EARTH – SUN RELATIONSHIPS

INTRODUCTION

The climate change debate - There is a great deal of heated discussion going on about climate change—specifically global warming. Some of the people involved in the discussion are scholars in the fields of climatology and atmospheric physics. Many are ordinary citizens, without training or even understanding in those fields. Ordinarily, this would not be a problem. We are all of us educated laymen (at best) in a great many fields of knowledge.

However, we—as citizens—are being asked to make binding decisions on a variety of proposals engendered by the global warming debate. These decisions will affect our quality of life and the quality of life of our descendants. It behooves us, then, as citizens, to make these decisions intelligently and with full knowledge of the consequences.

Unfortunately, the problem is not a simple one; and various experts have—in all sincerity—proposed conflicting solutions. What is a prudent citizen to do? Obviously, a good citizen must learn as much as possible about the basics of the subject, trust to his or her instincts, and vote his or her conscience.

You are never going to know as much about the subject as the experts do. That's a given. However, since that superior knowledge has not led to unanimity on the part of the experts, your lesser understanding should not be too great a concern. You do what you can. And—since both you and the experts have to live with the consequences of your decisions—both of you are entitled to make those decisions.

Purpose of the series of papers – This series of papers is an attempt to present the fundamentals of climate change to the educated layman, in the hopes that he or she will be better informed when the time comes to choose courses of action.

It is not intended as a textbook, because no attempt will be made to present the fundamentals of the entire field of climatology—much less, the field of atmospheric physics. This series of papers has a much narrower focus. It is intended to answer only three questions:

1. What factors influence global climate changes?
2. What is our current state of knowledge about these factors?
3. What does the evidence suggest as to how these factors have changed in the recent past?

Sources and references – Since my target readership is the educated layman, rather than fellow professionals, the citation methodology is quite different that it would be if these papers were offered for publication in a refereed professional journal. The average reader is put off by extended bibliographies and frequent footnotes—all the traditional hallmarks of scholarship. When they are put off, they stop reading.

Therefore, I shall make no effort to document every statement. If the material may be found in most textbooks or standard reference sources, no reference will be given. New material, not likely to be found as yet in such works will be referenced. Statements or positions that the majority of reputable scholars in the field would find debatable will be referenced—unless the context clearly states that this is purely a matter of the author's opinion.

References will take the form [Name, Year] in the body of the text. Standard citation forms will be used at the end of the paper.

Purpose of this paper – I firmly believe that it is not possible to understand climate change without a good understanding of the Earth's heat budgets. That is, a good understanding of where the Earth's heat energy comes from and where it goes. I further believe that you cannot understand the global heat budgets without a good understanding of Earth – Sun relationships, since the Sun is the ultimate source of virtually all of the Earth's heat energy. Therefore, any understanding of climate change must start with a firm understanding of Earth – Sun relationships.

THE BASICS OF EARTH – SUN RELATIONSHIPS

Measuring incoming solar radiation – This being so, it is obvious that we should start with some understanding and evaluation of how much energy we actually get from the Sun. Over the years, we have developed a number of ways of doing this. 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. Estimates are never as good as actual measurements.

With the development of artificial satellites in the late 1970's, 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.

This latter measurement is spoken of as being of equal importance, because the two components of the global budget must balance—assuming that long-term storage is negligible. Having both readings allows us to check on the validity of this assumption.

Calibration – Just because we now have satellites capable of directly measuring insolation at the outside of the atmosphere does not mean that we have stopped using other methods. It simply gives us a tool to calibrate the other methods of measurement more accurately. Since satellite measurements started less than thirty years ago, and other methods of measurement date back over a century, having both types of measurements allows us to more rigorously evaluate the historical record. Consequently, we have a fairly good idea how much insolation has varied over the past century or so.

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 of **1,366.1 joules per square meter per second** [Scafetta & West, 2005]. 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.

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.**

Annual global budget constraint – Simple multiplication of the solar constant by the number of seconds in the vernal equinox year produces the global constraint or outer limit of the Earth's annual heat budget. This value is some 4.311×10^{10} joules per square meter per year**,** measured normal to the direction of insolation at the outside of the Earth's atmosphere—that is, for the effective terrestrial disc of interception.

However, outgoing radiation is produced by the entire global surface. Since the area of a sphere is exactly four times the area of a circle of equal radius, we must divide the above number by four to produce a budget constraint for a unit area of global surface. This gives us a value of **1.07775×10^{10} joules per square meter** of global surface per year.

Insolation variations – Although the solar constant is a mathematical constant, the real 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, cannot be directly predicted, but must be estimated using statistical methods. The bulk of the remainder of this paper will be devoted to examining the nature of these variations.

The five controls of global climate change – The amount of insolation received and absorbed by any part of the Earth's surface at any given time is subject to five major controls: solar emissivity, Earth-Sun distance, atmospheric attenuation, angle of incidence, and the albedo of the surface. Since the Sun is the only significant source of energy for the Earth's heat budgets, these five factors are on the only ones that can have a significant effect on global climates. We will examine each of these five factors.

There are three other factors that affect the distribution of climates over the face of the globe: latitude, altitude, and continental position. These factors do play a significant role in atmospheric attenuation, angle of incidence, and the albedo of the surface, and will be touched upon in those sections. However, they do not really affect Earth – Sun relationships, and must be dealt with more fully in discussions of regional rather than global heat budgets.

VARIATIONS IN 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 surface measurements for the recent past. Estimates for the more distant past were derived from observations of sunspot numbers and groupings, and from concentrations of cosmogenic isotopes in sediments and organic materials.

Period of direct measurement –We have been using satellite measurements of solar emissivity only since 1978. During this period of measurement, 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.

Period of surface measurements – Before satellite measurements were available, the intensity of solar radiation was measured at the surface—usually in deserts or at higher mountain elevations. Such records date back to the seminal work of Abbot at the Smithsonian from 1902 to 1954. These measurements are limited in their value by the natural variability of insolation from place to place and time to time over the face of the Earth due to non-solar factors, and by significant variations in the measurement instruments themselves.

Sunspot activity and solar emissivity – There is a strong positive correlation between sunspot activity and solar emissivity. 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 three-hundred years has data been gathered that meet even the most rudimentary standards of scientific acceptance.

Proxy measurements – It should be noted that values for insolation based on sunspot activity and other related phenomena are derived measurements, not actual ones. They are usually termed "**proxy**" measurements. The most commonly used proxies are concentrations of cosmogenic isotopes.

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 of insolation were available nor sunspot activity accurately observed. Using these measurements, we have been able to hypothecate sunspot activity (and, by derivation, solar emissivity) back some 11,400 years [Solanki *et al*, 2004].

Solar emissivity and climate change – The correlation between these various proxy 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 a very strong 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** [Solanki *et al.,* 2004].

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. Most published studies suggest that the observed variations (since 1978) appear to be too small to account for major climate changes on their own. Variations on the order of 0.1% require some sort of feedback mechanism in order to produce the climatic changes that the historical record suggests.

It should be noted that these studies are based on largely theoretical models of energy balance. However, a recent study [Scarfetta & West, 2006] based on an empirical rather than theoretical model suggests that emissivity increases account for as much as 45% to 50% of the 1900-2000 global warming, although only 25% to 35% of the 1980-2000 period.

This latest study aside, most scholarly arguments tend to revolve about the validity of derived (proxy) measurements and the magnitudes of both positive and negative feedback mechanisms.

VARIATIONS IN THE EARTH – SUN DISTANCE

Mean Earth – Sun distance – We must start off by emphasizing that the mean distance between the Earth and the Sun (averaged over the course of the year) is not subject to significant change. It is established by the physical laws governing planetary motions.

Although the mean stays the same, the actual distance at any given instant does vary over the course of the year, and this annual variation is in its turn subject to variation over the course of a much longer time span.

This variation does not affect the Solar Constant, which is defined at a distance of one Astronomical Unit. It does affect how much insolation is received by each hemisphere over the course of a year, and how intense is the seasonal (summer versus winter) variation. These variations, in turn, can and do affect three of the controls of global climate: attenuation of insolation by the atmosphere, angle of incidence of insolation, and the albedo of both the atmosphere and the surface of the Earth. Therefore, it behooves us to understand these orbital variations.

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 1,413 joules per second—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 1,322 joules per second—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 joules per second per square meter**.

Periodic Variations in Eccentricity – The eccentricity of the Earth's orbit varies over a cycle of roughly 100,000 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 a range of roughly **24% of the mean value**.

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

Recent Trend in Eccentricity – The Earth's eccentricity is in the diminishing portion of its 100,000 year cycle. That is, each passing year finds the eccentricity slightly less; and the seasonal variation slightly less, as well.

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 (earthshine), and some of it will find its way to the Earth's surface (skylight). The remaining insolation will pass through the atmosphere undiverted and unimpeded and strike the Earth's surface as direct sunshine. 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 (**c**). As they travel, the photon's energy contents are believed to alternate 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 (cps) or Hertz (Hz), and is customarily symbolized by the Greek lower-case letter *nu* (**v**).

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) or microns (μ), and is customarily symbolized by the lower-case Greek letter *lambda* (**λ**). For atmospheric studies, wavelength is more useful than frequency, and we will use that measure unless there is specific reason to do otherwise.

Equivalence – The frequency and wavelength of a photon are related to the speed of light by the formula:

$$v\lambda = c$$

That is, the frequency times the wavelength is equal to the speed of light.

Energy Levels – The energy content of each photon is directly and rigorously related to its frequency and wavelength. This energy is expressed as:

$$e = hv = hc/\lambda$$

Here **e** is the energy content of the photon and **h** is Planck's Constant, whose precise values depends upon the system of units being used. The other parameters have their previously defined values. Note that high energy photons have short wavelengths and high frequencies. Low energy photons have long wavelengths and low frequencies.

Quantum Constraints – The essence of quantum thermodynamics is that the photons emitted by a substance or absorbed by it may not have an infinitude of values. Each chemical (H_2O, CO_2, O_3, etc.) has a set of 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 and emit at one or more particular wavelengths. However, their overall spectra will be different. For example, both water vapor and carbon dioxide gases 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.

Liquids and solids present special cases. In gases, the molecules are discrete entities as they move about. They only come into "contact" with one another during their frequent collisions. In liquids and solids, the molecules are in close contact with many other molecules. In terms of quantum thermodynamics, this means that liquids and solids possess many, many more possible energy levels. Consequently, the spectra of liquids and solids present virtually continuous bands. The individual energy levels are present in these bands, but our current technology is incapable of distinguishing them.

From a climatic standpoint, this means that liquids and solids at normal atmospheric temperatures absorb almost all of the infrared radiation that strikes their surfaces and a considerable portion of the visible spectrum. What visible light that they don't absorb, we perceive as color (wavelength) and tone (intensity).

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 given by the Stefan-Boltzmann Equation and is:

$$\varepsilon = kT^4$$

Here, ε is the emissivity, **T** is the absolute temperature, and **k** is a constant of proportionality whose value depends upon the system of units being used. This expression is for a perfect radiator (the *blackbody*). Real substances will have an emissivity that is slightly lower than this ideal value.

Note that the emissivity goes up as the temperature of the emitting surface goes up, and that the increase in proportional to the **fourth power** of the 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. Wien's Law gives this point of maximum intensity as:

$$\lambda_{max} = 2898 \div T$$

Here, λ_{max} is the wavelength of maximum intensity in microns, and **T** is the absolute temperature in degrees Kelvin.

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 this 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.

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 [Kiehl & Trenberth, 1997] put the absorption by the atmosphere at 24.8% of the insolation received at the outside of the atmosphere. As we shall see in later papers on heat budgets, two-thirds of this absorption of insolation is undertaken by water vapor, twenty percent by clouds and particulates, and most of the rest by ozone and oxygen. Carbon dioxide absorption is not significant.

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. Visible light passes through the clear atmosphere without significant absorption.

Absorption of Ultraviolet and Hard Radiation – Very little ultraviolet radiation or hard radiation reaches the surface of the Earth. It is almost all absorbed by ozone and—to a lesser degree—molecular oxygen. What little 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 severe sunburn on a cloudy day.

Absorption of Infrared Radiation – Clouds and other aerosols absorb most 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 [Ibid.] put the attenuation of insolation by scattering at 22.5% 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 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 52.7% 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 space. Which of these two actions occurs in any give case is a function of surface albedo. We will deal with the concept of albedo later.

Effects of atmospheric attenuation on global climate change – It should be obvious that attenuation of insolation by the atmosphere has a significant effect on global climate. We are not talking here about the blanketing or "greenhouse" effect of the atmosphere. That will be dealt with in subsequent papers. Here, we are only concerned with how the atmosphere keeps insolation from reaching the surface of the Earth.

The effect of attenuation is to reduce the amount of insolation reaching the surface. Any increase in cloud cover will decrease incident visible and infrared radiation. Any increase in ozone or (to a lesser degree) molecular oxygen will decrease somewhat the incidence of ultraviolet radiation (this is, indisputably, a good thing). Any increase in water vapor will decrease the amount of infrared. An increase in the levels of particulates will also decrease incident insolation on the surface directly; and also indirectly by increasing cloud cover. Carbon dioxide plays almost no role in the attenuation of insolation.

Recent trends – Cloud cover was thought to have been increasing over the northern hemisphere from the industrial revolution onward. Significant "global dimming" was first noted by Ohmura in 1989, this has been confirmed by subsequent studies [Stanhill & Cohen, 2001].

However, there is some slim evidence that there has been a significant diminution in recent years due to efforts to reduce pollution (particulates and industrial gases are a significant initiating factor in cloud formation). If true, the most recent trend is toward decreasing cloud cover. Further studies are obviously needed.

The amount of water vapor in the atmosphere represents a state of dynamic equilibrium with the watery surface of the planet. Any increase in atmospheric temperature will result in an increase in the mean water vapor concentration. This in turn, will result in increased global precipitation, as the residence time of water vapor is the atmosphere is a matter of days, not years. Globally, the total annual precipitation increased by some 2% in the period from 1900 to 1980 [Dai *et al*, 1997]. Water vapor concentration is thus thought to be increasing.

ANGLE OF INCIDENCE OF INSOLATION

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 apparent diameter. 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. That is,

$$I = I_{max} \sin \alpha$$

Here, **I** is the intensity in joules per second per square meter of receiving surface, **I$_{max}$** is the intensity normal to the solar beam before striking the surface, and **α** is the angle of incidence.

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 ($\alpha = 0$), some insolation will still strike the surface of the Earth from the upper limb of the Sun.

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 cycles upon which the **Milankovich Hypothesis** is based.

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

Summary – This effectively sums up the relationships between the Earth and the Sun that have a direct effect on climate change.

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