

Dear Presenter,

Thank you for accepting the challenge of helping people understand the concept of global climate change – both its foundation in science, and its broader social and economic implications.

We all face the difficult task of describing the causes and likely impacts of climate change in a way that members of the public can digest. Only a clearer understanding of global warming and climatic disruption will enable others to identify and examine appropriate responses to this timely and crucial issue. We hope that you, as a presenter, also will want to incorporate climate change into other programs, including environmental and natural history presentations.

Through the Climate Change Backpack, a unique educational tool, we address global warming by bringing its science and potential consequences down to earth. Simple, easily replicable presentations and exercises convey the complexities of climate science, the state of the research and the implications for the Northeast. The materials you will find in the Backpack are designed to help you engage your audience in exploring how climate change can affect real people where they live.

Success, however, will hinge on our skill as educators and communicators. The New England Science Center Collaborative, formed in 1999, is committed to bridging the gap that exists between current public understanding of global warming and the conceptual framework that will be necessary to nurture an effective citizen dialogue and response. Our work at NESCC focuses on linking the science and the scientists to the educators and the public.

We hope you'll agree that the Climate Change Backpack is an important component of the gear that will be needed to scale this monumental challenge. Again, we thank you, wish you well and look forward to news of your journey.

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Table of Contents

Introduction.....	1
• The Climate Change Backpack	
• Suggestions for the Presenter	
• Tips for Your Presentation	
• Take-Away Concepts on Climate Change	
• Backpack Components	
Section 1 - Climate Change:	
Introduction.....	3
• Concepts and Issues	
DISCUSSION: Introducing Climate	
• Scientific Background	
• Current Level of Scientific Understanding	
Section 2 - Carbon and Life.....	13
• Carbon in Plants	
ACTIVITY: Photosynthesis	
• Carbon Cycles	
ACTIVITY: Follow the Carbon	
• Scientific Background	
DEMONSTRATION: Please Pass the Carbon	
Section 3 - The Greenhouse Effect.....	23
• Greenhouse Gasses	
ACTIVITY: Greenhouse Globes	
• Global Carbon Dioxide and Temperature	
ACTIVITY: Graphs -- A Look Back	
Section 4 - What Science Says.....	33
• Past Climates	
• Investigate Climate Change	
ACTIVITY: Greenland Ice Cores	
• Natural Variability	
ACTIVITY: The Timeline Clothesline	
• New England Temperature Graphs	
ACTIVITY: Seeing and Believing	
• Future Climate Scenarios	

Section 5 - Climate Change Impacts.....50

- New England Forests
DISCUSSION: Maple Sugar Farming
- Seacoast and Oceans
DISCUSSION: Fishing
- Tourism and Recreation
DISCUSSION: Inn keeping

Section 6 - Finding Solutions.....58

- Individuals
ACTIVITY: What Can You Do?
- Businesses

Resources.....65

Glossary.....66

Acknowledgments.....75

Backpack Components

- **Photosynthesis Poster**
- **Carbon Cycle Poster**
- **1 Plastic Dome**
- **2 Thermometers**
- **Thermometer Covers**
- **Tree Cookie**
- **2 Mock Ice Cores**
- **33 Timeline Cards**
- **Clothesline and clothespins**
- **Piece of Foam Insulation**
- **Biodiesel Vial**
- **Toy Car**
- **Light Bulb (compact fluorescent)**
- **Plastic Bottle**
- **9 4x6 Index Cards**
- **Ballot**

We know that many human activities contribute to climate change.

If those activities continue at their current pace, it is likely that the earth's temperature will rise 4 to 11 degrees over the next two generations.

Though it will be challenging to prepare for or deflect the environmental changes expected to result, if we fail to act, millions of people will face a heightened risk of disruption, disease, displacement and death.

We know how to slow down climate change - but will we?

It's up to us.

Introduction

The Climate Change Backpack

In the guise of a rucksack, the Climate Change Backpack provides a brief, down-to-earth introduction to the science of climate change. Its contents, supplemented by this Guide, summarize – at an accessible level – the main points of scientific understanding and agreement, and then present that information in the form of activities well-suited to environmental and natural history programs. The background information and simple exercises outlined in this Guide are designed to help you and your audiences learn how natural systems work, how human activities can have an impact on those systems, and how we in turn are affected by that impact.

In the Climate Change Backpack, we present five New Englanders, each having a special – yet broadly representative – relationship to climate and the environment. Their lives have been or could be affected by climate change. These personal stories will help your audience develop a more direct connection to an issue that sometimes suffers from a high level of abstraction, and they will assist you in making the point that climate change and related environmental impacts affect economies, businesses, landscapes and – most of all – real people.

Suggestions for the Presenter

The Climate Change Backpack is a flexible tool to assist you as a teacher. The Backpack draws on investigative learning, a teaching approach well suited to interpretive natural history. It can support a stand-alone program lasting an hour or more, or be adapted to an impromptu talk of only a few minutes. It also can serve as the core curriculum for a short course on climate change. You can use some of it or all of it, add to it or subtract from it, expand on a topic of interest or ignore a given subject entirely. The Backpack also may prove useful when presenting units on other areas of natural history, such as photosynthesis, geology, energy, the water cycle, land stewardship and forestry -- to name just a few.

We encourage presenters to develop their own materials to supplement the Backpack. Helpful references drawn from *Project Learning Tree* and other resources are listed at the end of this Guide.

Last but not least, have fun!

Although climate change is worrisome (to put it mildly), it doesn't need to be presented in a way that dwells only on doom and gloom. The approach adopted by the Backpack emphasizes scientific understanding of a subject that deserves to play a more central part in our ongoing civic dialogue. As environmental science educators, both professional and volunteer, we are in a key position to nurture an awareness of natural systems, and foster an appreciation for the services and benefits we all derive from them. There is no more powerful system on Earth than our climate. And there is no more important issue right now than climate change – what it is, and what it holds for our future.

Tips for Your Presentation

It is important to convey that the global climate system is extremely complex, and that climate science involves considerable uncertainty. Much remains to be learned, and it's perfectly fine to let your audience know this. Always keep in mind that you are introducing general concepts, not delving into the highly technical details.

Here are a few tips for making your programs as authoritative and effective as possible.

- Remember these basics:
 1. “Tell ‘em what you are going to tell ‘em, tell ‘em, then tell ‘em what you told ‘em.”
 2. Before speaking, make sure you can make eye contact with each member of your group, then do it.
 3. Stand with the sun at the audience’s back whenever possible.
 4. Do your homework! Buy into the topic in some way – draw up an inventory of the carbon emissions produced by your own lifestyle, cut your driving by 25 percent and keep a log of the experience, do a home energy audit, plant a tree. Don’t forget to be yourself.
- When heading into areas beyond your own comfort level or expertise, try to use phrases like “It’s my understanding that...” or, “It appears to be...” or, “Scientists have found...”.
- “I’m sorry but I don’t know” is a perfectly appropriate response to a question. If you think you can find an answer, you might offer to look it up later.
- Make review part of your preparation. A good time to do this is when you pack materials away at the end of a presentation.
- Give your group one or two take-away messages. Here are some ideas:
 1. Carbon moves in cycles through the earth, the oceans and the atmosphere.
 2. Climate systems are extremely complex, and we have much more to learn about them.
 3. Scientists investigate clues from the past to learn about climate.
 4. Human activities have an effect on the climate.
 5. Adding greenhouse gasses to the atmosphere may change the climate dramatically -- in ways we can’t predict.
 6. Human activities magnify the earth’s natural greenhouse effect, but they don’t create it.
 7. People’s jobs, health, and quality of life can change when climate changes.
 8. There are many things we can do to reduce the amount of carbon dioxide in the atmosphere.

Section 1 – Climate Change

Take-Away Points

- ▶ **Carbon cycles through the environment along two major pathways**
- ▶ **During part of its cycle, it resides in the atmosphere as carbon dioxide**
- ▶ **Carbon dioxide is a powerful greenhouse gas that plays a natural role in stabilizing the earth's temperature**
- ▶ **Changes in the carbon cycles can affect global temperature**
- ▶ **Carbon dioxide emissions that are caused by people can alter the carbon cycle and increase global temperature**
- ▶ **Even very small temperature changes can represent a big change in the climate**
- ▶ **Rapid climate change will change ecosystems and the species that live in them**
- ▶ **Earth's average temperature has fluctuated a great deal over the past 10,000 years**
- ▶ **But during the past 100 years, average global air temperature has registered its sharpest increase since humans first appeared on earth**
- ▶ **A big part of that increase is the direct result of greenhouse gases emitted through human activities**

Summary of Concepts and Issues

Please review the following summary of key points before your presentation. In addition, look over the resources listed in the back of this Guide. They provide additional information on the current state of knowledge about climate change. Your efforts as a presenter will be more effective if you devote several hours to becoming familiar with the basic concepts and issues, or attend a docent training session run by the New England Science Center Collaborative.

The global climate system is extremely complex, and our knowledge about it is incomplete. Nonetheless, important climate change mechanisms and components are well understood.

The global climate has undergone fluctuations in the past, and in fact has changed more than it is changing today. Examination of this long history shows that rapid global warming, as well as global cooling, can cause severe disruption to life on earth – whatever the cause.

Although worldwide temperature swings have taken place naturally over hundreds of millions of years, the term “global warming” is commonly used to refer to a rise in average global temperature of about 1.1 °F, measured over the course of the past century. Some people use the term to refer specifically to the warming caused by human activity; others use it in a more general sense to describe any increase in global temperature. Either way, we look to a key indicator – *average global* temperature. This tells a more complete story than local readings, which can vary from year to year, and place to place.

That the average global temperature is increasing, and that a portion of this increase is directly caused by human actions is no longer a matter of scientific debate [see IPCC 2001 Climate Change Assessment: <http://www.ipcc.ch/>]. The second-warmest year in history was 1997. The warmest was 1998. The top 10 warmest years in the past Millennium, and perhaps longer, have all been recorded since 1984. No known natural climate change mechanism can account for the extent of the temperature increase measured in the past three decades.

Changes in global temperature lead to changes in many of the components of our climate. Besides temperature, those components include:

- Moisture – rainfall patterns and amount, clouds, and humidity.
- Wind – its speed, direction and frequency.
- Seasons – their duration and timing.
- Storms – their distribution, frequency and intensity.
- Global circulation patterns – in the atmosphere and in the oceans.
- Atmospheric chemistry – and related air quality

Drawing on computerized global circulation models, leading climate scientists around the world have reached a consensus that the earth is likely to experience a 2.5-to-10.4 °F increase in average global temperature in the course of the 21st century. That rate of warming would surpass all other such temperature fluctuations over the past 10,000 years.

Most of the warming between 1970 and the present has been caused by human activity, particularly fossil fuel combustion and deforestation. As a result, atmospheric levels of major greenhouse gasses, especially carbon dioxide, are rapidly increasing. The concentration of atmospheric carbon dioxide (CO₂), in fact, is at its highest point in at least 420,000 years – and some believe as long as 20 million years.

Carbon dioxide – like water vapor, methane and several other airborne compounds – contributes to the so-called “greenhouse effect.” An important natural phenomenon, the greenhouse effect heats our atmosphere in a manner that is not unlike the way that a greenhouse stays warm in the winter. The light from the sun travels through the atmosphere until it hits the earth’s surface, when much of it bounces back and heads toward outer space. The greenhouse effect prevents some of the heat converted from light from leaving the earth’s atmosphere. This helps keep temperatures on the surface of the earth within a 30 °F range of livability. Without the greenhouse effect, the average temperature would plummet to zero, a drop of 60 °F or so. If that happened, life, at least as we know it, almost surely would cease to exist. On the other hand, too effective a greenhouse can also pose a catastrophic risk. That is where we find ourselves today. To understand why the atmosphere might contain an overabundance of CO₂ and other greenhouse gases, we need to know more about carbon cycles.

Carbon is always in motion. Moving along two separate pathways, it cycles through the atmosphere, the earth, the oceans and all green plant life. One carbon cycle takes millions of years to complete, the other only tens to hundreds of years. The long-term cycle moves

carbon into the atmosphere, across the ocean floor, through fossil fuel deposits and volcanoes, and into rocks and the earth's crust. Set against the human time scale, long-cycle carbon moves so slowly that for all practical purposes it is locked in storage forever. By contrast, carbon in the short-term cycle flows relatively briskly through the air, the ocean, the plants and the soil. Key drivers include photosynthesis and decomposition. During photosynthesis, green plants take in carbon dioxide and emit oxygen. Conversely, microorganisms that decompose plants consume oxygen and emit CO₂.

In the short run, elemental cycles, such as for carbon tend to remain relatively stable. But human intervention can change that. When we extract and burn fossil fuels like coal, oil and natural gas to heat our homes, power our cars and generate electricity, large amounts of carbon suddenly jump the track from the long-term cycle to the short-term cycle. Most of that carbon ends up as CO₂ and methane (CH₄) in the atmosphere. This intensifies the greenhouse effect, and raises average global temperature further. Today, in fact, more carbon travels from the earth's surface to the atmosphere than the other way around.

When plants and trees burn or rot, the carbon stored inside of them is also emitted into the atmosphere. If the sum total of all plants and trees on earth – its total biomass – decreases, then the amount of carbon dioxide emitted into the atmosphere will increase. This reduction in biomass further alters the short-term carbon cycle.

The movement of stored carbon from the long cycle into the short cycle raises atmospheric concentrations of CO₂, and this in turn increases average global temperature. All across the globe, higher temperatures affect regional climate and weather patterns, and cause sea levels to rise. A hotter climate may spark other changes that release even more carbon dioxide, raising temperature further – and setting off another round of carbon emission. This is an example of a positive feedback loop that reinforces and magnifies the risk of climate change.

A fast-changing climate imposes a multitude of stresses on earth's ecosystems. If the species of plants and animals that live in those ecosystems cannot adapt to rapid change, they will need to migrate – or die out. Climate change could lead to a decline in the ecosystem goods and services that natural ecosystems produce and that we depend upon – resources like clean air and water, as well as adequate food and shelter. Such a loss will make it more difficult to meet the needs of a growing global population, and could lead to increased loss of human life due to disease, starvation and displacement.

Ways exist to blunt the impact of these changes. For example, we could cut emissions of CO₂ and other greenhouse gasses by reducing energy consumption and rates of deforestation. This would at least slow the rate of greenhouse gas accumulation in the atmosphere. Increasing global biomass would increase the terrestrial storage of atmospheric CO₂.

How much will it cost to reduce the risk of global warming? Some people contend that the price tag will be exorbitant. Others argue that there are a number of effective and inexpensive strategies of reducing greenhouse gas emissions. For now, let's just note that a very active political debate continues over how we should respond to humanity's impact on the earth's climate – and its threatened impact on us.

Though still uncertain in some respects, the basic science is subject to less disagreement. This alone makes climate change an important and timely issue. And its importance is magnified given the other stresses that we have already placed on the biosphere.

DISCUSSION: Introducing Climate and Change

Start out your presentation by asking people to share opinions and information about global warming and climate change. They may want to discuss something that they heard on the news or read in a newspaper. They may ask questions. Simply listen and acknowledge their input. There is little need at this point to respond at length. But it would be helpful to ask them how they feel about what they have observed or described. This process connects you to the group.

After a few minutes, sum up what you've heard. Keep in mind the key concepts that relate to the Backpack's climate change activities. You will cover some of these during your presentation:

- Global temperature is rising and the climate is changing.
- Climate change is caused by two basic phenomena: natural events and human intervention.
- Carbon plays a major role in climate change.
- The natural greenhouse effect warms the earth.
- Human activities intensify the greenhouse effect.
- Scientists examine evidence from the past to predict future climate characteristics.
- A changing climate will affect individual people – lots of them.
- Right now we may not be prepared to deal with some potential changes.

The following graphics are included in color format elsewhere in this Guide. Show them to your group while introducing the topic.

GRAPHIC #1

Climate Change

- Human activities can alter the global temperature
- When global temperature changes, so does the climate and the environment
- A big part of the current increase in global temperature, known as ...

Global Warming

... is caused by human activities like

- Burning fossil fuels, and
- Deforestation

Slow Climate Change

When climate changes slowly, people and the species living in the world's ecosystems can adapt.

But when the climate changes rapidly, people and other species cannot change fast enough to insure their survival.

Enhanced by human activity, the earth appears to be entering a period of

Rapid Climate Change

GRAPHIC #2

Background

Climate Change Patterns

Twenty thousand years ago, at the height of the most recent ice age, the average surface temperature of the earth was about 45 °F, some 15 °F colder than it is today. That marked a time when ice sheets more than one mile thick covered 30 percent of the globe, including all of New England.

Over the next 10,000 years, this great ice sheet receded as the earth's temperature rose, possibly to a level somewhat warmer than it is today. This was not a time of steady, gradual change. It was a period of volatility. In a mere 5 to 20 years, temperature changes on the order of 20 °F took place. Dramatic alterations in the landscape were the result.

Over most of the past 10,000 years, as the ice sheets receded to their present size and location, the earth's average temperature increased between 5 and 10 degrees. In the final thousand years of that period, average temperature rose and fell only slightly, perhaps a third of a degree each way.

However, during the past century – since 1900 – global temperature has shot up about 1.1 °F, with the lion's share taking place in the three decades since 1970. If this rate persists, the current warming trend could turn out to be the most rapid worldwide temperature increase in 11,000 years – since the end of the last major glaciation.

It is important to remember that the global climate system has exhibited very fast rates of warming with no help from humans – in fact, well before there were any of us around to offer a hand in the process. But those rapid increases generally occurred right after the coldest part of a cyclical cold cycle known as an ice age. The current jump is different in two critical ways. First, it is happening at a time when global temperature already is quite high. Second, and more importantly, it comes during a hundred-year period when global ecosystems already are under great stress due to a five-fold increase in global population and the enormous impacts of industrial pollution.

The earth's climate has shown that it can change dramatically, and do so at a fast clip and it is well understood that greenhouse gasses can play a significant role in this rapid change. Thus, to suddenly load the atmosphere with large quantities of greenhouse emissions – as we are doing today – is a lot like poking a sleeping monster with a short stick. It is risky.

A Little Temperature Variation Can Have a Big Impact

One degree may not sound like much, but it can be. An average temperature drop of only about one-third of a degree, for example, accompanied what is known as the “Little Ice Age.” During this period, which lasted from the 15th century to the 19th century, rivers froze over in England, glaciers advanced in the Alps, and Europe and North America (and possibly the entire non-tropical world) experienced harsh winters and cool summers. Earlier, during the Medieval Warm Period (the 9th to 13th century), a mere one-third of a degree increase in average global temperature helped smooth the path for Viking settlements in Greenland. The one-degree increase we are seeing now is already altering ecosystems across high northern latitudes, and contributing to rising sea levels.

Historical data show that a fractional change in global temperature can cause social disruption on a regional scale. Over the next hundred years, scientists forecast, average global temperature is expected to skyrocket by 2.5 to 10.4 °F – if no action is taken soon. If this scenario comes to pass, environmental and lifestyle changes appear to be inevitable. Given the interconnectedness of today’s world, it seems likely that the ensuing disruption would be global.

The Current Level of Scientific Understanding

Although sometimes it seems that scientists disagree about many aspects of global warming, when it comes to the basic picture, there actually is considerable common ground...

Scientists Know That...

- The greenhouse effect is a natural process that helps to keep the earth about 60 °F warmer than it would otherwise be.
- Carbon dioxide is an important greenhouse gas.
- The amount of carbon dioxide and other greenhouse gasses in the atmosphere is increasing rapidly as a result of human activities that include fossil fuel combustion and deforestation.
- The greenhouse effect is not the only mechanism that causes climate change.

Scientists Agree on Key Estimates...

- The earth's average annual temperature has increased at least 1.1 °F over the past 100 years.
- Average sea level has risen 3 to 7 inches over the past 100 years.
- Earth's rate of warming is now increasing.
- The 1990's were the warmest decade in at least 1,400 years.
- CO₂ levels are the highest they've been in 420,000 years -- and possibly for far longer.
- Much of the global temperature increase since the 1970's has resulted from human activity.

Many Scientists Believe That...

- CO₂ levels will continue to increase unless we cut emissions by more than half – at least.
- If the trend continues, it is likely that the global temperature will rise between 2.5 and 10.4 °F over the next 100 years.
- If so, sea levels also will rise one to five feet.
- Some big climate surprises, caused by shifts in ocean currents, may be in the offing.
- There will be economic and ecological winners and losers; developing countries will likely be the biggest losers.

If Warming Continues at the Present Rate, Scientists Think...

- Species will be forced to migrate, or will vanish.
- Tropical diseases will spread into formerly temperate climates.
- The location of prime agricultural areas will change, placing extreme pressure on food distribution systems.
- Millions of people will be displaced or killed by increased flooding.

Scientists Wonder...

- Will extreme weather events occur more frequently?
- Why the earth isn't warming even faster than it is.
- Where some of the carbon dioxide deposited in the atmosphere over the past 100 years has gone.
- What role clouds play in warming and cooling the earth?
- The extent to which variation in the sun's output contributes to climate change.

Uncertainty and Precaution

Some of the few disagreements about the science of climate change center on forecasting methods. The majority of scientists agree that the most likely climate scenario – average warming of 2.5 to 10.4 °F during the next century – is based on the best information available. But, they acknowledge, uncertainties remain. Some scientists argue that climate forecasting must attain a higher level of certainty before nations commit money and time to mounting a response. Others are convinced that the evidence is sufficiently compelling to justify action now to mitigate impacts that could be catastrophic if our response is delayed. Because of the momentum in the carbon cycle, action today would have a larger impact than the same action tomorrow.

Uncertainty is part of decision making in all parts of life. You could ask your group to talk about how certain they need to be before they decide to do something themselves. How do different levels of certainty influence action? Here are a few examples: bringing along a raincoat, wearing a bicycle helmet, choosing a doctor, investing in the stock market, buying a car. How do you know whether an activity or product is safe? What about “products” that people don't have much choice about – air and water, for instance? How about nuclear power and genetically modified foods? In what ways do you “consume” scientific information to help you make decisions?

A key concept here is something known as the “precautionary principle.” The precautionary principle counsels action – especially low-cost action – whenever we are faced with a potential threat of great magnitude, but are uncertain of the likelihood that it will actually materialize. A typical way to evaluate a situation like this is to multiply the estimated likelihood that the risk will materialize by the cost of the resulting damage if it does, and then compare the result to the expense of taking precautions now. If the cost of precaution is less than the risk-adjusted cost of damage, then it would make sense to act. But this way of looking at things may not apply very well, or even apply at all, to situations in which the potential damage is massive – damage of the sort that could displace nations and economies and people all across the earth. Climate change may be such a risk. If so, the precautionary principle would counsel a different, and more protective response. You may want to take this up with your group.

DID YOU KNOW?...

Back in 1896, the great Swedish chemist Svente Arrhenius suggested that burning enough fossil fuels to double atmospheric CO₂ concentrations might raise average global temperatures by 10 °F. This is not far from the current forecast. The unprecedented increase in atmospheric CO₂ and other greenhouse gases during the past 100 years has already put us on the path of the earth's temperature rising 2 to 4 °F – even if all climate change emissions were stopped immediately.

Section 2 – The Role of Carbon

Take-Away Points

- ▶ Carbon is an important part of life on earth, and is found in everything from plants and animals, to rocks, the oceans and the air.
- ▶ Carbon moves through the atmosphere, oceans, plants, soil and the earth in cycles over time.
- ▶ Trees and other vegetation – called biomass – obtain energy through a process called photosynthesis, which removes carbon from the atmosphere. Other processes, such as decomposition or forest fires, return carbon to the atmosphere.
- ▶ Biomass plays a vital role in maintaining the balance of carbon dioxide in the atmosphere.
- ▶ When trees are removed and not replaced, or when fossil fuels are burned, more carbon remains in the atmosphere, increasing atmospheric levels of CO₂ and enhancing

Carbon in Plants and in the Atmosphere

ACTIVITY: Understanding Photosynthesis – Nature’s “Carbon Engine”

The Key Message

Through a process called *photosynthesis*, carbon dioxide is removed from the atmosphere and stored in plants as carbohydrates. When plants die and decay, carbon returns to the atmosphere as carbon dioxide, written as “CO₂.” Because this generally is an equal exchange, CO₂ levels remain in balance. But if the amount of plant life declines, more CO₂ will be emitted into the atmosphere than will be removed. Although forests in New England and the Northeast were once only a shadow of their current selves, today they are thriving and hold large quantities of carbon. Worldwide, however, the story is less positive. Total plant material – also known as *biomas* – is in decline, a casualty of deforestation, as well as increasing agricultural demand for fiber and land.

Materials Needed: Photosynthesis Poster in Backpack

Introduction

Photosynthesis is the process that allows green plants to use light to make organic compounds from carbon dioxide and water, releasing oxygen and water. As a result, plant life on earth stores a vast amount of carbon.

During photosynthesis, carbon dioxide (CO_2) that is removed from the air, and water (H_2O) that is drawn up by roots from the soil are combined to form glucose ($\text{C}_6\text{H}_{12}\text{O}_6$). This process also releases oxygen (O_2) into the atmosphere. A carbohydrate, glucose is stored in the plant until the energy it holds is needed to create plant tissue, or to maintain existing cells.

When plants die and decay, the stored carbon in the plant material returns to the atmosphere in the form of carbon dioxide. In addition, living trees emit some carbon dioxide each day through respiration, although this is offset by the carbon fixed through photosynthesis. Through the processes of photosynthesis and respiration, plants help regulate the amount of CO_2 in the atmosphere, as do the microorganisms involved in the decomposition of plants and animals. They are critical actors in the short carbon cycle, a complex system that maintains a fairly constant amount of carbon in the atmosphere. Through decay and eventual fossilization of plants, a small amount of carbon will be transferred from the short cycle to the long cycle each year.

The sugar maple depicted on the poster represents a common species of tree found throughout the Northeast. If possible, stand near a sugar maple or another tree during your presentation.

You need to know that the small spheres, or dots, represent atoms.

- Blue dots are oxygen atoms (O)
- Green dots are carbon atoms (C)
- Yellow dots are hydrogen atoms (H)

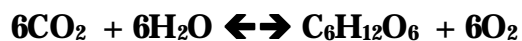
Procedure

1. Show the poster to your group and ask them to describe what they see. Make sure they notice the different colored dots. Now they are ready to discover that the clusters of dots represent molecules. Start with the yellow and blue molecules. Point out that each of these has two hydrogen atoms and one oxygen atom. This can be written as " H_2O ." If they haven't encountered this before, explain that it is the chemical name for water. The yellow and blue clusters are water molecules.

2. Next explore the blue and green molecules. What would their chemical name be? The answer is CO₂ -- carbon dioxide. CO₂ is present in the air in very small quantities, a fraction of 1 percent of the atmosphere.
3. How about the pairs of blue dots? They are oxygen molecules, O₂. About one fifth (21%) of our atmosphere consists of O₂ molecules. We and other land animals depend on oxygen in the air to be able to breath.
4. The big blue, green and yellow cluster? It is a glucose molecule. How many of each type of atom are used to make it? Careful counting will reveal its chemical name: C₆H₁₂O₆. Glucose is a carbohydrate: a type of food. Carbohydrates are complex molecules made of carbon, hydrogen and oxygen. The sugars, starches and cellulose found in plants are examples of carbohydrates.
5. Now that all of the components have been laid out, take a look at the process depicted on the poster. Ask your group what they think is happening. The main things to notice are that (1) the leaf absorbs CO₂ from the air, (2) liquid water comes up the stem, (3) assisted by sunlight, water and CO₂ combine to form glucose, (4) oxygen is released as a byproduct, and (5) the glucose travels from the leaf to be stored in the plant

Summary

Summarize the process by writing the chemical notation for the photosynthesis and decomposition reaction:



As you can see, the reaction goes both ways. Left to right is photosynthesis, and right to left, respiration. The first takes CO₂ out of the atmosphere; the second puts it back.

Together, these two processes are key elements in the short-term carbon cycle, which keeps a relatively constant amount of CO₂ in the air and in the plants. In recent years, however, more carbon dioxide has flowed into the atmosphere annually than the world's plant life can store. Deforestation has reduced the number of trees that consume and store carbon, while at the same time human beings have done things that add large amounts of carbon dioxide to the air. These include cutting down and often burning large tracts of forest to create farmland, and consuming huge quantities of fossil fuels like oil and coal. Burning forests disrupts the short carbon cycle by transferring carbon from vegetation to the atmosphere; burning fossil fuels takes carbon from the long cycle and deposits it in the short cycle.

If real leaves are handy, end the discussion by summarizing the process of growth and decay, using a leaf as a model. If you have a magnifying glass, ask the group to look

closely at the underside of the leaf for the stomata – the tiny pores in the leaf’s skin through which carbon dioxide, oxygen and water vapor pass to and from the atmosphere.

The Carbon Cycle

ACTIVITY: Sources and Sinks

The Key Message

Carbon dioxide moves through the atmosphere, oceans, plants, soil and the earth (rocks and volcanoes) in cycles over time. As in any cycle, it has to come from somewhere and go somewhere else. Where it comes from is called a **source**; where it goes is called a **sink**. Carbon dioxide doesn’t simply disappear into a sink and stay there. Eventually, it returns to its starting point, even if that takes a long time. This means that sinks can be sources, and sources, sinks. If carbon dioxide moves through the atmosphere at a constant rate, the entire cycle is balanced. However, if we remove carbon from trees and fossil fuels and put it into the air, we disrupt that balance. The result is an increase in atmospheric levels of CO₂.

Materials Needed: Large Carbon Cycle Poster in Backpack

Introduction

This poster provides you and your group with an opportunity to explore the carbon cycle, the sources of and sinks for atmospheric carbon, and the human activities that increase the amount of carbon dioxide in the atmosphere.

Procedure

1. Start by working together to identify **sources** – all the activities and processes that introduce carbon, as carbon dioxide, into the atmosphere. Some are more obvious than others. Look at a range of human activities and talk about how each one contributes to this process. Clearing land and generating electricity are two you might discuss. Natural processes, of course, are the largest source of carbon dioxide. Natural processes you could mention include the decaying of plants and the release of CO₂ from volcanoes.
2. Now identify carbon dioxide **sinks**, places where CO₂ goes after it leaves the atmosphere. Sinks include oceans, plants, soil and the earth.

You can wrap up at this point, or you may choose to briefly discuss the concept of carbon’s “footprint.” Here is the basic idea: Whenever we manufacture something or

alter the natural state of things (for instance, by establishing a farm), we affect the long and short carbon cycles, and thus the amount of carbon residing in the atmosphere.

The carbon footprint of a house or apartment, for instance, encompasses all the carbon dioxide emissions that are by-products of the manufacturing of the materials used in building that house or apartment. You might discuss how carbon is emitted as a result of the many activities associated with its construction and occupancy. Consider the process of clearing the land at the construction site, and transportation for the workers. Also take a look at construction materials. Where did they come from and how did they get there? Be sure to list the things that will be needed to keep the house in good working order. These might include heat and electricity, as well as periodic repairs. Don't forget the transportation the occupants will use to get to work, not to mention shopping and recreation. Depending on the location of the house or apartment, as well as the choices it occupants make, transportation can be a major source of carbon emissions.

To make these concepts real, discuss the carbon footprint of the poster itself. What is it made of? Were any fossil fuels used in the process? Was land cleared? How did the poster get from the place it was made to where you stand now? How will it be disposed of? Are there net emissions associated with the harvesting of trees to make the paper?

Background Science

Carbon Cycles

Carbon combines easily with other molecules in the air, as well as in water, plants, animals, rocks and fossil fuels. In the process, it changes form. When vegetation decomposes, for instance, it is chemically transformed from plant tissue to CO₂ through a process called oxidation. It will end up as carbon dioxide emitted to the air.

The earth's carbon moves from place to place. Some storage places hold carbon for only minutes to hours; some do so for millennia to eons.

However, carbon moves through two cycles, which we might envision as a small, rapidly spinning wheel inside a much larger and slower one. On occasion, these wheels or systems intersect. The two systems move hundreds of billions of tons of carbon dioxide into and out of the atmosphere each year.

- The short-term cycle carries carbon dioxide through surface ocean water, the atmosphere, soils and vegetation, taking tens to hundreds of years to compete.
- The long-term cycle moves carbon very slowly through the atmosphere, oceans, as well as through underground rocks, deep-sea sediments and volcanoes. A complete cycle can take millions of years.

When the cycles are in equilibrium, atmospheric levels of carbon remain relatively stable. But today human activity has altered each cycle.

Before the age of industrialization, atmospheric concentrations of CO₂ stood at about 280 parts per million. They are now 370 parts per million. A doubling of the pre-industrial level – to more than 550 parts per million – is likely in about 50 years if the current rates of increase in CO₂ emissions continue.

A New and Risky Equilibrium

The Earth's natural CO₂ cycle transports massive amounts of CO₂ into and out of the atmosphere. Acting as a system, the oceans and vegetation release and absorb over 200 billion metric tons of carbon each year. [Note that throughout this guide, we use the words “tons” to refer to “metric tons.” A metric ton (sometimes called a “tonne”) weighs about 2205 pounds. You will find more detail on this in the Glossary.]

This system is no longer in equilibrium. Human activities add some 7 billion tons of carbon to the atmosphere every year. Although this is only about 3 to 4 percent of the carbon that moves through the carbon cycle in a year, that's enough to upset the equilibrium and allow a build-up of atmospheric CO₂. The oceans and land vegetation absorb about half the excess, but the rest – 3.5 billion tons a year – remains in the atmosphere for a century or more. This huge carbon build-up overshadows natural fluctuations in CO₂ levels, by enhancing the greenhouse effect and raising average global temperatures.

Where is all the carbon?

For every **ton of carbon in the air**, there is also about:

- 1 ton in the world's **biomass**
- 2 tons in the **soil**
- 5 tons in **fossil fuel deposits**
- 50 tons in the **ocean**
- 35,000 tons in **rocks**

These are all **carbon sinks**. These storage areas for carbon are not bottomless; there is only so much they can hold. In addition, sinks act as sources. By reducing the size of two of these sinks – biomass and fossil fuel deposits – human activities have led to an increase in CO₂ emitted into the atmosphere.

1. Biomass

All plants contain carbon. Because of their vast numbers, they help regulate the amount of CO₂ in the atmosphere. But if the amount of plant life diminishes,

atmospheric carbon dioxide increases. As a result, deforestation over the past 200 years has contributed to increases in atmospheric CO₂ over the same period of time.

2. Soil

Another major carbon sink, soil, stores large amounts of carbon, particularly in the forest soils of high latitudes. As higher levels of atmospheric CO₂ lead to higher average global temperatures, the amount of carbon stored in soils will change. As air temperatures increase, more CO₂ will be released to the atmosphere in what is known as a **positive feedback**. This warms the air further, causing the soil to release more CO₂.

3. Fossil Fuels

Coal, oil and natural gas deposits are part of the long-term carbon cycle. The long-term cycle moves so slowly that these fossil fuels could almost be thought of as locked away forever. They normally would remain underground for hundreds of millions of years. But not any more. Now they are being extracted at ever-increasing rates. When we burn them to generate electricity or to operate our cars, their primary element, carbon, is pumped into the air as carbon dioxide.

4. Oceans

Carbon permeates the water of the oceans. Carbon dioxide is highly soluble in seawater, it is found in plant and animal material, and carbon exists in seashells on the ocean floor. Photosynthesis occurs in ocean plant life, as does respiration. In the carbon cycle, a net exchange of CO₂ occurs between the atmosphere and the oceans. Carbonate shells transfer carbon from the ocean's surface to its floor when they sink. As the ocean warms due to climate change, its role in the carbon cycle will be altered.

5. Underground Rocks

Due to a process known as ocean floor **subduction**, carbon in the ocean is forced into long-term underground storage in the earth's crust by colliding tectonic plates. This carbon comes from two sources. The first source is shells, which consist mostly of calcium carbonate. The second is carbon-laden minerals, which are dislodged from rocks by the chemical action of the carbonic acid in rainwater (rain is naturally acidic even without acid aerosols), and carried by streams and rivers into the ocean. The minerals then drop to the ocean floor, where plate collisions drive them underground. Subducted carbon may remain locked in the crust for millions of years, re-entering the atmosphere – in the form of CO₂ – only as a result of volcanic action.

DID YOU KNOW?

Atmospheric CO₂ levels are approaching 370 parts per million by volume, up from 280 ppm 100 years ago. That doesn't sound like much, but just 1 part per million translates into 2.13 billion tons of CO₂, and 370 ppm is almost 800 billion tons. Even though the entire atmosphere weighs 5.7 *million billion* tons (try to find a scale!), a little CO₂ goes a long way when it comes to altering global temperatures.

DEMONSTRATION: Please Pass the Carbon

This activity helps the group focus attention on the various components of the carbon cycle, and illustrates the path carbon molecules take as they pass through the cycle. It also shows how fossil fuel extraction and combustion, as well as deforestation increase the concentration of carbon in the atmosphere.

You'll need six people to act as the six carbon sinks. They can choose **atmosphere, biomass, soil, ocean, fossil fuel deposits or underground rocks**. The atmosphere, plants, soil and ocean people should form a small circle or square, with the fossil fuels and rock people standing outside the circle. Moving from right to left, organize the circle sequence as follows: start with atmosphere, then plants, soil, and ocean, and then back to atmosphere.

Using the clothespins found in the backpack to represent carbon, give everyone, including fossil fuels and rocks, **three** pieces of "carbon" each.

Step 1. Atmosphere, plants, soil, and ocean begin by passing one piece of carbon at a time to the left. All four pass and all four receive. They continue passing while you explain that this is how a cycle (or system) stays in equilibrium. When the point is made, ask the group to stop for a moment. Each member should still be holding three pieces of carbon. The cycle is stable.

Step 2. Now explain that sometimes "trades" are made directly between carbon sinks – for instance, photosynthesis and decomposition trade carbon back and forth. Ask your atmosphere person to trade one piece of carbon for a piece from the plant person. The atmosphere person will also do a one-to-one trade with the soil, and another one with the ocean. Each of these should be done separately, between the trades described in Step 1 (see below).

To summarize: everyone except fossil fuel and rocks passes once to the left and then stops; at that point, atmosphere trades with plants, everyone passes one to the left,

DID YOU KNOW?

With the exception of a few specially adapted microorganisms found near deep ocean vents and in anaerobic (airless) soils, all living things depend on oxygen. An important aspect of this, and one relevant to the climate story, is that even plants take in oxygen and release CO₂. This can be observed by measuring the net gas exchange of leaves or plants during the nighttime when no photosynthesis occurs.

The process, so-called “**dark respiration**,” is in fact going on all the time in living plants. However, it is often overwhelmed by the net consumption of CO₂ and production of O₂ during photosynthesis.

Dark respiration is part of the story because, among other things, it's possible that warmer temperatures will cause plant respiration to increase faster than photosynthesis, with the result being less net photosynthesis and more CO₂ in the atmosphere. This is another example of a positive feedback loop that stimulates global warming.

- *David Bartlett, University of New Hampshire*

stops, then atmosphere trades with soil, everyone passes one to the left again, atmosphere trades with ocean, and the process repeats. Facilitate this for a bit, then ask everyone to stop. Point out that, because everyone continues to hold three pieces of carbon, the initial carbon distribution still exists.

Step 3. Over hundreds of millions of years, comparatively tiny amounts of carbon go underground, and eventually come back out. To show this, bring the fossil fuel and the rocks people into the circle and put both of them between plants and soils. Now, the whole group of six does one pass to the left without trades. That's it. Rocks and fossil fuels step back out. Again, point out that the cycle remains in equilibrium.

Step 4. Many things in the real world can throw the carbon cycle out of balance. The two of greatest concern today are deforestation, and fossil fuel extraction and combustion. To show the impact of deforestation, simply ask plants to give a piece of carbon to the atmosphere. For fossil fuel combustion, ask your fossil fuels person to give another piece of carbon to the atmosphere. Now, do a couple of simple passes as explained in Step 1. Have everyone stop and count his or her carbon. Atmosphere now should have five carbon pieces, fossil fuels two, and plants two. Discuss.

More carbon dioxide is in the atmosphere now than ever before due to human actions such as deforestation and fossil fuel combustion.

Project Learning Tree – A Resource for Outdoor Education

Here are three excellent activities from *Project Learning Tree* (PLT), an education program developed by the American Forest Foundation. PLT, designed for educators working with students pre-K through 12, offers teaching approaches that emphasize natural interrelationships and patterns of change, each with a focus on trees.

- **Every Tree for Itself** – This exercise examines the natural conditions that help trees live and grow. Changing climate is one of a number of stresses that may combine to alter New England's forests. Others include water pollution, ecosystem fragmentation, poor air quality and the symptoms of global warming – drought, more intense storms and species migration, among others.
- **Tree Cookies** – this activity looks at annual tree rings, a sensitive indicator of long-term environmental change. It ties in nicely with the ice core activity in Section 4 of this Presenters' Guide by showing some of the tools scientists use to examine the history of climate change.
- **Air Plants** – The structure and scale of an ecosystem are influenced by climate, soil, human activity and water. Air Plants help learners understand how photosynthesis works.

Each of these activities offers an excellent way to enhance the *Climate Change Backpack*. Your organization might already be a PLT certified institution and have access to them. If not, contact PLT at www.plt.org.

Several other organizations have developed climate change activities and curriculums, including *Ranger Rick* and *Green Teachers*, as well as U.S. EPA. You might consider adding these or others to your activity and resource library, while creating a special section in the library for climate change and global warming.

Section 3 – The Greenhouse Effect

Take-Away Points:

- ▶ **The earth's natural greenhouse effect captures radiation from the sun and retains it in the atmosphere as heat, warming the planet. The process is analogous to the way a greenhouse remains warm on a sunny but cold day.**
- ▶ **The natural greenhouse effect is mostly produced by relatively small amounts of water vapor and carbon dioxide in the atmosphere.**
- ▶ **The natural greenhouse effect raises average global temperature by about 60 °F, making the earth suitable for life.**
- ▶ **Human activities can increase atmospheric concentration of carbon dioxide, as well as those of other substances – some also found in nature, some not – that add to the greenhouse effect.**
- ▶ **Though average global temperatures have fluctuated a great deal over the past 2 million years, they have remained mild and quite stable for the past 10,000 years, with one exception: Over the past 100 years, average temperature has increased sharply.**

The Key Message

The **greenhouse effect**, although natural, is amplified by human activities like the burning of **fossil fuels** and **deforestation**. These add greenhouse gasses to the atmosphere, especially **carbon dioxide**. Because of rapid increases in fossil fuel combustion and deforestation, much of our focus right now is on carbon dioxide's role in climate change. Although **global warming** can simply mean an increase in global temperature, regardless of the cause, today the term is commonly used to refer to an increase in average atmospheric temperature or climate changes brought about by human beings. Evidence that this is occurring has begun to accumulate in the past several decades.

Background

The sun, earth's only external heat source, primarily emits visible short-wave radiation – light – and invisible ultraviolet radiation. The atmosphere absorbs one-quarter of the radiation that reaches the earth, and clouds reflect another quarter back into space. The remaining visible and ultraviolet (UV) radiation passes through the atmosphere.

The earth in turn radiates some of the incoming energy back out toward space, just like other bodies do. In fact, much of the energy that reaches the earth's surface bounces all the way back into outer space – but not all of it does so. Being far cooler

than the sun, the earth also absorbs some of the sun's energy – particularly the invisible long-wave or infrared radiation, which is weaker and less able to escape from the atmosphere. Another name for infrared radiation is heat.

Heat released by the earth's surface is trapped by naturally occurring gasses -- greenhouse gasses – that together constitute less than 0.05 percent of our atmosphere, a minute fraction. These greenhouse gases are water vapor, carbon dioxide, methane and nitrous oxide, or, in chemical notation, H₂O, CO₂, CH₄ and N₂O.

The glass in a greenhouse performs a function similar to that of greenhouse gases by allowing the sun's short-wave radiation, light and ultraviolet radiation to travel unimpeded into and out of the atmosphere, while preventing a lot of the long-wave radiation, heat, from passing through the atmosphere. On earth, much as in a greenhouse, trapped heat causes the temperature of the atmosphere to rise. This is the earth's natural greenhouse effect. It keeps the surface air 60 degrees Fahrenheit warmer than it otherwise would be, and sustains the life that we know. (As a technical matter, terrestrial greenhouses stay warm in part due to the effect described here, but also because their glass enclosures keep hot air in and the cooler wind out.)

The greenhouse effect is amplified when the concentration of greenhouse gasses in the atmosphere increases. A major part in the current increase is played by human activities like deforestation and fossil fuel combustion. These activities intensify the greenhouse effect by short-circuiting the carbon cycle. Carbon, which would otherwise be stored in plant biomass or deep below the ground in fossil fuel deposits, is instead transferred to the atmosphere in the form of carbon dioxide. Thus, a direct link exists between emissions of carbon dioxide caused by humans, and global warming.

Greenhouse Gasses

The major greenhouses gasses, in order of atmospheric concentration, are:

- **Water vapor – H₂O**
- **Carbon dioxide – CO₂**
- **Methane – CH₄**
- **Nitrous oxide – N₂O**
- **Synthetic gasses –**
 - Chlorofluorocarbons (CFC's)**
 - Perfluorocarbons (PFC's)**

The first four of these are predominantly from natural sources and processes, although concentrations of some, like CO₂, can be enhanced by human intervention. The last group – CFC's and PFC's – are human-made substances known generally as fluorocarbons. Here is a list of the major natural gasses that together form our atmosphere. Note the comparatively tiny amounts of the greenhouse gasses.

Natural Atmospheric Gases (including greenhouse gasses)

Gas	Formula	Greenhouse Gas	Atmospheric Abundance (%)
Nitrogen	N ₂	no	78%
Oxygen	O ₂	no	21%
Water Vapor	H ₂ O	yes	1 to 3%
Argon	Ar	no	0.1%
Carbon Dioxide	CO ₂	yes	0.037%
Ozone	O ₃	yes	0.00003 to 0.010%
Methane	CH ₄	yes	0.0017%
Nitrous Oxide	N ₂ O	yes	0.0003%

Water vapor accounts for 1 to 3 percent of the atmosphere. Its distribution is not uniform. More water vapor is found over oceans and equatorial regions, although concentrations fluctuate regionally with changes in the weather. Water vapor accounts for nearly two-thirds of the greenhouse effect, but controlling the amount of water vapor in the atmosphere is not really an option – at least not without incurring major costs and risks.

The other gasses, both non-greenhouse and greenhouse, are distributed more or less evenly within the atmosphere. Atmospheric amounts of the latter have increased sharply since the 1850's, the dawn of the industrial age. In the past 150 years, for instance, concentrations of carbon dioxide, methane and nitrous oxide (CO₂, CH₄ and N₂O) have climbed by more than 30, 145 and 15 percent, respectively.

Although in general these greenhouse gasses result from natural processes, human activity is causing them to be released into the atmosphere at a far faster rate than at any time in recorded history. This alters a critical balance that has kept the earth's temperature as stable as it has been for much of past 160,000 years.

Global Warming Potential (GWP)

Greenhouse gasses are evaluated not only on the basis of their relative abundance, but also on their global warming potential – the ability of a given gas to absorb and re-emit terrestrial radiation – or, in simpler terms, its capacity to hold heat. The following scale illustrates this. It assigns an arbitrary value of 1 to the global

warming potential of carbon dioxide as a basis for comparison. Although less prevalent, methane is far better at trapping and re-radiating heat than carbon dioxide. Fluorocarbons, which are anthropogenic in origin, are present in minuscule amounts, but – due to their long lives and heat-trapping qualities – possess a very large global warming potential.

Global Warming Potential of Key Greenhouse Gasses

Greenhouse Gas	GWP	Lifetime in Years
Carbon Dioxide	1	50 to 150
Methane	35	10.5
Nitrous Oxide	260	132
Fluorocarbons	4500-6100	55 to 500

Carbon Dioxide

Carbon dioxide is produced in the natural world when plants respire, decay or burn. Volcanoes also contribute some CO₂ through periodic eruptions, and this helps to regulate temperature over periods of hundreds of millions of years. In addition, humans are responsible for emitting carbon dioxide, but within a much shorter time frame. Examples include burning fossil fuels to generate heat and electricity, to run industrial processes and to provide transportation, as well as cutting down or burning forests. Trees play a key role in removing CO₂ from the atmosphere. They use it to convert sunlight into useful chemical energy through a process called photosynthesis. Plant life in the oceans relies on carbon dioxide, too.

Methane

Methane, CH₄, is a major greenhouse gas. Although about 20 times less prevalent in the atmosphere, it wields a global warming potential about 35 times greater than carbon dioxide. Methane is formed naturally in marshes and bogs when dead plant and animal matter decays in the absence of oxygen, and also through termite activity. Humans release methane by growing rice, raising cattle, burying trash in landfills, and extracting and burning fossil fuels.

Nitrous Oxide

Nitrous oxide, N₂O, is a greenhouse gas naturally produced in the ocean and by lightning, although the manufacture of nylon and fertilizer has increased the amount of it in the air.

Fluorocarbons

CFC's and PFC's, two of many fluorocarbons, are chemicals that contain chlorine, fluorine and carbon. They were invented in the 1930's for use in refrigeration, but they later gained widespread use in numerous applications, particularly as aerosol propellants. CFC's and PFC's are potent greenhouse gases, in part because they remain in the atmosphere for a very long time. Fluorocarbons are perhaps better known for their ability to destroy stratospheric ozone, causing the ozone holes above the Polar Regions.

Common Misconception

The ozone hole does not cause global warming!

*(but fluorocarbons, which destroy the ozone layer,
also are powerful greenhouse gasses)*

ACTIVITY: Greenhouse Globes

In your backpack, you will find both halves of a clear plastic globe. You'll also see two small thermometers and two small paper thermometer shades. By shielding the thermometers from direct sunlight, the shades act just like an instrument shed at a weather station. This experiment works best in direct sun, or indoors under a strong incandescent light. The idea is to show that the greenhouse effect places a shield around the earth, permitting the sun's short-wave energy to enter, but preventing the escape of long-wave heat energy.

Procedure

1. Place both thermometers on the ground, each under a thermometer shade.
2. Put the globe over one of the thermometers.
3. Let the greenhouse globe and thermometers sit for 10 minutes or so as you talk to the group about the greenhouse effect.
4. Then, take a look at the thermometers. Notice which one has the highest reading. Ask the group how they account for any observed difference. The uncovered thermometer, which will display a lower reading, illustrates what life without the greenhouse effect would be like. (Remember that the greenhouse analogy is not perfect. Greenhouses – including greenhouse globes – retain their warmth for the most part because they prevent the warm air inside from mixing with the cool air outside.)

DID YOU KNOW?

The greenhouse effect exists on Venus and Mars, too. Venus, which has a thick carbon dioxide atmosphere, maintains a surface temperature of about 800 °F – hotter, in fact, than the surface of Mercury, which is nearly twice as close to the Sun. Mars also has a carbon dioxide atmosphere, although it is very thin. There, temperatures rarely if ever get above freezing. Mars is about 50 percent farther from the Sun than the Earth is.

Which planet – Earth, Venus or Mars – has the more effective “greenhouse”?

ACTIVITY: Following CO₂ and Temperature

The backpack contains six graphs that show how temperatures and CO₂ concentrations have changed over time. The activities here are quite detailed, so they may work better in a classroom. Please look over the graphs and feel free to use them as part of your discussion. It might even be enough simply to point out the obvious yet quite compelling correlation between CO₂ concentrations and temperature records.

The Key Message

Over the past two million years, global temperatures have evidenced strong variation – alternating from 15 to 20°F colder than today, to 5°F warmer than today. Compared to this prehistoric record, average global temperatures during the past 8,000 to 10,000 years – the period of human civilization – have been fairly mild and stable.

Temperature and CO₂ concentration tend to change together. Although the amount of CO₂ in the atmosphere fluctuates with the season, on an average annual basis it has been steadily climbing since the beginning of the industrial revolution. At the same time, global temperatures have increased about 1.1°F, and they continue to rise.

Procedure

Make sure that everyone can see the graph. You might have to walk around and show it to people if you have a large group. As with any graph, point out the exact title, explain the units of measurement on both the x- and y-axis, and ask a few questions to make sure that everybody is with you.

Graph 1 – 4.8 Billion Years of Changing Temperature

The cycles of glaciation, and the drift and collision of continents over the estimated age of the earth, a period of 4.8 billion years, has tended to erase many clues to climatic conditions of the past. For example, the average temperature range over that long period is hard to pinpoint exactly. It is believed to be on the order of 15 to 20 °F on either side of the current average. Yet some general trends are relatively clear. One generalization is that temperatures have varied dramatically.

(You should point out that the center line on Graph 1, marked “today,” represents the earth's average temperature – about 60 °F.)

In the past two million years or so – the most recent ice age – the world has gone through a series of glaciations, cooling off and then getting warmer again. Temperatures during most of this period have been colder than today.

During the era of the dinosaurs, 66 to 205 million years ago, earth was far warmer. During that time, plants covered most of the earth. As they died and decayed, their remains accumulated and eventually, under great pressure from sediments that built up on top of these deposits, turned into coal, oil and natural gas – today's fossil fuels.

(The Timeline Clothesline activity in Section 4 relates to Graph 1; you may find it helpful to use this graph as part of that activity, too.)

Graph 2 – Antarctic Temperature Over the Past 160,000 Years

This graph shows the temperature record in Antarctica as derived from ice core samples. It is very likely that average global temperature follows the same basic pattern, but at higher temperature values.

About 135,000 years ago, temperatures were about the same or a little warmer than today. During the next 115,000 years – until about 20,000 years ago – they rose and fell many times, while generally maintaining a cooling trend. This continued until about 20,000 years ago, when average temperatures were some 18 °F lower than today. This was the height of the most recent glaciation, the so-called Ice Age, when ice one to two miles deep covered New Hampshire.

At that point, temperatures started to rise dramatically. This continued over the course of the next 8,000 to 10,000 years. The warming trend included at least one incredible decade when temperature skyrocketed by at least 10 °F. During the most recent 10,000 years, temperatures again dropped, this time by about a degree. But starting about 100 years ago, a 1-degree Fahrenheit rebound took place (you can see this in the rising line at the end of the Graph 2). This is the increase that many people now refer to as global warming.

This graph follows a pattern similar to what has happened during the 10 or so glaciations of the past 2 million years. Temperatures fluctuated for a period of about 100,000 years, while maintaining a general downward trend. Then, relatively rapidly, they bounced back – perhaps in only 10,000 years. This then was followed by 10,000 to 20,000 years of fairly mild "interglacial" temperatures. The pattern then repeats itself. We are now in an interglacial period. Although temperatures will again descend, that may not occur for thousands of years – much longer than the time frame of the global warming that has been caused by human activities.

Remind your audience that during periods of rapid temperature change in the past people did not inhabit the earth. The rapid change in temperature currently being experienced is unique in human history.

Graph 3 – CO₂ Concentration Over 160,000 Years

Next, consider the graph showing atmospheric carbon dioxide concentrations during the past 160,000 years. Again, the data were gathered in Antarctica, but concentrations should be the same worldwide – CO₂ mixes evenly throughout the atmosphere. Be sure the group notices that temperature and CO₂ concentrations depict parallel trends. When one of them moves up or down, a significant and consistent change in the other takes place as well.

Graph 4 – Average Global Surface Temperature

During the final 10,000 years on the temperature graph spanning 160,000 years (Graph 2), notice that the mercury fell slightly – less than one degree Fahrenheit. On this graph, look more closely at what global temperatures have been up to during the most recent thousand years. The dotted line projects average global temperatures out into the future. It estimates that the average will reach 64-70 °F over the next century – way off the chart. Although changes look fairly minor from 1000 to 1900, they have been far more pronounced since the turn of the 20th century.

In fact, overall temperatures were slightly cooler between 1450 and 1900 than they had been over the prior 400 years. The period from 1450 to 1900 is known as the Little Ice Age, and it was characterized by advancing glaciers, as well as harsh winters and cool summers in Europe and North America. It illustrates how a fairly small change in average global temperature can have significant regional impacts.

Finally, draw the group's attention to the 20th century by asking them to point to the times during the past thousand years when temperature changed the fastest. The dips and rises in the 1100's, 1300's and 1400's represent instances when it fluctuated about half a degree in less than 50 years – a very fast pace. Yet the biggest overall change – more than 1 °F – has clearly taken place during the past hundred years.

How does this rapid change stack up against the historical record? The 160,000-year temperature graph (Graph 2) shows several sharp upward surges. The steepest of these, coming out of the most recent major glaciation (the Ice Age), is similar to what has happened globally during the past hundred years. In other words, spikes are not unprecedented, but they tend to occur during deglaciation, when temperatures are cooler – rather than well into a warm cycle like the present. Moreover, they have never happened when people resided on earth.

Graph 5 – Average Global CO₂ Concentration

Now take a look at the graph of CO₂ concentrations during the past 1,000 years. The patterns here are quite dramatic. Ask the group to comment on what they see. Things to notice include:

- CO₂ concentrations changed very little from the year 1000 to 1800.
- Starting in the 1800's, concentrations started to head upward.
- In the past century, atmospheric CO₂ increased dramatically.

Compare these data to the temperature data for past 1,000 years. As with the much longer time frame of Graphs 2 and 3, temperature and CO₂ here follow the same general pattern. They change little prior to 1800, and increase steeply over the 20th century.

Now ask your group how the CO₂ increase observed during the past two centuries compares to atmospheric CO₂ changes over the past 160,000 years. A key point to note is that CO₂ concentrations are now much higher than they were at any time during the past 1,600 centuries.

Graph 6 – CO₂ Concentrations at Mauna Loa

This graph shows atmospheric CO₂ readings at Mauna Loa, a mountaintop observatory in Hawaii. CO₂ is mixed very evenly in the atmosphere, so readings from remote locations like this one represent a global average.

The important thing to notice here is the wavy pattern of the steadily rising curve. During spring in the Northern Hemisphere, the amount of atmospheric CO₂ begins to drop off. Over the course of the summer, this trend continues. Then, in the fall, CO₂ starts to climb again. The explanation has to do with rates of photosynthesis and vegetation. During the growing season, plants are actively engaged in photosynthesis, removing CO₂ from the air and “storing” it in their leaves, stems and roots. Since the amount of land and vegetation is far greater in the northern hemisphere, the pattern of uptake of CO₂ between the northern and southern hemispheres is not equal, with the northern hemisphere pattern dominating the global pattern.

The other obvious pattern is that total atmospheric CO₂ is steadily rising from year to year. This pattern will not change as long as we continue to burn large quantities of fossil fuels and cause new deforestation around the world. Both processes release large amounts of carbon into the atmosphere.

DID YOU KNOW?

Carbon dioxide weighs 44/12 or 3.67 times more than carbon. Take a look at the Periodic Table of the Elements to see why. CO₂ has one carbon and two oxygen atoms, each of which is about 25% heavier than carbon. With the exception of airborne soot particles from combustion processes, carbon is found in the atmosphere only as an invisible gas, carbon dioxide.

Sources of the data in the Graphs:

- *Graph 1: Michael A. Parsons, Global Warming: The Truth Behind the Myth (New York: Plenum, 1995) p.113.*
- *Graph 2: Ice Core Contribution to Global Climate Change Research (Durham, N.H.: University of New Hampshire, 1998) p.9.*
- *Graph 3: Ice Core Contribution to Global Climate Change Research (Durham, N.H.: University of New Hampshire, 1998) p.9.*
- *Graph 4: From M. Mann, et al. (1999) Geophysical Research Letters.*
- *Graph 5: From M. Etheridge et al., (1998) and C. D. Keeling (1999) Carbon Dioxide Information Analysis Center and Oak Ridge National Laboratory.*
- *Graph 6: C. D. Keeling (1999) Carbon Dioxide Information Analysis Center and Oak Ridge National Laboratory.*

SECTION 4 - Scientific Investigation

Take-Away Points:

- ▶ **Ice core and other proxy evidence allows scientists to study atmospheric carbon dioxide concentrations over very long time periods**
- ▶ **Average global temperature and carbon dioxide concentrations go up and down in cycles – together**
- ▶ **Over the very long term, small changes in earth’s orbit and tilt appear to have a strong effect on temperature and climate**
- ▶ **Over the past century, manmade carbon emissions are the key factor in the rise in global temperature and changes in climate**

Investigation of Past Climate Conditions

Photograph – Ice Core Researcher

Dr. Deborah Meese is a research scientist at the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. Here, in a refrigerated lab, she holds a cylinder of 65,000-year-old ice, recently “mined” from the massive Greenland ice sheet. Scientists study these ice cores to find the fingerprints of past climates – up to 200,000 years back and maybe more. They do this in much the same way that other scientists examine tree rings.

The goal is to gather what is called proxy evidence of past climate. Proxy evidence doesn’t directly tell us what past temperatures were, but it does reveal changes in the chemical or physical structure of the ice layers, tree rings and sediment cores that have been caused by changes in global temperature and precipitation patterns.

Proxy evidence also is useful in spotting climate change that’s happening now. To see or feel climate patterns over a short time span is very difficult. Short-term fluctuations in the weather mask the overall trend. However, some phenomena – rising sea level, longer growing season, melting glaciers, and more frequent and intense rainstorms, among others – are signs that climate change is taking place. And we are able to gather information on these changes using proxy evidence.

In fact, hundreds of scientists across New England are now studying different aspects of climate change. These climate scientists will help New England’s citizens, politicians and business leaders plan for the future.

ACTIVITY: Greenland Ice Core Models

Introduction

There are two ice core models in the backpack. One represents an ice core whose bottom (oldest) layer dates back 10,000 years. (The arrows point in the downward direction.) The bottom layer of the other is twice as old, having been formed from snows that fell 20,000 years ago. Ask your group how many generations ago that was. (Depending on the length of the average generation, a reasonable answer would be 800 to 1,000). How far back can you trace your own ancestors?

Each model shows annual layers of ice that fell as snow at different times in the past. In one of the layers in each model, air bubbles are magnified to show you how carbon dioxide molecules remain in the trapped air. By measuring the amount of CO₂ in the air bubbles, scientists can determine how much carbon was in the atmosphere when the snow fell thousands of years ago.

By studying the composition of the air bubbles and measuring the thickness of the annual layers of ice, we can determine what the temperature was when the ice formed. Ice cores from ice sheets and glaciers in different parts of the world all tell the same general story: Air temperature and CO₂ concentrations have increased and decreased in tandem for at least 100,000 years.

Background

Each year new snow falls on Greenland. Sometimes, a thin layer of dust from a volcanic eruption separates it from the previous year's snowfall. As more snow builds up, past layers are compressed into ice. At its deepest point, the Greenland ice sheet is about 10,000 feet thick. It contains ice layers dating back some 250,000 years. Scientists drill holes into the ice to extract cores, yet only samples less than 110,000 years old are "fresh" enough to provide reliable information.

As noted, the ice core models in the backpack represent sections of ice cores extracted from two different depths. One shows a thick band of ice from 5,131 feet below the surface that fell as snow 10,000 years ago; the other, bands of ice from 6,302 feet down – more than a mile -- that are 20,000 years old.

Trapped in each ice layer are bubbles of air from the year that the snow fell. Each bubble provides a sample of what the atmosphere was like when it was trapped in the snow. Each bubble provides evidence about the relative importance of atmospheric gasses, including nitrogen, oxygen and carbon dioxide. (Question for your audience: Would you expect to find CFCs in these ice core samples? Answer: No, because CFCs are anthropogenic (manmade), and were first manufactured in the 1930's). In one layer of each model, some of the air bubbles have been enlarged for better viewing. Some of the magnified bubbles contain little green dots that represent CO₂. In real cores, a lot of information can be gathered from the structure of the ice crystals themselves.

Carbon dioxide is distributed fairly evenly throughout the atmosphere. Thus, CO₂ trapped in bubbles in ice from Greenland directly reflects the atmospheric concentration of CO₂ when the ice was formed.

Each green dot on the air bubbles in the ice core models represents a concentration of 10 parts per million (ppm) of CO₂. So, for example, 25 green dots represent 250 ppm of CO₂ in the atmosphere that year.

Procedure

Hold up the ice core models and explain that these show cylinders that are from two different depths of Greenland ice. They are similar to the ice that Dr. Meese is holding in the photograph. Also, explain that looking at the tree rings visible in the tree cookie in the Backpack is very similar to looking at the annual layers in the ice core. Each ring shows how much the tree grew that year, and gives an indirect (“proxy”) picture of weather and related conditions the tree experienced that year and a year or two earlier.

Pass the models around, and ask people what they notice about them. Observations might include the annual layers themselves, the date on each model and the “bubbles” with green dots that appear in one layer of each model.

Discuss the group’s observations. Explain that the “bubbles” represent tiny pockets of air containing nitrogen, oxygen, CO₂ and other gasses that existed in the atmosphere when the pocket was formed.

The ice core model from around 10,000 years ago has more green dots than the one from around 20,000 years ago. This means that the amount of CO₂ in the air increased over that 10,000-year period. If they’re interested, group members can calculate CO₂ concentrations by counting the number of green dots. Each green dot represents 10 molecules of CO₂ per million molecules of air, expressed as 10 parts per million, or 10 ppm. This means that, out of 1,000,000 molecules in the air, just 10 of them are carbon dioxide molecules. Note that ppm refers to the number of molecules, not their weight; some molecules weigh more than others.

In the 20,000-year-old sample, the CO₂ concentration was 190 parts per million, and in the more recent one, it was 280 ppm. Possible reasons for this 90-ppm difference are discussed below.

Next, ask why the layers in the two models differ in thickness. In the discussion, you may want to raise the following points:

- Deeper (and older) ice layers tend to be thinner. Generally that’s because they have been compressed by the ice and snow lying on top of them.

- Ice thickness is influenced by weather. The amount of snow that falls in a year depends on how cold it is. In colder years, less snow forms and falls, and the layers are thinner.
- The Northern Hemisphere, including Greenland, was at the height of the Ice Age roughly 20,000 years ago – this was a relatively cold time with less snowfall.
- The temperature of the air at the time the bubbles were trapped in the snow 20,000 years ago was about 47 °F below zero. In the 10,000-year-old core, it was about 31 °F below zero.

✓ CHECK POINT

This is a good place for a quick review. By now, your group should understand the following:

- **Climate change is associated with the amount of carbon dioxide in the atmosphere.**
- **We know this relationship exists because of our ability to learn about past climates using proxy evidence like ice cores and tree rings.**
- **Natural phenomena as well as human activities have led to an increase in atmospheric CO₂ concentrations of about 30 percent over the past century.**
- **This increase has contributed to the recent rapid rise in average global temperature.**

Drilling for Ice Cores in Greenland: Carbon Dioxide and Temperature

Many of the connections between the earth's atmospheric chemistry and its climate are complex and poorly understood. But one link is clear: For the past 140,000 years, the amount of carbon dioxide in the air and the average temperature of the planet have maintained a consistent and proportional relationship. Based on a variety of evidence, it also is now clear that the amount of atmospheric CO₂ influences global temperature far more than temperature influences CO₂.

The importance of carbon dioxide in regulating earth's temperature has been confirmed by Russian, British and U.S. scientists working in eastern Antarctica, and by American and European scientists working in Greenland. Drilling deep into glaciers, scientists extract and analyze long ice cores. Some of these are up to three miles in length. The glaciers, which formed as layer upon layer of snow accumulated over the years, serve as time capsules from the past, uncontaminated by more recent events and climate. Drilling into ice is like drilling back through time.

The deepest sections of the ice cores consist of water that fell as snow 1,400 centuries ago. Tiny bubbles in the ice contain samples of the air from a very long time ago. When a small piece of the core is broken up in a special evacuated chamber, the trapped air is released, allowing its composition to be measured. Scientists also use sophisticated instruments that can identify the ratio of rare isotopes in the frozen water. They then use these data to estimate the atmospheric temperature at the time the water became frozen. (Isotopes are molecules of the same chemical element whose masses differ – due to different numbers of neutrons.)

These data provide an unbroken record of both temperature and atmospheric concentration of carbon dioxide over a span of more than 100,000 years. During almost every period of glaciation, carbon dioxide levels dropped, as did temperature. As each period ended and the earth returned to interglacial warmth, atmospheric carbon dioxide increased. Generally, the level of carbon dioxide in the past 140,000 years has fluctuated between 190 and 280 parts per million, but has never gotten much higher.

Since the beginning of the Industrial Revolution, though, that's all been changing. Present day atmospheric concentrations of CO₂ are 370 parts per million. This is a full 90 ppm above the high point of the record from the last 140,000 years – a range that, itself, spans only 90 ppm.

Ice cores document atmospheric history. They identify massive and rapid changes in climate, volcanic activity, forest and grassland fires, and major storms, as well as instances of widespread atmospheric pollution like the Chernobyl nuclear disaster or the use of DDT.

-- Deborah Meese, Ph.D., Cold Regions Research and Engineering Laboratory, Hanover, N.H.

Natural Variability

Background

One of the challenges faced by climate scientists is distinguishing global warming caused by today's more intense greenhouse effect from warming or cooling resulting from natural climate variability. If human activities were not pumping greenhouse gasses into the atmosphere, the earth's temperature would be determined solely by two natural factors: the amount of the sun's energy that reaches earth, and the level of (non-manmade) greenhouse gasses in the atmosphere. In other words, temperature would be set by how much heat we get, and by how the earth holds that heat.

While this relationship sounds simple, it is in fact very complex. Temperature is only part of a larger climate system, with many interrelated parts – some of which change over geologic time and some of which can change in only a few years. They include tectonic movement (that is, shifting of the continents), sun cycles, ocean-atmosphere interactions, ocean currents, and the distribution of biomes.

The relationship among the pieces of the climate system are far too complicated to detail here, though you may want to mention them as a way of pointing out that long-term climate is defined by a massive and complex system, not a simple, linear cause-and-effect relationship. Systems, which involve many interactive parts, include “feedback loops,” where a change in one part can alter another part, which in turn affects the first part, and so on (positive feedback), or where change in one part can keep another part from changing as much as it otherwise would (negative feedback). It takes very sophisticated computer models to characterize these systems and to make useful predictions about the future climate.

Nonetheless, some things are well understood. The long-term patterns of warming and cooling, and the approximate 100,000-year pulses of glaciation during the current 2 to 3 million-year-old ice age – the Pleistocene Epoch – are largely the result of variations in the earth's orbit and the angle at which solar radiation reaches our planet. Manmade changes in greenhouse gas concentrations also effect the climate, but over much shorter periods of time.

For its part, the sun is expanding and getting hotter, but at such a slow pace that most scientists believe the solar energy the earth receives has been relatively constant for all of human existence. They also believe that solar storms or sunspot activity might cause some climate variation, though probably not as much as other forms of climate “forcing” – like the emission of greenhouse gasses.

The earth's position relative to the sun changes, as we know, in 24-hour and approximately 365-day cycles. But the earth cycles through much longer-term variations, too. Our current understanding suggests that these longer-term cycles have been responsible for the rhythmic pulse of glaciation over the past several million years. The

last of these cold periods, the Ice Age, reached its height about 20,000 years ago and ended 10,000 years ago.

Scientists have been working hard to separate the effects of this long-term variability from changes caused by the anthropogenic increase in greenhouse gases. But this is difficult. By identifying all long-term climatic cycles, including those that involve changes in the earth's position relative to the sun, it is possible to better understand the importance of human influence on the climate system.

In the early 1900's, a Serbian mathematician named Milutin Milankovitch developed a mathematical description of the earth's orbital variability. His theory, controversial at first but more widely accepted today, was that cyclical changes in the position of the earth's orbit could influence climate over time.

There are three Milankovitch Cycles, and their effects interact. The first cycle takes about 22,000 years. It is a periodic wobble in the earth's axis referred to as the "precession of the equinoxes." The axis wobbles relative to the earth-sun plane like the handle of a spinning top. Combined with the other Milankovitch Cycles, especially eccentricity (discussed below), procession can alter the amount of solar radiation that reaches earth, especially at high latitudes where glaciers form. In addition, procession causes the seasons to shift slowly over the course of a year. For instance, in 11,000 years, summer in the Northern Hemisphere will be in December.

The second cycle also involves the earth's axis – but this time, how much it tilts rather than where. The angle of axial tilt oscillates between 21.6 and 24.5 degrees over a period of about 41,000 years. The combined variation caused by procession and tilt can alter the amount of solar radiation reaching high latitudes by as much as 15 percent.

In the third and final Milankovitch cycle, called "eccentricity," the path taken by the earth's 600-million-mile orbit around the sun – not the tilt or wobble of its axis – varies over a 100,000-year period from an almost perfect circle to a slight oval or ellipse. Of the three cycles, this one is both the longest and the one that is believed to have the greatest influence on the earth's temperature.

Together, these three components of the earth's orbit determine the degree to which the sun warms the earth – particularly the Northern Hemisphere, where glaciers have waxed and waned over the past 2 to 3 million years. The strength of the sun's energy reaching the earth, as well as its distribution, depends on the earth's tilt and distance from the sun.

How do we know that the very recent sharp increase in average global temperature isn't solely the result of these three changes in the shape of earth's orbit, and the angle and location of axial tilt? The brief answer is that the current global warming trend is too rapid to be solely a result of the long, slow cycles described by Milutin Milankovitch.

DEMONSTRATION: The Sun's Warmth

Orbital Variation

Here's one way to help your group understand how the earth's orbit and axial tilt creates seasonal variation, as well as long-term climate variability. Use a stick to represent the earth and its axis (or, better yet, an orange with a couple toothpicks sticking out at the "poles"). Whoever holds the "earth" should tilt it at about a 24-degree angle, and walk around another person, representing the sun. In general, try to make sure that the earth's axis is pointing in the same direction as earth orbits the sun – that is, if the axis points at a tree in "winter," it should also do so in "spring," and so forth. With this as your basic platform, you can demonstrate both the overall yearly cycle, as well as the more subtle, long-term 22,000-, 41,000-, and 100,000-year variations. This exercise works best if you encourage group members to use their imagination. For more details on the Milankovitch theory, check this website:

www.earthobservatory.nasa.gov/Library/Giants/Milankovitch/Milankovitch_2.html

Differential Heating

An easy way to show that solar intensity decreases at higher latitudes is to shine a flashlight at a wall or any other flat surface. From a foot or so away, direct the light straight onto the wall. This is like the effect of the sun's radiation near the equator. Now tilt the flashlight so that its barrel is parallel to the wall's surface. This represents the sun's angle at either pole. Although the amount of energy coming from the light stays constant in both cases, at the poles the area covered by the beam increases. This means that, at any given point, the light is dimmer or weaker. On earth, instead of a flashlight, we have the sun, and in addition to light, we have heat and other forms of electromagnetic radiation. This simple experiment shows why earth is warm near the equator and cold near the poles.

ACTIVITY: The Timeline Clothesline

Stand with your arms held out to each side and let the extent of the earth's history be represented by the tips of the fingers on your left hand to the tips of the fingers on your right. Now, if someone were to run a file across the fingernail of your right middle finger, then the time that humans have been on the earth would be erased.

- From *Basin and Range*, by John McPhee (1980)

Introduction

When talking about climate change, it is important to convey the concept of geologic time, and to discuss how the earth's climate system has changed without human influence. Climate responds to physical and chemical changes in the atmosphere, changes that can vary over millions of years. By looking at the magnitude of the changes that have taken place over earth's long history, we can get a sense of the earth's natural climate variability.

This activity gives your audience the opportunity to contemplate the enormous time scales involved in climate science, and to think about the major events in the distant past that created the systems that today govern climate, weather and temperature.

This activity draws on four timelines. For each one, you will need a set of cards, a rope and some clothespins, all of which you will find in the Backpack. The cards are to be hung on the rope, using the clothespins. The first timeline uses 13 blue cards, the second five green cards, the third six yellow cards and the fourth six red ones. The name of an event or process is written on the front and back of each of the cards. The cards are then folded in two. Inscribed inside each card is the age of the event or process that is written on the outside.

Note that most of these numbers are approximations, representing the midpoint within a range. The goal of this activity is to understand the sequence of events, not precisely when each one happened.

Procedure

Step 1

Ask two people to stretch the rope ("time") between them (or you can tie one or both ends to a tree, a post or doorknob). Tell the group that the line represents a time span equal to the one being examined in that step of the game (4.8 billion years, 50 million years, and so forth). The exercise begins by distributing the first (blue) set of cards to members of the group. You could assign cards randomly, or break the group into teams. Ask each to clothespin the card to the line where he or she thinks it belongs. Participants then can see how they did by opening the cards, checking the dates and

reading the additional information provided inside about the era in which the specific event happened. This activity can proceed quickly or at a more leisurely pace, depending on time constraints and educational goals.

Steps 2, 3 and 4

The above process is repeated with the green cards, then the yellow cards, and finally the red ones. The same length of rope should be used for each step.

Each timeline is 1/100th as long as the previous one. Once the first step has been completed, you can explain to the group that the next one – spanning the past 50 million years – represents the period covered by only the very last inch of the preceding timeline. This holds true for each of the following timelines, too.

Text of the Timeline Cards

Blue - 5 Billion Years Ago to the Present

Solar System

4.8 Billion Years Ago

- The sun consists of 99% of all the material in the solar system.
- The sun is 30% stronger than it is now.

Earth

4.8 Billion Years Ago

- The earth's first atmosphere is 98% CO₂.
- An asteroid collision tilts the earth's axis by 23.5 degrees.
- Global air temperature is much higher than it is today.

Life

3.5 Billion Years Ago

- The first living things appear, simple cells without a nucleus.
- Life in the oceans develops and fails many times; the oceans boil away several times.

Photosynthesis

3.0 Billion Years Ago

- Photosynthesis appears for the first time.
- $6 \text{ CO}_2 + 6 \text{ H}_2\text{O} \leftrightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{ O}_2$
- Blue-green algae consume CO₂ and release oxygen.

Water World

2.2 Billion Years Ago

- The first half of earth's history is now complete.
- The earth is covered with oceans and wetlands; large landmasses have not yet emerged.

Huge Ice Caps Form

2.0 Billion Years Ago

- After a billion years of photosynthesis, the earth cools enough to allow huge polar ice caps to form.

Fish and Plants

500 Million Years Ago

- The stratospheric ozone layer is developing.
- The earth's climate is generally mild.
- Predatory fish are evolving rapidly.
- The first land plants appear; they have no leaves.

Land Animals

420 Million Years Ago

- Spiders appear, representing the first air-breathing animals.
- Worms and crawling insects abound.

Present Atmosphere

400 Million Years Ago

- Atmospheric gasses stabilize near current concentrations:
78% - Nitrogen
21% - Oxygen
0.003% - Carbon Dioxide
- Water vapor levels vary from 1 to 3 percent, depending on the weather.
- Water vapor is responsible for more than half of the greenhouse effect.

Fossil Fuels Form

300 Million Years Ago

- Large tropical plants cover most of the earth. Their death, partial decay and burial by sediments produce, over millions of years, vast fossil fuel deposits.
- New England's mountains are forming.

Pangea

210 Million Years Ago

- All continental plates have joined together to make one big land mass.
- New England is near the equator.
- One year is about 400 days long.
- This is the Age of Dinosaurs.

Flowering Plants

200 Million Years Ago

- Magnolias are the first flowers.
- Some dinosaurs evolve into the first birds.
- Palm trees grow in the arctic.

Dinosaurs Disappear

65 Million Years Ago

- This the last of four mass extinctions since life began (99% of all species that once lived are extinct today).
- The Rocky Mountains are still rising.
- The White Mountains are getting shorter as a result of erosion.

Green - 50,000,000 Years Ago to the Present

Mammals

50 Million Years Ago

- Global temperatures are cooling.
- Many animal and bird species are similar to their present form.
- Antarctic ice sheet forms.

Early Hominids

5 Million Years Ago

- Both primate and human ancestral species live in Africa.

Continents Take Current Shape

3 Million Years Ago

- North and South American continents join.

Stone Age

2.5 Million Years Ago

- First arrowheads and axes are developed by humans.
- World population totals about 100,000.

Great Ice Age

2 Million Years Ago

- Our most recent long-term ice age begins.
- There have been 20 periods of glaciation since then.

Yellow - 500,000 Years Ago to the Present

Fire Harnessed

500,000 Years Ago

- Fire is first used by humans for warmth and cooking.

Neanderthals

300,000 – 30,000 Years Ago

- The last humanoid species exists on the earth.

Homo sapiens

150,000 Years Ago

- Humans appear.

Latest Glacier Retreats

10,000 Years Ago

- Human Age begins.

Humans in New England

9,000 Years Ago

- Maple trees and humans arrive.

Agriculture

8,000 Years Ago

- Hunting and gathering are starting to decline, and the agricultural way of life is beginning to appear.

Red – 5,000 Years Ago to the Present

City States

5,000 Years Ago

- Great civilizations are on the rise in the Middle East and Southwest Asia.

Land Use

1,200 Years Ago

- Earliest evidence of timber harvesting in Europe, doesn't reach America for another 1,000 years.

Coal Combustion

1700's to Early 1800's

- Steam-fired engines are developed.
- The Industrial Revolution begins.

Gas and Oil Combustion

The 1850's

- First oil wells are drilled.
- Industrial Revolution is in full swing.

Mass Production of Automobiles

1900

- Global temperature starts its rapid rise.
- Scientists theorize that human actions can intensify the greenhouse effect.

Global Warming Recognized

Mid-1980's

- Research about and awareness of climate change increase.
- Human activity is identified as an influence on climate.
- World population nears 6 billion.

DID YOU KNOW?

You can use a thermometer to measure average annual temperature right at your museum or nature center. There are two ways to do this:

1. Using a standard outdoor thermometer, record the high and low temperature each day, add them together and divide by two to get the daily average temperature. Then, at the end of the year, take all the daily averages, total them up and divide by 365 (if it's a leap year, divide by 366). Or,
2. Dig a hole.

If you decide to dig, find a good shovel and make a hole that is at least 6 to 10 feet deep. Get a thermometer that has a LONG wire attached to a sensor, and place the sensor end at the bottom of the hole. Feed the buried portion of the wire through a small-diameter PVC pipe. Fill in the hole around the wire and the pipe, then run the wire from the hole to a place indoors where you can read the thermometer. If the hole is deep enough, the thermometer will display the average annual temperature at all times. The reading will change only if the climate itself changes. One thermometer of this type is the Computemp5, available at: www.athingweather.com/wxstore/thermometers.asp

Future Climate Scenarios

In predicting the rates of global warming over the next century, we are dependent on the use of models. Models allow atmospheric scientists to predict future climates by applying known physical principles to realistic sets of atmospheric conditions. The models that have been developed to make these predictions are called “general circulation models,” or GCM’s, and to make predictions they require some of the most powerful computers available. GCM’s are related to the models used to predict tomorrow’s weather, but instead focus on global processes and long-term trends in temperature and precipitation.

Computer models are mathematical representations of what we know about dynamic natural systems like climate. They attempt to characterize key real-world processes in order to generate accurate predictions about the future. Although models require us to simplify nature’s complexity, they nonetheless often represent the most effective predictive tools we have available.

Can you identify other predictions that depend on model outputs? Here are a few examples: identifying one’s location (maps are graphical models), calculating future energy prices, determining whether a new source of water pollution will violate federal health standards, forecasting stock market behavior two weeks from now, and mapping the dispersion of air pollution emissions from a proposed power plant

To increase the accuracy and, thus, real-world usefulness of GCM’s, scientists try to combine the outputs of several global circulation models. This gives them a range of likely temperature trends – a helpful approach under conditions of uncertainty.

Scientists check the validity of a model by using it to “hindcast” – to pretend that it’s 50 or 100 years ago, and then to try to forecast climate for the next 50 to 100 years, right up to today. They then compare model output to what has actually happened. If the model output and the real world correspond closely, the model is properly calibrated and can be used to predict future trends. The data used to validate the model are always different than data used in constructing the model. This ensures that the testing of the model is independent of the structure of the model itself.

The IPCC

The Intergovernmental Panel on Climate Change, the IPCC, is investigating the state of knowledge concerning potential climate change and its impacts, both natural and social. It is the largest scientific assessment effort ever undertaken. Sponsored by the United Nations and the World Meteorological Organization, the IPCC for more than a decade has relied on the work of more than 3,000 scientists from all over the world.

In March 2001, the IPCC released a comprehensive assessment, its third in the past 11 years. All of its assessments use only peer reviewed scientific literature to address

five tasks: presenting a description of what is known and not known about how the climate system works; describing likely future climate change scenarios; describing the likely impacts of the different climate change scenarios on natural and social systems; estimating the potential for societies to adapt to those scenarios; and proposing mitigation strategies to reduce the impacts of potential climate change.

Model predictions of global climate change accepted by the IPCC project a 2.5- to-10.4 °F increase in average global temperature over the next 100 years.

You can download summaries of the scientific assessments from the IPCC website at: <http://www.ipcc.ch/>.

Scientific Assessment Process and the IPCC

The World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. Its mandate is to provide objective scientific, technical and economic assessments of the current state of knowledge about various aspects of climate change.

Each report is written by some 200 scientists and other experts from academic, scientific and other institutions, both private and public, in approximately 120 countries around the world and is reviewed by another 400 independent experts. The experts are neither employed nor compensated by the IPCC or by the United Nations system for this work.

The IPCC currently has three Working Groups: on the Scientific Basis, on Impacts and Adaptation, and on Mitigation. The Third Assessment Report is the result of almost three years of work by interdisciplinary teams that have assessed the scientific literature. During this process, the reports were subjected to an extensive review process, firstly, a scientific peer review, and secondly, a combined government and expert review. Independent "review editors" ensure that all comments from these two review rounds are taken into account by the authors and that genuine scientific controversies are addressed adequately in the reports.

GRAPHIC #3

Future climate scenarios include:

- Heat waves and drought
- Glacial melting
- Coastal flooding
- Extreme weather

SECTION 5 – How Climate Change Could Affect New England

Take-Away Points:

- ▶ **New England’s climate has generally warmed over the past hundred years, affecting the pattern of the seasons.**
- ▶ **Extreme weather events are becoming more common.**
- ▶ **Sea level in New England is rising faster now than at any time in the past several thousand years.**
- ▶ **Climate change along with other sources of environmental stress can cause serious harm to New England’s forests.**
- ▶ **Climate change poses risks to the region’s economy, particularly traditional occupations like maple sugaring, commercial fishing and tourism.**
- ▶ **Global warming can interact with other climate phenomena, causing a variety of weather and temperature changes – not all of them resulting in increased temperature.**

The Changing Climate of New England

- New England’s climate has increased 0.7 °F in the last hundred years. Winter in northern New Hampshire is now 3.8 °F warmer than it was a century ago; coastal areas are 1.9 °F warmer year round. By contrast, Maine is 1 °F cooler statewide.
- Lakes in the Northeast freeze over later in the fall and thaw earlier in the spring.
- Heavy rains and snowstorms are happening more often.

New England Forests

Maple Sugar Farming

Pictured on the previous page is **the LaPlante family of West Burke, Vermont**. The LaPlantes own and operate a maple sugaring business. The whole family pitches in whenever possible. They also log some of their wooded land, operate a gift shop and offer sleigh rides – at least when their horses aren’t too busy with the strenuous late-winter labor of hauling buckets of maple sap to be boiled into syrup. The LaPlantes represent a long-standing New England tradition. They work in and live off the forest.

If New England forests change, people like the LaPlantes who depend on trees for their livelihoods might be forced to adjust rapidly to unpredictable events – a daunting task – or suddenly have to find other ways to make a living. Those of us who enjoy maple products and benefit from the vitality maple sugaring brings to the regional economy would suffer from this as well.

Rural New England communities are woven into the forest landscape, and that has been the case for 300 years. Though the character of a community may not be something you can put a precise dollar value on (in fact, it may not even be something you think about all that often), you'd probably feel a strong sense of loss if communities like this disappeared forever.

A change in the forest ecosystem is not just an abstract concept. Such a change would affect the region's wooded hillsides and their particular blend of deciduous and coniferous trees; it would alter our lakes and streams and wetland-dotted meadows; and it would increase stress on native species of birds and mammals. In other words, a change in the forest ecosystem could also change the identity of New England – permanently. As a result, the next generation would lose something priceless: its sense of place.

DISCUSSION

Show the photo of the sugar farming family to your group. Pass it around if you wish, while leading a discussion that makes reference to the picture. These questions and comments will serve as a guide:

What do you think the parents do for a living?

- Note that the children help out with the work.

Where do you think the family lives?

- The Northern Forest region of northeastern Vermont.

Who else makes a living from trees?

- Loggers, woodworkers, carpenters, tool and equipment manufacturers, paper company workers, scientists, conservationists and surveyors; also, those who support them – truckers, clothing manufacturers, retailers, administrators, and many others.

How would environmental changes in forests hurt people like these?

- There would be fewer maple trees in the region and those that did persist would be less healthy;
- Warmer, shorter winters could reduce the flow of maple sap;
- Problems would arise for loggers, who use frozen ground in the winter to get their trucks in and out of the woods;
- New types of invasive insects and pests would appear;
- The tree species that would do better under these new conditions are less likely to be valuable, fast growing timber species;
- More intense rainfall would increase erosion and flooding;
- Winds would be stronger; and
- Freezing rainstorms would be more frequent.

(Some forecasts suggest that maple trees may eventually disappear entirely from New England if the current rate of warming persists.)

Background

Multiple Stresses On Forests

Climate change, acting on its own, will not bring about all of the ecological changes described in the previous paragraphs. But it will have broad impact when acting in conjunction with other stresses that are currently affecting New England's ecosystems. Anything that has a negative impact on a forest is called a **stressor**. A stressor can cause rapid change in the quality or concentration of any of the important factors that a forest and its inhabitants – plants and animals – need to survive. These inputs include sufficient water, adequate temperature level and available energy resources.

Storms, soil erosion, drought, insects and disease impose stress on forests. **Multiple stressors** interact with each other – another potential example of a positive feedback loop – and together they can have a significant impact on ecosystem structure and function. Human activities can make the situation worse. Here are some examples:

- Demand for forest products;
- Air pollution;
- Acid rain and fog;
- Introduction of non-native insect pests;
- Introduction of invasive and exotic plant species;
- Fragmentation of large forest areas by roads and development;

and now....

- Stress caused by climate change.

New England Seacoast

Sea level is rising faster now than at any time in the past several thousand years. On the coast in Portland, Maine, the Atlantic Ocean is 1.7 inches higher now than it was only two decades ago.

Every time the ocean rises an inch, the sea moves inland by several feet, an effect amplified by high tides and storms. For the most part, New England's coast is rocky and steep, so flooding is not a region-wide concern. Nonetheless, the coastline harbors many low, sandy spots that are vulnerable to inundation. Many of these low-lying areas are within the estuaries within which some of our most populous cities and towns are located.

Even an increase in sea level of only a few inches exposes New England's shoreline communities to greatly increased risk from storms and hurricanes.

Could this happen here?

Rising Sea Places Maryland Wildlife Refuge at Risk

The Blackwater National Wildlife Refuge, located on Maryland's Eastern Shore along the Chesapeake Bay, consists of 24,000 acres of wetlands, woodlands, and croplands, and is a critical habitat for many species of terrestrial and marine life. Today, Blackwater is experiencing environmental changes that may affect other low-lying coastal areas during the next couple of decades.

Increased flooding as sea level rises – especially during storms and possibly exacerbated by global warming – has accelerated in the refuge for a variety of reasons. Low elevation and relief, land subsidence, modified hydrology, and overgrazing by native and introduced herbivores, which severely damages vegetation, have effectively caused the loss of about 30 percent of the preserve (7,000 acres) over the last 70 years.

An estimated 125 acres of the refuge are lost each year. According to Dr. John Morton, supervisory wildlife biologist at the Chesapeake Marshlands National Wildlife Refuge Complex, "Seawater could inundate much of the existing refuge lands by the next century."

What is occurring in the refuge may soon affect other areas of the U.S. coastline as well, especially the East Coast where the slopes of the coastal areas are so gentle that a small increase in sea level creates a large inland shift of the shoreline.

The U.S. Environmental Protection Agency estimates that along the U.S. Gulf and Atlantic coasts, a one-foot rise in sea level is likely to occur by 2050 and could occur as soon as 2025.

[From a March 29, 2001, media release from U.S. EPA]

Fishing Industry

Will Guild from the Portsmouth, New Hampshire, Fishing Co-op makes his living in one of New England's most demanding and traditional jobs, fishing. The Atlantic waters off of the New England Coast and out into the North Atlantic are some of the world's richest fishing grounds. However, along with pollution, over-fishing has placed major stress on fish populations. Alterations in ocean circulation patterns and increases in

temperature caused by climate change could introduce yet more change to the delicately balanced natural systems that support fish habitat.

When discussing this picture, you may want to chronicle some of the primary resources needed to catch fish and transport them from the sea to your dinner plate. These would include the construction and operation of fishing boats and their gear, refrigeration, air and ground transportation, packaging and much more.

Climate Changes That May Affect the Environment and Economy of New England's Seacoast

- Higher sea level;
- Warmer ocean water;
- More frequent storms;
- Changes in salinity; and
- Migration of species.

Leading To...

- Beach erosion;
- Property damage;
- Higher insurance costs;
- More danger for fishermen;
- Fewer fish and shellfish; and
- Changes in an entire way of life.

El Niño

El Niño is a natural phenomenon caused by a shift in water temperature in the Pacific Ocean along the Equator. Over a period of five to 10 years, the surface water in this region shifts from warm to cool, then back to warm again. Sometimes the change is large; sometimes it isn't.

El Niño's oscillations begin by affecting ocean currents. Changes in current patterns then alter the location of the jet stream, along with the boundary between the major warm and cold air masses. Moisture levels also change, and this in turn affects the weather in the Northern Hemisphere. When El Niño is strong, New England's winters are warmer on average, and summers cooler. Other parts of the world experience more extreme storms or droughts in El Niño years.

Global warming does not cause El Niño, but it can intensify its effects.

Scientists are now discovering how crucial the North Atlantic Ocean is in determining the character of the global climate. One major feature of this influence is the North Atlantic Oscillation or NAO, a phenomenon described in more detail in the NERA report found in your Backpack.

Climate Flip-Flop?

Just to show how volatile climate can be, consider this: Some scientists think that global warming actually might cause rapid cooling in New England, the Maritimes and northwestern Europe. The reason has to do with salt water.

The idea is that global warming heats the air, and this in turn increases precipitation and melting in and around the far northern Atlantic Ocean, particularly the Greenland area. Melting of the Greenland ice sheet adds fresh water to the ocean (glaciers and icebergs consist of fresh water). This then reduces salt levels in the water on the ocean's surface, making the water less dense. Less dense ocean surfaces can affect the Thermohaline cycle, a massive vertical current that circulates through the world's oceans. The current sinks in the North Atlantic because the water is cold and salty, and it rises in the north central Pacific. However, if climate change causes North Atlantic salt levels to decline, this could prevent the current from sinking, interfere with the entire Thermohaline cycle, and, possibly, bring the mighty Gulf Stream to a halt. Without the warm water and warm air that flows north with the Gulf Stream, the North Atlantic area would cool down fast – maybe 5 to 10 °F in only a decade or two. That's believed to be enough to bring on the next ice age.

What other kind of surprises could be waiting for us if the earth continues to warm so rapidly? When interfering with complex systems, the answer is: Nobody knows.

DID YOU KNOW?

Sea level is rising. Nearly all of that increase is due to the expansion of the water. Water expands when it warms, and contracts when it cools, just like metal. Although the melting of the ice caps and glaciers reduces the salinity of ocean water in some areas, this has relatively little effect on sea level.

Tourism and Recreation

This is the Kanzler family in North Conway, New Hampshire. They own and operate the Cranmore Inn, which provides four-season food and lodging in the much-visited Mount Washington Valley. The Kanzlers represent both the present and future of the tourism industry in New England. Innkeepers and others involved in that industry could be affected by a quickly changing climate.

Show this photo to your group, and ask them for their thoughts on how climate change may affect tourism in the region.

The Kanzlers operate their own inn, and they play a role in helping their visitors recognize the connection between climate change and its potential effect on tourism in New England. The next box lists some of the ways that climate change could affect tourism.

Potential Changes Effecting Tourism and Recreation

- **Fall Foliage**
 - Maple trees could be displaced by less colorful species migrating from the south.
 - Drought, high winds and intense rainfall could interfere with autumn foliage.
- **Ski Industry**
 - Winters will be shorter (the season has lost about 10 days since 1900).
- **Recreational Fishing**
 - Cold-water species could find it more difficult to survive.
- **Hiking and Health**
 - Views will suffer from poor air quality, even in the mountains.
 - Air pollution will continue to cause or worsen respiratory problems.
 - More 90 °F days will be recorded.
 - Incidence of Lyme disease will increase.
 - More mosquitoes carrying West Nile Virus will be present.
- **Agriculture**
 - Summer vegetable crops, vulnerable to extreme weather conditions, might be damaged.
 - Sensitive to heat, dairy cows would be less productive.

Selected New England Temperature Records

Often people want to know whether average temperature has changed in their hometown. The following graphs display temperature records from a number of places around New England. They were chosen because they represent a variety of climates, and include locations having some of the longest continuous temperature records in the region.

The data are expressed as five-year running mean temperatures – that is, a rolling average over a five-year period. This helps to smooth out what would otherwise be a jagged curve, while continuing to provide an accurate look at temperature trends spanning many years.

Although you may want to concentrate on the locations nearest you, when comparing different graphs be sure to look for common patterns. For instance, almost all of the graphs from these locations (as well as average global temperature records in general) show that temperatures declined from about 1950 until about 1970, then steeply shot back up again from 1970 to the present.

This pattern is thought to be a result of the sudden increase in fossil fuel combustion during the burgeoning of worldwide economic activity following World War II. The spurt of industrial growth not only increased atmospheric levels of CO₂, but it also led to increased emissions of sulfate and soot particles, aerosols and greenhouse gases such as CFCs. The particles and aerosols do not immediately fall out of the atmosphere, and while they are suspended they reflect some incoming sunlight back into space. This in part overcame some of the global warming effect caused by the higher level of CO₂. As a result of this push and pull, average global temperature did not increase as much as it otherwise would have purely as a result of the additional greenhouse gases pumped into the atmosphere. However, because CO₂ remains in the atmosphere significantly longer than sulfates particles and soot do, after a few decades the warming caused by the additional CO₂ began to overtake the cooling caused by the sulfates. All records show that this shift occurred around 1970.

Finally, ask the group whether they can guess what the average annual temperature was in the location nearest to the place you are standing. How does it compare to a global warming rate of 1°F in 100 years?

A Caution About Graph Reading

The first three graphs look very different, but they tell the same exact story. By changing the scales on the x- and y-axes of a graph, you can do the same thing with almost any data. The lesson here is to exercise care whenever you compare graphs. Look at their scales, not just the shape of their curves.

SECTION 6 - Global Warming Solutions

Take-Away Points:

- ▶ **Carbon dioxide and other greenhouse gas emissions can be reduced now.**
- ▶ **Individuals and entire nations can achieve these reductions using a wide range of existing technologies and strategies.**
- ▶ **An individual could reduce personal carbon dioxide emissions by nearly 5 tons a year, by taking simple steps like using more efficient appliances and better insulation.**
- ▶ **A number of companies in the region have achieved large reductions in their carbon emissions.**
- ▶ **Today's high level of atmospheric carbon dioxide will persist for 50 to 150 years, so action should not be delayed.**

Introduction

Perhaps the best news about global warming and climate change is that there are ways to slow it down. Individuals, businesses and government all have a role to play. One big way is to reduce the amount of CO₂ emitted into the atmosphere is to limit the combustion of fossil fuels. Still, doing so won't slow the rate of climate change overnight. That's because molecules of CO₂ emitted today will persist in the atmosphere for 50 to 150 years. Yet, if we are serious about controlling carbon emissions, it is still a very good idea – and an illustration of the precautionary principle in action – to take whatever steps we can as soon as possible to stop global warming before it becomes irreversible.

Each year about 5 billion tons of carbon dioxide is released into the atmosphere in the United States alone.

For each person in the country, that's 20 tons – four elephants – worth of CO₂!

Where Are Your Elephants?

Individual Solutions

Reduce Your Own CO₂ Output

- Plant a tree Reduction: 20 lbs/yr
- Use a high-efficiency refrigerator Reduction: 230 lbs/yr
- Buy products with reusable or recyclable packaging Reduction: 220 lbs/yr
- Use a low-energy, low-water washing machine Reduction: 440 lbs/yr

- Install a passive solar hot water system Reduction: 720 lbs/yr
- Recycle newspaper, glass, cardboard and metal Reduction: 850 lbs/yr
- Leave your car at home two days a week and share a ride, ride a bike, walk or take the bus Reduction: 1,590 lbs/yr
- Replace two frequently used light bulbs with compact fluorescents Reduction: 2,300 lbs/yr
- Tune-up your furnace, use a low-flow shower, add house insulation Reduction: 2,480 lbs/yr

When it comes to climate change, two of the biggest emitters of greenhouse gases are electricity generation and cars. Each of us could reduce carbon dioxide emissions by several tons a year if we reduced our use of electricity by employing more efficient appliances and driving more efficient cars less far.

Electricity

Across the U.S., an average of 2.3 pounds of carbon dioxide is emitted into the atmosphere for every kilowatt-hour (kWh) of electricity we use. You can calculate the kWhs that a given appliance consumes by multiplying the number of watts (W) it uses by the number of hours (h) it operates, then dividing by 1000. For example, the kilowatt-hour usage of a 60-watt light bulb that stays on day and night is:

$$(60 \text{ watts}) \times (24 \text{ hours}) / (1000) = 1.44 \text{ kWh/day}$$

If this amount of electricity had been generated by burning coal – as is some 55 percent of the power consumed in the U.S. – carbon dioxide emissions would be calculated this way:

$$(1.44 \text{ kWh}) \times (2.3 \text{ lb CO}_2 \text{ per kWh}) = 3.3 \text{ lb CO}_2/\text{day}$$

Fortunately, only about 10-15 percent of New England’s electricity comes from coal-fired power plants. The rest is a combination of natural gas, nuclear, oil and hydro power, with a few small renewable sources as well. As you can see, some power plants burn other fossil fuels to generate electricity, and burning any of them emits carbon dioxide as a byproduct. Even a new, highly efficient natural gas-fired plant will emit many hundreds of tons of CO₂ a year.

... Where does your electricity come from?

Automobiles

From a University of New Hampshire Press Release, March 23, 2001:

“After more than 20 years of studying the impact of automobile emissions on the environment, University of New Hampshire botanist and forester Barry Rock realized it was time to practice what he preached.

The forestry professor, who has studied the impact of pollution on the health of forests from New Hampshire's White Mountains to the Black Triangle area of central Europe, is now the owner of a Toyota Prius. His Prius, one of only three sold in the state since its release in August, is a hybrid vehicle. It runs using both a regular gasoline engine and one using electricity from a battery that never needs to be 'plugged in' because the gasoline engine continually charges it. Honda also makes a hybrid called the Insight.

'Hybrid vehicles reduce carbon dioxide emissions because they get such great gas mileage,' Rock says. 'In every gallon of gas there is about 20 pounds of carbon dioxide,' and adds 'When you get 20 mpg, that's like taking a 20-pound bag of charcoal and tossing briquettes out the window as fast as you can as you drive to Concord. If CO₂ levels continue to rise at current rates and we don't do anything to reduce our emissions, in about 100 years New England will experience an increase in the average temperature of 6-10 °F.'

That might not seem like a big deal, until Rock points out that if you take the 30-year average temperature for Boston and add six degrees Fahrenheit, the average temperature of Boston would be that of the 30-year average for Richmond, Virginia. Add 10 degrees, and temperatures are like those currently in Atlanta, Georgia. A few degrees increase in average temperature would make a huge difference in the climate of New England.

The Prius also reduces nitrogen oxide emissions, which are the precursor to ground level smog, by 90 percent. The impact of smog on both humans and forests could be reduced dramatically if nitrogen oxides from automobiles could be reduced. The Prius is a big step in that direction.

'If we don't do anything, we're going to double pre-industrial CO₂ levels in 50 years,' Rock says. 'CO₂ levels are higher than they've been in the last half million years and we're the cause – it's our cars. In the last 105 years, temperatures in New Hampshire have gone up 1.8 °F. In the White Mountains region, there's been an increase of 4 °F in the winter months. We can't say that increasing CO₂ levels are the only cause, but the New England of the future is going to be fundamentally different if we don't change the way we think about cars.'

ACTIVITY: Save the CO₂

Introduction

In your backpack you will find a set of materials (described below) that will help you demonstrate the effectiveness of taking steps to cut CO₂ emissions. Distribute them to the group (there may not be enough to go around, but that's OK for this exercise).

Next, take out the CO₂ information cards, and distribute these as well. No one should have both one of the props and the card associated with it.

Ask the people with props to hold them up for all to see, one person at a time. Group members should then try to identify the prop, while the person holding the card associated with it reads the text aloud.

Here is the text for each card. The identity of the related object is in boldface type. Note that symbolic props denote some of the objects. One represents the car, for instance; a tree cookie, the tree; and the light bulb box, EPA's Energy Star label.

- **Compact fluorescent bulbs** use one-quarter of the energy of a standard bulb to produce the same amount of light, while lasting up to 10 times longer. If every U.S. household replaced four incandescent bulbs with compact fluorescents, it would reduce carbon dioxide emissions by an amount equivalent to taking seven million cars off our roadways – forever.
- Without the existing level of **home insulation**, U.S. carbon dioxide emissions would increase by 156 percent -- that's equal to 1.4 trillion pounds every year. To compensate for these emissions, nearly 300 million acres of trees would have to be planted. That's an area three times the size of California.
- If insulation levels in all residential buildings in the U.S. were brought up to the Model Energy Code, an additional 250 billion pounds (125 million tons) of carbon dioxide could be avoided annually, reducing total CO₂ emissions in the U.S. by 30 percent.
- If you need an **automobile**, consider buying one that offers better gas mileage than your current vehicle. A car that gets 32 miles to the gallon (and a number do even better than this) will cut carbon dioxide by 5,600 pounds a year. If every car in the US achieved 40 miles per gallon – performance that is feasible using existing technologies – we would save more oil in one year than is believed to lie under the Arctic National Wildlife Refuge.
- If you dry clothes on a **clothesline**, whether inside or outside, instead of using a dryer, you prevent about 10 pounds of CO₂ from reaching the atmosphere – per wash.
- **Biodiesel fuel** is a clean-burning alternative fuel. It often is used in combination with petroleum diesel. Pure biodiesel performs like

conventional diesel, yet produces 78 percent less CO₂ over its lifetime than petroleum based diesel.

Biodiesel fuel can be made from a variety of vegetable products and byproducts, including soybeans and restaurant cooking grease. It can be put into any diesel engine and, if restaurant grease is a fuel source, the exhaust may have the recognizable odor of French Fries.

- *Recycle aluminum cans, **plastic bottles**, glass, cardboard and newspaper. Recycling can reduce your home's carbon dioxide emissions by 850 pounds a year.*
- *Planting **trees** creates carbon reservoirs. Even one tree in your yard will hold an average of 20 pounds of CO₂ a year over its lifetime.*
- *Voting knowledgeably, utilizing the **ballot box** is an important way to help cut greenhouse gas emissions by thousands of tons! Before Election Day, be sure to find out where candidates stand on climate issues.*
- *Make sure to use products with the **Energy Star**[®] label whenever you can. Look for the label on light bulbs, appliances, home insulation and electronics goods, among others. Energy Star products use less energy and save you money compared to other products.*

Business Solutions

Employees and business leaders can make significant reductions in greenhouse gas emissions by taking the lead in implementing energy-saving policies in the workplace. This is a photo of Kathy Loftus, one employee who is making a difference. She is the energy and regulatory affairs manager for Shaw's Supermarkets, Inc., one of the largest grocery chains in New England.

In recent years, Shaw's has achieved remarkable progress in reducing its energy usage. It has installed high-efficiency lighting and upgraded its refrigeration systems. As a result, CO₂ emissions have declined by 112,500 tons since 1993, the equivalent of taking more than 15,000 typical passenger cars off the road for a year. In addition to cutting air pollution, these measures have saved Shaw's more than \$6 million.

When showing this photo to your group, you can discuss the ways in which stores and other businesses are able to increase their energy efficiency. Ask the group for suggestions based on what they see in the photo.

Questions to consider include:

- Where do products come from?

- How is energy used in the entire product cycle – including collecting the raw materials, manufacturing or growing the product, transporting it to the marketplace, using it, and disposing of it or its residue later?
- In what ways could we reduce the energy we require to produce and dispose of products?

SHAW'S SUPERMARKETS RAISES THE BAR IN THE FIGHT AGAINST GLOBAL WARMING

Major Food Retailer Working with Climate Change Organization To Develop Model Programs for Northeast

Shaw's Supermarkets, already a leader in environmental and energy efficiency programs, has made a new commitment to reduce its emissions of greenhouse gases. Shaw's is joining forces with Clean Air-Cool Planet, a New England-based environmental non-profit group that focuses on solutions to climate change, as part of an ongoing effort to transform Shaw's into the greenest retail supermarket chain in the region, if not the nation.

"We want to do our part to preserve and protect the environment, and we want to continue to take a leadership role in our industry," said **Kathy Loftus**, Shaw's Energy and Regulatory Affairs Manager. "We know that our customers care about these issues, and so do we."

Shaw's is the first business in the region to partner with Clean Air-Cool Planet (CA-CP). The two will work to develop and implement a corporate-wide target to reduce carbon dioxide (CO₂) emissions. CO₂ is the leading cause of global warming.

"We have been very impressed by Shaw's commitment to leadership on environmental issues, including climate change" said Adam Markham, Executive Director of Clean Air – Cool Planet. "Shaw's has implemented perhaps the most advanced energy management systems used by any supermarket in the country. We believe that together we can take their pioneering efforts on climate and energy solutions to an even higher level. Shaw's understands that these initiatives not only help the environment, but also improve the bottom line. We hope that other New England businesses will accept the challenge and follow their lead".

CA-CP plans to convene an alliance of architects, engineers and energy experts to help the company evaluate state-of-the art technologies and practices designed to cut carbon pollution. The partnership will evaluate strategies that include vehicle fleet emissions, the benefits of natural light in stores and the use of renewable sources of energy like solar and geothermal power. The partnership also will focus on raising awareness about climate change and on helping Shaw's customers learn how to reduce their own impact on global climate.

The climate change partnership between Shaw's and CA-CP is the latest addition to a comprehensive environmental program that Shaw's is developing. The company-wide program includes initiatives in the areas of waste reduction and packaging, recycling, energy efficiency, refrigeration/ozone depletion, building design, and the promotion of sustainably harvested wood products. Shaw's was honored by the U.S. Environmental Protection Agency as an Energy Star Partner of the Year, in March of 2001.

DID YOU KNOW?

All the carbon in the world – in every form and location – is natural. It was created as the planet developed and changed over its 4.8 billion-year lifetime.

Nonetheless, carbon “unlocked” from fossil fuel deposits deep in the ground is considered to be **new carbon**. New carbon hasn’t been in the atmosphere for a very long time – at least 300 million years. If we didn’t extract it and burn it, forming CO₂, the only kind of carbon we would have in the air would be “old” carbon.

Old carbon is atmospheric carbon that has been cycling through the plants, soils and oceans, also for a very long time. If you burn fuels derived from vegetation that is replaced after harvest – biodiesel or wood fuels, for instance – you are merely transforming old carbon from one form to another, and so not adding to the average amount of carbon in the atmosphere.

Be aware that “new” carbon is carbon that is taken from the long-term carbon cycle and injected into the short-term cycle, in the form of carbon dioxide. “Old” carbon is already in the short-term cycle, and generally stays there over very long time periods as well.

Resources

<http://www.iclei.org/iclei.htm>

Excellent organization focusing on community solutions to global warming.

<http://www.arm.gov/docs/education/warming.html>

In-depth background, especially regarding impacts; good slides

<http://www.igpp.lanl.gov/climate.html>

Well-written scientific summary, but not for the layperson.

<http://www.doc.mmu.ac.uk/aric/eae/enter.html>

The Encyclopedia of the Atmospheric Environment.

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

The best science and policy summary information available.

<http://www.epa.gov/oppeoe1/globalwarming/index.html>

Environmental Protection Agency, very comprehensive.

<http://www.strategies.org/Climate/StickySituation=REV.pdf>

Climate change and K-12 National Science Education Standards.

http://climatesolutions.org/global_warming_is_here/index.html

Very readable research and global warming evidence section.

Alley, Richard B., *The Two-Mile Time Machine: Ice Cores, Abrupt Climate Change, and Our Future*, Princeton University Press, 2000.

Clark, Peter U., *Mechanisms of Global Climate Change at Millennial Time Scales*, American Geophysical Union, Monograph series, volume 112, 1999.

Dotto, Lydia, *Storm Warning: Gambling with the Climate of our Planet*, Toronto: Doubleday Canada, 2000.

Gelbspan, Ross, *The Heat is On: The Climate Crisis, The Cover Up, The Prescription*, Cambridge, MA: Perseus Books, 1997, 1998.

Parsons, Michael L., *Global Warming: The Truth Behind the Myth*, New York: Plenum Press, 1995.

Stevens, William K., *The Change in the Weather: People, Weather, and the Science of Climate*, New York: Delacorte Press, 1999.

Climate Change Glossary

From the CLIMATE NETWORK (www.climatenetwork.org)

Sources: United States Environmental Protection Agency (EPA), Intergovernmental Panel on Climate Change (IPCC), Green House Office of the Commonwealth of Australia (Australia).

A

Acid Rain. Also known as "acid deposition." Acidic aerosols are removed from the atmosphere by wet deposition (rain, snow, fog) or dry deposition (particles sticking to vegetation). Acidic aerosols are present in the atmosphere primarily due to the discharge of gaseous sulfur oxides (sulfur dioxide) and nitrogen oxides (NO_x) from both anthropogenic and natural sources. In the atmosphere, these gases combine with water to form acids. (EPA)

Aerosols. Particles of matter – solid or liquid – that are larger than a molecule, but small enough to remain suspended in the atmosphere. Natural sources include salt particles from sea spray and clay particles from the weathering of rocks, which are carried upward by the wind. Aerosols can also originate as a result of human activities. In that case, they often are considered to be pollutants. See also Sulfate Aerosols. (EPA)

Albedo. The ratio of reflected to incident (incoming) light. Albedo can be expressed as either a percentage or a fraction of one. Snow-covered areas have a high albedo (up to about 0.9 or 90%) due to their white color, while vegetation has a low albedo (generally about 0.1 or 10%) due both to its relatively dark color and to light it absorbs during the process of photosynthesis. Clouds, which have an intermediate albedo, are the most important contributor to the Earth's aggregate albedo, approximately 0.3 or 30%. (EPA)

Alliance of Small Island States (AOSIS). The group of Pacific and Caribbean nations that have called for relatively fast action by developed nations to reduce greenhouse gas emissions. The AOSIS countries fear the effects of rising sea levels and increased storm activity that are predicted to accompany global warming. The organization's goal is to hold Annex I Parties to a 20% reduction in carbon dioxide emissions by the year 2005. (EPA)

Anthropogenic. Derived from human activities. (EPA)

Atmosphere. The mixture of gases surrounding the Earth. The Earth's atmosphere consists of about 79.1% nitrogen (by volume), 20.9% oxygen, 0.036% carbon dioxide and trace amounts of other gases. The atmosphere can be divided into a number of layers defined by their mixing or chemical characteristics, characteristics heavily influenced by thermal properties (temperature). The layer nearest the Earth is the troposphere, which stretches to an altitude of about 8 km (5 miles) in the Polar Regions and to 17 km (nearly 11 miles) above the equator. The stratosphere, which extends to about 50 km (31 miles) above Earth, lies atop the troposphere. The mesosphere reaches from the end of the stratosphere to about 80-90 km above the Earth's surface. After that, the thermosphere, or ionosphere, gradually fades into outer space. There is relatively little mixing of gases between layers. (EPA)

B

Biogeochemical Cycle. The chemical interactions that take place among the atmosphere, biosphere, hydrosphere and geosphere. (EPA)

Biomass. Organic, nonfossil material of biological origin. Trees and plants are examples of biomass. (EPA)

Biomass Energy. Energy produced by the combustion of renewable biomass materials like sustainable wood products. The carbon dioxide emitted as a result will not increase total atmospheric carbon dioxide if combustion is done on a sustainable basis (that is, if within a given period of time, regrowth of biomass takes up as much carbon dioxide as the combustion process releases). Biomass energy is often suggested as a substitute for fossil fuel combustion and its massive greenhouse gas emissions. (EPA)

Biome. A naturally occurring community of flora and fauna, adapted to the particular conditions in which they occur (e.g., tundra) – or the region occupied by such a community. (IPCC)

Biosphere. The region on land, in the oceans and in the atmosphere inhabited by living organisms. (EPA)

Borehole. Any exploratory hole drilled into the Earth or its ice layers to gather geophysical data. Climate researchers often take ice core samples, a type of borehole, to predict past atmospheric composition and behavior. (EPA)

C

Carbon Cycle. The global-scale exchange of carbon among its reservoirs – namely the atmosphere, oceans, vegetation, soils, and geologic deposits and minerals. This exchange involves components in food chains, as well as the atmosphere, the hydrosphere and the geosphere. (EPA)

Carbonaceous Aerosol(s). Aerosol(s) (q.v.) containing carbon. (IPCC)

Carbon Dioxide (CO₂). The greenhouse gas whose concentration is being most directly increased by human activities. CO₂ also serves as the yardstick for all other greenhouse gases (see carbon dioxide equivalents). The major source of CO₂ emissions is fossil fuel combustion. CO₂ emissions also result from clearing forests and burning biomass, and from certain types of industrial production like cement manufacturing. Atmospheric concentrations of CO₂ have been increasing at a rate of about 0.5% a year, and are now approximately 30% above preindustrial levels. (EPA)

Carbon Dioxide Equivalent (CDE). A metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). Carbon dioxide equivalents are commonly expressed as "million metric tons of carbon dioxide equivalents (MMTCDE)" or "million short tons of carbon dioxide equivalents (MSTCDE)." The carbon dioxide equivalent of a gas is derived by multiplying its weight by its associated GWP. $MMTCDE = (\text{million metric tons of a gas}) * (\text{GWP of the gas})$. For example, the GWP for methane is 24.5. This means that the emission of one million metric tons (or any other weight x) of methane is equivalent to the emission of 24.5 million metric tons (or weight x) of carbon dioxide. Carbon, rather than CO₂, may be used as the reference, with other greenhouse gases converted to carbon equivalents. To make the conversion, multiply the weight of the CO₂ by 11/3 (the ratio of the molecular weight of carbon dioxide to carbon). (EPA)

Carbon Equivalent (CE). A metric measure used to compare the emissions of the different greenhouse gases based upon their global warming potential (GWP). Greenhouse gas emissions in the U.S. are most commonly expressed as "million metric tons of carbon equivalents" (MMTCE). Global warming potential is used to convert greenhouse gases to carbon dioxide equivalents. Carbon dioxide equivalents can then be converted into carbon equivalents by multiplying the carbon dioxide equivalents by 3/11 (the ratio of the molecular weight of carbon to carbon dioxide). The formula for deriving carbon equivalents is: $MMTCE = (\text{million metric tons of a gas}) * (\text{GWP of the gas}) * (3/11)$. (EPA)

Carbon Sequestration. The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, then release the oxygen while storing the carbon. Fossil fuels were at one time biomass. They continue to store the carbon that was in the biomass until the fossil fuels are burned. (EPA)

Carbon Sinks. Carbon reservoirs – the processes that take in and store more carbon than they release. This is sometimes called carbon sequestration. Carbon sinks can serve to partially offset greenhouse gas emissions. Forests and oceans are large carbon sinks. (EPA)

Chlorofluorocarbons and Related Compounds. This family of anthropogenic compounds includes chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide and the hydrochlorofluorocarbons (HCFCs). These compounds have been shown to destroy stratospheric ozone, and therefore are referred to as ozone-depleting substances. The most powerful among them are being phased out under the Montreal Protocol. (EPA)

Climate. The average weather for a particular region and time period (usually 30 years). Climate is not the same as weather, but rather the average pattern of weather for a particular region. Weather describes the short-term state of the atmosphere; climate is longer-term. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, and phenomena such as fog, frost and hail storms, among others. (EPA)

Climate Change (also referred to as “global climate change”). The term “climate change” is sometimes employed to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. Some consider “climate change” to be synonymous with “global warming.” Scientists, however, tend to use the latter term in a broader sense that encompasses natural changes in climate. See also Enhanced Greenhouse Effect. (EPA)

Climate Feedback. An atmospheric, oceanic or terrestrial process that is activated by the direct climate change induced by alterations in radiative forcing. Climate feedback may increase (positive feedback) or diminish (negative feedback) the magnitude of the direct climate change. (EPA)

Climate Lag. The delay between the introduction of a factor that promotes climate change, and the resulting change itself. For example, the effects of releasing more carbon dioxide into the atmosphere may not be known for some time because a large part of that CO₂ dissolves in the ocean and is released again only after many years. (EPA)

Climate Model. A quantitative way to represent the interactions of the atmosphere, oceans, land surface and ice. Models can range from relatively simple to quite comprehensive. See also General Circulation Model. (EPA)

Climate Modeling. Climate simulation using computer-based models. Also see General Circulation Model. (EPA)

Climate Sensitivity. The response of a given state of climatic equilibrium to a change in radiative forcing – for example, a doubling of the carbon dioxide concentration. (EPA)

Climate System (or Earth System). The atmosphere, the oceans, the biosphere, the cryosphere and the geosphere together make up the climate system. (EPA)

Cloud Condensation Nuclei. Airborne particles that serve as an initial site for the condensation of liquid water, and assist in the formation of cloud droplets. (IPCC)

CO₂ Fertilization. The enhancement of plant growth as a result of elevated atmospheric CO₂ concentrations. (IPCC)

Cogeneration. The process by which two different and useful forms of energy are produced at the same time. For example, water can be boiled to generate electricity, with the leftover steam used to drive industrial processes or captured for space heating. (EPA)

Compost. Decayed organic matter that can be used as a fertilizer or soil additive. (EPA)

Cryosphere. The frozen part of the Earth's surface. The cryosphere includes the polar ice caps, continental ice sheets, mountain glaciers, sea ice, snow cover, lake and river ice, and permafrost. (EPA)

D

Deforestation. Those practices or processes that convert forested lands to non-forest uses. This is often cited as one of the major ways that the greenhouse effect has intensified. Two reasons are given: (1) burning or decomposition of wood releases carbon dioxide into the atmosphere, and (2) trees remove carbon dioxide from the air through photosynthesis, and cutting them down means that they are no longer storing carbon. (EPA)

Desertification. The progressive destruction or degradation of existing vegetative cover to form desert. This can result from overgrazing, deforestation, drought and extensive burning. Once formed, deserts can only support a narrow range of sparse vegetation. More desert means increased albedo, reduced atmospheric humidity and greater aerosol loading. (EPA)

E

El Niño. A climatic phenomenon occurring irregularly, but generally every 3 to 5 years. El Niños often first become evident during the Christmas season (El Niño means Christ child) in the surface currents of the eastern tropical Pacific Ocean. The phenomenon involves seasonal changes in the direction of the tropical

winds over the Pacific and abnormally warm surface ocean temperatures. The changes in the tropics are most intense in the Pacific region. They can disrupt weather patterns throughout the tropics, and also extend to higher latitudes, especially in Central and North America. The relationship between these events and global weather patterns are currently the subject of much research on how to improve prediction of seasonal and interannual climate fluctuations. (EPA)

Emissions. The release of a substance (in the context of climate change, usually a gas) into the atmosphere. (EPA)

Enhanced Greenhouse Effect. The natural greenhouse effect as enhanced by anthropogenic emissions of greenhouse gasses. Increased concentrations of carbon dioxide, methane, nitrous oxide, CFCs, HFCs, PFCs, SF₆, NF₃, and other photochemically important gases caused by human activities – such as fossil fuel consumption and increased landfill waste – trap more infrared radiation, thereby exerting a warming influence on the climate. See Climate Change and Global Warming. (EPA)

Equivalent CO₂. The CO₂ concentration that would result in the identical degree of radiative forcing as a given mixture of other greenhouse gasses. (IPCC)

Evapotranspiration. The sum of evaporation and plant transpiration. Potential evapotranspiration is the amount of water that could be evaporated or transpired at a given temperature and humidity, assuming that plenty of water is available. Actual evapotranspiration cannot be any greater than precipitation, and will usually be less, since some water will run off into rivers and flow to the oceans. If potential evapotranspiration is greater than actual precipitation, it means that soils are extremely dry during most if not all of the year. (EPA)

F

Feedback Mechanism. A mechanism that connects one part of a system to another. The connection can either be amplifying (positive feedback) or moderating (negative feedback). See also Climate Feedback. (EPA)

Fertilization. A term used to denote efforts to enhance plant growth by increased application of nitrogen-based fertilizer or increased deposition of nitrates in precipitation. (EPA)

Fluorocarbons. Carbon-fluorine compounds that often contain other elements like hydrogen, chlorine or bromine. Common examples include chlorofluorocarbons and related compounds (also known as ozone-depleting substances), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

Flux. Shifts or flows of carbon over time from one pool to another (e.g., from the atmosphere to the forest). (Australia)

Forcing Mechanism. A process that alters the energy balance of the climate system, i.e., changes the relative balance between incoming solar radiation and outgoing infrared radiation. Such mechanisms include changes in solar irradiance, volcanic eruptions and enhancement of the natural greenhouse effect through the emission of greenhouse gasses. See also Radiative Forcing. (EPA)

Fossil Fuel. A general term for combustible geologic deposits of carbon in reduced (organic) form. Fossil fuels are of biological origin, and include coal, oil, natural gas, oil shales and tar sands. A major concern is that they emit carbon dioxide when burned, significantly contributing to the enhanced greenhouse effect. (EPA)

Fossil Fuel Combustion. Burning of coal, oil (including gasoline) or natural gas. This burning, usually to generate energy, releases carbon dioxide as well as combustion by-products that can include unburned hydrocarbons, methane and carbon monoxide. Carbon monoxide, methane and many of the unburned hydrocarbons slowly oxidize into atmospheric carbon dioxide. Common sources of fossil fuel combustion include cars and electric utilities. (EPA)

Fossil Fuel Reserves. The quantity of a fossil fuel that is known to exist, based on geological and engineering evidence, and that can be recovered under current economic conditions and operating capabilities. (IPCC)

Framework Convention on Climate Change (FCCC). The landmark international treaty unveiled at the United Nations Conference on Environment and Development (UNCED, also known as the "Rio Summit"), in June 1992. The FCCC commits signatory countries to stabilize anthropogenic (i.e., human-induced)

greenhouse gas emissions to “levels that would prevent dangerous anthropogenic interference with the climate system.” The FCCC also requires that all signatory parties develop and update national inventories of anthropogenic emissions of all greenhouse gases not otherwise controlled by the Montreal Protocol. The U.S. was the first industrialized nation to ratify this accord, out of 155 countries to do so. (EPA)

G

General Circulation Model (GCM). A global, three-dimensional computer model of the climate system that can simulate human-induced climate change. GCMs are highly complex and they represent the effects of such factors as reflective and absorptive properties of atmospheric water vapor, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries. The most recent GCMs include global representations of the atmosphere, oceans and land surface. (EPA)

Geosphere. The soils, sediments and rock layers of Earth’s crust, both continental and beneath the ocean floors. (EPA)

Global Warming. An increase in the near-surface temperature of the Earth. Global warming has occurred in the distant past as the result of natural forces, but the term is most often used to refer to the warming predicted to occur as a result of increased emissions of greenhouse gases. Scientists generally agree that the Earth's surface has warmed by about 1 °F in the past 140 years. The Intergovernmental Panel on Climate Change (IPCC) recently concluded that higher concentrations of greenhouse gases are causing an increase in the Earth's surface temperature and that greater concentrations of sulfate aerosols have led to relative cooling in some regions, generally over and downwind of heavily industrialized areas. Also see Climate Change and Enhanced Greenhouse Effect. (EPA)

Global Warming Potential (GWP). The index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emission of one kilogram of the greenhouse gas in question to the forcing from the emission of one kilogram of carbon dioxide over a given period of time, usually 100 years. Some gasses have not been assigned GWPs due to their complex atmospheric chemistry. The GWP of greenhouse gases is expressed in terms of Carbon Dioxide Equivalent. The International Panel on Climate Change (IPCC) has presented these GWPs, and it regularly updates them as new assessments warrant.

Greenhouse Effect. The thermal effect that results from greenhouse gases allowing incoming solar radiation to pass through the Earth's atmosphere, but preventing most of the outgoing infrared radiation from the surface and lower atmosphere from escaping into outer space. This process occurs naturally and has kept the Earth's temperature about 59 °F warmer than it would otherwise be. Current life on Earth could not be sustained without the natural greenhouse effect. (EPA)

Greenhouse Gas. Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), halogenated fluorocarbons (HCFCs), ozone (O₃), perfluorinated carbons (PFCs) and hydrofluorocarbons (HFCs). (EPA)

H

Hydrosphere. The part of the Earth composed of water. It includes clouds, oceans, seas, ice caps, glaciers, lakes, rivers, underground wells and atmospheric water vapor. (EPA)

I

Ice Core. A cylindrical section of ice removed from a glacier or an ice sheet in order to study climate patterns of the distant past. By performing chemical analyses on the air trapped in the ice, scientists can estimate the percentage of carbon dioxide and other trace gases in the atmosphere at the time the ice was formed. (EPA)

Infrared Radiation. The heat energy that is emitted from all solids, liquids and gases. In the context of climate change, the term refers to the heat energy emitted by the Earth's surface and its atmosphere.

Greenhouse gasses strongly absorb this radiation, while redirecting some of it back towards the surface and creating the greenhouse effect. (EPA)

Intergovernmental Panel on Climate Change. The IPCC was established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988. The purpose of the IPCC is to assess information in the scientific and technical literature related to all significant components of the issue of climate change. The IPCC draws on hundreds of the world's leading scientists to serve as authors, and thousands as reviewers. Key experts on climate change and the environmental, social and economic sciences from some 60 nations have helped the IPCC prepare periodic assessments of the scientific underpinnings of global climate change and its consequences. With a capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of climate change. For example, the IPCC organized the development of internationally accepted methods for conducting national greenhouse gas emission inventories. (IPCC)

K

Kyoto Protocol. An international agreement reached in 1997 in Kyoto, Japan, which extends the commitments of the UNFCCC. In particular, it sets targets for future emissions in developed countries. (Australia)

L

Lifetime (Atmospheric). This refers to the approximate time it would take for the anthropogenic increment of an atmospheric pollutant's concentration to return to its natural level (assuming emissions cease) as a result of either being converted to another chemical compound or taken out of the atmosphere via a sink. The duration depends on the pollutant's sources and sinks, as well as its reactivity. The lifetime of a pollutant is often considered in conjunction with the mixing of pollutants in the atmosphere; a long lifetime will allow the pollutant to mix throughout the atmosphere. Average lifetimes can vary from about a week (sulfate aerosols) to more than a century (CFCs, carbon dioxide).

M

Mauna Loa. A volcano on the island of Hawaii. At collection sites there, scientists have compiled the longest continuous reliable daily atmospheric records. (EPA)

Megatonne (Mt). One million tonnes. Greenhouse gas emissions are often measured in megatonnes. (Australia)

Meteorology. The science of weather-related phenomena. (EPA)

Methane (CH₄). A hydrocarbon that is a greenhouse gas carrying a global warming potential recently estimated at 24.5. Methane is produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and oil, coal production and incomplete fossil fuel combustion. The atmospheric concentration of methane has been shown to be increasing at a rate of about 0.6% per year, and its concentration of about 1.7 parts per million by volume (ppmv) is more than twice its preindustrial value. However, the rate of increase may be stabilizing. (EPA)

Metric Ton or Tonne. Common international measurement of greenhouse gas emissions. A metric ton is equal to 2,205 lbs or 1.1023 short tons. A metric ton is equal to 1,000 kilograms. A short (U.S.) ton is equal to 2,000 lbs. Finally, the U.K. long ton is equal to 1.016 metric tons, and 1.12 short tons. (EPA)

Mount Pinatubo. A volcano in the Philippine Islands that erupted in 1991, ejecting enough particulate and sulfate aerosol matter into the atmosphere to prevent some incoming solar radiation from reaching Earth's atmosphere. This effectively cooled the planet from 1992 to 1994, masking the warming that had been occurring for most of the 1980s and 1990s. (EPA)

N

Nitrogen fertilization. Enhancement of plant growth through the deposition of nitrogen compounds. In IPCC reports, this typically refers to fertilization from anthropogenic sources of nitrogen, such as man-made fertilizers and nitrogen oxides released as a result of fossil-fuel combustion. (IPCC)

Nitrogen Oxides (NO_x). Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules – often NO and NO₂. Nitrogen oxides are produced by vehicle exhaust emissions and power plant flue gas streams. In the atmosphere, nitrogen oxides can contribute to the formation of photochemical ozone (smog), impair visibility and cause health problems. They are considered pollutants. (EPA)

Nitrous Oxide (N₂O). A powerful greenhouse gas with a global warming potential of 320. Major sources of nitrous oxide include soil cultivation – especially from use of commercial and organic fertilizers – fossil fuel combustion, nitric acid production and the combustion of biomass. (EPA)

O

Ozone (O₃). Ozone consists of three atoms of oxygen bonded together – in contrast to the two bound atoms in normal oxygen. Ozone is an important greenhouse gas, and is found in both the stratosphere (about 90% of the total atmospheric loading) and the troposphere (about 10%). Ozone has other effects as well. In the stratosphere, it provides shields the Earth from ultraviolet radiation and harmful health and environmental impacts. In the troposphere, oxygen molecules in ozone combine with other chemicals and gases (via oxidization) to generate smog, a respiratory irritant and risk factor in heart disease. (EPA)

P

Particulates. Tiny pieces of solid or liquid matter, such as soot, dust, fumes or mist. (EPA)

Photosynthesis. The process by which green plants use light to manufacture organic compounds out of carbon dioxide and water. Oxygen and water are released as byproducts. Heightened levels of carbon dioxide can increase net photosynthesis in some plants. Plants represent a very important reservoir, or sink, for carbon dioxide. (EPA)

Pollutant. Strictly speaking, too much of any substance in the wrong place or at the wrong time is a pollutant. Atmospheric pollution is caused by the presence of substances in the atmosphere – the result of human activities or natural processes – that adversely affect human health, property and the environment. (EPA)

R

Radiation. Energy emitted in the form of electromagnetic waves. Characteristics differ depending on the wavelength. Because the radiation from the Sun is relatively energetic, it has a short wavelength (ultraviolet, visible and near infrared). Energy reradiated from the Earth's surface and the atmosphere has a longer wavelength (infrared radiation), because the Earth is cooler than the Sun. (EPA)

Reforestation. The Revised 1996 IPCC Inventory Guidelines define reforestation as the planting of forests on land that has historically contained forest but that has been used for another purpose since last being covered by forest. (Australia)

Regeneration. Renewal of forest or tree crop by natural or artificial means. (Australia)

Residence Time. The average time spent in a reservoir (q.v.) by an individual atom or molecule. Also, the age of a molecule when it leaves the reservoir. With respect to greenhouse gases, residence time usually refers to how long a particular molecule remains in the atmosphere. (EPA)

Reservoir. A component or components of the climate system in which a greenhouse gas or precursor of a greenhouse gas is stored. (Australia)

Respiration. The process by which animals use up stored foods through oxidation to generate energy. (EPA)

S

Sink. A reservoir that takes up a pollutant from another part of its cycle. Soil and trees tend to act as natural sinks for carbon. (EPA)

Source. Any process or activity that releases into the atmosphere a greenhouse gas, an aerosol or a precursor to a greenhouse gas. (Australia)

Sulfur Dioxide (SO₂). A compound composed of one sulfur and two oxygen atoms. Sulfur dioxide emitted into the atmosphere through natural and anthropogenic processes is transformed through a complex

series of chemical reactions into sulfate aerosols. These aerosols cause negative radiative forcing, and thus tend to cool the Earth's surface. (EPA)

Sustainable Development. Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (IPCC)

T

Terrestrial Biosphere. A collective term for all living organisms on land. (IPCC)

Thermohaline Circulation. Large-scale, density-driven circulation in the oceans, driven by differences in temperature and salinity. (IPCC)

Ton. See Metric Ton.

Troposphere. The lowest layer of the atmosphere. The troposphere extends above the Earth's surface for about 10-15 km. See also Atmosphere.

Tropospheric Ozone (O₃). Ozone that exists in the troposphere and plays a significant role in both global warming and in the formation of urban smog. See Ozone for more details. (EPA)

W

Water Vapor. The most abundant greenhouse gas and an important part of the natural greenhouse effect, it is the water present in the atmosphere in gaseous form. While humans are not significantly increasing its concentration, it contributes to the enhanced greenhouse effect because the influence of other greenhouse gasses reinforces its warming properties – an example of a positive feedback loop. In addition to its role as a natural greenhouse gas, water vapor plays an important role in regulating the temperature of the planet. (EPA)

Weather. Weather is the specific condition of the atmosphere at a particular place and time. It is measured in terms of such phenomena as wind, temperature, humidity, atmospheric pressure, cloudiness and precipitation. In most places, weather can change from hour to hour, day to day, and season to season. Climate is the average of weather over time and space. A simple way of remembering the difference is that 'climate' is what you generally expect (e.g., cold winters) and 'weather' is what you actually get (e.g., a blizzard). (EPA)

The New England Science Center Collaborative *Addressing the topic of climate change*

The New England Science Center Collaborative helps institutions engaged in science education in New England develop the skills and resources needed to effectively address climate change, and to integrate those resources into their particular goals and missions.

The Collaborative combines the scientific expertise of New England's internationally recognized research institutions with the experience of informal educational institutions to present climate science in interesting and informative ways. Members of the Collaborative share the conviction that each institution has a responsibility to help all sectors of society engage in an informed discourse about climate change.

Acknowledgements

The New England Science Center Collaborative would like to thank Dave Thurlow and Dennis Sullivan of Cumulus Interactive for heading up the research and design work associated with producing the first set of Climate Change Backpacks in October 2001. Their interest in climate science and their dedication to this project demonstrates a strong commitment to the creation of versatile and effective educational materials.

Thanks also are due to all of those who assisted in the production of the Climate Change Backpack, including:

Dave Anderson, SPNHF
Mike Cline, Tin Mountain Conservation Center
Donna Curtin, Tundra Design Studios
Doreen Curtin, Tundra Design Studios
Jan Derby, Christa McAuliffe Planetarium
Tracy Fredericks, Seacoast Science Center
Steve Hamburg, Brown University
Brad Hurley, ICF, Inc.
Mary Lou Krambeer, New England Science Center Collaborative
Melissa LeBlanc, Massabesic Audubon Center
Deborah Meese, Cold Regions Research & Engineering Laboratories
Nancy Ritger, Appalachian Mountain Club
Barry Rock, University of New Hampshire
Susan Ross-Parent, Cumulus Interactive
Cameron Wake, University of New Hampshire

Supporters and Contributors

Cumulus Interactive
Environmental Defense
JKRL - USA
John F. and Dorothy H. McCabe Environment Fund
Mount Washington Observatory
Richard Polonsky, Innovation Works
Shaw's Supermarkets, Inc.
Sunpark Electronics Corporation
The Timberland Company
World Energy, Inc.

Special Thanks To:

Dr. David Bartlett, Durham, New Hampshire
Will Guild, Portsmouth, New Hampshire
Ginny, Chris and Taylor Kanzler, North Conway, New Hampshire
The LaPlante Family, West Burke, Vermont
Kathy Loftus, West Bridgewater, Massachusetts
Dr. Deb Meese, Hanover, New Hampshire

Photography by John McKeith,
John McKeith Location Photography, All Rights Reserved

The Climate Change Backpack and activities were designed and created by Dave Thurlow and Dennis Sullivan.

The Presenters Guidebook was compiled and written by Dave Thurlow, and edited by Rusty Russell and Steven Hamburg

Backpack concept by
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Brown University, Center for Environmental Studies, *Providence, R.I.*
Cold Regions Research & Engineering Laboratory, *Hanover, N.H.*
Earth, Ocean & Space Institute, UNH, *Durham, N.H.*
Hubbard Brook Ecosystem Study, U.S. Forest Service, *Woodstock, N.H.*
Mount Washington Observatory, *North Conway, N.H.*

Programs and projects overseen by the Collaborative

To address a growing disparity between the public's understanding of global warming and the need for a more informed public discussion about this major environmental issue, the New England Science Center Collaborative has developed a series of hands-on climate change exhibits, outreach activities and educational programs. We make climate change real and immediate by focusing on the connection between the international science of global warming, and the specific impacts of global warming that may be felt in our own New England region. Current Collaborative projects supporting this objective include:

- Interactive, computer-based traveling exhibits.
- For member organizations, staff training workshops on the science of climate change provided by experts at research institutions.
- The Climate Change Backpack, a teaching tool for the field, designed for both formal and informal science education settings.
- Speakers that can address the scientific, economic and policy implications of climate change.
- A docent training program for volunteers at member institutions.
- Promotion of the 2001 New England Regional Assessment (NERA), which examines climate change impacts in our area. (This scientific work was undertaken in conjunction with the National Assessment, a landmark study in the continuing effort to understand what climate change means for the U.S. That study, set in motion through federal legislation in 1990, was carried out under the auspices of the U.S. Global Change Research Program.)

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