BASIC FUNDAMENTALS

Brief Summary of the Heating of the Earth and Atmosphere

In a nutshell, both the Earth and the atmosphere absorb heat from solar (short-wave) radiation in the ultraviolet, visible light, and infrared spectrum from the Sun. The Earth and atmosphere heat up and reradiate this heat in an infrared (long-wave) spectrum, characteristic of their temperatures. Gases which slow the transfer of this infrared radiation into space are called greenhouse gases.

In addition to radiation warming of the atmosphere, the Earth heats the atmosphere by thermals (rising currents of hot air) and by evaporation of water, resulting in the formation of clouds. Because water vapor has a molecular weight of 18, compared to 28 for nitrogen and 32 for oxygen, it rises up into the atmosphere and condenses into clouds (either as water droplets or ice), giving up its heat content to the atmosphere. The atmosphere receives about 660 calories for each gram of water evaporated and frozen.

When the Earth is warmer than the atmosphere (daytime), long-wave infrared radiation flows from the Earth to the atmosphere. At night, when the Earth is cooler than the atmosphere, long-wave infrared radiation flows from the atmosphere to the Earth. The lower atmosphere (troposphere) and the Earth also radiate heat to the stratosphere and to outer space during both the day and the night.

A more complete description of this follows in the section on Short-Wave Radiation and Long-Wave Radiation, and in Appendix A.

Factors Which Affect Climate

First, let's define "climate". Climate is "the prevailing or average weather conditions of a place, as determined by the temperature and the meteorological changes over a period of years." The following factors significantly affect the climate:

Factors which remain fairly constant for centuries

- Latitude
- Location and orientation of the global masses
- Mountains
- Local elevation

Proximity to major bodies of water
Earth's tilt and precession of its axis
Precession of Earth's solar orbit
Ice Age cycles
Ocean currents

Factors which can change within a short period of time

Sun's solar output (solar constant)
Greenhouse gas concentrations
Seasons
Albedo of surfaces (fraction of light reflected)
Volcanic activity
Cloud cover
Wind patterns
Special ocean + wind interactions, e.g., El Nino, La Nina
Aerosols and dust

Discussion of Fairly Constant Climate Factors

As you can see, there are many more factors than ***greenhouse gases*** that affect the climate. The ***latitude*** on the Earth is probably the most important. We recognize that Polar Regions, which are heated only by the slanted rays of the sun, are considerably colder than the Equatorial Regions. The ***location and orientation of global masses*** is important. Hawaii enjoys moderate temperature swings because the ocean surrounding it is at a nearly constant temperature, whereas central United States is exposed to chilling air masses coming from the Arctic in the winter and warm moist air masses traveling north from the Gulf of Mexico in the summer. ***Mountain*** ranges cause rains to fall on the windward sides and, often, deserts to form on the leeward sides, such as the Sahara Desert (because of the Atlas Mountains), or the deserts in California and Nevada caused by the Sierra Nevada Mountains. Higher ***Elevations*** are cooler. The temperature drops about 5.4F for every 1000 feet of elevation above sea level. The ***proximity to major bodies of water*** has a moderating effect; thus, coastal areas, such as along the Gulf of Mexico, have different climates than inland areas.

The ***Earth's axis*** is presently tilted approximately 23.5 degrees to the plane of its orbit. As a result we experience seasons. During the summer, the Northern Hemisphere is inclined toward the sun and during the winter, it is inclined away from the Sun. During the summer solstice (June 21), the Sun's rays are perpendicular to the Earth at the Tropic of Cancer: during the winter solstice (December 21) the Sun's rays are perpendicular at the Tropic of Capricorn.

During the equinoxes (March 21 and September 23), the Sun's rays are perpendicular to the Equator.

The Earth's axis actually undergoes three movements. The axis is presently pointed at the star Polaris, but wobbles like a top which is losing energy, and approximately every 26,000 years, it makes a complete wobble circle (precession). In addition, the axis angle changes through a cycle of 21.5 to 24.5 degrees of tilt to the Earth's orbital plane around the sun every 41,000 years. Finally, the planet undergoes small variations in the tilt angle, called nutations. The major nutational change occurs every 18.6 years, although smaller changes occur every 180 days.

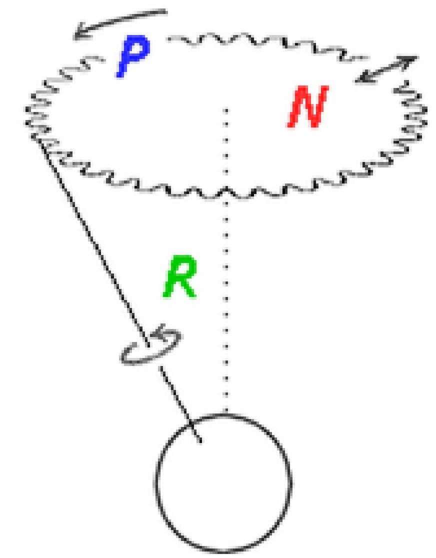

Figure 1. Earth's Axis Rotation (R), Precession (P), and Nutation (N)

Thus, over a period of time, the tilt of the Earth changes and this can be related to ice-age cycles (For more information, see Milankovitch Cycles on Wikipedia).

The ***precession of the Earth's solar orbit*** is another long-term effect which changes the amount of solar heating received from the sun. The Earth's orbit is nearly circular, but over a period of time, the eccentricity changes from 0.01 to 0.07 within periods of approximately 95,000 years. When the eccentricity is a maximum, the Earth will be 5% closer to the sun and will receive nearly 11% more solar radiation.

Neither of the above affect climate significantly over a short period of 100-200 years, but are major drivers for ***ice age cycles***. The last ice age peaked about 21,000 years ago and in the last 11,000 years, we have been in an "interglacial warming period." More about that later!

Ocean currents have a significant effect on the climate. The Gulf Stream sends heat to Northern Europe and England, moderating their climates.

Discussion of Climatic Factors Which Change over Short Periods of Time

Short-time changes in temperature are generally considered to be “weather” changes, rather than “climate” changes, nevertheless, the media and environmentalists often interpret these as climate changes (in spite of the dictionary definition of climate).

The ***solar constant*** refers to the energy per unit area put out by the sun at the distance the Earth is from the Sun. Although it is called a constant, the value varies due to the actual distance the Earth is from the Sun as it follows its eccentric orbit. Measured values vary from 1412 Watts/m^2 in early January to 1321 Watts/m^2 in early July. It can also vary due to sun spot cycles.

The topic of ***Greenhouse gases*** will be covered in more depth on pages15-17 in this write-up.

We are all familiar with the differences in climate between the ***seasons.*** One thing we quickly recognize is that some winters seem harsher than others or some summers seem hotter than others, or drier than others, etc. Because there is such a wide variation of temperatures during summers or winters, or even for the same day of the year, ***it is difficult to determine what the normal weather variation is and what a bona fide climate change is.*** For example, in the last 120 years the following temperature extremes have been recorded in US cities below:

Phoenix	17F----122F	Reno	-16F----108F
Hartford	-26F----102F	Concord	-37F----102F
Portland	-39F----103F	Bismarck	-44F----111F
Kansas City	-23F----109F	Huron, SD	-41F----112F
Lander, WY	-37F----101F	Honolulu	53F----95F

Many US states have experienced spreads of temperatures of greater than 170F in the last 120 years.

Albedo is a measure of the solar heat reflected by the Earth or clouds. Some 31% of incident solar radiation is reflected back into space and does not warm the Earth. Typical albedos (with sun overhead) in percent are:

– Oceans 2-6 (3.5 avg.)
– Forests 9 (pine); 13 (deciduous)
– Barren fields 5-40 (depending on soil color)
– Cities 7 (temperate); 12 (tropical)
– Farmlands 15

– Grasslands 20
– Beaches, deserts 25
– Snow 90 (fresh); 80 (old snow)
– Smooth cloud tops 80 (Can drop to 0, depending on the cloud)
– Earth (Average) 31

The ***albedo*** of an area can be significantly changed by plowing the ground, planting crops, paving parking lots and roads, or by the falling of fresh snow. Temperatures in urban cities are often higher than surrounding farmlands, reflecting this climate change.

Volcanic activity puts aerosols and dust into the upper atmosphere and in some cases, into the stratosphere. ***With the recent eruption of Pinatubo in 1991 in the Philippines, the mean world temperatures dropped by about 2F for nearly 2 years***. In 1815, the eruption of Tambora in Indonesia resulted in a year without a summer. New England and Europe were hard hit. Snowfalls and frosts occurred in June, July, and August and almost all grains were destroyed, resulting in the massive slaughter of farm animals.

Cloud cover in the daytime during the summer results, as everyone knows, in cooler days. Cloud cover at night traps the long-wave infrared radiation from the Earth and results in warmer nights.

Wind patterns result in hurricanes, tornadoes, and cyclones, but also in seasonal arid or stormy conditions like Santa Ana winds, monsoons, Nor'easters, etc. Special interactions of winds and ocean surface temperatures in the Pacific result in ***El Ninos***, and ***La Ninas***. These affect the rainfall not only in the United States, but in Europe and Africa. These can last more than one season and appear to be "climate changes".

Increases in ***aerosols and dust***, even of non-volcanic origin, act to change climates by absorbing sunlight in the atmosphere. Perhaps the most common of these are the clouds of fine sand that cross the Atlantic Ocean from the Sahara desert and are deposited in the Amazon of South America. Another example was the "dust bowl" in central United States in the 1930's. The significance of dust on climate change is discussed in more detail on page 45 and shown in Figure 18.

Conclusion: There are many factors which can bring about climate changes other than an increase in greenhouse gases.

SOLAR HEATING--SHORT WAVE RADIATION

Source of the Earth's Heat

The Earth receives 99.998% of its heating from the sun. The remainder comes from the molten Earth core and its internal radioactive decay. The sun's surface (photosphere) is about 10,400^{o}F and delivers a spectrum of ***short-wave*** radiation to the earth. This spectrum consists of ultra-violet radiation (5.8%), visible light (48.6%), and near-infrared radiation (45.6%). A portion of the ultraviolet light, which is lethal to most living organisms, is almost completely filtered out by reacting with ozone in the stratosphere, whereas, the visible light and the infrared rays heat the earth. The amount of heat the Earth absorbs depends on the ***albedo*** (reflectance of the Earth's surface and the cloud tops). The absorbed radiation warms the Earth during the daytime.

Solar Radiation

The sun's radiation level, the solar constant, as measured by satellite, is approximately 1366 Watts/square meter of the Earth's cross-section.
If the Earth were shaped like a hockey puck or disc, the side perpendicular to the sun's rays would all be receiving 1366 W/m^2 during the daytime, while the backside (night time) surface would be receiving zero. If the disc suddenly flipped sides every 12 hours, the average solar energy falling on both sides would be 683 watts per square meter.

But our Earth is not a disc, it is a sphere. The surface area of a sphere is twice the area of both sides of the disc; therefore we receive an ***average*** of 342 Watts per square meter of Earth's surface. Some 49% of this actually warms the Earth. The rest warms the atmosphere or is reflected back into space.

Because of its spherical shape, the Earth is not heated evenly. The equatorial regions receive the more direct sunlight while the higher latitudes receive ever decreasing heat due to the surface curving away from the sun. At the poles very little solar energy is received. The temperature of the Earth is, therefore, not uniform. This results in atmospheric high and low pressure areas, warm and cold air masses, and winds, as the Earth attempts to equalize temperatures and pressures. Winds also occur from the rotation of the Earth.

RADIATION BY THE EARTH AND ATMOSPHERE – LONG-WAVE

Any atom, molecule, or object above absolute zero radiates its energy to outer space in a spectrum characteristic of its temperature. In the case of the Earth and the atmosphere, this spectrum is in the infrared range and ranges in wave lengths from 1.6 microns to 50 microns with the peak at about 10 microns. This infrared range is termed ***long wave-radiation*** and allows the Earth and atmosphere to exchange radiant heat with each other and to reradiate its daily incoming heat to outer space.

For a more complete description of the details of heat transfer between the Sun, Earth, atmosphere and outer space, see Appendix A

Radiation Interactions with Matter

When radiation interacts with matter, it is either reflected, transmitted, or absorbed. Energy is only passed unto the molecules when the molecules ***absorb*** it. Most of the Earth's atmosphere is transparent to solar radiation, resulting in no heat pickup by the atmosphere.

However, molecules that contain 3 or more atoms, such as CO_2, H_2O, NO_2, and CH_4, absorb radiation at particular wave lengths or ranges of wave lengths, allowing for solar (short-wave) heating of the atmosphere. Appendix A shows that O_3 and water vapor (H_2O) absorb significant incoming ***solar*** radiation. CO_2 absorbs only a tiny bit of ***solar*** radiation (absorption band at 2.1micorns or 2100 nanometers).

The long-wave spectrum of radiation from the Earth and atmosphere, as previously stated, lies in the infrared spectrum, where these gases absorb and reradiate energy back and forth between the atmosphere and the Earth, and eventually to outer space. These gases are called "greenhouse gases", because, like the glass in a greenhouse, they let most of the solar radiation in, but block some of the long-wave infrared radiation from leaving.

Clouds are composed of fine droplets of water. Cloud tops can reflect solar radiation back into space or allow the passage of "diffuse" light through the clouds to the Earth. Diffuse light results from multiple reflections in different directions and "soft" shadows are formed, rather than sharp shadows from direct sunlight.

Radiation Balance

Heating of the Earth is analogous to weight control. If you take in more calories than your body burns, you gain weight. If you take in less than your body burns, you lose weight. If you take in the same amount as your body burns, your weight stays the same.

So it is with solar heating. Because of the tilt and rotation of the Earth, the amount of radiation received by a particular place on earth constantly changes. In winter, the Northern Hemisphere is tilted away from the sun. Because of the slanted rays and shorter days, the Northern Hemisphere receives less heat than it radiates to the atmosphere and outer space. The result is cooling of the earth's surface. In summer, the Northern Hemisphere is tilted toward the sun, and its surface receives more heat than it reradiates to space, so the temperature rises. There is a lag in both winter and summer, so the coldest or hottest days do not occur at the shortest day (Dec. 21,) or the longest day (June 21) because of the heat level that remains in the Earth's surface or the atmosphere. The coldest and hottest days lag the start of winter and the start of summer, typically, by more than 60 days.

Over a year's time, the surface of the Earth should dissipate about the same amount of heat it received in the year to stay in balance. By the same token, the atmosphere should radiate to outer space the same amount of heat it received from the Sun and the Earth. But this is never exactly so. Some years winters are colder than others and some years, the summers are hotter than others. For more details, see charts in Appendix A.

Ice Ages

Like weather, the climate goes through periods of heating and cooling. Major periods are called "ice age cycles". The period of cooling is called a "glacial period" and that of warming is called an "interglacial period". Nevertheless, climatic variations or trends, during these cycles, may extend for several centuries.

Some 20,000 years ago, the last ***ice age*** ended. About 11,000 years ago, a significant global warming trend developed (Figure 2). During this last ice age, glaciers, some well over 1½-miles thick, covered large areas of North America, Europe, and Western Siberia. Since they started melting, the oceans have risen 394 feet. The Great Lakes, the Finger Lakes, and thousands of fresh-water lakes in Canada and Upper United States (Wisconsin, Minnesota, and Michigan) were formed by the melting glaciers. Long Island, New York, was formed as an accumulation of glacial debris.

Is it not reasonable to think that some global warming will continue until we start into another ice age cycle? A further description of the warming is found on page 17 in the section called “IS THE EARTH REALLY WARMING?”