NARRATED BY LIAM NEESON

DYNAMIC EARTH

Exploring Earth's Climate Engine

EDUCATOR GUIDE

DYNAMIC EARTH

Dynamic Earth is a 24-minute immersive fulldome documentary that explores the inner workings of Earth's climate system.

The show uses stunning visualizations based on satellite monitoring data and advanced supercomputer simulations to explore the interlocking systems that shape our climate: the atmosphere, hydrosphere (oceans) and biosphere.

This **Educator Guide** is designed for use with students in grades 7–12 in conjunction with a viewing of the planetarium show. It supplements the documentary by offering classroom resources that address and reinforce the topics of Earth's climate systems and climate change. The guide includes content overview, related reference guides, and four classroom activities.

Dynamic Earth was designed for fulldome theaters in museums, planetariums, and science centers. It features narration by actor Liam Neeson. The show was produced by Spitz Creative Media, the Advanced Visualization Lab at the National Center for Supercomputing Applications at the University of Illinois, NASA's Scientific Visualization Studio and Thomas Lucas Productions, Inc. in association with the Denver Museum of Nature and Science and NASA Earth Science. The distributor of *Dynamic Earth* is Spitz, Inc. (http://www.spitzinc.com).

This educator guide was written by Lisa Bruck, a science educator with the Frederick County, Maryland, Public School District, and members of the Dynamic Earth Production team. The authors were assisted by members of the NASA Earth Science Education and Public Outreach Forum: Russanne Low, Ph.D., and Theresa Schwerin, Institute for Global Environmental Strategies (IGES), and Elizabeth Burck, Wyle Information Systems, LLC.

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About this Guide

This guide addresses many of the questions that commonly arise when discussing and learning about Earth's climate system and climate change, and presents several classroom activities that will help students understand this important topic. The information provided in this guide includes additional resources for educators and students to further their knowledge about climate and weather. This guide is designed for use by educators teaching students in grades 7–12.

National Science Education Standards (NSES)

Unifying Concepts and Processes: As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes:

- Systems, order, and organization
- Evolution and equilibrium
- Evidence, models, and explanation
- Form and function
- Constancy, change, and measurement

Content Standards: 5–8

- **Science as Inquiry**
  Abilities necessary to do scientific inquiry
  Understandings about scientific inquiry
- **Physical Science**
  Properties and changes of properties in matter
  Motions and forces
  Transfer of energy
- **Earth and Space Science**
  Earth in the solar system
- **Science and Technology**
  Understandings about science and technology
- **Science in Personal and Social Perspectives**
  Science and technology in society
- **History and Nature of Science**
  Science as a human endeavor
  Nature of science
  History of science

Content Standards: 9–12

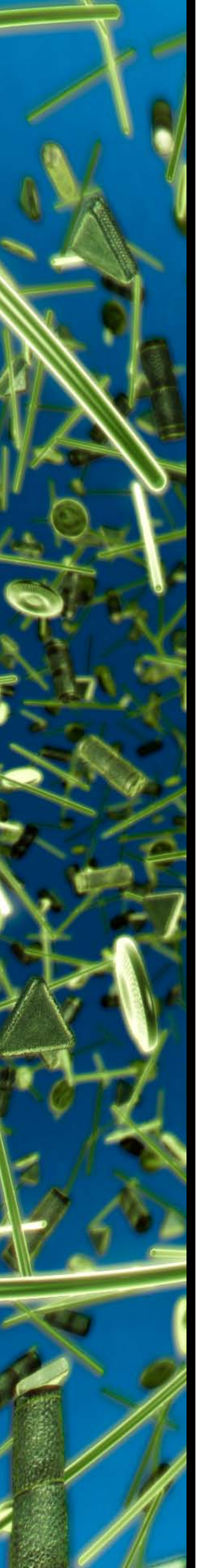
- **Science as Inquiry**
  Abilities necessary to do scientific inquiry
  Understandings about scientific inquiry
- **Physical Science**
  Structure and properties of matter
  Motions and forces
  Conservation of energy and increase in disorder
  Interactions of energy and matter
- **Earth and Space Science**
  Origin and evolution of the universe
- **Science and Technology**
  Understandings about science and technology
- **History and Nature of Science**
  Science as a human endeavor
  Nature of scientific knowledge
  Historical perspectives

The Essential Principles of Climate Science

U.S Climate Change Science Program 2009. *Climate Literacy: The Essential Principles of Climate Science.* Washington DC:

"The Essential Principles of Climate Science" summarizes the most important principles and concepts of climate science. It presents important information for individuals and communities to understand Earth's climate, impacts of climate change, and approaches for adapting and mitigating change. Principles in the guide can serve as discussion starters or launching points for scientific inquiry. The guide can also serve educators who teach climate science as part of their science curricula.

Supernova Explosion (left)*: A supernova explosion seeds the galaxy with heavy elements in this visualization by the Advanced Visualization Lab at NCSA, University of Illinois.*



Each essential principle is supported by fundamental concepts comparable to those underlying the National Science Education Standards (NSES) and the American Association for the Advancement of Science (AAAS) Benchmarks for Science Literacy. See http://www.climatescience.gov/Library/Literacy/ or http://cleanet.org/cln/climateliteracy.html.

The following Essential Principles of Climate Science are described in Appendix C:

1. The Sun is the primary source of energy for Earth's climate system.

2. Climate is regulated by complex interactions among components of the Earth system.

3. Life on Earth depends on, is shaped by, and affects climate.

4. Climate varies over space and time through both natural and man-made processes.

5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling.

6. Human activities are impacting the climate system.

7. Climate change will have consequences for the Earth system and human lives.

Dynamic Earth Content Overview

Dynamic Earth integrates the physical and biological sciences in exploring the impact of solar and terrestrial energy sources on the climate. Examinations of the Earth-Sun system, plate tectonics, and the carbon cycle are presented as foundational background to the primary focus of the program: the intricate connection between Earth's energy trails and the environmental systems that shape its climate.

Stunning satellite data visualizations, supercomputing simulations, and photorealistic animations are combined to allow the student unprecedented insights into the inner workings of Earth's dynamic climate system. Students will find the science captivating, the images enthralling and the narrative, by actor Liam Neeson, compelling.

Commonly Asked Questions About Earth's Climate

How does climate differ from weather?

Climate is very different from the weather. Weather is the minute-by-minute and highly variable state of the atmosphere on a local scale. An area's climate amounts to its average weather conditions and the extent to which those conditions vary over longer time scales.

Measurements of climate include the long-term pattern of temperature and precipitation averages and extremes at a location. That location can be local in scale, but is often applied to regional, or global scales. Climate is also used broadly to refer to measurements over periods of time ranging from decades and years, down to seasons, months, or specific dates of the year.

How does Earth's distance from the Sun affect the climate?

The Earth's distance from the Sun makes liquid water, and hence, life, possible on our planet. The amount of solar energy reaching its surface helps ensure that water is neither all frozen nor all vaporized. The presence of liquid water on our planet enabled the early evolution of life billions of years ago and continues to support a wide diversity of living organisms.

Earth orbits the Sun at a distance known as the "Life Zone" of our solar system. The planet closest to the Sun, Mercury, is so hot that any water there would long ago have evaporated into space. Venus is another hothouse, made worse by a runaway greenhouse effect due to the buildup of carbon dioxide in its atmosphere. Mars, on the other hand, is too far away from the Sun to maintain liquid water. Any moisture present on the planet's surface today is frozen solid at the polar ice caps or in the soil itself.

DIATOMS (left) *are one-celled organisms whose numbers explode where ocean currents carry nutrients up from the deep.*

What is the carbon cycle?

Elemental carbon exists on Earth in a variety of molecular forms. The carbon cycle describes the chemical reactions that propel carbon-containing molecules through the different parts of the Earth system-air, water, land and life. From a climate perspective, the carbon cycle is critical, because it "sets the Earth's thermostat" and plays a role in regulating the temperature of the planet.

Plants, for instance, absorb carbon dioxide in the air and use it to grow. Animals eat the plants and use the carbon as building blocks for their own tissues. When plants or animals die, the carbon in their bodies is broken down into simpler forms by decomposers. In the ocean, waste and dead organisms rain down on the sea bottom, where they are incorporated into ocean sediments. Through heat and pressure, the sediments lithify and the carbon is locked up in rock. In rock, carbon can be removed from active cycling for millions of years. Eventually, the carbon sequestered in rock returns to the atmosphere through physical and chemical weathering processes, or as gases released during volcanic eruptions.

How does plate tectonics affect the carbon cycle?

While the Sun is responsible for the energy that powers Earth system processes taking place on the surface of the planet, the scientific theory of plate tectonics describes our understanding of the dynamic Earth processes powered by internal Earth energy. In tectonically active zones, large slabs of the lithosphere, called plates, make contact- they slide under, push over, or slip alongside each other. The energy released from the interactions of the plates powers the earthquakes and volcanoes responsible for releasing into the atmosphere carbon that was once locked up in rock.

Why did Venus, Earth's sister planet, go wrong?

With an atmosphere composed of 96% carbon dioxide, Venus provides an example of the greenhouse effect gone wild! At a glance, Venus seems very much like the Earth, both in terms of size and composition. One of the biggest differences between the two planets, however, is Earth's active carbon cycle. Carbon dioxide in Earth's atmosphere is continually absorbed into the oceans and the crust. On Venus, volcanoes are continually adding more carbon dioxide into the atmosphere, where they trap more and more heat. However, there are other factors that contribute to Venus' inability to sustain life. One of the most important is that Venus, unlike Earth, does not have a magnetic field to shield it from solar radiation that strips water from the atmosphere.

What Earth can tell us about the search for extraterrestrial life?

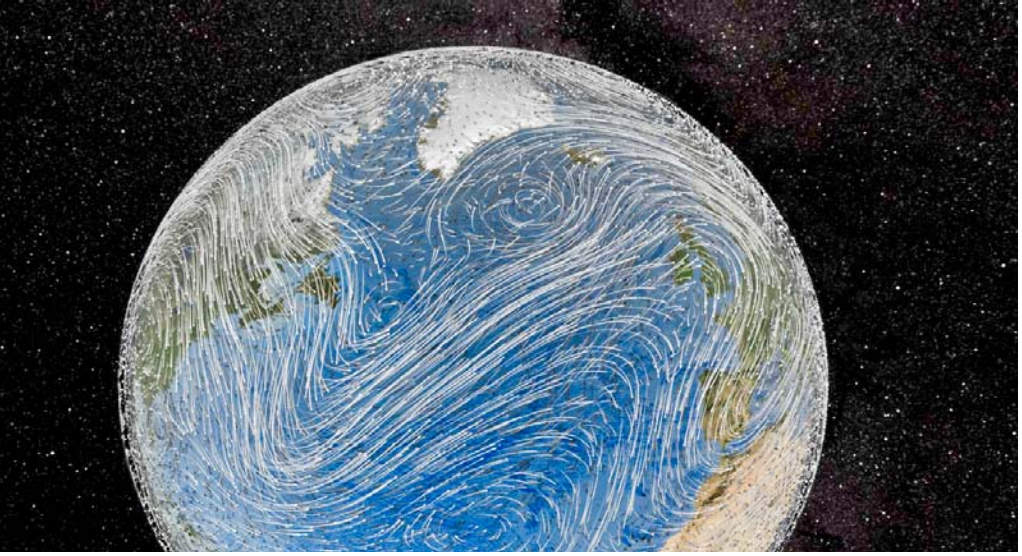
Not all planets positioned in their star's "life zone" are expected to support life. Given all the factors that had to come together to support living organisms on our planet, extraterrestrial life could turn out to be exceedingly rare. Some of those factors include the presence of a magnetic field to protect against solar radiation, an abundance of liquid water, a near circular orbit. Earth is, in fact, the only data point we have in this historic search. It may turn out that life arises and flourishes only under very special circumstances.

What is climate change?

Climate is defined as the long-term average of conditions in the atmosphere, ocean, and ice sheets and sea ice, including averages and extremes.

Climate change is a change in these conditions persisting over periods of time ranging from decades to millions of years. On the broadest time scales, the climate of Earth is determined by the rate at which energy is received from the Sun and absorbed into environmental systems such as the atmosphere or oceans. However, there are a number of factors that can lead these systems to absorb more or less solar energy, including variations in solar radiation, eccentricities in Earth's orbit, tectonic activity, and changes in the composition of Earth's atmosphere. Of concern to scientists today is the continuing rise of atmospheric carbon dioxide due to our extensive use of fossil fuels, and the additional heat the atmosphere is now absorbing.

Earth's Magnetic Field (left) *protects Earth from cosmic rays that would strip away the upper atmosphere, including the ozone layer that protects Earth from harmful ultraviolet radiation.*



SECTION I
How Solar Energy Drives the Climate

Wind Currents Visualization *(left):* Visualization by NASA's Scientific Visualization Studio.

GRADE LEVEL

Grades 7–12

NATIONAL STANDARDS

Science as Inquiry

Earth and Space Science

Physical Science

Science and Technology

History and Nature of Science

Science in Personal and Social Perspectives

MATERIALS

Empty Aquarium

Heat Lamp or Desk Lamp

Cereal Sized Bowl of Ice

Matches

Wax Paper

ACTIVITY TIME

45 minutes

EDUCATOR'S NOTES

Which Way Does the Wind Blow?

Learning Goals/Objectives
Students will be able to explain how different temperatures affect the way in which the wind circulates and relate that to global wind circulations.

Introduction
Wind is the driving force of weather around the world. The energy to fuel this force comes from the Sun. Wind is formed when a difference in temperature creates a pressure variation. Global wind circulation is a complex phenomenon involving the interaction of air masses with the land and ocean, and the rotation of the Earth. In this activity you will observe wind on a smaller scale as a convection current. Warmer air will expand and rise and cooler air will contract and sink.

Classroom Activity
1. Set up the lamp at one end of the aquarium.
2. Place the bowl of ice at the other end of the aquarium.
3. Since air is invisible, you need to create smoke so that you can see the current. Roll up a piece of wax paper into a tube about the size of pencil. Light one end of the tube with a match and allow it to burn for a few seconds. When you blow it out, smoke is produced. Hold the smoking wax paper near the bowl containing ice.
4. Have students explain what they are observing in the aquarium and have them relate that to the formation of wind.
5. Have students discuss how global wind patterns might be influenced by changing temperatures due to global climate change.

Activity Resources and Extensions
http://www.nasa.gov/pdf/62325main_ICS_Winds.pdf
Investigating the Climate System Winds at Work- series of modules about the Earth's wind system.

http://www-spof.gsfc.nasa.gov/stargaze/Sweather2.htm
Global Climate Global Wind Flow

SECTION II

Greenhouse Effect Simulation & Activities

Venus Volcanoes *(left)*: Volcanoes belch C02 on Earth' sister planet, Venus. Visualization by the Advanced Visualization Lab at NCSA, University of Illinois.

GRADE LEVEL

Grades 7–12

NATIONAL STANDARDS

Science as Inquiry

Earth and Space Science

Physical Science

Science and Technology

History and Nature of Science

Science in Personal and Social Perspectives

MATERIALS

Internet access: **http://phet.colorado.edu/en/simulation/greenhouse.**

The simulation can also be downloaded onto the school computer.

ACTIVITY TIME

45 minutes

EDUCATOR'S NOTES

Exploring the Earth's Greenhouse

Learning Goals/Objectives:

- Describe the effect of greenhouse gases on photons and the temperature
- Describe the effect of clouds on photons and the temperature
- Compare the effect of greenhouse gases to the effect of glass panes
- Describe the interaction of photons with atmospheric gases. Explain why greenhouse gases affect the temperature.

Scientists use computer models or simulations to understand and predict a wide array of natural phenomena. This activity invites students to explore an interactive simulation of the atmospheric "greenhouse effect." In this simulation, students experiment with a number of parameters, including greenhouse gas concentrations, to see how the temperature changes in response.

Extension Activities:

Have students research the following:

1. Research Venus' Greenhouse Effect. How is it different from Earth's Greenhouse Effect?

2. Find out why surface temperatures on Mars are so low despite a high percentage of atmospheric carbon dioxide in its atmosphere.

3. Develop a plan for countries to help decrease their amounts of greenhouse gas emissions.

SECTION III

Observing Landscape-Scale Change from Space

Arctic Sea Ice *(left)*: Visualization by NASA's Scientific Visualization Studio.

GRADE LEVEL

Grades 6–12

NATIONAL STANDARDS

Science as Inquiry

Earth and Space Science

Physical Science

Science and Technology

History and Nature of Science

Science in Personal and Social Perspectives

MATERIALS

Computers with Internet Access

ACTIVITY TIME

60 minutes

EDUCATOR'S NOTES

World of Change: How Remote Sensing Views our Dynamic Earth

Learning Goals/Objectives

Students will identify how remote sensing has provided information about all aspects of the changing Earth over time: Land, Ocean, Atmosphere, Biosphere, and the Sun.

Introduction

For over thirty years scientists have been collecting data about our Earth through a method called remote sensing. Remote sensing is the gathering of information about something without directly coming in contact with it. This allows scientists to see an entire picture of how the Earth has been changing due to volcanic activity, forest fires, and desolate places without putting scientists in danger. Data that would take years to collect can take a few days and provides immediate feedback for scientists to observe.

Classroom Activity

1. Have students discuss how using satellites to study our Earth would be more efficient than scientists collecting all of the data.

2. Have students research the types of measurements taken by satellites, and how those measurements could be used to learn more about Earth.

3. Use the following NASA website to observe decades of changes on the Earth: http://www.earthobservatory.nasa.gov/Features/WorldOfChange/. For each category have the students click on an image for an in-depth view. Have students discuss how the effects of volcanic activity, forest fires, drought, urbanization, organisms, global temperatures and more have changed our planet over time.

Resources

http://science.hq.nasa.gov/kids/imagers/teachersite/RSresources.htm
NASA's collection of remote sensing resources

http://www.agci.org/dB/PDFs/Publications/1992_GTSHB.pdf
This legacy resource provides an excellent teacher guide to support this lesson.

SECTION IV
How is Weather Different from Climate?

Hurricane Katrina *(left):* Visualization by the Advanced Visualization Lab at NCSA, University of Illinois.

GRADE LEVEL

Grades 7–12

NATIONAL STANDARDS

Science as Inquiry

Earth and Space Science

Physical Science

Science and Technology

History and Nature of Science

Science in Personal and Social Perspectives

MATERIALS

Weather station or instruments to measure temperature, humidity

Computer with Internet access

ACTIVITY TIME

One week of daily environmental measurements

Two class periods for analysis

EDUCATOR'S NOTES

Weather vs. Climate

Learning Goals/Objectives

Students will be able to explain the difference between weather and climate.
Students will use scientific instruments to make environmental observations.
Students will use scientific visualization software and be able to describe patterns of change exhibited in a graphed data set.

Introduction

The climate of a region is determined by the interaction of the components of the Earth system, including the atmosphere, hydrosphere, cryosphere, land surface, and biosphere. Locally, it's also determined by such factors as latitude, terrain, proximity to water bodies, and elevation.

In climate studies, scientists also look at changes in weather conditions in a particular place over long periods of time. In this activity, students will monitor weather conditions at their school for a week, and then compare the weather record with a longer data record from the same location using My NASA Data's Live Access Server.

Classroom Activity

Part I

1. Have students establish a weather station and measure the daily weather conditions for one week. Have the students record the temperature, relative humidity, barometric pressure precipitation and sky conditions for each day: it should be at the same site each day.

2. Students can then compare their daily data with a long record of weather data using the MY NASA DATA Live Access Server by following instructions in the lesson plan, below:

My NASA Data Lesson 62: "Is Grandpa Right, Were Winters Colder When He Was a Boy?" See: https://mynasadata.larc.nasa.gov/preview_lesson.php?&passid=97/

Part II

Review the NOAA Paleoclimatology website (lesson link) to learn about weather events and climate trends over the past 100 years. Also, click the link on that page called Climate History. Discuss as a class the trends shown on the NOAA graphs of carbon dioxide, cloud cover and precipitation.

activities continued on next page

EDUCATOR'S NOTES

Part III

Background: Students often hear that winters were colder or had more snow in the past. This activity will help them to determine if this is a true or accurate statement for their location.

1. Locate your school latitude and longitude by using Google Earth or by another method. Use the Live Access Server (lesson link) to create graphs of the same parameters for your location.

2. Have students create a Venn Diagram with one circle labeled WEATHER, one circle labeled CLIMATE, and the overlap labeled BOTH MEASURE.

3. Have the students work through NASA tutorials entitled Great Graph Match and "To Plant or Not to Plant" from the Mission: Biomes website. http://www.earthobserva-tory.nasa.gov/Experiments/Biome/

Activity Resources and Extensions

http://weather.noaa.gov/
Weather conditions around the United States

http://www.ncdc.noaa.gov/oa/climate/severeweather/extremes.html
Extreme weather and climate events in the United States

http://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html
The differences between climate and weather

http://classic.globe.gov/fsl/html/templ.cgi?measpage
Protocols that can be used to conduct weather observations in the classroom, with lesson extensions.

APPENDIX A
Climate Change: The Evidence in Brief

Excerpted from: http://climate.nasa.gov/evidence/

Sea Level Rise
Global sea levels rose about 17 centimeters (6.7 inches) in the last century. The rate in the last decade, however, is nearly double that of the last century.

Global Temperature Rise
Three major global surface temperature reconstructions show that Earth has warmed since 1880. Most of this warming has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and the 10 warmest years in the past 12 years. Even though the 2000s witnessed a solar output decline resulting in an unusually deep solar minimum in 2007-2009, surface temperatures continue to increase.

Warming Oceans
The oceans have absorbed much of this increased heat, with the top 700 meters (about 2,300 feet) of ocean showing a warming of 0.302 degrees Fahrenheit since 1969.

Shrinking Ice Sheets
The Greenland and Antarctic ice sheets have decreased in size**.** Data from NASA's Gravity Recovery and Climate Experiment show that Greenland lost 150 to 250 cubic kilometers (36 to 60 cubic miles) of ice per year between 2002 and 2006, while Antarctica lost about 152 cubic kilometers (36 cubic miles) of ice between 2002 and 2005.

Declining Arctic Sea Ice
Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades.

Glacial Retreat
Glaciers are retreating almost everywhere around the world — including mountain ranges such as the Alps, Himalayas, Andes, Rockies, and throughout glaciated geographic (or geopolitical) areas such as Alaska and Africa.

Extreme Events
Since 1950, the number of record high temperature events in the United States has been increasing, while the number of record low temperature events has been decreasing. The U.S. has also witnessed increasing numbers of intense rainfall events.

Ocean Acidification
Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30 percent. This increase is the result of humans emitting more carbon dioxide into the atmosphere and hence more being absorbed into the oceans. The amount of carbon dioxide absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year.

APPENDIX B
Climate Glossary

Excerpted from: http://www.cpc.ncep.noaa.gov/products/outreach/glossary.shtml

Climate
Climate is a conceptual description of an area's average weather conditions and the extent to which those conditions vary over long time intervals. Climate is described by scientists as average environmental conditions over a period of 30 years or longer. There is an old expression that says climate is what we expect and weather is what we get.

Climate Change
Climate change is a significant, persistent change in the statistical distribution of weather conditions over periods ranging from decades to millions of years. The change may be due to natural or human-induced causes.

Climate Model
A mathematical model for quantitatively describing, simulating, and analyzing the interactions between the atmosphere and the underlying surface (e.g., ocean, land cover, ice).

Condensation
The physical process by which water vapor in the atmosphere changes to liquid in the form of dew, fog, or clouds. It is the opposite of evaporation.

Convection
The transfer of heat by fluid motion between two areas with different temperatures. In meteorology, it is the rising and descending motion of air caused by heat. Atmospheric convection is almost always turbulent and is the dominant vertical transport process over tropical oceans and during sunny days over continents.

Cyclone
In general use, the term cyclone is applied to any storm, especially violent, small-scale circulations such as tornados, waterspouts, and dust devils. In meteorology, the term refers to a type of atmospheric disturbance centered on a low-pressure center that often results in stormy weather.

Drought
Drought is a deficiency of moisture that results in adverse impacts on people, animals, or vegetation over a sizeable area.

Forecasts
A weather forecast, or prediction, is an estimation based on an anticipated future state of the atmosphere with respect to temperature, precipitation, and wind. Weather forecasts are now routinely provided for up to 14 days in advance, and more outlooks are provided for seasonal and longer timescales.

Global Warming
This term refers to rising global temperatures due to either naturally occurring or human-produced gases that prevent the sun's energy from escaping back to space.

Greenhouse Effect
The atmosphere allows solar radiation to reach Earth's surface relatively easily. The atmosphere then absorbs some of the infrared radiation that is re-radiated off Earth's surface. This is similar to the way a greenhouse traps heat as the sun's rays pass through the glass, while preventing the heat from passing back through the glass.

Greenhouse Gas
Certain gases, such as water vapor, carbon dioxide, and methane that effectively trap solar radiation and affect Earth's surface temperature.

Jet Stream
Strong winds concentrated within a narrow zone in the atmosphere about 30,000 feet aloft that generally move in an easterly direction and drive weather systems around the globe. In North America, jet streams are more pronounced in winter.

Meteorology
The scientific study of the physics, chemistry, and dynamics of Earth's atmosphere, especially weather and climate.

Monsoons
Seasonal winds (and the associated heavy rains) caused primarily by the greater annual variation in air temperatures over large land surfaces as compared to ocean surfaces.

Normal (meteorological)
To understand variations of precipitation and temperature over the course of seasons and longer timescales, normal is defined as the average weather over a 30-year period. The National Weather Service has compared normal values from 1961 to 1990 to those of the period 1971 to 2000. Since the cool decade of the 1960's has been replaced with the mild 1990's, normal temperatures in many areas have increased.

Sea Surface Temperatures (SSTs)
The term refers to the mean temperature of the ocean in the upper few meters.

Relative humidity
An estimate of the amount of moisture in the air relative to the amount of moisture that the air can hold at a specific temperature. For example, if it's 70°F near dawn on a foggy morning, the relative humidity can be near 100%. During the afternoon, when the temperature soars to 95°F, the fog disappears. The moisture in the atmosphere has not changed appreciably, but the relative humidity drops to 44% because the air has the capacity to hold more moisture at a higher temperature.

Thermocline
A layer within a large body of water that sharply separates regions differing in temperature, so that the temperature change across the layer is abrupt.

Upwelling
In ocean dynamics, it is the upward motion of water toward the surface of the ocean. Strong upwelling occurs along the equator where easterly winds are present. Upwelling also occurs along coastlines. The nutrients brought to the surface provide food for many aquatic organisms. The resultant concentration of fish in those areas supplies the fishing industry.

Weather
Weather is the minute-by-minute variable condition of the atmosphere on a local scale.

Wind Chill
The portion of the cooling of the human body caused by air motion. Wind chill becomes important for human health as air motion accelerates the rate of heat loss from a human body, especially when temperatures are below 45°F.

APPENDIX C
Additional Resources on the Web

This following is a sampling of the hundreds of NASA Earth and Space Science educational resources.

General Reference On Climate And Climate Change

http://www.smdeponews.org/
NASA Earth & Space Science Education News. Go here to find education resources, upcoming workshops, events, and much more.

http://icp.giss.nasa.gov/education/modules/eccm/
GISS Institute on Climate and Planets. This Earth Climate Course explores what determines a planet's climate.

http://mynasadata.larc.nasa.gov
Students of all ages can investigate microsets of NASA Earth science satellite data, including atmosphere, biosphere, cryosphere, ocean, and land surface. Data are available along with lesson plans, computer tools and an Earth science glossary. Science fair and citizen science project ideas are also available.

http://climate.nasa.gov/
NASA's Earth Now includes vital signs of the planet including the Eyes of the Earth in 3D, Sea level viewer, Climate time machine, and Global Ice Viewer.

http://visibleearth.nasa.gov/
Catalog collection of images and animations of Earth from space

http://www.earthobservatory.nasa.gov/GlobalMaps/
Explore how key parts of the Earth system change from month to month in animated form

The Carbon Cycle

http://globecarboncycle.unh.edu/cmap1.shtml
This is a summary of how the carbon cycle works and its major components.

http://www.windows2universe.org/earth/climate/carbon_cycle.html
A cool carbon cycle game.

http://www.education.noaa.gov/Climate/Carbon_Cycle.html
Educational resources, lesson plans, multimedia information on the Carbon Cycle.

Climate Versus Weather

http://www.nws.noaa.gov/om/csd/index.hp?section=cVSw
Climate vs. weather, definitions and images

Climate And Plate Tectonics

http://www.volcano.si.edu/reports/usgs/index.cfm?content=worldmap
Global Volcanism Program, see active volcanoes around the world.

Earth Sun Connections

http://solarsystem.nasa.gov/index.cfm
NASA's one-stop shop for all planetary information

http://eo.ucar.edu/educators/ClimateDiscovery/SEC.htm
Sun Earth Connection Climate Discovery Teacher's Guide

http://spaceplace.nasa.gov/menu/sun/
Games, activities and tutorials about the Sun, Earth, and Solar system

http://www.spaceweather.com/
Daily solar activity data with archives available, aurora forecasts and links to other essential Sun Earth websites.

APPENDIX D
The Essential Principles of Climate Science

Extracted from: http://cleanet.org/cln/climateliteracy.html

Guiding Principle for Informed Climate Decision: Humans can take actions to reduce climate change and its impacts.

a. *Climate information can be used to reduce vulnerabilities or enhance the resilience of communities and ecosystems affected by climate change. Continuing to improve scientific understanding of the climate system and the quality of reports to policy and decision-makers is crucial.*

b. *Reducing human vulnerability to the impacts of climate change depends not only upon our ability to understand climate science, but also upon our ability to integrate that knowledge into human society. Decisions that involve Earth's climate must be made with an understanding of the complex interconnections among the physical and biological components of the Earth system as well as the consequences of such decisions on social, economic, and cultural systems.*

c. *The impacts of climate change may affect the security of nations. Reduced availability of water, food, and land can lead to competition and conflict among humans, potentially resulting in large groups of climate refugees.*

d. *Humans may be able to mitigate climate change or lessen its severity by reducing greenhouse gas concentrations through processes that move carbon out of the atmosphere or reduce greenhouse gas emissions.*

e. *A combination of strategies is needed to reduce greenhouse gas emissions. The most immediate strategy is conservation of oil, gas, and coal, which we rely on as fuels for most of our transportation, heating, cooling, agriculture, and electricity. Short-term strategies involve switching from carbon-intensive to renewable energy sources, which also requires building new infrastructure for alternative energy sources. Long-term strategies involve innovative research and a fundamental change in the way humans use energy.*

f. *Humans can adapt to climate change by reducing their vulnerability to its impacts. Actions such as moving to higher ground to avoid rising sea levels, planting new crops that will thrive under new climate conditions, or using new building technologies represent adaptation strategies. Adaptation often requires financial investment in new or enhanced research, technology, and infrastructure.*

g. *Actions taken by individuals, communities, states, and countries all influence the climate. Practices and policies followed in homes, schools, businesses, and governments can affect climate. Climate-related decisions made by one generation can provide opportunities as well as limit the range of possibilities open to the next generation. Steps toward reducing the impact of climate change may influence the present generation by providing other benefits such as improved public health infrastructure and sustainable built environments.*

1. The Sun is the primary source of energy for Earth's climate system.

a. Sunlight reaching the Earth can heat the land, ocean, and atmosphere. Some of that sunlight is reflected back to space by the surface, clouds, or ice. Much of the sunlight that reaches Earth is absorbed and warms the planet.

b. When Earth emits the same amount of energy as it absorbs, its energy budget is in balance, and its average temperature remains stable.

c. The tilt of Earth's axis relative to its orbit around the Sun results in predictable changes in the duration of daylight and the amount of sunlight received at any latitude throughout a year. These changes cause the annual cycle of seasons and associated temperature changes.

d. Gradual changes in Earth's rotation and orbit around the Sun change the intensity of sunlight received in our planet's polar and equatorial regions. For at least the last 1 million years, these changes occurred in 100,000-year cycles that produced ice ages and the shorter warm periods between them.

e. A significant increase or decrease in the Sun's energy output would cause Earth to warm or cool. Satellite measurements taken over the past 30 years show that the Sun's energy output has changed only slightly and in both directions. These changes in the Sun's energy are thought to be too small to be the cause of the recent warming observed on Earth.

2. Climate is regulated by complex interactions among components of the Earth system.

a. Earth's climate is influenced by interactions involving the Sun, ocean, atmosphere, clouds, ice, land, and life. Climate varies by region as a result of local differences in these interactions.

b. Covering 70% of Earth's surface, the ocean exerts a major control on climate by dominating Earth's energy and water cycles. It has the capacity to absorb large amounts of solar energy. Heat and water vapor are redistributed globally through density-driven ocean currents and atmospheric circulation. Changes in ocean circulation caused by tectonic movements or large influxes of fresh water from melting polar ice can lead to significant and even abrupt changes in climate, both locally and on global scales.

c. The amount of solar energy absorbed or radiated by Earth is modulated by the atmosphere and depends on its composition. Greenhouse gases—such as water vapor, carbon dioxide, and methane—occur naturally in small amounts and absorb and release heat energy more efficiently than abundant atmospheric gases like nitrogen and oxygen. Small increases in carbon dioxide concentration have a large effect on the climate system.

d. The abundance of greenhouse gases in the atmosphere is controlled by biogeochemical cycles that continually move these components between their ocean, land, life, and atmosphere reservoirs. The abundance of carbon in the atmosphere is reduced through seafloor accumulation of marine sediments and accumulation of plant biomass and is increased through deforestation and the burning of fossil fuels as well as through other processes.

e. Airborne particulates, called "aerosols," have a complex effect on Earth's energy balance: they can cause both cooling, by reflecting incoming sunlight back out to space, and warming, by absorbing and releasing heat energy in the atmosphere. Small solid and liquid particles can be lofted into the atmosphere through a variety of natural and manmade processes, including volcanic eruptions, sea spray, forest fires, and emissions generated through human activities.

f. The interconnectedness of Earth's systems means that a significant change in any one component of the climate system can influence the equilibrium of the entire Earth system. Positive feedback loops can amplify these effects and trigger abrupt changes in the climate system. These complex interactions may result in climate change that is more rapid and on a larger scale than projected by current climate models.

3. Life on Earth depends on, is shaped by, and affects climate.

a. Individual organisms survive within specific ranges of temperature, precipitation, humidity, and sunlight. Organisms exposed to climate conditions outside their normal range must adapt or migrate, or they will perish.

b. The presence of small amounts of heat-trapping greenhouse gases in the atmosphere warms Earth's surface, resulting in a planet that sustains liquid water and life.

c. Changes in climate conditions can affect the health and function of ecosystems and the survival of entire species. The distribution patterns of fossils show evidence of gradual as well as abrupt extinctions related to climate change in the past.

d. A range of natural records shows that the last 10,000 years have been an unusually stable period in Earth's climate history. Modern human societies developed during this time. The agricultural, economic, and transportation systems we rely upon are vulnerable if the climate changes significantly.

e. Life—including microbes, plants, and animals and humans—is a major driver of the global carbon cycle and can influence global climate by modifying the chemical makeup of the atmosphere. The geologic record shows that life has significantly altered the atmosphere during Earth's history.

4. Climate varies over space and time through both natural and man-made processes

a. Climate is determined by the long-term pattern of temperature and precipitation averages and extremes at a location. Climate descriptions can refer to areas that are local, regional, or global in extent. Climate can be described for different time intervals, such as decades, years, seasons, months, or specific dates of the year.

b. Climate is not the same thing as weather. Weather is the minute-by-minute variable condition of the atmosphere on a local scale. Climate is a conceptual description of an area's average weather conditions and the extent to which those conditions vary over long time intervals.

c. Climate change is a significant and persistent change in an area's average climate conditions or their extremes. Seasonal variations and multi-year cycles (for example, the El Niño Southern Oscillation) that produce warm, cool, wet, or dry periods across different regions are a natural part of climate variability. They do not represent climate change.

d. Scientific observations indicate that global climate has changed in the past, is changing now, and will change in the future. The magnitude and direction of this change is not the same at all locations on Earth.

e. Based on evidence from tree rings, other natural records, and scientific observations made around the world, Earth's average temperature is now warmer than it has been for at least the past 1,300 years. Average temperatures have increased markedly in the past 50 years, especially in the North Polar Region.

f. Natural processes driving Earth's long-term climate variability do not explain the rapid climate change observed in recent decades. The only explanation that is consistent with all available evidence is that human impacts are playing an increasing role in climate change. Future changes in climate may be rapid compared to historical changes.

g. Natural processes that remove carbon dioxide from the atmosphere operate slowly when compared to the processes that are now adding it to the atmosphere. Thus, carbon dioxide introduced into the atmosphere today may remain there for a century or more. Other greenhouse gases, including some created by humans, may remain in the atmosphere for thousands of years.

5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling.

a. The components and processes of Earth's climate system are subject to the same physical laws as the rest of the Universe. Therefore, the behavior of the climate system can be understood and predicted through careful, systematic study.

b. Environmental observations are the foundation for understanding the climate system. From the bottom of the ocean to the surface of the Sun, instruments on weather stations, buoys, satellites, and other platforms collect climate data. To learn about past climates, scientists use natural records, such as tree rings, ice cores, and sedimentary layers. Historical observations, such as native knowledge and personal journals, also document past climate change.

c. Observations, experiments, and theory are used to construct and refine computer models that represent the climate system and make predictions about its future behavior. Results from these models lead to better understanding of the linkages between the atmosphere-ocean system and climate conditions and inspire more observations and experiments. Over time, this iterative process will result in more reliable projections of future climate conditions.

d. Our understanding of climate differs in important ways from our understanding of weather. Climate scientists' ability to predict climate patterns months, years, or decades into the future is constrained by different limitations than those faced by meteorologists in forecasting weather days to weeks into the future.

e. Scientists have conducted extensive research on the fundamental characteristics of the climate system and their understanding will continue to improve. Current climate change projections are reliable enough to help humans evaluate potential decisions and actions in response to climate change.

6. Human activities are impacting the climate system

a. The overwhelming consensus of scientific studies on climate indicates that most of the observed increase in global average temperatures since the latter part of the 20th century is very likely due to human activities, primarily from increases in greenhouse gas concentrations resulting from the burning of fossil fuels.

b. Emissions from the widespread burning of fossil fuels since the start of the Industrial Revolution have increased the concentration of greenhouse gases in the atmosphere. Because these gases can remain in the atmosphere for hundreds of years before being removed by natural processes, their warming influence is projected to persist into the next century.

c. Human activities have affected the land, oceans, and atmosphere, and these changes have altered global climate patterns. Burning fossil fuels, releasing chemicals into the atmosphere, reducing the amount of forest cover, and rapid expansion of farming, development, and industrial activities are releasing carbon dioxide into the atmosphere and changing the balance of the climate system.

d. Growing evidence shows that changes in many physical and biological systems are linked to human caused global warming. Some changes resulting from human activities have decreased the capacity of the environment to support various species and have substantially reduced ecosystem biodiversity and ecological resilience.

e. Scientists and economists predict that there will be both positive and negative impacts from global climate change. If warming exceeds 2 to 3°C (3.6 to 5.4°F) over the next century, the consequences of the negative impacts are likely to be much greater than the consequences of the positive impacts.

7. Climate change will have consequences for the Earth system and human lives.

a. Melting of ice sheets and glaciers, combined with the thermal expansion of seawater as the oceans warm, is causing sea level to rise. Seawater is beginning to move onto low-lying land and to contaminate coastal fresh water sources and beginning to submerge coastal facilities and barrier islands. Sea-level rise increases the risk of damage to homes and buildings from storm surges such as those that accompany hurricanes.

b. Climate plays an important role in the global distribution of freshwater resources. Changing precipitation patterns and temperature conditions will alter the distribution and availability of freshwater resources, reducing reliable access to water for many people and their crops. Winter snowpack and mountain glaciers that provide water for human use are declining as a result of global warming.

c. Incidents of extreme weather are projected to increase as a result of climate change. Many locations will see a substantial increase in the number of heat waves they experience per year and a likely decrease in episodes of severe cold. Precipitation events are expected to become less frequent but more intense in many areas, and droughts will be more frequent and severe in areas where average precipitation is projected to decrease.

d. The chemistry of ocean water is changed by absorption of carbon dioxide from the atmosphere. Increasing carbon dioxide levels in the atmosphere is causing ocean water to become more acidic, threatening the survival of shell-building marine species and the entire food web of which they are a part.

e. Ecosystems on land and in the ocean have been and will continue to be disturbed by climate change. Animals, plants, bacteria, and viruses will migrate to new areas with favorable climate conditions. Infectious diseases and certain species will be able to invade areas that they did not previously inhabit.

f. Human health and mortality rates will be affected to different degrees in specific regions of the world as a result of climate change. Although cold-related deaths are predicted to decrease, other risks are predicted to rise. The incidence and geographical range of climate-sensitive infectious diseases— such as malaria, dengue fever, and tick-borne diseases—will increase. Drought-reduced crop yields; degraded air and water quality, and increased hazards in coastal and low-lying areas will contribute to unhealthy conditions, particularly for the most vulnerable populations.

DYNAMIC EARTH

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