Climate Science for the Classroom

An archive of climate-science focused labs and games for middle and high school teachers and their students. Includes links to blog posts written by graduate student lesson developers that point to expertise from education scientists and K-12 educators that contributed to development of the lessons.

Initial e-publication July 2020.

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Preface

Summer, 2019

Dear Reader, Educator, Contributor and the Curious,

In the early 2000's the University of Washington gathered many vested in the interdisciplinary climate education of graduate students under the umbrella of the Program on Climate Change (UWPCC). Over time UW scientists and graduate students associated with the UW PCC developed partnerships with teachers, and since 2010 have been co-creating teaching materials based on the current state of knowledge in climate science, climate communication, and societal needs. Teachers across the planet need teaching materials that can be readily accessed and a means to connect with others using these materials. Here we offer our works to the educational community, with a creative commons copyright to encourage adaptation while maintaining attribution to the original developer. In this way we hope to contribute to more equitable classroom opportunities.

Who are our authors? Some are faculty members at the University of Washington with deep expertise in a climate related topic. Most are graduate students passionate about broadening understanding in the science and in solutions to the climate challenges that are here now. Many are fulfilling the capstone requirements of our Graduate Certificate in Climate Science, an addition to their PhD or Masters Programs. These students take coursework that spans disciplinary boundaries of climate science, seminars in current research and science communication, and design capstone projects that bring a new understanding of climate science to their chosen audience.

We, the compilation editors, envision this to be a living lab manual. As we are able to upload and format labs for this work, we will make them publicly available. Visit the pcc.uw.edu education section for a list of materials we are working to share here.

We invite constructive feedback and expect to add and update the compilation as long as the UW PCC community continues to create.

Miriam and Surabhi

Seattle, Washington

Miriam is an Oceanographer and Assistant Director of the UW Program on Climate Change (UWPCC). She has worked with graduate students in curriculum development since 2010.

Surabhi is an undergraduate student at the University of Washington studying Atmospheric Sciences and Earth and Space Sciences with a focus on climate. She is currently the undergraduate assistant for the UW PCC and enjoys envisioning how the materials being incorporated in this book could be made most useful in the classroom.

Read more about the development of the program in this EOS article published in February 2019: https://eos.org/project-updates/preparing-graduate-students-for-21st-century-climate-conversations

Other excellent (free) climate and energy teaching materials :

Climate Literacy and Energy Awareness Network (esp. for K-12) https://cleanet.org/index.html

Integrate (esp. for undergraduate earth science) https://serc.carleton.edu/integrate/index.html

Data Nuggets (co-designed by scientists and teachers, designed to bring contemporary research and authentic data into the classroom) http://datanuggets.org/

More labs developed by University of Washington Program on Climate Change affiliates. https://pcc.uw.edu/education/k-12-educator-resources/classroom-resources/climate-teaching-modules/

How to use this book

These teaching tools were created by civil engineers, oceanographers, atmospheric scientists, geologists, policy experts, and more. Collectively they represent the interdisciplinarity of the climate problem, and interconnectivity of the earth system. You'll find tools that incorporate data from the Pacific Northwest to explore local issues with global application, like Ocean Acidification and Extreme Events. Others use data from across the globe to look at climate change variability or focus on communicating climate change issues to a target audience. All take a deep look into specific issues, building skills while learning concepts.

The labs, demos and games were designed with a middle school or high school target audience in mind, and many are adaptable for museums and intro college courses.

Each teaching tool contains some or all the following:

- Overview, often linked to a blog post on development of the resource.
- Focus Questions
- Learning Goals
- Background Information for Teachers
- Prior Knowledge for Students
- Anticipated Challenges
- Ways to Assess Learning
- Unit Materials and Instructions. Some of this material is stored in a Public Google Drive Folder.
    - Answer Keys (for teachers, password protected**)
    - Excel spreadsheets (data)
    - Powerpoint slides
- Supplemental Resources
- Reuse and Copyright. These materials are offered under a creative commons license (CC BY NC SA)–they may be shared and adapted, but **not** for commercial purposes. If adapted, their adaptations must be shared with this same license.
- Attribution. Suggested format for referencing these works.

**To gain access the answer keys email uwpcc@uw.edu with information about where and what you teach, so we can confirm that you are a teacher (not a student!).

Share your feedback!

Have you used one of these lessons in your classroom? Let us know how it went!

Climate Science for the Classroom Feedback Form: **https://forms.gle/P1RksKXJTtLhVyem9**

Thank you!

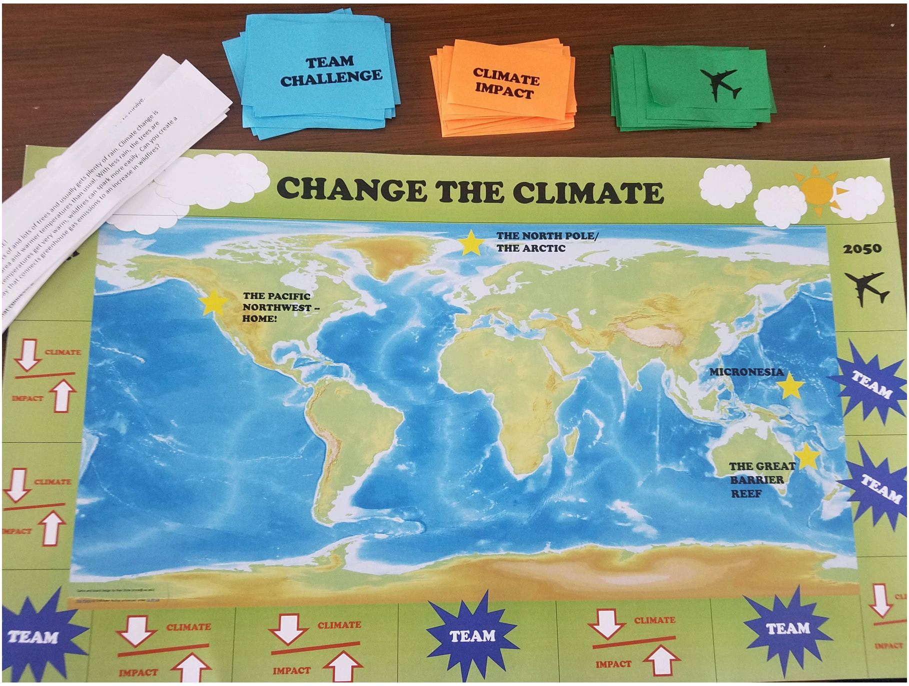
-Miriam and Surabhi

PART I

GAMES

Ready, Set, Curb!

ALEXANDRA STOTE



> *Ready, Set, Curb! is a strategic, interactive board game designed for use in an academic setting. Two versions of game play are available, one for middle school students (MS) and an adaptation for high school audiences (HS). Created by Alexandra Stote in partial fulfillment of the requirements of the Graduate Certificate in Climate Science with guidance from Dr. Karin Lohwasser, UW College of Education, now at UC Santa Barbara.*

Read about game development : "Ready, Set, Curb! A Challenge for Young Students to Act on Climate" Blog Post by Alexandra Stote, June 2019.

Objective:

Can your team reduce the earth's greenhouse gas emissions to zero by the year 2050? Working together, you must answer team challenges and link climate impacts to greenhouse gas emissions in order to help sequester, or remove, greenhouse gases from the atmosphere. The game ends in the year 2050, and the goal is to remove all greenhouse gases by the time you get there! But be careful, some cards and actions require you to add greenhouse gases along the way. How close to zero emissions can your team get by 2050? Good luck!

Required Materials:

- Game Board (MS) (HS)
- Three Types of Playing Cards ("Climate Impact (MS)(HS) ," "Team Challenge (MS)(HS) ," and "Impact Pathway (MS)(HS) ")
- Dice
- Twenty Paperclips
- Bucket
- Game documents (editable versions available at the end of this chapter.)
    - Facilitators Guiding Questions (HS) (MS)
    - Student Guide (HS) (MS)
    - A vocabulary list for students and teachers (adapted from EPA 2013)

Setting up:

The game starts with 20 paper clips in a bucket in the middle. The bucket represents the earth's atmosphere, and the paper clips represent carbon emissions. The goal is to remove all paper clips by the end of the game, which represents achieving zero emissions by the year 2050.

Each player should start with 5 "Climate Impact Pathways" (airplane cards) in their hand and should have their own game piece on the starting line. You only need to start with these cards.

Sort the different cards face down in different piles before beginning.

Description of different cards:

“Climate Impact”: These cards are just like “chance” in monopoly. They tell you what actions to take, and they affect the atmosphere either positively or negatively.

“Team Challenge”: These cards challenge your team to collectively think of a solution to the problem presented to you on the card.

“Climate Impact Pathways” (Airplane symbol): Whenever you land on an airplane, you will have a chance to construct a “climate impact pathway” from the cards with the airplane on the back. The ecosystems (described in *High School Student Guide*) each tell a different story of how climate change is affecting those regions, giving you clues about how an increase in greenhouse gases leads to the climate impact that ecosystem is experiencing. Using the clues, the students will have to put together a full “climate impact pathway” to trace the climate impact back to greenhouse gases. Examples of these scenarios are given in *Facilitators Guiding Questions*.

Game Play:

Everyone starts at the first square. Take turns rolling the die and moving around the board. The square you land on tells you which action to take (described below). Keep playing until every player reaches 2050 and try to get as close to zero paper clips as possible!

Whenever you pick up a card, read it out loud to your team.

When you land on a “**Climate Impact**” square, it could be good or bad for the environment. Read the card and find out!

When you land on a “**Team Challenge**” square, you have the chance to remove greenhouse gases from the atmosphere if you work together and find a solution to the challenge presented on the card. Teamwork makes the dream work!

When you land on a square with an **airplane**, you have the chance to unlock a climate pathway. This means that you can fly to any ecosystem on the board that is labeled. Each ecosystem is described in the "*Guiding document for students*" to give you an idea about how climate change is impacting that ecosystem. Once you fly to the ecosystem, you can construct a "climate impact pathway" using the airplane cards in your hand. The pathway must connect that ecosystem to climate change in some way. For example: If you choose to go to the Great Barrier Reef, and you know that corals are threatened by climate change, you can use your cards to put together a linkage that looks something like this: Greenhouse gases→ Ocean temperatures warming→ Coral bleaching. The point is to create a pathway that illustrates the climate impact in that specific region. Do you want to visit a specific ecosystem but you don't have the right cards to put together a full pathway? That's okay! You can trade your airplane cards with anyone who wants to trade with you.

When you fly to an ecosystem, you must deposit a paperclip in the bucket because flying is one of the biggest contributors to greenhouse gas emissions. However, if you successfully put together a climate impact pathway during your visit there, you may remove as many paper clips as linkages you've made. For instance, in the Great Barrier Reef example I gave above, you could remove 3 paper clips because I linked 3 items. The longer the pathways, the more emissions you can remove!

After you visit an ecosystem and construct a climate impact pathway, you can return to the square you started on to keep playing. Pick up as many airplane cards as you put down so that you still have 5 airplane cards in your hand.

Rules:

- You can only construct one climate impact pathway per ecosystem per game.
- Other players can help you construct the pathways– this is a team game after all!
- Remember to deposit one paper clip when you fly and remove the same number as the linkages you've made.
- Don't be afraid to share ideas during the team challenge! The more

feedback the better.

The future lies in your hands– it's time to turn back the clock on climate change!

Middle School Student Guide:

MICRONESIA

Micronesia is an area in the Pacific Ocean that is made up of thousands of islands. Over half a million people live on the coasts. Many people make a living by fishing or by working in tourism, such as diving. Sea levels have risen by eight inches on average in the last 150 years, which leads to homes flooding and forces people to move. What leads to sea-level rise, and how does sea level rise impact animals or people? Can you create a climate impact pathway that connects greenhouse gas emissions to sea level rise and impacts on humans?

THE GREAT BARRIER REEF

The Great Barrier Reef is the longest coral reef in the world (1400 miles long!) and is located off the coast of Australia. Coral reefs are home to fish, turtles, sharks, and other kinds of marine life. Corals are tiny animals that are very sensitive to water temperature. They turn white when the water is too warm, and if they stay white for too long, they will die. If the corals die, this is also bad for the creatures that depend on reefs for survival and for people who like to go diving on the reef. Can you create a climate impact pathway that connects greenhouse gas emissions to corals dying and impacts on other animals?

THE NORTH POLE/THE ARCTIC

The Arctic is at the North Pole. It is home to land and marine animals who depend on the ice to survive. Polar bears stand on the ice while they hunt for their favorite food– seals. Ice in the North Pole is melting because the temperature of the earth and the water is getting warmer. If the ice melts too much, the polar bears won't be able to hunt, so they won't be able to eat. Can you create a climate impact pathway that connects greenhouse gas emissions to ice melting and impacts on animals?

THE PACIFIC NORTHWEST– HOME!

The area that we live in has lots of and lots of trees and usually gets plenty of rain. Climate change is causing less rainfall in this area and warmer temperatures than usual. With less rain, the trees are getting drier, and when temperatures get very warm, wildfires can spark more easily. Can you create a climate impact pathway that connects greenhouse gas emissions to an increase in wildfires?

Middle School Facilitators Guiding Questions:

Description of different cards:

“Climate Impact”: These cards are just like “chance” in monopoly. They tell the students what actions to take, and they affect the “atmosphere” (greenhouse gas deposits) either positively or negatively

“Team Challenge”: These cards challenge the team to collectively think of a solution to the problem presented to them on the card

“Climate Impact Pathways”: At the end of the game, the students will have to choose one ecosystem out of the four options (Arctic, Micronesia, Great Barrier Reef or the Pacific Northwest) and connect a “climate impact pathway.” The ecosystems each tell a different story of how climate change is affecting those regions, giving the students clues about how an increase in greenhouse gases leads to the climate impact that ecosystem is experiencing. Using the clues, the students will have to put together a full “climate impact pathway” to trace the climate impact back to greenhouse gases. Examples of these scenarios are given below. Note: students will have the descriptions of each of the ecosystems, but they won’t have the guiding questions or the examples that are shown in bullets. The guiding questions and the examples below are for the facilitators to help guide the discussion in groups.

MICRONESIA

Micronesia is an area in the Pacific Ocean that is made up of thousands of islands. Over half a million people live on the coasts. Many people make a living by fishing or by working in tourism, such as diving. Sea levels have risen by eight inches on average in the last 150 years, which leads to homes flooding and forces people to move.

- **What leads to sea-level rise? Hint: it could be something happening in another part of the worl (i.e. sea ice melting)**
- **How does sea level rise impact animals or people?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Sea ice melting→ Sea levels rising→ Habitat loss/Threat to homes and people/Increased risk of floods/Threat to tourism

GREAT BARRIER REEF

The Great Barrier Reef is the longest coral reef in the world (1400 miles long!) and is located off the coast of Australia. Coral reefs are home to fish, turtles, sharks, and other kinds of marine life. Corals are tiny animals that are very sensitive to water temperature. They turn white when the water is too warm, and if they stay white for too long, they will die. This process is called "coral bleaching" because the corals turn white. If the corals die, this is also bad for the creatures that depend on the reefs for survival and for people who like to go diving on the reef.

- **What factors led to corals turning white and dying (i.e. coral bleaching)?**
- **What are some future impacts if corals don't recover from "bleaching" or turning white?**
- **Can you trace warming water temperatures back to greenhouse gases?**
- **How does corals dying affect other animals?**
- **How does corals dying affect people?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Ocean temps warming→ Coral bleaching→ Habitat loss/ Threat to tourism/Harder to find food (for the animals that live on the reef)

ARCTIC

The Arctic is at the North Pole. It is home to land and marine animals who depend on the ice to survive. Polar bears stand on the ice while they hunt for their favorite food– seals. Ice in the North Pole is melting because the temperature of the earth and of the water is getting warmer. If the ice melts too much, the polar bears won't be able to hunt, so they won't be able to eat.

- **What factors of climate change make it more difficult for polar bears to hunt?**
- **What will eventually happen if polar bears can't find enough food?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Sea ice melting→ Habitat loss/Harder to find food

Pacific Northwest– HOME!

The area that we live in has lots of and lots of trees and usually gets plenty of rain. Climate change is causing less rainfall in this area and warmer temperatures than usual. With less rain, the trees are getting drier, and when temperatures get very warm, wildfires can spark more easily.

- **What causes wildfires?**
- **How does climate change contribute to wildfires?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Ground gets drier→ Trees get drier→ Wildfires can happen more easily→ Habitat loss/Threat to homes and peopl3

High School Student Guide:

MICRONESIA

Micronesia is an area in the Pacific Ocean that is made up of thousands of islands, including the islands of Palau, Kiribati, and Guam. Over half a million people live on the islands in homes close to the shoreline. Many people make a living by fishing or by working in the tourism industry. Since 1870, sea levels have risen by eight inches on average and have already started to displace families and flood homes. What factors led to sea-level rise, and what are some potential future impacts if sea levels keep rising?

THE GREAT BARRIER REEF

The Great Barrier Reef is the longest living structure on earth (over 1400 miles!) along the eastern coast of Australia. Coral reefs support diverse communities of fish, turtles, sharks, and other marine life because they provide shelter and food for various species. In 2017, the Great Barrier Reef experienced two of the largest coral bleaching events in history. Coral bleaching happens when the coral (which are live animals!) expel the tiny colored organisms that live on them, which is what makes the coral turn white. If the coral stays white for a while, it will eventually die, which is bad news for the creatures that depend on the reefs for survival and for people who enjoy exploring the reefs. What factors led to coral bleaching, and what are some potential future impacts if corals don't recover from bleaching? Alternatively, can you think of another climate impact pathway that would lead to coral bleaching?

THE ATLANTIC OCEAN

The Atlantic Ocean supports countless fisheries including lobster, black sea bass, bluefish, and blue crab. Like humans, fish are sensitive to temperature, and can get too hot or too cold when the temperature increases or decreases. If the fish are uncomfortable for an extended period of time, they might start to look for new waters to live where the temperature is more comfortable for them. If the fish move far away, this creates problems for fishermen, who rely on catching these fish in a certain area. With no fish around, there's nothing to catch! Trace the climate impact pathway that leads to this disruption of fishing patterns. Can you think of another impact of changing fish migrations?

THE EVERGLADES

Coastlines are the parts of land that are closest to the ocean, and are therefore usually very close to sea level, or at "low elevation". The Everglades in Florida are one example of a low elevation coastline. The Everglades also represent an estuarine wetland habitat, which is an area where freshwater near the coast mixes with saltwater from the ocean that washes up with the tides. This unique interaction supports a special variety of life that depends on this mixing. How can changes in the ocean affect this unique habitat? What climate impact pathway leads to those changes?

THE AMAZON

The massive Amazon rainforest spreads across 8 South American countries and is home to the greatest biodiversity on the planet. The vastness of the forest represents one of the largest carbon "sinks," or carbon storage, in the world. Can you think of a pathway that would decrease the Amazon's ability to store carbon (hint: think of what makes the Amazon a forest)? What other effect(s) would that pathway have?

THE HIMALAYAS

The highest mountain range in the world supports animals that are especially adapted to cold temperatures, such as the snow leopard. Warming temperatures in high altitude lead to melting snow and warmer climates. Snow leopards, which have adapted to live in cooler temperatures, are especially vulnerable to these shifts. Seeking colder weather, snow leopards continue to migrate north to find weather that is more suitable for them to live in. They have already disappeared from places they used to live because the habitat is no longer suitable. Trace the climate impact pathway that has led to snow leopards leading north. How has this migration affected the lives of snow leopards?

THE ARCTIC

The northernmost part of the globe, the Arctic, is home to terrestrial and marine animals who depend on the ice for their daily activities. Recently, polar bears who rely on the ice as platforms for hunting their favorite source of food, seals, have had an increasingly difficult time hunting. If polar bears continue to have difficulty finding enough food for themselves and their cubs, they will face an even greater danger of becoming extinct. Can you trace the climate impact pathway that may be making it more difficult for polar bears to hunt?

CITIES

Over one half of the world's population lives in cities or urban environments. Cities are impacted by climate change in different ways. Cities on the coast can be at-risk of sea-level rise, while cities that are inland can be at risk of drought or intense heat waves. Many cities are trying to adapt to or mitigate the effects of climate change. Can you think of a climate impact pathway in cities that either shows how cities might contribute to climate change (think of factories, or maybe lots of traffic), OR a pathway that shows how people who live in cities might be affected by climate change?

SAHARA DESERT

The Sahara Desert is the largest and driest desert on earth. In the face of climate change, these conditions are becoming even more extreme and leading to the expansion of the Sahara Desert, a process known as desertification. What is a possible climate impact pathway that could be expanding the area of the Sahara, and what are some human or animal impacts from desertification?

CALIFORNIA– HOME!

The area that we live in has lots of trees and gets plenty of sunshine. Climate change is causing less rainfall in this area and warmer temperatures than usual. With less rain, the trees are getting drier, and when temperatures get very warm, wildfires can spark more easily. Can you create a climate impact pathway that connects greenhouse gas emissions to problems we are already experiencing due to a changing climate?

OR— THE PACIFIC NORTHWEST– HOME!

The area that we live in has lots of and lots of trees and usually gets plenty of rain. Climate change is causing less rainfall in this area and warmer temperatures than usual. With less rain, the trees are getting drier, and when temperatures get very warm, wildfires can spark more easily. Can you create a climate impact pathway that connects greenhouse gas emissions to an increase in wildfires?

High School Facilitators Guiding Questions:

Description of different cards:

“Climate Impact”: These cards are just like “chance” in monopoly. They tell the students what actions to take, and they affect the “atmosphere” (greenhouse gas deposits) either positively or negatively

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MICRONESIA

Micronesia is an area in the Pacific Ocean that is made up of thousands of islands. Over half a million people live on the coasts. Many people make a living by fishing or by working in tourism, such as diving. Sea levels have risen by eight inches on average in the last 150 years, which leads to homes flooding and forces people to move.

- **What leads to sea-level rise? Hint: it could be something happening in another part of the world (i.e. sea ice melting)**
- **How does sea level rise impact animals or people?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Sea ice melting→ Sea levels rising→ Habitat loss/Threat to homes and people/Increased risk of floods/Threat to tourism

GREAT BARRIER REEF

The Great Barrier Reef is the longest coral reef in the world (1400 miles long!) and is located off the coast of Australia. Coral reefs are home to fish, turtles, sharks, and other kinds of marine life. Corals are tiny animals that are very sensitive to water temperature. They turn white when the water is too warm, and if they stay white for too long, they will die. This process is called "coral bleaching" because the corals turn white. If the corals die, this is also bad for the creatures that depend on the reefs for survival and for people who like to go diving on the reef.

- **What factors led to corals turning white and dying (i.e. coral bleaching)?**
- **What are some future impacts if corals don't recover from "bleaching" or turning white?**
- **Can you trace warming water temperatures back to greenhouse**

gases?

- **How does corals dying affect other animals?**
- **How does corals dying affect people?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Ocean temps warming→ Coral bleaching→ Habitat loss/ Threat to tourism/Harder to find food (for the animals that live on the reef)

THE ATLANTIC OCEAN

The Atlantic Ocean supports countless fisheries including lobster, black sea bass, bluefish, and blue crab. Like humans, fish are sensitive to temperature, and can get too hot or too cold when the temperature increases or decreases. If the fish are uncomfortable for an extended period of time, they might start to look for new waters to live where the temperature is more comfortable for them. If the fish move far away, this creates problems for fishermen, who rely on catching these fish in a certain area. With no fish around, there's nothing to catch! Trace the climate impact pathway that leads to this disruption of fishing patterns. Can you think of another impact of changing fish migrations?

- **How can warming ocean temperatures lead to migration?**
- **How could the fish migrating affect people?**
- **How could the fish migrating affect other animals? (hint: think about changes in food availability and predator/prey relationships)**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Ocean temps warming→ Habitat loss→ Habitat loss/Threat to tourism/[Create your own impact]

THE EVERGLADES

Coastlines are the parts of land that are closest to the ocean, and are therefore usually very close to sea level, or at "low elevation". The Everglades in Florida are one example of a low elevation coastline. The Everglades also represent an estuarine wetland habitat, which is an area where freshwater near the coast mixes with saltwater from the ocean that washes up with the tides. This unique interaction supports a special variety of life that depends on this mixing. How can changes in the ocean affect this unique habitat? What climate impact pathway leads to those changes?

- **This is a challenging one, but an opportunity to talk about how sea level rise can affect wetlands through a process called "desalination." As ocean water mixes with freshwater in the wetlands, animals and plants that depend on the freshwater will be negatively affected by the introduction of salt water to their communities.**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Sea level rising→ Habitat loss→ [Create your own impact]

THE AMAZON

The massive Amazon rainforest spreads across 8 South American countries and is home to the greatest biodiversity on the planet. The vastness of the forest represents one of the largest carbon "sinks," or carbon storage, in the world. Can you think of a pathway that would decrease the Amazon's ability to store carbon (hint: think of what makes the Amazon a forest)? What other effect(s) would that pathway have?

- **How does cutting down trees add more greenhouse gas emissions to the atmosphere? (Hint: think about the carbon that was stored in the trees).**
- **This is another challenging ecosystem that is meant to help students think about how the loss of carbon "sinks" will contribute to climate change by releasing greenhouse gases that have traditionally been stored for a long time.**
- Example of a climate impact pathway: Deforestation → Greenhouse gases OR Habitat loss→ (can connect either to impacts to people and animals in the area or even in other parts of the world)

THE HIMALAYAS

The highest mountain range in the world supports animals that are especially adapted to cold temperatures, such as the snow leopard. Warming temperatures in high altitude lead to melting snow and warmer climates. Snow leopards, which have adapted to live in cooler temperatures, are especially vulnerable to these shifts. Seeking colder weather, snow leopards continue to migrate north to find weather that is more suitable for them to live in. They have already disappeared from places they used to live because the habitat is no longer suitable. Trace the climate impact pathway that has led to snow leopards leading north. How has this migration affected the lives of snow leopards?

- **The snow leopard trajectory is pretty straightforward. This example can also be used to talk about reduced snowpack in regions that are used to seeing snow.**
- **How can warmer temperatures at higher altitudes affect the seasons? (Hint: migration patterns and food availability!)**
- **What does warmer temperatures in the mountains mean for the snow that's there? What does that mean for the water supply that billions of people rely on?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Shift in suitable habitat for animals/ Habitat loss/Harder for animals to find food

THE ARCTIC

The northernmost part of the globe, the Arctic, is home to terrestrial and marine animals who depend on the ice for their daily activities. Recently, polar bears who rely on the ice as platforms for hunting their favorite source of food, seals, have had an increasingly difficult time hunting. If polar bears continue to have difficulty finding enough food for themselves and their cubs, they will face an even greater danger of becoming extinct. Can you trace the climate impact pathway that may be making it more difficult for polar bears to hunt?

- **What factors of climate change make it more difficult for polar bears to hunt?**
- **What will eventually happen if polar bears can't find enough food?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Sea ice melting→ Habitat loss/Harder to find food

CITIES

Over one half of the world's population lives in cities or urban environments. Cities are impacted by climate change in different ways. Cities on the coast can be at-risk of sea-level rise, while cities that are inland can be at risk of drought or intense heat waves. Many cities are trying to adapt to or mitigate the effects of climate change. Can you think of a climate impact pathway in cities that either shows how cities might contribute to climate change (think of factories, or maybe lots of traffic), OR a pathway that shows how people who live in cities might be affected by climate change?

- **This one is best used with “create your own” cards so that students can link development to the emission of greenhouse gases. Some examples include: more traffic, more housing, more building, etc.**
- Example of a climate impact pathway: Create your own→ Greenhouse gases → Earth temps warming→ Increase in air pollution

SAHARA DESERT

The Sahara Desert is the largest and driest desert on earth. In the face of climate change, these conditions are becoming even more extreme and leading to the expansion of the Sahara Desert, a process known as desertification. What is a possible climate impact pathway that could be expanding the area of the Sahara, and what are some human or animal impacts from desertification?

- **What do you think will happen when the driest place on earth gets even drier?**
- **What impact will that have on animals, people, food, and water?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Lack of water/drought conditions → / Habitat loss/Harder for animals to find food

CALIFORNIA– HOME!

The area that we live in has lots of trees and gets plenty of sunshine. Climate change is causing less rainfall in this area and warmer temperatures than usual. With less rain, the trees are getting drier, and when temperatures get very warm, wildfires can spark more easily. Can you create a climate impact pathway that connects greenhouse gas emissions to problems we are already experiencing due to a changing climate?

- **What causes wildfires?**
- **How does climate change contribute to wildfires?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Ground gets drier→ Trees get drier→ Wildfires can happen more easily→ Habitat loss/Threat to homes and people

OR

Pacific Northwest– HOME!

The area that we live in has lots of and lots of trees and usually gets plenty of rain. Climate change is causing less rainfall in this area and warmer temperatures than usual. With less rain, the trees are getting drier, and when temperatures get very warm, wildfires can spark more easily.

- **What causes wildfires?**
- **How does climate change contribute to wildfires?**
- Example of a climate impact pathway: Greenhouse gases→ Earth temps warming→ Ground gets drier→ Trees get drier→ Wildfires can happen more easily→ Habitat loss/Threat to homes and people

Vocabulary:

Climate: The average weather conditions in a particular location or region at a particular time of the year. Climate is usually measured over a period of 30 years or more.*

Atmosphere: the layer of gases that surrounds the earth and separates us from space

Climate change: A very big change in the Earth's climate. The Earth is currently getting warmer because people are adding **greenhouse gases** to the atmosphere that trap heat. "**Global warming**" refers to warmer temperatures, while "climate change" refers to the broader set of changes that go along with warmer temperatures, including changes in weather patterns, the oceans, ice and snow, and ecosystems around the world.*

Greenhouse gases: Greenhouse gases are natural or man-made gases that trap heat in the atmosphere and contribute to the greenhouse effect. Two examples of greenhouse gases are carbon dioxide and methane.*

Methane: a type of greenhouse gas

Carbon dioxide: a type of greenhouse gas. People are adding carbon dioxide into the atmosphere, mostly by burning fossil fuels such as coal, oil, and natural gas.*

Weather vs. climate: Weather is what happens on any certain day, but climate is the pattern of weather over years and decades

Emissions: When a gas (such as carbon dioxide) is released into the air or atmosphere.*

Carbon footprint: The total amount of greenhouse gases that are emitted into the atmosphere each year by a person, family, building, organization, or company.*

Energy: The ability to do work. Energy comes in many forms, such as heat, light, motion, and electricity. Most of the world's energy comes from burning fossil fuels to produce heat, which can then be converted into other forms of energy, such as motion (for example, driving a car).*

Renewable energy: A natural resource that can be produced, regrown, or reused fast enough to keep up with how quickly it is used. Wind, tides, and solar energy, for example, are in no danger of running out and can be consumed by people almost forever!*

Wind farm: an area where lots of windmills are placed to collect energy from the wind. This is a type of renewable energy!

Fossil fuels: types of energy that releases bad greenhouse gases when they're burned

Diesel gas: a type of gas that powers ships and trucks. This comes from fossil fuels and releases bad greenhouse gases when it's burned

Pollution: something harmful or destructive that is introduced into the environment. For example, plastic and greenhouse gases are both considered types of pollution because they're harmful for the environment.

Produce: to make

Reduce: to lower; the opposite of increase

Reusable: something that can be used again and again

Recycle: To collect and re-process, or reuse, a material so it can be used again to make a new product.*

Increase: to go up; more of something; to get bigger; the opposite of reduce

Community: a group of people who all share similar characteristics and face similar challenges. For example, a city, a neighborhood, or a class can all be considered a community.

Policy: an action or decision that is enforced to try to solve a problem or make something better. A policy can be made by a government, a business or any community of people.

Ecosystem: an area where plants and animals live together in one system; the weather, climate, and environment are the same for everything that lives there.* Example: a rainforest, or a desert, or a tropical coral reef

Habitat: The place or environment where a plant or animal lives and grows.*

Coral bleaching: When corals turn white because they are unhealthy. One way this can happen is if the water temperature is too warm. Corals that remain white, or "bleached" for a long time will eventually die.

*These definitions and more can be found on the EPA website.

Editable Documents for Instructors:

Student Guide: MS or HS

Powerpoint Gameboard: MS or HS

Attribution: Stote, Alexandra. "Ready, Set,Curb!" *Climate Science for the Classroom* edited by Bertram and Biyani, 2019. https://uw.pressbooks.pub/climate/chapter/ready-set-curb/ Date of Access.

PART II
MIDDLE SCHOOL LABS AND DEMOS

Harmful Algal Blooms

Harmful Algal Blooms

ROBIN MCLACHLAN, ISAIAH BOLDEN, ANGIE BOYSEN, AND CHRISTINE BAKER

Overview

Curriculum includes 4 lessons, each with powerpoint presentations, worksheets, videos, readings, and hands-on lab activities which can take up to 3 weeks to complete. Some parts can be excluded, for a one-week exploration of HAB's.

> Harmful algal blooms (HAB's) on Washington state's coast and around the world provide a marine context for a grounding phenomenon to teach ideas from biology and chemistry. Students build a conceptual model of harmful algal bloom occurrence and evaluate the socio-economic impacts of climate change on blooms. These lessons were developed by Robin McLachlan, *(mclachlan.rl@gmail.com), Angie Boysen, Isaiah Bolden, and Christine Baker, all graduate students at the University of Washington,* with advising from Professor Mark Windschitl (UW College of Education) *and in partnership with the teachers and students of Jane Addams Middle School. Partial support for this work came from the IGERT Program on Ocean Change and the Program on Climate Change*. This project fulfilled the capstone requirement for Robin McLachlan's G*raduate Certificate in Climate Science.*

Read about the team and curriculum development in Robin McLachlan's November 2018 blog post "Teaching Climate Science Using A Local Phenomenon: Harmful Algal Blooms".

Grade Level: 6th-8th Grade

Meets Next Generation Science Standards MS-LS1-6, MS-LS2-1, MS-LS2-2, MS-LS2-3, and MS-LS2-4.

Lesson 1. Introduction to Phenomenon: Harmful Algal Blooms (HABs)

Students create a conceptual diagram and then grow an algal bloom in the classroom.

Lesson 2. Ecosystem Trophic Interactions

Students play a game (Trace the Toxin) to explore trophic level interactions and trace the flow of energy throughout the marine environment.

Lesson 3. HABs Case Studies and Links to Climate Change

Students analyze real case studies to learn the environmental factors that cause algal blooms and evaluate the impact of climate change.

Lesson 4. Plankton Identification, Scientific Drawing, and Conceptual Model Revision

Students use microscopes to look at plankton and practice scientific drawing. Students conclude by revisiting and revising their conceptual models.

Background Information for Teachers

What are algae?

Basic definitions of algae can be found here and here.

Harmful Algal Blooms (HABs):

Algal blooms occur when water conditions are ideal for phytoplankton growth. Therefore, blooms tend to occur when water is relatively warm and full of nutrients. Algal blooms become harmful when the phytoplankton produce toxins that cascade through trophic levels. The species Pseudo-nitzschia produces a neurotoxin called domoic acid. The toxin is concentrated as it travels through the food chain from phytoplankton to zooplankton to fish and so on. Human consumption of domoic acid can cause vomiting, diarrhea, cramping, and even death.

The 2015 HAB on the US west coast:

In 2014, a huge patch of ocean water that was anomalously warm (~4.5 °F warmer than normal) persisted off the west coast of the US. It was termed The Blob when its size reached 1,000 miles long, 1,000 miles wide, and 300 feet deep. The persistent warm water triggered a large bloom of Pseudo-nitzschia, a toxin-producing phytoplankton. The toxin was passed up the food chain to razor clams and crabs. In 2015, extremely high levels of domoic acid were detected in common fishery species, such as clams and crabs. In response, recreational razor clam harvests were closed in Washington and Oregon, and recreational and commercial fishing for Dungeness and rock crab were closed on the northern California and Oregon coasts.

Resources:

An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016GL070023

Harmful algal blooms and climate change: Learning from the past and present to forecast the future:

https://www.sciencedirect.com/science/article/pii/S1568988315300615

Ocean warming since 1982 has expanded the niche of toxic algal blooms in the North Atlantic and North Pacific oceans: http://www.pnas.org/content/114/19/4975?ijkey=c9a9f3e1d90b1a1f5f6f97b05c515a418a7f798f&keytype2=tf_ipsecsha

Lesson 1: Introduction to Phenomenon: Harmful

Algal Blooms (HABs)

Students create a conceptual diagram and then grow an algal bloom in the classroom.

NGSS

- MS-LS2-3 – Ecosystems: Interactions, Energy, and Dynamics. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
- MS-LS2-4 – Ecosystems: Interactions, Energy, and Dynamics. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Materials

- Pens/pencils
- Lesson 1 Worksheets (.docx file)
  - Conceptual Diagram (1 per student or group)
  - Bloom Hypothesis Notecard (1 per student or group)
  - Exit Slip (1 per student)
- *Let's Grow A Bloom materials:*
  - At least 4 glass jars
  - Water sample (containing plankton) from a lake, ocean, and/or fish tank.
    - Request from the Seattle Aquarium at least one week before the lab is to be done. Send your plankton sample request to: registration@seattleaquarium.org with "plankton request" as the subject line.
    - Or collect your own sample in a jar from a fish tank or lake with a lot of algae (the water will be green or brown). If the water source does not have a high concentration of algae, you can collect a sample with a plankton net. If you don't have access to a plankton net, you can build your own.
  - Liquid algae fertilizer (e.g. Seachem Flourish)

Introduction

Introduce students to HAB's using Lesson 1 Presentation.

Activity 1: HAB Conceptual Diagram

1. Give students five minutes to write down/draw (1) what they know about HABs and (2) any wonderings/questions they still have [e.g.: what algae are, what a bloom is, what do you know about the Pacific Northwest marine ecosystems, what do algae need, how do they fit into the food web].Have them write down their thoughts in the "What do I know?" column.
2. Break the students into groups. Instruct them to share what they know and what questions they still have. While students share, the others should write down things they learn and new questions that arise.
3. As a group, the students will create a model on the Conceptual Diagram worksheet provided. This should include drawings and words.
4. Discuss as a class. Before moving on to the next activity, make sure students agree that algae need warmth, sunlight, and nutrients to bloom.

Activity 2: Let's grow a bloom!

This activity guides students through building real algae blooms in jars. Each jar receives a different combination of ingredients – light and nutrients. To expand this activity to include temperature as an ingredient, you can add heat lamps and ice baths. This activity can either be done as a class or as a "cooking show" style activity in which the process is discussed and then the premade jars are presented.

1. Fill at least four glass jars with water that contains algae. Algae are naturally present in lakes, ponds, oceans, fish tanks, etc. Do not cap the jars.

    - Jar 1: place in a dark area such as a closet
    - Jar 2: place in a well-lit area such as a window
    - Jar 3: add liquid fertilizer and place in a dark area
    - Jar 4: add liquid fertilizer and place in a well-lit area

2. Give each group or individual a notecard (Bloom Hypothesis Notecard under "Materials") and assign them a jar. Ask them to write their hypothesis of what will happen to their jar on the notecard.

    - Questions to consider:
        - Will the algae grow to create a bloom?
        - What will the water look like? Why?
        - What will it smell like? Why?
        - How long will it take? Why?

3. Conclusion: Have students complete exit slips before leaving class.

Lesson 2: Ecosystem Trophic Interactions

(Based in part on the New York State Department of Environmental Conservation Freshwater Fisheries "I FISH NY" Program)

Students will develop new and apply existing knowledge of marine organisms to trace the flow of energy throughout the marine environment.

NGSS

- MS-LS2-2 – Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.
- MS-LS2-3 – Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

Materials

- Life cards (1 per student)
    - This version uses only zooplankton, small fish, seal, and shark cards
    - Class size may vary, but always have ≥ 55% of total organisms as zooplankton for standard rounds of play.
- Colored tokens
    - > 100 tokens
    - Plastic poker chips work well
    - At least 3 different colors with 1 color ≅ 30% of the total pool

- Cup/containers (1 per student)
- Exit Slips (1 per student)

Introduction

Prepare and deliver a brief (5 minutes maximum) presentation on the importance of energy flow and cycling within marine ecosystems, using the Lesson 2 Presentation.

Activity 1: Marine Food Pyramid and Food Web Brainstorming

1. Ask the students to think about where energy for a variety of marine organisms comes from, gradually working your way toward the sun as the main source and phytoplankton as primary producers in the marine food web. Define terms as necessary. Ask the students to consider which organisms constitute the next stop in energy flow, zooplankton, and that they represent primary consumers.
2. Ask students to think about where energy flows from the primary consumers. Ask them to volunteer types of organisms beyond phytoplankton and zooplankton that are found in the marine environment. Write these on the board, asking the students to think about connections between each organism (who consumes whom?). Draw arrows that represent the flow of energy and nutrients between these organisms.
3. After all of the arrows have been drawn, emphasize the intricacies of the web. Shift focus to filling in an energy pyramid. Ask the students to think about the arrows they drew and the fact that organisms that eat other organisms are in distinctly different levels of the pyramid to fill in the trophic spaces (secondary consumers through tertiary consumers) of the pyramid.

    - Primary producers: Phytoplankton
    - Primary consumers: Zooplankton
    - Secondary consumers: Small fish, etc.
    - Tertiary consumers: Large fish, crabs, seals, etc.
    - Quaternary consumers: Sharks, orcas, etc.

4. Ask the students where they think humans may fit in on the trophic pyramid and the food web. Allude to the possibilities of feedbacks of human activities (overfishing, nutrient loading, etc.) on connections throughout the ecosystem.
5. Draw attention to the fact that the energy diagram is shaped like a pyramid because there isn't a lot of energy available for organisms the higher their trophic level. For example, relatively, there aren't a lot of sharks but there are a lot of phytoplankton. It also signifies that energy accumulates up through trophic levels, a fact that will be best demonstrated by the "Trace the Toxin" game.

Activity 2: Trace the Toxin

1. Make a clear open space in the classroom by pushing the desks to the sides.
2. Scatter colored tokens (at least 3 different colors with 1 color ≅ 30% of the total pool) throughout the classroom. These tokens represent phytoplankton. Designate one of these colors as a phytoplankton species that produces harmful toxins, but do not reveal this information to the students yet.
3. Hand out a Life Card (under materials) to each student. Students should quietly read their life card to themselves as it contains important information for what their role will be during each round of the game. Class size may vary, but always have ≥ 55% of total organisms as zooplankton for standard rounds of play.

    - Organisms on Life Cards: zooplankton, small fish, seal, shark.
    - After each round, **keep a tally of remaining organisms in each trophic level on the board**. This will be useful for conveying energy pyramid dynamics AND biomagnification.

4. **Round 1** – Ask the students which organism(s) out of the 4 in play would most likely consume phytoplankton (zooplankton, which represent the primary consumer level of the marine energy pyramid and food web).

    - Hand out a food bag/cup to each of the zooplankton. These students will have 10 seconds to "graze" upon the phytoplankton

tokens scattered throughout the classroom. In order to graze, students must bend down, pick up one token, stand up, and place it into their cup. All students must walk while doing this for safety reasons. Students are also not allowed to take whole handfuls of tokens at a time. Emphasize that students follow the instructions on their Life Card.
    - At the end of the 10 second period, stop the collection of tokens. Tally remaining organisms on the board.

5. **Round 2** – Ask the students which organism(s) out of the 4 in play is the next level of the food web and pyramid (small fish, which represent secondary consumers).

    - Zooplankton will continue feeding on phytoplankton tokens scattered throughout the classroom, but now, there are predators! If phytoplankton are tagged on the elbow, they must hand their food bag/cup to their predator and exit the game.
    - Small fish will have 10 seconds to “eat” zooplankton (tag them on elbow). Remind the students to follow their Life Card instructions for a reminder on how much they can eat.
    - After the 10 second period, stop the round. Tally remaining organisms on the board.

6. **Round 3** – Ask the students which organism(s) out of the 4 in play is the next level of the food web and pyramid (seals, tertiary consumers).

    - Remaining zooplankton will once again continue feeding on phytoplankton tokens while attempting to avoid small fish.
    - Small fish will continue consuming zooplankton (if their Life Card quota has not been met) while avoiding seals.
    - Seals will have the length of the round to “eat” small fish by tagging them on the elbow.
    - After the 10 second period, stop the round. Tally remaining organisms on the board.

7. **Round 4** – Ask students to verify the only remaining organism (sharks, quaternary consumers).

    - Remaining zooplankton will once again continue feeding on phytoplankton tokens while attempting to avoid small fish.

- Small fish will continue to consume zooplankton (if their Life Card quota has not been met) while avoiding seals.
- Seals will continue to consume small fish (if their Life Card quota has not been met) while avoiding sharks.
- Sharks will have 10 seconds to "eat" seals by tagging them on the elbow.
- After the 10 second period, stop the round. Tally remaining organisms on the board.

8. Summarize the game, asking students why rounds became progressively more difficult and what it suggests about predator-prey interactions in the marine environment. What patterns did they see? What caused the patterns? Think about how much energy was needed at higher trophic levels and what the implications are of not being able to meet the quota on a Life Card due to competition. What would be the implications of human populations overfishing the small fish population on the rest of the web AND on nutrient loading sparking phytoplankton blooms? What has this got to do with the 2015 Blob? How else may humans impact the cycling of energy in marine ecosystems?
9. Reveal the identity of the "harmful" token to the students. Explain that some phytoplankton produce harmful toxins that can be deadly to other organisms. Have the remaining students with food cups/bags count the number of tokens and the total number of harmful tokens within their entire trophic level. Write these values, along with the associated organisms, on the board, and calculate the average amount of toxic chips per trophic level.
10. Conclusion: Wrap up with a discussion of marine food webs and pyramids and general Q&A. Hand out exit slips.

Lesson 3: HABs Case Studies and Links to Climate Change

Students will learn about recent Harmful Algal Blooms (HABs) around the world, the environmental factors that caused them, and predict the link with and impact of climate change.

NGSS

- MS-LS2-1 – Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
- MS-LS2-3 – Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
- MS-LS2-4 – Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Materials:

- Pens/pencils
- Worksheets (.docx file)
    - Entrance slips (1 per student)
    - Jigsaw Worksheets (1 per student)
    - Expert Jigsaw reading material (1 case study per student)
    - Exit Slips (1 per student)

Introduction:

After students have completed their Entrance Slip, present the initial slides on the Lesson 3 presentation until the Jigsaw Activity.

Activity: Jigsaw

1. Divide students into jigsaw groups (ideally 5 students per group)
2. Divide the material into 5 case studies
    - Assign each student one case study to become an expert on.
    - Provide a worksheet for students to record information.
    - Case studies: West Coast, Great Lakes, Chesapeake Bay, Florida, Arabian Sea
3. Allow students to individually read their case study and fill out the worksheet.
4. Form temporary “expert groups” by having one student from each jig-

saw group join the other student assigned to the same case study. Allow expert groups time to discuss the main point of their case study and prepare a short explanation that they can present to their jigsaw group.

5. Bring students back into their jigsaw groups, ask each student to present their case study to the group, and then fill out the rest of the worksheet with an overview of each topic.
6. Note: The structure of the reading and note-taking will need to be tailored to the class level.
7. Conclusion: Use Lesson 3 presentation for classroom discussion and have students complete exit slips before leaving class.

Lesson 4: Plankton Identification, Scientific Drawing, and Conceptual Model Revision

Students will use microscopes to look at plankton and practice scientific drawing, and then revisit their conceptual models.

NGSS

- MS-LS2-1 – Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.
- MS-LS2-3 – Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
- MS-LS2-4 – Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
- MS-LS1-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.

Materials:

- Pens/pencils

- Worksheets (.docx file)
    - Entrance slips (1 per student)
    - Plankton worksheet (1 per student)
    - Exit slips, (1 per student)
    - Plankton ID sheets (1 for each microscope group)
- *Let's Grow A Bloom* from Lesson 1
- Microscopes, slides, droppers
- Zooplankton samples (either scooped from a pond, a net tow, or your local Aquarium)
- Zooplankton image links
    - https://askabiologist.asu.edu/images/plankton-gallery
    - http://cfb.unh.edu/cfbkey/html/begin.html

Introduction

After students have completed their Entrance Slip, recap as a class the results of the *Let's Grow a Bloom* activity. Did we build a bloom successfully? How can we tell? Why did it work? Or why not? Then, introduce HAB species on Plankton ID sheets. Use the Lesson 4 presentation.

Activity 1: Plankton ID

1. Have students in groups at microscopes look at plankton from local water sources (ponds, rivers, etc.) and the bloom experiment. Can they ID any?
2. Practice scientific drawing. Think about scales (sizes). Think about how this fits with the activity we did on Wednesday.

Activity 2: Re-visit Phenomena Models

1. Did anyone see any phytoplankton? Zooplankton? Which caused the problem?
2. Generate a word bank from the previous activities.
3. What problems do humans feel from HABs?
4. Revisit models. (Individually for 3 min sketch ideas, then 12 min in groups)

5. In groups: have students with 'roles' so they stay on task. Someone to make sure we've got all the ideas from the word bank. Someone to make sure everyone is participating. Timer. Someone to re-state ideas. Someone to share out at the end (this person will come up to the front where we have the big drawing).
6. Draw a big model on the board and have each group add to it with a different color.
7. Conclusion:

    - Hear from each group about how they revised their original model from day one
    - Hear from each group about their connection between Climate Change and People's' actions
    - Group discussion – drawing up key ideas on the board for a group model
    - Complete exit slips

Attribution: Mclachlan, R., Bolden, I., Boysen, A., Baker, C."Harmful Algal Blooms" *Climate Science for the Classroom* edited by Bertram and Biyani, 2019. https://uw.pressbooks.pub/climate/chapter/harmful-algal-blooms/ Date of Access.

An Exploration of the Glacial History of Puget Sound

KRISTIN POINAR

Overview

This module guides elementary and middle school students through explorations of regional topography that lead to discoveries about the geology of the Pacific Northwest, focusing on local landmarks in Seattle. This simple exploration can be a foundation for more advanced glaciology and erosion lessons for high school students. *Originally created by Kristin Poinar, UW Earth and Space Sciences (2015) to fulfill the capstone requirement of the Graduate Certificate in Climate Change.*

Background Information

About 15,000 years ago, much of the Pacific Northwest was covered by a part of the Laurentide ice sheet. It was called the Puget Lobe, and it was the southernmost extension of the ice sheet that once covered most of Canada and some of the northern USA. This glacier was 3000 feet thick – it extended as high as planes fly as they pass over Seattle on their way to land at SeaTac. The ice sheet carved channels into the land around us, like a rake carving channels in soil. Lake Washington is one of the furrows that was carved by the glacier. On the other hand, View Ridge and Delridge hills are ridges that were left behind as other areas were carved out. Most of the features carved are long and skinny and north-south oriented, because that was the direction the ice flowed (i.e., the direction the rake was being pulled). 100,000 years ago, before the glaciers had come and carved out these furrows, what did our region look like? The Wedgwood Erratic at NE 72nd Street and 28th Ave NE is a huge boulder that these glaciers brought down from the mountains near Bellingham.

Glacier flow and erosion

Introduce the impact of glacier flow using the silly putty model of a glacier. You an follow the instructions from The Science Education Resource Center at Carelton that contains instructions on how to make the silly putty, demonstrate glacial flow, and questions to ask the students. In brief, the silly putty glacier illustrates that ice can flow like a viscous liquid. Sticking straws into the glacier shows how friction from the sidewalls affects its flow, slowing it down – the straws in the center of the glacier move faster. The straws also topple over after a few minutes, showing how the surface of the glacier flows faster than the bottom. This also illustrates friction. A piece of cardboard peeled to expose the ribbing is a nice illustration of how the land underneath a glacier will look. The glacier drags rocks along with it, which "rake" and erode the ground.

View the Data with Google Earth

Google Earth is free software available at www.google.com/earth . It is a relatively small program (download size 42 MB) that accesses most of its data from the internet as needed. It's great for open-ended exploration of the earth – the natural environment as well as cities and human development.

1. Download and install Google Earth.
2. The lidar data (gray topography data) are contained in .kmz files. Copy these .kmz files from the PCC Google Drive Folder to your computer and save them.
3. From Google Earth, go to File – Open. Browse to where you saved the files and select them. They will appear in the "My Places" folder on the browser.

Visualize the Earth's Surface Using LIDAR Data

Lidar datasets reveal the topography of land. The maps are produced by flying airplanes over the land, and shining lasers down from the planes. By measuring the amount of time it takes the laser beam to leave the plane, hit the ground, and bounce back, the exact elevation of the land surface can be calculated. The lidar can see through trees.

Datafiles (.kmz) can be downloaded from the PCC Google Drive Folder.

Data is available for the following locations:

- Bainbridge Island
- Ballard High School
- Bremerton
- Cedar Hills Landfill
- Chief Sealth High School
- Cleveland High School
- Cougar Mountain
- Delridge
- Fall City
- Husky Stadium
- Kitsap Grooves (North)
- Kitsap Grooves (South)
- Magnolia Bluffs
- Nathan Hale High School
- Ravenna Park
- View Ridge

What to look for in the Data

Evidence of water erosion in our region. There are many features that were carved by water in the past few hundreds or thousands of years – Ravenna Park, Carkeek Park, etc. They are often on steep slopes (bluffs above Puget Sound or Lake Washington) and are arborescent (tree-like) in nature. We know they have been recently carved because (a) the river channels incise down through other smooth features, and (b) rivers or creeks still often run through them.

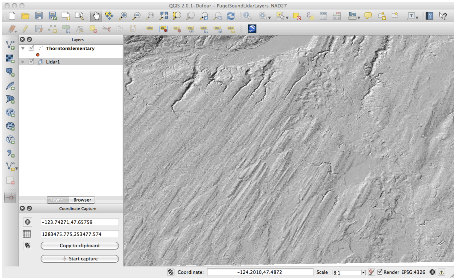


Figure 1: LiDAR topography data of the Kitsap Peninsula south of Bremerton, showing evidence of largescale glacial erosion. The students have previously found that glaciers erode the earth underneath them in a pattern that looks like corrugated cardboard; very many of them leap to connect that concept to this image.

Evidence of glacial erosion in our region. The Kitsap Peninsula shows longitudinal furrows carved by the glacier. Why are the furrows oriented north-south? The furrows are also apparent within Seattle, although they go in a slightly different direction (more northwest-southeast). Cougar Mountain also shows these features. Can you see them "start" on the north end and trail out on the south? These ridges remained whereas the valleys between them were eroded away. The ridges remained because they were directly underneath subglacial tunnel.

More complex geology. Maple Valley shows evidence of both waterbased and glacial erosion. First, a large river, or many large rivers over time, carved the main east-west valley many thousands of years ago. Smaller north-south tributary rivers also flowed into the main valley. Next, the glaciation occurred – we can see how the ice, which flowed from north to south, eroded the walls of the valley differently. Which is steeper, the north wall or the south wall? Why? You can also see this on the east-west creeks on Cougar Mountain – or any sufficiently incised east-west creek in the area.

Attribution: Poinar, Kristin "Glacial History of Puget Sound Exploration" *Climate Science for the Classroom* edited by Bertram and Biyani, 2020. https://uw.pressbooks.pub/climate/chapter/glacial-history-of-puget-sound-exploration/ Date of Access.

1. Climate Change and Hydrology

ORIANA CHEGWIDDEN

Overview

This climate change and hydrology exploration was originally created by Oriana Chegwidden, a recent PhD graduate of UW Civil and Environmental Engineering. Oriana initially created the lesson for the 2017 Mount Baker season of Girls on Ice, a branch of Inspiring Girls.org. Oriana discusses the effectiveness of teaching this lesson in outdoor and indoor settings in her blog post: https://pcc.uw.edu/blog/2020/08/30/its-better-outside-water-and-climate-science-education/.

Target Audience: Middle School Students

Background Vocabulary

Hydrology, precipitation, evapotranspiration, streamflow, infiltration, groundwater, sunlight/radiation/energy, distinction b/w snowpack/glacier, ablation, water year

Materials

- Paper
- Pencils/Markers

Procedure

PART 1: Thinking about hydrologic processes (20 minutes total – 5 minutes explanation, 10 minutes small group, 5 minutes back together for group discussion)

Groups of three draw the different sources and sinks of water and energy in the landscape around them. They draw arrows and make it as pretty as they want. If the landscape is varied, get one group to do bare ground, one group to do snow-covered and one group to do glacier. Key ideas to try to get them to think about: vegetation, groundwater, different forms of precipitation, evaporation, runoff, soil moisture

PART 2: Linking processes to time (10 minutes total – 2 minutes explanation, 5 minutes small
group, 3 minutes discussion)

Give each group a piece of paper with four columns representing the seasons of the year. Groups take the pictures they drew in part 1 and fill in the columns with which processes are happening during each season of the year. (i.e. They'd put snowmelt in the spring/summer column and snowfall in the winter column).

PART 3: Making a streamflow hydrograph (10 minutes total – 2 minutes explanation, 5 minutes
small group, 3 minutes discussion)

For each season of the year choose whether they think there will be low, medium, or high streamflow in the stream coming off of the landscape. Then connect those dots and have a seasonal hydrograph. Then hand them each the actual hydrograph for a nearby stream and they can see how they figured it out!

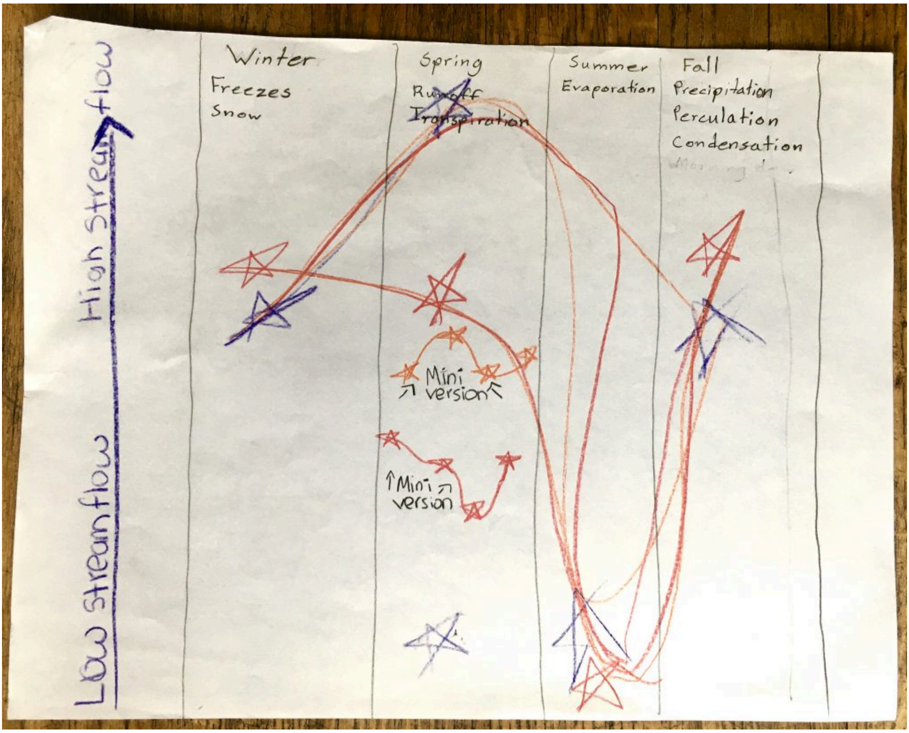
PART 4: Predicting the future (10 minutes total – 2 minutes explanation, 5 minutes small group,
3 minutes discussion)

Given that we know it will get warmer going through the 21st century, how will those processes change? Have them take the plots they drew in Part 2 and decide how streamflow will change under a warmer climate (key points: get them to think about snow falling as rain instead, snow melting earlier and maybe changes to groundwater). Have them guess what the future streamflow could be.

Example drawing and streamflow graphs:


Ground
Groundwater


cloud
pond
Ocean



Attribution: Chegwidden, Oriana "Climate Change and Hydrology" *Climate Science for the Classroom* edited by Bertram and Biyani, 2020. https://uw.pressbooks.pub/climate/chapter/climate-change-and-hydrology/ Date of Access.

PART III

HIGH SCHOOL LABS AND DEMOS

Biological Pump

KATHERINE HEAL

Overview

> This module is an introduction to the marine biological pump and uses representative organisms to demonstrate the interconnectivity between the biosphere and the global carbon cycle. *Created by Katherine Heal while she was a graduate student in Oceanography at UW, this module complements other labs created by the UW PCC team as part of a year long high school climate science curriculum. May be readily used in non-major college courses that build on student knowledge of food webs to gain understanding of the carbon cycle.*

Grade level: 9-12

Focus Questions

- How are photosynthesis and respiration related to the global carbon cycle?
- How does the biological pump work to maintain the oceanic carbon reservoir?
- What controls the biological pump?

Learning Goals:

1. To relate the ocean's primary producers to terrestrial plants as and acting as consumers of CO2
2. To be introduced to a variety of globally important marine organisms

3. To understand how the biology of the ocean is important in the global carbon cycle
4. To understand why phytoplankton growth is limited in some areas of the ocean
5. To appreciate the ecological balance of a few different organisms contributing to the upkeep of the biological pump

Background Information for Teachers

What is the biological pump? As we know, photosynthesis consumes CO2 while respiration produces it. In the ocean, these two processes can be spatially separated. Net photosynthesis occurs in the sunlit (upper) portion of the ocean, while net respiration occurs deeper. As CO2 dissolves in the ocean, it becomes available to phytoplankton that fix it into organic carbon (photosynthesis), or used to form calcium carbonate shells (CaCO3). Some of this organic carbon (in the form of biological matter) sinks and is consumed (respiration) or dissolves (in the case of CaCO3 shells) in the deeper ocean. Because the deeper ocean does not come in contact with the atmosphere very often, it traps the carbon in the deeper ocean, creating a large reservoir of carbon. The biological pump is thought to be bottom-up limited, meaning that the ocean would be able to act as a larger sink for CO2 if there were more phytoplankton growth. In this way, the marine biological pump is closely related to other biogeochemical cycles, especially nitrogen, phosphorus, and iron which make up the main nutrients needed by phytoplankton to grown.

Prior Knowledge for Students

Students should be familiar with the importance of CO2 as a greenhouse gas and be introduced to different global carbon reservoirs. Students have been introduced to photosynthesis and respiration as important biologically important mechanisms, but may have not yet related this to the marine carbon cycle, except as an aspect of short-term variability. Introduction to the solubility of CO2 in the oceans would be helpful before this module, but not necessary.

Materials

- Projector and screen
- Introductory presentation – can be edited (.pptx)
- Suggested readings from:
    - The Earth System (3rd Edition) (*Kump et al.)*
- Other reference books on marine biology or biology of microorganisms
- Access to reference articles
- Whiteboard/chalkboard with colored markers/chalk or projector and screen
- Template for Facebook profiles (Teacher needs to create)

Procedure

Introduction:

It may be helpful to assign pages 154-159 as reading from Kump et al. before this module.

Write the equations for photosynthesis and respiration on a whiteboard so the students may refer back as necessary during the powerpoint presentation. It would also be helpful to provide the slides to the students to follow along and take notes. The key words provided here are important for students to know to understand the slides. They are introduced and defined on the indicated slides.

Keywords mentioned on slides:

- Photosynthesis – slide 2
- Respiration – slide 2
- Phytoplankton – Slide 6
- Zooplankton – slide 10
- Filter Feeders – slide 10
- Decomposition – slide 12
- Nutrient Limitation – slide 19
- Nitrogen Fixation – slide 20

The following are notes for the instructors to accompany the provided slides:

- **Photosynthesis and Respiration –** The presentation begins with a review of photosynthesis and respiration as chemical formulas. It is not important for students to memorize these, but to know which is a sink and which is a source for CO_2.
- **Photosynthesis and Respiration and atmospheric CO_2 –** On the second slide of the Keeling curve, probe the students to identify how photosynthesis and respiration affect the Keeling curve (the short term variations). This is an example of how seasonal differences in photosynthesis and respiration can change atmospheric CO_2.
- **The ocean is a large carbon reservoir –** The ocean is a large and important carbon reservoir. Only the upper ocean is in equilibrium with the atmosphere (exchanging carbon), but the deep ocean holds much more carbon than both the upper ocean and the atmosphere. Remember that the deep ocean only comes in contact with the atmosphere every 1000 years and that the upper ocean is usually considered only the top 100 m while the deep ocean can be over 4000 m deep.
- **Photosynthesis and Respiration in the Ocean –** Much like land plants and animals, there are many organisms that photosynthesize and respire in the ocean – in fact, a huge amount of the global fixation of carbon takes place in the ocean!
- The following slides are taken from MBARI's lesson plans for introducing the biological pump. They go through the steps of the biological pump .
- **Overview of the Biological Pump (slide 19) –** Each of the organisms mentioned in the previous slides are here, but in a better representation. We will be coming back to this figure in Part III, so make sure that the students are very familiar with it. Also, this figure shows how this system is balanced by upwelling. Stress that the pump is not a sink for carbon, but rather just a mechanism that maintains the large carbon reservoir in the deep ocean.
- **What limits phytoplankton growth?** – This slide presents a question that is the topic of many oceanographers research. It also gives one commonly accepted school of thought that most of phytoplankton growth is limited by nutrients. Part III of this module deals with the complexity of nutrient limitation and how it is connected to the biological pump in further detail.

- **Sources of N, P, and Fe –** This slide is a super quick overview of the sources of the major limiting nutrients in the ocean. It is important to emphasize that

A good reading that could be inserted here for homework or class discussion is the recent review article by Falkowski called “The Power of Plankton.” 2012. Nature. 483, S17-S20.

Group Presentations:

In this lab, groups of students will put together a short presentation and Facebook profile page on a different marine organism. Groups of 2-4 would work well for this. Use all of the first 5 organisms, and if there is a larger class, use the optional additions.

Each of these organisms represents an important part of the biological pump. The teacher is not expected to be an expert on any of these organisms, so it is up to the groups of students to introduce the organisms to the class by presenting their own research. The will include an internet search (good websites to start at are provided in the student handout), using textbooks (a list of texts that can be used is provided and could be rented from a local university library), and one provided piece of primary literature or relevant review article.

Assign groups of 3-4 an organism and provide them with the appropriate primary literature article and the student handout (both provided). Each of these organisms is important and unique, so below is a very brief description of each of the organism. I suggest that after the groups have broken off and started the research, that the teacher visit each group and prompt the group to make sure that they understand the important information they should be conveying by using these talking points. The teacher should also be available as a resource for where to start looking (see provided list of appropriate resources), but it should be stressed that the students are to become the experts. Many of these articles will be vocabulary- heavy so use the glossaries in the books listed to help students understand the vocabulary. Important terms that students should introduce to the class within each organism group are listed below.

EXAMPLE TEXT FOR STUDENT HANDOUT:

Your assignment is to become an expert on a globally important marine organism. You will use the provided resources to answer the following questions about your organism. You will then make and present a Powerpoint presentation that will answer these questions and provide background on your organism for your peers. Finally, you will create a Facebook profile for your organism for distribution that will synthesize what you have learned about your organism. Use the provided template for your Facebook page, but feel free to get creative. If you want to add a category or something doesn't make sense with your organism, change the template, not all organisms are created equal! Remember to cite your sources.

Questions to address in Presentation and on Profile:

1. What type of organism is it?

2. What do they look like? How big are they? How common are they?

3. Where are they located in the ocean?

4. What do these organisms eat/need to survive?

5. What are some other important or interesting facts about this organism?

6. How is this organism related to the biological pump?

Resources:

1. Your teacher will provide a piece of primary literature that will provide answers to many of these questions – remember that these are written by scientists who study these organisms every day so they will probably be very scientific, don't be discouraged.

2. Your teacher will also have a number of textbooks available for

3. Microbewiki is wiki created for microbes (and their fans) – some of your organisms will have information here

LIST OF ORGANISMS/GROUPS

(citations of the primary literature sources are located at the end of the chapter)

- *Prochlorococcus*
    - *Prochlorococcus* is a genus of one of the smallest and most com-

mon photosynthetic organisms on earth. *Prochlorococcus* dominate in nutrient-poor regions of the ocean.
    - Keywords: cyanobacteria, picoplankton, oligotrophic
    - Primary literature: pages 116-120 of "Prochlorococcus, a Marine Photosynthetic Prokaryote of Global Significance" by Partensky Hess and Vaulot, in *Microbiology and Molecular Biology Reviews,* 1999.
- *Thalassiosira*
    - *Thalassiosira* is a genus of important photosynthetic eukaryotes called Diatoms. Diatoms dominate in nutrient-rich areas of the ocean, but in addition to the N, P, and iron requirements, also require silica to make beautiful shells. Due to their rather large size, diatoms sink quickly and are often cited as important to the flux of the biological pump.
    - Keywords: diatom, frustule
    - Primary literature: "The life of diatoms in the world's oceans" by Armbrust in *Nature*, 2009.
- *Trichodesmium*
    - *Trichodesmium* is a genus of cyanobacteria that can perform nitrogen fixation and photosynthesis. This provides an essential nutrient to areas of the ocean that otherwise have very little nitrogen. They have very high iron requirements.
    - Keywords: Nitrogen fixation, diazotroph, colonial cyanobacteria
    - Primary literature: "Trichodesmium, a Globally Significant Marine Cyanobacterium" by Capone, Zehr, Paerl, Bergman, and Carpenter in Science, 1997
    - Optional 2nd primary literature: "Marine nitrogen fixation: what's the fuss?" by Capone in Current Opinion in Microbiology, 2001.
- Planktonic Copepods
    - Copepods are important zooplankton and voracious grazers of phytoplankton. Their fecal matter is especially dense and significantly contributes to sinking particles. Vertical migration also contributes to the biological pump.
    - Keywords: zooplankton, vertical migration
    - Primary literature: pages 55-58 of "Upper Ocean Carbon Export and the Biological Pump" by Ducklow, Steinberg, and Buessler in *Oceanography*, 2001
- *Pelagibacter*
    - *Pelagibacter* is a genus of the globally important heterotrophic

    - bacteria in the SAR11 clade. The SAR11 clade of organisms were not known until very recently, and they might be the most numerous bacteria on earth! They can thrive in low-nutrient waters and are important recyclers of organic carbon
    - Keywords: heterotrophic bacteria, mesopelagic
    - Primary literature: "SAR11 clade dominates ocean surface bacterio-plankton communities" by Morris, Rappe, Connon, Vergin, Siebold, Carlson and Giovannoni in *Nature*, 2002.
- Optional – *Emiliania huxleyi*
    - *Emiliania huxleyi* is a species of important algae, coccolithophores. *Emiliania huxleyi* are calcifiers and can form huge blooms in the oceans and therefore cause large carbon export events.
    - Keywords: phytoplankton bloom, calcifiers
    - Primary literature: "Emiliania huxleyi: bloom observations and the conditions that induce them." By Toby Tyrrell and Agostino Merico
- Optional – *Roseobacter*
    - *Roseobacter* is a genus of heterotrophic bacteria in the ocean and our example of very important particle associated bacteria.
    - Keywords: heterotrophic bacteria, marine snow, particle associated
    - Primary literature: "Possible Quorum Sensing in Marine Snow Bacteria: Production of Acylated Homoserine Lactones by Roseobacter Strains Isolated from Marine Snow" by Gram, Grossart, Schlingloff, and Kiørboe in *Applied and Environmental Microbiology* 2002.
- Optional – Planktonic Salps
    - Salps are zooplankton that filter feed on phytoplankton (and whatever else may be in its path). They respond very quickly to blooms and their death result in a sticky substance which can sink, significantly contributing to marine snow.
    - Keywords: filter feeder, marine snow
    - Primary literature: pages 55-58 of "Upper Ocean Carbon Export and the Biological Pump" by Ducklow, Steinberg, and Buessler in *Oceanography*, 2001

After an appropriate amount of time working on the presentations, students should present each organism as a group and handing out their Facebook page as a resource for the other students. Each student will end up with a packet of Facebook pages for each organism and can take notes on these.v

Class Synthesis:

The final part of this module is to have a class discussion about the interconnectivity of their organisms and to understand how each of the groups' organisms fit into the biological pump by connecting them in a "carbon web." This idea will be familiar to the students who have made food webs in introductory biology courses. The figure is based on the figure from Part I on the final overview of the biological pump slide, from Z. Johnson in the Nature Magazine.

First I would encourage each group to come up with a simple way to draw each of the organisms and to define each drawing on the board. Having different colors would be helpful (little green = Prochlorococcus, little blue = heterotrophic bacteria). As you go farther along, define other symbols (flow of carbon, sinking organic material).

Encourage students to use colored pencils or different colored pens and provide blank sheets of paper to take notes and create their own drawing. The provided slides goes through these steps as well.

Draw on the board a schematic of the ocean with the surface ocean, deep ocean, and seafloor. Stress that only CO2 in the surface ocean is in equilibrium to the atmosphere. Probe the class to identify which of the presented species are phytoplankton. Add the phytoplankton – *Prochlorococcus*, *Thalassiosira*, *Trichodesmium*, and *Emiliania huxleyi* – to the surface ocean. They live only in the surface ocean because they require light to survive.

Next add grazers to the surface ocean (those who eat phytoplankton, copepods and salps). They are in the surface ocean because their food (phytoplankton) are in the surface ocean.

Now add sinking organic material throughout the water column. Brainstorm different sources of sinking organic material in this small system.

- Fecal pellets from grazers
- Death of a large phytoplankton bloom
- Dead grazers
- "Messy" feeding by grazers resulting in sinking "crumbs" of their food

Add heterotrophic bacteria to surface and deep ocean. *Roseobacter* should be particle associated, *pelagiabacter* can be on or off particles.

Add direction of CO_2 to or from each depicted organism/group of organisms. Which are the organisms that respire (give off carbon) and which are the ones that photosynthesize (consume carbon)? Overall, you should have net photosynthesis in the upper ocean and net respiration in the deep ocean.

Quantifying the biological pump is an active area of research in oceanography. Probe the students to understand why. Why is the biological pump important? Pumps CO_2 from the surface ocean to the deep ocean

- Why is the biological pump important?
    - *Pumps CO_2 from the surface ocean to the deep ocean*
- Would the atmospheric CO_2 be different if the biological pump didn't exist?
    - *Yes!!!!! The CO_2 of the atmosphere would be much higher than current if there was no biological pump.*
- How does the biological pump affect climate?
    - *Lowers atmospheric CO_2 and therefore decreases the greenhouse gas effect.*

Using our small-system example of organisms, discuss the interconnectivity of the different organisms

- What limits the growth of each type of phytoplankton?
    - *Tricho – generally thought to be iron or phosphorus limited since it can fix its own nitrogen*
    - *Thaps – could be limited by N, P, Fe or Si (to grow shells)*
    - *Prochlorococcus – could be limited by N, P, Fe (but can survive at much lower concentrations than other phytoplankton), can't survive well in cold environments*
    - *Ehux – could be limited by N, P, or Fe, doesn't survive well in warm environments What limits the growth of the grazers?*
- Both copepods and salps are limited by their food source, phytoplankton (and oxygen) What limits the growth of the heterotrophic bacteria?
    - *Both types of heterotrophic bacteria are limited by their food supply, decaying organic matter (and oxygen)*
- What if there were no phytoplankton? What would happen to this food web and the biological pump of our system?

- *It would collapse! No phytoplankton = no food for grazers = no food for heterotrophs = no biological pump!!*

- What if there were no grazers? What would happen to this food web and the biological pump of our system?
  - *No grazers = much less respiration in the upper ocean. Bacteria would only feed on decaying phytoplankton material and no fecal matter. This would lead to a much more efficient biological pump, less atmospheric CO2, cooler planet!*
- What if one or more species/groups of species were affected by a viral attack?
  - *Depending on the species/group of species affected, this could increase or decrease the biological pump's strength.*

A lot of research is being put into predicting how the biological pump will change with global climate change. Discuss possible scenarios of both ocean acidification and increased stratification and how they could change the biological pump. Please note that there really is no consensus on this yet scientifically as there are many.

- Ocean Acidification
  - Could affect the ability for coccoliths to grow and affect blooms, decreasing strength of bio pump (because they grow calcium carbonate shells)
  - Could affect nitrogen fixation by Trichodesmium (quite a bit of literature on this)– increasing N2 fixation could increase the strength of the biological pump, decreasing N2 fixation could decrease the strength of the biological pump.
  - Could have physiological effects on higher trophic levels
- Increased stratification leading to less mixing nutrients
  - Especially affecting diatoms (who thrive in nutrient-rich areas and require the extra nutrient of silica), could decrease bio pump
  - Overall the phytoplankton would be under nutrient limitation more than now – decreasing the biological pump

If students have other ideas of what could change the biological pump – open the floor to them.

Primary Literature Sources

Armbrust, E. The life of diatoms in the world's oceans. *Nature* **459,** 185–192 (2009). https://doi.org/10.1038/nature08057

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ENSO (El Niño-Southern Oscillation) Investigation

NANCY FLOWERS, LUANNE THOMPSON, AND STEPHEN PO-CHEDLEY

Overview

In this module students analyze sea surface temperature data collected over half a century and use this data to determine if the year was an El Niño, La Niña, or "normal". Students learn about climate variability and data analysis with the goal of being able to make predictions. *This module was created by Nancy Flowers (Everett High School) and enhanced with data through collaboration with LuAnne Thompson (UW Oceanography) and Stephen Po-Chedley. The lab is part of the high school climate change curriculum but is also taught in Oceanography and other Earth Systems courses.*

Learning Goals

1. To understand and identify the differences between El Niño, La Niña, and normal climate patterns

2. To be able to analyze precipitation data for the Pacific Northwest during El Niño and La Niña years

3. To use Excel to analyze and display data

Prior Knowledge

Students will be asked to perform some basic statistics on a real data set. It is expected that students have some prior experience finding the average, standard deviation and linear line of best fit. Students must also be familiar with climate variability (such as El Niño and La Niña events), understand terminology and vocabulary used (such as upwelling), have basic knowledge of geography, and understand and know how to read contour maps.

Background

Suggested Textbook Reading:

- *Pg. 221-225 in Oceanography: An Invitation to Marine Science*, Tom Garrison. 4th edition. Brooks/Cole, 2002.
- *Pg. 92-96 in The Earth System* by Kump, L. R., J. F. Kasting, and R. G. Crane, Prentice Hall, 3rd ed., 2010.

NASA article: https://earthobservatory.nasa.gov/features/ElNino

NOAA website: https://www.climate.gov/enso

Animations and graphics

- http://www.pearsoned.ca/highered/mygeoscienceplace/ElNinoLaNina.html (requires adobe flash plugin)
- https://www.pmel.noaa.gov/elnino/animations-graphics
- https://svs.gsfc.nasa.gov/4695

Materials

- Powerpoint Lab Instructions (ppt) (suggestion…add favorite snow-related images!)
- Lab: Parts 1 -3 (.docx)

- (alternative) Part 1 as a homework assignment (.docx)
- Lab Data (.xlsx)
- Answer keys (request password from uwpcc@uw.edu)

Attribution: Flowers, N., Thompson, L., Po-Chedley S., "ENSO (El Niño-Southern Oscillation) Investigation" *Climate Science for the Classroom* edited by Bertram and Biyani, 2020. https://uw.pressbooks.pub/climate/chapter/enso-investigation/ Date of Access.

Historical Temperature Records

SARAH PURKEY, SURABHI BIYANI, AND STEPHEN PO-CHEDLEY

Overview

Climate change is experienced differently by people in different locations at different times. These experiences are directly connected to regional factors that determine temperature but also reflect how fast temperature is changing. In this lab, students graph and use basic statistics to analyze century-long temperature records from weather stations around the world and then look at modeled predictions of future temperature. Students gain skills in data analysis, gain experience examining observational data as evidence of regional and global warming, and develop an understanding of spatial and temporal scales of climate variability. *This module was originally developed by Sarah Purkey while she was a graduate student working on her Graduate Certificate in Climate Science at the University of Washington in 2012. Additional weather station data were added in early 2020 by Surabhi Biyani; Stephen Po-Chedley knew how to grab the data from the NOAA website. This material was designed to be part of a year-long High School Climate Science curriculum. We have modified the lessons to be independent of the year-long curriculum, and recommend for use in high school courses including Statistics and Environmental Science.*

Grade Level: 10th-12th Grade

Lesson 1: Seasonal Variability

Students pick a station (location)and make predictions about the region's climate by calculating and plotting mean monthly temperature and examining variability within the monthly mean. As a class, share graphs and evaluate differences in regional seasonal variability.

Lesson 2: Local and Global Historical Trends:

Students calculate the yearly mean at each station. As a class, compare yearly regional trends to IPCC trend maps.

Lesson 3: Climate Model Predictions and Local Impacts:

Students apply statistical tools learned in lesson 2 to model output for the next 100 years, then research and report on how the predictions for their region will impact local communities.

Focus Questions

1. How is climate change experienced in different parts of the globe? Variability can be thought of as differences between regions or differences within a region. Consider how fast temperature is changing in one region compared to other regions (e.g. temperate vs. polar vs. tropics). Consider how variable the climate can be in a particular region in a particular season.
2. What are surface warming trends in different parts of the globe. How are they calculated? How are these different from one another and from the global temperature trends? Why are there differences?
3. How will local communities be impacted by climate change? Explore this idea by considering how regional temperatures are predicted to change in the future.

Learning Goals

Students will be able to:

1. Create and interpret time series from observed and modeled temperature data.
2. Plot and calculating trends, variance, means, and statistical error from raw data in Excel.
3. Be able to distinguish between local weather (regional variability) and

global climate by examining short and long-term trends in temperature data

Prior Knowledge (for students and teachers)

Students will perform some basic statistics on a real data set. It is expected that students have some prior experience finding the average, standard deviation and linear line of best fit.

Students place their findings in the context of what they already know about weather, global variability of temperature and precipitation, and other factors influencing local climate such as proximity to water, latitude, and elevation.

Readings that help contextualize the data analysis are listed below for each lesson. These readings are from Kump, L. R., J.F. Kasting, and R. G. Crane, The Earth System, 3rd Edition (hereafter referred to as **Kump**) and IPCC AR4 (https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter11.pdf)

Lesson 1: Read chapter 4 of Kump. Be familiar with basic excel functions including how to find the mean, variance, max, min, and standard deviation.

Lesson 2: Read chapter 15 from Kump and the IPCC report AR4 section TS.3 (https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-ts-1.pdf).

Lesson 3: Read chapters 15 and 16 in Kump and be familiar with the framework of Global Climate Models (GCM's). A good introduction to GCMs can be found in the IPCC AR4 Chapter 8 (https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter8.pdf). For this lab, students are asked to read a section (10 pages or less) of the IPCC AR4 report describing the future predictions for a given region. The sections discuss the weather phenomena affecting the different regions and how these will likely change. Students are expected to know basic large-scale atmospheric weather drivers. If they have questions, students can look up terms in Kump.

Additional resources:

https://www.bloomberg.com/graphics/2015-whats-warming-the-world/

Anticipated Challenges:

Students are expected to have some experience using Excel. A number of online Excel tutorials can be found for students to do prior to this lab. If students try to do the lab with no prior knowledge of Excel, they will spend a great deal of time working on Excel when they should be focused on thinking about the science.

As there are always hiccups in teaching with any software. To minimize this the teacher should complete the lab (prior to having students do the lab) on the same version of excel used in the classroom .

Materials:

- Computers with Microsoft Excel
- Temperature Data. Open the “Historical Temperature Records” folder in the UW PCC Google Drive Folder
    - The folder “Station Data” contains observational data and model predictions for 18 different stations (xxxxx_obs.csv or xxxxx_model.csv where xxxxx=station number) through the year 2011 when this lab was originally created.
    - “943260_example.xlsx” is an example file for station 943260 with figures generated (thru 2011).
    - “New Station Data” folder contain station data (observations) through 2019. The way weather stations are named in the database changed between 2011 and 2019. Visit the “New Station Num-

bers" file for latitude, longitude, old station number, corresponding new station number and the time period represented in the data set (some weather stations go back further than others).
    - The "Trend Figures" folder contains the final figures students generate in labs 1 and 2.
    - global_temp.xls is a spreadsheet of global average temperature data for use in lesson 2.
- Worksheet template is a (.docx) file with notes for the instructor, but that can be converted to a student worksheet.

Please email uwpcc@uw.edu if you have any questions, and let us know how using the new data goes!

Procedure:

Before the Lab:

Download Data: Station data needs to be downloaded for the students prior to the lab from the UW PCC Google Drive folder. There is also an example spreadsheet with the calculations students will be asked to do (943260_example.xlsx). See the Materials section above for additional information on what is in this Google Drive resource.

The station files contain station location information and the monthly mean temperature over all years of observation recorded (or 100 years into the future for the model data) in degrees Celsius.

Edit Worksheets: The worksheets for each lesson are provided with notes for the instructor. These need to be edited and tailored for your use. Edit any instructions on how to navigate Excel so they apply to the version of Excel used in your classroom.

One Approach. A Procedure for Teachers.

Lesson 1: Seasonal Changes. Focus on a single month of data, from a sin-

gle station see how it varies over time. Compare with that from other locations.

1. Tell the students they will be working with raw data to determine the seasonal temperature cycle around the globe. (15 min)
   a. Why do we have seasons?
   b. How would you expect the surface temperature to change with latitude and why? Why would two cities at the same latitude, one on the east coast of the United States and one on the west coast of Europe have different climates?
   c. Where on the globe would you expect large fluctuations between winter and summer temperatures and where would you expect small?
   d. How would you expect surface temperature fluctuations to change with altitude?
2. Explain that the instrumental record is coming from weather station data. Volunteers have recorded temperature and precipitation daily at 1000's of stations around the globe over the last 150 years. NOAA has collected this data and made it available to the public. Tell the students that today, they will each be given the temperature data for a station to work with.
   a. Information on the data used for this lab can be found at: http://www.ncdc.noaa.gov/ghcnm/
   b. Ask students: What kinds of things do we need to keep in mind when working with weather station data (have a discussion about missing data, spatial coverage, etc.)?
   c. Tell students they will be studying data from a particular weather station and finding the climate, or climatology, for their region.
3. Hand out the Worksheet for Lesson 1. Divide students into groups, each must have their own computer with Excel. Assign each group a weather station. Have students complete the first part of the Lesson 1 worksheet (30 minutes).
   a. Have students open Excel and import their data.
   b. Have the students work through Parts I-III of Lesson 1.
      - Teachers should be circulating around the classroom to make sure students are progressing and not getting stuck on something in Excel.

- Students discuss the questions as a group and individually write up short answers.
- Students print out the final figure from Part III.

4. Have students proceed to Part IV of the lesson. (20 min)
   a. Have each group pin up their plot with a string.
   b. Allow students to circulate and look at all the graphs. Have the students go back to their groups to discuss the part IV questions and individually write up short answers.
5. Bring the class back together for a discussion. (10 min)
   a. Ask the students to discuss the differences between the plots generated by the different groups. Discuss the differences in climatology around the globe and ask the students why they think some areas might differ.
   b. Discuss data and noise. Ask the students if there was anything they found surprising about working with raw data.

Lesson 2: Calculate annual average temperature and see how that has varied over time at a single station. Compare with that from other stations.

1. Tell the students they will be working in teams to discover trends in climate around the globe. (10 min)
   a. Ask students: How do we know about past changes in climate? Discuss time scales. If paleoclimate has been covered start with a recap of methods for knowing long term variability. Then ask how we know about the last 100 years? Last 20 years? Yesterday? How does the precision and accuracy of our knowledge of past temperatures change as we get closer to today?
   b. (If you have done Lesson 1 you've already talked to the students about the data set and can skip some of this; groups and stations can be the same as used for the previous lesson). Tell students that the instrumental record is coming from weather station data. Volunteers have recorded temperature and precipitation daily at 1000's of the stations around the globe over the last 150 years. NOAA has collected this data and made it available to the public. Tell the students that today, they will each be given the temperature data for a station to work with.

- Information on the data used for this lab can be found at: http://www.ncdc.noaa.gov/ghcnm/

c. Ask students: What kinds of things do we need to keep in mind when using weather station data (have a discussion about missing data, spatial coverage, etc)? Ask students about collection methods and accuracy (e.g. 100 years ago vs. today when air temperature can be measured are recorded every minute electronically). Briefly touch on data collection and human error.

d. Tell students they will be researching the region for their particular weather station and looking at the quality of the data set.

2. Hand out the worksheet for Lesson 2. Divide students into groups, each must have their own computer with Excel. Assign each group a weather station. Students complete the first part of the worksheet (30 minutes).
    a. Students open Excel and import their data.
    b. Students work through Part 1 of Lesson 2. Have the students print out their final figures.
    c. Students discuss the Part I questions as a group and individually write up short answers.
3. Have students do part two of the lesson (20 minutes)
    a. Have each group pin up their plot with a string.
    b. Allow students to circulate and look at all the graphs. Have the students discuss the part II questions as a group and individually write up short answers.
4. Have students complete part three of the lesson (20 minutes)
    a. Students go back to their computer work stations with their group.
    b. Students import global data ('global_temp.xls').
    c. Allow students to work through part III of the lesson and answer questions.
5. Bring the class back together for a discussion (10 min)
    a. Ask the students to discuss the differences between the plots generated by the different groups. Discuss the differences in global trends and ask the students why they think some areas might warm more than others.
    b. Discuss the global trend. Ask students to explain different aspects of the plot (ie, the different trends, smoothed line, dots)

to reiterate what they just learned.

c. Ask the students why they think it is important to look at both regional and global trends.

Lesson 3: Explore model projections of temperature.

1. Tell the students they will be working in teams to study future climate projections. (10 min)
    a. Ask students and discuss: What is a climate model? What can they be used for ? (one answer: to look for possible responses of a system to change) What are GCMs (Global Climate Models)? What are the different "carbon scenarios"?
    b. Additional information can be found in chapter 8 of the IPCC AR4 report (https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter8.pdf)
2. Explain to the students that there are many different GCMs and today they will be looking at data from a GCM developed by the Geophysical Fluid Dynamic Laboratory (GFDL) located in Princeton, N.J. They will be looking at data produced under the A2 scenario. They will be receiving data for their station.
    a. Addition information on the GFDL GCM can be found at: (http://www.gfdl.noaa.gov/model-development)
3. Hand out the Worksheet for Lesson 3. Divide students into groups (perhaps the same groups as you had in Lessons 1 and 2), each must have their own computer with Excel. Assign each group a weather station (these groups and stations can be the same as used for the previous two lessons). Have students complete Part 1 of the worksheet (30 minutes).
    a. Students open Excel and import their data.
    b. Students work through Part 1 of lesson 3 and print out their final figures.
    c. Students discuss the part I questions as a group and individually write up short answers.
4. Have students do part II of the lesson either in groups in class or as homework.
    a. Pass out a copy of chapter 11 of the IPCC Working Group I "The Physical Science Basis" (https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-chapter11.pdf).

b. Students should read the section of the report that contains information about their individual station (4-10 pages).
c. The lesson provides some leading questions to be considered but the format of this is left fairly open. Students should pick a topic they think is the most interesting to write up about climate change in their regions.
d. Report should include facts about predicted and temperature changes in their region taken from the IPCC report and include facts about the current economic (including agricultural) conditions. Past this, the report can be highly speculative with no right or wrong answer. The students are simply asked to think about the societal impacts of the predicted climate change.
e. **NOTE** Teachers should decide how much time they want students to spend on this project outside of class and give students a page max if they are asking for a formal written report. I would suggest two signal spaced typed pages (roughly one page summarizing the predictions made in the IPCC report and one page discussing the impacts on local communities. The later part will be highly speculative so should be easy for students to write. Teachers should emphasize that this part of the project can be their educated guess and they do NOT need to research other published opinions).

    - An alternative to individual reports, each group could give a 15-20 minute presentations.

Additional Resources

Weather Stations

- http://lwf.ncdc.noaa.gov/oa/climate/stationlocator.html
- The station data used in this lab are downloaded from the Global Historical Climatology Network (GHCN) and is comprised of surface temperature data gathered at weather stations from around the world. The data is maintained by NOAA and is public for educational purposes. The data and further information can be found at http://www.ncdc.noaa.gov/ghcnm/.

IPCC report

- https://www.ipcc.ch/report/ar4/wg1/

Similar data analyses activities can be found at:

- http://cleanet.org/resources/41827.html – Climate around the world
- http://cleanet.org/resources/41823.html – US Historical Climate: Excel Statistical
- http://cleanet.org/resources/41830.html – Global temperatures
- http://cleanet.org/resources/41852.html – Exploring Regional Differences in Climate Change

Attribution: Purkey, S., Biyani, S., and Po-Chedley, S., "Historical Temperature Records" Climate Science for the Classroom edited by Bertram and Biyani, 2020. https://uw.pressbooks.pub/climate/chapter/historical-temperature-records Date of Access.

Ocean Acidification and Oysters

HILARY PAVELSKY

Overview

This module provides a hands-on learning activity where students analyze real-world data to explain how ocean acidification is affecting the oyster aquaculture industry in the Pacific Northwest. Students learn how seawater chemistry affects organisms' ability to build shells, as well as how short-term variability and long-term changes influence seawater chemistry. The module is designed as a stand-alone unit for students with no prior exposure to ocean acidification OR can be used as an extension to supplement existing ocean acidification teaching resources. The modules focuses on answering the question of what is controlling the ability to successfully raise oyster larvae at the Whiskey Creek Hatchery in Netarts Bay, Oregon. Students investigate this question through guided analysis of real, published scientific data using Microsoft Excel.

Note: Additional materials relating the concepts in this lab to general high school chemistry are available. Please contact uwpcc@uw.edu for more details.

Focus Questions:

1. How does seawater chemistry –both pH and aragonite saturation state – affect larval oyster growth?
2. How do local physical and biological processes control the short-term

variability of seawater chemistry in the Pacific Northwest?
3. How will seawater chemistry change over the 21st century and how will this affect Pacific Northwest oyster growers?

Part 1:

Students calculate the saturation state of aragonite (the $CaCO_3$ mineral in oyster shells) in the hatchery's seawater and graph its relationship with the success of larval oyster growth.

Part 2:

Students analyze variations in seawater pH and aragonite saturation state at the hatchery over a two month period and determine how daily cycles of photosynthesis and respiration as well as episodic upwelling cause these variations.

Part 3:

Students compute how ocean acidity is projected to change in the future and predict how this will affect the ability to grow oyster larvae at the hatchery.

Learning Goals:

Students will be able to…

1. Explain how increasing carbon dioxide in the atmosphere is changing ocean chemistry.
2. Explain how and why organisms with calcium carbonate shells are affected by ocean acidification.
3. Connect ocean acidification with its impacts on the local Pacific Northwest economy through the oyster aquaculture industry.
4. Identify and explain the dominant processes controlling short-term variability and long-term changes in coastal Pacific Northwest ocean chemistry.
5. Calculate changes in ocean acidity and predict how these changes will affect oyster aquaculture.

Background Information for Teachers

As carbon dioxide from burning fossil fuels is added to the atmosphere, much of that carbon – 30% of all fossil fuel carbon dioxide emitted to date – is absorbed by the ocean. The carbon dioxide combines with water to form carbonic acid, leading to an increase in ocean acidity (a decrease in ocean pH). This alters the balance of carbonate chemistry in seawater, decreasing the concentration of the carbonate ion (CO32-), an important building block for the calcium carbonate shells made by many marine organisms. (For more detail see the additional background materials under supplemental resources.)

The oyster aquaculture industry in the Pacific Northwest is a case study in how ocean acidification can impact socially, economically and environmentally-important marine ecosystems worldwide. It also provides a positive example of how scientific information can guide effective human adaptation to the challenges posed by climate change, as oyster hatcheries now routinely use results from coastal water chemistry monitoring programs to guide their decisions about how to schedule larval production and maintain favorable seawater quality.

The data for this activity comes from a collaboration between the Whiskey Creek Hatchery and scientists at Oregon State University, initiated to determine whether ocean acidification was responsible for observed declines in oyster larval production at the hatchery. The same data the students work with in their Excel analyses, and graphs very similar to those the students generate, were published in the journal Limnology and Oceanography in 2012[1] and have been adapted for this module.

[1]Barton, A., B. Hales, G.G. Waldbusser, C. Langdon, R.A. Feely (2012). The Pacific oyster, *Crassostrea gigas*, shows negative correlation to naturally elevated carbon dioxide levels: Implications

for near-term ocean acidification effects. *Limnology and Oceanography* 57(3), 698-710

Prior Knowledge for Students

This module is designed so that it can be used both with students who are already familiar with ocean acidification as well as students who are new to the subject. The introductory lesson and accompanying PowerPoint slides include sufficient background on ocean acidification for all students to complete the rest of the module. Teachers can easily modify the introduction to remove or move more quickly through information already covered. Also see the supplementary materials for additional ocean acidification resources that we recommend for use in combination with this module.

Part 2 assumes that students are already familiar with the biological processes of photosynthesis and respiration and how they consume/produce CO2, as well as the physical process of upwelling in the ocean. If these subjects have not previously been covered, three additional PowerPoint slides have been included to facilitate the teacher giving a very general overview of these subjects prior to students beginning Part 2 in order to prepare students to complete the activity. Be sure to allow for additional time to complete Part 2 if this material needs to be covered.

Anticipated Challenges

Experience has shown that students are more successful in completing the data analysis if they have some prior experience with Microsoft Excel. However, this module can still be completed by students with little to no prior Excel experience as long as extra time is allowed. The detailed instructions provided in the worksheets are written for PC version of Microsoft Excel 2010. If student computers have a different version of the software, worksheet instructions should be modified by the teacher to match the version used in class.

Assessment

If desired, students' completed worksheets from this module could be collected and graded using the teacher key provided. For a more formal assessment of student learning, exam questions based on the data and learning goals from this module are included in the accompanying teacher materials.

Materials

- Lesson Powerpoint Slides
- Microsoft Excel workbook with data to analyze (in the PCC Google Drive folder)
- Worksheets to accompany each part of the module
- Answer keys (request password from uwpcc@uw.edu)

Procedure

Preparation:

Download both the student and teacher (key) versions of the Microsoft Excel data workbooks and accompanying worksheets, as well as the PowerPoint slides.

Prior to using the lesson in class, teachers should complete the entire module to ensure they are prepared to answer student questions while completing the activity in class. Follow the worksheet instructions to complete the calculations and graphing in the student version of the Microsoft Excel data workbook, and review the worksheet answers provided in the key for teachers. The teacher should also review the accompanying PowerPoint slides to prepare to give the introductory lecture with any necessary modifications to appropriately fit what has been previously covered in the course. Prior to beginning Part 1 in class with the students, ensure that there are computers available with Microsoft Excel and that students will have access to the student version of the data workbook (through a course website, Moodle, Edmodo, etc.).

Introduction: Teachers should select how to introduce this module based on the extent to which ocean acidification has been previously covered in the course. A set of PowerPoint slides with accompanying lecture notes is provided with sufficient information to provide an introduction for classes that have no prior exposure to the topic of ocean acidification. Teachers are encouraged to modify these slides to fit their class. Slide #6 presents the equations that students will be expected to use in Part 1, and slides #9-11 introduce the specific case of the oyster aquaculture industry in the Pacific Northwest that will be addressed in this module, so it is recommended that these slides be used in all classes even if other portions of the introduction are omitted or modified.

Part 1: In this part, students compare their theoretical predictions with actual data showing how changes in the aragonite saturation state of seawater affect larval oyster growth. Students should each individually or in pairs (depending on how many computers are available) to work through Part 1 of the worksheet and complete the calculations and graphing using the Part 1 tab of the Microsoft Excel workbook. The student worksheet gives detailed instructions on how to make the graph in Part 1. However, it is **strongly recommended** that the teacher work through the worksheet and data analysis in advance using the same version of Excel that the students will use in class in order to check that the instructions match the version of Excel that will be used and in order to anticipate any student challenges.

Questions 1-4 ask students to demonstrate their understanding of the calcium carbonate dissolution reaction, how to calculate the aragonite saturation state, and how to use that information to determine which direction the reaction will proceed. This information will have already been covered in the introduction, but the teacher should observe the students' answers to ensure that they understand this material before proceeding.

While the students are completing Excel calculations and graphing, the teacher should circulate among the students to answer questions and check for major errors in student progress. If many students are having problems with the same part, it is helpful to have the Excel data loaded onto a computer connected to a projector so that you can demonstrate the correct procedure.

At the end of the class period, review the students' responses to the worksheet as a class, including showing an example of the final graph they each should have produced (in the accompanying PowerPoint slides) and asking students to share their interpretations of the data in questions 8-9.

Part 2: In this part, students observe how diurnal photosynthesis and respiration and episodic upwelling control short-term variability in seawater chemistry. Students should continue to work individually or in pairs through Part 2 of the worksheet, completing the calculations and graphing in the Part 2 tab of the Microsoft Excel workbook. This part does not include graphic illustrations of how to use Excel, although step-by-step procedures are still provided for graphing. If students have not previously used functions in Excel, the teacher should briefly explain how to do this before they calculate the 1-day running mean in Question 4 using the AVERAGE function. It is again **strongly recommended** that the teacher work through the worksheet and data analysis in advance of the students completing the activity in class.

At the end of the class period, again review the students' responses to the worksheet as a class, including showing examples of the final graphs they each should have produced (in the accompanying PowerPoint slides). Ask students to explain the role of photosynthesis, respiration and upwelling in the data and ask them to share their ideas about how the hatchery can use this information to change their practices. This is a good opportunity to conclude the class period on a positive note by explaining that Pacific Northwest oyster hatcheries are in fact using this information to adapt their practices, and that the industry has recovered as a result of improved scientific understanding and monitoring.

Note that three optional slides are provided in the PowerPoint for this part, which are designed for use in classes where students are not already familiar with photosynthesis, respiration and/or upwelling to provide an overview of these concepts prior to students beginning work on Part 2. These slides can be skipped if this material has already been covered.

Part 3: In this part, students calculate how ocean acidity is projected to change over the 21st century, compare this long-term change to the existing variability in Netarts Bay that they described in Part 2 and predict how continued anthropogenic carbon emissions will affect the oyster hatchery. Once students have completed the worksheet, review the students' responses as a class using the accompanying PowerPoint slides for additional figures showing projections of future changes to pH and aragonite saturation state.

Selected Supplemental Resources

Materials on oyster aquaculture in the Pacific Northwest (suggested for a deeper overview of the social and economic context):

- http://vimeo.com/93272507 – 4-minute video from Taylor Shellfish Farms in Shelton, WA about their business and how it is affected by ocean acidification
- http://apps.seattletimes.com/reports/sea-change/2013/sep/11/oysters-hit-hard – article from the Seattle Times on oyster farmers' adaptations to ocean acidification (Part 3 of an excellent reporting series on ocean acidification – the entire Sea Change series is recommended if you want readings covering ocean acidification in a variety of contexts)

Additional teaching resources on ocean acidification:

- Institute for Systems Biology Ocean Acidification module (including links to a variety of outside content): http://baliga.systemsbiology.net/drupal/education/?q=content/ocean-acidification-systems-approach-global-problem
- Virtual Urchin online lab from Stanford University: http://virtualurchin.stanford.edu/AcidOcean/AcidOcean.htm
- Center for Microbial Ecology Education and Research (C-MORE) Ocean Acidification science kit (hands-on labs focused on corals): http://cmore.soest.hawaii.edu/education/teachers/science_kits/ocean_acid_kit.htm
- Ocean Carbon and Biogeochemistry (OCB) hands-on labs and demo: http://www.us-ocb.org/publications/OCB-OA_labkit102609.pdf

Additional background on ocean acidification:

- http://www.nanoos.org/education/learning_tools/oa/ocean_acidifica-

tion.php – Recommended for an excellent collection of additional ocean acidification-related websites and videos in the right sidebar. NANOOS also hosts a Visualization System for exploring ocean chemistry data from all around the Pacific Northwest.
- http://www.skepticalscience.com/docs/OA_not_OK_Mackie_McGraw_Hunter.pdf – Comprehensive but accessible overview of the chemistry behind ocean acidification, also including a lot of additional context about the global carbon cycle
- http://www.aseachange.net/ – 83-minute documentary about ocean acidification, through the eyes of a retired teacher concerned about the world his grandson will live in, who travels around the world to learn from scientists about their current research on ocean acidification (including great footage of field research). Not freely available, but can be rented/purchased from the website.

Attribution: Pavelsky, Hilary. "Ocean Acidification and Oysters" *Climate Science for the Classroom* edited by Bertram and Biyani, 2019. https://uw.pressbooks.pub/climate/chapter/ocean-acidification-and-oysters/ Date of Access.

Rain-on-Snow Flooding

NICHOLAS WAYAND AND RYAN CURRIER

Overview

Rain-on-snow flood events can be both destructive and costly and are projected to become more frequent due to climate change. The risk is especially high in the mountainous regions of Western North America, where communities need to be prepared for potential events. In this module, students analyze data from a study site at Snoqualmie Pass, WA to predict how rain-on-snow flooding might change with climate change. Students will use their knowledge of the Earth's energy budget and a simple excel model to apply this knowledge and determine where the energy and heat required to melt snow comes from. *This module was created by Nicholas Wayand and Ryan Currier, UW Civil and Environmental Engineering, with NSF support to Jessica Lundquist (CEE)*

Read more about the authors' work here: https://www.washington.edu/news/2014/12/17/improving-forecasts-for-rain-on-snow-flooding/

Focus Questions

- What is a Rain-on-Snow Flood?
- What causes the snow to melt?
- How might Rain-on-Snow events change in the future within the Pacific Northwest?

Learning Goals

Students will be able to…

1. Explain what parts of the energy balance are important for melting snow during different weather conditions.
2. Relate changes in climate projections of the PNW to our snowmelt model.
3. Explain that water for rain-on-snow flooding comes largely from the rain itself, with a number of forms of heat energy contributing to the <25% of the water from melting snow.

Materials

- Background Information video (Youtube)
- Introduction Powerpoint (in PCC Google Drive folder)
- Excel Model (.xlsx)

Procedure

Introduction:

Introduce the class to Rain-on-Snow flood events by watching the video (linked above) and using the provided slideshow.

Activity: Simulating the Snoqualmie Pass Snowpack

This model simulates the components of the energy balance of a snowpack over a day (24 hours) and calculates the snowmelt, rainfall and total water available for runoff.

Model overview:

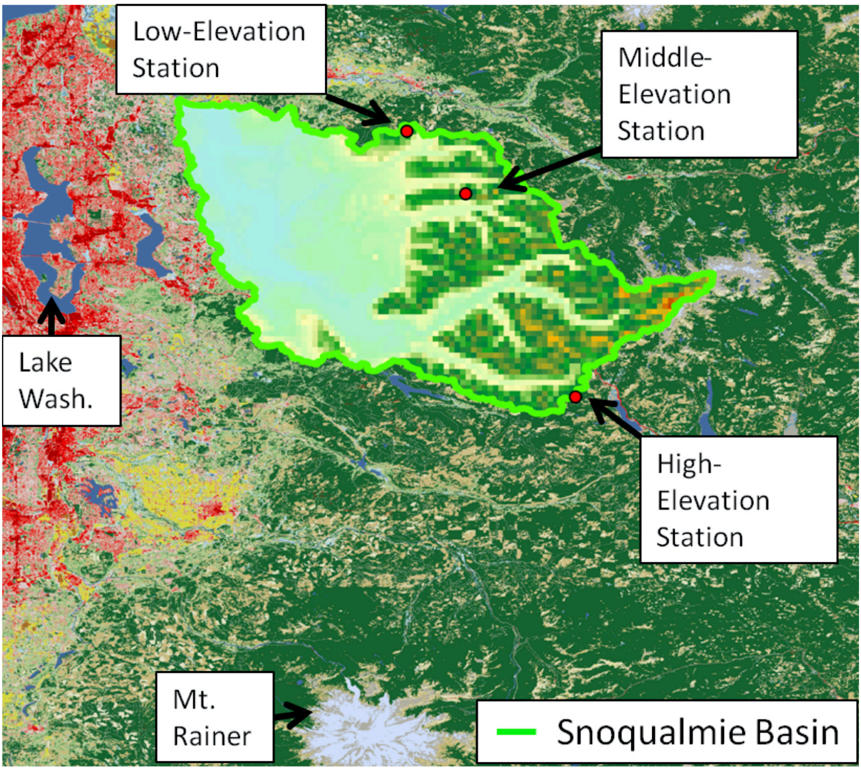
- Open up “Snow Melt Activity.xlsx”.
- The Inputs required are the meteorological weather conditions above the snowpack that day:
    - Air temperature (C)

- Wind speed (m/s)
- Relative humidity (%)
- Precipitation (mm/day)
- Solar Radiation (W m2 day-1)
- Thermal Radiation (W m2 day-1)

- These values need to be averaged over a 24 hour period. Changing these values will update the Output boxes that show modeled rainfall and snowmelt from each energy balance component.
- The equations used to calculate each component of the snow surface energy balance are shown to the right (Columns Q-AD). These equations take the input weather conditions and calculate the total energy from each component in the Red output box.
- Then, the sum of all components is converted into a depth of meltwater.
- Finally, any rainfall that drains through the snowpack is added to the snowmelt to produce the total Water available for Runoff. Runoff is any water that does not enter the soil, but literally runs-off and would eventually enter a river, where it can cause flooding, generate power, or provide drinking water.

Questions for students:

1. What energy balance components melt the most snow at Snoqualmie Pass?
    - Click on the second tab "INPUT Options", which contains meteorological input data for three different distinct days at the Snoqualmie Pass station.
    - Copy and paste the input data from each day into the Input box on the main tab.
    - What components provide the most energy on each type of day?
    - What days generated the most melt at the site?
2. What matters more for basin flooding during an extreme rain-on-snow event? Snowmelt or rainfall?



- Examine the map of the Snoqualmie Basin and locations of three stations at high, middle, and low elevations. (This figure is also included in the PowerPoint presentation)
- Move to the third tab "Historic Snoqualmie Flood".
- Use the meteorological input from the three stations at High, Middle and Low elevations within the Snoqualmie Basin to run the snow model at each station.
- Comment on the importance of snowmelt vs. rainfall at different elevations on the 8th of January 2009. What is the ratio of snowmelt to rainfall at each elevation?
- Assuming that each station represents one-third of the total basin area, what is the total basin ratio of snowmelt to rainfall?

3. The future climate of the PNW is projected to be warmer and see extreme storms more often. In what ways could an increased winter air temperature and more frequent extreme precipitation impact rain-on-snow floods in the Snoqualmie Basin and PNW?

Additional Resources

Overview of Rain on Snow Events
Kattelmann, R. (1997) Flooding from rain-on-snow events in the Sierra Nevada. Destructive Water: Water-Caused Natural Disasters, their Abatement and Control (Proceedings of the Conference held at Anaheim California, June 1996) IAHS Publ. no. 239.

1996 Flood Event in Oregon
Marks, D., Kimball, J., Tingey, D. and Link, T. (1998) The senstivity of snowmelt processes to climate conditions and forest cover during rain-on-snow: a case study of the 1996 Pacific Northwest flood. Hydrological Processes, 12, 1569-1587.

Source for Excel Snow Model Equations
Storck, Pascal (2000) Trees, Snow and Flooding: An Investigation of Forest Canopy Effects on Snow Accumulation and Melt at the Plot and Watershed Scales in the Pacific Northwest. Water Resources Series Technical Report No. 161. March 2000. Seattle, Washington.

Musselman, K.N., Lehner, F., Ikeda, K. *et al.* (2018) Projected increases and shifts in rain-on-snow flood risk over western North America. Nature Climate Change, 8**,** 808–812. https://doi.org/10.1038/s41558-018-0236-4

Mazurkiewicz, A.B., Callery, D.G., McDonnell, J.J. (1997) Assessing the controls of the snow energy balance and water available for runoff in a rain-on-snow environment. Journal of Hydrology. https://doi.org/10.1016/j.jhydrol.2007.12.027

Terrarium Model of Earths' Energy Balance

CHRIS TERAI AND STEPHEN PO-CHEDLEY

Overview

> The terrarium demo is a lab demonstration that allows students to actually see the relevant processes (radiation, evaporation, convection, and condensation) involved in the Earth's energy transport. In essence, we simulate a mini Hadley circulation inside a glass aquarium. The construction of the terrarium takes some time and resources, but once constructed, the terrarium can be used multiple times for the demo with little preparation.

Focus Questions:

1. What keeps the equator from getting hotter and hotter and the poles from getting cooler and cooler?
2. In what ways is energy transferred around the Earth?
3. What causes the Hadley circulation?

Learning Goals:

Students will be able to…

1. Understand how energy is conserved and transported in the Earth's climate system.
2. Identify and describe the physical processes that result in heat transfer (radiation, evaporation, convection, advection, condensation).

3. Answer the questions, “What is the fundamental cause of atmospheric circulation on the Earth? How is the Earth’s energy balance affected by this circulation?”

Background Information for Teachers

The energy budget of Earth, as a whole, is determined by incoming shortwave radiation in the form of sunlight and outgoing longwave radiation, infrared radiation that depends on the temperature of the Earth. Within the different components of the Earth’s climate system, the energy budget is determined by a variety of energy transport mechanisms (radiation, atmosphere, ocean heat transport).

Sunlight warms the tropics more than the polar latitudes, producing a difference in the temperature between the poles and the equator. The ocean and atmosphere move heat poleward to help warm the polar latitudes. In the atmosphere, the warmer tropical atmosphere holds more water vapor than the rest of the atmosphere. During evaporation, energy is transported from the warm ocean into the atmosphere. That energy can be transported in the form of water vapor, until the water condenses, usually in clouds, to help heat the atmosphere. Therefore, when moist warm air is transported from the tropics towards the poles where it condenses, energy is being transported from the tropics to higher latitudes.

We recreate this kind of situation inside the terrarium. One side of the terrarium will be heated with a 250W light bulb. The other side will be cooled with a glass of ice water. There will also be about a centimeter of water in the aquarium. A thermally direct circulation will develop within the terrarium. There will be an upward motion of air under the lamp and downward motion under the ice water. The air circulation will be visible once you strike a couple of matches and drop them into the terrarium. Water vapor will condense onto the smoke particles and create cloud droplets.

Since you can see the circulation in motion, the demo provides a way of getting the students to figure out what is going on in the terrarium. Many layers of complexity can be added to the questions, depending on the students’ backgrounds.

Prior Knowledge for Students

Students will know from experience that warm air rises and cold air descends from looking at hot air balloons or from noticing that in winter it tends to be cooler closer to the floor, even when the heater is running. This will help them understand the basic things that drive convection in the terrarium. They will also know from experience that when they jump out of the pool, it tends to feel cold, even if the air temperature is warm. The coolness comes from the loss of thermal energy when the water evaporates from the skin. During evaporation, the body's thermal energy is being used to turn liquid water into water vapor. This transfer of energy also happens when water evaporates from the sea surface into the air. The energy is transferred from the water into the air.

All of the students should know the general shape of the Hadley circulation, since the worksheets will be asking the similarities and differences between the circulation seen in the terrarium and the Hadley circulation.

Many of the students should also understand the different mechanisms of heat transfer: conduction, radiation, convection, evaporation, condensation. It will be very helpful if they understand evaporation and condensation, such as the concept that when water droplets condense, heat is released. For example, a cold can in a humid environment where droplets form on the side of the can will warm up quicker than a cold can in a dry environment at the same temperature, where droplets don't form on the side, because the air is too dry.

Anticipated Challenges

Most of the challenges will be in preparing the demo. First, the terrarium needs to be constructed. Then it needs to be tested before it can be used in the classroom setting.

When running the demo and having the students do the worksheets, the students' backgrounds on heat transfer may span a wide range. It is up to the teacher to decide whether a lesson on different heat transfer mechanisms is necessary.

Sometimes when the terrarium is run for longer than 30 min, condensation starts to form on the glass walls. You may need to reapply the defogging liquid in that case.

Assessment

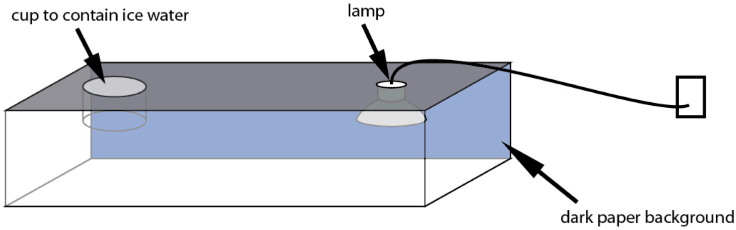
The students will be evaluated on their answers to the worksheet.

Materials

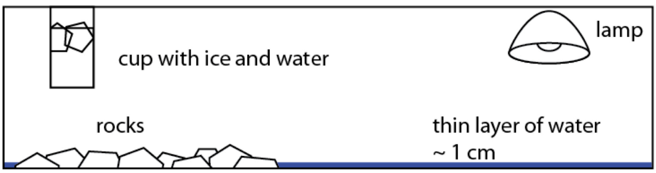
- See-through box with lid (aquarium…)
- Lamp (preferably high wattage ~250W)
- Dark-colored paper
- Defogging liquid
- Ice Cup for ice (preferably with a lip)
- Water
- Matches
- Rocks (optional)
- Documents
    - Student Handout (.doc)
    - Terrarium Schematic (.pdf)
    - Answer Key (request password from uwpcc@uw.edu)

Procedure

Preparation:



Set up



Build the terrarium as seen in the figures above.

1. Cut out a hole in the lid of the aquarium so that the cup that holds the ice can fit through, but not too big that it falls through (if the cup does not have a lip, attach the cup to the lid using some epoxy).
2. Cut a hole on the other side of the lid to slip through the power chord that attaches to the lamp.
3. Attach the lamp to the underside of the lid (see figure above).
4. Arrange rocks (optional) underneath the cup of ice.

Before class:

1. Apply the defogging liquid to the inside of the aquarium (otherwise, when it gets warm and humid in the terrarium condensation will form on the inside, making it very difficult to view the experiment).
2. Turn on the lamp.
3. Let it run for ~10 min (or less depending on the strength and position of the lamp).
4. If there are enough dust particles (aerosols) in the air, you should start seeing a steady stream of clouds flowing down from the side of the cup of ice and mushrooms of clouds forming over the water. Note:

These are clouds of liquid water droplets that form, not water vapor. Water vapor is invisible.

5. If you don't see any of these clouds, then light a match or two, blow it out, and drop it into the terrarium. The smoke from the matches is a good source of aerosols, and that is why we drop the matches into the terrarium.
6. If the clouds were not visible, they should show up after introducing some smoke into the terrarium.
7. Observe the general circulation inside the terrarium, the evaporation of water from the water surface, the condensation along the outside of the cup, and the melting of the ice.
8. If you want, ask why the introduction of smoke particles made the clouds visible.

In class:

Have the students first take a look at what's going on inside the terrarium.

Suggested plan:

10 min: Have an initial discussion about different forms of heat (energy) transfer

5 min: Have the students look at the terrarium in action. Have them identify the different forms of energy transfer.

20 min: Split up students into smaller groups, hand out the worksheet, and have them fill out the questions to the best of their ability.

20 min: Go over the worksheet with the students, as a class and see what they came up with.

Suggested questions to get students thinking while looking at the terrarium:

- How does the air flow in the terrarium? Where does the air rise and where does the air sink? And why?
- After a while, you may start seeing water droplets along the glass beaker. Where did the water come from? How did it get there? What are the relevant processes called? Is any water gained or lost inside the terrarium?
- Now let's track the energy in the terrarium. Where does the bulk of the

energy come from? Where does it go? Is energy created or lost inside the terrarium?
- When will the temperature inside the terrarium stop rising? – Does the circulation in the terrarium look like any other kind of circulation on Earth?
- Now let's suppose that we stopped the air from flowing in the terrarium (by putting in a divider, for example). What would happen to the temperature a) by the lamp? b) by the beaker with the ice? And why? What does that tell us about convection?
- Now let's suppose we took out the water from the terrarium, but still allowed air to flow. What would happen to the difference in temperature between the air by the lamp and the air by the beaker? Would it increase? Decrease? Stay the same? And why? What does that tell us about water and water vapor?

Note: For the questions above, look at the Terrarium Schematic and Answer Key (linked under Materials)

Selected Supplemental Resources

Practical and interesting ways to demonstrate a thermally direct cell (hot fluid rises, cold fluid sinks) and other useful references.

- Lava lamp
- Fill a plastic container with water and keep it up using plastic cups. Then carefully apply dye at the surface, in the middle of the container. Then put a cup filled with hot water underneath the spot of dye and see the water start to rise.
- Get students to participate in a group activity to illustrate the Hadley cell. Use the classroom to represent the Earth, where the length represents the longitude and the width represents altitude. Then have the students to carry cups and get into two rings, representing the two cells of the Hadley cell. Then, put a bucket of water along the 'surface' part of the classroom. Then put a bucket where the students can drop the water. Then have the students walk around the room, to represent the flow in the Hadley cell.
- Concentrating on downwelling zones. Similar to the second example, but putting the warm cup of water along the sides of the container to

see the downwelling in the middle of the container.

Online resources on geosciences:

Short article on water and water cycle (NASA): http://earthobservatory.nasa.gov/Features/Water/

SERC quantitative skills portal: https://serc.carleton.edu/quantskills/index.html

SERC geosciences: http://serc.carleton.edu/introgeo/index.html

NASA earth observations: http://neo.sci.gsfc.nasa.gov/Search.html

phET simulations: http://phet.colorado.edu/en/simulations/category/new

MERRA winds: http://svs.gsfc.nasa.gov/vis/a000000/a003700/a003733/index.html

Attribution: Terai, Chris, and Po-Chedley, Stephen. "Terrarium Model of Earths' Energy Balance" Climate Science for the Classroom edited by Bertram and Biyani, 2020. https://uw.pressbooks.pub/climate/chapter/terrarium-model. Date of Access.

Understanding Paleoproxies using Ice Cores

ASHLEY MALONEY

Overview

A solid understanding of earth system processes and their timescales is crucial for any climate change discussion; this lab allows students to study changes in Earth's atmospheric CO_2 composition and temperature on millennial to orbital timescales. This paleoproxies lab provides teachers instructions on building an ice core in their freezer. Students work with these ice cores to generate data that reconstructs that obtained from EPICA Dome C, Antarctica. This fun hands-on lab can be used or adapted for use by teachers of middle school science, high school geology , chemistry, environmental and climate science. Ashley Maloney (past graduate student in the UW School of Oceanography) originally designed this lab as a supplement for the University of Washington in the High School Climate and Climate Change (ATMS 211) curriculum.

Focus Questions

1. How do we know about Earth's climate before instrumental records (e.g. weather stations, ship board and buoy measurements) ?
2. What is a proxy?
3. What are the timescales of cycles and processes captured in ice core data?

4. What caused the cyclic changes in CO_2 and temperature over the last 800,000 years?
5. What are the two main differences between patterns and causes of natural CO_2 variability during the past 800,000 years and recent CO_2 levels recorded by modern instruments since the start of industrialization?

Learning Goals

Students should be able . . .

1. To explain the difference between tectonic, orbital, and anthropogenic timescales.
2. To use marbles as a proxy for isotopes and temperature in ice cores to understand how ice cores are used in scientific investigations of paleoclimate .
3. To generate CO_2 and isotopic data from ice cores that illustrate how the two variables naturally co-vary during glacial-interglacial cycles.
4. To use scientific data to explain variability in the rate and magnitude of change associated with in anthropogenic emissions of CO_2 and naturally cycling CO_2.

Background Information for Students

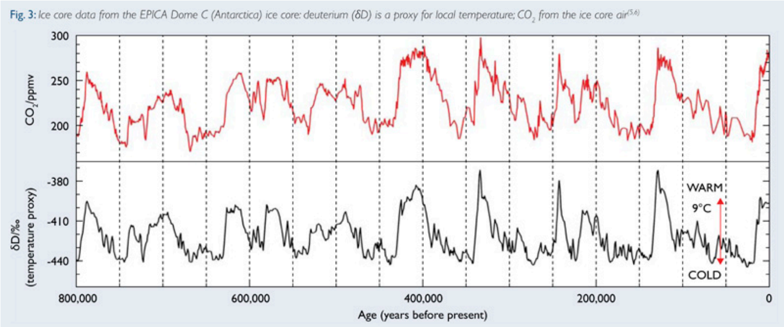
Earth's climate was quite different during the Last Glacial Maximum about 20,000 years ago when ice sheets were at their full extent. Sea levels were about 120 meters (400ft) lower, much of the Northern Hemisphere was covered in ice sheets, woolly mammoths, giant sloths, and saber-toothed cats still roamed, and the climate was cooler and drier. We learn a great deal about past climates by examining paleoproxies, and students may already be familiar with the idea that ice cores, tree rings, speleothems (cave deposits), marine sediments, lake sediments and coral skeletons can all store information about the past.

Ice cores come from every place in the world that ice accumulates over time, including tropical glaciers (see Kump et al. chapter 6 pp. 113 – 117 for glacier and ice sheet information). The most famous ice cores are from the Greenland and Antarctic ice sheets. Trapped within layers of ice are bubbles that preserve samples of the atmosphere from the past, and isotopes of hydrogen and oxygen in the frozen water that help us reconstruct past temperature.

The longest and most robust records of atmospheric CO_2 are from Antarctica and the longest ice core record collected by scientists extends back 800,000 years. The CO_2 record comes from gas trapped in the ice: atmospheric gases diffuse into the top layer of snow. As the top layer ("firn") densifies it becomes ice, trapping the gas in bubbles. Old ice far below the surface has bubbles that were trapped thousands of years ago – leaving scientists with a way to directly measure Earth's past atmosphere.

Less straightforward is the temperature record inferred from the stable hydrogen or oxygen isotopic composition of the water molecules that make up ice. Variations in temperature through time cause variations in the deuterium/hydrogen (D/H) ratios in ice. Isotope data is expressed using "delta" (δ) notation. Very negative δD_{ice} values represent colder temperatures (glacial periods) and less negative values are found during warmer climate conditions (interglacial periods).

Background Information for Teachers



This ice cores and data in this lab are modeled off the longest ice core record available to date: EPICA Dome C, Antarctica (record shown above). The homemade ice cores you will construct for your students **represent just the last 20,000 years** as it is impractical to construct the entire ice core in your freezer. There are ~10 CO_2 and ~80 isotope measurements for each 1000 years of ice. For the purposes of this lab CO_2 concentrations and isotope date are averaged every 1000 years.

You will find all data required for this lab on six tabs of the Excel spreadsheet linked under Materials. The procedure section along with the Excel spreadsheet should provide the information needed to run the lab.

Years Before Present (yrBP) means years before 1950 as the radiocarbon standard was set to a date proceeding excessive carbon produced during nuclear bomb testing. CO_2 units are PPMV = parts per million volume which reflects the concentration of CO_2 in an air sample.

Image from British Antarctic Survey

Materials

- Reference textbook: Kump LR, Kasting JF, Crane GC (2010) The Earth System. Pearson (optional)
- To make ice cores
  - Freezer space for five 1 ft tall tubes
  - Hacksaw or pipe-cutter to cut the acrylic tube into 5 sections
  - Order plastic tube ($17.22 for 6ft) at http://www.usplastic.com/catalog/ite m.aspx?itemid=32520&catid=440
  - Order endcaps ($1.85 for 5 caps) at http://www.usplastic.com/catalog/ite m.aspx?itemid=29228&catid=841
  - Electrical tape to attach endcaps
  - Waterproof sharpie
  - Green, purple, and orange marbles
  - Write-in-the-rain paper
- To dissect ice cores
  - Large cutting board(s) or dish bins
  - Hacksaw(s)
  - Hammer and chisel(s)
  - Hot water
  - Strainer
  - 10-20 dish towels
  - 20 small Dixie cups
  - Work gloves and safety goggles
- Files
  - Excel Spreadsheet for instructors – request access from uwpcc@uw.edu
  - Worksheets (.docx) – for student

Procedure

Pre-lab (allow 1-2 weeks for preparations)

This lab is designed for five student groups (but can accommodate six). It takes a week to assemble all the material and 4 days to make the ice cores since each layer needs a day to freeze. You will make 20,000 years worth of an ice core in 5 sections. Each section has four layers and every layer represents 1000 years. The CO_2 and temperature proxy data you need for each layer are on the first sheet of the Excel file (called "Making Ice Cores") and shown in two figures below. The second sheet of the Excel file (called "Understanding the Data") explains how the raw data were manipulated to create the twenty CO_2 and twenty temperature proxy data points needed for making the ice core.

1. Assemble all materials and plan out the ingredients for each layer for the 5 cores.
2. Label all 5 tube-sections with dates using electrical tape and sharpie. For instance, the first tube section for Group #1 should have four layers labeled 0-1000 yrBP, 1000-2000 yrBP, and so on.
3. Tape the end cap on the tube and pour in ~½ cup of water (it is better to add more rather than less water so that students have enough ice to hold on to during the dissections).
4. Drop in a piece of Write in the Rain paper with the CO_2 concentration written on it.
5. Add the marbles that represent the hydrogen isotope data (marbles work best so they all settle in the same place whereas beads or beans tend to float and this can lead to students attributing data to the wrong layer).
6. After water and marbles are added, drop in a piece of wax paper cut to fit the diameter of the tube (this step is optional but it helps make it easier for students to separate the ice layers), and then place in freezer for a day.
7. Make sure the first layer is completely frozen before adding the next layer or layers will mix and students will get confused. **Be sure to add the correct data to the correct layer.**

Introducing the Lab (30-60min discussion)

PRE-SURVEY

Please have each student fill out the Pre-Lab Survey (found at the end of the worksheet document). The point of this introduction is to expose students to different timescales – they should be able to explain the difference between tectonic/geologic, millennial to orbital, and anthropogenic timescales. Additionally, this introduction should answer any questions students may have about ice cores. Discuss the adventure and difficulties associated with obtaining a real ice core.

PRIOR KNOWLEDGE

Query the class to find out what they already know about past climate.

- How do scientists know about ancient CO_2?
- How can we know what temperatures were like before thermometers were invented?
- When were thermometers invented ?
- When was the instrument that measures present day atmospheric CO_2 levels invented? Who invented it?
- Why do we care about past climate?

TIMESCALES

Earth's processes operate on a number of vastly different timescales, from diurnal, seasonal, decadal, anthropogenic, millennial, geologic/tectonic, and orbital. Understanding these timescales is one of the most important, fundamental concepts in paleoclimate. Before diving into the millennial to orbital timescale that this lab is devoted to, review changes in temperature and CO_2 that occur on other timescales. Examining the Keeling Curve for a record of earth's seasonal CO2 cycle is a good way to connect with what students already understand about photosynthesis and respiration. You could revisit the Keeling curve (https://scrippsco2.ucsd.edu/history_legacy/keeling_curve_lessons.html).

Have students visit the NOAA Paleoclimatology TimeLine http://www.ncdc.noaa.gov/paleo/ctl/index.html. Check out Earth maps from different periods in Earth history at https://deeptimemaps.com/. Chapter 12 (p.233) in Kump et al. is devoted to long-term climate variability, which is controlled by very different processes (for example silicate weathering in Chapter 8, p.159) than the climatic variations that occur on millennial or orbital timescales. Students may be surprised to learn that Earth is presently in an "Ice Age" (albeit an interglacial within the ice age) because there are large permanent ice sheets in both Polar Regions. Other Ice Ages are rare and occurred millions of years ago (geologic timescale). We can't use ice cores to study ancient ice ages because that ice is long gone so the long-term climate record is inferred from deep-sea sediment cores (until about 200 million years ago), continental rocks, and geologic deposits (pp. 240 – 252 Kump et al.).

FIELDWORK

A good way to introduce the lab is to engage the students in an animated discussion about going to the field to obtain ice cores and then having them guess what the data will show. Some questions you might ask: It is time to plan an expedition to Antarctica! What does it take to plan a scientific field expedition? Who pays for it? Who is in charge of the logistics? What tools do we need? What clothes do we need? How do we get ice cores back to the lab? Where do we store them once they are here? How are we going to divvy up the ice to measure all the different parameters (CO_2, N_2O, CH_4, stable isotopes, snow accumulation, grain radius, dust, conductivity, ionic chemistry…)? What do you think CO_2 levels looked like in the past? Has temperature been constant during the last 20,000 years? The last 800,000 years? How do you think it has varied? Why has it varied?

Watch interviews with PCC climate scientists https://www.youtube.com/watch?v=jul5Tyzrg4c and a conversation with Spruce Schoenemann about his research on Antarctic ice cores https://www.youtube.com/watch?v=ywYfW0jps-w.

Part 1: What is the temperature proxy? (20-40 min discussion + activity)

In Part 1, Students learn how hydrogen isotopes are used as a proxy for temperature – and how marbles are a proxy for isotopes!

DISCUSSION/LESSON

A proxy is a substitute for an actual measurement. **CO_2 data** from ice cores is **not** proxy data because the CO_2 record is derived from measurements of CO_2 in ancient air bubbles trapped in ice. However, ice core **temperature data is** derived from a proxy. Isotope measurements of the water molecules that make up the ice reveal past temperature changes. Isotopes are identical atoms with different masses due to different numbers of neutrons (see p. 15 and p. 274 in Kump et al. for the basics). There are two stable hydrogen isotopes: "protium" which is normal hydrogen with one electron, one proton, and zero neutrons, and "deuterium" which is the rare stable hydrogen isotope with one electron, one proton, and one neutron.

To start with glaciers have less of the heavy hydrogen isotope than does seawater. Glaciers are formed from water that evaporated from the oceans. When water evaporates the heavy water is left behind and the water vapor is enriched in light water. So the water that forms the ice in the glaciers has more of the heavy isotope than does the surface ocean. This "fractionation" occurs because it takes more energy to evaporate water molecules containing the heavy isotope from the surface oceans. Also, as the moist air is transported polewards and cools, the water molecules containing the heavier isotopes are preferentially rained out. The extent to which this "fractionation" occurs–during precipitation and evaporation–is dependent on temperature.

During a cold glacial period, the equator to pole temperature gradient is large and very few heavy hydrogen isotopes make it to the poles. They rain out very soon after leaving the ocean surface. During a warm interglacial however, there is more energy in the Earth system and the equator to pole temperature gradient is relatively small which leads to more water molecules with a heavy isotope reaching the pole.

ISOTOPE DATA NOTATION

Because deuterium is very rare, hydrogen isotope ratios are very small numbers and they need to be related to a standard. Thus isotope data is expressed in delta (δ) notation (the relative deviation of a sample's isotopic ratio compared to the isotopic ratio of the standard VSMOW) with units in per mil (‰). Ice core "delta" values are negative because the D/H ratio of the ice core sample is compared to VSMOW. The "delta" value of mean ocean water (VSMOW) is zero. The ocean has more deuterium than most natural substances – so most samples have a negative value according to "delta" notation because they are depleted in deuterium relative to the standard. The units are per mil (‰) so that the numbers are not much less than unity.

Just knowing what the variations in isotopes are down an ice core can tell us a lot about changes in temperature – and that is as far as this lab goes. But this data can be taken a step further and be converted into actual temperature values. Spatial observations of isotopic variation in precipitation have allowed scientists to calibrate the relationship between temperature and isotopic ratios.

$$\delta D_{ice} = \frac{(D/H)_{ice} - (D/H)_{VSMOW}}{(D/H)_{VSMOW}} * 1000$$

PROXY ACTIVITY

Key Point: Very negative δD_{ice} values represent colder temperatures and less negative values represent warmer climate conditions.

To illustrate this key point, try the following exercise

1. Talk about isotopes and delta notation.
2. Give each group the PROXY Worksheet found in the worksheets file.
3. Point out that marbles are used here as **proxies** for isotopes–and isotopes are proxies for temperature!
4. Provide groups of students with one of two sets of marbles Set 1: 3 big green marbles, 9 small purple marbles, and 7 small orange marbles. Set 2: 4 big green marbles, 4 small purple marbles, and 2 small orange marbles.
5. Students use the worksheet to determine the isotopic ratio represented by their set of marbles (either -397‰ or -442‰).
6. Write the findings on the board. To illustrate that students understand the main point of this exercise, ask them which δD_{ice} value represents a colder temperature? (Answer = the more negative -442‰). This crucial activity will ensure that each group understands how they are going to get isotope data from their ice core.
7. Make sure everyone understands what all parts of the proxy worksheet mean (why the units for CO_2 are PPMV and any other isotope clarifications).

Part 2: Dissecting the Ice Cores (30-45 min activity)

In this part, students explore a mock ice core, in a way that models how a scientist would gather data and analyze these samples. Students will learn how ice cores can reveal past climate and in what ways the climate during the Last Glacial Maximum was different than it is today.

DATING THE ICE

Dating ice cores is not a focus of this lab, but it should be mentioned how we determine the age of the gas and the age of the ice.

Layers of ice (if visible) are counted to infer the age of the ice core matching parameters to other known dates from proxies, tying ash layers to known volcanic eruptions, and using flow models to account for the movement of deep ice away from its original deposition location. Ways to improve age dating of the gas and the a ice is a very active area of research.

DISSECTING THE ICE CORES

Now that students are familiar with the special isotope proxy and entering their data on a worksheet – it is time to produce data! Distribute work-sheets and review the parts that need to be filled out and what the units mean. Hand out ice cores, towels, hammer and chisel, hacksaw, cutting board, and cups. Everyone should wear safety goggles.

Allow 30-45 minutes for the dissection to proceed. Help students check that they don't mix up CO2 data and marbles between layers. Everyone should enter the CO_2 and temperature data extracted from the ice core on their own worksheet. Once a group has all the data from the four layers, help them enter it in the Excel spreadsheet (the tab called "Dissecting Ice cores"). **The correct data is also graphed on the Excel tab called "Lab Answer Key" so you can easily check if a group mixed up any data.** Once the graph is finished display the completed graph.

Explore some key points. If any student-generated points are different from the lab answer key, discuss the possibility of human error. What is going on during the transition from the Last Glacial Maximum to the present? Were CO_2 concentrations higher or lower 20,000 years ago? What do the isotopes tell us – was it warmer or colder 20,000 years ago? Do the data meet our expectations? Are there any surprises? Is there anything strange about the graph? What are some possible reasons for the jumpy shape of the CO_2 and Isotope plots? What does this data tell us about what has been happening to Earth's climate since the Last Glacial Maximum? What kind of timescale does this data represent?

Part 3: Extending the Record (15-30 min discussion or homework)

The point of this activity is for students to be able to explain the character of glacial-interglacial cycles during the last 800,000 years and visualize the orbital timescale. Now that students have created and analyzed the 20,000-year CO_2 record, let them extend that record another 740,000 years!

The Excel tab called "Extending the Record" has 1095 CO_2 data points and 5787 temperature data points. You can make this a homework assignment by deleting the graph and asking students to create it. Ask discussion questions like "What triggered the CO_2 and temperature to go up and down?" "Why are the glacial periods longer than interglacial periods?"

Here you can address a popular climate skeptic argument that some of your students may be familiar with, as well as starting to address local vs global phenomenon. Close inspection of the CO_2 and isotope record from Dome C show a rise in temperature during the last transition from glacial to present that precedes an increase in atmospheric CO_2. Skeptics latch onto this phenomenon and claim that CO_2 does not cause temperatures to rise. However, **this ice core record reflects local conditions at Dome C in Antarctica**. Combining proxy records from around the world (Shakun et al. 2012) reveals that **on a global scale CO_2 increases before global temperatures**, while local conditions in Antarctica stray from the global mean. Potential reasons for the local differences relate to the timing of changes in ocean circulation, sea ice cover, permafrost and terrestrial plant growth, and albedo – all of which were experiencing major changes during the transition. Regardless of the mechanism, the main point is that the timing of CO_2 and temperature records from the Antarctic ice core represent local, not global, conditions and can therefore not be used as evidence to suggest that CO_2 is not a cause for changes in temperatures. Also – it is possible that ice core ages and gas ages are not perfectly reconstructed.

Part 4: Adding Modern Data to the Record (30-60 min discussion or homework)

In this activity students learn to use scientific data to explain two key differences between anthropogenic CO_2 and natural CO_2 variability: rate and magnitude. They construct an argument about how natural variability is different than anthropogenic climate change.

The Excel tab called “Add Instrumental Data” includes two new data sets:

- the modern record from CO_2 measurements made for the past 53 years, and
- a different ice core from Law Dome to connect the gap between the instrumental record and the Dome C ice core

There are two key ideas to focus on.

1. Observe the scale of human-caused CO_2 change. Natural CO_2 variability during the past 800,000 years has been between 180 and 300 ppmv. Looking at the instrumental record on these graphs you see that humans have added over 90 ppm to the atmosphere (since this lab was written note CO_2 concentrations in May 2020 reached 415 ppmv, increasing this difference between natural and human-caused to 115 ppm).

2. This leads us to examine how fast CO_2 changed in the past and how fast we are adding CO_2 to the atmosphere now. It may help to change the scale on the x-axis or plot the best fit lines that describe CO_2 increase at glacial-interglacial transitions and compare those slopes to the recent increase in atmospheric CO_2. It took humans only 100 years to cause this change while it takes the natural cycle 10000 years to add 100 ppmv CO_2 to the atmosphere.

Understanding how fast humans are altering the carbon cycle by burning fossil fuels and increasing atmospheric CO_2 is one very important reason to study Earth’s past climate. Without this knowledge, we would have no baseline to compare the human impact on climate. Students should watch this instructive video on past CO_2 fluctuations more than once! http://www.esrl.noaa.gov/gmd/ccgg/trends/history.html

References

Textbook: Kump LR, Kasting JF, Crane GC (2010) The Earth System. Pearson

Shakun, JD, Clark PU, He F, Marcott SA, Mix AC, Liu Z, Otto-Bliesner B, Schmittner A, Bard E (2012) Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation. Nature 484 pp. 49-56 (http://people.oregonstate.edu/~schmita2/pdf/S/shakun12nat.pdf)

Additional Resources

ICE CORES

- Similar data analysis activities based on the 400,000 year Vostok, Antarctica record
  - http://serc.carleton.edu/usingdata/datasheets/Vostok_IceCore.html
  - http://serc.carleton.edu/introgeo/mathstatmodels/examples/Vostok.html
  - http://eesc.columbia.edu/courses/ees/climate/labs/vostok/
- Another approach to making ice cores that study weather events during a winter season from NASA's Education Student Observation Network at: http://www.nasa.gov/audience/foreducators/son/winter/snow_ice/students/F_Snow_and_Ice_Students.html

PALEOCLIMATE

- Timescales: NOAA timeline http://www.ncdc.noaa.gov/paleo/ctl/index.html
- Paleoclimate animations http://emvc.geol.ucsb.edu/1_DownloadPage/Download_Page.html
- Paleoclimatology overview http://serc.carleton.edu/microbelife/topics/proxies/paleoclimate.html
- NOAA Paleoclimatology data portal http://www.ncdc.noaa.gov/paleo/paleo.html
- What's the connection between low sea level and big ice sheets? Deep Sea Paleoclimate http://oceanexplorer.noaa.gov/explorations/05stepstones/background/paleoclimate/paleoclimate.html
- Antarctic marine sediment core lesson plan: http://serc.carleton.edu/eet/cores/index.html

MILANKOVITCH CYCLES

- Lesson: http://www.sciencecourseware.org/eec/GlobalWarming/Tutorials/Milankovitch/

- Visualization: https://cimss.ssec.wisc.edu/wxfest/Milankovitch/earthorbit.html

Attribution: Maloney, Ashley. "Understanding Paleoproxies using Ice Cores" *Climate Science for the Classroom* edited by Bertram and Biyani, 2020. https://uw.pressbooks.pub/climate/chapter/understanding-paleoproxies-using-ice-cores/ Date of Access.

PART IV

SCIENCE COMMUNICATION AND POLICY MODULES

Presenting Science for Policy

BRANDON RAY

Overview

In a traditional education context, there is a tendency to focus on academic areas in the silo-ed approach with limited ability to work across disciplines. There are very few "science communication" courses available to undergraduates – and of those that exist, most are focused on communicating to scientific audiences or do not incorporate much practical experience (the same is also true at the graduate level). Thus, most students who do not pursue a purely academic career are left at a disadvantage. Those who work for government agencies or non-governmental organizations will be required to work in the domain of policy or, at a minimum, policy-relevant. This module is designed for students to gain exposure to different formats and styles for communicating climate science (i.e. designed for different audiences). This will give the undergraduates exposure on how to turn their research into something upon which policy-makers can act. Although this module is being tested in ATM/OCN/ESS 475 at the University of Washington, it can be revised for different topics and used in the seminar series every year or incorporated into other classes. *Created by Brandon Ray, UW School of Marine and Environmental Affairs.*

Focus Questions

1. What is policy? What are some attributes of public policy?

2. What does policy-relevant mean?
3. What are attributes to be used in policy-relevant writing?
4. What are attributes to be used in policy-relevant speeches?

Performance Expectations

Students will be able to:

1. Describe public policy
2. Define the levels of policy relevance
3. Describe the style and techniques used in policy-relevant writing
4. Describe the style and techniques used in policy-relevant speeches
5. Write a policy-relevant paper based on their research interests
6. Give a policy-relevant speech based on their research interests

Background Information

This module is created generically for the instructor to tailor to his/her class focus. The parts of the lesson the instructor will need to customize are bolded in the "Conducting the Lesson" section below. The resources that may be helpful for the instructor are located on slides 16-17 "Writing Policy for Science" and slide 12 of "Presenting Policy for Science" (linked below).

Prior Knowledge

This unit is designed as an introduction to policy and policy-relevant writing and presentation for scientists. It presumes no prior knowledge of public policy or writing/presentation skill and is intended to scaffold students through the activities.

Anticipated Challenges

Given that students generally don't have any academic background with policy, they may be hesitant to provide answers. When requesting student input on various slides (e.g., M1.3, M1.8, M1.14), it would be beneficial to develop some questions related to your topic or area of expertise to highlight applicable portions.

Assessment

Students will be evaluated on their ability to incorporate the styles/ techniques of policy-relevant writing and speech to create a policy paper based on their research and then present their policy proposal. The rubrics are attached to each assignment.

Materials

- Presentations (for reference)
  - Writing Policy for Science – Module 1 (pdf)
  - Presenting Science for Policy – Module 2 (pdf)
- Whiteboard markers (at least two colors)
- Policy paper samples
  - Example 1 (one-pager)
  - Example 2 (one-pager)
  - Example 3 (one-pager)
  - Example 4 (infographic)
- Computer speakers (if insufficient audio on computer)
- Example Assignments
  - Policy Presentation Assignment
  - Policy Paper Assignment

Procedure

PREPARATION FOR INSTRUCTOR

Prep time for this module will be 6-8 hours to allow for review of PPTs and background materials, determine appropriate examples (as shown in bold in conducting lesson section), and to find useful policy paper samples for students to analyze.

MODULE 1

Slides 1-2 – overview to lesson

Slide 3 – Stop after showing the title of the slide and ask students what their definition of public policy is. There is no "right" answer, as the rest of the slide will show. Write the student answers down on the whiteboard, so they can see how their answers compare to various academic conceptions. (5 min)

Slides 4-7 – Overview of public policy, policy processes, and policy-relevant definitions. Provide examples of various steps in policy processes, as well as of policy-relevant definitions. Examples will help make the distinction between steps and definitions very concrete. Slide 7 is motivation for case studies on slide 8. (10 min)

Slide 8 – Case Studies. You will need to find examples of policy one-pagers for the students to analyze. Pick two examples and show them to the class on the projector. Have students analyze what they like or dislike about it. This will simulate what government staffers will experience when forced to research a topic for their boss. Write the students' perceptions on the whiteboard (this will be the start of a student-generated list of tips/techniques for writing the policy-white paper). For clarity, use two different colored markers for positive and negative traits. (10 min)

After walking through this exercise, break the students into groups of 2-4. Give each group another sample policy paper for them to analyze. Each group will be given 10 minutes to read the policy paper and discuss what they like and dislike about the paper. Then have each group present their paper, while displaying on the projector. Continue to document the student-generated tips/techniques on the whiteboard. After the lesson, these should be compiled to provide a resource to the students when working on their policy paper. (20 min)

Slides 9 -13 – Overview of policy papers, policy analysis, and writing techniques. The writing techniques should be compared to those the students generated. (20 min)

Slide 14 – In collaboration with the students, make a draft outline for a policy paper. Have the students suggest a topic (not one of their research topics) on which everyone can contribute. You should develop a couple of thematic areas in case the students are not forthcoming with suggestions. This is not intended to be a complete product, but merely to model the process the students must conduct on their policy paper assignment. (10 min)

Slide 15-17 – Quick overview of the assignment students will complete, as well as some resources for them to consult when preparing the policy paper. (5 min)

MODULE 2

Slides 1-5 – Overview of lesson and review (5 min)

Slide 6 – Case Studies. You will need to find examples of policy speeches for the students to analyze. Pick two examples and show them to the class on the projector. Have students analyze what they like or dislike about it. This will give the audience a perspective on how to deliver a message. Write the student's perceptions on the whiteboard (this will be the start of a student-generated list of tips/techniques for presenting on policy-relevant topics) (15 min).

Example case studies:

Obama at Georgetown:

Video link (youtube)

Transcript

Grab: 1:00-2:00

Need: 4:00-5:30

Goal: 29:30-30:15

Conclusion: 46:40-end

Leonardo DiCaprio at the 2014 United Nations Climate Summit:

Video link (youtube)

Slides 7 -9 – Overview of oral presentation techniques. The speech techniques should be compared to those the students generated. (10 min)

Slide 10 – In collaboration with the students, you will make a draft outline for a policy speech. Use the same thematic area as for the draft policy paper in the previous module. You should develop a couple of thematic areas in case the students are not forthcoming with suggestions. This is not intended to be a complete product, but merely to model the process the students must conduct on their policy paper assignment. Once the outline is established, have the students develop a brief (1-2 min) speech. Ask several of the students to give their speeches to the class, ask students to give feedback. (25 min)

Slide 11-12 – Quick overview of the assignment students will complete, as well as some resources for them to consult when preparing their speech. (5 min)

Scientific Evidence for Anthropogenic Climate Change

NICOLE WIGDER

Overview

This module provides students with the opportunity to read and synthesize information from published IPCC reports. Students are asked to choose a topic to focus on and present the information. This is designed to be a culminating project for high school students. Created by Nicole Wigder (2012), updated by Surabhi Biyani (2019).

Focus Questions

1. How have people influenced the Earth's climate?
2. How has our understanding of anthropogenic climate change shifted over time?
3. How certain are we that anthropogenic climate change is occurring?

Learning Goals

1. Read and understand scientific reports
2. Write a research report with citations
3. Develop expertise in a climate change topic
4. Present research results visually and orally

Background Information

- For this project, students will create a consensus scientific report similar to the Climate Change Assessment Reports developed by the Intergovernmental Panel on Climate Change (IPCC).
    - Background information on the IPCC is available at: https://www.ipcc.ch/about/
    - As of 2019, there are five assessment reports (AR1-AR5) and the sixth report is scheduled for completion in 2022. The preface for AR4 gives a brief introduction to the history of IPCC reports: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-frontmatter-1.pdf

- Each of the five assessment reports represents the scientific consensus on climate change at the time the reports were written (AR1: 1990; AR2: 1995; AR3: 2001; AR4: 2007; AR5: 2014).
- The five assessment reports, along with other IPCC reports, are located on the IPCC website: https://www.ipcc.ch/reports/

- The students will need to cite sources in their research papers. The IPCC reports are written using citations, so they provide a good example to students on how to cite sources.
- We recommend that the students use APA style citations, since there is a lot of background information about this style on the Purdue OWL website (http://owl.english.purdue.edu/owl/resource/560/1/).

Materials

- Access to the internet and word processing software
- Materials to create poster or video presentations of the research

Procedure

The following procedure is a suggestion that includes ideas from teachers participating in the 2011 UWHS/NASA Climate Science Workshop. Other options and suggestions for modifying the procedure are listed below.

Overall, we recommend that teachers modify the student instructions/ expectations based on what fits best with their class.

1. The students will work in groups of 3-4. Each group will pick a climate research topic from the provided list.
2. Each group will read the assigned reading for their topic and write an 8-10 page research report.
    - The assigned reading includes excerpts from each of the four IPCC assessment reports. Therefore, it will give the students perspective on how scientific understanding of their topic has changed over time.
    - The groups should write a first draft of the report and get comments from another group and/or the teacher before turning in the final draft.
    - After finishing the reports, each group will prepare a poster describing the main points from their paper.
3. At the end of the unit, each group will present their topic to the rest of the class using their poster. (This is very similar to a poster presentation at a scientific meeting.) Presentations should be about 20 minutes, with 10 additional minutes for discussion.
    - The discussion will be led by the students and should focus on further scientific research that should be done on the topic. The group presenting should take notes on what the class decides.
4. Finally, the class will compile its consensus report on climate change. This could be a binder with a page for each topic. Each topic's page would include the abstract copied from the students' paper and a bulleted list of the future research ideas brainstormed by the class.

Other options and suggestions for modifying this procedure:

1. Grading could be mostly focused on the consensus report and presentation, with the full report just graded for completeness.
2. Students could be required to find and read 1-2 additional papers or articles outside of the assigned reading.
3. It was suggested that students could take field trips to shadow scientists at their work.

4. If more than one school is working on the project at the same time, it was suggested that it would be educational to bring all the students together for the presentations, to make the experience more like a scientific meeting.
5. It was also suggested that UW graduate students might volunteer to “grade” or provide feedback on the poster presentations.
6. During the 2012 school year, one teacher implemented this project in his class. He had each group pick one of the topics and create a video or give a PowerPoint presentation on their topic, in addition to turning in a written report. (And, many of the students prepared AMAZING videos!)

Instructions for Students

Introduction

Your goal is to research a climate change topic and how scientific understanding of that topic has changed over time. You will work with a group to write a research paper about your topic and create a poster presentation similar to the posters that scientists prepare for research conferences. You will present your poster to the rest of the class and then lead a discussion about your topic. You will use the results of this discussion to write a summary of your topic that will be included in a class consensus report on climate change.

Research Paper Instructions

The research topic list includes required reading for each topic. The required reading includes background information on your topic as well as excerpts from the four Intergovernmental Panel on Climate Change (IPCC) assessment reports, which are known as AR1, AR2, AR3, AR4, and AR5. Each of the assessment reports summarizes the scientific consensus on climate change at the time the report was written. The reports were written in 1990 (AR1), 1995 (AR2), 2001 (AR3), 2007 (AR4), and 2014(AR5). The sixth assessment report, AR6, is scheduled to be completed in 2022. By reading the portions of each assessment report that focus on your topic, you will be able to explore how the scientific consensus on your topic has changed over time.

Each member of your group should read all of the assigned reading materials. You will probably need to read all of the materials more than once in order to fully investigate the differences between the four assessment reports. You can also choose to read additional documents related to your topic that you find in the library or online. Be careful with information you find online. It is important to only consult websites from reputable sources, such as government agencies or universities. There may be abbreviations or words that you do not understand in the documents that you are reading. Take time to look up the definitions online or in the IPCC AR5 glossary (https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_AnnexIII_FINAL.pdf). If you don't know what an abbreviation stands for, look at the pages before your assigned reading section to find the meaning of the abbreviation.

Your group will write an 8-10 page double-spaced paper on your topic. This is a research paper, which means that it should include scientific citations. This means that every fact or statistic you write should be attributed to the source where you found the information. You'll notice that the IPCC reports contain citations; use these reports as an example of how frequently you should be citing sources in your own paper. In your paper, cite only the four IPCC assessment reports (not the papers that are cited in these reports) and the other websites or documents that you have read. You will be using the APA citation style (http://owl.english.purdue.edu/owl/resource/560/1/). You don't need to follow all of the paper formatting requirements listed on this website, but you do need to follow the guidelines for in-text citations (http://owl.english.purdue.edu/owl/resource/560/03/) and writing out the reference list at the end of your paper (http://owl.english.purdue.edu/owl/resource/560/08/ or http://owl.english.purdue.edu/owl/resource/560/10/). Hint: treat the IPCC assessment reports as books with 'IPCC' as the author.

You can use abbreviations in your paper, but you have to define them the first time you use the abbreviation. For example:

"There are no ice shelves in the mainland United States (US), but there are ice shelves in the Arctic and Antarctica. The US assists other countries with research on these ice shelves. This research is documented in the Intergovernmental Panel on Climate Change (IPCC) assessment reports. The IPCC reports are written by US scientists in collaboration with scientists of other nationalities."

Your paper should have five sections in the following order:

Abstract: The abstract is a one paragraph summary of your entire paper. Even though it is located at the beginning of your paper, you should write this section last.

The abstract should include: (1) 1-2 sentences introducing your topic and why it's related to climate change, (2) 1 sentence describing each of the results detailed in the 'Scientific Consensus Over Time' section, (3) 1-2 sentences explaining the main results in the 'Scientific Certainty' section, and (4) 1-2 sentences describing your main conclusions. The abstract should be no more than 1000 words long.

Introduction: The introduction should provide background information on your topic. When writing this section, pretend that your audience doesn't know anything about your topic. Provide a lot of details about your topic and explain why it is related to anthropogenic climate change. This section should be 2-4 paragraphs.

Scientific Consensus Over Time: This should be the longest section of your report, covering 4-6 pages. Show in detail how the scientific consensus on your topic has changed over time by describing the differences between the information in the four IPCC assessment reports.

To do this, make a list of main concepts related to your topic. For example, if your topic is stratospheric ozone, your list of main concepts could be: (1) Arctic stratospheric ozone, (2) Antarctic stratospheric ozone, (3) seasonal variations in stratospheric ozone, (4) stratospheric ozone concentrations in the future, and (5) methods for measuring stratospheric ozone. Next, write a paragraph about each of these concepts explaining how the scientific consensus changed over time. For some of the concepts you choose, the earlier assessment reports will have no information about the concepts. This is not a problem; just make sure to document in your paper that the scientific community didn't have a consensus on the topic until the later assessment reports.

Scientific Certainty: In this section of your report, describe the amount of scientific certainty about your subject, focusing on the information in the

IPCC AR5 report. For example, you could focus on answering some of the following questions:

- How sure is the scientific community about the future trends related to your topic?
- Are there multiple explanations for what is occurring now or what will occur in the future?
- When you look at the graphs of data related to your topic, how large are the error bars?
- When statistics are quoted in AR5, what is the uncertainty in these numbers (what is the number after the ± sign)?

Conclusions: This 1-2 paragraph section should provide a broad overview of the main ideas detailed in your paper. For example, you could focus on answering some of the following questions:

- In general, how has scientific consensus on your topic changed over time?
- Is there more information on your topic now than there was in the past?
- In general, what are the future trends related to your topic and what is the uncertainty in those predictions?
- Are there areas where further research is needed?

References: This section should include the full citations for all of the sources you cited in your paper. See: http://owl.english.purdue.edu/owl/resource/560/08/ and http://owl.english.purdue.edu/owl/resource/560/10/). There should be a citation for each of the IPCC reports and for each of the other documents or websites you read.

Poster Instructions

After you finish the research paper, your group should prepare a poster summarizing the main points of your paper. You will use the poster to present your topic to the rest of the class. Be creative in how you present the information and make sure to include lots of pictures and graphs. If you include any of the graphs or pictures from the IPCC reports or other online sources, make sure to cite the source of those graphics on the poster. (For example, write (IPCC AR4, 2007) next to a plot copied from the fourth IPCC assessment report.) At a minimum, your poster should contain: a title, your names, background information on your topic, the main points from the 'Scientific Consensus Over Time' and 'Scientific Certainty' sections of the report, and the main points from your 'Conclusions' section.

Presentation Instructions

Your group will have approximately 30 minutes to present your topic to the rest of the class. During the first 20 minutes, describe your topic to the class and point to the relevant graphs or pictures on your poster as you describe them. During the final 10 minutes, you must lead the class in a discussion about what concepts around your topic need further research in the future. Ask the class questions like, "what concepts are least clear or least certain about this topic?" or "do you have ideas about what other information scientists need to better understand this topic?". There are no wrong answers! Take notes on the ideas that the class comes up with, because you'll need these to write your section of the class consensus report.

Consensus Report Instructions

Each group will contribute a 1-2 page summary of their topic for the class consensus report. Use the provided template to create your summary for the consensus report. There are two main sections of the summary: (1) the abstract, which is exactly the same as the abstract in your research report, and (2) a bulleted list of areas of future research on your topic, which should be a summary of the ideas brainstormed by the class during your presentation. Each bullet should be 1-2 sentences describing the area of future research and why it is important.

Potential Research Topics

Below is a list of potential research topics. Included with each topic is a list of articles and websites that you must read if you choose the topic. The five IPCC assessment reports can be found on the following websites:

- IPCC AR1 (1990): https://www.ipcc.ch/report/ar1/wg1/
- IPCC AR2 (1995): https://www.ipcc.ch/report/ar2/wg1/
- IPCC AR3 (2001): https://www.ipcc.ch/report/ar3/wg1/
- IPCC AR4 (2007): https://www.ipcc.ch/report/ar4/wg1/
- IPCC AR5 (2013): https://www.ipcc.ch/report/ar5/wg1/

1. **Sea ice:** explore the relationship between temperature and sea ice extent in the Arctic and Antarctic.
    - Background information
        - Read all of the information in the sea ice section of the National Snow & Ice Data Center website (http://nsidc.org/cryosphere/seaice/). (Start on the 'Introduction' page. Keep reading until you have reached the end of the 'Studying: Modeling' page.)
    - IPCC AR1
        - Section 7.8.2 (Sea-ice extent and thickness)
    - IPCC AR2
        - Section 3.2.5.3 (Sea ice extent and mass)
    - IPCC AR3
        - Section 2.2.5.2 (Sea ice extent and thickness)
    - IPCC AR4
        - Section 4.4 (Changes in sea ice), including sub-sections 4.4.1-4.4.4.3.
    - IPCC AR5
        - Section 4.2 (Sea Ice)
2. **Sea level change:** explore the connection between climate change and sea level.
    - Background information
        - Read section 5.5.1 (Introductory Remarks) in IPCC AR4. This section explains that there are two major processes affecting sea level change. Next, read about each of the processes in section 5.5.3 (Ocean Density Changes) and 5.5.5 (Ocean Mass Changes), including sub-sections 5.5.5.1-5.5.5.4.
    - IPCC AR1

        - Section 9.3 (Has Sea Level Been Rising Over the Last 100 Years?), including sub-sections 9.3.1-9.3.3.
        - Section 9.5 (How Might Sea Level Change in the Future?), including sub-sections 9.5.1-9.5.2.
    - IPCC AR2
        - Section 7.2 (How Has Sea Level Changed Over the Last 100 Years?), including sub-sections 7.2.1-7.2.2.
        - Section 7.5 (How Might Sea Level Change in the Future?), including sub-sections 7.5.1-7.5.5.
    - IPCC AR3
        - Section 11.3 (Past Sea Level Changes), including sub-sections 11.3.1-11.3.3.
        - Section 11.5 (Future Sea Level Changes), including sub-sections 11.5.1-11.5.4.3.
    - IPCC AR4
        - Section 5.5.2 (Observations of Sea Level Changes), including sub-sections 5.5.2.1-5.5.2.6.
        - Section 5.5.6 (Total Budget of the Global Mean Sea Level Change). Also, read Frequently Asked Question 5.1 (Is Sea Level Rising?).
    - IPCC AR5
        - Section 13.2 (Past Sea Level Change), including subsection 13.2.1.
        - Section 13.3.6 (Budget of Global Mean Sea Level Rise).
        - Section 13.5 (Projections of Global Mean Sea Level Rise).

3. **Atmospheric carbon dioxide:** explore the relationship between carbon dioxide and atmospheric temperature.

    - Background information: Read section 1.2 (Carbon Dioxide) in IPCC AR1, including sub-sections 1.2.1-1.2.1.3. In IPCC AR4, read Frequently Asked Question 2.1, including Box 1: “What is Radiative Forcing?”
    - IPCC AR1
        - Sub-sections 1.2.4.1-1.2.4.3 within section 1.2.4 (The Contemporary Record of Carbon Dioxide- Observations and Interpretation).
        - Section 1.2.6 (Sensitivity Analyses for Future Carbon Dioxide Concentrations).
    - IPCC AR2

        - Sub-sections 2.1.1-2.1.3.2 within section 2.1 (CO_2 and the Carbon Cycle).
    - IPCC AR3
        - Sub-sections 3.5.1-3.5.2 within section 3.5 (Observations, Trends and Budgets).
        - Section 3.7.3.2 (Concentration projections based on IS92a, for comparison with previous studies).
    - IPCC AR4
        - Section 2.3.1 (Atmospheric Carbon Dioxide).
    - IPCC AR5
        - Section 8.3.2.1 (Carbon Dioxide).

4. **Atmospheric methane:** explore the relationship between methane and atmospheric temperature.
    - Background information
        - Read the NASA article, "Methane: A Scientific Journey from Obscurity to Climate Super-Stardom" (http://www.giss.nasa.gov/research/features/200409_methane/)
        - In IPCC AR4, read Frequently Asked Question 2.1, including Box 1: "What is Radiative Forcing?"
    - IPCC AR1
        - Section 1.3 (Methane), including sub-sections 1.3.1-1.3.5.
    - IPCC AR2
        - Section 2.2.2.1 (Methane).
        - Section 2.2.3.1 (The methane budget).
    - IPCC AR3
        - Section 4.2.1.1 (Methane).
    - IPCC AR4
        - Section 2.3.2 (Atmospheric Methane).
    - IPCC AR5
        - Section 8.3.2.2 (Methane).

5. **Ocean heat content:** explore the role that ocean heat content plays in changes to the Earth's climate.
    - Background information

        - Read the NOAA article, “Climate Change: Ocean Heat Content” (www.climatewatch.noaa.gov/article/2011/climate-change-ocean-heat-content).
        - Read the NASA article, “Earth’s Big Heat Bucket” (http://earth-observatory.nasa.gov/Features/HeatBucket/). Read all the pages (1-5) of this article.
    - IPCC AR1
        - Section 7.7 (Sub-Surface Ocean Temperature and Salinity Variations).
    - IPCC AR2
        - Section 3.2.4 (Subsurface Ocean Temperatures).
    - IPCC AR3
        - Section 2.2.2.5 (Sub-surface ocean temperatures and salinities).
    - IPCC AR4
        - Section 5.2.2 (Ocean Heat Content), including sub-sections 5.2.2.1-5.2.2.3.
    - IPCC AR5
        - Section 3.2 (Changes in Ocean Temperature and Heat Content), including sub-sections 3.2.1 – 3.2.5.

6. **Atmospheric aerosols:** explore the relationship between aerosols and atmospheric temperature.

    - Background information
        - Read the NASA article, “Aerosols: Tiny Particles, Big Impact” (http://earthobservatory.nasa.gov/Features/Aerosols/).
        - In IPCC AR4, read Frequently Asked Question 2.1, including Box 1: “What is Radiative Forcing?”
    - IPCC AR1
        - Section 2.3.2 (Direct Aerosol Effects)
        - Section 2.3.3 (Indirect Aerosol Effects)
    - IPCC AR2
        - Section 2.3 (Aerosols), including sub-sections 2.3.1-2.3.4.
    - IPCC AR3
        - Section 5.1 (Introduction), including sub-sections 5.1.1-5.1.2.
    - IPCC AR4

- Sub-sections 2.4.1-2.4.3 of section 2.4 (Aerosols).

- IPCC AR5
  - Section 7.3 (Aerosols).

7. **Glaciers:** explore the relationship between temperature and glacial retreat.
   - Background information
     - Read the National Snow & Ice Data Center website (http://nsidc.org/cryosphere/glaciers/). Focus on the information in the 'Introduction', 'The Life of a Glacier', 'About Glaciers' and 'Photo Gallery' sections of this website. (Start on the 'Introduction' page. At the end of each page, there is a link for the next page of information. Keep reading until you have reached the end of the 'Drumlins' page.)
   - IPCC AR1
     - Section 7.8.3 (Land Ice).
   - IPCC AR2
     - Section 3.2.5.1 (Retreat of glaciers).
     - Section 7.3.2 (Glaciers and Ice Caps), including sub-sections 7.3.2.1-7.3.2.3.
   - IPCC AR3
     - Section 2.2.5.4 (Mountain glaciers).
   - IPCC AR4
     - Section 4.5 (Changes in Glaciers and Ice Caps), including sub-sections 4.5.1-4.5.3.
   - IPCC AR5
     - Section 4.3 (Glaciers), including sub-sections 4.3.1-4.3.3.

8. **Ocean salinity and circulation:** explore the salinity of Earth's oceans and how salinity changes can affect ocean circulation, especially in the Atlantic Ocean.
   - Background information
     - Read the NASA article, "Science: Ocean Circulation & Climate" (http://aquarius.nasa.gov/science-ocean.html). If you want, you can also watch the videos linked at the bottom of this article.

        - Read pages 1-3 of the NOAA article, "The Global Conveyer Belt" (http://oceanservice.noaa.gov/education/kits/currents/06conveyor.html).
    - IPCC AR1
        - Section 7.7 (Sub-Surface Ocean Temperature and Salinity Variations).
    - IPCC AR2
        - Section 3.4.3 (Northern Hemisphere Circulation). When reading this section, just focus on the part that discusses the North Atlantic Oscillation (NAO).
    - IPCC AR3
        - Section 7.3.7 (Thermohaline Circulation and Ocean Reorganisations).
    - IPCC AR4
        - Section 5.2.3 (Ocean Salinity).
        - Section 5.3.2 (Atlantic and Arctic Oceans).
        - Sub-section 5.3.2.1 (North Atlantic Subpolar Gyre, Labrador Sea and Nordic Seas).
        - Box 5.1 (Has the Meridional Overturning Circulation in the Atlantic Changed?)
    - IPCC AR5
        - Section 3.3 (Changes in Salinity and Freshwater Content).
        - Section 3.6 (Changes in Ocean Circulation).

9. **Tropical cyclones:** explore recent changes in the tropical cyclones (a category that includes hurricanes).
    - Background information
        - Read the NCAR article, "Hurricanes and Climate Change" (www.cgd.ucar.edu/research/climate/hurricanes.html).
        - Read the NASA website, "Hurricanes: The Greatest Storms on Earth" (http://earthobservatory.nasa.gov/Features/Hurricanes/hurricanes_3.php). Read just the "Hurricane Climatology" portion of this website.
    - IPCC AR1
        - Section 7.11.3 (Tropical Cyclones).
    - IPCC AR2

        - Section 3.5.3.1 (Tropical cyclones).
    - IPCC AR3
        - Section 2.7.3.1 (Tropical cyclones).
    - IPCC AR4
        - Section 3.8.3 (Evidence for Changes in Tropical Storms), including sub-sections 3.8.3.1-3.8.3.6.
        - Box 3.5 (Tropical Cyclones and Changes in Climate).
    - IPCC AR5
        - Section 2.6.3 (Tropical Storms).
        - Section 14.6.1 (Tropical Cyclones).

10. **Extreme temperature and precipitation events:** explore changes in temperature and precipitation in recent years.
    - Background information
        - Section 3.8.1 (Background) of the IPCC AR4.
    - IPCC AR1
        - Section 7.11.2 (Droughts and Floods).
    - IPCC AR2
        - Sub-sections 3.5.2.1-3.5.2.2 in section 3.5.2 (Climate Variability).
    - IPCC AR3
        - Sub-sections 2.7.2.1-2.7.2.1 in section 2.7.2 (Is There Evidence for Changes in Variability or Extremes?)
    - IPCC AR4
        - Section 3.8.2 (Evidence for Changes in Variability or Extremes), including sub-sections 3.8.2.1-3.8.2.2.
        - Frequently Asked Question 3.3 (Has there been a Change in Extreme Events like Heat Waves, Drought, Floods and Hurricanes?)
    - IPCC AR5
        - Section 2.6.2 (Temperature Extremes).
        - Section 2.6.2.1 (Precipitation Extremes).
        - Frequently Asked Questions 2.2 (Have there been any changes in climate extremes?)

11. **Oceanic dissolved carbon:** explore the connection between anthropogenic carbon emissions and oceanic dissolved carbon.

- Background information
  - Read Section 1.2 (Carbon Dioxide) in the IPCC AR1, including sub-sections 1.2.1-1.2.1.3.
  - Read the NASA article, "Climate Change Seeps into the Sea" (https://www.nasa.gov/topics/earth/features/climate_acido-cean.html)
- IPCC AR1
  - Sub-sections 1.2.4.2 (Uptake by the ocean).
- IPCC AR2
  - Sub-sections 2.1.4-2.1.5 within section 2.1 (CO2 and the Carbon Cycle).
- IPCC AR3
  - Section 3.2.3 (Ocean Carbon Processes), including sub-sections 3.2.3.1-3.2.3.3.
- IPCC AR4
  - Section 5.4.2 (Carbon), including sub-sections 5.4.2.1-5.4.2.4.
- IPCC AR5
  - Section 3.8.1 (Carbon), including sub-sections 3.8.1.1-3.8.1.2.

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