

# **Global Warming: Global Threat**

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Professor Michael B. McElroy  
Harvard University

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Global Warming: Global Threat  
Professor Michael B. McElroy



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**Course Syllabus**  
**GLOBAL WARMING: GLOBAL THREAT**

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Course Text: McElroy, Michael B. The Atmospheric Environment: Effects of Human Activity. New Jersey: Princeton University Press, 2002.



### About Your Professor - Michael B. McElroy

Michael B. McElroy received his PhD from Queen's University in Belfast, Northern Ireland. In 1970, he was named Abbott Lawrence Rotch Professor of Atmospheric Sciences at Harvard University, and in 1975 he was appointed Director of the Center for Earth and Planetary Physics. He served as Chairman of the Department of Earth and Planetary Sciences from 1986 to 2000. He was appointed Director of the newly constituted Harvard University Center for the Environment in 2001 and now leads an interdisciplinary study on the implications of China's rapid industrial development for the local, regional, and global environment. In 1997, he was named the Gilbert Butler Professor of Environmental Studies. He is a Fellow of the American Academy of Arts and Sciences.

McElroy's research interests range from studies on the origin and evolution of the planets to a more recent emphasis on the effects of human activity on the global environment of the Earth. He is the author of more than 200 technical papers contributing to our understanding of human-induced changes in stratospheric ozone and to the potential for serious disruptions to global and regional air quality and climate due to anthropogenically related emissions of greenhouse gases. His recently published text, *The Atmospheric Environment*, provides a comprehensive introduction to the atmosphere, highlighting changes that occurred in the past while offering context for the disturbances underway today as a consequence of human activity.



## Introduction

The issue of global warming has captured the attention of people world-wide over the past 20 years. Scientists looking at what humans are doing to the global environment believe that we are changing the climate of the planet and that we are warming the Earth. If you think of the Earth the way you might think of the human body, the human body lives at a relatively constant temperature, 98 degrees or so, and if our temperature rises, we are sick. If our temperature rises 4 or 5 degrees, then we run the risk of dying. So the issue is, are we risking the health of our planet? Are we causing the climate to change? Are we causing our planet to warm up? What are the consequences of these actions?

This course examines the complex interdependent system that regulates the environment for life on Earth. The objective of this course is to provide the listener with a comprehensive account of the science that is underlying the environmental issues that have forced the people of the world to stand up and pay attention.

Some of the problems we will discuss are air pollution, acid rain, depletion of the stratospheric ozone, destruction of tropical forests, and the resulting climate changes. We will also learn how greenhouse gases such as carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), nitrous oxide ( $\text{N}_2\text{O}$ ), and industrial chlorofluorocarbons (CFCs) have all played a significant role in what is happening globally today.

Upon completion of the course, the listener will better understand the overwhelming result of the human influence on the planet and what steps can be taken to better safeguard our environment in the future.

## Lecture 1: Perspectives on Earth History

### Before beginning this lecture you may want to ...

Read Nick Lane's [Oxygen: The Molecule That Made the World](#).

### Introduction:

In this lecture we place the human influence in a larger geological context.

### Consider this ...

1. We believe the Earth began over 4.5 billion years ago.
2. Organisms have existed on the planet since the beginning or soon thereafter.
3. Humans have only been on Earth for the last 150,000 years.

### I. The Earth in the Beginning

The Earth is about 4.5 billion years old and life has been present almost from the beginning. Rock has been recovered dating back 3.8 million years, which shows clear signs that life has been present on the Earth since or at least soon after it formed.

- A. The Earth was formed from a spinning mass of gas and dust that represents the original composition of the solar nebula. All of the planets, meteorites, the moon, and the sun that compose our present solar system were formed from the solar nebula.
  1. The original nebular mass had a very high temperature but eventually the mass cooled down and elements began to form structures, particles, and ultimately the primitive planets, comets, meteorites, and the sun. Particles began to coagulate and continued to grow until the Earth got close to its present size.
  2. The surface of this planet was composed mostly of liquid water with no continents, forming a planet-wide ocean. Over time, the radioactive material that composed the planet began to decay and provide an internal heat source that caused the planet to turn itself inside out.
    - a. Material from the interior blasted all over the Earth and began to settle and segregate, establishing the primitive Earth. This is how the continents were formed.
      - i. Continents were formed when lighter rock that rose to the surface after the decomposition occurred rested atop the denser rock floating underneath the surface.
    - b. The early Earth had an atmosphere and an ocean. Through time, it began forming continents.

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**II. Early forms of life consisted of simple unicellular organisms known as prokaryotes.**

- A. The life-forms at that time were fairly simple. They had a very simple lifestyle, were single-celled organisms, had simple energy dependence, and didn't have a long life span.
- B. Two theories exist on how life got here.
1. Seeds of life were formed elsewhere in the universe or perhaps the outer regions of the primitive solar nebula and it rained manna from heaven to provide the seeds for the plethora of life-forms we find here today.
  2. Life formed in-situ in the earth. The first area of the formation of life was at the Black Smokey vents that erupted in molten material into the depths of the primitive ocean.
    - a. Scientists recently discovered vents in the ocean floor where water at 300°C was coming to the surface with sulfur, chemicals, and other kinds of material. As this material is released from the vents, it begins to condense in the cold ocean water. Around these vents you find a remarkably complex but still simple life-form that is living off the energy of the vent material. These organisms take sulfur from the vents and use the oxygen present in the water and extract energy by oxidizing the sulfur to sulfur dioxide creating sulfate, in the process gaining the ability to grow. Even today you can find life-forms that exist and perpetuate from this process.
    - b. Genetic complexity developed as a consequence of the fusion of the genetic material of these simple organisms, leading to the evolution of organisms capable of accomplishing functions impossible for their prokaryotic ancestors.

**PROKARYOTIC VS EUKARYOTIC ORGANISMS**

Prokaryotic, in the simplest terms, means "having a primitive nucleus." These are single-celled organisms that lack a membrane-bound nucleus, have a single circular DNA strand that lacks the proteins associated with a eukaryotic organism, and can function in both aerobic and anaerobic environments. Prokaryotic organisms are most familiar to us as blue-green algae and bacteria. One astonishing fact about these organisms is that they have been seen to grow in both excessive heat and cold.

Historically it is believed that prokaryotic organisms appeared upon the Earth shortly after the Earth was formed, billions of years prior to the appearance of eukaryotic organisms.

Eukaryotic organisms can be single-celled organisms, such as protozoa, or multicellular organisms such as humans. These are distinguished by the fact that they have cells with nuclei and those nuclei are membrane-bound, contain organelles not found in prokaryotic organisms, and have cells that are much larger in comparison. The genetic material is also more complex and held in the nucleus.

Although there are few similarities, both eukaryotic and prokaryotic organisms have DNA that directs protein synthesis through mRNA and contains both the messages for metabolism and chromosomal heredity.

c. Evolution proceeded slowly after the development of the early eukaryotes. A rapid profusion of life-forms, recorded in the Burgess Scale (Shale), took place roughly 1.5 billion years ago. The roots of many of the plant and animal species present today can be found in this remarkable development. Evolution is not a steady Darwinian process where the strong survive and the weak die away. That's not really the way evolution progresses. Evolution is in fact a process in which changes occur almost in steps. There are times of rapid environmental changes that lead to rapid change into the type of organisms that can survive it, resulting in winners and losers rather than weak and strong. Biologists refer to this as punctuated equilibrium. It's not a steady process but something that occurs in spurts, supporting rapid appearance and disappearance of organisms of various types.

C. The best publicized part of this is the history of the dinosaur.

1. Dinosaurs were common on the Earth with a wonderful variety of life-forms—big, clumsy, creative creatures that were all over the Earth living in an environment very different from today, probably when the Earth was quite a bit warmer. Over a relatively brief period of time, the Earth was smacked by a large meteor or by a series of meteors. These meteors triggered global climate change. Most of the dinosaurs went extinct over this brief period of time. But other life continued and new life-forms developed.
2. Changes in the global environment, including changes in climate, had an important influence on the evolution of new life-forms and on the extinction of organisms that were previously successful. Ecological niches were created and destroyed.





3. The human is a late arrival on the stage of life. Current studies suggest that one species—homo sapiens—can be traced back to a common maternal ancestor who lived most probably in east central Africa about 150,000 years ago.
- a. These first ancestors lived very simple lives, but with time they became more skilled and more migrant and moved around the world, initially into the Middle East and then into Europe, Asia, and the Americas.
  - b. From this early origin, humans spread to different parts of the world. First arrival in the Americas occurred as recently as 50,000 years ago.
    - i. Fifty thousand years ago represented mid-term or the last major ice age that the planet has had. Sea level globally was 120 meters, 350 feet or so lower than it is today, and you could walk from Siberia to Alaska through the Bering Strait. Humans arrived in the Americas through this long migratory path around this time.



## ECOLOGICAL NICHES

Ecologists worldwide use “ecological niches” to help theorize mass extinction and opportunistic evolution.

Studies have shown that every plant and animal occupies a specific “space” in an ecological system. It lives there, it eats there, and it reproduces there. Every organism alive will carve out a niche in an ecological system and, providing the system isn’t disrupted, can exist there forever.

When a niche is vacated, however, either through extinction or disruption of the ecological system, the remaining organisms see this as an opportunity to expand their reach. This results in multiple species competing to occupy the vacant niche. This opportunistic behavior will inevitably leave one winner and one or more losers due to the fact that no two organisms can occupy the same ecological niche. This could result in the extinction of one or more of the opportunistic organisms.

When mass extinctions occur it is primarily due to the fact that organisms are fighting with each other to gain control of the vacant niches. This again leaves winners and losers.

As we continue to grow and expand, the ecological homes of many organisms are being destroyed and, along with that, many of those organisms are near extinction.

## PUNCTUATED EQUILIBRIUM

Punctuated equilibrium is a theory of evolution whereby organisms were not involved in continual growth and change within their evolutionary time period, but there existed times in the past when no evolutionary changes were occurring at all.

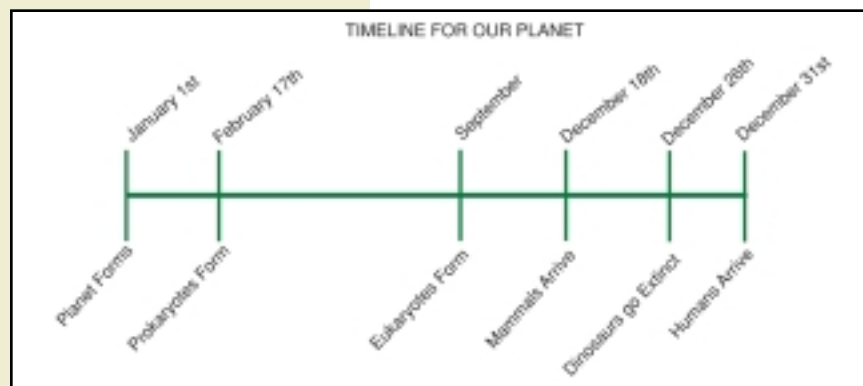
In 1972, two scientists, Niles Eldredge and Stephen Jay Gould, proposed this as an alternative to Darwin's theory of evolution. Their contention was that even though there may be broken fossilized records, evolution in small groups occurred rapidly and eventually overtook the parents.

This theory of evolution is contradictory to Darwin's theory of continuous progression along the evolutionary chain—where changes occurred in small steps over time. Punctuated equilibrium demonstrates, however, that evolutionary changes occurred rapidly and then leveled off where virtually no changes were occurring at all. This represents equilibrium in the ecological system.

- ii. During the first period of humans in the Americas the population wasn't large, but the people did a fair amount of damage. When they arrived this planet was rich with megafauna. Woolly mammoths were having a fine time living in the Americas. In a very short time after their arrival, our human ancestors had eliminated many species.

### Conclusion:

The history of the Earth and life can be viewed on a more comprehensible time scale. Imagine that the history of the Earth is compressed into a single year. Earth formed from the spinning mass of gas and dust that composed the primitive solar nebula in January. The early prokaryotes were established by February 17. Almost 7 months elapsed before the eukaryotes appeared in early September. Mammals arrived on the scene first about December 18, while dinosaurs disappeared on December 26. Humans made a late appearance at about 9 p.m. on the evening of December 31. The industrial revolution developed at about 2 seconds to midnight on December 31 and we are grappling with events that will unfold over the next few tenths of a second.



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## FOR GREATER UNDERSTANDING



### Consider

1. What is man's impact on the planet?
2. How does the process of extinction happen? Could it be avoided?
3. What are the very different theories of evolution?

### Suggested Reading

- Lane, Nick. Oxygen: The Molecule That Made the World. New York: Oxford University Press, 2003.
- Liebes, S., E. Santouris, and B. Swimme. A Walk Through Time: From Stardust to Us: The Evolution of Life on Earth. New York: Wiley & Sons, 1998.

### Other Books of Interest

- Gould, Stephen Jay. The Book of Life: An Illustrated History of the Evolution of Life on Earth. New York: WW Norton & Co, 2001.

### Websites to Visit

1. [www.isgs.uiuc.edu/dinos/dml/history.htm](http://www.isgs.uiuc.edu/dinos/dml/history.htm) - Geological history of the Earth presented in an easy-to-understand chart of time.
2. [www.thinkquest.org/library](http://www.thinkquest.org/library) - Comprehensive look at the scientific approach to dating our planet.
3. [www.usgs.gov](http://www.usgs.gov) - Site of the US Geological Survey clearly outlining the biology, geology, and geophysical life on Earth.
4. [www.extremescience.com/earth.htm](http://www.extremescience.com/earth.htm) - An exciting and interesting perspective on the formation and history of our great planet. Site is filled with wonderful detail and a number of illustrations.

## Lecture 2: Stratospheric Ozone Depletion

### Before beginning this lecture you may want to ...

Read Richard Elliot Benedict's [Ozone Diplomacy: New Directions in Safeguarding the Planet](#).

### Introduction:

In this lecture we will look at stratospheric ozone depletion.

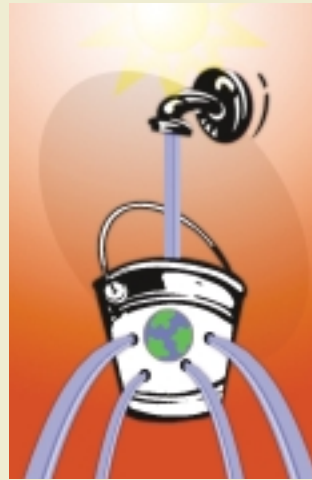
### Consider this ...

1. What is ozone and how does it affect us?
2. Everyone has heard the term "hole in the ozone layer." Is this term literal?
3. Are global warming and ozone depletion related?

### I. The Ozone and How It Works

- A. Ozone is present in the region in the atmosphere that we call the stratosphere, which typically begins 15 km above the surface of the Earth.
- B. The stratosphere is the portion of the atmosphere where air stays for a very long time. It is a very stable environment. If you put "stuff" into the stratosphere it will stay there for years.
  1. If a volcano erupts and the sulfur reaches the atmosphere, it will affect what happens in the stratosphere for the next 2 to 3 years and the difference will be seen on the surface of the Earth.
  2. Conversely, if you pollute the lower atmosphere, those pollutants will dissipate within a matter of weeks.
- C. Ozone is formed in the stratosphere by ultraviolet sunlight, which has wavelengths shorter than we can see with our eyes. UV sunlight is absorbed in the stratosphere by oxygen molecules that are torn apart in the process. So you get separate atoms of oxygen where you had previously cojoined pairs of atoms in oxygen. The chemistry of the stratosphere essentially scrambles the oxygen molecules and you end up with a significant number of atoms arranged in a triatomic ( $O_3$ ) form rather than the diatomic form of oxygen ( $O_2$ ).
  1. The importance of ozone is that it absorbs sunlight that would otherwise be extremely damaging to biological material. It absorbs light of wavelengths that could fragment DNA molecules. Ozone protects the surface from this form of radiation.
  2. Scientists believe that if the ozone layer didn't exist, life on the surface would be destroyed, or at least transformed.
  3. Most ozone created in the stratosphere is also removed there and converted back to  $O_2$ .

a. Supersonic Transport (SST) is an aircraft that was first conceived in the 1950s using governmental funds at Boeing. By the mid 1960s many politicians were questioning using government funds for the development of this aircraft. This plane would have flown about 20 km above the surface, while normal planes fly at 10 km above the surface. So in order for this plane to fly successfully it would have to go into the stratosphere. The exhaust from the plane would therefore be released into the stratosphere where it would stay for extended periods of time (1 lb of pollution in the stratosphere will have the same impact of hundreds of pounds of pollution in the lower atmosphere). Scientists began focusing their research on nitric oxide, which is an inevitable by-product of plane exhaust. Nitric oxide has the potential to destroy ozone, so scientists did some studies to determine the effect of the SST aircraft on the ozone. The calculated ozone depletion was only a few percentage points, which didn't sound like a big deal until a meteorologist, James McDonald, began questioning the effect of a few percentage point loss of ozone and its effect on the surface and on humans. He began to study the incidence of skin cancer in an Irish community in Houston, Texas, and compare it to a similar ethnic group in Minneapolis and was able to discover that there was a higher rate of skin-cancer incidence in the southern city than there was in the northern city. He attributed this to the lower amount of ozone protecting the southern city versus the amount of ozone protecting the northern city. Through this research he was able to calculate that 1% depletion of the ozone increased the incidence of skin cancer by 2 to 3% depending on the geographical location. Suddenly, a small amount of ozone depletion that was thought of as



#### **OZONE DEPLETION: AN ANALOGY**

The best way to describe ozone depletion is with an analogy. Picture the ozone layer as a bucket. If you poured water into a bucket that had holes in it but you were able to add as much water as was leaking out, the water level in the bucket would stay at a stable level. If you punched additional holes in the bucket but did not increase the amount of water you poured into the bucket, the water level would decrease. It's the same with the ozone layer. As more "holes" are punched into the stratosphere and more pollutants are reaching the stratosphere, the ozone layer is depleted, allowing for more harmful UV sunlight to reach the surface of the planet. This creates serious environmental issues and creates a genuine human health risk.

### BOEING AND THE SST

In the early 1950s when air travel became popular, some engineers in the industry predicted that in a short time aircraft would be developed that would fly passengers faster than the speed of sound—making the journey across the Atlantic take less than 5 hours.

Trying to beat the British and French, who were then developing the Concorde, and the Russian KGB, who produced the TU-144, the Congress of the United States of America appropriated \$100 million for the development of the Supersonic Transport. The year was 1964. Aviation companies across the country began competing for this lucrative opportunity that would revolutionize the commercial airline business.

Boeing beat out Lockheed and North American and won the contract to build the SST. That same year, 1964, the Air Force began testing Boeing's supersonic aircraft in Oklahoma. As a result, there were over 8,000 complaints about the sonic boom and 5,000 claims for damages. This proved very costly in and of itself.

Stronger opposition would come from elsewhere though—American environmentalists. The SST was nothing but a gas guzzling polluter and was a detriment to the environment. By September 1969, more than \$500 million in federal funds had been spent on this project and in 1971, the Senate ended the federal funding and Boeing's chances of successfully developing the SST.

inconsequential was now a bigger problem. His work was critical in the decision of the government to suspend further funding of the SST aircraft project.

D. Chlorofluorocarbons (CFCs) were used for a whole variety of industrial purposes. In 1974, in the United States, 3 billion spray cans were sold in which the propellant was CFCs. The CFC gas was therefore released into the air. CFCs were also used as cleaning agents, as refrigerants, automobile air-conditioning systems, and more. This was a rapidly growing global chemical product invented in the 1930s by chemists at General Motors. The CFC gas had the unique property of being almost indestructible. It was non-toxic, invisible, and non-flammable. A pair of scientists discovered, however, that CFC gas eventually decomposed and released chlorine atoms. Chlorine atoms have the potential to destroy ozone just like nitric oxide. Mario Malina and Sherwood Roland shared the Nobel Prize in chemistry with Paul Crutzen for this discovery.

1. In the 1980s the models that predicted certain changes in the ozone levels in the atmosphere and the air quality at lower levels were discovered to be deficient. In certain regions of the world, the ozone started to disappear, primarily over Antarctica.
2. Scientists began calling this the ozone hole. This was an absolutely unexpected phenomenon since there were no models to suggest that it might occur. The loss of ozone over the polar region now had UV light that had never been seen there before piercing the stratosphere and reaching the surface. Scientists became very concerned about the few humans, fish, and wildlife that live in the region along with the other biotic life.

It became a concern this phenomenon would spread to the northern hemisphere where more people were at risk. Globally, people decided it was time to do something about it, eliminating the chemicals that cause the problems. A meeting took place in Montreal about the CFCs in 1986 and it produced a document called the Montreal Protocol, which initiated the process of phasing out many of the CFCs and other chemicals that were suspected of damaging the stratospheric ozone.

- a. The Montreal Protocol determined that we needed to phase out the use of these chemicals in a relatively brief period of time and that the phaseout should involve developed as well as developing countries.
- b. It assessed penalties for non-compliance with the reduction of harmful chemical production. These penalties were incredibly important. One of the penalties for non-compliance was that no country that signed the Montreal Protocol was allowed to import items that contained CFCs from a country that was not a party to the Montreal Protocol. This had huge economic implications for developing countries, especially in the automotive and electronics industries.
- c. The Montreal Protocol also made available the Global Environmental Fund to developing countries. The fund was financed by developed countries through windfall profit taxes on the CFCs. This fund aided the transition of non-developed countries to a non-CFC future world.
  - i. It's been a remarkably successful venture in the sense that the amount of CFC gases in the atmosphere has now begun to decrease following the extended growth that dominated from the early 50s to the 80s.

#### **DR. JAMES E. MCDONALD AND THE SST**

James McDonald received his PhD in physics from Iowa State University in 1951. He joined the Arizona University faculty in 1954 and specialized in meteorology. Although popularly known for his research on unidentified flying objects, he was the first scientist to study the impact our changing lifestyle had on the atmosphere and the ozone layer.

When Boeing was developing the SST, McDonald began to study the effects that the aircraft would have on the atmosphere. In a statement to Congress in March 1971, McDonald clearly outlined what the SST would do to the ozone layer and the effects such as an increase in the incidence of skin cancer seen in the United States. In his address, he presented three significant theories as to what the effect of the SST would be. He deduced that 1) the SST would be severely damaging to the stratosphere because the air didn't clear from there as quickly, 2) as the damage increased the protection the stratosphere afforded would decrease, and 3) the incidences of skin cancer due to this would raise considerably. He was right.



### MONTREAL PROTOCOL

The Montreal Protocol was an agreement unlike any the world had ever known up until this point. The Montreal Protocol was a treaty among all the participating countries to take active steps to protect the stratospheric ozone layer. This treaty was signed in 1987 and stipulates that the production and consumption of certain compounds (i.e., chlorofluorocarbons, halons, and carbon tetrachloride) were to be phased out by the year 2000. Scientists en masse agreed that the prolonged use of these compounds would damage the stratospheric ozone layer and would therefore no longer prevent the planet from receiving the harmful UV rays generated from the sun.

This original meeting, which was attended by over 50 nations from around the globe, was followed up in 1990 and 1992 where further proposals were made to save the ozone layer from further depletion and to fight the cause and effect of global warming. In later lectures you will learn the results of these conventions. However, it is important to realize that this was the very first convention of its kind, where the world as a collective unit came together to fight the damage to the global atmospheric environment.

3. Some positive messages were sent as a result of the Montreal Protocol:

- a. The chemical industry did not try to obscure the issue and formed an umbrella panel group of the major manufacturers and joined with governments in a global research program to try to understand the problem.
- b. Industry was therefore not surprised and was anticipating the transition to the non-CFC world. Industry approached the Montreal Conference knowing the problem existed and did not try to politically or scientifically avoid the issue. It turned into a cooperative arrangement.

### Conclusion:

#### Global Warming Issues

1. The economic interests that are at risk in the global warming issue are enormously larger than the economic interests that were at risk in the CFC arena. The entire oil industry, coal industry, and fossil fuel industry will be affected in some way by the climate issue and the response one might take to deal with it.
2. The developing countries were smarter by the time the climate issue came along. They charged the developed countries to make the first steps before they began considering any action of their own.



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## FOR GREATER UNDERSTANDING



### Consider

1. What was the Montreal Protocol and what were the results?
2. How was the CFC issue brought to light?
3. What are the lasting effects of ozone depletion?

### Suggested Reading

Benedict, Richard Elliot. Ozone Diplomacy: New Directions in Safeguarding the Planet. Massachusetts: Harvard University Press, 1998.

Makhijani, Arjun and Kevin Gurney. Mending the Ozone Hole: Science, Technology and Policy. Massachusetts: MIT Press, 1995.

### Other Books of Interest

Jurgielewicz, Lynne M. Global Environmental Change and International Law. New York: University Press of America, 1996.

### Websites to Visit

1. [www.epa.gov/ozone](http://www.epa.gov/ozone) - Official site of the Environmental Protection Agency providing a thorough look at the ozone situation.
2. [www.al.noaa.gov/WWWHD/pubdocs/Strato3.html](http://www.al.noaa.gov/WWWHD/pubdocs/Strato3.html) - This site sponsored by the NOAA Aeronomy Laboratory provides an excellent resource for information on stratospheric ozone depletion.
3. [www.nasa.gov/About/Education/Ozone](http://www.nasa.gov/About/Education/Ozone) - NASA's official site on the depletion of the ozone layer and its effects on the planet.
4. <http://wlapwww.gov.bc.ca/air/ozone> - The official site of the Water, Air and Climate Branch of the British Columbian government provides a new perspective on the global issue of ozone depletion.

## Lecture 3: The Human Role of Life on Earth

### Before beginning this lecture you may want to ...

Read Michael Williams' Deforesting the Earth: From Pre-history to Global Crisis.

### Introduction:

The Earth's human population is over 6 billion and is still growing. Man's influence on the global environment is now undeniable. In this lecture we'll examine when man and technology began to have an impact: the Industrial Revolution.

### Consider this ...

1. Are humans changing the global climate?
2. Is the Earth warming up?
3. What can we do about it?

### I. Problems That Arose in the Post-Industrial Period

- A. The consequences of what we did were not often seen and perhaps if the consequences of our actions were foreseen, it's possible we would have taken a different path. We traditionally react to problems once they have become an epidemic and the climate issue (global warming) is another challenge that is precisely this type of situation.

### II. The Industrial Revolution

- A. The 17th century was a time when England was becoming relatively affluent and had a presence that was spreading far beyond the British Isles. The Royal Navy was becoming significant globally and its maintenance and expansion began depleting the British Isles' natural resources. The forested areas declined and it was difficult to meet the Royal Navy's need for tall trees for the masts of their ships so they could set sail. This country was rich and when a country is rich it allows for creativity in many ways. The affluence provides the opportunity for further creativity. However, with the continued depletion of natural resources and the demand for products, this was the stimulus that led to the Industrial Revolution.
- B. The Industrial Revolution was fueled by coal. That became the resource that substituted wood products, which were now in short supply. England had abundant sources of coal but up to the time of the invention of Watt's steam engine, most of the coal was not accessible. You could track and mine only the stuff near the surface as England has a wet climate, and a coal mine that you are not pumping the water out of will become filled with water very fast. The invention of the steam engine therefore allowed the coal mines to be functional to greater depths. Afterward, England had an abundant source of energy.

C. As the country becomes more industrialized and more affluent, there are inevitable changes in the society.

1. Factories now become the site of industrial activity rather than homes, where most people used to work. You now have machines that bring people from the countryside to operate. The country therefore undergoes urbanization and that rate accelerates dramatically.
2. Industrial towns eventually emerge into cities and they are often integrally built around factories that belch smoke from coal fires into the air. People are living in row houses, which use coal for heat and cooking. So the consequence is that these cities very quickly become dirty.
3. People took this for granted as part of city life. Rich neighborhoods and poor neighborhoods soon developed. The poor neighborhoods always had worse air pollution than the rich neighborhoods due to their location near the factories.

D. Air pollution, notably sooty air, was the first signal of a problem. Initially accepted as the price of progress, society moved eventually to deal with this issue in the 1940s and 1950s, prompted by well-publicized disasters in Donora, PA, and London, England (the so-called killer smog of 1951).

E. Watts and other industrialists did not predict what the outcome of industrialization would be. Problems began to be recognized only recently.

### III. Why did it take so long for pollution to become an issue?

A. Most people didn't even think about the environment as something that needed protection. There was no EPA, public health concern was focused on other issues, and people had yet to recognize the damage caused by air pollution.

### DONORA VALLEY

Up until the turn of the century, Donora, PA, was a small town of many names. First founded as Pittsburgh in 1814, the town had a very undistinguished history. In May 1899, however, the Union Improvement Company began to purchase large blocks of land in this little valley nestled between two mountains. In May 1900, the Union Improvement Company broke ground for a large industrial development. They were joined there by three steel companies, a manufacturing plant, a fence company, and several others, which led to the industrial boom of this tiny town. Soon the village was filled with workers and their families, who lived a happy and healthy existence until a strange meteorological event brought this tiny town into focus—along with the damaging effects of industrialization.

On October 30 and 31 in 1948, 19 people died suddenly, two of tuberculosis, and the remaining of heart failure and asthma. In addition to these sudden deaths, over 500 people became ill and complained of respiratory problems. It was discovered that under normal circumstances, the air that circulates between the mountain ranges would drag the industrial pollution out of the area on a daily basis. However, at this time, the pollution hung like the angel of death over the town. The term smog was now a household word.

### ACID RAIN

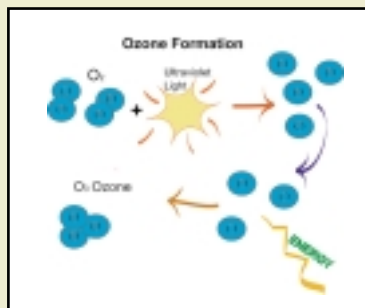
Although industrialization was an inevitable part of the culture in which we live, it didn't come without a price. Killer smog in both London and Donora Valley, PA, were stepping stones along the path of discovery on the effects of pollution on our environment.

In Scandinavia, a relatively pristine environment with beautiful lakes, people began to notice that the fish in the southern lakes of Norway were beginning to die and disappear. As a result of this discovery, scientists began measuring the acidity of the lake water and found that the lakes were becoming more acidic. Someone decided to look at the rain water and by capturing it and measuring the acidity they discovered that indeed the rain was bringing more acidity to their lakes. The rain was found to contain increasing levels of sulfuric acid and nitric acid. Norway was not a big industrial power so scientists began looking at the way the wind came across the country. Germany, the UK, and Poland all were found to be causing the increase in acidity of the rain. So when it was decided to put the smokestacks higher to displace the pollution to another area, it created yet another problem called acid rain. Acid rain occurred too in the United States. Its effects were felt most severely in the northeastern part of the States but were generated from coal burning factories mostly in the Midwest.

- B. The solution to local air pollution involved building high smokestacks and sending the problem elsewhere. This led to a new problem—the issue of acid rain.
- C. Acid: If you take any acidic material and pour it onto any metal surface, the metal surface will dissolve. When you have acid rain, as the rain becomes more acidic, it leaches into the soil and begins taking toxic metals out of the soil and transporting them into waterways, lakes, etc. These toxic metals then become dangerous to the aquatic life that lives there.
  - 1. When scientists discovered the effects of industrialization on the environment and acid rain was first observed, certain changes that were previously made came into question. The initial reaction of lengthening of the smokestacks so that rather than remain in the immediate vicinity, the smoke would trail off somewhere else, obviously caused additional problems. To rectify this, devices were built to filter out the pollutants before they got out in the air. Sulfur oxide and nitrogen oxide were of particular concern at this point.
  - 2. The original increasing of the height of the smokestacks helped to better the air quality in places like Pennsylvania and London, but it did not solve the problem elsewhere. It effectively moved the problem to another location. The new region that suffered was the region downwind.
- D. A further problem was recognized even later—the issue of photochemical smog or  $O_3$ . This first came to attention in Los Angeles.
  - 1. Another example of our inability to project what will happen comes when we take a closer look at the automobile. This situation became dramatically evident in Los Angeles, where the population there counted on the automobile for transportation. Air quality was

superficially very good. But there seemed to be a particularly bad stagnant air mass sitting over the city and people started to get seriously ill. There was no clue as to what was causing the increase in illness and “coughing” throughout the city. Haagen-Smit was the professor at the California Institute of Technology who first had the idea that maybe automobiles were part of the problem. He began measuring the exhaust gases from his automobile and he subjected these exhaust gases to a cycle of sunlight such as they would experience in the outside environment. He discovered that ozone was being synthesized from the molecules comprising the exhaust if there was sunlight available to do this. So his discovery led to the conclusion that exhaust gases can produce ozone and ozone can make people sick. Even today, however, we don’t know what level of ozone makes people sick.

2. This resulted in the development of the catalytic converter—the catalytic converter arrests emission of some of the chemicals responsible for ozone production.
- E. Now we are confronted with climate change arising as a consequence of  $\text{CO}_2$ , the primary product of combustion. These by-products are called “greenhouse gases.” Greenhouse gases insulate the Earth from the cold temperatures of outer space.
1. The energy we receive from the use and burning of fossil fuels essentially turns organic carbon into carbon dioxide by adding oxygen atoms to carbon. This process produces energy. This is precisely what happens when we burn coal. Coal is composed of carbon atoms. Adding oxygen atoms will result in a chemical



### FORMULATION OF OZONE

Scientific researchers in the Los Angeles area attempting to learn the cause of the “smog” that hung over the city were astounded to discover that the culprit of the problem was ozone.

Ozone was not a by-product of industrial production nor was it directly emitted from tailpipes or smokestacks. Haagen-Smit along with Margaret Brunelle discovered that ozone was created in the atmosphere. They learned that it is a photochemical reaction, sparked by the sun, combining hydrocarbons from oil refineries with exhaust of automobiles, and nitrogen oxides would join to form ozone.

Haagen-Smit and Brunelle conducted numerous experiments on the effects of ozone. One interesting thing they discovered was that rubber disintegrated in just seven minutes after exposure to high levels of ozone. Tires in Los Angeles were wearing out fast.

### ARIE J. HAAGEN-SMIT

In 1947, a chemistry professor from the California Institute of Technology began to unravel the mystery of the dense and odoriferous cloud that hung over the city of Los Angeles, California.

Haagen-Smit, a Dutch perfume chemist, knew that the air pollution was unlike anything he'd ever known and despite efforts to control smoke from factories, a curious odor also hung over the city. The smog, as it was termed, also led to severe eye irritation. He determined that the air was chiefly composed of sulfur dioxide from the burning coal and oil in the industrial plants.

Haagen-Smit was on the trail of a highly oxidizing element in Los Angeles air. By 1950, his nose and research led him to the culprit: ozone. By exposing plants to ozone in sealed chambers, he showed they suffered similar symptoms as those damaged by smog.

Haagen-Smit also demonstrated in the early 1950s that ozone caused eye irritation, respiratory problems, and damage to materials.

reaction that releases a predictable amount of energy. The burning of coal, however, doesn't make the coal disappear. It turns the coal into something else. Matter is not created or destroyed! Coal is converted to carbon dioxide, which accumulates in the air. This works for oil as well.

2. Our solutions to all these problems have been piecemeal. We use technology to clean up emissions. The problems are not resolved; however, the immediate issue may be remedied but new issues, more recalcitrant, inevitably emerge. We simply transfer the problem to something else.

a. The carbon dioxide that is released into the environment is going to be there for a very, very long time. Fifty percent of all the CO<sub>2</sub> released in the environment since the start of the Industrial Revolution is still present.

#### Conclusion:

The coal that we burn produces sulfur, which doesn't stay in the atmosphere for more than a few days before it turns into acid rain and is back on the surface of the Earth. Such problems would essentially go away if we changed the way these compounds got into the atmosphere. But burning fossil fuel and releasing it into the atmosphere continue to be a problem and appropriate measures need to be taken to alter this course of action sooner rather than later. We must also guard against the tendency of people to ignore the problem.



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## FOR GREATER UNDERSTANDING



### Consider

1. What effect did the Industrial Revolution have on the environment?
2. What is acid rain and where did it come from?
3. What are we doing to prevent further pollution issues from arising?

### Suggested Reading

Ray, Dixie Lee and Lou Guzzo. Trashing the Planet: How Science Can Help Us Deal with Acid Rain, Depletion of the Ozone and Nuclear Waste. New York: HarperPerennial Library, 1992.

Williams, Michael. Deforesting the Earth: From Pre-history to Global Crisis. Illinois: University of Chicago Press, 2002.

### Other Books of Interest

Kosobud, R., D. Schreder, H. Biggs. Emissions Trading: Environmental Policy's New Approach. New York: Wiley & Sons, 2000.

### Websites to Visit

1. [www.ec.gc.ca/acidrain/index.html](http://www.ec.gc.ca/acidrain/index.html) - A complete look at the global issue of acid rain and its effects on the global climate.
2. [www.penweb.org/issues/mining](http://www.penweb.org/issues/mining) - An interesting look at how the state of Pennsylvania deals with mining and its effects.
3. [www.epa.gov/oar](http://www.epa.gov/oar) - From the Environmental Protection Agency, this site provides clean statistics on the increase in acid rain on our planet.
4. [www.let.leidenuniv.nl/history/migration/chapter3.html](http://www.let.leidenuniv.nl/history/migration/chapter3.html) - An excellent time-line resource for the Industrial Revolution and the consequences leading to the issue of global warming.

## Lecture 4: The Greenhouse Effect

### Before beginning this lecture you may want to ...

Read D. Crissoulidis' [Electromagnetics and Optics](#).

### Introduction:

The sun acts as the ultimate source of heat on the planet. In this lecture we'll take a look at the ability to change the environment and how the role of the sun is changing.

### Consider this ...

1. What is the "greenhouse effect"?
2. What role does the color of the Earth play in the greenhouse effect?
3. What is the electromagnetic spectrum of light?

### I. Global Warming

The carbon dioxide that was released in the air after the Industrial Revolution is the essential cause of global warming. You can try to remove the sulfur oxide from the smokestacks before it gets into the air, which is doable as the sulfur is a relatively small fraction of the total material produced by burning the coal. It is much more difficult to remove  $\text{CO}_2$ . The production of  $\text{CO}_2$  is much more critical than the release of sulfur oxide. This is the ultimate link to global warming.

### II. The Greenhouse Effect

- A. The ultimate source of heat on our planet is the sun. The center of the sun is a massive nuclear reactor burning hydrogen at the core at very, very high temperatures, which produces energy.
- B. That energy is transported out through the different layers of the sun and eventually it is released in the form of light into space.
- C. There are two principles that we need to consider.
  1. The property of any body is that it glows and emits light. Basic physical principles tell us that if we double the temperature of a body we can increase the light radiating from the body by a factor of 16. Emission varies as the 4th power of the temperature.
  2. The wavelength at which light is emitted depends also on the temperature (i.e., if you warm up an iron bar and get it really hot, you begin to see it glow). It initially glows a sort of reddish color, then yellow and then white. Every body emits light: if the body is cold, light is emitted at very long wavelengths you can not see with your eye; if it gets quite hot, you begin to see the light coming from that body at wavelengths your eye is sensitive to. We see with our eyes only a tiny part of the electromagnetic spectrum of light. Different organisms have developed the ability to see light in the different portions of the electromagnetic spectrum.



- D. The outer regions of the sun are at a temperature of about 6 thousand degrees and emit most of the sun's energy in the visible spectrum at a wavelength you can see (blues, reds, yellows, etc.). It's not surprising that species such as us evolved to utilize the available spectrum of light. We are basically diurnal beings. We live most of our lives during the day and we navigate around by taking advantage of the fact that there is so much visible light.
- E. The fuel that runs the climate system is absorbed mainly at the surface of the Earth. A significant fraction of the energy that is coming from the sun in the visible spectrum is reflected back to space by clouds. The part that is not reflected back by the clouds is able to reach the surface and be reflected back off the surface or absorbed by the surface.
- F. The average color of the Earth determines how much light is absorbed/visible and how much reflects back to outer space. The term scientists have for this is albedo. Albedo is defined as the measure of the fraction of light that is absorbed. It has a range from zero to one and is ultimately a measure of a planet's ability to absorb sunlight.
1. A certain amount of energy will be absorbed by the planet from incident sunlight and the rest will be reflected back to outer space. That energy is not stored. Otherwise, the Earth would get hot. There is a lot of energy coming in from the sun.
  2. We can calculate the average temperature of the Earth by balancing what is absorbed from the sun with what is emitted to space. Calculated in this way, the average temperature of Earth turns out to be about  $-18^{\circ}\text{C}$ .

## INFRARED (NIGHT) VISION

When people hear the term night vision they think of a James Bond-type thriller where good overcomes evil because the hero has an awesome pair of night vision goggles. That's partly true, but there is a far greater application for the use of infrared vision than what is posed by Hollywood.

Visible light is only a fraction of the total light that is emitted from the sun. The amount of energy released by light is determined by its wavelength. The shorter the wavelength, the higher the energy that is produced. The mid-range of infrared light has a wavelength of about 2 microns, which is impossible to see with the human eye. When you point the remote control at your TV and hit a button, mid-range infrared energy wavelengths are used to change the channel for you.

There are two applications of infrared vision. One is image enhancing, which collects tiny amounts of light and amplifies them to the point where they can be seen with the human eye. The second is thermal imaging, which captures the upper portion of the light spectrum, which is emitted as heat, and converts it to light. The warmer the item you are looking at, the brighter the image will appear.

Some of the most obvious uses of infrared vision are in the military, law enforcement, wildlife observation, and hidden-object detection.



### INSULATING A HOUSE NOT UNLIKE THE OZONE

As an analogy, consider a house heated in winter by an oil-burning furnace. The furnace supplies heat and the energy supplied by the furnace is balanced by infrared radiation emitted to the outside by the walls and windows. We could take an infrared photograph of the house from the outside and observe where heat was emitted. For example, the windows would probably show up as hot spots. Well-insulated walls would be cold; poorly insulated surfaces would show up as warm. Consider now a second house, identical in construction, burning oil from an identical furnace at precisely the same rate. Suppose that house is well insulated and the other is not. Could we tell the difference from infrared measurements taken from outside? The answer is no.

Energy emitted from both houses would be identical because energy in must equal energy out (otherwise the houses would either heat up or cool down). Could we tell the difference if we were to go into the houses? Yes; the well-insulated house would be warmer inside.

- a. The average temperature of the Earth is determined by a balance between energy absorbed from the sun and emission of long wavelength infrared radiation to space.
  - b. Greenhouse gases are very good absorbers of infrared light but very poor absorbers of visible light. They are an ideal insulator that lets the light in but doesn't let the light out.
- G. What this analogy (on left) has to do with global warming:
1. The sun is the global furnace and the oil is the nuclear energy that produces the light that comes from the sun that is absorbed by the Earth. The greenhouse effect provides insulation. Otherwise the Earth would be very cold. Giving the formula energy in = energy out and knowing how much energy is absorbed from the sun, there is a simple calculation that a scientist can do to calculate what the average temperature of the Earth should be. The average temperature of the Earth is  $-18^{\circ}\text{C}$ . The temperature required to get rid of the energy absorbed from the sun by the entire Earth is significantly below the freezing point of water. The energy that goes back to space does not come from the surface.
  2. Selected components of the atmosphere act as insulation on the Earth (these are the greenhouse gases). They inhibit emission of infrared (long wavelength of light) heat to space. So the greenhouse gases act as the roof on the Earth that maintains the interior where we live at a relatively warm temperature. One would reasonably expect that with more insulation, the Earth would be warmer.
- H. The major constituents of the atmosphere ( $\text{O}_2$ ,  $\text{N}_2$ ) are unable to absorb infrared radiation. If the atmosphere was solely composed of these two gases, one

would expect the average temperature of the Earth to be  $-18^{\circ}\text{C}$ . If the Earth was frozen over, think about what that does to the color of the Earth. If you take the ocean, which currently looks dark and absorbs a lot of light, and cover it with a sheet of ice, it will look white and not absorb very much sunlight. In this case, the albedo of the Earth will have decreased.

1. We require molecules with more complex structure (polyatomic molecules) to absorb infrared radiation. Of particular importance are  $\text{H}_2\text{O}$  vapor and  $\text{CO}_2$ .
  2. How can we reconcile this with our experience? The answer is that emission to space does not occur from the surface but from high in the atmosphere. The surface is insulated by the greenhouse gases present in the atmosphere, notably  $\text{H}_2\text{O}$  and  $\text{CO}_2$ .
- I. How do we expect the Earth to respond to the input of more insulation?
1. If we add greenhouse gas to the atmosphere—increase the insulation—we might reasonably expect the surface to warm. We are adding  $\text{CO}_2$  and other greenhouse gases to the air and detailed calculations indicate that the average temperature of the surface should increase accordingly. This is the essence of the global warming issue.
  2. The fundamental principle of the greenhouse effect is that the major gases in the atmosphere today (oxygen and nitrogen) do not absorb infrared light. More complicated molecules (water vapor and carbon dioxide) are required to absorb infrared light.

## MONATOMIC, DIATOMIC, AND POLYATOMIC MOLECULES

In the very basic sense, everything in our lives is composed of atoms. Atoms are often referred to as the building blocks of matter. When more than one atom bonds together, they are referred to as molecules.

All atoms have central nuclei that are surrounded by varying numbers of negatively charged particles called electrons.

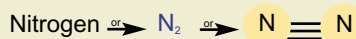
Some atoms are stable in nature due to the fact that they have a sufficient number of electrons in their outer shells, preventing further electrons from bonding. These atoms are called monatomic. From the periodic table, noble gases are monatomic elements. Diatomic molecules are composed of atoms with incomplete outer shell electrons and therefore pair with another atom to complete their outer shell. Oxygen and nitrogen exist primarily in the atmosphere as diatomic molecules. Polyatomic molecules are combinations of atoms bonded together to form stable, multi-atom structures.

Here are some examples:

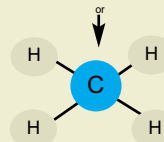
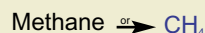
Monatomic



Diatomic



Polyatomic



### ELECTROMAGNETIC SPECTRUM OF LIGHT

Since nearly the beginning of time, scientists have been speculating on the properties of light. Sir Isaac Newton proposed that light was a stream of particles bouncing off each other and forming light. But in the 18th century, a scientist named Thomas Young first theorized that light was not particles but waves. His experiments in this area allowed him to deduce that light must exist in waves because there were times when these waves cancelled each other out. It is impossible for particles to do that. Although his theory was rebuffed by many, renowned scientist Albert Einstein was able to prove that light existed both as waves and particles.

Much to the amazement of everyone, there is actually only a tiny strip of visible light that exists in the whole spectrum of wavelengths of light. From radio waves on one end of the spectrum to gamma rays on the other, there is a vast difference in light. Very short wavelengths of light are exemplified by x-rays and tend to be absorbed high in the atmosphere. A slightly longer wavelength in the electromagnetic spectrum is the extreme ultraviolet, which is also absorbed high in the atmosphere. These wavelengths literally tear atoms and molecules apart, producing electrons that provided the means for radio wave communications before we had satellites. Light in the ultraviolet portion of the spectrum is invisible to the human eye but visible to some organisms that are able to navigate using ultraviolet reflectivity. Visible light is detectable by the human eye and has a variety of wavelengths also. Short wavelength visible light is blue and long wavelength visible light is red. Infrared wavelength is the next longest on the spectrum and is not detectable by our eyes. Microwave is the next in the spectrum and is absorbed pretty heavily by water. Radiowaves are the next part of the spectrum and are lights of very long wavelengths. These wavelengths may be miles long and have the ability to penetrate into the ocean.

Solar energy, which governs our global climate, is delivered to Earth in the form of light. Some of that light is returned to space and some is absorbed by the planet, allowing for a global energy balance.

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## FOR GREATER UNDERSTANDING



### Consider

1. What are the greenhouse gases?
2. What happens when the concentration of greenhouse gases increases?
3. What effect do greenhouse gases have on light?

### Suggested Reading

Crissoulidis, D. et al. Electromagnetics and Optics. New Jersey: World Scientific Publishing Co., 1992.

Moroto-Valer, M. Mercedes et al. Environmental Challenges and Greenhouse Gas Control for Fossil Fuel Utilization in the 21st Century. New York: Plenum Publishing Co., 2002.

### Other Books of Interest

Gottinger, Hans. Global Environmental Economics. New York: Kluwer Academic Publishers, 1998.

### Websites to Visit

1. [www.panda.org](http://www.panda.org) - Home site for the World Wildlife Federation. There is an excellent section on climate change and its effects.
2. [www.eere.energy.gov/climatechallenge](http://www.eere.energy.gov/climatechallenge) - The official website of the Department of Energy, which discusses global climate change.
3. [www.enn.com/specialreports/climate](http://www.enn.com/specialreports/climate) - Online information from the Environmental News Network with continual updates on climate changes.
4. [www.climatehotmap.org](http://www.climatehotmap.org) - An interactive website that tracks up-to-date information on global climate changes, including storms, ocean level changes, melting glaciers, and general information.

## Lecture 5: The Efficiency of the Natural Greenhouse Effect

### Before beginning this lecture you may want to ...

Read Naomi Oreskes' [Plate Tectonics: An Insider's History of the Modern Theory of the Earth](#).

### Introduction:

Carbon is an essential part of life. There is carbon in almost everything—but when is it too much?

### Consider this ...

1. What is the life cycle of an atom of carbon?
2. What role do tectonic plates play in the carbon cycle?
3. What occurs during photosynthesis?

### I. Carbon on Earth

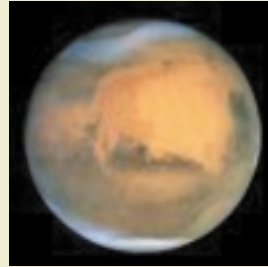
The Earth has a certain amount of carbon that is distributed between various parts of the surface layers of the Earth. There is carbon in the atmosphere and in our bodies. Carbon is an essential element for life. There is carbon in trees, green plants, sedimentary rocks, and soils. Carbon is absorbed in the ocean. There is an enormous amount of carbon distributed over the Earth and the question is how does it move around and how is it dispersed?

A. It may be useful to tell a story about two other planets:

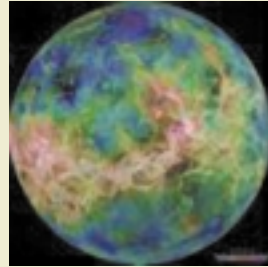
1. Venus actually absorbs less energy from the sun than does the Earth. If you measured the temperature from the outside of Venus, it's actually a little colder than the Earth, even though it is sitting closer to the sun. The roof of Venus is high above the surface and the surface temperatures are searing hot. Venus is receiving less energy from the sun but the surface temperature of Venus is 750°C. How can that be? Well, Venus' atmosphere is made of carbon dioxide, much more carbon dioxide than the atmosphere of the Earth, and the carbon dioxide in Venus' atmosphere plays a role as a greenhouse agent in insulating the surface from outer space. A relatively small amount of visible sunlight gets to the surface of Venus but the energy produced at the surface has a very hard time getting out because of the atmosphere that can absorb the infrared light. So Venus has the mother of all greenhouse effects if you want to talk about it in that way.
2. Mars actually has more CO<sub>2</sub> in its atmosphere than the Earth has, curiously enough. However, Mars is colder at its surface than the Earth, relatively speaking. The problem with Mars is that it is so far from the sun. It's not absorbing that much sunlight and so despite the fact that it has a fair amount of CO<sub>2</sub>, the atmosphere is too cold to hold much water vapor.

So it has a greenhouse effect that is marginally significant, despite the fact that it has a lot of  $\text{CO}_2$  in its atmosphere.

3. So here we have three planets, Venus, Earth, and Mars, moving sequentially away from the sun. For all three,  $\text{CO}_2$  is important, and we have more  $\text{CO}_2$  in the atmosphere of Venus than in the atmosphere of Mars and more in the atmosphere of Mars than in the atmosphere of Earth. Yet all three of these planets, we believe, came from the same solar nebula. They formed in different places, probably at different temperatures and slightly different materials. They were also hit with the same cometary material that fell in and hit these planets especially during the early phases of their life histories. All three of these planets would have received inputs of water, vapor, carbon dioxide, and nitrogen from outside. Carbon, nitrogen, oxygen, and hydrogen are all the building blocks of life.
- B. So how can we account for the differences between the three planets?
1. Well, in the case of Venus, remember that it's very hot and it's closer to the sun. Had Venus started off with an ocean of water vapor or of water, it's likely that water would have evaporated into space. We can make a case for how hydrogen and oxygen would have been lost into space. So our belief is that Venus might have begun with a large amount of water but lost it over the early part of its life history. That has left  $\text{CO}_2$  more abundant than water on Venus.  $\text{CO}_2$  has accumulated in the atmosphere and that's the story with Venus. Venus also has nitrogen to a lesser extent; 7% of the atmosphere of Venus is made up of nitrogen.



**MARS**



**VENUS**



**EARTH**

## ORGANIC MATERIAL

In a very basic sense, organic material is the stuff that plants and living organisms are made of. From the beginning of time, the life and death of early organisms constructed a layer of organic matter atop our planet. As new plants grew and old ones died, the layer of organic matter grew and became what we call soil. Through time, soil developed the ability to acquire and hold moisture, acting like a sponge during times of heavy rainfall. This moisture allows the dead plants to decompose, releasing their vital chemicals into the atmosphere where they begin the cycle of life all over again.

From a chemical standpoint, organic material is typically one carbon atom, two hydrogen atoms, and one oxygen atom ( $\text{CH}_2\text{O}$ ). During the process of photosynthesis, oxygen is released into the atmosphere while carbon dioxide is taken up. When the plant dies and begins to decompose, carbon and water are released into the organic material, which allows other organisms to pick it up and use it to grow.

An interesting note to this is that in areas near the poles, organic material is rare. The Arctic tundra, for example, has very little to no topsoil and therefore does not produce organic material. Any animal who feeds off this will need to move elsewhere.

2. Let's take the Mars story. Mars is cold. It also received water,  $\text{CO}_2$ , and nitrogen as it formed. What was the fate of the water? The water on Mars was more than likely in a frozen form and was captured by the rocks. So Mars, we believe, has abundant amounts of water, but it's frozen. If we could warm up Mars the rivers would flow. In the case of carbon dioxide, carbon dioxide can be absorbed by liquid. So the ocean actually captures the carbon dioxide that would otherwise be in the atmosphere of the Earth. If Mars does not have a liquid ocean, then the  $\text{CO}_2$  is stranded, so Mars has more  $\text{CO}_2$  in its atmosphere than has the Earth. Mars also has nitrogen in its atmosphere.  $\text{CO}_2$  is number one and nitrogen is number two, as far as abundance goes.
3. So let's think about what happens on the Earth. We have these primitive volcanoes that begin to emit these volatile materials ( $\text{CO}_2$ ,  $\text{N}_2$ ) from the interior of the Earth. We have comets that are hitting the Earth and bringing in more volatile materials and they are evaporating and going into the air. The water vapor in these materials is going to condense and create the primitive oceans. So our expectation is that the Earth would have started its history with this fairly large atmosphere of  $\text{CO}_2$ . That large atmosphere of  $\text{CO}_2$  would have provided a very potent greenhouse, so the early Earth would have been warm despite the fact that the sun is only beginning to generate its nuclear energy. As the liquid ocean begins to form, there is now the possibility of taking some of that  $\text{CO}_2$  and moving it into the ocean. The water absorbs part of the  $\text{CO}_2$  and the content of the atmosphere is now limited by the capacity of the ocean to take up  $\text{CO}_2$ .



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## II. The Carbon Cycle

### A. The Volcano Erupts

1. A volcano erupts and vents water, CO<sub>2</sub>, and nitrogen into the air. Suppose we were to follow a carbon atom, color it blue, and watch what happens to it. It would stay in the atmosphere for maybe ten years.

### B. Photosynthesis Begins

1. Photosynthesis is the process by which you take carbon dioxide, water, and light from the sun and you transform the carbon dioxide and water into what we call organic material. It's going to become part of a plant and perhaps part of the cellulose that allows a tree to grow.

### C. Decay and Return to Atmosphere

1. A tree is formed in significant measure by carbon—carbon that was eventually taken out of the atmosphere as CO<sub>2</sub> and converted into organic material. Trees have a finite life: they die. Plants die. Bacteria are feeding on and extracting energy from this decaying organic material and producing CO<sub>2</sub>. So our blue-colored carbon that came out of the volcano may have gone through a cycle from air to plant to soil and bacteria and back out to atmosphere.

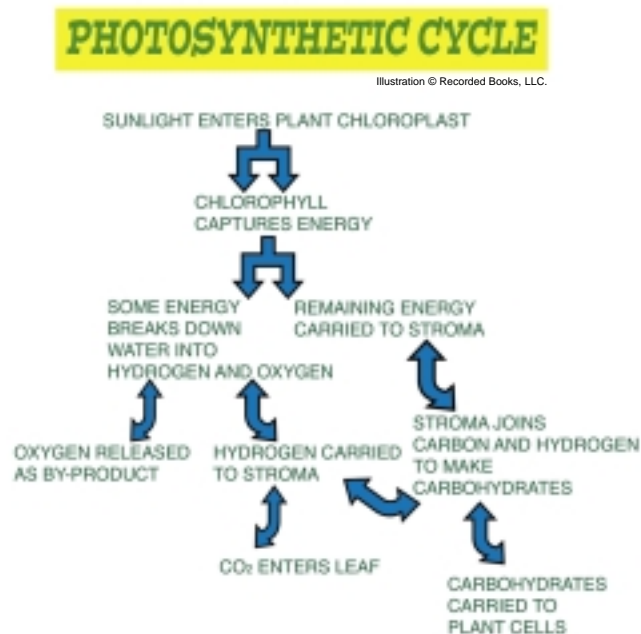




Image Courtesy United States Geological Survey

### TECTONIC PLATES

In 1912, scientist Alfred Wegener was the first to propose the idea that at one time, all of the continents were one and that some geological force drove them apart. At that time, the lack of any evidence to support his theory left many uncertain as to its validity. However, Wegener was determined to learn the truth. He discovered that fossilized remains located on South America and Africa were identical, proving his hypothesis that at one time, these two continents were close enough to share organisms. He believed that as the Earth rotated, the centrifugal force of the planet's orbit pulled the continents apart from the south pole and drew them toward the equator. After Wegener proposed this theory, physicists and mathematicians joined forces to calculate the rotational force of the Earth. They determined that there was an insufficient centrifugal force that would break up and pull the land masses apart.

By the 1960s, however, two other scientists, Harry Hess and R. Dietz, began examining Wegener's theory and developed a theory of their own. Although much more information has been uncovered concerning the Earth's crust and formation of planets, their original ideas are what sparked this magnificent discovery.

The Earth's crust, called the lithosphere, is actually formed by segments laid out in a fluid mosaic atop the Earth's surface. There are nine major tectonic plates and several smaller ones that form the jigsaw puzzle that we live on. Most of the plates exist beneath land as well as water. There are two plates, however, that exist singularly on one or the other. The Pacific Plate is an entirely oceanic plate where the Turkish-Aegean plate is entirely a land plate. The others are some variation of both.

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#### D. Into the Ocean

1. The next trip around, that carbon may find itself in the ocean where it transforms into a bicarbonate ion of one carbon, one hydrogen, three oxygen, and a negative charge ( $\text{HCO}_3^-$ ).
  - a. Organisms living in the ocean are often enveloped by shells. That shell is made of calcium carbonate. So the carbon in the ocean can be used to make the shell of a marine organism. Inside the shell you have the organic material. The typical marine organism is microscopic and has shelly material and organic material that is made photosynthetically from sunlight interacting with carbon and water in the ocean.
2. The ocean has its own life cycle. The photosynthetic organisms are at the bottom of the food chain. The ultimate source of the food in the ocean depends on energy captured by photosynthesis. There are also little organisms called zooplankton that eat the organic matter in these photosynthetic organisms, and the food chain may go on to fish and larger animals. In summary, there is a life cycle in the ocean that is fueled ultimately by food provided by  $\text{CO}_2$  transformed by photosynthesis.
3. Suppose an organism is not consumed by another organism. It dies and falls to the bottom of the ocean. If it falls to the bottom and more material falls on top, it may be withdrawn from the ocean or it may be buried in the bottom of the ocean sediment. If the burial is fast enough in local regions, the bacteria may not be able to keep up with the pace at which the dead bodies are raining down. So there is a net accumulation of organic material at the bottom of the ocean going into sediments. Our hypothetical carbon atom that came out of that volcano on day one has gone through this complicated cycle many, many times, but eventually loses the game and finishes up dead at the bottom of the ocean. How long does it take to wind up dead? About 100,000 years.
  - a. Over those 100,000 years, that carbon atom is going to be many, many different times in the atmosphere, many, many different times in different plants and trees, many different times in the ocean and many different times in living organisms both in the sea and on the land.

#### III. The Next Part of the Carbon Cycle

- A. The bottom of the ocean is not a permanent grave. It's a transient reservoir. It's a place where stuff goes for a little while before the tectonic plate motions of the Earth carry it away somewhere else. The sediments of the ocean are not static. They are continuously moving on giant plates that are driven by motions deep in the Earth. The crustal plates carry the sedimentary load deposited by the dead bodies raining down from above.

#### B. When Two Plates Collide

1. Two Possibilities
  - a. Part of the material may be uplifted. You can make a mountain out of the collision of the two plates, but under different circumstances the material of one plate can be subducted. It can be withdrawn deeper into the Earth. It can sink below the plate with which it is colliding. In this process, you carry the carbon of the dead bodies down into the

Earth, where the temperatures are very hot. At some point it gets hot enough that the dead bodies are turned into  $\text{CO}_2$  and the water begins to turn into steam and the pressure of this water and steam and all the other things absorbed in it, including nitrogen and notably  $\text{CO}_2$ , cause an explosive release—that is what a volcano is. It vents explosively and knocks all the rock above out of the way and you get a release of the volcano into the atmosphere. Now our  $\text{CO}_2$  molecule is back in the atmosphere. In the sediment on the average is where it spends most of its life, maybe 100 or 200 million years. So the 100,000-year trip through the atmosphere, ocean, green plant, and living organisms is interrupted by burial. It stays buried for 100 million years but then it gets another chance. So life begins again, and the volcano starts the cycle. The  $\text{CO}_2$  goes back into the atmosphere and the process begins again.

2. When we think about what we do by burning fossil fuel, it's very important to see it in this natural context. The fossil fuels that we are talking about, coal and oil, represent the dead parts of organisms such as plants and animals that were buried, sequestered, and withdrawn from the air. The means that nature has to get the carbon back into the atmosphere and begin the life cycle one more time, to keep the life cycle functioning and moving, is the one in which the volcano plays the critical role, but the slow return from volcanoes is something we are now accelerating. Nature supplies carbon back to the atmosphere to offset the burial at a rate we exceed 20 times today by burning fossil fuels. If you think about what we do by burning fossil fuel, we drill into the sediments, we find a source of oil, the chemically decomposed body parts of organisms living millions of years ago, and we bring those body parts carefully to the surface. We don't wait for a volcano to process the material. We bring it to the surface, then we light a match. We burn it and turn the stuff into  $\text{CO}_2$ . So we are operating as part of the natural cycle, but we are accelerating that natural cycle. We do the same thing with coal, which represents plant material preserved in a frozen grave rich with organic material. We go down and we drill into the coal mine and we bring the fossilized trees and plants to the surface and we light the match. We don't have to wait for nature to very slowly recycle that material as part of the tectonic motion as part of the slow dynamic changes that regulate the motion of giant crustal plates that are so important to the history of the Earth.
  - a. We are accelerating a natural procedure and returning carbon to the atmosphere 20 times faster today than occurs in nature. Under those circumstances we see an increase in the  $\text{CO}_2$  content of the atmosphere. Eventually the system will find its new equilibrium and  $\text{CO}_2$  will be shared among the atmosphere, the ocean, plants, and soils. Eventually it will make its way into the sediments, but remember the critical point. How long does it take the average carbon atom to get into the sediments? We said in nature maybe 100,000 years. So the disturbance that we initiate by burning fossil fuel is a disturbance that is likely to be present at the surface for a very long time. The atmosphere will store some of that carbon for a period that is measured in

hundreds of years. So even if we stop burning fossil fuel instantaneously, the excess that is present in the atmosphere will only slowly decay. It has to make its way eventually into the sediments before the game is over, before the disturbance has been completely offset.

- b. The famous oceanographer Roger Revell clearly saw the indication of the increase of this  $\text{CO}_2$  in the atmosphere as a disturbance of nature he termed as man's first great global geophysical experiment. We are not just changing the atmosphere, we are actually accelerating one of these giant geochemical cycles that distribute carbon among the range of parts of the Earth that we have talked about in this lecture.

#### IV. Oxygen

Another important element in the atmosphere is oxygen. The atmosphere is composed primarily of nitrogen and oxygen. The nitrogen is the end product of that volcanic activity. Oxygen is produced by photosynthesis. A common misconception, however, is that if you chop down all the trees in the world, you will destroy the oxygen content of the atmosphere and all life will end. That view is wrong. The oxygen molecules in the atmosphere came originally from the photosynthetic joining or marriage of  $\text{CO}_2$  and water. So to every oxygen molecule there is a carbon atom somewhere in the world in organic form, one to one. Oxygen molecules that are in the air are married to carbon atoms in the organic part of the sediments. If you take all the trees in the world, and burned them, the amount of oxygen consumed would lower the oxygen content of the atmosphere by a percent or so. To significantly deplete the oxygen content of the atmosphere you have to bring several hundred million years worth of photosynthetic activity to a halt.

#### ROGER REVELL

Roger Revell (1909-1991) was one of the 20<sup>th</sup> century's most eminent scientists. After receiving a PhD in oceanography from the University of California-Berkeley, he was affiliated with the Scripps Institution of Oceanography and was later a part of the University of California-San Diego.

Revell enhanced the status of oceanography in world science, pioneered in the study of global warming, and brought a fresh approach to issues of population, world poverty, and hunger. One of his major accomplishments was his proposal that the continuing addition of fossil fuel-generated carbon dioxide to the atmosphere, oceans, and biosphere could lead to global warming. In 1957, scientists from around the globe began to join forces in what was called the International Geophysical Year. During a conference of all 67 participating countries, Revell's address still lingers in the minds of scientists everywhere. His famous quote: "Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future."

Following this geophysical year, scientists made incredible strides in uncovering the truth about the harmful effects of the burning of fossil fuels and carbon dioxide released into the atmosphere.

### NITROGEN'S ROLE IN THE ATMOSPHERE

The element nitrogen along with oxygen constitutes almost 99% of the Earth's atmosphere—79% of which is nitrogen.

Nitrogen gas, or  $N_2$ , is the basic building block of the atmosphere and is an extremely stable molecule that can not easily be broken down. It takes a significant amount of energy (lightning in the atmosphere) to break down an  $N_2$  molecule into nitrogen atoms.

All life requires nitrogen in one form or another. It is used as a compound in the formation of proteins and nucleic acids. Proteins and nucleic acids are the structural elements of deoxyribonucleic acid—more commonly known as DNA. Without DNA, life would cease to exist.

Nitrogen is also a critical component in the biotic cycle of plants and animals. Nitrogen is broken down in this cycle normally by microbes (bacteria). One of the significant places you will find this nitrogen-fixing bacteria is in rice paddies. Cyano-bacteria is essential to maintaining the fertility of the soil in these types of aquatic environments.

- A. Life, nature, and the Earth live in this wonderful harmony in which elements are not in competition but are mutually supportive. If we didn't have the opportunity to recycle carbon, we wouldn't have life as we know it today.
- B. Water vapor is the most important greenhouse gas in the atmosphere today. If the atmosphere was primarily composed of  $O_2$  and  $N_2$ , the greenhouse effect would be minimal. Solar energy absorbed at the surface would be reradiated directly to space. The average temperature at the Earth's surface would be below  $0^\circ\text{C}$ . As a consequence, the water vapor content of the air would be extremely low and the water vapor greenhouse effect would be minimal.
  1.  $CO_2$  provides insulation raising the surface temperature to the point where significant quantities of  $H_2O$  can evaporate from the ocean. Water vapor amplifies the greenhouse effect. Eventually, the temperature rises to where energy absorbed from the sun is radiated to space, primarily from the atmosphere. The atmosphere provides the insulated roofing material to maintain the surface temperature at a relatively comfortable, global average, about  $15^\circ\text{C}$ .
  2. The  $CO_2$  content of the atmosphere reflects equilibrium among the atmosphere, land, plants, soils, and the ocean.
  3. A carbon atom present as  $CO_2$  in the atmosphere today can be taken up by green plants through photosynthesis. Plants can be eaten by animals, including humans. When we breathe, we extract energy by converting organic carbon back to  $CO_2$ . Carbon is recycled; it moves from air to plants and soil to animals and back to air in a never-ending cycle. Photosynthesis in the ocean is just as proficient as on land.

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4. The sediments also are recycled. If not, life would run out of essential carbon in a few hundred years. A critical question is how carbon gets from the sediments back to the atmosphere-plant-soil-ocean system.
  5. Continental drift—plate tectonics—provides the answer. Carbon in sediments is sucked into Earth's interior where it is heated to high temperature and vented back to the atmosphere by volcanoes and hot springs.
  6. When we mine fossil fuel, we accelerate this natural component of the carbon cycle.

**Conclusion:**

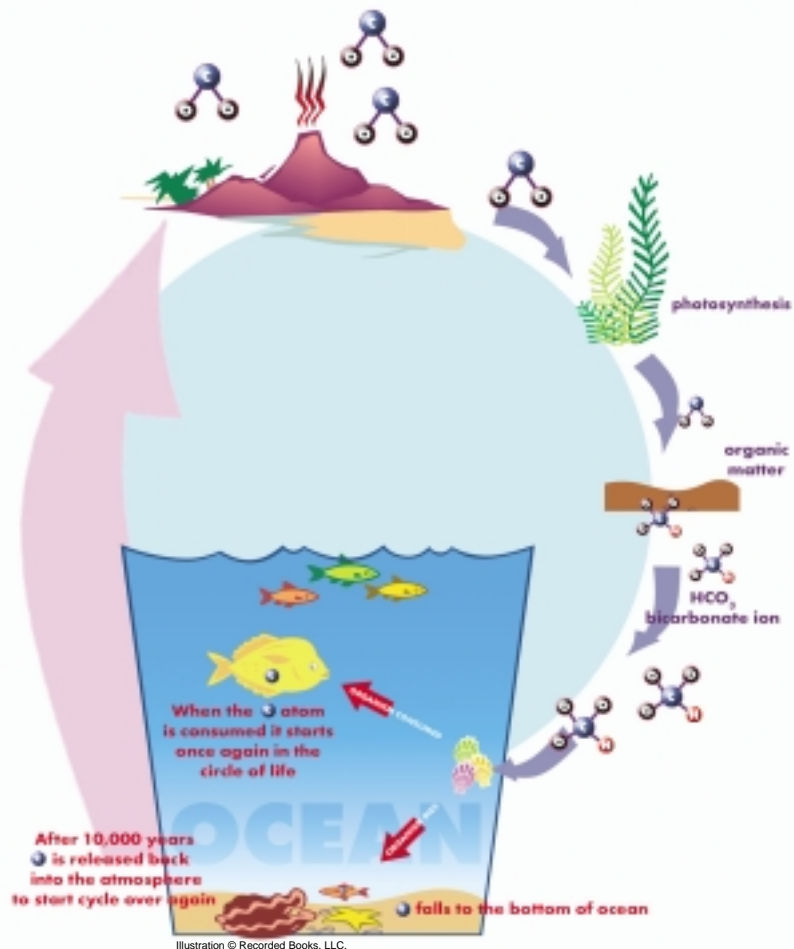
Today, by burning fossil fuel, we have far surpassed the process found in nature. We are responsible for more than 20 times the quantity of CO<sub>2</sub> produced globally by volcanoes and hot springs over the course of an average year.

### **CONTINENTAL DRIFT**

In 1912, German geologist Alfred Wegener proposed the theory of continental drift, stating that parts of the Earth's crust slowly drift atop a liquid core. Wegener theorized that at one time, there was a single huge landmass covering the planet and surrounded on all sides by water. Fossilized evidence has been found that proves that at one time, all of the continents were close enough to share organisms. Similar to the action of the tectonic plates, continental drift involves the movement of the landmasses as we know them today.

Interestingly enough, the continental crust is believed to be about 20 to 80 kilometers thick and has an estimated age of about 3 billion years. The oceanic crust, which lies beneath the ocean, averages 10 kilometers in thickness and is estimated to be hundreds of thousands of years old.

# The Carbon Cycle





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## FOR GREATER UNDERSTANDING



### Consider

1. What is continental drift and how does it affect the climate?
2. How long does it take for a carbon atom to complete its life cycle?
3. How important a role does photosynthesis play in global warming?

### Suggested Reading

Davies, G. F. Dynamic Earth: Plates, Plumes and Mantle Convection. Massachusetts: Cambridge University Press, 1999.

Oreskes, Naomi. Plate Tectonics: An Insider's History of the Modern Theory of the Earth. New York: Westview Press, 2002.

### Other Books of Interest

Dalrymple, Rawdon. Continental Drift: Australia's Search for a Regional Identity. Australia: Ashgate Publishing Company, 2003.

### Websites to Visit

1. <http://www.enchantedlearning.com/subjects/dinosaurs/glossary/Contdrift.html> - Great pictorial presentation of continental drift and tectonic plates.
2. [www.usgs.gov](http://www.usgs.gov) - Home site of the US Geological Survey providing an excellent resource for further information on the structure of our planet.
3. <http://www.ftexploring.com/photosyn/photosynth.html> - Comprehensive site on exploring photosynthesis, the process, and the outcome.
4. <http://www.galvnews.com/report.lasso?wcd=6614> - Interesting article on the discovery of a new form of organic material that was brought to Earth as part of a meteorite.

## Lecture 6: Changing Concentration of CO<sub>2</sub>

### Before beginning this lecture you may want to ...

Read Coleman and Fry's Carbon Isotope Techniques.

### Introduction:

In this lecture we will discuss how CO<sub>2</sub> concentration is changing now and how it has changed in the past.

### Consider this ...

1. Why were scientists concerned about CO<sub>2</sub> concentration?
2. What methods were used to determine the age of the planet?
3. What were the scientific limitations of the time?

### I. Scientists began to measure the atmosphere by direct sampling of air in 1958.

These measurements were pioneered by Charles David Keeling. His focus was primarily on changes in the global concentration of CO<sub>2</sub>. Keeling decided that the best place to monitor what was going on in the northern hemisphere was the middle of the Pacific Ocean and selected Hawaii specifically. In Hawaii, he opted to gather his data from the top of a volcanic peak. He set up an instrument that would record CO<sub>2</sub> almost continuously at that particular location.

### II. In 1958, a group of scientists also got together to launch the International Geophysical Year.

This marked the first time a global political commitment was made to pool resources to better understand the Earth as a whole. It was also an opportunity, during the middle of the Cold War, for Soviet scientists, American scientists, and European scientists to combine forces to address a variety of Earth issues.

- A. One of the decisions made by this group of scientists was to place instrumentation in Antarctica. As the last unpopulated place in the world, Antarctica was a target of opportunity to set up stations that would provide a record of geophysical parameters. The United States took on the responsibility to build a permanent station at the South Pole. This is the most inhospitable place in the world. The Soviet Union, France, United Kingdom, Poland, and other countries also set up stations in Antarctica. Keeling asked the scientists to set up his instrumentation at the South Pole to monitor CO<sub>2</sub> concentration. So as of 1958, CO<sub>2</sub> concentration has been continuously monitored at two stations, one in the northern hemisphere and one in the southern hemisphere (except for a brief temporal lapse at the South Pole).

B. From the site in Hawaii, you can observe a steady climb in the concentration of CO<sub>2</sub> in the atmosphere, starting off at about 315 parts per million in 1958 to 370 ppm in 2002.

Superimposed on this steady climb you see an up-and-down behavior.

The curve goes up in fall and winter and down in spring and summer. This annual cycle reflects the growth of vegetation in the northern hemisphere during spring and summer, which draws carbon dioxide out of the air. The southern hemisphere shows a small cyclic trend but since there is no vegetation at the South Pole, the changes aren't as dramatic as we see in the northern hemisphere.

C. Determining the concentration of CO<sub>2</sub> before the 1958 recordings takes advantage of the fact that when it snows in regions where the snow is accumulating, air is isolated in the growing snow cover. And with further accumulation air is isolated in little bubbles in the ice under the accumulating snow. If you go to the central part of Antarctica there you have the opportunity to see very far back in time. The accumulation rate from year to year is only a few centimeters or less but you have many, many years worth of accumulation. This accumulation allows you to go back 450,000 years before present. From this 450,000-year-old record scientists were able to discover that CO<sub>2</sub> concentrations in the atmosphere over this period have for the most part been limited on the high side to about 280 ppm and limited on the low side to about 200 ppm.

D. Over the last 450,000 years, the Earth has wandered in and out of ice ages. These ice ages occur when water comes out of the ocean and lowers sea level by about 120 m, with the extra water stored in these large blocks of ice covering portions of the

### CHARLES DAVID KEELING

Charles David Keeling (1928-) is a professor of oceanography at Scripps Institute of Oceanography at the University of California-San Diego. He received the National Medal of Science in 2002 and is a world leader in research on the carbon cycle and the increase of carbon dioxide (CO<sub>2</sub>) in the atmosphere. Keeling was the first person to precisely measure CO<sub>2</sub> in the atmosphere on a continuous basis at two stations located in Hawaii and Antarctica.

While monitoring the concentrations, he discovered that annual fluctuations existed with the seasons. He attributed this to the increase in vegetation in the northern hemisphere.

Keeling was the first to recognize and substantiate the claim that global atmospheric concentrations of CO<sub>2</sub> were rising. In verifying his measurements taken at both collection stations, he was able to produce the data set now known as the Keeling curve.

### SURVIVING ANTARCTICA

A group of Russian scientists was the first to attempt to recover ancient ice from the central heart of Antarctica. Recovery of air from this ice has allowed scientists to determine past levels of CO<sub>2</sub>. While the Russians were drilling the ice, an equipment failure forced them to make a decision that could ultimately have cost them their lives.

Drilling in Antarctica is a long-term project. You can drill during the summer with heavy protection gear. Come winter, the harsh climate precludes drilling further. When drilling, the hole must be filled with fluid to prevent closure over the winter or all progress on the ice hole will be lost. A generator runs constantly to keep the liquid and the core warm enough so that you can resume drilling the following year.

One year that generator failed and the group of Soviet scientists who were wintering over had two choices: use the generator they were using to keep alive or give up the drilling site and begin again the following year. The next year, the team was able to complete the project and it became a wonderful record of the past.

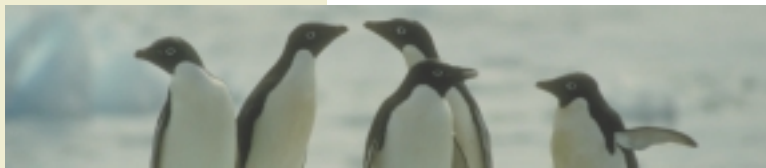
continents primarily in the northern hemisphere. These cold periods are associated with the lower limit range of CO<sub>2</sub>. The 280 ppm time periods are seen during warm parts of the cycle.

#### E. CO<sub>2</sub> concentration in the deep distant past:

1. One way to help scientists determine this is to find isotopic carbon deep in ocean sediments. If we look at ancient shells from the ancient ocean, we can determine the age based on the oxygen composition of the shell. Initial attempts to determine the CO<sub>2</sub> concentration suggest that the concentration was about 1,000 ppm and since that time the concentration level has obviously declined. Recent discoveries have been made that suggest that in the deep distant past, the Earth actually underwent a global ice age. This happened when the change in the plate tectonics of the Earth reflected in the decrease of input of CO<sub>2</sub> below the point where the greenhouse was effective.

### III. Recovering from an Ice Age

- A. If the planet is iced over, all sunlight is reflected. However, volcanoes continue to move. Even though you've isolated the ocean from the atmosphere by covering it with ice, CO<sub>2</sub> is put into the atmosphere from volcanoes erupting above and below sea level. This allows the buildup of the greenhouse effect in the atmosphere, which melts the surface ice and brings the CO<sub>2</sub>-rich atmosphere in contact with the sea. These periods sparked rapid evolution of life-forms on the Earth. A large number of species couldn't make it and the survivors began to populate the niches that were vacated by the losers in this grand competition for space.



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## FOR GREATER UNDERSTANDING



### Consider

1. How did scientists eventually discover historical levels of CO<sub>2</sub>?
2. What is an ice age and how does the planet recover?
3. Why are CO<sub>2</sub> concentrations different at each pole?

### Suggested Reading

Bocknek, Jonathan. Antarctica, the Last Wilderness: Understanding Global Issues. New York: Smart Apple Media, 2003.

Coleman, D and B. Fry. Carbon Isotope Techniques. New York: Academic Press, 1991.

### Other Books of Interest

Long, John A. Mountains of Madness: A Scientist's Odyssey in Antarctica. New York: Joseph Henry Press, 2001.

### Websites to Visit

1. [www.globaltechnoscan.com/27thDec-2ndJan/carbon.htm](http://www.globaltechnoscan.com/27thDec-2ndJan/carbon.htm) - Comprehensive look at carbon cycling and what it means for life.
2. [www.mrsars.usda.gov/morris/crisproj/carbon.htm](http://www.mrsars.usda.gov/morris/crisproj/carbon.htm) - US Department of Agriculture-sponsored research programs on carbon cycling.
3. [www-bprc.mps.ohio-state.edu](http://www-bprc.mps.ohio-state.edu) - Website for the Byrd Polar Research Center specific to scientific study on the continent of Antarctica.
4. [www.asoc.org](http://www.asoc.org) - Website sponsored by the Antarctic and Southern Ocean Coalition to promote education about this last untamed wilderness on the planet. Includes excellent historical accounts of early exploration.

## Lecture 7: Current CO<sub>2</sub> Trends

### Before beginning this lecture you may want to ...

Read Michael Williams' Deforesting the Earth: From Prehistory to Global Crisis.

### Introduction:

In this lecture we investigate the current trend in CO<sub>2</sub> production by humankind.

### Consider this ...

1. What is causing the current trends in CO<sub>2</sub> production?
2. What effect is the burning of fossil fuels having on CO<sub>2</sub> levels?

**I. In 1700 AD the concentration of CO<sub>2</sub> in the atmosphere was about 280 ppm. Over the last 300 years there has been a significant change in the concentration of CO<sub>2</sub> in the atmosphere.**

#### A. Contributing Factors:

1. Use of fossil fuel, burning of coal, oil, and natural gas, is largely responsible for the current increase in CO<sub>2</sub>. Of these fossil fuels, coal is the worst in terms of quantities of CO<sub>2</sub> produced per unit of energy delivered, followed by oil and then gas. Coal is black carbon and by burning it, you convert that carbon to CO<sub>2</sub>.
2. We also have to consider the trends of burning oil. Oil is also a source of CO<sub>2</sub>. The chemical composition of oil is a little less carbon and a little more hydrogen than coal. So when you burn oil, the hydrogen is converted to water and the carbon is converted to CO<sub>2</sub>. You get a little more energy production per unit of CO<sub>2</sub> by burning oil than you do with burning coal.
3. Natural gas (methane) is CH<sub>4</sub>, meaning for every carbon atom there are four hydrogen atoms attached to it. You get energy by turning the hydrogen atoms into water and the carbon atoms into CO<sub>2</sub>. This produces more energy per unit of CO<sub>2</sub> than either oil or coal.
4. Deforestation, mainly in the tropics, represents a second important source of CO<sub>2</sub>. Burning timber is no different from burning coal in terms of CO<sub>2</sub> production, especially if the timber is not allowed to regrow. Current evidence suggests that conversion of land from forest to grass in the tropics is responsible for a source of CO<sub>2</sub> equivalent to about one third of that from fossil fuel. That makes countries such as Brazil and Indonesia as culpable as the United States and China for the current increase in CO<sub>2</sub>.

5. The Midwest of the United States is a strong agriculturally productive area. The area was unfarmed in the 1700s with the farming coming later stimulated by the opening up of the west in part as a consequence of construction of the railroads. The soil in the Midwest is very thick, rich with organic material and when it's plowed and planted, the surface layer of the soil is turned over and it stimulates the bacteria to decompose that organic matter. By oxygenating the soil, you are liberating nutrients, primarily releasing the nitrogen that is accumulating there. In doing this, some of the microbes that are now working on decomposing this organic matter release CO<sub>2</sub> into the atmosphere.

**II. By the late 19th century, however, it was apparent that the increase in CO<sub>2</sub> in the atmosphere was largely due to the burning of fossil fuels.**

The amount of CO<sub>2</sub> added to the atmosphere in the late 19th century is more than enough to account for the increase of CO<sub>2</sub> in the atmosphere. You can measure the concentration in the atmosphere and calculate how much the atmosphere is storing.

A. Some of the excess CO<sub>2</sub> in the atmosphere makes its way into the ocean and we have to be able to make an estimate of how much is going to be absorbed by the ocean. We need to understand this in order to predict the amount of CO<sub>2</sub> that will be retained in the atmosphere in the future. The critical issue therefore is determining how much CO<sub>2</sub> can be absorbed by the ocean.

1. The way the ocean works in contact with the atmosphere is that, as the wind blows across the surface of the ocean, gases in the atmosphere enter the water and set up an equilibrium where they are entering and leaving at about the same rate.

### **COAL, OIL, AND NATURAL GAS: COMPARATIVE**

The burning of fossil fuels, coal, oil, and natural gas, is the largest contributing factor to the global warming problem. All produce carbon dioxide as a by-product of burning, yet coal is the worst by comparison.

In 1999 alone, the United States consumed 852.4 million tons of oil, 551.2 million tons of natural gas, and 533.7 million tons of coal. When coal is burned, it produces 2.86 short tons of carbon dioxide for every short ton of coal burned. Based on this analysis, more than 1.5 billion tons of carbon dioxide were released in the atmosphere in 1999. That number has steadily increased over the years.

The United States is not alone. In 1999, the carbon dioxide emissions for the UK reached 1.4 million tons for coal, 1 million tons for oil, and 60 thousand tons for natural gas.

As we move into the 21<sup>st</sup> century, researchers, scientists, and inventors are joining together to try to solve the CO<sub>2</sub> emission problem. Under consideration currently are carbon sequestration, carbon capture and separation and storage. At the present time, carbon sequestration is cost prohibitive for most companies, approximately \$300 per ton of emissions avoided. By 2015, however, the goal of the developers is to have the cost at \$10 or less per ton.

2. Release of CO<sub>2</sub> due to deforestation in the tropics is offset by regrowth of forests, specifically at mid-latitudes of the northern hemisphere. The eastern portion of North America was largely deforested in the 18th and 19th centuries as land was converted to agriculture. The process has been reversed more recently as eastern US farmland was abandoned and as forests were allowed to recover.
3. At the present time, global use of fossil fuel accounts for a source of CO<sub>2</sub> in excess of 20 billion tons per year, more than 6 billion tons of carbon. To put this in context, it represents a source of more than 3 tons of CO<sub>2</sub> per year for every man, woman, and child alive on the planet. The United States, with about 5% of the world's population, is responsible for about 22% of global emissions. Again, in context, this means that, on average, Americans dump about 15 tons of CO<sub>2</sub> in the atmosphere per year per person. That makes CO<sub>2</sub> the largest waste product we produce as an industrial society.
  - a. But we are largely unaware of it. CO<sub>2</sub> is nontoxic and invisible. But when you drive around and empty your gas tank, the gas doesn't simply disappear. It largely turns into CO<sub>2</sub>. Likewise for the gas that you use to cook or to heat your house, and for the coal consumed in a power plant to produce electricity.

#### Conclusion:

Fossil fuels are likely to supply the bulk of the world's demand for energy for the foreseeable future. The demand in the larger developing countries such as China is particularly impressive. China has abundant sources of coal, which accounts for close to 80% of China's current primary energy use. The Chinese economy has been growing and is projected to continue to grow. The demand for coal has increased accordingly. China is now the second largest emitter of CO<sub>2</sub>, after the United States, and, given current trends, is likely to move to number one at some point over the next few decades. Taking account of current trends and future demand for fossil fuel, most experts believe that emissions of CO<sub>2</sub> will continue to grow, driven to a larger extent than in the past by demand from developing countries. The concentration of CO<sub>2</sub> is expected to exceed 700 ppm by the end of this century in the absence of aggressive policy measurements to limit growth. This implies that CO<sub>2</sub> levels will be larger in this century than at any time over the past 50 to 100 million years of Earth history—a sobering thought.

#### DID YOU KNOW?

Diamonds are the purest form of the element carbon? Carbon crystallizes under tremendous heat and pressure, which occurs deep underground. Concentrations of diamonds large enough to mine are found in the Earth's oldest continental regions. Diamond is the hardest natural substance known, due primarily to its unique elemental bonding structure. Since all the carbon atoms are bonded together, they don't break easily.



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## FOR GREATER UNDERSTANDING



### Consider

1. What is the greatest stumbling block for reducing CO<sub>2</sub> emissions?
2. What role are developing countries playing in the increase of CO<sub>2</sub>?
3. What effect is deforestation having on CO<sub>2</sub> concentration?

### Suggested Reading

Barracrough, S. and K. Ghimire. Agricultural Expansion and Tropical Deforestation: Poverty, International Trade and Land Use. London: Earthscan Publications, 2000.

Williams, Michael. Deforesting the Earth: From Prehistory to Global Crisis. Illinois: University of Chicago Press, 2002.

### Other Books of Interest

Office of Technology Assessment. The Direct Use of Coal: Prospects and Problems of Production and Combustion. Toronto: Books for Business, 2002.

### Websites to Visit

1. [www.energy.gov/sources](http://www.energy.gov/sources) - Excellent website providing an in-depth look at fossil fuel production and usage worldwide.
2. [www.fe.doe.gov/coal\\_power/sequestration/index/shtml](http://www.fe.doe.gov/coal_power/sequestration/index/shtml) - Incomparable resource for learning of the great strides the government is making in eliminating CO<sub>2</sub> emissions.
3. [www.millenniumenergyinc.com](http://www.millenniumenergyinc.com) - Home page for Millennium Energy, Inc., providing a thorough look at eliminating CO<sub>2</sub> emissions.
4. [www.wri.org/gfw](http://www.wri.org/gfw) - Home page for the World Resources Institute providing insight into deforestation and its effects.

## Lecture 8: Methane, Nitrous Oxide, and Other Greenhouse Gases

### Before beginning this lecture you may want to ...

Read The National Academy of Sciences' Methane Generation from Human, Animal and Agricultural Wastes Crisis.

### Introduction:

In this lecture we take a look at the other contributors to greenhouse gases: nitrous oxide and methane.

### Consider this ...

1. What role has agriculture played in greenhouse gases?
2. What are the drawbacks to using natural gas for alternative energy?
3. How has nitrous oxide influenced global warming?

I. **CO<sub>2</sub> is the second most important greenhouse gas after H<sub>2</sub>O.** Other important greenhouse gases include CH<sub>4</sub> (methane), N<sub>2</sub>O (nitrous oxide), the chlorofluorocarbons responsible for the hole in ozone over Antarctica, and O<sub>3</sub> (ozone) itself.

#### A. Methane:

1. Methane is the second most abundant carbon compound in the atmosphere. Carbon dioxide is the most abundant carbon compound in the atmosphere.
  - a. Current measurements place about 2 ppm of methane in the atmosphere, significantly less than CO<sub>2</sub>. However, since it is 10 times more efficient on a molecule per molecule basis in trapping heat, it is of concern. In light of this we can assume that one molecule of CH<sub>4</sub> is doing 10 times the damage of one molecule of CO<sub>2</sub>.
2. During the ice ages, the atmospheric concentration of CH<sub>4</sub> was about 300 parts per billion. During interglacial warm periods, CH<sub>4</sub> concentration rose to about 600 ppb. Over the last 300 years, we observe a rapid rise of CH<sub>4</sub> concentration that parallels the rise of CO<sub>2</sub> except in many respects it's been faster. Today we have 1,800 ppb concentration of CH<sub>4</sub> in the atmosphere. So the proportional rise in methane has been larger than the proportional rise in carbon dioxide.
3. Bacterially mediated decay of organic matter provides the dominant source of atmospheric methane. The bacteria responsible for methane production are most effective in environments where oxygen is in scarce supply. One example is a swamp with stagnant water where plants and trees grow. These bacteria are called anaerobes—they are anaerobic, which means without oxygen. Bacteria that function in an aerobic environment, one rich with oxygen, take up the organic material, join the carbon from the organic material with oxygen, and then release CO<sub>2</sub> as a

by-product of this function. When there is no oxygen available, aerobic bacteria are not able to function. When this occurs, the anaerobic bacteria take over and process the organic material. Rather than release  $\text{CO}_2$  as a by-product, since there is a lack of oxygen, the bacteria release methane,  $\text{CH}_4$ . When released, this methane contributes to the atmospheric burden.

4. Methane is best known as “natural gas” that is also a fossil fuel. We know this is a fossil fuel because if we measure for the amount of Carbon-14 in natural gas we discover that there is no Carbon-14 present, which signifies that this product is very, very old. Methane was most likely formed by anaerobic bacteria in the deposits of organic material in the distant past. When oxygen ran out, the anaerobes created methane. If you have a convenient geological reservoir beneath the surface of the Earth where gas can be stored without escape then it accumulates over time.
  - a. Most deposits of natural gas are found with oil. Often there is no efficient way to collect both the oil and the natural gas, and deposits of natural gas are burned in favor of the collection of oil, which means that natural gas is burnt uselessly and converted into  $\text{CO}_2$ .
  - b. Burning vegetation at a smoldering rate, where very little oxygen is being consumed, also produces methane and carbon monoxide. This occurs during deforestation, clearing of lands for agriculture or in some areas where crops are burned to make the land ready for the next year's crops. If this is done in a “smoldering” way then methane is produced.

### RADIATIVE FORCING

This is a measurement based on a model. In order to determine the radiative forcing of  $\text{CO}_2$ , you take the lower atmosphere as it is today and you double the amount of  $\text{CO}_2$  that is present. Then one calculates the amount of radiation that gets out to space. If you have more  $\text{CO}_2$ , less radiation gets out to space. The difference is what is forcing the climate change. You have decreased the cooling and increased the heating ability of the planet. This calculation is used to determine what the effect of a greenhouse gas might be. Methane is about 10 times more important than is  $\text{CO}_2$ . Nitrous oxide is about 100 times more important than  $\text{CO}_2$  on a molecule per molecule basis. Sulfur hexafluoride ( $\text{SF}_6$ ), which is used as an industrial electrical insulating agent, is a very small part of the Earth's atmosphere but its concentration is increasing at a significant rate.  $\text{SF}_6$  is good at absorbing infrared radiation and therefore contributes disproportionately to the changing of the climate.  $\text{SF}_6$  remains in the atmosphere for a very long time. The efficiency of these gases to change the environment is assessed based on how long a molecule remains in the atmosphere once it gets in. One molecule of nitrous oxide remains in the atmosphere for about 120 years since it isn't absorbed by vegetation or the ocean. Molecules such as these have a long-term significant impact on the climate.

## RUMINANT FLATULENCE

Scientists (and most other students) are aware of the fact that cows, sheep, deer, and other livestock have double stomachs. They chew grass, swallow, regurgitate, and swallow again. During this process, which is called enteric fermentation, the animal is converting the food it eats into something useful for its body. Unfortunately, one of the by-products of this bodily function is methane gas.

In the early 1990s scientists who were involved in researching the increase of methane in the atmosphere began looking at the worldwide cattle industry. They discovered that over 80 million tons of methane are produced per year by ruminants. That equals greater than 20% of the entire methane production globally. This was a cause for great concern.

During the Kyoto Protocol (see Lecture 13) some scientists suggested significantly reducing the amount of methane being released in the atmosphere would allow for less stringent restrictions on carbon dioxide production. Some of the suggestions made to reduce the methane concentration (which disappears from the atmosphere 10 times faster than  $\text{CO}_2$ ) involved genetically engineered cattle to alter the bacteria in their stomachs, improved grazing systems, alternate feeds to reduce methane production, and even vaccines to alter the microorganisms.

c. Animals with a second stomach, ruminants, are also important sources of  $\text{CH}_4$ . Ruminants include cattle and sheep. Ruminants are able to eat a low quality diet—grass for example. Bacteria in the rumen convert this food to higher quality products that can be assimilated by the animals. In the process,  $\text{CH}_4$  is produced and released to the atmosphere.

## II. Why is methane increasing?

A. Domestic animals, or more specifically ruminants, produce a lot of methane. These animals eat low quality food like grass, which is very high in carbon and can not be easily converted to protein to be useful to the animal. So they have a double stomach, rumen, which allows the animal to process this food and “upgrade” it through the use of anaerobic bacteria. Part of the anaerobic mechanism in these ruminants converts carbon to methane.

1. This is important because about 10% of what a cow ingests is converted to methane.
2. The United States has a population of over 110 million cows at any given time that are used in both dairy and meat production. All of these cattle are efficient at producing methane.
3. The cattle population worldwide exceeds 1.2 billion.
4. This class of animal also includes sheep, goats, and others.

B. Another contributing factor is the cultivation of rice, which is the staple grain for many parts of the world. Much of the rice produced is done in “controlled swamps.” A rice paddy field is a wonderful environment for the production of methane because the sediment is rich with either organic material or fertilizer. Since rice grows in water-logged soil, you create the perfect environment for methane-producing bacteria.

1. Swamps provide an important natural environment for these bacteria. Rice paddy fields represent a human controlled swamp, in many respects an ideal environment for  $\text{CH}_4$  production. A significant portion of the increase in  $\text{CH}_4$  is attributed to rice cultivation.
2. Once all of these things are considered, rice cultivation, the proliferation of cattle, and other domesticated ruminants, it is easy to see how the concentration of methane in the atmosphere has increased.
3. It has been observed, however, that over the last 10 years, the increase in methane has been slowing down. It remains unknown if that signifies the end of the rise. The number of cattle has stabilized where it had been increasing previously parallel to the growth of the population. Rice cultivation is also leveling off presumably because as much land is allocated for rice cultivation as is possible.

#### C. Other Sources of Methane

1. The other source of methane that we need to be aware of is the by-product of methane from the production of fossil fuels. We saw a rise in the methane concentration in the 1990s with the rise of the new Soviet Union. The decrease in the economy of the new Russia led to enormous inefficiency in infrastructure.
2. The primary rises in methane are related to agriculture and food production. The demand of the people to eat rather than the demand of the people for energy is the most important difference.

### III. Nitrous Oxide

- A. Nitrous oxide, known more commonly as laughing gas, is also produced by bacteria. Two classes of bacteria are effective in this context. One operates largely in media where oxygen is mod-

### THE FALL OF THE SOVIET UNION

On November 9, 1989, millions of people around the globe watched as the Berlin Wall collapsed—ending the decades-long struggle of the Eastern Bloc countries of Europe. Most of them were economically, scientifically, and financially destitute and the resulting struggle to rebuild a nation out of those ruins caused an identifiable and extreme effect on global warming.

Much of the former Soviet Union was in disarray. The infrastructure of the country was in shambles. Along the Trans-Siberian railroad lay one of the Soviet Union's most important economic entities—natural gas pipelines that had been built along the rail track to transport gas from Siberia into civilized Russia. This stretch of pipeline was poorly maintained, however, and gas allowed to leak out into the environment. Therefore, natural gas flowed freely out of the pipeline unchecked, often causing massive explosions. All of this had a major impact on the increase of methane in the atmosphere seen in the early 1990s.



erately available. It plays an important role converting reduced forms of nitrogen, ammonia for example, to more oxidized forms such as nitrite and nitrate. Nitrous oxide is produced in this manner as a by-product of what we refer to as nitrification. Nitrous oxide is also produced by bacteria under low oxygen conditions, as a by-product in this case of reduction of nitrate, a process known as denitrification.

- B. Nitrous oxide is about 100 times more efficient molecule per molecule than  $\text{CO}_2$ . The concentration of nitrous oxide is also increasing at about the same rate as  $\text{CO}_2$ . The current concentration is about 310 ppb. Scientists no longer believe that this is a by-product of burning coal. Now scientists believe that the major source of nitrous oxide is bacterial and what is observed is a human forcing of the nitrogen cycle that is provoking an increase in nitrous oxide production by bacteria that are basically processing nitrogen both as human waste and animal waste. Importantly, as we create our own food today, we are creating our own nitrogen fertilizer. We are chemically producing nitrogen fertilizer and spreading it on fields. In order to do this, we take molecular nitrogen out of the air that is useless from a biological point of view and convert it to ammonium nitrate or sulfate that can be delivered to the fields in the form of fertilizer. We are adding chemical fertilizer to soil, stimulating the bacteria, and in return stimulating the production of nitrous oxide.

**Conclusion:**

The increase in nitrous oxide can be attributed to food production, waste production, and to the six billion people (and that number continues to rise) who populate our planet. Thus, if the increase in  $\text{CO}_2$  is largely due to energy-related activity—consumption of coal, oil, and natural gas—the increase in  $\text{CH}_4$  and  $\text{N}_2\text{O}$  must be attributed primarily to processes relating to agriculture and waste disposal. Ultimately, the increase in  $\text{CH}_4$  and  $\text{N}_2\text{O}$  reflects growth in human population and affluence favoring a diet of animal and animal products in contrast to plants (grains for example). Worldwide, we feed about twice as much grain to domesticated animals as we ingest directly ourselves.

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## FOR GREATER UNDERSTANDING



### Consider

1. How has the cattle industry affected the global warming issue?
2. Why was the end of the cold war a serious contributor to the increase in CH<sub>4</sub> concentrations?
3. What role do bacteria play in methane production?

### Suggested Reading

Clark, M. and A. Brunick. Handbook of Nitrous Oxide and Oxygen Sedation. New York: Mosby Press, 1999.

National Academy of Sciences. Methane Generation from Human, Animal and Agricultural Wastes. Toronto: Books for Business, 2001.

### Other Books of Interest

Ljungdahl, Lars G. Biochemistry and Physiology of Anaerobic Bacteria. England: Springer Verlag, 2003.

### Websites to Visit

1. [www.epa.gov/methane](http://www.epa.gov/methane) - Official website of the Environmental Protection Agency discussing methane emission control.
2. [www.csmonitor.com/2002/0103/p3s1-usgn.html](http://www.csmonitor.com/2002/0103/p3s1-usgn.html) - Excellent article that appeared in the Christian Science Monitor about the capture of natural gas.
3. [www.ciesin.org/TG/AG/liverear.html](http://www.ciesin.org/TG/AG/liverear.html) - Site provides an in-depth look at livestock and the methane issue.
4. [www.findarticles.com/cf\\_dls/m3066/n6\\_v160/20411079/p1/article.jhtml](http://www.findarticles.com/cf_dls/m3066/n6_v160/20411079/p1/article.jhtml) - Gripping article on nitrous oxide emission and the control of these emissions.

## Lecture 9: Total Climate System

### Before beginning this lecture you may want to ...

Read Dennis L. Hartmann's Global Physical Climatology.

### Introduction:

In this lecture we will concentrate on the role of the atmosphere.

### Consider this ...

1. What does energy balance mean?
2. What are trade winds and how do they affect the global climate?
3. What is the jet stream?

### I. Energy Balance of the Earth

A. In the tropics, significantly more energy is absorbed from the sun than is radiated back out to space in the infrared. "Tropics" indicates latitudes of  $\pm 25^\circ$ . Here is a region where the Earth is gaining energy in excess of what it is returning to space. In the extra-tropics, latitudes greater than  $25^\circ$ , there is an energy deficit. Less is being absorbed than is sent back into space. Taken as a whole, the Earth maintains an approximate energy balance: energy absorbed from the sun on a global basis is balanced more or less by energy radiated to space.

1. There are two ways to move energy:
  - a. Circulation of air; energy from the low latitudes is transported to the high latitudes.
  - b. The ocean; currents take energy from low latitudes to high latitudes.
2. The climate of the Earth is basically determined by the energy imbalance between low latitudes and high latitudes, and the response of air and water to that imbalance. A portion of the energy excess in the tropics is transported to higher latitudes to offset the energy deficit in the extra-tropics. An approximately equal amount is transferred by the ocean.

### II. Circulation of Air

A. Warm air rises in the tropics, drawing moisture from the warm oceans. There are three regions of tropics in which the air rises in particular. One is in Indonesia, in the Western Tropical Pacific. The second is over the Amazon Basin in South America and the third is in Africa. In other parts of the tropics the air isn't rising, it's actually sinking. These are called strong centers of convective activity. Air moves from the equatorial area to higher latitudes at an altitude of 10 km or so above the surface. This is how the warm dry air is moved from one area to another. Tropical air is unable, however, to make it past latitudes of about  $30^\circ$ . Once it gets to this region,



it now begins to sink back to the surface. The rotation of the Earth prevents it from rising above 30° latitude and causes it to turn to the east. Eventually it runs out of momentum toward the poles and sinks back to the surface. It returns to the tropics at the surface, setting up a circulation loop known as the Hadley circulation, named in honor of the English meteorologist, George Hadley, who first described this process more than 250 years ago.

1. As it begins its journey at the surface in the tropics, the air contains a relatively large content of water vapor. Water vapor is removed by rain as the air rises. As the air moves to higher latitudes, its moisture content is severely depleted. The sinking portion of the Hadley circulation is responsible for the band of deserts that ring the Earth in the subtropics—the Sahara, for example. It rains where air rises. It is dry and hot where it sinks. When we think about possible climate change, we need to think about the implications for the latitudinal extent of the Hadley circulation. An expansion of deserts to higher latitudes would have important implications for those who live on the margins. For that matter, a retreat would also be significant.

### III. Trade Winds

- A. Trade winds are surface winds that blow from the southeast in the southern hemisphere and from the northeast in the northern hemisphere at a generally reliable clip. This is the return flow of the Hadley circulation.
- B. This is how air is exchanged between equatorial regions and mid-latitudes.

### IV. Air Circulation at Higher Latitudes

- A. We must think of this in terms of summer and winter. In summer, the Earth is getting a lot of energy from the sun at the higher latitudes, because of the tilt

## GEORGE HADLEY

George Hadley (1685-1768) was an English physicist and meteorologist. He directed meteorological observations for the Royal Society and formulated the first theory describing the trade winds and circulation pattern now known as the Hadley cell. In 1735, Hadley published his theory in a famous paper “Concerning the Cause of the General Trade Winds.” Hadley realized that wind particles moving toward the equator would come from a region of lower eastward velocity and enter a region of higher eastward velocity as they move toward the equator. Thus, the wind would have a westward motion.

Almost 100 years after publishing his famous paper, Gustave-Gaspard Coriolis produced the equations that proved Hadley’s theory of the trade winds rotational system.

Interestingly, it was Christopher Columbus who recognized the utility of the trade winds on his infamous voyage across the Atlantic. He observed that trade winds could power transcontinental shipping, especially when heading from west to east across the Atlantic.

### THE JET STREAM

Anyone who's ever heard a weather report has heard the term "the jet stream." The local weather person always has interesting graphics to demonstrate the flow of air across the continent. It's easiest to consider the jet stream to be a river of fast-moving air, high above the surface of the Earth. It moves from west to east and generally at speeds greater than 60 mph and divides colder air in the north from warmer air in the south.

Movements in the flow of air are the largest contributing factors to the ambient temperature felt when you walk out the door. If the jet stream dips south, it's pulling very cold air from the polar regions down and the result is frigid temperatures in the area above the jet stream. When the jet stream flows across the northern part of the continent, the area below enjoys balmy temperatures.

Severe weather is triggered by changes in the jet stream. Jet streaks are pockets of wind moving at a faster rate than the jet stream as a whole. As these jet streaks travel, they are modifying the air pressure along the jet stream. As it pulls the air higher, it creates a low pressure situation on the surface of the Earth, which is favorable for precipitation and storms. In high-pressure areas, the warmth prohibits the formation of clouds, leaving only sunny days in its wake.

of the axis of the Earth. In the polar circle, for example, the sun is shining 24 hours a day. In winter, however, you have the exact opposite. In these areas, the summer climate is virtually working on its own. In the winter, you don't have a lot of energy input from the sun, allowing the surface to get really cold. In polar regions it does get cold, but not as cold as it could be, because of the energy supply coming from the atmosphere and the ocean at lower latitudes.

- B. There is a relatively sharp transition between warm tropical air and cold high latitude air, especially in winter. This boundary is marked by a stream of high-speed air travelling in a generally west-to-east direction around the Earth. This system is referred to by meteorologists as the jet stream. The velocity of the jet stream is highest at an altitude of several kilometers above the surface in the northern hemisphere. On the high latitude side of the jet stream, the air is cold. On the low latitude side it is warm. The greater the difference in temperature from the warm to cold side, the higher the speed of the jet stream.
1. The jet stream does not always maintain a constant latitude as it flows around the Earth. Occasionally, it can develop a significant meander: it can swing temporarily in a loop to higher latitudes in one region with a compensating loop to lower latitudes elsewhere. Those of us who live in cold winter regions such as Boston have frequently experienced the dramatic impacts of such swings in the jet stream. Temperatures can jump by tens of degrees in a matter of hours as the jet stream migrates from south to north, as a major meander passes overhead. We can go from cold to warm then back to bitter cold in a matter of days.
2. Whether winters are mild or cold depends on where we live relative to the average position of the jet stream.

3. A key question for the future concerns the response of the jet stream to changes in the energetics of the atmosphere arising as a consequence of the increasing burden of greenhouse gases. In general, we may expect winters to be milder. This may be considered a boon for those who live in regions that are presently cold in winter. But a change in winter climate can have important implications for ecosystems. The type of vegetation that grows in a particular region has adjusted to a particular climate. If the nature of this climate regime were to change dramatically and rapidly, natural ecosystems might find it difficult to adjust.
4. The atmosphere is often unstable in the vicinity of the winter jet stream. These instabilities take the form of storms that can spin off and carry air to higher latitudes. Meteorologists refer to these instabilities as eddies. Eddies play a very important role in carrying heat from low latitudes to high latitudes, especially in winter.

#### V. Jet Stream: Land vs Sea

- A. The ocean maintains relatively the same temperature from day to night or indeed from day to day. This is possible because the wind is churning up 10 to 100 meters of surface water, allowing the heat to be stored in the summer and released in the winter. The ocean is a good way to store heat.
- B. Over the land, the heat that's absorbed from the sun in the summer is absorbed right at the surface. The continent will heat up during the summer and cool down during the winter. This sets up a very important circulation loop that works like this:
  1. During the summer, you are warming up the continent. Air over the continent tends to rise and then sink over the bordering ocean. So you build up

#### DEVELOPING STORM FRONTS

At the Earth's surface, atmospheric pressure is the key to understanding the weather. Air in a high pressure area compresses and warms as it descends. When the air is warm and dry, formation of clouds is inhibited, meaning the sky is normally sunny in high-pressure areas. Just the opposite occurs within an area of low pressure. In areas of low-pressure, the air is rising and cooling down. The cooler air forms clouds and precipitation.

When the weather man says a low pressure area is moving toward your region, cloudy weather and precipitation result as the low-pressure area approaches. Low-pressure systems have different intensities with some producing a gentle rain while others produce hurricane-force winds and a massive deluge.

Thunderstorms are the key ingredient in most severe weather. Lightning results from a buildup of electrical charge high in the atmosphere. Thunder happens because lightning heats the air to more than 43 thousand degrees, causing the air to expand. As this air cools, it begins to contract. This quick expansion and contraction of air around the lightning starts air molecules moving back and forth, making sound waves, which we hear as thunder.

## MONSOONS

The word monsoon is derived from the Arabic word “mauism,” which means season. It is used to describe the seasonal change in the direction of the winds that develop as a result of pressure changes in the atmosphere. The best-known monsoons are those that affect India and Southwest Asia.

There are two well-known monsoon patterns. The summer monsoon blows southwesterly across the Indian Ocean and causes very wet conditions. In contrast, the winter monsoon blows northeasterly and is generally dry.

India and Southwest Asia lie between two climate zones, the tropical and subtropical. In winter, the northeasterly flow of wind goes from the subtropical high-pressure area to the tropical low-pressure, creating dry weather. In summer, however, as the continent of Asia heats up, it creates a seasonal low pressure area bringing with it rain and wind.

Scientists believe that the intense South Asian monsoon phenomenon was created about 20 million years ago when India collided with the Asian continent, resulting in the Himalayas and the Tibetan Plateau.



high pressure over the ocean and low pressure over the land. This process is reversed in winter.

2. The Indian monsoon is another element of the land/sea circulation. During the monsoonal period the Indian continent warms up and the circulation is generated by the low-pressure system on the Indian sub-continent and the high pressure outside coming from the ocean. As this air comes across the ocean, it picks up moisture and drops rain on the continent. In the winter, the opposite happens.

### Conclusion:

1. The total amount of rain is limited by the amount of evaporation that occurs from the world's oceans. It can't rain more than it evaporates. The water vapor in the atmosphere doesn't stay there very long.
2. Evaporation is the result of heating up a body of water, energy driving water from the liquid to the gas phase. Absorption of sunlight on the surface of the world's oceans plays a major role in determining how much evaporation is going to take place and consequently how much rainfall will occur.
3. We have focused here on the role of the atmosphere in transporting heat from the tropics where the energy balance (the difference between heat absorbed from the sun and infrared radiation emitted back to space) is positive, to higher latitudes, where it is negative. In the next lecture, we turn our attention to the role of the ocean.

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## FOR GREATER UNDERSTANDING



### Consider

1. How does the jet stream affect the global climate?
2. What causes severe weather?
3. Why is air circulation critical to the weather and climate?

### Suggested Reading

Hartmann, Dennis L. Global Physical Climatology. New York: Academic Press, 1994.

Warneck, Peter. Chemistry of the Natural Atmosphere. New York: Academic Press, 2000.

### Other Books of Interest

Ahrens, C. Donald. Meteorology Today With Infotrac: An Introduction to Weather, Climate, and the Environment. London: Thompson International, 2002.

### Websites to Visit

1. [www.usatoday.com/weather/wstorm0.htm](http://www.usatoday.com/weather/wstorm0.htm) - Comprehensive site detailing weather, its patterns, and effects.
2. [www.spc.noaa.gov/climo/reports/yesterday.html](http://www.spc.noaa.gov/climo/reports/yesterday.html) - Informative site sponsored by the National Weather Service detailing current weather trends.
3. [www.nws.noaa.gov/](http://www.nws.noaa.gov/) - Official site of the National Weather Service providing a detailed look into weather's past, present, and future.
4. [www.weatherimages.org/data/imag192.html](http://www.weatherimages.org/data/imag192.html) - Interesting interactive site showing the jet stream as it moves and changes, and the results.

## Lecture 10: The Role of the Ocean

### Before beginning this lecture you may want to ...

Read Andrew F. Bennett's [Inverse Modeling of the Ocean and the Atmosphere](#).

### Introduction:

In this lecture we learn about the ocean's role in the atmosphere.

### Consider this ...

1. How does the ocean affect the weather?
2. What is an ocean gyre and what does it mean?
3. What is the Gulf Stream?

### I. The ocean has an important influence on climate.

- A. A phenomenon known as the Gulf Stream carries warm water from the Caribbean up the east coast of the United States. The current turns off-shore near Cape Hatteras and from there it moves across the Atlantic toward northwestern Europe. The current splits as it nears Europe. A portion turns north past Ireland, Scotland, and Norway, entering the Arctic Ocean. The balance turns south, passing along the coasts of France, Spain, Portugal, and countries in northwest Africa. The current turns west when it reaches a latitude of about 20° North. The entire system defines a continuous loop. Oceanographers refer to circulations such as that in the North Atlantic as an ocean gyre.
1. The atmosphere is driving this Gulf Stream, that is being pushed in different directions. The westerly winds that are blowing across the Atlantic push the water toward the east on the northern extremity of this west/east circulation.
  2. On the other side you have the trade winds that are generally from the east, pushing the water toward the west.
  3. So it's ultimately the wind that is the driving force in pushing the surface of the water.
- B. Gyres such as those in the North Atlantic can be found in all of the world's major oceans. The analogue of the Gulf Stream in the North Pacific, for example, is known as the Kuroshio Current, which carries warm water from the south past the east coast of Japan before turning across the Pacific Ocean on a track toward western Canada. The Pacific gyre continues with a southward moving current along the west coasts of Canada and the United States. Known as the California Current, this current carries cold water from the north and is responsible for the relatively mild summer weather and cold

ocean water experienced along the California coast.

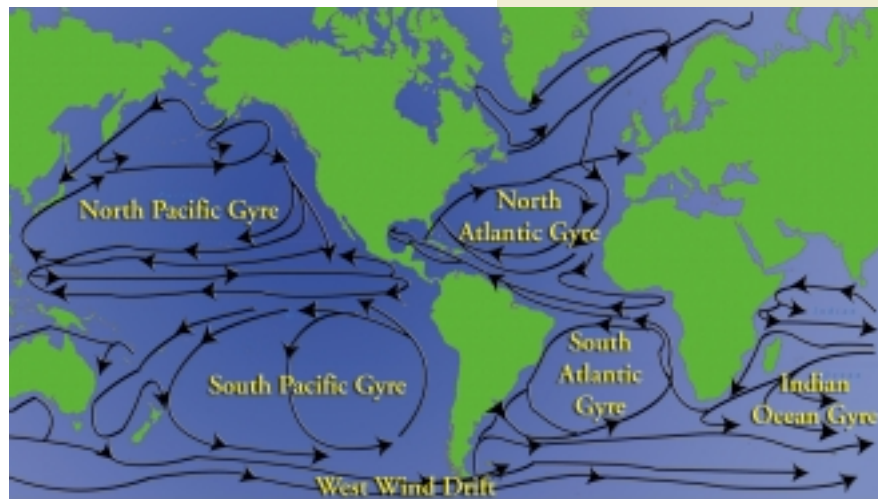
1. The gyres circulate in a clockwise sense in the northern hemisphere, counterclockwise in the southern hemisphere. The existence of these gyres, and their influence on climate, depends ultimately on the strength and direction of the prevailing winds. Winds at mid and high latitudes blow generally from the west. Winds at low latitudes blow generally from the east (northeast in the northern hemisphere, southeast in the southern hemisphere). We can think of the gyres as spinning under the driving influence of these winds blowing from opposite directions on the high and low latitude edges of the gyres.
- C. The bulk of the water in the ocean is extremely cold, at temperatures close to zero degrees centigrade. Even at the equator, if you were to probe the ocean as a function of depth, you would find that while temperatures were warm near the surface, they would decrease precipitously below a depth of a few hundred meters. What is the source of this cold water? Deep water forms exclusively at high latitudes. There are two principal regions where deep water forms, one in the North

## OCEAN GYRES

There are two types of circulation systems in the oceans. One is driven by the wind and is basically surface circulation. The second is deepwater circulation that is driven by the density (temperature and salinity) of the ocean.

About 5% of the total volume of water in the ocean is subject to surface water circulation. Surface water circulation is organized into varying sectors of currents. These currents are called gyres.

There are six major gyres in this circulation system. They are the North Atlantic, South Atlantic, North Pacific, South Pacific, Indian Ocean, and the West Wind Drift. The West Wind Drift is also called the Antarctic Circumpolar Drift, as it is the current that flows around the continent of Antarctica.





## EL NIÑO

The El Niño effect is something most people worldwide are familiar with. It is the name given to an amazing weather phenomenon that occurs every few years.

El Niño forms with the circulation of the Pacific Ocean pattern known as the El Niño Southern Oscillation. During the El Niño year, the low-pressure area normally seen over northern Australia is replaced by a high-pressure area. This change in pressure causes the normally easterly flow of wind to reverse itself and blow in a westerly direction. This allows for the transport of warm water from the equator back across the Pacific to accumulate along the coastline of South America. The warm water forms a barrier atop the cold water underneath and prevents the supply of nutrients the fish need for survival in that region. This drastically alters the fishing industry, especially in the countries of Peru and Ecuador. This warm air and high-pressure area increases rainfall and flooding on the eastern side of the Pacific as well.

Normally an El Niño event develops at the end of the year. In 1991, an El Niño event occurred that persisted until 1995. It is possible that the continuing global warming situation can increase the occurrences of the El Niño effect and therefore the poverty-ridden countries in South America will be economically altered irrevocably.

Atlantic in the vicinity of Norway, the other in the Southern Ocean near the coast of Antarctica.

- D. While generally the salt concentration in the ocean is relatively the same, there are parts of the ocean that are saltier than others. The density of the Mediterranean water is higher than the density of the Atlantic water and you can float more easily in the Mediterranean. If you look at the salinity distribution of the world's oceans, you'll find that on the average, the North Atlantic at its surface is the saltiest ocean in the world.
1. Salt buildup occurs as the water evaporates. In the case of the North Atlantic, more water evaporates than is replaced by runoff or rain. This is a little surprising as most of the big rivers that are flowing end up in the Atlantic Ocean. The largest river in the world, the Amazon, flows into the Atlantic. Based on this, one would think that the salt content would be reduced in the Atlantic Ocean rather than the other way around. One of the reasons this is the case is because it's very difficult to carry water vapor from the Pacific to the Atlantic, primarily due to the mountain ranges where the water vapor precipitates as rain or snow, leaving only dry air to make it to the Atlantic Ocean. The other factor has to do with the mountain geography. In Central America there aren't any mountains so you don't have an interruption in the flow. In that area, however, the trade winds are blowing air from the Atlantic to the Pacific. Transversely, water vapor moves easily from the Atlantic to the Pacific as there are no mountain ranges to inhibit the flow of air across Eurasia.
  2. The salinity of the ocean does have a major effect on the global climate.



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As that water gets up into the Arctic Ocean with a very high salt content and begins to cool off in winter, the temperature of the water depends both on density and salinity. Fresh water as it cools has relatively low density compared to salt water when it cools. Salt water is denser. So the higher the salt content, the denser the water will be, especially as it cools down. In the North Atlantic, as it cools, the surface water becomes more dense than the water underneath and eventually sinks to the bottom. So there is a sink hole operating in the North Atlantic somewhere near Norway that is sucking water all the way down from the Caribbean up to that sink hole. With it comes warm water, drawing heat to supply this sink hole. The total amount of water flowing in this situation is far greater than the amount of water flowing in all the rivers all over the world.

- a. Deep water forming in the North Atlantic flows south, passing around Antarctica where it is joined by an additional contribution from water sinking notably in the Weddell Sea. Deep water from the Atlantic enters the Pacific and Indian Oceans before eventually slowly returning to the surface. The circulation loop that began with water sinking from the surface in the North Atlantic is completed by a return flow of water at the surface, defining a giant loop known as the global Conveyor Belt. It takes water close to a thousand years to complete a single loop of the Conveyor Belt.
- b. The trade winds set up an important circulation of waters near the surface in the tropics. Surface water is moved away from the equator by these winds and replaced by water moving up from below. Water entering the surface region in the equatorial zone from below is generally colder than water that was there previously. This newly formed surface water warms up as it moves away from the equator. The loop is completed by water sinking from the surface in the subtropics. This shallow circulation loop has an influence comparable to the atmosphere in transporting heat from the tropics to the subtropics.

## **II. El Niño and La Niña Phenomena**

- A. These two changes in the weather of the tropics have far-reaching effects from where they are immediately felt. In Indonesia, during the normal cold

### **LA NIÑA**

Coupled with El Niño, La Niña is a distinct weather pattern of its own, bringing increased precipitation to western regions of the tropical Pacific with dry conditions to the east.

Usually following the El Niño event, La Niña events can be very powerful and destructive. When the easterly winds become increasingly strong and cause an inordinate amount of cold water to settle in the central and eastern Pacific along the equator, global weather patterns are altered significantly.

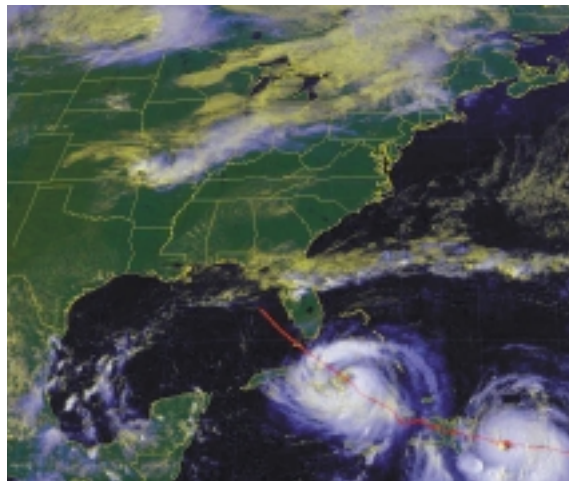
The world's oceans absorb the heat that drives the global climate because they have the ability to cool or heat the atmosphere above.

phase there is all this warm water near Indonesia, and it typically rains a lot. Rain forests are the dominant form of vegetation in that environment. When you shift into the El Niño phase, the rain actually shifts away from Indonesia and it moves into the middle of the Pacific Ocean. Over Indonesia, the air is sinking and it gets very dry. When these forests dry out is often when you have very serious fires. Sometimes fires, scientists believe, have been illegally set to clear land that could then be used for something else.

- B. The other widespread effect of El Niño can be seen as far as the other side of the South American continent. Often you will have very dry conditions in other parts (i.e., Northeast Brazil). You can also see these effects as far away as Africa. This represents a dramatic change in rainfall patterns. In regions where people depend on rainfall agriculture, this can be a very serious problem indeed.

**Conclusion:**

The atmosphere and ocean play comparable roles in determining the state of the global climate system. A model for climate, either past or future, must treat both atmosphere and ocean as a coupled system. The state of the ocean depends on the state of the atmosphere and vice versa. Modeling the atmosphere and the ocean as a coupled system defines a challenge of daunting complexity, challenging capabilities of even the largest computers available.



Satellite photo of hurricane storms resulting from the El Niño phenomenon in 1998—a record-breaking season for this weather pattern. The Atlantic hurricane season got off to an early start, and changes in upper-level winds over the Atlantic have made conditions ideal for hurricane formation. Conditions were favorable to generate tropical depressions like clockwork every three or four days.

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## FOR GREATER UNDERSTANDING



### Consider

1. What is the El Niño phenomenon?
2. How do the oceans contribute to the climate?
3. Are all weather patterns bad?

### Suggested Reading

Bennett, Andrew F. Inverse Modeling of the Ocean and the Atmosphere. New York: Cambridge University Press, 2002.

Gill, Adrian E. Atmosphere-Ocean Dynamics. New York: Academic Press, 1982.

### Other Books of Interest

National Research Council. From Monsoons to Microbes: Understanding the Ocean's Role in Human Health. New York: National Academic Press, 1999.

### Websites to Visit

1. [www.nationalacademies.org/opus/](http://www.nationalacademies.org/opus/) - Official website for the National Academy of Sciences with a superb presentation of global weather.
2. [www.cpc.ncep.noaa.gov/products/analysis\\_monitoring/ensostuff/](http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/) - Official website of the National Weather Service devoted to El Niño and La Niña.
3. [www.glacier.rice.edu/4\\_windcirculation.html](http://www.glacier.rice.edu/4_windcirculation.html) - Comprehensive website describing the ocean currents and wind circulation.
4. [www.epa.gov/OWOW/oceans/](http://www.epa.gov/OWOW/oceans/) - Excellent website sponsored by the Environmental Protection Agency that gives an in-depth view of the role the ocean plays in the atmosphere.

## Lecture 11: The History of Climate Changes

### Before beginning this lecture you may want to ...

Read M.K. Hughes's [The Medieval Warm Period](#).

### Introduction:

In this lecture, we focus on determining climate changes in the past.

### Consider this ...

1. How do we know about historical changes in climate?
2. What does the Earth's rotation have to do with the global climate?
3. What was Antarctica's role in the historical discovery of climate?

### I. Earth's Temperature History

- A. We live today at a relatively warm period in Earth's history. For much of the past million years or so, the Earth has been cold, subject to what we refer to as ice ages interrupted by relatively brief warm epochs known as interglacials.

### II. Ice Ages

- A. An ice age is a condition in which an ice sheet slowly builds in a few places on the Earth. It builds notably in North America and in northern Europe. Over a long period of time, the ice sheet advances and it thickens until it reaches its maximum extent. Even in the middle of summer the ice sheet would be several kilometers thick. The wind blowing across the ice sheet would be bitterly cold.
- B. The last ice age reached its peak about 20,000 years ago. At that time, much of North America, down to the latitude of about New York, was blanketed in a thick layer of ice. Conditions, even at the peak of summer as far south as New York, would have been bitterly cold as icy winds blew across this frozen landscape. An ice sheet also blanketed large parts of northwestern Europe. Sea level globally was about 120 meters lower than today, a consequence of the vast amount of water stored in these extensive land-based ice sheets. Even the continents reformed during this period. For example, during the ice age, Asia was connected to North America. This, remember, allowed the first humans to arrive in North America.
- C. The expansion and retreat of the ice sheets are thought to be controlled ultimately by subtle changes in the orbital parameters of the Earth. Today, we are at about the midpoint of the range. The tilt angle of the axis about which the Earth rotates is about  $23.5^\circ$ , heading toward a minimum value of about  $22^\circ$  from a maximum of  $25^\circ$ . When the axis is pointing away from the

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sun in the northern hemisphere, the highest latitudes are completely dark. There is no daylight. When the axis is pointing toward the sun, then you get 24 hours of daylight. This change in the axis of rotation allows for the change in seasons.

1. The tilt of the axis of rotation of the Earth bobs up and down through a total range of about  $3^\circ$  relative to a vertical axis through the plane on which the Earth travels around the sun. This  $3^\circ$  bob has a very important influence on the climate of the Earth at least by modulating the type of seasonal changes we would expect. When the tilt is at  $25^\circ$  it drags the Arctic Circle down toward the equator.
2. It takes about 41,000 years to complete this cycle of the up-and-down rotational axis of the Earth. This is extremely important in determining the ice ages and timing of interglacial periods.
3. The tilt of the rotation axis plays a critical role in determining the seasonal distribution of climate. If the rotation axis was oriented at  $90^\circ$  to the orbital plane, there would be no seasons and days and nights would be of equal length everywhere on Earth. The tilt completes a cycle from high to low back to high every 41,000 years.
4. The Earth describes an elliptical orbit on its path around the sun. Earth is slightly closer to the sun today during northern winter (December) than it is in northern summer (June). Eleven thousand years from now the situation will be reversed and in a further 11,000 years we will be back to where we are today. Scientists refer to this phenomenon as the precession of the equinoxes. A complete cycle of precession takes 22,000 years. The seasons modulate accordingly.
5. There is a third orbital change that affects the amount of sunlight received

### MILUTIN MILANKOVITCH

Milutin Milankovitch (1879-1958) was a Serbian mathematician who devoted the whole of his career to developing a mathematical theory of climate based on seasonal and solar changes received by the Earth.

Milankovitch was born in a rural village in Serbia and attended the Vienna Institute of Technology, graduating with his doctorate in 1904. He accepted a faculty position at the University of Belgrade in 1909 and remained there until his death in 1958.

Milankovitch developed a theory, which is named after him, suggesting that as Earth travels through space and around the sun, there are variations in three elements of Earth-sun geometry that cause variations in the amount of solar energy reaching the surface of the planet. The three elements were the shape of the orbit around the sun, the changes in the angle of axis rotation, and changes in the plane of the Earth's orbit.

He was the first to describe how ice ages could occur. He believed that in summer, if the amount of sunlight reaching the southern edge of the ice sheet is increasing, then the ice sheet would recede. As the ice sheet recedes, then you expose dark-colored rock underneath that will begin to absorb more sunlight. His theory was that as the sun warmed up the ice sheet, the secondary effect would be the warming up of the rock underneath, which would then drive the ice further back.

### YOUNGER DRYAS

The Younger Dryas was initiated, it is thought, by a flood of fresh water released into the Saint Lawrence Seaway and from there to the North Atlantic when an ice dam broke that previously restricted drainage of a large lake located in glacial times to the northwest of the current Great Lakes (referred to by geologists as Lake Agassiz). The Younger Dryas ended when this infusion of fresh water was absorbed by the Atlantic and when the salt content of surface water built back to the point where deep water formation could resume in the North Atlantic. Changes in the operation of the Conveyor Belt were clearly implicated in the Younger Dryas transition but it is apparent that the adjustment of the climate was even more complex. Large changes in temperature were experienced not only in the North Atlantic but also in the tropics. Changes in the tropics may have arisen as a result of changes in the shallow circulation of the tropical Pacific.



at specific latitude at a specific time of year. The ellipticity of the Earth's orbit on its path around the sun is also subject to change, slowly in this case. It takes about 100,000 years to implement a cyclic change in eccentricity from a near-circular path to a more extended elliptic path and from there back to a circular configuration for the orbit of the Earth around the sun.

6. The impact of these orbital variations is an irregular but predictable change in sunlight arriving at any given latitude at a particular time of year. The conventional explanation for ice ages and related climate changes involves feedbacks triggered by these orbitally related variations in seasonal sunlight. Imagine that the amount of sunlight reaching the southern edge of the ice sheet in summer is increasing with time. The idea is that this would cause the ice sheet to recede, exposing dark rock underneath, thus enhancing the amount of sunlight absorbed by the surface, forcing further retreat of the ice sheet.
7. Conversely, if summer sunlight were decreasing, these conditions would favor an advance of the ice sheet. My own view is that the sequence of cause and effect is more complicated than this, that it involves also important changes in the circulation of the ocean, driven at least in part by the orbitally modulated seasonal changes in sunlight. These changes in circulation, I have argued, may arise as a response to changes in the spatial extent of sea ice, most notably in the Southern Ocean, with these changes in sea ice arising as the direct effect of the changes in the seasonal variation of incident sunlight.
8. Recovery of the Earth from the last ice age began about 19,000 years ago. The ice sheets of the northern hemi-

sphere began slowly to recede and sea level rose accordingly. The pace of warming accelerated about 15,000 years ago but then abruptly the Earth returned to frigid ice age temperatures. The cold snap began about 13,000 years ago and lasted about 2,000 years. Climate scientists refer to this episode as the Younger Dryas climate reversal. A growing body of evidence suggests that it was global in extent. It ended in less than a decade or so. Worrying about climate change in the present context, the story of the Younger Dryas is instructive. It suggests that changes in global climate can occur abruptly. Those who believe that future changes will necessarily occur slowly may be flying in the face of history.

9. Warming resumed following the end of the Younger Dryas epoch. Global temperatures reached a maximum about 6,000 years ago. Since then, at least until recently, the Earth has been cooling off on its way, one might think, to the next ice age. The general cooling was punctuated for periods of a few hundred years when the Earth was either slightly warmer or colder than the long-term average. One of the warmest periods in recent history is called the Medieval Optimum, in which the Vikings went into the North Atlantic Ocean to explore in relative safety and in smaller boats. This allowed for the Vikings' colonization of Greenland. The most recent cold snap, known as the Little Ice Age, began about 700 years ago and ended at about the same time as the onset of the rise in CO<sub>2</sub> observed to begin in the latter half of the 18th century.
- D. Was it coincidence that the Little Ice Age ended with the rise in CO<sub>2</sub>? This is an important question. If the Earth was ready to warm up anyway, then skeptics could argue that the additional warming observed in the present century simply

### MEDIEVAL OPTIMUM

From the 10th to the 13th century the Earth experienced an unusual warm period that preceded the last ice age. During this time, grapes could be grown in Europe 300 miles north of where they can be grown today. The Vikings also took advantage of the ice-free north seas to colonize Greenland.

Global temperatures were thought to be only a few degrees higher than in the previous global period. However, this affected primarily the far northern hemisphere of North America and northern Europe. It also happened that during this period of warming, a famous Viking, Eric the Red, was able to leave his home in Iceland and settle the island of Greenland. Exiled from his home, Eric set sail toward the west to find an island that fellow Icelanders often spoke of but knew little about. He sailed around the southern coast of Greenland until he found an area with a deep, warm fjord and settled there. He called the island Greenland, believing that a beautiful name would draw the attention of other settlers. Before the year 1300, ships regularly sailed from Norway and other European countries to Greenland.



may be part of a natural fluctuation. The question underscores the importance of context and the need to understand the factors responsible for natural variability of climate.

## ICE AGES

When most people hear the term ice age, they automatically conjure up a notion of the entire planet encased in a sheet of ice, where animals and humans alike dwell in ice castles and feed off each other for survival. This is only partially true.

Ice ages are indeed periods of time when large areas of the Earth are covered with ice sheets or glaciers. Ice ages normally refer to long periods in history when the size of the global glaciers extended or receded for many years. These periods could have lasted from tens to hundreds of millions of years. Generally scientists have broken up the four major ice ages in particular time periods.

The Proterozoic Ice Age was the first ice age and occurred between 800 and 600 million years ago. The Proterozoic was followed by the Ordovician and Silurian at 460 to 430 million years ago, the Pennsylvanian and Permian Ice Age at 350 to 250 million years ago, and the Neogene to Quaternary Ice Age at 4 million years ago.

Scientists have discovered that ice ages don't just suddenly happen but appear to be the culmination of longer periods of global climatic cooling that took place tens of millions of years before the start of the ice age. This resulted in the "growth" of the glacier. As the climate continued to cool it caused the glacier to begin spreading. Because ice reflects sunlight back into the atmosphere the surface of the Earth remained colder and therefore allowed for further growth of the ice sheet. One thing to note with regard to this, the continents were not in the familiar form that we know of today. It has been suggested that millions of years ago the Earth was formed of water and one land mass called Pangea. This land mass existed at very high latitude. Reduced concentrations of CO<sub>2</sub> in the atmosphere are also a contributing factor for an ice age. Since CO<sub>2</sub> is a greenhouse gas and partially responsible for maintaining the global temperature of the Earth, an absence of or decrease in CO<sub>2</sub> concentration would cause the global temperature to decrease.



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## FOR GREATER UNDERSTANDING



### Consider

1. What was the Medieval Warm Period?
2. What was the Younger Dryas?
3. How does the Earth's rotation affect climate?

### Suggested Reading

Dawson, Alastair G. Ice Age Earth: Late Quaternary Geology and Climate. New York: Routledge, 1992.

Hughes, M. K. The Medieval Warm Period. New York: Kluwer Academic Publishers, 1994.

### Other Books of Interest

Troelstra, S.R. et al. The Younger Dryas. Netherlands: Royal Netherlands Academy of Arts and Sciences, 1996.

### Websites to Visit

1. <http://earth.agu.org/revgeophys/mayews01/node5.html> - Interesting look at the medieval warm period.
2. [www.co2science.org/journal/2001/v4n50c1.htm](http://www.co2science.org/journal/2001/v4n50c1.htm) - Official site for the Center for the Study of Carbon Dioxide and Global Change.
3. [www.museum.state.il.us/exhibits/ice\\_ages/](http://www.museum.state.il.us/exhibits/ice_ages/) - Sponsored by the Illinois Natural History museum describing ice ages and why they occur.
4. <http://zebu.uoregon.edu/1996/ph123/l13i.html> - Excellent look at the ice age periods and overall climate changes based on rotation of the Earth.

## Lecture 12: Weather Modeling

### Before beginning this lecture you may want to ...

Read Eugenia Kalney's Atmospheric Modeling, Data Assimilation and Predictability.

### Introduction:

Here we study the contemporary changes in climate and future prospects.

### Consider this ...

1. What is weather modeling?
2. How important a role in weather prediction is weather modeling?
3. How is weather monitored globally?

### I. Surface Temperature

- A. Globally averaged values of surface temperature have risen by about one degree centigrade over the past 150 years. This increase did not develop at a uniform rate. It was confined largely to two periods, from about 1910 to 1940 and to the most recent interval from 1970 to the present.

### II. Using Models to Determine Climate

- A. The ability of models to reproduce trends in climate observed over the past 150 years is now considered an important test of the credibility of models with respect to their ability to predict the future. Reproducing the past 150 years, however, is no easy task. It is necessary to account for the complex interactions between the atmosphere and ocean and for the hydrological cycle, the complex processes responsible for evaporation, clouds, rain, and snow, and for the retention of moisture in soils and for runoff of water to rivers and eventually to the ocean. We need to account for the formation of sea ice and for the cracks known as leads that have an important influence on transfer of heat from the underlying ocean to the atmosphere.
1. First attempts to account for the trend in globally averaged surface temperature observed over the past 150 years were unsuccessful. Models allowing solely for the influence of the rise in the concentration of greenhouse gases suggested an increase in globally averaged temperature greater than that observed. It was recognized at this point that there were other factors that must be considered, notably the possible influence of sulfur dioxide emitted as a by-product of the combustion of coal and oil. Sulfur dioxide is transformed in the atmosphere to particulate sulfate. Sulfate particles are white in color and consequently have the property that they can reflect sunlight, offsetting thus at least part of the warming effect of the increase in greenhouse gases. Accounting for the influence of sulfur and allowing for variability in the output of energy from

the sun led to a significant improvement in the agreement between models and observation. Questions, however, remain. In particular, we need to account not only for reflective particles such as sulfate, but also for black sooty particles produced also by combustion. It is clear that further work must be done before we can be fully confident in the ability of models either to reproduce the past or to provide a credible vision for the future.

2. There is currently a brown cloud over Asia that extends over the Indian Ocean. Coal burning, forest fires, and burning using wood fuels, plant fuels, and even animal waste are feeding this cloud. This brown cloud is cutting down on the amount of sunlight that is getting to the Indian Ocean and affecting the health of the people that live in that area. Some say this brown cloud has had a significant impact on the flooding in China in recent years. It has essentially altered the pattern of the Asian monsoon.
- B. Despite difficulties in detail, models are in general agreement as to a number of likely effects on climate of the increase in greenhouse gases. There is little dispute, for example, that if we continue to rely on fossil fuels as the primary source of global energy, the Earth is likely to warm significantly. There is disagreement as to the magnitude of the globally averaged warming, however. Estimates range from as little as 1.4° centigrade to as much as 5.8° centigrade. The increase in temperatures over the land will generally exceed those over the ocean and affect the higher latitudes significantly. This is due to the fact that in the winter months, when no sunlight is getting in but you've altered the amount of "insulation" in the atmosphere the summer heat will be retained through the winter months. This will in turn prolong the time it takes to cool down the polar regions. An authoritative assessment (the Intergovernmental

## WEATHER MODELING

Ever wonder where your daily weather report is generated? Daily weather forecasts start as initial values taken from various locations and entered into the National Weather Service supercomputer. Data from satellite, radar, and balloon observations are assimilated and provide initial conditions for computer models of the atmosphere. Unfortunately, these models have a high degree of uncertainty. Once all of the information has been input to the super computer, a weather model is generated and is then read by meteorologists and eventually the information is filtered down to your local forecaster.

Many times, weather predictions are inaccurate. Nature and the global environment form an ever-changing beast. Information we receive is based on a variety of assumptions, air pressure, surface temperature, ocean temperature, wind velocity, jet stream, and a whole host of other variables, as we've discussed in this lecture. The alteration of a single one of these items facilitates in altering the entire weather picture as a whole. If, for example, a storm front was moving at a certain speed and velocity and the wind were to shift direction, it could strengthen, weaken, or move the front into an entirely separate phase of its existence. At the time you are presented with the forecast it truly is the best guess.

Panel on Climate Control report published in 2001) suggests that temperatures are likely to climb globally to values not seen over at least the past 10,000 years.

1. Models suggest that the warming is likely to be most pronounced at high latitudes in winter. This could lead to a significant decrease in sea ice cover at high latitudes and could result potentially in an ice-free Arctic Ocean. There are indications of a significant decrease in the aerial extent of sea ice in the Arctic, especially in summer, in recent years.
  2. Some of the positive effects of this are that if the Arctic Ocean is ice free, you have a new shipping lane with which to transport goods across the globe. One of the negative effects, however, is that Siberia has a lot of natural resources but getting those products to a market has been extremely difficult. If the Arctic Ocean is now an open waterway, exploitation of those natural resources could have a serious impact on the ecosystem of Siberia. It is likely that the permafrost level will decrease with winter warming. If this occurs, then all of the construction that has taken place based on this permafrost level is now in jeopardy. Another example that arises from this warming trend involves the polar bear. The polar bear walks out onto the ice until it finds a lead and then it catches fish. Without ice, the polar bear has no way of getting to the fish that it eats for survival.
  3. The water vapor content of the atmosphere is likely to increase. As a consequence, when it rains, precipitation is likely to be heavier than today, leading to floods in some regions, offset by droughts elsewhere.
- C. At least one model suggests that there may be significant changes in climate also in the tropics. The UK Hadley Center model forecasts a shift in tropical rainfall patterns, reflecting changes in ocean circulation. It suggests that rainfall over the Western Pacific may increase significantly over the next 50 years, but that drought may be the rule for the Amazon Basin and for parts of equatorial Africa. This change in outflow would create a disturbance in the general circulation of the world's oceans and would conspire to change the current way in which the rain forests work. The consequence of this type of change over the Amazon Rainforest would be little rain where before rain was abundant. The rainforests may disappear in Amazonia to be replaced with dry savanna-type vegetation and temperatures may climb by as much as 5° relative to today.
- D. The warmer Earth that we are predicting for the future is likely to hold more water vapor in the atmosphere. If this warmer Earth holds more humidity, then evaporation and retention of water vapor should remain constant. However, since there is more water vapor in the atmosphere, when it does rain, it will rain more. These scenarios are bad for people.

**Conclusion:**

Predicting overall climate changes is an extremely difficult task based on the limited abilities of our models and the computer systems that generate them.

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## FOR GREATER UNDERSTANDING



### Consider

1. What is weather modeling?
2. Why is global climate change difficult to predict?
3. Think of examples of how wildlife is affected by global climate changes.

### Suggested Reading

Bennett, Andrew F. Inverse Modeling of the Ocean and Atmosphere. New York: Cambridge University Press, 2002.

Kalney, Eugenia. Atmospheric Modeling, Data Assimilation and Predictability. New York: Cambridge University Press, 2002.

### Other Books of Interest

Peng, Gongbing. Environmental Modeling and Prediction. London: Springer Verlag, 2001.

### Websites to Visit

1. [www.emc.ncep.noaa.gov/gmb/](http://www.emc.ncep.noaa.gov/gmb/) - Official website for the National Center for Environment Prediction.
2. [www.ccic.gov/pubs/blue97/acc-weather.html](http://www.ccic.gov/pubs/blue97/acc-weather.html) - Official website on weather modeling including interactive graphics.
3. [www.acl.lanl.gov/GrandChal/GCM/gcm.html](http://www.acl.lanl.gov/GrandChal/GCM/gcm.html) - Informative site on monitoring global weather patterns and changes.
4. <http://humbabe.arc.nasa.gov/MGCM.html> - Official NASA website devoted to weather modeling not only on Earth but on the surrounding planets as well.

## Lecture 13: Environmental Policy

### Before beginning this lecture you may want to ...

Read Swart and Zwerer's Climate and Energy: The Feasibility of Controlling CO<sub>2</sub> Emissions.

### Introduction:

In this lecture we will address the policy changes and governmental responses to global warming.

### Consider this ...

1. What was the outcome of the Montreal Protocol?
2. How have countries fared in reaching emissions goals?
3. What is the Kyoto Protocol?

### I. The Aftermath of the Montreal Protocol

A. Following the implementation of the Montreal Protocol addressing human impacts on the abundance of ozone in the stratosphere, the global community turned its attention to the climate issue. Dealing with climate change is enormously more complex than dealing with ozone. Significantly reducing emission of greenhouse gases will require a major change in the way humans use energy. Billions of dollars were at stake in the ozone issue but the stakes for climate change are measured in trillions.

### II. The World Summit

A. The first international initiative to address the climate issue was developed at the World Summit in June 1992. Most of the world's leaders were present for this summit. The outcome of this meeting is summarized in a document known as the United Nations Framework Convention on Climate Change (FCCC).

1. The following are some of the highlights of the FCCC:

- a. It declares that global warming is a serious issue and needs the attention of the world community.
- b. It establishes an Intergovernmental Body on Climate Change that involves a number of scientists from around the world to purvey what we know about the climate issue.

B. The FCCC makes strong distinctions between the developed and undeveloped countries. The developed countries are called Annex 1 countries. The Annex 1 countries include the United States, Europe, Japan, Australia, Canada, and the countries of the former Soviet Union.

1. The responsibility of developed countries is to take the lead in reducing emissions of greenhouse gases, to protect the climate system for the benefit of present and future generations of humankind ("on the basis of equity and in accordance with their common but differentiated responsi-

bilities and respective capabilities”).

The goal was set so that the emissions of greenhouse gases by 2000 did not exceed emissions from the year 1990.

- C. The FCCC also sets up a series of meetings known as the Conference of the Parties (COPs) to carry forward the agenda of the FCCC.
- D. The FCCC went into force as an instrument of international law when Portugal became the 50th country to ratify it on 21 December 1993.
  - 1. It had been ratified earlier by a unanimous vote of the US Senate, but many politicians still fail to recognize that the US assumed obligations under FCCC.

### III. Kyoto Protocol

- A. The Kyoto Protocol is an international treaty establishing target levels for the reduction of Greenhouse gases that, once ratified, will bind member countries to meet their commitments. The text of the protocol was adopted in December 1997 at the third COP session of the FCCC in Kyoto, Japan.
- B. The conditions by which the Kyoto Protocol would become international law:
  - 1. More than 55 countries will have to ratify the protocol.
  - 2. For the Annex 1 countries, more than 55% of their total emissions must be obligated to the protocol before the treaty will go into effect.

### IV. The Response of Governments to the Kyoto Protocol

- A. The European countries took this agreement very seriously and immediately began taking measures to adhere to the agreed-upon standards to protect the ecosystem in Europe.
  - 1. In preparation for Kyoto, the European community was arguing for a 16% reduction in greenhouse gas emissions relative to 1990 but changed the target date to 2008.

### EMISSION EXCHANGE

The idea of emission exchange was first brought to the table by the United States during the Kyoto Protocol. The basic premise of this proposal was to offer countries that could not economically decrease greenhouse gas emissions the opportunity to purchase greenhouse gas emission levels from countries that were well below the level of emissions required by the Kyoto Protocol. For the majority of the countries, the US idea of emission exchange was largely ignored—until after the United States dropped out of the Kyoto negotiations.

Since that time, Europe has developed a plan to corner the “emission trading” industry. Fueled by the fact that only one other country needs to ratify the Kyoto Protocol for it to become law in over 100 countries, the European market has made the emission exchange big business. By the year 2005, the European market expects trading to be a multi-billion dollar exchange whereby companies as well as countries are buying and selling emission reductions on the commodities market. The idea is that whoever can lower emissions cheaply can sell unused permits, thereby creating a profitable way to increase pollution reduction. Overall, as the amount of pollution becomes less and less, governments can reduce the number of permits available and in doing so keep the price high.

2. The European leaders formed an alliance and joined forces to reduce emissions of greenhouse gases but allocated that to individual countries depending on their ability to meet the obligation.
- B. The United States, having increased its greenhouse gas emissions over 8% from 1990, found it impossible to meet the suggested terms under the Kyoto Protocol. Instead, the United States offered several alternatives such as buying emission allocations from other countries or assisting developing countries with their own reduction of greenhouse gas emissions.
  1. Vice President Gore, representing the US at the conference, negotiated a compromise: the flexibility mechanisms were agreed on as well as the following reductions:
    - a. The Kyoto Protocol identifies specific targets for reduction of greenhouse gas emissions to be met by a group of developed countries identified as Annex 1 countries in the protocol.
    - b. Under the terms of the protocol, the European Union would be obliged to reduce emissions by 8% relative to 1990 in the period of 2008 to 2012. The United States would reduce by 7% and Japan by 6%. Russia and the former Soviet Republics would be allowed to keep emissions at the 1990 standard, while Australia would be allowed to grow its emissions by 8%.
    - c. The Kyoto Protocol imposes no obligations on developing countries. It also includes a number of flexibility mechanisms to allow Annex 1 countries to meet their obligations if they are unable to do so by reducing domestic emissions. These flexibility mechanisms allow for trading of greenhouse gas emissions among Annex 1 countries and permits Annex 1 countries to receive credit for investments in developing countries.

#### V. Why the United States Distrusts the Kyoto Protocol

- A. By the end of 2002, the emissions from the United States were up by 14% over what they were in 1990. There is no possibility the US could meet the deadline of 2008 without doing very serious damage to its economy.
- B. Due to the happenstance of the 1990s, it's easier for European countries and Russia to deal with their obligations under the protocol.
- C. The Clinton administration returned from the Kyoto Protocol without any intention of sending it to the Senate for ratification and simply passed it on to the next administration. The George W. Bush administration refuses to send it for the following reasons:
  1. It will damage the economy of the United States.
  2. Developing countries such as China and India have not assumed any obligations. The United States, however, under the Framework Convention agreed that the developed countries had to go first. This is in fact a contradiction of the ratified law under the first Bush administration.
- D. To date, the Kyoto Protocol has not been submitted to the US Senate for ratification. The US continues, however, to adhere to its obligations under the FCCC.



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### Conclusion:

The Kyoto Protocol represents the most significant global effort ever to address a major environmental threat. Most of the developed countries have approved the protocol and are working toward meeting the requirements. Of all the Annex 1 countries, however, 33% of greenhouse gas emissions come from the United States. Although the United States continues to refuse to ratify the protocol, it seems the remaining Annex 1 countries will join and this should be enough to establish the Kyoto Protocol as international law.

## FOR GREATER UNDERSTANDING



### Consider

1. What were the conditions of the Kyoto Protocol?
2. Why did the United States opt for emission exchange rather than reduction?
3. What was so critical about the Annex 1 countries' support?

### Suggested Reading

Manne, Alan S. and Richard A. Richels. Buying Greenhouse Insurance: The Economic Costs of CO<sub>2</sub> Emission Limits. Massachusetts: MIT Press, 1992.

Swart, R.J. and S. Zwerer. Climate and Energy: The Feasibility of Controlling CO<sub>2</sub> Emissions. New York: Kluwer Academic Publishers, 1990.

### Other Books of Interest

Forsyth, Timothy. Critical Political Ecology: The Politics of Environmental Science. New York: Routledge, 2003.

### Websites to Visit

1. [http://cdiac.esd.ornl.gov/trends/emis/em\\_cont.htm](http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm) - This site provides a comprehensive look at the global emissions changes.
2. <http://unfccc.int/resource/convkp.html> - Official website for information about the Kyoto Protocol.
3. [www.ipcc.ch/](http://www.ipcc.ch/) - Official website for the Intergovernmental Panel on Climate Change.
4. [www.unep.org/ozone/montreal.shtml](http://www.unep.org/ozone/montreal.shtml) - Official site of the United Nations Environmental Programme concerning the Montreal Protocol.

## Lecture 14: Summary

### Before beginning this lecture you may want to ...

Read Peter Hodgson's Nuclear Power: Energy and the Environment.

### Introduction:

In this lecture we will summarize the climate change issues and the international policies that are being debated.

### Consider this ...

1. Are we doing enough to eliminate fossil fuel emissions?
2. What are the alternative energy sources?
3. What has prevented the US from ratifying the Kyoto Protocol?

### I. Summary

- A. There is no question at this point that humans are a major global influence and that this is the first time in the history of the Earth that this has ever been a factor for the global environment.
- B. The human population has grown now to over 6 billion people and it continues to grow.
- C. More than 10% of the total area of the Earth is devoted to agriculture. The human race has harnessed the Earth and used it to meet its requirements and purposes.
- D. Humans have freed themselves from energy dependence on local resources and can use fossil fuels and make machines to replace animals or humans in work production. It's not surprising that the result from this is globally increasing CO<sub>2</sub>.
- E. It is also evident that the rise in CO<sub>2</sub> is essentially a result of what we are doing. The human race is undeniably responsible for those changes.
  1. Some of these increases are a direct result of our use of natural resources, coal, fossil fuel, natural gas, deforestation, and our reliance on large numbers of domestic animals, which has led to an increase in organic waste.

### II. Implications for Climate

- A. The probable implication is that the Earth is slowly warming and it is almost beyond dispute that it will warm to an extent that we haven't seen for a long time.
  1. The Intergovernmental Body on Climate Change believes that the Earth's relative temperature is almost back to where it was nearly 5 thousand years.

### III. The Likely Effects

- A. High latitude winters will get warm.
- B. Some regions will benefit and some will suffer, particularly with regard to agriculture.
  - 1. Forecasting the winners and losers in this scenario is very unpredictable.
- C. A number of the climate changes have serious implications. The fate of polar bears, the possibility of microbes migrating to different environments, the spread of malarial viruses, cholera, etc. all have the potential to destroy ecosystems.

### IV. What Can We Do About These Effects?

- A. Cut down on our use of fossil fuels.
- B. Conserve our energy sources.
- C. Optimize things such as lightbulbs to produce more visible light.
- D. Design buildings that are more light and energy efficient.
- E. Significantly improve the fuel efficiency of automobiles.

### V. Automobiles and Conserving Energy

- A. We consume gasoline unnecessarily by driving the cars we do. Hybrid vehicles utilize part of the gasoline to generate electricity, which is then used to drive the car. In these vehicles, even the energy created by braking is captured and used rather than expelled as heat. When you stop a hybrid car, the engine converts to an electric engine and therefore basically shuts off, eliminating the production of CO<sub>2</sub>. Hybrid technology is currently dominated by Japanese car manufacturers.
- B. Fuel cells are also a way of generating electricity using hydrogen as the fuel. The end product is a harmless gas.

### VI. Building Construction and Conserving Energy

- A. Energy usage can and should become a major concern when architects develop a building design. Designing structures for

### NUCLEAR POWER AS AN ALTERNATIVE ENERGY SOURCE

The development of nuclear energy made available another source of energy. The heat of a nuclear reactor can be used to produce steam, which can then be directed through a turbine to drive an electric generator, the propellers of a large ship, or some other machine. At the end of the year 2000, there were 438 operating nuclear power reactors worldwide. However, construction and application of nuclear reactors has been slowed by controversy over the dangers of the resulting radioactive waste and the possibility of an accident at a nuclear reactor or fuel plant, such as those that occurred at Three Mile Island (1979), Chernobyl (1986), and Takaimura, Japan (1999).

As the movement toward nuclear power as an alternative energy source sparked the path to better energy, the concern over nuclear weapons quickly became a convincing argument against the development of nuclear energy. For many people it is felt that you can't have one without the other and therefore the issue of global warming and greenhouse gas emissions is simply an unfortunate consequence of life. However, this short-sighted view on nuclear power has resulted in the failure of many countries to further develop this as an energy source.

## HYBRID AUTOMOBILES

For years NASA has used fuel cell technology to generate electricity and power spacecraft. The fuel is fed into an electrolyte near the electrodes and an electric current is created. In hydrogen fuel cells, water and heat are the only by-products. Fuel cells offer a clean alternative not only for electricity generation, but also for powering automobiles and other vehicles. Mercedes-Benz, Honda, and Toyota—to be followed by a number of automakers—are in the process of producing hydrogen-powered vehicles, which use an advanced fuel cell to generate power. The only emission as a result of this is water.

Hybrid automobiles are taking this technology one step further. Hybrid means that the vehicle runs on two or more energy sources. Current production centers around vehicles that utilize both gasoline and electricity for operation. A parallel hybrid car has a gas tank to support the engine as well as a bank of batteries that can operate with the gas tank simultaneously. A series hybrid, however, powers the engine with gasoline where the engine acts like a generator and powers the transmission. And emissions are a lot less.

Hybrid vehicles are the wave of today where fuel-celled vehicles are the future.

more efficient use of natural light and optimal temperature control will obviously lead to less dependence on fuels.

## VII. Alternate Energy Sources

A. Wind power: harness the energy of the wind to make electricity.

European countries have been able to utilize this technology to the fullest due to the fact that governments have provided significant incentives to develop this technology.

B. Nuclear power does not generate CO<sub>2</sub> or contribute to greenhouse gas production.

## Conclusion:

The most important thing to take away from this course is that we are all one. We have the most advanced genetic techniques that clearly demonstrate that we are all one species and, although we live in different countries in different states of development, we all need to cooperate as one unit to address the climate problem. The climate issue was NOT created by one country on its own. It is a world problem and it will require the world to fix it. The climate issue is important in its own right, but it's equally challenging as a model for how we are going to organize global society to cope with the problems of the 21st century and beyond.

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## FOR GREATER UNDERSTANDING



### Consider

1. Are we doing enough to stop global warming?
2. What steps can be taken to safeguard the planet in the future?
3. Are hybrid cars the wave of the future?

### Suggested Reading

Berinstein, Paula. Alternative Energy: Facts, Statistics and Issues. New York: Oryx Press, 2001.

Hodgson, Peter. Nuclear Power: Energy and the Environment. Toronto: Imperial College Press, 1999.

### Other Books of Interest

Manwell, J. F. Wind Energy Explained. New York: John Wiley and Sons, 2002.

### Websites to Visit

1. [www.eere.energy.gov/wind/](http://www.eere.energy.gov/wind/) - Official government website for the Department of Energy on wind energy.
2. <http://supct.law.cornell.edu/supct/> - Supreme Court Collection maintained by Cornell Law School. Contains a large electronic collection of decisions.
3. [www.soton.ac.uk/~engenvir/environment/alternative/hydropower/energy2.htm](http://www.soton.ac.uk/~engenvir/environment/alternative/hydropower/energy2.htm) - Site differentiates between alternative energy use and application.
4. <http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ClimateFutureClimateGlobalTemperature.html?OpenDocument> - Official EPA site on climate future.

## GLOSSARY OF TERMS

**Aerobe:** An organism that requires air or free oxygen to maintain its life processes.

**Anaerobe:** An organism that does not require air or free oxygen to maintain its life processes.

**Chlorofluorocarbon:** (CFC) Any member of a group of substances that is a derivative of methane or ethane with the hydrogen atoms replaced by combinations of chlorine and fluorine.

**Continental Drift:** The concept of continent formation by the fragmentation and movement of land masses on the surface of the Earth. Also known as continental displacement.

**Eukaryote:** A superkingdom that includes living and fossil organisms comprising all taxonomic groups above the primitive unicellular prokaryotic level.

**Glaciation:** Alteration of any part of the Earth's surface by passage of a glacier, chiefly by glacial erosion or deposition.

**Greenhouse Effect:** The effect created by the Earth's atmosphere in trapping heat from the sun; the atmosphere acts like a greenhouse.

**Gulf Stream:** A relatively warm, well-defined, swift, relatively narrow, northward-flowing ocean current that originates north of Grand Bahama Island where the Florida Current and the Antilles Current meet, and which eventually becomes the eastward-flowing North Atlantic Current.

**Jet Stream:** A relatively narrow, fast-moving wind current flanked by more slowly moving currents; observed principally in the zone of prevailing westerlies above the lower troposphere, and in most cases reaching maximum intensity with regard to speed and concentration near the troposphere.

**Messenger Ribonucleic Acid:** (mRNA) A linear sequence of nucleotides that is transcribed from and complementary to a single strand of deoxyribonucleic acid and which carries the information for protein synthesis to the ribosomes.

**Nebula:** Interstellar clouds of gas or small particles.

**Neogene:** An interval of geologic time incorporating the Miocene and Pliocene of the Tertiary period; the Upper Tertiary.

**Ordovician:** The second period of the Paleozoic era, above the Cambrian and below the Silurian, from approximately 500 million to 440 million years ago.

**Ozonosphere:** The general stratum of the upper atmosphere in which there is an appreciable ozone concentration and in which ozone plays an important part in the radiative balance of the atmosphere; lies roughly between 6 and 30 miles above the Earth (10 and 50 kilometers), with maximum ozone concentration at about 12 to 15 miles (20 to 25 kilometers). Also known as ozone layer.

**Pennsylvanian:** A division of late Paleozoic geologic time, extending from 320 to 280 million years ago, varyingly considered to rank as an independent period

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or as an epoch of the Carboniferous period; named for outcrops of coal-bearing rock formations in Pennsylvania.

**Permafrost:** Perennially frozen ground, occurring wherever the temperature remains below 0°C for several years, whether the ground is actually consolidated by ice or not and regardless of the nature of the rock and soil particles of which the Earth is composed.

**Permian:** The last period of geologic time in the Paleozoic era, from 280 to 225 million years ago.

**Polyatomic Molecules:** A species formed by the covalent bonding of atoms of two or more different elements, usually nonmetals.

**Prokaryote:** A primitive nucleus, where the deoxyribonucleic acid-containing region lacks a limiting membrane. 2. Any cell containing such a nucleus, such as the bacteria and the blue-green algae.

**Proterozoic:** Geologic time between the Archean and Paleozoic.

**Protozoa:** A diverse phylum of eukaryotic microorganisms; the structure varies from a simple uninucleate protoplast to colonial forms, the body is either naked or covered by a test, locomotion is by means of pseudopodia or cilia or flagella, there is a tendency toward universal symmetry in floating species and radial symmetry in sessile types, and nutrition may be phagotrophic or autotrophic or saprozoic.

**Punctuated Equilibrium:** A model of evolution that proposes long periods without change punctuated by periods of rapid speciation, with natural selection acting on species as well as on individuals. Also known as punctuated evolution.

**Quaternary:** The second period of the Cenozoic geologic era, following the Tertiary, and including the last 2-3 million years.

**Rumen:** The first chamber of the ruminant stomach.

**Ruminant:** Characterized by the act of regurgitation and re-chewing of food.

**Ruminantia:** A suborder of the Artiodactyla including sheep, goats, camels, and other forms, that have a complex stomach and ruminate their food.

**Silurian:** A period of geologic time of the Paleozoic era, covering a time span of between 430-440 and 395 million years ago.

**Solar Nebula:** The planets originated from the solar nebula surrounding the proto-sun; as the sun cooled, it contracted, rotated faster, and thus caused a ring-like bulging at the equator; this bulge eventually broke off and formed the planets.

**Symbiosis:** An interrelationship between two different organisms in which the effects of that relationship is expressed as being harmful or beneficial.

**Tectonic Plate:** Any one of the internally rigid crustal blocks of the lithosphere that moves horizontally across the Earth's surface relative to one another. Also known as crustal plate.

**Tectonics:** A branch of geology that deals with regional structural and deformational features of the Earth's crust, including the mutual relations, origin, and historical evolution of the features.

## SUGGESTED READING

### COURSE TEXT:

McElroy, Michael. The Atmospheric Environment: Effects of Human Activity. New Jersey: Princeton University Press, 2002.

### OTHER SUGGESTED READING:

Benedict, Richard Elliot. Ozone Diplomacy: New Directions in Safeguarding the Planet. Massachusetts: Harvard University Press, 1998.

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National Academy of Sciences. Methane Generation from Human, Animal and Agricultural Wastes. Toronto: Books for Business, 2001.

Moroto-Valer, M. Mercedes et al. Environmental Challenges and Greenhouse Gas Control for Fossil Fuel Utilization in the 21st Century. New York: Plenum Publishing Co., 2002.

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Williams, Michael. Deforesting the Earth: From Pre-history to Global Crisis. Illinois: University of Chicago Press, 2002.