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Climatic Paradox

Historic Temperatures of Early Earth

Today, the Earth is the one planet out of all the planets in the solar system that has an atmosphere providing a favorable climate for the evolution of life (both flora and fauna) on its surface. To better understand the historic development of the Earth and its atmosphere, geologists have divided the age of the Earth into eons, eras and periods. Figure 1.1 displays the geologic system of time division used in this book, showing the development of life and how it relates to the changing environmental geologic development of the Earth. When discussing the climate of the Earth, a critical component is that of temperature. A temperature chart covering the entire history of Earth is presented in Figure 1.2. The arrow on the right side of this figure points to today's average surface temperature of the Earth. The Earth has experienced both cooler and warmer periods of temperature with cyclic occurrence. In general, Figure 1.2 reveals that the Earth has been much warmer in the past than it is today, and that over the past 65 million years (MY) has progressively cooled.

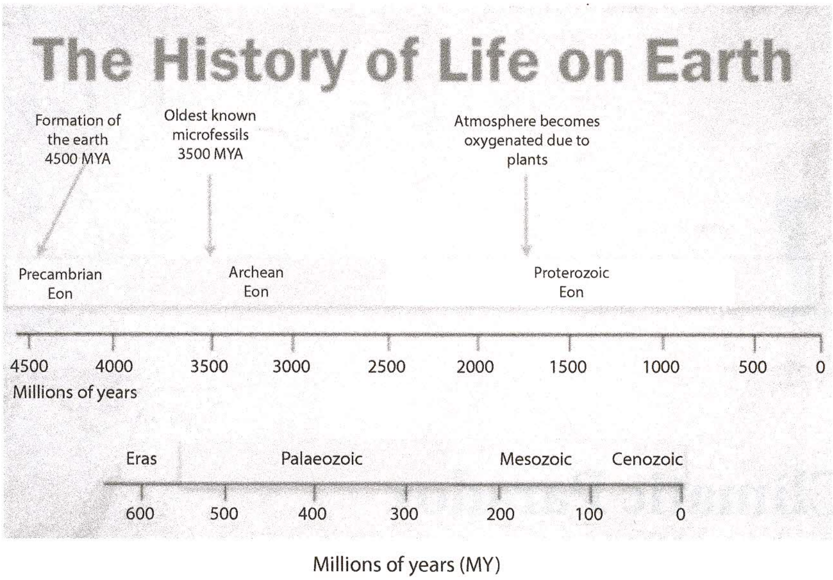

Figure 1.1 Development of life on Earth for the past 4.5 BY. (After pbhslifescience, https://pbhslifescience.wordpress.com/2016/11/04/evolution-slides-1.)

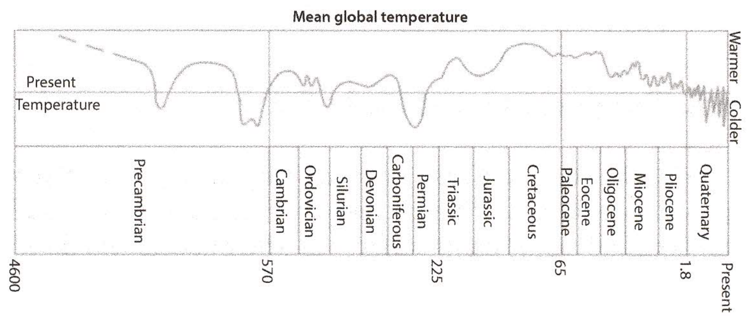

Figure 1.2 Schematic 4.5 BY Earth chart. (Original data from Frakes (1979); in: Watts, *https:// Wattsvpwiththat.com/2014/09/08/Monday.*)

Sorokhtin *et al.* (2011) defined life on the Earth as a concourse of several circumstances. These circumstances include: (1) a quiet star, e.g., Sun; (2) the optimum distance of the Earth to the Sun throughout the Earth's orbit about the Sun; (3) the presence of a massive satellite, e.g., the moon; (4) chemical composition of the primordial Earth and its atmosphere; and (5) several other causes reviewed in detail in the monograph by Sorokhtin and Ushakov (2002). Climatic conditions for life habitation on the Earth was a result of changing atmospheric composition (see Figure 1.3) and pressure and to a feedback between the evolution of the Earth biota and atmosphere.

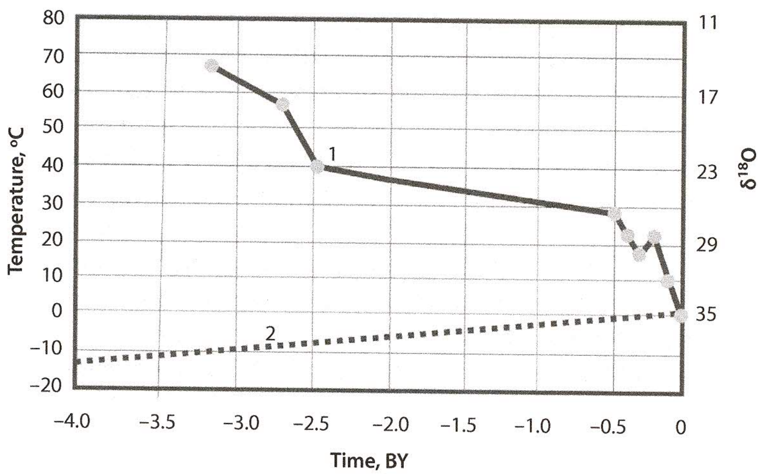

Figure 1.3 A climatic paradox: The sun luminosity increases over time, whereas Earth's temperature gets cooler. *Curve 1* – average isotopic water temperature that is sea-flint forming in, also describes the average temperature for the global, near-bottom of sea floor ocean water. The dots are $\delta^{18}O$ values for the sea-flint (after Schopf, 1982). *Curve 2* – temperature of an absolutely black body at the distance of Earth-from-sun, which describes the sun's luminosity.

Concepts by Some of Global Warming

Today by some, a major environmental concern is the release of human generated carbon to the atmosphere (anthropogenic). It is thought by these individuals, without either historic or scientific evidence, that humans are putting too much carbon in the form of carbon dioxide (CO_2) or methane (CH_4) into the atmosphere and that this anthropogenic carbon is somehow responsible for what they feel is *global warming.*

The Earth's climate (temperature) is primarily determined by: (1) the Sun's radiation intensity, (2) the composition and density of the Earth's atmosphere and (3) the Earth's atmospheric capability to absorb and retain the Sun's energy. It is often, incorrectly assumed, that the heating of the Earth's atmosphere and surface is, to a substantial extent, only due to the capacity of various atmospheric gases that absorb the IR (heat) radiation from the Sun, ignoring the atmospheric pressure.

The concept that the Earth's atmosphere is heated by the greenhouse gases was first proposed by the Swedish scientist Svante Arrhenius at the end of the nineteenth century. This idea is now postulated as obvious and accepted without verification [Maslin (2004) in: Enzler (2015); Budyko (1974 & 2002); Greenhouse effect (1989); and Petrosyants (1994)]. Svante proposed a relationship between atmospheric carbon dioxide concentrations in the atmosphere and global temperature, i.e., if only one increased the concentration of carbon dioxide, the atmosphere would absorb more energy.

Since then, this concept today is found within the conclusions of the Intergovernmental Panel on Climate Change (IPCC), Greenpeace, United Nations Environmental Program (UNEP), and World Meteorological Organization (WMO). This same viewpoint was totally supported in the resolutions of the International Ecological Congresses in Rio de Janeiro, Brazil (1992) and Kyoto, Japan (1997).

It is assumed that the main danger to the Earth's climate arises from the fundamental energy sources of the modern economy through the release of greenhouse gases, especially carbon dioxide, into the atmosphere. Under some forecasts of the proponents of the manmade (anthropogenic) *global warming* concept, a warming of the Earth's surface temperature could increase 2.5 to 5 °C by the year 2100. The rise in the ocean level caused by this warming would reach 0.6 to 1.0 m, resulting in problems for the densely populated areas of the Earth along the continental shores. Other consequences of *global warming* have also been forecast, e.g., the spread of deserts, permafrost melting, soil erosion, etc.

The conventual theory of *global warming* states that the heating of the atmosphere's troposphere occurs as a direct result of the anthropogenic addition of carbon dioxide (CO_2) and the methane (CH_4) that is added to the Earth's atmosphere by man. As a result, the petroleum industry has often been *singled out for blame*, for the release of additional carbon (methane and carbon dioxide) into the atmosphere as it produces, handles and burns hydrocarbons. Some of these environmentalists also believe that today's increase in atmospheric carbon dioxide can be primarily attributed to any human activities that are related to the release of CO_2 or CH_4 to the atmosphere.

Earth's Historic Temperature Charts

Today's literature is filled with a wide variety of options about global warming and climate change. Unfortunately, these opinions are not always grounded in the Earth's temperature history or scientific facts, but rather in emotional feelings. This range of opinions include those by: (1) The National Oceanic and Atmosphere Administration (NOAA) which has claimed that *there has been no recent slowdown in global warming*; (2) the Space and Science Research Corporation stating that *the Earth is presently* *in a sustained phase of global cooling*; and (3) some experts who state that *we have been in a transition phase without significant warming or cooling for the past 20 years*. These opinions are made without looking at the historic temperature charts of the Earth, leaving open the question of "***Are we cooling, transitioning, or warming?***"

Misuse of Temperature Charts

To correctly answer the question of the *Earth's cooling or warming controversy*, one must first look at temperature charts over the whole time of the Earth's geologic history to understand where we have been and where are we going. Understanding where we have been requires obtaining temperature charts (records) of temperatures before recorded history. Unfortunately, before recorded history, there was no recording of temperatures; however, there are several methods we can use to infer temperatures during these earlier periods of time. Temperature charts can be prepared by inferring temperatures obtained from ice cores, tree rings, etc. It should be noted that these values of temperatures obtained are approximations and not necessarily the exact values of the Earth's average surface temperatures (see Figure 1.2). Therefore, temperature charts, with values obtained by one method, may not always exactly match those temperatures obtained by a different method for the same period. Whenever possible, in preparing a temperature chart, it is preferable to use only temperatures that have been obtained by one technique. It has been said, *Oranges are easily comparable to other oranges, but not necessarily when you directly compare apples to oranges*. Also, many times it is not the inferred values of temperature that are important, but rather, the trends that a temperature chart data displays for a given period of time. This is particularly true when you have inferred temperatures from more than one method indicating slightly different numbers, but showing a similar trend.

Today, some portions of our planet experience extreme heat, whereas other areas experience the opposite. Temperature inferred at the poles should be expected to be cooler than the average surface temperatures inferred in other areas of the Earth and, therefore, not necessarily be expected to represent an average surface temperature for the Earth at that time. It has also been noted that climatic conditions of the two poles are not always similar. In examining a temperature chart, it is crucial to: (1) know what method was utilized to determine the temperatures and (2) whether in preparation of the chart, only one method was used to determine the temperatures.

Use of Paleoclimatology to Estimate Prehistoric Temperatures

Paleoclimatology is the study of historic climatic conditions, examining their causes and effects in the geologic past, using current data found in glacial deposits, fossils, sediments, etc. This chapter reviews the study of historic climatic conditions (temperature charts) of the Earth's temperatures as inferred by a particular method, e.g., analyzing ocean sediments. One should remember that before recorded history, neither satellites nor thermometers existed. But one may use the fossil record, for example, to infer/deduce temperatures at the time when the fossil of that flora or fauna was alive. For example, palm trees do not grow well in Arctic weather; therefore, the existence of palm tree fossils indicates a temperature at the time that fossil was laid down. Therefore, looking at fossils within the rock, we can infer an estimated temperature at that period of time the sediment was laid down, although the temperature may not be the exact value.

Estimates of the Earth's surface temperatures can be made by many different methods based upon the data from oxygen isotope ratios, ice cores, ocean sediments, dendroclimatology, etc. The various methods of temperature inference can result in slightly different values for the approximate temperatures inferred by other methods for the same time period. There is no one perfect method that can be used to measure historic temperatures over the age of the Earth. One should select a technique of determining temperature, where the data is available over the entire period of time under consideration.

Not all methods of temperature inference are of equal significance, because the technique of gathering temperature data can directly affect the precision of the results. Because of this, researchers have been known to adjust the results of collected data to make them more representable. Unfortunately, literature has several examples where these adjustments have been made, likely introducing the researcher's biases into the data. The temperature charts presented in this chapter present prehistoric inferred temperature data, but where possible, the authors have also identified the method used in temperature determination. Although no one method of gathering temperature data is possible for extended periods of time, examining the results of using several different methods can establish and confirm the trends in temperature. Verification of the trends in temperature-change, using several different methods of temperature determination is critical to understanding the Earth's climate.

Use of the Oxygen Isotope Ratio to Estimate Historic Temperatures

A critical factor defining the Earth's climatic environment is temperature. The temperature of prehistoric geological epochs can be estimated by the oxygen-isotope ratio. An example of this would be the work of Sorokhtin *et al.* (2011) who used the oxygen-isotope ratio of sea flint, which was formed in equilibrium with its surrounding ocean water. At the time of formation, the $\sigma^{18}O$ ratio in the sea flint was the same as its surrounding water as it was deposited on the ocean floor. This ratio is dependent on the temperature of the water, in which the siliceous deposits were formed. Studies of this ratio in sea flints show that for the Earth, a high atmospheric temperature existed in the Archaean time (≈3.4 BY ago) (Perry and Tan, 1972). By the mid-Archaean time oceanic water temperature rose to 72 °C (Knauth and Lowe, 1978). Other studies indicate that the oceanic water temperature for the mid-Archaean Eon (3.2 BY ago) may have reached 90 °C (Perry, 1967), and based on the isotope composition of siliceous schists even up to ≈100 °C (Knauth and Lowe, 1978). Schopf (1972) recognized the extent that $\delta^{18}O$ ratios in ancient flints reflect their origin and, the temperature of the water in which the flints had been formed. It is possible that the observed regular isotope ratio declines with age as the $\delta^{18}O$ ratios are associated not only with changes of the oceanic water temperature but also due to other reasons, e.g., with the $\delta^{18}O$ value decline in the Archaean oceanic water (Sorokhtin and Ushakov, 2002).

Sorokhtin *et al.* (2011) estimated that the seawater isotope composition in the pre-Cambrian time, as affected by the exchange reactions with iron oxides, declined to $\delta^{18}O \approx -10‰$. Galimov (1988) estimated that the Archaean oceanic water isotope composition was $\delta^{18}O \approx -15$ to $-10‰$, the $\delta^{18}O = 0$. After the disappearance of the metallic iron in the ocean from the Earth's mantle by the end of the Proterozoic time (Sorokhtin and Ushakov, 2002), probably $\delta^{18}O = 0$ for the seawater. In this case, the near-ocean-floor water temperature in Early Archaean would have been much more moderate, no higher than 70 °C. Figure 1.3 shows not only the oxygen heavy isotope $\delta^{18}O$ distribution in the seawater of various ages, but also their approximate isotopic temperature of the near-sea-floor water (considering the correction by $\delta^{18}O \approx -10‰$ as quoted above). Thus, it follows that the global ocean near-bottom-floor water temperature and the average Earth's surface temperature both began declining beginning in the Archaean time.

Historic Temperature Charts for the Past 4.6 BY

Figure 1.4, a temperature chart covering the past 65 MY, or the period that life has been on the Earth, shows not only the ocean temperature, but also the *flow of energy* (primarily from the Sun) that has warmed the surface of the Earth over time. The inferred temperatures in this graph were based on the oxygen-isotope ratios obtained from polar oceanic sediments of various ages. Significant glaciations are indicated on the graph. During most of the Earth's history, global temperatures were much warmer than they are today. This figure also indicates several earlier periods of colder temperature (glaciation). Over the last 65 MY, the Earth has experienced a steady decrease in temperature.

Glacial Periods and Interglacial Periods (4.5 to 0.54 BY AGO)

Examination of Figure 1.2 between 4.5 to 0.54 billion years (BY) ago indicates four major glacial and interglacial periods occurred in the early geologic history of the Earth. The Earth's surface, during these cooler periods, was often covered with massive sheets of ice, sometimes covering entire continents. This had a pronounced impact on: (1) Earth's climate, (2) sea levels (total oceanic water volume), (3) climatic belts, and (4) distribution of biota throughout the world (Sorokhtin *et al.*, 2007).

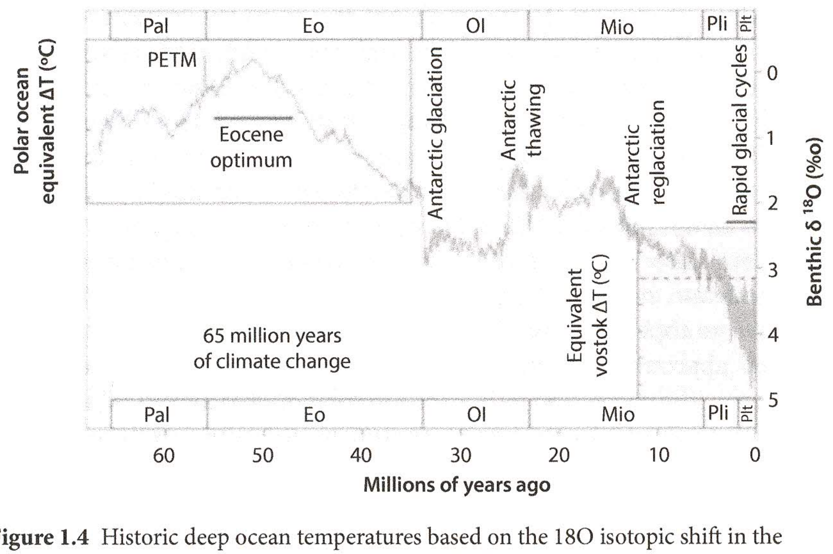

Figure 1.4 Historic deep ocean temperatures based on the 18O isotopic shift in the benthos fauna of carbonates. (isotope data from Zachos *et al.*, 2001.)

A traditional explanation for the development of these major ice ages in the past geologic periods has been a variation in the Earth's distance from the Sun, e.g., variation in the Milankovitch orbital cycles (also see http://earthobservatory.nasa.gov/Library/Giants/Milankovitch). The parameters of the Earth's orbit exhibit semi-cyclic changes with periods ranging from 0.1 to 2 MY. Sorokhtin (2005) has noted that corresponding changes in temperature at the Earth's poles can reach up to 15 °C. The periodic variations in the orbital parameters of Earth are correlated with the occurrence of glacial periods (http://geosciences.ou.edu/). This data on this temperature chart (Figure 1.4) show historic cycles of global temperatures going from warm-to-cool-to-warm with interglacial periods in between.

Historic Temperature Record of the Past 540 MY

Scotese (2003) presented the Earth's temperature chart showing relative changes in global average temperature of the past 540 MY (Figure 1.5). These temperatures of the Earth's ancient climate were computed by the Paleomar Project utilizing several methods of inferring temperature, which is reflected in the use of various time scales. This project mapped the past positions of the continents and showed the distribution of rock types that had formed in the specific time periods, recognizing the climate required to produce that rock type. Climatic conditions were inferred, as certain types of rocks, e.g., coals, require abundant rainfall and only form under specific conditions (tropical rainforests or temperate forests). Paleomar's diagrams

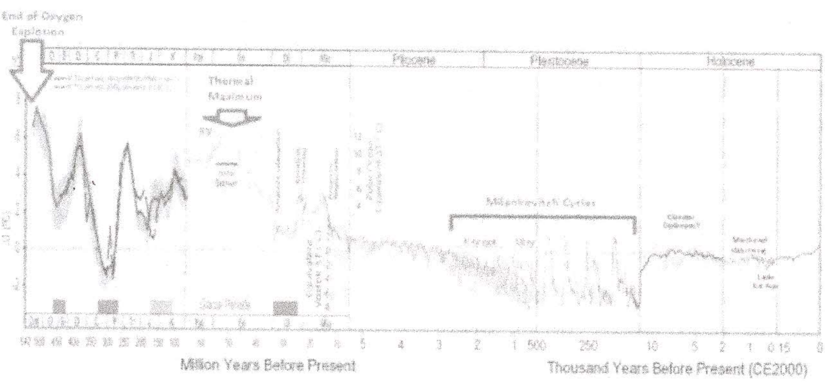

Figure 1.5 Temperature chart for the past 540 MY based upon several methods of temperature inference from various researchers. The horizontal time scale is a mixture of linear and logarithmic scales. Note that the Earth has been generally warmer in the past than it is today. (Data from U.S. DOE; in: http://theconversation.com/sudden-global-warming-55m-years-ago -was-much-like-today-35505.)

indicate which rock types formed in which climatic belts. By mapping the past distribution of thousands of these rock types, they reconstructed this chart inferring the ancient temperatures. This data indicates a shift of global temperature, alternating between frigid and warm, in the earlier periods of geologic time to almost a steady decline of temperature over the past 65 MY. Again, this temperature chart demonstrates that today's global temperatures are significantly lower than those in the past. The horizontal line in the figure represents the value of today's average global temperature.

Examination of temperature charts for the various periods of time helps identify those factors influencing the Earth's climate. Figures 1.2 and 1.5 clearly display the energy transfer from the Sun to the Earth over time. The declining temperature indicates that there is a decay in absorbed energy by the Earth occurring during the past 65 MY. Other temperature charts, using different methods of inferring temperature, support this decay of energy flow. This decline of temperature suggests a continual decrease in the Earth's absorption of energy over this period. This decay is so small that it cannot be seen if one is looking at temperature charts that cover only a few years; however, this decay of temperature can only be seen over millions of years. This absorption of energy is the primary climatic factor controlling the Earth's temperature, demonstrating that the Earth, due to decreasing absorption of energy, continues to cool today. Figures 1.2, 1.4 and 1.5, utilizing various methods of inferring the temperature, indicate a continuous decrease in the energy absorbed by the Earth with respect to time, which directly affects the Earth's climate.

These charts also show, historically, that the Earth has been cooling over the past 65 MY and continues to cool today regardless of minor cyclic variations in the Earth's temperatures. This Earth temperature chart (Figure 1.5) was assembled by the U.S. Department of Energy. Although there may be problems with the specific temperature values which were obtained by various methods, this chart clearly shows a declining trend in the Earth's temperature. What is also shown in Figures 1.2, 1.4 and 1.5, is that between 450 and 65 MY ago (C3, 2016): (1) the historic climate of the Earth had major cooler (glacial) and warmer periods lasting for long periods of time; (2) the length of time for these earlier cycles of cold and warmth far exceed what one observes in the past 65 MY; (3) the temperatures observed in today's global cooling era are neither extreme nor unique, even when compared to the relatively recent period of the Minoan/Bronze age civilization (Figure 1.6); (4) long-period temperature chart data indicates that we are in a cooling period (either glacial or interglacial) and not a warming one.

Figure 1.7 displays a cyclic relationship between the Sun and the Earth over the past ≈1 million years governed by the distance between the two

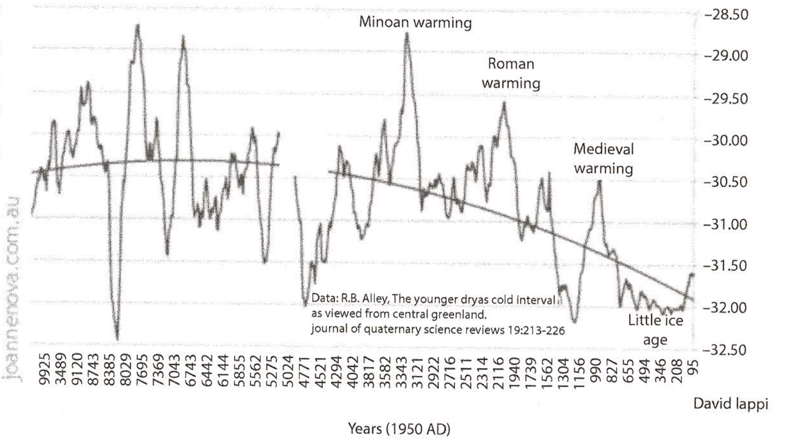

Figure 1.6 Temperature chart of Greenland interglacial temperatures for the last 10,000 years as determined from ice-sheet cores. (After Lappi, 2010.)

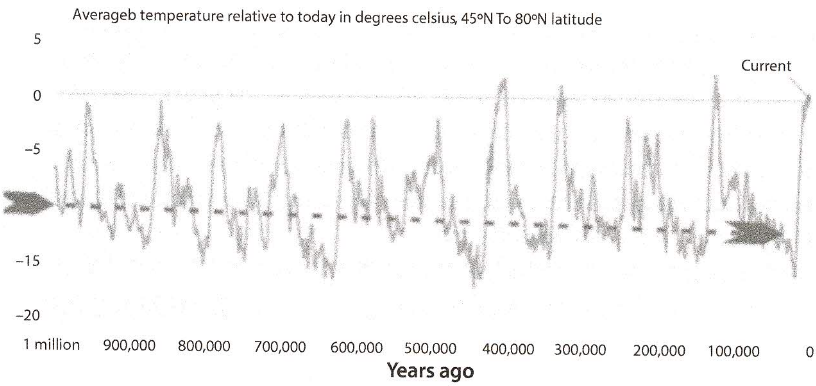

Figure 1.7 Temperature fluctuations over the past one million years. Global reconstructed temperature. (After, R. Britanja and R.S.W. van der Waal, "Global 3Ma temperature, sea level, and ice volume reconstructions." National Oceanic and Atmospheric Administration, August 14, 2008. https://www.ncdc.noaa.gov/paleo/study/11933 (Accessed April 5, 2016.)

bodies. Cycles of 100,000 years are indicated by this chart, where temperature is governed by the varying distance between the Sun and the Earth (*orbital distance*). The reason why one examines charts of global temperature over various periods of time, utilizing various methods of inferring temperature, is that charts of different periods of time often emphasize different factors that influence the Earth's climate over that time period. In this case, Figure 1.7 demonstrates that there has been a cyclical period for temperature of ≈100,000 years over the past ≈1 MY. Any temperature chart showing less than 100,000-year period would not clearly show this Earth/Sun separation-distance or *Earth's orbital effect* on the Earth's temperature. The primary controlling climatic factor of a continual cooling of the Earth was shown by charts (Figures 1.2, 1.4 and 1.5) and a secondary factor is shown over a 1 MY time period (the cyclic nature of Earth's temperature is demonstrated in Figure 1.7). Today we see people attempting to make future temperature forecasts based upon brief time periods of 25,000 or 1,000-year time periods. These periods of time are far too short to recognize the primary and secondary climate forces controlling the change of the Earth's temperatrure.

There are several problems with the horizontal scale for inferred temperatures utilizing a variety of temperature inferring methods in Figure 1.5 (C3, 2016): (1) The DOE scientists who produced this chart utilized various methods of inferred temperature data and treated all inferring methods as equal on this temperature chart, e.g., mixed methods of data determination were used (instrument thermometer values, ice core data, and dendroclimatology reconstructed estimates); (2) This chart contains swaths of historic temperature data in the chart that has had the climate records "adjusted" upward by at least 0.4 °C over the last 20 years; and (3) Much of the information in this chart was estimated by the dendroclimatology method. However, this chart is valuable as a comparison to other charts prepared utilizing different techniques of inferring temperature and identifying trends in the Earth's climate.

An example of the dendroclimatology method, used to prepare Figure 1.7, would be the use of tree rings to tree ring thickness and temperatures and then relate it to age. Generally, a year's growth of tree ring responds to changes in climatic variables by speeding up or slowing down the growth, which, in turn, is reflected in a greater or lesser thickness in growth rings. A historic tree-ring record can be established by compiling information from many living trees in a specific area. This history identifies climatic condition by year for the area. These studies can be extended to other areas by comparing the data to other groups of trees. Older intact wood that has escaped decay can extend the time covered by the record by matching the ring depth changes to contemporary specimens for several thousand years. By using this method, one can obtain tree records for one area and project the climatic data to other similar areas. Growing temperatures of older wood not connected to a contemporary record of group of trees can be dated with radiocarbon techniques and the rings then utilized to determine climatic data for temperatures of that period. A tree-ring record is also useful to produce historic information regarding precipitation, temperature, hydrology, and sometimes fire corresponding to a particular area.

Another example of the use of dendroclimatology is looking at various species (either flora or fauna) or their fossils, which respond in an analogous manner to changes in climate. There is a temperature range in which they can exist.

Geologists often utilize dendroclimatology techniques to determine climatological data for the sedimentary record (Wikipedia, 2016):

1. *Sediments*—sometimes lithified to form a rock, may contain remnants of preserved vegetation, animals, plankton or pollen, which may be characteristic of certain climatic zones.
2. *Biomarker molecules*—such as the alkenones may yield information about their temperature of formation.
3. *Chemical signatures*—particularly Ca/Mg ratio of calcite in Foraminifera tests, can be used to reconstruct past temperatures.
4. *Isotopic ratios*—can provide further information. Specifically, the $\delta^{18}O$ record responds to changes in temperature and ice volume, and the $\delta^{13}C$ record reflects a range of factors.

Underwater life, as shown in Figure 1.1, developed on Earth during the Paleozoic time (542 to 251 MY ago). This was a period that began with the breakup of the supercontinent Rodina (Pappus, 2013). The climate of this period has been determined by the dendroclimatology technique using a variety of geological evidence to deduce ancient temperatures.

In Figure 1.5, palaeotemperature charts of various geologic periods, estimated by the dendroclimatology technique, have been compressed together to show the global temperatures of the Earth over a period of 540 MY. Because of compression of several graphs, the horizontal axis (time) includes several different time scales (a mixture of log and linear). However, this figure is a useful temperature chart illustrating the exponential decay in Earth's temperature of ≈25 °F over the last 65 MY.

The temperature data presented in Figure 1.5 is based on work by Scotes (Paleomar Project) who calculated the approximate global temperatures required for the distribution of, (1) ancient corals, (2) desert deposits, (3) tropical soils, (3) salt deposits, (4) glacial material, and (5) the fossils of flora and fauna sensitive to climate, e.g., alligators, palm trees, mangrove swamps, etc. This figure illustrates that for much of this period, the average global temperatures were about 25 °C, but for short periods of time has alternated between frigid (recent age) and warmer (Cambrian, Jurassic, etc.) periods. Heib (2009) has also noted that (1) the geologic record shows that the Earth has often been much warmer and more humid than it is today; (2) the only period of the Earth's history that appears to have similar values of global temperature and atmospheric carbon content is 300 MY ago, during the late Carboniferous Period; and (3) the last 65 MY show a decrease in global temperatures of approximately 25 °C.

The late Precambrian climate, ≈600 MY ago, had several major glaciation events covering much of the Earth, resulting in a cooler period. The Cambrian Period of the Paleozoic (≈530 MY ago) was a time of explosion of organic life on the Earth. Pappus (2013) has noted that this period included the evolution of arthropods (ancestors of insects and crustaceans) and chordates (ancestors of organisms with rudimentary spinal cords). During this period, the continent of Rodina fragmented into Gondwana (which would eventually become today's continents of the Southern Hemisphere) and smaller continents made up of bits and the pieces of the land which would eventually make up today's northern continents. These changes in life and shifting of continents also affected the climate of the Earth's surface.

Another method of inferring temperatures for this time period was suggested by Zachos *et al.* (2001) using the ^{18}O isotropic ratio in benthos fauna of carbonates (see Figure 1.4). Looking at the temperatures determined from deep-water sediments, one sees a similar temperature trend when compared to the Paleomar Project data, thus verifying the global trend of a temperature decrease over the past 65 MY.

Literature is filled with global temperature forecasts ignoring these historical facts and projecting erroneous predictions of future temperatures for the Earth based only on 1,000 years or less of historical temperature data. They do not recognize their fundamental error that Earth's global climate has been cooling for over 65 MY. They also ignore the fact that ***without either a new source of energy or a change in Earth's atmosphere's capability to absorb heat, there cannot be an increase in temperature***. The ignorance of these facts has resulted in both fictitious and imaginary projections of the Earth's future global temperatures, melting glaciers, rising sea levels, and climate calamities that do not reflect reality.

Today's Temperature Charts

Today there are a vast variety of tools to measure and record the Earth's atmospheric and surface temperatures. The advent of satellites over the past few years has permitted detailed studies of atmospheric temperature from

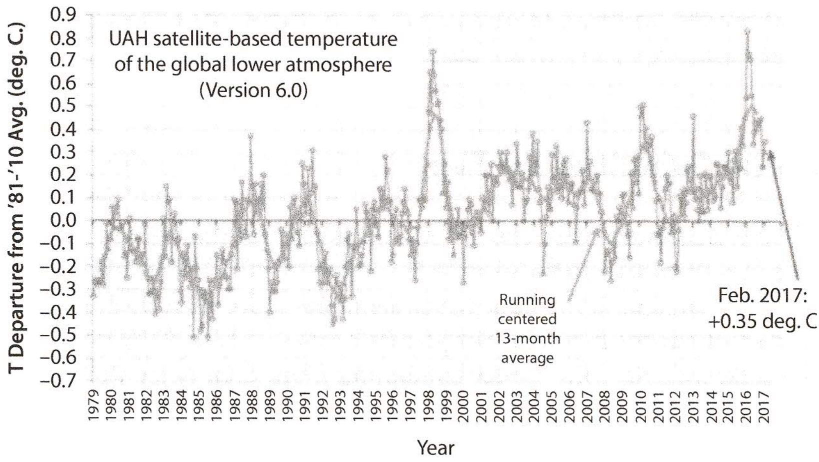

Figure 1.8 Temperature chart, 22-year history of UAH satellite-based temperature measurements of the global lower troposphere. (After Spenser, 2017.)

outside of the Earth. The temperature chart in Figure 1.8 is a 22-year chart utilizing the UAH satellite-based measurements of the Earth's atmosphere. The base value of temperature (Oct,1981) is its x-axis. Between 1979 and 2017, the value of the temperature has fluctuated, but never more than 0.9 °C. The conclusion is that over this period, there has been no significant temperature increase or decrease; however, to see a creditable change of the Earth's temperatures, as indicated by the temperature charts, requires time periods of thousands of years.

The Sun—a Primary Source of Energy

The Sun is the primary source of energy for the Earth's climate system. This concept is the key to understanding the Earth's temperature charts and energy balance between the Earth and the Sun. The Sun (1) warms the planet, (2) drives the hydrologic cycle, and (3) makes life on the Earth possible. The temperature charts (Figures 1.2, 1.4 and 1.5) demonstrate, that today's Earth is absorbing less energy from the Sun than 65 MY ago, which is reflected in the decline of the Earth's temperature.

There are three primary sources of energy to the Earth: (1) Sun, (2) radio-active material within the Earth's core, and (3) flow of energy throughout the universe. Of these sources of energy, the Sun is by far the greatest source of energy to the Earth.

Physical Aspects of the Sun

The Sun is a medium-sized star within the galaxy: its mass places it among the top 10% of its stars in the galaxy (Nine Planets, 2017). The largest object in our solar system is the Sun, which contains more than 99.85% of the total mass of our solar system. The planets contain only 0.135% of the mass of the solar system, with Jupiter containing more than twice the mass of all the planets combined. Jupiter is the second-largest member of our solar system.

The composition of the Sun is ≈70% hydrogen and ≈28% helium by mass. This composition changes slowly over time as the Sun utilizes the hydrogen as a fuel and converts it to helium. The Sun rotates around its axis like that of the Earth; however, the Sun acts as a plastic body and not a solid body like the Earth. The Sun's rate of rotation is from east to west, but its velocity varies throughout the physical sphere of the Sun. At the Sun's equator, the Sun's surface rotates once every 25.6 days, whereas near the poles it is slower (about 33.5 days). Viewed from the Earth as it orbits the Sun, the apparent rotational period of the Sun at its equator appears to be ≈28 days. This differential physical rotation of the Sun also extends down into its interior; however, the Sun's core rotates like that of a solid body (Space Weather, 2016).

Sunspots

The core of the Sun is approximately 25% of its radius. The temperature at the core is 15.6 million degrees Kelvin and the pressure is 250 billion atmospheres. At the surface of the Sun, the photosphere temperature is upward of 5,800 degrees K. The surface of the Sun (photosphere) has cooler areas, that are upward of 3,800 degrees K and appear as darker areas, known as sunspots. Sunspots vary in size, some as great as 50,000 km in diameter. *Sunspots* look dark only in comparison with the brighter and hotter regions of the Sun's surface (Nine Planets, 2017). Sunspots form where magnetic field lines come up from the Sun's interior through the solar surface causing every sunspot to have its own polarity. A sunspot consists of two parts: (1) the dark portion (umbra) and (2) the lighter part around the dark part (penumbra). The sunspot regions follow the rotation of the Sun. In size, there is a great variation; some are many times larger than the Earth and there are many that are much smaller. A large sunspot can have a temperature of 3700 °C compared to the surrounding typical photosphere temperature of about 5500 °C. The sunspot region travels across the solar disk from east to west as seen from the Earth (Space Weather, 2016).

The number of sunspots appearing in the Sun's photosphere varies cyclically, from none or a few, to a much higher number. The average length of time for this cycle appears to be about 11 years. But the length of the cycle varies and some recent investigators are suggesting a longer cycle period. Between 1700 and today, the sunspot cycle (from one $solar_{min}$ to the next $solar_{min}$) has varied in length from nine to 14 years. Figure 1.9 presents the data for the Sun's irradiance, solar flares and number of sunspots from 1975 to 2005. The term Solar maximum ($solar_{max}$) is the period of greatest number of sunspots in the solar cycle of the Sun. Around the $solar_{min}$, only few or even no sunspots can exist. As shown in Figure 1.9, the number of sunspots and the Sun's irradiance are related.

The energy produced by the Sun is $\approx 3.86 \times 10^{33}$ ergs/s or $\approx 5 \times 10^{23}$ horsepower by nuclear fusion. The Sun consumes $\approx 7.00 \times 10^{8}$ tons of hydrogen each second, converting it to $\approx 6.95 \times 10^{8}$ tons of helium and $\approx 5.00 \times 10^{8}$ tons ($3.86e^{33}$ ergs) of energy in the form of gamma rays. As energy travels through the Sun (out toward the surface of the Sun) it is continuously absorbed and re-emitted at lower temperatures (frequencies). By the time energy reaches the surface of the Sun, it is primarily a visible light.

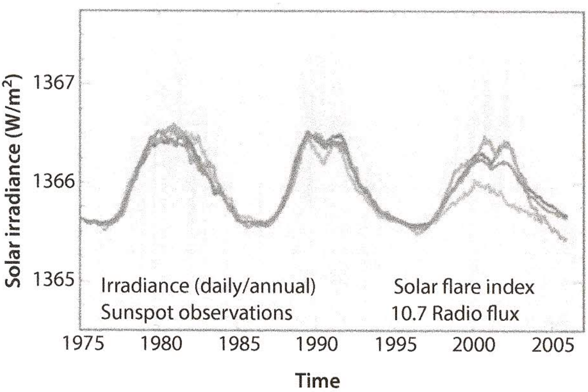

Figure 1.9 Solar cycle variation of sunspots, irradiance and solar flare index. Solar flare index is a measure of the solar radio flux per unit frequency at a wavelength of 10.7 cm. The vertical scales for each quantity have been adjusted to permit over plotting on the same vertical axis as TSI. Temporal variations of all quantities are tightly locked in phase, but the degree of correlation in amplitudes is variable to some degree. (After Wikipedia, 2017; in https://en.wikipedia.org/wiki/Solar_cycle.)

For the last 20% of the pathway to the Sun's surface, the energy is carried more by convection than by radiation (Nine Planets, 2017).

Solar Irradiation Reaching the Earth

Figure 1.10 shows the variation of the Sun's ratio,

$$\left[\frac{\text{Solar irradiation}_{\text{value at various times}}}{\text{Solar irradiation}_{\text{todays value}}}\right],$$

for luminosity, radius, and effective temperature versus time. This figure shows that with time, there has been an increase in the Sun's radius and luminosity and effective temperature.

Figure 1.11 is a temperature chart showing the annual mean surface temperatures, of the contiguous United States, between 1880 to 2006. The trend of variation of temperature over this period, calculated by the least squares technique, was an increase of 0.5 °C/century. Figure 1.12 superposes a graph showing the values for solar irradiance during the same period.

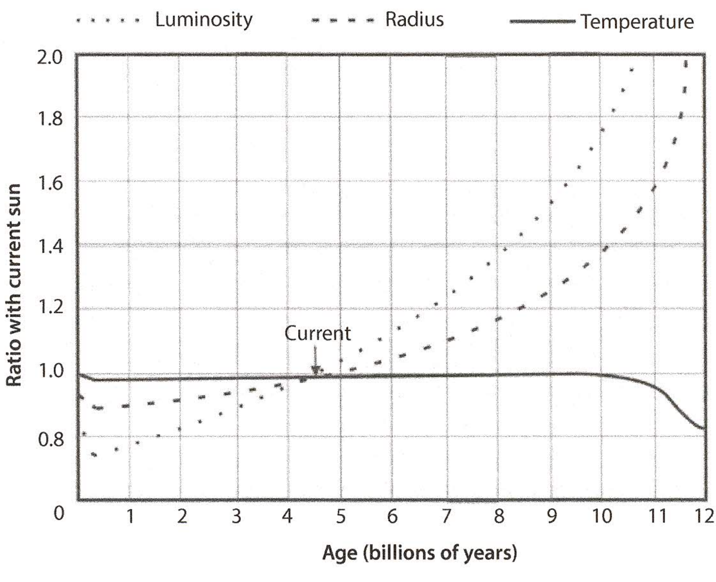

Figure 1.10 Variation of the (1) ratio of solar irradiation to the present day and (2) to the sun's luminosity; and (3) the sun's radius with time. (After Ribes, 2010.)

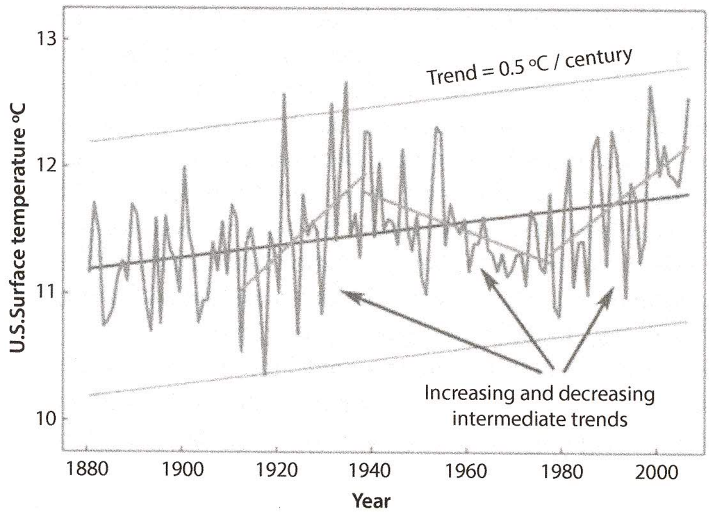

Figure 1.11 Temperature chart showing the annual mean surface temperatures in the contiguous United States between 1880 and 2006 (NCDC, 2007). The slope of the least-squares trend line for this 127-year record is 0.5 °C per century. (After Robinson *et al.*, 2007.)

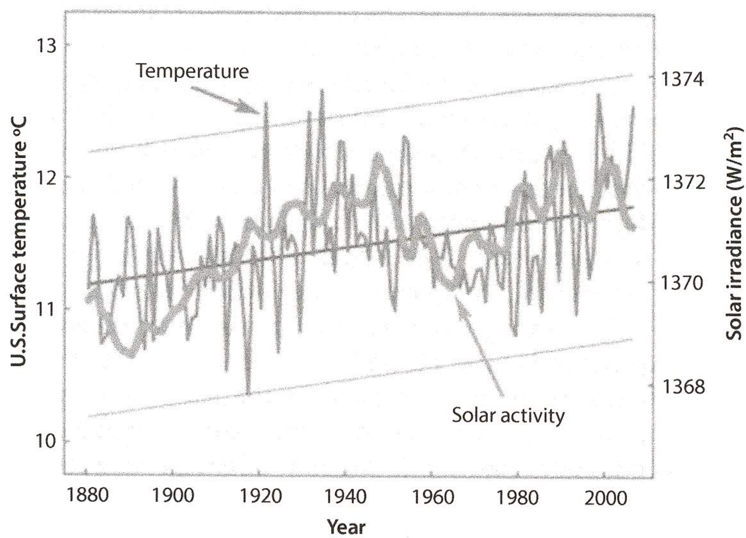

Figure 1.12 Annual mean surface temperatures in the contiguous United States between 1880 and 2006 (NCDC, 2007). The slope of the least-squares trend line for this 127-year record is 0.5 °C per century. (After Robinson *et al.*, 2007.)

Robinson *et al.* (2007) noted the percent carbon-content (carbon dioxide and methane) in the atmosphere does not correlate with the observed Earth's surface temperatures; however, solar activity correlates very well with surface temperature (see Figure 1.12). This does not exclude other potential relationships between temperature fluctuation and other phenomena; however, variations in percent carbon in the atmosphere appear to have a negligible effect on temperature chart fluctuations. Several other studies have recognized a similar correlation between surface temperature, carbon dioxide and solar activity [Baliunas and Soon (1995); Neff *et al.* (2001); Jiang *et al.* (2005); and Maasch *et al.* (2005)].

Robinson *et al.* (2007), who prepared Figure 1.11, also discussed the uncertainties introduced to temperature data by limited (short) time records and sampling locations used by researchers, e.g., if the Arctic air temperature data before 1920 had not been available for Figure 1.11, essentially no increase in temperature would have been observed for this period. A problem often occurring in temperature data is the question of what, who and why specific data was included or rejected. In this situation, Robinson *et al.* (2007) acknowledged that the inclusion or exclusion of specific temperature data would show a downward rather than an upward trend. When researchers report findings, they need to review not only the source and location of the data, but also look at long periods of time, not just a few years. Otherwise the results of their research are possibly influenced by local phenomena and/or their bias.

Variation in solar activity is not limited to just the Sun, but appears to be typical of other stars that are similar in size and age to ours (Baliunas *et al.*, 2007). It should be noted that observers have recognized warming trends rather than cooling trends on other planets and moons with different atmospheres: (1) Mars (Fenton *et al.*, 2007); (2) Jupiter (Marcus *et al.*, 2004); (3) Neptune (Hammel *et al.*, 2006; Hammel *et al.*, 2007); (4) Neptune's moon Triton (Elliot *et al.*, 1998): and (5) Pluto (Elliot *et al.*, 2003; Sicardy *et al.*, 2003). This warming trend on other planets may partially be the result of an expanding Sun (see Figure 1.10) or changes in the atmospheric pressure due to changes in the composition of the planet's atmosphere.

The variance in temperature found in the Earth's temperature charts indicates a continuous reduction in the flow of energy between the Sun and Earth for the past 65 MY. The major source of energy that the Earth receives and is retained by the Earth's surface and its atmosphere, is directly from the Sun. The absorbed energy from the Sun directly affects the Earth's temperature. There are other sources of energy, e.g., (1) energy which flows from the core of the Earth, fueled by the breakdown of radioactive materials within the Earth's core; and (2) energy that flows from the center of the

Table 1.1 Sources of Earth's heat flow - First order climate drivers. (After Sorokhtin *et al.*, 2007.)

Source of heat.	**Estimated heat**	**Percent of total energy**
Directly from Sun reaching Earth's surface	17500×10^{20} ergs/s	99.95%
From the Earth's core transmitted through crust	4.3×10^{20} ergs/s	0.025%
Generated by man	1.34×10^{20} ergs/s	0.0077%

universe and passes through our solar system. As discussed in the later chapters, as the constituents of the atmosphere vary, the atmospheric pressure varies and so does the ability of the Earth's atmosphere to absorb heat. The total average solar energy flux currently reaching today's Earth's surface is $S_0 \approx 1.75 \times 10^{24}$ erg/s, which is determined by the so-called solar constant $S \approx 1.37$ kW/m^2 or 1.37×10^6 erg/cm^2 s (Horrell, 2003). The total heat flux through the Earth's surface due to energy generated within the Earth's core and transmitted through the mantle and crust is estimated at $\approx 4.3 \times 10^{20}$ erg/s (Sorokhtin and Ushakov, 2002), which is ≈0.0257% of the total Earth's solar irradiation. The world's total energy production in the year 2003 was $\approx 1.34 \times 10^{20}$ erg/s (Key World Energy Statistics, 2004), which is ≈0.0077% of the total solar irradiation reaching the Earth.

Table 1.1 shows that the solar irradiation is the dominant source of energy to the Earth's atmosphere, continental surface and hydrosphere. One can estimate that solar irradiation supplies more than 99.95% of total energy driving Earth's climate. Thus, heating and cooling of the atmosphere is primarily due to variations in insolation of the Earth (Hoyt and Schaten, 1997). Comprehensive data on the Sun as a primary source of energy for the Earth's climate are presented by Pekarek (2001).

The Sun's Energy

The Sun is ≈4.65 BY old. Since its birth, it has used up approximately half of the original hydrogen stored within its core as fuel (Nine Planets, 2017). The Sun has sufficient fuel to continue to radiate energy *peacefully* for another ≈5 BY, when it will run out of hydrogen fuel. The Sun will then destroy itself and its associated solar system. Its luminosity has gradually increased throughout the time of its existence and the present-day energy output is about 40%

higher than that at the time of its formation (Gribbin, 1991). This energy output is expected to increase by about 15% in the future 1.5 BY. Figure 1.10 illustrates Ribes (2010) projection for the increase in the Sun's radius, luminosity and effective temperature with respect to time. The significant fact is that the Sun's energy, size and temperature are increasing with time.

The Sun radiates electromagnetic energy throughout the entire electromagnetic spectrum. The Earth's atmosphere absorbs and reflects this radiation from the Sun (Figure 1.13). Today's satellite technology provides the measurements that one needs to measure the Total Solar Irradiance (TSI) for the distance from the Earth to the Sun. These satellite observations are required to develop a quantitative climatic theory and explanation of changes in the Earth's climate. The satellite data measurements have been available since 1978 (Wilson, 1997). In lieu of direct satellite measurements, one can also use variables correlated with TSI, e.g., the number of sunspots recorded since 1610, or solar magnetic activity (Baliunas and Saar, 1992; Baliunas and Soon, 1996). The Total Solar Irradiance (TSI) is cyclic, dependent upon the number and size of the sunspots, being strongest at the peak of magnetic activity (maximum number of sunspots) and varying directly with the intensity of Sun's activity. Tinsley (1997) has noted that the statistical confidence for the correlations between the number of sunspots and irradiation is high.

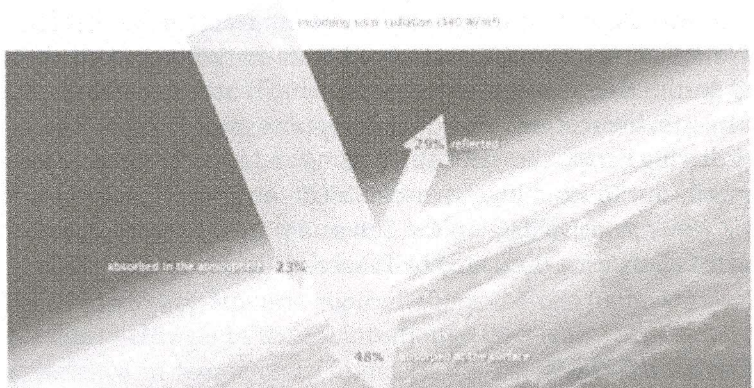

Figure 1.13 Absorption of sun's energy by the Earth's atmosphere. Of the 340 watts per square meter of solar energy that falls on the Earth, 29% is reflected into space, primarily by clouds, but also by other bright surfaces and the atmosphere itself. About 23% of incoming energy is absorbed in the atmosphere by atmospheric gases, dust, and other particles. The remaining 48% is absorbed at the surface. (After NASA illustration by Robert Simmon. Astronaut photographISS013-E-8948.)

As noted earlier, the energy output of the Sun is not constant and is related to the Sun's size (Figure 1.10) and number of sunspots, which vary daily over an ≈11-year cycle. A historic period of very low sunspot activity occurred in the latter half of the seventeenth century, referred to as the *Maunder Minimum*. It coincided with an abnormally cold period in northern Europe, often called the *Little Ice Age* (see Figure 1.6). Since the formation of the solar system, the Sun's luminosity has increased by about 40% (Figures 1.10 and 1.14).

The effect of solar irradiation on global atmospheric temperature can also be evaluated using the adiabatic model of heat transfer within the Earth's atmosphere. Analysis of the Sun's temperature changes, attributed to variations in energy and matter flux, can be made using the following formula:

$$\frac{T_h}{T_o} = \left(\frac{S}{S_o}\right)^{\frac{1}{4}} \left(\frac{p_h}{p_o}\right)^{\alpha} \qquad \text{(Eq. 1.1)}$$

where T_h is the global atmospheric temperature at any given altitude *h;* T_o is the present-day global temperature at sea level, in degrees' Kelvin (T_0 = 288 K); *S* is the total solar energy flux reaching the Earth's surface; S_0 is the total present average solar energy flux ($S_0 = 1.75 \times 10^{24}$ erg/s); p_h is the global atmospheric pressure at the altitude *h;* and p_0 is the global average atmospheric pressure at sea level (p_0 = 1 atm).

A rough estimate of global atmospheric temperature change at sea level attributed to variations in the Sun's insolation *S*, Eq. 1.1 can be rewritten in the following form:

$$\Delta T = T - T_o = T_o\left[\left(\frac{S}{S_o}\right)^{\frac{1}{4}} - 1\right] = 288\left[\left(\frac{S}{S_o}\right)^{\frac{1}{4}} - 1\right] \qquad \text{(Eq. 1.2)}$$

Global temperature changes attributed to variations in the Earth's insolation with corresponding changes in the Earth's global temperature at sea level are presented in Table 1.2. As shown in this table, a 1% increase in current solar radiation reaching the Earth's body translates directly into ≈0.86 °C increase in the Earth's global temperature. This equation can also be utilized to determine an upper estimate for a possible atmospheric temperature increase due to anthropogenic activities.

Even if the entire world energy generated by humans, estimated at ≈1.34×10^{20} erg/s, could be utilized for only heating the Earth's atmosphere,

Table 1.2 Global Temperature Changes Attributed to Variations in Earth's Insolation. (After Sorokhtin *et al.*, 2007.)

S/So	0.85	0.90	0.95	0.99	1.00	1.01	1.05	1.10	1.15
AT, °C	−11.5	−7.49	−3.77	−0.86	0.00	0.86	3.77	7.49	11.5

the corresponding atmospheric temperature increase would not exceed 0.01 °C at sea level. If, in addition, one takes into consideration that changes in the global atmospheric temperature are closely correlated with the changes in solar activity as indicated in Figure 1.9, then the conclusion is that solar irradiation must be the dominant source of energy driving the Earth's climate (see also Kondratiev, 1992; Hoyt and Schatten, 1997). Later chapters will discuss the effect of changing the composition of the Earth's atmospheric and its ability to absorb energy.

As shown in Figure 1.13, about 29% of the solar energy that arrives at the top of the Earth's atmosphere is reflected into space as: (1) clouds, (2) atmospheric particles, (3) bright ground surfaces such as sea ice and snow and (4) so forth. This reflected energy plays no role in the Earth's climate system. About 23% of the incoming solar energy is absorbed in the atmosphere by water vapor, dust, and ozone, and 48% passes through the atmosphere and is absorbed by the Earth's surface. Thus, about 71% of the total incoming solar energy is absorbed by the Earth system (NASA, 2017).

Energy Received by the Earth from the Sun

Reviewing the short-term temperature chart (Figure 1.11), which presents the history of the annual mean surface air temperature of the contiguous United States between 1880 and 2006, Robinson *et al.* (2007) determined the slope of this temperature chart (Trend ≈0.5 °C/Century) using a least-squares method. This natural warming trend agrees with other surface temperatures observed for the United States during the past century, even though this data may be suspect due to the selection process of what temperature data should be included or excluded in its base data. However, Robinson *et al.* (2007) noted that their compiled U.S. average surface temperatures show an increase of ≈0.5 °C per century, which is consistent with other historical rate values found in literature of 0.4 to 0.5 °C per century during the similar time period from the Little Ice Age, as determined by Groveman and Landsburg (1979), Esper *et al.* (2002), Tan *et al.* (2004) and Newton *et al.* (2006).

Again, as noted earlier, the Earth's atmospheric temperature is primarily regulated by the Sun, which fluctuates in solar activity as measured by (1) sunspot cycle amplitude, (2) sunspot cycle length, (3) solar equatorial rotation rate, (4) fraction of penumbral spots, (5) variations in Earth's atmospheric composition, and (6) decay rate of the 11-year sunspot cycle (Soon, 2005, and Hoyt *et al.*, 1993). Between 1900 and 2000, on absolute scales of solar irradiance and degrees Kelvin, solar activity increased 0.19%, whereas the temperature change was 0.21% (Robinson *et al.*, 2007). It is estimated that the Earth's temperature would be reduced by 0.6 °C by particulate blocking of the Sun's radiation or 0.2% (Teller *et al.*, 1997). Figure 1.12 demonstrates that there is a close relationship between the solar activity and the U.S. average surface temperatures. The total solar irradiance can be measured by the: sunspot cycle amplitude, sunspot cycle length, solar equatorial rotation rate, fraction of penumbral spots, and decay rate of the 11-year sunspot cycle (Soon, 2005; Hoyt and Schatten, 1993).

In summary, the solar irradiance correlates well with Arctic temperature charts, whereas the content of carbon in the atmosphere does not (Marland, 2007). Robinson *et al.* (2007) have noted, that for particularly short periods of time, e.g., 100 years, uncertainties can be introduced into the temperature charts by limited time records and the location of temperature sampling. For example, the Earth's temperature charts in Figures 1.11 and 1.12 would look quite different if the Arctic air temperatures before 1920 were not included. In this case, the basic temperature chart would be affected and one would not see an increase in temperature.

The Paradox Reviewed

The climatic paradox: "***The Sun's luminosity is increasing, whereas the Earth's temperatures are decreasing***" (Figures 1.4 vs. 1.10).

The conclusions of the chapter defining this paradox are as follows:

1. Temperature charts for the sediments of the Earth's deep oceans show that temperatures have steadily declined ≈12 °C over the past 65 MY (Figure 1.4).
2. Other long-term temperature charts, e.g., Figures 1.2, 1.4, and 1.5) also show that the Earth has been cooling over the last 65 MY.
3. Shorter-term temperature charts of ≈1 MY show that Earth's temperature has been cyclic over this period along with the long-term cooling shown in the 65 MY charts (Figure 1.7).

4. The Sun is the primary source of energy warming the Earth's surface and its atmosphere, as reflected in Figure 1.12, illustrating a strong relationship between the Sun's irradiance and the Earth's temperature.
5. In preparation of temperature charts, to determine the Earth's cooling or warming, one must use long-term temperature charts greater than 0.1 MY. Shorter-term charts do not cover a sufficient period to observe the change in temperature.
6. Short-term charts of 1,000 years or less can be strongly affected by localized phenomena, e.g., the location and number of sampling as shown in Figures 1.11 and 1.12.
7. The irradiation of the Sun has increased since the formation of the Earth and will continue to increase with time (Figure 1.10).
8. The Sun's radiation, the Earth's atmosphere (composition and pressure) and the Earth's orbital distance from the Sun have not remained constant over time, resulting in a variation in absorbed energy.
9. There have been changes in the Earth's atmospheric pressure (due to a variation of atmospheric composition), which directly affect the ability of the Earth's atmosphere to absorb energy.

The original question arises: "**How *can the Sun be transmitting more energy to the Earth, and yet the Earth has been definitely cooling over the past 65 million years, particularly when the Sun is the primary source of energy to the Earth?*"**

The answer is that the ability of the Earth and its atmosphere to absorb heat is constantly changing. The reasons why are covered in the following chapters.