EENS 1110	Physical Geology
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Our Changing Planet

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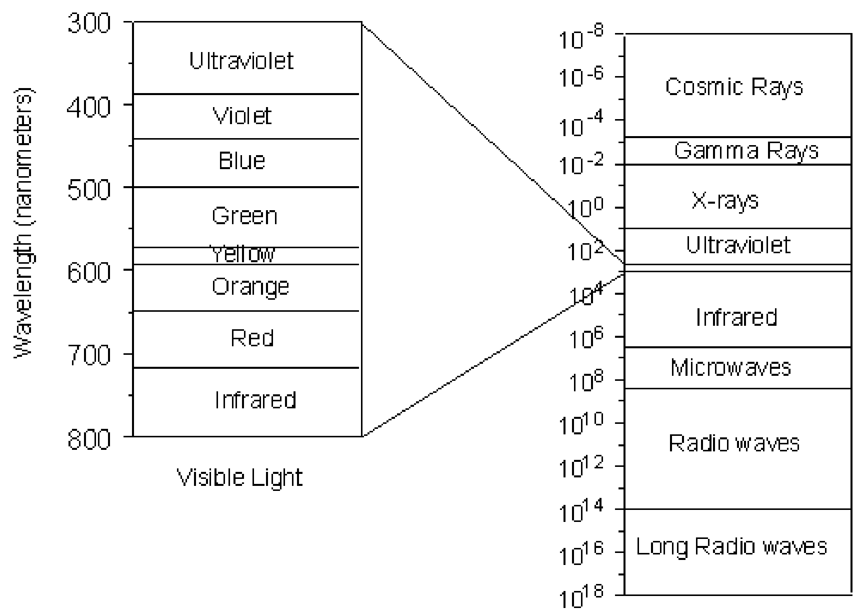
We started this course by stating that the Earth is a complex system. Changes that take place in one part of the system have effects on other parts. The tectonic system is driven by the heat in the Earth. This drives the rock cycle, which is also affected by the atmosphere and biosphere. The atmosphere is in chemical equilibrium with the oceans and exchanges matter with the biosphere. All process act on a variety of time scales from hundreds of millions of years to microseconds. We as human beings are only now realizing that, as part of the biosphere, we have an effect on the Earth. What the effect is, we are only now beginning to understand. Here we try to put this in perspective.

One of the reasons life exists on Earth is that the surface has a controlled temperature in the range between the freezing and boiling points of water. The Earth is the only planet in the solar system where this is true. Part of the reason for this results from the distance from the Sun. But, the reason that temperature remains fixed is controlled by the atmosphere.

Solar Radiation and the Atmosphere

Radiation reaching the Earth from the Sun is electromagnetic radiation. Electromagnetic radiation can be divided into different regions depending on wavelength. Note that visible light is the part of the electromagnetic spectrum to which human eyes are sensitive. The lowest wavelengths of the spectrum have the highest energy. Infrared & microwaves carry considerable amounts of heat energy.

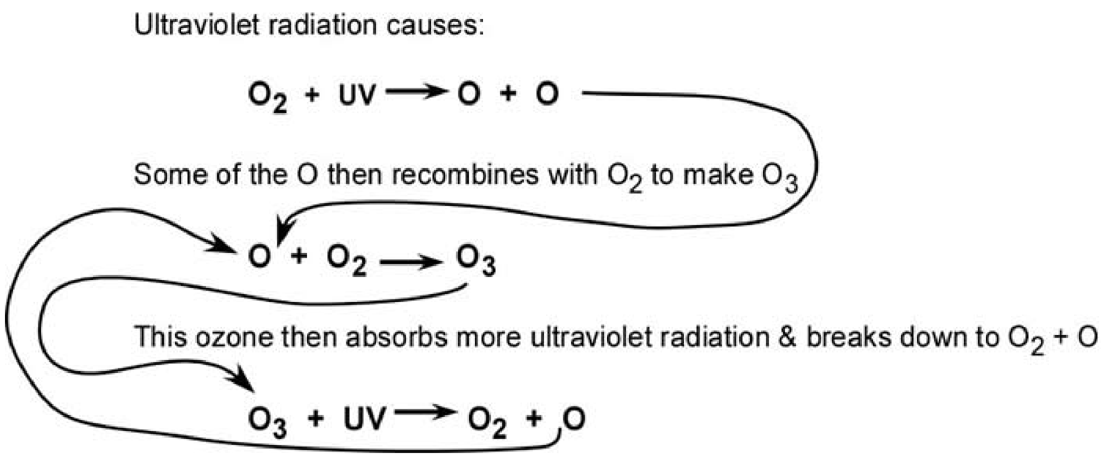


Earth receives all wavelengths of solar radiation. But certain gases and other contaminants in the atmosphere have different effects on different wavelengths of radiation.

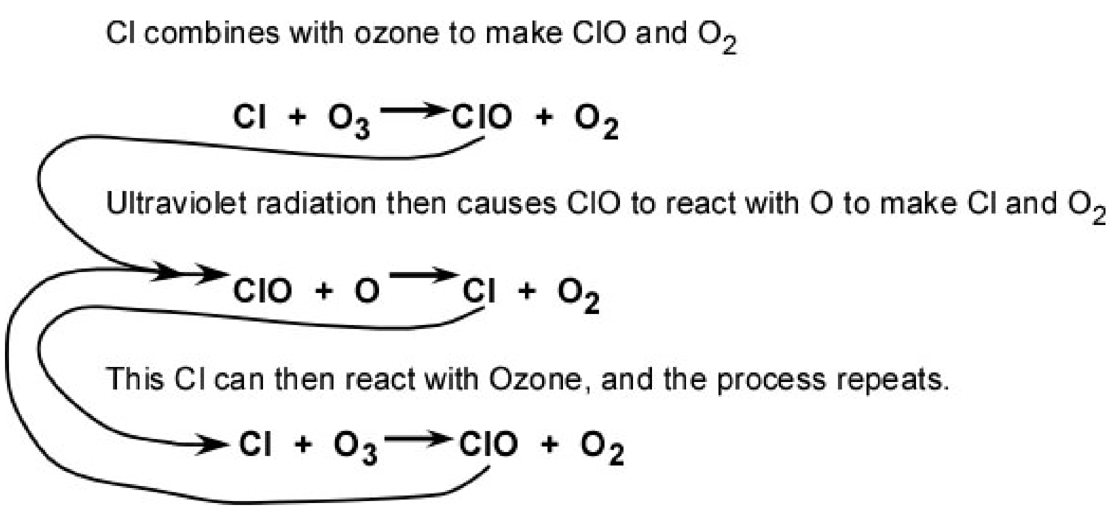
Dry air is composed of about 78% Nitrogen, 21% oxygen, and 1% Argon. It also contains water, 4% at saturation, but saturation depends on temperature. In addition trace gases have an effect. Among the trace gases are:

Ozone (O_3)

Ozone is produced in the upper atmosphere (30 - 35 km above surface) by incoming ultraviolet radiation. Ultraviolet radiation causes O_2 to go to O + O. Some of the O then recombines with O_2 to make O_3. This ozone then absorbs more ultraviolet radiation and breaks down to O_2 + O. This O can then can recombine with O_2 to make more Ozone. The process is self regulating and results in less ultraviolet radiation reaching the Earth's surface.



Ultraviolet radiation is harmful to organisms because it is high energy radiation that damages cells. In humans, excessive exposure to ultraviolet light causes sunburns and skin cancer.
Chlorofluorocarbons (CFCs) are produced to make refrigerants and styrofoam. Chlorine from these human made products enters the atmosphere and catalyzes the breakdown of ozone.



It is estimated that for every Cl molecule in atmosphere, 100,000 ozone molecules can be destroyed.

It has been observed that the protecting ozone layer in the upper atmosphere has deteriorated over the last 50 years, a result thought to be produced by human introduction of CFCs into the atmosphere.

Fortunately, we have seen some progress in solving this problem. In 1990 an international treaty, the Montreal Protocol, agreed to reduce CFCs and other sources of Chlorine released into the atmosphere with the goal of restoring the ozone layer to its pre 1960 values by 2050. So far the results have been encouraging as the pattern of ozone depletion seems to have bottomed out.

- ***Greenhouse Gases***

  Energy coming from the Sun is carried by electromagnetic radiation. Some of this radiation is reflected back into space by clouds and dust in the atmosphere. The rest reaches the surface of the Earth, where again it is reflected by water and ice or absorbed by the atmosphere. Greenhouse gases in the atmosphere absorb some of the longer wavelength (infrared) radiation and keep some of it in the atmosphere. This keeps the atmospheric temperature relatively stable so long as the concentration of greenhouse gases remains relatively stable, and thus, the greenhouse gases are necessary for life to exist on Earth.

  The most important green house gases are H_2O (water vapor), CO_2 (Carbon Dioxide), CH_4 (methane), and Ozone. H_2O is the most abundant greenhouse gas, but its concentration in the atmosphere varies with temperature. Venus, which has mostly CO_2 in its atmosphere, has temperature of about 500^oC (also partly due to nearness to Sun).

Carbon Dioxide in the Atmosphere

The Carbon Cycle

We must look at how carbon moves through the environment. Carbon is stored in four main reservoirs.

1. In the atmosphere as CO_2 gas. From here it exchanges with seawater or water in the atmosphere to return to the oceans, or exchanges with the biosphere by photosynthesis, where it is extracted from the atmosphere by plants. CO_2 returns to the atmosphere by respiration from living organisms, from decay of dead organisms, from weathering of rocks, from leakage of petroleum reservoirs, and from burning of fossil fuels by humans.

2. In the hydrosphere (oceans and surface waters) as dissolved CO_2. From here it

precipitates to form chemical sedimentary rocks, or is taken up by organisms to enter the biosphere. CO_2 returns to the hydrosphere by dissolution of carbonate minerals in rocks and shells, by respiration of living organisms, by reaction with the atmosphere, and by input from streams and groundwater.

3. In the biosphere where it occurs as organic compounds in organisms. CO_2 enters the biosphere mainly through photosynthesis. From organisms it can return to the atmosphere by respiration and by decay when organisms die, or it can become buried in the Earth.

4. In the Earth's lithosphere as carbonate minerals, graphite, coal, petroleum. This is by far the largest reservoir. From here it can return to the atmosphere by weathering, volcanic eruptions, hot springs, or by human extraction and burning to produce energy.

Cycling between the atmosphere and the biosphere occurs about every 4.5 years. Cycling between the other reservoirs occurs on an average of millions of years.

For example, carbon stored in the Earth in sedimentary rocks or as fossil fuels only re-enters the atmosphere naturally when weathering and erosion expose these materials to the Earth's surface or volcanoes erupt. When humans extract and burn fossil fuels the process occurs much more rapidly than it would occur by natural processes. With an increased rate of cycling between the Earth and the atmosphere, extraction from the atmosphere by increased interaction with the oceans, or by increased extraction by organisms must occur to balance the input. If this does not occur, it may result in increasing concentrations of CO_2 in the atmosphere and result in global warming.

- Volcanic Effects

  Volcanoes produce several things that result in changing atmosphere and atmospheric temperatures.

  1. CO_2 produced by volcanoes adds to the greenhouse gases and may result in warming of the atmosphere.

  2. Sulfur gases produced by volcanoes reflect low wavelength radiation back into space, and thus result in cooling of the atmosphere.

  3. Dust particles injected into the atmosphere by volcanoes reflect low wavelength radiation back into space, and thus can result in cooling of the atmosphere.

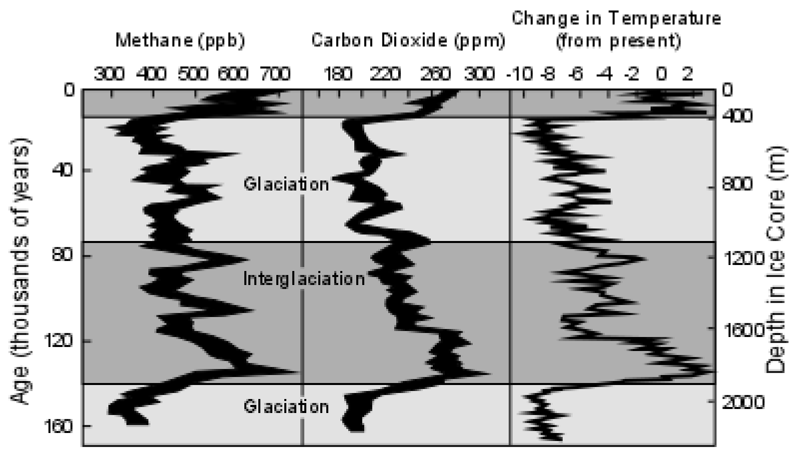
  4. Chlorine gases produced by volcanoes can contribute to ozone depletion in the upper atmosphere.

  The Mt. Pinatubo eruption in 1991 and El Chichón eruption in 1981 released large quantities of dust and sulfur gases - resulted in short term cooling of atmosphere.

  Volcanism in the middle Cretaceous produced large quantities of basalt on the seafloor and released large amounts of CO_2. The middle Cretaceous was much warmer than present, resulting in much higher sea level.

Paleoclimatology

Before we can assess the human impact on global climates, we need to first look at how climates have varied in the past. The study of such past climate change is called ***paleoclimatology***. Such study involves the study of earth history using stratigraphic methods to look for indicators of ancient climates. It also involves the study of how sea level has changed through time, again using clues left in the rock record and how ocean temperatures have changed in the past using stable isotope ratios observed in fossils. Because air can get trapped in glacial ice, drilling through the ice to find air bubbles trapped in the ice can be used to obtain samples of ancient atmospheres.



After Skinner & Porter (1993)

Combining this with radiometric age dates allows us to determine how concentration of CO_2 and methane in the atmosphere has changed over time, as well as how dust concentrations in the atmosphere have varied. Paleoclimatology also involves using the data to construct computer models in attempt to understand the causes of past climate change and project how climates might change in the future.

From our study of glaciations we know that climate can change as result of natural processes, both becoming warmer and colder than present. Although these climatic fluctuations appear to be caused by Malinkovich cycles, it is interesting to note that during glaciations in the past the concentrations of greenhouse gasses in the atmosphere were lower, atmospheric dust was higher, and the Earth's albedo was higher, all of these factors could have contributed to cooler climates. Similarly, during past interglacial episodes, the atmosphere contained less dust, higher concentrations of greenhouse gases, and the Earth had a lower albedo, all of which contribute to warmer climates. The questions that remain to be answered are:

- Are there higher concentrations of greenhouse gases and lower dust concentrations in the atmosphere due to the warmer temperatures or did they cause the warmer temperatures?
- Are these differences simply due to Malinkovich cycles, or is there some other natural

self regulating process that allows for cycles?

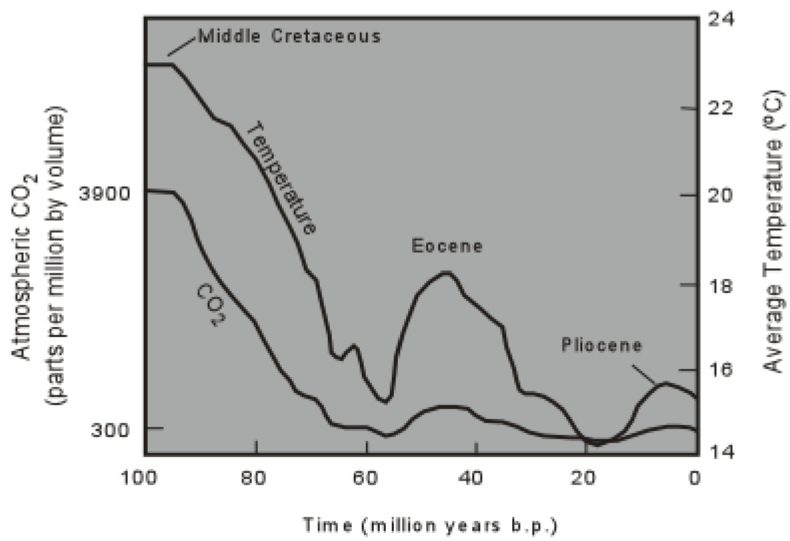
- How do human affect these cycles?

Geologists have been able to reconstruct CO_2 concentrations in the atmosphere for the past 100 million years, and average atmospheric temperature based on a wide variety of geologic and geochemical evidence. From this reconstruction, it appears that temperature was much higher than present during the Mid-Cretaceous, during the Eocene, and during the Pliocene. We will next look at what might have caused these periods of global warming.

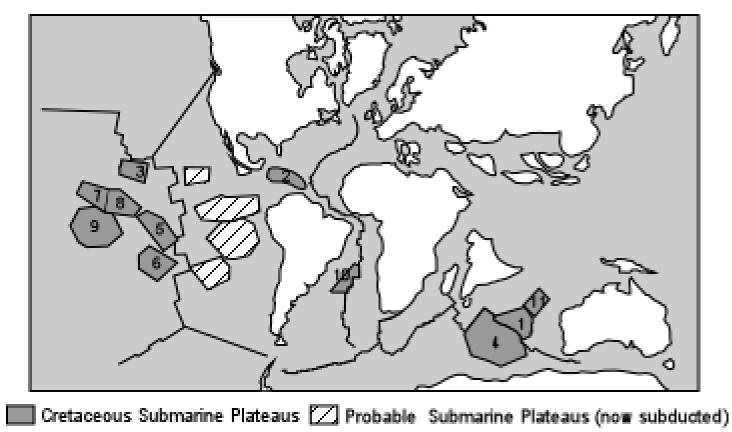
Mid-Cretaceous

During this period we note the following observations:

- The rate of production of new oceanic crust between 120 and 90 million years ago (mid Cretaceous) was nearly twice the rate prior to and after that time.



- Large volcanic plateaus were emplaced in the ocean basins. The total volume of these eruptions of basalt are unknown, as some may have been subducted, but many are greater than 10 million km^3. (The Ontong Java plateau of the southwestern Pacific alone has a volume of ~ 55 million km^3.



After Larson (1991)

- The time interval during which these volcanic plateaus were emplaced correlate with:
  - A long interval of normal magnetic polarity.

- A peak in oceanic paleotemperatures.
- Deposition of oxygen depleted sediments like black shales.
- A peak in sea level stands, which became 100 to 200 m higher than present.

This information can be interpreted in the following manner:

- Magnetic polarity remained constant because a superplume originated at outer core/mantle boundary taking with it a large amount of heat. This resulted in increasing the Temperature gradient in the core and thus resulted in vigorous convection in the core, which then became resistant to magnetic polarity changes. (Convection currents in the core are what are thought to cause the Earth's magnetic field. If the rate of convection is high, then it is more difficult to change the polarity of the magnetic field).
- CO_2 released from the magmas erupted on the ocean floor by these plumes resulted in a super green house effect, causing mid Cretaceous climates to increase to 10 to 12^o C above current average global temperatures.
- Increased ocean temperatures resulted in an increase in productivity of marine life which resulted in the formation of increased formation of petroleum.
- Increased global temperatures resulted in sluggish circulation of ocean water which resulted in oxygen depleted waters and the deposition of Carbon-rich black shales. These shales were preserved because shallow seas flooded the continents.
- The large volume of basalts erupted on the ocean floor displaced sea water resulting higher stands of the sea.

This example serves to show how events deep within the Earth, (events taking place at the core - mantle boundary) could have a drastic effect on conditions at the Earth's surface.

Eocene Global Warming

During Eocene we note the following:

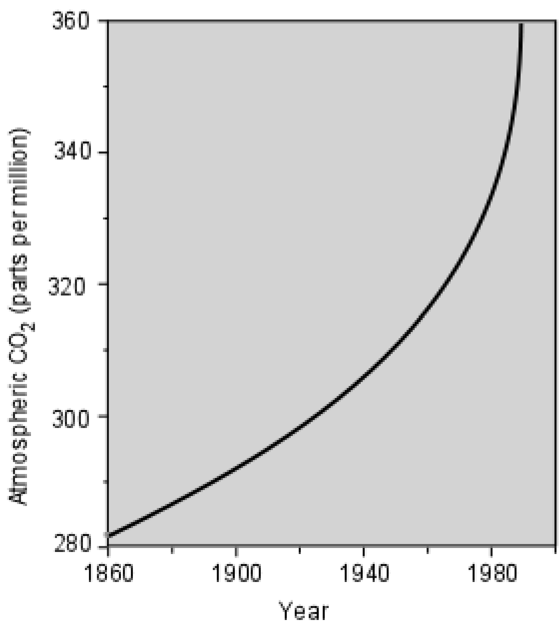
- Fossils of alligators are found on Elsmere Island at 78^o North Latitude
- Tropical vegetation and tropical marine organism fossils occur up to 45 to 55^o North and South Latitude, about 15^o higher than today.
- Estimates of atmospheric CO_2 concentrations show values between 2 and 6 times current values.

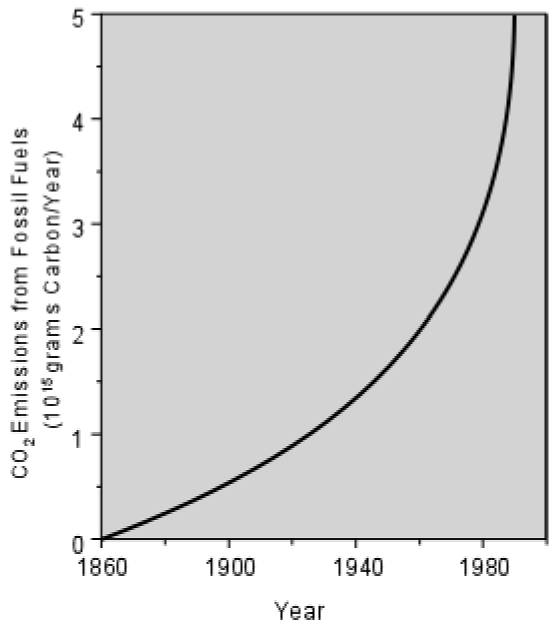
The increased CO_2 concentrations have been attributed to a large scale metamorphic event that occurred as a result of the continent-continent collision that began to uplift the Himalayas, and other metamorphic events that occurred in the Mediterranean region and the Circum-Pacific region during the Eocene. Such metamorphic events, particularly in the upper parts of the metamorphic areas where greenschist metamorphism would occur, would release large amounts of CO_2 into the atmosphere.

This example shows how the rock cycle itself, aided by tectonic processes could affect atmospheric conditions.

Humans and Climate Change

The CO_2 concentration in the atmosphere has been increasing since the mid 1800s. The increase correlates well with burning of fossil fuels. Thus, humans appear to have an effect.





Methane concentration in the atmosphere has also been increasing. Naturally this occurs due to decay of organic matter, the digestive processes of organisms, and leaks from petroleum reservoirs. Humans have contributed through domestication of animals, increased production of rice, and leaks from gas pipelines and gasoline.

Global Warming

Average global temperatures vary with time as a result of many processes interacting with each other. These interactions and the resulting variation in temperature can occur on a variety of time scales ranging from yearly cycles to those with times measured in millions of years. Such variation in global temperatures is difficult to understand because of the complexity of the interactions and because accurate records of global temperature do not go back more than 100 years. But, even if we look at the record for the past 100 years, we see that overall, there is an increase in average global temperatures, with minor setbacks that may have been controlled by random events such as volcanic eruptions or El Niño events (See figure 23.27 in your text). Records for the past 100 years indicate that average global temperatures have increased by about 0.7^{o}C. While this may not seem like much, the difference in global temperature between the coldest period of the last glaciation and the present was only about 5^{o}C.

In order to predict future temperature changes we first need to understand what has caused past temperature changes. Computer models, called ***Global Circulation Models*** have been constructed to attempt this. Although there is still some uncertainty, most of these models agree that if the greenhouse gases continue to accumulate in the atmosphere until they have doubled over their pre-1860 values, the average global temperature increase will be between 1 and 5^{o}C by the year 2050. This is not a uniform temperature increase. Most models show that the effect will be greatest at high latitudes (near the poles) where yearly temperatures could be as much as 16^{o}C warmer than present.

Effects of Global Warming

- Global Precipitation changes - A warmer atmosphere will lead to increased evaporation from surface waters and result in higher amounts of precipitation. The equatorial regions will be wetter than present, while the interior portions of continents will become warmer and drier than present.

- Changes in vegetation patterns - because rainfall will distributed differently, vegetation will have to adjust to the new conditions. Mid latitude regions are likely to be more drought prone, while higher latitude regions will be somewhat wetter and warmer than normal, resulting in a shift in agricultural patterns.

- Increased storminess - A warmer, wetter atmosphere will favor tropical storm development. Hurricanes will be stronger and more frequent.

- Changes in Ice patterns. - Due to higher temperatures, ice in mountain glaciers will melt. This is now being observed. But, because more water will be evaporated from the oceans, more precipitation will reach the polar ice sheets causing them to grow.

- Reduction of sea ice - Sea ice will be greatly reduced to the increased temperatures at the high latitudes, particularly in the northern hemisphere where there is more abundant sea ice. This is now being observed.

  Ice has a high ***albedo*** (reflectivity), and thus reduction of ice will reduce the albedo of the Earth and less solar radiation will be reflected back into space, thus enhancing the warming effect.

- Thawing of frozen ground - Currently much of the ground at high latitudes remains frozen all year. Increased temperatures will cause much of this ground to thaw. Organic compounds and gas hydrates in the frozen ground will be subject to decay, releasing more methane into the atmosphere and enhancing the greenhouse effect. Ecosystems and human structures currently built on frozen ground will have to adjust.

- Rise of sea level - Warming the oceans results in expansion of water and thus increases the volume of water in the oceans. Along with melting of mountain glaciers and reduction in sea ice, this will cause sea level to rise and flood coastal zones, where much of the world's population currently resides.

- Changes in the hydrologic cycle - With new patterns of precipitation changes in stream flow and groundwater level will be expected.

- Decomposition of organic matter in soil - With increasing temperatures of the atmosphere the rate of decay of organic material in soils will be greatly accelerated. This will result in release of CO_2 and methane into the atmosphere and enhance the greenhouse effect.
- Breakdown of gas hydrates - This is basically solid water with gas molecules like methane locked into the crystal structure. They occur in oceanic sediments and beneath frozen ground at the high latitudes. Warming of the oceans or warming of the soil at high attitudes could cause melting of the gas hydrates which would release methane into the atmosphere. Since methane is a greenhouse gas, this would cause further global warming.

Hopefully this will give you an idea about how human beings can effect the way the Earth works, and also give you an idea about the complexity of the interactions between various parts of the Earth and processes that occur throughout the Earth.

Unfortunately, the complexity of the processes are not completely understood. This has major political implications. For example, scientists are uncertain about the reliability of models that attempt to predict future conditions. This uncertainty is taken by some political factions as a denial that an event like global warming will take place.

Most scientists, however, agree that global warming is taking place and that human input of carbon dioxide into the atmosphere is most likely responsible. Politicians want, or expect you to want, exact answers with no uncertainty. That is not the way science works.

The real question, however, is whether or not we should be preparing for such events to avoid disaster if the warming trend continues, or, since we can't be absolutely certain, just wait until the disaster has occurred and we can do nothing about it.

Examples of questions on this material that could be asked on an exam.

1. What causes the breakdown of ozone in the upper atmosphere, what effect does ozone depletion have on life, and what has been done to decrease further depletion of ozone?
2. What effect do greenhouses gasses have on solar radiation?
3. What are the greenhouse gasses and which of these is the most abundant?
4. Why is the carbon dioxide concentration in the atmosphere of particular concern in terms of global warming?
5. During the Pleistocene, how did the concentrations of carbon dioxide, methane, and dust vary with temperature?
6. Why were mid-Cretaceous and Eocene climates so warm?

7. What is the evidence that global warming has taken place since the mid 1800s and that humans are responsible for the warming?

8. What are the main changes to be expected from global warming?

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