1. Greenhouse Gases and Climate Change

Description

This lesson is designed to provide an overview of greenhouse gases (GHGs) and how increasing concentrations of GHGs from human activities are leading to global warming and climate changes here in North Carolina. Mitigation and adaptation will also briefly be introduced, and covered in more detail in the next two lessons.

Objectives

- Describe how GHGs make Earth habitable.
- Explain how human activities are increasing GHG concentrations
- Describe how global warming is leading to local climate changes
- Define adaptation and mitigation in the context of climate change

Learners

Extension Master Gardener Volunteers and other adults interested in climate change in North Carolina.

Lesson Materials

Slide Deck (see https://climate.ncsu.edu/learn/climate-change-lessons/)

Instructor notes (subsequent pages)

Summative Assessment (questions at end of instructor notes)

Lesson Outline

1. Engage

Assess prior knowledge with activity for learners to share what they know about GHGs.

2. Present Content

Presentation on GHGs, climate change, and introduction to mitigation and adaptation.

3. Support Practice

Make hypotheses about NC climate change and test them using NCSCO Climate Trends Plotter.

4. Assess Learning

Quiz (questions at end of instructor notes)

5. Reflection

Reflection activity for learners.

Note: If audience already has background knowledge on climate change, suggest skipping to next lesson in the series.

Global Carbon Cycle and Greenhouse Gases

Instructor Materials and Notes

Title Slide: The Big Picture

The aim of this presentation is to cover global climate change from the 'big picture' -- that is, the global perspective. In later units, we'll tie this more closely to North Carolina.

Accessing Prior Knowledge: Greenhouse Gas Knowledge

Begin by checking in on our understanding of global climate change and its causes.

Question for audience: "What do you know about greenhouse gases?"

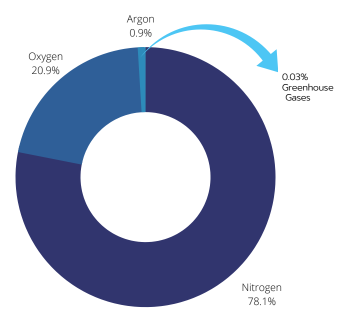
Recommendations for Instructors:

- If on Zoom or similar, have attendees type a few words in the chat. To avoid people being nervous about being put on the spot and saying something wrong, you can instruct them to type their words and then for everyone to hit 'enter' at the same time.
- A mentimeter or similar software for creating word clouds could also be used here.
- If in person, could ask attendees to raise their hands and verbally share, or write on sticky notes and post on a wall.

Earth's Atmosphere: Composition

The Earth's atmosphere is comprised of a mixture of gases. The most abundant of these is nitrogen (accounting for 78.1% of our atmosphere), followed by Oxygen (20.9%), and Argon (0.9%).

The remaining 0.03% of our atmosphere is composed of a brew of trace gases, which include the 'greenhouse gases' carbon dioxide, methane, and nitrous oxide. While 0.03% is a tiny fraction of our atmosphere, the gases in this fraction are responsible for moderating our planet's temperature, making it habitable.



The Atmosphere: How Greenhouse Gases Work (1)

- The Earth receives energy from the Sun in the form of ultraviolet, visible, and a limited portion of infrared energy (together sometimes called "shortwave radiation").
  - Some of this incoming shortwave radiation is reflected off of cloud tops or off the surface of the Earth (e.g., where there is snow or ice).
  - A small percentage is also absorbed directly by aerosol particles the atmosphere, but most incoming solar radiation passes through the Earth's atmosphere and reaches the surface, warming it.
- The Earth radiates the absorbed heat back as longwave radiation.
  - When this encounters greenhouse gases in the atmosphere, those gases vibrate and re-radiate that longwave radiation in all directions, including back to the surface.
  - This re-radiation warms the atmosphere and the surface, making life habitable.
  - This process is sometimes described using the metaphor of a blanket: the greenhouse gases in the atmosphere act like a heat-trapping blanket to keep warmth in, much like a blanket keeps us warm by trapping our body's heat close.

Sources: NOAA, NASA, EPA, NNOCCI

The Atmosphere: How Greenhouse Gases Work (2)

- When we burn fossil fuels like coal and natural gas for energy, we add greenhouse gases, namely carbon dioxide, to the atmosphere. More greenhouse gases mean that more of that outgoing, longwave radiation is being re-radiated back, further warming the Earth.
- Returning to the blanket metaphor, adding greenhouse gases to the atmosphere is like "thickening" the blanket around the Earth. Much like a thicker blanket keeps you warmer, a thicker blanket around the Earth traps more heat underneath it, leading to warming which disrupts the climate.

What is the Carbon Cycle?

- There are several greenhouse gases that are important -- namely carbon dioxide, methane, and fluorinated gases (F-gases).
- Carbon dioxide receives a lot of attention because this is the gas that has contributed the most to our current global warming.
- To understand this a bit more, we're going to watch a video on the carbon cycle.

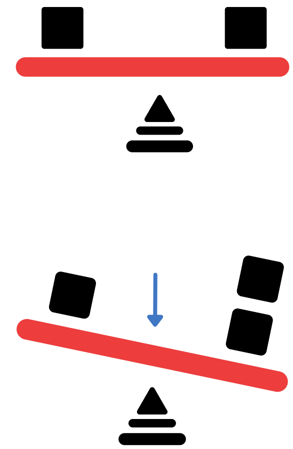
Global Carbon Cycle - Video

Key points covered in the video:

- Carbon is the foundation of all life on Earth, required to form complex molecules like proteins and DNA. This element is also found in our atmosphere in the form of carbon dioxide (CO_2). Carbon helps to regulate the Earth's temperature, makes all life possible, is a key ingredient in the food that sustains us, and provides a major source of the energy to fuel our global economy.
- The carbon cycle is the process by which carbon continually moves from the atmosphere to the earth and then back to the atmosphere. On the earth, carbon is stored in rocks, sediments, the ocean, and in living organisms. Carbon is released back into the atmosphere when plants and animals die, as well as when fires burn, volcanoes erupt, and fossil fuels (such as coal, natural gas, and oil) are combusted.
- The carbon cycle ensures there is a balanced concentration of carbon in the different reservoirs on the planet. For instance, plants grow by using the carbon dioxide that animals exhale, and so some CO_2 is part of normal life processes on the planet -- we can call this "regular CO_2".
- A change in the amount of carbon in one reservoir affects all the others. Today, people are disturbing the carbon cycle by burning fossil fuels, which release large amounts of carbon dioxide into the atmosphere (we can refer to this as "rampant CO_2") and through land use changes that remove plants, which absorb carbon from the atmosphere.
- Rampant levels of carbon dioxide build up in the atmosphere and ocean where it causes problems for the earth's climate and ecosystems.
- Humans play a major role in the carbon cycle through activities such as the burning of fossil fuels or land development. As a result, the amount of carbon dioxide in the atmosphere is rapidly rising; it is already considerably greater than at any time in the last 800,000 years.

Sources: NOAA, NASA, EPA, NNOCCI

What is the Carbon Cycle: Recapping the Video



To recap what was just covered in the video and connect it to our current global climate change:

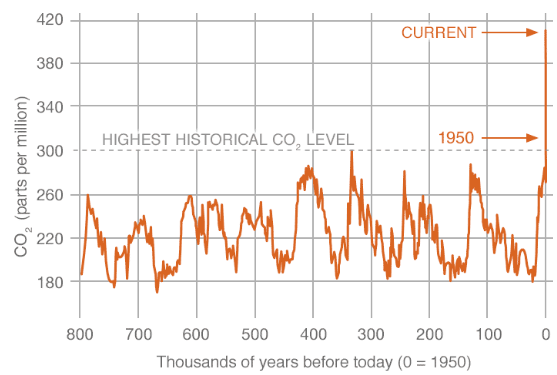
- Carbon, and carbon dioxide, is a part of Earth's system.
- Prior to the industrial revolution, the amount of carbon dioxide that was emitted through things like fires or animals breathing was balanced by the amount that plants and oceans absorbed.
- Since the industrial revolution, when humans began burning fossilized fuels, that amount of carbon dioxide going into the atmosphere has outweighed the amount that natural processes have been able to remove.
- The result has been a build up of carbon dioxide.

Current Carbon Dioxide Level

As of February 2022, the current global carbon dioxide level is 418 parts per million. The graph on this slide shows how carbon dioxide levels have increased over the past few decades based on direct measurements of the atmosphere from NASA.

Instructors:
To obtain the most up-to-date CO2 concentration, visit NASA's Vital Signs of a Changing Planet website: https://climate.nasa.gov/vital-signs/carbon-dioxide/

Current-Historical CO2 Comparison

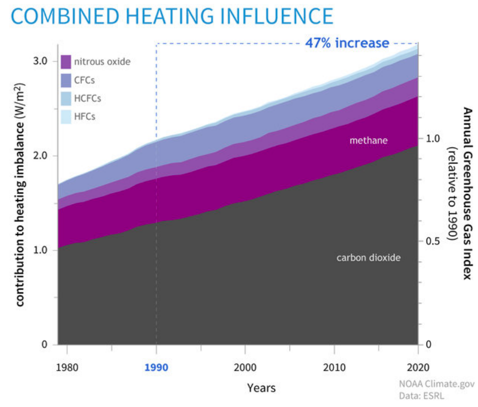


https://climate.nasa.gov/vital-signs/carbon-dioxide/

- Scientists have used proxy data sources to reconstruct carbon dioxide levels in the atmosphere for thousands of years in our history, as this graph from NASA shows.
- Two important takeaways from this: our global carbon dioxide levels have historically cycled every couple thousand years between relatively higher and lower amounts. But, importantly, the amounts we're observing today are much higher and cannot be accounted for from this natural cycling.
- Humans play a major role in the carbon cycle through activities such as the burning of fossil fuels or land development, which have added carbon dioxide to the system.
    - As a result, the amount of carbon dioxide in the atmosphere is rapidly rising; it is already considerably greater than at any time in the last 800,000 years.

Sources: NASA, NNOCCI

GHGs' Contribution to Warming

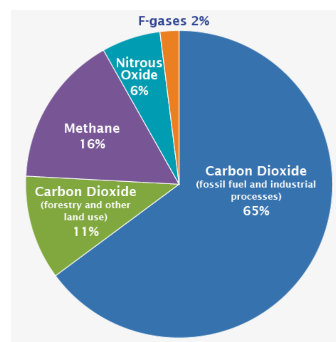


- The National Oceanic and Atmospheric Administration conducts an annual greenhouse gas index (AGGI), shown here, which compares the warming influence of the greenhouse gases carbon dioxide, methane, and fluorinated gases to their influence in 1990. Basically, this is an estimate of how much additionally warming of the Earth these gases have contributed.
- (Why 1990? This is the year that countries who signed the U.N. Kyoto Protocol agreed to use as a benchmark for their efforts to reduce emissions.)
- As of 2020, data indicated that the warming influence of greenhouse gases has increased by 47% since 1990, with 80% of that warming attributed to carbon dioxide.
- Scientists have further estimated that the atmosphere of today is absorbing an additional 3 watts of energy per square meter of the Earth's surface relative to pre-industrial times.

To obtain the latest AGGI value, visit NOAA Climate.gov: https://www.climate.gov/news-features/understanding-climate/climate-change-annual-greenhouse-gas-index

Greenhouse Gases: What are they, where are they coming from?

So far we've focused a lot on **Carbon Dioxide (CO2)** because it has been the primary contributor to our global warming. CO2 is primarily emitted through fossil fuel use, but it can also be emitted from direct human-induced impacts on forestry and other land use (e.g., deforestation, land clearing for agriculture, and degradation of soils). Land can also remove CO2 from the atmosphere through activities like reforestation and soil improvement. Some of the excess carbon dioxide will be absorbed quickly (e.g., by the ocean surface), but some will remain in the atmosphere for thousands of years.



Global greenhouse gas emissions by gas (based on 2010 global emissions.). Source: EPA

Other gases also play a role in our current global warming:

Methane (CH4): Agricultural activities, waste management, energy use, and biomass burning all contribute to CH4 emissions. **Methane stays in the atmosphere for ~12 years,** and over a 100 year period, **methane can trap 25 times more heat than carbon dioxide**.

Nitrous Oxide (N2O): Agricultural activities, such as fertilizer use, are the primary source of N2O emissions. Fossil fuel combustion also generates N2O. **Nitrous Oxide stays in the atmosphere for 114-121 years**. The impact of 1 pound of N2O on warming the atmosphere is **almost 300 times** that of 1 pound of carbon dioxide.

Fluorinated Gases (F-gases): Industrial processes, refrigeration, and the use of a variety of consumer products contribute to emissions of F-gases, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). **F-gases stay in the atmosphere for a few weeks to thousands of years** and are tens of thousands of times as efficient at trapping heat as carbon dioxide.

Sources: EPA - Climate Change Indicators; EPA - Global Emissions by Gas; NOAA - AGGI

Key Points: Checking In

- Greenhouse gases in the atmosphere act as a blanket around the Earth, keeping our global climate habitable.
- Historically, annual fluctuations in greenhouse gases are balanced. But as humans have burned fossil fuels (e.g., coal, oil, natural gas), we have added more greenhouse gases to the atmosphere, and they are trapping more heat.
- The biggest greenhouse gas contributor to our current global warming is carbon dioxide, and current levels are greater than they've been in the past 800,000 years.
- The heat that is trapped by these greenhouse gases emitted from human activities is warming the planet and is causing impacts across the globe (i.e., rapid climate change).
- The atmosphere of today is absorbing an additional 3 watts of energy per square meter of the Earth's surface relative to pre-industrial times.

Note to instructors: This is a good moment to check in with attendees to assess their understanding and answer questions.

Global Temperature Anomaly

- The graph on this slide illustrates the change in global surface temperature relative to 1951-1980 average temperatures.
- This graph was generated with data from NASA, and is up-to-date through 2021
- Nineteen of the hottest years globally have occurred since 2000, with the exception of 1998, which was helped by a very strong El Niño.
- The year 2020 tied with 2016 for the hottest year on record since record-keeping began in 1880.

Note to instructors:
The above information was obtained from NASA Vital Sights of a Changing Planet (https://climate.nasa.gov/vital-signs/global-temperature/) and downloading all data through 2021 (the most up-to-date data at the time these lessons were put together).

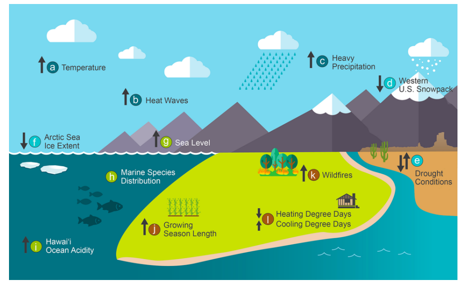
Warming Stripes for the Globe from 1850-2020

- Another way to visualize the change in temperatures we've observed globally is with this graphic, called the "climate stripes." Each bar represents a year in the globe's historic record, in this case the data goes back to 1850.
- The average temperature over the period 1971-2000 is set as the boundary between blue and red colors; anything cooler than the average temperature over this period is in blue, anything warmer than the average temperature over this period is in red.
- Using colors on this graphic makes it clear not only that we've been warming globally, but, as shown by the concentration of redder colors to the right side of the graphic, that the warming that we've experienced has been accelerating over the past few decades.
- This graphic can be obtained at the URL at the bottom of this slide (https://showyourstripes.info/s/globe) where you can also obtain stripes for different countries.

Sources: NASA, University of Reading (ShowYourStripes)

Indicators of Change

- Warming is just one indicator of the climate change we are currently experiencing.
- This figure, from the 4th National Climate Assessment, shows climate-relevant indicators of change based on data collected across the US. Upward-pointing arrows indicate an increasing trend in the US; downward-pointing arrows indicate a decreasing trend in the US Bidirectional arrows (e.g., for drought conditions) indicate a lack of a definitive national trend.



https://nca2018.globalchange.gov/chapter/1/

Key Indicators:

- Average temperature has increased (a), heat waves are occurring in more parts of the year (b), the average length of the growing season has increased (j), and heating needs have decreased while cooling needs have increased (l).
- More intense, single-day precipitation events are being observed (c).
- Large declines in snowpack have occurred in the western US (d)
- There is currently no detectable change in long-term drought statistics over the US (f), but warmer and drier conditions have contributed to an increase in large forest fires in the western US (k)
- The annual minimum sea ice extent has decreased at a rate of 11-16% per decade since the early 1980s (f). Annual median sea level along the US coast has increased (g). Marine species along the northeast US coast and Bering Sea have moved northward or to deeper depths for cooler waters (h).
- Oceans are currently absorbing more than a quarter of the carbon dioxide emitted to the atmosphere annually by human activities, increasing their acidity (i).

What Warming (and Other Changes) Have We Observed in NC?

- To discover more about the types of climate changes we've observed locally here in North Carolina, visit the Climate Trends Plotter, a tool from the North Carolina State Climate Office that enables users to view and plot historic trends for long-term monitoring stations in North Carolina and surrounding states.

https://products.climate.ncsu.edu/climate/trends/

For Instructors:

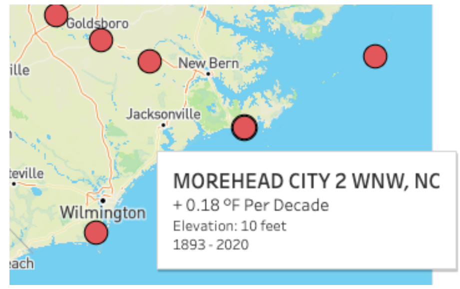
- This is designed as an activity for attendees and should take 5-10 minutes. If there is not time for this, the next slide contains an example that can be shared.
- Step 1: Instruct attendees to write down a question or hypothesis about how their local climate has (or has not) changed over recent decades and to jot down how they could answer this question or test this hypothesis with data. Depending on the size of the audience, attendees could be grouped into groups of 2-3 people to work together.
- Step 2: Instruct attendees to go to the Climate Trends Plotter tool. Once there, instruct them to spend a few minutes playing around with the tool. You can also walk them through some of the tool features, such as adjusting start/end dates, and changing the variable from temperature to precipitation.
- Step 3: Instruct attendees to revisit their question or hypothesis and to use the trends plotter to answer it. Once they have explored data, instruct them to write down their findings, and to include a reaction, such as whether their findings were surprising or not.
- Step 4 (optional): Once every attendee (or group if using groups) has finished, invite some to share out their questions/hypotheses and findings.

Example: Using the Climate Trends Plotter

For instructors: this is an example of using the climate trends plotter, following the steps outlined on the previous slide.

Climate Trends Plotter: https://products.climate.ncsu.edu/climate/trends/

Step 1: Question or Hypothesis:
Are winters getting warmer in Morehead City, NC? If they are, by how much? (Morehead City is located in eastern NC).

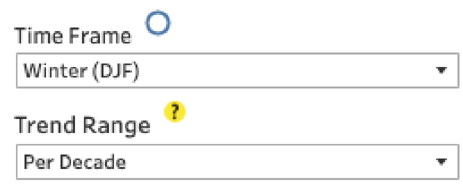


Step 2: Explore the tool.

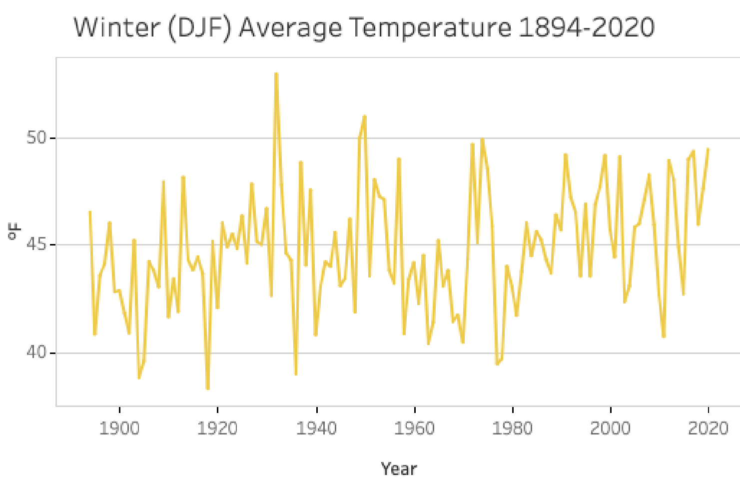
Step 3: The questions posed will be explored by viewing historic trends for a station in Morehead City.

First, select a station in Morehead City by clicking on it on the map.

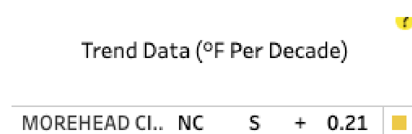
Then change the time frame from "Annual" to "Winter (DJF) using the dropdown menu to the left of the map.



The graph under the map should automatically update.



The decadal trend will appear to the left of the graph with a letter to signify whether that trend is significant (S), not significant (NS), or if there is insufficient data to estimate (I).



Step 4: Based on this tool, there is a lot of year-to-year variability in the winter temperatures that Morehead City experiences (graph). This location has been warming at a rate of 0.21 degrees Fahrenheit per decade between the period 1849 and 2020. While this may not seem like a lot, this is statistically significant.

Future Warming Depends on Future Emissions

So far we have covered how and why the Earth's climate is changing and a bit about some of the local climate changes we've experienced in North Carolina.

Now we'll turn our attention to the future.

- The latest assessment report from the Intergovernmental Panel on Climate Change modeled future global warming under a series of different future carbon dioxide emissions scenarios, ranging from very low emissions to very high emissions. Each of these scenarios are designed to provide guidance about how the world might respond given different pathways of human actions.
- These global emissions projections suggest that over the next two decades, the planet is likely to experience additional warming no matter what our emissions pathway is. This is because we are 'locked in' to short term warming path that is based on past emissions.
- Beyond this window, however, projections for future warming vary drastically based on what the world's future emissions are. Under a very low carbon dioxide emissions scenario, we could see a near-return to current levels of warming by the end of the century. In contrast, under a very high carbon dioxide emissions scenario, substantial additional warming is projected.
- Future warming therefore depends on future global emissions of greenhouse gases.
- The next lessons in this series will explore climate change in North Carolina and actions to adapt to and mitigate climate change.

Climate Actions

In future lessons as part of this series, we will cover the topics of climate adaptation and mitigation and the role these play in meaningfully addressing climate change.

- **Adaptation** consists of actions taken at the individual, local, regional, and national levels to reduce risks from even today's changed climate conditions and to prepare for impacts from additional changes projected for the future.
- **Mitigation** consists of actions reduce the amount and speed of future climate change by limiting emissions or removing carbon dioxide from the atmosphere.

Both will be needed for us to not only survive, but thrive, under a changing climate. The next lesson will explore climate changes and impacts in North Carolina and adaptation measures that promote resilience to these changes. The final lesson will explore climate mitigation.

End of Lesson Reflection

Think back to the exercise where you explored historic climate trends for a location in North Carolina. Reflect on the prompts below:

- What was your hypothesis or question and why was this of interest to you?
- What did you learn from exploring the data?
- How can this information help you (or others) make plans about how to respond to our changing climate?
- What questions do you have about climate change in North Carolina after doing this exercise?

A short assessment for this lesson can be found on the next page.

Assessment

The following four questions can serve as a summative assessment for this lesson. Instructors can give these as a quiz at the end of the lesson (e.g., as handouts or a Zoom poll) to check for understanding.

1. True or False: The greenhouse effect refers to the process by which certain gases in our atmosphere re-radiate longwave radiation that is emitted by the Earth back to the surface, warming the planet.

True

2. Which greenhouse gas has contributed the most to our current global warming?
a. Methane
b. Carbon Dioxide
c. Nitrous Oxide
d. Chlorofluorocarbons
e. None of the above

b. Carbon Dioxide

3. *Approximately* how much has Earth warmed since 1880?
a. 0.10°C (0.18°F)
b. 1.0°C (1.8°F)
c. 3.0°C (5.4°F)

b. Earth's temperature has risen by approximately 1.0°C (1.8°F) since pre-industrial times.

4. To understand how much future warming the planet may experience, scientists run climate models under different future scenarios of greenhouse gas emissions, also called climate ___________.
a. forecasts
b. predictions
c. projections
d. emissions

c. projections