ACS Climate Change Advocacy Workshop

Audio Transcript: (1) Module 1: The science of climate change

1.1 Earth's atmospheric chemistry overview

1.1.1 Earth's atmosphere

Earth's atmosphere is composed of many different gases, including 78% nitrogen, 21% oxygen, and 1% other gases, including carbon dioxide, methane, and nitrous oxide. The atmosphere also contains water vapor, particulate matter, and microbes.

1.1.2 The greenhouse effect

The purpose of a greenhouse is to let in the sun's light, so plants have a warmer environment to grow. The Greenhouse Effect is a phrase often used in relation to Earth's atmosphere. This is a natural process, which is described in more detail on the next slides.

1.1.3 The greenhouse effect

The sun's light passes through Earth's atmosphere, and is absorbed and radiated upward from the land as heat. Certain gases in Earth's atmosphere absorb the heat and radiate it back toward Earth, warming the planet. These are called greenhouse gases – or GHGs - and include carbon dioxide, methane, nitrous oxide, ozone, and fluorinated gases such as hydrofluorocarbons (0:34-0:38-ish) and perfluorocarbons. Without GHGs, the world would be much colder. (0:44-0:50) At the core of the world's climate change issue is the increasing amount of these GHGs in the atmosphere due to human activities, which is resulting in a warming planet.

1.1.4 GHG warming impacts

Take a look at this breakdown of greenhouse gases in Earth's atmosphere from a 2021 C&EN article. The graph shows the contributions of different GHGs to warming, considering their different warming impacts and lifetimes in the atmosphere.

1.1.5 Greenhouse effect video

This video by NASA will help to explain how the Greenhouse Effect works in Earth's atmosphere.

1.1.6 CO_2 and CH_4

In particular, CO_2 and CH_4 are a major problem for climate change. Carbon dioxide is introduced by power plants fueled by burning coal or natural gas, and burning fossil fuels through car engines, shipping, factories, and more. Carbon dioxide has many sources of emissions which makes it difficult to track and pinpoint. Methane, on the other hand, can be introduced primarily through natural gas leaks which are 94 percent methane, landfill methane emissions from the breakdown of organic matter, and livestock agriculture. Methane is mainly a type of point-source pollution, which is easier to track where gases came from.

1.1.7 What's the deal with CO_2 and CH_4?

While they are both naturally present in the atmosphere, human activity, specifically burning coal, oil, and natural gas have substantially increased levels of both CO_2 & CH_4 since the Industrial Revolution. Drag an option to each space to identify the correct answer and find out more about these two greenhouse gases. Click the “Check” button at the bottom to verify your answers.

1.1.8 CO_2, CH_4, and human activity

Drag an option to each space to identify the correct answer and find out more information about these two greenhouse gases. Click the “Check” button at the bottom to verify your answers.

1.1.9 Fluorinated compounds

According to the U.S. Environmental Protection Agency – or EPA – fluorinated compounds are the most potent and longest lasting type of GHGs on a per molecule basis emitted by human activities. Chlorofluorocompounds, or CFC's, are compounds used by humans for many uses like refrigerants, aerosol hairsprays, etc. from the 1950's to 1990's.

1.1.10 Ozone

The figure shows a cross-section, or slice, of Earth’s atmosphere and some of its different layers. At Earth’s surface, there’s surface level ozone pollution called smog from industrial activity and cars. The ozone layer is located within the stratosphere and protects life from harmful UV-C radiation as well as most UV-B and some UV-A radiation. Once the CFC’s are released, they are highly efficient at depleting Earth’s ozone layer.

1.1.11 Earth’s ozone layer

The image on the right by the National Aeronautics and Space Administration – or NASA -- shows Earth’s ozone layer and the ozone hole over Antarctica. Green color on the image indicates thicker ozone, whereas blue and purple indicate thinner ozone. The Montreal Protocol, a worldwide agreement which will be discussed later, phased out the use of CFC’s. Today, NASA can see evidence that the ozone hole is in recovery. This worldwide agreement remains one of the most successful policy efforts to combat human activity that impacts the planet.

1.1.12 Transition

But, the question remains, how exactly do scientists measure CO_2 and CH_4, and record temperatures in the atmosphere? How do these relate to climate change? The work described in the next section is critical to understanding what is “normal” for Earth versus what is caused by human activity, and projecting future global climates. The next section will discuss all of this in detail.

1.2 – Measuring and recording Earth’s atmosphere

1.2.1 Measurements

Scientists measure contemporary GHGs and temperature through a ground-based network of monitoring stations, towers, buoys, commercial aircraft, and more. Satellites are used for space-based measurements of current GHG levels. Ice cores, among other things, are used to examine historic atmospheric conditions. Together, they provide a comprehensive look at past and present conditions on Earth.

1.2.2 NOAA concentrations video

Before you dive into this topic, check out this video by the National Oceanic and Atmospheric Administration – or NOAA. It provides a comprehensive overview of how carbon dioxide concentrations in the atmosphere changed over time, and a visual to see how different datasets come together. This work allows people to see how humans changed the Earth’s atmosphere. The next few slides will provide more context.

1.2.3 Measuring present levels of CO_2
Atmospheric CO_2 levels have been closely monitored for decades at the Mauna Loa Observatory in Hawaii. Scientists established the observatory there because it was far from industrial areas that could skew the measurements. The graph on the left by NOAA shows recent monthly average CO_2 at Mauna Loa Observatory. On the y-axis, CO_2 is measured in parts per million, and on the x-axis the year runs from 2016 to 2022. On the next slide, you will get a little more perspective as the timeline expands.

1.2.4 Looking back a little further
The graph on the left provides a better trend of directly measured CO_2 since 1960 as provided by NOAA. CO_2 has risen from 320 parts per million to almost 415 parts per million. Again, it is apparent that CO_2 is rapidly rising... but how does that compare to the atmosphere before 1960? The observatory was established just before 1960, so scientists must turn to other data sources.

1.2.5 Paleoclimate
'Paleo', or ancient, climate data is a way to investigate conditions of the past and understand changes that occurred. Sources for paleoclimate data include tree rings, ice cores, corals, ocean and lake sediments, and more. In addition to modern instrumentation, scientists can also gather information about Earth's temperature, among many other things, from paleoclimate data.

1.2.6 Getting to the ‘core’ of it
Glaciers are a great window into the past. As snow falls on glaciers each year, it accumulates, the pressure builds up, and creates layers of ice. The layers of ice have tiny bubbles that contain trapped air from when the ice layer formed. Scientists can dig out a 'core' down through the layers of ice (pictured here) and examine the air chemistry in those bubbles. The cores can give us information about past temperatures and what aerosols or GHGs were in the atmosphere.

1.2.7 Reconstructing past climate from ice
This NOAA and Scripps plot shows ice core CO_2 measurements that go back to the Ice Ages, about 800,000 years before today. The red line from the previous graph showing 415 parts per million CO_2 today, is now at the very top right of this graph. Essentially, this graph says that even with the natural cycle of Earth's climate, CO_2 in the atmosphere is substantially higher than pre-industrial times, where CO_2 was 278 parts per million. It is also higher today than during the Ice Ages, where it was about 185 parts per million. In other words, humans have added a lot of CO_2 to the atmosphere!

1.2.8 Satellites, remote sensing, and other technologies
In addition to direct air measurements in Hawaii and in other locations around the world, towers and commercial aircraft take GHG measurements at specific locations. Infrared cameras detect

methane leak points at target locations such as leaking landfills and oil & gas infrastructure. This technology helps to expand scientific knowledge about the Earth and address issues.

1.2.9 Climate measurements from space
Scientists can also use satellites to track methane and other GHG emissions. Satellites today include the GeoCARB Satellite, which will produce carbon dioxide, carbon monoxide, and methane maps. The TEMPO Satellite measures nitrogen dioxide, formaldehyde and other air pollutants. Additionally, NASA OCO-2 and OCO-3 satellites, European Copernicus Programs CO2M satellite, and Japan's GOSAT and GOSAT2 all measure GHGs.

Like towers and commercial aircraft, satellites provide essential data about where emissions originate, their levels, and are key to drafting policy and legislation to remediate or mitigate these activities that are contributing to climate change.

To learn more about all the satellites currently flying and how they help inform climate science, click the resource icon at the bottom right.

1.2.10 An important note
While technology has advanced the knowledge of Earth's climate, there are limitations to each. Ground- and air-based measurements provide high accuracy but low coverage, while space-based measurements provide high coverage and resolution but less accuracy. Another challenge for these measurements is the high amount of carbon dioxide in the atmosphere. With all of it floating around, it's difficult to detect human-induced emissions sources. Another major challenge is the need for very high precision and accuracy to pinpoint sources of emissions since currently only the largest sources of emissions provide a change large enough -- 1 part per million -- to detect. With these challenges and limitations, it is essential to access high coverage and spatial resolution which can only be obtained if all ground, sea, and airborne networks work together with space-based measurements.

1.2.11 Tracking methane from space
As a specific example of the kind of data that this technology can collect, look at the aerial map provided. It shows point-source tracking of methane emissions in the Permian Basin in the Southern United States. Yellow indicates a higher intensity of methane, whereas purple denotes a lower intensity.

Identifying these locations and repairing leaks can quickly reduce emissions and overall help in combating climate change.

1.2.12 Transition
In the next section, you will learn more about how global temperatures are measured, how future climate change projections are made, and will begin to explore different global temperature visualizations.

1.3 Global temperatures, modeling, and visualizations
1.3.1 Global temperatures and CO_2

Global temperature and carbon dioxide levels are tightly connected. As global carbon dioxide and GHG levels increase due to human activity, the amount of the Sun’s heat that’s unable to escape Earth’s atmosphere also increases thanks to the greenhouse effect. Due to this, average global temperatures also increase and there is a clear long-term global warming trend. The changes to Earth's surface temperature are a bit delayed due to natural processes like volcanic eruptions and El Niño and La Niña climate patterns. Additionally, areas on Earth (like the oceans) are able to absorb or take in CO_2. This is why the temperature fluctuates year-to-year and doesn't react instantly to the current year's record-breaking CO_2 level.

1.3.2 Global temperatures
An example of the type of information scientists can get from all these technologies is presented at the bottom in a graph tracking temperatures since 500AD. Green indicates proxy measurements gathered from paleoclimate data and blue indicates direct measurements. Based on this graph by NASA from year 500 to 2000, the global temperature anomaly normally hovers around 0 degrees Celsius, but since approximately the 1900's, that anomaly has increased substantially. 0.5 degrees Celsius may not seem like much, but it can have some big impacts!

1.3.3 Climate change models and projections
Scientists build and run climate *models, or simulations,* to understand future climate conditions under different scenarios. Climate models are a diverse group in terms of complexity and comprehensiveness, which lend themselves to different uses. The next slide will explain models in more detail.

1.3.4 Overview of climate change models
Climate models help to explain how long-term patterns of weather parameters like temperature, precipitation, humidity, sunlight, and wind can change using mathematical analysis based on physics and Earth observations. Variables include the atmosphere, land cover, sea ice and the oceans, among others.

Earth System Models are the most complex and comprehensive climate models. In addition to climate processes, they include many other physical, chemical, and biological processes that shape the planet. They help unravel the relationships between climate and humans, plants, and other life on Earth. The different scenarios projected can be useful tools for designing future energy, land, or infrastructure plans. They can be based on potential policies to learn how certain decisions might impact the future.

To learn more about climate models and their limitations, click on the resource icon below.

1.3.5 Global surface temperature changes
These maps by NASA’s Goddard Institute for Space Studies show the stark differences in average global surface temperatures for the years 1881-1885 when modern record keeping began and 2017-2021. White indicates normal temperatures, blue shows areas that are cooler than normal, and red shows areas that are warmer than normal. Since direct measurements began, seven of the eight warmest years happened after 2015. To learn more about climate visualizations, click on the resource icon below.

1.3.6 So, what about global temperatures?
Here's a striking visual of the global average temperature anomaly from 1850-2020 created by scientist Ed Hawkins. Blue colors on the left transition to red colors on the right. Blue indicates less of an anomaly than red, which indicates a greater anomaly.

1.3.7 Visualizing global temperatures
Each stripe represents the Earth's temperature averaged over a specific year. The transition from blue to red visually shows the rise in global average temperatures. The visual really demonstrates how the planet has consistently increased in temperatures since the Industrial Revolution.

1.3.8 Future global temperatures
Now, look at what climate models say about global temperatures. Here is one projection of what the stripes look like through 2090 if action is taken to limit warming to 1.5° Celsius – as is depicted in the bottom right – and what it looks like if action is delayed – as is depicted in the top right. If action is taken to limit warming, the red color will be lighter compared to if action is delayed. Delayed action results in a very dark red color.

1.3.9 Global temperatures and your city
The image here shows the warming stripes for Washington, D.C. from 1872-2020. Click on the link at the bookmark in the corner to visit the Climate Central website and see what your city looks like.

1.3.10 Limiting impacts of climate change
At current annually averaged GHG emissions levels, the world is on track to exceed 3°C of warming which would have severe consequences for societies.

The worst impacts of climate change can be avoided if the world unites to limit globally averaged temperature changes to less than 1.5°C to 2°C.

The graph by Climate Action Tracker shows warming projections, emissions, and expected warming for the year 2100 based on current policies. The graph highlights the amount of policy work still needed to ensure warming of the planet is limited to less than 1.5 to 2° C.

1.3.11 Transition
For more about the science behind climate change, check out the American Chemical Society's Climate Science Toolkit by clicking the resource icon in the bottom right corner of the screen. In the next section, you will be introduced to societal and environmental impacts from climate change.