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.

Chapter 20

THE ATMOSPHERE, CLIMATE, AND GLOBAL WARMING

20.1 FUNDAMENTAL GLOBAL WARMING QUESTIONS

In the past 100 year 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.

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.

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 WEATHER AND CLIMATE

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, such as the atmosphere around a leaf or 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.

● The Climate Is Always Changing at a Variety of Time Scales
Climate change 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, little because it was brief.

Understanding today's climate changes requires a knowledge of climate trends. These trends change over long period of geologic time, but also over the course of a few decades. One of the key questions in climate change study to what degree our current warming can be attributed to natural cycles.

20.3 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.

20.4 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.

● Structure of the Atmosphere

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. Regions of divergence at the surface and high pressure at 30^o N and S, and a region of westerly flow, convergence, and rising air at the equator can be seen as 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. 30% of incoming radiation is reflected back to space by the Earth (5%) and the atmosphere (25%). 25% is absorbed by the upper atmosphere, producing warm layers. 45% is absorbed by the Earth, causing warming of the surface.

All of the absorbed energy is eventually radiated back to space as infrared radiation (except for the 1-2% captured by plants). 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. (Note: Unless this is clearly understood, students have a great deal of trouble with the mechanism of global warming.)

20.5 HOW WE STUDY CLIMATE

● The Instrumental Record

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.

● The Historical Record

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

● The Paleo−Proxy Record

Climate data that can be gathered from a "proxy", such as from plant fossils and pollen distribution patterns, from which we reconstruct the history of vegetation.

● Proxy Climate Records

Ice core data (where we obtain paleo-CO_2 trapped in bubbles) shows that Earth's temperature has varied over time. Bubbles trapped in ice also show changes in atmospheric CO_2 concentrations. **Tree rings** obtained from logs or cores can show seasonal variability of a climate.

Sediments on land and in water can show patterns of animal and plant growth and allow deduction of the climate conditions. For example, deposits of ocean Foraminifera can be used to reconstruct temperature based on measurements of oxygen isotopes. **Coral** growth patterns also reflect climate variability.

Carbon-14 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.

20.6 THE GREENHOUSE EFFECT

The fundamentals of the greenhouse effect were presented in Section 20.4 - it is wise to be sure your students understand this simple model before starting this.

● 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_2**O, 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.

20.7 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 of CO_2 being released by fossil fuel combustion.

● Carbon Dioxide

The CO_2 is primarily from fossil fuel combustion and secondarily from deforestation (fire and decomposition). Destruction of vegetative carbon dioxide sinks contribute to the total effects.

● Methane

Anthropogenic sources of methane include farm animals (ruminants), rice paddies, 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).

20.8 CLIMATE CHANGE AND FEEDBACK LOOPS

● **Possible Negative Feedback Loops for Climate Change**
In a negative feedback loop, something acts to *continue 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.

20.9 CAUSES OF CLIMATE CHANGE

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

● **Milankovitch Cycles**
Milankovitch 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**
Often studied by carbon-14 data, variations in the Sun's output have altered climate in the past, although it is not likely the main cause of today's changes.

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

● **The Surface of Earth and Albedo (reflectivity) 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. The 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.

● 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.

● Climate Forcing
Climate forcing is an imposed perturbation of Earth's energy balance. The term **forcing** is used a lot 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 (which would increase IR absorption in the atmosphere) at the bottom of the ocean might have had impacts on past climate.

20.10 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.

Variation in the ocean circulation, known popularly as the ocean conveyor belt, delivers warm water to the North Atlantic. 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.

● El Niño and Climate
El Niño, also know as the **El Niňo/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 across the Pacific.

20.11 FORECASTING CLIMATE CHANGE

● Past Observations and Laboratory Research

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.

● Computer Simulations

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.

20.12 POTENTIAL RATES OF GLOBAL CLIMATE CHANGE

By 2030 we expect CO_2 concentrations will have doubled from the pre-industrial levels, resulting in a 1-2 ^oC warming on average (see Fig. 22.21), with greater warming at the poles (polar amplification). Consequently, we expect semiarid areas will become dryer, other areas wetter; the global distribution of biomes will change (they are changing now); agricultural production will decrease in some areas, increase in others; the geographic distribution of tropical diseases will expand; sea level will rise; the biogeography of plants and animals will change and extinctions will rise. These effects will cause great disruptions to human populations regionally as they cope with crop failures, new diseases, and changing coastlines.

20.13 POTENTIAL ENVIRONMENTAL, ECOLOGICAL, AND HUMAN EFFECTS OF GLOBAL WARMING

● Changes in River Flow

Shortages of mountain glacial ice will likely reduce streamflow, which will in turn reduce amounts of water available for human and environmental use. Water shortages may develop as water tables decline.

● Rise in Sea Levels

Sea level is now 120 m higher than at the end of the last ice age. Further increases of 1 m or more would seriously threaten coastal cities around the world and island nations. Just the cost of protecting or moving cities threatened by sea level rise will be enormous. Various models predict a change in sea level of between 20 cm and 2 m in the next century.

A Closer Look 20.1: Some Animals and Plants in Great Britain Are Adjusting to Global Warming

After listening to debates about climate change, students are sometimes surprised that organisms have the ability to adapt to change in conditions. (I suspect this is due to a lack of understanding of genetics and possibly natural selection.) Certainly we would expect some species to adapt to some degree of change, as the great tit and the grasses in this example. An interesting discussion could concern the scenarios where a keystone species could NOT adapt.

- **Glaciers and Sea Ice**

The relationship between glaciers, sea ice, and the atmosphere is complex and delicate, with relationships to stream flow and sea level as well as precipitation patterns and albedo. Data shows that land glaciers are reliably retreating. The rate of melting of the Greenland ice sheet has doubled since 1998, although parts of the Arctic and Antarctic caps are increasing.

- **Changes in Biological Diversity**

There will be ecological consequences to species as their ranges change and in some cases (e.g. polar bear, Kirtland's warblers) they will lose habitat to the point of extinction. Doubtless other species will adapt and possibly take advantage of changes. The only sure thing is that disruption could be severe, especially if species relied upon by humans disappears or moves.

- **Agricultural Productivity**

Global climate change may greatly alter the distribution of global food production primarily because of changes in the distribution of rainfall. The prospects for agriculture will improve in some areas and decline in other. North America, which is currently the bread basket for the world, could loose this advantage. This has geopolitical implications.

Another aspect of global climate change is the rising concentration of CO_2 in the atmosphere. This is a factor that, all else being equal, will raise the rate of photosynthesis and hence the productivity of many crop plants (C3 plants), but not others (C4 plants).

- **Human Health Effects**

There will be public health consequences as tropical diseases spread into the temperate zone. The intensity and frequency of storms is expected to increase because the latitudinal temperature gradient will increase, as would temperature-related deaths.

20.14 ADJUSTING TO POTENTIAL GLOBAL WARMING

Critical Thinking Issue: What is Valid Science in the Global Warming Debate?

Global warming reaches into so many people's lives that it is a hard issue to not hear about, therefore it is a hard issue not to have an opinion on. Many opinions floating around are not based on accurate scientific evidence but they have found their way into scientific debate. This is a great time to revisit Chapter 2.

Peak CO_2 emissions will likely occur within the next 50-100 year, but there will be a lag in climate response of 100s-1000s of years, so climate change and warming is probably inevitable.

Adjusting to global warming will take the form of **adapting** and **mitigating**. Adapting requires developing strategies to minimize negative impacts of climate change and possibly take advantage of some. Biological adaptation could include moving some species at risk to new habitats and establishing new nature preserves and wildlife corridors.

Mitigating would attempt to control warming and reduce undesirable impacts. Some possible strategies would be to reduce our production and release of GHGs; find ways to sequester (store) GHGs in rock and forests; or take actions to increase albedo, such as injecting sulfur oxides into the upper atmosphere. The latter amounts to a global scale experiment with unknown consequences, as is adding enormous quantities of CO_2.

● International Agreements to Mitigate Global Warming

The first steps to control CO2 emissions were taken in 1988 at a conference in Toronto. Scientists recommended at 20% reduction by 2005.

A second step was taken in 1992 at the Earth Summit in Rio de Janeiro where a general blueprint for reducing global emission was suggested.

In December 1997, legally binding emission limits were discussed in Kyoto, Japan, but specific aspects of the agreement divided the delegates. The U.S. eventually agreed to cut emissions to about 7% below 1990 levels. However, that was far less than the reductions suggested by scientists, who recommended reductions of 60 to 80% below 1990 levels. In fact, after the conference, it was realized that emissions of carbon dioxide in 2010 would likely be about 30% higher than the 1990 emissions.

The U.S. Congress has been slow to act, and the United States, in the Hague meetings of late 2000, refused to honor reductions in emissions of CO2 that were agreed to at Kyoto in 1997.

Web Resources

http://www.epa.gov/climatechange/index.html This is the EPA's climate change site.

http://climate.gsfc.nasa.gov/ NASA's climate-related site.

http://cdiac.esd.ornl.gov/pns/pns_main.html This is the entry to ORNL's comprehensive collection of climate change-related data, including the most up-to-date statistics from Mauna Loa and elsewhere.

http://www.ucmp.berkeley.edu/fosrec/Wetmore.html In case you were wondering what is a foram?

http://www.es.jamstec.go.jp/esc/eng Home page of the Japanese Earth Simulator

http://www.eia.doe.gov/oiaf/1605/ggrpt/ An annual inventory of anthropogenic greenhouse gas emissions in the United States

http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html The NOAA ENSO site with animations and updates on the current state of the Pacific.

http://www.fe.doe.gov/programs/sequestration/ This is DOE's carbon sequestration site.

http://www.museum.state.il.us/exhibits/ice_ages/ This exhibit answers basic questions about the Ice Ages, which are "intervals of time when large areas of the surface of the globe are covered with ice sheets (large continental glaciers)." Includes a video clip depicting the retreat of glaciers in North America. From the Illinois State Museum.