A Climate Change Resource for K-12 STEM Teachers

Introduction

The AAAS STEM Volunteer Program has prepared this resource on climate change for K-12 STEM teachers. We encourage educators to read, discuss, share, and use the information in their classrooms. Possible uses could include: constructing climate change problems, placing green school activities in the context of climate change, providing the information to IB and AP high school courses, or just adding to your own knowledge about this very important topic.

In the document, we offer information to support the following:

- The Earth’s atmosphere and oceans are warming.
- The Earth’s climate and ecosystems are responding to this warming of the atmosphere and oceans.
- What is the scientific understanding of these changes?
- What does this scientific understanding predict for Earth’s future climate?
- What do we do to address the consequences of climate change?
- What actions can be taken to reduce the emissions of greenhouse gases?
- What actions can be taken to protect from impacts?
The Earth’s atmosphere and oceans are warming.

Earth’s land, ocean, and atmosphere temperatures have been steadily increasing since the Industrial Revolution. Satellite and surface measurements indicate that Earth’s land and ocean surface temperatures have increased by almost 2°F during that time.*

Global annual average temperature has increased by more than 1.2°F (0.7°C) for the period 1986-2016 relative to 1901-1960. The red bars show temperatures that were above the 1901-1960 average, and blue bars indicate temperatures below the average.


*As a point of comparison, the historical difference between an ice age and the earth temperature at year 1850 is about 4°C or 7°F.
There have been marked changes in temperature extremes across the contiguous United States. The number of high temperature records set in the past two decades far exceeds the number of low temperature records. *(Very high confidence)*

The Earth’s climate and ecosystems are responding to this warming of the atmosphere and oceans.

1. Glaciers around the world are receding.

Credit: 1899 Olympic National Park archives. 2008: Jim Patterson, ONP
Source: https://www.nps.gov/olym/learn/nature/glaciers.htm
2. Arctic sea ice is steadily receding.

3. Sea level is rising around the world.

The light blue line shows seasonal (3-month) sea level estimates from Church and White (2011). The darker line is based on University of Hawaii Fast Delivery sea level data. For more detail on the data sources, see the end of the article.

4. There is extensive bleaching of corals, due primarily to increase of water temperature. A contributing factor is increased acidity, due to dissolved carbon dioxide. This graphic provides an overview on how coral becomes bleached.

5a. There has been an increase in heavy precipitation.

Credit: Figure adapted from article in Bulletin of the American Meteorological Society. See caption for details.
Source: http://nca2014.globalchange.gov/highlights/report-findings/extreme-weather
5b. The intensity, frequency and duration of hurricanes have increased.

There has been a substantial increase in most measures of Atlantic hurricane activity since the early 1980s, the period during which high quality satellite data are available. These include measures of intensity, frequency, and duration as well as the number of strongest (Category 4 and 5) storms. The recent increases in activity are linked, in part, to higher sea surface temperatures in the region that Atlantic hurricanes form in and move through.

Credit: Photo courtesy of NOAA.
Source: http://nca2014.globalchange.gov/highlights/report-findings/extreme-weather
6. There has been an increase in heat waves.

Heat waves are periods of abnormally hot weather, lasting days to weeks. The number has been increasing in recent years. This trend has continued in 2011 and 2012, with the number of intense heat waves being almost triple the long-term average. Recent heat waves in Texas (2011) and the Midwest (2012) set records for highest monthly average temperatures. Analyses show that climate change has generally increased the probability of heat waves. Prolonged (multi-monthly) extreme heat has been unprecedented since the start of reliable instrumental records in 1895.

Earth’s 2015 surface temperatures were the warmest since modern record keeping began in 1880, according to independent analyses by NASA and the National Oceanic and Atmospheric Administration (NOAA).

Credit: Scientific Visualization Studio/Goddard Space Flight Center
7. Extreme and unusual temperature trends continue after 2016 which was a record year.

What is the scientific understanding of these changes?

The changes in the environment and climate are due to increasing emissions of greenhouse gases, primarily carbon dioxide. The gases are called greenhouse gases because they trap heat in the atmosphere just like a greenhouse traps heat. But the heating mechanisms differ. For a conventional greenhouse, the heat transfer mechanisms are conduction and convection, while the mechanism for Earth is radiation.

How does a greenhouse work? The sun’s radiation comes in through the glass roof of the greenhouse and heats the ground and vegetation which heat the air on contact. The hot air rises but is trapped by the glass. The result is heating of the greenhouse above the outside temperature.

Source: Botanical Gardens, V.L. Komarov Botanical Institute, obtained from https://en.wikipedia.org/wiki/Greenhouse
The Greenhouse Effect: How Greenhouse Gases Work to Keep the Earth Warm

The **greenhouse effect** is the trapping of heat by gases in the earth's atmosphere.

- Earth has naturally occurring greenhouse gases.
- These naturally occurring greenhouse gases are primarily water vapor, carbon dioxide, plus to a lesser extent, methane, and nitrous oxides.
- These greenhouse gases keep Earth warm because:
  1. The heat from the sun’s *short wave radiation* can come in through the atmosphere and a portion of it is re-emitted as longer wave radiation.
  2. The *long wave infrared radiation* (heat) from the ground and plants is trapped by the greenhouse gas and keeps us warm, keeping Earth at temperatures that are comfortable for animal and plant life.
  3. Without these greenhouse gases, Earth’s temperature would be about the same as on the Moon, or an average temperature of near 0°F or -18°C. The actual surface temperature is about 14°C or 57°F.
Life on Earth depends on energy coming from the sun. About half the light reaching Earth’s atmosphere passes through the air and clouds to the surface, where it is absorbed and then radiated upward in the form of infrared heat. About 90 percent of this heat is then absorbed by the greenhouse gases and radiated back toward the surface, which is warmed to a life-supporting average of 59 degrees Fahrenheit (15 degrees Celsius).

Source: Global Climate Change: Vital Signs of the Planet, https://climate.nasa.gov/causes
The Greenhouse Effect: Too Much of a Good Thing

The increase of Earth’s temperature is primarily due to increasing concentrations of carbon dioxide in the atmosphere.

- Earth’s greenhouse gas increases are primarily due to human activities.
- Earth’s greenhouse gas concentration was at about 270 parts per million (ppm) prior to the Industrial Revolution in 1850.
- Careful measurements of carbon dioxide in the atmosphere began in 1958.
- These measurements show the atmospheric carbon dioxide:
  - Increases every year.
  - Goes up and down each year, with the decreases in the summer due to growth of vegetation in the northern hemisphere.
  - There is a decrease in greenhouse gases during the northern hemisphere summer when all the northern hemisphere trees are growing. When they grow, the trees take carbon dioxide out of the atmosphere. This intake of carbon is how the trees get their material to grow.
  - There is an increase in carbon dioxide every winter when the trees are dormant and industry is releasing carbon dioxide.
  - Overall, each year there is more increase in carbon dioxide than decrease.
  - This gradual increase in carbon dioxide causes global warming.
  - Computer climate models, which replicate the climate’s history, are used to make projections of Earth’s environment in the future.
Atmospheric CO$_2$ at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

Source: https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html
The Greenhouse Effect: Outlook for the Future

Climate Models are based on the mathematical equations that represent the laws of Earth’s physics, chemistry and biology. Models can evaluate and isolate the specific causes of climate change and can explore the consequences of different scenarios of future greenhouse gas emissions, aerosol emissions, changes in land use, and other influences on climate. Models can replicate the major events of the industrial age climate, including the gradual warming as greenhouse gases have been emitted, the transient cooling effects of volcanoes, etc. Studying how climate responded to major changes in the past is a major way of checking that we understand how different processes work and that models are capable of performing accurately under a wide range of conditions.

The top panel shows observed and reconstructed mean sea level for the last 2,500 years. The bottom panel shows projected mean sea level for six future scenarios. The six scenarios—spanning a range designed to inform a variety of decision makers—extend from a low scenario, consistent with continuation of the rate of sea level rise over the last quarter century, to an extreme scenario, assuming rapid mass loss from the Antarctic ice sheet. Note that the range on the vertical axis in the bottom graph is approximately ten times greater than in the top graph.

What does this scientific understanding predict for Earth’s future climate?

A warmer Earth can significantly affect conditions around the planet. These changes will include:

- Increases in global precipitation, with significant movement of precipitation toward the poles.
- Loss of water storage in seasonal snow pack.
- Changes in seasonal stream and river flow.
- Movement of ecosystems toward the poles and the precipitation moves.
- Increased weather extremes including severe weather such as storms, flooding, and droughts.
- Increased desertification in equatorial to mid-latitudes.
- Reduced food productivity in large areas around the Earth, primarily equatorial to lower latitude.
- Increased ocean acidity, with resultant death of coastal and other sea life, and consequent loss of important human food sources.
- Increases in sea level that will affect coastal cities and island populations worldwide, with likely increases of about 2 meters by 2100.
Scientific Concerns: Tipping Points that Change Earth’s Climate in Unpredictable Ways

A tipping point refers to the concept that very small inputs can sometimes cause a large change in something. A simple tipping point example is an airplane flying. Here the tipping point is a flight speed greater than the stall speed. As long as the airplane flies faster than the stall speed of the wing the airflow over the wing stays smooth, lift is produced, and the airplane keeps flying. However, if the airplane slows slightly to just below the stall speed, the air flow becomes turbulent, the wing loses lift, and the airplane starts to fall out of the sky.

The science of tipping point global warming impacts:

- Tipping points are poorly understood, except to know that they often occur in nature.
- It is often extremely difficult to accommodate or reverse tipping points.
- This is a great worry to scientists.

Examples of tipping points are:

- the release of methane from melting permafrost in the northern hemisphere
- the meltdown of Greenland’s ice sheet is speeding up
- the melting of Antarctic glaciers resulting from the disappearance of the protecting ice shelves
A Permafrost Tipping Point in the Northern Hemisphere

The tipping point for this process is the freezing point (0°C) of permafrost in the northern hemisphere. Permafrost is land that has been frozen stretching back to the last ice age, 10,000 years ago. As the Arctic warms at twice the global rate, the frozen soils thaw and decompose, releasing the trapped greenhouse gases into the air. Scientists estimate that the world’s permafrost holds twice as much carbon as the atmosphere.

If the permafrost melts, the methane that was previously held is released, and bacteria within the permafrost generate more methane which is a strong greenhouse gas. It is estimated that permafrost contains 1,400 billion tons of carbon; Earth’s atmosphere today contains 850 billion tons of methane.

A massive permafrost thaw documented in Canada may indicate a huge carbon release. A study by the Northwest Territories Geological Survey shows 52,000 square miles is in rapid decline, with sediments and carbon threatening the surrounding environment and potentially accelerating global warming. Similar large-scale landscape changes are evident across the Arctic including in Alaska, Siberia and Scandinavia.


Photo Source: Permafrost thaw ponds in Hudson Bay, Canada by Steve Jurvetson. Licensed under CC-by-2.0 ([creativecommons.org/Licenses/by/2.0](https://creativecommons.org/Licenses/by/2.0)), via Wikimedia Commons.
Greenland is Melting—A Tipping Point in the Arctic

The mass of the Greenland ice sheet has rapidly declined in the last several years due to surface melting and iceberg calving. Research based on observations from the NASA/German Aerospace Center’s twin Gravity Recovery and Climate Experiment (GRACE) satellites indicates that between 2002 and 2016, Greenland shed approximately 280 gigatons of ice per year, causing global sea level to rise by 0.03 inches (0.8 millimeters) per year. These images, created from GRACE data, show changes in Greenland ice mass since 2002. Orange and red shades indicate areas that lost ice mass, while light blue shades indicate areas that gained ice mass. White indicates areas where there has been very little or no change in ice mass since 2002. In general, higher-elevation and coastal areas experienced up to 13.1 feet (4 meters) of ice mass loss (expressed in equivalent-water-height; dark red) over a 14-year period. The largest mass decreases of up to 11.8 inches (30 centimeters equivalent-water-height) per year occurred along the West Greenland coast. The average flow lines (grey; created from satellite radar interferometry) of Greenland’s ice converge into the locations of prominent outlet glaciers, and coincide with areas of high mass loss.

Source: https://grace.jpl.nasa.gov/resources/30/
A Glacier Melting Tipping Point in the Antarctic

Princeton University researchers have analyzed data from the GRACE gravitational satellite which measures changes in the local density of the Earth. Ice loss from West Antarctica's unstable glaciers doubled from an average annual loss of 121 billion tons of ice to twice that by 2014. The ice sheet on East Antarctica, the continent's much larger and overall more stable region, thickened during that same time, but only accumulated half the amount of ice lost from the west.

The contribution is primarily from melting of the glacier shelves, which are floating on the sea. This makes a minor contribution to a rise in the sea level. However, when the shelves have gone, the portions on land will melt, making a major contribution to sea level.

Christopher Harig, one of the Princeton researchers, said, "The fact that West Antarctic ice-melt is still accelerating is a big deal because it's increasing its contribution to sea-level rise. It really has potential to be a runaway problem. It has come to the point that if we continue losing mass in those areas, the loss can generate a self-reinforcing feedback whereby we will be losing more and more ice, ultimately raising sea levels by tens of feet."

Image credit: Christopher Harig, Department of Geosciences, University of Arizona
What do we do to address the consequences of climate change?

Governments will be responsible for taking actions. They have to factor in a number of issues:

- How certain is the scientific basis?
- How large is the reduction?
- What is the societal impact, including funding?
- Should the program be a collection of individual actions, or one which targets total carbon emissions? Examples are the Climate Leadership Council, [https://www.clcouncil.org](https://www.clcouncil.org) and the Citizens Climate Lobby, [https://citizensclimatelobby.org](https://citizensclimatelobby.org).

While the scientific community is united in its concerns about climate change, there are still uncertainties in the ability of models to predict the future and its consequences. This is an argument for:

- “Insurance” actions
- An active program of monitoring critical Earth characteristics
- An active program to refine the models
- An improved understanding of the costs to societies of the various scenarios.
**What actions can be taken to reduce the emissions of greenhouse gases?**

Greenhouse gas (GHG) emissions can be reduced in several ways. Let’s start by looking at the sources of these emissions.

The contributions to global greenhouse gas emissions are:

- CO2 from fossil fuels and industrial processes (65%)
- CO2 from forestry and land use changes (11%)
- Methane from agriculture and permafrost melting (16%)
- Nitrous oxide fossil fuels and industrial processes (6%)
- Industrial gases and refrigerants (2%)

The major contributions to global greenhouse gas (GHG) emissions by economic sector are:

- Electricity, heat production, and buildings (31%)
- Agriculture, forestry, land use (25%)
- Industry (21%)
- Transportation (14%)
- Other energy production (10%)

Actions to Reduce GHG Emissions

1. Expand the generation of renewable energy.

In 2016, renewable energy contributed only 10% to the U.S. energy supply.

https://www.eia.gov/energyexplained/?page=us_energy_home
2. Develop solar cell farms

Source: http://www.publicdomainpictures.net/pictures/10000/velka/1-1244734425Lwol.jpg
3. Construct wind turbine farms.

Source: Shepherds Flat Wind Farm, Oregon USA (By Steve Wilson from Orpington, UK - flickr: More Windmills...; Licensed under CC BY 2.0, (creativecommons.org/licenses/by/2.0/), via Wikimedia Commons. https://commons.wikimedia.org/w/index.php?curid=22777884)
4. Increase the efficiency of transportation

The Light-Duty-Vehicle sector

The following chart from the Center for Climate and Energy Solutions shows how technology is projected to improve fuel efficiency.

**TABLE 2: Projected Fuel Economy Standard (mpg).**

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
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<td>34.4</td>
<td>35.2</td>
<td>36.4</td>
<td>38.2</td>
<td>39.6</td>
<td>41.1</td>
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<tr>
<td><strong>Light Trucks</strong></td>
<td>25</td>
<td>25.6</td>
<td>26.2</td>
<td>27.1</td>
<td>28.9</td>
<td>28.1</td>
<td>29.6</td>
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<tr>
<td><strong>Combined Cars &amp; Trucks</strong></td>
<td>29.8</td>
<td>30.5</td>
<td>31.4</td>
<td>32.5</td>
<td>34.3</td>
<td>35.1</td>
<td>36.1</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2019</th>
<th>2020</th>
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<th>2023</th>
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<tr>
<td><strong>Passenger Cars</strong></td>
<td>42.5</td>
<td>44.2</td>
<td>46.1</td>
<td>48.2</td>
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<td>52.9</td>
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<tr>
<td><strong>Light Trucks</strong></td>
<td>30.0</td>
<td>30.6</td>
<td>32.6</td>
<td>34.2</td>
<td>35.8</td>
<td>37.5</td>
<td>39.3</td>
</tr>
<tr>
<td><strong>Combined Cars &amp; Trucks</strong></td>
<td>37.1</td>
<td>38.3</td>
<td>40.3</td>
<td>42.3</td>
<td>44.3</td>
<td>46.5</td>
<td>48.7</td>
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</table>

Source: [https://www.c2es.org/federal/executive/vehicle-standards](https://www.c2es.org/federal/executive/vehicle-standards)
5. Make improvements beyond the Light-Duty-Vehicle Sector

The following chart is from the Transportation Energy Futures Study.

<table>
<thead>
<tr>
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<th>2030</th>
<th>2050</th>
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</thead>
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<tr>
<td>Medium- and Heavy-Duty Trucks</td>
<td>15%–30%</td>
<td>25%–50%</td>
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<tr>
<td>Aviation</td>
<td>30%–40%</td>
<td>50%–65%</td>
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<tr>
<td>Marine</td>
<td>40%</td>
<td>50%–75%</td>
</tr>
<tr>
<td>Pipeline</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>Rail</td>
<td>15%–17%</td>
<td>30%–35%</td>
</tr>
<tr>
<td>Off-Road Equipment</td>
<td>15%–18%</td>
<td></td>
</tr>
</tbody>
</table>

6. Increase the efficiency of buildings

Chapter 5 in the 2015 Quadrennial Technology Review by the Department of Energy describes how to increase the efficiency of building systems and technologies. The report says that the buildings sector accounts for about 76% of electricity use and 40% of all U.S. primary energy use and associated greenhouse gas emissions. Opportunities for improved efficiency are enormous. By 2030, building energy use could be cut more than 20% using technologies known to be cost effective today and by more than 35% if research goals are met. Much higher savings are technically possible.

What actions can be taken to protect from impacts?

Examples of Actions by US and International Communities to Accommodate to Consequences of a Warmer Climate

1. Metropolitan Washington Council of Governments

2. Miami Beach, Florida

To combat flooding, Miami Beach has launched a $400 million project that's begun installing as many as 80 pump stations throughout the city. In addition, more roads on the island's low-lying western edge will be rebuilt higher.

Source: http://www.npr.org/2016/05/10/476071206/as-waters-rise-miami-beach-buildest-higher-streets-and-political-willpower

3. Louisiana

The Coastal Protection and Restoration Authority has developed a plan which “details $50 billion in investments over five decades in ridges, barrier islands, and marsh creation.”

“In areas where a so-called 100-year flood is expected to produce between 3 ft. and 14 ft. of water, the plan recommends paying for homes to be raised and communities preserved. In places where flood depths are expected to exceed that height, residents would be offered to leave.

“According to the coastal authority, its plan would prevent $150 billion worth of damage over the next 50 years.”

Bloomberg Business Week, January 30 – February 5, 2017

4. Alaska

“The impacts of climate change in Alaska are already occurring. These impacts include coastal erosion, increased storm effects, sea ice retreat and permafrost melt. The villages of Shishmaref, Kivalina, and Newtok have already begun relocation plans.”

“On September 14, 2007, former Governor Sarah Palin signed Administrative Order No. 238, officially forming the Alaska Change Sub-Cabinet. The Sub-Cabinet is charged with preparing and implementing an Alaska Climate Change Strategy. This will be a transparent document which deals with state policies for anticipated climate change.”

Source: http://climatechange.alaska.gov
5. New Jersey

“Sea level rise is a major concern for New Jersey. Sea level in the Northeast region is projected to rise more than the global average. The State is especially vulnerable to significant impacts due to geologic subsidence, the topography of its coastline, current coastal erosion, and a high density of coastal development. A sea level rise in line with median projections would threaten the majority of New Jersey’s coastline. These effects will be magnified during storm events, increasing the severity of storm-related flooding in coastal and bay areas. Atlantic City is predicted to experience floods as severe as those that today happen only once a century every year or two by the end of the century. In addition, if the recent measures showing a dramatic increased rate of melting of the Greenland ice sheet are substantiated by further data, and if the melting continues at this rate or accelerates further, the rate of sea level rise throughout the world will increase significantly, and the severity and frequency of coastal flooding in New Jersey will be even greater.”

“Currently, responses to rising sea levels and increasing erosion along the New Jersey coast have been to construct sea walls and bulkheads, raising land elevation with beach nourishment projects, and the building of jetties to capture sand. All of these approaches are expensive, and the costs can be expected to increase as sea level rises further. The additional impact of anticipated more-intense storms and floods when coupled with higher sea levels will likely compound the growth in costs. (See the report, Beach Replenishment, in this Environmental Trends series.)”


6. The Netherlands

Global warming is a cause for serious concern in low-lying countries. The Dutch aren’t waiting for a catastrophe; they’re taking measures to solve the problem now. New projections of sea-level rise and other potential consequences of climate change, coupled with the aftershock from Hurricane Katrina, prompted Dutch officials to ask this question: What would it take to climate-proof our country for the next 200 years?

In 2007, the Dutch parliament assigned a team of experts, the Delta Committee, to come up with an answer. The group’s final report proposed a combination of aggressive new steps—extending the coastline and building surge barriers—and time-tested strategies like fortifying levees. The cost: about $1.5 billion a year for the next 100 years.

Global warming is a cause for serious concern in low-lying countries. The Dutch are taking major actions to protect from the effects of global change. The following reference is an excellent review of what they are doing in the port of Rotterdam.

7. London, England

The Thames Barrier is one of the largest movable flood barriers in the world. The Environment Agency runs and maintains the Thames Barrier as well as London’s other flood defenses. The Thames Estuary 2100 plan describes how flood risk will be managed in the River Thames estuary to the end of the 21st century and beyond. It also recommends what actions the Environment Agency and others will need to take over the years. The plan is based on current guidance on climate change but is adaptable to changes in predictions for sea-level rise and climate change over the century.

Source: [https://www.gov.uk/guidance/the-thames-barrier](https://www.gov.uk/guidance/the-thames-barrier)
Summary

The scientific community has concluded that human emissions of gases, which absorb in the thermal portion of the spectrum, are increasing the temperatures of the earth’s air, land, and oceans, due to the “greenhouse effect.” This is causing harmful environmental changes, which could become extreme if remedial actions are not soon implemented.

Recently, the scientific community released the following statements to the US Congress:

**June 28, 2016: A Letter from 31 scientific societies to members of Congress** [https://www.aaas.org/sites/default/files/06282016.pdf](https://www.aaas.org/sites/default/files/06282016.pdf)
“Observations throughout the world make it clear that climate change is occurring, and rigorous scientific research concludes that the greenhouse gases emitted by human activities are the primary driver. This conclusion is based on multiple independent lines of evidence and the vast body of peer-reviewed science.”

“Global climate is changing faster than at any time in human history. There is no substitute for dramatic reductions in greenhouse gas emissions to mitigate the negative consequences of climate change.”
Authoritative discussions of climate change and its issues are:

- Climate Science Special Report, https://www.globalchange.gov/content/cssr


There are many experiments and lessons available on the Internet. Examples are:

- http://sciencenetlinks.com
- https://ncse.com/classroom-resources
- https://climatekids.nasa.gov (excellent source for younger students)

A recent article of interest:

- *The Crisis on the Ice*: National Geographic, July 2017 (An extensive discussion of the melting of ice shelves and glaciers in the Antarctic, with excellent graphics)