AEROSOLS AND THEIR IMPACT ON CLIMATE
by Stephanie McLain

Lesson Overview:
This activity introduces students to global dimming. They should have an understanding of the atmosphere, solar radiation, and global warming (greenhouse gases).

Length: 3 days (90 minute blocks)

Grade Level: 9–12

Additional Teacher Notes are in blue.
Read the entire activity for teacher prep.

Objectives:
• Determine how weather conditions and geography affect the amount of aerosols in the atmosphere.
• Understand how chemical hazards (pollutants in the air) affect our climate.
• Demonstrate a sound understanding of the nature and operation of technology systems.
• Use technology to locate, collect, and evaluate information.

Materials Needed

Activity 1 (per group)
• 2–250 mL Erlenmeyer flasks
• Labels or pen
• 2 rubber stoppers with opening
• 75 mL of children's sand
• 25 mL of volcanic ash
• 2 digital thermometers
• 1 lamp with 100 watt bulb
• Handout 1—Activity 1 Worksheet

Activity 2 (per group)
• Map of the School (or satellite photo) for projection
• 2 pieces of clear contact paper (14 cm²)
• 2 copies of Aerosol Sampler Grid (p. 7)
• 2 pieces of cardboard (30 cm²)
• Cellophane tape
• Duct Tape
• Mini Thermo-Anemometer
• Compass
• Stereo scope
• 1 six sided die
• Handout 2—Activity 2 Worksheet

Activity 3 (per student)
• 1 piece of clear contact paper (14 cm²)
• 1 copy of Aerosol Sampler Grid (p. 7)
• 1 piece of cardboard (30 cm²)
• Cellophane tape
• Handout 3—Activity 3 Worksheet

Day 1

INTRODUCTION (10 MINUTES)
• Students will take out their notebooks and define the terms found on the board. (I have a vocabulary notebook that students use throughout the year)

DISCUSSION (20 MINUTES)
• Lead into a discussion/lesson on aerosols: what are they, where do they come from, what impact do they have on the atmosphere. (Students will take notes throughout the discussion—depending on your process)

ACTIVITY 1 (15 MINUTES)
• Lab stations should be set up prior to class
• Students will complete the lab and then return to their seats.

*Stephanie McLain is a teacher from West Virginia who developed this lesson plan for Montana State University's ERTH 591 Understanding Climate Change graduate course as part of a tool-kit of teaching activities relating to climate change. The course is part of the National Teachers Enhancement Network (NTEN) of online graduate courses for science teachers based at Montana State University.

This material is based on work supported by the National Science Foundation under Grant EPS-1101342. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.
Volcanic aerosols can significantly affect the Earth’s climate.

- Discuss examples. Types/Causes of aerosols (Teacher information is at the end of this document)
- Discuss global dimming and how it is related to climate change. (Teacher information can be found in an excellent website with animations: https://www.ldeo.columbia.edu/~liepert/media/flash/globalDimming.swf)

ACTIVITY 2 & 3 (35 MINUTES)
- Introduce the Aerosol activity
  - To apply what they have learned about airborne aerosols, students will work in groups to make an aerosol sampler, a simple adhesive tool that allows students to collect data and estimate the extent of aerosols present in their school community and neighborhoods. By participating in this activity, students will obtain a quantitative measurement of the aerosols present in the neighborhood of the school and, as an optional activity, at students’ homes.
  - Project a map of the school and discuss locations to collect samples—mark the locations with letters (one for each group). I break students up into groups of 2 to increase trials and assign each group a location.
  - Hand out Activity 2 Worksheet and review the instructions with the students.
  - Teacher lead instruction on how to set up samplers—demonstration.
  - Tape 1 piece of contact paper in the center of the cardboard with the sticky side up. Keep the protective backing on the contact paper (see Figure 1—Activity 2 Worksheet).
  - Explain to students that they will have to use the tape to anchor the sampler to the location
  - Release students to their locations.
  - When students return instruct them to pick up Activity 3 Worksheet and prepare a sampler for home.

WRAP UP OF DAY 1 (10 MINUTES)
Exit Ticket: Have students complete a graph of their data from Activity 1.

Day 2
INTRODUCTION: (10 MINUTES)
- Review aerosols. (Possible addition: add demonstration using smoke paper to show aerosols.)
- Have them collect their samples from the school and take out home samples along with all worksheets. Discuss what their initial thoughts are based on just glancing at the aerosol samples.

ACTIVITY 2 & 3 CONCLUSION (65 MINUTES) (split between finishing activity and discussion)
- Have students complete the Day 2 Procedure from Activity 2 Worksheet. This will also include analyzing their home data.
- Have students share their school data and home data.

WRAP UP OF DAY 2 (15 minutes)
- Write a three sentence summary. Explain aerosols and their impact on the environment.
Day 3

INTRODUCTION: (5 MINUTES)
- Review classroom data; and have students take out all of their information from previous days.

ACTIVITY 3 (25 MINUTES)
- Have students complete the Day 2 Procedure from Activity 2 Worksheet to analyze their home data, Activity 3.
- Have students share their school data and home data.
  - County Map—Divide a map or diagram of your community or area into 4 regions: Northwest, Northeast, Southwest and Southeast. Have students place their labeled adhesive notes on the map/diagram where they live. I also include a table on a white board that is filled in by the students. (Teacher Table 2)
  - Discussion: look at the map and the data you collected from home.
    - What is the relationship between where a student lives and the number of aerosols collected? (Answers vary according to population, industry, agriculture and geography. For example, combustion products from cars, fireplaces, volcanic eruption, and a variety of other sources, including meteorites and comets, could contribute to the amount of aerosols collected in a community.)
    - Discuss world-wide aerosols and their movement, impact, etc

ACTIVITY 4 (60 MINUTES)
- Hand out the Activity 4 Worksheet to the students and have them work on it.
- Students need to turn in all of the activities (because Activity 1 and 2 are group work but 3 was independent, I have them attach their Activity 3 work (all members) to their group work) and the “appetizer” section of the menu before they leave.
- All other portions of the menu must be completed for homework. (1-2 days: depending on the class)
ACTIVITY 1 WORKSHEET

Names _________________________________________________________

Your lab station should have all of the materials needed for the activity.

**Procedure:**
1. Label your flasks A and B, then move your flasks directly in front of your light source, be careful not to disturb the sand.
2. Insert the temperature probes into the rubber stoppers.
3. Check thermometers and make sure they are recording the correct temperature.
4. Put a rubber stopper in both flasks and adjust the probe, it should be in the center of the flask and not touching the sides.
5. Remove the stopper and thermometer from flask B and put your hand over the top and shake vigorously. Replace the stopper and thermometer.
6. Record the initial temperature for both flasks in the chart.
7. Turn on the lamp, wait one minute and record the temperature.
8. Record the temperature every minute for 10 minutes.

<table>
<thead>
<tr>
<th></th>
<th>Flask A Temperature (°C)</th>
<th>Flask B Temperature (°C)</th>
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</thead>
<tbody>
<tr>
<td>Initial</td>
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<td>10 minutes</td>
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</tbody>
</table>
ACTIVITY 2 WORKSHEET—DIRECTIONS

Names__________________________________________________________

Procedure:

DAY 1
1. Write down your location letter and describe the location.
2. Prepare two aerosol samplers.
3. Tape 1 piece of contact paper in the center of the cardboard with the sticky side up. Keep the protective backing on the contact paper (see Figure 1).
4. Pick up the following supplies and go to your designated location
   a. Mini Thermo-Anemometer/compass
   b. Duct Tape
   c. Complete the Weather Conditions in Table A for Initial Conditions. Use the Mini Thermo-Anemometer to collect dew point, wind speed, temperature. Other measurements can be obtained using the internet (www.noaa.gov, type in city, state or zip)
5. Place the aerosol samplers in your designated area on a flat surface, preferably a meter or two above the ground.
6. Remove the protective backing from the contact paper.
7. Return to class.
   a. Pick up Activity 3 Worksheet
   b. Prepare one Aerosol Sampler for home.

DAY 2
1. Retrieve your Aerosol Samplers
   a. Place the Aerosol Sampler Grid, grid side down, over the collecting surface and return the sampler to the classroom.
2. Complete the Weather Conditions in Table A for Final Conditions.
3. Return to classroom.

Complete the following for your School and Home Samples:

4. Remove the sampler from the cardboard and observe the aerosols from the back side of the clear contact paper (grid should be showing through). (see Figure 2.)
5. Using the stereo scope/ magnifying glass or holding the contact paper up to a light (i.e., an overhead projector), count the number of aerosols found in each of 10 randomly selected squares on the Aerosol Sampler Grid.
   a. Randomly select the squares by tossing one die twice. For example, if the numbers come up 2 and 5, the square is found in the second column, fifth row.
6. Record the number of aerosols in each sample square in the “# aerosols (A)” column of Table B: Aerosol Sampler Collection Data. Add up all the aerosols in the 10 randomly selected squares to get a total. Next, divide the total number of aerosols counted by 10 to get an average or mean number per square.
7. Repeat the steps for “# aerosols (B).”
8. Each individual student should now complete steps #4-6 for their Home Sample.
ACTIVITY 2 WORKSHEET

Names: __________________________________________________________

Table A. Observations of Weather Conditions—School Data

<table>
<thead>
<tr>
<th></th>
<th>Initial Observation</th>
<th>Final Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date</td>
<td>Time</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather Conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(cloudy, rainy, sunny)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Humidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Speed and Direction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust or other Visible Aerosols</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table B. Aerosol Sampler Collection Data—School Data

<table>
<thead>
<tr>
<th>Sample Square</th>
<th># Aerosols (A)</th>
<th># Aerosols (B)</th>
<th>Describe the location:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Square 1</td>
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<td></td>
<td></td>
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<tr>
<td>Sample Square 2</td>
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<td>Sample Square 3</td>
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<td>Sample Square 4</td>
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<td>Sample Square 5</td>
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<td>Sample Square 6</td>
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<td>Sample Square 7</td>
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<td>Sample Square 8</td>
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<td>Sample Square 9</td>
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<tr>
<td>Sample Square 10</td>
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<tr>
<td>AVERAGE number of aerosols per square</td>
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</tbody>
</table>
AEROSOL SAMPLER GRIDS
(cut out grids—you need the numbers)
ACTIVITY 3 WORKSHEET (HOME)

Name ________________________________

Procedure:
1. At your home, find a suitable location.
2. Complete the Weather Conditions in Table A for Initial Conditions (Use your equipment or the internet (www.noaa.gov type in your city, state or zip).
3. Place the aerosol samplers in your designated area on a flat surface, preferably a meter or two above the ground.
4. Remove the protective backing from the contact paper.
5. Leave the sampler for at least 24 hours.
6. Place the Aerosol Sampler Grid, grid side down, over the collecting surface and return the sampler to the classroom.

Aerosol Sample Grid

![Aerosol Sample Grid Diagram]

Figure 1. Sampler
## ACTIVITY 3 WORKSHEET (HOME)

Name __________________________________________________________

### Table A. Observations of Weather Conditions – Home

<table>
<thead>
<tr>
<th></th>
<th>Initial Observation</th>
<th>Final Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date</td>
<td>Time</td>
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<tr>
<td>Temperature</td>
<td></td>
<td></td>
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<tr>
<td>Weather Conditions (cloudy, rainy, sunny)</td>
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<tr>
<td>Relative Humidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind Speed and Direction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust or other Visible Aerosols</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table B. Aerosol Sampler Collection Data – Home

<table>
<thead>
<tr>
<th>Sample Square</th>
<th># Aerosols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Square 1</td>
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<td>Sample Square 2</td>
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<td>Sample Square 9</td>
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<td>Sample Square 10</td>
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</table>

AVERAGE number of aerosols per square

Describe the location:
ACTIVITY 4 (FINAL ACTIVITY)

Name __________________________________________________________

AEROSOL MENU

Directions: All work is to be written in your own words.
This is an independent activity, but you can use all notes/book to help you.

APPETIZER (Everyone Shares)

- Compare the aerosol samplers from the school and home.
- Explain any differences in the amount of aerosols.
- Looking at your data/graph from Activity 1 and the discussions, what impact would these aerosols have on the environment if they were permanent?
- Once created, are they a permanent part of the atmosphere? Why or why not?

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ENTRÉE (Select One)

- Design a poster
- Write a news report
- Create a song/rap

All Entrées must include a description of aerosols, and list at least five typical aerosols (include their source and potential hazards.)

SIDE DISHES (Select Two)

- Design a pamphlet that compares the environmental impact of at least two aerosols.
- Write an opinion article about limiting aerosols in the environment.
- Create a cartoon that contains the issues associated with aerosols.

DESSERT (optional)

Alone or with a partner create a short video that serves as a public service announcement for limiting aerosols.
### TEACHER TABLE 1
Weather Condition Summary: Complete as a class, general summary

#### Class Data—School Samples

<table>
<thead>
<tr>
<th>Location Description</th>
<th>Average A</th>
<th>Average B</th>
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<tbody>
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</tbody>
</table>

Continue table for number of groups, I leave the most space for location description.
<table>
<thead>
<tr>
<th>Location Description</th>
<th>Weather Condition Summary</th>
<th>Aerosol Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW</td>
<td></td>
<td></td>
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<tr>
<td>NE</td>
<td></td>
<td></td>
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<tr>
<td>SW</td>
<td></td>
<td></td>
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<tr>
<td>SE</td>
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</tbody>
</table>

I usually put about 10 lines per area (NE, SE, etc) and leave more space for writing. The teacher could also type it in as the students go through the data.
Atmospheric Aerosols: What Are They, and Why Are They So Important?

Aerosols are minute particles suspended in the atmosphere. When these particles are sufficiently large, we notice their presence as they scatter and absorb sunlight. Their scattering of sunlight can reduce visibility (haze) and redden sunrises and sunsets. Aerosols interact both directly and indirectly with the Earth’s radiation budget and climate. As a direct effect, the aerosols scatter sunlight directly back into space. As an indirect effect, aerosols in the lower atmosphere can modify the size of cloud particles, changing how the clouds reflect and absorb sunlight, thereby affecting the Earth’s energy budget.

Aerosols also can act as sites for chemical reactions to take place (heterogeneous chemistry). The most significant of these reactions are those that lead to the destruction of stratospheric ozone. During winter in the polar regions, aerosols grow to form polar stratospheric clouds. The large surface areas of these cloud particles provide sites for chemical reactions to take place. These reactions lead to the formation of large amounts of reactive chlorine and, ultimately, to the destruction of ozone in the stratosphere. Evidence now exists that shows similar changes in stratospheric ozone concentrations occur after major volcanic eruptions, like Mt. Pinatubo in 1991, where tons of volcanic aerosols are blown into the atmosphere (Fig. 1).

Volcanic Aerosol

Three types of aerosols significantly affect the Earth’s climate. The first is the volcanic aerosol layer which forms in the stratosphere after major volcanic eruptions like Mt. Pinatubo. The dominant aerosol layer is actually formed by sulfur dioxide gas which is converted to droplets of sulfuric acid in the stratosphere over the course of a week to several months after the eruption (Fig. 1). Winds in the stratosphere spread the aerosols until they practically cover the globe. Once formed, these aerosols stay in the stratosphere for about two years. They reflect sunlight, reducing the amount of energy reaching the lower atmosphere and the Earth’s surface, cooling them. The relative coolness of 1993 is thought to have been a response to the stratospheric aerosol layer that was produced by the Mt. Pinatubo eruption. In 1995, though several years had passed since the Mt. Pinatubo eruption, remnants of the layer remained in the atmosphere. Data from satellites such as the NASA Langley Stratospheric Aerosol and Gas Experiment II (SAGE II) have enabled scientists to better understand the effects of volcanic aerosols on our atmosphere.

Desert Dust

The second type of aerosol that may have a significant effect on climate is desert dust. Pictures from weather satellites often reveal dust veils streaming out over the Atlantic Ocean from the deserts of North Africa. Fallout from these layers has been observed at various locations on the American continent. Similar veils of dust stream off deserts on the Asian continent. The September 1994 Lidar In-space Technology Experiment (LITE), aboard the space shuttle Discovery (STS-64), measured large quantities of desert dust in the lower atmosphere over Africa (Fig. 2). The particles in these dust plumes are minute grains of dirt blown from the desert surface. They are relatively large for atmospheric aerosols and would normally fall out of the atmosphere after a short flight if they were not blown to relatively high altitudes (15,000 ft. and higher) by intense dust storms.
Through the suppression of storm clouds and their consequent rain, the dust veil is believed to further desert expansion.

Recent observations of some clouds indicate that they may be absorbing more sunlight than was thought possible. Because of their ability to absorb sunlight, and their transport over large distances, desert aerosols may be the culprit for this additional absorption of sunlight by some clouds.

**Human-Made Aerosol**

The third type of aerosol comes from human activities. While a large fraction of human-made aerosols come in the form of smoke from burning tropical forests, the major component comes in the form of sulfate aerosols created by the burning of coal and oil. The concentration of human-made sulfate aerosols in the atmosphere has grown rapidly since the start of the industrial revolution. At current production levels, human-made sulfate aerosols are thought to outweigh the naturally produced sulfate aerosols. The concentration of aerosols is highest in the northern hemisphere where industrial activity is centered. The sulfate aerosols absorb no sunlight but they reflect it, thereby reducing the amount of sunlight reaching the Earth’s surface. Sulfate aerosols are believed to survive in the atmosphere for about 3-5 days.

The sulfate aerosols also enter clouds where they cause the number of cloud droplets to increase but make the droplet sizes smaller. The net effect is to make the clouds reflect more sunlight than they would without the presence of the sulfate aerosols. Pollution from the stacks of ships at sea has been seen to modify the low-lying clouds above them. These changes in the cloud droplets, due to the sulfate aerosols from the ships, have been seen in pictures from weather satellites as a track through a layer of clouds. In addition to making the clouds more reflective, it is also believed that the additional aerosols cause polluted clouds to last longer and reflect more sunlight than non-polluted clouds.

**Climatic Effects of Aerosols**

The additional reflection caused by pollution aerosols is expected to have an effect on the climate comparable in magnitude to that of increasing concentrations of atmospheric gases. The effect of the aerosols, however, will be opposite to the effect of the increasing atmospheric trace gases - cooling instead of warming the atmosphere.

The warming effect of the greenhouse gases is expected to take place everywhere, but the cooling effect of the pollution aerosols will be somewhat regionally dependent, near and downwind of industrial areas. No one knows what the outcome will be of atmospheric warming in some regions and cooling in others. Climate models are still too primitive to provide reliable insight into the possible outcome. Current observations of the buildup are available only for a few locations around the globe and these observations are fragmentary.

Understanding how much sulfur-based pollution is present in the atmosphere is important for understanding the effectiveness of current sulfur dioxide pollution control strategies.

**The Removal of Aerosols**

It is believed that much of the removal of atmospheric aerosols occurs in the vicinity of large weather systems and high altitude jet streams, where the stratosphere and the lower atmosphere become intertwined and exchange air with each other. In such regions, many pollutant gases in the troposphere can be injected into the stratosphere, affecting the chemistry of the stratosphere. Likewise, in such regions, the ozone in the stratosphere is brought down to the lower atmosphere where it reacts with the pollutant rich air, possibly forming new types of pollution aerosols.

**Aerosols As Atmospheric Tracers**

Aerosol measurements can also be used as tracers to study how the Earth’s atmosphere moves. Because aerosols change their characteristics very slowly, they make much better tracers for atmospheric motions than a chemical species that may vary its concentration through chemical reactions. Aerosols have been used to study the dynamics of the polar regions, stratospheric transport from low to high latitudes, and the exchange of air between the troposphere and stratosphere.

**Future NASA Aerosol Studies**

NASA's ongoing Atmospheric Effects of Aviation Project (AEAP) has measured emissions from the engines of several commercial and research aircraft. Jet engine emissions have been shown to affect the concentrations of atmospheric water vapor and aerosols, and they may affect how clouds form and the concentrations of atmospheric ozone. Few actual measurements of their effects have been made, however.

In the spring of 1996, the Subsonic Aircraft Contrail and Cloud Effects Special Study (SUCCESS) focused on subsonic aircraft contrails and the impact of the aerosols in those contrails on cirrus clouds and atmospheric chemistry. Researchers have determined that aircraft contrails can prolong the presence of high altitude cirrus clouds while also decreasing the size of the ice crystals that make up the clouds. Studies like SUCCESS and AEAP will be ongoing as scientists continue to try to understand how aerosols affect our atmosphere and climate.

**ANOTHER GREAT SOURCE**

http://www.eoearth.org/view/article/149855/
EDUCATIONAL STANDARDS

Next Generation Science Standards:

PERFORMANCE EXPECTATIONS
This lesson provides students with experiences that support their readiness to demonstrate mastery of the following NGSS Performance Expectations:

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

[Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.]

**HS-ESS3-6** – Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

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

INDIVIDUAL SEP, DCI, AND CCC ALIGNMENTS:

This lesson plan directly supports students in their understanding of a range of Science and Engineering Practices (SEP), Disciplinary Core Ideas (DCI), and Crosscutting Concepts (CCC).

SCIENCE AND ENGINEERING PRACTICES:
All text for these alignments is taken from Appendix F of the Next Generation Science Standards available at: http://nextgen-science.org/get-to-know.

3. Planning and Carrying out Investigations: Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.
   • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

4. Analyzing and Interpreting Data: Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.
   • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.
   • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations.

5. Using Mathematics and Computational Thinking: Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.
   • Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m³, acre-feet, etc.).

6. Constructing Explanations and Designing Solutions: Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.
   • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

7. Engaging in Argument from Evidence: Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.
   • Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.

8. Obtaining, Evaluating, and Communicating Information: Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs.
   • Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).

DISCIPLINARY CORE IDEAS:

Text for these alignments are taken out of the foundation box of the NGSS and can also be found on page 199 of A Framework for K – 12 Science Education.

**ESS3.D: Global Climate Change**

• Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts.
• Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.
**Montana NSF In CLIMB 4. Systems and System Models:**

3. Scale Proportion and Quantity:

In grades 9-12, students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena.

2. Cause and Effect:

In grades 9-12, students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects.

3. Scale Proportion and Quantity:

In grades 9-12, students understand the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. They recognize patterns observable at one scale may not be observable or exist at other scales, and some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly.

4. Systems and System Models:

In grades 9-12, students can use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. They can also use models and simulations to predict the behavior of a system, and recognize that these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models.

**Alignment to Common Core State Standards for ELA: Grades 6 – 12 Literacy in History/Social Studies, Science, & Technical Subjects**

**Reading – Science & Technical Subjects**

Craft and Structure:

**CCSS.ELA-LITERACY.RST.11-12.4**

Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11 – 12 texts and topics.

**Integration of Knowledge and Ideas:**

**CCSS.ELA-LITERACY.RST.11-12.7**

Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

**CCSS.ELA-LITERACY.RST.11-12.9**

Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

**Writing**

**Text Types and Purposes:**

**CCSS.ELA-LITERACY.WHST11-12.1**

Write arguments focused on discipline-specific content.

**CCSS.ELA-LITERACY.WHST.11-12.1B**

Develop claim(s) and counterclaims fairly and thoroughly, supplying the most relevant data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims in a discipline-appropriate form that anticipates the audience’s knowledge level, concerns, values, and possible biases.

**CCSS.ELA-LITERACY.WHST.11-12.2**

Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

**Production and Distribution of Writing:**

**CCSS.ELA-LITERACY.WHST.11-12.4**

Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

**CCSS.ELA-LITERACY.WHST.11-12.6**

Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.

**About the Montana Institute on Ecosystems**

The Montana Institute on Ecosystems is a community of scientists and partners that studies Montana’s complex ecosystems, including the impacts of climate change on ecosystems and the ways in which people and nature are interconnected. Formed in 2011 with funding from the National Science Foundation’s EPSCoR program, the IoE has offices at Montana State University and the University of Montana. Partners are located at other Montana University System campuses and Montana tribal colleges.

The culminating research and outreach product of the EPSCoR / IoE will be the Montana Climate Assessment (MCA), which involves university researchers, decision makers, and other stakeholders with the goal of providing timely and relevant information for the citizens of the State. The inaugural MCA will focus on climate issues that affect agriculture, forests, and water resources in Montana.

View more education and outreach resources at the Climate in My Backyard site: [http://eu.montana.edu/CLIMB](http://eu.montana.edu/CLIMB)

CLIMB is an educational outreach program serving K-12 teachers and informal educators.