art Sussman, courtesy of WestEd.
Long description of Figure 8.47.

Students can make a conceptual model of Earth's energy budget using an analogy of the line for a ride at an amusement park. The constant stream of eager visitors arriving at the end of the line represents solar radiation. As visitors get on the ride at the front of the line, they act like energy radiating out into space. Earth's global average temperature measures the amount of heat stored internally in Earth's system and so it is like the number of people waiting in line at any given time. The line will remain the same length if people get on the ride as quickly as new people arrive at the end of the line. Earth's temperature will remain **stable [CCC-7]** as long as the energy input and output remain unchanged.

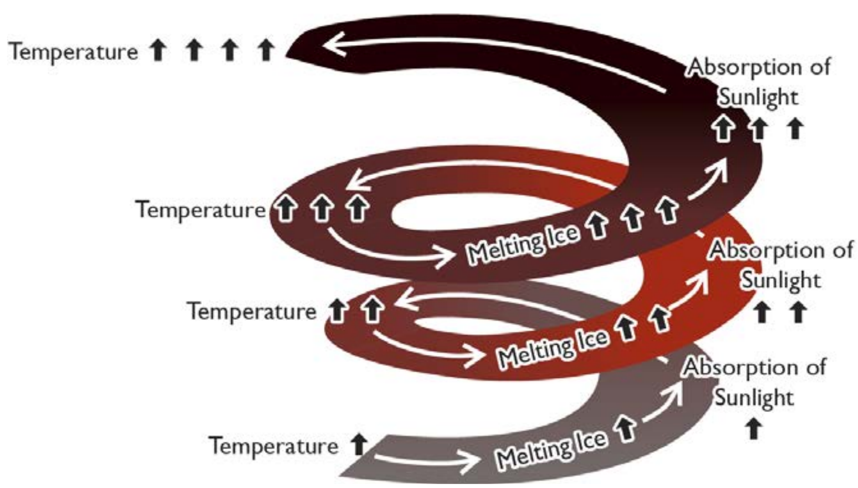
Earth's **energy [CCC-5]** input comes almost entirely from the Sun. While there is a small amount of radioactive decay within Earth's interior that generates heat, the flow of solar energy to Earth's surface is about 4,000 times greater than the flow of energy from Earth's interior to its surface. Relatively small changes in the solar input can result in an ice age or the melting of all of Earth's ice, much like the sudden arrival of a large group at an amusement ride can cause the line to quickly grow longer. The line will stabilize at this new length (without continuing to grow) as long as the influx of people returns back to its original rate. Planets can do the same thing, maintaining their temperature at a new value after a temporary disturbance.

Most of the sunlight that reaches Earth is absorbed and transformed to thermal **energy [CCC-5]**. If there were no atmosphere to hold that energy, it would radiate right back into space as infrared radiation (like an unpopular amusement park ride where people get on as soon as they arrive because there is no line). Gases in the atmosphere, such as CO_2, absorb infrared energy heading into space and **cause [CCC-2]** it to remain within the Earth system for a longer period of time. Because these gases have the same effect as a greenhouse where heat is trapped inside the system, gases like CO_2 are referred to as greenhouse gases. Calculations by scientists show that if Earth had no greenhouse gases, its surface temperature would be near 0°F (or -18°C) instead of its current value of a much warmer 59°F (15°C). The energy coming into the Earth is still balanced almost exactly by what is leaving the planet but there is enough heat trapped in the system to allow life to thrive (like the amusement park ride whose line is always the same length).

By increasing the amount of greenhouse gases in the atmosphere, human activities are increasing the greenhouse effect and warming Earth's climate. In a given year, less energy leaves Earth than arrives. It's like one of the seatbelts breaks on the amusement park ride and fewer people are able to get on the ride at a time. All of a sudden, the line gets longer and longer as new people arrive because people are not able to leave the line as quickly at the front. At the amusement park, this might lead to impatient children. On Earth, the imbalance in energy flows leads to an overall rise in average temperature.

Amusement parks and planets are **systems [CCC-4]** with complicated inner workings. When lines for one ride at an amusement park get too long, visitors inside the park may respond by going to another ride or park operators may add additional workers or cars to help move people through more quickly. Similar changes happen in Earth's system of systems. While the greenhouse effect seems like a simple **cause and effect [CCC-2]** relationship viewed from outside the system, interactions *within* the system can often give rise to more complicated chains of cause and effect referred to as *feedbacks*. Climate scientists are particularly concerned about feedback effects that could increase the amount and rate of global climate change. One example is that global warming is clearly reducing the amount of ice on our planet (figure 8.48). Glaciers around the world are shrinking in size and even disappearing. The amount of ice covering the ocean in summer and fall is also shrinking. As the ice melts, the surface beneath it is darker in color and absorbs more incoming sunlight. More absorption causes more heating, and this heating causes even more absorption of sunlight. This kind of feedback loop amplifies or reinforces the change, and the distinction between **cause and effect [CCC-2]** begins to blur as each effect causes more change. The clarification statements in the CA NGSS and many scientists use the term *positive feedback*, but this term should be replaced because it leads to confusion—many *reinforcing feedbacks* have very negative outcomes.

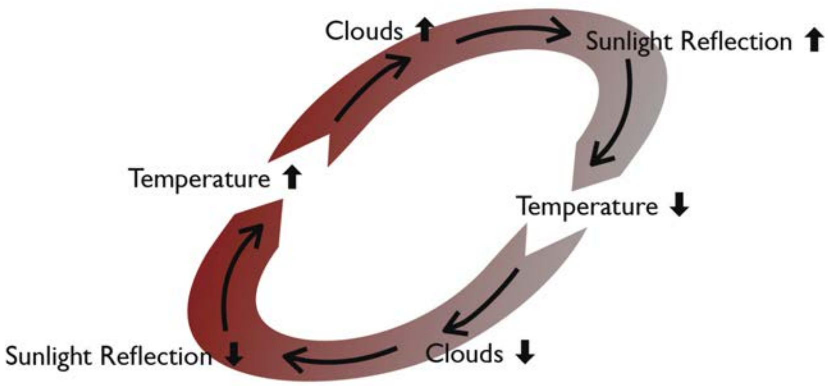
Figure 8.48. A Reinforcing Feedback in Earth's Climate



A reinforcing feedback in Earth's climate system. As the planet warms, more ice will melt, which will expose darker ground surfaces that absorb more sunlight, which will in turn make temperatures rise even more. Diagram by M. d'Alessio and A. Sussman.
Long description of Figure 8.48.

A *counterbalancing feedback loop* reduces the amount of change (figure 8.49). For example, warmer temperatures cause more water to evaporate, which enables more clouds to form. Since clouds reflect sunlight back into space, more clouds cause more incoming solar energy to be reflected before it has a chance to be absorbed by the planet. This causes decreasing global temperatures. More warming could cause more cloud formation and reflection, which would then lead to less warming again.[7] These changes are opposite and can balance each other out.

Figure 8.49. A Counterbalancing Feedback in Earth's Climate System



Temperature changes cause changes to the number of clouds because of evaporation. Clouds, in turn, reflect light. Diagram by M. d'Alessio and A. Sussman.
[Long description of Figure 8.49.](#)

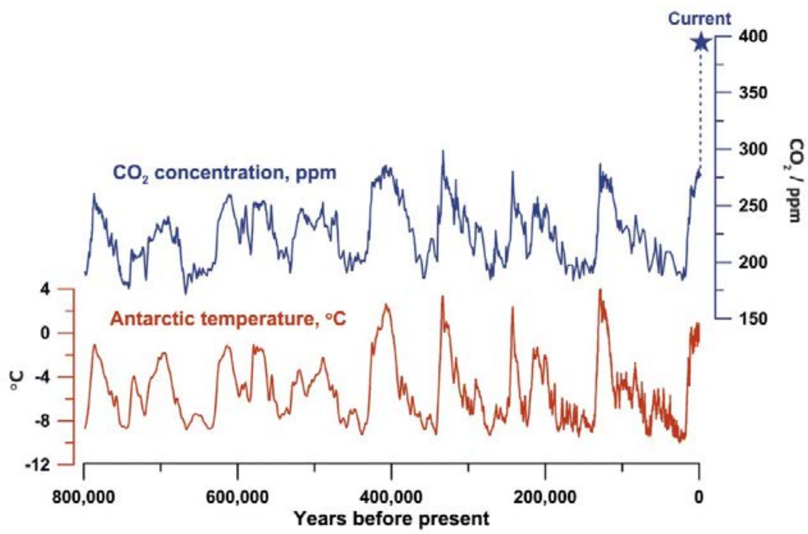
Scientists discover these complicated interactions between different components of Earth's **systems [CCC-4]** by looking for trends and **patterns [CCC-1]** in climate data. The CA NGSS have a strong emphasis on data analysis, especially in the sections related to weather and climate:

> An important aspect of Earth and space science involves making inferences about events in Earth's history based on a data record that is increasingly incomplete th[e] farther you go back in time … . Students can understand the analysis and interpretation of different kinds of geoscience data [that] allow students to construct explanations for the many factors that drive climate change over a wide range of time scales. (NGSS Lead States 2013c)

7. Even though this example describes a counterbalancing feedback involving clouds, clouds are also involved in a reinforcing feedback where they trap more heat, causing more evaporation, and more clouds that trap more heat. Both of these mechanisms occur on Earth. The question researchers are currently trying to answer is, "Which feedback loop is more powerful, reinforcing or counterbalancing?" **Cause and effect [CCC-2]** gets very complicated in the Earth system.

Some of the strongest **evidence [SEP-7]** about our changing climate comes from ice-core records (figure 8.50). As snow accumulates over time in glaciers around the globe, it traps both the water that recently fell as precipitation and air bubbles. These air bubbles act as tiny time capsules that allow scientists to study actual samples of the ancient atmosphere. Since snow and ice build up seasonally, the timing of each layer of ice and its trapped air bubbles can be counted like tree rings. Scientists make detailed chemical analyses of the water to reconstruct the global average temperature.[8]

Figure 8.50. Temperature and Carbon Dioxide Over the Last 800,000 Years



Source: The Royal Society 2014
Long description of Figure 8.50.

The temperature record from the last half-million years reveals some dramatic **patterns [CCC-1]** as temperatures go up and down with a periodicity of about 100,000 years, each low temperature an ice age (NOAA 2015). When students examine such data, they should be able to **ask questions [SEP-1]** about which parts of the climate **system [CCC-4]** might have **caused [CCC-2]** these changes. If students compare temperature reconstructions with reconstructions of the amount of **energy [CCC-5]** received from the Sun (which varies as the Earth's orbit wobbles and the Sun's energy output changes cyclically over time), they will discover that the data sets have a similar **pattern [CCC-1]**: many warm periods in the ice core data correspond to periods of higher solar energy input (EP&C II). This seems quite

8. Details of how this isotopic analysis provides a proxy for global temperature is beyond the scope of high school performance expectations, but is a fascinating example of physics, chemistry, and Earth science working together.

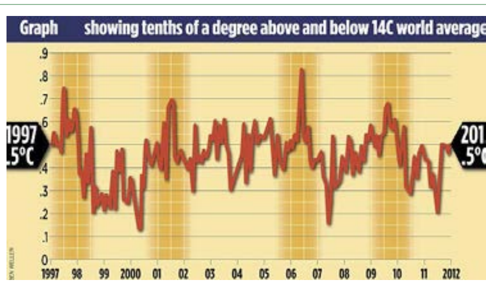
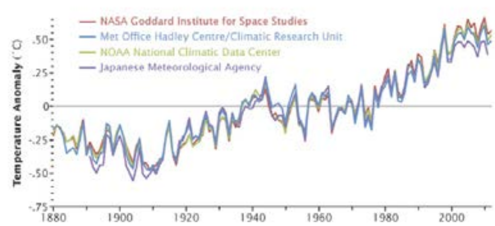
reasonable because the Sun's input should influence our temperature. However, there are also time intervals where the Earth was hot that do not correspond to high solar energy. The **pattern [CCC-1]** in the history of the concentration of CO_2 in Earth's atmosphere and temperatures is very similar; the two are highly correlated. This correlation is a key piece of **evidence [SEP-7]** that CO_2 also plays a role in affecting Earth's temperature. In a classroom, this correlation can motivate a discussion of Earth's energy budget and the greenhouse effect.

Earth and Space Science Snapshot 8.9: Letters to the Editor and Evaluating Climate Change Graphs

Anchoring phenomenon: Two news stories about the same scientific research have different headlines and are supported by different graphs of the same data set.

Earlier in the year, Ms. Q had her students read about how to **evaluate [SEP-8]** the scientific arguments made in media sources using a checklist called the Science Toolkit (see UC Museum of Paleontology at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link48). To begin this unit, she had them read two Internet articles with radically different headlines that each used a graph of global temperature as **evidence [SEP-7]**. Students worked in pairs to evaluate the two articles based on the criteria outlined in the Science Toolkit. As Ms. Q walked around the room, Fernando asked her about the sources: “This article is from NASA, but what is the Weekly Star? Who wrote it?” She encouraged him to do a quick internet search about the newspaper’s editorial board. A bit later, Cynthia mentioned that both articles use graphs (figure 8.51), but they look totally different.

Figure 8.51. Two Representations of the Same Data Set by Different Sources

Global warming stopped 16 years ago, reveals Met Office report quietly released ... and here is the chart to prove it	Long-Term Global Warming Trend Continues
	
Weekly Star (fictitious)	NASA’s Earth Observatory 2013

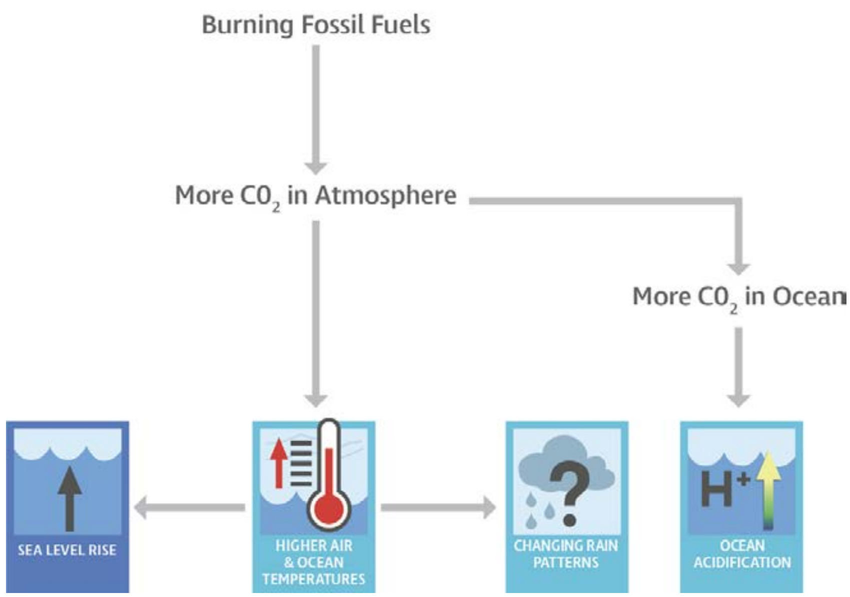
Long description of Figure 8.51.

Ms. Q then asked the whole class to discuss the graphs and construct an **argument [SEP-7]** about which graph contained stronger **evidence [SEP-7]**. Ali noticed that one graph included a much longer span of time, “and climate is supposed to be a long-term thing.” Jenni said, “This graph has four lines from scientists all over the world that all show the same ups and downs. That shows science is repeatable, and I like that.” To conclude the lesson, students wrote letters to the editor in response to the *Weekly Star* article articulating their **argument [SEP-7]**.

In the CA NGSS, students combine their general understanding with **computational thinking [SEP-5]** by using simple computer simulations (see PhET, *The Greenhouse Effect* at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link49) to model the **flow of energy [CCC-5]** into and out of the Earth and the role that CO_2 and other greenhouse gases play in that process (HS-ESS2-4). Scientists use simulators of Earth's climate called global climate **models [SEP-2]** (GCMs) that are much more detailed and include many other processes and interactions between Earth **systems [CCC-4]**. The assessment boundary of HS-ESS3-6 states that students should not be required to run their own **models [SEP-2]**, though simplified versions of GCMs exist for educational purposes (see Columbia University, Educational Global Climate Modeling Web site at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link50 and Java Climate Model at https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link51). The advantage of these models is that they enable students to turn on and off different parts of the Earth system to see how they affect the climate. For example, students can compare a model of the Earth without the biosphere to a model that includes the biosphere. As CO_2 increases in the atmosphere, plant growth decreases the impact of global warming (a counterbalancing feedback). Comparing the predictions of a computer model that allows ice to melt with one in which ice is not allowed to melt is another form of **analyzing and interpreting data [SEP-4]** and can help build students' mental **models [SEP-2]** of the climate system. **Models [SEP-2]**, as defined in the CA NGSS, represent a system that allows for predicting outcomes, so the output of a computational model can sometimes be more useful at anticipating the future than simply examining historical data. Ultimately, students need to be able to communicate their mental model by describing specific feedbacks in the Earth system using an argument (HS-ESS2-2). In a classroom, various student teams could examine different elements of an Earth system using teacher-provided results of model runs or creating their own with educational GCMs. They could then compile brief reports to share with their classmates about the **effects [CCC-2]** of these different processes on global climate.

Another crucial observation about Earth's climate is that the concentration of CO_2 and other greenhouse gases in our atmosphere has been growing steadily since the dawn of the industrial era. Students should be able to make connections to the previous instructional segment and know that the vast majority of this increase comes from humans' extraction and combustion of fossil fuels. GCMs allow scientists and students to see how the climate is expected to change as greenhouse gases trap more energy in the atmosphere. Because of the linkages between different components of Earth's **systems [CCC-4]**, these impacts extend to all of Earth's systems. Figure 8.52 shows a few of these linkages. In a classroom, different student groups could **obtain information [SEP-8]** from library and Internet resources to construct a report on the impact predicted for different parts of the world so that the class as a whole could create a product to share with the rest of their school that summarizes the global impacts (HS-ESS3-6).

Figure 8.52. Cause and Effect Chains Illustrate How Human Activities Affect Natural Systems



One example of how humans affect the climate, which impacts all parts of Earth's systems. Illustration by Dr. Art Sussman, WestEd, and Lisa Rosenthal, WGBH.
Long description of Figure 8.52.

The remaining instructional segments in this course **investigate [SEP-3]** different Earth **systems [CCC-4]** and their interactions. By placing climate change early in the course, teachers can use climate impacts in California as a common thread that highlights the interdependence of Earth's systems (ESS2.A). This document describes specific climate impacts in each of the subsequent instructional segments.

EEI Curriculum units—*The Life and Times of Carbon* and *The Greenhouse Effect on Natural Systems* (https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link52 and https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link53)—explore human practices that can influence the global carbon cycle and how human activities affect quantities of greenhouse gases. These units can be used in conjunction with this instructional segment to provide materials that examine EP&Cs III and IV.

Engineering Connection: Evaluating Renewable Energy Options

Ultimately, any discussion of climate change should begin to explore technological solutions that could reduce emissions of greenhouse gases. In a classroom, students can calculate their own carbon footprints to further understand how they contribute to the human impacts on the global carbon cycle. They can explore renewable energy options and debate the pros and cons of each possible energy source for meeting society's needs (National Energy Education Development Project 2012b) (HS-ESS3-2, HS-ETS1-1). They can complete the project by creating another summary product for their school that **communicates [SEP-8]** some steps that individuals could take to reduce their impact on the climate system, or recommend broader actions that their school and community could take that will have an even larger effect.

IS3 Earth and Space Sciences Instructional Segment 3: Mountains, Valleys, and Coasts

Earth scientists look at landscape and **ask questions [SEP-1]** about the processes that shaped it and the specific sequence of events in the past when those processes occurred. Scientists **plan and carry out investigations [SEP-3]** to answer those questions, but investigations in Earth and space science cannot always take the same experimental form with the testing of hypotheses as they might in analytical chemistry or experimental physics. Many Earth processes take millions of years and cover thousands of miles of area occuring too slowly and at too big a scale to reproduce in a lab. Geologists often refer to the Earth as their natural laboratory, but they are only permitted to look at the final result of its ancient experiments (Earth's present-day landscape). These investigations often begin when Earth scientists make careful observations of what the Earth looks like today and then try to reproduce similar features in small-scale laboratory experiments or computer simulations.