

Climate Toolkit 2.0

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FRANK D. GRANSHAW



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Introduction

These activities in this manual exist to help the reader navigate the complex and perplexing issue of climate change by providing tools and strategies to explore the underlying science. Though originally aimed at undergraduate non-science majors, it has been broadened for a wider audience. Most activities make use of readily available on-line resources developed by research groups and public agencies. These include web-based climate models, climate data archives, interactive atlases, policy papers, and “solution” catalogs. Unlike a standard textbook, it is designed to help readers do their own climate research and devise their own perspective rather than providing them with a script to assimilate and repeat.

Structurally the activity portion of the manual is divided into five sections that include the following.

- *Weather and climate basics* – These activities focus on the distinction between and relationship of weather and climate, how climate statistics are derived, and which ones are most important for understanding our current climate dilemma. It also delves into what climates zones are all about, how the earth’s climate system works, and how modeling provides information for understanding the climate systems and how they change.
- *Present impacts* – The activities in this section look at the key changes we are seeing in the weather and climate over the past two centuries.
- *Past climate change* – These activities look at past climate changes, what drove them, how we derive this information, and how a knowledge of past climate is useful for forecasting and responding to future climate

change.

- *Future change and impacts* – The activities here are a more in-depth look at present climate impacts and what these may look like over the next century.
- *Going forward* – A final section consisting of activities that focus on strategies for climate mitigation and adaptation.

The activities are followed by three appendices. The first provides information about the on-line tools used in the activities in this manual. The second is a collection of on-line and print resources produced by research groups, government agencies, and community groups involved in climate and sustainability work. The third looks at the history and key players in the international climate negotiation process.

Ours is a time marked by accelerating and increasingly problematic changes in the earth's climate. Understanding, controlling, and coping with these changes is a critical and defining challenge of our times. While climate change is not the only issue now facing the global community, it is a key issue that underlies and amplifies many other problems. It is one that will likely have grave consequences for the current and future generations if not dealt with now. It is also an issue that is very complex, frequently abstract, and often contentious. As a result, our response to it ranges from anxious concern to adamant denial, with a fair amount of protective indifference, wishful thinking, and cynicism filling the space between. It is also tempting, particularly for scientists, to view it as a purely scientific issue that one can be clinically dispassionate about. However, because of the immediacy and scope of the changes now upon us, such "objectivity" while seemingly comfortable, is a luxury we can no longer afford. Furthermore, the fact that these changes have cultural, economic, and personal repercussions makes professional detachment unrealistic and unethical.

As you navigate the information in these pages, here are

some ideas and experiences that may be helpful in coping with the information and implications presented in this manual.

- *When the going gets tough turn to wonder* – Climate systems and climate change issues are often complex and sometimes rather abstract. It is tempting to retreat when the science or the issues seem cryptic. However, a certain amount of curiosity can be an immensely valuable tool to help you decode and appreciate what at first feels insurmountable. It also provides a much-needed counterbalance to some of the more depressing facets of our current climate dilemma.
- *While uncertainty can be discomforting, it also opens up new possibilities* – Every human enterprise comes with a degree of uncertainty. It is tempting to react with fear and paralysis when faced with ambiguity and risk. However, uncertainty drives scientific inquiry and a great many other endeavors. It also requires us to devise new approaches to old problems, which can provide abundant opportunities to be creative.
- *Responding to our climate dilemma doesn't come with a script* – The fact that our current situation has few (if any) parallels in human history means that we as a species are experiencing something new. Consequently, we have to create solutions that are different from anything we have created in the past. While this can be unsettling, it is important to remember that inventing new strategies are something that we humans have done more than once during our brief history.
- *The most effective response to our current situation is not to wait for "leaders" to fix the problem for us, but to discover what each of us can do in conjunction with other people* – Over the past two years my wife and I had the privilege of attending two major UN climate conferences in Europe. These followed in the wake of COP21, the 2015

conference in Paris France. COP21 resulted in an unprecedented commitment by nearly all the countries of the planet to keep the rise in global temperature at the end of the 21st century to no more than 2.0°C [1].

The two follow-up meetings that we attended (COPs 23 and 24) were intended to develop a framework by which the signatories were to act on the commitments they brought to the table in Paris. Unfortunately, as governments changed and global emissions continued to rise, the promise of the Paris agreement seemed to fade. International negotiations be agonizing slow, messy, and unproductive.

However, one thing we learned from the rich tapestry of the civil society events that accompanied these meetings is that even as the negotiators became mired in conflict, there were a host of new players stepping up to take on the mantle of leadership. These are representatives from a variety of community groups, indigenous communities, local governments, and companies busy devising and following through on a wide range of creative and effective strategies. Some unlikely alliances to these efforts highlighted new recognitions that we are increasingly in a situation that requires “all hands and minds on deck”. It seems a hopeful sign that the difficulties with our current response can be overcome and that impossible things are indeed possible.

Footnotes

[1] More accurately the collective commitment was to keep the rise in average annual global temperature to no more to 2.0°C with a strong effort being made to stay as close to 1.5°C as is possible. This rise is calculated using the preindustrial (1850s) average as a baseline. More about this in the present impacts activities.

Acknowledgements and Dedication

Acknowledgements

Like any project of this type, this manual is a community effort. The following people make up that community via their comments, suggestions, edits, and review.

Sharon Delcambre (University of Portland), Sydney Brahmavar (Clark College), Neeraja Haviligi (Greater Portland Sustainability Education Network), Jessica Kleiss (Lewis and Clark College), Judy Lumb (Quaker Institute for the Future), David Percy and John Perona (Portland State University), and Owen Rudloff (Greater Portland Sustainability Education Network)

A special thank you goes to my wife, Annette Carter, for her many edits and patience with me throughout this project.

Dedication

To my grandchildren, Amelie and Ichiro, and their contemporaries.

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Listing of the creators of the resources used in this manual

- 2° Institute
- Applied Climate Science Lab / University of Idaho
- Cameron Beccario
- Climate Central
- Climate Change Institute / University of Maine
- Climate Impacts Lab
- Climate Interactive
- Google Inc.
- Howard Hughes Medical Institute Biointeractive Program
- Intergovernmental Panel on Climate Change
- Lawrence Livermore National Laboratories
- National Oceanic and Atmospheric Administration
- Our World in Data
- University of Manchester
- United States Department of Energy

PART I

WEATHER / CLIMATE BASICS

1: Weather, Climate, and Climate Change - Mt. Rainier Washington

Key questions for this investigation

- How do you describe the weather of a specific place at a specific time?
- How do you describe the weather of this place over a period of time (climate)?
- How do you go about determining how the climate of this place has changed over time?

Tool used in this investigation

A virtual field site for Nisqually Glacier on Mt. Rainier Washington
<<http://vfeprojcts.research.pdx.edu/WeatherClimateMORA>>

Background

Weather is defined as the condition of the atmosphere at a specific time, often for a specific place. As such, it is directly observable making it much less abstract than climate. In

observing weather, we break it down into elements that are discrete characteristics which vary over time and that are readily measurable (e.g. temperature or cloud cover).

Climate on the other hand, is a statistical portrait of the weather for specific places, regions, or even the entire planet. This information is meant to provide us a sense of what's normal, what's unusual, and what's changing and how. To determine climate for a single station we use days, months, or years of data from that station to calculate averages and extremes of each of the elements observed at that station. To determine the climate of a region, we calculate these same statistics using data from several of the stations in the region. To calculate these statistics for the entire planet we use data from as many stations around the planet as is possible, as well as data from satellites and other mobile data collection platforms.

A weather report is like snapshot. By comparison, a climate record is a broad, long view of the data. The climate record enables us to see trends over the “noise” of the short-term fluctuations of our local, daily weather. Activity A in this investigation illustrates this idea by having you analyze weather and climate data from a weather station on that has been in operation at Mt. Rainier, Washington for nearly a century.

While determining how the climate of a place or region has changed over time is determined in part by direct observation of the weather, more often it is determined by looking at physical indicators referred to as climate proxies. These indicators include a broad range of chemical, geological, historical, and biological clues of past climatic conditions and changes. More about this in Investigation 11.

Activities B and C in this investigation involve looking at changes in the local climate of Mt. Rainier based on changes in size of one of its major glaciers, Nisqually Glacier.

See the additional resources at the end of this investigation for supplemental background information

Investigation

ActivityA – Weather and Climate in Paradise

To start this activity, access the virtual field site [Weather and Climate Nisqually Glacier](#). This site is a interactive panorama of three location near Nisqually Glacier on Mt. Rainier. The location you will come to first is a weather station near the Paradise Ranger station that has been in operation since 1916. The weather station is visible to the north and is marked with a label and two green dots (figure 1).

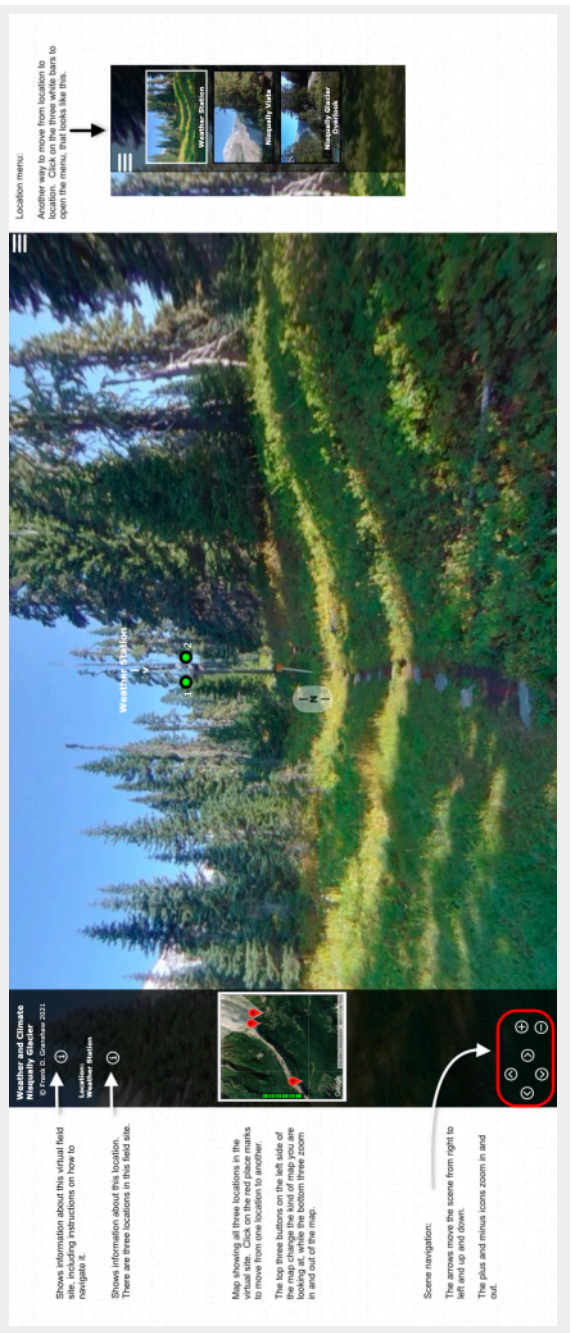


Figure 1 – Paradise RS Weather Station.

This is what you see when you first open the virtual field site. The controls for navigating the site are marked on both sides of this figure.

The weather at Paradise Ranger Station on 2 October 2020

Here you will be making simple observations of the weather at this location to answer the following questions.

1. *Without accessing the data from the weather station, how would you describe the weather at the date and time this photograph was taken? To do this make a list of the distinct elements of the weather you can see by looking around in the scene. For each element describe what you see.*
2. *Access the weather for this station by moving your cursor over green dot #1. What weather elements are listed for this station and what is the value recorded for each station?*

Daily weather statistics for 2 October 2020

To get a sense of what the rest of the day was like use the climate statistics in the bottom right corner of the same data panel that you used for the previous question.

3. *What elements are listed in this panel and what are the values for each?*
4. *How do these values compare to the conditions recorded at 11 am?*
5. *What does your conclusion for question 2 tell you about the rest of the day?*

Comparing daily weather statistics for 2 October 2020 to the longer term climate record

To make these comparisons use data panel #2 that is accessed by moving your cursor over green dot #2.

1. *How does the air temperature, precipitation, and snowfall for 2 October 2020 compare to the rest of October?*

2. *How do these values compare to rest of 2020?*
3. *How does the air temperature, precipitation, and snowfall for 2 October 2020 compare to the average value for 2 October from the 1916-2020 record?*
4. *How does the October 2020 air temperature, precipitation and snowfall compare to the October average from the 1916-2020 record?*
5. *How does the 2020 air temperature, precipitation, and snowfall compare to the annual average from the 1916-2020 record?*

Activity B – Nisqually Vista

For this activity move to the second location, Nisqually Vista. This can be done using either the map on the left side of the scene or the location menu in the upper right. Figure 2 shows you what you should see when you do so.

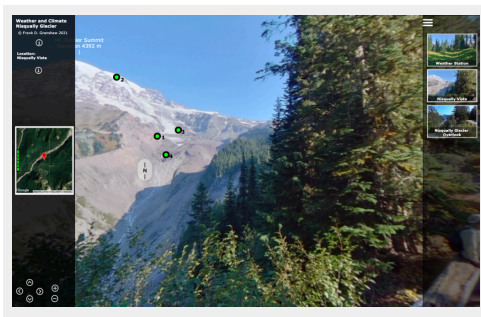


Figure 2 – Nisqually Glacier from Nisqually Vista

An alpine glacier is a mass of ice that forms on mountain slopes and is able to flow downhill much like streams do, only much slower. Here are the mechanics that make this possible...

- In the upper reaches of the glacier, *the **zone of accumulation***, more snow accumulates than melts each year. As old snow is buried by new snow, the old snow is

compressed, eventually becoming ice.

- As the ice is buried deeper in the glacier it is able to flow, something that is evidenced by fracturing (**crevassing**) of the more brittle ice near the top of the glacier.
- At the lowest elevations of the glacier, melting outpaces snowfall. This section of the glacier (**zone of ablation**) is bounded by the **terminus**. The terminus marks the end of the glacier with the pile of material it was pushing, and is often accompanied by meltwater streams flowing from caves in the exposed ice.

Because of how they form, alpine glaciers are particularly sensitive to changes in regional climate. This sensitivity is important for three reasons. First, changing glaciers and the landforms they create are important indicators of changing climate (more about this in Activity C). Second, in areas with dry summers glaciers act as water storage, buffering summer stream flows important to agriculture, fish populations, hydroelectric power generation, and habitats (more about this in Investigations 18 and 21). Finally, as glaciers retreat, communities downstream from them become susceptible to increased flash floods as lakes and other landforms created by them fail.

As a first step in understanding all of this, use the four green dots in the Nisqually vista scene to answer the following questions. Refer to the four ***bold, italicized terms*** in the previous section.

1. Referring to green dots 2 through 4, in which closeup do you see the ***bold italicized features*** mentioned in the previous paragraph on the mechanics of a glacier? The closeups appear when you move your cursor over the dots.
2. Referring to green dot 1, find the lateral moraine. This is a

pile of rock and sediment deposited along the side of the glacier when it was much larger. The crest of the moraine marks the former surface of the glacier several centuries ago. Dot 4 now marks the surface of the glacier now. What climatic changes could have taken place to cause the changes in the glacier visible in this scene?

3. *Dot 4 also marks the end of the glacier. At the time when the glacier surface was even with the crest of the lateral moraine, where would the end of the glacier be?*

Activity C – Nisqually Glacier Overlook

For this final activity move to Nisqually Glacier Overlook. Figure 3 shows you what you should see when arrive at this location.

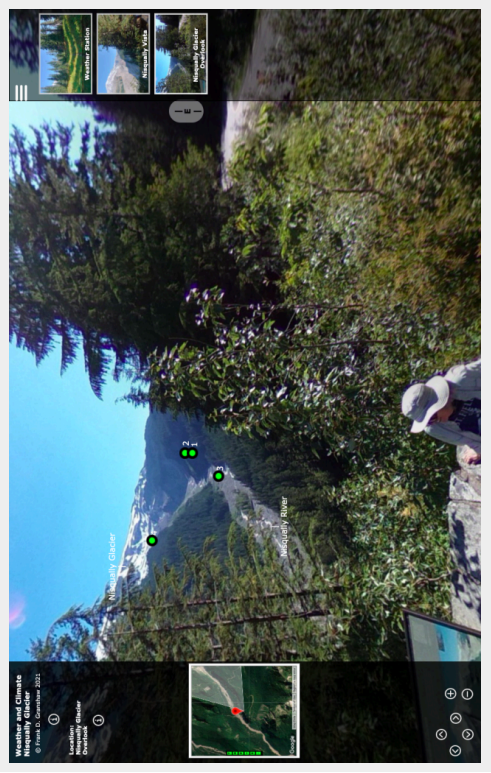


Figure 3 – Nisqually Glacier from Nisqually Glacier
Overlook

While the terminus of Nisqually Glacier is hidden in this view, the overlook does provide an excellent view of where the glacier has been. Using the closeups accessed by the four green dots in the view answer the following questions...

1. *Which dot corresponds to the current terminus of Nisqually Glacier? Which dot corresponds to terminus in 1912?*
2. *Given your answer to question 2 in the last activity how has regional climate changed between 1912 and 2020?*
3. *Using the graphs in closeup 2 and 3, how has climate changed between 1912 and 2020? The graphs in both closeups include bold black lines that show trends in the data. To address this question use those lines rather than the individual data points.*
4. *On the basis of the the image accessed from green dot 4, how did regional climate change between 1840 and 2020? To determine this make a graph of terminus distance from the 2020 terminus vs. year.*
5. *How does your answer to question 4 compare to the one you gave for question 2? What accounts for the differences in your answers?*

2: Weather and Climate for a Single Station

Key questions for this investigation

- How are climate statistics calculated?
- How do we visualize weather and climate data in meaningful ways?

Tool used in this investigation

Weather data page for the Portland International Airport
<[https://www.wrh.noaa.gov/mesowest/
getobext.php?wfo=pqr&sid=KPD&num=72&raw=0](https://www.wrh.noaa.gov/mesowest/getobext.php?wfo=pqr&sid=KPD&num=72&raw=0)>
from the National Weather Service.

Background

NOAA is a scientific agency within the United States Department of Commerce that focuses on the conditions of oceans, major waterways, and the atmosphere. As such NOAA is a major supplier of ocean and atmospheric data, a provider of stewardship services, and a major player in related research.

< <https://www.noaa.gov> >

The National Weather Service or NWS < <https://www.weather.gov> > is a division of NOAA tasked with

providing weather forecasts, hazardous weather warnings, and other weather products to business, public agencies, and the public for protection, safety and general information.

Since weather transcends national boundaries NWS frequently teams with sister agencies throughout the world through the World Meteorological Organization or WMO < <https://public.wmo.int/en> >. The WMO is an agency within the United Nations mandated to facilitate the flow of meteorological and climatic data between nations and provide a framework for international cooperation in related research.

Data accumulated by NOAA, NWS, WMO, and other related organizations is accumulated by several key tools. These include the following.

- *Ground-based weather station* are collections of fixed weather instruments that monitor air temperature, precipitation, wind speed and velocity, and humidity. Specialized stations also include devices for measuring solar radiation, cloud height and types, percent sky cover, and snow depth. Such stations regularly appear at airports, government buildings, schools and research centers.
- *Doppler radar* is a form of ground-based radar that is able to detect oncoming precipitation, determine what type of precipitation it is, and measure wind velocity. NEXRAD (Next Generation Radar) obtains all three types of data and so is often used to detect and analyze oncoming storm systems
- *Weather buoys* are floating instrument packages that are either moored along coastlines or able to drift with ocean currents. Since many storms originate offshore, weather buoys and satellites are key components of storm early warning systems.
- *Airborne weather platforms* include weather balloons or weather instruments mounted on aircraft. Data from

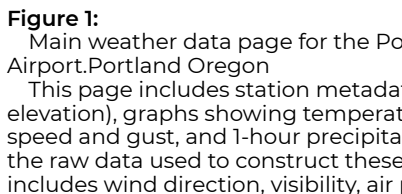
these platforms is particularly important since the atmosphere and the weather taking place in it is three dimensional.

- *Satellites* are essentially orbital weather stations able to visualize large sections of the atmosphere. In addition to tracking the movement of large storm systems, satellites are able to measure wind velocity and direction at different heights within the atmosphere, track the concentration and movement of significant gasses like CO₂ and water vapor, and track the flow of energy into and out of the atmosphere.

In this activity set you will be looking at information derived from a single ground-based station, an NWS facility at the international airport in Portland Oregon. Much of what you will be looking at is raw data that includes the following.

- *Air temperature (AT)* – The temperature of air in a shaded location that is approximately 2 m above ground level.
- *Relative humidity (%RH)* – The amount of water vapor in the air relative to how much it can hold at a given temperature.
- *Dew point temperature (DPT)* – The temperature air needs to be cooled (at a constant pressure) for it to reach RH = 100%.
- *Wind speed (WS)* – The average speed of the wind over a given period of time such as 15 minutes or half an hour
- *Wind gust (WG)* – The maximum wind speed recorded during a given period of time.
- *Precipitation (Pct)* – This is the amount of rain, snow, sleet, or hail that collects in a standardized container during a given period of time – In the case of the data you will be looking at this is volume of precipitation that collects in one hour.

Begin by launching the NWS weather conditions page
<<https://www.wrh.noaa.gov/mesowest/getobext.php?wfo=pqr&sid=KPD&num=72&raw=0>> . Once you have it you should see something like figure 1.



1. *What is the latitude longitude and elevation of the station?*
2. *What kinds of data are being shown for this station? List the data types and write a definition for each one?*
3. *How is the data being shown on the page? A way of showing data is often referred to as a data visualization strategy.*

4. *What for you are the strengths and limitations of each data visualization technique?*
 5. *Look at the graph of temperature, dew point, and relative humidity. What seems to be the relationship between air temperature and relative humidity?*
-

ActivityB–Calculating climate statistics for a single station

Many of the data pages on the NWS site include a mixture of observational weather data (what is at the moment), forecast (what's likely), and climate data¹ (what's normal and what's extreme). The page you are looking at right now is unique in that it's only observational data. What we will do with it now is to calculate some short-range climate statistics.

Climate statistics – Questions

1. *What is the highest and lowest temperature for all three days?*
 2. *What is the temperature range for all three days?*
 3. *What is the average temperature for all three days? This one may take you a while with a calculator.*
 4. *Answer questions 1, 2, and 3 for each day*
 5. *How does the average for each day compare to the three-day average? The difference between the daily averages and the longer period average is referred to as a temperature anomaly.*
 6. *Finally graph of the temperature anomalies you calculated.*
-

Footnotes

- 1 Climate statistics are customarily calculated on the basis of what's normal for at least 30 year periods.

3: Biomes and Climate Zones

Key questions for this investigation

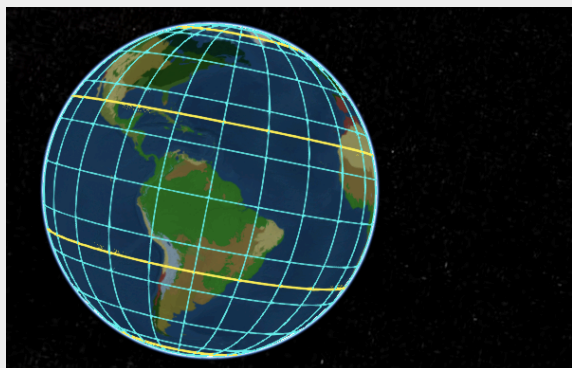
- What are the principal climate zones found on the earth?
- What controls climate in these zones?

Tool used in this investigation

Biome Viewer < http://media.hhmi.org/biointeractive/biomeviewer_web/index.html > from the Biointeractive Program at the Howard Hughes Medical Institute

Background

A Biome is a section of the earth's surface that is home to a characteristic community of plants and animals. Because the makeup of a biome is dependent on its climate, biomes are often regarded as synonymous with climate zones. A Climate zone being section of the earth's surface defined by its average annual temperatures and total precipitation, as well as its monthly and seasonal averages and extremes.



Polar regions – That part of the globe between 60° N and 60°S latitude. Includes the poles as well as the Arctic Circle (66.5°S) The yellow line represents the Arctic Circle.

Mid-latitudes – That part of the globe between 30°N to 60°N and 30° to 60°S latitude. The yellow line represents the Tropic of Cancer (23.5°N) and the Tropic of Capricorn (23.5°S). The yellow line represents the Tropic of Cancer (23.5°N) and the Tropic of Capricorn (23.5°S).

Tropics – That part of the globe between the Tropic of Cancer (23.5°N) and the Tropic of Capricorn (23.5°S). The yellow line represents the Tropic of Cancer (23.5°N) and the Tropic of Capricorn (23.5°S).

Figure 1 – A view of the western hemisphere taken from biome viewer. The color-coded regions represent the major biomes, which are in part defined by latitude. See the side panel for the latitudinal sections of the globe.

Investigation

Activity A – Examining basic climate data

Launch *Biome Viewer* < http://media.hhmi.org/biointeractive/biomeviewer_web/index.html >. By default, you will be shown a rotatable globe that will enable you to access climate data and biome information for major areas of the globe (figure 2).

To do this click on the globe or type in the name of a city, state, or country in the search box in the upper right corner of the frame.

For this part of the activity, type in the name of the city you

live in. Use the data panel that appears to the right of the globe (figure 3) to answer the following questions...

1. *What biome is the city in?*
2. *What is the maximum and minimum monthly average temperature?*
3. *What is the average annual temperature?*
4. *What is the maximum and minimum monthly precipitation?*
5. *What is the total annual precipitation?*



Figure 2 – Default screen for Biome Viewer. The panel to side of the globe lists the major biomes of the planet. Click on any of the labels for a brief description of that biome.

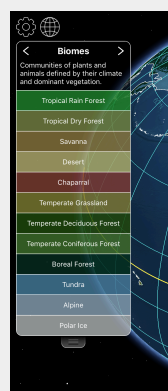


Figure 3 – the station data panel on the right side of the globe.

Activity B – Gathering information about biomes and Climate zones

Begin this part of the activity by selecting a country and typing

its name in the search box. The program will display this country with a virtual “stick pin”. Once it does, use the map of the country to answer the following questions....

1. *What biomes are present in the country?*
2. *What plant communities are present in each biome?*
3. *What is the climate of each biome?*

Activity C – Examining the global distribution of climate zones

In this part of the activity you will be looking at how latitude and elevation impact climate. Begin by selecting “Biomes” from the menu on the right. Then flatten the globe into a map by clicking on the grid symbol in the upper left.

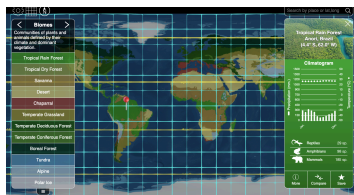


Figure 4 – B
Make sure th
These can be
settings men
map (look fo

Use this map to answer the following questions....

1. *What biomes are in the tropics? What are the general climatic characteristics of these zones and what is the major type of vegetation found there? The tropics is the area between 30°N and 30°S.*
2. *Which of the climate zones you identified in question 1 is*

shaped largely by elevation?

3. *The area between 30°N and 60°N, as well as the area between 30°S and 60°S are called the mid-latitudes. What biomes are found in these latitudes? What principle types of vegetation are found in each and what are the general climatic conditions in each?*
4. *The area above 60°N and above 60°S are the polar latitudes. What biomes are found here and what are their climatic conditions and major vegetation types of these biomes.*

4: Atmospheric Energy Budget

Key questions for this investigation

- What is the atmospheric energy budget and how does it shape variations in surface air temperature?
- What is happening with this budget have to produce the increasing annual global temperature that we are currently experiencing?

Tool used in this investigation

Build Your Own Earth <
<http://www.buildyourownearth.com> > from University of
Manchester

Background

Much of our discussion about climate change begins with temperature. The reason for this is rather simple, namely that surface air temperature is a consequence of the amount of heat energy in the lower atmosphere where we live. To understand what this means and how it relates to the climate changes we now seeing, it is useful to look at the earth's atmospheric energy budget.

Simply put this budget is an accounting of how the energy that drives winds, ocean currents, the hydrological cycle, and other parts of earth's climate system flows through the system. In its simplest form, shortwave electromagnetic radiation

(visible light) from the sun strikes the earth at the top of the atmosphere. Approximately 30% of this energy is reflected back out into space, while nearly 70% is of this incoming radiation is absorbed by the atmosphere and converted into thermal energy (heat). Eventually this heat energy is radiated out into space in the form of long wave electromagnetic energy (infrared). The trick about the latter step is that some of this long wave radiation is absorbed by greenhouse gasses such as water vapor and carbon dioxide on its way out of the atmosphere. This means that these gasses heat the lower atmosphere to temperatures that are higher than they would be if greenhouse gasses were not present (see figure 1).

As long as the earth's outgoing energy is roughly equal the incoming energy, average global surface temperature remains constant. However, if there is an imbalance then surface temperatures either fall (incoming is less than outgoing) or rise (incoming is greater than outgoing). The latter case describes our current predicament.

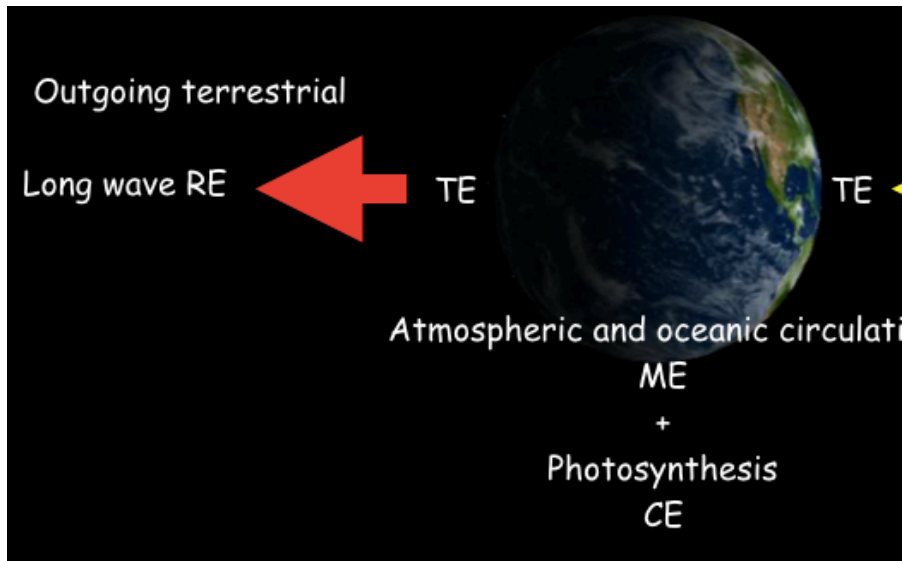


Figure 1 – A simplified diagram of energy flow through the earth's climate system

RE is radiant or electromagnetic energy which includes visible light, infrared, x-rays, and gamma rays. Radiant energy having a short wavelength. Approximately 30% of this is reflected from the earth's surface. The degree of reflectivity of a surface is referred to as its albedo. High albedo (highly reflective) surfaces include snow, ice, ocean, asphalt roadways, and forests.

TE is thermal energy (heat). In the case of the atmospheric energy budget, the incoming solar radiation and the outgoing terrestrial radiation are related, they are not the same thing. This is best understood by noting that the temperature response of a substance to the amount of thermal energy it possesses is related to its specific heat. The temperature response of a substance to the amount of thermal energy it possesses is related to its specific heat. The temperature response of a substance to the amount of thermal energy it possesses is related to its specific heat.

ME is mechanical energy which in this case is moving air (winds) and water (ocean currents). This is related to the atmospheric energy budget. ME is mechanical energy which in this case is moving air (winds) and water (ocean currents). This is related to the atmospheric energy budget.

CE is chemical energy produced by photosynthesis. Though only a small portion of the energy budget, it is important in regulating carbon dioxide concentrations. A major determinant in surface air temperature is the amount of chemical energy produced by photosynthesis.

The outgoing terrestrial on the left is principally infrared radiation – radiant energy. The outgoing terrestrial on the left is principally infrared radiation – radiant energy. The outgoing terrestrial on the left is principally infrared radiation – radiant energy.

Investigation

Activity A – Investigating Surface Temperature

Launch [Build your own Earth](#). When the title screen for the model appears click on “Getting Started”. This should give you a screen that looks like figure 2.

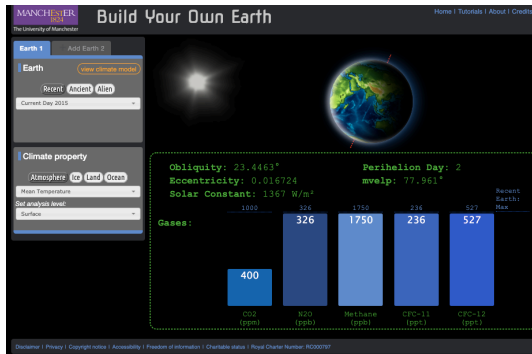


Figure 2: The startup screen for the model. The principle control panels for the model are on the left side of the screen. The central display shows the square meter received by the Earth (solar constant), factors controlling the climate (eccentricity), and principle greenhouse gases that affect the energy balance of the climate, h

Begin by making sure that the “Earth 1” tab in the control panels on the right is highlighted blue and that the pull-down panels on the left are set for “Current Day 2015”. In the lower panel (Climate Property) make sure that the “Atmosphere” button is dark grey and the pull-down menus under the button reads “Mean Temperature” and “Surface”. Then click on “view climate model” in the top panel. The screen that appears should look like figure 3.

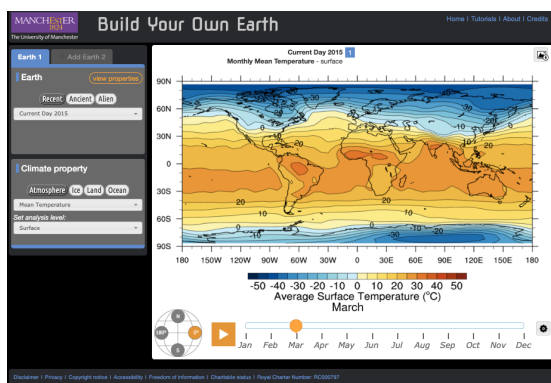


Figure 3:

Screen showing mean monthly temperature for the entire planet.

Like the previous screen the controls are in the two panels on the left. The timeline button controls the month the map represents. Changing the timeline changes the map projection.

When the map first shows up it will automatically start scrolling through all the months of the year. Click the pause button on the left end of the timeline and then select January. Using this map answer the following questions...

1. What is the range of temperature shown on the map?
2. Where is temperature highest and where is it lowest?
What are the values at each place?
3. What do you notice about the temperature of the interior of the continents in the northern hemisphere compared to the temperature of the oceans at the same latitude?
What part of figure 1 explains the observed difference?

Now set the timeline to July to answer the address the next three questions...

4. Where are the temperatures highest and where are they lowest? What are the values at each place?
5. How does the distribution of high and low temperatures change from January to July?
6. How does the temperature of Northern Africa compare to that of the Atlantic Ocean at the same latitude? How does what you concluded in question 3 explain what you

are see here.

Activity B – The Atmospheric Energy Budget and Surface Temperature

Now set the climate property in the left-hand control panel to “Top of the atmosphere”. If you are in the climate model mode, you should have a screen that look like figure 4.

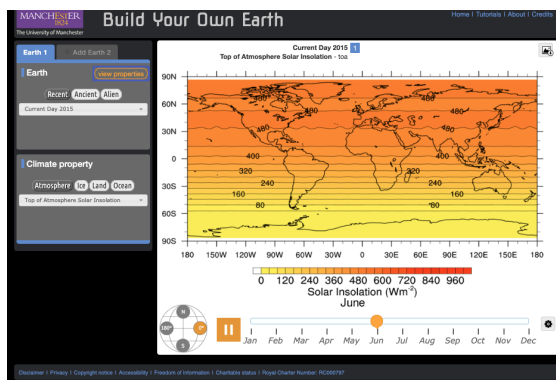


Figure 4:

Screen showing solar insolation at the top of the atmosphere for the entire planet.

Like the previous screen the controls include the timeline and the month. The timeline controls the month the map represents. As the timeline changes the map represents the month, the map shows the solar insolation at the top of the atmosphere for the entire planet.

If the map is scrolling through the months, pause it and set the month for March. Using this map answer the following questions.

1. What is the range of values shown on the map?
2. Where is insolation the most intense and where is it the least? What are the values at each place?
3. What is controlling the intensity of the insolation at each place? Remember that insolation is presented at energy per unit area (watts per square meter). Another hint is that March 21 is the spring equinox, which means that the

sun is directly overhead at the equator at noon.

Now switch the date on the timeline to January.

4. *Where are the minimum and maximum insolations?
What are the values at each place?*
5. *Switch the date to July. Where are the minimum and maximum insolation now? What are the values at each place?*
6. *How do the maps for January and July look different from that of March?*
7. *What accounts for these differences?*

Begin this next part by switching the date back to March and make sure that you have selected “Top of the Atmosphere” in the pull-down menu in the control panel. Create a second map by clicking on the “Add Earth 2” tab in the left-hand control panel. In the new Earth 2 panel select “Mean Temperature” in the control panel. After you have done this you should have a screen that looks like figure 5.

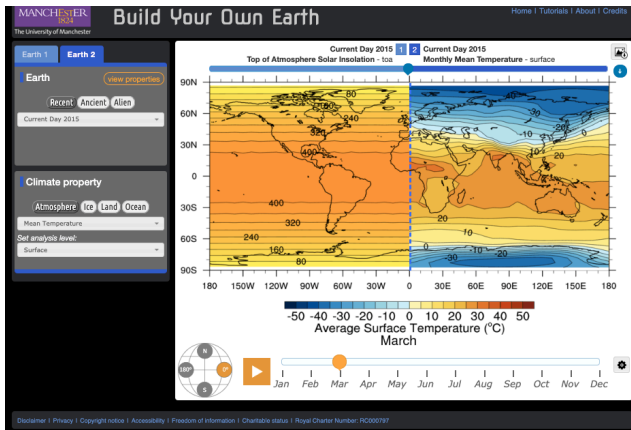


Figure 5:

Screen showing both
atmosphere (left side)
(right side) for March
The blue dashed line
be moved left and right
maps. Click on hold o
the top of the map to

Using these two maps address the following questions

8. In what ways are the two maps similar?
 9. In which ways are they different other than the fact they are displaying two entirely different variables?
 10. How does the insolation map explain what you see in the temperature map?
 11. What about the temperature map does the insolation map not explain?
 12. What other factors need to be taken into account to explain what the insolation map does not explain?
Suggestion go the Earth 1 tab and try some of the other options in the “Climate Property” panel.
 13. With the model still in the dual map mode it's time to investigate the energy out portion of the atmospheric energy budget. To set it up for this part of the activity set Earth 1 to “Current Day 2015” / “Atmosphere” / “Top of the Atmosphere Insolation” and set Earth 2 to “Current Day 2015” / “Atmosphere” / “Net Longwave Radiation” / “Top of the Atmosphere”. Pause the timeline and set it to March.
 14. *What are the maximum and minimum values on the insolation and the long-wave radiation maps? Where are they?*
 15. *In ways are the two maps similar? In what ways are they different?*
 16. *What factors need to be taken into account to explain the differences?*
-

Activity C – The Atmospheric Energy Budget and Changing Global Climate

Beginning with the same dual earth configuration you used

at the end of Part B, set Earth 1 to “Current Day 2015” and “Mean Temperature” / “Surface”. Set Earth 2 to “No Greenhouse Gasses” and “Mean Temperature” / “Surface”. Pause the timeline and set it to March.

1. *How does the temperature map for Earth 1 (2015) compare to Earth 2 (no GHG)?*
 2. *How much of Earth 2 is habitable?*
 3. *Now set the climate property of both Earths to “Top of the Atmosphere Solar Insolation”. How do the two Earths compare?*
 4. *Next set the climate property of both Earths to “Net Long-wave Radiation” / “Top of the Atmosphere”. How do the two Earths compare?*
 5. *Now set Earth 1 to “CO₂” / “Low” and “Earth 2” to “CO₂” / “IPCC A1F1 CO₂ Scenario, Year 2010”. Then set the climate properties for both Earths to “Mean Temperature” / “Surface”.*
 6. *What is the CO₂ level in ppm (parts per million) for the Low and A1F1 scenarios? To find this out click on the “view properties menu” and toggle back and forth between Earth 1 and 2.*
 7. *How does the January and June surface temperatures of the Low scenario compare to the A1F1 scenario? To find this out you will need to click on the “view climate model” button unless you have already done so. Also in answering the question talk about what parts of the world show the most significant change and estimate what the temperature increase or decrease is.*
-

Activity D – Synthesis

1. In the BYOE model what factors control surface temperature?
2. In some corners of society CO₂ is referred to as a pollutant when talking about climate change, in others increased CO₂ is promoted as a benefit to society. How do the results of activity C support and challenge both arguments?

5: The Carbon Cycle

Key questions for this investigation

- How does carbon exist and flow within the earth's climate system?
- How does the cycling of carbon regulate climate?
- How might human interaction with this cycle shape future climate?

Tools used in this investigation

- [Carbon Cycle Interactive \(I\): Natural Flows](#)
- [Global CO₂ Levels](#) – *Climate Dashboard from the 2^o Institute*

Background

A major player in changing climate is carbon in its various forms. This is in large part because of how increasing levels of carbon dioxide in the atmosphere are impacting the energy budget of the earth's climate. Key to understanding this impact is understanding how carbon moves through the climate system via a process known as the carbon cycle.

The carbon cycle is the continuous exchange of carbon between living organisms, the oceans, atmosphere, and the earth's crust. During this exchange various carbon compounds are continuously created, destroyed, and stored. Chief among

these compounds are carbon dioxide (CO_2), methane (CH_4), calcium carbonate (CaCO_3), and hydrocarbons (H_xC_y). The chief mechanisms by which this happens include...

- Respiration of animals, plants, and microbial life
- Production of methane via digestion and decomposition
- Photosynthesis by plants and microbial life
- Atmosphere-ocean exchanges
- Combustion of fossil fuels and vegetation
- Volcanic eruption
- Weathering of rock at the earth's surface

Figure 1 is the title screen for the tool that you will be using for Activity A. The centerpiece of this screen is a diagram of the carbon cycle, showing both principle carbon flows and storages. One of your tasks in this activity will be to identify these exchanges and major carbon reservoirs. Your task in Activity B will be to investigate how we influence this cycle and the consequences of that influence.

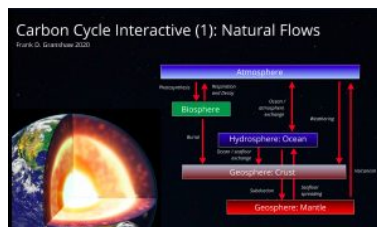


Figure 1 is a diagram of the global carbon cycle showing principal flows and storage of carbon in its various forms. The diagram is divided into five reservoirs connected with red arrows. The reservoirs you will probably recognize as the major planetary subsystems talked about in the introduction to this manual. The red arrows represent the principal types of carbon

exchange between these reservoirs. If an exchange puts carbon into the atmosphere it is emitting carbon, if it is removing carbon then the exchange is sequestering carbon.

Residence time – In the case of the carbon cycle, this is the average length of time that carbon compounds remain in the various reservoirs shown in the diagram. Understanding how major greenhouse gasses influence the climatic energy balance of our planet is largely a matter of looking at the warming potential of these gasses and their abundance in the atmosphere. In turn, atmospheric abundance of these gasses is dependent on their atmospheric residence time.

The table below (Table 1) lists five key greenhouse gasses (GHGs). In addition to showing their approximate abundance in the atmosphere and their contribution to the greenhouse effect, it also shows their Global Warming Potential (GWP) and their atmospheric residence time. The latter is a measure of the warming potential of each gas relative to an equal mass of CO₂. For instance, a kilogram of CH₄ has 28 times the warming potential of a kilogram of CO₂. However, CO₂ contributes more to the greenhouse effect because of its higher abundance. Something that is strongly influenced by its longer residence time.

Table 1

*Key characteristics of principal Greenhouse Gasses. From Kiehl and Trenberth
https://cdiac.ess-dive.lbl.gov/pns/current_ghg.html >*

Gas	Abundance in the atmosphere (%)	Atmospheric residence time
Water vapor (H ₂ O)	1 to 3	Hours – days
Carbon dioxide (CO ₂)	~ 0.038	100 – 300 years
Methane (CH ₄)	~ 0.00018	12 years
Nitrous oxide (N ₂ O)	~ 0.0006	121 years
Ozone (O ₃)	~ 0.0006	Hours – days

Because of CO₂ abundance in the atmosphere, its effective atmospheric residence time, and the fact that it makes up such a significant percentage of human produced GHGs, CO₂ emissions are what we often turn to first when looking at the human impact on the carbon cycle. With this in mind, we look at CO₂ emissions in two ways.

First, is CO₂ emission rates. This is the rate at which CO₂ is released into the atmosphere. The last two questions in Activity look at historical changes in emission rates due to human activity and has you compare these to natural emission rates.

Second, is CO₂ concentration in the atmosphere. This concentration is measured in parts per million (ppm). As a point of reference 1000 ppm is the same as 1%, so a CO₂

concentration of 350 ppm is equivalent to 0.35%. Activity B looks at historical changes in CO₂ concentration and has you compare this to changes in mean annual global temperature.

Investigation

Activity A – Examining the Carbon Cycle

Using [Climate Cycle Interactive](#) address the following questions...

1. *What is the total carbon storage in gigatons for each of the four major spheres of the earth? These spheres are the atmosphere, geosphere, oceans, and biosphere. Note in the diagram the geosphere is broken up into crust and mantle.*
2. *How do these spheres compare in terms of their carbon storage? To answer this question rank them in terms of their total storage and calculate what percentage of the total global storage each represents.*
3. *What are principal exchanges shown in the diagram? Which emit carbon into the atmosphere? Which sequester it?*
4. *What is the total yearly flow rate of carbon into the atmosphere from all exchanges that **emit** carbon?*
5. *What is the total yearly flow rate of carbon out of the atmosphere from all exchanges that sequester carbon?*
6. *You have probably noticed when answering question 5 that no flow rate was available weathering. Assuming that for global average annual temperature to stabilize that emission should be equal to sequestration, what*

would you estimate the annual flow rate for weathering should be?

7. The graph below (figure 2) shows global CO₂ emissions since 1860. Given that the number you got for question 4 represents total annual natural emissions, how far above this baseline were all human emissions in 2012? Express this as a percentage of total annual natural emissions.
8. Again referring to figure 2, what reservoirs shown in the carbon cycles diagram are humans drawing carbon from and emitting it into the atmosphere?

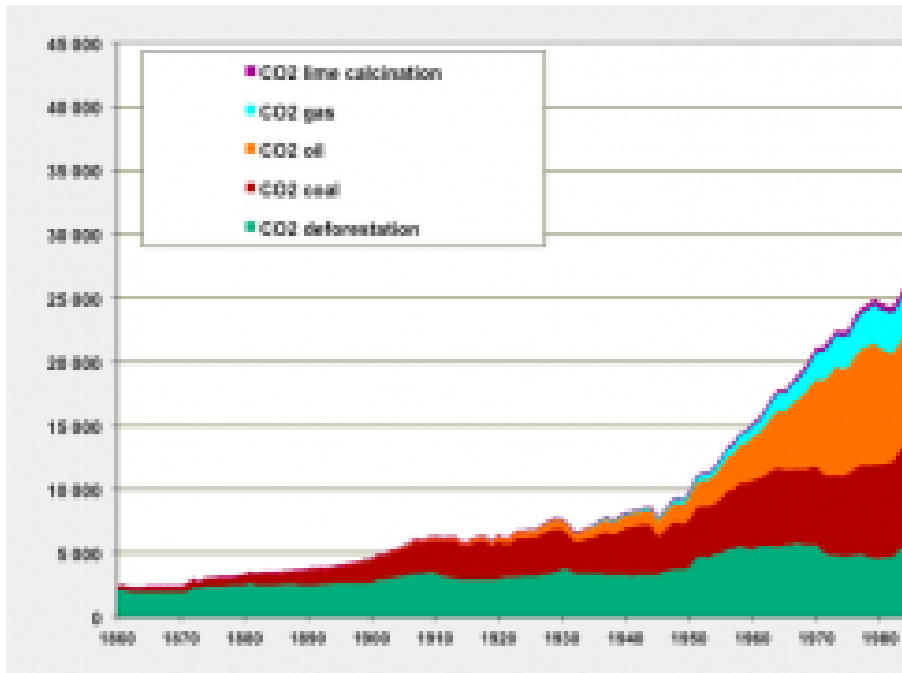


Figure 2 – Global CO₂ emissions since 1860 (adapted by Jean-Marc Jancovice from Carbon Dioxide Information Analysis Center / US Department of Energy).

The emission units are in millions of tons per year. So 10,000 is actually 10 GT per year.
CO₂ lime calcination is involved in the production of cement

Activity B – Human Impact on the Carbon Cycle

Using the interactive graph for [Global CO₂ Levels](#) address the following questions...

1. Unlike what you looked at in Figure 2, the CO₂ Levels graph is showing you the concentration of CO₂ in the atmosphere rather than annual CO₂ emissions. Using this graph what was the atmospheric CO₂ concentration in the year 1000 AD? What was it on the last date shown on the graph? If you move your cursor over the graph it will show these values.
2. At what year do you see an abrupt rise in CO₂ concentration?
3. Zoom in to some place on the graph between 1958 and 2021. How does the graph look different here and why? Hint on answering the why – click on the three bars next to the 2° institute icon on the upper right. Select Data Source and Credits from the menu that appears when you do so.
4. Finally click on the globe / thermometer icon in the upper left corner of the graph. This shows you the variation in annual mean global temperature from a long term average (temperature anomaly). What is the general correlation between CO₂ concentration and global temperature? Are there places where that correlation is not readily apparent?

6: Atmosphere/Ocean Circulation

Key questions for this investigation

- What role does atmospheric and oceanic circulation play in the distribution of excess heat from lower latitudes (areas near the equator) to higher latitudes (areas closer to the poles)?
- What are the principal patterns of atmospheric circulation and what drives them?
- What are the principal patterns of surface ocean currents and what drives them?

Tool used in this investigation

- *Earth* < <https://earth.nullschool.net/> > from nullschool.net.

Background

Atmospheric circulation is the movement of air throughout the atmosphere, while oceanic circulation is the movement of water within the ocean basins. In both cases fluids (air and water) flow in complex three-dimensional pattern distributing thermal energy from warm low latitude areas to colder, higher latitude areas. What is important to consider is that heat is

not only being moved from place to place, but it is also being exchanged between the oceans and the environment – the topic of activity set 7, *Atmosphere / Ocean Interactions*. In this way atmosphere / ocean flows regulate climate throughout the system.

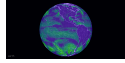
To really understand this, we need to work our way through a number of simpler models like we did in activity set 4, *Atmospheric Energy Budget*, when we used the model output viewer *Build Your Own Earth* to understand the flow of energy through the earth's climate system. However, before we do this it is useful to look at the actual patterns of circulation to better understand how they regulate the earth's climate system. This is the focus of this activity set.

Investigation

Activity A – Atmosphere/ocean circulation and climate regulation

To begin this activity, launch *Earth* < <https://earth.nullschool.net/> >. This should give you a view of the earth that looks like figure 1.

Figure 1

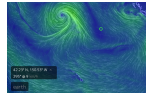


Default screen for Earth. This view is showing wind direction and speed. The word "earth" in the lower left accesses the main control panel for the viewer.

As you examine the globe you will notice four things. First, you can click and drag it to rotate it. Second, you can either swipe on your computer track pad or move the scroll wheel on your mouse to zoom in and out of the globe. Third, the globe shows wind direction with moving white streaks and wind speed by the length of the streaks and the color underlying them.

Finally, if you click on the globe you will see a marker (green circle) appear at that place and a message panel in the lower right of the screen that gives the longitude, latitude, wind direction, and wind speed (figure 2).

Figure 2



A section of globe showing a marker placed in the North Pacific Ocean. The information box (lower left) shows the latitude and longitude of the marker and the wind direction (295°) and speed (9 kph) at that place. Note wind direction is given in degrees (0 to 359°) the wind is coming FROM, with 90° from the east, 180° from the south, and 270° from the west.

Once you have succeeded in setting up *Earth* in the previously described manner, create a worksheet in which you will record your answers to the following questions.

1. What is the approximate latitude and longitude of where you are?
2. What is the wind speed and direction there?
3. Where near you is the wind speed the lowest?
4. Where is it the fastest?
5. Where does air seem to be flowing into a point? Looks

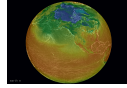
rather like water flowing into a drain.

6. *Where does the air seem to be flowing away from a point?*

For the entire planet to maintain a stable average annual temperature the solar energy it receives at the top of the atmosphere should equal the energy it radiates out into space in the form of infrared. However, even under equilibrium conditions like this, whole regions of the globe receive more energy than they lose (places like the tropics), while other sections lose more than they receive (polar areas). The implication of this is that heat energy must be moved from areas of excess to areas of deficit. Otherwise cold places would be much colder than they are now and warm places would be much warmer.

To investigate how atmospheric circulation causes the needed redistribution you will need to display surface air temperature on the globe. To do this click on the word “earth” in the lower-left, and then “Overlay” and “Temp” (see figure 3). This will replace the windspeed overlay with current air temperature (figure 4). Click the title “Earth” again to hide the control menu.

Figure 3



Display controller that appears when you click on the “earth” label. Click on “Temp” to overlay surface air temperature on the globe.

Figure 4



The viewer with both air temperature and wind displayed. The colors ranges from blue violet (cold air below zero) to dark red (hot air).

With both wind direction and surface temperature being shown, Look for lines of fixed latitude (horizontal lines) where temperature changes. investigate these questions.

7. *Where do you find tongues of cooler air with neighboring warmer air to the left and right?*
8. *What is the temperature difference between the center of one of these cool air tongues and the surrounding air at the same latitude? Click on the globe at each location to*

get a latitude and longitude and an air temperature for each.

9. *How does wind direction correspond with this tongue?*
10. *Repeat questions 7-9 for a tongue of warmer air compared with cooler air to the left and right.*
11. *How does your answer to the previous questions address the question of how heat energy is distributed from areas of energy excess to areas of deficit?*
12. *Do you see the pattern more clearly over the ocean or over the land? What might cause differences between these patterns over ocean and land?*

For the last part of this activity display the controller and select “Ocean” from the “Mode” menu, “Currents” from the “Animate” menu, and “SST” from the “Overlay menu (figure 5). This will give you a display that looks something like figure 6.

Figure 5

*Display controller.
The options
you need to
select to
show ocean
currents
and sea
surface
temperature
(SST) are
circled in
red.*

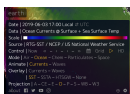
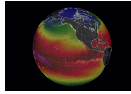


Figure 6 –



The viewer with both surface currents (animated white lines) and SST shown. The colors for surface temperature range from blue (cold, barely above 0°C) to purple (warm, above 30°C)

With both ocean currents and SST displayed answer the following three questions.

13. *Where do you find tongues of cooler water reaching out toward the equator? Where do you find tongues of warmer water moving towards poles?*
14. *What is the temperature difference between a point in the center of these tongues and the surrounding water at the same latitude? Give the longitudes, latitudes, and temperatures of the points you used to answer this question.*
15. *Based on your response to question 14 in this activity, what would you expect about the relationship between*

these tongues and the direction of current flow?

16. *Zoom in on one of these tongues until you can see the animated current lines. Was your response to question 15 accurate?*
 17. *What complicates giving a simple yes or no your answer in question 16?*
-

ActivityB – Atmospheric circulation: Patterns and drivers

For this activity you will need to set the display to show the flow of air near the earth's surface and surface air pressure. To do this open the control menu and select "Air" from the "Mode" menu and "MSLP" from the "Overlay" menu. MSLP is short for Mean Sea Level Air Pressure. Air pressure is the force that air exerts on a surface. Here in the US MSLP is often measured in pounds per square inch, with average air pressure being around 14 lb/in². In the viewer it is measured in hectopascals (hPa) with average MSLP being around 1012 hPa. Like everything else about the earth there is a lot of variation from the average. The colors of the overlay range from almost black (600 hPa or lower) to white (more than 1030 hPa).

Armed with this information what would you say in response to following questions.

1. *Find a low-pressure area near the equator. Look for a broad band rather than a spot. What is the lowest MSLP you find in this band?*
2. *Is air flowing into or out of this area?*
3. *Based on your answer to the previous question is air rising from or falling onto the center of the band? Note this area is referred to as the Inter Tropical Convergence Zone or*

ITZC.

4. *Now rotate the globe until you are looking at Antarctica. Find a high-pressure area near the south pole. What is the highest MSLP you find in this area?*
5. *Is air flowing to or out of this area?*
6. *Based on your answer to question 5 is air rising from or falling onto the center of this area?*
7. *Surface air pressure is largely dependent on air temperature. Warm air tends to be associated with low MSLP since air expands and becomes less dense as it warms. Cold air on the other hand tends to be associated with high MSLP since air contracts and becomes denser as it cools. Based on this bit of basic physics what's driving the air flow you observed in questions 2, 3, 5, and 6?*

For the final segment of this activity look at a low-pressure spot in the Northern Hemisphere. Atmospheric scientists refer to this as a low-pressure center.

8. *What is the MSLP in the center of that spot?*
9. *How is the air flowing relative to the center of the spot? In other words, is it flowing into or out of it? Is it moving clockwise or counterclockwise?*
10. *Now look for a high-pressure area next to the low-pressure center. What is the MSLP in the center of that area?*
11. *How is the air flowing relative to the center of this area? Make sure to talk about into or out of and clockwise and counterclockwise.*
12. *Given that these two centers are in close proximity to each other explain create an overall description of what is happening with airflow going from one center to the next.*
13. *Next look for a similar spot in the southern hemisphere.*
14. *What is the MSLP in the center of the spot and how is air flowing relative to that point?*

15. *Look for an area of high-pressure next to the low pressure center. What is MSLP in the center of that area and how is air flowing relative to that point?*
 16. *How is what you concluded in questions 13 and 14 similar to what you concluded in 8 through 12 and how is different?*
 17. *What do you think causes these differences?*
-

Activity C – Ocean circulation: Patterns and drivers

For this activity you will need to set the globe to show ocean currents and current velocity. To do this open the control menu (click on “earth”), select “Ocean” from the “Mode” menu, and “Currents” from both the “Animate” menu. This last selection will set automatically set the overlay to currents, so you get colors ranging from dark blue (low velocity) to red (high velocity). A point of information – Surface currents are the bulk movement of water near the surface of the ocean. Water flows differently at different depths. A topic for other activities.

1. *What are the highest and lowest velocities you found on the globe? Where were they?*
2. *Turning your attention toward the equator, how does the current velocity there compare to the oceans north and south of it? You will probably need to zoom in on part of the equator to answer this.*
3. *In general, which way are the currents flowing in the area you zoomed in on?*
4. *Without changing the place on the equator, you are looking at open the control menu and select “Air” from the “Mode” menu. How does the air flow around the*

equator correspond with the current direction you observed in question 3? How might this explain what drives surface currents?

Next reset the display for currents and current velocities and turn your attention to Antarctica. Make sure to zoom out to where you can see the entire globe.

5. *Find the high velocity stream surrounding the continent. Generally, in which direction is it flowing? Again, you will need to zoom in to see the current lines.*
6. *Zoom out again until you can see the entire globe with the south pole in the center of the view. How does the general air flow around Antarctica correspond to what you observed in the previous question?*
7. *Is this consistent with what you concluded in question 4? What complicates your answer?*

For the final part of the activity reset the display to show ocean current direction and velocity and turn the globe so you can see the North Atlantic.

8. *What happens to the high velocity current on or near the equator as it approaches South America? Concentrate on the northern section of that stream.*
9. *How does the velocity and direction of that current as it flows along the eastern coast of North America compare to the surround ocean? Use numbers in your answer. The current as it passes along east coast of the US and Canada is called the Gulf Stream.*
10. *Now set the display to show currents and SST (sea surface temperature). How does the temperature of the Gulf Stream compare to the surrounding ocean?*

The Gulf stream is part of a basin wide circulation of water that moves warm water northward on one side of the Atlantic and cool water southward on the other side. Note this is the general trend, as you probably notice the details are a bit more complicated than this. An important aspect of oceanic circulation is that the oceans regularly exchange mass and energy with the atmosphere above them, so sea surface temperature has a strong influence on the temperature of the air above warm and cold currents.

11. *Given all this how might the currents off the coast of North America, Europe, and Africa influence the climate of the communities along those coastlines?*
12. *Is your answer to the previous question consistent with what you know about the climate of those areas? If not, what are some additional factors, we might need to look at to explain those climates?*

7: Atmosphere/Ocean Interactions

Key questions for this investigation

- *How does the earth's ocean and its atmosphere interact with one another?*
- *What types of interactions have the largest impact on climate?*
- *How does rising global temperature impact these interactions?*

Tool used in this investigation

- *Earth* <<https://earth.nullschool.net/>> from nullschool.net

Background

In some climate models from late 20th century only atmospheric circulation was taken into account. This made them simpler, a necessary requirement given the limited computing power of the time, but far less accurate. A key reason for this is that a considerable amount of mass and energy is continually being passed from one to the other. For instance, the hydrologic cycle involves ocean water evaporating and moving up into the atmosphere as vapor. This

water condenses forming clouds and is returned to the oceans as precipitation or as runoff if the precipitation falls on land. Likewise, warm ocean currents lose thermal energy as they warm the atmosphere above them.

As a result of this continual mass / energy handoff there are a number of major weather systems that shape the climate in particular parts of the world and are readily altered by changes in the earth's energy balance. The following activities look at three of these.

Investigation

ActivityA – Monsoonal flow

A monsoon is a seasonal cycle of intense precipitation followed by an extended period of dry, hot weather. Southeast Asia is one of the places on the planet where this cycle is the most dramatic. Countries in this area, India being a prime example, receive nearly 90% of their annual rainfall between mid-June and late September. In contrast winter and spring is often characterized by clear, sometimes cold weather. The aim of this activity is understanding how this cycle is possible and what it has to do with atmosphere / ocean interactions.

Launch Earth by typing in the address <<https://earth.nullschool.net/>> into your browser. Once you have done so turn the globe until you see India and southeast Asia. Then click on the “earth” label in the lower left corner of the screen. This will open up a panel that controls the kind of information displayed on the globe. From the controller select TPW (Total Precipitable Water) from the “Overlay” menu and then click on the calendar symbol from the “Control” menu (see figure 1). From the calendar select July 1, 2018 – Make sure

to click on “Apply” at the bottom of the calendar to show TPW and wind direction for this date.

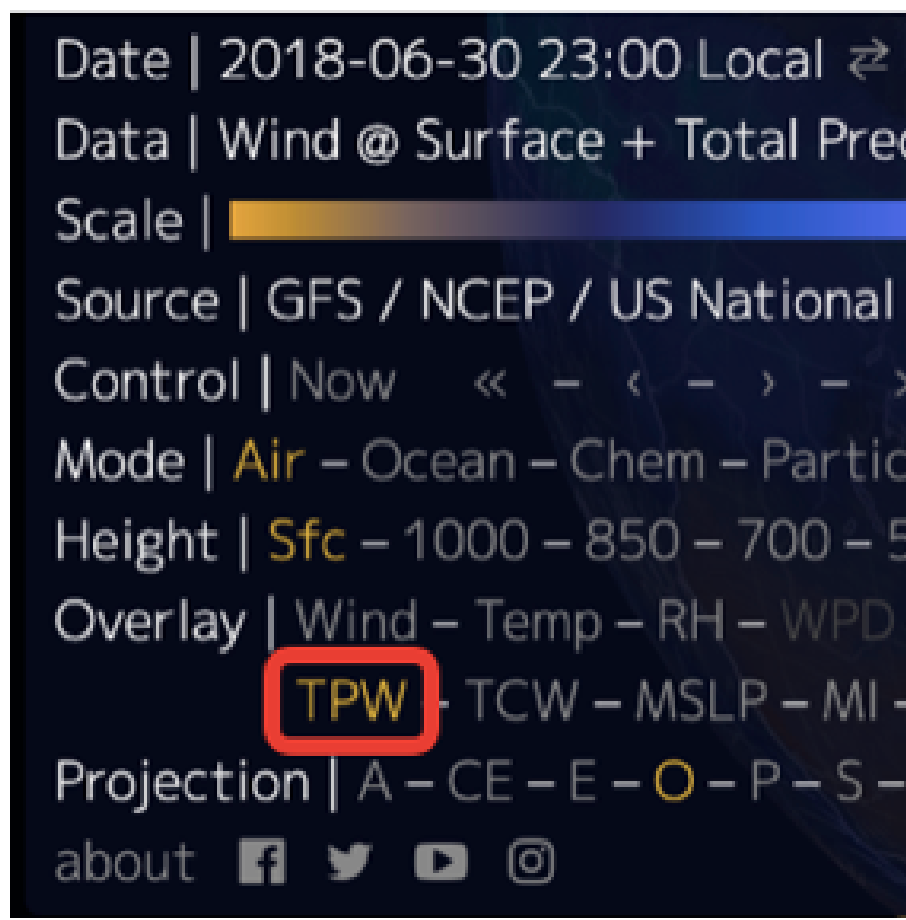


Figure 1 – Display control panel with initial selections highlighted. Figure 2 shows a map of the United States with precipitation. Areas in blue are wet (high precipitation) while areas in brown are dry (low precipitation).

Questions to investigate:

1. *What is the windspeed, wind direction, and precipitation over the center and over the southern tip of India?*
2. *What is the windspeed, wind direction, and precipitation over these same two places on December 31, 2018? To find this out you will need to reopen the calendar and set it for this date. Remember to click on “Apply” to show wind and TPW for this time.*
3. *How does the wind and precipitation over of these two places change from July to December?*
4. *The following paragraph describes a commonplace event that can help you understand how monsoons work. Using the information from this paragraph, draw a diagram showing the relative temperature of land and water, the direction of the wind, and determine whether this would correspond to the rainy or dry season of a monsoon.*

Land-sea breeze

If you have every spent any time at a coast, you have probably experienced a land-sea breeze. You may also have noticed that the breeze changes direction with time of day. This is because during the day the land becomes warmer than the ocean. As a consequence, the air over land warms, becomes less dense, and rises. This then, pulls in air from the ocean. At night, the land cools more than the surrounding ocean, with air over the land sinking and flowing out into the ocean, where air is rising. In many respects, this is similar to air rising over India during the summer.

ActivityB – Tropical cyclone and hurricanes

Tropical cyclones are storms that originate in tropical oceans above but not at the equator. Hurricanes are a subset of these storms characterized by intense precipitation, winds, and markedly low pressures at their center. Satellite imagery and data from weather aircraft has given us remarkably detailed and comprehensive insight into the structure and dynamics of these phenomena. Chief among these insights is that the intensity and frequency of these storms is dependent the incredible heat stored in tropical ocean water. This has raised concerns among climate researchers that as

the earth's climate system warms so do the tropical oceans, meaning that even more energy becomes available for creating larger and more frequent storms. While this idea may seem straightforward, the complications of atmosphere / ocean exchanges makes for a picture that is not quite so clear. Never-the-less the appearance of several major hurricanes in the Northern Hemisphere during the past decade tends to support the link between a warming of the earth and an increase in hurricane strength and/or frequency.

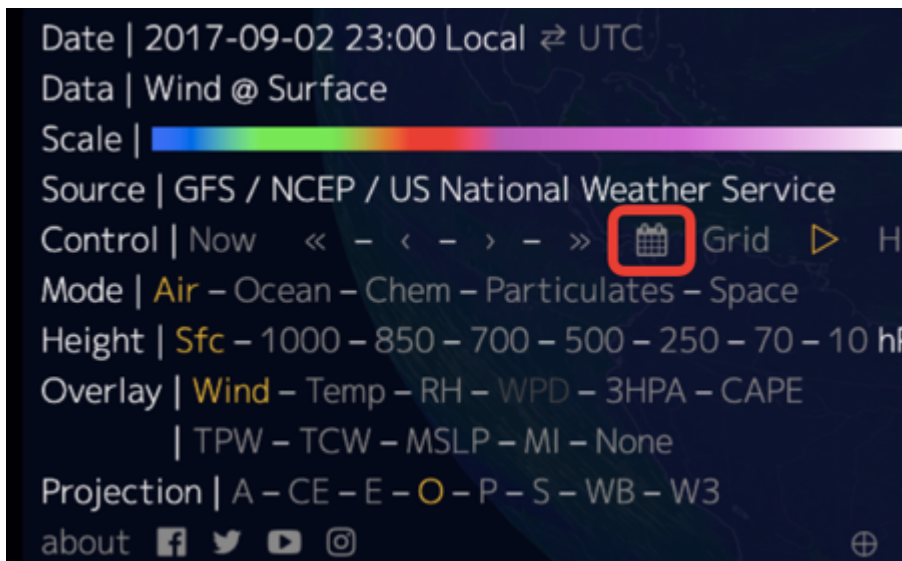


Figure 2 – Display control panel with the calendar tool highlighted. Figure 3 shows the Atlantic ocean centered on the northern equatorial Atlantic and the Gulf of Mexico. The tropical cyclone circled in red in Figure 2 is highlighted in Figure 3.

In this part of the activity you will be looking at several weeks of hurricane activity that took place in September 2017. To start this activity, turn the globe until you are looking down on the Gulf of Mexico and the tropical Atlantic Ocean. Next open the display controller and access the calendar. From the calendar select September 3, 2017. When you click “Apply” you should get a display that looks like figure 4.

You will begin with the hurricane located at in middle of the Atlantic Ocean to investigate the general structure and dynamics of Hurricanes.

Questions to investigate

1. *What is the direction of air flow relative to the center of*

the storm?

2. *How does wind speed and direction change as you move from the center of the storm outwards? To address this question, begin at the center of the storm and select five points going from the center to a point 5° from the center of the storm. Click on each of those four points (they should be in a line) recording the latitude, longitude, wind speed, and wind direction at each point.*
3. *How does air pressure change as you move from the center of the storm outwards? To address this question, open the display controller and select “MSLP” from the “Overlay” menu. Click on the same points you used for the previous questions and record the latitude, longitude, and air pressure at each place.*

To continue, open the display controllers and look for the double arrow next to calendar symbol. Clicking on this will advance the display 1 day. Using this control look for the following.

4. *When and where the hurricane first makes landfall?*
5. *When and where the hurricane makes landfall in North America?*
6. *What happens as the hurricane moves further inland in North America*
7. *Given that hurricanes derive their energy from atmosphere / ocean exchanges how do you explain what happened in question 6?*

An additional useful on-line resource
Historical Hurricane Tracks from NOAA <
<https://coast.noaa.gov/hurricanes/> >

Activity C – Interdecadal and interannual variations

Interdecadal and interannual variations are large scale fluctuations in oceanic and atmospheric conditions that produce multi-year cycles of regional climate change. One of the best known examples, ENSO or El Niño / Southern Oscillation, involve alternating cooling and warming at opposing sides of the equatorial Pacific Ocean resulting from changes in air pressure and surface winds in the overlying atmosphere. Because these changes take place over such a large area what happens in the equatorial Pacific affects seasonal temperature and precipitation throughout much of the Western Hemisphere. For instance, during a warm phase of an ENSO (El Niño) January-March temperatures in northwestern North America tend to be warmer than average, while during cool phase ENSO (La Niña) January-March temperatures in this same area tend to be colder than average.

In this part of the activity you will be looking at conditions in and above the equatorial Pacific Ocean during an El Niño and a La Niña year to understand how an ENSO works. To get started with this open the display control panel and select “Ocean” from the “Mode” menu, “Currents” from the “Animate” menu, and “SSTA” from the “Overlay” menu. Also select “E” from the “Projection” menu (figure 5). The last selection will switch the view from a globe to a flat map, which will make it possible to see the entire Pacific Ocean. Selecting “SSTA” means that you are displaying sea surface temperature anomaly, meaning that you are looking at the deviation of sea surface temperature from a long-term average (figure 6).

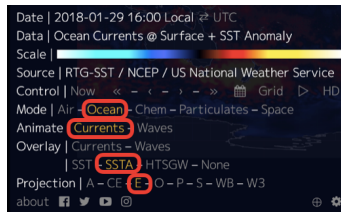


Figure 5

Display control panel with initial selections highlighted.

Figure 6

Flat map of the temperature (SSTA) showing areas where SST is colder than average (blue) and warmer than average (red).

1. Once you have set up the map, reopen the display control panel and click on the calendar symbol. Using the calendar set the date to the 30th of January 2018 – 2018 was an La Nina year. Using this map answer the following questions.
2. What country is nearest to $10^{\circ}\text{S} / 83^{\circ}\text{W}$? Is the sea surface warmer or colder than average? By how much?
3. What country is nearest to $1^{\circ}\text{N} / 141^{\circ}\text{E}$? Is the sea surface warmer or colder than average? By how much?

Now select the 30th of January 2016 – 2016 was a El Nino year.

3. What is the SSTA at $10^{\circ}\text{S} / 83^{\circ}\text{W}$ and $1^{\circ}\text{N} / 141^{\circ}\text{W}$?
4. How does the SSTA at each place compare to the SSTA on the 30th of January in 2018?

Next open the display controller and select “Air” from the “Mode” menu. The display will show wind speed and direction?

5. *What is the wind speed and direction at 10°S / 83°W, 0° / 150°W, and 1°N / 140°E?*
6. *What is the wind speed and direction at these same points on the 30th of January 2016?*
7. *Based on what you just looked at how would you describe the changes in ocean and atmospheric conditions that occur when you switch from an el Nino to a la Nina?*

PART II

PRESENT IMPACTS

8: Today's weather – Temperature

Key questions for this investigation

- What does the earth's air and ocean temperature for today look like?
- How do those temperatures compare to what is “normal”?

Tool used in this investigation

- *Climate Reanalyzer* – Climate Change Institute / University of Maine < <https://climatereanalyzer.org/> >

Background

A key part of human existence is that we live in “climate bubbles”. In other words, many of us tend to view what is happening with the earth's climate as a whole on the basis of today's, this month's, or this year's weather in the place where we live. Furthermore, since air temperature is something fairly tangible that affects our level of comfort, it is not uncommon to accept or reject claims that the earth climate is warming on the basis of what is happening within our bubbles. This set of activities is designed to examine the validity of that practice

by comparing the current weather for where we live to daily climate statistics for that and other places around the world.

To accomplish this, you will be looking at several averages of the temperature in your area and comparing this to the same statistics for other places in the world. You will also be doing this for sea surface temperature. The reason for looking at ocean temperature will be explained later in this background section.

The first average you will be looking at is a *daily average* for any given spot on the earth's surface. This is quite simply the mean of all the temperature readings for the day for a specified place. When you select the 2 m average temperature map from the "Today's Weather" menu of Climate Reanalyzer, this is what you are seeing. The 2 m indicates the altitude of the air measurement, namely 2 meters above the earth's surface.

The second statistic is the daily mean air temperature for a given date averaged over a 30- or 50-year period. In other words, to determine the "normal" temperature for January 15 at any one place we average all the daily average temperatures for that date at that place over a 30- or 50-year period. While Climate Reanalyzer does not display this average, it does display another statistic derived from it, the 2 m temperature anomaly. This anomaly is the difference between the long-term normal daily average for a given date and place and the daily average for that place measured on that date during any one year. In the Climate Reanalyzer temperature anomaly map, areas where the average temperature for a given date are above the long-term average for that date appear in shades of red, areas where temperatures are below normal appear in shades of blue, and areas where the temperature are at or close to normal are white.

In the second activity in this set, you will be looking at sea surface temperature (SST). This is because much of the heat energy in the earth's climate system resides in the oceans. Because energy exchanges between the atmosphere and

ocean are important determinants of surface air temperature, looking at trends in SST is important to understanding how and why surface air temperature changes as it does. In later activity sets we will be looking how these exchanges work and how they impact the larger climate system.

Investigation

ActivityA: Ground level air temperature

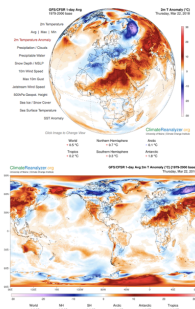


Figure 2: Climate Reanalyzer map of surface air temperature anomaly.

Next, select the 2 m Temperature Anomaly from the menu to the left of the globe. This displays the variation from the 1979-2000 average of the daily temperature for the current date. This should look like figure 2. Variations from normal for the world, the Northern and Southern hemispheres, tropics, Arctic, and Antarctic are shown under both the globe and the flat map.

Questions to investigate with this map

4. Were the places you identified in question 2 warmer or colder than the average for this day?
5. By how much did they vary from normal?
6. How did the average temperature for today for the world, for each hemisphere, for the tropics, the Arctic, and the Antarctic compare to the 1979-2000 average for this date?

Activity B – Sea surface temperature

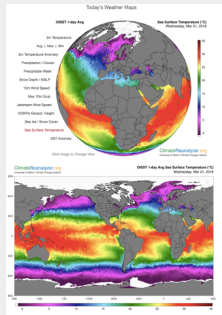


Figure 3: Climate Reanalyzer map of sea surface temperature.

Select sea surface temperature from the menu to the left of the globe. This displays today's sea surface temperature (SST) for the entire planet (figure 3)

How the data used to construct this map was derived is explained in the narrative below the map.

Questions to investigate with this map

1. What is the general relationship between SST and latitude?
2. Where was the ocean the warmest, where was it the coldest?
3. How was the data shown on this map collected?

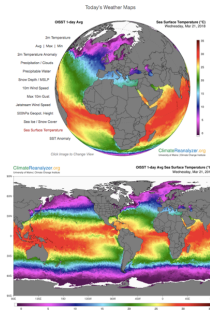


Figure 4: Climate Reanalyzer map of sea surface anomaly.

Select SST Anomaly from the menu to the left of the globe. This displays the difference between today's average sea surface temperature (SST) and the average SST for this same date from 1971 to 2000 (figure 4).

SST anomalies for the world, both hemispheres, and the oceans are listed below both the globe and the map.

Questions to investigate with this map:

4. How does the SST for the places you identified in question 7 compare to what is normal for this date?
5. By how much did they vary?
6. How did the SST for today for the world, for each hemisphere, for the North Atlantic, for the North Pacific, and for the Equatorial Pacific compare to the 1971-2000 average for this date?

9: Investigating Recent Global Temperature

Key questions for this investigation

- *How has global temperature changed over the past 1000 years?*
- *How do you see trends in widely varying data?*
- *What trends are visible in the record?*

Tool used in this investigation

- *Climate Dashboard* from the 2° Institute <
<https://www.climatelevels.org/>>

Background

The Climate Dashboard is a collection of interactive graphs looking at six major climatic elements over the past millennia. These include global temperature, mean sea level, and oxygen (O₂), methane (CH₄), nitrous oxide (N₂O), and carbon dioxide (CO₂) levels. Each of the graphs allows you to zoom in enabling you to look at it more closely and zoom out showing changes back through several major ice ages – the last 800 thousand years.

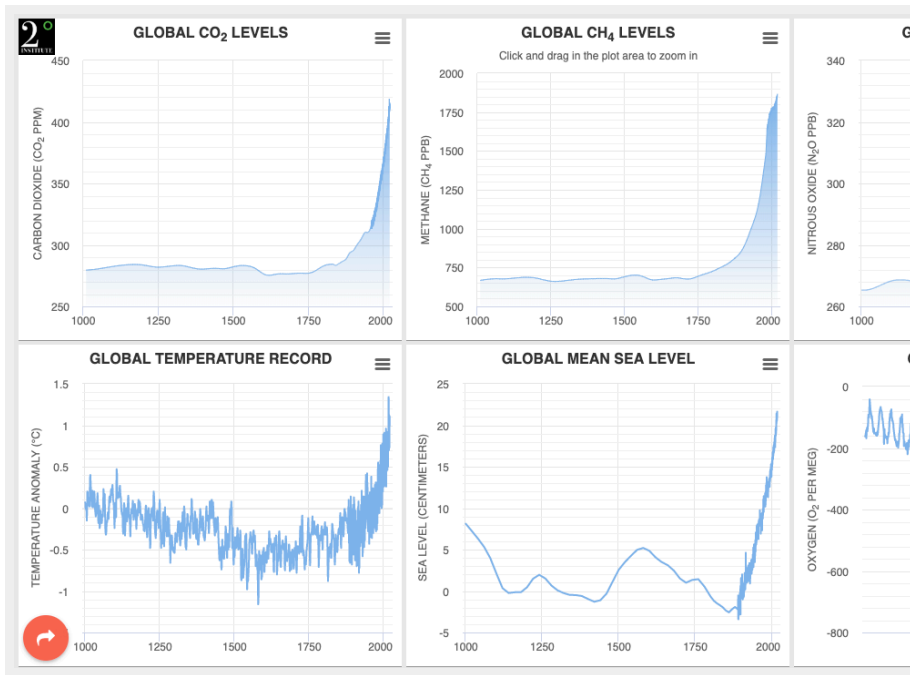


Figure 1: The default screen for the Climate Dashboard. Each of the six graphs can be expanded to full screen using the drop-down menu in the upper right-hand corner of each graph.

The temperature graph on the dashboard shows the difference between the global average annual temperature for any one year and the global average for the 1850s, often regarded as the start of the industrial revolution. This difference is referred to as a temperature anomaly and is displayed for the past millennia.

on the default graph. The graph can be expanded to show temperature variation over the past 800,000 years.

The other environmental factor shown in the dashboard is global mean sea level. Since we will only be dealing with the temperature graph in this activity set, an explanation of what mean sea level is, how it is measured, and its impacts will appear in a later activity in this manual, Activity 16, Sea Level and Coastal Flooding.

The other graphs on the dashboard show levels of major atmospheric gasses. Though we won't be dealing with these, either, in this activity set, here is a bit of useful background.

Of the four gases shown on the dashboard, one of these, oxygen, is a major constituent of atmosphere. At sea level, the atmosphere is approximately 78% nitrogen and 21% oxygen. The remaining 1% of the atmosphere is a combination of gasses that occur in such small concentrations that they are referred to as trace gasses. Three of these gasses (CO₂, CH₄, and N₂O) that appear in the dashboard are also Greenhouse Gasses. Their significance is explained in two earlier activity sets, Activity 4: Atmospheric Energy Budget and Activity 5: Carbon Cycle.

Investigation

ActivityA – Browsing the Data

Begin this part of the investigation by accessing the Global Temperature Record graph < <https://www.temperaturerecord.org> >. What you should see should look like this Figure 1.

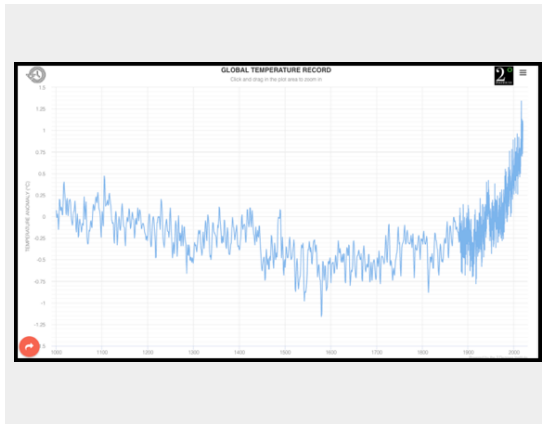


Figure 2: Default appearance of the Global Temperature Record graph. The temperature is actually the temperature anomaly, which is the difference between the mean global temperature for a year or a month and the long-term average.

If you move your cursor over the blue plot line you can read the temperature anomaly for any one year. Note – this works a bit differently on the denser right-hand side of the plot. More about that later. The three bars in the upper right corner of graph is a pull-down menu that allows you to change the graph, print it, and so on. The clock symbol in the upper left corner expands the time scale to 800 thousand years.

For this activity use the temperature record for the past 1000+ years to address the following questions...

1. *What and when was the highest temperature shown on*

- the graph? What and when was the lowest?*
- 2. What are the time differences between adjacent temperature record on the left side of the graph? On the right side of the graph?*
 - 3. What is the reason for this switch? Hint – if you click on the menu in the upper right and select “Data sources and credits” you can read about how the data for this graph was collected.*
-

ActivityB – Establishing trends

In determining whether global temperatures are rising or falling we need to look for long-term trends rather than focusing on short-term variations. In part B you will be looking at trends in the millennial temperature records and strategies for identifying these trends. To do so use the 1000-year graph to answer the following questions...

- 1. How does temperature seem to vary from year to year?*
 - 2. Given the year to year variation in temperature you saw, how would you go about determining where temperature was rising or falling for two or more centuries?*
 - 3. Using the strategy, you outlined in question 5, what is the trend in Global temperature over the entire record (1000 to present)?*
 - 4. What was the trend in temperature from 1000 to 1500? From 1500 to 1800? From 1800 to the present?*
-

ActivityC – Examining the instrumental

record

Climate data collected since the beginning of the industrial revolution is often referred to as the instrumental record. This is because the climate data that was collected was measured directly with weather stations and satellites, rather than being estimated or inferred from historical records, tree rings, ice chemistry, or other physical evidence.

To see the instrumental record in greater detail in this graph move the cursor to 1880 and then click and drag the cursor to present day. This will highlight the part of the map you want to magnify. Once you've done this, the graph should zoom into the selected period. Having done this, address the following questions...

1. *What and when were the highest and lowest temperatures shown on the graph?*
2. *What is the general trend in the temperature?*
3. *During what years was the rate of increase the highest?*
4. *During what years was there an extended period of cooling?*
5. *During what years was there neither cooling or warming?*
6. *How did the temperature change from 1880 to 1950 compare to that from 1950 to the present?*

10: Climate Changes – Temperature and Precipitation

Key questions for this investigation

- *How has average annual temperature and precipitation changed from the last ice age until now?*
- *How might temperature and precipitation change between now and 2100 given an average global temperature that is 4°C warmer than now?*

Tool used in this investigation

- *Climate Reanalyzer from the Climate Change Institute / University of Maine < <https://climatoreanalyzer.org/> >*

Background

The Environmental Change Model in Climate Reanalyzer presents projections of regional temperature, precipitation, and other environmental parameters based on global average temperature. The latter, written as “Global ΔT °C”, is actually degrees Celsius above or below the 1850 global average annual temperature.

All the negative values for ΔT (-6 to -0.5°C) correspond with either the Last Glacial Maximum (LGM) or the Little Ice Age. Both of these were cooling periods characterized by larger glaciers and ice sheets and lower sea level. The positive values (1 to 4°C) are associated with future dates. These are the projected date that a given ΔT will occur based on IPCC RCP-8.5. RCP is short for Representative Concentration Pathway, which are climate change projections based on changes in greenhouse gas emissions and atmospheric concentration. In RCP-8.5 atmospheric CO₂ concentrations in the year 2100 resulting from increased emissions from human activities are forecasted to be nearly four times that of 1850 concentrations and three times current concentrations.

IPCC is short for Intergovernmental Panel for Climate Change, a UN related science review and advisory group who assemble scenarios like RCP-8.5 from a collection of climate models produced by researchers from around the planet.

Investigation

ActivityA – Changes in Surface Air Temperature

To begin part A, launch Climate Reanalyzer < <https://climatoreanalyzer.org/> >

Next, select “Environmental Change Model” from the menu along the left side of the globe. Then select “World” from the “Region” pull down menu. Finally select “Temperature” from the “Parameter” menu.

This display you should get after doing all this should look

like figure 1. It shows average annual surface air temperature for the entire planet

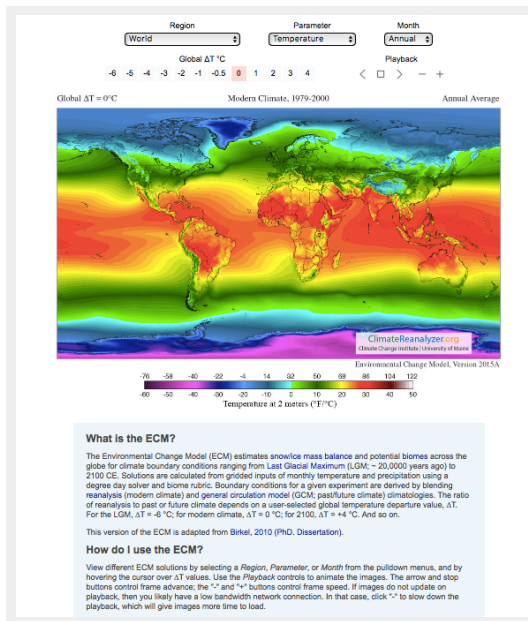


Figure 1

Surface air temperature map from Climate Reanalyzer

Questions to investigate with this map

1. What global ΔT corresponds to what times? For instance, global $\Delta T = 0$ corresponds to the Modern Climate, 1979-2000. Global ΔT is the difference between the global average annual surface air temperature for a given time period and the average annual SAT for 1979-2000.
2. What happens to the band of tropical temperatures as you move forward in time from the Last Glacial Maximum (LGM) into the present?
3. What happens to the band of Polar temperatures as you move from the LGM into the present?
4. How does what you observed in questions 2 and 3 change as you move forward into 2100?
5. What is the average annual temperature in the Arctic

Ocean forecasted for 2100? What impact should this have on sea ice in that area?

- In 2100 which areas will have the highest average annual temperature?*

Activity B – Changes in Precipitation

To begin this part of the activity, select “Precipitation” from the “Parameter” menu.

The display, which looks like figure 2, shows average annual precipitation for the entire planet. To look closer at a particular region, select the area you are interested in from the “Region” menu.

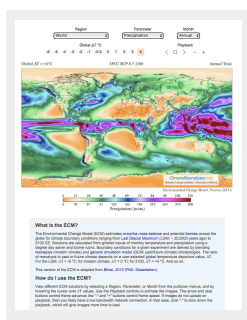


Figure 2

*Precipitation map
selected from
Climate
Reanalyzer*

Questions to investigate with this map

- For present times (Modern Climate, 1979-2000) where are the driest and wettest places on the planet? The present is where $\Delta T = 0$.*
- Are there any significant patterns you notice in precipitation from this map?*
- What changes do you notice in the general amount of precipitation and precipitation patterns as you go from*

present day ($G\Delta T = 0$) back to the LGM ($G\Delta T = -6$)?

4. *What changes do you notice in the general amount of precipitation and precipitation patterns as you go from present day ($G\Delta T = 0$) back to 2100 ($G\Delta T = 4$)?*
 5. *As you move from the present to the 2100 forecast, do you notice any places that get drier? Do you notice any places that get wetter? Where are they? Remember if you can't quite make out an area you can zoom in on it using the "Region" menu above the map.*
-

Activity C – Synthesis

Based on the results from of the previous two sections and any additional research you may need to do create some generalizations the impact of rising global temperatures on regional temperature and precipitation by answering the following questions.

1. *With rising global temperature what regions of the world show the greatest change in the regional temperature?*
2. *How does rising global temperature correlate with changes in precipitation?*
3. *Why are some parts of the world not affected equally by rising global temperature and general changes in global precipitation?*

PART III

PAST CLIMATE CHANGE

11: Climate History of the Clarno Basin

Key questions for this investigation

- *What evidence can be used to construct climate histories for specific locations?*
- *What are the strengths and limitations of each type of evidence?*
- *How far back in time does each type of evidence allow you to look?*

Tool used in this investigation

- *Biome Viewer* < http://media.hhmi.org/biointeractive/biomeviewer_web/index.html > from the Biointeractive program of Howard Hughes Medical Institute

Background

Paleoclimatology is the science of ancient climates. Since systematic observation of weather goes back less than two centuries, constructing a climate history for a specific place or the planet as a whole depends on using three types of data.

Instrumental – Direct observation of the weather using ground based and mobile weather stations, satellites, weather

balloons, and other instrumentation. Systematic, global gathering of weather data in this way extends back less than two centuries.

Historical – Inference of past climate from historical documents such as ship logs, church records, government documents, crop records, harbor records, and other documentary evidence. This kind of data allows us to expand our view of climate almost five millennia.

Proxy – Physical evidence of past climate that includes tree rings, seafloor sediment, ice cores, cave formations, lake levels, pollen in lake sediments, corals, sedimentary rocks, and fossils. Proxy evidence enables us to see climates back hundreds of millions of years ago.

In these activities you will be looking at instrumental and proxy data to create a climate history for a unique place in north central Oregon named the Clarno Basin. The area is unique because it contains three units of the John Day National Monument, an area that contains a rich collection of evidence for nearly 50 million years of regional climate change. Additional information on the monument can be found at < <https://www.nps.gov/joda/index.htm> >.

Investigation

ActivityA – Determining present climate of Clarno Basin

Launch Biome Viewer < http://media.hhmi.org/biointeractive/biomeviewer_web/index.html >. By default, you will be shown

a rotatable globe with which you can access Climate data and biome information for major areas of the planet (see figure 1)

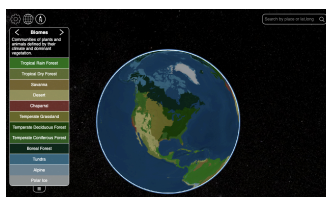


Figure 1 – Biome viewer default screen (left) and the viewer with a climate location.

To begin this part of the activity, type “Clarno Oregon” in the search box in the upper right corner of the frame. Use the data panel that appears when you do this to address the following questions...

1. What biome is Clarno in?
2. What are the climate characteristics of this biome?
3. What is maximum and minimum average temperature for Clarno?
4. What is the average annual temperature?
5. What is the maximum and minimum monthly temperature?
6. What is the total annual precipitation?
7. Clarno is actually located in a transitional climate that is very similar to what you get when type “Gilliam County Oregon” into the search bar. What are the characteristics of the climate for Gilliam County?
8. How do the two biomes compare in terms of vegetation?

ActivityB – Determining the ancient climate of the Clarno Basin

Figure 2 (see below) shows four fossil plants found in the Clarno Unit of the John Day National Monument. These fossils are preserved in a type of volcanic mudstone and are dated at between 54 and 40 million years of age. Modern day relatives of these fossils are most commonly found in semi-tropical rainforests.



Sabalites eocenica

Fan Palm that is low and shrub-like.



Sycamore Leaf

Figure 2– Fossil plants found in the Clarno Unit of the John Day National

Questions to investigate

1. *Provided these fossil plants were found in the same type of climate as their modern descendants, what was the climate of the Clarno Basin like 40 to 54 million years ago?*
2. *How does this ancient climate compare to the modern-day climate of the Clarno Basin?*
3. *Write a short climate history for the Clarno Basin beginning with its climate 40 to 54 million years ago and ending with present day. An important question to answer is what was the climate like between these two end points? Hint looking at the climates of Mexico and Central America may be helpful here.*
4. *What kinds of proxy data could be used to confirm your climate history? To answer this, refer to the descriptions of the different types of proxy data listed on the Paleoclimatology Datasets page by the NOAA National Centers for Environmental Information < <https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets> >. When you list the types of data you could use, make sure to describe the datasets you selected and why they would be appropriate.*
5. *What might have caused the climate changes that took place in the Basin during the past 54 million years?*
6. *How would you test your hypothesis?*

12: Climate Change and Earth History

Key questions for this investigation

- What is geologic time?
- How has the Earth's climate changed during its history?

Tool used in this investigation

- *Earth Viewer* < http://media.hhmi.org/biointeractive/earthviewer_web/earthviewer.html > from the Biointeractive program at the Howard Hughes Medical Institute

Background

There are two pieces of background that are important for these activities. The first is how earth scientists tell time, and the second is the major elements involved in recounting the Earth's climate history.

In regard to earth history researchers customarily resort to something called the geologic calendar. In a nutshell the calendar is a global timeline of the events that have shaped the current structure of the planet. As such it extends back in time to the Earth's formation, nearly 4.5 billion years and it is

divided into major segments on the basis of the appearance and disappearance of major types of life as evidenced by the fossil record. The latter is a term used by paleontologists to refer to the total number of fossils that have been discovered to date. One of the goals of activity A on the following page is to familiarize yourself with the divisions of the calendar and the types of life common to each division.

In regard to the elements that make up a climate history the key ones that appear in Earth Viewer that you will be working with in these activities are as follows...

- Mean global air temperature – An average annual temperature for the entire planet. Largely inferred from oxygen isotopes in marine carbonates.
- Luminosity – The energy from the sun received at the top of the atmosphere measured in percentage of the Sun's current output. Based on stellar evolution modeling.
- Day length – The average annual day length. Calculated from modeling of the formation of the Earth's core and tidal dissipation.
- CO₂ – The amount of carbon dioxide in the atmosphere in parts per million (ppm). Modeled using geochemical data from the carbon cycle.
- O₂ – The amount of oxygen in the atmosphere expressed in percentage of total gas volume. Based on data from carbon and sulfur cycles.

Investigation

ActivityA: Becoming familiar with Earth Viewer and the Geologic Time Scale

Begin by launching *Earth Viewer* < http://media.hhmi.org/biointeractive/earthviewer_web/earthviewer.html >. On the right side of the frame you see a globe that you can rotate. On the left side is a graphic timeline that you use for seeing the earth at different times in its history. There are actually four timelines available in this Atlas. One of these, “Paleo Earth”, is visible when you first launch the viewer and encompasses the last 550 million years of earth history. “Ancient Earth” shows all of earth history. “Ice Age Earth” goes from 21,000 years ago to 8,000 years into the future – The last 8000 years of this timeline (future) being based on climate modeling. The final timeline, “Warming Earth”, displays changes in average annual temperature from 1912 to 2012.

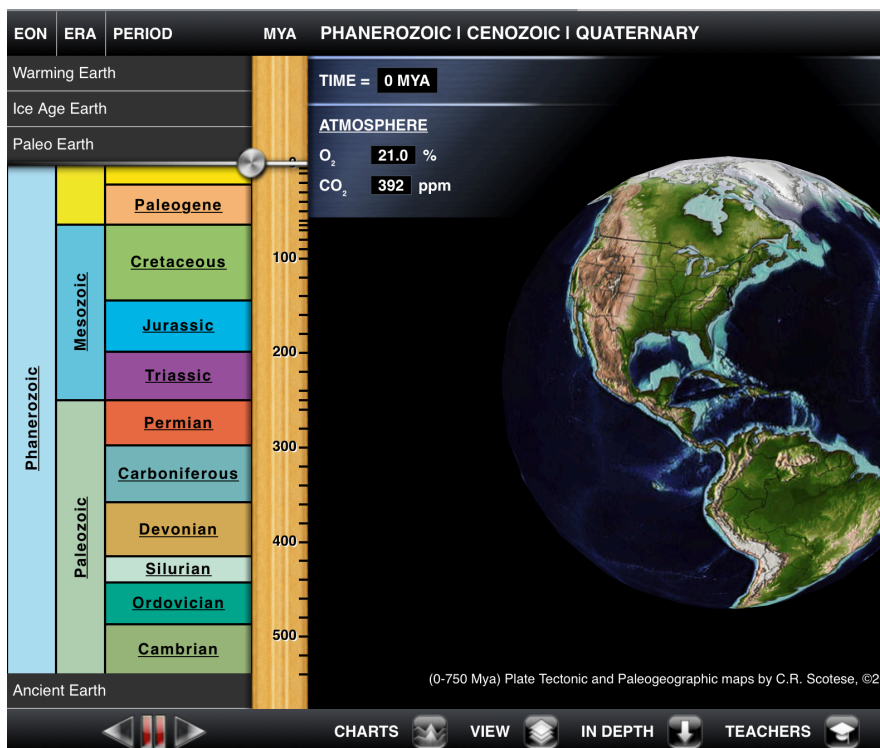


Figure 1 – Default screen for Earth viewer. The multi-colored chart on the left shows geological time scales. The task bar across the bottom contains navigation icons and buttons for CHARTS, VIEW, IN DEPTH, and TEACHERS. Additional controls and data displays appear above the globe.

Using both the “Paleo Earth” and “Ice Age Earth” timelines answer the following questions...

1. What is the Phanerozoic? To do this find this term in the timeline and click on it. When you answer the question identify how long it lasted, when it started and when it ended, what happened in terms of life, and what the name means.

2. *What are the three major divisions of the Phanerozoic?
List and describe each of these.*
 3. *What is the Pleistocene?*
 4. *What is the Quaternary?*
 5. *What is the Anthropocene?*
-

Activity B – Tracking Geographic and Climatic Change

Reset the viewer timeline to “Paleo Earth”. Using your finger or cursor (depending on whether you are using a tablet or a computer) click and drag on the timeline slider. This should move you back and forth through time, in which case you will see the geography of the planet change.

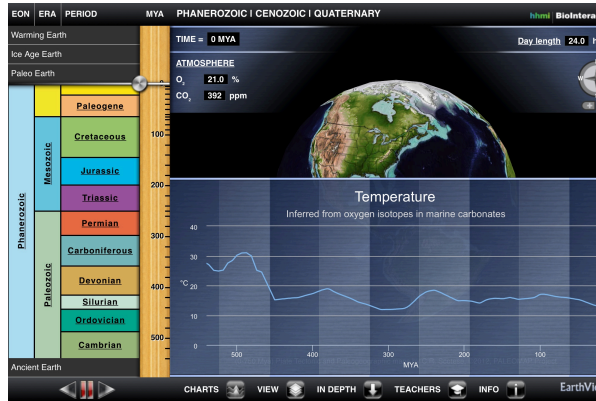


Figure 2 – EV screen showing a graph of global average temperature for 500 million years)

Using the slider on this and the other timelines answer the following questions...

1. How did the geography of the earth change during the past 550 million years?
2. What is the current mean surface air temperature of the earth? To find this turn on the temperature chart. The icon for this is on the bottom of the frame in the web version, and the top right corner of the tablet version.
3. When were the high and low temperatures during the Phanerozoic? To answer this give the time and magnitude of the peaks and valleys in the chart.
4. Where do you see the most abrupt change in temperature? Hint you may have to resort to the “Ice Age

Earth” to find this.

5. *Compare these temperature highs and lows to the oxygen, carbon dioxide, day length, and solar luminosity graphs. Which of these seems to show the closest relationship to temperature? Note – The mobile app version allows you to display two graphs simultaneously, the web version does not, so you have to go to the icon at the bottom of the frame to change the parameter being shown.*
-

ActivityC: Synthesis

1. *Earth Viewer has four time–controllers (timescales). How are these related to each other?*
2. *The geologic record is the evidence for past events found in fossils, rocks, soils, seafloor sediment, ice, and landscapes. Based on the relationship between the four timescales you noted in question 1, what can you say about the detail of the geologic record for recent events vs. the record for ancient events?*
3. *Why is the detail different for recent events?*
4. *Based on your results for Activity B, how is the climate change taking place during the past 200 years different from other periods of warming or cooling during the past 550 million years.*

13: Hothouse / Icehouse

Key questions for this investigation

- *What is the range of climate change that has taken place on this planet?*
- *What factors have driven that change?*
- *How have sea level and global ice been impacted by these changes?*

Tool used in this investigation

- *Earth Viewer* < http://media.hhmi.org/biointeractive/earthviewer_web/earthviewer.html > from the Biointeractive program at the Howard Hughes Medical Institute

Background

An old adage is that the only constant in the universe is change. The bulk of the evidence available to paleoclimatologists (researchers who study past climate) indicates that this is certainly true when it comes to climate history. In general, this history alternates between cold, dry periods referred to as icehouse and much warmer, wetter periods called hothouse.

During icehouse episodes annual average global temperature falls enough that global ice (glaciers, sea ice,

tundra, and ice caps) expands significantly. During hothouse episodes annual average temperature rises sufficiently that global ice becomes negligible or even disappears. One of the goals of the following activities is investigate what other changes take place during these episodes.

Another goal of the following activities is to examine what causes these episodes. Key factors that appear in Earth Viewer that you will experiment with include the following...

- Geography – The location and shape of the continents.
- CO₂ – The amount of carbon dioxide in the atmosphere in ppm (parts per million)
- Solar luminosity – The amount of energy received by the earth.
- Impacts – Asteroid or large meteorite collisions.

Investigation

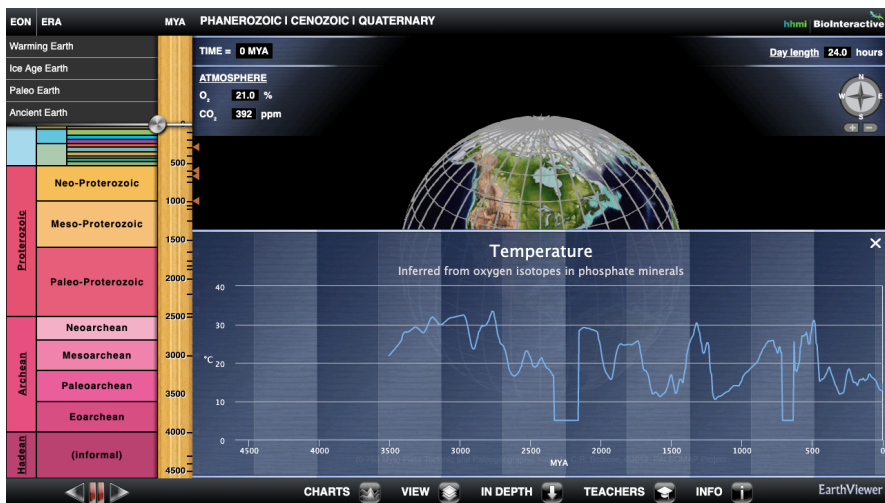
ActivityA – Hothouse / IcehouseEpisodes

Begin by launching Earth Viewer < <http://www.hhmi.org/biointeractive/earthviewer> >. When the viewer appears set its timescale to “Ancient Earth”. Next display the temperature graph by clicking on the charts button. This is located in the upper right corner of the mobile app version and lower left quadrant of the web version. Finally use the timeline to answer the following questions...

1. *During the past 4.5 billion years when were the high temperature peaks and what was the average global temperature at those peaks? These points on the graph*

represent the height of Hothouse episodes.

2. *During the past 4.5 billion when were the low temperature valleys? These represent the depth of Icehouse episodes.*
3. *What is the fastest and slowest rate of temperature change during past 4.5 billion years? To do this find adjacent Hothouse peaks and Icehouse valleys. Determine the temperature and the time difference between the two. The rate of change is the temperature difference divided by the time difference in °C per year.*
4. *Change the timescale from “Ancient Earth” to “Paleo Earth”. Repeat questions 1, 2, and 3 for the past 550 million years.*
5. *Set the time scale to “Ice Age Earth” and calculate the rate of temperature change from 20,000 to 8,000 years ago, 4,000 to 800 years ago, 800 to 200 years ago, and 200 years ago to present (Time = 0). How do these rates compare to each other and those you calculated in questions 3 and 4?*
6. *Calculate the rate of temperature change modeled for the next century. How does it compare to all the other rates you calculated?*



Activity B – Climate forcings and feedback

Set the calendar to “Ancient Earth”. Using the slider on this and the other timelines answer the following questions...

1. For each of the hothouse episodes you identified in question 1 of the previous activity, what was the CO₂ concentration, luminosity, and day length?
2. For each of the icehouse episodes you identified in question 2 of the previous activity, what was the CO₂ concentration, luminosity, and day length?
3. Which of these factors is most closely correlated with rises and falls in average global temperature?

Next set the calendar for “Paleo Earth” and rotate the globe so you are looking straight down onto the south pole (see figure 2).

4. Between 540 million years ago and the present when did icecaps appear at the South Pole?
5. How did the appearance of these ice caps correspond the with the timing of icehouse and hothouse episodes you identified in question 4 of the previous activity?
6. During the past 540 million years when did ice appear at the North Pole?
7. How did this the appearance of polar ice at the North Pole correspond to appearance at the South Pole?
8. What do you think accounts for any of the differences you may have noticed in question 7?

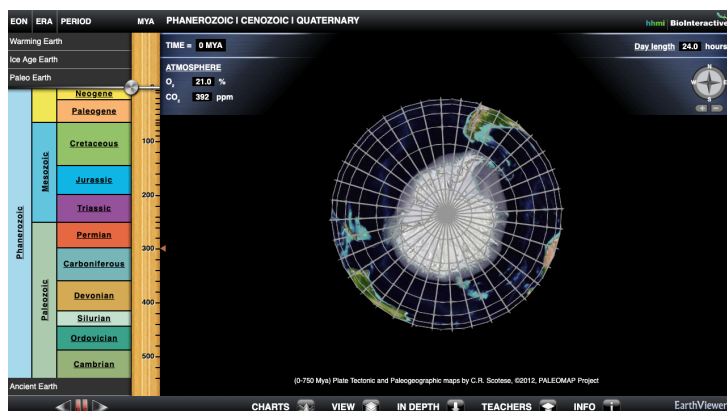


Figure 2

Earth Viewer
“Paleo Earth
are looking s
Pole. The
ice-covered l
a dark blue.

Activity C – ClimateImpacts

To begin set the calendar to “Ice Age Earth” and the time slider to 21,000 years. With these settings as your starting point use the viewer to answer the following questions...

1. *Between now and 21,000 years ago what happened to the global ice of the world? Be specific here by referring to places that either gain or lose ice as you move forward in time.*
2. *What is meant by relative sea level? For information about this question click on the label "Relative Sea Level" in the upper right corner of the screen.*
3. *Between now and 21,000 years ago what happened to relative sea level? Again, be specific. What was RSL 21,000 years ago? What was it now?*
4. *When was the change in sea level the most rapid? When was it the most stable? To answer this question, open the RSL graph by selecting Relative Sea Level from the "Charts" menu at the bottom of the screen (Figure 3).*
5. *For the climate model used in Earth Viewer, how much is average global temperature forecasted to increase by 1000 years from now?*
6. *Given this temperature increase what is the forecasted rise in sea level?*
7. *What changes in the Arctic and Antarctic might you expect to see in the next millennium?*
8. *Continuing forward in time when might the earth become ice free? In other words when would all the major glaciers, ice sheets, and sea ice disappear from the planet?*
9. *What is relative sea level at this time?*

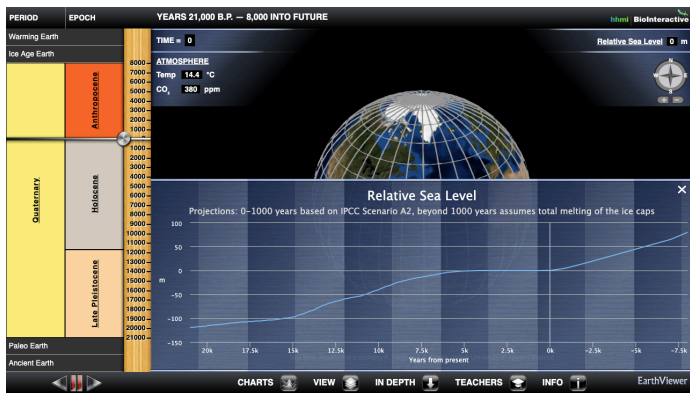


Figure 3

Earth Viewer with Age Earth". The globe is for Relative Sea Level relative to present. The graph is accessed by selecting the "Charts" menu from the "Chart" menu on the screen. Other menus and that menu are t

ActivityD – Synthesis

1. Given what you found out in the past three activities write a more complete definition for Icehouse and Hothouse than the one in the background section of this activity set?
2. Summarize what causes icehouse and hothouse episodes on the basis of what you discovered in activity B.
3. Explain the relationship between sea level, global ice, and temperature on the basis of your results in activity C. Are there other factors in this relationship that were not explored in that activity?

14: Climate of the “Recent” Past

Key questions for this investigation

- *How has global temperature varied during the last 800,000 years?*
- *What has been the relationship between global temperature and sea level and CO₂ levels?*
- *What has been the relationship between global temperature and changes in the earth’s orbit and rotation?*
- *How do current global temperatures compare with past temperature highs?*

Tool used in this investigation

Climate Dashboard from the 2° Institute <
<https://www.climatelevels.org/>>

Background

The past 800,000 years includes our current time period, the Holocene, and the last third of a much longer period called the Pleistocene. The Pleistocene is a geologic epoch that lasted from 2.6 million years ago (mya) to about 11,700 ya. Sometimes

referred to as the Ice Age, the Pleistocene is actually a period of repeated glaciations separated by warm periods. The Holocene, on the other hand, is a twelve-millennium time span during which human civilization emerged and developed. In other words, it is the part of the geologic calendar we now live in.

In this set of activities, you will be looking at five key variables that are involved in the questions above.

- *Global temperature* – The graph for this in Dashboard is actually for temperature anomaly. This anomaly is the difference between the Mean Global Temperature (MGT) for a given year and the average of MGTs over an extended period of time.
- *Sea level* – The graph for this shows mean global sea level in relation to present sea levels. Present levels being zero.
- *Carbon dioxide levels* – The graph for this show atmospheric concentration of CO₂ in parts per million.
- *Eccentricity and tilt* – Characteristics of the earth's orbit and rotation that influence the amount, distribution, and timing of energy received from the sun – a key driver of climate.

Investigation

Activity A – Annual global temperature over the past 800 millennia

Access the Global Temperature Record graph by launching the *Climate Dashboard* < <https://www.climatelevels.org/> >. Then click on the graph in lower left corner of the set of six graphs that appear. What you see when you do so should look like figure 1. Since this graph only goes back a thousand years you will need to click on the clock icon in the upper left corner

of the frame. When you do this you should see something that looks like figure 2.

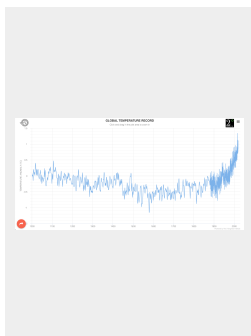


Figure 1

Global Temperature Record graph for the last millennium. This is the default graph for Climate Dashboard. The arrow indicates the clock icon you will need to click on to see 800,000 years of temperature record.



Figure 2

Global Temperature Record graph for the last 800,000 years. Like the previous graph, this one is actually showing temperature anomaly – the difference between global annual temperature for any one year and the long term mean for global annual temperature.

Questions to investigate

1. What and when were the highest and lowest

temperatures during the past 800,000 years?

Once you have accessed the temperature graph for the past 800 millennia use it to address the following questions.

2. *How do the highest and lowest temperatures compare to the most recent temperature?*
 3. *Between 123,000 and 22,100 years ago what were the highest and lowest temperatures? How would you describe the temperature variations between these two times?*
 4. *What happens to mean global temperature (MGT) after 22,100?*
 5. *How is the temperature variation between 330,000 and 270,00 years similar to what happened between 123,000 and 22,100 years ago?*
 6. *Find at least three other time periods that show similar trends to the two periods mentioned in the previous question. When were they and what were their maximum high and low temperatures?*
 7. *On the graph, troughs correspond with periods of cooling and glacial advance (glacials), while peaks correspond with periods of warming and glacial retreat (interglacials). For each of the periods listed in questions 5 and 6 how many glacials and interglacials did you count in each period?*
 8. *Based on what you observed for questions 4 and 5 what kind of temperature variations would you expect to see on the planet during the next 100,000 years?*
-

Activity B – Impact of varying global temperature on sea level

Click on the three bars in the upper right corner of the frame. When you do so you should get a menu of other graphs in the dashboard. Select “Global Levels” from the list. When you do you will get a graph of Global Mean Sea Level for the past millennium. Again, click on the clock icon in the upper left corner of the frame to see sea level over the past 800,000 years. Sea level is shown here in meters above or below present mean sea level.

1. *Was there ever a time when mean global sea level was estimated to be greater than present day mean sea level? When was it and how much higher was it than present?*
 2. *What was the temperature anomaly for that time? To find this out click on the globe / thermometer icon in the upper left corner of the frame. This will superimpose a global mean temperature graph onto the sea level graph.*
 3. *What seems to be the relationship between sea level and temperature?*
 4. *How do you explain this relationship?*
 5. *How “tight” is this relationship? In other words, are there any mismatches that challenge the conclusion that you reached in question 3?*
 6. *How do you explain the mismatches?*
-

ActivityC – Drivers of varying global temperature over the past 800,000 years

Click on the upper right corner of the frame to get the menu

of other graphs in the dashboard. This time select “Carbon Dioxide Levels”. Since the graph that appears will only show atmospheric CO₂ concentration for the past millennium click on the clock icon in the upper left to show CO₂ levels for the past 800,000 years. When this appears use the graph to answer the following questions.

1. *What are the highest and lowest concentrations shown on the graph? When were they and how much were they?*
2. *How do they compare to present day CO₂ levels?*
3. *How do these high and low concentrations compare to mean global temperature? To make this connection click on the globe and thermometer icon in the upper right.*
4. *Are there any instances where peaks in CO₂ happen before peaks in temperature? Are there any instances where the peaks in CO₂ happen after temperature peaks?*
5. *Are there any instances where lows in CO₂ happen before lows in temperature? Are there any instances where the lows in CO₂ happen after temperature lows?*
6. *Over the past 800,000 years temperature seemed to go from extreme highs to extreme lows (for instance 126,000 to 22,100 years ago) on a regular basis. Look back at the other cycles like this identified in questions 5 and 6 in Activity A. What is the length of these other cycles? What is the average of all the cycles?*
7. *Referring back to question 7 in part A what seems to be the average time between interglacials in a cycle?*
8. *The earth’s orbit changes from a circle to an ellipse and back to a circle every 100,000 to 413,000 years. The tilt of its axis changes from 22 to 24° every 41,000 years. How do these changes compare to in orbit and tilt compare to the length of the cycles outlined in question 6? How do they compare to the average time between interglacials?*

Activity D – Synthesis

In debates about past, present, and future climate change, a couple of challenges that are frequently raised by people skeptical of mainstream climate science are...

- It really isn't possible to talk about past climate with any degree of certainty since no one was around to make reliable observations.
- There are so many mismatches between past global temperature and atmospheric CO₂ concentration that the conclusion that increasing CO₂ leads to increasing global temperature is a highly suspect.

In this synthesis you will be using the observations and conclusions you made in the past three activities to reflect on these two challenges. To do so answer the following questions.

1. *What is the temperature record for the past 800,000 years based on? To address these questions, scroll down to the informational text below the graph.*
2. *How are some of these same techniques used to establish past CO₂ levels?*
3. *Based what you said in question 8 of Part C, how would you explain the “mismatches” you observed in questions 4 and 5 of that same activity? In other words, if CO₂ were the only factor controlling temperature controlling global temperature, why is it that some temperature peaks and valleys come after CO₂ peaks and valleys rather than before?*

PART IV

POTENTIAL CLIMATE CHANGE

15: Regional Climate Impacts - IPCC WGI 2021 Report

FRANK D. GRANSHAW

Key questions for this investigation

- What climate impacts can be expected in the next 30 to 70 years?
- How do these impacts vary by region?
- What factors determine the frequency and magnitude of these impacts?

Tools used in this investigation

- [IPCC WGI \(Intergovernmental Panel on Climate Change – Working Group I\) Interactive Atlas](#)
- AR6 Working Group Report 1 Report – [Regional Fact Sheets](#)

Background

The principal tool in this investigation, the Interactive Atlas, is a product of the 2021 IPCC working group, [AR6 Volume 1: The Physical Science Basis](#). This document is the first of three

reports that summarizes the science describing the present state of the earth’s climate system. These reports, collectively known as the [Sixth Assessment Report \(AR6\)](#), look at the current and probable extent of global climate change (volume 1), the impacts of and adaptation to this change (volume 2), and strategies for mitigating this change and its impacts (volume 3). Volume 1 was released in August 2021, while the other two volumes are scheduled to be finalized in February 2022 (volume 2) and March 2022 (volume 3).

ipcc

Sixth Assessment Report

Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

AR6 Climate Change 2021: The Physical Science Basis

The Working Group I contribution to the Sixth Assessment Report addresses the most up-to-date physical climate system and climate change, bringing together the latest advances in climate science, and combining evidence from paleoclimate, observations, process understanding, and global and regional climate models.

Disclaimer: The Summary for Policymakers (SPM) is the approved version from the 14th session of Working Group I on the Intergovernmental Panel on Climate Change and remains subject to final copy-editing and layout.

The Technical Summary (TS), the full Report Chapters, the Annexes and the Supplementary Materials are the Final Government versions, and remain subject to revisions following the SPM approval, corrigenda, copy-editing, and layout. Although these are from the Final Government Distribution "Do Not Cite, Quote or Distribute" they may be freely published subject to the report has now been approved and accepted.

SUMMARY FOR POLICYMAKERS (SPM)

TECHNICAL SUMMARY (TS)

FULL REPORT

EXTRAS

INTERACTIVE ATLAS

FREQUENTLY ASKED QUESTIONS (FAQ)

REGIONAL/FOCUS STUDIES

DATA ACCESS

SUPPLEMENTARY MATERIALS

128 | Regional Climate Impacts

The atlas provides access to the data and projections contained in the report. Using a map interface, users can assess changes in a variety of climate variables and related impacts on a global, regional, or local scale. Key variables include annual and seasonal air and ocean temperatures, precipitation, snowfall, surface wind, air quality, sea ice concentration, surface seawater pH, and sea level. Users can investigate different possible outcomes by selecting the database, models, or model assumptions used for determining them. They can also examine these for selected future time periods – near, medium, and long term (2021-2040, 2041-2080, and 2081-2100, respectively), as well as different emissions scenarios.

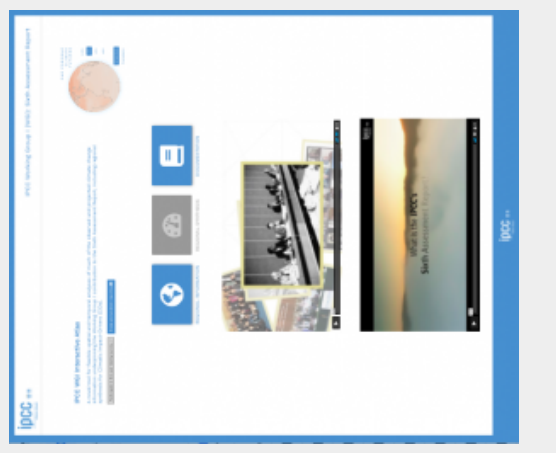
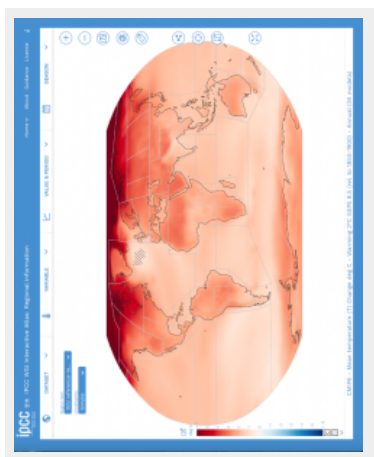


Figure 2 – Gateway page for the interactive atlas (left) and the regional information screen for the atlas (right).



Investigation

This investigation begins by having you explore temperature and precipitation changes on a global level for several different emission scenarios. As it progresses you will look at additional climate impacts for progressively smaller areas for these same scenarios. In each of the three activities in this investigation you will use either the interactive active atlas or the regional fact sheets to answer a series of questions.

Activity A: Evaluating climate impacts – A global view

In this first activity you will be looking at regional changes in average annual temperature and precipitation for four climate scenarios. To begin, launch the Interactive Atlas < <https://interactive-atlas.ipcc.ch/> >. What should appear when you do this should look like the following figure.

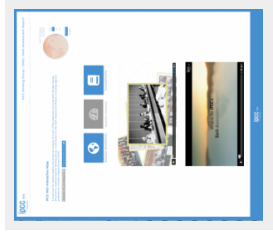


Figure 3 – Title screen for the Interactive Atlas

This page includes a brief description of the atlas, a globe in the upper right corner that you will be using for Activity A, links to a regional atlas and additional information about it. Summary information about the atlas and the IPCC report it is part of can be found in the two videos in the lower half of the page.

The spinning globe in the upper right provides you with a qualitative perspective of the regional changes in temperature and precipitation under global warming scenarios varying from +1.5° to +4.0°C above pre industrial average annual temperatures. By default the globe shows regional temperature for a +2.0°C warmer world. Warming is shown in shades of red, while cooling is indicated by shades of blue. The darker the red the greater the warming. Likewise the darker the blue the greater the cooling.

Moving the cursor over the left side of the globe accesses information about these projections and the models used to construct them. Click and drag on the globe to rotate it. To the immediate right of the globe is a list of warming scenarios (climate futures) you can choose from. Below that list are buttons that allow you to switch between regional temperatures and precipitation.

Like the temperature display, the precipitation display is qualitative. This means that there is no legend or overlays that tells you the magnitude of the changes shown. The general rule of thumb is that bluish-greens indicate areas that are wetter than the pre-industrial average, while white indicates little or no change, and orange shows areas that are drier than the pre-industrial average. Like temperature, the darker the color the more intense the change. The regional maps used for Activities B and C provide you with tools for doing quantitative analysis.

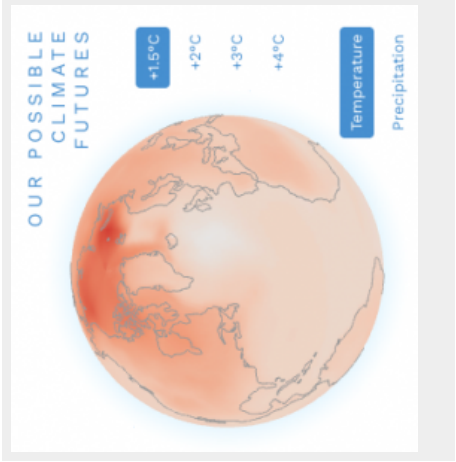
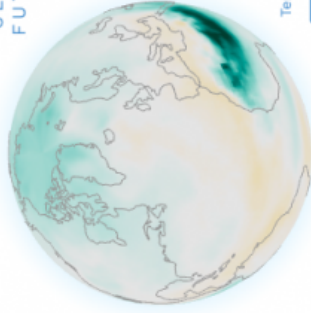


Figure 4

Title globe showing regional changes in temperature and precipitation for a 1.5°C increase in average annual global temperature.

OUR POSSIBLE CLIMATE FUTURES



+1.5°C

+2°C

+3°C

+4°C

Temperature

Precipitation

Beginning with the default view (Temperature in a +2.0°C world) answer the following questions.

- 1. Where is the regional temperature change the highest? Where is it the lowest?*
 - 2. How does the temperature change of the oceans compare to that of the continents?*
 - 3. Are there any parts of the ocean which are an exception to the rule you stated in the previous question?*
 - 4. Now switch to temperature in a +2.0°C world. In general is a +2 world wetter or drier than a pre-industrial one?*
 - 5. Where in the world would it be wetter? Where would it be drier?*
 - 6. Finally try out the other warming scenarios. How does the +1.5° compare to the +2°C world? How does the +3°C and +4°C compare to the +2.0°C world?*
 - 7. In each case what areas show the largest impact?*
-

Activity B: Evaluating climate impacts – A regional view

While the globe you used in the previous activity is useful for getting quick glimpses into regional changes in annual temperature and precipitation, it has no tools for numerically analyzing potential changes, assessing impacts other than temperature or precipitation, or looking at results from a variety of climate models and databases.

In this activity you will be using the regional information module in the interactive atlas. To access it click on the “Regional Information” button on the atlas gateway page

(figure 5). What appears should look like the screenshot in figure 6.

the right
allow for
more
detailed and
localized
analysis.

To begin familiarizing yourself with the atlas Interface, open the Region Set menu and answer the following questions.

1. What options do you have for Region Set? This menu should have defaulted to WGI Reference-regions when you launched the atlas. If it did not select that option from the list.
2. In a +2°C world which region shows the greatest change in average global temperature? Which shows the least change? To identify the region click on it. What you should see is a pop-up information panel that looks like figure 7. The region name is in the second line of the title – circled in red.
3. What is the magnitude of the change? To find this click on “Table Summary” – circled in green in figure 7. What you should get should look like figure 8.



Next find and open the “Variable” menu in the upper left portion of the frame. Select one of the other climate impact variables from the list and observe what happens to the map and the table. Note you will need to move your cursor away from the menu for it to disappear so you can see the change.

Using the “Variables” menu complete the following table (Table 1). Note – For the impacts listed in this table the changes are also shown for a +1.5°C, +3°C, and +4°C world. Also note – Because not all the impacts are relevant to the location you have selected, these should be marked as n/a (not applicable).

Table 1: Data Sheet for recording impacts regional climate impacts for four warming scenarios

Climate impact	+2°C	+4°C	+3°C	+1.5°C
Mean temperature change – Median (°C)				
Change in minimum temperature – Median (°C)				
Change in maximum temperature – Median (°C)				
Change in days with max temp > 40°C – Median (days)				
Change in number of frost days – Median (days)				
Total precipitation change – Median (%)				
Change in max 5 day precipitation amounts – Median (%)				
Consecutive dry days – Median (days)				
Change in snowfall – Median (mm/day)				
Surface wind change – Median (%)				
Sea surface temperature change – Median (°C)				
Ocean acidity – Change in surface pH – Median (pH)				

Activity C: Evaluating climate impacts – A “local” view

An additional aspect of the interactive atlas is the ability to look at climate impacts on a more local level. If you zoom in as close as you can the map begins to look like a patchwork quilt, each patch having a single color. These patches, referred to as cells, are a key component of the models used to produce the maps in this atlas.

Climate models are essentially sets of equations that simulate the flow of energy and matter throughout the earth's climate system. This implies that the models are simulating mass / energy flows between points that are spaced equidistant apart. However, rather than points, climate models break the atmosphere and oceans up into stacks of equal sized cubes (cells) that mass and energy constantly flow out of and into. This means that what you are seeing through the magnifying glass in Figure 8 is the bottom of stacks of cells extending up to the top of the atmosphere.

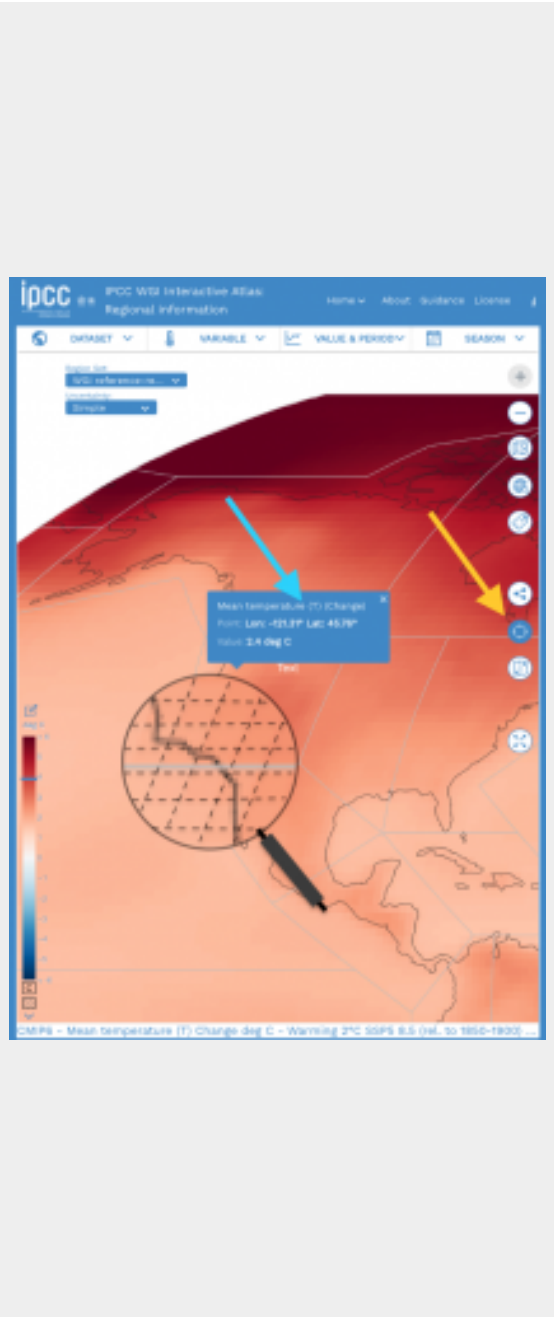
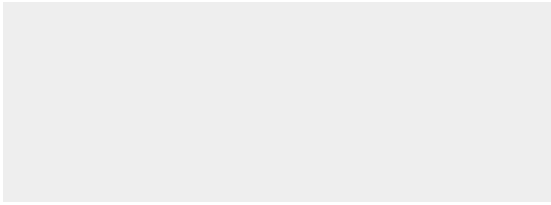


Figure 9 – Screenshot of the atlas in the “Point Information” mode.

- The yellow arrow is pointing at the control that turns this mode on and off.
- The blue arrow is pointing at an information panel that appears when you click on a point on the map.
- The magnifying glass shows an enlargement of a section of the map. Note the blocky nature of the map indicating that it is made of cells having uniform value throughout. In other words wherever you click inside one of the cells you will always get the same number for



the climate variable being displayed on the map.

Due to limitations in available data and the processing power of computers used to run climate models there are limits to how small these cells can be. In the case of the interactive atlas the cell size is on the order of 2500 to 10,000 square kilometers. This means that the value of any climate variable being displayed is the same no matter where you are inside a cell.

A tool for determining the value of each cell is the “Point information” mode. To turn on this mode click on the icon indicated by the yellow arrow in figure 8. Once this mode is active you can click anywhere on the map to see the value of that point. So rather than seeing statistics for an entire region you can drill down to a much smaller, more local area. Just like you did in the previous activity, you can change the climate impact being displayed using the “Variable” menu. There are two cautions to keep in mind when you do this, however.

- First, whenever you change the variable displayed the information panel that pops up whenever you click on a point disappears. So you need to remember the longitude and latitude of the point you clicked on so you can find it again on the new map.
- Second, these cells cover large areas, so you need to remember that when you look at climate impacts for a city or town, what you get is highly generalized.

Equipped with this information, select a specific place (e.g. the city you live in, a rural area some of your food comes from, a favorite vacation spot) and complete the first two columns of

the following table. Note – You will need the longitude and latitude of that place.

Table 2:
Data Sheet for recording impacts location specific climate impacts for four warming scenarios

Climate impact	+2°C	+4°C	+3°C	+1.5°C
Mean temperature change – Median (°C)				
Change in minimum temperature – Median (°C)				
Change in maximum temperature – Median (°C)				
Change in days with max temp > 40°C – Median (days)				
Change in number of frost days – Median (days)				
Total precipitation change – Median (%)				
Change in max 5 day precipitation amounts – Median (%)				
Consecutive dry days – Media (days)				
Change in snowfall – Median (mm/day)				
Surface wind change – Median (%)				
Sea surface temperature change – Median (°C)				
Ocean acidity – Change in surface pH – Median (pH)				

Unlike that information panel that pops up in Activity B when you click on a region, the panel that appears when you select a place in the “Point information” mode only says what the climate variable you are looking at would be in a +2°C world. To complete table 2 for a +1.5°C, +3°C, and +4°C world you need to change the map itself. To do this select the variable you are interested in from the “Variables” menu and then open the “Value and Period” menu. Select either a +1.5°, +3°, or 4°C warming from the first column in the menu. Then repeat what you did in the first part of this activity for the degree of warming you just selected. Record this information in the appropriate column in table 2.

Activity D: “Improving the odds”

By default the interactive atlas shows climate impacts between now and the year 2100 assuming an emissions scenario dubbed SSP5 8.5. An emissions scenario is a set of assumptions used to construct a climate model that is based on the amount of greenhouse gases being emitted into and removed from (sequestration) the atmosphere by human activity. An SSP5 8.5 scenario is one in which fossil fuel extraction and use continues to expand and little if anything is done to sequester the GHGs being emitted.

At the opposite end of the spectrum is the SSP1 1.9 scenario. This is IPCC’s most optimistic scenario where global CO₂ emissions are cut to net zero by 2050. To accomplish this societies switch to low / no carbon energy sources, increase energy and resource efficiency significantly, and improve forestry and agricultural with an emphasis on sequestering rather than emitting carbon. Because this is regarded as an extremely optimistic scenario, it has not been included in the

Atlas. Instead it begins with SSP1-2.6, a less ambitious, and thereby plausible scenario.

The control for which emissions scenario you are looking at is found in the middle column of the “Value & Period” menu. That list actually begins with a slightly less ambitious proposal (SSP1 2.6). In this scenario GHG emissions are cut severely but not as fast, net zero being achieved after 2050. Also like SSP1 1.9, there is the same emphasis on low / no carbon energy sources, energy and resource efficiency, and sequestration via improved forestry and agricultural practices.



Figure 10
– Value & Period menu

The items in the red box are options for emission scenarios.

The items in the yellow box are the periods that the climate impacts are shown for based on the selected emissions scenario.

The first column in the menu (outlined in yellow in Figure 10) is the period of observation given the selected emissions scenario. For instance, if we wanted to get a sense of what the year 2050 might look like under a high emissions scenario

you would want to select SSP5 8.5 from the center column and “Medium Term (2041 to 2060) from the first.

Begin this activity using the same place you selected in the previous activity. Now using both the “Variable” and “Value & Period” menus complete the following table (table 3) for that place.

Table 3: Climate impacts for a selected place under both low and high emissions scenarios. Short term is 2021 to 2040. Long term is 2041 to 2060.

Climate impact
Mean temperature change – Median (°C)
Change in minimum temperature – Median (°C)
Change in maximum temperature – Median (°C)
Change in days with max temp > 40°C – Median (days)
Change in number of frost days – Median (days)
Total precipitation change – Median (%)
Change in max 5 day precipitation amounts – Median (%)
Consecutive dry days – Media (days)
Change in snowfall – Median (mm/day)
Surface wind change – Median (%)
Sea surface temperature change – Median (°C)
Ocean acidity – Change in surface pH – Median (pH)

16: Assessing Change with the Climate Impact Map

Key questions of this investigation

- *What is normal temperature for your area based on current averages?*
- *How might the temperature of your area change in the next 20, 30, and 70 years?*
- *How might different development scenarios impact the rate of this change?*

Tool used for this investigation

- *Climate Impact Map* – Impact Lab < <http://www.impactlab.org/map> >

Background

The Climate Impact Map is an online interactive map showing potential changes in regional temperature through the year 2100. The viewer shows forecasted temperature based on different development scenarios. It displays both temperature and change in temperature from historical average for

individual states within the United States and entire countries outside the US. The time periods displayed included historical averages (1981-2010), the next 20 years (2020-2039), mid-century (2040-2059), and the end of the century (2080-2099). You control the development scenario, hence the degree of temperature change, by selecting the potential greenhouse gas concentration for each time period.

Investigation

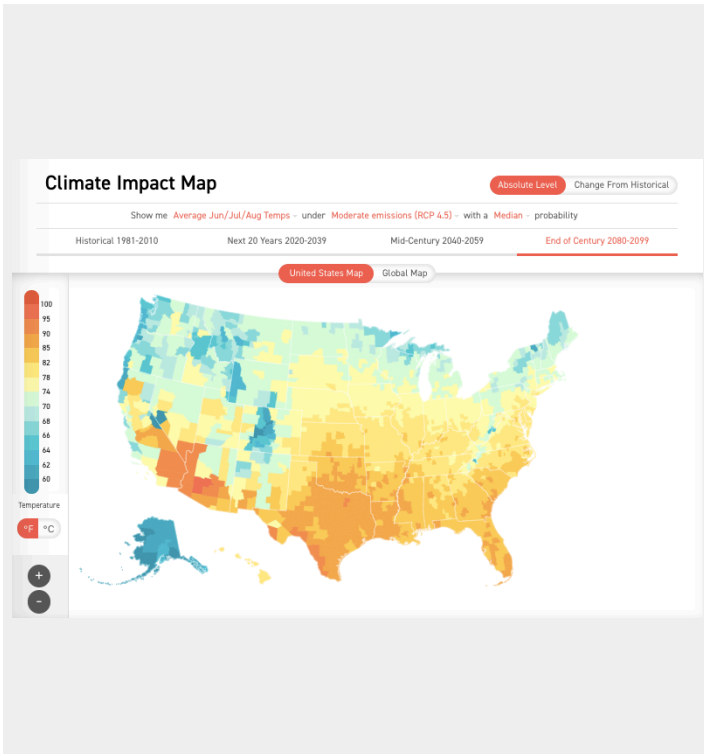
Activity A – Determining what’s normal for your area

Launch the *Climate Impact Map* <<http://www.impactlab.org/map>>. The map that appears when you do this will show the historical average summer temperature by county for each state in United States. Historical average is defined as the period 1981-2010 and summer is defined as June, July, and August.

A color scale to the left of the map can be used to estimate the temperature in either °F or °C. Clicking on the state of interest displays the average for the entire state.

Figure 1

Default screen for the climate impact map. Most of the controls for the viewer are in the banner at the top of the map.



To begin looking at what is normal for your area make sure that “Historical 1981-2010”, and “United States Map” are highlighted in red. Also click on “Average June/Jul/Aug Temps” to access a pull-down menu and select “Average Annual Temps” from that list. When you are finished the banner across the top of the map should look like this...

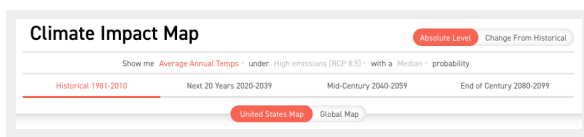


Figure 2 – Banner settings to start activity
A. Where you should be to address question 1.

Current climate – Questions

1. What is average annual temperature (in both °F and °C) of the state you are in? Click on the state to find this. Use the controller under the color bar to the left of the map to switch between °F and °C.
2. What is the average summer temperature of the state? To find this click on “Average Annual Temps” and select “Average Jun/Jul/Aug Temps” from the pull down menu that appears (the “Show me” menu).
3. What is the average winter temperature of the state? Select “Average Dec/Jan/Feb Temps” from the “Show me” menu.
4. What is the average number of days where average daily temperature is below freezing? For this select “# Days < 32°F / 0°C”.
5. What is the average number of days rated as extreme heat events? For this select “# Days > 95°F / 35°C”.

ActivityB – Projected temperature change

For this activity reset the viewer to display the average annual temperature for 1981-2010. In other words, reset everything so

the control banner looks like figure 2. To begin looking at forecasted temperatures select one of the other time periods in the banner such as “Next 20 Years 2020-2039”. You will be using this facet of the viewer to investigate the following question.

Projected changes – Questions

1. *What is the average annual temperature of your state during 2020-2039, 2040-2059, and 2080-2099?*
 2. *What is the average summer temperature in each period?*
 3. *What is the average winter temperature in each period?*
 4. *How much did the annual, summer, and winter temperatures increase in each period? The increase being the difference between the period temperatures and the average for the historical period.*
 5. *What is the number of days of temperature below freezing for each period?*
 6. *What is the number of days rated as extreme heat events for each period?*
 7. *How might the number of freezing days and extreme heat events change in each period relative to 1981-2010? Make sure to use numbers to back up your conclusions.*
-

ActivityC – Impact of projected temperature change

In this final activity you will be examining how what we collectively choose to do could impact future temperatures. To begin again reset the viewer to display average annual temperature for 1981-2010 (figure 2). This time note the phrase “High Emissions (RCP 8.5)”. RCP stands for Representative Concentration Pathway 8.5. This is a term used by the

Intergovernmental Panel on Climate Change (IPCC) to describe a world in which there are high concentrations of greenhouse gasses (largely CO₂) brought on by expanded use of fossil fuels with little or no carbon mitigation, continued deforestation, and other human activities releasing large quantities of GHGs into the atmosphere. By default this is the pathway that appears in the viewer because this is the pathway we have historically been on. It is also grayed out, meaning it is an inactive control as long as we are looking at historical data.

To change the RCP select one of the other time periods (e.g. 2020-2039). When you do this RCP 8.5 will be highlighted in red. Click on it and you will see a pull-down menu (the under menu) with two other options – “Low emissions (RCP 2.6)” and “Moderate emissions (RCP 8.5)”. The RCP 2.6 scenario is one in which net carbon emissions from global human society has been reduced to zero by switching to a strong dependence on renewable energy sources, reduction of per capita resource consumption, and large-scale carbon sequestration. RCP 4.5 is essentially a midpoint between the low and high emission scenarios in which dependence on fossil fuels has been decreased but not eliminated and there is a modest movement toward reducing per capita resource consumption and carbon sequestration.

The impact of RCP on climate – Questions

1. *What is the average annual, winter, and spring temperatures of your state at the end of the century under the low, moderate, and high emission scenarios?*
2. *How much might each of these averages change under each scenario? To answer this question, you are comparing historical averages to the end of the century.*
3. *How do these scenarios compare in terms of changes in the number of freezing days and extreme heat events between 1981-2010 and the end of the century?*

17: Sea Level and Coastal Flooding

Key questions for this investigation

- What are the impacts of probable changes in global sea level?
- What factors determine the severity of those impacts?
- What are the implications of these impacts for future urban development?

Tool used for this investigation

Surging Seas Risk Finder – Climate Central <
<https://riskfinder.climatecentral.org/>>

Background

Determining how much sea level rises or falls along coastlines is complicated by the fact that the sea surface continually fluctuates. For instance, waves and tides produce cyclic changes in the surface that vary over a period of seconds to hours. Strong storms, rapid runoff from coastal streams, and earthquakes generate localized, one time increases in sea level like storm surges, coastal flooding, and tsunamis. Finally, over

a much larger and longer span, changes in the volume of the oceans result in global changes in sea level.

It is the latter that is of interest to any discussion about climate change impacts. During the past few millennia changes in global sea level were largely a product of thermal expansion of seawater and changes in planetary ice cover. The idea of thermal expansion of sea water is simply that water increases in volume as it warms. Modeling of sea level change over the past two centuries indicates that this expansion has been a major contributor to the observed rise in sea level. Though a lesser factor, diminishing ice cover is still significant since shrinking land ice (glaciers and ice caps) contributes additional water to the oceans.

A significant risk of likely global sea level rise is that around 10% of the world's population live in coastal areas are less than 10 m above sea level, with an additional 30% living within 100 km of the coast. Furthermore, with nearly 10% of the world's cities being located on or near coastlines the issue of rapidly rising sea level poses a number of major development issues. Each community faces a complex mix of specific issues related to their natural setting, size, and population character. These activities are designed to look at these factors.

Investigation

Activity A – Sea Level rise impact on a Coastal City

Launch the *Risk Finder* from your web browser <

<https://riskfinder.climatecentral.org/> >. Once it appears, type Seaside Oregon into the search bar in the search bar in the center of the screen. What you will see should look like Figure 1.

Seaside and sea level rise – Questions

1. *How would you describe the landscape of Seaside? Pay particular attention to elevation, the presence and size of areas that are flat or mountainous, where beaches, streams, and bays are.*
2. *Find the water level indicator on the left side of the frame. Set it for 3 ft. What does this mean? To help with this question click on the question mark in the label at the top of the scale.*
3. *Thinking of water level as projected sea level rise, which areas are affected by this rise? What physical factors determine which areas are affected?*
4. *For a sea level rise of 3 ft how many people now live in areas that would be chronically flooded by that rise?*
5. *For a 3 ft rise what is the probability of at least one flood exceeding this value taking place during the next 30 years (2020 to 2050)?*
6. *Answer questions 4 and 5 for water levels of 5 and 10 feet.*



Figure 1 – The Risk Finder information page that appears when you select a location. This page is for Seaside Oregon, a coastal city on the Northwest Oregon Coast.



Figure 2 – Full-Feature map for Seaside Oregon. Other locations can be selected by typing them in the search window in the upper right corner of the screen.

Click on the label “Full-Feature Map” in the upper right corner of the map near the top of the page. Doing this should open a map in a new tab in your browser that looks like Figure 2. Once you have accessed this map, set the water level indicator to 3 ft and then click on “Legend” in the display bar at the bottom of the map.

7. Where are the areas that are below water level and where are the areas that are below water level but isolated? Which of these areas are not affected by rising and falling tides?
8. What happens to these areas at 5 and 10 ft rises?

Reset the water level indicator to 4 and select “Social vulnerability” from the display indicator.

9. *Where do you find the highest and the lowest vulnerability in Seaside?*
 10. *What do you think determines vulnerability? Hint – look at the other options in the display bar.*
-

Activity B – Comparison of two coastal cities

Return to summary page for Seaside and type “Miami, Florida, USA” into the search bar. When the page appears set the water level indicator should default to 3 ft, if it does not set it to that level.

Comparing Seaside,OR to Miami FL – Questions

1. *What is the landscape of Miami like? How does this compare to that of Seaside?*
2. *What areas in Miami would be affected by a 3 ft rise in sea level?*
3. *What areas would be affected by 5 and 10 ft rises in sea level?*
4. *How does the proportion of Miami impacted by a 5 and 10 ft rise in sea level compare to the proportion of Seaside that would be impacted by same rises?*
5. *For a 3 ft rise in sea level what is the probability of a flood over 3 ft taking place during the next 30 years? How does this compare to the same probability for Seaside?*
6. *What makes for the differences you observed between*

Seaside and Miami?

For this next part select the full-feature map for Miami and reset the water level indicator to 3 ft.

7. *Select legend from the display options bar. Where are the areas that are below water level vs. the areas that are below water level but isolated?*
 8. *What do you estimate the ratio of below water level to below isolated areas to be? How does this compare to the same ratio for Seaside?*
 9. *What happens to these areas with 5 and 10 ft rises?*
 10. *Reset the water level indicator to 3 ft and select social vulnerability. Where are the most vulnerable and the least vulnerable populations?*
 11. *How does population density, income, ethnicity, and property values determine social vulnerability?*
 12. *How do these factors for Miami compare to that of Seaside?*
 13. *Which of the two cities would seem to be the most impacted by sea level rises of 5 and 10 ft and why?*
-

Activity C – Sea level rise impact on an inland city

For this part of the activity, select Portland, Oregon. Portland is an inland city which would seem to be immune to the rising sea level. The goal of this activity is to see if this assumption

is accurate. Once you have arrived at the summary page for Portland set the water level indicator to 3 ft.

Portland and sea level rise – Questions

1. *What is the landscape of Portland like?*
 2. *Referring to the map on the right where are the areas likely affected by a 3 ft rise in sea level?*
 3. *What additional areas would be impacted with 5 and 10 ft rise in sea level?*
 4. *Given a 3 ft rise in sea level what is the probability of at least one flood over 3 ft taking place in the next 30 years?*
 5. *For the next questions select the full-feature map and set the water level indicator for 3 ft.*
 6. *Which areas are below water level vs. which are below water level but isolated?*
 7. *What happens to these areas with a 5 and 10 ft sea level rise?*
-

Activity D – Synthesis

Questions

1. *Rank Seaside, Miami, and Portland in terms of their vulnerability to rising sea level.*
2. *What are the physical and social factors you used to make your ranking?*
3. *Which of these factors were most significant for each of the cities?*
4. *For each of the three cities propose at least two specific strategies that they could develop that would help them*

adapt to 9 ft rise in sea level deemed probable under the Business as Usual scenario outlined by the IPCC in one of their recent climate assessments.

18: Climate and Energy Infrastructure

Key questions for this investigation

- What are the principal climatic conditions threatening the US energy infrastructure?
- How are these conditions threatening this infrastructure?

Tools used in this investigation

- *Energy Sector's Vulnerability to Climatic Conditions* – US Department of Energy < <https://www.energy.gov/articles/actonclimate-its-earth-week-energygov> >
- *Energy Flowcharts* – Lawrence Livermore National Laboratory < <https://flowcharts.llnl.gov/commodities/energy> >

Background

In 2018 the US economy consumed over 100 quads of energy. A quad is equal to 29 trillion kilowatt-hours (kWh), where a kWh is roughly equivalent to the amount of energy required to operate your average toaster for one hour continuously. Of this 29 trillion kWh, 80% was supplied by burning fossil fuels, 8% by nuclear fission, and the remaining 12% were derived from a constellation of renewable resources (Figure 1).

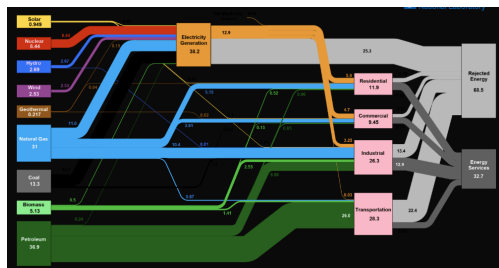


Figure 1 – A flowchart of 2018 US Energy Consumption and Production developed by the Lawrence Livermore National Laboratories
https://flowcharts.llnl.gov/content/assets/images/charts/Energy/Energy_2018_United-States.png.

As discussed in other parts of this manual, global society's reliance on fossil fuels is a key factor in changing climate. One of the ironies of this dependence is that the climatic changes wrought by the use of these fuels threatens the structures used to produce and deliver energy derived from those and other resources. The infographic you will be using in these activities looks at key elements of the United States energy infrastructure that have been affected by extreme weather events, sea level rise, and other climatic stressors during the 21st century. This graphic was developed in 2013 by the US Department of Energy to summarize their report on this topic.

As shown in figure 2, the report lists five climatic conditions that pose some type of threat to the U. S. Energy Infrastructure. These conditions include the following...

- Increasing temperature – Included in this are rising air and

water temperatures, increase in the frequency, duration, and intensity of extreme heat events, and melting permafrost.

- Decreasing water availability – Though it is generally agreed that a warming world will be a wetter one, this is not a consistent trend. While some areas see increased precipitation, others see longer and more intense drought.
- Increasing storms and flooding – With a warmer world comes additional heat energy fueling stronger storms. With these comes increased, high intensity precipitation resulting in increased flooding.
- Sea level change – Unlike flooding associated with heavy precipitation, sea level change results in flooding that can take place during clear as well as stormy weather. Furthermore, violent storms such as hurricanes often produce storm surges that augment high tides and heavy precipitation.

Investigation

Activity A – Investigating energy infrastructure and impact

Begin this activity by accessing the infographic *The Energy Sector's Vulnerabilities to Climatic Conditions* <

<https://www.energy.gov/articles/actonclimate-its-earth-week-energygov> >. This graphic (figure 2) appears on a US

Department of Energy web page having the same title.

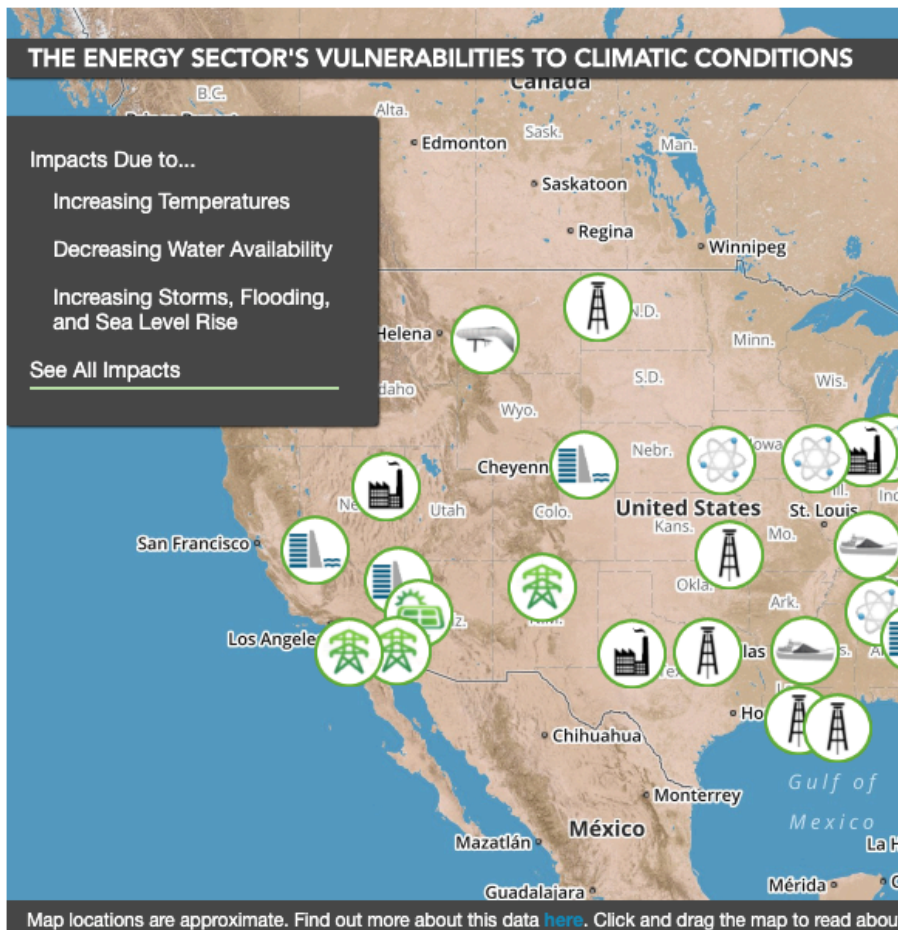


Figure 2 – The default appearance of for the infographic described above

Each of the icons represents a particular element in the national energy system that is vulnerable to damage by extreme weather events or changes in sea level. The list of climatic conditions is a control panel enabling you to filter elements by the climatic conditions that affect them.

US Infrastructure and Climate – Questions

1. What are the principle types of energy infrastructure shown on the map? List and describe the types shown.
2. What climate impacts are shown on the map? To answer this click on the three climate impacts in the upper-left panel to see which energy infrastructure facilities are affected by each. To record this use an entire sheet of paper to make a table that will summarize the climate change impact on each infrastructure type.
3. How does each impact affect each type of infrastructure? To answer this, click on each climate change condition, read through the bubbles for each infrastructure type, and summarize how the climatic conditions impact each infrastructure type.

Activity B – Filling in the gaps

The infographic used in these activities only shows impacted infrastructure in the continental United States. Alaska has not been included. However, it too contains energy infrastructure that is vulnerable to changing climate conditions. Answer the

following questions, given the energy flow chart showing energy production and consumption in Alaska (figure 3) and what you concluded in activity A.

Alaska Infrastructure and Climate – Questions

1. *Based on figure 3 what types of energy infrastructure would you expect to find in Alaska?*
2. *What parts of Alaska would be affected by each of the climatic conditions listed in the control panel on the map? You may wish to consult the fourth National Climate Assessment chapter on Alaska:
<<https://science2017.globalchange.gov/chapter/11/>>*
3. *How would the infrastructure you listed in question 3 of this activity be impacted by conditions you listed in question 2?*

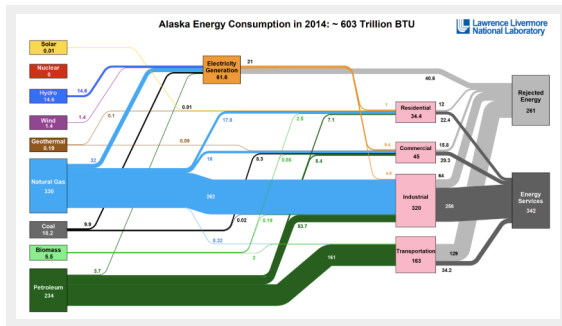


Figure 3 – Energy consumption and production flowchart for Alaska (2014).

The resources used to provide energy are shown on the left side of the graph. Note energy export is not clearly shown in the flowchart and Alaska is a major fossil fuel exporter.

https://flowcharts.llnl.gov/content/assets/images/charts/Energy/Energy_2014_United-States_AK.png

19: Climate and Streamflow

Key questions for this investigation

- How does streamflow vary during the year?
- What factors determine how it varies?
- What impact does increasing regional temperature have on streamflow?

Tool used for this investigation

- *Future Streamflow Tool* <<https://climatetoolbox.org/tool/Future-Streamflows>> from the *Climate Toolbox* – Applied Climate Science Lab at University of Idaho <<https://climatetoolbox.org/>>

Background

One of the resources impacted by current climate changes is water. In particular, streams and their watersheds will likely change dramatically as regional climate (largely precipitation and temperature) changes in predicted ways. This activity is designed to help you investigate what those impacts might be

for selected watershed. To prepare you to do this here are some key concepts.

Watershed – A defined area that acts like a funnel to capture precipitation and direct it downhill into the ocean or a landlocked lake. Watersheds consist of their upper reaches; there rain or snowmelt drains into small streams that then merge to form even larger streams before joining in the lower reaches to form rivers that course over the floor of a central valley.

Stream gauge station – A measuring station located on a strategic location on a stream to determine stream velocity and discharge (the amount of water passing through the stream at that spot over a given time period).

Hydrograph – A graph showing discharge as a function of time. In the following activities you'll be looking at graphs showing monthly discharge averaged over multiple years. The graphs will do this both for historical records and for currently projected climate changes.

Water resources – Water from streams and aquifers (underground water) available for irrigation, manufacturing, and consumption. One of the tricks about managing water resources is providing for these needs while ensuring that enough water remains in a watershed to provide for the needs of its natural inhabitants (e.g. plants and animals).

Investigation

Activity A – Historic and projected streamflow for the Willamette River

Launch the *Future Streamflows Tool* in your web browser <<https://climatetoolbox.org/tool/Future-Streamflows>>. When the page loads it will ask you if you want to take a tour of the tool or go right to it. To simplify this activity, select “Go to the Tool”. What you see should look like figure 1.

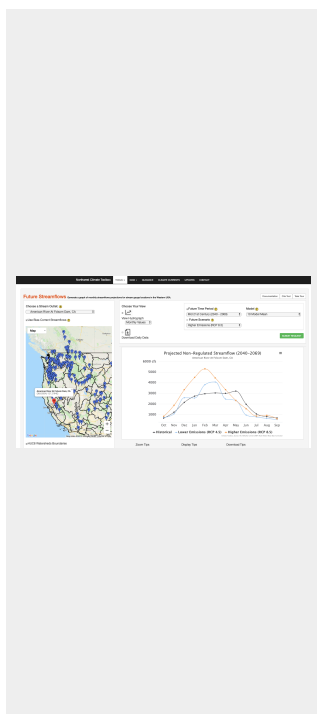


Figure 1

Default screen for the Future Streamflows tool.

The map defaults to historical and projected annual streamflow for the American River at Folsom Dam.

Begin by selecting a gauging station on the Willamette River in Portland Oregon. To do this click on the pull-down menu above the map on the left side of the screen. From the list select the “Willamette River at T.W. Sullivan, OR” and click on the green “Submit Request” button.

Having done this turn your attention to the graph of

streamflow on the right side of the frame. The vertical axis of the graph is in cubic feet per second (cfs), while the horizontal axis is month. The graph is showing historic long-term average monthly streamflow (the black line) and projected monthly streamflow for the early, middle, and late 21st century. It is showing the latter for both low and high emissions scenario.

Historical average flow – Questions

1. *In which month is streamflow highest for the year? What is it in cfs?*
2. *In which month is it lowest? What is the average flow for the month?*
3. *During what seasons is stream flow decreasing, when it is increasing?*

Now focus on projected changes in streamflow. To do this set the future time period to the late 21st century (2070-2099). This can be done using the pull-down menu above the graph that has this same title.

Changes in flow – Questions

4. *Answer questions 1-3 for both the RCP 4.5 and 8.5 scenarios?*
5. *Is there any change in the timing of the highest and lowest flow months?*
6. *For each projection what is the difference between the projected highs and lows and the historic high and low flows?*

Activity B – Historic and projected streamflow for the Skagit River

For this part of the activity switch the gauging station to the Skagit River at Ross, WA. Make sure that the future time period is set for the late 21st century and then click on the green “Submit Request” button.

Questions

1. *For the historic averages which month has the highest flow? Which month has the lowest flow? What is the average flow during each month?*
2. *When is there a second lower peak in the curve that is lower than the one you identified in question 1? What is the average flow during that month?*
3. *When is there a second low that is higher than the one you identified in question 1? What is the average flow during that month?*
4. *Looking at the two peaks in historical average curve, is there any change in timing in either the RCP 4.5 or 8.5 curves?*
5. *What is the difference between each of the peaks in historical curve and the two projected curves in cfs?*
6. *Are there any differences in timing between lows in the historical curve and the two projected curves?*
7. *What are the differences between these lows in cfs?*

Activity C – Comparison of change in two watersheds

For this last part you will look at the timing and % percent change in average monthly streamflow for both of the watersheds you just examined. Select the Willamette River at

T.W. Sullivan Oregon from the stream outlet menu. Then select the late 21st century as the Future Time Period and click on “Submit Request”. The graph you get when you do this should look like figure 2.

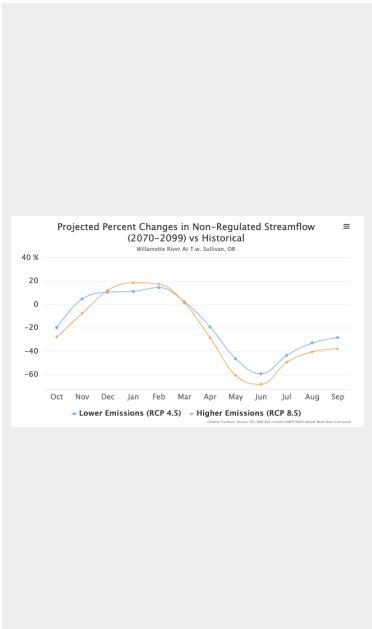


Figure 2

Graph of projected change in average monthly streamflow for the Willamette Valley gauging station at T.w. Sullivan, Oregon.

Comparing watersheds – Questions

1. Which months showed the largest decrease? How much less is it for each projection? For each of the two projections which month shows the largest increase in streamflow? How much larger is it?
2. Are there any months that showed little or no decrease?

Now switch over the Skagit River at Ross Lake WA and answer questions 1 and 2 for this station. For record keeping purposes record your answers as 3 and 4

Activity D – Synthesis / Reflection

Here is some additional background to help with this synthesis.

Willamette Valley:

Bounded on the east by the Cascade Range and to the east by the Coast Range, the Willamette River flows north through a broad valley before merging with the Columbia River. It drains more than 29,784 sq km (11,500 sq mi) and descends from elevations of up to 10,000 feet down to nearly sea level. The temperate climate and low elevation of much of the watershed means that summers tend to be hot, dry, and generally cloudless, while the winters tend to be cool and wet. While the surrounding mountains can receive significant snowfall during the winter, much of these highlands tend to be snow free by late spring or mid-summer. The exception to this is the High Cascade region which has a number of large volcanic peaks that rise to as much as 3350 m (11,000 ft). Many of these have glaciers and perennial snowfields where ice survives throughout the year, though with rising regional temperatures the volume of this ice has been decreasing significantly over the past two centuries.

Skagit River Valley:

The Skagit River watershed is located in the North Cascades of northern Washington State and southern British Columbia. It drains an area of nearly 6900 sq km (2664 sq mi). Unlike the Willamette Valley, the Skagit Valley is a narrow, deep trough carved into heavily glaciated, mountainous terrain. The seasons in the lower parts of the watershed tend to be similar to that of the Willamette Valley, with hot, dry summers and cool, rainy winters. However, the higher parts of the watershed tend to be much colder and snowier. This means that a higher percentage of the watershed remains covered with glaciers and snow for much of the year. Consequently, melting snow and ice supply

water to area streams throughout the summer. However, like the Cascade Mountains the percentage of the highlands covered in ice has diminished rapidly in response to warmer winters and hotter drier summers.

Consider this background as you answer the following questions.

1. *Why do the Willamette and Skagit Rivers have the peak flows when they do during the year?*
2. *Why does the timing and magnitude of the two peak flows for the Skagit at the end of the 21st century shift like they do under both emission scenarios (RCP 4.5 and 8.5)?*
3. *What is the implication of the changes in winter streamflow for future flooding in the lower reaches of the valleys?*
4. *How might changes in winter streamflow affect the frequency and magnitude of landslides along the valley walls?*
5. *What is the implication of the changes in summer streamflow for agriculture in the Willamette and Skagit Valleys?*

20: Shifting Biomes

Key questions for this investigation

- How does rising global temperature impact the distribution of biomes on land?
- What factors are driving these changes?
- What are the implications of these changes on the plants and animals in the biomes?

Tool used for this investigation

- The *Environmental Change Model* <<https://climatereanalyzer.org/clim/ecm/>> in *Climate Reanalyzer* from the Climate Change Institute at the University of Maine <<https://climatereanalyzer.org/>>

Background

A Biome is a community of plants and animals inhabiting a region defined by climate and dominant vegetation. For instance, a tropical rain forest is defined as an area having rapid tree growth and high species diversity made possible by high year-round temperature and high annual rainfall. Biome Viewer, a tool used in an earlier activity, uses a largely biological scheme for classifying biome. The Environmental Change Model (ECM) in Climate Reanalyzer, on the other hand, uses a hybrid classification scheme for planetary biomes, so it defines

the climatic characteristics of each biome more precisely than Biome Viewer does. ECM also breaks the earth's biomes down into more categories than the viewer does. For instance, ECM defines a tropical rainforest as a region where the average monthly temperature is 21°C or above year-round.

A major concern about present changes in global climate is the extent to which changes in regional climate affect life in the planet's biomes. The concern here is not only about the scale of regional climate changes, but also how quickly those changes take place. As the climate of a biome changes its inhabitants must either adapt to the new conditions or migrate to areas where the new conditions are like what they are accustomed to. In the case of the latter, the ability of plants and animals to survive the transition depends on whether or not regional climates are changing slowly enough that these organisms can successfully migrate and that there are no geographic obstacles to their doing so. This is an issue not only for wildlife and forest management, but also for agriculture and public health. There is strong evidence that many international conflicts and human migrations are a result of crop failures and climate related dislocations.

Investigation

Activity A – Biomes of North America

Launch the Environmental Change Model. See the first page of this activity for web address for the model. When you do this, you should see a screen that looks like Figure 1. Next select the region you in which you live, from the drop-down menu labeled "Region". Then make sure that "Parameter" is set to

Potential Biomes, “Month” is annual, and “Global $\Delta T^{\circ}C$ ” is set to 0. For instance, if you select North America you should see something that looks like Figure 2

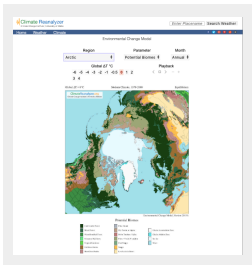


Figure 1

Default screen for the Environmental Change Model. The map here is showing biomes in the northern hemisphere from an arctic view.



Figure 2

The Environmental Change Model showing presents day biomes of North America. Information about the ECM and biomes is located further down on the page.

Biome Characteristics – Questions

1. *What biomes are present in the region you selected?*

With the ECM set up to show the region you live in, use the biome map and the information panels below the map to address the following questions.

2. *What are the primary characteristics of each biome?*
3. *Approximately where are these biomes?*
4. *Where do you currently live and in what biome is this*

place?

Activity B – Impact of rising global temperature on biomes

Begin this activity by switching the parameter to temperature.

Current temperatures – Questions

1. *What is the present range of the annual temperature on land in °C for your region? To find this make sure that Global ΔT °C is 0 and Month is set to annual.*
2. *Where on land is average annual temperature below freezing ($T < 0^\circ\text{C}$)? Where is annual temperature above 20°C ?*

With Parameter still set to temperature slowly shift Global ΔT °C from 0 to 4°C noting what happens to the temperature map as you do so.

Changes in temperature and precipitation – Questions

3. *At Global $\Delta T = +4^\circ\text{C}$ where on land is average annual temperature below freezing. Where is annual temperature above 20°C ?*
4. *As you move from $\Delta T = 0^\circ\text{C}$ to 4°C what happens to the areas where annual land temperatures are below freezing and those areas where it above 20°C ?*
5. *Now switch Parameter to precipitation and reset ΔT to 0°C . Make sure that Month is still set to annual.*
6. *What is the present range the precipitation on land in cm for the region you selected?*

7. *Where on land is it the driest and where is it the wettest? What is the value for precipitation at each place?*
8. *At Global $\Delta T = +4^{\circ}\text{C}$ where on land is it the driest? Where is it the wettest?*
9. *As you move from Global $\Delta T = 0^{\circ}\text{C}$ to $+4^{\circ}\text{C}$ what happens to these wet and dry areas?*

Finally switch Parameter to Potential Biomes and reset Global ΔT to 0°C . Make sure that Month is still set to annual.

Biome Changes – Questions

10. *What biomes appear in those areas where the average annual temperature is below 0°C ?*
 11. *What biomes appear in those areas where annual temperature is above 20°C ?*
 12. *What biomes appear where the land is the driest?*
 13. *What biomes appear where it is the wettest?*
 14. *As you move from Global $\Delta T = 0^{\circ}\text{C}$ to $+4^{\circ}\text{C}$ what happens to the biomes you listed in questions 9 through 12?*
-

Activity C – Synthesis

Synthesis questions

1. *What general statement can you make about the impact of rising global temperature and the distribution of biomes?*
2. *How does what you found out in questions 1 through 8 in activity B explain what you concluded in the previous question?*

3. *What is the implication of what you concluded in questions 3 and 4 of activity B on the extent of permafrost in upper Canada and Alaska?*

21: Climate and Agriculture

Key questions for this investigation

- *Where in the Pacific Northwest is it currently suitable to grow certain key crops?*
- *What determines crop suitability?*
- *How might this suitability be impacted by the rising regional temperatures forecasted by low and high emission scenarios?*

Tool used for this investigation

Future Crop Suitability Tool <https://climatetoolbox.org/tool/_Future-Crop-Suitability> from the *Climate Toolbox* – Applied Climate Science Lab at University of Idaho <<https://climatetoolbox.org/>>

Background

A critical human activity that is heavily impacted by changing climate is agriculture. Because what is grown in a region is determined by temperature and water availability, regional climate change alters what can and cannot be grown there.

One measure of an area's ability to sustain certain crops is thermal suitability. This metric is derived from the range of temperatures in an area, the coldest temperatures a crop can survive, and the amount of heat needed for it reach maturity. Another significant measure is irrigation demand. This is the annual unmet water requirements of a crop that must be provided by irrigation. Obviously, this demand increases whenever the climate of an area becomes warmer and/or drier.

Like Biomes¹ ranges migrate as regional climate changes. However, unlike the natural migration of biomes the introduction of crops into new areas requires human intervention to accomplish its purpose, which is to provide a growing human population with food. Two important questions come along with this intervention.

First, is there sufficient water available in the new areas into which crops are introduced? It is important to note that the projected suitability ranges shown in FCST are based on thermal suitability, not irrigation demand.

Second, are regional climate changes taking place slowly enough that the crops introduced into new areas can establish themselves, or will rapidly changing climate create a target that moves too quickly for farmers to adjust?

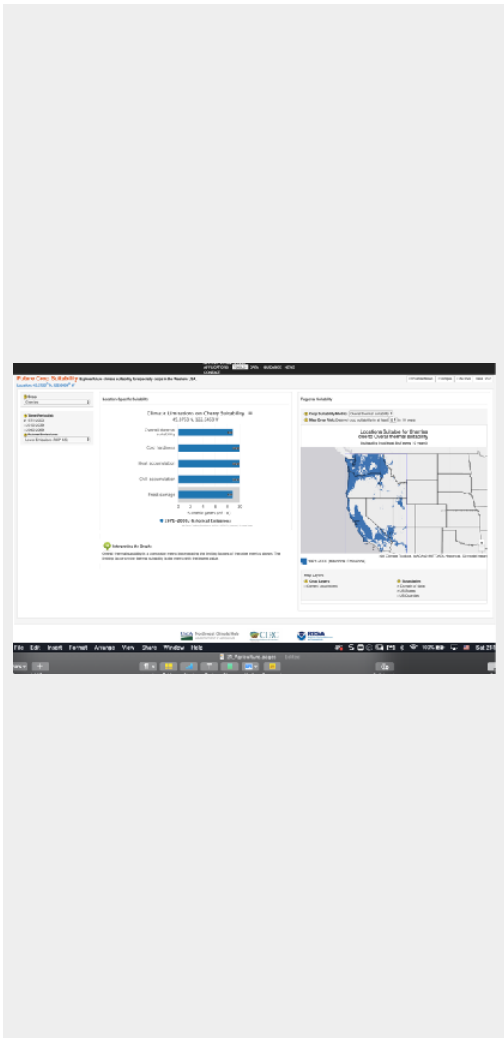
Investigation

Activity A – Present Crop Suitability Range

Launch the *Crop Suitability Tool* in your web browser <https://climatetoolbox.org/tool/_Future-Crop-Suitability>.

When you do this, you will get a dialog box that will ask you if you want to “Take a tour”, “See an example”, “Set location”, or “Go to tool”. Select the latter. What you will see when you do so should look like figure 1.

Figure 1 – The default screen for the Crop Suitability tool.



Crop type is selected from the pull down menu in the upper left the location of areas suitable for growing the crop are shown on the map on the right side of the screen, the time period of the suitability is selected from the pull down menu under the crop selector, and the middle bar chart shows location specific suitability.

Questions – Current crop suitability

1. What are crops listed in the crop selector menu?
2. Which tend to be southern crops (abundant in southern Oregon and Idaho)?
3. Which tend to be northern crops (abundant in northern Washington and Idaho)?

4. *How does the climate of the southern areas compare to that of the northern?*
 5. *Which tend to be coastal crops?*
 6. *Which tend to be inland crops?*
 7. *How does the climate of coastlines compare with that of the interior?*
-

Activity B – Changing climate and crop suitability in a low emission scenario

To begin this activity reload the Future Crop Sustainability Tool. By default, the selected crop will be almonds. Starting with this crop, answer the following questions.

Questions – Projected crop suitability (low emission scenario)

1. *During 1971-2000 where were the locations suitable for growing almonds?*
2. *Keeping future emissions at RCP 4.5 where might you find suitable locations for growing almonds during 2010-2039?*
3. *Again, with future emissions at RCP 4.5 where might you find suitable almond locations during 2040-2069?*
4. *Repeat questions 1 through 3 for the other crops in the list?*
5. *What seems to be the trend in the location and size of the range in which these crops can be grown in the late 21st century?*

Activity C – Changing climate and crop suitability in a high emission scenario

For this part of the activity begin by selecting almonds as the crop, set the time period to 1971-2000, and select RCP 8.5 from the future emissions menu.

Questions – Projected crop suitability (high emission scenario)

1. *For emissions of RCP 8.5 where might you find suitable locations for growing almonds during 2040-2069?*
2. *How does this compare to the suitability range for 2040-2069 under the RCP 4.5 scenario?*
3. *Repeat questions 1 and 2 for the other crops in the list.*
4. *Is the trend in the location and size of the range in which these crops can be grown in the late 21st century consistent between the two scenarios?*

Activity D – Synthesis

Questions – Synthesis

1. *What is happening in terms of climate zones for these suitability ranges to migrate as they do?*
2. *Using only suitability range, which crops would seem to do better in a low emission scenario?*
3. *Using only suitability range, which crops would seem to do better in a high emission scenario?*

4. *The Future Crop Suitability tool shows areas that are thermally suitable for raising selected crops. While the suitability range for any of these crops may expand under RCP 4.5 or RCP 8.5 it does not necessarily mean that these crops will expand into new areas. What other factors besides suitability based on temperature might determine whether these crops could be introduced into new areas?*

Footnotes

- ¹ Biome – A naturally community of plants and animals occupying a major habitat. E.g. a forest, grassland, or desert.

22: Climate Change on the Community Scale

Key questions for this investigation

- How changes in regional temperature and precipitation impact the hydrology and vegetation of a small coastal community?
- How do these changes impact the culture and economy of that community?

Tool used for this investigation

- *Tribal Climate Tool* < <https://climatetoolbox.org/tool/future-tribal-climate> > from the *Climate Toolbox* – Applied Climate Science Lab at University of Idaho < <https://climatetoolbox.org/> >

Background

Federally recognized tribal lands are rural communities that are highly dependent on the natural resources in and around them. As such they are good case studies of the impact of changing regional climate on local communities. The Tribal Climate Tool (TCT) forecasts changes in eight climate-related variables over the next century for both low and high emission

scenarios. These variables include annual and seasonal temperature, precipitation, snow-water equivalent, stream temperature and flow, vegetation, wild-fire risk, and changes in relative sea level.

Though TCT looks at nearly 80 reservations, colonies, and other tribal lands spread out over the western continental United States, we will only look at one, the Quinault Indian Nation. The reservation was established in 1855 and is located on the western shore of the Olympic Peninsula 72 km (45 mi) north of Hoquiam, Washington. Included below are some key statistics for the Quinault Nation that will be useful in the following activities.

- The reservation is 819,294 sq km (316,331 sq mi) of coastal land bordered by the Olympic National Park to east and the Pacific Ocean to west.
- Two major rivers, the Queets and Quinault flow westward across a forested coastal plain making up most of the reservation.
- The population of the reservation has during the 21st century has fluctuated from 1000 to 1500, with most members living in three settlements (Taholah, Moclips, and Queets).
- The economy of the reservation is based largely on tourism, timber, and fishing.

Investigation

Activity A – Temperature and precipitation

egin by launching the *Tribal Climate Tool* in your web browser

<<https://climatetoolbox.org/tool/future-tribal-climate>>. You will first be asked to select a tribe. Select “Quinault Indian Nation” from the drop-down menu that appears and click on “Go to Tool” button in dialogue box. Figure 1 shows the screen you should see after you do all this.

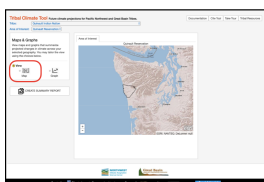


Figure 1

Default screen for the Tribal Climate Tool with the Quinault Tribal Lands selected. The center map display can be changed to a graph of climate variables by selecting graph in Maps and Graphs control panel to the left of the map.

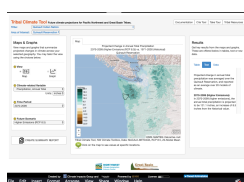


Figure 2

Frame showing projected change in annual total precipitation for the late 21st century in a high emission scenario.

Begin your investigation of this community by selecting the map option in the view menu in the left panel of the frame. This is circled in red in Figure 1. What you will see when you do so should look like figure 2. By default, you will see a map of projected change in annual total precipitation for 2070-2099

vs. 1971-2000 for Western Washington. The projected change is based on a high emission (RCP 8.5⁴) scenario. Using the “+” / “-” below the color scale, zoom in on the reservation. This area is on the central Washington coast and is outlined in black.

Questions – Current and projected temperature and precipitation

1. *How much of a change in annual total precipitation is the forecast for the late 21st century? Where in the reservation is the change the largest? To answer this question, click anywhere within the boundaries of the Quinault?*
2. *How does Apr-Sept precipitation in 2070-2099 compare to 1971-2000 for the high emission scenario? How does Oct-Mar 2070-2099 compare to the same season in 1971-2000? What is the magnitude of these changes? To address these questions, select “Precipitation, Mar-Oct Total” and “Precipitation, Apr-Sept Total” from the pull-down Climate-related variables menu.*
3. *Based on the high emission scenario how much does the average annual daily temperature of the Quinault change between the late 20th and late 21st centuries?*
4. *What is the change in the number of high heat days ($T > 30^{\circ}\text{C}$) by the end of this century?*
5. *What is the change in the number of freeze free days?*
6. *What general statement can you make about the relationship between changes in temperature and precipitation? Is this relationship consistent when you look at temperature and precipitation changes under the low emission scenario?*
7. *Given the basic characteristics of the Quinault lands found in the background of this activity set, what would be some key impacts of the temperature and precipitation changes on the people living on this land?*

Activity B – Streams and snow pack

Two variables closely tied to temperature and precipitation changes is peak stream temperature and seasonal flow. To investigate these variables, switch the “Future Scenario” back to higher emissions and then select “Stream Temperature, Aug Average” from the “Climate-related variable” menu.

Questions – Current and projected stream flow

1. *How much does peak average stream temperature change by the end of the 21st century? Note – Peak temperatures customarily occur in August.*
2. *How many stream gauges appear in the Quinault reservation? What streams are they on? To find this out select “Streamflow, Jul-Sept Minimum” from the “Climate-related variable” menu and then click on any of the dots that appear within the reservation boundaries.*
3. *For the Jul-Sept period, what is the percent decrease or increase in the flow at each station?*
4. *For the Jan-Dec period, what is the percent decrease or increase in the flows at each station?*
5. *What general statement can you make about late 21st century changes in stream temperature and seasonal flow under the high emission scenario? Does this relationship stay consistent when you look at stream temperature and flow changes in a low emission scenario?*
6. *What would be the impact of the forecasted stream temperature and flow changes on the fisheries of the Quinault? The tribe runs ocean going fisheries and a*

seafood canning operation, as well as a fish hatchery.

A climate variable included in the *Tribal Climate Toolkit* (TCT) is snow water equivalent (SWE). SWE is a measure of the amount of water stored as snow or glacier ice at key times of the year. In the case of TCT this is either April 1 or May 1. The importance of this to the Quinault area is that many of the streams passing through the reservation have their headwaters in the neighboring Olympic Mountains. These mountains receive considerable snowfall during the winter which remains in storage until late spring and summer when it melts and feeds surrounding streams. To investigate changes in this storage, switch the future scenario back to high emission.

Questions – Current and projected snow pack

7. *How does the late 21st century change in SWE within the reservation compare to that of the mountains the east? To investigate this question, select “Snow Water Equivalent, May 1st Average” from the climate-related variable menu.*
 8. *How would you explain the changes you saw in the previous question?*
 9. *How did the change in SWE and April-September precipitation explain the change in July-September stream flow?*
 10. *Under which emissions scenario does highland snow and ice provide a better buffer for reduced summer stream flow? In other words, in which scenario is there more late season water storage?*
-

Activity C – Vegetation and Fire

Two interrelated variables, that are highly dependent on changes in temperature and precipitation, are the vegetation composition and frequency of high fire danger days. The former is the mix of major vegetation making up the land. In TCT the mix forecasted for the late 21st century is dependent on the emission scenario and whether or not forest fires are actively suppressed (the traditional approach to US forest management) or left to burn in controlled circumstances. In TCT fire danger is represented as projected change in the number of days per year in which the danger was rated as either “very high” or “extreme”. These determinations are based on the amount of moisture in dead vegetation that is between 2 and 8 cm in diameter.

Begin investigating changes in vegetation by selecting “Vegetation Composition (with Fire Suppression)” from the climate related variable menu. When you do this, you should get a map that looks like [Figure 3](#).

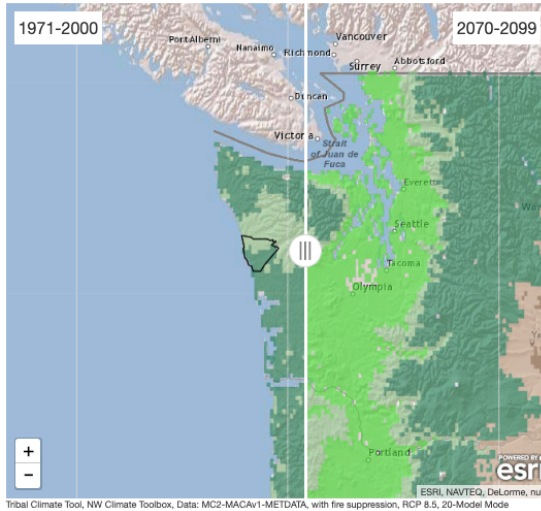


Figure 3

Map of vegetation composition in the Pacific Northwest. Left of the vertical line is the historical vegetation composition (1971-2000). Right of the vertical line is the 21st century projected composition under a specific emission scenario. The two maps can be slid left or right to compare the two scenarios. A function key is provided for making comparisons between the two scenarios.

Questions – Current and projected vegetation

1. What is the historical composition of the vegetation in the reservation?
2. What is the late 21st century composition of the vegetation given active fire suppression?
3. Assuming a high emissions scenario, does fire suppression have any impact on the late 21st century composition?
4. How does selecting a low emissions scenario impact the late 21st century composition of the reservation forest?
5. Which scenario would have the least impact on current logging operations? What is the rationale for your hypothesis? What additional information do you need to test your hypothesis?
6. Many native peoples still practice traditional foraging activities such as gathering berries, herbs, etc. What

relevance does what you concluded in questions 1-4 have to these activities?

To examine changes in fire danger, select “Very High Fire Danger Days Annual Total” from the climate-related variable menu.

Questions – Fire hazards

- 7. How does the projected change in the number of annual very high danger days under a high emissions scenario compare to the projected change under a low emissions scenario?*
- 8. What factors influence what you concluded in the preceding question?*
- 9. Given the problems associated with active fire suppression, increased use of controlled burning is being widely advocated by forestry experts. Given what you concluded in question 8, in which of the two emission scenarios would controlled burning need to be used more actively and why?*

Activity D – Synthesis

To synthesize what you’ve found out in the past three activities, make a table listing the climate-related variables you’ve looked at, the expected changes under the low and high emission scenarios and the cultural and economic activities of the tribe that will be impacted by these changes. In the final column of the table list one or two strategies that could use to adapt to these changes.

Final note:

An additional climate-variable to investigate and include in your synthesis table is sea level. This variable is important to consider largely because the two major settlements in the reservation are located at the mouth of two rivers that run through it. While rising sea level can be a problem for low lying communities in and of itself, it is also a factor that can exacerbate flooding from increased stream runoff and storm surges (bulges of water that develop under cyclonic storms). Furthermore, rising sea level increases the community's vulnerability from tsunamis, and since the Washington coast is an active earthquake zone, it is increasing a factor to be considered. Therefore, a final question to consider in your synthesis table, is, what the projected late 21st century sea level rise is under both high and low emission scenarios.

PART V

GOING FORWARD – MITIGATION, ADAPTATION, AND ACTION

23. Climate / Development Pathways

Key questions for this investigation

- What human activities influence the earth's carbon balance?
- What would it take to keep the 2100 increase in mean global temperature to below 2.0°C above preindustrial levels?

To investigate these questions you will be running three major development scenarios to determine how carbon emission and sequestration rates will likely impact average global temperature for the year 2100. You will also be examining the probable environmental impacts associated with projected temperature increases.

Tool used for this investigation

- C-ROADS < <https://croadsworldclimate.climateinteractive.org> > from Climate Interactive.

Background

C-ROADS is a major component of the World Climate Simulation (WCS) developed by Climate Interactive < www.climateinteractive.org >. WCS is a role-playing exercise for groups meant to acquaint students, community groups, and others with the purpose and mechanics of UN climate negotiations. In this process *C-ROADS* serves as a tool for analyzing the outcome of proposals put forth in mock negotiations.

Despite being designed to be a central component of the WCS, *C-ROADS* can be used separately from the negotiations exercise, as you will be doing in the following activities. In brief, the model enables you to set carbon emission and sequestration rates for global society or regions of it to see what impact these rates and their timing have over mean average global temperature until the end of the 21st century. The model also computes and displays the impact of these rates on sea level, ocean acidification, and greenhouse gas concentrations. The carbon emissions you set in the simulator are largely carbon dioxide related to energy production, while adjusting sequestration includes decreasing the destruction of forest lands (deforestation) and the replace of forested through planting (afforestation).

Investigation

Activity A: Business as usual scenario

Begin by launching *C-ROADS* in your web browser < www.climateinteractive.org >. Figure 1 shows what you will first see when *C-ROADS* has finished launching.

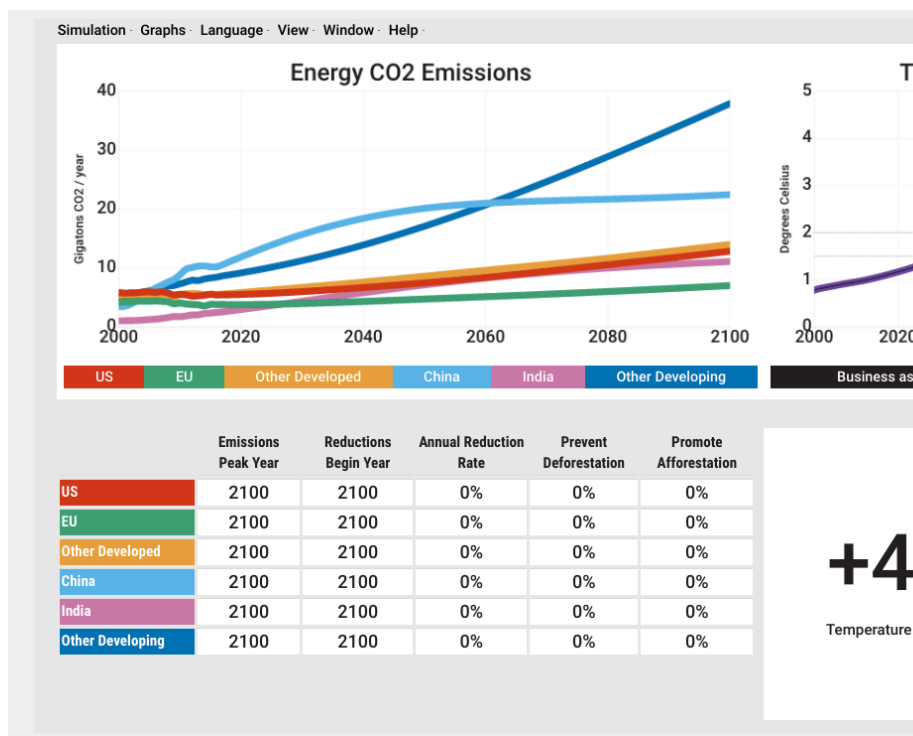


Figure 1 – The default screen for C-ROADS: Most of the controls for the simulation are located in the upper left corner of the screen. Additional controls include the controls on the right that control the timing and rate of emission reductions, deforestation, and afforestation. The graph on the left shows CO2 emissions per year from 2000 to 2100, and the graph on the right shows the increase in MGT (mean global temperature) for the same time period.

Note: C-ROADS does not work on browsers on mobile devices, so you need to use a laptop or a desktop computer to run it.

By default, C-ROADS begins with a “Business as usual” scenario or BAU. To understand what this means consider that approximately 85% of the energy consumed by global society comes from burning fossil fuels. Also consider that global fossil fuel consumption has risen from 29,138 Twh in 1950 to 113,845

Twth in 2017. Under the BAU scenario, fossil fuels remain as the world’s dominant energy source with production and consumption continuing to increase at a similar or even faster rate than they did between 1950 and 2017. The goal of this activity is to become familiar with C-Roads and examine the climate impact of continuing with along the BAU pathway.

To begin, select “Global” from the drop down “Simulation” menu in the upper left corner of the screen. Once you do this you will see the graph on left change so it looks like figure 2. The graph on the right should remain unchanged.

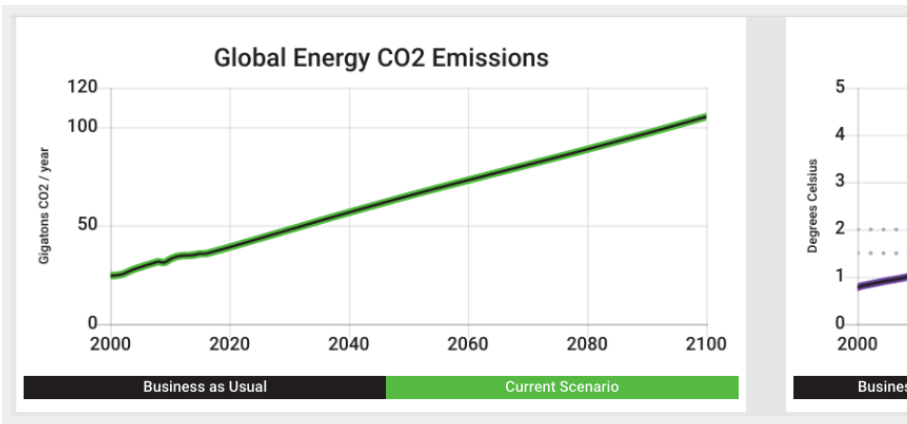


Figure 2: Projected Global CO2 emissions from burning fossil fuels (left graph) and the expected temperature increase above the pre-industrial average (right graph) from 2000 to 2100 under the Business as Usual scenario. Move the cursor over the green or purple plot lines to read values for emissions and temperature increase for specific years.

Questions – Business as Usual

1. What were the total emissions in the year 2000? What are they expected to be in 2020 and again in 2100?
2. What is the expected temperature increase in 2100?
3. What was the atmospheric CO2 concentration in 2000?

What is it expected to be in 2020 and again in 2100?

- *To answer this go to the “Graphs” menu in the upper right and select “CO2 concentration” from the menu that appears when you scroll over “Impacts”.*

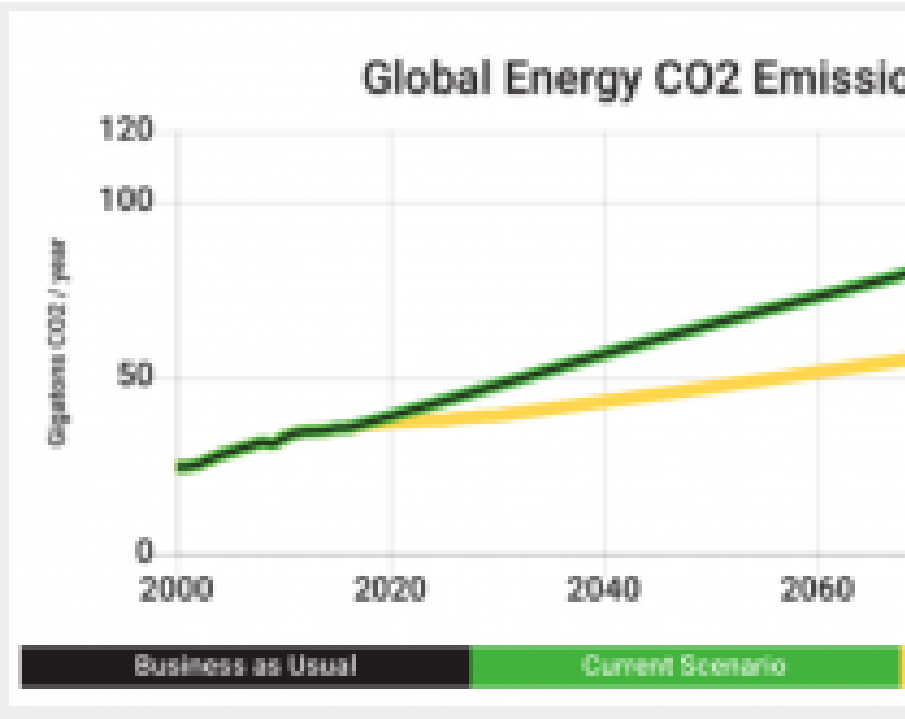
4. *What is the expected rise in sea level in 2020 and again in 2100?*

- *This is sea level rise relative to 2000. To find this go the “Graphs” menu and select “Sea level rise” from the menu that appears when you scroll over “Impacts”.*

Activity B: Paris commitment

The 2019 version of C-ROADS contained a preset scenario titled the “Paris Outcomes”. This scenario showed global temperature increase based on the carbon reduction and sequestration commitments that signatories to 2015 Paris climate agreement brought to that international conference (Nationally Determined Contributions or NDCs). For reasons explained on the [Climate Scoreboard: UN Climate Pledge Analysis](#) this scenario was deleted from the 2020 release of the program. While the developers reasons for making this change are understandable it makes it difficult to investigate the gap between NDCs and the agreed upon 2100 global temperature increase of 1.5 to 2.0°C. For that reason, figure 3 contains screenshots of global CO2 emissions and temperature increase from the 2019 version of C-Roads. To answer the

following questions you can use Figure 3 and the Climate Scoreboard.



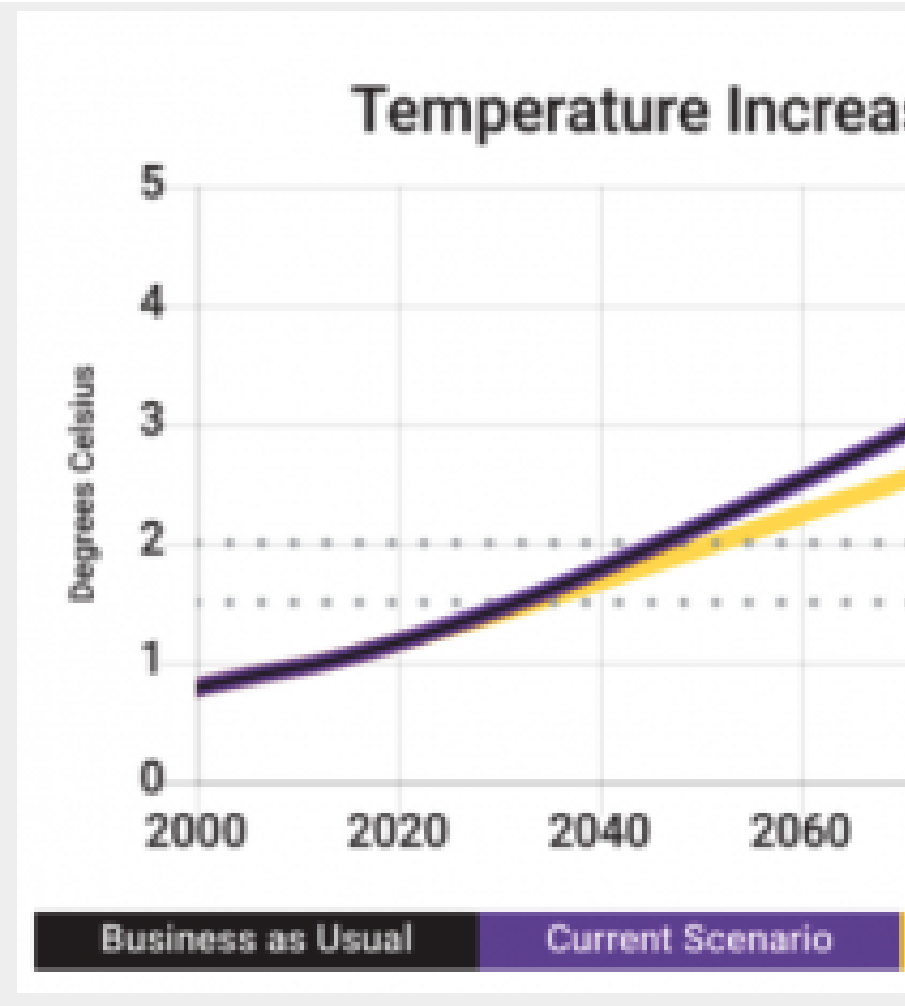


Figure 3: Projected Global CO2 emissions and temperature increase for b Outcomes (yellow line) scenarios. You may have to go to the “Graphs” me Increase” from the “Impacts” sub menu to change the right graph to sho

Questions – Paris 2015 Committments

1. *For the Paris Outcomes what are the expected emissions in 2100?*
2. *For the Paris Outcomes, what are the expected atmospheric CO₂ concentration, sea level, and ocean acidification in 2100?*
3. *How do all these values compare to the 2100 values from the BAU scenario?*
4. *How far above the temperature increase target set by the 2015 Paris climate agreement is the temperature increase resulting from the current reduction commitments?*

The two dotted lines on the temperature increase graph represent the long-term commitment made in the 2015 agreement.

Activity C: Accelerated commitments

For this last activity you are going to experiment with what it would take to keep the 2100 MGT to between 1.5°C and 2.0°C above the pre-industrial MGT. You will be doing this by adjusting the timing and rate of emission reductions, deforestation, and afforestation.

- Emission reductions – Decreasing greenhouse gas emissions from energy production, manufacturing, agriculture, and other technological activities.
- Deforestation – Clearing forest for lumber and the creation of land for agriculture and other development. In short removing trees that would otherwise sequester carbon.
- Afforestation – Replanting cleared land in forest to provide a mean of carbon sequestration.

To begin make sure that your graphs look like figure 3. This may require selecting “Global” and “Reset” from the “Simulation menu”, “Show Paris Outcomes” from the “View” menu, and “Temperature Increase” from the “Impacts” submenu of the “Graphs” menu.

Once your screen is set up, go to the table under the emissions graph (figure 4) and click on the 2100 in the “Emissions Peak Year box. Change that value to 2060.

	Emissions Peak Year	Reductions Begin Year	Annual Reduction Rate	Def
Global	2100	2100	0%	

Figure 4: Controller for the timing and rate of emission reductions, deformation

Questions – Accelerated commitment

1. What happens to the Global Energy CO₂ Emissions (the green line) and 2100 temperature increase (purple line) when you set the Emissions Peak Year to 2060? Make sure to use numbers when you answer this.
2. What happens to the 2100 global emissions and temperature increase when you also set the Reductions Begin Year for 2060 and the Annual Reduction Rate to 5%?
3. What would it take to create each of the following scenarios?
4. The Temperature increase never goes above 2.0°C.
5. The temperature increase never goes above 1.5°C.
6. The temperature increase goes above 2.0°C but falls to 1.5°C by 2100.

For each scenario record the Emissions Peak Year, Reductions Begin Year, the Annual Reduction Rate, Prevent Deforestation, and Promote Afforestation necessary to achieve the goal. Make a table for this.

Activity D: Mock Global Climate Summit

C-ROADS was designed by Climate Interactive as a part of the [World Climate Simulation](#), an activity where groups of people play the role of UN climate negotiators working to create an agreement limiting global climate change. The page describing the simulation also provides links to material supporting the simulation.

24: Climate / Energy Pathways 2100

Key questions for this investigation

- How might global society's energy production be changed to keep MGT increase to the Paris target of less than 2.0°C?
- How could energy efficiency be changed to meet this goal?
- How could carbon sequestration play a role in meeting this goal?

To investigate these questions you will design a pathway for achieving the 2015 Paris goal of keeping the increase in mean annual global temperature (MGT) to less than 2.0°C. To do so you will be using three tools, 1) a graph of world energy consumption and production, 2) a flowchart of global energy flow for 2011, and 3) an online energy / climate model.

Tools used in this investigation

- *Global primary energy consumption* <<https://ourworldindata.org/grapher/global-primary-energy>> from *Our World in Data* developed by University of Oxford
- *World Energy Flow* <https://flowcharts.llnl.gov/content/assets/images/charts/Energy/ENERGY_2011_World.png> from the *Energy Flow Charts* developed by Lawrence Livermore National Laboratory
- *EN-ROADS* < <https://en-roads.climateinteractive.org/>

[scenario.html?v=2.7.6](#) >from Climate Interactive.

Background

Many proposals for reducing global carbon emissions involve doing one or more of the following...

- Reducing carbon emissions from energy production.
- Increasing the efficiency of energy consumption to reduce the amount of energy that needs to be produced to do the work we require.
- Sequestration – Removing carbon from the atmosphere or removing it before it enters the atmosphere.

As a general rule of thumb, organizations like the Intergovernmental Panel on Climate Change and the Rocky Mountain Institute recommend that to achieve the Paris target we need to be pursuing all three efforts simultaneously. Of course, any strategy we propose in pursuing them comes with trade-offs. The trick in reducing global carbon emissions will be to select a mix of strategies that will create the most equitable, economical, and environmentally sustainable pathway possible.

You will be exploring these concepts by creating your own “blueprint” for energy production and consumption from now until 2100. To do this you’ll need to 1) determine how to create sizable increases in global energy efficiency, 2) select a mix of energy resources to produce lower carbon emissions, and 3) select strategies for sequestering CO₂.

Investigation

Activity A – History of global energy consumption and production

Begin this activity by launching the interactive graph of global primary energy consumption from *Our World in Data* <<https://ourworldindata.org/grapher/global-primary-energy>>.

Use this tool to determine the total energy consumed and the percentage of that energy provided by the sources listed in table 1 on the following page for selected years between 1800 and 2017. Record your results in Table 1. Then use your results to answer the questions following the table.

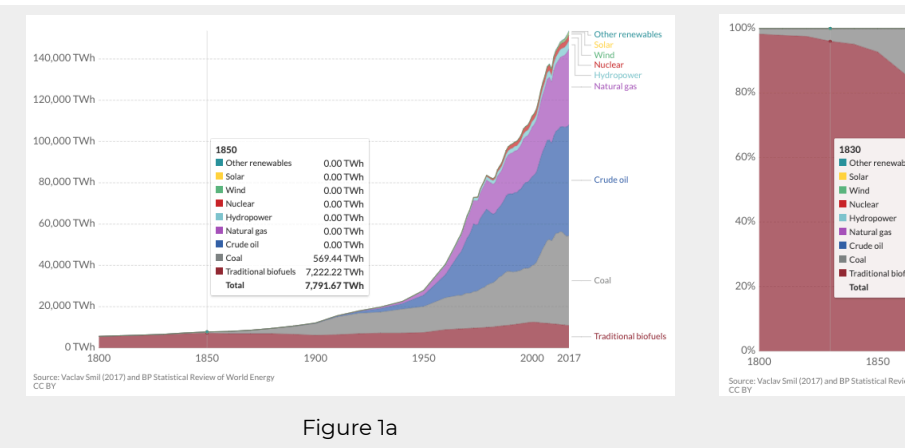


Figure 1a

Figure 1 – Global primary energy consumption in Terrawatt-hours between 1800 and 2017 (Figure 1a) and the percentage of total consumption provided by nine principal energy resources (Figure 1b). You can access the graph in 1b by checking on the “Relative” tab. The graph shown in 1a. In both figures an information panel showing energy consumption for selected years appears when you scroll over the graph.

A terawatt hour is a unit of energy equal to outputting 1 trillion watts for one hour. This is the equivalent of the amount of energy consumed by one billion households in one hour.

Table 1 – Worksheet for recording results of Part A

	1800	1850	1900
Total energy consumed			
Percentage of total energy provided by th			
Traditional biofuels			
Nuclear			
Hydropower			

Wind			
Solar			
Other renewables			

Questions – Historical energy productions and consumption

1. *When did the “fossil fuel age” begin? Fossil fuels include coal, oil, and natural gas.*
2. *When does nuclear appear in the energy mix?*
3. *When does hydropower appear in the energy mix?*
4. *When does wind, solar, and other renewables appear in the mix?*
5. *How has the percentage of the total energy provided by each of these fuel groups changed since they first appeared?*

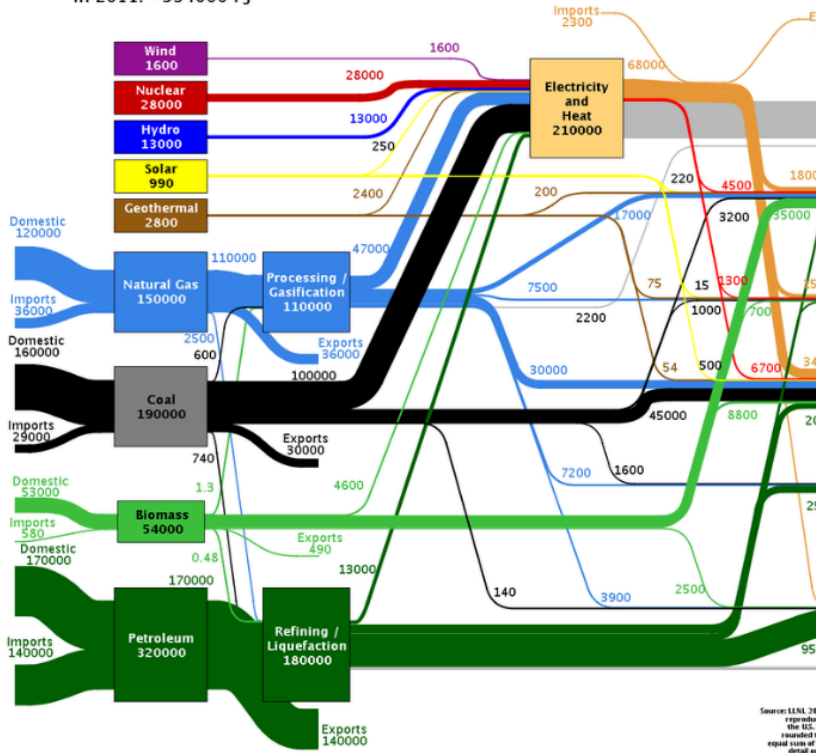


Activity B: Global energy present

Begin Part B by accessing the world energy flow chart produced by Lawrence Livermore National Laboratory’s *Flow*

Charts project <https://flowcharts.llnl.gov/content/assets/images/charts/Energy/ENERGY_2011_World.png>.

World Energy Flow
in 2011: ~534000 PJ



Energy sources and consumption by sector

Figure 2 – World Energy Flow – This diagram shows the major energy sources for modern civilization and how that energy is used (consumption by sector) for 2000.

The two boxes on the right edge of the graph show how much of the energy is used for energy services (energy services) vs. how much is simply released to the environment. The arrows connecting the various boxes represent energy flow between sources and users.

The energy units in this graph are petajoules (PJ). One petajoule is 0.37 trillion kilowatt-hours.

Questions – Present energy production and consumption

1. What is the overall energy efficiency of global energy consumption? How do the four sectors on the right side of the diagram compare in terms of energy consumption and efficiency? The box non-energy is excluded from these sectors. Energy efficiency (SEE) is calculated this way

$$EE = \frac{\text{Energy consumed by a sector that does useful work}}{\text{Total Energy consumed by that sector}}$$
2. What percentage of the world's total energy production is converted into electricity?
3. What is the efficiency of the world's electric power generation?

Part C – Global energy 2100

In Part C you will be designing a global energy mix for the year 2100 that will keep the increase in annual mean global

temperature (MGT) in the year 2100 to less than 2.0°C. To do so you will be using the climate / energy simulator *En-Roads*.

To begin part C, launch EN-ROADS < <https://en-roads.climateinteractive.org/scenario.html?v=2.7.6> >. Figure 3 shows what you should see after EN-ROADS has launched.

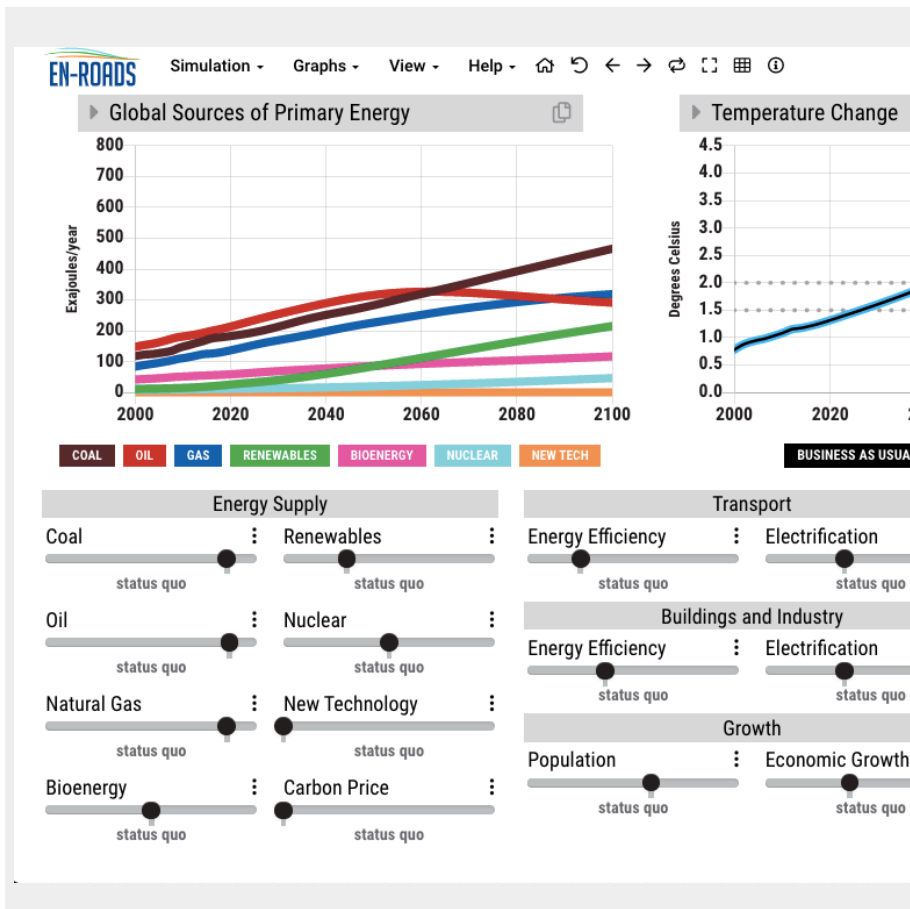


Figure 3 – The default screen for En-Roads.

The graph in upper left shows global primary energy sources projected from 2000 to 2100 in Terawatt hours. The graph on the right shows the increase in MGT given the same scenario. The sliders below the graphs are how you control those factors. These factors include the degree of electrification of sector consumption, global population and economic growth, and carbon sequestration strategies.

This default screen shows the “business as usual” (BAU) scenario. The BAU is what we might expect to see if stay on our current development pathway of increased energy use matched with increased use of fossil fuels. In this scenario the increase in MGT in 2100 is 4.1°C, nearly 2°C above the upper target of the 2015 Paris Accord. To reach the Paris target you will need to adjust some, or all of the factors controlled by the sliders in the bottom half of the screen. Here are the questions you will be addressing as you do so.

1. *Beginning with any of the existing energy sources (coal, oil, natural gas, bioenergy, renewables, and nuclear) what does it take to reduce or increase the amount of energy provided by that source? Watch the caption underneath each slide as you adjust that energy source.*
2. *Given that in 2017 three fossil fuels provided nearly 85% of global energy consumption and produced 95% of all energy / industry related CO₂ emissions, what would be the impact on the 2100 MGT increase of reducing all three fuels the maximum amount?*
3. *Reducing which fuel has the greatest impact on the 2100 MGT increase? To do this reset the simulation and adjust each fuel separately, making sure to set it back to status quo before trying the next fuel.*
4. *For the BAU scenario (reset the simulation) what impact does maximizing carbon price have on 2100 MGT increase? What is carbon price? Click on the three dots above the carbon price slider for an explanation?*
5. *For the BAU scenario, what impact does setting population and economic growth to a minimum have on 2100 MGT increase? What impact does setting population and economic growth to a maximum have?*
6. *What impact does setting all three fossil fuels to minimum, while increasing renewables to maximum have on 2100 MGT increase? Make sure to reset all sliders to*

status quo before doing this.

7. *What impact does setting all three fossil fuels to minimum, while increasing nuclear to maximum have on 2100 MGT increase? Make sure to reset renewables to status quo before maximizing nuclear.*
8. *For the BAU scenario, what impact does setting electrification to maximum for transport, and buildings and industry have on 2100 MGT increase?*
9. *For the BAU scenario, what impact does setting energy efficiency to maximum for transport, and buildings and industry impact 2100 MGT increase?*
10. *For the BAU scenario, what is the 2100 MGT increase if land and industry emissions are reduced and carbon removal is increased the maximum amount?*
11. *What is meant by deforestation, methane and other, afforestation, and technological carbon removal? Click on the three dots next to each title for an explanation.*

Having done this background work, adjust energy supply, sector energy efficiency and electrification, land and industry emissions, and carbon removal, population, and economic growth to achieve the Paris target – 2100 MGT increase below 2.0°C with concerted effort to stay as close to 1.5°C as possible.

Record your results in Table 2 on the following page. Once this is done complete the graph in figure 4 to show your global energy plan from now until 2100. Finally, write a paragraph summary of your plan that outlines its major features and the tradeoffs inherent in the plan (strengths, limitations, risks, and benefits).

**Table 2 – Worksheet for recording your results
for the final problem in part C**

2.1 Increase in MGT by 2100 _____ °C

2.2 Energy Supply

Energy produced by each source as read from the graph is in exajoules (EJ). Once you have recorded the contribution of each source, sum them to derive the total global consumption for each year.

Source	2020	% Total	2060
Coal			
Oil			
Natural Gas			
Bioenergy			
Renewables			
New Tech			
Total Consumption			
EJ			
2.3 Carbon Price _____			
2.4 Sector Consumption			
Sector	Energy Efficiency		
Transport			
Buildings and Industry			

2.5 Growth		
Population		
Economic		
2.6 Land and Industry Emission		
Deforestation		
Methane & Others		
2.7 Carbon Removal		
Afforestation		
Technological		

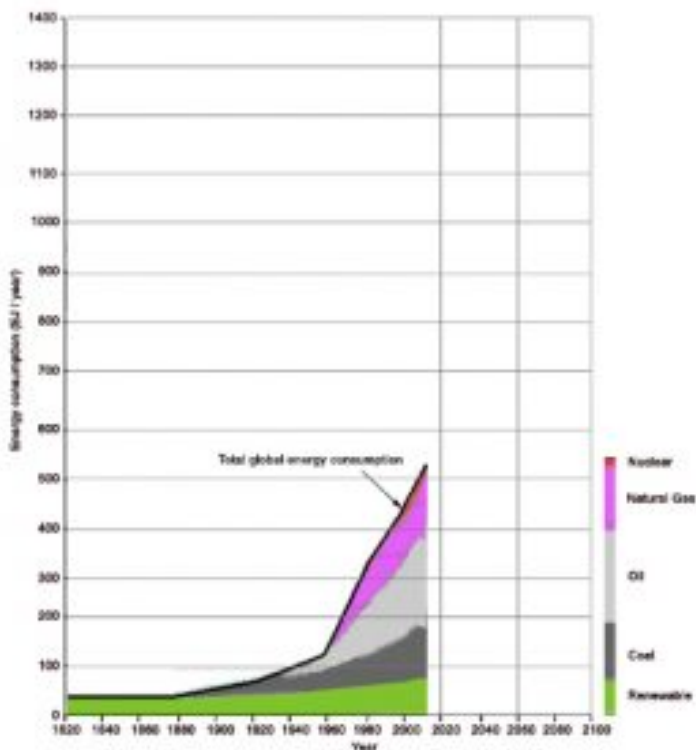


Figure 4 – Global energy consumption and production from 1820 to 2100. Complete this figure by continuing the black line at the top of the stack out to 2100 based on each of total global consumption for 2020, 2060, and 2100. Then divide the space under the consumption curve at each of these years into segments based on the %total provided by each energy source.

25: Designing a Climate Resilient Community

Key questions for this investigation

- What are the current characteristics of your community?
- How might the community be impacted as its regional climate changes?
- How might the community be restructured to survive these changes?
- How might the community be restructured to limit even worse changes?

To investigate these questions you will be using several online tools to determine how to improve the climate resilience of a small town or neighborhood. This means that you will be looking at how to restructure a community to reduce its carbon emissions, sequester carbon where possible, and adapt to probable climate changes in the area. In doing so you will be addressing the four key questions.

Tools used in this investigation

- *Biome Viewer* < https://media.html.or/biointeractive/biomeviewer_web/index.html > developed by the Biointeractive Group of the Howard Hughes Medical Institute
- *Future Climate Dashboard* <

<https://climatetoolbox.org/tool/Future-Climate-Dashboard> > from the Climate Toolbox developed by the Applied Climate Science Laboratory at University of Idaho.

- *Google Earth* < <https://www.google.com/earth/> > from Google Inc.
- *Project Drawdown Solutions Catalog* < <https://www.drawdown.org/> > developed by Project Drawdown.
- *Surging Seas Risk Finder* < <https://riskfinder.climatecentral.org> > developed by Climate Interactive.

Background

Today, 55% of the world's population lives in cities. Estimates suggest that nearly 75% of global annual CO₂ emissions come from urban areas¹. As such the principal activities and structures that make up these communities include...

- Residential – Houses, apartment complexes, etc.
- Commercial – Shops and warehouses.
- Transportation – Trains, planes, trucks, autos, ships, bicycles, etc. and the structures needed to support them.
- Manufacturing – Factories, mines, etc.
- Agriculture – Farms
- Energy production – Power plants, mines, well fields, refineries.

The process of redesigning our communities to be climate

resilient means redesigning these activities and structure so we can continue to provide for our needs while ensuring that future generations can do the same. This requires retaining and restoring the integrity of the natural systems on which we depend. To accomplish this is a two-part process that involves changing our communities to slow climate change by reducing net carbon emissions to near zero and altering our communities to survive natural disasters associated with unavoidable climate change. As a general rule of thumb, the more mitigation the global community does the less adaptation individual communities will have to do. Note – Economists, such as Nicholas Stern, argue that mitigation generally is less expensive than adaptation.

Investigation

ActivityA– Currentcharacteristics

Begin by launching *Google Earth* < <https://www.google.com/earth/>>. Once the program has launched, locate the community (city, town, or village) you are interested in by typing its name in the search box that appears when you click on the magnifying glass icon in the upper left corner of the frame. This will access a 3D model of the community, which will be outlined in red and accompanied by an information panel in the upper right corner of the frame (Figure 1).

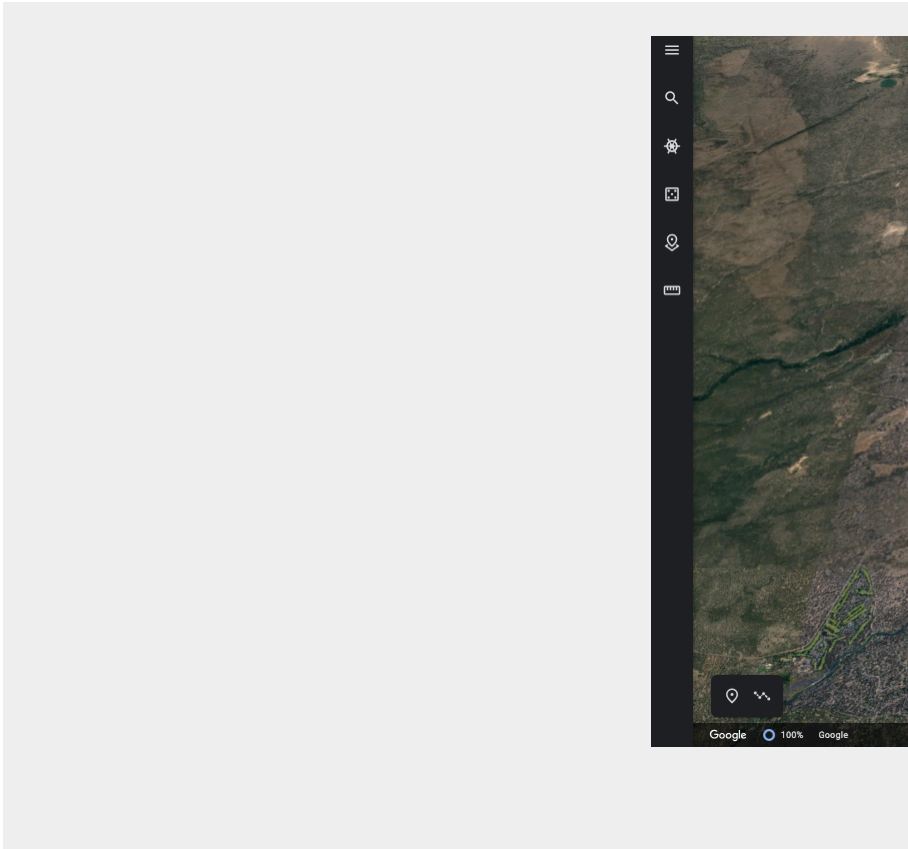


Figure 1 – An oblique view of Bend, Oregon as seen in Google Earth. The red line m

Questions – Community characteristics

1. *Where is this community? Latitude and longitude, continent, country, state or province.*
2. *How big is it? Length, width, and area*
3. *Is it a rural or urban community?*
4. *The people of this community? How many people live in this place, ethnicity, income distribution, etc.*

5. *What is the economic base of this place? The industry and business that is prominent in this community.*
6. *What is the surrounding landscape like? Elevation, location (coastal or inland), rivers or streams that run through it, valleys it is in, surrounding mountains or hills, major geographic features.*
7. *What biome is the community in? Name and describe its biome, and list some of the plants and animals native to it.*
8. *What is the normal climate? This includes average annual temperature and total yearly precipitation. Seasonal average temperature and total precipitation. Seasons of interest include winter (December / January / February) and summer (June / July / August)*

To help with questions 7 and 8 use another on-line atlas, *Biome Viewer*. Refer to *Activity 3: Biomes and Climate Zones* for operating instructions for *Biome Viewer*.

Activity B: Assessing impacts

Begin this activity by launching the *Future Climate Dashboard* < <https://climatetoolbox.org/tool/Future-Climate-Dashboard> >.

Questions – Climate impacts on your community

1. *What is the projected average annual temperature for your community in 2050 and 2100 under the business as usual (BAU) and enhanced ambition (EA) scenarios?*
2. *What is the change in the number of extreme heat days ($T > 95^{\circ}\text{F}$) projected for each scenario?*
3. *What is the change in the number of freezing days (T*

< 32°F) projected for each scenario?

4. *What is projected change in annual and seasonal precipitation?*

Before redesigning your community to meet the challenge of these changes, examine the following list of environmental and social impacts likely in an increasingly warmer world. Select those that are most relevant to your community and determine which part of your community would be most affected by each impact and how.

- Increasingly severe droughts during summers.
- Increase in the number and intensity of extreme heat events.
- Increase in precipitation and flooding during rainy seasons.
- Increase in slope failures from increased precipitation.
- Sea level rise – *If this is an issue in your community use the Surging Seas Risk Finder to determine what parts of your community would be impacted by a 0.5 and 1.0 m rise in sea level. The sea level rises possible under BAU and EA scenarios.*
- Changes in stream flow from diminishing glaciers and snowpack.
- Increase in coastal erosion from melting permafrost.

Activity C: Community Redesign for Adaptation

Propose some specific strategies that this community could implement to adapt to each significant impact. What

strategies does the community already have in place? Which of these strategies would they need to improve on and how?

To address these questions, make a list of relevant impacts based on the list at the end of part B. For each impact list and describe a proposed or existing strategy and identify where in your community it is found or could be implemented.

Activity D: Infrastructure Redesign for Mitigation

Use the Project Drawdown's solution catalog < <https://www.drawdown.org/> > to identify five specific strategies that this community could implement to reduce its carbon emissions. Also identify at least one strategy that this community could implement to sequester carbon. What has the community already started doing to reduce emissions or sequester carbon? Which of these strategies would they need to improve on and how?

As you list the mitigation strategies you selected for your community, describe each, discuss the impact of selecting this strategy (where does Drawdown rank it and why), and identify where in your community it is found or could be implemented.

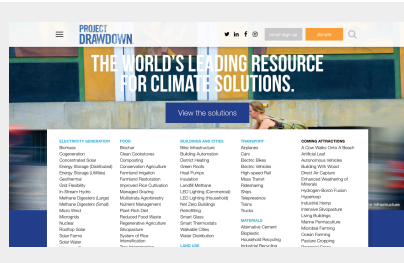


Figure 3 – Drawdown solutions catalog screen. Solutions are listed by general category.

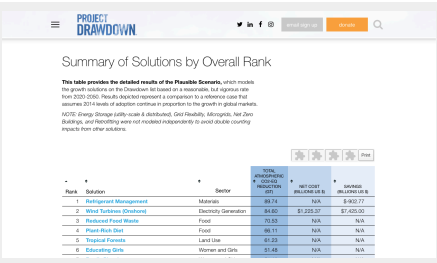


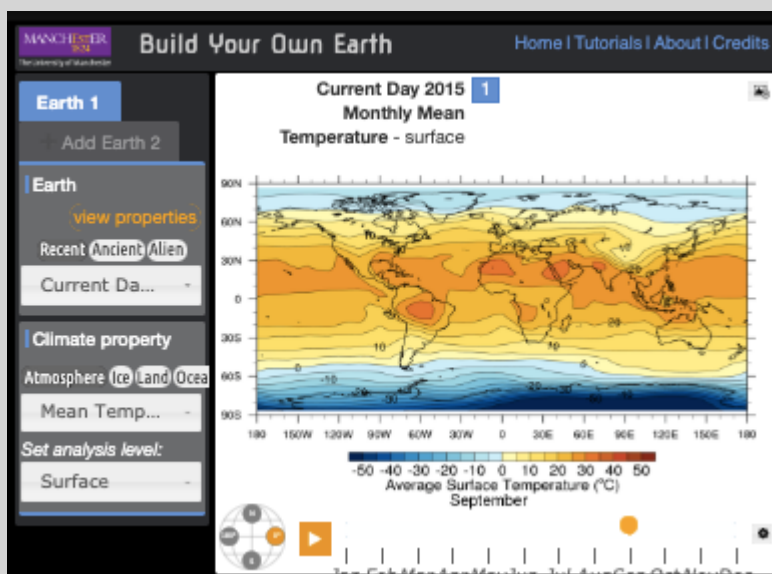
Figure 4 – Draw solutions listed by ranking in terms of their effectiveness for reducing or sequestering carbon.

Footnotes

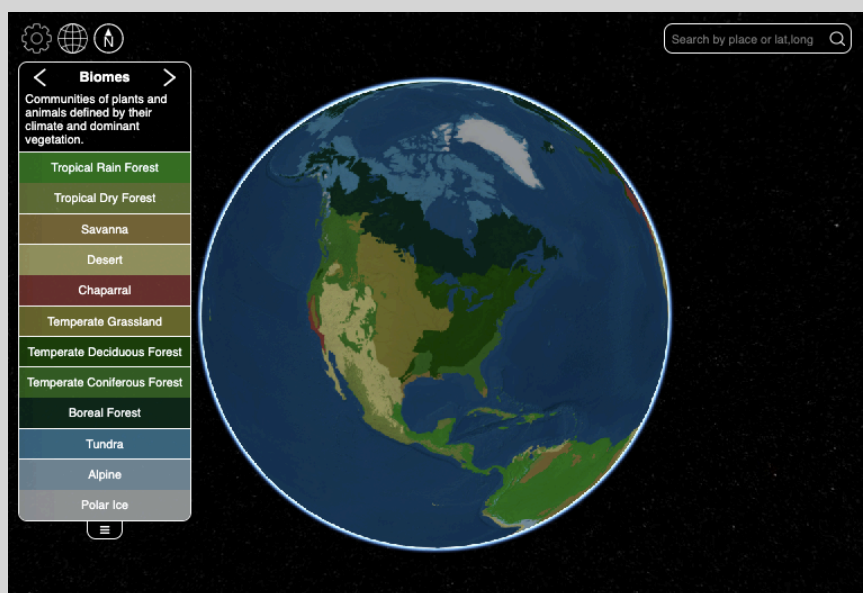
1 Cities and Climate Change, UNEP – UN Environmental Programme <https://unenvironment.org/explore-topics/resource-efficiency/what-we-do/cities/cities-and-climate-change>

Appendix A: Tools used in this Manual

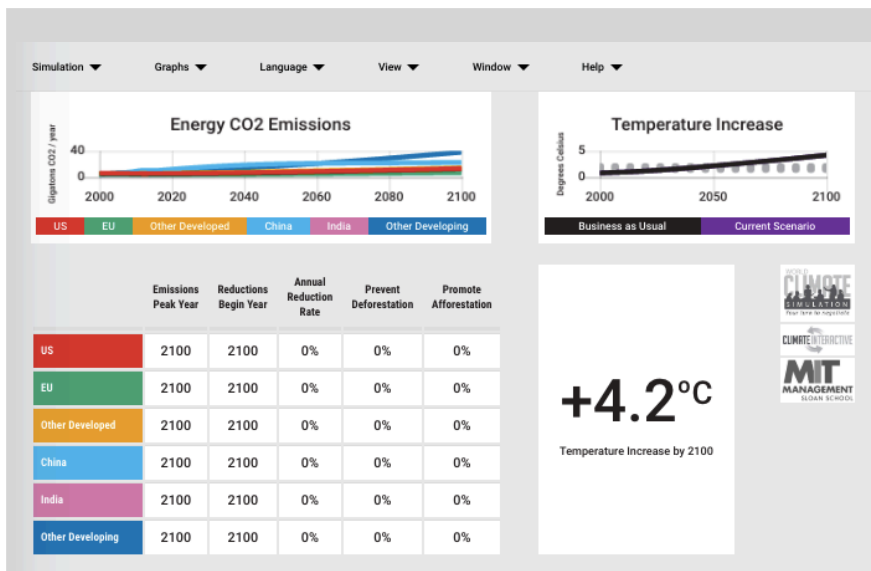
This appendix contains descriptions of the on-line climate models, climate data viewers, interactive atlases, and other web-based resources used in the activities in this manual.



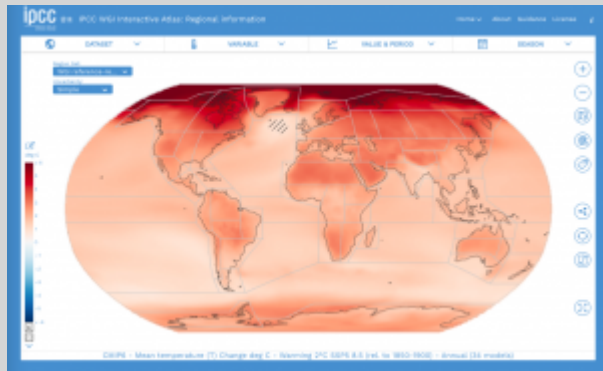
<http://www.buildyourownearth.com/>



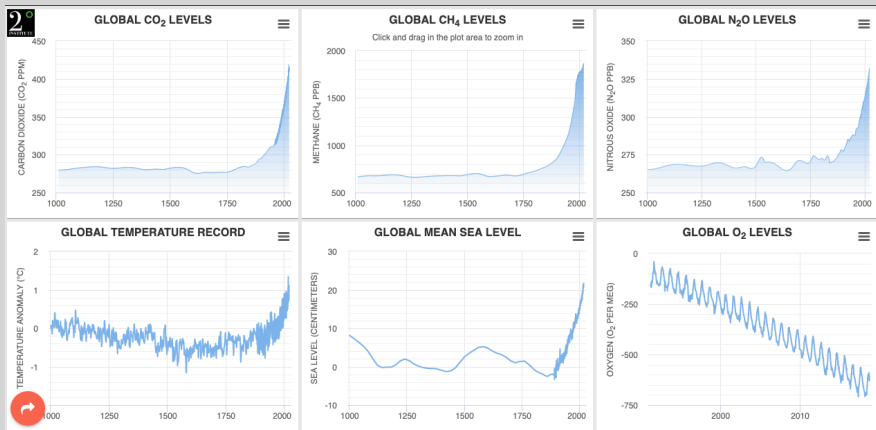
<https://www.hhmi.org/biointeractive/biomeviewer>



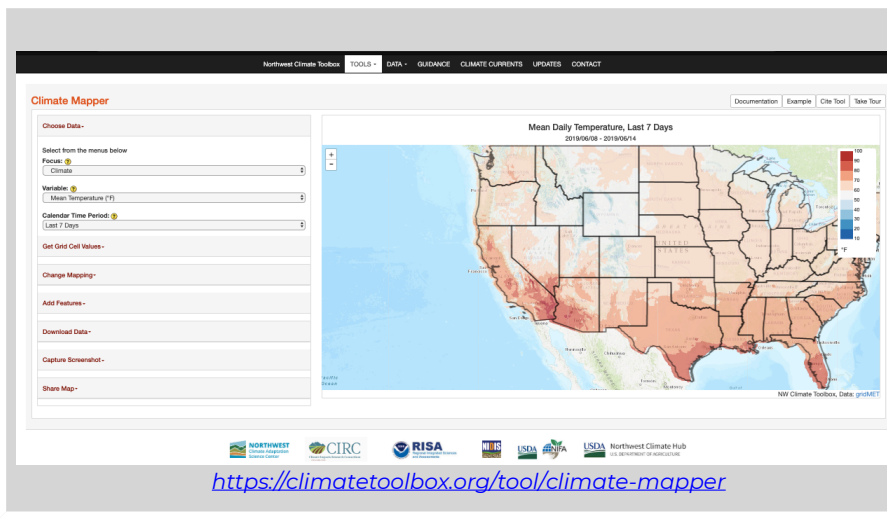
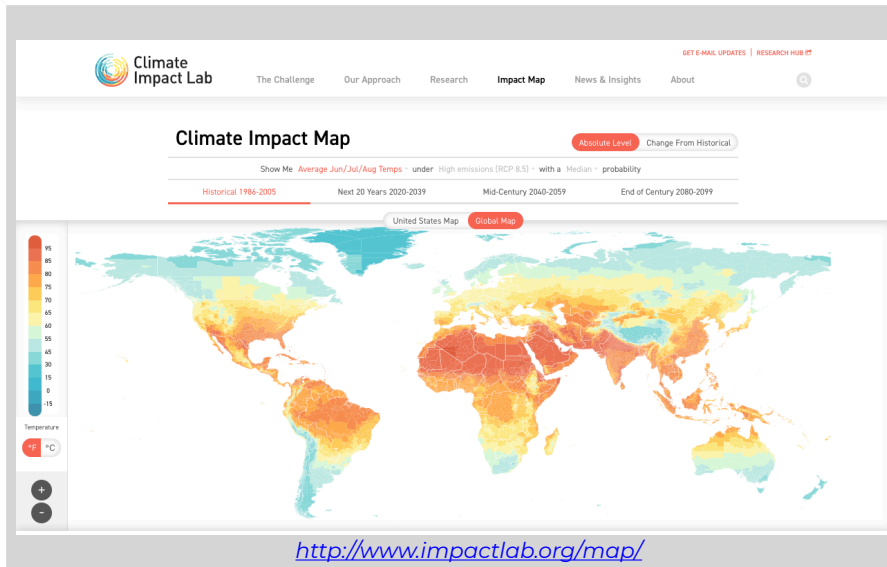
<https://croadsworldclimate.climateinteractive.org/>



<https://interactive-atlas.ipcc.ch/>

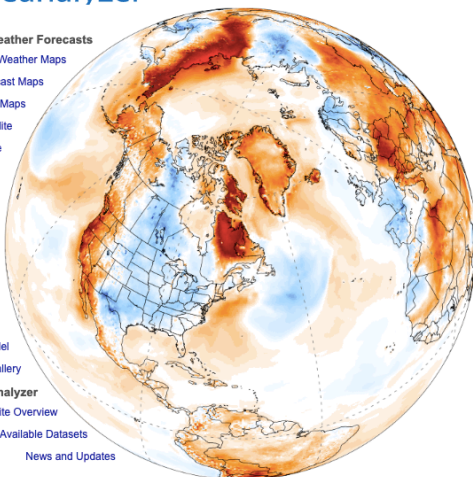


<https://www.climatelevels.org/?pid=2degreesinstitute&theme=grid-light>

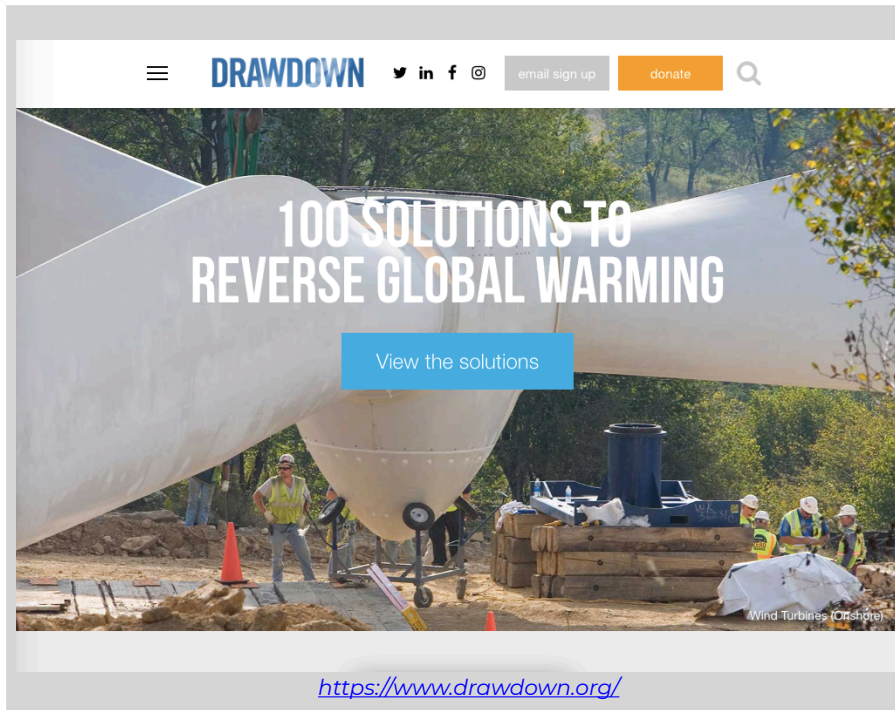


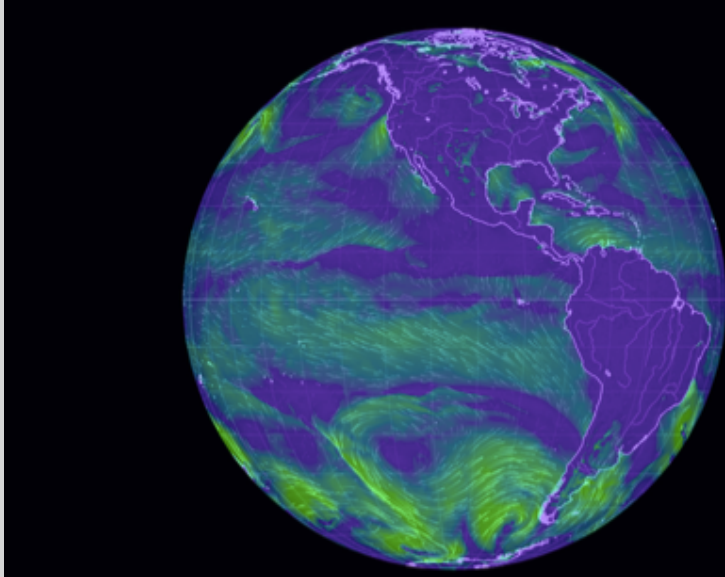
Climate Reanalyzer

- Weather Forecasts**
 - Today's Weather Maps
 - Outlook Forecast Maps
 - Hourly Forecast Maps
 - U.S. Radar & Satellite
 - Archived U.S. Satellite
- Climate Models and Data**
 - Daily Reanalysis & Sea Ice Maps
 - Monthly Reanalysis Maps
 - Monthly Reanalysis Timeseries
 - Monthly Reanalysis Correlations
 - Monthly U.S. Timeseries & Maps
 - Global SST Timeseries & Maps
 - Daily GHCN Station Data
 - Environmental Change Model
 - Animation Gallery
- About Climate Reanalyzer**
 - Site Overview
 - Available Datasets
 - News and Updates



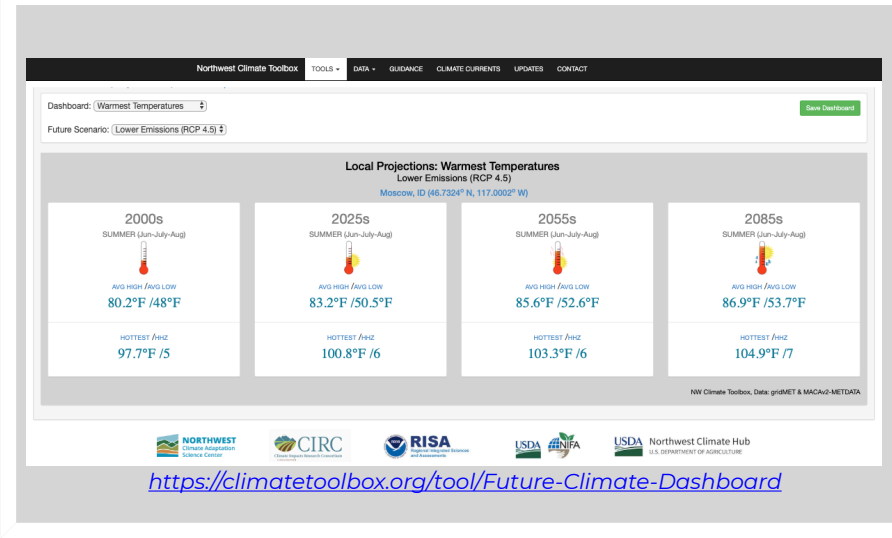
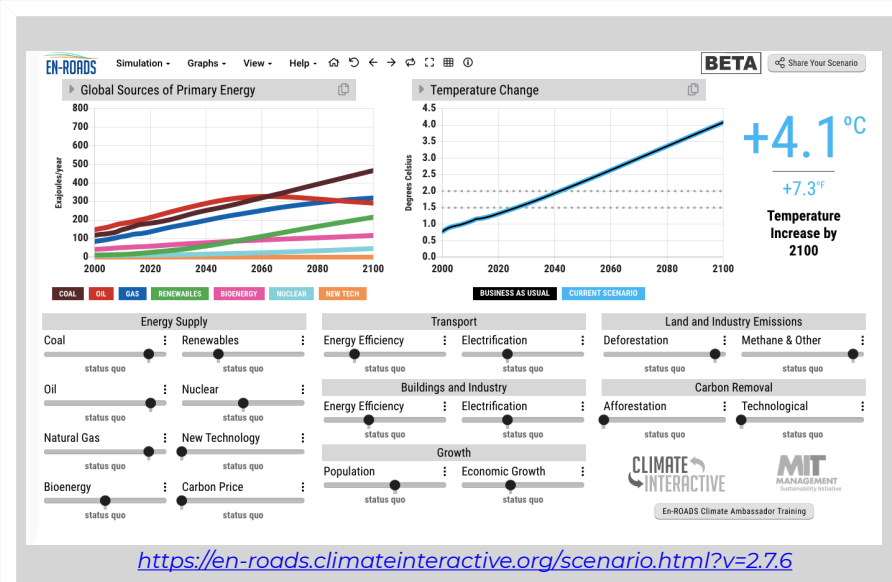
<https://climatoreanalyzer.org/>

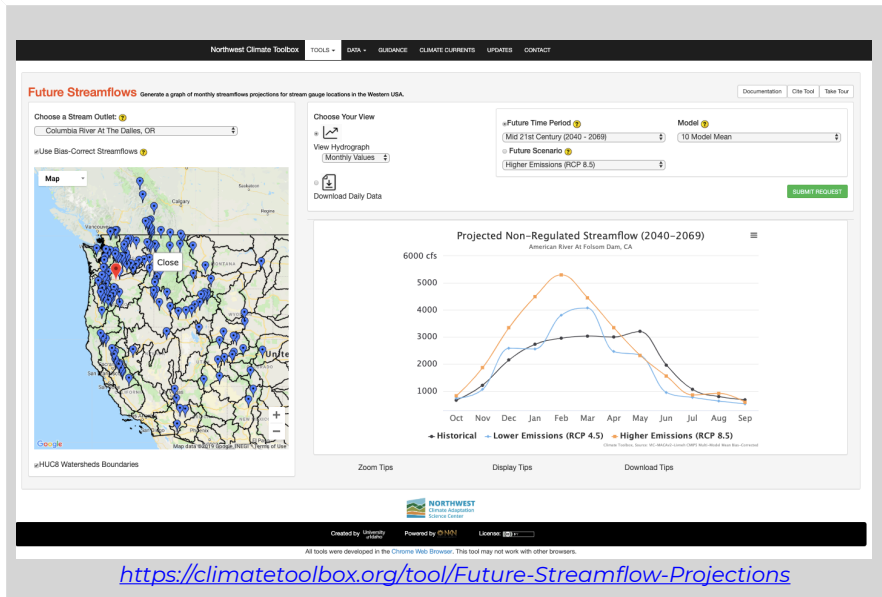


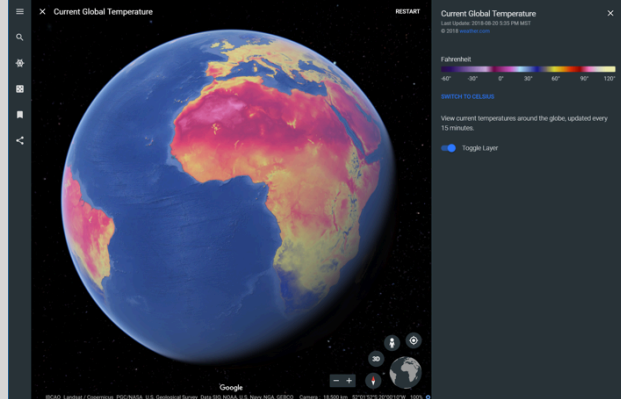


earth.nullschool.net

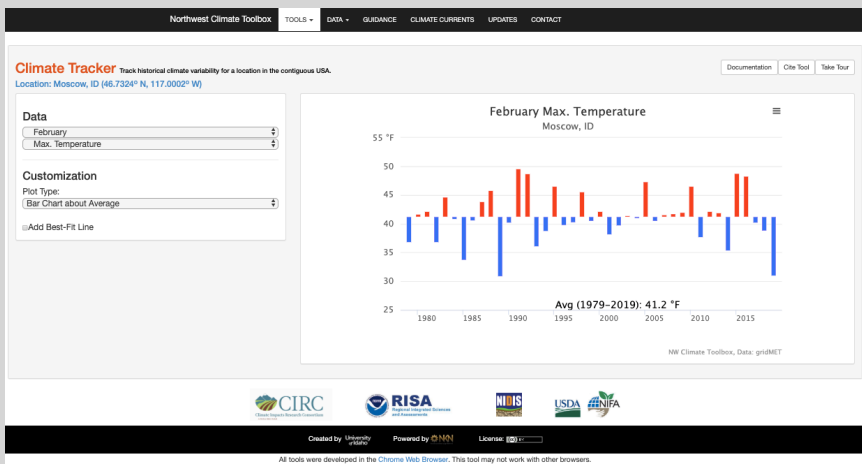




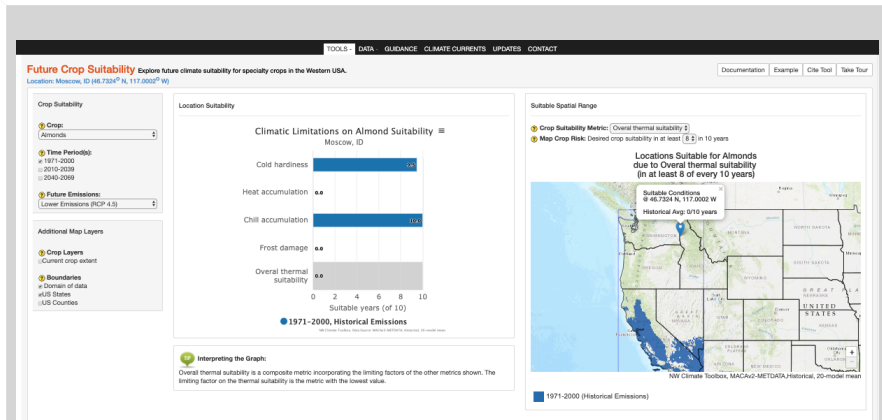




<https://www.google.com/earth/>



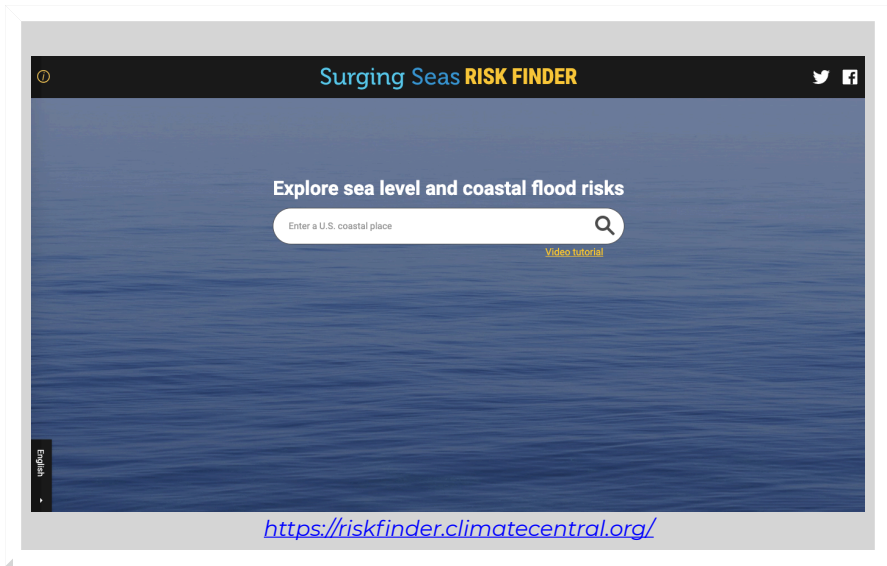
<https://climatetoolbox.org/tool/Historical-Climate-Tracker>



<https://climatetoolbox.org/tool/Future-Crop-Suitability>



<https://climatetoolbox.org/tool/Seasonal-Forecast-Maps>



Appendix B: Other Resources

This section is a list of websites and print media related to climate issues. In addition to science background and links to science related agencies, it includes a number of resources related to climate and urban / community design, economics, education, communications, psychology, and public policy.

Climate Science

Books and other print media

- Kitchen, David E., 2014, **Global Climate Change: Turning Knowledge into Action**
- Mathez, Edmond, 2009, **Climate Change: The Science of Global Warming and Our Energy Future**, Columbia University Press
- Moran, Joseph M. 2010, **Climate Studies: Introduction to Climate Science**, American Meteorological Society
- Ruddiman, William F., **Earth's Climate: Past and Future**, 3rd Edition, Macmillan Press
- Ruddiman, William F., 2014, **Earth Transformed**, 3rd Edition, Freeman and Company
- Wolfson, Richard, 2008, **Energy, Environment, and Climate**, Norton Press
- IPCC, 2018, [Special Report: Global Warming of 1.5°C \(SR15\)](#)
- IPCC, 2014, [Fifth Assessment Report](#)
- IPCC, 2021, [Sixth Assessment Report](#)

- US Global Climate Research Program, 2018, **Fourth National Climate Assessment**

Data Portals

- **Charctic Interactive Sea Ice Graph** < <http://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph/> > An interactive graph of annual sea ice extent for 1979 through 2019 developed by the National Snow and Ice Data Center.
- **Climate Dashboard** < https://www.climatelevels.org/?pid=2degreesinstitute&the_me=grid-light > Interactive graphs of global temperature, sea level, carbon dioxide, methane, oxygen, and nitrogen oxide levels for the past millennium and the past 800,000 years. Developed by the 2° Institute.
- **Climate Reanalyzer** < <https://climatechange.umaine.edu/climate-matters/climate-reanalyzer/> > A viewer of climate data and model outputs developed by the University of Maine, Climate Change Institute.
- **Landscape Climate Dashboard**: Climate Protections for Federally and Tribally Protected Lands in the West < <http://climatedashboard.org/> > A viewer projected climate changes through 2075. A project of the Conservation Biology Institute.
- **National Climate Change Viewer** < <https://toolkit.climate.gov/tool/national-climate-change-viewer> > A viewer for climate related maps and graphs produced by climate models used by the World Climate Research Programme.
- **NOAA View Data Exploration Tool** < <https://www.nnvl.noaa.gov/view/globaldata.html> > A map viewer of atmosphere, ocean, and land data developed by the National Oceanic and Atmospheric Administration.
- **UN Atlas of the Oceans** < <http://www.oceansatlas.org/> > An

internet portal to information relevant to sustainable development of the oceans. Developed under the authority of UN-Oceans.

- Agencies and Organizations
- **National Center for Atmospheric Research** < <https://ncar.ucar.edu/> > NCAR is a federally funded research and development center devoted to service, research, and education in atmospheric and related science.
- **National Oceanic and Atmospheric Administration** < <https://www.noaa.gov/> > A branch of the US Federal Government tasked with monitoring and evaluating atmospheric, oceanic, and climatic changes, distributing information derived from this activity, and conserving and managing coastal and marine ecosystems.
- **National Snow and Ice Data Center** < <https://nsidc.org/> > NSIDC is a research group located at the University of Colorado Boulder that focuses on the cryosphere and its interaction with climate. The cryosphere includes snow, sea ice, glaciers, ice caps, and tundra.
- **UN Atlas of the Oceans** < <http://www.oceansatlas.org/> > World Meteorological Organization < <https://public.wmo.int/en> > An agency of the United Nations tasked with coordinating the global collection and distribution of weather and climate data. The WMO also works closely with the IPCC in developing regular climate assessments and special reports.
- **World Glacier Monitoring Service** < <https://wgms.ch/> > WGMS is an international agency for monitoring glaciers worldwide.

Energy and Climate

Books and Reports

- Rocky Mountain Institute, 2018, **Public Collaborative for Puerto Rico's Energy Future**, <<https://rmi.org/insight/public-collaborative-for-puerto-ricos-energy-future/>>
- Rocky Mountain Institute, 2015, **Renewable Microgrids: Profiles from islands and Remote Communities across the Globe**, <https://rmi.org/blog_2015_11_04_report_release_renewable_microgrids/>
- Rocky Mountain Institute, 2018, **The Carbon-Free Regions Handbook** <<https://rmi.org/insight/carbon-free-regions-handbook/>>
- Rocky Mountain Institute, 2017, **The Carbon-Free City Handbook** <<https://rmi.org/insight/the-carbon-free-city-handbook/>>
- Union of Concerned Scientists, 2009, **Climate 2030: A National Blueprint for a Clean Energy Economy**, <<https://www.ucsusa.org/global-warming/solutions/reduce-emissions/climate-2030-blueprint.html>>

Data Portals

- **Energy Flowcharts** <<https://flowcharts.llnl.gov/>> Flow charts of energy consumption and carbon emissions for most of the countries of the world. Developed by Lawrence Livermore National Laboratories.
- **Energy Sector's Vulnerabilities to Climatic Conditions** <<https://www.energy.gov/maps/climate-vulnerabilities>> An interactive map of the United States showing how major energy facilities have been impacted by increasing

temperatures, decreasing water availability, increasing storms, flooding, and sea level rise. Developed by the US Department of Energy.

Agencies and Organizations

- **Cool Climate Network** < <https://coolclimate.berkeley.edu/index> > A University / Government / Business / NGO partnership at the University of California, Berkeley.
- **International Renewable Energy Agency** < <https://www.irena.org/> > An intergovernmental organization that supports countries in their transition to renewable energy economies. IRENA accomplishes this through research, consulting, workshops, and publication.
- **International Atomic Energy Agency** < <https://www.iaea.org/> > An organization with the UN that works with UN member states and multiple partners to promote the peaceful use of nuclear technologies. Included because some climate activists see an expanded nuclear power system as the quickest and most realistic options for curtailing carbon emissions.
- **Rocky Mountain Institute** < <https://rmi.org/> > RMI is a US based organization dedicated to research, publication, consulting, and lecturing in environmental sustainability. It's special focus is on market-based measures to encourage energy and resource efficiency.
- **U.S. Department of Energy** < <https://www.energy.gov/> > The US Federal agency responsible for administrative oversight of national energy production.

Policy and Economics

Books and Reports

- Stern, Nicholas, 2006, **The Economics of Climate Change: The Stern Review**, Cambridge University Press
- U.S. Environmental Protection Agency, 2017, **Economics of Climate Change** < <https://www.epa.gov/environmental-economics/economics-climate-change> >

Data Portals

Climate Watch < <https://www.climatewatchdata.org/> > A portal for data, visualizations, and analysis designed to help policymakers, researchers, and other stakeholders gather insights on countries climate progress. Developed by the World Resources Institute.

Agencies and Organizations

World Resources Institute < <https://www.wri.org/> > A global organization spanning +60 countries with offices in Asia, Europe, North and South America, and Africa. WRI does research, consulting, and education to help governments, businesses, and communities develop environmentally sustainable economies.

Sustainable Development

Climate Action Plans – Policy documents for cities and states involving climate mitigation and adaptation

- **Anchorage Climate Action Plan** < <http://www.muni.org/Departments/Mayor/AWARE/resilientanchorage/pages/climateactionplan.aspx> > Anchorage, Alaska. This plan is noteworthy because of the unique problems that rising global temperature poses for Arctic regions.
- **Milwaukie Climate Action Plan** < <https://www.milwaukieoregon.gov/sustainability/climateaction> > Milwaukie, Oregon. A smaller city in the northern Willamette Valley of Oregon known for its efforts to promote sustainable development.
- **Portland Climate Action Plan** < <https://www.portlandoregon.gov/bps/49989> > Portland, Oregon. This document is particularly noteworthy because it was one of the first such city plans in the United States.
- Sustainable communities – Towns, cities, and villages in which renewable energy generation and energy efficiency are key features
- **Freiberg Germany** <<https://www.freiburg.de/pb/Len/644009.html>> This small German town is an example of sustainable urban development known for its emphasis on energy efficiency, local renewable energy development, and transportation network.
- **Global Ecovillage Network** < <https://ecovillage.org/>> A network of approximately 10,000 communities designed through local action to be socially, culturally, environmentally, and economically sustainable.
- **Georgetown Texas** < <https://gus.georgetown.org/>

[renewable-energy-faqs/](#) > A net-zero town in the midst of Texas oil country. This development was pursued largely for economic reasons.

- **Hafencity Hamburg** < <https://www.hafencity.com/en/overview/the-hafencity-project.html> > A redevelopment zone in Hamburg Germany that characterized as an example of urban sustainable development. **Themes**
Quarters Project < [HafenCityProjekte_March_2017_english.pdf](#) >
- **Wildpoldsried Germany** < https://www.wildpoldsried.de/index.shtml?energie_homepage > A Bavarian village known for its dairy and energy farming.
- **Woking England** < <https://www.woking.gov.uk/nature-and-sustainability> > A town of 90,000 in Surrey England known for its Combined Heat and Power (CHP) system and efforts at building energy efficiency. A remarkably detailed website with considerable policy and technical information.

Communications and psychology

Books and reports

- Yale Program on Climate Change Communication, 2016, **Global Warming's Six Americas** < <https://climatecommunication.yale.edu/about/projects/global-warmings-six-americas/> >
- Agencies and Organizations
- **Understanding Risk Research Group** < <http://www.understanding-risk.org/> > A multi-national research group based at Cardiff University (UK) that looks at attitudes towards climate change in Europe.
- **Yale Program on Climate Change Communications** <

<https://climatecommunication.yale.edu/> > A social science research group at Yale University that conducts research to help leaders communicate more effectively about climate issues and actions. One of their chief goals is to increase public understanding of climate risks and opportunities.

Appendix C: The International Process

The most challenging question of the current climate crisis is how we as individuals, communities, and a species can respond to it. As mentioned in the introduction to this manual we are confronted with a problem that requires “all hands and minds on deck” to solve it. This means that we are faced with a problem that extends far beyond the basic science, to involve individual choice, grassroots action, technological, economic, and social innovation, and government action at all levels. Having said this, climate issues know no political boundaries meaning that for all its complexity and frustration, a collective international response is a necessity, providing a framework for action at all other levels.

This appendix provides a look into the international process in terms of who the major players are, what has been said in key documents, and what key events have shaped this process. It also includes an examination of how this process connects with local action and why it is important to keep this connection alive even though the international process may feel agonizingly slow and compromised.

Major players



Intergovernmental Panel on Climate Change

<<https://www.ipcc.ch>>

The IPCC is the United Nations body responsible for assessing the science related to climate change. Its mission is to provide governments with scientific information that they can use to develop climate policies. IPCC reports provide key inputs into international climate change negotiations, enabling transparency and objectivity to address climate challenges.

The IPCC does not conduct its own research but is composed of researchers who regularly review and summarize the thousands of scientific research papers published every year. Their summaries, assessment reports, are continually published and updated on a multi-year basis. These assessments identify areas of scientific agreement, and also highlight areas where further research is needed.

Historically, the IPCC was created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP). Since its inception, the IPCC has produced five major assessments and several special reports which have informed ongoing international negotiations and a number of national climate assessments and climate action plans.

The IPCC is divided into three Working Groups and a Task Force. Each of the working groups is responsible for assessing and summarizing the literature in a key area. These include the physical science of climate change (Working Group I),

adaptation and vulnerability (Working Group 2), and climate change mitigation (Working Group 3). The Task Force on National Greenhouse Gas Inventories (TFI) is charged with developing and refining a methodology for the calculation of national greenhouse gas emissions and removals. Other task groups are convened for set time periods to consider special topics or questions.



UNFCCC secretariat

< <https://unfccc.int/about-us/about-the-secretariat> >

< <https://unfccc.int> >

The UNFCCC secretariat is the United Nations body responsible for administrative oversight of the United Nations Framework Convention on Climate Change (UNFCCC). This body was established in 1992 when countries adopted the Convention to enable a global response to climate change. The secretariat currently has over 450 staff members representing nearly 100 countries and has been located in Bonn, Germany since 1995. Over the past 27 years the secretariat has had the following key responsibilities...

- Providing technical expertise and assisting in the review of climate information provided to the parties to UNFCCC.
- Maintaining the registry for National Declared Contributions (NDC) established under the Paris Agreement.
- Organizing and supporting two to four negotiating

sessions per year. The largest and most important of these being the Conference of the Parties or COP. The COP is held annually (unless the parties decide not to).

- Organizing and supporting annual sessions of subsidiary bodies and a large number of meetings and workshops throughout the year.
- Informing stakeholders of the negotiating process and climate action through a variety of communication products, including social media.



United States Global Change Research Program (USGCRP)

< <https://www.globalchange.gov/about> >

The USGCRP is a federal program mandated by the US Congress to coordinate federal research and investments in understanding the forces (both human and natural) shaping global society, and their impact on national society. USGCRP coordinates climate research amongst 13 federal agencies and regularly completes a national climate assessment meant to support the development of climate related policy. Though not an international organization its work is heavily dependent on the work of the IPCC. The USGCRP develops a new strategic plan every ten years. These plans evolve with triennial revisions and updates and provide updated scientific information, tools, and resources to help people and organizations manage climate risks and respond to climate change.

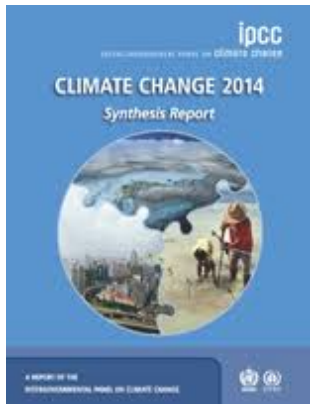
Major reports



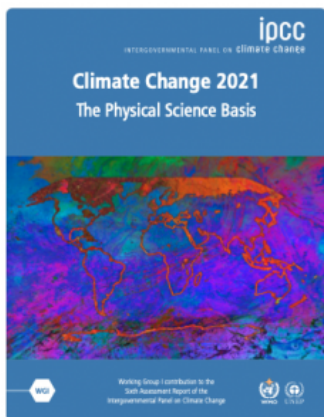
Fifth Assessment Report (AR5)

A four-volume assessment and summary of major climate research conducted by the IPCC. These include...

- AR5 Synthesis Report: Climate Change 2014 < <https://www.ipcc.ch/report/ar5/syr/> >
- AR5 Climate Change 2013: The Physical Science Basis < <https://www.ipcc.ch/report/ar5/wg1/> >
- AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability < <https://www.ipcc.ch/report/ar5/wg2/> >
- AR5 Climate Change 2014: Mitigation of Climate Change < <https://www.ipcc.ch/report/ar5/wg3/> >



As implied by the title, AR5 is the fifth such assessment since the first report was released by the IPCC in 1990.



Sixth Assessment Report (AR6)

The last of the four volumes of this report is due to be released in its entirety by September 2022. < <https://www.ipcc.ch/assessment-report/ar6/> >

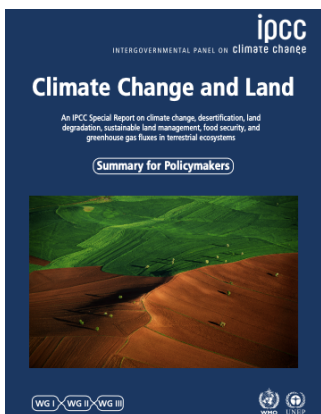
Volume 1: *The Physical Science Basis* was released in August 2021 and is available at < <https://www.ipcc.ch/report/ar6/wg1/> >



Global Warming of 1.5°C (SR1.5)

< <https://www.ipcc.ch/sr15/> >

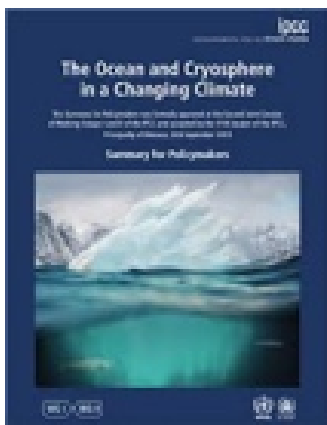
SR 1.5 is a special report released by the IPCC in 2018 which focused on the impacts of global warming of 1.5°C above pre-industrial levels. This report looked at potential temperature trends and global greenhouse gas emission pathways in terms of their impact on global ecosystems and human communities. It also examined options for sustainable development to keep warming to the 1.5°C target.



Climate Change and Land

< <https://www.ipcc.ch/srccl/> >

This special report, released by IPCC in April 2019, looks the impact of climate change on desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Recommended reading for novices is the Summary for Policy Makers.



Special Report on the Oceans and Cryosphere in a Changing Climate

< <https://www.ipcc.ch/srocc/> >

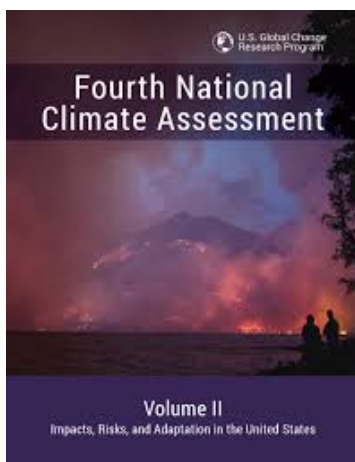
This special report, released by IPCC in September 2019, looks at the impact of climate change on oceans, coastal zones, alpine glaciers, tundra, ice caps, and sea ice. Recommended reading for novices is the Summary for Policy Makers.



The Emissions Gap Report

< <https://www.unenvironment.org/interactive/emissions-gap-report/2019/> >

An annual report produced by the UN Environmental program, that examines the gap between global greenhouse gas emissions and the pledges that countries have made to reduce their emissions under the Paris Agreement on Climate Change. The interactive graphic accessed by the web address above and the Executive Summary are the recommended reading for novices.



Fourth National Climate Assessment (NCA4)

NCA4 is a report developed by the USGCRP that builds upon IPCC assessments and special reports by examining the impact of climate change on the United States and its regions. Like the IPCC assessments, this multi-volume report is periodically updated to reflect insights gained through advances made in scientific research.

Volume 1 of the report is an assessment of the climate science released in 2017 <

<https://science2017.globalchange.gov/> >. Volume 2 is an assessment of the impacts, risks, and adaptation in the United States released in 2018 < <https://nca2018.globalchange.gov/> >.

Major Agreements



United Nations Framework for Climate Change Convention

The UNFCCC is an international agreement adopted during the Rio Earth Summit of 1992 with the aim of preventing destabilizing human interference with the earth's climate system. Provisions of the agreement include mitigation of further climate change, adapting to unavoidable change, and continuous monitoring of human impacts on the climate system.



Kyoto Protocol

The protocol is an international agreement reached during

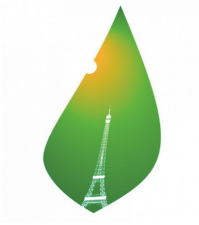
the annual conference (1997) in Kyoto, Japan. This agreement commits its Parties to setting internationally binding emission reduction targets. The Protocol placed much of the responsibility for reduction on developed countries arguing that developed countries are principally responsible for the current high levels of greenhouse gasses in the atmosphere, a result 150+ years of industrial activity.

Under the Kyoto Protocol, countries must meet their targets primarily through national measures and a set of market-based mechanisms. The latter included international emissions trading schemes and mechanisms for clean energy developments



Marrakesh Accord

The Marrakesh Accords is an agreement reached at the 7th Conference of the Parties to the UNFCCC (COP7), which includes detailed rules for the implementation of the Kyoto Protocol. This Conference of the Parties took place in Marrakesh, Morocco in 2001.



Paris Agreement

Adopted in 2015 in Paris, France, this agreement, is regarded as a major milestone in the UNFCCC process. In this agreement, 186 countries agreed to the goal of limiting mean global temperature (MGT) in the year 2100 to less than 2°C above preindustrial MGT. To achieve this goal, the parties agreed to reach carbon neutrality as soon as possible – keeping anthropogenic emissions in balance with carbon removals by the second half of this century. To accomplish this, each party brought to the conference a voluntary set of emission reduction and carbon sequestration targets (Nationally Declared Commitments or NDCs). Under the treaty the international community would conduct a Global Stocktake to assess the effectiveness of these NDCs and enhance those commitments as necessary. The treaty also dealt with adaptation to unavoidable climate changes and financial mechanisms whereby members of the international community would help each other with that adaption.

Where we are and the way forward: September 2021

Where to find summaries of the state of the global climate

- **Climate Monitoring** < <https://www.ncdc.noaa.gov/climate->

[monitoring/](#) > Produced by the National Centers for Environmental Monitoring / National Oceanic and Atmospheric Administration, this site contains both global and national climate reports, as well as more specialized monthly reports (droughts, wildfires, snow and ice, tropical cyclones, and upper atmospheric conditions)

- **State of the Global Climate 2020** < <https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate> > Produced by the World Meteorological Organization, these reports are produced annually, with provisional reports being produced between yearly releases. While the reports tend to be technical and lengthy, the WMO provides very readable on-line summaries of their conclusions. The WMO also produces annual regional climate reports.

Some of the highlights of the latter report, outlined in a WMO video < <https://www.youtube.com/watch?v=pmUCGcBy8tM> >, include the following.

- Surface air temperature – 2020 was one of the three warmest years on record, despite a cooling La Nina. The six warmest years in the past nearly 2 centuries have all been since 2015.
- Ocean temperature – Sea surface temperatures are now the highest on record and are accelerating resulting in ocean heat waves that have impacted nearly 80% of the oceans.
- Related ocean climate trends – Acidification and deoxygenation increased, severely impacting marine life.
- Snow and ice – Arctic sea ice extent at the end of summer was the second lowest on record.
- Extreme weather events – Siberian heat waves led to a record 38°C and serious wildfires. Heavy rain and extensive flooding hit large parts of Africa and Asia. The

Atlantic hurricane season set a record, with 30 named storms,

In the wake of COP21¹ over 95% of the countries of the planet signed onto to the Paris Agreement. Collectively, these countries are responsible for more than 87% of all anthropogenic greenhouse gas emissions. COP21 concluded with NDCs insufficient to meet the 2100 treaty target of 1.5 to 2.0°C above pre-industrial average global temperature². COP21 also concluded with an agreement to regularly take stock of countries' progress on their NDCs and work towards increasing these commitments to achieve the 2100 temperature target. The purpose of UNFCCC meetings since then has been to work out the details of how to make this happen.

Fast forward to 2021, the UNFCCC process has become so mired in political and economic complications that many of the critical details have been worked out. Consequently, many a citizen observer at COPs 22 through 25, have come home feeling that the entire UN climate effort has been hopelessly compromised by entrenched interests. Add to this the upswing in climate change denialism during the past five years, and it is easy to despair that any meaningful progress can or is being done in coping with our current climate crises.

However, speaking as an official observer at two recent COPs, it is important to note that the negotiations are only a piece of the puzzle. Equally important is the presence of observer delegations representing education, research, environmental action, social justice groups, service clubs, business, agriculture, trade unions, indigenous peoples, faith communities, local government, youth, etc. Though their voices may be overlooked in the negotiations, they are a critical catalyst to the process in that their presence is a reminder that dealing with climate issues is a complicated social problem that impacts all of us. Their presence is also a

valuable window into what is happening at the subnational and grassroots level, and that where nations fail to address climate issues there are a lot of local and regional efforts that are taking these issues seriously and making significant progress in dealing with them.

Finally, writing as an observer delegate to an upcoming COP (COP26 in Glasgow, UK), it is important to note that we are at a unique moment in history, where we may be reaching a tipping point in how we as a global society respond to the issues explored in this manual. While destabilization of global climate has accelerated, so has public concern about the impact these trends. Furthermore, global society has been thrust into the position rebuilding global economy in the wake of an unprecedented pandemic at the same time that renewable energy development and electrification of transportation has seen unprecedented growth. Where all this is headed is highly uncertain, but it does give a foundation for hope.

¹ COP21 is the UN conference where the Paris Agreement was forged.

² The 2100 increase in average global temperature resulting from faithful follow-through on the NDCs by all the Paris Agreement signatories is estimated to be between 3.0 and 3.8°C above the pre-industrial global average.