HEATING THE EARTH

1. Virtually all of the Earth's heat energy comes ultimately from the Sun. The Sun provides virtually all of the energy that is used in the circulation of the atmosphere and in the circulation of the oceans. It is the ultimate source of energy for all known living things.

2. This emission of electromagnetic energy is derived from nuclear fusion within the Sun. The output of solar radiation varies from time to time because of processes and events taking place within the Sun itself. This variation appears to be within a range of plus or minus 1.5%. Most of this increase or decrease in emissivity lies within the ultraviolet spectrum. The resulting average emissivity appears to be about 3.90×10^{33} ergs per second.

3. If the Sun were a blackbody, this emissivity would correspond to a surface temperature of 5798°K. However, the wavelength of maximum intensity is at 0.475 microns (green light). By Wien's Law, this is the maximum that would be produced by a blackbody at a temperature of 6101°K.

4. About 98% of the solar radiation has wavelengths between 0.03 microns and 3.0 microns. This results in an emissivity that is 9% in the ultraviolet range, 45% in the visible range, and 46% in the infrared range.

5. The amount of insolation received by the Earth at any given instant is a function of the Sun's emissivity as described above and of the Earth-Sun distance at that time; since solar radiation follows the inverse-square law, and the amount received by the Earth is inversely proportional to the square of the distance between the Earth and the Sun.

6. The Earth's orbit about the Sun approximates an ellipse. The point on that orbit that is closest to the Sun in called ***perihelion***, and is reached during the first week in January each year. The point on that orbit that is farthest from the Sun is called ***aphelion***, and is reached during the first week in July of each year. These changes in the Earth-Sun distance bring about an annual variation in the amount of solar energy received at the outside of the Earth's atmosphere of some plus or minus 4.0%.

7. If the variations in the solar emissivity and the Earth-Sun distance are averaged out, the solar energy intercepted by the Earth at the outside of its atmosphere has a mean value of 342 Watts per square meter, measured normal to the Sun's rays.

8. This solar electromagnetic radiation received at the outside of the Earth's atmosphere is termed ***insolation***. Some of this insolation will be absorbed directly by the atmosphere, some will be scattered or reflected by the various components of the atmosphere, and the remainder will be transmitted directly to the Earth's surface.

9. Absorption of insolation will be accomplished primarily by the minor gases and by oxygen. Nitrogen and argon play little part in the absorption of radiation of any kind. Water vapor does most of the absorption of insolation, absorbing strongly in scattered bands throughout the infrared spectrum. Ozone absorbs strongly in the ultraviolet spectrum, and has scattered absorption bands in the visible and infrared. Absorption by carbon dioxide occurs mostly in the infrared spectrum, with its absorption bands largely overlapping those of the much more abundant water vapor. Clouds and dust absorb virtually all of the infrared insolation that falls upon them, but very little of the visible and ultraviolet.

10. Absorption of the photons of electromagnetic radiation, of course, results in an increase in the temperature of the matter doing the absorbing. This increase in temperature, in keeping with the Stefan-Boltzmann equation, results in an increase in the emission of electromagnetic radiation in turn. The atmosphere is a strong emitter of electromagnetic radiation in the infrared range, and absorbs most of its own radiation. As we have seen, above, it also absorbs radiation from the Sun. Finally, it absorbs a tremendous amount of infrared radiation from the Earth's surface..

11. Scattering and reflection of solar radiation within the atmosphere is accomplished principally by clouds, and secondarily by the air molecules themselves. Dust and other particulates are important only to a minor degree in their normal concentrations.

12. Clouds cover about 62%of the Earth's surface an any given time, and reflect an average of half the visible and ultraviolet radiation that falls upon them. Clouds reflect on virtually all visible wavelengths, and thus appear white on their reflecting sides.

13. Air molecules, on the other hand, scatter only those wavelengths at the shorter (blue) end of the visible spectrum. This scattering of blue light gives the clear sky

its blue color. That part of the ultraviolet spectrum that is not absorbed by the atmosphere is almost completely scattered by air molecules. This scattering of both visible and ultraviolet radiation, together with the absorption and re-radiation of the infrared portion of the solar spectrum reaches the Earth's surface as diffused or "sky" radiation. This diffuse radiation can easily exceed direct solar radiation (direct sunshine) under even partially cloudy conditions.

14. Dust and cloud particles of the right size may also scatter the longer (red) wavelengths of visible light, thus giving the reddish colors to sunsets and sunrises. The longer solar path lengths at these times of day give the atmospheric particles greater opportunity to scatter the red light.

15. Insolation that is neither absorbed by the atmosphere nor reflected back into space eventually finds its way to the Earth's surface. Here, it is once more either absorbed or reflected. The percentage of radiation that is reflected by a surface is called the ***albedo*** of that surface. Since the albedo of most surfaces varies with wavelength, these surfaces appear to have tone (intensity of reflected radiation) and color (wavelengths of reflected light) when reflecting visible light. Although we cannot sense it directly, surfaces display similar characteristics for the ultraviolet and infrared portions of the spectrum.

16. That part of the radiant energy that strikes the Earth's surface and is not reflected must be absorbed, since no significant amount of transmission through the solid Earth occurs. The Earth's surface, in turn, is always emitting radiation in the infrared range. Some of this radiation escapes to outer space, but most is absorbed by the atmosphere.

17. Over an appreciable period of time, the Earth-atmosphere system will radiate to outer space as much radiation as it absorbs from the Sun—although on different wavelength, since all terrestrial radiation is in the infrared spectrum. If we assume a mean solar constant of 342 Watts per square meter, and an overall terrestrial albedo of 31.3%, then the system radiates to space an average of 235 Watts per square meter.

18. This is the amount of radiation that would be emitted by a blackbody at about 251° Kelvin. However, the wavelength of maximum intensity is about 10 microns. The latter value gives a blackbody temperature of 290° Kelvin, which is very close to the mean surface temperature of the Earth. The difference between these two values is due to the "blanketing" effect of the atmosphere's "greenhouse" gases.