CLIMATE CHANGE IMPACT

UNIT III: How will climate change affect life on Earth?

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

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

* This report is updated periodically. The Fourth National Climate Assessment, released on November 23, 2018, can be found here: https://www.globalchange.gov/nca4
III.A: Polar and Glacial Ice Melt

Key Concepts and Web-app Resources:

Polar bears became the early “poster child” for climate change impact. In the 1970s, our improving understanding of global warming converged with a decades-long study on polar bear population decline due to habitat loss and over-hunting.* Cue images of stranded polar bear families on floating ice or starving polar bears in a frozen desert landscape. While polar bears do rely upon arctic sea ice for hunting and resting, they are just one of countless species imperiled by diminishing sea ice. Seals and walruses use sea ice as breeding grounds, narwhals hide in sea ice from predators, and sea birds rest on the floating platforms. Sea ice formation at Earth’s poles creates microscopic spaces between the crystals where algae can grow in brine channels. Recent studies, like the one conducted by the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, show that this sea ice algae feeds a far reaching community of zooplankton and other arctic animals. “Ice-associated animals derive between 60 and 90 percent of their carbon from the ice [algae],” including animal life at great depths below the ice. The extent of sea ice in the Arctic has declined by about 2.8% per decade since 1978. Moreover, studies indicate a sharp decrease in the ice thickness. Continued arctic ice melt may have far-reaching consequences on the food web of the oceans.

Though sea ice melt can have consequences for the ocean current circulation, it does not affect sea levels. Melting glacial and Antarctic land ice, however, does cause global ocean rise. Since reliable records began, the oceans have risen 8 inches (.2 meters) due to a combination of thermal expansion and land ice melt, primarily from Greenland. According to the National Snow and Ice Data Center (NSIDC), if all of Greenland’s ice sheet were to melt, the ocean would rise 6 meters, or 20 feet. Luckily, Antarctica is buffered from extreme ice melt by the Albedo Effect and by being surrounded by frigid waters, because melting those ice sheets would cause a 200 foot rise in sea levels! Finally, two thirds of the Earth’s freshwater is found in land ice. Winter snow pack in the mountains of northern California is what primarily recharges their reservoirs each spring. Melting glaciers means a loss of freshwater supplies. *Polar bear populations are up since the 1972 passage of the Marine Mammal Protection Act (MMPA).

Unit IIIA. Web-app Resources:

> Climate Change Impact
  >> Polar and Glacial Ice
    >>> NASA Images of Change: Glacier Melt
    >>> Antarctic & Greenland Land Ice
    >>> National Snow and Ice Data Center (NSIDC)
    >>> Arctic Sea Ice and Albedo Effect
  > Oceans and Coasts
    >>> If Antarctica Melted
III.A: Polar and Glacial Ice Melt—Classroom Activity

Lesson: How is climate change impacting ice cover at the poles? How does variation in sea or land ice affect the ecosystem?

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


NGSS Standards:
- 5-ESS2-2 Earth’s Systems
- 5-LS2-1 Ecosystems: Interactions, Energy, and Dynamics
- MS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics
- MS-LS2-3 Ecosystems: Interactions, Energy, and Dynamics
- MS-LS2-4 Ecosystems: Interactions, Energy, and Dynamics
- HS-ESS2-2 Earth’s Systems

ENGAGEMENT

- Ask students: Do you know what the cryosphere is? A: It is the part of the geosphere that includes all the land and sea ice sheets. The amount of ice cover at the poles fluctuates with seasons. These ebbs and flows have been studied for their impact on weather systems, ocean currents, marine food chains, and feedback to the climate system.
- Introduce or review the idea of the Albedo Effect, if you haven’t covered it recently.
- Optional: Use the NSIDC Imaging tool to show them the seasonal changes of arctic sea ice extent for an earlier year (e.g: 1980) by putting in the desired parameters. Found here: [https://nsidc.org/data/seaice_index/archives/image_select](https://nsidc.org/data/seaice_index/archives/image_select)
- Recent warming of our planet has had an effect on the cryosphere and everything that goes with it. Ask students to name wildlife that live in the Arctic. They will likely name polar bears and seals. What about zooplankton and krill? What is there relationship to the ice? A: They feed on the ice algae that live in sea ice channels.

EXPLORATION

- Using the web-based application, load the Charctic Interactive Sea Ice Graph by following: >Climate Change Impact>> Polar and Glacial Ice >>>National Snow and Ice Data Center (also found here: [https://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph](https://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph))
  - You can either manipulate the data from the front of the room, or if students have access to a computer lab, have students navigate to this graph themselves. **NOTE: If the graph does not load, check your browser permissions at the top of the page. You may need to allow the app to “load unsafe scripts” first. That will reset you to the home-screen. If you navigate to the graph again, it should now work. Doing this once allows all other scripts on the app to load without a problem while the app is still open.**
- Have students begin by defining sea ice and land ice on their worksheet.
EXPLORATION (continued)

- Using the Ch@rctic Interactive Graph:
  - Start by selecting “Hide All” on the right-hand bar.
  - Toggle on the 1981-2010 Average—it will display as a dark grey line; and Standard Deviation—it will display as a light gray shaded region around the average. This represents degree of certainty from natural fluctuations, and measuring errors. The standard deviation given is +/-2 million kilometers squared.
  - Orient students to the graph. The Y-Axis is “Extent of Arctic Sea Ice,” measured in millions of square kilometers. The X-Axis is “Time,” specifically the calendar year from January 1 through December 31. When students select a year (let’s say 1980) from the right-hand bar to display, it will chart that year’s daily ice data in a colored line.
    - Show students that they can even see what that amount of ice would look like for a specific date, by clicking on the year-line at any point. A grey circle on the satellite image representation means no data.
    - They can look at the difference between winter and summer ice, visually. The orange line in the map represents the Median for that particular date.
  - Notice that Arctic Sea Ice extent grows in the winter months and shrinks in the summer months, following the pattern of temperatures in the Northern Hemisphere.
  - Have students begin working on question 2 on their worksheets by looking at the pattern of ice extent for the past 10 years. They should be recording any year where the curve of the line falls below standard deviation for the summer months. If it rides the lower edge of the light gray shaded area, they should record that year.
  - Next, we will look at changes in land ice over time. Climate data can come in a variety of forms. Surveyors and nature photographers returning to the same location decades later can provide a unique look into our changing planet. Satellite images can now also provide remarkable aerial perspectives of even difficult to reach locations. Using the web-based application, view the NASA image of Muir Glacier:
    >Climate Change Impact>>Polar and Glacial Ice>>>Images of Change NASA Glacier Melt
    (also found here: https://climate.nasa.gov/images-of-change?id=376#376-muir-glacier-melt-alaska)
    - Use the slider to see the difference between Muir Glacier, in Alaska, from 1941 to 2004.
    - Caption (Source—NASA): “The 1941 photograph shows the lower reaches of Muir Glacier and its tributary, Riggs Glacier. The two glaciers filled Muir Inlet. In the 2004 photograph, Muir Glacier, continuing a retreat nearly two centuries long, is located about 4 miles (7 kilometers) to the northwest, out of the field of view. Riggs Glacier has retreated some 0.4 miles (0.6 kilometers). Both glaciers have thinned substantially.”
    - Glaciers either advance or retreat in response to slight, but prolonged changes to climate. The current rate of glacial retreat is faster than it has been in 5,000 years, doubling in the past 25 years.
    - If there is time, you can allow students to explore other areas of the map, by clicking the “location” pointer button at the top right of the NASA widget. Have students answer question 3 and 4 on their worksheets in their own words.

EXPLANATION

- Review their answers using the Teacher Answer Sheet. By comparing past decades with the current one on the Ch@rctic Sea Ice Interactive Map, it starts to become more clear how abnormal the recent pattern of summer ice loss
III.A: Polar and Glacial Ice Melt—Classroom Activity

is, and why it may be a cause for concern to climate scientists... and lovers of polar bears.

- If students struggle to understand why sea ice melt does not contribute to sea level rise whereas land ice melt does, consider setting up the following demonstration:
  - Get 2 clear glasses, a small but rigid piece of mesh or chicken wire, and some ice.
  - Fill the first glass up with ice and water together until the level is to the brim of the glass. The ice in this glass represents sea ice.
  - Fill the second glass up to the top with water alone. Place the mesh over the second glass carefully and put approximately the same quantity of ice as the first glass onto the mesh over the second glass. The ice over this glass represents land ice.
  - Let the ice for both glasses melt.... Do they both spill over? No, only the land ice glass floods.
  - Explain that ice in the first glass—sea ice—is already displacing water in the glass. Because ice actually expands as it freezes, melting could even perceivable lower the level of water in the glass. The ice over the second glass melts from the “land” into the “sea”, raising its level.

- Why be concerned with sea level rise from ice sheet melt? A: We might not be in an ice age but we are in an Icehouse State. In other words, there’s still a lot of ice on Earth! If large quantities of ice melt, it would drastically change our geography. Most of the world’s population live on the coasts. Sea level rise of even a few feet could completely flood out cities like Miami, New Orleans, and even parts of Boston!

- Use the web-based application to explore maps of a world without ice:
  - >Climate Change Impact<< Oceans and Coasts>>> If Antarctica Melted Maps
    (also found here: https://climate.nasa.gov/images-of-change?id=376#376-muir-glacier-melt-alaska)
    - As stated in this chapter’s overview, if all the Antarctic ice sheets melted, the oceans would rise 200 feet higher than they are today! These images, while perhaps disturbing, are luckily still only an extreme of a distant future (a thousand years or more) if warming is unchecked. However, a 6-10 foot rise in sea-levels is still possible in our lifetime if we do not mitigate our carbon footprint.

ELABORATION

- Extend this lesson into the effects on polar animals and the arctic ecosystem by showing the PBS video on the web-based application and/or buying copies of the EcoChains—Arctic Life Card Game and having students play each other.

- >Climate Change Impact<< Wildlife>>> A Warmer World for Arctic Animals
  (also found here: https://ny.pbslearningmedia.org/resource/kqedcl11.sci.ess.warmerworldforarcticanimals/a-winter-world-for-arctic-animals/#_=_)

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1) Define the following terms:
   a) Sea Ice: ____________________________________________
   b) Land Ice: ____________________________________________

*Use the web-based application to load the interactive graph on Arctic Sea Ice Extent:*
>Climate Change Impact>>Polar and Glacial Ice>>>National Snow and Ice Data Center

2) Look at the graph comparing arctic ice cover from the past few decades and determine which years the data suggests that we are *losing arctic sea ice in summer months* beyond what can be accounted for by measuring errors (standard deviation). Record each year in the last decade where this is true.
   A: ____________________________________________________

*Next, use the web-based application to load the NASA Images of Change Widget:*
>Climate Change Impact>>Polar and Glacial Ice>>>Images of Change NASA Glacier Melt

3) Look at the images of Muir Glacier in August 1941 and August 2004. Describe the difference between the two images below:
   A: ____________________________________________________
   ______________________________________________________

4) Describe the relationship (if any) of sea ice melt and land ice melt to each of the following:

<table>
<thead>
<tr>
<th>Impact of:</th>
<th>Sea Ice Melt</th>
<th>Land Ice Melt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar Animals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshwater Availability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea Levels</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
III.A: Polar and Glacial Ice Melt—Teacher Answer Sheet

1) Define the following terms:
   a) Sea Ice:______ Frozen ocean water that grows and melts in the ocean at the poles, depending on the season.____
   b) Land Ice: Ice sheets that form on land when winter snows never melt and get compressed into ice over years.

Use the web-based application to load the interactive graph on Arctic Sea Ice Extent:
>Climate Change Impact>>Polar and Glacial Ice>>>National Snow and Ice Data Center

2) Look at the graph comparing arctic ice cover from the past few decades and determine which years the data suggests that we are *losing arctic sea ice in summer months* beyond what can be accounted for by measuring errors (standard deviation) Record each year in the last decade where this is true.

Next, use the web-based application to load the NASA Images of Change Widget:
>Climate Change Impact>>Polar and Glacial Ice>>>Images of Change NASA Glacier Melt

3) Look at the images of Muir Glacier in August 1941 and August 2004. Describe the difference between the two images below:
   A: Frozen rivers are replaced with a temperate looking climate and flowing water. In other words, the glaciers are ______

   receding or retreating.

4) Describe the relationship (if any) of sea ice melt and land ice melt to each of the following:

<table>
<thead>
<tr>
<th>Impact of:</th>
<th>Sea Ice Melt</th>
<th>Land Ice Melt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar Animals</td>
<td>Loss of habitat, possible starvation or drowning in summer without normal sea ice to rest on/hunt on. Migration into new areas for food?</td>
<td>Loss of habitat. Changes to food availability. Possible phenology changes.</td>
</tr>
<tr>
<td>Freshwater Availability</td>
<td>Not really, new ice still has saltwater brine channels in it, making it undrinkable.</td>
<td>Rapid snow pack and glacial ice melt depletes an important freshwater sources for downhill.</td>
</tr>
<tr>
<td>Sea Levels</td>
<td>No change. Sea ice is already in the sea—no displacement takes place.</td>
<td>Yes, land ice melts into the ocean, raising sea levels over time.</td>
</tr>
</tbody>
</table>
III.B: Water Cycle & Extreme Weather

Key Concepts and Web-app Resources:

The water cycle guides the movement of water molecules from land and oceans surfaces to the atmosphere where is condenses into clouds. Air movement circulates the atmospheric moisture and once it reaches a saturation point, we experience precipitation. Sometimes the rain can go on for days, slowly passing over the continents and recharging reservoirs and groundwater. This cycle is essential to life on land. Without adequate rain, grasslands become deserts, food production uses up our aquifers, and animal life must migrate or face local extinction. In recent decades, rapid climate change has fundamentally altered the water cycle as we know it. While year-to-year rainfall may still be as erratic as the weather, and different regions may experience more or less precipitation than they did historically, one overall trend is emerging: downpours are more intense and more frequent, but the total area of Earth’s land surfaces getting adequate rainfall in any given year is shrinking! In other words, deluge or drought extremes are becoming the new normal. Why is this?

A warmer hydrosphere, geosphere, and biosphere means higher rates of evaporation/evapotranspiration. A warmer atmosphere can hold more water before saturation. That means once it rains, it is more likely to pour. However, a warmer atmosphere also takes longer to recharge between storm events, which can lead to drought conditions—extensive periods of time without much rain, causing water shortages. Drought conditions can actually compound the consequences of heavy downpours because dry earth is less absorbent than moderately moist soils. Flooding and erosion occurs when heavy rains meet dry-cracked earth or over-saturated soils; the rain either sits on the surface causing flood contamination, or runs off, eroding topsoil.

The moisture that fuels extreme weather like typhoons and hurricanes originates over the ocean. As the ocean warms, it is capable of generating more powerful storms. Paired with rising sea-levels, hurricanes are causing unprecedented damage at our coasts.

Unit III.B. Web-app Resources:

> Climate Change Impact
  >> Water Cycle and Extreme Weather
    >>> Deluge
    >>> Drought
    >>> Freshwater Availability and Consumption
    >>> Extreme Precipitation (slideshow with captions)
    >>> NOAA State of the Climate (Drought Monitor)
    >>> Cost of Extreme Weather
III.B: Water Cycle & Extreme Weather—Classroom Activity

Lesson: How is extreme weather connected to climate change? What are the true costs of storms, like hurricanes, or extensive droughts to the economy and to human health and wellness?

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

Materials: Web-based climate app, prepared fact sheets about Billion Dollar Weather Disasters or computer access, student worksheets.

NGSS Standards:
MS.Weather and Climate
HS-ESS2-2 Earth’s Systems

ENGAGEMENT (5-8 minutes)

• Ask students: What causes droughts and floods?
• Use the web-based application to watch the following videos on flood and drought events:
  >Climate Change Impact>> Water Cycle and Extreme Weather>>>
  Deluge
  >Climate Change Impact>> Water Cycle and Extreme Weather>>> Drought
  (also found as a set, here: https://ny.pbslearningmedia.org/resource/dce5a696-4f0c-47c5-a2ba-5e517c779089/water-cycle-animation)
• Ask: what do you think are some of the consequences of each?

EXPLORATION (20 minutes)

• Before class, prepare copies of this list U.S. Billion Dollar Weather and Climate Disasters 1980-2018. (https://www.ncdc.noaa.gov/billions/events.pdf) You can either pre-select a few key storms/hurricanes or drought periods and create individual sheets, or ask students to choose either a severe storm, hurricane, or drought to profile themselves.
• Alternatively, if your students have computer access, they can use the following website to key into their home state. By clicking on their state on the map, a table listing billion dollar disasters from 1980-2018 for that state will load. https://www.ncdc.noaa.gov/billions/mapping
• Have students work in teams to research one extreme weather event of their choice and record the relevant data onto their student worksheets.
• Students will then take turns briefly summarizing their weather event data to the rest of the class.
• What are the long-term consequences of more frequent and more costly extreme weather disasters? Where are we most vulnerable?

EXPLANATION (20 minute slide-show with discussion)

• Use the web-based application to present a slideshow on the cost of extreme weather:
  >Climate Change Impact>> Water Cycle and Extreme Weather>>> The Cost of Extreme Weather
III.B: Water Cycle & Extreme Weather—Classroom Activity

• Captions for Slide-show:

  • (1/9): As extreme precipitation events become more common, so does extreme flooding. Our stormwater infrastructure was not designed for our rapidly changing climate. This slideshow shows the many effects that extreme rain and wind can cause.

  • (2/9) The map above shows the number of times between 1980 and August 2011 that a U.S. state has been involved in a weather or climate disaster whose region-wide damage totals were at least one billion dollars at the time they occurred. The maps are based on records of economic losses kept by NOAA’s National Climatic Data Center.

  • (3/9): It’s official: 2017 was the costliest year on record for the United States when it comes to natural disasters. According to NOAA, the disasters caused $306 billion in total damage in 2017, with 16 events that caused more than $1 billion in damage each. The bulk of the damage, at $265 billion, came from hurricanes Harvey, Irma, and Maria, as well as wildfires on the west coast.

  • (4/9): Once considered 500-year events, storms like Hurricane Katrina (2005) now occur decades apart or less. Hurricane Katrina destroyed much of the Gulf Coast, especially the city of New Orleans. Severe flooding and inadequate response left many without drinking water, food, or proper first aid for days, if not weeks. Over 1,200 deaths are attributed to Katrina and $161 billion in losses.

  • (5/9) Flooding in Louisiana has become more common in recent years, even in the absence of a hurricane. In August 2016, prolonged rainfall resulted in catastrophic flooding in the state. Thousands of houses and businesses were submerged.

  • (6/9) Hurricanes and heavy rain events have different impact depending on where they hit and when. Hurricane Irene (2011) brought 16 inches of rain to upstate New York after an already unseasonably wet August. Saturated soils gave out to erosion and roads and bridges were washed out. It is now considered the most costly Category 1 storm in history.

  • (7/9) Some storms bring surges along the coast from high winds, instead of heavy rain. This was the case for Superstorm Sandy (2012). Winds swept the peak tide into highly developed areas with great population densities. As a result of the salt-water flooding, economic losses topped $65 billion.

  • (8/9) As the number of billion dollar weather events continues to rise, what do you think that will mean for the cost of goods and services? For taxes and insurance rates? For equitable access to basic needs?

  • (9/9) Knowing how vulnerable a location is to costly weather disasters is important to the people who live there, and to emergency planners and insurers. Ultimately, records like this should help scientists figure out if, in addition to the known influence of population growth and development, long-term climate change is contributing to the cost of weather-related disasters.

ELABORATION (10 minutes + homework)

• Studies show that people are more likely to respond to news about climate change and extreme weather when it is personal to them. Most of us have experiences extreme weather in our lives, or have family members who have. For some, the losses may be more devastating than others. Try to be mindful that some students may have had to move due to extreme weather, or even lost loved ones.

• To encourage students to share their personal experiences, you can show one or more Youth Climate Story videos from the Alliance for Climate Education (ACE), found here: https://ourclimateourfuture.org/map.

• For homework, ask students to write a 1-2 page essay about their own extreme weather experience. For students who claim no personal experience to draw from, or for students who are uncomfortable sharing their story, they can choose another ACE Youth Climate Story to watch and write an essay about.
III.B: Water Cycle & Extreme Weather—Classroom Activity

Use the provided data source of billion dollar weather disasters to profile either a drought, severe storm, or hurricane of your choosing.

Record the reported human and economic losses from one of these super storms.

A. Event Choice/Name: _________________________________________________________

B. Event Type: ______________________________________________________________
   i. If it was a hurricane, what category storm was it? _____________________________

C. State(s) or region affected: _______________________________________________

D. When did this event take place? _____________________________________________

E. Any important details that made this weather event particularly costly? (e.g.: slow moving, coinciding with high tides, size or range)
   __________________________________________________________________________
   __________________________________________________________________________

F. Sectors most affected?: (e.g.: agriculture, forests, infrastructure, utilities, properties, natural resources)
   __________________________________________________________________________

G. Total estimated economic losses? ____________________________________________

H. Number of estimated deaths attributed directly or indirectly to event? ________________
III.C: Oceans and Coasts—Overview

Key Concepts and Web-app Resources:

We live on a blue planet. Seventy-five percent of the Earth’s surface is covered in saltwater. The vastness and depths of the oceans have buffered us against more severe changes to our climate. Ocean water heats much more slowly than land masses, meaning it absorbs much of our excess heat without large temperature changes. Our ocean is also a carbon sink because it can dissolve carbon dioxide from the atmosphere, mitigating the greenhouse effect from our additional carbon emissions. Still, we have learned from the previous chapters, that ocean ecosystems are threatened by sea-ice melt and that more powerful storms are being powered by warmer ocean temperatures. A marine ecosystem compromised by overfishing, pollution, coral and mangrove destruction (important fish nurseries), and now climate change, in turn impacts life on land—including us. Over one billion people around the world use the ocean as their primary source of food. According to NOAA’s Fisheries Economics of the U.S., commercial and recreational fishing generated over $208 billion in sales in 2017, contributing $97 billion to the gross domestic product. Additionally, the industry employed over 1.8 million people. Coastal tourism and recreation is another large economic driver that depends upon more stability. All over the world, people are still intrinsically linked to the ocean.

While warming has its own adverse consequences to our oceans, excess carbon dioxide emissions from burning fossil fuels for energy poses another unique threat: ocean acidification. In just 200 years, the Earth’s oceans have absorbed more than 150 billion metric tons of carbon from human activities. Dissolved CO$_2$ reacts with water to create carbonic acid molecules, which ionizes to form a mix of bicarbonate, carbonate and hydrogen ions. An excess of dissolved CO$_2$ causes an imbalance of reactants and leads to extra hydrogen ions which acidifies the ocean. Zooplankton and other marine organisms require carbonate ions to create their exoskeletons in a process called calcification. As the ocean dissolves more CO$_2$, it produces more hydrogen ions which also bond with carbonate ions to form bicarbonate, impeding the calcification process. Because ocean acidification impacts lower trophic level consumers, it affects the whole ocean food web.

Unit III.C. Web-app Resources:

> Climate Change Impacts
   >> Oceans and Coasts
      >>> Ocean Acidification (ACE video)
      >>> NOVA Impact of Ocean Acidification
      >>> NOAA Digital Coast Mapping Tool
      >>> If Antarctica Melted
Lesson: What Impact Will Climate Change Have on Marine Ecosystems?

App Resources: >Climate Change Impacts>>Oceans and Coasts

Subject / grade level: Chemistry, Environmental Science/ 9th – 11th grade

NGSS Standards:

HS-LS2-6. Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth’s systems.

ESS3.C: Human Impacts on Earth Systems

ESS3.D: Global Climate Change

Materials:

- Jars with different types of seashells: (make at least one week in advance)
- 2 jars with lids
- Seashells – snail, oyster, mussel
- Vinegar
- Water

To prepare: Put some shells in a jar and fill with water. Fill the other with shells in white vinegar. If done at least a week in advance, shells in vinegar will have started to disintegrate.

- Phenol Red Experiment: (Prep samples ahead of time)
  - Phenol red indicator
  - Glass jars with one-way valve tops
  - Straws (can cut in half to reduce waste)
  - pH Test strips or test kit

To prepare (can be done up to 2 days in advance): make a solution with 1:10 phenol red and water in each jar. Color should still be a deep red. Tightly screw in lids with one-way valves on top.

Lesson objective(s): Through a video and hands-on lab activity, students will understand the chemical process of ocean acidification and its effect on the marine ecosystem.

ENGAGEMENT

Ask students what kinds of impacts climate change may have on the marine environment. If they don’t offer it, ask if they’ve heard of warming water conditions, mass coral bleaching, or ocean acidification. Will this affect the animals that live in the oceans and rivers in our area? What change do they think may stem from these two issues?

Web-app Resource: Climate Change Impacts>>Oceans and Coasts>>Ocean Acidification (ACE Video)
III.C: Oceans and Coasts — Acidification (page 2)

EXPLORATION

- Ask students to explain in their own words what ocean acidification is. Show them the two jars of shells in different media. Ask which they think is the one with a higher level of acidity. Ask if they recognize any of the animals that built those shells. Do they think that would have an impact on any other organisms in the environment? Do any of these organisms provide habitat for other plants or animals? Would they impact the food web? Could it affect humans?

EXPLANATION

- What is going on chemically when we talk about ocean acidification? What is carbonic acid and how is it made?
- Students may not remember from the video, so prompt them:
  - When carbon dioxide enters the water, it combines with water molecules to make carbonic acid. Carbonic acid disassociates into bicarbonate and hydrogen ions.
  - There are also carbonate ions floating around in the water, which animals such as mollusks/bivalves (clams, mussels, oysters, scallops etc.) need to make their shells.
  - The extra free hydrogen ions (from the carbonic acid) “steal” the carbonate floating around and make bicarbonate which is not useful for mollusk-shell building.
  - Since there are fewer carbonate ions, the shells of mollusks become weaker. Crustaceans (crabs, lobsters, shrimp etc.) use chitin for their shell, not carbonate. But if their food sources die out that could impact the rest of the food webs in the environment. These cascading reactions harm the ocean but also harm people.

ELABORATION

- Students will do this lab activity to produce carbonic acid – they can measure the change in acidity both by sight and by testing the pH. They will learn how excess carbon dioxide can physically alter the water.

- Lab activity: Review the pH scale as logarithmic and remind students that each jump on the scale represents a tenfold change, rather than only 1 degree (like temperature).

- Take out the phenol red jar solutions. Split students into groups and have them test the pH of the solution before starting the experiment on datasheet. Now, have students use straws to take turns blowing air bubbles into the jar. After only 30 seconds to a minute they will start to see a change in color from deep red to orange. If they continue blowing air into the solution the color will continue to change. Have the students test and record the pH again at the end of the activity. The pH should have shifted slightly to be more acidic. Review the logarithmic scale again and have the class figure out how much more acidic the solution became.

EVALUATION

- By the end of the lesson, students should know:
  - The definition of ocean acidification.
  - How carbonic acid is made.
  - What effect ocean acidification will have on mollusks.
  - How that will affect the rest of the marine food web and ecosystem.
  - Students should fill out the attached worksheet for evaluation.

EXTENSION

- Further resources for students:
  - Ocean Acidification’s impact on oysters and other shellfish: [https://www.pmel.noaa.gov/co2/story/Ocean+Acidification%27s+impact+on+oysters+and+other+shellfish](https://www.pmel.noaa.gov/co2/story/Ocean+Acidification%27s+impact+on+oysters+and+other+shellfish)
III.D: The Future of Farming

Key Concepts and Web-app Resources:

There is perhaps no human activity more critical to civilization than modern agriculture. Our food system means by and large, our meals come to us. In the United States, less than 2% of the population are farmers, with each farm feeding 165 citizens. The ability to dependably produce crops is integrally linked to climate conditions. The Dust Bowl of the 1930s is a prime example of this. Severe drought and poor soil management turned over 75% of the once fertile topsoil in the Midwest states to a cloud of dust that swept over the nation. Today, climate change threatens farmland across the globe with drought, heat-stress, and soil fertility loss through heavy rain events. Warmer climates also tend to favor pest species and fungal diseases that bring heavy crop losses, or even total failures. Still, some regions, typically too cold for major agricultural production, may become more productive as winters become more mild and growing seasons lengthen.

Use the web app resources below to explore some of the noticeable impacts that climate change has had on agriculture on a regional or even global scale.

Unit III.D. Web-app Resources:

>Climate Change Impact
  >>Agriculture
    >>>Climate Change & Agriculture (NASA: Science for a Hungry World)
    >>>USDA Plant Hardiness Zone Map
    >>>Projected Crop Yields 2050 (World Resource Institute)
    >>>NOAA Drought Monitor (Animated Maps)
  >>Wildlife
    >>>Bees are Feeling the Sting of Climate Change
Name: ___________________________ III.D—The Future of Farming—Student Worksheet

On the climate app, navigate from the homepage to:
>Climate Change Impact>>Agriculture>>>USDA Plant Hardiness Zone Map
(adjust the page zoom if necessary to improve visibility, or just print the image)

1) What is zone hardiness?

____________________________________________________________________________________________
____________________________________________________________________________________________

2) What plant hardiness zone do you live in? _________________________________________________________

3) How are plant zones shifting according to the maps from 1990 and 2015?

_______________________________________________________________________________________________

Now, use the climate app to navigate from the homepage to:
>Climate Change Impact>>Agriculture>>>Projected Crop Yields 2050
(adjust the page zoom if necessary to improve visibility, or just print the image)

Deep green means crops produce twice as much yield, whereas deep red means half as much yield from current conditions.

4) a. If the global warming trend continues, what regions may experience better conditions for agriculture and improved yields?  
   b. Which regions will experience worse conditions and reduced yields?
   a. ______________________________________________________________________________________________
   ______________________________________________________________________________________________

   b. ______________________________________________________________________________________________
   ______________________________________________________________________________________________

5) Currently the top four food producing countries are China, India, United States, and Brazil. These countries also require the most food to feed their large populations. If projected crop yield estimates for 2050 are accurate, what effect will the new agricultural landscape have on trade, population, and world hunger? Why?

_________________________________________________________________________________________________
_________________________________________________________________________________________________
_________________________________________________________________________________________________
III.E: Threats to our Forests

Key Concepts and Web-app Resources:

Approximately 30% of the world is covered in forest. Forests are the lungs of world, absorbing CO$_2$ from the atmosphere and releasing oxygen gas as they photosynthesize. While forests alone cannot provide enough oxygen to sustain the world of consumers (algae, diatoms also assist in this), they do provide a home to over 80% of terrestrial organisms, sequester over 13% of human carbon emissions, and provide food and shelter resources for billions of people.

Climate change poses a threat to Earth’s forest cover in a number of ways. First, warming conditions often favor a select few species, especially invasive species, that outperform and choke out biodiversity. In the next few decades, we may see shifting forest types in our wild spaces. Secondly, warming conditions also favor pest species, such as insects and fungal disease, which can then spread more quickly and damage or even kill trees in urban, managed, and natural forests. Finally, long-term droughts paired with higher temperatures dry out the wood of trees, turning them into fuel for forest fires. Burning forests release stored carbon back into the atmosphere, contributing to the greenhouse effect for decades to come.

Use the web-app resources below to explore these threats to our forests, and the repercussions of forest loss to other plants, animals, and people around the world.

Unit III E. Web-app Resources:

> Climate Change Impact
  >> Agriculture
    >>> NOAA Drought Monitor (Animated Maps)
  >> Forests
    >>> Increase in Wildfires (slideshow)
    >>> Global Deforestation (slideshow)
    >>> Forest Pests (Associated Press Video)
    >>> Projected Shifts in Forest Types (slideshow)
    >>> Forests: Lungs of the Planet (NASA Visualization)
III.F: Impacts on Wildlife

Key Concepts and Web-app Resources:

Animals have a key advantage over forests when it comes to a changing planet: they can move! Around the globe, on land and in the oceans, animal species have been shifting their ranges towards the poles an average rate of 10.5 miles per decade. Still, diminished food and water availability as well as habitat loss (caused by forest fire, pests, and invasives) due to climate change put immense environmental pressure on animal life. When change happens slowly, more species of plants and animals have to migrate or adapt. Accelerated climate change is making that difficult. When population numbers decline rapidly, ecologists at the U.S. Fish and Wildlife Service can place a species on a federal list of “threatened or endangered wildlife” for protection. According the USFWS, protective measures include “restrictions on taking, transporting, or selling a species; authority for us to develop and carry out recovery plans; authority to purchase important habitat; and Federal aid to State and Commonwealth wildlife agencies that have cooperative agreements with us.” While this has helped to prevent extinction in many keystone species, it may not be enough to prevent regional ecological collapse in a rapidly changing environment.

Use the web app resources below to explore the different ways wildlife is responding to increasing environmental pressures from climate change.

Unit III.F. Web-app Resources:

> Climate Change Impact
  >> Wildlife
    >>> A Warmer World for Arctic Animals
    >>> Species Ranges Map
    >>> Bees are Feeling the Sting of Climate Change
III.G: Human Health and Disease

Key Concepts and Web-app Resources:

Climate change impacts human health and wellness in myriad ways. For instance, some areas that are more prone to natural disasters could see an increase in physical injury, while others that are vulnerable to high heat or poor air quality, such as our urban areas, could see a spike in respiratory or cardiovascular issues. Certainly, around the world, the strain of climate change on our environment, industry, freshwater and food availability, and stress levels contributes to mental health issues. Public health officials use information about regional vulnerabilities, vector species populations, and nutritional health to create proactive prevention and response plans. Such plans can mitigate the human losses due to disease and minimize their spread.

Understanding the transmission of pathogens to humans is crucial in disease prevention. This requires not only medical professionals, but also city planners, resource management officials, and biologists. That is because many diseases are spread through vector species or contaminated water. Climate change impacts on the water cycle and temperature affects the reproduction rates of both the vector species and the virus/bacteria they transmit. A vector species is any organism that can carry and transmit infectious pathogens from one organism to the next. Mosquitoes breed in stagnant waters, often left behind from flooding rains. More flood events mean more places for mosquitoes to lay eggs, leading to an increase in mosquito population. Warmer temperatures also allow mosquitoes and other vector species ranges to expand, as well as the number of reproductive cycles possible in a year. Each spring, newly hatched ticks look for a new host to feed from. They jump from host to host throughout their life cycle. Shorter winters and warmer springs aid in earlier hatching and more time for reproductive cycles between winters. In recent years, the incidence of West-Nile and Lyme disease in the U.S. has gone up dramatically.

Use the web app resources below and the student worksheets to explore how climate change and extreme weather is already impacting human health and the spread of disease from one region to the next.
Use the climate web-app to navigate from the homepage to:
**Climate Change Impact>>Human Health and Disease>>Climate Change & Human Health** and look at the image.

1) Starting in the center circle, choose a pathway and follow it outward. Each step is part of a pathway that a changing climate affects human health and wellness. Choose two to document below, drawing arrows from one step to the next.

   a. _______________________________________________________________________________________________
      _______________________________________________________________________________________________

   b. _______________________________________________________________________________________________
      _______________________________________________________________________________________________

2) Next, navigate to: **Climate Change Impact>>Human Health and Disease>>Regional Vulnerabilities** and look at the map. Why do health concerns from climate change vary from region to region?

3) Using the images to the right, give two reasons why climate change may contribute to the spread of disease. Hint: It has to do with the proliferation of vector species (like mosquitoes and ticks).

   a) _______________________________________________
      _______________________________________________
      _______________________________________________
      _______________________________________________
      _______________________________________________
      _______________________________________________