Unit 1: The Climate System

Learning Objectives

How does climate system work?

After studying this unit, you should be able to:

- Understand the characteristics of the Earth's climate system;
- Understand how the greenhouse effect occurs;
- Understand the role of human activity in the greenhouse effect.

Introduction and Overview

In Unit One we open the discussion about climate change. What is it? How is it occurring? Do we have any control over it? Here we try to provide you with the scientific foundation to answer these questions.

As this unit will explain further, our climate system is driven by energy received from the sun together with complex interactions between the Earth's atmosphere, oceans and land. The greenhouse effect that we always hear about occurs naturally within the climate system and is responsible for temperatures on Earth that are conducive to a healthy life. Increased concentrations of greenhouse gases caused by human activities, such as energy production, land clearance and agriculture, results in an "enhanced" greenhouse effect. This causes climate change.

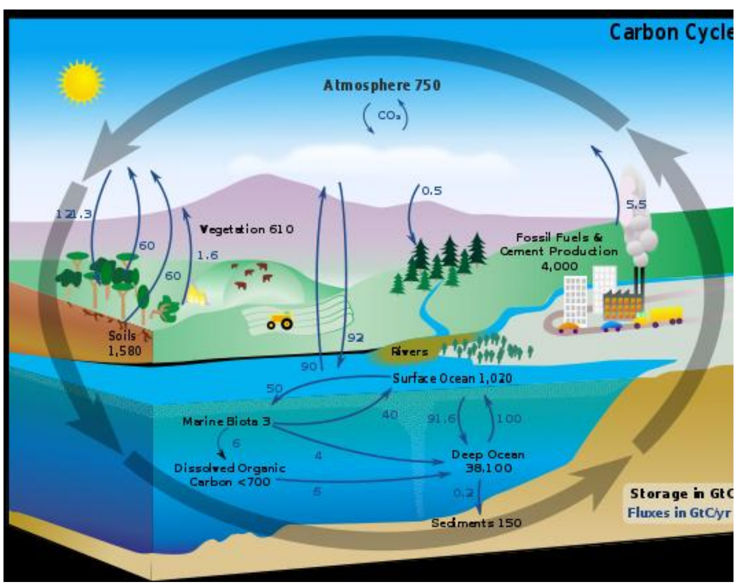
Atmosphere, Land and Ocean Interactions

As we said, the Earth's climate system is driven by energy from the sun, the Earth's atmosphere, oceans and land. Carbon, nitrogen and the water cycle are part of the climate system. Therefore, it is important to have a solid understanding of where carbon, nitrogen and water are stored, and how they move between the atmosphere, land and oceans in order to understand climate change.

The Global Carbon Cycle

Carbon, something we think about as toxic in our daily lives, is ironically the basis of life on Earth. When carbon is stored geologically (e.g. fossil fuel deposits in land and oceans) it changes slowly. When it is non-geological (e.g. soils and some of the ocean sediments), it is not. Stores become part of the active pools through volcanic activities, and, more recently, from human use of fossil fuels. The stores that change quickly (active pools) are those in living plants, animals and microorganisms, and the atmosphere.

Box 1: Carbon Cycle

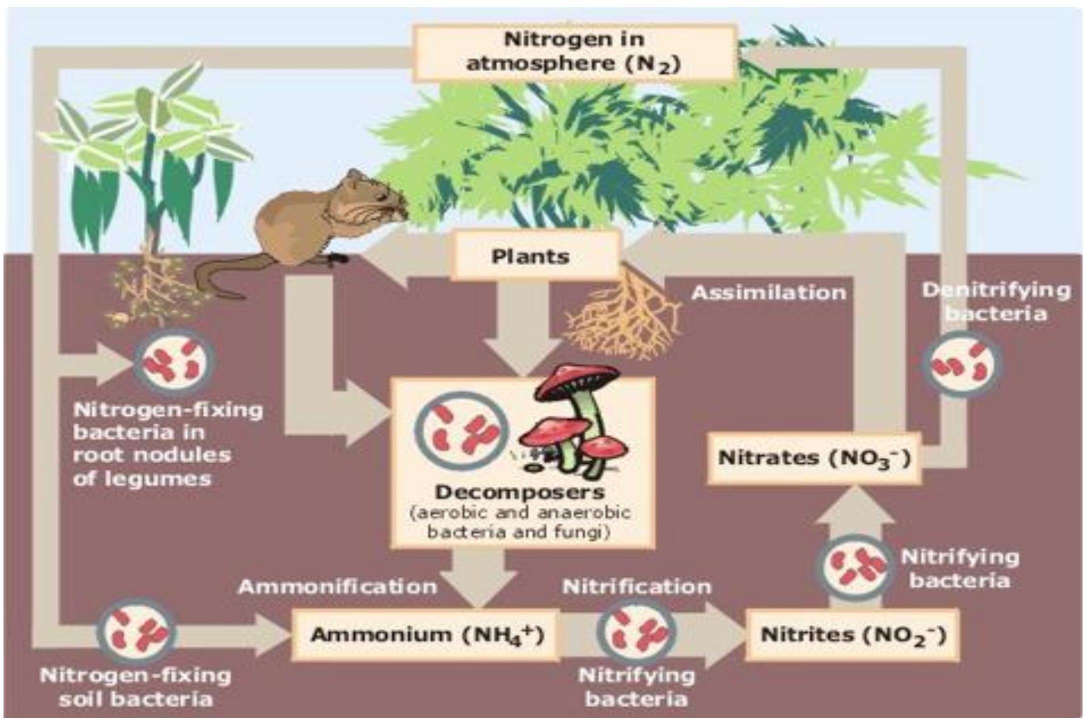


Source: US NASA

There is a natural exchange of carbon between the oceans, atmosphere and land that occurs through photosynthetic activities of plants/phytoplankton, decomposition, and anaerobic activities of bacteria (e.g. those in the paddy fields and guts of sheep and cattle that produce methane). These exchanges area called fluxes. When we burn fossil fuels, we release carbon into the atmosphere. In addition, about 1.7GtC/yr, or 1.7 giga tons of carbon per year, is emitted from land-use change, especially deforestation and agricultural practices. The oceans and the land take up about half of the carbon being emitted into the atmosphere, and the other half is being accumulated into the atmosphere.

Nitrogen Cycle

Box 2: Nitrogen Cycle



Source: US EPA

The flow of nitrogen is closely linked to carbon and water cycles. Fertilizer applications are now a significant component of the nitrogen cycle. Combustion of fossil fuels also releases oxides of nitrogen.

Earth's Atmosphere

The energy retained by the atmosphere is affected by the concentration of greenhouse gases and water in the atmosphere.

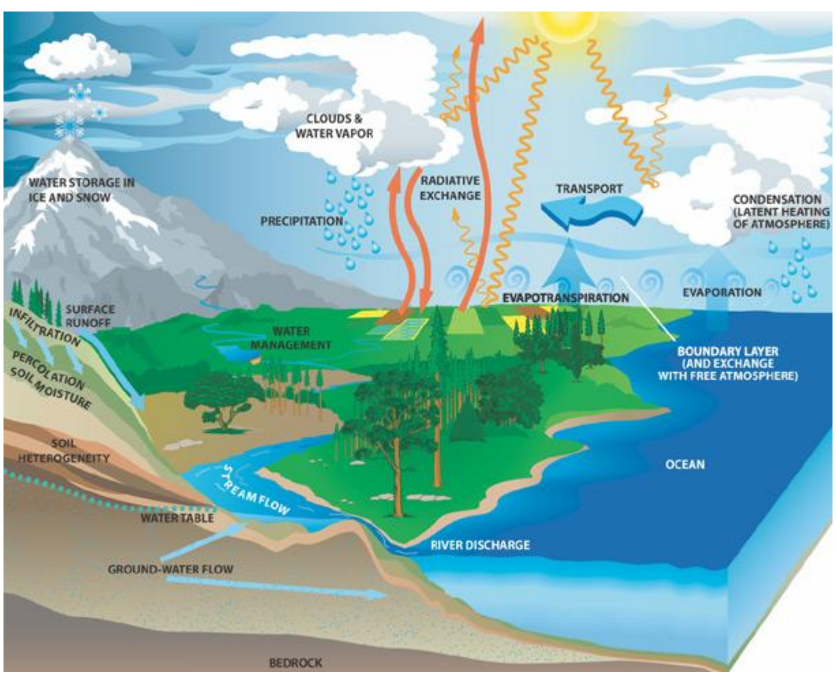
Land Cover

About 50 percent of the solar radiation from the sun is absorbed by the Earth’s surface. The amount of energy absorption is affected by land use and land cover. For example, plants tend to absorb and dissipate energy, while cleared areas and pavement absorb and reflect the energy as heat. The heat, also called infrared radiation, which is absorbed by the Earth's surface is also emitted back into the atmosphere.

Energy from the Sun

The Earth’s climate is driven by energy from the sun. Solar radiation provides the energy input to the climate system. There are also natural factors that affect long-term and short-term climate, which are caused by cyclical changes in the Earth's circumnavigation of the Sun, known as Milankovitch cycles. They are caused by variations in the shape of the Earth's orbit around the sun, the inclination of the Earth's axis in relation to its plane of orbit around the Sun, and the Earth's slow wobble as it spins on its axis.

Box 3: Water Cycle



Source: USA NASA

Oceans

Since oceans cover about 70 percent of the Earth's surface, they absorb a substantial portion of solar radiation. The ocean generally acts as a buffer against dramatic temperature changes by absorbing and retaining heat. Ocean currents also serve to transfer heat from the equator to higher latitudes.

How the Greenhouse Effect Works

Energy from the sun consists of shortwave radiation (30%), visible light and long-wave radiation. Some solar radiation is reflected back into space by gases like ozone in the upper atmosphere (stratosphere) and some of this absorbed energy is re-transmitted, and thus lost into space. The greenhouse gases in the atmosphere absorb and trap some of the radiation. Overall, about 31% of the incoming radiation is reflected from the outer atmosphere and the Earth's surface and the Earth absorbs about 69% of the radiation. The Earth's surface and oceans absorb the rest of the incoming radiation and become warmer. Land and darker vegetation absorb more and oceans absorb less; ice sheets and lighter surfaces reflect more than they absorb. The Earth's surface absorbs additional heat reflected back by the greenhouse gases in the atmosphere. Greenhouse gases in the atmosphere help retain heat, preventing it from escaping the from Earth's atmosphere, however, greenhouse gases make up less than one percent of the atmosphere.

Box 4: Radiation and The Global Warming Potential

Short wave radiation is what comes in the atmosphere and long wave radiation is what is radiated back out. How much comes in and how much goes out affects the temperature of the earth. Pollution (e.g., greenhouse gases) can affect how much radiation can go back out, so if you have too much pollution, then you have more coming in than is let back out and the temperature goes up.

The global warming potential (GWP) is the amount of heat absorbed by one molecule of each gas compared to one molecule of carbon dioxide. This indicates that while carbon dioxide is the greenhouse gas with the highest atmospheric concentration, methane and nitrous oxide still have an important impact since they each absorb substantially more heat than CO_2.

Water vapor is one of the most variable and abundant greenhouse gases. However, there is generally more than enough water vapor in the atmosphere and thus adding more will not result in more heat being retained.

Global Temperature

Box 5: How do Scientists Measure Greenhouse Effect?

Scientists have established a relationship between the concentration of greenhouse gases, particularly carbon dioxide, and the Earth's surface temperature. Ice cores, such as those in the Antarctic and Greenland ice sheets, have bubbles of trapped air that can be used to deduce the concentration of atmospheric CO_2 in the past. Scientists use this data to deduce past global temperatures, and have determined that both CO_2 concentrations and global temperatures have varied substantially during glacial and interglacial cycles which last approximately 10,000 years. The variation of CO_2 concentrations through past glacial and interglacial cycles is a part of natural variability, but has remained within tight bounds.

The global average temperature, another measure of climate change, is determined by a number of indicators including the history of mountain glaciers, geothermal borehole-based estimates of past ground temperature, ice cores (now going back to almost 600,000 years), tree ring measurements, layered sediments, and corals cores. The correlation between greenhouse gases and average global temperatures suggests that increasing greenhouse gas levels will lead to

Box 6: People, Fossil Fuels and the Climate

We know that the earth is warming. While historical periods of warming and cooling have averaged at the rate of about one degree per thousand years, today, global warming appears to be happening ten times faster than ever before, which many scientists believe to be partly due to human activity in which greenhouse gases are added into the air, including through the use of fossil fuels.

Fossil fuels, including coal, oil and natural gas, which release carbon dioxide, are labeled "fossils" because they were formed hundreds of millions of years ago from the fossilized remains of plants and animals. In use since around1000 B.C., and increased in use during the Industrial Revolution, coal inexpensive, was once abundant, and was the primary fuel for a long time for manufacturing, heating homes and providing power for railroad trains and steamships.

Coal: Today, coal is primarily used to power electricity and is said to power approximately 40% of the world.

Oil and Natural Gas: Produce electricity, heat homes and factories, fuel transportation

Fossil fuels release carbon whenever they are burned, but coal has a much higher carbon content than either oil or gas and is said to be the primary contributor of global warming as about 7 billion tons of carbon are released through the burning of fossil fuels annually; and when this reacts with oxygen, carbon dioxide is created—more than 20 billion tons of it.

increases in average global temperatures.

Atmospheric Concentrations of Greenhouse Gases

Global greenhouse gas emissions have increased since preindustrial times, with an increase of 70% between 1970 and 2004 alone. Global atmospheric concentrations of carbon dioxide, the most important anthropogenic gas, have increased by about a third, mainly because of the burning of fossil fuels and, to a lesser extent, land use change.

Emissions by Sectors

The greenhouse effect has been occurring naturally throughout history. However, as we indicated already, much of the change in greenhouse gas emissions since industrialization has been due to human activity, primarily through combustion of fossil fuels and land use and land cover change, such as conversion of forests for agriculture, urbanization, etc. Energy production, industrial use of energy, and forestry are the major sectors contributing to GHG emissions and, subsequently, GHG concentrations in the atmosphere. Note in the box below that the top 4 sources of greenhouse gas emissions – energy, industry, forestry and agriculture – account for 76% of greenhouse gas emissions.

Box 7: Sources of Greenhouse Gas Emissions

Of total greenhouse gas emissions, carbon dioxide accounts for approximately 70%, methane accounts for about 20%, and nitrous oxide accounts for about 9%. The remainder is comprised of powerful greenhouse gases such as chlorofluorocarbons (CFCs). Sources of greenhouse gases are important in deciding which mitigation options are needed. Approximately: Half of the carbon dioxide emissions are from industry and energy; Half of the methane (recall this is a more powerful greenhouse gas) emissions are from agriculture; and 60% of nitrous oxide emissions are from agriculture, and, with land use, land use change and biomass burning, the figure reaches almost 90%. The majority (57%) of cumulative emissions since the 1850s are from the US and the 25 EU countries.

Unit 1 Questions

Please answer each of the following questions. If you are taking this course in a group you may then meet to discuss your answers.

1. Why do greenhouse gases affect the Earth's temperature?
2. If you had a choice for reducing one greenhouse gas from your activities, which would you choose?
3. How was the correlation between the level of greenhouse gases in the atmosphere and global temperatures established?

Internet Resources

http://www.bbc.co.uk/climate/evidence/greenhouse_effect_img.shtml

http://www.sciencemadesimple.com/sky_blue.html

http://www.windows.ucar.edu/tour/link=/earth/Atmosphere/layers.html&edu=high

http://www.pbs.org/wgbh/nova/balloon/science/atmosphere.html

http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-faqs.pdf

http://www.oco.noaa.gov/index.jsp?show_page=page_roc.jsp&nav=universal

http://earthobservatory.nasa.gov/Features/Volcano/

http://www.epa.gov/

http://unfccc.int/ghg_data/items/3800.php

http://climatechangeblog.worldbank.org/