

CLIMATE CHANGE & Animal Agriculture

Why Does Climate Change?

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Project Partners

- University of Nebraska—Lincoln
- Texas A&M AgriLife Extension
- Cornell University
- University of Georgia
- University of Minnesota
- Washington State University

Why Does Climate Change?

Basic Scientific Principles and Terminology

The intent of this paper is to provide a basic understanding of Earth's climate system, its atmosphere, and natural and anthropogenic factors that influence climate change and variability. With this knowledge, you will better understand climate terminology, concepts and processes discussed in literature and in the media.

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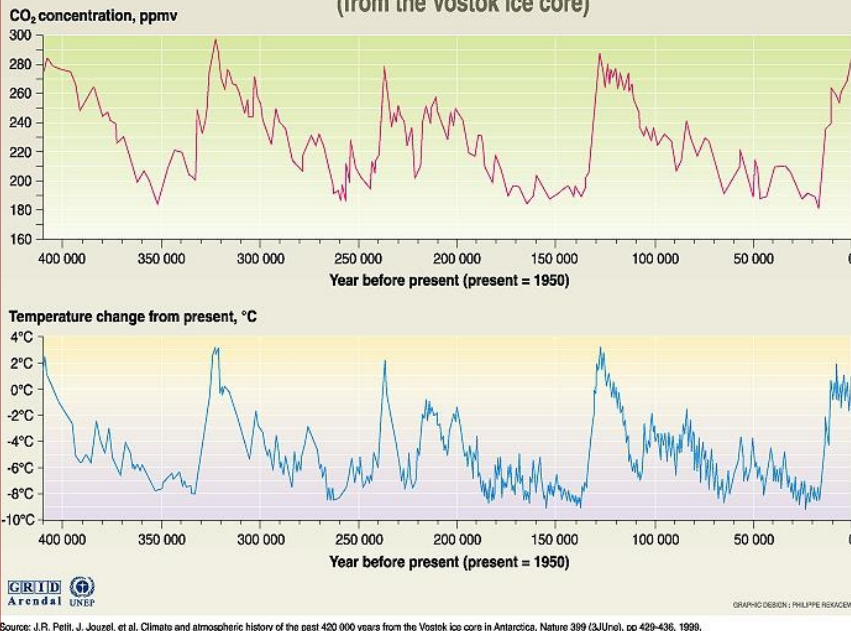
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Climate Changes. Evidence from ice cores, tree rings, stalagmites, marine and terrestrial deposits, and other proxies indicate that throughout the earth's history, surface temperatures, glacier and sea ice extent, sea levels, and the distribution of plant species have varied significantly over long periods. In fact, a reconstruction of ice cores taken at the Vostok Research Station in Antarctica shows that temperature has varied as much as 10 degrees Celsius over hundreds of thousands of years, causing extended ice ages and warming periods. The Vostok data also demonstrates a link between temperature and carbon dioxide levels.

Developing Extension Capacity to Address Issues Related to Climate Change and Animal Agriculture

Texas A&M AgriLife Extension Service—in conjunction with five partner Land Grant Institutions—is a part of a 5-year project to address issues related to climate change and animal agriculture. The overall goal is to develop national Extension capacity and build partnerships that foster animal production practices that are environmentally sound, climatically compatible, and economically viable.

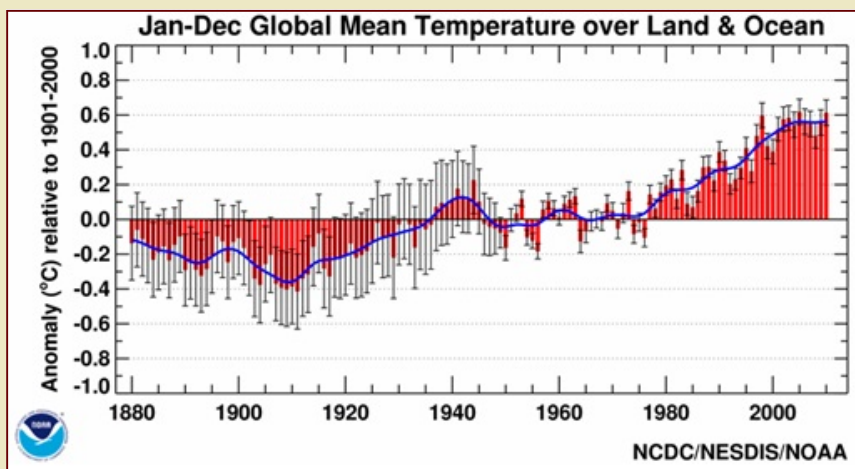
Temperature and CO₂ concentration in the atmosphere over the past 400,000 years (from the Vostok ice core)



UNEP/GRID-Arendal. Temperature and CO₂ concentration in the atmosphere over the past 400,000 years. UNEP/GRID-Arendal Maps and Graphics Library. 2000. Available at: <http://maps.grida.no/go/graphic/temperature-and-co2-concentration-in-the-atmosphere-over-the-past-400-000-years>

Before human influence, natural factors (such as the earth's orbital cycle and volcanoes) dictated climate change. Since the Industrial Revolution, man-made climate influences such as increases in fossil fuel emissions, urbanization, agricultural production, and deforestation have been added to the mix of influences on local, regional, and global climate.

Over the past century, average global surface temperature has warmed 0.6 to 0.8 degree Celsius (1.1 to 1.5 degrees Fahrenheit). Confirmation of global warming comes from warming of the oceans, rising sea levels, glaciers melting, sea ice retreating in the Arctic and diminished snow cover in the Northern Hemisphere (IPCC, 2007).



Terms and Definitions

Anthropogenic. Resulting from the influence or actions of human beings; man-made.

Climate. The statistical characteristics of weather over at least a 30-year period. The climate observed over different periods of time (100 years, 1,000 years) may vary considerably.

Climate change. A variation in climate measured over several decades or longer usually observed by temperature. This change may be due to natural or human-induced causes.

Climate feedback. A subsequent change to a climate process that can either intensify (positive feedback) or reduce (negative feedback) the initial forcing. One example of a climate feedback mechanism involves loss of polar ice in response to rising surface temperature. Loss of highly reflective ice surface area means more radiation will be absorbed by Earth, thus intensifying the initial temperature increase (hence, melting polar ice is thought to be a positive feedback).

Climate forcing. An agent that causes a change in the climate. For example, a volcanic eruption is an example of a natural forcing that can temporarily change the composition of the atmosphere.

Climate sensitivity. The amount of climate change (as measured by the change in globally-averaged surface temperature) for a given amount of climate forcing. It is often quoted as the temperature change that eventually results from a doubling of CO₂ concentrations.

Climate system. The system consisting of the atmosphere (gases), hydrosphere (water), cryosphere (ice), lithosphere (solid part of the earth), and biosphere (living) that determines Earth's climate.

Earth's Atmospheric Gases

Constant components. Proportions remain the same over time and location.

Nitrogen (N ₂)	78.08%
Oxygen (O ₂)	20.95%
Argon (Ar)	0.93%
Neon, Helium, Krypton	trace

Variable components. Amounts vary over time and location.

Water vapor (H ₂ O)	0–4%
Carbon dioxide (CO ₂)	0.039%
Methane (CH ₄)	trace
Sulfur dioxide (SO ₂)	trace
Ozone (O ₃)	trace
Nitrogen Oxides (NO, NO ₂ , N ₂ O)	trace

Reference: Egger, A. 2003. Earth's Atmosphere: Composition and Structure. Visionlearning Vol. EAS (5).

Today, scientists deploy satellites into space to measure the earth's outgoing radiation; the concentration of greenhouse gases such as water vapor, CO₂, and methane; and other climate factors to better understand how natural and anthropogenic (human) forcings impact global climate change. Ongoing research of climate sensitivity helps refine climate models used to project future change.

Earth's Atmosphere

Life as we know it would not exist without our atmosphere. Earth's atmosphere protects us from harmful radiation, slows down and burns up small meteorites, regulates temperatures, and consists of various mixtures of gases to support human, animal, aquatic, and plant life. The atmosphere consists mainly of nitrogen, oxygen, argon, and trace gases whose concentration varies little over time and location, while other atmospheric gases such as water vapor, carbon dioxide, and methane vary over time and location.

Terms and Definitions (continued)

Climate variability. Change that occurs in the absence of natural or human-induced climate forcing as a result of interactions within and between the various components of the climate system.

Greenhouse effect. A process where heat emitted from Earth's surface is absorbed by atmospheric greenhouse gases, and is re-radiated in all directions. Since part of this re-radiation is back towards the surface, energy is transferred to the surface and the lower atmosphere. This process increases surface temperatures higher than if direct heating by solar radiation were the only warming mechanism.

Greenhouse gas. Atmospheric gases, including water vapor, carbon dioxide, and methane that effectively absorb and emit infrared radiation.

Weather. The immediate state of the atmosphere, mainly with respect to its effects upon life and human activities. Weather is characterized by short-term variations in atmospheric pressure, temperature, precipitation, humidity, cloud cover, wind speed, and solar radiation.

Layers of the Atmosphere

Scientists delineate the atmosphere into five primary layers according to temperature: troposphere, stratosphere, mesosphere, thermosphere, and exosphere. Each layer has a unique role in protecting and sustaining life on the earth. Transition layers (tropopause, stratopause, mesopause, and thermosphere) define the boundaries between each of the five primary layers. Of particular interest to climatologists are the troposphere, tropopause, and stratosphere.

The **troposphere** is the layer closest to Earth, extending 10 to 15 kilometers (6 to 10 miles) above the surface depending upon latitude and time of year. The troposphere is wider at the equator than at the North and South Poles. Here, the atmosphere is relatively turbulent compared to the other atmospheric layers and contains almost all of the atmospheric water vapor. Thus, most of the weather occurs here. Temperature falls with altitude at an average rate of 6.5 degrees Celsius per kilometer (3.5 degrees Fahrenheit per thousand feet). Air pressure also declines with altitude and is highest at ground level.

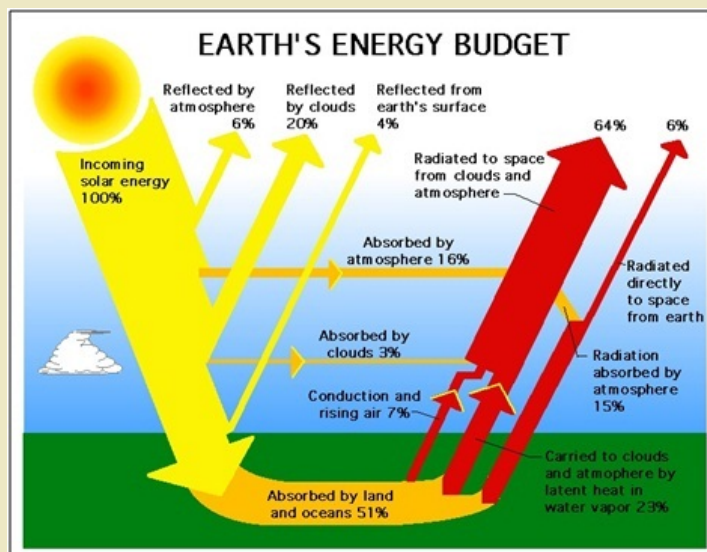
The **tropopause** is the atmospheric boundary between the troposphere and the stratosphere. Going upward from the surface, it is the point where air ceases to cool with height, and becomes almost completely dry.

The **stratosphere** lies directly above the troposphere and extends from 16 to 50 kilometers (10 to 30 miles) above the earth. Temperature here is well below freezing, nearly constant in the lower portion, and increases with height in the upper portion because of absorption of sunlight by ozone. Ozone (O₃) is a gaseous form of oxygen with three oxygen atoms per molecule. Stratospheric ozone absorbs most of the harmful ultraviolet radiation from the sun that causes skin cancer.

Earth's Energy Balance

Earth's energy balance is the fundamental driver of climate. Generally, all the solar energy that reaches the earth travels through space from the sun in the form of electromagnetic waves, or radiation. On average, the rate of solar radiation entering the earth's atmosphere almost exactly equals that leaving. However, solar radiation varies slightly with the sun's intensity, as well as the earth's orbit and tilt. These small variations are responsible for the cyclical patterns and seasons of our climate.

The figure below shows how solar radiation (or solar energy) is balanced. Without this balance, life as we know it on Earth would not exist.



Earth's Energy Balance: NASA Atmospheric Sciences Data Center. 2010. <http://eosweb.larc.nasa.gov/PRODUCTS/ceres/magery.html>

- Yellow arrows indicate how incoming solar radiation is immediately dispersed. Thirty percent is reflected back into space by atmospheric gases (6 percent), clouds (20 percent), and the earth's land and ocean surface (4 percent).
- Orange arrows indicate the amount of radiation that is absorbed. Seventy percent is absorbed by certain atmospheric gases (16 percent), clouds (3 percent), and land and ocean surfaces (51 percent).
- Red arrows indicate how the radiation absorbed by land and oceans is dispersed. Seventy percent is radiated back into space. The remainder is used through conduction of heat (7 percent), carried to clouds and the atmosphere in water vapor (23 percent), and absorbed by the atmosphere (15 percent).

GWP and Atmospheric Lifetime for Various Greenhouse Gases

Global warming potential (GWP)

Greenhouse Gas	Chemical Formula	For a 100-year time horizon	Lifetime (years)
Carbon dioxide	CO ₂	1	Variable
Methane	CH ₄	25	12
Nitrous oxide	N ₂ O	289	114
HCFC-12	CHClF ₂	1,810	12
Tetrafluoromethane	CF ₄	7,390	50,000
CFC-12	CCl ₂ F ₂	10,900	100
Hexafluoroethane	C ₂ F ₆	12,200	10,000
Nitrogen trifluoride	NF ₃	17,200	740
Sulphur hexafluoride	SF ₆	22,800	3,200

Source: (IPCC, 2007)

Over time, the total outgoing energy should equal the amount of energy coming in from the sun. If balance is disrupted, the earth's temperature will change until balance is restored. For example, if incoming solar energy were to decrease, the earth would be losing more energy than it gains, and its overall temperature would decrease. Because colder objects emit less radiation, a new balance will eventually be achieved at a colder Earth temperature.

Note that the energy balance diagram represents a global scale. Locally, parts of the earth regularly radiate more energy to space than they receive from the sun, and other parts do the opposites. This is because the motions of the atmosphere and oceans transport heat from the tropics to high latitudes, giving polar regions an extra supply of energy at the expense of the tropics.



Satellite image of cloud formations around North America. Source: NASA, 2012. http://commons.wikimedia.org/wiki/File:Earth%20s_northern_hemisphere_with_sea_ice_and_clouds.jpg

The Greenhouse Effect

Certain gases present in the troposphere (such as water vapor, carbon dioxide, and methane) have the ability to absorb and emit certain forms of infrared radiation. As a result, these compounds play a major role in regulating our climate even though they constitute only a small percentage of all gases in the atmosphere. Because they emit energy to space from high in the atmosphere where it's cold, their presence causes an overall reduction in the loss of energy to space at any given temperature. The climate system must be warmer in order to compensate and achieve balance. Without this **greenhouse effect**, the average global surface temperature would be -18 degrees Celsius (about 0 degrees Fahrenheit). The actual average global surface temperature of Earth is approximately 15 degrees Celsius (about 59 degrees Fahrenheit), (Pidwirny, 2006).

Global warming potential (GWP) and atmospheric lifetime vary among greenhouse gases (see table above). GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat

trapped by a similar mass of carbon dioxide. GWP is calculated over a specific time interval, usually 100 years. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1). For example, the 100-year GWP of methane is 25, which means if the same mass of methane and carbon dioxide were introduced into the atmosphere, methane will trap 25 times more heat than carbon dioxide over the next 100 years. Lifetime defines the length of time a gas molecule can exist in the atmosphere before it decays.

Climate versus Weather

Extreme weather events including hurricanes, tornadoes, flash floods, and extreme drought have occurred well before man roamed the planet; however, a comprehensive record of the occurrence, frequency, and intensity of these events exists only for about the last 100 to 150 years. In the future, researchers may be able to correlate weather patterns to a changing climate. In the meantime, it is important to recognize the distinction between “weather” and “climate” to avoid misinterpreting isolated extreme weather events as evidence of climate change. A cold day or big snowstorm is not proof that the climate has cooled, nor is a hot day, week, or month necessarily evidence that the climate has gotten warmer. However, over long periods, the frequency of certain extreme weather events may change as a result of changing climate.

- **Weather.** Weather defines the atmospheric conditions at a given time and place. Temperature, humidity, wind speed, and degree of cloudiness are observations used to describe weather conditions. Changes in weather result from large global circulation patterns in the atmosphere caused by the interaction of solar radiation, ocean and land temperature, and local topography. Global winds drive huge air masses causing warm and cold fronts and push jet streams (narrow bands of strong wind) that steer weather systems and transfer heat around the globe.

- **Climate.** In contrast, climate refers to the statistics of weather (such as average condition or the frequency of an occurrence) for different regions over time scales ranging from decades to thousands of years. The traditional averaging time for climate is 30 years. For the past million years, the earth has experienced cooling and warming cycles that take about 100,000 years to complete. Over the range of each cycle, global average temperature has varied about 5 degrees Celsius (or 9 degrees Fahrenheit), resulting in extended ice ages and warm periods (NOAA, 2009). That climate will change in the future is certain; however, what that change will be, the rate it will occur, and how sensitive climate is to human activity is the subject of intense research.



Supercell thunderstorm develops over Chaparral, NM on April 3, 2004. This weather system dropped 2-inch diameter hail, causing widespread damage. Source: NOAA, 2004. http://en.wikipedia.org/wiki/File:Chaparral_Supercell_2.JPG

Climate Forcing

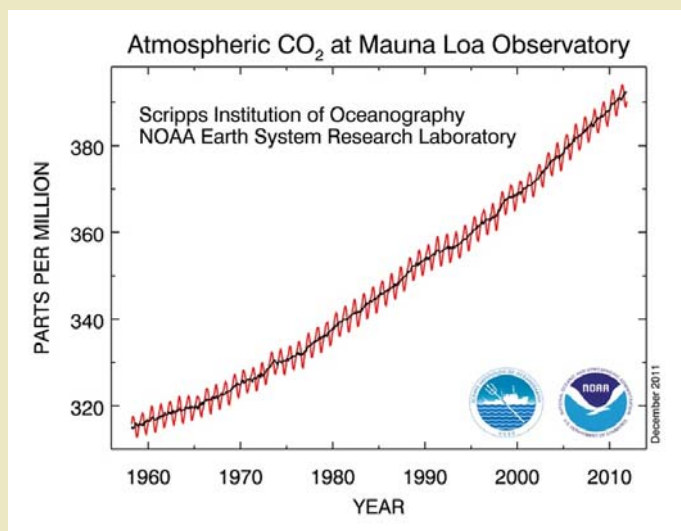
Climate forcing is a change imposed on the planetary energy balance that has the potential to alter long-term global climate responses such as temperature and precipitation patterns. The earth’s geologic records show that natural processes can have very large effects such as the cooling and heating cycles of the past million years. Scientists now believe that human activities such as the burning of fossil fuels, deforestation, agriculture, and urbanization can also alter the climate system.

Natural climate forcing mechanisms include fluctuations in the sun's radiative intensity, Earth's orbital cycle, volcanic eruptions, and ocean currents.

- **The Sun.** The amount of energy emitted by the sun is ever-changing. Changes in its intensity are typically small (a few tenths of a percent), but can influence the earth's temperatures if they occur over an extended period. The sun's energy output varies by a small amount over the observed 11-year sunspot cycle, and the solar output may vary by larger amounts over long periods.
- **Earth's Orbit.** Earth's elliptical orbit around the sun varies from tens of thousands of years to hundreds of thousands of years, thus slightly changing the intensity of solar radiation that reaches the earth. Scientists point to these orbital cycles (referred to as Milankovitch cycles) to explain the occurrence of glacial and interglacial periods throughout the earth's history.
- **Volcanoes.** Volcanic eruptions inject sulfur dioxide into the upper atmosphere. Since this compound forms droplets that are highly reflective to sunlight, its presence prevents some of the sun's radiation from reaching the earth, thereby reducing surface temperatures. Once in the upper atmosphere, these droplets can last several years after an eruption.
- **Ocean Currents.** Regular oscillations in the warm and cold ocean currents can influence atmospheric circulation patterns, weather, and climate variability. For example, the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) that occur in the Pacific Ocean (characterized by patterns of warm and cool sea surface temperature) alter precipitation variability in the United States. Climatologists have learned to use sea surface temperature and ocean current data to predict the probability of seasonal droughts in the southwestern U.S. Current research examines how these ocean circulations impact global climate change.

Anthropogenic climate forcing mechanisms include net emission of greenhouse gases that result from land use changes (such as deforestation and agriculture production), burning fossil fuels (such as coal, oil, and natural gas), and the release of tiny particulates called aerosols into the atmosphere.

- **Greenhouse Gas Emissions.** Perhaps the most significant human influence on climate change today is the increasing atmospheric concentration of greenhouse gases. Many greenhouse gases occur naturally in the atmosphere, such as water vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), ozone (O₃), and nitrous oxide (N₂O), while others are synthetic. Synthetic greenhouse gases include the chlorofluorocarbons (CFCs), hydro fluorocarbons (HFCs), and per fluorocarbons (PFCs), as well as sulfur hexafluoride (SF₆). Recent data shows that global CO₂ concentrations have risen from a preindustrial level of 280 parts per million to nearly 400 parts per million in 2011, primarily due to the burning of fossil fuels such as coal, oil and natural gas (Conway and Tans 2011). Atmospheric levels of CH₄ and N₂O have also increased as a result of energy and agricultural practices such as manure management and fertilization of soils.



Recent history of atmospheric CO₂ measurements recorded at the Mauna Loa Observatory in Hawaii. <http://www.esrl.noaa.gov/gmd/obop/mlo/>

- Land Use Changes.** Major land use and land cover changes such as deforestation, irrigation, and urbanization alter climate patterns. With deforestation, carbon (originally held in trees) is released to the atmosphere as carbon dioxide gas, either immediately if the trees are burned, or more gradually as unburned organic matter decomposes. Most of the carbon is released as carbon dioxide, however small amounts of methane and carbon monoxide may also be emitted during decomposition and burning. Deforestation also removes trees that retain large amounts of water, thereby altering the natural hydrologic processes involving evaporation and transpiration. Urbanized areas tend to absorb and retain more heat than rural landscapes, forming what is known as a “heat island.” This phenomenon is well documented in the vicinity of major metropolitan areas where local meteorologists now report separate temperatures for “in the city” and “outlying regions.”
- Other land use changes that affect climate and climate variability on a local or regional scale include large-scale irrigation used to supplement agricultural water needs, and construction of large reservoirs that alter natural streamflow, vegetation, and existing hydrologic processes. Both of these activities increase the amount of water available to evaporate into the atmosphere. On a local scale, this tends to make maximum temperatures cooler and minimum temperatures warmer.
- Aerosols.** Incomplete combustion of fossil fuels and other pollution sources produce tiny solid or liquid particles that can remain suspended in the atmosphere for days or weeks. These particles are called aerosols and are similar in size or smaller than the tiny particles that spray from an aerosol can. Most aerosols reflect incoming solar radiation away from Earth’s surface, creating a temporary cooling effect. Aerosols also strongly affect cloud formation and longevity, thereby having an additional indirect cooling effect on Earth’s climate that scientists are only now beginning to understand.



Removing trees for agricultural crop production affects the storage potential and release of carbon from trees and soils. Source: NRCS. <http://www.climatescience.gov/Library/stratplan2003/final/ccspstratplan2003-chap6.htm>



Center pivot irrigation system. Increased evaporation from large-scale irrigation affects local temperatures by increasing relative humidity. Source: NRCS. <http://www.az.nrcs.usda.gov/news/releases/Tedd-Haas-Irrigation-Efficiency.html>

Climate Feedback

When climate forcing provides an impetus, other affected processes will respond by amplifying (positive feedback) or reducing (negative feedback) the effect of the initial forcing. The magnitude of change depends upon many different interacting feedback mechanisms. Climatologists are researching how feedback mechanisms interact with each other and natural climate forcings. Some common feedback mechanisms include greenhouse gases such as water vapor and carbon dioxide, terrestrial plants and soils, and ocean-atmospheric interactions. A few feedback mechanisms being studied are discussed here.

- **Water Vapor.** When the atmosphere is warm, it holds more water vapor (the most abundant greenhouse gas). As more water vapor is held in the atmosphere, the temperature rises due to its greenhouse warming potential, and the increase in temperature allows even more water vapor to be held in the atmosphere—a positive feedback.
- **Melting Permafrost.** Another potential feedback involves large areas of frozen peat in the Arctic, called permafrost. High temperatures cause the permafrost to thaw, releasing methane into the atmosphere. Additional greenhouse gas could cause temperatures to climb higher, allowing even more peat to defrost—a positive feedback.
- **Wildfires.** As climate changes, some forests and grasslands will become more vulnerable to heat waves, drought, and, ultimately, fire. As vegetation burns, it releases carbon dioxide, further increasing atmospheric greenhouse gas concentrations and surface temperature—again, a positive feedback.
- **Clouds.** Perhaps the most uncertain climate feedback mechanism involves clouds. A change in almost any aspect of cloud formation, such as its type, location, water content, altitude, particle size and shape, or lifetime, affects the degree to which clouds warm or cool the earth.

Some changes amplify warming while others diminish it. Research is underway to better understand how clouds change in response to warmer surface temperature and how these changes affect climate—a positive or negative feedback.

- **Sea Ice.** Geologic records clearly show that global surface and sea temperatures have changed enough in the past to alter sea ice and glacier formation. Some scientists contend that the loss of polar sea ice would encourage more heating because the darker colored ocean would absorb more heat, much in the way a black shirt is hotter on a sunny day than a white shirt—a positive feedback.

The net effect of all feedbacks is thought by many scientist to be positive, that is, they will accelerate the rate of warming. Current estimates suggest that feedbacks will roughly double the effects of increased greenhouse gas emissions. However without a long record of observational data to support this assertion, there still remains significant uncertainty.

Summary

The purpose of this document is to provide a basic understanding of the earth's climate system, its atmosphere, and natural and anthropogenic factors that influence climate change and variability. Though we have only touched on the highly complex and chaotic nature of our climate system and our role in it, you should now have a basic foundation that will allow you to better understand climate change issues as they appear in scientific literature and in the media.

References

Conway, T., and Tans, P., 2011. *Trends in Atmospheric Carbon Dioxide*. National Oceanic and Atmospheric Administration, Earth System Research Laboratory. <http://www.esrl.noaa.gov/gmd/ccgg/trends/>

IPCC, 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (AR4)*. S. Solomon et al. eds. Cambridge University Press, Cambridge, UK & New York, NY. http://ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

NOAA, 2009. *Climate Literacy: The Essential Principles of Climate Sciences*. <http://www.climate-science.gov>

Pidwirny, M., 2006. "The Greenhouse Effect." *Fundamentals of Physical Geography*, 2nd Edition. <http://www.physicalgeography.net/fundamentals/7h.html>

Seinfeld, J. H. and Pandis, S. N., 1997. *Atmospheric Chemistry and Physics—From Air Pollutants to Climate Change*. John Wiley & Sons, Inc., NY.

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