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Earth Science Standard E.4.c.

Student Edition

California Education and the Environment Initiative

The Greenhouse Effect on Natural Systems

California Education and the Environment Initiative

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The Education and the Environment Initiative Curriculum is a cooperative endeavor of the following entities:

California Environmental Protection Agency

California Natural Resources Agency

California State Board of Education

California Department of Education

Department of Resources Recycling and Recovery (CalRecycle)

Key Partners:

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Office of Education and the Environment

1001 I Street • Sacramento, California 95814 • (916) 341-6769

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None required for this lesson.

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None required for this lesson.

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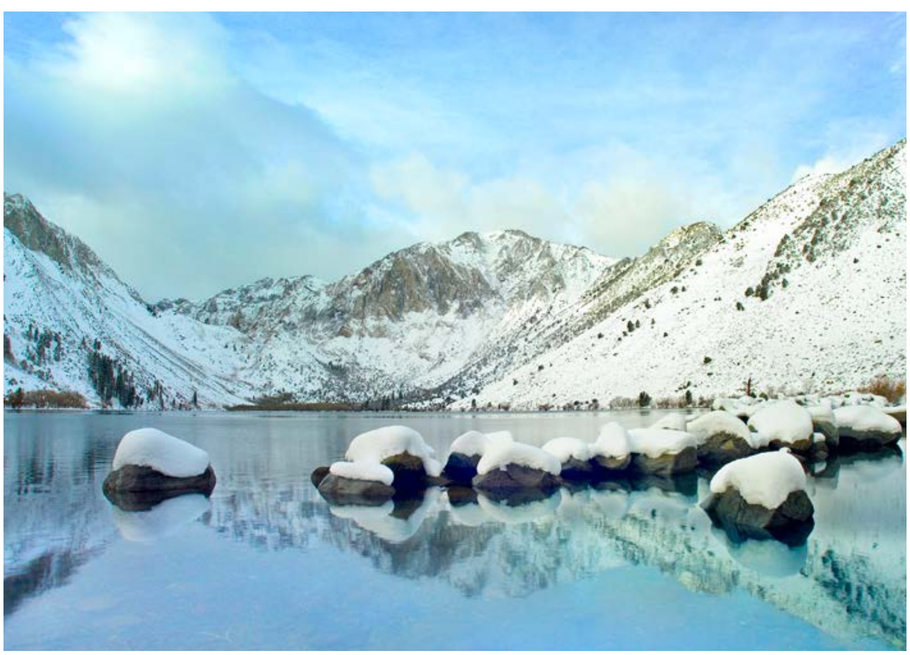
Climate Change in the Golden State

Earth has experienced natural climate changes since the planet formed billions of years ago. Many of these climate changes have been slow, occurring over centuries or millennia. Subtle differences in Earth's orbit around the Sun, or shifting landmasses (for example, moving tectonic plates or the uplift of mountain ranges) cause these slow climatic changes. Rapid changes in climate, those that happen over decades or even a few years, are triggered by sudden events, such as volcanic eruptions, collisions with meteors, or drastic shifts in ocean currents.

Constantly Changing Climate

Climate change is a shift in the "average weather" that a given region experiences. This is measured by changes in the features we associate with weather, such as temperature, wind patterns, precipitation, and storms. Global climate change means change in the climate of Earth as a whole. Global climate change can occur naturally; an ice age is an example of naturally occurring climate change. Earth's natural climate has always been, and still is, constantly changing. The climate change we are seeing today, however, differs from previous climate change in both its rate and its magnitude.



Snow melting in Sierra Nevada Mountains, California

Greenhouse Effect

To understand climate change, you have to know that Earth's climate is regulated by the greenhouse effect, without which life as we know it would be impossible. The greenhouse effect occurs when greenhouse gases are released on the planet, where they build up in Earth's atmosphere. This forms a layer in the upper atmosphere that allows heat and light in; then some of the heat/light energy is absorbed near and at Earth's surface. The rest escapes out into space. Without the effect of these naturally occurring gases, the average temperature on Earth would be -0.4° F (-18º C), instead of the current average 59° F (15º C). Life as we know it would be impossible.

The last 10,000 years has been a warm and stable period, and the last millennium, over which current societies have developed, has been one of the most stable climates observed. Yet, during the 20th century, we have observed a rapid change in the climate and atmospheric concentration of greenhouse gases attributable to human activities. These recent changes in greenhouse gases far exceed the extremes of the ice ages, and the global mean temperature is warming at a rate that cannot be explained by natural causes alone. The natural archives of Earth's climate, such as fossils, ocean sediments, and ice cores, record global temperature fluctuations that have resulted in ice ages and warm periods. During the last ice age, Earth was approximately 10° F (5.6° C) cooler than it is now. Sheets of ice a mile thick covered the poles and the northern United States. Now we are in a warm period. The global temperature has risen almost 2° F (1.1° C) in the last century. And the rate of warming is increasing.

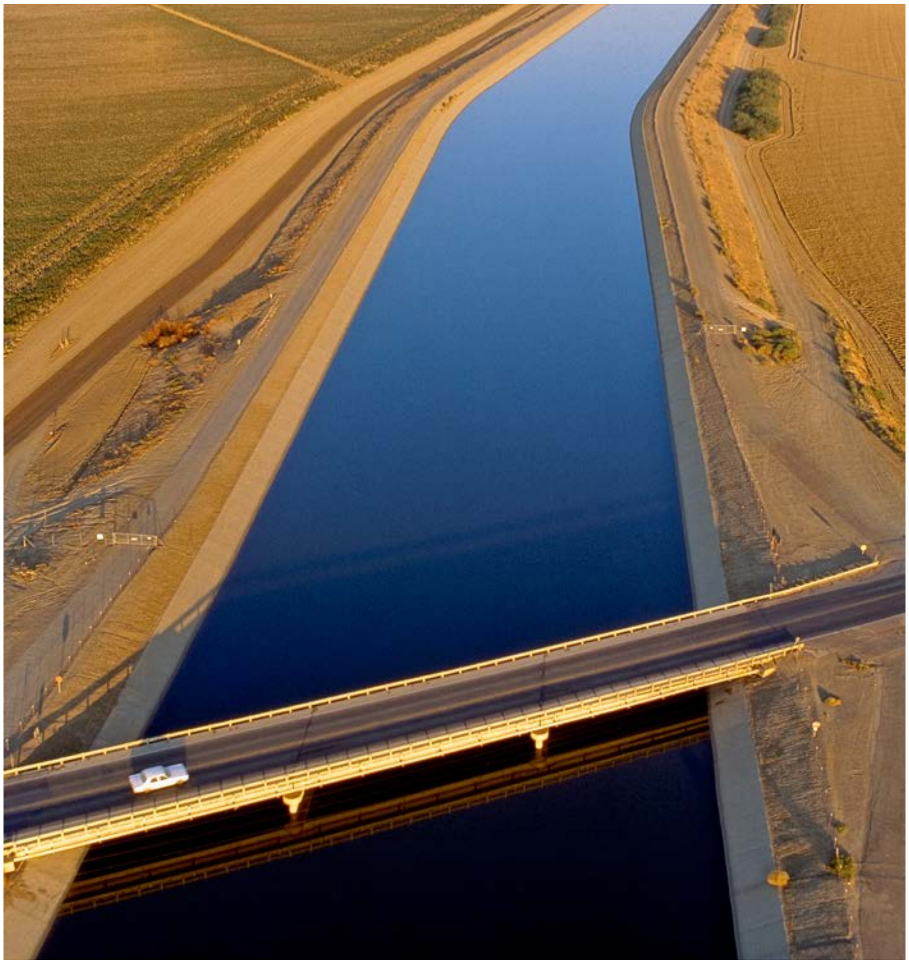
Observing Climate Change in California

Changes in California's own climate are in line with the warming trends in many other places. Our winter and spring temperatures have risen steadily in the last 50 years. This rise has caused the snowpack in the Sierra Nevada Mountains to melt earlier every spring. Even the wildflowers bloom two weeks earlier. Scientists predict that if the warming trend continues, the state's temperatures will rise as much as 10.5° F (5.8° C) by 2100. This increase will put a great deal of extra stress on both the people and natural systems of California.

In January 2007, the National Oceanic and Atmospheric Administration (NOAA) announced that 2006 was the warmest year on record in the United States. In 2006, NASA confirmed that 2005 was the warmest year recorded in human history. As the climate changes and periods of higher temperatures increase, there can be detrimental effects for people who suffer from heat-related illnesses. For example, elderly people, young children, and people who are already sick are at the greatest risk for heat-related dehydration, heatstrokes, heart attacks, or strokes.

Most of the rain and snow that falls in California falls in the northern part of the state. The greatest demand for water, however, comes from drier Southern California, home to two-thirds of the state's population. A system of reservoirs, aqueducts, and pipelines move massive amounts of water to the crowded cities of the Los Angeles Basin. This water comes from melting snow in the Sierra Nevada Mountains each spring.

If the climate continues to warm, more precipitation will fall as rain, and less will fall as snow. The snow that does fall will melt sooner. The snowpack could decrease by 70–90% by the year 2100. This loss of snow would cause huge problems for the people who manage the state's water resources. If not enough water is stored in the winter, people may not have enough drinking water or water for agriculture. Without enough water to flow through dams, power operators might



California Water Project

not be able to generate as much electricity. Without lots of snow, winter tourism (including skiing) would decline, causing hard times for snow-related businesses.

Effects of Climate Change in California

Climate change will also affect California's agricultural regions, which are considered to be some of the world's most productive and diverse growing regions. California produces 50% of the nation's fruits, vegetables, and nuts. If climate change continues, the state could experience severe drought. Many fruit and nut trees would not produce good crops if they were exposed to extreme heat. In order to develop healthy buds, these trees need "chill hours" with temperatures below 45° F (7.2° C). Loss of these cold conditions and the greater number of hot days could mean a great loss for California farmers.

Warming temperatures would also increase the number of pests and the frequency of plant diseases that affect California crops. Pest breeding seasons would become longer, and pests that like warmer weather will spread to new areas. For example, a certain type of leafhopper, the glassy-winged sharpshooter, spreads Pierce's disease when they eat grape leaves. Pierce's disease is a bacterial disease that destroys grapevines. These leafhoppers love hot, dry weather, so they would prosper with rising temperatures, leaving vineyard owners in northern California to deal with an increase of this damaging disease.

Rising temperatures, hot winds, and drought conditions could cause a 55% increase in destructive wildfires. Low-intensity fires actually help regenerate certain ecosystems. They clear woody debris and underbrush, release nutrients into the soil, crack open heat-dependent seed coats, and allow light to penetrate through thick foliage. However,

Forest fire

current trends are to not allow low-intensity fires to burn, so fuel sources like underbrush build up. Earth's warming trend could spark intense firestorms from this underbrush, destroying property and wildlife habitat. These fires could also cause the disappearance of plant and animal species in ecosystems already affected by human activity. Wildfires also have severe consequences for human health because they can cause air pollution to spike to unhealthy levels across a broad area.

Climate change already affects California's native trees and plants. Warmer weather in the north is causing cold-loving Douglas firs to die off. Drought-resistant madrone and oak are taking the place of these firs. Nonnative grasses are replacing burned-out forests with dry weeds that can spark dangerous fires. In the Sierra Nevada, the fragile plants that make up the alpine tundra are receding to higher and higher elevations. Scientists predict these plants will decline 60–80% by the end of this century.

Future effects would include an increase in extreme heat days, additional rise in sea level, significant loss of snowpack, and increases in forest fires and energy use. The magnitude of these effects depends on the temperature increase. Perhaps the greatest effect of climate change in the future will be felt along the coasts of California. Known for its beaches and recreation, the state attracts people from all over the world. During the last 100 years, sea levels along the California coast have risen seven inches. As Earth continues to warm, sea levels could rise as much as 35 inches by the year 2100. In this case, inland areas will flood with sea water, breaching levees and degrading freshwater supplies for drinking. Animal and plant habitats would also change, causing many species to move out of the area or disappear entirely. Severe storms, pushed inland by high winds, can erode beaches and cause billions of dollars of damage to property, water supplies, utilities, and businesses.

The natural systems of California have seen many climate changes. For example, the La Brea Tar Pits formed many thousands of years ago, trapping plant matter and animals that were part of the ancient Los Angeles ecosystem that existed during the last ice age, more than 10,000 years ago. The 3.5 million fossils collected in the Tar Pits give a glimpse of life before California's ancient native plants and animals had to either adapt to a different climate, or become extinct. The giant sequoia and the now-endangered California condor both survived this period. The question is: will we survive the changes of the future? The better we understand the causes and effects of climate change, the better we can predict how Earth will be affected. This understanding is key to our planetary and personal survival as the global climate continues to change.

Making Choices

The challenge of ensuring clean air and a healthy climate can be met. Choices made by businesses, communities, and individuals can lead to meaningful reductions in air pollutants and greenhouse gas emissions. Home energy improvements, tree planting programs, alternative transportation, beverage container recycling, and increased use of public transit are just some of the choices that can be acted upon at the individual, business, and community levels. In many cases, one action will reduce both air pollutants and greenhouse gas emissions. Many actions will save money in the short- and long-term. Actions taken now and continued over the long-term can make a significant difference in ensuring clean air and a healthy climate for California.

Storm surge

Water Vapor: A GHG

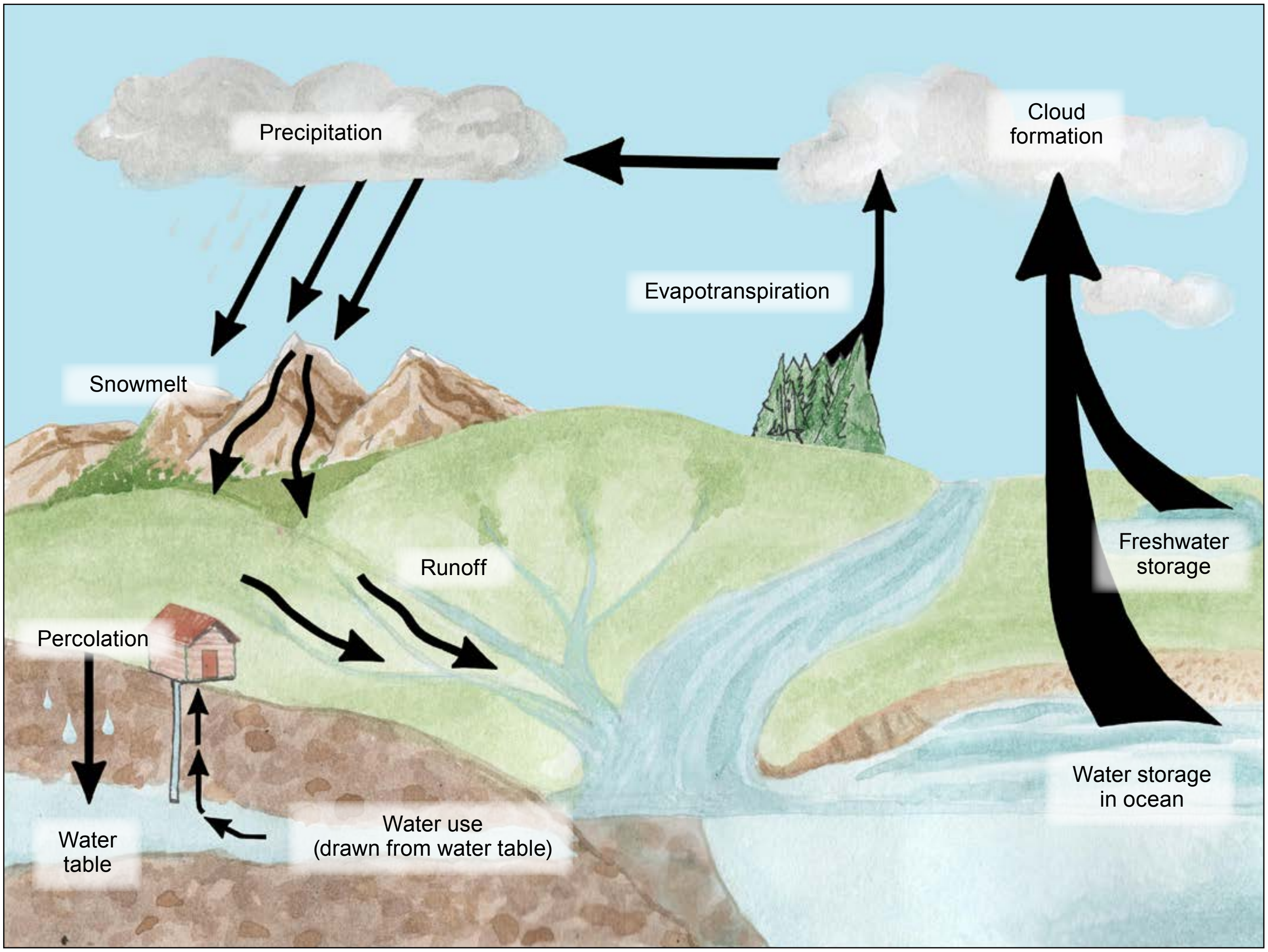
Water vapor in our atmosphere is an important greenhouse gas (GHG). On a cloudy day we can see evidence of the amount of water vapor in our atmosphere. During a heavy rainstorm—and especially during a hurricane—it is easy to see that our atmosphere is a huge reservoir of water vapor.

Water vapor is one of the greenhouse gases that is present around the planet and helps reflect heat back to Earth's surface, keeping it within the atmosphere. Water vapor has a bigger influence on Earth's climate than any of the other greenhouse gases.

Why do scientists think it is so important? Water vapor is the most abundant greenhouse gas on Earth. As a result, it is a very effective absorber of infrared radiation.

The water cycle is the major natural process that influences the amount of water vapor in the atmosphere, although it is evaporation that turns liquid water into a gas. Water evaporation from the ocean produces about 67% of Earth's water vapor, or approximately 505,000 km^3 (121,000 mi^3) of water, about 398,000 km^3 (95,000 mi^3) of it over the oceans. Ongoing evaporation helps cool the ocean (as heat is removed from the ocean's surface water molecules and transformed into gaseous water molecules). Without this natural process, the ocean would heat up and, in turn, cause global air temperatures to rise. Evaporation from lakes and other bodies of water also occurs, but since approximately 74% of Earth's surface (an area of some 361 million square kilometers) is covered by ocean, most water vapor comes from the ocean reservoir.

Ocean waves



Discuss the following with your group:

- Water vapor sources: Where does water vapor in the atmosphere come from?
- Water vapor sinks: What removes water vapor from the atmosphere and stores it for a long time?
- Which human activities could cause more or less water vapor to be in Earth's atmosphere?

Carbon Dioxide: A GHG

Carbon dioxide (CO_2) is a greenhouse gas (GHG) that is found in our atmosphere. Respiration by animals, including humans, and other organisms is the largest source of naturally produced CO_2 on Earth. Carbon exists in all living organisms and is needed for growth and reproduction. All living things act as carbon sinks, storing carbon. Plants take up CO_2 during photosynthesis and convert it into biomass (plant matter). Long-lived plants, such as trees, are natural carbon sinks. Carbon is also released into the atmosphere as wood is burned in natural forest fires or fires caused by deforestation.

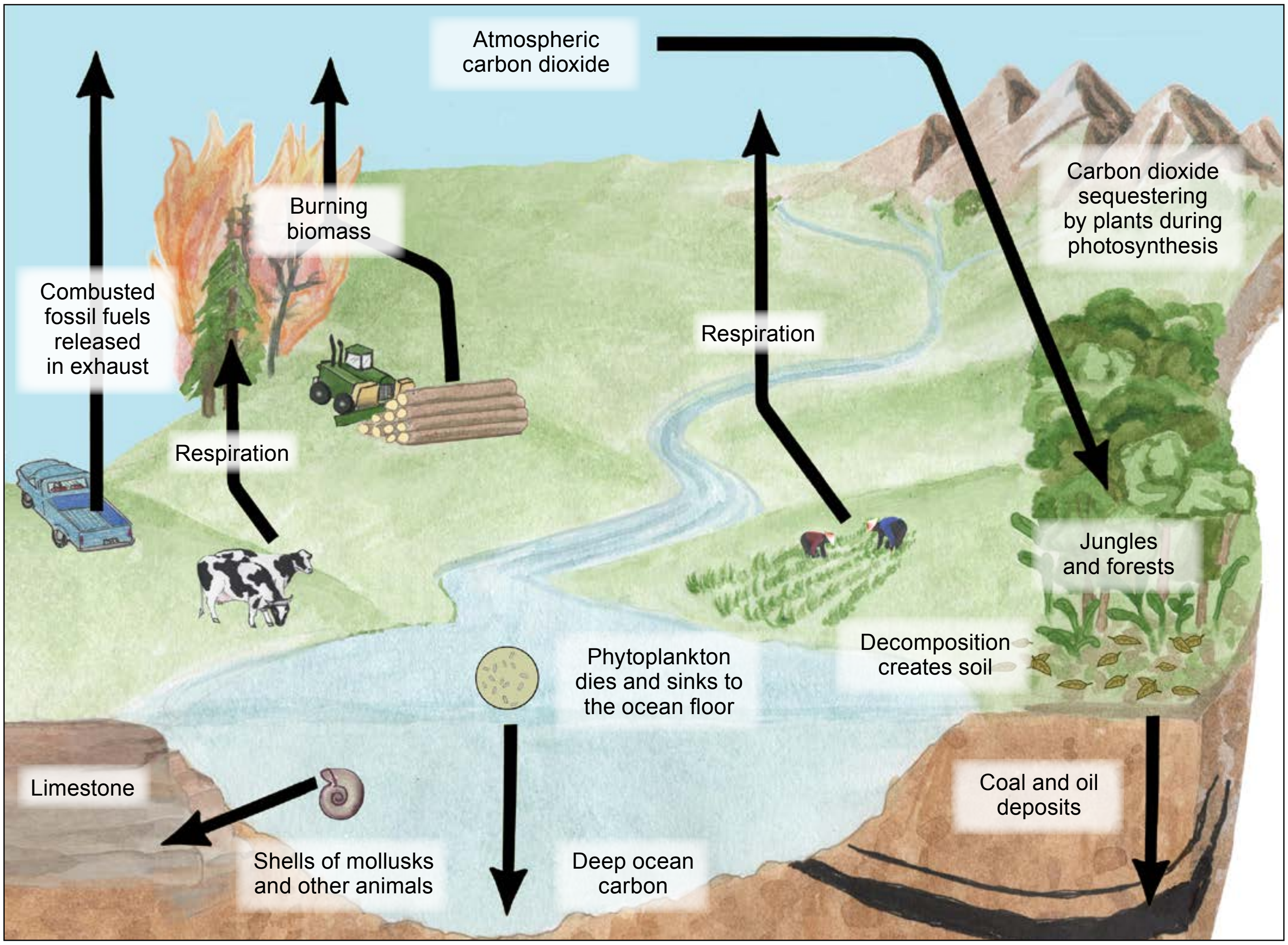
Short-lived plants, such as grasses, annual crops like corn, wheat, tomatoes, and other plants, take up carbon dioxide during growth and release this same CO_2 back to the atmosphere, or to the soil when they die in the fall. People and animals consume plants harvested by farmers, and their bodies convert carbon from the plants into carbohydrate energy needed for growth and reproduction.

Wind and wave action cause atmospheric carbon dioxide to mix into the ocean, where it becomes dissolved CO_2. Some CO_2 is also converted into calcium carbonate, the main ingredient in shells and skeletons. The ocean is home to vast numbers of shelled organisms. Because shells and skeletons are so hard and heavy, when organisms with shells or skeletons die, their bodies settle to the ocean floor or are washed ashore by tides. The shells and skeletons that sink to the deep ocean create a real carbon sink. When shells are compressed under weight, such as the weight of the entire ocean, they become carbonate rock, such as limestone and marble. These rock formations are a big reason why the ocean is a carbon sink. Weathering and temperature changes break apart carbonate rock and release the carbon locked inside.

When terrestrial organisms (plants and animals) die, microorganisms in the soil break down or decompose the dead material. Some of the carbon is released to the atmosphere as carbon dioxide, and some remains in the soil. In this way, soils are a sink for carbon. Soils store more carbon than the atmosphere or living organisms.

Fossil fuel deposits (oil, coal, and natural gas) are ancient plants that did not decompose completely and were compressed underground or under the ocean. These concentrated forms of carbon release energy and CO_2 when burned. In 2006 alone, California released over 400 million tons of CO_2 from human-related activities.

Logs



Discuss the following with your group:

- Carbon dioxide sources: Where does carbon dioxide in the atmosphere come from?
- Carbon dioxide sinks: What removes carbon dioxide from the atmosphere or stores it for a long time?
- Which human activities could cause more or less carbon dioxide to be in Earth's atmosphere?

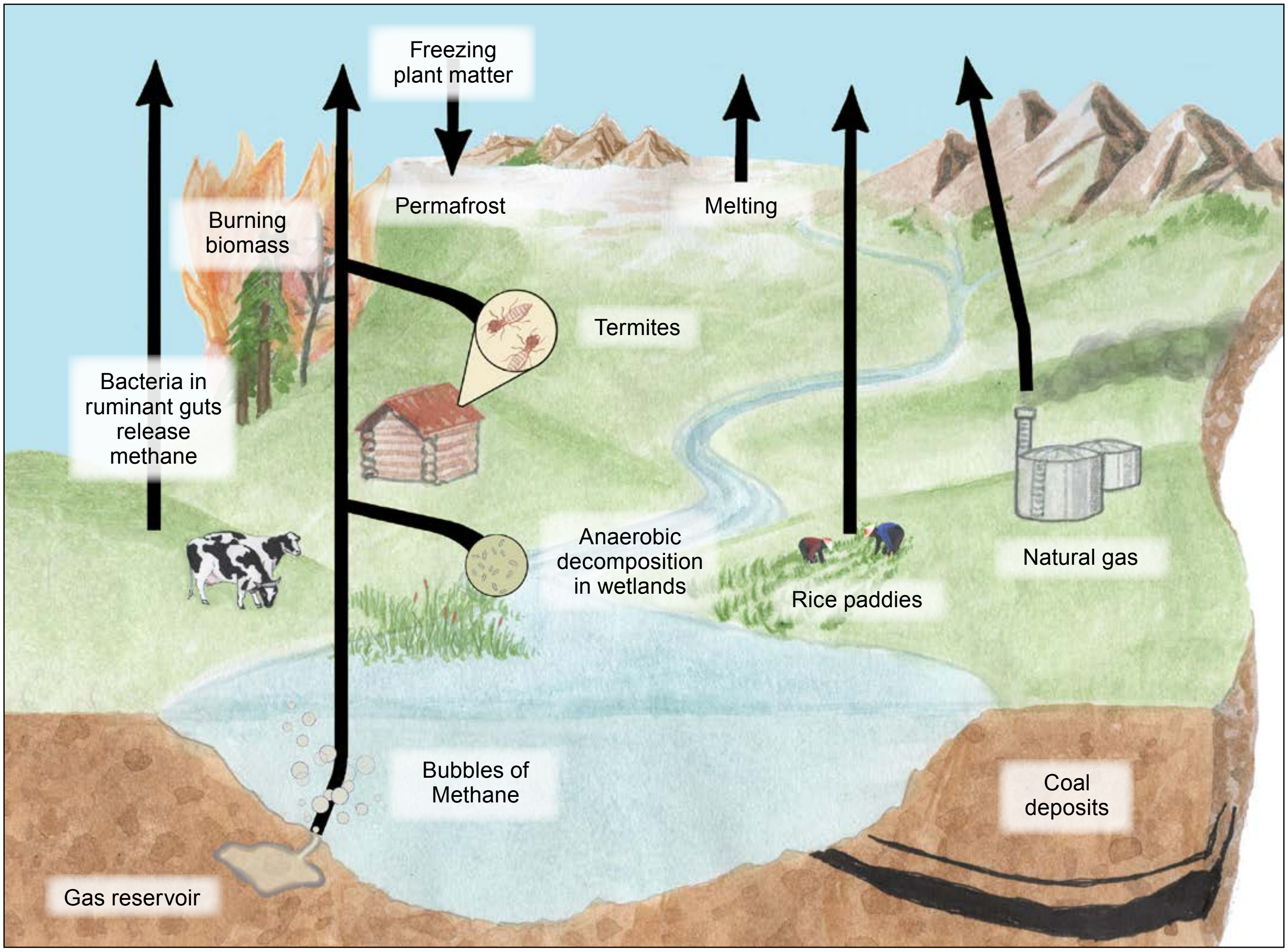
Methane: A GHG

Methane (CH_4) is a greenhouse gas (GHG) in our atmosphere. It is a carbon-based gas, like CO_2. Methane is produced when animal waste or dead organisms decompose and when plant matter is burned. Human activities, such as cattle ranching and decomposition of waste in landfills, also produce large quantities of methane. Methane gas is also a type of fossil fuel used for energy. Millions of years ago, plants that were only partially decomposed were buried underground. Under pressure, the carbon from these once-living organisms turned into methane gas. People burn methane as a source of energy—producing CO_2.

Methane is also produced by the decomposition of plants in wetlands. If you have ever gotten stuck in the muck along the edge of a pond, you have probably smelled the stinky gas that was released when your foot finally slurped out of the muck. Methane is a colorless, odorless gas; methane is the principal component of "natural gas" which has other components with odors. Other moist soils—even frozen ones—form methane, too. Moist soils that are frozen for at least two years in a row are called "permafrost." Permafrost exists at high latitudes and in alpine areas (high in mountains). Specially adapted low-growing plants can live in permafrost. When these plants die, the carbon stored within the plant material becomes trapped within the permafrost as methane. When permafrost melts, it releases methane into the atmosphere.

Plants take up carbon dioxide from the atmosphere and, through photosynthesis, convert it into plant material. Agricultural crops and other plant materials are frequently used as sources of

Forest fire



biomass for energy production. As the biomass is burned or decomposed, some of the carbon it contains is converted into methane, and released into the atmosphere.

Some animals can also release methane gas. Ruminants, such as cattle, goats, sheep, bison (buffalo), giraffes, and deer, have a special process for digesting grass and the other plant material they eat. Bacteria work as part of this digestive process, breaking down plant matter and releasing methane as animals exhale and emit gas. As termites consume wood, their digestive processes create methane in a similar manner. The amount of methane cows and termites produce is significant.

Discuss the following with your group:

- Methane sources: Where does methane in the atmosphere come from?
- Methane sinks: What removes methane from the atmosphere or stores it for a long time?
- Which human activities could cause more or less methane to be in Earth's atmosphere?

Nitrous Oxide: A GHG

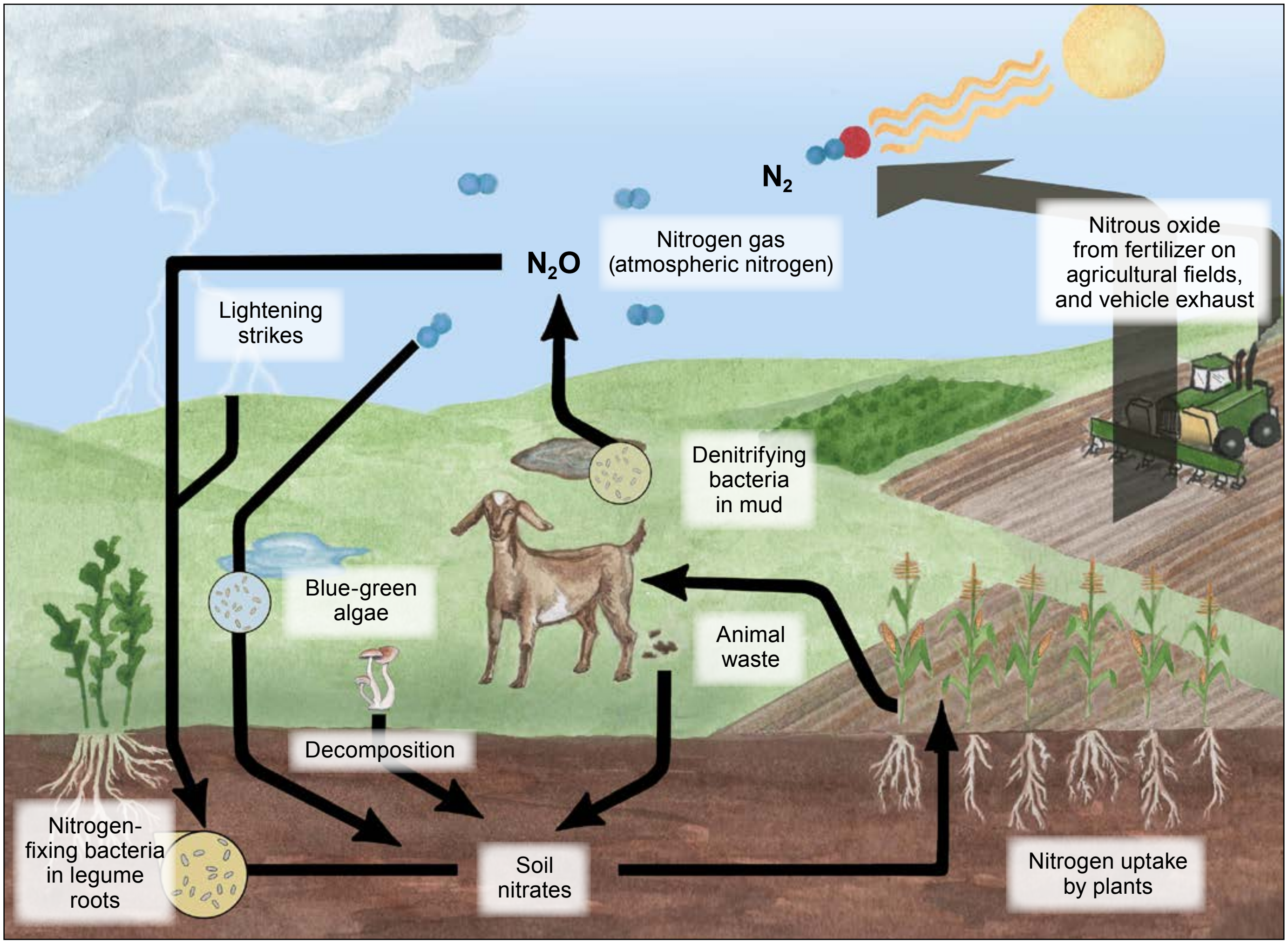
Nitrogen (N_2) is the most common gas in the atmosphere, where it comprises about 78% of the air by volume. Nitrogen, like carbon, is involved in a natural cycle, where, in different chemical forms, it moves between the atmosphere, ocean, fresh water, soil, plants, and animals. It is released into the soil when animal waste or dead plants and animals decompose. Human activities that release large quantities of nitrogen include fertilizing farmland, burning forests, burning wood for energy (heat), and turning soil.

Nitrogen atoms are found in many different molecules, including nitrous oxide (N_2O), in which two atoms of nitrogen combine with one atom of oxygen. Nitrous oxide, which has very different chemical characteristics from pure nitrogen, is one of the atmosphere's important greenhouse gases (GHG). Photolytic reactions (light-driven reactions) in the stratosphere are the major N_2O sink in the atmosphere.

Nitrous oxide is produced and released naturally and from human-related sources. About 66% of the largest human-related sources are associated with soil management for agriculture. The use of nitrogen-based fertilizers to improve the soil on farms is the largest contributor to this problem. Other human-related sources of nitrous oxide include sewage treatment, farm animals' waste products, burning of fossil fuels, and production of chemicals like nitric acid. The principal natural sources of nitrous oxide are decomposition and bacterial action in soil. Rather than just using oxygen for respiration, many species of bacteria can use nitrates, nitrogen-containing molecules in the soil, as the basis for respiration. This process, called "denitrification," releases nitrous oxide into the atmosphere.

Recent research indicates that concerns about nitrous oxide are of greater importance

Sewage treatment plant



than was once believed. The amount of nitrous oxide gas in the atmosphere increased during the 20th century, and that increase is continuing today. The annual increase in atmospheric nitrous oxide has been about 0.25% each year during the last century. Although this seems like a very small number, it is important in comparison to other GHGs because of its potential to increase global temperatures. Scientific research indicates that, over a 100-year period, nitrous oxide has a 300 times greater "global warming potential" than carbon dioxide.

Discuss the following with your group:

- Nitrous oxide sources: Where does nitrous oxide come from?
- Nitrous oxide sinks: What removes nitrous oxide from the atmosphere or stores it for a long time?
- Which human activities could cause more or less nitrous oxide to be in Earth's atmosphere?

What Can Ice Tell Us About Past Climate?

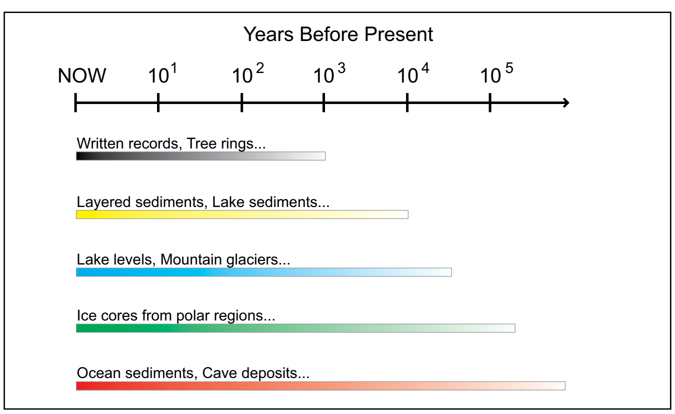
Imagine finding a time capsule containing clues of what Earth was like during the last ice age. Now, imagine finding hundreds of thousands of time capsules that date back 420,000 years, or even a million years! What a story these capsules could tell! Scientists who study past climates—paleoclimatologists—have found such time capsules.

Paleoclimatologists reconstruct past temperatures and climates by using fossil records from nature, such as rings from trees and skeletal remains from tropical coral reefs. When we want to know about the past before there were any trees or coral, we need to study things that are even older. Polar ice sheets are made from layers upon layers of packed snow. Using hollow steel tubes, scientists drill and extract ice cores that contain ice layers that are more than 700,000 years old! These scientists can also extract ancient ocean sediments this way.

What Can Ice Tell Us About Past Climate?

When snow forms, it crystallizes in the atmosphere around tiny particles, which fall to the ground with the snow. The snow crystals become frozen time capsules, storing whatever was floating around in the atmosphere at the time. Dust, volcanic ash, smoke, pollen, and radioactive isotopes from solar radiation in the snow crystals provide clues about the climate and environmental conditions when the snow formed.

Each year new snow settles on the ice, forming layers. The air bubbles trapped in this ice become an annual sealed record of the gases and particles in the atmosphere.



Timelines for paleoclimate reconstruction

Digging into Ice

Records of methane gas, for example, provide clues about how many wetlands covered the planet in the past. (Wetlands are a source of methane.) Similarly, records of the amount of carbon dioxide in ancient air bubbles can give us a picture of the number of living organisms at a given time. Dust records tell us approximately much of the planet was covered by dust; pollen records show which plants and trees lived in the past. All of these clues help us understand what the climate was like over time. The clues can tell us about temperature, precipitation, and the chemical composition of the lower atmosphere. Paleoclimatologists usually drill ice cores in Greenland and Antarctica, where the oldest ice sheets remain. Other times they drill into glaciers on different continents.

California's Global Warming Solutions Act of 2006

The Global Warming Solutions Act of 2006, also known as Assembly Bill 32 (AB 32), was written by California Assembly Speaker Fabian Núñez and Assemblywoman Fran Pavley. A separate video shows portions of the speeches given by Governor Arnold Schwarzenegger and Speaker Núñez during the signing of this landmark legislation on September 27, 2006.


California State Assembly chamber

Goals of the Act:

- Reduce statewide greenhouse gas emissions to the levels they were in 1990 by the year 2020.
- Establish regulations that will uphold and enforce these goals.
- Identify the most cost-effective strategies and methods to reduce GHGs, including CO_2, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

Timeline:

2007

- Make a list of "early action measures" that can be put into action before 2010.

2008

- Make a list of all statewide emissions.
- Establish a statewide GHG emissions limit for 2020 to equal what was emitted in 1990.
- Adopt rules businesses must use to report significant sources of greenhouse gases, such as power plants and various modes of transportation.

2009

- Adopt a plan to reduce emissions from significant GHG sources that includes regulations (rules), market mechanisms, and other actions.

2011

- Adopt regulations to reduce emissions of GHGs that are the most cost-effective and based on the best technology available.

Instructions: Read over the timeline below to identify the relationship between scientific discoveries and policies and decisions humans have made about climate over the past three decades.

Discovery	Policy or Decision
1979 U.S. Department of Energy reports GHGs increasing in the atmosphere.	**1979** First World Climate Conference held in Geneva. It is sponsored by the World Meteorological Organization, a specialized agency of the United Nations.
1985 Ice core data shows temperature goes up and down along with GHGs in the atmosphere. Climate models predict global temperature will increase 2.7–8.1° F (1.5–4.5° C) over the next 100 years. Scientists predict rising sea levels and changes to world ecosystems.	
1987 Global temperatures shown to have risen 0.9° F (0.5° C) in a century. James Hansen, NASA chief climatologist, testifies to Congress on the hazards of climate change and global warming.	
1988 National Aeronautics and Space Administration (NASA) reports there are indications of "global warming."	**1988** The Intergovernmental Panel on Climate Change (IPCC) is established by the United Nations. **1990** The second World Climate Conference is held, again in Geneva. The IPCC issues its first report on the dangers of climate change.
1991 Data from Mount Pinatubo eruption shows a correlated effect between particulate matter and increased CO_2 levels in the atmosphere.	**1992** IPCC calls for action on climate change: scientists develop the Framework Convention on Climate Change to address human interference with Earth's climate system.

Discovery	Policy or Decision
1993 Ice core data shows climate can change in shorter time periods (decades, rather than millions of years) than previously thought.	**1993** United Nations and New York State create the Cities for Climate Protection Campaign.
	1994 Alliance of Small Island States demands the world cut GHG emissions by 20% by 2005, because these countries will be threatened first by rising sea levels.
1995 IPCC reports "global warming likely due to human activities."	**1995** Meeting of the members (countries) of the United Nations Framework Convention on Climate Change (UNFCCC) signs the Berlin Mandate to cut worldwide GHG emissions.
	1996 Meeting of the members (countries) of the United Nations Framework Convention on Climate Change (UNFCCC) sets "legally binding emissions targets" for developed and developing countries.
	1997 Kyoto Protocol established to set GHG emission limits for participating countries.
1999 Ice core data shows 1990s to be hottest decade in 1,000 years.	
2001 Hottest year in (recorded) human history. IPCC announces that "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." Average ocean temperature is increasing.	**2001** United States rejects Kyoto Protocol, saying it will hurt the U.S. economy.

Discovery	Policy or Decision
2002 New high global temperature set.	**2002** California signs the nation's first law limiting GHG emissions from vehicles. Eighteen other states establish Clean Energy States Alliance to reduce GHG emissions. Japan, European Union member states, and Canada sign Kyoto Protocol.
2003 Unusually large ice sheets in West Antarctica and Greenland collapse.	**2004** California Air Resources Board (CARB) votes to cut vehicle GHGs by 30% by the 2016 model year; U.S. Environmental Protection Agency (U.S. EPA) prevents action at the time. Twelve other states join Clean Energy States Alliance.
2005 Hurricane Katrina causes debate about climate change and its relationship to intense storms. CO_2 levels in atmosphere reach 380 parts per million (ppm), higher than any level in Earth's history.	**2005** International governments and localities take efforts to reduce GHGs. New Jersey classifies CO_2 as a pollutant. **2006** Western Governors' Association files a lawsuit against the U.S. EPA about new fuel economy standards for SUVs, saying they are too low to be of use. California passes Global Warming Solutions Act (AB 32).
2007 IPCC reports CO_2 levels are at 382 ppm, and average global temperature is 58.1° F (14.5° C). IPCC states "global warming is 'very likely' caused by human activities." Arctic sea ice has shrunk to its lowest amount since measurements began.	**2007** Other states adopt vehicle emissions standards. The Climate Registry is established to share information about reducing GHGs and help countries and businesses calculate and register their carbon footprints. Former U.S. Vice President Al Gore and the IPCC are given Nobel Prizes for their work in communicating the threat of global warming.

Discovery	Policy or Decision
2008 A 25 mile-long stretch of ice breaks off the Wilkins Shelf along the Antarctic coastline.	**2008** Governors of 18 states sign Declaration on Climate Change (NJ, CT, CA, KS, AZ, CO, DE, FL, IL, MD, MA, ME, MI, NM, NY, OR, VI, and WA; asking for more action on climate policy at bothstate and federal levels. **http://www.pewclimate.org/node/5893**) **2009** A meeting of the members (countries) of the United Nations Framework Convention on Climate Change (UNFCCC) held in Copenhagen, Denmark. The goal was to develop new goals to address climate change as the Kyoto Protocol expires. In a reversal from its 2004 decision, the U.S. government signalled its intention to set goals for fuel-efficiency standards.

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