STAR★net

Hands-on

Tested & Approved STEM Activities

EARTH: ARTISTICALLY BALANCED

Activity Guide

STAR★net
Science-Technology Activities & Resources For Libraries

A product of the Science-Technology Activities and Resources for Libraries (*STAR_Net*) program.
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Developed by the Lunar and Planetary Institute/Universities Space Research Association
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EARTH: ARTISTICALLY BALANCED

Overview

Teens depict the science behind Earth's climate system as art, which may be created on a large scale and displayed at the library or made on a smaller scale to take home. First, they interact with a climate scientist to unravel, on a very basic level, the complexities of Earth's climate system (specific suggestions for connecting with climate scientists are provided). Then, the teens categorize the various influences that either warm or cool Earth's climate, including those from both natural and human sources. Next, they work together or independently to create a three-dimensional artistic representation of these influences, balanced on a mobile-style work of art. Teens leave the program with an understanding of the natural and human-influenced drivers of climate change and a message of hope and steps, both small- and large-scale, for taking action at home and in their communities. This adaptable activity may be undertaken in, with small-scale artwork as the final product, or extended as a series of meetings to create large-scale artwork.

Activity Time

1 ½ hours (for small-scale artwork) to several meetings (for large-scale artwork)

Intended Audience

Teens ages 14-18

Type of Program

☑Facilitated hands-on experience
☐Station, presented in combination with related activities
☐Passive program (with modifications)
☐Demonstration by facilitator

What's the Point?

- The global environment changes - and is changed by - our community's local environment.
- Earth's systems interact over long-term scales to determine our *community's* future environment.
- Earth's average global temperature is a delicate balance of many interrelated factors.
- The Sun is the source of Earth's warmth, but the amount of sunlight alone does not account for Earth's average global temperature.
- Several natural factors serve to warm Earth. Heat-trapping gases moderate Earth's surface temperatures. Without them, it would be too cold for life as we know it to exist. Certain types of clouds (which hold energy near Earth's surface) and darker surfaces (such as oceans and forests) are also natural warming influences.

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- Several natural factors serve to cool Earth and balance the effects of warming by heat-trapping gases: white snow and ice, particles added to the atmosphere by volcanic eruptions, and certain types of clouds reflect some of the Sun's energy; the ocean takes up heat and carbon dioxide, a heat-trapping gas, from the atmosphere. Life can also reduce the amount of carbon dioxide in the atmosphere, such as when forests expand.
- Carbon dioxide levels in our atmosphere are increasing, mainly from human activities.
- Earth's average temperatures are rising.
- Heat-trapping gases come from both natural and human sources. Volcanos and bacteria in natural wetlands are natural sources of heat-trapping gases. Other sources include our farm animals, deforestation, the production of cement, factories, the power plants that supply electricity to our homes and schools by burning fossil fuels, and cars.

Facility Needs

- ☐ Areas where teams of three to four children can sit and develop artwork
- ☐ Optional: large space with a high ceiling from which artwork could be suspended
- ☐ Optional: teen advisory board
- ☐ Optional: computer, projector, and access to the Internet

Materials

For the Facilitator

- ☐ Suggested resources for preparing a climate scientist to co-facilitate the activity, listed in "Research-based Approaches for Effective Engagement in Climate Change" (below)
- ☐ *Background Information* (below)

For Each Group of 10 Teens

- ☐ Optional: 1 set of "table topics" (below), printed and cut into strips
- ☐ 3 sets of *Earth's Climate Cards* (below) depicting the warming and cooling influences on Earth's climate, which are made up of two subsets:
    - ☐ *Nature's Balance Cards*
    - ☐ *Human Influences Cards*
- ☐ Large-scale art supplies
    - ☐ Discarded electronics, such as motherboards, cell phones, remotes, light bulbs, or small appliances
    - ☐ Discarded motor vehicle parts, such as steering wheels or hubcaps

OR

- ☐ Small-scale art supplies
    - ☐ 20 (12" × ¼") rigid rods, such as aluminum tubes or wooden dowels from a craft store
    - ☐ 4 balls of string
    - ☐ 10 (1¼") low-density Styrofoam© ball
    - ☐ 20 (¾" diameter or smaller) jingle bells

- ☐ 20 eraser caps (such as Paper Mate 73015 Arrowhead Eraser Caps)
- ☐ 3 (100 ct.) packages of ornament hangers
- ☐ 3 (100 ct.) packages of steel nuts (to serve as weights)
- ☐ 10 toothpicks
- ☐ Optional: material into which steel nuts can be imbedded, such as sponge pieces or (reused) Styrofoam peanuts
- ☐ 20 sheets of paper, preferably reused or made from 100% recycled paper
- ☐ Scissors
- ☐ Optional: provide old magazines for the teens to cut out images of various warming and cooling influences to hang on their mobiles

Supporting Media

Books

We Are the Weather Makers: The History of Climate Change
Sally M. Walker and Tim Flannery, Candlewick, 2010, ISBN: 978-0763646561
This teen-friendly book reveals the facts to audiences, ages 14 and up, of his scientific research about what we know about global warming, what could happen in the future, and what we can do to make a difference.

The Green Teen: The Eco-Friendly Teen's Guide to Saving the Planet
Jenn Savedge, New Society Publishers, 2009, ISBN: 0865716498
This guide offers helpful tips and ideas for working toward environmental stewardship. Appropriate for ages 14 and up.

Cooler Smarter: Practical Steps for Low-Carbon Living: Expert Advice from the Union of Concerned Scientists
Seth Shulman, Union of Concerned Scientists, et al, Island Press, 2012, ISBN: 161091192X
The Union of Concerned Scientists provides recommendations for how individual actions really can make a positive difference toward combatting global warming. Appropriate for ages 17 and up.

Interactive Websites

Climate Kids: NASA's Eyes on the Earth
http://climate.nasa.gov/kids/
Children ages 8 to 13 may enjoy the information, games, and videos on this award-winning site.

Bill Nye's Climate Lab
www.billsclimatelab.org
Children ages 9 to 13 may enjoy the fun missions and activities — and learn about ways to save energy — on this interactive website.

National Geographic's Global Warming Effects Map
http://environment.nationalgeographic.com/environment/global-warming/gw-impacts-interactive
This interactive world map shows likely effects due to global warming.

Videos

Climate Change, Wildlife & Wildlands
http://www.globalchange.gov/browse/educators/wildlife-wildlands-toolkit/video
This video offers explanations on climate change and how it impacts wildlife and their habitats in the U.S. High-school students and climate professionals are feature. Appropriate for ages 14 and up.

The Carbon Crisis in 90 Seconds
www.youtube.com/watch?v=85TQHzS88L4
NASA Earth Scientist Peter Griffith clearly and simply explains the difference between the "new" carbon that we eat every day and the "old" carbon that we burn as fossil fuels.

Young Voices for the Planet
http://youngvoicesonclimatechange.com
Ages 11 and up may benefit from the information, ideas, and inspiration from watching other young people make a difference in the "Young Voices for the Planet" series of films. The website offers suggestions for replicating their efforts.

Research-based Approaches for Effective Engagement in Climate Change

The following are suggested resources for climate change educators and scientists.

Public engagement with climate change: what do we know and where do we go from here?
Whitmarsh, L. E., O'Neill, S. and Lorenzoni, I. (2013). *International Journal of Media & Cultural Politics*, 9(1), 7-25
http://orca.cf.ac.uk/52547.

Why Frames Matter for Public Engagement
Nisbet, M. 2009. Communicating Climate Change. *Environment, 51* (2), 514-518.
www.environmentmagazine.org/Archives/Back%20Issues/March-April%202009/Nisbet-full.html.

Global Warming's Six Americas (2011)
Yale Forum on Climate Change & The Media, 2011
http://environment.yale.edu/climate-communication
This brief video provides an overview of the results of an ongoing public survey project tracking American attitudes about and knowledge of climate change.

Preparation

Six months before the activity

- Identify a climate scientist, preferably from a nearby area, who is willing to serve as an advisor for this program. (The teens may relate best to a young, enthusiastic scientist, and young women will especially benefit from seeing a successful female scientist.) Invite the scientist to bring his or her expertise in a 30-minute *discussion* (rather than lecture format) to teens. He or she will continue to advise the teens and (gently) critique their initial designs and the art pieces as they are built for scientific accuracy. Outline the types of assistance you are looking for, and stress that the teens will respond better to basic information, personal stories, and analogies than data. Specifically request that the format be a discussion, with the scientist interacting with teens and responding to teen-generated ideas, rather than lecturing:

- Briefly describe how invisible infrared radiation is emitted by the Earth as it is heated by sunlight, and explain the role of heat-trapping gases in capturing that energy to influence Earth's climate.
- Name the major factors that interact to create Earth's climate.
- Answer questions about the validity of climate science in the midst of confusing information through political debates and the media.
- Tell their personal story about becoming interested in science as a career.
- Leave the teens with a positive message of hope and courses of action (both small- and large-scale).
- Assist the teens as they create artistic representations of climate models, which will be used to engage their families or the broader community in thinking about Earth's systems and climate change.

Discuss some ideas for props that you might be able to have on hand for the discussion. Encourage the use of props for demonstrations in place of a computer-based presentation. Offer the suggested resources listed in the "Research-based Approaches for Effective Engagement in Climate Change" section.

Join the *STAR_Net* Project's Community of Practice at http://community.starnetlibraries.org and identify a climate scientist through the network there.

- If desired, invite a high school environmental science teacher to co-facilitate the activity and assist in mentoring the teens as they design and build their artwork.
- If possible, involve your teen advisory board in the planning process. Work together to bring together library staff and space, teen creativity, and materials from the community.
- Determine whether you have the space for a large-scale artwork display, or if you would like the teens to take home smaller-sized creations.
- Determine the time commitment you would like to request from the audience. Teens may undertake Parts 1 through 4 in one session with small-scale artwork as the final product. Part 4 may be undertaken as a separate meeting, or series of meetings, for large-scale projects.
- Consider hosting a materials drive prior to the event. Invite the community to contribute unwanted electronics and other materials for the teens to incorporate into their artwork.
- If desired, plan an "opening night" event to showcase the artwork to the community after the projects are completed and displayed.
- Prepare and distribute publicity materials for programs based on this activity. If possible, build on the children's knowledge by offering multiple science, technology, engineering, art, and mathematics (STEAM) programs. See the STAR_Net resources listed at http://community.starnetlibraries.org/resources for ideas.
- Review the *Background Information*.
- Become familiar with one or more resources for preparing to engage the community on the potentially controversial topic of human influences on global climate.

The day before the activity

- If desired, distribute conversation starters, cut from the sheet of "table topics," to help the teens get to know each other as they enter the room.

- Print copies of *Earth's Climate Cards*, preferably on card stock, and cut them out along the borders. Shuffle each set so that the "Warmer Cards" and "Cooler Cards" are intermixed.
- Set out the art materials.

Activity

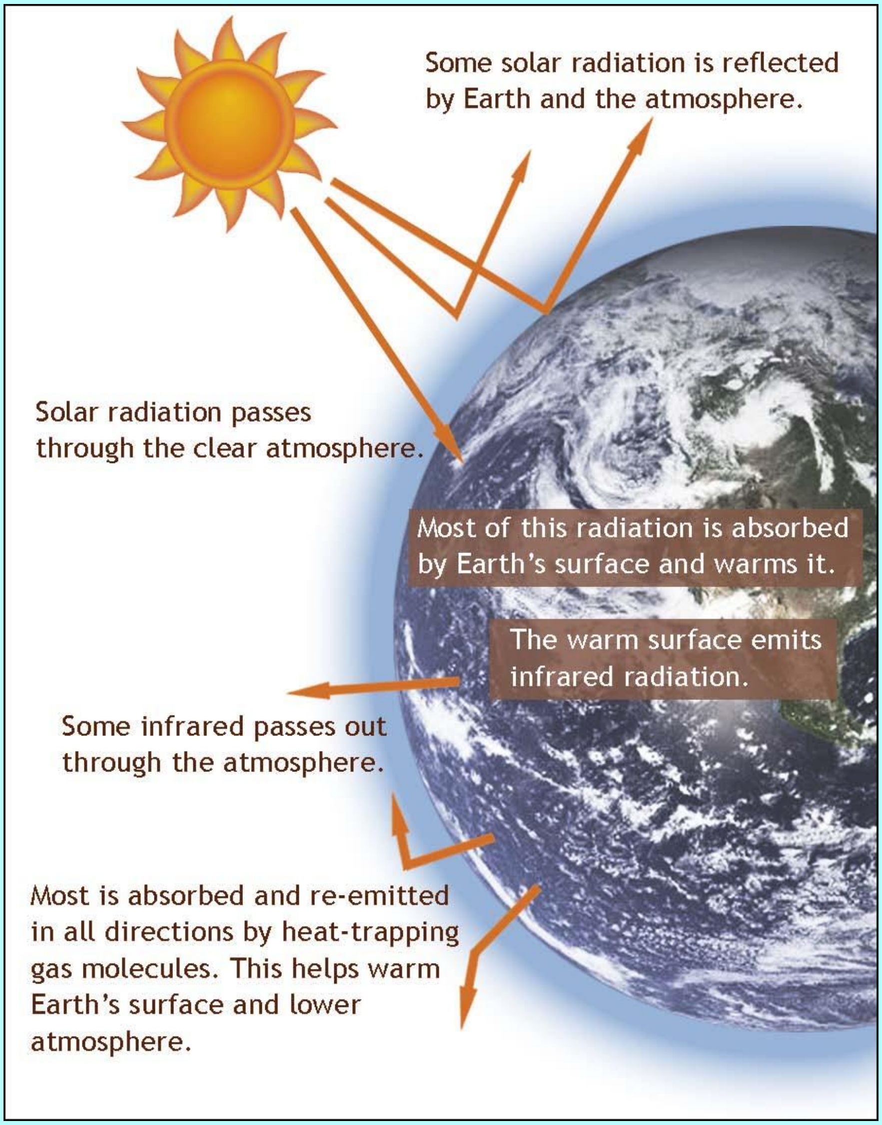
Part 1. Discover the scientific understanding of climate science through an open discussion, and prepare to incorporate the concepts into artwork.

1. **Optional, but strongly recommended: Have a discussion with a climate scientist.**

2. **Optional:** Watch ***Climate Change, Wildlife & Wildlands.***

3. **Summarize the factors that influence Earth's climate – or perhaps invite a co-facilitating environmental science teacher to do so:**
   - Most of Earth's energy comes from the Sun, but the Sun alone would give Earth a global average temperature of –2°F (–19°C). (Geothermal energy from the Earth's interior contributes less than 1% of our energy at the surface. Radioactive decay of elements and gravitational energy inside Earth add such a small amount of surface warming compared to the Sun that they can be ignored here.)
   - Because Earth also has heat-trapping gases that trap some of the Sun's energy, Earth's actual average temperature is 57°F (14°C). Earth is a comfortable place to live because volcanos and bacteria living in natural wetlands have produced heat-trapping gases like carbon dioxide (CO_2), water vapor, and methane. Those gases prevent some energy emitted by the Sun-warmed surface of Earth from escaping into space. Certain types of clouds also hold energy near Earth's surface.

Earth's warm global climate is created by a natural greenhouse effect. The Sun's radiation is mainly in the visible range of the electromagnetic spectrum, and most of this high-energy light passes through the atmosphere to strike the Earth's surface and warm it. The warm surface gives off (re-emits) a lower-energy form of electromagnetic radiation that is invisible to our eyes: infrared radiation (IR). Unlike visible light, infrared radiation can be captured by heat-trapping gases in the Earth's atmosphere. Heat-trapping gas molecules re-emit the infrared radiation, and it is often absorbed by other heat-trapping gas molecules or the surface of the Earth. Through the greenhouse effect, heat-trapping gases prevent energy emitted by the Sun-warmed surface of Earth from escaping into space, thus creating a much warmer climate than would occur without them. The addition of heat-trapping gases through human activities contributes to global warming beyond natural levels.



Note that the Earth, Earth's atmosphere, and Sun are not drawn to scale.
Credit: Lunar and Planetary Institute.

- Other factors help keep Earth's temperatures balanced with their cooling influence. Some types of clouds, particles added to the atmosphere by volcanic eruptions, and white ice and snow reflect the Sun's light back into space. (If necessary, remind the teens of the difference in temperature they experience when walking on a light-colored sidewalk compared to dark asphalt.) Some living things use up carbon dioxide. For example, expanding forests use carbon dioxide to make their own food, which they convert into hard trunks and swaying leaves.

Plants take up carbon dioxide during the day, but they also respire – returning some carbon dioxide back to the atmosphere. When plants decay, their trunks and leaves are broken down and carbon dioxide is released.

At times, life can collectively serve to take up carbon dioxide, such as when forests expand.

- Scientists are measuring an increase in the amount of CO_2 and other heat-trapping gases in the atmosphere. Scientists have also been measuring Earth's temperatures and they've found that the global average temperature has risen over 1°F in the last 100 years.

Earth's temperatures are shaped by various natural factors that interact to warm or cool the climate. Changes in Earth's orbit, in addition to less influential changes in the Sun's intensity, outgassing from volcanos and other sources, and changes in ocean currents, have resulted in long-term cycles of cooling and warming. While these influences are still not fully understood, the majority of scientists agree that their effects are secondary compared to the contributions of human activities. Changes in solar intensity and volcanos produced most of the warming from preindustrial times to 1950, but are not implicated in the current global change. For instance, when Mt. Pinatubo erupted in 1991, the global average temperature dropped by 0.9°F (0.5°C) as volcanic particles in the atmosphere reflected some of the Sun's energy. (The volcano also released carbon dioxide, a warming agent, but this addition is thought to be small compared to human contributions.) Studies by the National Center for Atmospheric Research (NCAR) attribute less than one-third of the current warming to changes in the Sun's intensity.

Earth's global surface temperatures are rising at an unusually rapid rate. The past century has seen an increase of a little more than 1°F (0.74°C). Today's global temperatures are the highest of the past 500 years, perhaps even for the past millennium. The scientific consensus is that the warming is due to heat-trapping gases emitted as a result of human activities.

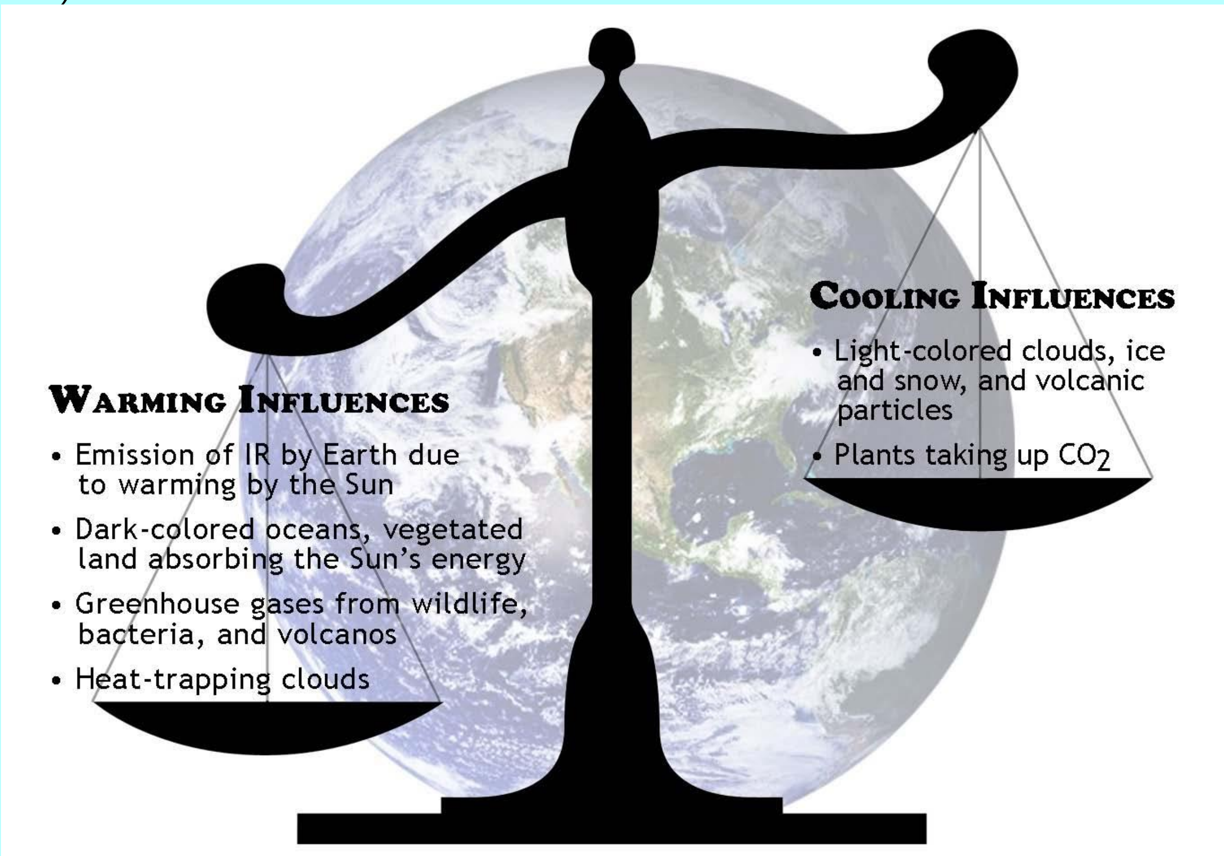
Ice cores and other data provide evidence that the amount of carbon dioxide in Earth's atmosphere, and Earth's temperature, have fluctuated in a cyclical pattern through time. These cycles of cooling and warming are natural, and triggered, over the last 750,000 years, primarily by cyclic changes in Earth's orbit. During that time frame, we have experienced alternating periods of warmth and periods of glaciations. However, at present, the levels of carbon dioxide in the atmosphere far exceed even the highest levels of the past half-million years because of the additional heat-trapping gas contribution by human activity. Our global temperature is increasing in response to this added heat-trapping gas.

Part 2. Determine what factors influence Earth's climate.

4. **Hand out the *Nature's Balance Cards* and have the teens sort them into groups, creating one pile of warming influences on Earth's climate and another of cooling influences.** Ask them to consider whether any of the influences are dependent on an influence depicted on another card.

Earth's global temperatures at any one time are a result of the balance between various natural warming and cooling influences. Thanks to these influences, Earth's temperatures are tipped enough to the "warm side" of the balance to have an average temperature near about 57°F

(14ºC).



Credit: Lunar and Planetary Institute.

5. **Hand out the *Human Influences Cards* and have the teens add these to the appropriate piles.**

6. **Discuss the "cooling" and "warming" piles and why the teens placed each card in that pile.**
   - Warming influences:
     - "Heat-trapping Clouds"
     - "Carbon Dioxide from Volcanos"
     - "Bacteria in Wetlands Releasing Gas"
     - "Darker Surfaces Like Oceans and Forests"
     - "Power Plants Burning Fossil Fuels to Make Electricity for Our Homes, Schools, and Stores"
     - "Heat-trapping Gases Released by Driving"
     - "Heat-trapping Gases Released in the Production of Food"
     - "Heat-trapping Gases Released in Making Our Lives Comfortable and Fun"
   - Cooling influences:
     - "Reflective Clouds"
     - "Reflective Snow and Ice"
     - "Reflective Volcanic Particles"
     - "Plants, Soil, and Oceans Taking Up Carbon"

- Do we need heat-trapping gases? *Yes, they trap the Sun's energy and provide the warmth that makes life possible.*
- Are white, fluffy clouds more like a reflective sidewalk or energy-absorbing asphalt? White snow and ice? Light gray clouds of particles from volcanos? *Reflective sidewalk.*
- Do we need cooling influences, like trees and ice and snow? *Yes, they keep us from getting too hot.*
- Ice and snow act as a cooling influence. What will happen to them as the Earth's temperatures warm? *They will melt.*

Clouds can have a cooling or warming effect, depending on their height (and therefore, composition) in the atmosphere. Low- and mid-level clouds are thick and reflect sunlight. They are made up of tiny water droplets (and mid-level clouds also have tiny ice crystals), which are not particularly effective at absorbing energy. High-level clouds are made of ice crystals, which absorb more energy than water droplets. They are also thin and wispy, and they allow sunlight to pass through to reach Earth's surface.

Furthermore, clouds that occur during the day in the summer tend to have a cooling effect. Clouds occurring at night have a warming effect.

Scientists are especially concerned about Earth's polar regions, where there is a lot of ice and snow. Ice is melting at Earth's poles and at high elevations and scientists are concerned about what the loss of that cooling influence will do to Earth's temperature balance.

- What are some warming influences that are caused by human activities? *Power plants burning fossil fuels to make electricity; fertilizers, which are used to grow our food, breaking down into gas in the soil; cars and trucks burning gasoline; gas released by farm animals as they digest grass and grain.*
- What do we use power plants for? *They generate the electricity we get through outlets at home, at school, and in stores. Electricity powers our lights, air conditioners, computers, and other appliances.*

7. **Brainstorm actions that the teens are inspired to take to slow human contributions to climate change.** Draw attention to the fact that while creating things like t-shirts and golf courses certainly has an impact on the overall balance of Earth's climate, our driving habits and energy use as well as food production have a much greater impact. Activities such as "Reduce, Reuse, and Recycle" help in a small way, but it will take a concerted effort in changing how we use fossil fuels and grow our food to make progress. Point out that their mission during this activity is to engage their communities about this issue through art; they have the opportunity here to get the conversation going!
   - What changes can you make in your life to help improve the balance of climate influences?
   - Could you use less of the warming influences when you go home today? How? *Turn off lights and computers when no one's using them, walk, bike, or take public transportation* ***— where it's safe to do so —*** *or carpool instead of asking for a ride in the car.*

Part 3. Design and construct a mobile-style work of art that represents Earth's climate system. If teens are creating large-scale artwork, have them first sketch their ideas on paper and present them with the scientist present. Construct the artwork during a series of meetings, which may be held with or without the scientist present. If the teens are creating small-scale art, combine steps 3 and 4 to include a critique of the finished product, rather than the paper sketch. Tell them that their three-dimensional models will depict the concepts explored through scientific computer simulations of climate.

8. **Challenge the teens to plan how to represent Earth's complex climate system as art.** If the teens are creating large-scale projects, be clear about the space limitations for display.
   - How will you depict Earth's natural climate system, with the natural warming influences creating the balanced climate that existed up until about 100 years ago?
   - How will you incorporate human influences on climate?
   - What words and images can you use that all library visitors or your family could easily identify with?
   - What materials will you use to represent each of the influences on Earth's climate? Can you identify second-hand items to create "recycled" artwork?

9. **Point out some examples of mobiles or other balances, such as**

   Explore! Ice Worlds! Balancing Act
   www.lpi.usra.edu/education/explore/ice/activities/ice_earth/balancingAct

   "Balancing Toy," Toys from Trash, by Arvind Gupta
   www.arvindguptatoys.com/toys/balancingtoy.html

10. **Have each team or individual present a design to the group and remind everyone to provide constructive criticism as well as positive comments.** Have the presenters detail what materials they will use and how they will arrange them. Remind them to consider that weights may be necessary to balance the mobile. Request that the scientist provide feedback about how the science is depicted.
    - Is Earth's climate system accurately represented, with the different factors on the proper side of the balance?
    - Is the art engaging?
    - Do you think that parents or the community will understand the meaning behind the representation?
    - How will you demonstrate that humans have the creativity and resources to reduce our warming influences?
    - For large-scale projects, what ideas do you have for collecting the materials?

Part 4. Create, display, and celebrate the artwork!

- How will you use your art to inspire your friends and family to help slow human contributions to climate change?

Conclusion

Congratulate the teens on their engaging creations and artistic depictions of complex science. Encourage them to discuss their artwork — and the climate science it represents — with friends and family. Leave them with a message of hope and action: their creativity is essential in combatting climate change!

Correlation to Standards

National Science Education Standards

Grades 9-12

Science as Inquiry - Content Standard A

Understandings about Scientific Inquiry

- Scientists usually inquire about how physical, living, or designed systems function. Conceptual principles and knowledge guide scientific inquiries. Historical and current scientific knowledge influence the design and interpretation of investigations and the evaluation of proposed explanations made by other scientists.
- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.

Earth and Space Science - Content Standard D

Energy in the Earth System

- Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from the earth's original formation.
- The outward transfer of earth's internal heat drives convection circulation in the mantle that propels the plates comprising earth's surface across the face of the globe.
- Global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans.

Science and Technology - Content Standard E

Understandings about Science and Technology

- Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.

Science in Personal and Social Perspectives - Content Standard F

Environmental Quality

- Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients. Humans are changing many of these basic processes, and the changes may be detrimental to humans.
- Materials from human societies affect both physical and chemical cycles of the earth.
- Many factors influence environmental quality. Factors that students might investigate include population growth, resource use, population distribution, overconsumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth.

Natural and Human-induced Hazards

- Human activities can enhance potential for hazards. Acquisition of resources, urban growth, and waste disposal can accelerate rates of natural change.

Science and Technology in Local, National, and Global Challenges

- Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges.

History and Nature of Science - Content Standard G

Nature of Scientific Knowledge

- Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public. Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific.
- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. The core ideas of science such as the conservation of energy or the laws of motion have been subjected to a wide variety of confirmations and are therefore unlikely to change in the areas in which they have been tested. In areas where data or understanding are incomplete, such as the details of human evolution or questions surrounding global warming, new data may well lead to changes in current ideas or resolve current conflicts. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

EARTH: ARTISTICALLY BALANCED

Background Information

Your Home Is Changing

Earth's water, ice, air, and life will continue to interact over long-term scales, shaping the particular features of that place we each call home. In one important aspect, however, the global community of humans has proven influential enough to fundamentally alter the future of our planet. We continue to shape our environments at the local level by expanding our cities, changing forests to agricultural lands, and diverting water to suit our needs. Equally powerful are the changes we are making to the atmosphere as we burn fossil fuels, creating heat-trapping gases and tipping the Earth's balance toward a hot global climate.

Earth's Global Climate Is a Balancing Act

In the past, Earth's climate was shaped solely by natural factors. Astronomical factors determine how much of the Sun's energy reaches Earth, and the following changes occur over thousands of years: the shape of Earth's orbit around the Sun, Earth's "wobble," and the tilt of Earth's axis. Changes to the Earth itself, such as the configuration of the continents and changes in the way the atmosphere and ocean circulate, also influence global climate. Small components of Earth's atmosphere — introduced by life and volcanos — play a part. Earth's surface is highly reflective in areas covered by ice, snow, and low clouds, but it absorbs sunlight — much like asphalt on a summer's day — in areas covered by forests and ocean. Together, these many details determine how much energy Earth receives from the Sun, as well as how effective it is at keeping that energy from escaping back into space.

Luckily, these factors interact in such a way as to create a comfortable planet. The Sun is the source of Earth's surface warmth; it provides over 99% of Earth's energy. Alone, energy from the Sun is enough for our planet to reach a rather chilly -2°F (-19°C) or so. (Geothermal energy from the Earth's interior contributes less than 1% of our energy at the surface. Radioactive decay of elements and gravitational energy inside Earth add such a small amount of surface warming compared to the Sun that they will be ignored here.) It is thanks to a small percentage of all the tiny gas molecules in our atmosphere that Earth is warm enough to inhabit. Naturally-occurring heat-trapping gases prevent some energy emitted by the Sun-warmed surface of Earth from escaping into space. Volcanos and bacteria in wetlands are examples of natural producers of heat-trapping gases. Earth is warmed to an average temperature of about 57°F (14°C) by a natural process called the greenhouse effect.

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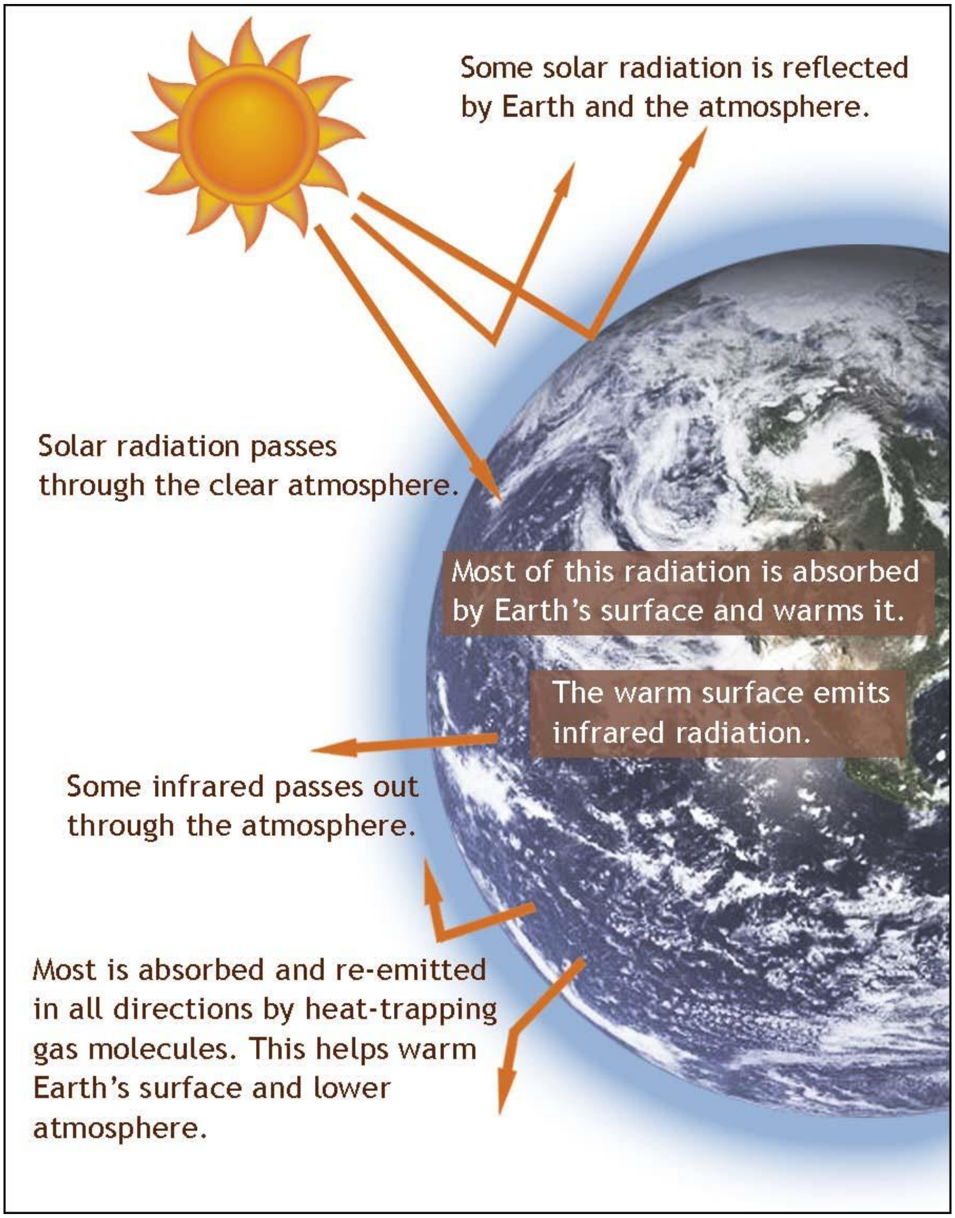


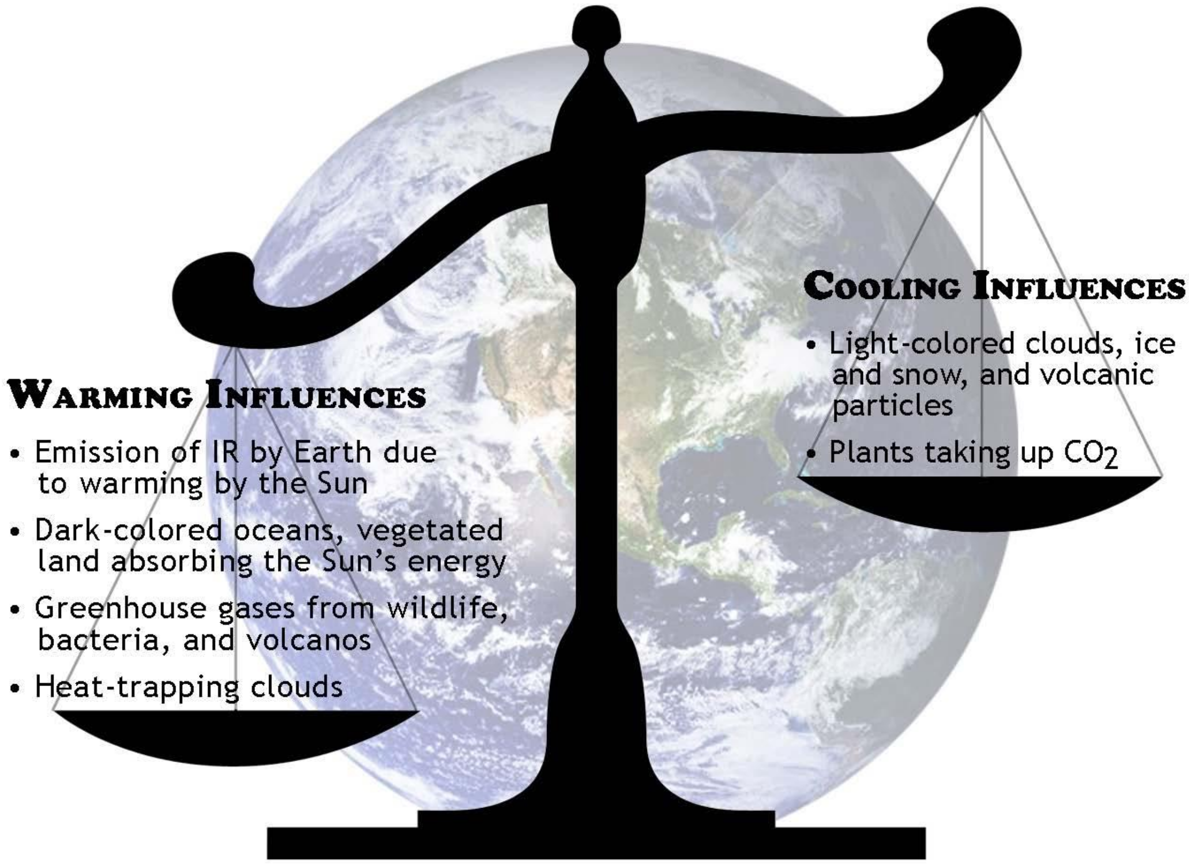
Earth's warm global climate is created by a natural greenhouse effect. The Sun's radiation is mainly in the visible range of the electromagnetic spectrum, and most of this high-energy light passes through the atmosphere to strike the Earth's surface and warm it. The warm surface gives off (re-emits) a lower-energy form of electromagnetic radiation that is invisible to our eyes: infrared radiation (IR). Unlike visible light, infrared radiation can be captured by heat-trapping gases in the Earth's atmosphere. Heat-trapping gas molecules re-emit the infrared radiation, and it is often absorbed by other heat-trapping gas molecules or the surface of the Earth. Through the greenhouse effect, heat-trapping gases prevent energy emitted by the Sun-warmed surface of Earth from escaping into space, thus creating a much warmer climate than would occur without them. The addition of heat-trapping gases through human activities contributes to global warming beyond natural levels. (Note that the Earth, Earth's atmosphere, and Sun are not drawn to scale.) Credit: Lunar and Planetary Institute.

Much of the Sun's radiation is in the visible range of the electromagnetic spectrum, and for the most part, this type of light passes right through our atmosphere. Earth absorbs this radiation and warms up. Like all warm things, Earth gives off radiation of its own (think of the glowing coils in your toaster, which are hot enough to radiate in the visible portion of the electromagnetic spectrum). Earth emits infrared radiation, which is invisible to us. Unlike the higher-energy radiation from the Sun, the low-energy, long-wavelength infrared radiation can't pass back through the atmosphere with ease. Some of it does manage to escape back into space, but most of it is captured by heat-trapping gas molecules.

All molecules are able to absorb and emit light energy, but at the molecular scale, that light has to have *just* the right amount of energy for a particular type of molecule to absorb it. Heat-trapping gas molecules are all made up of at least three atoms bonded together. They are able to absorb infrared radiation because its energy is just right for causing the atoms of the molecules to move slightly in relation to each other, or vibrate. The visible light from the Sun was too energetic for the molecules to "catch." The molecules then emit the energy as infrared radiation, which is often caught by another heat-trapping gas molecule or the surface of the Earth.

Carbon dioxide, methane, nitrous oxide, and water vapor are heat-trapping gases. While the atmosphere is 78% nitrogen and 21% oxygen, heat-trapping gases make up only a tiny fraction of the air we breathe. For instance, carbon dioxide (CO_2) makes up almost 0.04% of the atmosphere; methane is more efficient at absorbing infrared radiation from the Earth but makes up only about 0.0002%. Water vapor comes and goes in the form of clouds, fog, and humidity. It is highly variable, and may represent between 1-4% of the atmosphere at the surface. Even in relatively small amounts, these heat-trapping gases have a very big impact on Earth's atmospheric temperature! Small increases in the amounts of these gases mean increased warming of our atmosphere.

In addition to the greenhouse effect, other factors help moderate Earth's temperatures by absorbing more of the Sun's energy or reflecting it. These factors have influenced each other and changed to create Earth's evolving climate over time. The warming effect of certain gases in the atmosphere and the heat-trapping global ocean, combined with the cooling effect of certain types of clouds and the ice caps and glaciers, work as nature's thermostat to maintain temperatures necessary for life. Life — mainly bacteria — generated much of the heat-trapping gases in our atmosphere that act as crucial warming influences. Trees and further contributions from bacteria and other small organisms are cooling influences. They can help keep one kind of heat-trapping gas, CO_2, in check. Life is possible not only because Earth has a relative abundance of water, ice, and air, but because life continues to interact with these features to shape the dynamic place we call home.



Earth's global temperatures at any one time are a result of the balance between various natural warming and cooling influences. Thanks to these influences, Earth's temperatures are tipped enough to the "warm side" of the balance to have an average temperature near about 57^{o}F (14^{o}C). (In the past, the balance has also tipped toward the "cool side," perhaps even covering Earth entirely in ice!) Credit: Lunar and Planetary Institute.

Earth's climate is complex and dynamic, and the brief descriptions presented here cannot encompass all of the factors at play. The study of Earth's climate is in itself an entire field, and it is concerned with Earth's prehistory and a myriad of complex interactions not treated here. For more information on this topic, please see resources such as:

"Climate and Global Change," www.windows2universe.org/earth/climate/climate.html

"The Greenhouse Effect & Greenhouse Gases" includes an explanation of the important role played by water vapor: www.windows2universe.org/earth/climate/greenhouse_effect_gases.html

"Ocean and Climate Sciences for Teachers" includes materials, including videos, archived at http://cires.colorado.edu/education/outreach/ocean-climate/

TED articles and videos relating to climate change are available through www.ted.com/topics/climate+change.

"Frequently Asked Questions about Global Warming and Climate Change: Back to Basics," EPA-430-R08-01616, summarizes global warming and the likely impacts from climate change. Available for download at www.epa.gov/climatechange.

Earth's global surface temperatures are rising at an unusually rapid rate. The past century has seen an increase of a little more than 1ºF (0.74ºC). A degree may not seem large to us, but we are accustomed to thinking locally. Local temperatures change with the weather, season, and time of day, often much more than a degree in a single day. G*lobal* changes in temperature are averages that take into account the large local variations and represent a change in the balance of factors that shape Earth's climate. Today's global temperatures are the highest of the past 500 years, perhaps even for the past millennium.

Temperature change is nothing new; the Earth has undergone many changes in global temperature in its past. Changes in Earth's orbit, in addition to less influential changes in the Sun's intensity, outgassing from volcanos and other sources, and changes in ocean currents, have resulted in cycles of cooling and warming. Certain eras in the Age of the Dinosaurs were warmer than today, and the ice ages were colder. However, modern human society has never encountered such profound and rapid change. Large changes in temperature occurred in the last million years during the glacial cycles, but the global warming at the end of an ice age is thought to have taken 5,000 years. In addition, these changes were all due to natural factors.

Scientists attribute most of the current climate change to increases in heat-trapping gas concentrations in the atmosphere. Scientists also agree that carbon dioxide released to the atmosphere by human activities is the main culprit of climate change. It is released from burning coal, oil, natural gas in power plants, cars, factories, and to some extent, from the clear cutting of forests. Human activities release other heat-trapping gases. Methane is released by farm animals, rice paddies, rotting garbage in landfills, mining, and extraction of natural gas. Chlorofluorocarbons (CFCs) are well-known for creating the ozone hole — a separate environmental issue in itself — but are also implicated in their additional role as heat-trapping gases. The fertilizers used to grow our food add nitrous oxide.

Human activities contribute much more CO_2 to the atmosphere than volcanos. It is estimated that present-day volcanos release about 0.15 to 0.26 gigaton, globally, each year. Compare that to the amount released in 2010 due to human activities: 35 gigatons. Indeed, our use of cars, pickup trucks, and other light-duty vehicles releases at least about 12 times as much CO_2 as volcanos, at 3 gigatons per year.

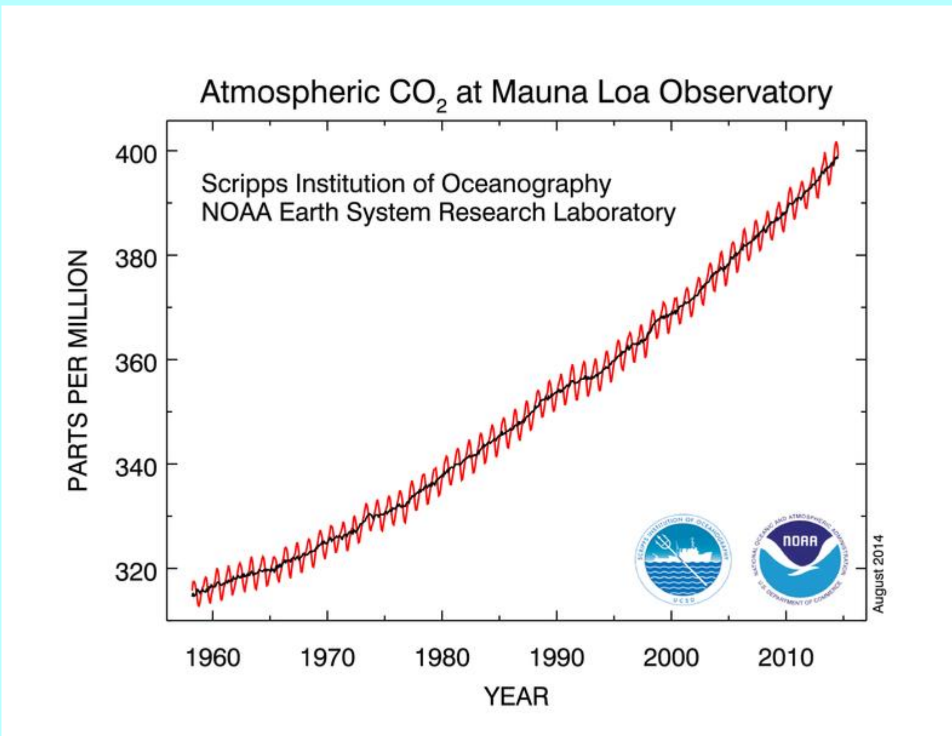
"Volcanic Versus Anthropogenic Carbon Dioxide," by T. Gerlach, *Eos*, Vol. 92, No. 24, 14 June 2011.

Scientists have records of the amount of carbon dioxide in Earth's atmosphere stretching thousands of years into the past.* A dramatic increase in the percentage of carbon dioxide in the atmosphere corresponds with the Industrial Revolution and has proceeded to climb sharply in the ensuing years. Today's levels far exceed even the highest levels of the past 750,000 years.

*Ice is a handy record-keeper.   Air bubbles trapped in ancient ice have allowed scientists to measure the components of Earth's past atmospheres. Scientists drill cores in glaciers and ice sheets and analyze the preserved bubbles of prehistoric atmospheres. Also contained in the core is wind-blown volcanic ash, which is used to date its layers. Slight differences in the kinds of elemental oxygen within the ice tell the scientists how cold the air was when the snow fell.

Ice cores and other data provide evidence that the amount of carbon dioxide in Earth's atmosphere temperature have fluctuated in a cyclical pattern through time. These cycles of cooling and warming are natural, and caused, over the last 750,000 years, primarily by cyclic changes in Earth's orbit. During that time frame we have experienced alternating periods of warmth and periods of glaciations. However, at present, the levels of carbon dioxide in the atmosphere far exceed even the highest levels of the past half-million years. Our global temperature is increasing in response to this added heat-trapping gas.

The carbon dioxide (CO_2) concentration in the atmosphere has been measured directly since 1957. The instruments at Mauna Loa, Hawaii reflect the seasonal uptake and release of carbon dioxide by plants as "wiggles," but show an overall sharp increase.



The amount of carbon dioxide in Earth's atmosphere has been directly measured at Mauna Loa, Hawaii for half a century. The data reflects a sharp increase in carbon dioxide to levels higher than our Earth has experienced in the past half-million years – and certainly higher than humans have ever experienced. The seasonal uptake and release of carbon dioxide by plants in the northern hemisphere were captured here as "wiggles." Credit: Scripps Institution of Oceanography/ National Oceanic & Atmospheric Administration Earth System Research Laboratory, www.esrl.noaa.gov/gmd/ccgg/trends*.*

The increases in atmospheric CO_2 are clearly due to human activities. The amount of CO_2 in Earth's atmosphere has risen in parallel with the increase in fossil fuel combustion. Furthermore, the carbon in fossil fuels has a unique signature: it lacks one particular type of carbon (i.e. isotope), called ^{14}C. (This isotope has decayed out of the fossil fuels, which are older than most other sources of carbon in the atmosphere.) From 1800 to 1950, the amount of naturally occurring ^{14}C in the atmosphere decreased as it was diluted by carbon originating from fossil fuels.

Scientists Work Together to Understand Our Changing World

Scientists work together to connect their understanding of local regions to a global vision...and they see great change happening now and into our future. Data from all realms of science are pulled together to understand our changing planet. For example, scientists note what species of flowers bloom earlier in the year and in what regions coral reefs die off because of warmer sea surface temperatures. They measure how increasing carbon dioxide is acidifying our oceans as it dissolves to form carbonic acid. Satellites take data on ice cover, precipitation, temperature, and other characteristics of our planet from above.

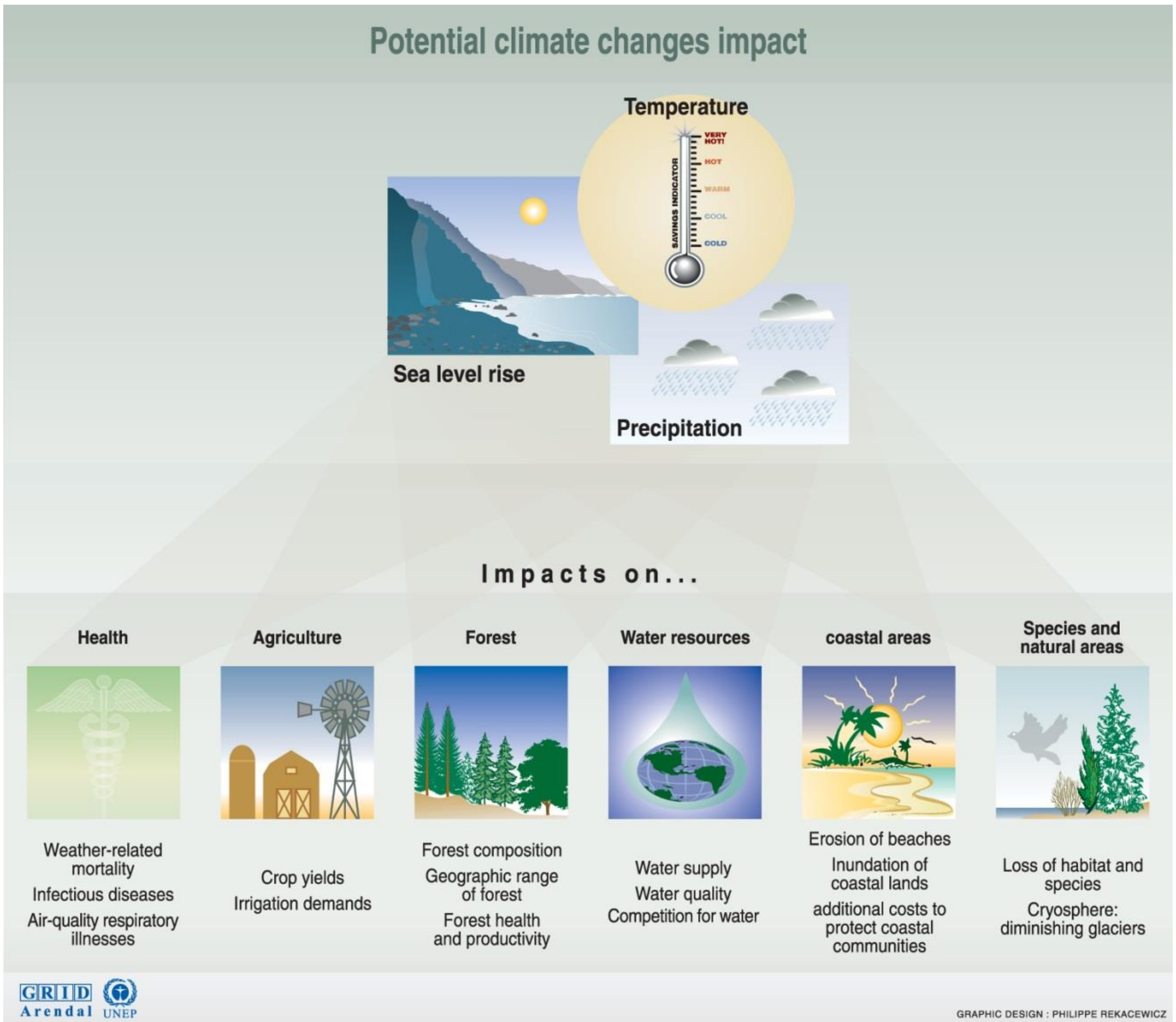
Our planet is so complex that climate scientists use complex computer algorithms, called climate models, to weigh the influences of the myriad of factors which shape our planet's climate. Computer models weigh the influences of heat-trapping gases from natural and human sources, changes in the Sun's intensity, ice and cloud cover, volcanos, ways in which different life forms shape their environments — and how these different factors interact in complicated ways over time.

The scientific understanding of climate change is not as provisional as it is often portrayed in politics, in the media, and by the entertainment industry. Indeed, a study in the *Proceedings of the National Academy of Sciences* found that 97-98 percent of actively publishing climate researchers support the basic understanding of human-induced climate change. While the contributions of *natural* warming are still not fully understood, it is generally agreed that their effects are secondary. Changes in solar intensity and volcanoes produced most of the warming from pre-industrial times to 1950, but are not implicated in the current global change. For instance, when Mt. Pinatubo erupted in 1991, the global average temperature dropped by 0.9 °F (0.5 °C) as volcanic particles in the atmosphere reflected some of the Sun's energy. (The volcano also released carbon dioxide, a warming agent, but this addition is thought to be small compared to human contributions.) Studies by the National Center for Atmospheric Research (NCAR) attribute less than a third of the current warming to changes in the Sun's intensity. Earth's climate is changing mostly as a result of certain human activities.

Beyond the political debate that has shrouded our understanding of climate change, this field of science offers a glimpse into the process of science. Individual scientists and teams of scientists work on a particular aspect of Earth's climate and publish any replicable results. Their contributions are tested, weighed, and debated by the scientific community. If the results are found to be valid by other scientists, they are integrated into the common knowledge base and our understanding moves forward. No one scientist or scientific team has all of the answers, and individual aspects of the scientific "puzzle" may be intensely debated — but the community moves together toward a broad understanding as the myriad details are tested and used to modify or advance existing theories.

Tomorrow's World Will Be a Different Place

The clothes in your closet, what you can plant in your garden — and when you can plant them — the varieties of local produce you buy at the grocery store, the types of plants and trees growing in your parks, and what wild animals live in or migrate through your area are all determined by your local climate. Imagine how your world might change as your local climate is reshaped by global climate change. While it might be tempting to blame a hot summer's day on global warming (or to say global warming is not happening because of high snow fall over one or two winters), short duration warmer- or cooler-than-average temperatures are a part of Earth's natural charm (just to keep us on our toes!). Scientists are trying to understand how changes in temperature, precipitation, wind, and sea level will impact Earth's diverse regions. Scientists use mathematical computer models to predict how the various warming and cooling factors will shape tomorrow's climate.



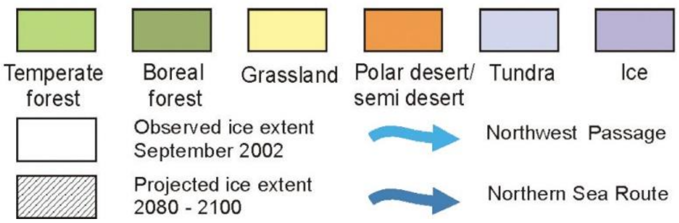
Source: United States environmental protection agency (EPA).

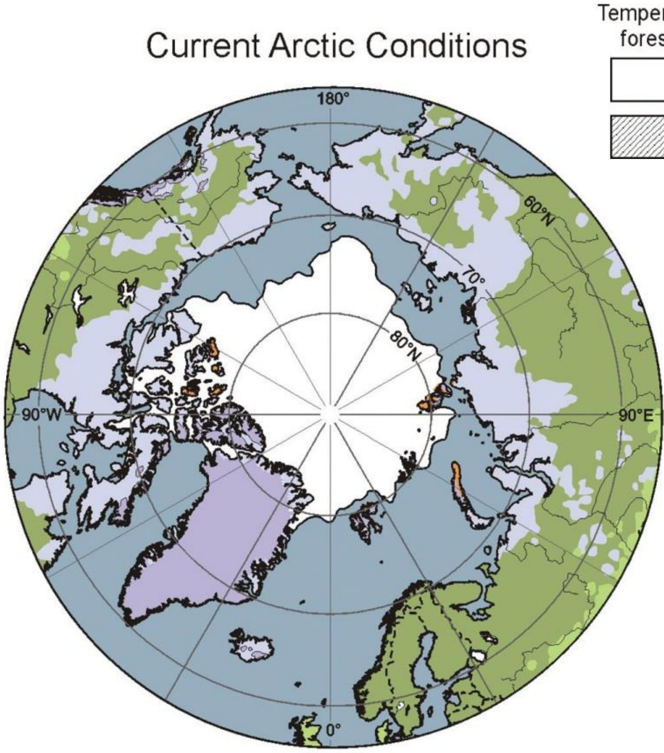
Climate change will potentially alter the temperature, precipitation, and sea levels, which will, in turn, impact human health, agriculture, forests, water resources, coastal areas, and species and natural areas. Image courtesy of United States Environmental Protection Agency (EPA) / Philippe Rekacewicz, UNEP/GRID-Arendal.

The thawing of Earth's freezers — the polar regions — will have far-reaching effects. The nature of the polar regions makes them more sensitive to the consequences of climate change than warmer latitudes. Reflective white ice and snow will melt into dark rivers and oceans that better absorb the Sun's energy. Like a freezer overdue for defrosting, increasing temperatures will expose organic matter long locked away in the frozen ground of the arctic tundra. This permafrost will thaw and plant matter decomposing in the resulting marshes will release the heat-trapping gas methane.

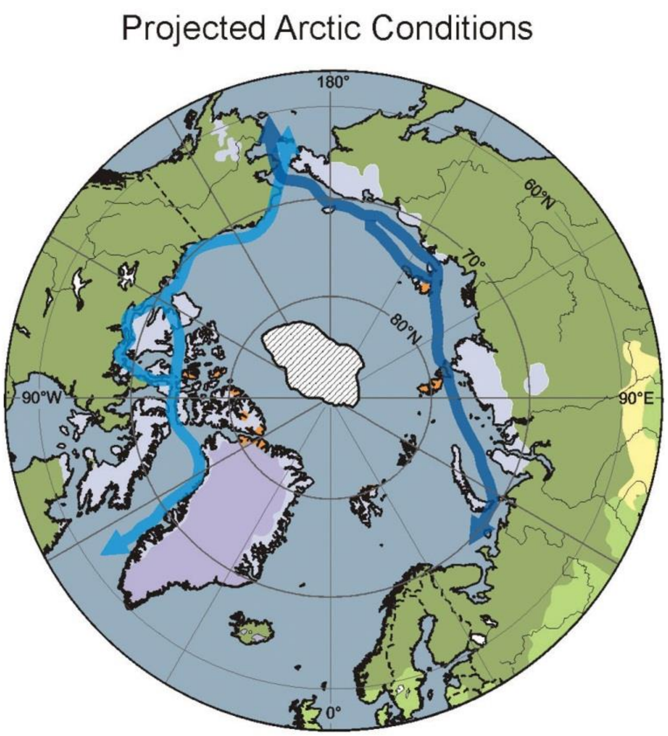
Antarctic sea ice is as necessary to penguins as forests are to songbirds. If the 3.6ºF (2ºC) rise in global temperatures predicted over the next 40 years comes to fruition, essential nesting and feeding grounds will have melted away. The warming would translate to a 50% decline of emperor penguins. The Pt. Géologie colony that increased this species' fame through the movie *March of the Penguins* already is in decline as northern Antarctic temperatures increase. With less sea ice, Adélie penguins have a shorter journey from their nests of rock to fetch food from the ocean for their chicks. However, Adélie penguins are adapted to the cold and overall are harmed by increasing temperatures. They face a loss of 75% with the predicted temperature rise. Climate change adds to the problems of pollution and over-fishing of the Southern Ocean.

Arctic sea ice is predicted to continue disappearing. Commerce by sea will have entirely new opportunities for transport through the opened Arctic Ocean, but the changes for humans and animals dependent of the ice are grim. According to a study by the United States Geological Survey, the predicted loss of Arctic sea ice in future years may result in the loss of 2/3 of the polar bear population by the middle of this century. Of the 19 subpopulations of polar bears, 8 are currently declining. For 7 of the subpopulations, there was not enough data to determine whether they were growing or falling. One subpopulation is increasing…and Arctic researchers are hopeful that humans can work toward mitigating climate change and other threats to all of the subpopulations.





Present and projected summer minimum sea-ice extent and vegetation types for the Arctic and neighboring regions. Credit: Figure 15.3, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, 2007,* Cambridge University Press*, www.ipcc.ch/graphics/ar4-wg2/jpg/fig-15-3.jpg .*



Changes will vary across the globe. More warming is expected in the interiors of continents and in the northern latitudes of the Northern Hemisphere than at the coastal regions and tropics. Heat waves are expected to become more intense. Higher temperatures will lead to faster evaporation, and rain, when it occurs, may fall in the form of heavy downpours. More precipitation may provide additional water to some regions, but floods and droughts are also expected to become more frequent. Storms might increase in intensity; in addition, rising sea levels will impact coastal areas. Crops may experience longer growing seasons and fewer frosts. The warmer temperatures and increased carbon dioxide in the air may help some crop varieties, but they, too, have a point at which it is too warm to survive. The ranges of plants and animals, biodiversity, and migratory patterns are expected to continue to change in response to climate change. Pests, parasites, and diseases are likely to thrive in the warmer temperatures, much to the irritation of the plants, animals, and humans they prey upon. While heat waves may contribute to heat-related illness and death, milder winters may be a benefit for health issues. Beach erosion, reduced snowfall, and changes in flora and fauna may limit opportunities for outdoor excursions, but milder temperatures in some regions may provide more opportunities to venture outdoors.

Humans Have the Power to Stabilize Global Change

Humans clearly have an impact on the global environment and the ecosystems it supports. Our use of fossil fuels, such as coal and oil, has added carbon dioxide to the atmosphere and warmed our planet. Now, our influence can be used to stabilize or *reduce* climate change!

Use of fossil fuels pervades our everyday life and it is challenging to know where to begin reducing it. Not only do fossil fuels power our cars and school buses, coal often produces the electricity that runs our air conditioners and charges our cell phone batteries. In addition, fossil fuels are often used in the production and transportation of our goods before we even take them home from the store. For instance, fossil fuels are used for the energy and materials to create plastic bottles and transport heavy drinking water across the country to the local grocery store. Thus, not only does driving less and conserving electricity help combat climate change, so does being a savvy consumer of local produce and recycled goods.

In addition to carbon dioxide, the heat-trapping gases methane and nitrous oxide are by-products of everyday practices. Methane, a natural waste product of certain microbes living in the intestines of cattle, is released by these animals in large amounts. Stocking up on protein from fish, and especially beans and other vegetables, instead of beef is one way grocery shoppers can help slow climate change. Human-produced fertilizers break down in the soil and release nitrous oxide, so composting the vegetable clippings from that high-protein bean salad to use as natural fertilizer can further help slow climate change.

It is amazing that something as tiny as heat-trapping gas molecules can create and change our global climate so drastically, even though they are vastly outnumbered by the nitrogen and oxygen molecules that make up the majority of our atmosphere. Though we may sometimes feel small and insignificant as individuals or communities in our complex societies, we likewise have the power to make a large impact — and make the changes necessary to manage Earth's resources wisely!

Activity Materials to Print