EARTH – SUN RELATIONSHIPS

The purpose of this particular paper is to present a very basic summary of what we currently know about these Earth-Sun relationships, couched in language and concepts accessible to the educated layman. If I were writing for fellow professionals, I would use an entirely different approach. However, professionals in the field of atmospheric sciences already know the things that I am about to discuss—or should.

The sun as the ultimate source of energy – Virtually all of the earth's heat energy comes ultimately from the sun. It may come directly as sunshine or indirectly as moonshine (solar radiation reflected from the surface of the moon) or even more indirectly from the energy of solar tidal forces. It may make itself manifest immediately, as in the warming rays of the sun on your skin. It may be stored in various ways and become sensible heat at some later time, as in the warming of the night air by the warm earth or as in the burning of fossil fuels. However it comes, the Sun is the source of virtually all of the earth's heat. When early peoples spoke of the sun as the source of all life, they spoke truly.

Non-solar sources of energy – A very small part of the earth's heat budget comes from non-solar sources. These include the steady flow of heat from the earth's molten interior to the surface of the planet and radiation from parts of the universe other than the sun. Heat flux from the interior is the next largest source of energy after insolation, but is still less than twenty thousandths of one percent of the solar energy input. The total energy from the rest of the universe is even less. The energy that mankind releases to the atmosphere in an entire year is less than the Earth gets from the Sun in ten minutes. All non-solar sources put together are—for all intents and purposes—insignificant in devising heat budgets for the earth and its components.

Measuring Insolation – Over the years, we have developed a number of ways of estimating how much energy the Earth receives from the Sun. Most of these have involved measuring solar intensity here on the surface, and then estimating how much of the original incoming radiation was absorbed and how much was scattered and reflected by the various components of the intervening atmosphere. With the development of artificial satellites, however, it became possible for the first time to directly measure insolation (**in**coming **sol**ar radi**ation**) at the "outside" of the

Earth's atmosphere; and—equally important—directly measure outgoing radiation from the Earth and its atmosphere.

Heat Budgets – As anyone who has ever prepared a monetary budget can tell you, you have to know with some accuracy what both the total "income" and the total "outgo" are in order to prepare a meaningful budget. The same thing is true with the Earth's heat budgets. Since the late 1970's, the use of various types of radiation sensors on artificial satellites has given us that information with a relatively high degree of precision and accuracy. Let us start with measurements of "income"; that is, incoming solar radiation.

The Solar Constant – Satellite measurements over a period of twenty-two years (two complete eleven-year sunspot cycles), have produced a value for incoming solar radiation (insolation) at the "top" of the Earth's atmosphere (TOA) of **1,366.1 watts per square meter.** This is the new ***solar constant***. It replaces earlier estimates, and will be replaced by a better value in the fullness of time. This is the starting point for all current studies of the various heat budgets of the Earth. For budget purposes, this is usually rounded down to 1366 watts per square meter.

Vernal Equinox Year – Most monetary budgets are based on the period of one year, and heat budgets use this same type of period for much the same reasons. Heat budgets, however, benefit by using the vernal equinox year rather than the calendar year. The vernal equinox year is the time it takes the Earth to go from the instant of one March equinox to the instant of the next March equinox. For the next several centuries, this year will have a value of **365.2424 days** or **3.155694336×10^7 seconds.**

Effective Terrestrial Disc and Area – Incoming solar radiation is intercepted by the ***effective terrestrial disc***. This disc represents the cross section of the solid/liquid Earth and its narrow outer rim of absorbing and reflecting atmosphere. The radius of such a disc is necessarily arbitrary. The question is avoided by adopting the convention of measuring the Earth's heat budget in watts per square meter. Since the surface area of a sphere is exactly four times the surface area of a circle of the same diameter, we get an average global value of 341.5 watts per square meter. This is usually rounded up to 342 watts per square meter.

Annual Global Budget Constraint – This value of 342 watts per square meter is the annual global budget constraint. Over any reasonable period of years, the outgo of reflected solar radiation and terrestrial infrared radiation plus global heat storage must total this amount.

Insolation Variations – Although the solar constant is a mathematical constant, the actual amount of insolation that is received by any square meter of surface in any one second at the surface of the Earth varies substantially from place to place and from time to time. Many of these variations are systematic, and the magnitude of the variation is (more or less) easily calculated. This makes prediction of future values a relatively simple matter. Some variations—especially those related to solar emissivity and atmospheric conditions—appear to be random at this time. The magnitude of these variations, therefore, can not be directly predicted, but must be estimated using statistical methods.

The Five Controls of Insolation – The amount of radiant solar energy that plays a role in the Earth's heat budgets is subject to five major controls: solar emissivity, Earth-Sun distance, atmospheric attenuation, angle of incidence, and the albedos of both the surface and the atmosphere itself.

Solar Emissivity

Measuring Solar Variability – Variations in solar emissivity are due to processes and occurrences taking place within the sun itself, and affect the sun's emissivity from its photosphere. Before the advent of direct measurements of solar emissivity by artificial satellites in the late 1970's, variations in solar emissivity were estimated from observations of sunspot numbers and groupings, and from concentrations of cosmogenic isotopes in sediments and organic materials.

Period of Direct Measurement - During the time that we have been using satellite measurements, the variation in solar emissivity has been slight—once the eccentricity of the Earth's orbit has been factored out. This non-orbital variation has been on the order of 0.1%; but it must be borne in mind that the period of record is still small—less than thirty years so far. Most climatologists consider a thirty-year record the absolute minimum period for reasoned characterizations. They feel much more comfortable with a sixty-year record, and don't really begin to relax until they have ninety years or more.

Sunspot Activity and Solar Emissivity – There is a strong positive correlation between sunspot activity and solar emissivity. A number of cycles of sunspot activity of various periodicities have been proposed by scholars, but there is strong evidence only for the eleven-year cycle and its multiples. Although the first recorded mention of sunspots dates to China some 2800 years ago, systematic observations and recordings date only to the invention and spread of telescopes in the seventeenth century. Even then, data were sketchy and comparisons unreliable. Only in the last two-hundred years has data been gathered that meet even the most rudimentary standards of scientific acceptance.

Cosmogenic Isotopes and Solar Emissivity – There is also believed to be a strong inverse correlation between solar emissivity and the concentration of cosmogenic isotopes. Both the concentration of beryllium-ten in ice cores and sediments and the concentration of carbon-fourteen in tree rings are thought to be inversely related to emissivity. Measurements of these isotopes allow us to hypothecate solar emissivity back through periods when neither direct measurements were available nor sunspot activity accurately observed.

Proxies – When we measure sunspot activity or cosmogenic isotope concentrations, we are not directly measuring solar emissivity. We are measuring something else that we believe to be strongly correlated with solar emissivity. Such indirect measurements are termed "proxies". Since measurements of temperature, rainfall, sea level, and other parameters important to theories of climate change are available only for the last hundred years or so, the use of proxies is an important part of climate science. It is also extremely controversial, with climatologist in hot dispute as to what proxies actually mean and how much scientific weight to give them.

Solar Emissivity and Climate Change – The correlation between these various estimates of past solar emissivity and historic climatic changes is strong but not conclusive. There is measurable correlation between increased sunspot activity and the **Medieval Warm Period** (1100 to 1250); and even stronger correlation between decreased sunspot activity (especially the Maunder Minimum) and the **Little Ice Age** (1450 to 1850).

Students of climate change should note that the present period of sunspot activity (since 1950) is outstanding in both its magnitude and its duration.

Time Lag of Insolation Forcing – It should be noted that although local temperatures are strongly forced by variations in insolation (witness the temperature changes from day to night), global temperatures respond much more slowly due to the enormous heat capacity and thermal inertia of the world ocean. It may take several years for any significant change to be observed. This, in turn, depends upon the magnitude of the variation and in which part of the solar spectrum the variation is concentrated.

Emissivity Variations and the Solar Spectrum – Most variations in solar emissivity have been recorded in the ultraviolet portion of the solar spectrum. The observed variations in the visible portion have shown a much lesser magnitude, and the variations in the infrared portion have had the least variance of all.

Long Term Changes – The consensus of informed opinion is that there has been an increase in solar emissivity over the past two centuries. The magnitude of this increase and the magnitude of its effects on global temperatures are both the subject of strong scholarly argument.

Very Long Term Changes – The Sun is gradually expanding and getting hotter. Astronomers estimate that the emissivity of the Sun is increasing by some 10% over each billion years.

The Role of Solar Emissivity in Climate Change – Scholars have advanced a large number of hypotheses as to the role of solar emissivity in climate change. Simple thermodynamics tells us that there is a role. The **observed** variations (since 1978) appear to be too small to account for major climate changes. Therefore, the arguments tend to revolve about the validity of derived and indirect measurements (proxies) and the magnitudes of both positive and negative feedback mechanisms.

Earth-Sun Distance

The Inverse-Square Law – Solar radiation obeys the inverse-square law. That is, its intensity in inversely proportional to the square of the distance between the Earth (the receptor) and the Sun (the emitter). This distance, in turn, varies with the position of the Earth at any given time on its annual orbit of the Sun; and with the longer-term (about 100,000 years) cycle of the variations in the eccentricity of the Earth's orbit.

Eccentricity of the Earth's Orbit – At the present time (2006), the eccentricity of the Earth's orbit is roughly 0.016726, which is not much by planetary standards. A truly circular orbit would have an eccentricity of zero. The greater the eccentricity, the more elongated the orbital ellipse becomes.

Perihelion – The earth is closest to the sun on or about the fourth of January each year. This date will vary over the next several decades from the 2nd to the 5th

depending upon a number of astronomic factors that need not concern us at this moment. At the instant of perihelion, the amount of energy that will be received by one square meter at the outside of the earth's atmosphere will approximate 353.25 watts—an increase over the Solar Constant of some 3.43%.

Aphelion – The earth is farthest from the sun on or about the 4th of July each year. This date will vary from the 3rd to the 7th over the next several decades, depending upon the same astronomic factors mentioned above. At the time of aphelion, the amount of energy that will be received by one square meter at the outside of the earth's atmosphere will approximate 330.50 watts—a decrease over the Solar Constant of some 3.26%.

Total Current Orbital Variation – The total variation in incoming insolation from aphelion to perihelion is **6.7%** or **91 watts per square meter**. This value will change with changes in the Earth's eccentricity.

Periodic Variations in Eccentricity – The eccentricity of the Earth's orbit varies over a cycle of roughly 97,357 years. On the one hand, it approaches zero eccentricity (a circular orbit). At that value, the variation in insolation from aphelion to perihelion becomes virtually insignificant. At the other extreme, the eccentricity approaches 0.06. At that value, the annual variation in insolation from aphelion to perihelion increases to roughly **24% of the mean value**.

Eccentricity and Climate Change – Although this increase has no affect on the annual heat budget (the solar constant remains the same) it has a very definite effect on the seasonal heat budgets. When combined with the precession of the equinox and the variation in obliquity (see below for both), the result is a strong increase in seasonal range of temperature. This 100,000 year cycle of variations in the Earth's eccentricity is one of the three orbital cycles upon which the **Milankovitch Hypothesis** is based.

Recent Trend in Eccentricity – The Earth's eccentricity is in the diminishing portion of its 97,357 year cycle. That is, the Earth's orbit is becoming less elliptical and more circular. Consequently, the difference in insolation received from perihelion to aphelion is diminishing each year over that from the previous year. In terms of the Milankovitch Hypothesis, this is consistent with the planet moving out of an ice age.

Precession of the Equinox – The times of year at which the Earth is closest to the Sun (perihelion) and farthest from the Sun (aphelion) vary over a period of about

25,920 years. At present, perihelion occurs during the northern hemisphere winter and aphelion occurs during the northern hemisphere summer. This makes northern hemisphere winters milder than average and northern hemisphere summers cooler than the average. When perihelion occurs during the summer solstice and aphelion occurs during the winter solstice (about 10,000 years from now), the northern hemisphere winters will be significantly colder.

It has been argued that this will cause snow and ice to linger in the northern hemisphere for long enough to trigger a new ice age. This is one of the three orbital cycles on which the **Milankovitch Hypothesis** is based.

Obliquity of the Earth's Axis – The elliptical orbit of the earth around the sun defines a geometric plane—the plane of the ecliptic. The Earth's axis of rotation is not perpendicular to that plane. Instead, it is tilted some 23°26'18.61" away from the perpendicular in the current year 2006.

Variations in the Obliquity – This tilt varies over time with various wobbles in the earth's axis. This tilt is diminishing at the present time as part of a 41,000-year cycle in which it varies between 22.1° and 24.5° from the perpendicular.

Obliquity and Climate Change – Although this variation has no affect on the annual heat budget (the solar constant remains the same), it has a very marked affect on the local heat budgets by affecting the seasonality. If the Earth's axis were perpendicular to its plane of revolution, there would be no seasons at all. The greater the tilt, the greater the temperature difference between summer and winter in the extra-tropical portions of the globe. This 41,000 year cycle is one of the three orbital cycles upon which the **Milankovitch Hypothesis** is based.

Atmospheric Attenuation

When insolation starts to penetrate the Earth's atmosphere, three things happen to it. Some of it will be absorbed, and go to heating the atmosphere. Some of it will be scattered. Some of this scattered insolation will end up in outer space, and some of it will find its way to the Earth's surface. The remaining insolation will pass through the atmosphere unimpeded and strike the Earth's surface. To understand why these things take place, we have to look at the nature of insolation.

The Photon Hypothesis – Let us consider insolation to consist of a stream of photons. Photons are defined as massless packets of energy traveling at the speed of light. As they travel, the photon's energy content alternates rhythmically between electrostatic and electromagnetic states.

Frequency – The time rate at which this alternation occurs is called the frequency of the photon or radiation. It is measured in cycles per second—sometimes called Hertz.

Wavelength – The distance traveled by a photon in the time it takes to complete a single alternation in energy states is termed the wavelength of the radiation or photon. It is commonly measured in nanometers (nm) for the shorter wavelengths or microns for the longer wavelengths (there are a thousand nanometers in one micron). For atmospheric studies, wavelength is more useful than frequency, and we will use that measure unless there is specific reason to do otherwise.

Energy Levels – The energy content of each photon is directly and rigorously related to its frequency and wavelength by Planck's constant. You should know that high energy photons have short wavelengths and high frequencies. Low energy photons have long wavelengths and low frequencies.

Equivalence – The frequency and wavelength of a photon are related to the speed of light—that is, the frequency times the wavelength is equal to the speed of light.

Quantum Constraints – The essence of quantum thermodynamics is that the photons emitted by a substance or absorbed by it may **not** have a continuous range of values. Each chemical (H_2O, CO_2, O_3, etc.) has a set of very specific and discrete wavelengths at which it may both absorb and emit photons. This set (the spectrum of that substance) may be quite large, but it is not infinite. That substance may not absorb or emit photons of any other wavelength. This characteristic of matter is the foundation of spectrographic analysis. By examining the wavelengths that a substance emits or absorbs, we may ascertain its chemical composition.

It should be noted that individual substances may share segments of their spectra. That is, both substances may absorb/emit at one or more particular wavelengths. However, their overall spectra will be different. For example, both water vapor and carbon dioxide absorb and emit at some of the same wavelengths, but not at others. Each of these two atmospheric gases has its own specific spectral signature.

Stefan-Boltzmann Equation – All matter in the universe emits radiation. Although discrete on an individual molecular level, this emittance is in effect continuous at the scale at which we live and observe. The amount of radiation emitted per unit time and unit area of emitting surface is in proportion to the fourth power (T x T x T x T) of the surface temperature. In other words, a small increase in temperature creates a big increase in emissivity.

Wien's Law – The average wavelength of emitted photons is also a function of the temperature of the radiating surface, as well as of the chemical nature of the substance. In general, for a given temperature, there will be a certain wavelength that is the mode of the distribution curve of emitted wavelengths. That is, there will be a certain wavelength that is the most probable, and the intensity of emitted radiation will be strongest at this wavelength.

By measuring the radiation from a distant body and ascertaining the frequency of its most intense radiation we may estimate the temperature of that body.

Heat Radiation and Light Radiation – Since few substances are uniform in either molecular "temperatures" or chemical composition, most large real substances—like the Earth and its atmosphere—emit radiation over a wide range of wavelengths. Generally speaking, the higher the temperature of a substance the shorter the mean wavelength of emissions. At temperatures below 2000°K, virtually all emissivity is in the thermal infrared range. At higher temperatures, some visible light may be emitted, but the bulk of the radiation is still in the infrared range. It is not until you get to temperatures on the order of the Sun's (6100°K) that the bulk of radiation will be of light wavelength or shorter.

Solar Spectrum – The wavelength of maximum intensity for insolation is 475 nanometers. This wavelength is toward the green end of the blue spectrum. However, the scattering of a portion of the blue light by the intervening atmosphere allows us to perceive sunlight as yellow light.

The various ranges of wavelength have been given specific names. It should be stressed, however, that these divisions are arbitrary and man-made. They are not natural. There is no change in character from one end of the electromagnetic spectrum to the other; simply a change in wavelength, frequency, and energy levels.

A rough outline of some of these divisions is given below. The divisions below are those advocated by the World Health Organization in 1979. Since the divisions are entirely arbitrary, other groups have advocated other criteria.

Name	**Wavelength in nanometers**
Radio waves	More than 300,000,000
Microwaves	1,000,000 to 300,000,000
Thermal Infrared	14,000 to 1,000,000
Optical Infrared	750 to 14,000
Red	620 to 750
Orange	590 to 620
Yellow	570 to 590
Green	495 to 570
Blue	450 to 495
Violet	380 to 450
Ultraviolet – A (black light)	320 to 380
Ultraviolet – B (sunburn)	280 to 320
Ultraviolet – C (germicidal)	200 to 280
Extreme Ultraviolet	100 to 200
“Hard” Radiation	Less than 100

Table 1: Spectral divisions and corresponding wavelengths

Broad Classification of Insolation – It is common to group the various categories in the above table into three broader classifications: infrared (>750 nm), visible (750 to 380 nm), and ultraviolet (<380 nm).

Absorption of Insolation by the Atmosphere – When a photon of insolation is absorbed by a molecule of the Earth’s atmosphere, it ceases to exist as a photon. The energy content of the photon then goes to increase the kinetic energy of the atom or molecule that absorbed it. An increase in the mean kinetic energy of a number of such atoms or molecules is made manifest as an increase in temperature. Recent studies put the absorption by the atmosphere at some 30% of the insolation received at the outside of the atmosphere.

Selective Absorption – As you might imagine, the absorption of insolation is not equally distributed over the solar spectrum. Atmospheric absorption is most pronounced in the ultraviolet and infrared portions of the spectrum. This absorption is accomplished almost entirely by the so-called “greenhouse” gases of the atmosphere (water vapor, carbon dioxide, and ozone) and by clouds and other aerosols. Visible light passes through the atmosphere without significant absorption.

Absorption of Ultraviolet and Hard Radiation – Very little ultraviolet radiation or hard radiation reaches the surface of the Earth on a direct path. It is almost all absorbed by ozone and—to a lesser degree—molecular oxygen. What isn't absorbed is scattered by the air molecules themselves, with much of the radiation going back into space. What gets scattered toward the Earth comes at us from all parts of the sky—much as blue light does. Since ultraviolet radiation is capable of penetrating to significant depths in water, clouds present only a slight barrier. You can get a nasty sunburn on a cloudy day.

Absorption of Infrared Radiation – Clouds and other aerosols absorb much of the thermal infrared radiation that strikes their surfaces—either from the Sun or from the Earth. Since the mean global cloud cover is estimated at 62% of the Earth's surface, this absorption is significant. Obviously, thicker clouds absorb more than thinner ones.

Scattering of Insolation by the Atmosphere – If the photon of insolation escapes being absorbed by the atmosphere, it must yet run the risk of being scattered. In scattering, the path of the molecule is changed but nothing else. This is normally termed reflection, but this term is somewhat misleading. It is extremely unlikely that a photon entering the Earth's atmosphere would change its direction only a single time on its way through the atmosphere. Statistical mechanics tell us that the number of changes in path would be extremely large. Consequently, there would be no preferred direction of onward movement as there is in ordinary reflection. At any given moment, the photon is as likely to go down as up, right as left, forward as back. This scattering is accomplished by the air molecules themselves, by clouds, and by other aerosols. Recent studies put the attenuation of insolation by scattering at some 39% of the insolation received at the outside of the atmosphere.

Selective Scattering – Most of the scattering by air molecules themselves takes place within the ultraviolet portion of the solar spectrum. In addition, there is some molecular scattering at the blue end of the visible spectrum. It is this latter scattering that gives the clear sky its blue color. Molecular scattering is achieved by a mathematical relationship between molecular "size" and photon wavelength.

Non-Selective Scattering – Visible light is scattered by cloud droplets and crystals. Because this scattering of visible light is relatively unselective, the clouds appear white (all wavelengths). There is some scattering of infrared by clouds and other aerosols, as well. This type of non-selective scattering is not influenced by particulate size.

The greater the thickness of atmosphere that the insolation passes through, the greater is the scattering. Near sunrise or sunset, when the insolation passes through the greatest thickness of air, almost all of the blue has been scattered away, leaving a red sky. This effect may be magnified by the presence of dust or clouds whose particles are large enough to scatter red light.

Transmission of Insolation by the Atmosphere – Photons that are neither absorbed when they encounter the atmosphere nor scattered by the encounter simply pass on through the matter involved without any change at all (photons are, after all, massless). This latter process is termed transmission, and accounts for the remaining 31% of the insolation received at the outside of the atmosphere. This is the insolation that reaches the surface of the Earth without being intercepted. Needless to say, transmission stops at the Earth's surface; and the insolation that gets that far is either absorbed by the surface of the planet or reflected back into the atmosphere or directly into outer space. We will deal with those two processes later.

The Angle of Incidence

Definition of Angle of Incidence – Imagine a line from the center of the solar disc to any point on the Earth's surface. Imagine a second line from that point to the true horizon along the solar azimuth. Those two lines enclose the angle of incidence. When the sun is directly overhead, the angle of incidence is 90°. When the solar disc is halved by the true horizon, the technical angle of incidence is 0°, but the actual angle of incidence is greater than that because of the Sun's parallax. The simpler center-of-the-solar-disc relationship breaks down when any part of the solar disc is below the horizon, but a mean angle of incidence may be calculated using simple trigonometry. When the entire solar disc is below the visible horizon, there is no angle of incidence for the point on the surface under consideration.

Insolation Intensity and the Angle of Incidence – The relationship between insolation intensity and angle of incidence approximates very closely a sine function.

Angle of Incidence	**I as % of I_{max}**
90°	100.0%
85°	99.6%
80°	98.5%
75°	96.6%
60°	86.6%
45°	70.7%
30°	50.0%
15°	25.9%
0°	See below

Table 2: Intensity of insolation as a percentage of maximum

The intensity is not a true sine function because the angle of incidence must be averaged over the entire solar disc, not just its center. Moreover, diffraction of the Sun's rays as they pass through the atmosphere also plays a part. When the center of the solar disc is on the horizon ($\boldsymbol{\alpha} = 0$), some insolation will still strike the surface of the Earth from the upper limb of the Sun.

Effects of Curvature on the Angle of Incidence – Picture the Earth's surface as a sphere. The amount of insolation received per square meter in any given second will vary from place to place over the surface of that sphere (it's obviously zero on the night side). These variations are primarily a function of latitude and longitude and how these two parameters affect the **angle of incidence** of solar radiation. Determining the amount of this variation is a simple exercise in spherical trigonometry.

In addition, the amount of insolation received by any particular square meter will vary from time to time. Most of these variations are systematic and may be calculated. The two simplest of these periodic variations are the **period of rotation** of the Earth (one day or 86,400 seconds), and the **period of revolution** around the Sun (364.2424 days or one vernal equinox year).

Controls on the Angle of Incidence – The angle at which the Sun's rays strike any particular area of the Earth's spherical surface are a trigonometric function of five factors:

1) Latitude
2) Longitude
3) Time of day (solar, not clock)
4) Time of year (vernal equinox year)
5) Obliquity of the Earth's axis

The Albedo of the Surface

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.

Visible and Ultraviolet Light: For wavelengths shorter than 4.0 microns (visible light and ultraviolet radiation), the following albedos have been measured. Where a range of values is shown, much of the variation in the individual values has to do with the angle at which the radiation strikes the surface (see Angle of Incidence, above). For other ranges, the spread is due to natural variations in composition.

Surface albedos exposed to ultraviolet and visible light (shortwave albedos)

ALBEDO	SURFACE	ALBEDO	SURFACE
09 to 11	gaseous air	25 to 30	deserts
05 to 50	atmospheric dust	15 to 30	savannas
44 to 50	cirrostratus clouds	15 to 20	chaparral
39 to 59	altostratus clouds	10 to 20	green meadows
59 to 84	stratus clouds	10 to 20	deciduous forests
70 to 90	cumulus clouds	05 to 15	coniferous forests
06 to 21	water surfaces	15 to 20	tundra
75 to 95	fresh snow	15 to 25	cropland
40 to 70	old snow	47	albino skin
30 to 40	ice	44	light skin
10 to 30	moist soil	35	medium skin
05 to 45	dry soil	22	dark skin
17 to 27	dry concrete	16	very dark skin
05 to 10	dry macadam	34 to 42	Earth, as a globe

Infrared Radiation: Of all the radiation that strikes the Earth's surface, only about a quarter of it is in the above visible and ultraviolet range. Most of this incoming radiation is infrared, from both the Sun and from the atmosphere. Infrared (more than 4.0 microns in wavelength) albedos have been measured as follows. Again, much of the variation has to do with the angle at which the radiation strikes the surface.

Surface albedos exposed to infrared radiation (shortwave albedos)

ALBEDO	SURFACE	ALBEDO	SURFACE
0 to 0.5	clouds	12 to 29	dry concrete
08 to 10	dust	08 to 09	deserts
04 to 08	water surfaces	10	grasslands
00 to 18	fresh snow	10	forests
11	old snow	05 to 09	leaves (general)
04	ice	47 to 95	leaves (0.8 microns)
08 to 16	dry soil	40 to 95	leaves (1.0 microns)
02 to 05	moist soil	03 to 30	leaves (2.4 microns)
06 to 07	frozen soil	02 to 03	leaves (10.0 microns)
05 to 11	white paper	06 to 13	window glass
08	bricks	05 to 09	white paint
09	white plaster	05 to 12	black paint
10	unpainted wood	45 to 57	aluminum paint
95 to 99	aluminum foil	98	polished silver
72 to 87	galvanized iron	05	human skin (any)

There you have it. You have been given a very brief and simplified introduction to the five major factors that influence the heat budgets of the Earth as a whole, and also influence the major climatic regions. They are: solar emissivity, the Earth-Sun distance, atmospheric attenuation, the angle of incidence, and atmospheric and surface albedos. Variation in any of these factors over time will induce climate changes.

The next step is to put these all together in creating a heat budget for the Earth.