Our Atmosphere:

The primary gases in Earth’s atmosphere are 78% nitrogen, 21% oxygen, 0.93% argon, 0.038% carbon dioxide, trace amounts of other gases, and a variable amount (average around 1%) of water vapor.

If we look at the gaseous planets in the outer part of the solar system, we see that they have abundant hydrogen and hydrogen-rich gases, such as methane and ammonia, in their atmospheres. Although there is no direct evidence of this, researchers believe that the earliest atmosphere of the Earth was rich in the same hydrogen gases. This idea is based on evidence in the oldest rocks and the geological ideas about the formation of the Earth, specifically that the Earth was hotter early on and has cooled significantly over time. The high temperature of the early Earth and other factors caused the gases to be driven away from the Earth by the solar wind (ions emitted by the Sun). It sounds a bit like science fiction, doesn’t it! But there is very little to counter this model and it seems to make sense!

If these early gases were lost by the Earth, how did we get the nitrogen and oxygen atmosphere we have today? Another result of this heat release in the Earth was abundant volcanism. Besides the rocky materials that erupt from volcanoes, significant amount of gas is also expelled. Most of the gases emitted from a volcano today are water vapor (80-90%), carbon dioxide (~10%) (note: carbon dioxide is abbreviated as CO₂), nitrogen (1-2%), and some other gases we term trace gases.

After the Earth cooled, the water vapor condensed to form the oceans and lakes, most of the carbon dioxide was trapped in limestone deposits in the oceans, and the nitrogen began to increase in percentage because nitrogen gas is not very reactive. However, the abundance of oxygen in today’s atmosphere is not as high as the emissions from volcanoes, so oxygen must have become abundant by other means.

Some of the water emitted early in the Earth’s history probably dissociated (broke into H₂ and O₂) from radiation from the Sun. Before the Earth’s magnetic field developed, more of the highly energetic charged particles that stream out from the sun could strike the Earth. The energy carried by these particles was sufficient to break the bonds between the hydrogen and oxygen in the water vapor. The free hydrogen was probably lost to space because hydrogen’s mass is so small that the Earth gravity is not sufficient to keep it in the atmosphere. This dissociation process may account for a small amount of the oxygen in our atmosphere but this period of time was not sufficient to develop today’s abundance of oxygen.

About 2.2 billion years ago plants first appeared and began to photosynthesize enough to change the atmosphere. Imagine that: for about the first half of the Earth’s history that the atmosphere would have been toxic to us. Only since photosynthesis developed has there been enough oxygen in the atmosphere for animals to exist.

If you enroll in IDS 103, you will learn more about photosynthesis and cellular respiration. Most people know that the plants and animals of Earth are dependent on our atmosphere, but many people are surprised to find out that the atmosphere is also dependent on photosynthesis and respiration.

Nitrogen and oxygen are the major gases of the atmosphere. All the remaining gases are “trace gases” including carbon dioxide and the other greenhouse gases. Some of these trace gases play a very important role in modifying the Earth’s climate. Carbon dioxide is released in cellular respiration in plants and animals.
The greater the amount of carbon dioxide and the other greenhouse gases in the atmosphere, the greater the amount of infrared radiation that is absorbed. The graph below shows measurements of carbon dioxide in the atmosphere since 1958 that were made at the Mauna Loa observatory on Hawai’i. This site is thought to be the least polluted air on the Earth because there is no source of air pollution upwind for thousands of miles from Mauna Loa.

**Figure 1. Atmospheric carbon dioxide concentration at Mauna Loa, Hawaii since 1958.**

![Atmospheric Carbon Dioxide Measured at Mauna Loa, Hawaii](http://en.wikipedia.org/wiki/User:Dragons_flight/Images#Carbon_Dioxide)

- Describe the pattern created by the data.
- If you average the carbon dioxide values on an annual basis, how much has the average CO\(_2\) concentration in the atmosphere changed since 1958?
- What advantages are there be to measuring CO\(_2\) content in the atmosphere in Hawaii rather than an urban area such as Seattle or New York City?
- What is the average rate of change in CO\(_2\) concentration per year? (show your work)
The wiggles seen on Figure 1 result from seasonal changes in CO\textsubscript{2} concentration. This is driven by changes during the winter season of the Earth’s Northern Hemisphere (which has more land mass and a higher population than the Southern Hemisphere).

- Suggest 2 reasons why CO\textsubscript{2} concentration would increase when it is winter in the Northern Hemisphere. (Hint: consider what happens to plants in the winter time and how this would affect CO\textsubscript{2} levels in the atmosphere and consider how the behavior of humans changes in the winter time.)

It is possible that some of the variation could be due to natural variations in carbon dioxide. To fully understand the issues related to greenhouse gases and global change, we need to examine the past to see if CO\textsubscript{2} levels have changed over time and if so, to what extent. We can use ice cores for Antarctica to understand past variations in trace gases. As snow falls it traps small amounts of air in the spaces between the snowflakes. Some of this gas forms small bubbles as the snow metamorphoses into glacial ice. These bubbles become fossil atmospheres providing us with a means to examine the gas content of the atmosphere thousands of years in the past.

Of primary interest to those studying global change and our present atmosphere, is the abundance of carbon dioxide and methane, the primary natural greenhouse gases. The graph below is the carbon dioxide concentration from an Antarctica ice core through the last approximately 400,000 years:

- How much has CO\textsubscript{2} varied over the last 450,000 years (What is the approximate difference between the maximum and minimum CO\textsubscript{2} levels?)
Approximately how long does it take the natural system CO$_2$ levels to change by 100 ppm?

What is the maximum level of CO$_2$ before 1850 and how does this compare with CO$_2$ values today?

We have learned that climate may be altered when the albedo of the Earth is changed and that the climate of both the Earth and Venus is heavily influenced by the absorption of re-emitted infrared radiation by atmospheric gases. *If the Earth did not have the greenhouse effect, our climate would be about 60°F colder and the Earth would not be hospitable for life.* However, human activities such as burning fossil fuels and cutting forests may create many undesirable environmental changes if the temperature increases as predicted by the climate models.

Figure 3. Global Fossil Carbon Emissions from human activity (check out the color version of this figure at [http://en.wikipedia.org/wiki/Carbon_dioxide_in_the_Earth%27s_atmosphere](http://en.wikipedia.org/wiki/Carbon_dioxide_in_the_Earth%27s_atmosphere)).

What was the major source of carbon emissions between 1850 and 1900? How did this change after 1950?
In summary: there have been natural variations in carbon dioxide through time as reported from this ice core and these changes reflect changes in global temperature. However, as we have mentioned several times in class, it is clear that “correlation does not mean causation”. In other words, just because carbon dioxide goes up during a warm period, does not mean that carbon dioxide necessarily caused the warming, although it is consistent with our model! Let look at some additional information and some recent climate data to further consider the relationship between CO₂ and temperature.

**The Global Carbon Cycle:**

"One hundred and fifty years ago humans started a grand, uncontrolled experiment with carbon on earth. We don't know exactly how the experiment will turn out, but it will certainly change our climate and our lives." –George Kling

Global warming is the observed increase in the average temperature of the Earth’s atmosphere and oceans over the last 150 years. The prevailing scientific opinion is that most of this warming is due to human activities, which have resulted in an increase in **greenhouse gases** in the Earth’s atmosphere. **Greenhouse gases** prevent heat from escaping into space from the Earth’s surface, thus they cause the temperature of the Atmosphere to slowly rise over time. Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Certain human activities (such as the burning of fossil fuel) add to the levels of most of these naturally occurring gases.

Global warming has long been predicted to result from increasing greenhouse gases in the atmosphere. Global surface air temperature has indeed increased in the past century, but at a rate less than 0.1°C/decade. Record global temperatures have been achieved several times in the last several decades, but a new record often exceeds the old record by only a few hundredths of a degree. What relevance, if any, do such small temperature changes have to most people? In the following exercises you will look at temperature records from a variety of location and examine the significance of these changes yourself.

More information about greenhouse gasses and global climate can be found at the links below:

The carbon cycle and global change:  


An explanation of how global temperatures are studied:  
[http://www.giss.nasa.gov/research/briefs/hansen_04/](http://www.giss.nasa.gov/research/briefs/hansen_04/)


Below is a figure showing the annual and five-year running mean surface air temperature in the contiguous 48 United States (= 1.6% of the Earth's surface) since 1880 compared to the mean (average) temperatures from 1951-1980. This is kind of an odd way to show the data, but it allows us to look for see how average temperatures have changed over the last century. Each square represents the average temperature for one year. The wiggly line represents the average temperatures over a 5-year period. Although this kind of graph does not show the actual temperatures, it allows you to look for potential long-term changes in temperature over time.

You can find the actual data for this figure and a color version of the graph on the web at:
http://data.giss.nasa.gov/gistemp/graphs/.

Examine the graph, or check out a table of the data shown above (on the website) and fill in the table below. Then determine whether or not temperature show a trend over time (is there a definite change?).

<table>
<thead>
<tr>
<th>Time period</th>
<th># of years with mean Temp. 0° to +1° above normal</th>
<th># of years with mean Temp. more than +1° above normal</th>
<th># of years with mean Temp. 0° to -1° below normal</th>
<th># of years with mean Temp more than -1° below normal</th>
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<td>2000-2006*</td>
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</table>

Trend over time? (circle one) Warming / Cooling, No-trend Warming / Cooling, No-trend Warming / Cooling, No-trend Warming / Cooling, No-trend

*Note the last time-period is much shorter than the others. You will need to take this into consideration when looking for evidence of trends.
USA temperature records cont.

<table>
<thead>
<tr>
<th>Date</th>
<th>What is the temperature variation? From normal</th>
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<tbody>
<tr>
<td>Hottest year</td>
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<td>Hottest 5-year period</td>
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<td>Coldest year</td>
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<td>Coldest 5-year period</td>
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- How do the dates of the coldest year compare to date of the coldest 5-year period (are the dates the same)?

- How do the dates of the hottest year compare to date of the hottest 5-year period.

- If you are looking for trend through time is it easier to identify changes in yearly mean temperatures or the 5-year mean temperature?

- Overall, do your conclusions change depending on which time-frame you examine? Explain your answer.

- On average have temperatures risen or fallen since 1900 in the US? Do the data suggest that this trend will continue? Explain your answer.

We must be careful not to use one example to try and explain global temperatures. Consider what other factors beyond global climate change may be influencing temperatures in USA.

- How has the amount of paved streets and parking lots changed in USA since 1900? How would this affect temperatures that were measured in the middle of large cities?
Below is a figure showing variations in GLOBAL annual since 1880 compared to the mean (average) temperatures from 1951-1980 average. The dotted black line is the annual mean and the solid red line is the five-year mean. The green bars show uncertainty estimates due to incomplete spatial sampling of data. Compare this graph to the one for USA and answer the questions below.

For a color version of this graph or to see that data in table form go to: [http://data.giss.nasa.gov/gistemp/graphs/](http://data.giss.nasa.gov/gistemp/graphs/)

Fill in the table below based on the global temperature record:

<table>
<thead>
<tr>
<th>Time period</th>
<th># of years with mean temp. 0° to +0.5°</th>
<th># of years with mean temp. more than +0.5°</th>
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<td>200-2006</td>
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</tbody>
</table>

*Trend over time? (circle one)*

- Warming / Cooling
- No-trend

*Note the last time-period is much shorter than the others. You will need to take this into consideration when looking for evidence of trends*

- How do these results compare with the results of the USA temperature data? (Are the trends in the same direction and are they stronger or weaker?)

- How does the size of the temperature changes differ from those seen in USA?
Are the years with the highest and lowest temperatures the same on both graphs? If not how much do they differ (i.e. how much time is there between them)?

Are the decades with the highest and lowest average temperatures the same on both graphs? If not how much to they differ (i.e. how much time is there between them)?

Suggest a reason why temperature in USA are more variable than average global temperatures:

On average have global temperatures risen or fallen since 1900, and how much have they changed? Does the global data suggest that this trend will continue? Explain your answer.

How does the overall pattern in global temperature changes compare with changes in atmospheric CO\textsubscript{2} levels? Which data set displays more variability? Explain your answer and suggest a reason for any difference you observe.

Examine some of the other data sets on the website listed for the graph and answer the following questions

How do temperatures changes differ between the Northern and Southern hemisphere?

How do temperature changes differ between high and low latitudes?

How do temperature changes differ between land records and ocean records?

Is there any data set that does not show a temperature increase since 1880?
The effects of global warming on Washington State.


- Click on the link for “EFFECTS OF CLIMATE CHANGE” and summarize at the 4 major impacts of climate change on Washington State. Give at least 2 specific examples of the results of each impact.

Click on the link for “FACTS ABOUT WASHINGTON’S RETREATING GLACIERS” and answer the following questions

- How many glaciers have vanished since the 1950s, how has the volume of glaciers changed in the North Cascades, and how has the average snow pack in the Cascades changed?

- How have the numbers of droughts and wildfires changes in Washington?

Click on the link for “ECONOMIC IMPACTS OF CLIMATE CHANGE” and answer the following questions

- How are average temperatures predicted to change for Washington State by 2040?

- What changes are predicted for average temperatures and rainfall in Washington State by 2040?
Describe how previous climate changes and the predicted climate changes will impact each subject listed below in Washington State.

Glaciers:

Snow-pack:

Peak steam & river flows:

Number of large wildfires:

Sea level in Puget Sound:

Can you think of any other factors in addition to climate that may have influenced the subjects listed above?

Describe 4 of the predicted impacts from climate change on the economy of Washington State.

Dams generate 72% of the state's electricity (compared to the national average of 7% from dams). Higher temperatures will directly affect power demand by reducing demand for heating in winter (when Northwest hydropower is cheap) and increasing demand in summer for air conditioning (when Northwest hydropower is more expensive). Click on the link for “FACING THE CHALLENGE OF CLIMATE CHANGE” to answer the question below

What percentage of the Pacific Northwest’s CO₂ emission come from transportation and what are the other top 3 sources of emissions?
On February 2, 2007, the Intergovernmental Panel on Climate Change concluded that “Global warming is very likely caused by man, meaning more than 90 percent certain.” That's the strongest expression of certainty to date from the panel. They also announced that if nothing is done to change current emissions patterns of greenhouse gases, global temperature could increase as much as 11 degrees Fahrenheit by 2100. But if the world does get greenhouse gas emissions under control something scientists say they hope can be done the best estimate is about 3 degrees Fahrenheit. (http://www.ipcc.ch/). Consider how these changes will influence our planet in the end of module questions.

End of Module Questions

1) As global temperatures rise, what will happen to the size of the polar ice caps and mountain snow pack? Why? How will this change global sea-levels?

2) Tropical rainforests are disappearing at a rate of 10-20 million hectares (1 hectare = 2.5 acres) per year. What effect would removing the tropical rainforests have on CO$_2$ concentration in the atmosphere and why?

3) Given that tropical storm intensity is related to ocean temperature, (warmer waters contribute to stronger storms), how would you expect the intensity of tropical storms to change with global warming?

4) How would increased temperatures influence the amount of rainfall we receive in the Pacific Northwest?

5) How would increased temperatures influence the amount of snow pack in the Cascade Mountains?

6) Given that the snow pack in the Cascades provide water to streams in the summertime and thus supplies much of the water that is used by cities in Western Washington and farmers in Eastern Washington, discuss how will increased temperature influence the fresh water supply in Washington State. Consider how the amount of snow that melts in the spring (the rate of spring melting) increase or decrease and how will this affect water levels in local rivers and the number of spring flooding events as well as how will the summertime level of local rivers will change? How will our ability to generate hydroelectric power in the summertime be affected?