Chapter 20

THE ATMOSPHERE AND CLIMATE CHANGE

Case Study – What Does History Tell Us about Global Warming's Potential Consequences for People?
Studies of the distribution of people on Earth indicate that climate was a major influence on colonization and the resultant success. Based on such observations, climate also affected the overall life quality in much of Europe and the Americas. While we know warming in the past was not affected by fossil fuel burning, today our warming is more extreme. It may be that human activities can combine with natural cycles the way two ocean waves combine, to produce more (or less) severe effects.

20.1 THE ORIGIN OF THE GLOBAL WARMING ISSUE

The idea that humans could contribute to a "greenhouse effect" by burning fossil fuel dates back over 100 years, although serious attention was not paid until the late 1900s. Since then the idea has become extremely controversial, with opinions being driven by science as well as by economic, political and even religious viewpoints.

In the past 100 years global average temperature has risen about 0.6 C. Humans need to be concerned, since an increase in global temperature accompanied by local fluctuations could cause major changes in the way we live. Key questions that need answering involve the extent of the temperature rise, the causes, the effects, and how humans may have contributed to it.

20.2 TWENTIETH-CENTURY METHODS TO RECONSTRUCT PAST TEMPERATURES

Weather data can be collected with such instruments as thermometers, barometers, hygrometers (humidity) and anemometers (wind speed). The invention of these devices has a rich history. Data recorded over time helps give clearer pictures of atmospheric trends. Climate data can also be gathered from a "proxy", such as from plant fossils and pollen distribution patterns.

● Historical Documents

Written records, stories, photographs, etchings and paintings can offer clues to historical climate conditions and variations.

● Discovery of Continental Glaciation and Ice Ages: What the Rocks Told Swiss Farmers

Based on studies of deposits typical of glaciation, glaciers once covered much more of Europe than is seen today. Later studies of plate tectonics revealed that once cold areas were now warmer. Clearly, the past Earth's climate conditions have varied.

● **Sediments** on land, particularly those containing pollen, can show patterns of plant growth and allow deduction of the climate conditions. Fossil animals can also be used for this purpose. In oceans, deposits of Foraminifera can be used to reconstruct temperature patterns based on measurements of oxygen isotopes.

● **Tree Rings**
Dendrochronology, the study of tree rings, can be a useful local measure of past climate conditions. Variances can be due to rainfall/droughts, length of growing season, infestation by insects or diseases (which may be indirectly tied to weather). Samples are taken with small diameter coring tubes; the holes are then patched to protect the tree.

● **Ice Cores**
Ice core data shows that Earth's temperature has varied over time. Paleo-CO_2 trapped in bubbles in the ice show changes in atmospheric CO_2 concentrations.

● **Corals**
Coral growth patterns also reflect climate variability. They produce enduring, hard deposits whose isotopes can be dated.

● **Carbon-14**
This is an isotope found in all living creatures, and the rate of its decay can be used to date plant and animal remains. Its amount increases in the atmosphere in periods of high solar activity, and can be matched with other data to deduce patterns of solar output. Carbon-14 is also used in dating tree rings and correlating these data with temperatures.

Climate change, at a variety of time scales, is a natural feature of earth. There was a major warm period between 1100 and 1300 AD when the Vikings colonized Iceland, Greenland and N. America, for example. This gave way to what is known as the little Ice Age; it was relatively brief by geologic standards.

20.3 HOW THE ATMOSPHERE WORKS

Climate is the characteristic or average state of the atmosphere for a given region and it refers to the long-term average, while **weather** refers to the current state of the atmosphere of short deviations from the mean climate. Earth's climate changes primarily because of variation in its energy budget.

Microclimate is a term that refers to the micro-scale, ranging from the atmosphere around a leaf to the climate within the boundaries of an urban area. The latter differs from the surrounding natural climate in several ways: urban areas are warmer, less humid, dustier, foggier, and have 5-10% more precipitation.

Understanding today's climate changes requires knowledge of climate trends. These trends change over long periods of geologic time, but also over the course of a few decades. One of the key questions in climate change study is to what degree our current warming can be attributed to natural cycles. The cause(s) of natural climate change are not well understood, but factors such as variation in CO_2 concentration and variations in the earth's orbit around the sun (Milankovitch cycles) are certainly involved. Climate has changed rapidly in the last 20 years. The 1990s was the warmest decade in the past 142 years.

● Structure of the Atmosphere

If you could shrink the earth down to the size of an apple, the atmosphere would be about the size of the peel. Ninety percent of the weight of the atmosphere lies within the first 12 km above the surface, and consists of nitrogen (78%), oxygen (21%) argon (0.9%), CO_2 (0.03%) and some traces of others such as ozone and methane. This layer of atmosphere is known as the **troposphere**, and this is where most of the weather occurs (cloud formation and precipitation). Above the troposphere lies the **stratosphere**, which is where a very important layer of ozone occurs (between 25-30 km aloft).

● Atmospheric Processes: Temperature, Pressure, and Global Zones of High and Low Pressure

Important atmospheric properties include **temperature**, **barometric pressure** (force of the atmosphere per unit area), and **water vapor content**. An atmosphere of pressure is equivalent to 10^5 N/m^2. Water vapor content varies from about 1-4%, depending on temperature. At saturation, the relative humidity is 100%.

There are prevailing wind patterns on a global scale that emerge when you compute average wind speed and direction. At the surface, there are regions of divergence and high pressure, regions of westerly flow, convergences, and areas of rising air, all part of the **three-cell model of circulation**. This model describes three circulating belts of air in the Northern Hemisphere as well as in the Southern. When combined with the **Coriolis Effect**, these belts produce the major air circulation patterns of the Earth. These patterns explain a great deal about the macroscale climate (e.g. the distribution of deserts) and biogeography of the earth.

Areas of falling air in the three-cell model produce areas of **high pressure**, while areas of rising air produce areas of **low pressure**. Their locations vary by season.

● Energy and the Atmosphere: What Makes the Earth Warm?

Earth's temperature is determined by four main factors: 1) *the amount of incoming solar radiation*, 2) *albedo*, 3) *atmospheric absorption of IR radiation* and 4) *evaporation and condensation of water vapor* (which affects 2 and 3).

Incoming solar radiation is composed of several frequencies of light, mainly in the UV, visible, and IR regions. 30% of incoming radiation is reflected back to space by the Earth's atmosphere. 25% is absorbed by the upper atmosphere, producing warm layers. 45% is absorbed by the Earth, causing warming of the surface.

● Milankovitch Cycles
These cycles involve changes in the Earth's position relative to the Sun. A wobble in the Earth's orbit changes the distance between Earth and Sun on an approximately 100,000 year cycle. Two other cycles are based on the Earth's axis position, and all three may explain long-term changes in the amount of solar radiation that reaches Earth and the differences in radiation affecting different parts of the Earth.

● Solar Cycles
Carbon-14 studies have shown variations in the Sun's output which have altered climate in the past, although it is not likely the main cause of today's changes.

20.4 HOW EARTH'S ATMOSPHERE, OCEANS, AND LAND AFFECT CLIMATE

Causes of global climate change have been debated since glacier evidence pointed out that changes over time have indeed occurred.

● Atmospheric Transparency Affects Climate and Weather
The amount of incoming solar radiation can be influenced by the types and amounts of clouds, natural atmospheric aerosols and dusts, volcanic eruptions, and anthropogenic sources, which in turn affects the amount of surface warming.

● The Surface of Earth and Albedo Affects
The amount of energy reflected by the Earth is called the **albedo**. Light surfaces such as snow cover and light vegetation increase albedo, as do increases in cloud cover and dust; dark surfaces decrease albedo. Vegetation also affects albedo; whether it increases or decreases albedo depends on the color of the vegetation compared to the color of the geologic substrate. The atmospheric temperature is very sensitive to small changes in albedo.

● Roughness of the Earth's Surface Affects the Atmosphere
Roughness caused by terrain or by vegetation affects air flow and local weather patterns, producing turbulence, as opposed to smooth flowing laminar air. Turbulence releases heat, which can affect weather.

● The Chemistry of Life Affects the Atmosphere
Living organisms affect the amounts of water and gases in the atmosphere, and thus are responsible for some variations in the weather.

20.5 THE GREENHOUSE EFFECT

All of the Earth's absorbed energy is eventually radiated back to space as infrared radiation (except for the 1-2% captured by plants) through the *atmospheric window*. Some of the outgoing long-wave radiation warms our atmosphere as it is absorbed by various gases, much like glass in a greenhouse retains heat, a phenomenon called the "greenhouse effect". It is extremely important to note that the LOWER atmosphere, the area of weather, is warmed primarily by radiation from the Earth.

Students often have trouble with this concept because of a lack of understanding that the entering radiation is of a different frequency than the exiting radiation. Explaining to them how a black light makes a poster glow different colors, including a little quantum theory of the atom, can help.

● How the Greenhouse Effect Works
The key to greenhouse effect modification is the exchange of heat between the Earth and the lower atmosphere. Gases absorb outgoing radiation, trapping it as heat which may be then transferred back to the Earth. **A greenhouse gas** (or GHG) is any one of the gases that absorb long-wave radiation or IR. Most natural greenhouse warming is due to water vapor in the air (about 85%) and small particles (12%). GHGs include CO_2, CH_4, CFCs, N_2O, and some others**.**

The exchange rate between Earth and the atmosphere (internal radiation flux) determines the temperature of the lower atmosphere, which is about 33° warmer than it would be without this effect.

20.6 THE MAJOR GREENHOUSE GASES

The anthropogenic sources of greenhouse gases (CO_2, methane, CFCs, nitrous oxide) are increasing as a consequence of industrialization and population growth. Per unit molecule, the greenhouse gases differ in their ability to absorb IR, but no anthropogenic source comes close in importance to CO_2 because of the massive quantities being released by fossil fuel combustion.

● Carbon Dioxide
Anthropogenic CO_2 enters the atmosphere primarily from fossil fuel combustion and secondarily from deforestation (fire and decomposition). Destruction of vegetative carbon dioxide sinks contribute to the total effects. Approximately 200 billion tons of carbon dioxide are cycled through the atmosphere each year. Since the Industrial Revolution, atmospheric carbon dioxide has increased, approximately, from 280 to 396 ppm. (See Table 20.1 for relative contributions of carbon dioxide and other gases to the greenhouse effect.)

● Methane
Anthropogenic sources of methane include farm animals (ruminants), rice paddies, landfills, and destruction of forests (termites). Atmospheric methane has doubled in the past 200 years.

● Chlorofluorocarbons
Phased out by the Montreal Protocol, these may be responsible for 15-20% of increases in the greenhouse effect due to anthropogenic sources.

● Nitrous Oxide
The major sources of NOx are fossil fuel combustion and agriculture (fertilizers).

20.7 GREENHOUSE GASES AND CLIMATE

As the text suggests, this is a good time to get students to reflect on the Earth's energy budget and predict which of the pathways will be affected by alterations in albedo, greenhouse gases, and other factors discussed above. It makes a great visual exercise in modeling for the class or for small groups.

20.8 THE OCEANS AND CLIMATE CHANGE

There are vast exchanges of carbon dioxide between the ocean and the atmosphere, the balance of which determines the extent to which carbon dioxide contributes to the greenhouse effect and global temperature.

20.9 FORECASTING CLIMATE CHANGE USING COMPUTER SIMULATION

The Principle of Uniformitarianism states loosely that present conditions can be used to extrapolate to the past and *vice versa*. It is based on the idea that physical laws are fixed and unchanging. (Some study of this Principle gives some key insights to the history of science, particularly geology.)

Laboratory science has provided information regarding the nature of the gases in the atmosphere and how they behave as they absorb light and react chemically.

Mathematical models can be used to simulate climate. Climate models of the atmosphere are referred to as Global Circulation Models (GCMs). Generally these models run on super computers, with the Japanese Earth Simulator currently the fastest. The models are predicting a rise in temperature of 1.4 to 5.8 C from 1990 to 2100 and a rise in sea level of 20 cm to 2 m. Such changes would have significant impacts.

20.10 CLIMATE CHANGE AND FEEDBACK LOOPS

● Possible Negative Feedback Loops for Climate Change
In a negative feedback loop, something acts to *reverse a trend back toward a norm*. For example, global warming could produce more algae and land plants, which would then absorb carbon dioxide, eventually producing a cooling effect. Other possible negative

feedback loops include evaporation and precipitation trends.

● Possible Positive Feedback Loops for Climate Change
In a positive feedback loop, something acts to *continue a trend away from the norm*. For example, a warmer Earth could produce fewer large dense clouds, which may then allow more radiation to enter, causing more heating. Other loops involve ice cap and permafrost melting, which reduces albedo, as well as human activities such as use of air conditioning.

● Climate Forcing
Climate forcing is an imposed perturbation of Earth's energy balance. The term **forcing** is used in the climate change literature, e.g. anthropogenic forcing, meaning caused by people. For example, there are some data to indicate that massive releases of methane from methane hydrates from the bottom of the ocean might have had impacts on past climate by increasing IR absorption in the atmosphere.

20.11 NEW UNDERSTANDING OF THE INTERPLAY BETWEEN THE OCEANS AND THE ATMOSPHERE

Scientists used to assume steady state conditions in environmental systems, but the study of regular oscillations in climate can be enlightening, such as the Milankovitch and solar cycles mentioned above. The Pacific Decadal Oscillation, the Arctic Oscillation, and the North Atlantic Oscillation are other examples.

● El Niño and Climate
El Niño, also known as the **El Niño/Southern Oscillation (ENSO)**, is a change in upwelling off the Peru coast that brings widespread climate changes, such as high rates of precipitation and flooding to Peru, and droughts and fires in Australia and Indonesia. El Niño is strongly linked to the atmosphere, because the upwelling is produced by westerly winds from South America pushing surface water offshore. El Niño occurs when these winds weaken.

● The "Ocean Conveyor Belt"
Variation in the ocean circulation, known popularly as the ocean conveyor belt, delivers warm water to the North Atlantic, which then sinks and proceeds as in Figure 20.23. It is thought to have a great effect on latitudinal gradients in atmospheric temperature. As the earth warms and polar ice melts, the density of the Arctic water decreases (fresh water is less dense than saline water). This freshening of the Arctic may prevent warm surface currents that flow north from the equator from sinking. This would stop the circulation and the delivery of warm water to the arctic, possibly plunging the Earth into an ice age.

Study Questions

1. Summarize the scientific data that indicate global warming is occurring as a result of human activity.

Ans: The major greenhouse gases that lead to global warming are being released in high concentrations by human activities. Carbon dioxide and methane are particularly important releases today. Students may also address anthropogenic changes in albedo.

2. What is the composition of Earth's atmosphere, and how has life affected the atmosphere during the past several billion years?

Ans: Approximately 90% of the weight of the atmosphere is in the first 12 km above Earth's surface. Major gases in the atmosphere include nitrogen (78%), oxygen (21%), argon (0.9%), carbon dioxide (0.03%), and water vapor in varying concentrations in the lower few kilometers. The atmosphere also contains trace amounts of ozone, hydrogen sulfide, carbon monoxide, oxides of nitrogen and sulfur, and a number of small hydrocarbons, as well as man-made chemicals, such as chlorofluorocarbons (CFCs). During the past several billion years life has increased the amount of oxygen in the atmosphere.

3. What is the greenhouse effect? What is its importance to global climate?

Ans: Certain gases in Earth's atmosphere are especially strong absorbers in the infrared and therefore absorb radiation emitted by the warmed surfaces of the Earth. Warmed by this, the gases re-emit this radiation. Some of it reaches back to the surface, making Earth warmer than it otherwise would be. The greenhouse effect keeps Earth’s lower atmosphere approximately 33°C warmer than it would otherwise be and performs other important service functions as well. For example, without the strong downward emission of IR from the greenhouse effect, the land surface would cool much faster at night and warm much more quickly during the day. The greenhouse effect helps to limit temperature swings from day to night and maintain relatively comfortable surface temperatures.

4. What is an anthropogenic greenhouse gas? Discuss the various anthropogenic greenhouse gases in terms of their potential to cause global warming.

Ans: Anthropogenic greenhouse gases are emitted into the atmosphere by the behavior of humans. They are emitted at different rates currently than they were in a pre-industrial age because to changes in behavior. Carbon dioxide (CO2) enters and leave Earth's atmosphere each year as a result of a number of biological and physical processes: 50–60% of the anthropogenic greenhouse effect is attributed to this gas. The concentration of methane (CH4) in the atmosphere more than doubled in the past 200 years and is thought to contribute approximately 12–20% of the anthropogenic greenhouse effect. Nitrous oxide (N2O) is increasing in the atmosphere and probably contributes as much as 5% of the anthropogenic greenhouse effect. The rate of increase of CFCs in the atmosphere in the recent past was about 5% per year, and it has been estimated that approximately 15–25% of the anthropogenic greenhouse effect may be related to CFCs. Potential global warming from CFCs is considerable because they absorb in the atmospheric window and each CFC molecule may absorb hundreds or even thousands of times more infrared radiation emitted from Earth than is absorbed by a molecule of carbon dioxide. Furthermore, because CFCs are highly stable, their residence time in the atmosphere is long.

5. What are some of the major negative feedback cycles and positive feedback cycles that might increase or decrease global warming?

Ans: Negative Feedback Loops for Climate Change

• As global warming occurs, the warmth and additional carbon dioxide could stimulate algae growth. This, in turn, could absorb carbon dioxide, reducing the concentration of CO2 in the atmosphere and cooling Earth’s climate.
• Increased CO2 concentration might similarly stimulate growth of land plants, leading to increased CO2 absorption and reducing the greenhouse effect.
• If polar regions receive more precipitation from warmer air carrying more moisture, the increasing snowpack and ice buildup could reflect solar energy away from Earth's surface, causing cooling.
• Increases in water evaporation from the ocean and the land could lead to cloudier conditions and the clouds would reflect sunlight and cool the surface.

Positive Feedback Loops for Climate Change

• The warming Earth increases water evaporation from the oceans, adding water vapor to the atmosphere. Water vapor is a major greenhouse gas that, as it increases, causes additional warming.
• The warming Earth could melt a large amount of permafrost at high latitudes, which would in turn release the greenhouse gas methane, a by-product of decomposition of organic material in the melted permafrost layer. This would cause additional warming.
• Replacing some of the summer snowpack with much darker vegetation and soil surfaces could increase absorption of solar energy, further warming Earth's surface.
• In warming climates, people use more air-conditioning and thus use more fossil fuels. The resulting increase in carbon dioxide could lead to additional global warming.