APPENDIX A.

ADDITIONAL DETAILS ON HEATING THE EARTH AND ATMOSPHERE

This Appendix is for the student who is more interested in the details of the heat exchange between the Sun, Earth, and atmosphere. The average person may choose to scan or skip this section.

On page 11, it was pointed out that the average area of the Earth receives 342 Watts per square meter from the Sun. The sun bathes the Earth in short wave radiation in the ultraviolet spectrum (Ultraviolet C, 0.001-0.280 microns; Ultraviolet B, 0.280-0.315 microns; and Ultraviolet A, 0.315-0.380 microns), in the visible light spectrum (0.380-0.765 microns) and in the infrared spectrum (0.765-3.0 microns).

Does this mean the average Earth's surface is heated by an average of 342 W/m^2 per day? No, certainly not! The average Earth's atmosphere and surface are hit by solar radiation levels of 342W/m^2 on an average day, but a significant portion of it is reflected back into space.

The accepted average distribution of the daily solar radiation is:

107 W/m^2----is reflected to outer space or 31% of
incident radiation. Of this:
30 W/m^2—reflects off Earth's surface (28%)
77 W/m^2---reflected off clouds and aerosols (72%)
77 W/m^2-----absorbed by Atmosphere (20%)
168 W/m^2—absorbed by the Earth's surface (49%)

<u>Total Radiation =342 W/m^2 (average) received by the Earth and Atmosphere daily</u>

The Earth then sends heat to the Atmosphere as follows:
24 W/m^2 ----thermals of heated surface air (14.3%)
78 W/m^2 ----evaporation of water which condenses into clouds,
giving up heat to the atmosphere (46.4%)
66 W/m^2 ----long-wave IR radiation sent to space from the
heating of earth (39.3%)

Total net energy transfer from Earth to Atmosphere = 168 W/m^2

The Atmosphere then radiates to outer space:

67 W/m^2 ---solar radiation absorbed (28.5%)
168 W/m^2---transferred from Earth (71.5%)
Total long wave energy radiated to space = 235 W/m^2

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 from 1.6 microns to 50 microns with the peak at 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 radiate its daily incoming heat to outer space.

If the Earth and the atmosphere radiated less heat to outer space than they receive, the Earth and the atmosphere would warm. Contrarily, if the Earth and atmosphere radiate more heat to outer space than they receive, the Earth and the atmosphere would cool. This is exactly what happens on a seasonal basis, wherein winters become cold and summers become hot. It also happens on a day-to-day basis where one day it is cloudless and more sunshine arrives at the Earth's surface or when a day is overcast and the clouds absorb or reflect a larger portion of the incoming energy.

Both the Earth and the atmosphere contain immense quantities of heat. When the Earth is warmer than the atmosphere, it radiates long-wave infrared radiation to the atmosphere, some of which is captured by the greenhouse gases. When the atmosphere is warmer than the Earth, it radiates long-wave infrared energy to the Earth. Thus, during a 24-hour period, large quantities of energy are exchanged between the two. This was not explained in detail in pages 62-63; only the net effect of the daily loss of the earth's heat was shown in the sections above.

Transfer of Heat between the Sun, Earth, Atmosphere, and Space

Figure 21, below is the IPCC diagram of the transfer of heat between the Sun, Earth, atmosphere and outer space. This may be found at Climate Change 2001: Working Group 1: The Scientific Basis, Chapter 1, http://www.grida.no/climate/ipcc_tar/wg1/041.htm. A slightly different version may be found in Reference 6, pages 257-258.

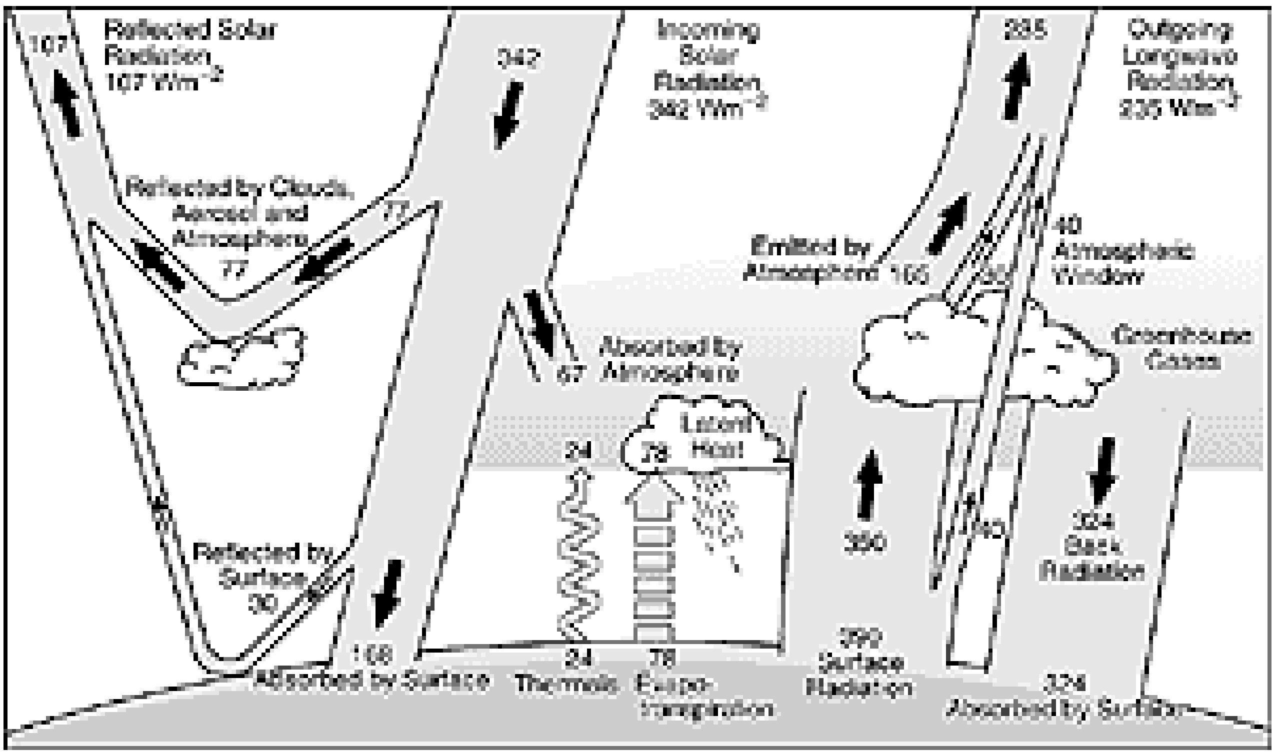

Figure 21. Transfer of Heat between the Sun, Earth, and Atmosphere

Figure 21 adds more details about the long-wave radiative heat exchanged between the Earth and the atmosphere. As just mentioned, the information presented on pages 62-63 only shows the average ***net*** daily transfer of heat, not the gross transfer. Actually, the ***atmosphere transfers an average of 324 Watts per square meter to the Earth each typical day*** and the ***Earth transfers 390 Watts per square meter. The atmosphere receives 350W/m^2 and outer space receives 40W/m^2.***

It's analogous to you and your wife playing poker with the neighbors. When you are short of chips, you borrow from her, and vice versa. In the end, however, no matter how much is transferred back and forth, there is a net loss at the end of the game.

As mentioned on pages 62-63, these are typical average values for an entire year, but we know as winter approaches, the Earth receives less heat from the sun and both it and the atmosphere grow progressively colder. As summer approaches, the Earth and atmosphere receive more heat from the sun and they warm up, because they are not transferring as much heat to outer space. We like to think in terms of equilibrium: that the Earth does not accumulate heat or the atmosphere does not accumulate heat and that each loses the same amount each day to stay in equilibrium. But this is simply not the case. We even have years when some appear colder than others or some appear warmer than others. We have years when the troposphere heats up or the stratosphere heats up as shown below:

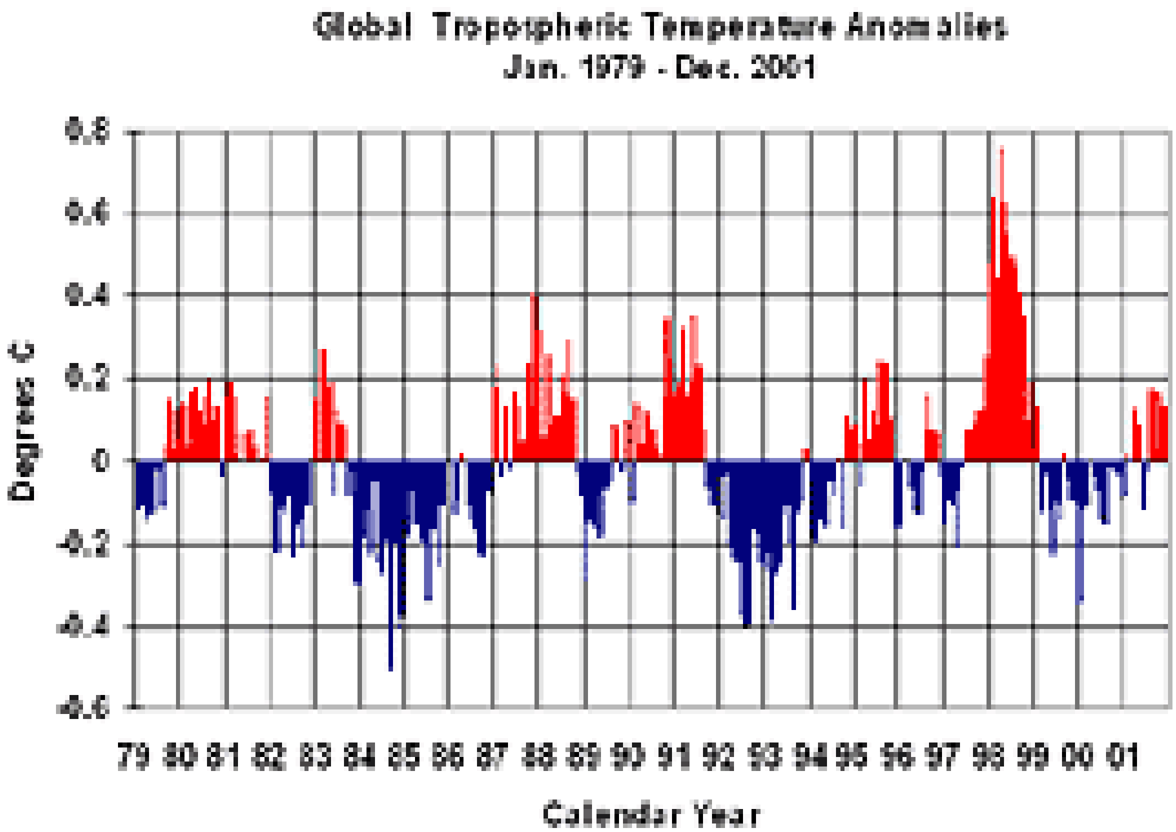

Figure 22. Global Tropospheric Temperature Anomalies---1979-2001

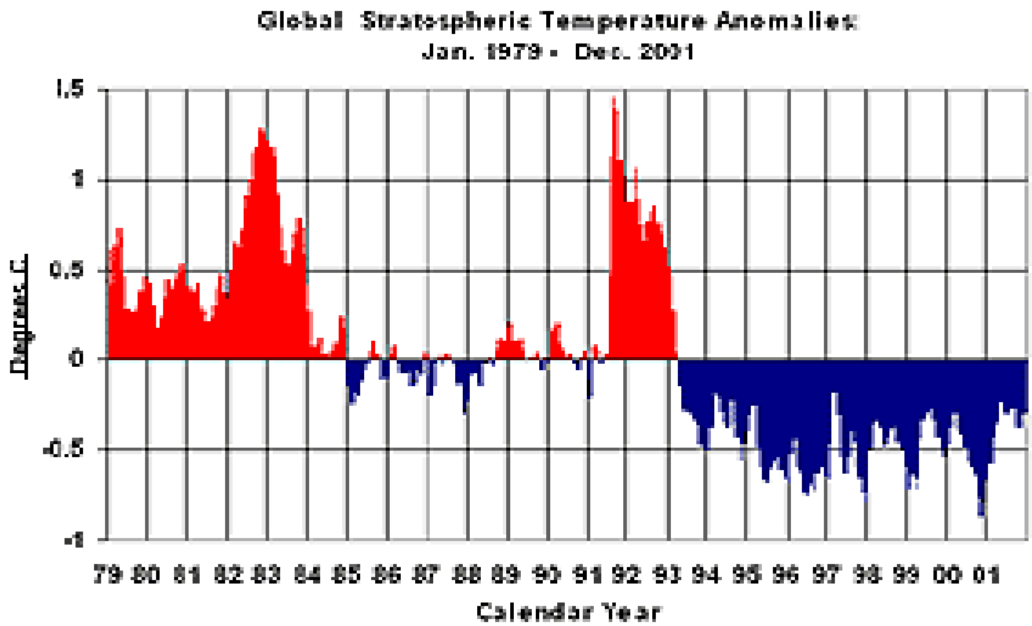

Figure 23. Global Stratospheric Temperature Anomalies---1979-2001

The radiation spectrum and absorption spectrum of both the sun and the Earth are presented below:

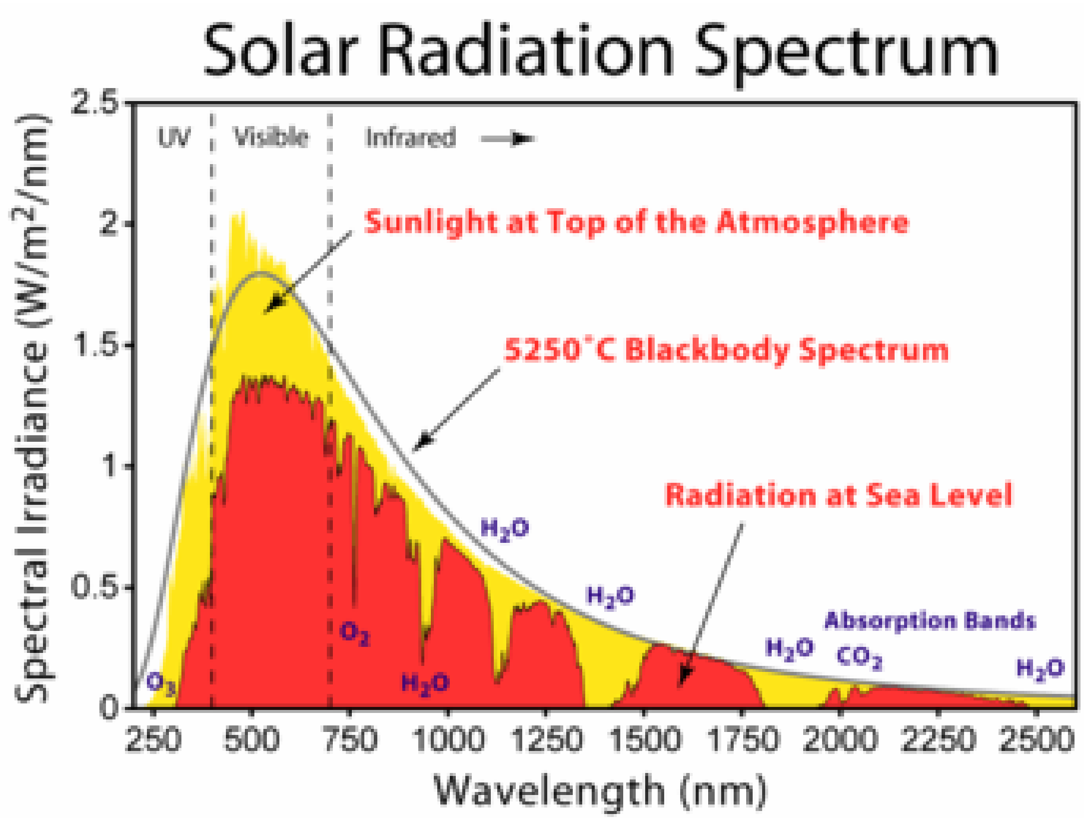

Figure 24. Solar Radiance Spectrum and Absorption Bands

Note that virtually all solar radiant energy is absorbed by water vapor or ozone. The rest of the atmosphere is ***transparent*** to solar energy. As mentioned on page 12, the atmosphere is transparent to monatomic and diatomic molecules, such as Argon, Nitrogen, and Oxygen, but molecules with 3 or more atoms can absorb energy of certain specific frequencies by resonance between electronic bonds (CO_2, CH_4, H_2O, N_2O, NO_2, etc.)

Of these, only water vapor and ozone (O_3) absorb short-wave radiation from the sun, except for a very tiny portion of solar energy absorbed by carbon dioxide. The gases with 3 or more atoms per molecule absorb mostly the long-wave radiation given off by the Earth and atmosphere and are called greenhouse gases.

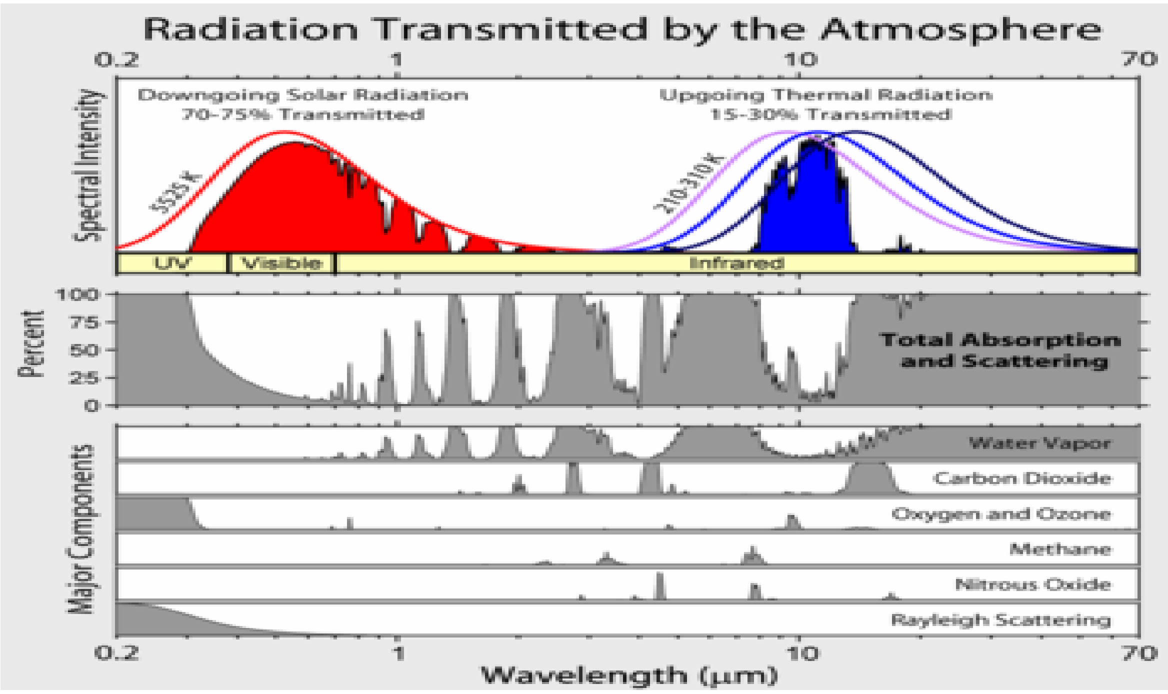

Figure 25. Solar and Long-Wave Radiation ---Transmitted by the Atmosphere

The uppermost chart shows the spectrum of solar radiation (left side) and long-wave (Earth and atmospheric) radiation given off (right side). The uppermost chart shows radiation ***transmitted by the atmosphere*** (red –solar radiation, blue—infrared long-wave radiation). The radiation levels not transmitted (i.e., ***absorbed***) are the gray areas in the middle chart. The various greenhouse ***absorption bands*** for water, carbon dioxide, methane, ozone, and nitrous oxide are shown in the lower chart. Note the bulk of the absorption for carbon dioxide is in the 15 micron wave length. While carbon dioxide can theoretically absorb at 5 other frequencies, there is virtually no energy transmitted at those frequencies, so essentially little heat is absorbed there.

Both the reflectance of solar (short-wave) radiation and the emission of the Earth's infrared (long-wave) radiation can be easily monitored by satellites. The picture below (Figure 26) is that of solar reflectance.

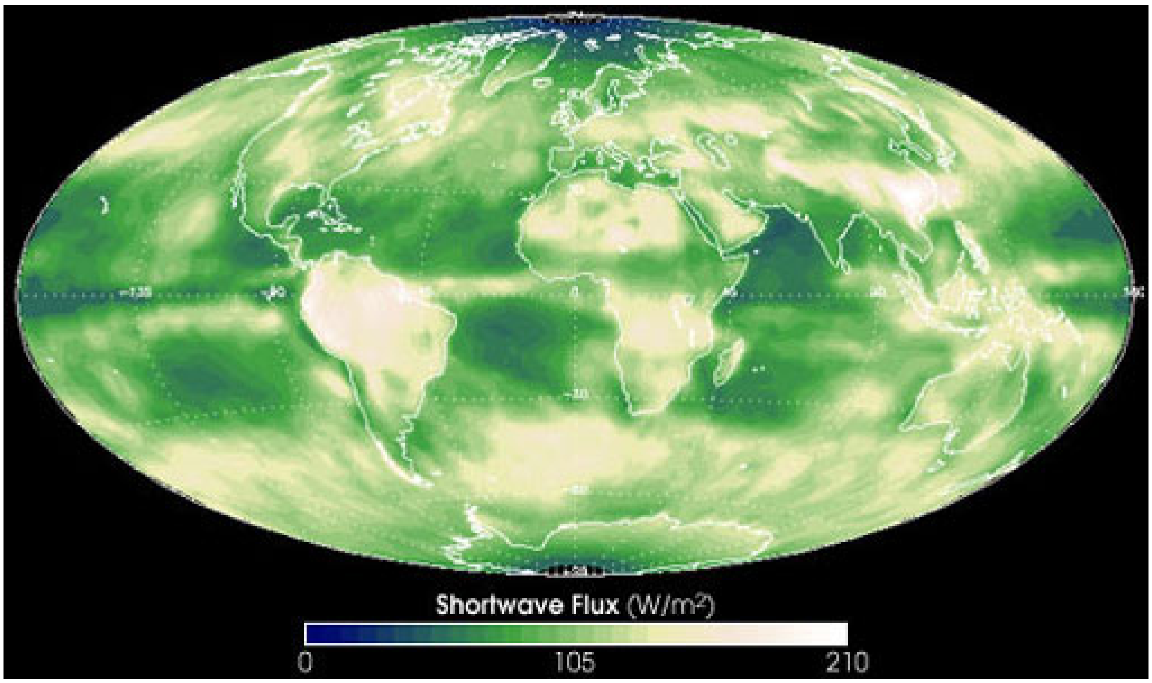

Figure 26. Satellite Picture of Solar Flux Reflectance

This picture may seem confusing. Why are all areas so reflective? All those continents do not receive the radiation at the same time. This is a composite satellite picture of the reflectance at ***noon*** for the entire world. Although the Earth receives an ***average*** of 342 Watts per square meter from the sun, more energy is obviously received in the equatorial regions throughout the year. When the equinoxes occur (March 21, September 22), the sun is directly over the equator. The land at the Equator receives 684 Watts per square meter during a 24-hour day. At other latitudes on these dates, the sun's rays are slanted (due to the Earth's curvature) and energy per unit area during the 24-hour day is equal to the cosine of the latitude multiplied by 684 Watts per square meter. Hence, the energy diminishes to essentially zero at the poles on these dates.

The emission of the Earth's infrared heat in watts per meter squared is shown in the satellite photograph below (Figure 27).

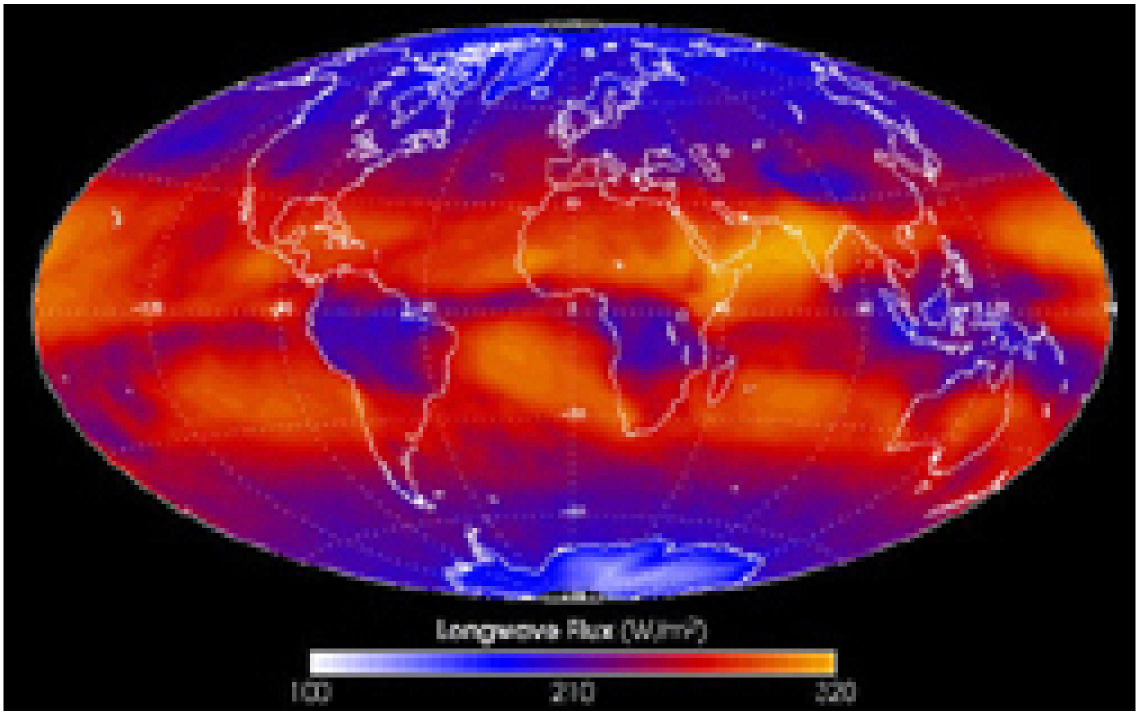

Figure 27. Satellite Picture of Earth's Long-Wave Radiation

Notice that emissions diminish toward the poles. This is because the temperature becomes lower and less heat is radiated from these regions.

Sunspot activity affects solar radiation flux and solar winds. It appears to have 11-year cycles and is shown in Figure 28.

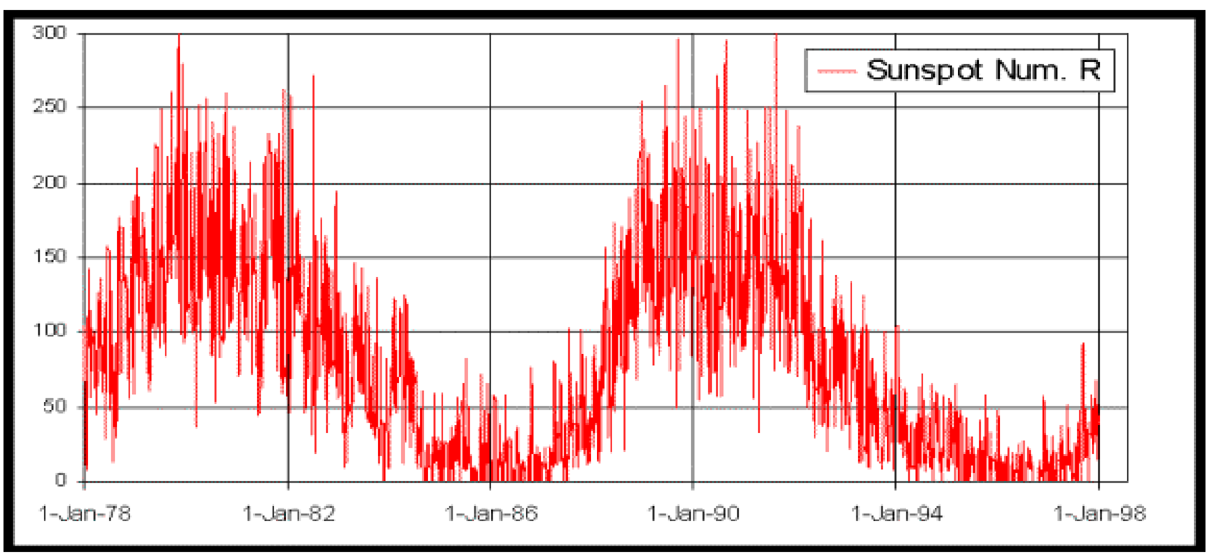

Figure 28. Sunspot Activity

This is a plot of the number of sunspots, not the radiation levels. However, the number of sunspots does affect radiation levels.